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Spectroscopic follow-up of novae

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Abstract. We report about the spectroscopic follow-up of three novae at Loiano Observatory, Italy. The observations are part of a monitoring program started in 2005. The three novae showed peculiar photometric or spectroscopic features during the decline. Nova V5558 Sgr showed secondary brightenings and a slow decline, V2467 Cyg underwent photometric oscillations during the transition stage, V458 Vul showed secondary brightenings and switched spectral class.

Key words. Novae – Cataclysmic binaries

1. Introduction

The light curves of classical novae generally show, after the maximum, a smooth decline curve towards quiescence, unless dust formation occurs. Some novae are remarkable exceptions, showing anomalous secondary brightenings or oscillations during the decline. The mechanisms leading to rebrightenings or oscillations are still a a matter of debate and deserve specific investigations.

The magnitudes of novae at maximum and during the initial decline make them practical targets for small and medium size telescopes. In 2005 we started a campaign of spectroscopic follow-up of novae at the Loiano Observatory, Italy, using the 152 cm telescope and the BFOSC imager and spectrograph. The most part of the spectra are secured with grism #4 to build an homogeneous data set of spectra over the range 4000 to 8500 Åwith a resolution of 3.97 Å/pixel. The monitoring program includes the most part of novae observable at the telescope latitude that underwent outburst in 2005 or later: V1663 Aql, V2362 Cyg, V2467 Cyg, V5558 Sgr, V458 Vul, V459 Vul, V2468 Cyg, V2491 Cyg, V2670 Oph, V5584 Sgr, V496 Sct, KT Eri, V1722 Aql, V407 Cyg. During the campaign the novae are observed at several epochs, trying to start as soon as possible after maximum and following them at least until the nebular stage. In the present paper I will present the results of the monitoring of the peculiar novae V5558 Sgr, V2467 Cyg, V458 Vul. The initial evolution of the above novae has been reported by Poggiani (2008a), Poggiani (2010), Poggiani (2009a), Poggiani (2008b).

2. V5558 Sgr

V5558 Sgr was discovered on 2007 April 14 by Sakurai (Nakano 2007a). The maximum (magnitude of 6.5) occurred on 2007 July 11. The object showed a long lasting pre-maximum, multiple rebrightenings during the early stage

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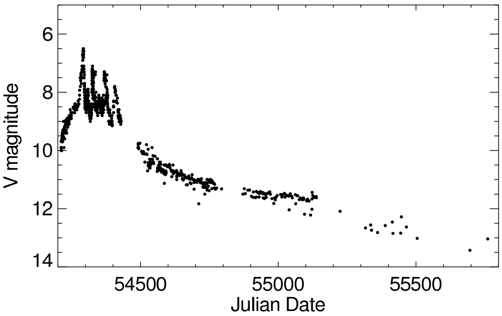

Fig. 1. Light curve of V5558 Sgr (VSNET data)

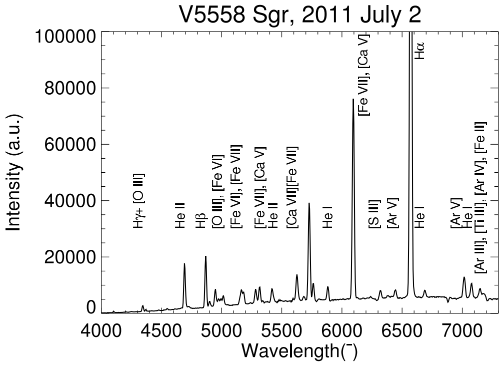

Fig. 2. Spectrum of V5558 Sgr during the nebular stage

and a slow decline (Fig. 1). The rebrightenings appear as flares superposed to the decline curve.

