IRSPEC: ESO's New Infrared Spectrometer

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Introduction

IRSPEC is a cryogenically cooled grating spectrometer equipped with an array detector for spectroscopy at R = 1,000–2,500 between 1 μm and 5 μm. It was successfully installed at the 3.6-m telescope in November 1985, underwent further testing in February 1986 and will be available for Visiting Astronomers from October 1986 as announced in the *Messenger* No. 42 and in the Announcement for Applications in Period 38. In this article we describe the instrument, discuss its performance with reference to some of the test spectra obtained and comment on its possible evolution.

Instrument Concept

The main characteristics of IRSPEC are summarized in Table 1. In order to meet our requirements for a large collimated beam diameter, high optical and mechanical quality and flexibility in the future choice of detector arrays, the overall concept departs substantially from the usual approach of designing infrared instruments to fit within the cold space in commercially available storage cryostats. Instead, the spectrometer design is rather classical except that all the optical components are cooled to ~80 K by a continuous flow liquid N_2 system and the detector to ≈50 K by solid N_2 contained in a separate cryostat inside the vacuum vessel. Figure 1 is a photograph of the instrument with the upper parts of the vacuum vessel and radiation shield removed. Various design aspects are described in more detail in the following sections.

Optical Design

The optical arrangement is shown schematically in Figure 2. As IRSPEC was designed for use at the 3.6-m F/8 Cassegrain focus (before implementation of the F/35 chopping secondary) and eventually at one of the F/11 Nasmyth foci of the 3.5-m NTT, it was necessary to incorporate the input opti-

