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# INTRODUCTION TO THE INFRARED SPACE OBSERVATORY (ISO)

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**Abstract:** The Infrared Space Observatory (ISO) is an astronomical satellite, which will operate at infrared wavelengths (2.5 – 200 $\mu$m) for a period of at least 18 months. Imaging, spectroscopic, photometric and polarimetric observations will be obtained by four scientific instruments in the focal plane of its 60-cm diameter, cryogenically-cooled telescope. Two-thirds of ISO's observing time will be available to the astronomical community. ISO is a fully approved and funded project of the European Space Agency (ESA) with a foreseen launch date of May 1993.

## 1. Introduction

IRAS, during its brief 10-month in-orbit existence, provided astronomers with their first unobscured glimpse of the infrared universe. Such was the wealth of the data – catalogues, sky maps and spectra – of this highly successful mission that now, five years later, they are still being digested, interpreted and producing fresh science. With the end of the IRAS mission, due to depletion of its liquid-helium coolant, observations of the majority of these sources are no longer possible. The Infrared Space Observatory (ISO, shown in figure 1) will give astronomers the capability of routinely making high sensitivity observations at all these wavelengths, but for detailed study of individual objects rather than as a survey mission. Compared to IRAS, ISO will have higher sensitivity – in part from improvements that have been made in detectors since IRAS, wider wavelength coverage, better angular resolution, a longer lifetime and more sophisticated instruments.

ISO results from a mission proposal submitted to ESA in 1979. After various assessments and studies, particularly a phase A study in 1981-2, ISO was chosen in March 1983 to be the next new start in the ESA Scientific Programme. The focal plane instruments were selected in mid-1985 and the industrial phase B study of the spacecraft started in December 1986. Currently, ISO is in its main development phase (C/D).

This paper presents, firstly, an overview of the ISO spacecraft (section 2) and mission operations (section 3) and secondly, a synthesis of the scientific capabilities (section 4) and detector systems of the four instruments (section 5).

## 2. Overview of Spacecraft

The ISO satellite (5.3 m high, 2.3 m wide and 2400 kg at launch) is dominated by its so-called "Payload Module", the upper cylindrical part seen in figure 1. This module, shown in section in figure 2, is essentially a large cryostat, containing the telescope and the scientific instruments. Inside the vacuum vessel is a toroidal tank filled with about 2300 litres of superfluid helium, which will provide an in-orbit lifetime of at least 18 months. Some of the infrared detectors are directly coupled to this helium tank and are at a temperature of around 2 K. Apart from these, all other units are cooled using the cold boil-off gas from the liquid helium. This gas is first routed through the optical support structure, where it cools the telescope and the scientific instruments to temperatures of 3–4 K. It is then passed along the baffles and radiation shields before being vented to space. A small auxiliary tank, containing about 60 litres of normal liquid helium, fulfils all of ISO's cooling needs for the last 72 hours before launch. Mounted on the outside of the vacuum vessel is a sunshield, which prevents the sun from shining directly on the cryostat. The solar cells are carried by this sunshield.

