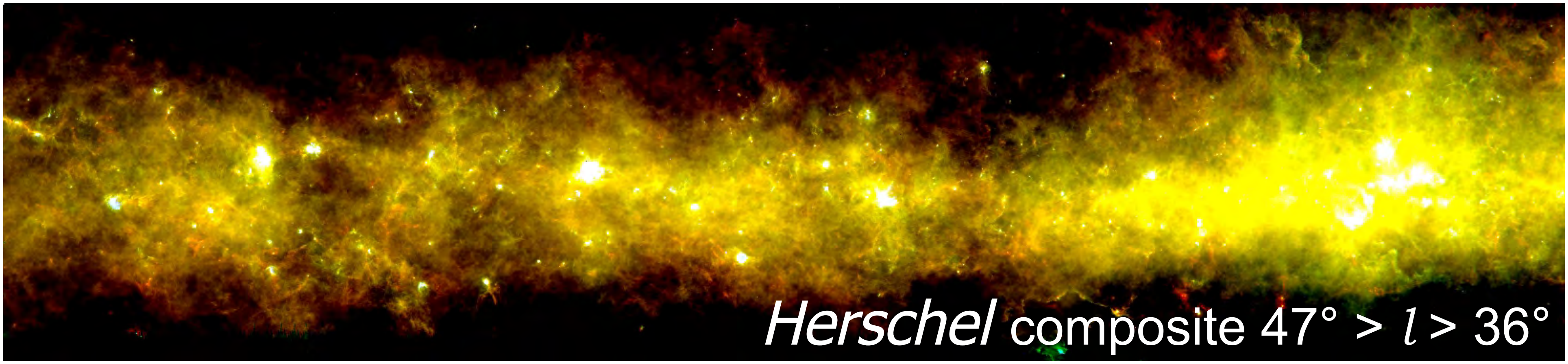


The Galaxy

In the Herschel Era

S. Molinari – INAF/IFSI, Rome

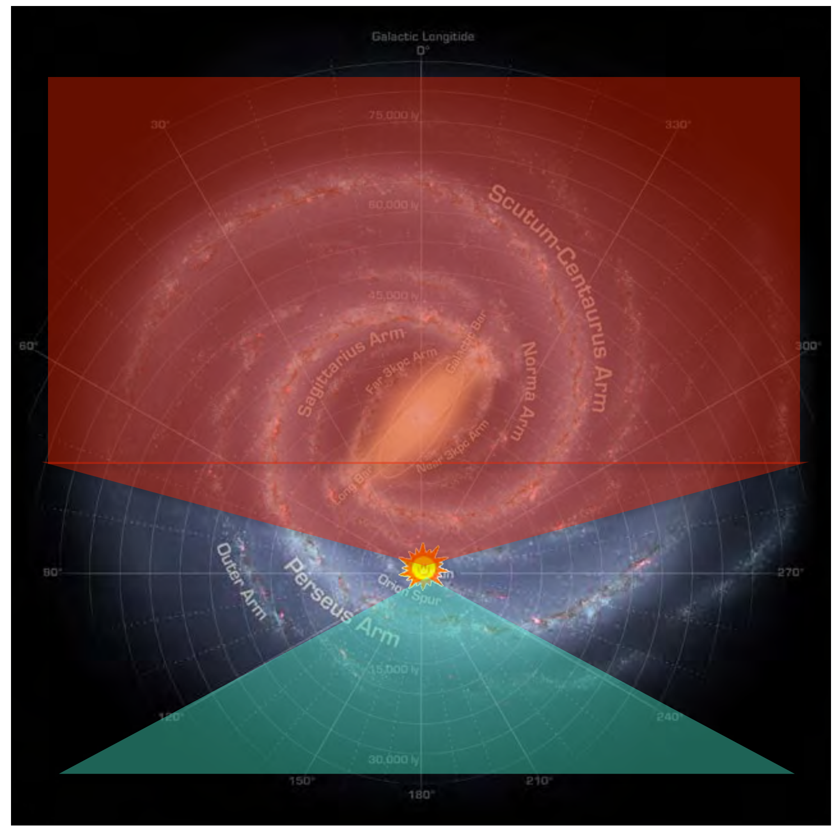
Hi-GAL team

IFSI - Arcetri - Univ. Rome 1/2 - Univ. Lecce (**Italy**), IRAP- LAM - IAS – CEA/SAp (**France**), RAL - Herts - Liverpool - Cardiff - UCL (**UK**), IPAC/SSC/JPL - Univ. Colorado - (**USA**), Toronto - Calgary - U. Laval (**Canada**), MPIfR - (**Germany**) et al.

Hi-Gal

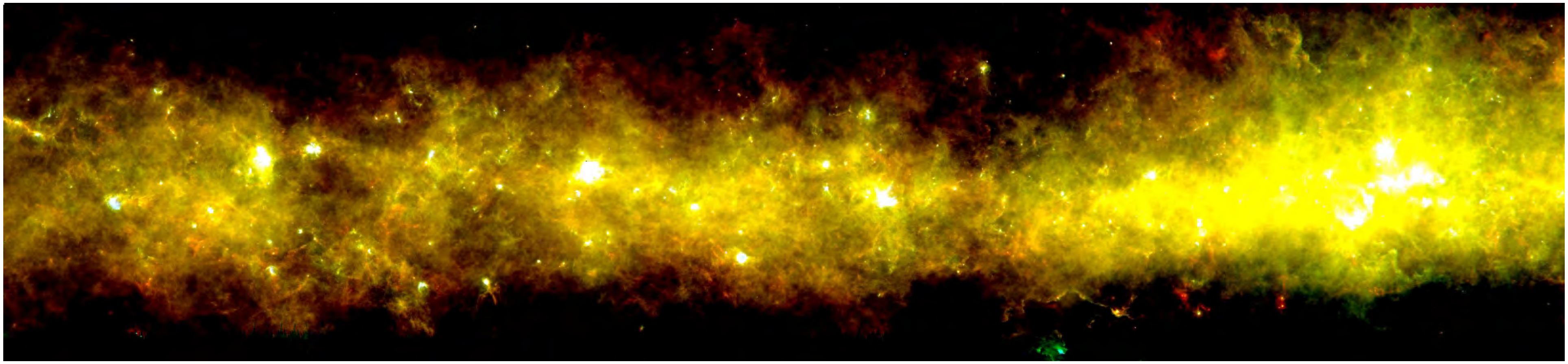
A Herschel Key-Project to map the Galactic Plane in the Far-IR

Simultaneous 5-bands (70-160-250-350-500μm) continuum mapping of 520 sq. deg. of the Galactic Plane ($|b|\leq 1°$)
With 620 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 Goals of the Herschel infrared Galactic Plane Survey



Toward a Predictive Global Model of Galactic Star Formation

- The High-Mass Star Formation Timeline
- Measure the star formation rate and history Galaxy-wide
- Cold dust in the Galactic Plane and the Formation of Molecular Clouds
- Understanding star formation laws and the nature of thresholds as a function of ISM properties across a full range of galactocentric radii metallicity and environmental conditions
- Determining the relative importance of global *vs* local, spontaneous *vs* triggering, agents that give rise to star formation.
- Build bottom-up recipes and prescriptions useful for Xgal science

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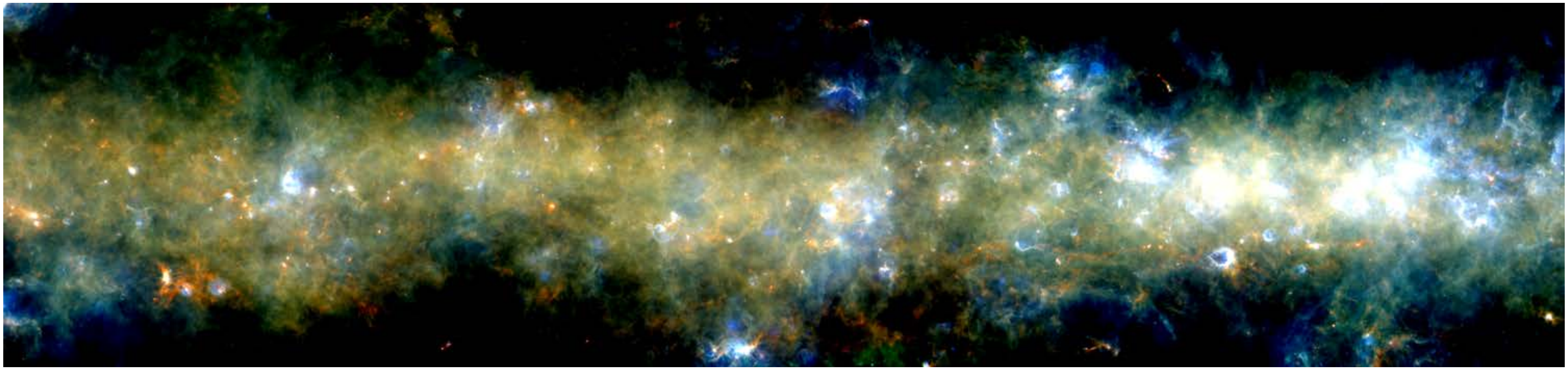

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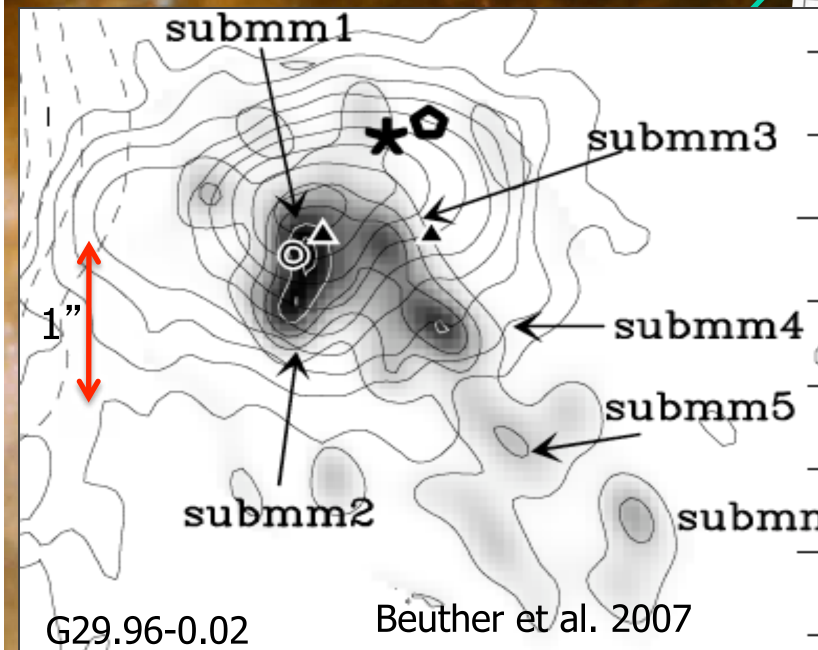
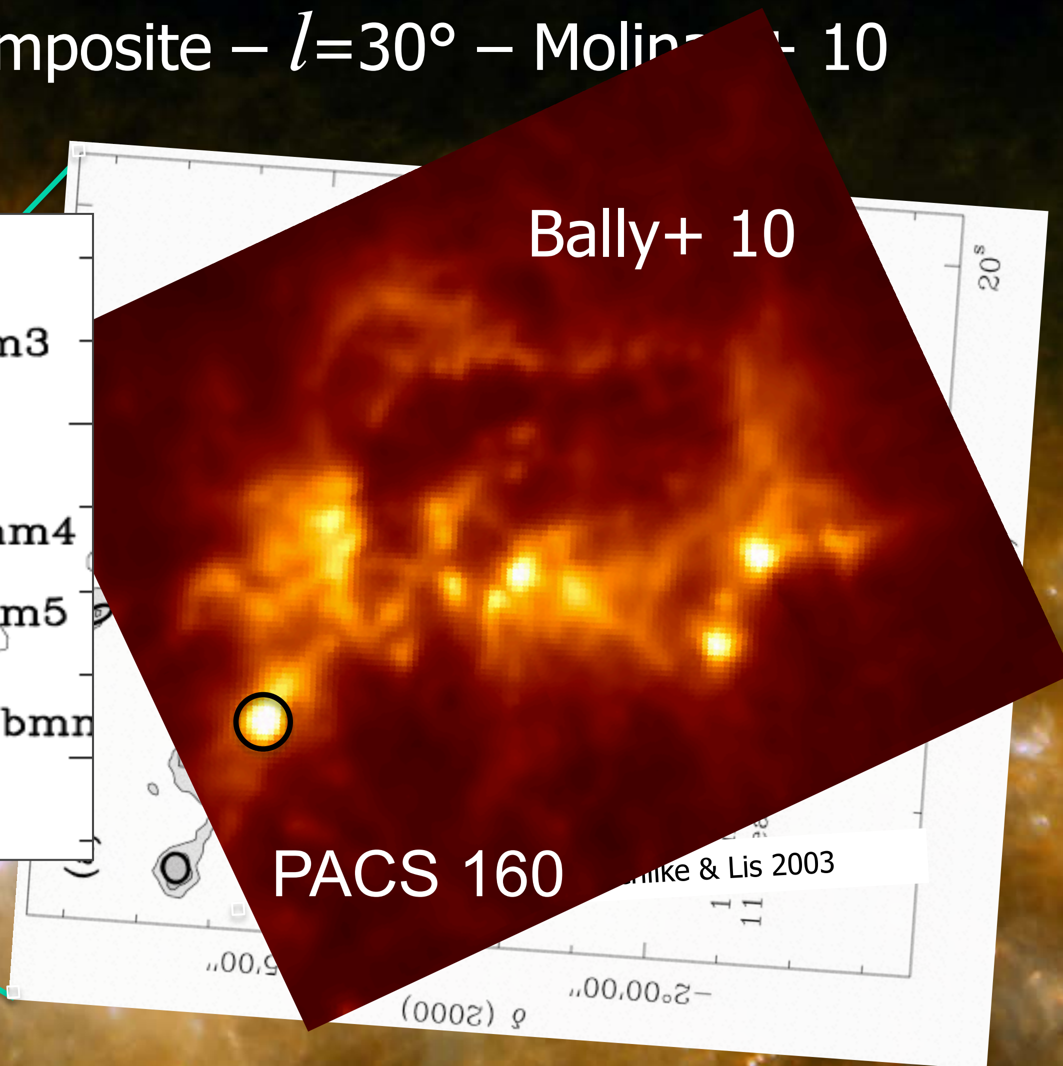
Hi-GAL 70/160/350 Composite – l=30° – Molin 10

