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IR INSTRUMENTATION FOR THE ESO VLT

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ABSTRACT

The ESO Very Large Telescope will be equipped with a complementary suite of instruments for infrared imaging and spectroscopy between 1 and 20μm. ISAAC (Infrared Spectrometer and Array Camera) is being developed by ESO and is scheduled to be commissioned during 1997 on the first of the 8m unit telescopes where it will provide for 1-5μm imaging and long slit, low and medium resolution spectroscopy. Its design provides for separate 1-2.5μm and 2.5-5μm cameras equipped with large format array detectors which can be used either to re-image the telescope focal plane or the intermediate spectrum formed by a grating spectrometer. HgCdTe and InSb arrays of 256x256 pixels are currently baselined but the possibility of accommodating larger arrays of up to 1024x1024 pixels is foreseen if and when these become available. The complete instrument will be cryogenically cooled using two stage closed cycle coolers and housed in a ~1 m diameter vacuum vessel attached to the adapter/rotator at one of the Nasmyth foci. Subject to satisfactory results of prototype tests now in progress it is planned to use diamond turned metal mirrors for the reflecting optics and cryogenic stepper motor drive systems for all moving functions. CONICA(Coude Near Infrared Camera) is being developed under contract to ESO by a consortium headed by the Max Planck Institute for Astronomy, Heidelberg and with the Max Planck Institute for Extraterrestrial Physics, Garching and Turin Observatory as partners. It also covers the 1-5μm range but is intended primarily for diffraction limited imaging and low resolution spectroscopy at the coudé focus either in combination with the VLT adaptive optics system or by the application of speckle interferometry or other high resolution imaging techniques depending on the specific application. A Phase A study has been contracted to a consortium under the leadership of CE-S DAPNIA in Saclay for a mid-infrared imager/spectrometer covering the 10μm and part of the 20μm atmospheric windows and a high resolution (R~100,000) cryogenic echelle spectrometer is in the definition phase which includes the development/evaluation of immersion and other types of gratings as the dispersive element.

1. INTRODUCTION

The ESO Very Large Telescope (VLT) comprises a fixed array of four 8m diameter telescopes plus three ~1.8m diameter moveable telescopes which can be used by themselves as a sub-array or in combination with the 8m telescopes for interferometry. It will be sited on Paranal mountain in the north of Chile and first light at the first of the 8m telescopes is scheduled for the end of 1996.Each of the 8m telescopes will have 2 Nasmyth, a Cassegrain and a coude focus and incoherent combination of the light from one or more telescopes is also possible at a combined focus which is separate from that used for interferometry. High optical quality (~0.2") is achieved and maintained with an active optics system similar to that pioneered on the ESO 3.5m NTT (New Technology Telescope) and each of the coude trains incorporates an adaptive optics system capable of yielding diffraction limited images down to wavelengths of 2μm or even shorter under excellent seeing conditions. Because of the importance attached to infrared observations the telescope pupil is located at the secondary mirrors which can also be used for sky chopping and rapid guiding (tip-tilt) which should also provide partial seeing correction at the foci not equipped with the full adaptive optics system. For imaging and spectroscopic observations the 8m telescopes will be equipped with ~10 permanently installed common user instruments covering the wavelength range from the UV to the mid infrared. Two of these, the Infrared Spectrometer and Array Camera (ISAAC) and the Ultraviolet and Visible Echelle Spectrometer (UVES), are being developed by ESO itself while the remaining instruments in the present plan are being contracted to Institutes or Consortia of Institutes in the ESO member states under an arrangement in which ESO pays the hardware costs and the Institutes provide manpower and expertise in return for guaranteed observing time. The main purpose of this paper is to provide an overview and status report on the progress of the infrared instruments for the 8m telescopes.

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2. OVERVIEW OF IR CAPABILITIES OF THE VLT

The basic characteristics of the infrared instruments currently planned are summarized in Table 1. while Fig. 1 gives a more pictorial view of the combined capabilities of these instruments in terms of their wavelength coverage and spatial and spectral resolution.

Table 1. Infrared Instruments for the VLT

As can be seen the instruments together provide for imaging down to the diffraction limit over the complete infrared range out to ~20μm accessible from the ground and for spectroscopy at resolving powers up to ~100.000.

Instrument	λλ (μm)	Field (")	Pixels(")	Modes	Focus
ISAAC (ESO)	1-5	150x150	.125-.5	Imaging Spectroscopy R~300-10^4 Polarimetry	Nas.
CONICA MPIA (Heidelberg) MPIE (Garching) Obs.Turin	1-5	~15x15	.015 -.125	Imaging (Speckle &Adaptive Optics) Grism Spec. R~500-1000 Polarimetry	Coude
Cryogenic Echelle Spectrometer	(1)2-5(10)		~0.1	Spectroscopy R~10^5	Nas.
Mid-IR Imager/ Spectr. Phase A. DAPNIA (Saclay) IAS (Orsay) SRON (Groningen)	7-18 (18-28)	60x60	0.1-0.6	Imaging Spectroscopy R~100 -2.10^4	Cass.

