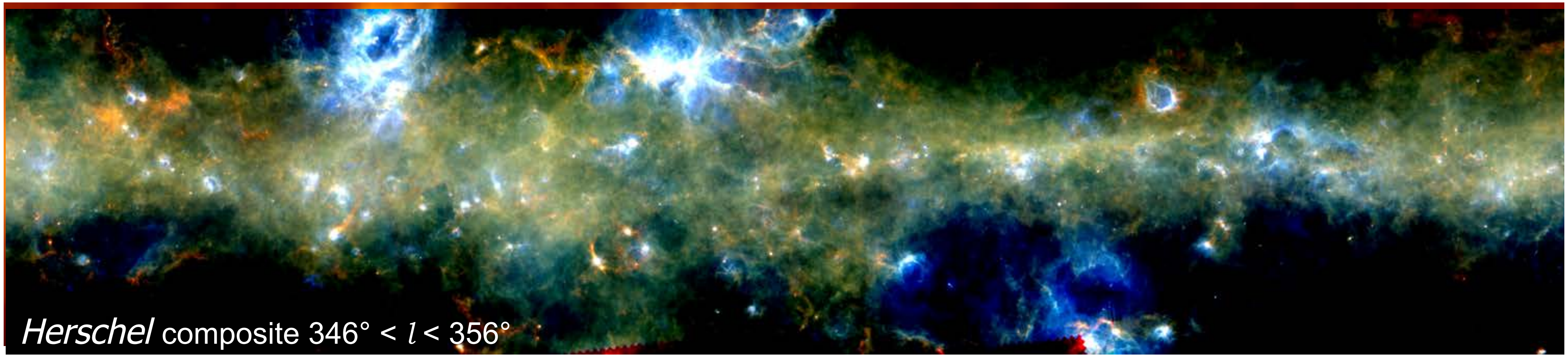


Hi-GAL

mining the Galactic Plane Goldmine

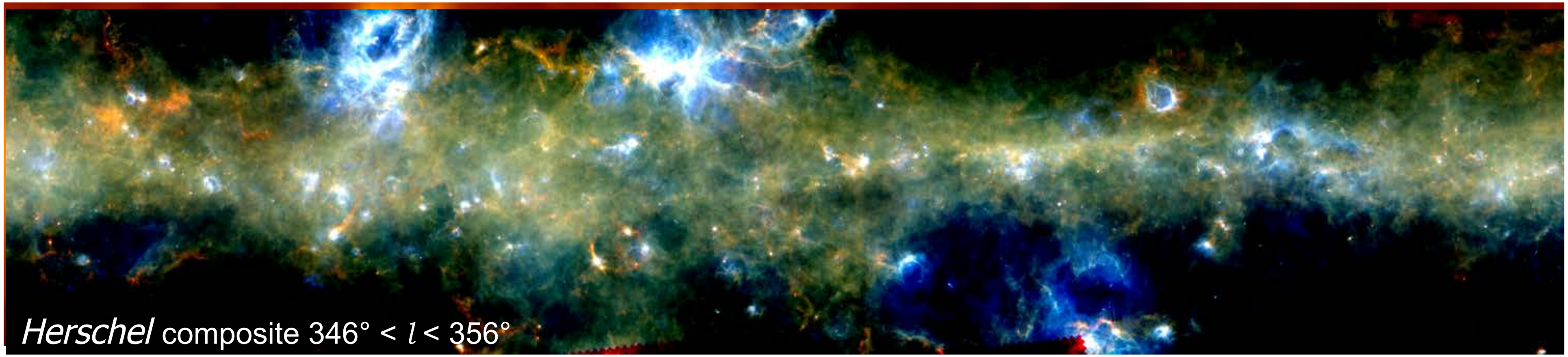
S. Molinari

INAF/IAPS, Rome

&

Hi-GAL Team

Italy: INAF-IAPS, Univ. Ferrara, Univ. Roma "La Sapienza", INAF-Oss. Arcetri, INAF-Oss. Catania, Univ. Salento. ***USA***: Caltech-SSC-IPAC, Univ. Colorado, University of Florida, JPL. ***UK***: STFC-RAL, Univ. Cardiff, Liverpool John Moores Univ., UCL, Univ. Hertsfordshire, Univ. Leeds, Univ. Manchester, Univ. Exeter. ***France***: CNRS-IRAP, LAM, IAS, CEA/Sap. ***Canada***: Univ. Toronto, Univ. Calgary, Univ. Laval. ***Germany***: MPIfR, MPIA. ***Japan***: Nagoya University. ***China***: NAO-CAS. ***ESO***-HQ. ***ESA***-ESTEC/ESAC



Simultaneous 5-bands
(*70-160-250-350-500μm*) continuum
mapping of 720 sq. deg. of the Galactic
Plane (|*b*|≤1°)

The entire Plane has been observed, also thanks to DDT allocated to cover 4 tiles that were left out by the HOTAC

Access to images (with registered astrometry and absolute flux calibration) and compact source photometry catalogues for longitudes between 65° and 290° will be publicly released through dedicated services once a set of data presentation and fast science papers are in acceptance stage (likely early 2014)

Hi-GAL Team & ESA

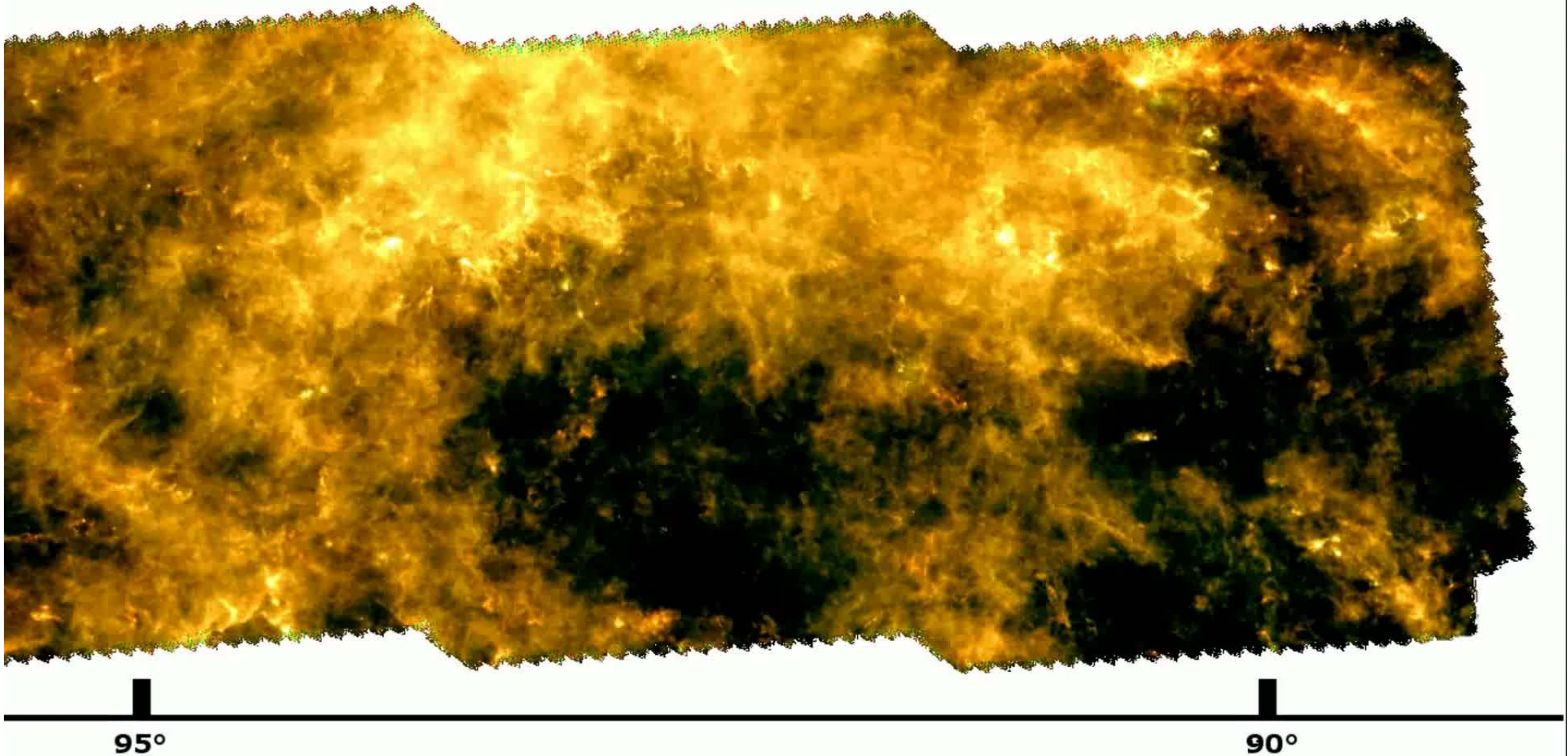
Hi-Gal

Molinari et al. 2010

Herschel infrared Galactic Plane Survey

The Second Quadrant

Herschel 160-250-350μm composite



Toward a Predictive Global Model of Galactic Star Formation

The *Hi-GAL* Team Institutes [PI: S. Molinari, INAF-IAPS Rome]