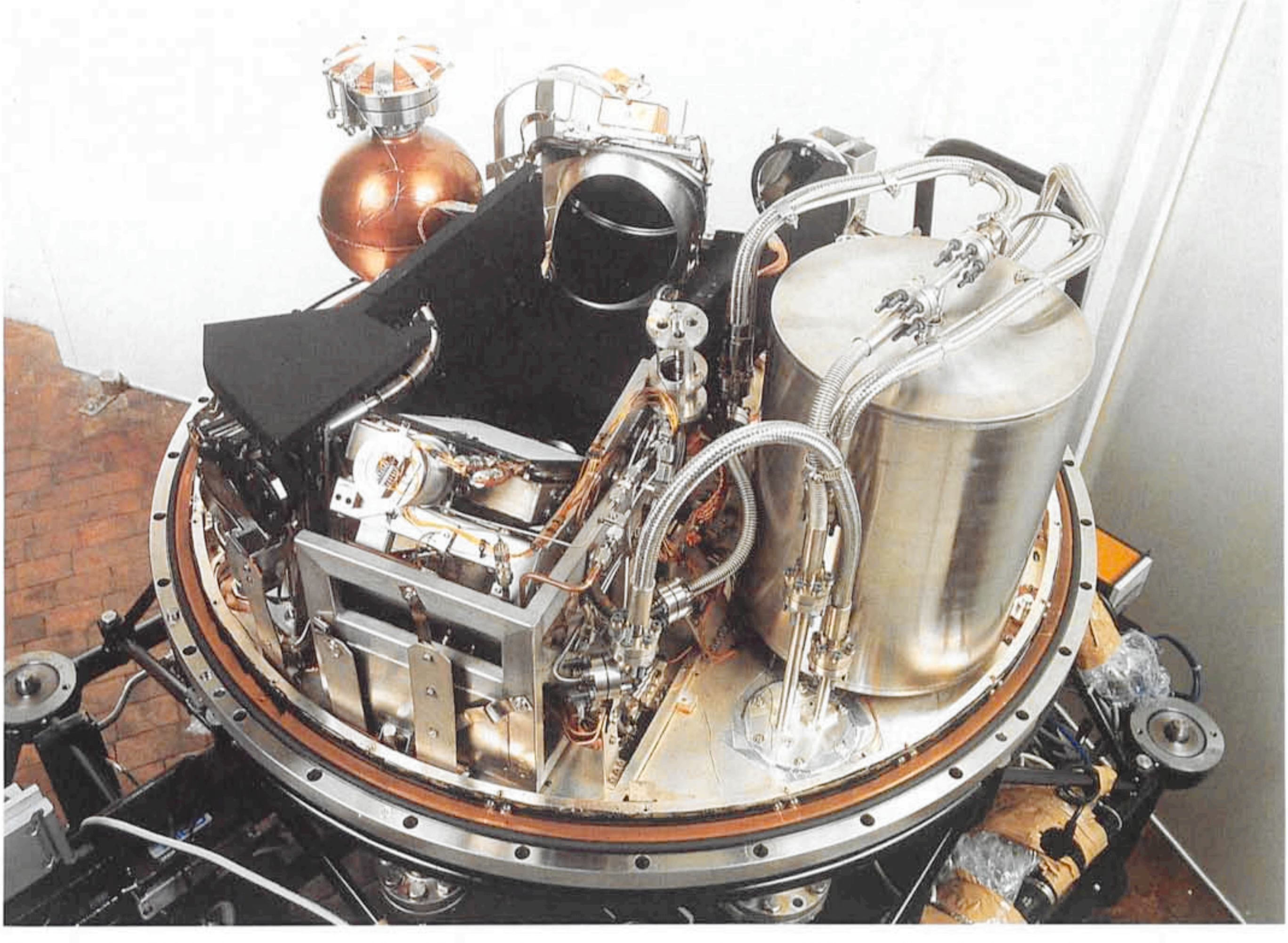

Figure 1: *IRSPEC with the upper parts of its radiation shield and vacuum vessel removed. The spectrometer is cooled by a continuous flow of liquid N_2 supplied either by the internal reservoir on the right or from an external tank while the detector array is cooled by solid N_2 contained in the copper cryostat (upper left).*

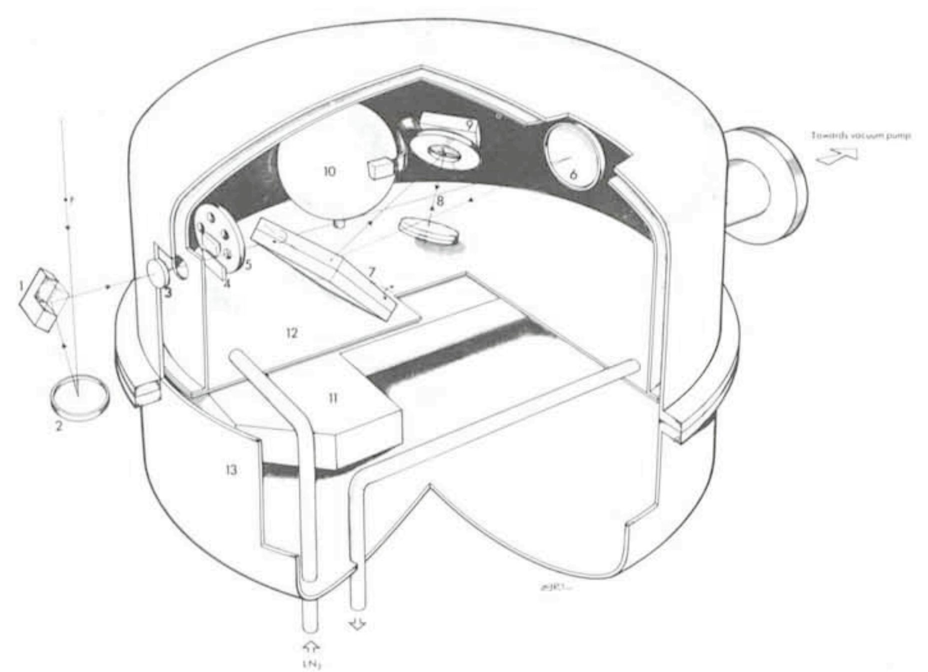

Figure 2: *Schematic of the optical arrangement.*

cal system comprising a spherical relay mirror (2 in Fig. 2) and a cylindrical mirror (1), on which the telescope pupil is imaged by 2 and which can be "wobbled" to provide for sky chopping. The slit unit (4) consists of a classical moving blade system plus a decker which can be scanned along the slit to define the projected detector size and position once the instrument is cold. Both the slit and decker blades are highly polished and slightly tilted to permit viewing of the field by a TV camera which is not shown in Figure 2. Behind the slit is the 8 position order sorting filter wheel (5) and just in front, a field lens which images the telescope pupil on a cold baffle at the off-axis (9°) parabolic collimator mirror (6). This latter has a focal length of 740 mm, accepts an F/7.4 beam from the field lens and directs a 100 mm diameter parallel beam to the two interchangeable gratings (120 × 150 mm ruled) which are mounted back to back (7) and operated in the Littrow Mode to maximize their efficiency and dispersion. Finally, an F/2 Pfund type camera (8) focusses the spectrum on the detector array (9).

As described below, the spectrometer is mounted on an uncooled optical bench to avoid misalignment during cooling. It is aligned interferometrically when warm, and after cooldown it is only necessary to optimize the spectrometer focus (using a three position Hartmann mask in front of the collimator) and the decker position. For calibration purposes, the slit can be illuminated by either of two spectral line lamps (Ne and Kr) or a variable temperature blackbody source which are permanently installed and remotely controllable via the instrumentation computer.

