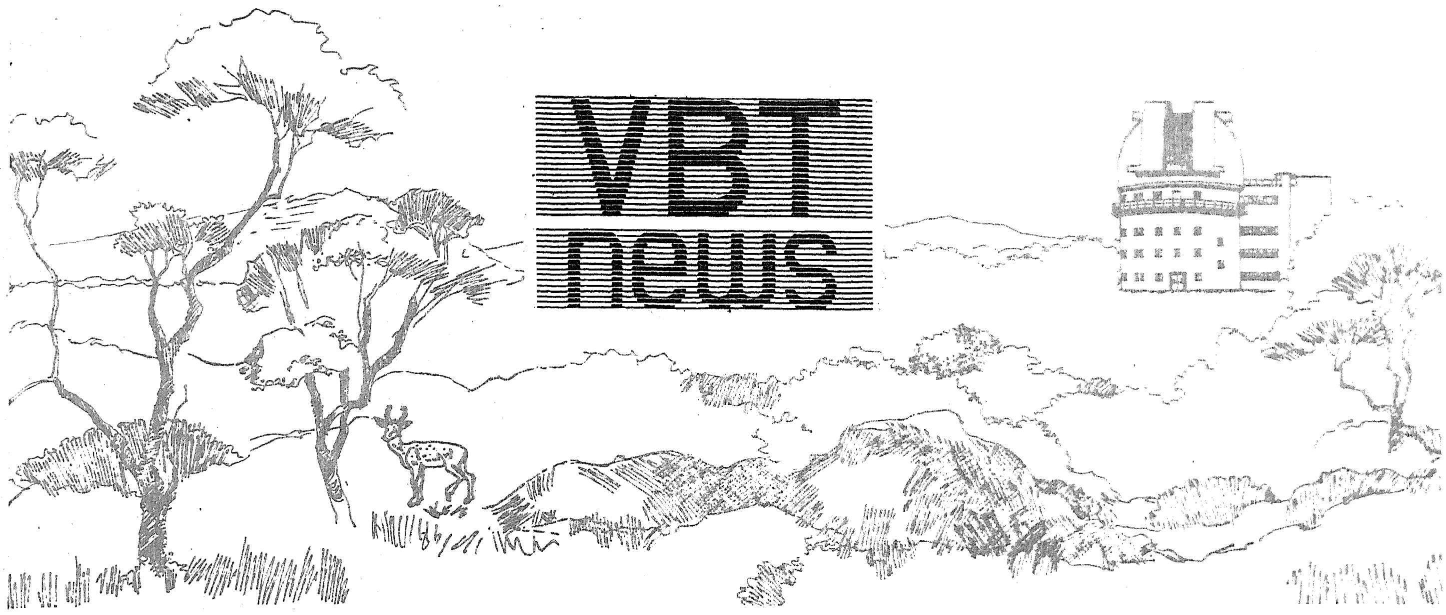

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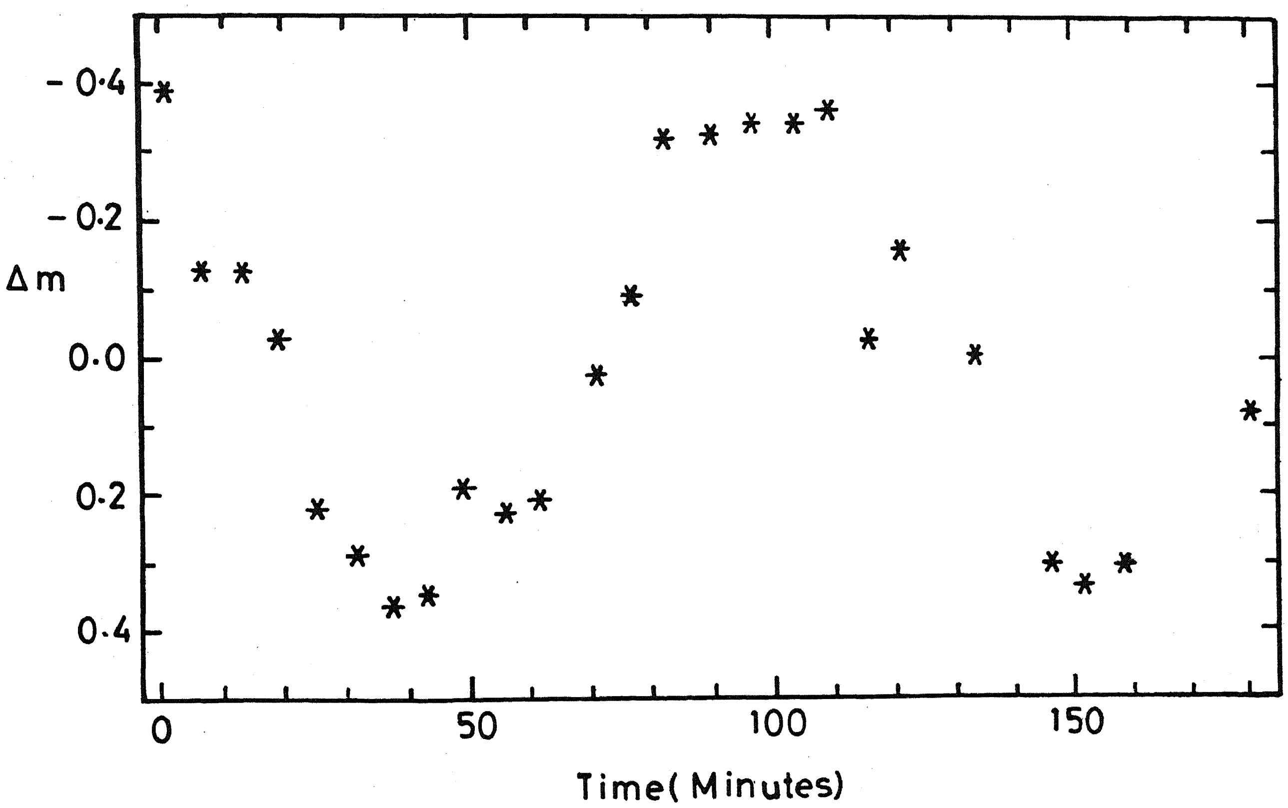

Figure 1. Light curve in R-band of PG 1550 + 191

PHOTOMETRIC STUDIES OF AM HERCULIS TYPE X-RAY BINARIES

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Detection of an intense soft x-ray source was reported in 1976 with the x-ray satellite SAS-3. The x-ray source was immediately identified with a 13th magnitude blue star found within the error box. Photoelectric photometry revealed it to be a close binary with a period of 3h. 5m. Polarization studies indicated the presence of strong and variable circular polarization in the optical band. The most startling finding was the detection of a linear polarization pulse which occurred once every binary cycle, reached a polarization level of about 5 to 6% for a few minutes and then suddenly disappeared. Further optical and x-ray studies showed that it occasionally makes a transition to a faint state (m_b>15) during which strong TiO bands are detected indicating that the binary companion is a low-mass cool star of spectral type M5. Based on these observations a model of the AM Her binary was constructed. In this model the x-ray source is a strongly magnetized white dwarf which is accreting matter at its magnetic poles via Roche-lobe overflow from its companion M star. An accretion column formed above the magnetic poles of the star, is a source of soft x-rays and polarized continuum emission by cyclotron process. The white dwarf is locked in synchronous rotation. During the rotation of the white dwarf, the linear polarization pulse is detected when the accretion column is perpendicular to the line of sight.

