The Infrared Space Observatory Camera

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Abstract. At the focal plane of the ISO 60 cm telescope, ISOCAM will take images of the sky in the wavelength range 2.5 to 17 µm. It will make maps at various spatial and spectral resolutions, and at high sensitivity (at > 4 µm, < 1mJy/10 σ in 200 sec). It features two 32x32 infrared array detectors: an InSb CID for the 2.5-5.5 µm range, and a Si:Ga DVR for the 4-17 µm range. Four different pixel fields of view are available on each channel: 1,5, 3, 6 and 12". The spectral range can be selected in each channel by a set of about 10 fixed band-pass filters (resolution from 2 to 100) and continuous variable filters (resolution ≈45); polarisation measurements are possible as well.
A very wide range of astrophysical problems can be tackled with ISOCAM. We present a brief description of the programme planned by the ISOCAM team in its guaranteed time.

1. INTRODUCTION

In 1983, just as the first results of IRAS were presented to the European astronomical community, the decision was taken at the European Space Agency to fly a second generation infrared cryogenic satellite, ISO (the Infrared Space Observatory). While IRAS was scanning the whole sky in four colours, ISO was destined to perform detailed studies of selected regions, with better angular resolution, wider wavelength coverage, enhanced imaging and spectroscopic capabilities, and a higher sensitivity.

Four instruments will be placed in the focal plane of the ISO telescope: a camera (ISOCAM), a photometer (ISOPHOT), and two spectrometers (SWS and LWS), which, together, cover the range 2.5 to 200 μm. This paper is devoted to a description of ISOCAM, which will be the first astronomical space infrared camera using array detectors.

ISOCAM is a two-way camera, featuring two (32x32) array detectors, one for short wavelengths (SW, 2.5 to 5.5 μm), the other for long wavelengths (4 to 17 μm). On each channel, there are two wheels, one carrying four lenses, allowing four different pixels fields of view (1.5", 3", 6", 12"), and the other carrying 10 to 12 fixed filters and one or two CVF, allowing to reach a spectral resolution ~ 45. A wheel at the entrance has four positions: 3 polarizers and a hole. A selection wheel carries Fabry mirrors which can direct the light beam of the ISO telescope towards one or the other of the detectors, or illuminate them uniformly with an internal calibration source, for flat field purposes. The layout of ISOCAM is shown on Figure 1.

With exposures of a few minutes, the long wavelength detector will easily detect sources at the sub-mJy level, and the short wavelength channel sources at the mJy range. With longer exposures, the sensitivity of the long wavelength channel will be limited, in most filters, by the flat field accuracy achievable, given the presence of the zodiacal background; then it will be necessary, as in ground observations, to use beam switching or microscanning techniques.

The development of ISOCAM has lasted seven years, involving over one hundred and fifty scientists, engineers and technicians. Table I and II list the hardware responsibility share among the laboratories, the co-investigators and scientific associates, and some of the key people. About the co-investigators, it is worth mentioning also that D. Rouan is responsible for the short wavelength channel, and D. Cesarsky for the software ; M. Pérault, after S. Cazès, is in charge of the calibration and L. Nordh of the filters.

Today, the flight model of the camera, duly tested and calibrated, has been delivered to the European Space Agency and integrated in the Payload Module of the satellite (Figs. 2 and 3); the first tests at helium temperature have given excellent results. The expected launch date of the ISO satellite is September 1995. I summarize here the main characteristics of ISOCAM, and sketch the scientific programme that the ISOCAM consortium intends to cover in its guaranteed observing time (6.25% of the total observing time of the satellite).

2. *ISOCAM* CHARACTERISTICS.

I give here a brief description of the instrument. A more detailed presentation of ISOCAM, and of the results of the Flight Model Calibration can be found in Cesarsky et al. (1994) and in Pérault et al. (1994).

