The W UMa-type variable star V759 Cen

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Abstract. The variable star V759 Cen has been used at Unisa for a number of years to teach third-year students the basics of photometry. In this article the properties of V759 Cen are reviewed and some of the outstanding problems related to stellar systems of the eclipsing contact binary type are highlighted. More observational work is required to understand the complex phenomena occurring in these systems.

Discovery

Objective prism plates of moderately high dispersion regularly contain a number of objects with abnormally wide or double spectral lines. The majority of these sources are visual binaries with nearly equal components and separations of a few arcseconds. A few cannot be explained this way, however. To investigate the nature of these stars, Bond (1970) carried out differential photometry through a Strömgren *y* filter on six candidates found on Michigan Curtis-Schmidt objective prism plates. Three of the stars were found to be variable and were observed occasionally over nine nights. On three nights complete four-colour *uvby* photometric measurements of the variable stars were obtained.

One of the variables, HD 123732, is listed in the Henry Draper catalogue as being of spectral type F8. Bond's photometry showed that HD 123732 had a variation of 0.16 magnitudes, $(b - y) = 0.39$ and a maximum V magnitude (obtained by transforming his *uvby* measurements to the Johnson UBV system) of 7.4. He derived an ephemeris of 244 0648.862 + 0.395 E for the periodic variations of the star, which he interpreted as an orbital period of 9.48 hrs. The broad spectral lines implied a binary system with rapid rotation and hence Bond identified HD 123732 as a variable star of the W Ursae Majoris (W UMa) type. Based on these observations, HD 123732 was given the variable star designation V759 Cen by Kukarkin et al. (1972) on behalf of Commission 27 of the IAU.

W UMa systems

W UMa-type systems are eclipsing binaries with orbital periods between 5 and 24 hrs (0.2 to 1 days). They are also known as EW systems. The mass ratio of the two stars is always different from unity, i.e. one component is always more massive than the other. Unlike the Algol-type binaries (or EA-type)

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which have constant light between eclipses, the EW systems show continuous variations of light. The minima in the light curves have a mean amplitude of 0.75 mag and are of almost equal depth, having differences of no more than 0.1 to 0.2 mag (Sterken & Jaschek 1996). They have a spectral type from late A to mid K and are dwarf stars (class V). Neither the spectral type nor the colour of the system changes during the orbital cycle. EW systems can be distinguished from the β Lyrae-type (or EB) systems which also have continuous light variations in that the EB systems have orbital periods > 1 day, spectral types of A or B, and secondary eclipses that are significantly different in magnitude to the primary eclipse.

Photometry

Wolf & Kern (1983) measured $V = 7.65 \pm 0.010$ when V795 Cen was at phase 0.729 and $(b - y) = 0.389$. A four-colour *uvby* photometric survey of A5 – G0 stars in the Henry Draper catalogue by Olsen (1983) includes HD 123732. He obtained values for the Johnson V magnitude and the $(b - y)$ index of 7.563 ± 0.005 and 0.370 ± 0.004 respectively. De Geus, Lub & van der Grift (1990) obtained values for Johnson V and $(B - V)$ of 7.60 and 0.61 respectively from their Walraven photometry of nearby southern OB associations. The Hipparcos Input Catalogue (Turoc et al. 1992) has $V = 7.563 \pm 0.031$ and $(B - V) = 0.594 \pm 0.015$ for V759 Cen. The on-line versions of the Hipparcos, Tycho 1 and Tycho 2 Catalogues [URL: http://archive.eso.org/skycat/servers/ASTROM] list values for $(B - V)$ of 0.594, 0.568 and 0.534 respectively. Rucinski & Duerbeck (1997) derived a value of $(B - V) = 0.59$ from Bond's $(b - y)$ value, which they converted to the Johnson system using relations established by Bessell (1979).

Mason et al. (1998) did not detect the presence of components in the V759 Cen system with their optical speckle observations made through a Strömgren *y* filter. The limit of the speckle observations, defined by the Rayleigh criterion, was 35 milli-arcseconds (mas).