Italy: INAF-IAPS, Univ. Roma "Tor Vergata", Univ. Roma "La Sapienza", INAF-Oss. Arcetri, INAF-Oss. Catania, Univ. Salento. ***USA***: Caltech-SSC-IPAC, Univ. Colorado, JPL. ***UK***: STFC-RAL, Univ. Cardiff, Liverpool John Moores Univ., UCL, Univ. Hertsfordshire, Univ. Leeds, Univ. Manchester, Univ. Exeter. ***France***: CNRS-IRAP, LAM, IAS, CEA-Sap. ***Canada***: Univ. Toronto, Univ. Calgary, Univ. Laval. ***Germany***: MPIfR. ***Japan***: Nagoya University. ***China***: NAO-CAS. ***ESO-HQ***. ***ESA-ESTEC/ESAC***

Hi-GAL data processing is carried out at INAF-IAPS (Rome) thanks to support from Agenzia Spaziale Italiana under Contract I/038/08/0

Papers from Hi-GAL Team

…..to date and to my knowledge

1. Molinari, S., Swinyard, B., Bally, J., et al. 2010, PASP 122, 314
2. Bernard, J.-P., Paradis, D., Marshall, D.J., et al. 2010, A&A 518, L88
3. Bally, J., Anderson, L.D., Battersby, C., et al. 2010, A&A 518, L90
4. Elia, D., Schisano, E., Molinari, S. et al. 2010, A&A 518, L97
5. Peretto, N., Fuller, G.A., Plume, R., et al. 2010, A&A 518, L98
6. Molinari, S., Swinyard, B., Bally, J., et al. 2010, A&A 518, L100
7. Zavagno, A., Anderson, L.D., Russeil, D. et al. 2010, A&A 518, L101
8. Martin, P.G., Miville-Deschenes, M.A., Roy, A., et al. 2010, A&A 518, L105
9. Paradis, D., Veneziani, M., Noriega-Crespo, A. et al. 2010, A&A 520, L8
10. Compiègne, M., Flagey, N., Noriega-Crespo, A. et al. 2010, ApJ 724, L44
11. Stamatellos, D., Griffin, M.J., Kirk, J.M. et al. 2010, MNRAS 409, 12
12. Russeil, D., Pestalozzi, M., Mottram, J.C. et al. 2011, A&A 526, 151
13. Wilcock, L.A., Kirk, J.M., Stamatellos, D. et al. 2011, A&A 526, 159
14. Molinari, S., Schisano, E., Faustini, F., et al. 2011, A&A 530, 133
15. Billot, N., Schisano, E., Pestalozzi, M., et al. 2011, ApJ 735, 28
16. Molinari, S., Bally, J., Noriega-Crespo, A., et al. 2011, ApJ 735, L33
17. Traficante, A., Calzoletti, L., Veneziani, M., et al. 2011, MNRAS 416, 2932
18. Battersby, C., Bally, J., Ginsburg, A., et al. 2011, A&A 535, 128

Papers from Hi-GAL Team

…..to date and to my knowledge

19. Paradis, D., Paladini, R., Noriega-Crespo, A., et al. 2012, A&A 537, 113
20. Paladini R., Umana G., Veneziani M., et al. 2012, A&A 760, 149
21. Longmore, S.N., Rathborne, J., Bastian, N. et al. 2012, ApJ 746, 117
22. Mottram, J.C., & Brunt, C.M. 2012, MNRAS, 420, 10
23. Li, J.J., Moscadelli, L., Cesaroni, R., et al. 2012, ApJ 749, 47
24. Wilcock L.A., Ward-Thompson D., Kirk J.M., et al. 2012, MNRAS 422, 1071
25. Anderson, L.D., Zavagno, A., Deharveng, L., et al. 2012, A&A 542, 10
26. Wilcock L.A., Ward-Thompson D., Kirk J.M., et al. 2012, MNRAS 424, 716
27. Tibbs, C.~T., Paladini, R., Compiègne, M., et al. 2012, ApJ 754, 94
28. Faimali A., Thompson M.A., Hindson L. et al. 2012, MNRAS 426, 402
29. Umana G., Ingallinera A., Trigilio C., et al. 2012, MNRAS 427, 2975
30. Veneziani M., Elia D., Noriega-Crespo A., et al. 2013, A&A 549, 130
31. Longmore S.N., Bally J., Testi L., et al. 2013, MNRAS 429, 987
32. Olmi L., Anglès-Alcàzar D., Elia D., et al. 2013, A&A 551, 111
33. Beltran M.T., Olmi L., Cesaroni R., et al. 2013, A&A 552, 123
34. Peretto N., Fuller G.A., Duarte-Cabral A., et al., A&A 555, 112
35. Elia D., Molinari S., Fukui Y., et al. 2013, ApJ 772, 45
36. Giannetti A., Brand J., Sanchez-Monge A., et al., 2013 A&A 556, 16

Papers from Hi-GAL Team

....to date and to my knowledge

37. Etxaluze M., Goicoechea J.R., Cernicharo J., et al. 2013, A&A 556, 137
38. Sanchez-Monge A., Lopez-Sepulcre A., Cesaroni R., et al. A&A 557, 94
39. Traficante A., et al. A&A submitted (3D dust decomposition)
40. Zhou J. & Huang M., A&A submitted (dust models in HII regions)
41. Schisano E., et al. ApJ submitted (filamentary structures)
42. Robitaille J.F. et al. ApJ submitted (morphology and properties of ISM)

10 more papers are close to submission

3 *Hi-GAL Data Release* papers in advanced preparation

About **30** ongoing Hi-GAL projects with papers in different stages of preparation

Talks and Posters featuring Hi-GAL

…. to my knowledge

Talks:

- A. Noriega-Crespo et al.: star formation on the ridges of the GC Bubble ?
- M. Pestalozzi et al.: Massive star formation in the Scutum-Crux Arm
- A. Zavagno et al.: Triggered star formation
- S. Molinari et al.: this talk.

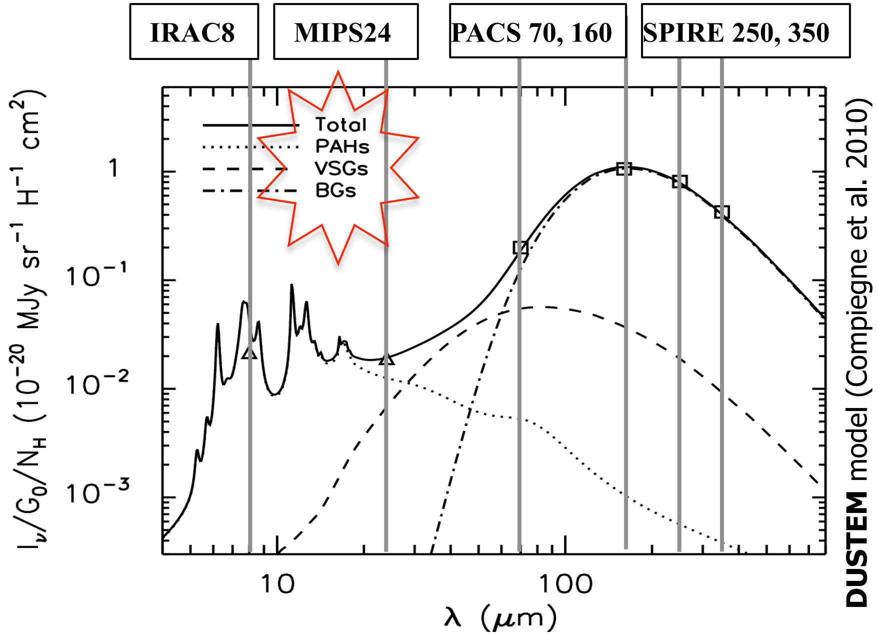
Posters:

- A3-P65: M. Etxaluze et al. – SgrB2
- A3-P70: G. Joncas et al. – Turbulence
- A3-P84: R. Paladini et al. – Dust in evolved HII regions
- A3-P86: J.F. Robitaille et al. – Component separation in ISM
- A3-P93: A. Traficante et al. – 3D inversion methods in the Galactic Plane

