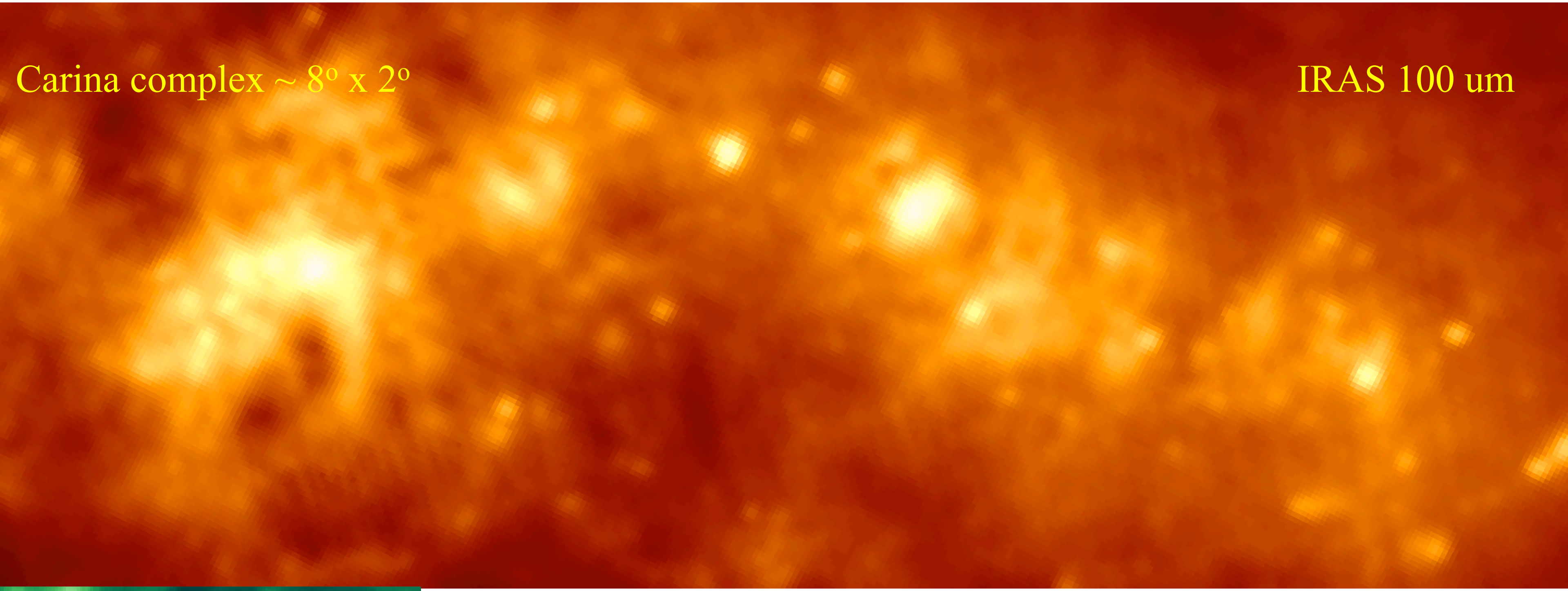
Image Background: Galactic Plane SPIRE 250 μm - Herschel observation
Hi-GAL project - field centered at (l,b))=(224°,0°)

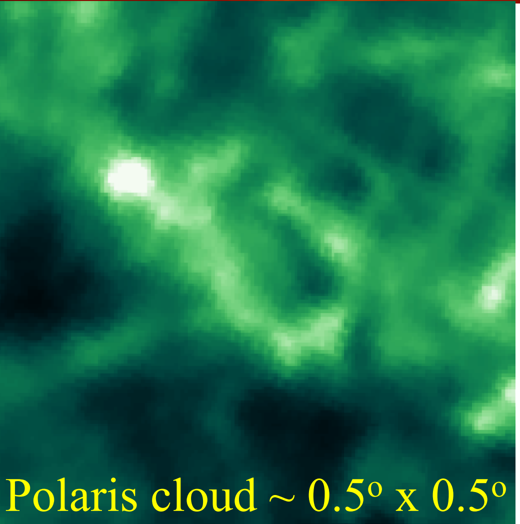
Dusty filamentary structures in the Milky Way:

Funneling matter from diffuse ISM to star-forming condensations

Eugenio Schisano on behalf of Infrared Team at
IAPS – INAF Roma

Several filamentary shapes in Interstellar Medium





"A wealth of filamentary detail is apparent on many different scales at all Galactic latitudes."

cited from IRAS paper Schlegel et al. 1998

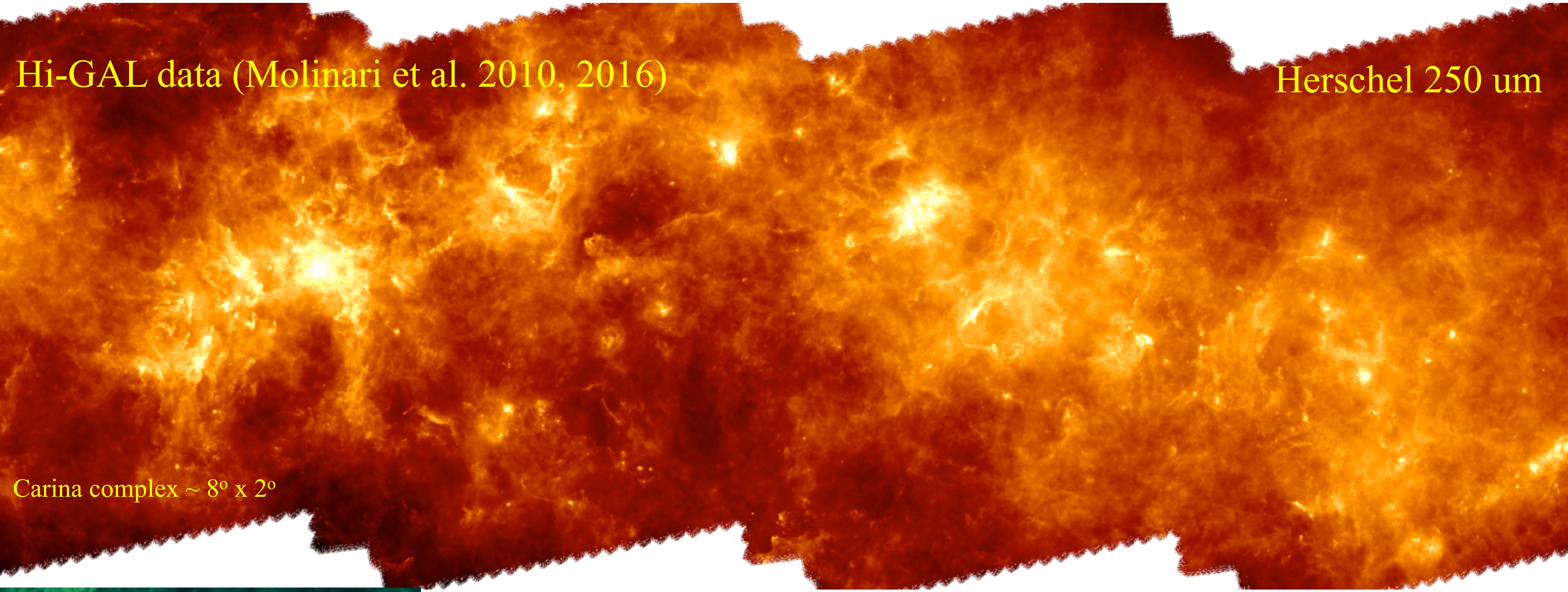
Discovery of "Infrared Cirrus" at every latitude

