Earliest phases of high mass star formation in the Galactic Plane

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Cold Cores 2016, ELTE, Hungary

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

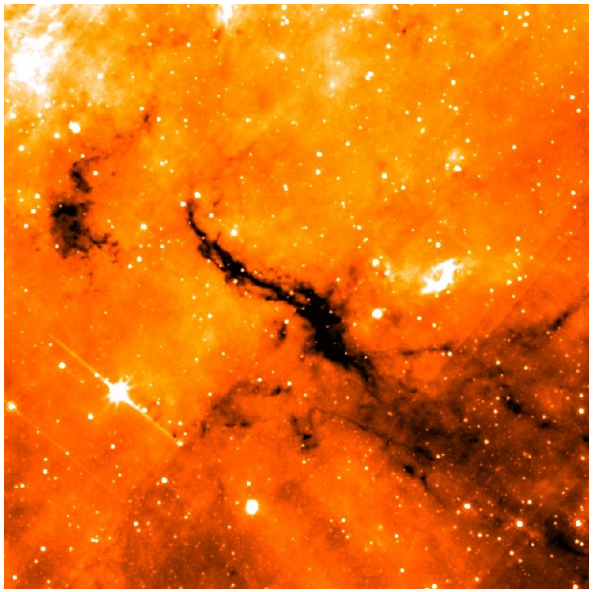
- cold (<20 K), dense (>10^4 cm^{-3}) with high column densities (>10^{23} – 10^{25} cm^{-2})

- 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

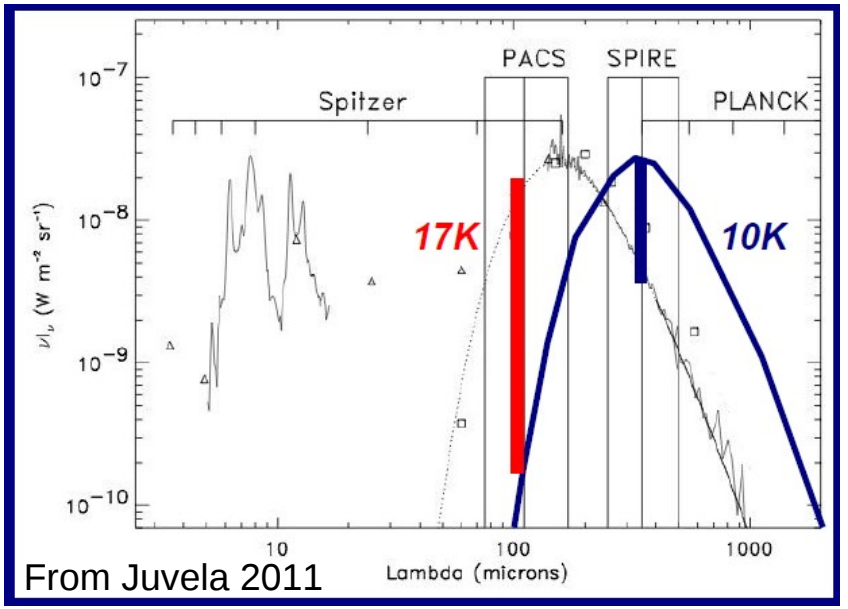


Spitzer GLIMPSE 8um image

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

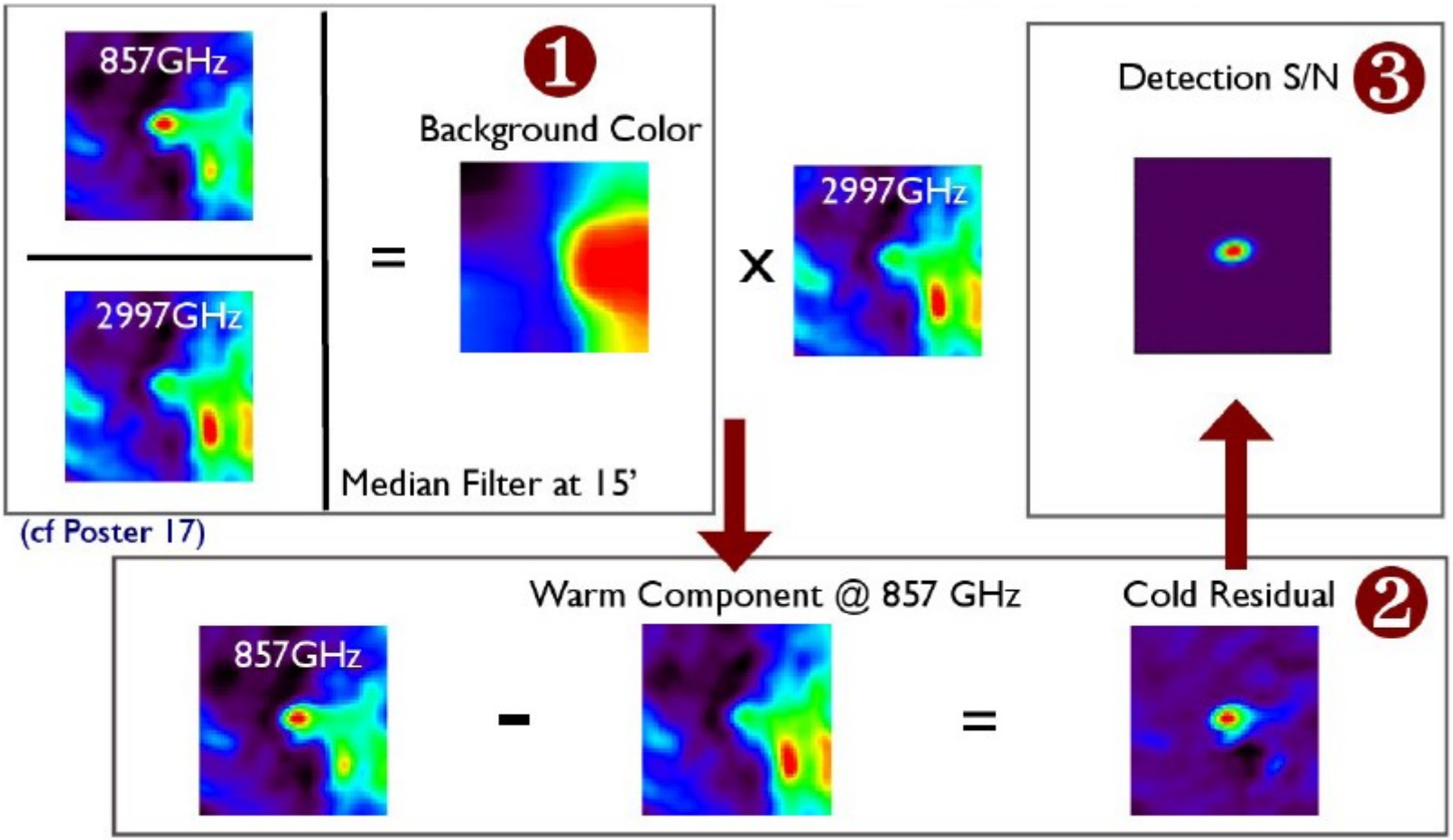
- Mapped the sky at 9 frequencies between 857 GHz and 30 GHz (350, 550, 850, ... 10000 μm)
- Better than 5' resolution in the submm



