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INFRARED PHOTOMETER SYSTEM FOR ASTRONOMICAL OBSERVATIONS

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ABSTRACT

An Infrared photometer system has been developed for photometry of astronomical sources in the spectral band 1 to 5 microns. The characteristics of the system and preliminary engineering tests using the 1- m optical telescope at Kavalur are presented with system sensitivity using standard near infrared astronomical sources and plans for future observations.

Key words : wide band Photometry, near Infrared

1. Introduction

Wide band *JHKLM* photometry of stars in the near infrared covering the spectral region 1 to 5 microns have been published since 1960s by Johnson and Mitchell (1963), Johnson (1965), Koornneef (1983a,b). Infrared photometric magnitude scales have been established by Johnson (1965) and refined over the years by Engels et al. (1981), Jones and Hyland (1982) and Thomas et al. (1973). Results of these wide band observations show that, the spectra of stars do not follow a black body distribution. Absolute methods of calibration were adopted by Johnson (1965) using the colours obtained from *(V-J)*, *(V-K)* and *(V-L)* magnitudes for the Sun (assumed to be G2V). An atmospheric model using Vega was made use of by Oke and Schild (1970) and Hayes and Latham (1975) and finally blackbody comparison method in which direct comparison of stellar flux densities with terrestrial blackbody sources was adopted by Selby et al. (1980, 1983) and Blackwell et al. (1983).

A programme in the near infrared astronomy was initiated in 1985 at the Indian Institute of Astrophysics (IIA) planned for Comet Halley observations in April 1986 and subsequently for astronomical observations in the *UBVRI* and *JHKLM* bands using the 1-m and 2.3-m optical telescopes at the Kavalur station of the IIA. We present an overall description of the photometer system in Section 2. In Section 3 we describe the detector and filters used for our observations and in Section 4 we present the results of the preliminary engineering tests as well as those of the calibration of the photometer system by observing standard stars at the 1-m reflector.

2. Photometer Description

Figure 1 shows the optical layout of the photometer system designed by the IIA and fabricated and tested by Infrared Laboratories (IRL), Tucson, Arizona and Figure 2 shows the external drive mechanism and control units for this photometer.

