

Probing the universality of ISM filaments: From *Herschel* to ArTéMiS and beyond

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Outline:

- *Herschel* imaging results on the « universality » of ISM filaments and their role in star formation
- High-resolution follow-ups with ArTéMiS
- Prospects with NIKA2-Polar Channel

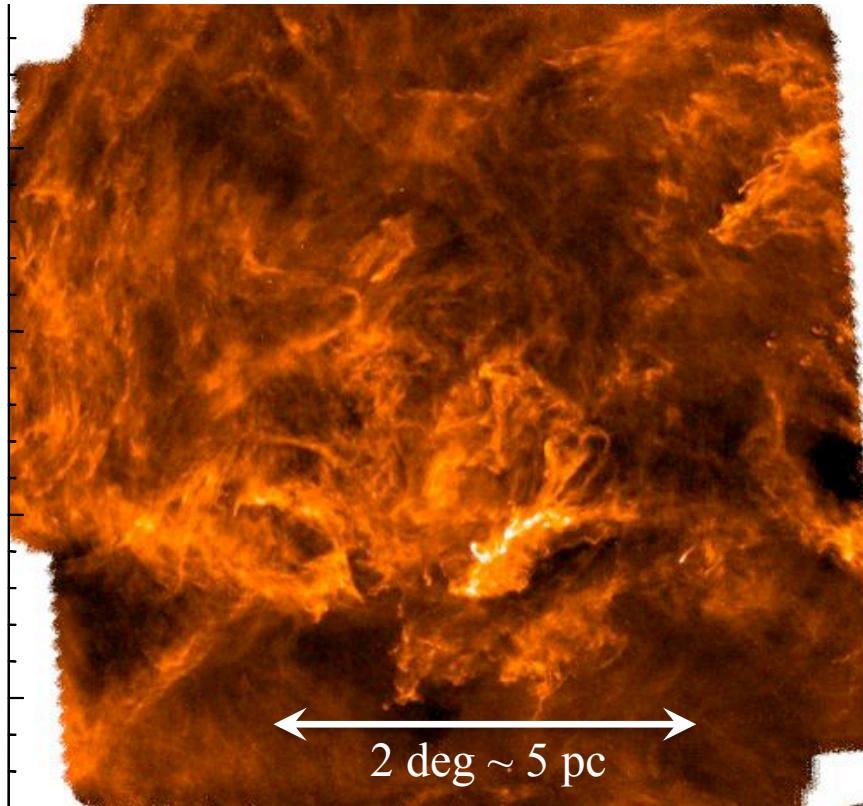
30' ~ 15 pc

With: V. Könyves, D. Arzoumanian, P. Palmeirim, A. Menshchikov, N. Schneider, A. Roy, Y. Shimajiri, T. Hill, A. Maury, F. Motte, S. Bontemps, A. Zavagno, D. Russeil & the *Herschel* Gould Belt Survey KP Consortium

