Probing the origin of the stellar initial mass function: A wide-field *Herschel* photometric survey of nearby star-forming cloud complexes

Proposal for a SPIRE/PACS GT Key Project submitted by: SPIRE SAG 3, CEA Saclay, IFSI Rome & INAF-Arcetri, KU Leuven, MPIA Heidelberg, and the *Herschel* Science Centre

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(Phase 2 version – June 28, 2007)

Abstract

Herschel provides a unique opportunity to study the earliest stages of star formation. What is the origin of the stellar initial mass function (IMF)? This issue is central in local star formation research and for understanding whether the IMF is truly universal or is likely to depend on metallicity, pressure, or temperature. As prestellar cores and young (Class 0) protostars emit the bulk of their luminosity at $\sim$ 80-400 microns, the Herschel imaging instruments SPIRE and PACS are ideal for taking a census of such objects down to $\sim$ 0.01-0.1 Msun in nearby ($<$ 0.5 kpc) molecular cloud complexes.

We propose an extensive imaging survey of the densest portions of the Gould Belt with SPIRE at 250-500 and PACS at 110-170 microns down to a 5-sigma column sensitivity $N_{\rm H2} \sim 10^{21}\,{\rm cm}^{-2}$ or $A_V \sim 1$. Our goal is to make a complete, homogeneous mapping of the $A_V > 3$ regions with SPIRE and of the $A_V > 6$ regions with PACS, and representative areas at $A_V \sim$ 1-3 levels with both instruments. The survey sensitivity is well matched to the expected cirrus confusion limit, so we should detect structures throughout the maps. The target clouds span a range of physical conditions, from active, cluster-forming complexes to quiescent regions with lower star formation activity.

We should detect hundreds Class 0 protostars and thousands prestellar condensations in the entire ~ 160 deg^2 SPIRE survey, i.e. ~ 10 times more cold objects than already identified from the ground. These numbers should allow us to derive an accurate prestellar core mass function. The temperature and density structures of the nearest ($<$ 0.2 kpc) cores will be resolved, revealing the initial conditions for individual protostellar collapse. The large spatial dynamic range of the proposed survey will probe the link between diffuse cirrus-like structures and compact self-gravitating cores. Our main scientific goal is to elucidate the physical mechanisms for the formation of prestellar cores out of the diffuse medium, crucial for understanding the origin of stellar masses.

1. Motivation of the proposed Gould Belt survey

Understanding star formation on both small and large scales is a major unsolved problem of modern astrophysics, which is fundamental in its own right and also has a profound bearing on both planet formation and the physics of galaxies. Despite significant progress in the past two decades (see, e.g., § 2 below), fundamental aspects of the star formation process remain poorly understood, including:

- What determines the distribution of stellar masses at birth, i.e., the IMF ?
- What generates prestellar cores in molecular clouds and governs their evolution to protostars ?
- What controls the efficiency of star formation within a giant molecular cloud (GMC) ? For instance, is there a threshold for core/star formation ?
- On the scale of a GMC, is star formation generally a slow process (taking several dynamical times) or a fast, dynamic process ?
- What are the detailed physical conditions at the onset of protostellar collapse and how is the latter initiated ? How does this affect protostellar evolution ?
- Are the initial cloud conditions required for the "clustered mode" of star formation fundamentally different from those of the "isolated mode" ?
- Is the formation process of brown dwarfs ($M_\star < 0.08\, M_\odot$) similar to the formation process of low- to intermediate-mass ($0.1 \lesssim M_\star \lesssim 8\, M_\odot$) stars or is it qualitatively different ?

The *Herschel* imaging instruments SPIRE and PACS will provide unique tools to address all of these fundamental issues. In order to make significant progress, we propose to carry out an extensive photometric imaging survey of the nearby ($d \leq 0.5$ kpc) molecular cloud complexes of the Gould Belt with SPIRE at 250–500 μm and PACS at 110 and 170 μm. We stress that the $\sim 15''$ angular resolution of *Herschel* around $\lambda \sim 200\,\mu$m is adequate for probing individual ($\sim$ 0.01-0.1 pc) star-forming cores up to $\sim$ 0.5 kpc. The target clouds correspond to the volume of Galactic space where *Herschel* imaging can best be used to characterize the earliest stages of star formation in detail (see § 5 below).

In the following, we provide more background (§ 2) and explain how the proposed survey will help address the science questions outlined above (§ 3).

2. The earliest stages of star formation and evolution: Present understanding

Stars form from the collapse of dense cloud cores in the molecular interstellar medium (mostly GMCs) of galaxies. A reasonably robust evolutionary sequence has been established for the formation and early evolution of individual low- to intermediate-mass ($M_\star \lesssim 8\, M_\odot$) stars within a molecular cloud. Five stages are distinguished (e.g. Shu, Adams, Lizano 1987; Lada 1987; André, Ward-Thompson, Barsony 1993, 2000; Shu, Li, Allen 2004). The first stage corresponds to the formation of gravitationally-bound starless ($M_\star = 0$) cores/condensations in the parent cloud. Such cold prestellar cores are observed in dense molecular gas tracers such as NH_3 or N_2H^+ (e.g. Jijina, Myers, & Adams 1999; Caselli et al. 2002), and in the mm/submm dust continuum (e.g. Ward-Thompson et al. 1994), but are opaque in the near-IR and mid-IR ranges where they often show up in absorption (e.g. Bacmann et al. 2000, Alves et al. 2001). The gravitational collapse of a prestellar core leads to the formation of a central protostellar object which accretes material from an envelope corresponding to the rest of the core. Accreting protostars are divided into two broad classes, depending on whether the envelope is still more massive than the central object (Class 0 protostars with $M_{env} > M_\star$ – André et al. 1993) or is only a remnant of the initial prestellar core (Class I objects with $M_{env} < M_\star$ – Lada 1987; André & Montmerle 1994). Observationally, Class 0 objects are characterized by high submillimeter to bolometric luminosity ratios ($L_{smm}^{\lambda>350\mu}/L_{bol} \gtrsim 1\%$) and overall spectral energy distributions (SEDs) resembling 15–30 K blackbodies (see Fig. 1b). When the central young stellar object (YSO) has accumulated most ($\gtrsim 90\%$) of its final mass, it becomes a pre-main sequence (PMS) star, which contracts approximately at fixed mass until it reaches the main sequence. The most evolved YSO stages correspond to PMS stars surrounded by a circumstellar disk but lacking a dense circumstellar envelope ($M_{env} \sim 0$). While the disk is still massive enough ($M_{disk} \sim 0.01\, M_\odot$) to be protoplanetary in nature at the Class II stage, it has evolved to an optically-thin debris disk at the Class III stage.

While *IRAS*, *ISO*, and ground-based near-IR studies have provided a fairly complete census of Class I–III YSOs in nearby clouds (e.g. Bontemps et al. 2001), no such census exists for cold prestellar condensations and Class 0 protostars yet. Only about thirty Class 0 protostars are known to date and only four in the nearest clouds ($d \leq 150$ pc) (cf. André et al. 2000). Consequently, the relative lifetimes of the prestellar, Class 0, and Class I stages remain a matter of debate (e.g. André et al. 1993; McLaughlin & Pudritz 1997; Visser, Richer, & Chandler 2002).

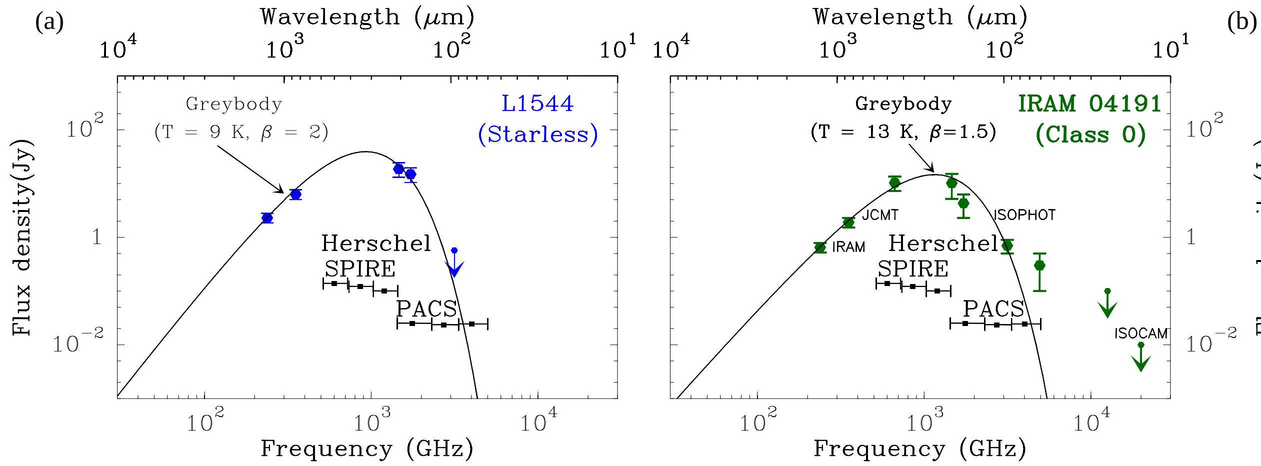

Figure 1: Spectral energy distributions of the starless core L1544 **(a)** and of the Class 0 protostar IRAM 04191 **(b)** in Taurus (from Ward-Thompson et al. 2002 and André et al. 1999, respectively). The six photometric bands of SPIRE and PACS are shown, along with the estimated 5σ sensitivities of the proposed *Herschel* survey. *Herschel* is ideally suited for taking a census of such cold protostellar objects down to $M_{proto} \sim 0.01$–$0.1\ M_{\odot}$ in nearby ($d \leq 0.5$ kpc) molecular cloud complexes.

