The role of interstellar filaments in regulating the star formation efficiency on GMC scales

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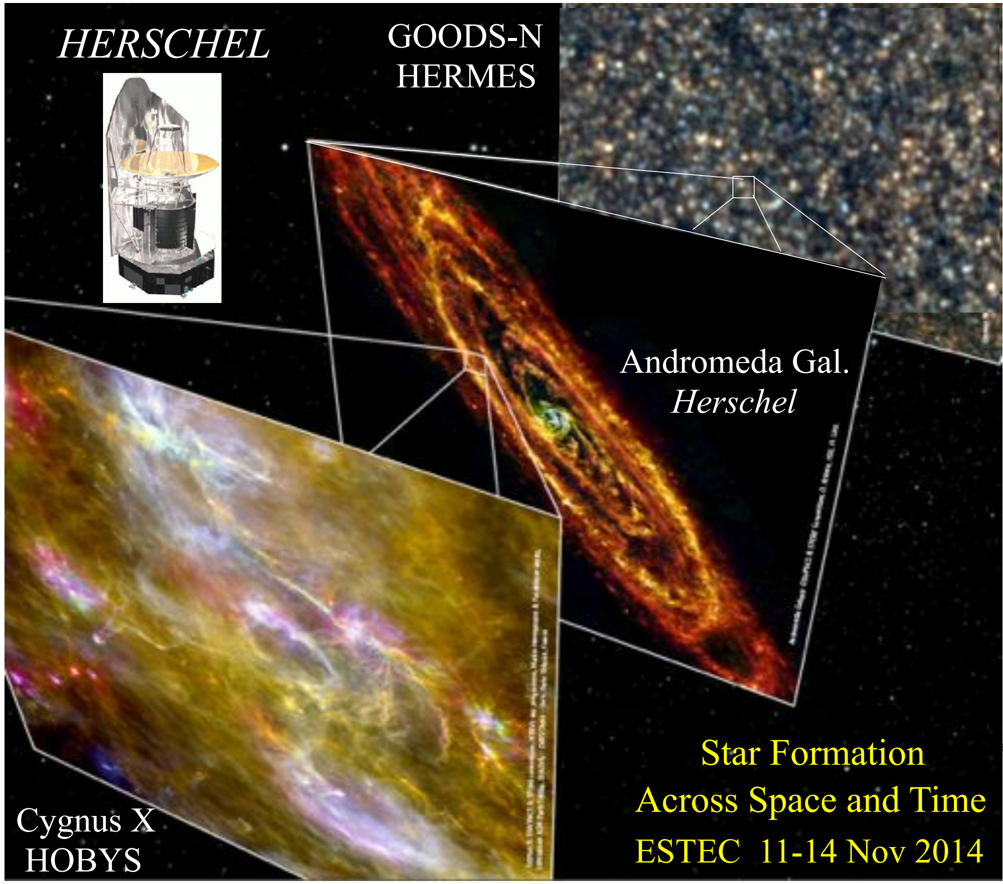
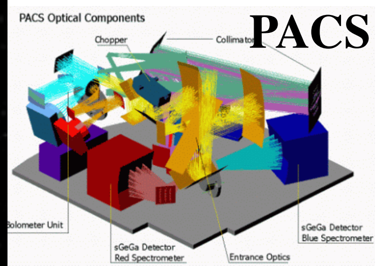


Insights from *Herschel* Gould Belt Survey

SPIRE SAG 3



Outline:

Polaris
Herschel
250/350/500 μm

- « **Universality** » **of the filamentary structure** of the ISM
- The key **role of filaments** in the star formation process
- Possible implications on galaxy-wide scales

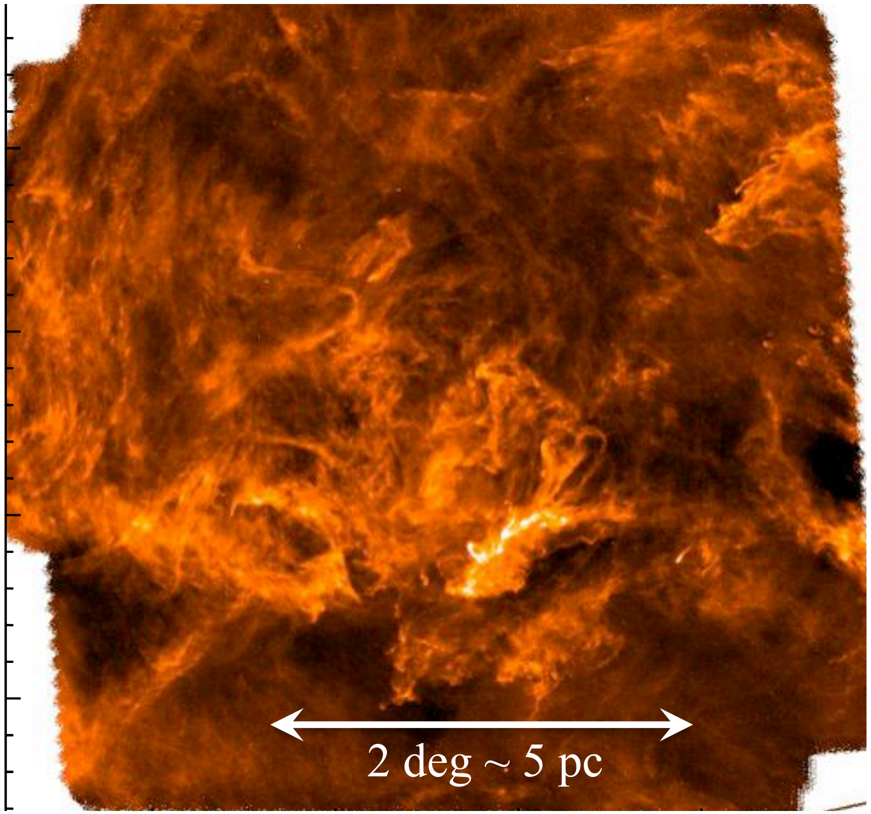
With: V. Könyves, D. Arzoumanian, P. Palmeirim, A. Menshchikov, N. Schneider, **A. Roy**, N. Peretto, P. Didelon, J. Di Francesco, S. Bontemps, F. Motte, D. Ward-Thompson, J. Kirk, M. Griffin, K. Marsh, S. Pezzuto, Y. Shimajiri, T. Hill, B. Ladjelate, A. Maury N. Cox, & the ***Herschel* Gould Belt KP Consortium**

