Eruptive stars spectroscopy
Cataclysmics, Symbiotics, Novae, Supernovae

ARAS Eruptive Stars
Information letter Supplement n° 2   15-03-2015

Steve Shore’s Notes

for Aras group

2013 - 2014

Introduction

Teach me how to name … the light

Margaret Lindsay Huggins
Astrophical Journal, Vol. 8. 1898

In July 2013, Steve Shore (University of Pisa) gathered several specialists of novae in Pisa : despite the numerous surveys of novae, some issues remain unsolved
(see http://www.ast.uct.ac.za/stellanovae2013/talks/ir02.pdf)
The idea is to co-ordinate multi-wavelenght observations from gamma rays to IR on the "next" nova.
The amateur community is associated to the project for visual and near ir observation.

At mid-august 2013, one month after, Nova Del 2013 is detected by Koichi Itagaki at mag 6.3. Nova Del 2013 (V339 Del), IS "Pisa Nova" : classic, CO, bright nova (V = 4.3) in the northern sky, THE PERFECT NOVA.
As soon as the detection is revealed, the amateur spectroscops catch the photons of Nova Del 2013. The fist spectrum (an eShel spectrum) is acquired just a few hours after the announcement of the nova.
At date, more than 1200 spectra have been obtained, at various resolutions, from R = 600 to R = 15000.

During the observation campaign, Steve Shore explained the behavior of the nova to ARAS members, throw periodic notes.

Since January 2014, the observations of novae, symbiotics, cataclysmics … from ARAS members are outlined in a monthly letter, ARAS Eruptive Stars Information Letter :
http://www.astrosurf.com/aras/novae/InformationLetter/InformationLetter.html

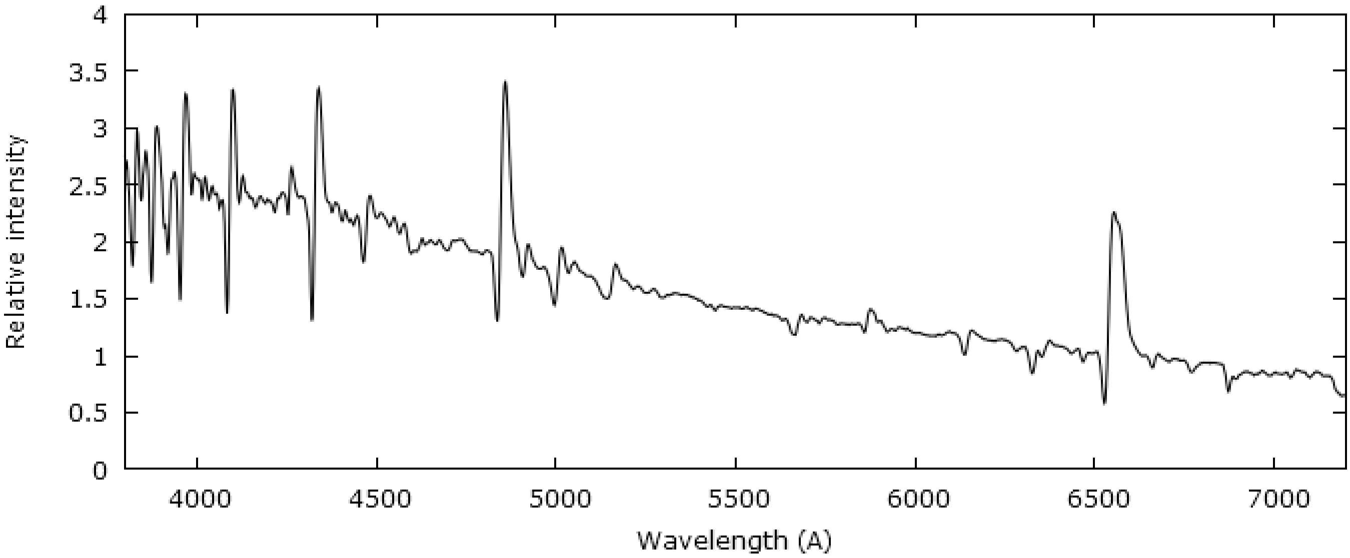
Every month, Steve’s notes explain the behavior of these fascinating objects to ARAS observers.

These notes, for 2013 and 2014, are gathered in this special issue of the letter.

Pisa meeting
July 2013

Summary

First, this is a stage not often accessed in the optical, even less in the ultraviolet. In the first stage, after the explosion (that we don't see), **the ejected outer layer of the white dwarf expand hypersonically and cool**. Two things. First, this is a mixture of the stuff that was accreted on the WD during the pre-nova stage, when it sits inside an accretion disk from the companion and like a garbage disposal just accumulates the stuff. Once a sufficient pileup occurs, the compressed layer can initiate nuclear reactions and explode (well, this is the surface, not the center, so there's nothing to constrain the event). BUT there's a question even here. The ignition of the nuclear fuel is like a flame, in fact physically it's very close, and propagates like a flame through the envelope. This, in turn, provokes a buoyant mixing (to avoid the word "boiling" but it's a similar thing) that also dredges material from deeper layers. **A major uncertainty**, of almost cosmological importance, **is how much of that mixed matter is blown off and whether the WD mass increases or decreases**. But that's for another time.



Nova Del 2014 - 2013-08-14.993 O. Thizy Alpy 600 (R = 600)

For this stage, **the explosion throws the gas off like a shell** but with a catch, the velocity depends on radius because the range of velocities is ballistic and within an interval from the escape velocity to whatever can be reached by the energy of the explosion. So you will see velocities up to thousands of km/s. On this, a word of caution.

I'll always, in any of these notes, emphasize that **what you see is NOT the whole story. The ejecta are not completely transparent at all wavelengths** and you see to different depths of this fog -- just like a fog -- depending on whether you're in the lines, continuum, the optical or UV or IR -- in other words, a radiographic image of a human is similar. You see to the depth from which the light can escape to you, **the surface -- the "photosphere" to those who want to be technical -- is wavelength dependent**.

The same with the velocities. You see different line profiles on, for instance, each Balmer line. Since the sequence from H-alpha to beta and so on is also one of intrinsic opacity (strength) you see deeper in H-gamma than H-alpha and the line is formed mainly ("weighted toward") the inner ejecta. So the combined line profiles, viewed in velocity, are the probe -- tomography -- of the ejecta. With this you can look for structure, dynamics, even variable abundances. The trick is following the sequences and seeing how each part of the spectrum develops. **The Fe lines appear because the UV is opaque and the absorption at high energy excited the optical (low energy) lines**. The same for the He and Balmer lines.

In all cases, the classes (Fe, He/N) are not anything but descriptive of this stage.

The spectra you all got last night were from the fireball, the initial stage of the expansion that is hard to catch. Now you'll see the next pass, as **the ejecta start to recombine and turn into a dense "fog".** Then, as they thin out (weeks from now, likely) **the emission will appear again** but in the first stage the lines pass from ionized and He and H to those of more easily ionized heavy metals that would have been too ionized to observe in the fireball.

Nova phenomenon and lines evolution

15-08-2013

The line profile is a map of the velocity with depth in the ejecta and also in 3D.

A sphere at any opacity has a different profile than a bipolar ejection. A sphere, for instance, always has material moving transversely to your line of sight, a bipolar ejection doesn't. A central source illuminating a sphere has its photons always intercepted, a nonspherical ejecta doesn't, some photons can escape without any effect whether emitted centrally or within the ejecta themselves. So the intensity at any radial velocity (with respect to the observer) maps into a position in the ejecta (but differently depending on the geometry). We know this from resolved ejecta but also from, for instance, T Pyx 2011 and V959 Mon 2012. Some of this is indicated by the ratio of the emission on the profiles compared to the absorption. You can have pure emission with no absorption for bipolar ejecta oriented at large inclination relative to the observer or only displaced absorption if the opposite holds.

As the ejecta expand, the density drops throughout regardless of the geometry. The part in emission increases at first because it's less dense and less opaque. The velocity difference within the ejecta adds to this, the periphery has the highest velocity so its absorption is shifted relative to the inner part. At first, if the ejecta don't recombine, the absorption zone should move inward toward higher density and lower velocity while the emission increases. That's what we're now seeing but there is a start of the recombination indicated by the Na I D lines and the O I 8446 lines. This will stop once the ejecta start again to turn very opaque, we're still in the transition phase you see after a nuclear explosion when the fireball seems to be shrinking.

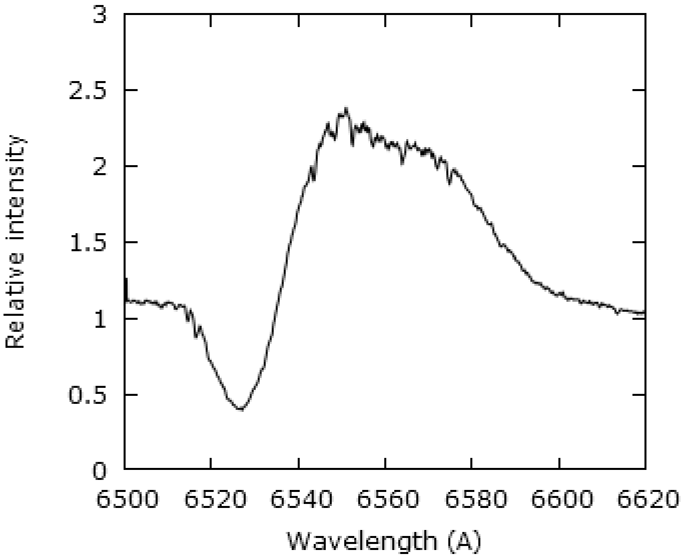
But unlike the nuclear tests, this is not the static atmosphere but the debris itself that is changing. As the ejecta get more opaque there should be absorption components appearing on all of the emission lines and these should seem to move outward (toward more negative radial velocities) as the wave moved toward the outer regions. At the same time, the ionization will change and the lower metallic ions (e.g. Fe II) will get stronger. You've now seen that starting. Then what happens isn't just a temperature effect.

The optical depth (the relative opacity) will continue to decline after total recombination and the matter will start to ionize again.

Before all hat happens, there's one more -- very brief -- phenomenon of importance. **If the density is high enough and the kinetic (gas) temperature low enough, meaning about 5000 K or lower -- the gas can form molecules. The most stable are simple radicals like CO, CN, and CH.** In ONe nova, the dust forming DQ Her 1934, CN was observed just about now relative to the start of the outburst, it lasted for about a week starting a bout 6a week after the detection. That's where we are. I have no idea whether this will happen here, but if it does then this will form dust in about 100 days by mechanisms I'll try to explain soon (it's beyond your patience and a bit too far in the future for the moment, I hope you won't mind).

Never forget that the main difference between a nova and supernova in this regard is **the survival of the WD. It is a hot, radiating source that ionizes the ejecta from the inside out**(just like a planetary nebula in fast forward!) so the inner region -- the moving photosphere -- starts to get hotter and radiate more in the UV. **This drives further ionization of the overlying layers and in time, the ejecta completely reionize. That's when the emission lines suddenly appear and there is no more optical absorption, the so-called nebular stage.**

When this happens depends on how rapidly the density drops, hence on the velocity and mass of the ejecta and the luminosity of the WD. In Del 2013, we don't know that yet. But once the ejecta are completely transparent, the line profiles give you a complete view of the structure even before the remnant becomes resolvable (if ever)



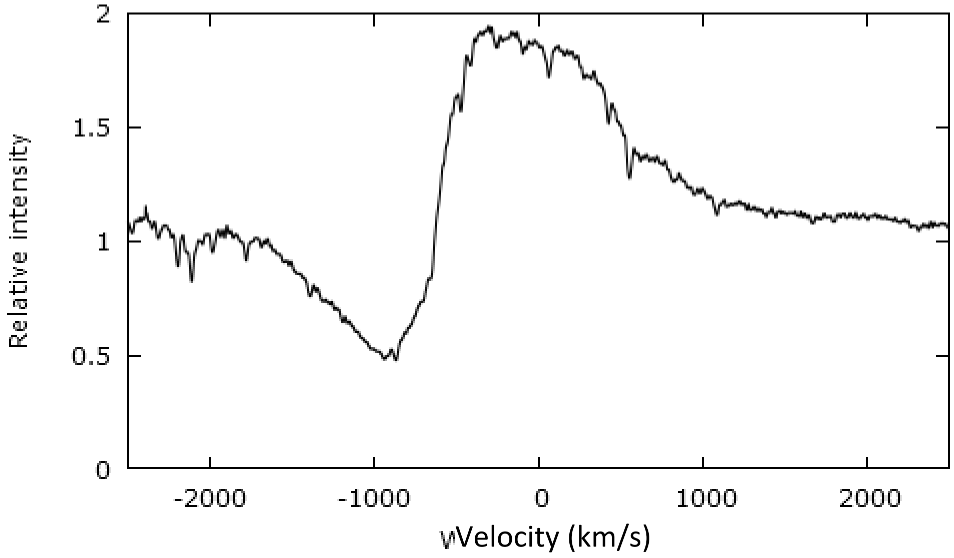
Nova Del 2013 - Ha profile
2013-08-14.865 O. Garde eShel (R = 1100)

The terminal velocity of the line profile is an absolute thing, relative to the rest , not the separation of maximum and minimum (you see that described, too often, in the older photographic literature).

So you're right in saying that there's been a change but it's mainly in the shape and minimum of the absorption. You'll notice that in the last profile the absorption has changed shape, this is the sort of thing some models predict for the evolution as the ejecta expand since the different layers have different temperatures and densities along with different velocities. You never see this sort of thing in winds unless they're very collimated (and that's rare enough). Instead, the decrease is when the line is formed deeper in. Remember, this was very hot and not that it's cooling the optical is becoming less opaque. This is a part of the spectrum where there are few absorbers, the main opacity sources are scattering and thermal (and the photosphere down to which you're seeing -- or rather a moving opaque surface). The timescale for the changes is consistent with the column density varying as $1/t^2$ and the optical depth varying as $1/t$. So you would expect that (since the intensity depends on the exponential of the optical depth) that the line intensity at any velocity should vary as

$$I(vel) \sim 1- \exp [- (t0/t)]$$

where the time t0 is a scaling time. In other words, as the expansion causes the opacity to drop the intensity at a given velocity increases (decreased absorption). This will go on for a bit until the Fe lines appear, as they seem to be now starting to do.



Nova Del 2013 - Ha profile
2013-08-18.910 Thierry Lemoult eShel R = 11000

The fireball stage

17-08-2013

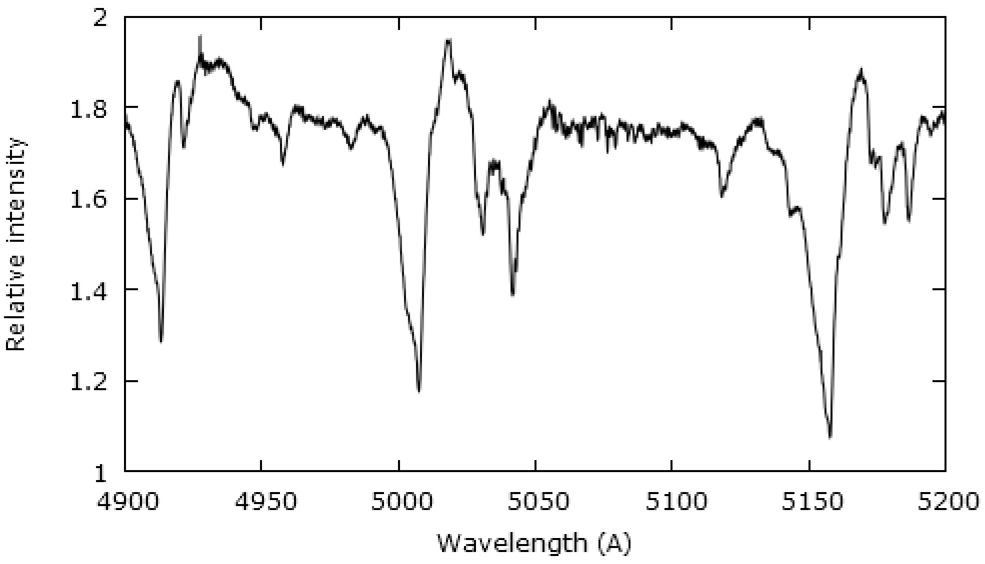
At the start of the expansion, at least when we see the nova visibly, the ejecta should pass through a stage called the **fireball**. This is an **opaque stage that resembles a single expanding surface, or a sort of thin atmosphere, with an almost uniform temperature**. Usually that isn't observed but in this nova it might have been caught. The expansion velocity is high enough that the matter can't radiate efficiently enough to cool by energy loss, **the temperature drops instead because of the increasing volume at constant mass --the energy density is dropping**. This is the same as saying that **the total energy remains almost constant but the temperature decreases.** Then something important happens. When the matter gets cool enough, **first the hydrogen and then heavier elements start to recombine.** This releases some energy (from the excess energy of the electrons as they're captured by the ions) but mainly that the neutral and low ionization stages have much higher line (and continuum) opacities and the absorption in the ultraviolet increases quickly. The lines that absorb there are the ground state transitions; that is, they're the strong zero volt states. Their upper levels are those that both pump the absorption strength of the optical transitions and excite the levels to reradiate. So **the Fe II spectrum, for instance, suddenly starts to appear.** There are coincidences with some of the He I lines, e.g. He I 5016 is close to Fe II 5018, the same for He I 4923 being near an Fe II line (in these cases they're both from the same lower level). The lack, in the last spectra, of He I 5875 gives the game away: the triplet series (He I 7065, 5875, 4471) being absent means the stuff at the near-coincidences if Fe II (and other heavy ions).

In the Ondrejov spectra, we have **Ca I 4226** yesterday suddenly making an entry. At the same time Ca II showed a higher velocity absorption than the H-beta line. So the ejecta seem to be showing some depth structure now.

What all this means is that we're watching a stage in a classical nova that hasn't been covered since photographic series on DQ Her, the last nova that was bright enough for such coverage in the modern era, although DN Gem and CP Pup were also well covered (but not like what all of you have produced!) As I've already written, we're in new territory here -- between observational capabilities and opportunities to catch individual events -- so it's important that you keep up your courage and bang away. It is possible that within the next week there it'll be a shortlived absorption stage in CN 4216 (and also 3883). In the IR there should be a CO 2 micron emission stage. If the nova isn't a DQ Her type, then we really have no analog.

The continuing fluctuations in the photometry, also known from other novae at maximum light, **remain a very deep problem** and, again, any observations with the highest possible cadence (this also means longitude coverage from all of you to get the most continuous sequences) will be critical. For instance, the disappearance of the He I corresponded to a "local" peak in the optical light, this could be a recombination event or it could be multiple ejections. To speculate, so early, is too risky (even for a theorist!) so I'll stop now and hope this explains the stages you're seeing.

One more point, though. The recession of the absorption velocity is something also known from the DQ Her outburst, this is an effect of the change in the transparency of the ejecta. If this is the effect of seeing deeper into the layers at first during the late fireball, then it should reverse as the recombination sets in and the ejecta cool.



Fe II (49) 4924, 2018, 55168
2013-08-17.818 - Olivier Garde - eShel R = 110000

Gamma rays in nova del 2013

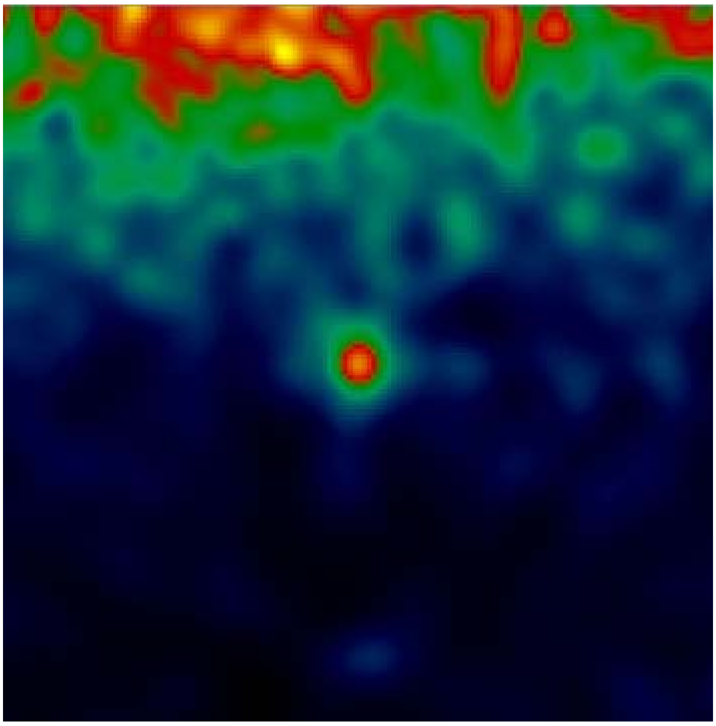
18-08-2013

Nova Del 2013 has been the in the energy range **above 100 MeV**. for perspective, is is an energy interval where thermal processes are irrelevant and indicate **something relativistic is happening**.

More on that in a moment.

The detection makes this the **second classical nova** (third if you count Nova Sco 2012 whose nature remains uncertain). The other was V959 Mon = Nova Mon 2012, although the gamma-ray detection occurred while the nova was invisible fro the ground due to the Sun. The first detected nova, V407 Cyg = Nova Cyg 2010, was like RS Oph, a recurrent (probably) nova that exploded within the wind of a red giant companion so it was a physically very different mechanism that accelerated the particles to the required energies although the avaklable energy was ultimately the same. The luminosity of Del 2013 is about 1/3 to 1/4 that of Mon 2012 at peak. If novae are, somehow, a new sort of "standard candle" in the gamma-ray range, then that implies a greater distance (a factor of about 2 at most), placing Del 2013 at around 6-7 kpc. That is a problem since the nova is not in the plane and such a distance is uncomfortably far above the height of the distribution expected for the main population candidates. It also makes the nova particularly luminous (and that is the next issue). The gamma's are generated by a variety of processes, all involving accelerating either electrons or protons to high enough energies that they either scatter visible and UV into the MeV and higher range, or that the protons collide and emit pions (remember those form the "nuclear glue", the mesons that bind nuclei) that decay at around that energy (but not higher). There's a hint that perhaps the energy range is more extended and that would favor relativistic electrons scattering photons up to higher energies (the inverse of the process, known from the birth of modern physics, as Compton scattering; an electron scatters a photon at low energy but releases it at high energy in the observer's frame of reference).

Why this is important is that the origin of cosmic rays has been a headache for almost a century (since shortly after they were discovered). These are particles that must be actively accelerated, likely by stellar sources such as supernovae, but the actual process is elusive. If even little novae can do this, it makes it far more likely that strong supernova shocks -- those expected when their ejecta slam into the surrounding interstellar gas -- can work. That makes astroparticle types salivate and for good reason, we have here something that happens on human rather than Galactic timescales. **The other reason is the likely presence of internal shocks and collisions between fragments of the ejecta**. It's well known, and you will all see this in the weeks ahead, that the ejecta are hardly uniform or homogeneous, they consist of fragments of a wide range of density and mass, and these will be clear once you start seeing multiple absorption components on the main emission lines (e.g. Balmer series, Na I, Ca II, Mg II, Fe II). But that's just barely staring and the next couple of weeks will show what the structure of the ejecta is. If these shocks are slamming into *each other*, the ejecta themselves may be the site of the acceleration and therefore it becomes a generic (!) phenomenon of novae depending only on the available energy and mass. We don't know the answer to this and it's one of the reasons the measurements of the slow peeling of the layers in which you're all engaged is so important.



Nova Del 2013 is the second classical nova detected in gamma rays
Image Credit: NASA/DOE/Fermi LAT Collaboration

Now the next issue, the luminosity and distance. During this very opaque phase, assuming complete covering (in other words a sphere of gas around the white dwarf), the ejecta are so efficient at absorbing whatever photons are emitted -- either by the underlying WD or the inner parts of the ejecta -- that we see only what can emerge in the part of the spectrum where there is lower opacity.
That's the visible and the UV. Most of the light, again assuming a spherical structure, emerges in the bands in which you're working -- 3000 - 9000A. This is a sort of "calorimeter" or "bolometer". We see almost all of the emitted energy shifted into the visible. That's why the nova brightens in the first place, the expansion cools the gas and it turns opaque in the UV and almost transparent in the optical (down to a sort of photosphere). If we measure the total flux in the optical and IR and know the distance, we have the luminosity (or at least that we've intercepted).

There's a sort of limit on the maximum luminosity for any stable spherically symmetric and not transparent object can have -- radiation pressure makes the layers unstable since the acceleration is oppositely directed relative to gravity. The limit, called or historical reasons the "Eddington luminosity", is that which precisely balances gravity for supporting electrons and the lighter absorbers and scatterers.
It's about 34,000 solar luminosities for a WD of 1 solar mass and increases with mass (that's because radiation pressure is really scattering of light with a kick back on the scatterer and since the photons emerge from below and gravity acts oppositely, there can be a balance point where the accelerations match; that's "Eddington luminosity".

If the distance to Del 2013 is the same as Mon 2012, about 3.5 kpc, then this luminosity implies a mass for the WD of about 1.2 or so solar masses. If it's greater than 6 kpc, that gets hard to explain.
But it's not impossible that the nova could have been so bright, one that would be unstable even for a WD at the mass limit (the so-called Chandrasekhar mass although Chandra was much less massive himself).

The catch is that if the ejecta are not spherical, not all of the light will be reprocessed so you obtain a LOWER limit on how bright the source is/was. Some of the light will not be intercepted. BUT in the gammas the problem is different and the mass measurement is more reliable, maybe?

Now this brings us back to the line evolution and profiles. The line profile is a map of the velocity with depth in the ejecta and also in 3D. A sphere at any opacity has a different profile than a bipolar ejection. A sphere, for instance, always has material moving transversely to your line of sight, a bipolar ejection doesn't. A central source illuminating a sphere has its photons always intercepted, a non-spherical ejecta doesn't, because some photons can escape without any effect whether emitted centrally or within the ejecta themselves. So the intensity at any radial velocity (with respect to the observer) maps into a position in the ejecta (but differently depending on the geometry). We know this from resolved ejecta, but also from, for instance, T Pyx 2011 and V959 Mon 2012. Some of this is indicated by the ratio of the emission on the profiles compared to the absorption.
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Before all that happens, there's one more -- very brief -- phenomenon of importance. If the density is high enough and the kinetic (gas) temperature low enough, meaning about 5000 K or lower -- the gas can form molecules. The most stable are simple radicals like CO, CN, and CH. In ONE nova, the dust forming DQ Her 1934, CN was observed just about now relative to the start of the outburst, it lasted for about a week starting a bout 6 week after the detection. That's where we are.

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When this happens depends on how rapidly the density drops, hence on the velocity and mass of the ejecta and the luminosity of the WD. In Del 2013, we don't know that yet. But once the ejecta are completely transparent, the line profiles give you a complete view of the structure even before the remnant becomes resolvable (if ever).

I hope this hasn't tired you all out too much. For those who have survived to this point, the next instalment will come in a few days

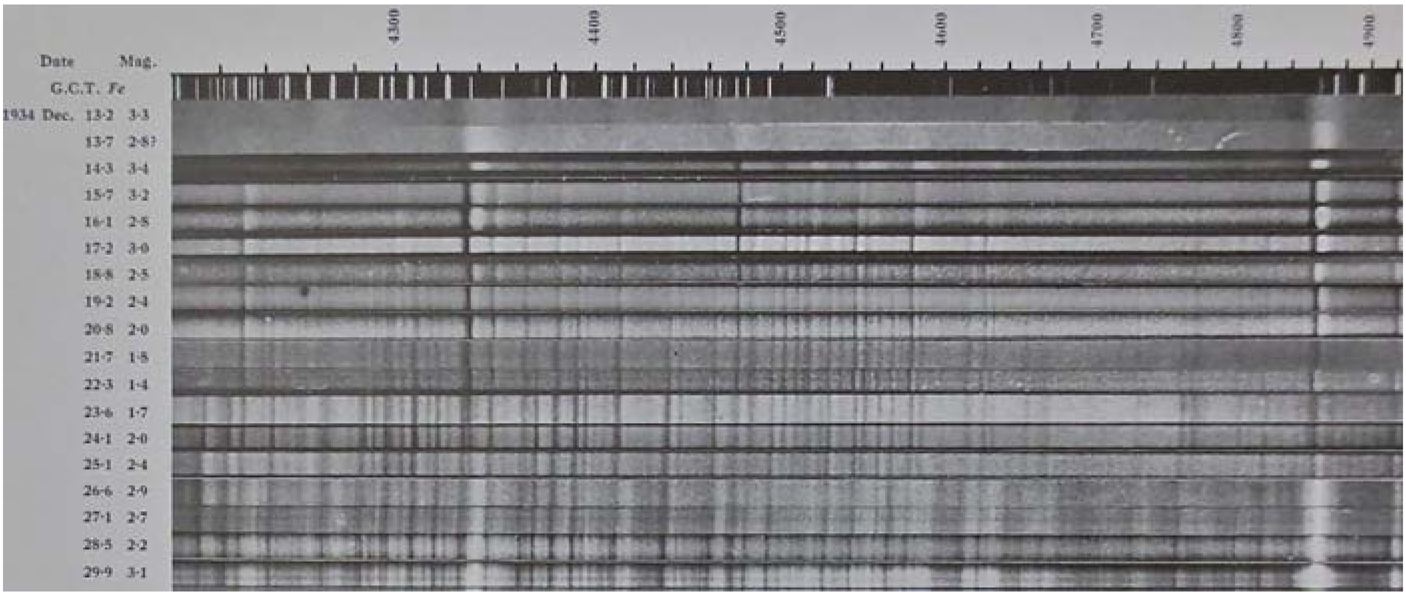
Dust formation and CN lines

22-08-2013

Now a quick word for the moment about CN and why this is so important.

One paper (!!) by Wilson and Merrill http://adsabs.harvard.edu/abs/1935PASP...47...53W reported this line and only in DQ Her. But they also discussed the Na I in another paper and Payne-Gaposchkin discussed this also. The molecule, CN, is amazingly stable for a radical (no, not a political comment). It has a high dissociation energy and can remain in stellar atmospheres to hotter values than the Sun (> 5800 K). The same for CH and CO but we don't see those in the optical; they've been detected in the IR. The usual molecule is CO that consumes almost all of the C w=o if that channel is saturated it means the C/O ratio is high enough for other organics and hydrocarbons to form. The others, often quite complex, are seen in winds from highly evolved stars. And the higher the C abundance the more is available from which the solid phase -- dust -- can condense. Any isotopic anomalies remaining from the nuclear burning will also remain locked in teh dust so after a while drifting through the Galaxy (shades of the Hitchhiker's Guide, no?) they can be incorporated through passage in a molecular cloud, into a star. The dust forms in a way we don't well understood but it is likely that molecular formation and growth is a signal of the right environment for the appearance of grains. This may be purely chemical, homogeneous condensation or "nucleation", or it may be induced (sorry, some of my own work) but whatever the mechanism, it happens. Therefore we can witness the dust formation process in a well constrained event and -- holy grail though it is -- figure out what triggers the dust formation. Other molecules have been detected in the IR, CO for example, but nothing from the cold matter in the ground state.

In Nova del 2013, it seems that the CN has not appeared but it may yet and there's every reason to continue at all resolutions.



DQ Her by Stratton and Manning (1939) with the CN 4216 band

P Cygni profiles

22-08-203

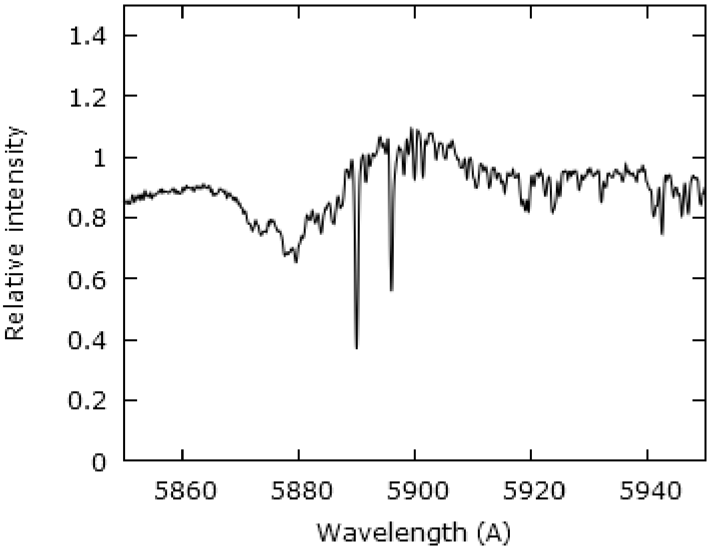
Even at low resolution, many of you have caught the sight of narrow absorption features at high velocity, that look like P Cygni profiles, on the metallic lines and also on He I. As I'd mentioned earlier, the explosion is initiated on the white dwarf by the pile-up of garbage from the companion, like a bad landfill that ignites. In fact, a silo explosion (a grain storage facility) isn't very different; the matter is compressed and heated to the point where a chemical reaction starts that is fueled by the combustible material.

The thermonuclear reactions, mainly involving CNO processed by protons (hydrogen) from the accreted material, triggers a mixing process at the interface between the accumulated layer and the envelope of the white dwarf. This is the part we can -- so far -- only model. The signature of the process should remain in the explosion since the transformation from a flame to a shock is very fast and unstable, leaving behind matter yet unburned and throwing off the outermost layers at supersonic speeds.

Because the expansion is above the speed of sound, pressure is irrelevant for the structures that might be imposed and they remain preserved in the flow. In fact, you've seen something analogous to this in everyday life. (the lovely thing about hydrodynamics is that you can actually, physically, compare flows of very different kinds when the processes are otherwise the same, a similarity notion). If you've ever seen a waterfall or cascade this will be familiar. Until the edge, the water is flowing slower than the speed of a gravity waver (in other words, a water wave). But at the edge it falls and decouples from any excitation, it's in freefall and the bits that start at a higher speed arrive ahead of those that were nearer rest at the start. But the sheet of water preserves all of the structure imposed at the last point of contact before the edge, the filaments and knots you follow downward that give a sense of the speed of the fall. That's what we see in the ejecta and that's why these discrete features, those now appearing, are tremendously important.

In the photographic era such lines were noted as "absorption systems" that appeared at different stages of the light curve on the metallic lines. These were difficult to track, often overlapping and highly subjective since the spectra were often poorly calibrated or not at all, and the zero levels were poorly defined. All of the observers before the '70s clearly knew this but some were amazingly skilled at recognizing the different absorption systems (and these were likely real, the most careful could distinguish multiple components reliably like McLaughlin -- who should be one of your heroes -- and Payne-Gaposchkin). On the Fe-group lines, and the Balmer and neutral helium lines, these also arise from the complex interconnections between transitions I'd mentioned earlier for the optically thick stage.

BUT the Na I lines -- the D feature -- is essentially different. It's one of very few ground state (resonance) transitions in the whole optical spectrum that isn't a forbidden transition (intrinsically very weak). In fact, this is one of the strongest lines in the spectrum and also neutral. The Ca II H and K doublet is another but it's an ion. The K I line is in a terrible part of the spectrum,, often (in many of your spectra, for instance, inevitably!) hidden under a curtain of atmospheric water and molecular lines and hence unusable. The Na I line is, instead, the unique tracer of the neutral medium and the features that have now appeared on the D1,D2 components (together) are at an intermediate velocity even with respect to the Fe II and Balmer lines.



Na I D interstellar
2013-0822.946 Thierry Lemoult - eShel - R = 11000

In other novae, especially the work we've just finished on T Pyx (an old friend of some of you) the velocities are intermediate but the same as we see in the later stages, more than a year later the same feature is still showing up in other ions. This means the structures, the density enhancements in the ejecta, are actually not moving with respect to the other gas in velocity and expansing as a frozen-in feature, just like the waterfall. The striking thing is that the velocities are intermediate, not the innermost of the ejecta and far lower than the outermost (in other words, these are sort of imbedded in the ejecta and "persistent"). Since the expansion is supersonic, they don't "grow" spontaneously within the ejecta -- they have to be imposed on the expelled matter at the time of ejection. This points back to the explosion site itself, buried at the start under the mass of the accreted layer. In T Pyx the broader narrow features (what a description, no?) dissolve into an ensemble of filaments of widths no more than 10's of km/s within a broader envelope of a few hundred km/s but still far lower than the several thousand km/s of the expansion. That these are seen in a certain stage is the result, it seems, of a recombination wave I'd discussed earlier. But the most important feature is that being resonance lines from a neutral species, these features trace the progress of the recombination better than any metallic or Balmer lines. Now, in the last spectra sent by Christian Buil, you see the two Na I feature but, if you displace to the first spectrum and use He I 876 (that then disappeared after Aug. 15) you'll see that He I also now has a detached feature. These absorb at a specific position (radial position) in the ejecta and they have to be large or we wouldn't see the absorption. In V705 Cas 1994 they formed as soon as the Nea I emission peak strengthened. The same in T Pyx. For V959 Mon we don't know because it was hidden, and few other novae have been caught at high time coverage (and also higher resolution, R > 1000) to make the evolution clear. And taking the Ca II to Na I ratio at each component is a direct measure of the ionization fraction (not just abundance since the Ca/Na elemental ratio doesn't change while Ca II/Na I will. As the wave progressed you will see different features appear on different lines but always within the same intervals.

“Forbidden” lines

25-08-2013

Let's concentrate on atomic lines since the molecular species (in novae) are few. The environment is usually too hot (both in a kinetic sense and that the radiation is too hard) for their formation and survival. Uniquely, during the opaque stage when the gas temperature can fall below 5000 K, some radicals I've mentioned (e.g. CO, CN) can both form and remain stable.

But in general, most emission lines from stellar sources are atomic. As a general statement, light is emitted when an electron (or more than one if they're strongly coupled) transitions from one state to another. A state is a specific energy level that has an associated spin and orbital angular momentum -- or rather a specific symmetry. You know these from orbitals in chemistry. If the electron distribution changes, it does so by emitting (or absorbing) a photon of the same energy as the ***difference*** in the energies (to be precise, divided by Planck's constant). Only the ground state, the most tightly bound energy that is usually taken as the zero point of reference, is stationary. Any excited energy level ultimately decays -- a transition to a lower state occurs in a finite time. The symmetries are the collective result of all the electrons in the atom (or ion), they interact electrostatically because they are charged and at different distances from the nucleus (hence from each other), they have spins that induce a magnetic moment (they behave like dipoles and combine according to their relative orientations (in the nuclear electrostatic field, spins are "up" or "down") and they also combine depending on their orbital angular momentum (for this read the angular pattern of the collective electron "cloud"). Different approximations have been developed to describe these couplings, this is the classification of each energy level you'll find in, say, the NIST tables http://physics.nist.gov/PhysRefData/ASD/lines_form.html). Within a coupling scheme, not all levels can directly couple to others, certain so-called transition rules are obeyed. For example, for hydrogen, the angular momentum must change by one unit in any jump between levels, so there are states that cannot be connected by what are called permitted (electron dipole) jumps. If this sounds technical, perhaps it's easier to think of the analogy with an antenna. A dipole has a particular radiation pattern. The same for a so-called permitted transition. These are the most probably jumps between two levels, and have the highest rate (highest transition probability); for hydrogen, the rate is about 10^8 - 10^9 per second (implying that an excited state statistically lasts for a few nanoseconds before decaying). These will have different intrinsic strengths depending on how the electric dipole changes in the transition. Any environmental disturbance, say a collision with a background charged particle, is an impulsively varying electric field hat induces a transition without emitting a photon. Since these occur randomly, the lifetime has a distribution and is reduced relative to its purely radiative decay. Thus, and the collision can also excite the electron if the perturbing particle has sufficient energy, the excitation and de-excitation couple the internal energy states to the background. This is what thermal equilibrium means on the microscopic level, the populations (the probability of the electrons being in any state) depends only on the local temperature that determines the energy distribution of the background charged particles (and neutrals, for that matter). For example, an absorption can occur but if before the state decays it's hit by a perturber, it de-excited without further emission and the gas is heated, this is the absorption process and happens when the gas is dense. The photons are therefore trapped within the medium; in a stellar or planetary atmosphere this means the spectrum will show absorption that depends on the number of atoms along a line of sight . In a low density gas, re-emission can occur because the level can decay freely but because the emission pattern is not only along the line of sight there are fewer photons arrive in your direction so the "missing" light will appear as an absorption feature. The difference is that this scattering process doesn't heat the gas and the process conserves the number of photons so is coherent (hence polarized). the best example of this is the blue of the daytime sky (although that is a molecular scattering process the process is analogous). Both absorption and scattering occur during the first optically thick stage of the expansion of the nova ejecta. But there are less probable transitions, those that according to coupling rules cannot happen by emission/absorption in a dipole mode. These are the so-called forbidden lines because they can't be connected by an electric dipole transition. These normally "thermalize", their lifetimes are so long that collisions always (except for very low densities) provoke the decay. The rate of collision (density dependent) compared to the decay rate (intrinsic) governs whether these lines appear. They don't in the laboratory except under very extreme conditions (they have lifetimes as long as seconds or more, in air in your room the collision times are nanoseconds) but in hot, low density regions (nebulae, or the expanded ejecta of novae and supernovae) they appear. The O I 6300 line, seen in aurora and the upper atmosphere of planets, is a good example. It isn't seen in the lower regions because its lifetime is about 180 sec. But if the density falls below 10^5 cm^{-3}, then O I can emit in this line. The same holds for higher ions, and the demonstration that a region has a low density is the presence of these highly improbable lines in the emission spectrum.

