# Earliest phases of high mass star formation with Herschel and ALMA

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# Overview

- Possible sites of massive star formation
- Source sample:
  - Planck catalog
  - ECC clumps in the Hi-GAL region
- Physical parameters of the clumps:
  - T, N
  - D
  - M, d
- Follow-up studies

# Possible sites of HMSF - IRDCs

Infrared Dark Clouds:

- significant mid-IR opacity

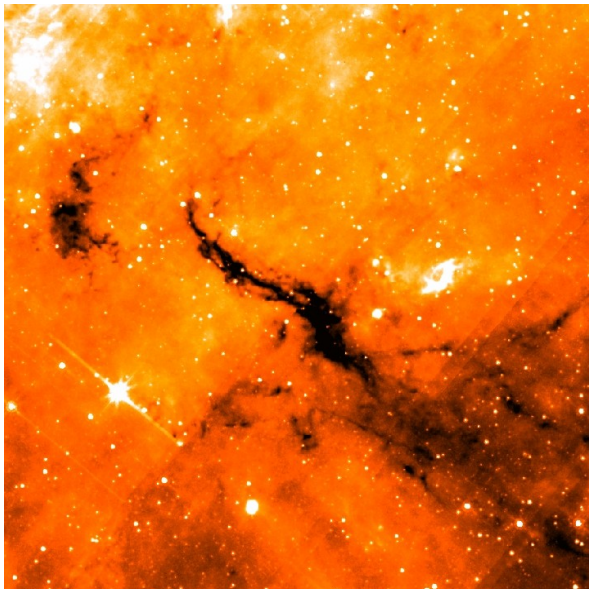
- cold (<20 K), dense (>$10^4$ $cm^{-3}$) with high column densities (>$10^{23}$ – $10^{25}$ $cm^{-2}$)

- dark at 100 μm

Sizes (few pc) and masses (few 1000 $M_\odot$) comparable

to warm, cluster-forming molecular clumps

-> Colder and with little obvious star formation



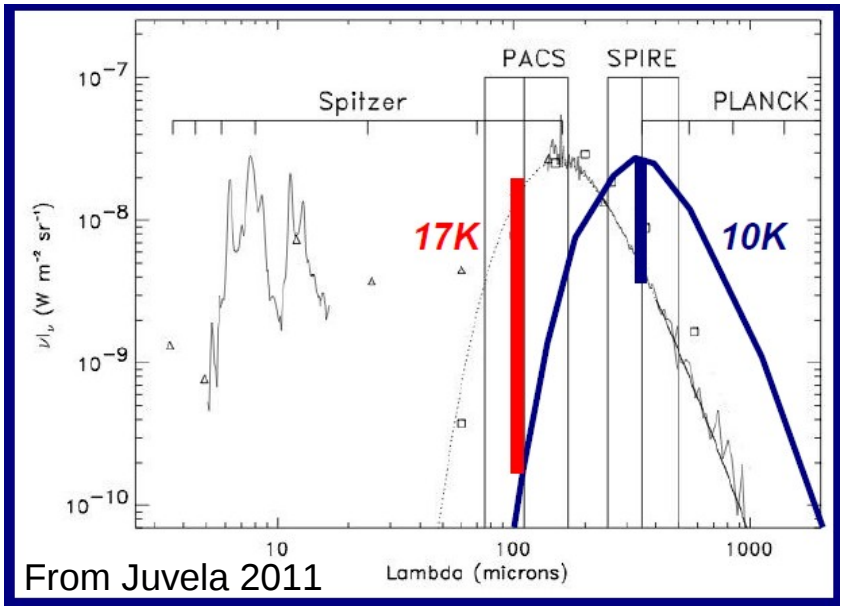
Spitzer GLIMPSE 8um image



Perault et al. 1996; Egan et al. 1998; Carey et al. 1998, 2000; Hennebelle et al. 2001; Simon et al. 2006; Rathborne et al. 2006

