Notes on novae, spectroscopy, and astrophysics
for the ARAS group

mainly V339 Del = Nova Del 2013 but also now on V1369 Cen 2013, radiative transfer in moving media, and more

Version – Date: 20 Jan. 2014

New preface

It's now a new year (2014) and two novae in progress and time for a moment's reflection. Novae are hardly the most extreme objects in the universe, but they are among the most accessible for a wide range of physical processes. These two illustrate the point well. They are likely from the same type of white dwarf, although there's an indication that the progenitor masses differ. They both have shown extended optically thick stages, as you know from the first part of these notes, but their behaviors have been dramatically different. They were both detected as γ-ray sources, indicating the generality of the process although not its origin, but they likely are not standard candles in the usual sense of the phrase: they probably differ in intrinsic luminosity. They're very similar, in spectral evolution, but they show distinct differences that are saying that the ejecta differ in structure. Why is another, at this point unaddressable, question. In one case the progenitor binary was observed, in the other no, but they're almost surely both from compact (short period) systems. All that being said, the coverage you all provided for V339 Del will stand as the definitive archive for *any* classical nova for a very very long time and is now invaluable in the interpretation of V1369 Cen. That said, on to the new comments, which are at the end of the text.

original preface, now a long time ago – Sept. 2013: Francois asked that I bore you all with some explanation of what's happening in these data and perhaps to give you all some idea of what the physical picture is. It's a pleasure, also because it's a chance to say thank you to all of you for this amazing, invaluable effort. Once the smoke clears (well, after possible dust formation?), we'll have a chance to work through all of this for the eventual complete analyses. You're all involved with that.

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.

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 – tomorgraphy – 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 descritpive 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.

The last spectra are showing what HAS to happen, Olivier, please encourage everyone to keep banging away. Let me explain, I'll try to keep these notes coming if people find them useful (and I hope not too long-winded).

steve

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 – he 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 '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 he recombination sets in and the ejecta cool.

The terminal velocity of the line profile is an absolute thing, relative to the rest wavelength, 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

$$I_{velocity} \sim 1 - \exp[-(t0/t)] \tag{1}$$

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.

The changes in the absorption velocities mean the absorption is formed progressively deeper (lower velocities) while the fraction filling the space that's transparent – that produces the emission – is relatively increasing. You'll see this comparing the Balmer profiles. One thing that may help with visualizing is to plot things in velocity, from -4000 to 4000 km/s with rest wavelengths of 6562.7 and 4861.4 (air). These will make the comparisons between the profiles at the same time simpler. The most intriguing part of the spectrum, aside from the Na I region, seems now to be the 4200 A region.

¿ ¿Is there any indication of what kind of star the accretion star is? ¿

Only one, not too indicative. The pre-outburst image is very blue and there's nothing on the 2MAS images. So it's likely the WD, mainly (I'll guess) the emission from the boundary layer of the accretion disk and the disk itself. It was faint but not impossibly so, normal for a system in "repose". The lack of a red image means no giant/supergiant so the system has to be short period (close) with a low mass companion and simple Roche lobe overflow. Sorry, that's jargon. The material is coming from the companion being sufficiently close that tidal forcing is removing the gas and it's steaming toward the WD and forming an accretion disk. Most novae are of this sort (in fact, for the symbiotic-like systems, those with giants like RS Oph, V3890 Sgr, T CrB, and V407 Cyg) there are only six known and all recurrents). ¿ ¿It seems that the Nova right now is on plateau in it's brightness from ¿the ¿photometric and some say's it's maybe not a "fast nova". How long can ¿we ¿expect the current state of brightness ? ¿ ¿

Mark Twain (the American Plato, I think) said :predictions are very hard,e specially about the future". But the likely state will be this plateau for a while, perhaps a week, perhaps two. It's hard to say now because the system's been caught so early (remember that comets often have this problem). But thsi could go on for a while. From what I can model of the ejecta it might be that they're not spherical in which case the orientation also affects the behavior. Don't give up at any cost, even though the weather's not the best in most of Europe now it's important to keep at least nightly monitoring going. And I'll have more notes coming soon.

As promised (or threatened), here are a few more notes on the latest developments and some further context-setting.

First to the immediate situation. As many/all will now know, 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 avalable 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.

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 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 L_{Edd}.

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 teh 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 tot his, 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 e 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 staring. 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).

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

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-grouop 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. 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 i 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 1993 they formed as soon as the Na I emission peak strengthened. The same in T Pyx 2011. For V959 Mon 2012 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.

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 the 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.

I'll repeat, ad nauseam, that what you are producing is a legacy of depth and range we've never had before. PLEASe don't get discouraged or tired. I'm writing this as the dawn breaks over Pisa thinking of all of you and I promise to explain more (as I'd previously promised) about the origin of the binaries in this state.

To this point I've concentrated on the optically thick stage because, well, that's where we are. But Francois suggested discussing the forbidden lines so first a bit of atomic physics in a cosmic context.

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, and 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 rat 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 o two lines, [N II] 5755 A and [Ca V] 5303. Th 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 i 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. Fo Nova Dl 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.

==========================

First, in the hope this won't seem merely rhetorical, to all of you, you've given the greatest gift of all, your warmth and enthusiasm and *curiosity*. You are part of the tradition that began with Huggins, Lockyer, Agnes Clerke, Cannon, Fleming, Pickering, Secchi, all of the founders who saw – as Hale put it – the power of this instrument. It's not by chance that the field of astrophysics, in fact the Astrophysical Journal itself, was started over a century ago with the inspired notion that this tool that links the laboratory to the universe is truly the way to touch the heart of the stars.

And my apologies if these notes are gting too heavy and/or frequent. It's such a pleasure to talk with you all through my fingers that it's hard to stop – just say when it gets to be too much, OK?

—— Dust

Since the nova is now, it seems, past the stage when the CN would have appeared, we can be pretty sure it won't form dust – at least not in the same way it happened in DQ Her. But that doesn't mean it won't so I should explain a bit more about what dust is, and then connect that process with other friends of yours, Be stars, B[e] stars, symbiotics, and the like. But first some news.

On Aug. 23, Linda Schmidtobreick (ESO) succeeded during engineering time on VLT in using SOFI to observe Nova Del. We're still in the process of analyzing it – this is from last night's work through the spectrum and a more careful study is underway – but the main emission between 1.0 - 2.7 microns, aside from Br and Pa series lines, is neutral carbon. There are no He I lines, nor any indication (on that date) of Na I although it is present in emission in all of your spectra with a P Cyg profile. The observation was at the time when O I 8446 was dramatically increasing (20% in the nights from 23024 Aug) and when the individual absorption features were starting to show on the D line. The spectrum of V723 Cas 1995 and V705 Cas 1993 at a similar stage (groundbased and ISO) showed similar lines and both of those were CO type novae. On top of that, the light curve now appears closer to OS And 1986 than any other for which we have UV archival data from the days of IUE.