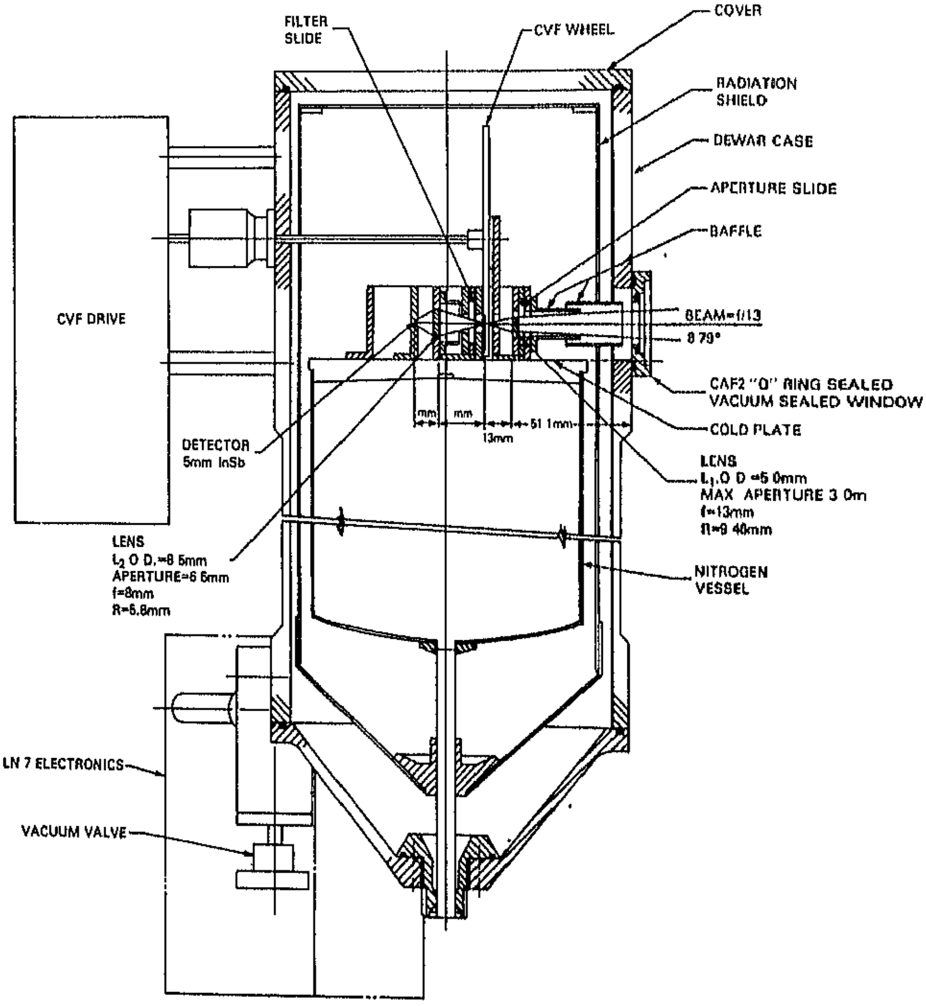

Fig. 1: Optical layout of the photometer system.

The photometer system is mounted on the cold deck (77K) of the standard 125 mm dewar provided by IRL. The radiation from the telescope enters through the 50mm diameter calcium fluoride window and passes through an aperture mounted on a disk in front of lens L_1 and driven by a linear actuator. The diameter of the apertures used are 0.5, 1.0, 1.5, 2.0 and 3.0 mm. The scale of the 1 m telescope at its cassegrain focus (f/13) is 15.5 arc sec mm^{-1} and the aperture sizes would correspond to angular beam of sizes 7.7, 15.5, 23.2, 31.0 and 46.5 arc sec respectively. The aperture wheel also has a blank aperture to enable determine the noise characteristics of the system at zero background. The field lens L_1 images the incoming f/13 beam either onto the low resolution filters or onto a two sector band circular variable interference filters (CVF) manufactured by Optical Coatings Laboratories Inc. (OCLI), Santa Rosa, California. The characteristics of the lenses and filters are listed in Table 1. The