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



Polaris :
Non-star-forming “cirrus” cloud
Herschel 250 μ m

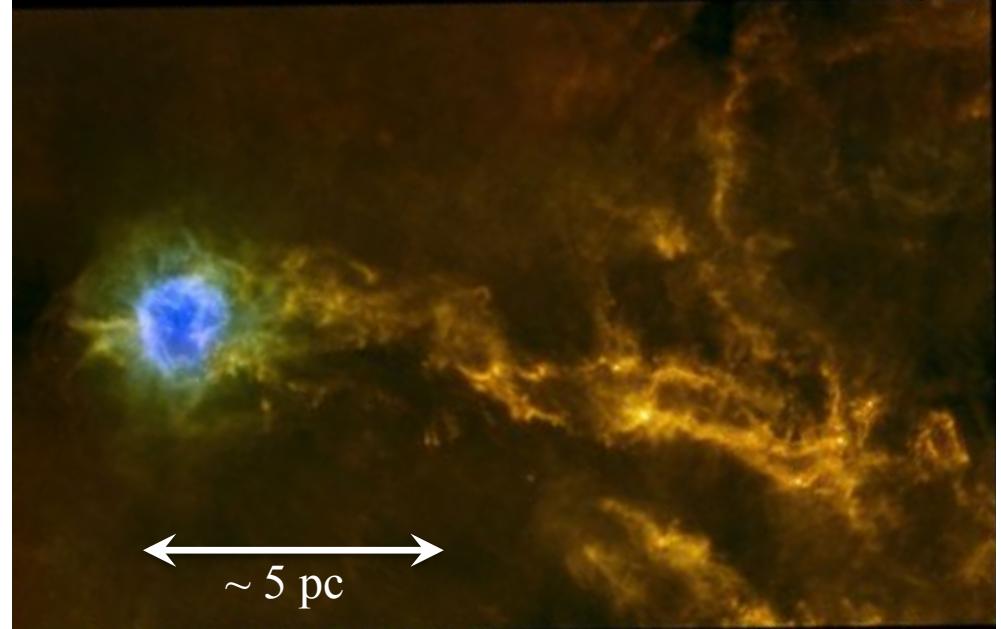


Miville-Deschénes+2010, Men’shchikov+2010,
André+2010

Ubiquitous + quasi-universal properties

IC5146 :
Actively star-forming cloud

Herschel Gould Belt survey 70/250/500 μ m

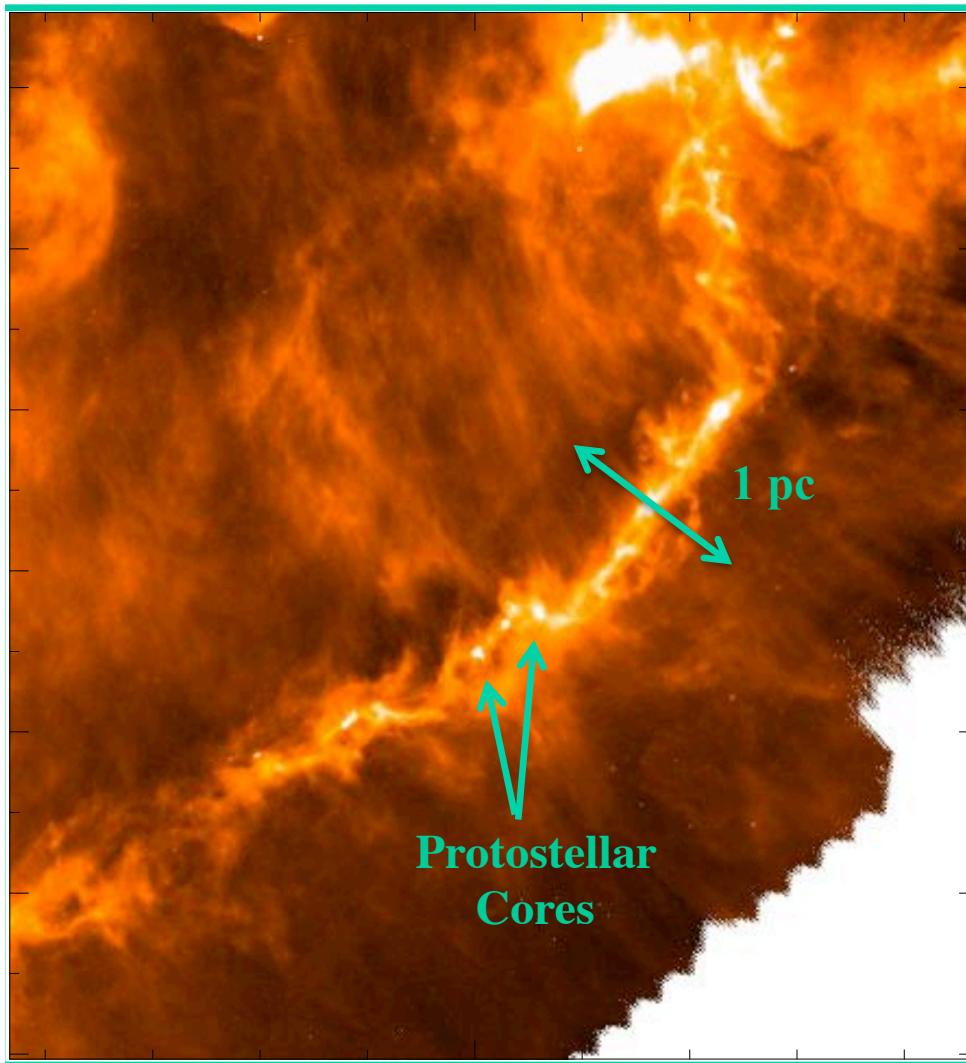


Arzoumanian+2011

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

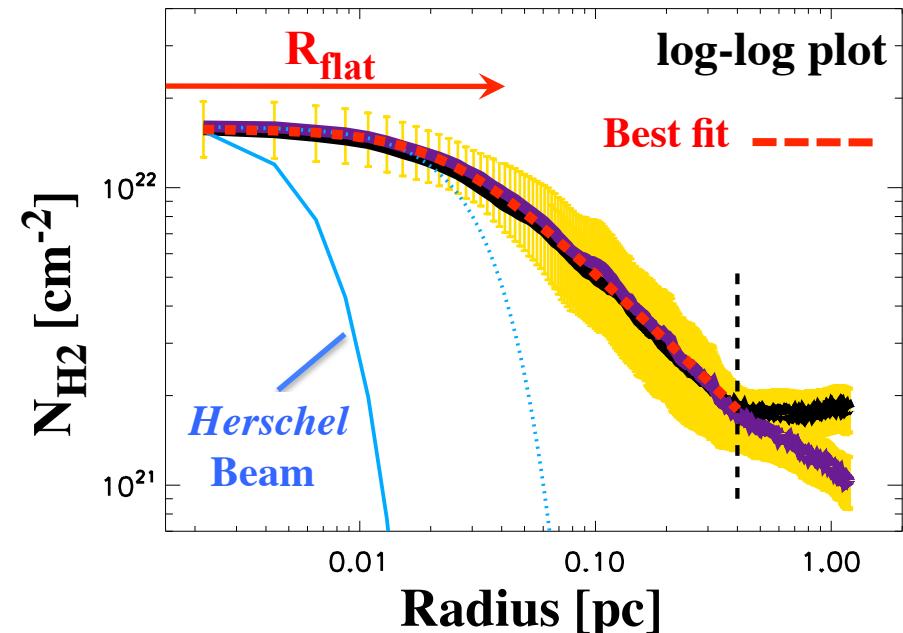
Resolving the structure of filaments with *Herschel*

Taurus B211/3 filament
Herschel 250 μ m



Arzoumanian+2011
Palmeirim+2013

Filament transverse profile



Plummer-like model:

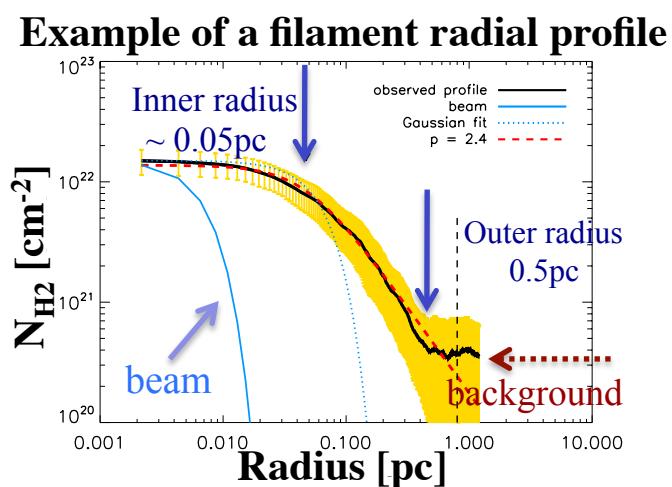
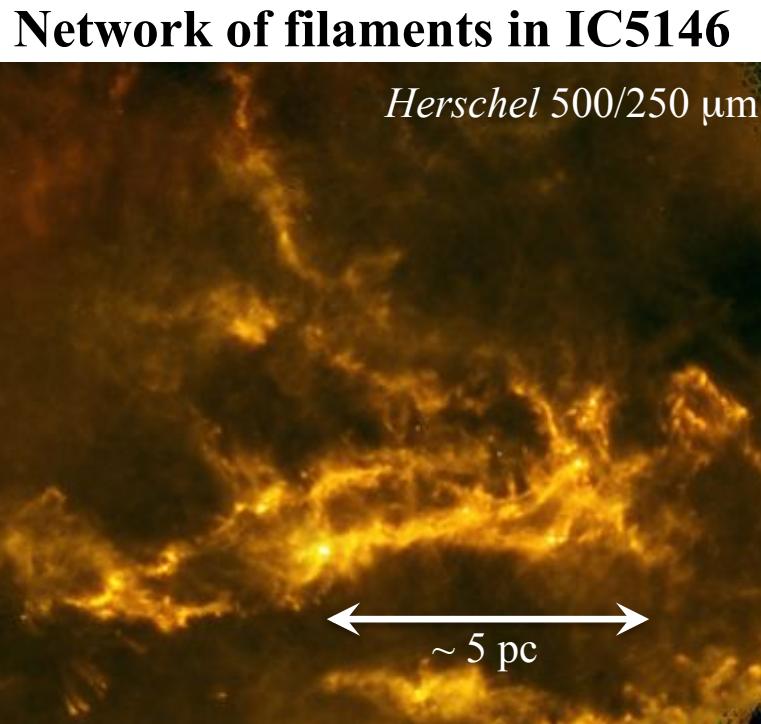
$$\rho(r) = \rho_c / [1 + (r/R_{\text{flat}})^2]$$

Diameter of flat inner plateau:

