The Peculiar Ellipsoidal Variable TU Horologii

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The peculiar nature of the lightcurve of the sixth magnitude variable A-type star TU Hor (HR 1081 = HD 21981) was first discovered at ESO by H.W. Duerbeck from Bonn Observatory. In subsequent spectroscopic work in collaboration with A. and J. Surdej, Dr. Duerbeck demonstrated conclusively that TU Hor is a close binary star with an orbital period of about 0.936 days.

We have been observing TU Hor since 1978, with the Geneva Photometer attached to the Swiss telescope at La Silla. Our 1980 visual magnitude lightcurve is shown in Fig. 1a and is similar to that obtained by Duerbeck. Two characteristics are quite unusual for a close binary system: the two maxima are strongly unequal, since they differ by as much as 0.05 magnitude; in addition, the deepest minimum occurs less than half an orbital period after the other minimum, while one would expect a zero eccentricity for an early A-type binary system with so short a period. Both features are constant over a three-year interval: the lightcurve repeats itself very accurately and no additional cycle-to-cycle variations are observed.

We did also observe small but significant colour variations. Fig. 1b shows the variations of the colour index B_2-V_1 and a sinusoidal fit to these data. The amplitude is 0.006 magnitude (0.012 magnitude peak-to-peak). Since this colour index is a temperature indicator, the variations can be interpreted as variations of the effective temperature. A simple application of the calibrations of the Geneva Photometric System shows that an amplitude of 0.006 magnitude of the B_2–V_1 index for a single star with the same colours as TU Hor would correspond to an amplitude of about 75 K (about 0.8 per cent) for the variations of the effective temperature, which in turn would lead to light variations with an amplitude of about 0.035 magnitude. For a double star like TU Hor, the situation is somewhat more complicated: the temperature variations corresponding to the same observed colour variations are larger, but the resulting light variations can be expected to be of the same order.

In fact, when a sinusoidal curve with an amplitude of 0.030 magnitude and the phase determined by the colour variations is subtracted from the lightcurve, one obtains the resulting lightcurve shown in Fig. 1c. As a matter of fact, this resulting lightcurve has two equal maxima, and the phase difference between the two minima is exactly 0.50, i.e. it is a normal close binary lightcurve!

The observed variations of TU Hor can thus be interpreted as those of a close binary system, for which one of the components, in synchronous rotation, shows a peculiar temperature distribution on its surface. It is important to note that the orbital variations and the temperature variations are not in phase: maximum temperature is observed about 0.1 period before maximum light. This fact is responsible fot the peculiar phases of the minima in the observed lightcurve.

The phase difference between temperature variations and orbital variations seems to rule out a possible explanation: the temperature variations are probably not due to an anomalous reflection effect in this close system. It is also unlikely that the variations are due to a hot accretion spot, since the regularity with which the lightcurve reproduces itself during each cycle rules out the presence of much circumstellar material. I favour a third explanation and will develop it below.

Some similar cases are known in the literature: b Per, V 525 Sgr, RT Scl and AG Vir. It is a remarkable fact that all these systems are of spectral type A. It is tempting to search for a link between these binary systems and the peculiar A-type stars. The Ap stars are characterized by enhanced spectral lines of some elements compared to the spectral lines of normal stars of the same temperature and luminosity. It is generally admitted that the overabundances (and underabundances) are only superficial features and do not correspond to real anomalies of the star as a whole. The most successful theory that accounts for these anomalies is the diffusion hypothesis. In suitably quiet envelopes (Ap stars are indeed slow rotators) the relative importance of radiation pressure and of gravity will cause some elements to rise, while others will descent towards the interior. For many Ap stars, important global magnetic fields are observed. The influence of these fields on the peculiarities is thought to be twofold: first, a magnetic field tends to stabilize the atmosphere ánd so favours diffusion; second, by a process called magnetic braking, the interaction of the magnetic field with the interstellar medium removes angular momentum from the star, thus slowing down the rotational velocity, and again favouring diffusion.

