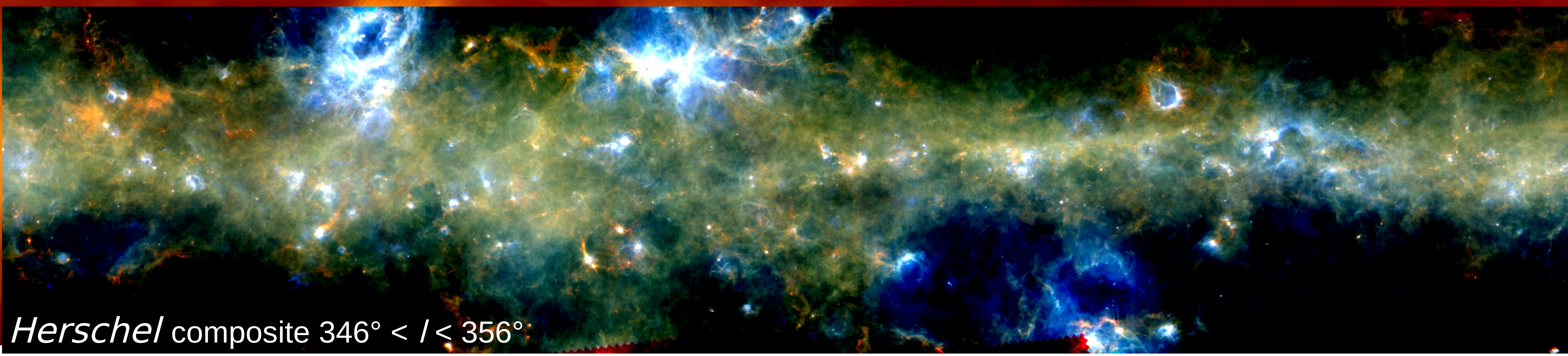


Herschel composite 346° < l < 356°

Cosmic rays and star forming regions in our Galaxy

S. Pezzuto

INAF/IAPS, Rome

on behalf of S. Molinari &

Herschel Hi-GAL Team

11th AGILE Science Workshop - "Gamma-rays and Galactic Cosmic Rays", May 16-17, 2013 - ASI Roma

One key problem to understand in the field of star formation is the origin of the low star-formation efficiency (SFE) observed in our Galaxy

The SFE can be estimated through the ratio M_*/M_g where M_* is the mass of the formed (or forming) stars, while M_g is the total mass of the available gas

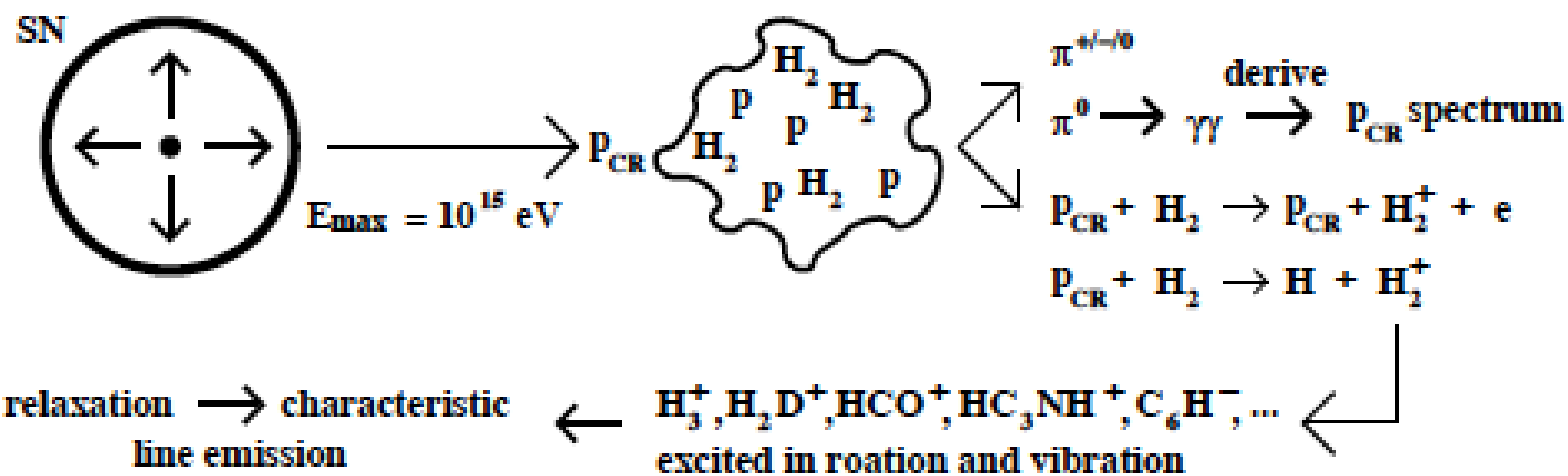
Typical values for SFR are few %; with Herschel data from the Hi-GAL program, Elia et al. (2013) find SFE < 1% in the outer Galaxy

Two mechanisms proposed to explain such a low values:

- Magnetic field: requires an agent (eg CR) to ionize the ISM
- Turbulence

Cosmic Rays are the sole source of ionization in the dense and heavily extincted molecular clouds

from Schuppan et al. 2012



Establishing a link between CR and star formation would answer two completely different questions : are the γ-rays produced in a hadronic scenario? Is the magnetic field dominant in keeping the SFE low?

Gravity & Magnetic field

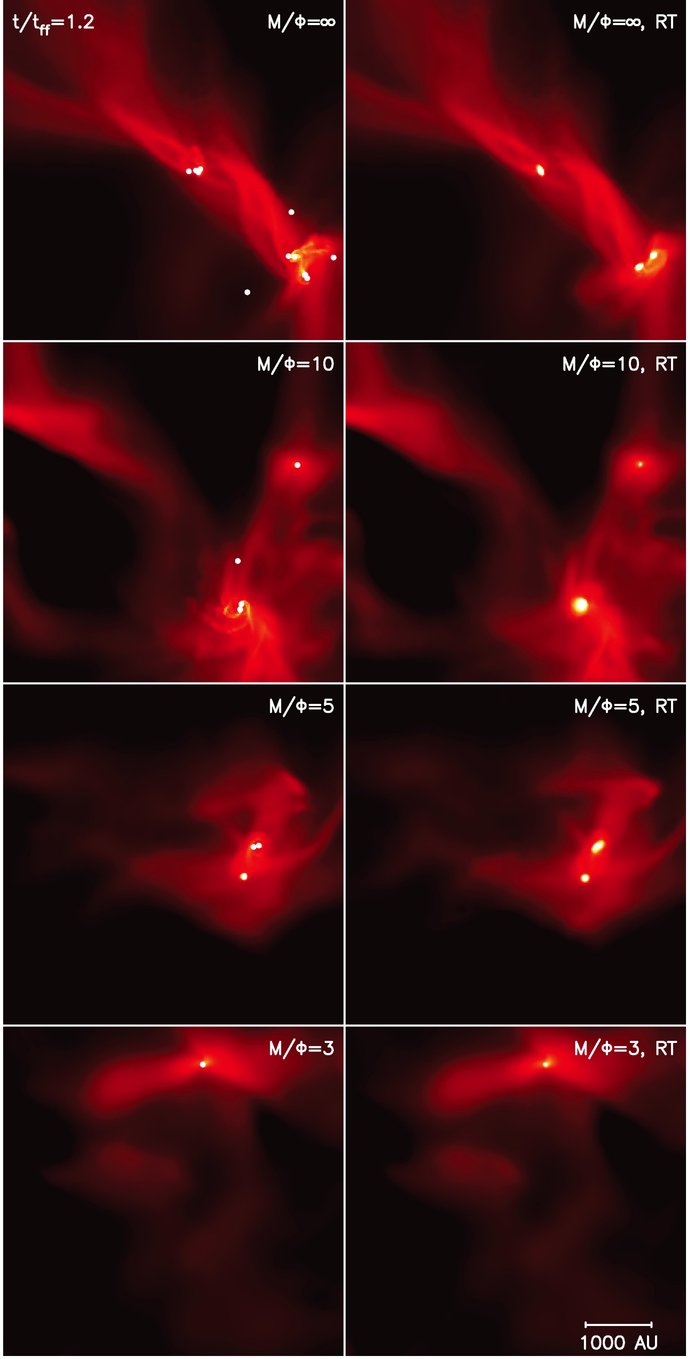
- During contraction, matter can slide freely along field lines. Ionized gas moving in the orthogonal direction tugs on the field and is retarded by thermal pressure, as well as by magnetic tension (function of the plasma density) that opposes self-gravity
- Neutrals drift w.r.t. the plasma with a frictional force $F_{ni}=m_{in}\, n_i\, n_n \langle \sigma v_{rel} \rangle (v_i - v_n)$, that also depends on the ISM ionization fraction
- The net result is a loss of magnetic flux, after which the cloud can now contract more easily

This process is called ambipolar diffusion

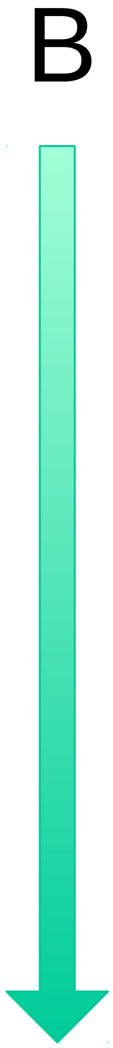
It depends on the ionization fraction of the ISM and solves the problem of how stars form in the presence of a magnetic field

It is also invoked as a self-regulating mechanism of star formation: the more stars are formed the higher the UV flux is → higher ionization fraction