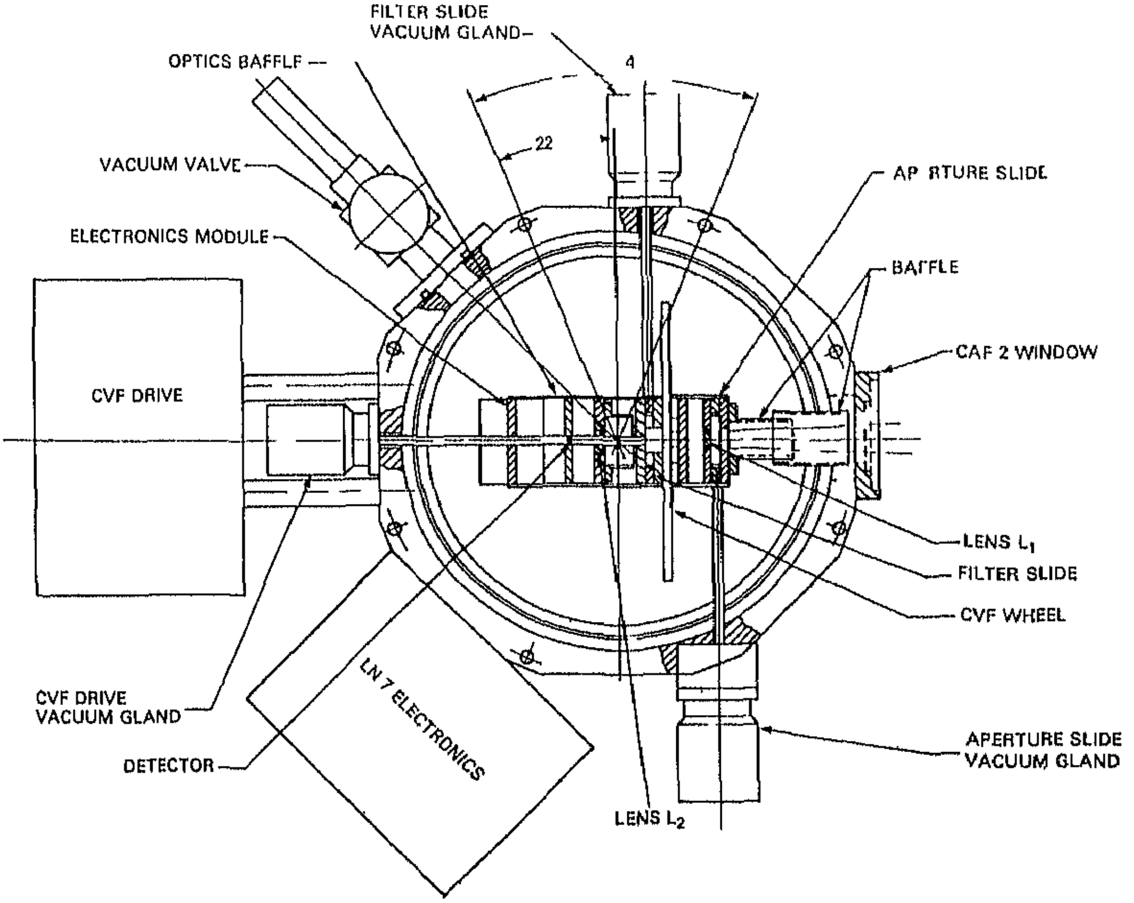

Fig. 2 External drive mechanism and control units of photometer

Table 1 : Telescope Parameters and Photometers

Characteristics

Telescope Diameter : 1 meter
F ratio : f/13
Apertures (mm) : 0.5, 1.0, 1.5, 2.0, 3.0
Beam Size (arc secs) : 7.7, 15.5, 23.2, 31.0, 46.5

Filter	Wavelengths	Half-Power Bandwidth (Microns)
J	1.25	0.32
H	1.63	0.28
K	2.25	0.35
L	3.75	0.60
M	4.7	0.50

Detector: Photovoltaic InSb
Detector Temperature: 77K

spectral response curves of the *JHKLM* filters were provided by the Infrared Laboratories and are shown in Figure 3. The filters are mounted on a slide mechanism similar

