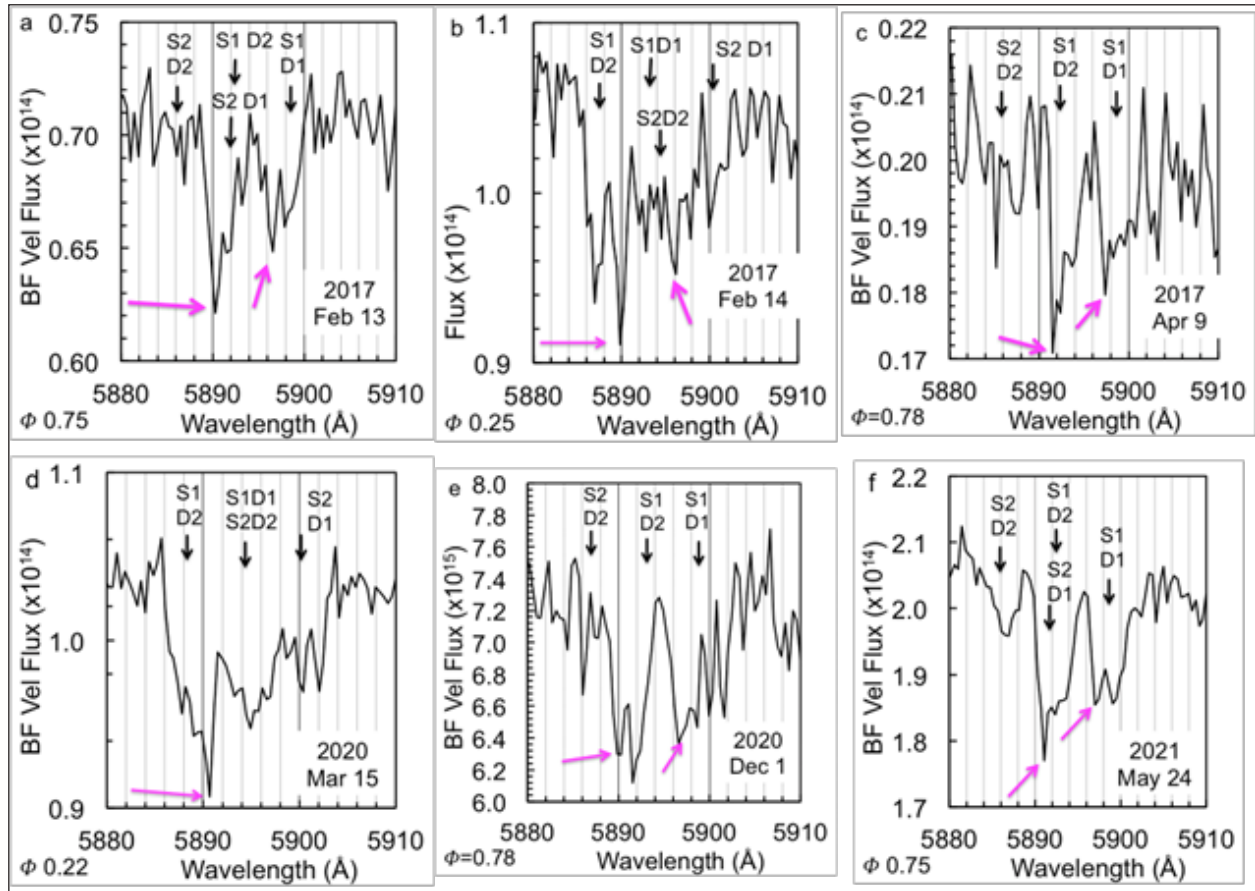




Spectra of the BF Vel Na I D couplet at various orbital phases (ϕ) with $R=7000$. David Moriarty used the ANU 2.3 metre telescope and wide field spectrograph at Siding Spring Observatory to observe spectra of several close eclipsing binaries. See David's article on page 26

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From the Director – *Mark Blackford*

Welcome to the third edition of the Newsletter for 2022, a bumper issue with articles from regular contributors and several new ones. I'd like to thank all the authors for sharing their projects with the community, in particular Lia Marta Bernabò in Berlin and Ari Siqueira in Brazil. Lia is PhD Student at German Aerospace Center (DLR) researching the internal structure of exoplanets using radial velocity curves, transit light curves and transit time variations, some of which have been provided by VSS member Carl Knight. Ari, a retired associate professor of biochemistry, recently joined VSS and wishes to expand the observations of Be stars in the Southern hemisphere, which are relatively less studied than their counterparts visible in the Northern hemisphere.



The 2022 RASNZ Conference was by all accounts a successful meeting. I would like to congratulate Nalayani Davies on her appointment to the role of RASNZ President. Congratulation also to Alan Gilmore who was recognised with the President's Award and Dr Duncan Steel who received the 2022 Murray Geddes Prize.

The program of presentations for the VSS online symposium is starting to take shape. See elsewhere in this Newsletter for details.

June saw a trio of bright(ish) southern optical transients. The first was an outburst of the recurrent nova U Sco reported by a Japanese amateur. See AAVSO Alert Notice 779 for details. A week later AAVSO Alert Notice 781 announced a nova in Musca (N Mus 2022) discovered by the All-Sky Automated Survey for Supernovae. Finally, congratulations to VSS member Andrew Pearse on discovering an optical transient in Circinus which ASAS-SN data showed peaked at g-magnitude 10.9. See Andrew's article on page 14.

My thanks to David O'Driscoll for his work improving the VSS website, including transitioning to the new platform which has greatly improved speed and ease of maintenance. Project leaders are gradually updating the content of various webpages, this will be an ongoing task as projects develop.

Observing conditions in June and early July have been quite good at Congarinni observatory, by far my most productive period since mid-November 2021. Some 21 eclipsing binaries were observed over 23 nights. I now have a backlog of about 11,000 images in need of analysis. I hope you've enjoyed some good observing conditions as well.

Wishing you all clear skies and good health,

Mark Blackford

Sixth VSS Symposium – Mark Blackford

The sixth VSS symposium will be a virtual meeting via ZOOM which is planned to run over three consecutive Saturdays, September 17th, September 24th, and October 1st. Each day will consist of one session of 3 to 4 presentations, lasting approximately 2 hours. Talks will be 30 minutes including question time, however longer or shorter presentations could be accommodated if necessary. We have the option of longer sessions or adding more dates if we get lots of talks.

The start time of each session is yet to be decided but it will be mid-afternoon Sydney time which should be convenient for those of us in Australian and New Zealand who we expect will make up the majority of participants. Presentations will be recorded for those who can't attend the live sessions.

There will be no charge, but people will need to register their intention to participate in the ZOOM sessions. More details will follow as they come to hand.

Poster presentations can be submitted in PDF format and will be viewable via links on the VSS website.

We hope to have a Q&A session to discuss topics that may not come up during normal presentations. If you have a particular issue (of an astronomical nature) please let us know beforehand.

In alphabetical order by speaker surname we have the following presentations so far:

Roy Axelsen	Variable star photometry with a ZWO ASI1600MM camera and the Star Adventurer Pro
Lia Bernabo	Constraining the Love numbers h_2 and k_2 of exoplanets
Ed Budding	Close Binary Stars attracting Recent Interest
Jeff Byron	Improved Time-of-Minimum Estimates of EW binary stars using JK-LC
Arne Henden	Twenty Years of V838 Mon
Arne Henden	AAVSOnet's southern nodes (especially in relation to building your own robotic system)
Carl Knight	Locating non-transiting exoplanets by transit timing variation
Tom Love	Wrangling photons: doing spectroscopy with small telescopes
Tom Love	Variable stars: what you can do with a rainbow
David Moriarty	Spectroscopic and photometric analyses of several eclipsing binary systems with pulsating components and complexities of determining radial velocities in systems with three components
Andrew Pearse	FQ Circinus - A Strange Nova?
Stan Walker	Dual Periods in Cepheid Variable Stars
Stan Walker	Dual Maxima Mira Variables - What Causes this Behaviour?

We would like to hear from others who are considering giving a presentation.



New reductions of LMC variables in UOC43– *Mati Morel*

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Abstract

A reduction of positions, from plate grids, has been carried out for a handful of variables in UOC43. This data may not have been taken into account previously, but yield useful results for several stars - V0059, V0073, and possibly two more. The suitability of the old plates is suspect.

Introduction

In the course of updating the 4801 LMC variables (Morel 2020) named in the GCVS *Catalogue of Extragalactic Variable Stars* (Sanus et al 1995, 2002) I came upon many which were not identifiable at that time. I have done more work on one small set of discoveries published by Innes and Wood (1918), hereafter abbreviated as **IW**. I reproduce their Table II (30 stars) as **Figure 1**. Plate numbers and in-house grid coordinates (**B and A**) are included. I have inserted the GCVS designations under the heading ‘LMC’. About 20 of the **IW** stars have also been found at Harvard, including two which **IW** missed. These HV stars are identified correctly by Hodge & Wright (1967).

UOC43, 379 (1918)												Table II.—Variable Stars.	
Plate.			1875.		Mag.		Harvard.					Remarks.	LMC
No.	B.	A.	R.A.	Dec.	Old.	New.	No.	x.	y.	M.	m.		
			h. m.	° ' "									
4762	31.1	17.8	4 46.2	−68 40.7	12, 14	12½, 13½		—800	11000			Fine, very short-period variable.	V0028
4762	33.4	6.8	4 49.0	−69 34.4	16	15		300	7800				V0043
4762	34.7	9.7	4 49.8	−69 20.0	14½	12½		500	8750			On north edge of a cluster.	V0057
4762	34.8	9.2	4 50.0	−69 23.0	15½	13½		550	8600				V0059
4762	35.0	6.2	4 50.5	−69 36.4	16½	14½		750	7750			Fine variable. = HV2236	V0073
4760	35.4	18.9	4 52.9	−66 30.7	16	15		300	19000				V0160
4762	41.2	3.2	4 55.8	−69 52.0	15½	14	2245	2650	7000	14.2	15.0	Is 0' .5 p. a cluster.	V0258
4761	41.2	27.3	4 55.8	−69 52.0	14	13½	2245	2650	7000	14.2	15.0		V0258
4762	43.7	25.4	4 57.7	−68 1.0	16	12½	2244	2750	13800	13.8	15.0	Is the S.p. of a pair 0' .3 apart, other 13th mag.	V0396
4760	49.5	0.9	4 57.7	−68 1.0	13	14	2244	2750	13800	13.8	15.0		V0396
4762	44.3	12.3	4 59.0	−69 9.9	15½	14½		3400	9750			End star of a row of four.	V0444
4762	45.7	23.3	4 59.8	−68 13.9	16	13½	2253	3300	13100	14.3	14.9		V0523
4760	45.7	3.9	5 1.0	−67 49.2	15½	14	2256	3800	14700	14.7	15.7		V0649
4762	46.4	10.1	5 1.0	−69 18.2	16	14		4000	9250				V0586
4760	46.4	7.7	5 1.7	−67 32.5	11½, 13	12	2258	3950	15950	13.4	14.4	Short-period variable.	V0694
4762	47.8	22.3	5 2.0	−68 16.4	12½	16	884	4100	12950	11.4	15.5		V0672
4762	50.1	17.3	5 4.3	−68 40.7	16	13½		5000	11550				V0831
4762	50.3	12.9	5 4.8	−69 2.4	15½	13	2291	5150	10300	14.3	15.0		V0832
4762	51.4	25.4	5 5.0	−68 0.0	16	13		5100	14050				V0899
4760	41.7	0.9	5 5.0	−68 0.0	14½	13		5100	14050				V0899
4762	50.9	14.7	5 5.0	−68 54.8	15	12½	892	5300	10800	13.8	14.5	Between a nebula and a 13th mag. star.	V0880
4762	50.9	12.3	5 5.5	−69 6.6	15	13½		5350	10050				V0915
4762	52.5	9.6	5 6.4	−69 19.7	16	14½	893	6000	9400	13.4	14.9		V1032
4762	53.7	15.6	5 7.5	−68 49.2	13	14½	2319	6100	11150	13.3	15.0		V1080
4762	53.6	15.7	5 7.6	−68 49.0	15	14	2320	6150	11100	15.1	15.8		V1084
4762	53.7	13.5	5 7.6	−69 0.0	15	13½	2323	6100	10500	14.5	15.2		V1077
4762	55.8	11.4	5 9.5	−69 10.3	15½	13½	2339	6800	9950				V1219
4763	33.9	18.1	5 10.5	−70 36.6	9½	11½	909	7400	4700	12.5	13.7		V1270
4763	40.8	21.9	5 15.5	−70 18.0	15½	13½	2421	9600	5900	14.9	15.6		V1847
4763	41.7	25.7	5 18.5	−69 59.3	inv.	14½	2429	9700	7000	14.5	15.1		V1909
4726	44.6	11.6	5 21.2	−69 9.3	9½	14½	2483	10600	10100	14.0	14.7	0' .3 N.f. C.P.D. -69°362	V2139
4726	48.8	2.8	5 25.2	−69 53.0	10½	13½		11900	7500			In a dense part of the cloud.	V2426
4763	51.7	24.4	5 28.2	−70 5.8	12½	10½	2540	12800	6700	13.9	14.8	Red star or nebulous.	V2671

Figure 1. Table II from Innes and Wood paper on their discoveries in the LMC. Referred to in the text as **IW**

Coordinates

The B1875 coordinates given by **IW** are only rough. My experience with them shows that they are particularly unreliable compared to modern astrometry and are to be treated with caution. Fortunately two other paths are available, hopefully more accurate. See **Figure 2**.

- An XY coordinate grid (referred to a particular Harvard plate) exists for HV stars. These have been copied by **IW**. For stars unknown to Harvard **IW** strived to emulate the Harvard system using the resources at Union Observatory. Their results are listed in the same x and y columns.

- Plate grid readings are given for each star, labelled “B” (RA) and “A”, (Dec.). One grid unit = 300”. It appears that the original plates were of compressed scale, which limited the degree of accuracy. **IW** concede that their scale readings are still only approximate, and are completely separate from XY values. Being reported to the nearest 0.1 unit, this implies $\pm 30''$.

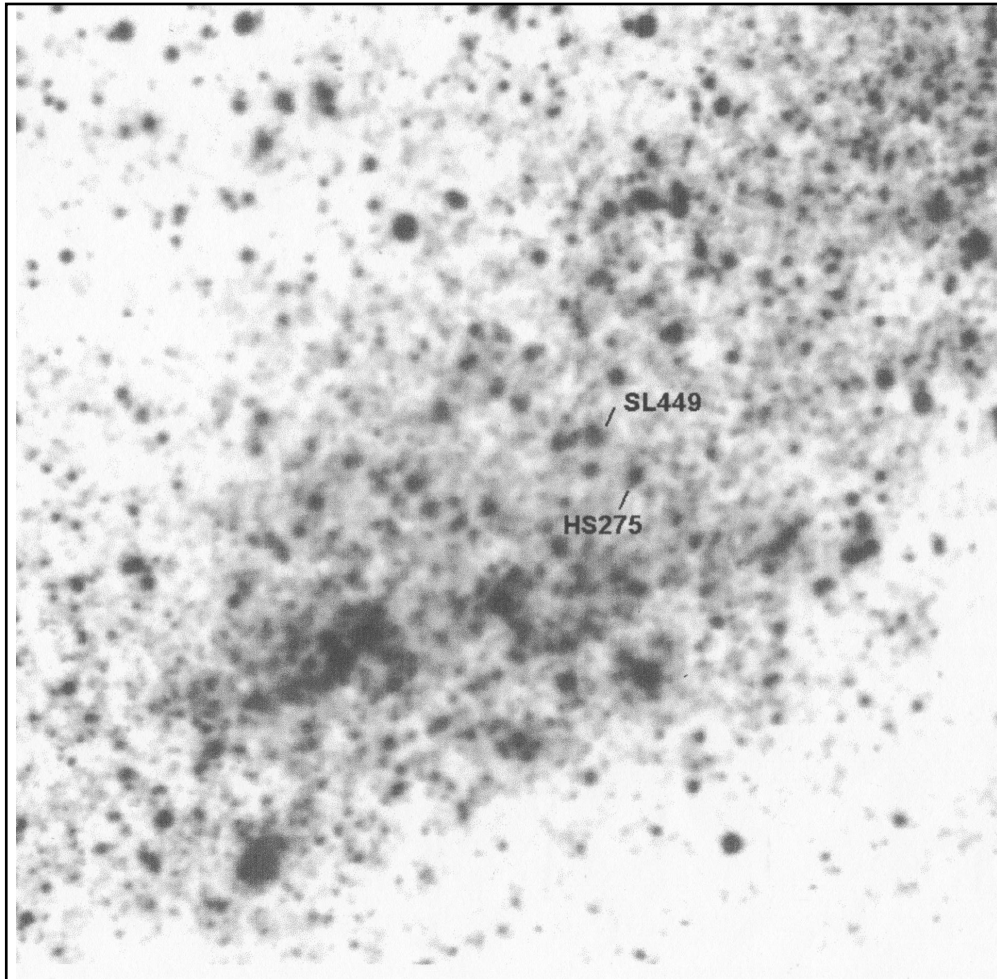
Having three positions to study, for most stars, and reduction to ICRS (J2000) coordinates, it is possible to draw some reasonable conclusions about each object. Most stars were on plate 4762 with numerous HV stars with precise positions, for reference. Many years ago Radcliffe Observatory, South Africa, published a reduction of Harvard HV and HDE stars (known only by XY coordinates) to B1875 coordinates. This publication was titled “Memorandum 1” (1961).