—— a glitch in the path, a memorial to an old friend —

an aside: you may not know, or have forgotten, that the International Ultraviolet Explorer satellite,IUE, was a spectroscopic explorer mission with the single purpose of obtaining low (R 1000) and high (R 10000) resolution spectra from 1170 - 3200 A using vidicons and echelles. It was – and this is what should bring you all a smile – a 45 cm telescope! It could point to a source within about one hour of announcement, the reason the V1974 Cyg 1992 sequence is unique – and could be operated on a source 24 hrs a day without Earth occultation because of it's geosynchronous orbit. This little marvel lasted – unattended and with a 64 KB memory and television detectors – for 18 years, the last spectra were in the mid-'90s. It obtained over 100,000 spectra and its sky coverage was astonishing but more important, all of the data is available in final, reduced form on the MAST site (the STScI multi-mission archive). I can't urge you all strongly enough to play around with these data for any object you find interesting, it's a resource the likes of which is still under-exploited and will always remain a record of the universe as it was in the UV. We can't do that with HST, the sequencing and commanding are rigid and the instrument is much more sensitive and precious so risks are out of the question. We're using these spectra now, from 1986, to project the behavior of Nova Del 2013, the same as we did for V959 Mon 2012 based on V1974 Cyg and Nova LMC 2000 and V382 Vel 1999.

One last thing. I remember as a USers' Committee member the discussion of the problem of publicizing teh work of the satellite. ESA even tried to produce a calendar but it was a sort of "lovely echelle spectra of your favorite freaks" that got only a yawn from everyone not otherwise a spectroscopy-type. So the plan was dropped but it was, for those who saw the spectra with knowledgable eyes, absolutely thrilling. Needless to say, when I was on the GHRS/HST commissioning team we didn't even think of it and, except for one slitless image of SN 1987A, neither has the STIS team.

— So back on the road ———-

The solidification process in the laboratory is difficult from a microphysical viewpoint but simple enoiugh for engineering. That is, the mean properties of the medium that condenses can be controlled and the process can be trated as a homogeneous phase transformation. So you get ice forming in water around nucleation sites but these are huge compared to individual molecules. In astrophysical environments, stellar winds, nova ejecta, accretion disks, the densities are so low and the collision rates so low that the process is "kinetic", treated one at a time. A snowflake is a closer analogy since that forms by collisions that stick, others that knock off pieces, and if these happen frequently enough they produce a growing structure that preserves the symmetry of the principal molecules (like water). But in the ejecta of novae and supernovae, or winds, the medium is mainly atomic and this is much more complicated. As the molecules grow, they're also exposed to radiation that ionized and also 'knocks off' atoms. There are some intermediate clusters, analogous to the "polycyclic aromatic hydrocarbons" (PAHs) – noxious hydrocarbons like coronene – that are inevitable in the process and have a few hundred atoms. There's also a possible component of fullerenes, also called "Buckyballs", that have 60 or so carbons linked in a cage-like structure. These are remarkable for their stability, especially when irradiated by ultraviolet light as any dust around a nova will be. They're somewhere between solids and molecules, too complex to show individual lines but not so dense and linked as to show only continua in emission. They're revealed by specific sets of bands, in the infrared between 3 and 11 microns, none of which has been successfully linked yet to any particular contributor. To add to the puzzle, the optical 'diffuse interstellar features" that many of you have actually seen in your spectra (the strongest are at 5785, 5796, 4430 A but there are hundreds) are almost like a set of multiplets but they don't al appear together and we still – since they were discovered in the 1930s in photographic spectra by Merrill – don't know what they are. But the IR bands were seen in novae in the '80s and we know they're all through the ISM so they should be precursors of the dust process. That such "granini" are present is attested to by polarization and extinction measurements that require both submicron size grains (big) and nanograins (small!) and they're dispersed throughout the medium.

When the grains condense, like polluted water, they preserve the chemical signatures of the medium in which they formed. But not just any pollution – this is isotopic. You see this in the meteoritic samples that have 13C and 18O and D substitutes for their principal component. In the Allende meteorite,m there was a strong 26Mg signature that was linked to the now decayed "primordial" presence of 26Al, the gamma-ray line of which has since been observed in the ISM. From supernovae, 44TTi leaves a trace in its decay product 44Ca. Once formed, the grains are so large that they serve as reaction sites for molecular formation, as in dark clouds. You can think of them as a wall or a beaker with irregular sites that are heated by cosmic rays and radiation. If an atom strikes the grain it can stick (bind) but loosely, and literally hop from site to site until it forms a bond with another similarly walking atom; these can leave the grain by a thermal kick or continue to grow. One thing is clear, the molecular hydrogen in the ISM requires such processes along with radiative dissociation of the molecules.

There are several different manifestations of grains in novae. The first, obvious, and unambiguous is thermal infrared emission. When the grains are exposed to the white dwarf radiation they get heated by absorption and re-emit at whatever wavelength is necessary to cool the matter. This is, for instance, why the Earth is cooler than the Sun. The radiation is lower energy density where we are so the planet gets as hot as is required to re-radiate to balance the absorbed energy. The grains can reach 1500 K or so, depending on their distance and the luminosity of the WD. Above that only molecules are stable. The second is polarization, which is a still-underexploited resource (think of putting a polarizer in front of the grating after which the light passes through a depolarizer to be recorded). Scattering produce that signature. The third is, as I'd mentioned in notes a while back, the signature in pre-solar grains.

Why grains form and how they form and are expelled is an outstanding problem in astrophysics that touches everything from the first star formation to the evolution of galaxies now. They're clearly "metallic", the atoms of the interstellar gas are depleted onto the grain mantles. This, in turn, changes the abundance of free ins in the diffuse medium so affects the collisions that lead to radiation and cooling. Novae are, then, important because we know the conditions at each point in the ejecta. When we see the dust form, and this always happens within a narrow interval around 100 days from outburst, the conditions must be "just right" (in the Goldilocks sense) to drive the formation of a solid phase. ** Even knowing that a nova has NOT formed dust is valuable in that sense! ** We understand so relatively little now about what conditions and mechanisms operate that every detailed view of the process, successful or not, is valuable.

——— The abundance subclasses of novae ——

I've threatened this for a while.

There are two main subgroups of white dwarfs on which the explosion occurs. The matter comes, somehow, onto the surface and incorporates into the WD structure. That stuff is hydrogen rich compared to the almost zero abundance on the mass gainer. This isn't a facile comparison: the process is an analogy to an internal combustion engine. The WD and boundary layer of the accretion disk act as a sort of carburettor, where the fuels are mixed and set into a combustable state. The star itself is the cylinder and the critical pressure is the spark. Like an engine, the piston, driven to expand, rapidly cools the mixture that then has to be flushed or the ashes pile up. That's the part that could increase or decrease the WD mass. The two different compositional groups, CO or ONe, are the stripped cores of progenitor stars of different masses. The lower mass stars burn He to C and O but no father. Higher mass stars reach Ne and even higher mass go on to C-C and beyond (finishing at Fe, but that leads to collapse). The core mass, in a degenerate state, reaches about 10% of the total mass of the original star so the CO are likely 0.7-1.2 solar masses and the ONe can reach practically to the stability limit (the Chandrasekhar mass). How a self-respecting normal star can reach such an absurd (Eddington's words) condition depends on keeping bad company: these systems are binaries and the stripping process happens because the originating system was too close after the main sequence for the components to remain unaltered. The more massive star evolves more quickly, its radius increases, and at some stage it may form a common envelope with its companion. The motion of the stars within this envelope, in the now standard scenario, expels the gas by turbulence and dynamical heating (differential motion within an immersion) and the system becomes compact due to loss of energy and angular momentum, finishing with a white dwarf that was once the more massive star and whatever is left of the less evolved companion. When that star starts to expand, mass transfer takes place and this is a cataclysmic variable of which novae are one breed.

