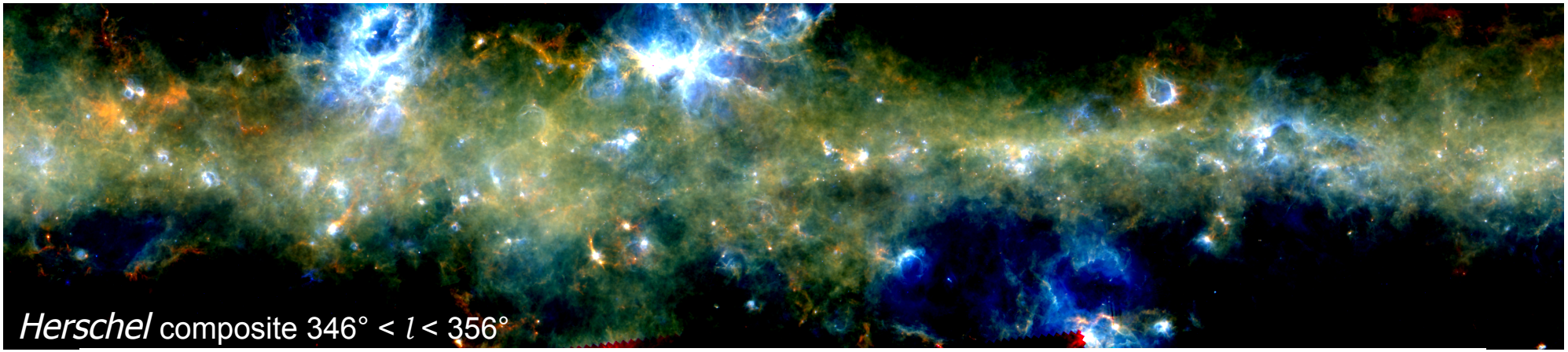


ISM, FILAMENTS AND CLUMPS IN THE NEW HERSCHEL MILKY WAY

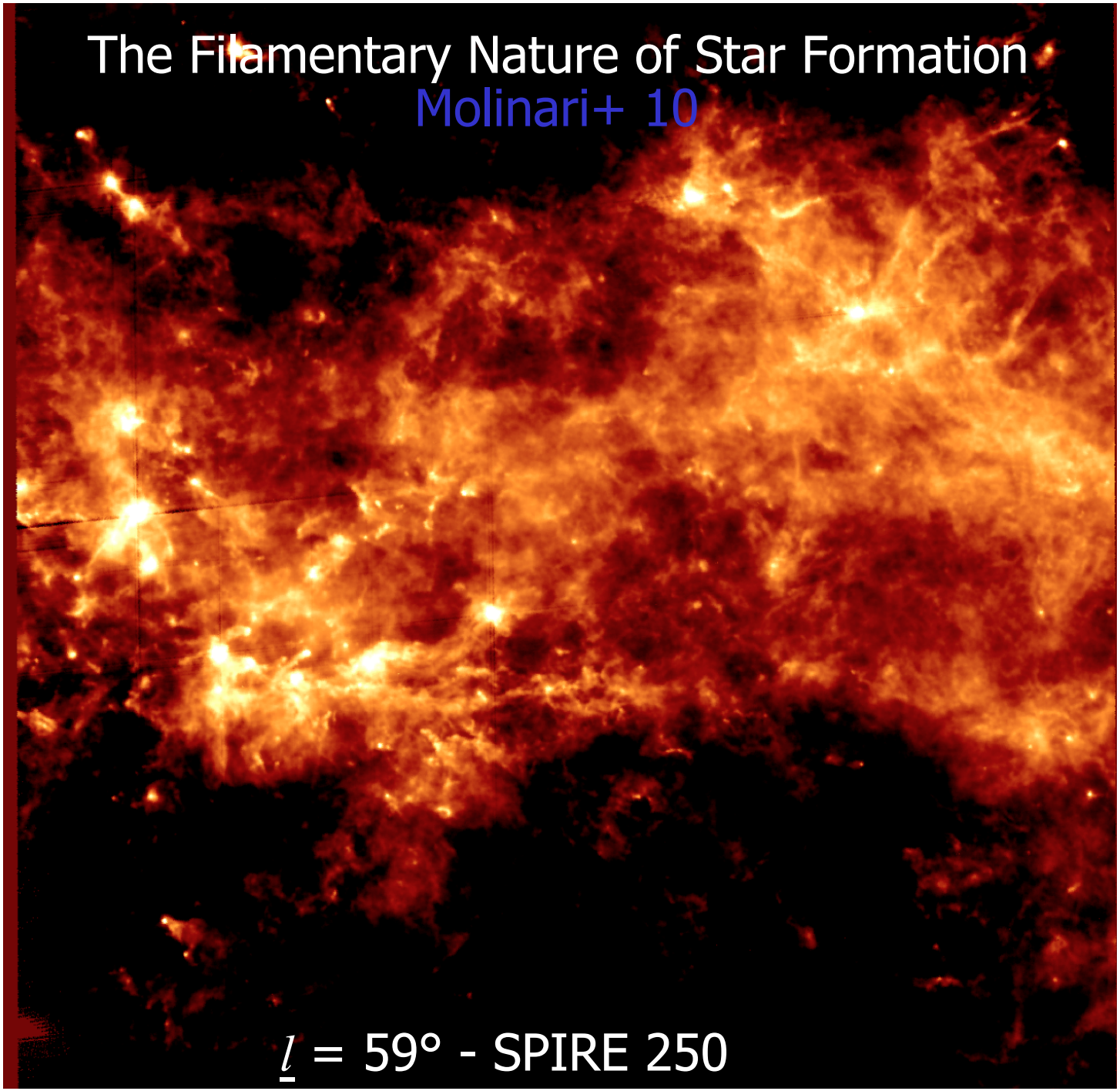
S. Molinari – INAF/IAPS, Rome

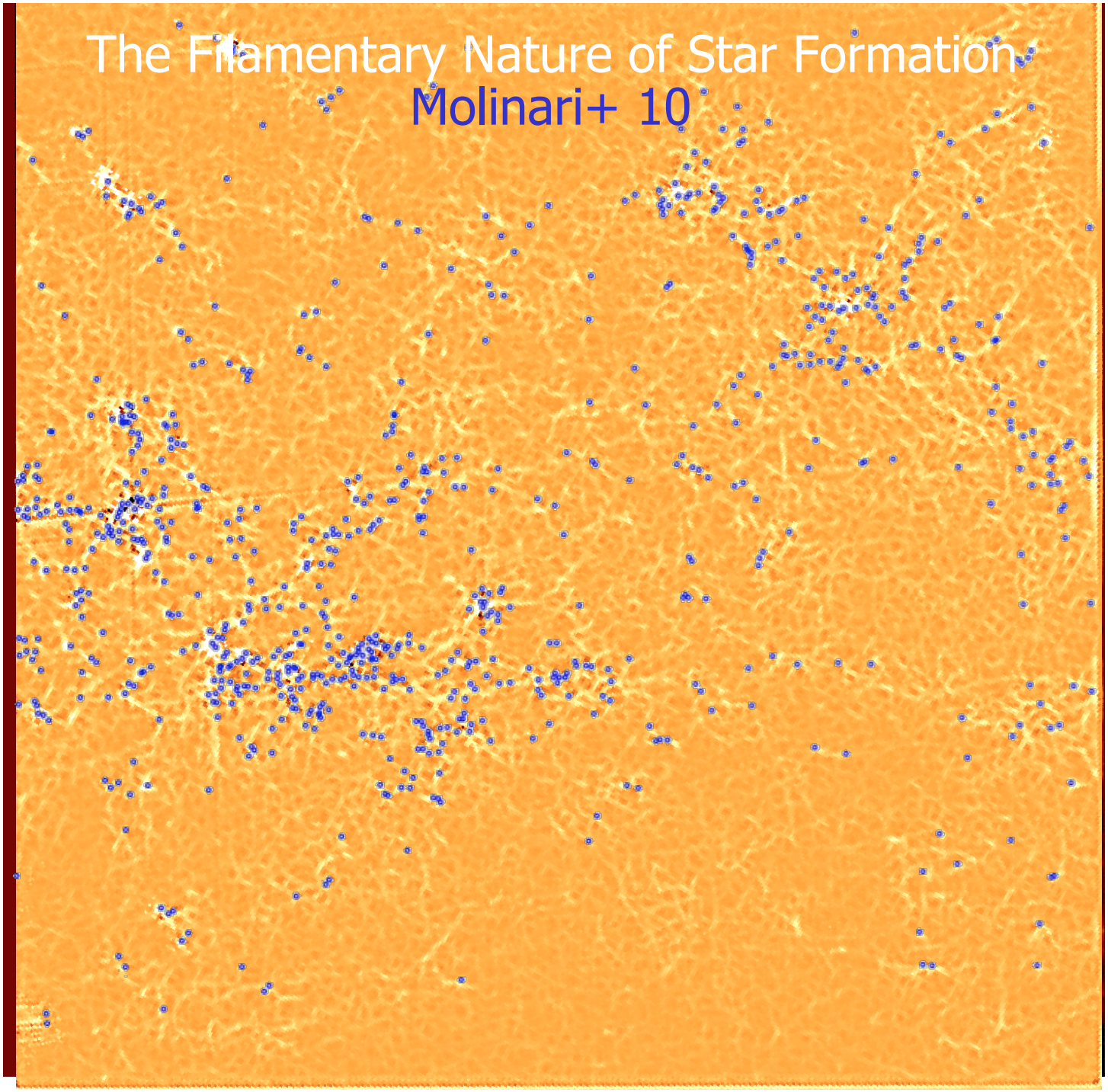
HI-GAL Team

IAPS - Arcetri Obs. - Univ. Rome 1/2 - Catania Obs. - Univ. Salento (**Italy**), *IRAP - LAM - IAS – CEA/SAp* (**France**), *RAL – Univ. Cardiff - Univ. Hertsfordshire - Liverpool JM Univ. – Univ. Leeds - UCL* (**UK**), *IPAC/SSC/JPL - Univ. Colorado – Univ. Florida* (**USA**), *Univ. Toronto - Univ. Calgary - Univ. Laval* (**Canada**), *MPIfR* - (**Germany**) et al.

Simultaneous 5-bands (*70-160-250-350-500*μm) continuum mapping of 720 sq. deg. of the Galactic Plane ($|b| \leq 1°$). With almost 900 hours observing time is the largest OPEN TIME Herschel KP

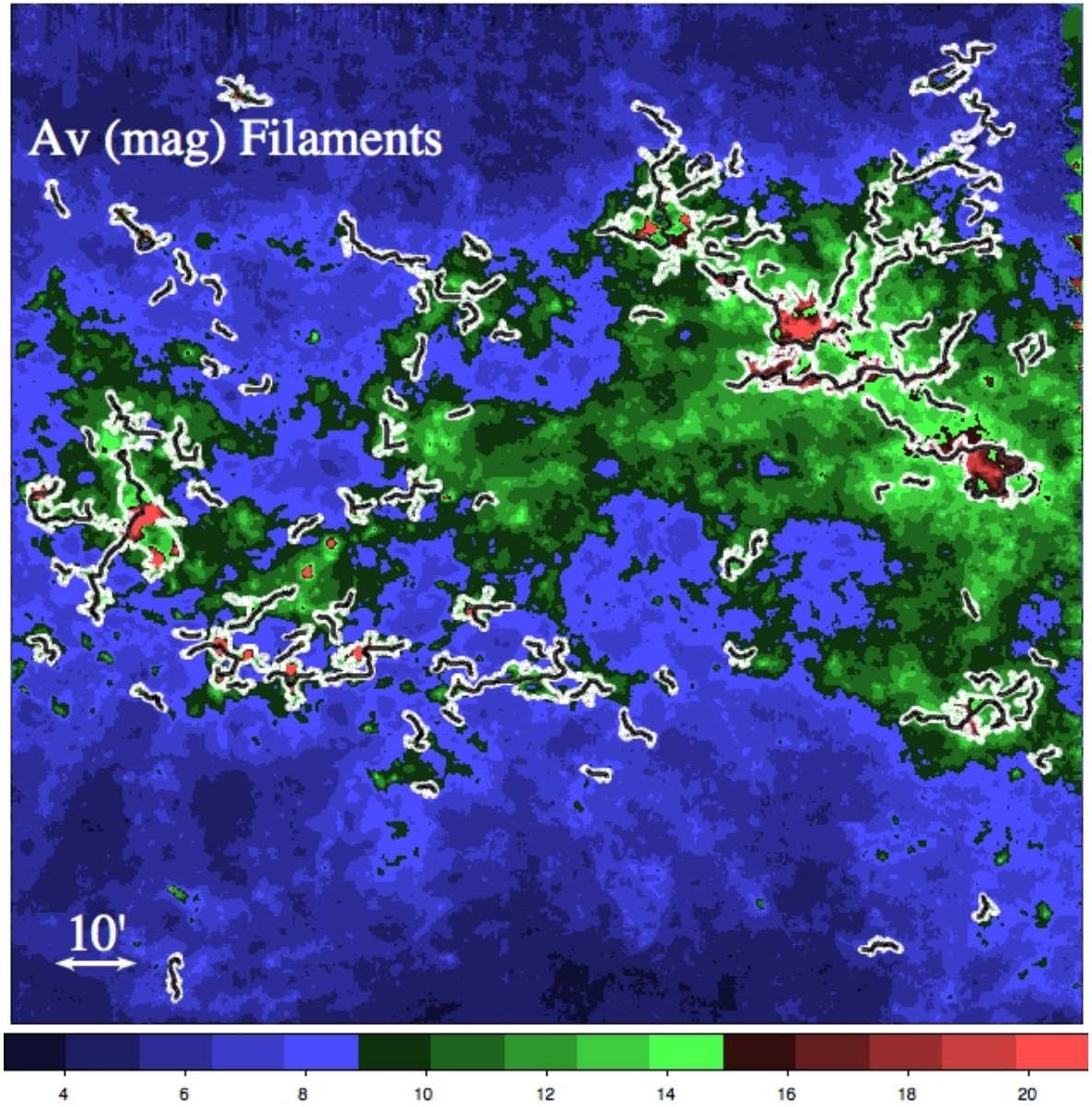
Galaxy-wide Census, Luminosity, Mass and SED of dust structures at all scales from massive YSOs to Spiral Arms


