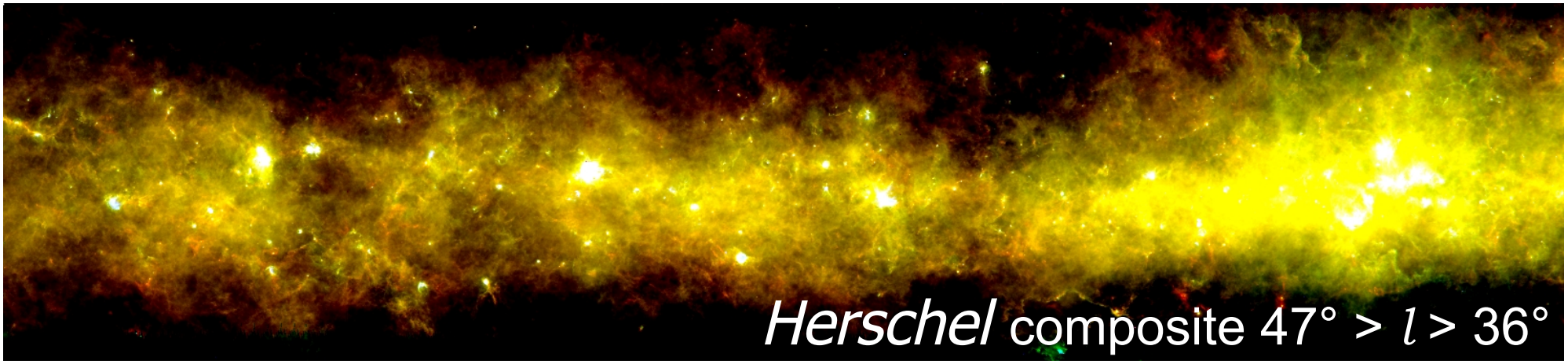


THE GALAXY

IN THE HERSCHEL ERA

S. Molinari – INAF/IFSI, Rome

HI-GAL team

IFSI - Arcetri - Univ. Rome 1/2 - Oss. Catania - 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.

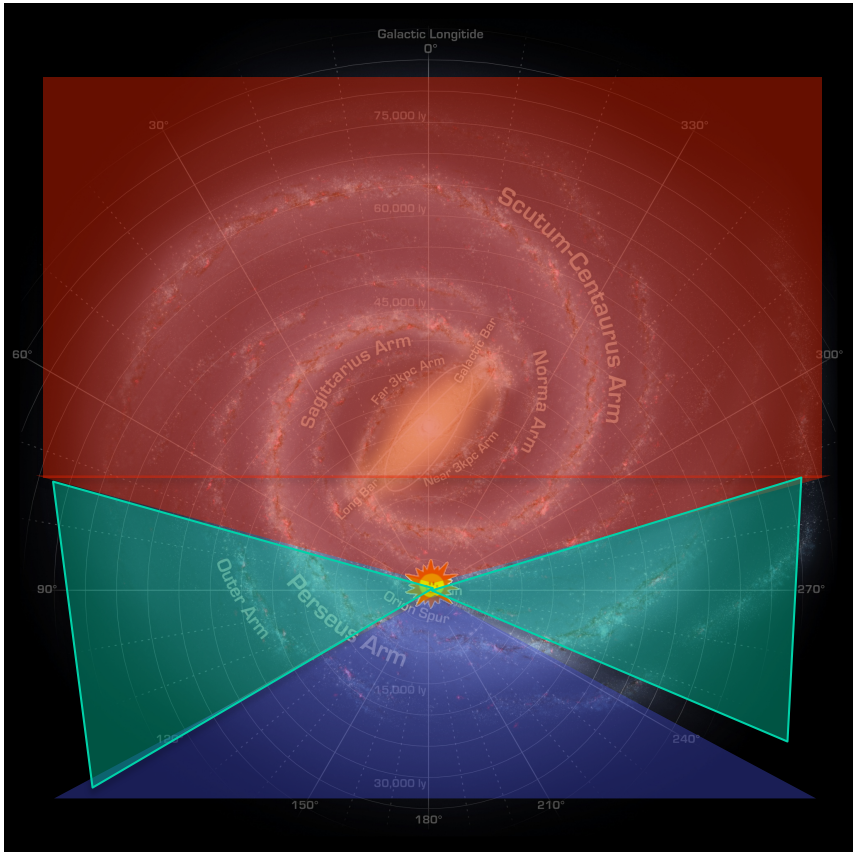
HI-GAL

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

Simultaneous 5-bands (*70-160-250-350-500*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

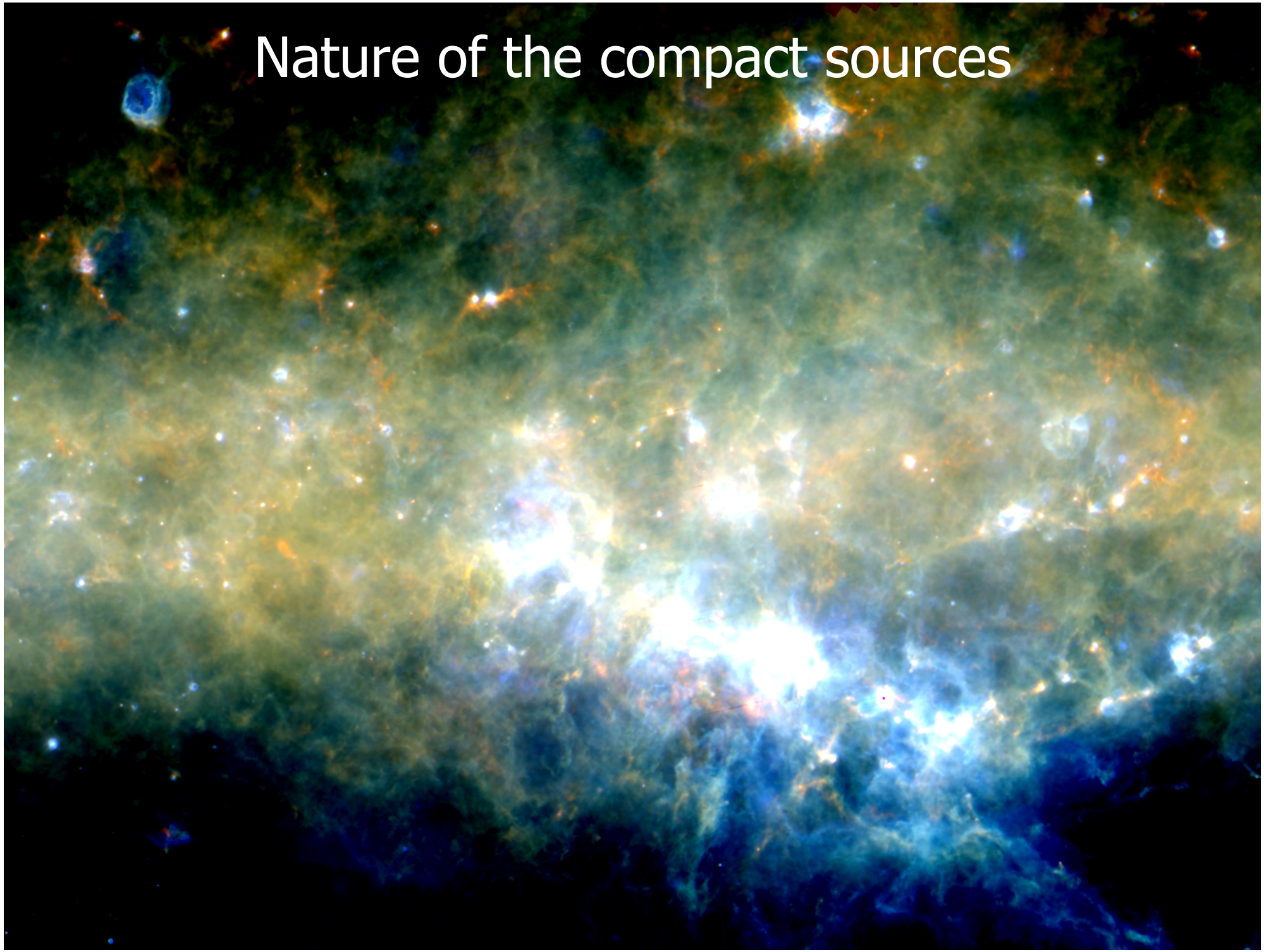


The Goals of the Herschel infrared Galactic Plane Survey

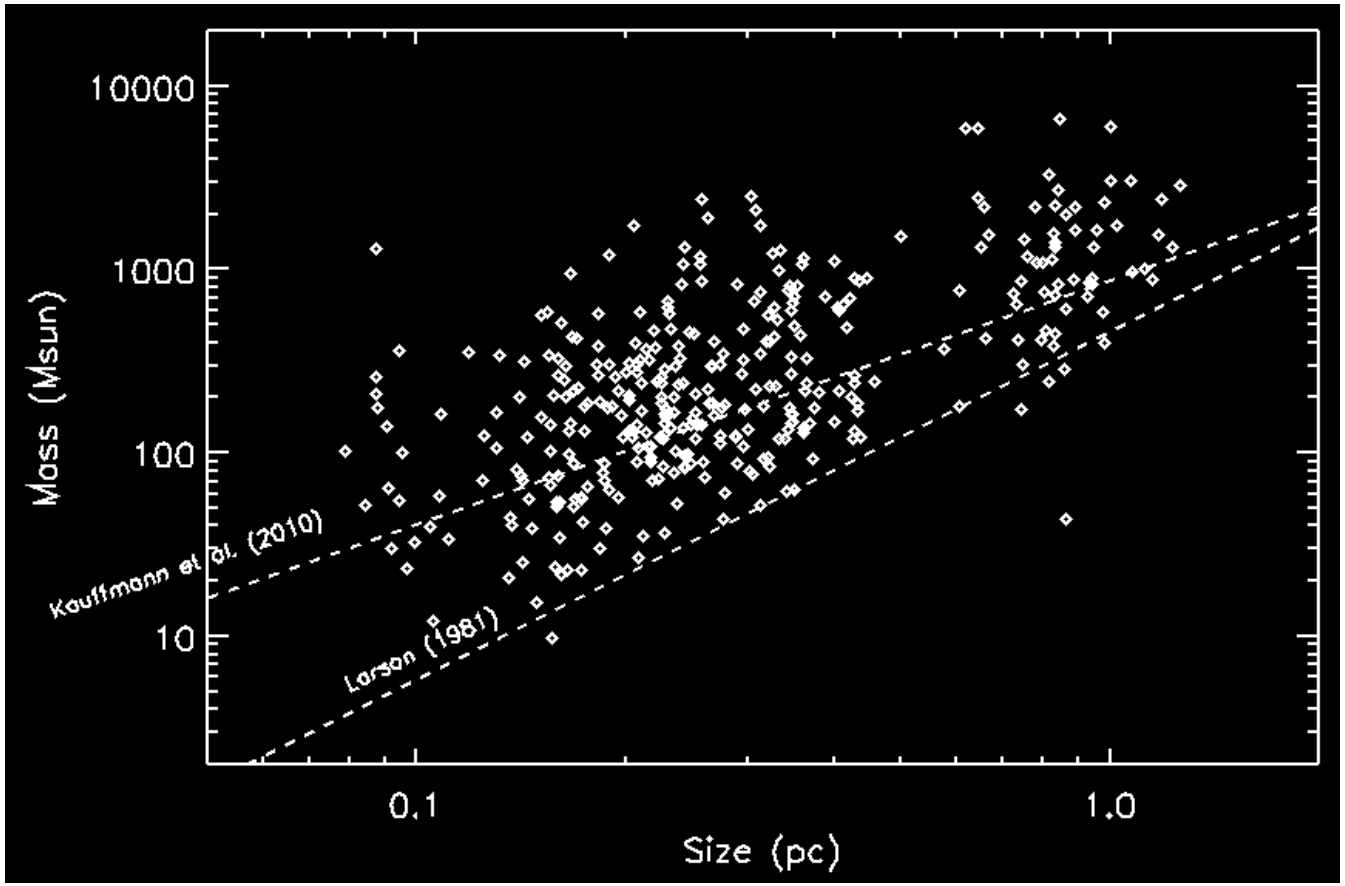
Toward a Predictive Global Model of Galactic Star Formation

- 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

Nature of the compact sources



A Mass-Size power-law with exponent 1.33 is found to discriminate structures on the basis of their ability to form massive stars (Kauffmann et al. 2010)

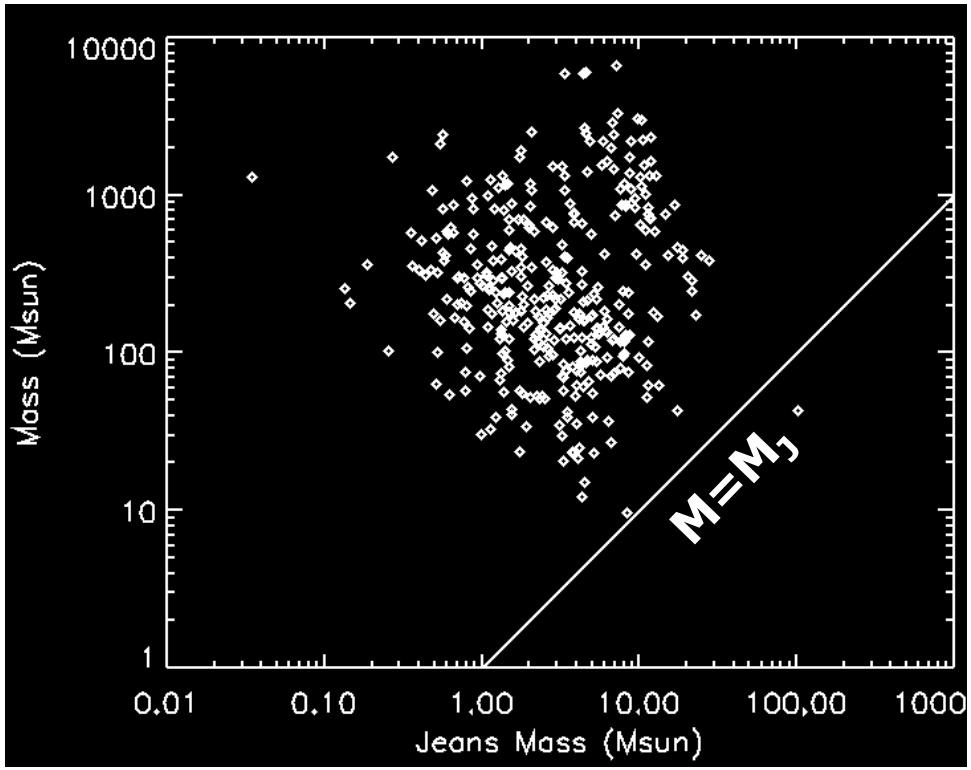


The majority of sources are dense clumps which should be able to form $M_* > 10\ M_\odot$ stars…but reliable kinematic information is accessible for a limited number of sources only.