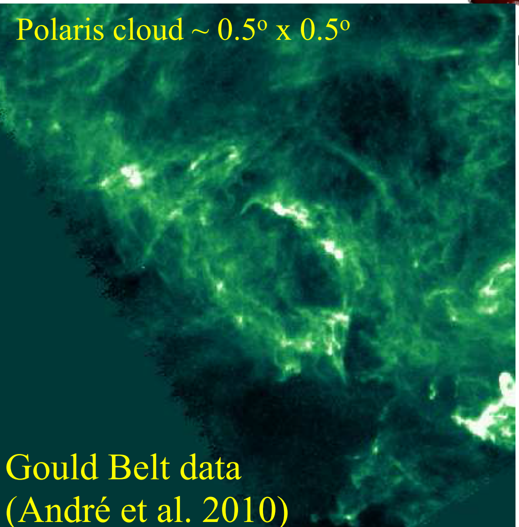
Cirrus as earth's cloud – filamentary, wispy

Presence of filamentary structures in the Galaxy

N_H down to ~ few 10^{21} cm^{-2}

Plethora of Filamentary structures





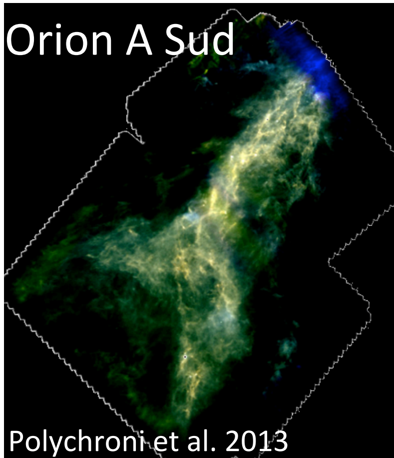
Filaments are found everywhere in the Galaxy at any scale:

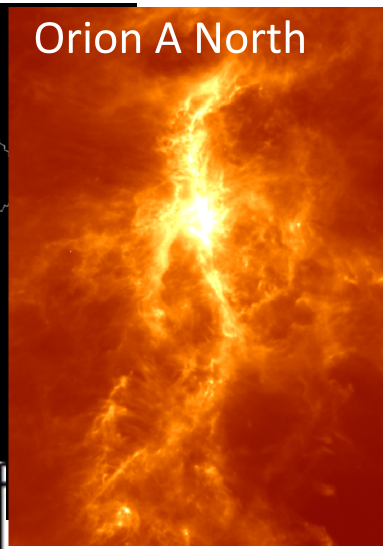
- **-) Extends to even lower column density - $N_H \sim 10^{20}$ cm^{-2}**
- **-) Extends to small-scale filaments (sub-pc scales)**
- **-) Strengthening the spatial correlation between early stellar precursors and filaments**

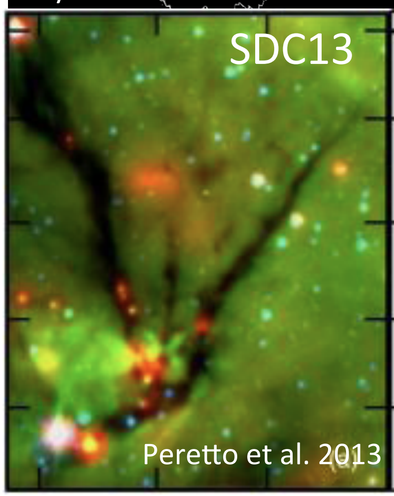
Star formation in Molecular Clouds

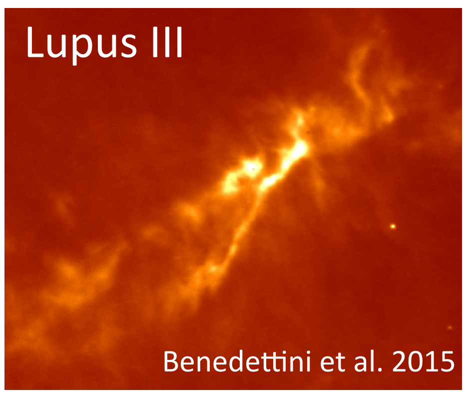
Gas and dust in <u>star forming molecular clouds</u> (SFMCs) <u>are often arranged in a filamentary pattern.</u>

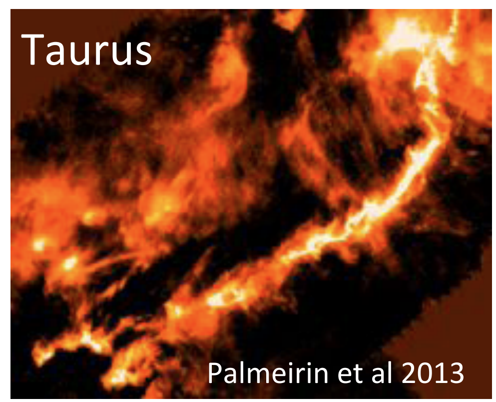
<u>Star formation (and early condensations) is mostly associated with filaments</u>.
(Molinari et al 2010, André et al. 2010)