# Planck all sky survey

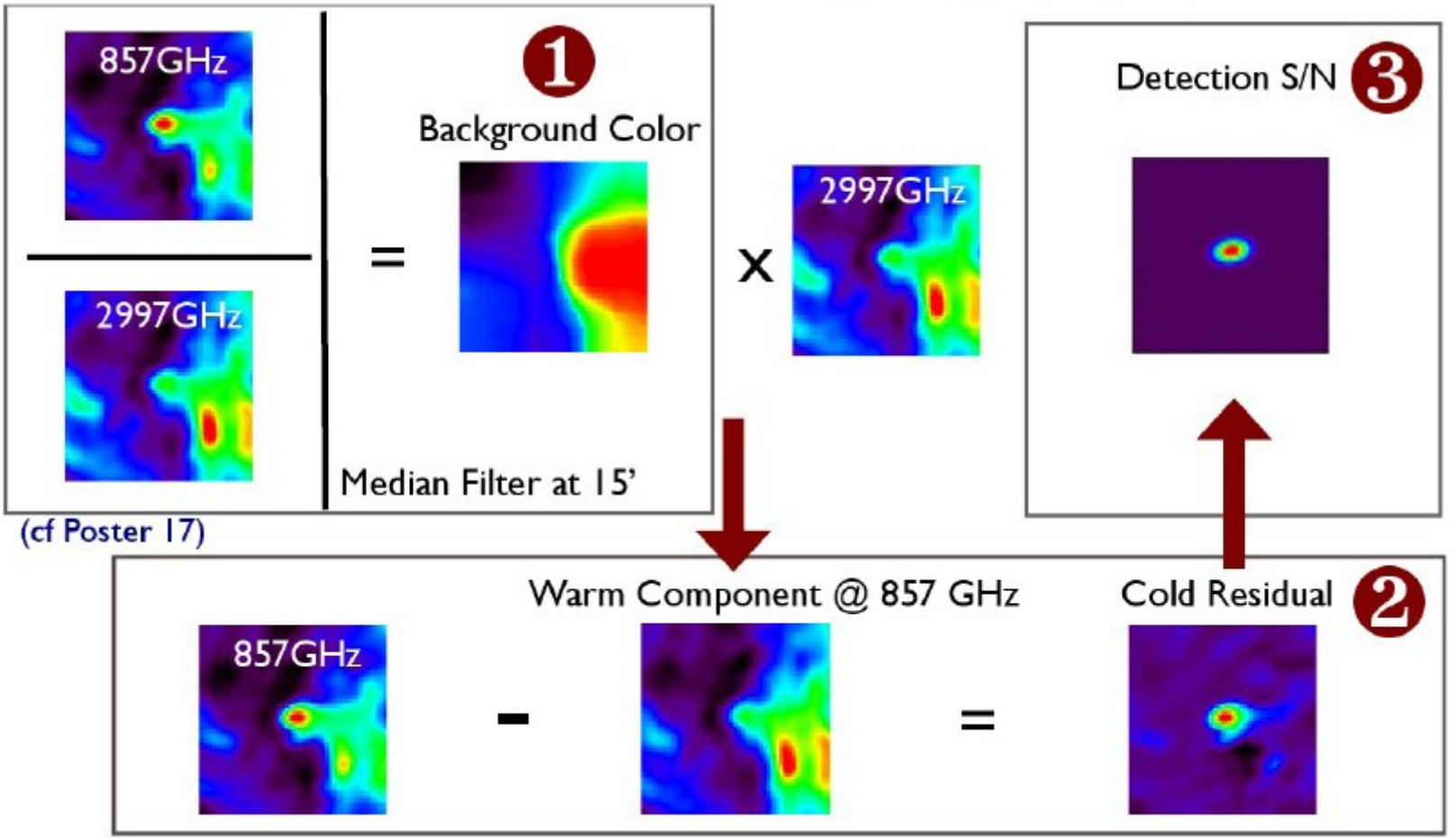
- Mapped the sky at 9 frequencies between 857 GHz and 30 GHz (350, 550, 850, ... 10000 μm)
- Better than 5' resolution in the submm



From Juvela 2011

Detection of cold clumps is possible

# Detection method




Planck Collaboration, 2011, A&A, 536, 23 + Planck Collaboration 2015

# C3PO, ECC, PGCC catalogs

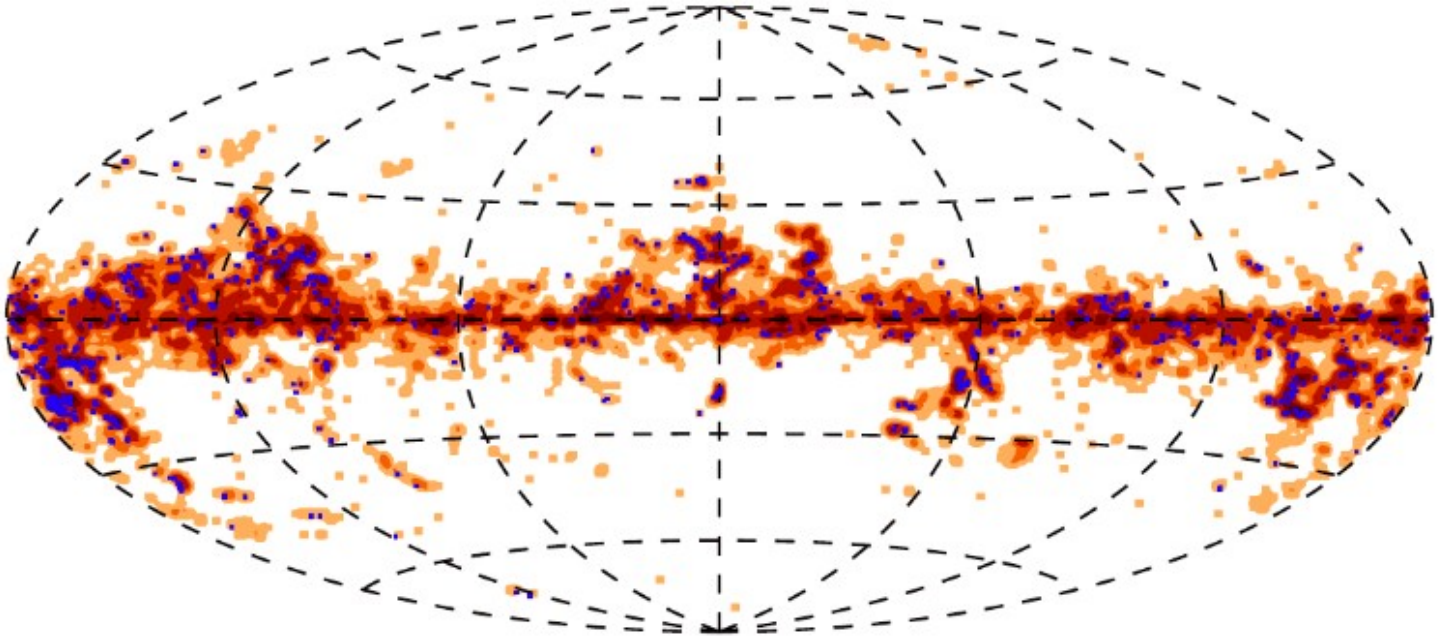
**C3PO**: Preliminary catalog ~10000 sources

