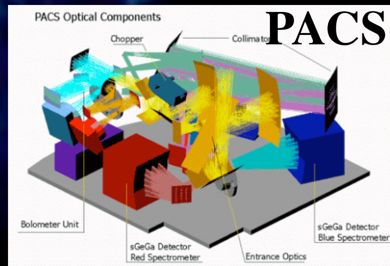
From the filamentary structure of the ISM to prestellar cores to the IMF: Results from the *Herschel* Gould Belt survey

Philippe André

CEA

Lab. AIM Paris- Saclay



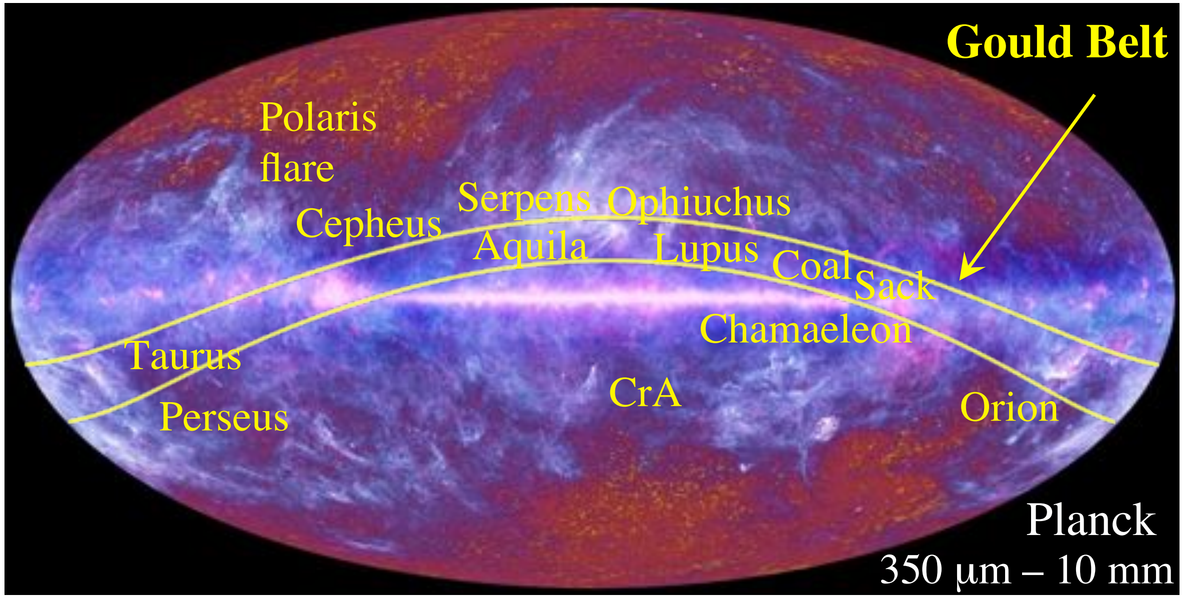
With: A. Menshchikov, V. Könyves, D. Arzoumanian, P. Palmeirim, N. Peretto, P. Didelon, N. Schneider, S. Bontemps, F. Motte, D. Ward-Thompson, J. Kirk, M. Attard, J. Di Francesco, P. Martin, P. Saraceno, J.Ph. Bernard & the *Herschel* Gould Belt KP Consortium

Part of Orion B 70/250/500 μm composite

The *Herschel* Gould Belt Survey

SPIRE/PACS 70-500 μm imaging of the bulk of nearby (d < 0.5 kpc) molecular clouds (~ 160 deg^2), mostly located in Gould's Belt.

➢ Complete census of prestellar cores and Class 0 protostars.



~ 15" resolution at λ ~ 200 μm

←→

~ 0.02 pc
< Jeans length @ d = 300 pc

Motivation: Probing the origin of the stellar IMF

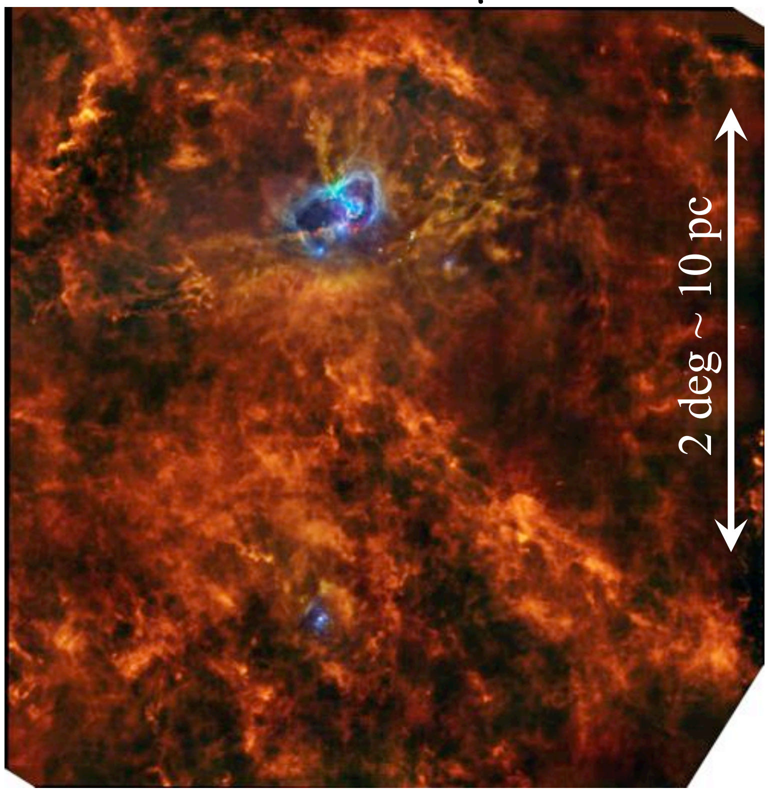
- Nature of the relationship between the CMF and the IMF ?
- What generates prestellar cores and what governs their evolution to protostars and proto-brown dwarfs ?

Herschel shows a "universal" filamentary structure in the cold ISM

Aquila: Actively star forming

d ~ 260 pc

SPIRE 500 μm + PACS 160/70 μm



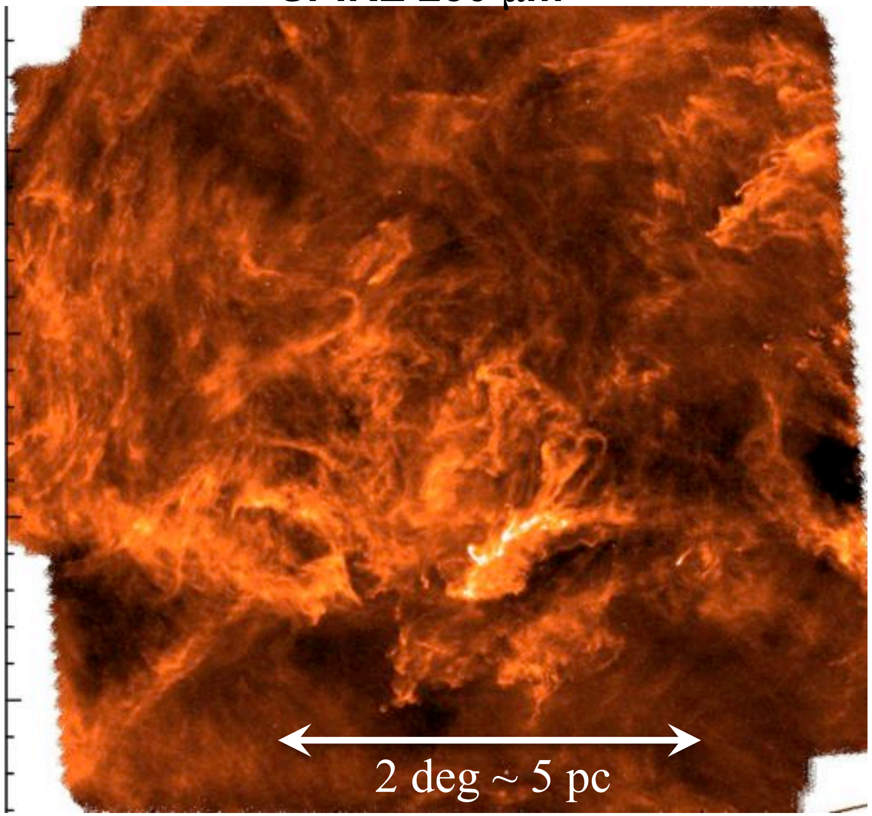
Aquila Rift - *Herschel* Gould Belt survey