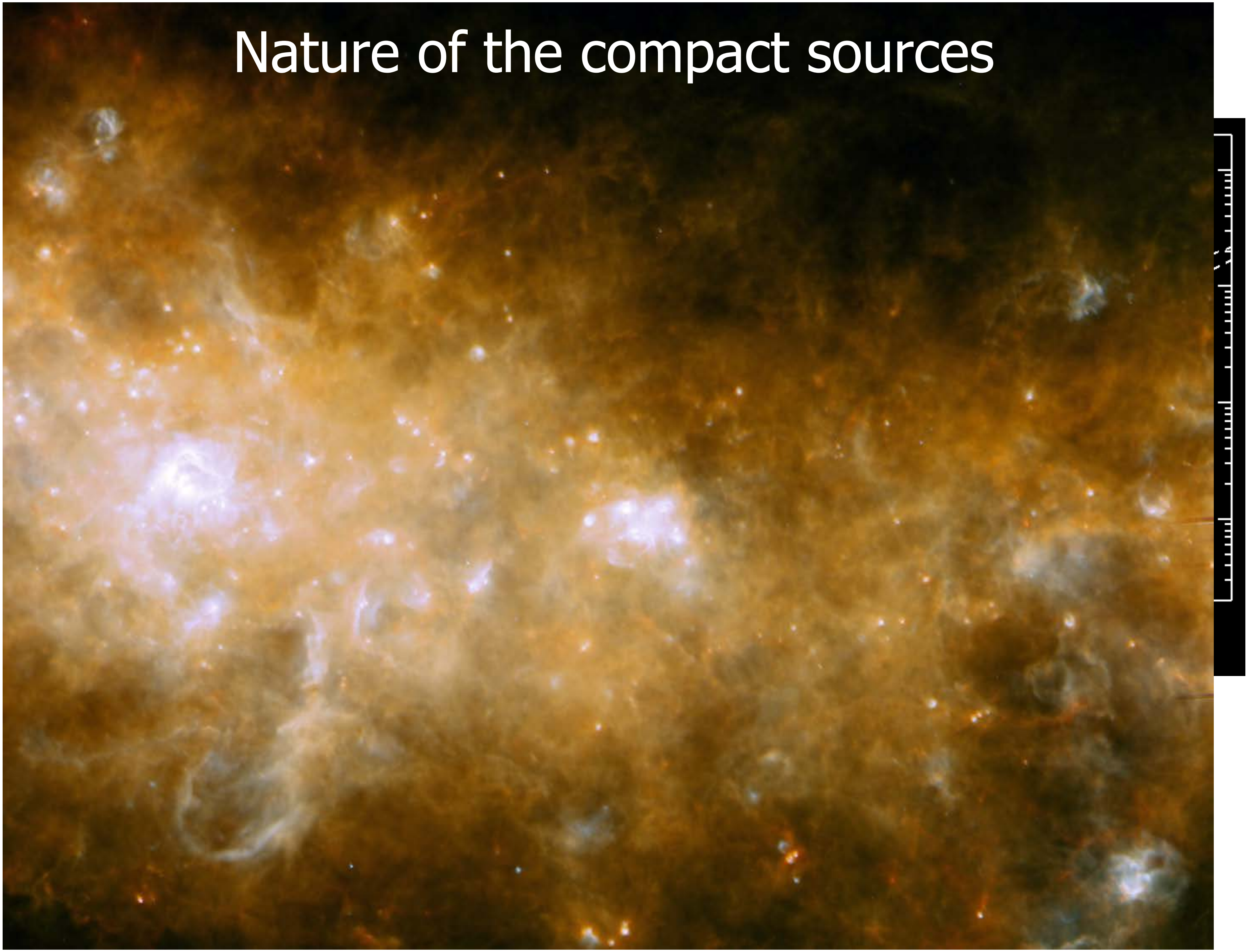




The black circle is the ALMA Band 9 primary beam !!

Herschel is crucial for ALMA

Nature of the compact sources

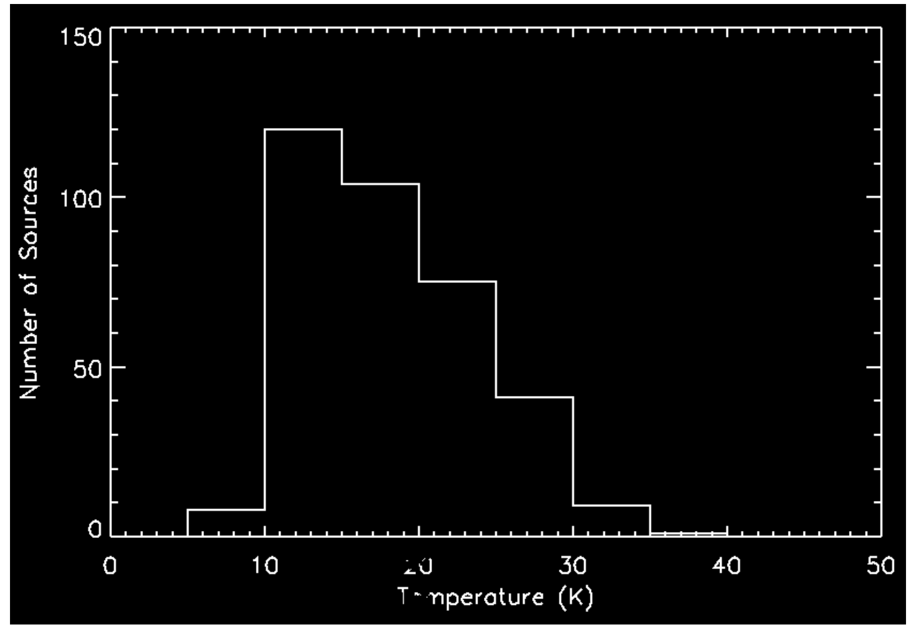


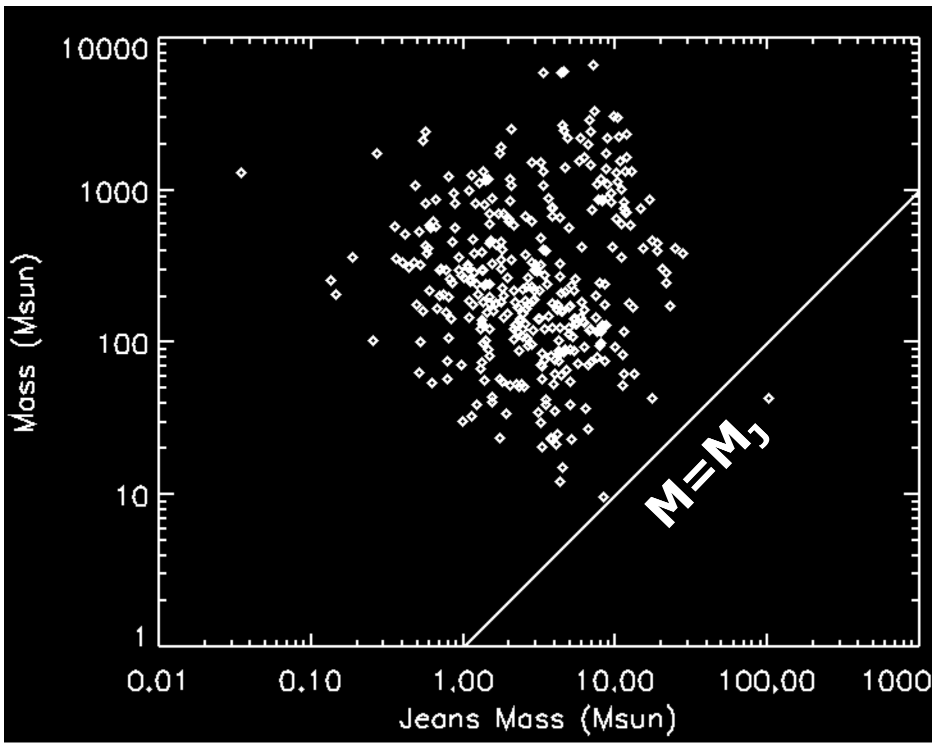
Nature of the compact sources (l=310°-320°)

Jeans conditions for gravitational instability

$$M_J(M_\Theta) = \left(\frac{T}{10K}\right)^{3/2} \cdot \left(\frac{n_{H_2}}{10^4\,cm^{-3}}\right)^{-1/2}$$

Mean Clumps Temperature

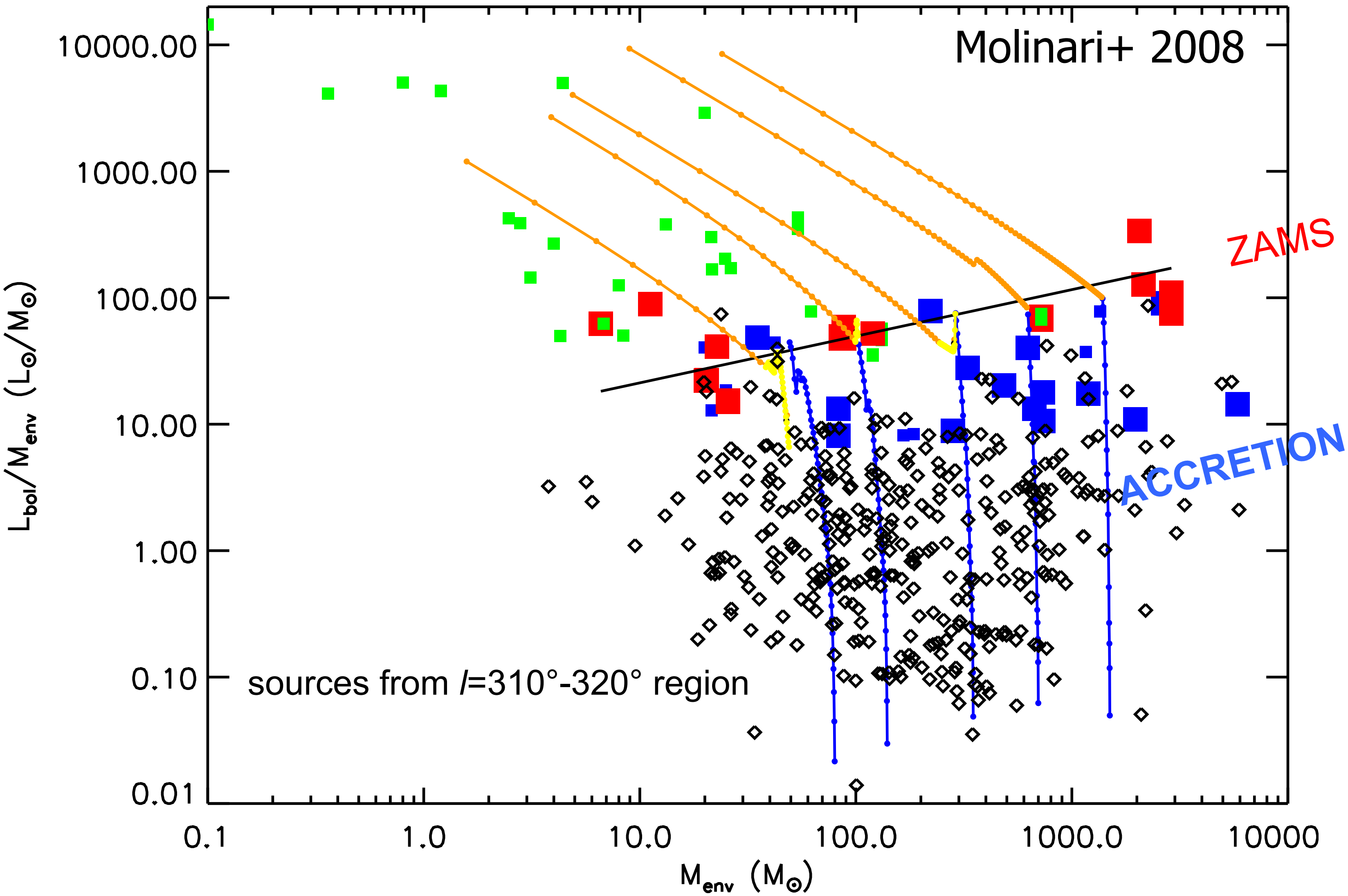




The majority of the detected cores may be gravitationally supercritical

again, kinematical information is the essential complement to confirm the dynamical status (bound, virialised, etc.)

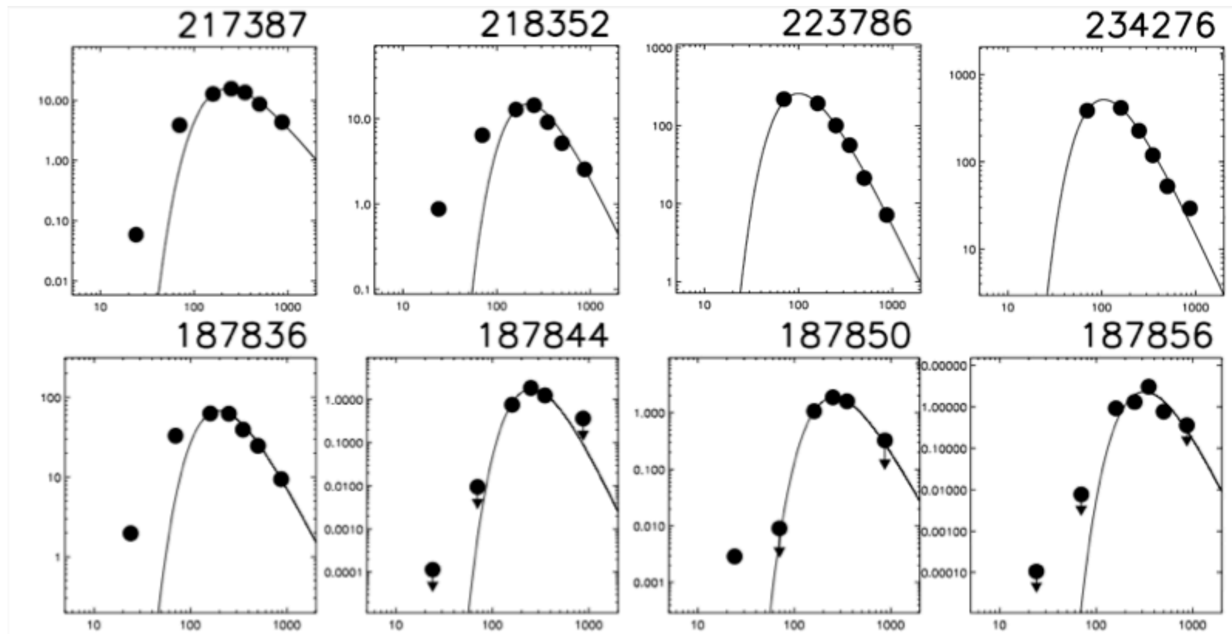
L/M: Evolution ?



