A Planck and Herschel View of Galactic High-Mass Star Formation

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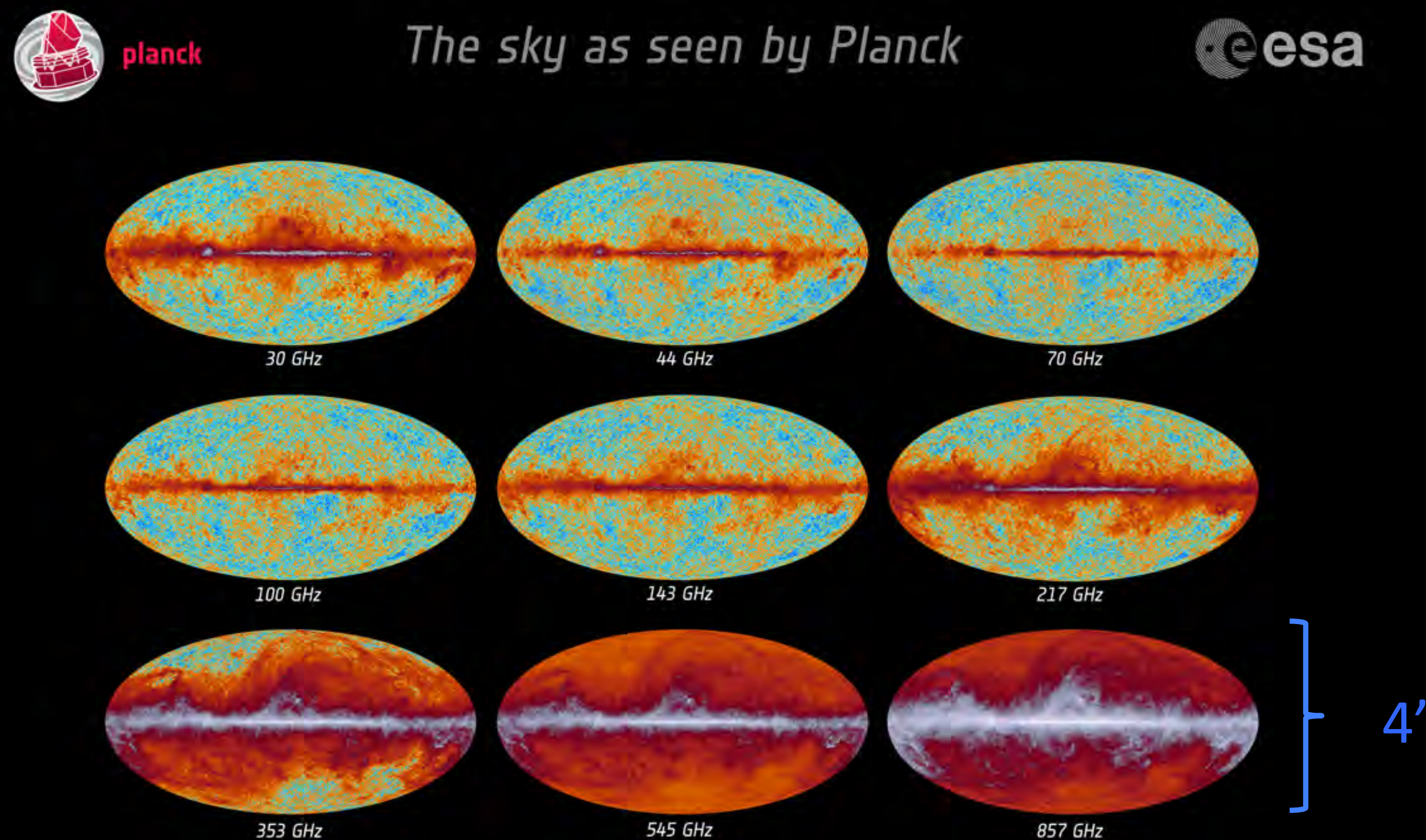
Outline of the Talk & Goals

- Why *Planck*
- Why Herschel
- The RMS sample of MYSOs/UCHIIs
- *Goals and results:*

1. characterize High-Mass Star Formation (HMSF) environment: Planck-only based
2. investigate variations in the inner/outer Galaxy: Planck-only based
3. explore the relation between the environment (i.e., 'clumps') and HMS: Planck + Herschel/Hi-GAL
   NOTE: → only 1st / 4th Galactic quadrants (Hi-GAL KP)

Why *Planck*

(http://www.cosmos.esa.int/web/planck)



Because of the low angular resolution, *Planck* probes the environment of HMSF rather than the proto-HMS

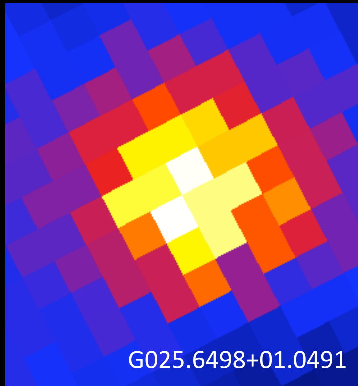
Why *Planck*

(http://www.cosmos.esa.int/web/planck)

→ *Planck* covers the entire Galactic Plane

→ Being a space mission, *Planck* is sensitive to emission on all angular scales (cfr. no filtering issues as for ground-based experiments: Bolocam, SCUBA, Apex, NIKA, etc…)