From Juvela 2011

Detection of cold clumps is possible

Detection method

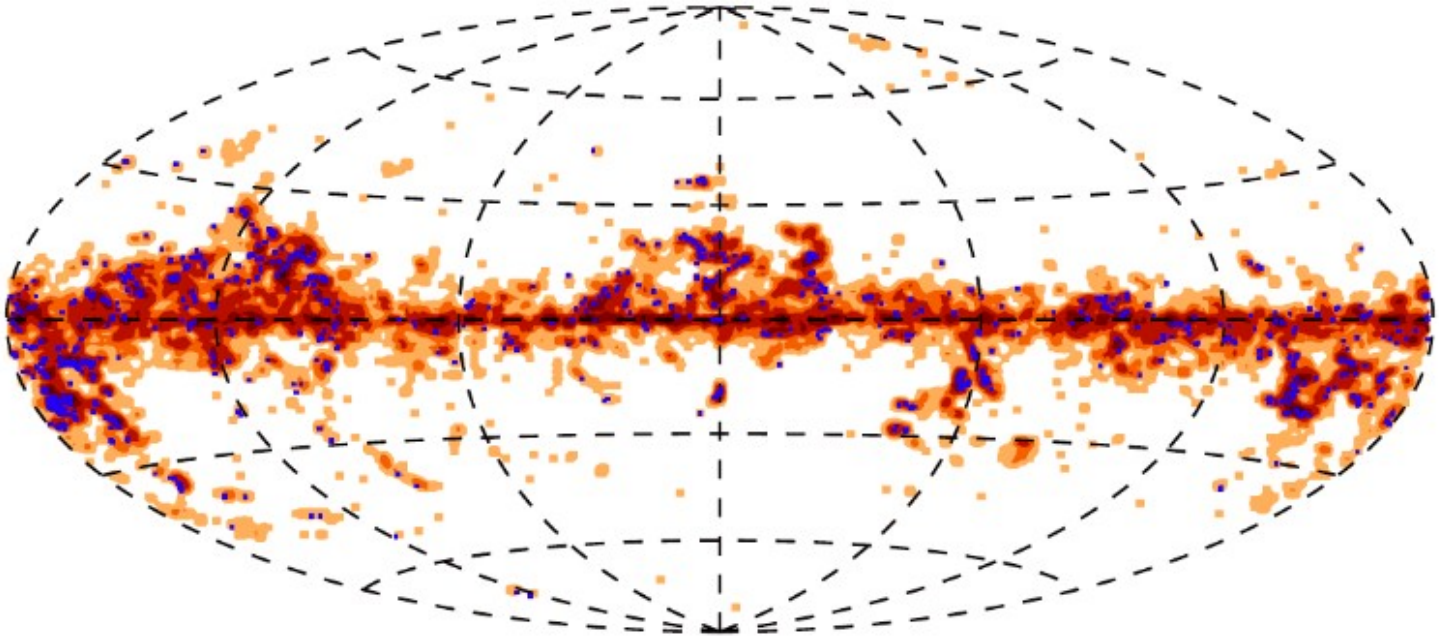


Planck Collaboration, 2011, A&A, 536, 23 + Planck Collaboration 2015

C3PO, ECC, PGCC catalogs

C3PO: Preliminary catalog
~10000 sources

Early Cold Core selection(**ECC**)
Most reliable sources ~ 900
S/N > 15
T < 14 K



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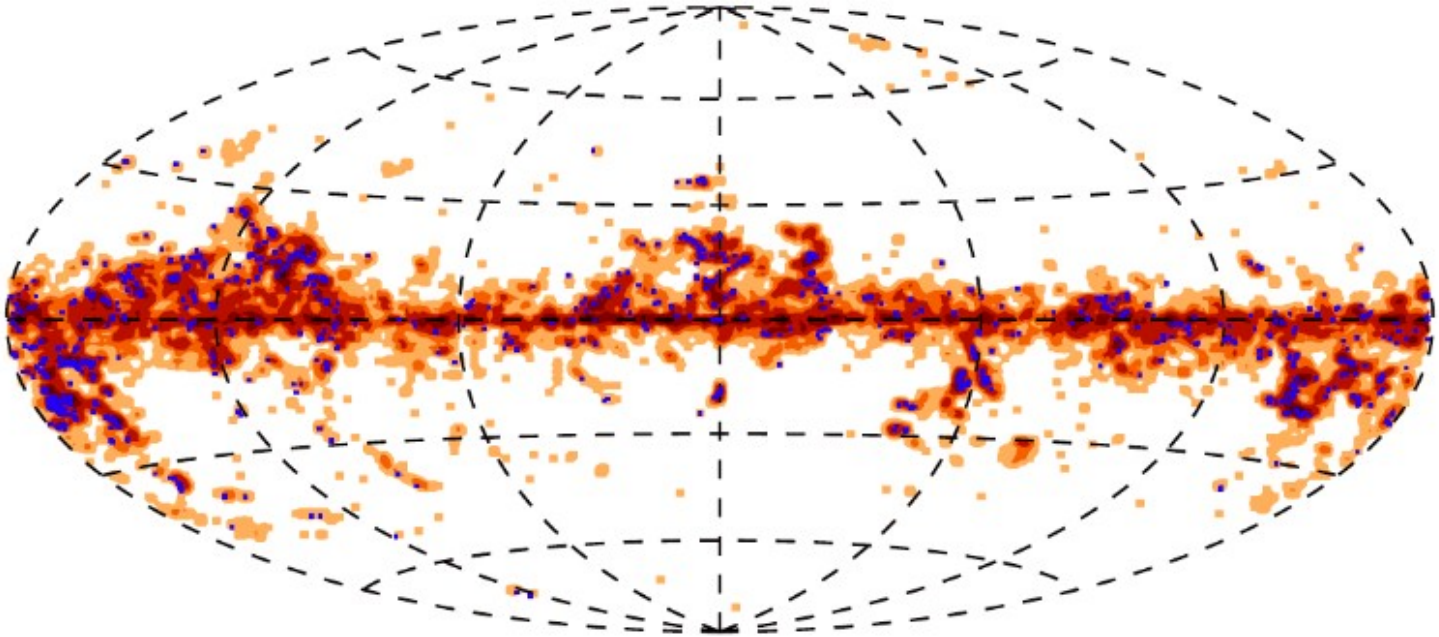
Distance for ~5000 sources