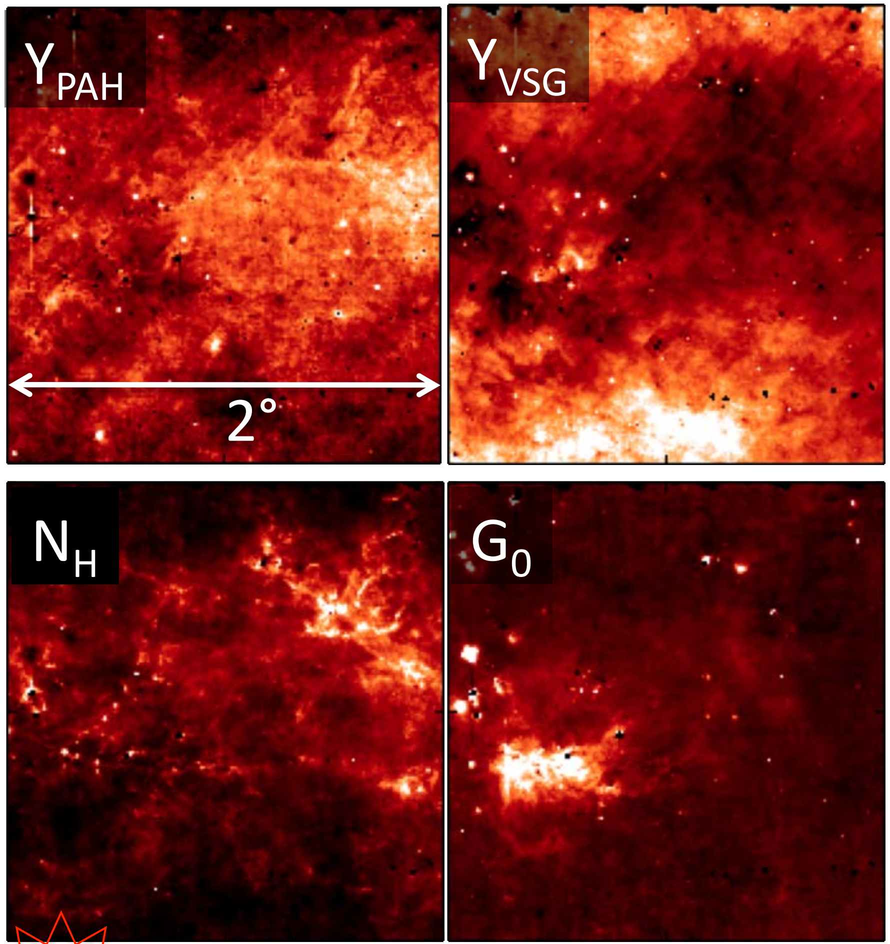
- B2-P24: R. Vavrek et al. – Diffuse emission analysis in the Galactic Plane

- B4-P28: A. Traficante et al. – Compact Sources in IRDCs
- B4-P33: N. Billot et al. – Source Clustering properties in the Galactic Plane
- B4-P39: D. Elia et al. – Star formation in the Carina Arm
- B4-P60: L. Olmi et al. – Dense Clumps mass function
- B4-P73: E. Schisano et al. – Filaments networks in the Galactic Plane
- B4-P77: M. Tapia et al. – Star formation in RCW121
- B4-P83: M. Veneziani et al. – Star formation at the Tips of the Bar

Dust mixture, distribution and evolution in the ISM



RESULTS: l=59° field [**Compiegne+ 2010**]

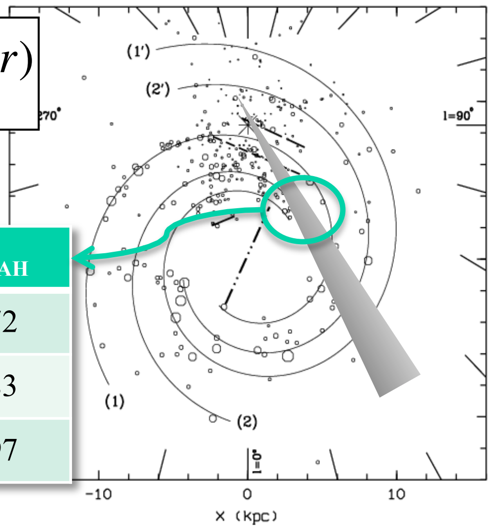


25" pxl-by-pxl SED fit of Hi-GAL maps using a PAH/VSG/BG dust mixture, **solving for**:

- ✓N_H : Column density of Big Grains
- ✓G_0 : ISRF intensity
- ✓ Y_{PAH} and Y_{VSG} : PAH and VSG abundance

3D decomposition of diffuse dust emission

$$I_\lambda = \sum_{Rings} \sum_{Gas} \varepsilon_H(\lambda, r) N_H(r)$$



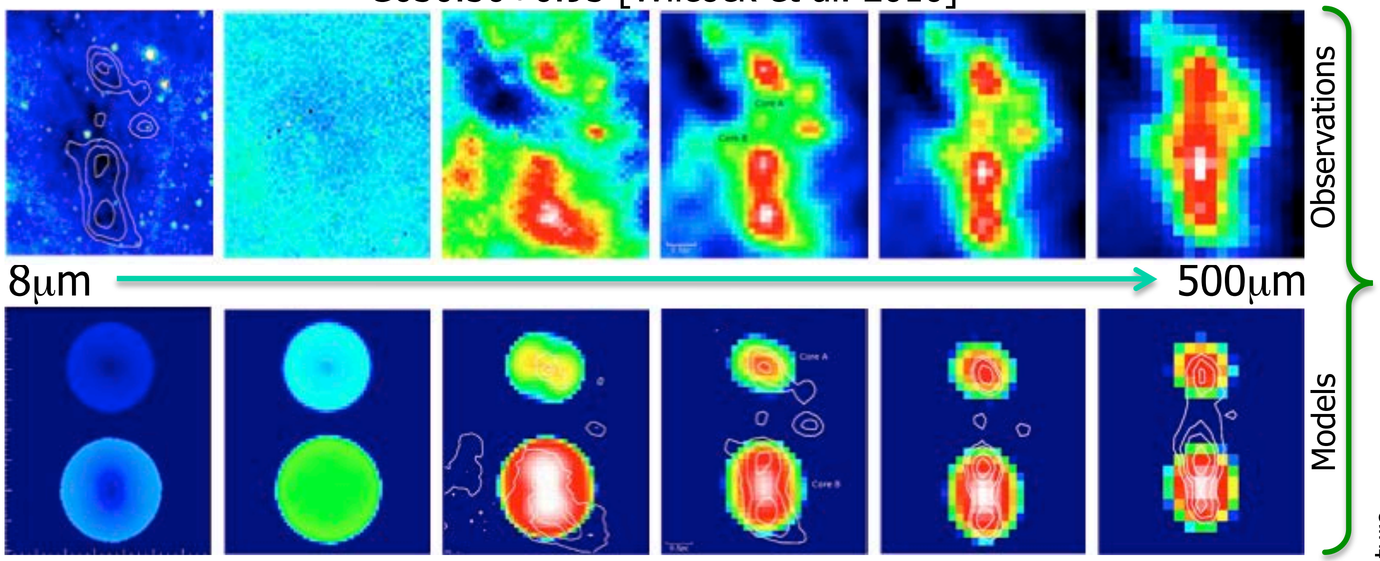
Dust in Scutum-Crux ring

Gas Phase	T_{BG}(K)	Y_{PAH}
IONISED	23.15	0.72
ATOMIC	19.52	1.83
MOLECULAR	19.91	0.97

Traficante et al. subm

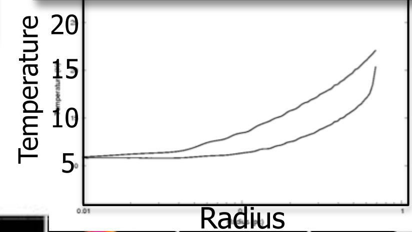
Revisiting Infrared Dark Clouds in Hi-GAL

G030.50+0.95 [Wilcock et al. 2010]



Full radiative transfer modeling with PHAETHON (Stamatellos et al. 2010)

