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 *HIFI*. We believe that for the impact of the scientific return, and the optimum usage of the facility, this project possesses the cachet of a *FIRST key project*.

Key words: Stars: formation – Missions: FIRST

1. Introduction

The formation of intermediate and massive stars has been object of a rapidly increasing interest in the course of the last decade. Our understanding of this process is very limited, compared to lower mass regimes. The intense radiation field radiated by young massive stars may be sufficient to even reverse the accretion process (Kahn 1974). The canonical accretion scenario of a collapsing dense core with a (proto)stellar object at its center, which is well established for the formation of low mass stars, cannot be scaled *as is* to higher masses. Recent results show that massive young stellar objects (YSOs) are often found in association with clusters of lower mass objects. Low mass stars, which evolve slower, are probably born first, suggesting the exciting possibility that more massive objects may form by *coalescence*.

A fundamental limitation to our investigations is posed by the relative paucity of known sites of ongoing massive star formation. Only Orion, among the closest (D$\leq$0.5 kpc) and best studied molecular clouds, hosts currently forming high mass objects. More of these sites are found further away from the Sun where, however, the decrease in spatial resolution poses a severe hadicap to our ability to 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, associated with compact or ultracompact HII regions (UCHII) (Wood & Churchwell 1989). Interestingly, UCHII regions tend to occupy a well defined area of an IRAS [60-12]*vs*[25-12] colour-colour plot (Wood & Churchwell 1989). One could then wonder about the evolutionary stage, relatively to UCHII regions, of IRAS sources similarly associated with dense gas but lying in different areas of the mentioned IRAS colour-colour plot. Using a *systematic* approach, Palla et al. (1991) started an investigation which showed that the latter sources are likely younger, on average, than UCHII regions.

An inital sample of 260 sources was selected from the IRAS-Point Source Catalogue (PSC) with 60μm flux greater than 100 Jy and according to the colour criteria of Richards et al.(1987) for compact molecular cores. This sample was then divided into two groups according to their IRAS colours: the *high* sources, which have [25$-$12]$\geq$0.57 and [60$-$12]$\geq$1.3, characteristic of association with UCHII regions (Wood & Churchwell 1989), and the *low* sources, with complementary colours. The lower association rate with H_2O masers for the *low* sources was interpreted as an indication of relative youth, and it was hypothesized that the *low* group might contain a fraction of young sources whose formation process has not yet proceeded far enough to produce a fully developed pre-main sequence massive star (Palla et al. 1991). We then searched for NH_3 (1,1) and (2,2) inversion lines towards a subsample of 80 *high* and 83 *low* sources to check for association with dense gas. For the detected sources we were able to derive the kinematic distances and the luminosities, which are of the order of $10^4 L_\odot$ (Molinari et al. 1996). Among

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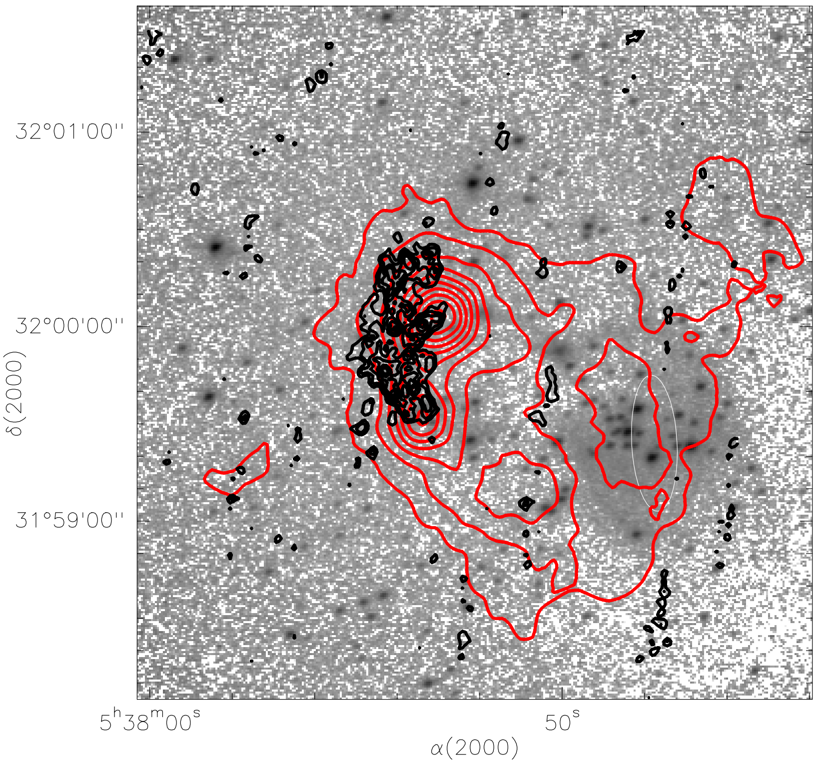