→ *Planck* 353 GHz channel (850 μm) allows accurate mass estimates

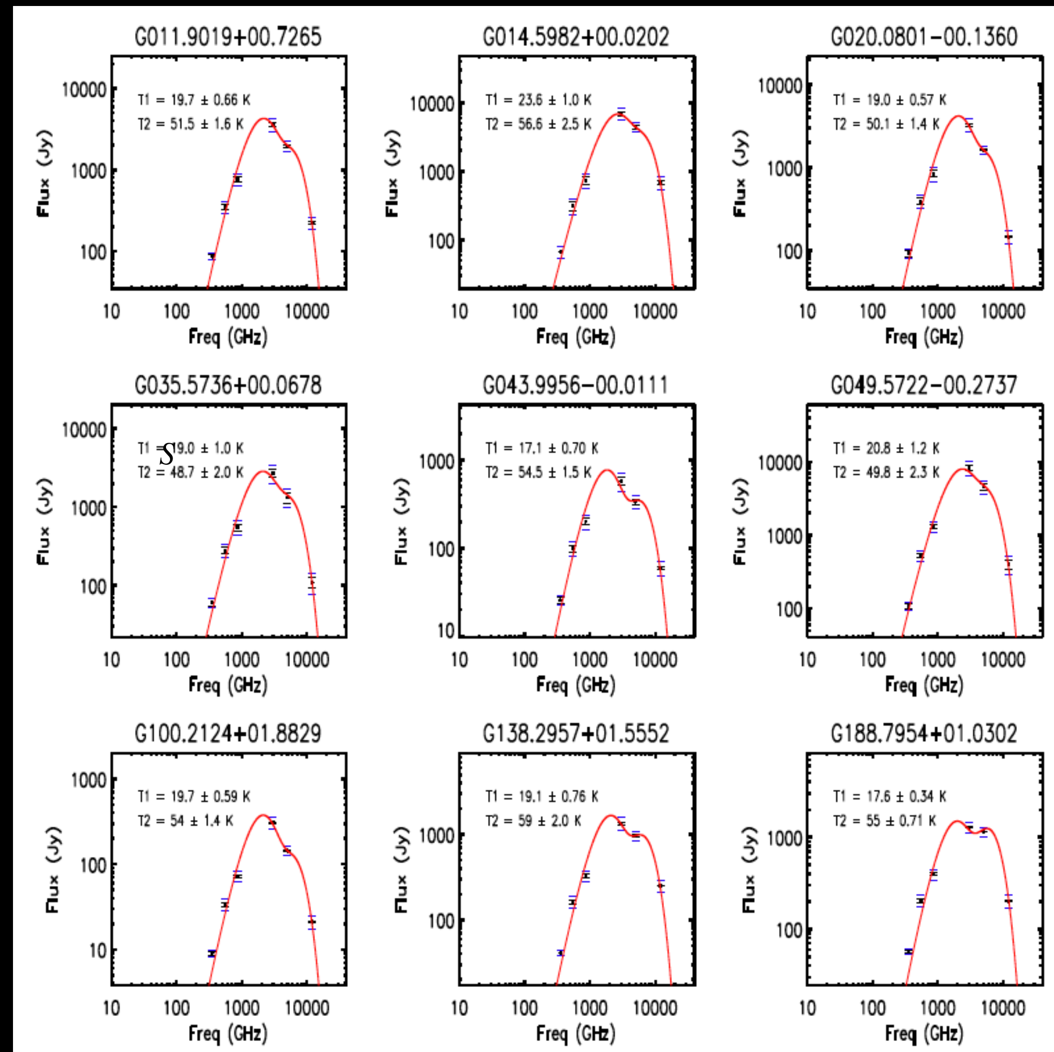


The *Planck* (+IRAS/IRIS) data

(http://www.cosmos.esa.int/web/planck)

- combine *Planck (350, 500, 850* μm) and IRAS/IRIS (Miville-Deschenes et & Lagasche 2005; 25, 60, 100 μm) data
- do aperture photometry (use code that works directly on the Healpix maps)
- do a two-component grey-body fit:

$$S_\lambda = A_1 \left(\frac{\lambda}{\lambda_0}\right)^{-2} B_\lambda(T_c) + A_2 \left(\frac{\lambda}{\lambda_0}\right)^{-2} B_\lambda(T_w)$$



Why Herschel/Hi-GAL

(PI: S. Molinari, https://hi-gal.ifsi-roma.inaf.it/higal/)

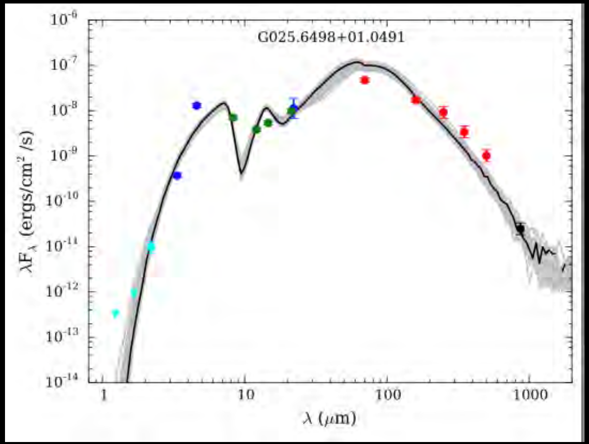
- survey of the entire Galactic Plane (-1 deg < b < + 1 deg <u>but</u> following the Galactic warp) in 5 spectral bands: 70 μm, 160 μm, 250 μm, 350 μm, 500 μm