3. INSTRUMENT DESCRIPTIONS

3.1 ISAAC (Infrared Spectrometer and Array Camera)

This instrument is being built under the responsibility of the Infrared Instrumentation Group at ESO, Garching for installation at one of the Nasmyth foci of unit telescope 1 during 1997 as the first major common user instrument. It is designed for direct imaging and spectroscopy over the 1-5μm wavelength range with the following baseline specification for its main observing modes:

- **Direct Imaging**
  - Field - ≥ 2x2'
  - Scale - ~0.125,0.25,0.5"/pix
  - Filters - ~40 including polarizing analyzers
- **Low resolution spectroscopy**
  - Resolving power - 300-500 (nominal)
  - Slit- 1x120"(nominal), 0.5x60", 0.25x30"
- **Medium resolution spectroscopy**
  - Resolving power - 3000-5000 (nominal)
  - Slit - 1x120"(nominal), 0.5x60", 0.25x30"

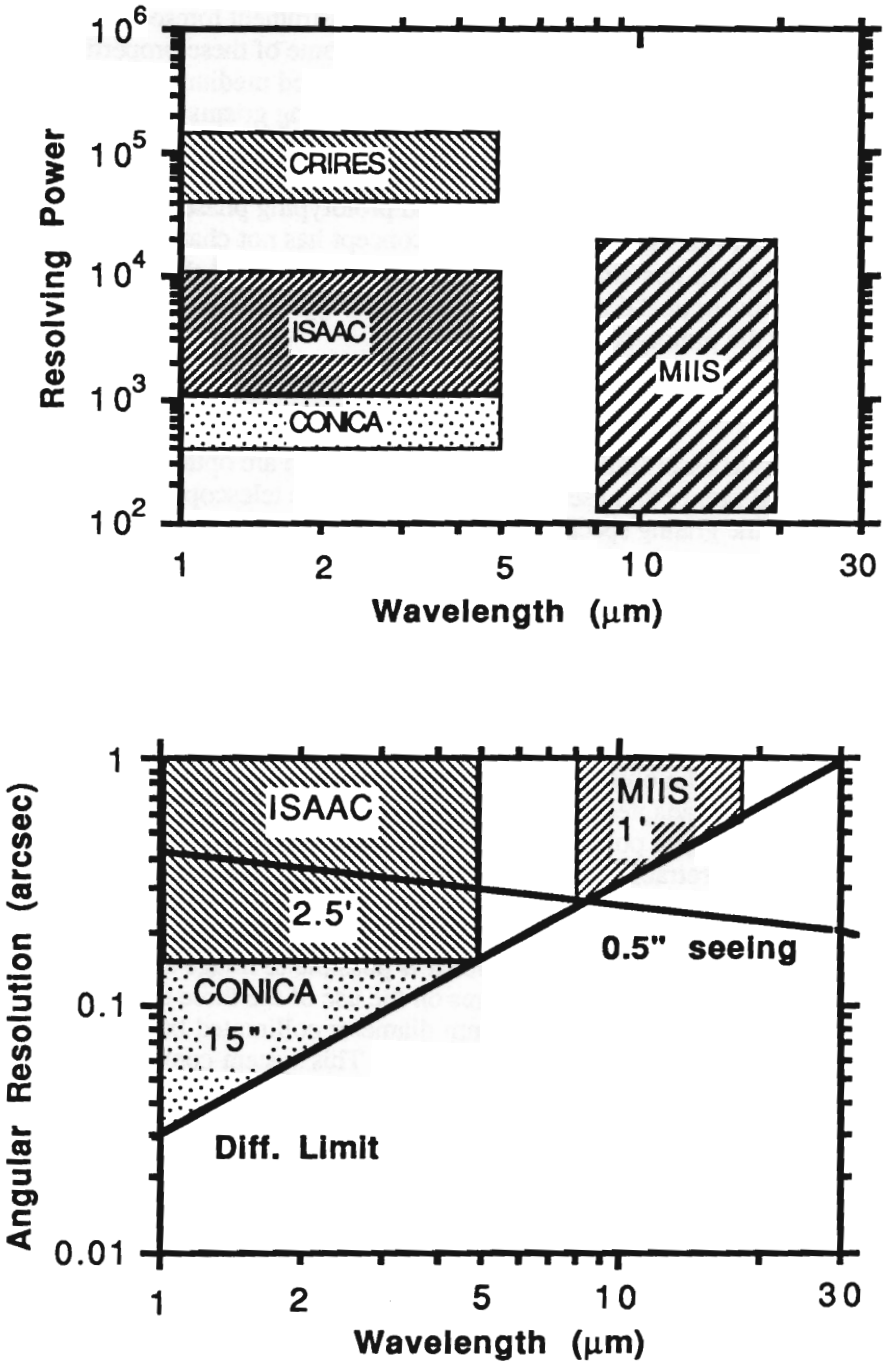


Fig. 1 (upper panel)- spectral resolving power versus wavelength for the planned VLT infrared instruments. (lower panel) - spatial resolution versus wavelength and the approximate fields of view for each instrument.

