ISAAC – Infrared Spectrometer And Array Camera for the VLT

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Overview

ISAAC is one of the two instruments in the VLT Instrumentation Plan being designed and integrated in-house at ESO. Identified formerly as the Medium Resolution Infrared Spectrometer/Imager it will provide mainly for both direct imaging and low and medium resolution spectroscopy at wavelengths from 1 to 5 μm and is scheduled to be installed at one of the Nasmyth foci of Unit Telescope 1 in early 1997. We are now in the detailed design and prototyping phase following approval of the instrument Technical Specification and Design and Implementation Plan by the ESO Scientific and Technical Committee in November 1991 and the Preliminary Design Review involving external experts in April 1992.

Scientific Capabilities

Infrared observational capabilities have been revolutionized by the availability of two-dimensional array detectors which have made both imaging and the efficient use of dispersive spectrometers at these wavelengths possible for the first time. Within the space of a few years we have evolved from single pixel photometers and spectrometers to cameras and spectrometers equipped with first 64×64 and now 256×256 element arrays. In terms of performance/pixel there is already little more to gain for ground-based instruments as the best of these arrays already exhibit quantum efficiencies in excess of 80 %, dark currents below 1e/s and read noises ~20e. Further increases in size up to formats of 512×512 in the near future and perhaps eventually 1024×1024 or even larger, however, are now being anticipated.

ISAAC is conceived as one of a new generation of infrared instruments which harnesses these new detector capabilities to the increased light gathering power of the VLT and provides the user with the flexibility to combine imaging and spectroscopic observations in a way not possible previously in the infrared. The baseline instrument currently being designed operates from 1 to 5 μm, has a 2×2 arcmin field and provides the following basic observing modes:

- Direct imaging through broad- and narrow-band filters with selectable scales in the range ~0.1–0.5 arcsec/pixel.
- Long slit spectroscopy at resolving powers in the range ~300–10,000 with a maximum slit length of 2 arcmin and slit widths of ~1–0.2 arcsec.
- Polarimetry by combining polarizing analyzers and filters in the pupil plane.

At present, the baselined detectors are the 256×256 arrays already available. The instrument is being designed to accommodate the larger arrays anticipated, however, in which case some of these characteristics may change somewhat e.g. due to the likely reduction in pixel sizes. The design also leaves open a number of additional options for future upgrades e.g. image sharpening by tip-tilt control of the telescope secondary mirror; imaging spectroscopy using Fabry Perot etalons and echelle spectroscopy using grism cross dispersers in the pupil plane. Given the complexity of the basic instrument, however, these additional capabilities still have to be carefully traded off against the possible increased technical risk and operational complexity.

ISAAC covers a wide spectral range over which the sky and telescope background increases by a factor ~10^5 from the shortest to the longest wavelength with a corresponding effect on the achievable performance. Nevertheless, we expect to be able to image objects down to magnitude ~25 in the J (1.25 μm) and ~15 in the M (4.8 μm) bands and to obtain spectra at resolving powers around 5000 of objects ranging from magnitudes ~20 to 12 over the same range.

With regard to the scientific potential of ISAAC it should be noted that the availability of infrared array detectors