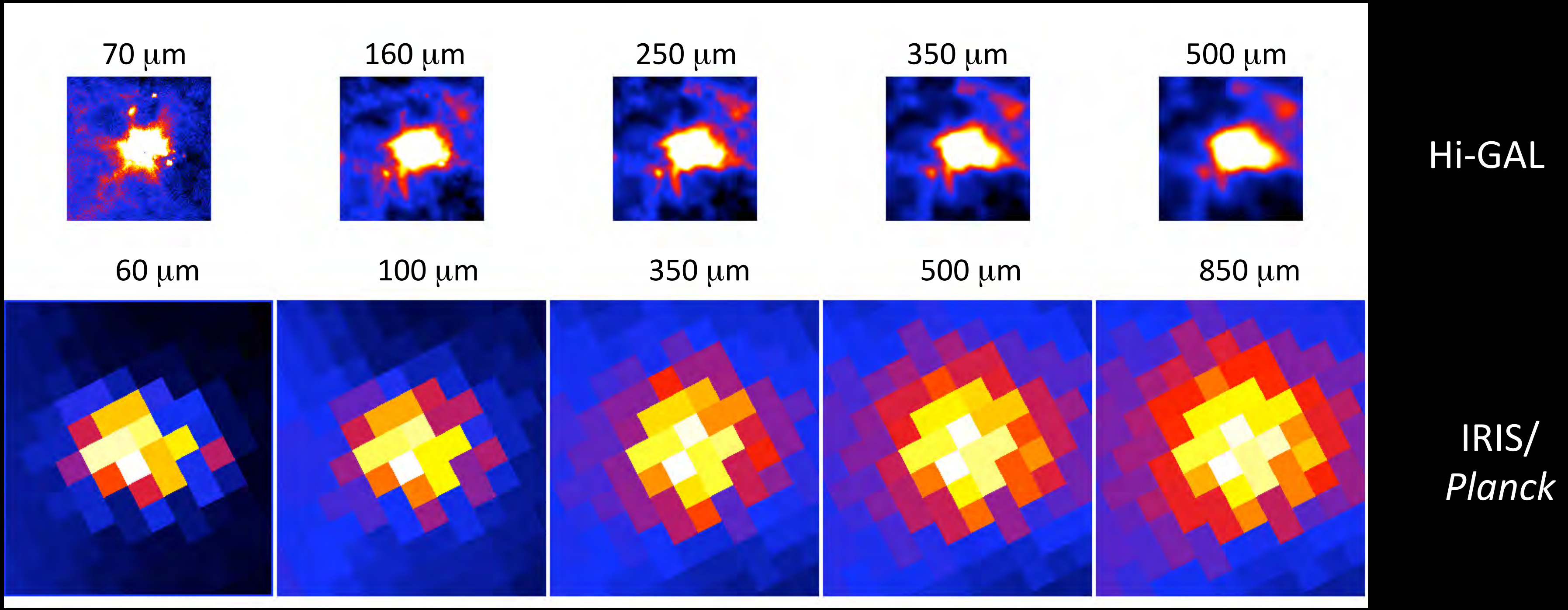
- angular resolution from: 6'' to 35''

- Herschel is a Galactic Star Formation 'machine': the Hi-GAL data provide a direct probe of HMS

The Herschel/Hi-GAL data

- Combine Herschel (70 to 500 μm) data with 2MASS (J, H, K), UKIDSS (Z, Y, J, H, K), MSX (8, 12, 21 μm), WISE (3.4, 4.6, 12, 22 μm) data
- do photometry with CUTEX (Curvature Thresholding Extractor, Molinari et al. 2011)
- fit SED with model fitter from Robitaille et al. (2007)

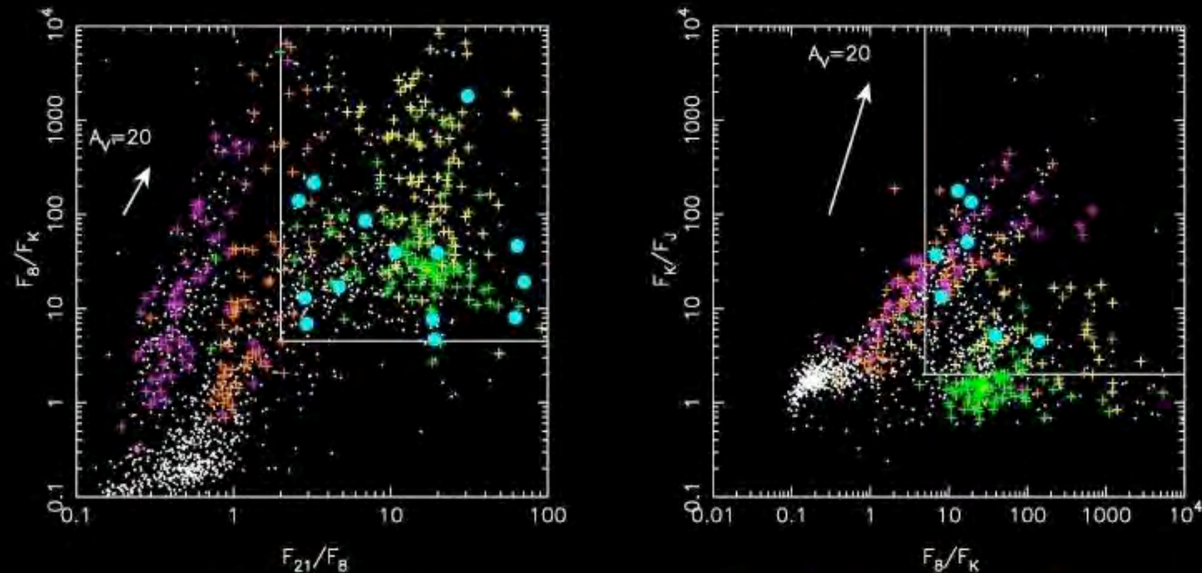




The RMS (The Red MSX Source) Survey

(Lumsden et al. 2013: http://www.ast.leeds.ac.uk/RMS/)