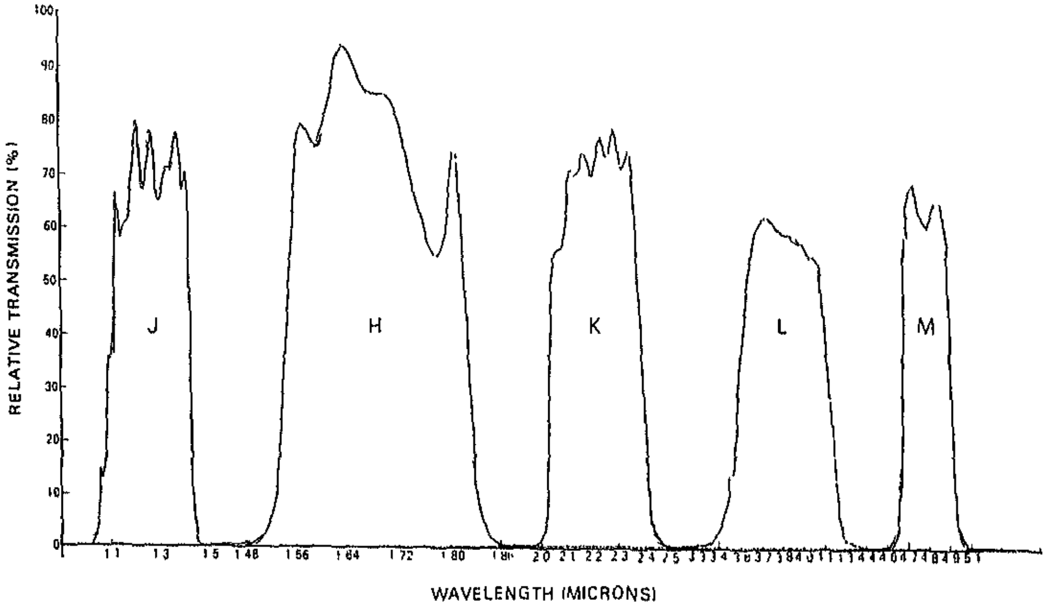

Fig. 3: Spectral response curves of the *JHKLM* filters

to the aperture slide design. An open position is included in the filter slide so that the incoming radiation can be transmitted through to the CVF. Circular variable filters are interference filters deposited on circular substrates, where the wavelength variation is dependent on substrate thickness, which varies linearly with angular rotation The bandwidth is virtually constant over all angles of rotational position, providing constant resolution over the wavelength region of interest Spinning the filter wheel will provide a continuous rapid scan of the filter's spectrum The CVF is attached to a shaft and projects from the rear of the dewar and is coupled to a motor drive unit A narrow slit is provided on the CVF wheel near the open position to establish a reference in rotation angle and the position of the slit will be indicated by the saturated detector signal resulting from the unfiltered wide band radiation Data showing bandpass as a function of rotation angle as provided by OCLI is presented in Table 2 A relay lens L_2 finally reimages the filtered radiation onto an InSb detector

Table 2 Circular Variable Filter

A Spectral Band: 1.4 microns – 2 5 microns

Angle of Rotation (Degree)	Half power Points (Microns)		Center Wavelength Half power bandwidth (Microns)	
5	1 410	1 383	1 397	1 95
15	1 547	1 516	1 531	2 02
25	1 688	1 656	1 672 (H 1 63)	1 91
35	1 831	1 797	1 814	1 87
45	1 974	1 937	1 956	1 89
55	2 116	2 077	2 097	1 86
65	2 259	2 218	2 239 (K 2 25)	1 83
75	2 400	2 356	2 378	1 85
85	2 539	2 492	2 515	1 91

B Spectral Band: 2 470 microns – 4 578 microns

Angle of Rotation (Degrees)	Half power Points (Microns)		Center Wavelength Half power bandwidth (Microns)	
2	2 482	2 458	2 470	0 97
	3 573	3 539	3 556	0 96
88	4 595	4 561	4 578 (M 4 7)	0 74

3 Detector and Electronics

Photovoltaic InSb detectors have been extensively used in ground based astronomy in the 1-5 micron band because of its low noise The InSb detector provided by Cincinnati Electronics, Ohio has a diameter of 0 5 mm and a nominal impedance of 1200M Ohms at 77K Two relay cold feedback resistors with values of 5800M and 77000M Ohms are used for different backgrounds The high valued resistor is used for low background conditions filters (J,H,K) and the low valued resistor is used for high background conditions filters *(L,M)* for calibration of bright objects like planets. A low noise current mode pre-amplifier with unity gain optimized for high impedance is shown in Figure 4 has as its first stage, matched JFET transistors located near the detector and operated at 77K. Two 9-volt transistor batteries provide power and bias voltages and the detector output is coupled through an operational amplifier. The lock-in phase amplifier shown in Figure 5 synchronously rectifies the A.C. signal from the amplifier with gains of 1, 10 and 100 and is coupled to a D.C. amplifier with gain settings of 3 and 10 with a variable D.C. offset, so that it can be used with different recording instruments.

