Hi-GAL: the Herschel infrared Galactic Plane Survey

S. Molinari – INAF/IAPS, Rome

on behalf of the Hi-GAL/VIALACTEA Teams
The Promise of FIRST

Toledo, Spain, 12-15 December 2000

FIRST, the Far InfraRed and Submillimetre Telescope, is ESA’s fourth cornerstone mission. FIRST is scheduled for launch in 2007, and will be the first space observatory to fully cover the submillimetre and far infrared parts of the spectrum.

Confirmed speakers, discussing the FIRST mission, its science challenges and capabilities:

Philippe André
Michael Barlow
Dominique Bockelée-Morvan
José Cernicharo
Ewine van Dishoeck
Jacqueline Fischer
Asunció Fuente
Reinhart Genzel
Maryvonne Gerin
Thijs de Graauw
Matt Griffin
Michel Guélin
Martin Kessler
Andrew Lawrence
Emmanuel Lellouch
Dieter Lutz
Max Pettini
Tom Phillips
Góran Pilbratt
Albrecht Poglitsch
Michael Rowan-Robinson
Rens Waters
Edward Wright

Symposium Website:
http://astro.estec.esa.nl/FIRST/Toledo/toledo.html

Registration deadline: 1 October 2000

Local Organising Committee: J. Cernicharo (CSIC, chair), J. Martín-Pintado (OAN, co-chair), A. Díez (CSIC, secretary), J.R. Goicoechea (CSIC), E. González-Alfonso (CSIC), F. Langa (U. Castilla la Mancha), F. Najarro (CSIC), M.J. Sempere (CSIC).

FIRST AND THE FORMATION OF MASSIVE STARS

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Abstract

Systematic observational programs are key tools for the study of the earliest stages of massive star formation. We review the status of a long term project that, starting from the IRAS Point Source Catalogue and going through a series of tests based on observational criteria, successfully produced a homogeneous sample of candidate intermediate and high mass protostars. We illustrate the importance of the FIRST mission for early massive star formation.

As an example of FIRST’s revolutionary impact for Galactic star formation, we will discuss the feasibility of a full Galactic plane survey with SPIRE and subsequent follow-up with PACS and HIIF. We believe that for the impact of the scientific return, and the optimum usage of study in detail these systems. The census of star forming regions in the Galaxy, however, is far from complete. In §2 we will describe an ongoing long-term project aimed at the systematic identification of massive YSOs possibly still in their protostellar phase. In §3 we will present an idea for a FIRST key-project, namely a full Galactic plane 3-bands photometric imaging survey with the SPIRE instrument (Griffin et al. this issue).

2. The Quest for Massive Protostars

Until recent years, from an observational viewpoint, the earliest evolutionary stage of massive star formation was that characterised by a bright IRAS source with a spectral energy distribution (SED) rapidly increasing with wavelength.

3. SPIREGAL: A SPIRE Galactic Plane Survey

An important point we want to emphasize from the investigation illustrated in the previous paragraph, is that we may have succeeded in finding a set of very young massive objects, but the regions which host these objects are probably relatively old. Since the infrared and the submillimetre radiation seem to come from different objects in different evolutionary stages, we conclude that any systematic search based on infrared catalogues, such as the IRAS PSC, would seemingly miss the youngest high mass star forming regions, i.e. those in which the first generation of low mass stars has not yet formed.

The complete census of Galactic star forming regions in a wide range of masses and evolutionary stages is the new frontier that FIRST will open for the first time. Indeed this task can be accomplished by surveying significant portions of the sky in the submillimeter continuum, where dust thermal emission is still substantially optically thin. The spatial resolution is also a critical parameter. It should not be too high, to make the task realistic in terms of the time required to complete it. It should not be too low, to resolve the structure of the detected dense cores. The instrument SPIRE (Griffin et al. this issue) offers a unique compromise in terms of wavelength coverage (250/350/500μm simultaneous mapping), field of view (FOV=4’×4’) and resolution (19’’×20’’/8’’/38’’/3 HPBW).