Sources in Hi-GAL are mostly clumps, while SED models are for single YSOs (Robitaille et al. 2006): increase spatial resolution or create synthetic protocluster SED model (probably both).

Hi-GAL is statistics: Huge output…

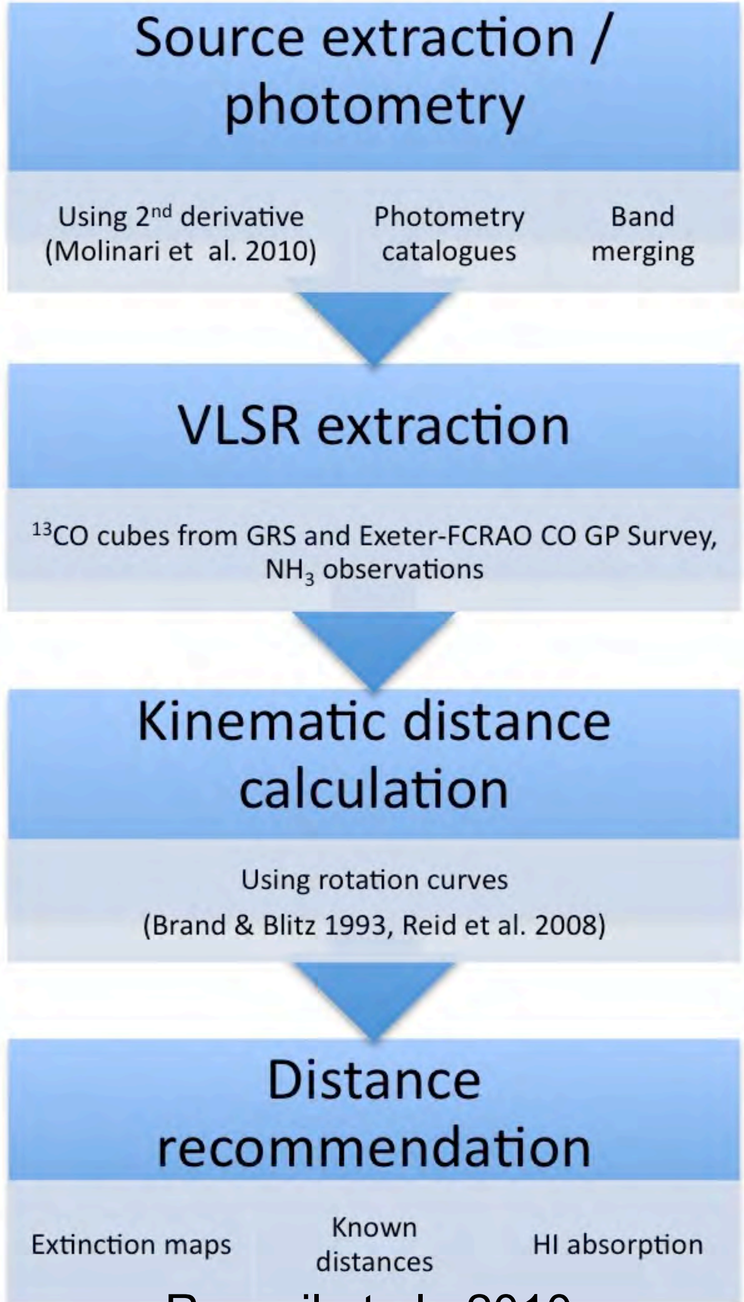
Using CuTEx package(Molinari+ 10) we attempted a first quick extraction from the entire inner Galaxy survey, resulting in a preliminar bandmerged catalogue of **428.000** entries.



The catalogue contains:
peak and integrated fluxes, sizes at the different wavelengths.
For sources with counterparts in at least three bands (more than 50000 at the moment) we augment SED coverage with on-target counterpart extraction from ATLASGAL and MIPSGAL24, with estimates of T, L, M and size for an arbitrary distance of 1 kpc, for **almost** all sources… **preliminar** is a key word ;)

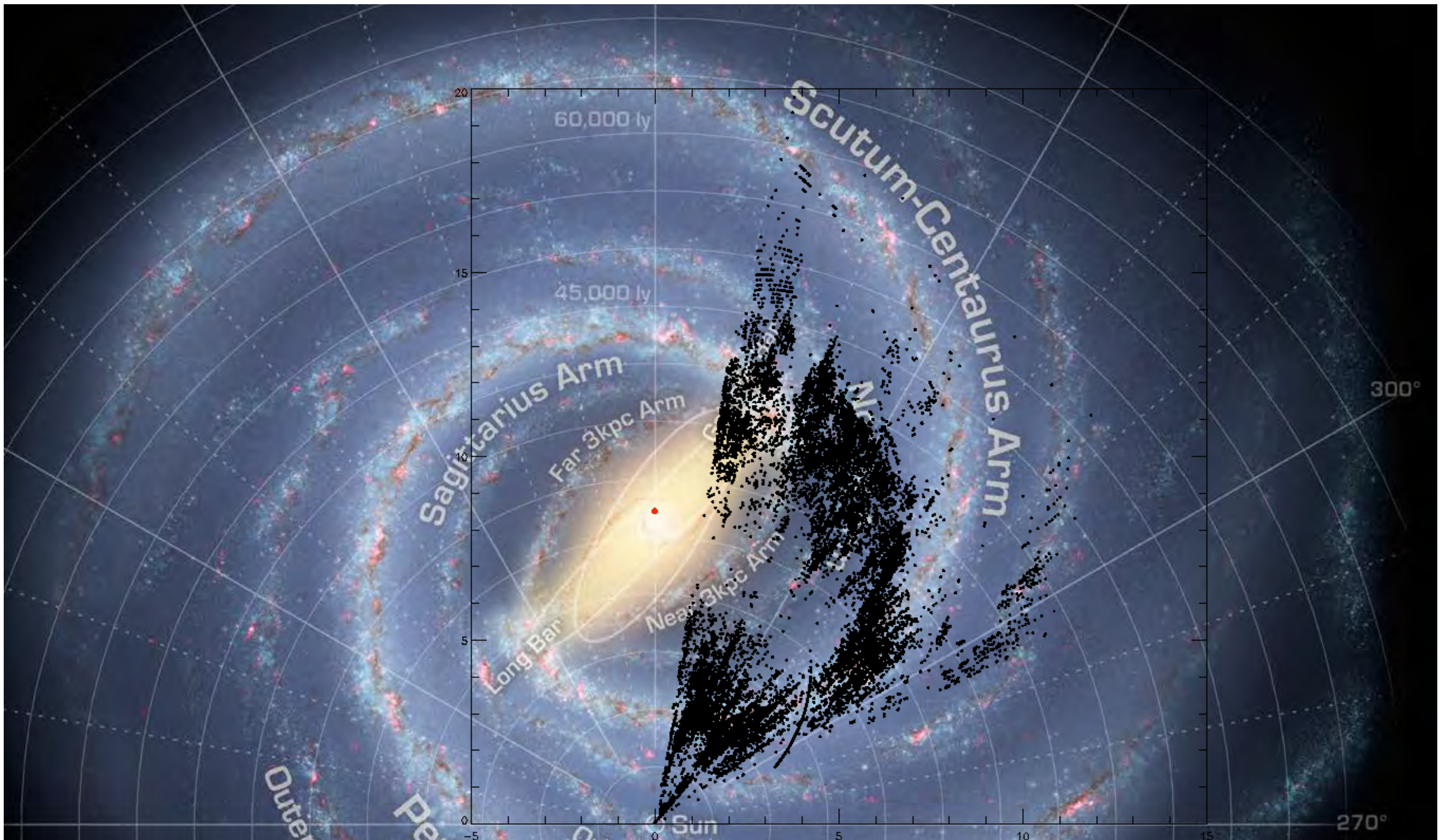
Distan stances

- Large obser btain V_{LSR} of compact obj
  - APEX for C elsberg for NH_3
- Exploitation pes
  - GRS (first c urth quadrant)
- To date: son stances available, m us!



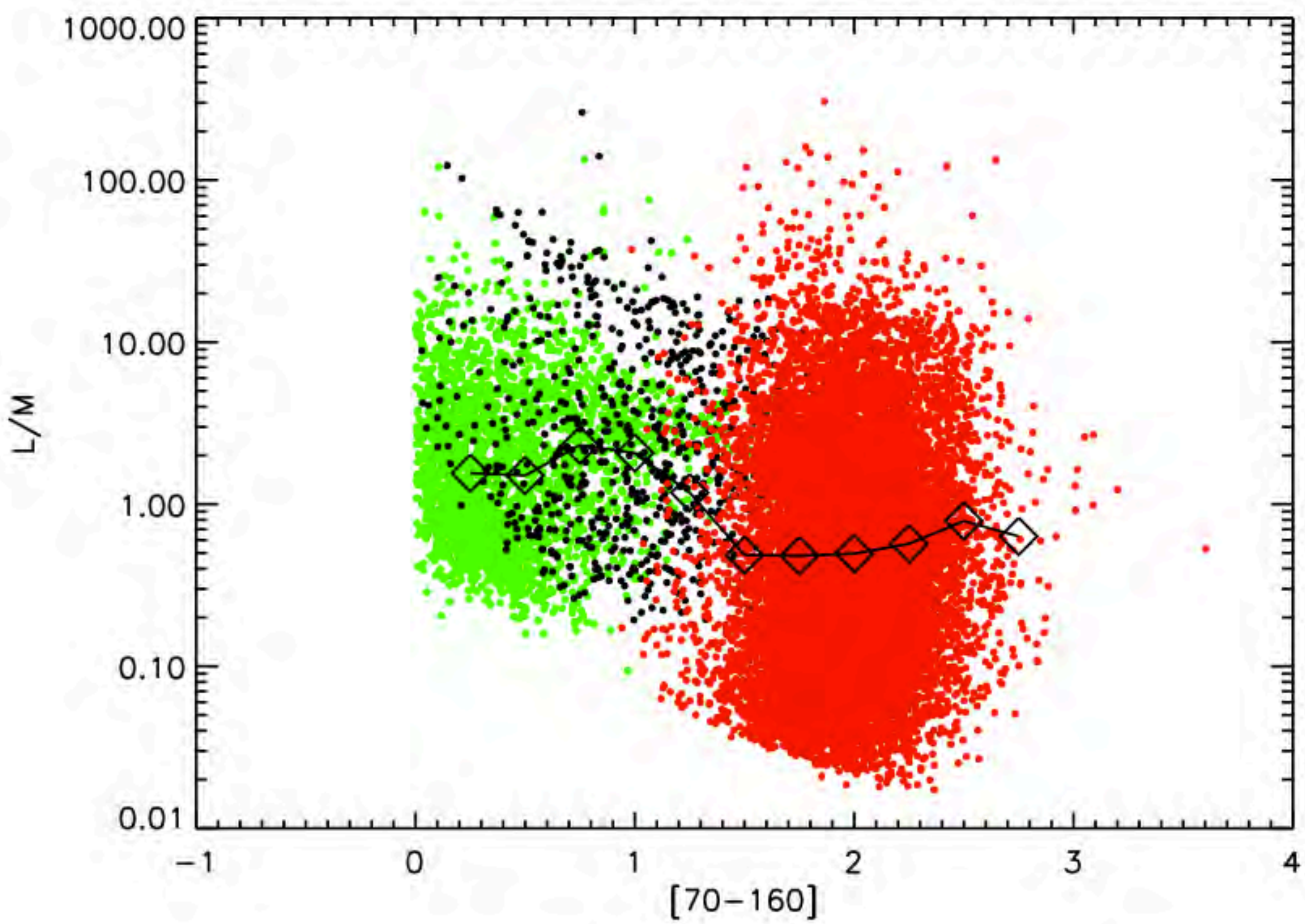
Russeil et al., 2010

Example: about 17000 sources with counterparts automatically extracted from the NANTEN CO cube and for which a near/far recommendation could be made