Till now 16 AM Her type stars, which are also commonly referred to as 'Polars' have been discovered almost all of them through x-ray observations. Strong and variable soft x-ray emission and the presence of a linear polarization pulse are the signature of a Polar. Most of the AM Her stars in their normal state are fainter than 15th magnitude. A study of the light curves of these binaries is important to derive information about the binary parameters, the geometry of the system and the accretion process responsible for their radiation.

We have undertaken the study of several recently discovered AM Her stars on which photometric observations are either lacking or rather sparse, especially in their low states. As these stars are faint they are best studied with a CCD based photometer on a large telescope like the VBT, The first observations of one such AM Her binary PG 1550 + 191 (MR Ser), which has a period of 113.6 minutes, were carried out on the 19th and 20th April 1991 from Kavalur with the 2.34m VBT and a liquid nitrogen cooled CCD photometer at the prime focus. The star was found to be very faint and is most likely in a low state. It was very faint in the B-band but brighter in the V and R bands. The preliminary R band light curve obtained on April 19 (Fig. 1) shows an eclipse at phase 0.4 and a modulation of the light curve with a period of 113.6 minutes. There is a change of about 0.8 magnitude over one orbital cycle. Note that the maximum in the light curve is flat. The V-band observations were carried out on April 20 and are yet to be analysed. Further photometric observations in the U and B bands are proposed to be carried out in the near future. Detailed studies of these light curves are proposed to search for any phase-lag of the minimum in the different bands. This will help in understanding the origin of the radiation in the different bands as well as throw light on the geometry of the system.