Mechanical and Cryogenic System

In order to minimize mechanical and thermal flexure, the optical elements are supported by a thermally isolated optical bench (11 in Figure 2) supported by a rigid frame attached to the telescope flange. This frame also carries the vacuum vessel which is mechanically decoupled from the spectrometer by means of bellows, however, and plays no structural role. Cooling of the spectrometer is by liquid N_2 flowing through a tube attached to the bottom plate of the radiation shield (12) to which the optical elements are attached via silver straps or copper braids. Additionally, liquid N_2 is also passed through a heat exchanger sandwiched between the two gratings in order to achieve a cooldown time of $\simeq$ 10 hours. The N_2 can be supplied from an external tank (usually during cooldown) or from the internal stainless steel reservoir visible in Figure 1. Temperature sensors are used to automatically control the N_2 flow both to limit temperature gradients during cooldown and to maintain the selected final steady state temperature ($\simeq$ 80 K). A separate copper cryostat (upper left in Figure 1) containing N_2 solidified by an external pump is used to cool the detector (to $\simeq$ 48 K) and also a small volume of active charcoal which acts as a cryogenic pump to maintain the vacuum.

The most complex mechanical unit is the grating support shown in Figure 3 which enables the two back to back mounted gratings to be interchanged by a 180° rotation and also rotated about their ruled surfaces for spectrum scanning. In order to achieve maximum accuracy and reproducibility the gratings are supported in a cradle mount and driven by a high precision "transroll" screw. All functions, except for the collimator drive and Hartmann mask, are remotely controlled via either DC motors and absolute encoders (slit, decker, grating rotation and drive) or stepper magnets (filter wheel, calibration source selector mirror). As the control shafts (plus all cryogenic and electrical connections) only penetrate the lower shell of the vacuum vessel, removal of the upper parts of the vacuum vessel and radiation shield is relatively straightforward and provides easy access for alignment, maintenance, modification, etc. as can be seen in Figure 1.

Detector

At present this is a monolithic array of 32 InSb diodes (each 200 μm × 200 μm) operated in the integrating mode and multiplexed onto a single amplifier. Their wavelength response is from 1 μm to 5 μm with a maximum quantum efficiency of ~ 70% at the long wavelength end. Under normal operating conditions at T $\simeq$ 50 K the charge capacity is $\simeq 10^7$ e, dark currend $< 10^4$ e/s and the read noise is close to the kTC limit of 10^3 e. The readout electronics (Fig. 4) comprises the "Head" electronics mounted on IRSPEC and modules in CAMAC. The Head electronics generates the readout clock signals, the detector bias voltage and the timing signals for the 15 bit A/D converter, while the CAMAC modules generate the readout sequence commands and the timing pattern for the wobbling mirror accord-

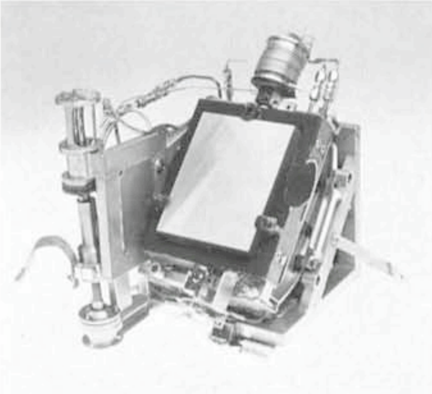

Figure 3: *The grating cradle support which permits interchange of the two back to back gratings and precision scanning about their ruled surfaces.*