Improving our knowledge of prestellar cores and Class 0 protostars is of prime importance for distinguishing between collapse models and shedding light on the origin of stellar masses. Recent studies suggest that the effective reservoirs of mass required for the formation of individual stars are already selected at the prestellar core stage: Several ground-based (sub)-millimeter continuum surveys of nearby, compact cluster-forming clouds such as ρ Ophiuchi, Serpens, and Orion B have uncovered 'complete' (but small) samples of prestellar condensations whose associated mass distributions resemble the stellar initial mass function (IMF) (Motte, André, Neri 1998 – MAN98; Testi & Sargent 1998; Johnstone et al. 2000; Motte et al. 2001; Stanke et al. 2006 – see Fig. 2). Albeit limited by small-number statistics (see § 3.4 below), these recent findings are encouraging as they support scenarios according to which the bulk of *the IMF is at least partly determined by pre-collapse cloud fragmentation.* The problem of the origin of the IMF may thus largely reduce to a good understanding of the processes responsible for the formation of prestellar cores/condensations within molecular clouds.

The core formation issue is currently the subject of a major debate: The classical picture of slow, quasi-static core formation by ambipolar diffusion in magnetically-supported clouds (e.g. Shu et al. 1987, 2004; Mouschovias & Ciolek 1999) has been seriously challenged by a new, more dynamic picture, which emphasizes the role of supersonic turbulence in supporting clouds on large scales and generating density fluctuations on small scales (e.g. Klessen et al. 2000; Padoan & Nordlund 2002). In principle, it should be possible to discriminate between these two pictures from the observed characteristics (e.g. density structure, shapes, lifetimes ...) of *complete samples of prestellar cores/condensations.*

3. Why *Herschel* mapping observations are essential

3.1 Unmatched mapping speed and angular resolution in the far-IR/submillimeter band

With present ground-based mm/submm telescopes, systematic surveys for pre-/proto-stellar condensations are possible only down to $\sim 0.1\,M_{\odot}$ in nearby ($d \sim 150$ pc), compact regions such as the ρ Oph cloud (MAN98; Johnstone et al. 2000). Recent discoveries of new Class 0–like objects in well-documented regions such as Taurus and Lynds dark clouds through limited mm/submm mapping (e.g. André et al. 1999; Visser et al. 2002) show that the current census of protostars in the nearby ISM is incomplete. Complete surveys of molecular clouds in the submm band are also needed to address the issue of whether or not there is a threshold for core formation. It has recently been suggested that cores cannot form below a minimum background column density $N_{H2} \sim 10^{22}$ cm^{-2} or $A_V \sim 10$ (Onishi et al. 1998, Johnstone et al. 2004, Enoch et al. 2005). However, present claims are unconvincing because (i) they are based on surveys whose detection thresholds are themselves close to $A_V \sim 10$, and (ii) the ISM is known to be highly structured down to much lower column densities (e.g. Elmegreen & Falgarone 1996). Much deeper surveys, sensitive to $A_V \sim 1$, are required to settle this issue.

With a mapping speed $\sim$ 2–3 orders of magnitude faster than SCUBA at 850 μm or SOFIA at 100–200 μm (cf. Becklin 1997) and nearly ~ 1 order of magnitude faster than SCUBA2 (see § 4), SPIRE will make it possible to search for low-mass, cold condensations over the entire extent of nearby cloud complexes in a reasonable time (see § 7). Carrying out such surveys with the high angular resolution of SPIRE and PACS will be essential (i) to limit cirrus confusion (see Appendix A), (ii) to probe individual ($\sim 0.01 - 0.1$ pc) condensations in nearby regions (up to ~ 0.5 kpc), and (iii) to resolve the structure of the nearest (< 0.2 kpc) objects (§ 3.3).

3.2 Deriving accurate bolometric luminosities

Prestellar cores, Class 0 protostars, and Class I objects emit typically $\sim$ 100%, $>$ 80%, and $>$ 40% of their bolometric luminosity, respectively, in the 75–500 μm wavelength range sampled by *Herschel* photometers. Because of typical source clustering in star-forming regions, high-resolution *Herschel* mapping at these wavelengths is essential to derive accurate L_{bol} values for these objects. It is important to stress here that L_{bol} is a fundamental variable of (proto)stellar astrophysics used in all evolutionary diagrams proposed to date for embedded YSOs (e.g. Adams et al. 1987; André & Montmerle 1994; Saraceno et al. 1996; Myers et al. 1998).

3.3 Temperature/density structure reconstructions

Combining PACS and SPIRE images to construct 110–500 μm SED maps for the nearest, spatially resolved sources, it will be possible to derive the temperature distribution within both prestellar cores and protostellar envelopes. Recent radiative transfer modelling of the thermal energy balance suggests that starless cores are significantly colder in their central regions (with T as low as $\sim$ 5–7 K) than in their outer parts (e.g. Evans et al. 2001; Stamatellos et al. 2004). *Herschel* will allow us to directly measure the magnitude of this effect for the first time (see Appendix A). Coupled with complementary ground-based dust continuum observations at longer submillimeter wavelengths, the column density structure of the same sources will also be derived with unprecedented accuracy, setting detailed constraints on the initial conditions for individual protostellar collapse. We stress that the only way to reach unambiguous conclusions on core structure is to reconstruct the temperature and column-density profiles simultaneously through multi-band imaging from the Rayleigh-Jeans part of the emission spectrum up to and beyond the peak of the SED (see § 3.3 of André et al. 2003).

3.4 Reliable determination of the core mass function down to substellar masses

In order to confirm the role of cloud fragmentation in shaping the IMF (cf. end of § 2), it is crucial to improve on the current estimates of the core mass distribution in nearby star-forming clouds, which are limited by small-number statistics, especially at the low- and high-mass ends (see Fig. 2). For instance, there are presently only 8 condensations more massive than $\sim 0.5\,M_\odot$ (i.e. in the Salpeter part of the mass spectrum) known in the ρ Oph main cloud (MAN98) and ~ 30 in the NGC 2068/2071 region (e.g. Motte et al. 2001), so that the standard CO clump mass spectrum ($dN/dM \propto M^{-1.6}$ or $N(>M) \propto M^{-0.6}$, which is substantially flatter than the Salpeter IMF – e.g. Blitz 1993) *cannot* be rejected with a high level of confidence ($\sim 2\sigma$ result only). Furthermore, the core mass distribution in the ρ Oph main cloud shows a tentative break at $\sim 0.4\,M_\odot$ (see Fig. 2) which is reminiscent of the flattening observed in the stellar IMF below $0.5\,M_\odot$ (e.g. Kroupa 2001). The break in the IMF defines a characteristic stellar mass $\sim 0.5 - 1\,M_\odot$ which is possibly related to the typical Jeans mass in the parent cloud (e.g. Larson 1999; Padoan & Nordlund 2002). In this case, one expects the location of this break to vary from region to region according to the local Jeans mass (which depends on the background density and temperature). To establish or rule out such an effect requires observations of a wide range of nearby clouds with much better statistics than presently available (see § 5).

In the nearest ($d \lesssim 0.2$ kpc) clouds, the mass sensitivity of the proposed SPIRE/PACS survey (see Tables 2 & 3 in § 7) will allow us to see whether the prestellar mass distribution remains consistent with the IMF in the substellar mass regime or not, which will provide important clues to the much debated brown dwarf formation mechanism(s) (Reipurth & Clarke 2001; Padoan & Nordlund 2004).

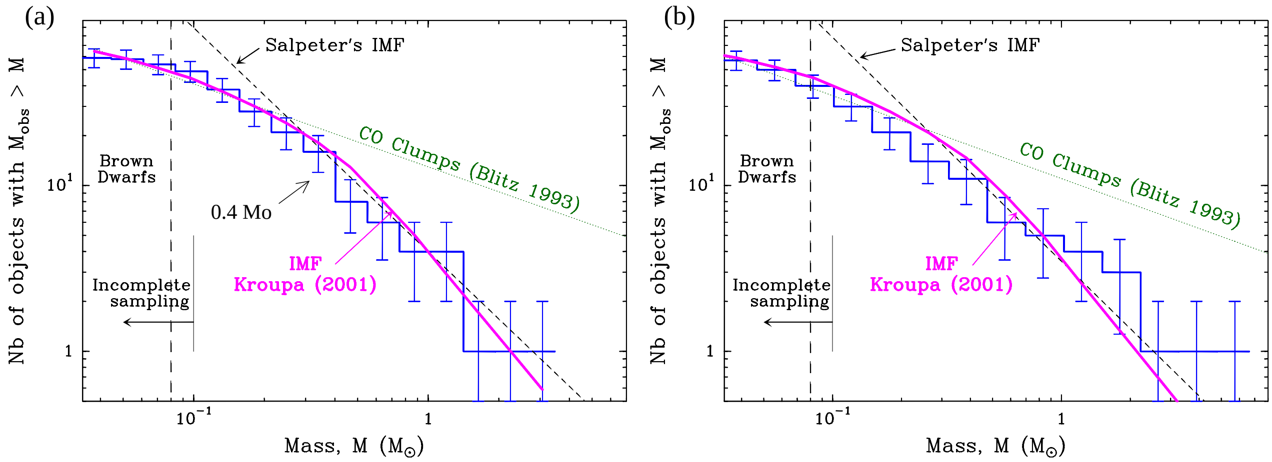

Figure 2: **(a)** Cumulative mass distribution of a sample of 57 prestellar condensations, complete down to $\sim 0.1\,M_\odot$, in the ρ Oph protocluster (histogram with error bars – from MAN98). (Here, the condensation masses were derived from a 1.3mm dust continuum map assuming the same dust properties for all condensations: $T_d = 15$ K, $\kappa_d(1.3\mathrm{mm}) = 0.005\,\mathrm{cm^2\,g^{-1}}$.) For comparison, the dotted and dashed lines show power-laws of the form $N(>M) \propto M^{-0.6}$ (typical mass distribution of CO clumps – see Blitz 1993) and $N(>M) \propto M^{-1.35}$ (Salpeter's IMF), respectively. The solid curve shows the shape of the field star IMF (e.g. Kroupa 2001). Note the flattening of these mass distributions below $\sim 0.4\,M_\odot$. **(b)** Same as (a) but assuming a distribution of dust temperatures for the ρ Oph condensations, in agreement with radiative transfer calculations which suggest that more massive, higher column-density condensations may be colder (e.g. Bouwman et al. 2006). Note that the flattening of the prestellar mass distribution near $\sim 0.4\,M_\odot$ goes away. *Direct temperature measurements, possible only with Herschel, are thus crucial* to derive reliable core mass distributions.