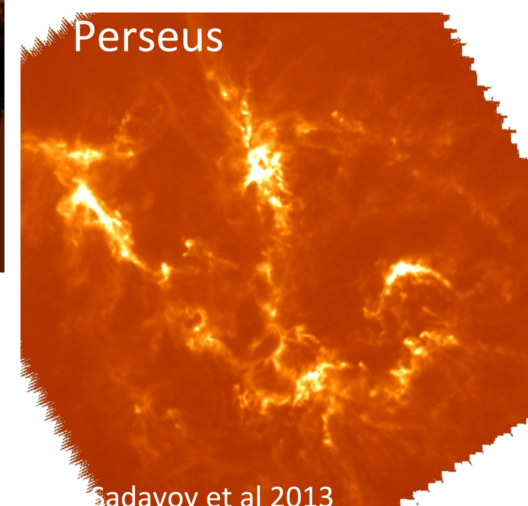


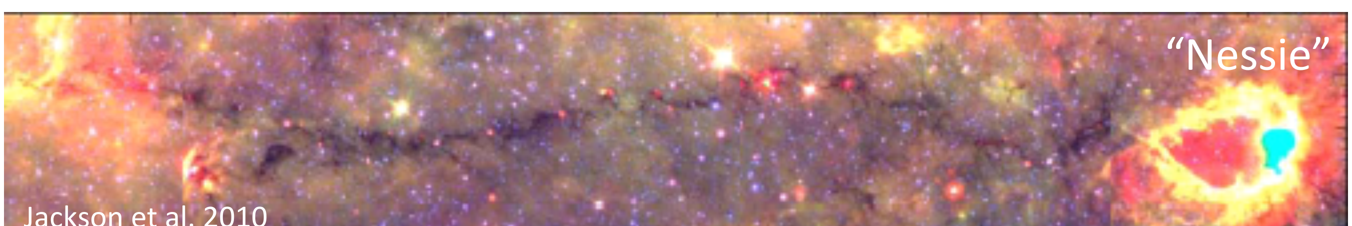


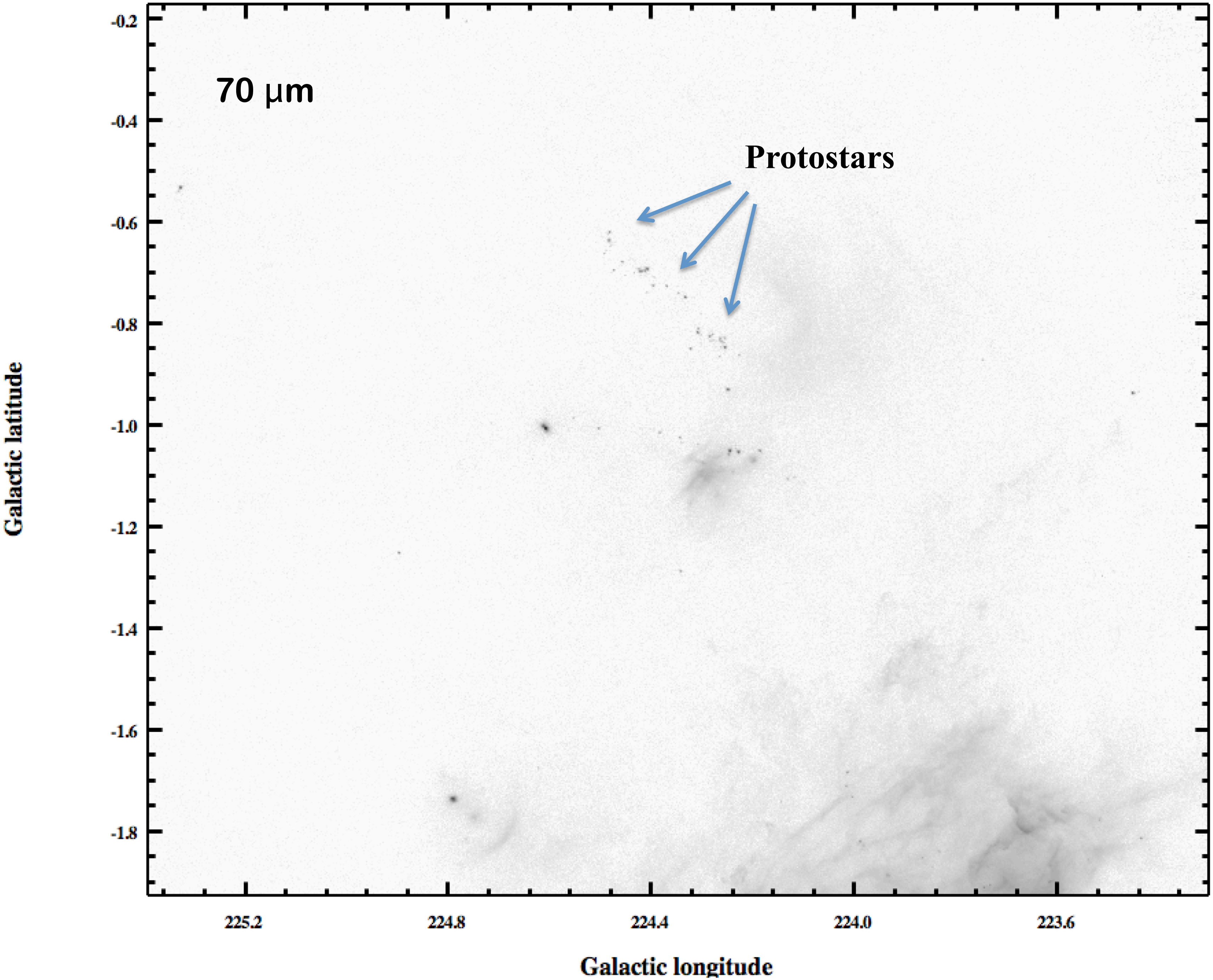




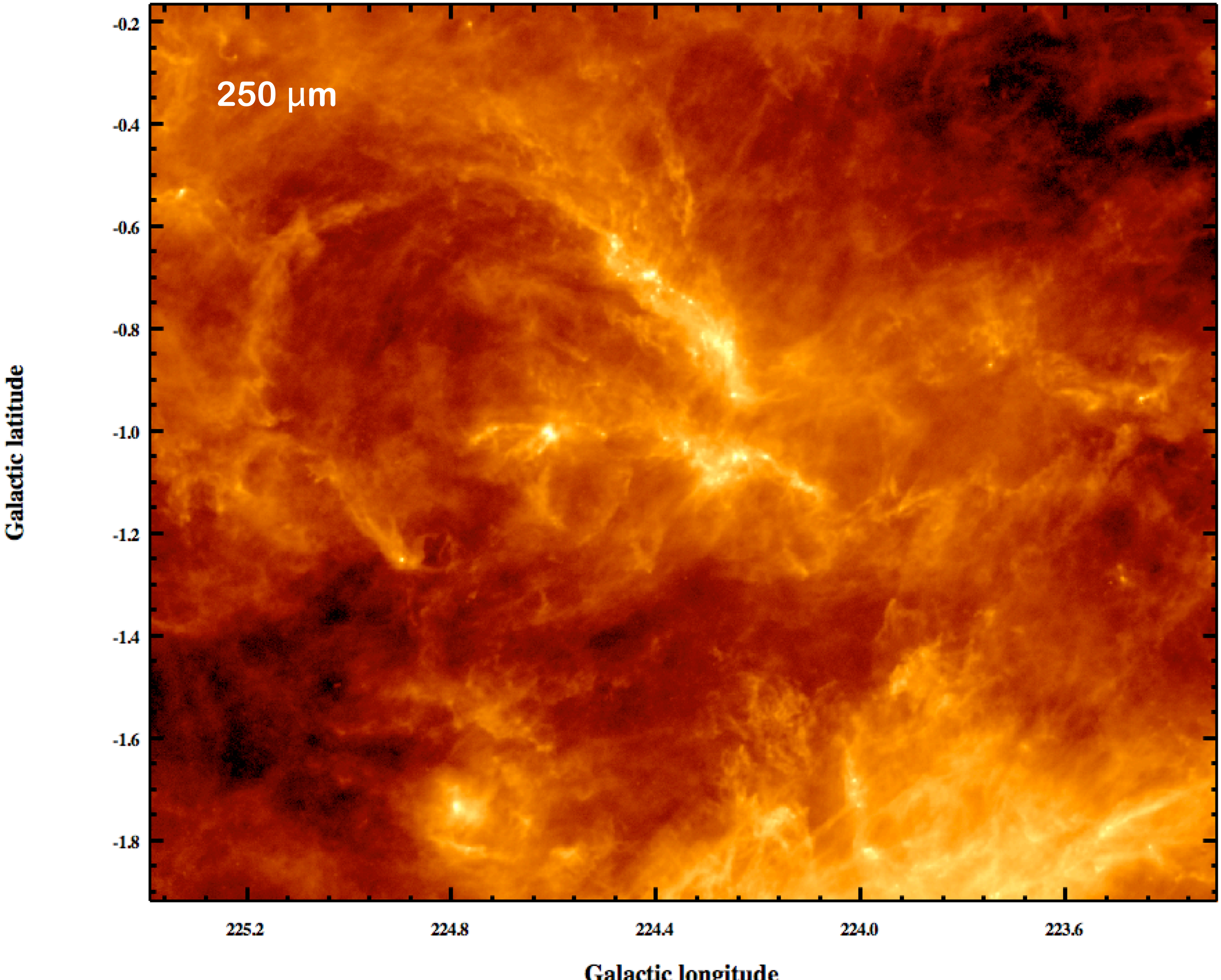








70 µm
Protostars
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
225.2
224.8
224.4
224.0
223.6
Galactic latitude
Galactic longitude


