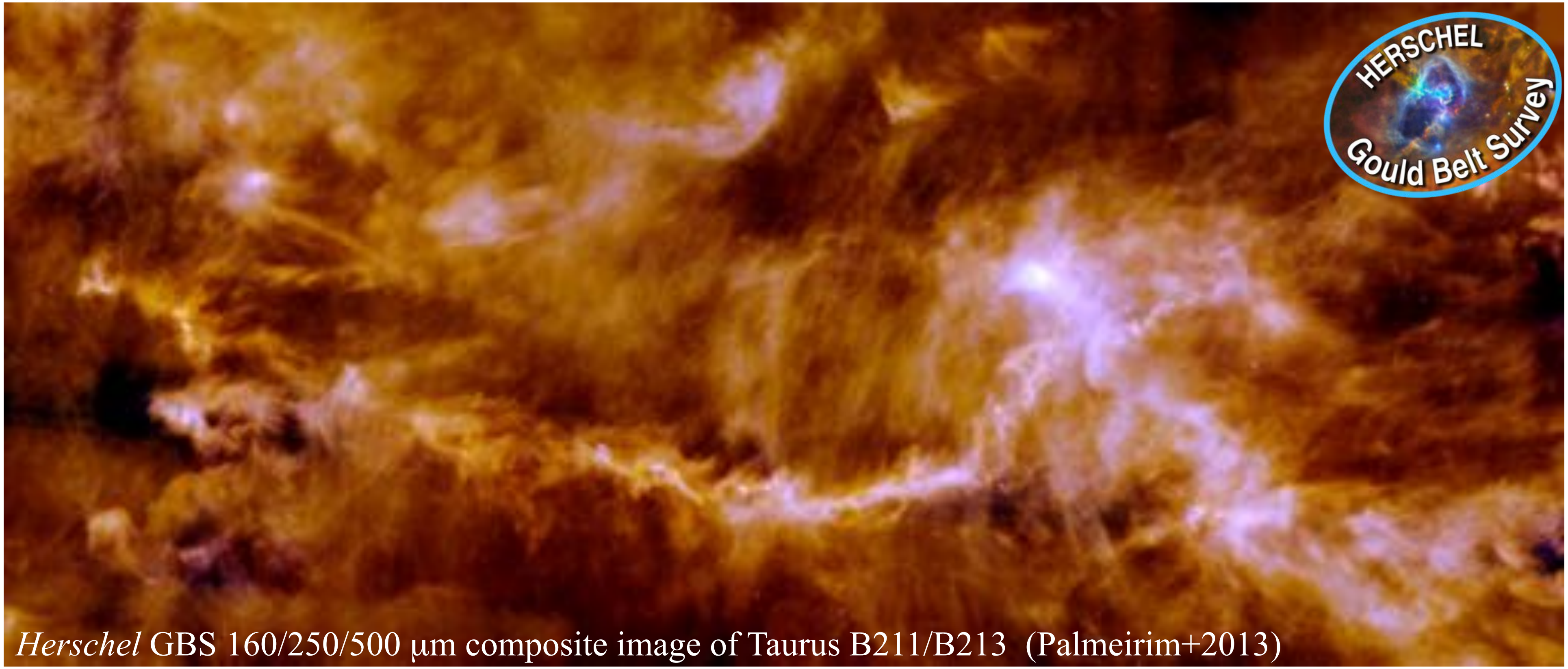
The role of molecular filaments in the origin of the CMF/IMF

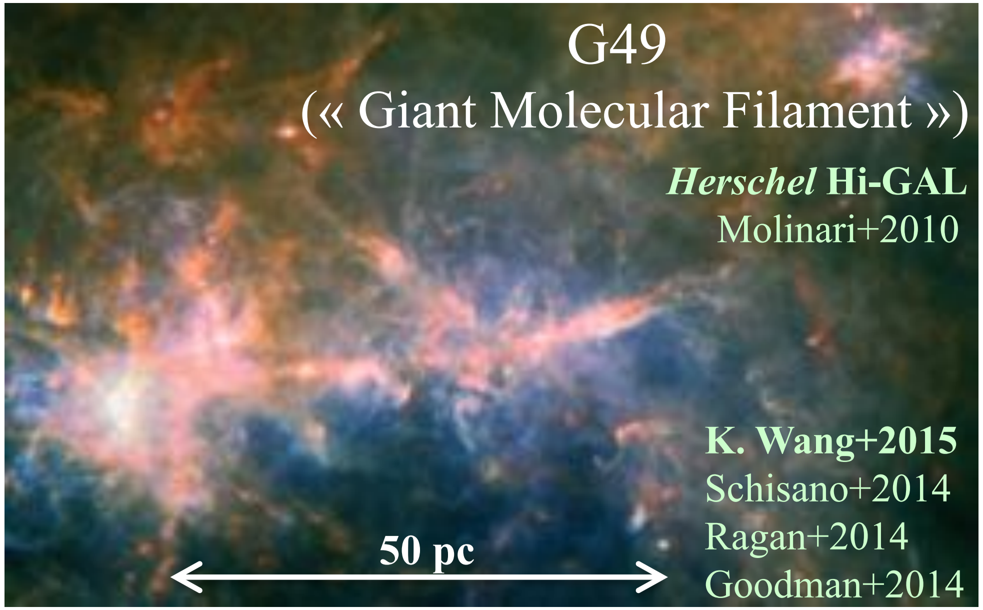
Philippe André CEA Lab. AIM Paris-Saclay

(2007-2010)

Main collaborators: D. Arzoumanian, V. Könyves, A. Roy, P. Palmeirim, A. Menshchikov, N. Schneider, Y. Shimajiri, B. Ladjelate, J. Di Francesco, F. Motte, D. Ward-Thompson, J. Kirk, A. Bracco + ***Herschel* GBS team**



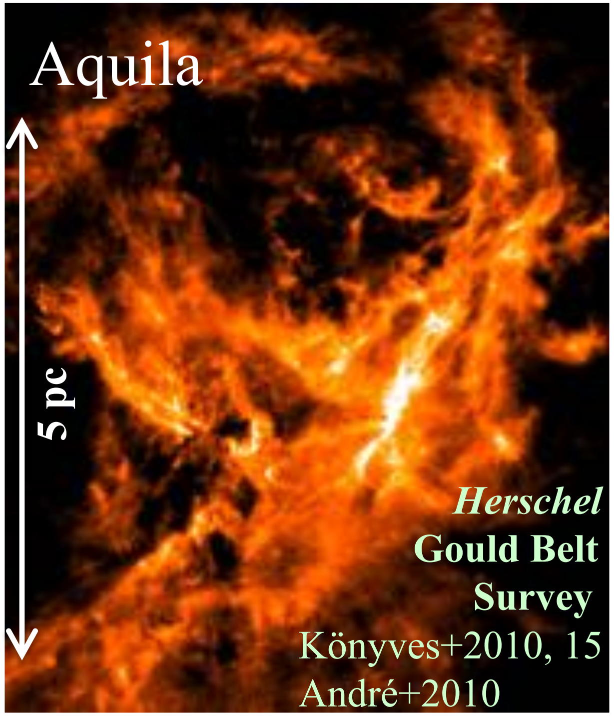
Herschel GBS 160/250/500 μm composite image of Taurus B211/B213 (Palmeirim+2013)



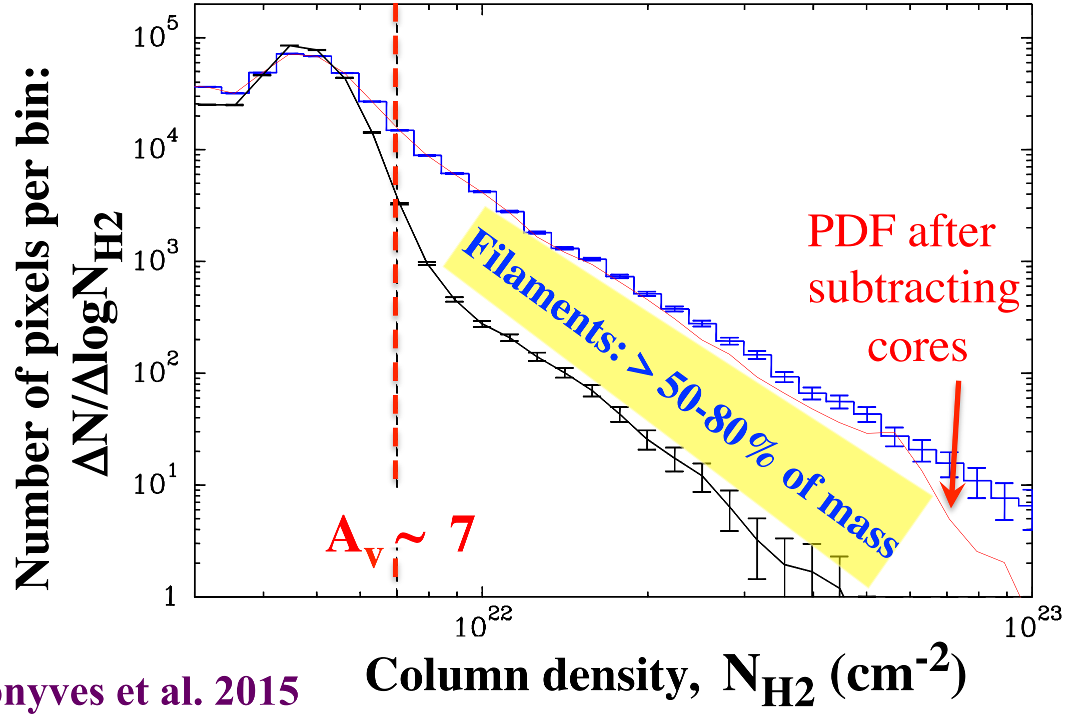
Herschel has confirmed the presence of a 'universal' filamentary structure in the cold ISM