I give the **IW** grid units high weight, followed closely by Harvard XY. The 1875 coordinates, adjusted to J2000.0 are usually given a low weight.

Results

- **LMC V0043.** (J2000) 04 47 44 -69 21 30 as reduced from **IW** grid position, plate 4762. No star at this spot. Lies 54” due N of NGC 1695, OC. Gaia EDR3 lists a tight group of three stars close to cluster centre, as follows, for J2000:
 1. 04 47 44.00 -69 22 24.3 G = 15.23
 2. 04 47 43.95 -69 22 26.1 G = 15.39
 3. 04 47 44.28 -69 22 24.5 G = 15.48
 Combined G = 14.2
- NGC 1695 = HDE 269626 sp. G. I suspect that this may be the source of the IW observations. The Harvard XY position is further east by RA 8.8s, and further N by 16”. The IW 1875 position is even further east, at 04h48m20s, and rejected. **POSSIBLE ID.**
- **LMC V0059** (J2000) 04 49 13.6 -69 09 55 reduced from plate 4762. Position from Harvard XY is reduced as 04 49 12.76 -69 09 40.2 Posn. of V0056 = HV 12451 : 04 49 12.46 -69 09 39.6 Good positional coincidence.
There is little doubt that **LMC V0059 = LMC 0056 = HV 12451.**
- **LMC V0073.** In previous work on the LMC variables (Morel 2020) I had already determined that **V0073 = V0061 = HV 2236.** **IW** describe V0073 as a “fine variable” but not cross matched. For comparison, the XY coordinates are as follows:
V0073 : X = 750 Y = 7750 **IW** emulation of Harvard system
V0061 X = 804 Y = 7662 HA109 (1942), HV 2236
- The **IW** 1875 position is erroneous, too far east by 25^s. No suitable candidate at that spot. V0061 is a confirmed variable M1 star. The XY coordinates are not brilliant, but from Gaia EDR3 we get: LMC V0061 : (J2000) 04 49 22.47 -69 24 34.3 LC, 14.9 - 15.8p sp. M1.
- **LMC V0586.** (J2000) 04 59 56.5 -69 06 11 Emulation of Harvard XY (reduced) by **IW**. The 1875 position by **IW** (adjusted) differs significantly at 05 00 18.7 -69 07 30. A position reduced from grid coordinates of plate 4762 has been rejected, being unreliable due to lack of suitable nearby reference stars. **NOT FOUND. LOST.**
- **LMC V0831.** Bad scatter of 3 available positions, with wide range in RA from 05 03 14 to 05 03 48.6. Declinations, as reduced, agree reasonably well, mean -68 30 35. **NOT FOUND. LOST.**
- **LMC V2426.** “In a dense part of the cloud”, acc. to **IW**. Three available positions are rather similar (within margin of error) but no star of 13^{mag} or brighter is in the vicinity.
(J2000) 05 24 06.8 -69 46 35 Transformed from 1875 position
" 05 24 10.9 -69 46 35 Grid position from plate 4726
" 05 24 12.5 -69 45 41 Harvard XY, emulated by **IW**.

The reliability of this data is unknown due to a severe lack of reference stars. The small open cluster [HS66]275 lies about 10s following, but unknown until 1966. Refer to **Figure 2**, an enlarged print of this region, taken with an 8" Schmidt-Cassegrain telescope in 1987 (courtesy of Manuel Lopez Alvarez, Argentina) He stated that under ideal conditions he could reach 16^m, but in the LMC Bar faint stars can be hard to discern, whereas even a minor cluster such as HS275 can be identified as a bright “star”. Otherwise this VS is **NOT FOUND**.



concluding remarks

The plates cited by IW, 4726 and 4762, were taken at Cape and lent to Union Observatory. These were the “old” plates, with the following details :

Plate 4726 exp. 1898 Jan. 21 Plate 4762 exp. 1898 Feb.25

I note the related remarks on page 377. HEW states : *(The plates) were not really suitable for critical examination in the stereocomparator; as the earlier plates were experimental plates with long exposures (about four hours),and had doubled or trailed images.*

New plates were taken on 1917 Oct,25 and 1912 Jan. 19 respectively. Aside from the difficulty of getting accurate positions in or near the LMC bar, I believe there may have been problems with the available plates, in attributing what was actually being observed (clusters vs stars) for at least two objects. This was a tricky area, for many decades!

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- Innes, R.T.A. and Wood, H.E. 1918 Union Observatory Circular 43, 377-379
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Abstract

Some 150 years ago Father Angelo Secchi (1818-1878) conducted an extensive spectroscopic study of thousands of stars – visually, with no photographic cameras – using the Vatican’s Observatory telescope. Noting the presence of absorption lines in the spectra of the stars and their color ranges, he set the foundations for the modern stellar classification based on their decreasing temperature.

He also detected H- β emission in γ Cassiopeia (γ Cas, B0.5 IV), creating the concept of a B star subtype capable of emitting electromagnetic radiation at 4861.35 Å, the Be stars. ‘B’ for the stellar temperature class, ‘e’ to indicate the presence of electromagnetic emission lines. At the time, he wrote: “a curious feature... a very beautiful light line and much brighter than all the rest of the spectrum.”

The most common and broad definition of a Be star is: *A non-supergiant B star whose spectrum has, or had at some time, one or more Balmer lines in emission* (Jaschek et al., 1981; Collins, 1987). Be stars are very rapidly rotating main sequence B stars, which, through a still unknown process, form an outwardly diffusing gaseous, dust-free Keplerian disk.

Be stars are at the centre of intensive research. They offer a precious opportunity for the study of the dynamics of stellar evolution and various astrophysical processes while holding many unsolved puzzles, as will now be detailed.

Introduction

Be stars are very rapidly rotating and non-radially pulsating B stars, forming a ‘decretion disk’, that is, an outwardly diffusing gaseous Keplerian disk. This disk is fed by mass ejected from the central star, and its subsequent destiny is dictated by the viscosity of such media (Pringle, 1992).

Until quite recently, Be stars did not attract much attention. Currently, these B-type stars are the subject of several extensive reviews and international conferences. It has been realized that Be stars provide an excellent opportunity for the understanding of upper main sequence astrophysics. Chances are now available for amateur astronomers to contribute to the field with photometric and spectroscopic observations of increasing quality. Actually, thousands of spectra are being made available to the ProAm community by means of the Be Star Spectra Database (BeSS; Neiner, et al., 2011, <http://basebe.obspm.fr/>), among other initiatives. It is also the right time to evaluate, especially in the Southern skies, which Be stars deserve more attention from the amateur photometrists, preferably in concert with ProAm conducted spectroscopy. To better understand the nature of the Be phenomena, monitoring of Be stars by photometric methods is highly desirable as accumulating evidence relates their short-period luminosity variability to simultaneous changes in their spectral profiles.

This short and limited review will concentrate on the classical Be stars, distinguishing them from other Be subclasses and similar spectral emission stellar bodies which are not the result of the same phenomena.

The Be star family

Be stars are not alone in displaying circumstellar spectral emission lines. Several other B stars do the same, at specific moments in their evolution. Luminosity classes III and IV (Giants), and V (Main Sequence) may also do so. However, they do it in other ways: stellar objects of different kinds may present visual electromagnetic emissions triggered by distinct phenomena. They are:

- **Supergiants:** some supergiants produce weak H α emissions which do not come from a disk but from strong hot winds;
- **Herbig Ae/Be:** being young stars in the final stages of their accretion phase, some Herbig Ae/Be more active sub-types produce emission lines with variability very distinct from those of the classical Be stars. Their quieter sub-types, however, can be confused with classical Be stars but, under

closer examination, may be found to display strong dust-related infrared excess which will set them apart;

- **Mass Transferring Binaries:** B-type primary components of mass transferring binary systems exist, such as Algol and WUMa variables, in which the secondary component fills the Roche lobe and the accretion disk gives rise to emission line(s). They are obviously a different breed, for no classical Be star has been found to have a Roche lobe filling companion;
- **B[e] Stars:** they form a heterogeneous group of B stars – of which five subgroups are described – showing Balmer line emission plus forbidden emission lines¹ (Lamers et al., 1998). Forbidden emission lines are not observed in classical Be stars;
- **Magnetic B stars:** depending on the field strength, wind, mass-loss, and rotation, these objects can have Balmer line emission forming in the magnetosphere (Petit et al 2013). Their circumstellar environment shows variability with strictly the same period as the photosphere’s rotational one, and little to no secular (long-term, non-periodic) variation, which distinguishes them from classical Be stars;
- **Other star types:** stars belonging to the O, A, and F types may produce spectral emission lines similar to the classical Be spectral profiles but it seems wise not to place these objects in the same basket, being such objects quite distinct in other aspects.

The way of life of classical Be stars

The classical Be stars – or simply ‘Be stars’ – are not rare objects, but correspond to about 15-20% of the B stars.

The most conspicuous characteristic of Be stars is their variability on all time scales from a few minutes to much longer. Their emission lines are transient, by definition. The emission may last for several decades. The observable changes can be monitored photometrically and this inspired the creation of the γ Cas class of variable stars, the ‘eruptive variables’ of the General Catalogue of Variable Stars.

Variability in the electromagnetic emission profile is also quite common. An example is the “violet-to-red cycles” (V/R variations), in which the two peaks of the H- α emission lines vary in height against each other. Events in the close circumstellar environment or the stellar surface cause variability on time scales of a few days.

The stellar rotational and typical pulsation periods and the Keplerian orbital period close to the star are very similar, and so are the viscous transport times through the inner disk, taking a few days to weeks, at most. While most photospheric variations are pulsational, the circumstellar environment contributes to cyclic phenomena, and with more secular variations in which the orbiting material is distributed radially. Stars in which such short-term periodic processes dominate the photometric variations are termed “ λ -Eri variables”².

¹ Forbidden lines, in astronomical spectroscopy, are bright emission lines in the spectra of certain nebulae (H II regions), not observed in the laboratory spectra of the same gases, because on Earth the gases cannot be rarefied sufficiently. The term forbidden is misleading; a more accurate description would be “highly improbable”. The emissions result from electrons in long-lived orbits within the radiating atoms – *i.e.*, the transition from an upper energy level to a lower energy level that produces the emissions requires a long time to take place. As a result, emission lines corresponding to such atomic transitions are extremely weak compared with other lines. In the laboratory, moreover, an excited atom tends to strike another particle or the walls of the gas container before it emits a photon, thereby further reducing the possibility of observation. In an H II region in interstellar space, by contrast, the atom will remain undisturbed long enough to emit the photon.
(<https://www.britannica.com/science/forbidden-lines>)

² λ Eridani Variable is a class of Be stars that show small amplitude variations of a few hundredths of a magnitude. The variations are highly regular with periods between 0.5 and 2.0 days, and they were initially described as periodic Be stars (Balona, L. A., 1995). λ Eridani is the prototype. This has been ascribed to non-radial pulsations, inhomogeneous rotating discs, or the rotation of the star itself (Jerzykiewicz et al., 2011; Carrier et al., 2002). These stars are rarely classified or are classified incorrectly. The General Catalogue of Variable Stars does not have a type for Lambda Eridani variables, only GCAS for γ Cassiopeiae variables and BE for non-GCAS Be star variables. λ Eridani itself is incorrectly listed as a β Cephei variable (Samus et al. 2017). The AAVSO International Variable Star Index defines a LERI type of variability, with 16 stars included as λ Eri variables, five

Time scales shorter than about half a day are often due to β -Cephei type pulsation modes when periodic, in particular in earlier type Be stars, but in later type stars, it is more common that the associated phenomena are transient.

Be stars' unique properties, their proximity in our galactic neighborhood, and a convenient brightness range, make them well accessible to observation and study with instruments available to the amateur astronomers. They, and possibly their non-emission line equivalents, the Bn stars, form the speediest rotating class of non-degenerate stars in terms of $V \sin i$, and possibly with respect to the fractional critical rotation. This makes them excellent objects to study the effects of rapid rotation.³

Having left the main sequence, the earliest B stars are counted among the “massive stars”, i.e., they have masses equal to or greater than $8 M_{\odot}$ and will evolve into core-collapse supernovae.

In several astrophysical systems, the interface regions between a comparatively compact object and its more extended environment are often marked by a gaseous disk. Be disks have exactly the same physics as the well-studied accretion disks around protostars but are called instead “decretion disks”, in reference to the fact that in Be disks mass is usually flowing away from the star whereas in protostar disks matter flows inwards. Within binary systems, the Be disks are subject to important and complex processes: precession, warping, tidal deformation, truncation, and, most importantly, viscosity, which will govern the fate of these disks.

Be Spectral Lines

The spectral lines intrinsic to Be stars can come from three regions: the star itself, the actual disk, and the circumstellar environment above the disk, up to the polar regions.

The appearance of the photospheric spectral lines is governed by the rapid rotation but not only through rotational broadening. In addition, the near-critical rotation alters the photospheric properties of the star itself. The other important process affecting the photospheric line profiles is stellar pulsation.

Typical appearances of Be star emission lines are shown in the lower part of Figure 1.

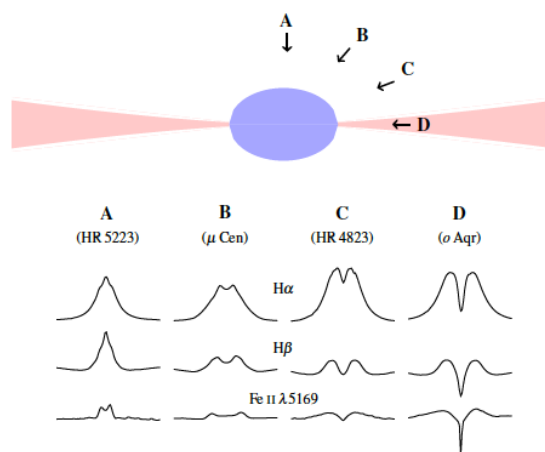


Figure 1. Schematic view of a Be star at critical rotation and with an expanded disk. At the bottom, spectral profiles from pole-on to shell Be stars are exemplified (Rivinius et al., 2013).

of them only suspected, and 13 combined with other types of variation (Otero et al., retrieved in 14 May 2022).

3 A star's rotation can be measured by looking at the broadening of spectral lines, and from this, we get the projected rotation rate, $V \sin i$, and possibly information on differential rotation and limb darkening. Since it is the Doppler effect that produces the broadening of spectral lines, only the line-of-sight component of the rotation velocity is involved. The angle i is between the line of sight and the rotation axis of the star. Pole-on view has $i = 0$, no rotational broadening; equator-on view has $i = 90$ degrees, maximum rotational broadening. The rotation period can be measured by detecting rotational modulation caused by a non-uniform surface on the star. Spectroscopically, we see rotation in the broadening of the spectral lines (Gray, D.F., <https://physics.uwo.ca/~dfgray/rotation.html>, retrieved on May 16, 2022).

The hydrogen lines are widened and recombination is the main underlying process, while many metal lines are thin. At polar and equatorial inclinations additional effects are noticeable. For optically thick lines, non-coherent scattering broadening shifts the peaks at polar inclinations and creates the profile seen in H- α and H- β of row A of Fig. 1. At equator-on inclinations, the disk is self-absorbing and also veils the star, with narrow and deep absorption lines being formed (row D of Fig. 1). The double-peak emission structure is not always symmetrical, the ratio between the two peaks, V/R, usually varies cyclically (Hummel, 1994).

Rapid rotators

Several Be stars seem to rotate very close to or at the critical boundary. One must be reminded that there are non-Be rapidly rotating B stars. E.g., α Leo (B8 IV) rotates at $W = 0.81$ (McAlister et al., 2005), and the entire spectral class of Bn stars is defined as rapidly rotating B, with no Balmer emission seen. For the Be stars, several studies point to a mean rotation value of $W = 0.75$. Townsend et al. (2004) pointed out that this is the consequence of a W upper-detection threshold.

In summary, the key properties of the Be star rotation are (Rivinius et al., 2013):

- The measured W for Be stars is ≈ 0.8 ;
- Some of these must rotate more rapidly;
- The minimum W for a B star to become a Be star is ≈ 0.7 ;
- There is a value of W above which all B stars become Be stars.

Pulsation

Multi-periodicity of Be stars is now routinely observed since Walker et al (2005) first reported from space-based observations. Only early-type Be stars pulsate strongly enough to be detected from the ground. Nevertheless, pulsation extends to late-type Be stars, though with smaller amplitudes. All Be stars, regardless of spectral subtype, that were analyzed with high-cadence, long-duration space-based photometry data have been reported to be multi-periodic and pulsate. So, it is accepted that Be stars are non-radially pulsating stars in general.