Figure 1. Field centered on source #11 of our sample. A K_s-band image obtained at the 60" Palomar telescope is shown in greyscale. Red contours represent the distribution of the 850μm continuum as observed with SCUBA@JCMT, while black contours trace HCO^+ (1-0) integrated emission as observed with the 6-elements millimeter array at OVRO. The IRAS positional uncertainty is represented by the white ellipse.

the ammonia-detected objects we observed 37 *low* and 30 *high* sources at the VLA at 2 and 6 cm: we found that 76% of *low* and 55% of *high* sources were not associated with UCHII regions, strongly confirming the initial assumption about the relative youth of the *low* group (Molinari et al. 1998a). Finally, we collected submilimeter and millimeter photometry for 30 *low* sources of the 37 observed at the VLA, including those found to be associated with UCHII regions as a comparison sample. The presence of compact dust cores could be convincingly established for a dozen of the *low* sources not associated with UCHII regions; it appears that dust may not be responsible for the non detection of the HII region towards these objects, suggesting that accretion could play an important role (Molinari et al. 2000). We could then conclude this *systematic* investigation with the compilation of a homogeneous sample of sources, not associated with UCHII emission, which may be young massive objects possibly in a pre-ZAMS stage (Molinari et al. 1998b).

A wealth of new data is currently being collected on these sources, including near infrared, submillimeter and millimeter imaging, to characterize in detail their properties. Results for a typical source are presented in Figure 1. The millimeter emission clearly traces the site where the formation process is at an earlier stage with respect to the south-west area of the region where a small cluster of K_s-band sources, presumably in a more advanced stage, is found. This appears to be a quite typical scenario; the 12 and 25μm emission, and possibly some fraction of the 60 and 100μm flux, come from a generation of already formed low-mass stars. A key aspect that only *FIRST*'s instruments will allow to investigate for the first time since IRAS, is exactly how the flux emitted in the 100μm region, where YSOs radiates the bulk of their energy, is divided among the members of the cluster. This has so far prevented a reliable estimate of the luminosity and circumstellar mass of the individual objects. Saraceno et al. (1996) have shown that the relationship between these two parameters is a key evolutionary diagnostic. *PACS* and, to a lesser extent, *SPIRE*, will be able to accomplish this task thanks to their FIR imaging capabilities at unprecedented spatial resolutions. However, the study of the mass function, possible toward close-by regions (Saraceno et al. this issue), is still beyond *FIRST*'s capabilities for high mass systems due to their relatively higher distance. Using the unique imaging spectroscopy capabilities of *PACS* and *SPIRE*, and the very high spectral resolution available with *HIFI*, we will be able to study the gaseous component of the young clusters where high mass stars form with an unprecedented detail in a spectral region which has only partially (up to 200μm) been accessible to ISO. The ability to model the PDR and shock conditions within the