Herschel has revealed a "quasi-universal" filamentary structure in the cold ISM

Ubiquitous + quasi-universal properties

Polaris : Non-star-forming "cirrus" cloud

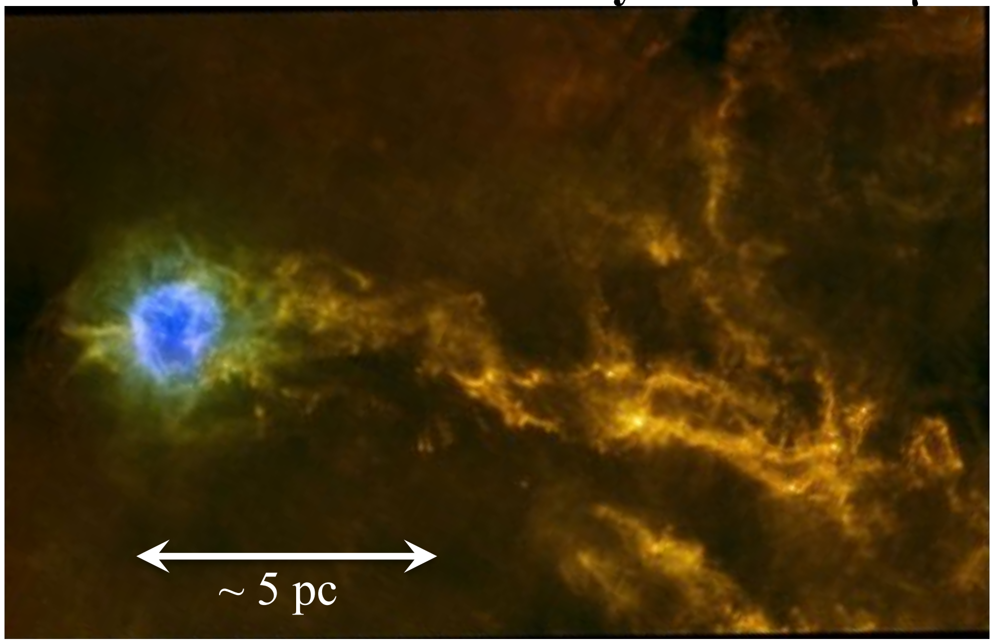
Herschel 250 μm



Men'shchikov+2010, Miville-Deschênes+2010, André+2010

IC5146 : Actively star-forming cloud

Herschel Gould Belt survey 70/250/500 μm



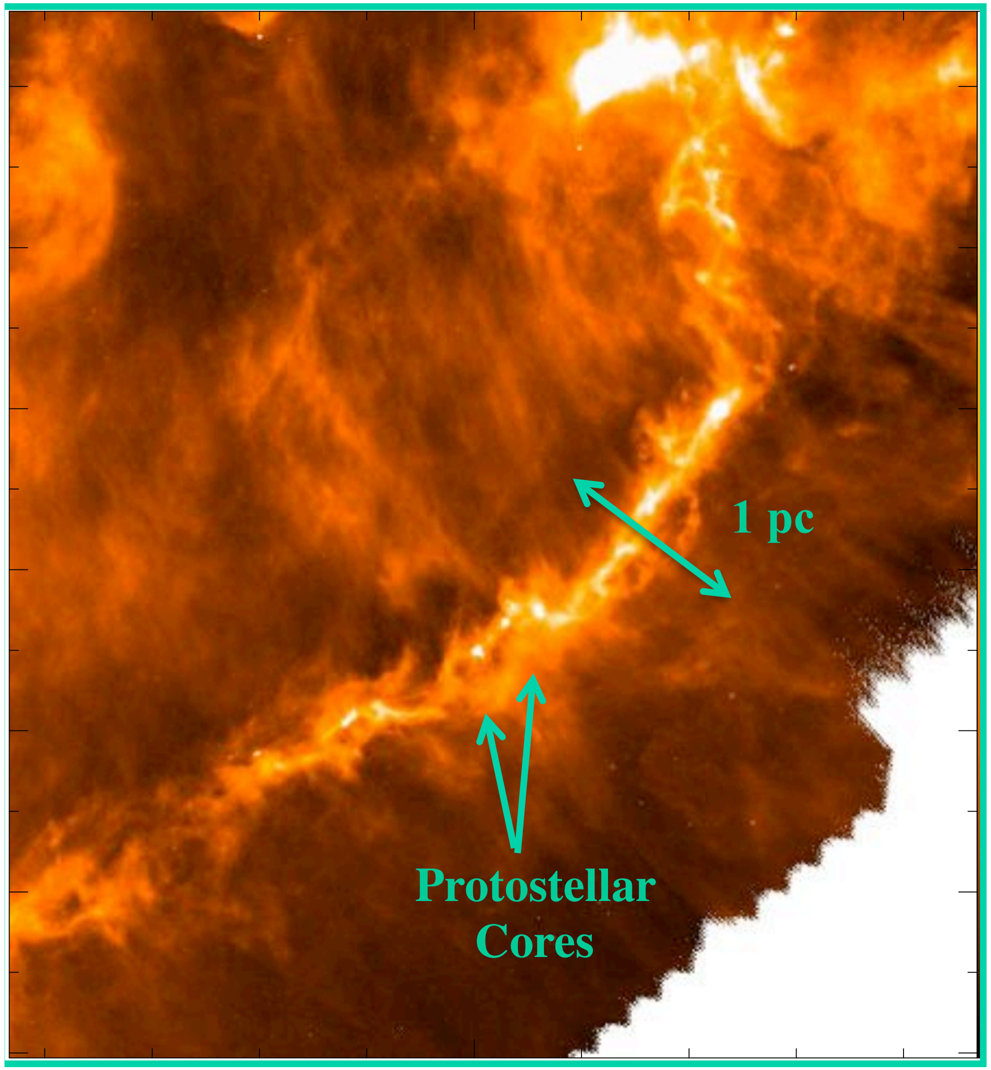
Arzoumanian+2011

Filaments also seen throughout the Galactic Plane (Molinari+2010)

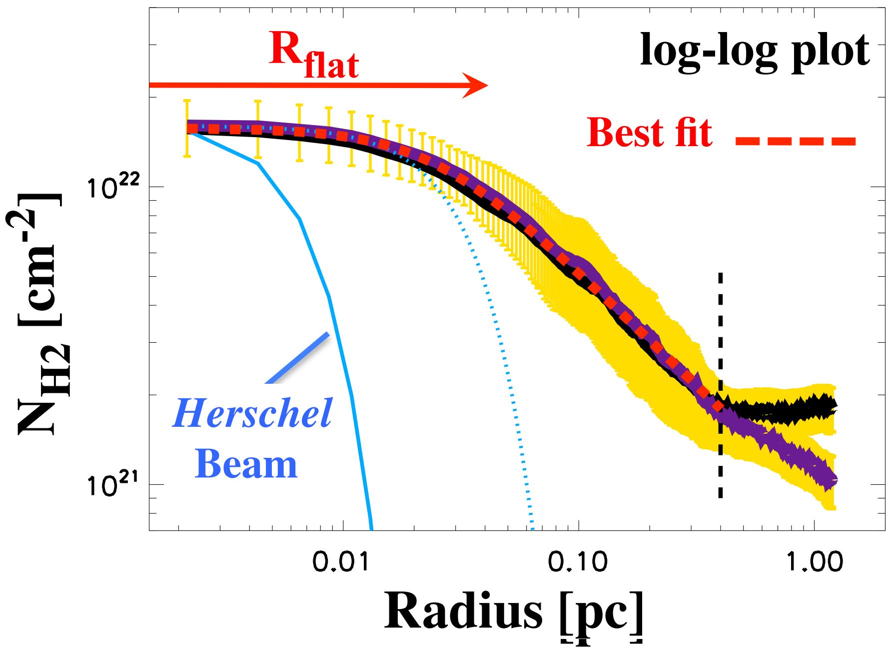
Resolving the structure of filaments with *Herschel*