These characteristics correspond to the use of the 256x256 format Hg:Cd:Te and InSb array detectors which are currently available from the Rockwell International Science Center and the Santa Barbara Research Center respectively. The present design of the instrument foresees installation of larger format arrays up to 1024x1024 pixels, however, in which case some of these properties could change slightly e.g if the larger arrays have smaller pixels. A cross dispersed medium resolution spectroscopic mode could also be implemented in the present design by including grisms in one of the filter wheels in the pupil plane.

This instrument is now in the detailed design and prototyping phase following a Preliminary Design Review held in April 1992. As the overall basic concept has not changed significantly relative to the preliminary design which has already been published elsewhere[1] the following description will be limited to aspects of the optical design which have been improved during the detailed design phase and to the first results of the prototype tests.

3.1.1 Optical Design

This is based on two essentially identical cameras which are optimized separately for the 1-2.5μm and 2.5-5μm spectral ranges and used either to re-image the telescope focal plane or the intermediate spectrum formed by the grating spectrometer. Whereas the spectroscopic slit was located off-axis in the original design, however, the optical layout has now been modified such that the slit can be centred in the imaging field. The new arrangement is shown in Fig. 2. Light enters via the plane window at the left and the telescope focal plane is located at the position of the slit which is mounted on a wheel used to insert either slits or field masks. For direct imaging the light is then diverted by mirror M1 through the collimator and into one or other of the cameras via mirror M7. Each camera is equipped with an array detector, objective wheel and two filter wheels near the plane where the telescope pupil is re-imaged by the collimator on a 25mm diameter cold stop. Fig. 3 shows the imaging/re-imaging optical scheme in more detail . The objectives are interchangeable and Fig. 4 shows provisional designs of three possible objectives adapted to a range of possible array formats. The overall imaging quality is demonstrated by the 1-2.5μm polychromatic spot diagrams reproduced in Fig. 5. In the spectroscopic mode the mirror M1 is retracted and the light is directed by M2 into the spectrometer unit which produces an intermediate spectrum in a plane conjugate to the focal plane which is then re-imaged via M6 by the selected camera. With the slit on-axis it is more convenient to switch between imaging and spectroscopy and to set the position angle plus it is possible to image objects through the slit to check the centering. The spectrometer design centres on the use of the three mirror system (M3-5) shown in Fig. 6 which used both to produce the 100mm diameter collimated beam and as camera to form the intermediate spectrum after diffraction at the grating. This system comprises three hyperbolic mirrors and is the most compact solution found which is telecentric, yields a flat field in the image plane and provides the required image quality over the relatively large angular input field of 4.5x2.7 deg. In perfect alignment the images are diffraction limited at 1μm over the complete field and a sensitivity analysis shows only a very small degradation of the image quality for misalignments at the ~0.1mm level which are larger than expected in practice. The grating unit carries two back to back mounted gratings operated in Littrow mode. In addition to having the slit on the optical axis this new design also has a plane input window rather than a field lens. It allows improved baffling of the spectrometer unit and requires two fewer cryogenic drives (mask wheel which is now combined with the slit and one collimator drive) but at the expense of a larger single collimator /field lens and the additional mirror in the spectroscopic mode.

3.1.2 Prototype Tests

Some key features of the cryomechanical design are the use of i) diamond turned metal mirrors ii) cryogenic stepper motor driven worm gears for the 11 cold functions iii) two closed cycle coolers for maintaining the optical assembly at 60-80K and the detectors at 30-60K iv) a liquid nitrogen pre-cooling circuit to accelerate cooldown and v) a magnetic bearing turbomolecular pump flanged directly on the vacuum vessel to maximize pumping speed and simplify maintenance operations vi) a cable rotatotor system to carry cables, closed cycle cooler hoses and cooling liquid to the electronics mounted on the Nasmyth rotator and vii) a track mounted maintenance carriage for easy installation and removal of the instrument.

