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A high-speed two-star photometer

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Abstract. Design and performance of a high-speed two-star photometer are presented in this paper. It is an ideal instrument for investigations of time variations of variable stars.

Key words : Instrumentation—photometry—observing techniques—variable stars

1. Introduction

Photometric observations of variable stars using single-star photometers are often plagued by light variations of terrestrial origin. Sky transparency variations due to a variety of reasons including the passage of very thin clouds over the field of view of the telescope, variations in scattering of moonlight by clouds, etc. may get added to the genuine variations of the program star and may render the interpretation of the observations rather difficult. One of the ways to overcome some of the above problems is to employ a two-star photometer in which the program star and a nearby field star are monitored simultaneously. Ideally the comparison star should be a non-variable, and have similar magnitude and colour as the program star, but such conditions are seldom satisfied in real situations. If the comparison channel remains constant during a particular observation, the observed variations of the program star can be described as genuine stellar variations. If both channels vary similarly and simultaneously, it is almost definitely due to variations of terrestrial origin. In such cases, the relevant part of the data string could be rejected straight away. It is possible to investigate the time variations of the program star with increased level of confidence by taking the ratio of the counts between the two channels as a function of time. Thus the total usable data from nonphotometric sites will increase significantly with the use of a two-star photometer. In addition, the comparison star in the second channel can also be used for centreing and guiding the telescope in order to collect an unbroken string of data on the program star.

Seveıal types of two-star photometers are in operation in different observatories around the world (*e.g.* Grauer & Bond 1981; Warner & Nather 1972; Geyer & Hoffman 1975 and references therein). We describe in this paper the first high-speed two-star photometer that has been designed and developed by us. Novel features incorporated in its design have been explained. Illustrative results obtained during photometric as well as nonphotometric nights are also presented.

2. Description of the instrument

A schematic diagram of the photometer is shown in figure 1. The main channel employs a conventional design. It consists of a 45° flip mirror M1 that reflects the incoming beam to a wide angle eyepiece of 50mm aperture. The latter provides an 8 arcmin field of view at the f/13 Cassegrain focus of the 102 cm telescope at the Vainu Bappu Observatory, Kavalur. A set of selectable diaphragms of diameter 10.1, 13.6, 17.5, 25.8, 32.5, and 79.0 arcsec are provided on a diaphragm wheel. A retractable prism—microscope arrangement is used for verification and centring of the program star. A set of six selectable filters of 22mm diameter each is placed on the filter wheel below the diaphragm. At present, the wheel carries filters which are equivalent of Johnson's *U, B,*