It's thought now that the lower mass WDs are the gainer within the accretion disks of dwarf novae and their cousins, while the more massive WDs are the sites of nova explosions. Ultimately the violence of the explosion depends on the fuel that's ignited and how deeply the accreted matter is mixed before the nuclear processing triggers. That's the idea behind the so-called Maximum Magnitude Rate of Decline relation, that the most luminous explosions are on massive WDs and require less mass to trigger, are more luminous and violent – hence faster ejection velocities – and throw off less mass. But the persistent X-ray emission after the explosion, the Supersoft Source stage, tells us that matter remains on the WD and continues to burn, that neither is all of the accreted material ejected nor is the nuclear source extinguished by the explosion and expulsion. Understanding how much mass remains from that which was first accreted, and given that the WD restarts the accretion process quickly (although how quickly is an open question), the slow whittling away of the WD or its ultimate buildu-up to collapse incuced by the accretion, is one of the holy grails of the business.

Another thing we could discuss is the actual accretion process and the stability of the post-explosion system, but only if you think you can tolerate more. Hoping that you've found this clear, I'd better stop now to not try your patience past limits.

———————————— 2/9/13

There's been interest in some explanation of what developments are yet to come so here are a few notes for the next week or so.

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 stronger. 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 asD^{-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.

So more notes coming, and as always thank you for the interest.

============= 040913

OOPS. The figure I'm sending now will be definitive for explanation, Francois.

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.

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), fro 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 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 $10^9 \mathrm{cm}^{-3}$ 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 8E-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 2E-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.

As always, I hope these explanations are clear. if – and please always keep this in mind – if you have any questions or comments I'm delighted to hear them.

——- and response to Myriam (3/9/13)

For the pre-nova, in this case, the object was reportedly blue. That doesn't rule out a cool companion but does indicate that the system is compact and likely dominated by the accretion disk of the white dwarf. A giant would have at least a few hundred solar luminosities, likely more (depending on the system), and would have dominated the light; you could say this would look like a symbiotic star (emission liens were a spectrum available but not distinguishable fro the giant by photometry alone of the sort available for the pre-outburst system). The contrast is for systems like T CrB or RS Oph, or even V407 Cyg (the one discovered as the first gamma-ray emitter). These are extremely rate and their overall behavior is very different. The other clue is that there's no indication of a shock as the matter would have to plow through the wind of the companion, we know that signature very well from several symbiotic-like recurrent novae (as they're known), of which the latest is V407 Cyg. The velocities are also exceptionally low for Nova Del 2013 were it that sort of system, the light curve quite is actually quite conventional and not one that resembles the others. There's no indication of the companion in any of the spectra, from the V407 Cyg outburst we know there should be chromospheric lines and shocked gas from the companion and its wind were it a symbiotic-type. Nova Del is, in that sense, ordinary, a comment that might irk some colleagues, but an important issue: the very "ordinariness" of this nova is what makes it so important, it is prototypical rather than exceptional and I think we desperately need such a system as an archival taxon while we're still capable of doing a panchromatic study. You see, we'll lose the UV as soon as STIS is turned off and that's whenever JWST is launched (that has only long visible and IR instrumentation).

At the meeting in July at Pisa, and the second at Minnesota, we collectively decide to throw all of our resources at a bright Galactic nova that is detected in gammas if it's a CO type, we have nothing for those comparable to what we have now for the ONe types. As luck would have it, we now can put that conspiracy into practice. We're able to use what partial information we've collected over the decades for other likely analogs, OS And 1986, LMC 1991, LMC 1992, V705 Cas, V723 Cas 1995, to predict and test ideas but none of these has anywhere near the coverage of V959 Mon 2012, V1974 Cyg 1992, or V382 Vel 1999 (or LMC 2000) that were the "Fabulous Four" of the ONe novae. Even the symbiotic-like systems are better covered (especially RS Oph 1985,2006 and V407 Cyg 2010) and the recurrents (T Pyx 2011, U Sco 1979, 1999).

— Some notes on static vs. dynamic media

The light curve has caused some amusing impatience, it's been amusing to see some of the comments. It's perhaps always good to remember that in an environment as complex as we must have in these ejecta, as in other time dependent structures, unexpected things happen. This brings to the fore a comment, in the hope it will put some of the present results in perspective.

The difference between a dynamical medium, like nova or supernova ejecta or even a stellar wind,and a static structure – a stellar or planetary atmosphere – is "locality". An atmosphere is a very particular sort of medium, whether optically thick or thin (or both). It's a gas that is constrained to satisfy a mechanical equilibrium constraint, that the run of pressure and temperature balance the effect of gravity (whether self-gravity or a thin layer above a mass). The gradient with radius of the pressure and density must everywhere counterbalance an acceleration. If radiation pressure is important, this effectively reduces the surface gravity but as long as it is low enough, the radiative acceleration will not destabilize the medium. At the same time, since the equation of state links the temperature, pressure, and density, and both are connected with the transfer of radiation through the layer, the luminosity enters the picture in a relatively simple way, at least in the sense that the radiation must pass from the interior to the outside through a "surface" and ultimately the only loss is radiative (OK, no magnetic fields, no neutrinos, just to be basic). As long as the luminosity stays roughly constant, and there is a very clear definition of what this means, the atmosphere will have a unique static structure. "Constant" means nothing changes faster than the thermal timescale of the medium (the rate of cooling) or the sound travel time (which sets the condition for hydrostatic – mechanical – balance. This doesn't mean that the only parameters entering the picture are the thermodynamic variables. The whole business is governed by the abundance of the elements since the different elements have different ionization energies, transition energies (lines), and different ionization states. The mix collectively produces the opacity and that's the key coupling between the radiation and the matter. But if the medium is stable and static, there is a solution to its structure and you can predict a spectrum emergent from the medium as a function of only a few variables (OK, knowing the metallicity).

A dynamic medium is a whole new problem. There's no mechanical constraint to govern the pressure and density. Those are imposed by the dynamics and depend on the driving. If the medium is a wind, let's be simple and take a steady outflow, then the condition that the mass loss remains constant links the density and velocity at each distance from the star. The mechanical requirement, that the velocity is determined by the driving, is the hard part: you have to impose a mechanism (radiation, rotation, magnetic, whatever) that is described by its own physical constraints, to determine the run of density with radius. This, in turn, affects the ionization and – through that – the opacity at each radius.

