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3.3 A GROUND BASED NEAR INFRA-RED DETECTOR SYSTEM

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Abstract

The problems connected with observations in the near infra-red from ground based locations are discussed. It is shown that optical telescopes located at high stations in India, can be used effectively for near infra-red observations in the dry seasons. A detector system developed for such studies is described.

In considering the feasibility of infrared observations from existing ground based facilities for optical work one comes across several factors needing careful attention. Unlike the narrow optical band, the wide infrared region has several deep absorption features due to atmospheric gases, and it becomes necessary to carefully choose the clear windows for such ground based observations. The properties of the reflecting surfaces and refracting materials normally employed in the optical systems change in the infrared region, and it becomes necessary to select materials with suitable reflection and transmission properties in this region. The thermal radiation from the telescope body and other background materials plays a prominent role as one advances deeper into this region. This when combined with the characteristics of the infrared detector elements, necessitates a radically different approach to the problem of signal processing, from those employed in optical work.

The problem of such observations assumes a big form as one probes deep into the infrared; but in the near infrared region, the optical facilities need only marginal adjustment for making a successful observational set up. The region between 1μ–5μ for example, has several clear windows, through which observations using ground based facilities are possible. Considering the importance of such observations in the background of recent advances of our knowledge in astrophysics, the attempts are amply justified.

Transmission through atmosphere:

The main constituents in the earth's atmosphere, viz. N_2 and O_2 do not hinder the flow of radiation in the near infrared, but certain minor constituents are not so transparent to these radiations. The main absorbers in these regions are H_2O and CO_2 The absorbing properties of these gases have been studied in detail (Yates and Taylor 1960). Figure 1 shows the absorption bands due to these gases in the near infrared. The absorption bands due to H_2O in these regions are around 1.1 μ, 1.4 μ

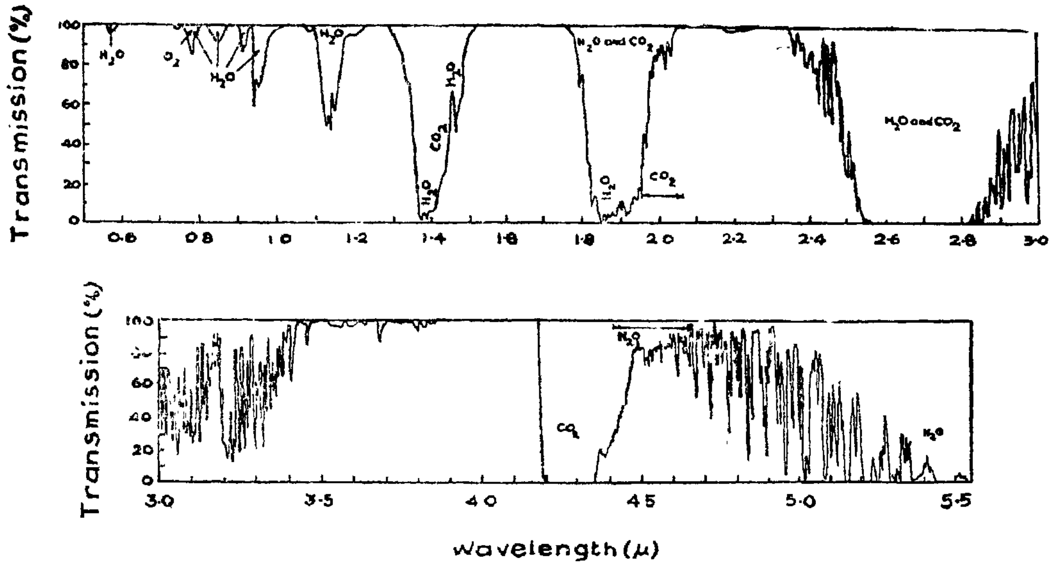

Fig 1: Absorption spectra of atmospheric gases in the near infra-red.

and 1.9 μ gradually becoming more and more prominent. At 2.7 μ we come across a combined absorption band of H_2O and CO_2, strongly absorbing almost completely upto 3.4 μ. A partially transmitting window exists between 3.5 μ to 4.2 μ, at which wavelength we come to a strong absorption band due to CO_2; another partially clear window exists between 4.5 μ to 5.0 μ followed by a totally absorbing band due to H_2O from 5.0 μ to 8.0μ.