Taurus B211/3 filament
***Herschel* 250µm**

Arzoumanian+2011
Palmeirim+2013



Filament transverse profile



Plummer-like model:

$\rho(r) = \rho_c / [1 + (r/R_{flat})^2]$

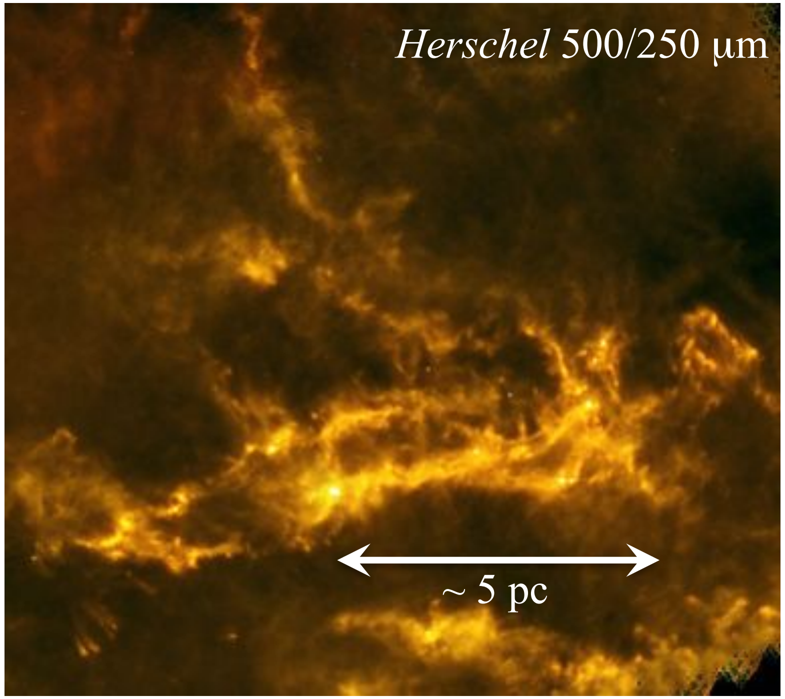
Diameter of flat inner plateau:

$2R_{flat} \sim 0.1$ pc

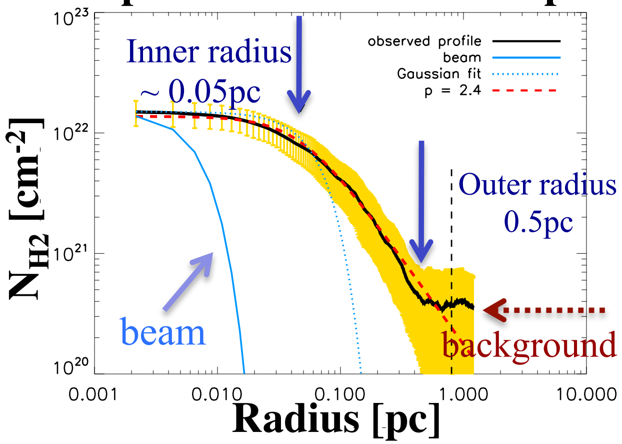
Depth along los ~ 0.1 pc (Li & Goldsmith '12)

Filaments have a characteristic inner width ~ 0.1 pc

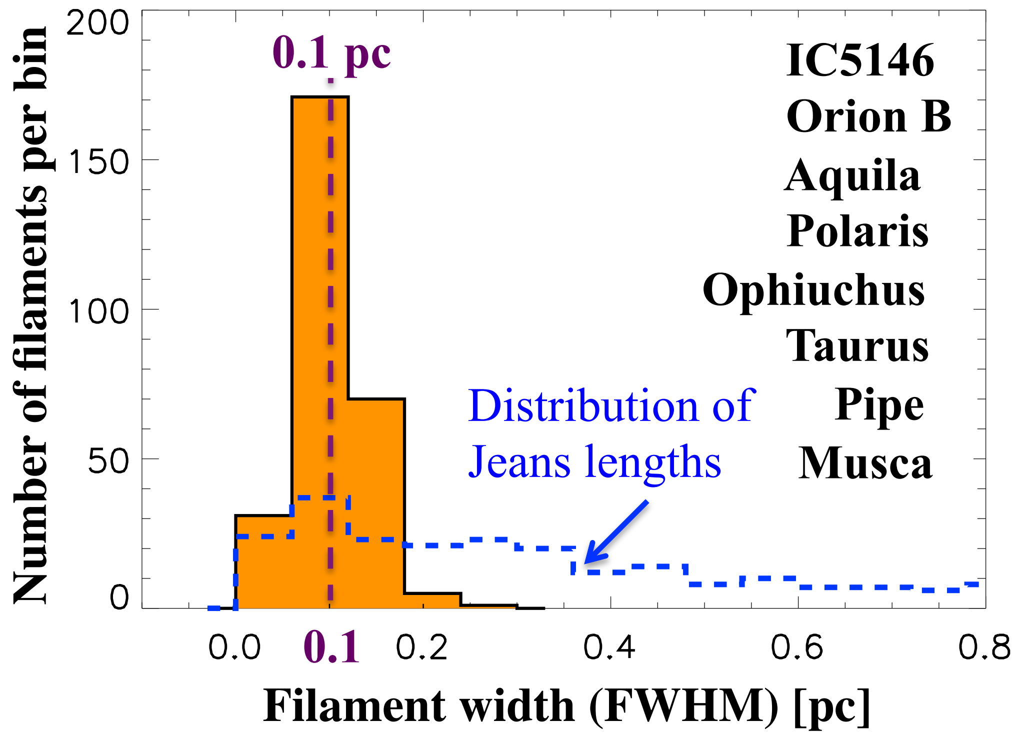
Network of filaments in IC5146



Example of a filament radial profile



Statistical distribution of widths for > 270 nearby filaments



D. Arzoumanian et al. 2011 + PhD thesis

[see also Alves de Oliveira+2014 for Chamaeleon;

Some variations along each filament: Ysard+2014]