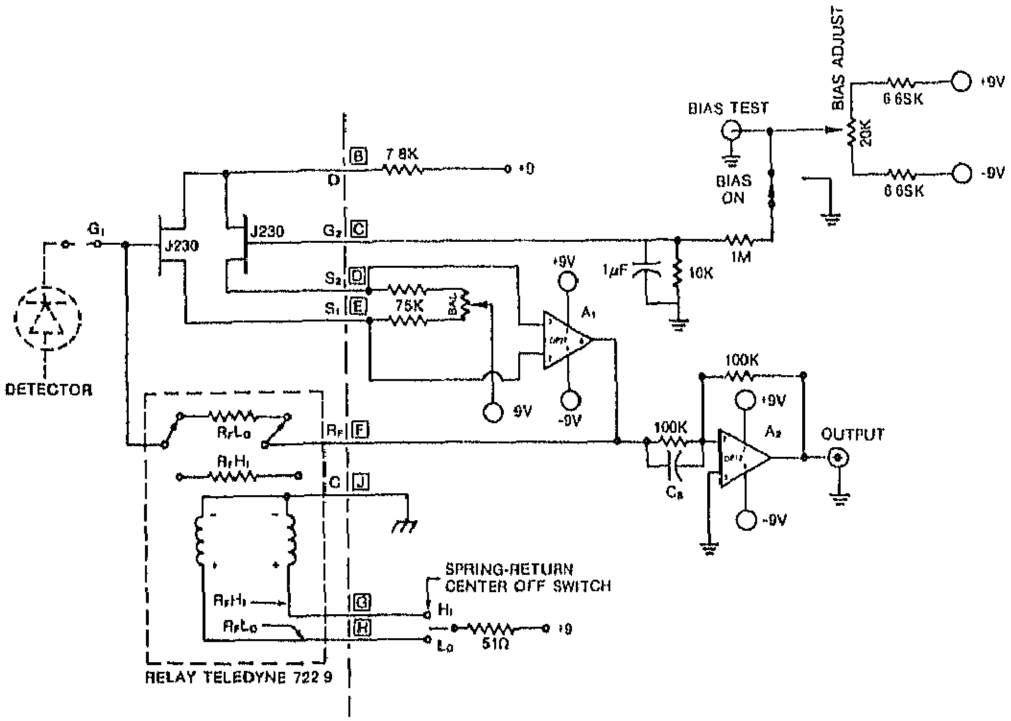

Fig. 4: Circuitry of pre-amplifier and post-amplifier system.

4. Calibration

The system was tested during Comet Halley observations on April 6, 1986 using the 1-m telescope. Out of two nights of telescope time, one night was not useful because of bad weather conditions. A focal plane chopper at 20 Hz was used at the exit of the tertiary mirror as shown in Figure 6 to modulate the incoming signal from the Cassegrain optical system and an optical sensor was used for co-aligning the

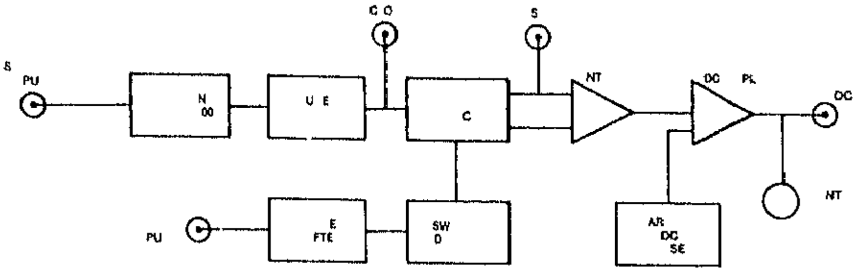

Fig [illegible] Block diagram of lock in phase amplifier

beam with the infrared beam Moving the chopper back and forth produces two nearly equivalent beams on the sky, thus exposing the detector to the source and to a nearby region of the sky The observations were carried out with a 31 arcsec beam and a beam throw of 60 arcsec Two stars, Alpha Boo and Alpha Sco were used for calibration Since spectra of these stars closely resemble blackbody spectral distributions (Gillett et al 1968), we obtained the radiance levels by integrating the spectral response of the detector and filters with the Plankian blackbody distribution using the effective stellar temperatures of these sources as determined by Johnson (1966) and the angular diameters as measured by Honeycutt et al (1977) The responsivity and the noise equivalent power (N E P) were determined using the observed signals with the low valued load resistor We present in Table 3 our results normalized to the dewar window which defines the system performance