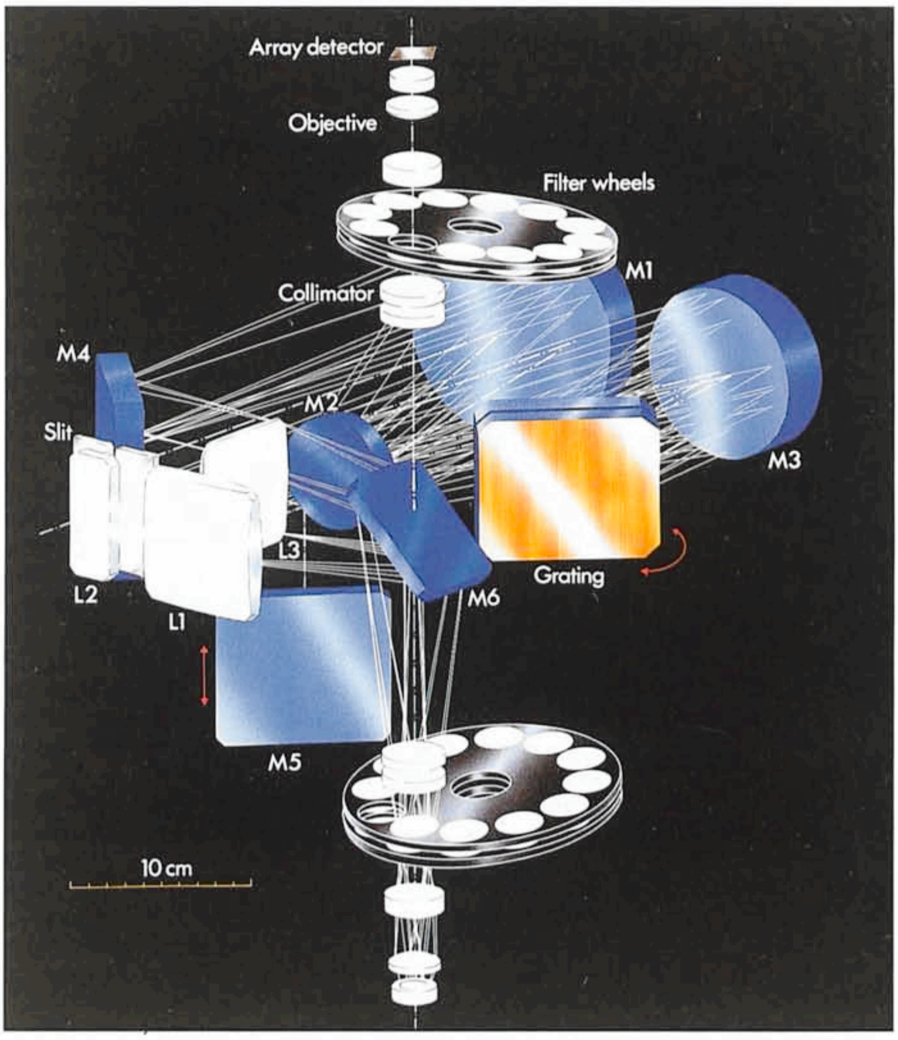

Figure 1: *Optical layout of ISAAC.*

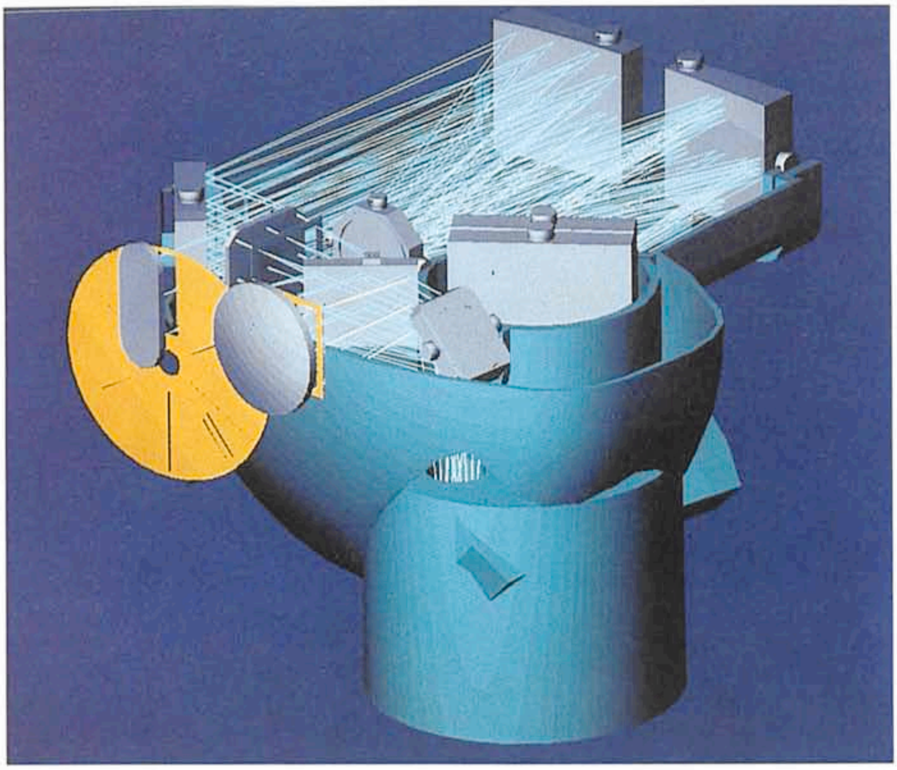

Figure 2: *ISAAC cryogenic optical assembly.*

has not only closed the technical gap but has also removed some of the mystique which previously separated visible and infrared astronomy. Observing with infrared arrays of CCDs in the visible is now very similar, and extrapolating from the interest currently shown for ground-based infrared imaging and spectroscopy it is expected that ISAAC will be in demand for a wide range of astronomical programmes involving observations of essentially all classes of object known. On the one hand infrared observations will remain the prime tool for the study of many objects which are either too cool or too heavily embedded in dust to be usefully studied at shorter wavelengths. These include the solar-system objects, cool stars, recently formed stars in molecular clouds, the centre of our own and many other galaxies, etc. traditionally associated with infrared astronomy. For such studies ISAAC offers a powerful multimode capability for imaging, photometry, polarimetry and spectroscopy. With regard to the latter it should be noted that its spectral range covers a number of important spectral features including the well-known 3.28-μm PAH feature, the ro-vibrational molecular hydrogen emission lines, CO and other molecular absorption bands, many hydrogen and helium recombination lines and various ionic forbidden lines spanning a wide range of ionization potentials from the important shock excited [Fe II] lines to the [Si VI and VII] coronal lines. Spectroscopy in this range also has much to offer therefore beyond its unique roles in the study of molecular gas and visually obscured sources. Similarly, many imaging studies only possible previously in the visible may be usefully extended to the near infrared either for astrophysical reasons or simply because the effects of extinction are much less. Examples include cluster photometry and morphological studies of galaxies where e.g. apart from much lower extinction the infrared images are dominated by late-type stars which constitute most of the mass. Where the VLT will obviously make its greatest impact is clearly for studies of those faint objects and spectral features which are below the detection limits achievable with smaller telescopes. It will be of interest to make deeper searches e.g. for low-mass stars in clusters and for the elusive brown dwarfs and to extend studies confined so far to our galaxy to the Magellanic Clouds. It will also substantially increase our