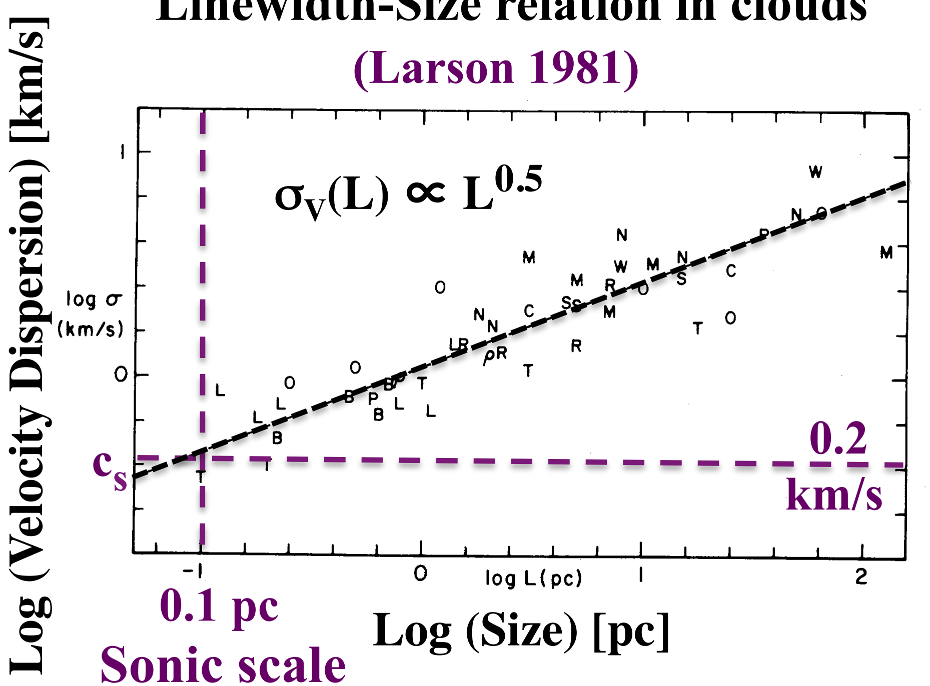
- **Strong constraint on the formation and evolution of filaments**

Filaments due to large-scale MHD supersonic flows ?
large-scale interstellar turbulence ?

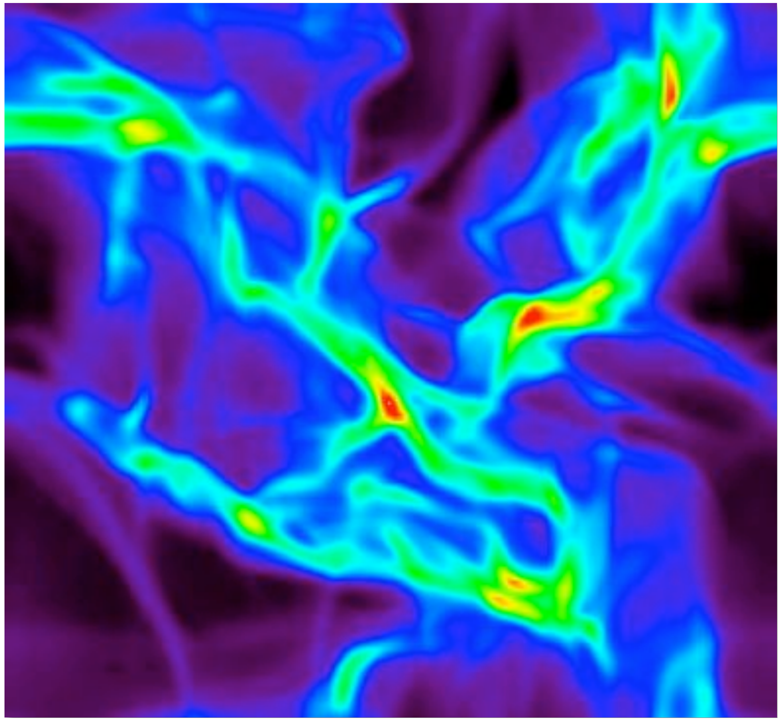
➢ **Filaments in non-self-gravitating clouds such as Polaris most likely result from a combination of MHD turbulent compression** (Padoan+2001) ***and* shear** (Hennebelle 2013)

Linewidth-Size relation in clouds

(Larson 1981)



Simulations of turbulent fragmentation

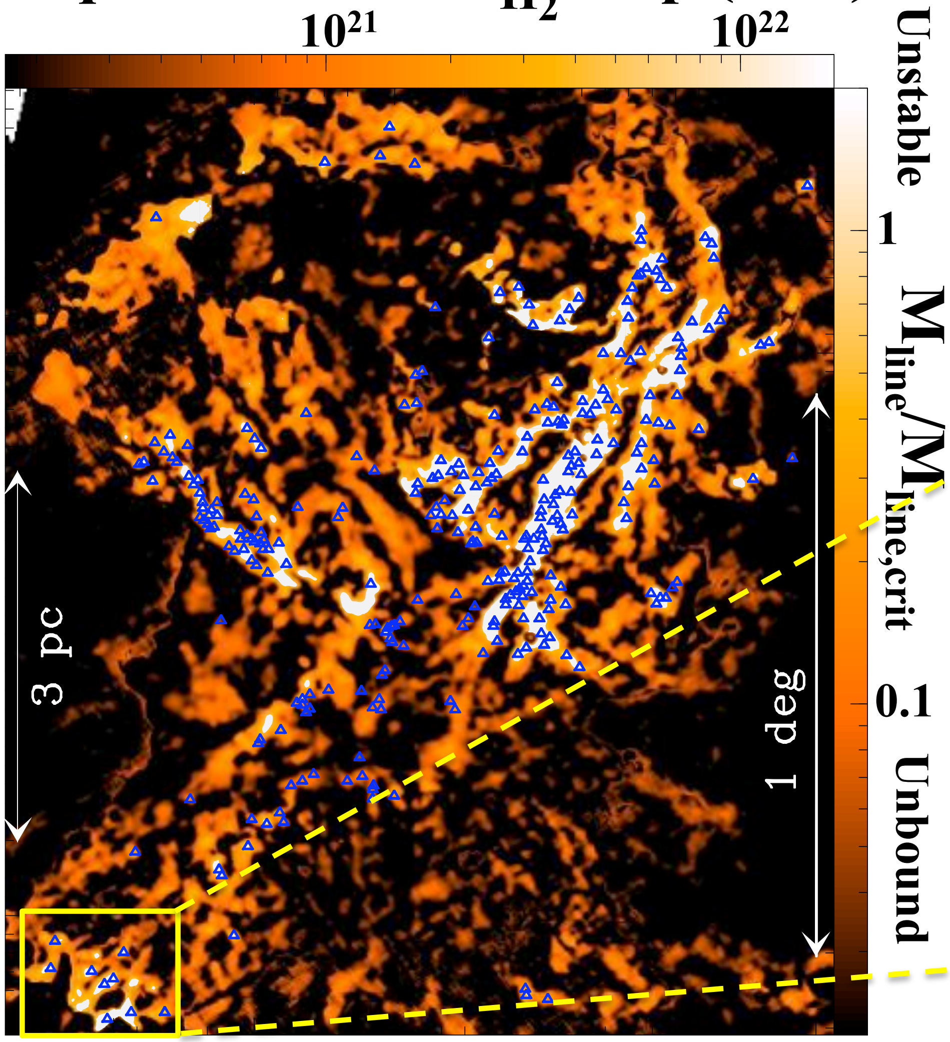


Padoan, Juvela et al. 2001

Filament width ~ 0.1 pc: ~ sonic scale of interstellar turbulence ?
~ dissipation scale of MHD waves ?