André et al. 2010, Bontemps et al. 2010, Könyves et al. 2010

Polaris: Non star forming, unbound cirrus

d ~ 150 pc

SPIRE 250 μm

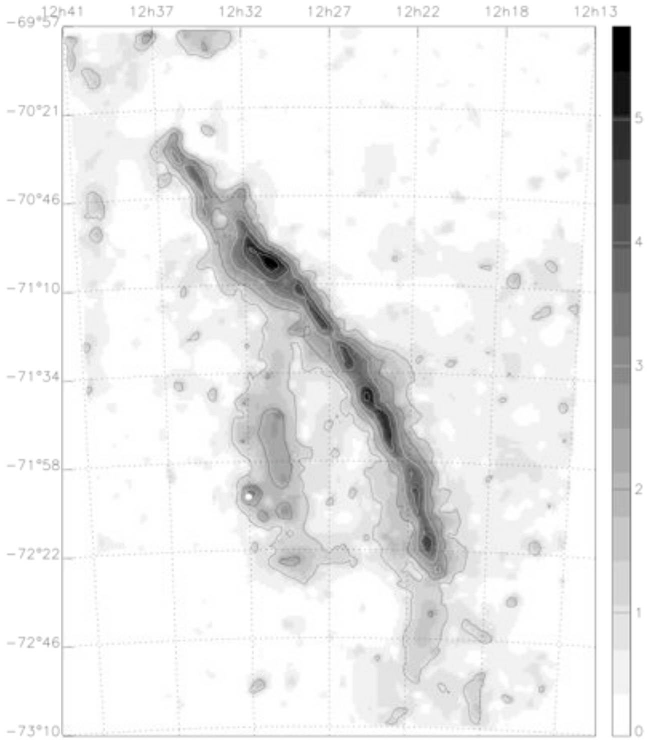


Polaris Flare - Gould Belt survey

Men'shchikov et al. 2010, Miville-Deschênes ea. 2010, Ward-Thompson et al. 2010

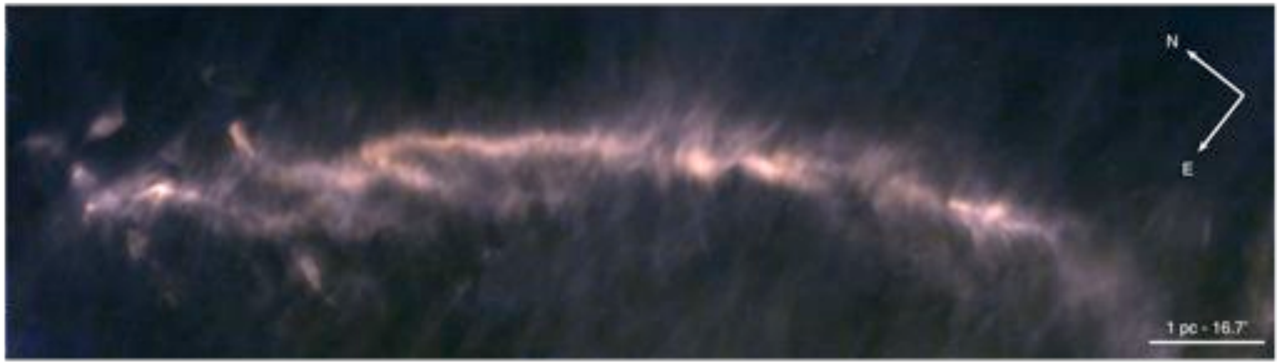
Evidence of the importance of filaments prior to *Herschel* but … much fainter filaments + universality with *Herschel*

Extinction map of Musca



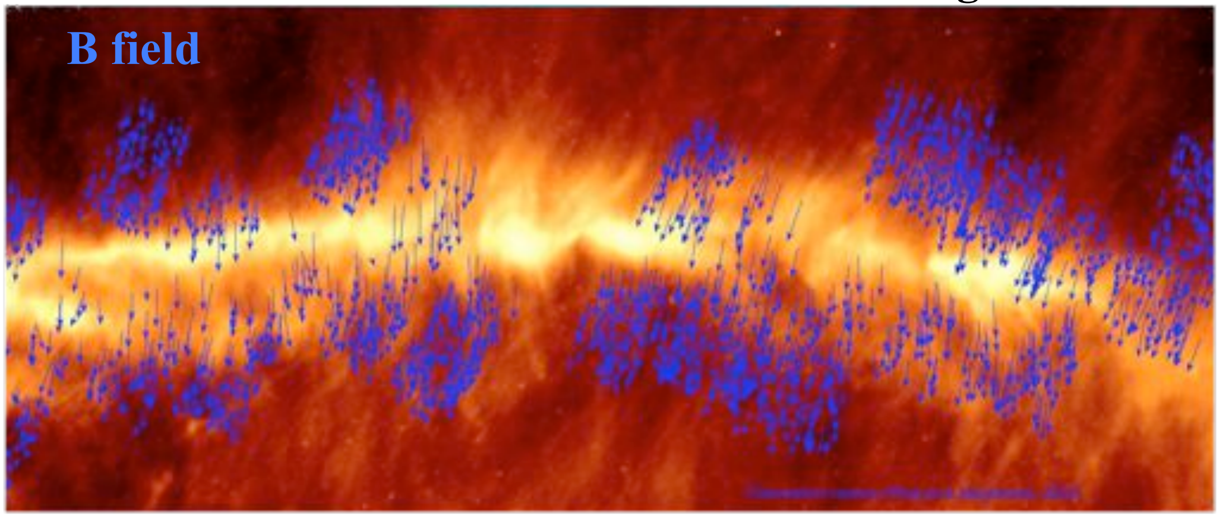
Cambrésy 1999

***Herschel* 160/250/350 µm composite image of Musca**



Gould Belt Survey: N. Cox, E. Winston, A. Kospal et al., in prep.

Polarization vectors overlaid on *Herschel* image of Musca



N. Cox et al. in prep.
+ Pereyra & Magelhaes 2004

See also:
Schneider & Elmegreen 1979;
Mizuno et al. 1995; Hatchell et al. 2005;
Goldsmith et al. 2008; Myers 2009 …

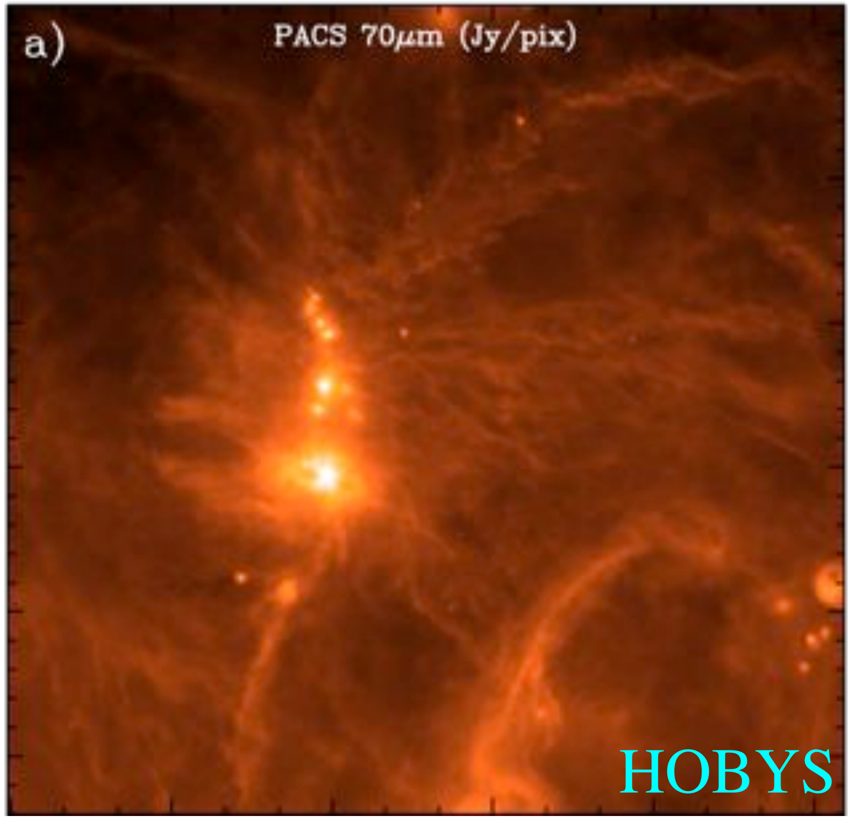
Very common pattern: main filament + network of perpendicular striations or "sub-filaments"

Taurus B211 filament: M/L ~ 50 $M_{\odot}$/pc

Palmeirim et al. 2012 - see Poster by P. Palmeirim

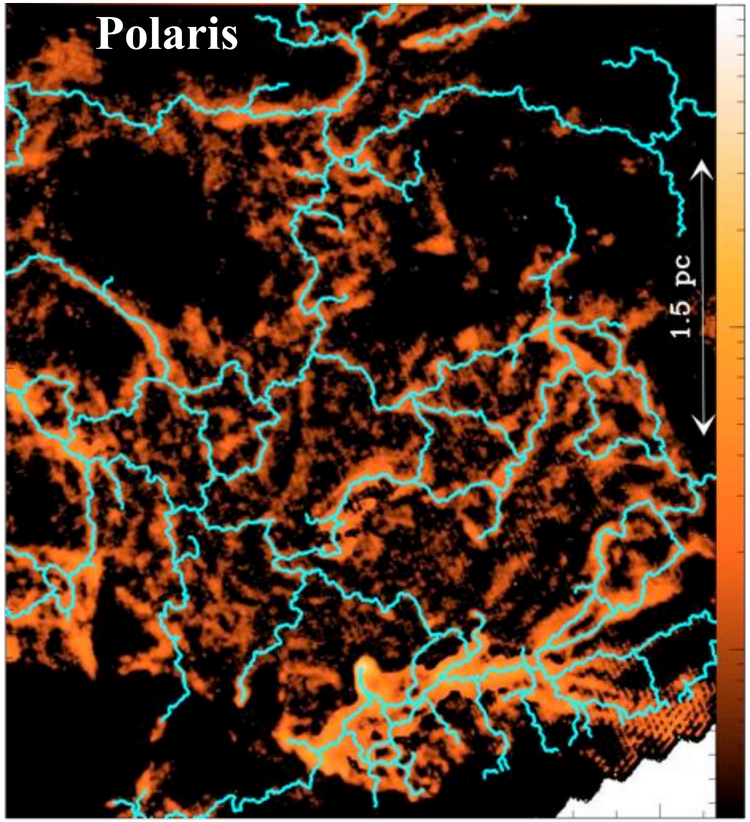
DR21 in Cygnus X:
M/L ~ 4000 $M_{\odot}$/pc