ability to detect and study a class of infrared object not so far mentioned – high-redshift galaxies. The stellar light of nearby 'normal' galaxies peaks around 1 μm and galaxies at redshifts $z > 1$ are expected to be more easily detectable in the infrared than the visible while important "visible" spectral features will only be observable in the infrared. Amongst the most exciting prospects offered by ISAAC therefore are the new possibilities it offers for surveys and studies of galaxies and clusters over a wide range of cosmologically interesting redshifts.

Optomechanical Design

The optical arrangement of ISAAC is shown in Figure 1. This concept aims at minimizing the compromises inherent in a multimode instrument by providing two cameras which can be used either to view the telescope focal plane directly for imaging or the intermediate spectrum produced by the grating spectrometer. It essentially comprises two separate instruments therefore which are housed together and share the same detector arrays. The two cameras are identical mechanically but are optimized separately for the 1–2.5 μm and 2.5–5 μm spectral regions optically and are each equipped with appropriate filters and detector arrays with formats of $\geq 256 \times 256$ pixels. The entrance window for imaging (L1) also acts as a field lens producing an image of the telescope secondary mirror on the cold pupil stops while the spectroscopic slit is located ~4 arcmin off the telescope optical axis behind a plane entrance window (L2). Each camera comprises a collimator unit (also used for internal focusing), two filter wheels, a pupil stop and a lens wheel carrying the different objectives required to provide magnifications in the range ~0.1–0.5 arcsec/pixel. In the imaging mode these cameras view the telescope focal plane via the plane selector mirrors M5 and M6. In the spectroscopic mode the light entering via the slit is collimated by the compact three mirror collimator (M1–3) to produce an 80 mm diameter beam at the grating unit which carries two back-to-back mounted plane gratings used in Littrow mode. After diffraction at the grating the beam returns via the same collimator unit to form an intermediate spectrum in a plane conjugate to the telescope focal plane which is then re-imaged by one or other of the two cameras. Although the nominal resolving power corresponds to a 1-arcsec slit using the fastest camera objective, the slower objectives can also be used allowing a reduction of the slit width and hence increases of up to a factor of ~5 in resolving power while retaining at least two pixel matching.

