The onset of star formation in EPoS sources: Herschel continuum and ground-based molecular line observations in concert

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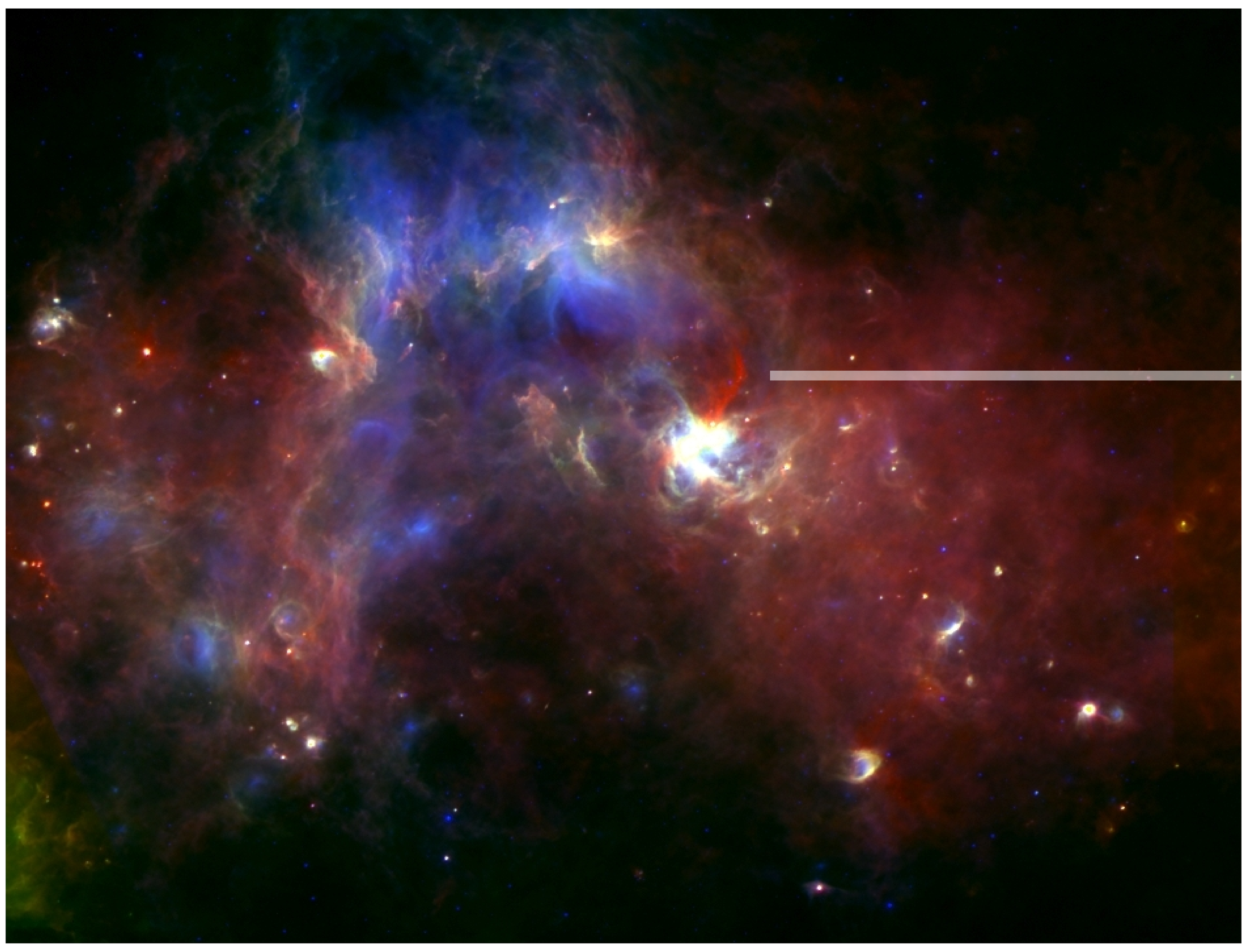
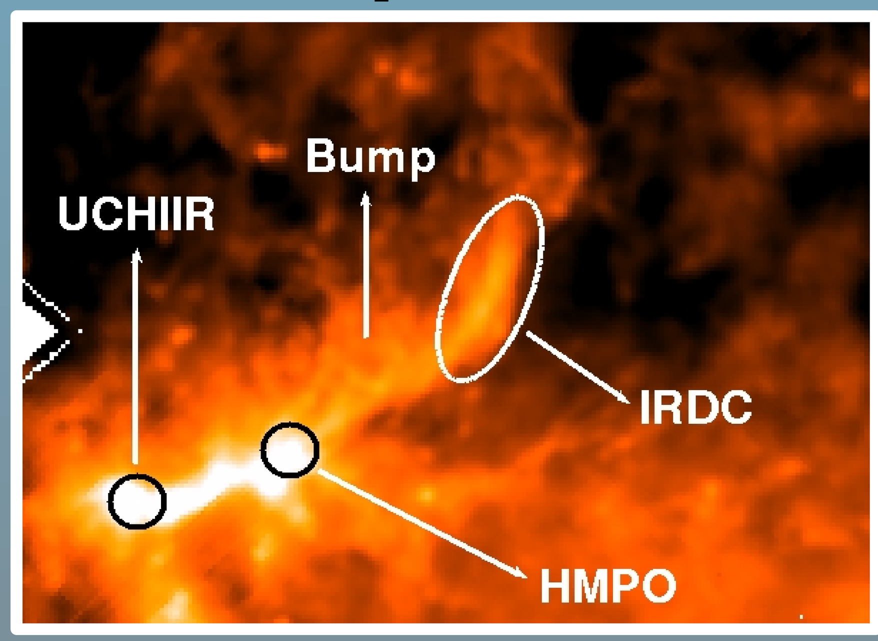
Herschel has brought us exciting new insights into the star-formation nurseries of our Galaxy. Our group has conducted a Herschel Key Programme on the Earliest Phases of Star Formation (whimsically termed EPoS) to scrutinise a well-selected sample of low- and high-mass star forming clumps in detail with the Herschel photometers from 70 to 500 microns. The high-mass sample comprises 45 IRDCs and sources from the ISO Serendipity survey. General results are described in the poster contribution by Ragan et al. (Poster 1B028). Here, we show the connection between the far-infrared (FIR) appearance of these objects, governed by the dust, and the properties of their dense molecular gas content. For this, we have conducted larger complementary studies, using both single-dish (Mopra, IRAM 30-m) and interferometer observations (ATCA, PdBI). We present two case studies: one compact IRDC with early outflow activity, and one filamentary IRDC attaining high column densities, being embedded in a complex environment.