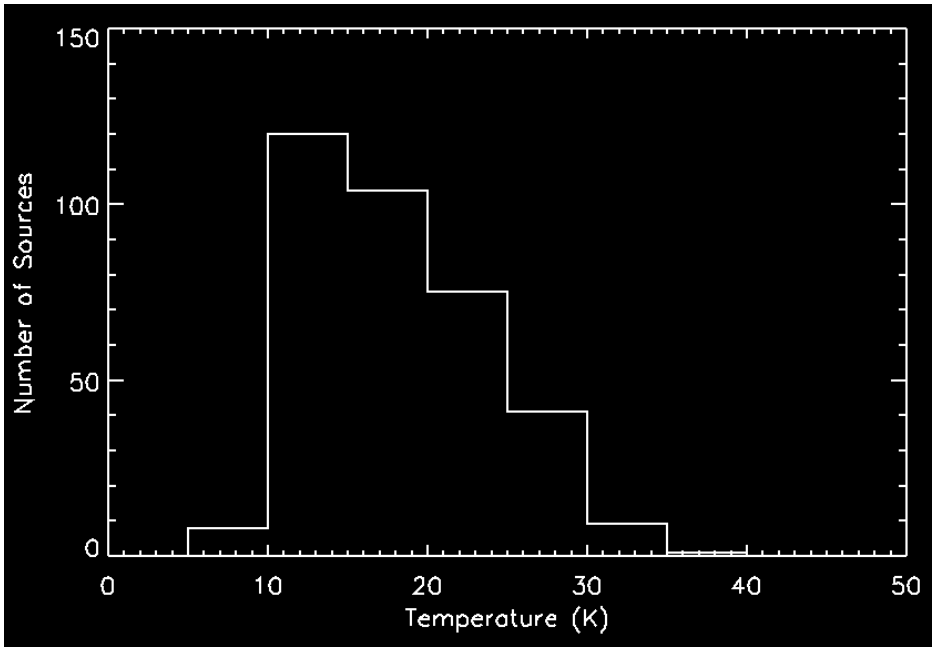
Nature of the compact sources (l=310°-320°)

Jeans conditions for gravitational instability

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



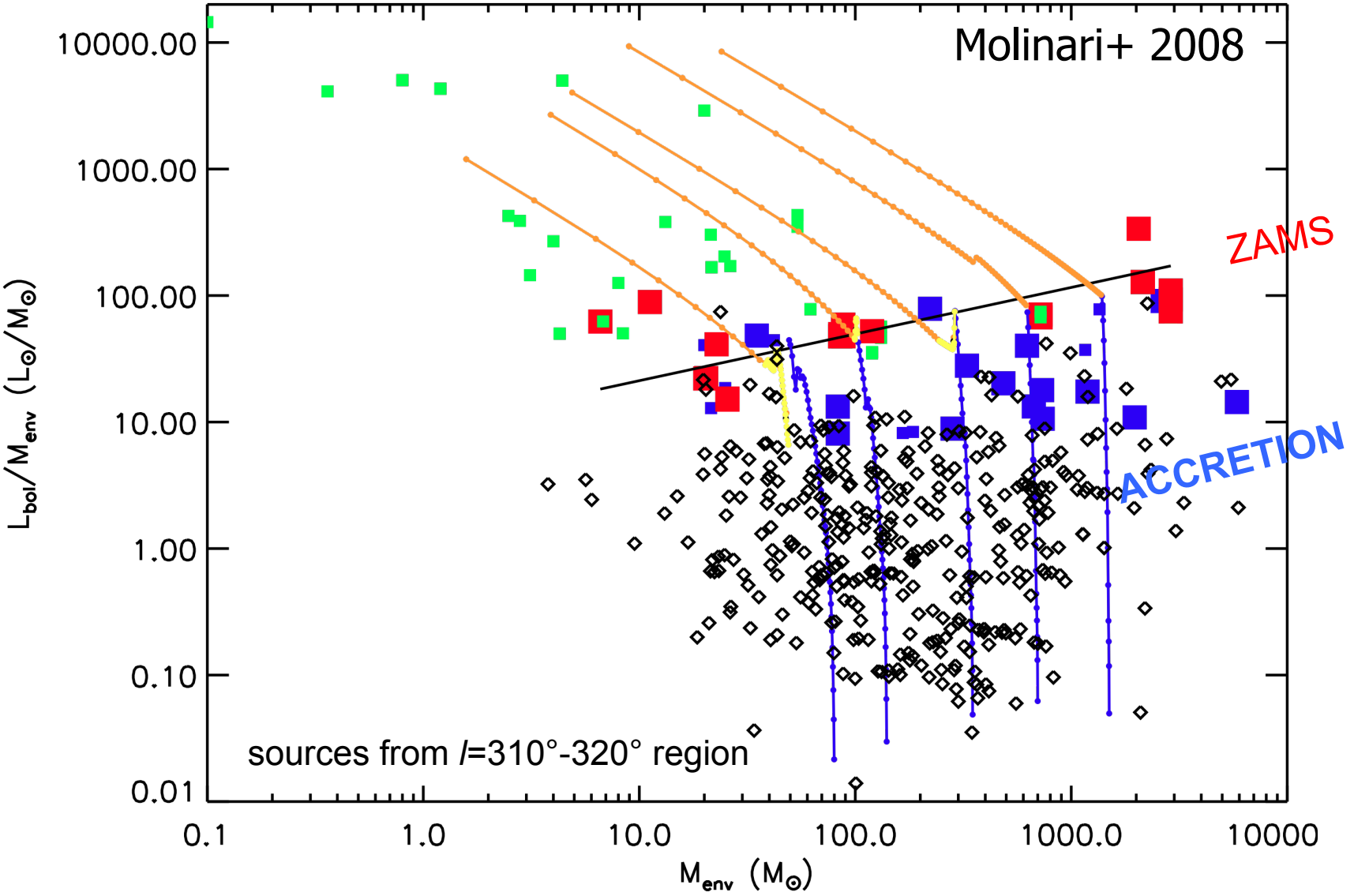
Mean Clumps Temperature



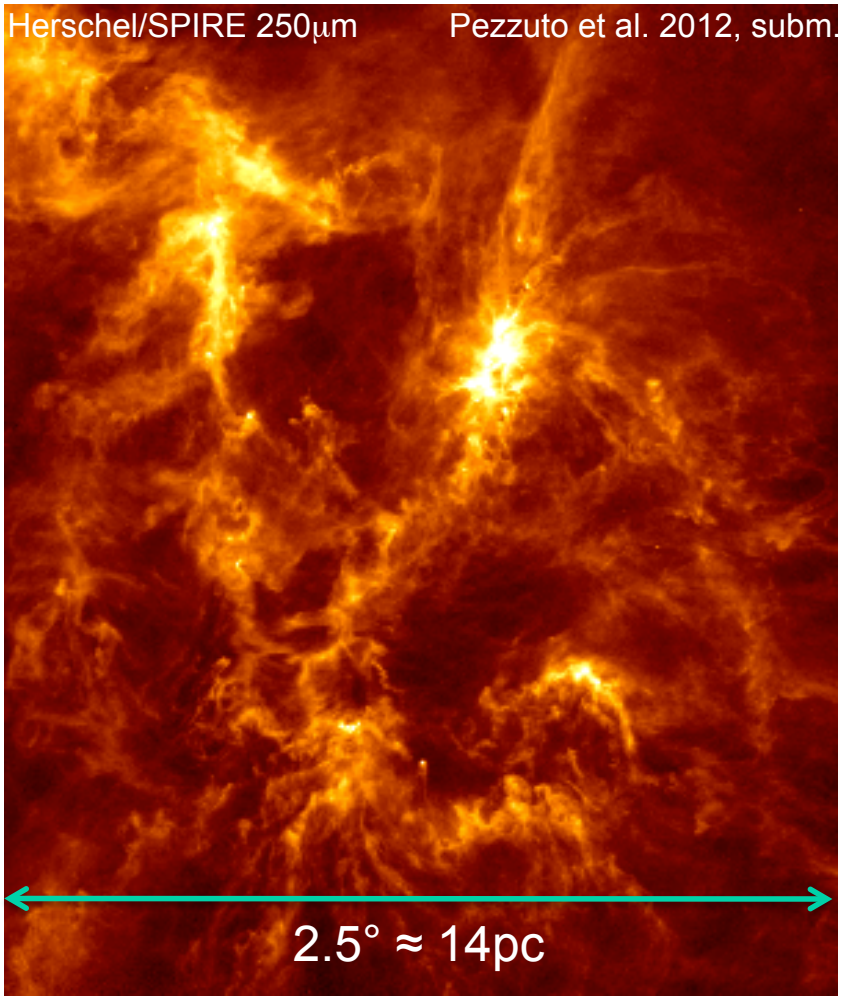
The majority of the detected cores may be gravitationally supercritical

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

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

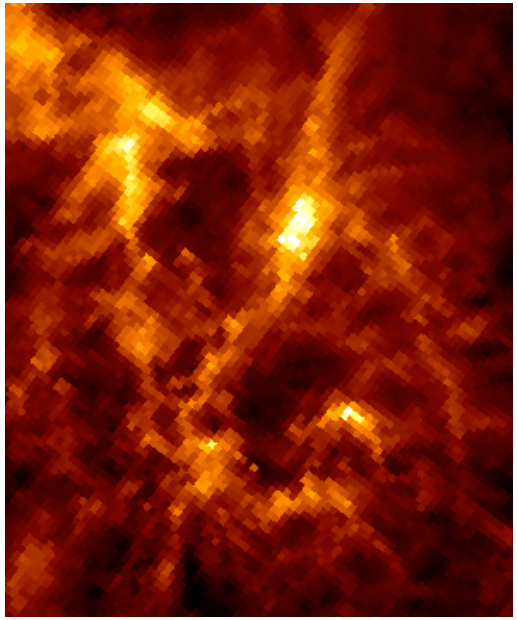


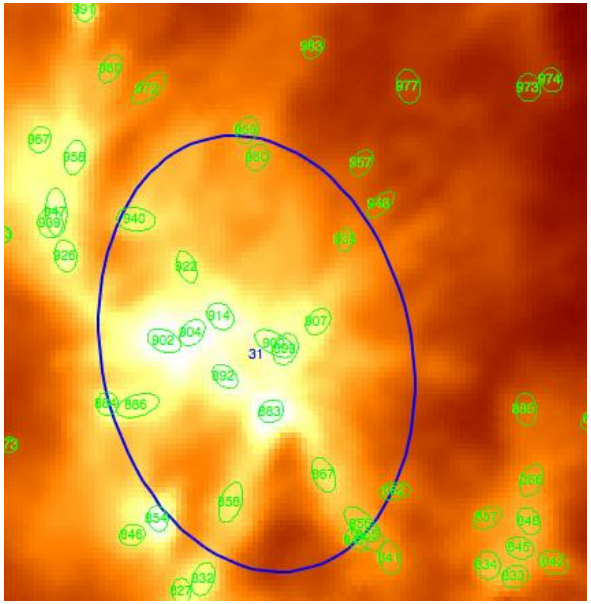
Problem: Sources in Hi-GAL are mostly clumps, while SED models are available for single YSOs (Robitaille et al. 2006)



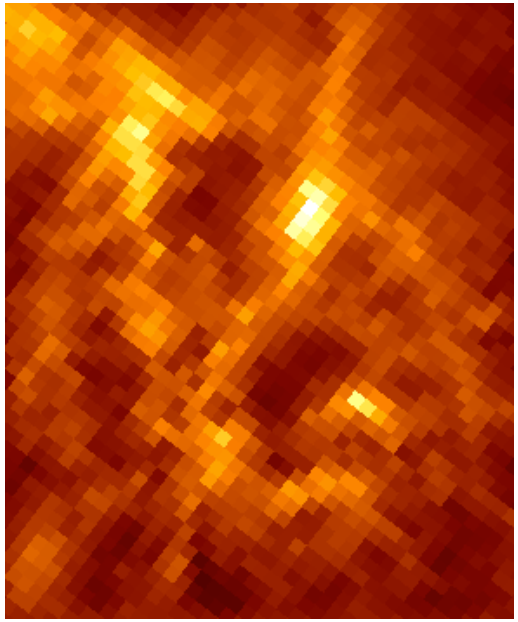
Perseus star-forming region (d ≈ 310pc)

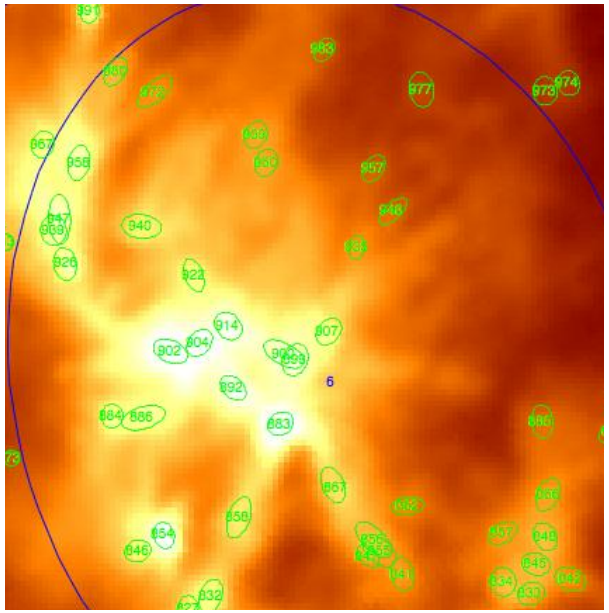
now push it to 5 kpc





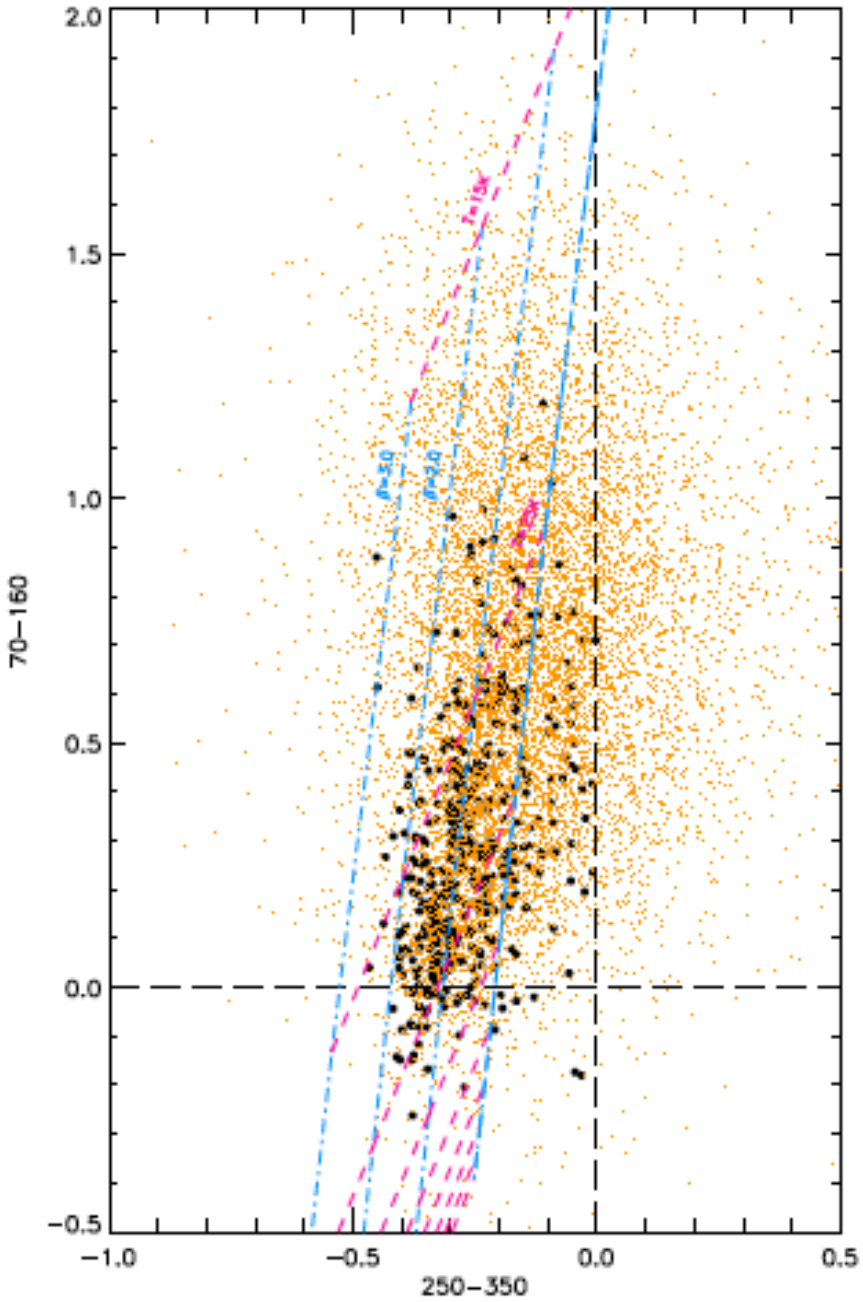
now push it to 10 kpc



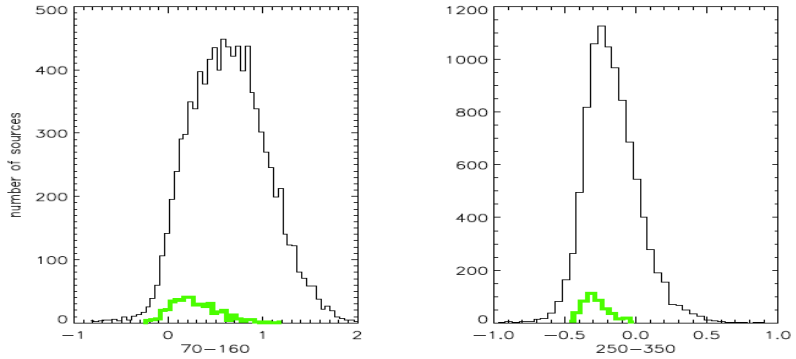


Need ancillary data at higher spatial resolution and create protocluster and SFR synthetic SED model (Facchini et al., in prep.)