Hennemann, Motte et al. 2012 - see Poster



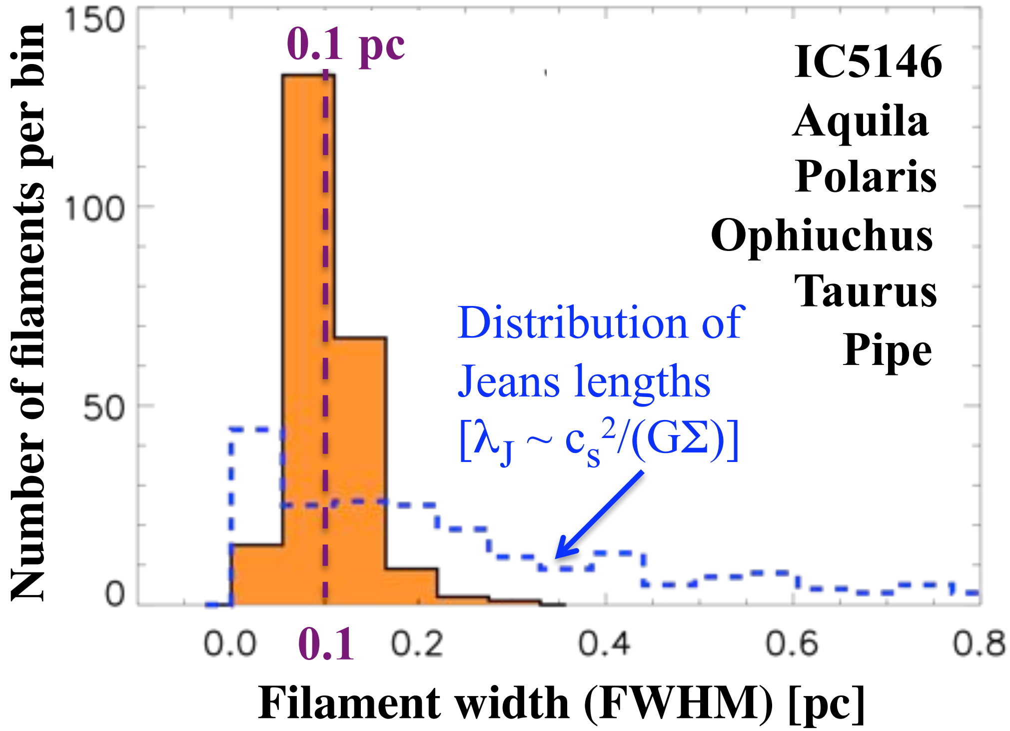
Interstellar filaments have a characteristic width ~ 0.1pc ~ sonic scale of ISM turbulence

D. Arzoumanian et al. 2011, A&A, 529, L6



Using the DisPerSE algorithm (Sousbie 2011) to trace the crest of each filament

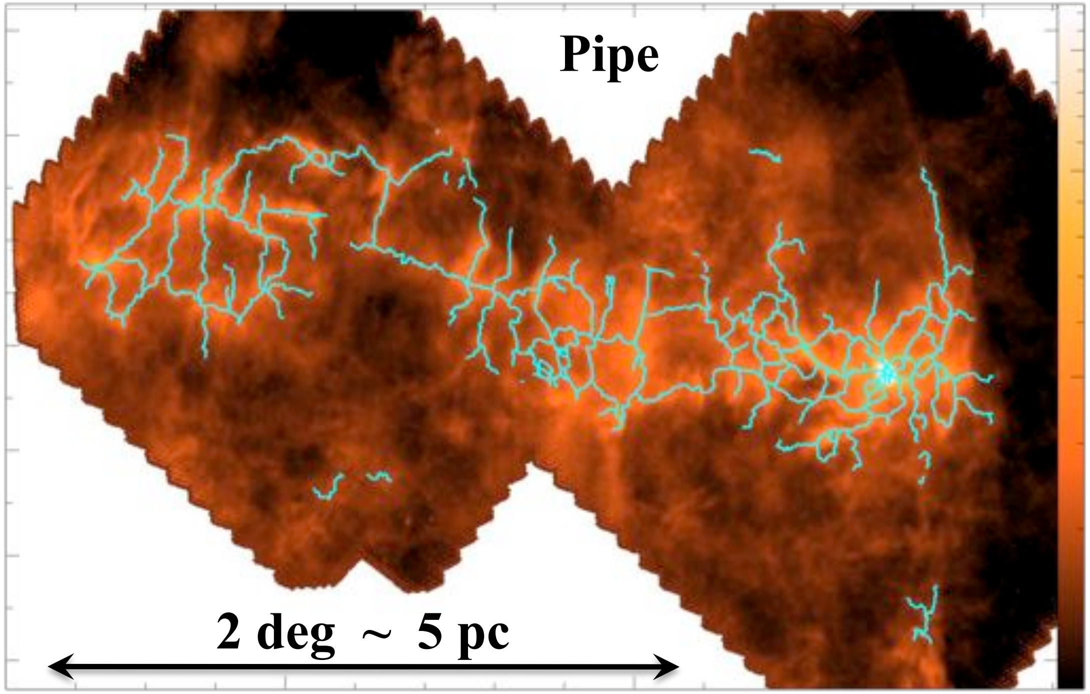
Statistical distribution of widths for > 200 filaments



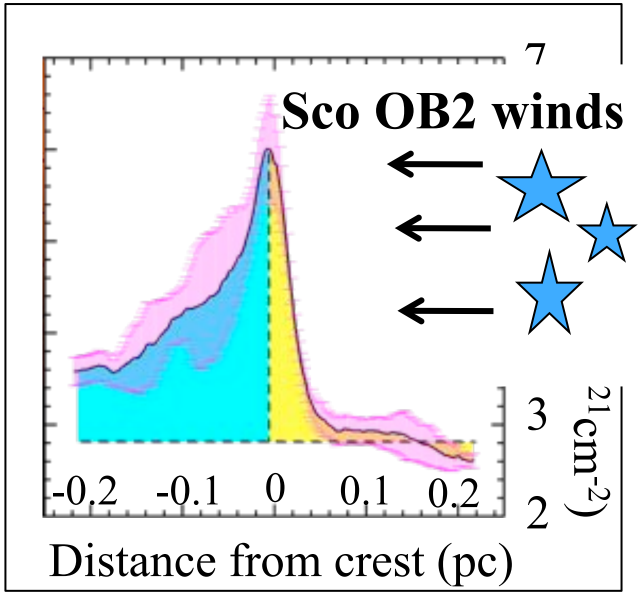
➢ Consistent with the view that filaments form as a result of turbulent compression in low-velocity shocks (cf. Padoan et al. 2001, but P. Hennebelle's talk)

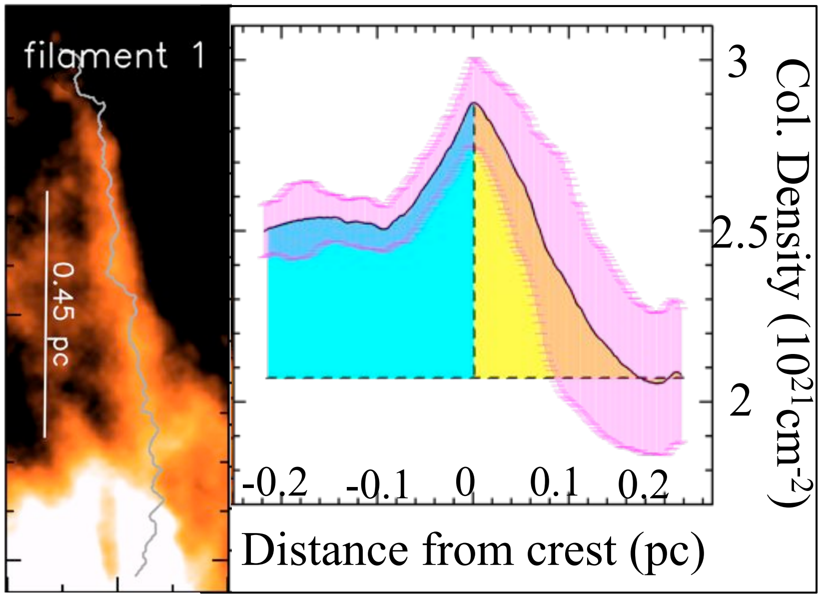
Evidence of the formation of filamentary structures by large-scale compression in the Pipe Nebula