ISOCAM is composed of 4 units :

- a 9 kg opto-mechanical unit, to be implemented at 3 K in the focal plane of the cryogenic telescope,

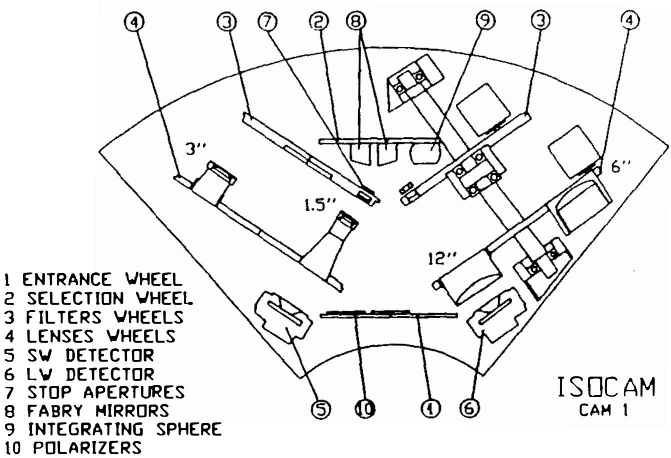

Figure 1. Schematic lay-out of the IR camera, ISOCAM. The optical beam enters in the camera through the entrance wheel and can be directed to a short or a long wavelength channel by field mirrors fixed on the selection wheel. Each channel includes a filter wheel and a lens wheel.

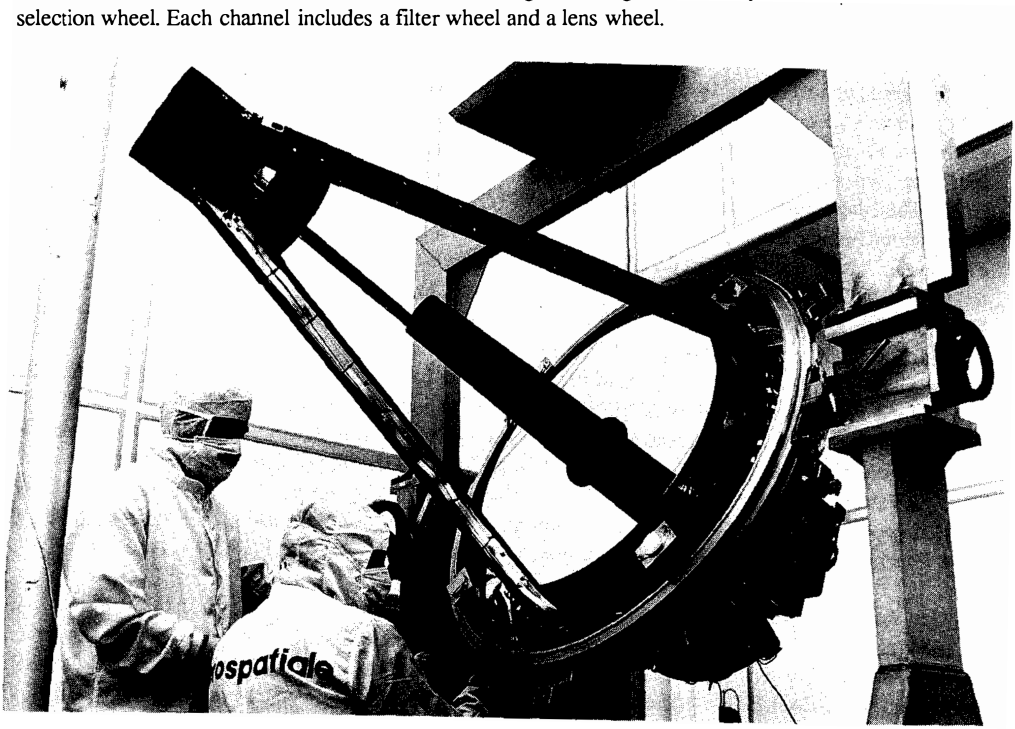

Figure 2. The Infrared Space Observatory telescope.

including 2 detectors and 6 wheels on which are mounted the optical components and the internal calibration device.
- a 2 kg pre-amplifier unit, fitted to the external wall of the cryostat as close as possible from the detectors, and working at 140K
- two 6 kg electrocnis units, implemented on the satellite service module, for instrument control and transmission to the ground of up to one 32x32 image every 2 seconds.