Star formation is mostly concentrated on the Galactic plane. The thickness of the molecular component of the Galactic disk is ~70 pc (Blitz 1990), corresponding to ~2.5° at a distance of 1 kpc. A 5°-wide band centered on the Galactic plane should then contain all star forming regions at a distance greater than 1 kpc. We can cover this region with a set of strips obtained by scanning the telescope along the 6 Galactic axis. Using the latest SPIRE instrument performance figures and allowing for reasonable...
2003

Dear HERSCHEL Colleague,

as many of you know, since the time of the "Promise of HERSCHEL" meeting in Toledo in 2001, the idea has been around (mainly in the SPIRE Consortium) to use HERSCHEL to map the Galactic Plane from 60 to 600 microns. First-cut estimates of the observing time needed clearly rule out the possibility to carry out such a survey in Guaranteed Time and qualify this programme as a candidate Key-Project. Although we do not officially know yet how the KPs are going to be implemented in HERSCHEL, there are rumors that a final and formal decision might indeed be taken relatively soon; so we feel this may be the right time to get all interested parties around a table and start organizing the work needed to prepare this specific KP proposal.

Please reply to molinari@ifsi.rm.cnr.it as soon as possible if you plan to attend this meeting, so that we will be able to consolidate the dates. More information about logistics will follow.

Best Regards,

Sergio Molinari & Bruce Swinyard
Option 1 - butterfly

- If we space at 12 arcmin – we need 1800 such patterns to cover 360 deg.
- Total “scan length” ~45.3 deg
- Takes ~2700 secs at fullspeed + 20% for telescope ~3300 sec
- Total 69 days
- But…..
Option 2 – reversed dog leg

- If we space at 8 arcmin – we need 2700 such patterns to cover 360 deg.
- Total “scan length” ~27.8 deg
- Takes ~1670 secs at full speed + 20% for telescope ~2000 sec
- Total 63 days
- Lose some redundancy in spatial sampling but get more complete 3 scan coverage
Free-wheel thoughts on pacs scanning

Mostly based on insane interpretation of available documentation

S. Molinari – IFSI/CNR Rome
Technical viewpoint

- In "standard" observing mode, i.e. using the PACS Guesstimator, 700 days are needed for a PACS 2-band map of the Galactic Plane area (1800 sq. deg.).
- The desired level of 100 mJy is reached with S/N ~ 18: not really needed. Going to S/N=5 reduces the required time to 70 days (same as SPIRE!!!)
- Time cannot be decreased unless the mapping speed is increased by a factor 10
- A possible way (perhaps the only way) to do this is to use the PACS chopper to freeze the frame as Herschel slews.

....a lot of scared Germans in the room....

....but eventually the PARALLEL MODE became reality....
Hi-Gal
A Herschel Key-Project to map the Galactic Plane in the Far-IR

Simultaneous 5-bands
\((70-160-250-350-500\mu m)\) continuum mapping of 720 sq. deg. of the Galactic Plane \((|b| \leq 1^\circ)\)

With almost 900 hours observing time is the largest OPEN TIME Herschel KP

Galaxy-wide Census, Luminosity, Mass and SED of dust structures at all scales from massive YSOs to Spiral Arms

Thanks to a GREAT PS
Field $\ell = 30^\circ$
Hi-GAL
the Herschel infrared Galactic Plane Survey

Covering the ten, re Galac, c Plane from 70 to 500 µm, mes higher spa, al resolu, on compared to Planck

more than 150,000 dense clumps from quiescent starless to HII Regions

Molinari et al. 2016

Credits: Gianluca Li Causi (INAF-IAPS)

70-160-250µm composite

from quiescent starless to HII regions

Molinari et al. 2016
Hi-GAL is statistics

- First-generation Hi-GAL Photometric Catalogues created using CuTEx package (Molinari+11) for the inner Galaxy
- Naïve band-merging produces a catalogue of 519400 entries Clump catalogue down-selected filtering “nice” SEDs with at least three adjacent counterparts 160-500\(\mu m\) yields 99180 entries

<table>
<thead>
<tr>
<th>Band</th>
<th>(N_{\text{sources}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACS-70(\mu m)</td>
<td>122,971</td>
</tr>
<tr>
<td>PACS-160(\mu m)</td>
<td>292,051</td>
</tr>
<tr>
<td>SPIRE-250(\mu m)</td>
<td>280,258</td>
</tr>
<tr>
<td>SPIRE-350(\mu m)</td>
<td>161,855</td>
</tr>
<tr>
<td>SPIRE-500(\mu m)</td>
<td>85,880</td>
</tr>
</tbody>
</table>

Estimating completeness limits is not for the faint-hearted!