Early Cold Core selection(**ECC**)

Most reliable sources ~ 900

S/N > 15

T < 14 K



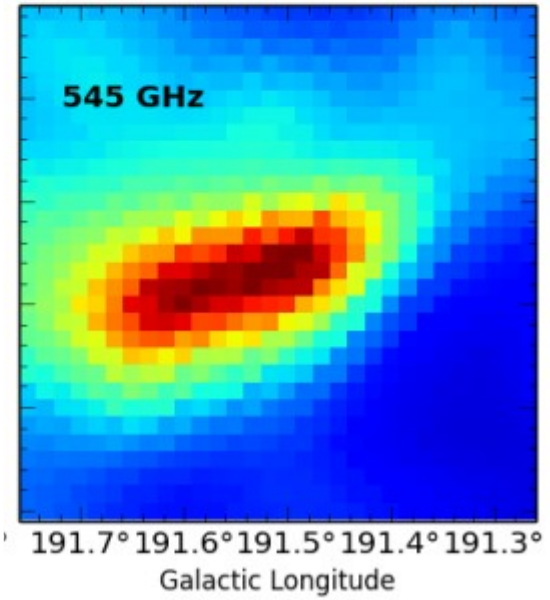
**PGCC**: Final catalog ~13000 sources

Distance for ~5000 sources



Planck Collaboration, 2011, A&A, 536, 23 + Planck Collaboration 2015

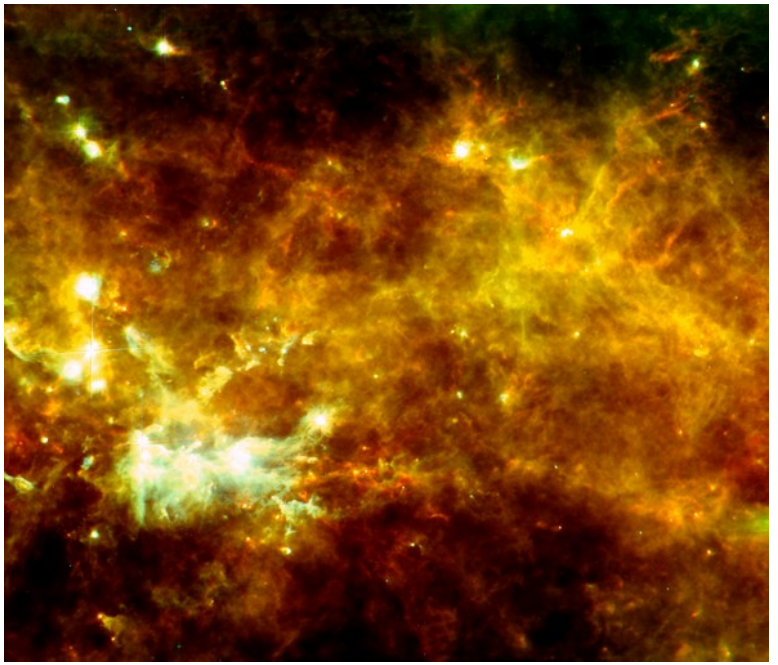
# Planck view of an ECC



# Hi-GAL survey

- Herschel Infrared Galactic Plane Survey, Open Time KP + extensions
- Herschel PACS (70-160 μm) and SPIRE (250-500 μm) survey of the Galactic Plane of the Milky Way
- -1 deg < b < 1 deg
- Resolution: 5”, 13”, 18”, 25”, 36”