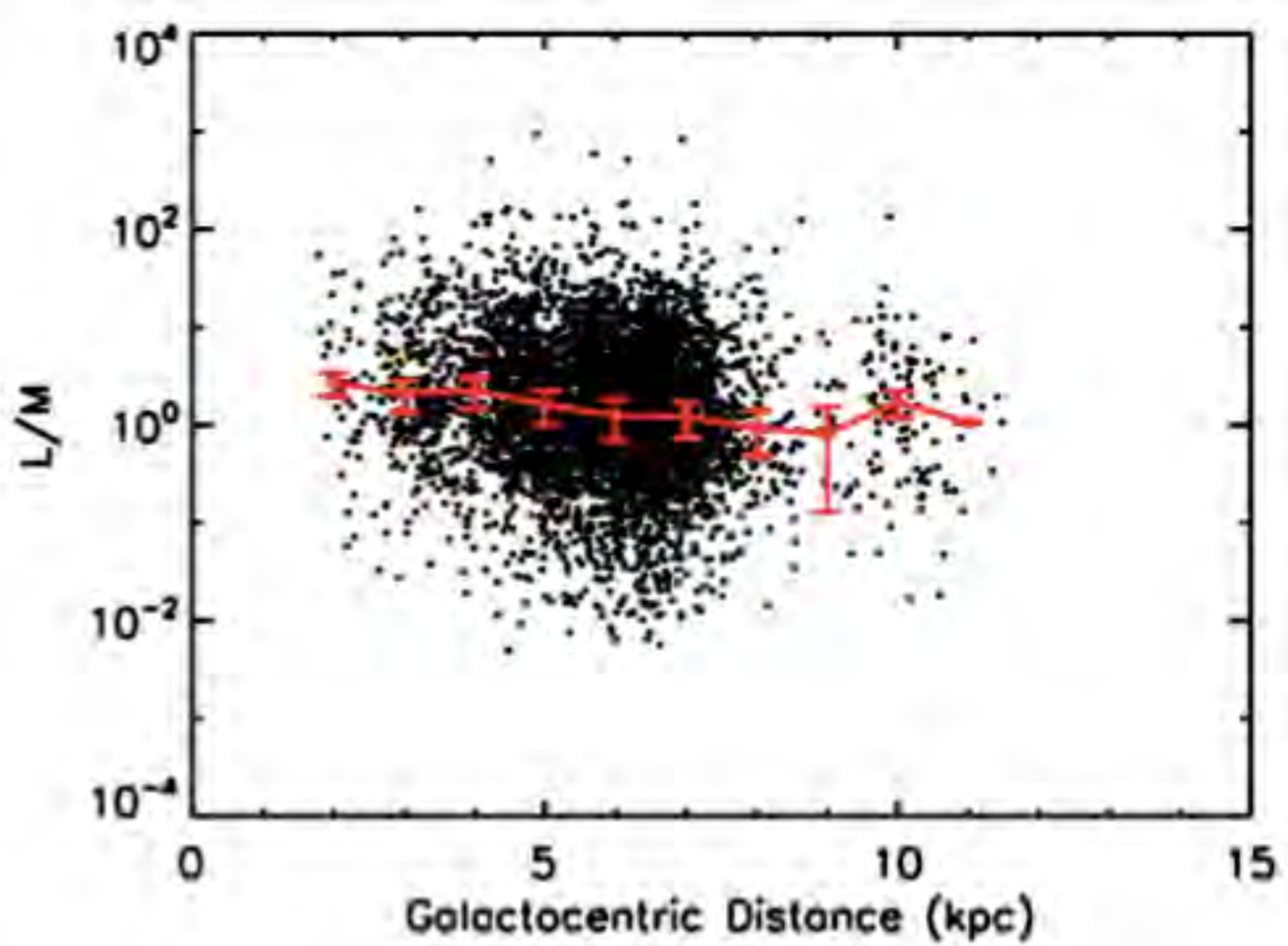


Where are the sources on the far Scutum Arm ?
Is NANTEN CO survey is not sufficiently sensitive ? Is Herschel confusion limited ?

Select sources with counterparts in at least three bands and while you try to make sense out of it, start looking for trends with distance-independent indicators….



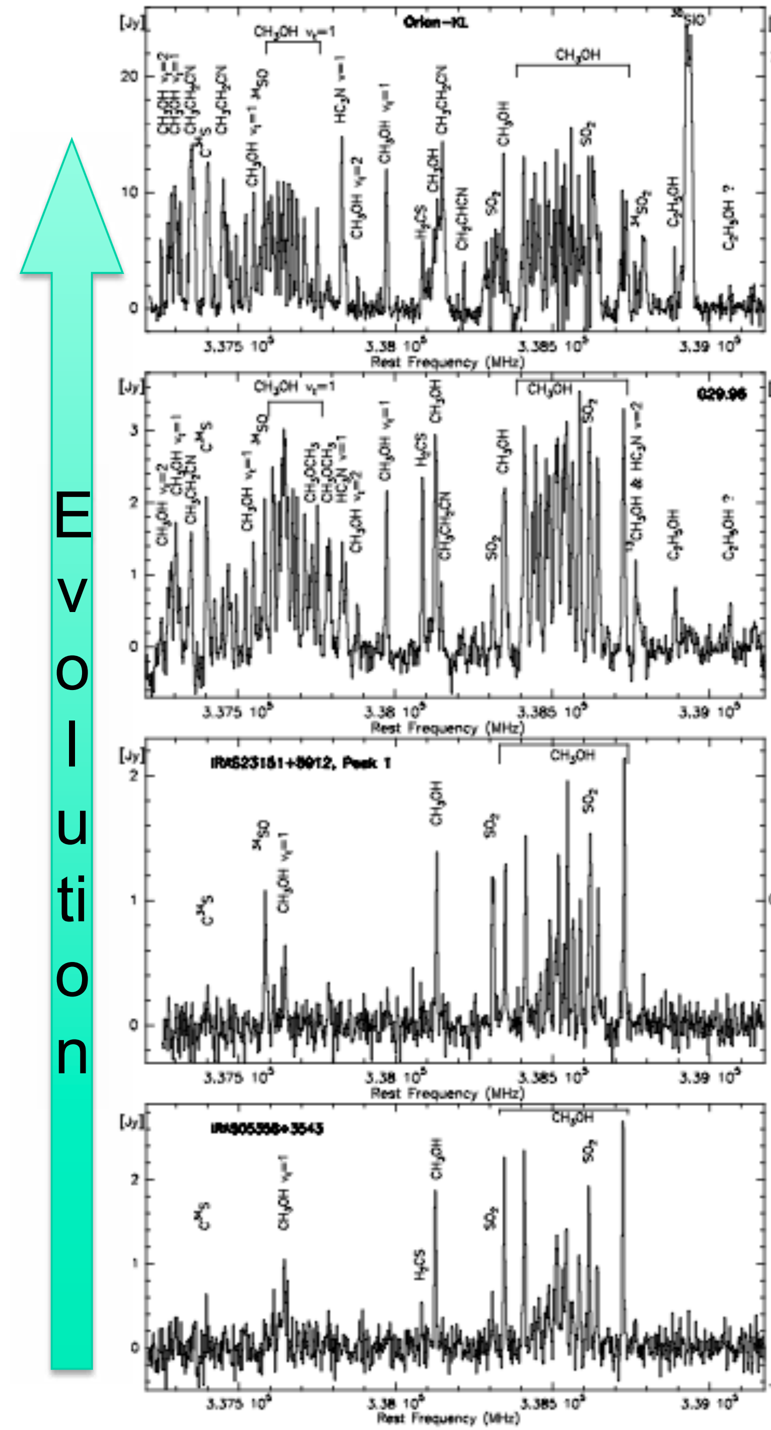
L/M as a proxy for evolution and Star Formation Efficiency: large scatter



L/M as a proxy for Star Formation Efficiency decreasing outward ? …but evolution (and a number of other effects and problems) needs to be disentangled….

Chemistry fingerprints are the essential complement for a correct evolutionary assessment

…only available on a numerable set of sources



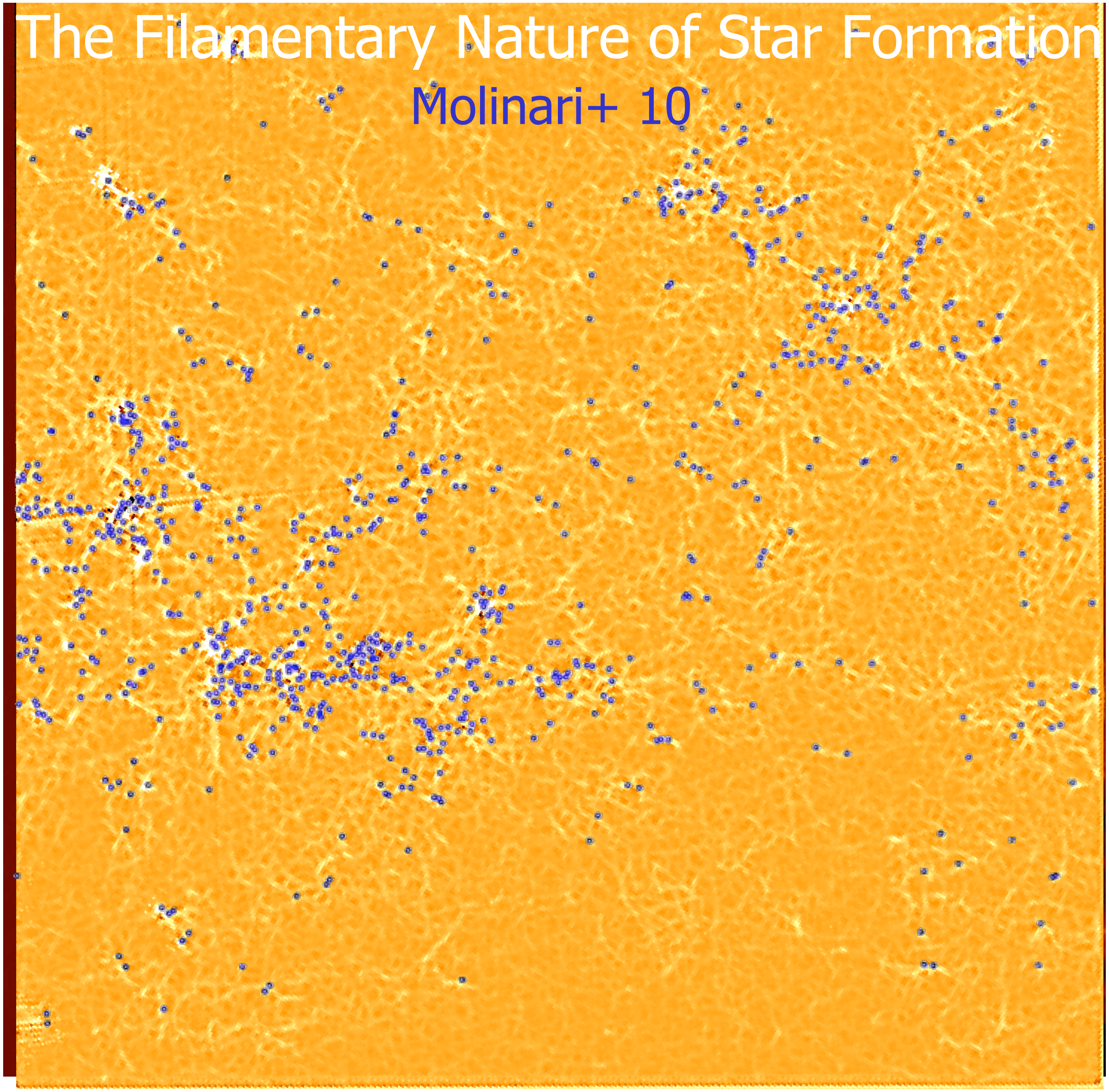
Hi-GAL is pushing Galactic Star Formation into the Mega-SED era: are we ready for the consequences ?

- 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 will mostly reveal clumps/protoclusters for $d \geq 2$kpc systems; a factor 10 jump in accessible spatial resolution at the peak of SEDs (about 200μm) is needed
- Chemical fingerprinting is the essential complement to the SED continuum characterization.
- High sensitivity submm continuum & spectroscopy is needed to unlock access to the far side of the Galaxy

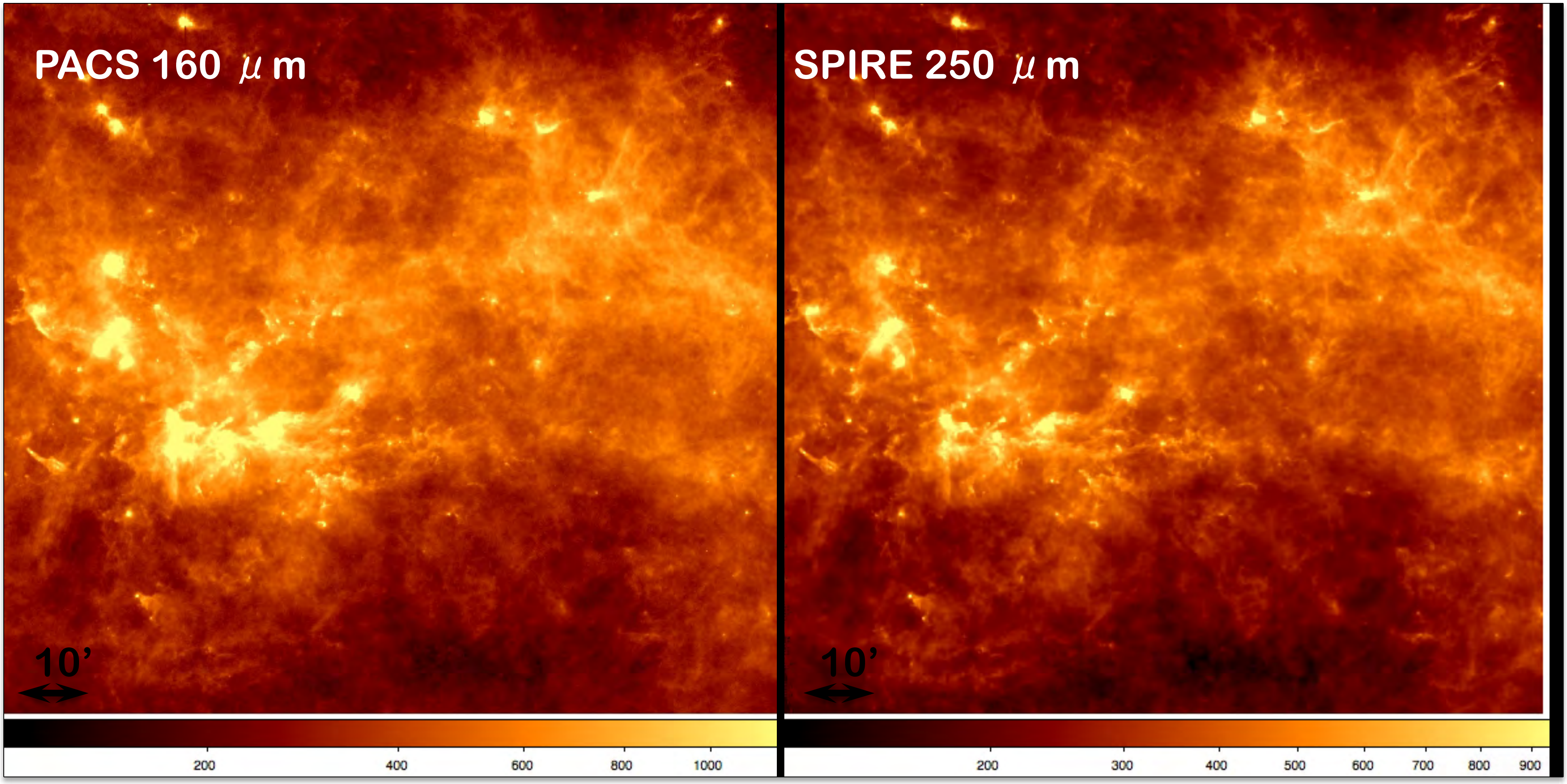
Rapid-fire & sensitive multiband continuum and spectroscopic snapshots for (tens of) thousands of clumps: Hi-GAL catalogues will be the master target list to select source samples of your choice

The Filamentary Nature of Star Formation

Molinari+ 10



A case of study - L59 region



Using the photometry package CuTEx (Molinari et al. 2010) we identified the compact sources in the Vulpecula field. Improvement in the extraction techniques allowed us to find 401 candidates with robust indipendent detection in the 3 consecutive bands of 160, 250, 350 μm.