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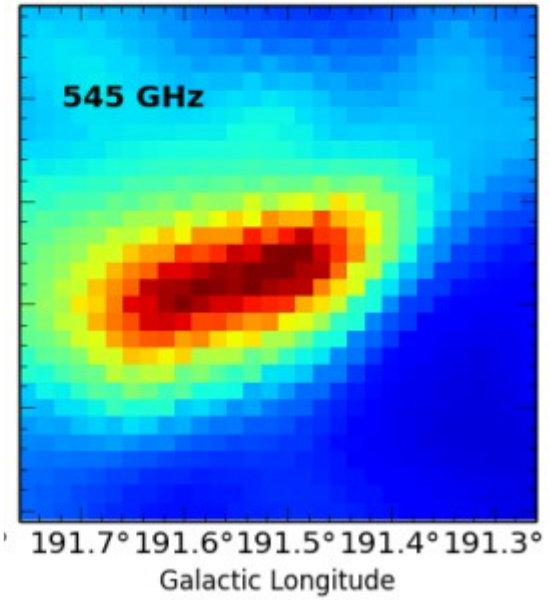
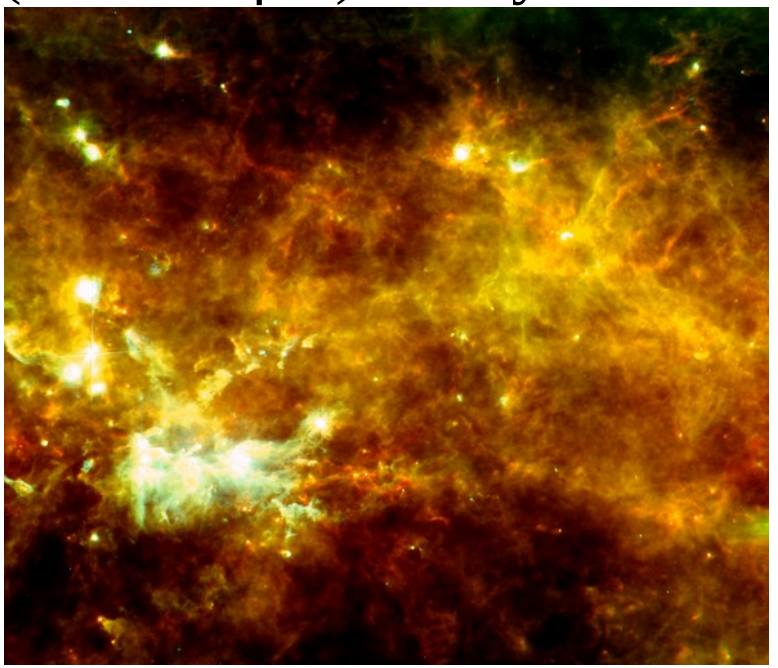
Planck view of an ECC



Hi-GAL survey

- Herschel Infrared Galactic Plane Survey, Open Time KP + extensions
  (Molinari et al. 2010, PASP, 122, 314)
- 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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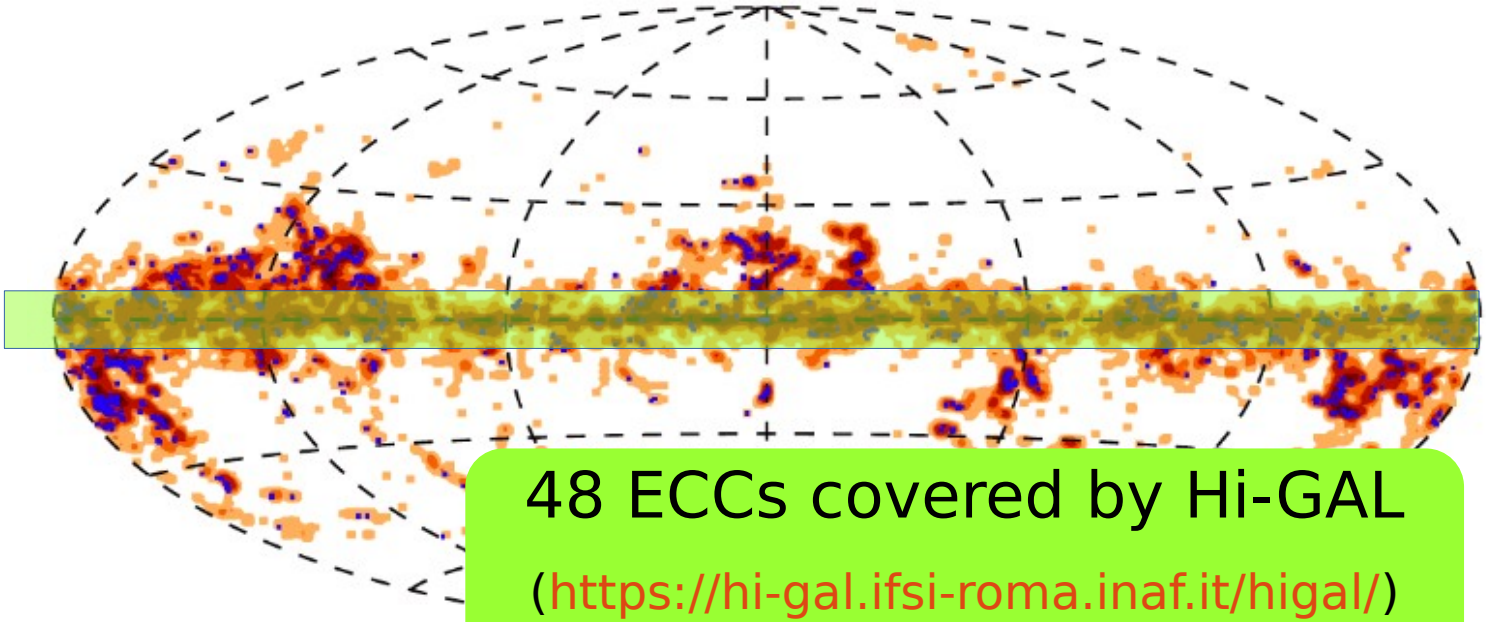

