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STATUS OF THE ISOPHOT DETECTOR DEVELOPMENT

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Abstract

ISOPHOT is one of the four focal plane experiments of the European Space Agency's Infrared Space Observatory ISO[1]. Scheduled for a 1993 launch it will operate extrinsic silicon and germanium photoconductors at low temperature and low background during the >18 months mission. These detectors cover the wavelength range from 2.5 to 200 μm and are used both as single elements and in arrays. A cryogenic preamplifier has been developed to read out a total number of 223 detector pixels.

Overview

The ISO observatory comprises four instruments: a camera ISOCAM[2] for $\lambda < 20\,\mu m$, two spectrometers SWS[3] and LWS[4] and ISOPHOT which consists of four subexperiments:

ISOPHOT - P	a photo-polarimeter with selectable apertures and spectral bands, $\lambda = 3 \ldots 120\,\mu m$,
ISOPHOT - A	a camera with selectable spectral bands, $\lambda = 8 \ldots 30\,\mu m$,
ISOPHOT - C	a three channel far infrared camera with selectable spectral bands, $\lambda = 30 \ldots 200\,\mu m$ and polarimetry,
ISOPHOT - S	a dual channel Ebert-Fastie spectrometer, $\lambda = 2.5 \ldots 5\,\mu m$ and $\lambda = 6 \ldots 12\,\mu m$, spectral resolution ~90.

The configuration of the experiment is shown in figure 1. A more detailed description of the experiment and its scientific goals has been given elsewhere[5]. The hardware phase C/D of the project has been started in 1988. The first model is the alignment-mass-thermal-model AMTM, which was delivered to ESA in March 1989. The engineering-qualification model is currently built and is due in March 1990; the flight model follows a year after that. The project is nationally funded in Germany by the Bundesminister für Forschung und Technologie, BMFT. The overall responsibility is with the Max-Planck-Institut für Astronomie, Heidelberg (MPIA), which also leads the scientific consortium including co-investigators of institutes in England, Denmark, Spain, Ireland and the United States. The industrial contract of phase C/D is managed by the Deutsche Forschungsanstalt für Luft- und Raumfahrt, DLR. The project's organisation is shown in figure 2.