250 µm
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
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-1.6
-1.8
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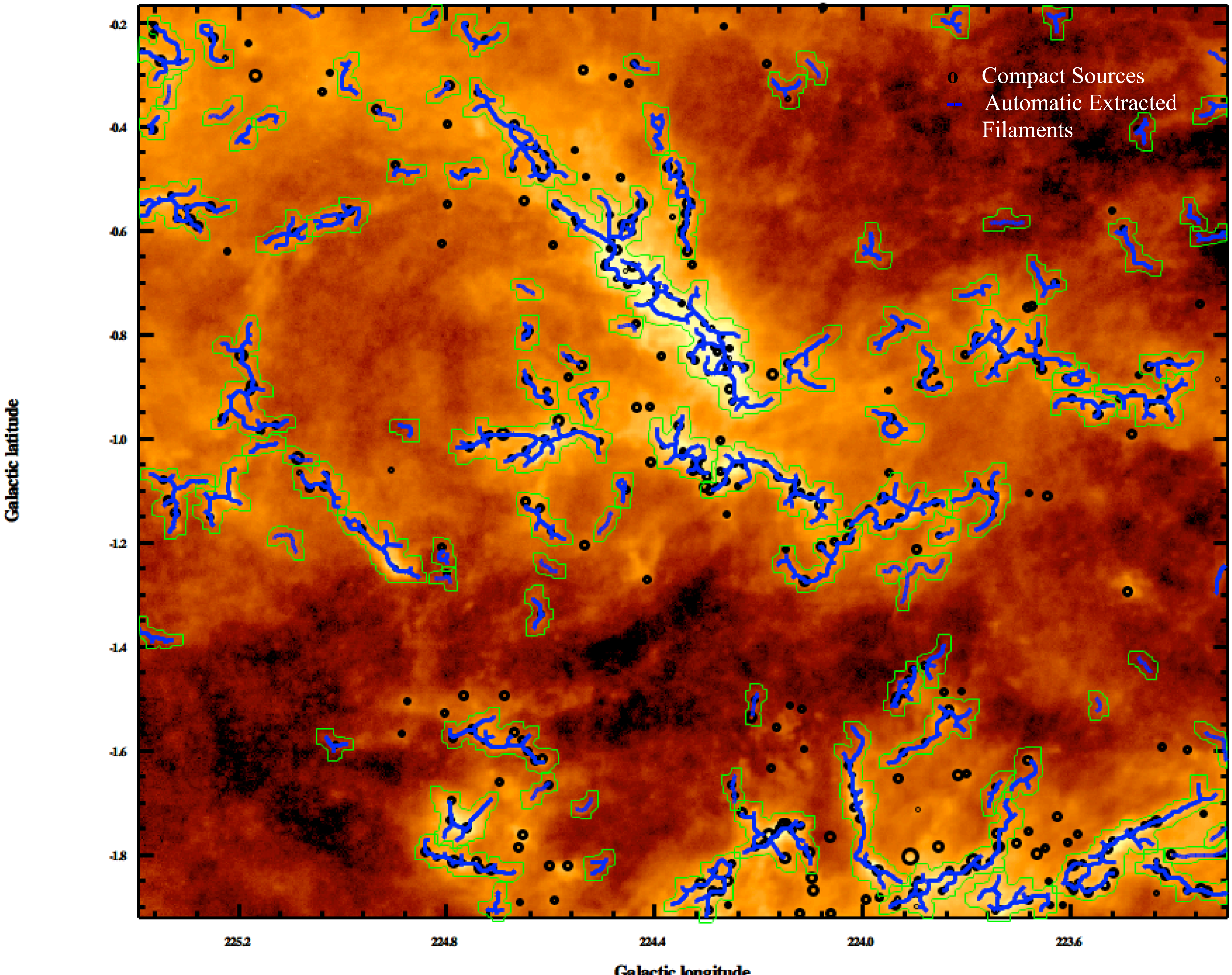
224.0
223.6
Galactic longitude



Column Density Map derived from Herschel data

Observational Evidences

1) Filamentary shapes are found everywhere in the ISM, but mostly form when the diffuse material aggregates into dense condensation.

2) It is in the filaments that the initial conditions for the star formation are set.

Scientific Questions

How do they nest in the paradigm of star formation? What is their role?

Should they be considered a intermediate state between diffuse material/large molecular clouds and cores/clumps?

Are all filaments the same? Do they trace a common underlying physical phenomena that define their shapes?

What are the observed properties of interstellar filaments?

How do interstellar filaments form? How do they evolve? How do they finally dissipate?

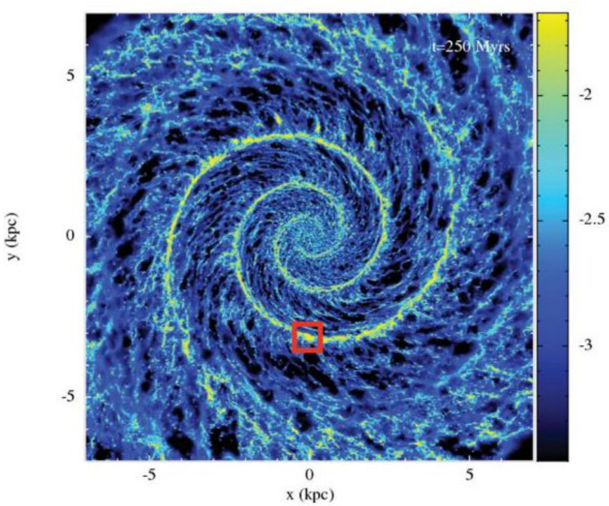
Current Paradigm

Results from few cases in nearby clouds (and first indications from theory) favour a scenario with the initial steps of star formation as a two stage process:

a) first a combination of large-scale flows, turbulence, magnetic field, gravity stirs up the gas, giving rise to a universal web-like structure in the interstellar medium.

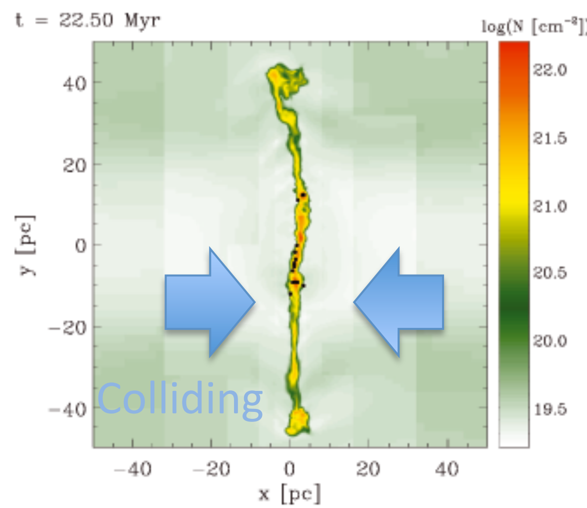
b) then gravity takes over and controls the <u>further fragmentation of filaments</u> into prestellar cores and ultimately protostars.

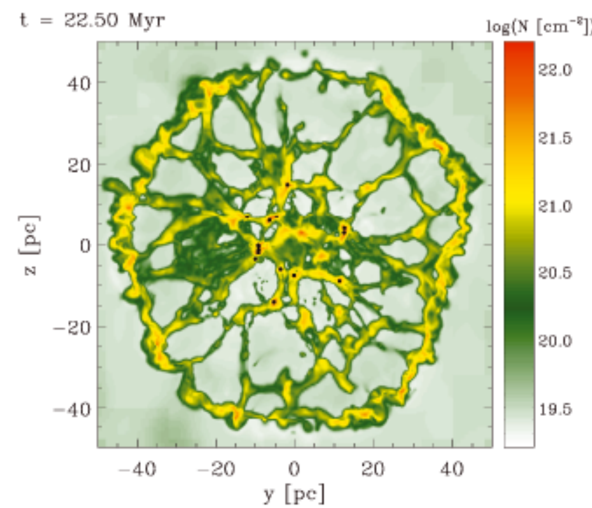
Large scale flow on Galactic shear



Dobbs & Pringle 2013, Smith et al 2014

Local scales - colliding flows – oblique or head-on





Banerjee et al. 2009 Gravitational framentation of sheet

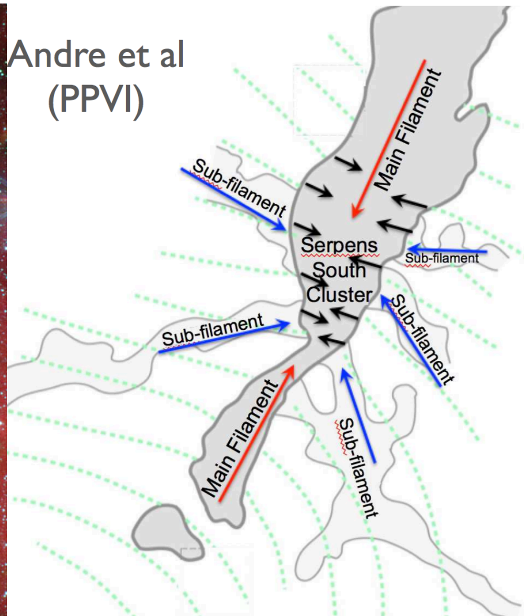
Comment on a) On theoretical simulations also HD turbulence or MHD alone makes filaments.