https://hi-gal.ifsi-roma.inaf.it/higal



Composite image (70-160-350) of the Galactic Plane in the Vulpecula region

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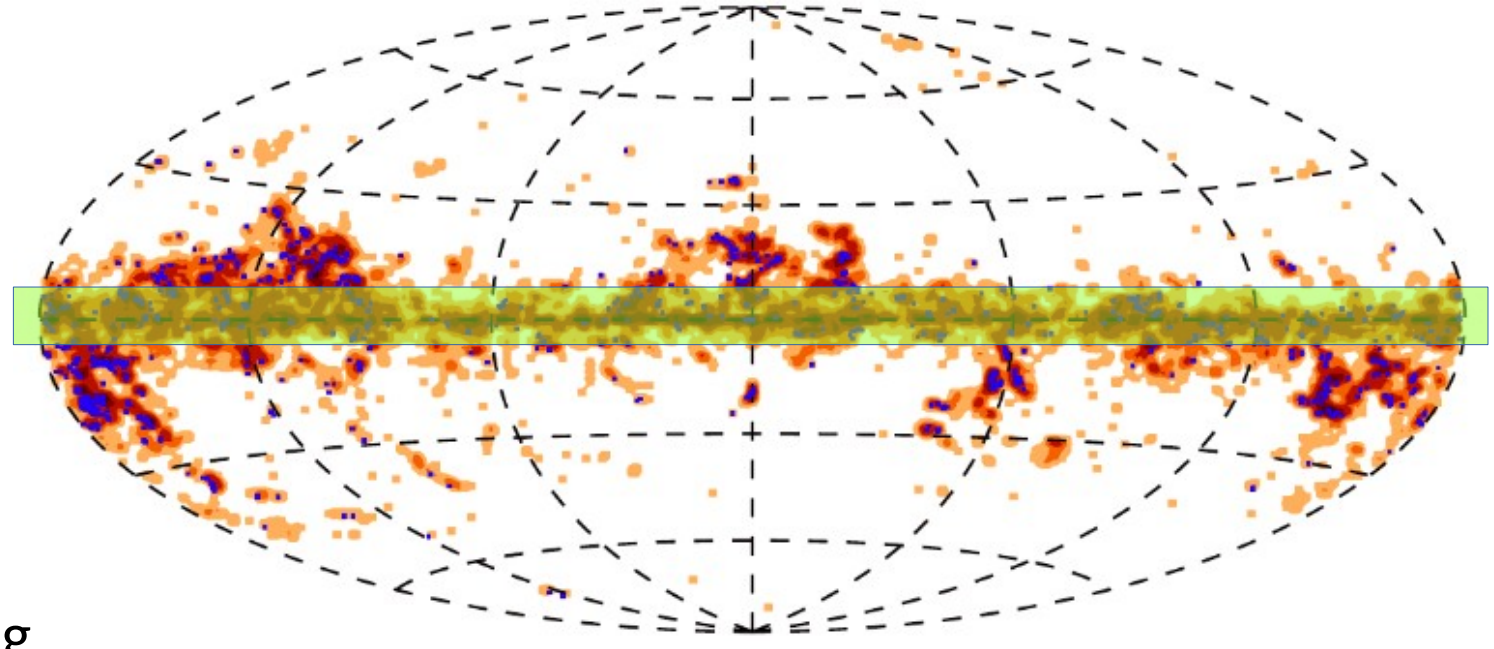
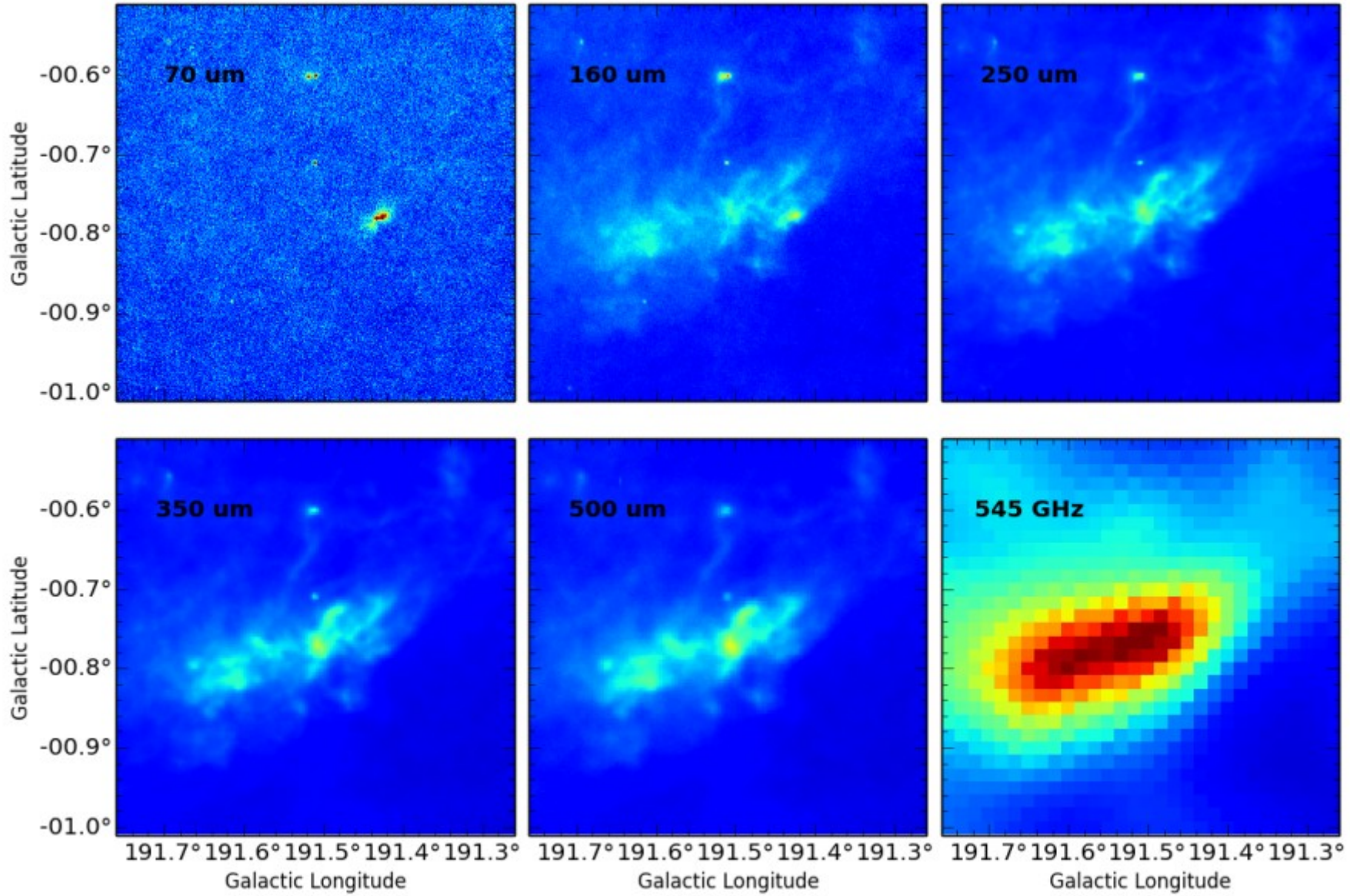