Spectroscopy

In the Henry Draper Catalogue star 123732 is listed as having a spectral type of F8. From objective-prism plates Houk (1978) determined a spectral type of G0 V for V759 Cen, a result confirmed by Lü (1982) from image tube spectra. Henry et al. (1996) took spectra in the range 3720 to 4180 Å which includes the H and K lines of Ca II. The strength of these lines is used as a measure of the chromospheric emission from stars. V759 Cen was one of the twenty most chromospherically active stars in the sample of over 800 southern stars selected from stars having $0.50 \leq (B - V) \leq 1.00$. Due to its fast rotation, however, the lines appear 'washed out' and the spectrum is listed as strange. High resolution spectra centred near Hα with coverage from 5600 to 7750 Å were obtained by Soderblom, King & Henry (1998), who showed that the spectral lines are both broad-lined and double-lined, and that V759 Cen undergoes significant radial velocity variations on short timescales. Because of the very large projected rotational velocities, no clean metal features were available to measure $v \sin i$, but an upper estimate of 150 km s^{-1} was determined from Hα.

Absolute Magnitude

The absolute magnitude M_V was determined by Lü (1982) from the spectral type and luminosity classification using the method of Keenan (1963). Because V759 Cen is within 100 pc of the Sun, no corrections for reddening were made in deriving the value $M_V = 4.4$.

Although the reddening $E(B - V)$ is a relatively small quantity for stars within 100 pc of the Sun, the interstellar medium shows strong inhomogeneities. Rucinski & Duerbeck (1997) used the relation $E(B - V) = 1.7 \times 10^{-22} N_{HI}$ to estimate the reddening, where N_{HI} is the neutral hydrogen column density. A large database of determinations of N_{HI} is available, based on the data of Fruscione et al. (1994). Errors of 0.01 – 0.02 mag in these values are due to the interpolation of N_{HI} values over an irregular grid of stars. The absolute magnitude was determined using

$$M_V = V + 5 \log \pi - 3.1\ E(B - V) - 10,$$

where the parallax π is in units of mas and V is the observed magnitude at maximum light. The value of V was taken from the maximum Hipparcos photometric magnitude H_p and transformed using $H_p - V = 0.22(B - V)$. With $(B - V) = 0.59$ (see above) they determined $V_{max} = 7.44$ mag. The parallax π measured by Hipparcos is $\pi = 15.9 \pm 0.9$ mas, placing V759 Cen at a distance of 62.9 pc (205 ly) from the Sun. Inserting the above values into the equation gives an absolute magnitude of $M_V = 3.38$.

Period

Sistero & Castore de Sistero (1976) made 231 UBV observations of V759 Cen, from which they determined the times of minima and the light elements. They got an ephemeris of 244 2196.09732 + 0.39395129 E for V759 Cen. Further observations of the system were made by Sistero et al. (1990), who realised that the primary and secondary minima had been interchanged in the previous work. They subsequently determined new times of minima and revised the period, getting an ephemeris of 244 3089.2898 + 0.39399903 E using all the available data.

EW systems show a complex behaviour of period changes interrupted by phases of constant period. A statistical study by van't Veer (1991) found that positive and negative period jumps are randomly distributed. Thus far, there have been no reports of period changes in V759 Cen. Sistero et al. (1990) found that the $O - C$ residuals calculated from their ephemeris were comparable to the estimated mean errors for all but two minima. This suggests that the period was constant over the 12 year timespan of their observations.

Period-colour relation

The period-colour relation for W UMa-type stars was discovered by Eggen (1961, 1967). The calibration of the relation has been refined over the years but the most accurate results are those using the parallax data from Hipparcos. Rucinski & Duerbeck (1997) used the Hipparcos parallax data of 40 W UMa type binary systems to derive a $(B - V)$-based absolute magnitude calibration of the form $M_V = M_V(\log P, B - V)$ for these stars. Using a period of 0.3939 days for V759 Cen, it was found to be brighter than predicted by the calibration.

Model

The two components of W UMa systems are normal main-sequence stars, each generating energy in their cores via the PP or CNO nuclear burning process. The short period of these systems requires that the components are very close to each other, forming what is known as a contact binary. In contact binaries, the photospheres of both stars equal or exceed an equipotential surface known as a Roche lobe. The stars in these type of systems touch at the inner Lagrange point, L1. Most contact binaries are overcontact systems: both stars are bigger than their lobes so that a big 'neck' joins the stars at the L1 point with a common envelope formed around the components. If thick enough, the common envelope will obscure the intrinsic nature of the two stars. The two stars have different masses and so there is probably a transfer of mass from the more massive to the less massive star. This mass transfer contributes to the luminosity of the system.

