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A search and modeling of peculiar narrow transient line components in novae spectra ☆

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HIGHLIGHTS

- A search for narrow line components during early novae decay was performed.
- Photoionization models rule out their origin from inside the primary Roche Lobe.
- The emission from a region at the outer Lagrangian point match the observations.

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ABSTRACT

The formation of peculiar transient narrow emission line components observed in the spectra of a few novae is discussed. We aim to constrain the possible physical sources responsible for those unexpected components that present orbital radial velocity modulations, which were first observed in the post-outburst recombination lines of Nova U Sco 2010. A search for candidates showing similar narrow components is presented. Exploratory photoionization simulations indicate that the forming region cannot be restricted to the Roche Lobe of the primary, but could be located around the outer Lagrangian point L_3. Further analysis disfavors an origin at the companion star. In addition, we analyze possible correlations between the presence of the narrow components, the basic nova parameters and the spectral classification in the initial permitted line phase.

1. Introduction

The analysis of nova spectral evolution is a powerful tool to study the physical properties of nova systems. Williams (1992) found correlations between the initial phase of nova spectra and their late nebular phase. Nova spectra show highly structured broad emission lines during decay. Those structures reflect a complex combination of optical depth, emissivity and velocity field (e.g. Shore et al. (2011)). During the permitted lines phase, a few novae present a peculiar narrow emission component superimposed on a broad one in their spectra. This component appears in the first days after maximum and has FWHM of a few hundred km/s. For instance, when the time after maximum $\Delta t = 3t_3$ (where t_3 is the time to decay by 3 magnitudes) and FWHM ~ 500 km/s for U Sco (Diaz et al., 2010). The curious characteristic of these components is that they present orbital radial velocity modulations (Mason et al., 2012), which implies that the emission region shares kinematic properties with the binary system.

Narrow components in nova outburst spectra are not uncommon. Some novae, especially the Fe II spectral type ones, usually present narrow components in their spectra. Those emissions are often associated with slower gas expansion velocities in the nova eruption. Different geometries can also reproduce narrow line profiles, as Munari et al. (2010) have shown in their model for V2672 Oph (Nova Oph 2009). They simulated a prolate structure for the nova system composed of polar blobs and an equatorial ring. The radiation emitted by the ring forms a narrow component in the modeled spectra that fits the observed one.

Regions that emit narrow lines in the binary system are the outer accretion disk and the companion star. In fact, these two regions were proposed to explain the narrow lines in U Sco spectra. Diaz et al. (2010) speculated that the forming region relies on the

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secondary star, but this has not yet been supported by simulations. On the other hand, Mason et al. (2012) suggested that it was actually the accretion disk that is responsible for the narrow emission, which then explains the presence of orbital velocity modulations. In this work, we approach this subject with a literature and database survey aiming to find other systems which may have presented those emissions, and by photoionization simulations of selected systems, aiming to constrain the possible emitting regions.

Despite the fact that narrow components are frequently observed during nova outbursts, they are not expected to present orbital velocity modulations in the early spectra. At this early stage, the receding nova pseudo-photosphere is larger than the binary system, at least for CVs with main-sequence companions. Therefore, orbital velocity modulations of emission lines should not be visible in the first days after outburst. The presence of narrow line profiles is also frequently observed in later-time nova spectra, specially in the nebular phase, as the expanding gas is decelerated by the interstellar medium. These are not the narrow components discussed in this paper.

Besides the published spectra, we also searched for well resolved emission lines in 3 synoptic nova spectroscopic surveys trying to identify more objects that present suspicious narrow line components. Then, we compare the presence of the narrow components in classical and recurrent nova spectra and analyze the differences and similarities found. Possible correlations of basic nova properties with the presence of the narrow components were also surveyed.

2. The search for transient narrow components

2.1. Synoptic observations

Using the optical spectral data from the CTIO Nova Survey (Williams et al., 1991, 1994), the SOAR Telescope Synoptic Survey of Novae and the Stony Brook/SMARTS Atlas of (mostly) Southern Novae (Walter et al., 2012), it was possible to identify nova candidates that present transient narrow line components similar to the ones found in U Sco 2010 spectra.

The synoptic nova surveys are essential sources of spectral data in the present analysis, because the nova eruptions are observed and followed as long as possible. One of the problems we found in our search was the lack of time coverage in most of spectral observations. As the components we are trying to locate are transient, it was very difficult to find the right spectra at the right time. It is likely that we have missed these components in many objects, what affects directly our statistical analysis (see Section 3).

