# EPoS – The Search for the Earliest Phases of Massive Star Formation


Th. Henning, O. Krause, H. Beuther, H. Linz, Z. Balog, S. Birkmann, M. Hennemann, R. Klein, R. Launhardt, M. Nielbock, S. Ragan, B. Stecklum, J. Steinacker, A. Stutz



We present the first results of the EPoS Key Program on massive star formation. The earliest phases of massive star formation are still poorly understood because the objects are very deeply embedded, evolve rapidly and are located at larger distances than the closest regions of low-mass star formation. We carefully selected a sample of 45 massive and cold cores for observations with Herschel. Multi-wavelength observations of these objects, including millimetre single-dish and interferometry data, are available for the entire sample. We are obtaining scan map observations with the Herschel PACS and SPIRE instruments to search for the embedded stellar population and to characterise the temperature and density structure of the clumps. We summarise selected results of our SDP observations, especially showing the amazing detection of very young pre-/protostellar cores deeply embedded in the observed clouds.


## G11.11-0.12: The Big Snake and the seeds of star formation

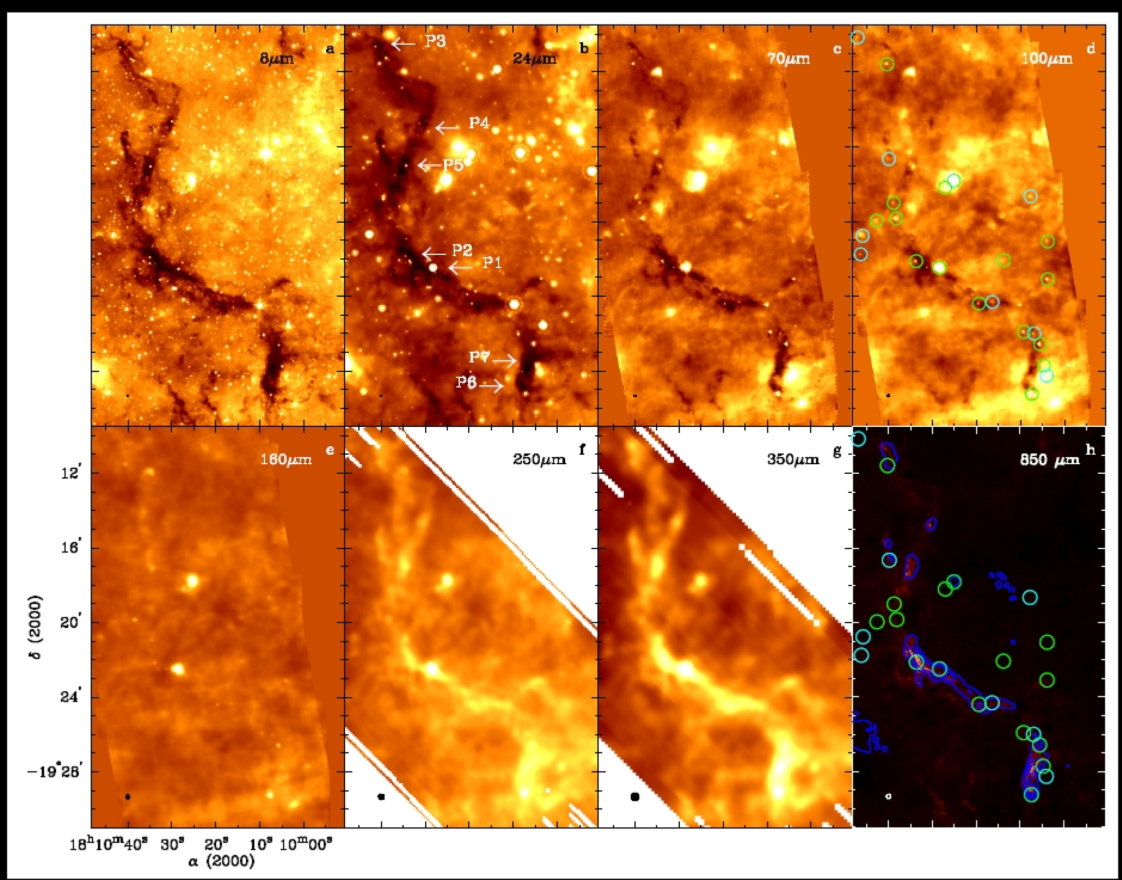
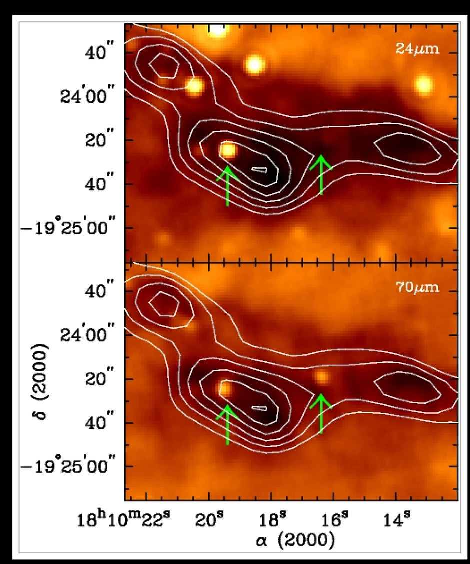



