A SIMULTANEOUS FIVE COLOUR THREE CHANNEL PHOTOMETER WITH FIBER OPTICS - DESIGN AND FIRST RESULTS

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Accurate photometry of fast variable objects requires simultaneous measurements of object, sky and comparison star with high time resolution. Additionally, if reliable colours of short time variations are of interest each light source has also to be measured simultaneously in several wavelength regions.

The prototyp of a 3 channel 5 colour photometer fitting these requirements was constructed at the Universitäts-Sternwarte München in 1983 and shall be described in the following. The development of this instrument was carried out in two steps: At first a 3 channel photometer had been designed for observations in integral light. It was successfully tested at Calar Alto Observatory (Mitt. Astron. Ges. 60, p. 474, 1983).

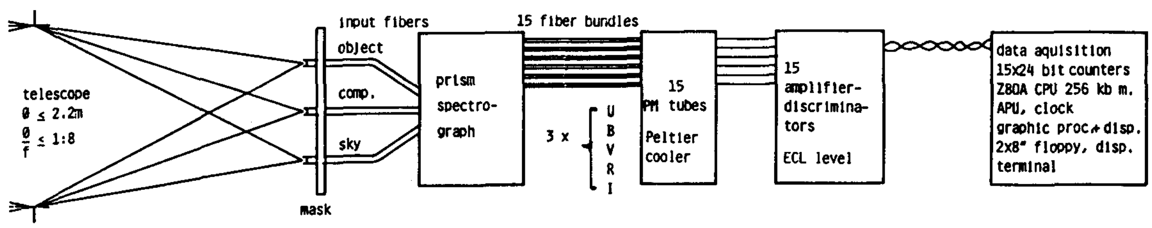

Fig. 1: Blockdiagram of the photometer

The second version also allows 5 colour photometry and is schematically shown in Fig. 1. It comprises the following units:

1. Fiber optics and positioning device
2. Spectrograph unit
3. Detector unit
4. Data monitoring and acquisition system

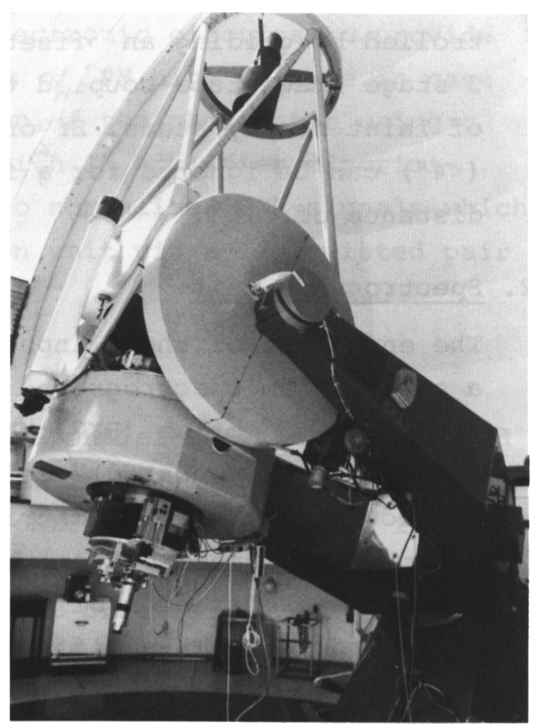

Fig. 2: The photometer in use at the ESO 1m telescope during Jan./Feb. 1984

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1. Fiber optics and positioning device:

Light from 3 sources in the focal plane of a telescope feeds a spectrograph by means of step index plastic monofibers with a core diameter of 1.5mm. The fiber entrance is covered by 3 interchangeable diaphragms with sky baffles. The corresponding fields of view on the 1m ESO Telescope are 18, 26, and 34 arc sec.

The flat field of the entrance diaphragms which may be degraded by dust particles and/or unfortunate bending can be checked and optimized using a scanning point light source mounted on top of each fiber. The disadvantage of poor UV transparency of the plastic fibers will soon be eliminated by a new optical setup in which a small Fabry lens transfers the telescope aperture into a quartz fiber of 400μ core diameter.

The position of the individual fibers is maintained by holes in an acryl plate. This mask is inserted in the focal plane after preparation in a quick and simple way on the telescope itself just prior to observation:

A movable eyepiece is successively centered on the objects to be measured, while an automatic drilling machine connected to it transfers the position to the acryl plate.

During measurement centering within the diaphragms is controlled by guiding an offset star on an optical crosswire. A 3 stage image tube coupled to a Newicon TV camera allows the use of faint nearby stars. Errors due to differential refraction (<4") can be ignored for a field diameter of <30' and a zenith distance of <70°.