The Filamentary Nature of Star Formation
Molinari+ 10
l = 59° - SPIRE 250


The Filamentary Nature of Star Formation
Molinari+ 10

Automatic Filament Extraction

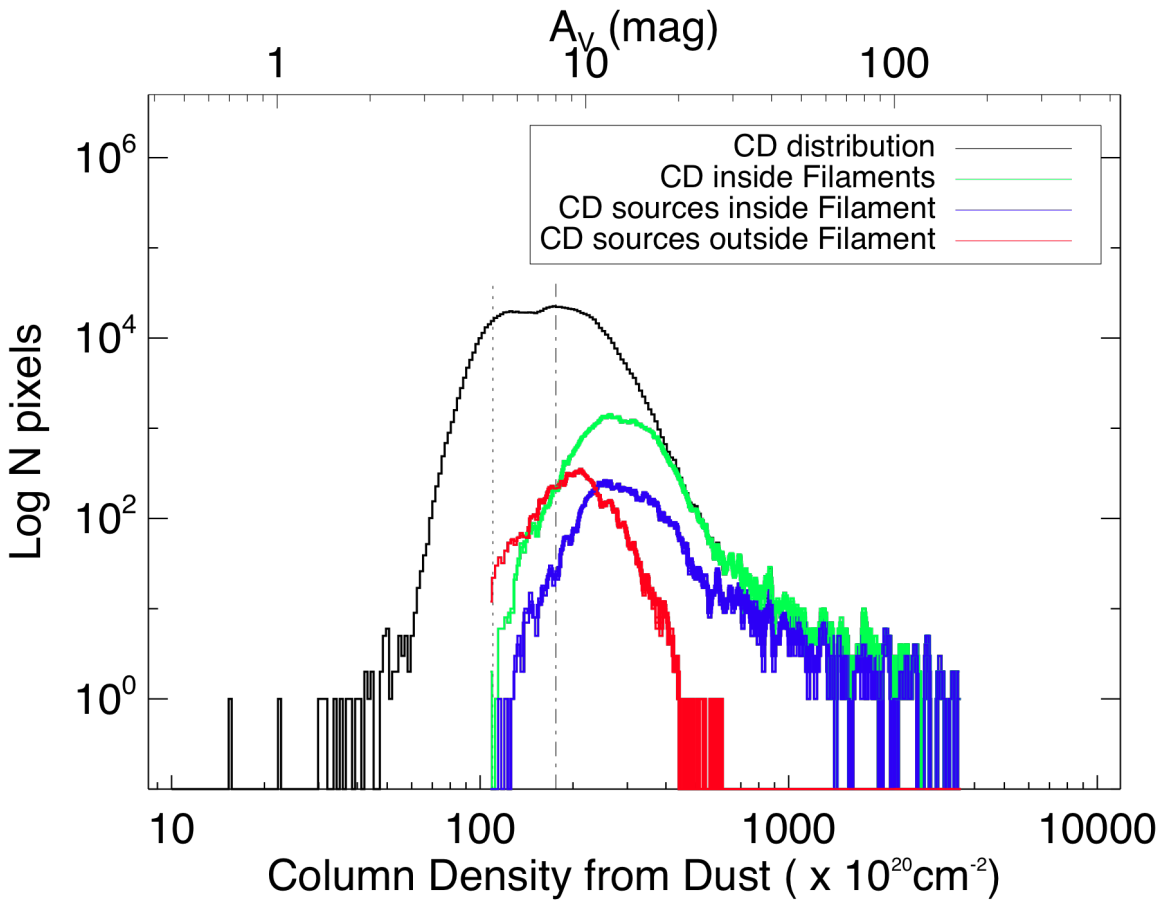
(Schisano et al. in prep)



- Elongated cylindrical-like patterns are traced by the lowest eigenvalue ($\lambda_1 << \lambda_2$) and the eigenvectors (A_1,A_2) of the Hessian matrix computed in each pixel of a column density map.
- Determine a threshold on Hessian eigenvalues to identify the pixels belonging to the filament.
- morphological operators of erosion (Gonzales & Wood 2002) to estimate the points of the central "Spine".
- "Spine" points are connected using a Minimum Spanning Tree
- Determine cross-spine filament size in each spine point

Approach used to identify cosmological structures (Aragon-Calvo et al.2007, Bond et al 2010)