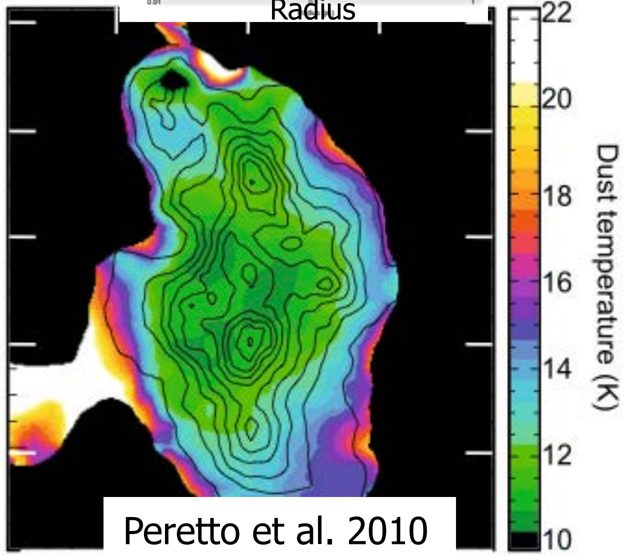
IRDC density and temperature structure from full 2D radiative transfer modeling of Hi-GAL maps confirms
negative temperature gradients
and upper limits as low as
$L<10\,L_\odot$
for embedded protostars,
uniquely pinpointing massive pre-stellar core candidates



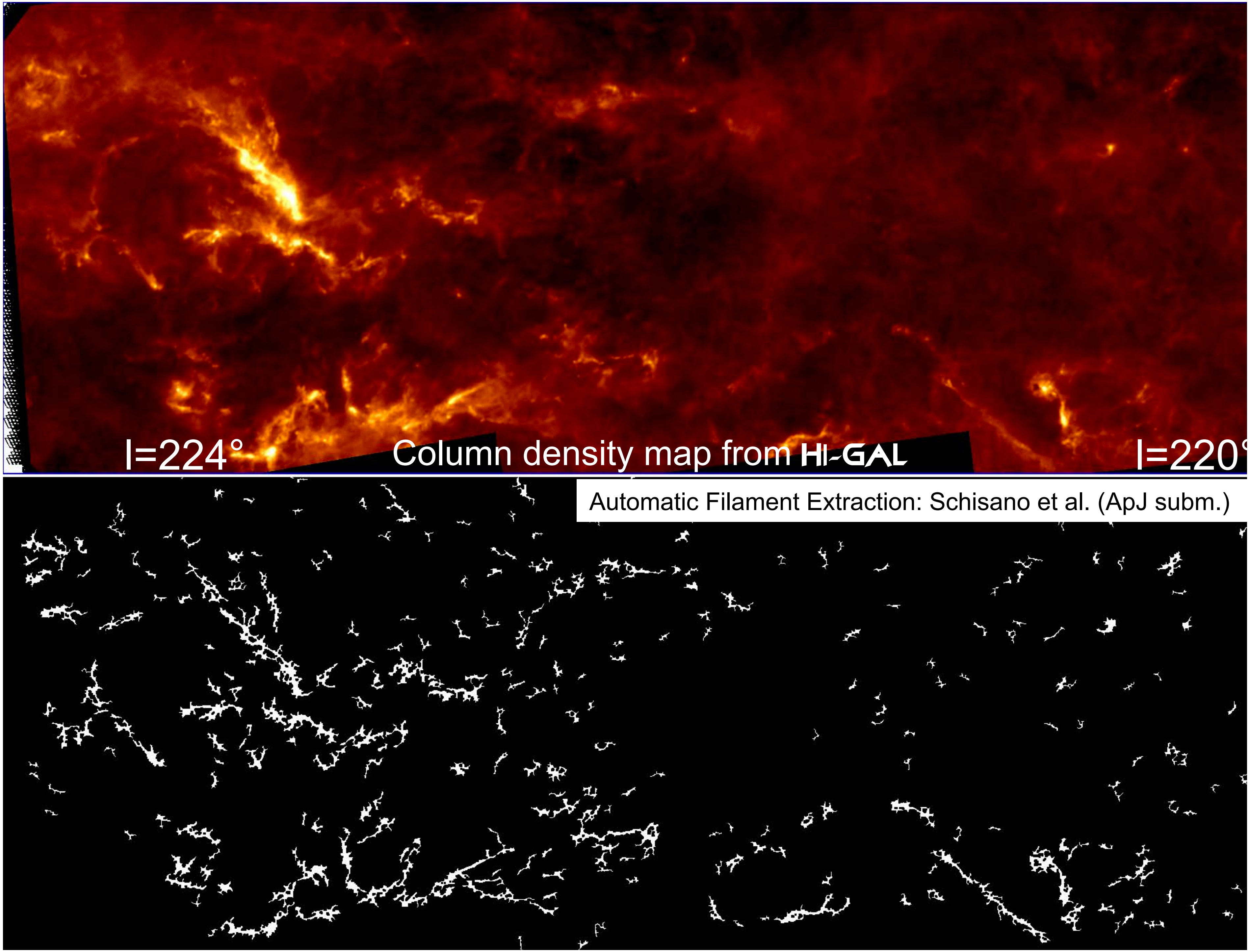
Large scale Hi-GAL statistical analysis of **3171** IRDCs catalogued using Spitzer data in the longitude range
300° < l < 330° show that
only half of pre-Herschel IRDCs are real,
with strong implications for global SFR estimates.

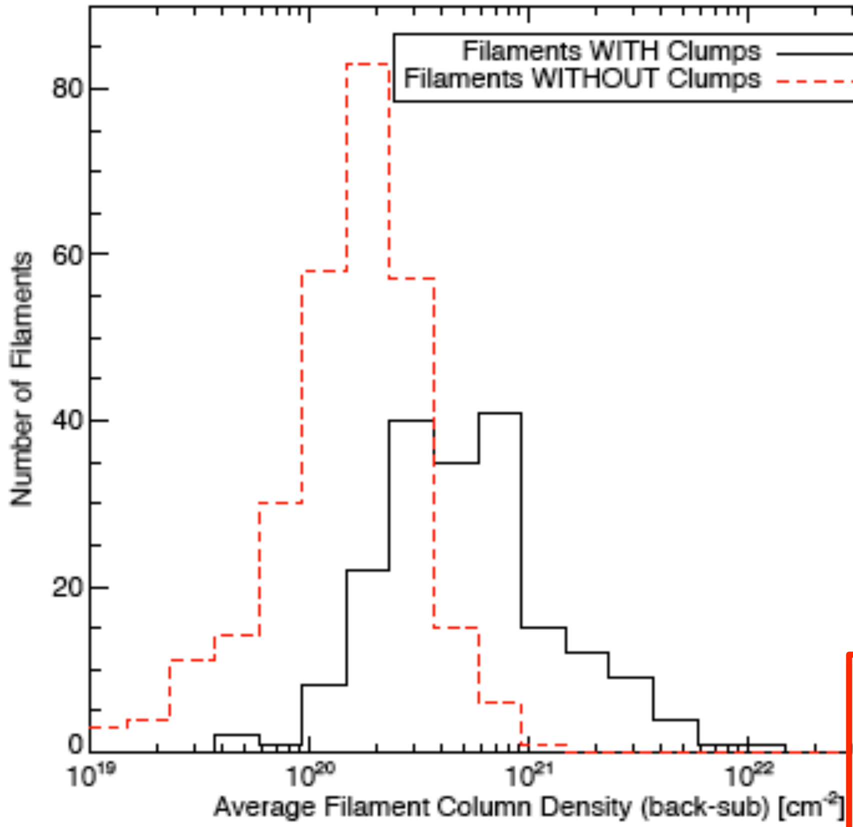
82% of *bona fide* IRDCs **are associated to a λ<24μm** source and are considered star-forming.