Molinari+ 2016
Hi-GAL is statistics

- For the 99180 inner Galaxy sources with counterparts in at least three bands, we augment SED coverage with ATLASGAL, BGPS, MIPSGAL, WISE, MSX

- A first set of distance estimates (with different levels of reliability) has been carried out excluding $\ell<14^\circ$ and $\ell>350^\circ$, yielding $T$, $L$, $M$ and size, for 56656 sources

Hi-GAL - MSX 21 µm $\rightarrow$ 1754
Hi-GAL - WISE 22 µm $\rightarrow$ 46414
Hi-GAL - MIPSGAL 24 µm $\rightarrow$ 44923
Hi-GAL - ATLASGAL 870 µm $\rightarrow$ 7159
Hi-GAL - BGPS 1.1 mm $\rightarrow$ 3938

Elia+ 2016, in prep
Properties and Nature of the compact Dense Clumps

ATLASGAL sources with $L > 10^4 L_\odot$ associated to HII regions and CH$_3$OH masers (Urquhart+ 2013)

Hi-GAL Inner Galaxy Prestellar Clumps (i.e. with NO 70µm counterpart). [Light blue area follows Kauffmann & Pillai 2010; violet area follows Krumholz & McKee 2008]

Hi-GAL Inner Galaxy Protostellar Clumps (i.e. with 70µm counterpart)
Clumps evolutionary stages for the entire Hi-GAL sample

• Pre-stellar Sources (*no* 70µm counterpart)
• Proto-stellar Sources (*with* 70µm counterpart) Elia+ in prep.

- Herschel counterparts (Cesaroni+ 2015) to CORNISH HII regions catalogue (Purcell+ 2013)
- Counterparts to CH$_3$OH masers from MMB survey (Pestalozzi+ 2015)

Confidence for the validity of the baseline evolutionary toolkit is growing on more solid statistical grounds
Clumps on Filamentary Clouds

Molinari+ 10
Column density map from Hi-GAL

\[ \text{~500 filaments} \]
Do more massive clumps form on more massive filaments? Or do filaments grow mass from the surrounding environments and channel more mass to the clumps? No clear evidence for thresholds.

Schisano+ 2014
Evolutionary effects are clearly visible as a function of the filaments linear masses.

**Blue**: filament branches with **protostellar clumps**, i.e. with a 70 µm counterpart.

**Red**: filament branches with **prestellar clumps**

**Black**: filament branches with **no clumps**

1) Accretion rates $\approx 10^{-2}-10^{-3} \, M_{\odot}/pc/yr$ are needed to explain the differences in evolutionary terms (see also Kirk +13, Peretto+ 13)

2) Differences in linear masses, clump masses and $L/M$ are imprinted at the time of filament formation.

A first complete catalogue of Hi-GAL-selected filamentary structures is in progress (Schisano+, in preparation).

Schisano+ 2014
Global distribution of Clumps from Hi-GAL

- Prestellar (no 70µm)
- Protostellar (70µm)
A first attempt in deriving the SFR in the two Hi-GAL SDP fields l=30° and l=59° (Veneziani et al. 2013), comparing YSO statistics for PROTOSTELLAR Clumps in the L vs M plot against evolutionary predictions (McKee & Tan 2003, Molinari+ 2008).

Star Formation Rates from Protostellar Clumps counts

\[ SFR = \sum_{i=1}^{N_{\text{Mzams}}} \sum_{j=1}^{N_{\text{Sources}}} n_M(i,j) M_{\text{ZAMS}}(i) / t_f(i) \]

Each bin \(i\) is associated to:
- final ZAMS mass \(M_{\text{ZAMS}}(i)\)
- formation time \(t_f(i)\)

Prescriptions have been updated (Veneziani+ 2016 subm.) to account for cluster formation rather than single massive stars

Generate synthetic protoclusters evolutionary models (Robitaille, SM+ in prep)
The Milky Way Map of the Star Formation Rate

A word of caution with spiral arms prescriptions:

e.g., we find structures best matching with Steiman-Cameron + 2010, and others best matching with Momany+ 2006

Local Arm detected with several SF regions.

....work in progress

≈ 1.60 [Integrated SFR ]
≈ 0.57 [CMZ @ 8.4 kpc]

2.17 M\(_\odot\)/yr

Molinari+ in prep.
Hi-GAL is a vision come true

it now looks so normal and natural that it happened.....but it isn’t

Thanks Mate !