2. Spectrograph unit:

The end faces of the 3 input fibers form the entrance slit of a small prism spectrograph. The parallel beam passes twice through a 60° prism (BK7, MgF_2 coated). An f/1.6 achromat (f = 80mm, MgF_2 coated) used as collimator and camera projects 3 spectra onto a fiber matrix consisting of 250 monofibers with 0.7mm core diameter. Proper bundling of these output fibers yields the separation of several, possibly overlapping wavelength regions. Thus different colour systems can be realized.

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In the current photometer version the output fibers of each channel were arranged to match approximately the UBVRI filter characteristics with the following restrictions: In U a short wavelength cut off is caused by the above mentioned absorption of the fiber material. In I bright objects can be measured only because of the low quantum efficiency of the S20 cathode. For both reasons the UBVR regions were shifted to longer wavelength compared to the standard system.

3. Detector unit:

The 15 output fiber bundles of the spectrograph (5 colours for each input channel) are connected to the detector unit (outer dimensions: 13cm x 19cm x 12cm). It consists of a very close arrangement of 15 Peltier cooled (-10°C to -20°C) miniature photomultipliers. For the UBV colours bialkali cathodes and for the RI channels multialkali cathodes are used.

Special precautions were taken by coupling the fiber bundles to the detectors. In order to minimize the light loss due to reflection on the entrance window the fiber ends were fixed in the center of small spherical mirrors reflecting to the front cathodes of the PM tubes.

Attatched to the photometer basic detector unit are high and low voltage power supplies and electronic circuits to provide several safety functions (e.g. cut off PM high voltage in case of bright light) and the operation of the photometer using a handset connected to it. A card with 15 amplifier/discriminators converts the PM pulses into normalized ECL signals which are linked to the data acquisition unit via a 12m twisted pair cable.

4. Data acquisition:

The PM pulses are received by differential ECL-TTL drivers and counted by 15 24-bit counters (AMD 9513 + Z80A CTC). 5 counters are mounted on a card. They are controlled via ECB bus from a Z80A microcomputer system (256 Kb core memory), which operates with an AMD 9511 arithmetic processor, real time clock, graphic processor and CPM system software. One of two floppy drives (8" floppy disk double sided, double density 1Mb) is

used mainly for the programs, the other for data storage (data are stored as 16 bit binaries as long as no overflow occurs, else as 24 bit binaries). On line light curves can be displayed on a graphic screen (512 x 512 points) while communications are possible from a seperate terminal and display.
For printout a fast printer (200 char/s) also belongs to the equipment.

Software facilities:

The acquisition software allows to define all observing parameters via a menue and to select which of the 15 channels will be subject to on line graphics and statistical analysis. Mean countrates, rms, mean error and drift can be obtained for selected time intervals.
Time and data are read from an internal clock. The range of time resolution covers 0.1s to 25.4s. With on line analysis of all 15 channels continuous data collection can be done only down to 3 s cycletime.

An editor program allows to correct input raw data for observational errors.

The reduction program calculates the object intensities relative to the comparison star. The corresponding time can be converted to heliocentric Julian Date.

Observation routine and reduction procedure

The observations of a program star have to be enclosed between at least two calibration sets each taking about 10 min. The calibration procedure comprises the measurement of a) a field light source (e.g. sky) in all 3 channels to correct for different diaphragm sizes, b) a point source (e.g. comparison star) in the object and comparison star channel to correct for different sensitivity and c) the dark current of all channels. For step a) and b) a time saving procedure is to mark the corresponding guide star position on the mask. The calibration and reduction methodes are described in Table 1.

Standard star observations for determination of colour transformation coefficients are easily performed by means of a

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Observation routine

Calibration (t_0) duration typ.10 min.
Measurement (t) long time interval
Calibration (t_1) duration typ.10 min.

Calibration set:

channels:	1	2	3	
measurement:	dark	dark	dark	(cts)
	sky	sky	sky	(cts)
	comp*	sky	sky	(cts)
	obj	comp*	sky	(cts)

Reduction procedure

For each measurement and each colour (ch, time)

$PO_i (1, t) = PO_c (1, t)/PC_c (1, t)$

$PO_c (1, t) = MTO_c (1, t) - PS_c (1, t) - D_c (1, t)$

$PC_c (1, t) = PC_c (2, t) \cdot Tr(*)(2\rightarrow1, t)$

$PC_c (2, t) = MTC_c (2, t) - PS_c (2, t) - D_c (2, t)$

$PS_c (1, t) = PS_c (3, t) \cdot Tr(S)(3\rightarrow1, t)$

$PS_c (2, t) = PS_c (3, t) \cdot Tr(S)(3\rightarrow2, t)$

$PS_c (3, t) = MTS_c (3, t) - D_c (3, t)$

$D_c (ch, t) = D_c (ch, t_0) + (D_c (ch, t_1) - D_c (ch, t_0)) \cdot (t - t_0)/(t_1 - t_0)$