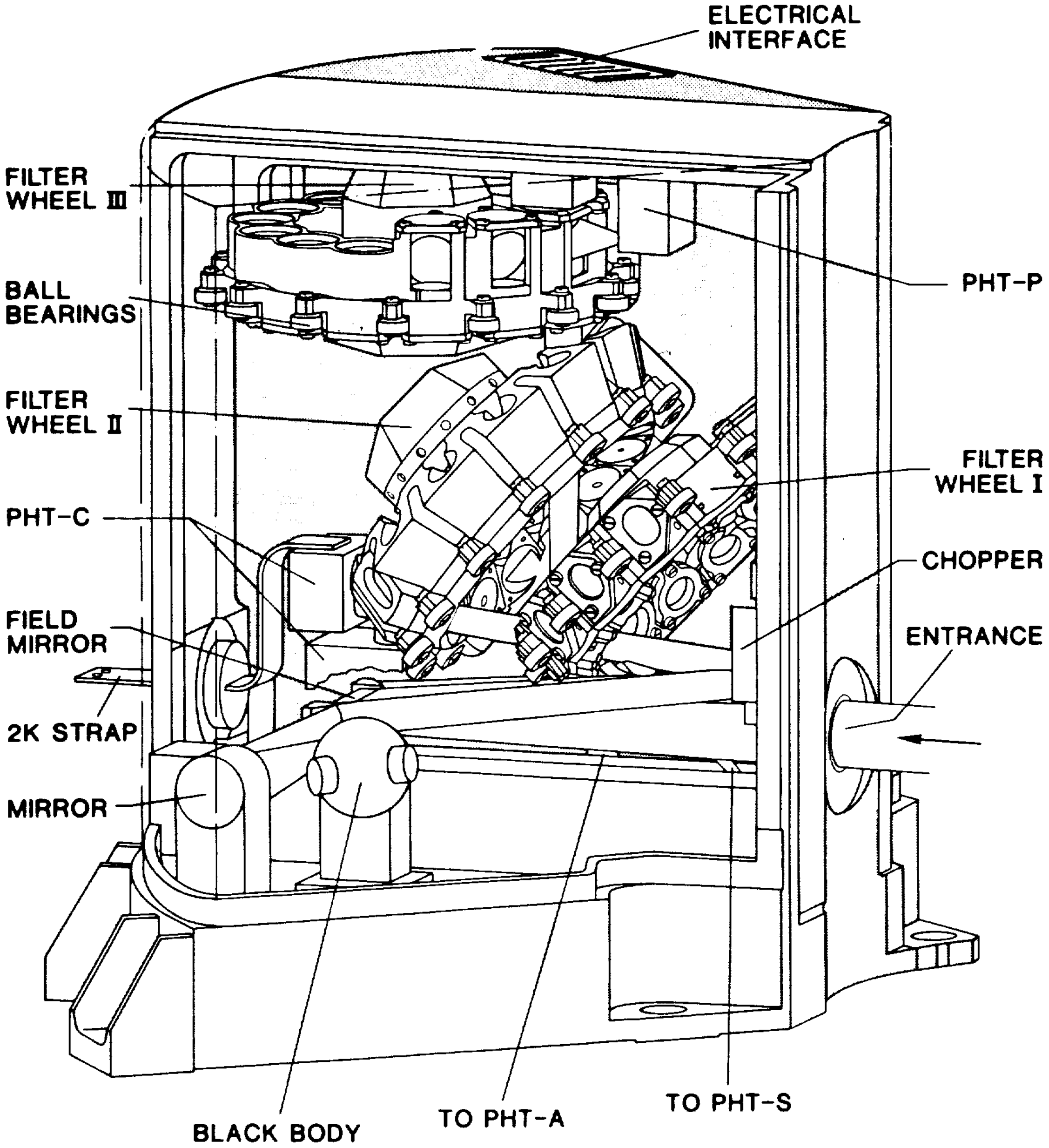

Figure 1 **ISOPHOT Configuration**

The telescope beam coming from the central pyramid mirror in the instrument chamber is distributed to the four subexperiments by three change wheels carrying mirrors, filters, field stops and polarizers. The germanium detectors of -C and -P are connected directly to the LHe-tank with a 2K–cold strap. A folcal plane chopper is used for differential measurements on the sky and, with larger throw, to deflect the beam of a blackbody radiation sources to the detectors. The calibrated radiation of these sources is used for inflight calibrations.

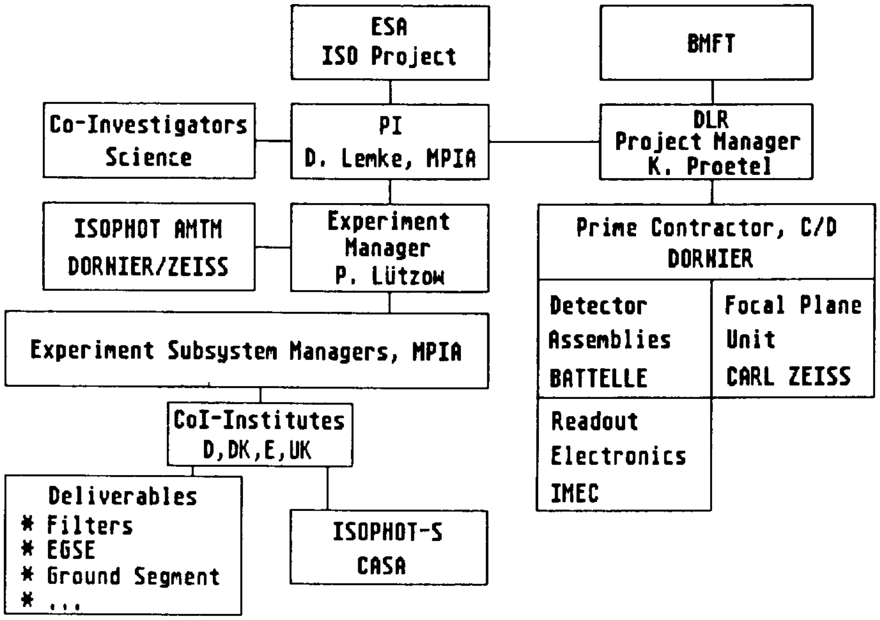

Figure 2 ISOPHOT Project Organization

Detectors

Nine detector assemblies with 223 pixels altogether are used in ISOPHOT. An overview of these assemblies is given in table 1. The -C and -S assemblies are hybrid arrays made of separate detector elements while -A25 is made out of a single piece of Si:P as a monolithic array. The NEP values given are defined as system-NEPs, i.e. measured at the telemetry output of the experiment's electronic box and therefore including all additional noise contributions such as EMI, digitization etc. All detector assemblies are supplied by Battelle, Frankfurt.

