Background: Overlay of the 20cm map (MAGPIS) of the G29.96-0.02 star forming region on the corresponding 160µm *Herschel* image

The IR-Radio Correlation in High-Mass Young Stellar Objects

R. Cesaroni[1], M. T. Beltran[1], A. Faimali[2], M. G. Hoare[3], M. Huang[4], P. G. Martin[5], S. Molinari[6], L. Olmi[1,12], C. Purcell[7], H. A. Smith[8], M. D. Smith[9], G. S. Stringfellow[10], L. Testi[11,1], M. A. Thompson[2]

[1]INAF- Osservatorio di Arcetri, [2]Univ. of Hertfordshire, [3]Univ. of Leeds, [4]National Astronomical Observatory Beijing, [5]CITA Univ. of Toronto, [6]INAF- IFSI, [7]Univ. of Manchester, [8]Harvard- Smithsonian CfA, [9]Univ.of Kent, [10]CASA Univ. of Colorado Boulder, [11]ESO Garching, [12]UPR U.S.A.

FOREWORD

Hi-GAL is a survey of the galactic plane in the range $|l| < 60^{o}$ and $|b|<1^{o}$, making use of PACS & SPIRE in parallel mode.

Images of the continuum emission at 70, 160, 250, 350, and 500 µm are obtained, with angular resolutions from 5" to 36", corresponding to ~0.1 and ~1 pc, at a distance of 5 kpc.

The existence of analogous surveys at shorter (GLIMPSE & MIPSGAL, MSX) and longer (BOLOCAM, ATLASGAL, CORNISH) wavelengths provide us with the unique opportunity to determine crucial physical parameters of the deeply embedded stellar population in star forming regions.

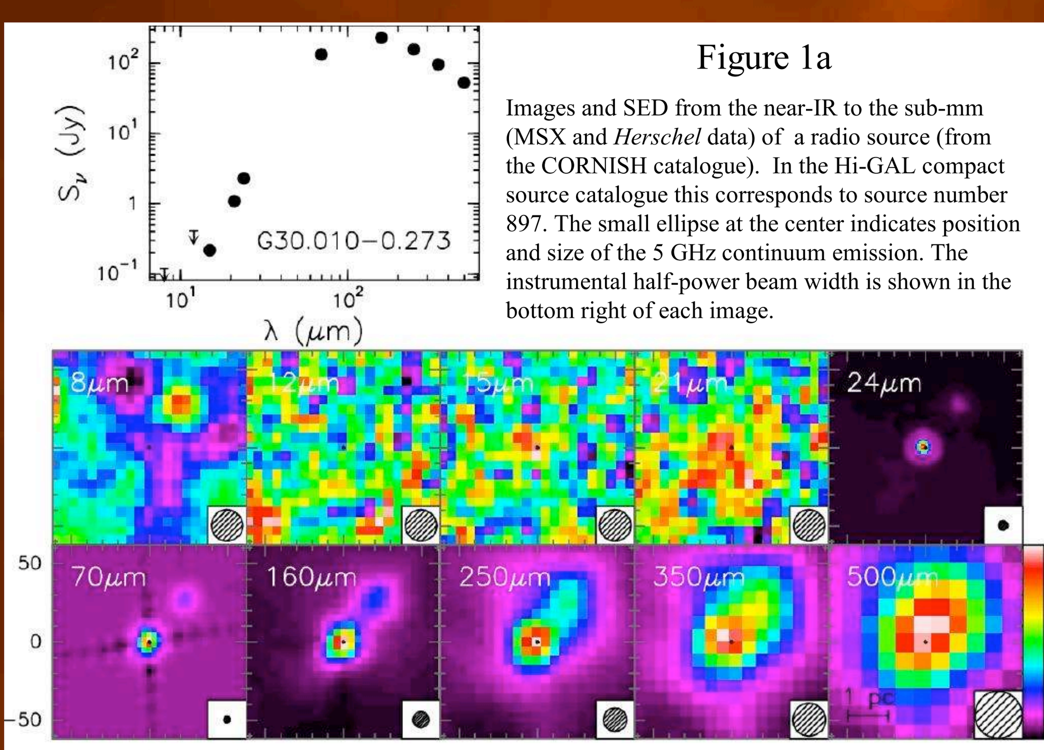


Figure 1a

Images and SED from the near-IR to the sub-mm (MSX and *Herschel* data) of a radio source (from the CORNISH catalogue). In the Hi-GAL compact source catalogue this corresponds to source number 897. The small ellipse at the center indicates position and size of the 5 GHz continuum emission. The instrumental half-power beam width is shown in the bottom right of each image.