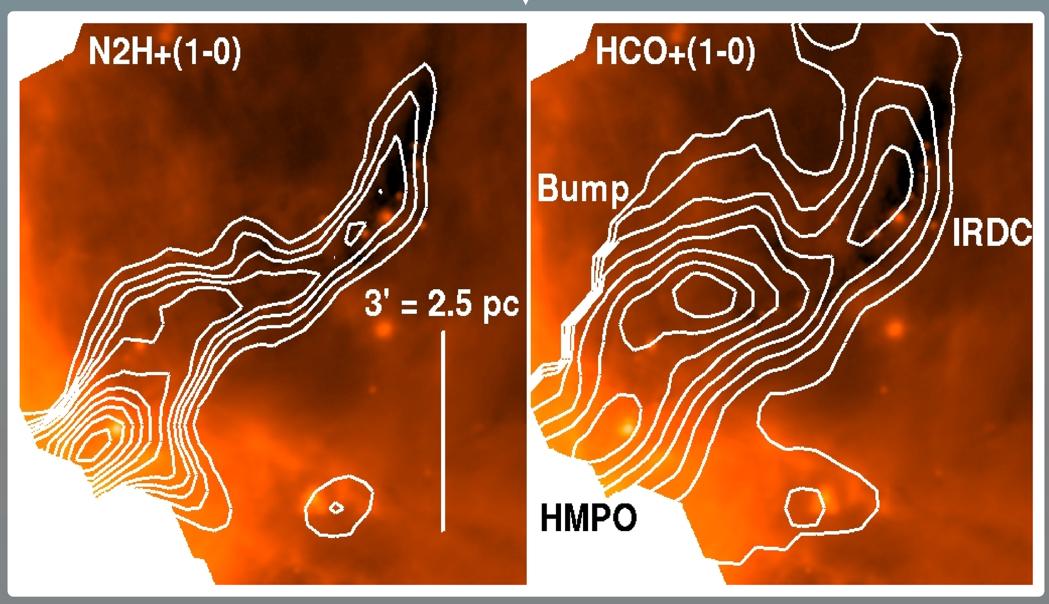
IRDC316.72+0.07 (d = 2.8 kpc): a filamentary IRDC within a complex environment