Add to this that if a medium is static a photon leaves a line, or is absorbed, at a wavelength that's symmetric around the line center and not shifted by the differential (Doppler effect) motion between strata. Not so in a wind. A photon emitted at the center of a line sees ahead of it a reduced opacity from the same transition because of the differential motion of the medium. On the other hand, depending on the spectrum, another line may be shifted in the way. This is the cross-coupling effect we've already discussed during the Fe-curtain phase of the nova outburst. In a wind, except in the most optically thin case, this is inevitable. It is the real reason for the absorption trough on the P Cyg profiles you've seen in windy stars. But there's another thing about a wind that highlights the "non-locality".

A wind is driven so it has to reach a terminal velocity. You don't have infinite energy to accelerate the flow forever. This means the rate of change of the velocity decreases with distance from the star (or the driver, more generally). So in the outer wind, a photon sees a longer effective absorption path length ahead of it because all of the material above a certain radius is almost moving at constant velocity. Not important that the density is decreasing, the velocity is constant. So the optical depth can be large even though the density (locally) is small. This produces the deep absorption that has a well defined edge in the P Cyg profiles of winds, the velocity gradient goes to zero at distance and the effective pathlength approaches infinity. OK, it doesn't become infinite, but all of the matter is at the same velocity.

Instead, in ejecta, the stuff has been blown off at a moment and the driving is over. Until there is a deceleration, and for matter far enough above the escape velocity this can be very far from the star, the expansion preserves the velocity field. Eventually there will be interaction with a background (if there is one, like the RS Oph-type novae) or a small nonlinear gradient can appear, but this is late. In general;, the matter is going at its terminal velocity and each piece is independent. The formation of the spectrum is, therefore, different than a wind – there's no terminal velocity, just a maximum – and the line profiles show this. Instead of well defined edges, the lines show the change in the density along the line of sight, not mediated by a decreasing velocity gradient. Unlike a wind, because there is no active driving, changes in the opacity just change the spectrum and the thermal state of the matter but this is completely dependent on the local densities and the highly non-local radiation field. So there is nothing to constrain the density to be any particular value locally, and the structures remain and don't advect (move outward relative to the ejecta) with time as they do in a wind.

The ejecta are also very different than an H II region or even a planetary nebula. The velocities are high and can be very different from one point to another, and very time dependent. The recombination timescale in an H II region is long but the ionization source remains on so the state of ionization of the gas can reach a balance. In a wind or ejecta, this can be very different. The state of ionization of a gas can remain very high even when there's no longer an ionizing source because of the expansion. The decrease in density slows recombination so even if the central source is extinguished the expansion can decrease the density fast enough to effectively halt recombination. An H II region doesn't expand supersonically even though it DOES expand so the state of the gas is governed by the collisions (rare though they are) and the ionizing photons (diffuse or central). The same is true for a supernova but there the mass and energy of the ejecta are so great that the shock from interacting with even a rarified interstellar medium is enough to power the ionization and emission until the ejecta fall to the local sound speed.

While this doesn't have anything in particular to do with what's happening now – at this moment – in our favorite nova, I hope it puts the observations in perspective. There's another reason for this tirade.

Stellar classification is the reflection of the regularity of stellar atmospheres that comes from this double equilibrium. Because the radiation and matter are coupled in a static medium, depending on the composition you would expect a particular spectrum to arise from a run of thermodynamic conditions in the atmosphere. So there is a sort of link between the features of the spectrum and the luminosity and radius – the latter are combined in the "effective temperature". This isn't true for ejecta of any kind, and even for winds. The spectrum is not unique for a structure, the worst non-equilibrium environment you could fear dominates its formation: the matter and radiation are coupled dynamically and locally and non-locally and may be time dependent. The desire to find a classification system of any kind for phenomena that have such a wide range of variation is potentially misleading and certainly much different thann the basic taxonomy of stellar atmospheres. One last example. The ionization of specific elements, line ratios among ions of the same element, is used as a temperature indicator. In a static medium this works. In a dynamical medium, as you know, this isn't true. In novae, for instance what you will see very soon, the same spectrum can show [Fe X] or He II and O I. They're coming, perhaps, from different pieces of the same ejecta with different densities at the same velocities.

—– question about Fe II strength

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.

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.

—– 18/9/13

The last spectra from Sep. 18, now show He I 4923, 5876, 6678 (weak, on the Hα 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 $\rightarrow$ n=2). 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 $\sim$ 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 bout 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 seems 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 emission 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 [NO 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.

Now 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.

22/9/13 – answers to questions from Lars Zielke

In answer to your question (I can't find the others), Lars, it's related to the nucleosynthesis in a supernova relative to that in other types of explosions so just a word on the background.

Following the collapse of a type II (core collapse) supernova and the formation event for the neutron star, a combination of neutrino emission from the core and the bounce of the stellar envelope on the newly formed neutron star drive a shock outward. This accelerates moving toward lower density and the matter is ejected – it reaches the escape velocity from the NS everywhere. This is essentially different than a nova explosion, the shock here is propagating outward through infalling matter and is powering the ejection and setting the outward velocity. The temperature is enormous behind the shock (after it passes), high enough to produce rapid neutron capture and nucleosynthesis. This, both neutron and proton capture, produce heavy elements of which Fe and related elements are important products. The rapid capture of neutrons (because the background number density is very high and the temperatures are as well, hence fast reactions) builds up neutron rich heavy isotopes (for instance, of the rare earths like Eu).. In a type Ia, which is not core collapse, the shock produces Fe and Co and Ni as its main nucleosynthesis. The ejecta are hydrogen poor, unlike TypeII, and the reactions are mainly through alpha and heavier ion captures. The r-process is not as important as for Type II, and the Ia's are responsible for much of the Fe in the Galaxy.

The terribly hard problem that's remained open for decades is: what's the progenitor of the Type Ia's. This i the link to novae for a large part of the community. Whee there's a WD accreting, if it continues to accumulate mass (the net mass increases even after explosions) then it may reach the Chandrasekhar mass (even though Chandra was a heavyweight as a mind he had a remarkably low mass himself, you see) that is the stability limit for a degenerate star supported by electrons, and the subsequent collapse forms a neutron star and ejects the remaining WD envelope with the associated nuclear processing. This is the physics (or scenario) behind the apparent uniqueness of Ia's, that thy have about the same absolute brightness. If they all collapse at the same mass "it's obvious" they'll release the same amount of energy. But it's certainly not clear that they'll be as close to standard candles as the Ia's seem to be.

∗∗The shock that's moving outwards, can I think off it as a wave front passing through infalling matter or has the shock an extent/dimension/size so it takes more time to pass through an area of the infalling matter. I guess I'm asking if the shock is a front like in a explosion or a shock is more like a storm thats takes longer time to pass.

More like a permeable wall, or a piston; the point of a shock is a pressure front that moves faster than the sound speed. The matter ahead of the shock isn't slowed by pressure waves, it's swept up in the front as it passes, what happens when a high velocity car or train passes to the leaves or papers on the ground is a good analogy. After the train passes, th papers follow at some slower speed as if swept up (which, for a number of reasons, they in fact are).