Much development work was necessary for the focal plane unit (Fig. 4), which has to satisfy stringent constraints: reliable operations at a temperature below 2.4 K, position accuracies of typically 100 microns, angular accuracy in the milliradian range, a mean thermal dissipation lower than 10 mW with peak dissipation below 50 mW. I briefly describe some of the solutions adopted.

a) *Cryomechanisms*

The ISOCAM mechanisms must whithstand difficult constraints, cryogenic temperature, high reliability, low dissipation, and good positioning accuracy. Of course, they must be designed to survive the high level of vibrations during launch. To save development time, we based the design of these mechanisms around a superconductor stepper motor developped by SAGEM which was already space qualified. The drawback of this solution was the small number of steps per turn, 24, and the high current required to drive the motor. A demultiplication gear train is required between the wheel and the motor to ensure the positioning of optical components. This is provided by a pinion on the motor axle driving the wheel through a gear on the edge of the wheel.

b) *Optics*

A very simple optical design has been adopted, where the beam intersects a Fabry mirror. The radius of the Fabry mirror (5.5 cm) is such that the pupil, 2.6 cm from the Fabry mirror, has a size of 1.7 mm. The filters or CVF are in the plane of the pupil, and the sky is then reimaged on the detector through one of the four relay lenses.

The filters have been manufactured by SPECTROGON, under the supervision of the Stockholm Observatory, which has verified that they adequately block the light out of their required range. Their transmissions have been .ieasured in the ISOCAM test facility at ROE, after having been mounted in their holders by AEROSPATIALE. The filters are tilted by 5°, to avoid ghosts due to reflections between the filters and the detectors. The mounting of the CVF, which have very fragile substrates, was a particularly difficult task, and it was not possible to tilt them.

The overall optical performance of the optical bench of ISOCAM was tested at AEROSPATIALE, in a specific facility, using individual Si:Ga detectors arranged in the shape of a cross (Astruc et al. 1991). These tests also allowed to determine the position at which the array detectors had to be integrated. The fully integrated camera was only tested at Orsay, in the ISOCAL facility designed for this purpose.

Overall, the image quality results of the flight model (Vigroux et al. 1993, Pérault et al. 1994) showed good agreement with expectations, showing that AEROSPATIALE had succeeded in satisfying the tight wheel positioning specifications and that the opto-mechanical design of ISOCAM is robust.

c) *The long wavelength detector*

In 1984, at the time of the ESA Call for Proposals for the ISO satellite, there was no detector available in Europe for the long wavelength channel. A specific development was undertaken at the Laboratoire Infrarouge du CEA-LETI in Grenoble (Agnèse et al. 1989). It is a photoconductor array in Si:Ga hybridized by Indium bumps to a direct voltage readout circuit. It has 32x32 pixels, a 100 μm pitch with a thickness of 500 μm. The dopant concentration is 5 10^{16}cm^3, giving a resistivity of $10^{13}\Omega$ cm^{-2}. To