Only 18% may be in a pre-stellar phase
[Wilcock et al. 2011]

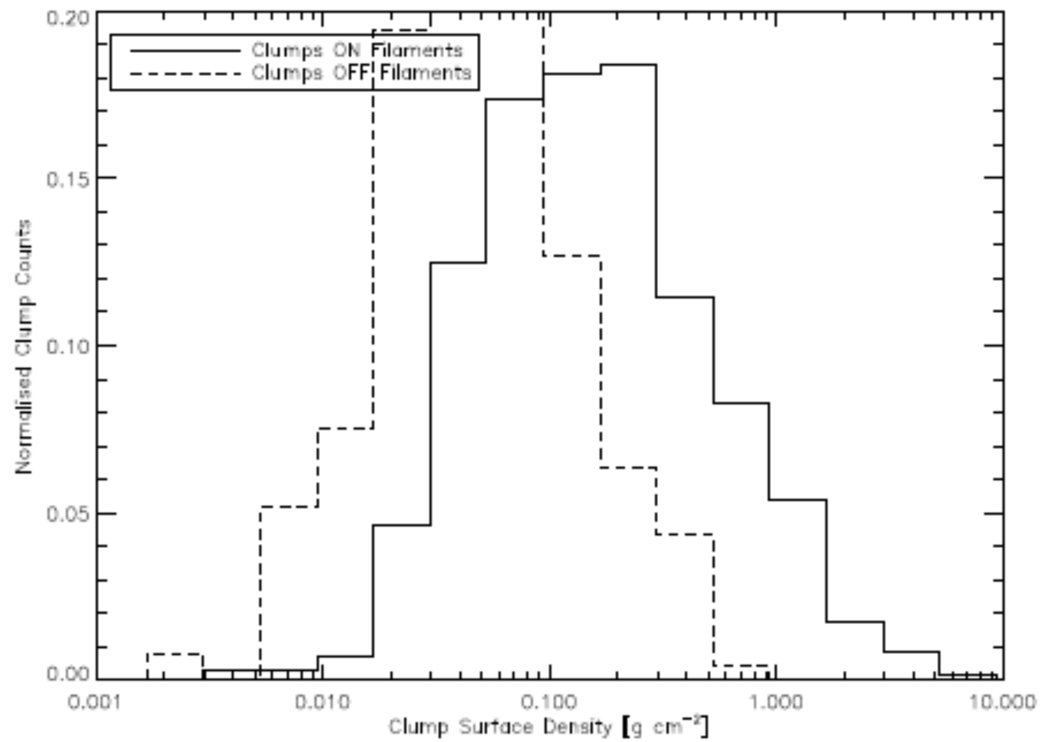


Peretto et al. 2010


l=224°
Column density map from HI-GAL
l=220°
Automatic Filament Extraction: Schisano et al. (ApJ subm.)

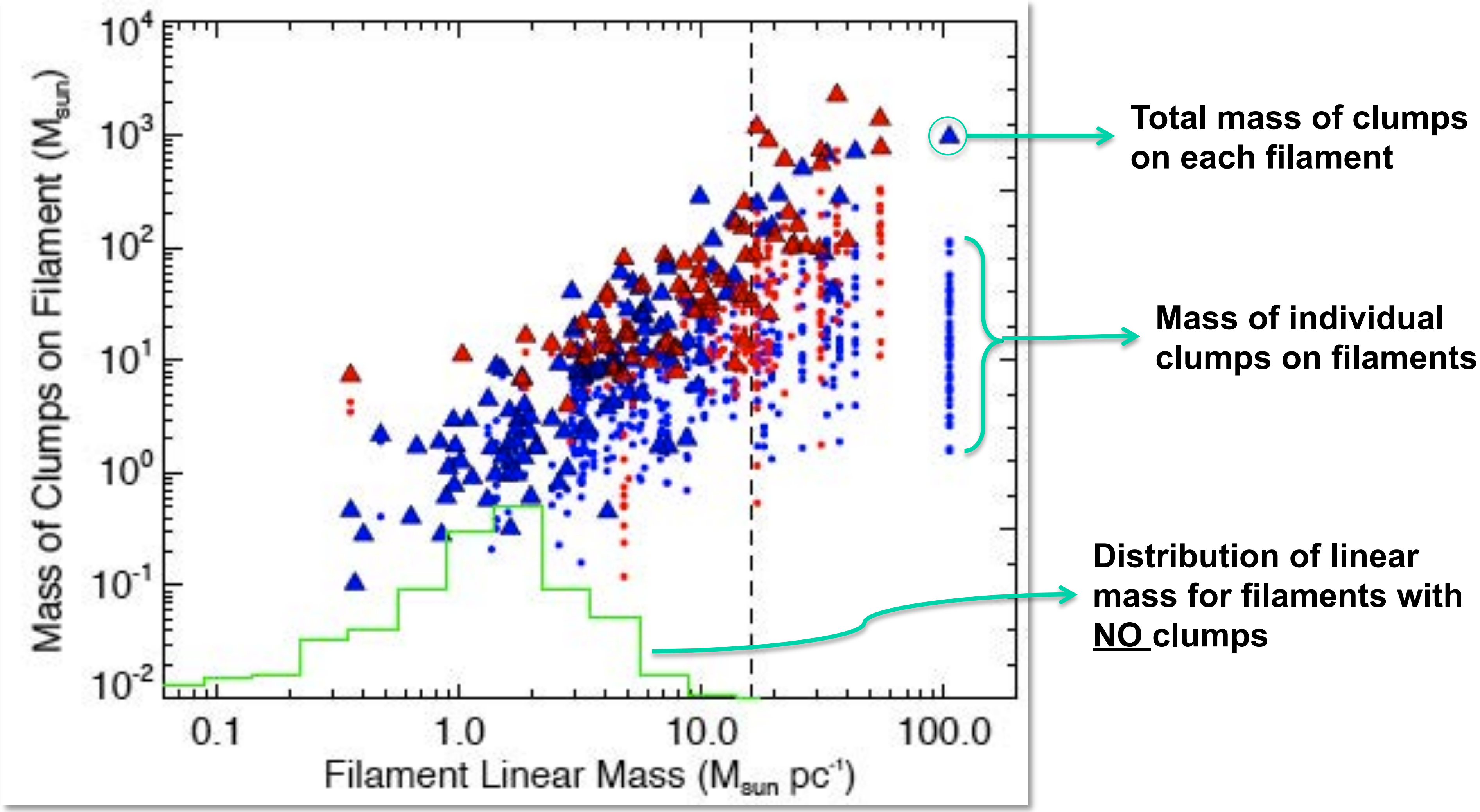


Filaments that host dense clumps are denser



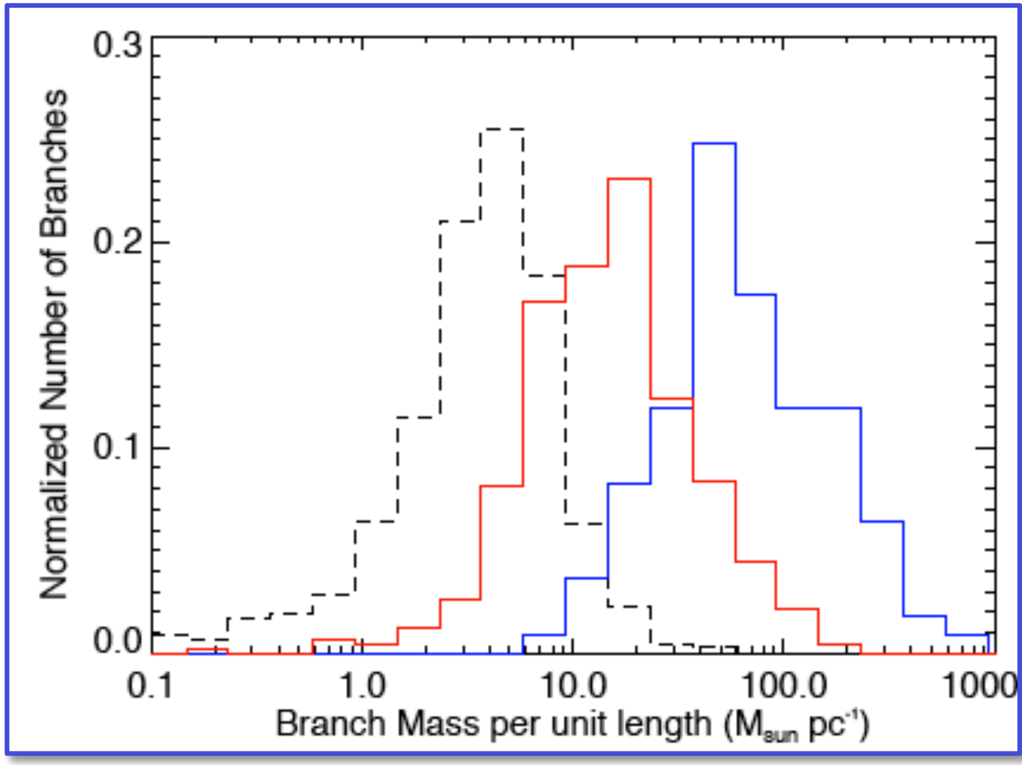
Clumps located on filaments are denser

Schisano et al. 2013, ApJ subm. (B4-P73)



Do more massive clumps form on more massive filaments ?
Or do filaments grow mass from the surrounding environments and channel more mass to the clumps ?
No clear evidence for thresholds

Schisano et al. 2013, ApJ subm. (B4-P73)