Filaments dominate the mass budget of GMCs at high column densities

cf. Schisano+2014, Könyves+2015



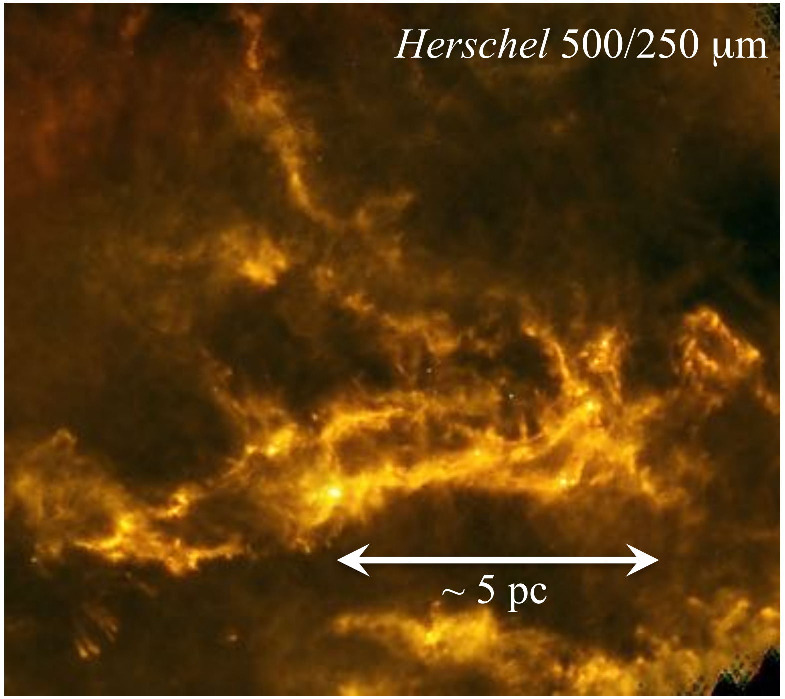
Column Density PDF for Aquila GMC



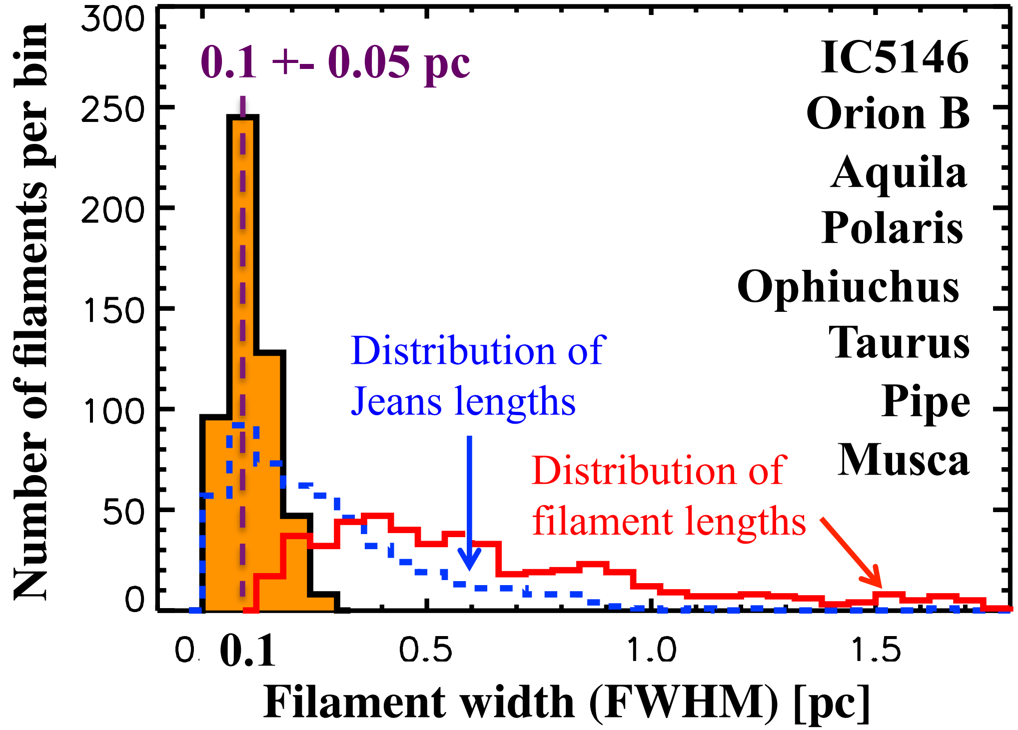
Könyves et al. 2015

Nearby filaments have a common inner width ~ 0.1 pc

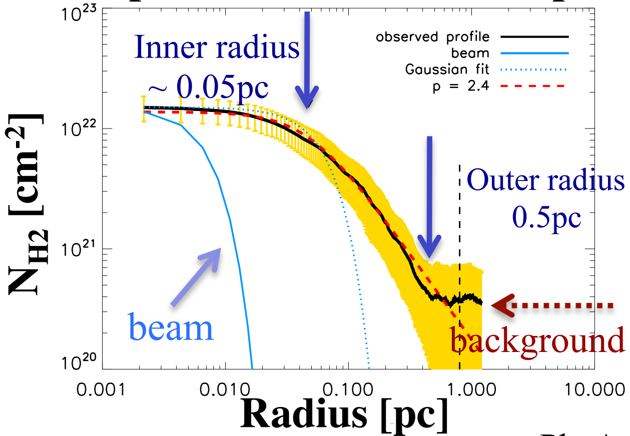
Network of filaments in IC5146



Distribution of mean inner widths for ~ 600 nearby (d < 450pc) filaments



Example of a filament radial profile



D. Arzoumanian+2011 & 2018

[but some width variations along each filament: Ysard+2013]

Possibly linked to sonic scale of turbulence?

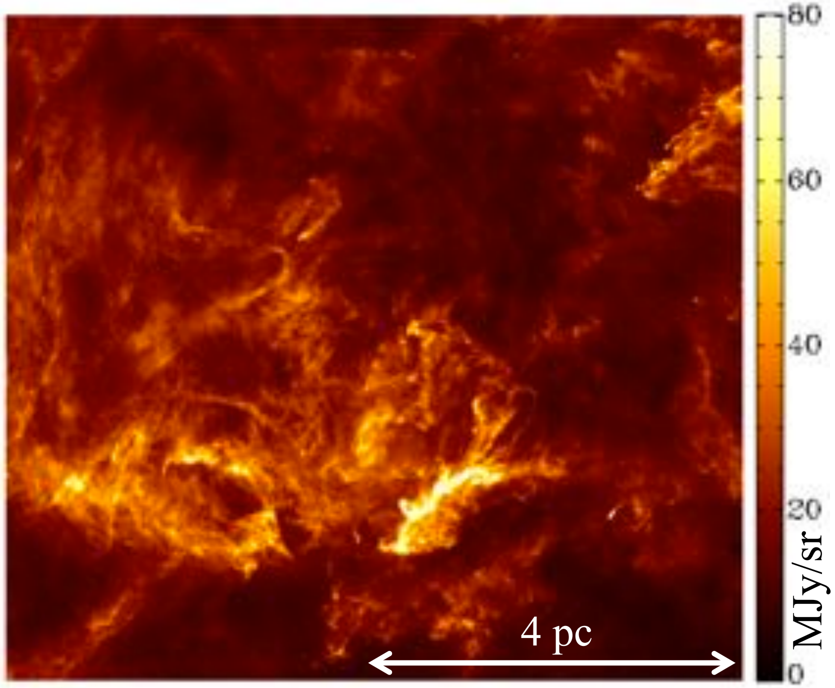
(cf. Padoan+2001; Federrath 2016)

Challenging for numerical simulations

(cf. R. Smith+2014; Ntormousi+2016)

Is a characteristic filament width consistent with the observed power spectrum of cloud images?

