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The RPCS Detector

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A one-dimensional dual array linear photon counting device for optical spectroscopy of faint astronomical objects has been developed and tested.

1. Technical Description

The RPCS (**R**eticon **P**hoton **C**ounting **S**ystem) is based on the principles given in its original form by Shectman and Hiltner (1) and utilizes a self-scanning RETICON dual photodiode array model CP 1008 (2 x 936 pixels, each 30 μ x 375 μ). One array is used for the "object", the other for the "sky".

The light amplification system consists of a 3-stage magnetic focused EMI image tube with a UV zinc crown entrance window and a standard S20 photo-cathode followed by a 3-stage electrostatic focused VARO image tube. The output from the EMI tube is optically coupled to the entrance of the VARO tube by an 85 mm f/1 Repro-Nikkor lense.

The light output from the VARO tube is transferred to the diode array through a short fiber-optic.

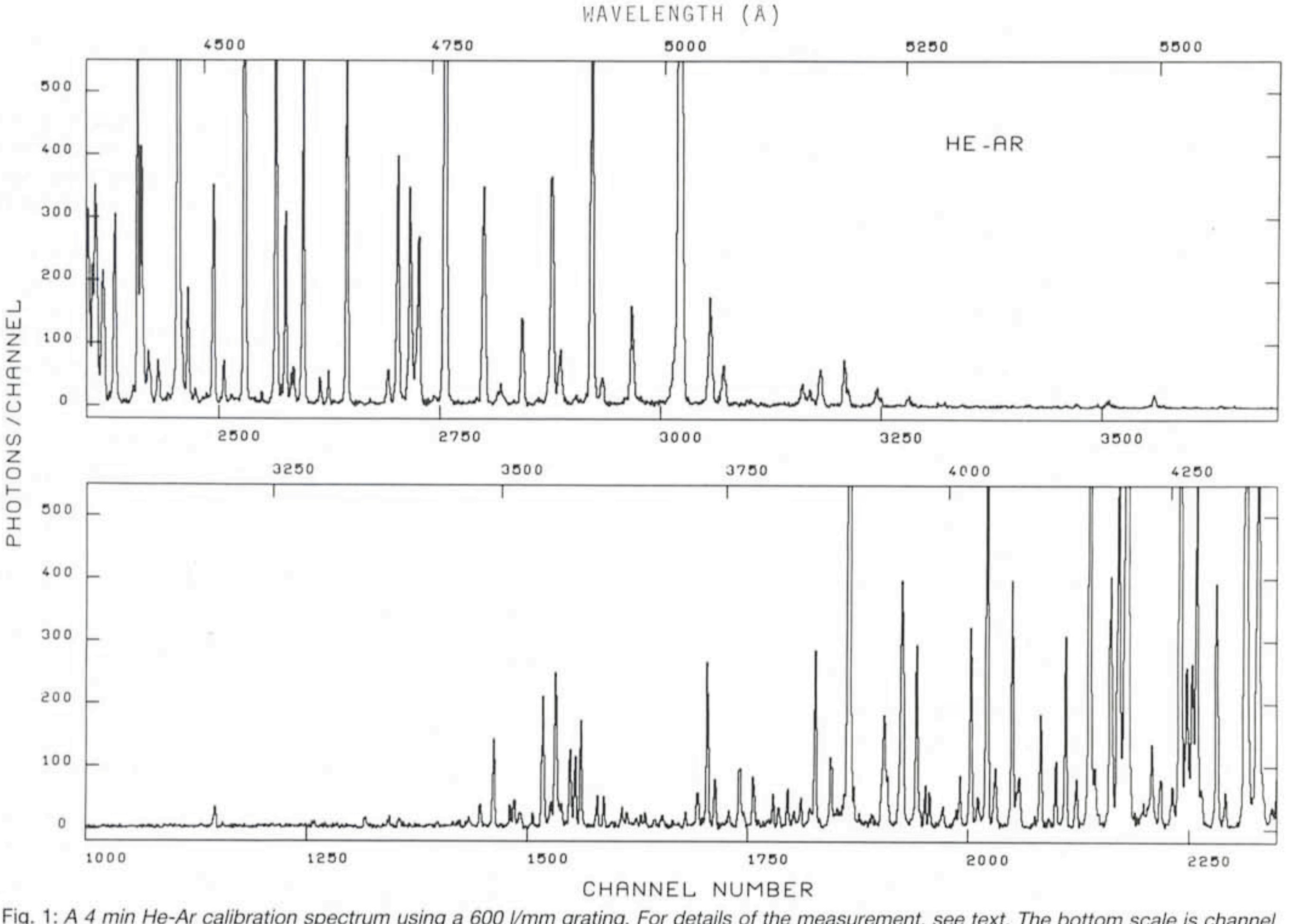

Fig. 1: *A 4 min He-Ar calibration spectrum using a 600 l/mm grating. For details of the measurement, see text. The bottom scale is channel numbers, and each channel is shown. The top scale is the corresponding wavelengths in Å and has been determined by fitting a 3' order polynomial. The ordinate is observed number of photons per channel.*

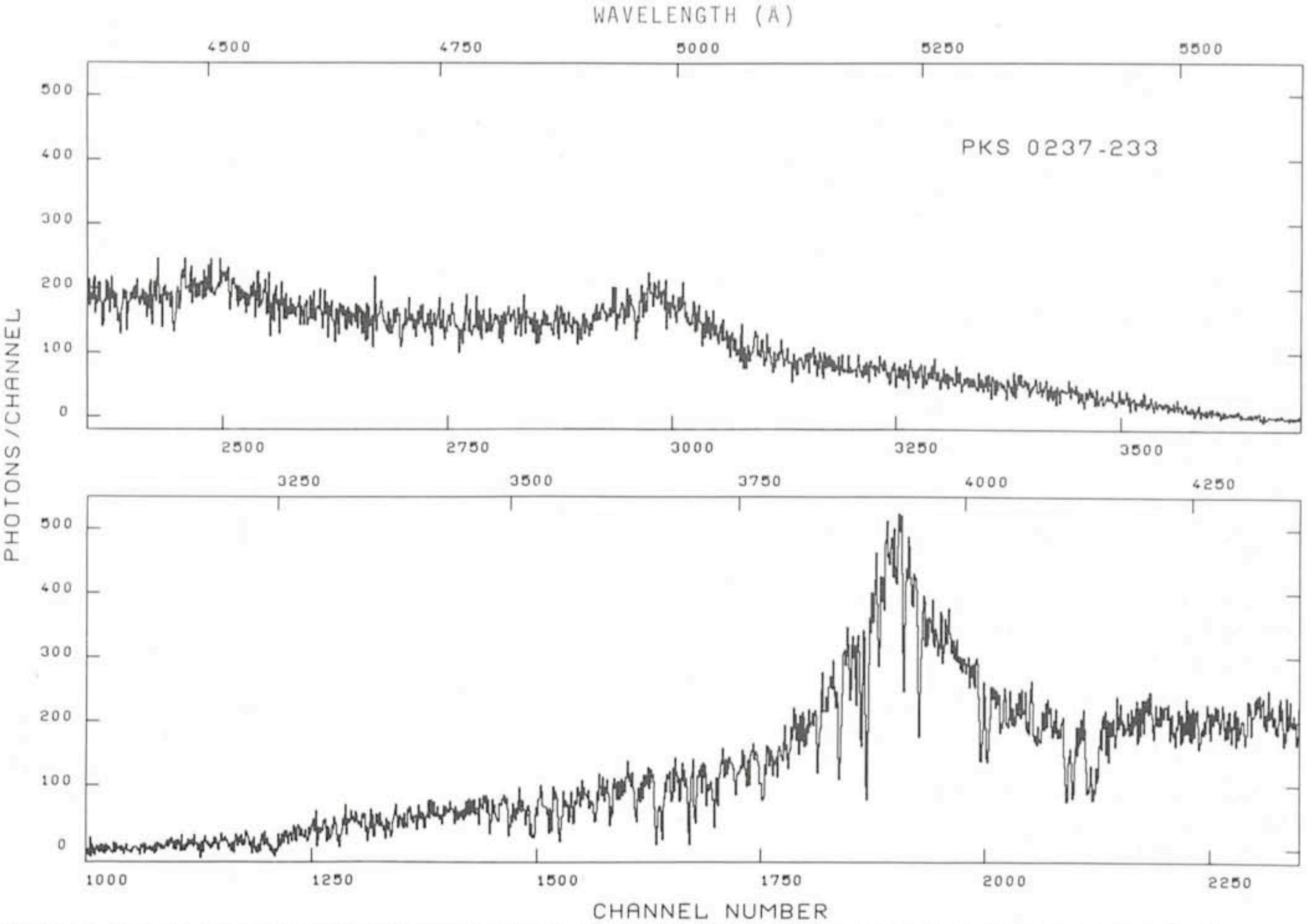

Fig. 2: *A 1 hour exposure of the QSO PKS 0237-233. For details, see text. The calibration is from Fig. 1. The layout is as in Fig. 1.*