The long lasting pre-maximum and the presence of secondary outbursts has been previously observed in the slow novae V723 Cas, HR Del and in the fast nova V1548 Aql. The duration of the pre-maximum is related to the speed class of novae, lasting some months in slow novae. The photometric evolution of V5558 Sgr was similar to that of V723 Cas (Poggiani 2008a), despite the very early decline could appear very steep. In fact, the estimated decline time by three magnitudes is 170±2 days, thus V5558 Sgr is slow nova. The absolute magnitude at maximum is in the range -6.3 to -5.9, while the white dwarf mass is 0.58-0.63 $M_\odot$, both comparable with the corresponding values for the other slow novae V723 Cas and HR Del. Such a low mass for the white dwarf suggests critical conditions of thermonuclear runaway: dwarfs less massive than 0.6 $M_\odot$ can produce explosions only in very slow novae (Kovetz & Prialnik 1985), (Kato et al. 2002), (Hachisu & Kato 2004). Our spectroscopic observations (Poggiani 2008a), (Poggiani 2010) confirm the similarity between V5558 Sgr and V723 Cas, whose evolution has been described by Iijima (2006).

A spectrum secured on 2007 June (Poggiani 2008a) during the pre-maximum showed Balmer and Fe II lines, as V723 Cas at the same stage (Iijima 2006). However, previous observations by Tanaka et al. (2011) on 2007 April 17 showed the presence of helium lines, later replaced by the Fe II lines. The appearance of helium lines before Fe II lines has been observed not only in V5558 Sgr, but also in T Pyx during the pre-maximum of the 2011 outburst (Tanabe et al. 2011), (Mason et al. 2011), (Izzo et al. 2011). Spectra of V5558 Sgr secured during the early decline in 2007 July showed Fe II and He I lines in emission (Poggiani 2008a), but no evidence of [O I] or [N II] lines, in analogy to V723 Cas at the same stage (Iijima 2006). The behavior observed during the second re-brightening on 2007 August 11 was peculiar, since Balmer and Fe II lines showed absorption components (Poggiani 2008a). The observation has been confirmed by Tanaka et al. (2011). A possible explanation for the appearance of P Cyg profiles is the occurrence of a secondary mass ejection, as in V1493 Aql (Bonifacio et al. 2000), (Dobrotka et al. 2004), (Venturini et al. 2004) and V2362 Cyg (Kimeswenger et al. 2008), (Poggiani 2009b), (Lynch et al. 2008), (Munari et al. 2008). During 2008, Fe II lines disappeared and He I lines strengthened (Poggiani 2010). The forbidden lines of [O III], the typical signature of nebular stage, appeared in July 2008 (Poggiani 2010), but they were weaker than Hβ. A stronger signature of onset of nebular stage is the appearance of the high ionization [Fe VI], [Fe VII] [Ca V] transitions, as in V723 Cas (Iijima 2006). V5558 Sgr entered the nebular stage in less than one year. However, the spectroscopic evolution is very slow. A spectrum secured on 2011 July 2 (Fig. 2), 1452 days after outburst, shows a strong contribution of the high ionization transitions. Now [Fe VII] 6087 is the most intense transition after Hα. The [O III] 4959, 5007 transitions are still weak. He II 4686 is as intense as Hβ. There is no evidence yet of the coronal line [Fe X] 6374. The spectrum is close to the spectra of V723 Cas in September 1999 (Iijima 2006).

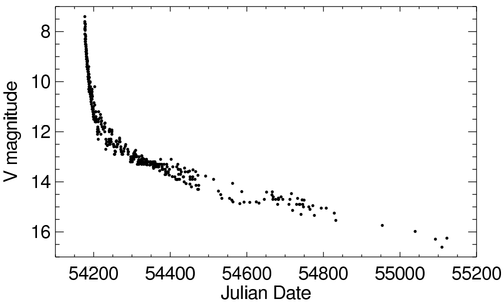

Fig. 3. Light curve of V2467 Cyg (VSNET data)

3. V2467 Cyg

V2467 Cyg was discovered by Tago (2007) on 2007 March 15. It achieved a maximum magnitude of 7.4 on 2007 March 17. The decline times by two and three magnitudes are 8 and 15 days, thus it is a fast nova. The absolute magnitude at maximum is -9.1..-8.5, while the white dwarf mass is 1.1 $M_\odot$. V2467 Cyg has been classified as a Fe II nova. During the transitions stage, that started at three magnitudes from maximum (Fig. 3), V2467 Cyg showed peculiar oscillations about the normal decline curve as the nova V1494 Aql. Different explanations for oscillations have been proposed. According to Bianchini et al. (1992) the oscillations can be explained by repeated thermonuclear flashes. According to Leibowitz (1993) the oscillations correspond to variations in the accretion disk luminosity that become apparent when the white dwarf contribution is fading. V2467 Cyg has been proposed as an intermediate polar candidate (Swierczynski et al. 2008).