Image gallery for G11.11-0.12, showing Herschel maps (70, 100, 160, 250, 350 μm), in contrast to Spitzer GLIMPSE (8 μm) and MIPSGAL (24 μm) data. The lower right panel shows archival SCUBA data at 850 μm as contours overlaid over an extinction map derived from the 8 μm GLIMPSE data.

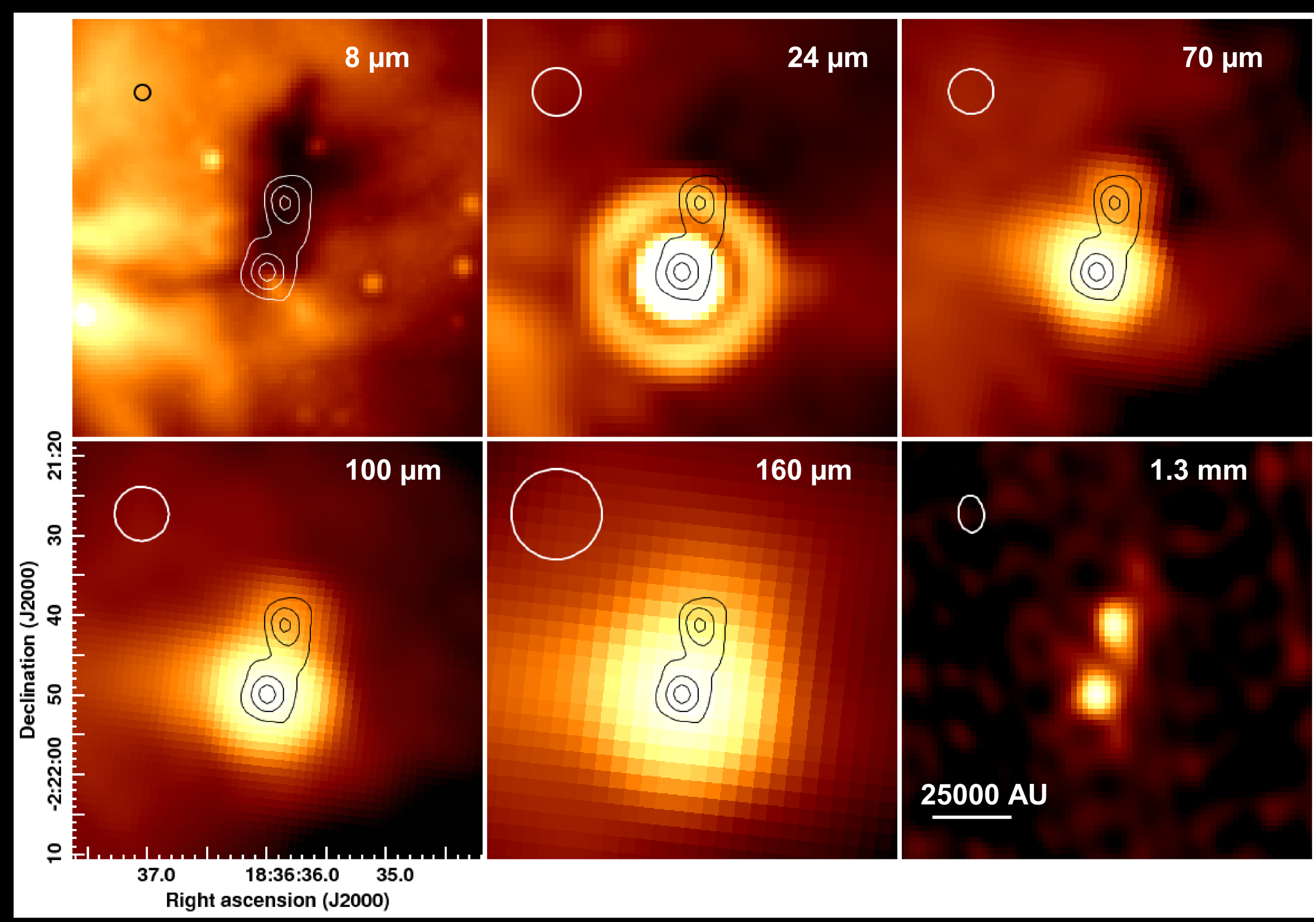



Zoom into an emblematic region of the IRDC at 24 μm (Spitzer) and 70 μm (Herschel) with SCUBA 850 μm data as contours. Three types of embedded objects within one clump: compact PACS sources with and without 24 μm contourpart, as well as a prestellar core (the strongest SCUBA peak) without far-IR emission.

