Contrib. Astron. Obs. Skalnaté Pleso **49**, 217 – 227, (2019)

Eruptive stars monitoring and the ARAS database

F. Teyssier

Observatoire Rouen Sud, France
(E-mail: francoismathieu.teyssier@gmail.com)

Received: October 31, 2018; Accepted: December 19, 2018

Abstract. Spectroscopic monitoring of eruptive stars (e.g. symbiotic binaries, classical novae) by amateurs around the world, in both the northern and southern hemispheres, is a fundamental activity of the ARAS (Astronomical Ring for Amateur Spectroscopy) initiative. The group of volunteers demonstrates what can be accomplished with a network of independent, very small telescopes (from 20 to 60 cm), furnished with spectrographs of different resolution, from ∼500 to ∼15000, and covering the range from 3600 to nearly 8000 Å. Acquisition, reduction and analysis of the spectra will be described. The observing program concentrates on bright symbiotic stars (57, to date) and novae (35, to date). The main features of the ARAS activity are rapid response to alerts, long term monitoring and high cadence. A part of the program involves collaborations based on requests from professional teams (e.g. CH Cyg, AG Dra, R Aqr, SU Lyn, V339 Del) for long term monitoring or specific events. Some examples of the evolution of basic observational parameters during outbursts and/or as a function of orbital phase (e.g. radial velocities, equivalent widths or line profiles) are presented. The spectra are gathered in the open access Eruptive Stars Database that has been used for several publications by professional teams.

Key words: novae – symbiotic stars – spectroscopic database

1. Introduction

Eruptive stars spectroscopic monitoring is a part of ARAS (Astronomical Ring for Access to Spectroscopy), an initiative dedicated to promote Amateur spectroscopy, originally intended for Be stars: BESS data base (Neiner et al., 2011).

The program was initiated in 2009 and developed from the 2013 Pisa meeting (multi-wavelength observation of bright novae on the initiative of Steve Shore, Università di Pisa): the aim of the project was the monitoring in all wavelengths of the next bright nova. Nova Del 2013 exploded a few weeks later (August, 14th), was bright (V magnitude at maximum = 4.3) and well placed in the evening sky. Since then, the monitoring of symbiotic stars, novae, dwarf novae and related objects has been coordinated. The program includes: 1. Long term monitoring of more than 50 bright symbiotic stars (orbital variations, outbursts and high states), monitoring of novae outbursts (35 to date), spectroscopic identification of new stars. 2. Collaboration with professional teams either by the use of the database (e.g. AG Peg outburst, T CrB active state, EG And) or on specific requests (e.g. CH Cyg, BF Cyg, AG Dra, R Aqr, SU Lyn, V694 Mon).

2. Setups and data reduction

The telescopes are mostly reflectors of various types, often Schmidt-Cassegrain, but also Newtonian, Dall-Kirkham, Cassegrain etc. The diameters range usually from 20 to 40 cm, exceptionally to 50 or 60 cm. Various spectroscopes are used. Most of them are produced by the Shelyak Company. Alpy600 is a low resolution slit spectroscope with a resolution of 600 which covers 3800-7500 Å range, particularly appropriate to fainter objects. LISA is a low resolution spectroscope (R = 1000) used by many regular observers. Lhires III has been designed in the context of the Be stars program. It is a slit spectroscope which comes with various gratings (150 to 2400 l/mm) and produces spectra with resolutions ranging from 700 to 15000. eShel is a fibre Echelle spectroscope working in the range 4000 - 7500 Å at a resolution of 11000. Other commercial spectroscopes are used (e.g. DADOS, equipped with two gratings 200 and 900 l/mm, LX-200, similar design to the Lhires III). Last, but not least a few observers have produced their own spectroscopes (slit or Echelle) with excellent results, e.g. Tim Lester (CA) and Joan Guarro (SP).