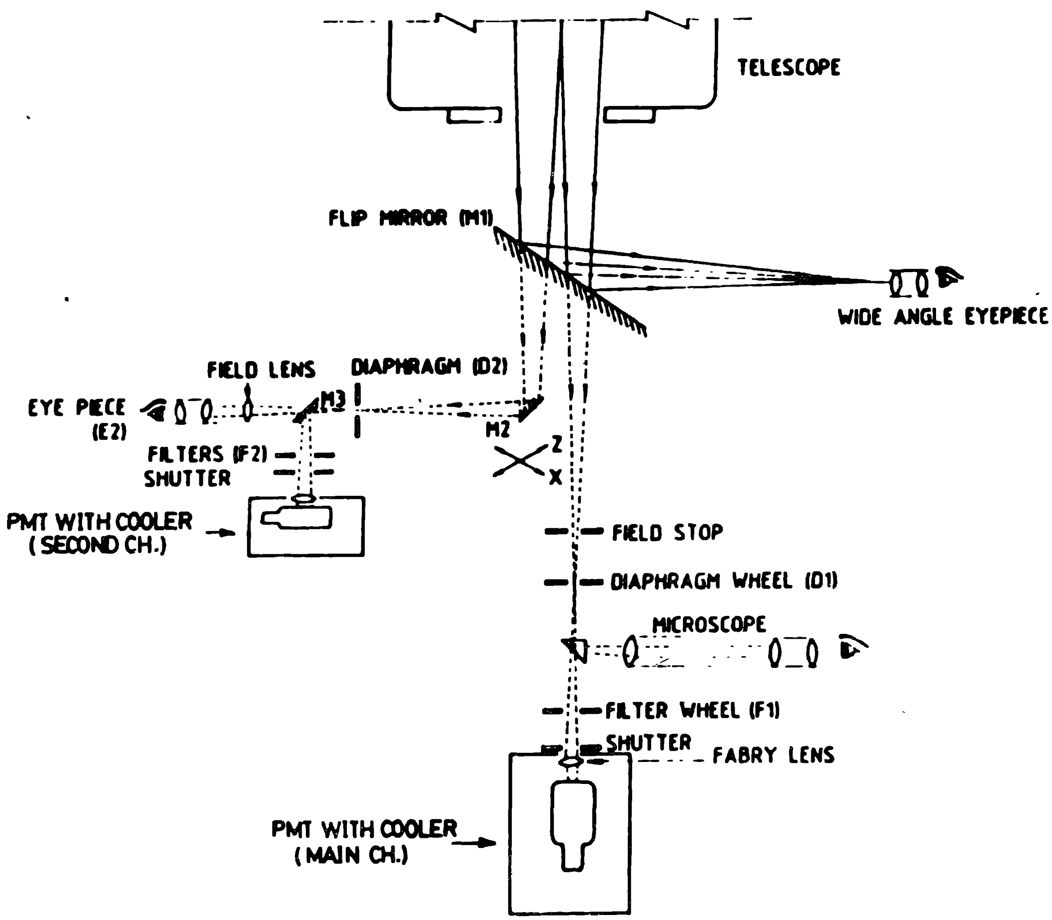

Figure 1. Two star photometer (schematic diagram).

V, R, and *I* filter system (Johnson & Morgan 1953). The *U* filter used by us has no red-leak. A detachable, thermo-electrically cooled PMT housing (Products for Research model No. TE-210TSRF) that carried a Fabry lens and an RCA C31034/RCA 8850 PMT completes the list of components incorporated in the main channel. Instead of designing two identical channels with equal number of reflections, we have designed the main channel for minimum light loss (i.e., without any reflections) that allows us to observe fainter objects.

The second channel consists of a cylindrical tube that carries a tiny mirror M2 at one end placed 45° to the incoming light from the telescope, a flippable semicircular plate D2 having two diaphragms of 14.5 and 24.5 arcsec diameters, another retractable mirror M3 kept 45° to the light beam reflected by the mirror M2, a field lens and an eyepiece E2 at the other end of the tube. The whole cylinder is mounted on a movable bench that provides X and Z motions such that a field of $\sim 8 \times 4$ arcmin^2 may be scanned in the focal plane to pick up the second star. The mirror M3 when pushed in deflects the beam through a set of filters F2 on to the fixed PMT housing that carries the Fabry lens and an uncooled RCA 8850 or 1P21 tube. When the diaphragm is flipped out, an unvignetted field of 2.5×2.5 arcmin^2 in the eyepiece E2 enables us to easily pick up the second star and to centre it within the diaphragm in this channel. The PMT housing is permanently fixed and hence the differential flexure between the main and the second channel is negligible.

After deciding on the program star and the comparison star, the program star is centred in the main channel as usual. In order to pick up the comparison star in the second channel the mirror M1, diaphragm D2, and the mirror M3 have to be flipped out. Viewing through the eyepiece E2 and using the X and Z movement, the second star is picked up and centred. The appropriate diaphragm ($\sim 10\%$ smaller than the corresponding diaphragm in the main channel) is then flipped back in and a fine centring is done using the X and Z movements. the mirror M3 is then pushed in such that the comparison star light reaches the PMT. After selecting the appropriate filters and sliding out the PMT shutters of both channels, the measurement of the signals can be started. Occasionally the sky background is also measured for a short while by moving out both stars from the diaphragms by moving the telescope as a whole.

The signals from the two channels are fed to two independent preamplifier-discriminators which in turn are connected through a Clemens interface card (supplied by Dr R. E. Nather of the University of Texas) to an IBM compatible PC-XT. The interface circuit counts the pulses during preselected integration times and the data are stored in the hard disc (or floppy) of the PC. The 'Quilt' software, also supplied by Dr Nather displays the data from both channels in real time at the desired level of magnification. This enables us to get a real feeling of the quality of the data and the time variations if any as the data are collected in real time. The fastest integration time available at present is 12ms, which is about three orders of magnitude faster than what is required for the study of rotations and non-radial oscillations of white dwarfs, a program currently pursued by us.