External to, but mounted on the instrument within the adapter flange (not shown in the picture) are a visible slit viewer and the calibration unit consisting of an integrating sphere equipped with spectral line lamps and a continuum halogen lamp which can be used to illuminate the spectrometer slit via a retractable diverter mirror for wavelength calibration and flat fielding.

A summary of the main instrument characteristics is given in Table 1.

Table 1. *ISAAC Main Characteristics*

Wavelength range	1–5 μm
Field	2×2 arcmin.
Image scales	~0.125, 0.25, 0.5″/pixel
Max. array format	~25×25 mm
Pupil diameter (camera)	25 mm
Collimated beam (camera)	25 mm
Collimated beam (spec.)	80 mm
Nominal Slit width (2 pixels)	1 arcsec
Slit length (max.)	2 arcmin
Resolving power (1″slit)	300–5000
Filters and analyzers	24/camera

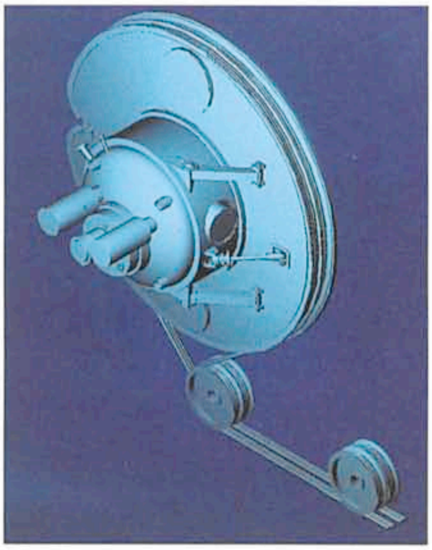

Figure 3: *ISAAC adapter flange and vacuum vessel showing the closed-cycle coolers and permanently mounted turbomolecular pump and the cable wind systems*

Apart from the slit viewer, calibration unit and the two entrance windows all optical elements together with their mechanical support structure are cooled to a temperature of ~80K using a continuous flow liquid nitrogen system and maintained at their normal operating temperature of 60–80K using the first stages of two closed-cycle coolers. The detectors are cooled to temperatures of between 20 and 60K using the second stages of the closed cycle coolers. Diamond-turned aluminium alloy mirrors and gratings ruled or replicated on aluminium are used in the cryogenic optical assembly and all moving functions are driven by cryogenic stepper motors. A simplified view of how the optics are integrated into the mechanical support structure is shown in Figure 2. The entire optical/detector assembly is surrounded by a light tight radiation shield which is also at 60–80K and is attached to mechanical support struts via which it is mechanically connected to but thermally isolated from the enclosing vacuum vessel. This latter, shown in Figure 3, is basically a cylindrical tank whose axis is on the horizontal optical axis and comprises a rigid central section which supports the cooled optical assembly and is attached to a stiff, dome-shaped, adapter flange bolted to the Nasmyth rotator. On the telescope side it is closed with a plane flange which carries the imaging and spectroscopic input windows and on the other by a light dome providing the space for, but not supporting part of the optical assembly and to which are attached the two closed-cycle coolers and the turbomolecular pump used for evacuating the vessel. The hinge system visible on the right allows the instrument to be swivelled away from the adapter flange to provide access to the front flange and to the units attached to it and within the adapter flange. The control and data acquisition electronic modules are located in a temperature controlled cabinet(s) attached to the instrument. Cables and the hoses for cooling fluid and the closed cycle coolers are wound on guides attached to the adapter flange and pass via a length compensation system to minimize the torque on the rotator during operation.