~ 75^{+15}_{-5} % of prestellar cores form in filaments, above a column density threshold $N_{H_2} \gtrsim 7\times10^{21}$ cm^{-2}

Aquila curvelet N_{H_2} map (cm^{-2})



André et al. 2010, Könyves et al. 2010 + in prep

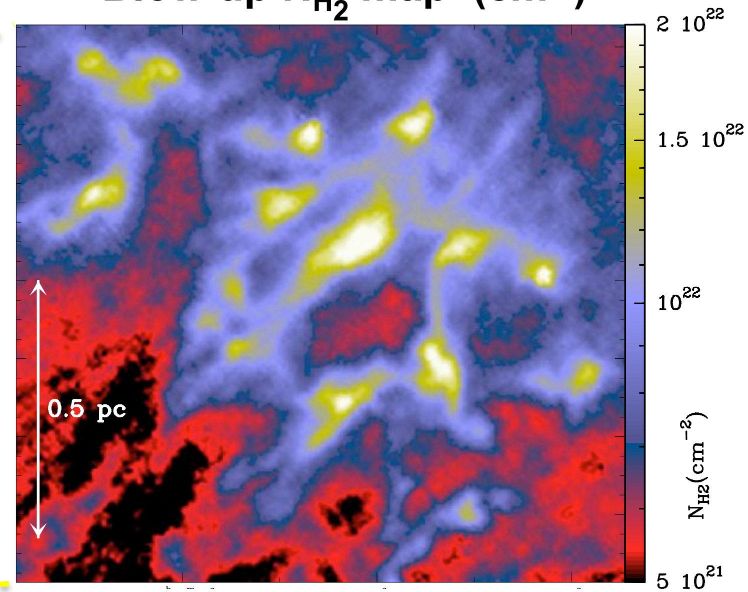
<=>

$A_V \gtrsim 7$

$\Sigma_{threshold}$ ~ 150 $M_{\odot}/pc^2$

Examples of *Herschel* prestellar cores (Δ)

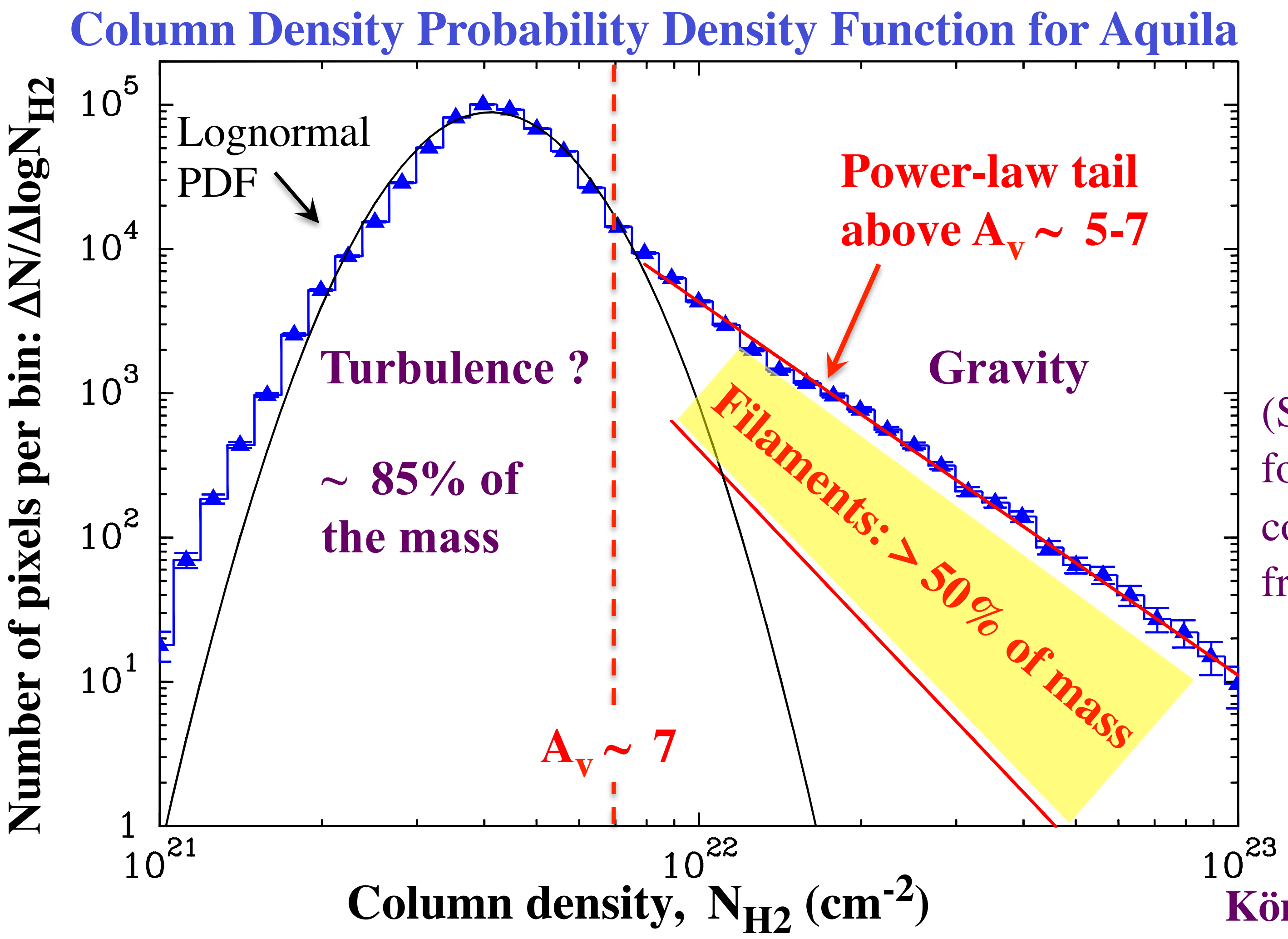
Blow-up N_{H_2} map (cm^{-2})