The spectroscopic monitoring by Poggiani (2009a) suggest a close similarity with the evo-

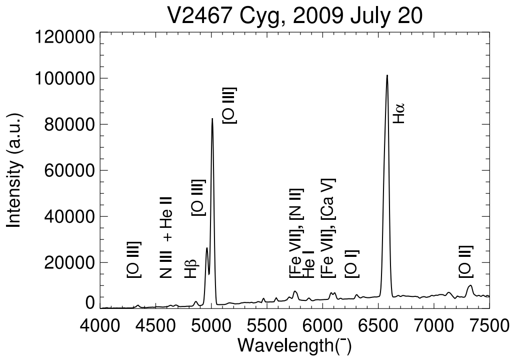

Fig. 4. Spectrum of V2467 Cyg during the nebular stage

lution of the nova V1494 Aql described by Iijima & Esenoglu (2003). The early decline showed Balmer, helium, nitrogen lines and an early appearance of forbidden [O III] lines. The spectra secured at the oscillation maximum (2007 April 26) and minimum (2007 June 25) shared a common set of lines, N III, [N II], [O I], He II, [O III], but there were strong differences. At maximum, N III 4640 and He II 4686 were blended, while [Ca V] was not visible. At minimum, [Ca V] 6086 appeared and the complex N III 4640 + He II 4686 was resolved. The same pattern was observed in V1494 Aql at the corresponding stages (Iijima & Esenoglu 2003). No P Cyg profile appeared during the oscillations, suggesting that the underlying mechanism is different from a secondary mass ejection, as in V1493 Aql and V2362 Cyg. V2467 Cyg has shown oxygen overabundance, see Tomov et al. (2007), Poggiani (2009a). The contribution of O I 8446 was steadily decreasing during the early decline (Poggiani 2009a), (Tomov et al. 2007). The transition is produced by fluorescence of Lyβ, suggesting that the ejecta contained dense regions with high radiation density and presence of neutral oxygen. During the later decline, at 856 days after maximum (Fig. 4), we observed a typical nebular spectrum. The [O III] complex was comparable, in intensity, to Hα. Several high ionization lines of [Fe VI], [Fe VII] were present. The spectrum is similar to the spectrum of V1494 Aql in September 2000 (Iijima & Esenoglu 2003), with the remarkable difference that for the present nova the lines are not double peaked.

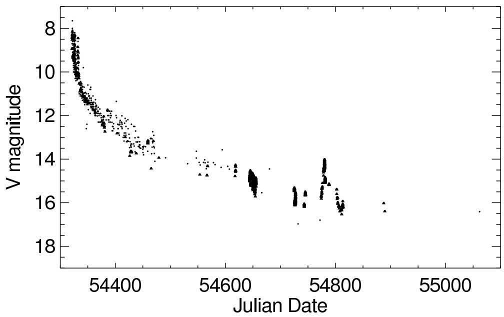

Fig. 5. Light curve of V458 Vul (VSNET data)

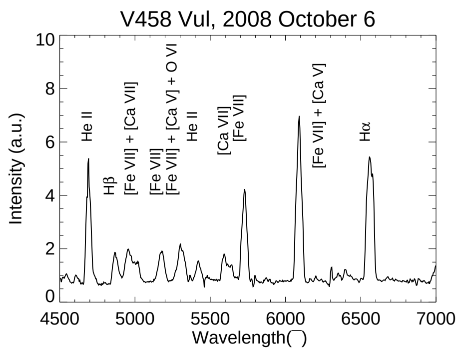

Fig. 6. Spectrum of V458 Vul during the late decline

4. V458 Vul

V458 Vul was discovered by Nakano (2007b) on 2007 August 8. The nova showed secondary rebrightenings during the very early decline (Fig. 5). V458 Vul achieved a maximum magnitude of 7.65 on August 10. The decline times by two and three magnitudes are 7 and 15 days, making it a fast nova. The absolute magnitude at maximum was in the interval -9.2..-8.5, while the white dwarf mass is 1.1 $M_{\odot}$ (Poggiani 2008b).

