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FR SCUTI: A TRIPLE VV CEPHEI-TYPE SYSTEM OF PARTICULAR INTEREST

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The VV Cephei-type binaries form a small but interesting group of massive binaries consisting of an M-type supergiant and a late O or an early B-type star (Bidelman, 1954; Cowley, 1969). They are related to, but distinct from two other classes of stars with composite spectra: symbiotic stars and ζ Aurigae systems. The optical spectra of VV Cephei stars are characterized by emission lines of hydrogen and [Fe II]. In addition, weaker emission lines, mostly forbidden, of the other single-ionized elements are observed. Because of the large radius of the M-type supergiant, the orbital periods in VV Cephei systems might be decades long, like for the prototype, VV Cep (20.4 yr), or KQ Gem (26.7 yr). In a few of them, including VV Cep itself, eclipses are observed. The VV Cephei systems are very rare; less than twenty are known in the Galaxy. This rarity comes from the fact that systems with very massive components evolve very fast.

FR Sct (HIP 90115) is a relatively poorly studied VV Cephei system. Its composite spectrum was discovered by Bidelman & Stephenson (1956). In contrast to the other VV Cephei systems, it showed emission lines of [Fe III] and [O III]. The photometric variability was discovered by Shajn (1934). Although Shajn (1935) noted that the star exhibits variability with a short period (of unknown length), the observations made so far (Tsessevich, 1952; Burchi, 1980, Hipparcos data) showed no more than erratic or semi-regular variations in the range of a few tenths of magnitude.

FR Sct is also known as a radio source (Florkowski et al., 1985). The radiation in the radio domain is probably due to a thermal emission of a cloud of plasma. The plasma originated probably as a result of ioniziation of the cool wind coming from M supergiant by the ultraviolet radiation of the OB component. The radio and optical positions of FR Sct were frequently used to define or compare astrometric reference frames (e.g., Johnston et al., 1985; Walter et al., 1997).

The star was also observed by the ASAS survey (Pojmański, 1997) where it is recognized as ASAS 182323−1240.9. Surprisingly, automatic classification applied by the authors of the ASAS catalogue to this star resulted in an ESD/ED classification, i.e., semi-detached or detached eclipsing binary, with a period of only 3.535 d (Pojmański & Maciejewski, 2005). What seemed to be at a first glance an incorrect classification, has been confirmed during our analysis, carried out according to the procedure described by Pigulski (2005). The only difference was that the search for periodic variations we present here was made using eclipse-freed light curves. This was a part of a much wider search for pulsating components of eclipsing binaries (Michalska & Pigulski, 2007). The original ASAS light curve (Fig. 1) does not show the eclipses in an obvious way, because they are contaminated by the quasi-periodic variations originating probably in the M-type supergiant. However, as these long-term variations could be well represented by means of a series of sinusoidal terms with frequencies smaller than 0.01 d^{-1}, we were able to separate them from eclipses. The contributions from the long-term variations and the eclipses are shown in Figs. 2 and 3, respectively. As can be seen in Fig. 2, the long-term changes, presumably due to the variability of the cool supergiant, have a range of about 0.4 mag and a mean V magnitude of about 10.28. The larger scatter after HJD 2453300 is due to the change of the exposure time to smaller value around this date in the ASAS observations. In consequence, the mean accuracy of a single measurement amounts to about 0.02 mag for observations made prior and 0.06 mag for observations made after that date.

