Spectroscopy of close visual binary components of the stable shell star 1 Delphini*,**
(Research Note)

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ABSTRACT

Stable shell stars are ideal objects for studying basic physical principles of the formation of disks in Be stars. If these stars have a close unresolved visual companion, its contribution toward the modelling of the disk cannot be overlooked, as is sometimes done. The study aims to spectroscopically resolve close visual binary Be (shell) star 1 Del, which up to now was only resolved by speckle or micrometric measurements. The integral field spectroscopy obtained by the SINFONI spectrograph at the VLT telescope in the European Southern Observatory (ESO) in the infrared region was used; we supplemented these observations with visual spectroscopy with the Perek Telescope at the Ondřejov Observatory. Spectra of 1 Del were successfully resolved, and, for the first time, spectra of 1 Del were obtained. We found that 1 Del A is a Be/shell star, while 1 Del B is not an emission-line object.

Key words. stars: emission-line, Be – binaries: visual – infrared: stars – stars: individual: 1 Del

1. Introduction

Be stars form an important subgroup of stars of spectral class B. They are defined as non-supergiant B-type stars, which exhibit, or at some time in their observational history have exhibited, emission superimposed over absorption lines in their spectra (Collins 1987). This emission is most commonly found in the Hα line of the Balmer series of hydrogen. Shell stars form a subclass of Be stars (see e.g. Hanuschik 1996). They are characterized by sharp absorption cores of rotationally broadened emission lines. These stars are often variable, for example the star Pleione (see Nemravová et al. 2010). Stable shell stars form their special subclass (see Gulliver 1981). Their stability makes them especially suitable for testing basic physical processes that may lead to the existence of a disk, since the time dependent phenomena do not complicate the analysis. An understanding of stable shell stars may shed light on Be and shell stars with much more complex and time dependent behaviour. For recent reviews about Be stars and their models, see Porter & Rivinius (2003) and Rivinius et al. (2013).

The importance of stable emission-line stars for developing basic physical models of emission formation was already noticed by Marlborough & Cowley (1974), who used the stable shell star 1 Del as a typical stable emission-line star for modelling. More sophisticated models were later calculated by Millar & Marlborough (1999) and Jones et al. (2004). These authors were able to reproduce the profiles of the observed Hα line profile of 1 Del with their model of the circumstellar envelope. They assumed that 1 Del is a single star.

However, 1 Del was discovered as a visual binary with components separated by less than one arcsecond (Burnham 1873a). Also, many other Be stars are in close visual binaries (see Oudmaijer & Parr 2010). Spectroscopic observations of these close visual binaries is not an easy task, since many times the observing conditions are not perfect and light from both stars overlaps. The small separation of the components of the close pair very often causes these stars to appear at the spectrograph slit as a single object. As a consequence, it is difficult or impossible to resolve individual spectra. Observed spectra contain mixed light from both stars. If the magnitude difference between components is not large, both stars significantly contribute to observed spectra and this fact has to be taken into account in analysis using single star disk models. In this paper, we aim to extract spectra of individual components of 1 Del.

2. Summary of basic facts about the star 1 Del

The star 1 Del (HR 7836, HD 195325, BD +10°4303, HIP 101160) belongs to the category of above mentioned stable emission-line shell stars in close visual binaries.

The shell spectrum of 1 Del was first detected on 9 August 1919 at the Dominion Astrophysical Observatory (see Bidellman 1988). Numerous emission lines were reported by Harper (1937, ...
of 3D datacubes with one spectral and two spatial dimensions. We used the programme QFitsView\(^1\) for visualization of 3D spectra in image cubes and spectrum extraction. The extracted spectra were normalized to continuum with a straight line.

4. Identification of binary components

4.1. Test of close binary visual spectra

Obtaining spectra of individual components of a visual binary when images of the stars overlap is a challenging task. Consequently, the observed spectrum contains spectra of both components. This is also the case of observations at the Ondřejov Observatory, where even the best seeing conditions are of the order of arcseconds, thus, larger than the apparent separation of the visual components of both binaries. They appear only as one object on a spectrograph slit.