$PS_c (3, t) = MTS_c (3, t) - D_c (3, t)$

From Calibration 1, 2

$Tr(S) (3\rightarrow1, t_{0,1}) = PS_c (1, t_{0,1})/PS_c (3, t_{0,1});$

$Tr(S) (2\rightarrow2, t_{0,1}) = PS_c (2, t_{0,1})/PS_c (3, t_{0,1});$

$Tr( ) (2\rightarrow1, t_{0,1}) = PC_c (1, t_{0,1})/PC_c (2, t_{0,2});$

$Tr\_ (\_\_, t) = Tr\_ (\_\_, t_0) + (Tr\_ (\_\_, t_1) - Tr\_ (\_\_, t_0)) \cdot (t - to)/(t_1 - t_0)$

Definition of Symbols:

- M measured
- Tr Transformation coefficient between channels (1,2,3)
- P pure data eg. Sky, dark subtracted
- T total
- O Object
- C Comparison star
- S Sky
- D dark
- i intensity relativ
- c counts
- t time
- ch channel
- s sky
- * star

Table 1

special mask configuration.Three equidistant holes parallel to the α or δ axis pick up the input fibers. For each channel a corresponding hole is drilled in a definite offset position. A star to be measured in all 3 channels is first centered in the offset position and then set to the input diaphragm preferably by means of the telescope offset switch.

Applying this method the fiber optic photometer can efficiently be used also for classical photometry.

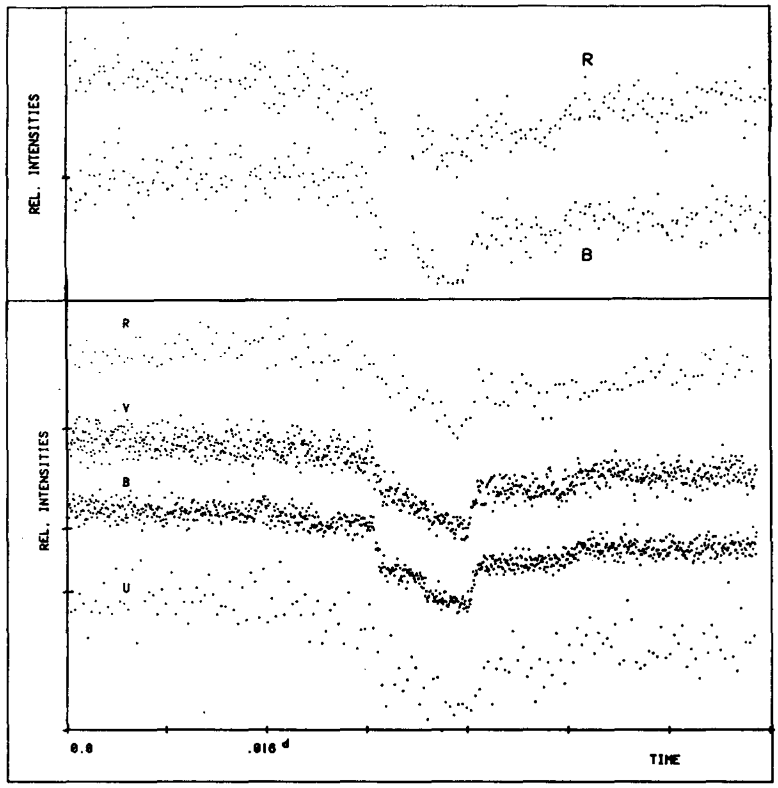
First results

The two light curves of the cataclysmic variable OY Car (Fig. 3) enable a comparison between results obtained for the same object at the same telescope with a conventional photometer and with the instrument described.

Fig. 3:

Top: Eclipse of OY Car (m_V = 15.6 - 17.8) observed with the single - channel photometer at the ESO 1m telescope. 6s time gaps between subsequent double integrations (IT = 2s) are due to sequential measuring method.

Bottom: Same observation using the new photometer. Originally 2s integration and cycle time. U and R data are binned to 12s. Zero points are marked on the ordinate.