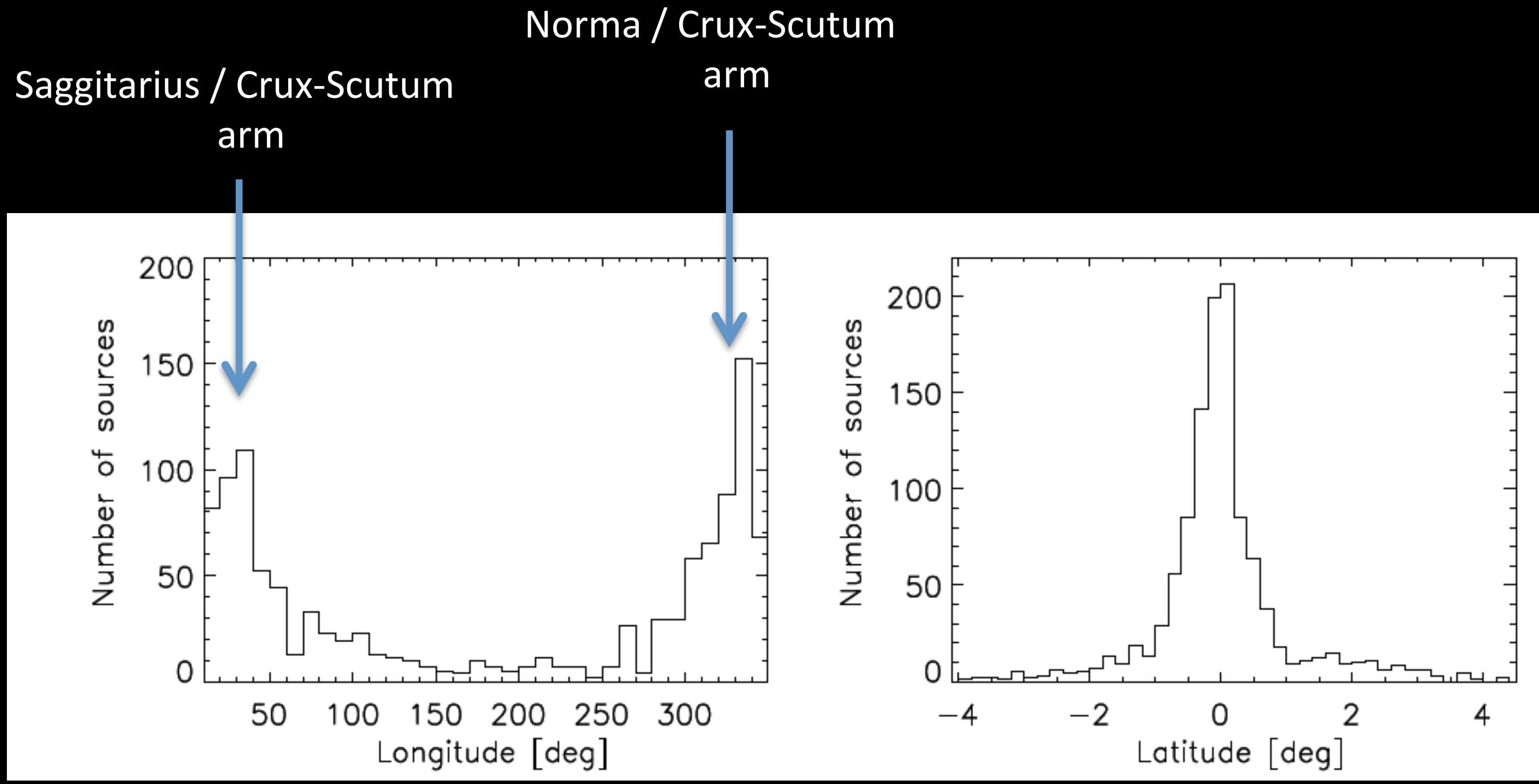
- MSX survey: 8, 12, 14, 21μm, 18” resolution, $|b| < 5^0$
- Color selection from MSX PSC and 2MASS
- Delivers ~2000 candidates
- Solar distances are available for ~1100 sources



• Massive YSOs + UC HII regions + PN + C stars + OH/IR stars

The RMS (The Red MSX Source) Survey

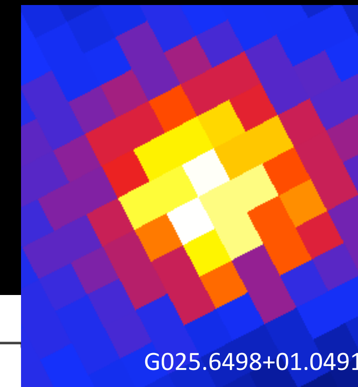
(Lumsden et al. 2013: http://www.ast.leeds.ac.uk/RMS/)



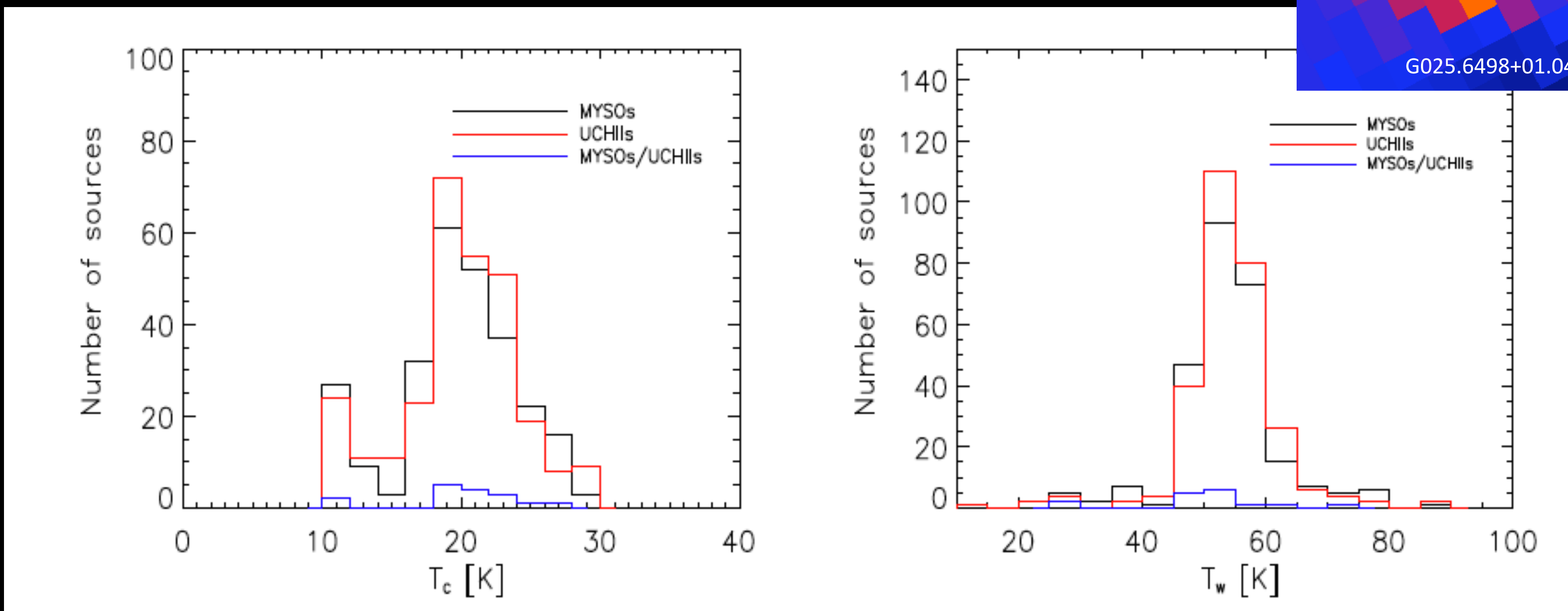
Mottram et al. (2011) estimate that the survey is 50% complete at L > 10^4 Lsol:

→ 561 sources: ~ ½ MYOs & ~ ½ UCHIIs

1. Properties of the HMS Environment:
Dust Temperatures



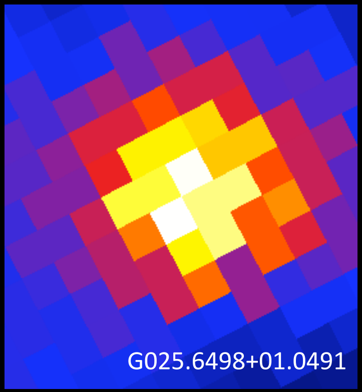
→ *Planck*-based analysis



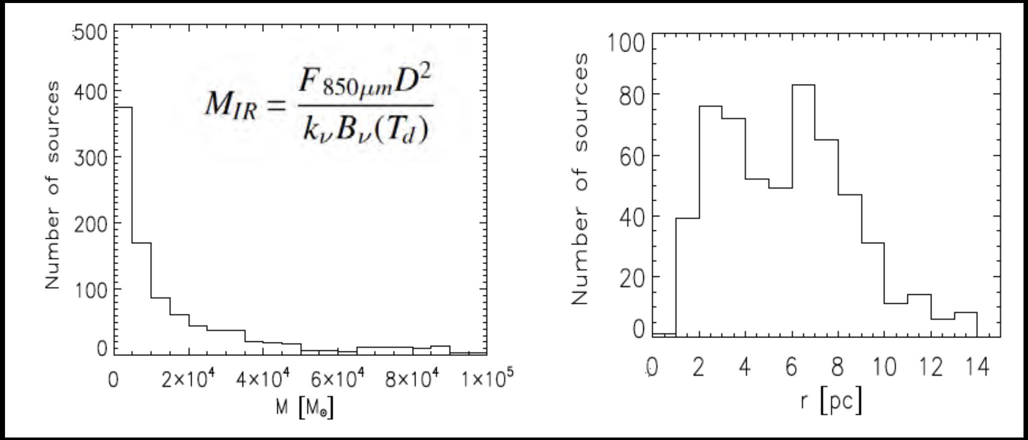
$< T_c > = 19.7 +/- 4.4$ K $\qquad < T_w > = 53.9 +/- 8.2$ K

→ Comparable to average temperatures of evolved HII regions (e.g. Povich et al. 2007, Paladini et al. 2012)

1. Properties of the HMS Environment:
Mass, Linear size & Surface density



→ *Planck*-based analysis



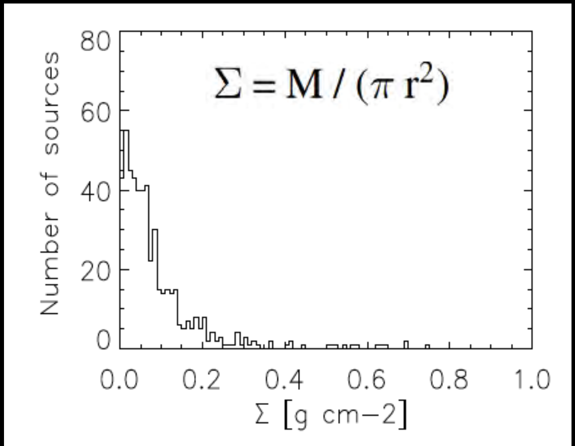
- $< M_{IR} > \sim 30000\ M_{sol}$
- $< r > = 5.3$ pc

