ELISA: A SMALL BALLOON-BORNE EXPERIMENT TO GUIDE FUTURE OBSERVATIONS WITH FIRST

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Abstract

ELISA (Experiment for Large Infrared Survey Astronomy) is a project for a small balloon-borne experiment designed to measure the galactic submillimeter continuum emission from 170 to 650 μm. This paper briefly presents its scientific objectives and the main instrument characteristics. The major goal of the ELISA project is to provide a complete census of the galactic dust emission in this wavelength range at an angular resolution similar to the IRAS all-sky survey (typically $3.5'$).

Current plans envision 3 flights (including one from South hemisphere), leading to a large survey along the Galactic plane ($b \leq 20°$) as well as deeper observations toward high latitude cirrus clouds, before FIRST launch in 2007. The ELISA survey will therefore be available and well suited as a guide to plan FIRST observations, similar to what IRAS was for ISO. In addition, by filling the angular resolution gap between the COBE and FIRST data set, the ELISA survey could enable routine cross calibration between the DIRBE and FIRST observations.

Key words: Galaxies: formation – Stars: formation – Missions: FIRST, ELISA

1. Introduction

Interstellar dust plays a key role in the process of star formation and in the energetic equilibrium of the Galaxy. It seems then essential to understand its physico-chemical properties, in particular in the densest phases of the interstellar medium. The current dust models consider three main components, differing in composition, size, structure and emission mechanism (e.g. Désert et al. 1990). The smallest particles (PAHs) and the very small grains (sizes $\leq$ 15nm) are transiently heated and emit in the infrared range, which has been extensively studied with ISO. The largest grains are in thermal equilibrium, dominating the far-infrared and submillimeter spectrum with a continuum emission following :

$$I_\nu = \kappa.(\nu/\nu_0)^\beta.B_\nu(T) \qquad (1)$$

where T is the average temperature, β the dust emissivity spectral index, and κ is proportional to the column density.

In order to constrain both parameters T and β, submm multi-band observations are needed, including the range $100-300\mu m$ (inaccessible from the ground), since it contains the peak of the emission spectrum for dust at $T \leq 30K$. These measurements are particularly well suited to characterize the interstellar cold component, trace the morphology and structure of the clouds, specially during the very early steps toward star formation, when the cloud opacity is determinant. The emission from large grains is so far poorly constrained by observations since the Far-IR and Submm domain is still almost quasi unexplored, excepted at the large angular scale of COBE (7 °) (e.g. Boulanger et al. 1996, Lagache et al. 1998). The PRONAOS balloon-borne experiment (Lamarre et al. 1994) has mapped the dust emission in four photometric channels from 200 to 650 μm, toward a few selected regions of the ISM during its 3 flights in 1994, 1996, and 1999. These observations have brought new insights about the nature of large grains in the ISM, and have raised a number of questions about the nature and evolution of dust: PRONAOS has directly revealed the existence of cold condensations ($T \sim 12$ K) in different sites of star forming regions (Ristorcelli et al. 1998, Dupac et al. 2001), but also in translucent and optically thin dust clouds at high galactic latitude. This cannot be explained by the standard dust models currently used and can be interpreted as the existence of porous dust aggregates (Bernard et al. 1999, Stepnik et al. 2001). In addition, the observations have also evidenced a significant correlation between the dust equilibrium temperature and the spectral index, which may reflect new quantum processes within the grains, specific to low temperatures. However, these observations are limited to a very small fraction of the sky (a few square degrees), and the characterization of dust emission clearly calls for more statistics and a larger survey. Due to a limited spectral range ($\lambda \geq 350\mu m$) and the subtraction of low spatial frequencies, ground observations cannot constrain both temperature and spectral index of dust, nor measure the low brightness extended emission.

2. Main Objectives

In that context, the ELISA experiment will have three main scientific objectives, that can be associated with two specific observing modes. A large survey will enable to map the galactic plane emission, building a catalog of

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young stellar objects, and a deep survey at high galactic latitudes will be performed to study the emission from more diffuse clouds. The expected sensitivities for each observing mode are given in table 1. A large census of the dust emission will be deduced from those surveys. From the temperature and spectral index maps, we will statistically study their correlations. Spectral and spatial variations of the large grains emissivities will be analysed in relation with the physical conditions (density, turbulence), the other dust components (VSGs and PAHs), and the molecular abundances. A specific study of the Galactic cold component will be performed. The grain properties in cold core are expected to be very different form the diffuse medium, and ELISA observations should enable to characterize both spatial and spectral changes of dust properties (due to molecular ice mantles, molecular and/or grain coagulation leading to aggregates,...).