Be stars are not alone as pulsating stars in their region of the Hertzsprung-Russell diagram. Plain B stars have been found to pulsate in the entire range. However, non-pulsating normal B stars exist as well, even as early as B0.5 IV.

Pulsation in Be stars can be sorted into several types:

- In the earliest Be stars, down to about B3, β Cep-type pulsation can be present;
- All over the Be range, periods with about 0.5 to 2 d are found, for which different mechanisms have been proposed: Low- l g-modes; a variant type of Rossby waves (r-modes); for some stars and frequency, rotational;
- Occasionally, very low frequencies;
- During outbursts, g-mode frequencies arise.

Be star disks

Once the disk has formed and is well-settled after an outburst that replenished the disk material, it stays in Keplerian rotation, geometrically thin, and in vertical hydrostatic equilibrium. Its further evolution is then dictated by viscous processes. As long as the material with Keplerian properties is added to the inner part of the disk, material and angular momentum will be transported outwards. In a steadily fed disk, material transported outwards will eventually cross a critical radius and leave the system. As soon as the mass injection fades, the disk will gradually turn into an accretion mode, with matter falling back to the star (Rivinius et al., 2013).

The viscous decretion disk model has successfully been used to explain V/R variability in Be stars and the observed photometric variations in disk build-up and decay. Long-term photometric databases, such as

OGLE (<https://ogledb.astrouw.edu.pl/~ogle/photdb/>) or MACHO (Hog et al., 1995), hold a great potential to be harvested, and spectroscopic databases, such as BeSS, are catching up.

One interesting subject is that of Be evolution. As a Be star evolves beyond the main sequence, the drop in surface rotation due to the expansion will stop the Be mechanism, and the circumstellar disk will dissipate. However, the fact that the evolved star has been a Be star may affect the post-main sequence evolution, at least because the fast rotation has altered the stellar and chemical evolution. According to Yoon et al. (2006) and Georgy et al. (2009), the most massive Be and Oe stars could become S Dor variables, especially at low metallicity. That remains to be confirmed.

The photometry of Be stars

Acknowledging that Be stars have generally been characterized by the emission lines in their spectra – and especially by the time variability of those spectroscopic features –, that they are known to also exhibit photometric variability at multiple timescales, but have not been broadly compared and analyzed by that behavior, Labadie-Bartz et al. (2017) conducted a comprehensive analysis of brightness variations among a large number of known Be stars. The photometric data came from the KELT transit survey, with a typical cadence of 30 minutes, a baseline of up to ten years, photometric precision of about 1%, and coverage of about 60% of the sky.

Labadie-Bartz et al. (2017) remarked that:

- Be stars are highly variable, with greater photometric variability seen in earlier spectral types;
- About one-fourth of Be stars have photometric outbursts at semi-regular intervals;
- Intermediate periodicity, longer than two days, is common in 38% of the sampled data;
- By combining KELT data with BeSS spectra, evidence was provided that photometric outbursts correspond to disk creation or disk building events, and global disk oscillations manifesting in V/R variability can also modulate the brightness of a Be star/disk system;
- Some systems listed as classical Be stars in the BeSS database have been misclassified as such.
- It is recommended that future work increases the statistics with larger sample sizes and baselines, more detailed investigations of particularly interesting systems and a more thorough treatment of the Be stars variability types.

It can be verified in Table I, based on the records available in the BeSS Database as of May 2022, that the Be star population visible in the Southern hemisphere has been much less observed than their counterparts from northern latitudes. Therefore, it would be highly desirable to concomitantly perform the photometry and spectroscopy of selected Southern Be stars to follow their brightness and spectral variations for a meaningful time.

Table 1. *Statistics of BeSS Database records of Be-like stars*

Objects and Spectra	Northern Hemisphere	Southern Hemisphere	Total
Classical Be stars	34%	66%	1,946
Classical or Herbig?	6	4	10
Herbig Ae/Be	29	25	54
B[e]	9	2	11
Total H- α emitting stars	708 (35%)	1,313 (65%)	2,021
Spectra of Northern Hemisphere Be stars	85%		
Spectra of Southern Hemisphere Be stars	15%		
Spectra by professionals	24%		
Spectra by amateurs	76%		
Total spectral records	259,389		

Out of the 1,313 Be, Herbig Ae/Be, and B[e] stars registered in the BeSS Database to date (May 16,

2022), located in the Southern celestial hemisphere, 673 objects (51%) have not had a single spectrum recorded; 429 have 1 to 5 spectra. Ninety-three Southern stars have been extensively studied, with 50 or more spectra deposited. Del Sco (HD 143275) has 6,069 spectra.

Several online tools were made available by European amateur astronomers that can provide a sure path for their colleagues in the Southern hemisphere to tackle the challenge. Among them:

- **The Be Star Spectra Database, BeSS:** containing the complete catalog of classical Be stars, Herbig Ae/Be stars, and B[e] supergiants. It assembles spectra obtained by professional and amateur astronomers. The database is maintained at the LESIA laboratory of the Observatoire de Paris-Meudon; as of this date (May 15th, 2022), there are 2,330 Be stars in the BeSS catalogue and 399,560 Be star spectra deposited, of which 98% refer to classical Be stars, 1,66% are from Herbig Ae/Be stars, and 0,44% are B[e] spectra. Roughly 10% of the 180 BeSS registered observers deposited more than 93% of the spectral data. As of 2019, 86 publications used data extracted from BeSS (<http://basebe.obspm.fr/basebe/>);
- **The ArasBeAm:** launched in Feb 2007, it was created by a group of amateurs. The goal of ArasBeam is to coordinate amateur Be spectroscopic observations, to have the best coverage in time and stars. The main objective for ArasBeAm program is to detect and track outbursts. Records of any sort are welcomed, as also mid- and long-term evolution in Balmer line profiles, mainly H- α . ArasBeAm is based on BeSS data (<http://arasbeam.free.fr/>).

Concluding remarks

In retrospect:

- Be stars form a rapidly rotating subset of non-giant B-type stars exhibiting line emission attributed to a gaseous circumstellar disk in Keplerian motion;
- This circumstellar viscous decretion disk is formed and subsequently sustained by mass ejected outbursts;
- If the flow of material from the Be star stops, the disk dissipates;
- Near critical stellar rotation combined with non-radial pulsation (NRP) might play a role in the mass transfer mechanism;
- Be stars exhibit variability in their brightness and spectral features across a large range of timescales, from hours to decades, often give insight into the physics of these changes;
- Periodicity on shorter timescales of hours to days is typically attributed to stellar NRP;
- Outbursts and quasi-periodic oscillations are typically found on intermediate timescales of days to months, though outbursts occasionally last for years.

Because they are relatively easy to observe and their basic nature has been established, Be stars are good model systems to investigate crucial astrophysical matters. An enormous amount of information about Be stars is already available but they still hold secrets that may be unveiled with the cooperation between amateur and professional astronomers. In this matter, what counts for the amateur astronomy community with access to the Southern skies is that much can be done in regards to Be star observations with smaller and simpler instruments, preferably by simultaneous photometric and spectrometric data recording.

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I've been visually observing variable stars on and off for 40 years originally submitting all my observations to RASNZ VSS and then more recently the AAVSO. Whilst it's something that I'll keep doing going forward and enjoy, my eyes are not as good as they used to be and it's become a challenge to make a lot of observations and my efficiency has dropped off.

A few years ago, I was thinking of other options I could pursue with VSOing and came across DSLR's. I'm not at all technically minded and have only very basic levels of mechanical and electronic understanding of imaging systems. I purchased a second-hand Canon 1200D DSLR camera and a 100mm lens and thought I could perform some DSLR photometry. I was given some good early advice from Roy Axelsen and Mark Blackford. After playing around with this for a few months, I found it quite difficult and didn't have the patience for it. The lack of one piece of software to acquire and fully process and reduce the images as well as the hassle of taking flat frames I believe is a significant impediment to beginner DSLR VSO'ers.

I became attracted to hunting for novae with some good recent successes by Rob Kaufman and a multitude of Japanese observers. I was initially sceptical that my images were going to be of good enough quality taken from my backyard located only 5kms from the Perth CBD, but I discovered the magic of image stacking! I found that I could detect variable objects to between 10-11th magnitude in my light polluted skies and in all phases of the moon so I thought I could be at least competitive and I had the advantage of Perth's favourable weather conditions mostly year round.

My programme consists of patrolling about 4,500 square degrees of sky centred on the Milky Way running between Canis Major and Sagittarius. I don't go too far north as I believe the competition gets too great. Last year I upgraded to a Canon 800D camera and a 85mm f/1.2 lens (both second-hand of course). The 85mm lens is fantastic and a real enabler for nova hunting.

I was lucky enough to discover V6595 Sgr in April last year ([Alert Notice 739: Nova in Sagittarius: N Sgr 2021 No. 2 = PNV J17581670-2914490 \[V6595 Sgr\] | aavso](#)) which was a real thrill. I was also able to make and maintain contact with a number of professional astronomers with an interest in novae. This was important as the most critical thing when making a discovery is to get spectroscopic confirmation as soon as possible and if I could alert the pros early, this could be achieved.

The 12-month period from June 2021 to May 2022 was quite a barren time for brighter novae. In this period I continued my search and refined my techniques.

On the evening of June 25th 2022, Perth was in the middle of a nice fine weather spell in the middle of winter and so it was important to make the most of it. In search area 16a, I immediately noticed a suspect in Circinus. Figure 1 shows the sky on 24 and 25 June. It was approximately magnitude 10.7 and visible on all 3 stacked images taken. A quick check showed that it was not a minor planet and no variable was listed at it's position in VSX. There was also no report from any of the professional surveys as listed on the TNS web site. A check on the DSS R image appeared to show a star roughly in this position but I didn't have the positional accuracy to confirm this.

I immediately pulled out my trusty 10" Dobsonian reflector and confirmed the object visually.

I felt confident enough by now to publish the report on the IAU TOCP web page ([CBAT "Transient Object Followup Reports" \(harvard.edu\)](#))

The trick now was to try and acquire some CCD images to perform astrometry and confirm its precise position. I have had access to the R-COP telescope at Perth Observatory ([R-COP Telescope - Perth Observatory](#)) for quite a while now and it's been invaluable in performing some important photometry for various variable stars to support professional campaigns with all observations sent to the AAVSO. And if it's clear at my location, it should be clear here as it's just on the east side of Perth. Unfortunately the telescope didn't appear to be available over this particular weekend!

Luckily it was clear at Siding Spring and I was able to use the 500mm T30 ITelescope to acquire images and perform astrometry. This did seem to indicate that the suspect did coincide with an existing 14th mag

star (5875610751015084544 in the Gaia DR3 catalogue). So I immediately thought this may be a new CV or symbiotic star since the amplitude was only about 3 magnitudes.

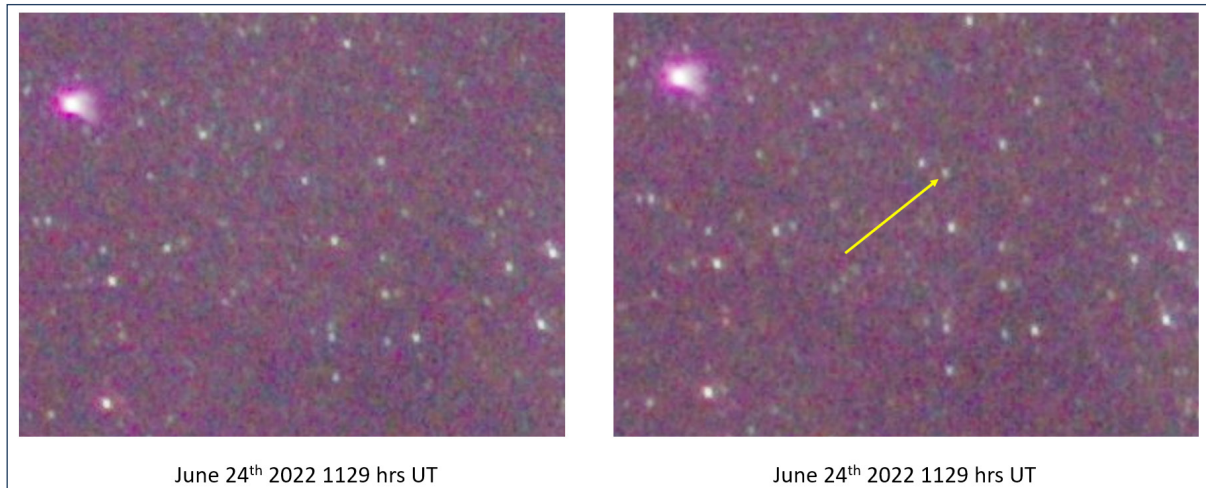


Figure 1. *Discovery images of nova FQ Circini. The left hand image shows the area prior to discovery with the right hand image taken 24 hours later.*

I privately notified Elias Aydi at Michigan State University who I had established contact with earlier and advised him of the discovery and of its relatively small amplitude. I didn't think any more of it as I knew that Elias was more interested in novae.

I also contacted Rob McNaught as to whether he may have any images around this time. He responded not long after that he had and would examine them and confirm. A few hours later Rob advised that he had captured the outburst in full. In a series of quite spectacular images, he had captured the very quick rise of the outburst which seems to have occurred in only 2 ½ hours on June 24th! On June 24.630 UT it was approximately mag 13.5 but by June 24.728 it was mag 10.9.

I reached out to Hamish Barker in New Zealand as I was aware that he had done some good work with spectroscopy recently and had been published in the ATel Circulars. I was also aware that it may be clear in some parts of New Zealand that night. That conversation opened up to include Tom Love, Peter Velez, Sean Curry and Terry Bohlsen. These guys were fantastic with Tom and Peter/Sean able to acquire spectra on June 26th.

In the meantime Elias Aydi got back to me to advise he had taken a spectrum on the 4.1m SOAR telescope in Chile and indeed it was a nova! He soon published an ATel Circular ([ATel #15473: SOAR spectroscopic follow-up of the Galactic optical transient TCP J15244460-6059200 \(astronomerstelegram.org\)](https://www.astronomerstelegram.org/?msg=15473)). It stated "The spectrum resembles that of a very fast classical nova after optical peak. The low amplitude of the transient raises questions about its nature and the possible progenitor match. TCP J15244460-6059200 could be an unusually low-amplitude, ultra-fast nova or a more exotic phenomenon. There is a slight chance that the actual progenitor system is much fainter and coincides with the bright (~14 mag) match, which would explain the unusually low-amplitude of the transient. Follow-up observations are encouraged in all bands."

Tom Love provided the following description of his spectrum "A low resolution ($R \sim 600$) spectrum was taken on 26 June, with mid exposure at JD 2459757.4462, using a 30cm Ritchey-Chretien telescope and a Shelyak Alpy spectrograph. The spectrum showed a reddened continuum and strong emission with a heavily broadened base in hydrogen Balmer lines, and in He I lines at 4922, 5016, 5048, 5876 and 7065 angstroms. P Cygni line profiles are weak or absent. The full width of the base of the hydrogen alpha line was approximately 320 angstroms, or around 14,600 km/s, giving an estimated velocity of over 7,000 km/s for the ejecta. The spectrum features and radial velocity are consistent with the object being a fast He nova after maximum brightness. The spectrum has been submitted to the ARAS nova database."

IAU CBET 5138 was then published describing the suspect as a "nova like variable" with an official GCVS designation of FQ Circini. Certainly people were having a hard time understanding the small out-

burst amplitude.

As communicated to me from Elias Aydi, “The main question for this transient is the progenitor system. If the 14 mag blue star is the companion, this would be a very interesting system, probably one of a kind. If the actual progenitor system is coincidentally behind the 14 mag star, then it might be just a normal fast nova, but that is a small chance coincidence.”

So the recent task has been to acquire further spectra to understand it’s nature. Tom Love has been able to capture additional spectra. Unfortunately there has not been much professional interest so far, so at the time of writing the exact nature of this object remains unknown. My personal view is that the blue progenitor star is a foreground object. Historical APASS photometry showed this star to have $B-V = 0.45$ and that has been maintained throughout the eruption.

Figure 2 shows a light curve from time of discovery up to July 8th. It was a very fast nova with t_3 approximately 6-7 days and t_2 only 2 days.