Star Formation in “dynamical” scenarios



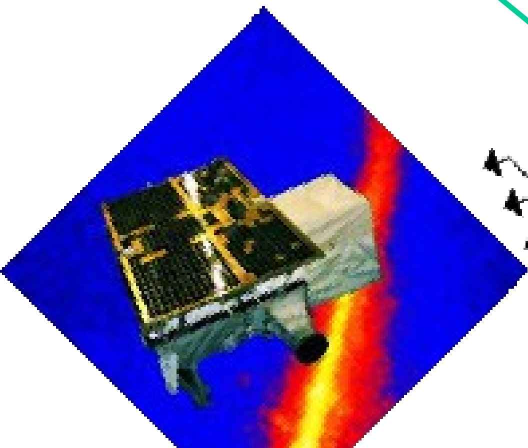
Price & Bate 2009

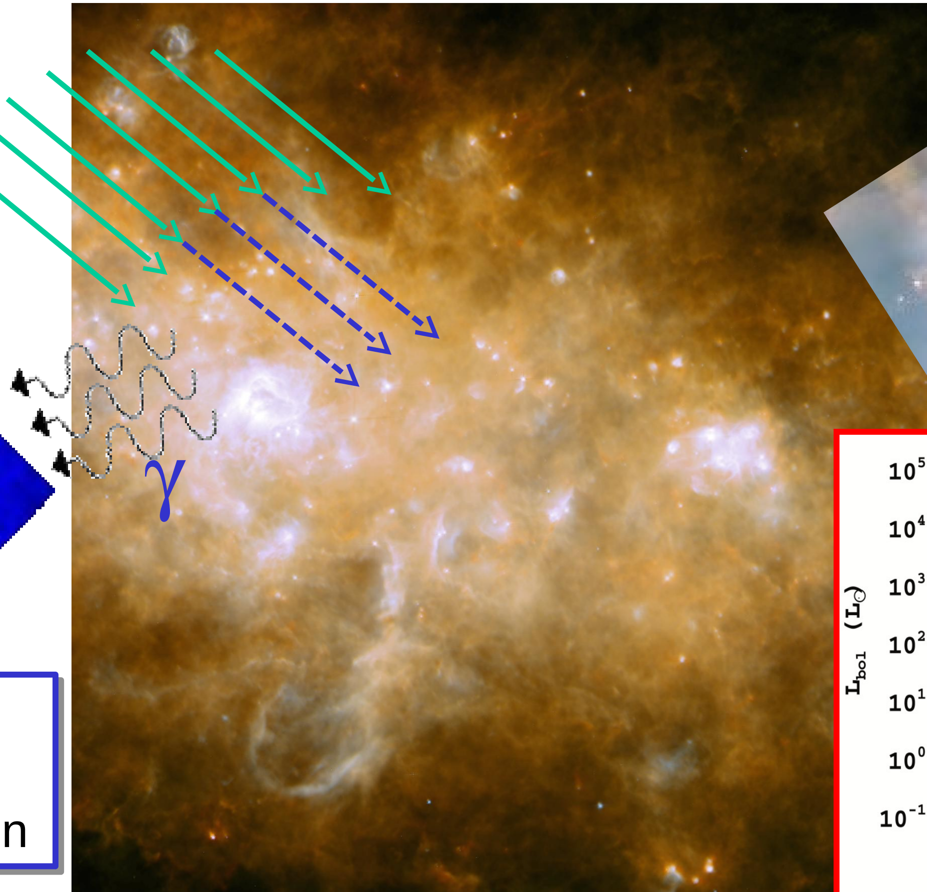


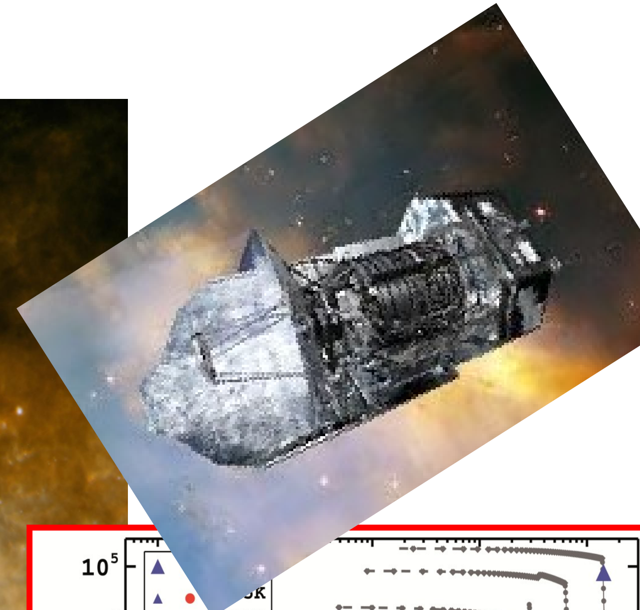
- Numerical simulations of star formation in cluster show that the efficiency and rate of the process strongly depend on the intensity of the magnetic field

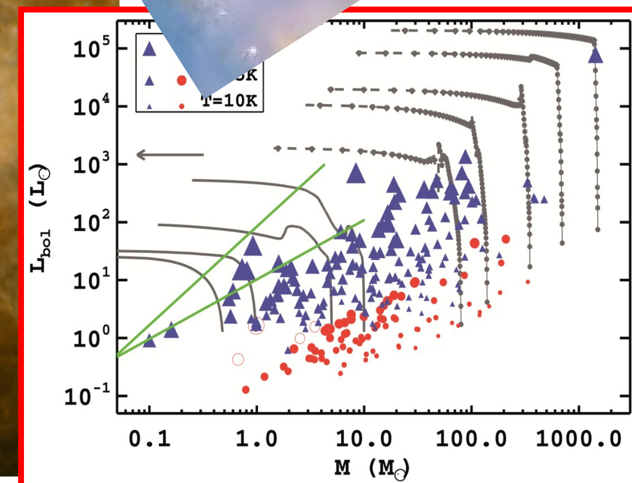
- The efficiency of B in opposing collapse is higher the higher is the ionization fraction in the early stages of star formation

Steady-state bath of Cosmic Rays









Estimate an initial ionization fraction in the star-forming region

Quantify the importance of magnetic field in star formation

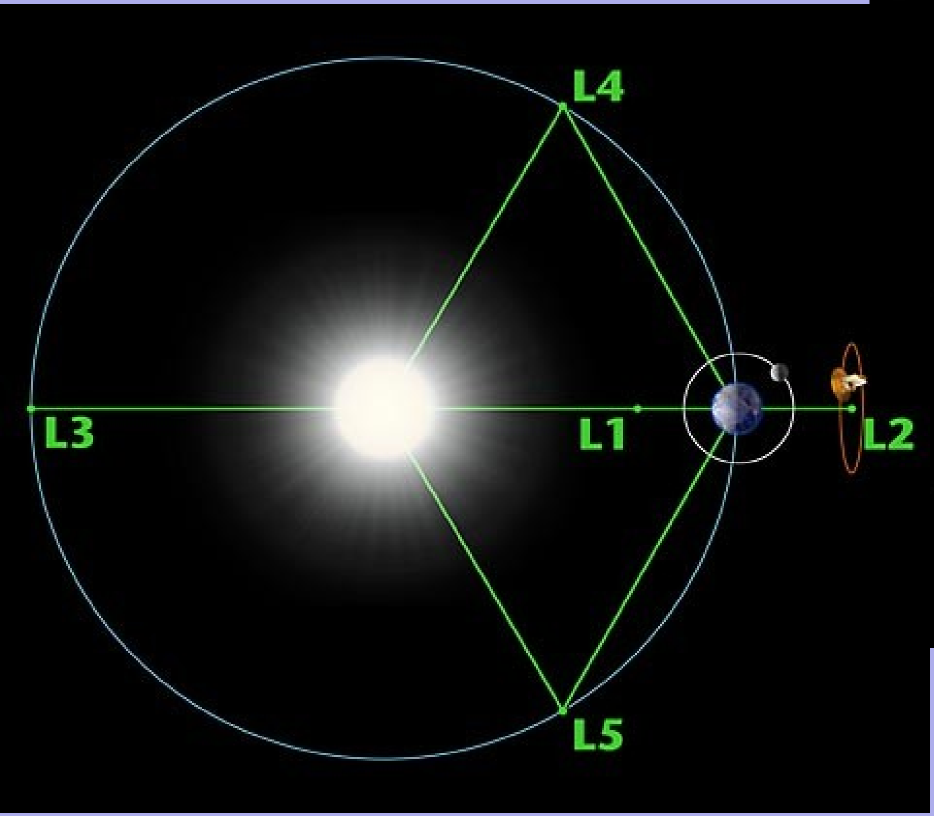
+

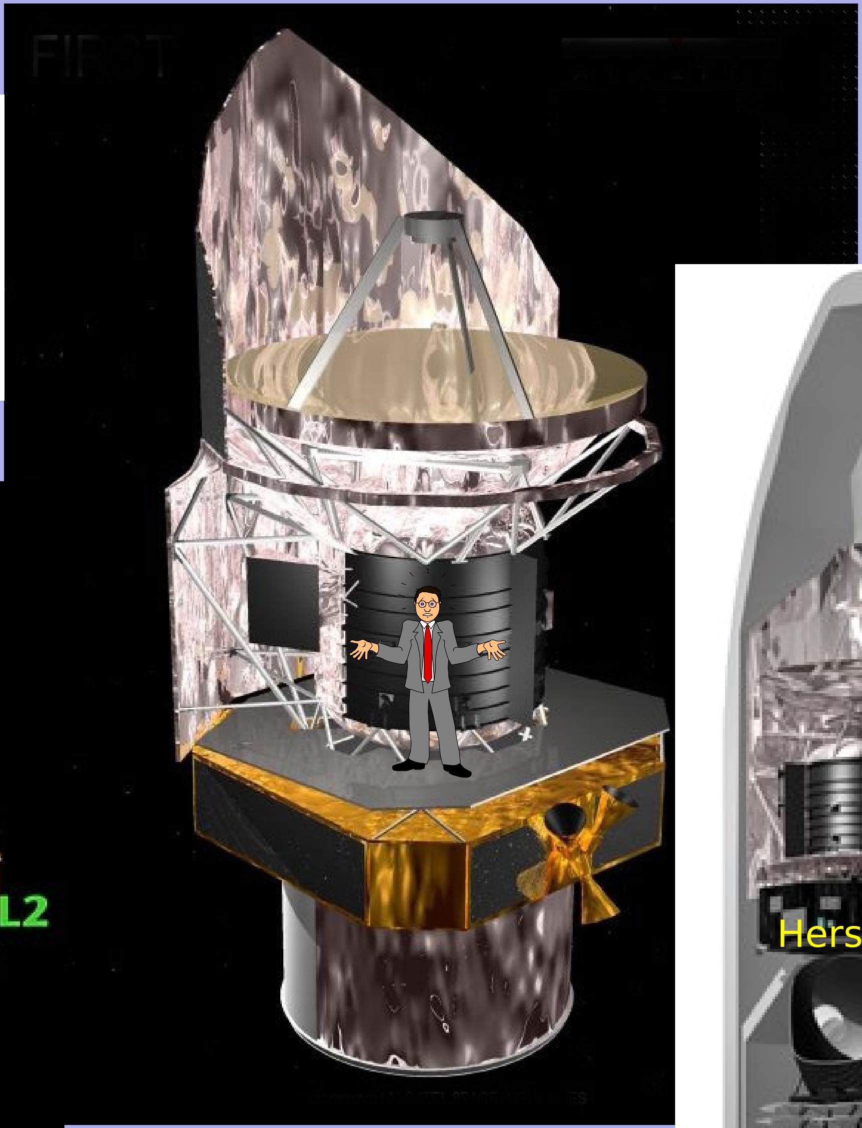
Derive the Star Formation Rate

Understand if and how a normal Galaxy self-regulates its star formation behaviour