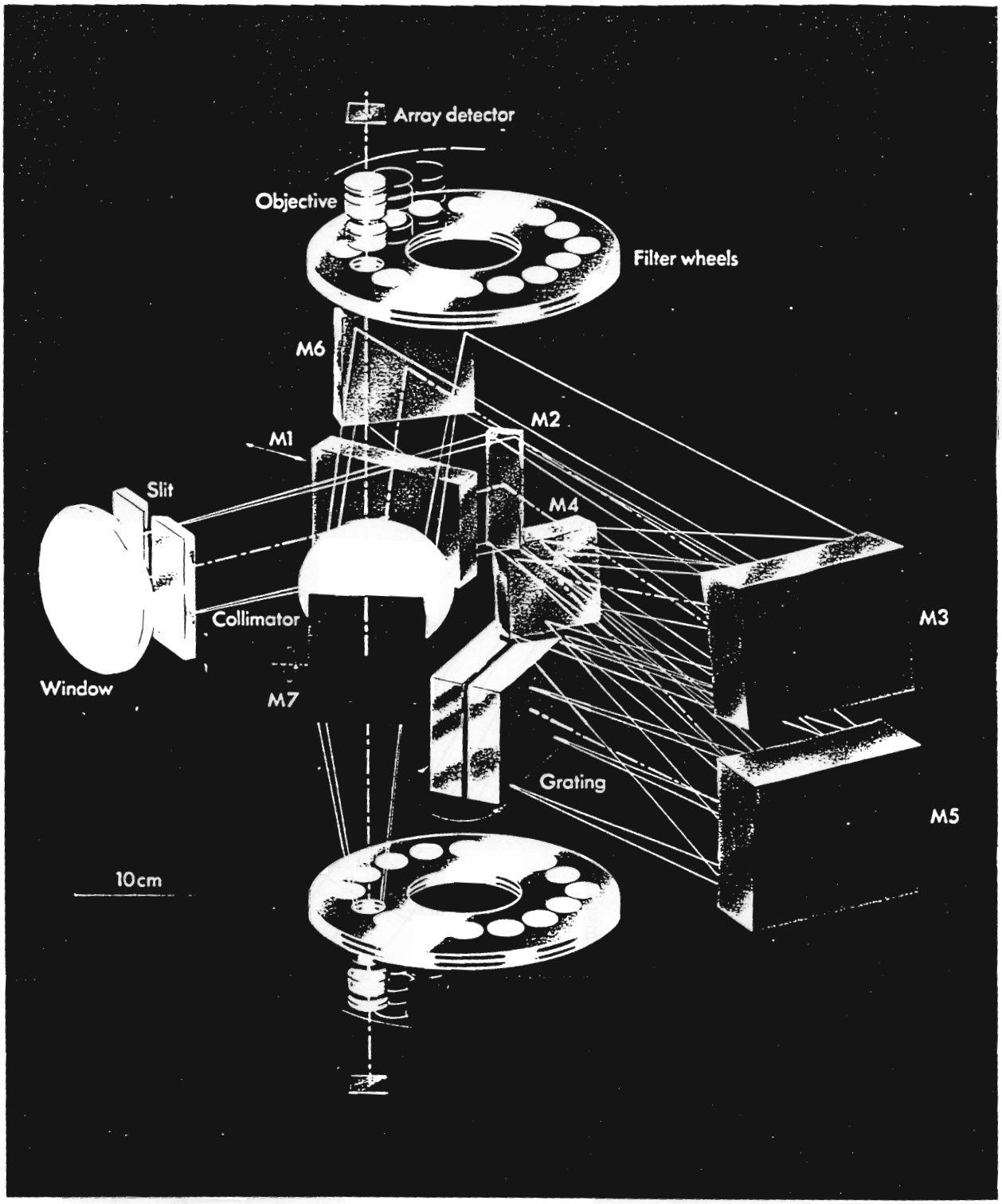


Fig. 2 Optical layout of ISAAC. The two cameras at the top and bottom are optimized separately for the 1-2.5μm and 2.5-5μm regions and can be used to re-image the telescope focal plane or the intermediate spectrum produced by the grating spectrometer.