➢ **In the Pipe several filaments have asymmetric column density profiles, most likely due to compression by the winds of Sco OB2 (Peretto et al. 2012)**



Column density map (Peretto et al. 2012)
***Herschel* Gould Belt survey**





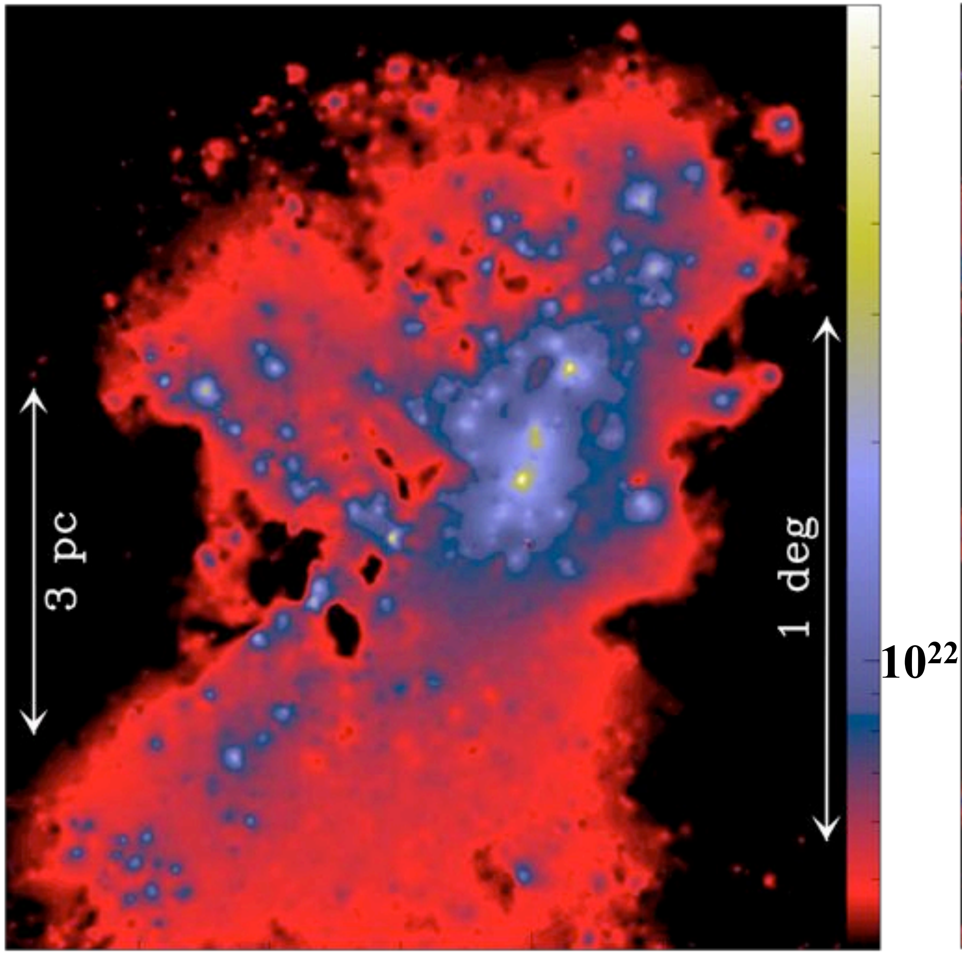
Dense cores form primarily in filaments

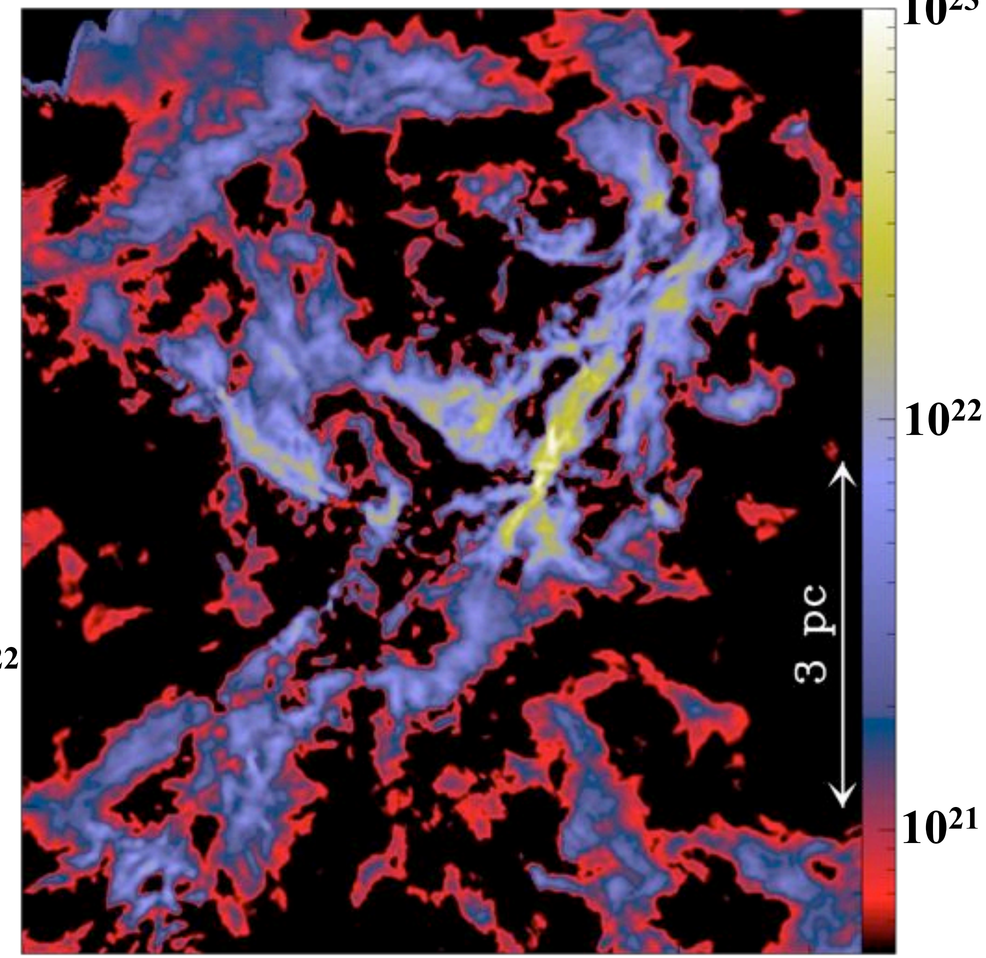
Morphological Component Analysis:

***Herschel* Column density map**

(P. Didelon based on Starck et al. 2003)

= Cores **Wavelet component (H_2/cm^2)** + Filaments **Curvelet component (H_2/cm^2)**

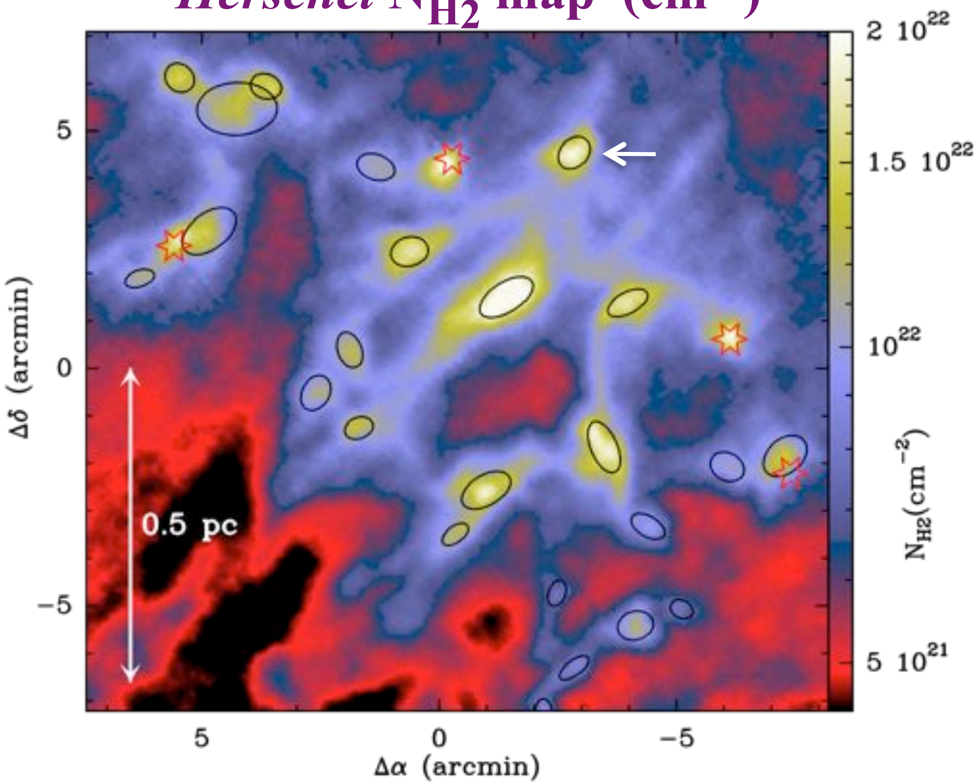




Examples of cores extracted in Aquila with "getsources" (Men'shchikov et al. 2010/12)