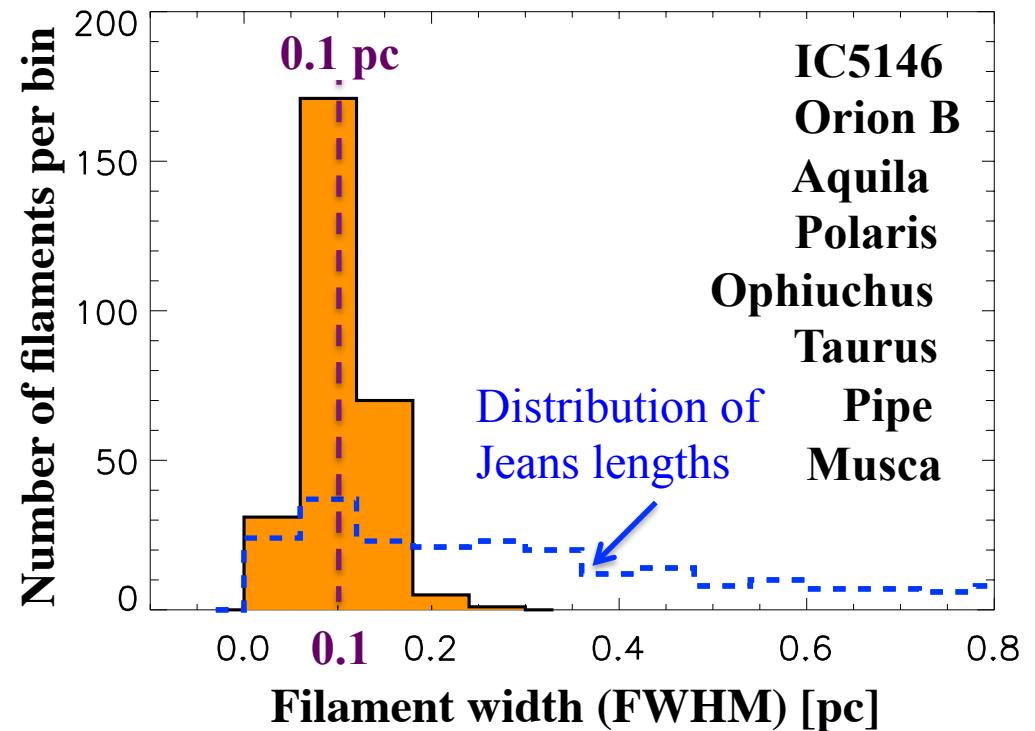
$$2R_{\text{flat}} \sim 0.1 \text{ pc}$$

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

Filaments have a characteristic inner width ~ 0.1 pc



Statistical distribution of widths
for > 270 nearby filaments



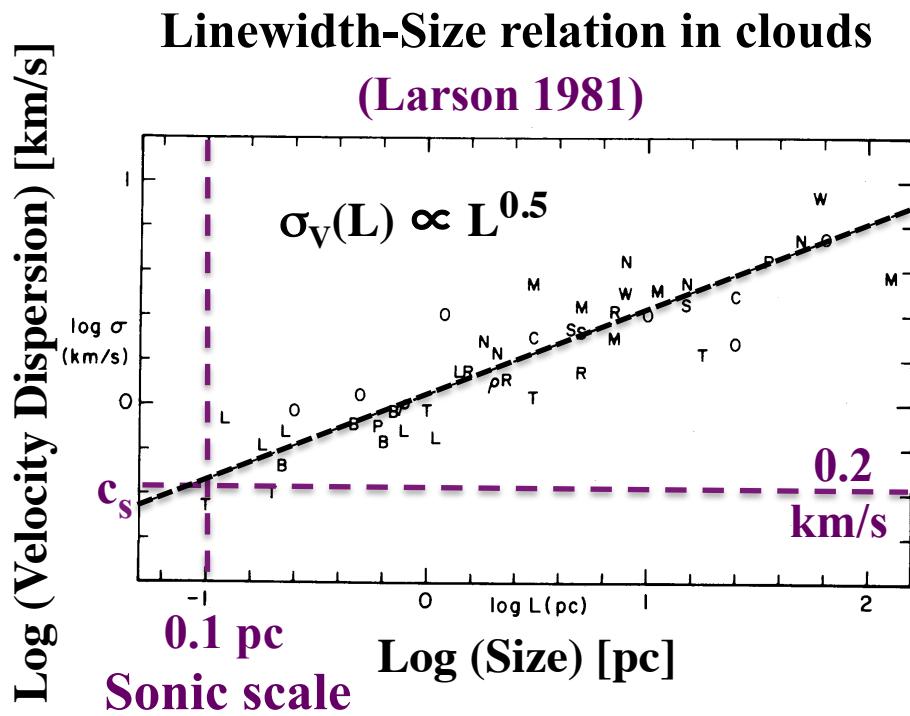
D. Arzoumanian et al. 2011 + PhD thesis

[Some variations along each filament: Ysard+2014]

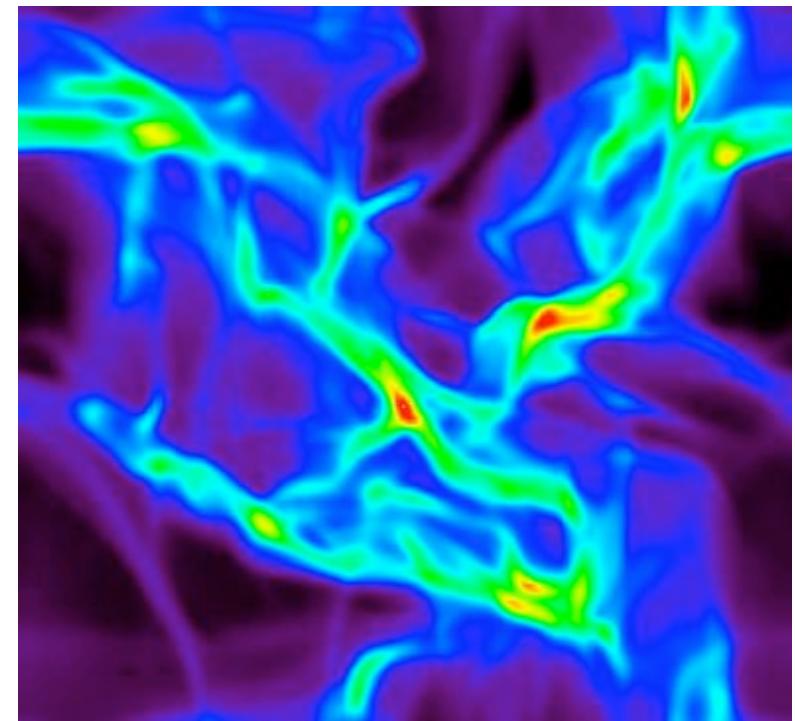
➤ Strong constraint on the formation
and evolution of filaments

Filaments due to large-scale supersonic 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)