Far-IR colours as evolutionary probes ?

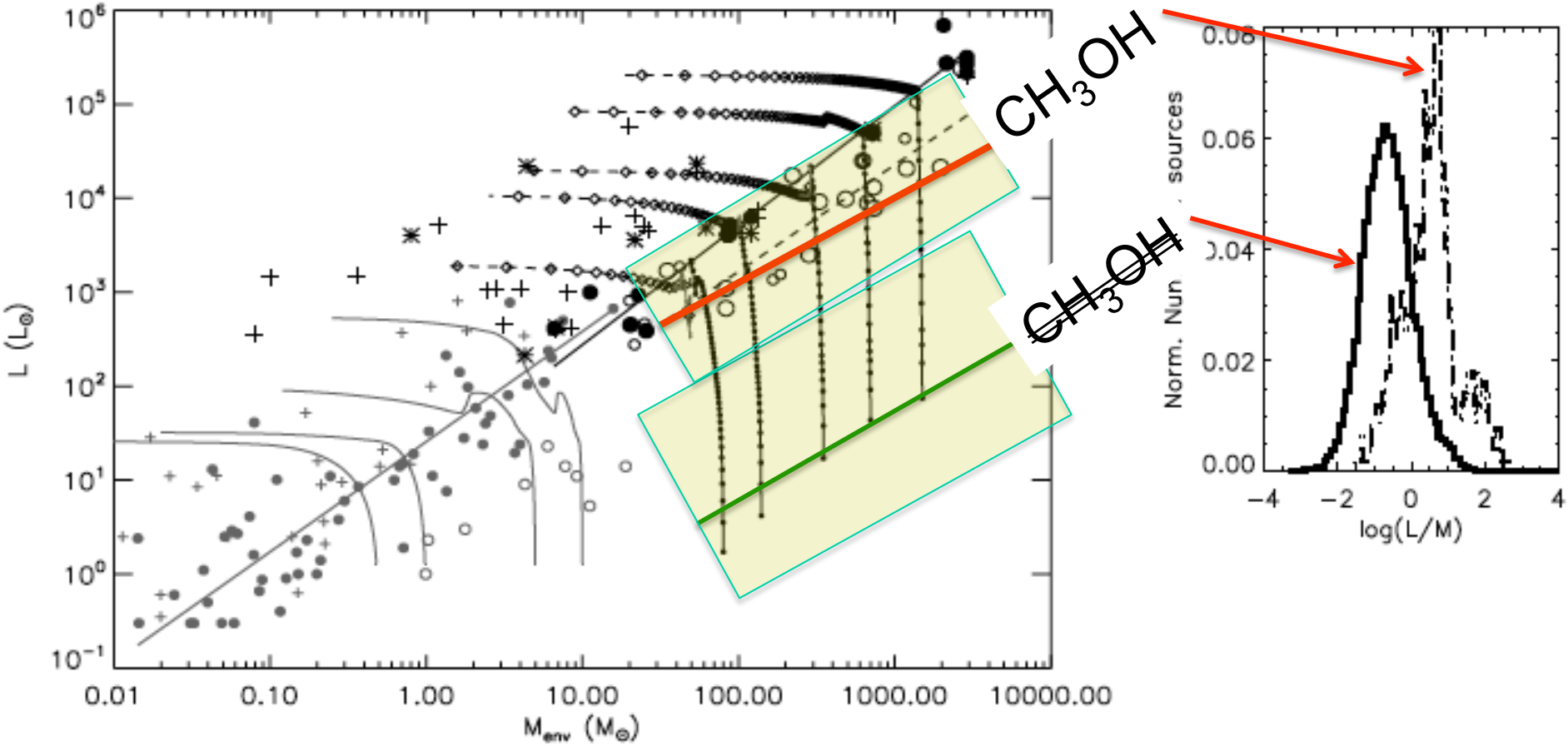


- Methanol maser emission is found to be associated with intermediate and high-mass young forming stars: circumstellar densities in excess of 10^6 cm^{-3} and strong 20-30μm continuum are required.
- Current line of thinking states that methanol masers characterize the **very early stages** of massive star formation, when the initial massive core is being formed and massive amounts of IR radiation are produced.



CH_3OH-associated Hi-GAL sources occupy the “bluer” (i.e. warmer) portion of the plot

Restating the evolutionary indication provided by CH_3OH masers



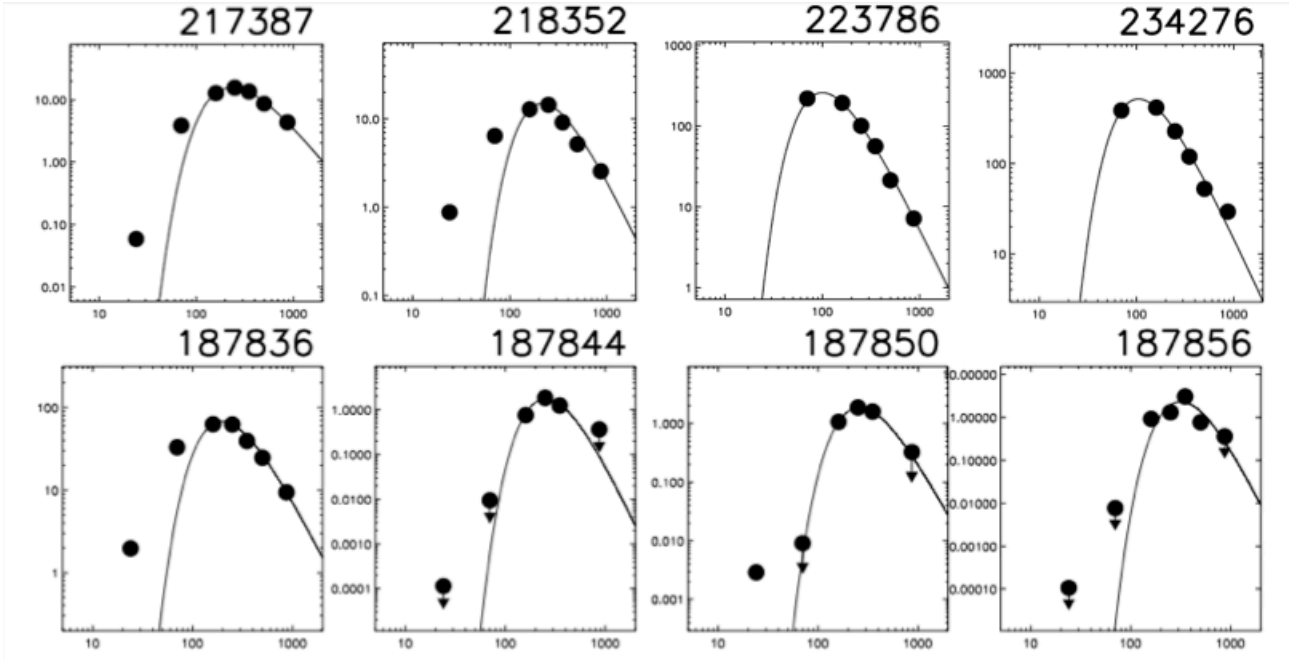
Conclusion: massive YSOs asociated with CH_3OH maser show colors similar to Ultracompact HII regions (i.e. ZAMS objects), so the intense 20-30μm field needed to pump the level inversion is likely reprocessed UV: the CH_3OH-YSOs do not seem to mark a very early stage in YSO formation at all.

Pestalozzi et al. 2012, in prep.

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

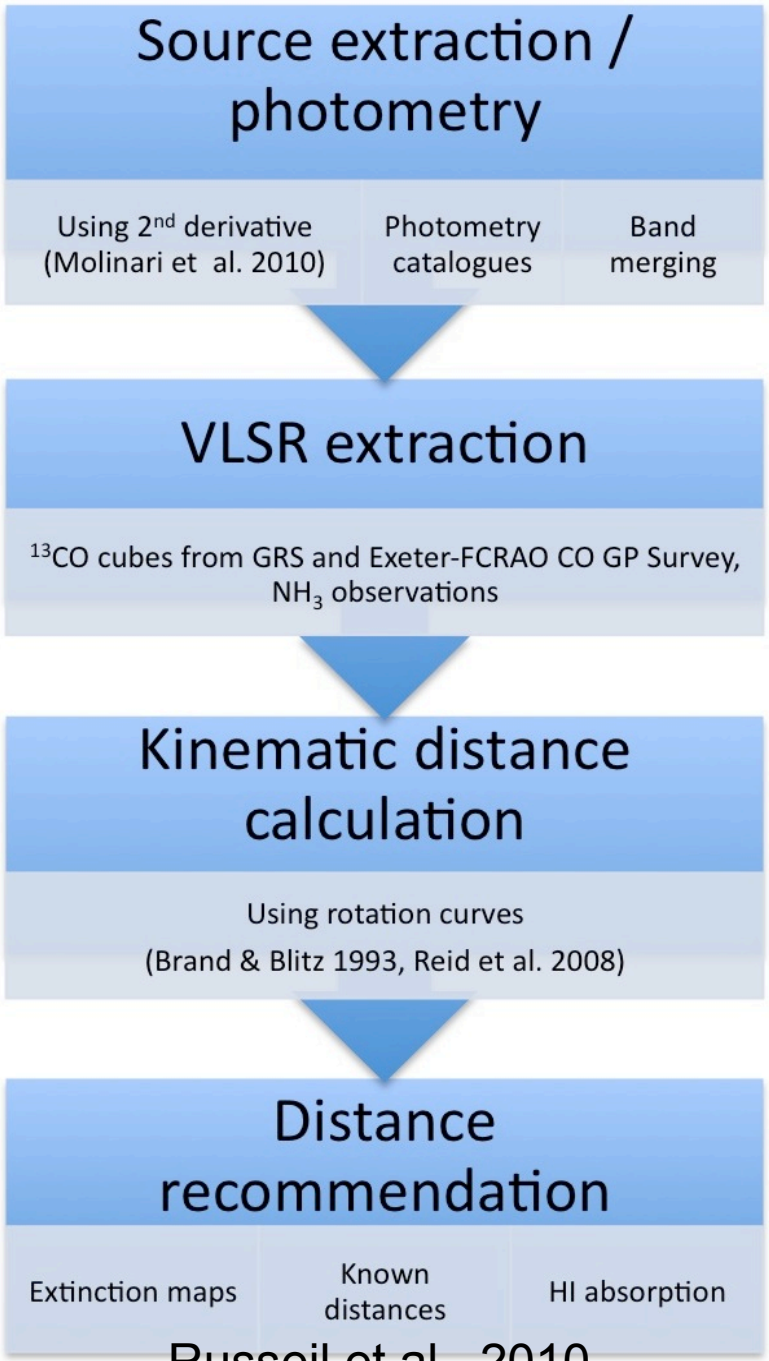
428.000 entries.



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 ;)