SPIRE 250 μm image of Polaris translucent cloud

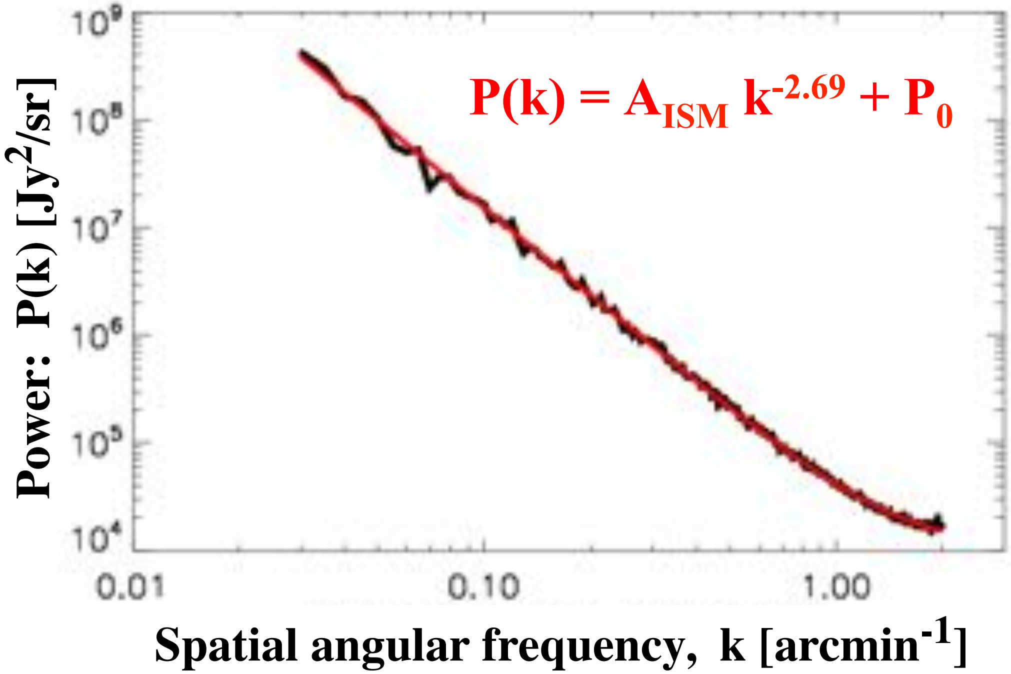


Miville-Deschênes et al. 2010

Tension with scale-free power spectrum

Panopoulou+2017

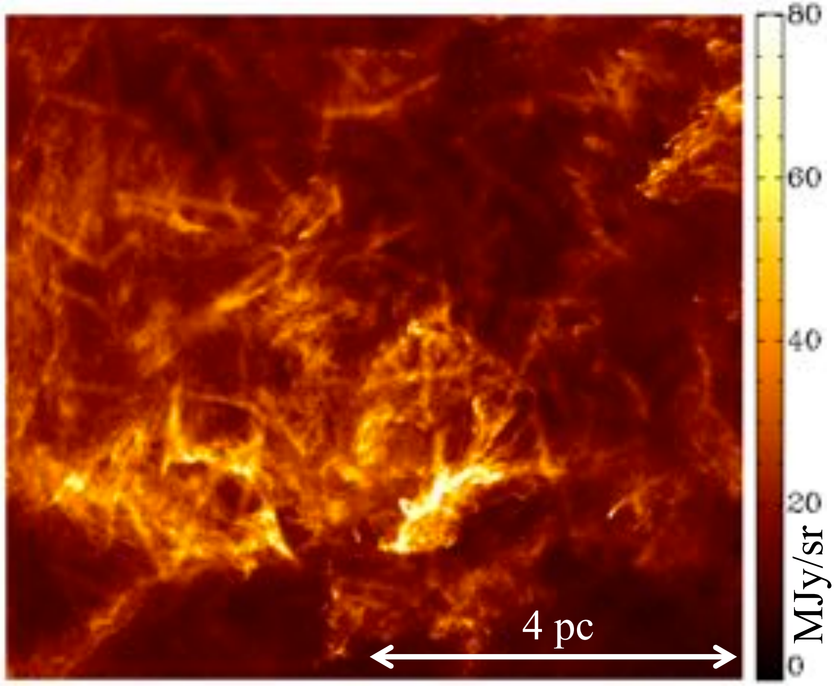
Noise-subtracted, deconvolved power spectrum of Polaris image



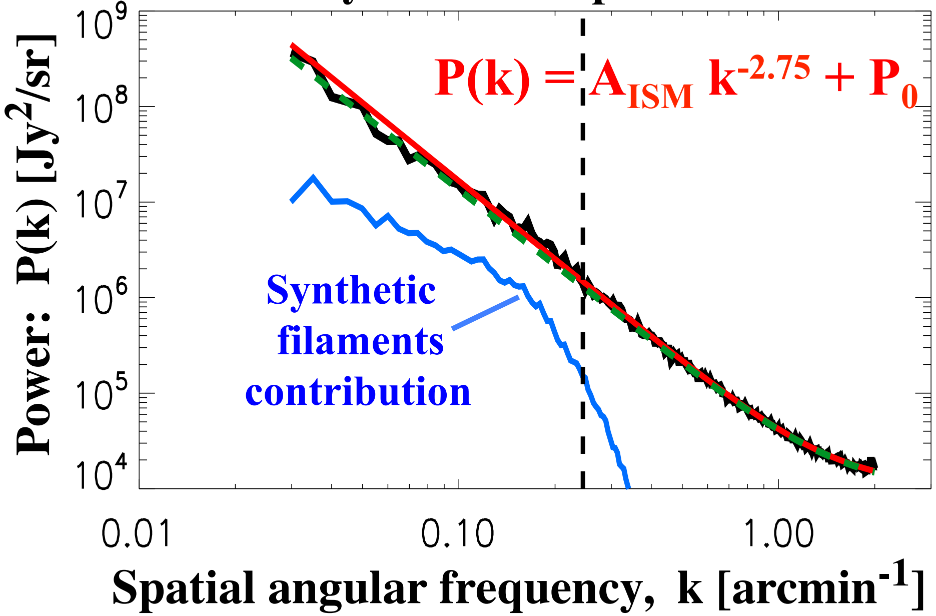
A simple experiment

A. Roy et al. 2018

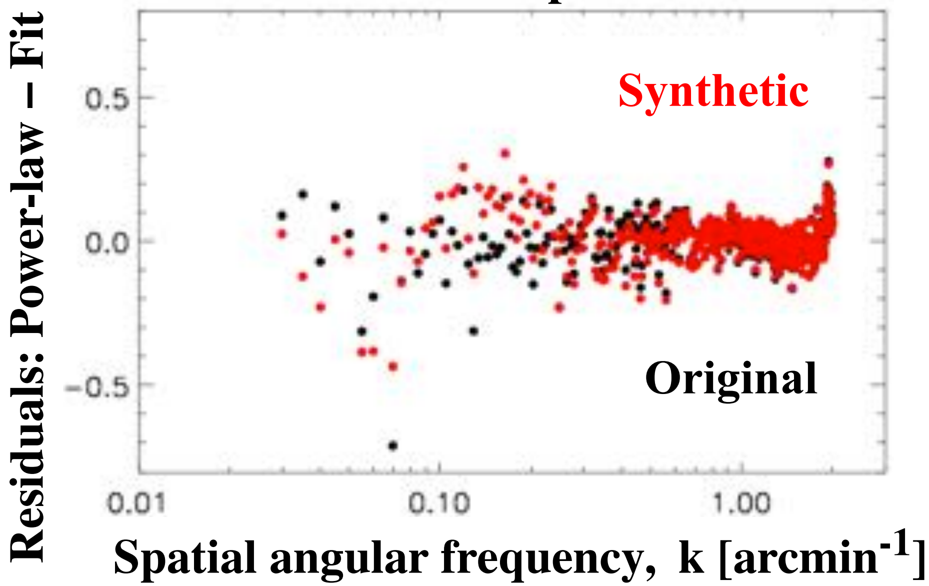
Injecting a population of synthetic 0.1 pc filaments with contrast ~ 50% in SPIRE 250 µm image of Polaris translucent cloud



Power spectrum of image with synthetic 0.1 pc filaments

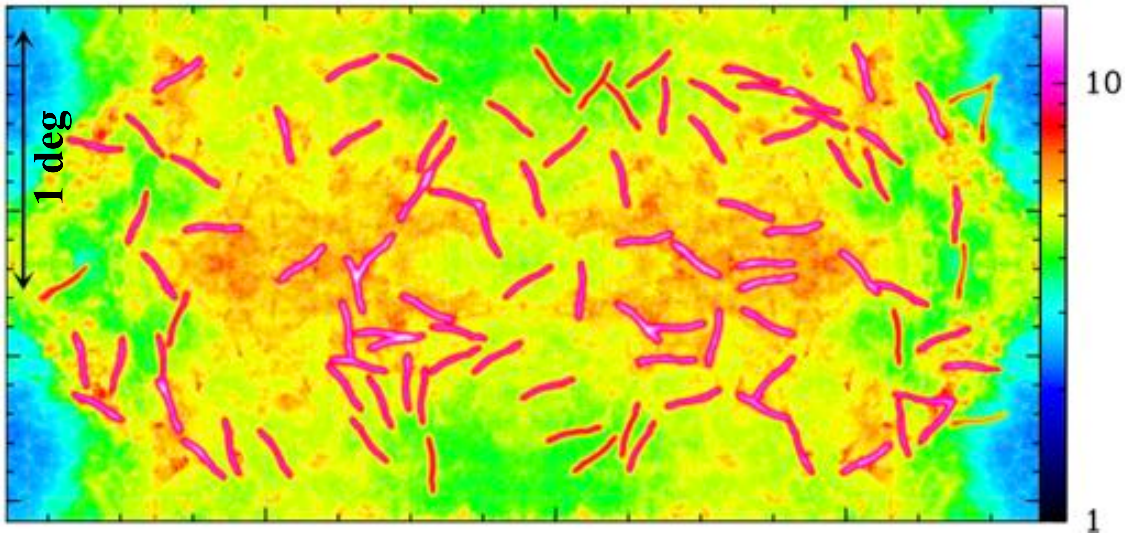


Difference from power-law fit



Conclusion: **Observed power spectra remain consistent with a characteristic filament width ~ 0.1 pc for realistic filling factors and filament contrasts**