In the Geneva System, a colour index Z has been defined (Cramer and Maeder, *Astron. Astrophys.* **88,** 135–140) which allows to separate the magnetic Ap stars from the normal stars. For normal stars, this index is essentially zero; for

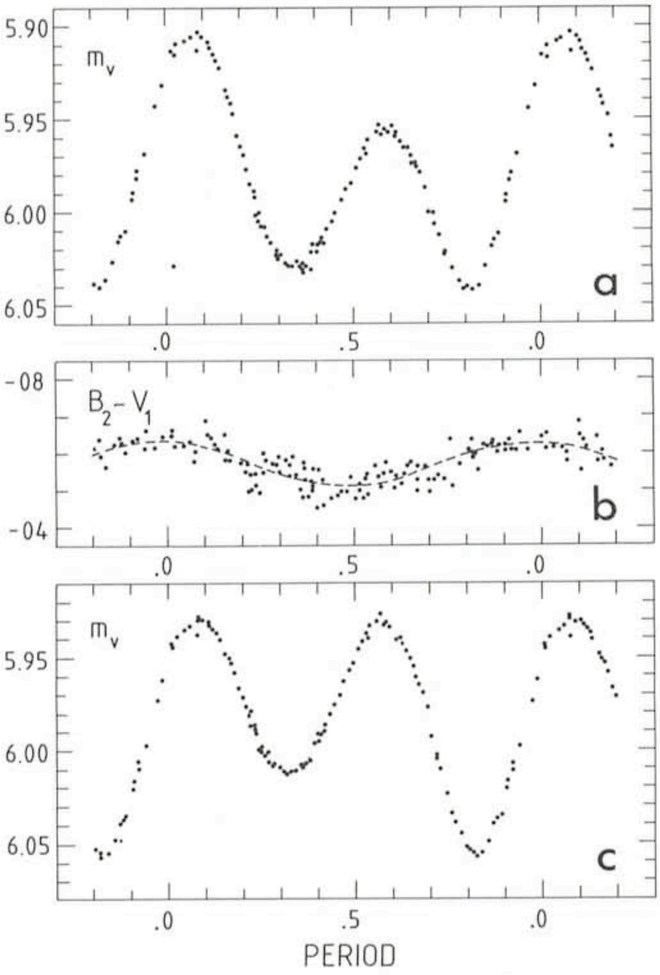

Fig. 1: *(a) visual magnitude lightcurve of TU Hor; (b) variations of the colour index B_2–V_1 through the phase and sinusoidal fit to the data; (c) lightcurve obtained by subtracting from the observed one a sinusoidal curve with an amplitude of 0.030 magnitude and a phase determined from the colour variations.*

extreme Ap stars it is smaller than −0.05. The value for Z is −0.016 in the case of b Per, it is −0.010 for TU Hor. The other peculiar binaries we mentioned have not yet been measured. So the Z-index for these stars does not indicate a pronounced Ap character. High-resolution spectra taken by Eric Maurice of ESO confirm that no strong peculiarities are present for TU Hor. Yet—since the value of the Z-index for TU Hor is a mean of more than 750 measurements—it possibly indicates a marginal, but genuine, peculiarity.

It can, however, be asked whether such a marginal Ap character can explain the large photometric variations. The mechanism generally admitted for the light variations of Ap stars is the oblique rotator model: the enhanced elements are not distributed homogeneously over the surface of the star, and the observed aspect changes during a rotation period. The light variations are then caused by the combined effects of blocking and backwarming. This mechanism cannot explain the observed behaviour of TU Hor, since the peculiarities, if they exist, are too small. However, several authors have argued that blocking and backwarming is not sufficient to explain the variations of some strongly magnetic stars, but that, in addition, a temperature variation up to some hundredths degrees, associated with the magnetic field, has to be invoked. This temperature variation is similar to that observed for TU Hor.