Readout Electronics

The cryogenic readout electronics CRE for the experiment was developed during phase B of the project by IMEC, Leuven. It consists of integrating amplifiers followed by a multiplexer. The schematic of the chip is shown in figure 3. Four different detector interface curcuits had been designed and built. In tests the option with a charge feedback loop (figure 4) proved to be most useful and was chosen for further optimisation. With the first generation devices which became available at the end of 1987 a NEP of about $5 \cdot 10^{-17}$ $W \cdot Hz^{-1/2}$ was achieved in the breadboard models of the -S arrays. The CREs were operational down to 2K and the readnoise was about 1300 electrons which could be reduced to about 800 electrons by using correlated double sampling. Although these numbers are quite impressive for a newly developed chip, there were problems with its stability, dynamic range and linearity.

Table 1 ISOPHOT Detector Assemblies

Sub-experiment	Pixel Number	Wavelength Range [μm]	Material	Readout	NEP [W $Hz^{-1/2}$] Goal	Requirement
PHT-P1	1	3 . . . 18	Si : Ga	CRE 1	2.0 10^{-17}	4.0 10^{-17}
PHT-P2	1	15 . . . 30	Si : P	CRE 1	1.5 10^{-17}	3.0 10^{-17}
PHT-P3	1	40 . . .120	Ge : Ga	CRE 1	1.5 10^{-17}	3.0 10^{-17}
PHT-A25	8 x 8	8 . . . 30	Si : P	CRE 66	1.5 10^{-17}	3.0 10^{-17}
PHT-C50	3 x 5	30 . . . 55	Ge : Be	CRE 18	1.5 10^{-17}	6.0 10^{-17}
PHT-C100	3 x 3	60 . . .120	Ge : Ga	CRE 18	1.5 10^{-17}	3.0 10^{-17}
PHT-C200	2 x 2	120 . . .200	str.Ge : Ga	CRE 1/4	1.5 10^{-17}	3.0 10^{-17}
PHT-S1	1 x 64	2.5 . . . 5	Si : Ga	CRE 66	4.5 10^{-17}	1.8 10^{-16}
PHT-S2	1 x 64	6 . . . 12	Si : Ga	CRE 66	2.0 10^{-17}	6.0 10^{-17}

A first redesign of the CREs was done in 1988. These second generation devices are now used for the engineering-qualification models of the detector assemblies. First measurements at Battelle and IMEC indicate that the noise has been reduced considerably - a factor 3 to 8 is expected depending on the sampling method and the readout mode. The dynamic range and linearity are also much improved, as measurements of a CRE1 at MPIA have confirmed. A complete knowledge of the performance will be gathered during the QM tests which are done in the first half of 1989. After these a second redesign is scheduled for the flight models.

ISOPHOT–P

ISOPHOT–P is a multi-band, multi-aperture photometer using single detectors. The telescope beam is deflected by a mirror of wheel I (see fig. 1), passes one of 14 selectable field stops on wheel II and then one of 14 selectable spectral filters on wheel III. Three polarizers on wheel I can also be put into the beam. From measurements of a source at three polarization angles (60°, 120°, 240°) its polarization degree and angle can be deduced. An image of the sky lies in the plane of the apertures (5 arcsec . . . 3 arcmin) on wheel II. These apertures are then imaged onto the -P detectors with a field optics. The filters are choosen to match features of the interstellar matter as well as to cover the entire wavelength range by broad band photometry. In addition the IRAS spectral bands at 12, 25, 60 and 100 μm are reproduced. The detector materials and the element sizes are given in table 2.