Another feature is that there are a lot of these, and from any excited state there will frequently be other than permitted transitions possible. Once the ejecta density drops far enough, the presence of the central white dwarf (that provided the radiation necessary to excite the ions in the first place) guarantees they will be observed. Think of planetary nebular, the part that's emitting in say [O III] or [N II] is the low density region exposed to the ultraviolet part of the central star's spectrum that is therefore excited by absorption and radiatively de-excited.

These lines are ideal diagnostic signatures of the physical conditions in the ejecta. If you see them at all, the density must be low regardless of the excitation source. The hotter (harder) the spectrum of the central star, the higher the ionization of the outer parts of the ejecta and the stronger (relatively) the forbidden lines. This is the stage that follows the optically thick phase of the expansion. Th transitions are transparent (no photon trapping) so you see every piece of the ejecta that radiates (is illuminated and has a high enough column density to produce observable emission along your line of sight). Since each piece of the ejecta has a outward velocity that depends on its distance, and the differences are large, the different parts contribute to different wavelength intervals around the line center and the line profile is the projection of the outward motion along the line of sight weighted by the amount of gas at that distance from the central white dwarf.

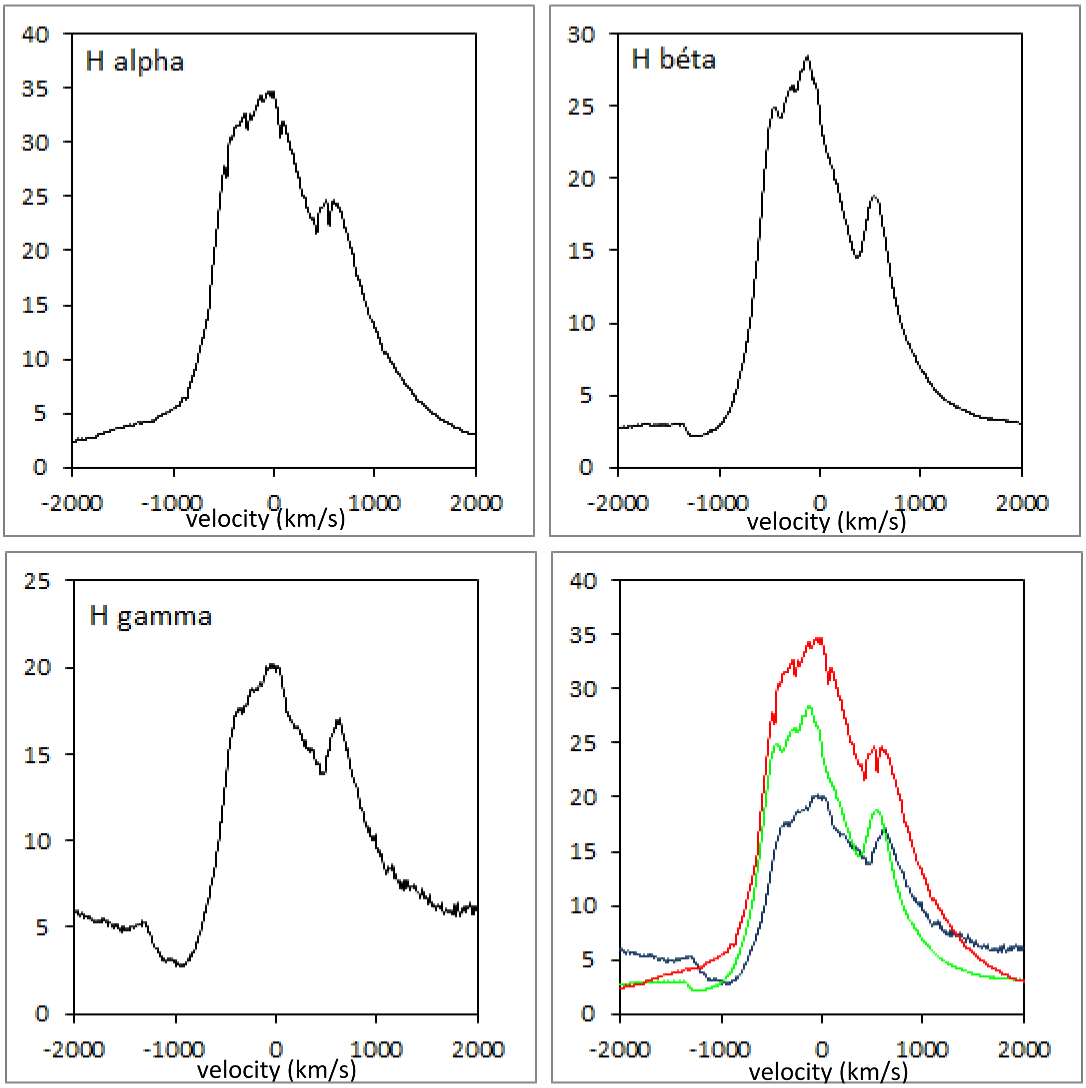
Now we come to the heart of the matter, what you see in the profiles. Take a sphere whose velocity is larger at its periphery than interior but whose density is lower. The highest velocity material will produce less emission so the wings of the profile will be fainter than the central (slower moving) part. If you have a cone (as in the resolved HR Del 967 ejecta, the images from HST are impressive, with the emission strongest on the boundaries, you get a different profile (one with peaks at high velocity and a deficit in the lower radial velocity). These saddle shaped profiles are seen when the ejecta turn transparent. Remember, each parcel of gas emits a photon in the rest frame of the ejecta but you, as an observer, see that Doppler shifted by the projection of that parcels outward velocity along your line of sight. in the sense, the line profile in the "nebular" stage is actually a two dimensional projection of the three dimensional ejecta. Since the forbidden lines are so intrinsically weak, and the densities so low , the comparison between line profiles of different ions of the same elect "maps" the 3D structure of the ejecta. As an example, think to two lines, [N II] 5755 A and [Ca V] 5303. The latter is more ionized (requiring a higher energy) hence traces the "hottest" (most ionized gas. Th N II is, instead, barely ionized. If these two have different profiles i indicates either different abundance distributions within the ejecta, o different excitation conditions, or both. Comparing, say, [N II] and [O II] you can get the N/O ratio, the same for any pair (set) of lines provided the local conditions and ionization energies are about the same. Otherwise corrections must be applied other measurements: you ned a way to estimate what fraction of an element you on't see because the higher ions don't radiate in the visible. So low resolution is needed to know what ensemble of lines is present, and high resolution to see the individual profiles and compare them to obtain the densities, masses of the ejecta, and some idea of what the structure is (knots, filaments). If you've survived to this state (I hope with some pleasure) you'll see that the nebular spectrum (the pure emission lines with both permitted and forbidden contributors) is the only stage at which abundances can be determined unambiguously since it's only in this stage that you see all of the gas.

For Nova Del 2013, this will likely occur in about a month, or at least start, for the CNO ions; for F and related metals it happens earlier because of the absorption and excitation in the UV. The state of the gas is given by which ions are present, and the ratios of the lines gives densities and temperatures. That's again because the states deca with different rates depending on their couplings. Absorption in the UV followed by emission in the visible (fluorescence, the same thing that happens in a kitchen bulb -- the UV lines emitted by atoms inside the tube and excited by an electric current is absorbed by an opaque paint that re-radiates the energy in the visible). This is he origin of the heavy metal emission lines even in the so-called iron curtain stage and fireball, the lines are not ever self-absorbng (photon trapping). A density and temperature diagnostic comes from the O III lines [O III]4636/([O III] 4959 + [O III] 5007), top line has a transition rate of about 2/sec while the bottom pair have 0.02/s. As the density increases the pair decrease relative to the 4363 whose decay goes to the upper state of the 4959,5007 pair. So if this makes sense, which I hope, the next step is understanding why the ionization varies in the ejecta but that's comparatively easy. Every ionization produces a charged pair. The higher the density the faster the matter recombines. The lower the UV the faster recombination (lower ionization/removal rate)hence, while the source is active the high ions are more in the inner part of the ejecta but that zone expands as the density drops. If he central WD turns off, then the peripheral layers recombine more slowly than the inner portions and remain more ionized. In the ISM, after a supernova, this is a fossil H II region. In novae, it's the state once the X-ray source extinguishes.

The evolution of the spectrum
“Think like a photon”

02-09-2013

First, a word of advice. In thinking about what your spectra are telling you, it's best to "think like a photon". By that I mean think about what a photon traversing a medium, in this case the ejecta, will encounter and what will happen. In fact, this is the origin of the Monte Carlo method, a technique for simulating the passage of a particle through a very complex environment, subject to a wide range of processes and a wide range of densities and states. You couldn't find a better description for the ejecta. Recall that the inner and outer parts, even were this a wind, have different outward velocities. So a photon emitted in one place sees the rest of the surrounding gas moving -- on macroscopic scales -- at different velocities and therefore differently Doppler shifted. So if a photon is emitted in the outer parts, where the density is low, it most probably escapes. If, instead, it's emitted in the inner part, where the density is higher, it will quite literally bounce around in both space and frequency (absorbed in a line center, emitted in a line wing, encountering another atom in the line core, perhaps, and being re-emitted there, etc). So in the initial stages, where the photons are actually from the hot gas itself, the thinning of the outer regions is like the expansion of a wind and the photosphere (an intrinsic one) moves inward. You see this in some of the film version of the spectral sequences some of you have produced (especially for H-alpha). At first the P Cyg absorption seems to move inward as the outer layers become optically thin, and then the absorption disappears on that line (leaving a sort of dent) as even the approaching material becomes transparent. The higher Balmer lines, on the other hand, have a smaller emission/absorption ratio (the emission is formed further in) and the absorption is progressively stron-



The higher Balmer lines, ..., have a smaller emission/absorption ratio (the emission is formed further in) and the absorption is progressively stronger

Nova Del 2013
2013-08-30_808
O.Garde - eShel

ger. At the same time, you see with increasing clarity and strength the structure of the whole ejecta, the various emission peaks, that signal the thinning of the material at the highest distances and velocities.

But don't forget the poor remaining white dwarf. It's now in the supersoft phase, although we don't yet see that, burning the residual material from the explosion in a source that reaches several 100,000's K (of order 0.05-0.1 keV). The nuclear source is deep, not at the surface, and has a photosphere of its own that depends on the newly established structure of the envelope of the WD. This is inside the ejecta, at this stage (as of 1 Sept) we don't yet see that directly. But we see another, important effect: the ionization produced by this source is gradually advancing outward in the ejecta from its base as the ejecta thin and the photosphere moves inward. This is the so-called "lifting of the Iron curtain" that's happening in the UV and the cause of the decline in the optical. Progressively more of the photons can escape in the UV without being degraded through optical or IR transitions and the continuum temperature increases as the two oppositely directed "fronts" approach. The individual transitions from the ground state of neutral and low ions are in the UV and some of them remain opaque although the continuum is increasing sufficiently to power emission lines in the optical. Oxygen, in the form of O I, is the best example. The [O I]6364 and 6300 lines are connected to the O I 1302, 1304 resonance lines. The latter are still thick, so the photons knock around and finally emerge through "open channels", e.g. 8446 and the two forbidden lines. Their presence indicates the density is finally low enough at the photospheric depth that the emission from forbidden line sis no longer collisionally suppressed. The transition is abrupt in the optical, hence the term "flash" used by the early observers, because when the right optical depth is hit, the transition is almost instantaneous since the emission becomes local. The [O I] line widths, you will have noticed, are lower than the wings of the Balmer lines so this is from the inner parts. The O I 8446 was visible for a longer time. In the UV, we would see absorption at O I 1302,1304 but that will gradually give way to P Cyg and then emission.

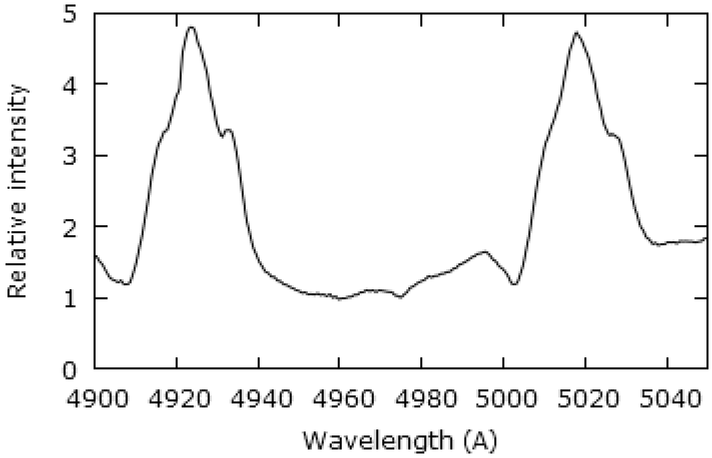
Something else to remember is that different elements ionize at different energies. Oxygen, for instance, is slightly more bound than H, so the Balmer lines will be strong when the O is still completely neutral. Once the O (and N) start ionizing, they also contribute recombination lines that can't decay to the ground state directly because of the blockage of the UV channels so they emerge where they can, at the exits marked "6300" and "6364" and so on. The same for the C I and C II, and the N II lines. We are not yet at the point where the N III 4640 lines appear but they will in due course.

The Fe II lines are now turning completely into emission as the peak moves toward Fe III and higher and the UV lines turn transparent. The Fe-curtain will, once the ionization reaches Fe^{+3}, disappear since that ion (Fe IV) has very few transitions in the part of the spectrum where the UV is strongest. All of this is powering the decline of the light curve and is what "the founders" didn't suspect: the changes in the UV from the light curve are timed to appearances of specific ions and transitions because the continuum temperature continually changes, moving toward stronger UV and even XR, while the optical is a passive responding medium. When the Lyman series turns transparent, and becomes recombination dominated, the P Cyg profile disappears. The same for the He I lines, they will reappear along with He II and other higher ions as the opacity in the UV drops. Once the two fronts meet, that's the nebular stage: the moment when the spectrum turns to emission, we see completely through it, and the line profiles all look basically the same. I say "basically" because density and structural differences leave their signature on individual lines depending on their transition probabilities (forbidden or permitted, as discussed a while back).

The nebular stage is a complicated period and very sensitive to the specifics of the explosion. If the ejecta are spherical and smooth, all profiles will be basically the same but differ in width because of their "weighted depth of line formation" (in other words, recombination line strengths depend on on density so the inner part always contributes more, but it also depends on where in the ejecta a specific ion appears). All of this changes quantitatively for nonspherical explosions, but not qualitatively. The strength and velocities are those we see projected along a line of sight through the expanding medium.

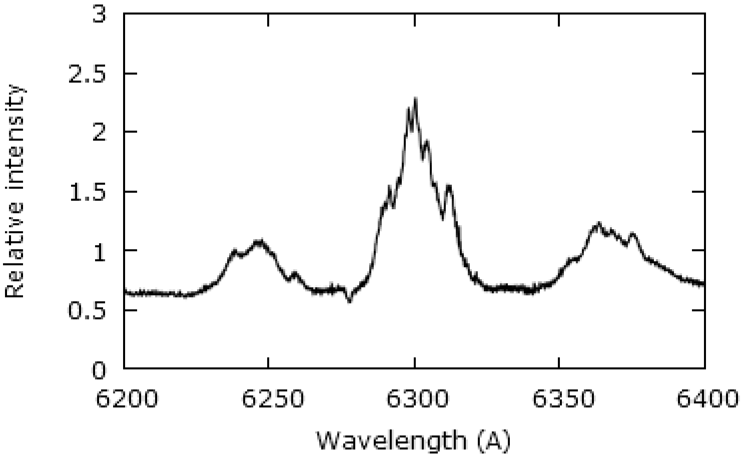
I apologize if this is staring to get heavy, it's not intended. You have here a problem of photons (motorcycles) weaving their way through traffic (cars, trucks) whose speeds depend on where they are in the lane of traffic. If the ejecta are spherical the only escape is along the direction of the flow. If aspherical, there's a way out and free escape by swerving to the side. This is something we're just starting to deal with in detail, and it's your work that will illuminate it even more clearly for this prototypical nova.

And as a last comment, one on the intensities/fluxes. In the next weeks, as the ejecta change ionization and approach the sate of freeze-out (when the recombinations are independent of the WD illumination and depend only on the rate of expansion), we will see how structured the ejecta really are, the density and ionization stratification, and the abundance inhomogenities. The absolute fluxes are the key, they tell you how much energy is in each transition and therefore the number of radiating atoms. It seems, for instance, that a few days ago H-alpha alone accounted for almost 8000 $L_\odot$ if the distance is 5 kpc (less as $1/D^2$ depending on the distance). From this we'll have a first estimate of the ejecta mass, one of the key unknowns in any explosion and the pointer to the conditions at the outburst. The other is that there is structure here in the ejecta, you've already seen that in emission and absorption, and as different ions appear that will link to the central engine.



The Fe II lines are now turning completely into emission as the peak moves toward Fe III and higher and the UV lines turn transparent

Nova Del 2013
2013-09-02_856
Paolo Berardi
LHIRES III 600 l/mm R = 2500



The [O I] 6364 and 6300 lines are connected to the OI 1302, 1304 resonance lines

Nova Del 2013
20130903_826
Stéphane Charbonnel
Eshel R = 11000

Evolution of the spectrum at t_3

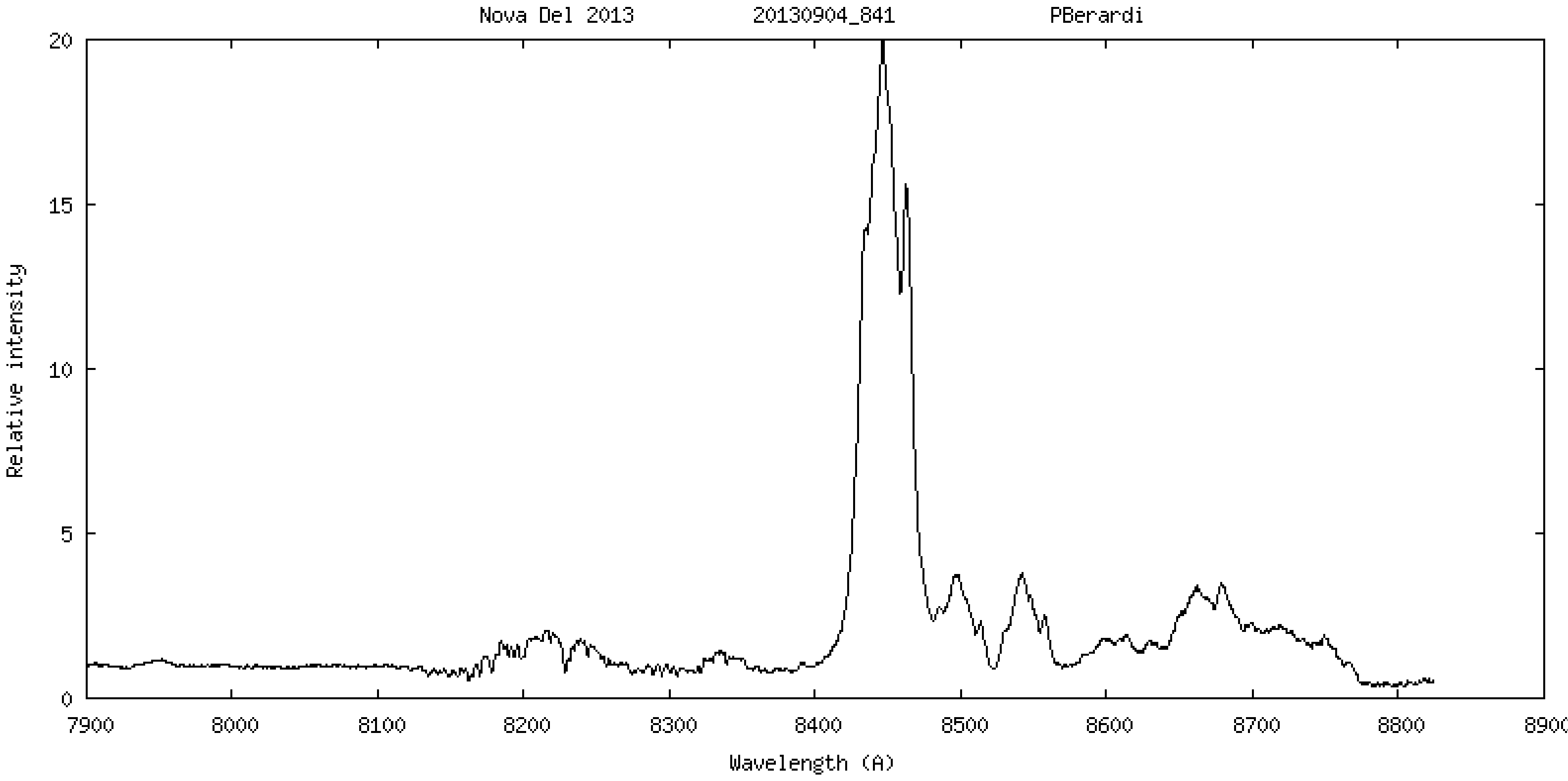
05-09-2013

First, we're nearly at the stage, t_3, where the optical spectrum usually goes through another transition. The emission lines should strengthen, the continuum should quickly fade, and emission lines of moderately ionized species should appear. That's the standard statement, that this timescale defines the nova event.

> ***The beauty of this stage is that we're beginning the transition when you get to see, like a tomogram of a body, the individual parts of the inner ejecta becoming visible***

But as we discussed earlier, the timing of these events is tied to the structure of the ejecta and the evolution of the underlying WD. In these spectra, for instance (And Christian's are also showing much of this) there's a new feature. Look at the Ca II lines (those around 8500A). There's virtually identical structure on these lines, it's not atmospheric water absorption as demonstrated by the [O I] and Ca II 3933. These tiny features, throughout the line profile, symmetric about zero, are signs of the ejecta structure and the signal that these transitions are optically thin. The lines from similar ions, or similar ionization/excitation conditions, should be the same and you see the same structure on a forbidden line ([O I]) as the permitted (Ca II), from a neutral and from an ion. The ejecta geometry, if we use a bipolar model, seems to fit a rather high inclination but it's also showing another effect. Notice in the second set of profiles that the O I 8446 extends to higher velocity in the wings (like H delta) than [O I] 6300. The O I is connected to the ground transition O I 1302 in its lower state, the upper state is fluorescent with Lyman beta, hence it looks like H-delta and the higher Balmer lines that are weighted toward the inner part of the ejecta. The forbidden line bleeds off the photons from O I 1302 so it's a different profile, more like the Ca II which are excited state transitions only. There are three of there, one of which is nearly coincident with O I.

As the shorter wavelengths become more transparent, the profiles will become more nearly the same. The next moment is when the UV starts to ionize the Fe and the curtain lifts, when the [N II] 5755, 6548, 6583 lines appear, and then when the [O III] 4363, 4949, 5007 are excited. The former are simple forbidden transitions, although with the same atomic configuration as the O III. This is called "isoelectronic" in having the same state structures (recall that N^+ is the same number of electrons as O^{+2} but with a different nuclear charge, that makes relatively little difference for the binding, hence the lines are near each other). In the ejecta, since the O I 8446 line is formed by pumping, it's intensity

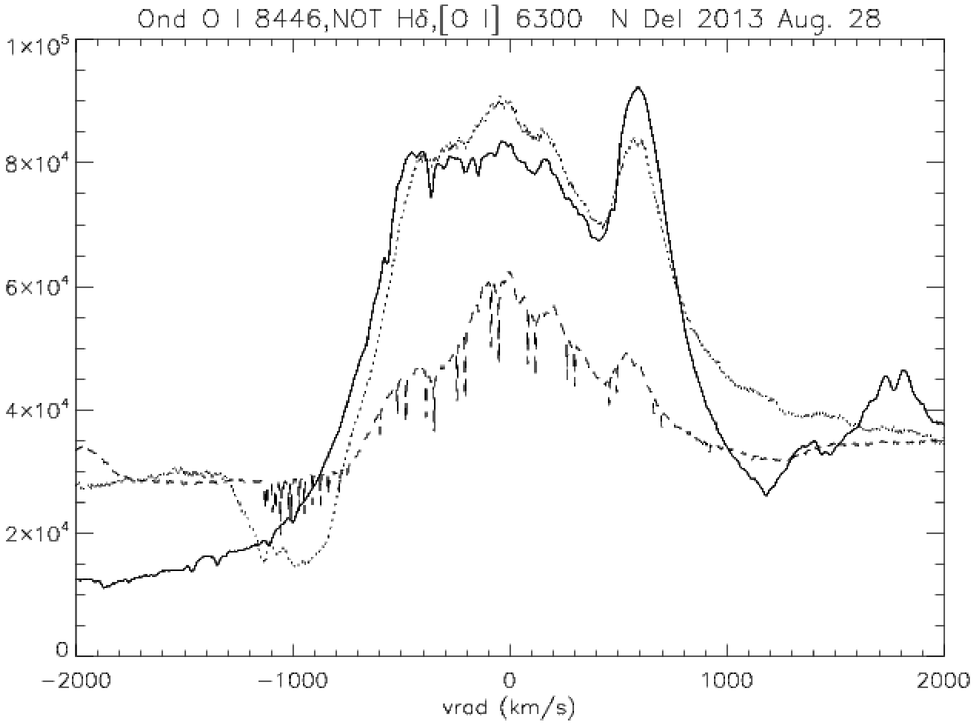


OI 8446 and Ca II 8498 and 8542 lines

Paolo Berardi - 2013-09-04.841 - Lhires III 600 l/mm R = 2500

Evolution of the spectrum at t_3

05-09-2013



O I 8446 extends to higher velocity in the wings (like H delta) than [O I] 6300

NOT 28-08-2013

varies linearly with density while the recombination lines, like Ca II (permitted and excited states) form by recombination so the intensity varies as density-squared. To be more precise, and I hope less technical, the formation of a line by recombination means that electron capture takes place so the emission depends on the number of captured electrons (one power of density) and the number of ions (the other power). Pumping depends only on the number of ions to be pumped and the availability of photons, so it's a different density dependence. Now recalling that the density is lower in the periphery of the ejecta where the velocity is highest (in this ejecta picture, but also for a wind), the wings are weaker but extend to the point of invisibility. The [O I] is formed, instead, by the 1302 photons being trapped and "leaking out" and that requires the inner region. But there's another important piece of information here, that the forbidden transitions aren't sen if the density is any region (for a temperature of about 10,000 K or so) is too high so there's an upper limit (about 10^9 cm^{-3}) for the inner part. If we take that to be about 1000 km/s, assuming what we know from other novae, then as a first pass guess the mass of the ejecta is about 8.10^{-5} solar masses (yes, you heard it first here). This depends on the filling factor which, from the NOT observations and what you've seen in the fine structure, suggests about 10% or 30% of the ejecta s filled with an aerosol of filaments so this could be as low as 2.10^{-5} $M_\odot$.This is a normal value for the ejecta and I'm assuming that the inner density is low enough to produce the [O I].

The calculation assumes that we're seeing this at 20 days with a velocity of 1000 km/s for the inner part and about 3000 km/s for the outer, fiducial numbers. It doesn't give an abundance but it's a start. The other is that the emission at H-alpha accounts for almost 8000 $L_\odot$ if the nova is at 5 kpc and scales as (D/5 kpc)^2, so a lot of energy is coming out in a single line.

It's this last point I wanted to also mention because the ejecta are acting as a sort of bolometer, or calorimeter. The energy now derives from the original hot gas and the heating from the WD radiation. That will keep up until the nova turns off, when the nuclear source collapses and the WD starts to cool. The rapidity of this stage is probed by the direct measurement of the XRs, which will appear shortly if all is right here, and by the appearance of very highly ionized species like Fe VII and Ca V, or even higher. That's still in the future but shouldn't be very long. I haven't heard whether the gamma ray source is still on but it shouldn't be, if the internal shocks are the powering agent, but the radio should also turn on soon as the ejecta turn optically thin in the centimeter wavelength range.

So that's what's to come, but the beauty of this stage is that we're beginning the transition when you get to see, like a tomogram of a body, the individual parts of the inner ejecta becoming visible. I don't know another stage, whether in stellar outflows (like luminous blue variables) or even planetary nebulae (this is the last stage after the superwind from the central star turns on) when you see the third dimension of the universe so clearly.

Evolution of the spectrum at t_3

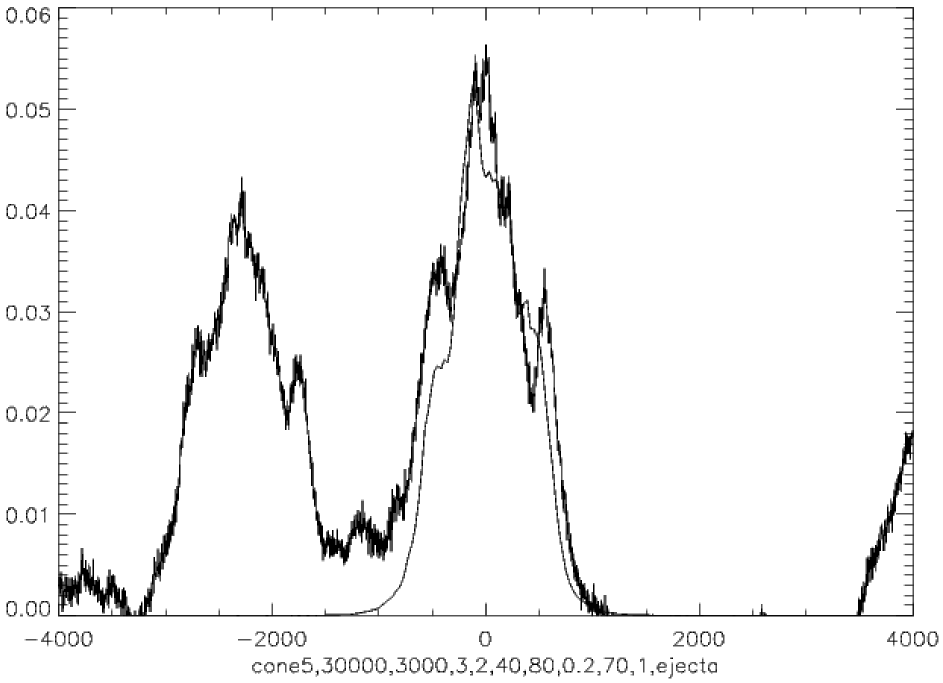
05-09-2013

The spectral evolution may seem slow but the changes, however subtle, are continuing. The most remarkable your data have shown is what ***looks*** like emission on the negative radial velocity filamentary structures seen on in the absorption features of the Na I D1 and D2 lines. The envelope of the absorption is seen on even the low resolution spectra, those are comparable to the data historically available at this stage. But in the interval between Aug. 28 and 5 Sept. the Na I features have apparently gone into emission. First, this is very hard to understand if real, the line has not changed on the positive velocity side at the symmetric velocity. More important, the resonance line would normally be expected to show emission were it scattering,and to produce these specific features the required column densities are high. You would also, were this recombination like what we saw in the environment of V407 Cyg, the wind of the red giant neutralizing after the passage of the ejecta, you should also see the connected lines of the cascade sequence, 6154.22, 6160.75. You don't. Instead, the feature here is Fe II 6148 with a similar profile to that seen on the other optically thin lines (compare the profile with, say, [O I]5577A). It's more likely the onset of the helium emission stage, the He I 5876A line. There's a detached absorption feature at -2500 km/s that appears to have shifted by about 200 km/s to the blue in this interval that may be the same effect observed in T Pyx and Nova Mon 2012. If so, this would mean the ground state is still optically thick. The emission-like features are at the highest velocity end of the Na I doublet, which is -- like the Fe II multiplets around 5000 A -- now starting to show fine structure as the line turns more transparent with the drop in density.

This variation at Na I is a really beautiful result, one that hasn't been possible to observe before at the onset of the transition to a fully ionized ejecta and your high cadence spectroscopy is showing all of the rich structure of the material.

One test is whether the Ca II H and K lines are also showing this kind of change, the Fe II is linked to the complex of UV absorption features that are now turning optically thin so the absorption will disappear on those and signal the lifting of the curtain. There is a hint of emission at He II 4686 Å but it's mainly the nascent N III/C III blend. And the O I 8446 remains strong and will persist for some time because of the pumping by the Ly-beta line. The N I 6486 line shows the same (even water laden) profile as [O I] so the neutral part of the ejecta is still dominant.

As to the light curve, this strongly depends on the details of the ejecta structure. Remember, we're still comparatively early in the decline and pauses happen as the changes in ionization take place in the dominant absorption spectral intervals. The interval from 2000-3000 Å is turning more transparent while the 1200-2000 Å interval is still dark. In earlier studies, mainly based on the UV sequences for OS And 1986 (out current prototype for this nova) and V1974 Cyg 1992, the t_3 point, which we're at now, is when the mean optical depth is of order unity, meaning the drop in the optical that's being powered by the UV redistribution is almost at the critical point for the ionization wave to start. This should be signaled by the changeover from Na I to He I and the so-called helium flash.



About the origin of Iron

This is the perennial problem in astrophysical plasmas, Francois.

Remember the original solar mixture, from the '20s, was mainly heavy elements because the Balmer lines are so weak. Payne (later Payne-Gaposchkin, yes, her!) demonstrated that requiring ionization equilibrium as a function of density and temperature together with hydrostatic and thermal balance produces a spectrum that changes appearance even with constant abundance. Novae are strange because they pass through so many regimes of temperature and density that, unlike a star, vary on short timescale (hence nova ejecta NEVER resemble a stellar atmosphere and rarely a wind). The Fe isn't a product of any nucleosynthesis during the nova, any more than it is in a red giant compared to a main sequence hot star. It's an effect of the ionization and line formation. The lines are relatively more intense because they arise from a dominant ion. For instance, were the temperature as high as during the fireball, you'd see only He I and Balmer lines, it's the same ejecta you were observing a month ago but the temperature and density conditions are very different now.

For the temperatures reached in the thermonuclear runaway, less than 0.3-0.5 GK (a few 100 keV), you don't obtain free neutrons (for the heaviest elements, as in r-process), you don't have enough time for s-process, and the explosion isn't the result of gravitational collapse so the energies available are far lower and you have reactions of charged particles that run similarly to a stellar interior. To get to iron and the heaviest elements requires continued special conditions that break out of the A < 40 region (e.g. calcium), and that doesn't occur

"Fe II novae"

This term "Fe II" nova is, again, just a way of saying "still optically thick and cool". The temperature of the ejecta drops from expansion, recombination leads to a more neutral medium, and the radiation field is shifted to the UV and absorbed there to be re-emitted in the visible. At the same time the excitation by collisions becomes less efficient for the higher states, it's linked to the kinetic (actual thermal motion) temperature of the ambient electrons, and the lower temperature also means recombinations are more effective in reducing the ionization. So the combination leaves the metal lines, which are present in two ionization stages (at least) and come from about a dozen possible species with literally millions of possible exciting coupled transitions, dominate the spectrum. The same sort of state change happens in a supernova expansion but at a different rate and is more complicated because of the radioactive material from the nucleosynthesis and the stronger shock (not to mention more matter). The abundances of the heaviest elements, e.g. Fe and higher, are so high because of internal nucleosynthesis in the fireball of the expanding envelope of the collapsed star.

Again, it's important to emphasize that the processes we see for line formation in a nova are like those in a star but in a dynamic medium so the complications result from the interplay of velocity differences and total abundances. The heavy elements, even at 10^-5 the abundance of H and He, are still the main contributors to the opacity in any cosmic plasma with solar abundances or the like in the temperature range below about 100 kK.

Universality of the optically thin profiles

The **universality of the optically thin profiles, the best examples being the O I lines**, makes for a useful tool -- the peak at +550 km/s is identical in all the profiles and just this one peak is enough to link to the rest wavelength. I've checked this with about a dozen examples and it works almost perfectly, meaning that the ionization and density structures are being identically sampled by all available lines (mainly neutrals).

One example: next to Fe II 5018 there's an emission that ***could*** be He II 5047. But using the profile, it is almost certainly C I, like the 7115 A line. The one for which it isn't working is the line aroun 6720A. That's still a sort of mystery and since it's even visible at low resolution (< 3000) I recommend keeping track of its development in the next few weeks. It could be something interesting

Although it wasn't clear from the earlier spectra,

11-09-2013

There's now a **clear detection of [N II] 5755A**, since about 10 Sept. but now much better. **The same (almost) profile as the O I lines so the opacity is starting to decrease rapidly now in the near UV.** This should be the start of other line appearances that signal the reionization of the ejecta and the next stage of the transition.

The STIS observations will be in a couple of days, and as soon as that comes down you'll all get a look. If possible, coverage around 18/9 would be gratefully welcome.

14/09/2013

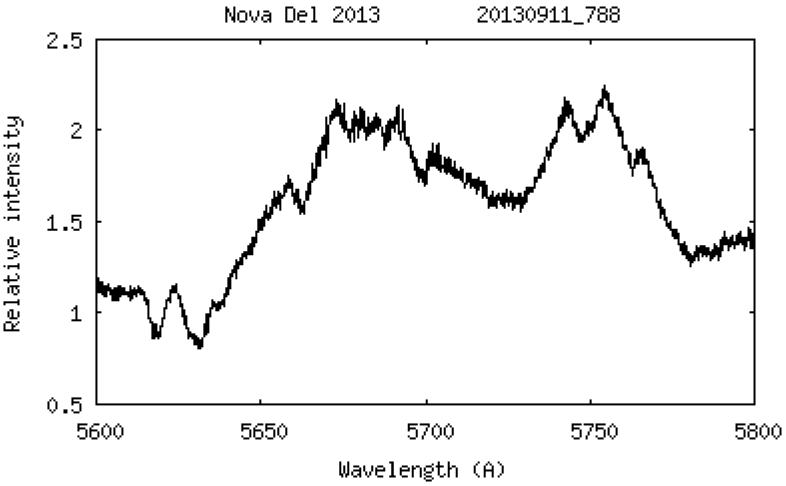
There's an interesting little hint of some changes. Subtle but important. There are few N I lines of interest in the optical spectrum and these are all tied to absorption < 980A and mechanisms like those for O I of fluorescence with the Lyman transitions. **Monitoring these specific lines is usefull, whether in novae or other evolving environments, for getting a handle on the UV opacities**. Notice that the Balmer wings are still very broad, at a very low level but out to almost 1800 km/s. Really lovely! The stability of the light curve and the line profile is quite pretty and the variations of specific transitions, like "6726". will give you an idea of how the physical conditions are changing.