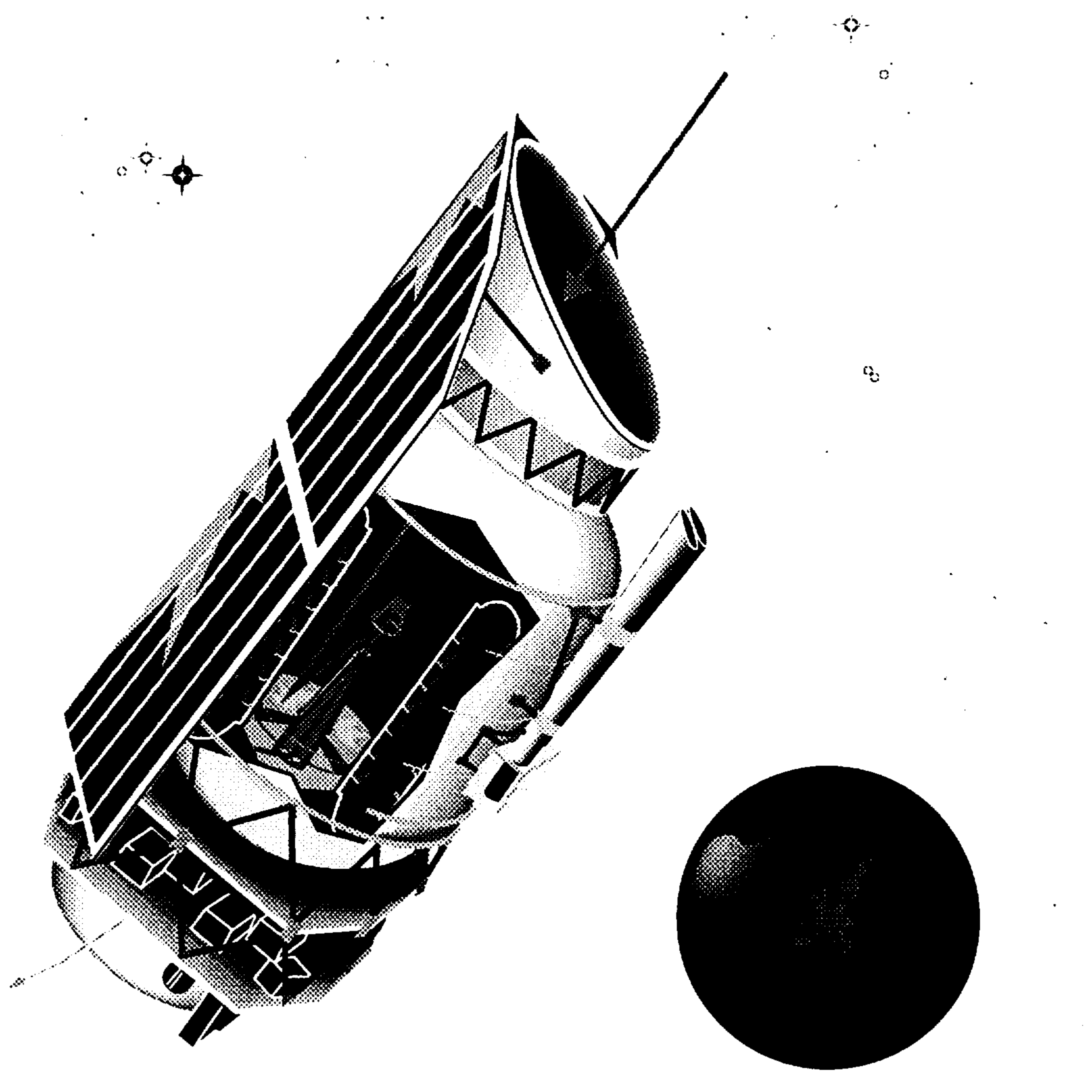

*Figure 1: Computer Graphic of ISO in Orbit*

The "classical" spacecraft functions are provided by a so-called "Service Module", which can be seen underneath the payload module in figure 1. These functions include the structure and the load path to the launcher, the solar array mounted on the sunshield, and sub-systems for thermal control, data handling, power conditioning, telemetry and telecommand (using two antennas), and attitude and orbit control. The last provides the three-axis stabilisation to an accuracy of a few arc seconds and also the raster pointing facilities needed for the mission. It consists of sun and earth sensors, star trackers, a quadrant star sensor on the telescope axis, gyros, reaction wheels and uses a hydrazine reaction control system. The nominal down-link bit rate is 33 kbps of which about 24 kbps are dedicated to the scientific instruments.

The definition study (phase B) for the ISO spacecraft was sucessfully completed early in 1988. The detailed design, development, integration and test phase (phase C/D) was started on 15 March 1988 by an industrial consortium led by Aerospatiale (F). The structure of this team is shown in figure 3. The next major milestone is the *System Design Review*, to be held in April 1989, with the aim of releasing (i) the structural and thermal model for integration and (ii) the qualification model units for manufacture. The scheduled launch date is May 1993.