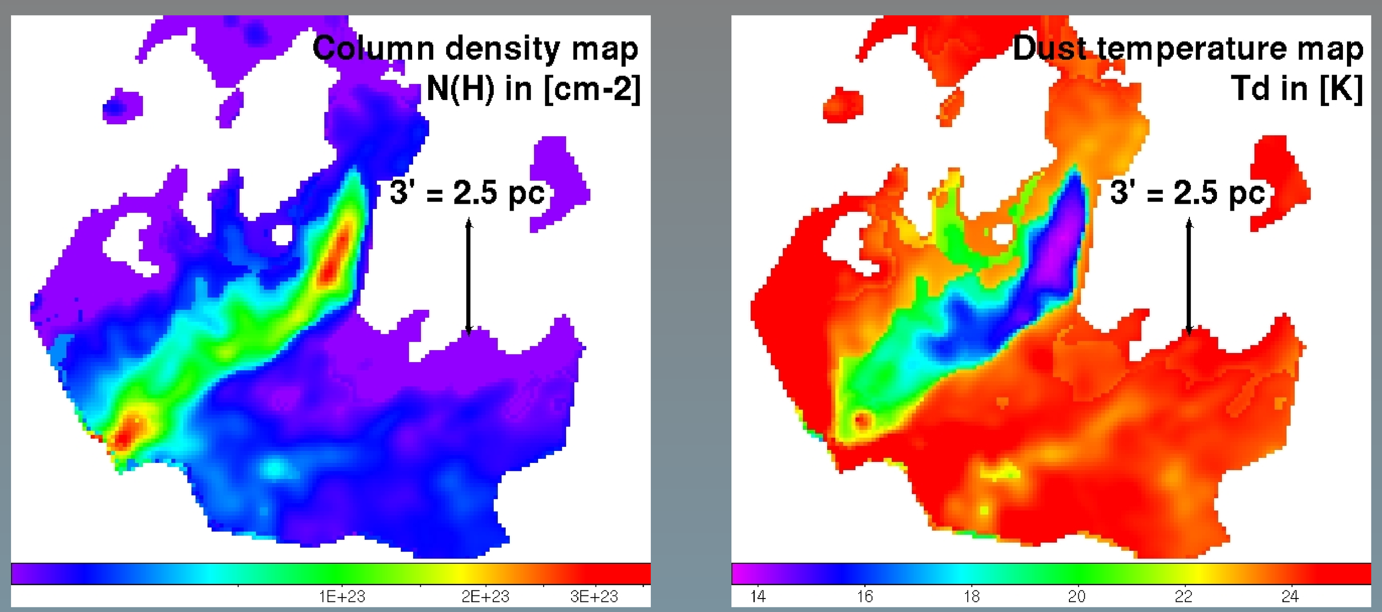
Three-colour composite of Spitzer/MIPSGAL and Herschel/Hi-Gal data: **blue** = 24 µm, **green** = 70 µm, **red** = 160 µm. The targetted IRDC (in deep red) is part of the most active region of this complex bubble environment.