Herschel

- Orbit around L2
- Launched: May 14th 2009
- End of Helium: April 29th 2013
- Loss of contact: June 13th 2013





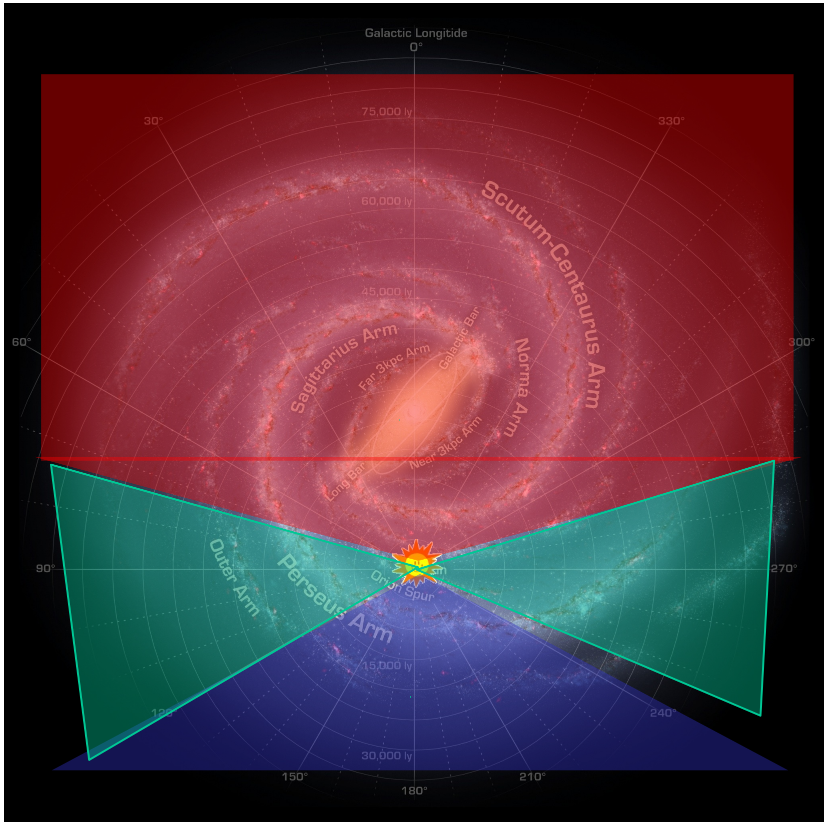
Hi-Gal

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

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

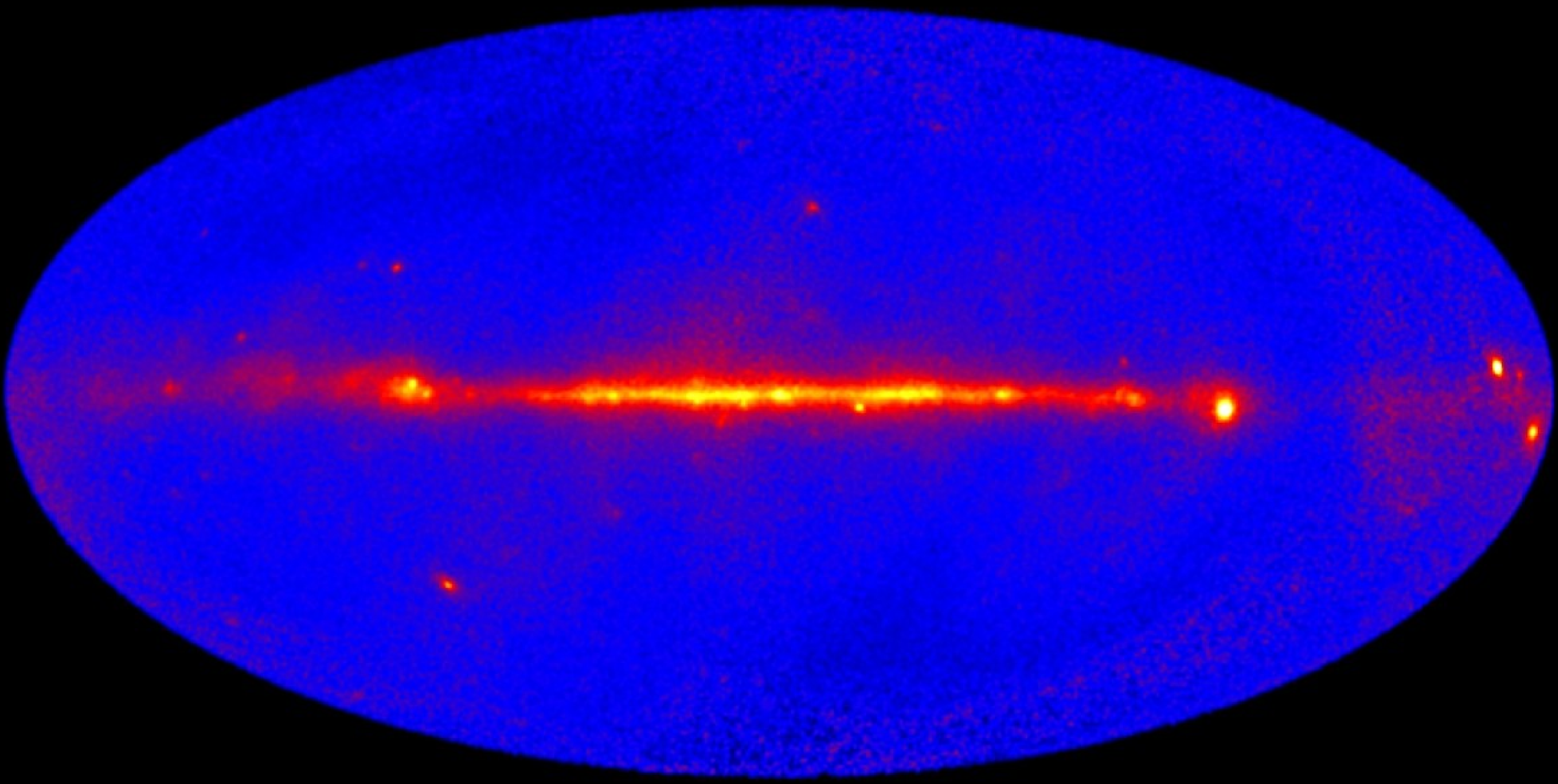
With almost 900 hours observing time is the largest OPEN TIME Herschel KP

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

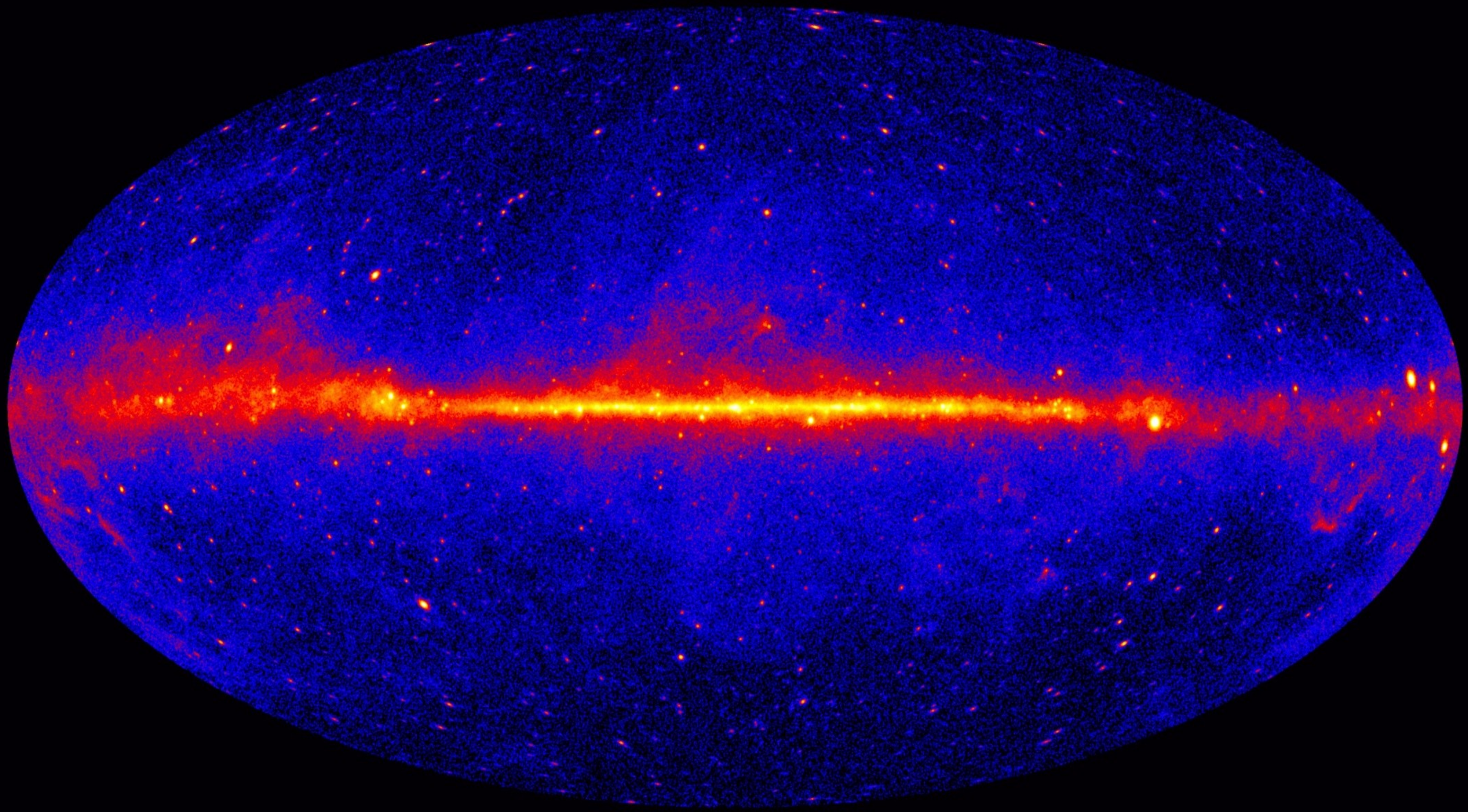


The AGILE gamma-ray sky (E > 100 MeV)

2 year exposure: July 2007 – June 2009



Three years of LAT scanning data (E > 1 GeV)