Comment on b) Only through a 1D structure it is possible to overcome a too fast collapse.

b’) Filament-Hub accretion: formation of Clusters/ High Mass stars

Gutermuth et al. 2009

Andre et al (PPVI)

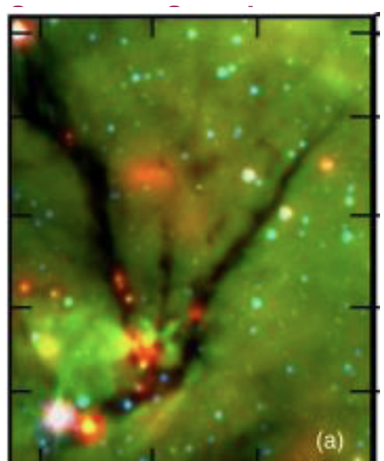


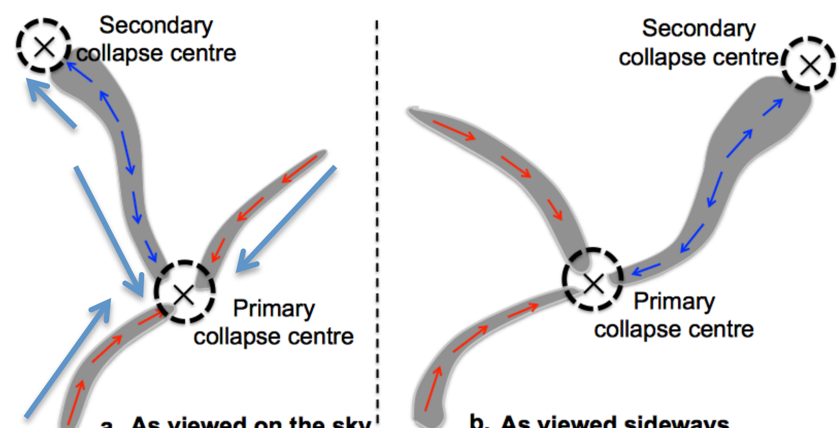
Forming/very young clusters tend to be associated with radiating filaments (Myers 2009)

Filamentary accretion onto central cluster: From detection of gradients & infall motions (Kirk et al. 2013)

Accretion rates ~ 30/130 M_{sun} yr^{-1} able to support high star formation rates in the cluster.

Accretion dynamic also found in filamentary IRDC





Peretto et al 2013

<u>Analyze such a scenario with a statistical large sample of filaments in different enviroments, hence we are looking at the Galactic Plane.</u>

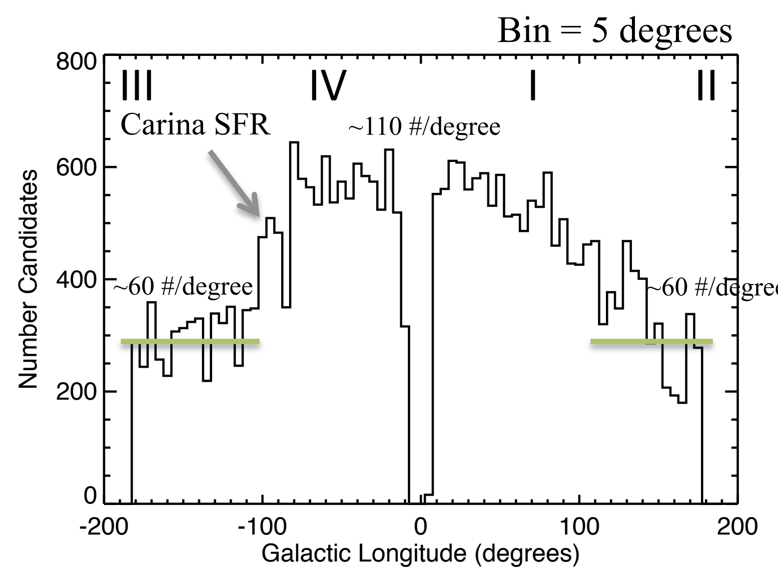
Herschel data is the <u>natural starting point</u> for such a study:

+) Extension: cover the whole GP.
+) Complete: offers any kind of possible enviroment.
+) Statistically significative.

-) Too Large sample! Automation needed.
-) Extended structures appears in projection.

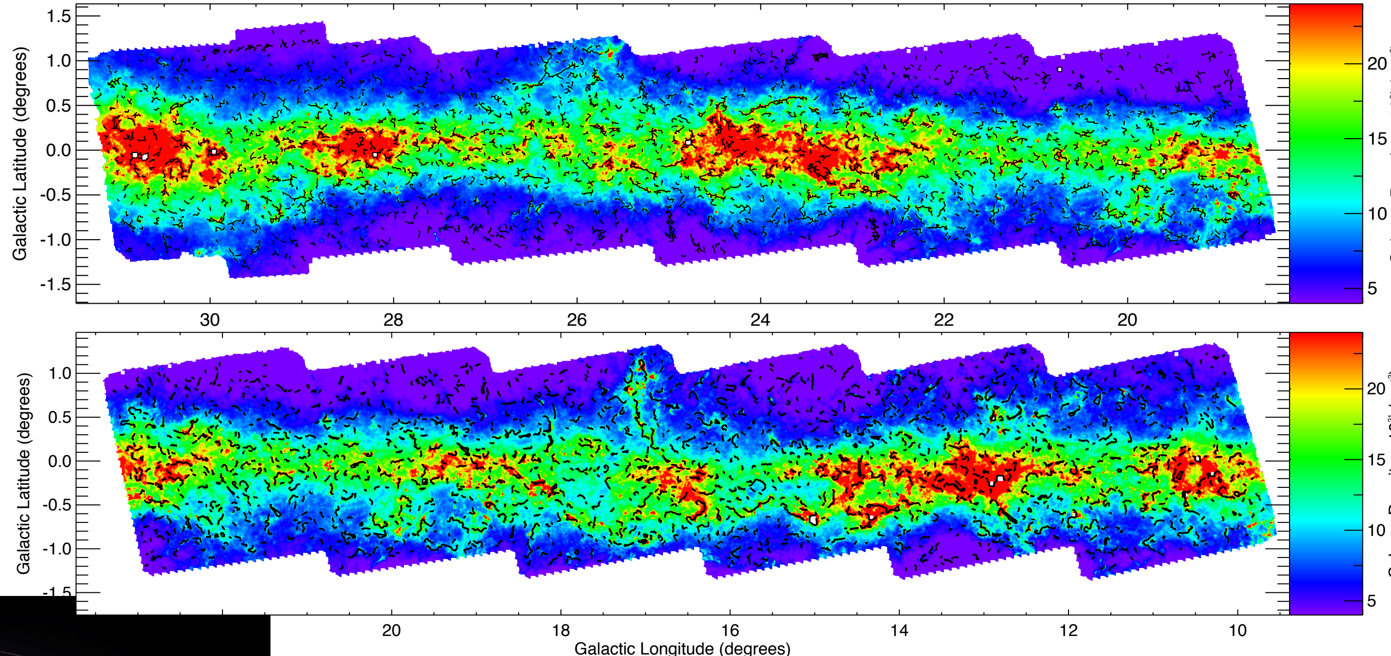
In the framework of the VIALACTEA project (EU FP7) we built a catalogue of about 30000 candidates filaments all along the Galactic Plane.

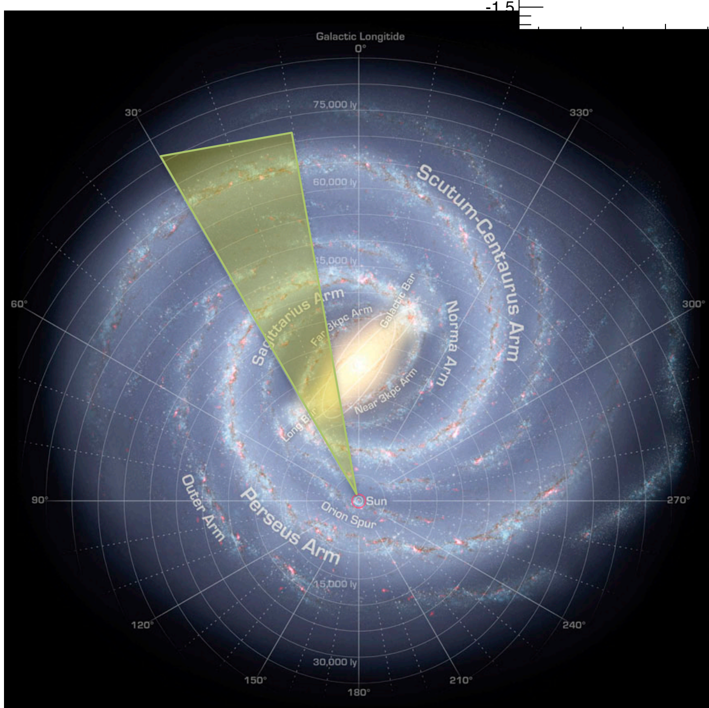
Large dataset that contain <u>any feature</u> that can be defined "filamentary".