48 ECCs covered by Hi-GAL (https://hi-gal.ifsi-roma.inaf.it/higal/)



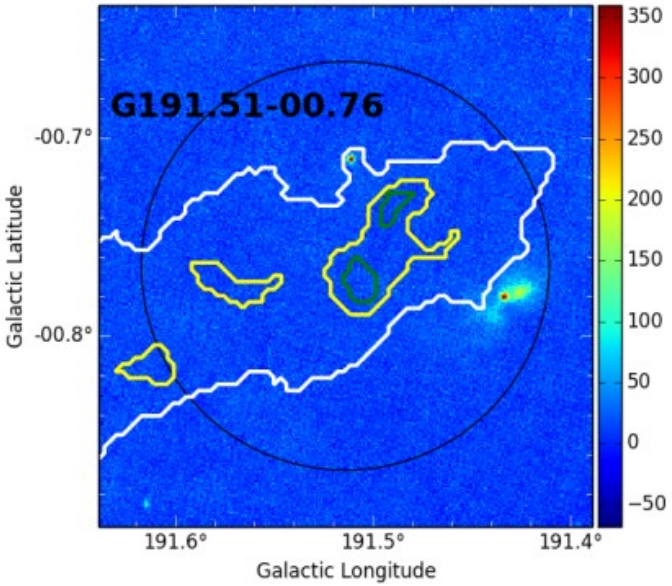
Planck Collaboration, 2011, A&A, 536, 23 + Planck Collaboration 2015