Hi-GAL Team & ESA

Hi-Gal

Herschel infrared Galactic Plane Survey

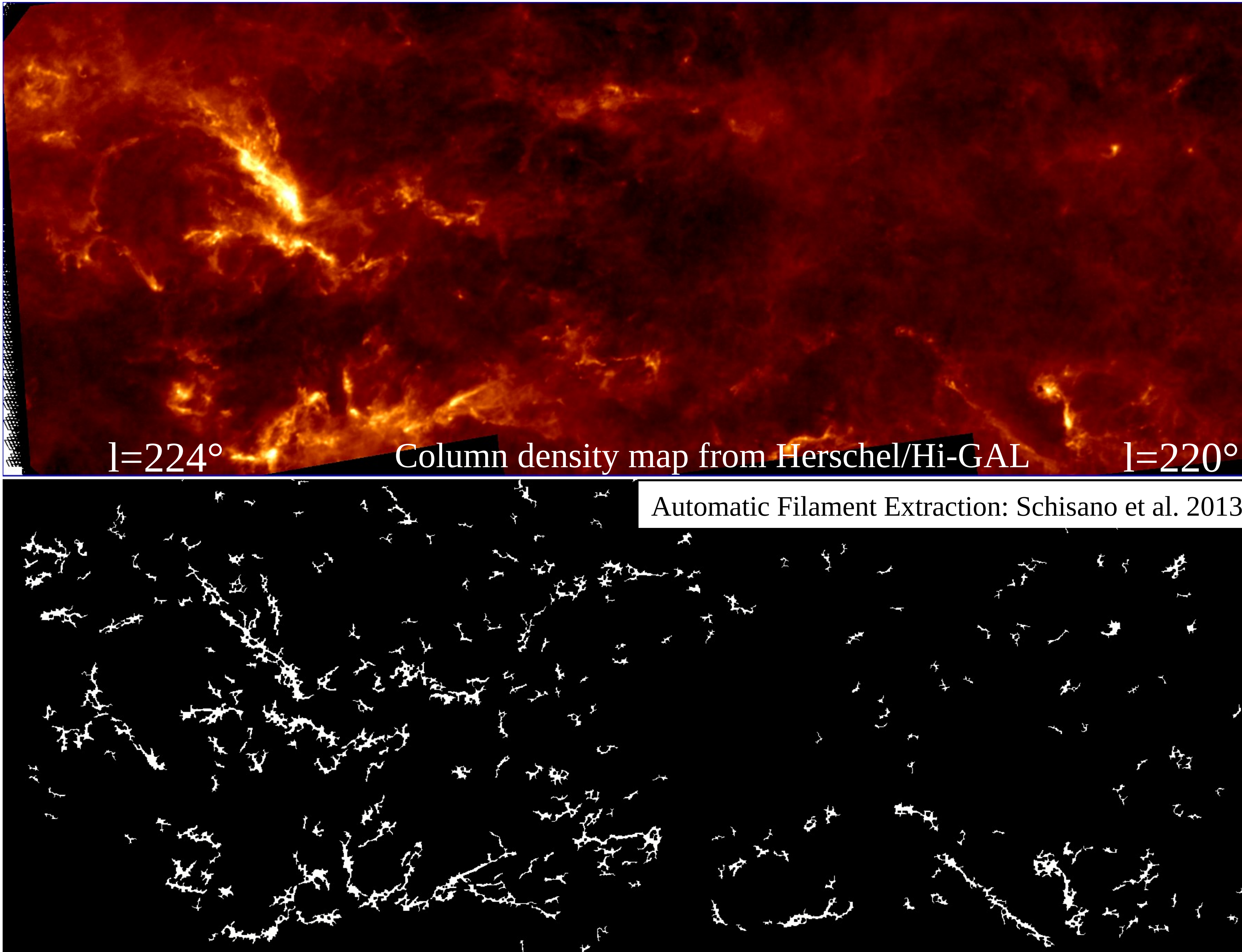
Molinari et al. 2010

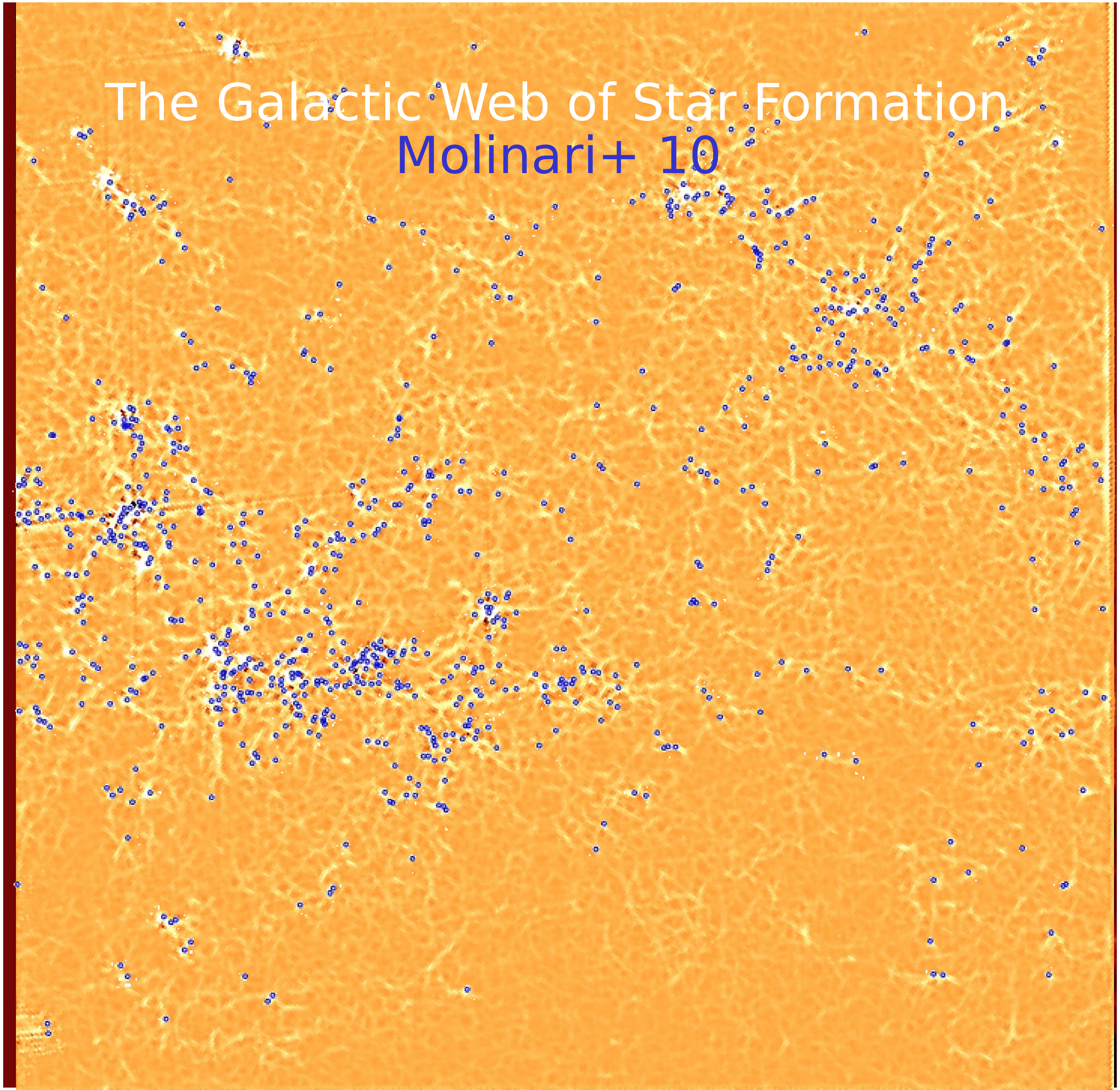
Toward a Predictive Global Model of Galactic Star Formation

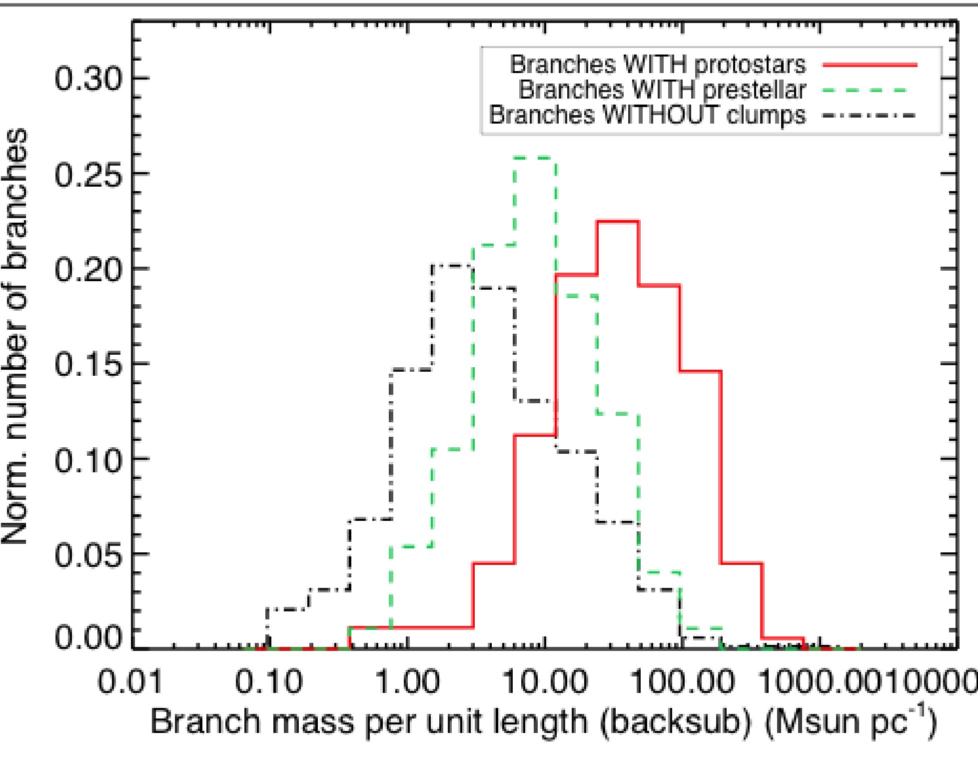
The *Hi-GAL* Team Institutes [PI: S. Molinari, INAF-IAPS Rome]