- **Core = single star-forming entity**
  (Need to resolve ~ 0.01-0.1 pc)
- **Starless = no central proto★**
- **Prestellar = bound & starless**

Herschel **N_{H2} map (cm^{-2})**



Könyves et al. 2010, A&A special issue

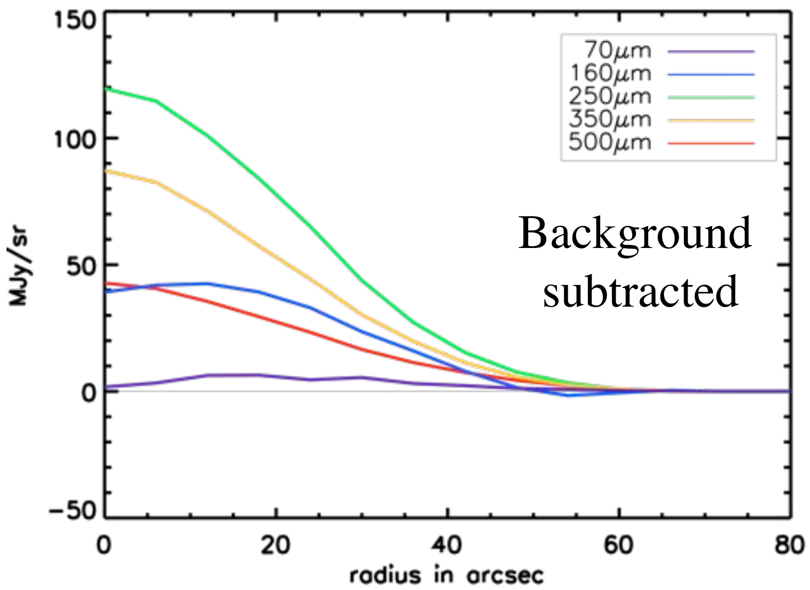
~ 500 starless cores (no PACS 70 μm), including ~ 300 prestellar cores

+

~ 200 YSOs (with PACS 70μm)

identified with *getsources* in Aquila

Examples of radial intensity profiles



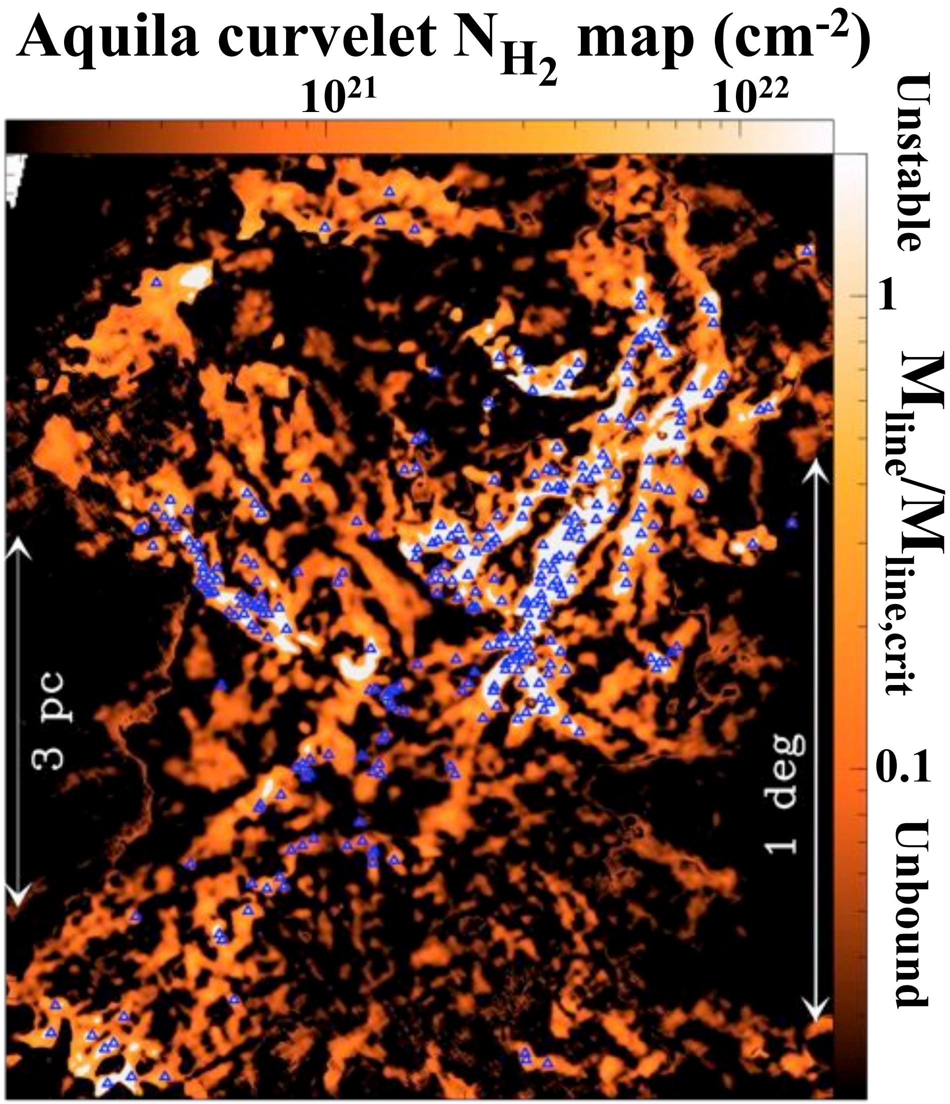
Ph. André - Herschel 2012 – Grenoble – 20/03/2012

Prestellar cores lie in the densest filaments, above a column density threshold $N_{H_2} \gtrsim 7\times10^{21}$ cm^{-2}