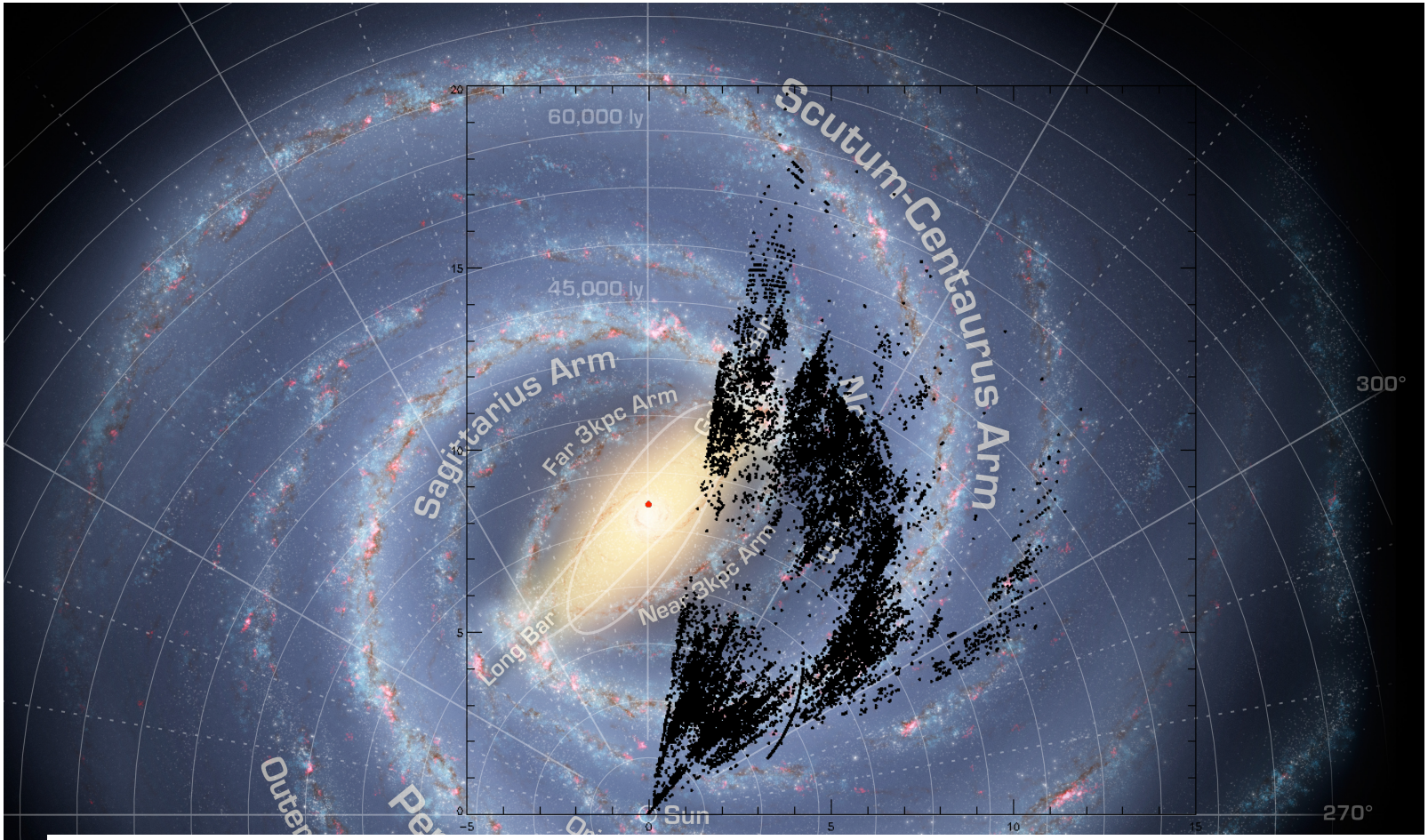
Distan stances

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



Russeil et al., 2010

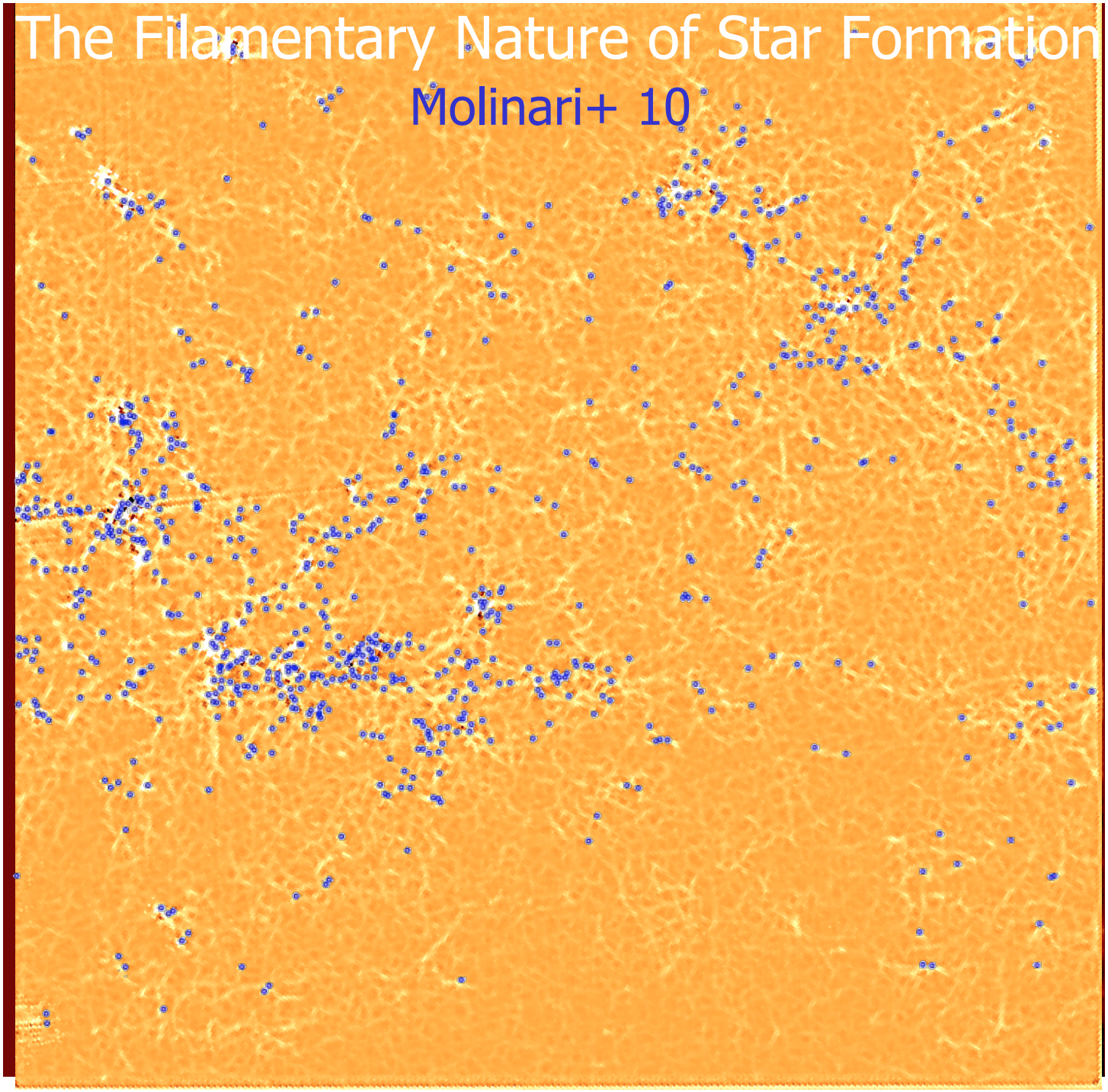
Example: about 17000 sources with counterparts automatically extracted from the NANTEN CO cube and for which a near/far recommendation could be made



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

The Filamentary Nature of Star Formation

Molinari+ 10



Filament identification in a nutshell - 1

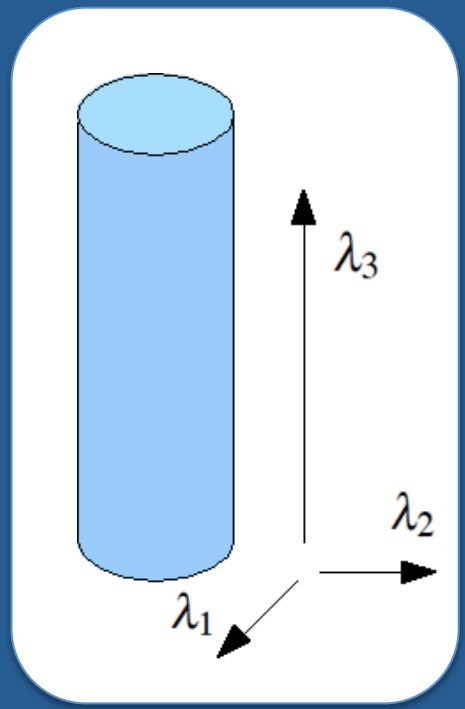
Filament: Structure that is concave down along two different principal axes and is almost flat in the other one.

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.

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)



Filament identification in a nutshell - 2

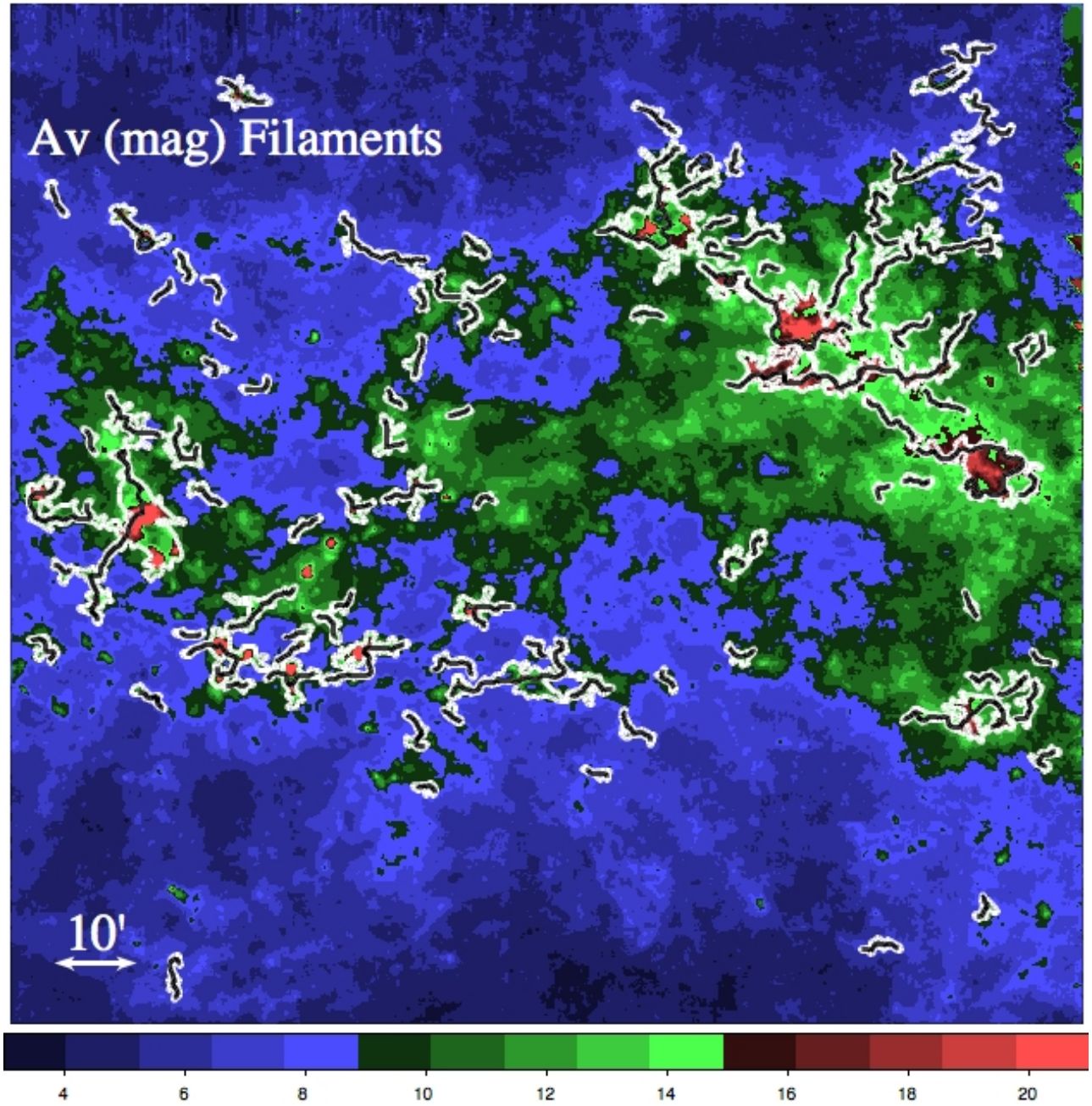
We complement the Hessian approach with an Edge Dectector-type method.

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)

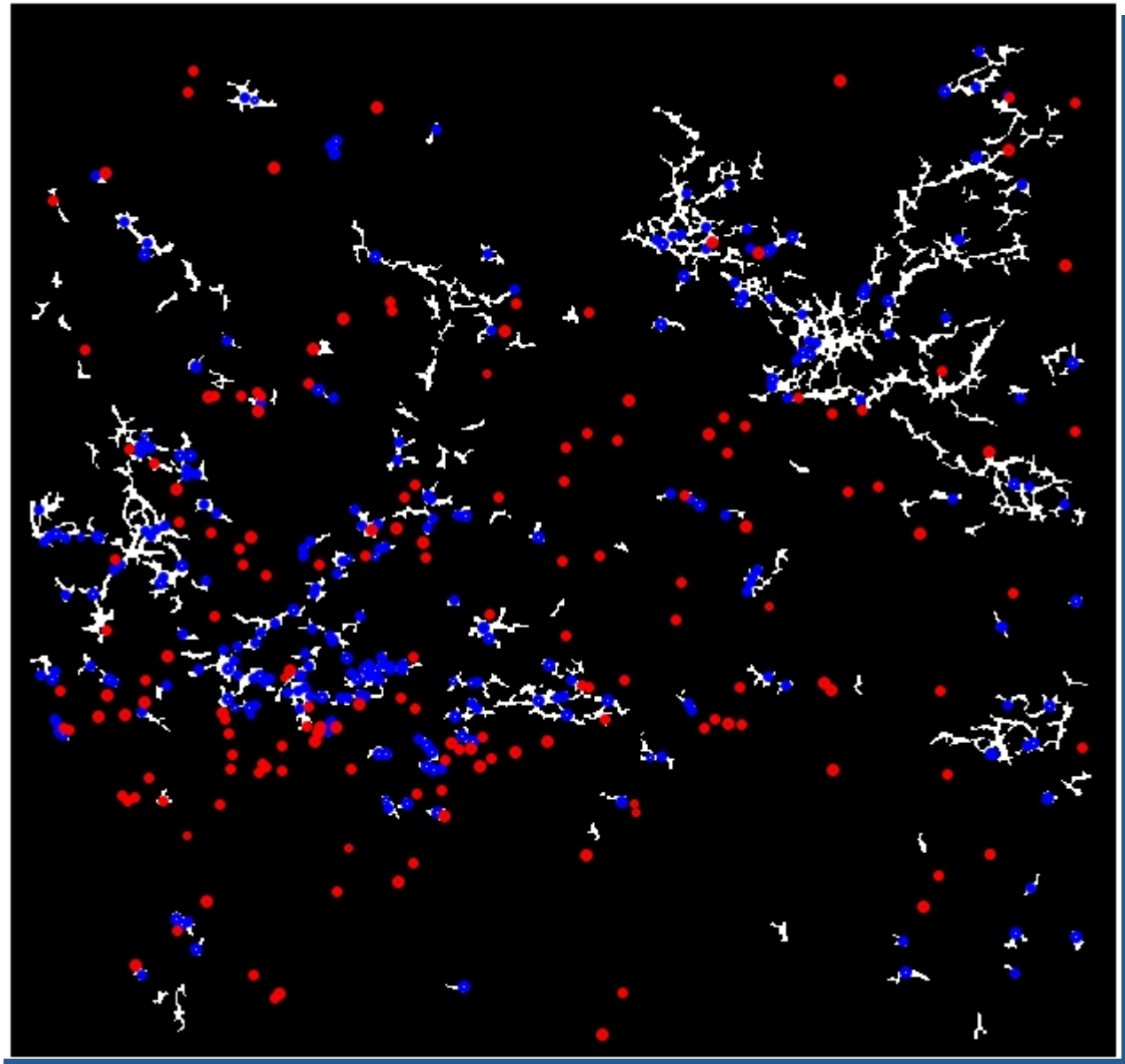
All the points of the "Spine" are then connected through a Minimum Spanning Tree (MST) that give the unique path linking together all the pixels of the spine.

A case of study - L59 region (Schisano et al. 2012, in prep.)



- 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.