$< \Sigma > = 0.1$ +/− 0.26 g cm-2

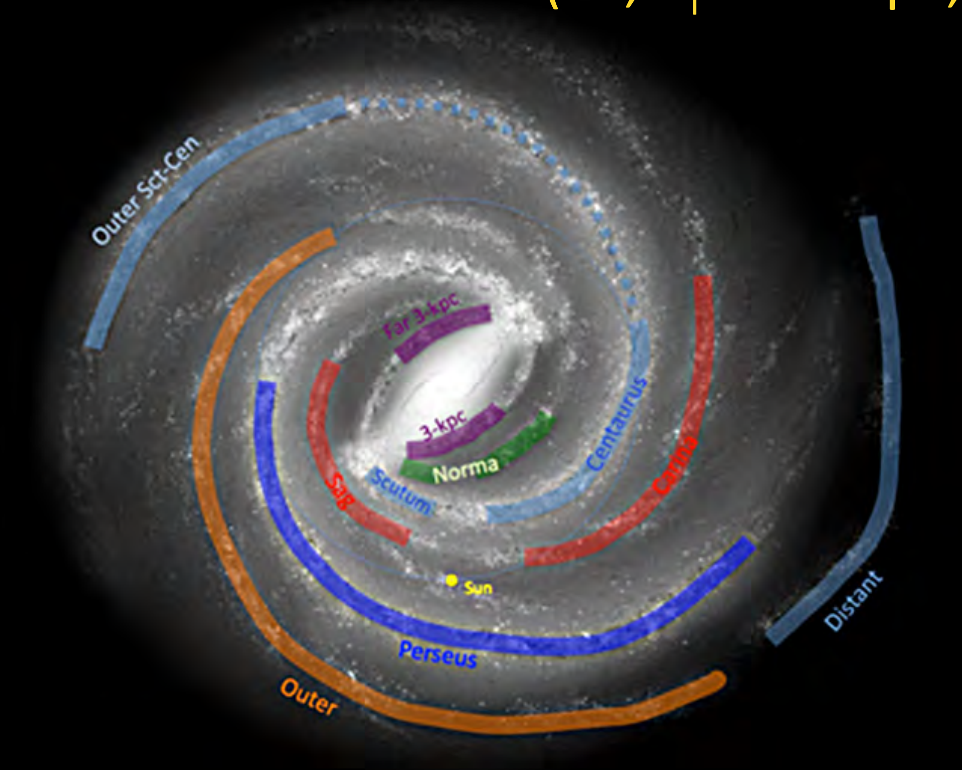
$< \Sigma > >> \Sigma$(GMC) ~ 0.035 g cm-2 (Solomon et al. 1987)
→ gravitationally bound structures

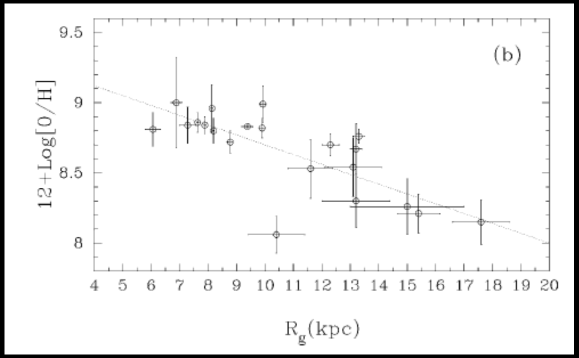
but

$< \Sigma > << \Sigma_{crit} = 1$ g cm-2 (e.g McKee & Tan 2003)
→ not the dense 'clumps' of Plume et al. (1997): contribution in the beam from less dense material

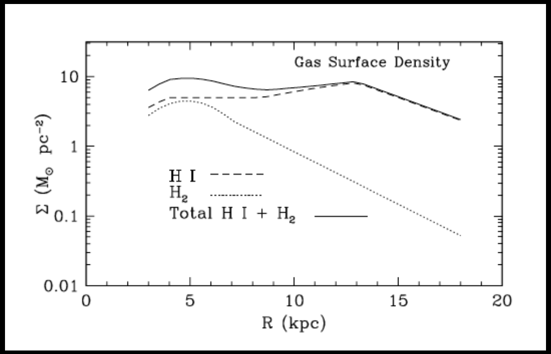


2. Variations in Inner/Outer Galaxy
(i.e, $R_i < 8.5$ kpc; $R_o > 8.5$ kpc)





Smartt + Rolleston 1997

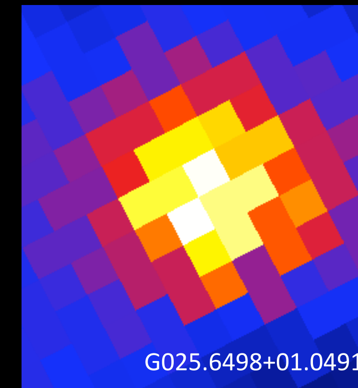


Wolfire et al. 2003

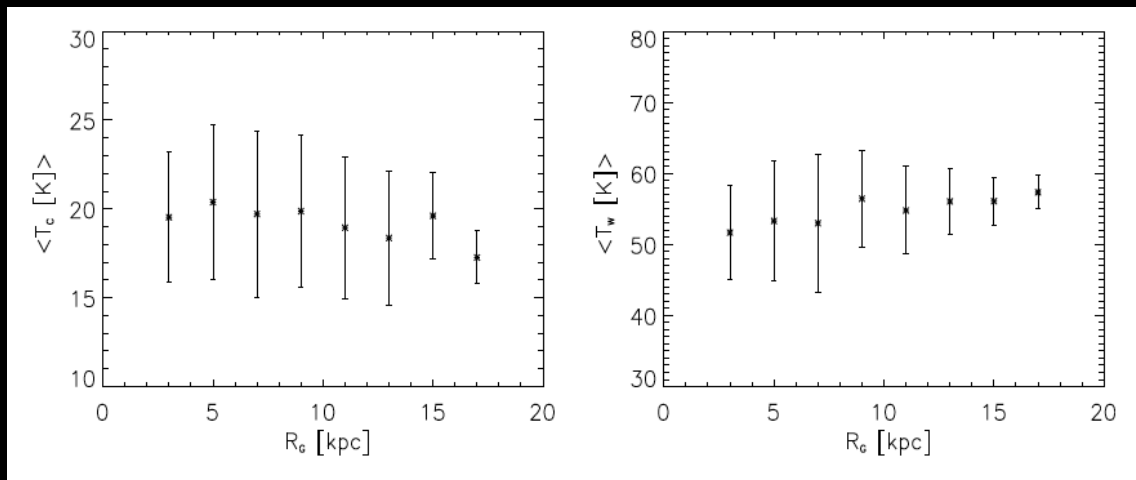
→Despite an "unfavorable" environment, patchy SF is observed in the outer Galaxy

