Infrared Instrumentation at ESO

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Introduction

The ESO infrared photometer/spectrophotometer, which was first made available at the 3.6-m telescope towards the end of 1980, has considerably expanded the scope for infrared observations on La Silla and has already led to an enlargement of ESO's active infrared community. Improvements made recently in this system plus the fact that a similar one is to be installed on the 1-m telescope later this year makes it timely to review the status and some of the uses being made of this instrument. In addition, this is a convenient opportunity to report on the progress of the F/35 wobbling secondary and the cooled array spectrometer, both of which will increase further the infrared observing possibilities at the 3.6-m in the future. Before discussing these developments specifically, however, I thought I would begin with a brief introduction to the fundamental considerations which affect infrared instrumentation design and to some of the terminology, which I hope will prove useful to readers who are unfamiliar with this subject.

Basic Considerations and Jargon

The ground-based infrared astronomer faces an analogous situation to that which would be experienced by an optical observer, maliciously scheduled during daytime, in that both the sky and his telescope are perpetually bright in the wavelength region he is trying to observe. This problem is particularly acute in the 3–20 μm region, i.e. around the wavelength of peak emission for room temperature objects, where the background may be orders of magnitude larger than the signal from the astronomical object of interest. Two fundamental aims underlying most infrared system designs therefore are to first minimize the amount of background radiation (and hence also its associated photon shot noise) reaching the detector and then to ensure that the astronomical signal can be discriminated against the background which remains. Under most conditions, the latter requirement can be satisfied by employing an observing technique which combines *sky chopping* and *beam switching* or *nodding*. Chopping involves rotating or oscillating a suitable optical element in the system such that the detector alternately views two areas of sky through the same, cold, defining diaphragm. These are separated by the *chopping amplitude* which, ideally, should be chosen just large enough to avoid overlap of the two beams although larger values may be necessary when observing extended sources. Clearly, if an astronomical object is present in one of the beams it will generate an AC signal at the chopping frequency, typically 10–20 Hz, which can be phase-sensitively detected, digitized, etc. Unfortunately, the fact that the two beams follow slightly different optical paths through the telescope means that the actual signal in practice normally contains an additional component, the *chopping offset*, because the radiation background is not exactly equal in the two beams. Whereas this signal however is independent of the telescope position, at least for small angular movements, the phase of the source signal can be shifted by 180° by moving the object into the other beam. It is possible to cancel the offset therefore by slowly nodding the telescope by an amount equal to the chopping amplitude, thus generating pairs of signals whose difference is simply equal to twice the source signal obtained in a single beam. Providing that the instrumental chopping offset is stable, this technique is extremely effective on a clear sky. The presence of clouds, on the other hand, even thin cirrus which may not be evident to the naked eye, adds an additional non-uniform and varying component of emission which can lead to a sufficiently large increase in the effective system noise to send the infrared observer to bed long before many optical astronomers would give up.

Even on a clear sky, the dominant noise at wavelengths longer than 2 μm is generally the statistical shot noise associated with the background, mentioned already. In order to minimize this, careful design of the instrument cold optics plus efforts aimed at reducing the effective telescope emissivity (such as increasing the focal ratio) are necessary. For point source observations at least, however, the limiting performance ultimately depends on the size of the smallest useable diaphragm which in turn is limited by the seeing and/or the accuracy with which the source can be centred and tracked. In general, therefore, infrared observations tend to be even more at the mercy of both the sky conditions and the telescope control system than those in the visible.

3.6-m IR Photometer/Spectrophotometer

Description. This instrument is intended mainly for conventional photometry, circular variable filter (CVF) spectrophotometry and mapping through diaphragms in the range 3–10″. As anticipated in the design, however, it is also suitable for speckle observations, as described already by C. Perrier in *The Messenger* No. 25 (1981), and has also been used in a slightly non-standard way to observe a stellar occultation by the rings of Uranus (Bouchet, Perrier, Lecacheux and Sicardy, *The Messenger* No. 26, 1981).

