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ARAS eruptive stars monitoring

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Abstract.
The ARAS eruptive stars group monitors novae, symbiotic stars, and eventually dwarf novae ... with small telescopes (typically 20-60 cm) equipped with slit (R=600 to 15000) and echelle (R=10000) spectrographs. 4175 spectra of 65 novae and 8379 spectra of 104 symbiotics secured since 2013 are accessible for free access from the ASDB spectral database.

We present four examples to demonstrate the long-term monitoring, high cadence program, and the reactivity of the members to special events such as outbursts or eclipses.

1. The 2021 outburst of the recurrent nova RS Oph was carefully studied with daily echelle spectra and flux-calibrated low-resolution spectra for a period of one month. This monitoring allowed the construction of the evolution of the ionization state of the system during the outburst.
2. One of the main tasks of our program is the long-term monitoring of classical symbiotic stars over several orbital cycles following the suggestion of S. J. Kenyon (1986) and J. Mikolajewska. The complex behavior of the eclipsing system AX Persei is briefly summarized to illustrate our purpose.
3. An example of monitoring an eclipse in an accretion-powered symbiotic star BX Mon in April 2023.
4. The behavior of the recurrent symbiotic nova T CrB (1866, 1946) before its next nova event which is expected in the very next months or years. The cadency of the observations has enabled us to time precisely the end of the long high state detected in 2015.

Key words: novae – symbiotic stars – spectroscopy

1. Introduction

The ARAS eruptive stars group gathers worldwide amateurs observing with small telescopes ("decimeter class"). The typical diameter varies from 20 to 40 cm, exceptionally 50 and 60 cm, the full range is 8 cm to 1 m. The telescopes are equipped with various types of long slit and echelle spectrographs whose resolution varies from 600 to 15000, exceptionally 30000. Most of them are produced by Shelyak Company (Lhires III, LISA, ALPY600, eShel, ...).

Some are homemade spectrographs among them we can cite two peculiar projects: the UVEX[1] developed by "Nice People" (FR) with the support of Christian Buil, which is a 3D printing long slit spectrograph efficient in the near UV; NOU-T project, an echelle spectrograph with a resolution of 9000 mounted at the focus of a Schmidt-Cassegrain 14" telescope was developed by Joan Guarro Flo (SP) from an optical concept designed by Tim Lester (CA).

The spectra are archived in the ASDB [2], ARAS eruptive stars database (Teyssier, 2019). The first version was based on a Visual Basic macro applied to Excel spreadsheets and was launched in August 2013. The design and functionality based on Python codes were improved in 2022 by J. Merc (Charles University, Prague), producing the current version. The ARAS database is open to all observers who want to share their results. The resolution must be over 500. The spectra are reduced according to standards (bias, darks, flats, instrumental and atmospheric corrections applied). Most of them are reduced using ISIS[3].

The observing program is firstly defined by observers themselves, individually or collectively. There are two main tasks: 1. monitoring of peculiar events such as outbursts, eclipses, and high states. 2. Long-term monitoring of symbiotic stars over several orbital cycles. We also respond to professional requests on peculiar programs.

The ASDB has been used by a number of publications [4] (e.g. Skopal et al., 2017; Aydi et al., 2023; Iłkiewicz et al., 2022; Azzollini et al., 2023).

Table 1. ARAS Eruptive Stars Database

Category	No. of Objects	No. of Spectra
Novae	65	4175
Symbiotic stars	104	8379
Dwarf novae	33	377

With four selected examples we demonstrate the value of long-term monitoring, a high cadency program, and the reactivity of the members to special events such as outbursts or eclipses.