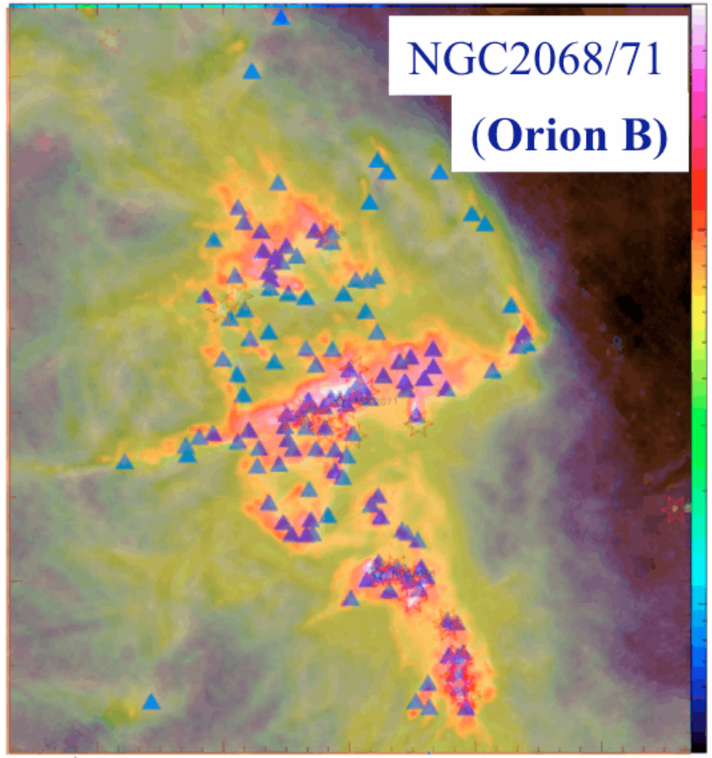
<=>

$A_V \gtrsim 7\text{-}8$

$\Sigma_{threshold} \sim 130\ M_\odot/pc^2$



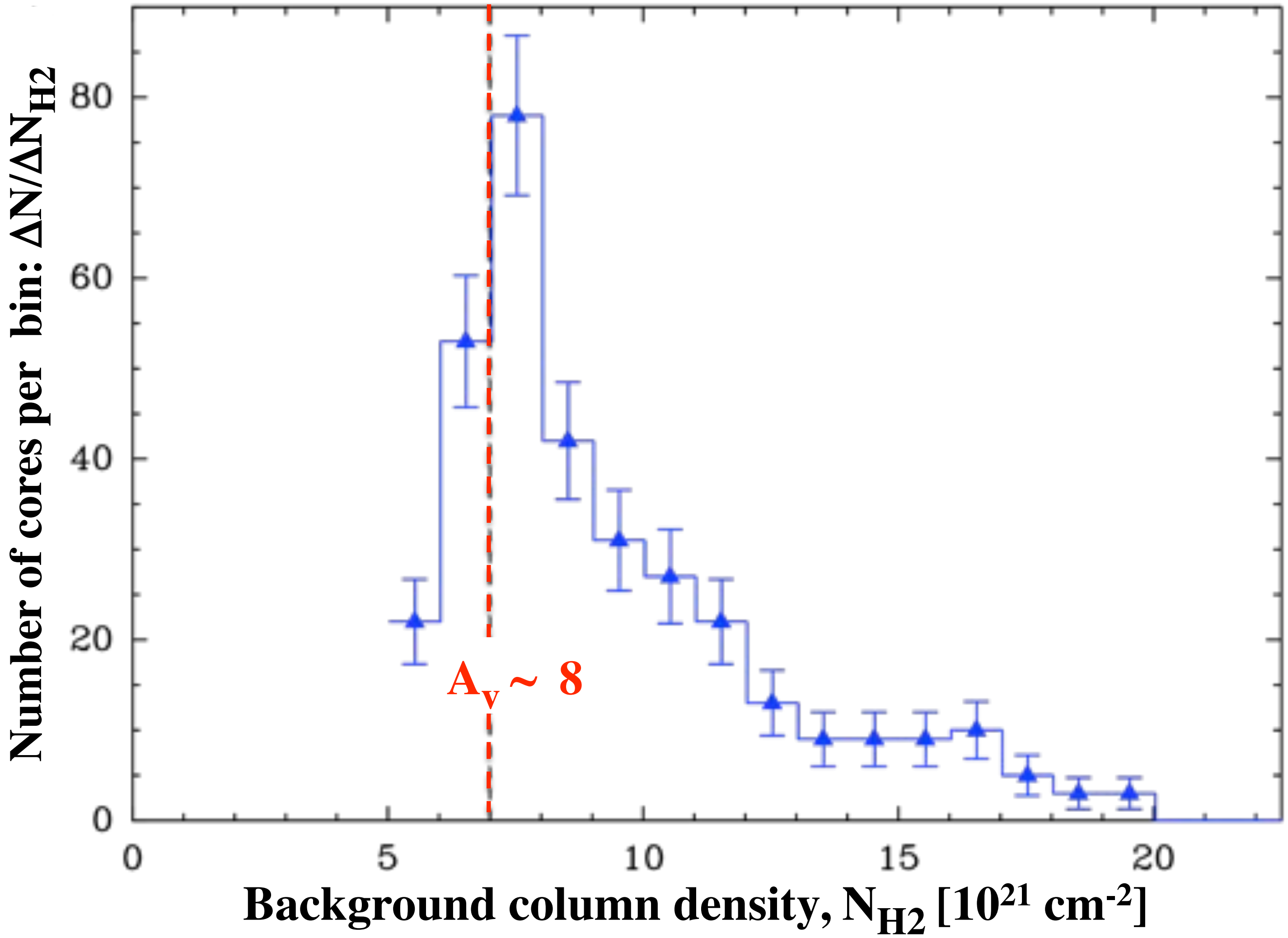
André et al. 2010, Könyves et al. 2010



Schneider et al., in prep.

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

Distribution of background column densities for the Aquila prestellar cores



In Aquila, > 80% of the prestellar cores identified with *Herschel* are found above $A_V \sim$ 7-8 ⇔ $\Sigma \sim 130\ M_\odot\ pc^{-2}$

Könyves etal. in prep

André et al. IAU270

See also:

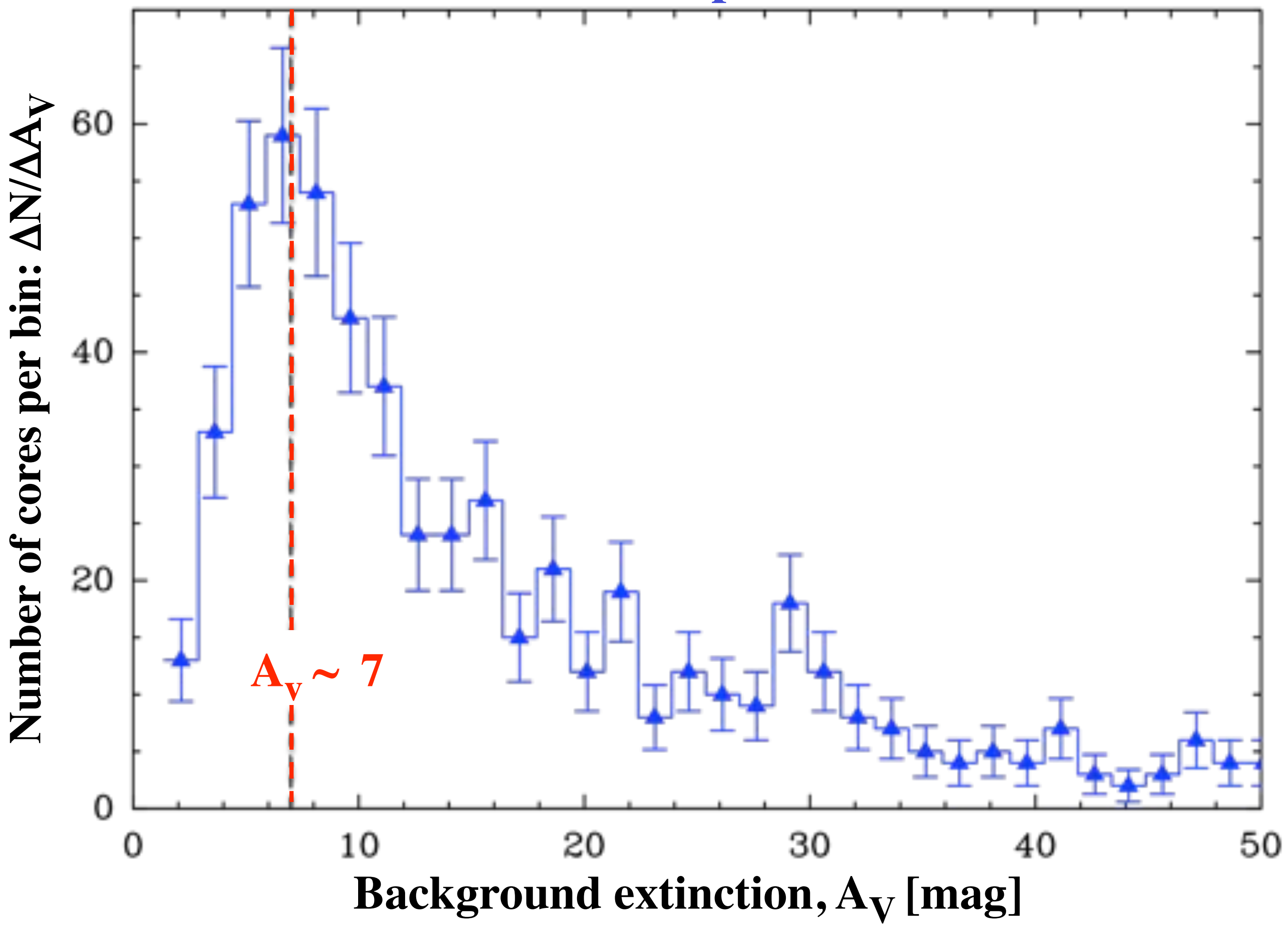
Onishi et al. 1998

Johnstone et al. 2004

Belloche et al. 2011

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

Distribution of background column densities for the Orion B prestellar cores



In Orion B, > 75% of the prestellar cores identified with *Herschel* are found above $A_v \sim 7$ ⇔ $\Sigma \sim 120\ M_\odot\ pc^{-2}$

Schneider et al. in prep.