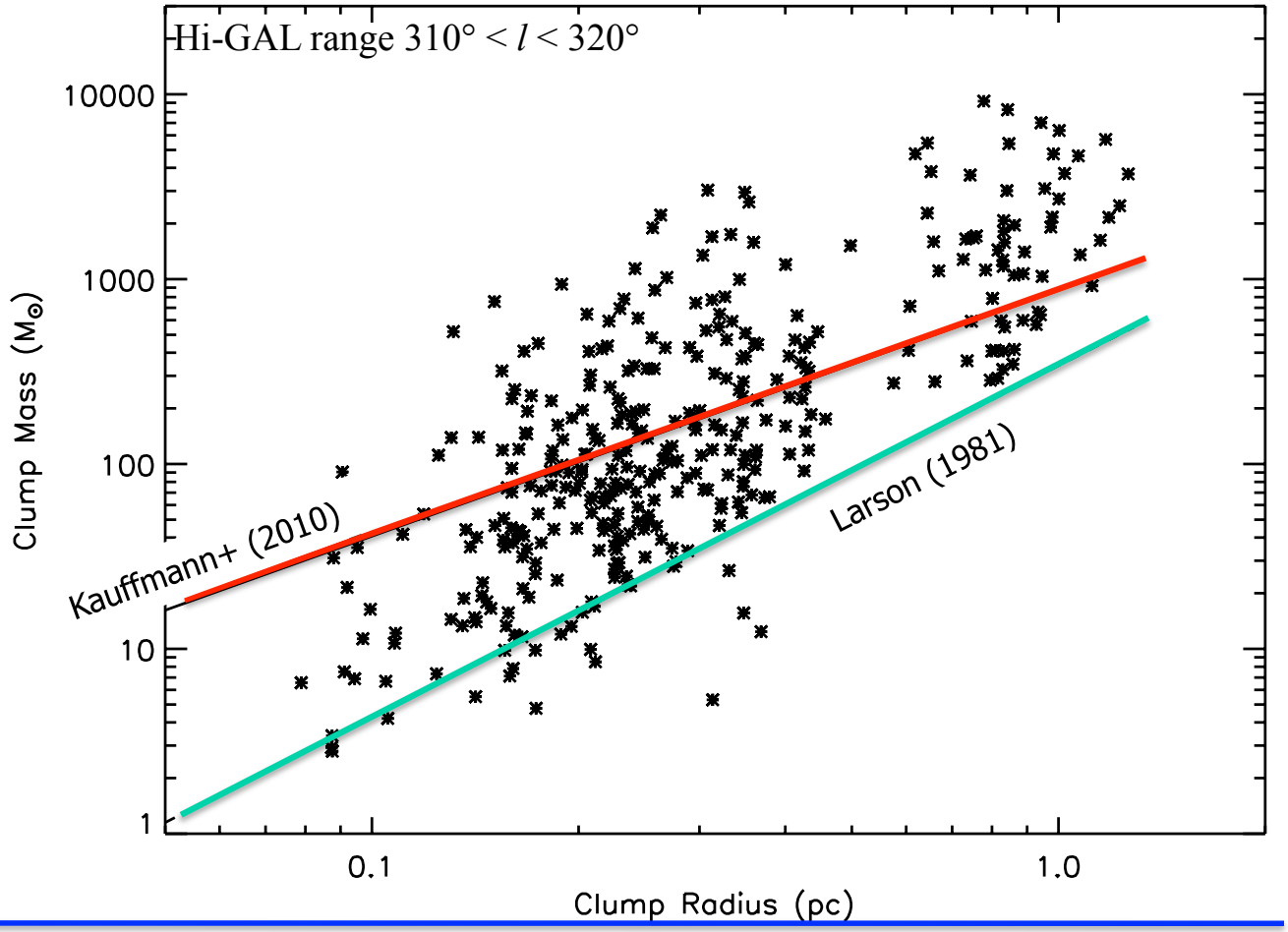
Fraction of Dense matter distributed in filamentary region



- All the observed higher density regions belong to filamentary regions
- About 50% of the matter with $A_V > 20$ is identified as belonging to a source inside the filament
- in good agreement with PDFs form numerical HD/MHD simulations of filament formation (Hennebelle et al. 2008)

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).

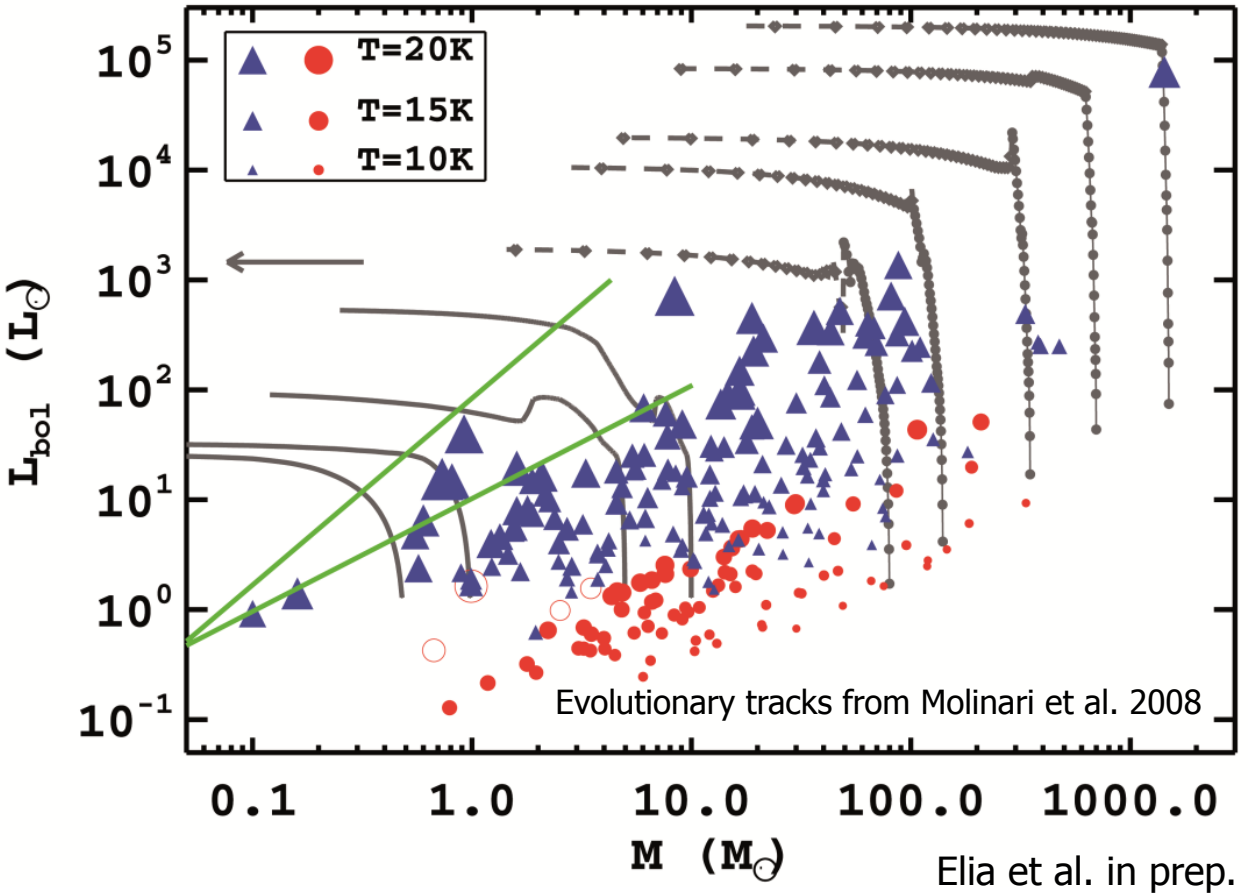
- Herschel sensitivity is such that a solid multiband Far-IR detection in the Galactic Plane is likely a solid dense clump detection

About 40% of the clumps lie above the Mass-Size power-law proposed to discriminate structures on the basis of their ability to form massive stars (Kauffmann et al. 2010)
….detailed analysis underway throughout the Inner Galaxy in a series of papers in preparation by the Hi-GAL Consortium

H-R diagram analogues. L/M: Evolution ?