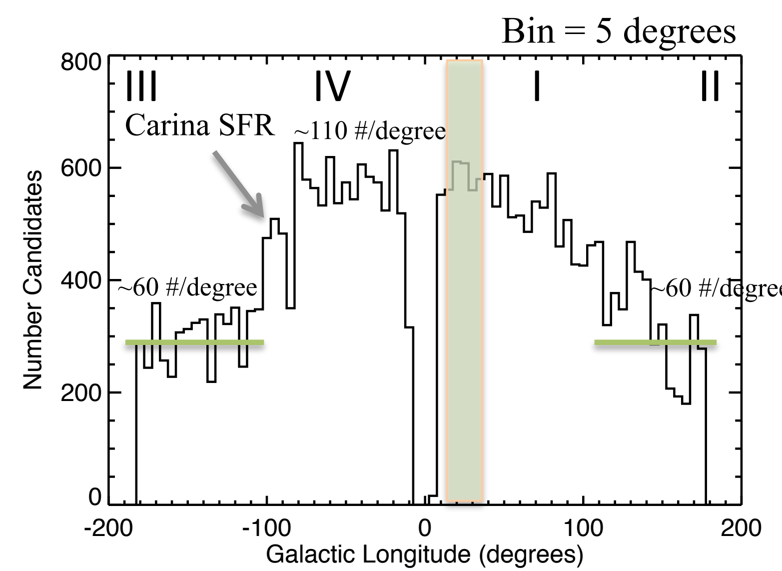


Sharp transition III – IV with respect to I-II

Catalogue includes:
-) morphological properties
-) physical properties and
-) spatial association
with sources







Sharp transition III – IV with respect to I-II

VIALACTEA

Catalogue includes:
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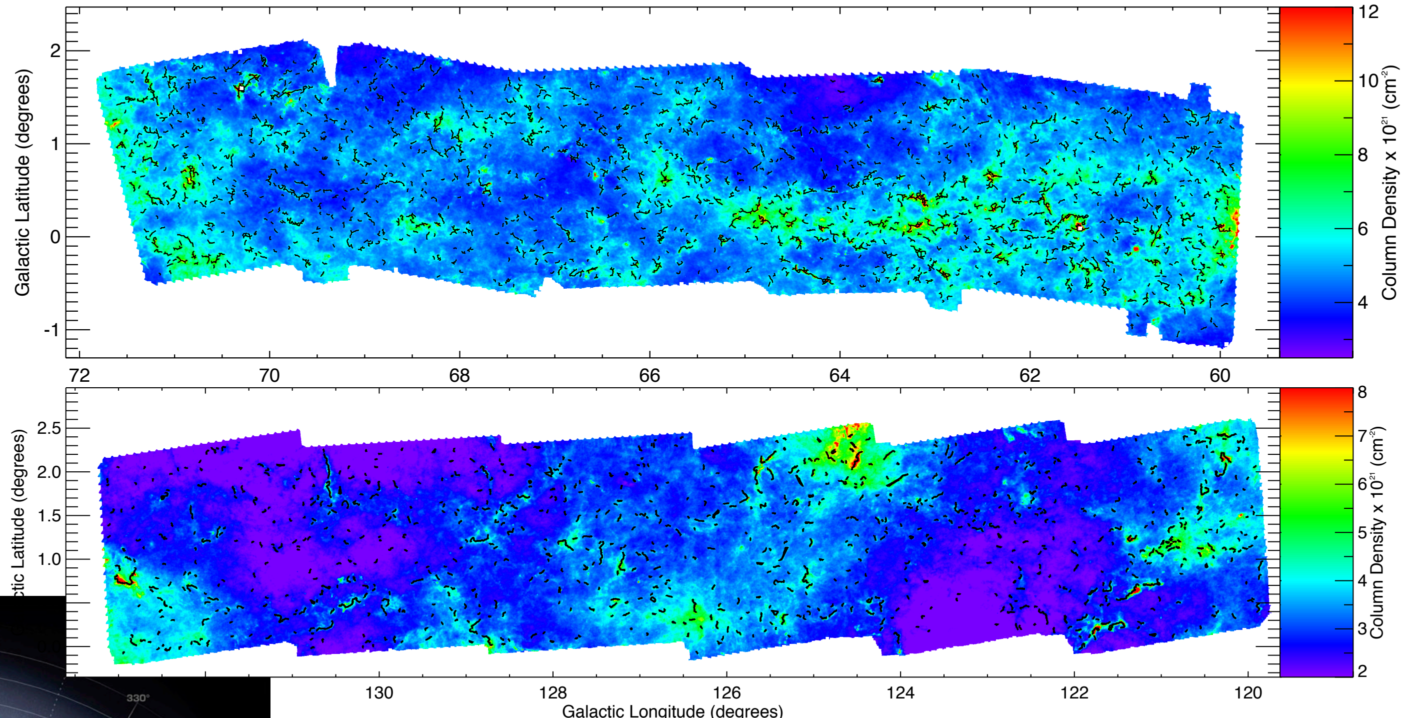
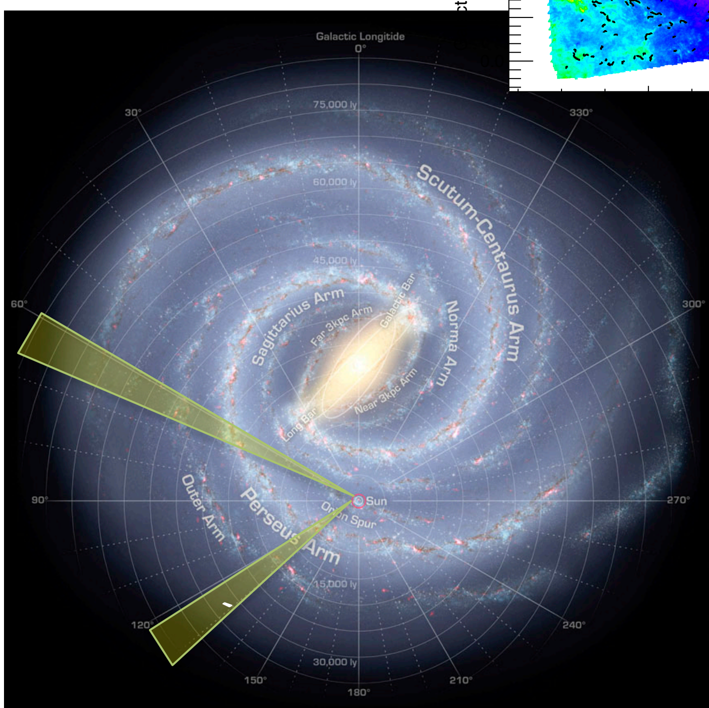
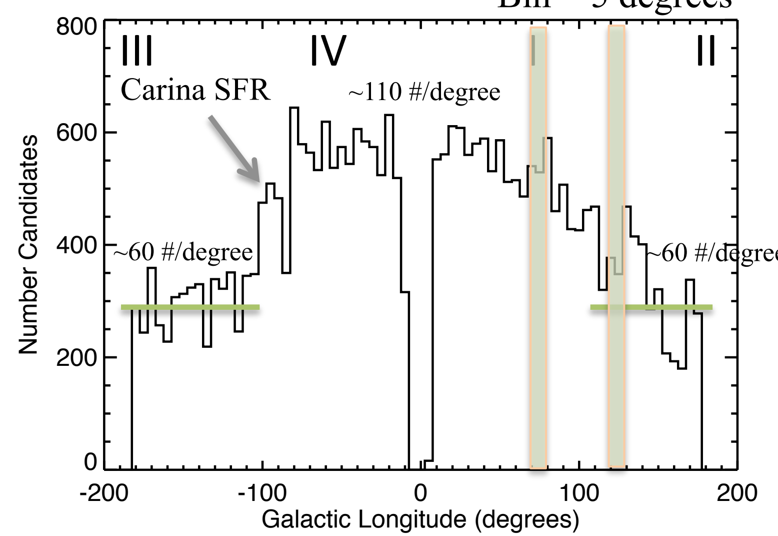