The ejection of one photo-electron from the first photocathode (in the EMI tube) results in a "light-spot" on the RETICON array with a diameter (FWHM) $\approx$ 100 μ ($\approx$ 3 pixels) and a time distribution with a rise time of $\approx$ 2.5 msec and a decay time of $\approx$ 10 msec for the first 80 % and a long (~1 sec) tail for the rest. The total number of photons in this "spot" is of the order of 10^8 photons.

Each diode accumulates photo charge in the interval between successive read-outs of the diode. This period is 3 msec. The basic principle for extraction of the position information from these video-signals is identical to the original idea by Shectman and Hiltner (1), but whereas they essentially use analogue circuits, the present system immediately converts the video signals to digital information, and the information remains digitized.

The system performs a determination of the "light-spot" position (along the diode array) to within 1/4 pixel, which we call a channel, and updates the content of this "address" by one in an external memory.

Each array thus gives rise to 4 x 936 channels (= 3,744 channels) spectra, each channel corresponding to 7.5 μ. For convenience the system is built in such a way that each spectrum is 4k (4,096) channels, with 352 empty channels.

The detector is interfaced with the HP computers at La Silla and is operated through a special segment included in IHAP.

2. Operation and Performance

2.1 Projection

The RPCS detector is used in connection with a Boller and Chivens spectrograph and a Schmidt camera. The projection factor from the entrance slit of the spectrograph to the RETICON array is $\simeq$ 6. As the scales for the 3.6 m telescope and the 2.2 m telescope are ~140 μ/arcsec and 86 μ/arcsec, respectively, a 1 arcsec slit projects into 23 μ at the 3.6 m telescope and into 14 μ at the 2.2 m telescope.

2.2. Deckers

Two different deckers are available. One is made for the 3.6 m telescope with a set of 2 by 2 arcsec apertures and a set of 4 by 4 arcsec apertures, and one for the 2.2 m telescope, again with a set of 2 by 2 arcsec and 4 by 4 arcsec apertures.

If the "3.6 decker" is used at the 2.2 m telescope, the apertures correspond to 3.3 by 3.3 arcsec and 6.5 by 6.5 arcsec, and if the "2.2 decker" is used at the 3.6 m telescope, the apertures correspond to 1.2 by 1.2 arcsec and 2.4 by 2.4 arcsec.

Due to the fixed distance between the two RETICON diode arrays, the distance between the two decker apertures (corresponding to each array, respectively) is 26.5 arcsec for the 2.2 m telescope and 16.2 arcsec for the 3.6 m telescope.

2.3. Resolution

By narrowing down the slit (<< 1 arcsec) and by careful alignment of the RETICON chip, one can obtain a resolution (FWHM) of $\approx$ 1.5–1.8 channels over approximately half the detector length, and somewhat less (~ 2.5–3.5 channels) outside this range. This degrading may be due to optical limitations in the B & C spectrograph.

The resolution to be obtained in an actual observation, where it is necessary to open up the slit in order to get enough light, is essentially determined by the slit width. A slit width of 1 arcsec corresponds to a resolution of ≈ 3.4 channels (≈ 25 μ) at the 3.6 m telescope, and ≈ 2.5 channels (≈ 19 μ) at the 2.2 m telescope.

Fig. 1 shows a He-Ar calibration spectrum using ESO grating No. 7 (600 groves/mm, 114 Å/mm) blazed at 7°30′. The apertures were ~ 1.0 arcsec (slit) by 3.3 arcsec (decker). The spectrum is a sum of 4 spectra, each integrated for 60 sec. Two of the spectra, one from each array, were recorded before a 1 hour measurement at the 2.2 telescope of the QSO PKS 0237-233, and two, also from each array, after the measurement. The resolution is ≈ 2.8 channels (≈ 2.8 Å) in the central region of the detector.

Fig. 2 shows the recorded spectrum of the QSO PKS 0237-233. It is a sum of 6 integrations each 10 min long. The object was switched between the two arrays after each integration. The sky has been subtracted. The spectrum compares well with a similar spectrum of PKS 0237-233 obtained by Young and Sargent (2).