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

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

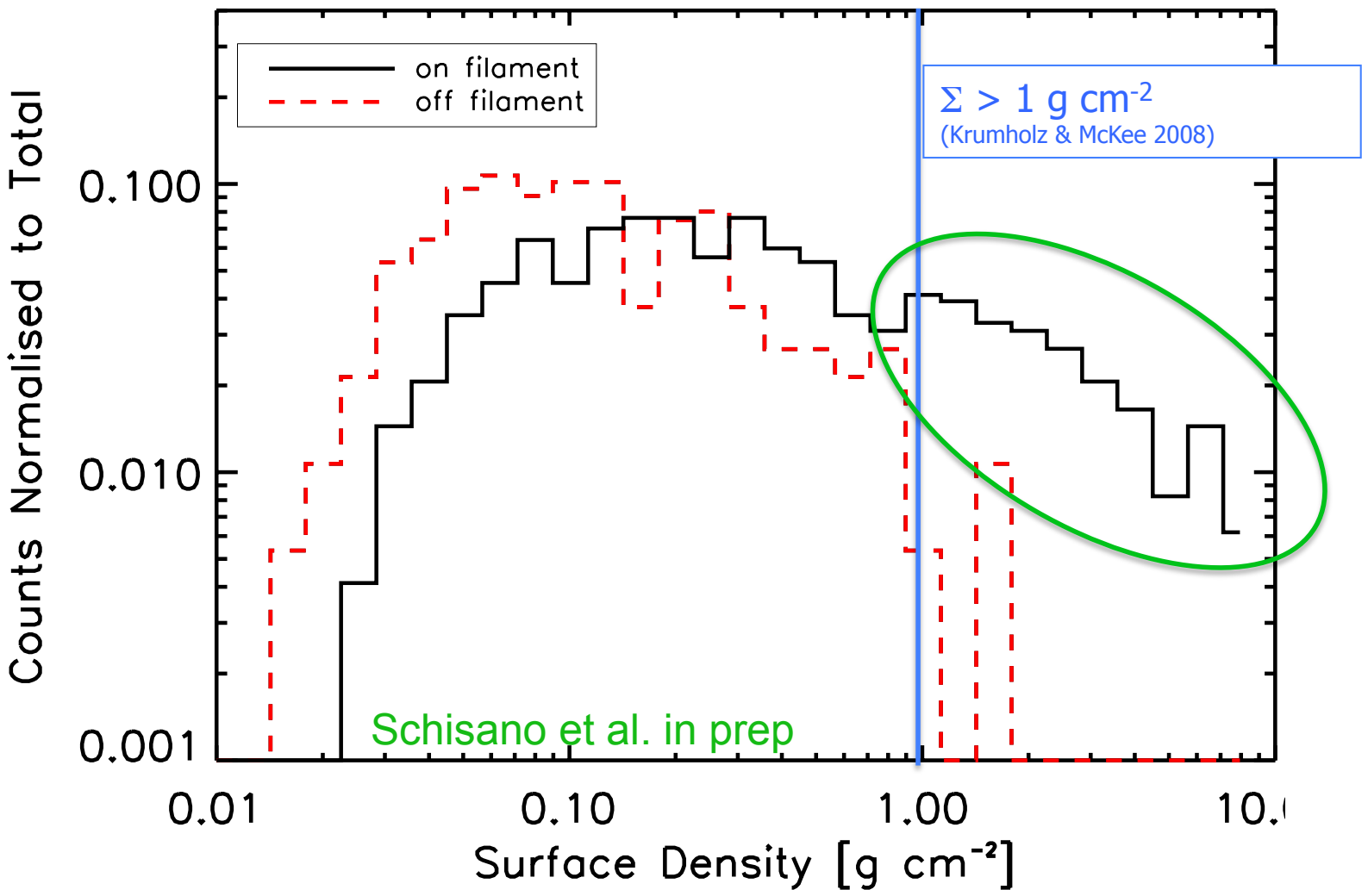


• A separation between **pre-stellar** and **proto-stellar** sources is quite clear in terms of L/M. The appearance and intensity of the 70μm (and shortward), clearly makes the difference.

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

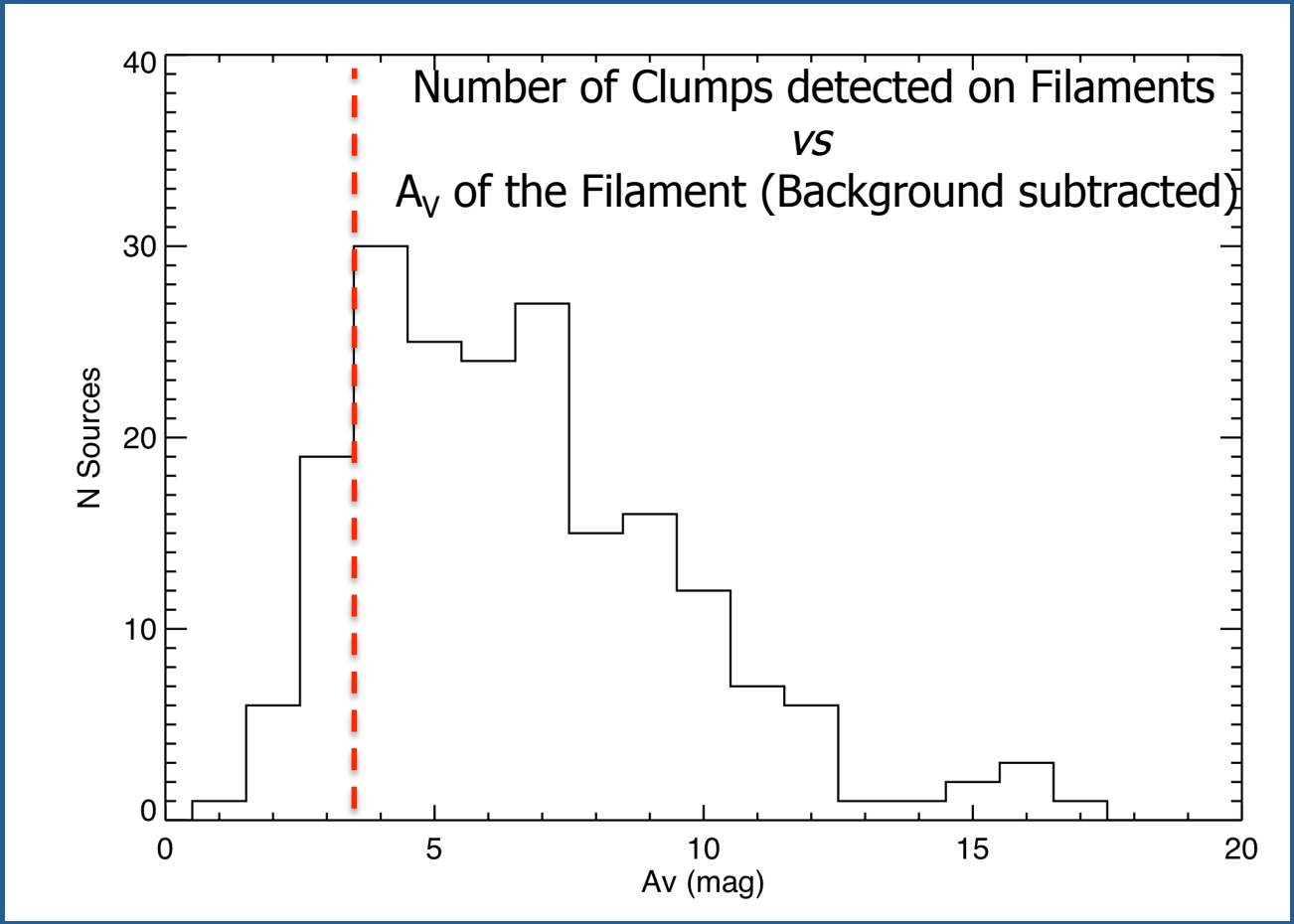
Star Formation drives up the energy budget in the clump, raising its global temperature and luminosity. This can be ideally followed in the [L,M] diagram