→ Elmegreen & Hunter (2006) suggest that in the outer Galaxy turbulence allows the formation of clouds and compensates for the lack of gravitational instabilities

2. Variations in Inner/Outer Galaxy:
Dust Temperatures



→ *Planck*-based analysis



→ no significant trend with Galactocentric radius: both warm and cold dust temperature components look quite constant

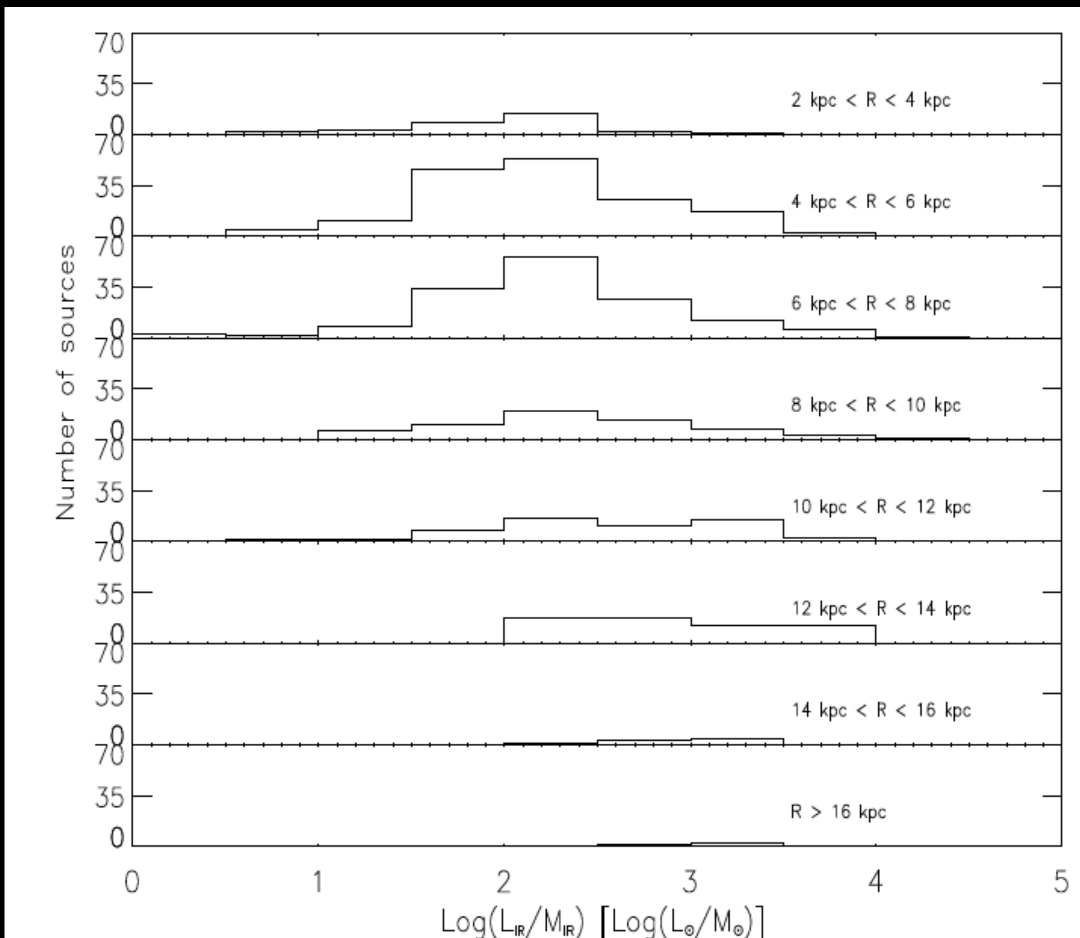
→ slight trend of colder temperatures towards outer Galaxy for cold dust component, consistent with overall Galactic trend highlighted in Planck Collaboration (2011)

→ but: warm component goes in opposite direction i.e., warmer towards outer Galaxy.
Likely cold component is a local measure of interstellar radiation field ($T_d \sim X_{ISRF}^{1/(1+\beta)}$), while warm component traces inner stellar radiation field (more luminous sources in outer Galaxy ?)

2. Variations in Inner/Outer Galaxy: L/M

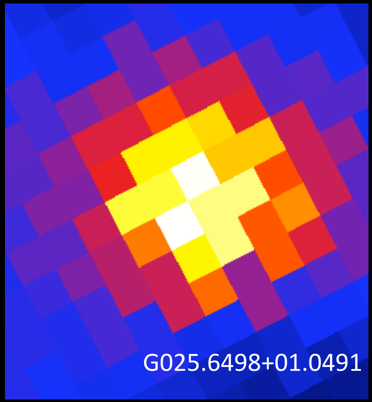
→ *Planck*-based analysis

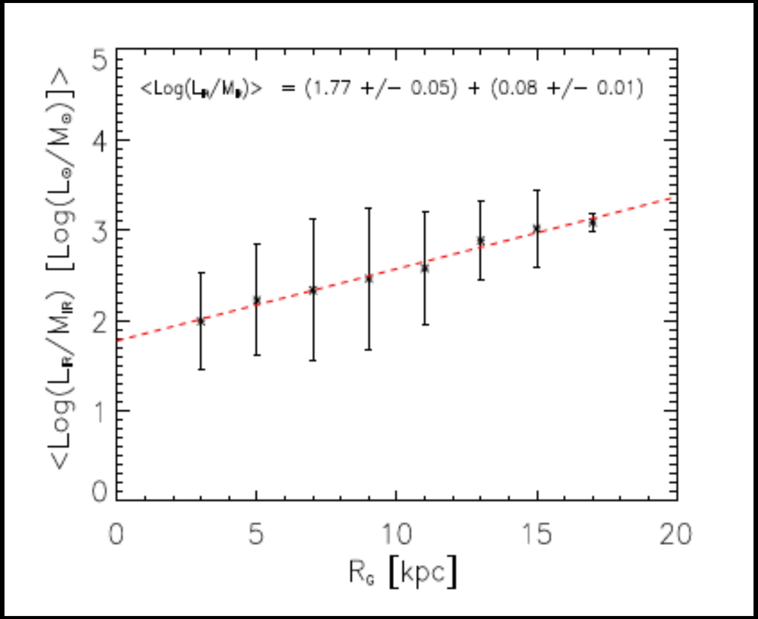
$$L_{IR} = 4\pi D^2 \int_{\lambda_{min}}^{\lambda_{max}} S_\lambda \lambda d\lambda$$