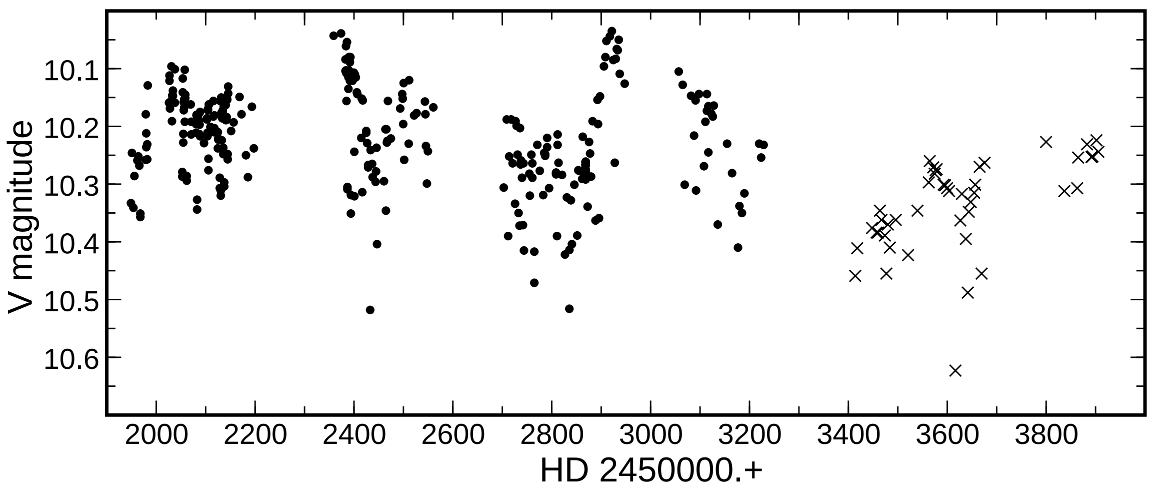

Figure 1. The V-filter ASAS light curve of FR Sct. The data cover the interval between February 2001 and June 2006. Data plotted as crosses are of lower quality

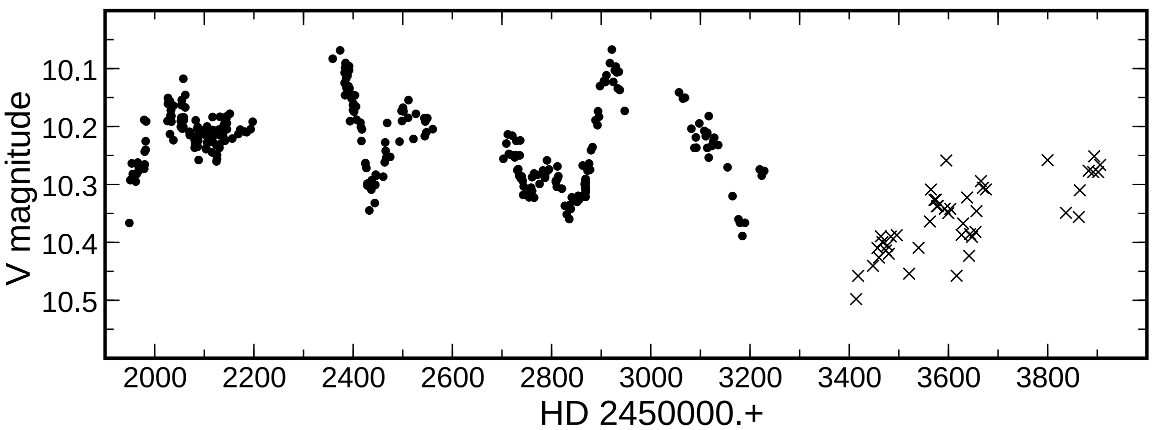

Figure 2. The same as in Fig. 1, but freed from the contribution from the eclipses

On the other hand, the eclipse light-curve (Fig. 3) shows two minima of unequal depth; about 0.23 mag for the primary and 0.13 mag for the secondary eclipse. The epochs of the primary minimum, as derived from the ASAS data, can be represented by the following ephemeris:

$$T_{\min \mathrm{I}} = \mathrm{HJD}\ 2452082.802 \pm 0.006 + (3.53405 \pm 0.00004) \times E, \qquad (1)$$

where E is the number of cycles elapsed from the initial epoch.