Lifetime of prestellar cores: t_{pre} ~ 1 Myr

Talk by V. Könyves on Wednesday

Mass budget in the Aquila cloud complex

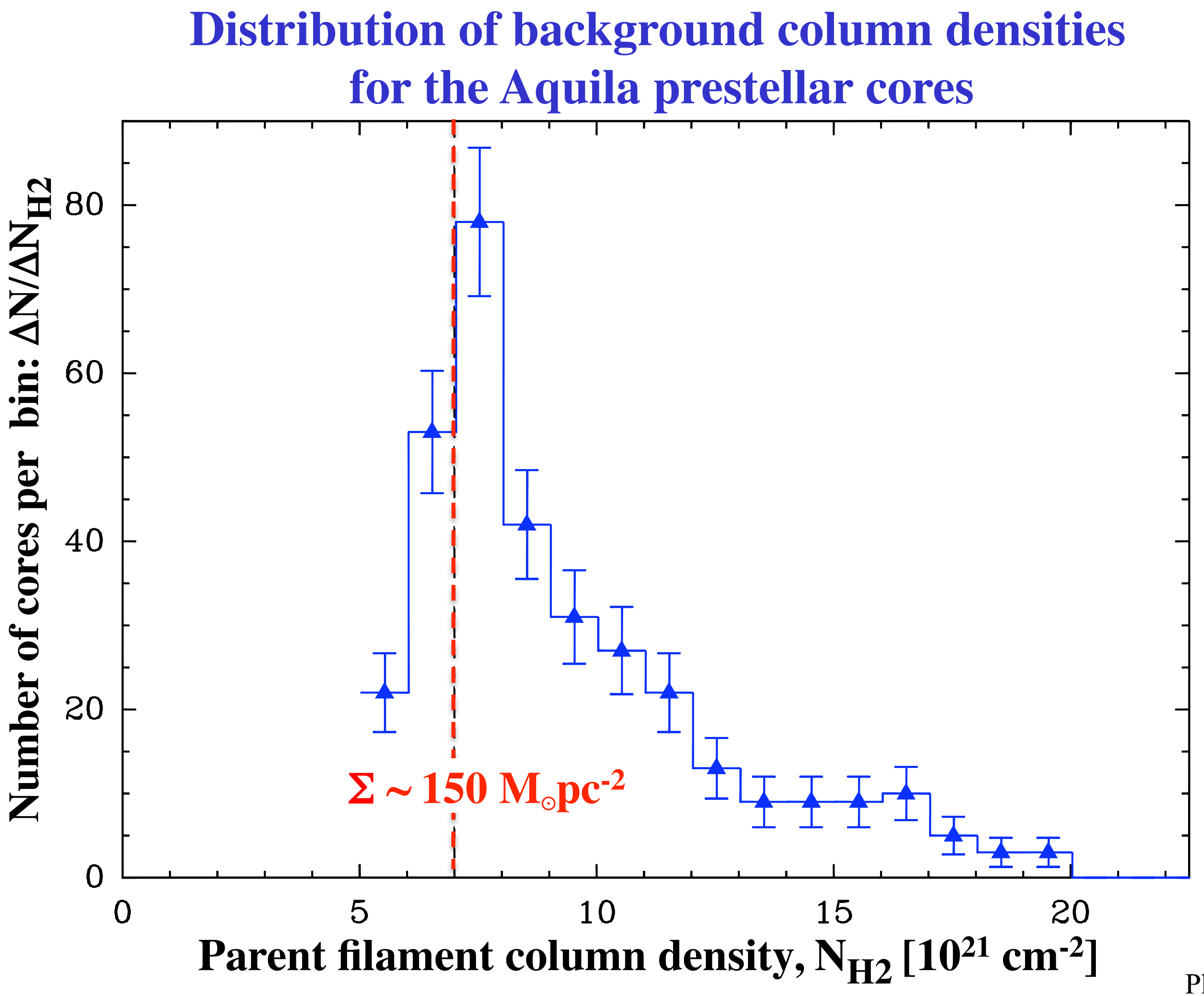


(See Schneider+2013 for other, similar column density PDFs from *Herschel*)

Könyves et al. in prep

- Below $A_V \sim 7$: ~ 20 % of the mass in the form of filaments, < 1% in prestellar cores
- Above $A_V \sim 7$: > 50 % of the mass in the form of filaments, f_{pre}~ 15+-5% in prestellar cores

Strong evidence of a column density "threshold" for the formation of prestellar cores



In Aquila, ~90% of the prestellar cores identified with *Herschel* are found above $A_v \sim 7$ ⇔ $\Sigma \sim 150\ M_\odot\ pc^{-2}$

Könyves etal. in prep

André+2014 PPVI

See also:

Onishi+1998

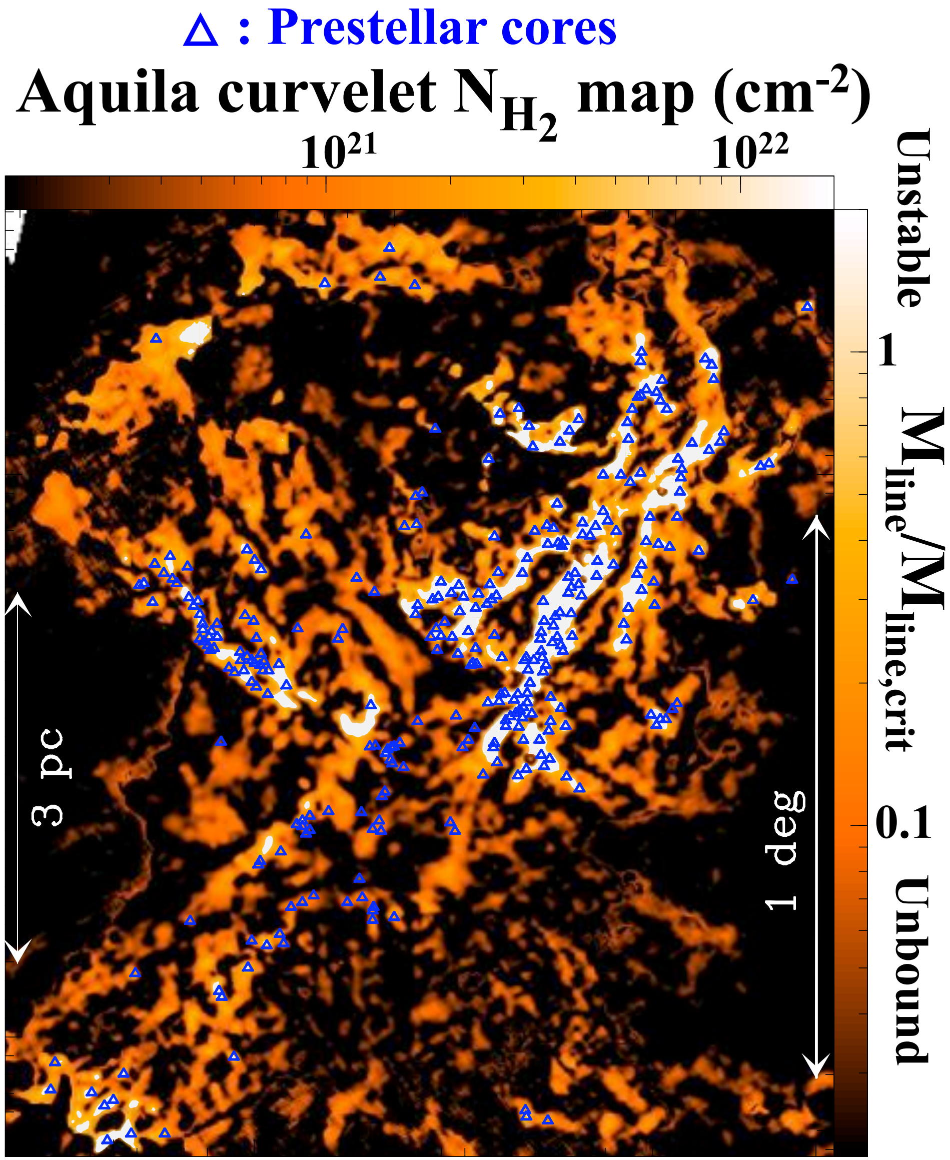
Johnstone+2004

and (for YSOs):