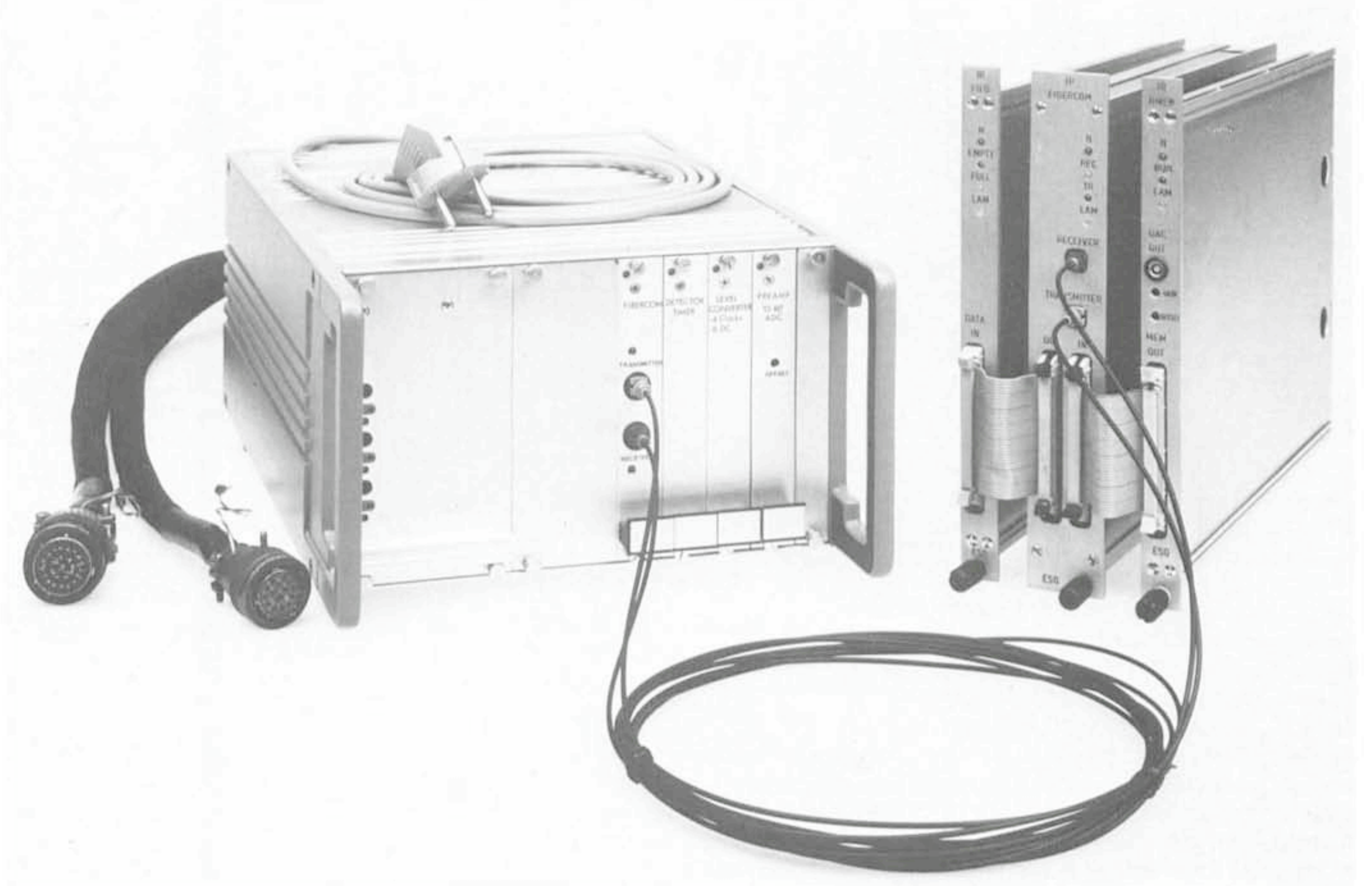

Figure 4: *Detector array electronics comprising the "Head" electronics (left) and modules in CAMAC which communicate via a fibre optic link.*

ing to the observing mode and integration parameters selected by the observer. All power is derived from the mains, thus eliminating the need for battery changes, and ground loops are avoided by employing a fibre optic link for communication between CAMAC and the sensitive (4.5 μV in a 10^5 Hz bandwidth) Head electronics.

Operating Modes and Software

As with the other major ESO instruments, user interaction with IRSPEC is by means of form filling, function keys and typed commands at the HP instrumentation computer console in the control room. One novel feature, however, is the provision of a colour Ramtek display of the complete instrument and measurement status. The complete instrumental set-up can also be saved in a file at any time and restored later by typing a simple command and the appropriate file name. IHAP is used for data acquisition plus spectrum displays and plots and is available to the user for on-line reduction during any spare moments.

Three basic operating modes can be selected via the function keys. Most measurements are made in the Observing Mode which is used to acquire and store (disk and magtape) astronomical spectra at either a fixed grating position (Discrete) or with automatic stepping of the grating to cover a specified wavelength range (Continuous). The desired centre wavelength or wavelength range is entered directly and translated into grating position by the software via a master calibration curve made at higher than the normal resolving power by centring lines from the spectral line lamps in the small gaps (20 μm) between pixels. Discrete spectra can be made at sub-pixel intervals to achieve a better sampling of specific spectral lines and the segments of Continuous spectra can be specified to overlap by any number of pixels from 0 to 16. With no pixel overlap, 10–15 grating steps are required to cover each of the standard J, H, K, L and M photometric windows. A complete measurement comprises a number (1–49) of cycles corresponding to a user specified integration time in the case of DC and chopped observations and a complete ABBA sequence when telescope beam switching is employed. All cycle measurements, plus the standard deviations computed for each pixel from the elementary detector integrations, can be displayed and are stored in the database together with the final average and standard deviations on the mean. Each spectrum file also contains all the instrument settings, coordinates, airmass, time and any comments entered by the user.