Actually, this highlights a point I hadn't mentioned before. You see that if you catch one of these beasts at any moment the spectrum may seem quite stable, like Nova Del is now, but if you get it at a very early stage it can look very different. That highlights the difference I was mentioning some time back between atmospheres and dynamical media, in a star the atmospheric structure is fixed so changes in the spectrum, which do happen, are always either periodic or subtle. If something happens that's out of mechanical balance the spectrum, reflecting the changes in the local and global environment (e.g. density, pressure) changes on a wide range of timescales (collisional/recombination; radiative/ionization, all of which are different than the dynamical -- expansion/collapse -- timescales) The weakness of the emission is an indication of ionization, I think.

The Balmer lines have the largest contrast, then O I, then C I (unfortunately there are few lines in the IR well resolved to check that for the lower states of carbon).

There's also an N I 6722.66 line that could be the identification, but yours makes very good sense since it's linked to the 8446 pumped states. The line is a doublet with the mean being 67.

The transition probability is very low, it's an intercombination line that's increased in flux by about a factor of 50% between 28/8 and 8/9 from the NOT spectra (the plot has the continuum scaled by 1/1.5 for the earlier spectrum, dots are 28/8/13). The one peculiarity is the symmetry of the emission, even with a doublet (the separation is only a few km/s).



... there's now a clear detection of [N II] 5755A
NII 5679 and [NII] 5755 lines

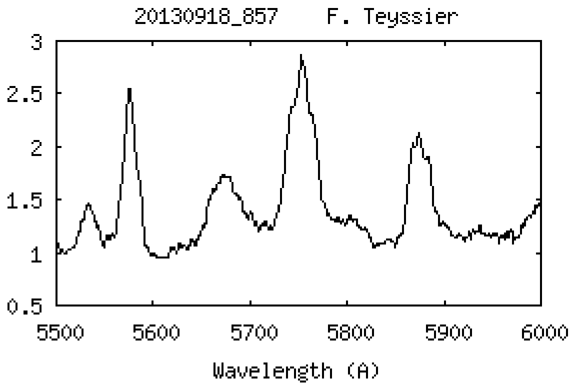
2013-09-11.788
C. Buil - eShel - R = 11000

Helium flash

18-09-2013

The last spectra from Sep. 18, now show He I 4923, 5876, 6678 (weak, on the Halpha wing), and 7065 so the ionization is progressing in the ejecta. The [N II] 5755 line seems to have been present as early as Sep. 8 but it's now not only quite strong but also shows the same profile as the other optically thin lines. The He I, in contrast, shows a strong emission but also possibly (at low resolution) an absorption at moderate velocity. The N III complex around 4640 has remained essentially unchanged, an indication that the UV is still marginally thick, but if it's not too much of a stretch it looks like He II 4686 may be present.

If you look now at the spectra you'll see one of the effects I was discussing earlier, something that shows up contrasting the Balmer and He I lines. The [N II] and [O I] aren't only forbidden, they're also ground state transitions. The others are from excited states which means their populations are determined by recombination and photons in the UV that populate these levels. For example, something I should have mentioned earlier, the Lyman series is responsible for the occupation of the Balmer line levels, Ly alpha couples to the n=2 state of hydrogen but Ly beta, because its upper state is n=3 -- if optically thick -- powers some (or most) of the emission on H alpha (n=3 -> n=2).

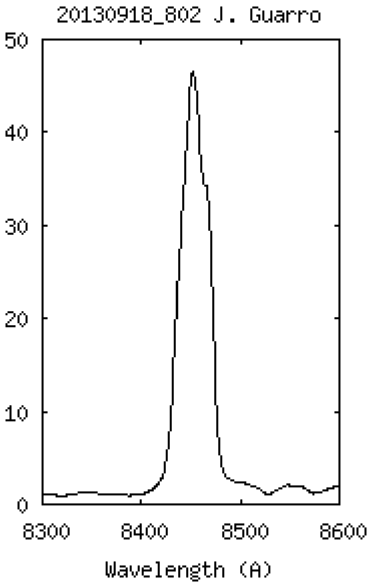


He I 4923, 5876, 6678 (weak, on the H alpha wing) , and 7065 so the ionization is progressing in the ejecta ….
The [N II] 5755 line seems to have been present as early as Sep. 8 but it's now not only quite strong

Now, again, think like a photon. If the ejecta are not spherical, these photons can leak out both through the main Balmer lines and also from the sort of surface that isn't a sphere. You see that in the highest velocity parts of the Balmer line profiles that are stronger than anything (by contrast) on the other lines that are intrinsically weaker (and also from much less abundant species). So the peaks have the same velocities but the relative contrast in densities between different parts of the ejecta you see more clearly in the Balmer lines than the others. The He I (and eventually He II) form in the inner ejecta so they have less visible "horns" since the line is weak from the outer ejecta.

These last spectra, at R ~ 1000, show the value of continuing the lower resolution work. Don't get frustrated that the details may not be as evident. If you have a resolution of ~ 100 km/s that's a good coverage of lines that spread over a few thousand km/s, remember that much of the UV work was based on IUE spectra with the same (or lower) resolution! For example, it looks now like the absorption on H delta is displaced from the line at about -2000 km/s, as it has been in other novae at this stage. But this is so far the only line that seems to show this (it can't be a blend with [S II]4076 since that's a doublet and has a high ionization energy, it's something seen in shocks of high velocity around protostellar jets, for instance, and in supernova remnants along with [S II]6713, 6730) but here the absorption seem real.

A few other diagnostics are important, in part because they're not yet seen. Neither [Fe VII] 6086 nor [Fe X] 6376 are present, so if there is any XR emissionn irradiating the ejecta it is still being absorbed by so much cooler mater in the inner part that it can't yet ionize the regions of lower density in the periphery. The [O III] 4363, 4959, 5007 lines are not there yet, again a strong pointer to the still high opacity in the middle and far UV. Yet **the O I 8446 remains strong, so there is a very strong pumping still by Ly alpha of the O I 1302 resonance line.**



I hope the emphasis on small things won't mean you're staring to lose the big picture. The reason for all these details is to give you an idea of how to diagnose this particularly ill patient. Like a prescription in Hippocrates or Galen, you look at all the symptoms before making a diagnosis. Look at which lines are visible noting the ionization state. At this stage it will be more important than which lines in a specific ion are there. Look at how the line profiles change with that ionization energy, this is the tomography of the body.

Dust formation episode ?

25-09-2013

There is an indication based ion the infrared and slight changes in the optical photometry that V338 Del may be entering a dust formation episode. If this is really happening there are several important things to note for observations in this next week. Note that this will be the first time since DQ Her, if really starting, that this stage will have been seen and it was impossible to follow that nova (in 1934) during the minimum. You all have the low resolution capability to keep going -- if you want to -- even through much of what could be a deep minimum (a drop of 5 or more magnitudes is not impossible). For high resolution observations, a question is where and how the dust forms.

We know something of this from the very old observation of V705 Cas 1993 that was observed in the UV during the start of the episode (http://adsabs.harvard.edu/abs/1994Natur.369..539S) but that was a chance observation not covered in the optical. First, assuming the ejecta are bipolar and inclined, the line profiles may change in a peculiar way: as the dust formation proceeds the portion of the ejecta (the outer part) should become opaque (depending on the geometry) and the blue part of the line will disappear. On the other hand, the whole profile will drop, especially for the N II line and He I lines, if the ejecta are more spherical because both parts of the line forming region will be absorbed. The UV has now been measured, we know how much energy is available for absorption by the grains and that emission in the infrared can be compared with that lost in the visible. If the two balance out (everything absorbed is re-emitted) we'll know that the ejecta are spherical (every photon wis intercepted in a spherical, completely opaque shell). On the other hand, if there is an imbalance, that will be due to the filling factor and geometry of the ejecta. So if this really is the start of the event, the ejecta will act as a sort of calorimeter, registering how the energy balance proceeds.

The changes in different lines (e.g. [O I] vs. He I) indicate where in the ejecta the dust is forming, although at this stage I have to say we don't know much -- only V705 Cas has been observed during such an event and in the UV at low resolution. When it happened there, the whole UV disappeared without the spectrum changing, as if a new "curtain" dropped uniformly over the line forming region. This time, it's anyone's guess and your work will be vital.

One more thing: none of the spectra showed ANY indication of molecular emission (CO, in the IR) or CN (in the optical, your hard work). If this nova forms dust, we will have learned something tremendous, that molecular formation is not a precursor event to dust condensation. If so, it is in line with the idea that reactions between neutral atoms and ions of carbon and silicon cause a sort of kinetic runaway in which the grains aggregate like fluffballs. No matter what now happens, without your spectra we would not know that this nova did not form the molecular seeds and that if this does condense it likely is particle-based process instead of a thermodynamic-like phase transition (the difference between agglomeration (kinetic) and homogeneous nucleation (like terrestrial clouds and rain, around nuclei in a saturated vapor) with apologies for referring to my own stuff but this paper is an example of what I'm talking about:

http://adsabs.harvard.edu/abs/2004A%26A...417..695S

see also

http://adsabs.harvard.edu/abs/2012BASI...40..213E)
http://adsabs.harvard.edu/abs/2007M%26PS...42.1135J

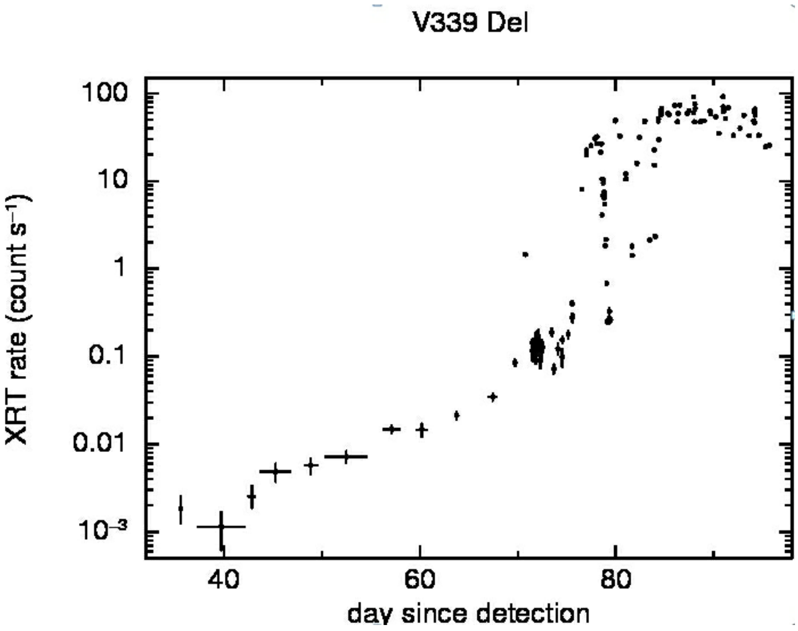
Only time will now tell but I hope you're getting some idea from this how important your observations have been and are. The important thing to note is that such events have been observed in supernova ejecta in early stages but, again, that is complicated by the very complicated ejecta structure. Here it is simpler and since we have the optical and UV just before this event the luminosity of the white dwarf and the continuum of the ejecta is known.

X-rays detection and strenghtening ionization

28-09-2013

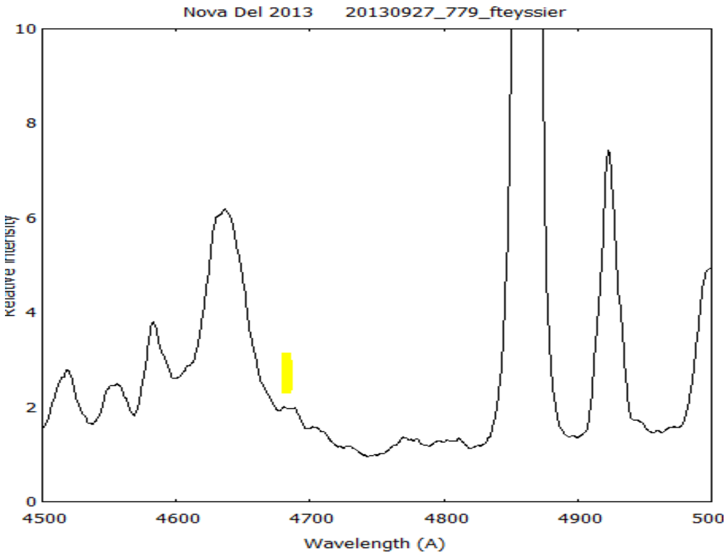
The Swift team has just announced the detection of X-ray emission from V339 Del (ATel #5429). They give a flux that is a very small fraction of the STIS detection: in the range from 1-10 keV (corresponding to a temperature of about 10 MK), 2.3 10^{-13} erg.s^{-1}.cm^{-2} while the UV (1200-3000 A) gives 1.7 10^{-8} erg.s^{-1}.cm^{-2}

This large ratio is at the start of the event but has already been corrected for hydrogen absorption. Interestingly, the Lyman alpha line in the UV observations seems weaker than would be expected from the XR data, a suggestion that **the ejecta are also not completely covering the central start but are covering the region of XR emission**. The nova remains very bright in the visible and this is a real problem for the XRT on Swift that suffers from optical leaks (it's the nature of the detector). Your spectra are indicating the **start of [O III] 4959, 5007 emission and also that He II 4686 is there. Now the He II 5411 line should also appear** (a check on the He II identification) and the disappearance of the Fe II and other curtain lines will be a very important (and pretty) thing to watch over the next one to two weeks.



To put this part in physical context, what's happening is an advance, from the inside out, of the ionization front as the WD emission strengthens. It's always the same basic picture, but the phenomenology accelerates now. **The ionization of the heavy metal lines removes the opacity faster than the change in density so the optical decline should also steepen (which may be mistaken for a dust-forming event), and the highest ionization lines from permitted transitions will have narrower profiles and come from the inner ejecta**. The outer part, and here the ionization state is a very good measure of the filling factor (how fragmented the ejecta are governs how much of the ionizing radiation penetrates to the outer part at this marginally thick stage); their profiles (*highest ionization lines*)at high resolution will be the best comparison with the [O I] and [N II] as a map of the ejecta structure. Remember, He II is from excited states but are all permitted transitions while the [O III] and others are low density transitions (forbidden).

To give some idea of what things look like in the UV I'm including the OS And - V339 Del comparison. The very narrow lines that go to zero in the V339 spectrum are all interstellar transitions (keep in mind that the resolution is about 100,000). For OS And, it is about 10000 (high resolution IUE from Dec. 1986). No extinction correction has been applied (no interstellar dust effects have been removed) for the comparison) so you can see the lines (e.g. He II 1640 + curtain, N III 1750, Mg II 2800, etc). The 1200A region is particularly important for the properties of the ISM and the ejecta -- this is where the Ly-alpha profile sits (you see there seems to be emission there, and in fact there is a P Cyg profile under the curtain on the line).



Your spectra are indicating the start of [O III] 4959,5007 emission and also that He II 4686 is there.

As you may know from the ATels, V339 Del was detected as a **supersoft source (SSS for short) last week**. To explain, this is when **the ejecta are finally transparent in the high energy range of about 100 eV to 1 keV**. Even though this would usually be thought optically thin because you're talking about X-rays after all (Superman notwithstanding), hydrogen has an enormous cross section at these wavelengths despite their distance in energy from the ionization edge (13.6 eV, 912 A) since the absorption cross section changes

X-rays detection and strenghtening ionization

28-09-2013

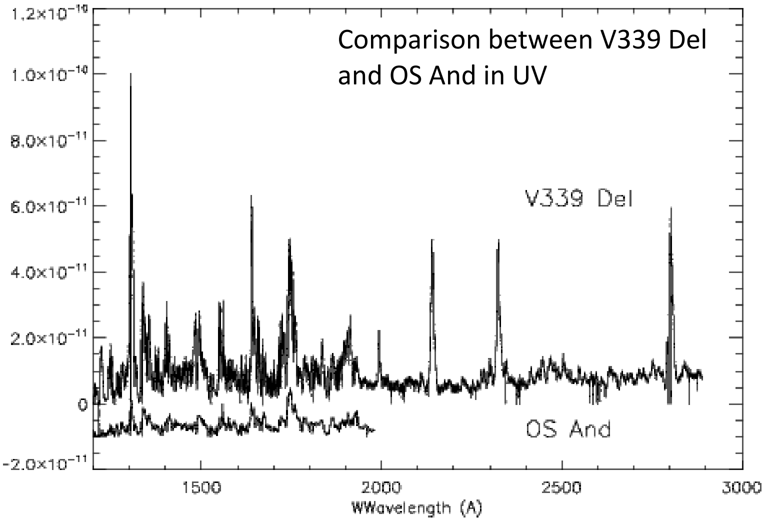
relatively slowly, by the inverse cube of the energy (so at 500 eV the cross section is lower by a factor of about 50000 than at 14 eV but there is so much hydrogen that this can still be opaque -- the column densities are high). This doesn't mean the source isn't there, on the contrary. As with the Fe curtain phase, this is when the effects of the XRs within the ejecta are observable even though there is no direct detection of the white dwarf. **The SSS is, as you recall, the signature of continuing nuclear burning on the central object after the explosion, when residual not ejected continues to process below the photosphere**. The high luminosities, this can be several thousand L_sun (hence enormous fluxes), and low envelope mass (hence not an enormous in situ absorption) leads to a photospheric temperature of a few 10^5K to 10^6 K for the duration of the event. **The larger the residual mass, the longer the source is active**. Its turn-on is at the same time as the explosion, but it remains like a covered "hot pile" until the ejecta finally thin out sufficiently to see the WD directly. The rise observed by us, as external observers, depends on the line of sight absorption, not the intrinsic absorption along a radial line to the WD within the ejecta, so it's possible to see the central star before the ejecta re completely thin if the ejecta aren't spherical (as is the case here). The slower rise we see is just the unveiling of the source along out sightline.

This is why I'd recommended noting if certain lines, formed in the ejecta at the periphery -- low density -- are detected: [Fe VII] 6086 and [Fe X] 6378. The latter is hard in low resolution spectra since it's blended with the O I 6364 line but it can show up. The former, and [Ca V] 5307, are ideal optical indicators of the hot source but they have to be emitting in those lines and, it seems from your latest set of spectra, that this nova it isn't. Yet. They must be there eventually.

The nova was behaving very well, for a degenerate, until a week ago when it went through a massive (factor of 10) increase in XR brightness for a few days before returning to its originally smooth rise. The spectrum also was temporarily very soft, meaning the range around 500 eV. The source, according to the Swift data we're collecting along with your spectra, confirms the soft nature but the column density indicated in neutral hydrogen is still an order of magnitude above the interstellar value. A minor mystery that, but the flare is much more intriguing. When the nuclear source is active, it seems to e decidedly unsteady, showing factor of 2 or so variability over hours to days. V339 Del is doing that. But such a singular brightening isn't normal. Whether it's from the ejecta or the source depends on the radiative transfer. At this point, I can't give you an explanation other than a suggestion based on your spectra. **There's been a dramatic shift in the structure of the line on the blueward side**. This significantly affects interpretation of the XR data since it's the side of the ejecta that shield the source. The rapid rise is likely the change in opacity in the UV of the Lyman lines that have now allowed an increasing emptying of the lower level of H-alpha so that side is completely optically thin. The red side of the profile hasn't changed much if you scale to flux (you can take the ratios of the profiles to see this in velocity). If the change in the XRs is a transparency effect it occurred very quickly, in a few days, that indicates an electron density of about (3-4) 10^7 cm^{-3} for that portion of the ejecta. This should have been seen in other lines and indeed it is -- **the He II 4686 shows the same (!) profile as H-beta and H-alpha** (comparing data from Graham, Potter, Buil, and Guarro). The low resolution data is ideal for showing the growth of the high ionization species.

If it's an ionization event, a spurt of emission from the WD, this would produce an ionization in the same timescale. So it will take a bit more work to give you a definitive answer but the observations you've all accumulated are a goldmine, this is -- yet again -- a stage not previously seen in thsi detail. And one more, important finding in your collective spectra: **He II 4686 IS there** [...]

The XR monitoring is continuing, there should be more very high resolution data when the weather permits at La Palma from the NOT (they've had some bizarre humidity and wind in the last few days, an observation on Friday failed) but as soon as it comes I'll write about it. There is an HST/STIS spectrum in the woks for mid-November, this should be the observation in the transition stage of the nova when the ejecta are free of the Fe curtain and we will get the velocities and abundances for the ejecta for the first time. There will also be an XMM/Newton XR spectrum at almost the same time (around 15 Nov).


Comparison between V339 Del and OS And in UV

About luminosity curve and dust formation

02-10-2013

Our friend continues a steady decline, with some bumps, despite the recent flurry of reports of dust formation. First, let me explain what the observations may be saying and then, to illustrate what you're seeing tin the data, add a few points about the ejecta structure.

Dust, being the solid state, behaves like bricks. Radiation is absorbed with an efficiency depending on the grain composition and re-emitted locally with whatever temperature the grain has to reach to balance the rate of absorption. This is referred to as "radiative equilibrium": if the temperature reaches a steady state while the irradiation is steady, it will get as hot as it "needs to be". The incident photons are energetic, optical and UV. But they are diluted by distance from the emitter. So the energy density is lower than near the central WD or even the inner ejecta. Thus the rate of absorption is lower with increasing distance. A solid doesn't behave like a blackbody in its spectrum, but the emission rate depends only on temperature so the farther the grain is from the central source the lower its temperature will be in equilibrium. This is almost independent of the size of the grain so it could be a peanut or a planet, the energy per unit area (flux) is all that has to balance (the book-keeping is: what comes in, goes out). Some critical temperature must be crossed for the solid to be stable, otherwise it will evaporate by heating (loss of atoms), that is the so-called "Debye temperature" below which the solid ()or atomic cluster) remains structurally intact.

This, for silicates and various forms of carbon (usually called "astronomical graphite" because of laboratory analogies) is about 1500 K. It means, in a kinetic (particle) sense that collisions with this relative velocity (the sound -- or gas -- speed corresponding to this temperature is about 1 km/s) can bind (stick) and nuclear clusters remain stable. As the cross section increases the quantity of energy absorbed increases so while the temperature doesn't change the luminosity does. Since the grains reach a low temperature, they radiate in the infrared and that's the tell-tale signature of their presence. It isn't only a drop in the light of the ejecta photosphere and WD. That depends on viewing angle, how you see through this growing smog. But the infrared is transparent so you see the cumulative radiation from the grains as an increase in the part of the spectrum where a solid would radiate. The controversy now is whether L and M band photometry (longward of a few microns) has increased sufficiently to signal the presence of this absorber. Two groups seem to agree on this now but as a recent event, around Sept. 29 but this requires further data. If we're in that stage, it's just preliminary and recall that neither CN nor CO were detected in the nova when the Na I lines were strong.

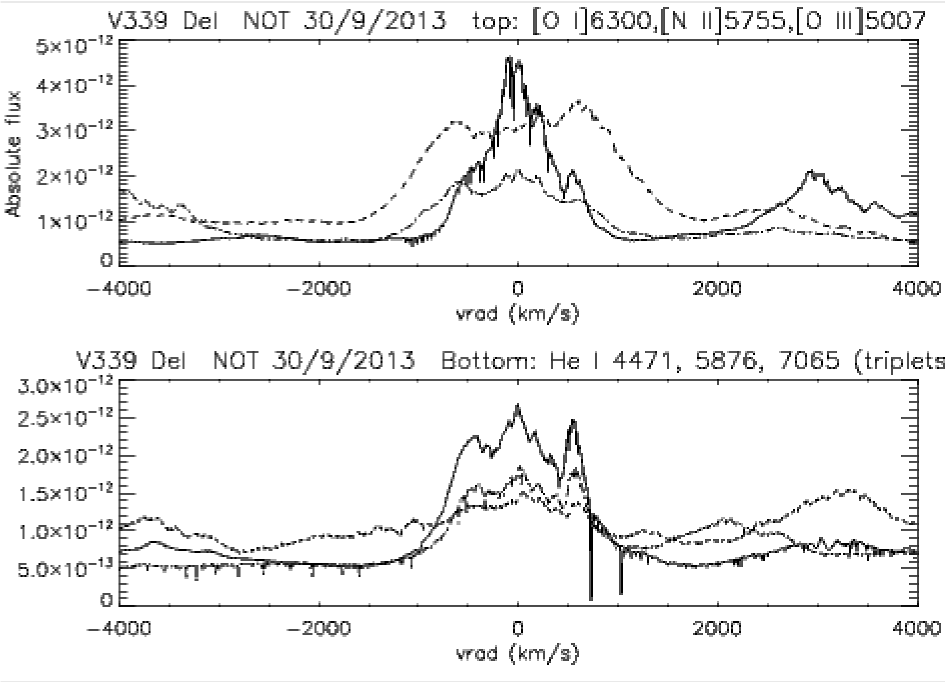
The cross section, if dominated by direct absorption, also has certain characteristics. Silicates (SiO complexes) are rather opaque at 10 and 12 microns (there's a peak in the broadband emissivity there) and rather inefficient absorbers in the UV. In contrast, the carbon complexes are very good absorbers at around 0.20 - 0.22 microns (2000-2200A) in the uv so they absorb where the irradiation is maximal and radiate less efficiently in the IR because they lack the bands of the silicates. Thus, graphite (carbon) grains will be systematically higher temperature in equilibrium than silicates. It's likely that the grains will be carbonaceous so they'll be hotter than silicate grains (that are inefficient absorbers, efficient radiators in the peak emitting range).

This all relates to where the dust will form. To date, the NOT profiles are the same as they were, no obscuration by the grains. This may change we'll have to wait a bit. The main interest now will be the process itself, if grans are there. But there's another, albeit slower, physical effect that we can now see.

About luminosity curve and dust formation

02-10-2013

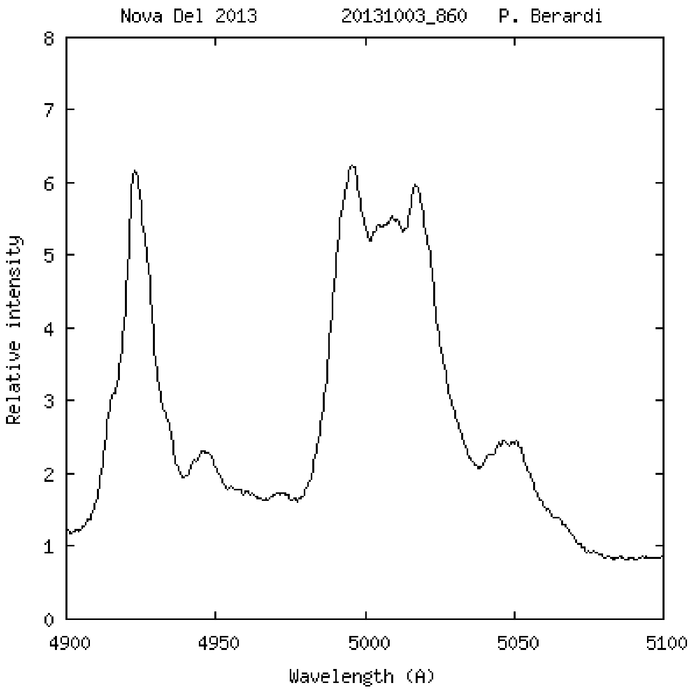
Lines profiles



Since the ejecta are ionizing now, the profiles of different ions will trace out different parts of the ejecta at the same time. In the enclosed figure, you see this. The top is neutral oxygen, ionized nitrogen, and twice ionized oxygen (the 5007 is a doublet with 4959, that is just barely present) and has the greatest velocity width and a unique profiles that resembles what was seen at the start on the Balmer lines. Yes, **the [O III] lines do seem to be there.** Since these are forbidden transitions, they trace low density ionized gas and the wings suggest these are in the outer portions of the ejecta. The [N II] is intermediate. And now the He I line profiles share the Balmer line structure, these require a very a high excitation energy so suggest that recombination formed these. The C II 8335 line is also now present, but there's nothing yet at the [Fe VII] or [Fe X] optical lines.

There's a flight scheduled for SOFIA and we'll keep monitoring the spectrum. Please don't give up now, remember that if we're ever going to understand such a simple thing as a nova, a lot of hard work will be preceding. The XR/Swift data to date requires about a factor of 10 higher column density than derived from the UV Lyman alpha line, have in the whole ISM toward the nova.

The XR turn-on was fast as far as can be known from the descriptions.



the [O III] lines do seem to be there

2013-10-03
Paolo Berardi Lhires III 600 l/mm R = 2500

29-10-2013

The **Hβ profile is the key for the Balmer sequence** and you see there are **substantial differences with Halpha**. This is an ionization effect but I haven't sorted out the details. the Hgamma looks weird, and that's another important indicator. It's blended with the [O III] 4363 line, the upper transition of the nebular triplet that gives a measure of the electron density. **The profiles for the [N II] and [O III] and He I lines are almost the same, but the [O I] 6300, 6364 are showing a completely different, narrower, more symmetric form so the ionization is clearly highly structured**. Some of the features agree but it's formed in a more limited velocity range 6678 which now shows the same profile as the other He I lines (a lovely result from the last spectra from you and Edlin).

18-11-2013 - Light curve

The light curve paper by Strope et al. http://iopscience.iop.org/1538-3881/140/1/34/pdf/aj_140_1_34.pdf is useful in this regard. Their "class P" is an extended state that can last for a hundred or so days, this nova entered that hiatus a bit earlier than many but not all. The odd thing is that most of the novae on their list are either ONe or recurrent types. V339 Del doesn't fit. It didn't show oscillations, or "outbursts" (short term increases during maximum). There's one other analog, CP Pup (which, interestingly, is one that Elena has been working on recently) that could be similar. The transition to the SSS visibility was quite abrupt, it would fit a high inclination to the line if sight that became transparent with a rapid reionization (when the He II appeared) , but that is just speculation now.

Actually, many novae go through a protracted period of light curve stability. For instance, V705 Cas, after the dust event, was very stable for a long time. Now the XRs are at their peak, there were oscillations for the first weeks but it seems to have settled down and now there is a hint of a slow decrease in the soft band. I've been keeping up with the spectra from the database, the low resolution is difficult to judge in some cases because of the profile changes that are not resolved except for He I

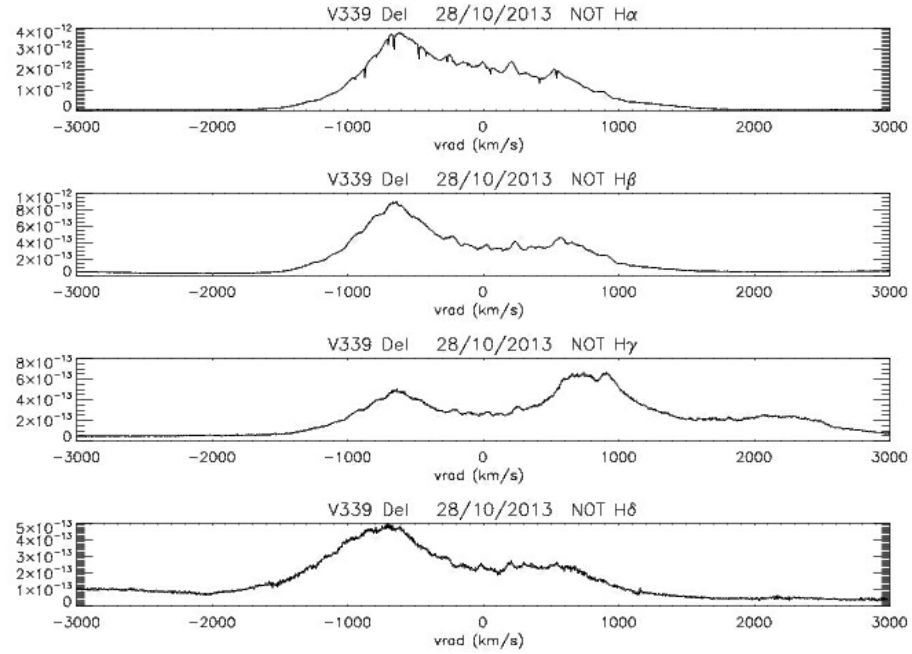
20-11-2013

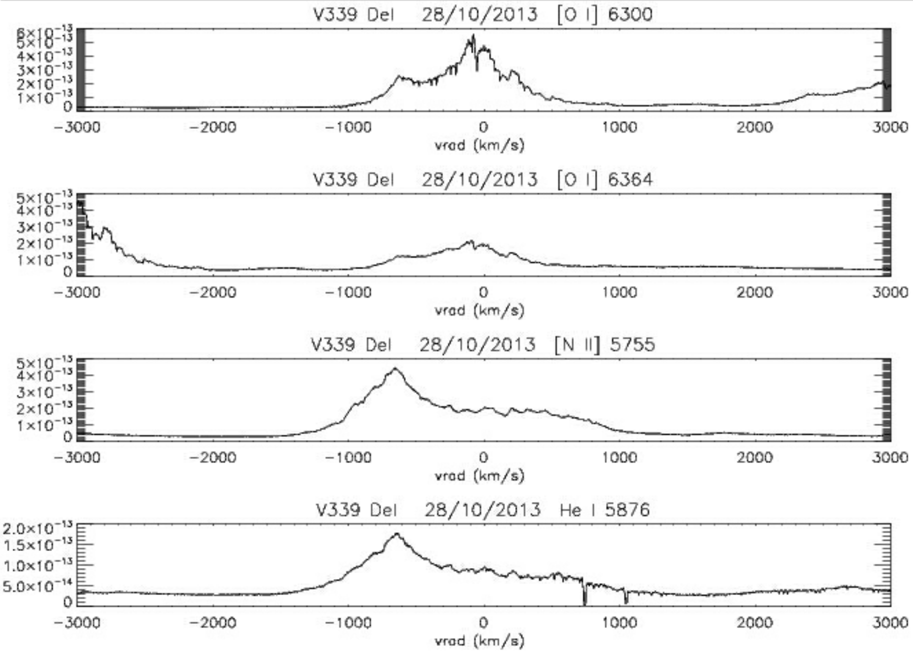
I've been working through the latest spectra. Just for the hell of it, **I ran a model for the [O I] and used it to see if the asymmetry in the profile could be quantified.** That's the enclosed figure. Using the usual maximum velocity, 2500 km/s (from the UV) and comparing with the observation from the NOT on 28/10, something interesting comes out. There wasn't an attempt to fit things precisely. This time I used the raw data from the model (no sum, no smooth, so this is one statistical realization). If you normalize and subtract the profiles then the lowest density region is on the red side; this is opposite the Hbeta and Balmer profiles (and others too). So it seems to be a clue to the asymmetries in the ejecta. Again the inclination is moderate, I haven't yet done the full radiative transfer solution but that will come after we have the STIS spectrum. As usual, I'm sort of shocked when the models work so well, they really shouldn't be so precise!

For the plateau phase, there can be several reasons, all of which are connected with the interplay of the illumination from the WD and the expansion. The density is dropping but the ionization is increasing so there is a point where the emission lines (depending on which) can remain constant. The higher ionization stages will be like this, your plot of the [O III] is a good example. We don't yet have access to the He II cleanly from the ARAS data, that's one of the hopes for the NOT and Ondrejov spectra (to separate the profiles). If the [N II] is constant, the N III 1751 and N V 1240 should be increasing. The anomaly is always O I but the change in the 8446 line is important. An interesting feature of the XRs is that they're now very stable, nothing like the coronary we saw earlier in the month.

There are two things that will be important to see now, and you all are in the position to see it. The

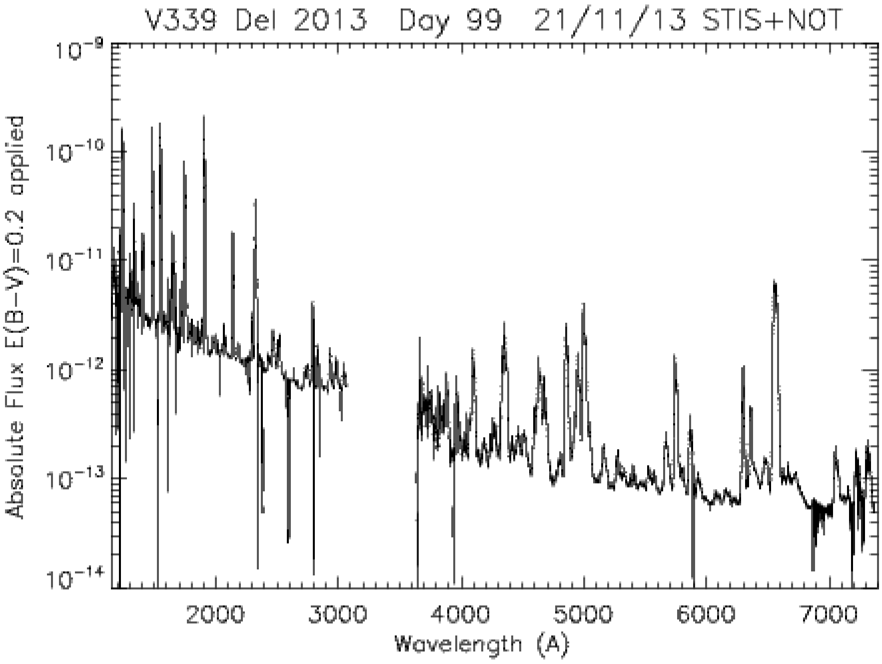
Halpha is so broad that he [N II] 6548, 6583 doublet is masked. That leaves only [O III] as a density indicator. But in the next weeks, before the nova is inaccessible, there could be evidence for the reformation of an accretion disk. Even low resolution data will be important here. The He II line is important, but the continuum is too. If the weather ever clears this is worth calibrating, a signature is a rise toward the blue. We haven't seen this with certainty in any nova to date but it has to happen sometime!





UV Spectrum and nebular phase

23-11-2013



The figure is the combined result of the (virtually) simultaneous observation of the nova with the NOT (optical) and HST/STIS (UV). It should illustrate why your low resolution observations are so important, especially if they can be calibrated. This is a full portrait of the energy distribution from about 1 to 10 eV (in other words from between 0.1 and 1 micron). You see that now, when corrected for an extinction of E(B-V)=0.2, the bulk of the emission is shortward of the atmospheric (ozone) cutoff (almost by chance, it's the small gap between the spectra). **The strongest UV lines are N V 1240, O I 1302, C II 1335, a complex feature at 1400 including Si IV, O IV, and possibly S IV, N IV] 1486, C IV 1550, He II 1640, O III] 16667, C III] 1909, N II 2146, C II 2324, Mg II 2800** with the deep absorption lines (that look like defects) all being interstellar absorption. We were not able to get to 3300 A with STIS or we would have covered the O I line near 3000 A, but there's enough to show the overall picture. Both N and C are very strong, there's no Ne in any transition.

As I'd written earlier, the UV is now where the flux is emerging, as it was "inside" the curtain. The XRs are also a significant fraction o the total. As a comparison, the nova is now about 30 times fainter in the 1200-3000 A range than it was on 19 Sept when we took our first UV spectrum, that amounts to a drop (equivalent) of about 4 magnitudes (well, 3.7), with respect to the drop in the optical. This because the flux peak is shifting toward higher energies.