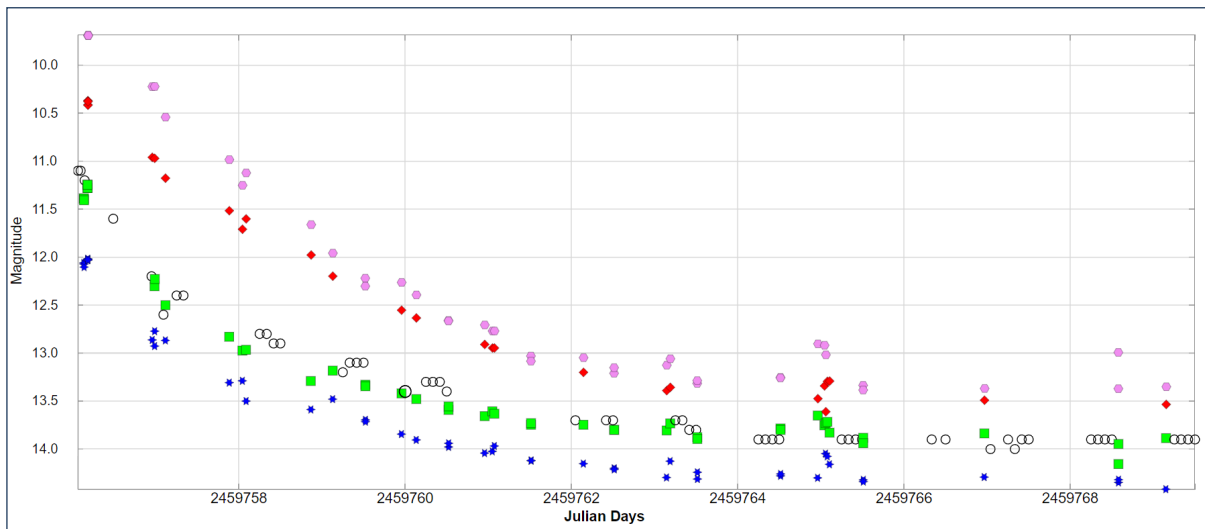


Figure 2. *Light curve of nova FQ Circini from 25 June 2022 to July 8 2022*

Abstract

This paper describes approaches to the spectroscopic follow up of transient targets when they are alerted. It considers why spectroscopic observations can be useful, identifies sources of different kinds of transient alert, notes the main techniques and instruments that can be used by amateur astronomers, and gives examples of successful follow up observations.

Background

The sky is constantly changing. Transient phenomena are generally considered to be new objects, or objects that exhibit a one off or at most intermittent change in brightness and are typified by novae and supernovae. But these are not the only changes that are discovered in the sky - new variable stars can be found, and unexpected secular changes can occur in the behaviour of stars.

This paper focuses upon transients as objects that have been newly discovered to have some kind of changing behaviour. An increasing number of survey projects, such as Gaia or ASAS-SN, have been implemented in recent years and these monitor large areas of the sky, looking for different kinds of variability. These surveys produce a significant number of new discoveries. Where amateur astronomers once had an advantage over professional researchers in having the time to scan the sky and find new objects such as comets or novae, the discovery of transient phenomena is now largely (though not quite entirely) the domain of large professionally designed survey programmes.

But the increased volume of transient discoveries arising from large surveys means that there is an increased need for short and long term follow up of those discoveries, and this is an area where amateur astronomers can make a significant contribution. There are a limited number of professional research telescopes that can be used for opportunistic observation of new transient targets, but amateur astronomers with their own equipment have the flexibility to observe new discoveries whenever they like, subject to the constraints of weather and the need for sleep.

Spectroscopy has an important role in the follow up of transients. When the brightness of a star is observed to change, the first question is about what kind of object this might be. A low-resolution spectroscopic observation can nearly always give a strong hint, and often be definitive, about the classification of the target. This is important because some kinds of object may be more time sensitive and rapidly changing than others, and consequently have different needs for follow up observation. Knowing what kind of object a given transient may be is important information for alerting the relevant specialist researchers, and for triggering other follow up observations, perhaps with higher resolution. So, an early spectroscopic observation of a new transient object can provide highly valuable information that may determine a lot about the subsequent follow up and study of the target.

It is also the case that, because there is more flexibility when using your own equipment, amateur astronomers are sometimes able to conduct higher cadence follow up observations than can be achieved with large, tightly scheduled, research telescopes. This means that when an object such as a fast nova is changing rapidly in a timeframe of hours or days, amateur observations at a range of longitudes can make an important contribution by providing higher cadence observations than can easily be managed with professional research equipment.

Spectroscopic follow up of new transient alerts is a powerful technique that can make an important scientific contribution. This kind of follow up is well suited to the traditional strengths of amateur astronomers since it is facilitated by having flexible access to equipment, and only relatively low resolutions are necessary to produce useful data. From an observer's perspective the rapid response and publication of data make this a very satisfying way of participating in meaningful astronomical research.

Transient alerts

The first pre-requisite for doing transient followup is to have an event to observe. The main sources are:

1. **GAIA alerts.** The GAIA spacecraft frequently finds changes in brightness of objects. These can range from rapidly changing targets such as novae, to slowly evolving objects that turn out to be quite different, such as Be stars entering an outburst phase or other similar changes in stellar activity. Gaia alerts have a dedicated web page that gives details of the object's position, brightness, previous observations (with a typical cadence around 7-14 days), and date of alert and, usually, an image of the DSS field that the target lies in. Gaia alerts are generally from around 9th to 20th magnitude. Alerts will give a time series of uncalibrated spectra of Red and Blue bands which can be a useful glimpse into the sort of behaviour that is occurring, or indicate whether very strong emission lines are present. In Gaia data release 3, calibrated spectra are available, but it requires python code to extract them. <http://gsaweb.ast.cam.ac.uk/alerts/alertsindex>
2. **ASAS-SN transients.** The All-Sky Automated Survey for Supernovae is a network of 24 small telescopes around the world, operated by Ohio State University, that surveys the entire sky every clear night. As well as the supernovae that are the main target, it finds many other kinds of transient. The alerts page includes coordinates, historic and transient magnitude (sloan-g filter) and the suspected or known nature of the transient light curve with a typical daily cadence. It has an excellent online light curve query tool. The limiting magnitude of ASAS-SN alerts is around 18, with bright saturation around 9th magnitude. <https://www.astronomy.ohio-state.edu/asassn/transients.html>
3. **The Transient Name Server (TNS)** is the official IAU site for alerts of supernova candidates. It is not generally intended to be for non supernova events, although Gaia Alerts are propagated to it. It provides alert details, the usual coordinates and object information, and usually a Digital Sky Survey field for the target. It provides a confirmation system for uploading classification spectra, although care should be taken when commenting on your interpretation of your spectrum, since this is an official site that will record your remarks permanently. If you do upload a spectrum, there is a very useful online viewing tool that allows you to overlay a variety of possible lines from different elements and degrees of ionisation, in order to help your interpretation. <https://www.wis-tns.org/search>
4. **Rochester astronomy.** The Astronomy Section of the Rochester Academy of Science is an amateur astronomical society in Rochester, New York. They maintain a web page that provides a curated list of current supernova and other transient alerts and findings. <https://www.rochesterastronomy.org/snimages/>

Each source of alerts has its own naming convention for an event, meaning that each event may have several names, assigned by Gaia, TNS and ASAS-SN, for example. A further official name may then be assigned once the object is classified. This can be confusing, and it is important to be clear about the alternative names for for a given event.

Spectroscopic techniques

There are various choices about how to go about spectroscopic follow up, and we suggest a number of aspects of conducting follow up based upon our own experience and advice from others.

Resolution and brightness

Classification does not usually require high resolution spectroscopy. This means that low resolution observations are often preferable, since they usually come with the ability to observe much fainter objects. We typically observe objects to a magnitude limit of around $V \sim 14$, which is enough to follow up a significant number of targets. Given the constraints of weather and sleep we would likely struggle to observe many more targets at fainter magnitudes, although collaboration with larger networks of observers at different longitudes would probably increase our combined capability to collect data on more, and fainter, objects.

Grating spectra

The simplest technique for collecting low resolution spectra is to use a stand alone grating. This can mean mounting a grating or grism (combination of grating and prism, used for simpler optical layout and/or aberration control) in front of a detector in a filter wheel or similar holder, and using it in slitless mode. This has the advantage of being very cheap and simple to set up, but the resulting resolution will be very

low. It is likely still to be adequate for an initial classification in many cases, and to identify large scale characteristics such as changing continuum level of a nova, but may not have enough precision to be useful for more detailed measurements (eg measuring the speed of ejecta from a nova). Slitless spectra can be enormously powerful - the first James Webb Space Telescope images included a slitless spectrum taken of an exoplanet, showing signs of water and allowing measurement of important parameters of the planet. The Hubble Space Telescope widefield camera instrument also includes slitless spectroscopy capability with grisms in some filter wheel slots. Slitless spectra can be very powerful!

Processing slitless spectra can sometimes be challenging, and the technique is not very effective in crowded fields, where background objects can result in spurious apparent emission features in the spectra. But slitless spectra are a good first step in monitoring transient phenomena, and represent a cheap and straightforward way to explore this kind of observation for somebody who already has a telescope and mount, and observations are even possible with dobsonian telescopes either in untracked drift exposures, or using an equatorial platform which provides a platform for the dobsonian telescope which rotates in equatorial frame to provide best case up to 30 second unguided exposures.

The image and spectrum below is of a nova in the Large Magellanic Cloud taken in 2019 using a 200mm f6 dobsonian telescope on an amateur-built equatorial platform, with a 100 lines per mm 'Star analyser 100' transmission grating and a colour DSLR camera. The image is a stack of approximately 25 frames, each of 30 seconds. Brightness and contrast of the composite image have been adjusted for clarity however such adjustment was not applied to the raw images processed to produce the spectrum charts.

The nova (Asassn-19qv) is the upper of the two stars at left frame and was approximately magnitude 11 at the time the observation was made. It is possible to make out broad emission peaks at the right end of the blue (Hydrogen Beta) and right end of the red (Hydrogen Alpha). Note that due to the complex response curves of the RGB bayer filter pattern of the colour DSLR sensor, the broad absorption troughs in the green parts of the image are most likely a resulting artifact. This artifact is eliminated in the processed 1D spectra by a standard technique of observing a known reference star to determine the instrument response and then applying that to the unknown spectrum of the transient target star.



Figure 1. *Raw slitless spectrum*

The first spectrum chart was taken one day after the peak brightness (see Asas-SN lightcurve), while the second, just a day later, showed considerably enhanced H alpha and Beta emission features plus some possible Fe features from 5000 to 5800 Angstrom.

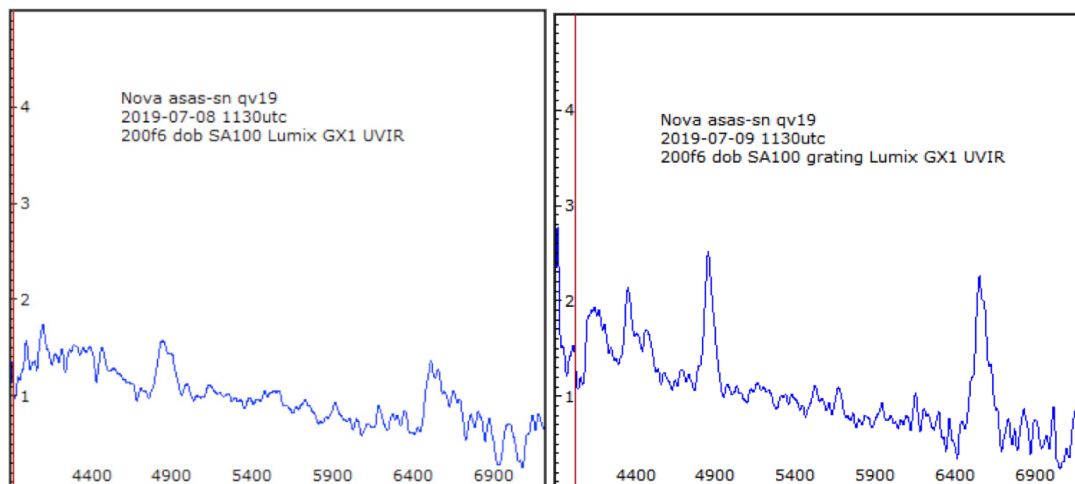


Figure 2. *Asassn-19qv spectra*

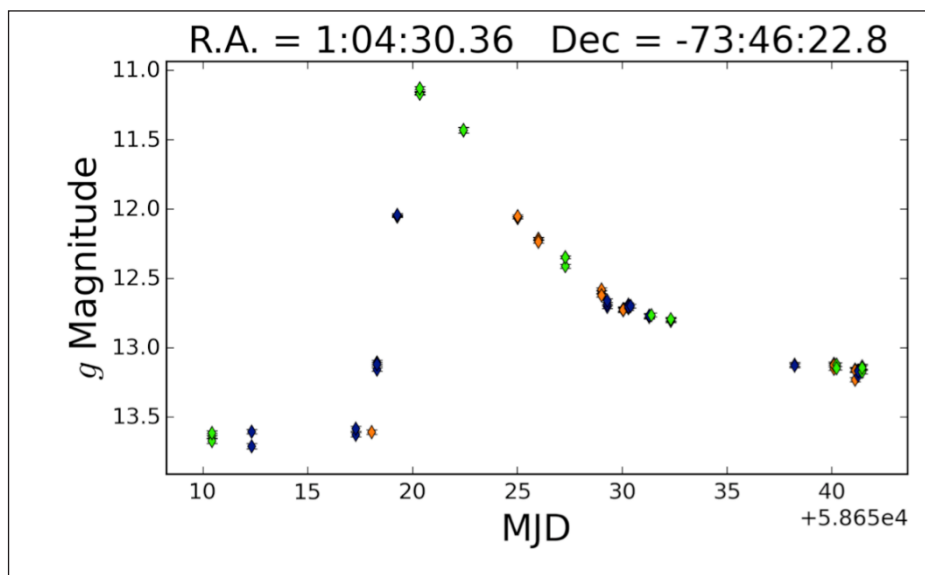


Figure 3. *Asassn-19qy* lightcurve

Slit spectra

There are a number of off the shelf options for those who want to try low resolution slit spectroscopy of faint objects. The two currently commercially available sources of spectrographs are the German DADOS spectrograph¹, available from Baader Planetarium and two low resolution spectrographs from the French firm Shelyak, the LISA² and the ALPY³ (note that an ALPY requires separate purchase of guiding⁴ and calibration⁵ modules). Shelyak sell a higher resolution instrument, the LHIRES⁶, that can be fitted with a diffraction grating that allows low resolution observations, but this is less efficient than a spectrograph designed specifically for low resolution data. While no longer in production, the Australian designed, Dutch produced L200⁷ has a broadly similar design, and can sometimes be found second hand in Europe or the US.

There are also a number of designs for small spectrographs that can be 3D printed and fitted with standard off the shelf optical components that can be purchased from international optical suppliers. There are a number of higher resolution instruments, but low resolution 3D printed equipment suitable for monitoring transients includes the UVEX⁸ (an instrument with fully reflecting optics that has the ability to take data into the near ultraviolet range), LOSPEC⁹ and Star'Ex¹⁰. The latter two are 3D printed instruments using reflection gratings and lenses for collimation and camera optics. Printed spectrographs potentially have issues of flexure and light leakage, although these can be mitigated with careful construction.

The basic working of a slit spectrograph involves placing the image of the desired target onto a slit, so that the peak brightness of the target star passes through and into the spectrograph. The front face of the slit is typically reflective, and has a guide camera pointed towards it through an arrangement of mirrors and lenses. The guide camera allows you to a) see that the target star is accurately lined up on the slit, and b) guide the exposure, using either part of the target image on the slit, or a nearby star that is not too far from the target.

Figure 4 shows an example of a spectrograph slit in a crowded field, taken from the guiding camera. The slit shows up clearly since this was taken near full moon with a relatively bright sky, but it is not always the case that the slit is seen this easily. The 14th magnitude target star is indicated with a white arrow, and needs to be moved down slightly in order to be centrally placed on the slit so that the maximum number of photons can pass through to the spectrograph. The yellow arrow indicates a brighter star, not too far from the slit, that is used for autoguiding. Because the slit is at an angle to the optical path of the telescope there is significant distortion of star images away from the centre of the field.

This guiding camera image is large enough, at around 12 arcminutes across, to be able to plate solve the images directly using astrometry.net. This means that it is possible to position the telescope very precisely, and almost entirely automatically, on the coordinates of the target with only a small manual correction

needed to nudge the target into position on the slit. This gives confidence that the correct object is being observed, which can otherwise be a significant challenge given a faint target in a crowded field.