48 ECCs covered by Hi-GAL

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

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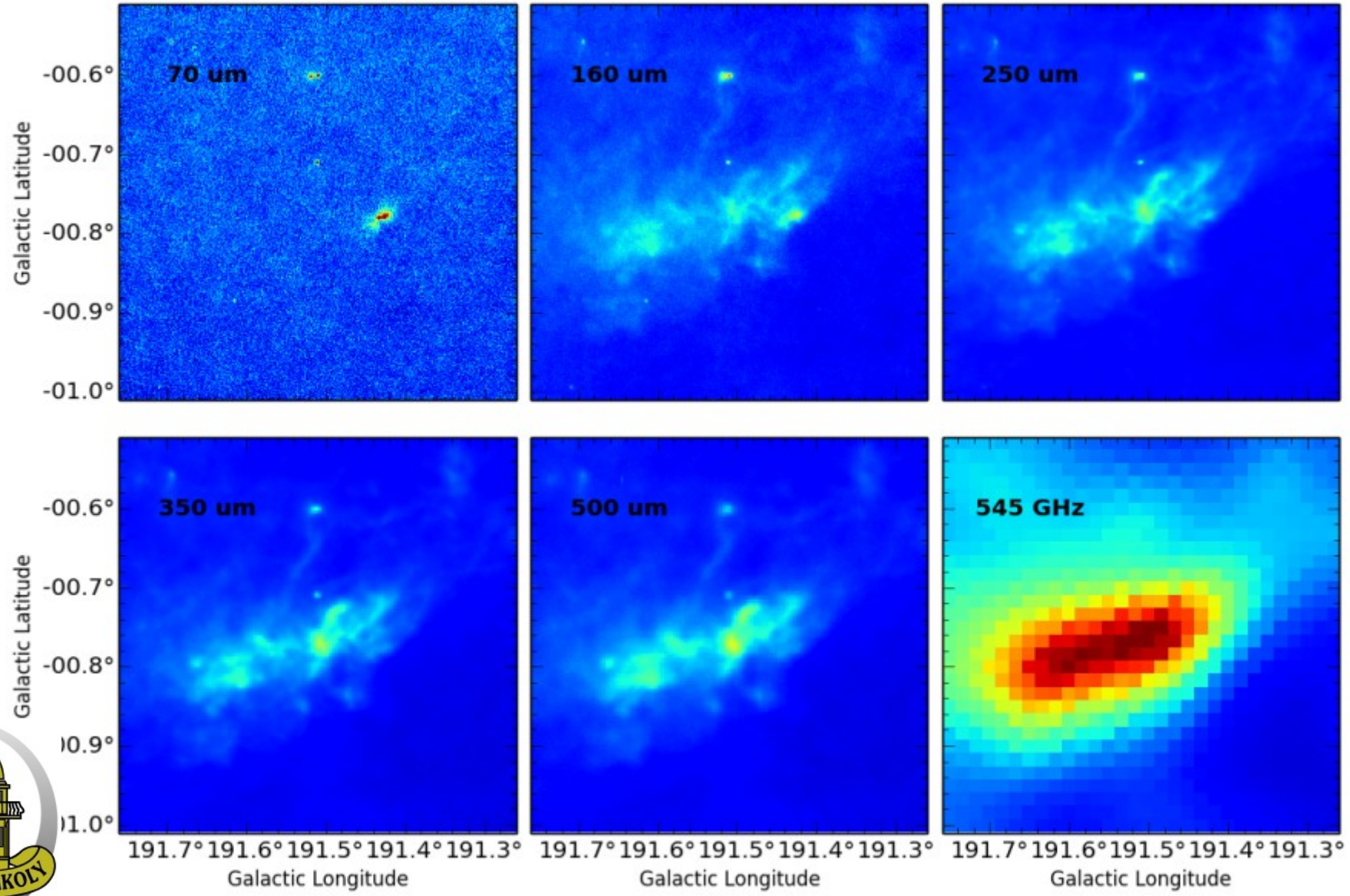
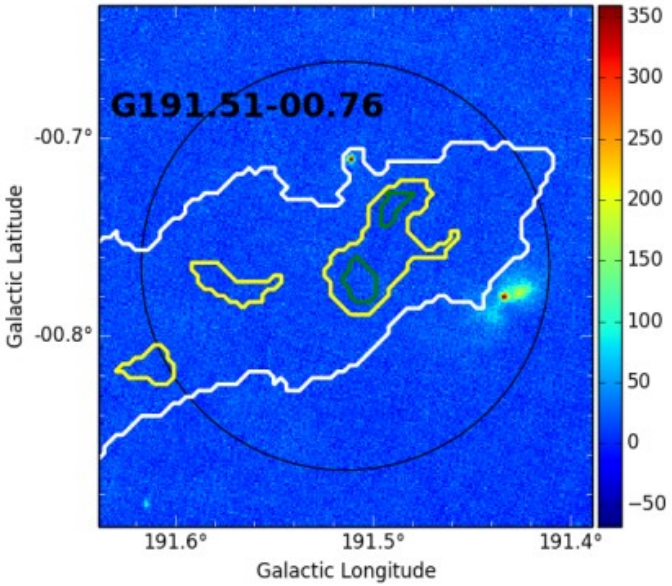
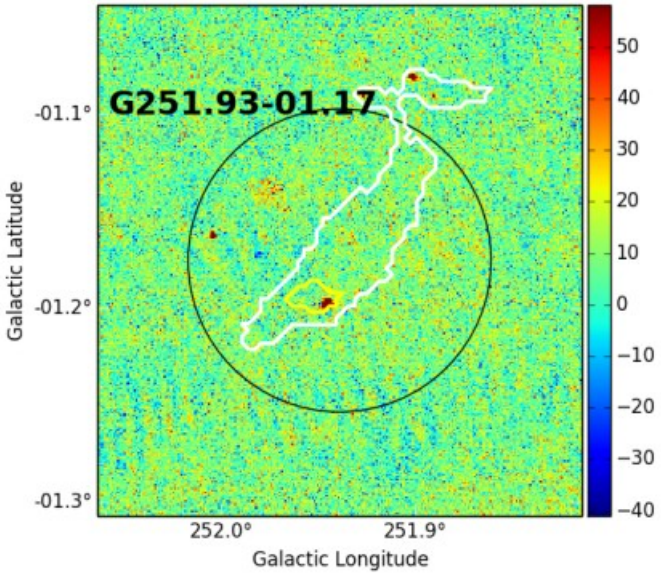
The role of Hi-GAL data