The Calibration Mode is similar but used to obtain spectra of the spectral line lamps and the blackbody for wavelength calibration and flat fielding respectively. As the wavelength calibration appears to be stable and flat field-

TABLE 1: IRSPEC Characteristics

Wavelength Range:	1 μm–5 μm
Resolving Power:	1,000–2,500
Sensitivity (1 σ, 60 s):	m ≈ 10.5–11 (1–2.4 μm), 6–7 (3–5 μm)
Slit:	6 × 6 arcseconds (= 200 μm pixel)
Detector:	32 element InSb integrating array
Optics:	Littrow arrangement
	2 interchangeable gratings (120 × 150 mm ruled)
	parabolic collimator, F/2 Pfund camera
Cryogenic System:	continuous flow liquid N_2 for spectrometer (80 K)
	solid N_2 cryostat for detector (~ 48 K)

ing better achieved on stars, however, this mode will probably not be used much by Visiting Astronomers except on cloudy nights.

A Peak-up Mode is available for use whenever it is required to centre an object by maximizing its infrared signal. Selection of this mode overrides any grating stepping and telescope beam switching, suppresses the storage of data and automatically displays each cycle measurement as intensity versus pixel number on the graphics terminal. An analogue signal corresponding to any selected pixel or to the average is also output to a chart recorder allowing either the continuum or any strong spectral line (whose pixel number can be identified on the graphics screen) to be peaked-up in the usual way.

Field recognition and centring of visible objects is possible using the normal Cassegrain adapter functions and/or the TV slit viewer (down to $m_v \sim 20$ on a dark sky). The standard ESO autoguider can also be used on the Cassegrain adapter guide probe, except if beam-switching when autoguiding is only possible at present on the slit viewer and is severely limited by the small field (no stars) and the fact that the object itself is usually not visible with the nominal 6" slit width.

Test Results

Both the installation and tests of IRSPEC went remarkably smoothly and with extremely satisfactory results in general. The most potentially serious technical problem arose towards the end of the second test when a rapid increase in friction caused us to restrict our remaining observations to a single order sorting filter rather than risk completely jamming the filter wheel drive. This problem was not entirely unexpected, however, because the bearing responsible had not been surface treated for low temperature and vacuum conditions due to lack of time and was due to be replaced anyway as soon as possible. No particular problems were experienced with the more complex functions. The grating drive proved to be reliable and reproducible to within 20 μm while the cryogenic system yielded hold times of 17 hours and nearly 5 days for the internal reservoir and the detector cryostat respectively and a pressure of $\simeq 2.10^{-6}$ τ for 9 days. Detector read noise was actually slightly lower than the best values achieved during laboratory testing and extremely close to the theoretical limit for this type of readout system. Although initially too high, mechanical flexure was finally reduced to less than 25 μm at the detector within zenith distances of up to ~ 50°.