3. Performance of the instrument

Figures 2 and 3 show parts of the light curves as displayed on the PC screen in real time under different sky conditions. Figure 2 shows the light curves of PG 1711+336 ($V \approx$

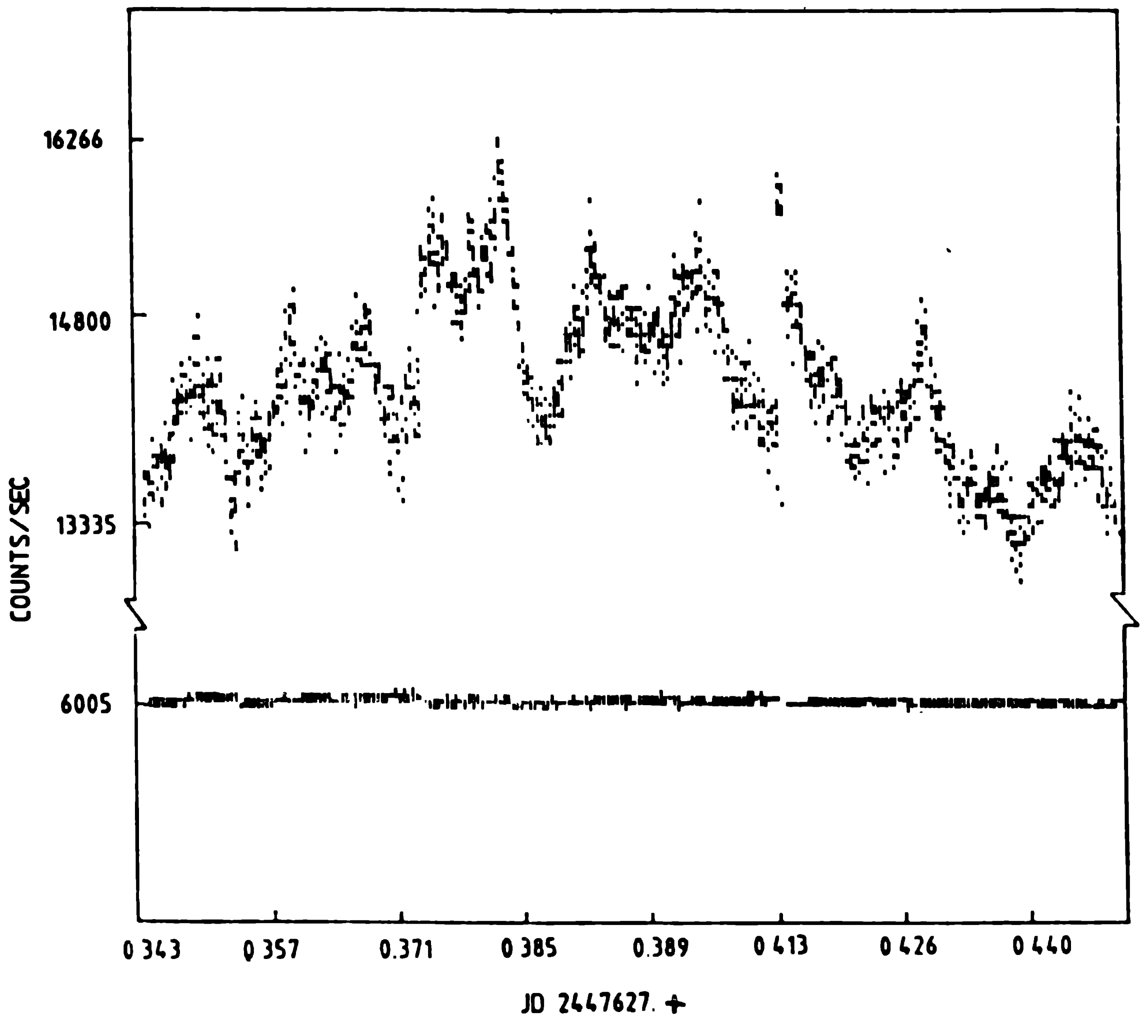

Figure 2. Light curve of PG 1711+336 (top) and the comparison star (bottom) on a clear night (see Ashoka *et al.* 1990).

13.0) in the first channel and a comparison star [star B of Mironov (1983)] sequence in the second channel during a clear night of observations (1989 April 10) made with the 102 cm telescope of the UP State Observatory, Naini Tal. The short duration flickers of PG 1711 + 336 are evident in the first channel data, corroborated further by the relatively constant light output recorded in the second channel.

Figure 3 shows the light curve, under very poor sky conditions, of V471 Tau, an eclipsing spectroscopic binary consisting of a K2V star ($V \approx 9.0$) and a hot DA white dwarf ($V \approx 14.0$), observed in U filter in the main channel (top light curve) and a comparison star (BD + 16° 620) in the second channel (middle curve) monitored during a world-wide campaign in 1988 November for observations of the oscillations in collapsed objects. The U band light of V471 Tau is primarily contributed by the white dwarf. The two channels started dancing together in step due to the presence of passing clouds. The overall decreasing trend in the light curve is due to the increased extinction. The method of signal rationing could be adopted to retrieve the signal as shown in the bottom light curve.