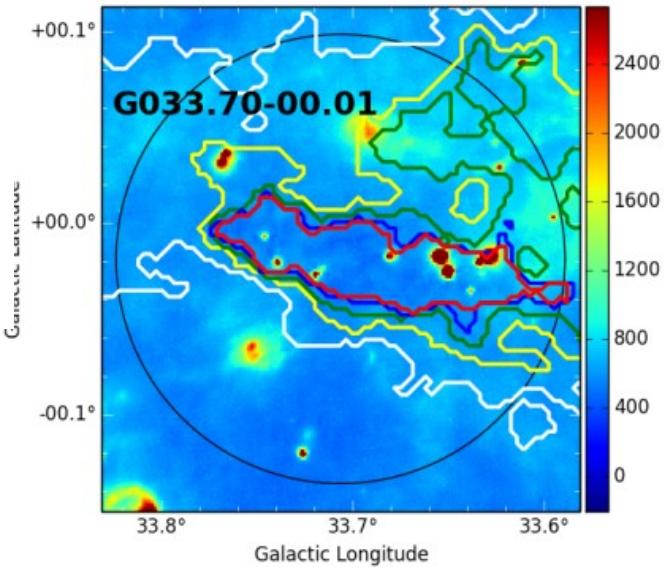


Star formation properties of ECC

- 24 / 70 μm images

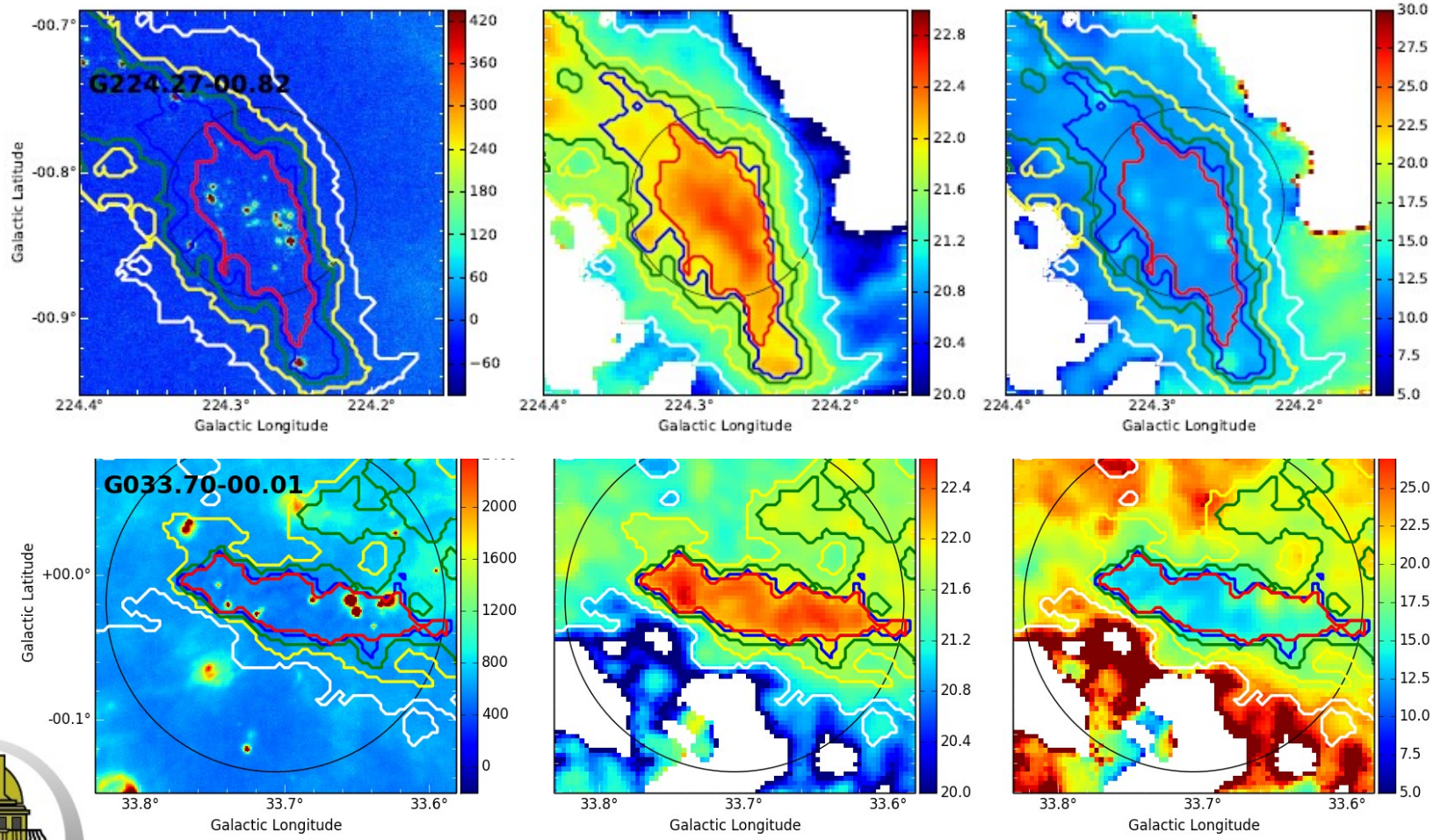






Physical properties of ECCs

- T, $N(H_2)$: 160 - 500 μm images



Cold Cores 2016, ELTE, Hungary

70 μm **$N(H_2)$** **T_{dust}**

Physical properties of ECCs

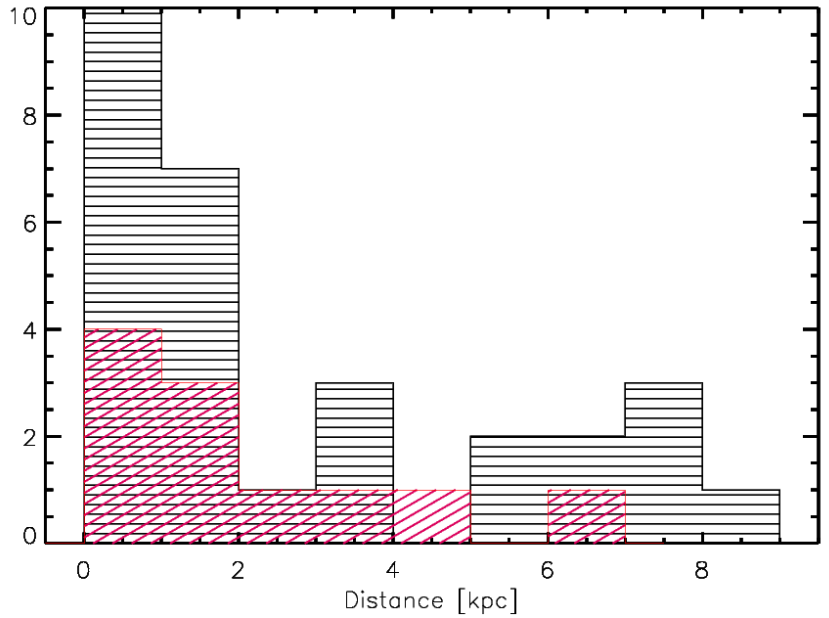
- size, mass determination -> distance estimation needed:
  - kinematic distance, based on:
    - Wu et al. 2012, CO survey
    - Jackson et al. 2013, MALT90 survey
    - APEX E-093.C-0866A-2014 observations
    - Dame et al. 2001 CfA CO survey
  - PGCC catalog