Evolutionary effects are clearly visible as a function of the filaments linear masses

Blue: filament branches with PROTOstellar Clumps, **i.e. with a 70μm counterpart**

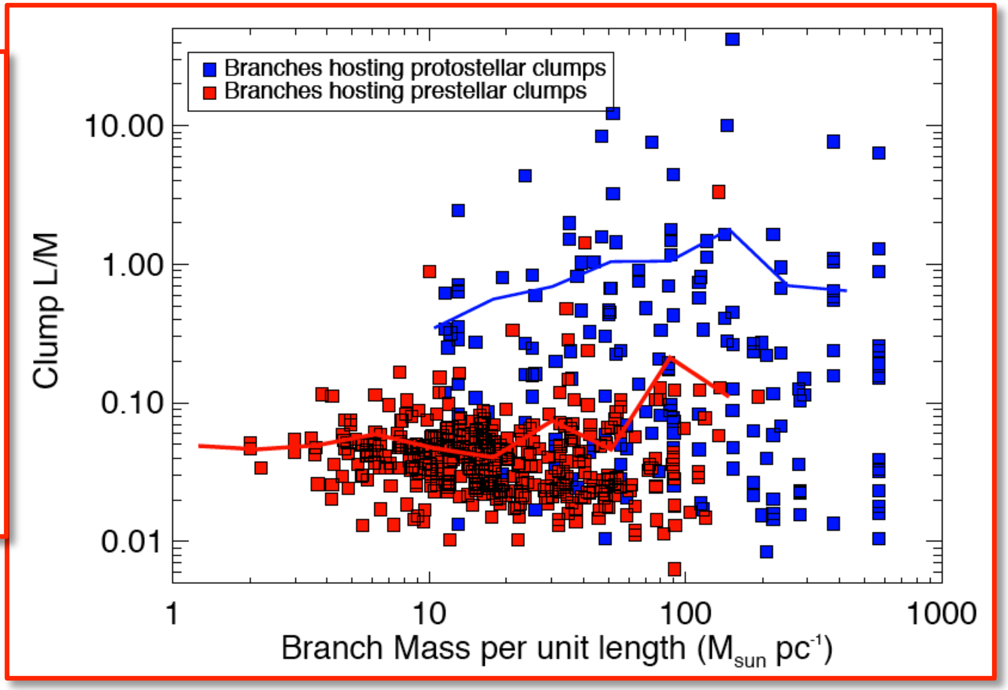
Red: filament branches with PREstellar Clumps

Black: filament branches with NO Clumps

1) Accretion rates ≈ 10^{-2}-10^{-3} $M_{\odot}$/pc/yr are needed to explain the differences in evolutionary terms (see also Kirk +13, Peretto+ 13)

or…

2) Differences in linear masses, clump masses and L/M are imprinted at the time of filament formation.

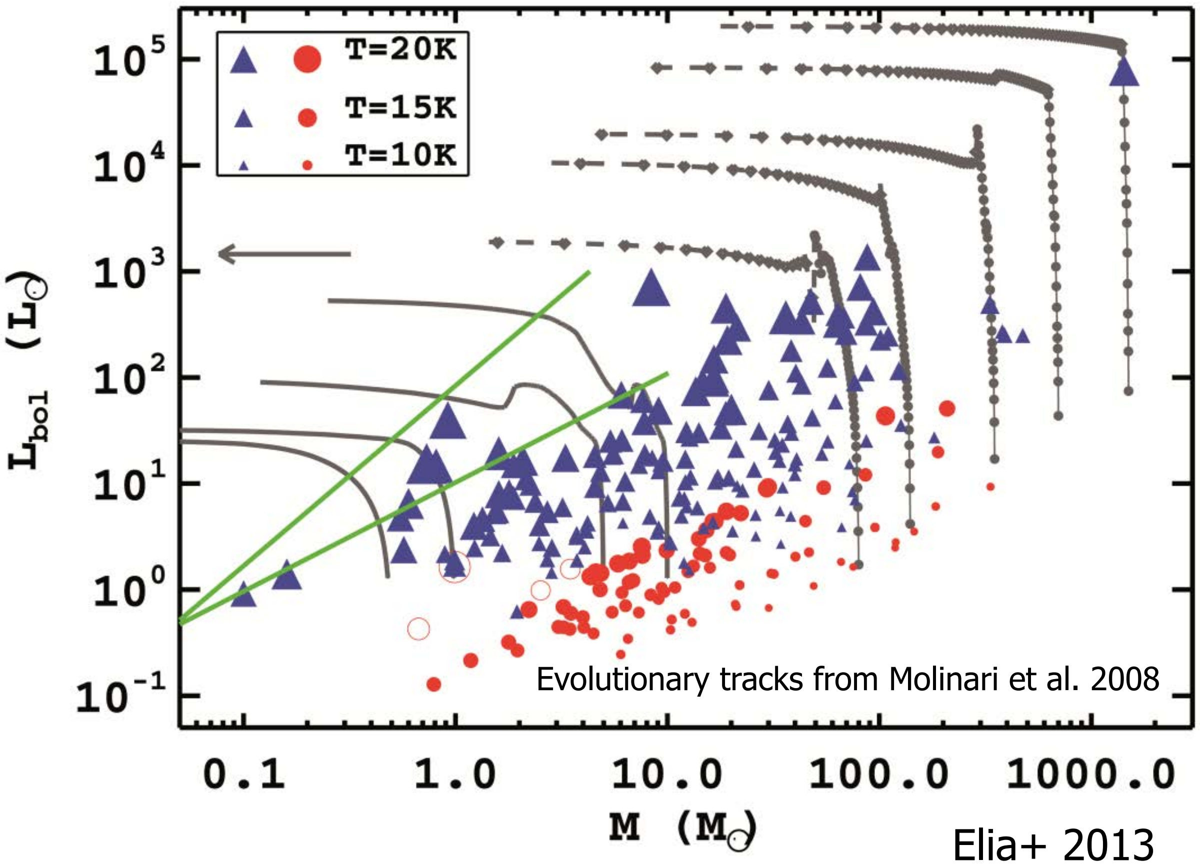


Schisano et al. 2013, ApJ subm. (B4-P73)