2. Recurrent symbiotic nova RS Oph in 2021

Nova outbursts of the symbiotic system RS Oph were detected in 1898, 1933, 1958, 1967, 1985, 2006, and 2021 making it a recurrent nova. The 2021 outburst was detected on 2021-08-8.93 UT by K. Geary at a visual magnitude 6.0. The peak of luminosity was reached on 2023-08-09.55 (JD 2459436.30) which was

[1]https://spectro-uvex.tech/
[2]https://aras-database.github.io/database/index.html
[3]http://www.astrosurf.com/buil/isis-software.html
[4]https://ui.adsabs.harvard.edu/public-libraries/jd9bULL8SU-uBHbblit3Xw

adopted as the start of the outburst T0. Our first spectra acquired around 2013-08-9.8 show broad emission lines of low ionized species (H I, Fe II, He I). The short recurrence time implies a massive white dwarf ($> 1.2\ M_{\odot}$) explaining the high velocity of the ejecta (> 4000 km.s^{-1}). The outburst occurs in the dense nebula of the symbiotic system which produces strong shocks (Azzollini et al., 2023) explaining the high degree (in comparison with classical novae) of ionization near the maximum luminosity (≈ 25 eV) with the detection of recombination lines of He I or N II.

During the outburst, the degree of ionization of the ejecta increased as a consequence of the retraction of the remaining envelope, shocks, and changes in the opacity of the ejecta. The highest ionization potential observed in our spectra is 755 eV with the detection of Ar[XIV] 58.5 days after the peak luminosity.

The echelle (R = 10000) and flux calibrated (R=1000) spectra secured during the outburst allow a precise description of the phenomenon. From the extensive information obtained, we present the evolution of the degree of ionization.

Method: the epoch of the appearance of the species is determined by visual examination of the profiles (an example is shown in Fig. 1(c) with He II λ 4686 Å) and of the measures of the flux of each line: Fig. 1(b1) and 1(b2) show examples with He II and the scattered Raman OVI λ 6825 Å) on the sample of echelle spectra. The evolution of the level of ionization is shown in Fig. 1 (a).

Results: We detect three phases of the evolution of the ionization: A slow increase from 25 eV to ≈ 55 eV during days 0 to 19 (± 1) with a slope of 2 eV/d.

Around day 20 the slope increases significantly (36 eV / day) until the appearance of [Ar X] (480 eV) on day 31 (± 1).

During the third phase, the slope remains positive with the lowest value.

The fluxes of He II and Raman OVI (Fig. 1) show strong variations during the rise of the lines and during the second phase. We detect the disappearance of He II λ 4686 Å two days after its rise and oscillations of the flux of Raman OVI λ 6825 Å between days 20 to 31.

3. Long-term monitoring of the nuclear burning symbiotic star AX Per

AX Per is an eclipsing (Skopal, 1991) classical symbiotic system consisting of an M4.5 III red giant (Mürset & Schmid, 1999) and a hot and luminous accreting white dwarf (for example L= 710 $L_{\odot}$, T = 105000 K on October 1984 in quiescence Muerset et al. (1991)) on a 680 days orbit.

AX Per is one of the bright symbiotic stars monitored in our program with 455 spectra acquired since 2011. Fig. 2 is an illustration of the monitoring: the equivalent widths of the two selected emission lines show a complex behavior over more than 5 orbital cycles. The dashed vertical lines mark the epoch of the eclipse according to ephemeris JDmin = 2436667(3) + 680.8(0.2) * E (Mikolajewska & Kenyon, 1992).