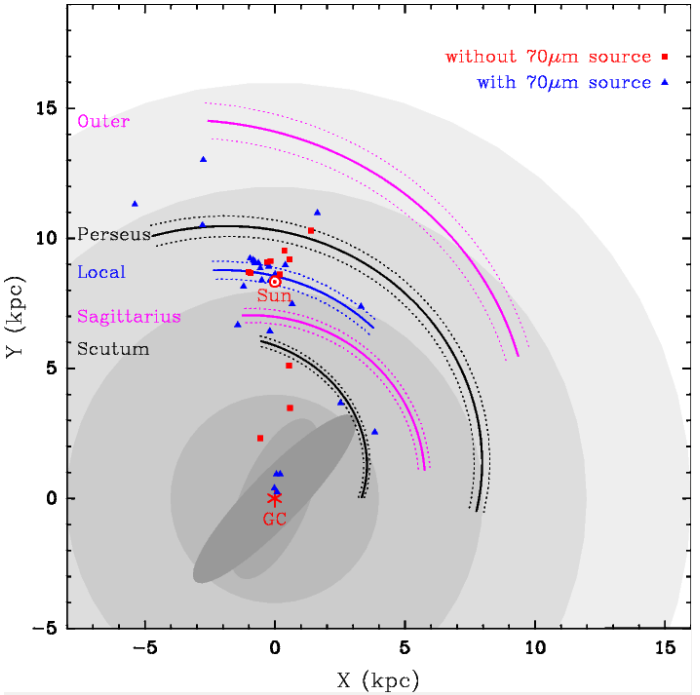
Distance estimation for 40 sources
- 0.1 – 8.1 kpc

Angular sizes:
- 0.5 – 29 pc

Physical properties of ECCs

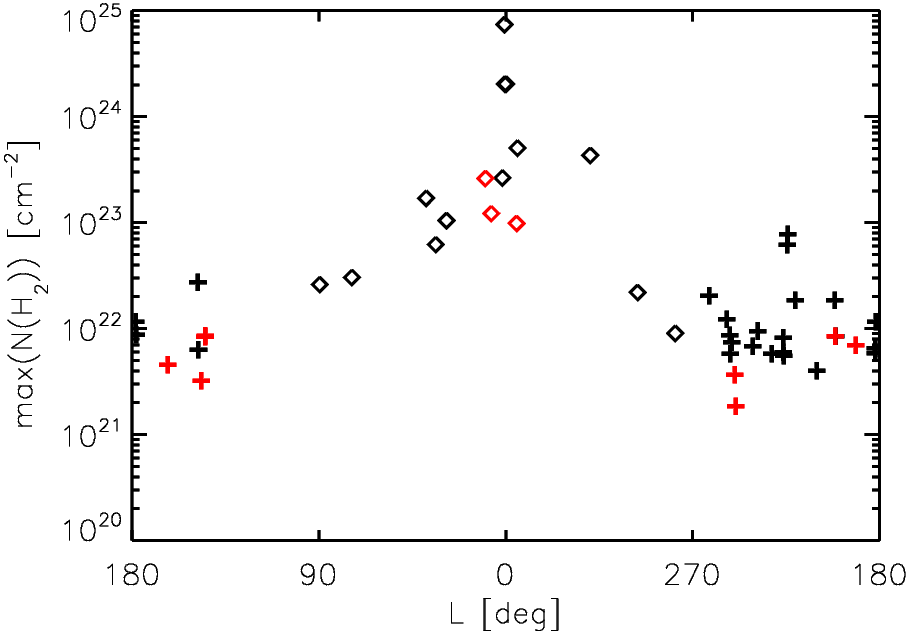
- Galactic distribution:
  - Location of spiral arms from Reid et al. 2014, ApJ, 783, 130