∗ ∗ ∗ The lost question:
When returning to the white dwarf, which we now believe is a CO type, we ran into some differences in the mass for the progenitor star. Some say below around 4 solar masses for a CO type, while others like Jordi José in "Classical nova explosions hydrodynamics and Nucleosynthesis" aug. 2012 says below 9 solar masses for a CO type. In this paper Jordi Jos also points out that the mass cut is not well known. So is the 9 solar masses the most accepted value for the moment?

Whatever the progenitor mass, it's only coming out of scenarios. Since we know that CO and ONe novae can also be recurrents in symbiotic stars, I think it makes relatively little difference now. Other than saying that the formation of the ONe core requires a higher mass star, with all the attendant physical differences that may happen in the advanced stages, there is little that I think can be said with the precision you're asking. This is a question mainly for the SN Ia controversy but we don't know if we need a WD of one or the other composition since that's hidden by the nucleosynthesis in the explosion (its sort of wipes out the memory of the original composition).

24/9/13: Dust ————

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.

28/9/2013 ———-

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), 2.3e-13 erg/s/cm^2 while the UV (1200-3000Å) gives 1.7e-8 erg/s/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 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).

More will be coming in the next few days, thank you all for the continuing hard work. The changes will now be quite remarkable as the nebular spectrum appears and the continuum disappears (this was already noted for T Aur by Agnes Clerke in her description of the transition, and also Huggins).

1 Oct 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 thsi 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.

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 e 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 kine 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.

11/10/13 ————

If it weren't a possible offense to French patriotism, I'd cite Henry V (Shakespeare) about "we happy few" to explain how important it is to continue observations of V339 Del for as long as possible. But instead, poetry notwithstanding, I should explain why this last stage is so important.

The X-ray emission from the nova is continuing to increase, we have hardly yet seen the maximum, and it is still "hard" (meaning it is stronger in the higher energy bands, around 10 keV, that indicate a temperature of ¿ 10 MK). This is still likely from internal shocks in the expanding ejecta but this should decrease and a soft source (¡ 1 MK) should appear shortly. When it does, it will be the brightest XR nova ever observed by Swift during its mission lifetime. When the soft source becomes visible, the optical proxies (like the coronal lines) will indicate the low density structure of the ejecta and allow the determination of the abundances. That's the other important reason for continuing low resolution observations, thee are the thermometers of the ejecta. While the individual structures i the line profiles matter, those can be obtained from the high resolution observations (e.g. NOT, Ondrejov, etc) and from HST. The low resolution data, instead, shows the morphology of the continuum and the total emissivity changes – this gives the mean properties of the ejecta. We don't have a record of a CO nova with this precision and coverage, as I've said before, but it is now at a stage where the data will be comparable in resolution to some for extragalactic novae (for instance, in the LMC and M 31).

As an example, the main electron density diagnostic is the ratio [O III] 4959+5007/[O III] 4363. This relates directly to the electron density and, in turn, gives an estimate of the mass. But it requires a temperature for that number, usually chosen on energetic arguments about cooling of the gas. BUT if you also have [N II] 6548+6583/[N II] 5755, then you have two independent estimates of the temperature and density that give a unique solution. It will be important to follow the developments of [Ar III]7135, the He I lines (especially He I 6678) and the Balmer lines (especially Hβ since the normalization of the uncalibrated spectra for plasma diagnostics is based on the emissivity of that line).

The other, more essential result that requires low resolution data over a broad spectral coverage is the determination of the abundances. I think the mass problem has been solved (personal prejudice only) but the abundances will drastically differ from one event to another. This is the detritus of the nuclear processing so it is the fundamental, virtually unique signature of the TNR. Only when the gas is completely transparent can standard methods be applied, those developed for H II regions. Until one knows that there is no pumping from the UV any flux is suspect and these density diagnostic ratios can't be converted into abundances for, as an example, O and N. Those two, along with C, are the overabundant species that record the temperature and density conditions at the moment of the explosion.

There's another reason to keep observing, although not with an extraordinary cadence. There are so few continued programs into this stage that we don't know if something *might* happen in the later stages. To see, for instance, if an accretion disk re-appears (as it must) requires certain lines (e.g., He II 4686) to remain invariant while the others decline. This line is a very good indicator of the high density, high temperature environment within the disks. And even at a resolution of 500 you should be able to distinguish the lines from the ejecta and disk (by the appearance of the line profile and it's stability).

It's not that this nova now needs to be observe very frequently, perhaps one observation every four or five days until it goes behind the Sun. But you have all already produced a great legacy and this is the last step. One of the advantages of this kind of work is that it has a beginning and a rational end with the product being a permanent mine of information. But we're not yet at the end andI hope this encourages you to keep going.

30/10/13 ——————————————

It's been a long silence, all, and my apologies but it doesn't mean there's nothing to write about.

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 Å) since the absorption cross section changes 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 $L_\odot$ (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 4686Å 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 this detail. And one more, important finding in your collective spectra: He II 4686 IS there, despite the statement in the recent report, ATel #5493, that it isn't there. You see, those in the business can make some pretty egregious mistakes. We are getting grating spectra with the UVOT on Swift that compare well with your low dispersion data, in quality and time coverage, but in the IV (2000-4000Å) so we will have complete continua for this entire stage of the nova.

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). We are now planning how to organize the first papers on this, I'll keep you all

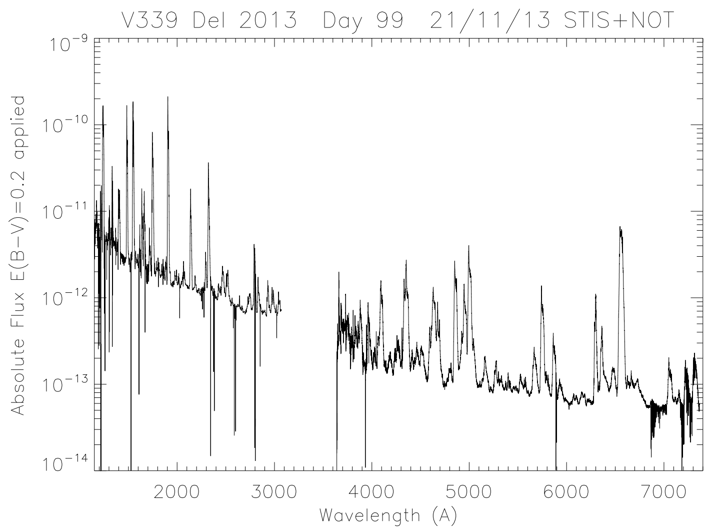

Figure 1: The combined NOT and STIS continua from 1150-7400Å, E(B-V)=0.2, from 21/11/2013. Note that what looks like noise, narrow features that go to very small flux levels, are actually *all*
interstellar absorption lines (there are a lot of them). The atmospheric bands are seen at the red end.

informed; for the first – including you all – we'll use the spectra from the fireball and Fe-curtain, possibly to the date of solar obscuration.

29/11/2013

It's been too long since I last wrote and there have been significant developments to explain. As ever, your collective contributions are wonderful, it is especially important to see the move to also obtain spectra longward of Hα.