The absorption features shown in the figure are somewhat idealised; they are true for short absorption paths only. For long absorption paths, there is also attenuation outside the absorption bands. Attenuations of infrared signals over long horizontal paths have been experimentally determined (Yates and Taylor) 1960 and they clearly indicate the need for selection of sites for infrared telescopes. As H_2O is the main absorbing agent in this region, and as the moisture content in our atmosphere is highly variable, dry places with low moisture content in the air are very desirable as telescope sites.

The main climatic feature of our country is the existence of clear wet and dry seasons. During the monsoon months June-September, almost the entire subcontinent is wrapped up in a wet blanket 2 kms. thick. Chances of successful infrared observations from any ground based station during this season are remote. Even the observations in the visible range are severely limited during these months due to cloudy skies.

During the remaining eight months there are distinct divisions of areas with wet and dry air. The north-western part has the lowest moisture content, the humidity progressively becoming more and more as one moves southward. At the extreme southern tip of the country, the annual range of variation in humidity is low; at sea level the humidity remains high in these parts even in the non-monsoon months.

The variation of humidity in the vertical direction is much more marked. In the lower layers of our atmosphere, the humidity falls steeply with height; distinct advantages are thus obtained by locating the infrared telescopes at high hill stations. Surface vapour pressure data are available for the past few decades for several hill stations (IMD Climatology Table, 1967).