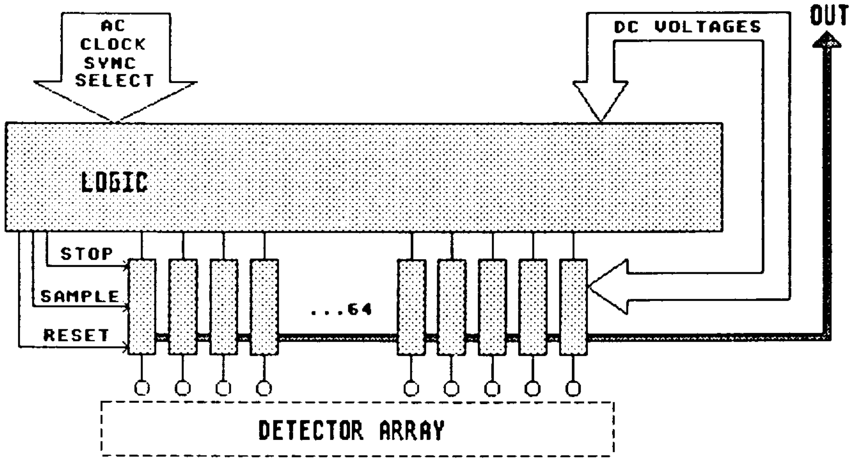

Figure 3 **Cryogenic Readout Electronics Chip Schematic**

The chip consists of a logic part and analog detector interface circuits. The logic circuit receives a "select"-pulse to enable the device and out of two external AC-lines "clock" and "sync" it forms all pulses to drive the multiplexer internally. The number of detector interfaces is adapted to the number of pixels in the arrays; two additional channels are normally used as monitors for the electronics behaviour and for room temperature checkout. In all assemblies the connection to the detector elements is made by wire bonds with the exception of A25 where a two dimensional bond matrix 8 x 8 is needed. A special connection technique of gold ball bonding combined with conductive epoxy has therefore been developed.

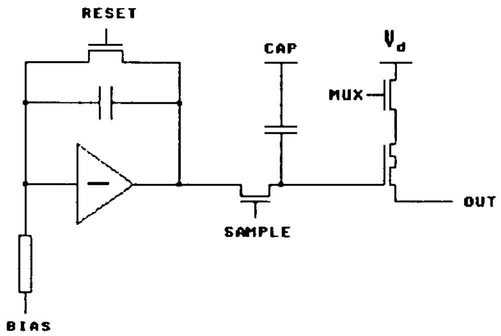

Figure 4 **Charge Feedback Detector Interface**

The detector is connected to an integrator. The charge accumulated on the feedback capacitor can be transferred to a sample capacitor for all detectors of an array in parallel. If a reset pulse is applied after the sample pulse, the integrator starts over while the charge on the sampler is read out through the multiplexer (destructive readout). Non-destructive readout is realised by applying several sample pulses between resets, so the charging ramp of the integrator is monitored at the output.

Although no special breadboard models of the -P detectors have been built during phase B, there is plenty of experience at MPIA and Battelle with such discrete detectors. Many have been built and tested for various aspects and the performances given in table 2 are results of the GIRL program obtained with trans-impedance-amplifiers (TIA). Currently the engineering- qualification models (EQM) of the -P detectors are manufactured. The readout is the CRE 1 which is a version without logic, sampler and multiplexer. The analog output of the integrator is sampled in the external electronics unit. The -P3 assembly is shown in figure 5.

Table 2 ISOPHOT - P Detectors

		P1	P2	P3
Material		Si : Ga	Si : P	Ge : Ga
Detector Size	[mm^3]	1.0 x 1.0 x 1.0	1.0 x 1.0 x 1.0	1.0 x 1.0 x 1.0
Breadboard Model Performance :				
NEP	[W $Hz^{-1/2}$]	2.0 10^{-17}	2.0 10^{-17}	5.0 10^{-17}
R	[A W^{-1}]	10	8.6	3
Current Activity		Manufacturing Of Engineering-Qualification Models		

ISOPHOT-C

ISOPHOT-C is made up of three far infrared cameras. Their dimensions are fitted to the 3 arcmin unvignetted field of view of the experiment with formats of 3 x 5 pixels in -C50, 3 x 3 in -C100 and 2 x 2 pixels in -C200 (figure 6). Filters and polarizers on wheel I and II are used to define a spectral band and for polarization measurements.

The detector matrix is made up of individual elements placed in integrating cavities. The crystal sizes are optimized for detector performance. The main characteristics of the ISOPHOT-C arrays are shown in table 3.

To achieve a high fill factor, fabry lenses are placed in front of the detector cavities. These lenses are square shaped and made of germanium for -C100 and -C200 and of silicon for -C50. The area of the field lenses defines the pixel's field of view. The lenses are seperated with an opaque material. This and the closed cavities of the detectors guarantee minimal crosstalk between the pixels (figure 7).