We wish to acknowledge the help rendered at the telescope by Mr. G. Selvakumar and Mr. Velu.

DISCOVERY OF SHORT PERIOD POLARIZATION BURSTS (6, 16 AND 80 MINUTES) IN THE BL LAC OBJECT OJ 287

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Extensive observations of Active Galactic Nuclei were conducted with the VBT between 8-16 February 1991. The sky conditions were favourable and the PRL Polarimeter and the VBT functioned well during these observations. As a result we have collected a wealth of valuable data on BL Lac objects, Seyfert galaxies, Elliptical galaxies and some variable stars.

Our main aim was to understand the energy mechanism in the nucleus of Seyfert galaxies which gives out energies of the order of 10^{42} to 10^{44} ergs/sec. Presently there is a controversy regarding the energy mechanism in the nuclei of Seyfert galaxies - whether the radiation is due to the incoherent synchrotron process or whether it is thermal in nature. A novel way to distinguish between these two is to study Seyfert galaxies in polarization with different apertures. If it were synchrotron radiation, one would expect a high degree of polarization from the nucleus which will be wavelength independent. On the other hand if the radiation from the nucleus were of thermal origin, one would get the polarization characteristics of the gas and dust in the host galaxy which will show a wavelength dependence, in polarization. We successfully observed four Seyfert galaxies during this observing run and the analysis of the data is in progress.

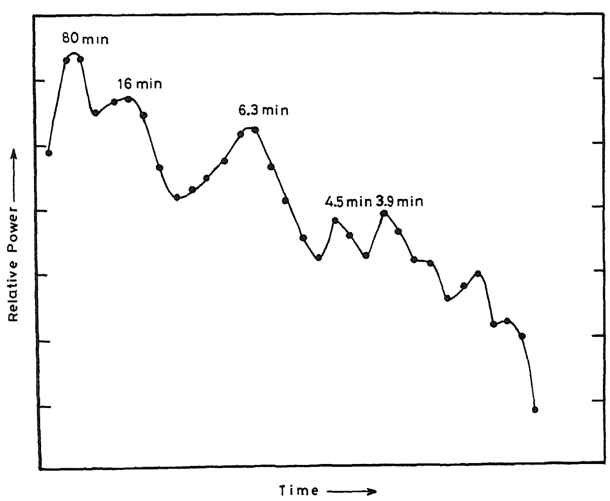

Figure 1. OJ 287 Polarization Spectrum

In the case of BL Lac objects our object was to study the nature of the central engine through polarization measurements. It is important to determine whether the radiation is due to the synchrotron process and also to estimate the size of the central engine. One of the methods to estimate the size of the engine is to find out the time variability in the polarized flux from the source. The product of C and T (where 'C' is velocity of light and T is the period of variations) will give the upper limit on the size of the source. Polarization studies will enable us to determine the magnetic field around the central engine and the electron energy spectrum in the jets of BL Lac objects. These parameters are vital to carry out model calculations for the central engine. During the observing run in February 1991 we have successfully observed three BL Lac objects. The preliminary analysis shows that in one of the objects OJ 287 we seem to have discovered 80, 16 and 6 minute variations in the polarization. Periods longer than 80 minutes are reported in the literature by several workers. The new periods of 16 and 6 minutes probably indicate that the size of the central engine is about 1 to 2 AU. Further work in this direction is in progress.

FAINT OBJECT SPECTROSCOPY WITH THE VBT

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Indian Institute of Astrophysics, Bangalore.

Spectroscopic observations of novae at quiescence have been carried out with the 1-m Zeiss reflector at VBO for several years. Although it has been possible to obtain low resolution (10 Å) spectra of some of these objects up to 14.5 mag with the CCD system at the 1-m telescope, the signal-to-noise ratio has been very poor for the fainter ones. Attempts were also made to obtain spectra of some nearby star-forming galaxies using the 1-m reflector. However, it was possible to obtain moderate signal-to-noise ratio only when the slit was opend to ~ 16 arcsec.