Infrared Dark Clouds (IRDCs) host the precursors to massive stars and clusters. The Big Snake is a prime example for a filamentary IRDC, appearing as dark silhouette on the bright mid-IR background. Although many compact emission sources are seen with MIPS 24 μm, only the new Herschel/PACS data can distinguish the genuine protostellar cores among them (green circles). Furthermore, the PACS data reveal several unresolved sources not visible at wavelengths < 70 μm (turquoise circles). These sources might be younger than the protostellar cores, however, also geometry effects can influence the spectral appearance. Modified black-body fits to the far-IR data points for the compact cores show temperatures of ~<22 K>, slightly warmer than the surrounding gas in the natal clumps, and attaining an average mass of <23 $M_{sun}$>.

The mean core separation is 0.9 pc, well in excess of the thermal Jeans length in the filament. Beyond 160 μm, the main bulk of material finally is seen in emission and is picked up by the SPIRE data. We find evidence for truly prestellar massive condensations along the filament, recognised by the existence of column density peaks in the SPIRE (and SCUBA) data in combination with the absence of compact PACS emission sources at these locations (zoomed view in the separate panel to the right). (Henning et al. 2010)

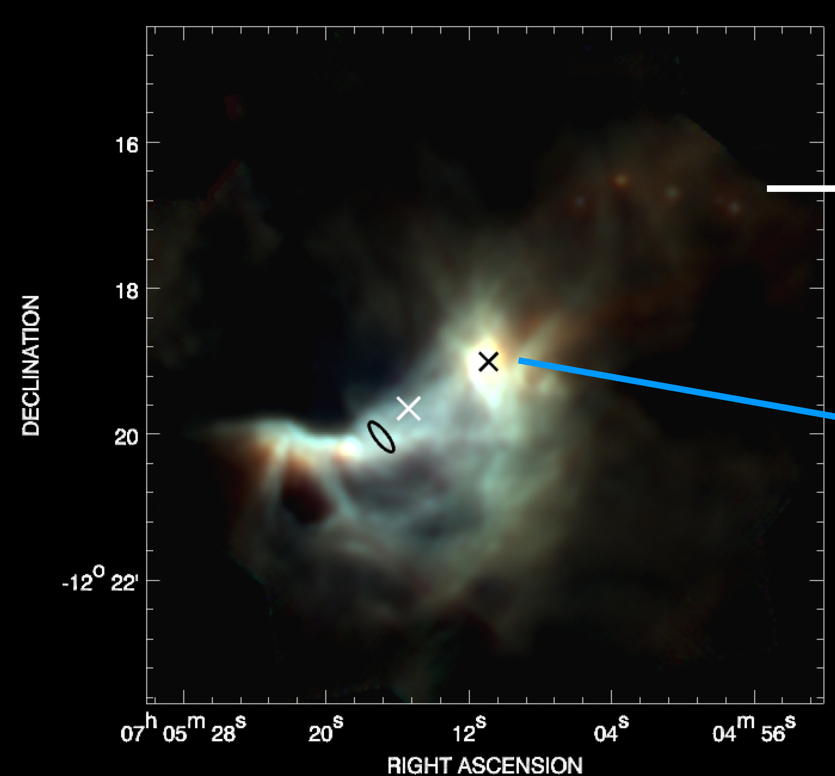
## ISOSS J18364-0221: The boon of high spatial resolution in the FIR