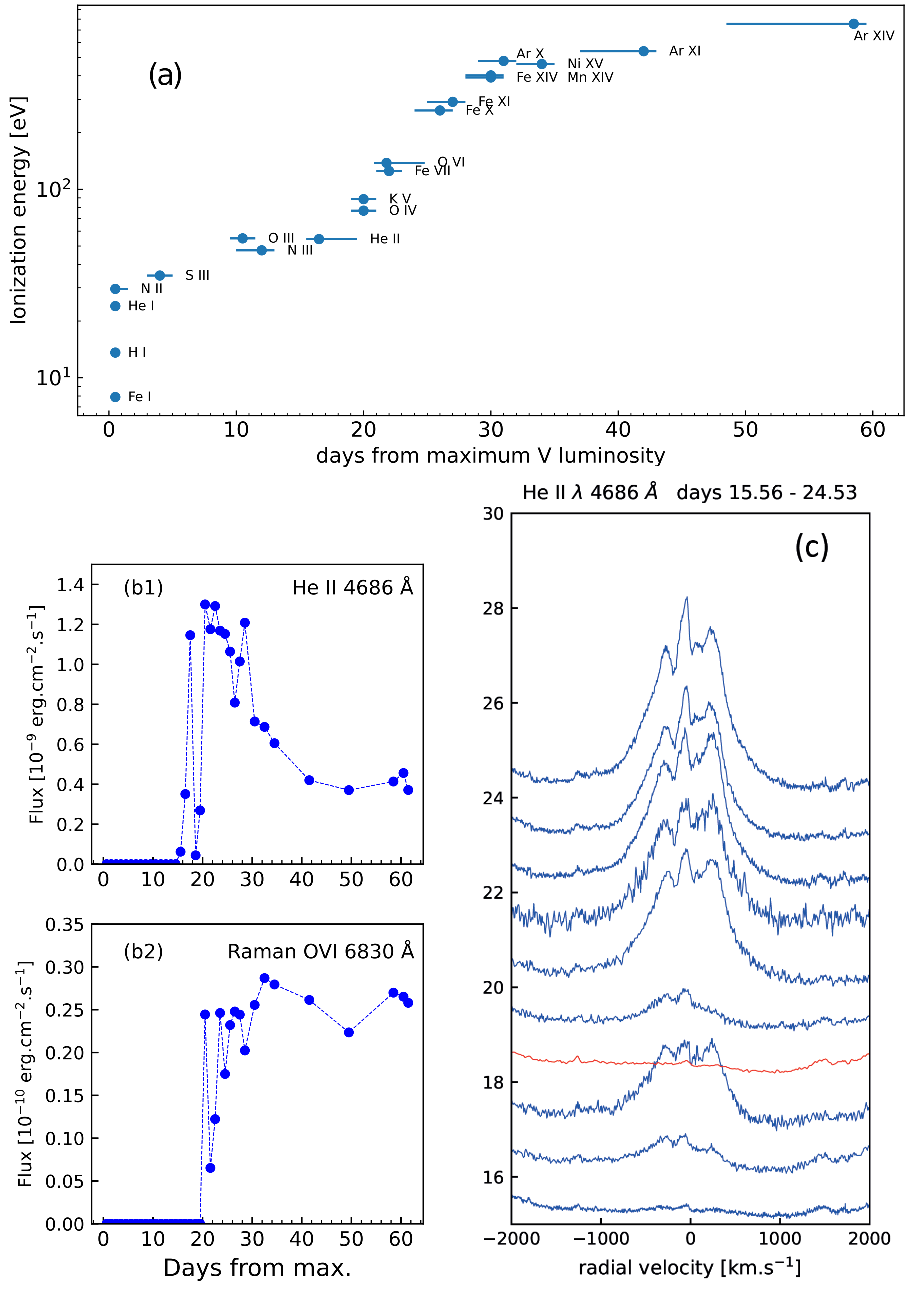

Figure 1. RS Oph, 2021 nova outburst. (a) level of ionization during the outburst; (b1,b2) flux in two lines He II λ 4686 Å and Raman OVI λ 6830 Å; (c) evolution of He II λ 4686 Å (days 15-24) in velocity space. The normalized continuum is shifted by the days since the peak of velocity.

In the 1950$^{'}$s, Merrill noted the complex variations of symbiotic systems and insisted on the necessity of long-term monitoring:

"Persistent observation, both spectroscopic and photometric, for 5 or 10 years of the brighter symbiotic stars would surely help us understand their mysterious behaviors and might develop ideas of considerable general interest." Merrill (1958).

This recommendation has been followed notably by S.J. Kenyon and J. Mikolajewska during the '80s and '90s producing monographic studies of these targets (e.g., Mikolajewska & Kenyon, 1992).

We continue this effort in the spirit of producing results that may constrain the models.