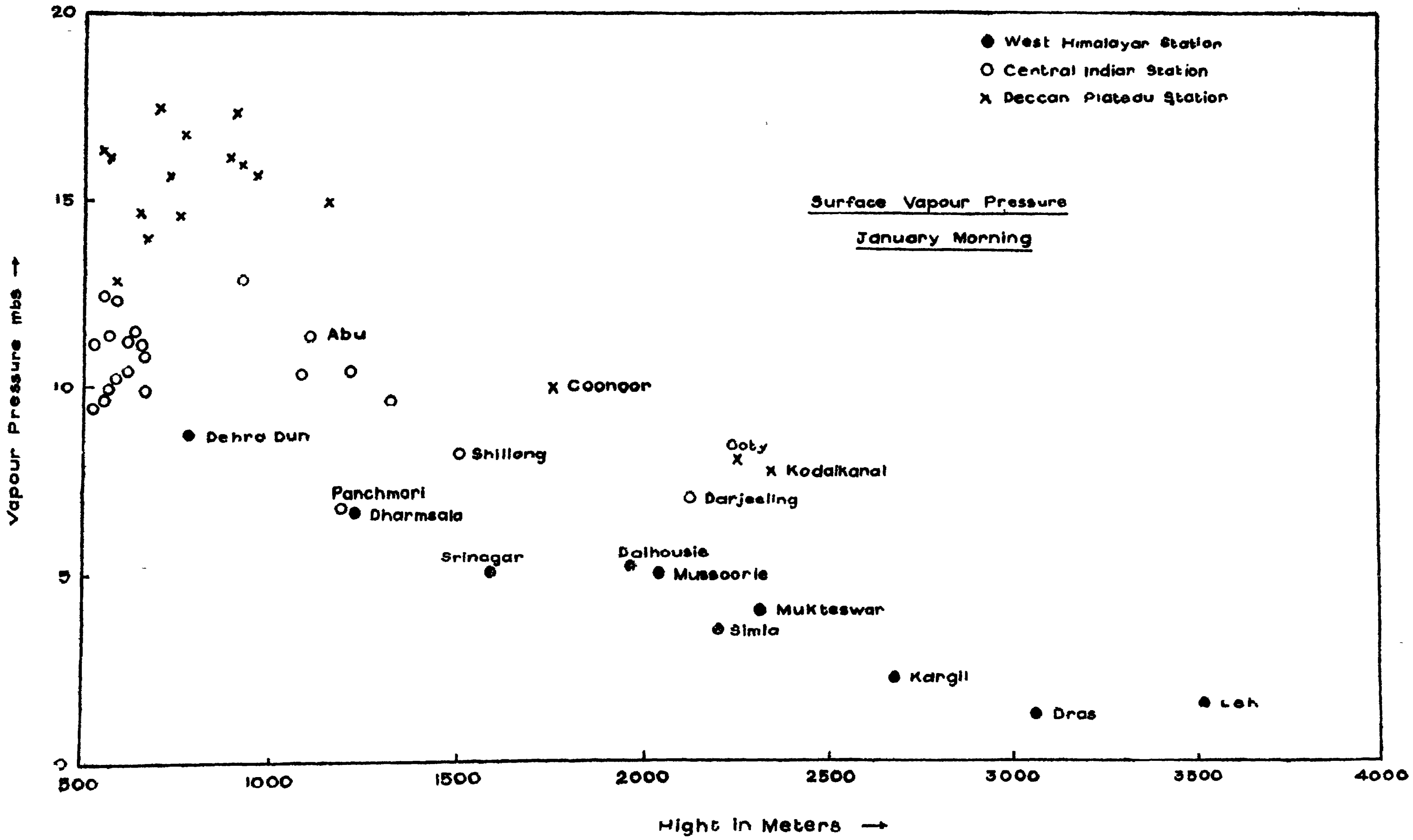

Fig 2: Vapour pressure at Indian Hill Stations.

Figure 2 shows a plot of mean vapour pressure on January mornings against height for a number of such hill stations, indicating the advantages of high stations located in dry regions, for siting of infrared observatories. Even stations like Ooty and Kodai kanal, because of their altitudes, can be used for observational work in the near infrared.

The apparent superiority of Kashmir and West Himalayan Stations, over other locations in the country, is largely offset by the fact that during the peak of this season, a series of western disturbances create extensive areas of high and low clouding, spoiling chances of good optical observations. And in the near infrared, where a tie-up with optical observations