Flexure and drift is not a very serious problem. Actual observations at the 2.2 m telescope show very little drift (≤ 1 channel) during a night, and flexure ≤ 1 channel for positions within 3 hours of the median.

2.4. Dark Current

The EMI tube is presently operated at 8° C, and at this temperature the thermic emission from the first photocathode results in a count rate of 2.4 x 10^{-3} counts/sec/channel in the central region of the detector, and falling off towards the ends.

2.5. Count Rate

Due to the slow component of the VARO exit phosphor and a limited dynamic range of the electronic system, together with some special "shadowing effects" in the optical amplification system, there are some restrictions on the count rate which can be tolerated in order not to distort the spectra. The maximum count rate is 1.2 counts/sec/channel in "any extended region" of the spectra. If one exceeds that, irregular patterns and "cross-talk" can show up in the spectra. The term "any extended region" is to be understood in such a way that if the count rate exceeds the maximum count rate in only very few and very narrow emission lines, only very narrow regions around the emission peaks are distorted, the rest of the spectrum being undistorted.

2.6 Sensitivity

The sensitivity has been determined by observing white dwarfs calibrated by Oke (3). Fig. 3 shows a RPCS spectrum of the DB EG 149 obtained at the 2.2 m telescope. The spectrum is a sum of 2 integrations, one in each array and both 5 minutes long. The sky background has been subtracted and the spectrum flat field corrected. The apertures were 2 arcsec (slit) by 4 arcsec (decker), and the grating was the ESO No. 7 (600 groves/mm), 114 Å/mm) blazed at 7°30′.

The relative photon sensitivity for this configuration is shown in Fig. 4. A sensitivity curve for a 300 groves/mm grating (224 Å/mm, ESO No. 2), blazed at 4°15′ is shown in Fig. 5. Both curves are based on observations of the white dwarf HZ 4 (3).

The count rate to be observed for a given object is dependent on the seeing and the aperture size, and also the efficiency of different gratings may be different. Absolute sensitivity measurements have been performed at the 2.2 m telescope on nights with good seeing (≤ 1 arcsec) and using apertures of 3.3 arcsec by 3.3 arcsec with the two abovementioned gratings. The results correspond to 1 detected photon/Å/sec for a star of magnitude 14.5 at the peak wave length (see Figs. 4 and 5). The equivalent magnitude at the 3.6 m telescope would be 15.6.