Assessment of the reliability of derived filament widths through extensive tests



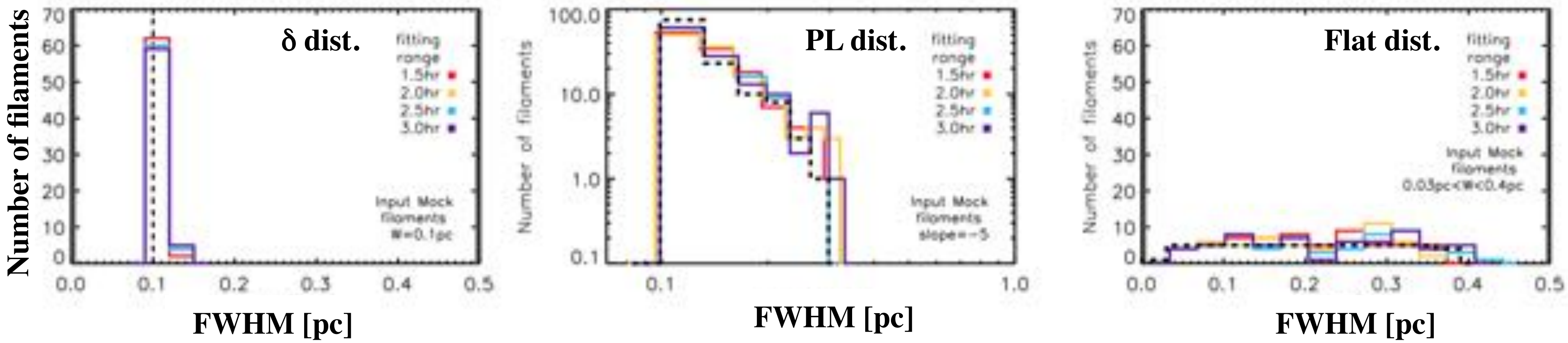
Arzoumanian+2018

Populations of synthetic Gaussian-shaped or Plummer-shaped filaments distributed in realistic background column density map

Comparison between measured and input distributions of filament widths

- - - - - : Input distributions of FWHM widths
Color: Measured distributions

→ No significant bias for high-contrast filaments (C > 0.5)

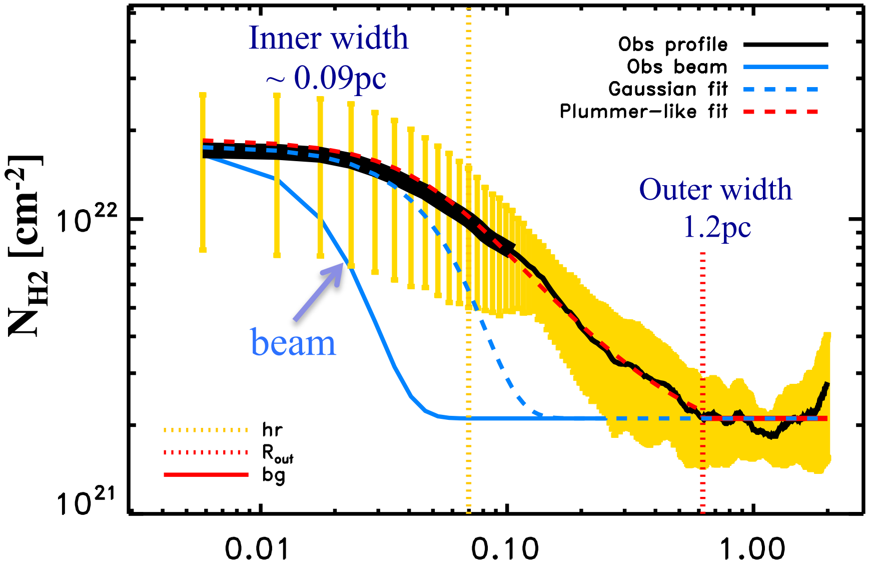


Comprehensive study of HGBS molecular filaments

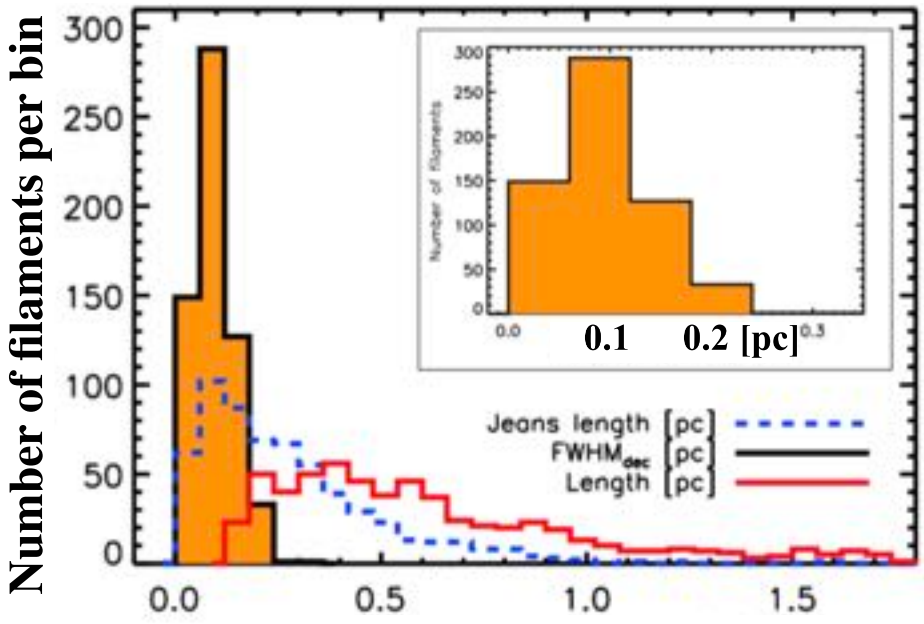
(for 1310 extracted filaments, including 599 `robust' filaments, in 8 regions of the GB)

Arzoumanian+2018

Example of a filament radial profile in Orion B



Distribution of mean inner widths for 599 filaments

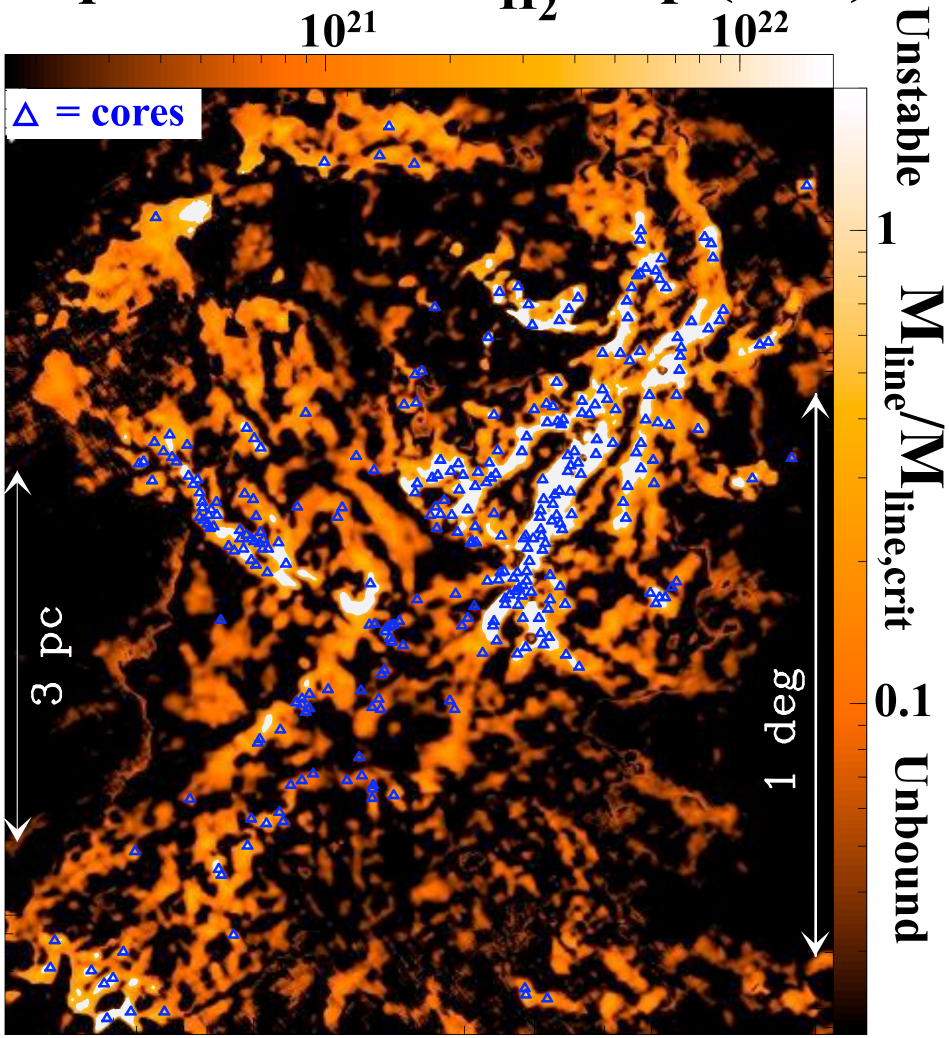


➢ **Confirmation of the main result of Arzoumanian+2011 with better statistics and better controlled measurements**

