Part II: Continuing Notes on V339 del, V1369 Cen, and now with the addition of V745 Sco 2014 for the ARAS group

Version – Date: 10 Feb. 2014

As if you all needed something to do, we have *another* nova. Fainter than V1369 Cen and V339 Del, faster than V959 Mon (sounds like the beginning of a Superman episode), V745 Sco last erupted in 1989. In that long forgotten era, *IUE* was able to observe it a few times and obtain low resolution 1200-3000Å spectra (about which more below). This time it's without the UV coverage but with a wealth of experience developed in the last 10 years from two other remarkable systems, RS Oph 2006 and V407 Cyg 2010. The nova is faint, it's heavily extinguished (being in the plane and toward the Galactic center) and more distant than the others in the last two years (T Pyx and V407 Cyg included) but it is a member of the rarest subtype of classical novae and even if you don't have a way of observing it I hope these notes will be of some interest in setting the context and the contrast.

We're almost at the point of observability again for V339 Del. You'll recall that the nova was in a plateau in its light curve that lasted for several months. While unusual it is not the only such event but after the relatively normal decline phase it's still not clear what is happening. We'll know in about a month or less when observations can restart. If it's still at V≈11.5 it should be possible to continue lower resolution spectroscopy and we'll be continuing observations with the Nordic Optical Telescope and, I hope, Ondrejov so if you are willing to keep up on it the cadence will not be the frantic scramble we had for the first months. Your archive is so enormous that it is still being worked through for the paper, I should have an outline shortly (with apologies for the delays). The STIS/HST observations should be taking place in about 6-8 weeks and the nova will also be observed with *Swift* as soon as the Sun limits are cleared.

Now for an update on the V1369 Cen. The last observations show that the absorption remains complex, with a number of narrow components now visible within what were previously broader absorption features. The velocities are comparatively high, above those seen in V339 Del but still above the maximum usually seen for the absorption systems in the classical observations of McLaughlin and Payne-Gaposchkin's era.

For comparison, this is an ESO FEROS spectrum, from 31 Jan. 2014, that shows the Balmer profiles. The feature at high velocity, isolated and comparatively sharp, is also seen on the He I lines (5876, 6678, 7065Å). Again, in T Pyx, which is the only nova for which we have late-time UV spectra, similar features were detected on the resonance lines of the highly ionized species, e.g. N V and C IV. This isn't indicating that V1369 Cen is a recurrent. In fact, there's something much more exciting here, I think: this behavior showing up in two completely unrelated subclasses, and different novae with different orientations and velocities and photometric behavior, is starting to smell like a generic feature that we have not captured before. The same is true for V339

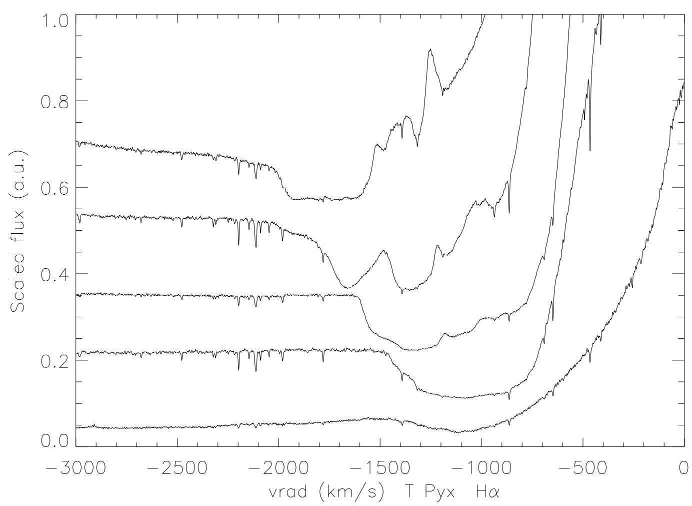

Figure 1: The Hα sequence for T Pyx through the end of the Fe-curtain phase. The profiles are, from bottom to top, MJD 55675, 55688, 55697, 55703, and 55712. The outburst started on MJD 455666.

Del, although the profiles are simpler (well, at least the Balmer and He I lines, the same can't be said for the Na I D lines). During the optically thick stage, and continuing through the expansion of the ejecta, these features have changed their absorption strength because the line of sight column through the ejecta has been dropping. When the matter is very opaque, these lines are as well and there's a masking effect of the absorption. Once the density, and column density (which varies like the optical depth and so decreases as $1/(\text{times})^2$) drops sufficiently, these individual features emerge. That there is also one relatively new feature at such high velocity is extremely important and your spectra have been essential in this detection: the distance originally quoted from the centimeter radio observations was based on a very low velocity, hence the derived value is a distinct lower limit. The same is important for the X-rays, which have not yet been detected. The nova is finally fading steadily, although it may start undergoing new oscillations if it's anything like V5588 Sgr, but for the time being the light curve is well-behaved. Whatever was happening during the ejection stage, it has a resemblance in both the line structures and the photometry to what took place in T Pyx. If this is a series of multiple ejections, then there might be a simple origin for the high velocity line. The γ-ray emission detected by the *Fermi* Large Aperture Telescope (LAT) had a long duration (the analysis is ongoing) but seems to have been confined to about the same interval as the other classical novae for which such emission was detected above 50 MeV. If the photometric variations were, instead,m some sort of shell flash series from

