Recent Results from a High-Resolution Spectroscopic Follow-up Survey of Classical Novae

L. Izzo
Instituto de Astrofisica de Andalucia, Granada, Spain
email: izzo@iaa.es

Abstract. This talk presented and discussed some recent results obtained from a photometric and spectroscopic optical follow-up survey of bright classical novae. The survey concerned the role of those objects in Galactic chemical evolution, with particular attention to the production of lithium.

Keywords. Classical novae, galaxy: evolution, nuclear reactions, nucleosynthesis, abundances

1. Introduction

Classical novae (CNe) represent the most dramatic event in the entire life-cycle of a cataclysmic variable; for a full review, see Bode & Evans (2008). In these binary systems the white dwarf (WD) primary accretes matter from a companion star that overfills its Roche lobe. The material piles up on the WD surface, and with time the pressure at the bottom of the accreted layer increases until it exceeds the degeneracy pressure, initiating thermo-nuclear reactions that commence with the proton-proton chain. As the temperature increases convective motions bring unburnt elements from the interior of the WD into the burning region, starting the ignition of the CNO reaction chains. Those cause H to burn into He, with the additional production of $\beta$-unstable isotopes like $^{13}$N, $^{15}$O and $^{18}$F that finally lead to an outburst and the ejection of material: the thermo-nuclear runaway (TNR, Truran & Livio, 1986; Starrfield et al. 2009). During those processes, freshly-produced He can also create $^7$Be via the $^3$He–$^4$He reaction channel, an isotope which decays into the stable $^7$Li after a half-life of $\sim$53 days (Cameron & Fowler, 1971).

While CNO elements have been found to be very abundant in nova ejecta – more than ten times their solar values (Gehrz et al. 1998) – we have little information about the Li abundance. Li is a fragile element, easily destroyed in many astrophysical environments via proton collision at a temperature of $\sim$2 × 10^6 K (Conti, 1968). In CN-progenitor WDs, however, convective motions can transport a large quantity of freshly produced $^7$Be to its most external regions, where Li can survive. Consequently, CNe represent one of the most probable astrophysical sources where Li can be produced in large quantities. However, long-term spectroscopic observations of CNe in outburst have never revealed the presence of Li in nova ejecta (see Della Valle et al. 2003).

2. First Detections of $^7$Li and $^7$Be in Classical Novae

V1369 Cen, a very bright slow nova in the direction of Centaurus, was discovered in 2013 (Aguiar & De Salvo 2013). It reached a magnitude of $V = 3.3$ a few days after the discovery. The high luminosity enabled us to observe it for a long time with high-resolution spectrographs like FEROS at the ESO 2.2-m telescope (Kaufer et al. 1999) until it entered the nebular phase. We also observed it with PUCHEROS (Vanzi et al. 2012),
Figure 1. **Left:** FEROS spectrum of V1369 Cen, centred near the $\lambda 6700$ Å region and obtained on Day 6 after the event. The upper plot is the observed spectrum; in the lower one the same spectrum has been corrected for a velocity of $-550$ km s$^{-1}$. The correction clearly shows the presence of Li I $\lambda 6708$ Å. **Right:** Radial velocities for three transitions (Li I $\lambda 6708$, Fe II $\lambda 5169$ and Na I $\lambda 5890$ Å) obtained from PUCHEROS observations of V5668 Sgr on Day 13 after the event. The presence of a faint blue-shifted absorption line at the same velocities of the Fe II and Na I lines confirms the presence of Li I.

an intermediate-resolution spectrograph on the 0.5-m telescope at the Observatory of the Pontificia Universidad Catolica de Santiago in Chile. Early observations revealed the presence of hundreds of narrow absorption lines, the majority of them blue-shifted at a common expansion velocity of $\sim 550$ km s$^{-1}$ (Izzo et al. 2013). Among those narrow absorptions we detected a feature at the observed wavelength of $\lambda 6695.6$ Å, which we identified and confirmed to be the resonance transition of Li I at the expanding velocity of $-550$ km s$^{-1}$ (Izzo et al. 2015); see also Fig. 1.

The observed expansion velocity for the Li I $\lambda 6708$ Å line implies that it has been ejected in the nova outburst and then produced during the TNR. Using a semi-empirical approach, we estimated the total mass of Li ejected by V1369 Cen to be $M_{Li} = (0.3 - 4.8) \times 10^{-10} M_\odot$. It is generally known that the interstellar medium in the Galaxy is enriched with elements produced in stellar explosions (Nomoto et al. 2013); that is also true for Li formed by novae. (i) Assuming that all slow novae produce the same amount of Li, (ii) considering their Galactic rate of 15–24 novae per year (Della Valle & Livio 1994), and (iii) using accurate numerical codes developed to compute the chemical evolution of the Galaxy (Romano et al. 2001), we have shown that novae can explain the observed over-abundance of Li observed in young stellar populations (Izzo et al. 2015). The detection of Li I in the early spectra of V1369 Cen does not represent a unique case. In 2015 V5668 Sgr, another bright slow nova, was discovered in the direction of Sagittarius (Williams et al. 2015). We observed it with PUCHEROS, and later with the high-resolution spectrograph UVES on the ESO VLT (Dekker et al. 2000). On Day 13 after the discovery, PUCHEROS spectra showed the presence of a faint absorption line corresponding to the Li I $\lambda 6708$ Å transition blue-shifted to a velocity of $v_{exp} \sim 500$ km s$^{-1}$. The same velocity was displayed by other typical transitions observed in novae spectra, such as Na I D2 at $\lambda 5890$ and Fe II $\lambda 5169$ Å; see Fig. 1.