In order to obtain good signal-to-noise spectra of novae at quiescence, and of galaxies with a narrow slit, observations were made using the Boller & Chivens spectrograph and the Astromed CCD at the Cassegrain focus of the VBT.

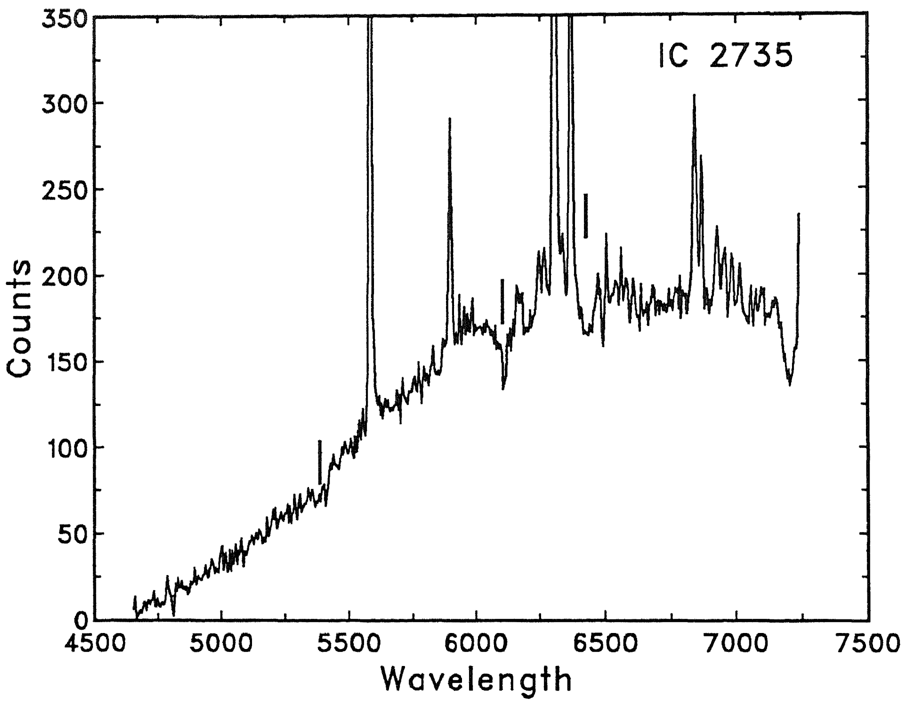

Figure 1. Average of four 30-min exposures of IC 2735, extracted from the raw frames, and wavelength-calibrated using RESPECT software. The emission lines are due to the night sky: [O I] 5577 Å, Na I D 5893 Å[O I] 6300, 6363 Å, OH (7,2) band 6829-6979 Å. OH (8,2) band flanks to the red side of Na I D. OH (9,3) flanks the blue side of [O I] 6300, 6363 Å. Vertical lines indicate Mg I + MgH 5175 Å, Na I D 5893 Å, and TiO 6180 Å, in the galaxy spectrum, redshifted by z = 0.037.