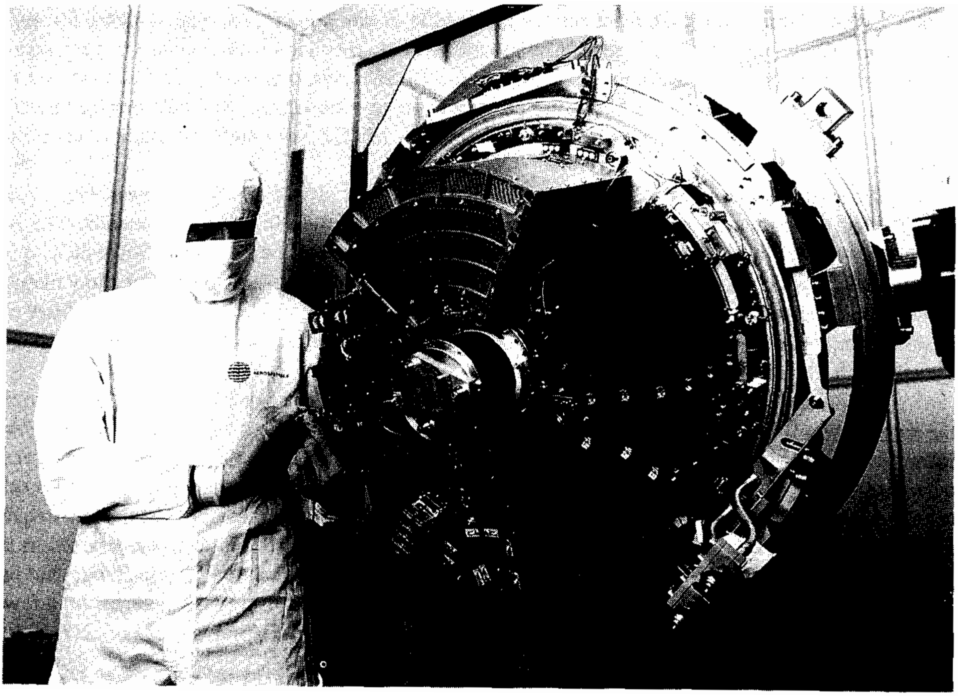

Figure 3. The four instruments mounted in the focal plane of the ISO telescope .

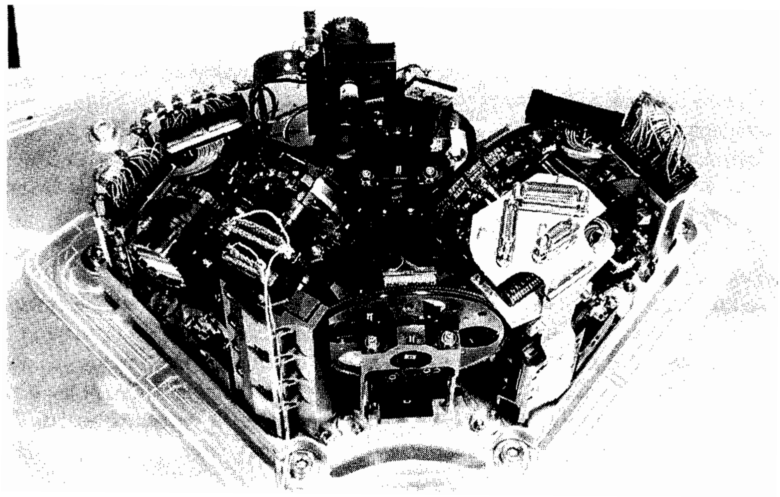

Figure 4. Focal plane unit of the ISOCAM flight model.

obtain a 100% filling factor, the front surface is doped to ensure a good electrical conductivity and the photoconductor voltage is applied to an Aluminium frame on the side of the optical sensitive area. An external guard, 3 pixel wide, has been added around the 32x32 arrays to prevent field line distortion at the edges. Despite the absence of a front grid, this detector has a very low optical crosstalk. For the fastest lens of the camera, the 12" lens which has a numerical aperture of f/0.6, the optical crosstalk remains below 1.5%.

The readout circuit has an integration capacitance of 0.12 pF and a MOS follower with a gain of 0.8. Typical individual integration times in flight will be between 0.2 and 20 seconds. The noise characteristics of this system present several components, a high frequency term which is well approximated by a constant readout noise of ~ 180 $e^{-} px^{-1}$ and photon shot noise , and a low frequency noise which becomes important after ~ 50 readouts. At high level, $>10^{6} e^{-} px^{-1}$, an amplifier noise becomes preponderant and limits the Signal to Noise ratio to < 500 in a single image. The corresponding sensitivity, for twenty 10 sec exposures, is shown in fig. 5.