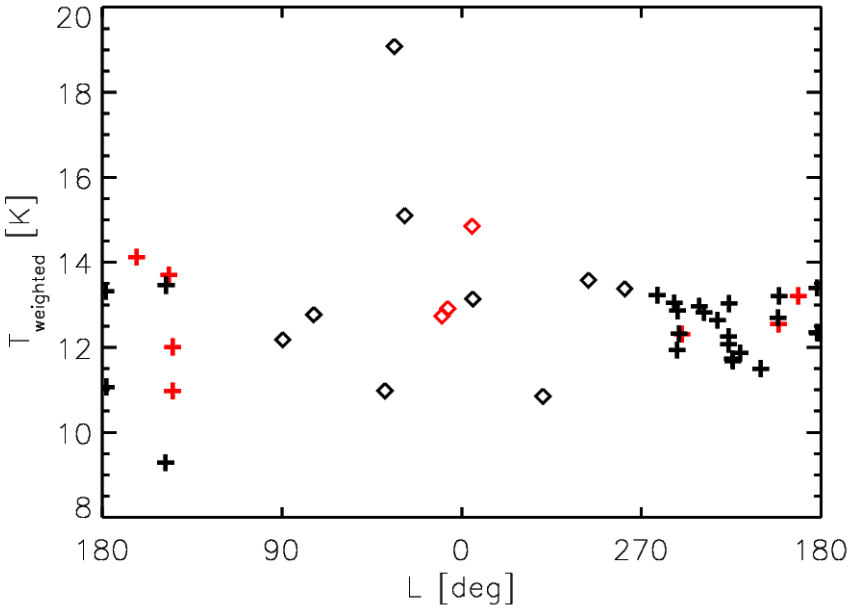




Physical properties of ECCs

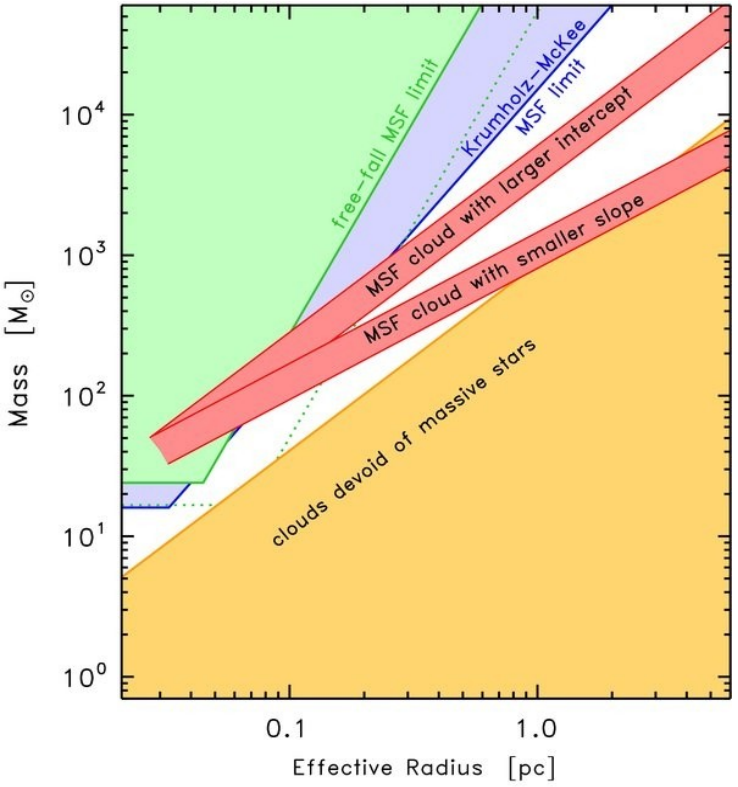
- Column density and dust temperature:



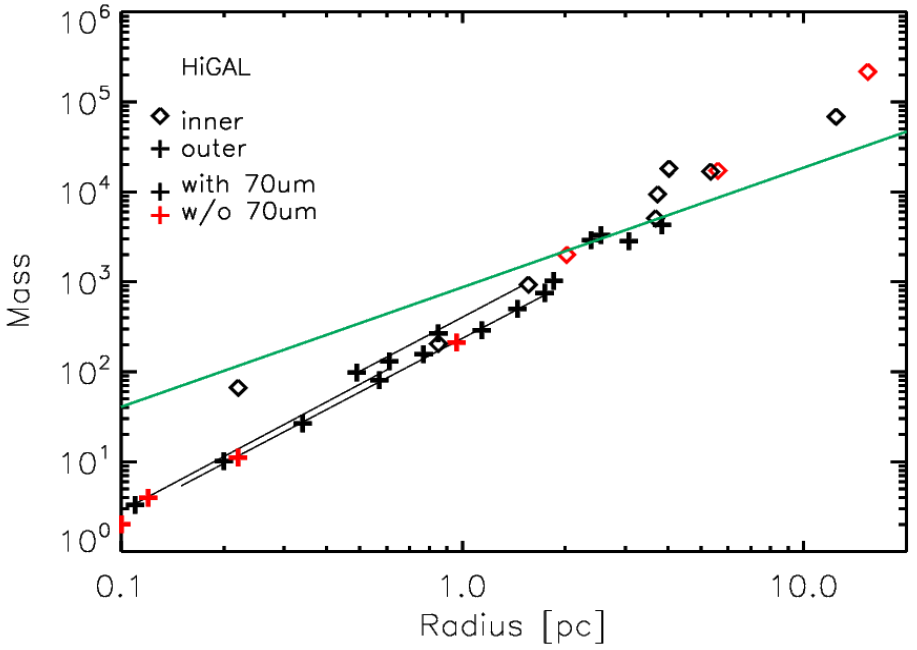


Possible candidates for HMSF?

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



Mass – size limit for HMSF



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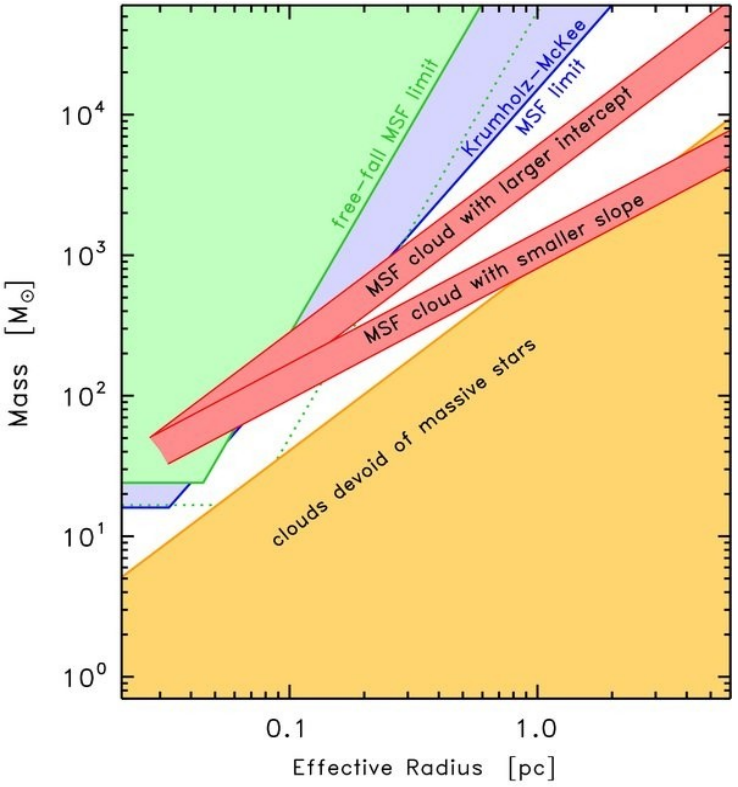