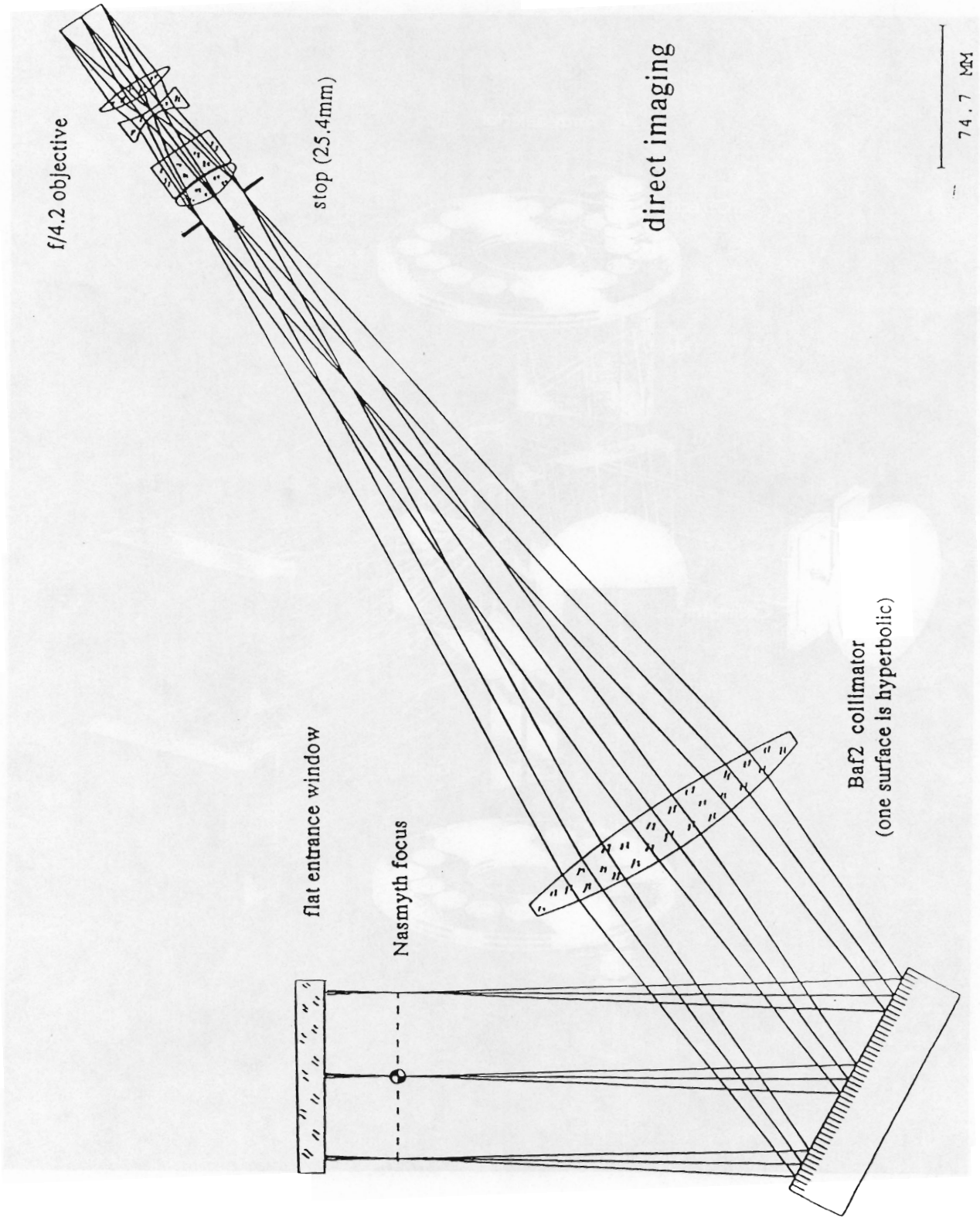


Fig. 3 The imaging/re-imaging optical arrangement in ISAAC. The lens collimator also re-images the telescope pupil on a 25mm cold stop in front of the interchangeable objectives which re-image the telescope focal plane or the intermediate spectrum on the array detector.