The flat fielding accuracy can be as good as $5\ 10^{-3}$ when the detector is stabilized. The flat field of the detector was found to be very stable all along the calibration ; this allows the use of a flat field library, instead of loosing observing time by making flat field calibration with the internal calibration device at each new observation. However, a limitation comes from the differential stabilization times between pixels in the array, which can be quite long. A good way to remove these small effects, as well as the low frequency noise mentioned earlier (which in fact may be related to these effects), is to use a beam switching procedure, switching the pointing from the source to an adjacent background, as is done on ground based telescopes. Alternatively, a microscanning procedure can be used, displacing the detector by a few arc seconds on the sky every few images ; this can be realized using the raster pointing mode of ISO.

d) *The short wavelength detector*

For the short wavelength channel, the basic device is a 32x32 pixels CID InSb array manufactured by the Société Anonyme de Télécommunications. At the time of ISOCAM selection, this detector was already qualified and presented the advantages of a low operating temperature and a large radiation tolerance, compatible with the ISO mission. Upgrades of the existing devices have been made along several tracks : increase of the pixel pitch up to 100 µm, increment of the surface filling factor to 89%, and a new design of the supporting ceramic to reduce electrical cross talk. A control and readout hybrid electronic was designed to work at 4 K close to the chip (Tiphène et al. 1989).

Measurements of the pixel charge can be done by sensing the voltages of the 32 output lines and sequentially injecting the pixel charges in the substrate through column voltage clocks. The analog chain uses an adaptive filter followeds by high gain preamplifiers. The sensitivity of this channel for point sources is displayed in Fig. 6.

e) *The internal calibration device*

The internal calibration device was designed to provide an internal flat field source, and a rough calibration reference. Calibration of the SW channel required sources near 350K which are difficult to fit in the low thermal dissipation allocation of ISO. The solution is a small resistor, 0.6 mm^{2}, mounted on a thin kapton film. These devices have been used all along the int'egration and calibration phases of the flight model, on a 1 year and a half time scale. During this period, a routine monitoring of the instrument has shown that the reproducibility of the calibration system is better than 10%, in all the configurations of ISOCAM, channels, filters and lenses.

f) ***Electrical design***

The electrical architecture is standard for a space experiment. It is organized around a 16 bit 80C86 microprocessor, powered by hybrid DC/DC converters using the satellite 28 volt power line. Redundancy is obtained by mounting two independent microprocessor units and DC/DC units which can be selected by external switches.

3. OBSERVING WITH *ISOCAM*

A very wide range of astrophysical problems can be tackled with ISOCAM. As the ISO satellite will be offered to the general astronomical community 2/3 of the time, I am sure that the readers of these proceedings already have their own ideas as to the problems they will wish to address; the ISO Call for Proposals will be issued in April 1994. As examples, I can give the outline of the programme that the ISOCAM team plans to perform in its guaranteed time. The rationale followed to establish this programme was to identify projects of a general or fundamental character, which take advantage of the specific capabilities of ISOCAM.

The ISOCAM Central Programme is divided into five sections.

The first section deals with solar system studies. There, we plan to investigate the structure of the zodiacal bands and of cometary trails, and to make spectral maps of comets. The goal is to study temperature distribution, sizes and albedos of grains, and the composition of the comet material.

The second section covers interstellar matter and star formation. We intend to obtain spectrophotometric data or CVF spectra of various components of the interstellar medium in various radiation environments. The aim is to ascertain that the 12 µm emission from the interstellar medium detected by IRAS is indeed due to "unidentified bands" emitted by small particles, and to understand the excitation conditions leading to this emission in various environments. We also want to map supernova remnants, old ones such as IC 443 and young ones such as Cas A, to study grain formation and destruction, and the interaction between supernovae and the interstellar medium. Finally, we plan to map large areas of nearby molecular clouds, to study the emission from dust and large molecules, and to search for protostellar objects and pre main sequence stars.

