SOLVING AN ASTROPHYSICAL PUZZLE WITH PHOTOMETRY

J.P. Sareyan.

Summary: Precise photometric observations have been obtained on a rather bright well-known spectroscopic binary. Photometry appears here as a decisive technique to build a complete -and coherent!- description of the system.

I) The star HR 8800 (= HD218407, B2V, V = 6.7) was chosen as one of the comparison stars for the photometric study of the Be variable o Andromedae.
Previous studies by Percy and Lane (1977) had shown HR 8800 to be constant on a short time scale, and it was included as a supposed constant in our observing cycles.
So the discovery of its variations are a by-product of a campaign (1992) in which some GEOS members were associated (see GEOS NC 714 , 1993).

The star has been observed during one week with a Strömgren spectrophotometer (simultaneous uvby) on a 1.5 m telescope at San Pedro Martir observatory (Baja California, Mexico).
Although these means are far from the average amateur astronomy (!) , the present detection could have been made a long time ago with *much* smaller telescopes and simple stable photometers, provided that the reductions are carried out carefully.

What seems important here is that *photometry* (here, very precise differential photometry, with high S/N ratio on the data acquisition as well as on the final light curves) allows one to completely "solve" a star system already partially known by other means (spectroscopy).

Should we insist here that many among the bright stars are still not well-known ?

II) Previous studies had shown HR 8800 to be a spectroscopic binary, with a probable magnitude difference of 2.0 ± 0.3 between the primary and the secondary. Its large line broadening ("v sin i" = 160 km/s) and its rotation axis inclination estimation (i = 30°) makes it a quick rotator.
The system eccentricity -about 0.25- is rather large, but not too large for a young binary: HR 8800 belongs to the Lac OB1 association, so its distance is about 600 pc, and its age 12 to 16 millions years.

III) When it appeared that we had observed night to night (small) variations, we analyzed the 600 data points available in each filter with different period finding methods (least squares sine function, phase dispersion minimization and Fourier) in the 0.1 to 10 days range. We clearly found a unique solution: a 3.4 days period P_1 (with r.m.s. error about 0.1 day) with an amplitude about 11 millimagnitude (mmag) in the ultraviolet filter, and 8.5 mmag in the visible... (we call here amplitudes half the light variation range).

The light curves are slightly dissymetrical (fig. 1), so we introduced with P_1 a simultaneous period $P_2 = P_1 / 2$ in order to represent better the light curves (fig. 2). With these two "components", the P_1 amplitudes are about 10 mmag whatever the wavelength, and the P_2 amplitudes increase from 1.7 to 4 mmag, from UV to yellow filter (this last result is only a trend, as the r.m.s. are of the same order as the P_2 amplitudes).

So on only six nights of observations, we detected a photometric period of 3.4 ± 0.1 days, an independant result quite close to the spectroscopic binary period of 3.3378 days determined by Van Albada and Klomp (1968).

Both periods are very probably identical, so we must deal here wih a same spectroscopic and photometric period.

IV) **What about modeling the star ?**

If most of the spectrum comes from the B2V primary, the secondary should be a B7V-B8V star (magnitude difference = 2 , as noted before). According to the classical models, the masses can be estimated around 9 and 4 solar masses for the primary and the secondary, with respective radii around 5 and 3 solar radii.
The spectroscopic period and the third Kepler's law give for the orbit a half major axis around 22 solar radii. So the system is well-detached.

The inclination I of the orbit can be estimated from the previous mass functions given by Petrie (1959): $I \approx 40°$. This value is close to the primary's rotation axis inclination $i = 30°$ (Ruusalepp, 1986, 1989), which is likely to occur in a binary system.
- Both values are far from the $I < 65°$ limit for eclipses to occur, given the above radii and distances.
Furthermore, eclipses should produce two light curve minima along a spectroscopic cycle. This is not observed.
For the same reason, gravitational distortion of the components is to be ruled out as the origin of the principal part of the light variations.

- The presence of surface inhomogeneities (bright "spots") could explain the light variations. However they are only expected for close systems (one of the components close to the inner Lagrangian point), and mean a synchronization of the rotation with the orbit. At least for the primary, synchronous rotation is improbable, given the eccentricity; but, above all, the rotation axis inclination and the projected rotational velocity mean a rotation period between 1 and 1.5 day, i.e. much smaller than the orbital period. So the primary's rotation is certainly *not* synchronized with the orbit (i.e. the variations are *not* due to bright "spots" on the primary, or to its geometric "elliptic" appearence).