Table 3 : Calibration Results

	J	*H*	*K*
Peak wavelength (microns)	1 25	1 63	2 25
Half power bandwidth (microns)	0 32	0 28	0 35
Responsivity (V/W) Volts/Watt (Alpha Boo 4960K)	3 8E+7	1 2E+8	2 2E+8
Responsivity (V/W) Volts/Watt (Alpha Sco 3600K)	4 3E+7	1 1E+8	2 4E+8
Noise (Observed)	3 5mv	3 5mv	3 5mv
N E P, Watts/$\sqrt{Hz}$	8 0E 11	3 2E-11	1 5E 11
Noise (Bkg)	0 05mv	0 02mv	0 02mv
Load resistor Johnson noise (77K)	0 07mv	0 07mv	0 07mv
Preamp noise (shorted)	0 004mv	0 004mv	0 004mv

Note : Responsivity and N E P are at the entrance window of the photometer

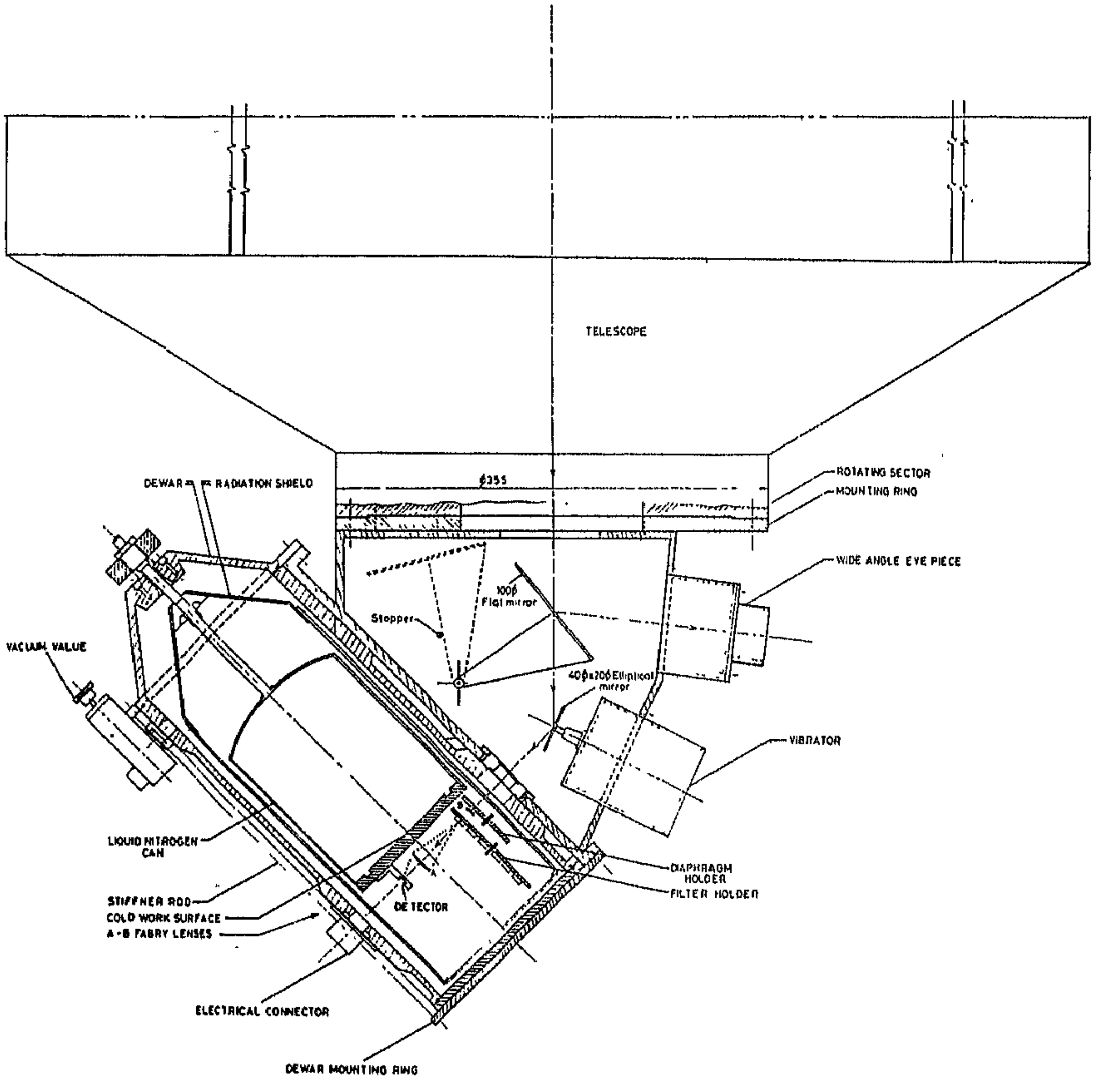

Fig. 6: Interface of photometer with 1-m optical telescope at Kavalur.