The comparison of line profiles is also included to show how different ions trace the structures when the ejecta are transparent. **We're now securely in the nebular stage so the lines, being optically thin,. provide a view through the entire ejecta.**

We are now **well into the nebular phase**. **The emission lines of all species show ionizationdependent structures but within a single ion the profiles are the same**. This maps the ejecta structure and leads to a three dimensional view that is especially important (for instance, in comparison with HR Del 1967 for which the ejecta are superbly resolved). A STIS/HST spectral sequence (1150 - 3050A) with a resolution of > 30000 was obtained simultaneously with a NOT observation (3700 7400A), an XMM/Newton XR pointing, and a number of your spectra. What's emerged from the UV is hat the emission lines are all asymmetric, with profiles similar to that seen in the optical (with the -1000 km/s peak stronger or dominant relative to +1000 km/s; for [O II] only the blue is seen) and that **all of the ions with ionization potentials above He I (about 25 eV) have the same profile**. There are no absorption lines other than interstellar, but those are a key to setting the continuum level since they're purely absorption and entirely foreground (not in the ejecta). This shows that a continuum, seen in the optical, is present and strong in the UV. At this stage, it's likely a mix from the white dwarf and the thermal emission from transparent gas in the ejecta. If it's due to the WD, which is now a strong (but as of today slowly declining) supersoft source (SSS), then it indicates an intermediate temperature since the slope in the UV band is quite visible. As a side note, the hotter the central source the more uniform the continuum in longer wavelengths will be singe the strongest change is near the maximum. While for now this seems just a technical point it's much more. The UV+optical luminosity, if a distance of 4+/-0.2 kpc assumed (which we have from the comparison with OS And 1986) and a reddening of E(B-V)=0.2, then the luminosity is the entire spectrum at lower energy than about 13 eV (i.e. roughly the ionization of neutral hydrogen) is only about 2000 L_sun or less. The XRs are very bright, the reported uncorrected integrated flux from Chandra is about equal to the UV/optical corrected value so it must be much stronger. A hopelessly naive assumption, that the emission behaves like a blackbody, provides a clue (but one to take -- as for any comparison with a Planck function -- with much caution) is that only about 5% of the flux has been measured in the longer spectral interval so the luminosity could really be quite high. In the absence of any spectral indicators of the WD temperature (or even presence other than the XRs) it's still a "to be seen eventually". Some lines might be masked by ejecta emission, for instance, but that could remain true for months to years.

You might be wondering if an accretion disk has reappeared yet. The 0.1-10 keV range (reported for Chandra observations by Nelson and collaborators) shows nothing in emission! OK, there's a reported continuum but there are no P Cygni type lines (indicative of a stellar wind). On the contrary, strong absorption was seen (this about a week before the STIS observations) . That's not so remarkable if it is photospheric, but all lines are blueshifted (!) by 1000 km/s or so. Strangely, this is the same velocity at which we see the asymmetric emission peaks. So think of what would happen if the outer ejecta, which have lower number density and higher expansion velocity, are nebular (transparent) but the inner, hotter parts of the ejecta are still marginally optically thick in the lines. Then what you should see are lines shifted, uniformly and completely, to the velocity of the inner ejecta. In this case, it's reasonable to take 1000 km/s. Thus, and this seems to very lovely part of the future work, as these features turn from absorption (by absorption I also include optically thick resonance line scattering) to optically thin emission, we will get a new, independent estimate of the mass and abundances in the ejecta. To encourage you, the Chandra and XMM/Newton data have about the same resolution in XRs that you are getting in the optical. I may have mentioned that in T Pyx this was detected only very late, after 300 days, and here we have nothing in the intermediate ions (e.g. N IV]1487, N IV]1718) that we saw in detached absorption features, but it's a new and essential probe of the ejecta. If this works, it will allow precise information to be obtained about heavy element abundances, the yields from the explosions, the correctness of the nuclear reaction modeling (nucleosynthesis is the sort of radioactive waste from a reactor gone bad, as you all know). There's been one claim that dust formed (when have you heard that one before?) but t's likely a red herring (we'll know once there's a SOFIA flight, the aircraft is grounded now for engine problems).

So what we have is: excited state transitions: O V] 1371, N IV] 1718, He II 1640; some of the strongest UV transitions detected: N V 1240, O I 1302, C II 1335, N IV] 1486, C IV 1550, He II 1640/2733, O II] 1667, N II 2143, C III 2297, O II 2470, O IV 2510/2517, Mg II 2800, C II 2837, F III 2932. The complex blend at 1400 is primarily O IV 1401 but likely has a contribution from S IV; the Si IV doublet is absent.

There's nothing particularly remarkable about the nova properties, the electron density is now about 1E7/cm^3 (so still marginally high), there's an indication that the filling factor (the knottiness of the ejecta, as seen on your profiles o Halpha, for instance), is about 0.1-0.5 (in other words, not large, not small, intermediate), and the ejecta mass is about a few 10^-5 M_sun, consistent with other classical novae but that will become more precise soon. Once this is all over, the next step is the detaled abundance analysis, He line profile modeling, and the writeup of the first paper.

Your spectral sequences will be the check against which all detailed modeling will be done since the density, quality, dispersion, and coverage make then precious.

UV Spectrum and nebular phase

01-12-2013

It's been too long since I last wrote, and there have been significant developments to explain. As ever, the collective contributions (ARAS gruppen) are wonderful, it is especially important to see the move to also obtain spectra longward of Halpha. We are now well into the nebular phase. The emission lines of all species show ionization- dependent structures but within a single ion the profiles are the same. This maps the ejecta structure and leads to a three dimensional view that is especially important (for instance, in comparison with HR Del 1967 for which the ejecta are superbly resolved). A STIS/HST spectral sequence (1150 - 3050A) with a resolution of > 30000 was obtained simultaneously with a NOT observation (3700-7400A), an XMM/Newton XR pointing, and a number of your spectra. 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As a side note, the hotter the central source the more uniform the continuum in longer wavelengths will be singe the strongest change is near the maximum (1) . While for now this seems just a technical point, but it's much more. The UV+optical luminosity, if a distance of 4+/-0.2 kpc is assumed (which we have from the comparison with OS And 1986) and a reddening of E(B-V)=0.2, then the luminosity is the entire spectrum at lower energy than about 13 eV (i.e. roughly the ionization of neutral hydrogen) is only about 2000 L_sun or less. The X-Rays are very bright; the reported uncorrected integrated flux from Chandra is about equal to the UV/optical corrected value, so it must be much stronger. A hopelessly naive assumption, that the emission behaves like a blackbody, provides a clue (but one to take -- as for any comparison with a Planck function -- with much caution) is that only about 5% of the flux has been measured in the longer spectral interval so the luminosity could really be quite high. In the absence of any spectral indicators of the WD temperature (or even presence other than the X-Rays) it's still a "to be seen eventually". Some lines might be masked by ejecta emission, for instance, but that could remain true for months to years. You might be wondering if an accretion disk has reappeared yet. The 0.1-10 keV range (reported for Chandra observations by Nelson and collaborators) shows nothing in emission! OK, there's a reported continuum but there are no P Cygni type lines (indicative of a stellar wind). On the contrary, strong absorption was seen (this about a week before the STIS observations). 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Once this is all over, the next step is the detailed abundance analysis, he line profile modelling, and the write-up of the first paper. Your spectral sequences will be the check against which all detailed modelling will be done since the density, quality, dispersion, and coverage make then precious. There are now Hamburg Remote Telescope observations (between 15000 and 20000 resolution with 3700 to 9000 A coverage in two groups of echelle spectra), about 20 days in the sequence from 30/8 to 7/11, but without your data, well enough said. I'll stop now, and some spectral plots will be coming soon.

[Fe VII]

17-12-2013

For new results from this morning's NOT spectrum, confirming the ARAS spectra that hinted at this, **there is definitely [Fe VII] 6087 with the He II 4686-type of profile.** The line wwas likely already detected a month ago, when the SSS was strong after the first oscillations, but the profile was weak and there was only a hint at lower resolution. [...] The only changes are on the inner (|vrad|<1000 km/s) portions of the Balmer lines and other permitted lines, but large changes (50%) in the blue to red ratio for the forbidden lines (e.g. [O III] 4363, 4959, 5007, almost none for [N II]). Still too broad an Halpha to distinguish the [N II] 6548.6583 lines but the Balmer lines are narrowing slowly. There's **still a strong continuum, essentially invariant since the last observation with NOT on 21/11.** No new features, the [Ar III] 7135 is very weak if present.

V339 Del , a review at the end of 2013 and V1369 Cen eruption

28-12-2013

So we arrive at the end of the year and the of the visibility of V339 Del for this year. It should come out from solar avoidance again in March. In the interim, as you all know, in this past month it's been surpassed - *in brightness* - by V1369 Cen, discovered about four weeks ago. Before continuing, there is one important thing to note here: without this campaign, V1369 Cen would be studied in a vacuum.

In the past month, during the last stages of fading of v339 Del, we've seen -- finally -- the higher ionization stages of the ejecta. From your spectra and from the NOT, there are indications of the **[Fe VII] 6087 A line as early as mid-Nov.** but this is now clearly resent and ill be the ``line to watch'' in the months after emergence from sola obscuration. **The He II 4686 A line is strong and of a similar profile, indications that the ionization and emission are still powered by the continuum of the central engine (the WD)**. Now, depending on the development of the X-ray emission -- whether the source is still ``on'' when we see the nova again in the early spring or has shut down and is in the cooling phase -- the ionization of the ejecta will display changes dominated by the interplay of expansion and photo-processes.

Perhaps now we can reflect on what we don't know from all we'e collectively seen and learned *this* nova because it prepares us collectively for all those to come.

For V959 Mon 2012 we had the disadvantage of not having seen the peak of the outburst, the mirror image of what's happening now for V339 Del. Having missed the Fe-curtain phase, we did not see the earlier optically thick stages of the ejecta that probed the recombination following the fireball. Instead, for V339 Del, we have an exquisite picture, in minute detail, of every moment of that period. It shows that **many of the phenomena seen in the earlier outburst of the recurrent nova T Pyx, in 2011, are *not* peculiar to that system but actually generic. The structure that you observed in the absorption troughs of the P Cyg lines, the disappearance and then re-appearance of the detached absorptions on the He I profiles, the Na I doublet complexity, are all standard features**. Now, for V1369 Cen, we're seeing the same thing, albeit with more complex structure and higher velocities. But *why* ? What imposes this feature of the ejecta? **The narrow lines are well known from other novae but the optical depth changes show that what starts out as a broad (hundreds of km/s feature decomposes on a drop in column density into an ensemble of individual components**. It appears that the filamentary character of the ejecta is far more complex than it seemed. But there is larger scale structure, otherwise we wouldn't see these distinguished features. The same lines appear on the Ca II H and K lines, ion resonance lines, as Na I, despite these being different ionization states they are both from high column density, low temperature gas. Again, why? There has to be something pointing back to the explosion.

In V1369 Cen we're seeing a very complicate light curve, one that is reminiscent of T Pyx in its excursions in V. The gamma-ray emission we saw in V339 Del, and V959 Mon (remember, this character was first seen in very high energy emission *months before* it as detected optically, was confined to a brief interval near peak. For V1369 Cen that's not so clear. But perhaps the difference in the photometric development -- along with the line profile changes -- will allow an eventual resolution of the structure question.

The second is for the future. V339 Del was spatially resolved very early, within a week of outburst, at optical and near infrared wavelengths. That data has yet to be digested thoroughly but for now it seems consistent with different interferometers (CHARA in the north, VLTI in the south) found different expansion rates that could indicate an axisymmetric (bipolar) sort of structure. When the nova emerges again, it will be after almost as long an absence as its presence, so it should be considerably more extended and *may* be accessible to direct imaging from groundbased telescopes like the Keck, VLT, or Gemini. The same is true for V1369 Cen, although there is no northern partner to provide that information. It isn't unthinkable that a direct comparison will be possible with HR Del 1967, for which HST/WFPC2 images were obtained in the '90s (nearly 30 years after outburst). Remember, once the central source ceases to control the ionization the gas continues to radiate by recombination, although always more weakly, so the line emission traces electron density. The advantage of brightness, of nearness of the nova, is purely geometric -- the closer it is, the easier the resolution of the ejecta. The same holds for the radio, interferometric observations of V339 del are the basis for interpretation of the more sparsely sampled V139 Cen cm-wavelength data.

The third is sill open: there is now accumulating evidence that V339 Del really *did* for dust although it isn't yet clear how much. The latest observations, by Fred Walter using near infrared spectra, is in strong support of that contention from earlier bolometer photometry in the IR by the Minnesota group. How much and where, and when isn't known -- yet -- but you all worked like daemons to cover the CN lines during the optically thick stages and nothing emerged. Neither was CO observed in the IR as it was for V705 Cas. So there is a crack in the edifice, perhaps molecular precursors are not necessary -- or are not visible -- if the ejecta have the right geometry. The dust didn't produce a DQ Her-type event, but the ejecta aren't spherical, so now to see what happens in V1369 Cen. I wish I could give you all a neat summary of this but it's new territory, as we've seen so often in this nova.

The line profile changes in the last month for V339 Del trace the electron densities. There is a hit of the [N II] 6583 A line (the analog of [O III] 5007 A on the wing of H alpha and a first trial in getting the electron density by using the ratio [N II] (6548+6583)/5755, along with the tracer [O III] (4959+5007)/4363, gives a limit on the density in the range between -1000 and 1000 km/s of (6-10).10^^{6} cm^{-3} but the temperature is uncertain. OK, this is a technical point but by combining the emission from lines whose de-excitation is from collisions with electrons in the ambient gas and otherwise only radiative de-excitation, the branching ratio (ratio of the different ``exit channels'' for the photons) shows the competition between the rates of collisional de-excitation and radiative decays for the excited states. The advantage of these two indicators, even if they arise from different ions, hence from different parts of the ejecta, is that they're *similar* enough that the differences can be understood by using the line profiles. You see, that's why spectra are so important -- in such rapid expansion, with so large a velocity difference between the inner and outer parts of the ejecta -- every piece of the volume leaves its radiative imprint projected along the line of sight. So if two profiles are similar in structure, they come from the same places in the ejecta and the differences are because of the peculiar sensivities to the ambient conditions of the transition in question. None of this is handwaving -- we have mow the necessary plasma diagnostics to proceed systematically with the time dependent analysis of the ejecta.

Here we turn again to the homogeneity problem: is the gas well mixed or not? What happened during the explosion?? **If V1369 Cen is showing multiple ejection events, the comparison with V339 Del will be an incredible chance to see if individual events are similar in the nuclear waste produced and expelled.** *We can, irrespective of whether V1369 Cen is a O or ONe nova, to do a quantitative compare-and-contrast analysis with any of the subtypes based on the last three years of novae*. Here I really mean **we**, you're all part of this! Those observing V1369 Cen now, those who have followed with such zeal V339 Del.

This has gotten very long and it's really only the beginning. The pair will remain visible *for years* at a level accessible even with small telescopes, albeit at low resolution. It will be worthwhile trying to restart observations when V339 Del re-emerges, we don't know what it will be in at that time.

And now it's time to reflect on all that's been accrued in this spectacular archive and begin the detailed analysis. You're all part of that now. For those who have had the stamina to reach this point in the notes, for a *whole community that has reaped the rich rewards of your collective effort, sincere thanks from the heart for ll you have done. The first paper is now being outlined, that will be sent around to you, and summaries of the analysis will be coming in the next month.*

The new year begins with a new era in the study of this elusive phenomenon. You are all the ones who have made that possible, turning voyeurism into a fine art through spectroscopy and thought.

Best wishes for the holiday and very best wishes for the New Year.

Steve Shore with ARAS observers at WETAL 2013 Lyon

Status of novae at the beginning of 2014

2014, Feb.

I t's been a long silence, for which I apologize to all -- this has been a pretty intense period for us all with too many novae at once (if that's possible). So let me update the situation and explain some of what is now happening.

V745 Sco

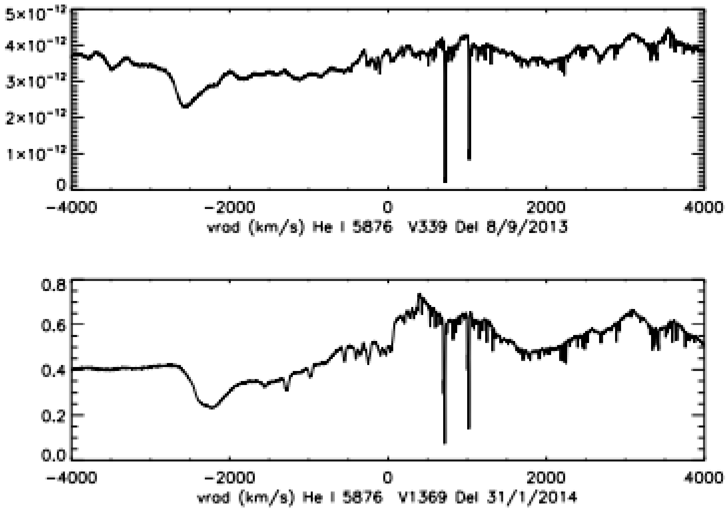
As discussed earlier, the recurrent nova V745 Sco was a shortlived event although it continues to be observable in XRs with *Swift*. The low level emission is only at energies about several keV, indicating that the shock is still with us but that the optical emission is well below the level of the red giant spectrum and unobservable. During the first roughly two weeks of the outburst the high ionization lines never developed broad wings, although they showed some acceleration (especially [Fe X] 6374 Å). There are still spectra coming from CHIRON (Fred Walter's observations) but the NOT specta show that the highest ionization never displayed the V407 Cyg sequence of post-shock broadening. In other words, the ejecta in this symbiotic-like recurrent nova seem to have undergone breakout quite quickly relative to the more extended traverse of the companion's wind in V407 Cyg. The V745 Sco event resembles RS Oph, except for the quicker soft XR turnoff (which might be a signal of a more massive WD, we don't know), where the system and wind are more compact that the very extended environment of V407 Cyg. In th next set of notes I'll try to go into more detail about this subclass. For now, one comment. In these novae we see what is likely a fast forward of the symbiotic nova vent. Whether explosive (like these) or impulsive (as in Z And or AG Dra or CH Cyg) the ejecta from the WD environment is structured by its passage through the wind and only the relative total energy seems to make a difference in the phenomenology. In the symbiotics there isn't enough kinetic energy,. or perhaps simply a lower shock velocity, to produce detectable γ-ray emission (for V745 Sco and RS Oph this was about 4000-5000 km.s^{-1}, for the symbotics with bipolar ejections this is a factor of 4-5 lower). Otherwise much of the behavior is the same, especially the high ionization lines.

339 Del

The nova re-emerged from solar obscuration more than one month ago and immediately posed a puzzle: the soft X-ray source that has dominated the previous months before the end of the year 2013 was gone. In early Jan., the He I spectrum was well developed with the lines extending to about -1500 km.s^{-1} (spectra from Martin Dubs) with similar profiles to the Balmer series (nearly flat-topped and symmetric). This is in striking contrast to the forbidden transitions, especially [N II] 5755 Å and the [O III] lines (4363, 4959, 5007 Å) that are more intense in the approaching side of the line (-1500 to -500 km.s^{-1}. The forbidden lines, those of the higher ionization species tan H I, are also broader. But this was stil when the X-rays were being strongly emitted. The current energy distribution is mainly detected, however weakly, above about 1 keV. To explain what this means, consider the post-explosion sate of the WD. There remains a thin shell, below the photosphere (buried within the envelope) that continues to burn until the accreted hydrogen has exhausted. The mixing continues but rather weakly, porting matter from the WD envelope and providing catalysts for the CNO cycle. The presence of a source, illuminating the envelope in XRs, at a temperature of several 10^5 K implies to important characteristics of the WD: it's massive and has a relatively long thermal timescale, and there remains a portion of the accreted layer that both screens the burning zone from view and responds structurally to the shell source. This thin layer, whose properties have been a bone of contention for a decade, must be H-rich and the only source for that matter is the accreted -- but not completely expelled -- stuff from the companion. But whether this is purely relic from the pre-explosion stage or is being supplied again by accretion disk deposition from the now regenerated flow from the red companion, is the main problem. How a burning zone would behave in the presence of a re-established accretion disk and its attendant boundary layer, where the inner disk joins onto the WD, is a fundamental unknown in the picture. In effect, what you are seeing now is another venture into new territory: many old novae are known and some have been followed into quiescence but here we have a range of bolometric (luminosity) and thermal probes in the combination of the UV and optical along with the XRs. The turn-off of the soft XRs, with the consequent cooing of the WD, depends on its mass and a rapid timescale is usually taken to mean that most of the accreted material is blown off in the ejecta and the remaining stuff is an excess, increasing the mass of the degenerate. Again, since there is a strict upper mass limit to a star with the pressure-density law (called the equation of state) of an electron degenerate gas, any increase in mass pushes the WD progressively closer to its stability limit and *it may* induce collapse to form a supernova and neutron star. The latter is possible because at nuclear densities (around 10^{14} g.cm^{-3}) the particle interactions produce a repulsive force when the nucleons -- protons and neutrons -- are very closely packed that makes a neutron star stiffer than an electron degenerate star. The maximum mass of the WD is about 1.4 M⊙ while that of a neutron star is close to 2 M⊙. This has been one of the reasons for the continued interest in the high energy and cosmology communities in novae: they are one of the inevitable avenues to SN Ia *if the mass keeps increasing despite induced explosions*. We simply don't know and, irrespective of the other beautiful ensemble of physical processes we see in these systems, their ultimate fate is still an open question. Having now the indication that their ejecta are neither densely filled nor spherical, the detailed dynamics of the explosion make a big difference in how much mass is actually processed and expelled and how much remains to continue burning. The length, then, of this *supersoft source* (SSS) stage becomes the one unambiguous measure of the amount of hydrogen remaining. You see that once the nuclear shell ignites, and rapidly turns turbulent (this is not a process that continues in the ejecta where all motions are frozen out by the supersonic expansion) the remaining hydrogen is completely redistributed by the random motions of the convection on timescales of a few kiloseconds, even longer than the nuclear decay time of the out-of-equilibrium abundances of the β-unstable nuclei (about a few hundred seconds).

With the cessation of the SSS, the ejecta once again recombine. But since they are differentially expanding and the density drops precipitously, as an inverse power of the time (as t^{-3} for ballistic motion) this recombination is throttled and the ionization freezes-out. This is the stage we're now in. From here on, the rate of change of the spectrum should be quite slow so cadences of a month or even longer will be quite enough and very useful. Since the ejecta are nearly optically thin throughout, and near the densities at which the forbidden lines become unique density tracers and the temperature slowly decreases, the geometry is completely revealed by the line profiles. I say *nearly* because the differences in the species' profiles, still evident from the Balmer to He I to forbidden line comparisons, suggests that there are still rather dense knots within the ejecta that dominate the H I line formation throughout.

He I 5876Å in V339 Del (top, NOT) and V1369 Cen (bottom, FEROS at almost the same time in their outburst. The start dates were 14/8/13 and 5/12/13, respectively. Both show the detached, shortlives He I absorption feature on all of the triplets (and also He I 6678Å , the one strong singlet).



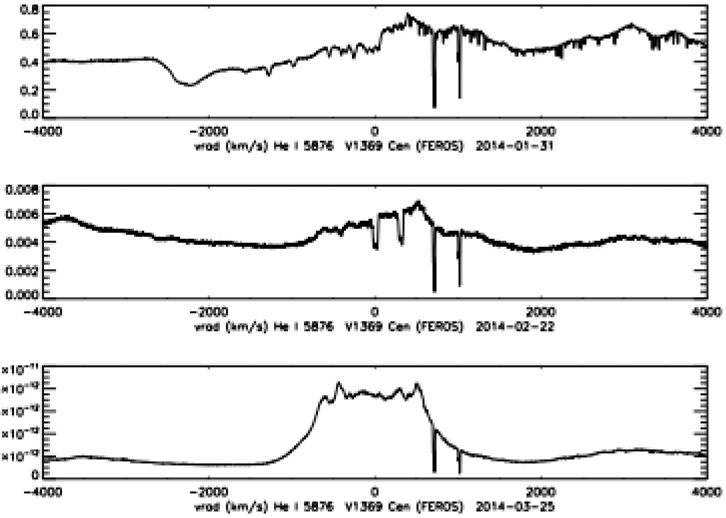
Status of novae at the begening of 2014
V1369 Cen

2014, Feb.

For you in the southern hemisphere, V1369 Cen has been a gift and your spectra have been the kind o coverage this needs. This nova, even brighter than V339 Del, has posed a serious problem for UV observations since it's still dangerously bright for the UV instruments (the MAMA detectors are very sensitive, like extremely delicate photomultipliers, and can actually be damaged in a way that reduces their lifetimes if overexposed). For now, the only information we have about what's happening at higher energies is from interpreting specific phenomena in the optical spectra. An example is this post-fireball He I spectral sequence. This is the same thing that T Pyx showed, and at later times was seen on the excited state lines of C III], N IV], and O V] in the UV shortward of 2400 Å . It's an effect of the overpopulation of the lower state of the transition, which in this case means the He I lines in the far UV are still very optically thick. This absorption stage lasts only for a short time, in the transition between the Na I and He I-dominated stages of the region around 5900 Å . The similarity of the Balmer lines, and the increase in the violet emission in all profiles, also indicates that we're now approaching the thinning out of the Fe curtain. But the XR emission is still very weak, so this is happening rather slowly and with halts in the light curve, as Francois' notes show. There is still Fe II 4923, 5169 emission but it appears that, like V339 Del, the 5018 line has been replaced by N II around 5003 Å . The [N II] 5755 and other forbidden lines have appeared so there is some ionized, low density gas at large velocity, and the profiles are different than the permitted lines so we will have a density structure soon for the ejecta.

The Fe II lines, and other permitted transitions, remain very broad. So we still have a long ait to see how this nova will develop, but it resembles the V339 Del sequence almost exactly so as more of your spectra accumulate the differences -- and there certainly are many -- will become clearer. At this stage, the ejecta are obviously structures but this is mainly in a relatively high filling factor and, perhaps, a greater radial thickness (perhaps a Delta(R)/R of about 0.7. The importance of the detached feature on the He I lines is the information it provides about the maximum radial velocity of the ejecta, it confirms what comes from the Balmer lines and will be essential in interpreting the interferometry that may be obtained for this nova. You may recall that V339 Del was imaged with CHARA, a northern hemisphere optical interferometer, within the first week. V1369 Cen is certainly close, likely closer than V339 Del, and this may even be visible as a resolved ejecta with ALMA when it's optically thin in radio. Now it is still (I think) thick.

What to expect is that the same stages we watched with V339 Del should occur here. The recombination is now over, the ejecta are marginally thin (making the transition to the nebular stage) and the profiles of the forbidden lines are *almost* indicating a uniform electron density and temperature in the line forming region. I say almost because the [O III] lines (4363, 4959, 5007 Å) don't quite have the same profiles and there isn't enough resolved emission at the [N II] 6548, 6583 Å lines to yet compare with [N II] 5755 Å . The [O I] 5577 Å line is now gone and no very high ionization lines, e.g. [Fe VII], have yet appeared (consistent with the still low count rate from Swift).

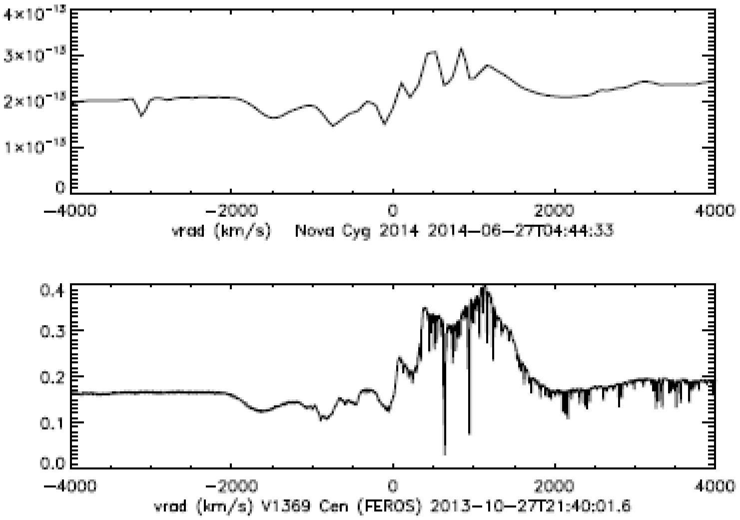


He I 5876Å and Na I 5889, 5895Å in V1369 Cen showing the three different forms of the profile (note, in the second spectrum, the strong absorption lines (detached) from the Na I D1,D2 lines in the ejecta. By now this should look familiar!

Comments on Nova Cyg 2014 : almost generic

06-07-2014

The last spectra of this nova show something unexpected and quite remarkable, even at low resolution. In the accompanying figure, the top spectrum is N Cyg 2014. The bottom is V1369 Cen about two weeks into the outburst. Both show similar light curves, and both are likely CO novae (although the definitive observation, in the UV, is still to come in the next month or so with STIS). Note that the He I line shows a high velocity feature at about -1500 km.s^{-1}, the same is seen in V1369 Cen.



V1369 Cen, Nova Cyg 2014 : He I 5876 Å and Na I D1,D2.
V 1369 : FEROS | Nova Cyg 2014 : Tim Lester's spectrum

I'll add that the same phenomenon, with about the same velocity, occurred after the peak in V339 Del and also in the early stages of T Pyx. In all cases, the velocity increased over time, indicating that the excitation was progressively moving outward though the ejecta. The maximum velocity on the Balmer absorption troughs is similar and shows a similar behavior. It's not rare! The same evolution is followed by a substantial number of novae, although this is just now obvious. The demonstration that this is truly He I comes from the same detached profile appearing on 6678 Å and 7065 Å (although compromised by water vapor absorption in many spectra, especially low resolution). Helium is a particularly difficult case since the lower level is populated by FUV transitions, much like the Balmer lines, but at even higher energies. This means that the external portions of the ejecta, even at the time when the recombination has produced lower velocity features on Na I (and Ca II H and K, I'll add), there is sufficient density and far ultraviolet flux to excite the periphery of the ejecta. The maximum velocity of this feature is the same as the Balmer lines, and clearly shows that the ejecta have much higher velocities than inferred from the emission (or full width half maximum) of the profiles (a too easily measured quantity, one that should be diligently avoided).

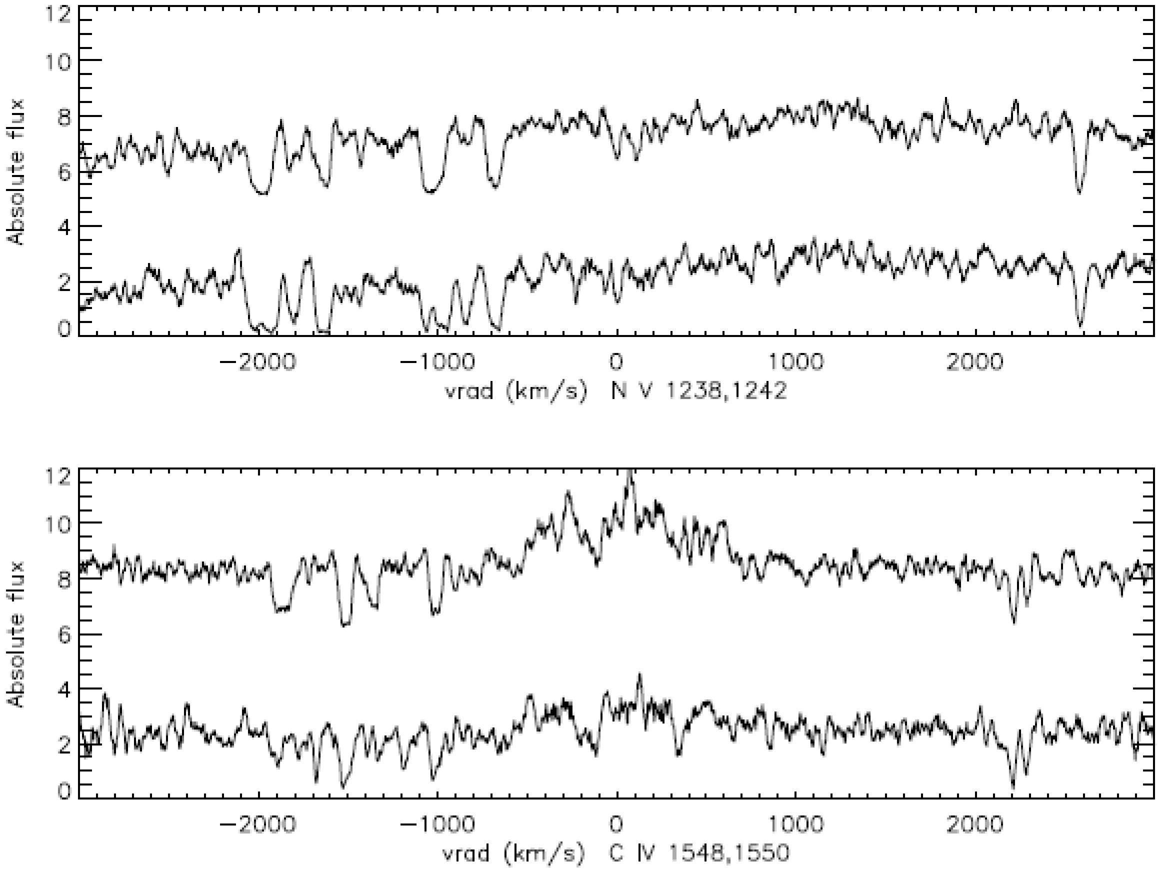
This has significance for measurements in other wavelength regions. The discrete features seem to have a typical optical depth (that is, they are either optically thin or not completely covering the central source).

Let me explain this since it relates to line formation. The Na I lines, for example, are resonance transitions, meaning they come from the ground state of Na^{0}. Since the population depends only on the ionization state (they are at a relative zero-energy level), the only thing that should differ between the D1 and D2 lines is their intrinsic atomic cross section, the *oscillator strength* weighted by the statistical weight of the state (in this case, it's the same). This is, for a single ion like Na^{0}, independent of temperature. So since the optical depth is linearly proportional to this intrinsic strength and the column density in the ground state (hence ion), the optically thin lines should have a ratio of about 1.7 (with the 5889 Å component being stronger). In the multiple line systems, this is often -- but *not always* -- the case. In some of the novae you've observed, even correcting for resolution effects (that change the ratio of the equivalent widths of the lines, the area of the profile indicating how much energy has been removed in a wavelength interval) , the ratio is closer to unity. The line is optically thin if there is residual flux at the profile minimum, but that is misleading in such complex structures as you've seen in these systems. It assumes complete covering. Think of a cloud seen against a bright sky. It appears dark (see the image, one I photographed during the drive this week to Trieste near Asiago).

Example of a dark, scattering cloud seen against a bright background and also an optically thick scattering surface (the bright clouds in the base of the picture.

Now think of the same picture blurred and combined. The individual features would merge. The same would be true for the absorption lines. There would be bright, scattering (or emission) lines from the one and absorption from the other. It isn't covering the field of view completely, in fact if you reduce the resolution enough it disappears. So you'd see residual flux even though it is a completely opaque filament or knot. That's what happens, it appears, in the spectra you've seen. The narrow features may be optically thick, meaning they are confined to a small interval in velocity, hence they must be truly denser than their surroundings, but they have a small solid angle seen against the brighter opaque surface of the ejecta or the central star. This is the same effect you see in stellar winds, and only the line ratios provide the information about whether they are large or small. In a stellar wind, the residual intensity is very near zero, in novae it can be as large as 50%. That's because winds are more nearly spherical and therefore cover the central star completely (in fact, over-fill the solid angle).

The N V 1238,1242 Å and C IV 1548,1550 Å discrete features in T Pyx on days 617 and 834 after outburst obtained with HST/STIS.



Now what this has to do with the Nova Cyg 2014 observations is that the same light curve behavior has been observed in the three novae V339 Del, V1369 Cen, and Cyg 2014 that was seen during the maximum of T Pyx. Yes, I know the last is a recurrent nova, but that's not important if the same mechanism acts. And without these sequences, the early spectra you've been providing with high cadence, we can't disentangle these effects as either radiative or dynamical (or, perhaps, both).

Steve Shore, 06-07-2014

Comments about Nova Cyg 2014

The most recent spectra of Nova Cyg 2014 in the database show that it has finally made the transition to a fully ionized state for the bulk of the ejecta. This was signaled by the so-called ``oxygen flash'', the rapid appearance of the [O III] nebular lines. We know nothing about the state of the X-ray source, but from the absence of the [Fe VII] 6087 it is a good bet that the central source is not a strong XR emitter.

From the line profiles, something about the ejecta structure can be reconstructed. The Hα line is still present and broad but the [N II] 6548, 6583 nebular lines are also blended with about the same strength as [O III] so this accounts for its excessive width at FWZI. The densities have fallen below about 10^7 cm^{-3} based on the strength of these nebular transitions, the [N II] 5755/(6548+6583) lines are isoelectronic to [O III] 463/(4959+5007), as we've discussed, but all have the problem of being severely blended. The other (permitted) N II lines, especially 5679 and 6482, are also strong but the 4636 feature is considerably weaker than He II 4686. Together this points to a complete ionization of the bulk of the ejecta with the line profiles for the most of the transitions are similar and a close match to He I 5876, 6678. The N II 6482 line is, on the other hand, broader than I might have expected from the structure and ionization state.

Now about that abrupt increase in the O^{+2} lines. Francois' plot of the ratio of the individual lines tells that tale well (*see page 4*). The transition to strong nebular emission took only a few days but remember that the expansion velocities range from about 1000 to 3000 km/s, depending on the geometry assumed for the ejecta. The [O III] lines are both recombination and pumped and the change in O II shows that ionization is the dominant cause. The He II 4686 line, which is a probe of the He ionization, increased but not by much so it isn't likely that only the He II 303 line is responsible for the sudden increase in the O III. As the ejecta expand, remember, the opacity changes because of changes in the condition at the WD and the column density and absorber abundance in the ejecta. When the light ions ionize, the continuum opacity decreases in the far UV and this provokes a further ionization of the outer parts that, because of the lower density, can't recombine. So you should see, in the next week or so, a new effect. When the density is low enough that the recombination rate is lower than that of the expansion, the ionization state freezes out. We've discussed this a long time back for V339 Del. This has been noted as one of the signals of the XR turnoff, but it is also an effect of the luminosity.

If the supersoft source is weak enough you will get the same effect.

For now, since the lines are increasing (especially the permitted lines) it is likely that a source of photons at around 100 eV is still on. The strange thing is the absence of any very highly ionized lines; an important observation will be to follow the lines of [Fe VII] 6087, [Ca V] 5309,6376, and [Ar III] 7135. The last may be there now,it has a profile similar to that on the [Ar IV] lines at 7237,7263.