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 - 3050Å) with a resolution of ¿ 30000 was obtained simultaneously with a NOT observation (3700-7400Å), 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 ≈ -800 km/s peak stronger or dominant relative to +800 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.[1] 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 $L_\odot$ 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 Cyg 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

[1] A clarification here, 30/11/13: the slope changes near the peak of the function so it you have a steep variation it means you're closer to the peak (OK, better said, the long wavelength limit depends on the temperature, that is $B_\nu(T) \sim T$ so at a fixed wavelength the slope of the function depends on the temperature. It's better to leave it out, just enough to mention that the slope at any frequency depends on the ratio of the frequency of observation to that of the maximum (in that sense at $\nu_{max} \sim T$ so you can use this to indicate if the peak is near or far from the observation.

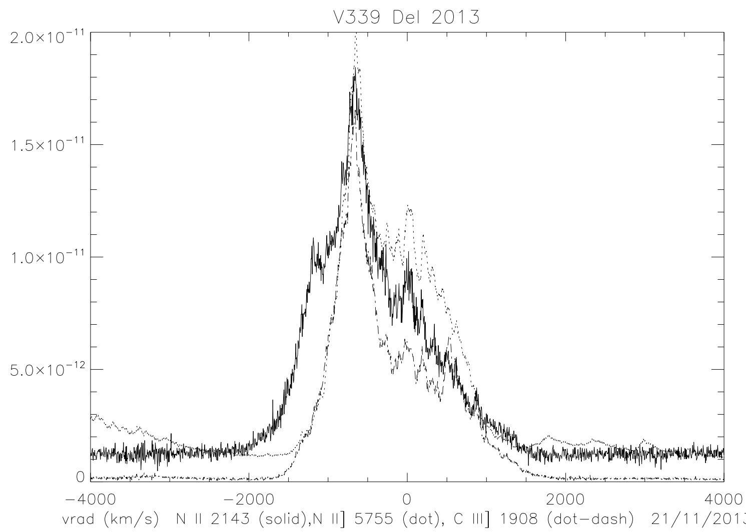

Figure 2: Comparison of N II] 2146, 5755Å and C III] 1909Å profiles for 2013 Nov. 21.

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.[2] 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,

[2]A clarification after a question by Francois: In the T Pyx spectra, after day 170, there were detached (high velocity) discrete (narrow in velocity, dV/V 0.1) absorption lines on the profiles. These remained at the same velocity when seen in absorption, much later, in ultraviolet spectra at C IV and N V. The thing I'm talking about here is that in V339 Del we have not (yet) seen this, but it may be what the XR is showing (so we're seeing the structure probed by a different set of ions now, perhaps in the next HST spectra we'll see this on the other lines). In the last T Pyx paper (the one called paper III in the series in A&A) the pumping is due to EUV and XR absorptions, at energies of 50-100 eV. The lines, in other words, that are in absorption (which are reported as He-like and H-like, i.e. C+5) are the transitions that should show this without an optical or nearer UV counterpart (they're too ionized) but could be showing up in the FUV (e.g. O VI instead of O V).

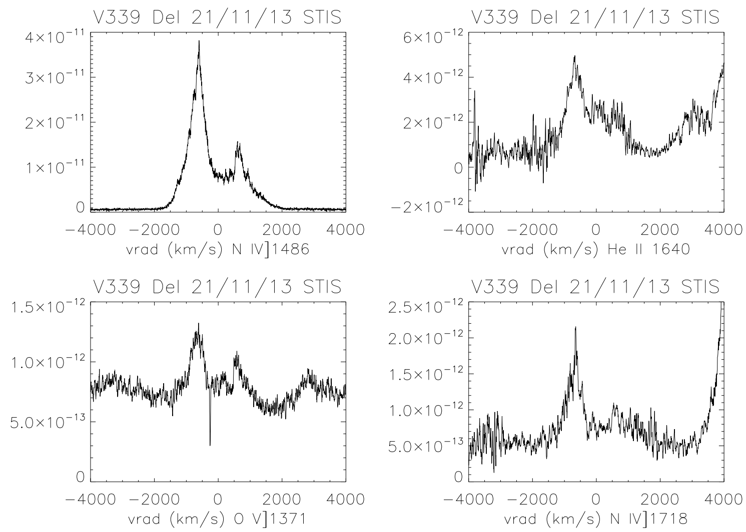

Figure 3: Comparison of O V 1371, He II 1640, N IV] 1718Å, all excited state recombination transitions, from STIS: 2013 Nov. 21.

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 $10^7 \mathrm{cm}^{-3}$ (so still marginally high), there's an indication that the filling factor (the knottiness of the ejecta, as seen on your profiles of Hα, 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} $M_\odot$, consistent with other classical novae but that will become more precise soon. Once this is all over, the next step is the detailed 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. There are now Hamburg Remote Telescope observations (between 15000 an 20000 resolution with 3700-9000 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.

28/12/13 ——————————————

Now a summary and a new comparison – V1369 Cen 2013 joins V339 Del

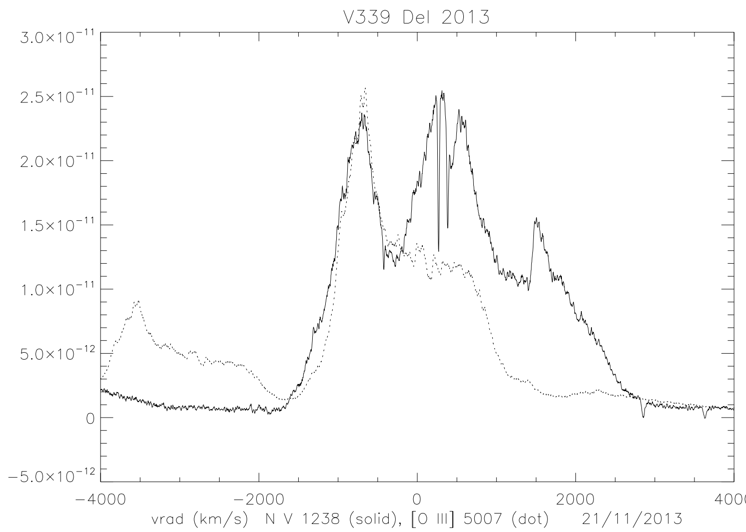

Figure 4: Further comparison of [O III] 5007 and N V 1240Å profiles from 2013 Nov. 21. Note that the N V is a doublet and that the individual components more likely have the He II-like profile than these forbidden transitions. The absorption features are Mg II interstellar lines.