- L and M have same (D^2) dependence on distance, so L/M is distance independent quantity
- L/M ratio provides measure of global star formation activity
- Significant L/M in each Galactocentric bin: star formation does not scale linearly with R_G

2. Variations in Inner/Outer Galaxy: L/M

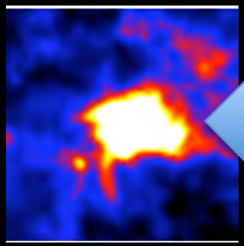
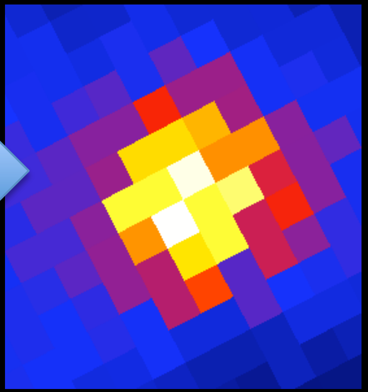




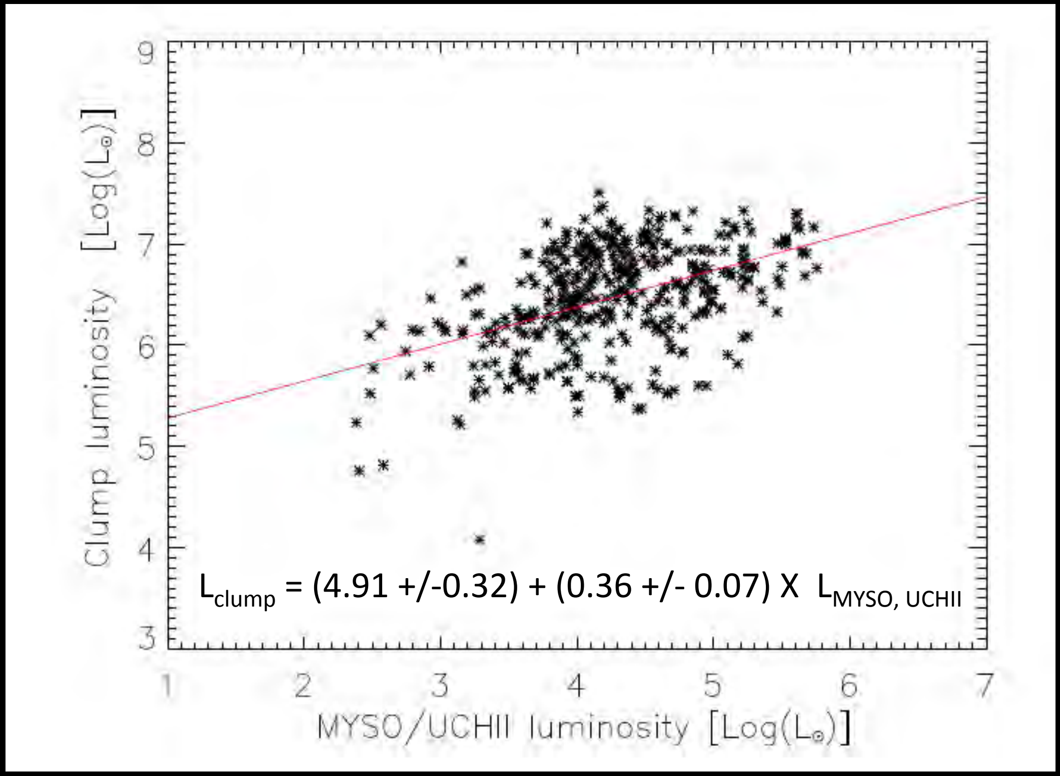
→ The mean luminosity-to-mass ratio increases towards the outer Galaxy : difference between the most inner Galactocentric bin (2 kpc < R_G < 4 kpc) and the most outer one (R_G > 16 kpc) is ~ 60%

→ cfr: average L_{IR}/M_{LTE} for outer Galaxy molecular clouds is higher than for inner clouds (Carpenter, Snell & Schloerb 1990): higher probability of cloud-to-cloud collision does not imply an increased SFR, as proposed by Scoville, Sanders & Clemens (1986)

3. Clump luminosity vs. MYSOs luminosity:
~ 400 sources

→ *Planck*/Herschel-based analysis



- the *Planck* clump and MYSO/UCHII luminosities are correlated: higher clump luminosities correspond to higher MYSO/UCHII luminosities
- the correlation is affected by a large scatter (multiplicity effect ? Others ?)

Summary

- *Planck* clumps have: < $T_{d,w}$ > ~ 20 K, < $T_{d,c}$ > ~ 54 K; < M > ~ 30000 $M_{sol;}$ < r > ~ 5 pc; < Σ > ~ 0.1 g cm-2
- The L/M ratio for the *Planck* clumps does not decrease with Galactocentric radius, so perhaps SF is rare in outer Galaxy but quite efficient
- *Planck* clump luminosity seems to correlate with MYSO/UCHII luminosity

Current Work

- Extending 3) by including RMS sources in the outer Galaxy (Hi-GAL data and source photometry became available in the meanwhile)