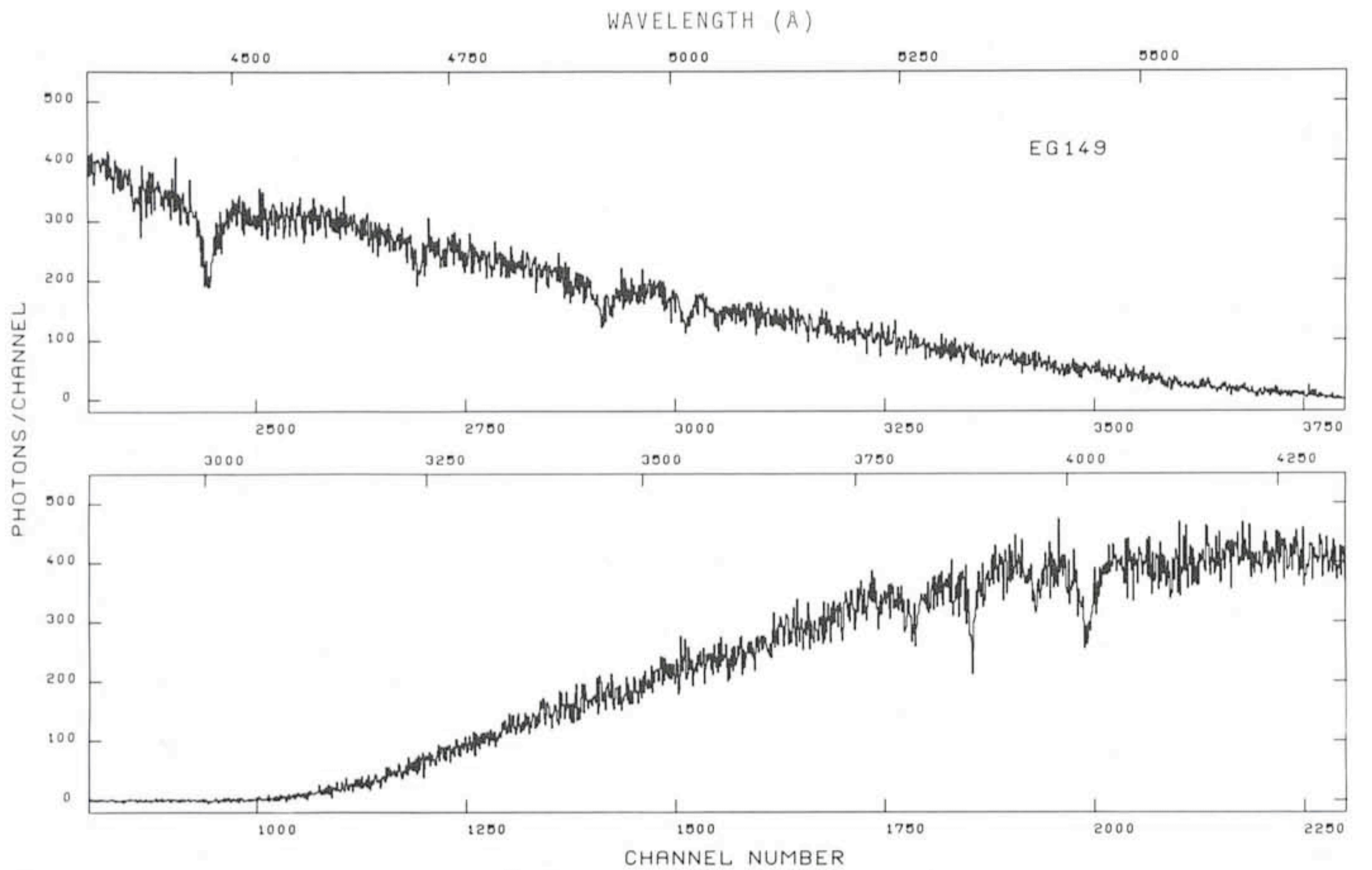

Fig. 3: *A 10-min exposure of the white dwarf EG 149. For details, see text. The layout is as in Fig. 1.*

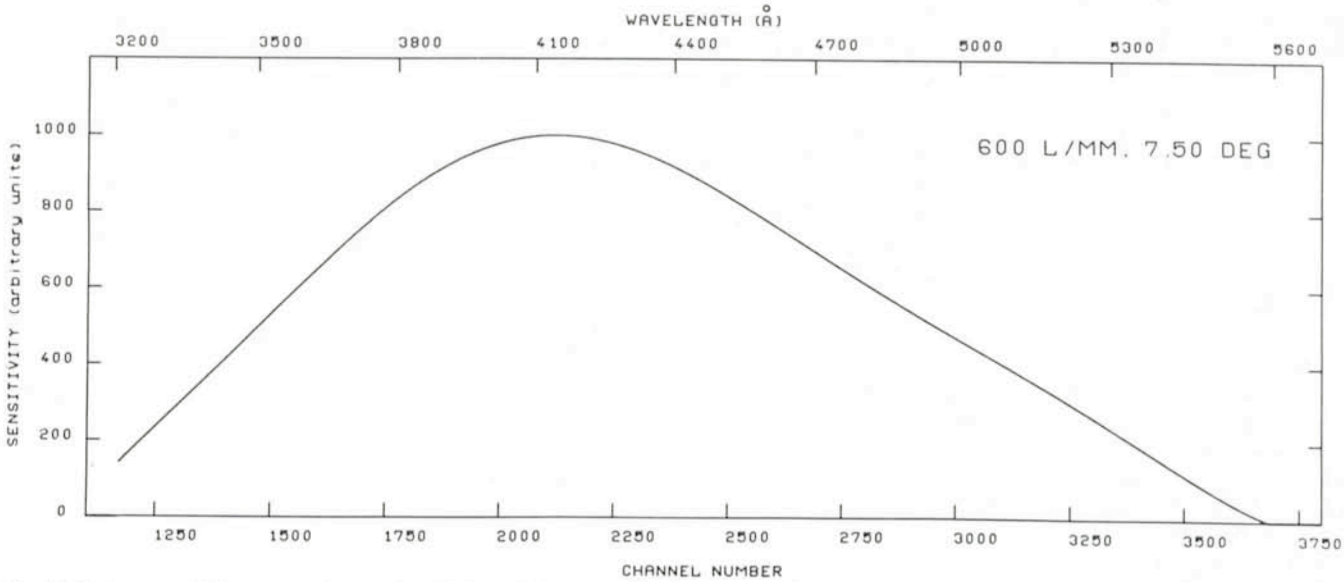

Fig. 4: *Photon-sensitivity curve using grating ESO no. 7 blazed at 7°30′. For details, see text. The curve was arbitrarily normalized to 1 000 at the maximum.*

