PROFILE OF AN ESO KEY PROGRAMME

Standard Stars for the Infrared Space Observatory, ISO

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The Infrared Space Observatory (ISO) is a European Space Agency (ESA) satellite to be launched in 1995. Operating at wavelengths ranging from 2.5 to 200 μm (Kessler, 1992), ISO will be a unique facility with which to explore the universe. Its targets will range from objects in the solar system, at one extreme, to distant extragalactic sources, at the other extreme. ISO will operate as an observatory with 65% of its observing time open to the general astronomical community. Observations will be selected by proposal submission and peer review.

The satellite will carry on board a 60-cm telescope and four scientific instruments, mounted inside a 2300-litre superfluid Helium cryostat and operating at a temperature of around 3 K. The instruments are:

1. ISOCAM, a two-channel camera, operating between 2.5 and 17 μm, with a 32×32-element detector array in each channel;
2. ISOPHOT, a broad-band multi-filter photo-polarimeter, covering the wavelengths between 2 and 200 μm, with a low-resolution spectrometer, covering the wavelength ranges 2.5 to 5 μm and 6 to 12 μm;
3. SWS, the short wavelength spectrometer, offering resolutions in the range 1000 to 20,000, for wavelengths between 2.4 and 44 μm;
4. LWS, the long wavelength spectrometer, offering resolutions in the range 100 to 10,000, for wavelengths between 45 and 180 μm.

These instruments are being built by four independent consortia from ESA member States, using national funding. ESA is responsible for the development and launch of the satellite, and for the observatory operations, which end when the liquid Helium cryogen is exhausted, i.e. after a baseline lifetime of at least 18 months.

One of the major concerns for such a mission is the calibration of the instruments and thus of the scientific data products. In addition to the pre-launch on-ground calibration and characterization of the instruments, the observatory must be calibrated in-flight. This involves the use both of internal calibration sources and a range of astronomical reference sources (i.e. stars and asteroids for the photometric calibration and planetary nebulae or HII regions for the spectroscopic calibration).

A full description of the plans for the in-flight calibration of the ISO instruments can be found in the "ISO In Orbit Calibration Requirements Document", which is regularly updated by ESA in consultation with the instrument consortia.

Stars as Calibrators, the ESO Key Programme

The most suitable sources for the photometric calibration of ISOCAM and the shorter wavelength region of ISOPHOT are stars with well-known monochromatic fluxes. Stars can also be used as photometric standards for SWS and for the short wavelength region of LWS, and for correlating SWS and LWS spectra. However, a homogeneous set of standard stars suitable for wavelengths up to at least 50 μm does not exist!

The ESO Key Programme, "Infrared Standards for ISO", is a first step towards the setting up of such a system of standard stars.

In order to make it possible to use stars as calibrators up to these wavelengths, their far-infrared fluxes must be known, on the basis of photometric and spectroscopic data obtained from the ground in combination with stellar model atmospheres. The aim of this Key Programme is to obtain near-infrared (NIR) and mid-infrared (MIR, at 10 and 20 μm) photometric data and NIR spectroscopic data of the stars selected in the southern hemisphere. Similar efforts are being undertaken in the northern hemisphere by the IAC (Tenerife) and Imperial College (London). The project, as a whole, runs under auspices of the ISO Ground Based Preparatory Programme working group (Jourdain de Muizon and Habing, 1992), which was formed on the initiative of the ISO Science Team. This working group not only initiated the observational programmes, but also established a collaboration with Blackwell's group (Oxford) and with Gustafsson's group (Uppsala) to carry out the theoretical part of the project: determining fundamental parameters of the stars and modeling their far-infrared spectra.

The goal of the working group is to deliver a database of standard stars and fluxes to the ISO Science Operations Team well before the launch of ISO.

Selecting the Stars

For an efficient calibration of observations by ISO, i.e. to minimize the slewing time of the telescope, there should be at least 1 standard star per hundred square degrees. In other words, the set of standard stars for ISO has to contain at least 400 stars, evenly spread over the sky.

