Bull. Astr. Soc. India (2001) **29**, 479–486

UPSO three channel fast photometer

S.K. Gupta[1], R. Sagar[1], S. Joshi[1], B.N. Ashoka[2], V.C. Babu[2], S. Seetha[2] and V. Girish[2]

[1]*State Observatory, Manora Peak, Naini Tal 263129, India*
[2]*ISRO Satellite Centre, Airport Road, Bangalore 560034, India*

Abstract. The design and performance of a modular portable three channel fast photometer is described. It can be disassembled as single individual channels such that the system can also be used as a single channel photometer. The instrument is put into operation since November 1999 on the 1-m UPSO telescope at Nainital. Since then, it is used extensively for the survey of roAp stars in the northern sky at UPSO. The discoveries made using this new photometer are also mentioned.

Key words : photometry, light curves, variable stars

1. Introduction

Using a conventional single-channel photometer, variations in the observed light of a star can be interpreted as variations in the star if the observations are made under ideal observing conditions. However, in practice, even in a so-called best site, under normal observing conditions, the variations may be due to :

- atmospheric effects, like thin clouds, transparency variations and change in the sky background.
- telescope tracking problems.
- instrument related problems such as electronics noise, misalignments of components and mechanical flexure.
- human errors such as improper centring and guiding.

Therefore, in order to detect and eliminate most of the above variations from the real variations in the light, a second channel is added to the single channel photometer to simultaneously monitor a nearby field star. Now, if there is any real variations, it can be seen only in the first channel and any variation of terrestrial origin can be seen in both the channels. Thus, the two channel data enable to distinguish real and spurious variations in the time series data.

In a two-channel photometer, whenever sky measurements are needed, the stars have to be moved out of the diaphragms for a small interval of time in both the channels. Such breaks in the data result as aliases in the Discrete Fourier Transform (DFT), which prevents detection of closely placed periods in the data. A solution is to have a third channel attached to the photometer to measure the sky background simulteneously. Thus as a necessity two stars+sky generally named as three- channel photometer has evolved. Since the main channel data is not broken for sky measurements in between, we get continuous data on programme star.

Thus in order to get reliable, continuous time series data even under moderate sky conditions, a three channel photometer is necessary. We have designed and developed a prototype three channel photometer that is currently being used at Uttar Pradesh State Observatory (UPSO), Nainital for study of pulsating white dwarfs and other rapid variables.

2. Schematic diagram

A schematic diagram of the three channel photometer is shown in Fig. 1. A wide angle eyepiece of 50-mm size and 32-mm focal length is used to cover a field of 8′ at the focal plane of the 1-m UPSO telescope and to identify the star field and select the star for the second channel. This is followed by the first channel of the photometer which has a diaphragm plate, a microscope to view the star within the diaphragm and a filter wheel. Then follows a photomultiplier housing which consists of a shutter, a fabry lens and a photo multiplier tube (PMT) with a wired base. The second channel has all the components as in the first channel with the addition of pickup prism. The entire second channel unit is mounted on a movable X-Y table to pickup a star in the same field other than the programme star. There is a dead region of 5-mm about the first channel from where a star cannot be picked up in the second channel. This is purposely introduced to avoid obscuration of first channel by second channel pickup prism. The third channel is a fixed channel which is used for the sky background measurement. This channel measures a sky region close to the first channel at a distance of 6-mm from the first channel star. In first and second channels three diaphragms of size 1.0-mm, 1.5-mm and 2.0-mm are provided. The filter wheel consists of four holes in which three holes are fitted with Johnson UBV band filters and one is left blank. Sometimes a neutral density filter is used in the empty hole while observing very bright stars. The PMT housing has a fabry lens (singlet) whose focal length is 60-mm such that at f/13 focus, it produce an image of 4.6-mm in size on the 10-mm photocathode of PMT. Both the first and second channel photometers are made modular so that they can be moved independently to get them focused on the stars.