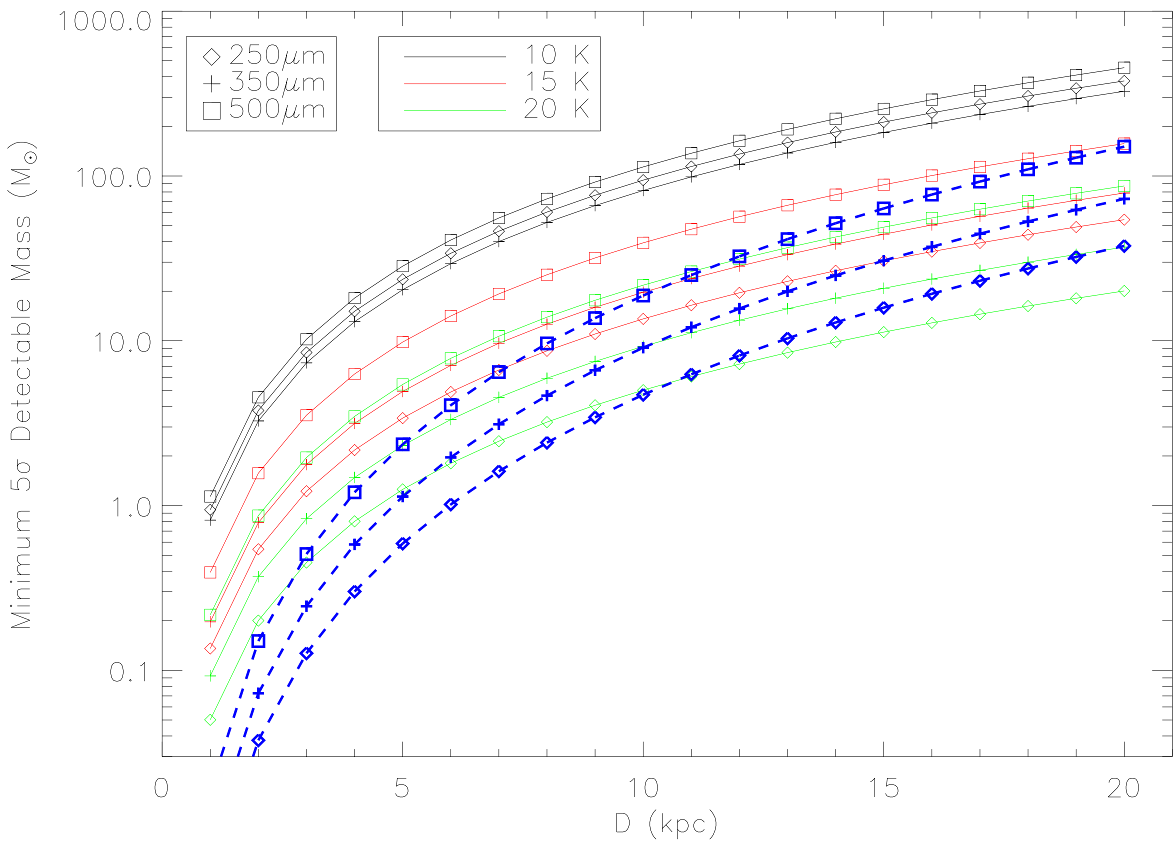

Figure 2. Minimum (gas+dust) 5-σ detectable mass as a function of distance from the Sun, for the 3 photometric bands (indicated by the three symbols), and for three dust temperatures (indicated by black, red and green colours). The β value of the dust emissivity-frequency law is assumed equal to 1.5. The dashed blue lines represent the integrated mass, along a line of sight, of the diffuse medium.

cluster via simultaneous observations of molecular, atomic and ionic lines will be invaluable to derive hints on how individual cluster members in different evolutionary stage influence their surroundings, and how they may trigger, or "interfere" with, subsequent star formation events.

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 older. Since the infrared and the submillimeter 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′x 8′) and resolution (19″.2/26″.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 $\sim 2.5°$ 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 b Galactic axis. Using the latest *SPIRE* instrument performance figures and allowing for reasonable redundancy and scan overlaps, the full survey of the Galactic plane down to a 5-σ sensitivity limit of 100 mJy in the three photometric bands can be completed in $\sim$70 days. This estimate assumes 21 hours/day observing time and includes 10% observations overhead. The potentiality of this survey is summarised in Figure 2, where the flux sensitivity limit has been converted into total(gas+dust) detection limits at the 3 photometric bands for three different dust temperatures as a function of distance from the Sun. Even a low-mass core like B335 (with a total mass of $\sim 3M_\odot$ and a dust temperature T$\sim$20 K) would be detectable at $\lambda = 250\mu$m up to a distance of 10 kpc from the Sun. The dashed blue lines on Figure 2 represent the mass of the diffuse medium integrated along a line of sight as a function of its depth. This estimate is based on a column density of $N_H \sim 3.1\,10^{21}$(D/kpc) cm^{-2} (Binney & Merrifield 1998) for the interstellar medium on the Galactic plane, and differs for the three *SPIRE* bands because of the different beamwidths. Poissonian fluctuations of this fore/background should not present significant problems for the detection of sources.

PACS and *HIFI* follow-up investigations toward the most interesting areas of the SPIREGAL survey are among its obvious outcomes. Physical and evolutionary charaterization of the detected sources will be optimised by cross-analysing the SPIREGAL database against similar databases in different wavebands but comparable spatial resolutions; obvious candidates for this type of study are the Midcourse Space Experiment (MSX, Shipman, Egan & Price 1996) 4.2-36μm survey of the Galactic plane, and the NRAO VLA Sky Survey (NVSS, Condon et al. 1998) at 6 cm for $\delta \geq -40°$.

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