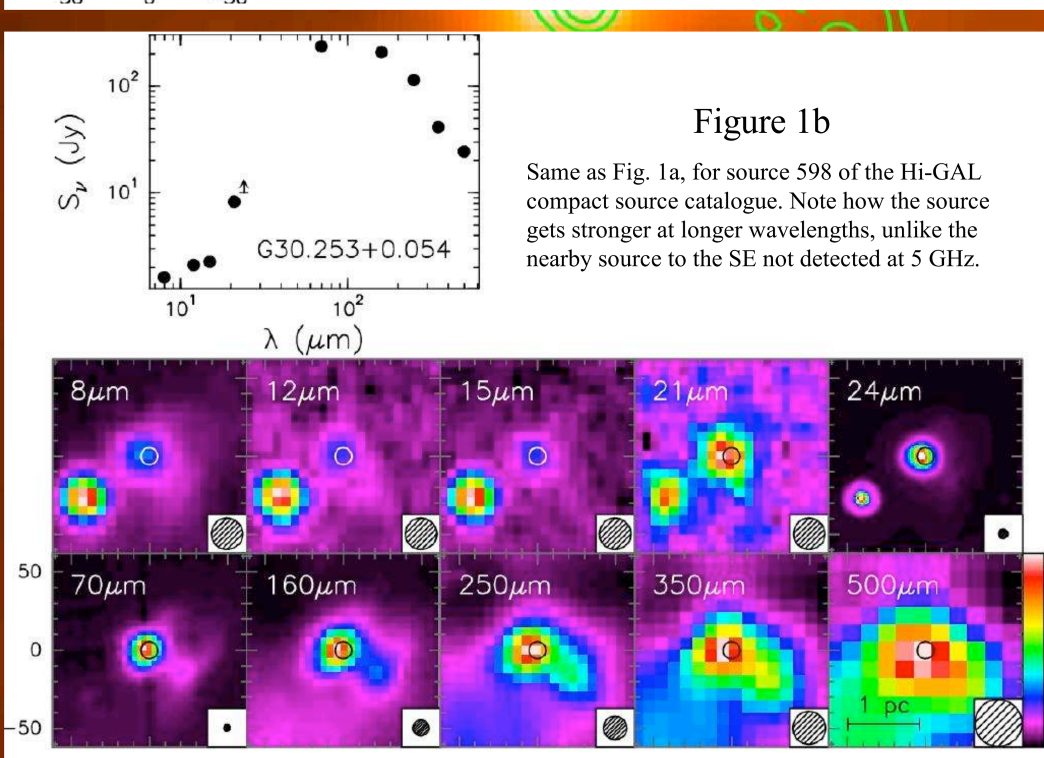


Figure 1b

Same as Fig. 1a, for source 598 of the Hi-GAL compact source catalogue. Note how the source gets stronger at longer wavelengths, unlike the nearby source to the SE not detected at 5 GHz.