Mean crest-averaged width: 0.1 pc
Median crest-averaged width: 0.09 pc
Standard deviation: 0.05 pc
Inter-quartile range: 0.07 pc

~ 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})

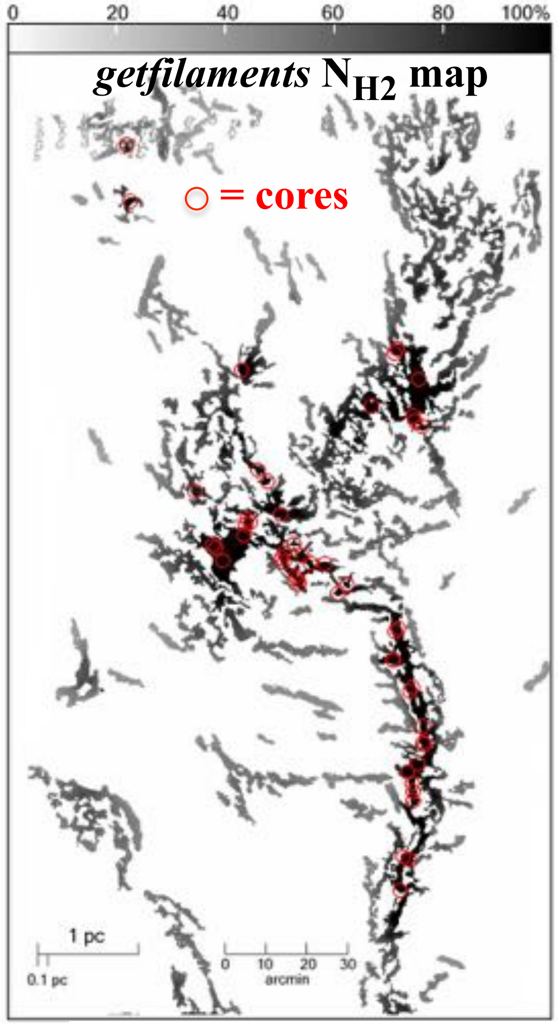


$\Sigma \gtrsim 150\ M_\odot/pc^2$

Also:

- Bresnahan+2017 (CrA)
- Benedettini+2018 (Lupus)
- Ladjelate+2018 (Oph)
- Könyves+2018 (Orion B)
- …

Taurus B211/3+L1495

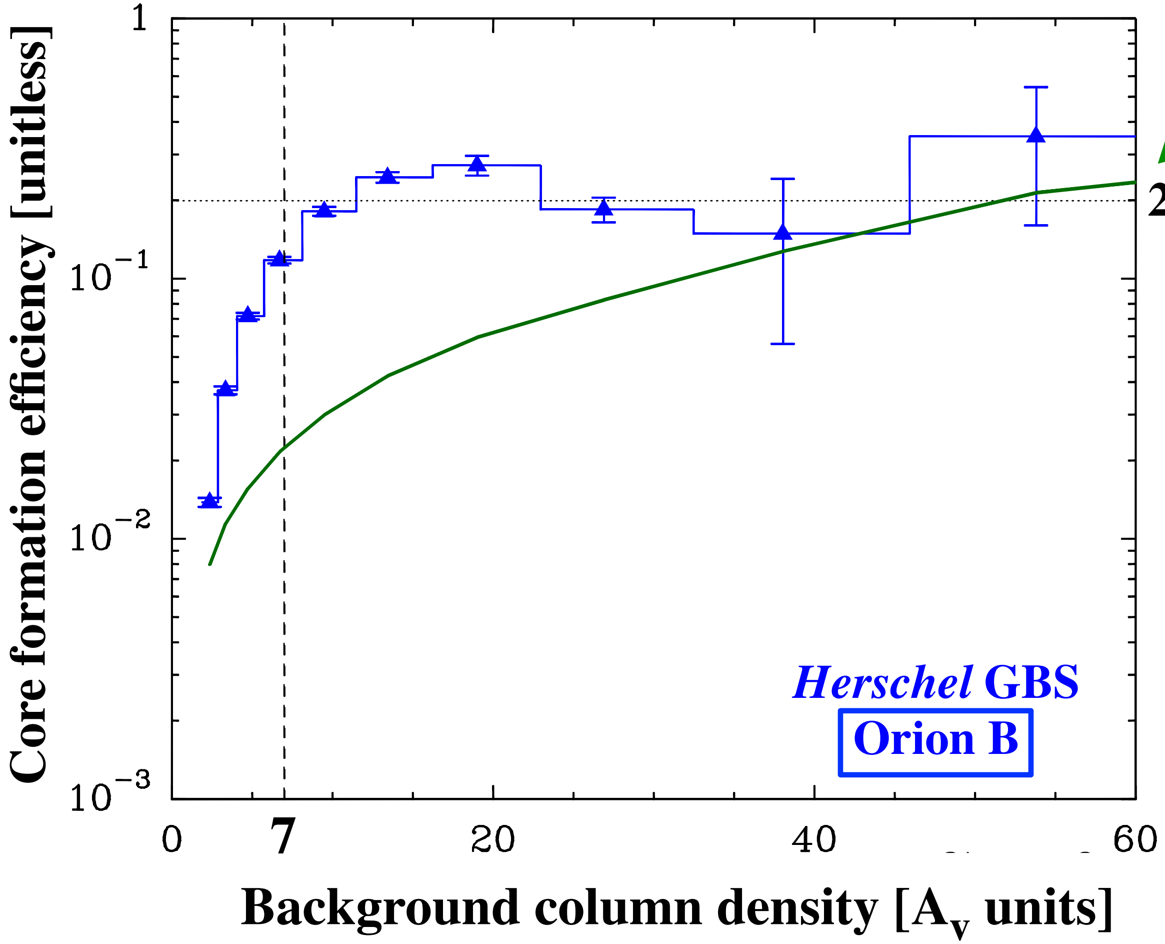


Könyves et al. 2015, A&A

Marsh al. 2016, MNRAS

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

Prestellar CFE as a function of background A_V



Turbulence-regulated models of SF (ϵ_{ff} ~ 1%) cf. Krumholz+2012

Sharp transition around a fiducial value A_v ~ 7 ⇔ $\Sigma \sim 150\ M_\odot\ pc^{-2}$ ⇔ $M/L \sim 15\ M_\odot/pc$