2.1. Acquisition and reduction

The very small diameter of the telescopes requires excellent tuning of all the equipment, notably focusing and autoguiding, to obtain valuable results with high enough SNR. The spectra, dark subtracted and flat divided, are reduced in most cases by the ISIS software, written by C. Buil [1]. The atmospheric and instrumental response is computed from a reference early A-type star. Figure 1 shows two spectra of AG Peg independently acquired/processed by J. Montier (FR) and J.P. Masviel (FR) using Alpy600 on 2015-09-07.071 and 09.065 UT. This is our target level. However, the atmospheric response remains a difficult issue. Each observing campaign is a school for new observers and the occasion for experienced observers to improve their technique through discussions on our forums (see e.g. ARAS Forum [2]).

2.2. How faint?

Most of the targets from the symbiotic stars program range from mag. V = 7 to 12 and are monitored at resolutions from 600 to 15000 with sufficient exposure time to obtain a SNR of about 100 in the red part of the spectrum. The exposure time can reach 3 hours for that purpose. Due to the spectral energy distribution

[1] http://www.astrosurf.com/buil/isis-software.html
[2] http://spectro-aras.com/forum/index.php

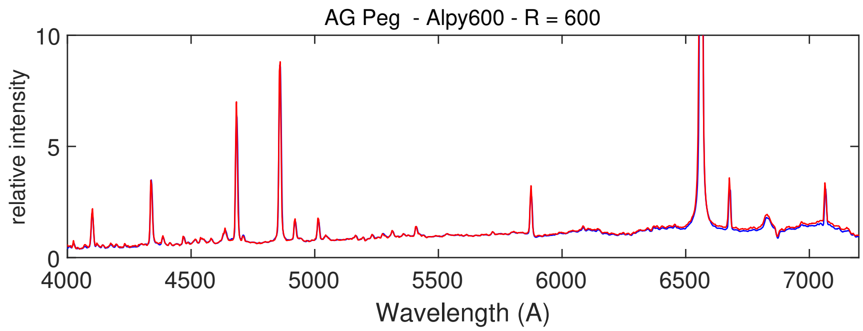

Figure 1. AG Peg - Comparison of two low resolution spectra

of most of the targets, the SNR is 10 - 20 in the blue part of the spectrum. Using a LISA or Alpy600 spectroscopes, spectra of targets with V = 14 can be obtained with a reasonable exposure duration.

3. Symbiotic star monitoring

Symbiotic stars are wide interacting binary systems comprising a cool giant as the donor star and a hot compact star, mostly a white dwarf (WD), accreting from the giant's wind. Their orbital periods run from hundreds of days (S-type systems containing a normal giant) to a few times 10 - 100 years (D-type systems containing a Mira variable). The accreting WD represents a strong source of extreme ultraviolet radiation ($T_h > 10^5$ K, $L_h \approx 10^1$ to 10^4 $L_\odot$) in the binary that ionises a fraction of the wind from the giant giving rise to nebular emission (Skopal et al., 2017). Symbiotic stars are considered as laboratories for many astrophysical phenomena such as winds from red giants, accretion and eruptive processes on compact objects, disks, jets, etc. A number of questions remain unsolved. Already Merrill (1958) suggested that *"persistent observations, both spectroscopic and photometric, for 5 or 10 years of the brightest symbiotics would surely help us to understand their mysterious behaviour and might develop ideas of considerable general interest"*.

In the following section, we present selected results obtained from our spectra.

3.1. Low resolution monitoring of the classical symbiotic star AX Per

AXPer is an eclipsing symbiotic binary comprising a M4.5 III giant and a luminous WD on a 680-d orbit (Fekel et al., 2000b).

David Boyd (UK) has monitored this system since 2014 with a LISA (R = 1000) simultaneously with photometry in the V band, which allows flux calibration of the spectra in, e.g. erg cm^{-2} s^{-1} $Å^{-1}$. For example, the integrated absolute flux of the forbidden line [Fe VII] λ 6087Å is shown in Fig. 2. The flux variation is strongly different from one cycle to another, but seems to be orbitally related. The maxima are located rather around the inferior conjunction of the giant according to the ephemeris of Fekel et al. (2000a). The monitoring is ongoing, together with higher resolution spectra.