Array Detectors

Two channels are provided in ISAAC primarily to permit the installation of optimized detectors for the short (1–2.5 μm) and long (2.5–5 μm) wavelength ranges whose requirements with regard to dark current, read noise and well capacity are different. At present the baseline detectors for the short and long wavelength channels respectively are the currently available 256×256 pixel Rockwell NICMOS3 Hg:Cd:Te and SBRC InSb arrays. Given the on-going developments in this field, however, the instrument is being designed to accommodate larger-format arrays if and when they become available in the future.

In order to gain experience with large-format arrays of relevance to ISAAC as well as providing new observing capabilities at the present ESO Observatory on La Silla, a new camera, IRAC2, and a flexible VME-based acquisition system have recently been installed and successfully tested at the 2.2-m telescope (see *The Messenger*, **69,** 61). This camera has been equipped initially with a NICMOS3 array and provides for imaging through broad- and narrow-band filters, including a K band scanning Fabry Perot etalon yielding R ~1000, with five selectable magnifications in the range 0.15–1.1″/pixel and a maximum circular field of 3″ diameter.

Electronics/Software

Both the function control and detector electronics will use intelligent VME-based LCUs (Local Control Units) housed in the temperature-controlled cabinet(s) attached to the instrument adapter flange. Each detector will have its own dedicated "front end" electronics (generating clock patterns and voltages, ADC conversion strobes, etc.) connected via a fibreoptic transputer link to a common pre-processor (performing number crunching e.g. for multiple sampling techniques and limited on line data reduction such as image co-adding, bad pixel removal, etc.). The control LCUs and the detector pre-processor will communicate via the VLT data/control LAN with the host Instrument Workstation through which the observer will interact with the instrument.

User Interface

ISAAC will be remotely controllable from the Instrument Work Station (IWS) which could, in principle, be physically located at any place which is connected by a suitable computer link. At this IWS the observer will interact with the instrument via User Interface which is common to all the VLT instruments and through which the required observing/calibration modes and parameters will be input. The IWS will also run instrument specific software providing for a simulation mode, the generation of automatic observing sequences, maintenance checks and status display. MIDAS will also be available on-line for image display and quick-look analysis.

Development Status

Detailed design work started after the Preliminary Design Review in April 1992 and is scheduled to be completed with the Critical Design Review in summer 1993. ISAAC is a technically complex instrument. Exploiting large array detectors on a large telescope requires a large instrument which has also to be operated at cryogenic temperatures but still meets the stringent flexure requirements imposed by its rotation on the Nasmyth adapter. Because of this rotation not only control and signal cables but also the high pressure helium lines for the closed-cycle coolers and fluid lines for the electronic cooling circuit have to be routed via a cable wind system which allows for the rotation and minimizes torque on the adapter. The high background modes of ISAAC also place difficult demands on the speed of the data-acquisition system. In order to meet these various requirements, the preliminary design of ISAAC incorporates a variety of technologies for which little practical experience is available and for which sound design and analysis alone is not considered sufficient. These include the use of diamond-turned metal mirrors, stepper motors, position sensors and large-diameter bearings at cryogenic temperatures and under vacuum. In order to minimize risk therefore, we are currently prototyping the most critical functions for test in a specially designed cryogenic test facility before finalizing the design and starting the manufacture which will be largely contracted to industry.