André+2010; Könyves+2015

$$CFE(A_V) = \Delta M_{cores}(A_V) / \Delta M_{cloud}(A_V)$$

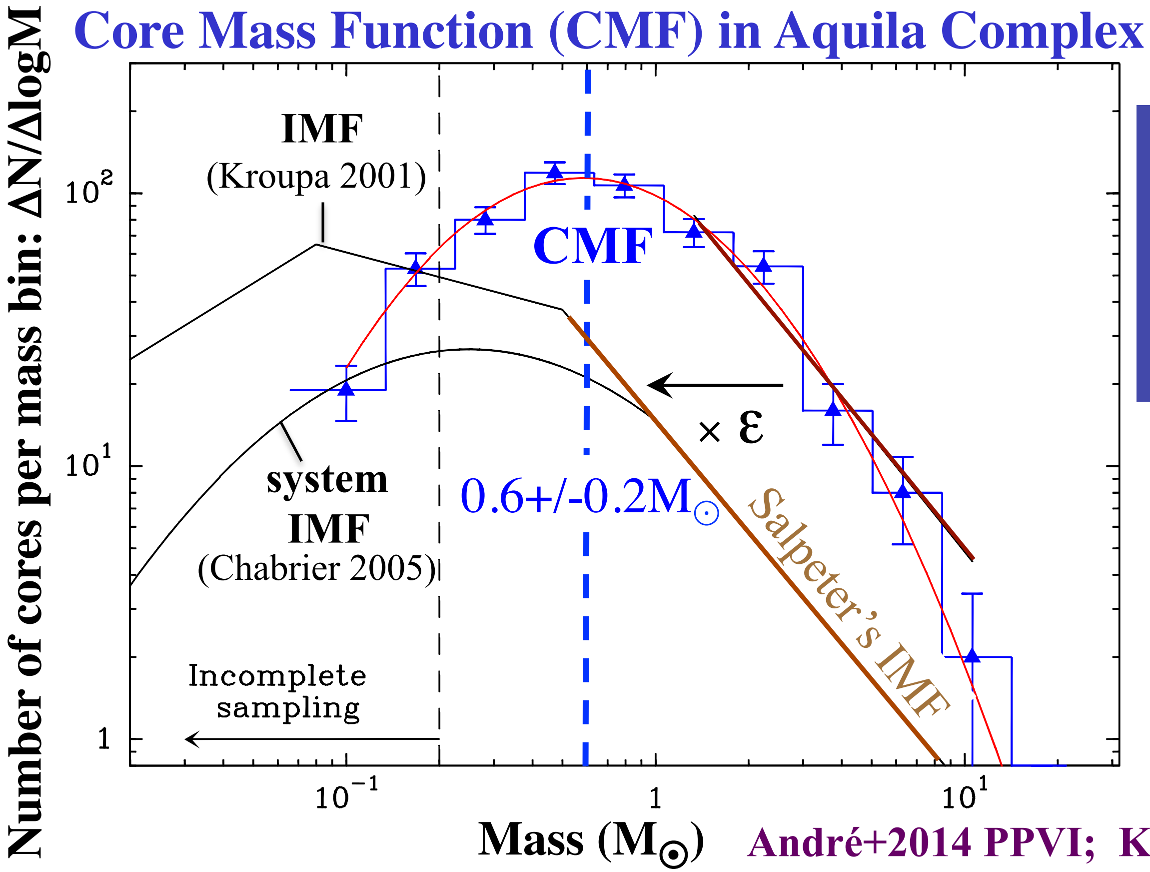
Könyves et al. 2018, A&A

Interpretation:

Critical M/L of nearly isothermal cylinders (Ostriker 1964; Inutsuka & Miyama 1997)

$M_{line,\,crit} = 2\,c_s^2/G \sim 16\ M_\odot/pc$ for T ~ 10 K

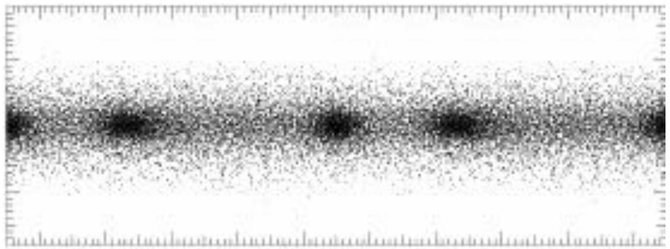
Filament fragmentation can account for the peak of the prestellar CMF and the "base" of the IMF



André+2014 PPVI; Könyves+2015

Jeans mass:

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

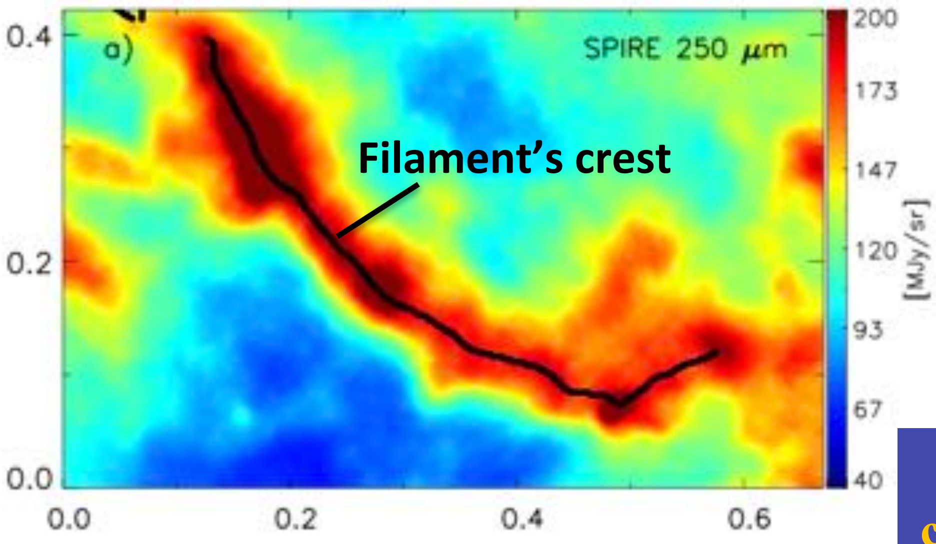


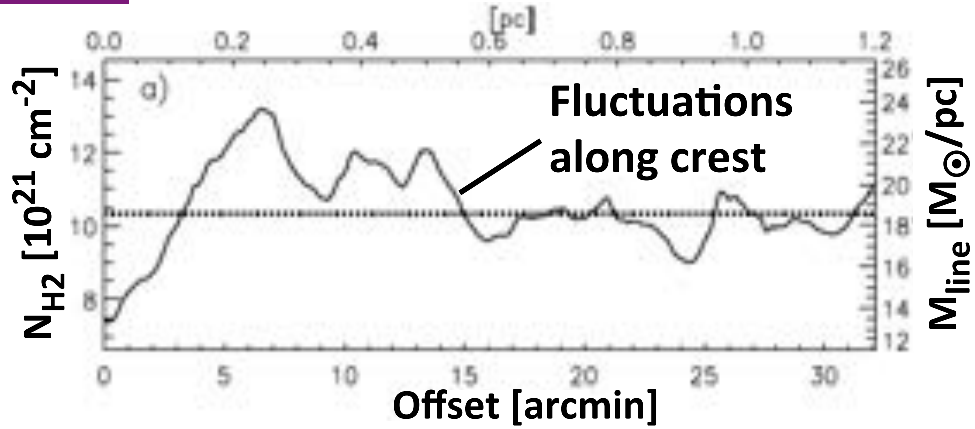
Inutsuka & Miyama 1997

- **CMF peaks at ~ 0.6 $M_\odot$ ≈ Jeans mass in marginally critical filaments**
- **Close link of the prestellar CMF to the stellar IMF: $M_\star \sim 0.4^{+0.2}_{-0.1} \times M_{core}$**
  (see also Motte+1998; Alves+2007)
- **Characteristic stellar mass may result from filament fragmentation**