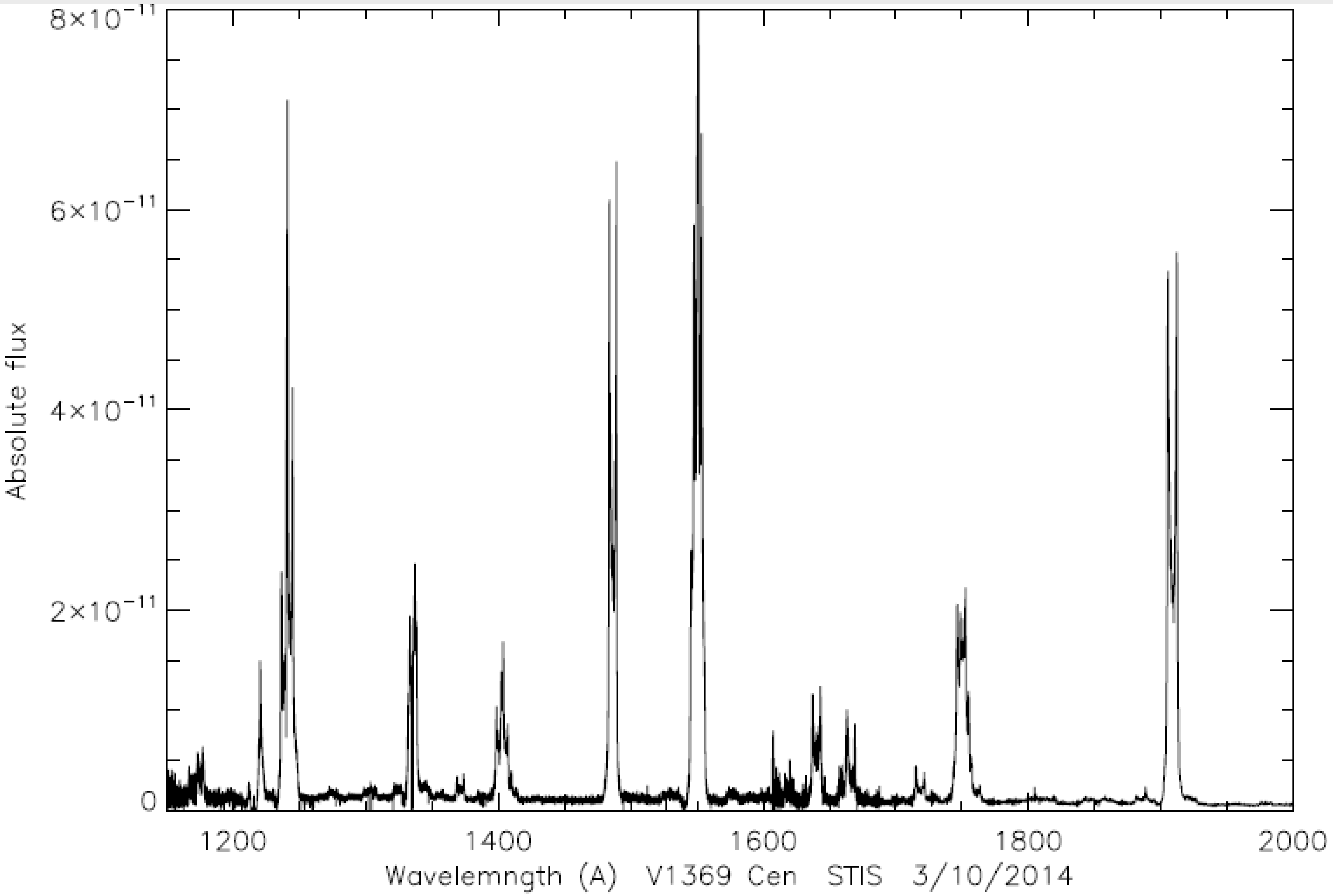
The Balmer line profile is, as seen now in many novae, quite different from that of the ions. It is a tracer of the recombination so to understand how the individualk portions of the ejecta are structured

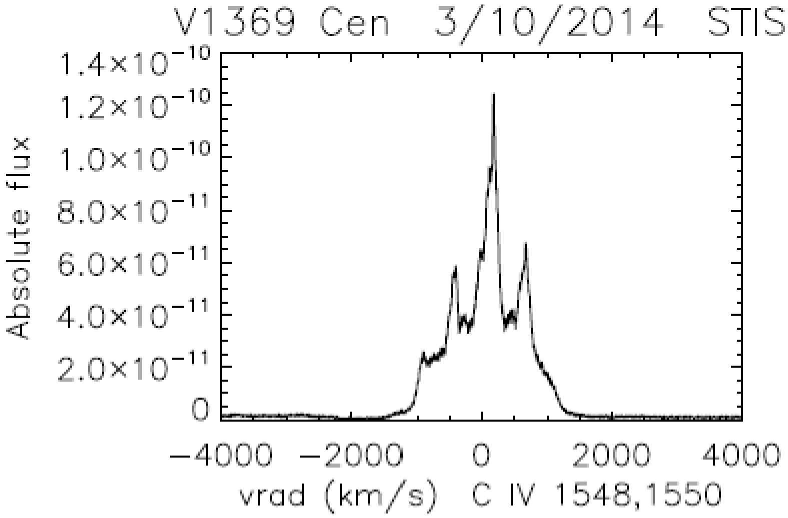
It's very important to have profiles of at least Hbeta and H alpha. The comparison is needed because the H beta is isolated and (as used for other systems) the benchmark profile for the hydrogen. Alas, this nova wasn't -- and won't -- be observed in the UV, it is too faint, so everything has to be done by comparison with other, active novae.

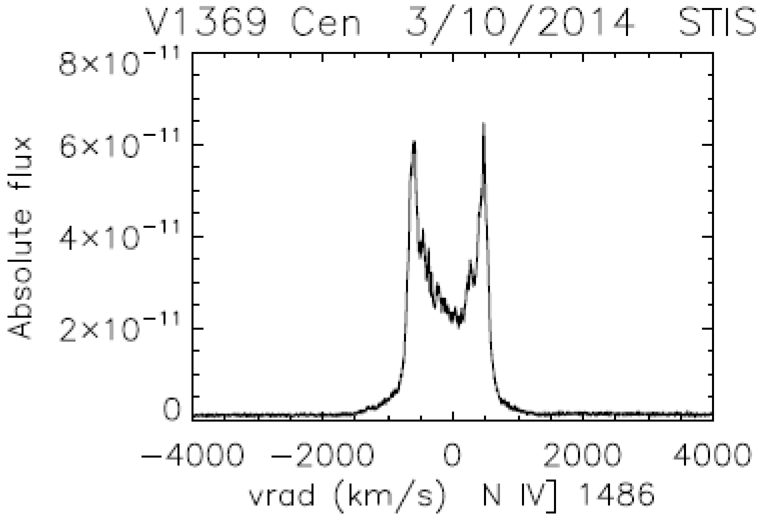
We have observations coming up of V339 Del, with STIS/GHST and NOT, and any coverage by the group will be a wonderful gift.

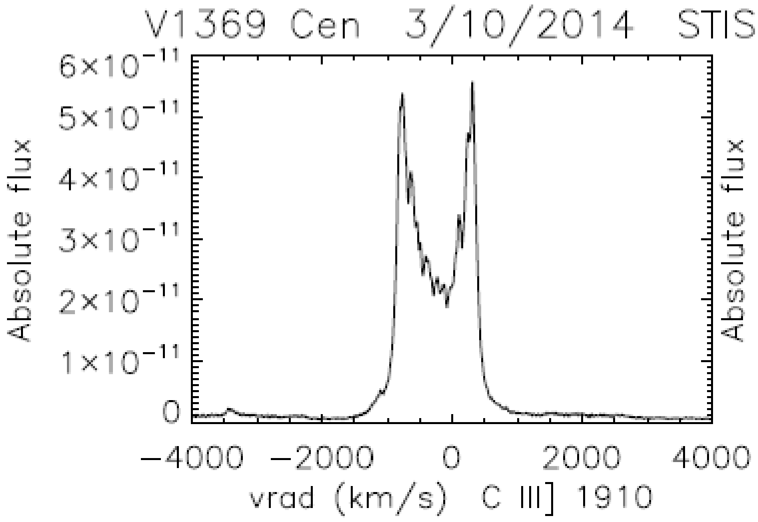
The V1369 Cen material from 3 Oct. is now being worked on but I'm sending one example of the spectrum so you can get an idea of what the star looks like in the UV (*see page 11*)

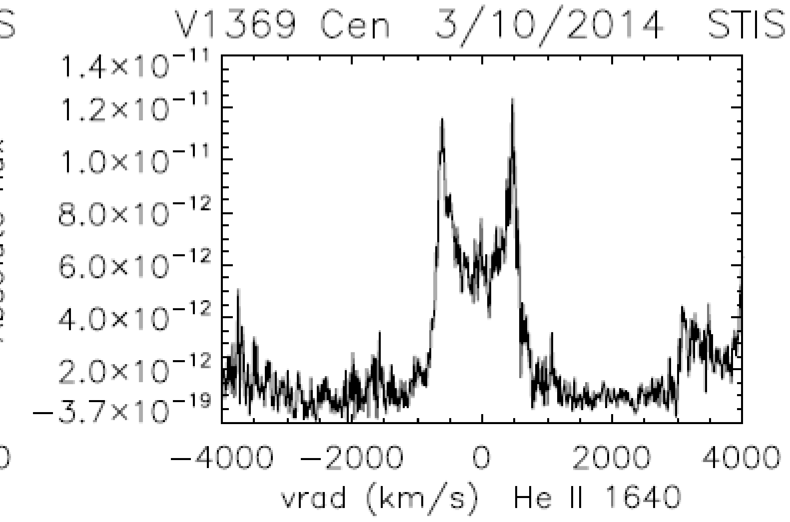
V1369 Cen in UV











SS 433 = V1343 Aql
The prototypical Galactic jet source

30-11-2014

In the past year, many of you have been following a very particular source, SS 433, whose bizarre and fascinating behavior signals a range of unique physical processes, mainly linked to the relativistic jet outflows from the source. To place this work in context, I'll start with a bit of background and then we can jump to a discussion of the recent observations.

The source known as SS 433 was first identified as a spectroscopically anomalous star in a catalog by Sanduleak and Stephenson:

http://adsabs.harvard.edu/abs/1977ApJS...33..459S

of emission line objects found on objective prism plates. This isn't a formal catalog, rather it is the list of stars that had not been included in the Luminous Stars survey and the previous CWRU/Warner and Swasey Obs. catalogs of emission line stars. The remark is important -- ``He I 6678 emission?'' -- because the line is *not* normally visible at such low resolution (the plates were designed to find mainly Balmer emission lines so with R ~ 200 (in older catalogs, using photographic plates, the dispersions are cited as Å/mm and the plate grains gave a resolution element of about 50 μm). Although there were other observations noted in the catalog footnotes, there's no mention of any variability in either the lines or the photometry (although the other plates should have been objective prism as well).
The star first came to anyone's attention with its identification with a variable radio source in the supernova remnant (SNR) W50

http://www.cbat.eps.harvard.edu/iauc/03200/03256.html

(an indication of how few deep catalogs existed in the late '70s) and it was given the name SS 433, which has stuck (although its real name is V1343 Aql from the GCVS). The follow-up Xray observations not only confirmed the high energy aspect of the source but added to the picture that this was not a pulsar or a normal X-ray binary:

http://www.cbat.eps.harvard.edu/iauc/03300/03314.html\#Item2

The observations of the spectrum, still in the photographic era, were difficult and produced some weird line identifications, although it was clear that it didn't fit into any standard categories. The breakthrough came with the discovery of the moving lines,

http://adsabs.harvard.edu/abs/1979ApJ...230L..41M

and the identification of the source in a supernova remnant

http://adsabs.harvard.edu/abs/1978Natur.276...44C

Now the main issue is that to find a point-like source in a SNR, even so long ago, wasn't unexpected - the pulsars in Vela and the Crab were already known - but this one showed an effect that couldn't otherwise be explained. The moving lines span over 30,000 km.s-1 when followed over years and are *periodic* in their displacement over 164 days.
The star was quickly shown to also be a spectroscopic binary with a period of about 13 days, similar to Cyg X-1 that was already well known to have a black hole source and high energy phenomena (e.g. XRs, radio emission). But that is in a binary with an O star while SS 433 looks like it's paired with a much more evolved companion.

The moving lines are explained as jets, with mildly relativistic velocities of about 0.26c. Mildly is a strange word, I know, since there are very few sources known that have such high *observed* speeds (others can be inferred from superluminal motions of emission knots, for example in quasars and blazars) but here it was an optical Balmer line measurement. That is its importance for our discussions.
This is the *only* known relativistic outflow that is so tightly collimated -- as determined from the emission line profiles -- and so well constrained in velocity -- since these are emission lines of a trivially familiar ion -- that there is no dynamical ambiguity in interpreting its structure. Let me expand on this. If a flow is launched from a central source and is completely ionized, as we see in radio galaxies, the only emission (aside from thermal bremsstrahlung, which is continuum emission from a fully ionized medium) is synchrotron. To see that in the optical requires moderate magnetic fields and very (!!) high energy electrons, like those in the Crab nebula. The synchrotron emission comes from electrons spiraling in the magnetic field as they advect (flow

outward, in this case) and the beaming produces an enhancement in the brightness of the source and strong polarization. The spectrum is a power law because the electron energy distribution is like that of cosmic rays, for which the low energy end is at a few MeV and the high energy end is above TeV energies. Clearly, this can't be thermal. But in this source, SS 433, the emission from the jets is in lines. These are primarily optically thin although there are several components, and that requires some energization mechanism. Either the ionization is from the launching site or it is maintained by radiation from the central object. We'll return to this in a moment.

At its most basic level, the spectrum of SS 433 shows two sets of lines: essentially stationary and moving. Those of the first type are associated with the binary itself, the accetion disk and the binary motion. There's been a push to identify a third component, a circumbinary disk, with a line component that remains stationary relative to the center of mass of the binary; more on this in a moment.

The binary motion is not clean, and that is an important issue for the picture. These the most complete studies I know of the binary properties:

http://adsabs.harvard.edu/abs/2008ApJ...676L..37H
http://adsabs.harvard.edu/abs/2010ApJ...709.1374K

that show the *absorption* spectrum of the mass losing star. The second reference is particularly useful for the discussion of the mass determinations based on the velocity curves. The key to the masses is the mass function, given by the period and radial velocity amplitude.

This just follows from Kepler's law but, in the absence of eclipses (as here), the mass ratio is the only way to determine the individual values (since that gives the ratio of the center of mass distance of each component, hence its mass). This is the ambiguous part of the picture and why there is -- after 30 years! - still a debate about whether the gainer can be a massive neutron star or is clearly a stellar mass black home.

It's been known for some time that the spectrum is not that of either a Wolf-Rayet star (as earlier thought and is true for a few systems) nor an O star. A number of Be-XR binaries, those that have Be star like characteristics according to some spectra and also strong, hard XR emission, seem to be mainly wind accreters (and some are also very high energy sources, e.g. LSI +61°303 or LS 5039 (by the way, the LS is ``Luminous Stars in the Milky Way'' for which some plates furnished the spectrum of SS 433). This is also why the system is so important.

Here we see a clean pair of jets emerging from the central object and there are direct correlations between the flares of the central source (in He II 4686 Å knot of radio emission. The jets show a corkscrew structure projected against the plane of the sky, one that agrees with a jet whose direction is fixed in some axisymmetric frame that is inclined to the line of sight (in three dimensions) and which precesses about that fixed direction on the 162 day period. The jet itself isn't emitting all the time but it is dynamically stable. It's also very ``rigid'' in maintaining its outflow direction without distorting while wobbling (precessing). *If* SS 433 is a neutron star, as in the Crab nebula, then the absence of a pulsar wind nebula would be explained by the dense accretion-induced environment. That would connect the jet with what's seen in the Crab (the XR and optical imaging of the central wind-jet). And a massive neutron star will have a radius quite close to a stellar mass black hole, although the latter would clearly be more massive. The available mechanical energy (and electromagnetic flux) to drive a relativistic outflow *and* collimate it is not very different between the two.

The core issue in, then, how does the jet form and launch? In this sense, SS 433 and the related black hole accreters are thought to be miniature analogs of the central engines in quasars and other active galactic nuclei. In one sense that's not a bad point: once near the Schwarzschild radius (a small multiple of which is the inner boundary for a stable orbit in general relativity) the amount of energy released by fall is the same whether a $10^9 M_\odot$ BH or one of stellar dimensions. And if you're in a binary system there's a feeder, a companion. In SS 433, this probably fills its Roche surface (although without being able to see eclipses it is almost impossible to tell that) and with an obviously evolved star (if the spectrum is right) or, at least, one so optically think, there's no obvious single photospheric temperature that gives the radius. The distance, ~ 5.5 kpc, is debatable without some parallax (this should be one of the results to come out of Gaia if everything works right, the geometric parallax and proper motions) but with that the source should be emitting near its Eddington limit to obtain such a high rate of mass loss by the jet. The picture of a jet driven outward from the center of an accretion disk by either radiation pressure or magnetic acceleration (called Poynting flux but actually just the electromagnetic momentum flux due to a wound up magnetic field in the inner disk). If it's radiation, the inner disk `funnel'' is a sort of hose created by the inner disk boundary zone. To explain, because this is a generic result, the innermost disk region around a relativistic object is extremely thin and the region surrounding it, further out, is puffed by by the difference in the equations of state when the density and temperature change. So the inner disk is a sort of plane while the outer one is more like a classical cataclysmic disk. There are different problems related to the corona and outer rim of the disk itself, but the essence is that the high luminosity of the inner region coupled with the scattering at the inner ``eyewall'' (like a hurricane) produces an outflow hat, depending on the luminosity (hence the mass accetion rate) reaches relativistic speeds to attain the escape velocity. This produces a highly ionized, collimated jet that streams away with small divergence from the center. But for the thermal component, why we see the Balmer and helium lines attached to the jet, that's a separate question that isn't well addressed in any (!) Current studies. Some of this is obviously entrained from the environment, from the wind around the companion, for instance, but how isn't understood. There's X-ray emission from the central source that modulates on the orbital timescale but this is also an indication of shocks in the nner jet. The jet never seems to turn off, nor do the emission lines, but they vary enormously in strength even over hours.

Keep in mind, though, that on timescales of days the two sizes of the jet are decoupled so any correlations must come from the central engine fluctuating (a tailpipe on a car that doesn't run well).

If there's no jet (and it's really marginal for some sources, e.g. V404 Cyg and Cyg X-1) this doesn't mean there's no outflow, just that it's not seen. Even period changes don't help here, those could/can be from mass loss in general. The other peculiarity of the SS 433 jet, like the disk in HZ Her = Her X-1, is its precession. That can *only* happen for a mis-alignment of something related to spin angular momentum, like spin angular momentum (!), and the orbital angular momentum (real, the two poles aren't alighed) *or* that the disk is not aligned and everything else is (that there's a waggle of the stream or a change in the accretion rate systematically, or whatever you can think of yourselves). In HZ Her, the neutron star has a distortion due to the magnetic field that may produce disk precession. At any rate, any system that's not aligned in all angular momenta will precess, in general relativity or classical (it's just that there's a natural version of free precession in GRT that is known as Lens-Thirring, a sort of relativistic component of the tidal acceleration in a binary).

The variability of the radio is on timescales of days or weeks, the same with the sequences you have for the jet and central source.

Looking at these one is struck by the rapidity of the changes, these must involve regions no more about $10^4 R_{\odot}$, which is really very small (about the same as the orbital radius in a symbiotic system like V407 Cyg or a very long period).

One thing, as a theorist: the timing of the discovery of the radio jets and the moving lines couldn't have been better for theory. The Blandford-Rees mechanism, the explanation of double lobed radio sources (those with cores and companion emission regions) had appeared in 1974 (MNRAS) and was being hotly debated. It requires jets to emerge from the central region but without a clear driving mechanism. What you're seeing -- on short timescales and manageable velocities and lines – is the same process on the stellar scale. In principle, the emission lines (those from the disk and from the jet) permit the timing and dynamics (and, perhaps, even the mass ejection rate) to be determined over time. This is a wonderful prospect, the one chance to see what the process is ike deep down. When you work on hour timescales you're seeing things from the disk (and the launch site) and nothing of the environment.

History repeats itself with the extragalactic ``ultra-luminous'' X-ray source NGC 5408 X-1:

http://adsabs.harvard.edu/abs/2003Sci...299..365K
http://adsabs.harvard.edu/abs/2010ApJ...725.2480F
http://adsabs.harvard.edu/abs/2013MNRAS.435.2896C

and a wonderful survey paper of the ULX binaries in general:

http://adsabs.harvard.edu/abs/2013ApJS..206...14G
(http://arxiv.org/abs/1303.1213)

One suggestion: please always plot the profiles *only* in velocity and also use the plots to show the comparative profiles of He II 4686, He I 5876, 6678, 7065, and Hα and Hβ whenever you can.

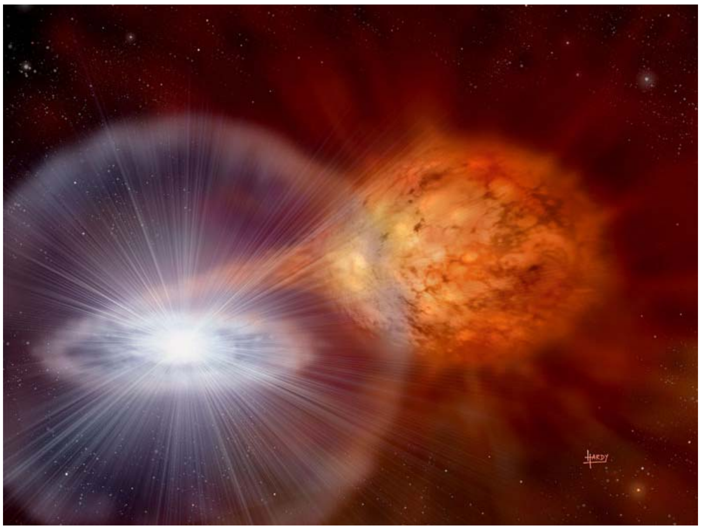
The wavelengths are misleading since the lines are formed by relativistic flows. It would also be interesting to see how the line profiles change as they alter in line of sight, and also as they move outward from the center on short timescales (the real dynamics of the ejection). It is important, I think, to NOT try fitting the profiles, but instead note the velocity ranges in which there are changes.

Forget about gaussians, that's for desperate people. Work in velocity slices (say every 100 km/s or so) to get an idea of how the profile is actually varying -- and how with time on the different components and species.

Symbiotic stars
and accretion phenomena in binary systems -1-

30-03-2014

So now that yet another symbiotic-like nova has appeared, Nova Sco 2014 (see C. Buil's spectrum p.7, editor's note), and V745 Sco has faded into memory, and some of you are interested in such systems, I thought it might be useful for you all to have a few notes on symbiotic stars and accretion disks. The two are not unrelated although they seem very different when considering the timescales for their orbits and constituents but I'll try to relate them.



An artist view of symbiotic RS Oph. The red giant loose matter which forms an accretion disk around the white dwarf and emits a strong stellar wind. Disk and wind are excited by the white dwarf (editor's note)
Credit : David A. Harty http://www.astronet.ru/db/xware/msg/1214949

Symbiotic stars: misbehaving degenerate dwarfs and self-important giants

The symbiotic stars, discovered by Fleming during the **Henry Draper** spectroscopic survey at the beginning of the XX century, so named by Merrill and summarized for the first time in Payne-Gaposchkin's monograph *The Galactic Novae*, were first distinguished by their bizarre (by the standards of the time) spectra. In the same spectral interval, the visible, these stars show the absorption spectrum and continuum of a very cool star, a red giant (sometimes even a Mira variable) along with a blue continuum (seen shortward of about 5000 Å) and emission lines from highly excited states of the iron group elements (mainly Fe II but also others),
the Balmer series, **and** [O III], He II 4686, 5411Å, and even higher ionization species (see Fig.1 ndlr)

That these should co-exist in the same spectrum is physically difficult to arrange with a single star (notwithstanding there were ingenious, although misguided models to the contrary). A clue is the blue continuum. While it's possible to have emission from a 10^6 K plasma if there is a non-thermal source for heating, for instance in the solar coronal gas that's energized by waves and reconnection of the magnetic field of the outer solar atmosphere, it isn't plausible that there should also be optically thick gas. The latter is required for the continuum, which must be either free-free (thermal bremsstrahling, from collisions of free, charged particles) or recombination from an ionized gas. But at a temperature indicated by the emission lines, these processes would be optically thin and would not give the colors associated with the symbiotics. The answer came nebula around itself because of its hard continuum. Planetaries have a hot WD sitting in their centers. These stars, in the stage called post-asymptotic giant branch stars, produce compact high density H II regions within their old winds. To put this more precisely, in the last stages of intermediate (around $10\ M_\odot$ mass stellar evolution, after the core has gone through carbon burning and when the star goes into an nuclear source-unstable phase of shell flashes, the envelope is removed by a very strong wind. This leaves the core exposed, and because of the reduced circumstellar density, the ultraviolet continuum below 912 Å strongly ionized the material. But not all of it! Planetary nebulae are *ionization bounded*, the available ultraviolet photons are only sufficient to ionize a fraction of the surroundings because there are recombinations on a timescale sufficiently short to balance the ionizations and still leave a part of the environment neutral. If this seems technical, don't be worried. It's really quite simple: every ionization produces an ion (surprise). Once ionized, hydrogen is transparent so if the photons keep coming they pass through the previously ionized medium and continue to ionize the medium. If, on the other hand, before the arrival of the next photon (statistically) the ion recombines with an ambient electron, it can again be ionized, thus increasing the opacity in the far UV and limiting the advance of the ionization front. In fact, if it reaches balance (called a Strömgren sphere), its radius will remain constant. This is what one means by ionization bounded. If, on the other hand, the medium, even recombined, is fully ionized, the region is called *density bounded*. H II regions are typically this latter state. Now if, instead, the medium is the outer wind of a star, which if the mass loser is a red giant is rather slow and dense, then the hot source will be surrounded by an *ionization* bounded region. You know from images of planetaries that they are remarkably well defined, in most cases. And if you look at images in individual lines of different ions, they have different shapes and radii since the ionization is highest near the WD or where the density is lower and recombinations are less frequent.

This is the key for understanding the symbiotics.

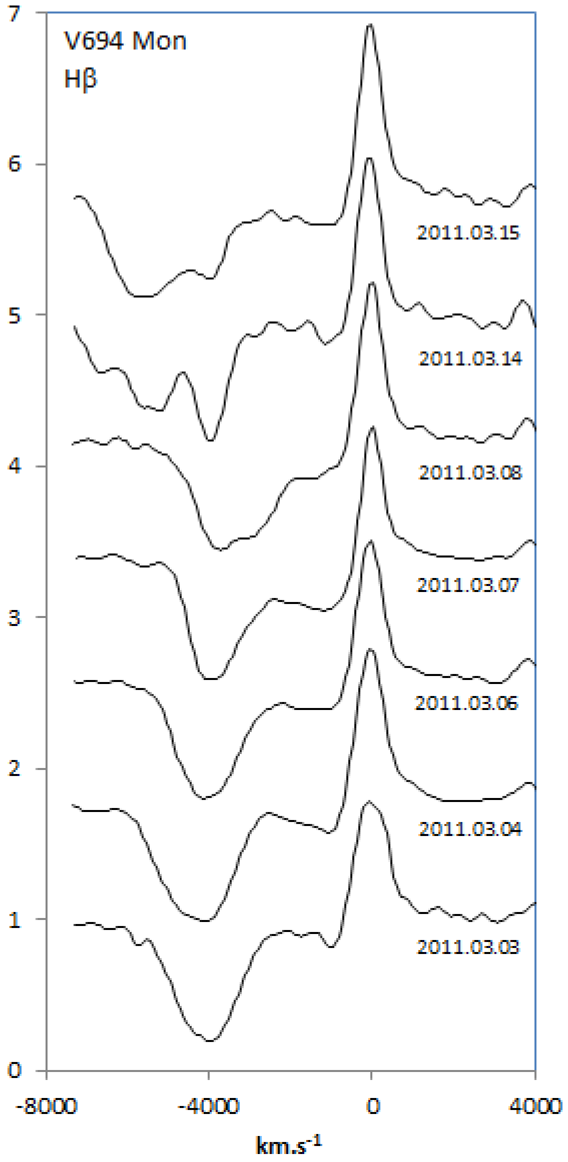
How they get into such a strange evolutionary state is still an active research topic but the fundamentals are clear. The WD and giant are well enough separated that they would be in simple orbital motion were it not for the wind. That's what makes identifying such systems' precursors so hard, before you have a red giant these stars look like ordinary red giant binaries. The WD is not an idle orbiting mass, however, it can deflect the outflowing wind and deviate it because of gravitational attraction and focusing of the wind and accrete some of the passing gas. That matter can't fall directly onto the WD. It has orbital motion despite being an outflow, and in being deviated does not lose its vorticity (angular momentum). So when it is being accreted, it forms a disk around the WD. While the structure of the accretion environment is poorly known, the disk is certainly present. Flickering on orbital timescales for matter at the WD surface radius (of order 0.01 $R_\odot$, such as seen in MWC 560, signals the boundary layer and accretion interface in the inner portion of a circulating disk. The energy release and angular momentum transfer happen because of something like internal fluid friction, *viscosity*, although the origin of this in *any* disk-accreting system is still far from well understood (a phrase that, from here on, will keep recurring). The loss of energy for an orbit around a point mass -- the loss of *kinetic energy*-- is balanced by an inward flow since the gravitational energy is negative (it's one of those cute features of gravitation, energy loss means the system contracts and, in this case, heats up). But because energy and angular momentum are directly related for a Keplerian orbit, this causes a loss of angular momentum -- hence the inward drift. The inflow is subsonic unil just about at the stellar surface here it infalls and, on being slowed by the pressure gradient of the WD envelope, produces a shock. Thus, the inner boundary of the disk is very hot, of order 10^{6}-10^{7}K, and the emission extends from the X-rays into the visible and even infrared. The luminosity from the shock depends only on the rate of mass accretion since the mass and radius of the WD are fixed. In effect, then, the accretion from the wind powers the emission from the WD while, slowly, increasing its mass. Only a small fraction of the outflow is captured, the so-called *gravitational capture radius* but the rate of energy loss (luminosity) depends on the accretion rate through the velocity of the wind and the mass of the WD.

This is the basic mechanism, the reason why a degenerate would be able to maintain such high temperatures instead of simply cooling. Unlike a normal star, you'll recall from discussions of novae that WDs are degenerate -- their pressure depends only on density. So if they accrete, they must compress to increase the pressure gradient that counterbalances the star's own weight. One of the current interests in symbiotics, like novae, is that here is a maximum stable mass for a degenerate star, the so-called **Chandrasekhar mass** (about 1.4 $M_\odot$ above which it can't become stable again until it collapses to nuclear densities. So if you could arrange the accretion to continue to the point of core collapse for the WD, it would have a fixed limit and all supernovae so produced would be nearly identical: enter the Type Ia supernovae, the distance scale, standard candles, and cosmologists.

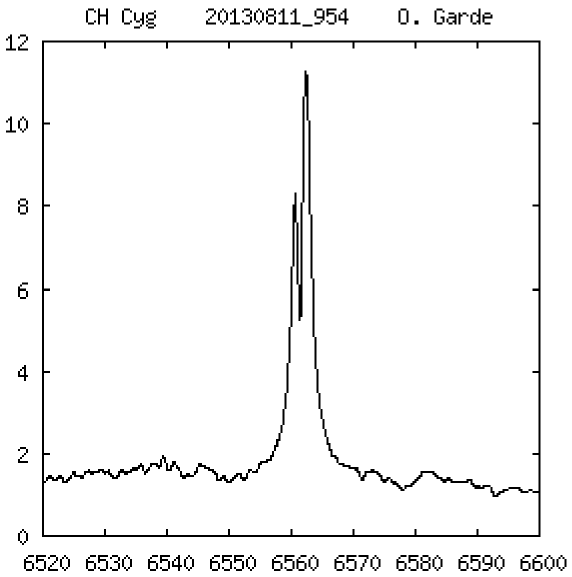
The connection with novae

The connection with novae, and of course there {\it *must*} be that, is the WD itself. Any degenerate can ignite a nuclear source if enough mass accumulates. Whether this ultimately explodes or fizzles is a question of the mass of the gainer. One of the basic features of a WD, the mass-radius relation, results from the pressure law - the more massive the star the denser it must be to remain in hydrostatic balance, so its radius decreases. This increases its surface gravity and since the critical pressure for thermonuclear ignition depends on that quantity, the more massive WD will produce a more violent runaway. The nuclear reactions go very far from their equilibrium abundances, but in a lower mass WD the same thing happens with less violence. There can be a wind, if the increase in luminosity is sufficient, but the matter never becomes completely ``ideal'' so there's no final explosion. Instead, like the supersoft phase of a post-explosion nova, the WD continues to chug away in nuclear burning until the accumulated, mixed hydrogen is spent. During this -- potentially very long -- time, the WD becomes a strong ionizer of its environment. The event is a *symbiotic nova* (alas, too close in terminology to a *symbiotic-like recurrent nova* such as RS Oph or V745 Sco) with an increasingly circumstellar ionization zone of increasing ionization state. The best example I can recommend is RR Tel, which has displayed everything from [Fe VII] to [Fe XIV] and even higher as the state of ionization has changed (Thackeray's classic study is, fortunately, available on the ADS:
http://adsabs.harvard.edu/abs/1977MmRAS..83....1T
To say this is a *must read* is an understatement, it is one of the great observational studies of the last century. The UV has been also extensively studied, for instance in:
http://adsabs.harvard.edu/abs/1993ApJS...87..337A
and you'll find lots of material on this particular system. These are also important for atomic physics, especially identification of energy levels and tranbsitions inaccessible in the laboratory because of the required low density (strongly forbidden lines of high ion species, especially iron peak elements), and as such they have been exploited for decades by atomic structure types to tease out transitions that are important for cooling very hot, low density astrophysical plasmas. The bright state persists for years or decades in some systems, but others go through intermediate states of activity, such as AG Dra (a figure in one of our papers, apologies for self-citation, may be useful:
http://adsabs.harvard.edu/abs/2012BaltA..21..139S
but see also:
http://adsabs.harvard.edu/abs/2004A%26A...415..273L

http://adsabs.harvard.edu/abs/2009A%26A...504..171B
These outbursts are less extended and, consequently, involve much less energy liberated but their origin is at least partly nuclear. It still isn't clear whether or how much is due to an accretion disk but



the systems that undergo such events, including CH Cyg, AG Peg, EG And, and Z And, often show something that looks a lot like jets at velocities that may exceed a few hundred km.s^{-1}. Perhaps the best example of this is MWC 560 that shows extreme outburst events with several thousand km.s^{-1} absorption lines that are detached (like those in V339 Del and V1369 Cen) but with what may be a characteristic timescale of years (see figure). At least two systems, CH Cyg and R Aqr, have extended spatially resolved jets that are even visible in the UV (and have been so studied).



Hα profile by O. Garde (eShel R = 11000)

Perhaps the best example of this is MWC 560 that shows extreme outburst events with several thousand km.s^{-1} absorption lines that are detached

Absorptions in the blue edge of H béta line during High state of MWC 560 (V694 Mon) - F. Teyssier LISA R = 1000

The systems also show extended circumstellar matter that produces a thermal (and perhaps also non-thermal) radio halo and in the case of an analog system α Sco (Antares) -- the H II region has even been resolved with radio interferometry. This certainly also contributes to the spectra if not resolved but how much is an open question. Again, it's enough to keep in your mind that the symbiotics and symbiotic-like recurrents are really the same phenomenon on different timescales from the observational point of view. Physically they're different but that has to be separated from the dynamics and the energetics, many of the same processes show up radiatively so we can transfer experience from one system to another. The symbiotic giants divide by mass into those that have cold enough winds to show dust (the D-type) and those that don't (S-type, for ``star'') based on their infrared colors and energy distributions. If the red giant has the right mass and evolutionary state it may pulsate, regularly (as in V407 Cyg, a long period Mira) or some of the shorter period systems. The high luminosity and dense wind (or rather, extensive wind with slow velocity) is a good amplifying medium for masers and some symbiotics are also maser sources (this for another set of notes). But in general, the easiest way to understand the complexity of the phenomenology is that the red giant is evolving *independently*, its internal processes are *not* governed by the companion, although in a few cases there may be a strong enough tidal interaction to distort the giant (Mikolajewska, Fekel, Kenyon, and collaborators have spent a great deal of effort cataloging this and it's worth looking at their papers!).

So I'll stop here to not overwhelm you all and hope this helps put some of your work in another perspective. The next thing to treat is the accretion process and that will take some graphics (cartoons, really). The V339 Del STIS/optical observation is this week so there'll be more on that as well.

Symbiotic stars
and accretion phenomena in binary systems -2-

28-04-2014

The accretion process

To return to a point from the last set of notes, the symbiotic systems were originally distinguished not only by their emission strength but by the incongruous combination of high ionization emission lines and very low temperature continuum emission. The giants are all about 4000 K or cooler. Some are Mira variables, an important characteristic since as pulsational variables also have a sort of period-luminosity relation. The nature of the ionizing source is, in fact, even more clearly illustrated by a comparison of α Sco and Mira itself and any of the systems you've been observing. Antares and Mira are binaries with the companion being a more normal, main sequence star. For Mira, the companion appears to be an accreting WD. In both cases, the systems are close enough that the ionized regiona around the hot component is resolvable with radio interferometry and also UV observations (for instance, Karovska et al. 1997, ApJ, 482, L178; Sokoloski and Bildsten 2010, ApJ, 723, 1188; Hjellming and Newell 1983, ApJ, 275, 704). The ionization cavity in Antares has been imaged in radio over time and the orbital motion can be detected. This is important as a comparison with normal symbiotic systems (if ``normal'' is the right word) such as R Aqr that have resolved emission nebulae. Mira is a particularly interesting case because it *doesn't* look like a symbiotic.

In the classical symbiotics, the emission is often from very strong high ionization states of heavy elements. The first lines that were noticed, He II 4686 Å and the [O III] nebular doublet, are the first indication of something emitting at above 25 eV. But in some systems, e.g. RR Tel, the ionization has increased to [Fe VII] and higher. This is only possible if there is a strong emitting source at >50 eV. No normal star can supply such hard photons. But the clue is the the combination of luminosity and hardness. Normal stars, in hydrostatic equilibrium, have extremely opaque interiors and their nuclear sources, even those that produce $10^4 L_\odot$ (like the O stars) transfer those photons from the boundary of the core to the surface through tens of solar masses of matter. The result is a surface temperature that rarely exceeds 50 kK. This is sufficient to produce the [O III] lines, if the surrounding medium is sufficiently low density, and [N III] but *not* the high ionization states of the iron group lines. The clue is the requirement of hydrostatic balance of a nuclear= powered source.