Our EPoS Herschel/SPIRE data at 250 micron: Along a structure of roughly 11 pc in length, several stages of high-mass star-formation can be distinguished that insinuate sequential star formation.





Zoom into the actual IRDC region:
Image: Herschel/PACS 70 micron data from EPoS
Contours: single-dish molecular line maps (Mopra)
Note the HCO+ enhancement in the "Bump" region.



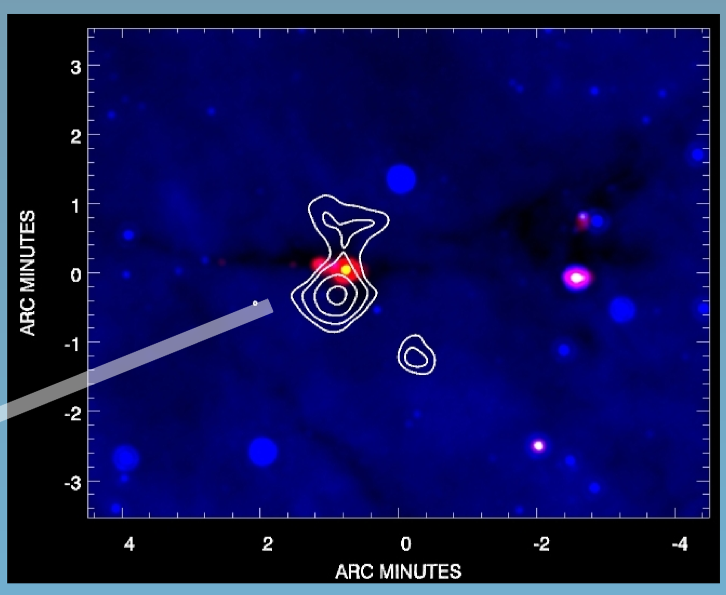
Derived quantities based on modified blackbody SED fitting of our Herschel data from 70 – 500 micron (+ATLASGAL 870 µm):
Left: Column Density map. Right: Dust Temperature map.
Note the high central column densities attained, and the low central temperatures of < 14 Kelvin.

Summary I:

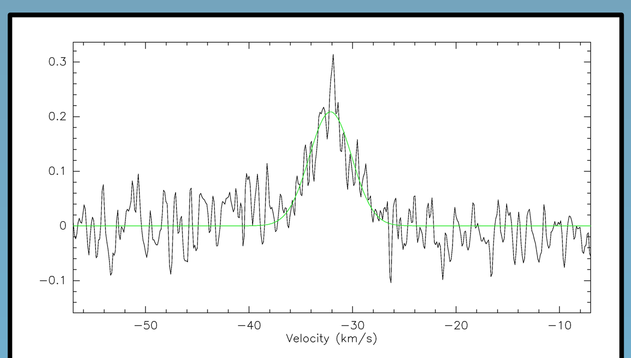
- The high column densities and the total mass (> 800 M_{sun}) indicate that this IRDC has the potential to form future high-mass star(s).
- The Bump region deserves further attention. Enhanced linewidth and abundances of HCO+ indicate more turbulent conditions there.
- This might be caused by <u>continuous infall of material onto the filament.</u> Confirmation can come from high-spatial resolution molecular line observations with ALMA which can provide the necessary dynamic range.

IRDC321.73+0.05 (d = 2.1 kpc): Outflow activity close to a deeply embedded Herschel/PACS source