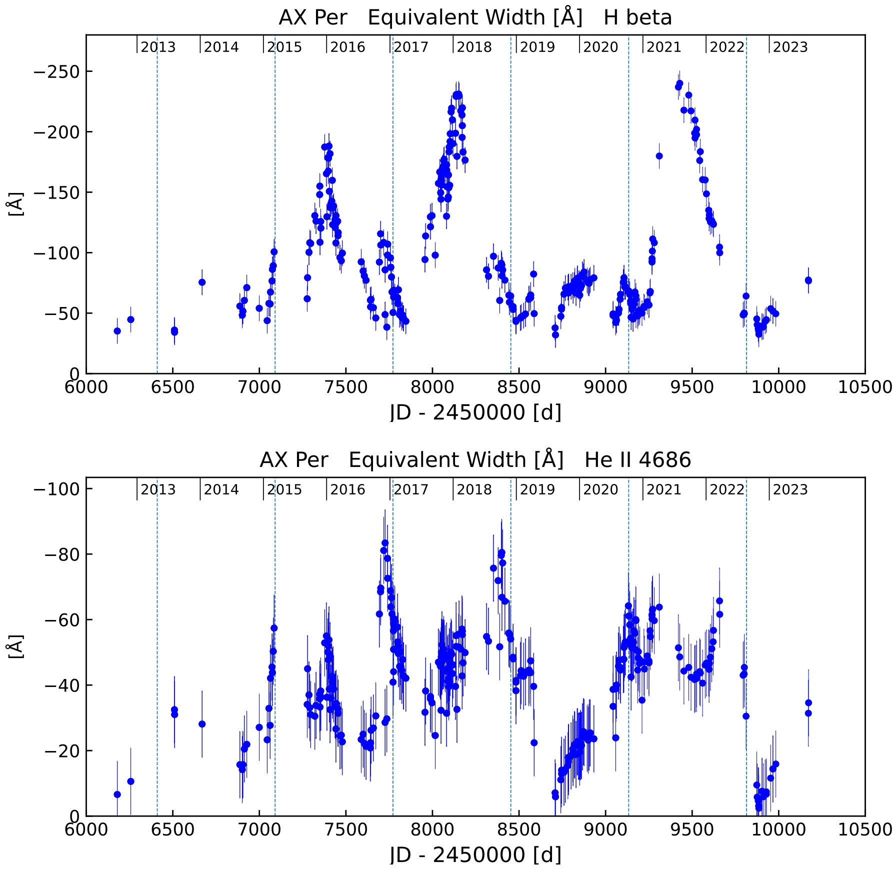

Figure 2. AX Per long term monitoring. Equivalent widths of Hβ and He II 4686 Å emission lines during 10 years. The vertical dashed lines mark the epoch of the mid-eclipse of the hot component.

4. An eclipse in the symbiotic star BX Mon

BX Mon is an eclipsing symbiotic system. The orbital period of 1259±16 days is long and the eccentricity (0.444±0.067) is high for a classical symbiotic (Fekel et al., 2000). Moreover, historical photometric studies produced inconsistent values of the photometric period (Leibowitz & Formiggini, 2011). In March-April of 2022, we obtained a series of spectra showing the egress of an eclipse.

