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

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Soul of Massive Star Formation - Puerto Varas 2015
Outline of the Talk & Goals

- Why Planck
- Why Herschel
- The RMS sample of MYSOs/UCHIIIs

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 \( \mu m \)) and IRAS/IRIS (Miville-Deschenes et al. & Lagasche 2005; 25, 60, 100 \( \mu m \)) 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 but 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, 21\(\mu\)m, 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: $\sim \frac{1}{2}$ MYOs & $\sim \frac{1}{2}$ UCHIIIs

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1. Properties of the HMS Environment: Dust Temperatures

→ *Planck*-based analysis

\( <T_c> = 19.7 \pm 4.4 \text{ K} \)

\( <T_w> = 53.9 \pm 8.2 \text{ K} \)

→ 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

- $M_{IR} \sim 30000 \, M_{\odot}$
- $r > 5.3 \, \text{pc}$

$\langle \Sigma \rangle = 0.1 \pm 0.26 \, \text{g cm}^{-2}$

$\langle \Sigma \rangle \gg \Sigma(\text{GMC}) \sim 0.035 \, \text{g cm}^{-2}$ (Solomon et al. 1987)

→ gravitationally bound structures

but

$\langle \Sigma \rangle \ll \Sigma_{\text{crit}} = 1 \, \text{g cm}^{-2}$ (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)

→ 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 (\( T_d \sim X_{\text{ISRF}}^{1/(1+\beta)} \)), 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 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?)

\[
L_{\text{clump}} = (4.91 \pm 0.32) + (0.36 \pm 0.07) \times L_{\text{MYSO, UCHII}}
\]
Summary

- **Planck** clumps have: $< T_{d,w} > \sim 20$ K, $< T_{d,c} > \sim 54$ K; $< M > \sim 30000$ $M_{\odot}$; $< r > \sim 5$ pc; $< \Sigma > \sim 0.1$ 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)