Two detector units, one containing a solid N_2 (~ 50 K) cooled InSb detector used in the 1–5 μm region and the other a bolometer, cooled to ≃ 1 K by pumping on liquid He, provide coverage of all the atmospheric windows out to 25 μm. Together, these detectors are equipped with some 14 broad and intermediate width interference filters plus 4 CVF's which cover the 1.5–5.5 μm and 8–14 μm regions at a resolving

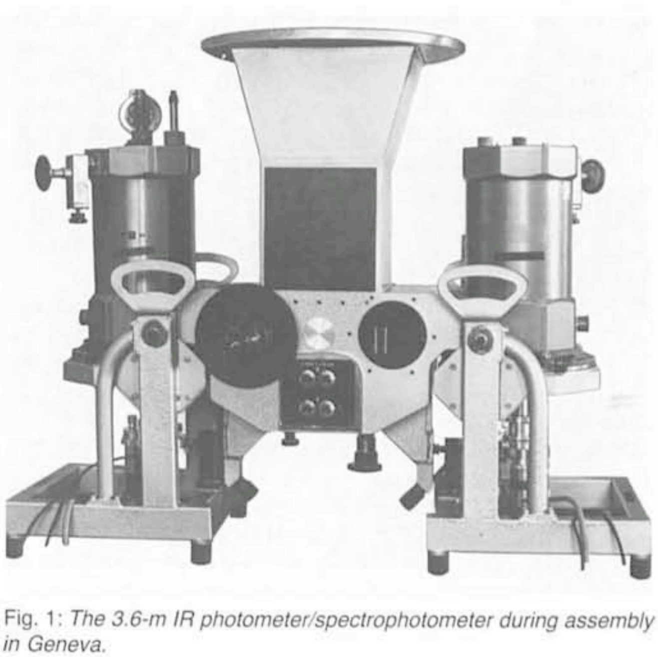

Fig. 1: *The 3.6-m IR photometer/spectrophotometer during assembly in Geneva.*

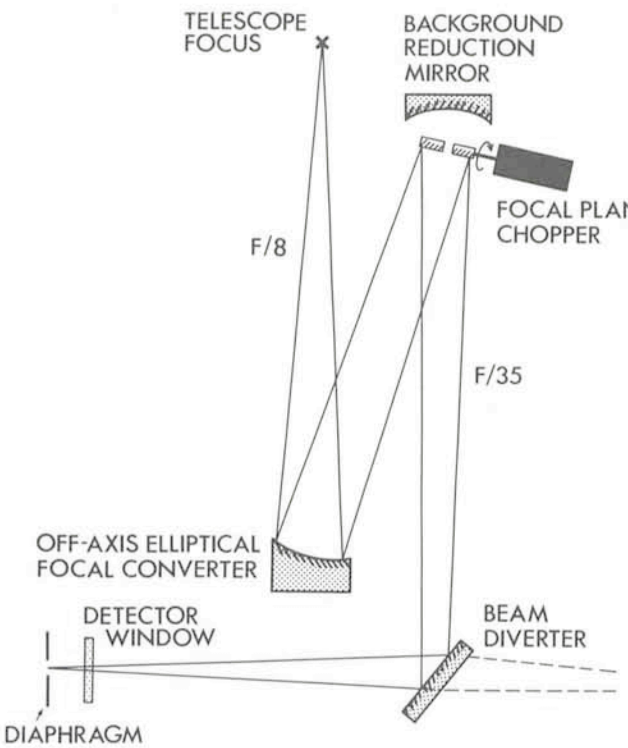

Fig. 2: *Optical schematic of the F/8 mount shown in Fig. 1. In reality the detector beams are perpendicular to the plane of the figure but have been rotated here for clarity.*

power of ≃ 70. (The latter are also multilayer interference filters but deposited on a circular substrate in such a way that the thickness of the layers and hence the transmitted wavelength is a function of angular position along the filter.) Fig. 1 is a photograph of the instrument taken during its assembly in Geneva. Both of the detectors are in fact designed to be used directly at F/35 once the wobbling secondary becomes available at the 3.6-m. In the meantime they are used on the photometer mount shown which contains optics (Fig. 2) to convert the F/8 telescope beam to F/35, provide sky chopping by means of a small wobbling mirror at an intermediate pupil image and reduce the emissivity of the central obscuration. The two cold photometer units are virtually identical. One of them can be seen in Fig. 3 and its optical layout is shown schematically in Fig. 4. The relatively complex off-axis optical arrangement was dictated by space limitations and the need to re-image the pupil at the filter wheel position in order to avoid a dependence of CVF resolution on the diaphragm size.