Clumps evolutionary stage

● **Pre-stellar Sources (no 70μm counterpart)**

△ **Proto-stellar Sources (with 70μm counterpart)**

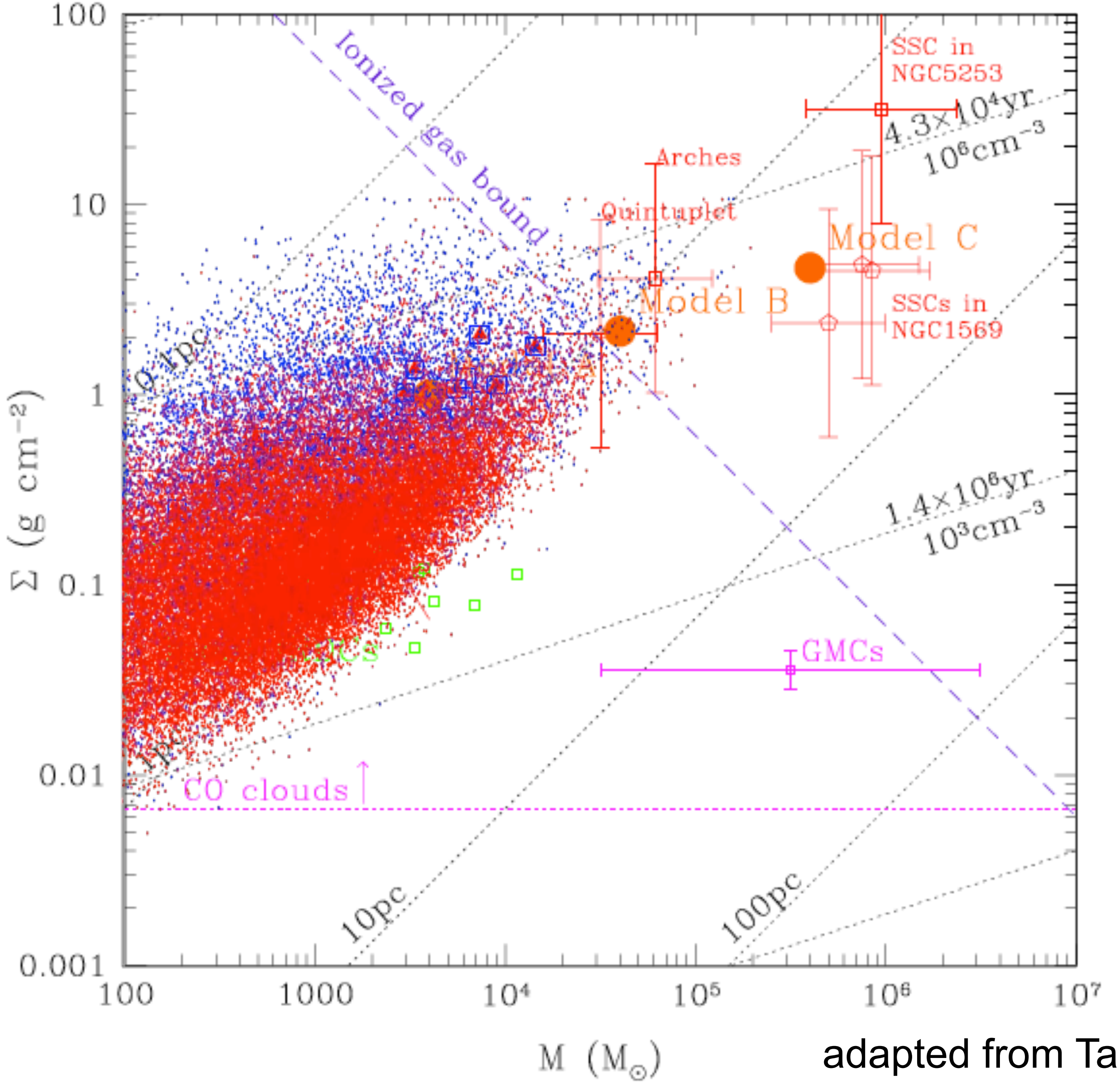


Elia+ 2013

- A separation between **pre-stellar** and **proto-stellar** sources is quite clear in terms of L/M. The appearance and intensity of the 70μm (and shortward), clearly makes the difference.

- Within each class, there is a clear trend of L/M with Temperature (estimated using only λ≥160μm)

Star Formation drives up the energy budget in the clump, raising its global temperature and luminosity. This can be ideally followed in the [L,M] diagram

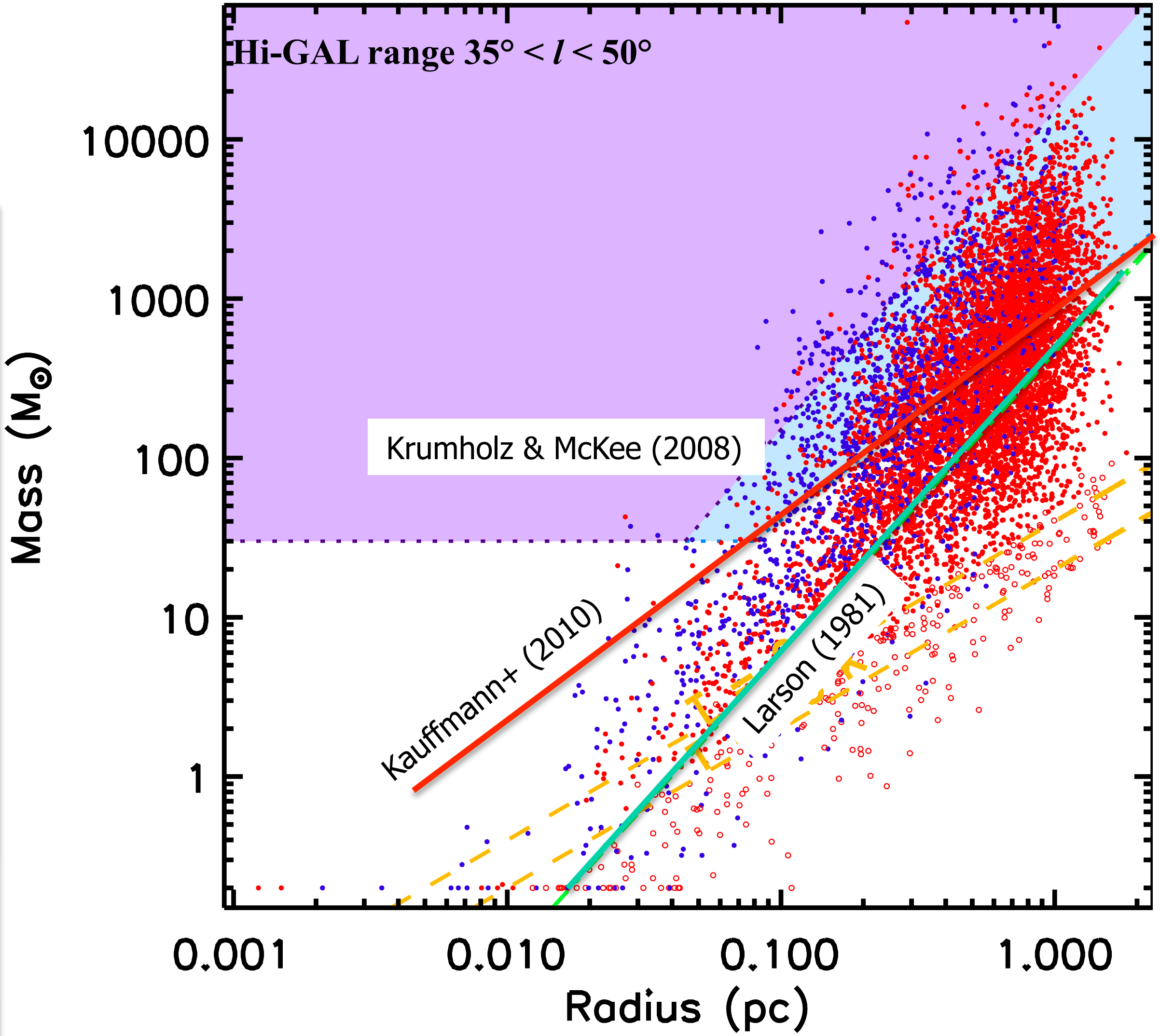


adapted from Tan 2005

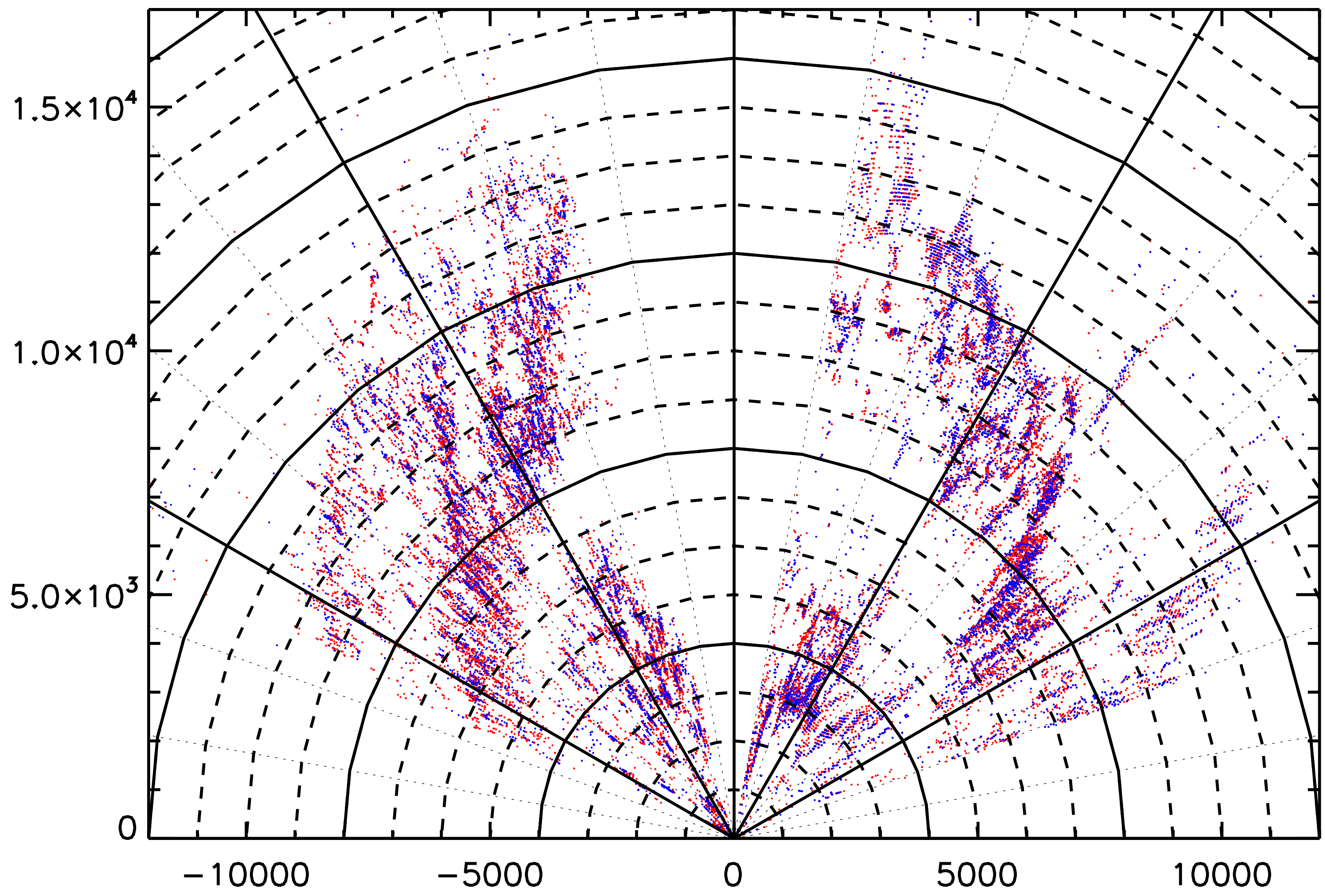
Nature of the compact Dense Clumps

* Hi-GAL sources with counterpart in at least 3 adjacent bands, and with known distance