The -C200 camera is of special scientific interest as it extends the wavelength range observed by IRAS to beyond 200µm. Spectra of the breadboard detectors show cut-off wavelengths around 240 µm. In addition to pointed observations of selected sources -C200 will perform a serendipituous sky survey during slews of the ISO satellite. These strip maps will be taken in a broad wavelength band around 200µm. The sky coverage will strongly depend on the observing program of the observatory and is estimated to 10 . . . 40%. With a limiting sensitivity of about 1 Jy this incomplete 200µm survey will be a valuable supplement to the IRAS survey.

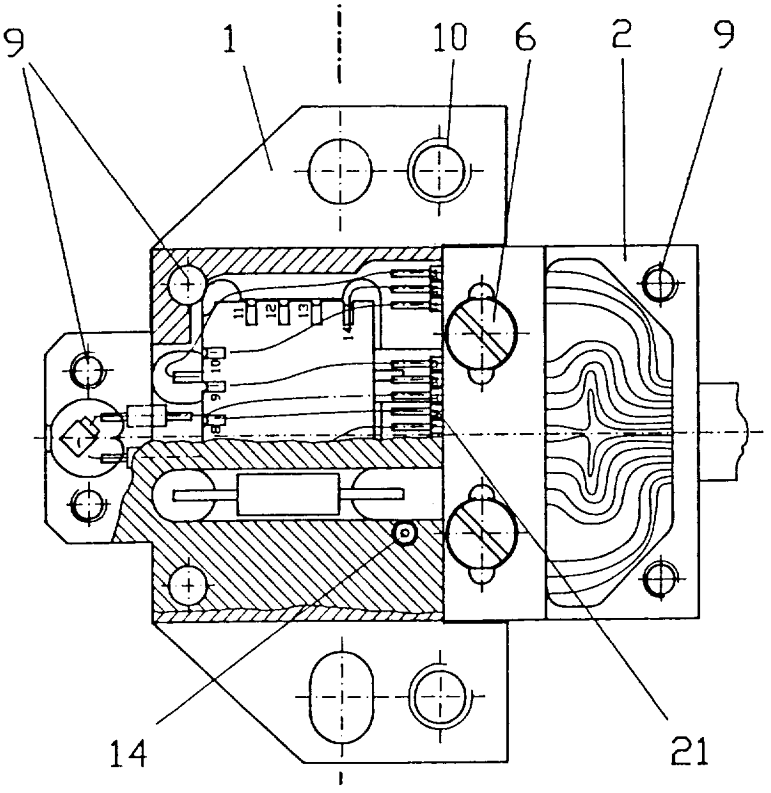

Figure 5 ISOPHOT-P3 EQM-Detector Assembly

The detector element has transverse contacts and is placed in an integrating cavity. Its orientation and the cavity shape have been optimized for maximum light absorption in the crystal. Two electrical feedthroughs connect the detector to the CRE which is mounted on a ceramics substrate. This Ge:Ga detector is mounted to the 2K-cooling strap of the experiment. Slightly higher temperatures can be obtained with a carbon resistor as a heater. A second carbon resistor is used as temperature sensor. To the right a pigtail harness is attached with a strain relief.

Table 3 **ISOPHOT-C Arrays**

	C50	C100	C200
Material	Ge : Be	Ge : Ga	stressed Ge : Ga
Array Size	3 x 5	3 x 3	2 x 2
Detector Size [mm^3]	0.5 x 0.5 x 1.5 30° Wedge	0.7 x 0.7 x 2.0 30° Wedge	1.0 x 1.0 x 1.0 30° Wedge
Fabry Lens Area [mm^2]	1.33 x 1.33	1.90 x 1.90	3.90 x 3.90
Array Area [mm^2]	7.05 x 4.19	5.90 x 5.90	7.90 x 7.90
Gaps [mm]	$\leq$ 0.1	$\leq$ 0.1	$\leq$ 0.1
FOV Per Pixel [arcsec^2]	30.5 x 30.5	43.5 x 43.5	89.4 x 89.4
Total FOV [arcmin^2]	2.69 x 1.60	2.25 x 2.25	3.02 x 3.02
Fill Factor	0.90	0.93	0.97
Breadboard Model Performance			
NEP [W Hz$^{-1/2}$]	3.0 10^{-16}	5.0 10^{-17}	3.0 10^{-17}
R [A W^{-1}]	1 - 2	3 - 4	6.5 - 10
Dark Current [e s^{-1}]			< 5 10^5
Current Activity	Manufacturing Of Engineering-Qualification Models		