3. Design criteria and calibration of the instrument

Following important criteria have been taken into account in designing this photometer to suit our scientific objectives and logistics :

1. Basically the instrument is designed for use at the Cassegrain focus of the 1-m telescope at UPSO, Nainital. However it can also be used on other telescopes. The focal ratio of the telescope is f/13 with a maximum available back-focal length of 300-mm. Therefore, the size of the photometer is optimized to suit these numbers.

2. If someone wants to use this photometer on the various telescopes in the country, a light, weight, modular design is ideal for easy transportation. All the three channels can be detached during transportation to accommodate in the suitcase and assembled easily at the telescope. The total weight of the photometer is ≈ 15 kg.

3. In order to minimize light loss from programme star unlike the second and third channels, the first channel is designed with minimum number of transmitting optics and without any reflecting optics. The second channel is made identical to the first channel except for an additional prism to pickup a star in second channel. The first and second channel can be interchanged, if necessary.

4. As a suitable field star has to be picked up always in the second channel without moving the telescope, provision for scanning a larger area (80 x 50 sq. mm) is provided in the second channel so that stars are always available in the field.

5. During observations, the differential flexure between the main and guide telescope results in a slow drift of the stars in the diaphragm. Therefore privision has been made for a guiding unit (which could be either a video CCD camera or a commercial ST-4 guiding CCD camera). To scan a larger area (200 sq. mm) to pickup a suitable bright star.