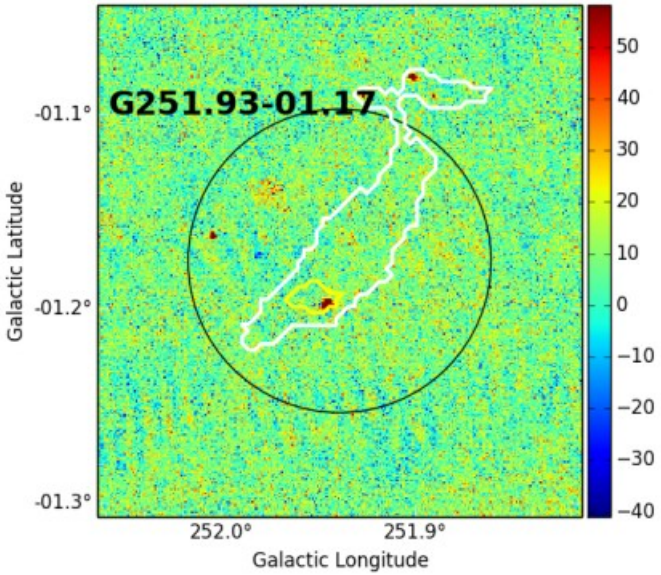
# The role of Hi-GAL data

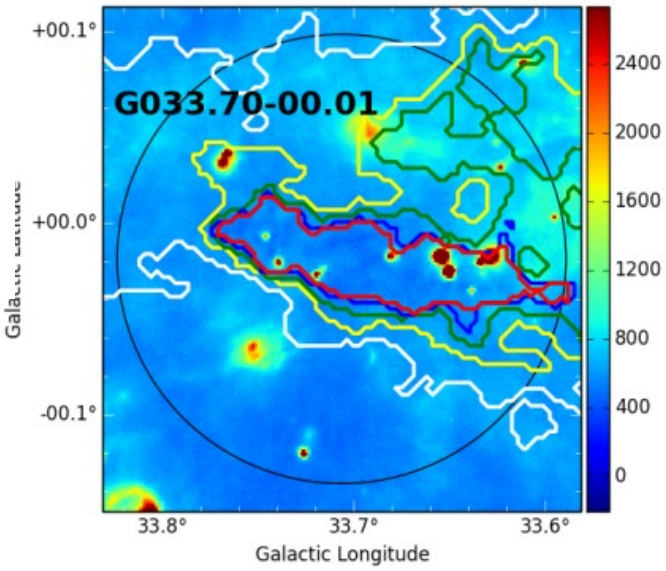


# Star formation properties of ECCs

- 24 / 70 μm images

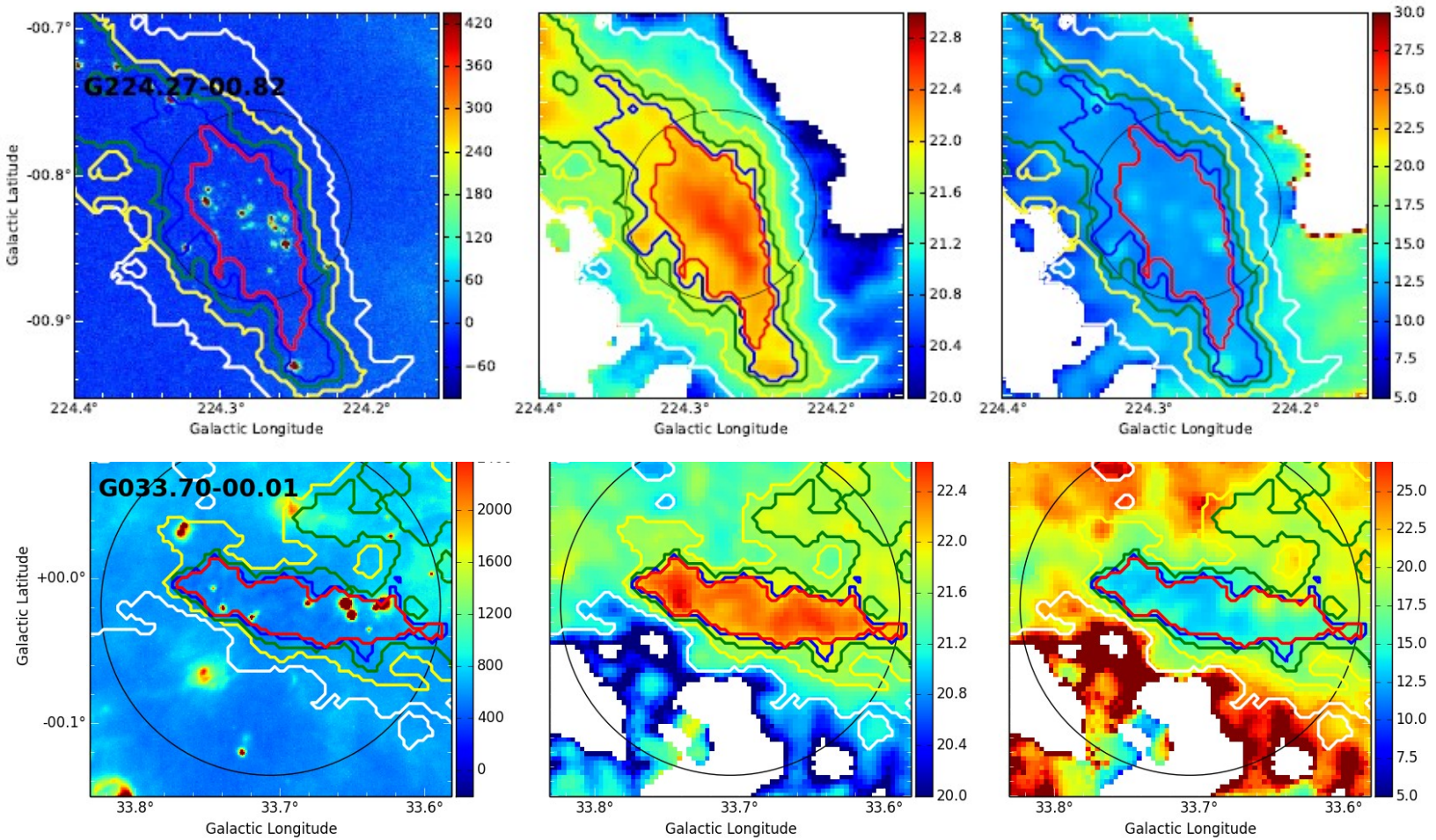


# Physical properties of ECCs

- T, $N(H_2)$: 160 - 500 µm images




ALMA Herschel 2015, ESO Garching

**70 µm** **$N(H_2)$** **$T_{dust}$**

# Physical properties of ECCs

- size, mass determination:

  -> distance estimation needed:

  PGCC catalog, Wu et al. 2012 – Purple Mountain Obs., Galactic Plane line surveys, CfA CO survey, APEX observations, ...)