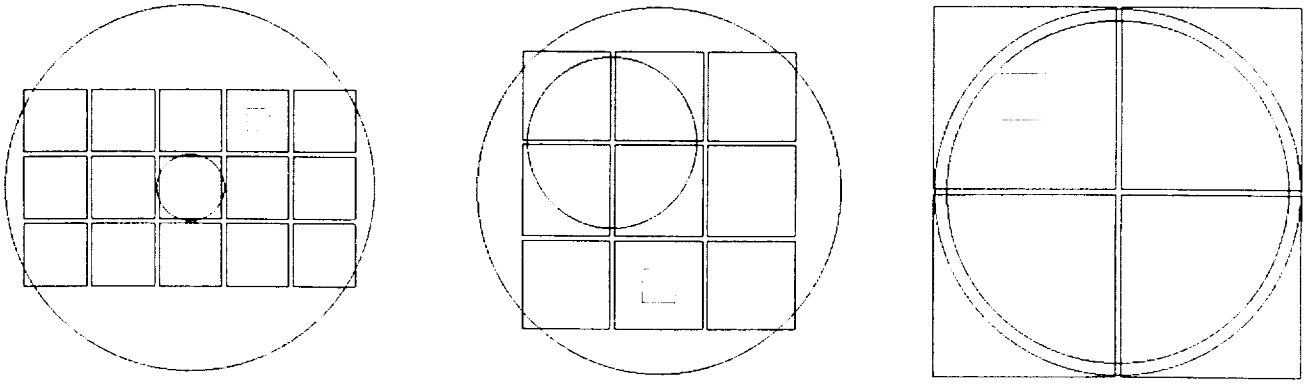

Figure 6 **Optical Layout of the ISOPHOT-C Arrays**

In -C50 the fabry lens size is matched to the Airy disk at the wavelength of maximal detector response $\lambda = 39\mu m$. The larger Airy disk at $100\mu m$ in -C100 is oversampled by four pixels. The big circles denote the 3 arcmin unvignetted field of view of the experiment. In -C200 the Airy disk at $200\mu m$ almost fills this field. Each of the four pixels Ge:Ga has its own stressing mechanism, providing important redundancy for this new technology in a space experiment. The dotted squares indicate the size of the detector elements located behind the lenses.