Italy: INAF-IAPS (*Rome)*, Univ. Roma "Tor Vergata", Univ. Roma "La Sapienza", INAF-Oss. Arcetri, INAF-Oss. Catania, Univ. Salento. ***USA***: Caltech-SSC-IPAC (*Pasadena)*, Univ. Colorado (*Boulder)*, JPL *(Pasadena)*. ***UK***: STFC-RAL (*Chilton)*, Univ. Cardiff, Liverpool John Moores Univ., UCL (*London)*, Univ. Hertsfordshire, Univ. Leeds, Univ. Manchester, Univ. Exeter. ***France***: CNRS-IRAP (*Toulouse)*, LAM (*Marseille)*, IAS (*Orsay*), CEA-SAp (*Saclay*). ***Canada***: Univ. Toronto, Univ. Calgary, Univ. Laval (*Montreal*). ***Germany***: MPIfR (*Bonn*). ***Japan***: Nagoya University. ***China***: NAO-CAS (*Beijing*) . ***ESO-HQ*** (Munich). ***ESA-ESTEC*** *(Noordwijk)*. ***ESA-ESAC*** *(Madrid)*

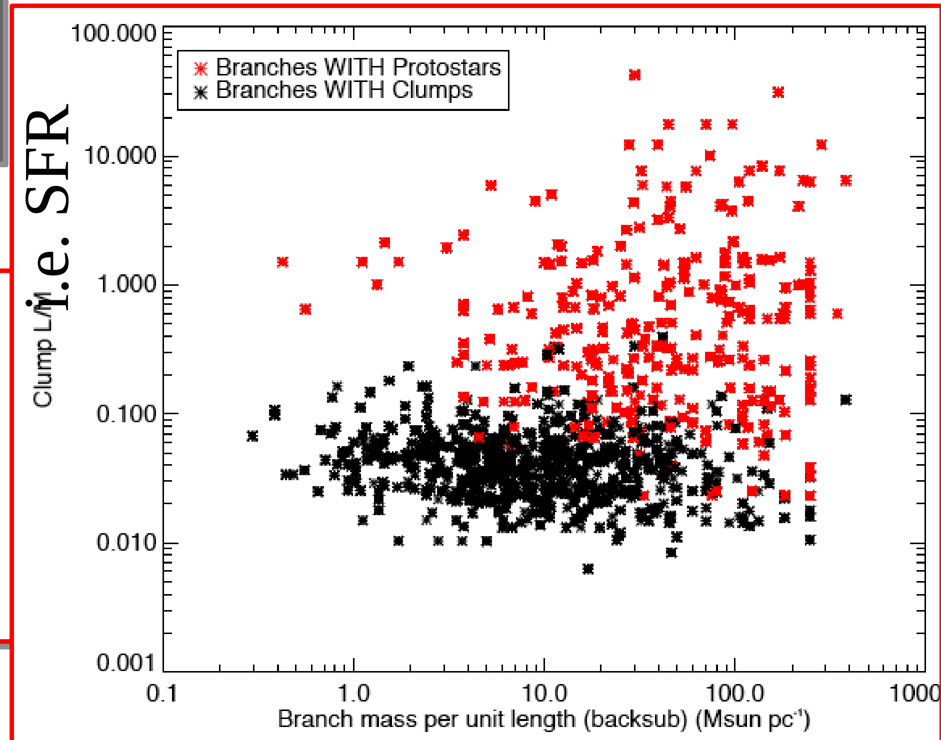
Hi-GAL data processing is carried out at INAF-IAPS (Rome) thanks to support from Agenzia Spaziale Italiana under Contract I/038/08/0


l=224°
Column density map from Herschel/Hi-GAL
l=220°
Automatic Filament Extraction: Schisano et al. 2013

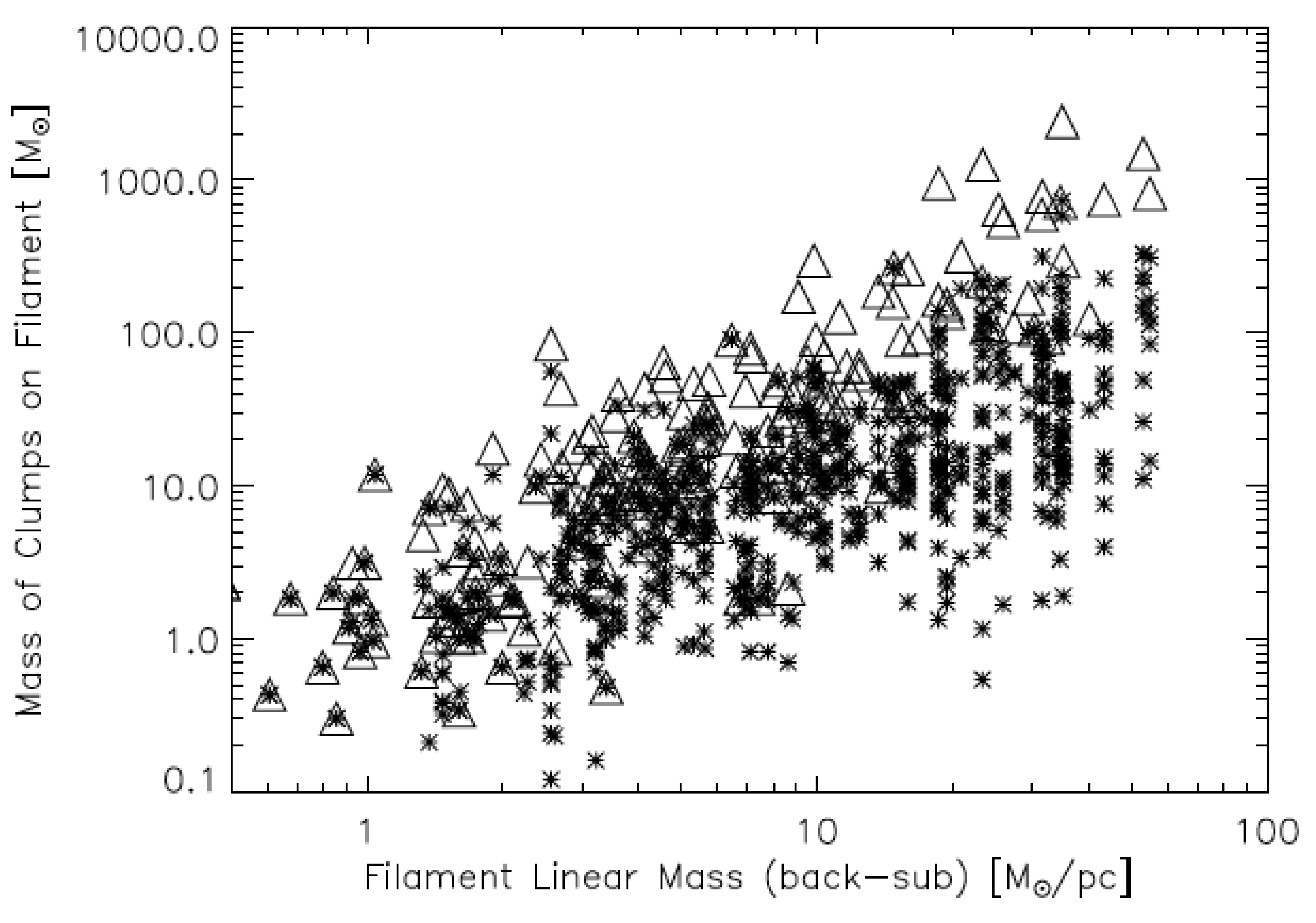

The Galactic Web of Star Formation
Molinari+ 10



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



Dense filaments are the critical incubators for Star Formation
They are an unexpected discovery of HERSCHEL, and the next Hot Topic in Galactic Star Formation



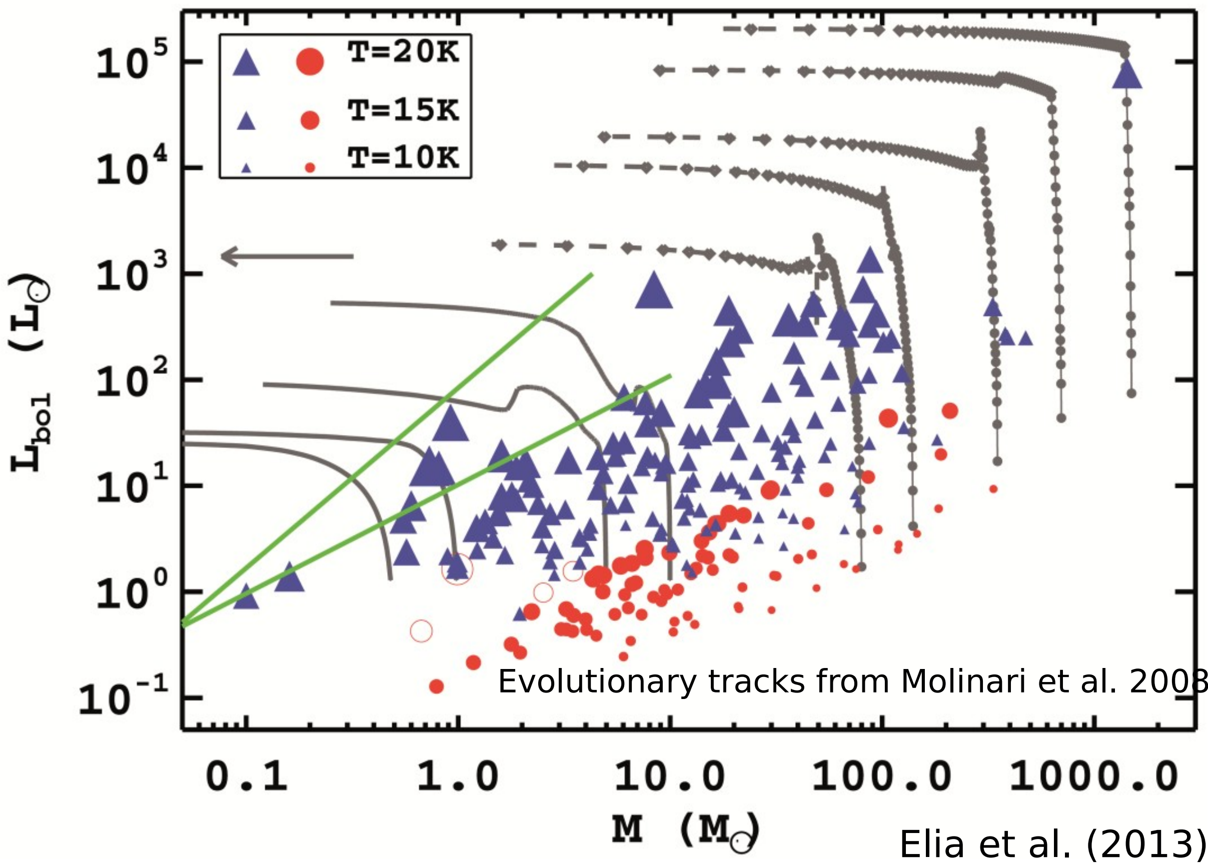
Do more massive clumps form on more massive filaments ?
Or do filaments grow mass from the surrounding environments and channel more mass to the clumps ?