# Possible candidates for HMSF?

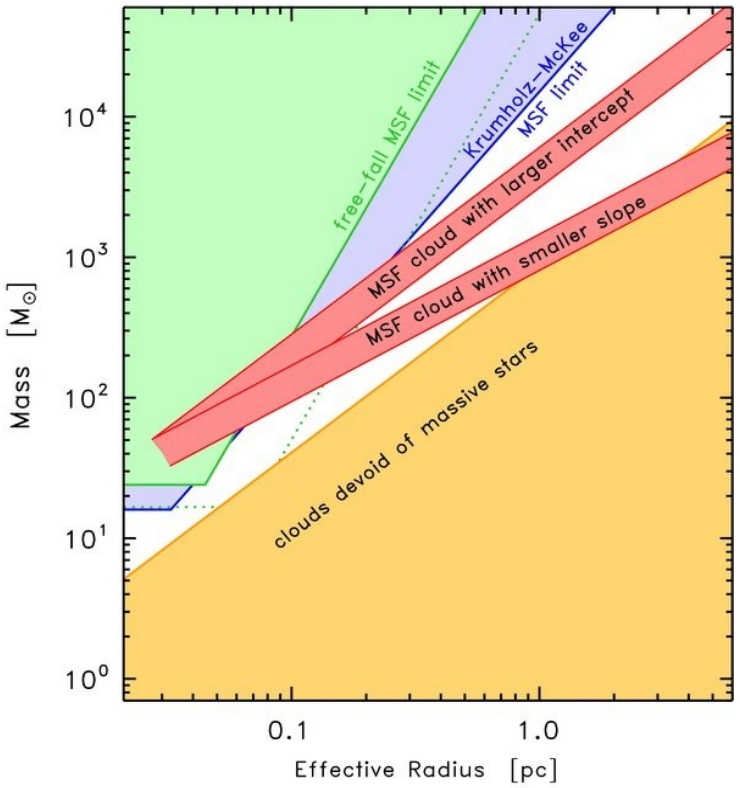
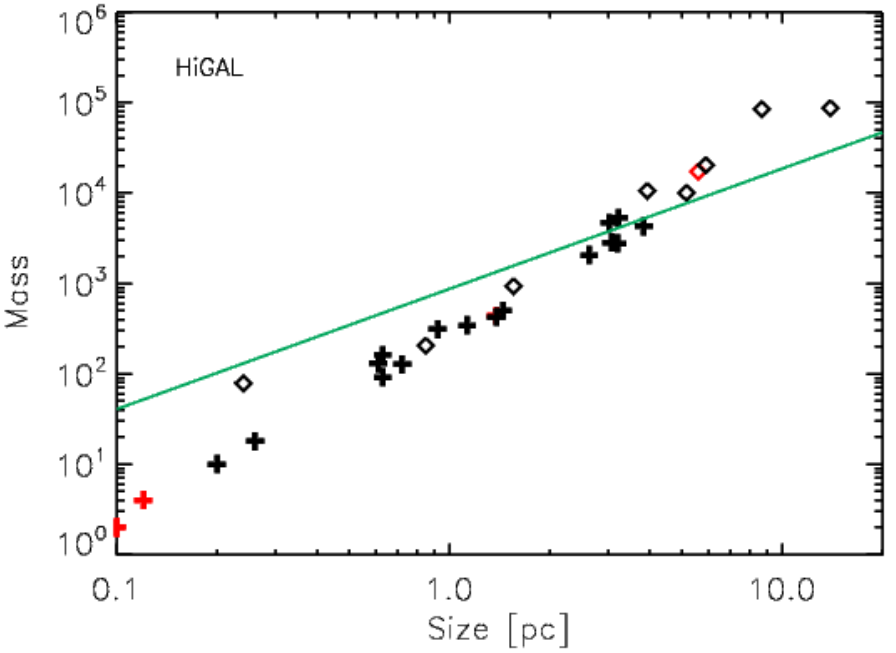