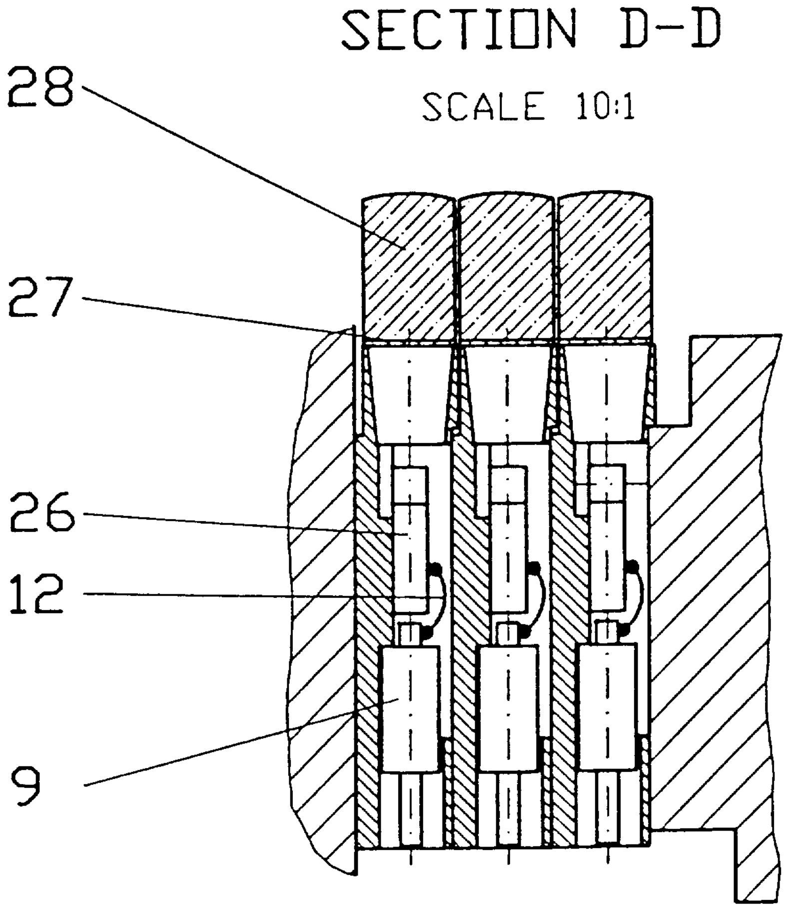

Figure 7 **Design of ISOPHOT-C50**

This cross section of -C50 shows the fabry lenses that are connected to the integrating cavity of the detectors by a cone. The detector elements are mounted to the metallic sides of the cavity and therefore have a common bias contact. The other contact is connected via a feedthrough to the CRE17 located behind the 15 cavities. The crystals have a 30° wedge at the front end to maximize light absorption by internal reflections. Three rows of 5 such elements each are made and stacked together to form the 2-dimensional array. A similar approach is taken for -C100 with three elements per row, while -C200 has four individual stress-cavities. By using two electrical feedthroughs for each element of the -C100 and -C200 arrays, they can be supplied with individual bias voltages. Some voltage scatter in the detector elements or the CRE input channels can therefore be accommodated.

ISOPHOT-A

ISOPHOT -A is a two dimensional array of 8 x 8 pixels filling the 3 arcmin field of view. Figure 8 shows the optical design. The detector array is monolithically made of Si:P and connected to a two dimensional CRE with matching geometry. For this direct hybrid a new, two dimensional matrix of connection points was needed. As the project's schedule did not allow the development of an indium bump technology, a simpler technique using gold ball bonds combined with silver filled epoxy was choosen.

The decision for that monolithic array was taken late during phase B, so no breadboard model could be built. Instead a test array was made in a pre-C/D phase. To minimize crosstalk between the pixels, the detector chip has sawing grooves at the backside and a metal grid at the front surface. Measurements with the test array showed that very deep grooves (950µm in a 1 mm thick wafer) gave the best performance. The grid size was choosen to 120 µm for the engineering qualification model (table 4). The performance of Si:P has earlier been tested with single elements and TIAs.

Table 4 ISOPHOT–A25 Array

Design Of The Qualification Model			Detector Material Performance	
Material		Si : P	NEP [W $Hz^{-1/2}$]	2.0 10^{-17}
Array Size		8 x 8	R [A W^{-1}]	8.6
Pixel Size	[mm^2]	0.83 x 0.83		
Array Area	[mm^2]	7.48 x 7.48		
Gaps	[mm]	0.12		
FOV Per Pixel	[$arcsec^2$]	19 x 19		
Total FOV	[$arcmin^2$]	2.9 x 2.9		
Fill Factor		0.79		

Current Activity Manufacturing Of Engineering-Qualification Model

ISOPHOT–S

ISOPHOT–S is the spectro-photometric subexperiment. The flight hardware will be supplied by the Spanish co-investigators. The telescope beam is deflected by a mirror on wheel I into the 24 arcsec aperture of that dual channel Ebert-Fastie spectrometer. The two 64 element linear arrays of Si:Ga cover the wavelength bands 2.5 to 5µm

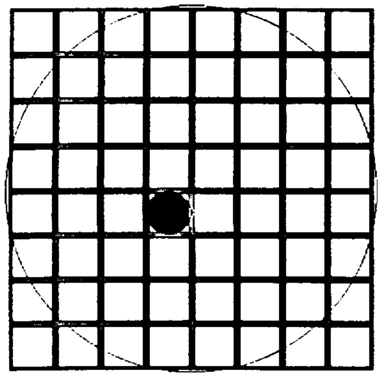

Figure 8
Optical Layout of ISOPHOT–A

The monolithic piece of Si:P covers the 3 arcmin FOV which is indicated by the circle. The pixels are at the front surface defined by a metal grid of 120 μm width. At the backside sawing grooves should minimize crosstalk. The pixel size is matched to the 915 μm Airy disk at 25 μm.

and 6 to 12 μm and are operated simultaneously. The main characteristics of the -S arrays are shown in table 5. While the long wavelength channel is close to the wavelength of the Si:Ga peak response, the short wavelength channel suffers from the short wavelength fall-off of the material's spectral response. Originally Si:In was planned to use, but existing materials all turned out to be very insensitive ($R < 1\ AW^{-1}$). The time schedule of the project did not allow for a new material development or switching to InSb. Two breadboard models of the -S arrays have been built during phase B (figure 9). As readout electronics the first generation CRE 66 was used.