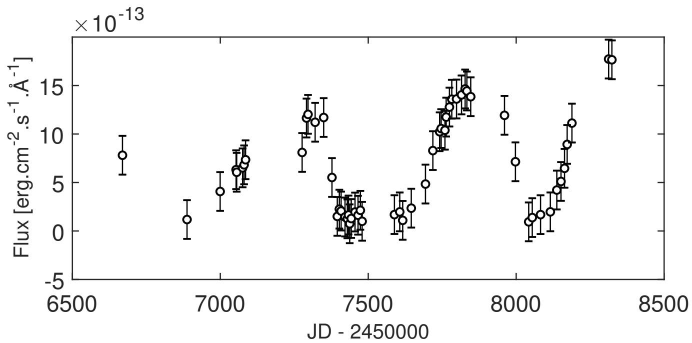

Figure 2. AX Per - [Fe VII] λ6087 Å flux

3.2. Orbital monitoring of CI Cygni

CI Cygni is a prototypical symbiotic star. It hosts a red M5.5III giant and a luminous hot component on a 853-d orbit whose nature remains controversial (e.g. Siviero et al., 2009).

36 Echelle spectra were obtained by F. Teyssier (FR), J. Guarro (SP) and T. Lester (CA) at R = 9000 to 13000 during the orbital cycle 8 according to the ephemeris of Fekel et al. (2000b). The system is in a quiescent state since its last active period 2008-2012 (e.g. Siviero et al., 2009; Teyssier, 2011). Radial velocities of the red giant have been determined by cross-correlation with the M6 III red giant 13 Lyr (using ISIS) within a range of free emission lines (6375-6545 Å). The radial velocity curve (red squares) is shown Fig. 3. The error of each individual measurement is estimated to 2 km s^{-1}. The second curve (blue circles) represents the radial velocity (RV) of the centre of the He II λ 4686 Å emission line. It is located at the anti-phase to the RVs of the giant, and thus can reflect the orbital motion of the hot component.

The orbital elements for the red giant have been computed using Spectroscopic Binary Solver, SBS hereafter (Johnson, 2004). The results shown in Table 1 are in good agreement with published values (Kenyon et al., 1991; Fekel et al., 2000b). The solution computed by SBS proposes an eccentricity of 0.126, at the

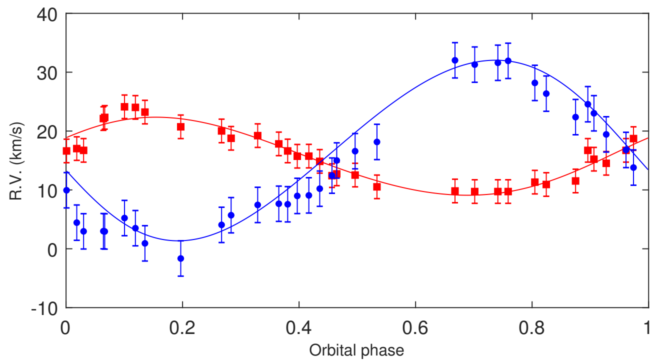

Figure 3. CI Cyg - Radial velocities of the red giant (red squares) and the center of the He II λ4686 Å emission line (blue dots). The orbital phase was calculated according to our solution.

limit of confidence. Similar eccentricities found in the two cited studies and our data reinforced the solution with an eccentric orbit.

Table 1. CI Cygni Orbital elements.

		Kenyon et al. 1991	Fekel et al. 2000b	ARAS this paper
P	(days)	855.25	853.8± 2.9	853.8 [1]
T	(HJD)		2450426.4 ± 59.6	2456512.9 ± 56.8
γ	(km/s)	18.5 ± 0.4	14.96 ± 0.23	15.34 ± 0.24
K1	(km/s)	7.0 ± 0.5	6.70 ± 0.23	6.63 ± 0.37
K2	(km/s)			15.3 ± 0.5
e		0.0	0.109 ± 0.048	0.126 ± 0.05

[1] adopted from Fekel et al., 2000b

As an example, the variation of the Hβ profile at the beginning of the orbital cycle, from phase 0.0 to 0.15 is shown Fig. 4. The classical central absorption seen in many Balmer lines of symbiotic stars is quickly filled in by an emission component. The high cadence coverage through the orbital cycle allows us to detect unexpected events and their precise dating will help to constrain a model.