Simulations of turbulent fragmentation

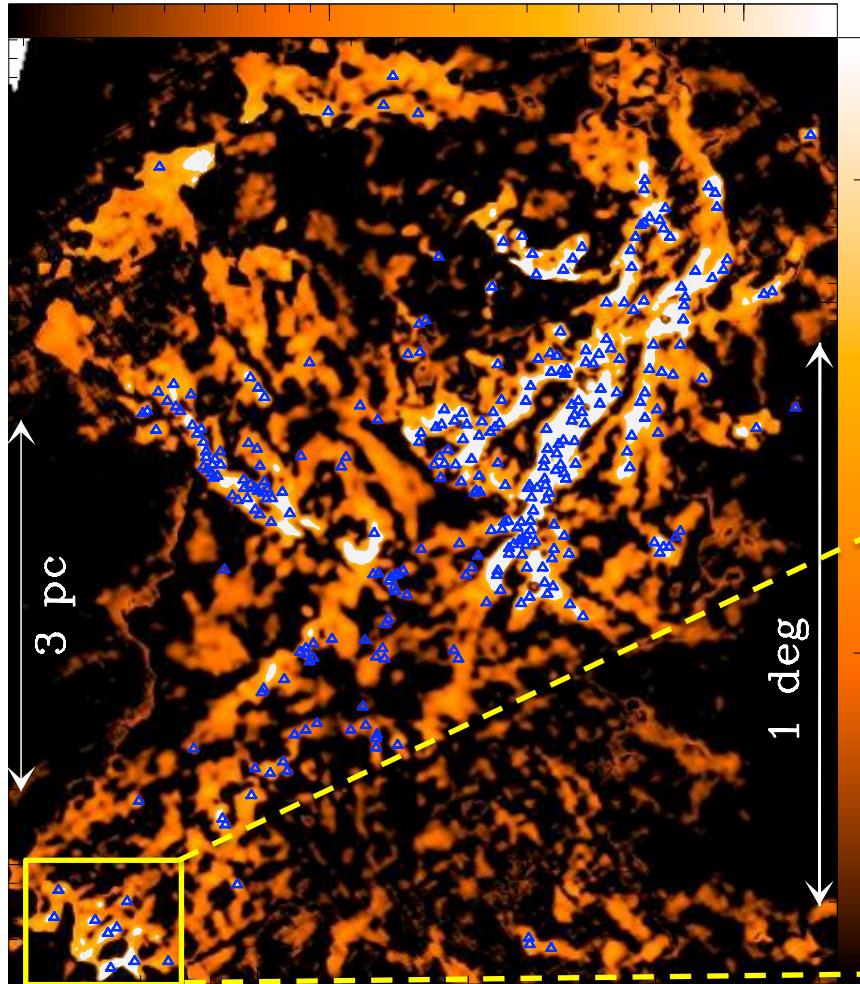


Padoan, Juvela et al. 2001

Filament width $\sim 0.1 \text{ pc}$: \sim sonic scale of interstellar turbulence ?
 \sim dissipation scale of MHD waves ?

$\sim 75_{-5}^{+15}$ % of prestellar cores form in filaments,
above a column density threshold $N_{\text{H}_2} \gtrsim 7 \times 10^{21} \text{ cm}^{-2}$

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



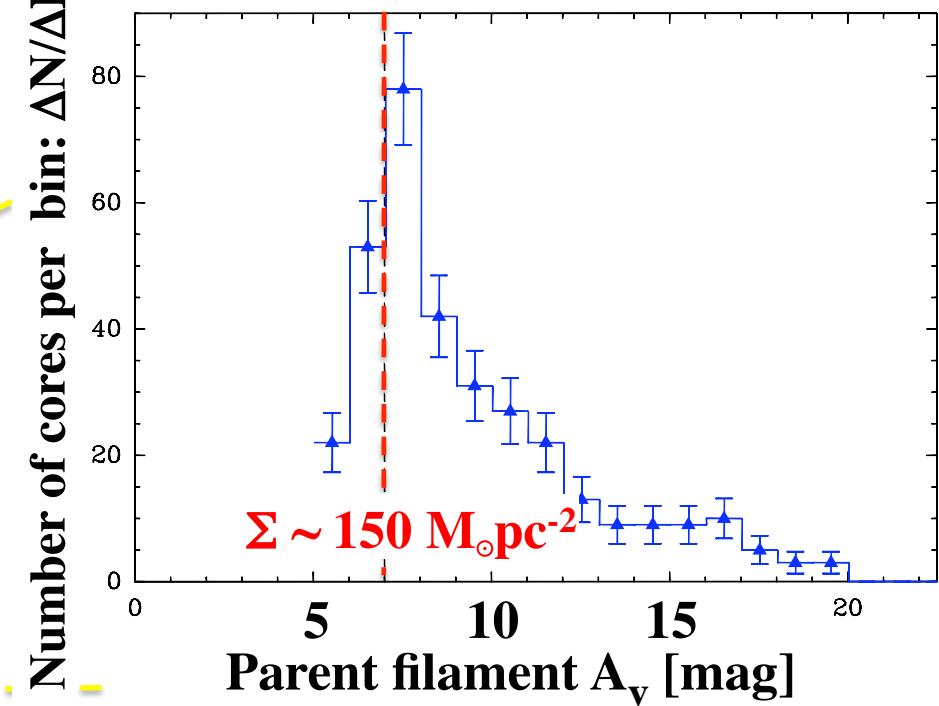
André et al. 2010, Könyves et al. 2010 + in prep