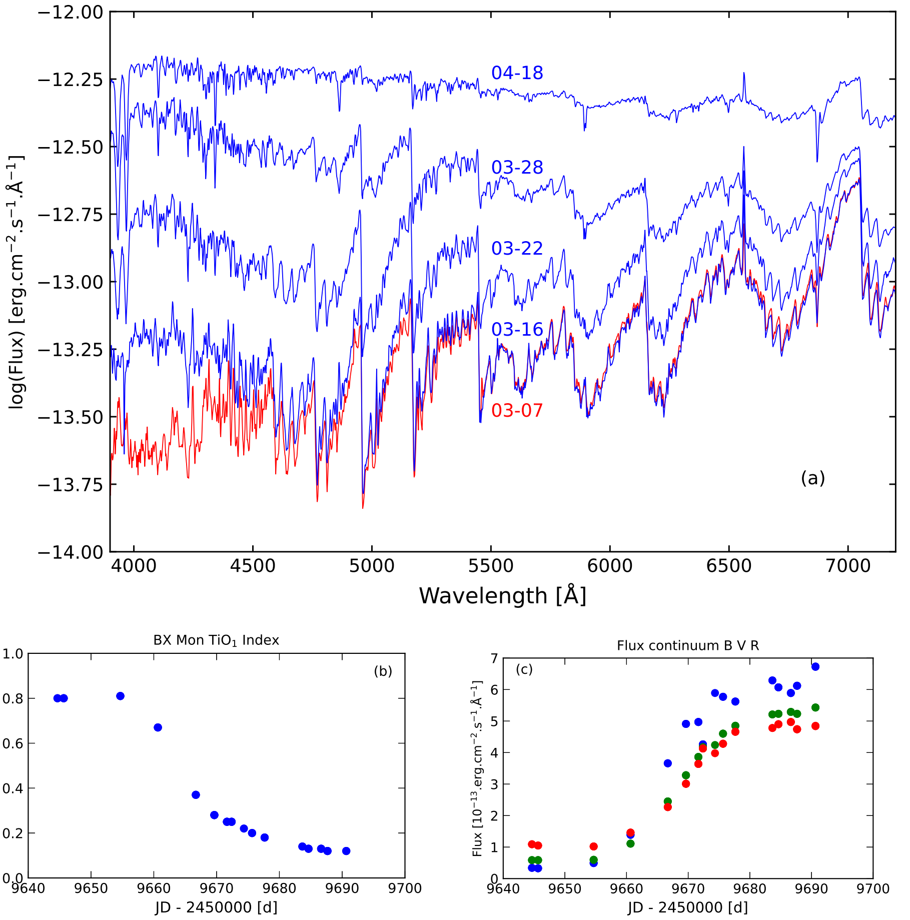

Figure 3. BX Mon spectral evolution during the egress of the eclipse (a). Variation of the TiO_1 index as the result of the overwhelming of the pseudo continuum of the red giant by the hot component (b). Evolution of the flux of the continuum in B, V, R (c).

Fig. 3 shows the spectral evolution of the egress with selected flux-calibrated spectra (R=1000) obtained by F. Sims and F. Boubault. The first spectra of our series are almost constant which we attribute to the fact that the hot component is fully eclipsed. The TiO_1 index described by Kenyon & Fernandez-Castro (1987) is 0.8 corresponding to a M5.8 III red giant. The change in the TiO_1 index describes the progressive overwhelming of the red giant spectrum by the hot component (Fig. 3b). This is also reflected in the evolution of the flux of the continuum measured at wavelengths 4361±10 Å, 5448±10 Å, 6407±10 Å (B, V, R in Fig. 3c) showing the strengthening of the blue part of the composite continuum.

5. Recurrent symbiotic nova T CrB before its next nova event

T CrB is an accretion-powered symbiotic which experienced two nova events in 1866 and 1946 making it a member of the small group of recurrent novae. The next nova event is expected in the next several years (Luna et al., 2020). Between the two nova-type outbursts, T CrB shows active phases during several years characterized by a brightening in B and V bands, an increase in the intensities of the emission lines, and the ionization level (He II). The last active phase began in 2014 (Iłkiewicz et al., 2016; Munari et al., 2016). Iłkiewicz et al. (2023) interpret the small and big active phases as an extreme case of dwarf nova outbursts and superoutbursts of SU UMa - type.

Our constant monitoring (850 spectra since 2012) allows tracing the evolution of the last superoutburst illustrated in Fig. 4 (a). The equivalent width of He II peaked (EW $\approx$ 18) in 2015 then declined monotonically until 2020 followed by a plateau with a remarkable burst to EW $\approx$ 12 in 2022 around JD 2459800. The high cadence coverage allowed us to detect precisely the end of the big active state in 2023 April on JD 2460046 ± 5 (Teyssier et al., 2023) with the sudden decrease of the equivalent widths of the emission lines (Balmer, He II, HeI) as shown in Fig. 4 (b) (Hα equivalent width).

Since then, both the lightcurve and the spectrum continue to evolve as before the active state according to double waved orbital phase shown in Fig. 4 (c). Ephemeris: JD =2435687.6 (±1.3) + 227.67 (± 0.02) E (Lines et al., 1988).