We do not know !

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

Pre-stellar Sources (no 70μm counterpart)

Proto-stellar Sources (with 70μm counterpart)



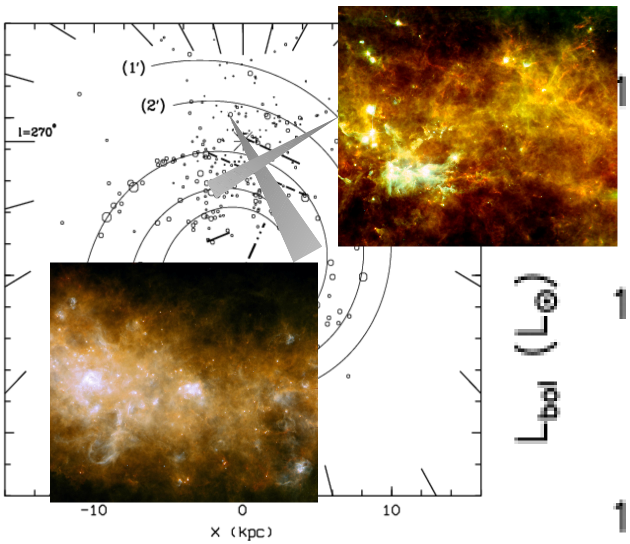
Elia et al. (2013)

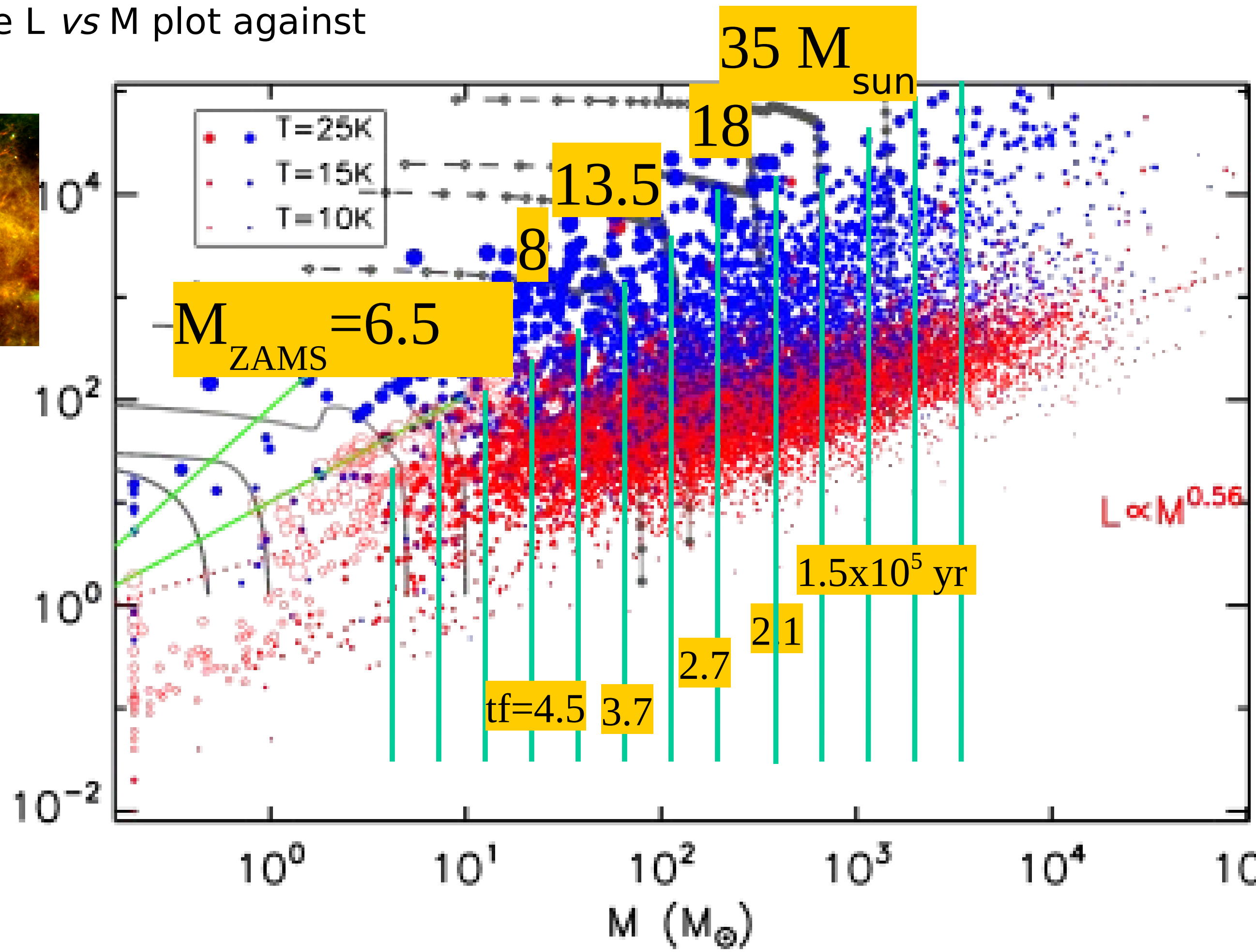
- A separation between **pre-stellar** and **proto-stellar** sources is quite clear in terms of L/M. The appearance and intensity of the 70μm (and shortward), clearly makes the difference.
- Within each class, there is a clear trend of L/M with Temperature (estimated using only λ≥160μm)

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

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 in the L *vs* M plot against evolutionary predictions





Each bin *i* will be associated to:

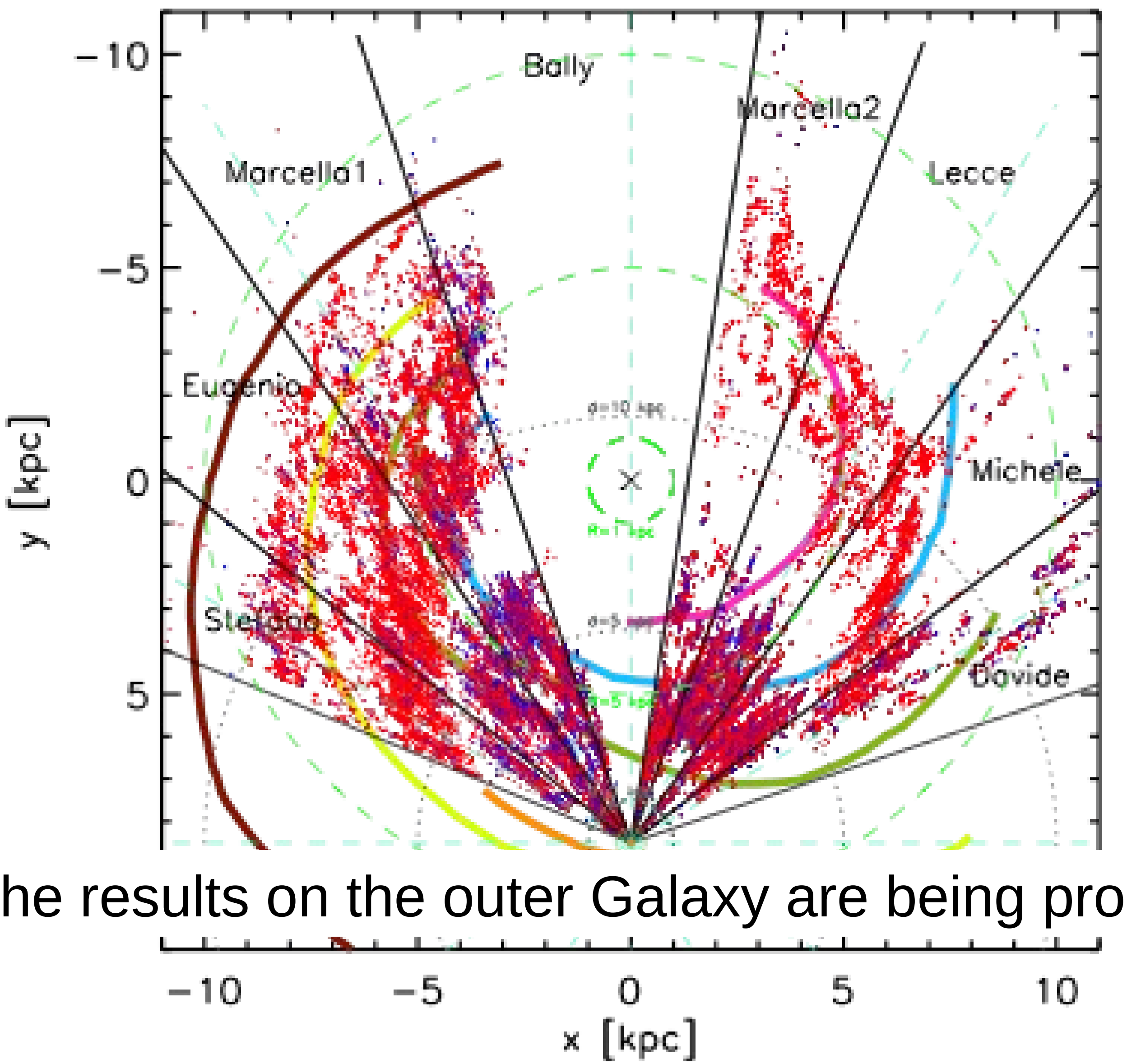
- final ZAMS mass *MZAMS (i)*
- formation time *tf(i)*