V) **So, where do the light variations come from ?**

- What about pulsations ? : a B2V star could be a β Cephei (or β CMa) variable. But the 3 days period is very far from the radial pulsation modes (periods around a few hours). A non-radial high order "g" (gravitational) mode synchronized with the orbit is difficult to imagine, since the rotation period of the primary is at most half the orbital period, as mentionned above. Furthermore, a short orbital period and/or fast rotation very probably inhibits the β Cep pulsation mechanism.

- A remaining explanation for the light variations is a reflexion (light transfer) from the primary on the secondary component.
With the spectroscopic ephemeris given by Van Albada and Klomp, we can calculate the date of periastron during our observations: T (Heliocentric Julian Day) = 2448900.18 ± 0.09
We observe a light maximum at HJD 2448900.38 ± 0.12 , which is in good agreement with the above spectroscopic value for the periastron.

We can as well calculate the actual orbit angle ω from the apsidal period existing in the litterature (we obtain $\omega = 323 \pm 31°$ for 1992.8).

So, at HJD 2448900.38 , we did observe the secondary "behind" the primary, and very close to it, i.e. in a position where the total light output of the system is likely to be amplified by the reflexion of the primary's light on the surface of the secondary (the *amount* of light variation observed is also well in agreement with theoretical calculations carried out with the "Wilson Devinney" code on the system's parameters).

VI) Now that we have an explanation for the principal light variations of the system, let's try to explain the (marginal) secondary effect already noted, i.e. the overmodulation by a period P_2 (half the orbital period P_1) in visible light.

We know that the primary doesn't exhibit "geometric" variations. However the secondary could be phase-locked on its orbit (like the moon in front of the earth), and its shape ellipsoidal. To explain the 8 mmag overmodulation, a 6% difference is sufficient in the apparent surface of the secondary, at 90° phase differences on its orbit.
This corresponds quite well with the phase difference observed (fig. 2) between maxima of the periods P_1 and $P_2 = P_1 / 2$, i.e. about 1/10 th of P_1, which is the time necessary for the secondary to travel from periastron to side-on view !

A last question: Why should this P_2 period appear better in the visible than in UV ?
Very probably because the primary's UV flux being much higher than the secondary's (spectral type B2 against B7-B8), it can conceal a part of the apparent surface variation of the secondary at these wavelengths.

VI) **Conclusion:** Description of the system:

A B2 dwarf illuminates its colder (B7-B8) companion, about 6 times fainter. Although well-detached, this companion is geometrically distorted, and phase-locked in front of the primary on its 3.3 days orbit.
As the system is young (12 to 16 millions years), the orbit still has a rather high eccentricity, and the primary is still a fast rotator.

Another conclusion:
More than 50 years of (discontinuous) high resolution spectroscopy, and 1 week of intensive precise photometry lead to a complete physical description of this system.
Such a description is impossible with only one of these techniques ...