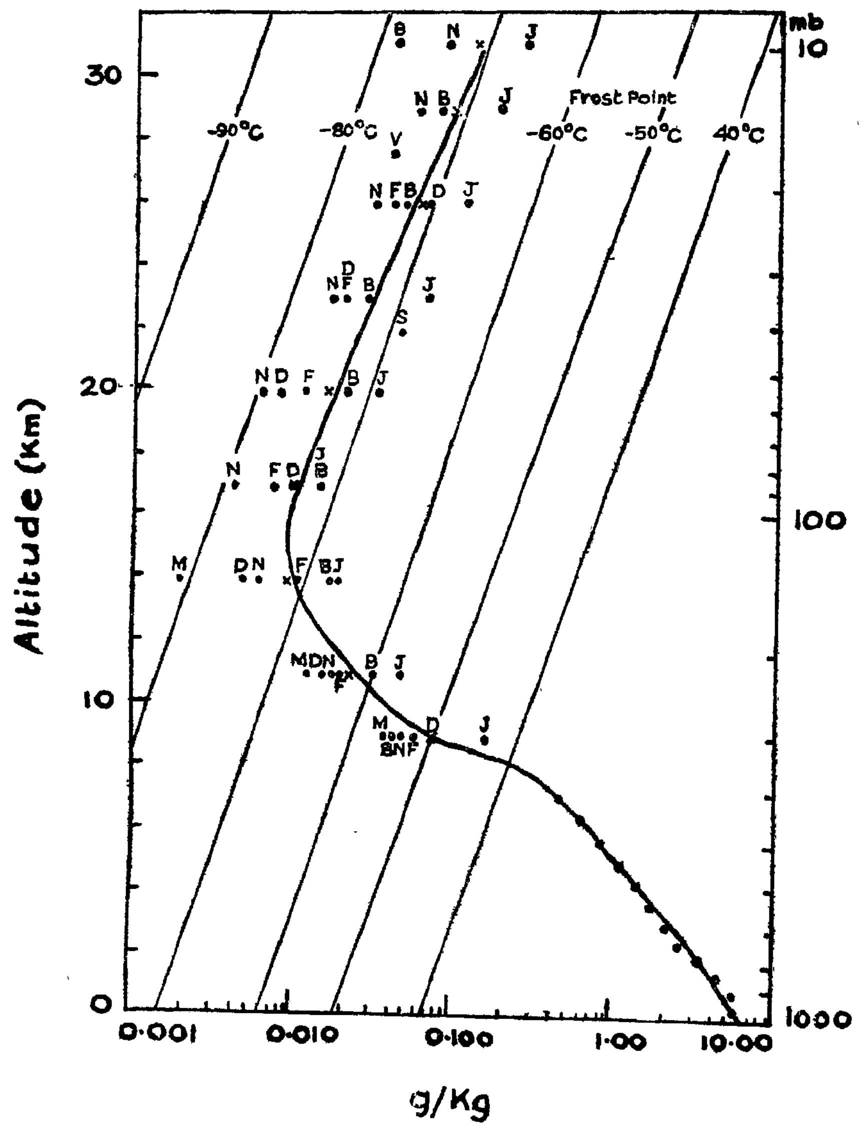

Fig 3: Variation of water vapour mixing ratio with height: N (U. S. Naval Research Lab. ascents), B (Ballistic Research Lab. ascents), F (University of Denver), J (Japanese ascents), M (British Meteorological Research Flight hydrometric ascents), V (U. K. Atomic Energy Authority ascents,), X (Mean of all symbols)

is highly desirable, this factor nullifies most of the advantages of this extremely dry location.

For infrared astronomical observations, information on the vertical extent of this atmospheric moisture is required for estimating the absorption during the passage of radiation. Extensive radiosonde observations are available for this area and they indicate that the steep fall in the moisture content continues upto the tropopause. This feature is global and no significant departure has been noticed over the whole country. A plot of a model atmosphere is shown in Figure 3 largely substantiated by actual observational results (Gutnick 1961).

The role of CO_2 in infrared astronomical observations is difficult to assess mainly because of paucity of data of its distribution. A few observations of the CO_2 in our atmosphere are available in the literature (Junge, 1958), and any choice of location of an infrared observing station based on its distribution has not yet been attempted. The general CO_2 concentration has been increasing over the past few decades and in any given place is believed to be highly correlated with the industrial development. However, new astronomical observing stations will be located preferably away from such centres and the problem, to some extent, is thus taken care of.

The scintillation and seeing fluctuations which impose severe restrictions on ground based optical observations also affect near infrared observations to a comparable degree. These fluctuations which decrease with increasing wavelength in the optical region appear to level off at the red end of the visible spectrum (Yates and Taylor 1960), and continue undiminished in the near infrared. Hopes of better seeing conditions in the near infrared are thus non-existent.

Working in the near infrared one does, however, get some advantage over optical observations due to the fact that the sky background is considerably reduced (Bell et-al). This is particularly true in the sunlit sky during daytime. Rayleigh scattering by the air molecules drops off steeply with increasing wavelengths, so that by the time one reaches the $3\ \mu$ region the scattered light intensity is ess than 10^{-3} of that in the visible region. Beyond this, however, the temperature radiation of the 300°K sky increases in intensity, reaching a peak around $10\ \mu$, and becomes more important than the weak scattered radiation at longer wavelengths. Around $3\ \mu$ it is, therefore, possible to carry out observations on infrared objects in broad daylight, thereby vastly increasing the observing time available on the infrared telescope.

Telescope behaviour in the near infrared:

In using an optical telescope for infrared work, one needs to make sure that the elements behave well in this spectral region. As almost all large telescopes are of the reflecting type, it is necessary that the coatings should have good reflecting properties in the infrared also. Two main coating materials used in optical reflecting surfaces are Ag and Al and both have excellent reflecting properties in the near infrared (Hass and Turner). Most reflecting telescopes thus behave excellently in these regions.