Figure 1 from Kauffmann & Pillai, 2010, ApJ, 723, L7

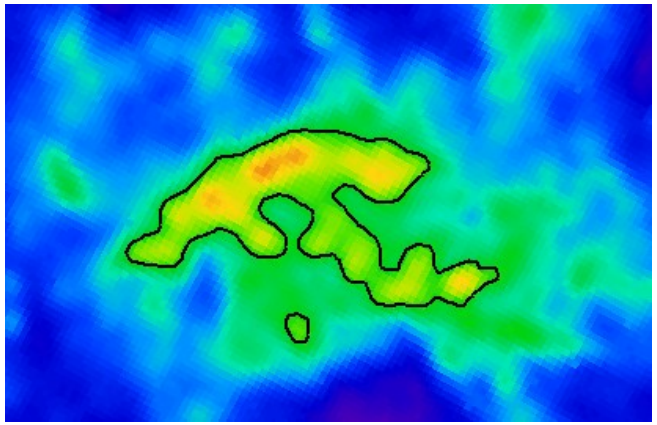
Mass – size limit for HMSF



# Importance of follow-up studies

Most massive, cold sources in their early phases

Molecular line follow-up: APEX, ALMA, eVLA



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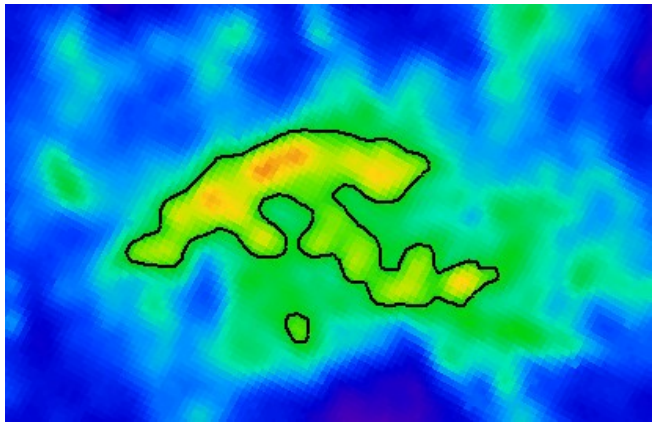

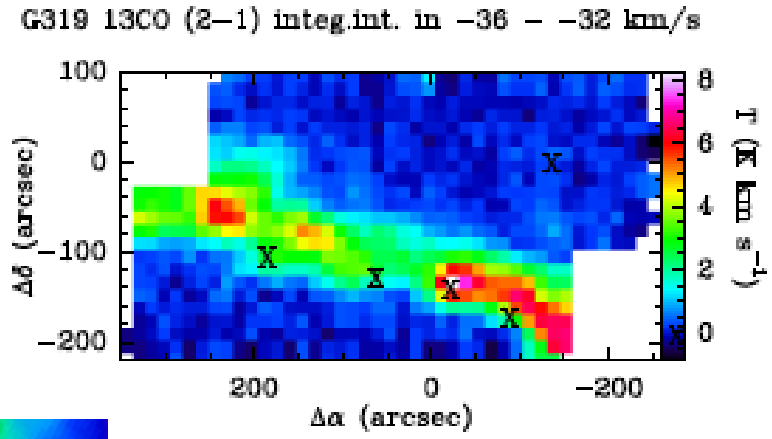


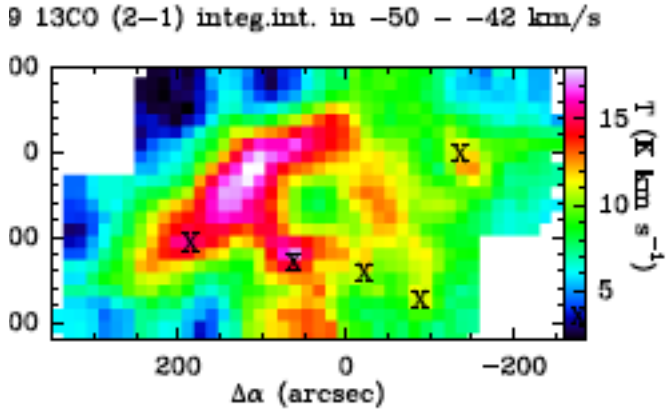


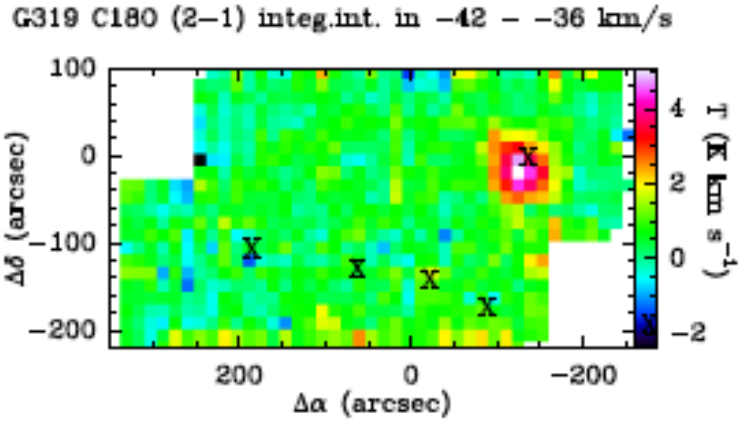

# Summary

- 48 ECCs in the Galactic plane
- D ~ 0.5 kpc to 8 kpc
- M ~ few $M_S$ to $10^5$ $M_S$
- ~60 % in the outer part of the Galaxy
- 23 % “starless”
- 10 objects are above the mass – size limit for massive star formation

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**ALMA Cycle 2 – G191.51-0.76, Band 3, 4” ~ 0.03 pc**