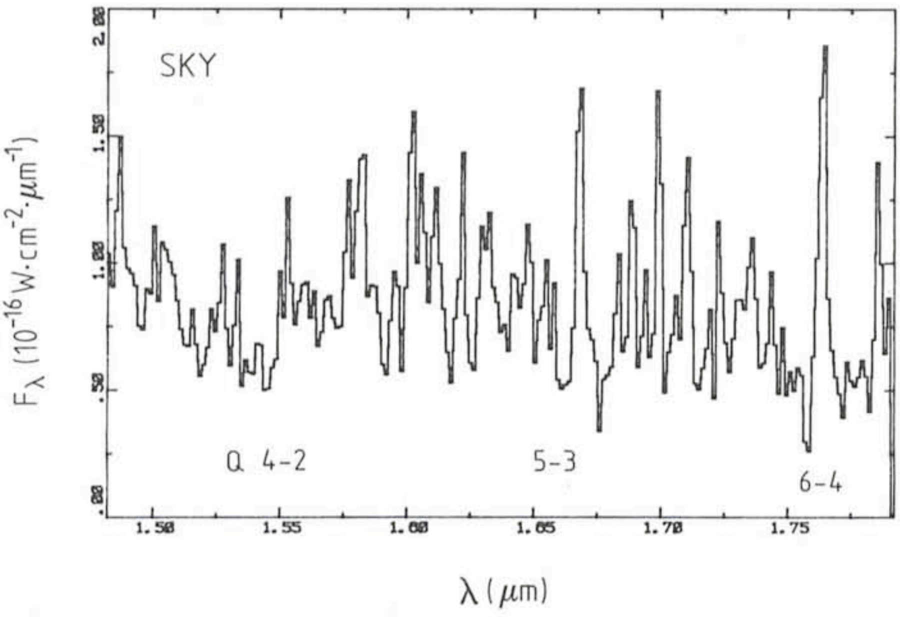

Figure 5: *Sky emission in the H band which is dominated by P, Q and R branch lines in the Δv = 2 system of OH. The spectrum was obtained in DC mode with 20s integration.*

The present resolving power is thus limited by the pixel size of 200 μm rather than the slit width (6 arcseconds), the optical quality (25 μm) or the mechanical stability of the spectrometer.

Sensitivity figures for the various wavelength range/order combinations were circulated with the Period 38 Announcement and will be documented in more detail in the Operating Manual. Between 1 μm and 2.4 μm the r.m.s. noise for a 1-minute observation corresponds to m ≃ 10.5–11 or ~ 3.10^{-21} W.cm^{-2} in the best case. At longer wavelengths the instrument becomes background limited at m ≃ 6–7 or 2.10^{-20} W.cm^{-2}.

Spectra

A sample of spectra which illustrate the capabilities of IRSPEC in its different modes are reproduced in Figures 5–10. These were all reduced using IHAP, following the simplest approach of dividing object and standard star spectra to remove the instrumental response and telluric absorption features and then