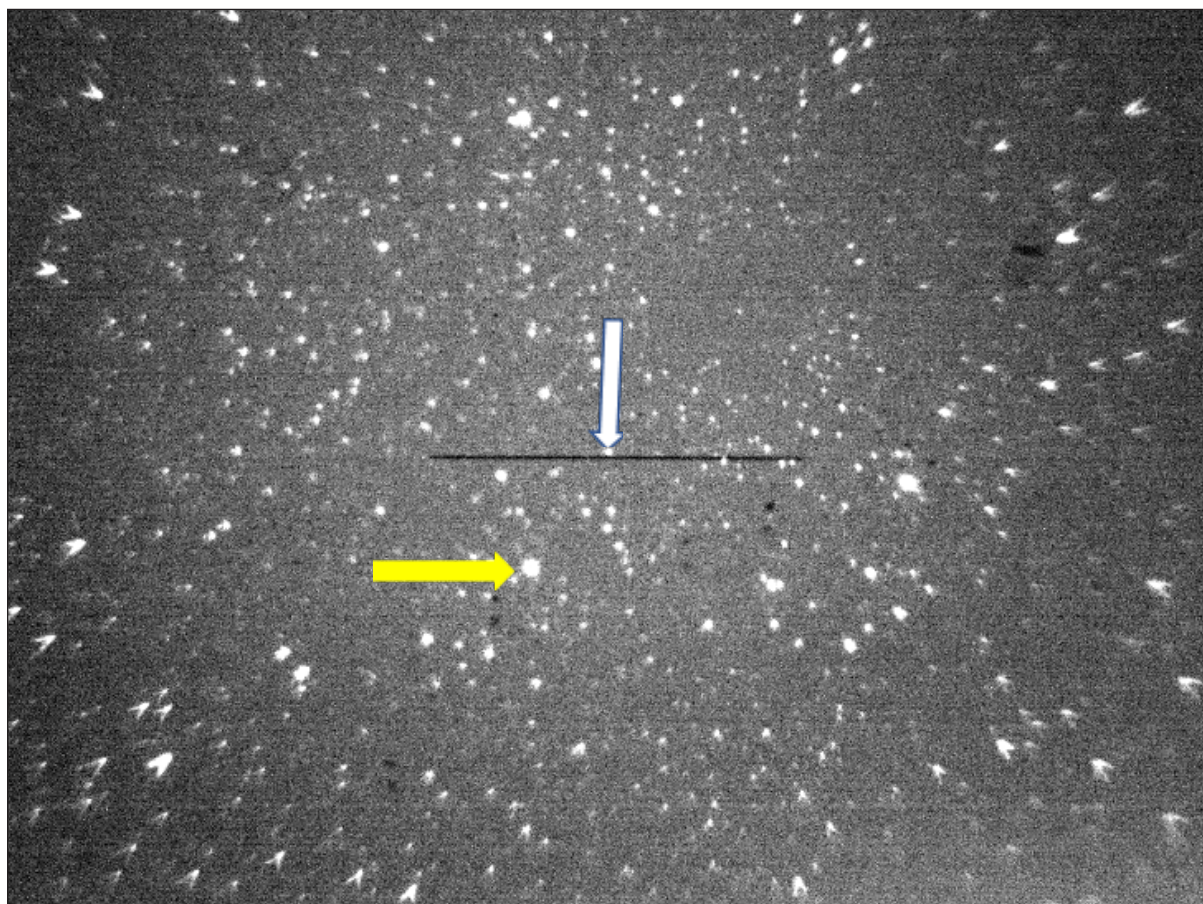


Figure 4. *Spectrograph guiding field for FQ Circini*

Targets and guiding

When observing any stellar object it is important to be confident that you are collecting data on the target, and not on some other star. Positive identification of the target can be challenging with faint objects in crowded fields, and this is compounded when the target is a transient that doesn't appear in existing field images or catalogues. Whether the pointed image is from an image of the spectroscope slit in a reflective plane, from a separate camera on a flip mirror, or from a piggy-backed telescope, accurate pointing with known errors or offsets is crucial to being able to take a spectrogram of a faint object, especially if it is in a crowded field. It is good practice to save an image of the field around the reflective slit of the spectrograph, so that it is possible to confirm that the right star was on the slit in case there is any question of this once the data have been reduced and inspected.

An automated guiding setup allowing the mount to keep the target accurately on the spectrograph slit to a precision of around 1-2 arcseconds is a key capability for spectroscopy. Unlike astrophotography, the requirement is not only to have a system that can track accurately for a short space of time, allowing a series of subsequent short exposures that avoid star trailing. A slit spectrograph means that the absolute position of a star in the field (ie. on the slit) has to be maintained for long periods of time. An active, accurate guiding system is therefore essential for success.

Since transients are often faint targets it is common to use an automated guiding algorithm on a star that is near to the slit, but brighter than the target, allowing reasonably short guiding exposures of 3-4 seconds. A number of readily available software options such as EKOS or PHD2 have the capability to guide with sufficient accuracy on a chosen star. A high quality mount with good guiding characteristics is very important for spectroscopy.

Telescopes

The preferred telescope setup for monitoring transient objects largely depends upon the spectroscopic equipment. A spectrograph and telescope have to be well matched in focal ratio in order to achieve the best performance. A Lhires spectrograph from Shelyak, a common off the shelf instrument with gratings for both low and high resolution work, is designed for a telescope at f/10 and works well with common Schmidt-Cassegrain telescopes, but can be used with slightly faster f/8 GSO Ritchey-Chretien instruments with minimal loss of performance. On the other hand the dedicated low resolution Alpy spectrograph, also from Shelyak, is optimally used on a f/4 telescope, but can work at up to around f/6 if necessary. Focal reducers or Barlow lenses may be used to alter telescope focal ratios to match a spectrograph, although lens elements in the optical pathway can distort the spectrum and reduce efficiency, altering the instrumental response of the system.

Focuser

Poor focus can rapidly lose many of the precious photons which have been gathered by the expensive telescope optics upstream and, is therefore worthy of attention.

Even the very compact Alpy spectrograph instrument (which is particularly light and robust), when loaded with the minimum two cameras (guide and science), and a calibration unit with miniature flat lamp and emission line arc lamp, exerts considerable leverage on the focuser. Most spectrographs are heavier than this, and sometimes a flip mirror is used for widefield platesolving, exacerbating the loads. Attention must be paid to either mechanical support (in case of a Schmidt-Cassegrain telescope with direct coupling to the rear port and using the primary mirror focuser), or a special high-load focuser. Skimping on the focuser means either poor focus or loss of collimation. Either of these means that the star image at the slit will be larger, and a consequent loss of light can rapidly degrade signal to noise of the observation.

With a particularly good mount and guiding performance an 8 inch telescope may be able to do useful transient classification work, although 10 inch or larger telescopes are likely to be more practical for most targets. Exposures for faint targets will be long - in our experience a low resolution spectrum with acceptable signal to noise can be collected on a 14th magnitude target in 4 hours (in practice 8 x 30 minute exposures) with a 12 inch telescope.

Reduction

Reducing the raw spectrum images to a well calibrated 1 dimensional spectrum that can be shared with other professional or amateur scientists can be challenging to begin with, but will become much faster and more straightforward with experience. There are several options for reduction, but the most commonly used is ISIS, written by French amateur astronomer (and professional optical designer) Christian Buil,¹¹ Teaching yourself how to use ISIS is another activity that can be time consuming, but once mastered it is a powerful tool for reducing spectra from a number of different kinds of instrument. Reduction will require dark, flat and bias frames in the same manner as a photometric observation, but in addition will require an observation of a calibration lamp, that has emission lines of known wavelength, so that the science frame can have accurate wavelengths assigned to it. The calibration observation should be taken immediately before the science frame, since inaccuracies can be introduced by mechanical flexure as the telescope moves across the sky, and by thermal expansion/contraction of the equipment.

Low resolution spectroscopy usually means having a single observation that covers most, or all, of the optical spectrum from around 3800 Angstroms to 7000 Angstroms. Because there is such a large wavelength range, and because there is value in having a reasonably accurate slope to the background continuum of the spectrum, it is important to have some kind of response correction that allows the reduction to take into account the varying response of the instrument and of the atmosphere to light at different wavelengths. This is usually accomplished by taking a spectrum of a reference star of known spectral type immediately before the science spectrum of the target. The observed spectrum of the reference star can be divided by a library spectrum of the relevant spectral type, and the result used to adjust the science observation accordingly. This correction during the reduction process is important for monitoring transient spectra, where the slope of the background spectrum may be important for identification of the type of object. Response correction tends to be less important for high resolution spectra that see only a small range of the visible spectrum.

Coordinating and reporting results

There are several places to send results of transient monitoring too, but there is also an informal network of amateurs and professionals who share results. Participating in an informal network allows coordination across different sites, weather conditions and targets for data acquisition. Colleagues can also be helpful with interpreting results. Some spectra are likely to be easy to interpret, but others will be more difficult, and involving both amateur and professional colleagues is likely to help avoid making mistakes.

There are several places in which results can be posted and brief publications made. If sharing data with a professional you may well contribute to an Astronomer's Telegram (ATEL)¹² or the Central Bureau for Astronomical Telegrams (CBAT).¹³ If you have contributed data that are mentioned in the publication you can expect to be listed as coauthor in an Astronomer's Telegram, and to be explicitly mentioned in a CBAT.

In the cases of both an ATEL and a CBAT there is an expectation that the data you have taken will be made generally available, and the place in which data can be found will be mentioned in the publication. There are a number of repositories to which you can send transient spectra for permanent archiving. Each have different strengths, and you can send your data to several repositories if you wish. The main ones are:

- The ARAS website database. ARAS is a loose web based organisation of amateur spectroscopists, largely based in France. They operate a database of spectra of novae, symbiotic stars and dwarf novae.¹⁴ Submitting data is as simple as emailing an accurately reduced spectrum to the database maintainer, Francois Teyssier.¹⁵
- The British Astronomical Association (BAA)¹⁶ and the American Association of Variable Star Observers (AAVSO)¹⁷ both maintain databases of spectra, complementing their longstanding photometric databases. In these cases it is necessary to submit a spectrum of a known object (the AAVSO has a specific list of targets from which you pick an object, the BAA does not) so that they can do an initial confirmation of the quality of your work before you submit a science spectrum. Once you are set up and your work is approved you can upload spectra to these databases at any time via a web interface.
- The Transient Name Server¹⁸ noted above is the official International Astronomical Union site for notifying new transient discoveries and classifications. In practice it is principally focused upon supernova discoveries, but other transients often crop up. It is possible to register as a user and to upload a spectrum. Care needs to be taken with this site, which will ask for comment on the nature of the classification you have made. Since this is the official transient site for professional researchers, you should be very confident of any notes you make about the classification of any spectra you upload. Consultation with amateur and professional colleagues is advisable before posting results to this site.

Recent examples, and next steps

The first example (Figure 5) below, the recent nova FQ Circini, shows classic emission lines in the hydrogen Balmer lines. The most prominent, as usual, is at hydrogen alpha, at 6563 Angstroms. The width of the lines allows an estimate of the speed at which the ejecta from the nova are traveling, in this case at up to 7,000 km/s. The hydrogen lines are double peaked. At the time of writing it is unclear whether this indicates a disk around the object, or whether there is a foreground star with absorption at these wavelengths that is superimposed over the nova spectrum. A mass of lines at around 4600-4700 Angstroms is likely to be caused by excited helium and neon.

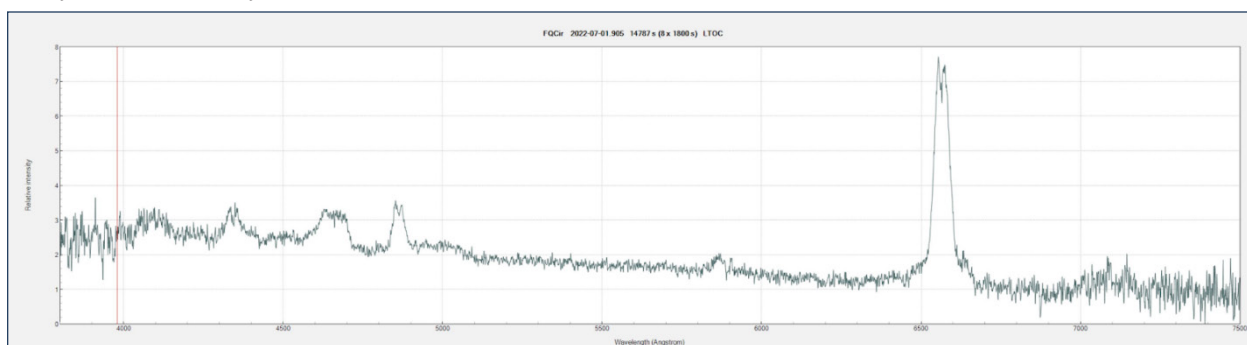


Figure 5. *Nova FQ Circini*

AT2022khw shows a more typical nova spectrum, some time after the peak brightness has been reached. Hydrogen balmer lines are narrower (showing a slower ejection of material than FQ Cir), but more prominent. A series of emission lines from about 4900 to 5300 Angstroms show iron emission, a signature of a classical nova.

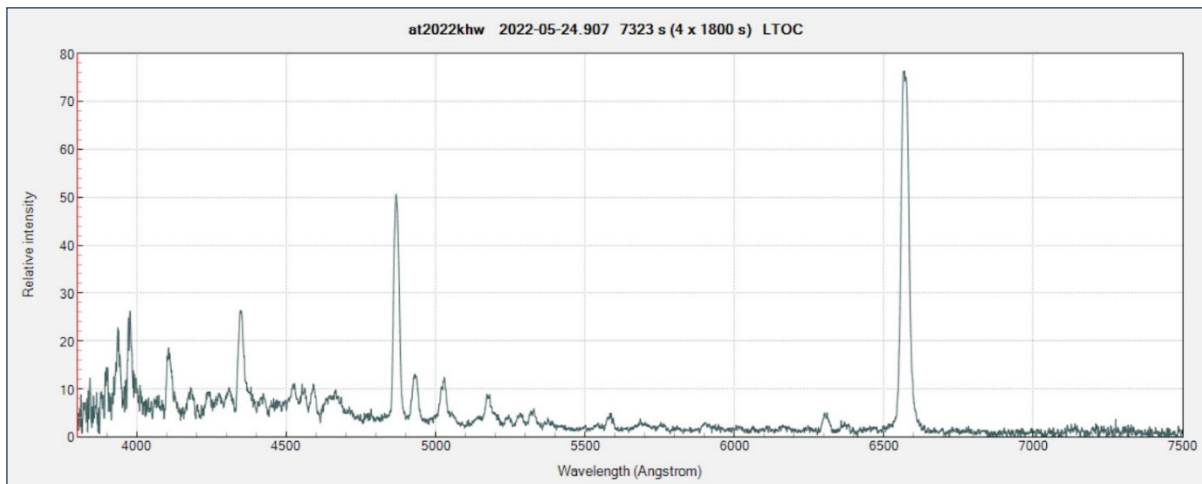


Figure 6. *Alert AT2022khw*

Novae appear regularly throughout the year, but especially in the southern winter when the Milky Way is high in the sky. With around 10-12 objects a year and few observers, there is plenty of scope for taking useful observations. Other kinds of transient can appear at any time, and many slightly odd objects appear in a fairly constant stream, with new observable objects at least every week or two. Between first detections and continued follow up observations there are enough transient objects to use up as much clear sky as is available to most amateur astronomers.

Monitoring novae and other transients with a higher cadence than has been possible in the past with professional telescopes has the promise of bringing new scientific insights to these objects, about which there is still much to be understood. There is high interest in some quarters of the professional astronomical community in the kind of high cadence follow up, especially of novae, that is difficult to conduct with large research telescopes.

A number of new programmes have been set up to detect transient objects in the sky, the most well known of which is probably the Vera Rubin telescope, for which first light is expected in 2023. The Nancy Grace Roman space telescope, scheduled for launch in 2027 is also expected to generate a large number of new transient discoveries. While many of the new objects detected by these instruments will be too faint for follow up with small telescopes, they will also have the impact of discovering brighter transient objects at an earlier stage, making timely follow up more important than ever. The ability to monitor transients with small telescopes, with a rapid response and at multiple longitudes, is likely to become increasingly important in the coming years, and to play a key role in our understanding of a range of fascinating astronomical objects.

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Determining radial velocities of the eclipsing binary components in BF Velorum, a triple system — *David Moriarty*

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In the last newsletter, Ed Budding commented on Russell’s “royal road” to stellar astrophysics, in which radial velocity data are combined with photometric observations to yield stellar masses, radii and luminosity in absolute units. I have been using the Australian National University 2.3 m telescope and wide field spectrograph at Siding Spring Observatory to observe spectra of several close eclipsing binaries and in particular, those that have a pulsating component. From the spectra, I determine the radial velocities of both components using the broadening function method of Rucinski (2002), as implemented in RAVESPAN, a programme written by Bogumil Pilecki (Pilecki et al. 2017). Radial velocities were calculated on spectra in wavelength ranges 4600-4840, 4880-5547 Å, i.e. with the H β line masked and effective temperature set at 5250 K and gravity coefficient at 3.0. These settings were chosen to emphasise the lines of the secondary component, with its expected later spectral type than the primary component. Most observations were made with exposures of 4 minutes; some quadrature phases were observed with 5 and 7 minute exposures to enhance the lines of the secondary component.

When I showed the light curves of V775 Centauri at the 2015 RASNZ symposium at Lake Tekapo, I was advised by a professional colleague that it would be too difficult to determine the radial velocities of its faint secondary component because its spectral lines would be blended with those of the much brighter primary star. However, by modifying the procedures in RAVESPAN, I have been able to calculate radial velocities for many systems where the secondary components are 3 to 5 magnitudes fainter than the primary stars. See Moriarty et al. (2019) and Liakos et al. (2022) for details of the procedures that I developed for calculating radial velocities in binary systems with faint secondary components. The secondary component of HM Pup is nearly 4 magnitudes fainter than the primary in the V band and 5 magnitudes fainter in the B band, yet its broadening function peak is detectable (Fig. 1 a). TT Vel provides another example of a system with a faint secondary component where the broadening function enables the orbital velocities of both components to be calculated (Fig. 1b).