2.1. Galactic plane : Large scale survey

The understanding of the very early phases toward star formation needs a better knowledge of the composition and physico-chemical properties of the pre-stellar cold and dense cores. In particular, the opacity, which is dominated by dust grains, must play a predominant role in the phase preceding the collapse, and may influence the fragments sizes. It is therefore expected that global quantities such as the Initial Mass Function and Star Formation Efficiency should be strongly linked to the dust absorption and emission properties. In addition, since dust grains participate directly to most of the physical processes influencing the gas ionization stage, their properties could significantly impact the ambipolar diffusion efficiency, which is thought to be one of the major regulating processes of star formation. With ELISA, we plan to conduct a large scale survey along the Galactic plane, at $b \leq 20$ °, down to 2 MJy/sr (3σ) at $650\mu m$. The famous nearby star forming regions (ρ-Ophiuchi, Taurus, Orion, Serpens,...) will be mapped, as well as more distant large molecular complexes (e.g. Cygnus). Such a large scale survey will also cover a large fraction of the Galactic ridge and therefore allow, toward the inner regions of the Galaxy, to derive dust properties as a function of the distance to the Galactic center, using the Galactic rotation curve and correlation with velocity information in the HI and molecular large scale surveys. This survey will allow a systematic search and study of very cold condensations. A large number is expected, including at least the thousands of cold cores detected in extinction against the infrared background with the MSX (Egan et al. 1998) and Isogal (Hennebelle et al. 2000) surveys.

2.2. High latitude clouds : Deep survey

The ELISA experiment will aim at limited observations (typically a few tenth square degree per cloud, due to the low level emission) of a representative sample of cirrus clouds. These will allow, for the first time, a complete census of dust temperature and emissivity properties of dust toward diffuse regions (typically $Av \leq 0.1$) at the angular scale of a few arcminutes. The size of the maps, the number of different cirrus and their careful selection should guaranty minimum observational bias and statistical relevance of the results. For these observations, comparison to HI and eventually molecular line observations measurements will be crucial, in particular to derive the dust emissivity. We plan to include several Intermediate and High Velocity HI Clouds (IVCs and HVCs respectively) in the cirrus sample, in order to search for their dust emission - if any - in the sub-millimeter. Detection of cold dust and derivation of dust temperature in those clouds may be the only way to derive their distance to the Galactic plane and help elucidate their origin. The results obtained toward diffuse clouds by ELISA should be very useful to anticipate the methods to be used to subtract Galactic foreground contribution in the PLANCK data. They will be particularly relevant to the problem of the separation between thermal dust emission and grain rotation which is likely to dominate the spectrum at longer wavelengths.

2.3. Statistical study of young stellar objects

The IRAS Point Source Catalog (PSC) remains the reference database for statistical study of star formation in our Galaxy. The IRAS wavelength coverage has allowed to evidence the evolutionary sequence from cold and deeply embedded young stellar objects to progressively hotter and older stars (class I, II, III). However, the coldest and youngest sources (class -I, 0), the protostars in the isothermal contraction phase and in the phase preceeding gravitational collapse can only be evidenced in the submillimeter, because their emission peak is expected in the $100-300\mu m$ region. Similarly, the study of the early stage of massive stars formation suffers from the lack of good candidates (which are expected to be rare, due to the very short time scales involved) which cannot be readily identified in the IRAS PSC. Submillimeter measurements seem to be the best way to distinguish them from the far more common solar mass YSOs. Yet no extensive point source catalog similar to the IRAS PSC exist in the FIR and sub-millimeter. Generally speaking, the short characteristic lifetime of YSOs and the necessity of unbiased studies calls for large surveys. An angular resolution better than that of DIRBE or FIRAS is necessary to separate efficiently individual sources.