Statistical properties of filament line-mass fluctuations

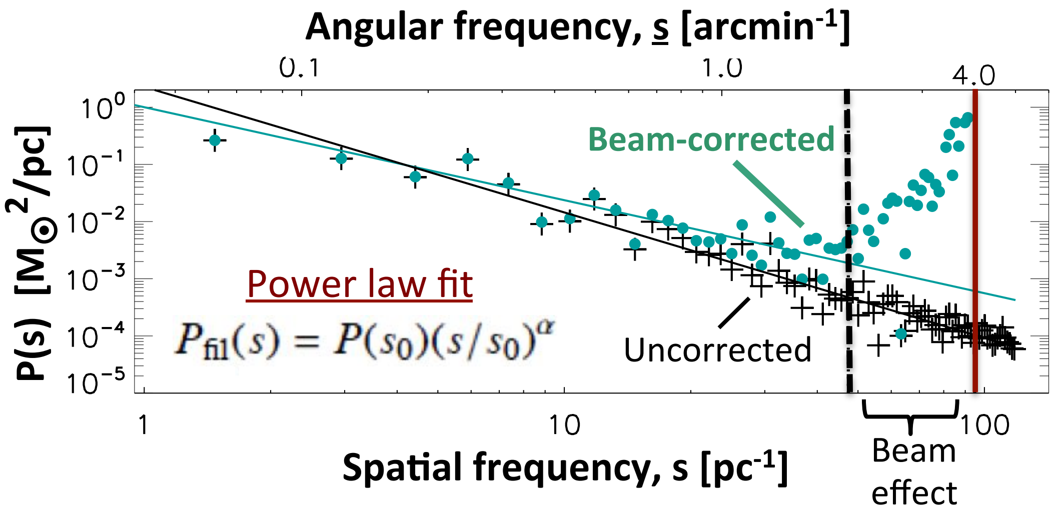
Roy+2015

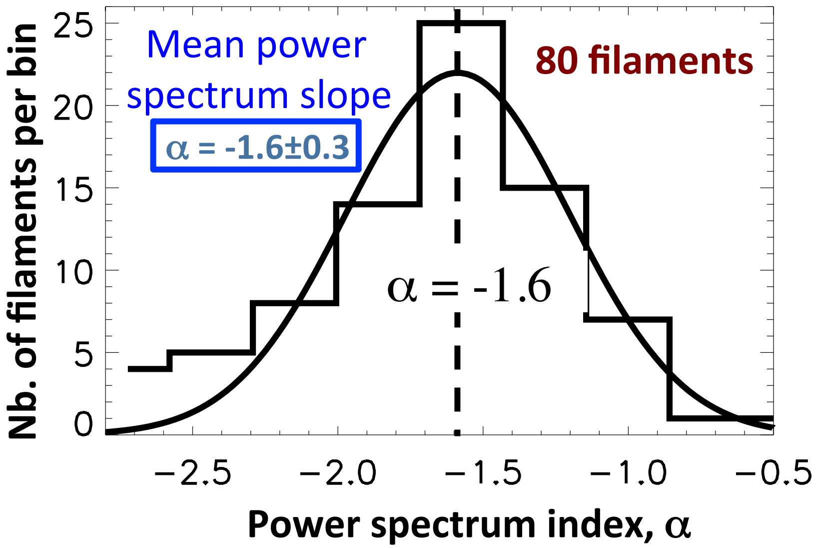




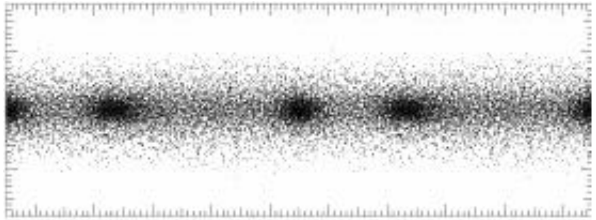
Distribution of power spectrum slopes consistent with 1D Kolmogorov spectrum (-5/3)

Power spectrum of line-mass fluctuations





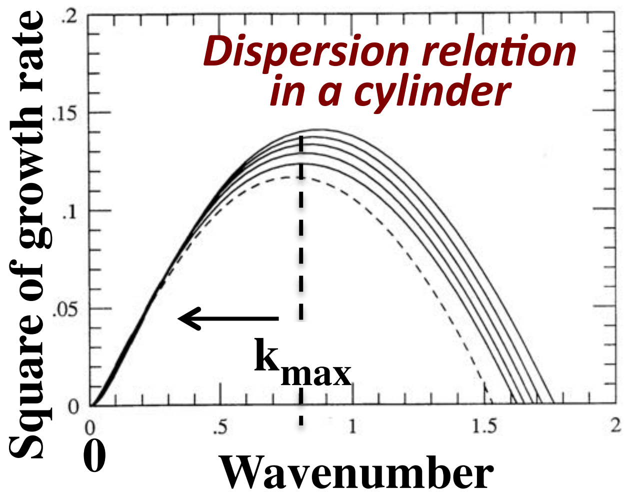
Implications for the prestellar CMF and the IMF



Inutsuka 2001

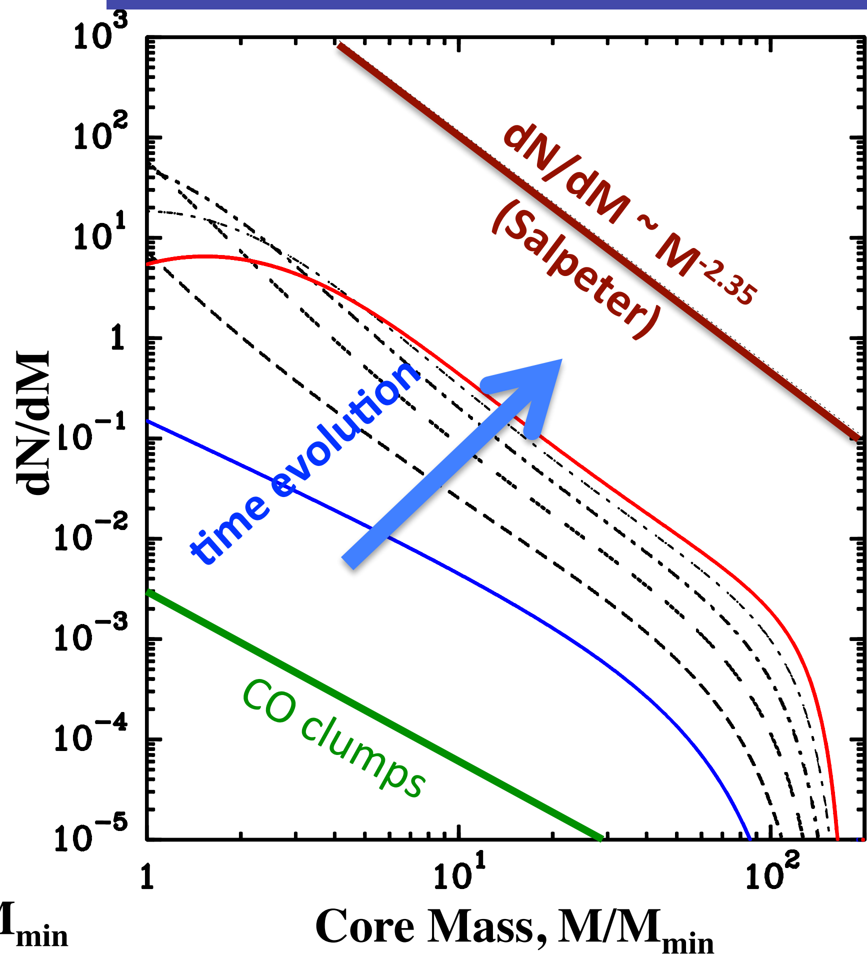
Evolution toward a Salpeter-like core mass function with initial power spectrum index $\alpha_{obs} = -1.6$

A Salpeter IMF can be produced by filament fragmentation provided turbulence has generated a Kolmogorov-like power spectrum of initial density fluctuations (Inutsuka 2001)



Inutsuka & Miyama 1992, 1997

$k_{max} \Leftrightarrow M_{min}$



Salpeter-like distribution of characteristic core masses from distribution of filament line masses

Local effective Jeans mass in a thermally supercritical filament:

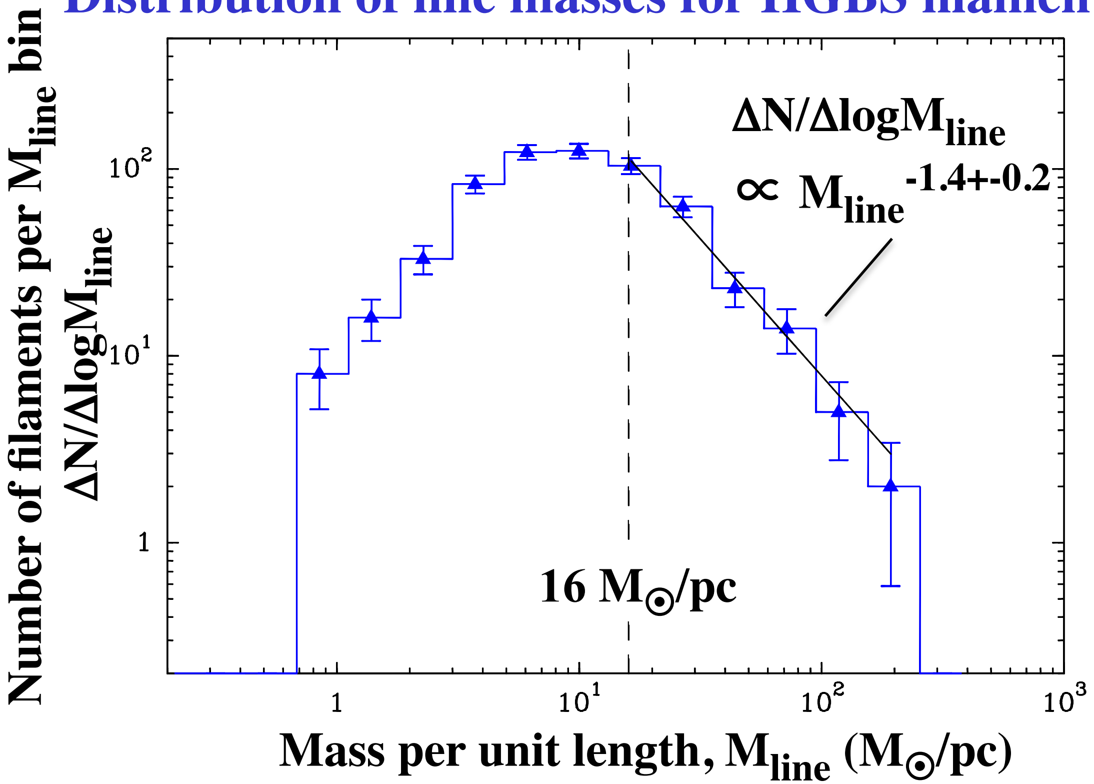
Given filament properties (cf. Arzoumanian+2011, 2013, 2018):

$$M_{line} \sim \Sigma_{fil} \times W_{fil} \sim M_{line,\,vir} \equiv 2c_{s,eff}^2/G \text{ with } W_{fil} \sim 0.1 \text{ pc}$$

$$M_{Jeans} \sim M_{BE} \sim 1.3\, c_{s,eff}^4/(G^2\Sigma_{fil}) \propto \Sigma_{fil} \propto M_{line}$$