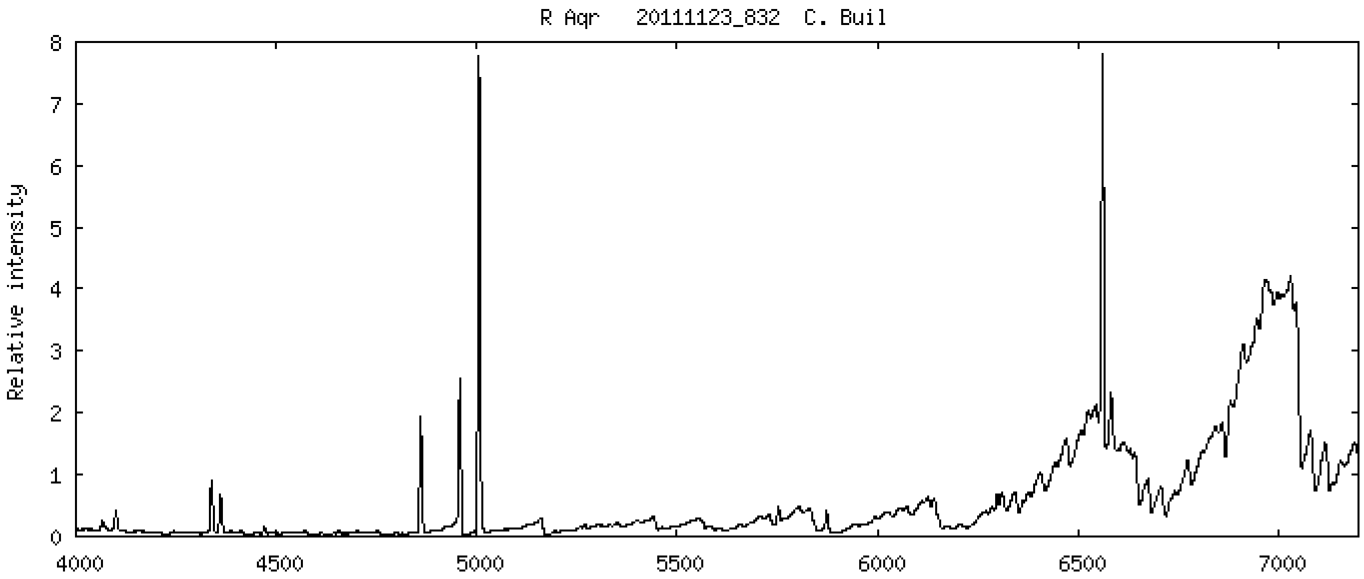


Figure 1. The Mira symbiotic star R Aqr at mag V = Strong emissions of Balmer, [O III] He II lines on the continuum of the Mira

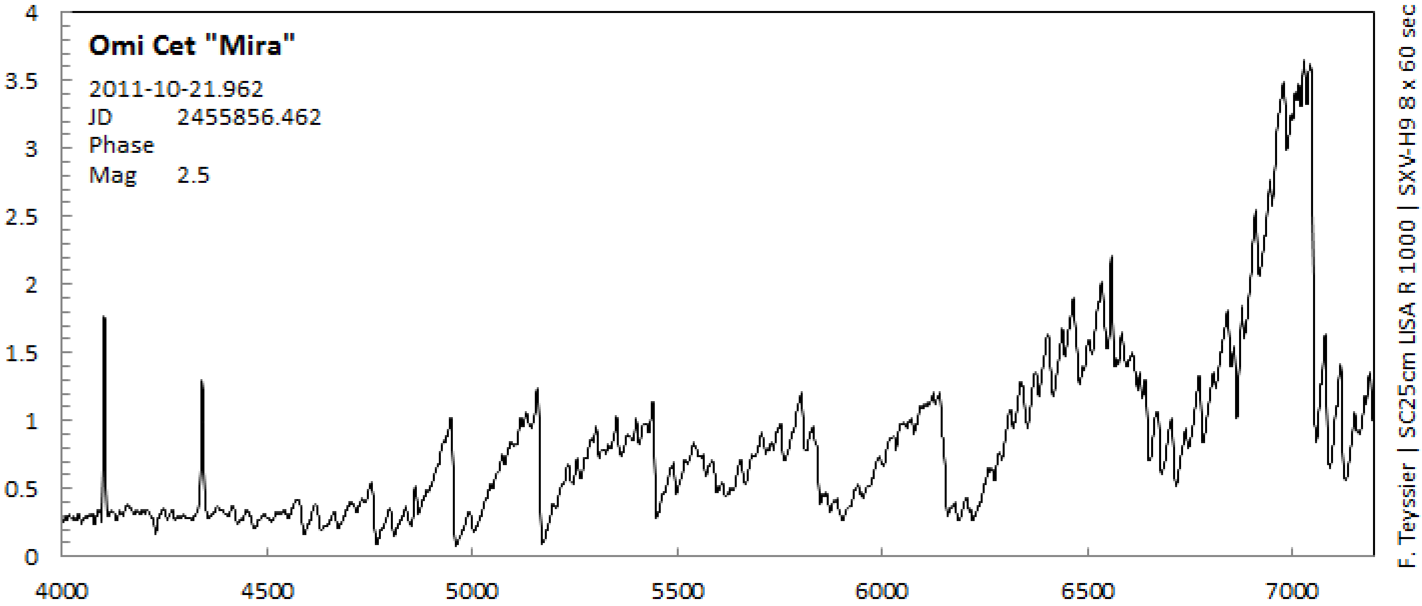


Figure 2. Mira (o Ceti) near maximum luminosity - Typical spectrum of a Mira at maximum luminosity : Bands of TiO and peculiar Balmer decrement : Hβ very faint and Hδ intense

The gas, being ideal, reacts to the high temperature produced by the core with a pressure gradient that balances the overlying layers. The result is a very large object and the radius of a normal star, on the main sequence (or later) increases with increasing luminosity. Because of the mass-luminosity relation of the nuclear powered main sequence stars -- the core temperature increases with increasing mass, hence the luminosity increases -- the surface gravity of such stars is rather low (about 30 times that of the Earth, about 10^4 cm.s^{-2}, and the escape velocity is low, $< 10^3\$$ km.s^{-1}. Imagine now that these stars accrete mass. The gravitational potential energy available from infall is determined by the mass to radius ratio of the gainer. For these stars, that is a decreasing function of mass. Some X-ray emission might be expected but only weakly and the density will be rather high around the star. On the other hand, let a 1 $M_\odot$ degenerate star accrete mass and the result is completely different. Degeneracy implies that the radius *decreases* with increasing mass and the gravitational potential energy available from infalling matter also increases. Immerse that star in a wind and it can capture the passing gas gravitationally if the outflow from its companion (as I discussed last time) is lower than the escape velocity. For a red giant, this is it *always* true. It doesn't matter what the mass loss rate is from the giant, it will be slow (the escape velocity from the giant is tens of km.s^{-1}. The capture rate depends on the same parameters as the rate of emission of the material, the mass to radius ratio of the white dwarf, and so does the temperature. So the matter, falling onto the surface, will release energy at X-ray energies (temperatures of 10^7K) and with a luminosity that depends only on the rate of mass accretion (the luminosity is proportional to the accretion rate).

Now let me step back for a moment. The matter doesn't fall in like stones dropped from any radial position. These are binary systems, not isolated WDs, and the matter has a small but not negligible angular momentum. To be more precise, the angular momentum depends on the orbital period but also on the rotation of the giant. If we ignore the latter, there is still a deviation of the material on its passage from one star to another and the accretion is not symmetric around the line of centers. This deviated matter, when captured, orbits WD. But being a continuous flow, when it intersects itself it isn't like a particle trajectory (although such analogies have been erroneously used to describe such flows). The returning matter slams into the incoming gas at supersonic speeds, resulting in a shock.

Symbiotic stars
and accretion phenomena in binary systems -2-

28-04-2014

Accretion disk

Oblique intersection produces streaming, strong emission (again, X-rays), and turbulent fluctuations that act like a viscosity, re-directing the flow and producing a circulating, hot, turbulent disk. At least this is the standard picture and it's quite consistent with the observed phenomena.

We don't understand the details of what happens next, but the big picture is pretty certain: some form of turbulent coupling of the shearing gas, whether magnetic or fluid or both, produces a strong tendency of the circulating matter to dissipate energy. The disks are heated by this process, vertically inflating to maintain pressure balance in the gravitational field of the mass gaining star, and the surface radiates locally like a photosphere. the main difference here is that the gravitation is not local, it's a tidal force produced by the central star, so the temperature varies across the surface of the disk with distance from the center. In other words, the disk {\it never} looks like a star. The shear, which is the source of the heating, increases as the matter gets closer to the center (assuming the disk is approximately in Keplerian motion so the orbital velocity varies as $r^{-1/2}$, and the inner par is hotter than the outer. This produces an integrated spectrum that looks like a power law continuum with a high energy cutoff (from the innermost orbit). The energy lost by this frictional heating comes from the kinetic energy of the circulating matter. In Keplerian motion, this is the same as a loss of angular momentum and the matter slowly drifts inward and accretes onto the star. What happens at the inner boundary is also not well understood but there must be a layer where the matter goes from circulation to infall, producing a shock when it hits the WD surface, and the ret of the energy is radiated there. The temperatures thus produced by this whole process vastly exceed anything that could be obtained from a normal star, even an accreting one, and this ionizes the surrounding gas. In a close binary system, such as a classical nova, there isn't anything but the disk surrounding the WD so the emission is coming only from the disk. In the symbiotics, the ambient wind of the red giant is high enough density and sufficiently extensive that the hard emission from the WD can be absorbed and radiated in emission lines. This is the i*onization bounded* region I mentioned in the last notes.

This process of forming a disk is a very general one in binary systems. The nature of the mass gainer is less important than the fact that the captured matter has sufficient shear and density to produce some kind of internal frictional coupling. Another way of seeing this is to consider what viscosity does. Imagine three radial annuli circulating around the WD. The inner one has higher velocity but lower angular momentum, the outer the contrary. Thus, any frictional coupling makes the outer region speed up at the expense of slowing down the innermost. This coupling is the same as a diffusion of orbital kinetic energy outward and, if the matter is bound, produces an inward drift. One usually says that viscous torques produce a slow inward drift whose rate depends only on the shear and the viscosity. Whether the mass is supplied by a stream, as in the close systems (and also Algol-type binaries, any system that is close enough to have one of the stars reach its dally limited radius will send matter toward its companion; this is the Roche surface) or a wind from a more distant star doesn't matter. The lower the angular momentum, the more nearly radial will be the accretion but a disk inevitably forms. In the boundary layer, there may be a very large shear (since the accreting star is a slower than Keplerian rotator) and this can produce intermittent accretion (and flickering on short, second, timescales), another signature of accretion in the symbiotic systems. The disk, if luminous enough, can also power outflows. These will be axially symmetric, since flow off the surface of the disk preserves angular momentum but can expand along cylinders, and the collimations jet-like. Such effects have been reported for a number of symbiotics, e.g. CH Cyg and Z And. The kinetic energy in these jets, which may be episodic, depends on the luminosity of the disk, hence on the mass accretion rate.

Symbiotic stars
and accretion phenomena in binary systems -2-

28-04-2014

I hope this makes sense. It's complicated phenomenologically but actually quite simple in its basis. Every step depends on the intensity of the central gravitational field. The more mass you pile onto the WD, the brighter the disk will be until radiation pressure itself governs the structure and produces an outflow (from the disk surface). You can maintain a wind and accretion at the same time if the disk viscosity is high enough. The problem, central to all such models (including when there are central black holes) is the origin of the viscosity. While one can model the process assuming a simple form for the friction, usually taken as a traction of the disk pressure for the stress producing the viscous torque, the origin of the high values required to account for the inward drift rates remains a subject of heated debate. Something that acts like turbulence is required, that is something macroscopic. The normal microscopic (molecular level) viscosity that causes a spinning bowel of soup to reach solid body rotation and eventually stop won't work because the densities are too low and the speeds too high. One of the ways to understand this is from the emission lines. Their luminosity is powered by the accreting source so by obtaining the energy balance and the timescales one can estimate what the viscous torque must be. From that, the mechanism should be discernible. At least that's the hope.

OK, I'll stop here and hope that any of this made sense. The next time I'll include some cartoons for illustration. In the meantime, I strongly recommend trying some experiments with spin-up of cups of coffee (take the cup and spin it without stirring around on its plate, you'll need an American-size cup, I'm afraid, and a low friction plate but I assure you it'll be worth it). The spin-up timescale is a very good measure of the viscosity and, by reversing the picture, will give you a feeling for how the accretion is taking place.

Steve Shore, 28-04-2014

Symbiotic stars
and accretion phenomena in binary systems -3-

22-05-2014

The accretion process

So far I've been concentrating in these notes on the specific objects, novae, that started this series of discussions. Now let's get to the central issue -- the physical process of mass transfer and accretion. It doesn't matter whether we're talking about compact systems such as cataclysmics, symbiotic stars, binary Be stars -- the conditions for any of the phenomena I've been discussing require that something external to the activity site serves as the driver.

To start with a basic point, consider the evolution of a *single* star. Summarized in a few words, and this isn't to oversimplify[1] stars are self-gravitating objects in global hydrostatic balance (mechanical equilibrium) and in thermal balance (that they emit the totality of the energy they internally release) of sufficient mass that they reach the temperatures and densities at which thermonuclear reactions can ignite and remain self-regulated. The key is that nuclei, structures of protons and neutrons, have a finite binding energy that can be released when the addition of other nuclei produces a more tightly bound state. This is an analog of what happens in atoms when, in passing from an excited to a lower energy state, photons are emitted. The strong interaction, the nuclear force, is attractive at short enough length scales that if the energetic conditions are right ambient charged particles can overcome the long-range electrostatic repulsion of the similarly charged particles and become bound. This is a random process in stellar matter, an ordinary gas that reaches sufficiently high temperatures and pressures in the interior of such an object that a mean rate of capture is established. The rate, which depends on temperature, also depends on the nuclei involved. For instance, as you know, the solar luminosity is generated by proton capture on hydrogen (the so-called proton-proton chain) that, because it doesn't require any heavier nuclei, is the basic reaction. It is a very slow process because the first step requires conversion of a proton to a neutron to form a stable state but this happens with a very low probability, but it happens. The result is the irreversible loss of energy that's released, in the form of photons (but also neutrinos, although not the dominant loss mechanism) and the net conversion of H into He, the next stable nucleus. In more massive stars, since the higher core temperatures permit the reaction, the next most abundant nuclei also participate and, in fact, dominate: the CNO cycle . In this, pH is converted through a range of successive captures and decays into He with the C nuclei serving as a catalyst. The reaction is much faster than the pp chain, and the luminosity is greater, but the net product is the same. The core composition changes and the released energy establishes the pressure and density structure of the envelope of the star, yielding larger radii and higher luminosities for greater masses.

All subsequent nuclear reactions during the cycle of thermonuclear processing follow from this simple picture. Each stage produces a range of residual nuclei that can, depending on the stellar mass, subsequently ignite. Since each is more charged and each has a higher binding energy, the process becomes progressively more centrally condensed. Regions outside the core also ignite because of the heating from the core and the processed material, which has a chemically different composition than the unprocessed envelope, increases in relative mass. For instance, the region outside the He core ignites hydrogen burning even while the core itself remains merely hot because there's still a supply of hydrogen. The core, continuing to lose energy, contracts and raises its pressure and temperature, thus powering the overlying layers. This has its limits, most of the star will never undergo thermonuclear processing but an increasing portion does and this continues until the reactions are no longer releasing energy (when the Fe region is reached, in the most massive stars) or when the energy loss is predominantly from neutrinos (which stream, rather diffuse, outward from the core and don't additionally heat the envelope). The details are not essential at this point for most of the systems you've been following. For chemical evolution of the Galaxy, for winds and outflows, for supernovae, yes. But for the basic understanding of the mass transfer in close binaries no (we can certainly discuss this at another time, it's very lovely stuff).

Suffice it for the moment that the more massive the star, the higher up the periodic table the nucleosynthesis pro-

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[1] Eddington is famous, among other things, for the global viewpoint concerning stellar evolution, summarized in the phrase ``At terrestrial temperatures matter has complex properties which are likely to prove most difficult to unravel; but it is reasonable to hope that in the not too distant future we shall be competent to understand so simple a thing as a star.''

ceeds. For stars below a couple of solar masses, the process essentially stops with core helium, or helium plus a CNO-processed shell. More massive stars ignite the core helium and convert it to carbon, those still more massive reach N, O, and eventually Ne through subsequent addition of the He nuclei α processing), but neon is the practical limit and those stars below about ten solar masses that then finish their nuclear cycles and simply cool. Well not quite ``simply''. There are several auxiliary stages of shell burning of CNO and He but that's it and these are shortlived relative to the main core processes. Once thermonuclear processes end, the core continuing to cool contracts and the outer layers, by expansion and continued heating, are lost in a wind. The mechanism for this stage is also still not well understood. But to connect with what we've already discussed, this is the stage in which the companions of the WDs in symbiotics find themselves, and also the stars in planetary nebulae at their initiation. The wind strips the envelope of the star, leaving a compact, eventually degenerate, core behind that we see as a white dwarf. The composition differs in these beats according to their progenitor's history. Those from solar mass stars are predominantly He, those from more massive parents are CO, while the most massive reach ONe. This, you may recall, is the distinction we drew when describing the WD on which the thermonnuclear runaway of the nova event ignites.

This nuclear reaction sequence also occurs for stars in multiple systems if they can evolve as single objects, that is if they are not so close that their envelopes merge (the so-called common envelope binaries) and the individual stars going through this nuclear processing (from now on called ``burning'') are known as the *main sequence* . The name, as you surely know, is because the stage is the slowest, hence longest, in the life of a star. Hence they are the dominant population in any ensemble of stars formed over time. The lower the mass of the star, the longer it stays in this state and for stars somewhat lower than the solar mass they last as hydrogen core burning objects for the age of the Galaxy to date (or longer).

Now put another star nearby. Much, but not everything, changes. For simplicity consider a binary system. The components, however the system forms, produce a mutual an external gravitational force that depends on their separation and masses. And radii. Every element of the mass of each is attracted by the other but, because the self-gravitation is dominant, the bodies distort without disrupting. This is the *tidal* force. Their centers of mass orbit, but to the next order there is a differential force for each. The closer portions of the star are more drawn toward the other than the center, and vice versa for hose more distant. Relative to the center of mass, the two ends appear to accelerate oppositely and, for a small perturbation, the distorted shape of the components is an elongated spheroid along the line of centers. The larger the radius, the greater the *differential* force even if the attraction is mutual. So if one of the stars is expanding relative to the other, it becomes progressively more distorted and, as its surface approaches the point of force balance between the two stars, progressively more asymmetric. The limiting radius, the point at which a mass element in a stars envelope isn't bound to either star, is the *Roche surface* (not because Roche was a distorted Frenchman, I should add). There's nothing particularly strange about the configuration if it's just a limiting orbit, this is the three-body problem is called the i*nner Lagrangian point* or L_1. It is only coincident with the center of mass if the two masses are equal and always farther from the center of the more massive member of the system. The Roche limit is, therefore, the largest radius a star can have and remain, for all practical purposes, a single object.

The limit isn't a hard wall, as you might imagine from the usual description. It's something like the approach to a toll booth. The pressure remains on one side, but the cars are free to accelerate on leaving (and, on the autostrada, certainly do with gusto). But there's a continual supply from the other side. The acceleration isn't identical but the mean is the same and the point of no return is the same but the cars start accelerating at slightly different points. In a stellar envelope, there's a pressure on one side (the envelope itself) and on the other just the open vista of the other more compact star. So matter accelerates toward the companion driven by a flux of mass from below and the pressure gradient adjusts to permit a steady outflow as if from a nozzle. The side of the region in contact is quite small relative to the radius, of order the distance over which the pressure can drop (the it *pressure scale height*, but for our purposes it can be taken as simply a small orifice through which material is flowing and lost from the star. The flow isn't direct, however. Were the two stars nailed to the sky so they can't orbit, it would be. But because of angular momentum, there's a deviation of the flow (the Coriolis acceleration, to be technical) that causes the flow to -- now supersonically -- follow an orbit of its own around the companion. Over time, and only a few orbits is needed, the self-intersection produces shocks and further energy loss and heating, and the flow circularizes around the companion. We can now pass to a new terminology: the two will be called the mass loser and mass gainer. This avoids the often confusing distinction of ``primary'' and ''secondary'' since it doesn't make any assumptions about the relative mass and/or luminosity of the stars.

How the circularization proceeds is still poorly understood although observationally evident: a circulating disk of continuous supply is formed that is maintained by the flow of mass from the loser and the collision of that stream with the outer parts of the flow. This is an *accretion disk*. But to pass from circulation to accretion requires that the angular momentum of the matter change, decrease, which requires in turn a torque. Some of this dissipation can occur in a hot spot, the impact site for the incoming stream at periphery of the disk. This is seen in both emission line variations (in fact, the basis of the so-called tomographic reconstruction of the disk that uses the variation of the emission line velocities with phase to reconstruct the orientation of the emission site) and also produces a bright phase in the light curve that leads the eclipse of the WD (in systems that eclipse). The shock redirects the flow continually and is thought to be a source for turbulence, at least locally. Something must act to slow the orbiting matter and convert angular into radial motion. And now we come to the Pandora's Box of accretion: how does the matter in the disk exchange its orbital kinetic energy with other parts of the disk so there is a net inward drift?

The accretion process and why it's a disk: a bit more in detail

Mass transfer through L_1 is dynamically very close to the blast from a firehose nozzle, if the hose is also on a carrousel. Since the mater was accelerated in a rotating system, there's a net acceleration from the motion. To be more precise, the Coriolis acceleration is a deviation in the flow because it's angular momentum doesn't match that required for strict corotation. Thing of sitting on a moving a carrousel, on one of the horses on the periphery. Aim the nozzle toward the center. The flow is starting with some angular momentum that depends on its distance from the center so that is higher than the inner parts. If you aim at one of the horses, the flow will inevitably miss because it's deviated by its different angular momentum. To slow it down requires some kind of torque and, for a free stream, there isn't anything available unless it's dragged by contact with the platform. The same is true, by the way, for motion on a sphere if the flow is meridional (along lines of longitude) but {\it *not*} zonal, along lines of latitude that are axially symmetric circles. The difference is that in line center of the binary system carrousel there's a gravitational source, a mass, that deviates the flow so if it starts from a bound state and at the sound speed of the envelope of the star filling its Roche surface, the initial speed is well below the escape velocity within the environment of the companion and the stream orbits. As I'd mentioned, this stream, can self-intersect, moving at an orbital speed that is the Keplerian velocity of the intersection point, and this is very fast and very supersonic (at the surface of a WD, the orbital speed is about 3000 km.s^{-1}, with the escape speed being about 40% higher. The mater spews out of the L_1 point at high pressure but essentially at the sound speed so it spreads but not much, especially in the vertical direction. In fact, since the stream is -- in this sense -- cold, it never reaches a significant height above the orbital plane before falling back in a precessing orbit. So the motion of the stream, and the subsequent dispersed matter after self-intersection, is confined to a plane with a thickness that depends on the distance from the center but is approximately given by the inverse of the Mach number times the distance, Δ z/r ~ $c_s/v_{orbital}$ where c_s is the sound speed. The outer parts of the disk are thicker because the Mach number increases with distance (the orbital velocity is lower even if the disk temperature is constant), a thin flaring disk, but it is still quite thin, a few percent of the distance.

The problem is not the formation of a disk, this is unavoidable in a rapidly rotating system, but accretion requires a net transfer of mass toward the companion. To do this requires some kind of internal stress. A global stress, for instance a magnetic field of the WD, would couple of the star to the surroundings. But since the orbital velocity is always greater than the stability limit of matter bound to the WD -- that is, it's always orbiting faster than the maximum allowed rotational velocity -- the field can act as a propeller to expel material from the system (and the mechanism is so named, in fact). Instead, some kin of local, collisional, random motion that leads to heating and dissipation of orbital kinetic energy will also force the material to slowly drift inwards. The rate is almost sonic but it's a sort of diffusion, random fluctuations on all scales up to the local disk thickness are the most effective. Since they're local interactions, any one fluctuation (OK, call it a blob), interacts with those around it to produce the same effect as a viscous coupling, shear driven by the differential motion of the disk, that transfers angular momentum outward while forcing the matter to fall slowly inward. The last step is at the WD-disk interface where the infalling matter finally loses the last part of its energy and that's the next item on our agenda.

Magnetically dominated accretion, magnetospheres and polars

If there's a magnetic field that is strong enough to support the disk, the standard picture is a funneling of matter toward the poles of the star where the accretion is confined to something like the auroral zone on the planets in the presence of the solar wind (Fig. 4) . Rotation of the field modulates the intensity of the observed emission, both line and continuum, as the pole change sits aspect relative to the observer with rotational phase. This is a *polar*, the signature of a magnetized mass gainer. Tidal forces acting over long enough time can (but don't necessarily) produce synchronous rotation - the WD rotational period is the same as its orbital period, analogous to the Earth-Moon system. If the spin of the WD and its orbital period differ, a so-called *intermediate polar*, there will be a phase shift between the line and orbital variations. The details are interesting but, for our general purposes, not critical. The bulk of the matter in the accretion disk has a standoff distance from the surface of the magnetic WD because of the magnetosphere (think of pictures you've seen of the van Allen belts of the Earth in the Solar wind) that depends on the field strength. So a signature of a magnetic WD is pretty direct but *only* in quiescence.

Boundary layers

The alternative is when there isn't a strong enough field to impede the inward motion in the equatorial plane of the star and the accretion occurs through a boundary layer. This is one of the most poorly understood aspects of turbulent fluids in general but here it's even more extreme. In a cup of coffee, if the cup is set into rotation, there's a drag from the rigid boundary that diffusively spins up the fluid. Eventually, at least a part of the fluid is co-rotating with the cup but the center may still lag. Over time the state of dissipative forcing yields a column of coffee that seems to rigidly rotating with the walls. Stars, on the other hand, have fuzzy boundaries and the disk is forcing the spin-up, not vice versa. As the material slows to the corotating state it loses energy that heats the boundary to more than 10^5 K. The emission extends into the UV and, if hotter, into the X-rays (Fig. 5). This emission also flickers, like a noise, and you see this in cataclysmics. The temperatures can get even higher if the central object is a neutron star but those are not the sorts of systems we're dealing with; in novae it should reach only (!) a few million K but this can be seen in quiescence from X-ray satellites. The disk is continuous in this case with no inner boundary other than the star. Another, important but also poorly understood feature of this layer is the shear mixing it may produce with the underlying WD. Remember that the matter coming in has a different composition than the star onto which it's falling. The mass loser is not a WD, even if it's not necessarily a normal main sequence star (or giant) it's likely hydrogen rich (unless somehow that part of the envelope has been remove and the helium core or shell has been exposed). So how the mixing takes place is important for understanding the ignition of the TNR.

Some of this may be recorded in the composition of the ejecta, and there could be mass loss from a wind produced by the boundary layer (this is implicated in protostellar disks such as T Tauri stars), but much of this remains in the ``open but frequently asked'' question category.

Wind accretion

One last point, since you've had the patience to bear with this discussion. If the WD is immersed in the wind of a mass losing giant, all of these processes still occur. There's a disk, not as massive or as observationally evident and not as well defines as with a stream. But observations of flickering in the light curves of symbiotics is a pretty good indication of a disk. There are other effects, a bow shock caused by the WD as an obstacle to the supersonic wind that also forms a trail behind the WD (an accretion wake) but all of these are happening simultaneously and to date, only a few systems have been observed for a long time to understand what's happening (an encouragement, I hope, to those of you who are interested in such systems). Again, the infall of matter into the strong gravitational field of the WD produces UV and XR emission but now the radiation is absorbed by the surrounding junk of the giant's wind. This is the source for the signature emission lines that define the symbiotic stars. Of the novae occurring in such systems, the few known seem to be extremely massive WDs but that's the main difference. Once the matter gets onto the star and mixes into the envelope of the gainer, how it gets there really isn't ``remembered'' by the system. At least at the moment that's the thinking.

a few last comments

The main point, that the matter accumulates over the whole equatorial region for an unmagnetized WD or predominantly at the poles for a polar, is what matters. In outburst you don't see any of this, either for a symbiotic binary or a nova. The ejecta hide whatever is happening in the innermost parts of the system because of their initially high opacity. But when the smoke clears and the system returns toward quiescence (whatever that means) the emission comes from the environment tied to the WD. It is usually stated that the quiescent presence of He II 4686 Å emission is the evidence for a disk. This is OK if there's otherwise no indication of the ejecta. The reason is simple: the disk is hot. Not so hot that it is thick, that would require temperatures above 10^7 K locally to approach the orbital speed, but at least a few tens of kK. That is hot enough to produce He II recombination emission. The characteristic line profile would then be disk-like, maxima at high or intermediate speeds (depending on the disk inclination) and a double peak structure that is roughly symmetric about zero. I'll repeat that this is expected in *late* stages of the outburst, by the time the ejecta are so low density that their spectral contribution is negligible. But in the early spectra, those taken when the ejecta are still visible, there are many ways of getting the same profile so the evidence for early disks is not unique. On another, related issue, the polar shows itself by *periodic* signals (also polarization) so if the periods are different there will also be evidence of that in the spectral time series (as there was in V1500 Cyg 1975, for instance). This is a very good reason for pushing on high cadence when the systems are still bright, there may be evidence from key lines (the He and higher elements in moderate ionization states, not likely the Balmer lines that are formed everywhere!) . There's little known about this. The orbital periods of novae are less than a day, except for a few classical systems like U Sco and GK Per, so I mean rates of one per hour, for instance.

So now, in the sincere hope that this hasn't been too heavy going, we've reached a good place to stop. Thank you all for your continuing interest and wonderful work.

Symbiotic stars
and accretion phenomena in binary systems -4-

06-07-2014

More on mass transfer in binary systems: something about dwarf novae

So far, the accretion disk has been a sort of magazine, a storage place for matter that slowly drifts inward and accumulates on the central star. Were this the only thing that happens, they would be rather simple beasts. The only problem would be the origin of the viscosity that transfers energy and angular momentum. But were the disks merely passive, the observed accretion rate would suffice to answer the physical question of origin (or at least bound the values for any possible mechanism). This seems to be alright for Be stars, for which the mater is almost optically thin. But that is a mater of structure. So for this installment, let's look a bit more at what goes on in cataclysmic systems. By these I mean *any* system that has a white dwarf accreting matter. For the moment, I'll exclude neutron stars and black holes, although you can observe those even at medium resolution with your equipment (both aperture and spectrographs; I'll discuss an example later, OK?). These don't necessarily merit such an apocalyptic name but that's the field.

To return to the structure issue, assume for now that the central star dominates over any local gravity from the matter of the disk itself. This isn't a problem for those formed in cataclysmics. If you're transferring only a relatively small amount of mater at any time, and you know how much has to accrete, then it's easy to estimate how much can remain in the disk. A way of seeing this is to ask how much mss has to accumulate to produce a recurrent nova, since that triggers when a specific pressure is reached within the accumulated layer. If that's about 10^{-5} M⍰, and these explode on timescales of a century (otherwise how would we know they're recurrent?) then the rate of mass transfer has to be about 10^{-5} M⍰ . yr^{-1} and that also means this has to transfer through the disk in that timescale. How much mass is actually accumulated on the star is estimated from the WD luminosity, if it comes strictly from loss of orbital kinetic energy and is released in a thin shock at the star's surface. This luminosity is proportional to the surface gravity times the mass accretion rate (well, to be honest, it's the rate of release of gravitational potential energy buy the infalling mass), so L ~ M' where M' is the rate of *mass accretion*. Actually, no matter where the energy is released, no more is available than the depth of the gravitational potential well into which the mass lost from the companion is falling. But there's a catch. The matter doesn't fall in radially so some accumulates within the disk. The maximum rate at which an object can accumulate mass also depends on whether the shock is optically thin (so it loses energy immediately and just arrives cold after the shock) or stays hot and radiates. The latter is the *thermal timescale* that depends on the amount of matter accumulated and its internal energy. Thermodynamically, this is the same as driving a steam engine too hard, heating it faster than it can get rid of the energy. The system becomes unstable and matter would be blown off. The same is then true if the *disk* is optically thick. If the rate at which matter releases energy generated by viscous drag -- internal frictional heating in a differentially orbiting disk -- then the disk itself becomes thermally unstable. This causes it to expand and contract, and depends on the opacity of the disk that, in turn, depends on the local temperature and column density. If the rate of accretion, the rate of supply from the companion, is too high, the disk goes unstable. But not throughout at once. The different regions are thermally connected and the heating waves propagate at the local sound speed (the thermal velocity of the gas particles). The disk locally inflates, its brightness increases, but the *spectral* interval in which this is seen depends on the disk temperature. That is higher for the inner than outer parts. This local disk inflation then shows up first in that portion of the spectrum at which that annulus radiates the bulk of its energy. The inner part does this in XRs, the outer in visible and IR ranges. The outbursts depend on how quickly the disk readjusts its structure and this is what you see in a {\it dwarf nova} outburst.

Actually, the process is amazingly simple and resembles the driving of a pulsating variable star, like an RR Lyr or ⍰ Cep. There the instability is deep within the envelope and the entire star expands and contracts with an amplitude depending on radius. The seat of the instability is the convection zone, where the opacity is due to ionization of the principal elements (e.g. H, He) and becomes resonant when the convection zone is overlain by the right amount of mass to produce counteracting compression when it cools and falls back. In accretion disks this never globally organizes, the disk is orbiting at different rates and the heating isn't uniform. The thickness also depends on radius (the peripheral regions are thicker because the surface gravity is lower) so you have different parts of the disk triggering and then propagating the trigger while expanding and cooling.

The spectrum of the disk is a clue to this process. Accretion boundary layers are hot, that's where the last energy release occurs at the highest gravity locally, and also geometrically thin. So you expect XR emission and also very high ionization lines. The local energy release at greater radii is lower but the disks are both more extended and cover a greater area, hence the flux times the area is large and the regions above the local photosphere (in other words, the optically thick surface of the disk if it {\it is} optically thick) is like a chromosphere. Hence you see ionized species like He II 1640, 4686 ÅÅ and C IV 1550 Å. This is the origin of the common wisdom that He II signals the presence of a disk. The line profile, since the emission region is within a finite annulus that doesn't extend the full radius of the disk, looks like the profile of a ring -- two peals separated at about the orbital velocity for that annulus whose separation also decreases as the disk is seem more nearly face on. If seen through the plane, there can be absorption from the colder regions in the outer disk against the hotter inner regions, a true absorption (not scattering) process. It is quite amazing that there are long-running debates about whether this is seen in cataclysmic disks (I won't make any other comment!).

The timescale for the outburst is a thermal timescale, not just an oscillation time, and the events last as long as the imbalance between the rate of energy generation by viscosity and loss radiatively persists. The heating, by the way, is also simple to understand if you think of bending a spoon (remember, perhaps, Uri Geller??). If you do this slowly you don't do anything but slowly distort the handle. The faster you do it, the hotter it gets. This is because you're stressing the system and its response is strain. The rate of heating is the product of the rate of stressing and straining. The temperature rises because conduction can't keep up with the rate of energy generation so, eventually, the spoon breaks (and is very hot). A less drastic (and non-destructive) example is to put a rubber band between your lips and stress it. You'll feel the change in the temperature. In an accretion disk the rate of stress is directly proportional to the rate of strain, a similar situation to a spring following Hooke's law (the deformation is directly proportional to the applied force). So the heating varies like the {\it square} of the strain. And the strain is the same as the orbital frequency (in this case, Keplerian motion). I know this is getting nasty but don't worry, it's not much harder than whipping cream and imagining the entanglement of the polymers in the fluid. Since this depends on the distance (lower strain at greater distance) the outer disks are cooler since the energy generation rate is lower for the same mass accretion rte. Changing the viscosity causes the energy generation to vary, if it increases so does the local luminosity, and that's the hard part of understanding dwarf novae.

It appears that the dwarf novae have, therefore, optically thick disks that are unstable to a thermal oscillation (a sort of local pulsation). Whether this happens in novae is another mater. Such fluctuations, quasi-periodic in nature, were seen in GK Per 1091 in the decline phase and there and the compilations by the AAVSO show, from photometry, that other novae do this too. How this relates to the mass transfer rate and disk dynamics should then be clear -- nova disks may accumulate enough mass, in non-recurrent systems -- to become optically thick and unstable. But hardly all. Or, at some point during the decline, the re-initiation of accretion may drive the already engorged white dwarf envelope into an oscillation for a while. We don't know and, more important, there's little spectroscopy available of this stage to know. Even low resolution spectra are very valuable here and, since this occurs during outburst, would be possible even with small apertures (think of SS Cyg and U Gem, the two longest records we have of photometry).

The other observation that provides a limit on the mass transfer rate (neither accumulation nor heating) is the change in the period because of the slow drift of the center of mass. The angular momentum of the system changes because of mass loss and dissipation but that may be minor compared to the slow movement of the center of mass toward the mass gainer. Depending on the initial mass ratio, this leads to a change in the period. But you know that there are dissipative processes and, to return to the point at the start, there is also a sort of storage of the angular momentum transported by the stream within the disk. So it's a bit more complicates since if mass is thrown out of the system some of the angular momentum of the binary is also lost. That's where observations of the line profiles for novae and dwarf novae is also important, if there is a wind it can transport both mass and angular momentum out of the system. We don't know the magnitude of either loss or how the driving of the wind (if present) is connected to the heating. Superhumps, driven by tides and local heating, are a very important for this process but how is still being sorted out.

But for the moment, I'd better stop and let you take a breath.

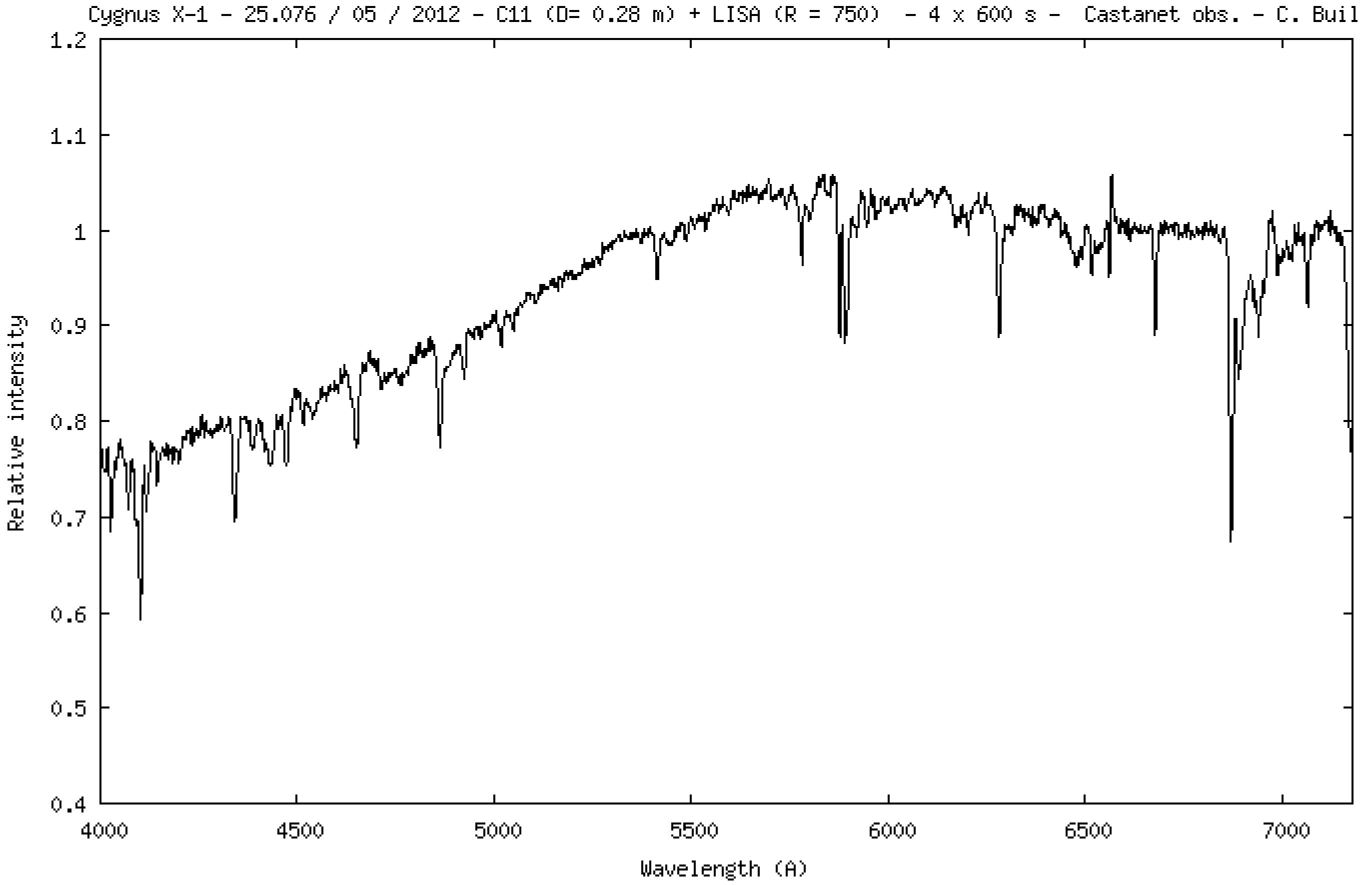
A few comments on Cyg X-1

Now for a last teaser. I promised earlier to mention one black hole system for which your observations would be particularly interesting. Cyg X-1, also known (by Interpol) with the alias HD 226868, is an O supergiant - black hole system, the first discovered. TAt V=8.9, it's a bright source and not a difficult observation. The orbital period is 5.6 days making it an ideal candidate for monitoring. This was the first high mass XR binary to be discovered with a BH companion (Bolton 1972), with an inferred mass well above the upper limit for a neutron star (it's about 10 $M_{\odot}$ depending on the mass of the O supergiant). The system is highly variable over decades, going into outbursts that depend on the mass accretion rate and the optical thickness of the disk. And since it has a black hole at its center, the phenomena under what is called ``strong gravity'' dominate the inner disk structure. This includes dragging of the inner boundary by the rotation rate of the central BH.

The disk in its outer parts should behave much like any other cataclysmic, except that it is likely more massive, but since it is unstable and there is also a wind (at least in part) from he companion it is important to monitor the changes in the system through outbursts. These are noted, for instance, in ATels and surveyed by XR satellites. If you need something to do in the next months, while you're being voyeurs of its neighbor in Cygnus, you might give a look at this wonder.

Remember, it's a close encounter with general relativity in the cosmos.

So now, in the sincere hope that this hasn't been too heavy going, we've again reached a good place to stop. Thank you all for your continuing interest and wonderful work.