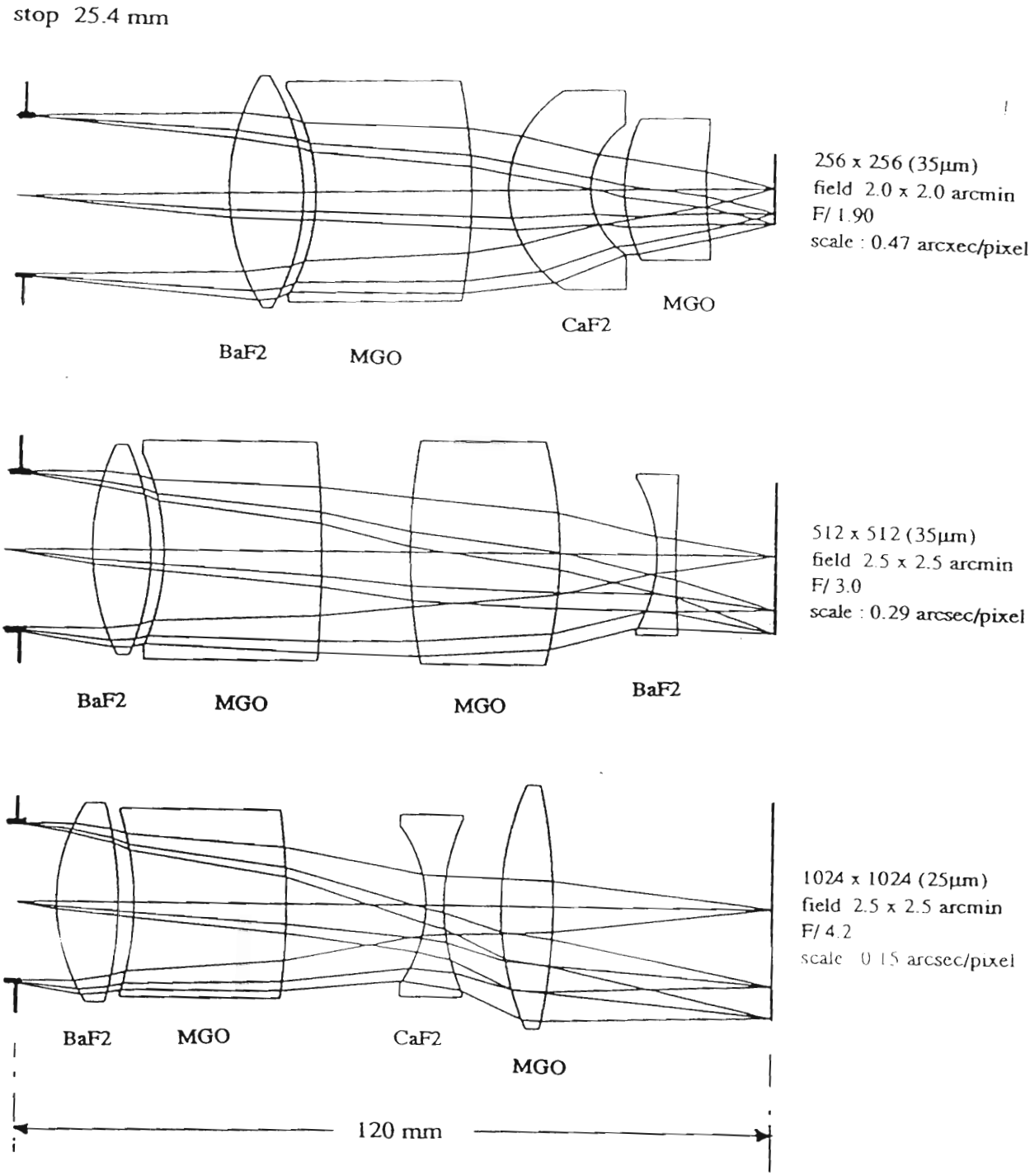
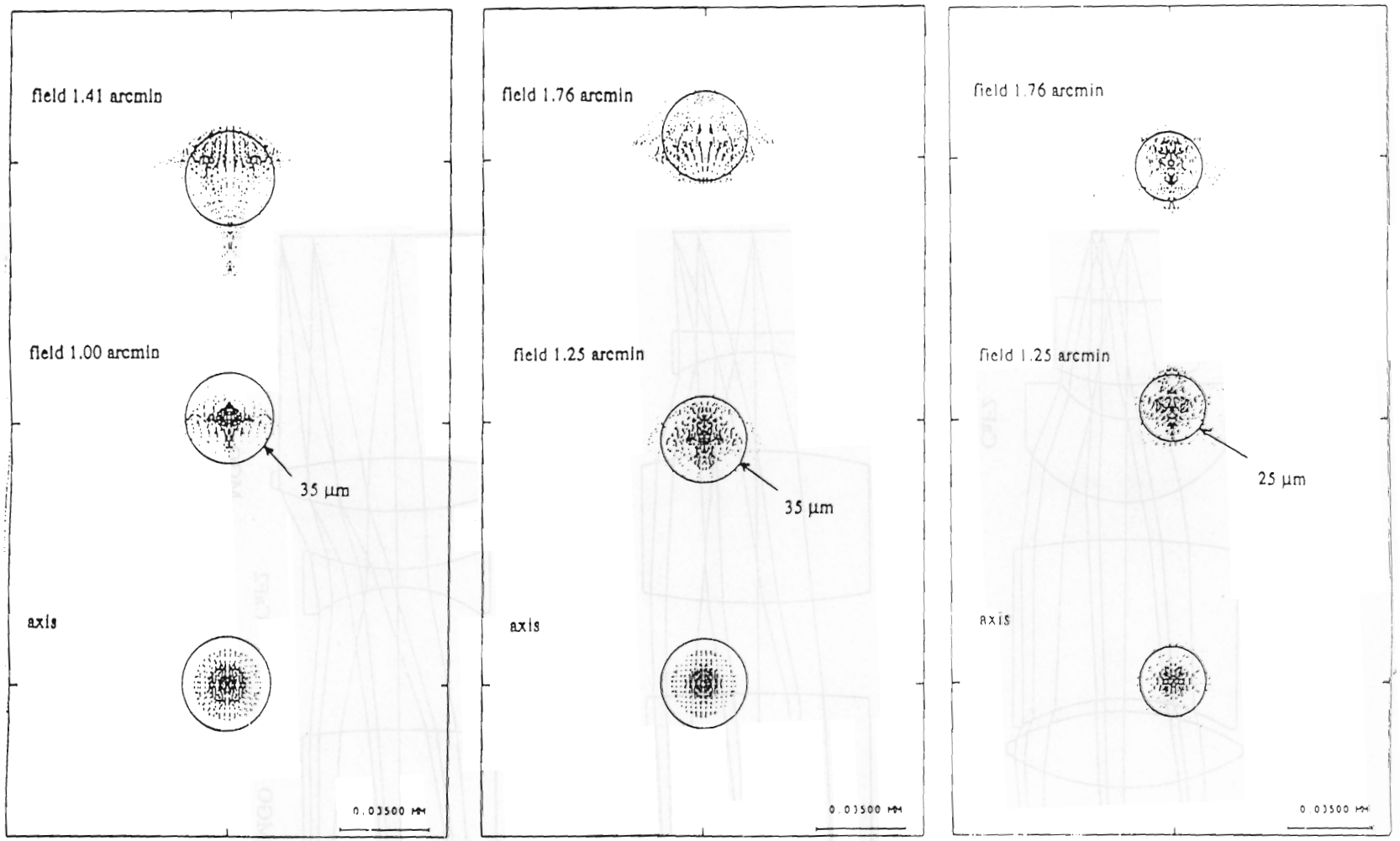


Fig.4 Provisional designs of large field objectives for three possible array detector formats.