In fact, several conditions have to be met by a set of standard stars for ISO. Since they will be used as standards for different instruments of ISO, the stars should cover a wide range of magnitudes as well as a wide range of spectral types. In summary, the selected stars should be:

1. non variable stars;
2. single stars;
3. stars without an infrared excess;
4. brighter than K = 12, and fainter than K = 0;
5. evenly distributed over spectral type and magnitude;
6. homogeneously spread over the sky.

The ESO Key Programme covers the observations for the southern hemisphere. We selected stars from the infrared standard star lists of ESO (Bouchet et al., 1991), SAAO (Carter, 1990), AAO (Allen and Cragg, 1983), and CTIO (Elias and Frogel, 1983). We extended the sample by selecting stars from the Bright Star Catalogue (Hoffleit, 1982) and the Henry Draper Catalogue. We used both catalogues and the Hipparcos Input Catalogue to discard multiple and variable stars. In addition, we used the IRAS catalogue to check that the spectra of the selected stars do not show an infrared excess. The sample contains 300 stars (see Fig. 1), of

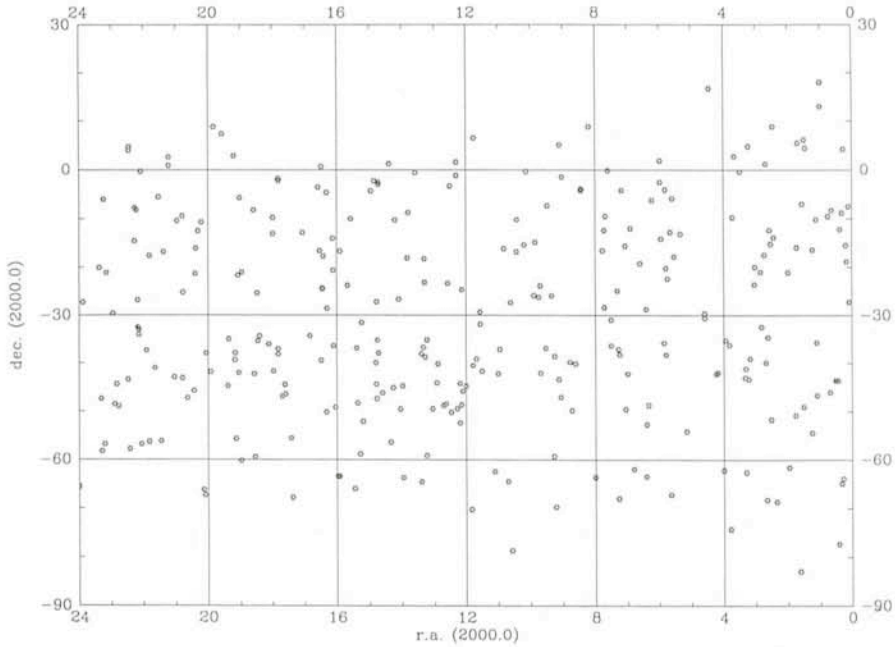

Figure 1: *Distribution of the stars over the southern hemisphere. In the present sample only very few stars have declinations smaller than 75°. We will therefore add some stars to the sample which are located in the polar region.*

which the 200 most suitable stars will be used as southern standard stars for ISO.

Photometry

For the entire set of stars we are acquiring J,H,K and L broad-band photometry as well as narrow-band NIR photometry. The narrow-band filters are CVF filters centred on 1.58 μm (H band), 2.16 μm (Brγ), 2.22 μm (K band), 2.29 μm (CO) and 3.70 μm (L band). The use of such narrow-band filters improves the accuracy of the photometry in two ways: 1. the narrow-band filters have pass-bands well within the atmospheric windows: their profiles are not defined by the edges of the atmospheric windows, and are therefore not changed by variations in the atmospheric transparency; 2. atmospheric extinction is colour dependent: narrow-band measures will be less affected by extinction variation than broad-band measures. Furthermore, the theoretical interpretation of narrow-band photometric data is more straightforward.