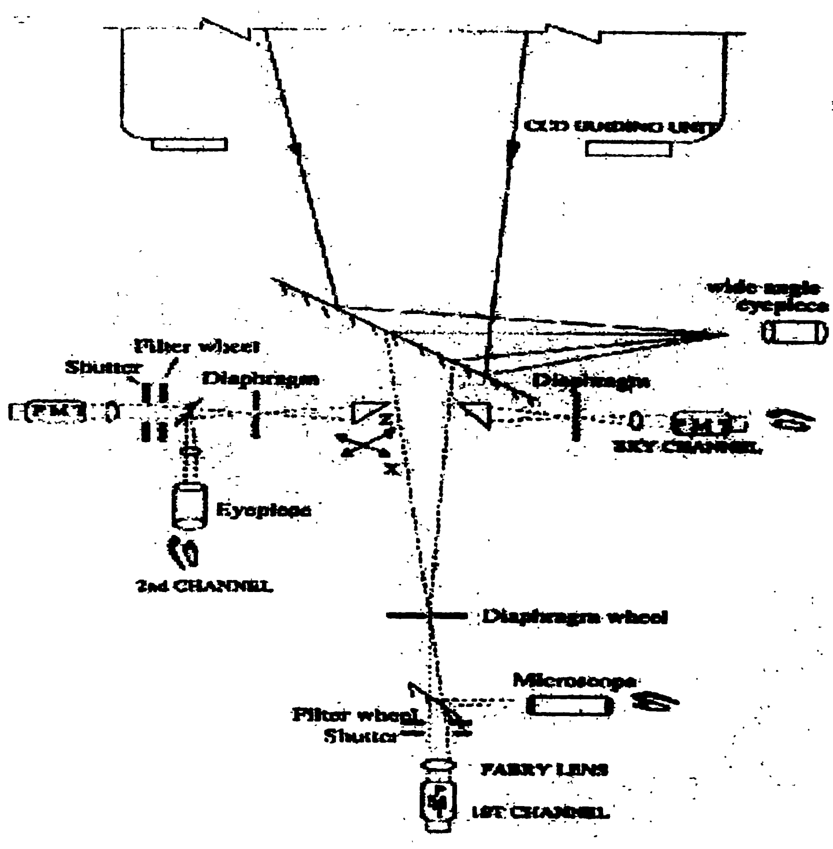

Figure 1. Schematic diagram of three channel photometer

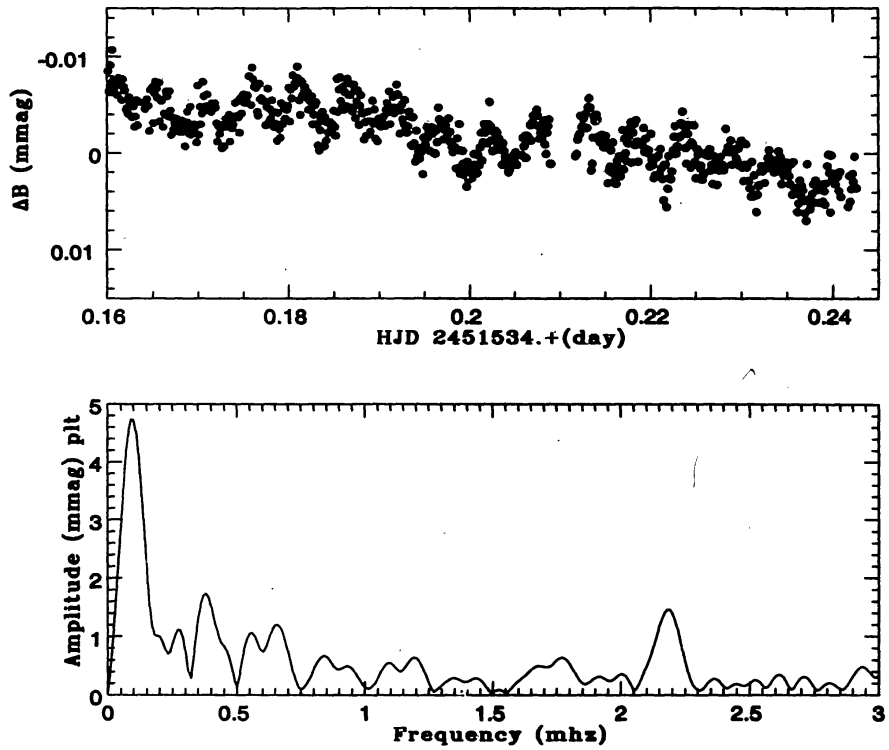

Figure 2. Light Curve and amplitude spectrum of the roAp star HD 12098

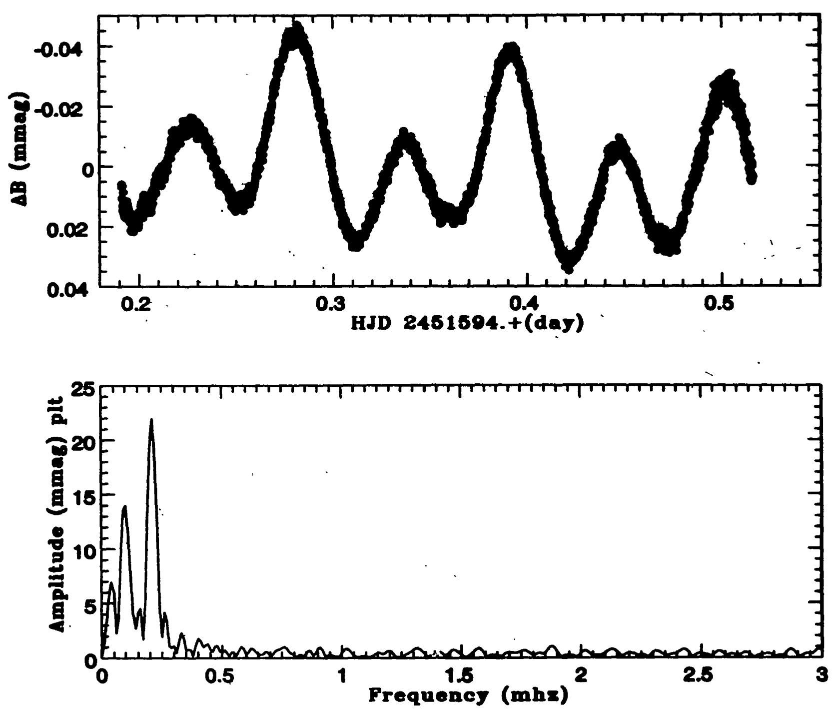

Figure 3. Light Curve and amplitude spectrum of the δ Scuti star HD 98851

6. The photometer is designed to use small size PMT with good quantum efficiency (≈ 30% at 4200 A) and very low dark counts (only ≈ 20 cps) at room temperature. The usage of these tubes enabled us to make the unit compact and light weight.