The third section, devoted to stars and circumstellar material, starts with specific observations of known young stellar objects as L1551, which are emitting strong winds. The goal is to combine ISOCAM and ISOPHOT observations to reduce the uncertainties in wind energetics, and better explain the collimation of the molecular outflow and its interaction with the interstellar medium. We also want to understand the nature of the extended 12 µm emission observed by IRAS around young stellar objects in the ρ Ophiuchi cloud. Our next proposal deals with observations of nearby stars, such as Vega, which have an excess infrared emission indicative of the presence of a dust disk around the star. We also plan to do spectral mapping of planetary and proto-planetary nebulae, in particular to study the faint, outer regions which cannot be detected by other instruments, and which are witnesses to the earlier phases of mass loss. All these studies will be complemented by polaro-imaging of different components of the interstellar and circumstellar dust, including the galactic centre region.

The fourth section deals with galaxies. A first part is devoted to nearby galaxies, where we will study star forming regions and compare the results with those obtained for galactic regions, with different

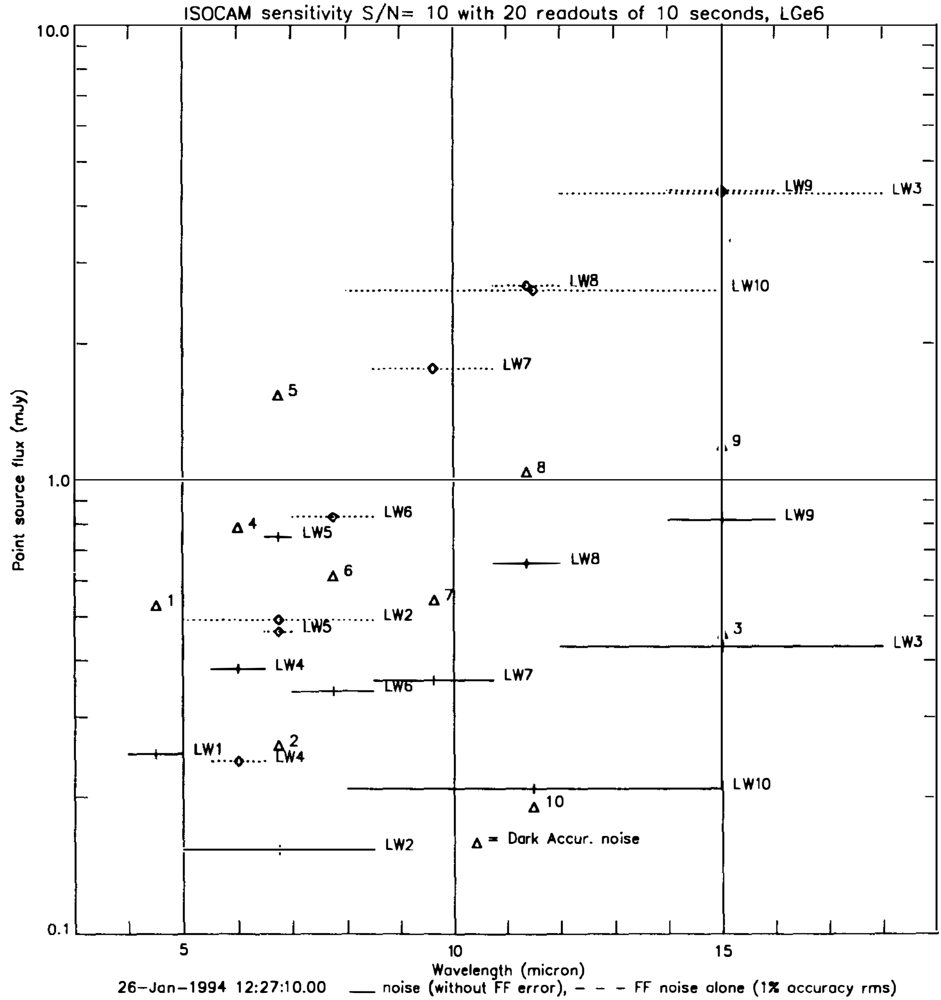

Figure 5. Point source flux giving a signal to noise ratio of 10, for all Long Wavelength filters, for 20 individual integrations of 10 s, and a 6" pixel field of view. The full line represents the sensitivity if the only limitation is the readout noise; the triangles represent the noise for standard dark frames (lower dark noises can be obtained, but at the expense of extra observing time), and the pointed lines the flat field noise for observations towards the ecliptic pole, with a 1% flat field accuracy (rms).