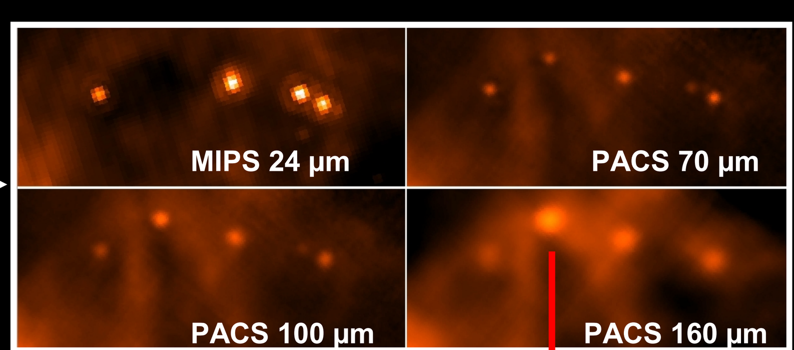

Zoom into the core region of the ISOSSJ18364 complex, comparing our Herschel/PACS data (70, 100, and 160 μm) with our Spitzer 8 and 24 μm data. The lower right panel shows the 1.3 mm continuum obtained with the Plateau de Bure Interferometer. The 1.3 mm contours are overlaid on the other panels as reference. In every panel, the spatial resolution is given.

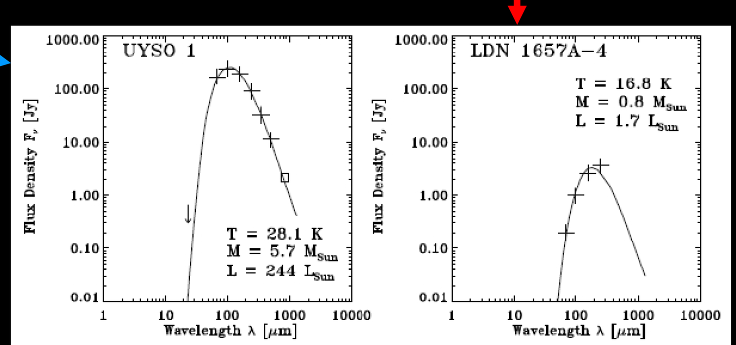
A subset of our EPoS targets is drawn from a sample of very cold high-mass clumps originally revealed by ISOPHOT due to their high brightness at 170 μm. The above figure shows Spitzer, Herschel and PdB observations of two high-mass (12 and 18 $M_{sun}$ for the southern and northern component, respectively) protostars in the cloud complex ISOSS J18364-0221. While both sources have about the same brightness in the mm-continuum, and the southern one is readily detected by Spitzer at 24 μm in the mid-infrared, the northern one only becomes visible in the Herschel-PACS image at 70 μm. The spatial resolution is indicated by circles/ellipses in the upper left corner of each image. Only due to the superior spatial resolution of PACS (5.6 arcsec at 70 μm), we can derive separate SEDs for the two cores now and thus substantiate the different spectral appearances. (Krause et al. 2010)

## UYSO1 / LDN1657A: The structured environment of star-forming cores




Three-colour composite of the PACS data for UYSO1 and surroundings (blue: 70 μm, green: 100 μm, red: 160 μm). UYSO1 itself is marked by the black cross. Also the IRAS 07029-1215 error ellipse as well as the position of the HII region Sh2-297 (white cross) are indicated. A multi-wavelength view onto the cores in the northern LDN 1657A region is given in the right panels.