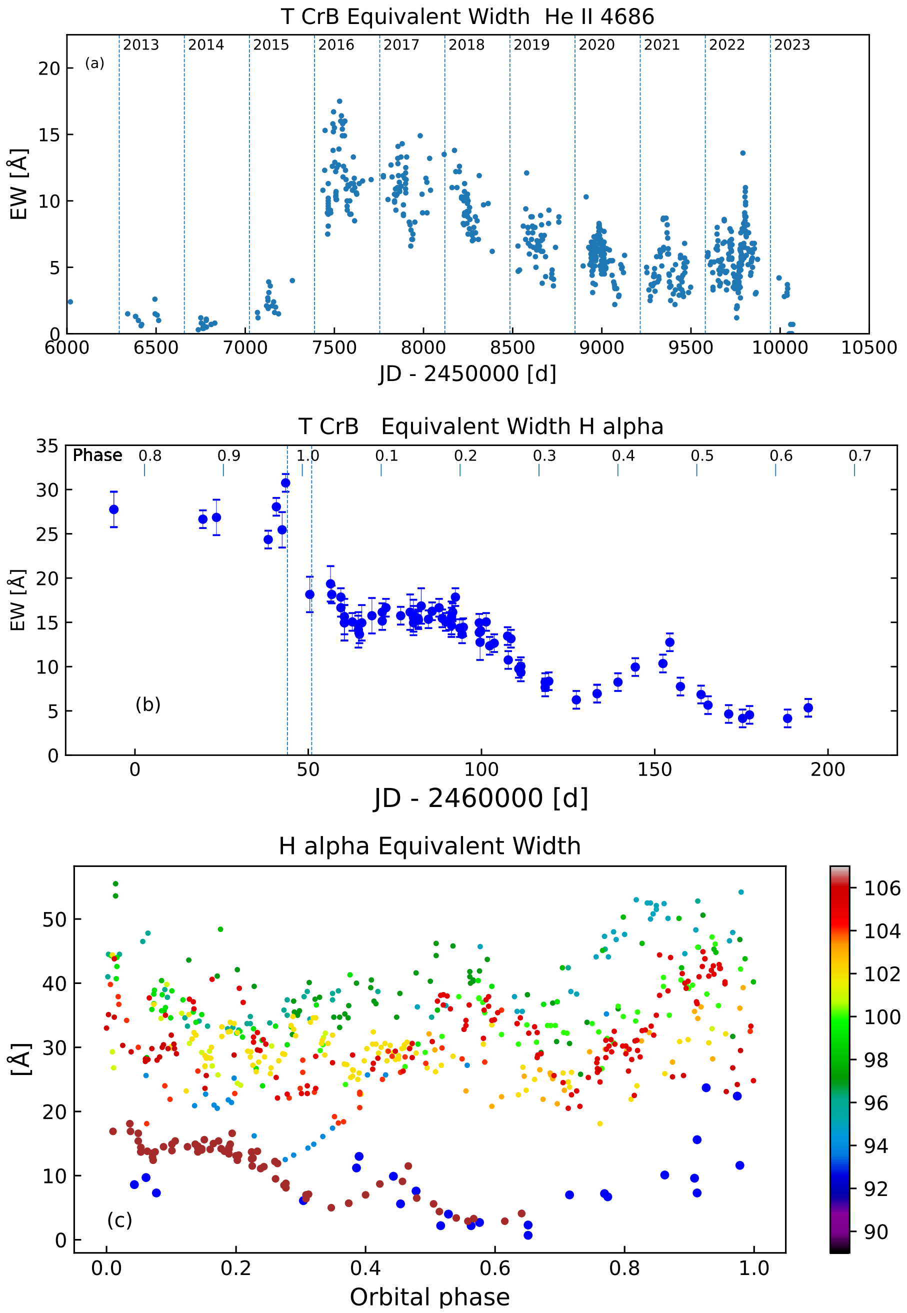

Figure 4. T CrB. Equivalent width of He II 4686 Å during the big active state 2015-2023. (a). The detection of the end of the active state in April 2023 (b). Variations of Hα equivalent width according to the orbital phase. The current cycle (brown) matches with the last cycle before the active state (blue) (c)

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