Current mm/submm continuum determinations of core masses have to rely on rather strong assumptions about the *dust (temperature and emissivity) properties*. Both T_{dust} and κ_{dust} are uncertain (by a factor $\gtrsim 2$) and may possibly vary from object to object. Radiative transfer calculations show that the dust temperature at the center of a starless condensation depends primarily on the degree of shielding from the external interstellar radiation field (e.g. Bouwman et al. 2006). Since more massive condensations tend to have higher column densities (cf. MAN98) and to be more shielded, one may expect them to be colder on average than low-mass condensations, which may lead to a differential distortion of the derived mass distribution if uniform dust properties are assumed. Using SPIRE and PACS observations for a representative selection of objects, it will be possible to substantially reduce the mass uncertainties via direct constraints on the dust temperature (see § 3.3 and Appendix A).

3.5 Sensitivity to low surface brightness structures and high spatial dynamic range

A *global view* of molecular cloud complexes is required if we are to explain the process(es) by which prestellar cores form out of the diffuse ISM at specific locations inside star-forming regions. In particular, there is ample evidence that dense cores are not distributed randomly within molecular clouds but are often organized along large-scale filamentary structures (see the example of the Taurus cores and filaments in Fig. 6 – Appendix B – below). The formation of prestellar cores thus appears to be intimately related to the formation of large-scale filaments within cloud complexes, and it has been proposed that both prestellar cores and molecular clouds form by collision of large-scale supersonic flows in the interstellar medium (e.g. Hartmann et al. 2001). Wide-field imaging surveys with SPIRE, coupled with follow-up molecular line observations with ground-based mm/submm telescopes, will provide powerful tests of such a scenario by probing a wide range of spatial scales from ~ 0.01 pc (corresponding to the $\sim 17''$ resolution of SPIRE in the nearest star-forming regions at $d = 140$ pc) to several pc. Adopting a scanning speed of $60''$/sec, structures up to ~ 1 deg in angular scale (i.e., ~ 2.5 pc at $d = 140$ pc) can easily be recovered with SPIRE if slow instrumental drifts occur on ~ 1 min timescales.

Besides a high spatial dynamic range, one needs a high surface brightness dynamic range to be simultaneously sensitive to compact condensations *and* diffuse cloud structure. This point is illustrated in the mass vs. size diagram of Fig. 3. Known prestellar condensations are more than an order of magnitude more massive than typical CO structures for a given radius and follow a different mass–size relation (close to $M \propto R$, as opposed to $M \propto R^2$ for CO clumps). Fig. 3 reflects the fact that prestellar condensations are centrally-condensed, self-gravitating structures, while most CO clumps are transient unbound structures primarily shaped by turbulence (e.g. Elmegreen & Falgarone 1996). The typical sensitivity of present ground-based mm/submm continuum surveys is insufficient to detect low-density CO clumps. With its improved surface brightness sensitivity (see solid curve in Fig. 3), *Herschel* will probe deep into the regime of diffuse CO clumps, *making possible direct comparisons between CO clumps and prestellar condensations with a single tracer.* (Recall that CO is a poor tracer of prestellar condensations due to CO depletion onto dust grains at high density and low temperature.)

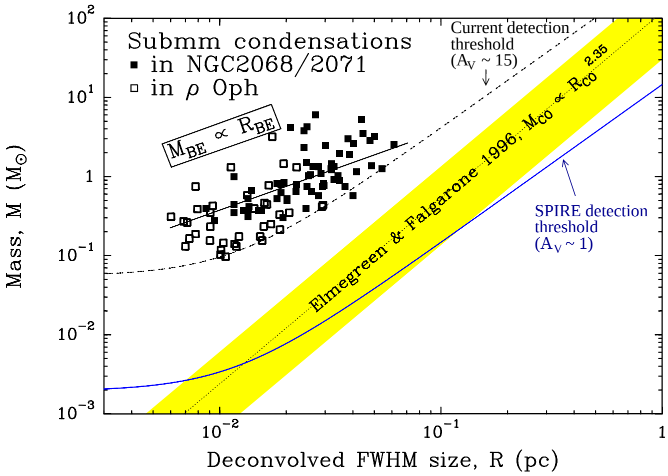

Figure 3: Mass vs. size diagram comparing the locations of the (sub)mm continuum prestellar condensations of ρ Oph and NGC2068/2071 (MAN98, Motte et al. 2001) with the correlation observed for diffuse CO clumps (shaded band – cf. Elmegreen & Falgarone 1996). The (5σ) detection threshold at $d = 150$ pc of current (sub)mm (e.g. SCUBA) surveys as a function of size is shown by the dashed curve. (The shape of this curve reflects a constant sensitivity to column density until source size approaches the beam size.) The detection threshold of the proposed SPIRE/PACS survey will be more than an order of magnitude lower (solid curve), allowing us to probe the genetic link between diffuse cloud structures (with $A_V \sim 1$) and dense, self-gravitating cores ($A_V > 10$).

4. Relation to observations with other facilities

• Similar wide-field surveys at comparable angular resolution are planned at longer (sub)mm wavelengths (e.g. 850 μm, 1.2 mm) with the next generation of bolometer arrays (e.g. SCUBA2) on ground-based telescopes. In particular, the SCUBA2 Gould Belt survey (e.g. Ward-Thompson et al. 2004) will be highly complementary to the proposed SPIRE/PACS survey: While a good temperature determination can only be done at *Herschel* wavelengths, the dust emissivity index (β) can be better estimated at longer wavelengths. The SCUBA2 survey will however be less sensitive to low surface-brightness, extended emission than the SPIRE/PACS survey, and will typically probe cloud structures only up to $\lesssim 10'$ and down to $A_V \gtrsim 5$ (as opposed to $\gtrsim 1$ deg and $A_V \sim 1$ for SPIRE).

• Existing and/or on-going surveys in the mid-/far-IR (e.g. *ISO*, *Spitzer*), near-IR (e.g. 2MASS), and X-rays (XMM-*Newton* and *Chandra*) (will) probe the YSO content of the same cloud complexes and help distinguish between the various classes of objects (e.g. prestellar cores, Class 0 protostars, Class I-III YSOs). Of particular relevance are the “Cores to disks” (c2d) and “Gould’s Belt” *Spitzer* legacy programs (cf. Evans et al. 2003 and Allen et al. 2006) which will provide IRAC (3.6-8 μm) and MIPS (24-70 μm) data over a substantial portion ($20 + 32 = 52$ deg^2) of the molecular clouds to be imaged at 110-500 μm in the proposed *Herschel* survey.

5. Cloud sample and justification of the total survey area

We propose a complete mapping survey of the densest portion of the Gould Belt, down to $A_V \gtrsim 3$ with SPIRE at 250–500 μm, and to $A_V \gtrsim 6$ with PACS at 110/170 μm. The baseline survey will cover a total of $\sim 145\,\mathrm{deg}^2$ with SPIRE and $\sim 55\,\mathrm{deg}^2$ with PACS, including most cluster-forming regions and isolated dense cores within $d < 0.5$ kpc of the Sun, as well as selected areas at low extinction levels. While all protostars should be located at $A_V > 6$, mapping regions at lower extinction ($A_V \sim 1-3$) will help us constrain the formation mechanism of prestellar cores out of the diffuse ISM.

A rough prediction of the number of protostars and prestellar condensations to be found by the proposed SPIRE/PACS survey may be obtained as follows. The star formation rate per unit area of the Galactic disk is estimated to be $\sim 7.5\,M_\odot$ pc^{-2} Gyr^{-1} in the Solar neighborhood (e.g. McKee & Williams 1997), which implies a total star formation rate $\sim 6\times10^{-3}$ M$_\odot$ yr^{-1} in an area of $d \leq 0.5$ kpc around the Sun, corresponding to the target complexes. Adopting the IMF of Kroupa (2001), for which the mean stellar mass is $0.36\,M_\odot$, this corresponds to a total creation rate $C \sim 0.02$ stars yr^{-1} in the same complexes. If C is approximately constant in time, the total number of protostellar objects of characteristic lifetime t_{proto} is also time-independent: $N_{proto} \approx C\,t_{proto}$ (e.g. Fletcher & Stahler 1994). In Table 1, we give the expected number of sources calculated in this way for various mass intervals and two types of objects: Class 0 protostars for which we assume $t_{proto} \sim 3 \times 10^4$ yr, and prestellar condensations for which we take $t_{proto} \sim 3 \times 10^5$ yr. We conclude that the target cloud complexes should harbor a few hundred Class 0 protostars and several thousand pre-stellar condensations, i.e., an order of magnitude more cold protostellar objects than those already identified from the ground.

Table 1: **Numbers of protostellar condensations detectable in the surveyed area**

Source Type	Substellar[1] 0.01–0.08 $M_\odot$	Low-mass 0.08–0.5 $M_\odot$	Solar-mass 0.5–2 $M_\odot$	Intermediate-mass 2–8 $M_\odot$	High-mass $> 8M_\odot$
Class 0	30	240	65	10	2
Prestellar	300	2400	650	100	20 ?

(1) Detectable only up to $d \approx 0.2$ kpc.

The expected number of prestellar condensations is both adequate and necessary to derive an accurate prestellar core mass distribution from the substellar to the intermediate-mass regime. For a good sampling of the mass distribution, we need a minimum of ~ 20 objects per 0.15 dex mass bin (spanning a factor $\sim \sqrt{2}$ in mass). Given the form of the IMF, the most demanding bins are the lowest and highest mass bins, corresponding to the prestellar precursors of $\sim 0.01\,M_\odot$ brown dwarfs and $\sim 5\,M_\odot$ stars, respectively. Using the same method as above, we estimate that the *entire* SPIRE survey will detect a total of ~ 24 and ~ 17 prestellar condensations in these two mass bins, respectively. Furthermore, we will achieve good enough statistics *in each region* around the characteristic stellar mass $\sim 0.5\,M_\odot$ to investigate possible environmental variations from cloud to cloud (see § 3.4).