We are automatically detecting what people have been calling IRDCs till now, with the ability to distinguish them from IRDP (Wilcock et al. 2012)



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 %

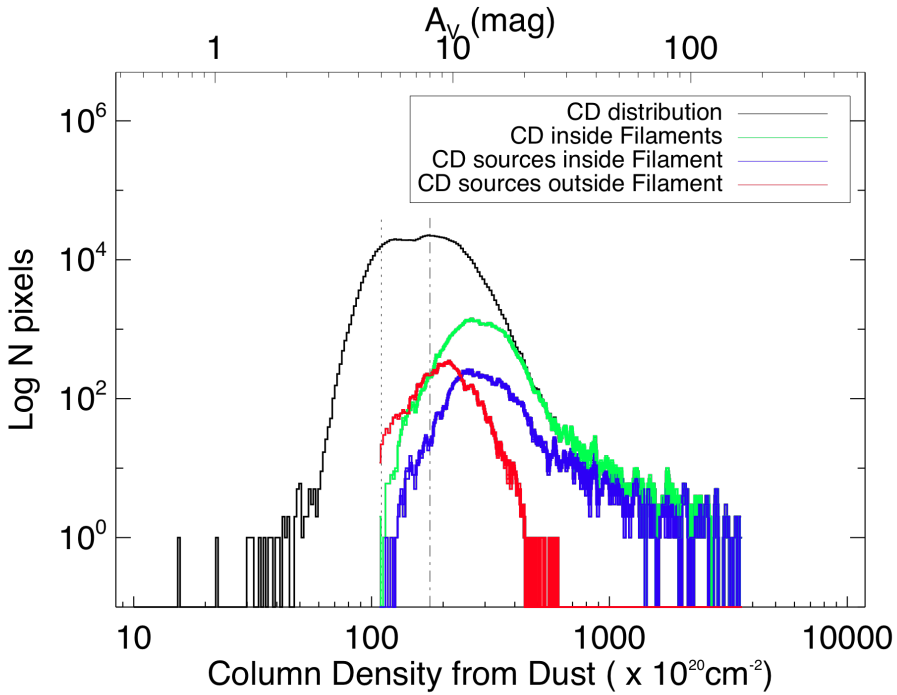
However, considering the sources that are detected only at SPIRE wavelengths we find that the number of sources inside and outside filament are evenly splitted

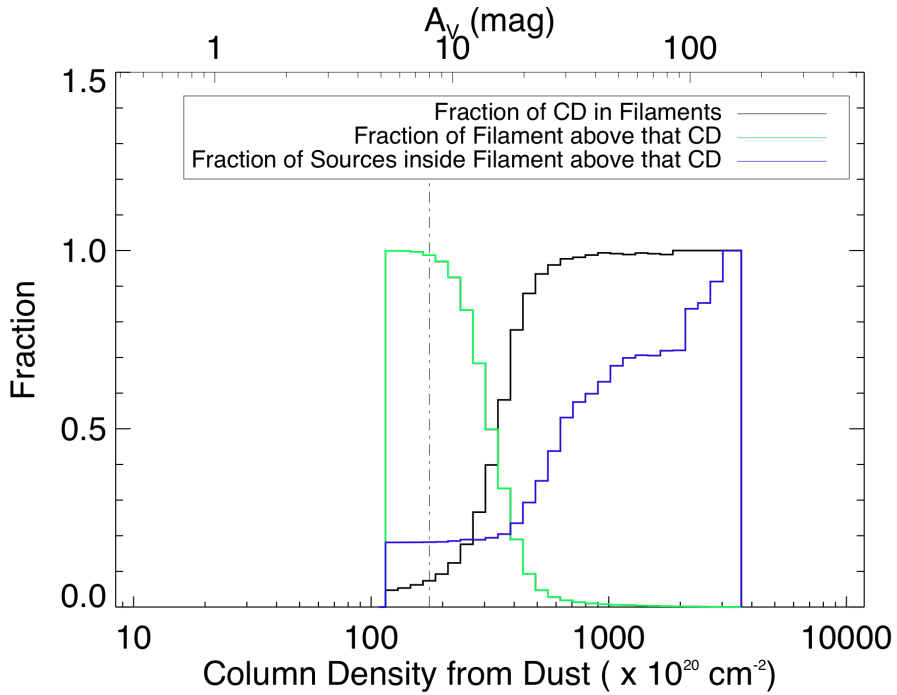
Still need to be investigated

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

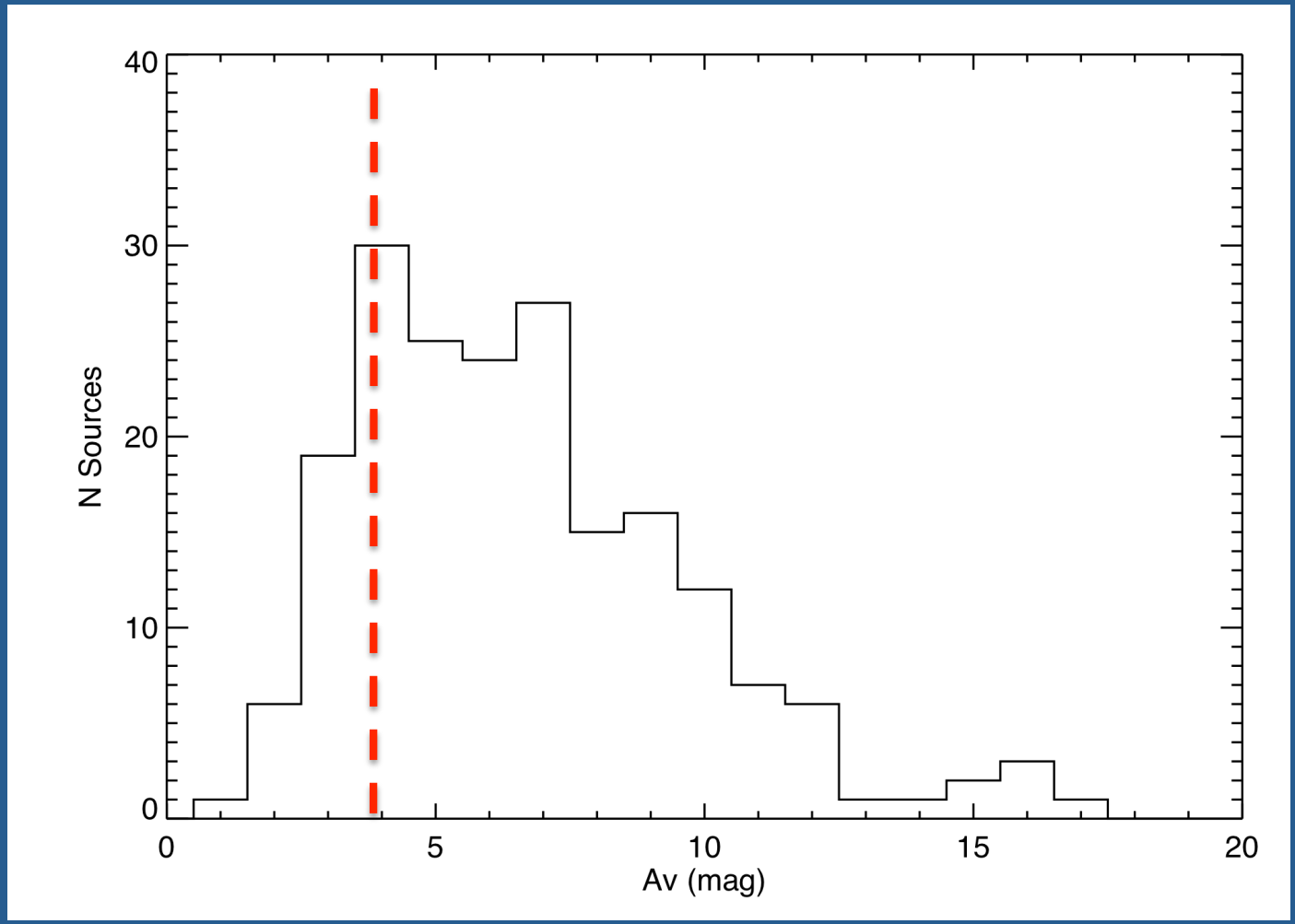


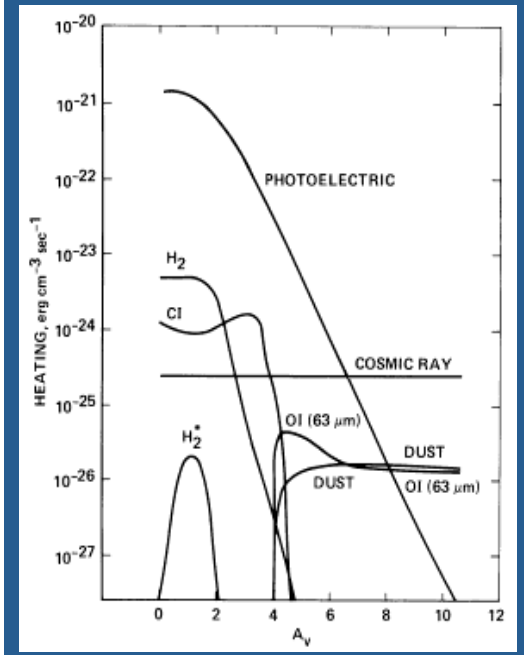


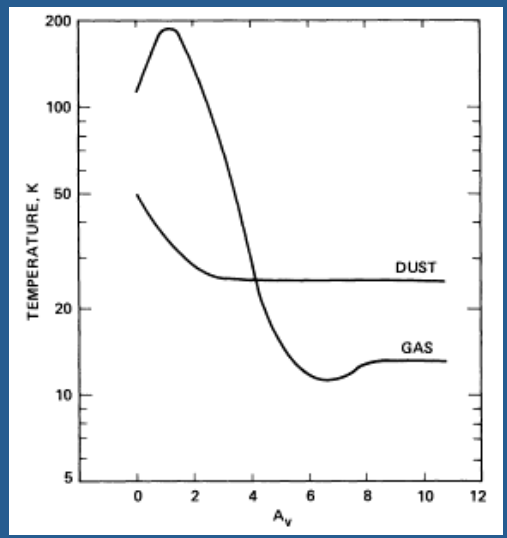
in good agreement with PDFs form numerical HD/MHD simulations of filament formation (Hennebelle et al. 2008)

Schisano et al. in prep

A threshold for clump appearance



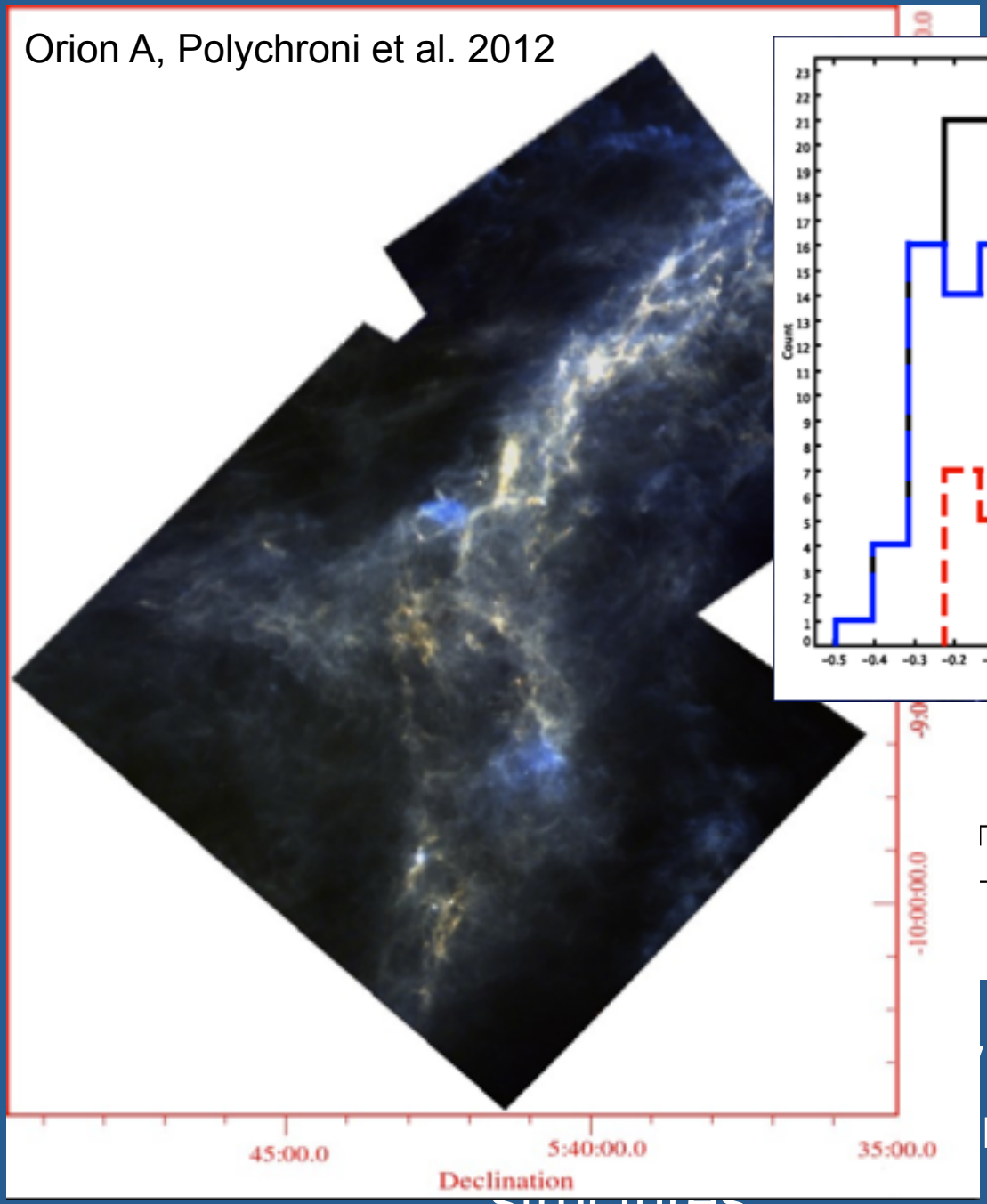


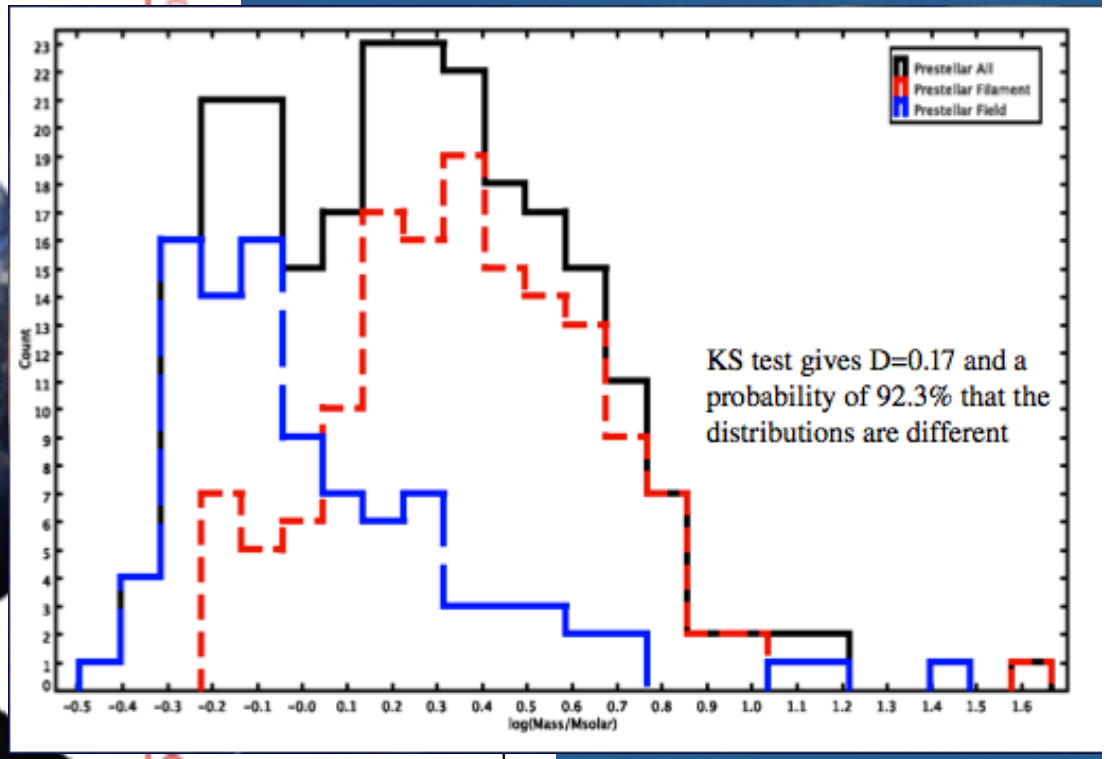


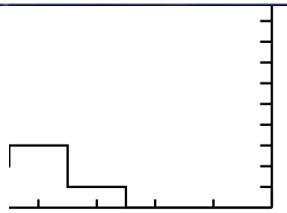
Most of star-forming clumps, certainly the more massive ones, are located along filamentary structures

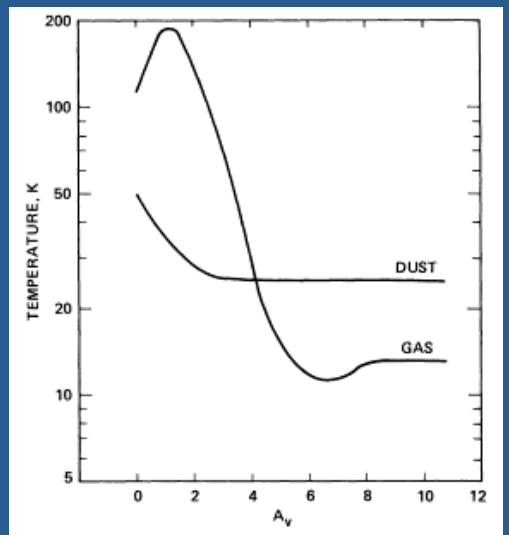
that's were the action is !!