3. Instrument main characteristics

The ELISA experiment is being designed to fly at a ceiling altitude of around 4 mB (37km) in the stratosphere, for a large galactic survey to be performed in 3 flights (10

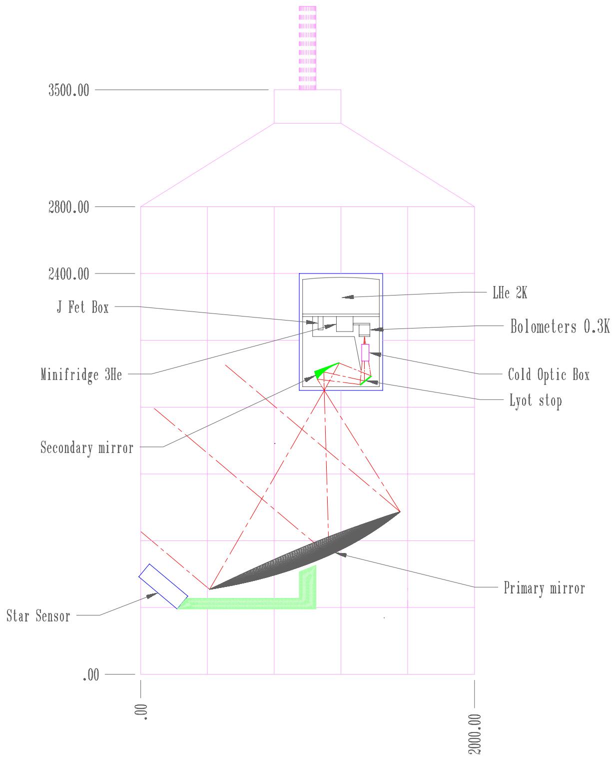

Figure 1. *Schematic view of the ELISA experiment.*

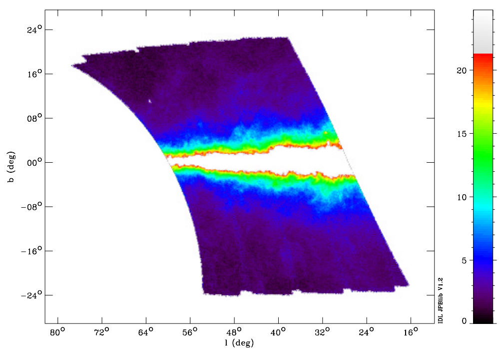

Figure 2. *ELISA simulated observation at 650μm (MJy/sr) corresponding to 2hours, during the large survey mode scanning (600 $^{\circ 2}/h$). The detection of a typical cold condensation is shown at (l,b)=(64 $^\circ$,11 $^\circ$)(see Section 4)*

to 20 hours each, including one flight in the South hemisphere). The institutes taking part to the project main developments are : CESR-Toulouse, IAS-Orsay, CEA-Saclay, CNES-Toulouse, DSRI-Copenhagen, SSD/ESTEC -Noordwik, QMW-London, LAT-Toulouse, La Sapienza U.- Roma, together with the scientific collaboration of Toronto, Nagoya and Tokyo Universities.

An angular resolution of 3.5′ has been chosen as a compromise between the need of having a resolution better or similar to IRAS and the aim of surveying a large galactic fraction per flight, with a small project carrying a 1m diameter telescope and a payload lighter than 500kg.

The telescope is a 1m diameter off-axis gregorian, which primary is the carbon-fiber mirror of the TOPHAT experiment, provided by DSRI. The secondary mirror is integrated within the cryostat, and the equivalent focal distance is about 2m (see the preliminary scheme on Fig. 1).

We propose to have one measurement channel coinciding with the COBE-Dirbe band at 240μm in order to monitor and correct for possible drifts due to remaining atmospheric emission or parasitic signal of instrumental nature. A preliminary study to optimize the best determination of T and β leads to 4 submm large band channels ($\delta\lambda/\lambda \sim 30\%$) centered at 170, 240, 400 and 650μm.

We are studying the possibility to use the PACS-type bolometers arrays for the four channels. An adequate cold optics scheme will allow to split the beam in order to have two 16×16 arrays per channel. This system should offer the advantages (1) to make easier the integration of specific filters and of possible polarisers, (2) compensate for the flatness of the arrays and (3) limit the internal straylight and background. The liquid He cryostat holding the cold optics and the detectors will be cooled down to 0.3 K using an He^3 closed cycle fridge. The expected sensitivity corresponds to the photon noise limit for each band, which estimate is given in table 1.