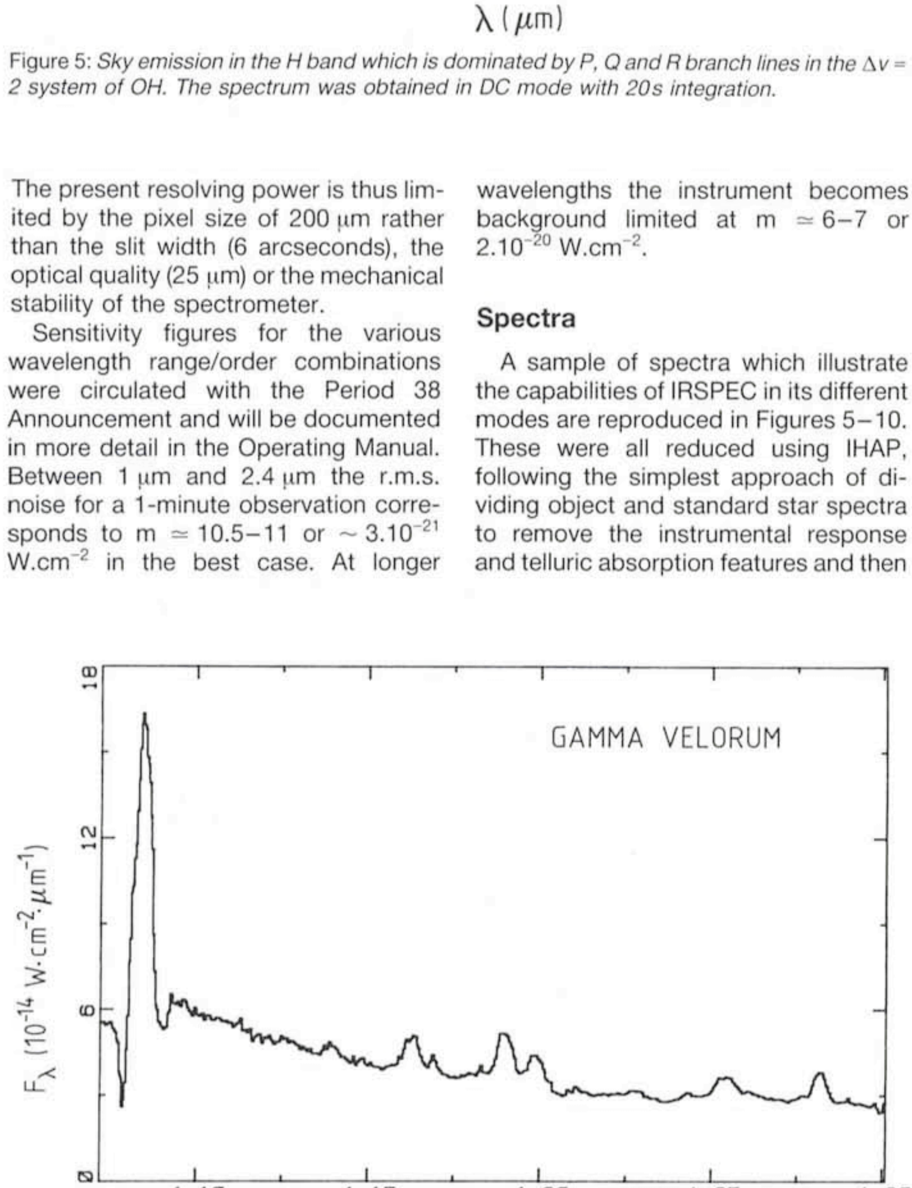

Figure 6: *J band spectrum of γ^2 Velorum (WC8+O8) obtained at R = 1,900 in the Continuous mode with sky chopping and 12s integration. Note the P. Cygni profile of the strong HeI (1.083μm) line. The other lines are from HI, HeI, CIII and CIV. Additional noise between 1.1μm and 1.15μm is due to the presence of strong atmospheric absorption features which are, nevertheless, removed quite well after division by the standard star.*

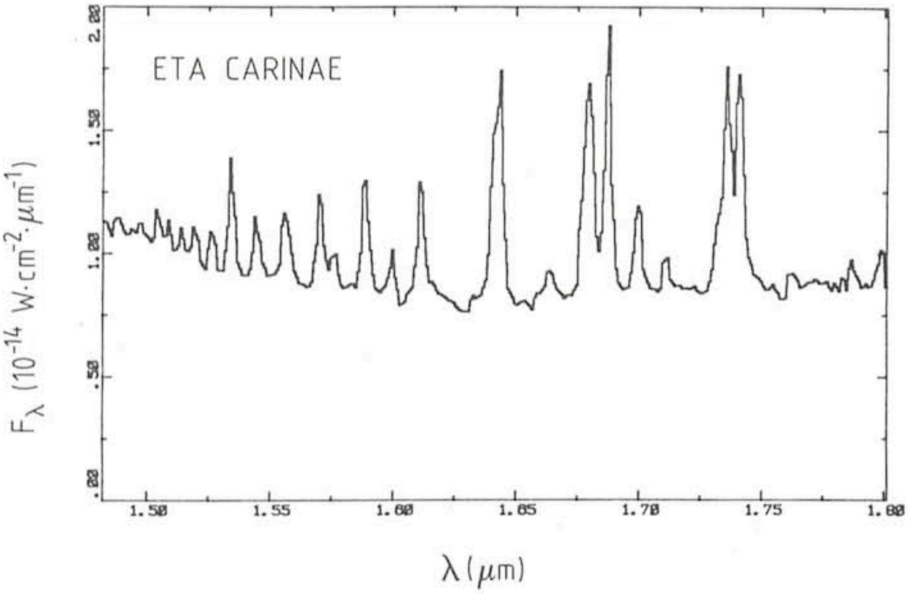

Figure 7: *H band spectrum of η Carinae obtained at R = 1,100 in the Continuous mode with sky chopping and 8s integration. Lines are from HI (Brackett series 28 to 10-4), HeI, FeII and [FeII].*

rebinning to a linear wavelength scale. Flux calibrations have been applied by interpolating between broad-band photometry of the standards and should be considered preliminary. Specific points of interest are mentioned in the relevant captions where all the integration times quoted refer to the total measurement time at each grating position.

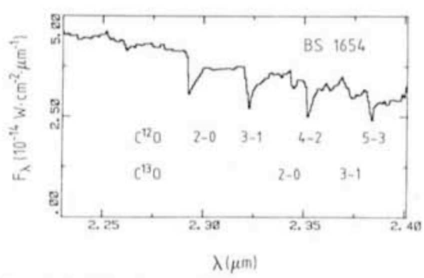

Figure 8: *The 2.3 μm CO band in the K giant "standard" star BS 1654 measured at R ≃ 1,600 in the Continuous mode, with sky chopping and 4s integration time. Note that the $C^{12}O$ and $C^{13}O$ band heads can be resolved separately at this resolution.*

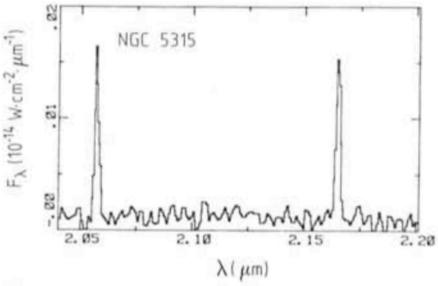

Figure 9: *HeI (left) and HI(Brγ) emission lines in the planetary nebula NGC5315 measured in Continuous mode at R = 1,700 with 24s integration time.*

Future Developments

Further performance gains with IRSPEC are largely dependent on future detector developments. A reduction in read noise would lead to improved sensitivity at $\lambda < 3$ μm while smaller pixels could yield resolving powers up to $\simeq 10^4$ with a $\geqslant 1$ arcsecond slit. The present design also already incorporates the possibility for long slit (~ 120 arcseconds) observations. Various possibilities for better exploiting these intrinsic capabilities of the instrument using an improved linear or, ideally, 2 D array are currently being investigated in Garching.