Sharp transition III – IV with respect to I-II

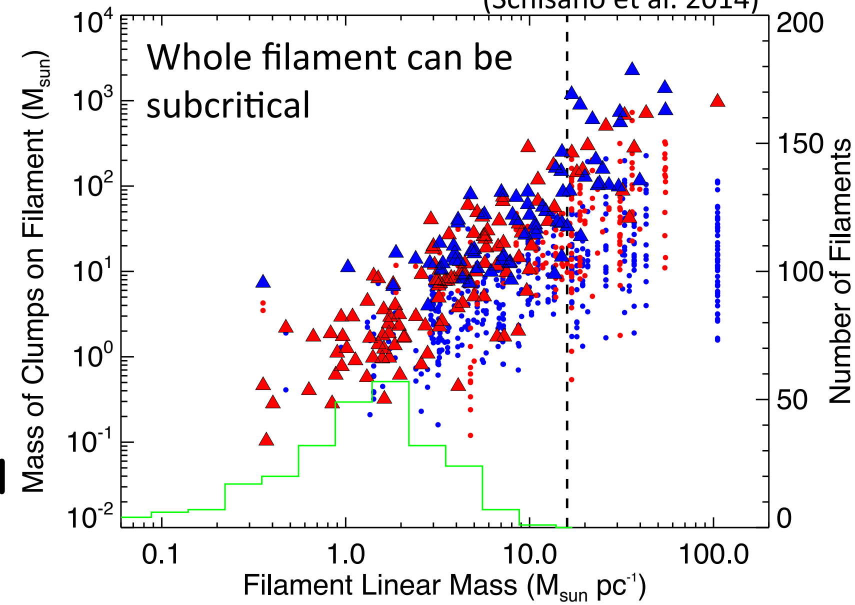
Some results in a portion of Galactic Plane

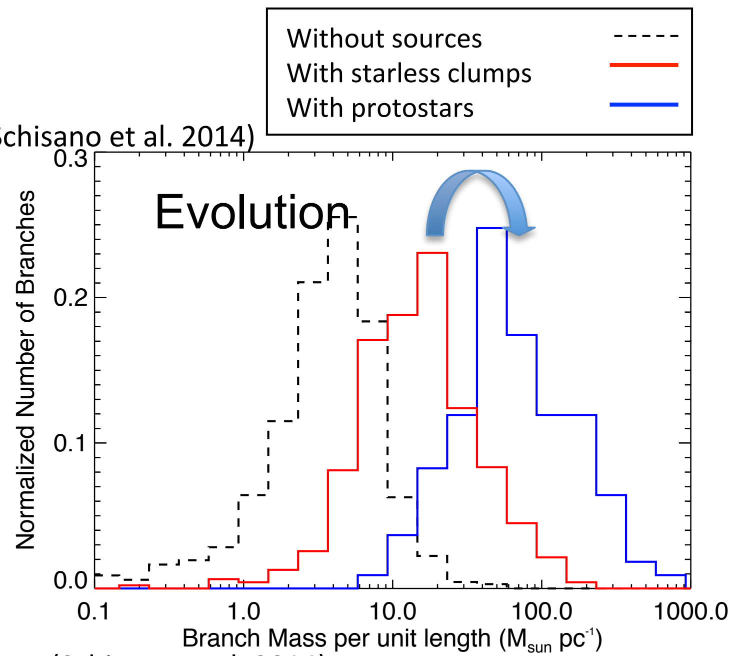
Large majority of high density material lies into structures that can be classified filamentary.

Amount of material channeled in clumps depends on linear density of the global filaments.

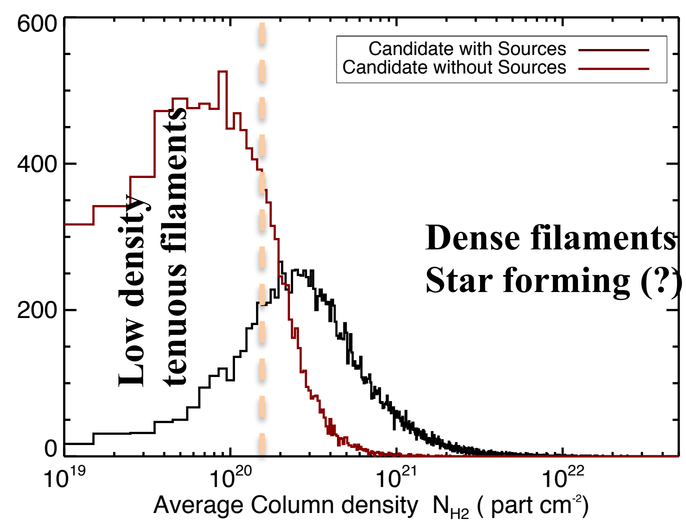
Initial attempt to define a local evolutive sequence of filament substructures based on linear density

(Schisano et al. 2014)





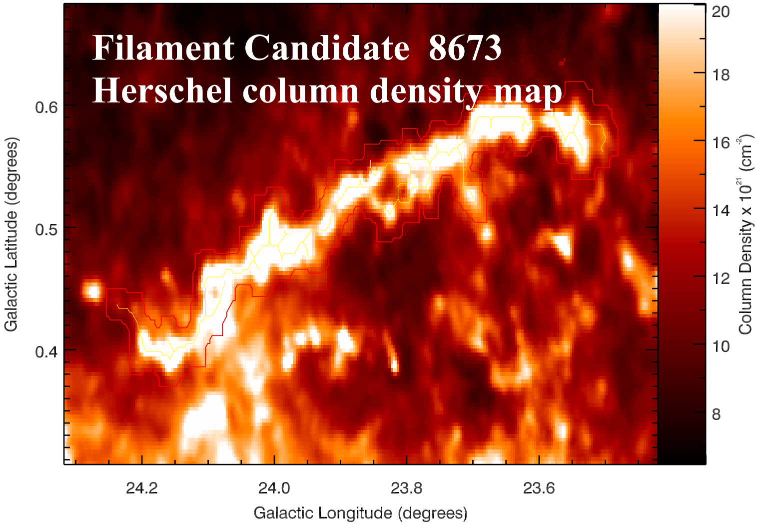
(Schisano et al. 2014)



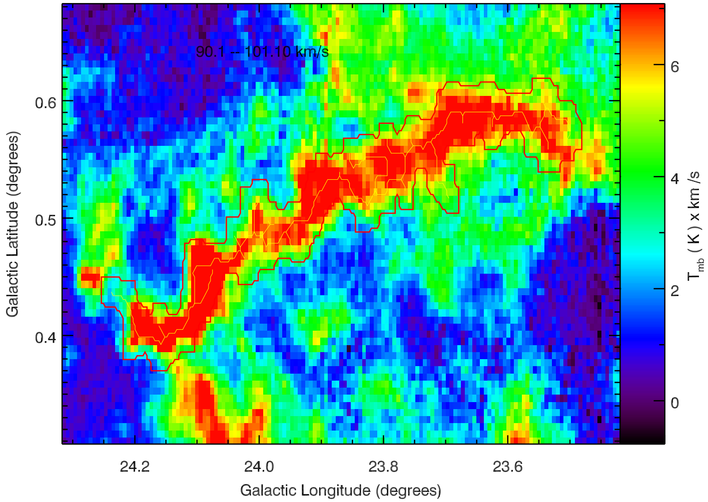
From candidate filaments to “real” filaments