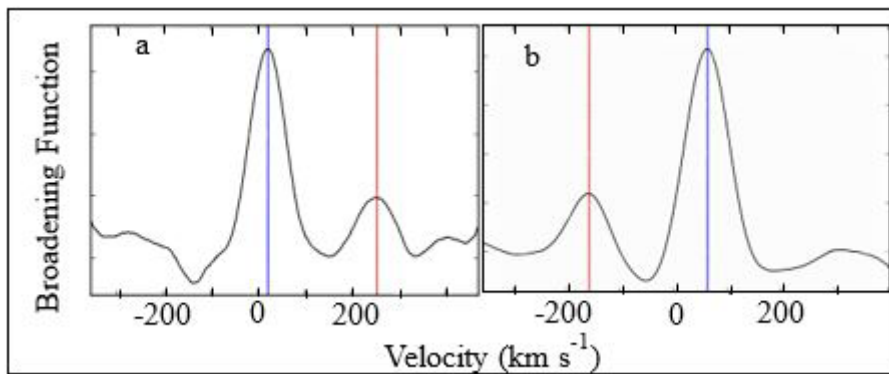


Figure 1. Examples of broadening function analyses with RAVESPAN on spectra of (a) HM Pup at phase 0.25 and (b) TT Vel at phase 0.75. Blue lines denote the radial velocities of the primary components and red lines those of the secondary components (taken from Liakos et al. in press).

HM Pup, TT Vel, V632 Sco, V775 Cen and ST Cen are the systems for which we have published absolute properties. As they do not have tertiary or multiple components, determining radial velocities of the pair of binary components is straightforward. In contrast, my broadening function analyses of BF Vel show that it differs in having a tertiary component, but it was evident in only some of the broadening function analyses. In this article I explain my progress in determining the radial velocities of the BF Vel binary components with the medium resolution spectra of the wide field spectrograph.

Broadening function values in the spectra of BF Vel at phase 0.75 observed on 2017 Feb 13 appeared to be noisy (Fig. 2a), whereas at phase 0.25 one night later a double peak with negative velocities was consistent with the presence of a tertiary component, but with an improbable velocity of -50 km s⁻¹ (Fig. 2b). One month later, the broadening function had a peak typical of a tertiary component with a zero

velocity; it was separated from the binary peaks at phase 0.78 (Fig. 2c). On 2020 Mar 15, the broadening function peak of the primary component at phase 0.22 was merged with that of the tertiary star (Fig. 2d). At phase 0.78 on 2020 Dec 1, the broadening function peak of the primary star was merged partially with that of the tertiary star, which had a positive velocity (Fig. 2e). At phase 0.75 on 2021 May 24, the peaks of the primary and tertiary stars were fully merged (Fig. 2f). Several broadening function values obtained between 2017 and the final set in 2021 were similar to those in Fig. 2f, with a merged peak for the primary and tertiary components.

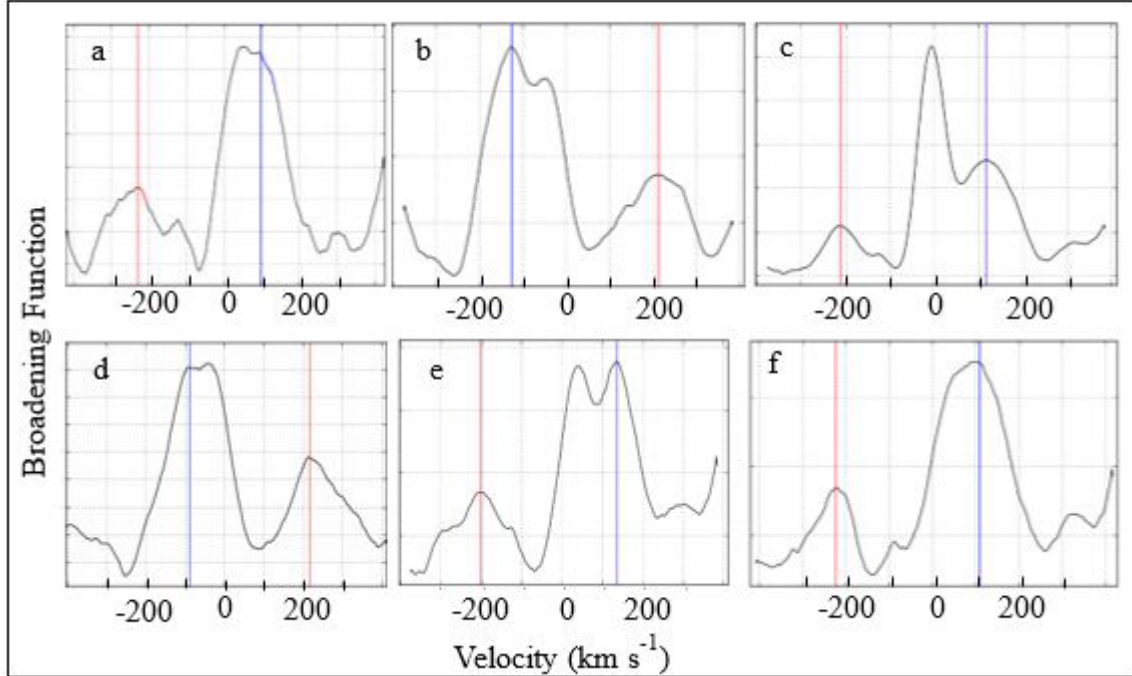


Figure 2. Examples of broadening function analyses with RAVESPAN on spectra of BF Vel at (a) phase 0.75, 2017 Feb 13, (b) phase 0.25, 2017 Feb 14, (c) phase 0.78, 2017 Apr 9, (d) phase 0.22, 2020 Mar 15, (e) phase 0.78, 2020 Dec 1, (f) phase 0.75, 2021 May 24.

On all occasions, the peak of the secondary binary component was obvious and well separated from the peaks of the primary and tertiary components, with velocities around quadrature phases of $>200 \text{ km s}^{-1}$ (Fig. 2). Velocities at the quadrature phases for the secondary component were set as inputs for iterations of the broadening function analyses. In order to improve the accuracy of the radial velocity solutions for the primary component, I used velocities calculated from wavelengths of the sodium D doublet and H α spectral lines as inputs to determine the optimum ravespan solution.

For the nights corresponding to the broadening function analyses in Figure 2, the Na I D spectra are shown in Figs. 3a-3f. The lines of the tertiary star are narrow and deeper than those of the primary and secondary stars, indicating that it rotates slowly and has a late spectral type. At the medium resolution of $R=7000$, the Na I D lines of star 1 and the tertiary were partly merged on most nights. However, the D2 line of the tertiary star was distinct at the rest wavelength on 2017 Feb 14 from the line centre of star 1 at phase 0.25, which had a blue shift of $2.3 \text{ \AA}$ and a velocity of -116 km s^{-1} (Fig. 3b). At that phase, although the D1 line of star 1 was blended with the D2 line of star 2, the sharp line of the tertiary star was apparent at the rest wavelength ($5896 \text{ \AA}$). The tertiary star's line centres were at or close to the rest wavelengths in 2017, and had positive velocities up to 50 km s^{-1} in 2021.

If the line centres of the tertiary star were consistently at the rest wavelength, it could be a distant field star and not associated with the binary. Therefore, I wanted to check whether the velocity of BF Vel system was close to zero, which would mean if the tertiary component was actually a distant field star, it would need to be confirmed by more than just radial velocities. After several iterations of ravespan analyses to determine the systemic velocity, I found the value that gave the best fit to the spectra was in the range of 3 to 5 km s^{-1} . To check this, I reviewed spectra at or close to the eclipse phases. At phase 0.51 on 2017 Apr 11, the sodium D lines had a small red shift of 16 km s^{-1} , which are in agreement with the velocity solutions from ravespan for the primary star as it starts to recede after occulting the secondary star (Figure. 3g, see also Figure. 6b).

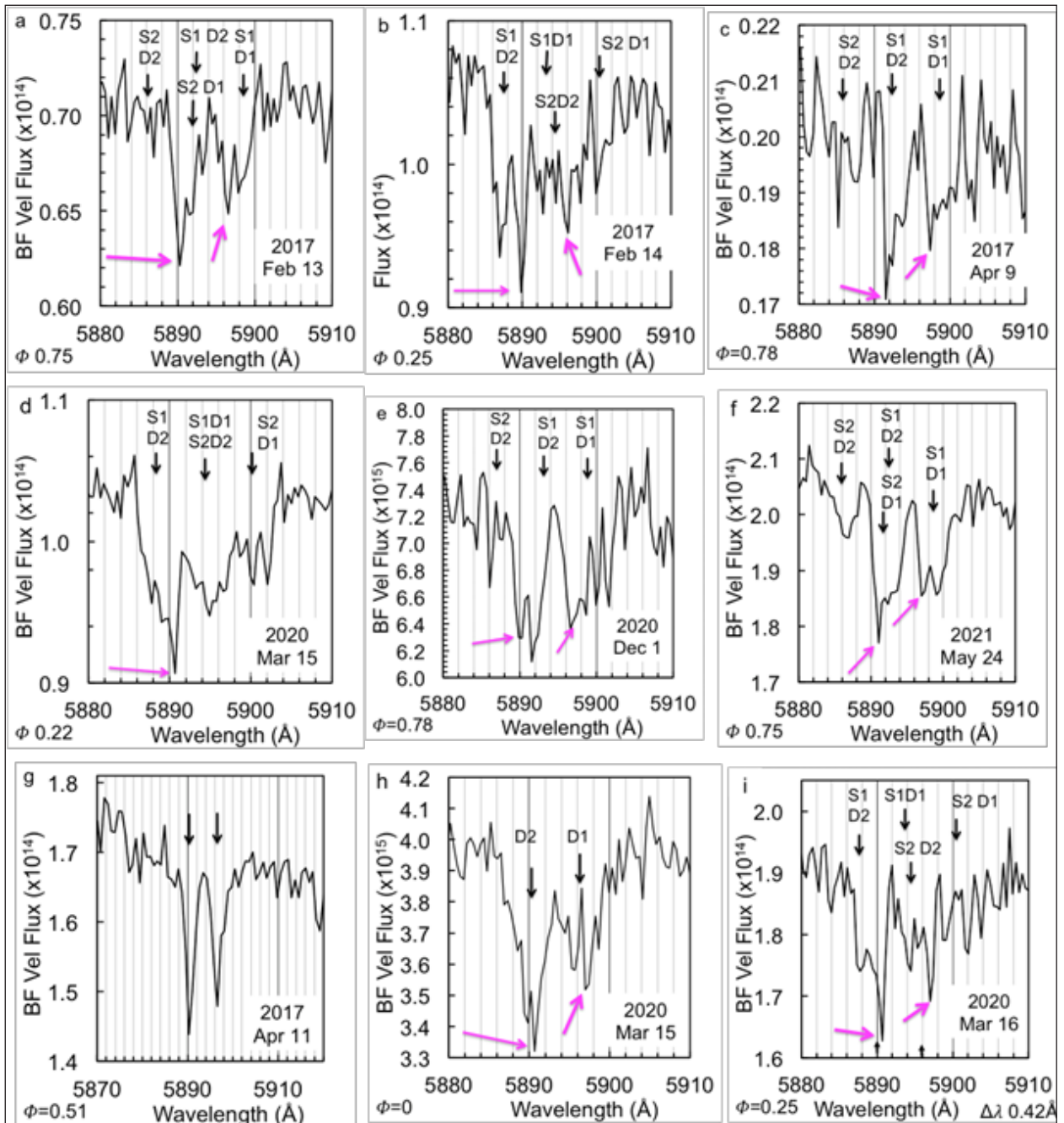


Figure 3. Spectra of the BF Vel Na I D couplet at various orbital phases (ϕ) with $R=7000$. Downward arrows mark the calculated positions of the line centres for the primary (S1) and secondary (S2) that give the best fit to the RAVESPAN analyses. Lines of the tertiary component are marked with magenta arrows. The rest wavelengths are marked with small upward arrows in Fig. 3h.

At phase 0 on 2020 Mar 15, the blended line centres of stars 1 and 2 were close to the rest wavelengths of the sodium doublet, whereas the sharp lines of the tertiary star had red shifts of 35 and 50 km s⁻¹ for the D2 and D1 lines respectively (Fig. 3h). Could those red-shifted lines be the actual values for the tertiary star or be the result of noise or another factor causing a splitting of a merged blend of the three stars in the system, as were the S1D1 and S2D2 lines at phase 0.22? On the following night, 2020 Mar 16 at phase 0.25, the lines of star 1 were blue shifted by 2.3 Å or -116 km s⁻¹, similar to the values recorded on 2017 Feb 14 (compare Figs. 3i and 3b). However, in contrast to the 2017 spectra, the Na I D lines of the tertiary star were red shifted with the same velocities as recorded on the previous night at phase 0. Therefore, it is a component of the BF Vel system, and as its Na I D lines are strong, it would have a late K spectral type.

The Balmer lines also provide a method to check wavelength accuracy. The H α line centre was 6565 Å ($v = 100$ km s⁻¹) at phase 0.75 on 2017 Feb 13 (Fig. 4a); at phase 0.51 on 2017 Apr 11 it was at or close to the rest wavelength 6563 Å (Fig. 4b). At phase 0 on 2020 Mar 15 the H α line centre was infilled with

emission at 6563 Å (Fig. 4c). Much stronger emission was observed in the centre of the H α line on 2017 Feb 14 (Fig. 4c). Emission was also apparent in the H β and H γ lines on the same night during the primary eclipse (Figs. 4e and 4f) and thus would be caused by chromospheric activity in the secondary star. Emission was not observed on other nights in the H β and H γ lines.

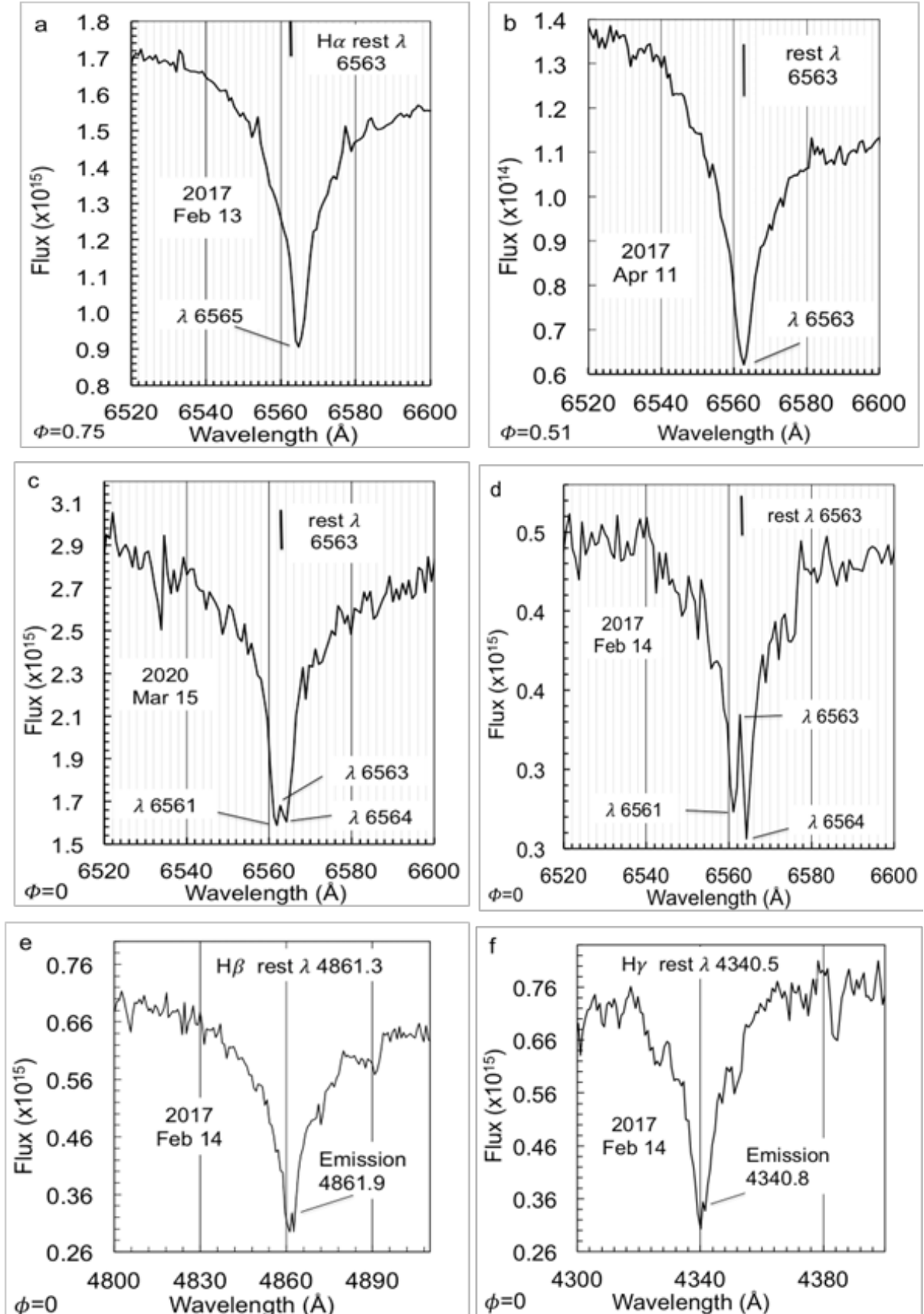


Figure 4. Spectra of the BF Vel Balmer lines at various orbital phases (ϕ) with $R=7000$

In conclusion, the velocities of the binary system that give the best fits to the spectra are: primary star $K_1 = 120$, secondary star $K_2 = 217$ and system $V_0 = 4 \text{ km s}^{-1}$.