The early spectroscopic evolution has been discussed by Poggiani (2008b), Tarasova

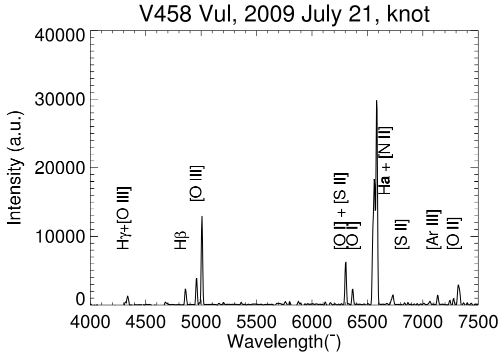

Fig. 7. Spectrum of SE knot of V458 Vul nebula

(2007). The spectra secured during the very early decline showed Balmer and Fe II lines, suggesting that V458 Vul is a Fe II nova Poggiani (2008b), Tarasova (2007). Later spectra showed that by 2007 September the Fe II lines had disappeared and that He lines had emerged: thus V458 Vul is an hybrid nova that switched from the Fe II to the He/N class (Poggiani 2008b), (Tarasova 2007), as Nova LMC 1998 n. 2. V458 Vul was extensively measured at high energies and it was detected as a supersoft X-ray source (Drake et al. 2008) in 2008 September. In the first half of 2008 the high ionization forbidden lines [Fe VI], [Fe VII] appeared, similarly to what happened in V2214 Oph (Tarasova 2008). Starting from 2008 August, we observed a steady increase of the intensity of high ionization iron lines [Fe VII] 5721 and 6087. The same stransitions have been observed by Rodriguez-Gil et al. (2010). We report that by 2008 October 6 (423 days after maximum) [Fe VII] 6087 had become more intense than Hα (Fig. 6). The maximum of [Fe VII] 6087 occurred when the X-ray hardness ratio secured with Swift was close to -1 (Ness et al. 2009). During the later decline the intensity of [Fe VII] 6087 faded and [Fe X] strengthened, confirming the similarity with the evolution of V2214 Oph.

V458 Vul is a very intriguing nova: in fact, it is surrounded by a planetary nebula (Wesson et al. (2008), Rodriguez-Gil et al. (2010), (Corradi et al. 2011)). The system underwent two common envelope episodes (Rodriguez-

Gil et al. 2010). The mass of V458 Vul exceeds the Chandrasekhar mass, thus the system is a candidate supernova Ia progenitor. The other known example of nova in a nebula is GK Per. The nebula surrounding V458 Vul shows the typical nebular emission lines, but the line widths are smaller that the typical widths associated to the nova ejecta (Wesson et al. 2008). V458 Vul has an orbital period of 98 minutes (Rodriguez-Gil et al. 2010). A peculiar region of of the nebula is the SE knot, that brightened in 2008 May because of flash ionization by the nova event. We have observed the spectrum of SE knot: by July 2009 a typical nebular spectrum is observed (Fig. 7).

5. Conclusions

Classical novae sometimes show peculiar behaviors during the decline, deviating from the standard curve. The anomalous photometric behavior is accompanied by a peculiar spectroscopic behavior. We have discussed the evolution of V5558 Sgr, a nova with secondary outbursts, and the evolution of V2467 Cyg, a nova with oscillations during the transitions stage. The spectroscopic behavior is very different, suggesting that different mechanisms are responsible for the flares and the oscillations. We have also discussed the evolution of V458 Vul, a nova that switched from the Fe II to the He/N class and that it is surrounded by a planetary nebula. The late evolution showed an anomalous contributions of high ionization lines, suggesting that novae should be monitored as long as possible, until the nebular stage and possible down to the quiescent state. The details of the analysis reported in the present paper will be published elsewhere (Poggiani, in preparation).

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