Orion A, Polychroni et al. 2012









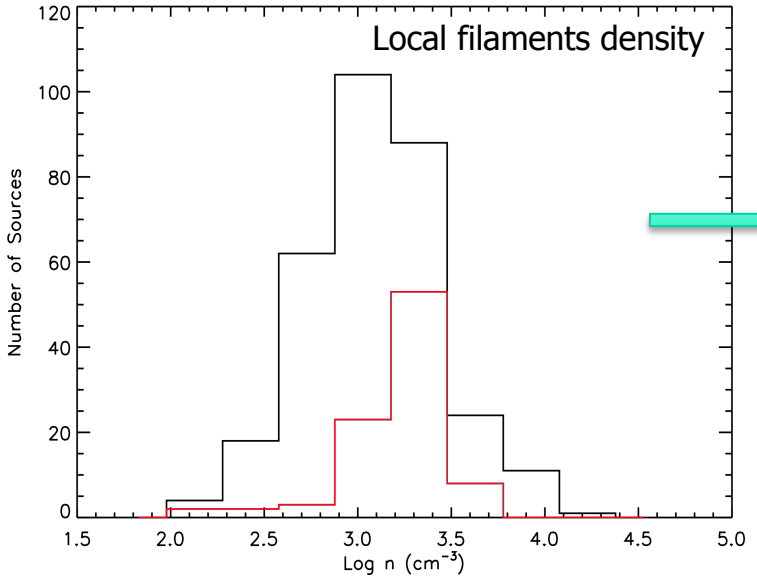
the more
mentary

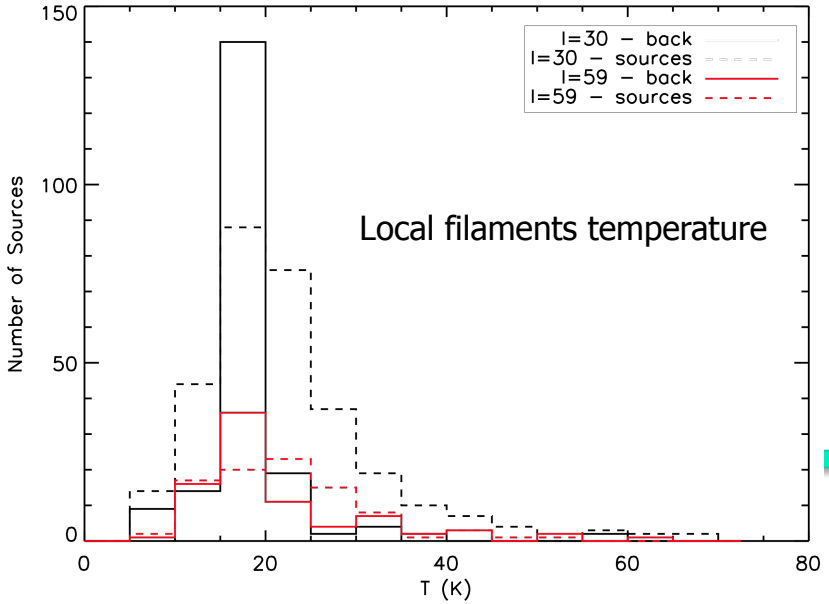
structures

that's were the action is !!

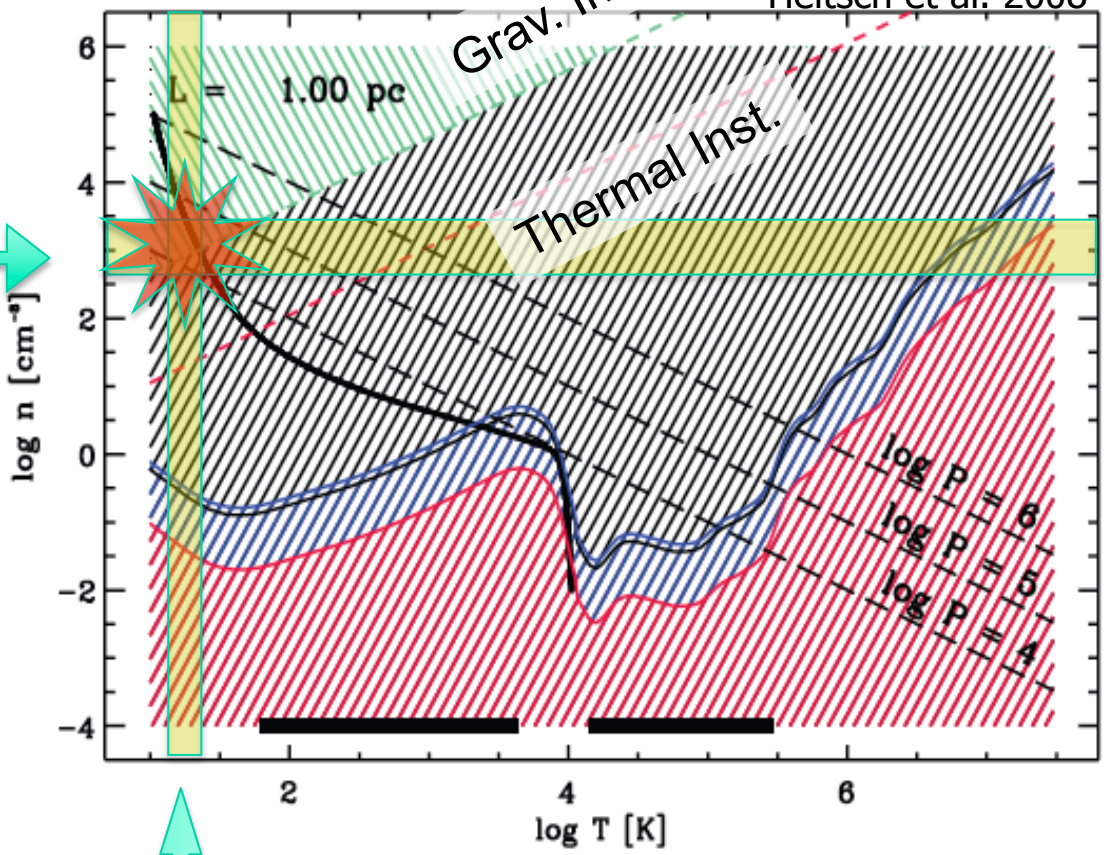
Filament fragmentation

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



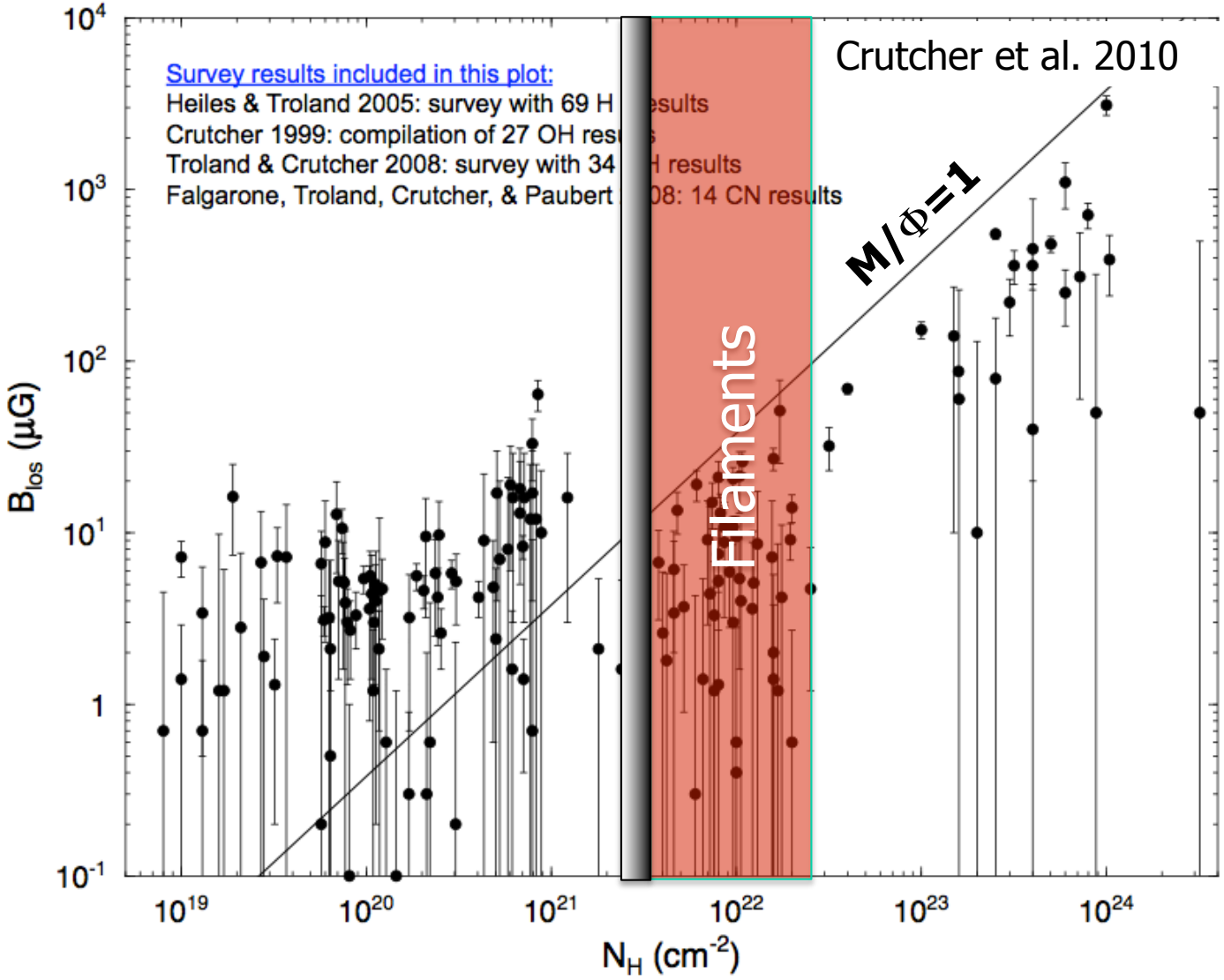


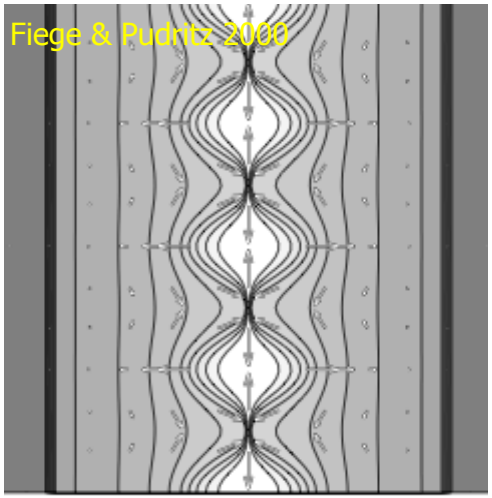
Heitsch et al. 2008

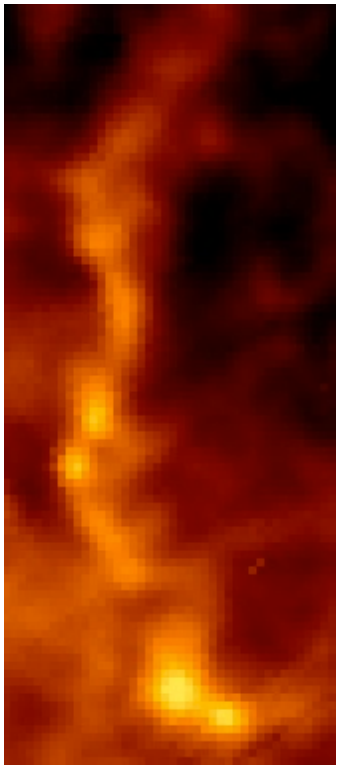


Conclusion: filaments form from diffuse ISM and grow in column density until at $A_V \approx 3$-4 heating and cooling go out of balance. Gravitational instability comes in and high-density fragments start to appear.

Is B important in filament fragmentation ?