3.3. CH Cyg

Although as a class, the symbiotic stars are enigmatic, CH Cyg is a particularly intriguing star. It was adopted as a standard star of the spectral class M6 III in the Morgan-Keenan classification until 1963 when a strong blue continuum and

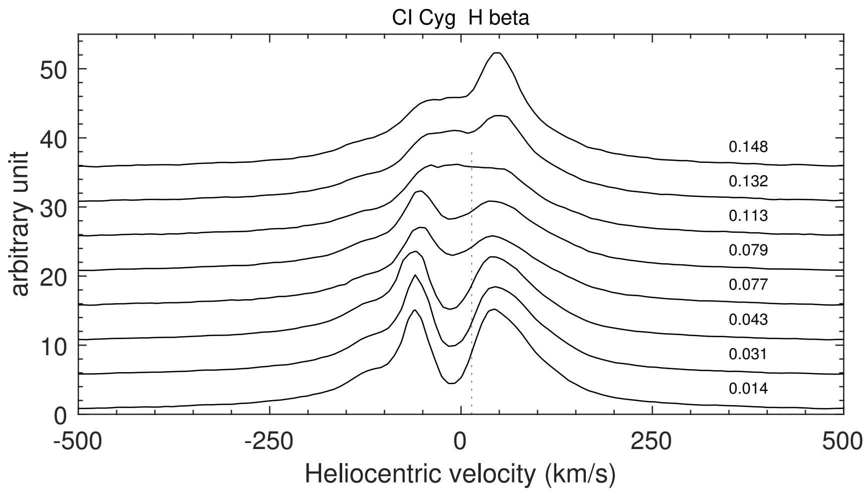

Figure 4. CI Cyg - Hβ profile from phase 0.01 to 0.14 during JD 2457268 to JD 2457383.

HI emission lines appeared in the star spectrum, thus revealing its symbiotic nature. The low luminosity of the hot component is attributed to accretion through a disk, with evidence for strong jets (velocity up to 3000 $\mathrm{km\,s^{-1}}$). 700 spectra are gathered in the ARAS database, with daily coverage during certain periods. Depending of its activity CH Cyg shows very complex variations. One of them is photometric and spectroscopic flickering on a time scale of minutes. This is illustrated in Fig. 5 with a 2.6 hour time series acquired by P. Somogyi (HU) with a 25 cm telescope equipped with a Lhires III 2400 l/mm (R = 15000). Each spectrum has a duration of 300 sec. and a SNR $\sim$ 30. The left view shows 31 spectra of the Hα line and strong variation of the blue part of the line. The right view represents a statistical study of the variation: the red line is the mean spectrum; the blue line is the variance, multiplied by a factor of 10 and shifted (+1) for clarity. The blue dashed line is the variance of the continuum (3 sigma), computed on 50 points. The flickering is established at a significant level of confidence in the range -20 to -150 $\mathrm{km\,s^{-1}}$. The radial velocity of the system (-60 $\mathrm{km\,s^{-1}}$) has been subtracted.

3.4. Publications and collaborations

The database has been used for several publications. The outburst of the symbiotic nova AG Peg in 2015 was studied by Skopal et al. (2017) and Ramsay et al. (2016). The study of the recurrent symbiotic nova T CrB in high state by Iłkiewicz et al. (2016) is widely based on ARAS spectra. On the request of