Additionally, we are obtaining MIR photometry at 10 and 20 μm for the brightest stars ($L \leq 2$) of the sample. For 10-μm photometry we use the standard filters N1 ($\lambda_0 = 8.36$ μm; $\Delta\lambda = 0.85$ μm), N2 ($\lambda_0 = 9.67$ μm; $\Delta\lambda = 1.65$ μm), and N3 ($\lambda_0 = 12.89$ μm; $\Delta\lambda = 3.7$ μm). We will use these data to investigate the presence of SiO and SiC features in the spectra of these stars. The 20-μm photometry (Q0; $\lambda_0 = 18.56$ μm; $\Delta\lambda = 5.6$ μm) will be used to check the far-infrared fluxes as predicted by theoretical atmosphere models.

Clearly this key programme will yield several by-products, which are useful for ground-based work:

- the existing set of standard stars for broad-band NIR photometry will be extended with standard stars having K magnitudes of up to 12;
- a system of standard stars for narrow-band NIR photometry will be defined;
- a system of standard stars for MIR photometry at 10 and 20 μm will be set up.

We reduce the photometric data with IR SNOPY, a reduction programme available at La Silla. For the narrow-band NIR photometry and the MIR photometry this is a preliminary reduction only: the sets of standard stars first have to be established. Therefore we will redo the reduction, when all photometric data have been collected, using a "global method", namely the one developed by Manfroid (1985). This method skips entirely the colour-transformation problem, i.e., only zero points are computed, instead of complete colour transformations. The method is ideally suited for setting up a new photometric system. For a large data set this method provides accuracies better than 0.01 mag for the broad-band NIR photometry, and 0.005 mag for the narrow-band NIR photometry. For the MIR photometry accuracies better than 0.01 mag in N1 and N2, 0.02 in N3, and 0.05 at Q0 can be reached.

Table 1: *The Royal Standard Stars*

	Spectral type	RA (2000)	Dec (2000)
A-type stars			
HR2421, γ Gem, Alhena	A0IV	06 37 42.7	+16 23 57
HR2491, α CMa, Sirius	A1Vm	06 45 08.9	−16 42 58
HR3314, C Hya	A0V	08 25 39.6	−03 54 23
HR7069, 111 Her	A5III	18 47 01.2	+18 10 53
HR7557, α Aql, Altair	A7V	19 50 46.9	+08 52 06
Early F-type stars			
HR0740, σ Ceti	F4IV	02 32 05.1	−15 14 41
HR5570, 16 Lib	F0V	14 57 10.9	−04 20 47
HR7469, θ Cyg	F4V	19 36 26.4	+50 13 16
HR7936, ψ Cap	F4V	20 46 05.6	−25 16 16
Solar-type stars			
HR0098, β Hyi	G2IV	00 25 45.3	−77 15 16
HR0448	G2IV	01 33 42.8	−07 01 31
HR0509, τ Cet	G8V	01 44 04.0	−15 56 15
HR1101, 10 Tau	F9V	03 36 52.3	+00 24 06
HR1983, γ Lep	F6V	05 44 27.8	−22 26 54
HR4903	G1V	12 54 58.4	−44 09 07
HR4989	F7IV	13 14 14.7	−59 06 12
HR5996	G4IV-V	16 07 03.3	−14 04 16
Red Giants			
HR1136, δ Eri	K0IV	03 43 14.8	−09 45 48
HR1907, φ 2 Ori	K0IIIbCN-2	05 36 54.3	+09 17 26
HR2990, β Gem, Pollux	K0IIIb	07 45 18.9	+28 01 34
HR4232, ν Hya	K2III	10 49 37.4	−16 11 37
HR5340, α Boo, Arcturus	K1IIIbCN-1	14 15 39.6	+19 10 57

Spectroscopy

Up to now we have obtained full IRSPEC spectra in the J,H,K, and L bands for 30 stars of spectral type A to K. These spectra are of medium resolution ($\lambda/\Delta\lambda \simeq 2500$) and span the following wavelength regions: 1.05–1.35 μm, 1.54 – 1.75 μm, 2.05–2.40 μm and 3.45–4.05 μm. To cover these four atmospheric windows, a total of 63 IRSPEC spectra need to be taken for each star. They are the first complete stellar spectra taken in the J,H,K and L bands and they will provide new constraints on the modeling of stellar atmospheres. We reduce the spectra with MIDAS and routines especially developed for the reduction of IRSPEC data (see also the article by R. Gredel in this issue of the *Messenger*).