Filament identification in a nutshell - 1

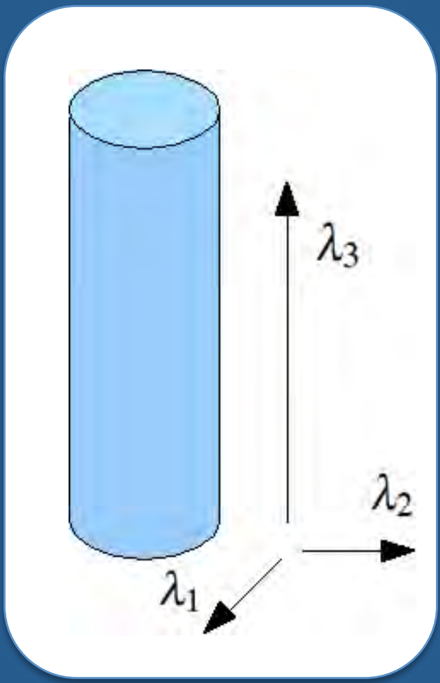
Filament: Structure that is <u>concave down</u> along two different principal axes <u>and is almost flat</u> in the other one.

Method used on cosmological datasets to identify underlying structures (Aragon-Calvo et al.2007, Bond et al 2010)

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.

Extended not elongated regions are rejected by criteria on the highest eigenvalue and the eigenvectors.

<u>However the method may miss structures with large variations of emission along the axis of the cylinder (flat condition along filament axis often are not fulfilled)</u>



Filament identification in a nutshell - 2

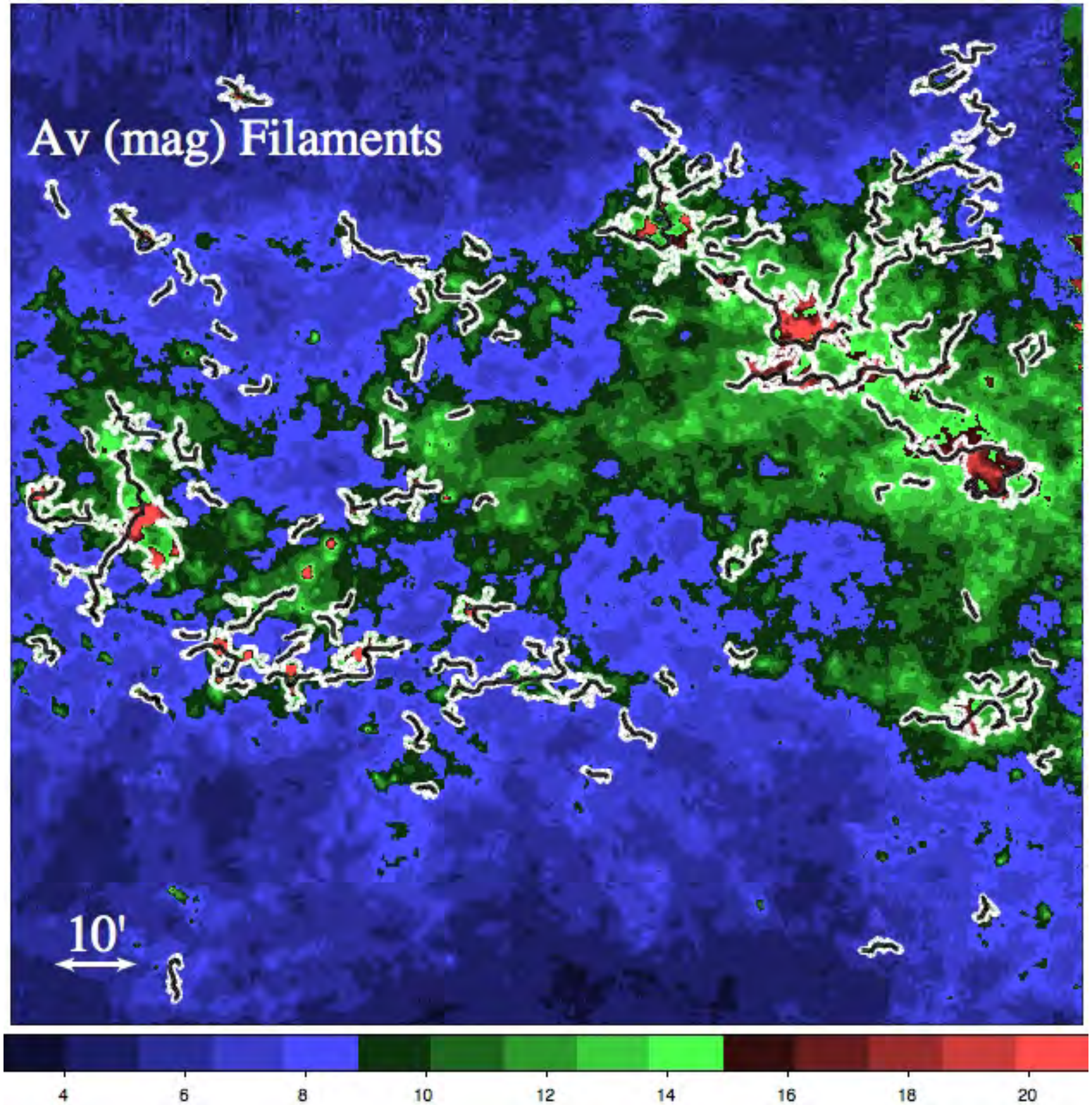
We complement the Hessian approach with an Edge Dectector-type method.

We compute the eigenvalues of the Hessian Matrix and determine a threshold value to identify the pixels belonging to the filament.

Assuming that the Filament is symmetric in its shape we apply the morphological operators of erosion (Gonzales & Wood 2002) to determine an estimate of the central "Spine" (see also Qu & Shih 2005)

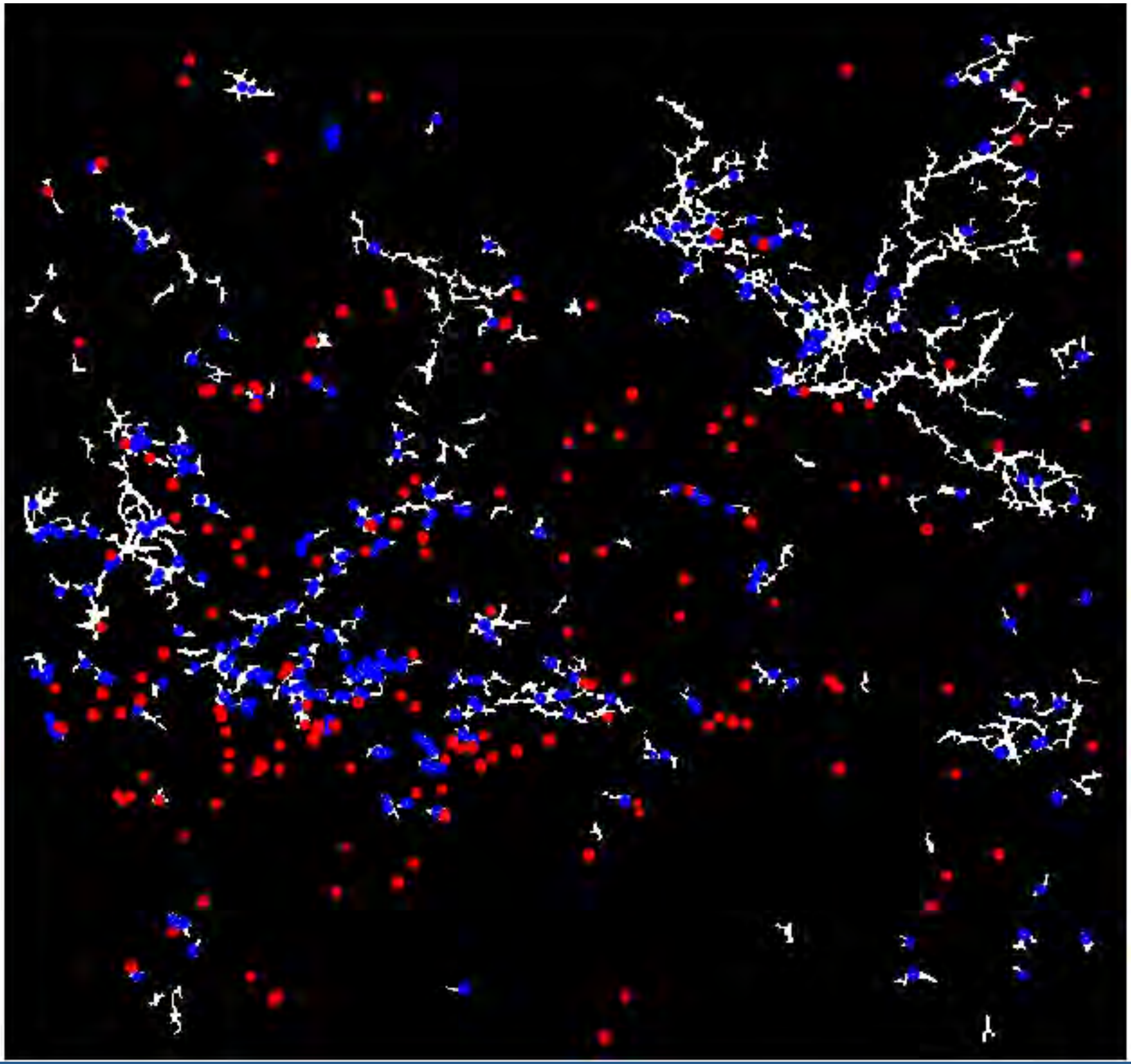
All the points of the "Spine" are then connected through a Minimum Spanning Tree (MST) that give the unique path linking together all the pixels of the spine.

A case of study - L59 region



- We identied 100 filaments that have a mean length longer than 200” (> 2 pc @ 2.2 kpc)
- 60 more structures are identified as candidates coherent structures (i.e. IRDC-like) but are shorter than 200” and we do not call them filaments.
- Original masks includes hundreds of small scale structures, highlighted by the derivative computation.

We are automatically detecting what people have been calling IRDCs till now, with the ability to distinguish them from IRDP (DW-T)



Blue: Sources inside filament

Red: sources outside filaments

Adopting the catalog of the compact objects with detections in at least 3 bands

260 sources inside ~61 %

163 sources outside ~39 %

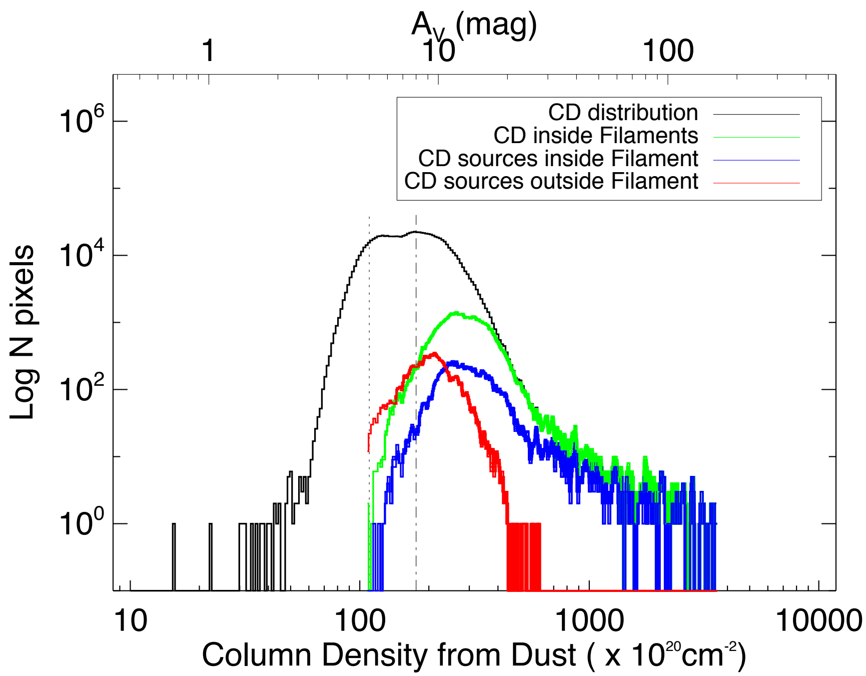
However, considering the sources that are detected only at SPIRE wavelengths we find that the number of sources inside and outside filament are evenly splitted

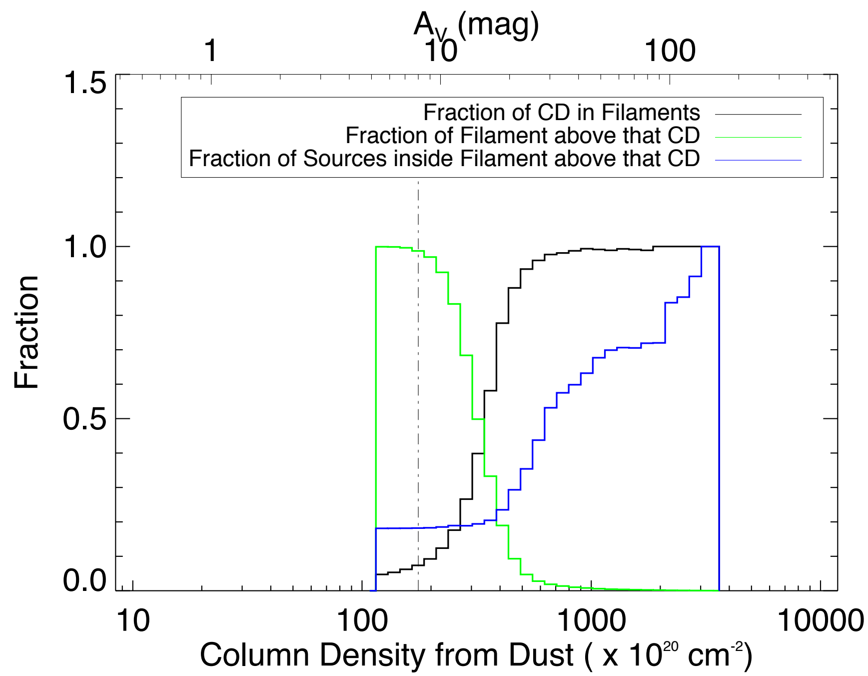
Still need to be investigated

Fraction of Dense matter distributed in filamentary region:

All the observed higher density regions belong to filamentary regions

~50% of the matter with Av > 20 is identified as belonging to a source inside the filament

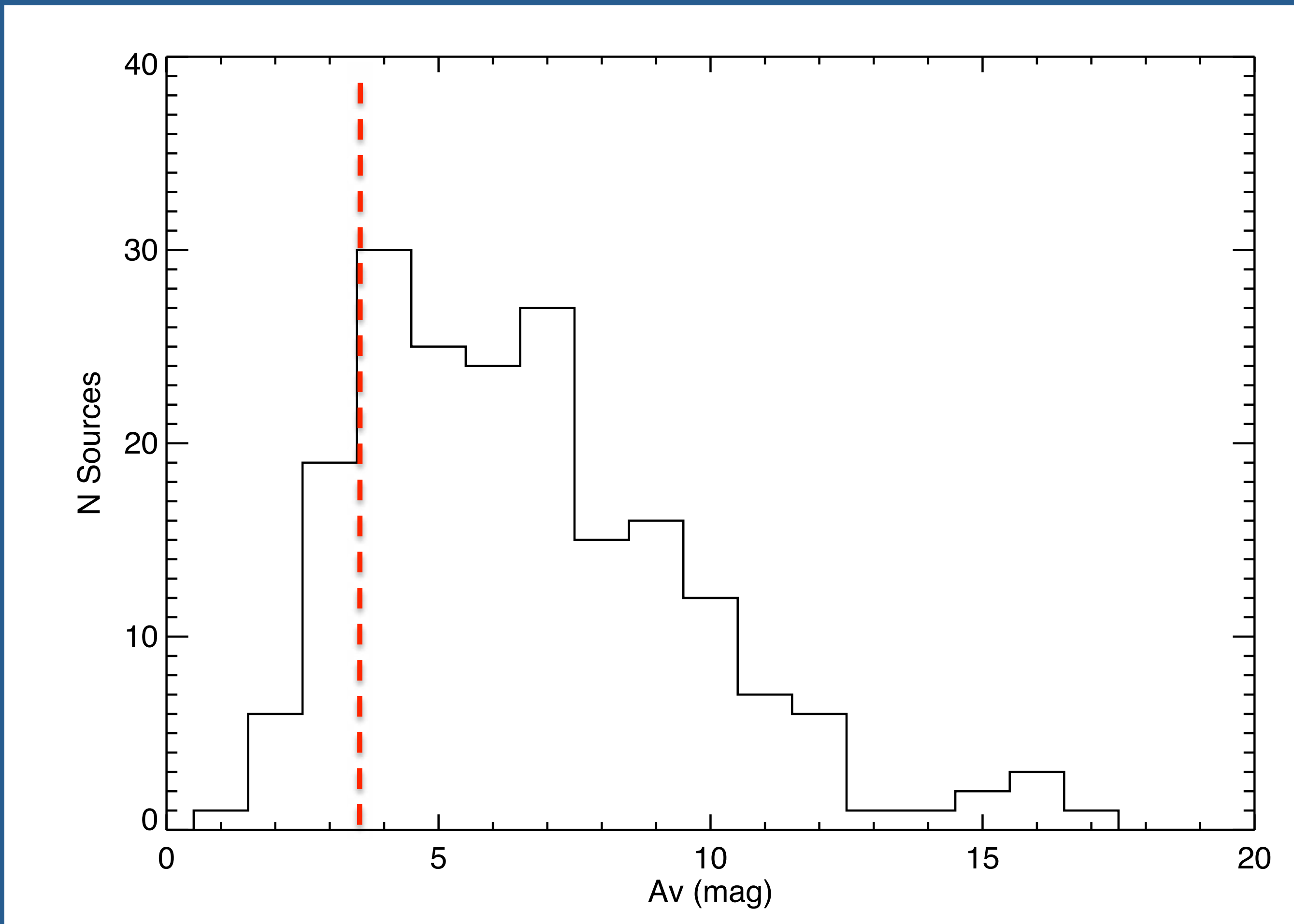


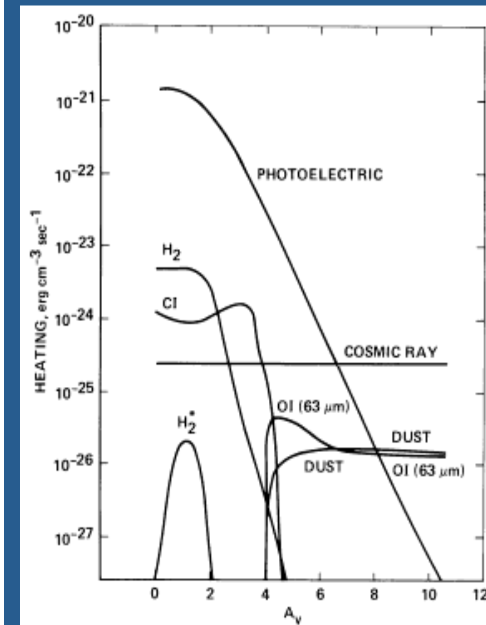


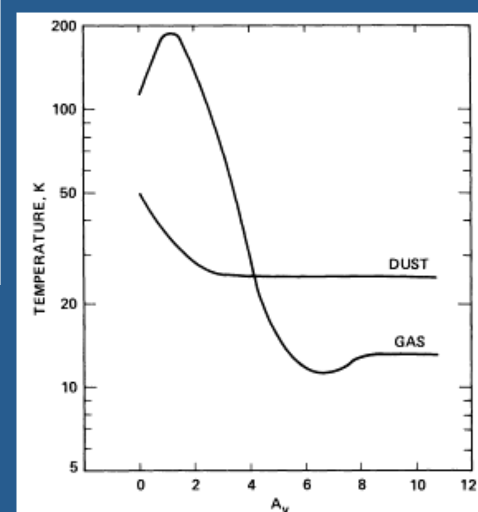
in good agreement with PDFs form numerical HD/MHD simulations of filament formation (Hennebelle et al. 2008)

Schisano et al. in prep

A threshold for clump appearance



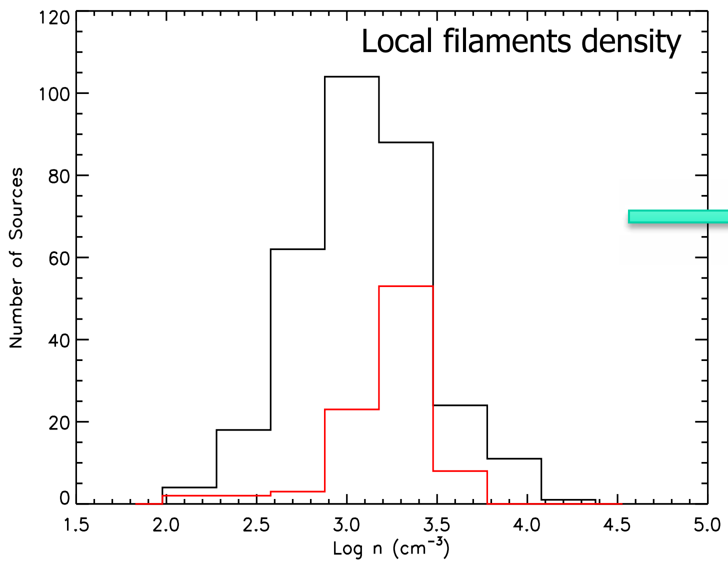


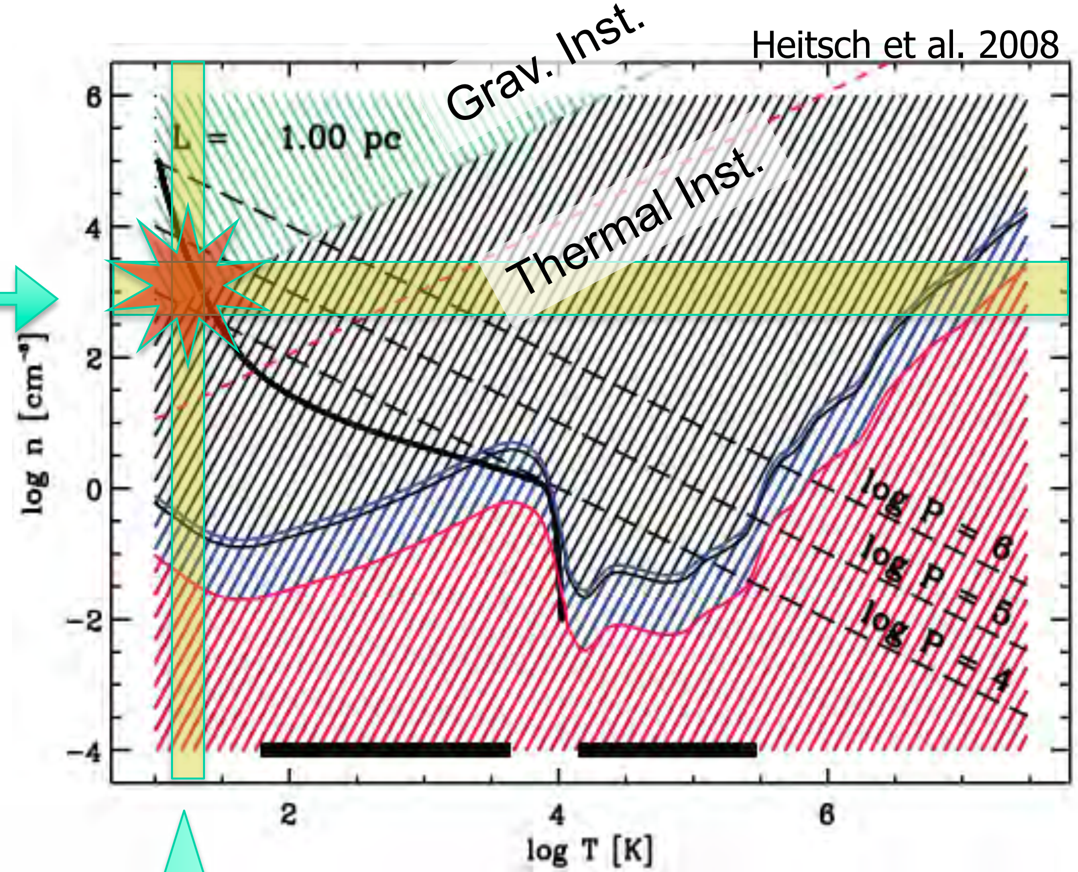


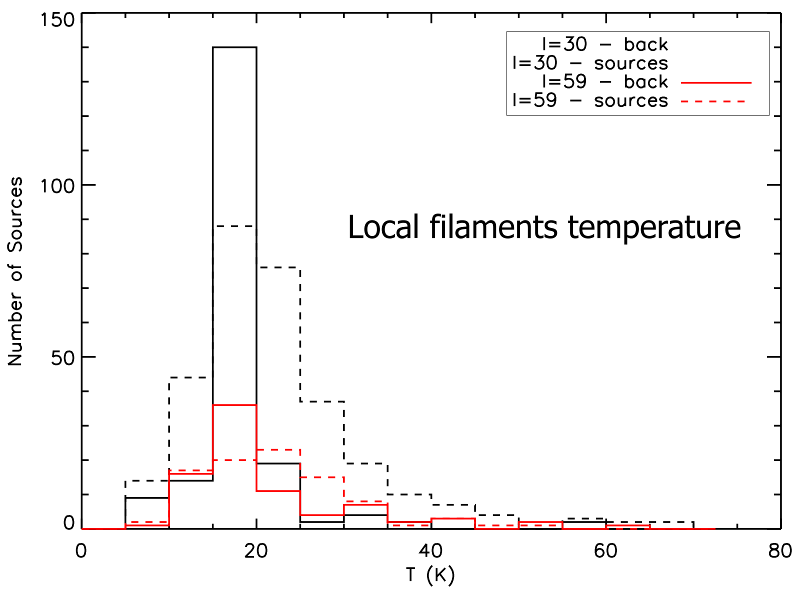
A threshold at A_V≈3-4 is lower than findings towards nearby clouds (André+10); are we looking at a different process ?

Filament fragmentation

Preliminary filament cross-section measurements in the l=59° region give values between 0.5 and 1pc.