6. Science exploitation plan

During the propietary period and the first years after the observations, our team will focus on:

• obtaining a complete census of compact starless condensations and young protostars in the sampled clouds, which will provide reliable lifetimes for the various stages as a function of mass, central density, and environment, and set unique constraints on models of slow *vs.* fast core/star formation (see end of § 2);

• measuring the associated luminosity and mass functions, allowing us (i) to probe the luminosity evolution of protostars and (ii) to relate the mass distribution of prestellar condensations to that of young stars, thereby giving insight into the possible cloud fragmentation origin of the IMF (see § 2 and Fig. 2);

• studying the genetic link between diffuse, cirrus-like structures/filaments in molecular clouds and compact self-gravitating condensations (see § 3.5 above), in order to shed light on the core formation mechanism(s);

• deriving temperature and density profiles for the nearest ($d < 0.2$ kpc) condensations observed with SPIRE and PACS (cf. § 3.3), which will give unprecedented constraints on the initial conditions for protostellar collapse.

7. Technical implementation

7.1 Source list

Based on large-scale CO surveys and (optical/near-IR) dust extinction maps (e.g. Dame et al. 2001, Cambrésy 1999), $\sim$ 15 molecular cloud complexes are known within 0.5 kpc of the Sun (cf. Appendix B). Most of these complexes are located in (or related with) the Gould Belt, a giant ($\sim$ $700\,\mathrm{pc} \times 1000\,\mathrm{pc}$), flat structure inclined by $\sim 20°$ to the Galactic Plane, which is possibly the nearest example of an expanding supershell resulting from supernova explosions (e.g. Guillout 2001).

We propose a complete mapping survey of the densest portions of these cloud complexes, down to $A_V \gtrsim 3$ with SPIRE and $A_V \gtrsim 6$ with PACS (see Tables 2 & 3). The target clouds described in Appendix B span a wide range of physical conditions, from 'active', cluster-forming complexes (Ophiuchus, Corona Australis, Serpens, Perseus, Orion) to 'quiescent' regions with no or only distributed, low-mass star formation activity (Coalsack, Lupus, Polaris flare, Taurus). They include the nearest examples of massive GMCs forming a significant number of intermediate-mass and high-mass stars (e.g. Orion). Some of them (e.g. Ophiuchus, Corona Australis, Serpens, Perseus, Orion) harbor compact embedded clusters containing large, homogeneous samples of YSOs and protostars, which have been the subject of detailed investigations at infrared wavelengths (e.g. Meyer et al. 2000; Lada & Lada 2003; Porras et al. 2003 and references therein). These embedded clusters are believed to be representative of the basic building blocks where most ($\sim 70-90\%$) stars form in the Galaxy (e.g. Lada & Lada 2003). Owing to their proximity, **the molecular cloud complexes of the Gould Belt offer the best opportunity to characterize the various steps of the star formation process in detail**. In particular, studying the whole range of clouds described in Appendix B will allow us to identify the conditions required for clustered star formation and to investigate the factors that control the (in)efficiency of dense core/star formation.

7.2 Observing strategy

In order to map the clouds decribed in Appendix B completely down to $A_V \gtrsim 3$ with SPIRE and $A_V \gtrsim 6$ with PACS, we have used optical and/or near-IR extinction maps (Cambrésy 1999; S. Bontemps, private communication) to define the boundaries of the fields to be observed (see examples in the figures of Appendix B). As can be seen in the extinction maps (e.g. Figs. 6–9 – see also http://starformation-herschel.iap.fr/gouldbelt/), the proposed fields – which do not follow the exact, fractal-like shape of the $A_V \sim 3$ and $A_V \sim 6$ contours – also include portions of the clouds at lower (e.g. $A_V \sim 1$) extinction levels.

To cover the fields shown on our web site (http://starformation-herschel.iap.fr/gouldbelt/ – see the figures of Appendix B for examples) we plan to use the scan mapping mode with a scanning speed of $60''$/sec with SPIRE and $20''$/sec with PACS in order to maximize sensitivity to extended emission. With both instruments, each region will be observed twice by independent scans taken at nearly orthogonal directions, in order to reduce the effects of 1/f noise. Our proposed *Herschel* observations will be carried out in two steps:

(1) A wide-field SPIRE/PACS survey of a total surface area $\sim 160\,\mathrm{deg}^2$ (see detailed breakdown in Table 2) using the parallel mode at $60''$/sec and the PACS 75 μm and 170 μm bands. In this first step, the main goal is to acquire adequate SPIRE 250–500 μm data for all of the target regions. The PACS data acquired simultaneously will provide very useful 'bonus' information at shorter wavelengths through most of the SPIRE survey, but will not have optimum sensitivity and angular resolution. We select 75 μm for the blue band of PACS since obtaining good data in this filter is deemed to be less critical to our project which is focused on the origin of cold prestellar cores.

(2) A dedicated PACS-only survey of a total surface area $\sim 65\,\mathrm{deg}^2$ (see detailed breakdown in Table 3), observing the 110 μm and 170 μm bands at $20''$/sec. This second step will provide data with optimum sensitivity and resolution in the two most important PACS bands for the project.

If the SPIRE and PACS sensitivities are nominal (as given by HSpot version 3.0), the wide-field parallel mode survey (2 coverages) will yield uniform 1σ noise levels $\sim$ 9 mJy/$18''$-beam, 12 mJy/$25''$-beam, 10.5 mJy/$36''$-beam at 250 μm, 350 μm, 500 μm (SPIRE), and 12.5 mJy/beam & 19 mJy/beam at 75 μm & 170 μm (PACS), respectively. The dedicated PACS survey (2 coverages) will provide 1σ levels $\sim$ 7.5 mJy/$7.7''$-beam at 110 μm and 11 mJy/$12''$-beam at 170 μm.

Table 2: **Fields to be surveyed with SPIRE/PACS in parallel mode at 60″/sec**

Cloud complex	Mapped Area (deg^2)	Distance (pc)	IRAS B_{100} (MJy/sr)	(1σ) Cirrus Noise at 250μm (mJy/beam)	(10σ) Mass Sensitivity[a] ($M_\odot$)	Required Time[b] (hr)	Responsible Team(s)
Taurus	26	140	35	10	0.01	49.0	Cardiff/Saclay
Ophiuchus	16.9	140	80	35	0.02	23.3	Saclay/Cardiff
Pipe Nebula	7.1	140	80	35	0.02	14.0	Saclay
Polaris flare	6.3	150	10	3	0.01	8.5	Orsay/Saclay
Lupus	7.9	100	50	15	0.008	14.9	Rome/RAL
Coalsack	2.5	150	150	90	0.02	4.9	Saclay
Cham I/III + Musca	16.3	160	20	5	0.01	25.6	HSC/Saclay
Corona Australis	9.7	170	30	10	0.01	14.6	RAL/Cardiff
Serpens	8.9	260	70	30	0.07	13.5	Rome/RAL
Aquila Rift	13.9	400	150	90	0.15	18.8	Saclay
Perseus	5.6	300	20-50	5-15	0.04	15.0	Rome/Canada
IC 5146	1.6	400	90	40	0.15	3.6	Marseille
Cepheus/Cassiopeia	6.4	440	20	5	0.1	15.0	Canada
Orion A	14.8	450	75	20	0.2	21.7	Rome/Canada
Orion B	15.4	450	75	20	0.2	22.2	Saclay/Cardiff
Entire survey	159.5					264.5	

(a) Expected mass sensitivity at 250 μm and 350 μm if $T_d = 10$ K; the mass sensitivity is worse by only $\sim 70\%$ at 500 μm. If $T_d > 10$ K, the mass sensitivity is better than the quoted number in all SPIRE bands.

(b) Times calculated with HSpot v3.0

Table 3: **List of fields to be surveyed with PACS at 20″/sec**

Cloud complex	Mapped Area (deg^2)	Distance (pc)	IRAS B_{100} (MJy/sr)	Cirrus (1σ) Noise at 170μm (mJy/bm)	Mass Sensitivity[a] ($M_\odot$)	(10σ) Required Time[b] (hr)	Responsible Team(s)
Taurus	9.9	140	35	4	0.03	27.6	Saclay
Ophiuchus	6.0	140	80	14	0.04	17.0	Saclay
Pipe Nebula	1.8	140	80	14	0.04	4.6	Saclay
Polaris flare	1.0	150	10	0.5	0.02	3.1	SAG3/SAG4
Lupus	3.5	100	50	7	0.01	11.6	Rome/Leuven
Coalsack	1.2	150	150	35	0.05	3.7	Saclay
Cham I/III + Musca	7.2	160	20	2	0.03	21.8	Leuven/HSC
Corona Australis	1.6	170	30	3	0.03	9.2	Heidelberg
Serpens/Aquila Rift	7.3	260	70	11	0.1	20.8	Rome/Arcetri
Perseus	6.7	300	35	4	0.1	19.1	Rome
IC 5146	0.25	400	90	16	0.3	1.0	Saclay
Cepheus	5.3	440	20	2	0.2	16.6	SAG3/Canada
Orion A	8.6	450	75	13	0.3	24.5	Rome/SAG3
Orion B	5.6	450	75	13	0.3	16.0	Saclay
Entire survey	65.95					196.5	

(a) Mass sensitivity achieved at 170 μm if $T_d = 10$ K; in this case, the mass sensitivity is worse by an order of magnitude at 110 μm. If $T_d = 15$ K, the mass sensitivity is better than the quoted number by more than a factor of 5 at both wavelengths.

(b) Times calculated with HSpot v3.0

Assuming the dust opacity of Hildebrand (1983) and a typical dust temperature of $T_d = 10$ K for starless condensations, the SPIRE surface-brightness sensitivities correspond to a 5σ column-density detection threshold of $N_{\rm H2} \sim 1 - 2 \times 10^{21}\,{\rm cm}^{-2}$ (i.e., $A_V \sim 1 - 2$). Adopting a factor of ~ 2 lower dust opacity and $T_d = 15$–17 K, more typical of the diffuse ISM (cf. Lagache et al. 1999), the 5σ **column-density sensitivity becomes** $\boldsymbol{N_{\rm H2} \sim 3 - 5 \times 10^{20}\,{\rm cm}^{-2}}$ **or** $\boldsymbol{A_V \sim 0.3 - 0.5}$. The PACS 5σ column-density sensitivities will not be quite as good (e.g. $N_{\rm H2} \sim 10^{21} - 10^{22}\,{\rm cm}^{-2}$ or $A_V \sim 1 - 10$, depending on temperature), but the data will have a factor of $\sim 2-3$ better angular resolution. Since the expected column-density sensitivities are comparable to (or better than) the visual extinction level used to define the fields, we expect to detect dust emission/structure throughout the maps.