Mapping of the sky will be accomplished by rotating the gondola over a large azimuth range ($\pm 30\,^\circ$) at constant elevation, in order to reduce the residual atmospheric contribution. A servo-control loop ensures the stabilisation in elevation with a 15″ accuracy, by mean of a reaction wheel, a magnetometer and a fast and large field (15 $^\circ$) stellar sensor, operating day and night. The elevation can range from 15 $^\circ$ to 60 $^\circ$. The selected 1.2 $^\circ$/s rotation speed for the scanning is a compromise between, on the one hand, the need to cover a large amplitude (inte-

Table 1. Instrument main characteristics

Payload instrument mass	$\leq 150kg$			
Primary mirror diameter	1100mm, F/1			
Azimutal scanning	$1.2\,^\circ/s$, $\Delta Az = \pm 30\,^\circ$			
Pointing accuracy	$\pm 15''$ in elevation			
Beam, field	$3.5'$, $22' \times 45'$			
Wavelength Band	1	2	3	4
$\lambda_{center}(\mu m)$ ($\Delta\lambda/\lambda \sim 30\%$)	170.	240	400	650
$NEB(MJy/sr/Hz^{1/2})$	1.23	0.93	0.63	0.49
Large scale survey : 600 $^{\circ 2}/h$				
Detection limit at 3σ	4.2	3.2	2.1	1.7
NH(cm^{-2}), Av(3σ)			1.6 10^{21}	0.9
Deep survey : 35 $^{\circ 2}/h$				
Detection limit at 3σ	1.3	0.9	0.6	0.5
NH(cm^{-2}), Av(3σ)			5 10^{20}	0.25

grating the sky rotation) and reduce the instrument drifts, and, on the other hand, the need to distinguish point sources detection from parasitic "spikes", and respect both the detectors and stellar sensor response times.

4. Observing strategies and simulations

The scientific objectives previously described requires two opposite needs in term of observing strategy: the need to reach a sufficient integration time per beam for the (T,β) determination even for low level brightness emission, and the need to survey a large fraction of the galactic plane. Those constrains lead to the trade-off of using two observing modes: a large survey mode corresponding to a sky coverage of 600°^2} per hour, and a deep survey corresponding to faint regions mappings, with a few 10°^2} per hour. These different coverage rates will be reached by adapting the elevation step between scans and/or repeating the observations in order to increase the signal to noise ratio. A detailed modeling will allow to optimize the observing strategy, and to adapt the parameters such as: scan speed, length of the scans, amplitude of the elevation corrections,.... A simulation of the ELISA observations during the large survey mode, is shown on figure 2. The Submm galactic emission has been extrapolated from IRAS with an average dust spectrum corresponding to T=17.5K, $\beta = 2$. A cold condensation with a typical spectrum T=13K, $\beta = 2$ has been superposed, scaled on the $100\mu m$ emission. Such cold component, undetected at $100\mu m$, and too diluted in the Dirbe beam could then be revealed with ELISA during the large galactic survey.

5. ELISA for Planck and FIRST missions

FIRST instruments will allow to analyse the dust grain emission and the gas-grain interaction with an unprecedented sensitivity, spectral coverage and angular resolution. However, as for ISO, the constraints of an observatory mission will lead to a limited number of observed regions, which will be selected in advance, on the basis of the current data-sets and models. The PRONAOS experiment has confirmed that a submillimeter extrapolation from IRAS emission is very uncertain. Most of the cold condensations discovered with PRONAOS are undetected at $100\mu m$, and a significant grain emissivity variation has been shown in the submm range, at the angular scale of a few arcminutes. Both are very difficult to study with DIRBE and FIRAS measurements due to an insufficient angular resolution (1° and 7°) . ELISA submillimeter survey will be very useful to prepare and optimize observations with FIRST, and identify new targets (in particular cold condensations). It will play a role similar to that of the IRAS survey for ISO. The PLANCK "early release" catalog will contain mainly point sources and galaxies clusters. The extended emission maps Planck maps will probably not be delivered in time for follow-up observations with FIRST.

The FIRAS instrument concept has provided the best absolute calibration in the far-infrared and submillimeter range. It will be a reference for the flight calibration of SPIRE, in particular on extended sources. However, the angular resolution is very different between the two instruments ($30''$ and 7°) which makes direct and systematic comparisons very difficults. ELISA will provide data at $3.5'$ resolution cross calibrated with FIRAS, which it will be possible to use as a secondary calibrator for SPIRE.

In addition, the results obtained with ELISA will be very useful to anticipate on the methods to be used to subtract Galactic foreground contribution in the PLANCK data. It will be particularly relevant to the problem of separation between dust emission and grain rotation which is likely to dominate the spectrum at longer wavelength.

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