- The majority of sources are gravitationally bound clumps according to Larson (1981).
- Herschel sensitivity is such that a solid multiband Far-IR detection in the Galactic Plane is likely a solid dense clump detection
- Less than half of the compact Clumps have densities high-enough to compare with known sites of intermediate and high-mass star formation (Kauffmann+ 2010).



Pezzuto+, in prep.

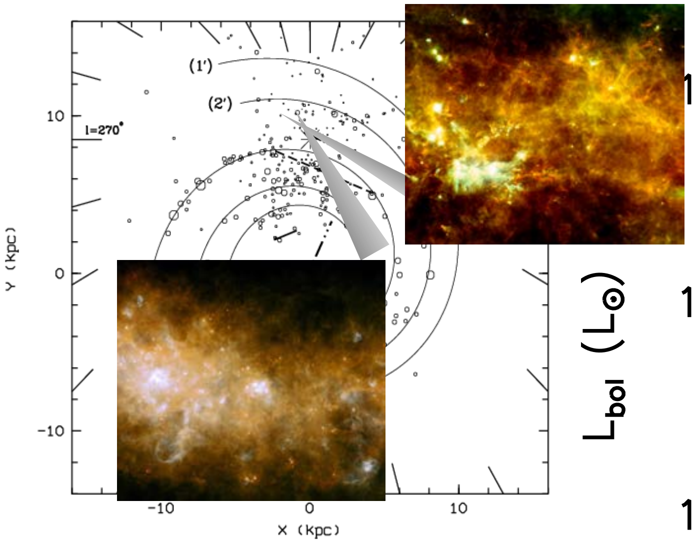


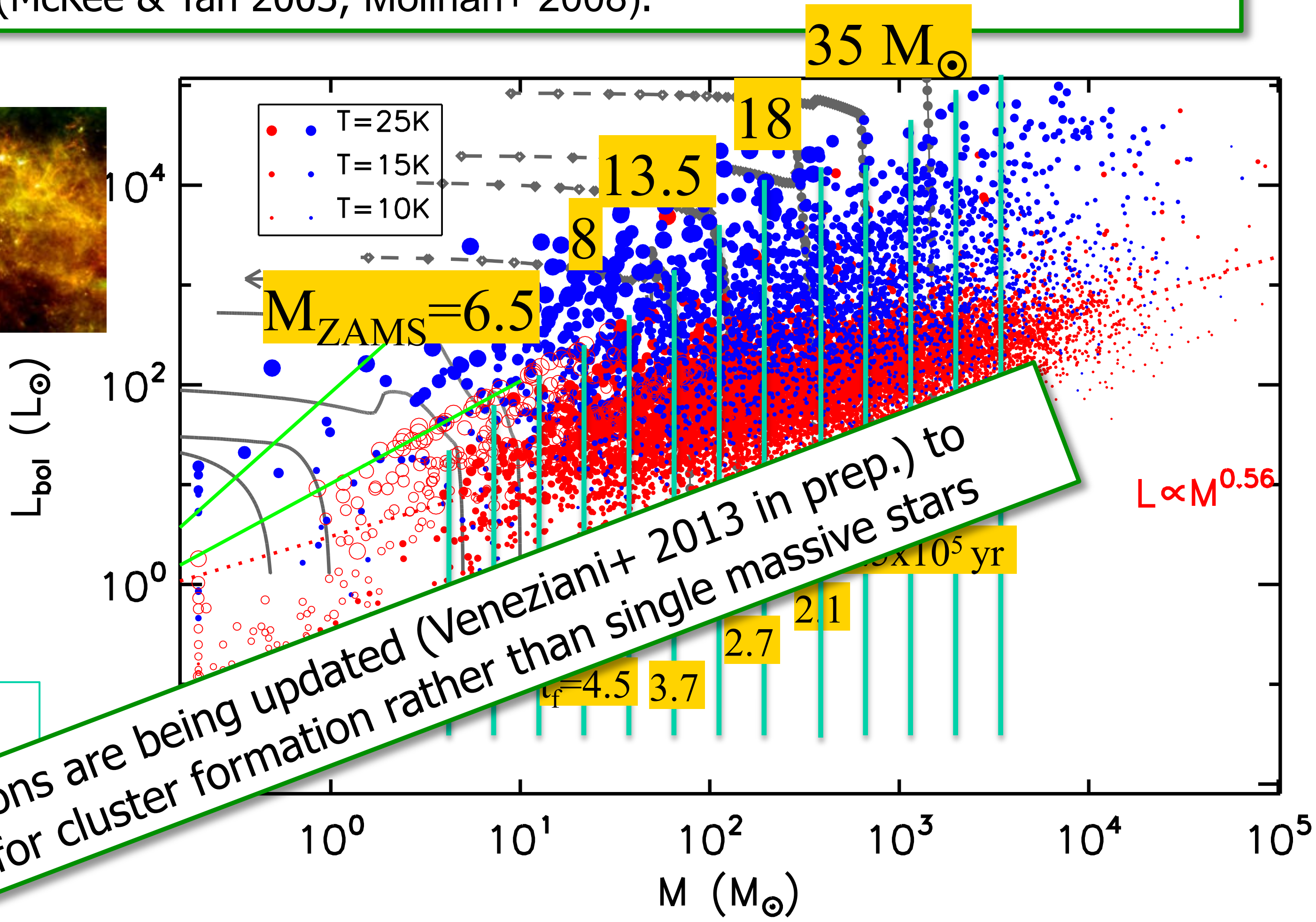
Initial sample of nearly 100,000 compact objects with counterparts in at least three adjacent bands and with a distance assignment: almost 60,000 are shown here outside the CMZ and with first estimates on distances.

[Molinari+, photometric catalogues – Pestalozzi+ physical catalogue – Elia+ global science analysis]

Star Formation Rate from YSO counts

A first attempt in deriving the SFR in the two Hi-GAL SDP fields l=30° and l=59° (*Veneziani et al. 2012*), comparing YSO statistics for PROTOSTELLAR Clumps in the L *vs* M plot against evolutionary predictions (McKee & Tan 2003, Molinari+ 2008).





Prescriptions are being updated (Veneziani+ 2013 in prep.) to account for cluster formation rather than single massive stars

Each bin i is associated to:

- final ZAMS mass $M_{ZAMS}(i)$
- formation time $t_f(i)$

$$SFR = \sum_{i=1}^{N_{Mzams}} \sum_{j=1}^{N_{Sources}} n_M(i,j) M_{ZAMS}(i) / t_f(i)$$

l=30° → 0.067 $M_\odot$/yr
l=59° → 0.011 $M_\odot$/yr

The Future

The full exploitation of the Hi-GAL goldmine, will require a new approach to Science analysis

- Obtain homogeneous and inter-calibrated evolutionary classifications of the cold and dense clumps hosting young forming clusters at a variety of evolutionary stages
- Deliver a new 3D model of the Galaxy, mapping the essential critical parameters like column density thresholds, rate and efficiency of star formation in the Galaxy
- Develop a suite of next-generation 3D-visualization tools that will integrate visual analytics, on-the-fly handling of multi-SED radiative transfer modeling
- Data mining/machine-learning technologies to incorporate the astronomer's know-how into a set of supervised workflows with decision making capabilities.

VIALACTEA

an FP7-SPACE Project approved with top grades for a 2.5 M€ funding for three years.