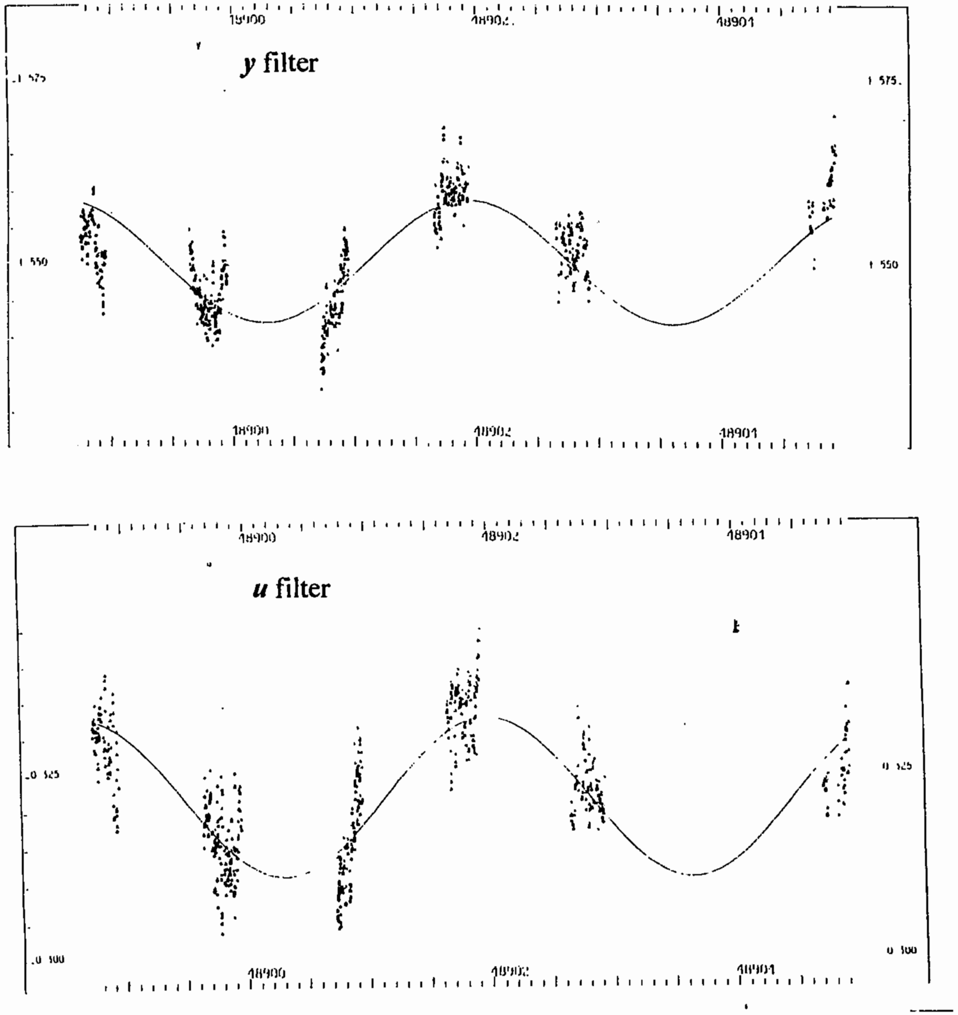

Fig. 1 : Light curves in y and u of (HR 8800 - HR 8766). Abcissae are Heliocentric Julian Days minus 2400000, and ordinate ticks are 5 mmag apart. Light fluxes increase downwards. The sinusoid is a least squares fit.

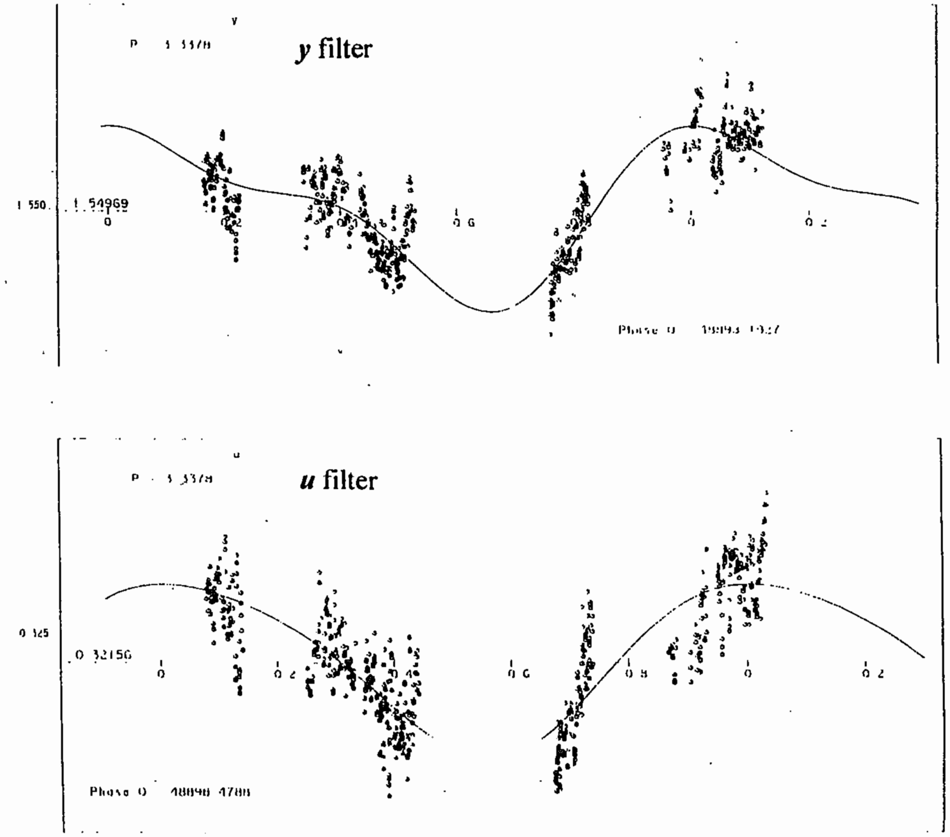

Fig. 2 : Phase diagram of HR 8800 in y and u filters, with P_1 and $P_2 = P_1/2$ simultaneous sinusoidal fits. Ordinate ticks are 5 mmag apart.