Where refracting optics are used, the situation is not so encouraging. Optical glasses normally transmit upto $2.7\ \mu$, beyond which wavelength they are opaque. Certain composition like calcium aluminate glasses do not cut-off until around $5.0\ \mu$, but beyond that only very special materials have transmission windows. Detailed reports about such materials are available in the literature and they have been used in optical elements for the infrared. Two materials of common use viz., plexiglass and polythene also have excellent transmitting properties in the infrared (Ballard et-al 1959).

Even in telescopes using all-reflecting optics, certain transmission elements are impossible to avoid in the accessories used for observational studies. In the case of a photometer, for example, use of a Fabry lens, or a window plate for cooled detectors may become essential. Proper choice of suitable materials must then be made to provide a transmission path with little absorption.

Detector System :

Common detecting elements used for astronomical observations in the visible region lose their sensitivity past the red end of the visible spectrum. The human eye fails to detect beyond 0.7 μ, and photographic emulsions hardly get affected beyond 1.1 μ, The S1 photo emissive surface starts losing sensivity from 0.9 μ, upwards and becomes dead at wavelengths beyond 1.1 μ, Past this limit, no satisfactory photo-emissive surfaces have been realised, and no high gain multiplier tubes using secondary electron multiplication exist. A different type of radiation transducer has to be used beyond these limits to change the incoming radiant power into some other form of signal where electronic amplification and detection are possible. Two main groups of detectors falling in this category are (i) thermal detectors, consisting of sensitive elements which are responsive to changes in temperature brought about by incident radiation and ii) photodetectors, where absorption of incident photons directly changes some characteristic of the responsive elements. Photoemissive surfaces described above fall in this category, but are almost ineffective over the entire range of infrared.

Thermal detectors employing thermistors, thermocouples or Golay cells are mainly used in the longer wavelength regions of the infrared spectrum, where incident photons have very low energy. Photodetectors are preferred in the near infrared for their intrinsic higher sensitivities and easier operating requirements. Besides photo-emissive surfaces, three other major classes are also used (i) Photo-voltaic, where changes in photon flux incident on a p-n junction cause fluctuations in the voltage generated at the junction; common materials used for these cells are GaAs, InSb, In As or Cu-Cu_2O (ii) Photo-conductive, where absorption of photons causes a change in the carrier concentration resulting in a change of conductivity; common materials used in this type of cells are Pb S, Pb Se, Pb Te etc., or Si, Te or Ge doped with Au, Cu, Hg etc. (iii) Photoelectromagnetic, where the carriers generated as a result of photon absorption are separated by an external magnetic field as they diffuse into the bulk from the surface, thereby creating a small signal voltage. Common materials used for this type of detector are InSb and HgTe.

In all these types of detectors, one gets an electrical signal which is a function of the incident radiation flux and which is then amplified by external circuitry. The lowest limit to which detection is possible is, of course, set by the various types of noise generated in the detector, and depends mainly on the detector characteristics and its temperature. The various types of noise, although having characteristic spectral shapes, are basically broad band. As the main detector noise is of the 1/f type, a positive S/N ratio advantage can be obtained by employing intensity modulation at a frequency as high as possible. The higher limit of modulation frequency is, however, dictated by the response time-constant of the detector.

The sensitivity of these detectors is, therefore, measured in terms of the inherent noise in the detector; the noise equivalent power (NEP) is defined as that power of incoming radiation which when incident on the detector generates a signal equal to the detector noise. The NEP or its reciprocal, detectivity (D) are both dependent on detector area, modulating frequency, band width of the amplifier system, the wavelength of the incident radiation and the temperature of the detector. As the various detectors manufactured by different firms are not of standard sizes, and as the amplifier system characteristics employed by different observers are different, intercomparison of the various detector materials becomes difficult. For this purpose, a normalised parameter D* (D-star) is introduced which takes into account the area of the detector element and the bandwith of the amplifier system. The D* characteristics over the usable spectral range are normally shown in the form of curves, and are brought out by the respective manufacturers. A good collection of these characteristics may be seen in hand-books on infrared techniques (Limperis 1965).