Compact Clumps surface density

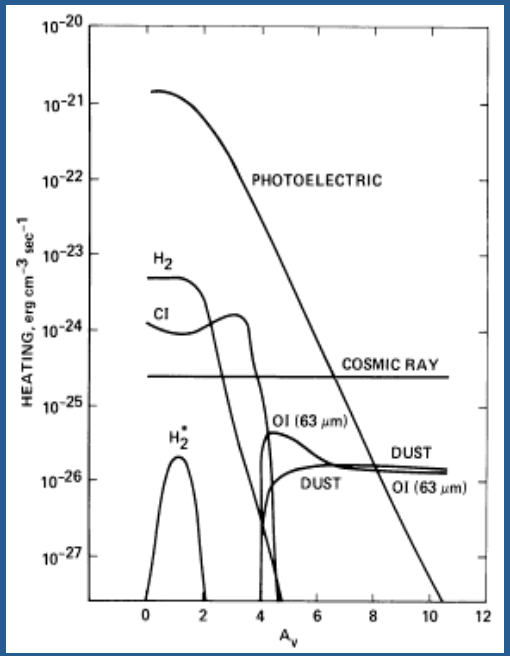


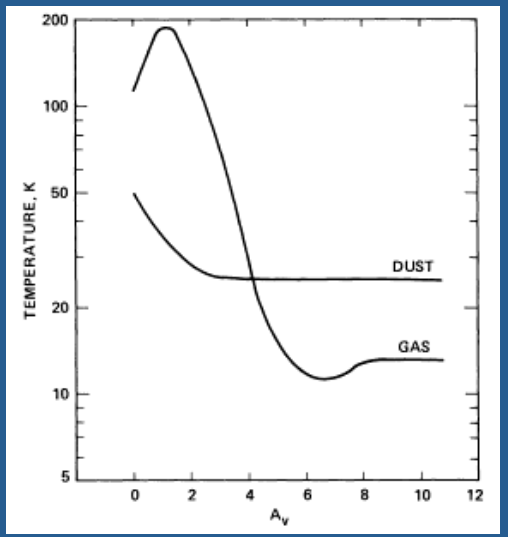
Dense Clumps with super-critical surface density $\Sigma > 1$ g cm^{-2} potentially able to form High-Mass stars, are preferentially found on filaments

A threshold for clump appearance



Tielens & Hollenbach 1985





A threshold at $A_V \approx 3$-4 is found, lower than towards nearby star forming regions (André+10, about $A_V=7$):

- are we looking at a different process ?
- beam dilution effects (our regions are more distant) ?
- different assumptions of background subtraction ?

Hi-GAL is pushing Galactic Star Formation into the Mega-Source era: are we ready for the consequences ?

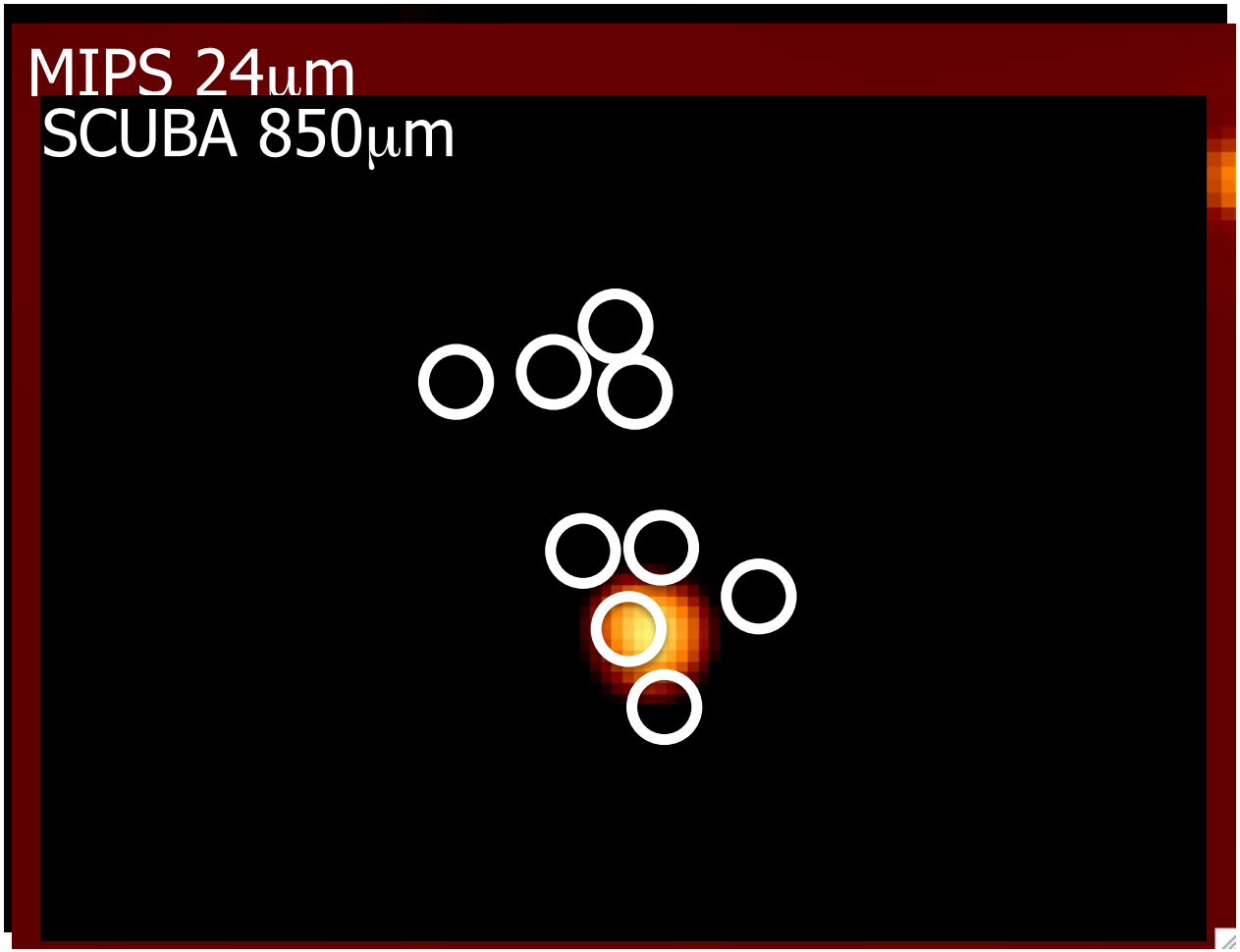
- Reliable bolometric luminosities are at the foundation of SFR estimates. Herschel spatial resolution improves an order of magnitude over IRAS, with the result that the bandmerging of Far-IR compact sources in the Galactic Plane is now a tractable nightmare…but yet a nightmare.