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

l=30° ~ 0.067 M_{sun}/yr

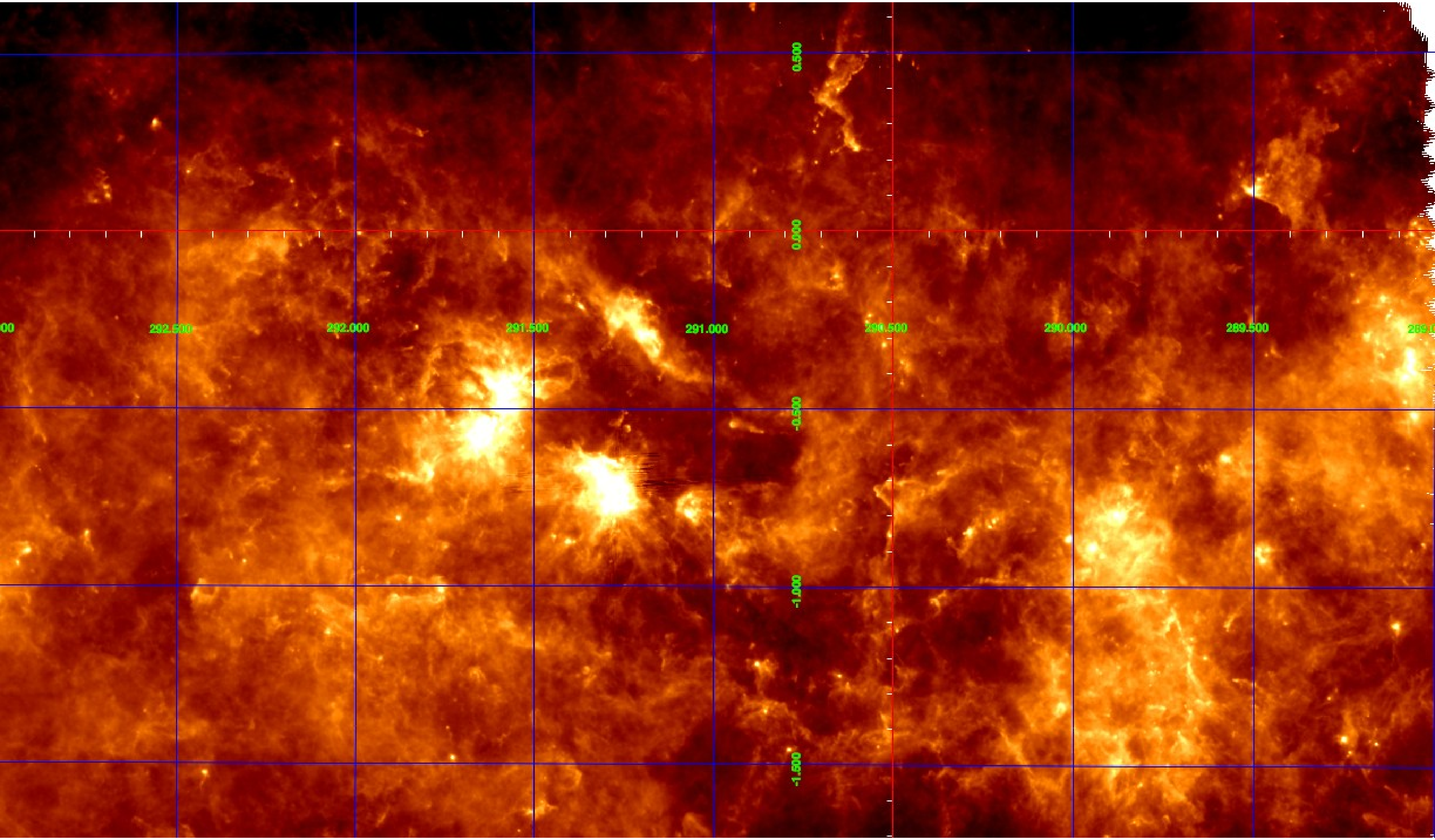
l=59° ~ 0.011 M_{sun}/yr

For the first time it will be possible to obtain a spatially resolved map of the Star Formation Rate and Efficiency in the Milky Way