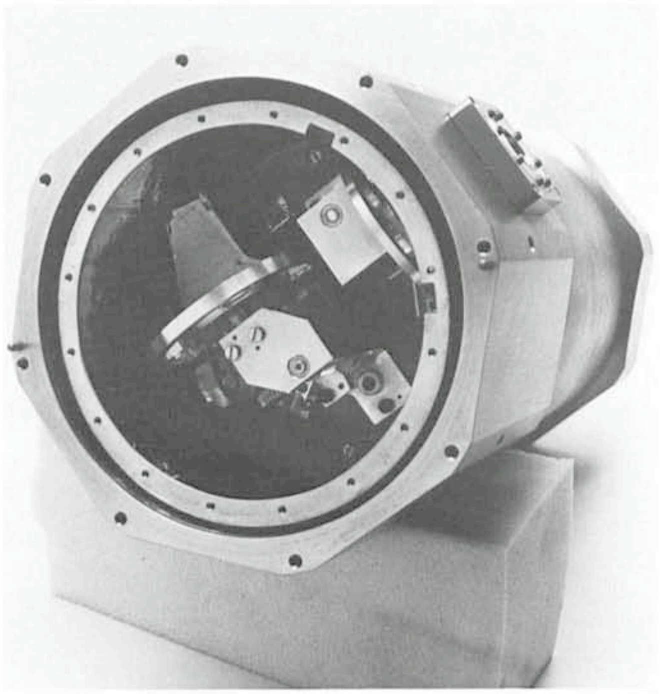

Fig. 3: *One of the detector units with its bottom cryostat cover and radiation shields removed to show the internal construction of the photometer assembly.*

Except for the beam diverter mirror used, to select the required detector, and the chopper controls, which at present have to be operated manually in the Cassegrain cage, all the instrument functions are controlled via the instrument computer from the control room. The HP *soft key* feature is utilized for selecting the observing mode and various software routines exist for automatic filter sequencing, CVF spectrophotometry and mapping and for computing on-line magnitudes and errors, displaying CVF spectra, etc. The instrument computer also communicates with the telescope computer, thus allowing automatic control of the telescope beam switching and coordinate printouts. Data are output on the line printer and magnetic tape and the CVF and mapping data will, in the future, be produced in FITS format to facilitate off-line reduction.

Performance. Apart from the usual teething problems and a few irritations such as vacuum leaks, common to IR systems, no fundamental problems have been discovered with the instrument concept. The F/8 chopper in particular, which was introduced into the system at a relatively late stage and has a somewhat unconventional design, has exceeded expectations in that it can be operated stably up to amplitudes in excess of 1.5′—large for a focal plane chopper on a telescope of this size. Less satisfactory initially were the detector beam profiles which suffer from the off-axis optics described above. This situation has been transformed however with the provision of new detector units, an InSb with a corrector lens and a set containing specially designed off-axis mirrors, which have now replaced those originally installed. Recent observations with InSb 2 gave reproduceable signals at the 1–2 % (p-p) level over three nights. Improved sensitivities (s/n = 1, T = 15 min) of J (1.2 μm) = H (1.65) = 19 mag, K (2.2) = 18 mag, L (3.6) = 13.5 mag (7″.5 dia) and N (10) = 8 mag (7″.5) have also been