The corresponding (10σ) sensitivities to protostellar masses depend on distance and are listed in Tables 2 & 3 for each cloud target. We adopt a more conservative (10σ rather than 5σ) detection threshold for masses as our goal is to achieve a *complete* census of pre-/proto-stellar condensations down to that level. We also have to account for the fact that in the nearest ($d \sim 140$ pc) clouds most condensations will be spatially resolved by SPIRE and PACS, with expected integrated fluxes typically a factor $\gtrsim 2$ larger than their peak fluxes (cf. MAN98 and Ward-Thompson et al. 1999).

7.3 Observing time requirements

The times requirements for the two steps of the proposed survey are summarized in Table 2 (parallel-mode observations) and Table 3 (PACS-only observations). These times were calculated using HSpot Version 3.0.3.

Altogether, we propose to map $\sim 160\,{\rm deg}^2$ with SPIRE and PACS (75/170 μm) in the parallel mode (step 1), and subsequently $\sim 66\,{\rm deg}^2$ with PACS only (step 2). HSpot v3.0 indicates that a total of $\sim 264.5 + 196.5 = 461$ hr are required for these mapping observations, which corresponds to the total guaranteed time invested by our Consortium in the project (see § 1.2 of the Consortium Constitution in Appendix D for a detailed breakdown of the time contributions by the participating GT holders).

7.4 Other requirements

To maximize the scientific return of the project, it would be best if the wider SPIRE/PACS parallel mode survey (step 1) were carried out first and the narrower PACS-only survey (step 2) observed subsequently after final optimization of the coverage based on the initial SPIRE results.

7.5 Robustness of the project against changes in instrument sensitivities

Factor of ~ 2 changes upward or downward in mass and column-density sensitivities would not have a serious impact on the science achievements, although we would of course probe the formation of low-mass prestellar condensations in the ISM to a lesser or greater extent, respectively.

If the SPIRE or PACS sensitivities turn out to depart from their nominal values, we will thus not change the total surface areas covered by our proposed SPIRE/PACS parallel-mode survey ($\sim$ 160 deg^2) and PACS-only survey ($\sim$ 66 deg^2).

If the 'instrument and observation' overheads turn out to be shorter than currently calculated by HSpot, we will not change the surface area covered by the SPIRE/PACS parallel-mode survey and use the extra time to enlarge the area of the PACS-only survey.

8. Data processing plans and archival value

8.1 Data processing and analysis plan

The ability to accurately identify objects in images observed with the SPIRE and PACS photometers is essential for rapid data exploration. In that spirit, our team has developed a data analysis process for both SPIRE and PACS. First, synthetic skies are created to serve as input for software that simulates the instrument observation and reduction. The produced images are then analyzed by various source extraction algorithms, including background subtraction.

• **Synthetic skies**
Numerical radiative transfer modeling is used for detailed simulation of the star-forming regions to be observed and will be employed throughout all the phases of the project. At the stage of preparation of the observations, we compute spherical models of four realistic populations of several hundred starless prestellar cores and protostars with central accretion energy source, as well as realistic interstellar cirrus emission background (Men'shchikov et al. in prep.). The populations are quasi-randomly distributed over the cloud in such a way as to best represent low-to high-mass star-forming regions with numbers according to the current best model of stellar mass function, from 0.01 to 10 $M_{\odot}$.

• **Simulation of *Herschel* observations**
The synthetic sky produced in this way serves as input for the SPIRE or PACS software simulator (Sibthorpe et al., 2004; Ali et al., priv. comm.) that is designed to produce realistic images, taking into account instrumental effects (e.g. uncorrelated 1/f noise) and observing modes. The simulator allows to test data reduction techniques and operating modes, and to evaluate instrument systematics.

• **Map making**
This project is concerned with both the compact dust emission from protostars/prestellar cores and the fainter extended cloud emission from the parent clouds. The default SPIRE and PACS pipelines should already do a fairly good job for compact sources, but optimized routines will be developed, e.g., in the framework of the dedicated "Compact Source Extraction Working Group" of the SPIRE Consortium. Concerning extended emission, we are collaborating with with SPIRE SAG 4 (ISM) members and mathematicians with strong experience in signal processing in order to optimize the map-making process, especially the treatment of 1/f noise, and maximize sensitivity to extended structures (e.g. Rodet et al. 2005).
During an initial phase, the map-making algorithms developed for BLAST (stratospheric telescope equipped with a SPIRE-like bolometer array) and ArTeMiS (ground-based submm camera using a PACS-like filled array on the APEX telescope) can be used to produce first versions of SPIRE and PACS images for the present project.

• **Source extraction**
In order to detect - and distinguish - compact and extended sources in SPIRE/PACS images, an automatic, objective routine is required that includes a well-grounded background subtraction. Based on our experience with using multi-resolution techniques to analyze millimeter continuum images (cf. Motte et al. 1998, 2001, 2007), we employ this method to decompose simulated SPIRE/PACS images in multi-resolution wavelet planes (Starck et al. 1998, 2006) containing small to large structures. The sources themselves are extracted using well-known algorithms like Gaussclumps (Stutzki & Güsten 1990) or Clumpfind (Williams et al. 1994). These programs, however, have to be adapted to our specific requirements and tested thoroughly.

Besides, we are using the approach of multiresolution filtering and source extraction provided by SExtractor ("Source Extractor", Bertin & Arnouts 1996). Standard wavelet, morphological component analysis and entropy filtering have been used on individual images. Taking advantage of the double image mode of Sextractor (detection made on one image can be be used as a template for another image of the same region but at a different wavelength), we work on improving detection by using data with highest Signal-to-Noise, contrast or resolution for other less good images taken at different wavelengths. The next step will be to test new techniques of detection on multi wavelength data cubes, using the multiresolution approach or segmentation through a Markov chain (Salzenstein et al. 2004).

• **Comparison and optimization of map-making and source extraction techniques**
The fact that we accurately know all the properties of synthetic skies gives a unique opportunity for

testing the pipelines and map-making algorithms. Simulated sky is also a perfect tool for optimizing background subtraction, source extraction, and extraction completeness levels. Last, but not least, it is an extremely valuable tool for devising best methods of the derivation of the physical parameters of sources (density and temperature structure, masses) and for most accurate reconstruction of the protostellar mass function, along with realistic uncertainties.

8.2 Description of archival data products and tools that will be produced

At the end of the proprietary period, we plan to provide the general community with a first release of reduced data from the project including:

- calibrated multi-band maps of the target regions at 110-500 μm;
- a preliminary catalog of compact sources extracted from the maps, with estimated sizes, peak and integrated flux densities, local background levels, and peak signal-to-noise ratios.

After the end of the proprietary period, our team will continue to work on the data processing, in order to optimize, e.g., the extraction and characterization of the extended emission features present in the maps. Updated releases of the compact source catalog, as well as an extended source catalog, will then be made public.

8.3 Archival value

Once public, the proposed SPIRE/PACS survey will provide a unique database, including in the Southern hemisphere, for follow-up high-resolution molecular line/dust continuum studies with ground-based mm/submm telescopes and interferometers such as ALMA. For the first time, the star formation community will be able to study the dynamics and multiplicity of complete samples of prestellar condensations and protostellar systems, in order to get detailed insight into the collapse process and binary fragmentation mechanism(s). The wide-field images produced by this project can also be used to constrain the evolution of dust properties from cirrus to dense cores (cf. complementary GT KP proposed by SPIRE SAG 4), as well as the circumstellar envelope/disk properties of all Class I/II young stars in the survey area.

9. Management and Outreach plan

9.1 Consortium resources and management plan

Our Consortium has the experience and resources required to process the proposed observations and deliver a useful Legacy product to the astronomical community. A summary of the *minimum* resources in terms of FTEs committed to the project by the various members of the Consortium is provided in Appendix C. The project is managed by the two Project Coordinators (Ph. André and P. Saraceno) and a Project Science Team with representatives from the various GT holders making up the Consortium, as detailed in the Constitution given in Appendix D. The Consortium is organized in localized sub-teams responsible for the work on the various regions of the survey (see breakdown in Tables 2 & 3). We also have two transverse technical working groups, on data simulations (e.g. B. Sibthorpe, A. Men'shchikov et al.) and a dedicated pipeline (e.g. P. Martin, G. White et al.), and two transverse science working groups, on prestellar cores and protostars, respectively.

A short description of the strengths of the various sub-teams making up the Consortium is as follows:

CEA Saclay team: The CEA Saclay sub-team is currently composed of 6 staff researchers (Ph. André, A. Men'shchikov, V. Minier, F. Motte, M. Sauvage, N. Schneider) and 1 PhD student. Two staff researchers from Bordeaux observatory (S. Bontemps) and IAS Orsay (A. Abergel) are closely collaborating with Saclay on the present "Gould Belt" key project as well as the related "OB Star Formation" project. The above-mentioned staff members will devote 50-80% of their time to these projects. For more than 10 years, their main scientific interest has been in the identification and modeling of the earliest phases of the star formation process, for both low- and high-mass objects. They all have a long-term expertise and good publication record in submillimeter (line and continuum) and infrared studies, e.g., using facilities such as the IRAM 30 m telescope and Plateau de Bure interferometer, as well as ISOCAM on *ISO*. The Saclay lab is currently building ArTeMiS, a ground-based submm camera using a PACS-like filled bolometer array which recently achieved first light on the APEX 12m telescope. Two staff members (André and Minier) are strongly involved in ArTeMiS. It is anticipated that the dedicated map-making routines developed for ArTeMiS can be used in the first version of the pipeline employed to produce PACS images for the present project.

IFSI and INAF Rome team: The INAF/IFSI team is composed of 6 staff researchers (P. Saraceno, A. DiGiorgio, S. Molinari, L. Spinoglio, S. Pezzuto, M. Benedettini) and 1 PhD student. The team collaborates with L. Testi (Arcetri Obs.) on both the "Gould Belt" and "OB Star Formation" projects. Besides, it is expected that at least one additional PhD student will be funded next year. All of the team members will devote at least 20-50% of their time to both projects. The team has expertise in observations and modeling of star forming regions both in spectroscopy and continuum, from the near-infrared to the radio range. The specific scientific interests are in the earliest stages of low and high-mass star formation, and the chemistry of the ISM, circumstellar envelopes and shock regions.