I used these values, together with the TESS 2021 light curves which Mark Blackford extracted for me, for a preliminary model in Binary Maker 3. The radial velocity curve produced with ravespan is shown in Fig. 5a and the model using the radial velocity values and TESS light curves is shown in Fig. 5b. Using the spectra with the 3000 grating, Julian West determined the spectral type of the primary star to be A5 V. Based on that, I selected 8250 K as the effective temperature of star 1 for modelling; the best result indicated the temperature of the secondary was about 5200 K, so its spectral type would be about K0/K1 V.

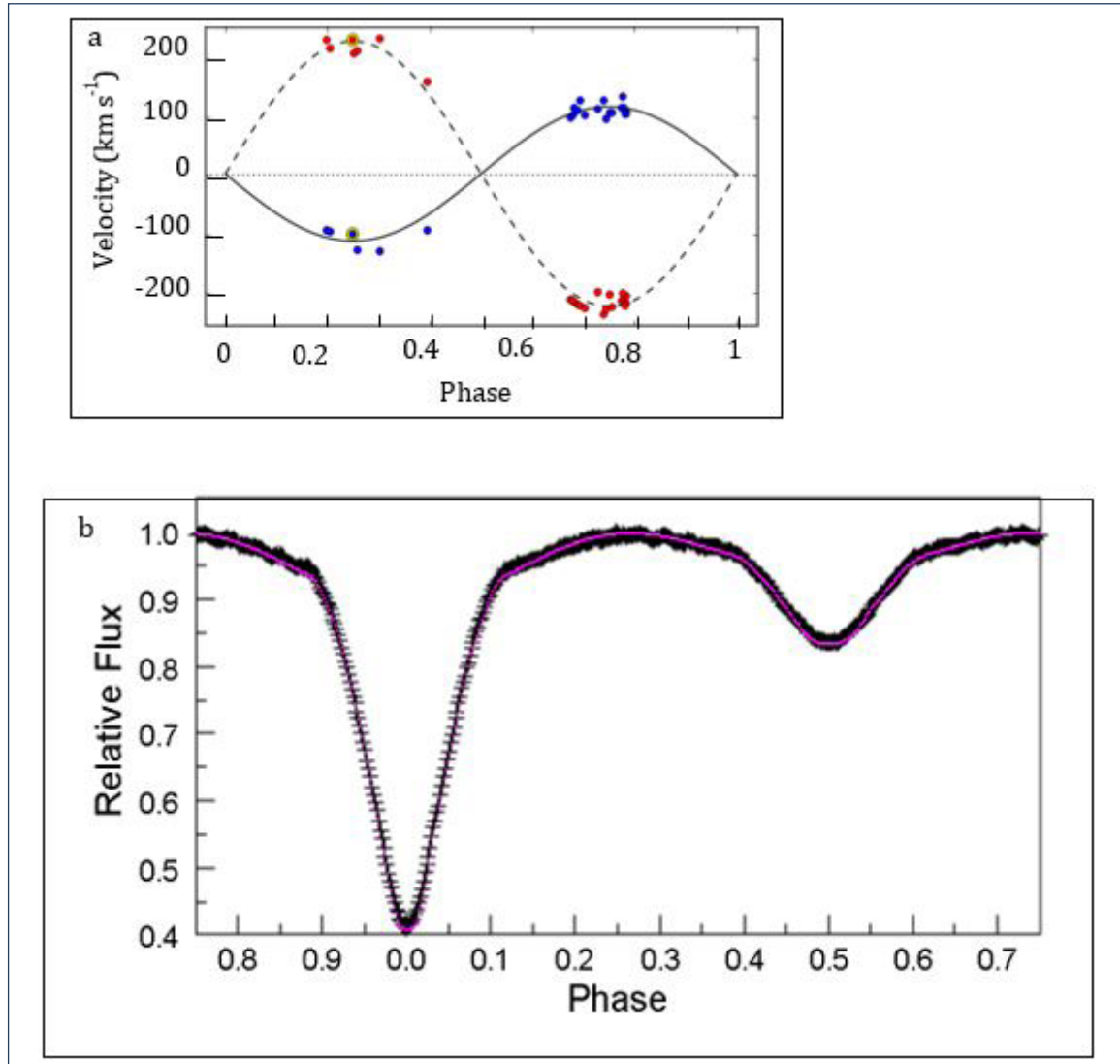


Figure 5. Radial velocity curve output from RAVESPAN (a), and the synthetic curve (magenta) plotted over 2021 data points from TESS, modelled with Binary Maker (b).

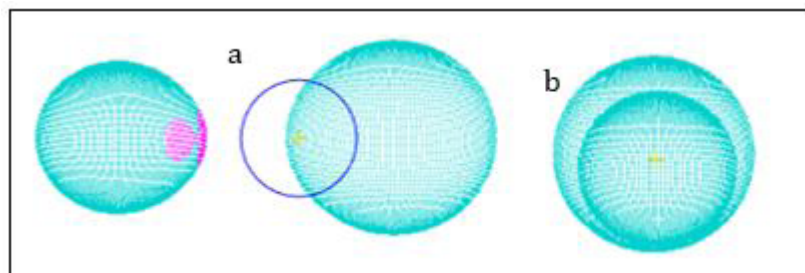


Figure 6. BF Vel binary drawn to scale with the Sun (dark blue circle). (a) phase 0.75, showing hot spots (magenta); (b) phase 0.

A good fit to the TESS light curve required three hot spots around the equatorial region of the secondary star. Graphical images showing the size and separation scale relative to the Sun were produced with Binary Maker (Fig. 6). Binary Maker output using the mass ratio of 0.53 showed that neither star filled its inner critical equipotential surface (“Roche lobe”), although they were close to doing so. The best fit required a value of 7% for third light and inclination of 87%. These are preliminary results. Alexios will model the system and derive uncertainties.

BF Vel was modelled with photometric data only by Manimanis et al. (2009). The main difference in the results they reported was their conclusion that star 2 filled its inner Roche lobe.

Acknowledgements

BF Vel is one of 15 eclipsing binary systems with a pulsating component that I am studying together with colleagues whose first names are shown in the first two papers below. Time on the ANU 2.3 m telescope was paid with research grants from the Edward Corbould Research Fund of the Astronomical Association of Queensland.

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Introduction

The majority of confirmed exoplanets were identified either through transits or radial velocity (RV) surveys. The candidates that are identified with both techniques are characterized by their mass and radius, which, combined, provide a third parameter, the mean density. Their density is a first indication of the internal composition of exoplanets. The importance of the study of the interior of exoplanets lies in understanding their formation and evolution and is also crucial for assessing their potential habitability: interior processes play an essential role in creating and maintaining the physical conditions that are required to support life (Van Hoolst et al., 2019).

Since the mean density is, by definition, a mean parameter, not determined point by point in the interior of the body, we can only have a hint on the class of planet: a giant gaseous planet like Jupiter, a sub-Neptune, an Earth-like rocky planet, etc. The mean density is not enough to fully describe the inner structure: the number of layers - core, mantle, crust, for example, their thickness, the chemical elements that compose them etc. This causes a degeneracy between the mean density and the internal structure. The same value of mean density can be reproduced by various internal structures.

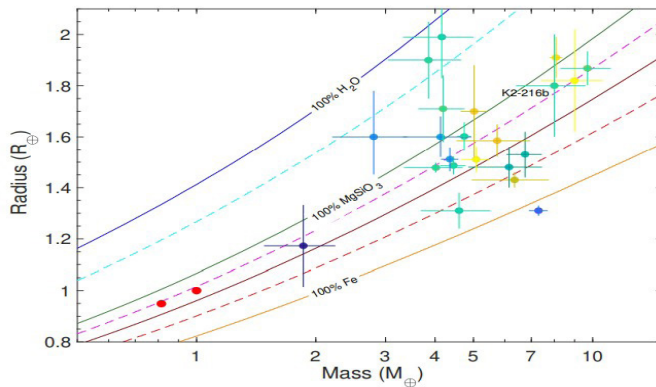


Figure 1. Mass - radius diagram of all small exoplanets ($R_p \leq 2 R_\oplus$ and $M_* \leq 30 M_\oplus$). Earth and Venus are plotted as red circles, for comparison. Persson et al., 2018.

We can use density profile models developed through the equation of state (EoS) to describe the interior structure and layers. The EoS gives a relationship between density, temperature, and pressure. All these three parameters are changing inside the planetary interior, and the change can be continuous (e.g., density decreases from the centre outward) or sudden (e.g., density has a jump as it decreases at the core-mantle boundary). The EoS plays a very important role in calculations of planetary interior models. When it is known, a planetary interior model can be calculated, i.e., the values of density, pressure and temperature can be given as a function of distance from the planetary centre.

Theorists calculate thousands of such models and can collect the corresponding planetary radius and mass values for each model. From such calculations, a curve for every chemical composition can be drawn: what radius the planets have at a certain mass with prescribed composition? That is what is called mass-radius relationship. Some are shown in Figure 1.

Through comparison with theoretical mass-radius curves (the so-obtained planetary structures) with the measured values of radius and mass (see Figure 1) we can investigate the probability of some density profiles (Wagner et al., 2011, Valencia et al., 2013, Baumeister et al., 2020).

As the figure shows, however, the measured values have error bars, and within the mass and radius measurement error bars more than one model fits the data, causing again degeneracy.

To break this degeneracy, some astronomers use a 4th independent parameter, the so-called Love

numbers, named after the mathematician A. E. H. Love (1863-1940) who introduced them (Love, 1911). They describe how the shapes of celestial bodies (stars and planets, for example) differ from spheres due to perturbations caused by gravitational interaction with other bodies in the system (planet and star, respectively), their rotation, and how their internal mass distribution changes when tidal forces or rotation deform their shapes.

The Love numbers are three infinite series of parameters, h_n , l_n and k_n . They describe the radial (h_n) and tangential (l_n) deformation of the surface as a reaction to the perturbing potential, and in particular k_n which is linked to the distribution of mass in the interior. How and by how much their shape is deformed is due to the internal structure: a rocky planet will deform differently from a gaseous hot Jupiter. One can easily imagine that it is much easier to deform the shape of a gaseous sphere like a hot Jupiter than the shape of a more rigid rocky super-Earth. Note that the second-degree Love number k_2 is proportional to the concentration of mass towards the centre of the planet.

In special cases it is possible to indirectly measure the Love numbers. For stars or giant gaseous planets, hydrostatic equilibrium is fulfilled and for any n of the series $h_n = k_n + 1$. When $k_2 = 0$, all mass is condensed in a point which is surrounded by a massless envelope, and for a homogeneous body $k_2 = 1.5$.

Usually, giant gaseous planets orbit so close to their host star that they are very likely to interact with it through tidal forces. Tidal forces change the shape and orbital properties of the planets. In fact, since the star and the planet are interacting, as happens between the Moon and the Earth, their shapes will change, slowly deforming them as rugby-ball shaped bodies. Moreover, the orbital parameters can also change: a deformed planet orbits differently from a point-like mass or spherical planet.

Method

Love numbers can be determined through several types of observations: Transit Light Curves (LC), Radial Velocity (RV) measurements and period variations manifested as Transit Timing Variations (TTVs).

The shape of the transit light curve depends on the shape of the planet. The stellar eclipsed area during transit differs from a transiting sphere. The shape of the planet influences the light curve which depends on the projected planetary shape onto the projection of the stellar disc on the plane-of-sky. The larger the planetary surface deformations, the easier the retrieval of the Love numbers from transit light curves (Akisanmi et al., 2019, Hellard et al., 2019, Hellard et al., 2020). Figure. 2 shows how the shape of the light curve of a Jupiter-like planet orbiting a Sun-like star changes by varying the Love number h_2 of the planet. The condensation of matter towards the centre increases as h_2 decreases.

Tidal interaction causes circularization (the eccentricity of the orbit approaches to 0), tidal decay (the shrinking of the orbit), synchronization of the rotational and orbital periods (as it can be seen in the Earth-Moon system) and periastron precession (the semi-major axis of the orbit rotates, along with the apsides).

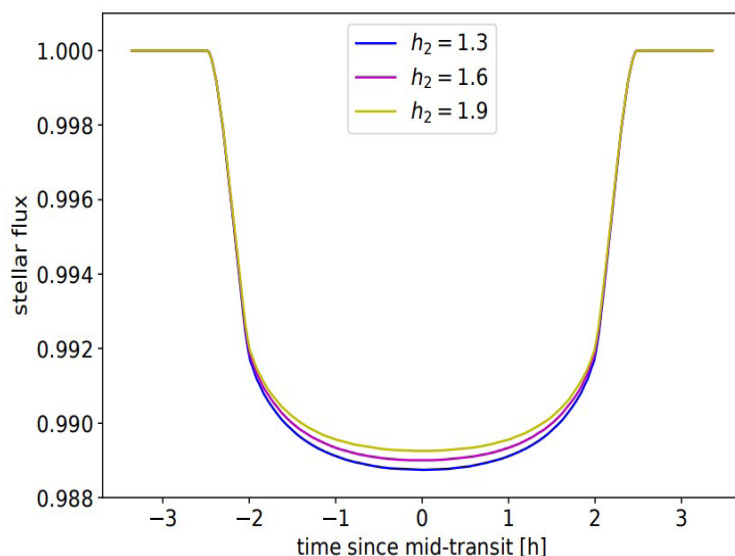


Figure 2. TLCs of a Jupiter-like planet orbiting a Sun-like star. Hellard H., PhD thesis.

The first three phenomena happen on timescales of at least millions or billions of years, therefore for exoplanets only the periastron precession - which sometimes can also occur in a few hundred years timescale - is worth studying. The apsidal motion is measurable from TTVs or from RVs.

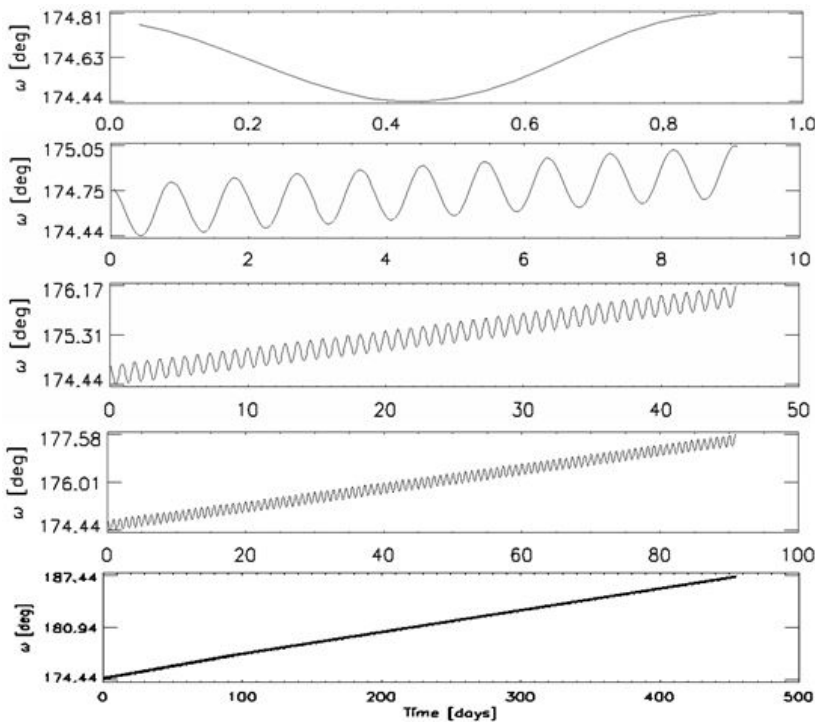


Fig. 3 shows how the angle of periastron (the angle from the body's ascending node to its periapsis, measured in the direction of motion) of the planet changes over 1, 10, 50, 100 and 500 orbits for the case of the WASP-18Ab system.

Figure 3 shows how the angle of periastron (the angle from the body's ascending node to its periapsis, measured in the direction of motion) of the planet changes over 1, 10, 50, 100 and 500 orbits for the case of WASP-18Ab system. The plot shows that over one orbital period, the angles oscillate, and over more than a few orbits we can detect a proper change, which is directly linked to tidal interaction and internal structure (Kopal, 1959).

The argument of periastron changes also because of general relativistic effects, as measured in the case of Mercury, and due to the non-sphericity and rotation of the components (star and planet), which produce rotational potential changes and tidal interaction.