Table 4

List of standard stars chosen from Johnson et al. (1966) for our observations. $(J-K)_c$ is the $(J-K)$ colour of Johnson et al. (1966). $(J-K)_o$ is the $(J-K)$colour observed through our IR system.

Standard star	Spectral class	$(B-V)$	$(J-K)_c$	$(J-K)_o$	$(J-K)_c - (J-K)_o$
O_2CMa	B3	-0.08	-0.03	-0.16	0.13
β UMa	AIV	-0.02	0.00	-0.18	0.18
δ CMa	F8	+0.68	0.38	0.14	0.24
ε Leo	G3	+0.80	0.48	0.22	0.26
BS2697	K2	+1.26	0.79	0.57	0.22
μ Leo	K2	+1.22	0.70	0.44	0.26
¶ Leo	M2	+1.60	1.04	0.82	0.22
α Ori	M2	+1.84	1.24	1.00	0.24

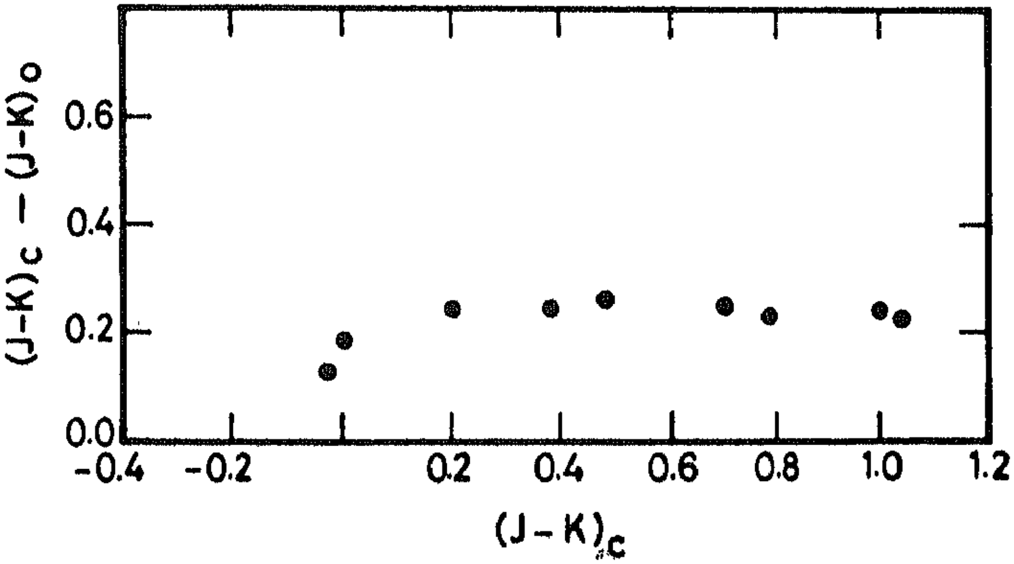

Fig. 7 : Plot of the residuals $(J-K)_c$ — $(J-K)_o$ vs $(J-K)_c$

See text and Table-4 for details.