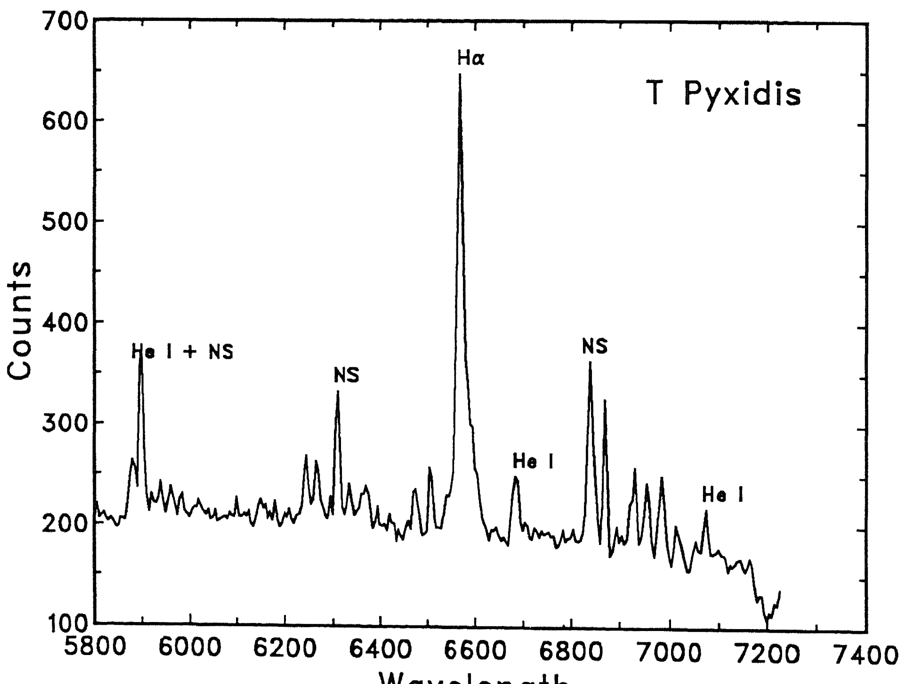

Figure 2. The spectrum of T Pyxidis extracted from four 30-min raw frames, wavelength-calibrated, and averaged using RESPECT software. The night-sky lines [O I] 6300, 6363 Å (NS) are faint in this spectrum exposed around midnight, about 2 hours before IC 2735 (Fig.1). The OH (9,3) band is dominating the region. The night-sky Na I D flanks to the red side of He I 5876 Å line from the star. The emission lines at Hα with contribution from [N II] and He I 5876, 6678, 7065 Å are marked.

Of the total of 5 nights allotted during 1991 January-March, one night was poor, two were fair, and two good. A grating with 300 l mm^{-1} blazed at 5000 Å was used since that was the lowest dispersion grating available. A slit width of 350μm corresponds to a projected slit width of 2 pixels and yields a resolution of 9 Å. The amplifier gain setting of the CCD controller was set to 9.0 resulting in 4 electrons per count.

The first observing run was in February. During this run a minor problem was noticed with the read-out of the CCD which affected the faint object spectra. This was diagnoised and rectified by Dr.R. Srinivasan and Mr. A.V. Ananth. Another problem was to acquire objects fainter than 14th magnitude on the slit since most of the slit was covered by the dekker. The dekker was subsequently dispensed with. Despite these problems, useful observations could be obtained of novae T CrB (10.0 mag), GK Per (13.0 mag) and T Pyx (14.5) mag. With the same slit width, the galaxies NGC 2903, NGC 3627, NGC 4314 and NGC 5236 were also observed.

With the minor problems resolved, and with skies clearer, the March run was much better. It was comfortable to observe T Pyx. In addition to this and T CrB, spectra of RS Oph (12.0 mag) were also recorded. The galaxy IC 2735 (UGC 6364; m_{pg} = 15.4 mag) was also observed during this run. The galaxy shows absorption bands due to Mg I + MgH 5175Å, Na I D 5893Å, and TiO 6180Å at a redshift of z = 0.037, a value in agreement with CfA redshift survey (Fig. 1). The Spectra confirm that the galaxy is an early-type spiral, as indicated by the Uppsala General Catalogue. The sharp component of Na I D is due to the interstellar matter in IC 2735 since the galaxy is seen almost edge-on.

The spectra of T Pyx show strong lines of Hα + [N II] and of HeI (Fig. 2). The continuum has 250 counts (equivalent of 1000 electrons) near 6700Å accumulated in 30 minute integration. The resultant signal-to-noise ratio is about 16 per frame. The results are encouraging enough to indicate that further observations of novae and galaxies using the VBT, will be profitable.

GAIN CALIBRATION OF THE ASTROMED CCD SYSTEM AT THE VBT

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Indian Institute of Astrophysics, Bangalore.