The "Royal Standard Stars"

The prediction of absolute fluxes of these standard stars will be subject to severe uncertainties in model atmospheres. These uncertainties, which may lead to systematic errors in the calibration of ISO fluxes of more than 10%, are in particular errors in fundamental parameters, in temperature structure and in continuous and molecular opacities. In order to get a handle on these uncertainties, we are studying the effects of perturbations of the above-mentioned parameters on the far infrared spectra of model atmospheres. To improve the calibration, we also will make a detailed comparison of observed and synthetic spectra and fluxes of a sample of stars, selected to be representative for the full set of standard stars. We selected 22 such stars, named "Royal Standard Stars": 5 A-type stars, 4 early F stars, 8 solar-type stars and 5 K giants (see Table 1). These Royal Standard Stars will serve as a basic set for checking the calibration of the entire sample of standard stars.

Fundamental Parameters, Model Atmospheres and Far IR Fluxes

We use the NIR photometry as input for the "Infrared Flux Method" (Blackwell, 1986) and determine the effective temperatures and angular diameters of the stars. Independently we shall determine effective temperatures and gravities of the stars by comparing the observed and theoretical infrared colours, as described by Bell and Gustafsson (1989). To be able to compare the NIR data obtained at ESO with theoretical infrared colours, we will extend the work by Bell and Gustafsson for both the ESO J,H,K and L filters and the narrow-band NIR filters, described before.

We will use the fundamental parameters as input for model atmospheres: recent versions of the Kurucz models (Kurucz, 1991) for the hotter stars, and recent models from the Uppsala model atmosphere codes (updated versions of Gustafsson et al., 1975, with the Kurucz [1991] atomic line lists implemented) for the cooler stars. We will extend model atmosphere codes into the infrared, and use them in combination with the NIR data to predict infrared fluxes for the complete set of standard stars. The stars with $K > 6$ will be used as a standard system for the short wavelength range of ISO, up to 20 μm. The stars with $K \leq 6$ will be used as calibrators up to at least 50 μm.

The aim of the project is to predict the infrared fluxes of the complete sample of stars, with accuracies better than 10% for flux densities ≥ 1 Jy and to compile a list of standard stars which are suitable for wavelengths up to 50 μm. The working group plans to deliver a database of standard stars and infrared fluxes to the ISO Science Operations Team well before the launch of ISO, presently scheduled for 1995.

Acknowledgements

We are very grateful to ESO and to the Max-Planck-Institut für Astronomie, represented by Professor Elsässer, for the numerous nights of observing time allocated to this programme. We would like to thank the infrared team at La Silla for their assistance during the observations, with our special thanks to Rolando Vega. We also thank C. Turon and D. Morin for helping us with the Hipparcos Input Catalogue before publication.

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SUSI Discovers Proper Motion and Identifies Geminga

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Twenty years have gone by since the discovery of the γ-ray source 195+5, the first UGO (Unidentified Gamma Object) seen by the NASA SAS-2 satellite. These years have been characterized by an endless quest for an identification of this puzzling object first in the γ-ray domain, with the ESA COS-B satellite (1975–82), then in the X-ray domain, with the NASA Einstein Observatory (78–81) and ESA EXOSAT (83–86) missions, finally in the optical (1983–today) using all the big telescopes of the world. Unfortunately, every step down in energy cost a factor of 1000 in the source strength (see table) and, adjusting the observing time, we ended up with ~1000 photons in each energy range.