In Herschel data extended structures might be produced from projection effects

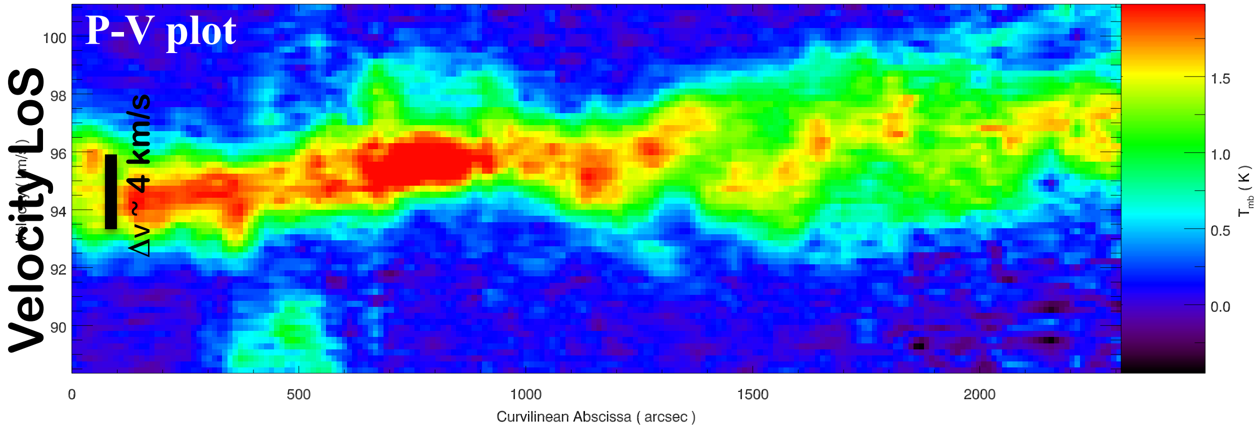
Needed further data to confirm their physically coherent nature



(90 – 100 km/s) ^{13}CO integrated map



Also, determine the kinematic along the structure



Follow up Projects

“The Forgotten Quadrant Survey” @ ARO 12m radio telescope mapping ^{12}CO, ^{13}CO (1-0)
Missing observations with < 1’ arcmin resolution toward III quadrant.

Project “KEYSTONE” @ GBT – 11 nearby molecular cloud ~550h awarded (NH_3 H_2O) large approved program involving institutes all around the world. (IAPS only Italian contributor).

Future observations of confirmed targets at higher spectral resolution to determine kinematic motion along the structure. (IRAM, APEX, SMA)
(Example: in II quadrant current data has $\Delta v \sim 1$ km/s. Ok for velocity coherence, but do not allow to study kinematic**).**

Classification of filamentary sample depending on their configuration and eventually emission at MIR wavelengths (PDR, shocked regions, correlation with Galactic bubbles):
Specific target SOFIA, JWST follow up observation

on basis of possible scenario for their formations (different type of filaments?)
their evolution with final products (contraction, fragmentation, clusters/massive star formation)

Importance of magnetic field: B alignment along or perpendicular the filamentary structure: From large scale with Planck data, intermediate SPICA (if photopolarimeter confirmed) , small scales connecting to the condensation with ALMA) .

Take out message

Filamentary shapes are found <u>everywhere</u> in the ISM.

They have a wide range of densities and cover a large set of spatial scales

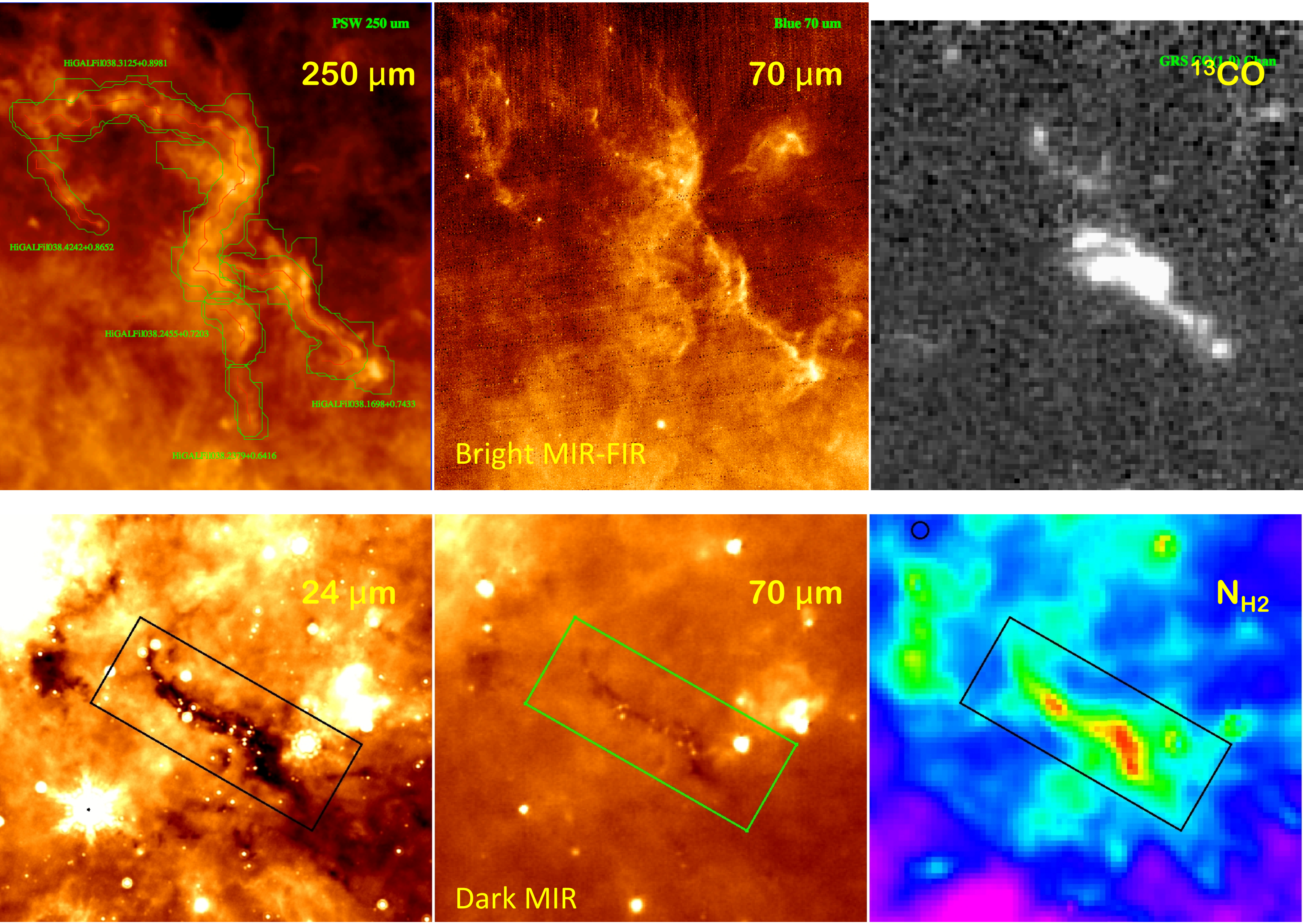
Filaments are deeply connected with the <u>initial conditions for the star formation are set</u>.

ISM-> Molecular Clouds -> (filaments) -> Stars.

With high probability fundamental for cluster/high mass star formation.

A mix of large scale flows, gravity, turbulence (influence magnetic fields) form them.

Starting point for confirm ideas on their action mechanism is analyzing large sample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250 μm
HiGALFil038.4242+0.8652
HiGALFil038.2455+0.7203
HiGALFil038.1698+0.7433
HiGALFil038.2379+0.6416
Blue 70 um
70 μm
Bright MIR-FIR
13CO
24 μm
70 μm
Dark MIR
NH2