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 – t the higher ionization stages of the ejecta. From your spectra and from the NOT, there are indications of the [Fe VII] 6087Å line as early as mid-No. but this is now clearly resent and ill be the "line to watch" in the months after emergence from sola obscuration. The He II 4686Å 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

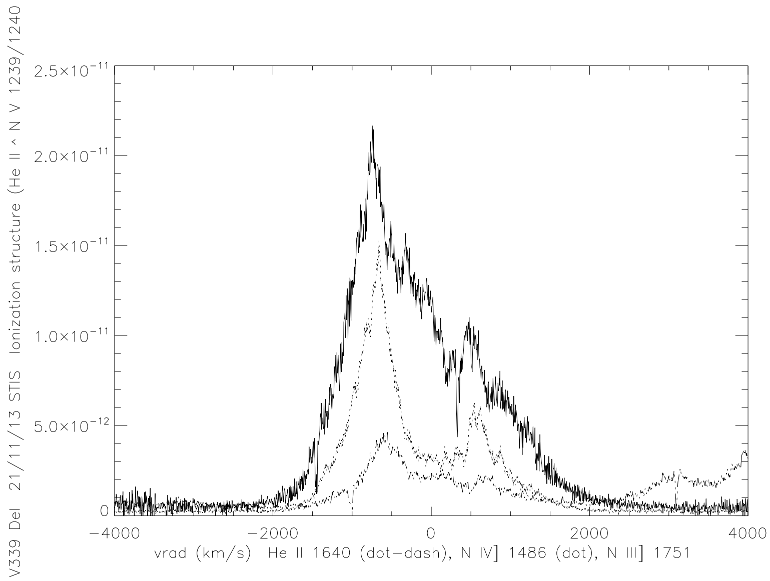

Figure 5: How to probe the ionization stratification of the ejecta using lines of nitrogen (there's a good sampling from the UV) from 2013 Nov. 21.

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^{-1}) 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 γ-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 aaain, it will be after almost as long an absence as its presence, so it should be considerably more extended and *ma* 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 *hint* of the [N II] 6583Å line (the analog of [O III] 5007Å) on the wing of Hα 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^{-1} of $(6-10)\times 10^6$ cm^{-3} but the temperature is uncertain. The mass is a few times 10^{-5}M$_\odot$ and a large filling factor seems to be emerging, but these statements are still very preliminary. The filaments that you've all noted are not ony still there but now more evident and on lines of different ion stages and elements – so it's now possible to study the homogeneity of the abundances in the ejecta at the level of a few percent of the volume. OK, this is a technical point but by combining the emission from lines whose de-excitation is from collisions

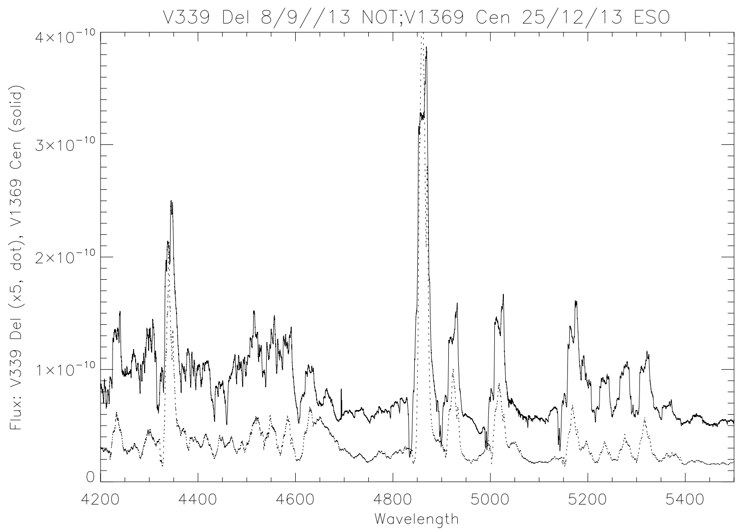

Figure 6: The spectra from V339 del (NOT) and V1369 Cen (ESO, FEROS from Luca Izzo) on about the same day (about three weeks) into outburst. The fluxes are absolute, the scaling is $3x$ for V339 Del, no extinction corrections (but you'll notice that the spectra are so close that it's likely the reddening is similar).

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 sensitivities 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 CO 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 V 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.

20/1/2014

The light curve of V1369 continues to show multiple events, now 5 major peaks with probable substructures, at intervals of about a week or so. Their amplitudes have decreased over time, but they remain possible for a while. This is not the only nova to show such effects but it is the first modern system (post-XCCD) to be so extensively studied (despite the bulk of the observations being visible). During the last peak, the attache spectrum showed He I clearly for the first time on all important transitions. He I 4471Å was also visible but complicated by local blends. The detached feature is reminiscent of T Pyx 2011, although this system is quite different, as is the extended optical maximum. You'll notice that with this one case you see the potential pitfalls of using the t_2 or t_3 parameterization of the light curve.

The Balmer lines show the optical depth effects in having a terminal portion of the profile and mean velocity that depends on the optical depth of the feature (the higher the line strength, the farther out in the ejecta the lines form and therefore, the higher velocity should trace the intrinsic absorption coefficient. There are multiple lines on virtually all transitions, the detached features show up especially well on O I (e.g. O I 8446Å that is pumped by the ground state and is a permitted line). The line cores are similar to the [O I] 6300, 6364Å profiles, and there's a core that is quite similar also for the Fe II transitions (e.g. 4923, 5018, 5169Å). If the individual peaks in the light curve are ejection events, the feature sin the absorption part of the profile should be mimicked on the emission side, and there's some indication of that. But the difference in the Balmer peaks is striking, especially compared to the other lines, and the [N II] and [O II] lines are also now starting to appear with very different profiles. The

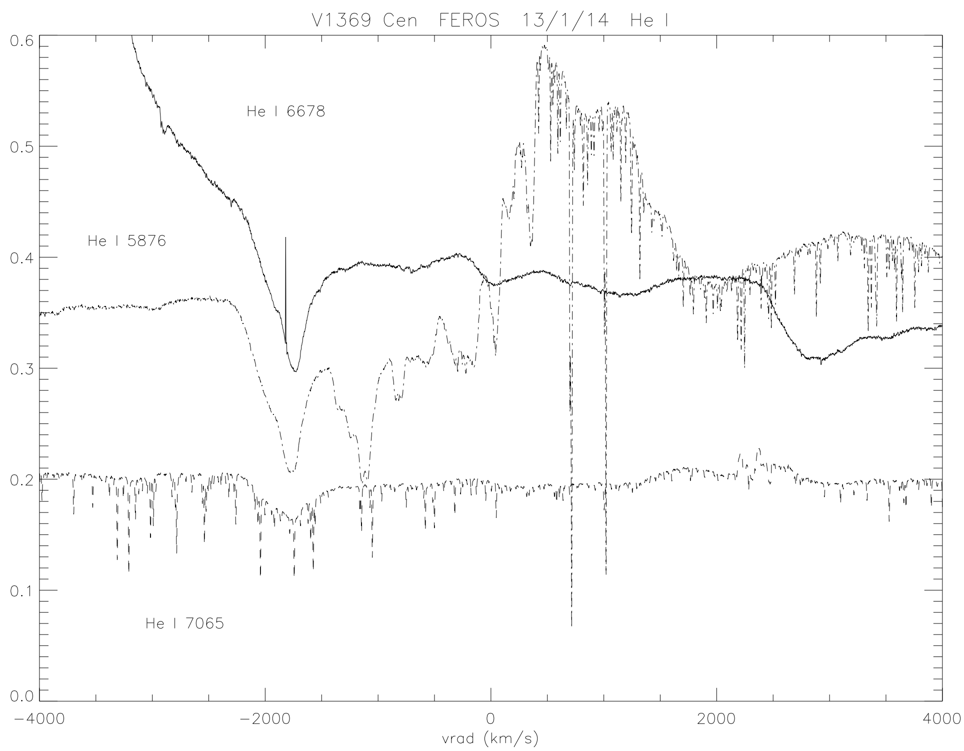

Figure 7: V1369 Cen (ESO, FEROS spectrum, Luca Izzo(PI)) deom 13/1/14 showing the detached absorption feature on the He I lines that appeared after the start of the year. The line is also blended with the extreme velocity components of Na I D 5889.5895Å and most clearly distinguished on the He I singlet 6678Å.

high opacity phase is nearly over, but this might still be the time for the IR to show evidence of molecules. It's still too early, though, to say anything about possible dust formation. The velocities are clearly higher than for V339 Del, but whether that's intrinsic or an inclination effect awaits the transition to a more transparent structure.