Nevertheless, we carried out the following experiment with the binary 1 Del. Since the Perek 2-m telescope is not equipped with the derotator, the right moment when the connecting line between the A and B components was roughly perpendicular to the slit had to be chosen. Three spectra in the region of the H\(\alpha\) line were secured, one after another. The 0.2′′ wide slit was placed at three different parts of the stellar image at the slit camera, at the left hand side (L), right hand side (R), and at the centre (C) of the stellar image. All three exposures were 900 s long. The raw signal was highest for C as expected, but the raw signal for R was about seven times fainter than for L. This means that the fainter component (1 Del B) was located at or near L at the time of observation.

Normalized spectra for C, R, and L are shown at the upper panel of Fig. 1. The emission height with respect to the local continuum is smaller for L than for R. This corresponds to the case when additional continuum (without an emission) is added to the radiation of the star, and the emission strength weakens. All this indicates that the H\(\alpha\) emission should come from the brighter component, namely 1 Del A, rather than from the fainter component, 1 Del B. In the difference spectrum C−L (see the lower panel of Fig. 1), the emission in the H\(\alpha\) line is stronger than in the C spectrum. This shows that the spectrum of 1 Del A is an emission spectrum and that the spectrum of 1 Del B is either an absorption spectrum or it has a weak emission, which appears in the difference spectrum (C−R). However, these observations involve strong uncertainties (mainly because of uncertain positions of components A and B during observations), thus, it is not possible to reach a firm conclusion. To obtain more information about the system, we decided to observe the binaries with an integral field spectroscopy device, which is available in the infrared spectral region.

4.2. Infrared integral field spectroscopy

The image of the binary 1 Del, obtained by the programme QFitsView\(^2\) from the observations in the J band, is given in Fig. 2. The secondary (1 Del B) is clearly visible in the right part of the image. Stellar spectra were extracted using the programme QFitsView, which enables extraction of spectra for individual spaxels or integrated over a circle of spaxels. The light was integrated from the regions occupied by A and B components with a minimized contribution of the other component. This way we obtained the spectrum of 1 Del A and the very first spectrum of 1 Del B.

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\(^1\) IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

\(^2\) http://www.mpe.mpg.de/~ott/QFitsView/
The spectra in the region of the Pβ line are plotted in Fig. 3, where the difference between spectra of 1 Del A and 1 Del B is clearly visible. While there is no emission in the Pβ line of 1 Del B, the shell features in the wings of the Pβ line are clearly seen in the spectrum of 1 Del A. Consequently, the A component is a shell star, as indicated by rough estimates from the Hα line profiles. The higher hydrogen Brackett series lines are in the upper panel of Fig. 4. In this region, the absorption in the lines of 1 Del A is sharper, confirming this component as a shell star. The highest members of the Brackett series (above Br17) are hardly seen in the spectrum of 1 Del B, while they are clearly visible for 1 Del A. The strong absorption line near 16 700 Å is caused by a vibrational transition of terrestrial methane (see e.g. Brown et al. 2003), which also causes other surrounding small absorption lines. The strong terrestrial, vibrational absorption of CO2 (see e.g. Rothman et al. 2005; Tashkun et al. 2015) blends with Br13 and Br15 lines. The Brγ line (not shown here) also has emission with a shell absorption core for the A component, however, the spectra in this spectral region are very noisy.

To summarize, the observations show that only the A component of 1 Del is an emission-line star. The B component seems to be of a similar spectral type as the A component (without an emission) with significantly broadened absorption lines. By comparing H-band spectra of Be stars presented by Steele & Clark (2001), we may classify 1 Del B as late B. Unfortunately, the H-band region is not suitable for more exact spectral type determination or for rotational velocity determination, since this region lacks uncontaminated photospheric features (cf. Steele & Clark 2001). Nevertheless, we tried to estimate the rotational velocity of 1 Del B from the Br11 line. We applied a technique used, for example by Slettebak (1967), for A-type stars in the visual spectral region, and obtained 370 km s$^{-1}$, which is a larger value than for 1 Del A. The most recent value by Royer et al. 2002 is 217 km s$^{-1}$. Since the apparent brightness difference between A and B components is only about 2 magnitudes, then if the components are not resolved, radiation from the B component has to be taken into account in fitting the spectrum of 1 Del.
5. Conclusions

Resolved spectra of both components of the stable shell star 1 Del were obtained for the first time with infrared integral field spectra. We showed that 1 Del A is a shell star, while 1 Del B is not an emission-line star.