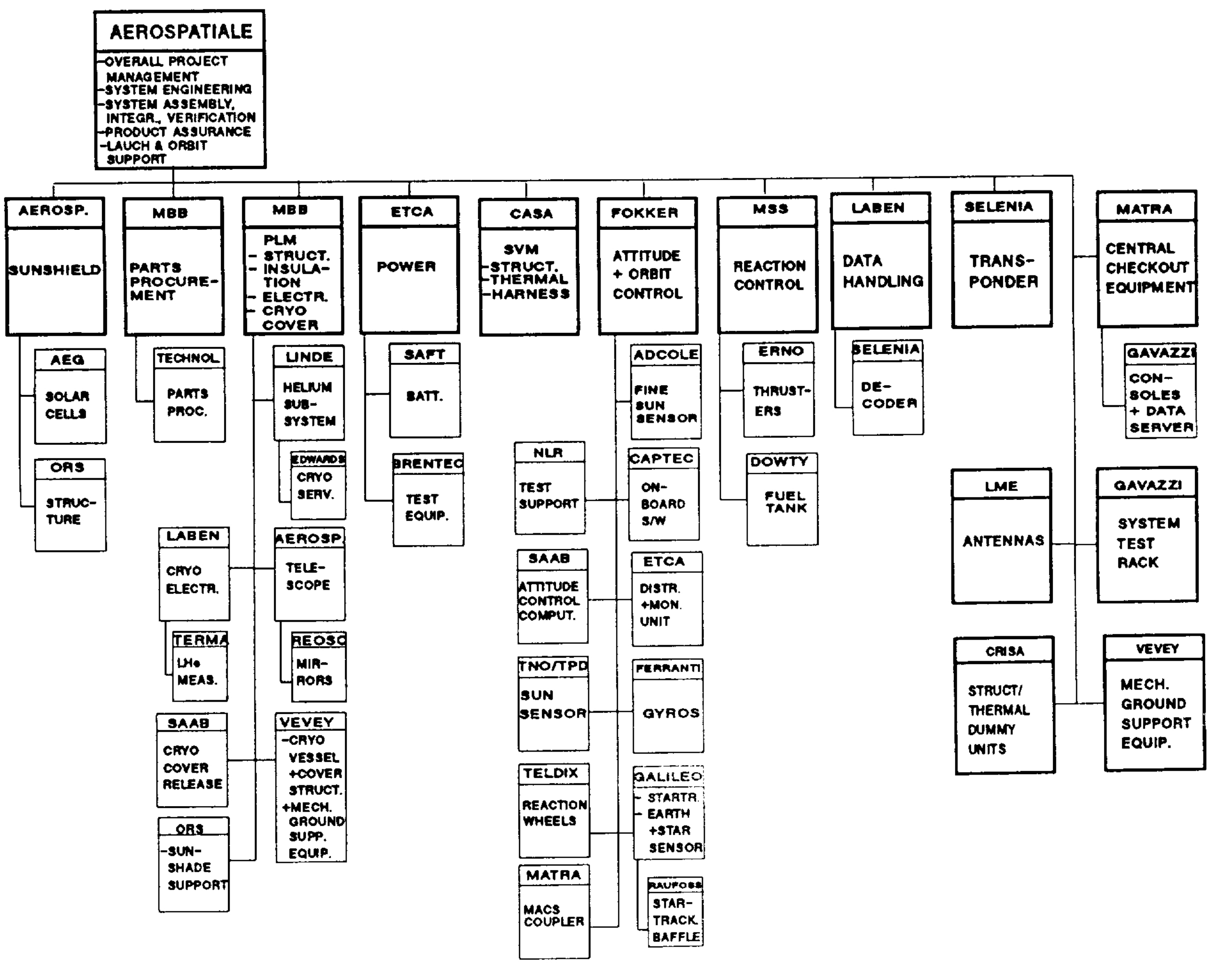


*Figure 3: ISO Industrial Organisation*

## 3. Launcher, Orbit and Operations

ISO will be launched into a transfer orbit by an Ariane-4 vehicle. Its hydrazine reaction control system will then be used to attain the operational orbit, which has a 24-hour period, a perigee height of 1000 km and an apogee height of 70000 km. The inclination to the equator will be between 5° and 20° (to be finalised later). ESA plans to supply only one ground station, enabling ISO to make astronomical observations during the best 14 hrs of each orbit. The mission's scientific return could be greatly increased by the addition of a second ground station, which would permit ISO to be operated for the entire time that it spends outside the main part of the Earth's radiation belts. An international collaboration is being sought by ESA to provide this second ground station.