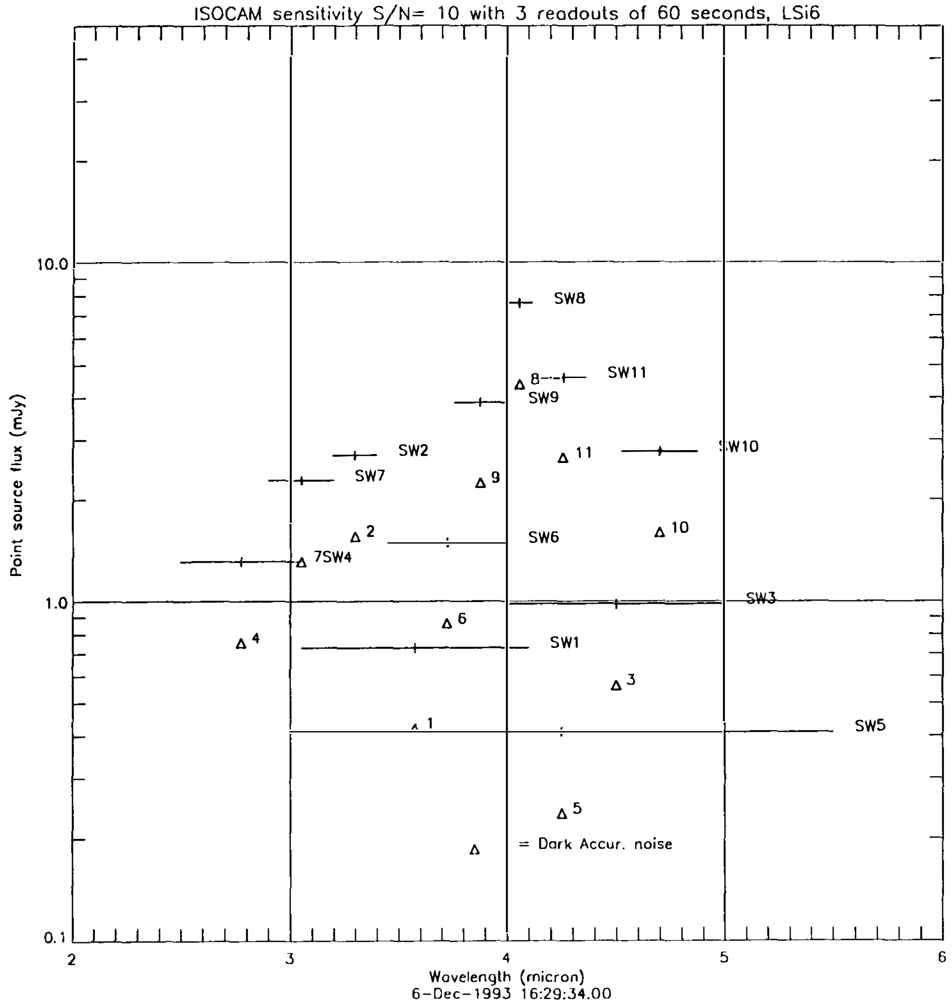

Figure 6. Point source flux giving a signal to noise ratio of 10, for all Short Wavelength filters, for 3 individual integrations of 60 minutes, and a 6" pixel field of view. At these wavelenghs, the flat field noise due to the zodiacal background is negligible. The triangles represent the standard dark noise.

chemical composition and stellar content. The second proposal, well co-ordinated with ISOPHOT, is devoted to a study of nearby normal galaxies: a variety of "typical" spirals and irregulars, spanning a large range of metallicities and physical conditions, will be mapped. The intention is to also observe a sample of galaxies in the Virgo cluster. The following proposals deal with barred galaxies which may be particularly prone to starbursts, and with early type galaxies, to study dust emission in cooling flows, and star formation in some elliptical galaxies. Several active and starburst galaxies will also be mapped; and an attempt will be made to detect an infrared halo, due to brown dwarfs, above or at the side of the disk of an edge on spiral galaxy.