7. All the three channels are made similar by using identical PMTs, filters and amplifier/ descriminators. All the electronics are powered by a single power supply and all the PMTs are powered by same high voltage (HV) source simultaneously so that any electronics related variations will be reflected in the three channels.

The Hammamatsu R647-P photomultiplier tubes made for photon counting application at low light levels are used. They are blue sensitive with S-11 response. The photocathode has a size of 10-mm and is made of bialkali material. It is an end window tube with anti-magnetic shield coating on outer glass. The output of the PMT goes to the amplifier-discriminator unit which amplifies the pulses coming from the PMT, discriminates them against the dark noise pulses using a low level threshold and then shapes them suitable for counting. The out put is a TTL pulse of width 10-75 ns and is fed to an interface card. The interface card is designed (Kalytis et al. 1995) to operate as a computer interface to photometer. The interface card receives and digitizes the data from three channels. It has a timing circuit to ensure an accurate clock and integration time. The interface card communicates with PC through a serial port. The software which communicates between the PC and the interface card is the data acquisition software "Quilt-9" developed by Texas group (Nather et al. 1990). The software along with the interface card can acquire the data simultaneously from three channels and has provisions for real time display of the data and their storage on hard disk and floppy. The data are stored as an ASCII file which contains header information and data. The header information includes relevent details such as file name, names of the observers, date of the observation, name of the object, start time to the run, integration time, filter used and observatory name. The data file can directly be read by the data reduction programme "QED" or "DRED".

After assembling the photometer the following checks and measurements were made at the telescope :

3.1 Focusing of the three channels

In designing the instrument, care has been taken such that a star is focused in the diaphragm of the first channel it will be focussed in the second and third channel and at the wide angle eyepiece. Due to small mechanical errors, the focussing need not be perfect. Therefore, the first channel photometer is independently moved such that the star is focused perfectly in the first channel. Focusing in the wide angle eyepiece is made by moving the wide angle eyepiece itself. Focusing in the third channel is not so critical since it measures only the sky.

3.2 Knife edge test

The "Knife edge test" is a method to ensure perfect focusing of the stars in the respective diaphragms of the photometer. To carry out this test the microscope eyepiece from the eyepiece holder is removed and a star image is put in the diaphragm such that part of the image is cut by the diaphragm edge. On changing the telescope focus, when the star is exactly focused at the diaphragm the edge of the diaphragm shines like a knife edge. If the focus is before or after the diaphragm this will not happen. Thus the best focus is determined. After this, the eyepiece is replaced and focused on the star.

3.3 High voltage setting

More effective way is to select the voltage within the plateau region of the gain versus high voltage curve where the signal to noise is maximum. First only the dark signal at different high voltage values are measured. Next the diaphragm is illuminated by a constant light source and the signal is measured at various voltages. The plateau, where the maximum S/N is obtained, is selected.

3.4 Fabry check

Fabry check is basically a method to check the optical alignment of fabry lens and the PMT. Generally as the star drifts from one end of the diaphragm to the other due to tracking error, etc the signal should not show any variation due to this movement. If there is some misalignment of the fabry lens, or any other obscuration in the path of the light or dust or finger prints on fabry or on the filter, their presence can be seen as a variation in the output signal when the star is put at different places within the diaphragm. Such variations can be mixed up with the actual star light variations and produce spurious results. Even in a best telescope it is practically impossible to make the tracking so perfect to avoid trailing of the star within the diaphragm. Therefore, we have to make sure that even if there is a drift of the star within the diaphragm it should not show any variation. This is possible by designing the Fabry lens such that it produces an image of the primary mirror which is about 50% of the cathode size such that star beam never goes out of the cathode as long as the star is anywhere in the diaphragm. Next the Fabry should be aligned, as perfect as possible, to the PMT. In order to check the alignement, first the star is moved across the diaphragm from one end to the other with a very slow speed on the telescope in one direction (in right ascension). During this, the star signal is recorded at a fast integration time e.g. 200 ms. Next the star is moved across the diaphragm in the perpendicular direction (in declination). The resulting light curve should produce a square wave pattern indicating that the star anywhere within the diaphragm, except close to the boundary of the diaphragm, will produce the same signal and the focusing is almost perfect at the diaphragm. Fabry check is the ultimate test for the perfect alignment of all the components in the photometer.