Observing time on ISO will be allocated on a "per object" basis, as was the case for EXOSAT, rather than on a "per shift" basis as is done with IUE. Two-thirds of ISO's observing programme will be determined by the scientific community via the submission and selection (by peer review) of proposals. The remaining time will be reserved for the groups who provide the instruments, for the Mission Scientists and for the Observatory Team who operate the satellite. Details of observations to be carried out in this reserved time will be included in the first Call for Observing Proposals, to be issued to the scientific community 18 months before launch.

The in-orbit operations of the spacecraft and instruments will be carried out by a team of scientists and engineers located at the ISO Control Centre in Villafranca, Spain. During scientific use, the satellite will always be in contact with the ground segment; however, it is planned to minimise real time modifications to the observing programme in order to maximise the overall efficiency of the satellite. A "quick-look" output, adequate for judging the scientific quality of the data, will be produced within a few hours of an observation being completed. A final product with more detailed data reduction and calibration will be supplied later. This product will be the one from which the guest observers make their astronomical analyses.

## 4. Scientific Capabilities of Instruments

The ISO scientific payload consists of four instruments: a camera (ISOCAM, PI: C.J. Cesarsky), an imaging photo-polarimeter (ISOPHOT, PI: D. Lemke), a long wavelength spectrometer (LWS, PI: P.E. Clegg) and a short wavelength spectrometer (SWS, PI: Th. de Graauw). Each instrument is being developed by a consortium of institutes, using national funding, under the authority of the Principal Investigator (PI). The scientific capabilities, provided jointly by these instruments, can be summarised in three categories: photometry/polarimetry, imaging and spectroscopy.

**Photometry** and **Polarimetry** will be possible in broad and narrow spectral bands across ISO's entire wavelength range from 2.5 to 200$\mu$m. Work using multiple apertures will be possible out to 110$\mu$m.

Suspended in the middle of the main helium tank is the telescope, which has a Ritchey-Chrétien configuration with an effective aperture of 60 cm and an overall f/ratio of 15. A weight-relieved fused-silica primary mirror and a solid fused-silica secondary mirror have been selected as the telescope optics. The optical quality of these mirrors is adequate for diffraction-limited performance at a wavelength of 5 $\mu$m. Stringent control of stray light, particularly from bright infrared sources outside the telescope's field of view, is necessary in order to ensure that the system sensitivity is not degraded. This control is accomplished by imposition of viewing constraints and by means of the sunshade, the cassegrain and main baffles, and an additional light-tight shield around the instruments.