Cardiff University and RAL teams: The Cardiff University sub-team is composed of 3 academic staff (P. Ade, M. Griffin and D. Ward-Thompson) and 3 post-doctoral research staff (P. Hargrave, B. Sibthorpe and J. Kirk). The RAL sub-team consists of one academic/staff researcher (G White), who is supported by 1 PDRA and one PhD student. The Cardiff and RAL sub-teams collaborate closely together on the design and development of SPIRE, and in the associated astronomy programme. The academic staff will devote up to 50% of their time on the present Gould Belt survey and the closely-related "OB Star Formation" project, and the post-doctoral staff will devote up to 100% of their time to *Herschel* post-launch. In addition, the group expects to have 3 PhD students in post by the time of *Herschel* launch (one for each of the academic staff) 100% dedicated to the SPIRE GT programmes on star formation and the ISM. The scientific interests include star formation, molecular clouds, and dust in the ISM. All staff members have long publication records in these fields. Their previous infrared and submm expertise includes working with (and assisting in building) *IRAS*, *ISO*, SCUBA and numerous other instruments and telescopes. Ward-Thompson is one of the three coordinators of the Gould Belt SCUBA-2 Legacy Survey and is also involved in the Gould Belt *Spitzer* Legacy Project.

HSC team: The HSC team is composed of 3 staff members (S. Leeks, T. Prusti, R. Vavrek), 2 of whom are Instrument and Calibration Scientists on *Herschel*. The team expects to have one research fellow to work on the data processing during the *Herschel* exploitation. All staff researchers have long experience in IR data photometric and spectroscopic analysis. Their scientific expertise includes Galactic structure, Galactic ISM, low- to high-mass star formation, PDRs and HII regions. During the exploitation of *Herschel* data, all involved team members will dedicate between 30% and 100% of their research time to the present survey and closely related "OB star formation" project.

Canadian (Herzberg Victoria, CITA Toronto, McMaster University) team: The Canadian team consists of 3 academic staff (J. Di Francesco, P. Martin, and C. Wilson) and one postdoc. Their main scientific interests are in prestellar cores, molecular clouds, and interstellar medium both in our Galaxy and nearby galaxies. They are all involved with the closely-related SCUBA-2 Legacy Surveys. Di Francesco is one of the three coordinators of the Gould Belt SCUBA-2 Legacy Survey and is also involved in the Gould Belt Spitzer Legacy Project. Martin is involved with BLAST (stratospheric telescope equipped with a SPIRE-like bolometer array) and has recently obtained observations of star-forming regions with that instrument. One postdoc is working with Martin on BLAST analysis. The dedicated map-making routines developed for BLAST can be used in the first version of the pipeline employed to produce SPIRE images for the present project.

LAM/OAMP team: The LAM team is composed of 3 staff researchers (J.-P. Baluteau, D. Russeil, A. Zavagno), one PhD student, and expect to be joined by 1 post-doctoral researcher after May 2007. During the exploitation of *Herschel* data, all involved people will dedicate between 80% and 100% of their research time to to *Herschel* GT Key programmes on star formation and the ISM. All staff researchers have long experience in (ground- and space-based) photometric and spectroscopic observations taken at infrared wavelengths. Their scientific expertise concerns the Galactic structure, the ISM, massive star formation and HII regions.

KU Leuven team: The Leuven team is composed of 3 members (C. Waelkens, J. Blommaert, P. Royer) with very good knowledge of the PACS instrument, thanks to their direct involvement at various levels of the PACS ICC (as co-PI, calibration scientist, and instrument specialist, respectively). All have a very strong expertise in infrared observations, especially with the ISO satellite instruments. The team expects a PhD student to enter the project near the *Herschel* launch date at the latest.

9.2 Outreach activities

The extensive survey of nearby molecular clouds planned in the present *Herschel* GT Key project is expected to produce several breakthroughs in our understanding of the birthplaces of low- to intermediate-mass stars. Full exploitation of this survey will require expertise in space techniques, infrared and submillimeter instrumentation, image processing, as well as physics and chemistry, to collect, reduce, and interpret the survey data. Besides the impact of new discoveries on the star formation process and the resulting spectacular images, the products of this key project can potentially be used as basic material to attract young people in all fields of physics, chemistry, computer science, and engineering. This is an important issue in Europe where students become less attracted by scientific studies at the University level.

We are planning to reach out to people and communicate our discoveries through four major media: Internet (web site), newspapers and radio networks (press releases) and TV networks (video releases). This Outreach effort will be coordinated by Vincent Minier. Our Internet web site (http://starformation-herschel.iap.fr/) will be the major instrument of our educational and public outreach effort. To date, the web page is mainly designed for preparing the Key projects. By the end of 2007, an Outreach section will be added that will be organized in three main sections:

- News from Space: main discoveries, most recent press and video release.
- Infrared and submillimeter astronomy introduction: basic information on Infrared, the IR universe, space techniques and the Herschel Space Observatory.
- Educational and public outreach for general public (image gallery with accessible captions for non-scientists and children), for students in science (images with captions, scientific explanations and detailed descriptions of the physics involved), for educators (same as for students, plus electronic text books and educational material for school children) and for media (press releases, video releases).

Our web site is designed first in English and French, and may be translated locally in other European languages. Press releases will be delivered nationally to media through the public relation office in each institute of the consortium.

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Appendix A: Cirrus confusion, source clustering, and temperature reconstruction

a) Estimation of the cirrus confusion noise

Galactic far-IR imaging surveys such as the one proposed here are limited by the confusion arising from small-scale cirrus/cloud structure. Previous work with, e.g., *IRAS*, *COBE*, *ISO* has established that the spatial fluctuations of the cirrus infrared background emission have a steep power spectrum [$P(k) = P_0\,(k/k_0)^{-3}$] (e.g. Gautier et al. 1992). The shape of this power spectrum is apparently universal but its normalization varies from region to region, scaling roughly as $P_0 \propto < B >^3$ where $< B >$ is the mean brightness at, e.g., 100 μm in the sky region (Gautier et al. 1992). The origin of the fluctuations, still poorly understood, is presumably related to the turbulent, fractal nature of the diffuse ISM (e.g. Elmegreen & Falgarone 1996). An important consequence of the steep cirrus power spectrum is that the confusion limit at a given wavelength improves very quickly with angular resolution, scaling roughly as $D^{-2.5}$ where D is the telescope diameter (see equation below). For instance, *the cirrus confusion limit will be a factor ∼ 35-55 lower with Herschel than with Spitzer and ASTRO-F*. In practice, the rms level of cirrus or "structure" noise at $\lambda = 250\,\mu$m in a given region can be estimated from the mean surface brightness B_{100} seen by *IRAS* at 100 μm in that region (e.g. Gautier et al. 1992; Kiss et al. 2001):

$$\mathrm{rms_{cirrus}} \approx 10\,\mathrm{mJy/beam} \times \left(\frac{\lambda}{250\mu\mathrm{m}}\right)^{2.5} \times \left(\frac{\mathrm{D}}{3.5\mathrm{m}}\right)^{-2.5} \times \left(\frac{\mathrm{B}_{100}}{35\,\mathrm{MJy/sr}}\right)^{1.5}.$$

Strictly speaking, in the above equation, one should use the mean surface brightness of the sky region at the wavelength of interest (e.g. 250 μm) instead of B_{100}. However, the typical dust emission spectrum of molecular clouds (on large scales) is such that one expects $B_{250} \sim B_{100}$ (e.g. Bernard et al. 1992; Bouwman et al. 2006), making the use of *IRAS* 100 μm maps adequate for the present purpose. Given the spectrum of cirrus emission and the resolution dependence, the rms cirrus level is expected to be ∼ 20% lower at 350 μm and ∼ 50% lower at 500 μm, as well as a factor 2.5 lower at 170 μm and a factor $\sim 7.5 - 20$ lower at 110 μm

b) Source clustering

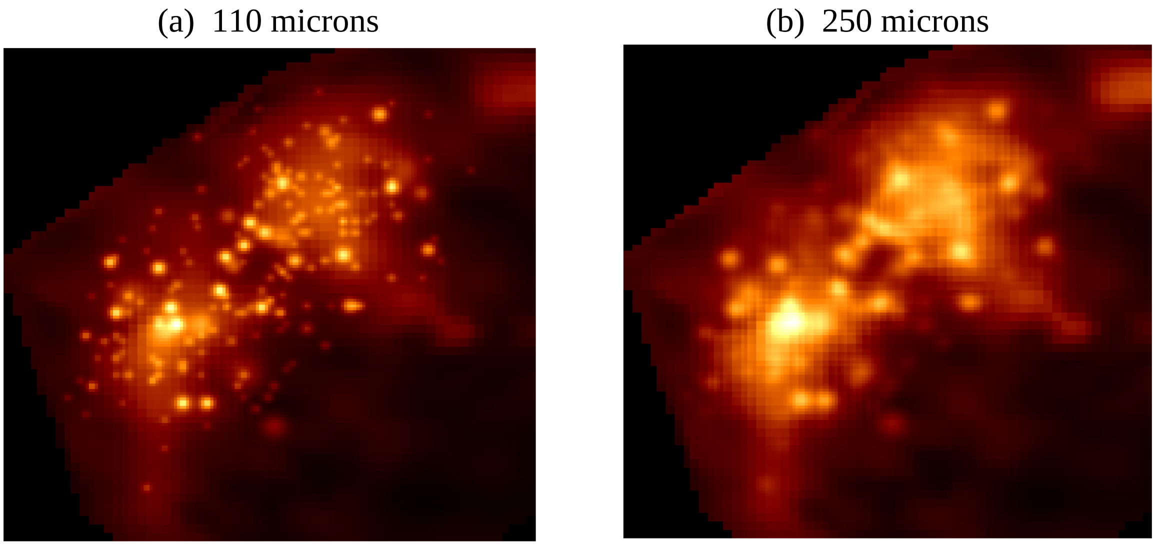

Figure 4: Simulated *Herschel* images of the Serpens protocluster (see Saraceno et al. 2003) based on an extrapolation of the 3mm OVRO map of Testi & Sargent (1998). **(a)** PACS image at 110 μm; **(b)** SPIRE image at 250 μm. This figure illustrates the importance of PACS high angular resolution observations in *Herschel* studies of protoclusters.