Since the intensity measurement is basically a photon counting technique, the brightness of the star is proportional to the number of photons detected. Due to the random arrival of the photons all the photons reaching the detector may not be counted, resulting in dead time loss.

This problem is obvious when bright stars are observed. Therefore we have to estimate the dead time loss due to overall system and correct for the loss. The dead time correction is determined by aperture method as follows. Two aperatures, one small and another large, are selected. Let S1 and L1 be the brightness measure for certain illumination in small and large aperture respectively. Let S2 and L2 be the respective brightness for an increased illumination. From the four counting rates, $a = S2 \times L1$, $b = S1 \times L2$, c = S1 + L2, d = S2 + L1 Then the dead time is given by $\frac{a-b}{ac-bd}$. Using this method the estimated dead time for the present system is 23 ns.

Aperatures in general are selected based on the telescope performance, sky brightness and on brightness of the star. The aperature size should be such that star should not drift within a consecutive guiding interval. Otherwise frequent guiding will be needed. In a three star photometer, the first channel aperature selection is based on the above criteria. Thus we can have clean data in the first channel in spite of tracking and guiding errors. The second channel diaphragms are kept 10% smaller than the corresponding first channel so that drift could be noticed first in the second channel and immediately corrected to avoid drift in the first channel. The third channel being a sky channel, its diaphragm size is kept the same as the first channel.

4. Performance of the instrument

The instrument is now continuously in use at UPSO, Nainital for the recently initiated programme titled "Survey for roAp stars in Northern sky". The survey involves observing more than 200 potential stars in Northern hemisphere to discover new roAp stars and study them in detail. The initial efforts resulted in the discovery of rapid oscillations in an Ap star HD 12098 (Martinez et al. 2000). The initial analysis of the data indicates the presence of an oscillation at ≈ 7 min with amplitude 3-m mag. The light curve and its DFT are shown in Fig. 2.

The survey also resulted in the discovery of a new δ Scuti star HD 98851 having a period around 75 min and amplitude ≈ 22 mmag were detected. The complex light curve indicates the presence of multiple periods (Joshi et al. 2000). A sample light curve and its DFT are shown in Fig. 3. All the above results indicate the optimal functioning of the instrument during its first operational phase.

5. Conclusion

The simultaneous monitoring of the programme star, a field star and the sky background is essential to ascertain genuine variability during time series photometric study. An instrument of this kind is also useful for photometric study of variables during non-photometric nights where the variability can be retrieved from first channel data using second and third channel data. It is also possible to make a good estimation of the extinction values from the second channel data for that night instead of using an average extinction cofficient. The sky transparency variation could be estimated from the second channel data. Since the three channel photometer monitors the sky background continuously, the sky estimation could be made accurately even during moon-lit nights, dawn / dusk, observations maximizing the utilization of telescope time.

Acknowledgement

We thank Mr. G. Venkata Rao and his colleagues for their help during the mechanical fabrication of the photometer at ISAC workshop. We also thank Mr. K.G. Gupta for his help in fabricating optical components for the photometer at UPSO optical shop. We are greatful to the anonymous referee for his comments and fruitful suggestions.

References

Joshi S. et al., IBVS, 2000, No. 4900
Kalytis R., Meista E.G., Baltic Astronomy, Vol 4, 497, 1995
Martinez P., et al., IBVS, 2000, No. 4853
Nather R.E., et al., 1990, ApJ, 361, 360