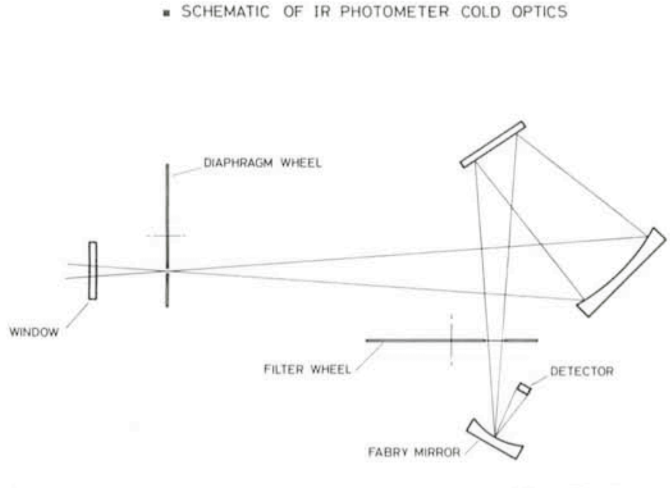

Fig. 4: *Optical layout of the cooled photometer assemblies. The beam folding and off-axis optics are dictated by space limitations and the need to re-image the pupil at the filter wheel position to avoid a dependence of CVF resolution on diaphragm size.*

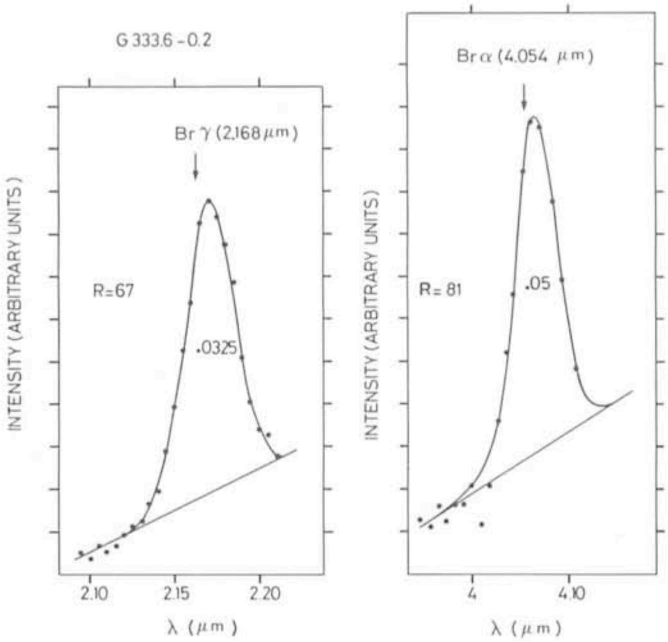

Fig. 5: *CVF scans of the Brγ and Brα hydrogen recombination lines on the H II region G333.6-0.2 made at the full position encoder resolution. The wavelength scale, derived from the laboratory calibration, is correct within about 1 step or 25 % of the filter resolution.*

obtained. Further work on the InSb preamplifier is expected to yield an extra magnitude at J and H while the the F/35 system should result in a gain of ~ 0.5 mag in the longer wavelength, background limited bands.

A large variety of photometric programmes are already in progress ranging from the study of truly infrared dust embedded objects to a wide range of extragalactic sources which are now accessible at the 3.6-m. An idea of the detectability of extragalactic objects can be given by noting that a normal elliptical galaxy at zero redshift has colour indices V-H ≃ V-K ≃ 3. At larger redshifts, near-infrared observations at a given V magnitude become increasingly more favourable due to the fact that the cosmological K corrections are negative. At $z = 1$ for example, V-H ~ 5 and the detection limits quoted above consequently begin to approach those in the visible.

The background limit at longer wavelengths restricts observations to the brightest normal galaxies but still permits many studies of galaxies exhibiting infrared excesses associated with non-thermal activity or star formation which tend to have V-N = 7–10 mag. CVF spectrophotometry is ideally suited to observations of solid state emission and absorption features. It can additionally however provide useful information on molecular absorption bands (e.g. CO and H_2O in late-type stars) and even emission-line intensities (e.g. H and He recombination lines, H_2). The actual-profile obtained with this type of filter can be seen in the oversampled test scans (Fig. 5) made of the Brγ and Brα H recombination lines on the H II region G333.6–0.2. Extragalactic applications so far at the 3.6-m have included the measurement of redshifted Pα in quasars (Fricke and Kollatschny, *The Messenger* No. 25, 1981) and observations of active galaxy nuclei. Fig. 6 shows a recent spectrum, obtained by the author, of the nucleus of the Seyfert 2 galaxy NGC 7582. In addition to possible molecular bands and the presence of the unidentified 3.3 μm emission feature, believed to be associated with dust, this spectrum reveals a rather different underlying continuum to that expected on the basis of the broad-band photometry.