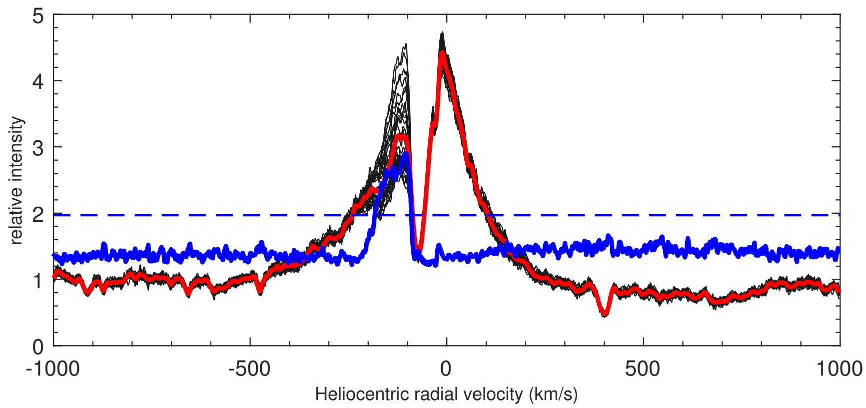

Figure 5. CH Cyg - Hα line rapid variability (see Sect. 3.3).

J. Merc and R. Gális, the activity of the yellow symbiotic AG Dra has been monitored since 2016 with a higher cadence during outburst activity (e.g. Merc et al., 2017; Gális et al., 2018; Merc et al., 2018). The ARAS group also provided spectra of R Aqr in support of HST observations by M. Karovska in 2017. The most recent campaign at the request of A. Lucy and J. Sokoloski sets out to detect new symbiotics among a selected list of faint red giant stars. The interest in monitoring symbiotic stars by the ARAS group was highlighted by A. Skopal during this conference: *Studying symbiotic stars and classical nova outbursts with small telescopes* (this proceedings).

4. Novae observations

Classical novae are thermonuclear explosions that take place in the envelopes of accreting white dwarfs in binary systems. The material piles up under degenerate conditions, driving a thermonuclear runaway (e.g. Casanova et al., 2016).

To date, 35 events have been observed by the ARAS group, with a total number of more than 2000 spectra. In the next sections, we present selected results of three peculiar events.

4.1. Nova Del 2013

The classical Nova Del 2013 (V339 Del) outburst on 2013 August 14th and peaked at mag V = 4.4 on August 16.47 (e.g. Chochol et al., 2014). It has been intensively monitored by the group at resolutions from 600 to 15000. More than 1200 spectra obtained by observers worldwide are stored in the database; for one day, August 15th, 52 spectra were acquired. See e.g. Shore et al. (2013) including 41 ARAS observers as co-authors. The spectra have been used in several publications (e.g. Shore et al., 2016; Skopal et al., 2014). Especially, among the various studies of this event, the first resolved images of the expanding fireball have been obtained by the CHARA Array (Schaefer et al., 2014). Six spectra obtained by Olivier Garde have been used to calibrate the observations. Usefulness of our spectra was demonstrated by Schaefer et al. (2014): *"From an analysis of spectra downloaded from the archive of the Astronomical Ring for Access to Spectroscopy, we estimated the outflow speed near the continuum-forming layer to be* $V_{\mathrm{ejection}} = 613 \pm 79\, km\, s^{-1}$ ".

4.2. The oscillations of Nova Sct 2017 near maximum

Nova Sct 2017 belongs to the small class of novae showing strong oscillations near maximum instead of the classical, more or less, smooth decrease of luminosity during the first decline. The nova has been monitored at high cadence during all the rebrightenings and fadings. See the contribution of D. Chochol in this proceedings (*Optical photometry and spectroscopy of V612 Sct: slow classical nova with rebrightenings*).

4.3. The narrow lines of Nova Per 2018 = V392 Per

Nova Per 2018 is an extraordinary nova event in an already known dwarf nova V392 Per. Moreover, the evolution of emission lines (Balmer, He I) showed the rare development of narrow lines superposed on a broad component with terminal velocity of $\sim \pm 4000\,\mathrm{km\,s^{-1}}$ or even more. Despite the difficult position in the evening sky of the target, the team obtained 61 spectra of the nova at resolution from 600 to 15000.

