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Unconventional observations of classical and recurrent novae

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Abstract. While it might appear unnecessary to monitor the early decline of classical novae through high resolution spectroscopy, or to follow-up very fast novae after ~40 days from their outburst, the observations of classical novae with the high resolution spectrograph FEROS, and of U Sco 2 to 3 months after maximum have revealed unexpected results with quite strong implications. This invited-talk reviews those results and their significance within our current understanding.

Key words. Stars: classical novae – Stars: U Sco – Stars: abundances

1. Introduction

There is still room in astronomy for unforeseen results in supposedly well know and understood topics such as, for example, cataclysmic variables (CVs). Despite the velocity and line profiles in classical novae (CNe) can be easily resolved at low spectral resolution, the combination of high resolution spectrographs and medium size telescopes has made CNe in their early decline a interesting and feasible target. For example, our group conducted an observing campaign in the period 2001-2006, while the 2.2m+FEROS at the ESO-La Silla observatory was available for service mode and target of opportunity observations. This has allow us to collect a number of unique spectra of CNe during their early decline and observe, for the first time, a number of narrow absorption lines of circumbinary origin.

Similarly the availability of large telescope (≥4m) offer the chance to follow-up CNe down to their nebular phase and to quiescence. For example, in occasion of its 2010 outburst, U Sco has been monitored well below V~17 mag, 2 to 5 months after outburst. U Sco revealed a nebular spectrum that is characterized by strong emission lines from forbidden transitions, which allowed to establish the composition of the underlying white dwarf (WD).

In this paper I will review the insight gained by our group (see Williams et al. 2008 and Williams and Mason 2010) through the analysis of high resolution spectroscopy of the CNe early decline, as well the results obtained by the analysis of U Sco nebular spectra (Mason 2011).

2. The high resolution spectra CNe campaign

During the period 2001-2006 we collected high resolution spectra of CNe in their early decline phases with the fiber-fed, cross-dispersed echelle spectrograph FEROS mounted at the 2.2m of the ESO-La Silla ob-

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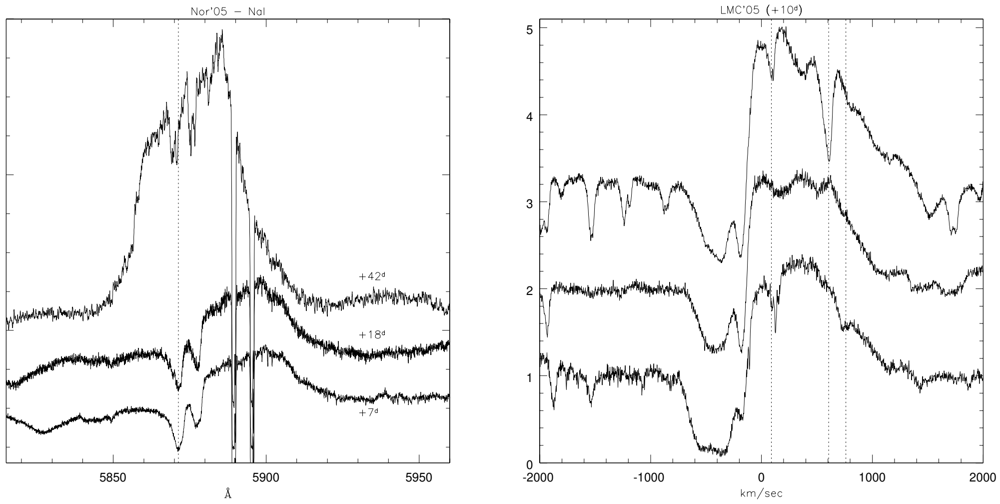