We used the same photometer on 4 nights in January 1987 at the 1-m reflector and observed a set of 8 standard stars chosen from the catalogue of Johnson et al. (1966), whose $(B-V)$ colours range from -0.08 to +1.84 to determine the transformation coefficients for our IR system. In Table 4, we give the list of these standard stars, their spectral classes and $(B-V)$ colours. A minimum of 3 observations on every standard star were obtained on each night. In Table 4 $(J-K)_c$ is the $(J-K)$ colour in the catalogue of Johnson et al. (1966), $(J-K)_o$ is the $(J-K)$ colour observed with the IIA infrared system and $(J-K)_c - (J-K)_o$ is the residual. Figure 7 is a plot of these residuals against their $(J-K)_c$ colours.

5. Discussion and Conclusion

The responsivity of the detector for the J, H and K bands agrees well for the two sources observed (Alpha Boo and Alpha Sco) and their magnitudes were derived using the zero magnitude radiance levels given by Thomas et al. (1973). The excess noise is due to a number of sources like sky noise, vibrations and electrical interference which we were not able to identify due to the limited time on the telescope. The plot of the residuals $(J-K)_c - (J-K)_o$ (Figure 7) shows that the transformation is linear for $(B-V)$ values greater than zero, although there is a possible presence of a colour term for $(B-V)$ values less than zero. Our future plans are to do extensive measurements with all bands and C.V.F., to determine the noise sources, measure beam profile, evaluate the stability of the system and its detection limits at various zenith angles. A *UBVRI* system is being developed so that concurrent measurements of astronomical sources could be done in the *UBVRI/JHKLM* bands.

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References

Blackwell, D.E., Legget, S.K., Petford, A.D., Mountain, C.M., and Selby, M.J., 1983, Monthly Notices Roy. Astron. Soc., **205**, 897.

Engels, D., Sherwood, W.A., Wamsteker, W., Schultz, G.V., 1981, Astron. Astrophys. Suppl. Ser., **45**, 5.

Gillett, F.C., Low, F.J., and Stein, W.A., 1968, Astrophys. J., **154**, 677.

Hayes, D.S., Latham, D.W., 1975, Astrophys. J., **197**, 593.

Honeycutt, R.K., Ramsey, L.W., Warren, Jr. W.H., and Ridgway, S.T., 1977, Astrophys. J., **215**, 584.

Johnson, H.L., 1965, Astrophys. J., **141**, 923.

Johnson, H.L., 1966, Ann. Rev. Astron. Astrophys., **4**, 193.

Johnson, H.L., and Mitchell, R.I., 1963, Astrophys. J., **138**, 302.

Johnson, H.L., Mitchell, R.I., Iriarte, B., Wisniewski, W.Z., 1966, Comm. Lunar and Planetary Lab., **4**, 99, University of Arizona.

Jones, T.J., and Hyland, A.R., 1982, Monthly Notices Roy. Astron. Soc., **200**, 509.

Koornneef, J., 1983(a), Astron. Astrophys., **128**, 84.

Koornneef, J., 1983(b), Astron. Astrophys. Suppl. Ser., **51**, 489.

Oke, J.B., and Schild, R.E., 1970, Astrophys. J., **161**, 1015.

Selby, M.J., Blackwell, D.E., Petford, A.D., and Shallis, M.J., 1980, Monthly Notices Roy. Astron. Soc., **193**, 111.

Selby, M.J., Mountain, C.M., Blackwell, D.E., Petford, A.D., and Leggett, S.K., 1983, Monthly Notices Roy. Astron. Soc., **203**, 795.

Thomas, J.A., Hyland, A.R., and Robinson, G., 1973, Monthly Notices Roy. Astron. Soc., **165**, 201.