5. Identification of "New Stars"

The responsibility and worldwide location of the group allow to obtain identification and confirmation spectra for a number of objects following alerts, with results published in Astronomer's Telegram, CBET, or on the Transient Objects Confirmation Page. As a recent example, Paolo Berardi (IT) obtained the first spectrum of the transient TCP J19544251+1722281 detected by Robert Fidrich (HAA/VSS) on 2018-08-8.938. The spectrum acquired with a Lhires III mounted on a 23 cm telescope is typical of a symbiotic star in outburst (Belczyński et al., 2000), with high ionization lines (e.g. He II) on the red continuum of a red giant. The identification is reported by Munari et al. (2018).

6. Aras Database for Eruptive Stars "asdb"

Spectra are gathered in the ARAS Eruptive stars database [3] and are publicly available. The spectra follow the BESS format specifications, i.e., they must be simple fits spectra with a header including at least a few mandatory keywords (Neiner et al., 2011). For each target, the web page shows the observations with the main information (date, time, observer, observatory, spectral range, duration). The name of each spectrum is built in the form: asdb_x_aaaammdd_hhh.fit', with asdb as reference for the base, x = name of the target, aaaa = year, mm = month, dd = day, hhh = time expressed in fraction of a day. Observer is expressed as a letter code, observatory as a 3 letter code followed by the country in 2 letters. There is a first level validation check prior to adding spectra to this table: identification, wavelength calibration, atmospheric response. Users should verify the quality of the spectra (possibly with the observer concerned). Use of these data in research publications is encouraged subject to the following conditions: *ARAS DataBase Eruptive Stars should be acknowledged and a link to the address of the database should be provided. * Observers contribution should be acknowledged * Observers contributing a significant amount of data or whose data are pivotal to the findings of the paper should be included as co-authors. If you use any ARAS Eruptive stars data in your research, please mention this publication in the references of your article. Any questions about the data may be directed to the author. zip files can be provided.

An Information letter [4] is published every 3 months with the main results and basic analysis. Professional teams using ARAS spectra are kindly asked for contributions to the letter as an educational involvement as most of the observers would like to understand the physics behind their observations.

Acknowledgements. The author warmly thanks Steve Shore for his continuous support, stimulation and his regular notes in the Information Letter, Augustin Skopal for his steady contribution, support and the invitation to this conference. David Boyd is thanked for correction of the English syntax of the text. All ARAS observers who contribute to this program are warmly commended for their tireless efforts.

References

Belczyński, K., Mikołajewska, J., Munari, U., Ivison, R. J., & Friedjung, M., A catalogue of symbiotic stars. 2000, *Astronomy and Astrophysics Supplement Series*, **146**, 407, DOI: 10.1051/aas:2000280

Casanova, J., José, J., García-Berro, E., & Shore, S. N., Three-dimensional simulations of turbulent convective mixing in ONe and CO classical nova explosions. 2016, *Astron. Astrophys.*, **595**, A28, DOI: 10.1051/0004-6361/201628707

[3] *http://www.astrosurf.com/aras/Aras_DataBase/DataBase_EruptiveStars.htm*

[4] *http://www.astrosurf.com/aras/novae/InformationLetter/InformationLetter.html*

Chochol, D., Shugarov, S., Pribulla, T., & Volkov, I., Photometry and spectroscopy of the classical nova V339 Del (Nova Del 2013) in the first month after outburst. 2014, *Contributions of the Astronomical Observatory Skalnate Pleso*, **43**, 330

Fekel, F. C., Hinkle, K. H., Joyce, R. R., & Skrutskie, M. F., Infrared Spectroscopy of Symbiotic Stars. II. Orbits for Five S-Type Systems with Two-Year Periods. 2000a, *Astron. J.*, **120**, 3255, DOI: 10.1086/316872

Fekel, F. C., Joyce, R. R., Hinkle, K. H., & Skrutskie, M. F., Infrared Spectroscopy of Symbiotic Stars. I. Orbits for Well-Known S-Type Systems. 2000b, *Astron. J.*, **119**, 1375, DOI: 10.1086/301260