Fig. 1. Selected portions of spectra showing evidence of the fact that the THEA gas is external to the main ejecta (which is producing the emission line and P-Cyg profile spectrum). On the left panel the sequence of spectra of nova V382 Nor/05 (day +7, +18 and +42 from bottom to top) shows as the NaI THEA doublet evolves independently of the main ejecta, whose emission has changed from NaI to HeI. On the right panel nova LMC'05 Hγ, Hδ and Hε (from top to bottom, at day +10) show how their profiles differs for the narrow absorptions superposed to the emission. The two lines on top of Hγ are TiII (on the "blue side") and FeII (on the "red side"), while the line on top of Hε is VII. Vertical lines are to guide the eye and better show that the features are a different positions and therefore cannot result from a structured emission line profile.

servatory. The spectra cover the wavelength range ~4000-9000 Å at the spectral resolution R=48000. In total we observed 15 novae and monitored each object with an average of ~5 epochs per object (see Williams et al. 2008). Among these, nova LMC 2005 showed particularly catching spectra as they presented numerous narrow absorption lines (see figure 4 in Williams et al. 2008) superposed to the usual FeII P-Cyg profile spectrum that is typical for slow novae (e.g. Williams 1992; Della Valle 2002). These absorptions were identified with low ionization energy heavy metals such as FeII, TiII, CrII, SrII, BaII, ScII, YII, and other s-processed elements. A more thorough analysis of all the spectra, revealed that similar absorption lines are common to the majority of the novae in our sample (see figure 2 and table 1 in Williams et al. 2008). Their characteristics are:

1. the narrow absorption lines from s-processed elements are possibly present in 85% of the novae in our sample;
2. they appear to be external to the main ejecta (Fig.1).
3. they disappear a few weeks or months after the outburst (Fig.2), when the emission line spectrum displays higher ionization energy species and/or shows the first signatures of forbidden nebular transitions;
4. they have low internal velocity: their FWHM is in the range 30 to 300 km/s;
5. they are expanding with low velocity: v_r ~ 400-1000 km/s and are slightly accelerated in time before they disappear;

We named these features *transient heavy element absorptions* (THEA) systems for their composition and their transient nature.

Points 2., 3., and 5. above, imply that the THEA gas is of circumbinary nature, as it is eventually affected by the faster expanding ejecta. In addition, Williams and Mason (2010, see their table 2) observed that the subsequent nebular spectrum had line widths which are comparable to the THEA terminal velocity,