Distribution of line masses for HGBS filaments

André, Arzoumanian et al., in prep.
cf. André+2014 PPVI



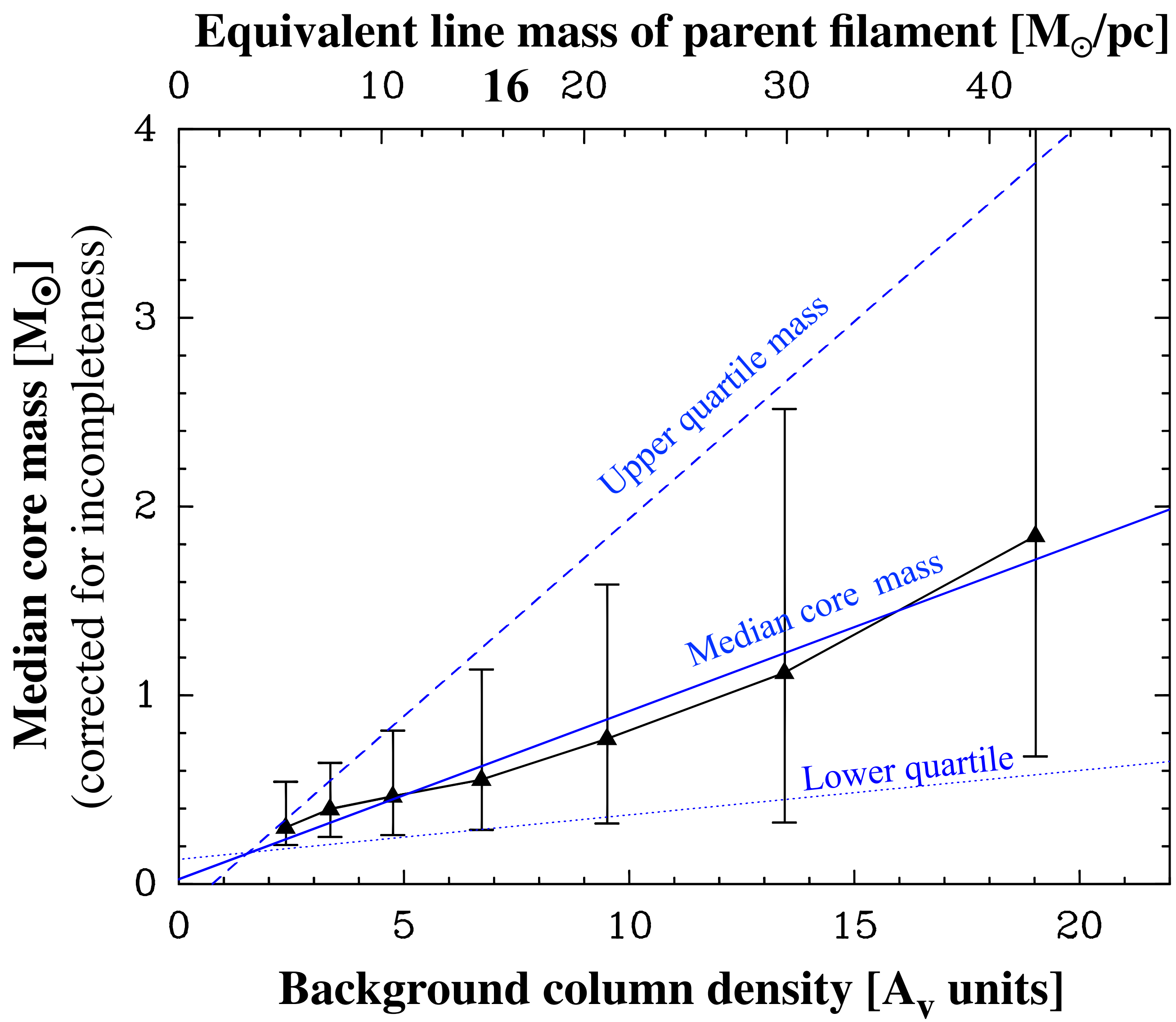
$\Rightarrow$ $\Delta N/\Delta \log M_{BE} \propto M_{BE}^{-1.4+-0.2}$

(Salpeter index: -1.35)

Full CMF/IMF results from the convolution of the distribution of filament line masses by the CMF in individual filaments
(Y.-N. Lee, Hennebelle, Chabrier 2017)

Median prestellar core mass vs. background column density

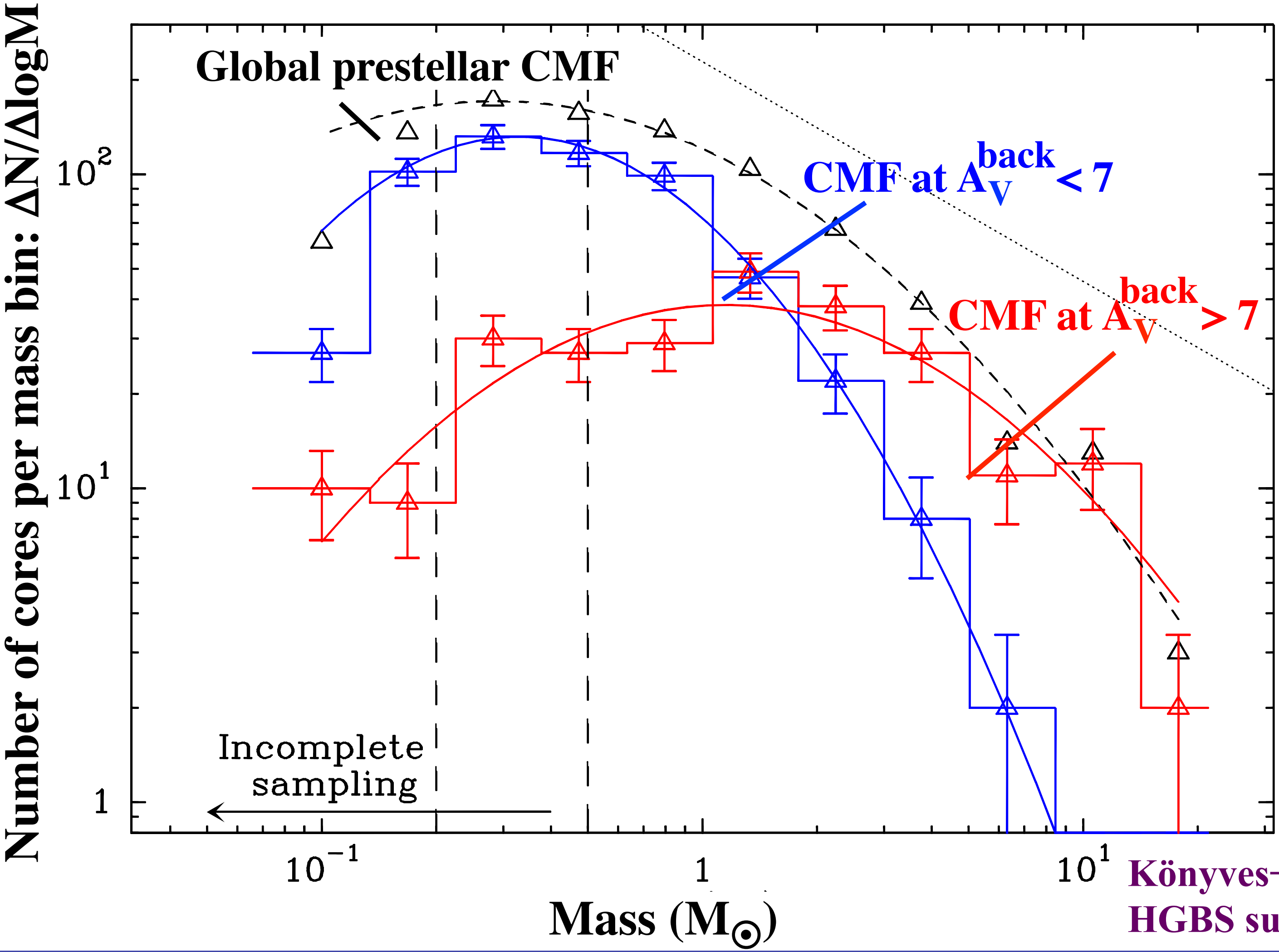
(Orion B)



Könyves+2018

Median core mass and dispersion of core masses increase with background column density

Dependence of the prestellar CMF on background cloud (column) density



(OrionB)

Könyves+2018
HGBS survey results

➢ **Broader CMF at higher background column densities (i.e. higher M_{line} filaments)**

Summary: A filamentary paradigm for star formation and the IMF?

- *Herschel* results support a **filamentary paradigm for star formation and the IMF** although many issues remain open and/or strongly debated
- **Filament fragmentation** appears to produce the peak of the prestellar CMF and likely **accounts for the « base » of the IMF**
- **Salpeter power law** of IMF may arise from a combination of two effects: 1) Salpeter power-law distribution of supercritical filament M/L (due to accretion ?), 2) differential **growth of an initial Kolmogorov spectrum of density fluctuations** along the filaments