Table 5 **ISOPHOT–S Arrays**

			Breadboard Model Performance	
Material		Si : Ga	NEP [$W\ Hz^{-1/2}$]	$5.0\ 10^{-17}$
Array Size		1 x 64	R [$A\ W^{-1}$]	10
Detector Size	[mm^3]	0.31 x 0.37 x 1.80 30° wedge		
Gaps	[μm]	17.5		
FOV Per Pixel	[$arcsec^2$]	24 x 24		
Current Activity		Manufacturing Of Engineering-Qualification Models		

High Energy Radiation Effects and Calibration

High energy radiation effects in the bulk detectors have been studied[6]. Responsivity increases of up to 35% in Si-detectors have been observed after simulated passages through the electron belt. With similar doses stressed Ge:Ga showed a factor of 32 R-increase. As self-relaxation takes many hours, curing procedures need to be applied. Currently heating and bias boost are planned. However, both concepts are problematic; for all Ge-detectors which are mounted to the 2K cooling strap, heating is almost prohibited due to the restricted power budget of 0.5 mW. Bias boost on the other hand can by itself upset the detectors and the CREs.

For monitoring the detectors' calibration during the mission, an onboard calibration source is foreseen. Thermal radiation sources similar to those used in IRAS are imaged with f/15 on the detectors via the chopper mirror using a large throw. In the ground calibration of the experiment these sources will be calibrated with a standard laboratory blackbody source. Their inflight stability can be checked with celestial standards.

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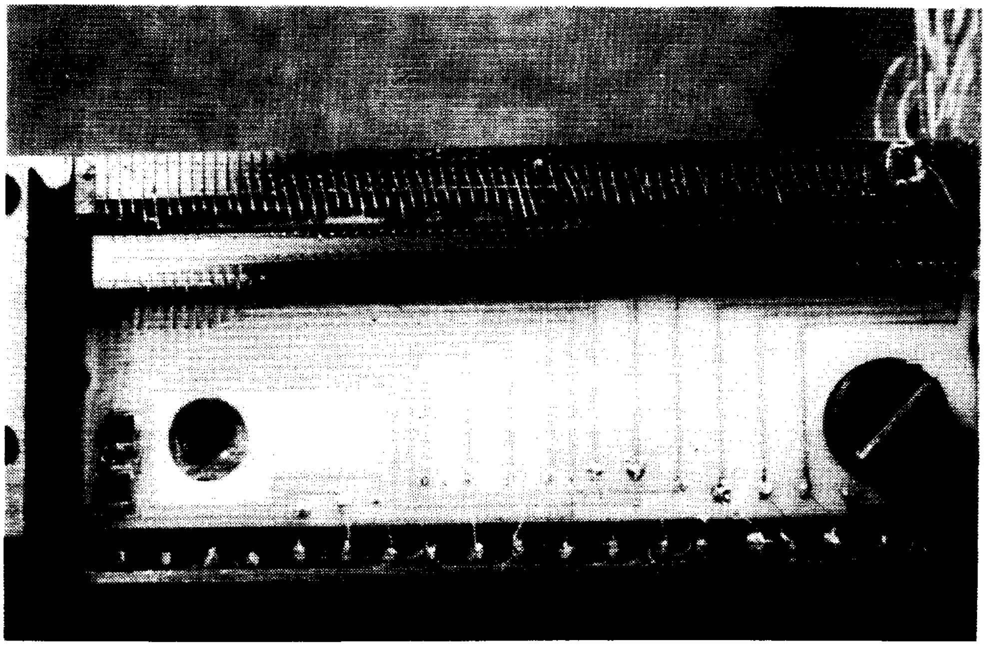

Figure 9 **Breadboard Model of the ISOPHOT-S Array**

The detectors are fabricated from a strip of Si:Ga material that is glued to a substrate. The individual pixels are then seperated by sawing. While the electrical contacts at the substrate provide the common bias to the detectors, the top contacts are wire bonded to the input pads of the CRE 66 which is mounted alongside the detector array.

Acknowledgement

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