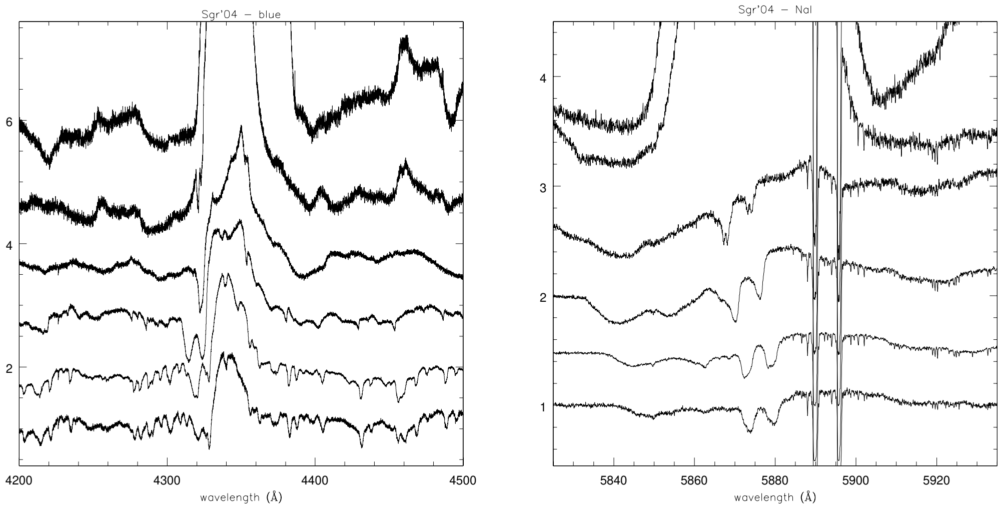

Fig. 2. Sequence of selected portions of nova Sgr 2004 (V5114 Sgr) spectra. The spectra were taken at epochs +1, +2, +9, +23, +32 and +57 days after discovery (from bottom to top). The left panel clearly shows how the earliest epochs spectra are characterized by a number of narrow absorption lines and how these disappear with time. Similarly in the right panel, where the evolution of the THEA NaI is shown. Note how the THEA accelerate (their blue-shift increase) with time and how they disappear when the emission line spectrum has changed displaying higher ionization potential energy lines (NaI to HeI) and first signatures of nebular/forbidden transitions (e.g. [OIII]λ5007 and/or [NII]λ5577, not shown).

rather than to the ejecta expansion velocity as measured from the P-Cyg profile of isolated emission lines. Therefore, Williams and Mason (2010), applying simple conservation of the momentum, suggested that circumbinary THEA gas is significantly more massive than the expanding ejecta and that the formation of the nebular spectrum is induced by the collision of the two systems (see Williams and Mason 2010 figure 2). It should also be noted that the THEA gas (see Williams et al. 2008, for preliminary abundance calculations), cannot be the product of the thermonuclear reaction just ignited at the surface of the WD, but it rather points to secondary star or accretion disk material. Williams and collaborators suggested that the THEA gas could have been piled-up around the binary, 1) either through discrete episodic ejections from the secondary star occurred before the nova outburst (and possibly triggering it), or 2) through continuous mass losses from the binary Lagrangian points (L2 and L3) and the secondary star surface. It is interesting to note that recent hydrodynamic calculations by Bisikalo, Sytov and collaborators (e.g. Bisikalo 2010, Sytov et al. 2007) have shown that a circumbinary disk is produced by steady mass loss from the L3 Lagrangian point. Moreover, circumbinary disks have been proposed in the recent past in the attempt to explain a number of discrepancies between the observations and the CV evolution theory (e.g Spruit et Taam 2001, Dubus et al. 2004). Also circumbinary dust disk have been detected around a number of CVs and in particular the nova like system V592 Cas (Hoard et al. 2009 see also Hoard in this proceeding book). Though the gas to dust ratio is unknown, it is tempting to combine Williams et al. and Hoard et al. observational findings with Bisikalo et al. simulations to suggest that the THEA is indeed formed by steady mass loss from the L3 point. Whether this is the case, it must be verified. Our group has recently been granted telescope time to observe in high resolution spectroscopy, both V592 Cas (at the TNG+SARG) and a number of nova-like systems (VLT+UVES). Should the circumbinary THEA gas be present, it can be detected similarly to the interstellar material thorough absorptions from CaII, NaI and CaI. Our sample of targets was selected on the basis of their proximity to us, their height above the galactic plane (which both limit the presence and bias of interstellar gas), their brightness and orbital period (the larger values imply higher mass transfer rate), their high orbital inclination (Bisikalo and collaborators simulations predict the formation of a disk rather than a shell) and their mass ratio (Bisikalo and collaborators simulations predict a more efficient mass loss in the case of mass ratio $q \sim 1$). At the same time it is fundamental to keep observing, through high resolution spectroscopy, CNe during their outburst, their maximum, their early decline and possibly their raising phase. In the last few years, our group collect high resolution spectra only for U Sco (Mason et al in preparation), which did not show any evidence of THEA and whose line width at maximum and during the nebular phase are perfectly matching, and T Pyx (Ederoclite et al. in preparation), which also is not showing convincing evidence of THEA and whose pre-maximum spectrum is opening the door to new interpretations of the ejecta evolution (Williams et al. in preparation, see also Izzo in this proceeding book).