On the other hand, for V339 Del, IR observations show that the system did form dust although continuing observations are needed. What is peculiar is the persistence at a plateau, the V hasn't changed by more than 0.3 magnitudes for two months although this is not the most extended possible plateau. XR and IR observations will have to complement the optical spectra. As an alert, the next HST/STIS observations will be after emergence from solar light, some time in miid-April, and a planned observation of V1369 Cen will be about a month before. Your careful coverage of the critical period, along with one IR spectrum to date, shows that dust formation is possible without observable

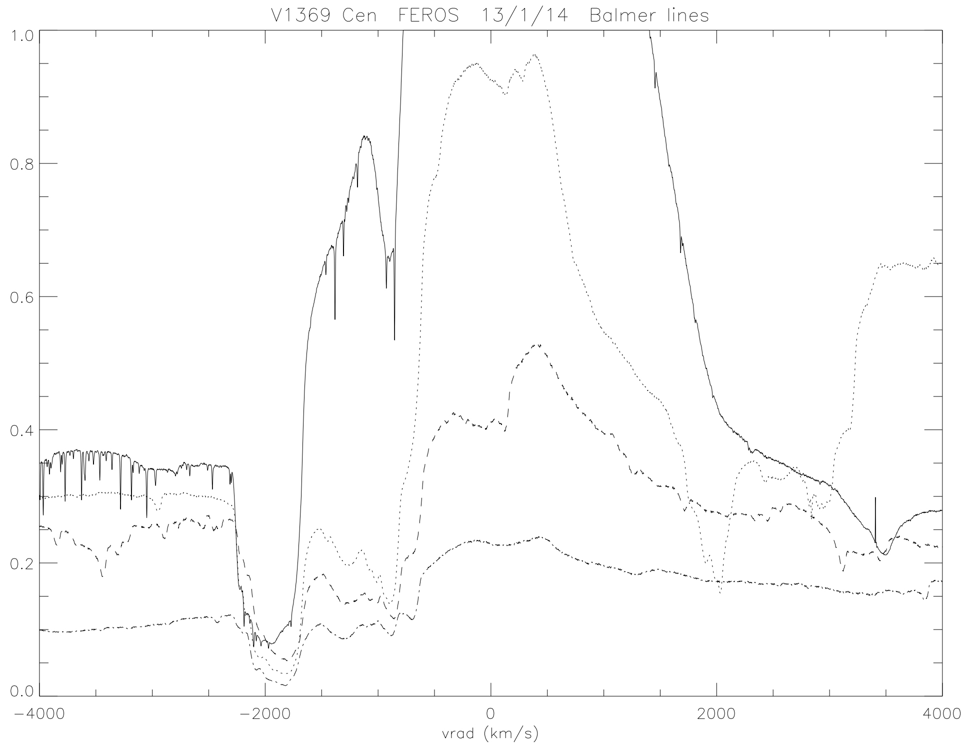

Figure 8: V1369 Cen (ESO, FEROS spectrum, Luca Izzo(PI)) showing the detached absorption feature on the Balmer lines (solid, Hα; dot Hβ, dash Hγ, dot-dash Hδ).

CN, CH, or CO. Whether this means the precursors weren't seen because of excitation effects or that the molecules are not prerequisites for solidification remains to be seen.

This brings me to a question asked last week. In these novae, you see line velocities that are (accounting for projection effects) lower than the escape velocity from the surface of a WD, One could then wonder how the ejecta can be ballistic and not reach the escape speed? Recall that the nova is initiated by a thermonuclear runaway. This extremely luminous source heats the envelope of the WD that expands – perhaps to the point of a common envelope around the two stars – that mimics a red giant. The escape from this engorged envelope is much lower than that of the original system and significant, deep mixing has already occurred. So when the β-decays take off, when the 15^O decays for instance, the extra heating ejects the envelope at lower velocities than would have been expected for a stable WF. Note, however, that this stage is still poorly understood and not modeled in the current simulations. Those use a means

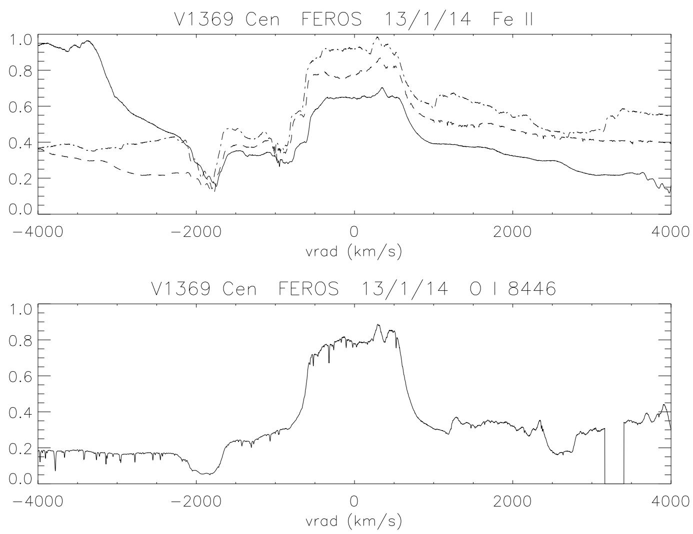

Figure 9: V1369 Cen (ESO, FEROS spectrum showing the detached absorption feature on the Fe II (solid: 4923Å; dash: 5018Å; dot-dash: 5169Å; bottom O I 8446Å.

for computing the nuclear processing that takes into account only the starting moments of the expansion, the rate becomes almost wind-like for a short time based on the sound speed. That is the usual criterion for the "explosion" in such models, the issue isn't one of dimensionality (as in one dimensional, radial)) but of the distinction between different parts off the envelope. To follow the actual explosion is still beyond the capabilities of most models and the instability of the layer is signaled by the transition to supersonic motion, as in a wind. I've said repeatedly in these notes hat a wind isn;'t necessary but that's not true in the first stages when the ejecta are forming. During that stage, there must be an acceleration of the envelope to ballistic expansion. Whether there is also fall-back is a separate, intriguing question that currently has the answer "no", there areb't inverse-P Cyg lines that would indicate such events.