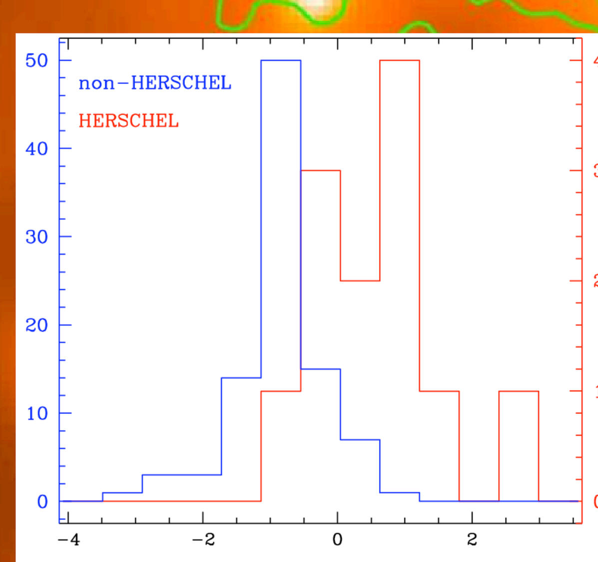
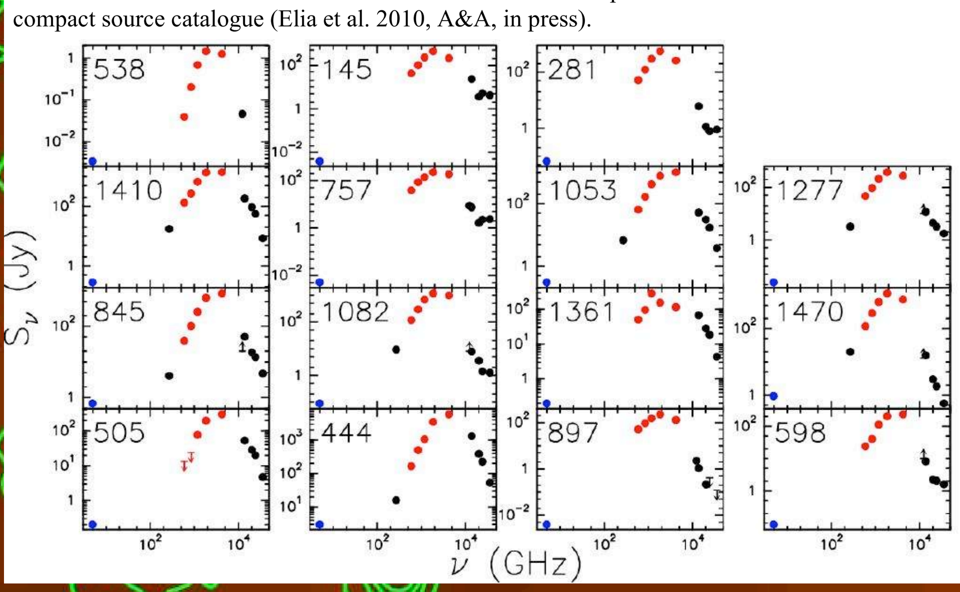


Figure 2

Distributions of the spectral indices of CORNISH radio sources in the SDP fields detected also at 20cm (MAGPIS). Note how sources without *Herschel* counterparts have lower spectral indices, consistent with being non-thermal emitters, i.e. extragalactic objects.

Figure 3

Spectral energy distributions of the 15 suitable Hi-GAL sources with CORNISH counterparts. Note how the *Herschel* fluxes (red points) are crucial for an accurate estimate of the source luminosities. The blue point indicates the CORNISH measurement, while the black points denote the MSX and BOLOCAM fluxes. The numbers correspond to the entries of the Hi-GAL compact source catalogue (Elia et al. 2010, A&A, in press).