\Leftrightarrow

$$A_V \gtrsim 7$$

$$\Sigma_{\text{threshold}} \sim 150 \text{ M}_\odot/\text{pc}^2$$

Distribution of background A_V
for Aquila prestellar cores

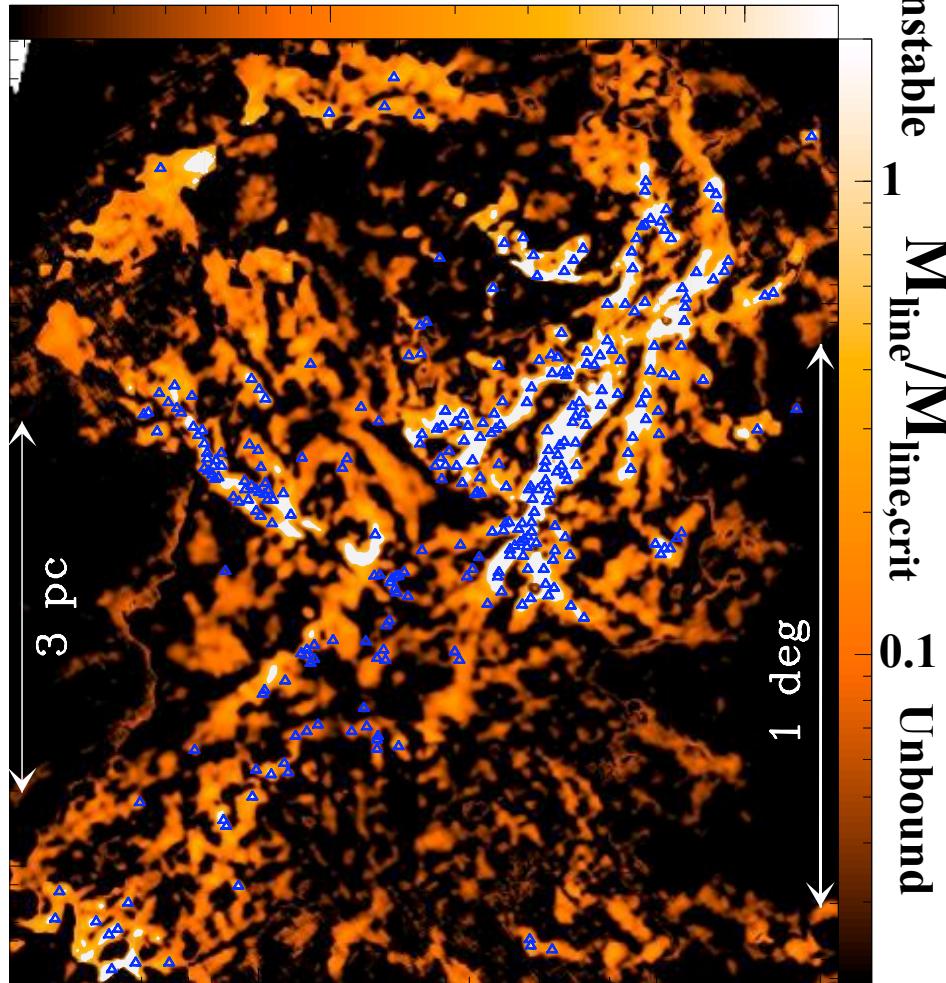


André+2014, PPVI

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

Δ : Prestellar cores

Aquila curvelet N_{H_2} map (cm^{-2})
 10^{21} 10^{22}



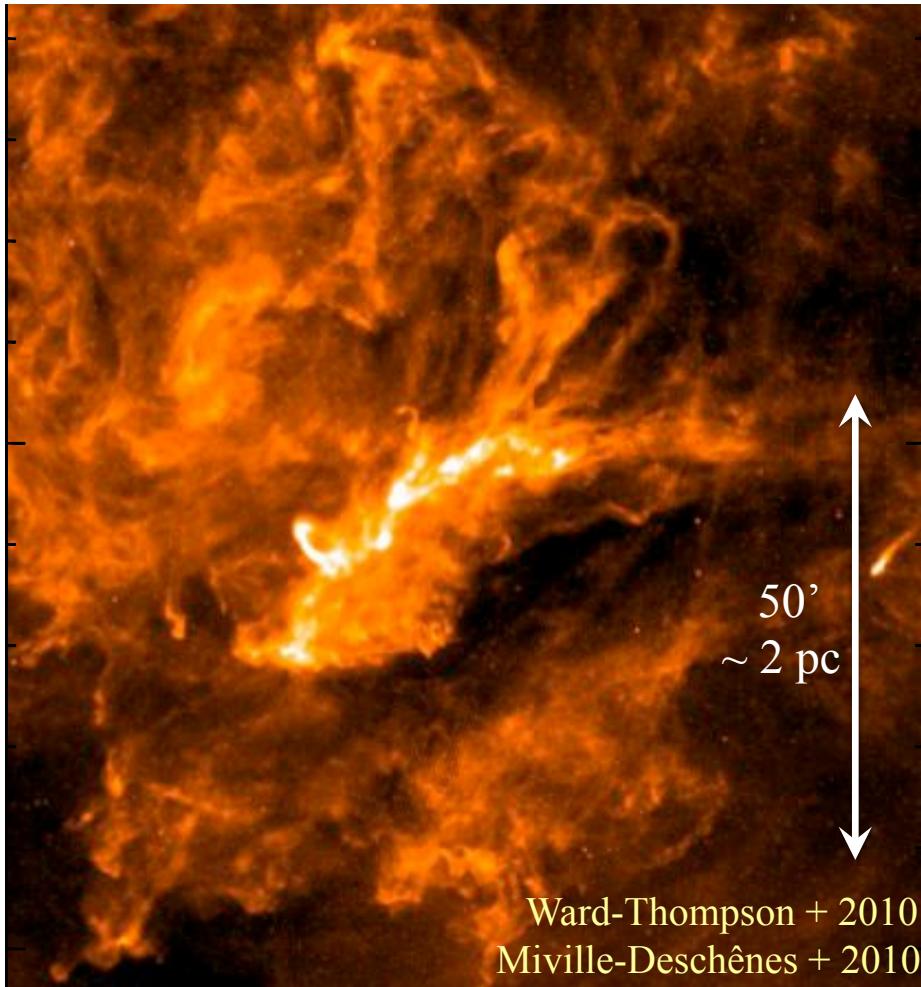
André et al. 2010

- Gravitational instability of filaments controlled by the mass per unit length $M_{\text{line}} = M/L$
(e.g. Inutsuka & Miyama'97):
 - unstable if $M_{\text{line}} > M_{\text{line,crit}}$
 - unbound if $M_{\text{line}} < M_{\text{line,crit}}$
 - $M_{\text{line,crit}} = 2 c_s^2/G \sim 16 M_\odot/\text{pc}$
for $T \sim 10 \text{ K} \Leftrightarrow \Sigma$ threshold
 $\sim 160 M_\odot/\text{pc}^2$
- Simple estimate:
 $M_{\text{line}} \propto N_{H_2} \times \text{Width} (\sim 0.1 \text{ pc})$
Unstable filaments highlighted in white in the N_{H_2} map

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

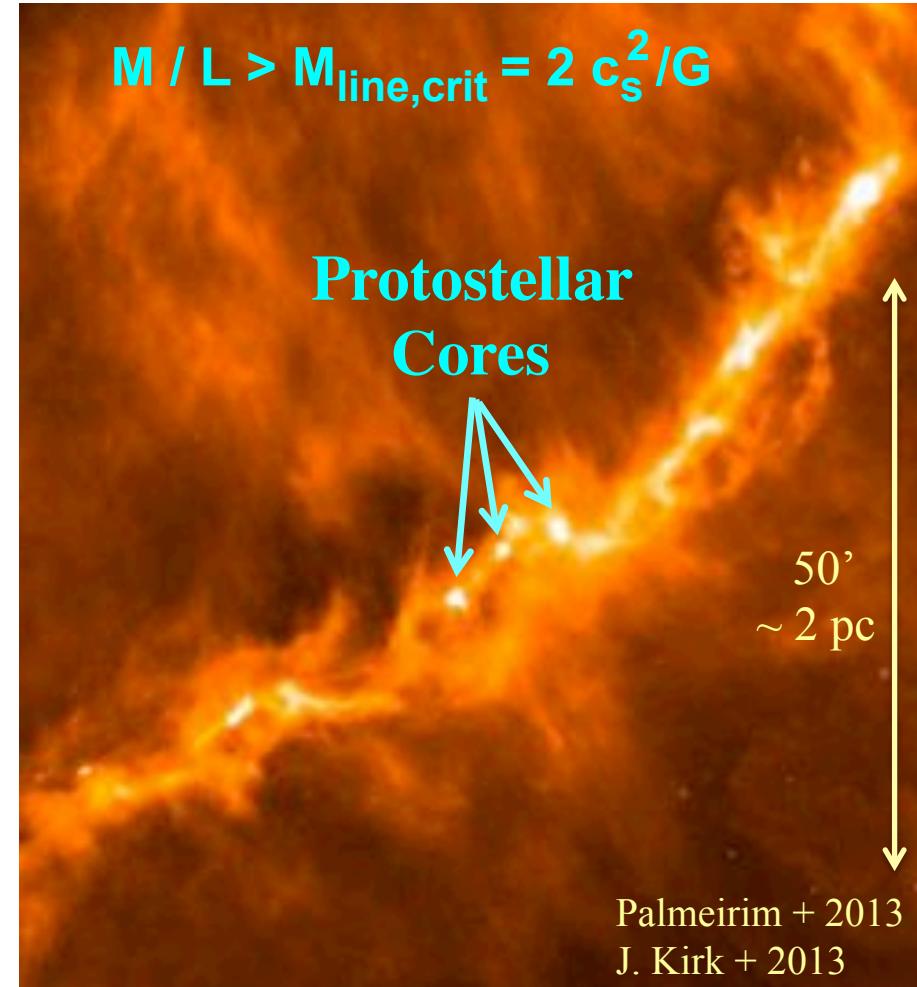
See PPVI chapter (André, Di Francesco, Ward-Thompson, Inutsuka, Pudritz, Pineda 2014 - astro-ph/1312.6232)