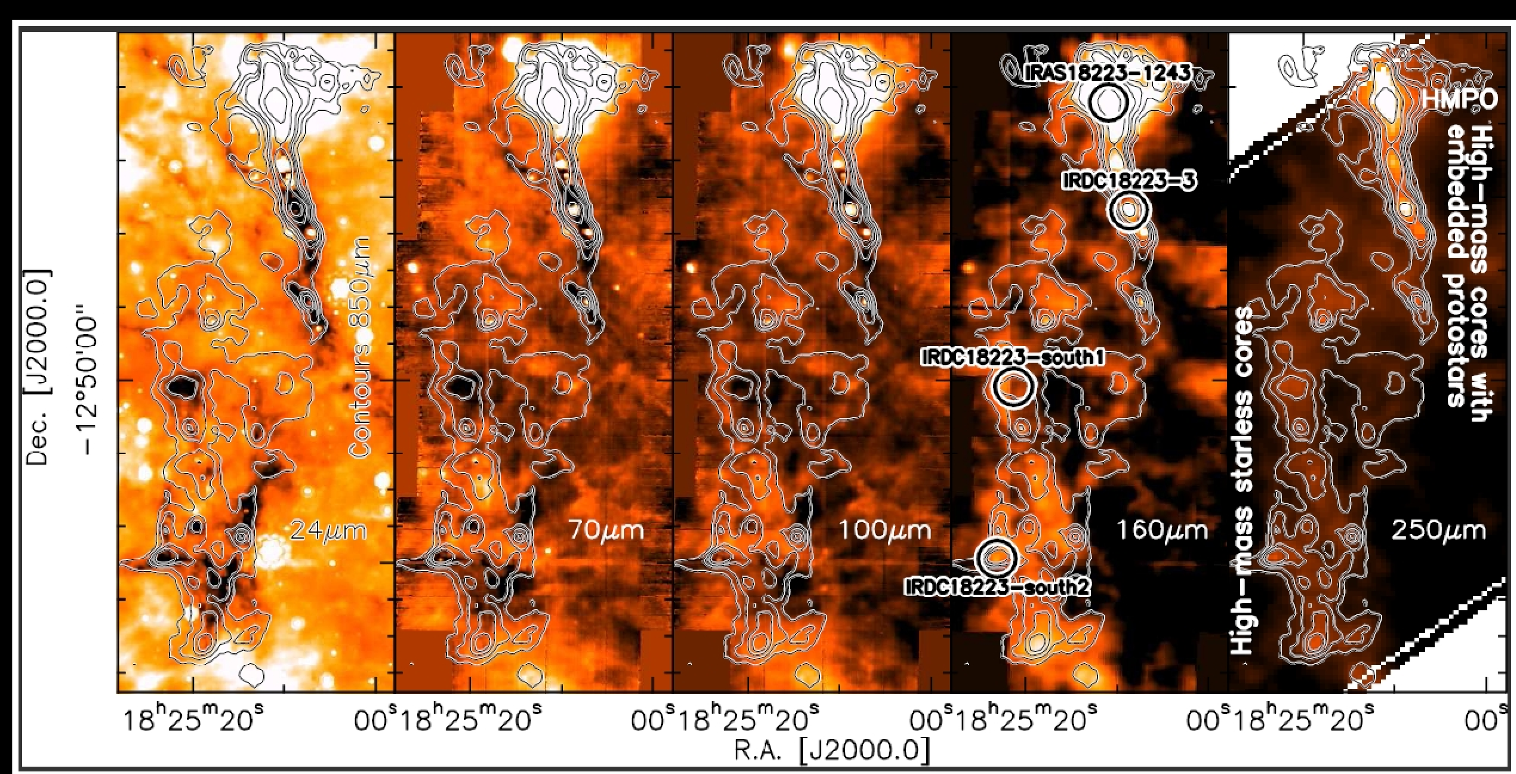




The SED of UYSO 1 (left) is very well approximated by one modified black-body component with a slightly elevated temperature (28 K). The most remarkable object among the northern LDN 1657A objects is a core with a 24 μm shadow and a very steep spectral slope in the far-IR (right). The data indicate a low-mass cold core in this case.

The intermediate-mass core UYSO 1 is known to drive two powerful, dynamically young outflows. On the other hand, it is deeply embedded and was previously just detected with SCUBA. Our new Herschel data revise a previous claim about the non-detection of the core at 70 μm. With the new Herschel data and a revised astrometry, we now have a clear detection of UYSO 1 at all Herschel wavelengths. This also affects other parameters like the luminosity that can be derived from SED fits. We find 244 $L_{sun}$ for this core, and fit a temperature of 28 K. An influence exerted by the neighbouring PDR is possible.

UYSO 1 is located at the interface between an optically visible HII region to the southwest and an optical dark cloud to the north-west. Within the dark cloud region, we reveal the presence of several low-mass cores which show compact emission at PACS wavelengths. Of particular interest is a core which still blocks the background extended emission at 24 μm and appears as a dark shadow there. The PACS data show an unresolved emission core with a steeply rising SED, and at ≥160 μm, it is the brightest object among these northern sources. Follow-up observations are in order to better characterise these serendipitously found cores. (Linz et al. 2010)

## I18223-1243: The possible sequence of high-mass star formation on display




Maps of the whole star-formation complex south of and including IRAS 18223-1243. The 24 μm data are from Spitzer/MIPSGAL. The other maps are our new Herschel data. The contours denote SCUBA 850 μm emission to indicate the column density peaks.

Some of the interesting features of this high-mass star-forming complex have already been recognised previously by Beuther and coworkers. In the north of the displayed region, one finds the IRAS source 18223-1243, which harbours a high-mass protostellar object. The direct southern extension is known to contain a younger protostellar core (IRDC18223-3), indicated by faint 24 μm emission. The new Herschel data at longer wavelengths shown above not only trace the embedded objects in this filamentary IRDC: in the region more to the south, even colder clumps are revealed that have no emission counterpart at 24 μm. While the south-2 source shows faint compact emission at 70 micron, the south-1 clump remains dark even at 100 μm. Only at longer wavelengths (≥160 μm), this object finally turns into emission and thus revealing a prestellar massive core containing cold dust but no protostars yet. The whole complex hence displays a possible sequence of phases along which high-mass star formation proceeds. (Beuther et al. 2010)