Cygnus X- 1 by Christian Buil - 2012-05-25.076 - R = 750

About a particular process:
Raman scattering in stellar spectra

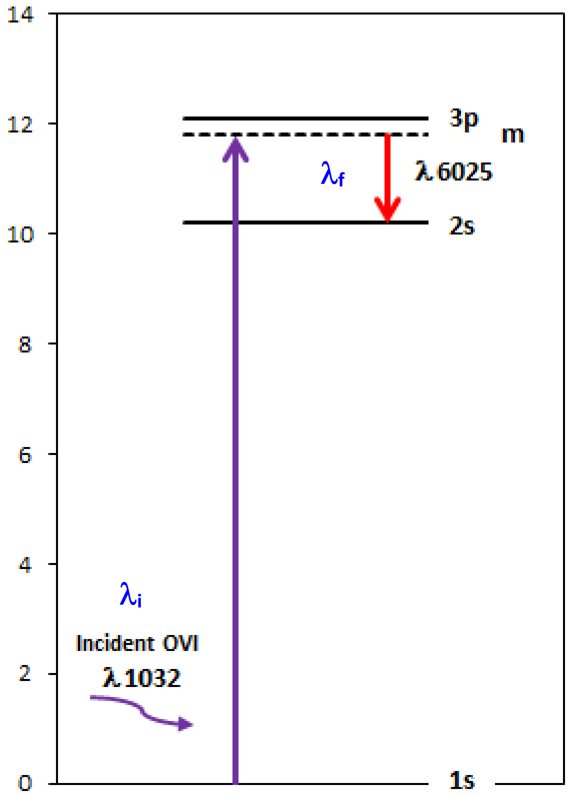
22-05-2014

Raman[1] scattering is one of the most important early demonstrations of quantum mechanical processes in atomic and molecular systems ; it's not all that different from Rayleigh scattering.

When two systems are near resonance, the difference in the frequency can -- if the interaction is strong enough -- create a third frequency. A well known effect in nonlinear wave scattering (think of two waves colliding near a beach and how a third wave can be formed that is the sum/difference of the other two), in an atomic case if a strong line is near (and that's the key) another strong line in energy, the excited state of one can be reached through a conversion process. Although there's a mismatch in the energies, the difference can produce an emitted photon. The process had its astrophysical debut in a remarkable piece of detective work by H-M. Schmid, Harry Neugebauer, and the ETTH-Zurich symbiotics group. For many (!) decades, since they were first noted by Merrill, two extremely broad emission lines around 6825 Å and 7080 Å were associated with a large number of symbiotic stars -- and only with that class. While all laboratory attempts at identification failed, it was proposed by Schmid[2] and company that these (and other) lines could be due to this previously neglected process. Their predictions -- especially the polarization of the lines and their variation in strength and degree and angle of polarization with orbital phase, were quickly confirmed. The identified culprit is the scattering of the FUV resonance lines of O VI 1032, 1038 Å from Ly β 1025 Å . Notice the very close match and the fact that the scattering produces a doublet with a large separation and large width. The cited paper actually identified several UV lines in active galaxies with highly ionized states of Fe, {\it *not*} the O VI. But, presciently, they included a table that listed the O VI doublet (I chose this one because it's the ``first'' suggestion and especially clear, if a bit technical). Note that the main difference is that the line is *shifted*from the scatterer and the energy of the emergent photon is *different* than the incident photon. In the case of no change in the energy, you would have Rayleigh scattering. Here there's a coherent process, in just the same way, but the energy changes because of the resonant interaction. Perhaps the most important result is:

$$\frac{\Delta\lambda_f}{\lambda_f} = \frac{\lambda_f}{\lambda_i}\frac{\Delta\lambda_i}{\lambda_i}$$

the statement that the line width is a scaled (larger) value for the scattered line (left side) than the observed width of the responsible transition by the ratio of the wavelengths. So, for instance, taking the O VI example, the observed line is about 6 times the width of the FUV lines. Why this should happen in symbiotics is the key to understanding the importance of the process: the degenerate is accreting in the wind of tits companion giant *so there's a very long pathlength for interaction within the neutral circumstellar medium for the emission lines formed in the ionized region immediately around the WD.* It's just a conversion process. We've discussed similar conditions for couplings between ground state and excited transitions *fluorescence* and *line pumping* when dealing with the optically thick stage of nova ejecta at the start of the fireball (and later). Some of those you know well now are the [O III] nebular lines, the Bowen N III lines (4636 Å) and other cases of pumping. Here the process is a probe of the two regions. It requires the high ionization states (the O VI forms in a very strong FUV radiation environment) and a sufficient optical depth that the bulk of the hydrogen remains neutral (an ionization bounded H II region). There are a number of possible additional lines that



Schematic ernergy diagram (Y scale in eV) for Raman scattering of OVI 1032 photon by neutral hydrogen

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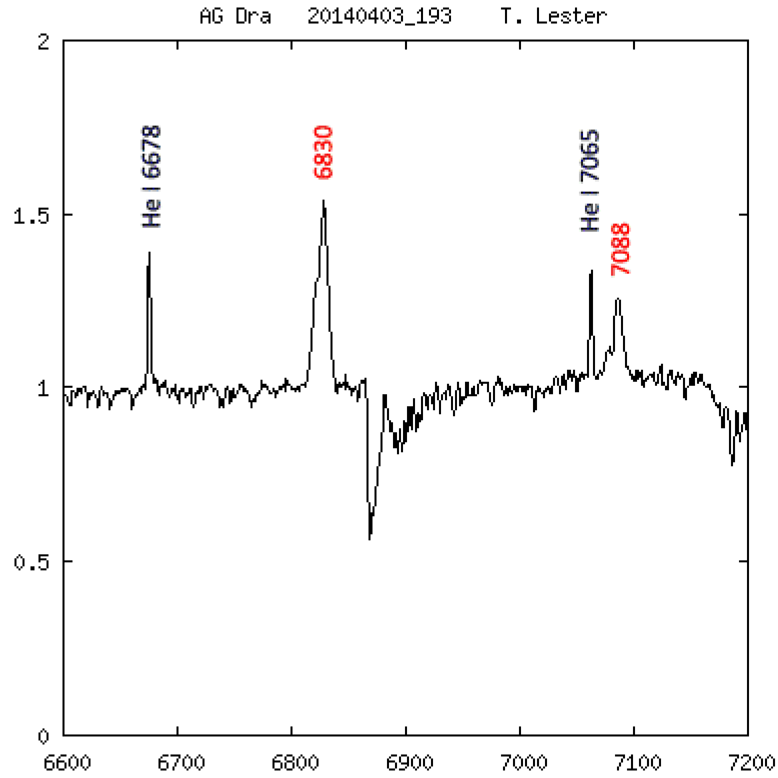
[1] http://www.nobelprize.org/nobel_prizes/physics/laureates/1930/raman-bio.html

[2] http://adsabs.harvard.edu/abs/1989A\%26A...211L..27N

can form, but regarding the O VI this is a *doublet* and *both* lines must be present (see also http://adsabs.harvard.edu/abs/1998RvMA...11..297S).

In nova ejecta, there's another interesting possibility, one that's been sort of staring us in the face. The Raman lines were detected in RS Oph, not a surprise since this is a symbiotic-like system. The pair was *not* seen in V407 Cyg, and I don't know the final result for V745 Sco (the problem is the star was so faint that there isn't enough to go on in the otherwise water-dominated part of the spectrum). But in classical ejecta, the inner region may be ionized while the outer portions are neutral once the ionization starts to increase before the lifting of the veil toward the WD (and the SSS it harbors) and the inner ejecta may reach the O^{+5} ionization state. If, and it's a big ***if***, the outer ejecta are still sufficiently optically thick, there could be an internal Raman conversion. But this is not the same as in a symbiotic: this medium is not nearly static around the H II region of the WD. It doesn't matter if the WD has a wind or not, in fact the O VI lines are likely formed in an outflow. The medium has to be nearly stationary (and that only requires spherical symmetry, somewhere there will be an interaction). Nova ejecta have a very large internal velocity gradient so the H I lines are shifted with respect to their rest wavelength as seen by the inner ejecta. They're redshifted. This means the O VI lines are actually at a different frequency difference (energy difference) from the neutral medium and there should be a shift in the wavelength of any Raman scattered line. As an example, if the velocity difference is 2000 $km.s^{-1}$, at 1025 Å this amounts to a shift of almost 7 Å toward the O VI. Instead of $\Delta\lambda$ approx 13 Å, this is closer to 6 Å so the resulting line should be in the IR and unobservable. There might be other lines, instead, that could appear depending on the nearness of the Lyman series of neutral hydrogen. It's also possible that He I resonance lines could produce some effect, this has been suggested for symbiotics, but it's not likely to be important for novae.

The variation of the Raman lines in symbiotics is, on the other hand, the *unique* view we now have into the FUV and the immediate environment of the WD. The variation of this line has been studied by a number of groups, I'm including a reference list link from a paper we did on AG Dra as a guide http://adsabs.harvard.edu/abs/2012BaltA..21..139S but it's just a window into this (see also the special issue Baltic Astronomy, Vol. 21, p. 1ff from a meeting a few years ago at Asiago on symbiotics and related systems, edited by Siviero and Munari.



The two Raman OVI 6830,7088 in AG Dra Spectrum

About Raman scattering in symbiotics, see also :

http://www.astronomie-amateur.fr/feuilles/Spectroscopie/Methodes_Spectro/Raman_OVI_6830_7088.html

New notes on spectra and line formation,
on the regularities of line spectra and the regularities of atomic structure
Isoelectronic sequences

11-08-2014

In the discussions at OHP, I didn't have a chance to explain one of the most useful diagnostic features of line spectra. Let's start with a simple case, hydrogen. In the neutral state, H has only one electron and this has three labels: *n*, principal quantum number that gives the mean distance of the electron from the nucleus; *l* that describes the angular distribution (symmetry) of the electron cloud; and *s*, the spin. For HI , the H^0 atom has states labeled *s, p, d, f*, etc. according to whether *l* = 0,1,2, … . The value of *l* and *n* are *always* integers. In contrast, the spin *s* is a multiple of 1/2. I hesitate to use the word but, like angular momentum, it's frozen in the vocabulary of quantum mechanics but you can think of *s* as the intrinsic magnetic dipole moment of the electron (it's alignment or anti-alignment in an external magnetic field and relative to the other electrons in the atom). You know the distribution of the energy levels for H I, they're the upper states of the Lyman (or Balmer) series and very simple. But this is also the case for He II (He^+), also a one-electron system. Only the nuclear charge is different (so the energy of each state (*n,l,s*) is shifted by a factor of Z^2 where *Z* is the atomic number (the number of positive charges in the nucleus). This displacement in energy is because the ionization energy (that is, the electrostatic binding energy) of the atom is increased and all of the states scale accordingly. So with an ionization energy of about 13.6 eV for H I, for He II it's about 54.4 eV. OK, the exact equivalence of all strictly one electron atoms can be extended throughout the periodic table, to Li III and Be IV and so on. But that would be of little use unless we were dealing with a plasma that is so hot that it can achieve C VI or N VII (or Fe XXVI, which actually happens in accretion disks around neutron stars!).

Instead, think now of Na I. With an atomic number Z=11, there is one electron outside of a closed set of shells. The ground state is $1s^2 2s^2 2p^6 3s$. In other words, since no two electrons can have precisely the same state (meaning they can only com at most in pairs at the same energy, anti-aligned in *s*) the Na^0 atom ``looks'' sort of hydrogenic. But the difference with H I is that there are inner electrons that *screen* the nuclear charge. Thus, the ionization energy for Na I is *not* 11^2 times that of hydrogen. In fact, it's far lower, 5.14 eV. So what has happened is that the inner 10 electrons, which are the ground state of Ne I, reduce the nuclear charge so far that the Na^0 atom is actually more easily ionized than hydrogen. But Na II, which is the same configuration as Ne I, has a much *higher* ionization energy (47.3 eV compared to 21.6 eV) because the nuclear charge is 11 instead of 10. No the systematics come into play. The ground state of Na II has the same form as Ne I. So the excited states are the same as well. The electrons are indistinguishable (they don't ``know'' that they're part of a different element!) so you expect the same distribution of lines but at different energies since the energy levels are all shifted by the different nuclear charge. That is, Na II and Ne I are *isoelectronic*.

For your spectroscopic experience, a much more familiar and more important, example is the sequence [C I, N II, O III]. Again, the number of electrons is identical and so is the *set* of available states. But the energies are shifted. For example, take N II and O III. The bright nebular lines of [O III] are at 4363, 4959, 5007 ÅÅ. These are the principal diagnostic forbidden lines in hot ionized low density plasmas; think the nebular stage of nova ejecta, the ionized circum-white dwarf environment of a symbiotic star wind, or an H II region around a massive, main sequence star, or a planetary nebula around a hot central white dwarf. The 4959, 5007 Å pair come from a common upper state, feeding two fine structure levels that are slightly different in energy. Both are fed by radiative (or collisional) decays of the 4363 Å transition. So the ratio of *F(4363)/[F(4959)+F(5007)]* depends on density and temperature because of the collisional de-excitation of the 4363 line and the upper state of the pair. The details, for now, are less important than the fact that the ``nebular'' lines, the pair, don't appear in the spectrum if the density is above about 10^6 cm^{-3} because they are forbidden transitions and collisions at higher density are more frequent than radiative transitions. Now look at the N II lines. There's an *identical* set of three: 5755, 6548, 6583 Å. They have *precisely* the same behavior with density as [O III] *but* they have different density sensitivity because the N II atom has different energies for the same states. They are a complementary density/temperature diagnostic and also appear at different temperature because of the different ionization energy of N^0 and O^+, the ions that feed the N II and O III spectrum. Another example, a bit more complicated, for another important pair of ions: Ca II and K I. Both have resonance lines in the visible region. For Ca II this is a doublet at 3933, 3968 ÅÅ, for K I they are at 7664, 7699 Å. To extend this, the S II spectrum also has a pair of resonance lines at 4077, 4215 Å and the Ba II shows up at 4554, 4934 Å. The latter are important in carbon stars and red giants (the Ba lines are especially important for nucleosynthesis studies, the Sr II lines are indicators of gravity because they are so strong and sharp). The important point here is that these are *all isoelectronic* so knowing that you have one set and not another is an indication of ionization state of the gas. And you can use these systematics in identifying lines. You recall (those who were at OHP) that one of the persistent questions was about how you know which lines you're seeing. This is a vitally important clue, the real basis of the fingerprint that is a spectral sequence *and this is why spectral classification makes any sense!*.

This is also the basis of the diagnostics of the solar corona when only filter imaging is used. Look at the SDO or SOHO images of the corona. These are taken in the X-rays, at specific transitions (e.g. 1600 Å is dominated by C IV, 303 Å is mainly from He II) so you're using the same isoelectronic sequences *in the form of narrow band images* that are just like integrating over the line profile. Since these images are flux calibrated, the ratios of bands becomes a temperature/density diagnostic. So you can actually do what for the Sun using spatially resolved narrow band images what we are struggling with using line profiles of point sources. The advantage of being close, however, is mitigated by the lack of spectral resolution: the images confound structure and dynamics because you don't have narrow enough bands or enough of them. But the combination of spatially resolved high cadence spectra and images helps.

In nova spectra, during the optically thick stage, the couplings insure that if an ion is present in the UV its accessible energy levels will produce optical and infrared lines. The complication of velocity shifting notwithstanding, the identification must be based on the systematics of the sequences. For instance, in the Balmer sequence, since the higher lines in any of the hydrogen sequences are intrinsically weaker, they absorb less so you see through the medium to a greater depth (hence to lower velocity). The absorption -- during the P Cyg profile stage -- will reach to progressively lower maximum velocities and the emission will be biased toward higher densities for progressively higher series members (e.g. Hα vs. Hβ vs. Hγ). This is well seen in Be star spectra, where the absorption edge (also for strong wind stars like P Cyg itself) are progressively lower in what is called the *Balmer progression*. This actually maps out the structure of the absorbing medium: the lower density in the outer region means only the strongest lines will have emission at the terminal (redshifted) velocity while the absorption will be coming from the inner parts of the medium (be it a wind or ejecta). The weaker the line, the higher the absorption to emission ratio in ejecta, for instance. This is one reason why Hα is useful but, simultaneously, why it is misleading if used alone. This is especially true for novae where there is no terminal velocity; i.e. in a wind, the material at large distance reaches a finite speed above the escape velocity and coasts at constant speed,. In contrast, novae and ballistic ejecta there is no such leveling off of the velocity. So for novae, as they develop, the line profile never has a sharp blue edge unless there is a finite radius very opaque pseudo-photosphere.

I don't mean to be getting too messy here. The use of these sequences is the same as use of multiplets: the individual electron states produce specific combinations of allowed sub-states. These have nearly the same energies and behave similarly. If you see one line of a multiplet, you will see the others unless there is a very weirdly non-equilibrium situation (like shocks).

Multiplets, just a mention

In more complex atoms than hydrogen or exactly hydrogenic, many electrons can be excited in different sequences. For instance, even in the simplest two-electron atom (He^0) you can have a 1s2s or 1s2p as the first excited state but excitations like 2s3d are also possible. In other words, analogous o any probabilistic process, if something *can* happen i *will* (only, perhaps, very rarely as for forbidden transitions). The only energy level with an infinite lifetime is the ground state. The more complex the atom, the more complicated the resultant spectrum (think of Fe II, for instance, with millions of possible lines). The aid in sorting this out is that for any electron state, the coupling of the electrons produces specific *multiplets* or combinations of the different possible interactions. As an example, the 1s2 state of He I, the ground state, is unique -- a singlet state (anti-aligned *s*) with spherical symmetry (the $^1S_0$ state). There is no $^3S_1$ state because of the exclusion principle (this would require all quantum numbers to be identical, precisely the same state, instead of anti-aligned moments). So, for example, although the first excited state of Na I is $1s^22s^22p^64p$, there is also a state in which a core electron is also excited, e.g. $1s^22s^22p^53s3d$ and so on. The clue comes from the closeness of the combined states. For He I, these form singlets and triplets (single lines and groups of three close together, spaced by perhaps 100 Å). For more complex systems the ways in which the electrons couple can be approximated differently but these are only ways to estimate the structure, the precise assignments of states and lines depends on the experimental study in the laboratory. But since the multiplet states arise from the same set of electrons, in different combinations, they should have nearly the same populations. So if one line of a multiplet is present, it's likely all will be (see the Multiplet Tables by C. Moore, or the tool at NIST that gives the diagrams, called *Grotrian diagrams* of these states).

A last comment: why winds and ejecta (and sort of disks) are not the same as atmospheres (or, sort of, disks)

A great advantage of stellar atmospheres (or planetary, for that matter) is that they are hydrostatic structures for which the pressure and temperature variations in the layers is whatever are required to maintain -- everywhere -- mechanical and radiative/thermal balance. There are no mean velocities, the layer is neither in secular expansion or collapse, so the optical depth is uniquely -- and directly -- related to the geometric depth in the layer. The conditions are close to locally determined, on the large scale the medium is stationary in time and static in space. This is also a good approximation for an accretion disk, at least vertically. The heating is both local an from the central star but the vertical structure is determined at each annulus (radial distance) by the local gravity (or the projection of the central gravity vertically in the disk). As I discussed in the last set of notes, the vertical structure of an accretion disk in equilibrium is a lot like an atmosphere, with the exception of possible long-distance illumination from the central source and the surrounding boundary layer. This affects the ionization and excitation state of the gas, but for the most part you can use the same reasoning as a star: the requirement of ionization balance is essential. If you have n atmosphere, it sees only the radiation emerging from the central regions of the star. Locally, the state of the gas is determined only by the temperature and density and those must, at least for a static structure, be what comes from the requirement that the pressure deceases outward monotonically (no pressure inversions even if there are temperature inversions). So there are only a limited set of ions of any element that ca appear together. You *cannot* have, say, Ne IV and O I in the same spectrum in absorption. But this isn't true for a wind, or ejecta, or the *integrated* spectrum of a disk. Since each annulus of the disk is in orbital motion, the radial structure is determined only by that requirement. So the surface of the disk does *not* have a unique temperature, unlike an atmosphere for a star. Then in the same spectrum you might have C IV or N V and He I or Na I, depending on how far that line forming region is from the center. Novae and symbiotics are the most extreme example of how this breaks down. In winds and ejecta, being supersonic (escaping) there is no such hydrostatic requirement and the density and velocity are the link. So you can have very weird combinations of ionization states, in the same ejecta you can see O IV, C IV, and N V -- and He I and even Na I, as in V339 Del and V1369 Cen -- because they're coming from different parts of the ejecta and uncoupled to each other. They are, in fact, completely dominated by the dynamical structure of the ejecta and the conditions of the central star.

This last point is why the taxonomy of Fe-novae and He/N novae -- makes no sense, or at least doesn't have the same physical meaning as spectral types. The regularity of absorption line spectra in stellar atmospheres results from their mechanical structure. When you see regular behavior of the ion ratios it is because there is a regular variation of the pressure at the photosphere and in the overlying atmosphere. So whereas an A star is dominated by ionized Fe-group lines and the Balmer lines, and B stars show weaker H I and strong He I, and M stars show Ca I and K I and molecules and weak Balmer lines and no He I, this is because they are hydrostatic and thermally balanced and no motions are faster than the sound speed. All parts of the atmosphere are coupled. In nova ejecta, at the same time, you can have [O I], [Fe VII], He II, and the Balmer lines. This is the ionization and excitation response of the medium to the central source, its luminosity and spectral flux distribution, and the *local* density (with the kinetic temperature being determined by the requirements of overall ionization and radiative balance in an expanding medium).

Remember, when you see a nova ``surface ' it is a *pseudo*-photosphere, it isn't stationary and only optically thick. Above that layer (which moved through the ejecta over time because of the expansion) there are lower density, more optically thin layers (which may, at the recombination event, be optically thick for a while). For example, what you see now in Nova Cyg 2014 is an example. The outer parts of the ejecta are producing emission, the denser inner parts are still contributing absorption against the non-stationary surface.

And one last point for now: Don't mistake opacity for temperature, especially in novae and winds. Absorption is seen because, locally, the medium is less excited than the surface against which they are projected (remember, this is like clouds seen against the Sun). So when you have a very extended dense wind, it can have a huge emission line (say, of $H\alpha$) and also strong absorption but as the ejecta expand and the medium becomes less opaque the absorption disappears and moves inward in radial velocity (only the innermost parts will absorb). The same is true for He I, for example. In such cases as ejecta or winds, where the thermal state of the medium is *not only* locally set, you can have both absorption and emission that depends even on geometry, as we've already discussed for non-spherical ejecta. It's no temperature, it's emissivity.

So as usual, in the hope that this is helping, I'll stop. But not without adding how wonderful it was to see so many of you at the workshop in July and to add the hope that though these notes more of us can be meeting. There will be a few more things to cover, related especially with your experience with absorption spectra (we have not spent time yet on the photospheres, especially of white dwarf stars) but I truly hope this isn't getting too heavy and now it's time to stop until the next installment.

Steve Shore with Participants to ARAS meeting at OHP - 2014, July (Crédit photo : François Cochard)

More on spectra and line formation

An example: application to symbiotic stars and composite spectra

07-09-2014

Now armed with mutliplets, profiles, and ionization states, it's time to deal with a few real world examples of how to approach a spectrum. Since they are about the most complete example of just about everything we've been discussing, and since many of you are following these easts, we'll start with *symbiotic stars*.

Schematic view of a symbtiotic star during a talk of Steve Shore (OHP meeting July 2014)

First, an aphorism for context: **spectra never lie and are only apparently contradictory ... so if something seems paradoxical it's because you're missing something**. This has proven a wonderful guide in astrophysics. Too often, it seems, we forget that stars are big and space is vast and there are lots of things that can reside in a point-like source. Galaxies are composite environments, galactic nuclei even more so, binary stars are wide and separated, and even ionized regions can live around stars -- all unresolved and, in angle, unresolvable from the Earth. But because the different excitation and ionization states of the gas are sensitive to local {\it *and*} distant influences -- local for kinetics, distant for photon processes -- you can use these contradictions to dis-entangle the sources. The greats, for instance Payne-Gaposchkin, McLaughlin, Bidelman, Merrill, Herbig, Wallerstein, Slipher, Osterbrock, Kraft --to name just a few of the founders -- kept this principle in mind always. Spatial structure is revealed by different dynamics from different spectral signatures, from ionization states that cant reside in the same place. If you think something can't be coming from one object, o with that intuition. We've been exploiting it successfully for discussing novae and cataclysmic binaries, now we'll pass to the ``mother of all paradoxes'', the symbiotic binary stars.

One last word before we get started: I hope these notes, and those following, will give a sense of how to interpret a complicated spectrum. This is much different than what you'll find in descriptions of stellar atmospheres, for instance. In those cases most of the line formation is in a stable temperature and pressure gradient environment, governed by mechanical equilibrium and lying on the outside of a stable star. Then the decrease in pressure, density, and temperature outward produces an absorption spectrum that shows ions whose relative strength is the main diagnostic of pressure and abundance. There are no emission lines if the medium is dense enough, the atmosphere is compact (if the surface gravity is high enough) and you get the familiar sequence of spectral types. Because so many of you are interested in the freaks of the universe, things that vary, show emission lines, show strange combinations of ionization and excitation, this time I'll go into more details about how to ``read'' a sample spectrum.

... so now forewarned, bring in the patient ... (sorry, I can't help thinking of *astrophysicien*} as a ``star-doctor'')

The first cases discovered are as old as astronomical spectroscopy, AG Dra was described by Fleming in her surveys before the HD catalog. The group we now call ``symbiotics'' was identified by its bizarre, distinct, anomalous combination of spectral properties: in the same spectrum you see the continuum of a very cool star (typically an M giant), Balmer emission lines (often with widths of tens or more $km.s^{-1}$, He I, He II (sometimes), and [O III] and [N II]. In some respects, these resemble the active galactic nuclei called Seyfert galaxies but that they are clearly stellar and *Galactic*, not extragalactic objects. The name was actually a sort of hypothesis, that the spectrum is composite. That is, there is more than one source present and this is actually some sort of unresolved binary system. The [O III] lines are well known from planetary nebulae and H II regions. Since the [OII] 4363, 4859, 5007 Å triplet are forbidden lines, and therefore fundamental density and temperature diagnostics, they indicate the presence of a strong ultraviolet ionizing source surrounded by a very low density medium. The same holds for the isoelectronic [N II] 5755, 6548, 6583 Å lines. But these stars are not, usually, imbedded in extended nebulosity (one of the exceptional cases is R Aqr, more on this later), and the luminosity class of the red continuum contributor is a giant, not supergiant. So it's unlikely that these are planetaries that are simply too distant to be resolved or that there is some local star forming region in which they're imbedded. Another clue comes from the pair of features that is uniquely associated with these objects, the 6825, 7083 Å lines that were identified in the 1980s as Raman scattered O VI 1038, 1042 Å from Lyβ. The last indication that something must be composite is the strong He II 4686Å line. This is a recombination line, the result of ionization by a continuum in the far UV that cannot be just a non-equilibrium effect. The He I lines, especially 5876, 6678, 7065 also indicate the presence of hot gas but these could be from a chromosphere (in principle). The He II is more difficult to produce. There are other indicators of something composite, especially the so-called coronal transitions. These, e.g. [Fe VII] 5721, 6087 Å, are ground state transitions with very low density thresholds and also require a very strong far UV or XR source as an ionizing agent. The resolution comes from observations in the UV below 3000 Å where the continuum of the ionizing star is directly observed (especially with IUE for which a very large number of spectra are available). Thus, the combination of indicators points to a composite origin and that can be explained by a hot (> 6.10^4 K source with moderate luminosity (about the same as the giant, a few hundred solar luminosities, that is imbedded in the wind of the companion red giant with a wide enough orbit that he radiation is able to ionize a substantial volume of the wind.

Let's get down to specifics. The [O III] lines don't directly provide the temperature of the gas, their presence is first an indicator of the ``hardness'' of the incident radiation. If there is no strong UV continuum, collisions alone are insufficient to produce this emission if it is not a very hot gas. The Balmer and He I lines coming from the same region as the O^{+2} is an argument against this. If the gas (kinetic) temperature is low, then the process must be predominantly *photoionization.* Then the line widths, if more than a few km.s^{-1}, are likely dynamical (that is, due to Doppler widths from flows rather than turbulence or thermal broadening). The O^{+2} ion is very pretty, having a set of three states

4363 Å: $2s^2 2p^2\ {}^1D_2$ - $2s^2 2p^2\ {}^1S_0$
4959 Å: $2s^2\, 2p^2\ {}^3P_1$ - $2s^2\, 2p^2\ {}^1D_2$
5007 Å: $2s^2\, 2p^2\ {}^3P_2$ - $2s^2\, 2p^2\ {}^1D_2$

that have the 4363 Å line feeding the upper states of the strongly forbidden doublet. The respective transition probabilities are 1.7E0, 6.21E-3, 1.8E-2 s^{-1}. OK, this is getting technical but the contrast is the transition rate for *permitted* lines such as the Balmer series for which the numbers are more like 10^6 s^{-1} or higher. In other words, at far lower densities than for the Balmer lines collisions succeed in de-exciting the upper state of the 4363 Å line without producing the pair so the flux ratio *F(4363)/F(4959+5007)* is a temperature and density diagnostic. This is because the rate of collisional damping depends on the density and temperature since the higher the temperature the higher the thermal speed and the more frequent the collisions. On the other hand, the rate of emission depends only on the transition probabilities (the radiative rates) so the stronger the lower pair, he lower the density. The same holds for the [N II] lines. In the low density limit, you can estimate that seeing these lines means the density is locally less than about 10^7 cm^{-3}. In contrast, in an H II region or planetary nebula the densities are more like 10^4 cm^{-3} or even lower, while in a stellar atmosphere (being optically thick you get this estimate from the absorption lines) the densities are more like 10^{14} cm^{-3} or higher.

Now for the red continuum. Calling a star type M signals the presence of molecules, especially ZrO, TiO, VO, and the like. This isn't because the star has been an industrial waste dump for heavy metals but that these species are favored at temperatures below about 4000K because of their relatively high abundance, especially strong absorption bands, and the high abundance of oxygen in stellar atmospheres. The same is true for C and N bearing molecules but they are not as strong because of their particular band structures and the carbides of the heavy metals don't form stable states at these densities and temperatures. Ca does, and it is also seen, and in the radio one sees SiC and SiO, OH, and other diatomic molecules. But that is not something you'll be detecting. You will see, instead, CN and CH in the optical, we've already discussed these for novae but they are stable, dominant absorbers in the cool giants. So the strong metallic oxide bands from 5000 Å and longward are the signature of the giant. That there is no emission seen in the >5000Å range from the companion is not a surprise, it means the companion star is both very hot and comparatively low luminosity. Were it brighter than the red giant it would be only marginally detectable since the fraction o its radiation in the relevant spectral window (optical) is only a small fraction of its continuum (for such a hot source). On the other hand, there is no emission from the continuum of the giant below 4000 Å so the only thing you see there is from the ionized region around the companion and the star itself.

Now the strong forbidden line emission is coming from a low density environment. Clearly this is not compatible with the chromosphere alone, that would give lower ionization species (since a chromospheric temperature is about 10^4 - 3.10^4 K) . But there are other lines that come from that relatively low density, warm gas: lines of Ca II , Mg II, [Fe II] and Fe II, [O I], and He I, that come from the giant chromosphere and lower wind. The heating source is a separate question, it is not photoionization since the chromosphere is largely shielded from the far UV by its optical depth. In fact, since the systems are binaries, it's possible to see the variations of the lines over time and note that there are some that vary with aspect angle to the hot source (clearly being photoionized) and other parts that are constant and ``live'' on the giant.

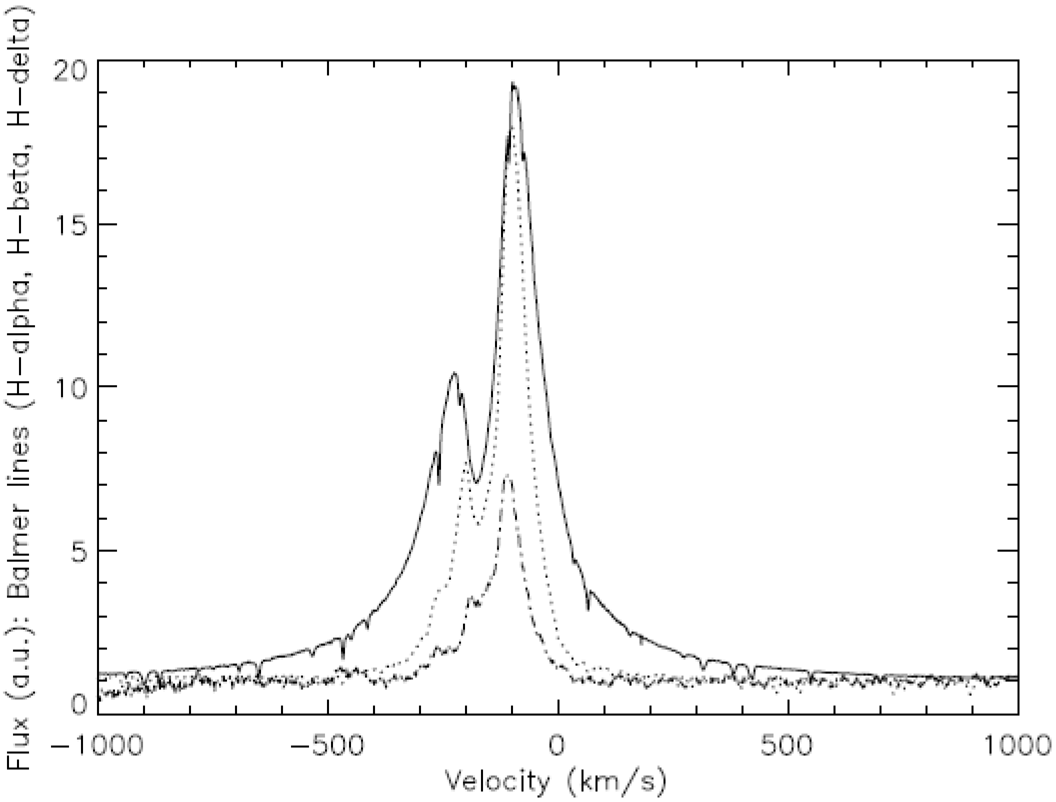


Figure 1. The Balmer lines in AG Dra

An example of the sequence of absorption and emission from a typical symbiotic star. The extraordinary width of the line wings is a combination of electron scattering and outflow, the region over which the line is formed is similar for all of the transitions but the line strength depends on the transition rates. Therefore, for the Hα the region over which the line is formed is much larger than for Hβ. The strength of the absorption, formed in the cooler red giant wind seen against the H II region around the hot component, also depends on density and is progressively weaker and lower velocity for the higher series members. This is a TNG spectrum (resolution about 60000)

The Balmer lines are recombination only. You see these from chromospheres but it's because the gas is thin in the visible and completely opaque in the UV. The same is true here. The ionization is supplied by the companion, the wind of the red giant is so optically thick that the Balmer lines can also absorb against the ionized region. This produces what you've seen in Christian Buil's spectra, for instance, the narrow displaced absorption line in Hα and Hβ seen against a much broader emission line. This is the same effect you will have whenever one source is viewed trough a rarified gas around another, true for any binary system (this could also be a Be star, for instance, if one of the stars is seen through the disk of the other). This is also expected for the massive-disk systems like β Lyr (I had to include that one, right?!).

More on spectra and line formation

An example: application to symbiotic stars and composite spectra

07-09-2014

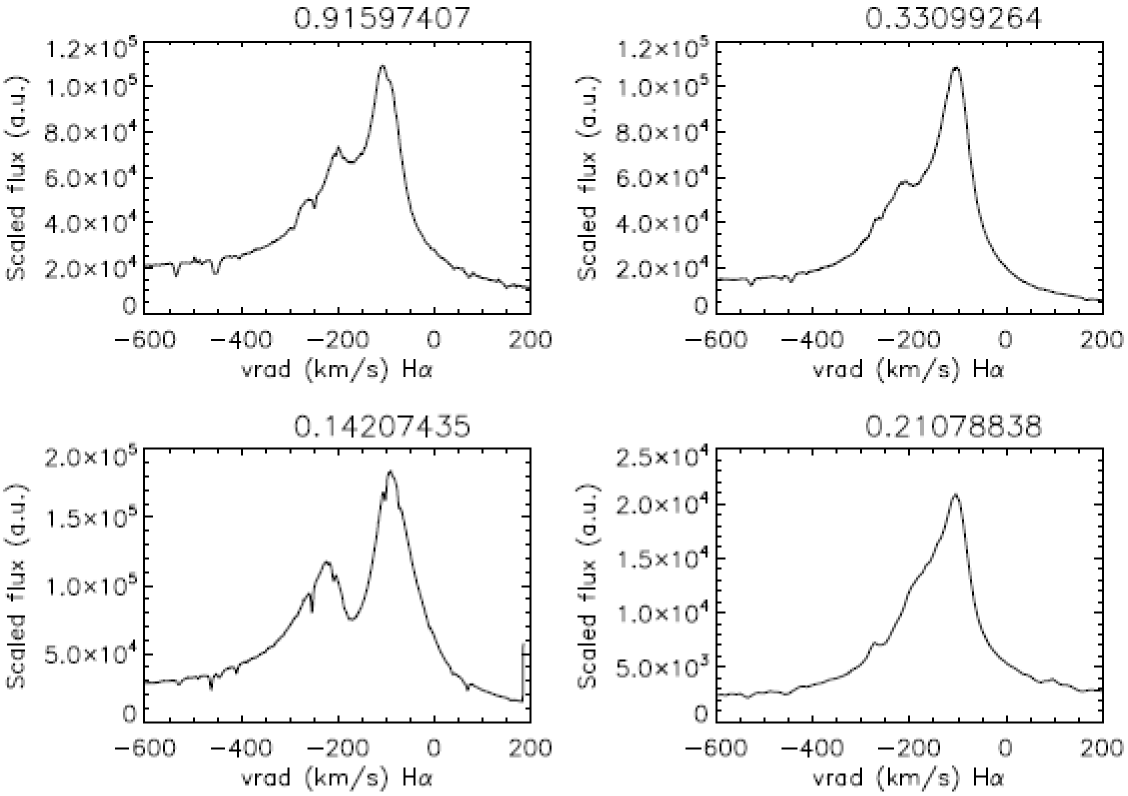


Figure 2. The Hα line in AG Dra displayed according to orbital phase

The Hα line in AG Dra displayed according to orbital phase (the binary period is long, 549.7 days). The absorption is from the intervening wind between the WD and the observer shows how the changing angle causes the absorption column to vary. This happens in any system in which a strong emission line is seen across a sufficiently optically thick line of sight. These are spectra from Asiago, resolution of about 15000. The orbital phase (to absurd accuracy, but I was in a hurry) is indicated at the top of each panel.