256 x 256 (35µm)
field 2.0 x 2.0 arcmin
F/ 1.90
scale : 0.47 arcxec/pixel

512 x 512 (35µm)
field 2.5 x 2.5 arcmin
F/ 3.0
scale : 0.29 arcsec/pixel

1024 x 1024 (25µm)
field 2.5 x 2.5 arcmin
F/ 4.2
scale : 0.15 arcsec/pixel

Fig. 5 1-2.5µm polychromatic spot diagrams for the three objectives shown in Fig. 4.

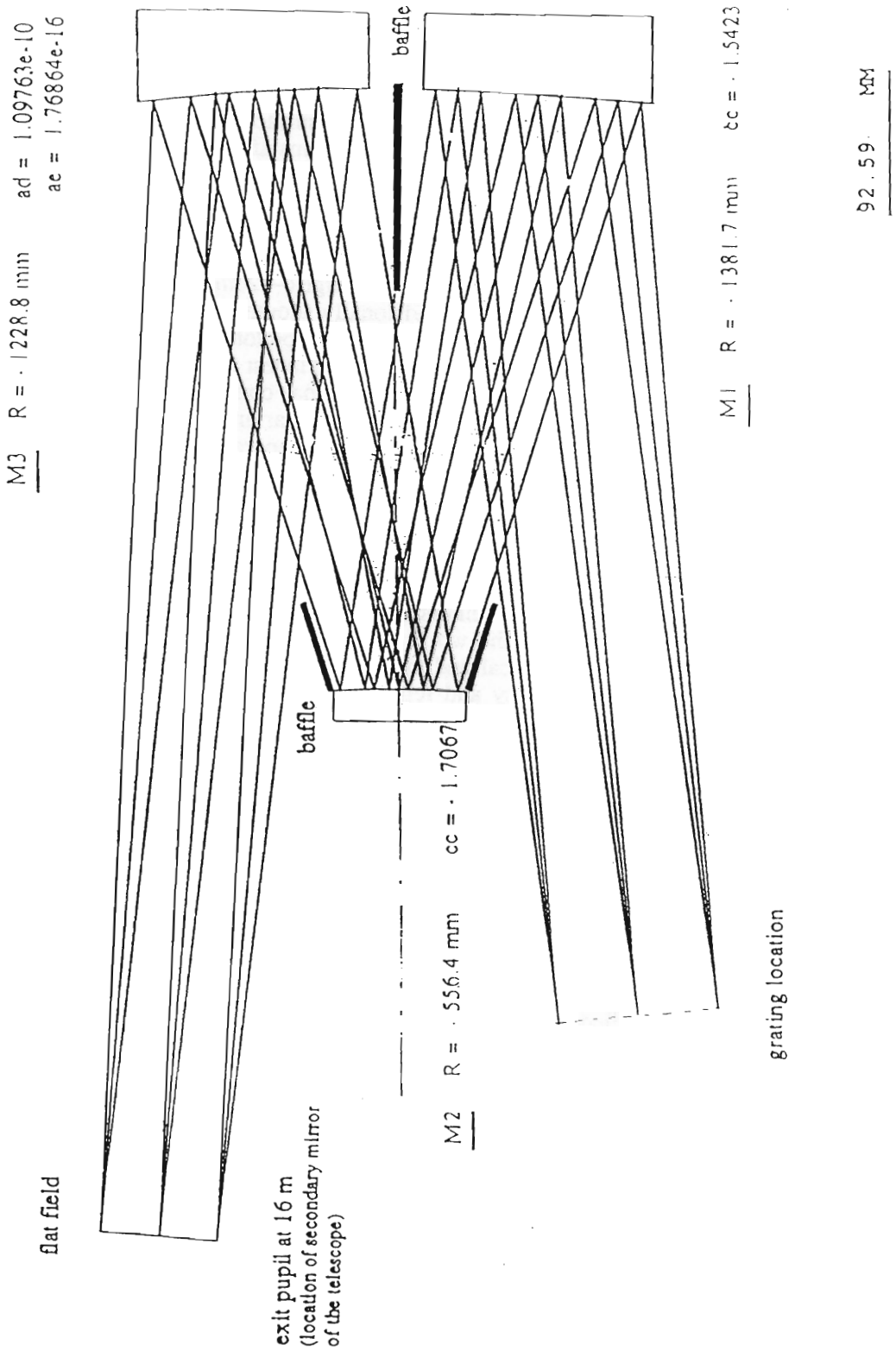


Fig. 6 Design of the three mirror collimator/camera for the spectrometer in ISAAC. This system is telecentric, gives a flat field in the image plane and yields diffraction limited images at 1μm over the complete field.