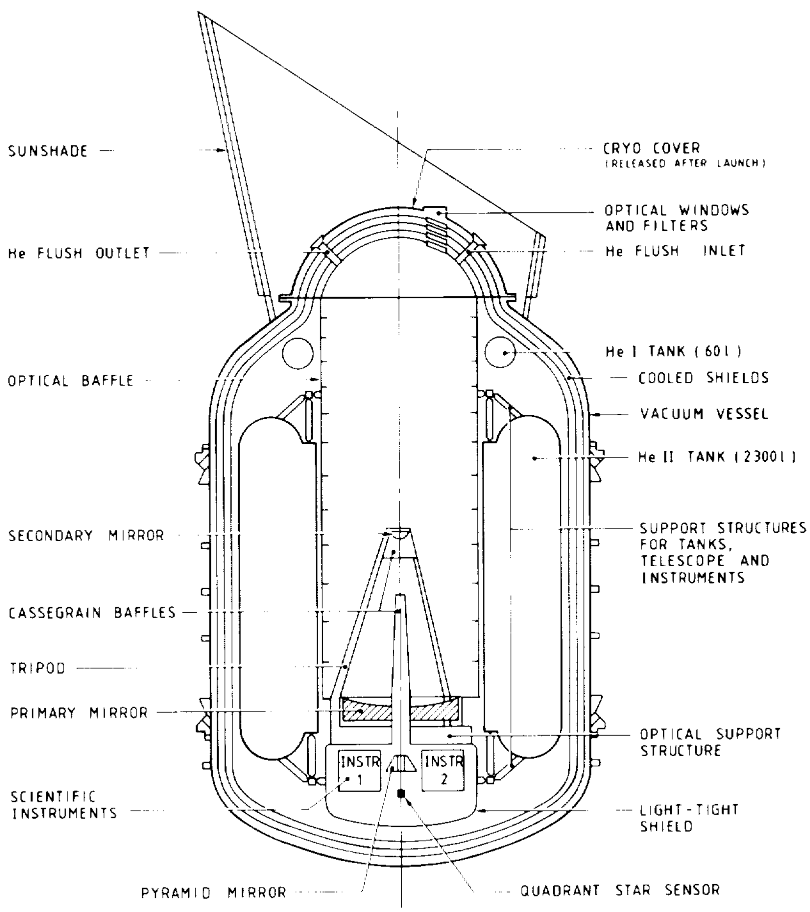


*Figure 2: Schematic of the Payload Module*

The scientific instruments are mounted on the opposite side of the optical support structure to the primary mirror, each one occupying an 80° segment of the cylindrical volume available. The 20 arc minute total unvignetted field of view of the telescope is split up between the four instruments by a pyramidal mirror. Thus, each instrument simultaneously receives a 3 arc minute unvignetted field centred on an axis at an angle of 8.5 arc minutes to the telescope optical axis. To view the same target with different instruments, the satellite has to be repointed.

ISO will be capable of **imaging** in broad and narrow spectral bands across its entire wavelength range from 2.5 to 200$\mu$m. The number of pixels and the pixel field of view vary as a function of wavelength. Details are given in table 1 below.

| Wavelength Range ($\mu$m) | No. of Pixels | Pixel f.o.v. (arc secs) |
|---|---|---|
| 2.5–5 | 32x32 | 1.5, 3, 6, 12 |
| 5–17 | 32x32 | 1.5, 3, 6, 12 |
| 18–28 | 8x8 | 19 |
| 30–60 | 3x5 | 31 |
| 60–120 | 3x3 | 44 |
| 120–200 | 2x2 | 90 |

*Table 1: ISO's Imaging Capability.*

For **Spectroscopy**, various resolutions will be available at different wavelengths. Details are given in table 2 below.

| Wavelength Range ($\mu$m) | Resolution ($\lambda/\Delta\lambda$) | Instrument |
|---|---|---|
| 2.5–12 | 90 | ISOPHOT-S |
| 2.5–16.5 | 50 | ISOCAM-CVF |
| 2.5–45 | 2000 | SWS-Grating |
| 14–30 | 20000 | SWS-FP |
| 45–180 | 200 | LWS-Grating |
| 45–180 | 10000 | LWS-FP |

*Table 2: ISO's Spectroscopic Capability.*

In principle, only one of the four instruments will be operated at a time; however, when ISOCAM is not the main instrument, it can be used in a so-called "parallel" mode either to gain extra astronomical data or to assist the other instruments in acquiring and tracking their targets. Whenever possible during satellite slews, ISOPHOT will be operated in its normal 200$\mu$m mode so as to make a partial sky survey ("serendipity mode") at these wavelengths which were not covered by IRAS.