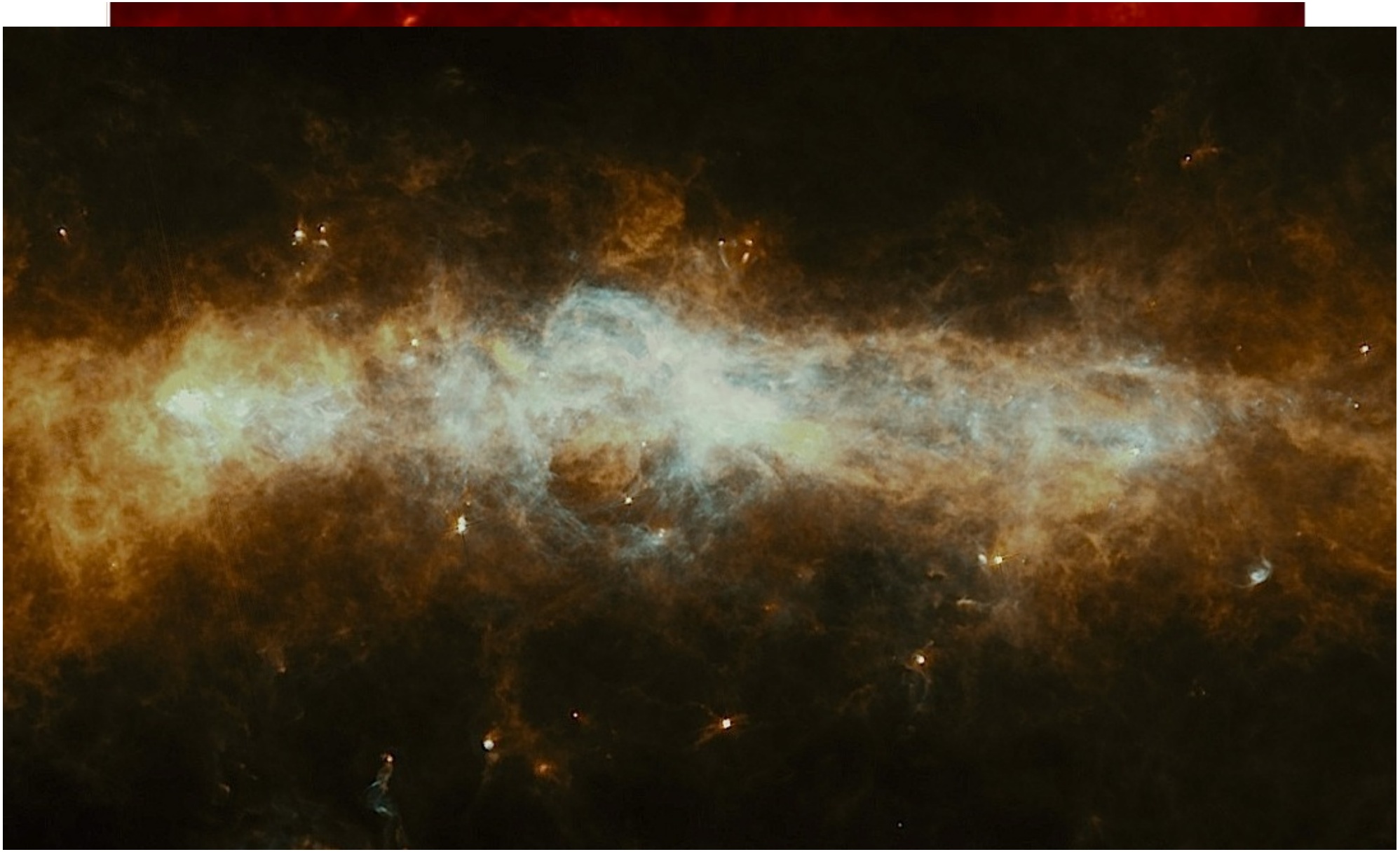


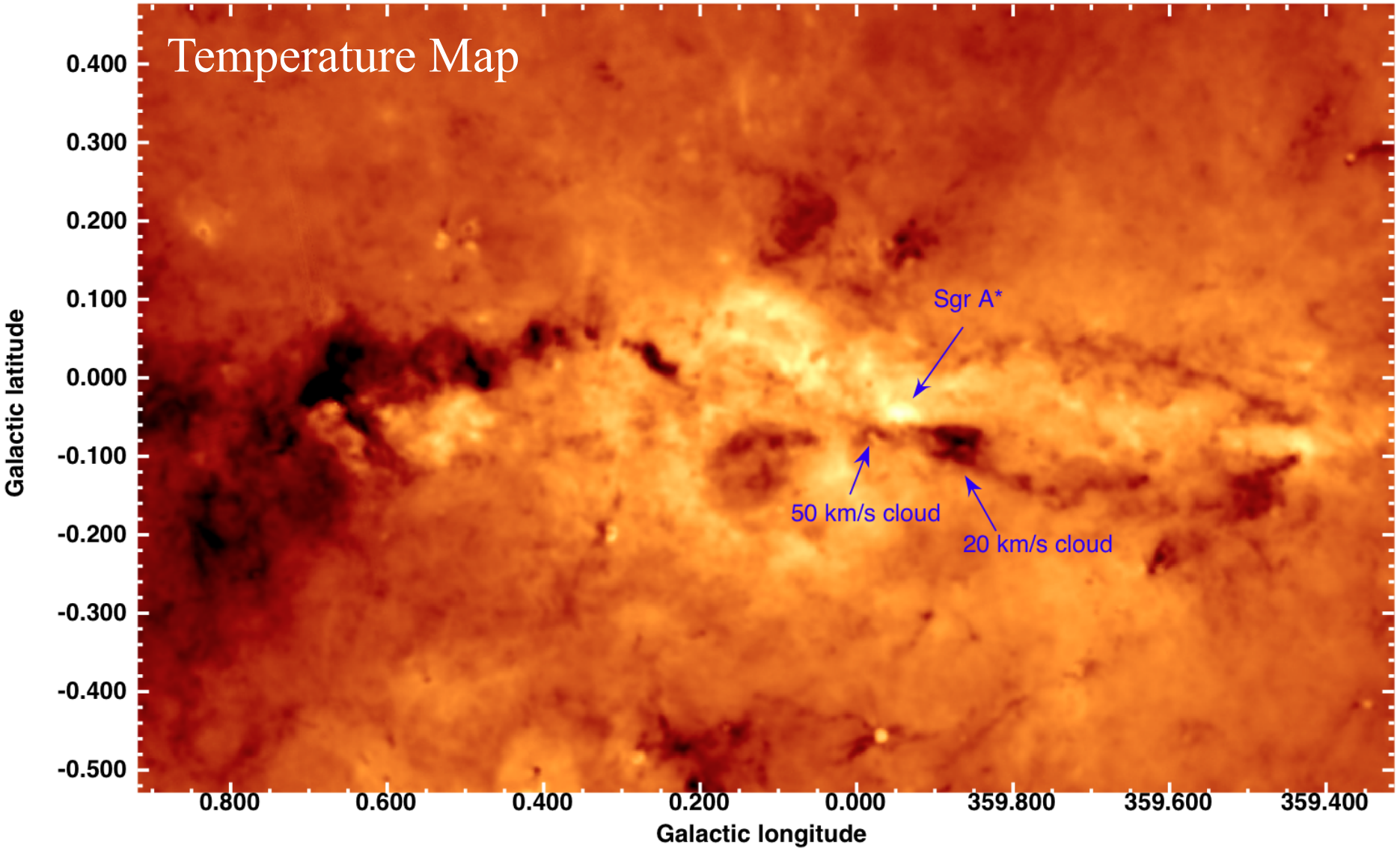




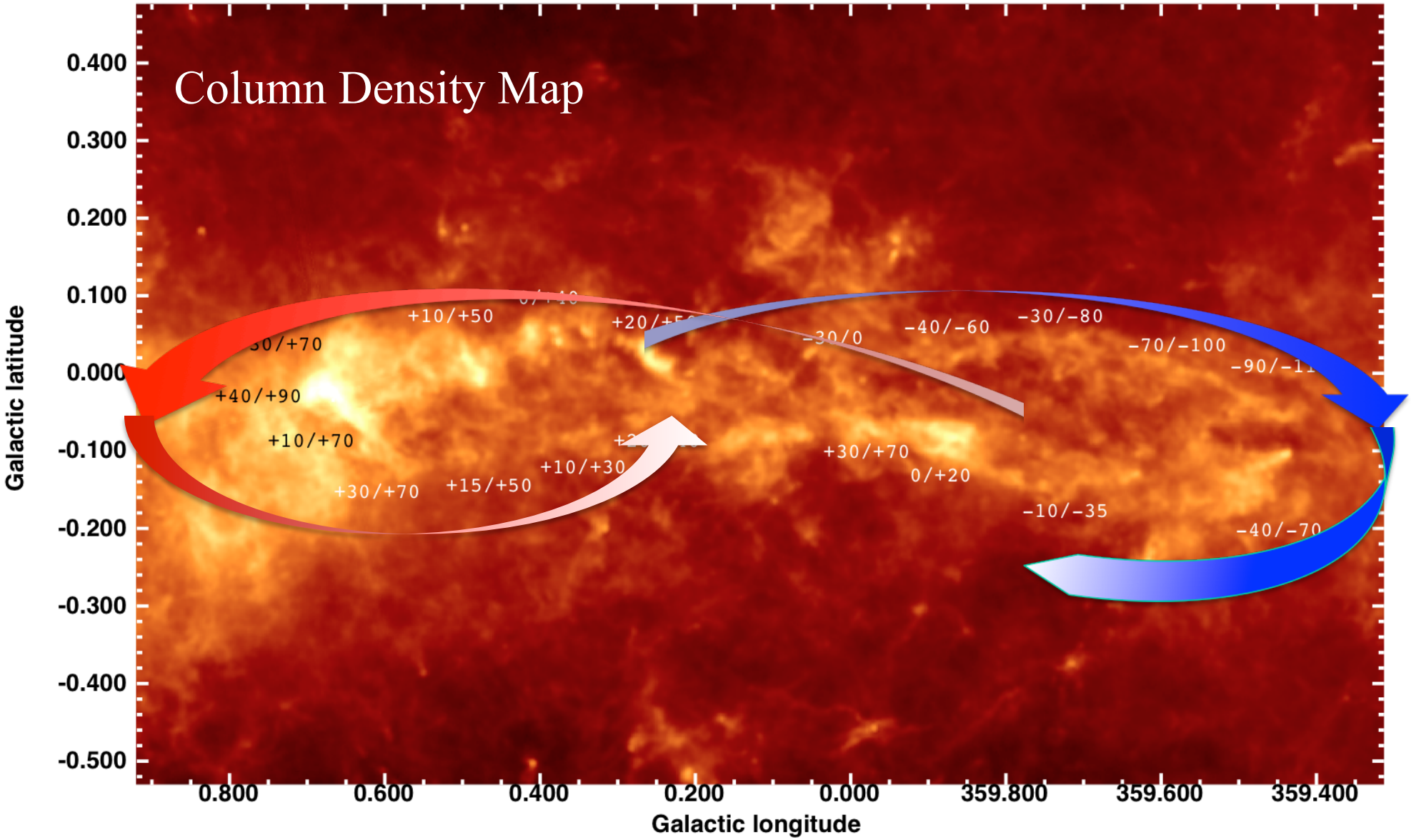
Filaments hosting compact sources span a N(H) range which is compatible with structures losing magnetic support and starting to collapse

The Galactic Center



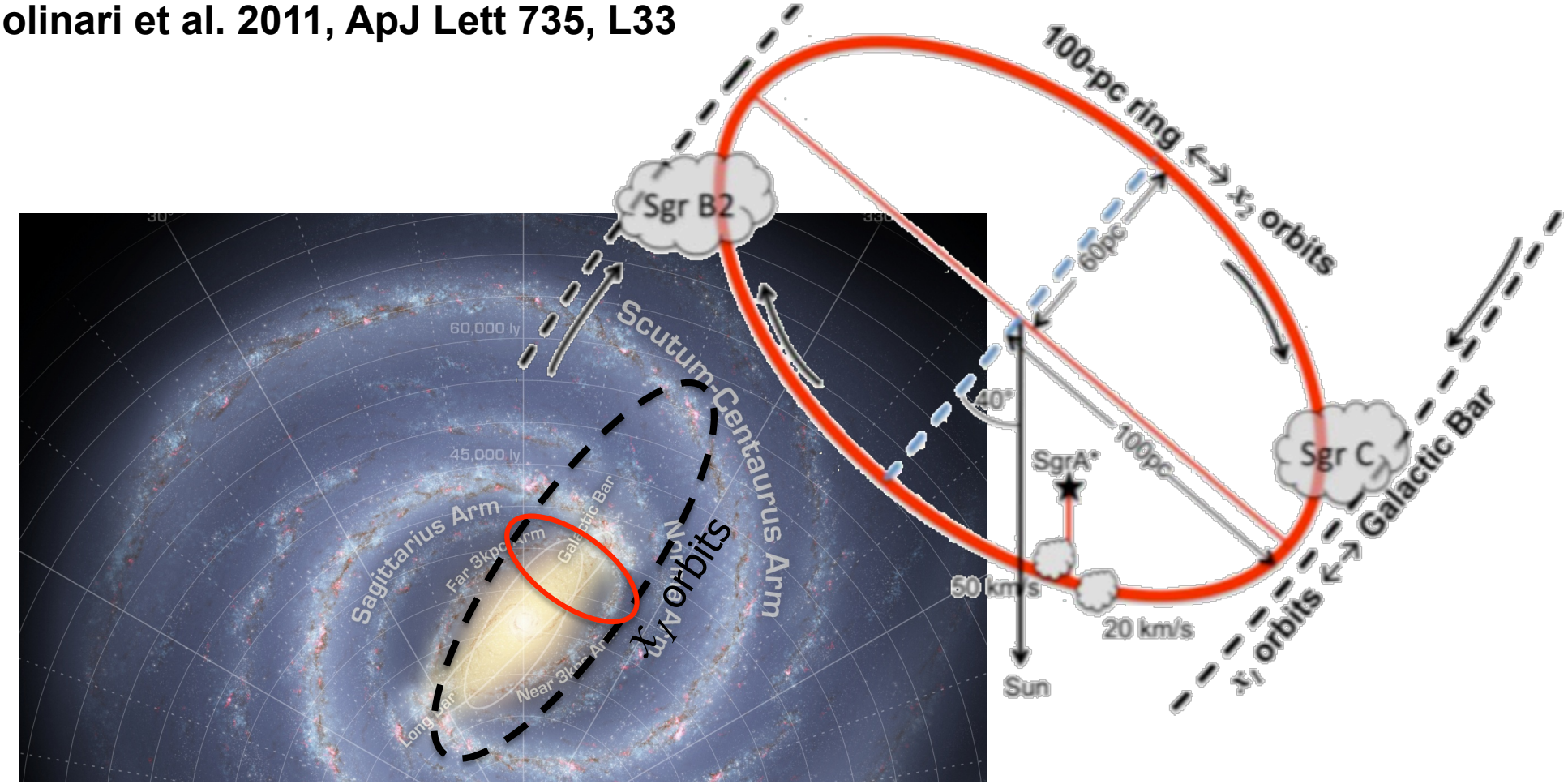


The 5 Hi-GAL maps were rebinned at the resolution of the 350μm (≈25″), and pixel-to-pixel SEDs were fit with DustEM (Compiegne et al. 2010) with opacities τ_{250}/N_H=8.8 10^{-26} cm^2/H, to obtain Temperature and Column Density