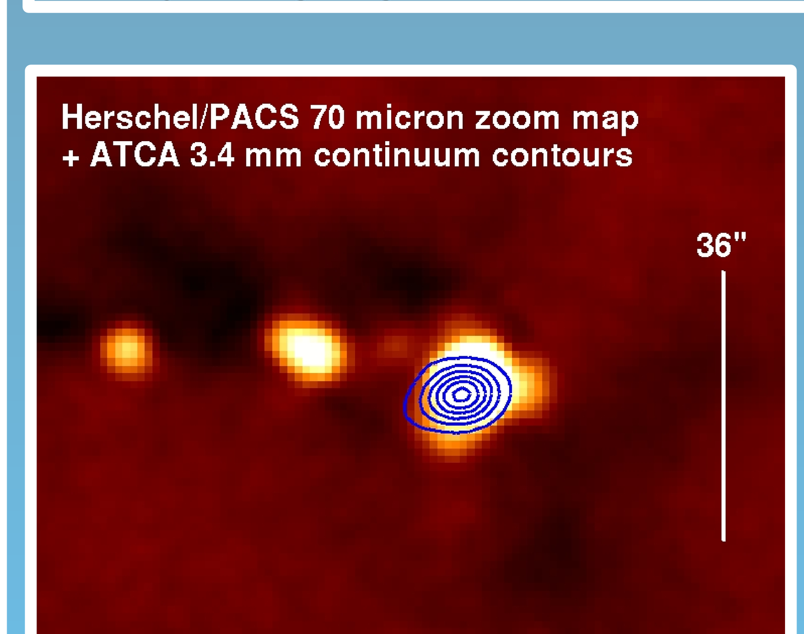
While just two weak 24 µm point sources are visible close to the column density and line emission peaks, more compact sources are revealed by the Herschel/PACS data. Among the new sources is an object with a very steep SED that dominates the region at ≥70 µm (seen in bright yellow), but is not clearly detected at 24 µm. The detection of bipolar SiO emission insinuates the presence of a young molecular outflow, hence, star-formation activity is ongoing in this IRDC.



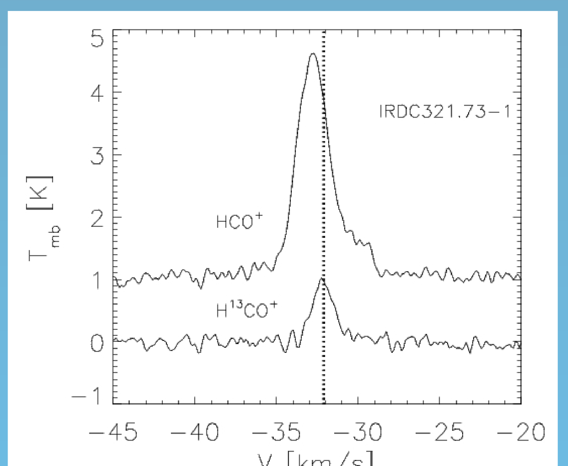
The image is a three-colour composite of 24 µm MIPS data in **blue**, PACS 70 µm data in **green**, and PACS 160 µm data in **red** (very modest PACS cut levels). Contours: Mopra SiO(2-1)map, integrated intensity.



The SiO spectrum is from a separate pointed Mopra observation toward the central red source (cf. Vasyunina+ 2011)



A first result from our interferometric mapping of this source: on top of our 70 µm Herschel/PACS map, the blue contours denote the 3.4 mm continuum emission, measured with ATCA in a 5" beam. ATCA proves that the column density peak is coinciding with the reddest compact source in the region.



Mopra single-dish spectra toward this red source: The blue-skewed HCO+ spectrum indicates infall motions with moderate velocities of around 0.6 km/s (when applying the Myers et al. 1996 formalism).

Summary II:

- Our Herschel/PACS mapping picks up compact sources with very red SEDs which sometimes do not even have a 24 micron counterpart.
- Despite a non-detection at 24 micron, star-formation activity can be ongoing nevertheless. The relatively strong SiO signal in this case can be seen as independent evidence.
- The <u>bipolar morphology</u> of the SiO map may indicate that the central source is rather strongly inclined to the line of sight.
- <u>Interferometric (sub-)mm data</u> are a way to proceed in order to disentangle the small-scale structure. The ATCA continuum data have successfully pinpointed the column density peak. Further exploitation of the ATCA line data will quantitatively refine the information on infall and outflow motions on scales < 10,000 AU.