Almost all of the analyzed spectra were obtained at the 3 sources mentioned above. The CTIO Nova Survey contains data of nova eruptions from 1987 to 1994. The spectra have broad wavelength coverage, but low spectral resolution (between 5 Å and 16 Å). The SOAR Telescope Synoptic Survey of Novae was active between 2007 and 2011, and has followed the spectral evolution of 16 novae. The wavelength coverage is slightly smaller than the CTIO Nova Survey, and the spectral resolution is about 2 Å to 3 Å. The Stony Brook/SMARTS Atlas of (mostly) Southern Novae is the most recent project – it started in 2003 and it is still in operation. Its data is public and covers more than 60 nova eruption spectra, with extended time coverage and spectral resolution from 0.1 Å to 17.2 Å.

For better understanding of the narrow profile variations, we need both time resolved and moderate to high-resolution spectral observations of novae that present the narrow emission components. Unfortunately, this is very difficult to obtain, because the most probable candidates are the very fast novae, as shown in Section 3. By the time we identify the narrow component, we would not be able to get the necessary time coverage.

2.2. Narrow component selection

The recurrent Nova U Sco 2010 is the prototype object (Diaz et al., 2010; Mason et al., 2012) roughly defining the expected width and intensities of these structures. Diaz et al. (2010) identified the narrow component velocity modulation in these nova spectra and it was later confirmed with better sampled, high-resolution data by Mason et al. (2012). In our survey, we searched for the presence of narrow emission line components with FWHM in the interval of 500–1000 km/s over a broader profile in their early permitted spectra. The narrow components seem to appear in the recombination lines at epochs ranging from 1 to 5 t_3. As the objects presenting the narrow components are mostly fast novae (see Section 3), this period is no longer than 30 days. We also tried to obtain radial velocity values when there were high-resolution spectra available. For relative velocity measurements, we used the interstellar medium Na I D absorption lines as wavelength reference.

3. Statistical analysis

We inspected the spectral evolution of 78 novae (11 recurrent and 67 classical). For 21 novae, we did not have enough time coverage, so it was not possible to rule out or confirm the presence of the narrow components. From the remainder (see electronic appendix), V394 CrA, Nova LMC 1990-2, U Sco, Nova LMC 1988-2, Nova LMC 2009a, Nova Oph 2009c, DE Cir, V444 Sct, KT Eri, YY Dor, Nova Sco 2007 and Nova Sco 2011b fit the selection criteria and are considered candidates to present the peculiar transient narrow components. Narrow components were independently found in KT Eri (Munari et al., 2014), Nova LMC 2009c and YY Dor (Mason and Munari, 2014). From this sample of selected novae, 5 of the objects are recurrent novae in contrast to 7 classical ones. We stress that KT Eri is suspected to be a recurrent nova, but until it is confirmed, we will consider it as a classical one (Jurdana-Šepić et al., 2012). Therefore, the narrow components seem more likely to appear in recurrent novae. Examples of nova Hα profiles with narrow components over a broad line base are shown in Fig. 1.

In this sample, only U Sco (Mason et al., 2012), Nova Sco 2007 and KT Eri (He II 4686 Å only (Munari et al., 2014)) are confirmed to present radial velocity variations in the narrow components. Besides the instrumental and sampling difficulties, the inclination of the orbital system may also hamper the radial velocity measurement, since they would not be detected at low inclinations. Therefore, if there are other cases among novae, the actual detections may represent a small subsample of a more frequent phenomenon. The narrow component peak velocities derived from our Hα and He II 4686 Å profiles of our U Sco data taken from SOAR are shown in Fig. 2.

For some of the novae exhibiting the narrow line system, we measured the broad to narrow line flux ratio for the most prominent lines along the time normalized by t_3. The results are shown in Fig. 3. The ratio presents a fast increase for all selected novae. For U Sco, it is possible to see this ratio decreasing as the narrow components completely merge into the broad ones. The narrow component fluxes can reach from $0.1F_{broad}$ to $3.5F_{broad}$, and they do not seem to scale with the broad component fluxes. Lower flux ratios may be present, but they would be difficult to identify.

We also searched for correlations between the emergence of the narrow system in the candidates spectra and the following basic nova properties: decay time, orbital period, absolute magnitude at maximum and spectral type according to Williams classification. Fig. 4(a) shows the distribution of decay times among the studied