If the temperature variations observed in the case of TU Hor are due to a magnetic field, why then did this field not cause the strong peculiarities observed for most strongly magnetic stars? I believe that the answer lies in the close binary nature of TU Hor. The synchronous rotation imposed by the close companion has rendered magnetic braking ineffective and so diffusion has not been able to lead to strong peculiarities. Also, the tidal interactions could hinder diffusion.

This would then also explain the conspicuous lack of close binary systems among the known magnetic Ap stars. Several theories have been advanced to explain this discrepancy. It has been argued that magnetic fields cannot develop or would be destroyed in close systems. Another possibility is clearly that magnetic fields can exist in close binaries, but that the high rotation velocities imposed by the orbital motion and the tidal interactions reduce the importance of diffusion. Strong magnetic fields would then manifest themselves through the associated temperature variations, and this is precisely what is observed for TU Hor.

Spectra have been taken at the coudé focus of the ESO 1.52 m telescope in collaboration with Eric Maurice from ESO. These spectra will be useful to better describe the behaviour of this close binary. However, it can be doubted whether the Zeeman splitting caused by the supposed magnetic field will be observed directly. Indeed, the lines are not enhanced as in the magnetic Ap stars, and strong rotational broadening occurs. It can, however, be hoped that indirect evidence for a magnetic field can be found. Since b Per—a similar star—is a known radio source, it would be interesting to search for synchrotron radiation from TU Hor.

Astronomical Colour Printing at ESO

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When the photographic labs in the new Garching Headquarters were planned, the installation of a colour lab was also foreseen. Following the removal from Geneva, a market survey of available colour equipment was carried out, leading to the purchase of a Durst 1800 Laborator enlarger featuring a CLS 2000 colour head and a negative carrier able to accommodate 25 × 25 cm originals, an Autopan 40–60 C processing machine and various equipment for process control.

The equipment was delivered in the course of 1981 and after trial runs, the processing machine was commissioned by the end of that year. The photographic process selected was the Cibachrome P-3 process, which has been described in detail elsewhere (Ilford AG: Cibachrome TB 29EN, TB 30EN [Ilford, Fribourg, 1979, 1980]). Suffice to say that one of the most significant advantages of this process is the very good sharpness achieved, due to highly limited light dispersion in the emulsion layers.

Following a period of producing plain colour prints from colour originals, we turned towards our ultimate goal, that of producing astronomical colour photographs. The motivations for astronomical colour photography are both scientific and aesthetic. A picture of a large area of the sky, of a complex nebula, or of an active galaxy shown in colour, gives immediate information on the distribution of different types of stars, or on different structures within a particular object; it is capable of clearly identifying various emission mechanics (continuum or lines), and of revealing the presence of peculiar objects, such as supernovae remnants. A beautiful object, such as a planetary nebula, becomes a polychromatic painting for an amateur astronomer and a source of important scientific information for a professional astronomer.

The Tri-Colour Method

As described elsewhere, ordinary colour film is not very suitable for astronomical photography. This difficulty has led many astronomers into obtaining their colour photographs from ordinary (b/w) spectroscopic plates. A study of the current methods of producing such composites from B-V-R plates lead us to chose the tri-colour method, the basic principles of which were described by Maxwell as early as 1861 (Malin, D.F., *Vistas in Astronomy,* Vol. 24, part 3, 1980, p. 220), who demonstrated that "white" light is composed of light of the three additive primary colours, blue, green and red. When printing colour pictures, this means that a colour print can be obtained by printing the original sequentially through standard broadband B-G-R filters. The colour balance is controlled by changing the relative amount of B-G-R exposures, whereas the density is determined by the total exposure. In the early days of colour photography the tri-colour method enjoyed much popularity, whereas now, with a few exceptions, it is generally regarded as being outdated. For most professional applications, the far more convenient and faster subtractive colour printing method is used. Contrary to the additive tri-colour method, the subtractive method only requires one exposure through one or two filters of the subtractive primary colours, yellow, magenta, and cyan.

As the tri-colour method requires three exposures (of one original), it goes without saying that it is possible to obtain a colour picture based on *three* (b/w) original films (or plates) which have been made with filters of the appropriate pass bands.