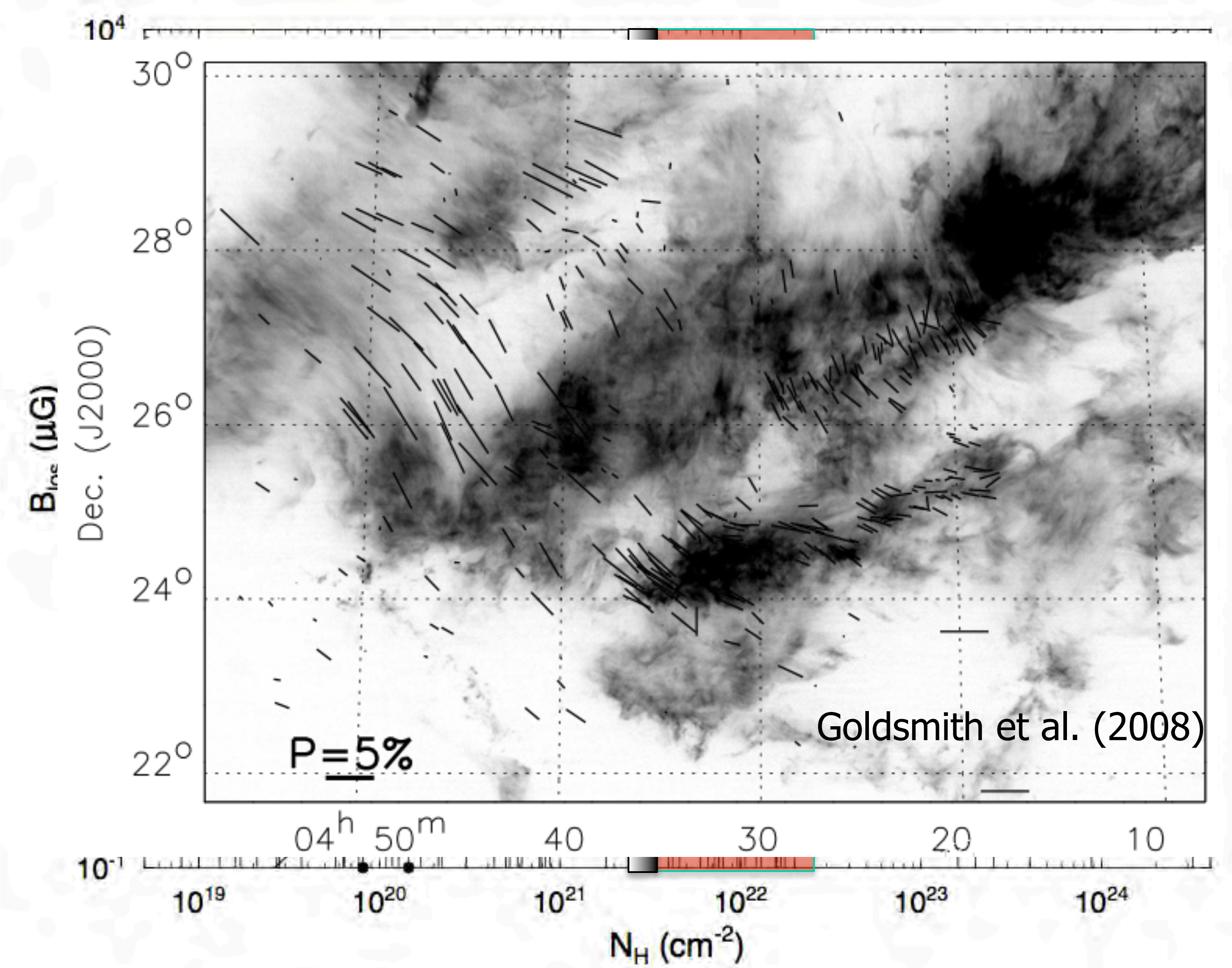


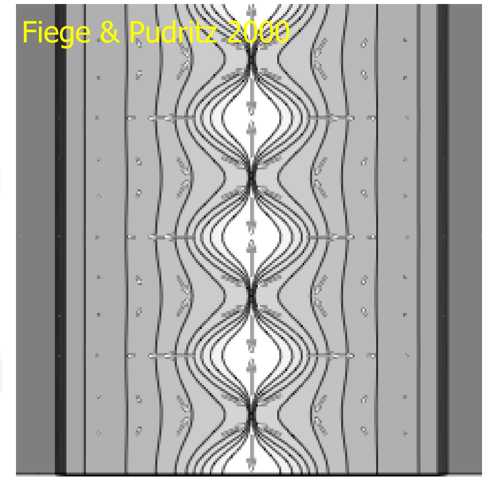


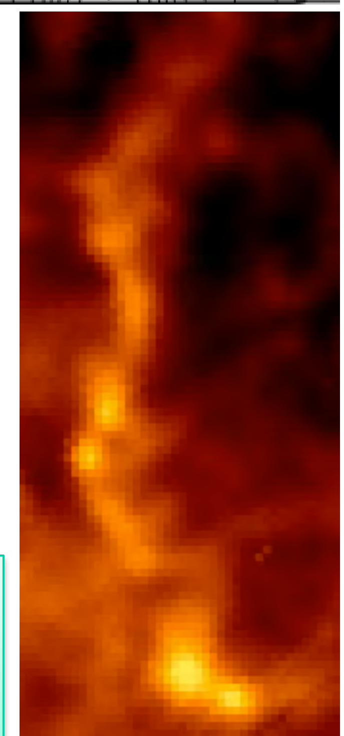


Conclusion: filaments form from diffuse ISM and grow in column density until at A_V≈3-4 heating and cooling go out of balance. Gravitational instability comes in and high-density fragments start to appear.

Is B important in filament fragmentation ?







Filaments hosting compact sources span a N(H) range which is compatible with structures losing magnetic support and starting to collapse

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 (around the filaments)
  - low [v_s ,n_0] shock tracers: low-J CO, SiO, [CII]…, to see if converging flows shocks really exist (e.g. Jimenez-Serra+ 2010 on G35.39, Schneider+ 10 on DR21): good for SPICA/SAFARI…can CCAT do it ?
  - velocity-resolved atomic and HI→H_2 transitions tracers to evaluate the role of turbulence and WNM pressure confinement: CI, low-J CO, NII, …
- Sensitive large-scale continuum polarimetry mapping

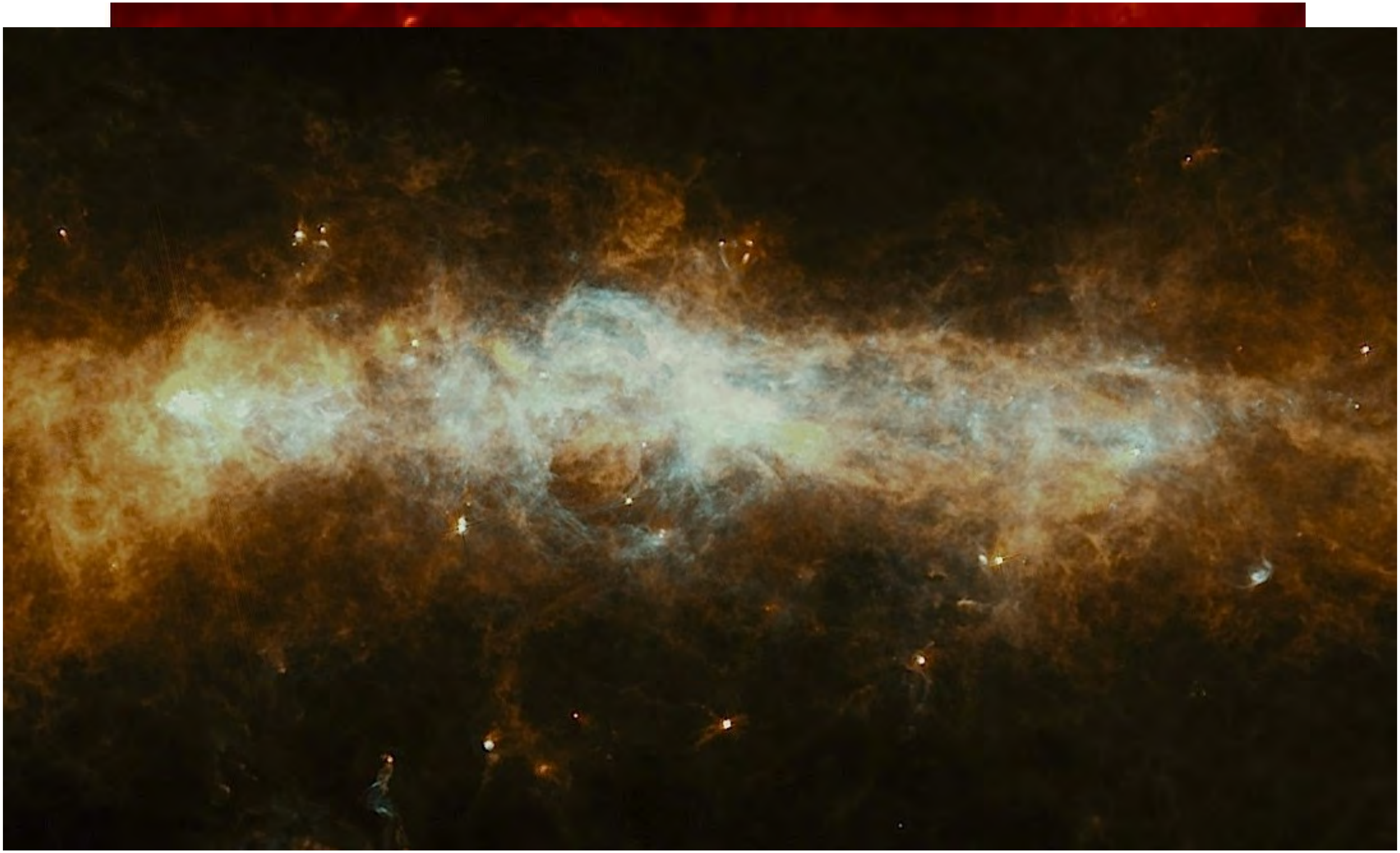
Hi-GAL is pushing Galactic Star Formation into the Mega-Cloud era: are we ready for the consequences ?

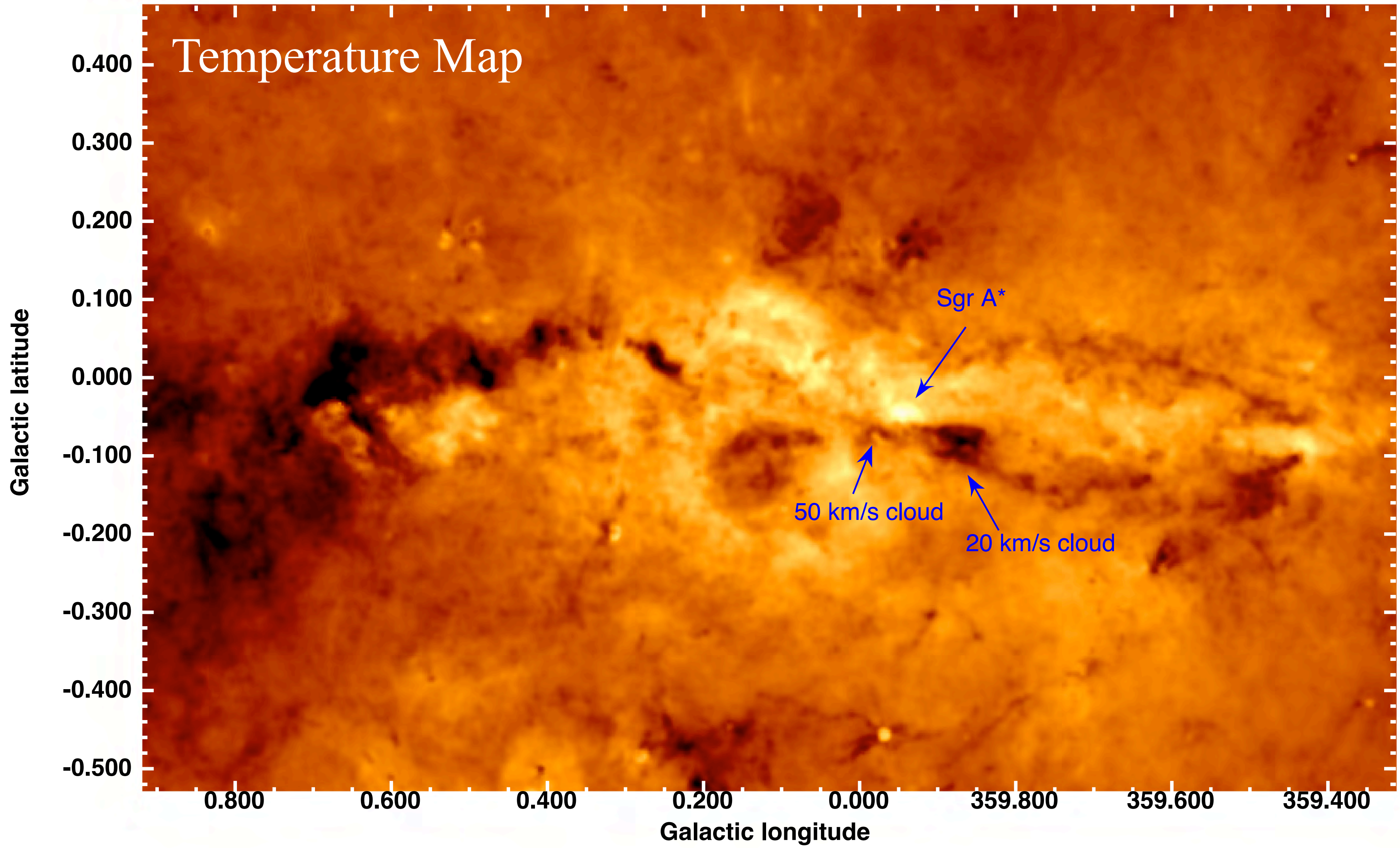
- How do filament fragmentation proceeds ?
  - Do clumps on filaments continue to accrete from the filament material ?
  - Do clumps on filaments move and merge (Inutsuka & Miyama 1997) ? many of the clumps on filaments show 24μm counterpart so it's unlikely that things go too fast ?
  - Role of magnetic field. Helicoidal B: do such things exist ?