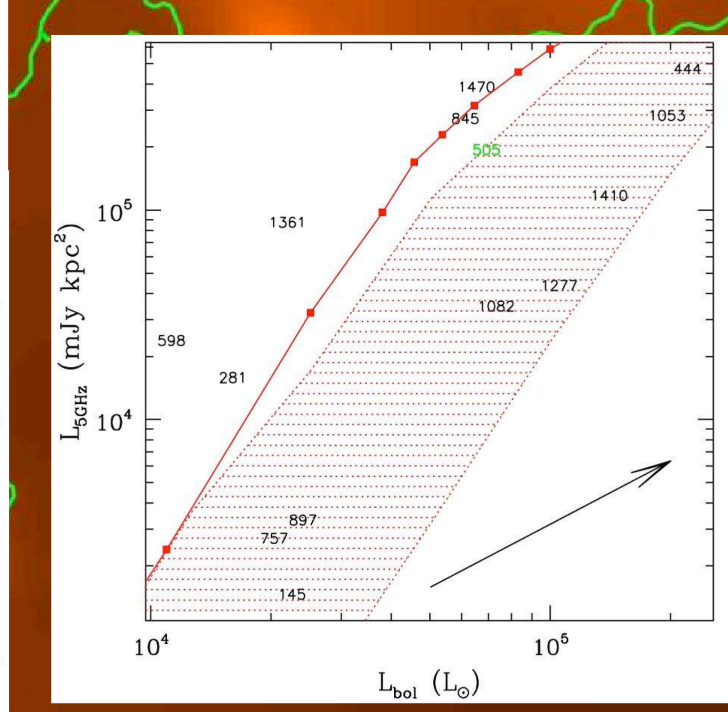


Figure 4

The numbers correspond to the entries of the band-merged Hi-GAL catalogue of compact sources in the SDP fields. The red line indicates the maximum radio luminosity at 5 GHz assuming that L_{bol} comes from a single ZAMS star (Panagia 1973). The shaded region denotes the range of L_{5GHz} expected if L_{bol} is due to a cluster with a Salpeter IMF. The green number is a source undetected at 500 µm. The arrow shows how a point would be shifted if the distance is increased by a factor 2. Sources above the red curve move below it, if the far kinematic distance is adopted instead of the near.

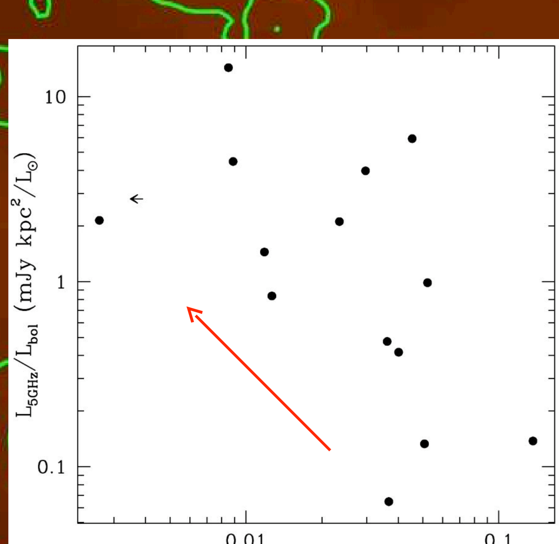


Figure 5

Distance independent plot for the 15 Hi-GAL sources with radio (5 GHz) counterpart. The arrow pointing to the right corresponds to an upper limit on M for the source not detected at 500 µm. We suggest that evolution could proceed in the direction outlined by the red arrow.

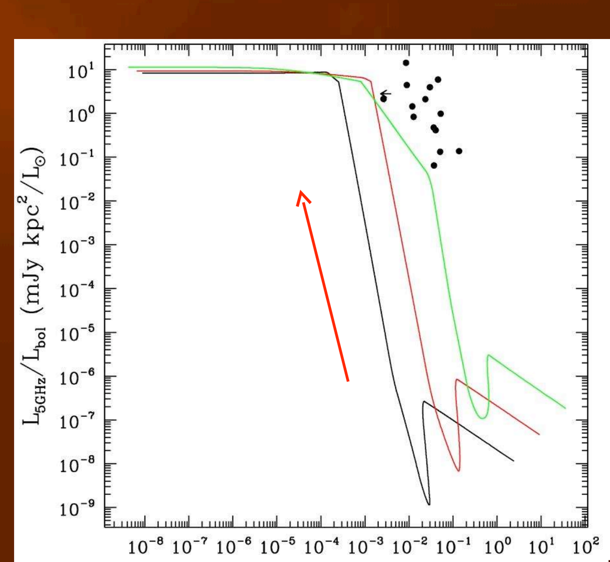


Figure 6

Same as Fig. 5, with overlayed three evolutionary tracks for accretion rates of 10^{-3} (black), 10^{-4},(red), and 10^{-5} M_{O} yr^{-1} (green). The offset between data points and model curves may be explained if only <10% of M_{gas} is accreting onto the star. The red arrow indicates how evolution proceeds.