Gális, R., Merc, J., Vrastak, M., et al., The fourth outburst during the present active stage of symbiotic binary AG Dra. 2018, *The Astronomer's Telegram*, **11559**, 1

Iłkiewicz, K., Mikołajewska, J., Stoyanov, K., Manousakis, A., & Miszalski, B., Active phases and flickering of a symbiotic recurrent nova T CrB. 2016, *Mon. Not. R. Astron. Soc.*, **462**, 2695, DOI: 10.1093/mnras/stw1837

Johnson, D. O., Spectroscopic Binary Solver. 2004, *Journal of Astronomical Data*, **10**, 3

Kenyon, S. J., Oliversen, N. A., Mikolajewska, J., et al., On the Nature of the Symbiotic Binary CI Cygni. 1991, *Astron. J.*, **101**, 637, DOI: 10.1086/115712

Merc, J., Gális, R., & Leedjärv, L., Recent outburst activity of the super-soft X-ray binary AG Draconis. 2017, *Contributions of the Astronomical Observatory Skalnate Pleso*, **47**, 192

Merc, J., Gális, R., & Leedjärv, L., Recent outburst activity of the symbiotic binary AG Draconis. 2018, *ArXiv e-prints*, arXiv:1806.05935

Merrill, P. W., 51. Symbiosis in Astronomy: Introductory Report. 1958, in Liege International Astrophysical Colloquia, Vol. **8**, *Liege International Astrophysical Colloquia*, 436–448

Munari, U., Dallaporta, S., Valisa, P., et al., HBHa 1704-05: a bright and newly discovered symbiotic star, currently undergoing an "hot-type" outburst. 2018, *The Astronomer's Telegram*, **11937**, 1

Neiner, C., de Batz, B., Cochard, F., et al., The Be Star Spectra (BeSS) Database. 2011, *Astron. J.*, **142**, 149, DOI: 10.1088/0004-6256/142/5/149

Ramsay, G., Sokoloski, J. L., Luna, G. J. M., & Nuñez, N. E., Swift observations of the 2015 outburst of AG Peg - from slow nova to classical symbiotic outburst. 2016, *Mon. Not. R. Astron. Soc.*, **461**, 3599, DOI: 10.1093/mnras/stw1546

Schaefer, G. H., Brummelaar, T. T., Gies, D. R., et al., The expanding fireball of Nova Delphini 2013. 2014, *Nature*, **515**, 234, DOI: 10.1038/nature13834

Shore, S. N., Cechura, J., Korcakova, D., et al., Continuing spectroscopic observations (3600-8800A) of V339 Del = Nova Del 2013 in the early nebular stage with the Nordic Optical Telescope, Ondrejov Observatory and the ARAS group. 2013, *The Astronomer's Telegram*, **5546**, 1

Shore, S. N., Mason, E., Schwarz, G. J., et al., The panchromatic spectroscopic evolution of the classical CO nova V339 Delphini (Nova Del 2013) until X-ray turnoff. 2016, *Astron. Astrophys.*, **590**, A123, DOI: 10.1051/0004-6361/201527856

Siviero, A., Munari, U., Dallaporta, S., et al., The ongoing 2008-09 outburst of CI Cyg. 2009, *Mon. Not. R. Astron. Soc.*, **399**, 2139, DOI: 10.1111/j.1365-2966.2009.15414.x

Skopal, A., Drechsel, H., Tarasova, T., et al., Early evolution of the extraordinary Nova Delphini 2013 (V339 Del). 2014, *Astron. Astrophys.*, **569**, A112, DOI: 10.1051/0004-6361/201424284

Skopal, A., Shugarov, S. Y., Sekeráš, M., et al., New outburst of the symbiotic nova AG Pegasi after 165 yr. 2017, *Astron. Astrophys.*, **604**, A48, DOI: 10.1051/0004-6361/201629593

Teyssier, F., CI Cygni 2010 Outburst and Eclipse: An Amateur Spectroscopic Survey - First Results From Low Resolution Spectra. 2011, *Journal of the American Association of Variable Star Observers (JAAVSO)*, **39**, 41