It is also planned to transfer IRSPEC to one of the 3.5-m NTT Nasmyth foci once this telescope is operational. Although unlikely to yield any significant performance gain directly, this move should bring considerable operational advantages and, hopefully, an increase in the available observation time.

Acknowledgements

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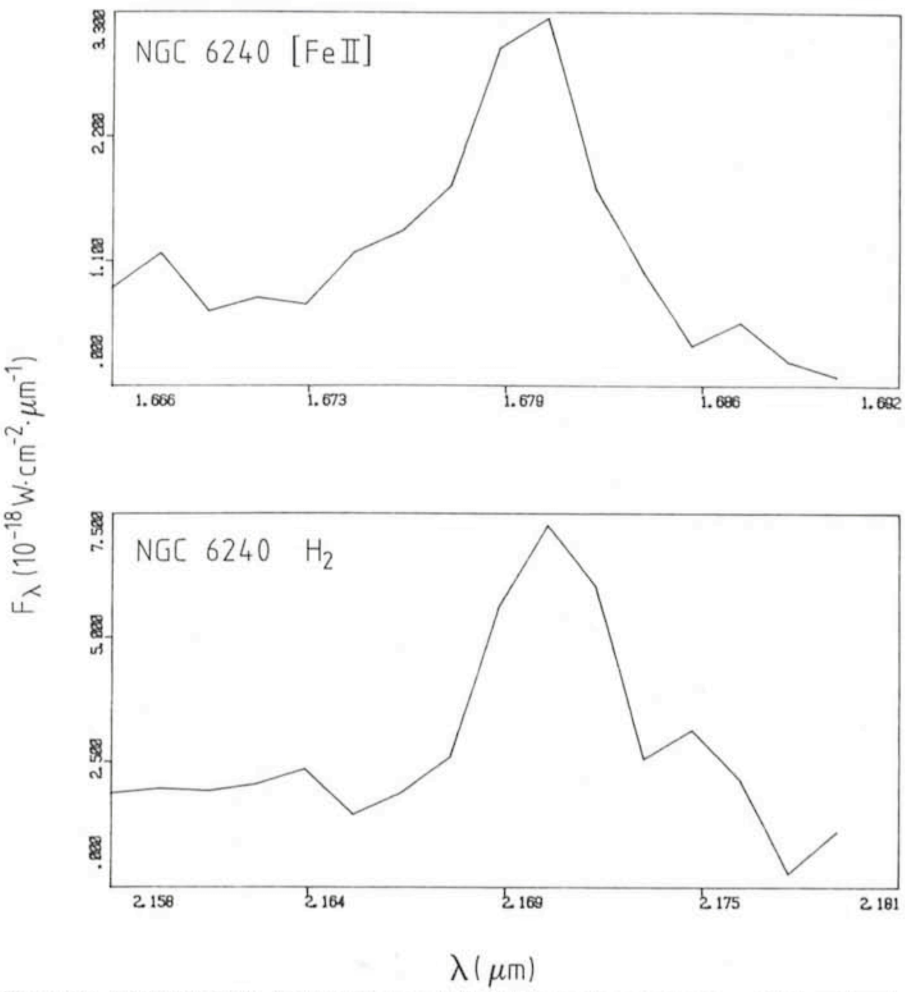

Figure 10: *"Profiles" of the [FeII] (1.64μ) and H_2[S(1)] lines observed to be ≃ 900 kms^{-1} and 500 kms^{-1} broad respectively in the merging galaxy system NGC 6240 (z = 0.025). These measurements were made in the Discrete mode, with sky chopping and integration times of 40 minutes and 20 minutes respectively.*

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NTT Mirror Leaves Factory

Early June 1986, the 6-ton mirror for the New Technology Telescope was being prepared for transport from the Schott factory in Mainz. The 3.58 m mirror of Zerodur, which is only 24 cm thick, was lowered into the steel frame in which it will be transported to Zeiss Oberkochen. The transport, which in-

Model of the ESO New Technology Telescope.