Confusion due to source clustering is a potential issue in cluster-forming regions where we hope to probe the core mass distribution down to the proto-brown dwarf regime. Fortunately, for sensitivity reasons, the proto-brown dwarf regime will only be accessible in the nearest ($d \leq 0.2$ kpc) clouds (cf.

Tables 2 & 3) where PACS and SPIRE will achieve their best *spatial* resolutions (e.g. $\sim$ 1200 AU at 110 μm and $\sim$ 2500 AU at 250 μm). A spatial resolution of $\sim$ 2000 AU is sufficient to separate the main individual members of a low-mass embedded cluster such as ρ Ophiuchi (e.g. MAN98, Bontemps et al. 2001). Simulations of *Herschel* imaging of a typical protocluster confirm that the source confusion problem is minimized for distances $d < 0.3$ kpc (Saraceno et al. 2003 – see Fig. 4).

c) Reconstruction of the temperature/density structure

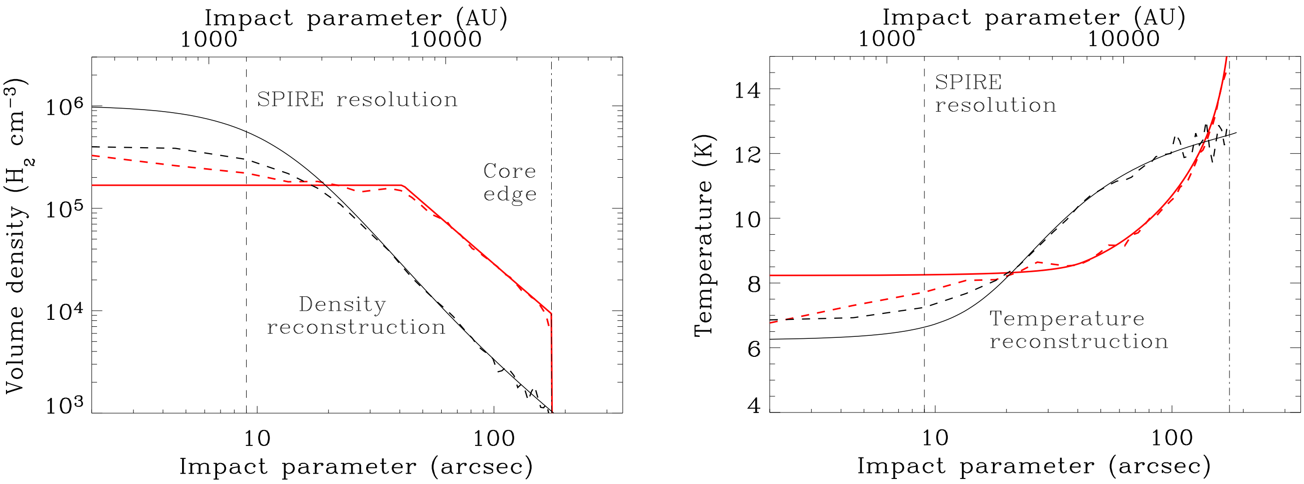

Figure 5: Reconstruction of the density (left) and temperature (right) structure of a prestellar core such as L1689B in Ophiuchus based on simulated PACS and SPIRE images of this core between 110 μm and 500 μm. The solid curves show two model density and temperature profiles consistent with present observations of L1689B (e.g. André et al. 1996; Bacmann et al. 2000). The dashed curves correspond to density and temperature profiles reconstructed from the simulated *Herschel* images assuming that the 3D geometry of the core is known. Note that the two models can be distinguished with *Herschel* and that the reconstruction becomes uncertain near core center, i.e., below the angular resolution of SPIRE.

Appendix B: Description of the target clouds and observations summary table

Table 4: **Properties of the target clouds**

Molecular cloud complex	Distance (pc)	Total Gas Mass ($M_\odot$)	Properties	References
Taurus	140	3×10^4	Prototypical of isolated mode of SF.	Kenyon & Hartmann 1995 Onishi et al. 1998, 2002
Ophiuchus	140	3×10^4	Nearest cluster-forming cloud.	Loren 1989; MAN98
Pipe Nebula	140	10000	Nearest example of triggered SF ?	Onishi et al. 1999
Polaris flare	150	5500	High-latitude, ‘cirrus-like’.	Heithausen & Thaddeus 1990 Heithausen et al. 2002
Lupus	100	1200	Nearby, old cloud ?	Hara et al. 1999
Coalsack	150	1.4×10^4	Low star formation activity, young cloud ?	Nyman et al. 1989 Cambrésy 1999
Cham I/III + Musca	160	3700	Nearby, isolated mode of SF.	Cambrésy 1999 Mizuno et al. 2001
Corona Australis	170	3000	Nearby embedded cluster	Wilking et al. 1992, 1997 Yonekura et al. 1999
Serpens/Aquila Rift	260	2.7×10^5	Rich, unexplored complex with well-known cluster(s).	Kawamura et al. 1999 Straizys et al. 2003
Perseus	300	2×10^4	Cluster-forming, well-documented.	Ladd et al. 1994 Padoan et al. 1999
IC 5146	400	4500	Filamentary dark cloud with low star formation activity.	Dobashi et al. 1994 Lada et al. 1994
Cepheus/Cassiopea	440	1.3×10^5	Bridge between low- and high-mass SFRs.	Yonekura et al. 1997 Kun 1998
Orion (A+B)	450	3×10^5	Nearest massive GMCs.	E. Lada et al. 1991 Tatematsu et al. 1998

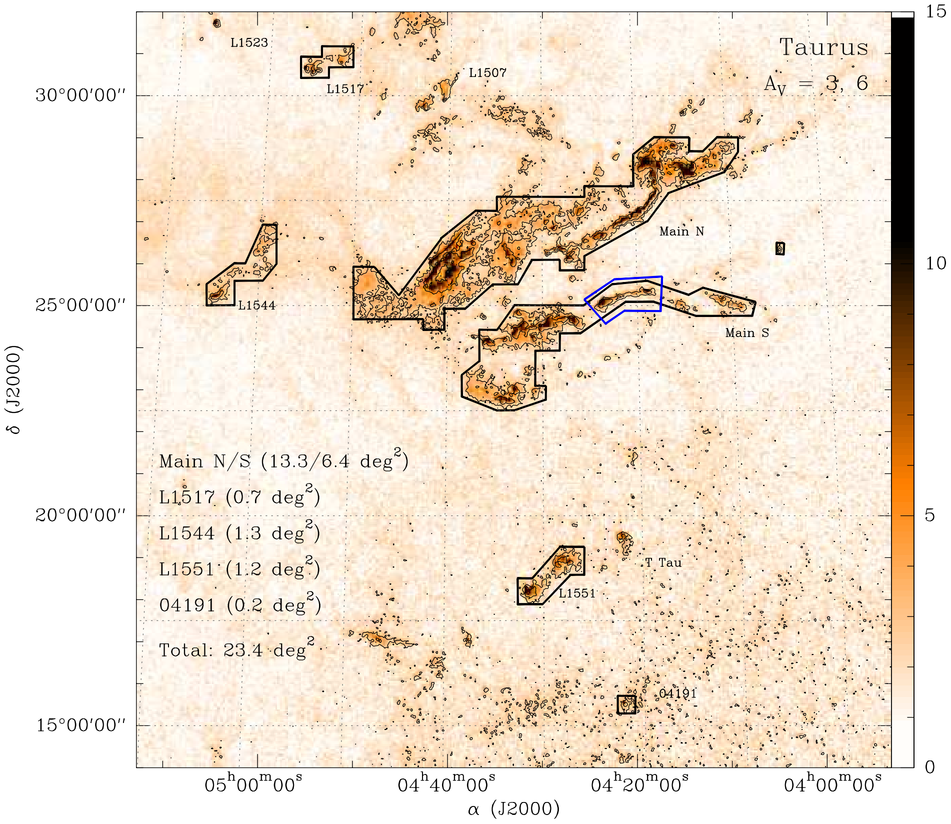

Figure 6: Near-IR extinction map of the Taurus cloud complex derived from 2MASS data (S. Bontemps – see also L. Cambrésy's map in Padoan et al. 2002). The angular resolution is 2.3′. The region we propose to map with SPIRE is outlined (see http://starformation-herschel.iap.fr/gouldbelt/ for a field image overlay with actual AORs). It was defined using the first contour ($A_V = 3$). Note that the dense cores of Taurus are primarily distributed in two coherent, filamentary structures stretching over ~ 10 deg (i.e., ~ 25 pc at $d = 140$ pc).

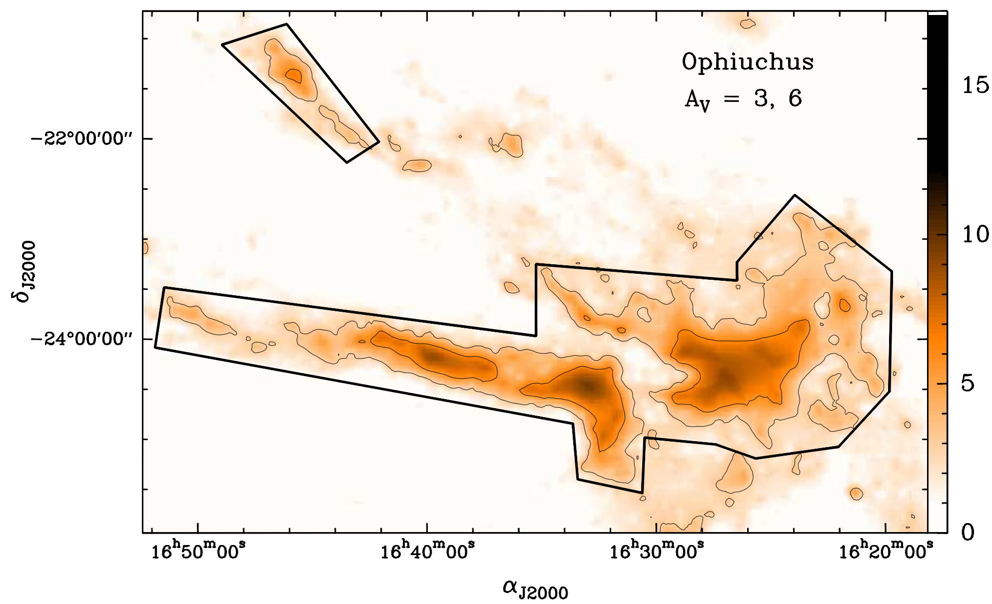

Figure 7: Visual extinction map of the Ophiuchus cloud complex obtained from star counts in the R band (Cambrésy 1999). Contours are plotted at $A_V = 3$ and 6. The region we propose to map with SPIRE, defined using the $A_V = 3$ contour, is overlaid (see http://starformation-herschel.iap.fr/gouldbelt/ for a field image with actual AORs). The region that we intend to map with PACS roughly corresponds to the $A_V = 6$ contour.