Due to their gravitational interaction on each other, the stars in W UMa systems have surfaces that are highly deformed from spherical shapes into ellipsoids. The continuous light changes in W UMa systems are due to eclipses and to the changing aspect of their tidally distorted shapes. Different amounts of their surfaces – the long sides or the short ends – are seen during the orbital cycle, producing a periodic variation in the brightness. Because the stars are tidally distorted, and there is probably a transfer of mass from one star to the other, W UMa systems violate the mass-luminosity relation of single main-sequence stars.

The lack of colour or spectral variation through the orbital cycle of W UMa systems implies that the common envelope is optically thick and has a uniform temperature. The uniform temperature explains why the minima are of almost equal depth. Note, however, that W UMa systems typically have mass ratios much less than unity, and therefore they should not be barytropic. An important and long standing problem is how energy is transferred between the stars.

W UMa systems have the least amount of angular momentum that two normal unevolved stars can have, i.e. they are as close as main sequence binaries can be. This is still many orders of magnitude more angular momentum than single stars can have. Most late-type binaries with periods less than eight days have circular orbits and synchronised rotational and orbital velocities (Rucinski 1983). The two stars of V759 Cen orbit each other approximately every 9.5 hours. They therefore also have to rotate every 9.5 hours to face each other.

Stellar magnetic fields are believed to be generated by a dynamo effect associated with differential rotation (spin) and convection within the star. The faster a star rotates, the stronger its magnetic field is likely to be. Emission from Hα and the H and K lines of ionized calcium (Ca II) is produced in the Sun's chromosphere (the region between the photosphere and the corona) and appears to be associated with magnetic fields. Regions of strong magnetic fields on stellar surfaces emit strongly in the H and K lines of Ca II, and hence the strength of these lines is used as a measure of the chromospheric emission of a star. The 9.5 h orbital and spin period of the stars in V759 Cen is much faster than the spin period of the Sun, and hence the magnetic fields generated are also much stronger. This explains the strong chromospheric emission observed by Henry et al. (1996) in V759 Cen.

Besides the transfer of mass from one star to the other, there is also a loss of mass from the system via a stellar wind. The stellar wind carries with it magnetic field lines which are attached to the stars. This mass loss via a magnetised stellar wind causes the system to lose angular momentum. When single stars lose angular momentum they spin more slowly. If the stars in contact binaries are tidally locked, they spin at the same rate as they orbit each other. An individual star cannot lose angular momentum but the system as a whole can lose angular momentum by moving closer together. When the stars move closer together, however, they revolve around each other faster (i.e. the orbital period decreases in accordance with Kepler's Law for planetary motion). If the tidal forces keep the spin and orbital motions synchronized, the stars will also spin faster. As they lose angular momentum the stars spiral in closer to each other. Close binaries eventually become contact binaries, and contact binaries finally merge to form a single star.

Roughly one in every thousand stars is a contact binary. They tend to be middle-aged or old and thus seem to be made rather than born. They probably descend from short period main-sequence RS CVn systems through angular momentum loss by magnetised stellar winds, and evolve into blue stragglers or into rapidly rotating spotted giant stars (FK Comae type) by merging. It may be that all close binaries eventually come into contact.

The cause of the period jumps observed in W UMa systems is still uncertain. Mass transfer from one component to the other would produce jumps in only one direction, and cyclic magnetic activity would produce alternating positive and negative jumps. Neither of these simple models is supported by the observations. It appears that the combination of mass loss, variable magnetic dynamo activity and mass transfer between the components of the binary systems all combine to produce a complex pattern of period changes. The period instabilities are very important indications of many different underlying physical processes in these binaries, but are not unambiguous tools for analyzing them.

Conclusion

The 4th edition of the GCVS (Kholopov 1985) lists 563 stars having EW-type light curves but only 514 of these have reasonably well-defined periods. Light curves are available for only a minor fraction of these, and radial velocity curves exist for an even smaller number of systems. The only published light curve of V759 Cen is that of Bond (1970) and there are no radial velocity curves.

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