A CCD detector is increasingly favoured for astronomical observations because of its high sensitivity, linearity and large dynamical range. However, it is an analog device, and the charges accumulated in its pixels are converted to voltage, amplified, and digitized such that a specific voltage V_0 is converted to a specific binary number. The bit saturation limits the dynamical range at the upper end, whereas the detector noise, called the read-out noise, limits it at the lower end. The amplifier gain needs to be optimized for astronomical observations so that most of the dynamical range of the CCD is available. Astronomers prefer to set the amplifier gain such that one bit corresponds to the read-out noise of the CCD so that one obtains a dynamical range of 10.5 magnitudes with a 14-bit ADC, 11.3 magnitudes with a 15-bit ADC, and 12.0 mangitudes with a 16-bit ADC. The last of these figures corresponds to the full dynamical range of a typical CCD chip with a full-well capacity of 500,000 electrons and a read-out noise of 8 electrons. These values are marginally reduced by the need to set the zero-exposure or bias value to a finite number. The optimal gain can be selected if the correspondence between the recorded counts and the electrons generated in a pixel of the CCD is determined. This conversion factor is measured either as Q, the number of electrons required to produce one digital count, or its inverse G, variously known as the system gain, gain factor, or transfer factor, measured in counts per electron. (*cf.*, I.S Maclean 1989, *Electronics and Computer-aided Astronomy* , Chichester: Ellis Horwood).

Two sets of CCD dewars and controllers are available at the VBT, one set belonging to IIA, and another of TIFR. Both these systems were procured from Astromed Inc., UK, and both the CCD chips are A grade GEC P8603 coated for enhanced UV response. The two controllers are identical except for minor differences in the digitization circuits. Data acquisition software has been developed by IIA (*cf.*, A.V. Ananth *et al.* 1991, *J Pure Appl. Phys.,* in press). The software has been recently duplicated for the TIFR controller. The data has 15-bits and hence a saturation level at 32767 counts. It was realized during observations in 1990 that the system gain was too high and the dynamical range was limited to about 7-8 magnitudes from detection to saturation. The available dynamical range was further limited in the case of sky-limited observations. In order to alleviate this problem, the amplifier gain was reduced from the 'standard setting' of 34.0 to 9.2, and the system gain was accurately determined in order to decide whether further change in the amplifier gain is necessary.

The system gain can be determined by studying the noise statistics of a uniform exposure called the flat-field. For a signal of N photons, the shot noise is $\sqrt{N}$. Since the electrons generated in a pixel are proportional to N through the scale factor of quantum efficiency of the pixel, it is generally assumed to the first degree of approximation that N_e electrons stored in a pixel have a noise component of $\sqrt{N_e}$. For a system gain of G, the observed counts would be $S=GN_e$ and the corresponding noise $\sigma = G\sqrt{N_e}$. One thus obtains $\sigma^2=GS$, and G can be determined through the observables S and σ.

In practice, the rms noise in counts is also affected by the read-out noise R_e and the rms variations in the sensitivity of the pixels which is proportional to the signal itself. Any nonuniformity in the flat-field exposure also adds to the rms variation proportional to the signal. Thus the total variance of the counts is

$$\sigma_T^2 = G^2R_e^2 + GS + f^2S^2 \qquad (1)$$

where f is the rms value of a normalized flat-field due to pixel-to-pixel variations and the nonuniformity of the illumination of the CCD. It may appear that a least-squares fit to the observed values of S and σ can yield the estimates for G, R_e and f. However, since the magnitudes of observables increases from the first term to the last term at the rhs of equation (1), the errors propagate in the direction of $f^2 \rightarrow G \rightarrow G^2R_e^2$. K. Horne (1988, in *New Directions in Spectrophotometry.*, eds. A.G.Davis Phillip, D. Hayes, S. Adelman; Schenectady: L. Davis Press) suggests a recipe for the determination of G and R_e which was adopted after some modifications.

Twenty one graded flat-field exposures were obtained using the IIA CCD dewar, with mean counts ranging from about 500 to 29000 counts above the bias value of about 190 counts. These were obtained in the laboratory without any optical filters, and using diffuse daylight. A similar number of bias frames were also recorded interleaving between the flat frames. The mean bias value corresponding to zero exposure was subtracted from all flat field frames. The flat fields were averaged and a normalized master flat was obtained by division of the average flat by a nautral cubic spline surface fit. Each of the flat-fields were then divided by this frame. A surface fit was subtracted from these flats leaving out only the noise image. The mean count S was determined from the flat-field before subtracting the surface fit, whereas the rms noise was determined after the subtraction of the surface. This procedure removes the third term on the rhs of equation (1). The least-sqaures straight-line fit to the data now yields the value G accurately though the estimate of R_e from the intercept of the straight-line would still be inaccurate.