It is generally true that detector performance improves considerably on cooling the detector element, with dry ice, or still better with liquid air. This calls for an arrangement in which the coolant does not come in the way of normal operation of the detector. A common arrangement is to provide a dewar flask attached to the back of the detector containing the necessary coolant like dry ice or liquid air which cools the detector by contact. Several commercial detectors e.g. ektron, (by Eastman Kodak) have such an arrangement. The electrical signal is taken out through long leads sealed through the glass, and the dewar vacuum prevents heat loss from the transparent window, which would otherwise fog. The limitation of this arrangement is usually the small capacity of the dewar, which, however, can be overcome by connecting it with an external dewar of larger capacity.

Modulating the incoming radiation is normally achieved by employing a chopper disc rotated by a synchronous motor. For astronomical work, two sets of slots are usually cut on the chopper disc so that the detector sees the object plus sky or only sky in alternate half cycles. The amplitude of the modulated signal from sources small compared to the diaphragm thus becomes proportional to their flux only, the sky contribution being differenced out in the output.

The electronics for amplifying the signal is generally straightforward. A preamplifying device is usually necessary for the purpose of matching the detector to the main amplifier. From input noise considerations, the preamplifier must be of a low noise variety; FET's with a low resistive load used as signal followers give satisfactory performance. A high gain selective amplifier with a narrow pass band centred around the modulating frequency is used for amplifying the weak signals. For astronomical observations a voltage gain of 10^7 - 10^8 is needed which may be obtained by a carefully planned amplifier employing several stages of selective and broadband amplification. The detection of the amplified signal is invariably achieved by synchronous detectors, of which several forms employing mechanical or solid state choppers are common.

A near infra-red system :

The near infrared detector system developed by the Indian Institute of Astrophysics team follows generally the above pattern. The system is meant for use mainly with the 50cm reflector at Kodaikanal and also with the 1 meter telescope at Kavalur during favourable periods. A few field trials have already been conducted on this system with the 60cm long focus planetary telescope at Kavalur with encouraging results.

The schematic arrangement of the system is shown in Figure 4. The attachment has been designed for use at the cassegrain focus of the telescope, and the detector head has been made light and portable. The first part is a photometer of conventional design; the filter drum contains Bausch and Lomb interference filters centred round 1.5 μ, 2.0 μ, 2.5 μ, and 3.5 μ. The second part, which is attached to this photometer by four fly nuts consists of a Bulova L8-C light chopper, the detector cell with a Fabry lens and a preamplifier. The chopper consists of two blackened blades mounted on the two prongs of a tuning fork and is operated by a built-in Oscillator powered by dry