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



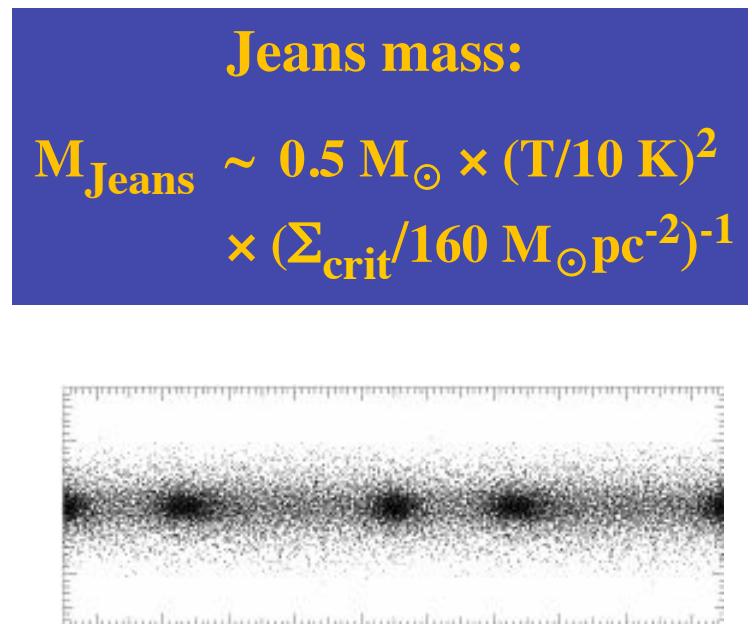
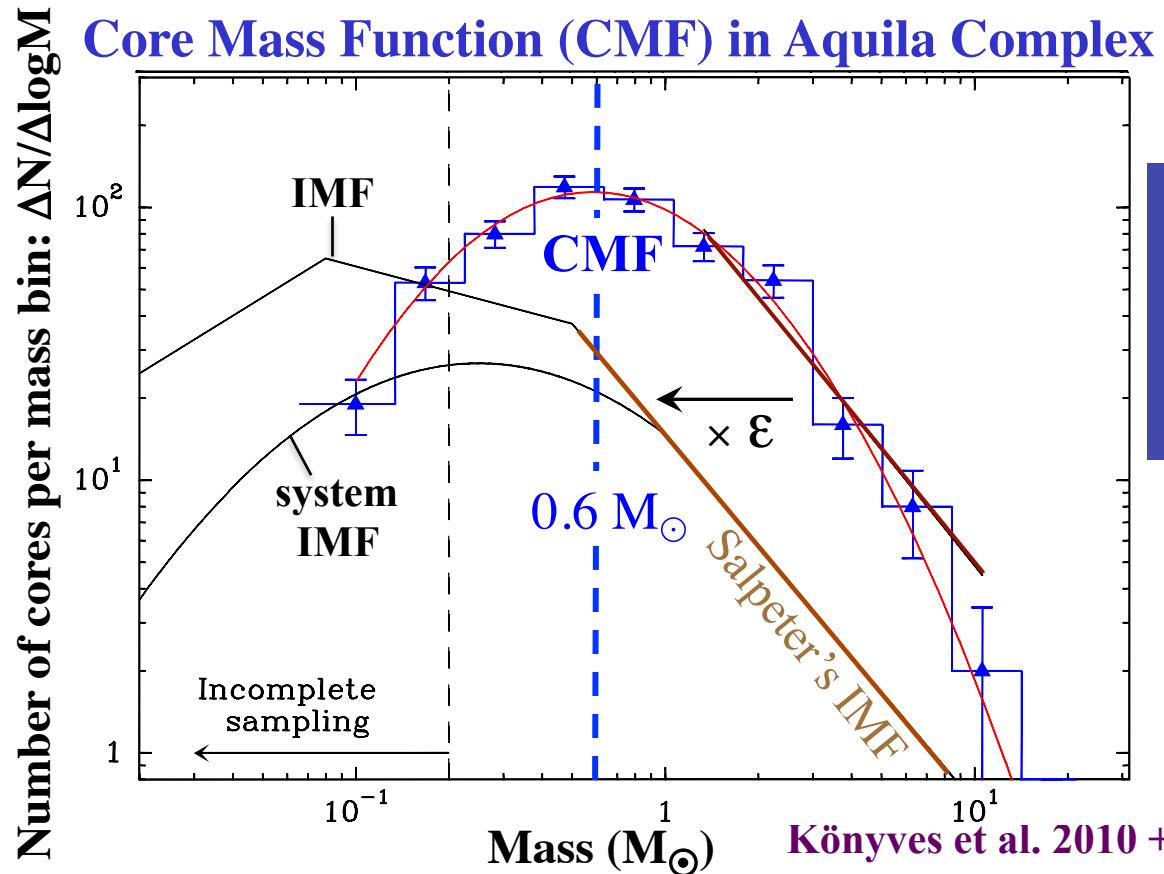
Polaris – Herschel/SPIRE 250 μ m

**2) Gravity fragments the densest
filaments into prestellar cores**



Taurus B211/3 – Herschel 250 μ m

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

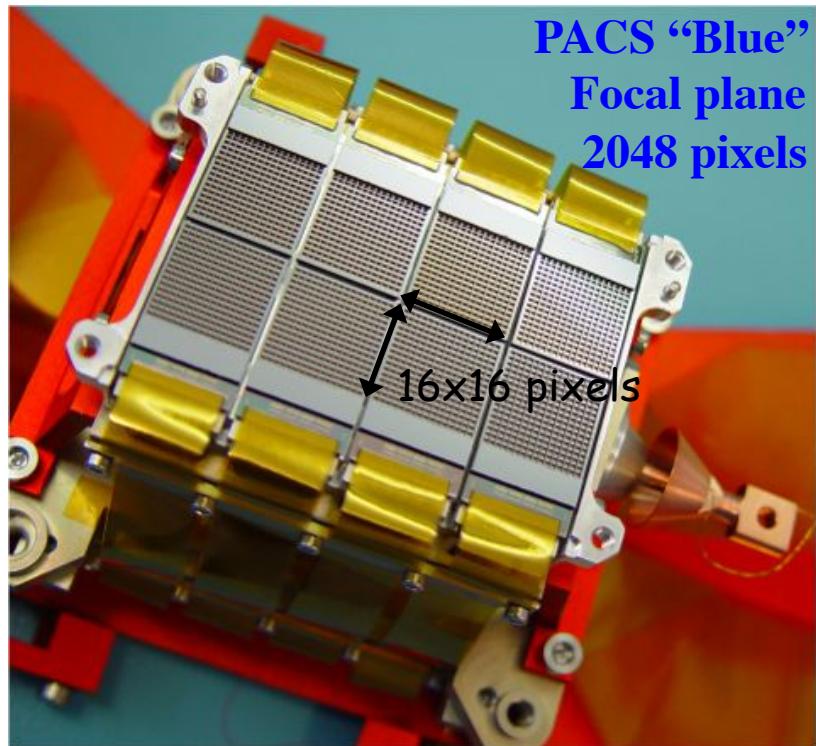


- CMF peaks at $\sim 0.6 M_{\odot} \approx$ Jeans mass in marginally critical filaments
- Close link of the prestellar CMF with the stellar IMF: $M_{\star} \sim 0.3 \times M_{\text{core}}$
- Characteristic stellar mass may result from filament fragmentation

ArTéMiS : A powerful tool to study massive star-forming filaments ('ridges') beyond the Gould Belt



APEX 12m
×3.4 higher resolution than *Herschel*/SPIRE
× 4-(10) faster than APEX/SABOCA
Open to ESO/OSO community since 2014