## 5. Outline Description of Scientific Instruments and Detector Systems

The ISOCAM instrument consists of two optical channels, each with a 32 x 32 element detector array, operating, respectively, in the wavelength ranges 2.5–5$\mu$m and 5–17$\mu$m. Each channel contains a wheel for selecting various filters (including circular variable filters, CVF) and a second wheel for choosing a pixel field of view of 1.5, 3, 6, or 12. Polarisers are mounted on an entrance wheel common to both channels. A sixth wheel carries mirrors for selecting between the channels, of which only one is operational at a time.

| | | Number of Elements and "Read-out" | | | |
|---|---|---|---|---|---|
| Material | Manufacturer | ISOCAM | ISOPHOT | LWS | SWS |
| InSb<br>InSb | SAT, France<br>Cincinnati, USA | 32×32, CID<br>— | —<br>— | —<br>— | —<br>1×12, IA-12 |
| Si:Ga<br>Si:Ga | LETI-LIR, France<br>Battelle, Germany | 32×32, DRO<br>— | —<br>1×64, CRE-66<br>1×64, CRE-66<br>1 individual, CRE-1 | —<br>— | —<br>1×12, IA-12 |
| Si:P | Battelle, Germany | — | 8×8, CRE-66<br>1 individual, CRE-1 | — | 1×12, IA-12<br>2 individual, JF-4 |
| Ge:Be | Battelle, Germany | — | 3×5, CRE-18 | 1 individual, JF-4<br>(non-destructive) | 1×12, IA-12<br>2 individual, JF-4 |
| Ge:Ga | Battelle, Germany | — | 3×3, CRE-18<br>1 individual, CRE-1 | 5 individual, JF-4<br>(non-destructive) | — |
| Ge:Ga (str) | Battelle, Germany | — | 2×2, CRE-1/4 | 4 individual, JF-4<br>(non-destructive) | — |

*Table 3: Baseline ISO Detector Systems*

The ISOPHOT instrument consists of four sub-systems:
- ISOPHOT-C: a photopolarimeter which also provides imaging capability at close to the diffraction limit in the wavelength range from 30 $\mu$m to 200 $\mu$m,
- ISOPHOT-P: a multi-band, multi-aperture photopolarimeter for the wavelength range from 30 $\mu$m to 110 $\mu$m,
- ISOPHOT-A: an multi-band array of 8 x 8 discrete elements for the wavelength range from $\sim$12 $\mu$m to 28 $\mu$m,
- ISOPHOT-S: a dual grating spectrophotometermeter which simultaneously provides a resolving power of $\sim$90 in two wavelength bands 2.5–5 $\mu$m and 6–12 $\mu$m.

A focal plane chopper with a beam throw of up to 3′ is also included in ISOPHOT.

The LWS instrument consists of a reflection diffraction grating used in two orders with an array of discrete detectors to provide a spectral resolving power of $\sim$200 over the wavelength range from 45 $\mu$m to 180 $\mu$m. Either of two Fabry-Pérot interferometers can be rotated into the beam to increase the resolving power to $\sim 10^4$ across the entire wavelength range.

The SWS instrument provides a resolving power of between 1000 and 2000 across the wavelength range from 2.4 $\mu$m to 45 $\mu$m by means of two reflection diffraction gratings used in 1st, 2nd and 3rd orders. Filters for order-sorting are placed at the instrument's various entrance apertures. Over a part (14–30 $\mu$m) of the SWS's operating range, the resolution can be increased to $\sim 2 \times 10^4$ by directing the incident radiation through either of two Fabry-Pérot interferometers.

Each of the instruments contains a variety of detector and read-out systems from various manufacturers. A summary is given in table 3 below; further details may be found in companion papers in this volume.

The first models of all the instruments (alignment, mass and thermal model) have been completed and are either already delivered to ESA or are undergoing final checks (vibration testing at liquid-helium temperatures) prior to delivery. The production of the second instrument models (engineering qulaification model) is well advanced and the due date for delivery to ESA is spring 1990.

## 6. Conclusion

ISO is a fully-approved and funded mission, which will offer astronomers unique and unprecendented observing opportunities in the infrared spectral region for a period of at least 18 months. Both the spacecraft and its selected complement of instruments are in their main development phase and the scheduled launch date is May 1993.