- Hi-GAL mostly reveals clumps/protoclusters for d≥1kpc systems; a factor 10 jump in accessible spatial resolution is needed to resolve the high-mass end of the mass function
- Improve diagnostic evolutionary tools: e.g. HII regions tracers like OIII, NIII and sensitive radio continuum to pinpoint the arrival on the ZAMS

- Chemical fingerprinting is the essential complement to the SED continuum characterization.

Rapid-fire & sensitive multiband continuum (full SAFARI range) and spectroscopic snapshots (single-dish and interferometry) for (tens of) thousands of clumps:
Hi-GAL catalogues will be the master target list to select source samples of your choice

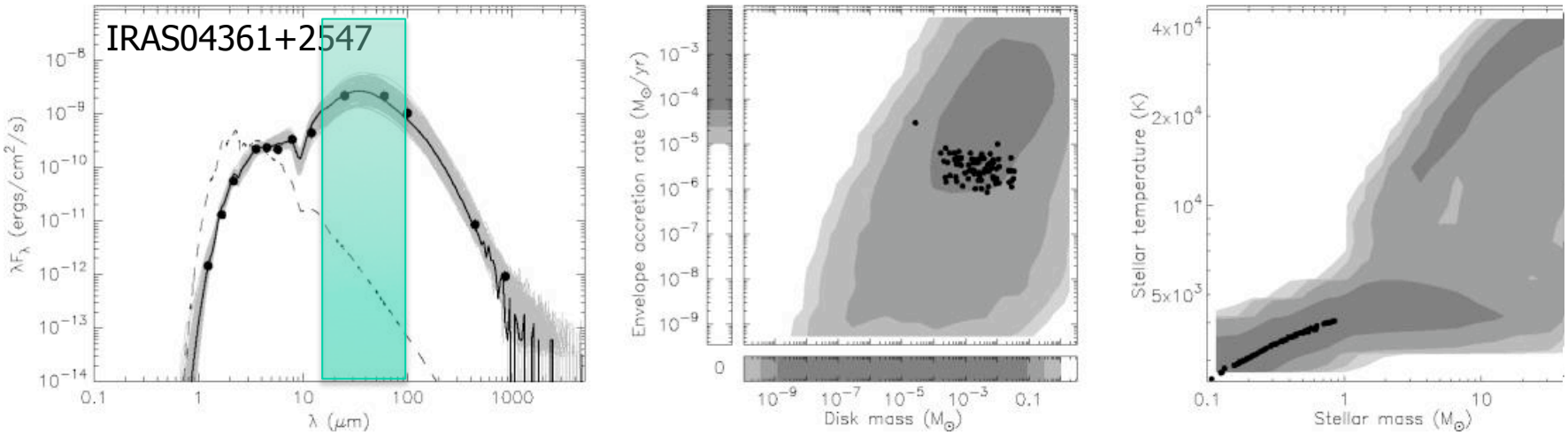
The continuum ZOO in Intermediate Mass SFRs



- Intermediate and High-Mass SFRs are systems where YSOs with very different SEDs coexist.
- Is the SED shape an age indicator ?
- Herschel is doing much especially in nailing down L_{bol}
- ….however, the $\lambda<70\mu m$ range is the critical one to constrain the SED models