Prototyping work is currently in progress to qualify the most critical aspects of the design. For testing the metal optics concept various spherical mirrors have already been manufactured to compare the optical quality achievable by fly cutting and diamond turning and to measure the thermal conductivity and deformations on cooldown for two alternative fixation systems based on v grooves and flat lugs. During their production these mirrors were thermally cycled for stress release between each phase. Diamond turning produced the better optical performance yielding an rms surface roughness of ~ 15nm and peak to valley variations within 330nm over 98% of the surface. After some minor modifications the additional deformations introduced by both fixation systems after cooldown could be reduced to <150nm. While this performance would be acceptable for ISAAC it should be possible e.g by increasing the mirror thickness to reduce the peak to valley errors in the final mirrors. For the drive systems the selected five phase stepper motors have already been extensively tested with slightly modified bearings and cryogenic lubrication without problems. The main concerns with the moving functions are the stability and thermal conductivity of the large (~120mm diameter) bearings required, the performance of the worm gearing system provisionally adopted, flexure under rotation and the accuracy and reliability of the motor initialization switches. Full prototypes of the linear collimator drive and the rotating grating unit have therefore been manufactured to test these aspects before finalizing the function designs. As the testing is still in progress no final conclusions have yet been drawn. Promising results have been obtained however with both linear and circular commercial bearings modified in-house at ESO by replacing the balls and using separators of PTFE impregnated with molybdenum sulphide and lead to provide the lubrication. Various ball materials have been tested including tungsten carbide which appears to give the best combination of mechanical and thermal performance. A special purpose spring loaded bearing designed in-house to improve the thermal conductivity is also being manufactured for test and comparison in the same grating prototype. The main result of the flexure/stability test has been to underline the need for accurate balancing of the functions to achieve the micron level requirements. Some problems have been encountered with the radial forces required for operation of the worm gear which is now being re-designed. Several initialization switches (mechanical, optical and magneto-restive) have also been mounted on this prototype for a comparison of accuracy and reliability which has still to be made. Additional prototyping is also underway to test the detector mount concept and stability and the cable/hose rotator system.

At present these prototype activities are scheduled to be completed in summer 1993 when the final final design will be frozen and reviewed before the start of the manufacturing phase.

3.2 CONICA (Coude Near Infrared Camera)

This instrument also covers the 1-5μm range but is optimized for high spatial resolution imaging over a much smaller field than ISAAC and offers only a low resolution spectroscopic mode using grisms in the pupil plane. It will be installed at the coude focus of unit telescope 1 during 1997 where it can be used in combination with the adaptive optics system designed to yield diffraction limited images at 2μm or even shorter under excellent seeing conditions. Observations will also be possible in speckle mode to ensure that diffraction limited images can be obtained down to 1μm. Development of this instrument has been contracted by ESO to a consortium headed by the Max Planck Institute for Astronomy in Heidelberg and with the Max Planck Institute for Extraterrestrial Physics and the Observatory of Turin as partners. It will not be further described here as it is the subject of a separate paper in these Proceedings [2].

3.3 MIIS (Mid-Infrared Imager/Spectrometer)

This instrument is proposed to provide similar observational capabilities as ISAAC but in the 8-14μm and possibly 20μm windows. Either the ISAAC design or a variant of it already presented elsewhere [3] could provide a basis for its optical design. Several aspects related to this instrument still require further study, however, before it can finally be defined. These include the specification of the highest spectral resolution mode and the extent to which its capabilities should/could be extended into the 20μm window. Final specification of this instrument will only be made, therefore, following a complete phase A study which has been contracted to a consortium of institutes led by CE-S DAPNIA, Saclay and which will include an estimate of the cost as well as technical aspects. In parallel, ESO and

DAPNIA are also collaborating with INSU to finance the development of a 128x128 Ga:Si array by LETI/LIR Grenoble as a follow-on to the 32x32 arrays built for ISO and the 64x64 arrays now used in several groundbased cameras including TIMMI at ESO 4.

3.4 CRIRES (Cryogenic Infrared Echelle Spectrometer)

Following a proposal made at the Workshop on High Resolution Spectroscopy with the VLT held at ESO Garching in Feb 1992 5 the development of a cryogenic echelle spectrometer for one of the Nasmyth foci has been selected as the high resolution infrared spectrometer to be developed with highest priority. Other options previously considered were a Fourier Transform Spectrometer, a cryogenic echelle spectrometer at the combined focus and inclusion of a near infrared camera in either the Nasmyth or combined focus 'visible' echelle spectrometers. A more detailed definition and design of this instrument is now being evolved at ESO. At present it is proposed to optimize it for the 2-5μm range and to aim for a resolving power ≥ 100.000. Using available conventional R2 echelles with a collimated beam of 20cm, however, would imply a slit width of ≤0.2". In parallel, therefore, the development of immersion gratings etched in silicon and germanium are being pursued as a possible means of increasing the Rθ product as described separately in these Proceedings 6. As arrays of 1024x1024 pixels are now in prospect for this wavelength range it is also considered attractive to provide for a cross dispersed format to maximize the instantaneous wavelength coverage.

4. ACKNOWLEDGEMENTS

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