- Detailed filament-scale spectroscopic mapping
  - detailed kinematic mapping on a wide range of aspect-ratio filaments to reveal infall profiles along the filament.
  - dynamics of clumps along the filaments
- Sensitive filament-scale continuum polarimetry mapping

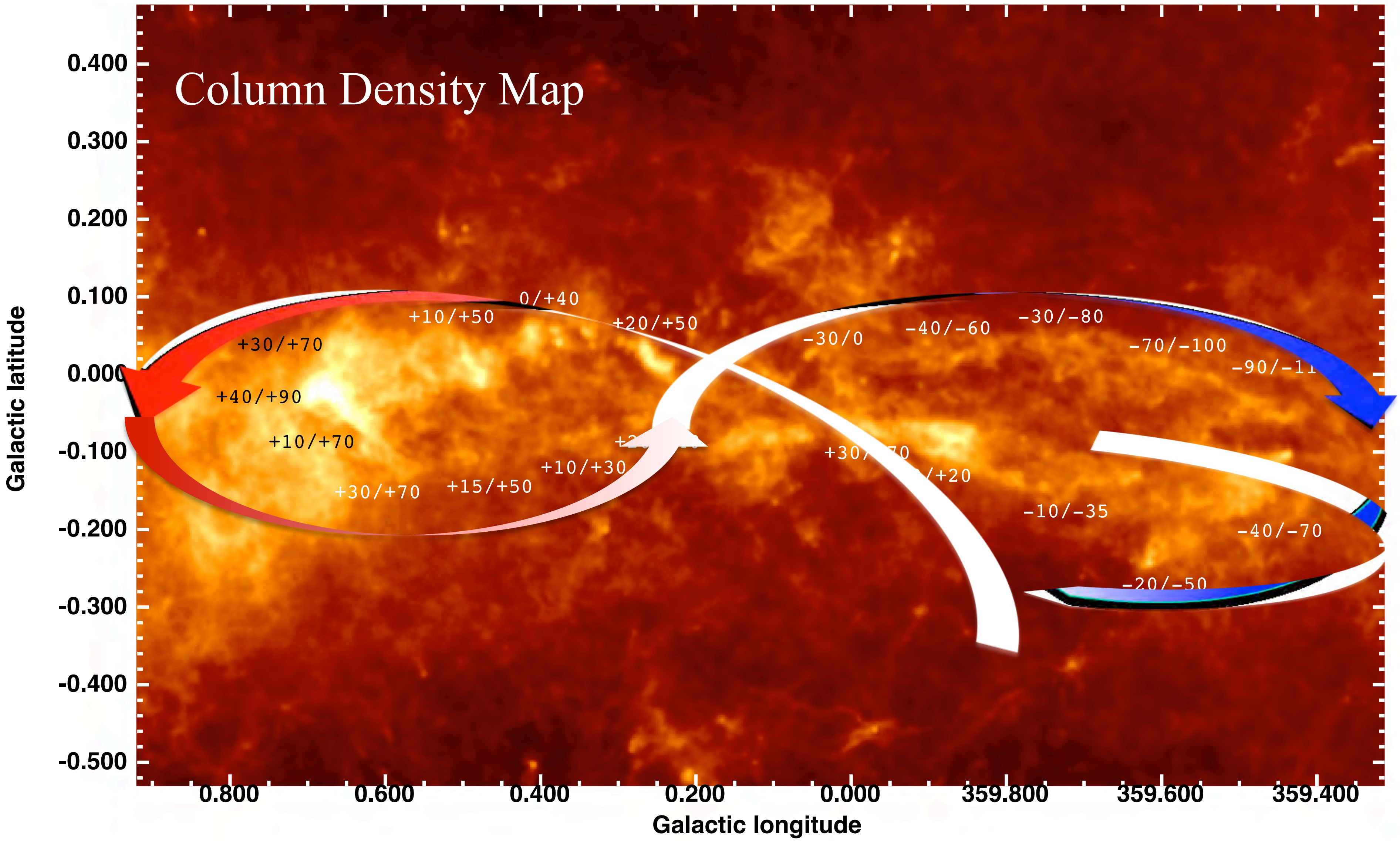
Hi-GAL will provide Galaxy-wide catalogues of characterised (n, N, T) filamentary clouds of all sizes to choose from

The Galactic Center



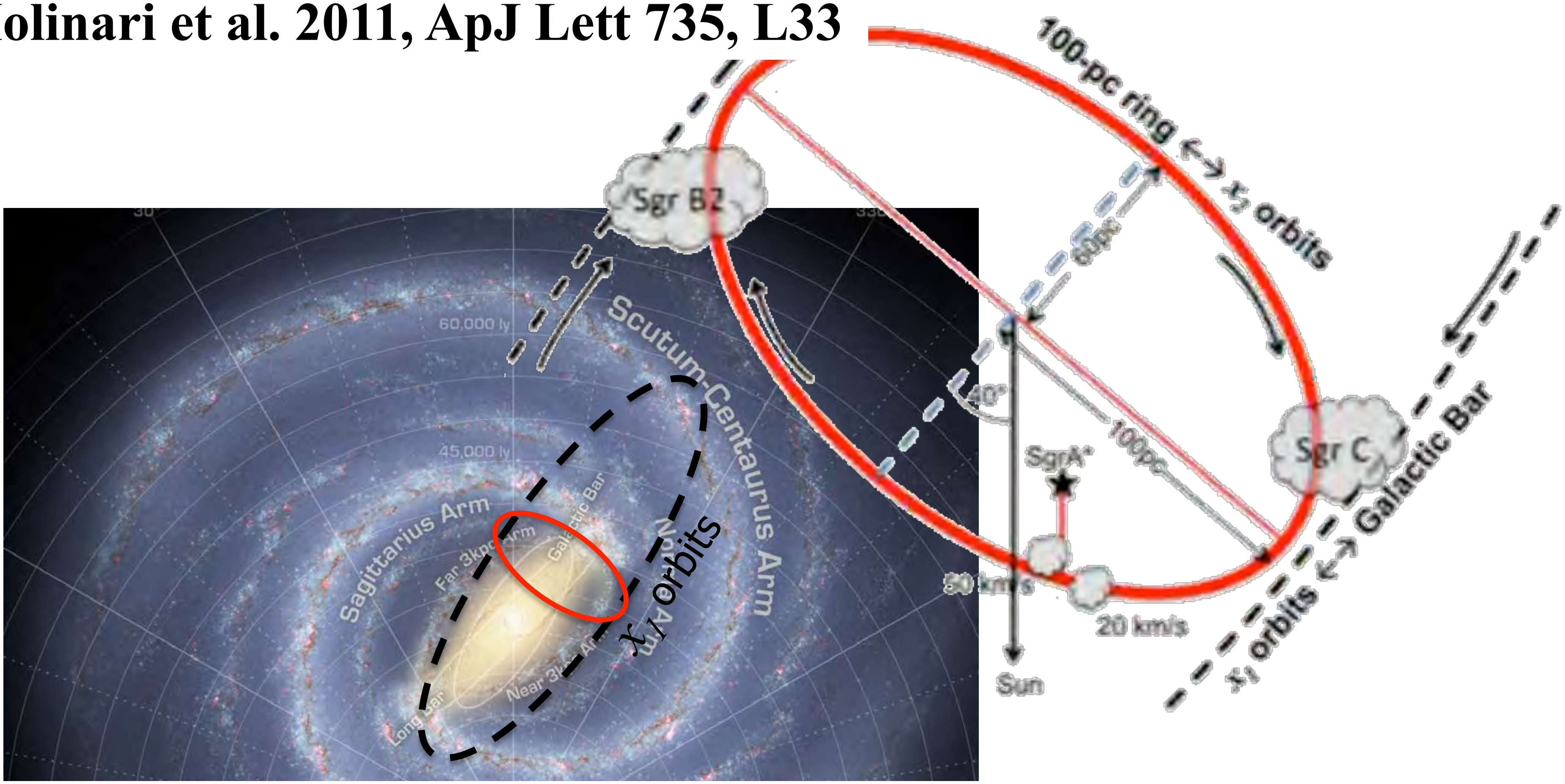


The 5 Hi-GAL maps were rebinned at the resolution of the 350μm (≈25”), and pixel-to-pixel SEDs were fit with DustEM (Compiegne et al. 2010) with opacities $\tau_{250}/N_H=8.8\ 10^{-26}\ cm^2/H$, to obtain Temperature and Column Density



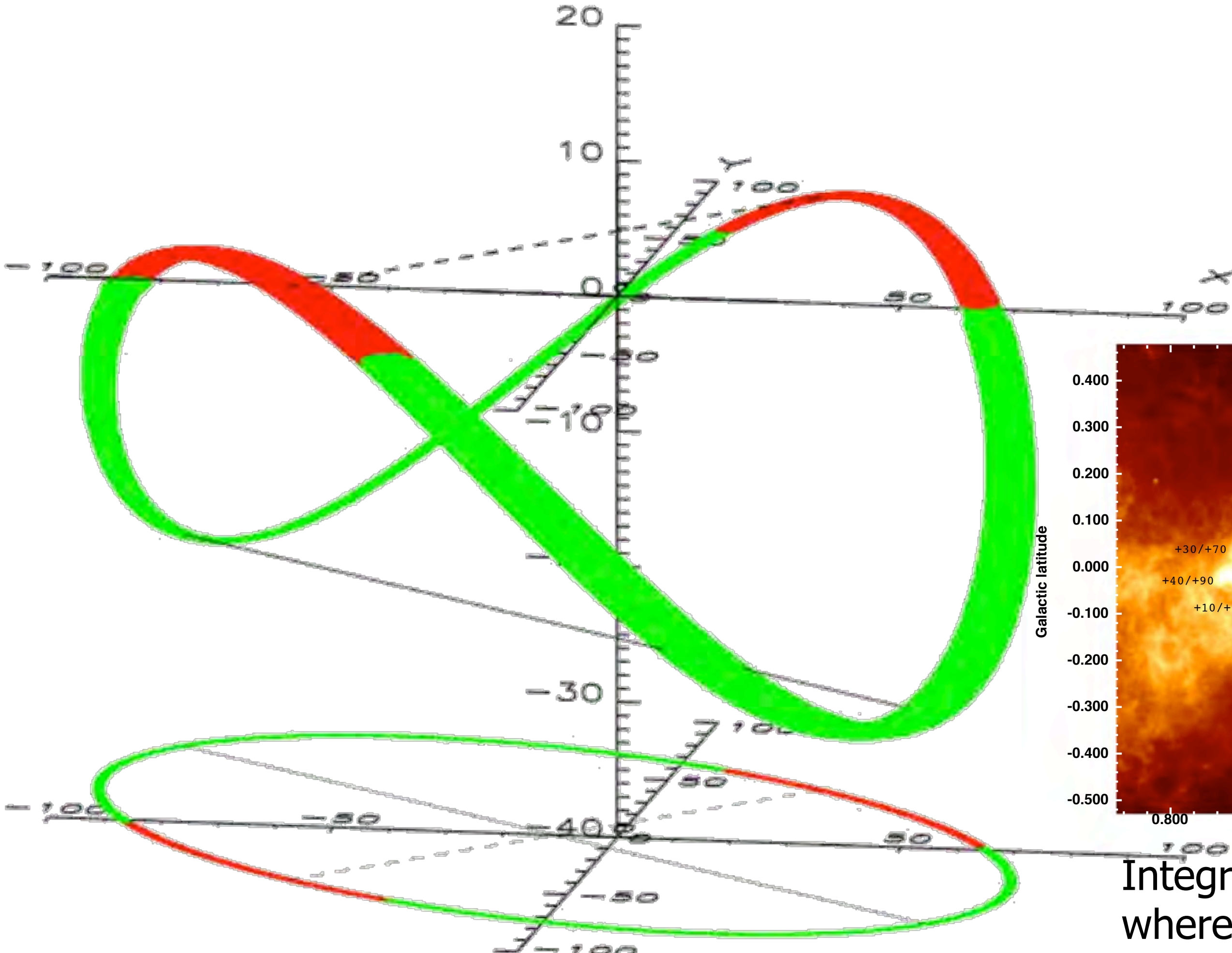
Radial velocities for several locations regularly spaced along ∞-shaped structure have been extracted from the CS survey of Tsuboi et al. (1999)

Molinari et al. 2011, ApJ Lett 735, L33

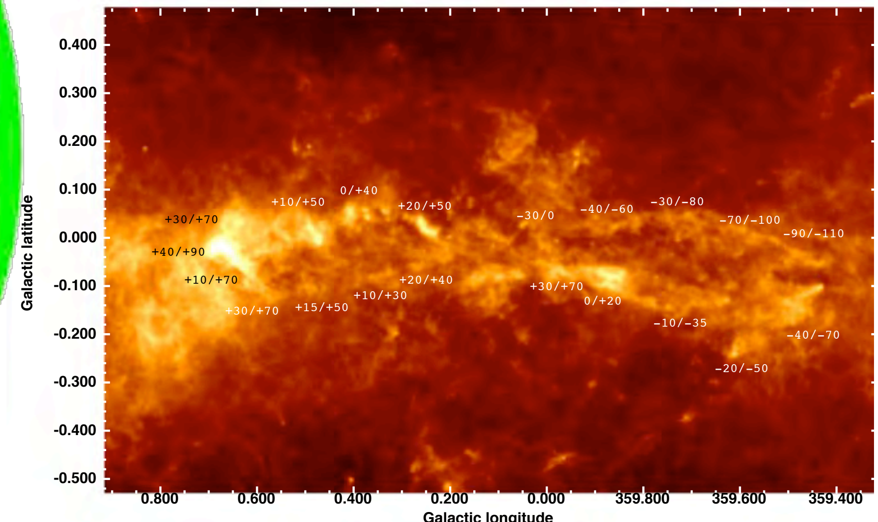


The 100pc ring revealed by Herschel is the counterpart to the x_2 orbits predicted by theory (e.g. Binney et al. 1991)

SgrB2 and SgrC are conveniently located at the converging points between the x_1 and x_2 *orbits*, where shock-focusing mechanism may favour the formation of massive clouds



a =100pc
b =60pc
θ_p = -40°
V_{orb}=80 km/s



Integrating the N_H map over the area where $N_H \geq 2\ 10^{23}$ cm^{-2} ($\Omega_{ring} \approx 4\ 10^{-5}$ sr), and subtracting a fore/background estimate $N_H \approx 2\ 10^{23}$ cm^{-2} yields a mass of $3\ 10^7\ M_\odot$

The twisting frequency is twice the orbital frequency, yielding a direct contraint on the flattening ratio of the central bulge potential of 0.5, in agreement with 2MASS star counts (Fernandez & Combes 2008)

Galactic structures like the 100pc GC ring, its dynamics and SF properties need to be studied in detail with a sensitive, relative high-resolution and fast mapping Far-IR/submm facility.

Conclusions

Hi-GAL is throwing us into a yet uncharted Mega-SEDs/Mega-Clouds realm opening new frontiers for next-generation facilities

- Rapid-fire & sensitive multiband continuum and spectroscopic snapshots for (several tens of) thousands of clumps
- Chemical fingerprinting is the essential complement to the SED continuum characterization.
- Sensitive large-scale spectroscopic mapping (around the filaments)
  - low [v_s ,n_0] shock tracers: low-J CO, SiO, …, to see if converging flows shocks really exist (e.g. Jimenez-Serra+ 2010 on G35.39, Schneider+ 10 on DR21)
  - velocity-resolved atomic and HI→H_2 transitions tracers to evaluate the role of turbulence and WNM pressure confinement: CI, low-J CO, NII, …
- Sensitive large-scale and filament-scale continuum polarimetry mapping
- Detailed filament-scale spectroscopic mapping
  - detailed kinematic mapping on a wide range of aspect-ratio filaments to reveal infall profiles along the filament.
  - dynamics of clumps along the filaments