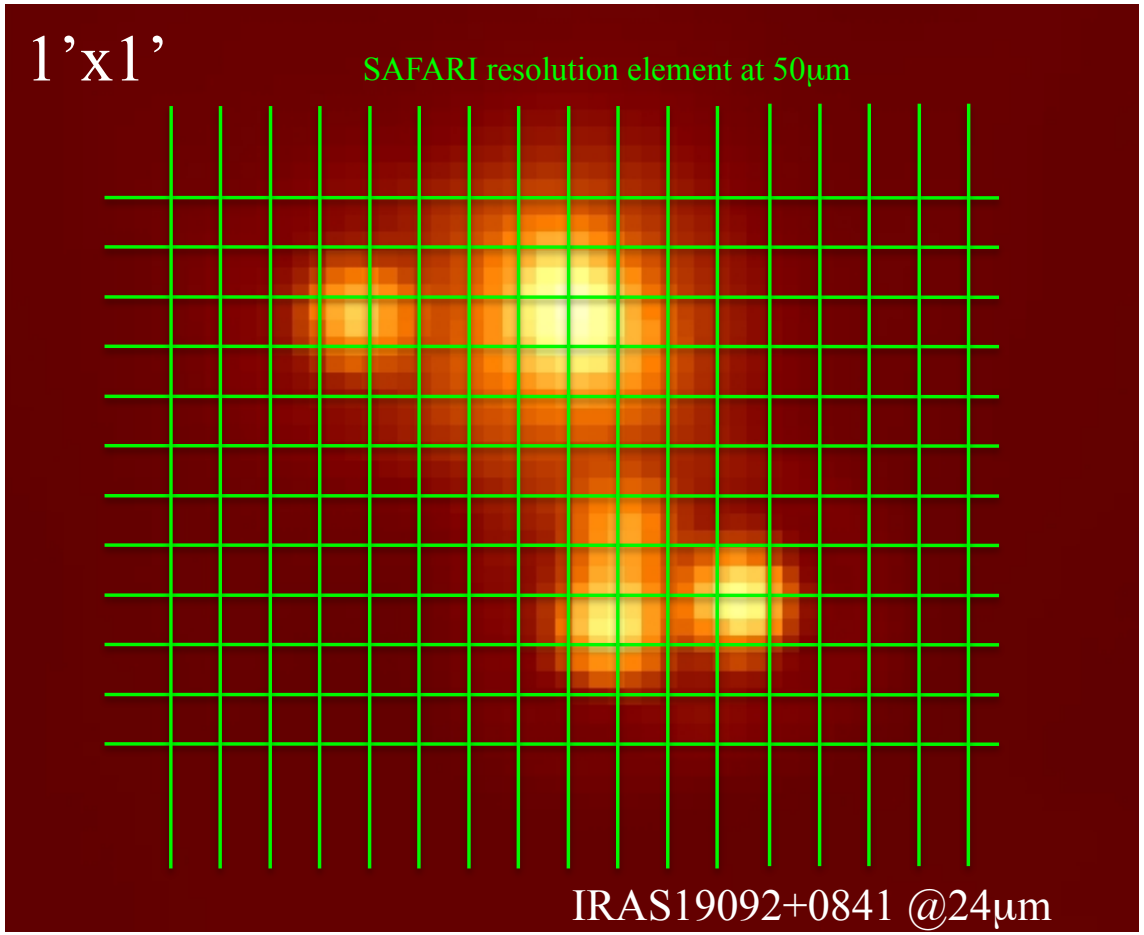
Nailing down the SED modeling of YSOs

Robitaille et al. 2007



- SED models now take by far more input parameters than available data: 3D geometries, scattering, holes, clumpiness, etc.
- Order-of-magnitude uncertainties in several critical parameters still in the Spitzer/Herschel era.
- SAFARI, as a high-sensitivity k-points SED-machine, will enter the era of spatially-resolved high-precision SED modeling.

Intermediate Mass SFRs



- One-shot demographic in intermediate and high-mass SFRs.
- Luminous YSOs are often resolved down to few 10^{-2} pc (less than half of SAFARI res. at 50μm at 5kpc): spatial resolution is a limitation (d≤ 1kpc ?)
- Saturation Problems: are NDF filters still an option ?

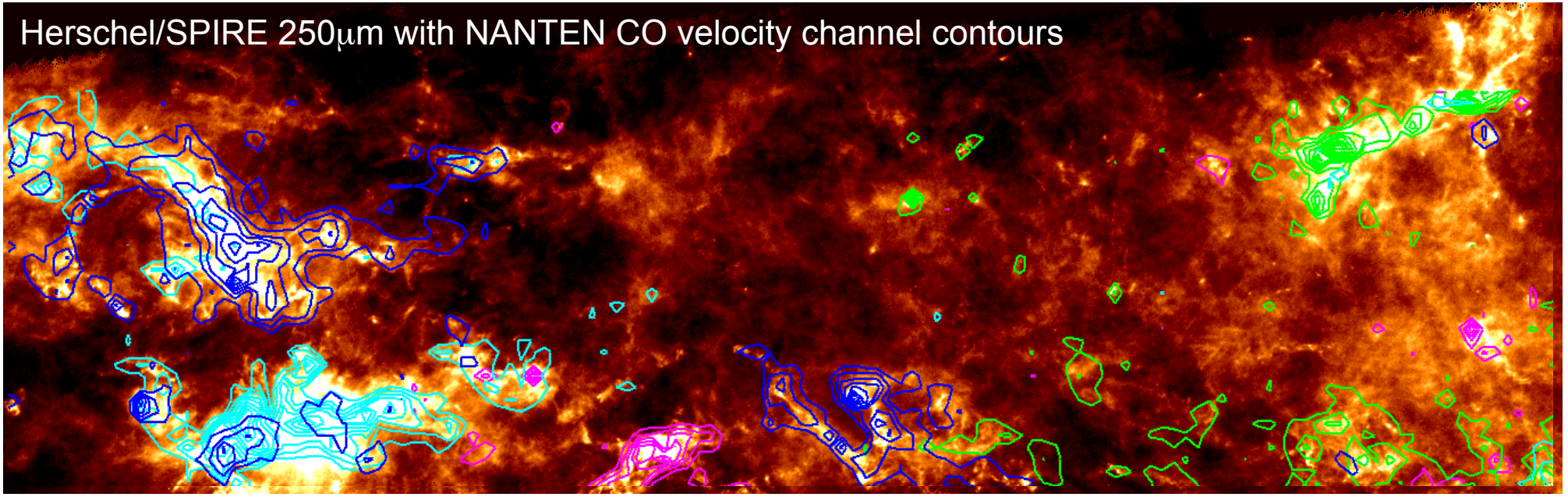
Hi-GAL is pushing Galactic Star Formation into the Mega-Cloud era: are we ready for the consequences ?

- How do filamentary molecular clouds form ?
  - Role of turbulence (?)
  - Is WNM pressure confinement important to keep clouds confined till thermal instability, and then gravitational instability, take over ?
  - Do we understand the HI→H_2 transition ? HISA, HINSA, $\tau_{HI \rightarrow H2}$
  - Do converging flows really exist ? are they relevant (i.e. is this the way molecular clouds form fast) ?
  - Role of magnetic field in channeling ISM onto the filaments.

- Sensitive large-scale spectroscopic mapping (on and around the filaments)
  - low [v_s ,n_0] shock tracers: low-J CO, SiO, [SiII],[OI],[CII],[NII]… to see if converging flows shocks really exist (e.g. Jimenez-Serra+ 2010 on G35.39, Schneider+ 10 on DR21): good for SPICA/SAFARI…CCAT ?
  - Chemistry evolution ISM→Filaments→Clumps: ices vs gas species: OH, H_2O, CO, CH_3OH…
  - atomic and HI→H_2 tracers to evaluate the role of turbulence and WNM pressure confinement: CI, CO, NII, …
- Sensitive large-scale continuum polarimetry mapping

A first look at the Outer Milky Way

$218° < l < 226°$



The Outer Galaxy is really THE unique place where the star formation process can be studied on different spiral arms relatively free of confusion

Elia et al., 2013 subm.