The fifth section is devoted to cosmology. ISOCAM will carry out deep surveys in chosen regions of the sky, devoid of cirrus; the aim is to establish the luminosity function of galaxies and active nuclei in spectral intervals where it is unknown at present. The waveband of the ISOCAM long wavelength channel is particularly well suited for the study of faint active galactic nuclei; this mid-infrared range may be in fact the only one where it is possible to pick out the nuclear component, without being hampered by the stellar and dust emission from the galaxy. The deep surveys in empty fields will be complemented by deep surveys of clusters of galaxies at various distances, up to $z \sim 1$. The results will be useful for studies of galaxy evolution, and in particular for an assessment of the frequency of galaxy encounters and starbursts at various epochs in various environments. All these surveys will be supplemented with measurements in the far infrared with ISOPHOT.

Finally, ISOCAM may detect *brown dwarfs* in the solar neighbourhood and in star-forming regions, or, at least, set meaningful upper limits on their number.

4. CONCLUSION

ISOCAM is the first of a new generation of complex infrared instruments, featuring infrared arrays, to be used on a cryogenic spacecraft. The original scientific specifications were challenging in several domains, detector performance, cryomechanics, and optical design with regards to the severe constraints imposed by ISO. Most of the difficulties has been overcome during definition studies and during the testing of the qualification model. Minor modifications to improve stray light have been implemented after the first optical tests of the flight model. After the calibration of the flight model, we know that ISOCAM performances are within the expected range to carry out the scientific programs for which it has been designed, and hope that it will provide interesting results, not only to the ISOCAM team, but to the whole international astronomical community.

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Table 1

ISOCAM Hardware Responsibilities

SAp-Saclay

Principal Investigator:	C. Cesarsky
Project Manager:	D. Imbault
System Engineer:	L. Vigroux

Management
Long wavelength detector
Read out electronics
Instrument command electronics

Meudon Observatory

Short wavelength detector
Read out electronics
On board calibration source

I.A.S. Orsay

Integration and calibration facility

R.O.E. Edinburgh

Optical concept
Optical components

Stockholm Observatory

Filters

Italian laboratories (TESRE, Padova Observatory)

Equipment for ground support equipment and for observatory ground segment

The optical bench was subcontracted to AEROSPATIALE.
The SW detector was manufactured by the Société Anonyme de Télécommunications.
The LW detector was manufactured by the LIR/LETI.

Table 2

ISOCAM Scientific Team

Principal Investigator: C. Cesarsky (SAp, Saclay) **Co-Investigators**		**Scientific Associates**	
S. Cazes+	IAS Orsay	A. Abergel	IAS Orsay
D. Cesarsky	IAS Orsay	C. Bonoli	Padova Observatory
A. Chedin	L.M.D.	O. Boulade	SAp, Saclay
M. Combes	Meudon Observatory	F. Boulanger	IAS Orsay
M.S. Longair	ROE	M. Casali	ROE
A. Franceschini	Padova Observatory	L. Danese	Padova Observatory
M. Gorisse	SAp, Saclay	J.K. Davies	ROE
T. Hawarden	ROE	X. Desert	IAS Orsay
P. Lena	Meudon Observatory	F. Lacombe	Meudon Observatory
R. Mandolesi	TESRE Bologna	P.O. Lagage	SAp, Saclay
L. Nordh	Stockholm Observ.	J. Lequeux	ENS Paris
M. Perault	ENS Paris	G. Olofsson	Stockholm Observ.
P. Persi	IAS Frascati		
D. Rouan	Meudon Observatory		
A. Sargent	Caltech, USA		
F. Sibille (proj. sci.)	Lyon Observatory		
L. Vigroux	SAp, Saclay		
R. Wade	ROE		