3. The nebular spectra of U Sco

Both Diaz et al. (2010) and Mason (2010, 2011), following U Sco late decline at large class telescope (>4m) have realized that the recurrent nova showed a nebular spectrum characterized by strong emission lines from [NeIII], [Nev], [OIII] and [NII], starting from day +45 after outburst (Fig.3, see also Mason 2011 figure 1). The detection of forbidden transition was unexpected as it was believed that U Sco returned to quiescence without emitting any such transition (e.g. Warner 1995). In addition, the intensity of the Ne emission lines was sufficiently strong to lead to suspect that the WD progenitor was an ONe white dwarf, rather than a more common CO white dwarf. The different nature of the underlying white dwarf has strong implications about the system evolution and its role as candidate supernova Ia progenitor. In particular, while accreting CO WDs explode as SN-Ia once they reach the Chandrasekhar limit of 1.4 $M_\odot$; ONe WDs will collapse into a neutron star if increasing their mass (Nomoto and Kondo 1991).

Following Kingdon and Williams (1997) line chart, it is possible to calculate the relative abundance [Ne/O] from the line flux ratio [NeIII]λ3869/[OIII]λ5007. The [Ne/O] relative abundance can then be compared with that of other novae in the literature for which exist accurate abundances determination and for which the composition/nature of the underlying white dwarf has been determined (see Mason 2011 table 2 and reference therein). It turned out that CO WD novae have negative or null value for the [Ne/O] relative abundance in their ejecta; while ONe WD novae have positive [Ne/O] values. U Sco, having a positive [Ne/O] abundance belongs to the ONe WD novae and is bound to collapse into a neutron star or a millisecond pulsar, unless current models about accreting ONe WD and current estimate about U Sco WD mass and accretion rate are in error. I conclude remarking the importance of establishing the WD composition of all single degenerate SN-Ia candidates, without limiting the data analysis to the determination of the WD mass and of the ejected/accreted mass ratio - when serarching for SN-Ia progenitors.

4. Discussion

GIORA SHAVIV: Did you measure the C/O relation? I appreciate your results concerning the s-elements. This I think is a very important discovery because if the s-elements come from the donor, how did the system pass the giant phase? but if the s-process elements were produced by a previous generation then the age of CVs might be much shorter.

ELENA MASON: No. In Williams et al. (2008) we reported preliminary relative abundances (e.g. Sc, Ti, V, Cr over Fe) which appear to be larger than solar, but the uncertainties are large and we were aiming at even larger resolution (e.g. UVES) on new objects. It is