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

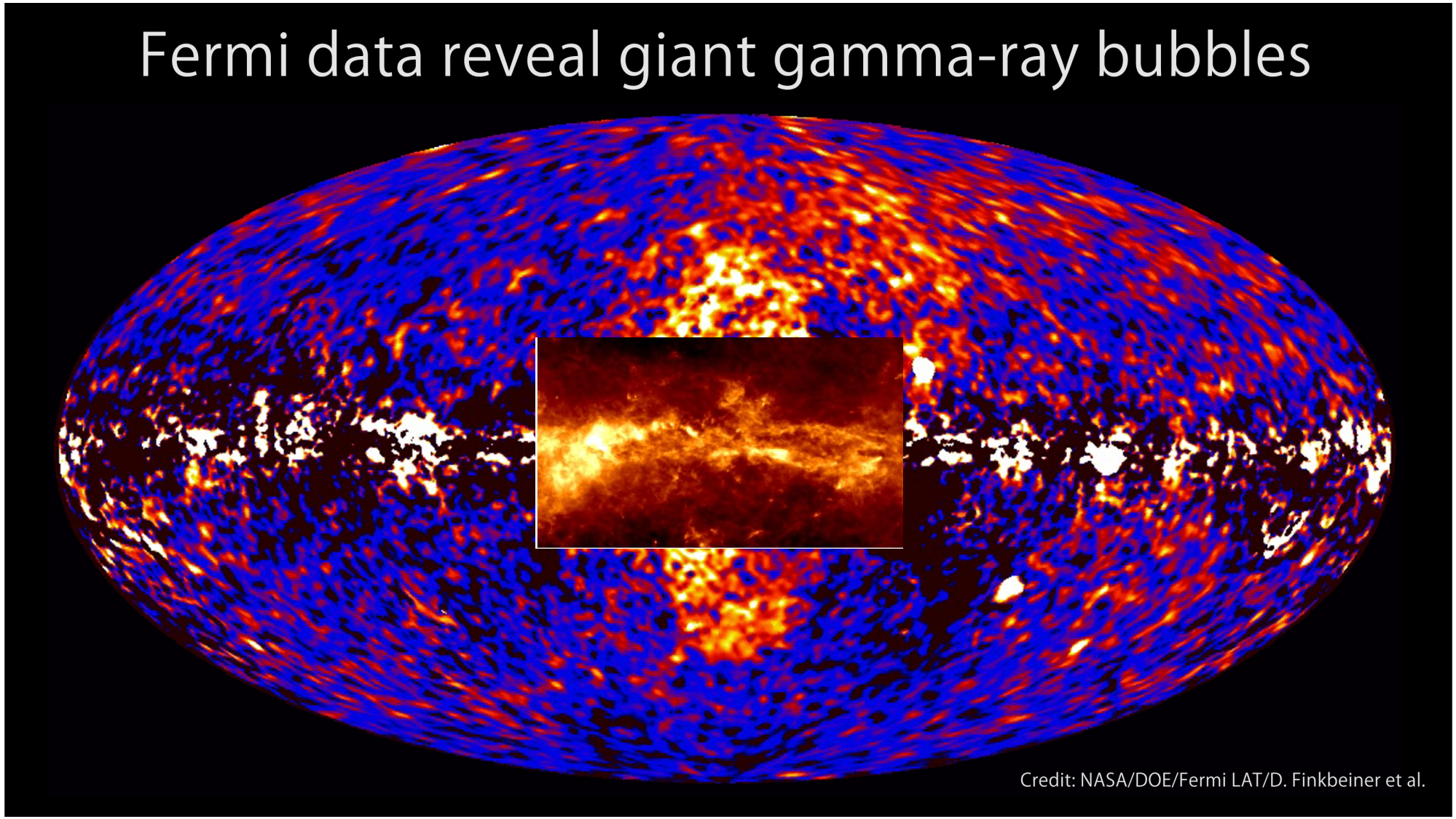
Molinari et al. 2011, ApJ Lett 735, L33



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

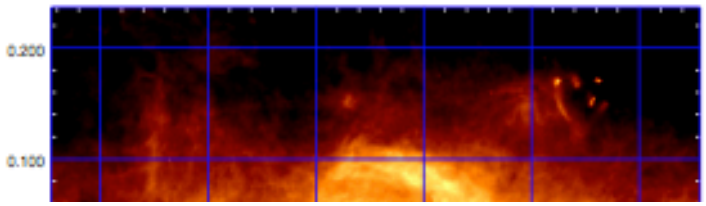
SgrB2 and SgrC are conveniently located at the converging points between the x_1 and x_2 *orbits*, where shock-focusing mechanism may favour the formation of massive clouds

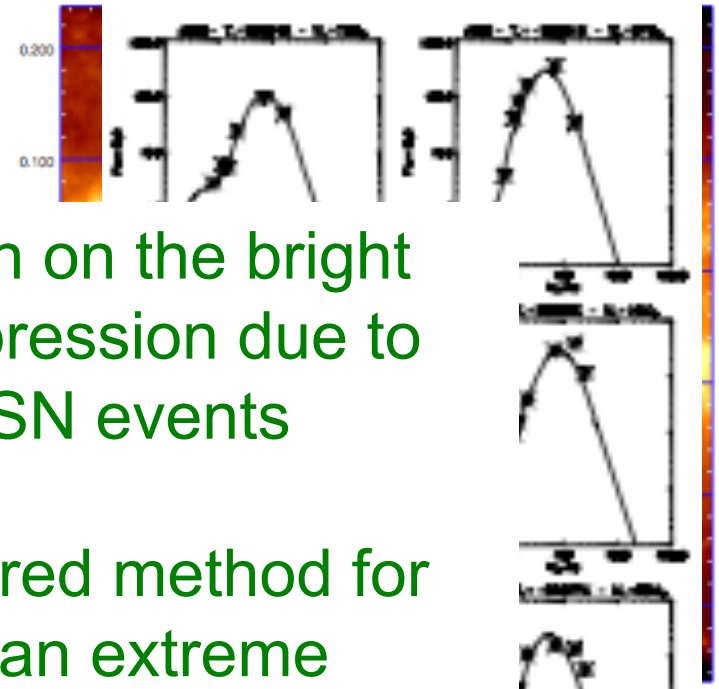
A past AGN phase for the Milky Way ?



Could the 100-pc ring be the remnant of the large AGN dusty torus ?

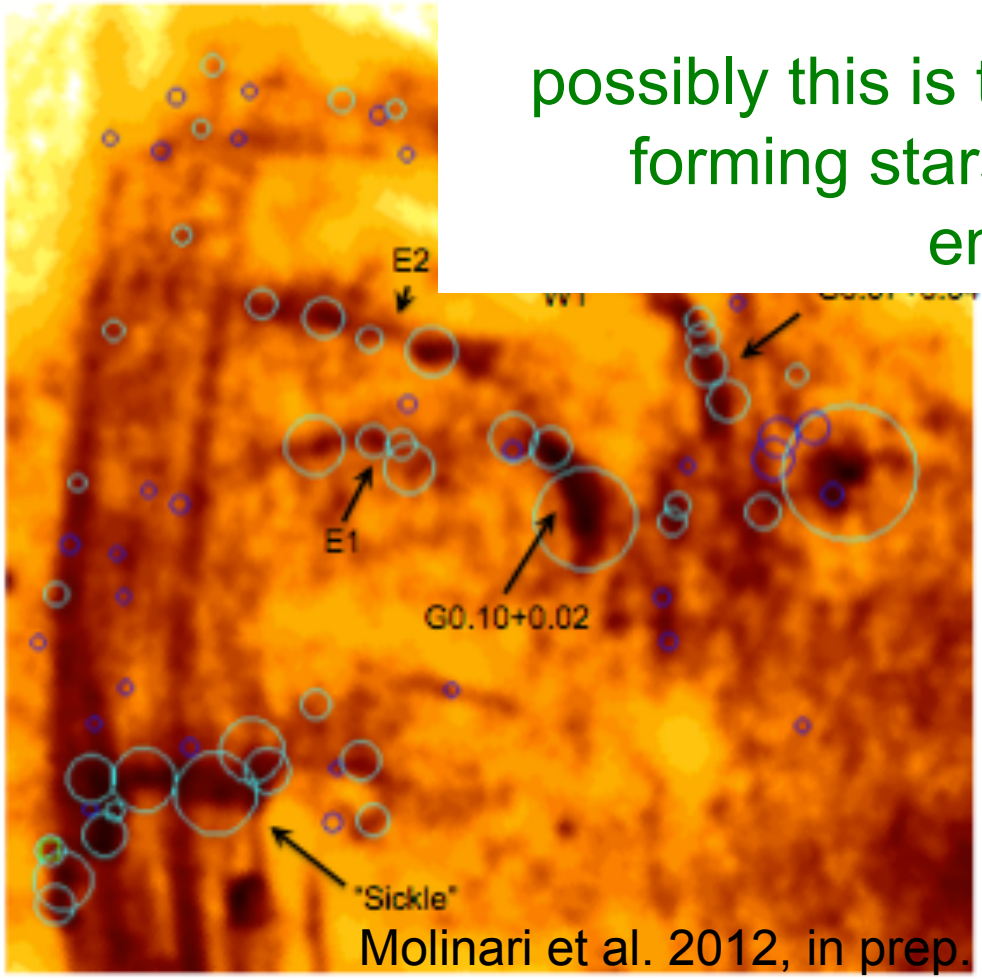
The Galactic Center Bubble

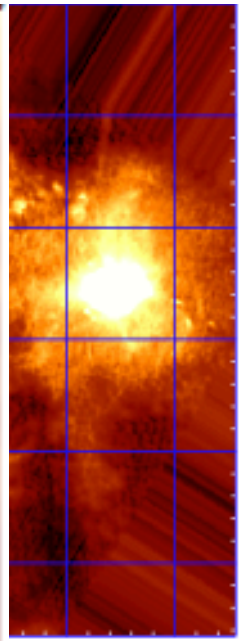


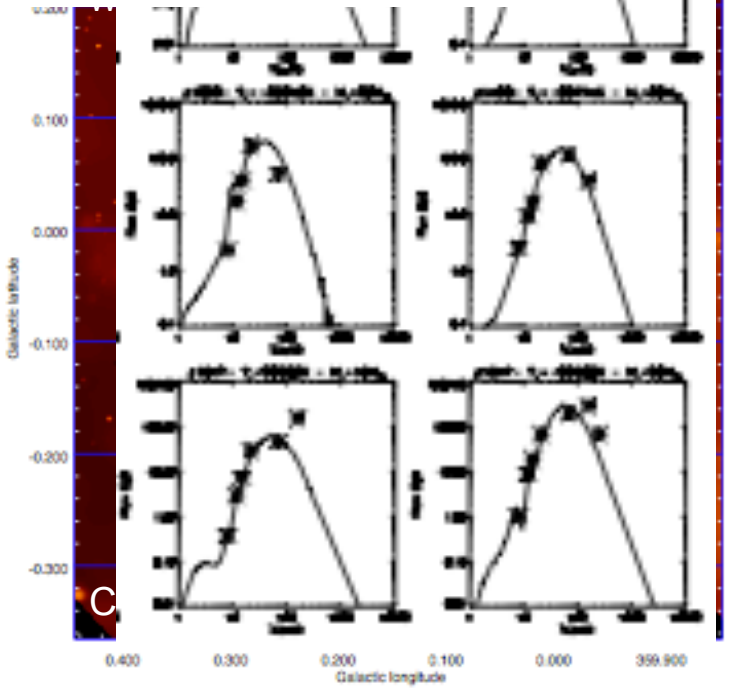


Triggered Star Formation on the bright bubble ridges from compression due to winds from WRs or SN events

possibly this is the preferred method for forming stars in such an extreme environment

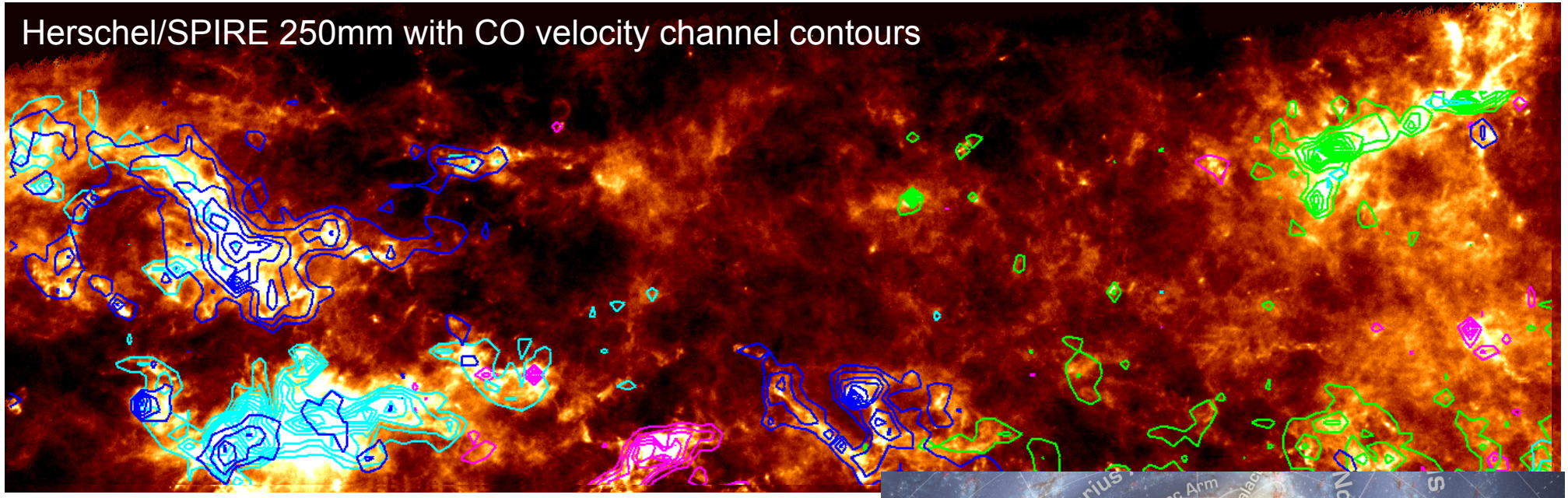




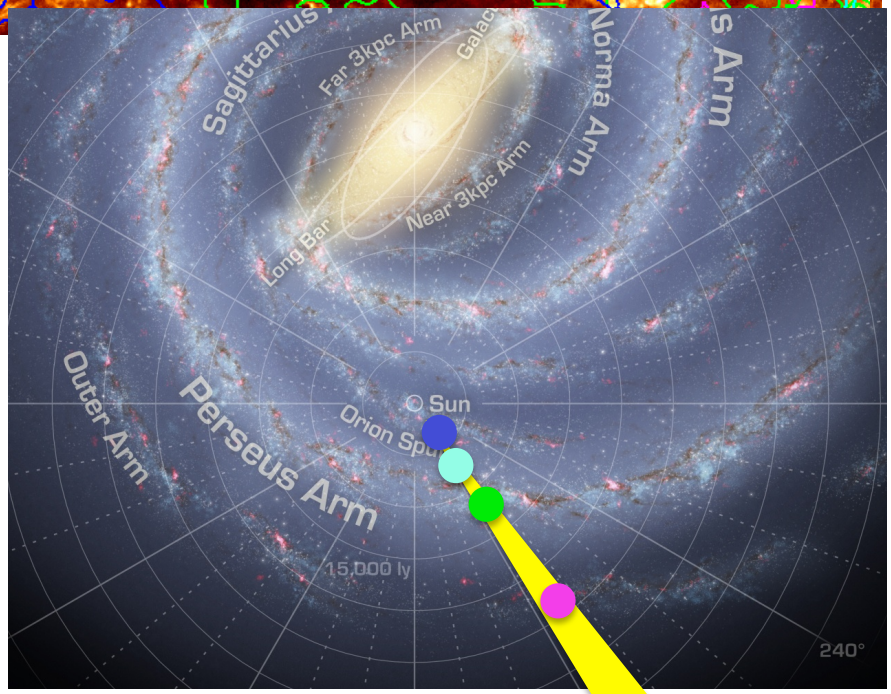


Molinari et al. 2012, in prep.

A look at the Outer Milky Way



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



Conclusions

- *Hi-GAL will obtain the census, temperature, luminosity, mass and Spectral Energy Distribution of star forming regions and cold ISM structures in all the environments of the Galactic Ecosystem, at unprecedented resolutions, and at all scales from massive objects in protoclusters to the full spiral arm.*

- *This dataset will enable decisive steps toward the formulation of a global predictive model of the ISM/star formation cyclic transformation process which is the engine responsible for most of the energy budget in normal star-forming galaxies.*

- *Hi-GAL will deliver a dataset of extraordinary legacy value for decades to come, with a strong potential of systematic and serendipitous science in a wide range of astronomical fields.*