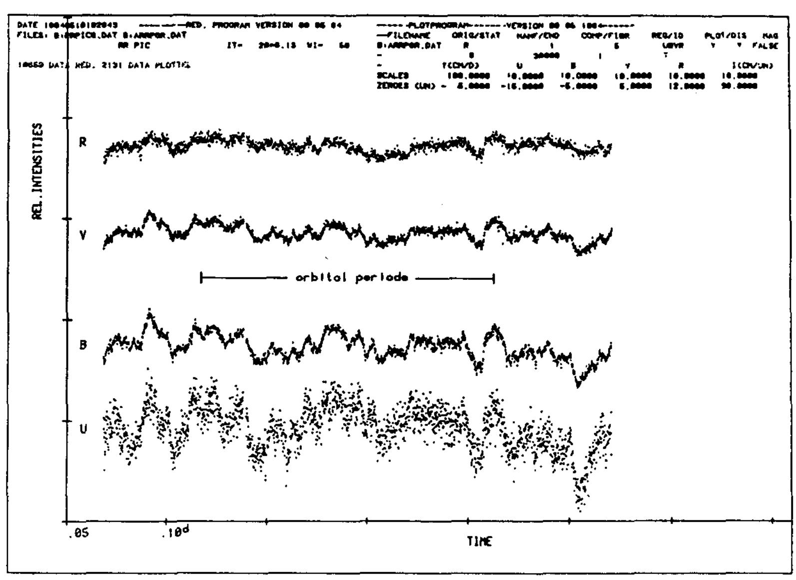


Scientific outcome

Multicolour photometry of the old nova RR Pic is displayed in Fig.4. The light curves clearly show the extremely blue colour of the flickering. The wellknown eclipse feature is missing indicating an unusual state of activity.

Fig. 4:

Light curves of RR Pic (m_V = 12.0 - 12.5). Original IT = 2s Each dot represents 5 integrations. Instrumentation as in Fig. 3,bottom.



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The following light curves of OY Car in quiescence (Fig. 4), obtained during two different nights reveal the existence of a beat phenomenon: amplitude of the hump, shape of the hot spot egress and the flat part in between are changing regularly within two to three oribtal periods. This suggests that the ellipticity of the accretion disc persists from superoutburst throughout quiescence state.

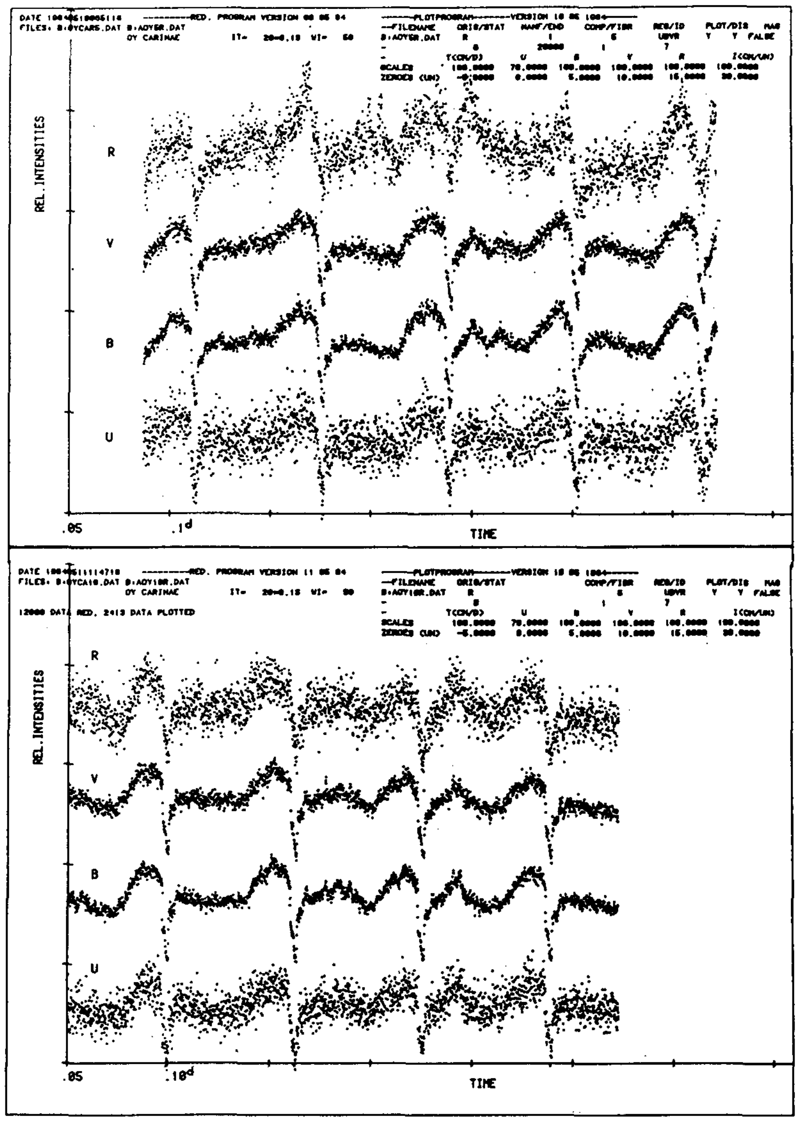

Fig. 5:

Light curves of OY Car. Observational parameters as in Fig. 4. (Note different scaling in U)

After implementation of the mentioned quartz fiber optics the equipment may also be used by other observers on request.

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