Southern Horizons in Time-Domain Astronomy
Proceedings IAU Symposium No. 339, 2019
E. Griffin, ed.

doi:10.1017/S1743921318002223

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

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 novæ. The survey concerned the role of those objects in Galactic chemical evolution, with particular attention to the production of lithium.

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

---

1. Introduction

Classical novæ (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 β-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 $\sim 2 \times 10^{6}$ 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 Novæ

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),

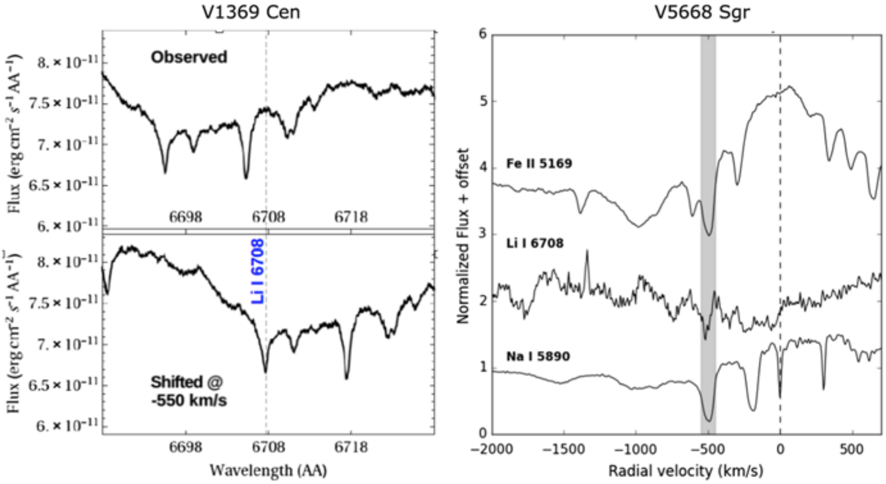

Figure 1. *Left:* FEROS spectrum of V1369 Cen, centred near the λ 6700 Å region and obtained on Day 6 after the event. The upper plot is the observed spectrum; in the lower one the same spectrum has been corrected for a velocity of –550 km s^{1}. The correction clearly shows the presence of Li I λ 6708 Å. *Right:* Radial velocities for three transitions (Li I λ 6708, Fe II 5169 and Na I 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 ∼550 km s^{1} (Izzo *et al.* 2013). Among those narrow absorptions we detected a feature at the observed wavelength of λ 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 λ 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 novæ. (i) Assuming that all slow novæ produce the same amount of Li, (ii) considering their Galactic rate of 15–24 novæ 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 novæ 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 λ 6708 Å transition blue-shifted to a velocity of v_{exp} ∼500 km s^{1}. The same velocity was displayed by other typical transitions observed in novæ spectra, such as Na I D2 at λ 5890 and Fe II λ 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 λ 3130/3131 Å (Fig. 2). Through our spectroscopic follow-up we were able to monitor the

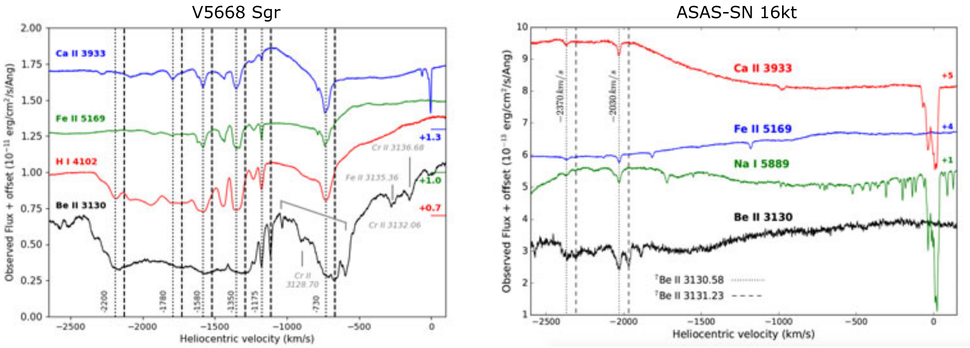

Figure 2. Nova spectra near Be II $\lambda\,3130$, Fe II 5169 and Ca II 3933 Å, respectively, plotted on the velocity scale for V5668 Sgr (*left*) and ASASSN-16kt (*right*). The left plot also shows H I $\lambda\,4102$ Å, while the right plot includes Na I $\lambda\,5890$ Å. The fluxes have been scaled to show the common absorption components, which are indicated by the vertical dashed line corresponding to Be II $\lambda\,3130$ Å, the dotted one for Be II $\lambda\,3131$Å.