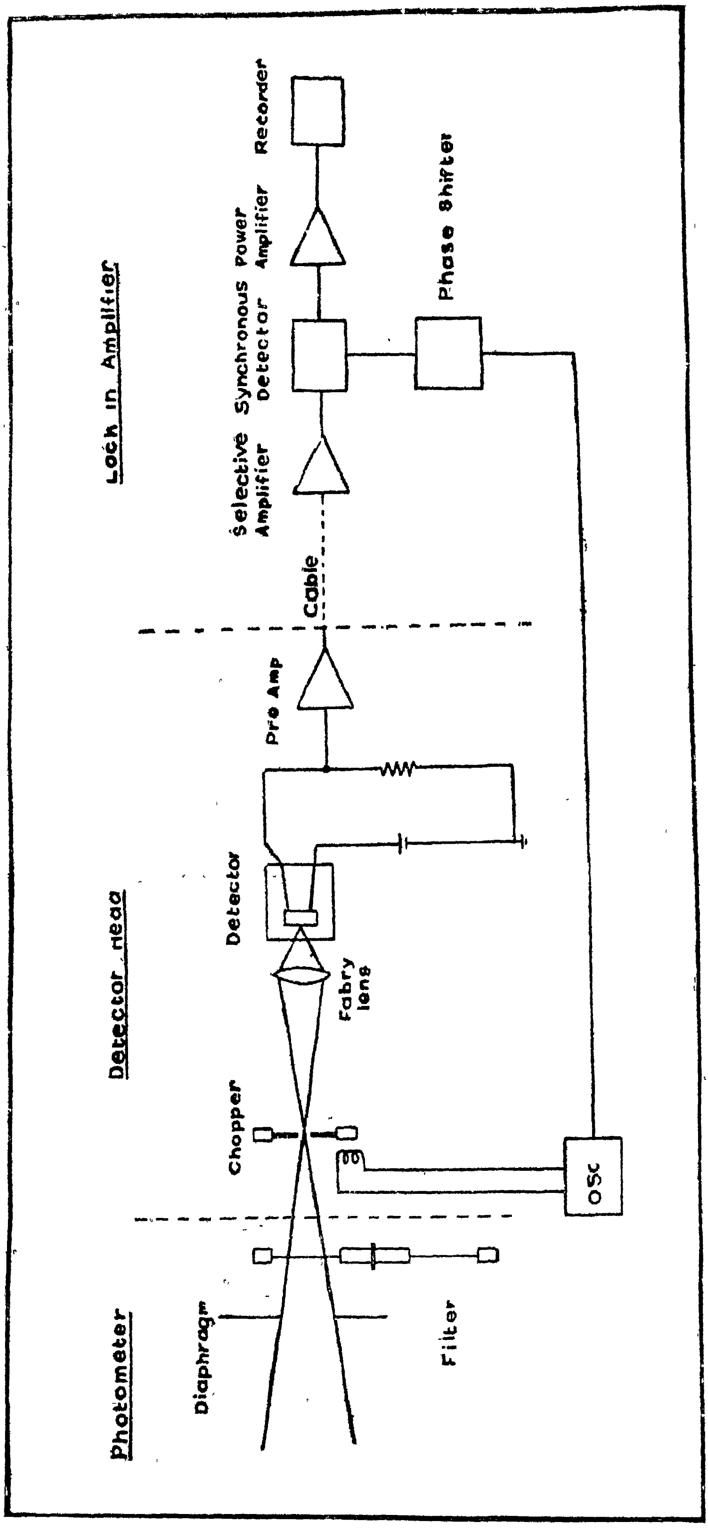

Fig 4 : Schematic arrangement of IIA Near infra-red detector system.

batteries. The nominal oscillator frequency is 400 Hz; the reference signal for the synchronous detector is also taken from this unit. Two alternative detectors are available for this unit; one is a PbS cell, marketed by Messrs. Carl Zeiss, and the other is an Ektron E-6 Pb Se cell manufactured by Messrs. Eastman Kodak, with a built in dewar for cooling the detector. The output from the cell is amplified by a FET preamp, specially designed for the unit, which also transforms the signal impedance of the unit to a low value for coupling with a long shielded cable from the cassegrain end of the telescope to the amplifier rack. The latter unit provides the bulk of the amplification; the amplifier chain is specially designed for this purpose with two selective and three broadband stages giving a total voltage gain of 10^7. The synchronous detector employs a diode bridge, and the output is fed to a time constant circuit. The post amplifier presently used is a D.C. electrometer amplifier, Keithley 610C, which drives a Honeywell potentiometric recorder.

The present system chops the beam from the telescope, but does not compare and substract the sky brightness as is usual. With this system, it is necessary to take several sets of readings moving the object in and out of the diaphragm and to compute the brightness of the object from the recorded data. In a new model, presently under design, a light weight optical scanner will rapidly shift the beam between the object and the adjacent sky and thus automatically perform the subtraction.

The PbS cell of the existing equipment is operated at room temperature with consequent spectral sensitivity limitations. The Ektron cell has been cooled with only dry ice so far; arrangements for providing an external high capacity dewar flask for operation with liquid air are in progress.

In the trials so far performed with the equipment, deflections were obtained from a few bright infrared objects. It is hoped that regular infrared observations will commence this winter at both Kodaikanal and Kavalur.

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Discussion

V. Radhakrishnan : Why is there an optimum chopping frequency?

J. C. Bhattacharya : The detectivity of NEP is dependent on the spectral shape of the noise curve, which is dominated by the 1/f noise. The response of the detectors has similar profile, but not identical. This may perhaps explain why we get a maximum detectivity over certain bands of chopping frequency.