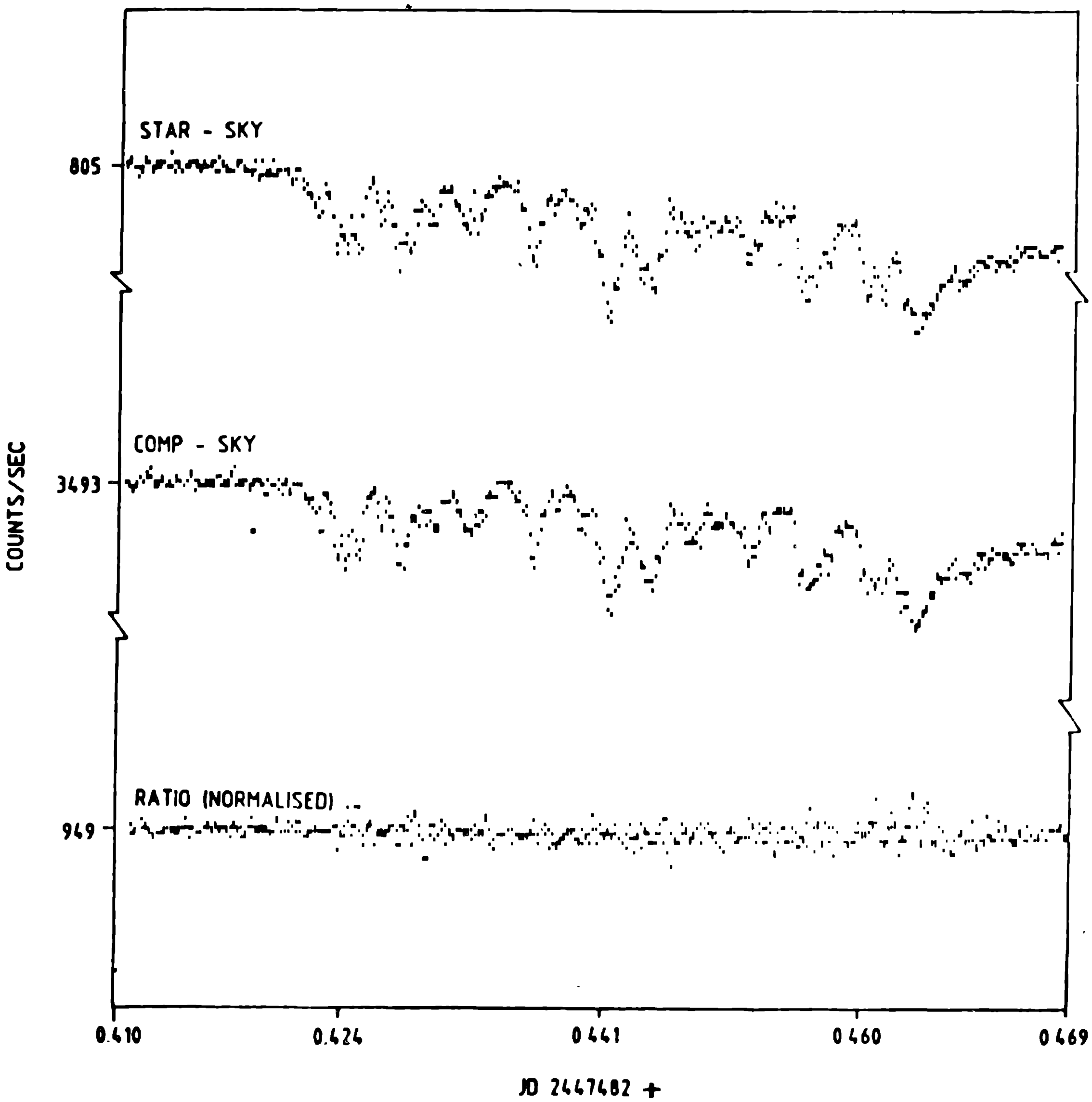

Figure 3. Sky subtracted light curves of V471 Tau (top) and its comparison (middle) during poor sky conditions. The curve at the bottom is the ratio of the two curves.

4. Conclusions

The simultaneous monitoring of a program star and a nearby field star enables us to correct to a large extent the effects of atmospheric transparency variations. Significant improvement in the quality and scientific productivity of data obtained from unfavourable photometric sites may also result from the use of a two-star photometer. Although many two-star photometers employing different design philosophies are operational in many observatories around the world, the instrument described in this paper, incorporating some new design concepts, is to the best of our knowledge, the first working instrument of its kind in India and has already started yielding high quality data on a number of variable stars. Further improvement to this instrument will involve the addition of a sky channel and simultaneous multicolour monitoring of all three channels.

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