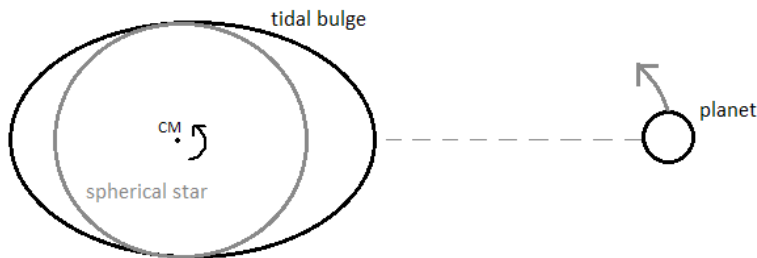


Figure 4. Asymmetrical and rotating bulge on the star created by the tidal interaction with the close-by planet.

The RV curve is made of two contributions. The first one is the periodic oscillation caused by the orbit of the star around the centre of mass of the system. Through this contribution, the orbital parameters of

the planet(s) can be evaluated. The second contribution is due to the rotationally and tidally distorted stellar shape. It leads to the presence of an apparent effect in the RV curve, which is summed on the orbital contribution. In fact, if the star is distorted by tides, there is an additional term arising from its axial rotation of the tidal bulge along with the star. Spectra of the star are asymmetric and depend on the part of the bulge facing the observer. Moreover, as shown in Figure 4 the tidal bulge is asymmetric - it is elongated in the direction of the planet - and is also rotating, shifting the spectrum, too.

With new and precise RV data, alongside long baselines of observations, we can estimate the periastron precession and therefore indirectly measure the Love number k_2 of the planet in order to constrain the internal structure.

The periastron precession can be fitted through the sum of the following three effects that are contributing to the change of the periastron angle ω over time (Csizmadia et al., 2019):

$$\dot{\omega} = \dot{\omega}_{tidal} + \dot{\omega}_{rot} + \dot{\omega}_{GR}$$

where the tidal component is:

$$\dot{\omega}_{tidal} = 15 \frac{n}{(1 - e^2)^5} \left(\frac{m_p}{M_\star} k_{2,\star} R_\star^5 + \frac{M_\star}{m_p} k_{2,p} R_p^5 \right) \left(1 + \frac{3}{2} e^2 + \frac{1}{8} e^4 \right)$$

the rotational one is:

$$\dot{\omega}_{rot} = \frac{4\pi^2}{G} \frac{n}{(1 - e^2)^2} \left(k_{2,\star} \frac{R_\star^5}{M_\star} + k_{2,p} \frac{R_p^5}{m_p} \right)$$

and the term due to General Relativity:

$$\dot{\omega}_{GR} = \frac{6\pi G M_\star}{a c^2 (1 - e^2)} \frac{1}{P_{orb}}$$

In these equations, the parameters are: G is the gravitational constant, $M_\star$ and m_p the mass of the star and the planet respectively, $R_\star$ and R_p their radii, $k_{2,\star}$ and $k_{2,p}$ their second degree Love numbers, P_{orb} the orbital period, n the mean motion $n = 2\pi/P_{orb}$, e the eccentricity of the orbit and a its semi-major axes.

Through the fitting of these parameters to the RV data, we can determine the value of $k_{2,p}$ and provide a hint on the internal structure.

A case study: WASP-18Ab

We carried out a preliminary study on the system WASP-18Ab before applying the results on the tidal theory and Love numbers.

WASP-18 is a binary star system (Csizmadia et al., 2019, Fontanive et al. 2019) 300 light years from Earth in the southern constellation Phoenix. Star A is V magnitude 9 and has a temperature of 6400 K. Component B is an M-dwarf star at around 3500 AU.

Hellier et al., 2009 discovered a hot Jupiter exoplanet, WASP-18Ab, orbiting very close to star A, with an orbital period below one day, which makes it the perfect candidate to study tidal interactions. In 2019 Pearson proposed the existence of a second planet, named WASP-18Ac, with an orbital period around 2.16 days.

A second planet in the system would add an orbital contribution in the RV curve which must be modelled with accuracy in order to determine the value of periastron precession

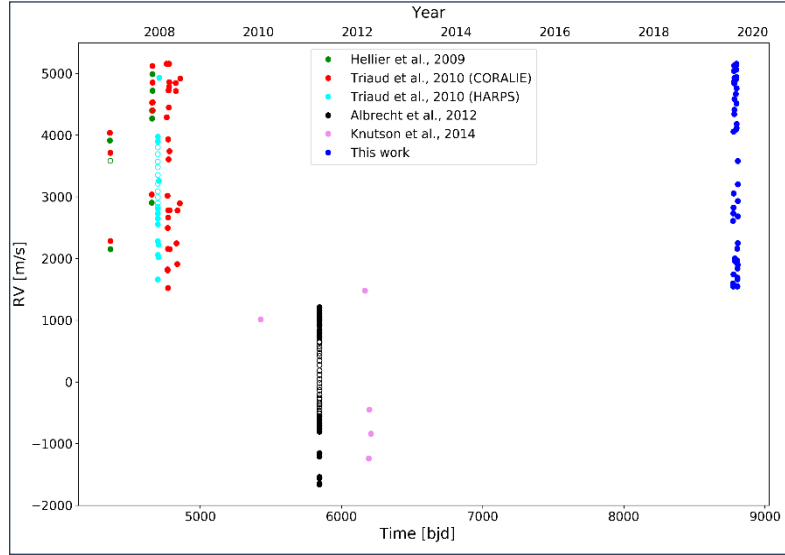


Figure 5. Radial velocity observations of WASP-18Ab, time vs radial velocities. The different data sets are represented by different colours. Empty circles denote in-transit observations which were not used in this study because they suffer from the Rossiter-McLaughlin effect.

We conducted a study to confirm or disprove the existence of WASP-18Ac by acquiring new RV data in 2020. Figure 5 shows all RV dataset since its discovery, including the new ones collected by HARPS, a high-precision planet-finding spectrograph installed on the ESO’s 3.6m telescope at La Silla Observatory in Chile.

In order to do so, a model with only one Keplerian orbit (only planet b) and one with two Keplerian orbits (planets b and c) were fitted (without gravitational perturbation effects between the two planets), adding the non-orbital apparent contribution due to the tidal bulge on the stellar surface. It was modelled from Kopal, 1959, and has the shape of an oscillating function, with the period double that of the orbital period:

$$\Delta V = -\frac{3}{2}K \sqrt{1-e^2} \frac{M_{\star} + m_p}{M_{\star}} \frac{P_{orb}}{P_{rot,\star}} \left(\frac{R_{\star}}{a}\right)^4 (1 + k_{2,\star}) \sin i \cdot \sin(2(v + \omega))$$

where K is the RV amplitude due to the orbital motion of planet b, $P_{rot,\star}$ the rotational period of the star, i the inclination of the orbital plane relative to the plane perpendicular to the line of sight and v the mean anomaly.

Moreover, we searched for an additional signal in the RV data by inserting a second planet with random orbital parameters. We repeated the process more than one billion times, but no evidence was found. As a last attempt, we applied the Discrete Fourier Transform (DFT) technique on the dataset. We detected a peak in correspondence with the orbital period of planet b, but no peak was observed corresponding to the period of 2.16 days proposed by Pearson for planet c of the system. Therefore, we discarded the existence of the second planet orbiting around WASP-18A.

After this preliminary study, we are proceeding with evaluating the change of the angle of periastron ω in order to determine the Love number k_2 from the equations for $\dot{\omega}_{tidal}$ and $\dot{\omega}_{rot}$ to try to break the degeneracy introduced in Sec. 1 between the density and the internal structure of the planet.

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Publication watch

Mark Blackford and **Phil Evans** have assisted **David Moriarty** with an analysis of several southern eclipsing binary systems with pulsating components resulting in a paper by lead author Alexei Liakos.

Liakos, A. ; Moriarty, D. J. W. ; Blackford, M. G. ; West, J. F. ; Evans, P. ; Moriarty, C. M. ; Sweet, S. M., *Comprehensive analysis of southern eclipsing systems with pulsating components: The cases of HM Pup, V632 Sco, and TT Vel*, *Astronomy & Astrophysics*, Volume 663, id.A137, 26 pp. (<https://doi.org/10.1051/0004-6361/202243313>)

Abstract

This work presents an extensive analysis of the properties of three southern semi-detached eclipsing binaries hosting a pulsating component, namely HM Pup, V632 Sco, and TT Vel. Systematic multi-filtered photometric observations were obtained using telescopes located in Australia and Chile mostly between 2018-2021. These observations were combined with data from the Transiting Exoplanet Survey Satellite (TESS) mission for a detailed analysis of pulsations. Spectral types and radial velocities were determined from spectra obtained with the Australian National University's 2.3 m telescope and Wide Field Spectrograph. The data are modelled and the absolute parameters of all components are derived. The light curve residuals are further analysed using Fourier transformation techniques for the determination of the pulsation frequencies. Using theoretical models, the most probable modes of the principal oscillations are also identified. Eclipse-timing variation analysis is also made for all systems and the most likely mechanisms modulating the orbital period are proposed. The physical properties of these systems are compared with other similar cases and the locations of their components are plotted in the M-R and HR diagrams. Finally, the pulsational properties of the oscillating components are compared with currently known systems of this type within the orbital-pulsation period and log g-pulsation period diagrams. These systems are identified as oEA stars by definition, with the primaries to be pulsating stars of δ Scuti type, while evidence of mass flow from the evolved secondary components is present in their Na I D spectra.

Mark Blackford has also two further publications on variable stars:

Poro, Atila; Paki, Ehsan; Blackford, Mark G. et al. *The Photometric Study of Six W UMa Systems and Investigation of the Mass–Radius Relations for Contact Binary Stars*, *Publications of the Astronomical Society of the Pacific*, Volume 134, Issue 1036, id.064201, 15 pp.

Abstract

We present the photometric analysis of six short-period systems (EI Oct, V336 TrA, NX Boo, V356 Boo, PS Boo, and V2282 Cyg). This is the first photometric analysis of these systems except for V336 TrA. Observations were conducted for 27 nights at three observatories in the northern and southern hemispheres. We calculated a new ephemeris for each of the systems using our minimum times and additional literature. The Markov Chain Monte Carlo (MCMC) approach was used to determine the eclipse timing variation trends of the systems. We found a likely orbital growth for V336 TrA and PS Boo; four other systems show a linear trend in orbital period changes, which is most likely due to the accumulation of measurement errors in their linear ephemeris parameters. The light curve analysis was performed using the Physics of Eclipsing Binaries (PHOEBE) 2.3.59 version code with the MCMC approach. The absolute parameters of the systems were calculated by using the Gaia Early Data Release 3 (EDR3) parallax. The positions of the systems were also depicted on the Hertzsprung–Russell (H-R) and logJ0–logM diagrams. According to a sample, we were able to present relations for the mass-radius (M-R) relationships of contact binary systems. There is also a strong relationship between the mass ratio and the radius ratio in the W UMa systems for which we also provided a new relation. We compared the M-R updated relationships in this study with seven systems in other studies obtained using the spectroscopic method. In addition, we estimated some of the absolute parameters for 1734 EW systems, based on the new relationships.

Poro, Atila; Blackford, M. G. et al. *The First Photometric Study of AH Mic Contact Binary System*, *Research in Astronomy and Astrophysics*, Volume 22, Issue 5, id.055020, 8 pp.

Abstract

The first multi-color light curve analysis of the AH Mic binary system is presented. This system has very few past observations from the southern hemisphere. We extracted the minima times from the light curves

based on the Markov Chain Monte Carlo (MCMC) approach and obtained a new ephemeris. To provide modern photometric light curve solutions, we used the Physics of Eclipsing Binaries (PHOEBE) software package and the MCMC approach. Light curve solutions yielded a system temperature ratio of 0.950, and we assumed a cold starspot for the hotter star based on the O'Connell effect. This analysis reveals that AH Mic is a W-subtype W UMa contact system with a fill-out factor of 21.3% and a mass ratio of 2.32. The absolute physical parameters of the components are estimated by using the Gaia Early Data Release 3 (EDR3) parallax method to be $M_h (M_\odot) = 0.702(26)$, $M_c (M_\odot) = 1.629(104)$, $R_h (R_\odot) = 0.852(21)$, $R_c (R_\odot) = 1.240(28)$, $L_h (L_\odot) = 0.618(3)$ and $L_c (L_\odot) = 1.067(7)$. The orbital angular momentum of the AH Mic binary system was found to be 51.866(35). The components' positions of this system are plotted in the Hertzsprung-Russell diagram.

Phil Evans is a co-author on two recent TESS papers published on the arXiv:

Rodriguez, Joseph E. ; Quinn, Samuel N. ; Vanderburg, Andrew *et al*: *Another Shipment of Six Short-Period Giant Planets from TESS.* 2022arXiv220505709R.

Abstract

We present the discovery and characterization of six short-period, transiting giant planets from NASA's Transiting Exoplanet Survey Satellite (TESS) -- TOI-1811 (TIC 376524552), TOI-2025 (TIC 394050135), TOI-2145 (TIC 88992642), TOI-2152 (TIC 395393265), TOI-2154 (TIC 428787891), & TOI-2497 (TIC 97568467). All six planets orbit bright host stars ($8.9 < G < 11.8$, $7.7 < K < 10.1$). Using a combination of time-series photometric and spectroscopic follow-up observations from the TESS Follow-up Observing Program (TFOP) Working Group, we have determined that the planets are Jovian-sized ($RP = 1.00\text{--}1.45 R_J$), have masses ranging from 0.92 to 5.35 MJ, and orbit F, G, and K stars ($4753 < T_{\text{eff}} < 7360 \text{ K}$). We detect a significant orbital eccentricity for the three longest-period systems in our sample: TOI-2025 b ($P = 8.872$ days, $e = 0.220 \pm 0.053$), TOI-2145 b ($P = 10.261$ days, $e = 0.182 \pm 0.039\text{--}0.049$), and TOI-2497 b ($P = 10.656$ days, $e = 0.196 \pm 0.059\text{--}0.053$). TOI-2145 b and TOI-2497 b both orbit subgiant host stars ($3.8 < \log g < 4.0$), but these planets show no sign of inflation despite very high levels of irradiation. The lack of inflation may be explained by the high mass of the planets; $5.35 \pm 0.32\text{--}0.35$ MJ (TOI-2145 b) and 5.21 ± 0.52 MJ (TOI-2497 b). These six new discoveries contribute to the larger community effort to use {it TESS} to create a magnitude-complete, self-consistent sample of giant planets with well-determined parameters for future detailed studies.

Psaridi, A. ; Bouchy, F. ; Lendl, M. *et al*. *Three new brown dwarfs and a massive hot Jupiter revealed by TESS around early-type stars.* 2022arXiv220510854P

Abstract

The detection and characterization of exoplanets and brown dwarfs (BDs) around massive AF-type stars is essential to investigate and constrain the impact of stellar mass on planet properties. However, such targets are still poorly explored in radial velocity (RV) surveys because they only feature a small number of stellar lines and those are usually broadened and blended by stellar rotation as well as stellar jitter. As a result, the available information about the formation and evolution of planets and BDs around hot stars is limited. We aim to increase the sample and precisely measure the masses and eccentricities of giant planets and BDs transiting AF-type stars detected by the Transiting Exoplanet Survey Satellite (TESS). We followed bright ($V < 12$ mag) stars with $T_{\text{eff}} > 6200 \text{ K}$ that host giant companions ($R > 7 R_\oplus$) using ground-based photometric observations as well as high precision RV measurements from the CORALIE, CHIRON, TRES, FEROS, and MINERVA-Australis spectrographs. In the context, we present the discovery of three BD companions, TOI-629b, TOI-1982b, and TOI-2543b, and one massive planet, TOI-1107b. From the joint analysis we find the BDs have masses between 66 and 68 MJup, periods between 7.54 and 17.17 days, and radii between 0.95 and 1.11 RJup. The hot Jupiter TOI-1107b has an orbital period of 4.08 days, a radius of 1.30 RJup, and a mass of 3.35 MJup. As a by-product of this program, we identified four low-mass eclipsing components (TOI-288b, TOI-446b, TOI-478b, and TOI-764b). Both TOI-1107b and TOI-1982b present an anomalously inflated radius with respect to the age of these systems. TOI-629 is among the hottest stars with a known transiting brown dwarf. TOI-629b and TOI-1982b are among the most eccentric brown dwarfs.

About

Variable Stars South is an international association of astronomers, mainly amateur, interested in re-searching the rich and under-explored myriad of southern variable stars.

Renamed from the Variable Star Section of the Royal Astronomical Society of New Zealand, it was founded in 1927 by the late Dr Frank Bateson, OBE, and became the recognised centre for Southern Hemisphere variable star research.

VSS covers many areas and techniques of variable star research, organised into projects such as Beginners' Visual Observations and Dual-Maxima Miras. The goal of each project is to obtain scientifically useful data and results. These may be published in recognised journals, or supplied to international specialist data collection organisations.

VSS is entirely an internet based organisation, working through our website <http://www.VariableStars-South.org> and its e-group <http://groups.google.com/group/vss-members>. It also encourages members to work in with major international organisations such as the British Astronomical Association, the Center for Backyard Astrophysics and the American Association for Variable Star Observers.

To find out more, please visit our website, where, incidentally, you will find PDF copies of all our newsletters. Our website has a great deal of information for VSS members, and for anyone interested in southern hemisphere variable star research. All VSS project information and data is kept here too.

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