Project and Science Teams

The ISAAC Project Team within ESO is:
- A. Moorwood, Instrument Responsible/Scientist
- P. Ballester, MIDAS reduction software
- P. Biereichel, Control and data acquisition software
- J. Brynnel, Control electronics
- B. Delabre, Optical design
- G. Finger, Detectors and system performance
- G. Huster, Mechanical design
- J.-L. Lizon, Cryogenics, integration, tests.
- M. Meyer, Detector electronics
- A. van Dijsseldonk, Instrument Manager and procurements

Members of the ISAAC external Instrumental Science Team which reports to the VLT Programme Scientist are G. Miley (Leiden, Chairman), R. Chini (Bonn), E. Oliva (Florence) and J.-L. Puget (Paris).

UVES, the UV-Visual Echelle Spectrograph for the VLT

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Overview

UVES is one of the two instruments in the VLT Instrumentation Plan being designed and built by ESO. It is a crossdispersed echelle spectrograph with a nominal resolution of 40,000 with a 1 arcsec slit. This double-beam instrument uses 22×85 cm mosaic echelle gratings, grating crossdispersers and thinned CCD detectors with 2048^2 pixels each, one for each arm. It will be mounted at the Nasmyth platform on a horizontal optical table inside a protective enclosure (Fig. 1). We are now in the preliminary design phase following the approval of the Design and Implementation Plan by the Scientific Technical Committee and Council in their May/June 1992 round of meetings. The Preliminary Design Review is planned for 20/21 April 1993. UVES will be built in two copies; the instrument schedule foresees the installation of UVES1 at the Nasmyth focus of Unit Telescope 2 in the second half of 1997, of UVES2 at UT3 about 12 months later.

Observing Capabilities

Echelle spectrographs are instruments of highest priority in all of the large telescope projects because high resolution spectroscopy is one of the observing modes which benefits most from the larger collecting area. The stellar flux is dispersed over a large number of detector elements and for objects of faint magnitudes the shot noise of the signal is comparable to the detector read-out and dark current noise. In this regime, the S/N ratio increases with the second power of the telescope diameter, and the gain in using the VLT becomes very significant. In the observations of brighter objects where the photon statistics is dominating other sources of noise, the large aperture of the telescope is still needed to achieve in reasonable exposure times very high S/N ratios and to follow spectral variations on short time scales. It is also

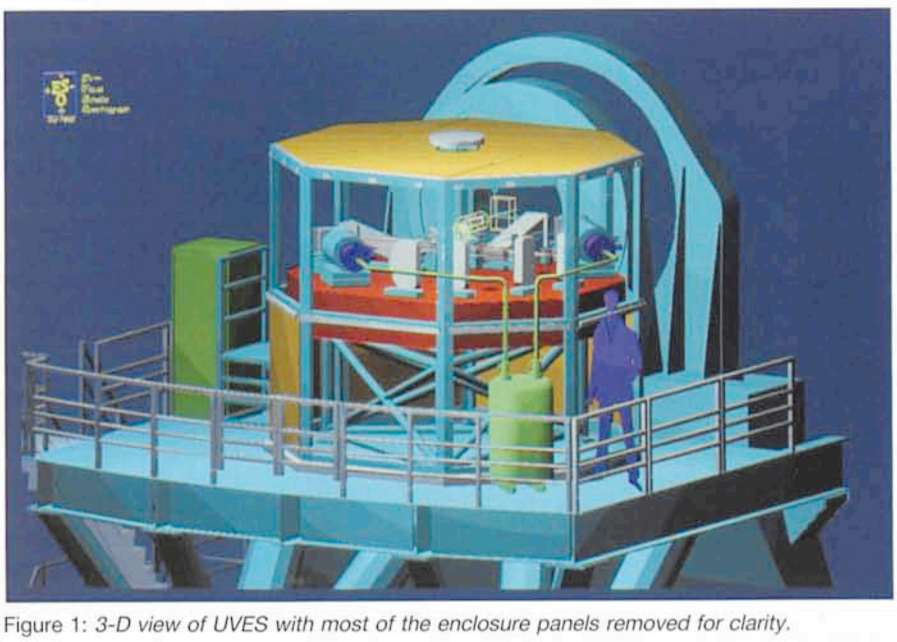

Figure 1: *3-D view of UVES with most of the enclosure panels removed for clarity.*