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 $M_{Be,Sgr} = 7 \times 10^{-9}\,\mathrm{M}_\odot$. Assuming a typical nova life-time to be 10^{10} yrs, we conclude that it takes only two novæ like V5668 Sgr per year to produce the total amount of ^{7}Li that is estimated to be present in the Galaxy, i.e., $M_{Li} \approx 140\ \mathrm{M}_\odot$ (Fields *et al.* 2014).

Moreover, recently we found that oxygen-neon novæ 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 II absorptions blue-shifted at very high velocities v_{exp}, of –2000 –2300 km s^{-1}; see Fig. 2. The mass of Be estimated in this explosion is a bit less than for V5668 Sgr: $M_{Be,Lup} = 5 \times 10^{-9}\ \mathrm{M}_\odot$, but fast novæ explosions should have shorter recurrence times than for slow novæ (Truran *et al.* 1986), so the actual Li yield from all novæ 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 novæ 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 novæ 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 ∼53 days, we should expect to detect such an emission feature from very nearby novæ (Gomez-Gomar *et al.* 1998). However, recent observations have not reported the detection of that feature in novæ; 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 novæ. Future multi-wavelength facilities will help to provide definite answers to many open problems in nova science.

References

Ackermann, M., *et al.* 2014, *Science*, 345, 6196
Aguiar, G. de S., & Salvo, R. 2013, *IAUC*, 9266
Bode M. F., & Evans A. (eds.) 2008, *Classical Novæ* (CUP, Cambridge, UK)
Cameron, A. G. W., & Fowler, W. A. 1971, *ApJ*, 164, 111
Cheung, C. C., *et al.* 2016, *ApJ*, 826, 142
Chomiuk, L., *et al.* 2014, *ApJ*, 514, 339
Conti, P. S. 1968, *ApJ*, 152, 657
Dekker, H., D'Odorico, S., Kaufer, A., Delabre, B., & Kotzlowski, H. 2000, *Proc. SPIE*, 4008, 534
Della Valle, M., & Livio, M. 1994, *A&A*, 286, 786
Della Valle, M., Pasquini, L., Daou, D., & Williams, R. E. 2003, *A&A*, 390, 155
Fields, B. D., Molaro, P., & Sarkar, S. 2014, *Chin. Phys. C*, 38, 339
Gehrz, R. D., Truran, J. W., Williams, R. E., & Starrfield, S. 1998, *PASP*, 110, 743
Gomez-Gomar, J., Hernanz, M., Jose, J., & Isern, J. 1998, *MNRAS* 296, 913
Jose, J., & Hernanz, M. 1998, *ApJ*, 494, 680
Kaufer, A., Stahl, O., Tubbesing, S., Nrregaard, P., Avila, G., Francois, P., Pasquini, L., & Pizzella, A. 1999, *ESO Messenger*, 95, 8
Izzo, L., Mason, E., Vanzi, L., Fernandez, J. M., Espinoza, N., Helminiak, K., & Della Valle, M. 2013, *ATeL* 5639
Izzo, L., *et al.* 2015, *ApJ*, 808, L14
Izzo, L., *et al.* 2016, *ATeL* 9587
Izzo, L., *et al.* 2018, *MNRAS*, 478, 1601
Li, K. L., *et al.* 2017, *Nature Astron.*, 1, 697
Molaro, P., Izzo, L., Mason, E., Bonifacio, P., & Della Valle, M. 2016, *MNRAS*, 463, 117
Nomoto, K., Kobayashi, C., & Tominaga, N. 2013, *ARA&A*, 51, 457
O'Brien, T. *et al.* 2015, in: *Proc. Advancing Astrophysics with the SKA*, POS (*AASKA14*), 062
Romano, D., Matteucci, F., Ventura, P., & D'Antona, F. 2001, *A&A* 374, 646
Spite, F. 1990, *MmSAIt*, 61, 663
Starrfield, S., Iliadis, C., Hix, W. R., Timmes, F. X., & Sparks, W. M. 2009, *ApJ*, 692, 1532
Tajitsu, A., Sadakane, K., Naito, H., Arai, A., & Aoki, W. 2015, *Nature*, 518, 381
Truran, J. W., & Livio, M. 1986, *ApJ*, 308, 721
Vanzi, L., *et al.* 2012, *MNRAS*, 424, 2770
Williams, S. C., Darnley, M. J., & Bode, M. F. 2015, *ATeL*, 7230