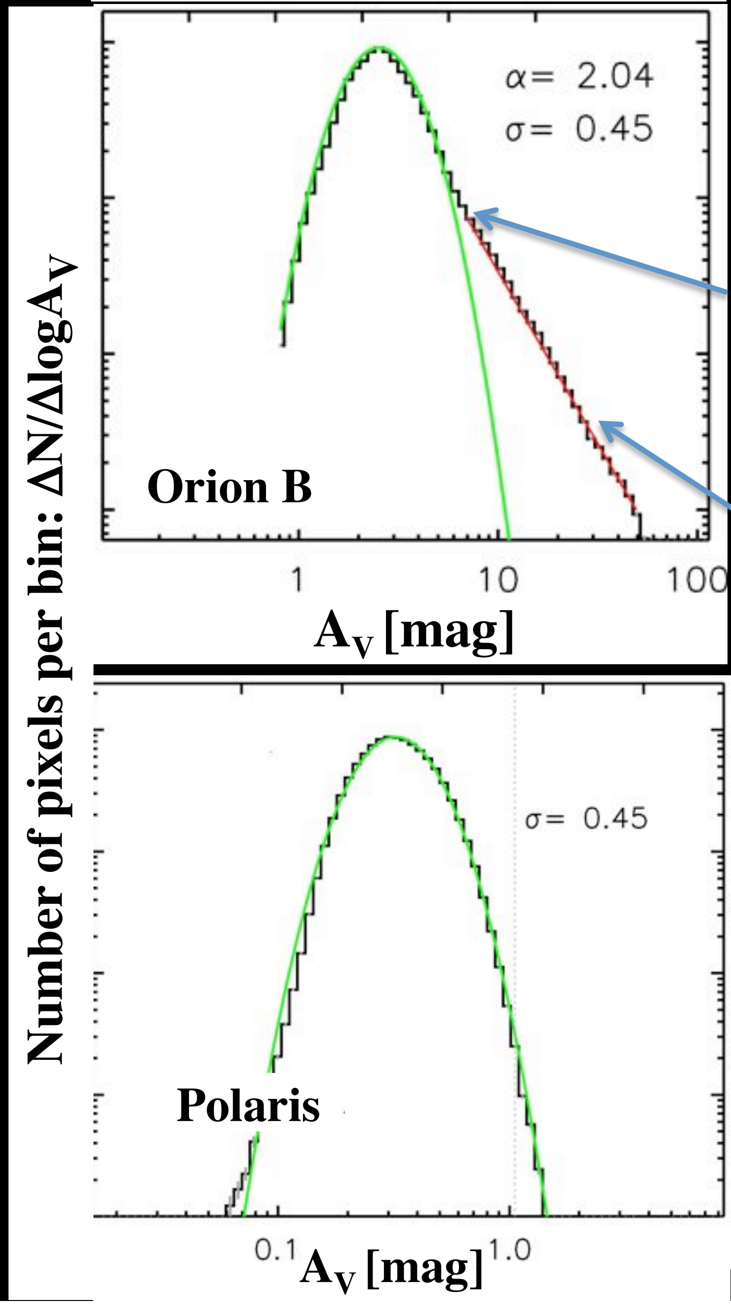
Orion B: *Above threshold*

Many prestellar cores, active SF

Polaris: *Below threshold*

No prestellar cores, no SF

Column density PDFs



Deviation $A_v \sim 7\text{-}9$

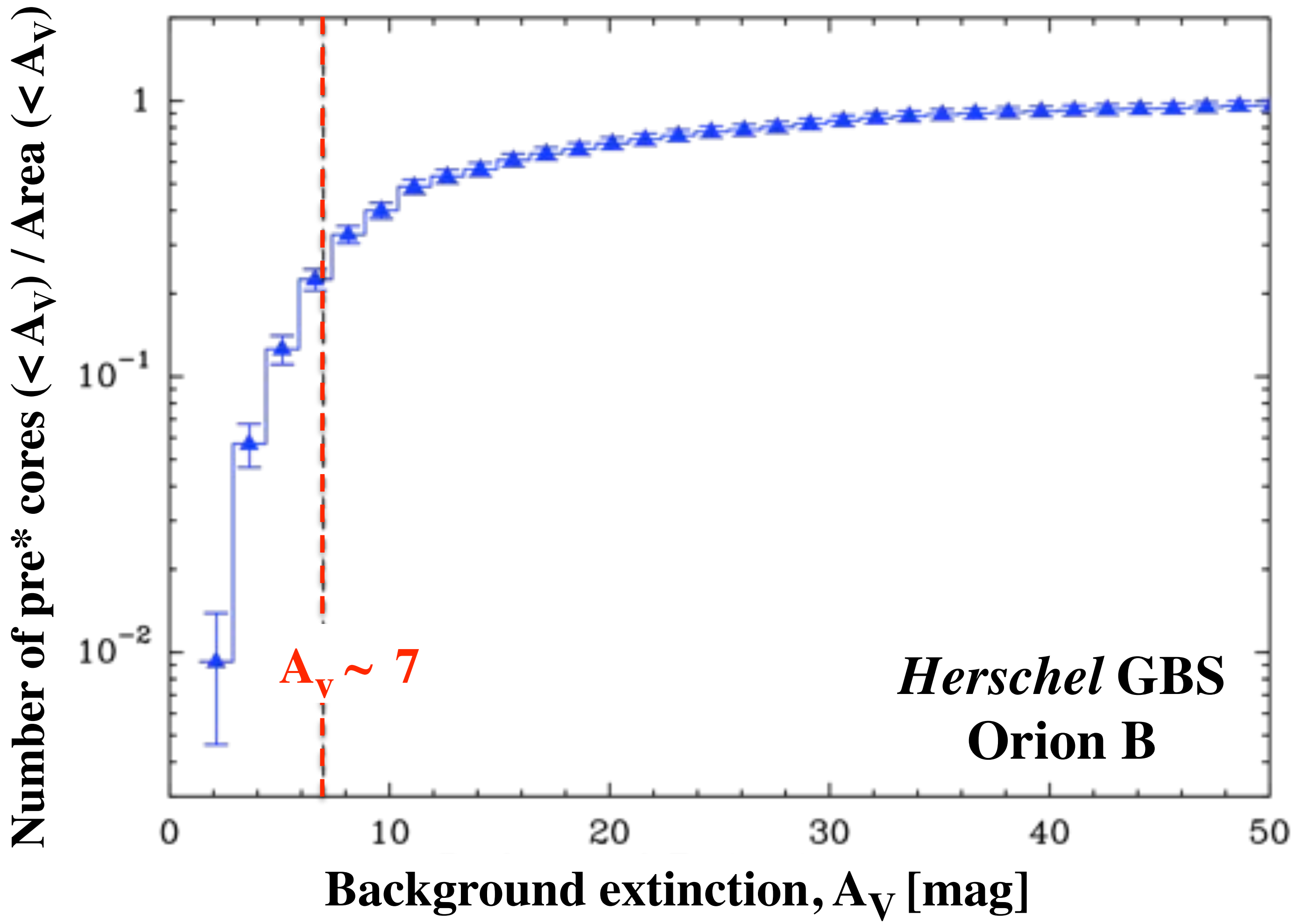
power-law tail (gravity ?)

log-normal PDF (turbu-lence ?)

Schneider et al., in prep

Real "threshold" or rising probability of core/star formation with increasing A_V ?

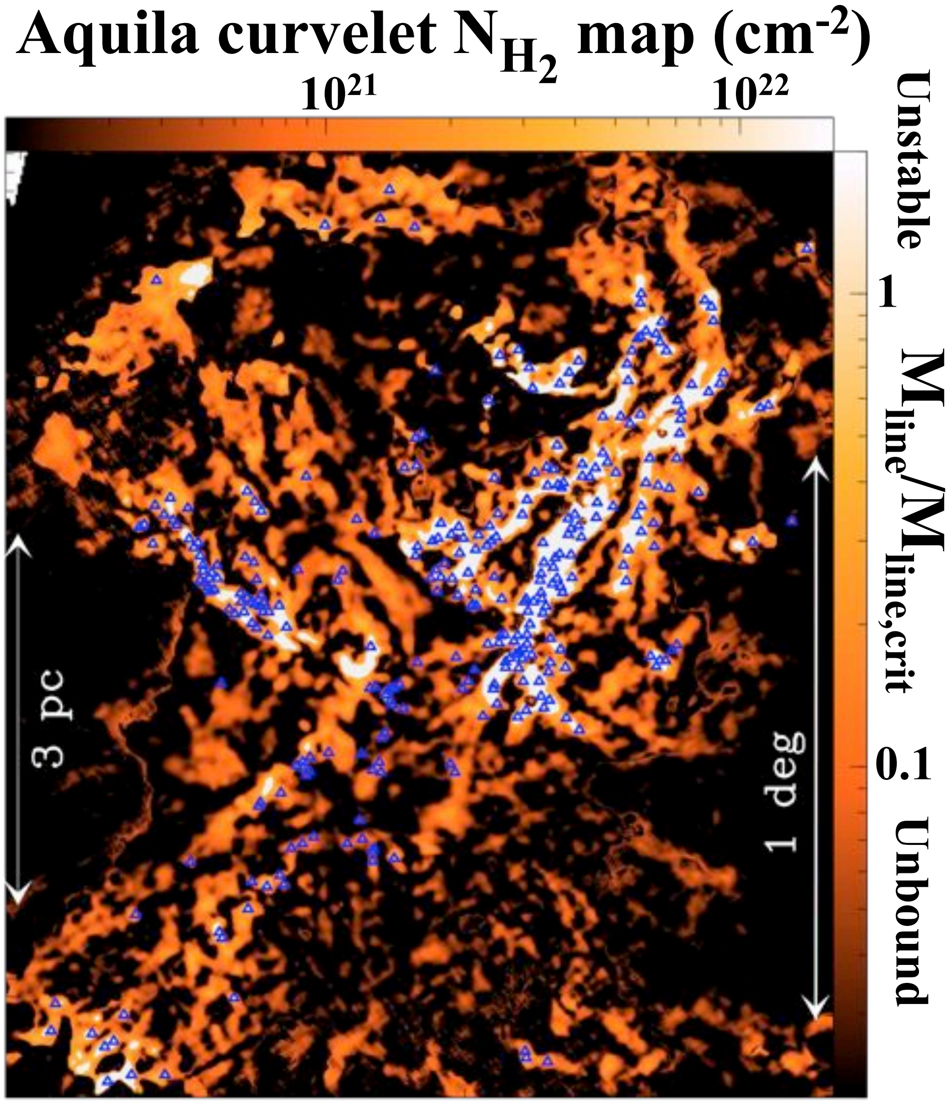
Probability of finding a prestellar core below a given extinction