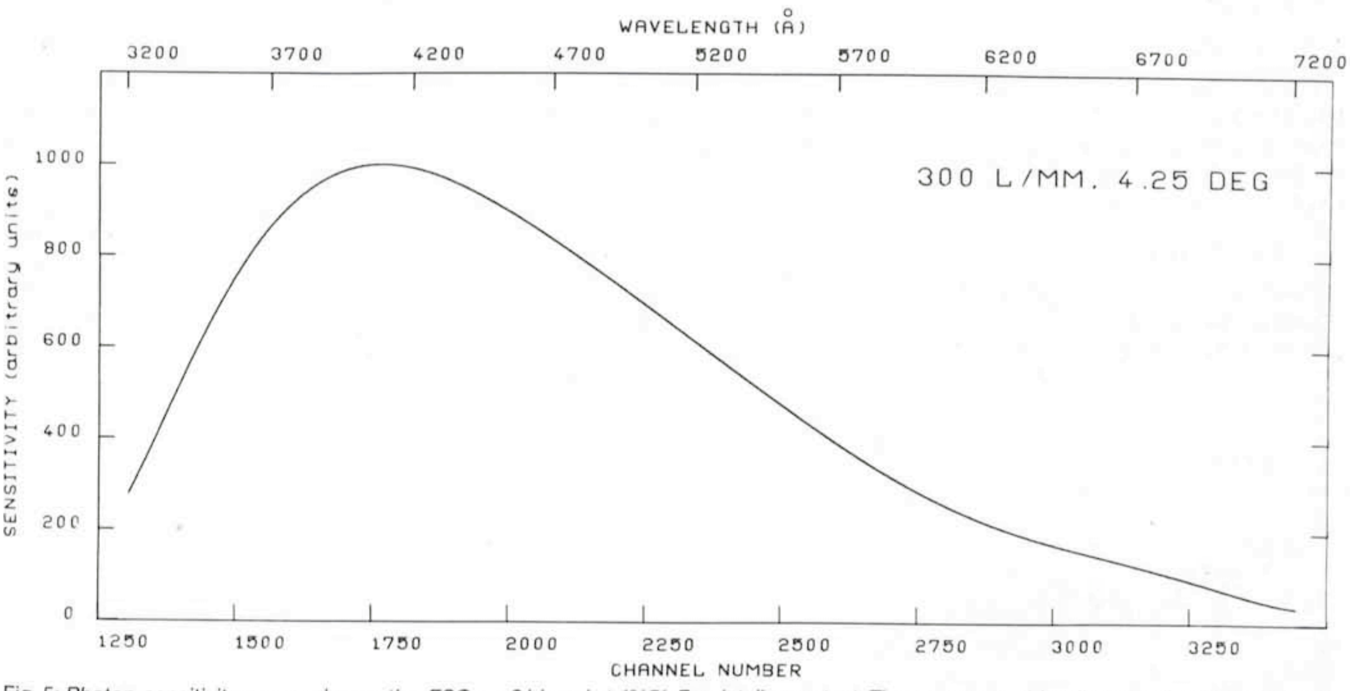

Fig. 5: *Photon-sensitivity curve using grating ESO no. 2 blazed at 4°15′. For details, see text. The curve was arbitrarily normalized to 1 000 at the maximum.*

2.7. Spectrum Pattern

Due to the methods used in the RPCS detector to determine the centre of the light spot to 1/4 of a pixel and to the fact that the odd and even pixels (in each array) are read out by different video-amplifiers, the spectra will show a pattern which repeats itself every eighth channel. The pattern can be interpreted as differences of channel-widths within each 8 channels, corresponding to one odd pixel and one even pixel. A FORTRAN programme, called COR8, which determines the pattern by averaging over the whole spectrum and subsequently transforms it to a spectrum with channels of equal widths, is available at the La Silla VAX 750. The spectra shown in Figs. 2 and 3 have been corrected using this programme.

3. Acknowledgement

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