Heiderman+2010

Lada+2010

Interpretation: M/L threshold above which interstellar filaments are gravitationally unstable



André et al. 2010

➢ Gravitational instability of filaments controlled by the mass per unit length $M_{line} = M/L$ (e.g. Inutsuka & Miyama'97):

- unstable if $M_{line} > M_{line,\,crit}$
- unbound if $M_{line} < M_{line,\,crit}$

- $M_{line,\,crit} = 2\,c_s^2/G \sim 16\ M_\odot/pc$ for $T \sim 10$ K ⇔ Σ threshold $\sim 160\ M_\odot/pc^2$ ⇔ density $\sim 1600\ M_\odot/pc^3$ $\sim 2 \times 10^4\ cm^{-3}$

➢ Simple estimate:

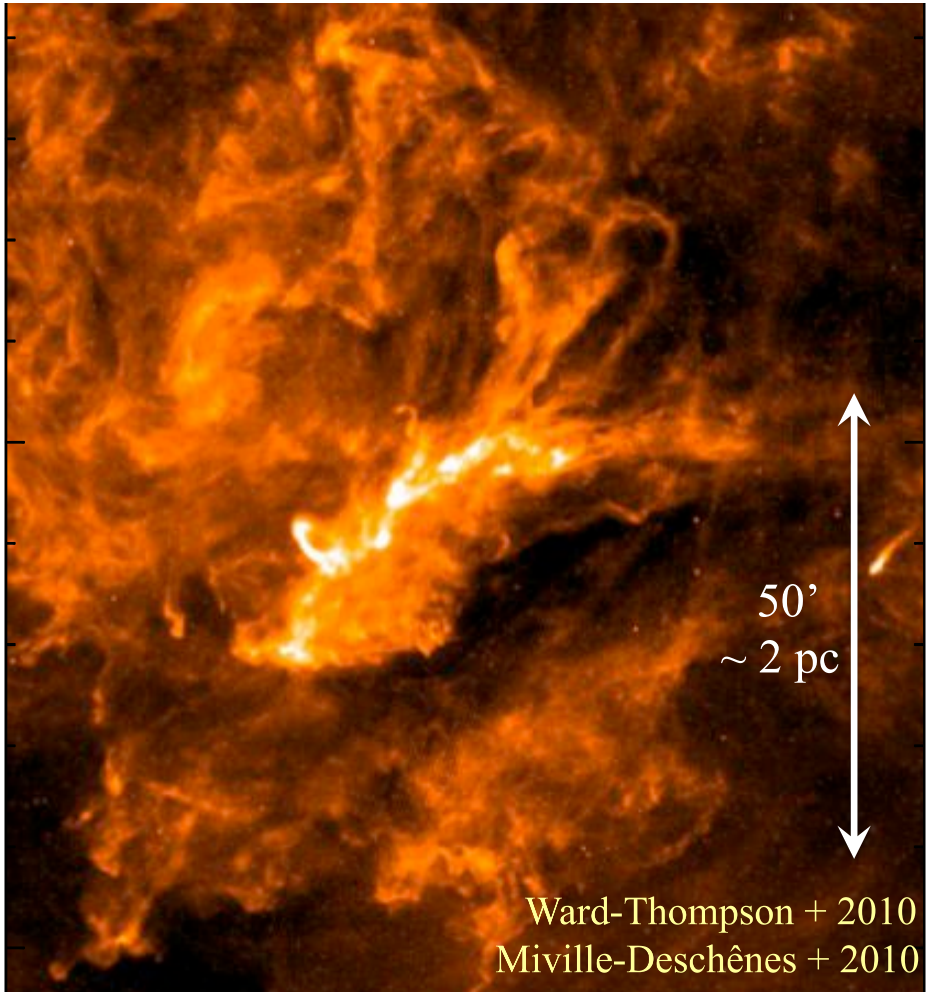
$M_{line} \propto N_{H2}$ x Width (~0.1 pc)

Unstable filaments in white

Toward a new paradigm for ~ $M_{\odot}$ star formation ?

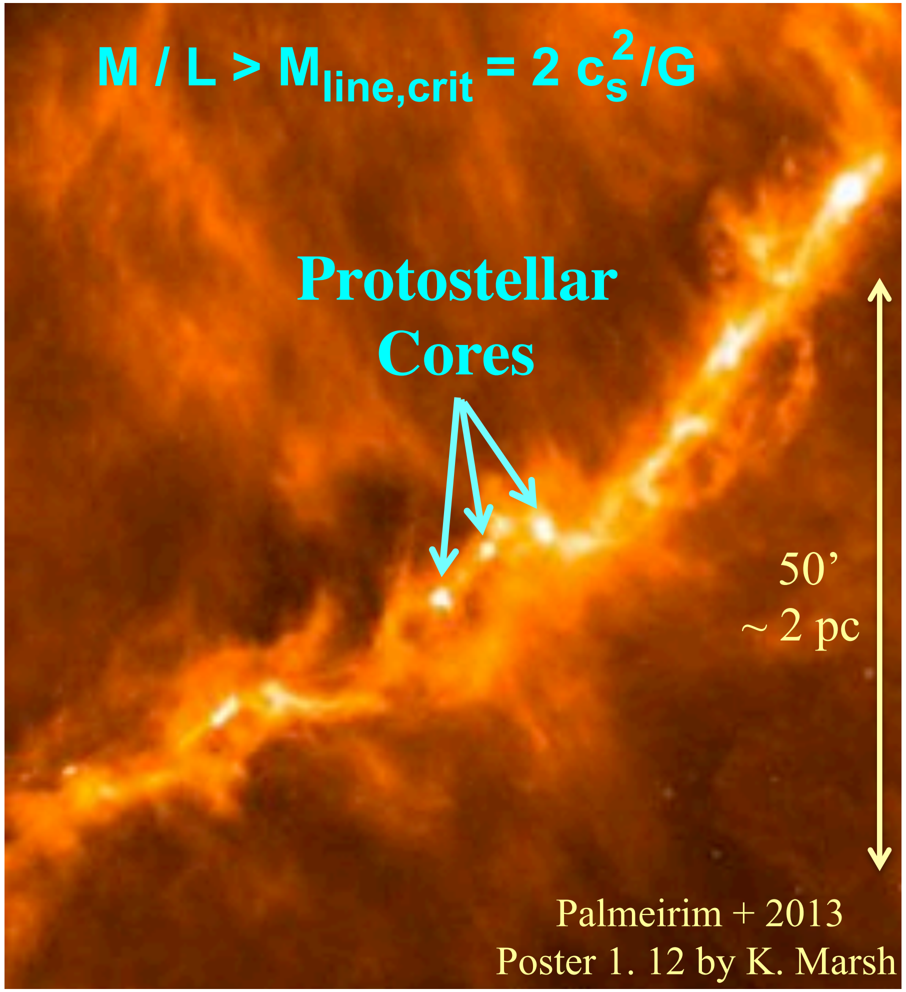
cf Protostars & Planets VI chapter (André, DiFrancesco, Ward-Thompson, Inutsuka, Pudritz+2014 astro-ph/1312.6232)