While further improvements in performance can be expected in the future, I hope that the figures and examples quoted above serve to demonstrate that this instrument is already proving itself to be a useful additon to the 3.6-m instrument zoo.

F/35 Wobbling Secondary

Although sometimes erratically, due to the pressure of other projects, moving country, etc., this system is progressing and passed a critical phase last year when a successfull top ring exchange test was made on La Silla. Users of the 3.6-m will probably have seen the actual infrared top ring and will now appreciate the foresight which went into planning the size of the dome! The wobbling unit itself exists and has wobbled both in Garching and during the test on La Silla. Still remaining however is the construction of a new photometer mount which will have to accommodate an F/35 TV acquisition and guiding system to replace the functions presently provided for in the Cassegrain adaptor at F/8. When completed, hopefully in 1983, the F/35 system will reduce the diameter of the telescope central obscuration from about 1.6 m to 0.7 m and, with the exception of wobbling the primary mirror, provide the optimum method for sky chopping.

ESO 1-m Telescope

This telescope has already been used successfully for many years with the InSb and bolometer infrared photometers developed in Bonn and Groningen respectively. In order mainly to increase its flexibility and achieve better compatibility with the 3.6-m, however, it is now planned in June this year, following the installation of a new RTE computer system, to test the new ESO system which employs identical detector units to those at the 3.6-m and a similar although somewhat more complex photometer mount. One reason for the latter is the inclusion of an offset guiding eyepiece which can be used with either detector. The CVF mode will be new at the 1-m as will the possibility of using different diaphragms and chopper throws

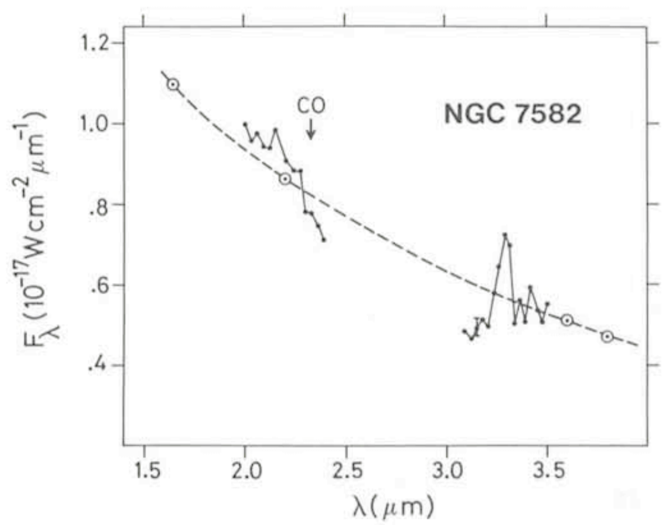

Fig. 6: *CVF spectra from 2 to 2.4 μm and 3.1 to 3.5 μm plus H, K, L, L' photometry of the Seyfert 2 galaxy NGC 7582 obtained by the author with the 3.6-m. Internal accuracy around 2 μm is roughly equal to the size of the plotted points. The structure is attributed to molecular bands associated with the stellar population plus some small residual atmospheric effects. The 3.3 μm feature, unidentified but circumstantially associated with dust, is extremely strong and the true underlying continuum clearly departs from a smooth curve drawn through the photometric points.*

with the InSb detector. For many programmes on extended sources the larger diaphragms (≤ 30″) and chopping amplitudes (≤ 4′) will compensate to some extent for the smaller telescope aperture compared with the 3.6-m and in some cases may even make this telescope more attractive.