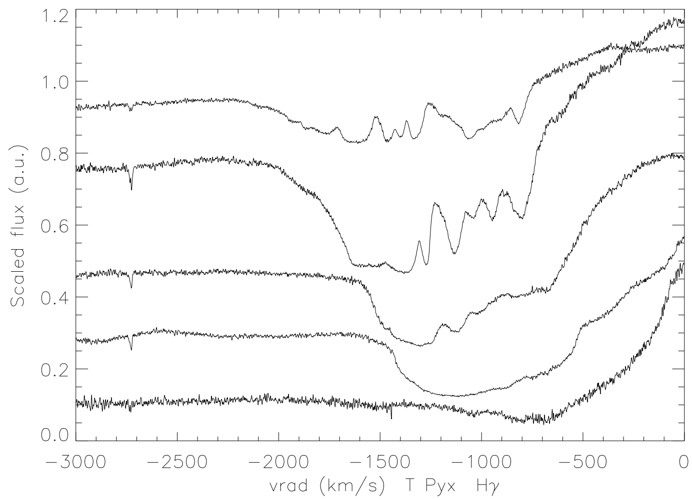

Figure 2: T Pyx: The same sequence for H′γ.

the nuclear source, buried inside the still-optically thick ejecta, then the line changes should reflect the flux as it diffuses outward. I'll mention that this is a very difficult computational problem to model the time dependent behavior of the ejecta with a variable central source so the observations you are obtaining will be a key set against which the models will be compared. The distinguishing feature, suggesting that these profiles are not the result of individual explosive ejections, is that they've remained at the same velocities throughout when all of the components are included. While individual features change, the structure of the ejecta appears to be stationary. The comparison with V339 Del is now almost possible, in the sense that the same level of multiwavelength coverage is now available through the same stages of the decline. Another notable change is that since the start of this month (Feb. 2014) the O I 8446Å— line, which showed a detached absorption feature aikin to those on the Balmer lines, now shows the same profile as [O I] 6300, 6364Å. This started at around Day 30 in the event so watching as the individual emission features appear will be the test of whether the absorption is linked to individual knots that are symmetric about line center. Looking at the red wings of the profiles is suggestive but hardly definitive and i's too early yet to say what the ejecta structure is. There is a plan to get UV observations in a few months when the light curve guarantees that there are no instrumental issues – for you the brightness is a benefit, for space observations (especially with STIS) it can be a curse (the instrument brightness limits require strongly attenuated signals which means unacceptably long exposures and too many orbits). The coverage from the ground will continue to be important for many many months yet. One thing to note is that

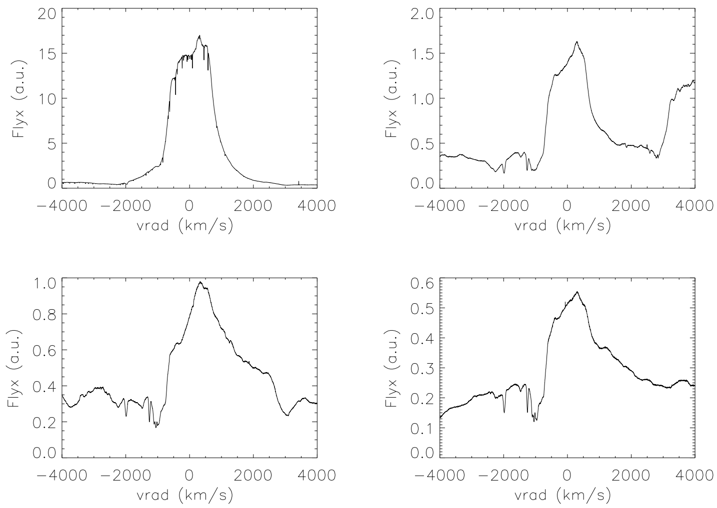

Figure 3: V1369 Cen, 31 Jan. 2014. This shows the Balmer profiles, top: Hα (left), Hβ (right; bottom: Hγ (left), Hδ (right). Note especially the feature at about -2000 km s^{-1}

.

there was no indication here, as in V339 Del, of the molecular bands but the phase is shortlived. If the nova forms dust that is still in the future.