1) Large-scale MHD supersonic 'turbulence' generates filaments



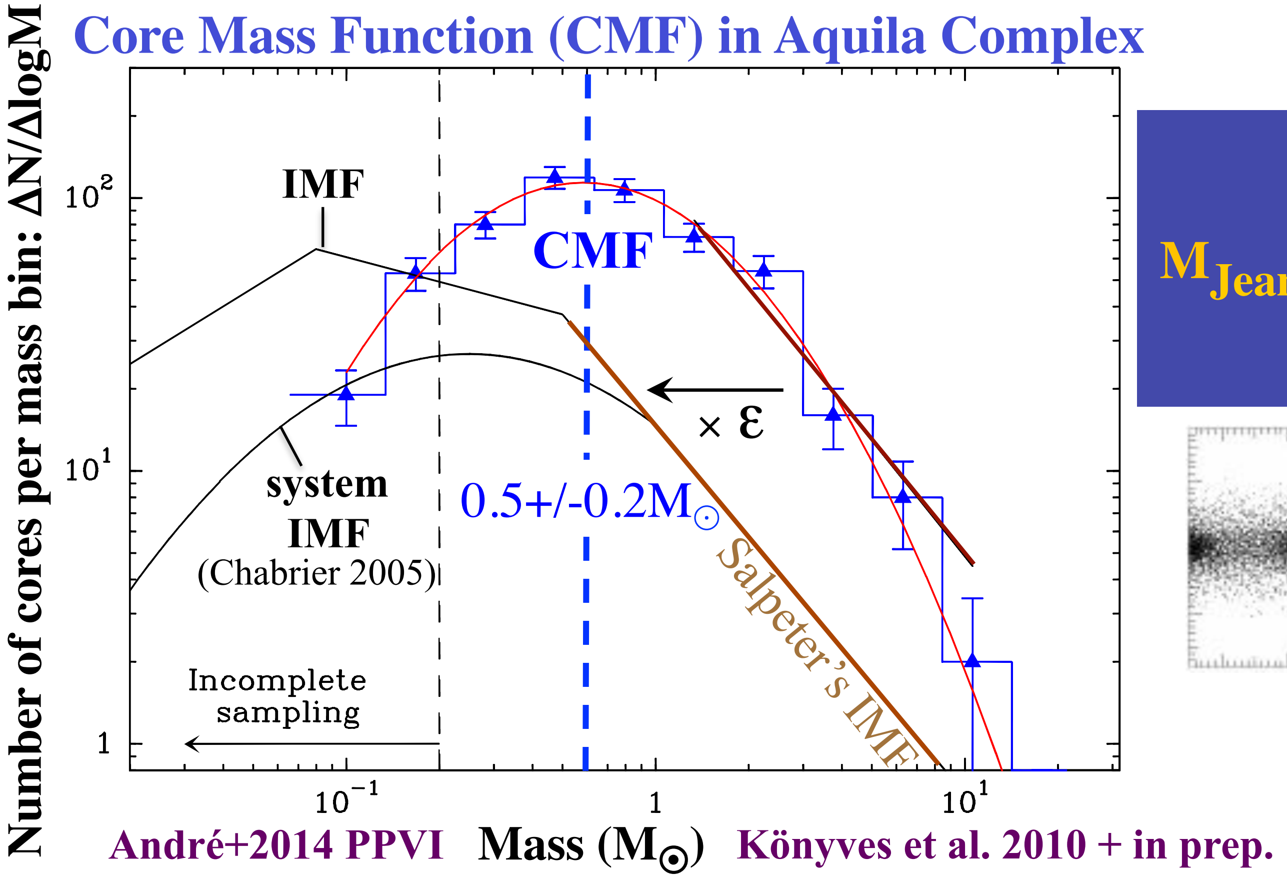
Polaris – *Herschel*/SPIRE 250 μm

2) Gravity fragments the densest filaments into prestellar cores



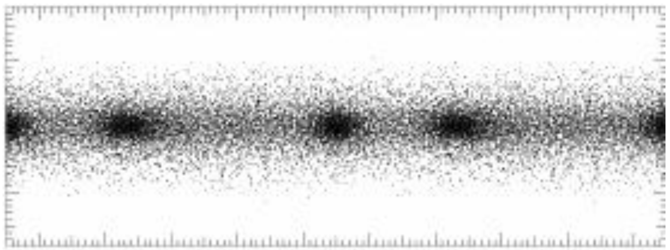
Taurus B211/3 – *Herschel* 250 μm

Filament fragmentation may account for the peak of the prestellar CMF and the "base" of the IMF



Jeans mass:

$M_{Jeans} \sim 0.5\ M_\odot \times (T/10\ K)^2 \times (\Sigma_{crit}/160\ M_\odot pc^{-2})^{-1}$



Inutsuka & Miyama 1997

See talk by A. Roy for Salpeter slope

- CMF peaks at ~ 0.5 $M_\odot$ ≈ Jeans mass in marginally critical filaments
- Close link of the prestellar CMF with the stellar IMF: $M_\star \sim 0.3 \times M_{core}$
- Characteristic stellar mass may result from filament fragmentation

Summary: A filamentary paradigm for SF

- Observational facts: Most SF occurs in dense gas above $A_V \sim 7$;
  > 50% of this dense gas is in the form of filaments;
  > 75% of prestellar cores are within dense filaments.

- *Herschel* results suggest **star formation occurs in 2 main steps**:
  1) ~ 0.1 pc-wide filaments form first in the cold ISM, probably as a result of the dissipation of large-scale **MHD turbulent flows**;
  2) The densest filaments grow by accretion and fragment into prestellar cores via **gravitational instability** above a critical density threshold $\Sigma_{th} \sim 150\ M_\odot\ pc^{-2} \Leftrightarrow A_V \sim 7 \Leftrightarrow n_{H2} \sim 2 \times 10^4\ cm^{-3}$

- The filamentary nature of SF in GMCs may be responsible for a quasi-universal SF efficiency in dense gas ($t_{dep} \sim 20$ Myr).

- ***IAU Symp. 315* "From interstellar clouds to star-forming galaxies: universal processes ?" @ *IAU GA, Honolulu, 3-7 Aug. 2015***