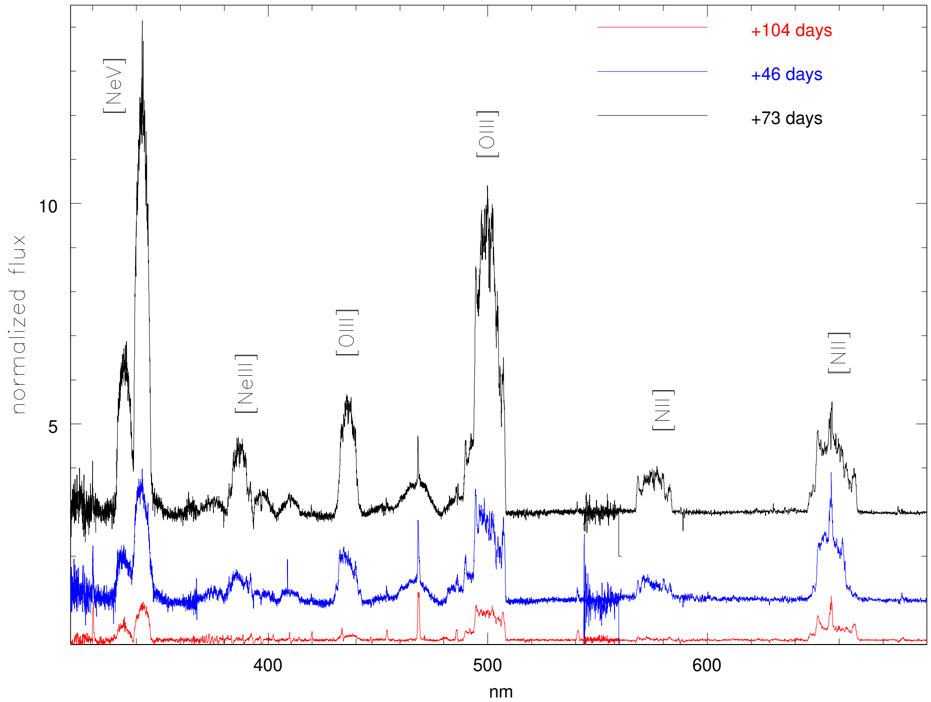

Fig. 3. The three nebular spectra of U Sco. The epoch of each spectrum is marked in the figure. The spectra have been normalized and arbitrarily offset. Note that they hare not ordered according to time but according to line intensity. Maximum line strength relative to the continuum was observed in the +73 days spectrum.

very difficult (if not impossible) to determine the THEA C/O in the outburst spectra; though maybe one could attempt to measure the C/O in the secondary at quiescence through NIR spectroscopy. Thanks for the comment it might be worth to pursue it with NIR observations.

VALERIO RIBEIRO: If the THEA lines are due to a circumbinary disk, can you explain all the systems as eclipsing ones and/or close to edge on?

ELENA MASON: The number of CNe showing THEA during their outburst is too large (~85%) to be compatible with geometrical effect and detection of edge-on systems. Therefore if the THEA origin is the steady mass loss during the CV life and the gas is distributed in a circumbinary disk before the outburst, it must acquire a more spherical distribution during the outburst and/or shortly before. Currently there are no models but it is easy to imagine something similar to a dusty table in a dry environment. If we wipe the dust away with a sudden and fast movement, we will produce eddies that will spread the dust well above the table plane.

MARIKO KATO: I'm wondering if the CNO-breakout is occurring in making the Ne. Also, in mass increasing WD, weak He-shell fleshes occurs, which may produce some Ne. (comment) In the binary solution scenario to type Ia supernovae, U Sco has a complicated history which is very different from that of a classical nova binary. So I am not surprised if the secondary star in U Sco has a peculiar chemical composition. From its relatively long SSX phase, U Sco is considered to be increasing in mass, your large Ne/O ratio could be an indication of such a mass increasing WD.

ELENA MASON: The CNO breakout is not a concern in this case: first of all, the CNO breakout can explain moderate increase of the Ne abundance (e.g. Livio and Truran 1994) and the intermediate or large mass elements (Glasner and Truran 2009). In addition theory could produce the CNO breakout only in the case of massive white dwarf and very low accretion rate ($\sim 10^{-11}$-$10^{-10}\,M_\odot$/yr Glasner and Truran 2009), while U Sco is accreting at high rate ($\sim 10^{-7}\,M_\odot$/yr). Last but not least the IUE observations taken during U Sco 1979 outburst showed spectral characteristics and evolution that are typical of ONe WD novae and not of CO WD novae.

MARGARETA HERNANZ's Comment: The overabundance of Ne cannot be explained by breakout of the CNO cycle during the thermonuclear runaway; even for large WD masses the peak temperature obtained in the burning shell is not high enough to break the CNO cycle.

References

Bisikalo D., ASP Conf. Series, 435, 287

Della Valle M., 2002, AIP Conf. Proc, 637, 443

Diaz M.P. et al., 2010, AJ, 140, 1860

Dubus G., et al., 2004, MNRAS, 349, 869

Hoard D.W., et al., 2009, ApJ, 693, 236

Kingdon J., Williams R.E., 1997, AJ, 113, 2193

Mason E., 2011, A&A, 532, L11

Nomoto K., Kondo Y., 1991, ApJ, 367, L19

Spruit H.C., Taam R.E., 2001, ApJ, 548

Sytov A.Yu. et al., 2007, ARep, 51, 836

Warner B., 1995, *Cataclysmic variable stars*, Cambridge University press

Williams R.E., 1992, AJ, 104, 725

Williams R.E. et al. 2008 ApJ, 685, 451

Williams R.E., Mason E., 2010, Ap&SS, 327, 207