GOAL

We wish to study the earliest stages of the formation of OB-type stars through a comparison of their radio and IR properties. Here we present a preliminary analysis based on the two galactic fields (2^{o} x 2^{o} centered at $l=30^{o}$ and $l=59^{o}$) observed in the Science Demonstration Phase (SDP).

METHOD

We estimated four fundamental physical parameters:

L_{bol}: The bolometric luminosity, obtained by integrating the emission under the SED

L_{5GHz}: The radio luminosity, $L_{5GHz} = 4 \pi d^2 S_{5GHz}$ where the 5 GHz flux density has been measured in the CORNISH maps

T_{dust}: The dust (gas) temperature, from the peak of the SED

M_{gas}: The gas mass of the parental molecular clump, from the 500 µm flux measured with *Herschel*, assuming $T=T_{dust}$

DISCUSSION

L_{5GHz} vs L_{bol} (Fig. 4): 65% of the sources fall in the region of the plot where the radio flux is due to a single OB star or to a cluster of stars with total luminosity equal to L_{bol} (we assume a Salpeter IMF). No point should fall above the red solid curve, as this is a robust upper limit to L_{5GHz} obtainable from a single star with luminosity L_{bol}. The sources with "radio excess" could lie at a larger distance than adopted by us, but might also be different types of objects deserving further investigation.

L_{5GHz}/L_{bol} vs M/L_{bol} (Fig. 5): This plot is distance independent, as luminosities and mass scale like d^2. Some correlation is seen, suggesting that evolution could proceed from the bottom right to the top left, as expected if gas mass goes into the OB (proto)stars, the Lyman continuum grows, and the associated HII regions undergo expansion. This is confirmed by a simplified model assuming accretion onto the (proto)star at a fixed rate. In Fig. 6 the data points are compared with three **evolutionary tracks** obtained with our model.

CONCLUSIONS

Our preliminary analysis based on a very limited number of sources provides us with three indications:

3. Most *Herschel*+radio sources are compact HII regions powered by one or a cluster of OB stars
4. A handful of objects present a "radio excess" which cannot be explained as free-free emission from an HII region. These could be located at a larger distance than assumed by us or belong to a new class of objects.
5. We find a correlation between L_{5GHz}/L_{bol} and M/L_{bol} that can be reproduced with an evolutionary model of a (proto)star accreting mass from the parental core.

STRATEGY

Using the CORNISH survey of the galactic plane at 5 GHz (Purcell et al. 2008, ASP Conf. Series, 387, 389), we searched for the radio counterparts of the compact IR sources identified in the two SDP fields (Elia et al. 2010, A&A, in press). The corresponding spectral energy distributions (SEDs) were reconstructed using also the MSX, MIPSGAL 24µm, and BOLOCAM 1.1 mm continuum data (see e.g. Fig. 1).

RESULTS

- 90% of CORNISH sources do not have a Hi-GAL counterpart: their radio fluxes and spectral indices indicate that they are extragalactic objects (see Fig. 2)
- 30 associations Hi-GAL & CORNISH found
- 5 out of 30 are detected in only 1 Hi-GAL band
- Out of the remaining 25 sources, 7 are known Planetary Nebulae (PNe) and 3 have too complex/extended IR emission

➔ **15 useful radio + IR sources** (14 with known distance – Russeil et al. in prep.). For these we reconstructed the SEDs as previously explained (see Fig. 3). The mean size at 5 GHz is 5 arcsec.

REMARKS

While L_{bol} of a given source is due to all stars forming in that region, only O- and early B-type stars contribute significantly to L_{5GHz}. Thus, one can use the ratio L_{5GHz}/L_{bol} to establish the content of high-mass stars in the cluster and their evolutionary stage: **higher L_{5GHz}/L_{bol} should indicate more numerous/more evolved OB stars**.

During star formation a significant fraction of the mass of the parental clump is expected to go into stars. Therefore, **one also expects the ratio M/L_{bol} to decrease with time**.

FUTURE PERSPECTIVES

The results obtained have limited statistical reliability, due to the low number of sources. Extrapolation to the whole region covered by the Hi-GAL survey suggests that **~1000 compact sources with radio counterparts should be detected**, providing us with an excellent benchmark for our study of the radio emission from high-mass young stellar objects.