IRSPEC (Infrared Spectrometer)

This is a cooled array spectrometer which is being developed for the 3.6-m telescope where it should provide for observations in the 1–5 μm region at a resolving power of ≃ 3000 through an input slot of up to 3 × 7″. The mechanical construction is now in progress and most of the critical assemblies should be delivered within the next 2–3 months. Final completion will depend largely on when we actually receive the 52-element InSb array being produced specially for this instrument and on the difficulties encountered in developing its associated electronics. A more detailed account of this instrument therefore will be reserved for a future *Messenger.*

Acknowledgements

Without wishing to offend the many other ESO staff involved with the projects described here, I feel that special mention should be made of P. Salinari who was responsible for most of the IR photometer design before escaping to Florence, A. van Dijsseldonk who alternately builds and repairs detector units with great enthusiasm in Garching and, on La Silla, D. Hofstadt, F. Gutierrez, J. Roucher plus J. Koornneef and C. Perrier who face the unenviable task of demonstrating to visiting astronomers what has been written here.

ANNOUNCEMENT OF AN ESO WORKSHOP ON

"GROUND-BASED OBSERVATIONS OF HALLEY'S COMET"

to be held in PARIS, 29–30 APRIL 1982

With the aim of stimulating and planning ground-based observations of Halley's comet during its next apparition in 1985–1986, ESO is organizing a workshop entitled "Ground-based Observations of Halley's Comet".

This workshop will take place at the Institut d'Astrophysique de Paris on 29–30 April 1982. It will include both review papers and short contributions with ample time for discussion.

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Mass Determination of Massive X-ray Binaries

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Introduction

Massive X-ray binaries consist of a normal component of spectral type O or B which is transferring matter to a compact companion, generally a neutron star, with possibly one exception, Cyg X-1, where the compact component could be a black hole. These compact stars have enormous magnetic fields (of the order of 10^{12} gauss), and extremely large gravities; accreted matter will be accelerated to velocities of half the light velocity, and guided by the field lines to restricted areas near the magnetic poles, the hot spots. These regions acquire in this way temperatures of the order of 10^7 K, and X-rays are generated. The X-rays are transported outwards as beams, and since the compact objects rotate rapidly, X-rays are observed as pulse-shaped beams.

In order to enable a good physical description of compact objects and to derive an equation of state, their masses have to be determined as accurately as possible.

Mass ratios for binary systems can be derived from the radial velocity curves of the two components. In the case of a double-lined spectroscopic binary this is possible from measurements of the amplitude of these variations. For X-ray binaries the optical spectrum of the non compact component leads to the radial velocity curve of this component; from the Doppler delay of the arrival time of the X-ray pulse the radial velocity curve of the compact companion can be derived. Hence when the compact star is a pulsar the system can be treated exactly as a double-lined spectroscopic binary.

Massive X-ray Binaries

A list of massive X-ray binaries with their characteristics is given in Table 1. The table shows the names, spectral types, magnitudes, orbital periods in days, eventual pulse periods in seconds, the optical luminosity and the distance in kpc. As can be seen from the table the best suited candidates for the determination of physical parameters are Vela X-1 (4U 0900-40), 4U 1700-37, SMC X-1, LMC X-4, Cen X-3, Wra 977, 1538-52 and Cyg X-1, since they have short periods and are not too faint. Vela X-1, SMC X-1, Cen X-3, Wra 977 and 1538-52 are pulsars so that in principle the two radial velocity curves can be derived.

The best suited one is Vela X-1, since its magnitude of $6^{m}_{.}9$ offers the possibility to acquire high-resolution coudé spectrograms, and moreover it is a pulsar (already discussed by Mauder in *The Messenger* No. 24).

The Case of Vela X-1

Some hundred blue plates were taken by the Amsterdam-Brussels group (Astrophysical Institute, Brussels; Royal Belgian Observatory; Astronomical Institute, Amsterdam) with the 152-cm spectrographic telescope of ESO with reciprocal dispersions of 12 and 20 Å/mm in the wavelength range 3700-4900 Å. The plates were collected between April 1973 and May 1976. From the line positions, heliocentric radial velocities were derived (Van Paradijs et al. 1976, *Nature,* **259,** 547). In