No real threshold according to, e.g., Hatchell et al. 2005 (Obs.) and Hennebelle & Chabrier 2011 (Theory)

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

△ : Prestellar cores



André et al. 2010, A&A Vol. 518

➢ The gravitational instability of filaments is controlled by the mass per unit length M_{line} (cf. Ostriker 1964, Inutsuka & Miyama 1997):

- unstable if $M_{line} > M_{line,\, crit}$
- unbound if $M_{line} < M_{line,\, crit}$
- $M_{line,\, crit} = 2\, c_s^2/G \sim 15\, M_\odot/pc$

for T ~ 10K ⇔ Σ threshold $\sim 150\, M_\odot/pc^2$

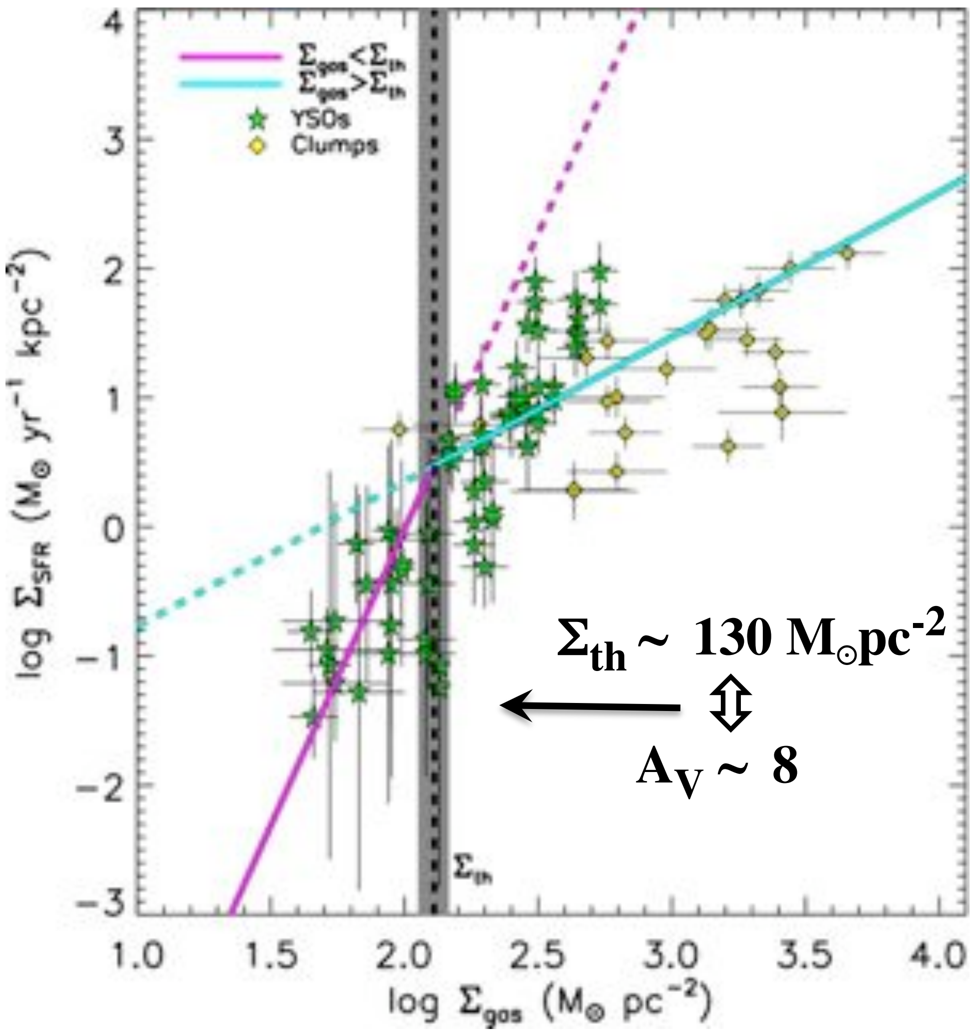
➢ Simple estimate:

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

Unstable filaments highlighted in white in the N_{H2} map

Importance of the star formation threshold on (extra)galactic scales

Star formation rate vs. Gas surface density



Heiderman, Evans et al. 2010

$\Sigma_{SFR} \propto \Sigma_{gas}$

for

$\Sigma_{gas} > \Sigma_{threshold}$

Heiderman et al. 2010

Lada et al. 2010

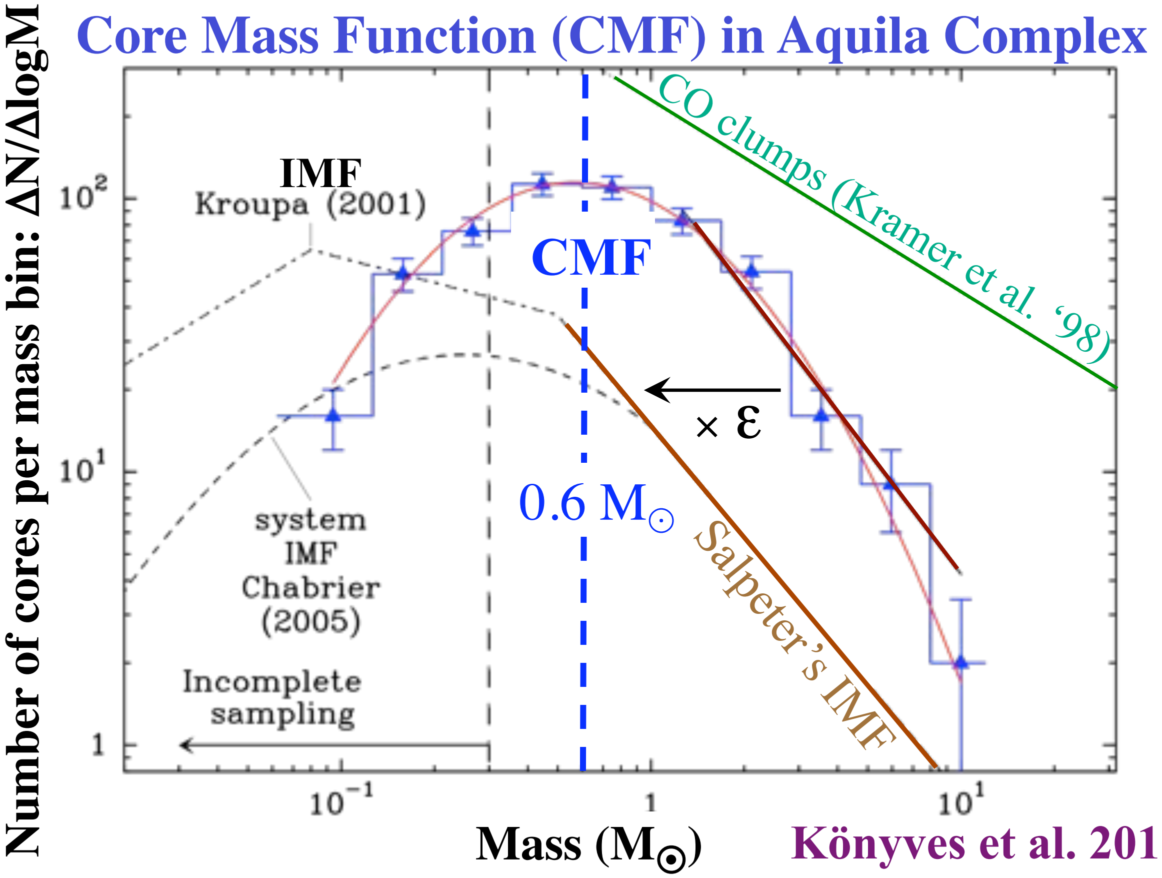
See

Gao & Solomon 2004

for external galaxies

[NB: however, Gutermuth et al. 2011 find $\Sigma_{SFR} \propto \Sigma_{gas}^2$]

Filament fragmentation may be responsible for the peak of the prestellar CMF and the IMF



Könyves et al. 2010, André et al. 2010

- Good (~ one-to-one) mapping between core mass and stellar system mass: $M_* = \varepsilon\, M_{core}$ with $\varepsilon \sim 0.2$-0.4 in Aquila
- Cloud fragmentation models of IMF (Padoan & Nordlund; Hennebelle & Chabrier)
- **CMF peaks at ~ 0.6 $M_\odot$ ≈ Jeans mass in marginally critical filaments**

Conclusions: Toward a « universal » scenario for star formation on global (GMC) scales ?

- *Herschel* results suggest **core formation occurs in 2 main steps**:
  1) Filaments form first in the cold ISM, probably as a result of the dissipation of **MHD turbulence** (cf. Padoan et al. 2001);
  2) The densest filaments then fragment into prestellar cores via **gravitational instability** (cf. Inutsuka & Miyama 1997) above a critical threshold $\Sigma_{th} \sim 150\ M_{\odot}\ pc^{-2} \Leftrightarrow A_V \sim 8$

- Filament fragmentation appears to produce the prestellar CMF and likely accounts for the « base » of the IMF

- This scenario may possibly also account for the global rate of star formation on galactic scales