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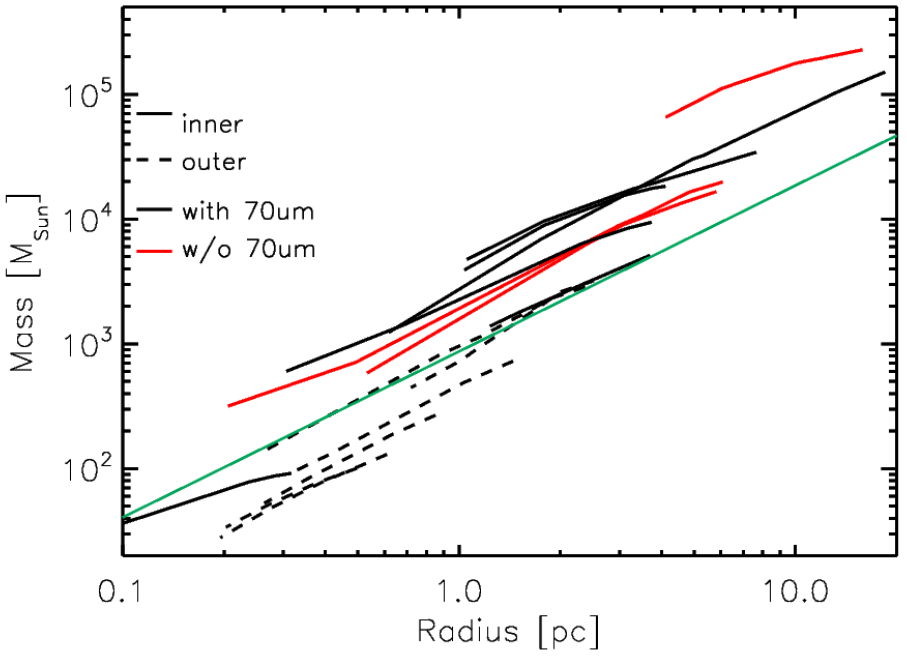
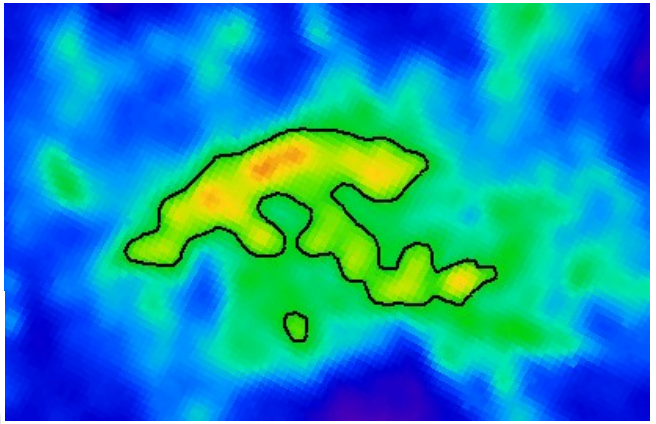


Importance of follow-up studies

Most massive, cold sources in their early phases

Molecular line follow-up: APEX, ALMA, eVLA



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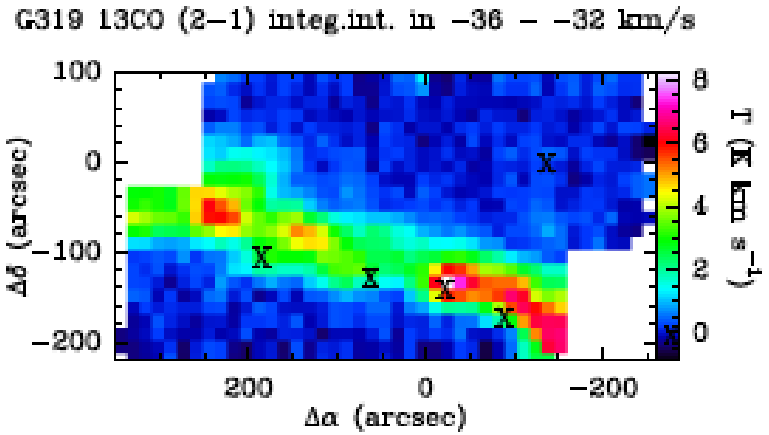

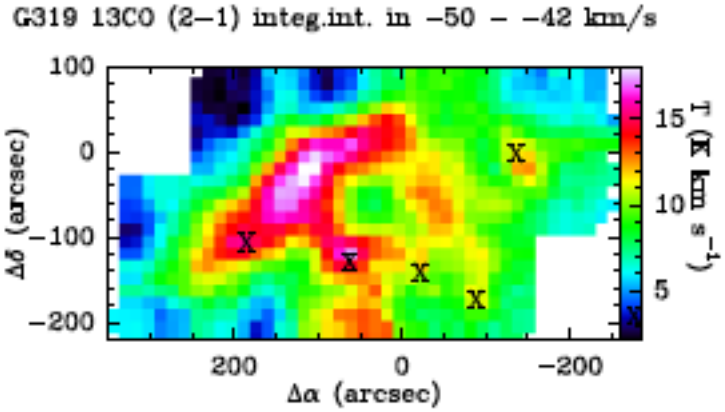

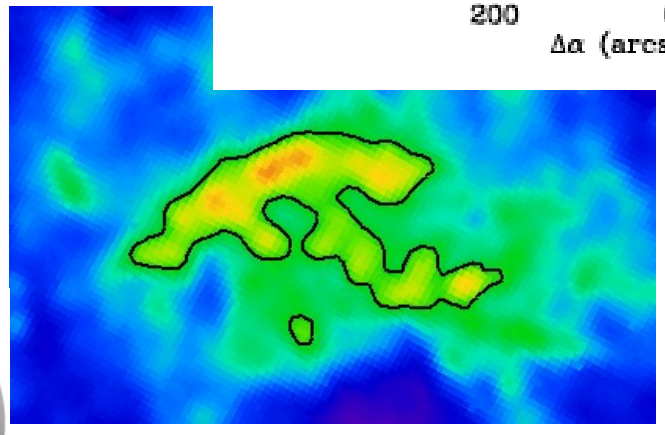

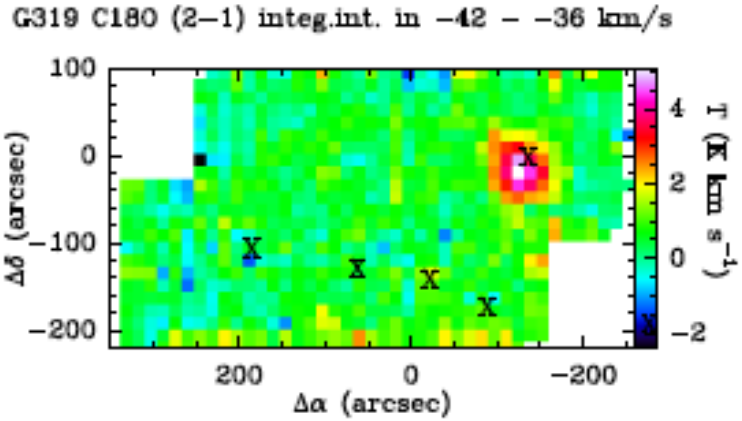

Summary

- 48 ECCs in the Galactic plane
- D ~ 0.1 kpc to 8.1 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

Zahorecz et al. 2016, accepted to A&A, arXiv1603.04102