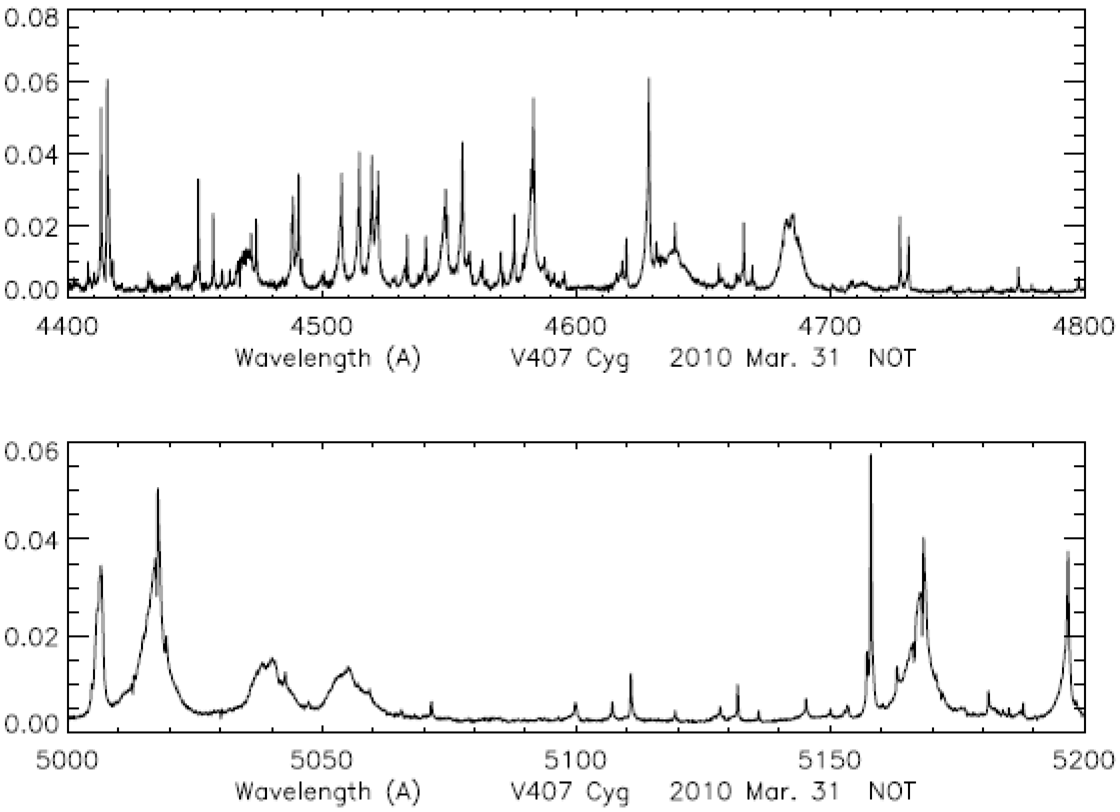


Figure 3. The optical spectrum, two weeks into outburst (2010 Mar. 31), of V407 Cyg

The optical spectrum, two weeks into outburst (2010 Mar. 31), of V407 Cyg. This is a symbiotic-like recurrent nova (well, it is *likely* a recurrent, the 2010 outburst was the first recorded). The broad lines are all permitted, highly shocked gas from the giant in the post-ejecta flow. The narrow lines are from the ionized region around the WD and in the wind, ahead of the shock, and from the chromosphere of the red giant. This is a unique spectrum for such a system, obtained with the NOT at a resolution ~ 65000. Notice the narrow [O III]5007Å and the broad *and* narrow components on Fe II 5018 Å and 5169 Å. The *very* sharp features are *not* noise! These are the chromospheric lines from the giant, mainly Fe-group elements, in low ionization stages, e.g. Fe I/II, Ni II, etc).

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An example: application to symbiotic stars and composite spectra

07-09-2014

This is a particularly complicated case to unravel, the main reason for choosing it. There are a number of separate contributors to the spectrum. Remember that V407 Cyg was a nova event. The ejecta were expelled at a velocity of >4000 km.s^{-1} into the surrounding wind and formed a shock that accelerated that environment to very high speeds. But the separation is also very large, the red giant has a radius of >300 R$_\odot$ so the separation is greater than 1 AU and the orbital period is likely more than 50 years. This is at the extreme end of symbiotics, just from the observational statistics but still smaller than a planetary nebula (for instance). The ejecta were slowed down by transfer of momentum to the wind through which they plowed and their emission produced an additional UV source (the temperature post-shock reached -ray levels, about 10^7 K, but ejections at lower velocities are known from many symbiotics (e.g. Z And, CH Cyg, AG Peg). The hot star, the white dwarf, also irradiated the gas. Between these, the UV produced fluorescent emission (you'll recall we discussed this before for novae) since the wind absorbs in the UV and de-excited by emission in the optical and infrared where the opacity is lower. These are mainly from the lower parts of the giant's wind, its chromosphere, so many of these lines are {\it not} normally seen in either giants or less extreme symbiotic stars. But they are, nonetheless, accessible transitions. Other symbiotic-like recurrents, V3890 Sgr, V745 Sco, RS Oph, T CrB, were not observed at such high resolution or signal to noise so early in the outburst but they should also show these features. Notice that the narrowest lines are thermal widths, that is, about 1 km.s^{-1}, while those from the shock are hundreds of km.s^{-1}. There are also some that are broader but not as broad, for instance the Fe II permitted lines, that are coming from the ionized wind from the shock precursor.

One last point of physics. A shock produces both compression and heating in the gas through which it propagated. This is sufficient, depending on the speed of the front, to produce UV and XR emission. Those photons have nowhere to go but straight ahead so they pass through the front and ionize and excite the *pre-shocked* gas. You see this in atmospheric tests of nuclear weapons, an optically thick ionized surface forms immediately (at the speed of light) from the gamma-ray emission at the explosion site, the ejecta (the actual shock front) arrives some time later and beaks out of the recombining fireball. This doesn't happen in a normal nova, that explodes in a vacuum, but will if there is an enveloping wind. That there could be a nova explosion in a symbiotic system is only a surprise in that the white dwarfs are usually much less massive than those in novae, more like 0.5 to 1 M$_\odot$ instead of near the Chandrasekhar limit at 1.2-1.4 M$_\odot$.

Otherwise, it is a very fast version of what happens when the planetary nebula stage forms after the slow wind ejection of the supergiant precursor that strips bare the core of the star and leaves the white dwarf nucleus exposed. There a fast wind slams into the slower one from the earlier stage of evolution. The region you see produces the characteristic nebular lines of the planetary because the densities are low enough and the WD hot enough, so it's the same as V407 Cyg or RS Oph in slow motion. Finally, when a hot star, of type O, illuminates the interstellar medium there is a strong enough continuum to produce the O^{2+} lines but not enough, usually, to get the high ionization states seen in some symbiotics (the coronal-type lines that require 100 eV photons or higher). That's the effect of the relatively ``cooler'' continuum; there's little emission shortward of the He II ionization limit, around 54 eV, to produce those ions since the temperatures of the stars do't exceed 40-60 kK. The motion of the O star through the surrounding gas mimics, in *very* slow motion, that of the WD through the wind of the giant but on timescales of millions of years. Th star can leave an ionization trail in its wake, and so does the WD as the wind flows past it (hence the open-shape of the ionized region). The lines in the wind will also have different widths depending on where in the wind they form. The narrowest, like the fluorescent lines, are formed near the stellar surface so there's almost no outward motion. Those formed throughout the wind, especially near its outer parts where the density is lowest, are the broadest. And anything formed in the post-shocked gas in the V407 Cyg spectrum will be the broadest of all, not the shock velocity but a fraction of it.

I'll stop at this point and let you all catch your breath, we'll pick this up in the next set of notes. For the moment, an exercise: take a look at the spectrum of V407 Cyg and, using the NIST tables for atomic spectra, and knowing that you're looking at a symbiotic star-type object, find some of the identifications of the strongest lines (yes, I know this is a figure with relatively little information, but that's deliberate. Think of those who were doing this for the first time, like Maury, Fleming, and Cannon).

Steve Shore 07-09-2014

More on spectra and line formation

An example: application to symbiotic stars and composite spectra

07-09-2014

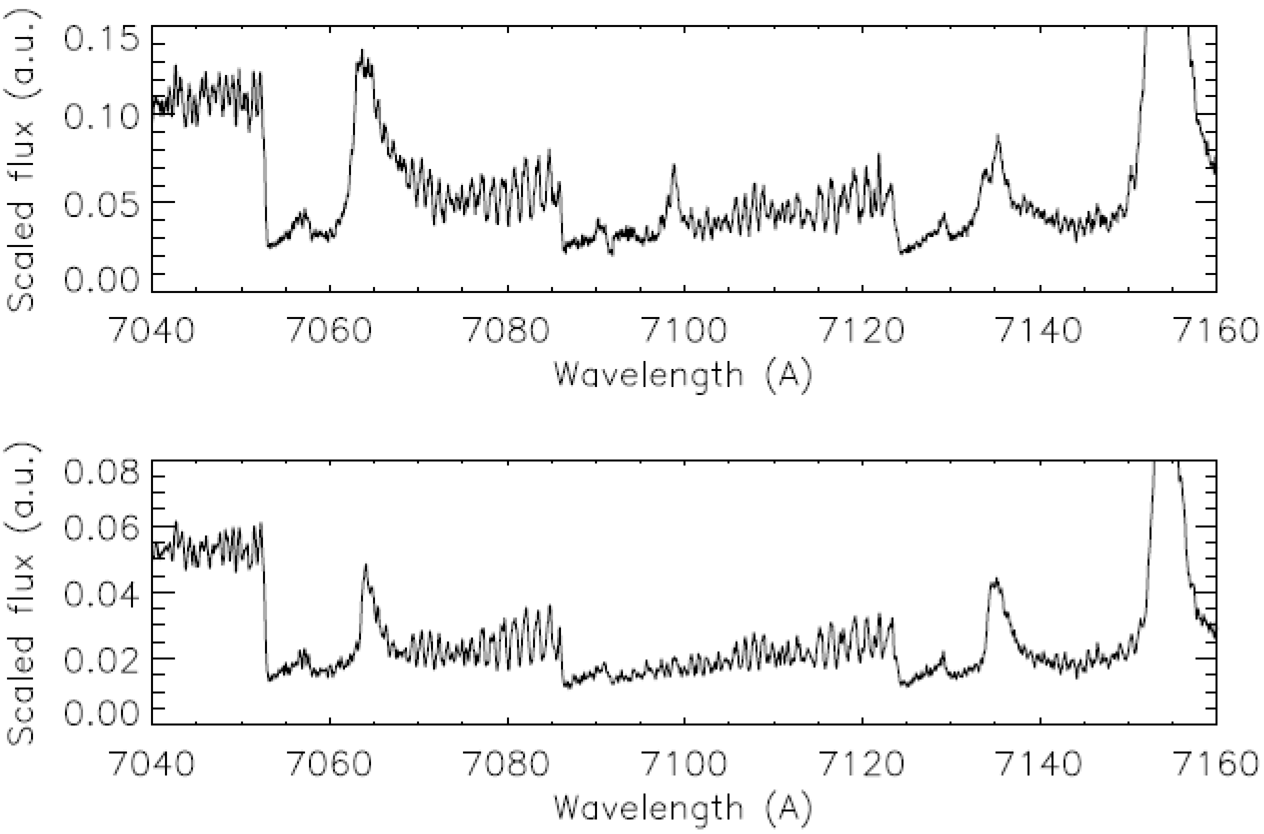
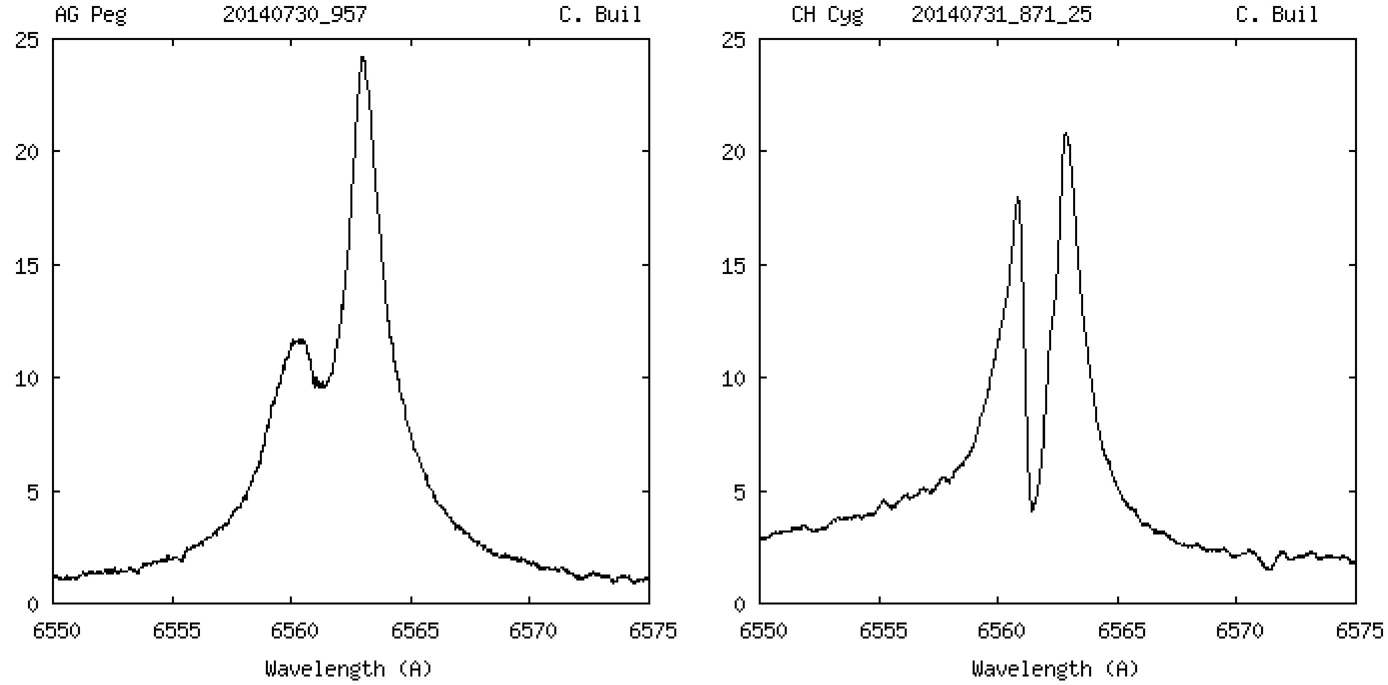


Figure 4. The red spectrum of V407 Cyg on 2010 Jul. 15 and 2011 Aug. 21.
This is the same star as the emission line object in the previous figure! Note the absorption band spectrum, this is *not* terrestrial. The emission at He I 7065 Å while difficult to separate from the underlying absorption, is still visible.



Hα profiles of AG Peg and CH Cyg at very high resolution (R = 50 000) by Christian Buil

Balmer line formation and variations and a comment on abundance determinations

05-01-2015

1 The hydrogen lines in symbiotic spectra

When discussing symbiotic stars, the overwhelming impression is that they are a sort of nebula superimposed on a red giant that has to be ionized by some other source than the visible star.

For most of the emission lines this is actually not a bad picture, especially the higher ionization transitions such as [O III] and He II. Those clearly, as we've discussed, require a strong UV and EUV continuum source to produce sufficient ionization while not so completely ionizing the medium that lower ions, [N II] for example, are not observed. The region surrounding the WD must therefore be sufficiently dense that each zone is ionization bounded within the nebular spectrum-forming region.

The forbidden lines require low density so the highest ionization stages must also be low density. This precludes the formation of such lines within the wind of the WD,if there is one, since the densities for reasonable mass loss rates exceed the threshold for the forbidden transitions (about 10^6 cm^{-3}). But this ignores what happens outside the ionized region, at lest outside that producing the He$^+$. Hydrogen will be both neutral (outside of the ionized region, within the outer wind of the red giant) and also present in the Heo zone, even in the region where ionized Fe-peak transitions and C$^+$ form. Remember these all have lower ionization potentials than H. But the wind of the red giant isn't low density near its photosphere, at the base of the wind. For mass loss rates typical of this stage of evolution, 10^{-7}M$_\odot$.yr^{-1} or so (the so-called thermal rate, what the star would lose if it were to be at its limit of thermal stability or at the Kelvin-Helmholtz timescale for the star's luminosity and mass) the densities are rather high (chromospheric), about 10^{10} cm^{-3} and the gas is largely neutral. The emission lines surrounding the WD are therefore seen through this denser gas and, well, like any photons encountering an opacity source they can be scattered and absorbed.

A way to see this is to recall the discussion, for novae, of what happens during the Fe-curtain stage. Absorption from resonance transitions in the UV populates the excited levels that are the lower levels of optical Fe-peak lines. This leads to absorption in transitions that, based on the density and temperature, would be thought optically thin. As long as the lower states can be populated because the photons radiated in then UV are trapped and scatter many times before escaping, the optical lines will show P Cyg-like absorption (the upper states of these transitions are also populated and this produces both emission, from radiative de-excitations, and additional population of the lower states). Just recall how to think like a photon and you'll see why this doesn't depend on the local number density. Collisional de-excitation have to be comparatively important if the lines observed are forbidden transitions. Now pass to hydrogen. The UV transitions are the strongest in the spectrum, the Lyman series, of which Lyα 1215 Å is the absolute strongest. The upper state of this line is 2p^{2}P – transitions of 1s –>2s are strictly forbidden and produce a two-photon continuum in the blue part of the spectrum. This is the lower state of Hα and the rest of the Balmer lines. Therefore, if the Lyman series is opaque, and at low temperatures (<10^4 K, like a red giant wind) and high column densities (of order 10^{22} cm^{-2} or more) it will be, then the Balmer lines can be absorbed.

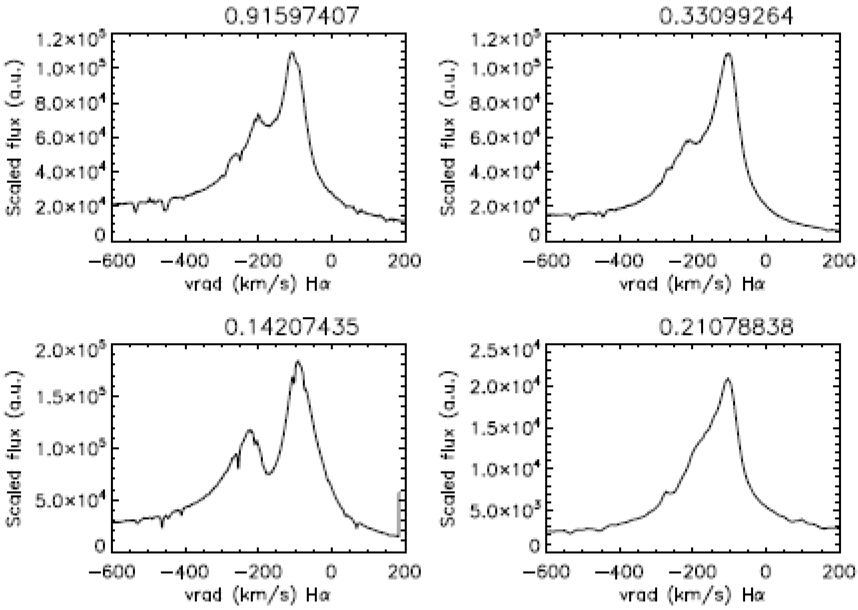


Figure 1: AG Dra: Asiago spectra showing Hα variations phased on the known binary orbital period.

Balmer line formation and variations and a comment on abundance determinations

05-01-2015

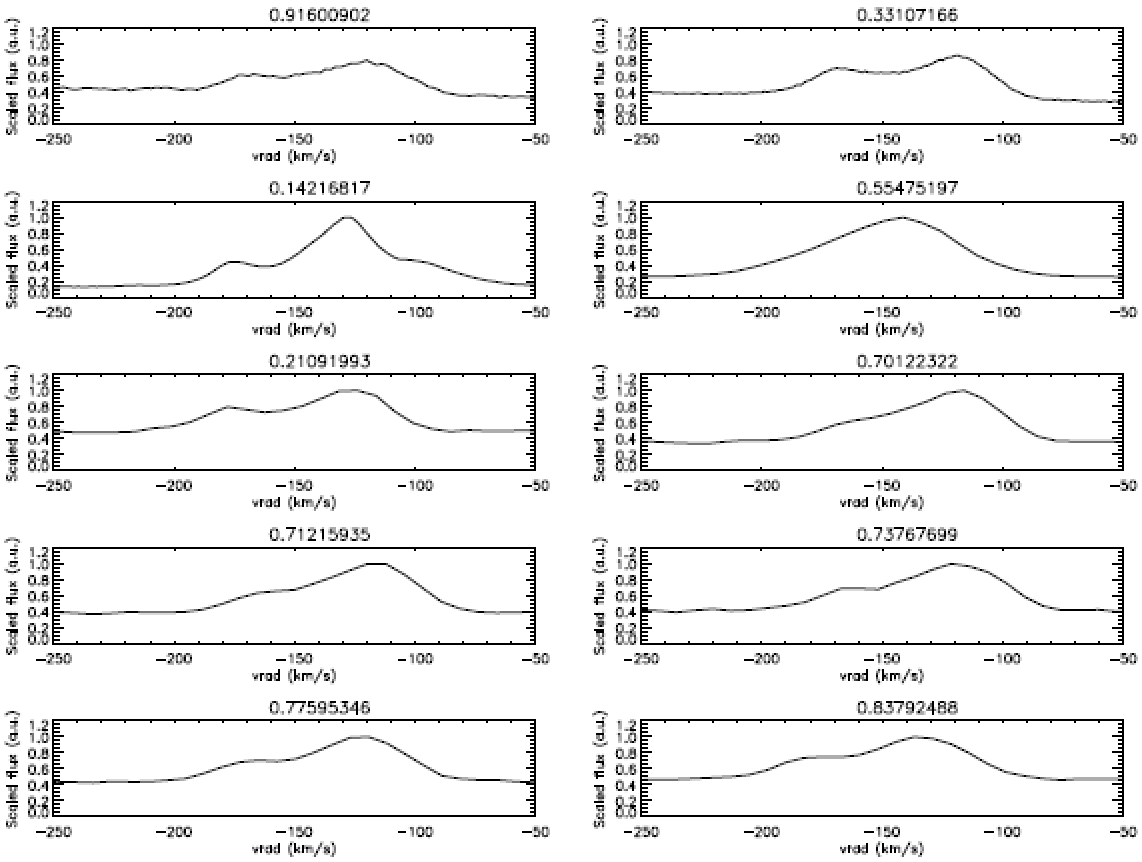


Figure 2: AG Dra, from Ondrejov spectra showing the phased variations of He I 5876 Å

The WD is a negligible continuum source at these wavelengths relative to the giant, but the emission isn't. So seen through the red giant, the Balmer lines will show absorption profiles with characteristic velocities of the red giant wind (a few tens of km.s^{-1}). These absorption lines can be very strong, depending on the orbital phase and inclination of the system, and will vary with phase angle as you sample different lines of sight. An example is the orbital modulation of the Balmer and He I 5876 Å lines in AG Dra (an old favorite).

To show what happens along the line of sight, taking a sample Balmer line (in this case with no absorption intrinsic to the profile and only observing through the wind at steps of 0.1 in phase (assuming a broad gaussian for the H II region and the orbital motions in AG Dra) you see the variations produced by the orbital modulation. Depending on the mass ratio and orbital period, the line of sight through the giant wind can also produce a redshift of the absorption (since the H II region around the WD has the same orbital motion as that star.

But this isn't the only type of variation shown by the Balmer lines and, as you've seen from your observations, things can happen far more quickly than the hundreds of days (or more) required for the orbit. Changes on even nightly bases are seen, your data show this and it has been especially well observed in some extreme systems such as MWC 560 by Tomov and collaborators. These changes are clearly dynamical, features move within the absorption line profiles in a way hat indicates optical depth changes at different velocities while the line of sight is at a fixed phase. What these are is not clear and your observations, taken with higher cadence than usually followed in the literature (always that damned nagging issue of telescope time) will be key to understanding this in a broad range of systems. Notice that the He I lines also show this feature (and that He II doesn't, there isn't any He$^+$ in the surrounding wind at sufficient opacity to absorb, remember?). Coordination of the various Balmer line measurements is very important since the opacity of the line depends on the intrinsic strength of the transition. Hoping you recall the discussion of the Balmer decrement, the sequence of terminal velocities for the different lines of the Balmer series, you can dissect the wind structure by seeing how the different lines vary at the same time. The higher series members are formed deeper so they will reveal what the Hα line is "hiding" because of its extremely strong absorption. Then the timing of line variations, both short term and orbital (and longer) will separate the contribution of the smooth wind and individual structures.

How these might arise is another question. Red giants likely have some magnetic fields, although these stars are not strong X-ray sources and show only weak chromospheres and coronae. The giants in many symbiotics are, however, Mira variables and pulsate. So the winds are likely time variable as pulses of mass loss move outward. It may be possible to separate these contributions over timescales of days and weeks. Magnetic structuring of the winds is another possibility, this has been seem as sector structures in the solar wind but also likely present in massive, hot star winds. And there is always the structuring of the wind because of the orbital modulation, the formation of equatorially flattened structure and standing shocks within the flows. In other words, the shorter the timescale the closer it has to be to the dynamics of the wind and/or the accretion zone around the WD. I don't know any studies that look for disk-outflow interactions around the WD although the extreme variations of MWC 560 require jets (Z And and CH Cyg also likely show this, there are discrete emission events in these that don't show the extreme velocities or mass loss changes of MWC 560).

Finally, the Lyα line shows its presence in another, important way – aside from the Raman features we've already discussed. When talking about the O VI 6825, 7890 Å doublet, I mentioned Rayleigh scattering. This is produced by the elastic scattering (no change in the energy, unlike the Raman effect) of photons from the far wing of the Lyman line, much more separated in energy from Lyα than that required for the O VI transitions. This produces a continuum, strongly peaking toward the blue, that has been noted in these stars. And it will be highly polarized (yet another plug for that capability, sorry!).

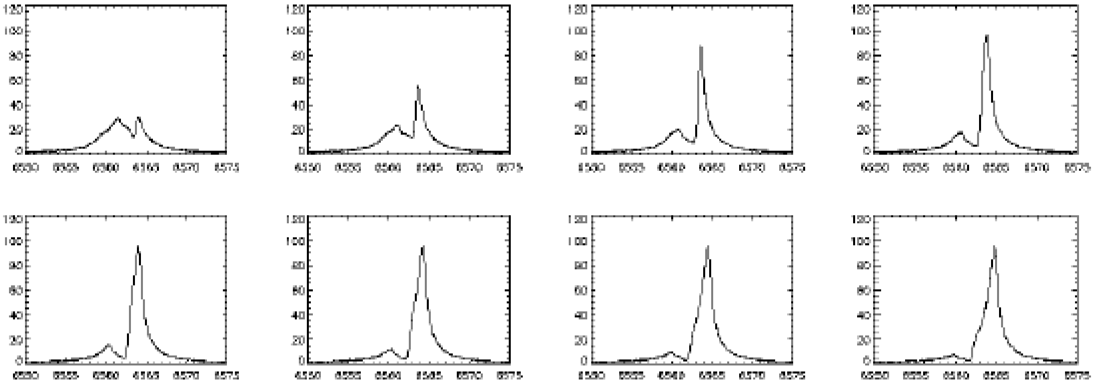


Figure 3: Model simulation of the Balmer line variations for a symbiotic-like wind. The relative motion of the two stars is important, the amplitude of the orbital motion suffices to produce both blue and redshifts of the two components relative to each other around the center of mass. Thus, the absorption can also fall on the red side of the emission line. This is *not* accretion.

Balmer line formation and variations and a comment on abundance determinations

05-01-2015

2. A start on abundance determinations, a start

In the discussions to this point, I've been concentrating on the processes produce spectra but we haven't yet discussed what forms the spectrum of a run-of-the-mill star, one without strong outflows or other dynamics in its atmosphere. In the hope that this doesn't get too detailed, I'll try this time to explain something about the origin of stellar types and how abundances are determined.

We can assume the whole star is, more or less, static and the internal pressure gradient balances the weight of the overlying gas, hydrostatic equilibrium. In a medium that is sufficiently compact, and opaque, the photosphere will occur in that part of the outer layers that are still sufficiently dense that collisions dominate the population of the atomic levels. In other words, we can assume that the ionization and recombination, and the excitation and de-excitation, of the atoms is due to environmental electrons that collide with the atoms. Although this can't hold for the entire atmosphere out to its farthest portions, it can apply near the surface if the radiative decay times are longer than the mean time between collisions. Then the rate of knocking the atom into an excited state has a threshold – the excitation energy of the lower or upper state of a transition – and if this is of the same order as the thermal (kinetic) energy of the electrons the upward transitions will be effective and the level will be populated. The greater the difference between the thermal energy and that of the levels, the lower the population. This is the main reason why resonance (ground state) lines are the strongest in any ion's spectrum.

We've already discussed the extreme case where the collisions are not important, such as the symbiotic stars or planetary nebulae of very low density. But in stars, especially those on the main sequence that are at relatively low luminosity, the atmospheres are compact (a few percent of the stellar radius in thickness). Unlike symbiotic binaries, where the source that ionizes and excites the giant's wind is external, the nuclear source within stars is central and the radiation emerges from the atmosphere. As you'd expect, this means the deep layers are not only denser but also hotter. The overlying mass produces a greater pressure and this leads to the more extreme thermal conditions than father out. All this is intuitive. What may not be is that the higher temperature can mean that the opacity of the deeper layers is actually lower than the outer parts so radiation passes more easily from those layers. In the center, the temperatures are high enough in stars more massive than, say, an M main sequence star that electron scattering – not absorption – dominates the opacity and impedes the radiation passage. This is independent of wavelength and, since a free electron cannot absorb, the only other opacity source is thermal bremsstrahlung (the absorption and/or emission of photons when electrons are scattered by positive ions such as protons). This all happens within the envelope so is hidden from view. Remember, the spectrum you see is formed by the escaping photons, not those that are still diffusing through the envelope and our problem is to start from that deeper portion and ask how the lower density gas – in emitting and absorbing light – leaves its signature on the emerging photospheric distribution because of the wavelength dependence of line opacities.

This is where the link comes between spectrum and structure. The flux of radiation from below diffuses rather than "streams". When the density is low, the distance a photon can travel before encountering a target is comparable to the scale over which the density changes. Since that decreases outward, the atmosphere (the escape zone), will be comparatively cool since it is through the absorption and collisions that the gas is heated. Diffusion is a gradient process, by which I mean that the differences in temperature drive the flux. The greater the temperature gradient, the greater the flux. But opacity reduces this radiative conductivity, serving as a bottleneck to the photon passage, thus reducing the flux. The only problem is that the interior is the source of the light and that sets the rate at which the atmosphere must pass the light. So the decrease in temperature and increase in the opacity can only be balanced by increasing then temperature gradient. Since the radius of the star is set by the hydrostatic condition, and the gas pressure depends on both density and temperature, the change in the run of temperature also alters the pressure and density. In equilibrium, this establishes a spectral energy distribution.

When you look into the atmosphere, as you do whenever you take a spectrum, the lines are formed at different depths. Those from the highest ions and/or atomic levels are formed deeper than lower excitation or ionization. So He I, for instance, is formed deeper than Fe II and at a higher density.

This also samples a stronger pressure broadening effect, the Stark effect. The wings of the strongest lines are far broader, in general, than thermal velocities would indicate. This is because the atom, while sitting minding its own business in the plasma of the atmosphere, is surrounded by ions and electrons that fluctuate in number and have near pass accidents with the atom. These impulsive electric fields are too weak and too low energy to induce transitions but they do broaden the energy levels. This is a sort of environmental harassment, the more perturbed the level is (the more hits it suffers over time) the broader it will be. Hydrogen is so overwhelmingly abundant that the Balmer (and other level) series are the most visibly affected. The core of the line is formed at the lowest densities since it has the highest opacity. The wings, on the other hand, have lower opacities but are far from the line center. So when you look at the Balmer lines, for instance, they are incredibly broad in the main sequence stars (the defining characteristic), since the line is formed over a huge range of continuum optical depth (down to the photosphere) and therefore at very high pressure compared with a giant of the same ionization characteristics (hence, loosely speaking, temperature), whose lines are always much narrower. The difference, the essential feature of the MK luminosity classes, is therefore explained as a density – hence surface gravity (by hydrostatic equilibrium) – and therefore pressure effect. The more compact stars have a higher photospheric pressure and that translates into higher values throughout their atmospheres.

This also affects the abundance determination. The strength of the lines depends on their broadening. If they are broadened, they are formed over a larger pathlength through the atmosphere and therefore, can be stronger. On the other hand, depending on their ionization state, they may be restricted to certain continuum depths.

I realize this is getting a bit hairy, and I apologize if it is starting to get too heavy. Its importance for your background is that without this appreciation of how the appearance of a spectrum depends on the details of the medium in which it's formed, you might not appreciate the incredible wealth of information contained in a single profile from a static atmosphere. You've already seen how the lines formed in outflows sample the medium and give you a sort of tomographic probe of the outflow (winds) and ejecta (novae, explosions). But the same reasoning applies, with constraints, to atmospheres and once you get past this you can think about any atmosphere, whether a star or an exoplanet. You see, the spectrum seen in absorption during the transit of an exoplanet in front of its parent star is exactly the same thing. And it's the same for the Earth's atmosphere or a planet in the solar system. The key is to understand that how strong a line is depends not only on the abundance of the responsible element but also on the thermal and density structure of the atmosphere through which you're looking.

In the hope that this is more encouraging than off-putting, and with warmest wishes for the new year, I'll stop here for this installment. Your interest, questions, contributions, and enthusiasm are golden. I can't tell you all that too often! This year of our combined efforts has been the start of a new era that, with your continued force and involvement, your curiosity and excitement, will only get better.

your observations, taken with higher cadence than usually followed in the literature … will be key to understanding this in a broad range of systems.

ARAS Eruptive stars - Publications in 2014

With ARAS observers as authors or co-authors

Fermi establishes classical novae as a distinct class of gamma-ray sources

Ackermann, M.; Ajello, M.; Albert, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bellazzini, R.; Bissaldi, E.; Blandford, R. D.; Bloom, E. D.; Bottacini, E.; Brandt, T. J.; Bregeon, J.; Bruel, P.; Buehler, R.;Buson, S.; Caliandro, G. A.; Cameron, R. A.; Caragiulo, M.; Caraveo, P. A.; Cavazzuti, E.; Charles, E.; Chekhtman, A.; Cheung, C. C.; Chiang, J.; Chiaro, G.; Ciprini, S.; Claus, R.; Cohen-Tanugi, J.; Conrad, J.;Corbel, S.; D'Ammando, F.; de Angelis, A.; den Hartog, P. R.; de Palma, F.; Dermer, C. D.; Desiante, R.; Digel, S. W.; Di Venere, L.; do Couto e Silva, E.; Donato, D.; Drell, P. S.; Drlica-Wagner, A.; Favuzzi, C.;Ferrara, E. C.; Focke, W. B.; Franckowiak, A.; Fuhrmann, L.; Fukazawa, Y.; Fusco, P.; Gargano, F.; Gasparrini, D.; Germani, S.; Giglietto, N.; Giordano, F.; Giroletti, M.; Glanzman, T.; Godfrey, G.; Grenier, I. A.;Grove, J. E.; Guiriec, S.; Hadasch, D.; Harding, A. K.; Hayashida, M.; Hays, E.; Hewitt, J. W.; Hill, A. B.; Hou, X.; Jean, P.; Jogler, T.; Jóhannesson, G.; Johnson, A. S.; Johnson, W. N.; Kerr, M.; Knödlseder, J.;Kuss, M.; Larsson, S.; Latronico, L.; Lemoine,Goumard, M.; Longo, F.; Loparco, F.; Lott, B.; Lovellette, M. N.; Lubrano, P.; Manfreda, A.; Martin, P.; Massaro, F.; Mayer, M.; Mazziotta, M. N.; McEnery, J. E.;Michelson, P. F.; Mitthumsiri, W.; Mizuno, T.; Monzani, M. E.; Morselli, A.; Moskalenko, I. V.; Murgia, S.; Nemmen, R.; Nuss, E.; Ohsugi, T.; Omodei, N.; Orienti, M.; Orlando, E.; Ormes, J. F.; Paneque, D.;Panetta, J. H.; Perkins, J. S.; PesceRollins, M.; Piron, F.; Pivato, G.; Porter, T. A.; Rainò, S.; Rando, R.; Razzano, M.; Razzaque, S.; Reimer, A.; Reimer, O.; Reposeur, T.; Saz Parkinson, P. M.; Schaal, M.; Schulz, A.;Sgrò, C.; Siskind, E. J.; Spandre, G.; Spinelli, P.; Stawarz, Ł.; Suson, D. J.; Takahashi, H.; Tanaka, T.; Thayer, J. G.; Thayer, J. B.; Thompson, D. J.; Tibaldo, L.; Tinivella, M.; Torres, D. F.; Tosti, G.; Troja, E.;Uchiyama, Y.; Vianello, G.; Winer, B. L.; Wolff, M. T.; Wood, D. L.; Wood, K. S.; Wood, M.; Charbonnel, S.; Corbet, R. H. D.; De Gennaro Aquino, I.; Edlin, J. P.; Mason, E.; Schwarz, G. J.; Shore, S. N.;Starrfield, S.; Teyssier, F.; Fermi-LAT Collaboration

Science, Volume 345, Issue 6196, pp. 554-558 (2014)
http://adsabs.harvard.edu/abs/2014Sci...345..554A

Early evolution of the extraordinary Nova Del 2013 (V339 Del)

Skopal, A.; Drechsel, H.; Tarasova, T. N.; Kato, T.; Fujii, M.; Teyssier, F.; Garde, O.; Guarro, J.; Edlin, J.; Buil, C.; Antao, D.; Terry, J. N.; Lemoult, T.; Charbonnel, S.; Bohlsen, T.; Favaro, A.; Graham, K

Astronomy & Astrophysics, Volume 569, id.A112
http://adsabs.harvard.edu/abs/2014arXiv1407.8212S

Observations of rapid line variations of the H alpha line of SS 433 following a large optical flare

S. Charbonnel, O. Garde, J. Edlin

The Astronomer's Telegram, #6381

Spectroscopic classification of ASASSN-14fc as a cataclysmic variable in outburst

T. Lester (ARAS)

The Astronomer's Telegram, #6381

Spectroscopic classification of ASASSN-14cv as a cataclysmic variable in outburst

Berardi, Paolo; Lester, Tim; Teyssier, Francois

The Astronomer's Telegram, #6258
http://adsabs.harvard.edu/abs/2014ATel.6258....1B

Spectroscopic classification of ASASN-14cl as a cataclysmic variable in outburst

Teyssier, Francois

The Astronomer's Telegram, #6235
adsabs.harvard.edu/abs/2014ATel.6235....1T

The first detection of the Raman scattered O VI 1032 A line in classical novae - the case of Nova Del 2013 and Nova Cyg 2014

Skopal, A.; Wolf, M.; Slechta, M.; Teyssier, F.; Montier, J.; Lester, T.; Garde, O.; Buil, C.; Lemoult, T.; Charbonnel, S.

The Astronomer's Telegram, #6132
http://adsabs.harvard.edu/abs/2014ATel.6132....1S

Publication using spectra from ARAS Data Base

The expanding fireball of Nova Delphini 2013

G. H. Schaefer, T. ten Brummelaar, D. R. Gies, C. D. Farrington, B. Kloppenborg, O. Chesneau, J. D. Monnier, S. T. Ridgway, N. Scott, I. Tallon-Bosc, H. A. McAlister, T. Boyajian, V. Maestro, D. Mourard, A. Meilland, N. Nardetto, P. Stee, J. Sturmann, N. Vargas, F. Baron, M. Ireland, E. K. Baines, X. Che, J. Jones, N. D. Richardson, R. M. Roettenbacher, L. Sturmann, N. H. Turner, P. Tuthill, G. van Belle, K. von Braun, R. T. Zavala, D. P. K. Banerjee, N. M. Ashok, V. Joshi, J. Becker & P. S. Muirhead

Nature 515, 234–236 (13 November 2014)

K. Alton
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J. Briol
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ARAS Spectroscopy

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https://groups.yahoo.com/neo/groups/spectro-l/info

ARAS preliminary data base
http://www.astrosurf.com/aras/Aras_DataBase/DataBase.htm

ARAS BeAM
http://arasbeam.free.fr/?lang=en

About ARAS initiative

Astronomical Ring for Access to Spectroscopy (ARAS) is an informal group of volunteers who aim to promote cooperation between professional and amateur astronomers in the field of spectroscopy.

To this end, ARAS has prepared the following roadmap:

- Identify centers of interest for spectroscopic observation which could lead to useful, effective and motivating cooperation between professional and amateur astronomers.
- Help develop the tools required to transform this cooperation into action (i.e. by publishing spectrograph building plans, organizing group purchasing to reduce costs, developing and validating observation protocols, managing a data base, identifying available resources in professional observatories (hardware, observation time), etc.
- Develop an awareness and education policy for amateur astronomers through training sessions, the organization of pro/am seminars, by publishing documents (web pages), managing a forum, etc.
- Encourage observers to use the spectrographs available in mission observatories and promote collaboration between experts, particularly variable star experts.
- Create a global observation network.

By decoding what light says to us, spectroscopy is the most productive field in astronomy. It is now entering the amateur world, enabling amateurs to open the doors of astrophysics. Why not join us and be one of the pioneers!

Web pages on Nova Del 2013
http://www.astrosurf.com/aras/novae/Nova2013Del.html

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