Now, for a quick note, we come to V745 Sco. This is a completely different class of explosive variable although the outburst is still the result of a thermonuclear runaway on a massive white dwarf (by now you may be tired of that description). The recurrent novae are so called because their outbursts are separated by decades instead of millennia. This is usually taken to mean that the WD is very near its stability limit and that only a small amount of mass is needed to trigger the explosion. The TNR triggers at a fixed temperature and pressure, not because of the mass of the accreting object alone but also because of the mass accumulated. Since it's assumed that the accumulated layer is in hydrostatic balance once it passes through the accretion disk and settles through the shock on the WD, the pressure at the base of an accreted layer depends on the amount of mass and on the surface gravity of the gainer. The WD has a higher gravity as the mass increases, both for the mass and because there's a mass-radius relation for the degenerate equation for the pressure that results from the departure from an ideal gas. Just a side comment here. For a degenerate gas, the pressure depends only on the density. Te more massive the star the greater must be the pressure and the pressure gradient. So if the temperature doesn't affect the pressure, and the thermal energy of the matter is "carried" by the heavier ions (e.g. protons) that that don't support the medium, the only way to increase the pressure is with a corresponding increase in the density. This means a more compact star, one closer to its stability limit, and a higher surface gravity. Hence, the pressure produced by the accreted mass is higher and the ions are also more heated. It's the protons and heavy elements that undergo thermonuclear reactions so if both the density and temperature increase above the critical threshold to ignite the CNO process, the TNR begins. This critical point is fixed, but it's reached with lower accumulations for higher mass WD stars. Hence, if the explosions involve low mass ejecta and recur frequently (although *not* like dwarf novae and related cataclysmic variables), the WD must be massive (and, therefore, a candidate for a SN Ia progenitor).

In the end it doesn't matter how the garbage gets into the landfiill, nor how the mass accumulates on the WD. In a compact binary, like T Pyx, an accretion stream feeds a disk that viscously transfers mass onto the central body. In the systems like RS Oph, T CrB, and V745 Sco, the companion is a red giant with an orbital period of a year or more. Hence the name "symbiotic-like recurrent novae" (SyRNe) for this subclass. Note that there are *only* recurrent novae in this group while the compact systems (with periods of a day or less) display the entire range of outburst frequency from recurrents of about a decade (U Sco) to only one known outburst ever recorded. The main difference is in what you will be observing. The amount of mass is small in both systems, but the environment is dramatically different. While in the compact systems the ejecta cross the system in minutes to hours, in the SyRNe they're plowing into a dense wind environment where the number density is $\geq 10^5\mathrm{cm}^{-3}$. Note that in the free ejecta this density isn't reached for many weeks. In the SyRNe, it's already there and even denser in the inner wind (whose density varies as the inverse square of the distance from the red giant). In fact, watching films of atmospheric nuclear tests give syou a very clear idea of what happens, and it's very different from a normal freely expanding ejecta. The ejecta form a shock front that plows into the wind, reaching temperatures of 10^7K or even higher for velocities of the sort now being seen in V745 Sco, about 5000 km s^{-1}. This forms something not seen in the classical systems, a radiative precursor. This is UV and X-ray photons that propagate ahead of the front (at the speed of light) and flash ionizes the surroundings. The narrow emission lines that appeared in the first spectra of V745 Sco (and V407 Cyg and RS Oph) are a sort of H II region, that continues to expand until the shock slows down. The ejecta are optically thick for a very short time, almost all of the thermalization behind the shock produces radiation that can freely stream out into the red giant's wind. You see this as the flash-vapor cloud during the first moments of a thermonuclear bomb blast. The shock is inside that mantle (which is ionized air). The rapid decline of the light curve is due to the shock deceleration and cooling but the velocities are actually much higher than seen from the line profiles and only the first spectra will show the full range. The Fe-curtain phase passes extremely quickly, the ejecta masses are as low as 1% of a classical nova, Butt here's another novel feature that is a gift of these events. You see the ejecta *through* the wind so it's a moving light source within the environment. You can, therefore, probe the environment and see, over time, the propagation of the ionization wave and the shock by the changes in the species present and the amount of their line absorption. The precursor dies away when the shock reaches a low enough density that the emission driving it falls below the threshold to continue ionizing the wind, the “breakout” stage. We’re not there yet, that should happen within a few weeks (if this behaves like the last time and like RS Oph).

I’ll stop now and continue the description of the physics in the next set of notes. But a word on some of the observational features to look for, even at low resolution. Remember, this nova is faint (V = 11 today). The Balmer and He I lines are now the dominant emission but there will be narrow emission and absorption lines from the red giant wind, depending on the orientation of the binary orbit and inclination of the system. The [Fe X] 6386Å and [Fe VII] 6087Å lines should appear soon, signaled by at the same time by He II 4686Å which come from the high temperature gas behind the shock. The emission lines will be affected by the wind absorption so may even show inverse P Cyg profiles at low resolution, and the orientation of the shock front (which now propagates into *and* out of the wind at the same time, experiencing different decelerations) will produce an asymmetric profile (which may also have either an extended red or blue wing). At this stage, the observations of the maximum velocity will show a rapid decrease in the Balmer line wings but some of that is an illusion because the low mass ejecta turn transparent quickly and you won’t see the highest velocities anymore. The narrow emission spike will persist on almost all of the profiles, and some forbidden lines will appear soon from what would normally be H II region-like emission.

In the hope this is starting to get interesting, more notes will be coming. Sincere thanks for your enormous contributions!