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### Appendix A

#### Table A.1. Measurements of angular separation of components of the triple system 1 Del.

| Date       | Angle  | Separation | n  | Magnitudes | Reference |
|------------|--------|------------|----|------------|-----------|
|            | AB     | AC         | A  | B          |           |
|            |        |            | A−B| C          |           |
|            |        |            | A−C|            |           |
|            |        |            |     |            |           |
| 1874.54    | 343    | 0.7        | 6  | 11         | B73       |
| 1874.74    | 348.3  | 0.85       | 6.0| 8.0        | B74       |
| 1874.76    | 351.9  | 0.75       | 6.0| 8.2        | P51       |
| 1948.77    | 349.9  | 0.83       | 6.0| 8.0        |          |
| 1957.498   | 345.7  | 0.86       | 6.0| 8.2        |          |
| 1973       | 345.9  | 0.86       | 6.0| 8.2        |          |
| 1974.590   | 347.5  | 0.92       | 6.0| 8.2        |          |
| 1974.598   | 349.7  | 0.84       | 6.0| 8.2        |          |
| 1975.475   | 346.7  | 0.91       | 6.0| 8.2        |          |
| 1980.78    | 347.2  | 0.91       | 6.0| 8.2        |           |
| 1991.25    | 346    | 0.929 ± 0.003 | 6.1| 8.1        |           |
| 1996.7013  | 349.5  | 0.915      | 1  | 2.2        |           |
| 1999.47    | 350.5  | 1.         | 1  | 2.2        |           |
| 1999.74    | 352    | 0.96       | 3  | 2.1        |           |
| 1998.789   | 349.0  | 0.90       | 6.0| 7.9        |           |
| 2000.44    | 340.1  | 17.16      | 6.0| 7.9        |           |
| 2000.5000  | 349.7  | 0.907      | 1  | 2.2        |           |
| 2000.5002  | 349.8  | 0.911      | 2  | 2.2        |           |
| 2001.365   | 339.8 ± 0.1 | 16.572 ± 0.113 | 7.700 ± 0.340 | 13.950 ± 0.06 |
| 2003.788   | 348.9  | 0.89       | 6  | 2.2        |           |
| 2004.878   | 349.4 ± 0.007 | 0.919 ± 0.007 | 2.2 | 2.2        |           |

**Notes.** n: number of measurements; (**D**73) observations by Dembowsk; (**D**74) HIPPARCOS RV magnitude. Additional measurement of positions was reported for 2009 in the current version of the Washington Double Star Catalog, but no further details were found.

**References.** (B73) Burnham (1873a): micrometer, Chicago, 6-inch Alvan Clark telescope; (B74) Burnham (1874): micrometer, Washington, 26-inch telescope; (P51) Prêtre (1951): micrometer, Pic du Midi, 38-cm; (vdB58) van den Bos (1958): micrometer, Lick, 12-inch reflector; (H61) Heintz (1961): micrometer, München, 28.5-cm refractor; (vH66) van Herk (1966): micrometer, Observatoire de Nice, 38-cm; (E97) ESA (1997): HIPPARCOS; (DN00) Dommanget & Nys (2000): HIPPARCOS; (FM00) Fabricius & Makarov (2000): HIPPARCOS; (H00) Hartkopf et al. (2000): speckle, Mount Wilson, 2.5-m telescope; (A98) Alzner (1998): micrometer, Hemhofen, 32.5-cm Cassegrain and 360-mm Zeiss-Newtonian; (D00) Douglass et al. (2000): micrometer, Washington, 66-cm refractor; (W06) Wycoff et al. (2006): from 2MASS observations using data mining; (D04) Docobo et al. (2004): speckle, Calar Alto, 1.52-m telescope; (H13) Hartkopf et al. (2013): 20-cm, UCAC R; (M04) Mason et al. (2004): speckle, USNO Naval, 26-inch refractor; (S06) Scardia et al. (2006): speckle, Brera, Merate, 1-m Zeiss telescope; m: mean values (*in italics*).