The observed points are shown by circles in Fig. 1. A formal least-squares fit gives

$$\sigma_T^2 = 80.7 + 0.2340S. \qquad (2)$$

The system gain was thus determined to be G = 0.234 counts per electron. This corresponds to Q = 4.27 electrons per count. The read-out noise determined from the intercept is 38.3 electrons, which is certainly inaccurate due to the propagation of errors. The rms noise in the bias frames was 1.9 counts. Since this equals GR_e, the read-out noise was estimated as $R_e = 8.1$ which agrees with the manufacturers' specifications.

The above exercise was repeated using flats obtained through the telescope at the prime focus, using broadband and narrowband filters and twilight sky as well as dome flats. The number of flat field exposures used was small - 3-7 in number. It was found that the corrections for the quadratic term in equation (1) is possible, only if at least 10 well-exposed flats are averaged to determine the master flat. If the number is smaller, the masterflat carries the memory of noise in individual flats and removes a part of it after division of individual flats by the master. This results in an under-estimation of noise and consequently of the system gain. Fig. 1 shows the results for two sets of flats, one with 7 flats another with 4 flats, both sets exposed to a medium range. It is also now evident that a few points in the laboratory calibration that show lower variance than expected from the least-squares fit are also similarly affected. These are the ones having better mean counts, and the ones that contribute significantly to the master flat. With due allowance to this effect, we adopt a

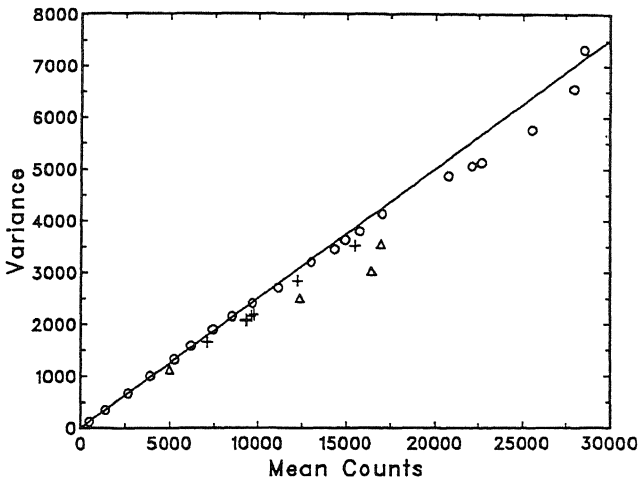


Figure 1. The variance in observed counts as a function of mean signal counts. Circles represent results based on 21 flats recorded in the laboratory. Other symbols represent results based on a smaller number of dome flats obtained at the prime focus of the VBT. The straight line is the fit with a read-out noise of 8 electrons, and a system gain of 0.25 counts per electron, or Q = 4 electrons per count.

value of G = 0.25 shown by a straight line in Fig.1. Future exercises in calibration should be modified to take this into effect. It is suggested that a large number of well-exposed flats be used for making the master flat. These should not be used individually for a determination of shot noise.

The available dynamical range at this setting is 32567/1.9 = 17140 or 10.6 magnitudes following the standard definition, and a mean bias value of 200 counts. For a 3σ detection the dynamical range is reduced to 9.4 magnitudes, and if one wishes to undertake photometry with at least 1% accuracy, the dynamical range is further reduced to 2.8 magnitudes for a single, read-out-noise-limited exposure. Further, if one is interested in faint objects, and hence in an accurate subtraction of sky, the sky needs to be exposed at least to three times better accuracy than the desired threshold for detection. This reduces the available dynamical range further. Obviously, it is desirable to reduce the amplifier gain by another factor of 2 in order to increase the dynamical range. Since this would reduce the read-out noise to only one count, no loss of accuracy results in read-out-noise-limited observations such as speckle interferometry or high-dispersion spectroscopy of bright objects.