What renders V5668 Sgr unique is that the UVES observations, starting on Day 58, revealed the presence of blue-shifted absorptions related to the resonance doublet of $^7$Be II $\lambda 3130/3131$ Å (Fig. 2). Through our spectroscopic follow-up we were able to monitor the
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Figure 2. Nova spectra near Be $\lambda$ 3130, Fe $\lambda$ 5169 and Ca $\lambda$ 3933 Å, respectively, plotted on the velocity scale for V5668 Sgr (left) and ASASSN-16kt (right). The left plot also shows H $\lambda$ 4102 Å, while the right plot includes Na $\lambda$ 5890 Å. The fluxes have been scaled to show the common absorption components, which are indicated by the vertical dashed line corresponding to Be $\lambda$ 3130 Å, the dotted one for Be $\lambda$ 3131 Å.

The evolution of Be up to Day 89 and beyond (Molaro et al. 2016). Since all the $^7$Be decays into Li, we can estimate the Galactic enrichment of Li from the estimated mass of $^7$Be that was ejected. Following an approach similar to the one developed by Izzo et al. (2015) for V1369 Cen, we estimated the ejected mass of $^7$Be to be $M_{Be,Sgr} = 7 \times 10^{-9} M_\odot$. Assuming a typical nova life-time to be $10^{10}$ yrs, we conclude that it takes only two novae like V5668 Sgr per year to produce the total amount of $^7$Li that is estimated to be present in the Galaxy, i.e., $M_{Li} \approx 140 M_\odot$ (Fields et al. 2014).

Moreover, recently we found that oxygen-neon novae also produce a similar quantity of $^7$Be, which then yields $^7$Li (Izzo et al. 2018). In 2016 ASASSN-16kt, a fast nova in Lupus, was discovered (Izzo et al. 2016). We immediately observed it with PUCHEROS and UVES, finding evidence, on Day 8 from the event’s discovery, of $^7$Be $\Pi$ absorptions blue-shifted at very high velocities $v_{exp}$, of $-2000$ to $-2300$ km s$^{-1}$; see Fig. 2. The mass of Be estimated in this explosion is a bit less than for V5668 Sgr: $M_{Be,Lup} = 5 \times 10^{-9} M_\odot$, but fast nova explosions should have shorter recurrence times than for slow novae (Truran et al. 1986), so the actual Li yield from all novae could be much higher than previously thought.

3. Conclusions

The presence of $^7$Be and Li in nova ejecta has been confirmed in recent years from high-resolution spectroscopy of novae in outburst (Tajitsu et al. 2015, Izzo et al. 2015, Molaro et al. 2016). The amount of Li inferred from those observations not only explains the observed over-abundance of Li in young stellar populations (Spite, 2016), but is in fact much greater than the quantity expected according to numerical simulations (Jose & Hernanz, 1998). That suggests that the same physical mechanisms responsible for the discrepancy between theory and observation regarding primordial Li (Fields et al. 2014) are also at work in present epochs. Our results provide an alternative channel for investigating the origin of Li depletion in stars, and also the long-standing problem of missing primordial Li.

An alternative confirmation of our previous results can be provided by observations of novae at very high-energies: the $^7$Be decay which creates $^7$Li is an electron-capture process, and emits a photon with energy of $E_\gamma = 478$ keV. Given the half-life of $\sim 53$ days, we should expect to detect such an emission feature from very nearby novae (Gomez-Gomar

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et al. 1998). However, recent observations have not reported the detection of that feature in novae; CNe have been confirmed as sources of gamma-ray emissions (Ackermann et al. 2014), but the mechanism of the emissions is completely different (Li et al. 2017; Cheung et al. 2016). Important information will also be provided by the up-coming large-scale radio telescopes, like the SKA (O’Brien et al. 2015). The evidence at radio wavelengths that nova ejecta are not spherical (Chomiuk et al. 2014) has important consequences for the final computation of the total mass ejected in a nova outburst, and thence of the total Li mass.

We are living in a golden age for studying novae. Future multi-wavelength facilities will help to provide definite answers to many open problems in nova science.

References
Aguiar, G. de S., & Salvo, R. 2013, *IAUC*, 9266
O’Brien, T. et al. 2015, in: *Proc. Advancing Astrophysics with the SKA*, POS (AASKA14), 062
Spite, F. 1990, *MmSAI*, 61, 663