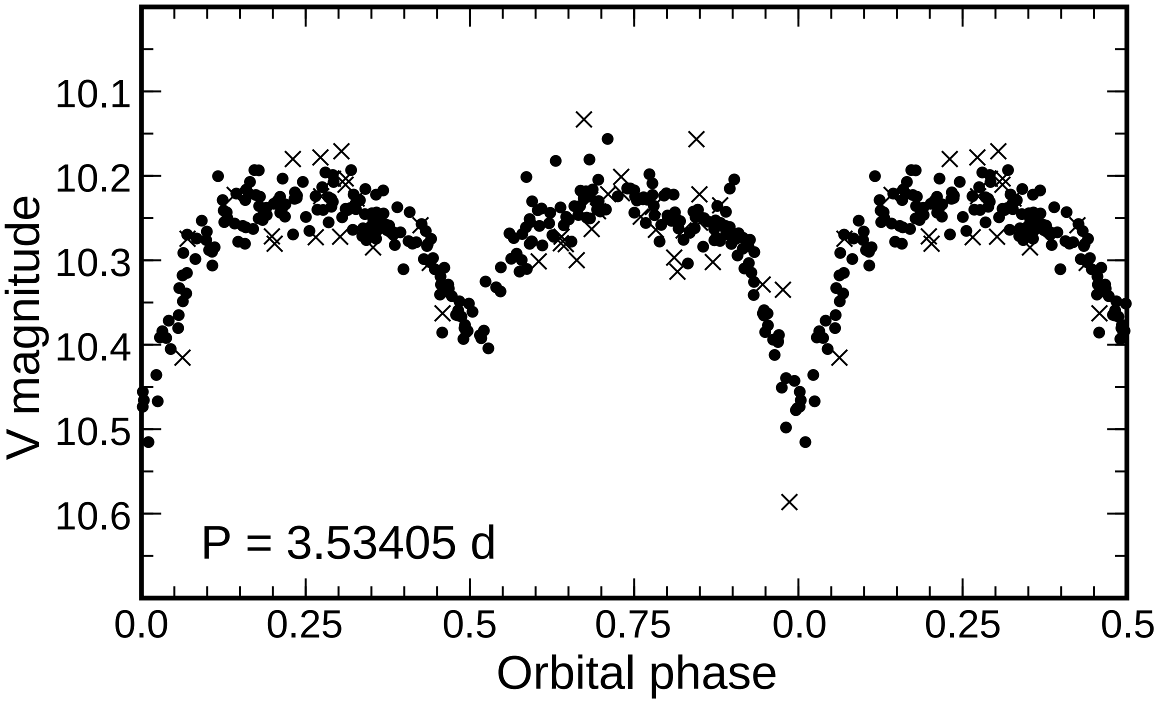

Figure 3. The eclipses in FR Sct. The light curve was folded with the orbital period of 3.53405 d. Like in Figs. 1 and 2, the data obtained prior to HJD 2453300 are plotted with dots, after that date, with crosses. The data were freed from the long-term changes seen in Fig. 2

The immediate conclusion coming from the length of the orbital period is that the eclipses cannot occur between the hot component and the cool M-type supergiant. In that case we would expect the orbital period of at least a few years. Consequently, the most plausible explanation is that the hot component of FR Sct is itself a binary, and what we see are the eclipses in this system. Thus, FR Sct would be a hierarchical triple system consisting of very massive stars. This makes it a very interesting star for the follow-up study and unique among VV Cephei stars.

It has to be pointed out that the separation of the eclipsing light curve (Fig. 3) and the long-term changes (Fig. 2) we made does not mean that Figs. 2 and 3 represent the light changes of the M-type supergiant and the hot binary as if they were seen separately. First, in both cases the contribution from the other component(s) leads to the reduction of the amplitude of the light curve. Next, we cannot exclude that some erratic changes seen in Fig. 2 come from the hot components. The presence of the [Fe III] and [O III] emission lines in the spectra of FR Sct (Bidelman & Stephenson, 1956) may be related to the duplicity of the hot component. The other possibility is that the hot components in FR Sct are hotter than usually the case in VV Cephei systems.

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