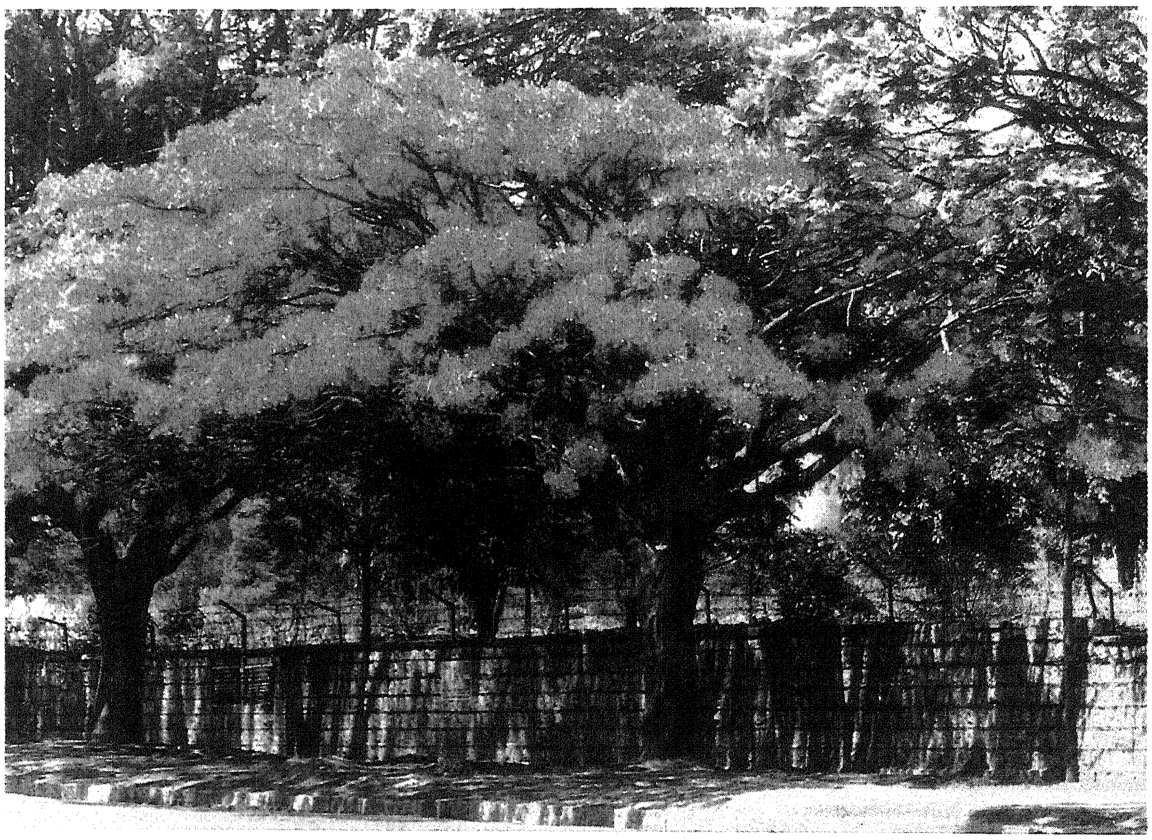
The master flat-field image was examined to determine the quality of the chip. The rms variations in the flat-field after removal of low-frequency variations is 1.83% which agrees with manufacturers' specification. There are 14 pixels with low sensitivity in the range 64-85%. Also, the main Gaussian distribution of sensitivity has a low sensitivity tail consisting of nearly 500 pixels in the range 85-94%. A good flat-field frame can correct for all these variations. The first row as well as the first and last columns generally show large counts and are not usable. The above statistics excludes these pixels. The total number of usable pixels out of the 385 x 578 array are thus 383 x 577 = 220991 and the low sensitivity pixels in these comprise only about 0.2%.

We acknowledge the help of the electronics staff at VBT in obtaining the laboratory data and of the telescope assistants in obtaining the sky and dome flats. The latter flats were obtained in collaboration with Prof. Ajit Kembhavi and Dr. Ranjan Gupta (IUCAA, Pune), and Dr. P.N. Bhat (TIFR, Bombay). All the reductions were carried out using the STARLINK EDRS package at the VAX 11/780 installation at the VBO.

VAINU BAPPU OBSERVATORY

Sky condition at Kavalur, October 1990 - March 1991

Month	Spectroscopic Hours	Photometric Hours
October	42	11
November	115	29
December	110	31
January	174	44
February	225	181
March	208	95



Photograph by K.K. Scaria

Gul Mohur is a large deciduous tree growing up to 40 to 50 feet in height with spreading branches and very handsome feathery leaves. The flowers appear with the onset of hot weather, usually by mid-May. The tree is a vivid and brilliant mass of scarlet blooms. Each flower is seen to be composed of four scarlet petals while the fifth is larger in size usually white or yellow with red streaks. There are several trees both in Kavalur and Bangalore Campus.

A. Vagiswari

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