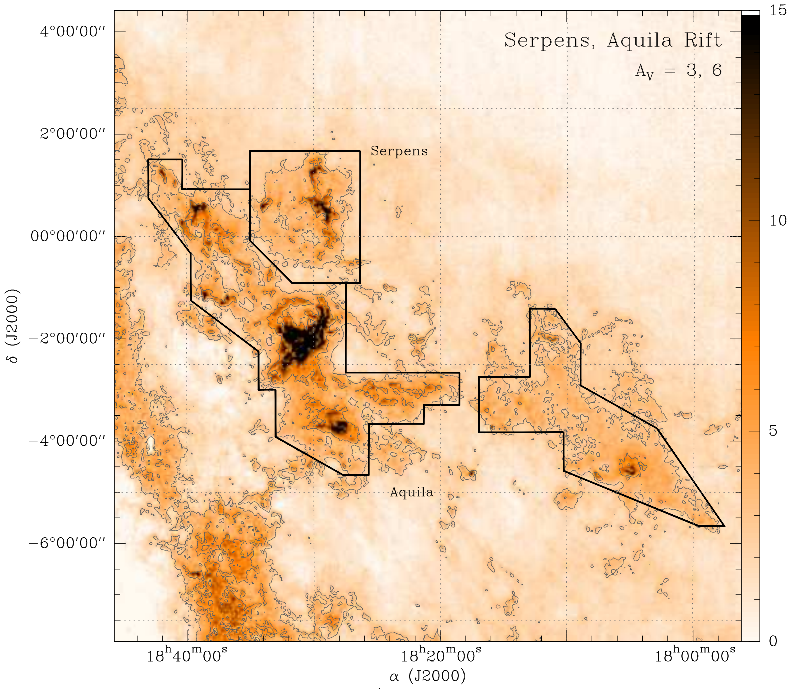

Figure 8: Near-IR extinction map of the Serpens/Aquila Rift cloud complex obtained by S. Bontemps from 2MASS data. The region we propose to map with SPIRE is outlined (see http://starformation-herschel.iap.fr/gouldbelt/ for a field image overlay with actual AORs). It was defined using the $A_V = 3$ contour also shown.

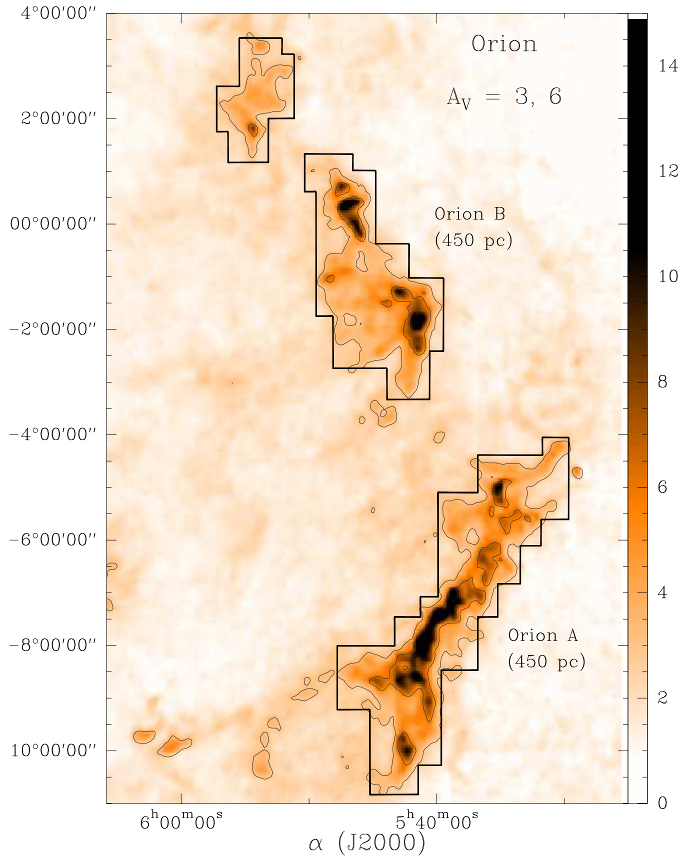

Figure 9: Near-IR extinction map of the Orion (A + B) GMC obtained by S. Bontemps from 2MASS data (see also Cambrésy 1999). The region we propose to map with SPIRE is outlined (see http://starformation-herschel.iap.fr/gouldbelt/ for a field image overlay with actual AORs). It was defined using the first contour ($A_V = 3$).

Appendix C: List of 'Gould Belt' consortium members with associated roles

Name	Affiliation	Status	Expertise	Role	FTE[a]
Ph. André	CEA Saclay	Staff	Protostars/prestellar cores	Coordinator	60%
P. Saraceno	IFSI Rome	Staff	Infrared observations	Co-Coordinator	50%
A. Abergel	IAS Orsay	Staff	Interstellar dust	Extended emission	20%
P. Ade	Cardiff Univ.	Staff	Bolometers	Calibration	10%
J.-P. Baluteau	LAM Marseille	Staff	ISM	Spec. follow-ups	10%
M. Benedettini	IFSI Rome	Staff	Protostellar outflows		20%
J.-Ph. Bernard	CESR Toulouse	Staff	ISM	Polar. follow-ups	10%
J. Blommaert	KU Leuven	Staff	Circumstellar dust		20%
S. Bontemps	Bordeaux/Saclay	Staff	High-mass protostars	Extinction maps	50%
L. Cambrésy	CDS Strasbourg	Staff	Extinction maps	Archiving	20%
P. Cox	IRAM Grenoble	Staff	ISM	PdB follow-ups	5%
P. Didelon	CEA Saclay	Staff	Large data sets	Source extraction	50%
J. Di Francesco	Herzberg Victoria	Staff	Prestellar cores	Sub-team leader	50%
A. Di Giorgio	IFSI Rome	Staff	PMS objects	SPIRE A.S.	20%
M. Griffin	Cardiff Univ.	Staff	Protostars/Calibration	Simulations/Calib.	15%
P. Hargrave	Cardiff Univ.	Staff	Instrument/Calibration	Calibration	10%
Th. Henning	MPIA Heidelberg	Staff	Disks & protostars	Sub-team leader	10%
M. Huang	NAOC Beijing	Staff	Compact HII regions	SPIRE A.S.	20%
J. Kirk	Cardiff Univ.	Postdoc	Prestellar cores	Data reduction	80%
O. Krause	MPIA Heidelberg	Staff	Cold cores		10%
R. Launhardt	MPIA Heidelberg	Staff	Binary protostars		10%
S. Leeks	HSC	Staff	High-mass protostars		20%
J. Li	NAOC Beijing	Staff	Young star clusters	SPIRE W.M.	20%
P. Martin	CITA Toronto	Staff	ISM dust	Map making	20%
A. Men'shchikov	CEA Saclay	Staff	Radiative transfer	Modeling	70%
V. Minier	CEA Saclay	Staff	High-mass protostars	Website/Outreach	50%
S. Molinari	IFSI Rome	Staff	High-mass protostars	Sub-team leader	50%
F. Motte	CEA Saclay	Staff	Protoclusters (high-mass)	Source extraction	80%
G. Olofsson	Stockholm Obs.	Staff	Circum. disks	SPIRE Co.I.	20%
A. Omont	IAP Paris	Staff	Stellar populations	SPIRE A.S.	5%
S. Pezzuto	IFSI Rome	Staff	Circum. disks	SPIRE A.S.	50%
T. Prusti	HSC	Staff	T Tauri stars	Sub-team leader	20%
P. Royer	KU Leuven	Staff	Massive stars		30%
D. Russeil	OAMP Marseille	Staff	Galactic HII regions	Spec. follow-ups	20%
M. Sauvage	CEA Saclay	Staff	Extragalactic star clusters	PACS support	20%
N. Schneider	CEA Saclay	Associate	Molecular clouds	Source extraction	70%
B. Sibthorpe	Cardiff Univ.	Postdoc	Prestellar cores	Data simulations	20%
A. Sicilia-Aguilar	MPIA Heidelberg	Postdoc	Circumstellar disks		10%
L. Spinoglio	IFSI Rome	Staff	Extragal. star formation		10%
L. Testi	INAF Arcetri	Staff	Protoclusters	Sub-team leader	30%
R. Vavrek	HSC	Staff	Cloud structure		20%
C. Waelkens	KU Leuven	Staff	Herbig Ae/Be stars	Sub-team leader	10%
D. Ward-Thompson	Cardiff Univ.	Staff	Prestellar cores	Sub-team leader	25%
G. White	RAL	Staff	Triggered star formation	Sub-team leader	20%
C. Wilson	McMaster Univ.	Staff	Extragal. star formation	Link with SAG 2	20%
A. Woodcraft	UKATC	Staff	Bolometers	Calibration	10%
A. Zavagno	OAMP Marseille	Staff	Triggered star formation	Spec. follow-ups	40%

(a) Estimated fraction of time spent on this project and the closely related "OB Star Formation" SPIRE/PACS GT key project during the *Herschel* exploitation phase (e.g. after launch).