ArTéMiS : 2304 pixels @ 450 μm
2304 pixels @ 350 μm } +200 μm

Ph. André - PCMI AstroRennes2014 – Rennes – 27 Oct 2014

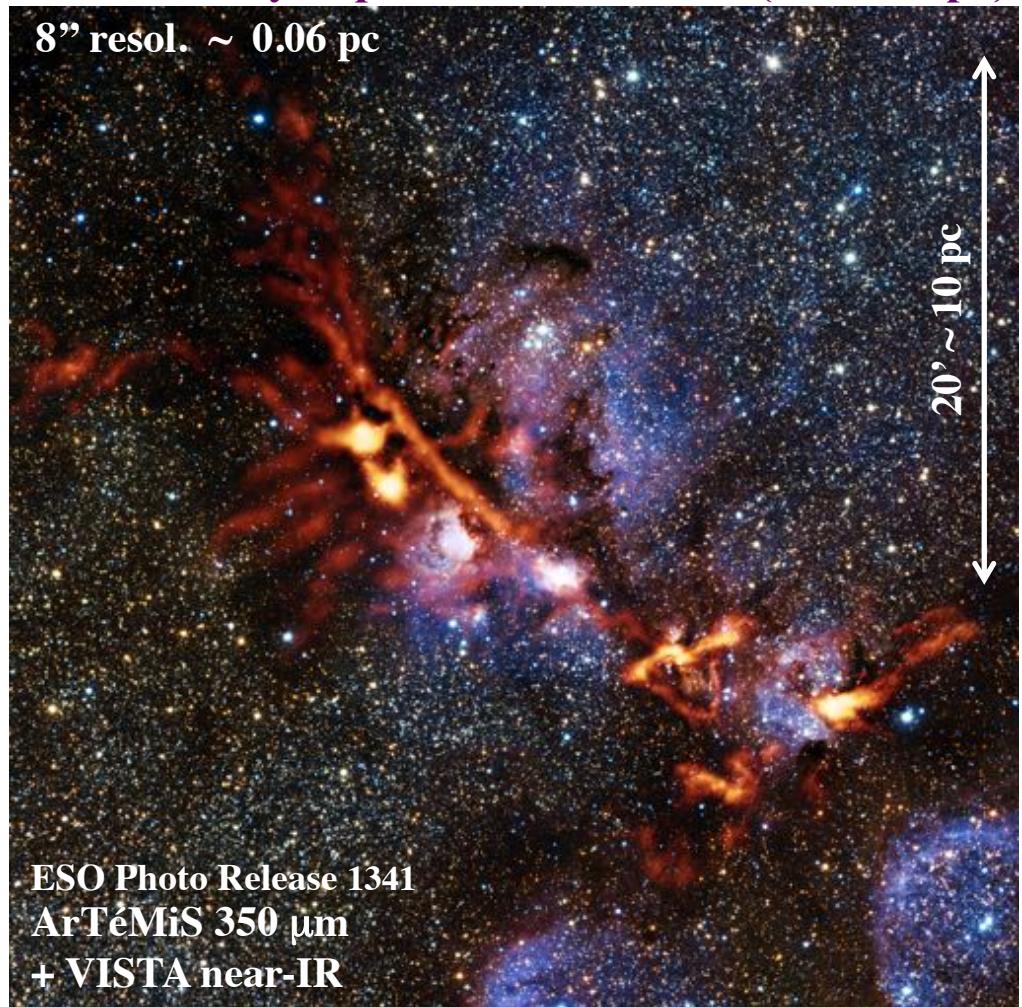


PCMI

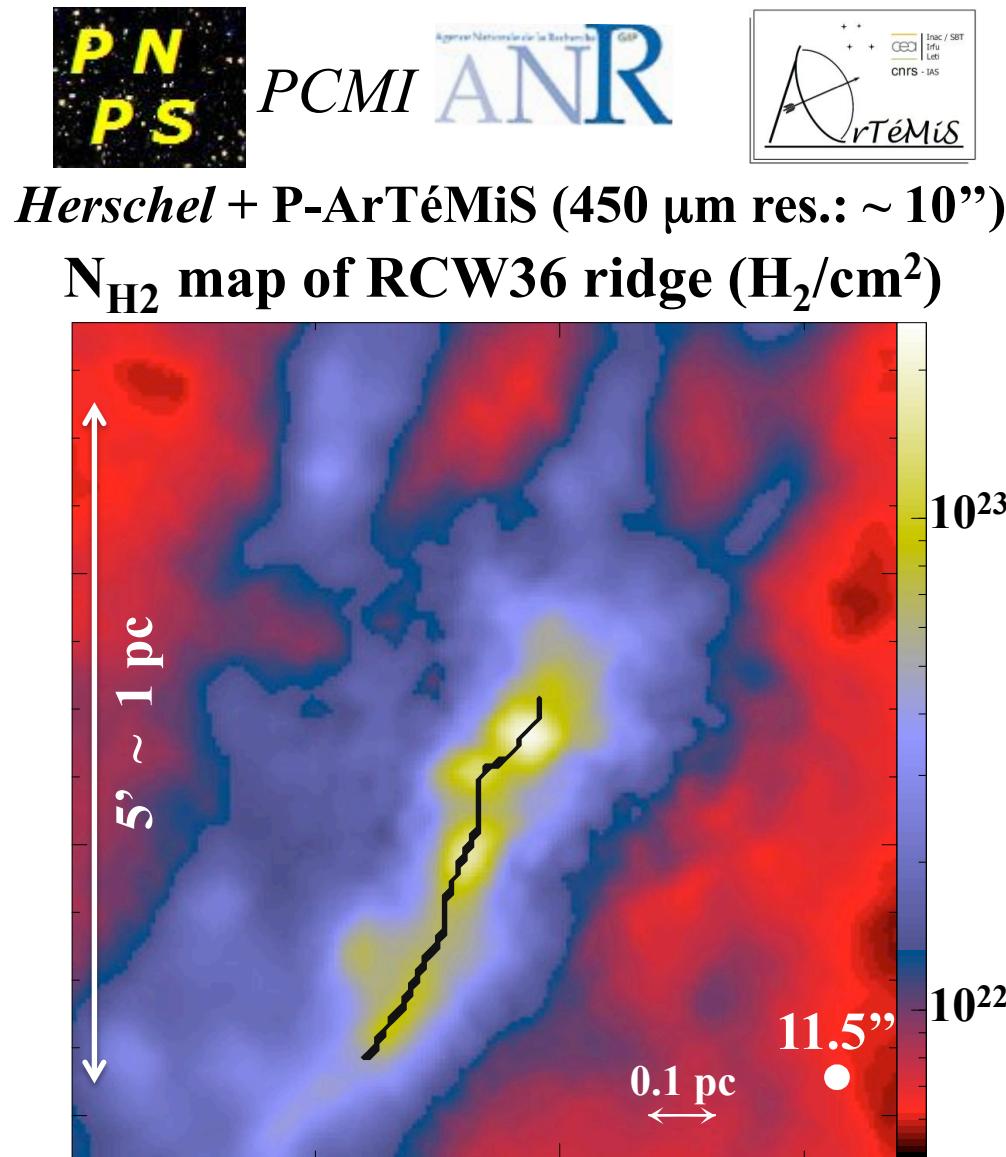


First 350 μm observations with ArTéMiS at APEX in July/Sep 2013 : NGC 6334 (d ~ 1.7 kpc)