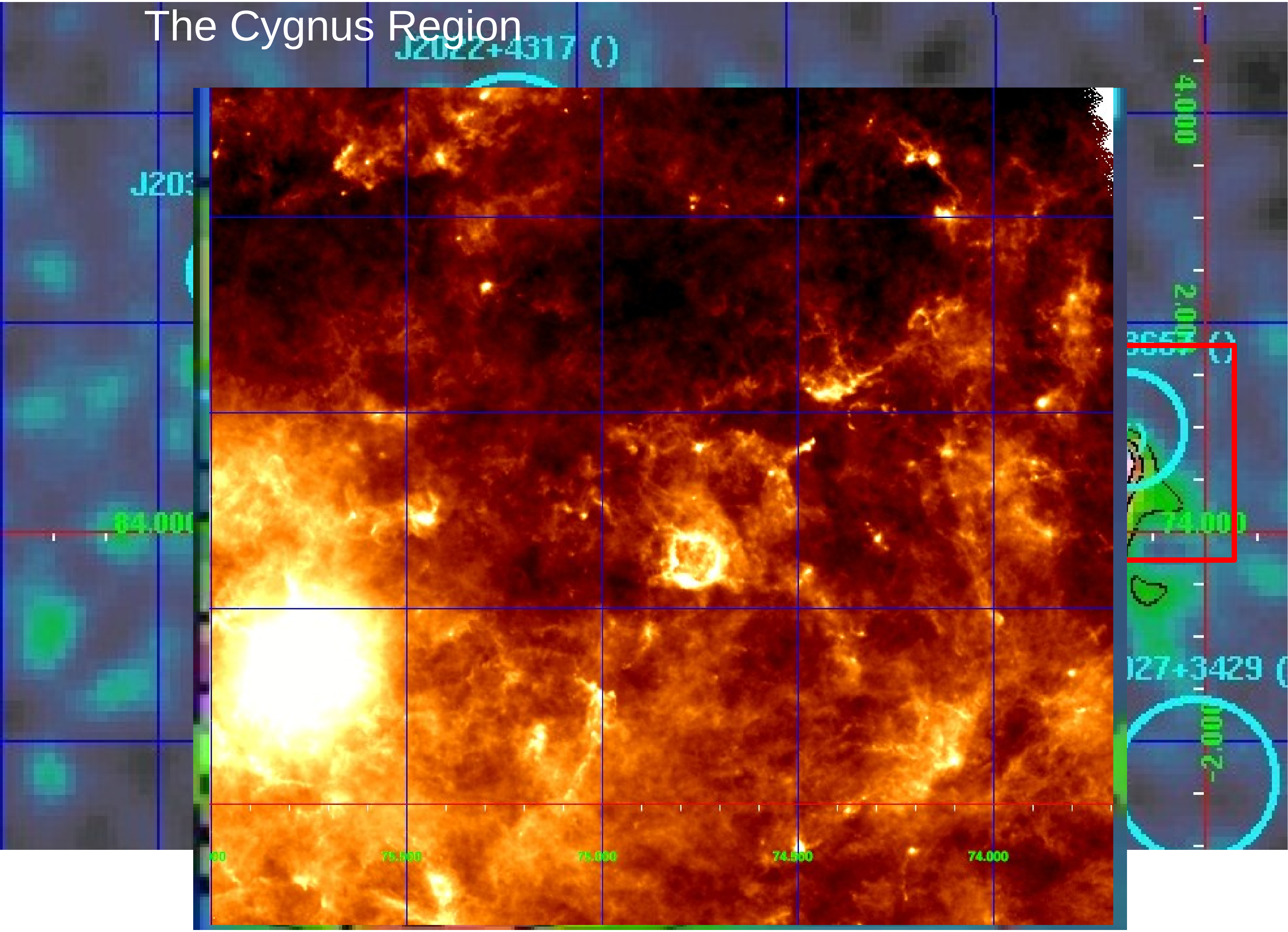


The results on the outer Galaxy are being produced

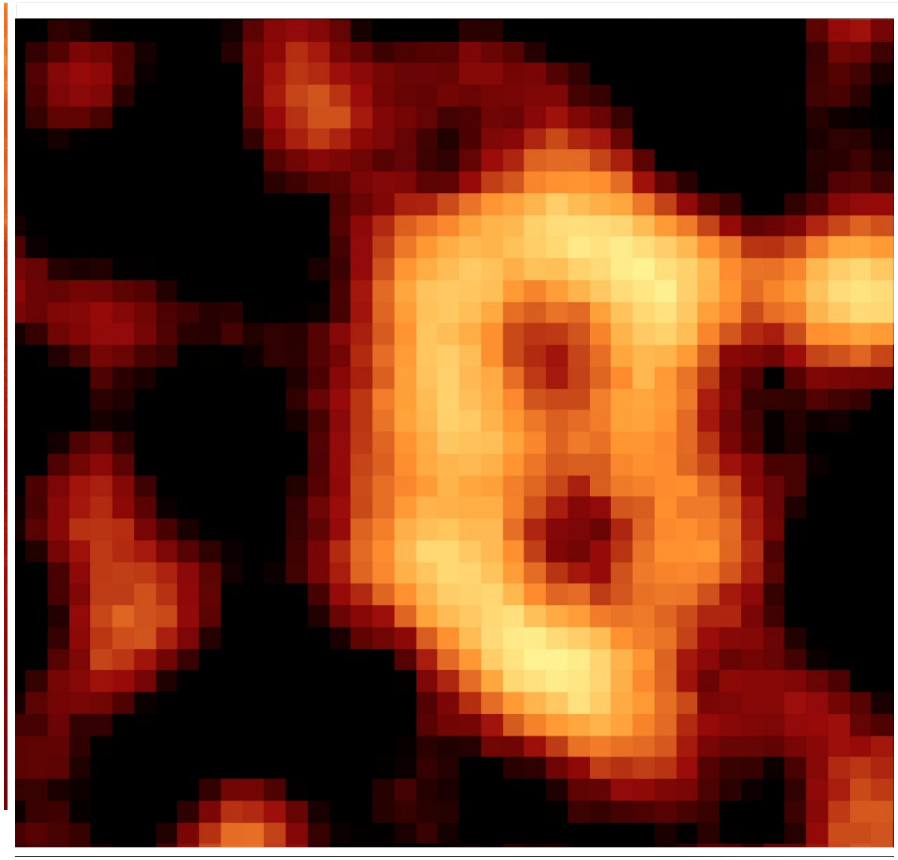
near ηCarinae

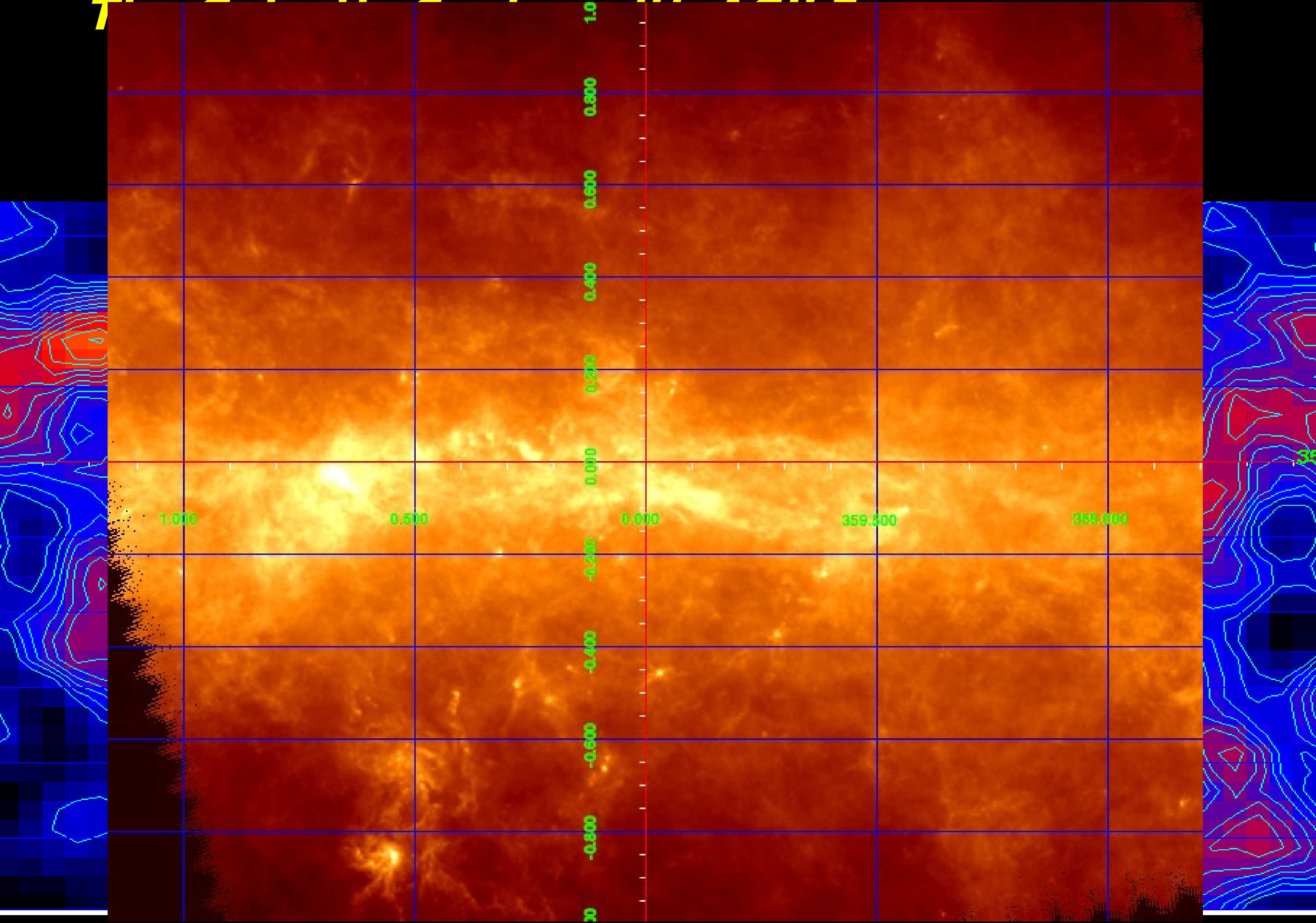


The Cygnus Region



W44 (Giuliani et al. 2011)



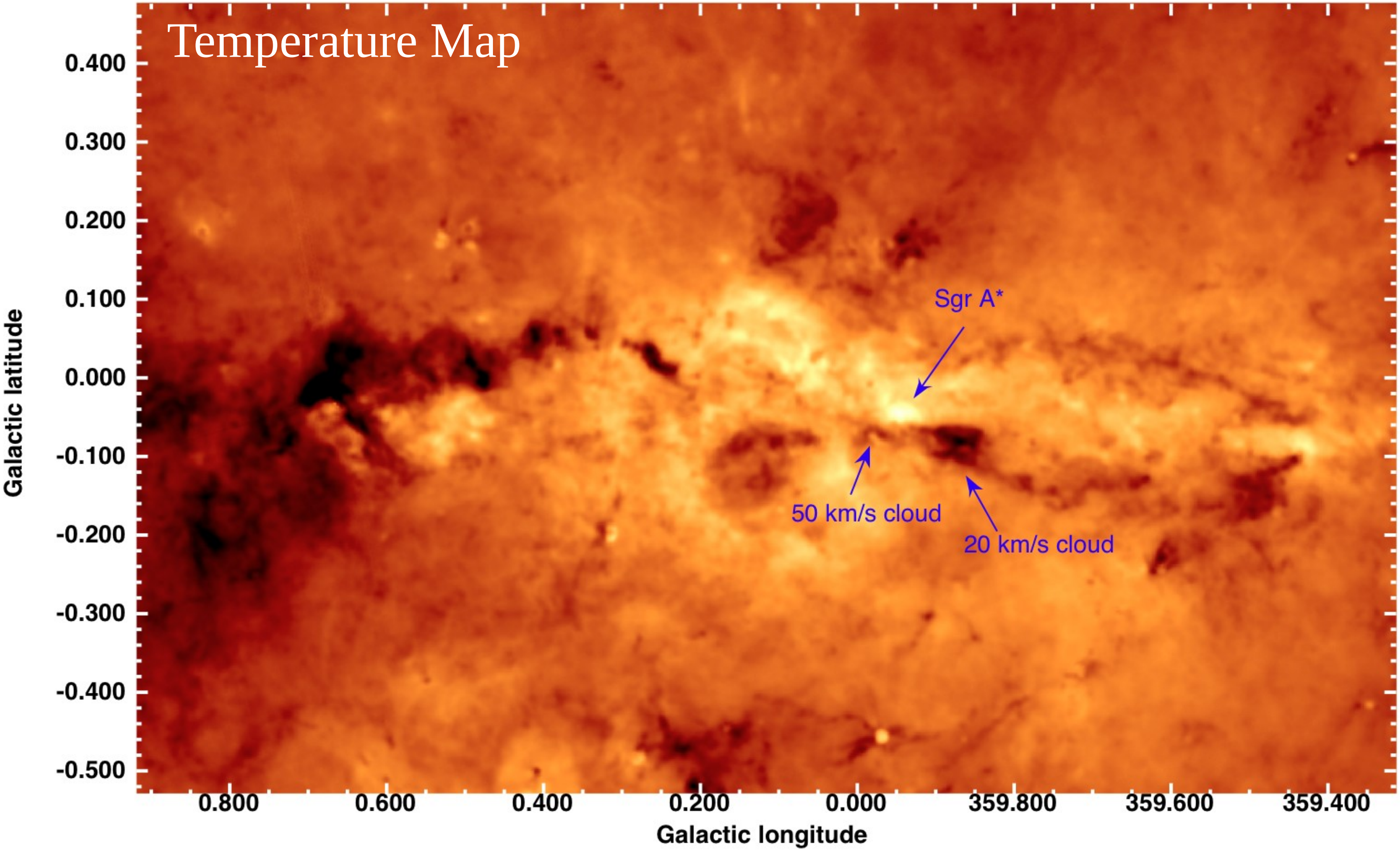


1.0
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
1.000
0.500
0.000
359.500
359.000

The Galactic Center with Herschel

The 5 Hi-GAL maps were cross-calibrated to Planck and IRAS (e.g Bernard et al. 2010) and rebinned at the resolution of the 350μm (≈25")

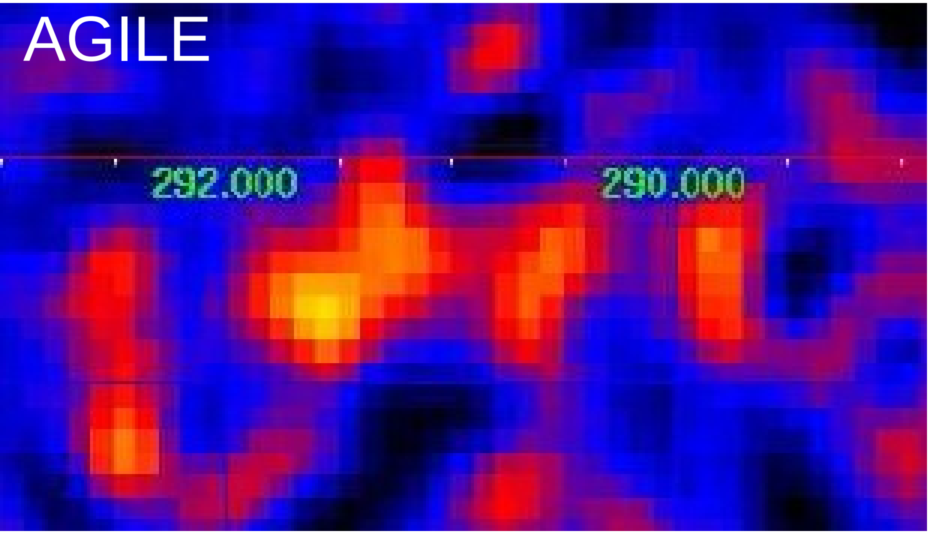
Pixel-to-pixel SEDs were fit with DustEM (Compiegne et al. 2010) with opacities $\tau_{250}/N_H = 8.8\ 10^{-26}\ cm^2/H$, to obtain Temperature and Column Density

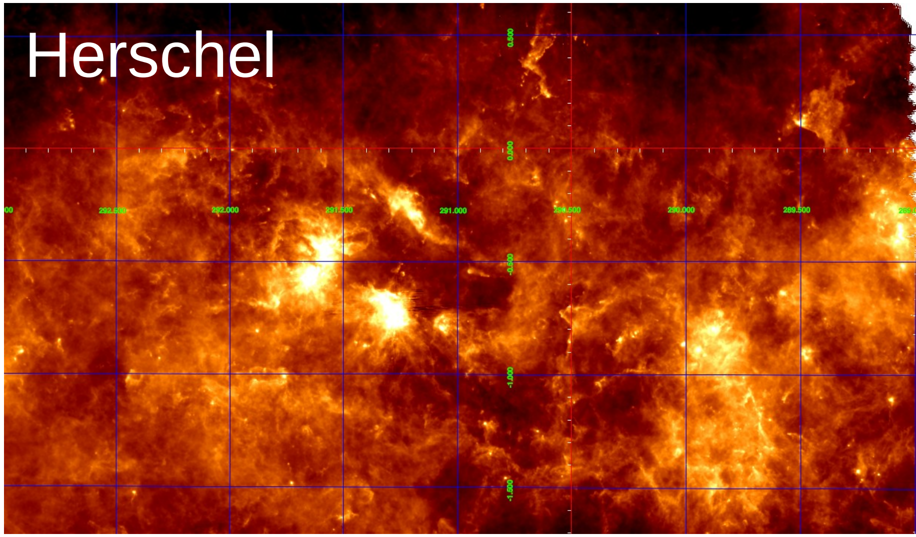


Conclusions

- There are very promising and largely unexplored synergies between γ-ray and infrared astronomy in the field of Star Formation
- We are starting now with the AGILE Group the work of correlating the results from Hi-GAL with the diffuse γ-ray maps of AGILE and Fermi; this will be one of the tasks for our recently approved FP7-SPACE project, called VIALACTEA

but….





more resolution in the γ-ray…..please.