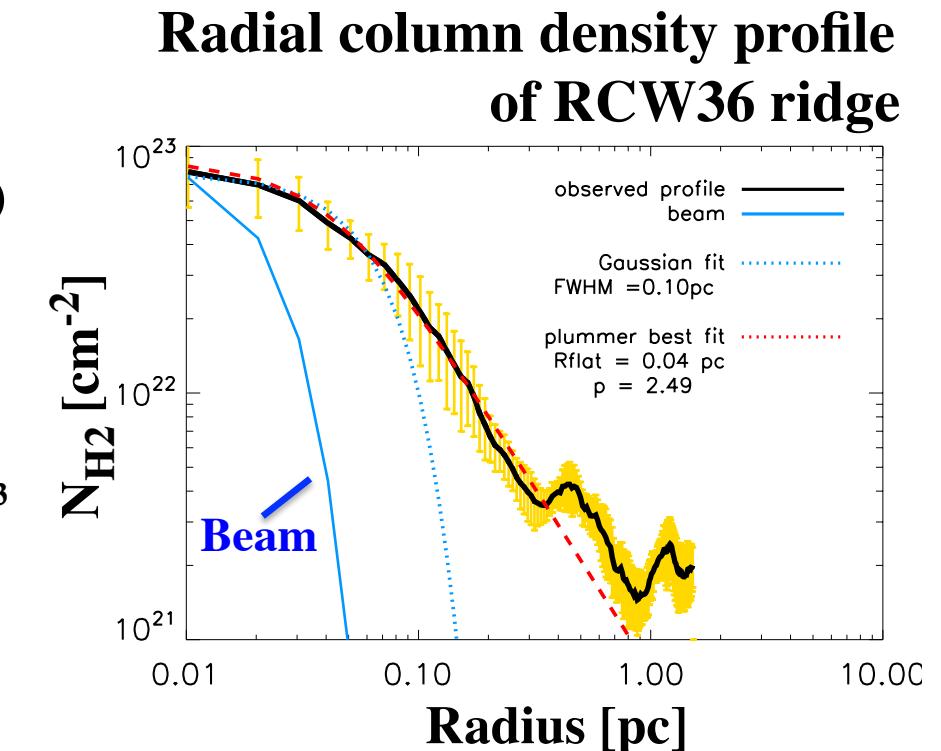
8" resol. ~ 0.06 pc



Resolving the structure of the massive ridges giving birth to high-mass stars



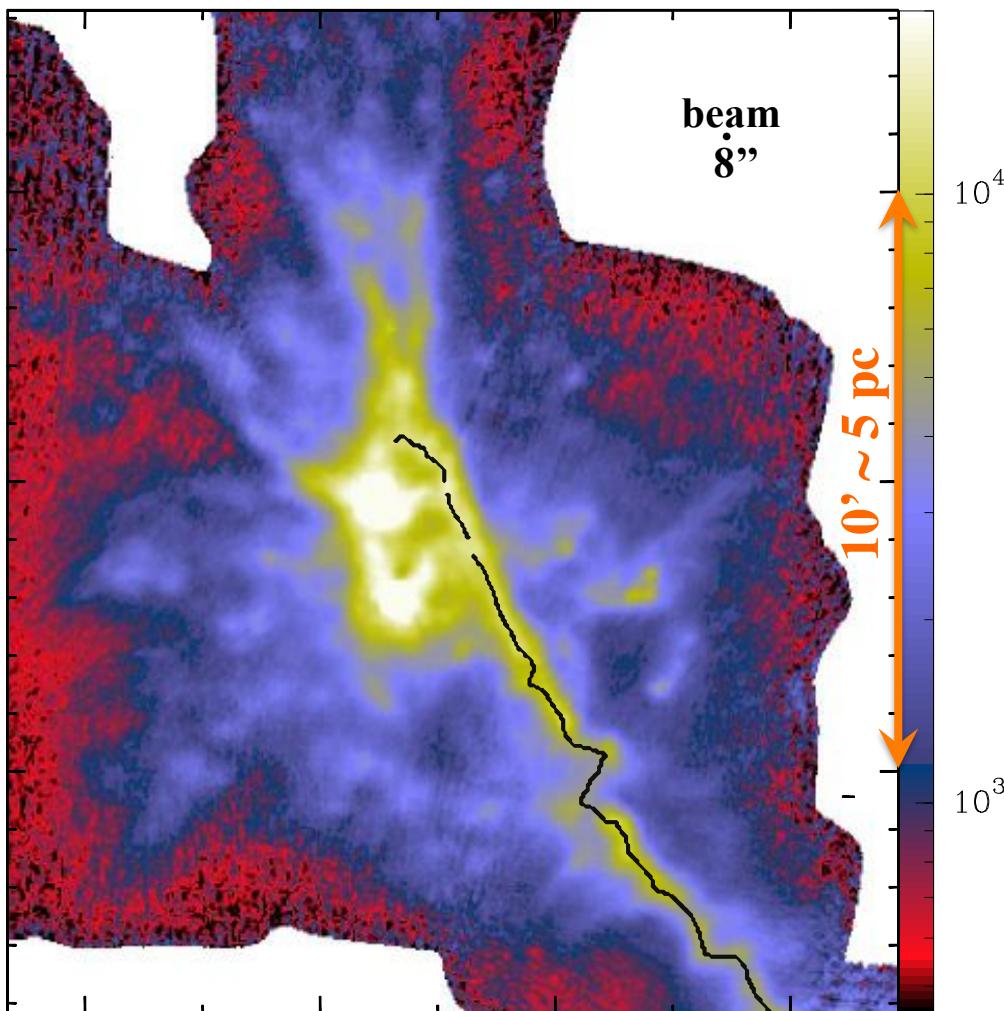
Hill, André, Arzoumanian, Motte et al. 2012



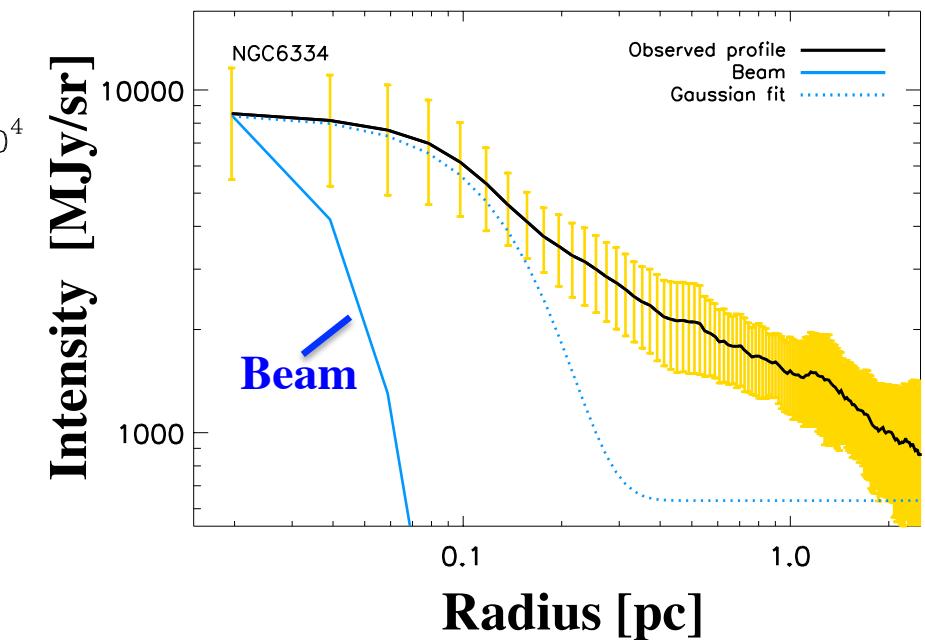
- Deconvolved FWHM width:
 0.12 ± 0.01 pc
- Diameter of flat inner plateau:
 0.1 ± 0.04 pc
- Linear resolution: $\lesssim 0.04$ pc

Resolving the NGC 6334 main filament (d \sim 1.7 kpc) with ArTéMiS + *Herschel*

ArTéMiS + SPIRE (350 μ m res.: $\sim 8''$)



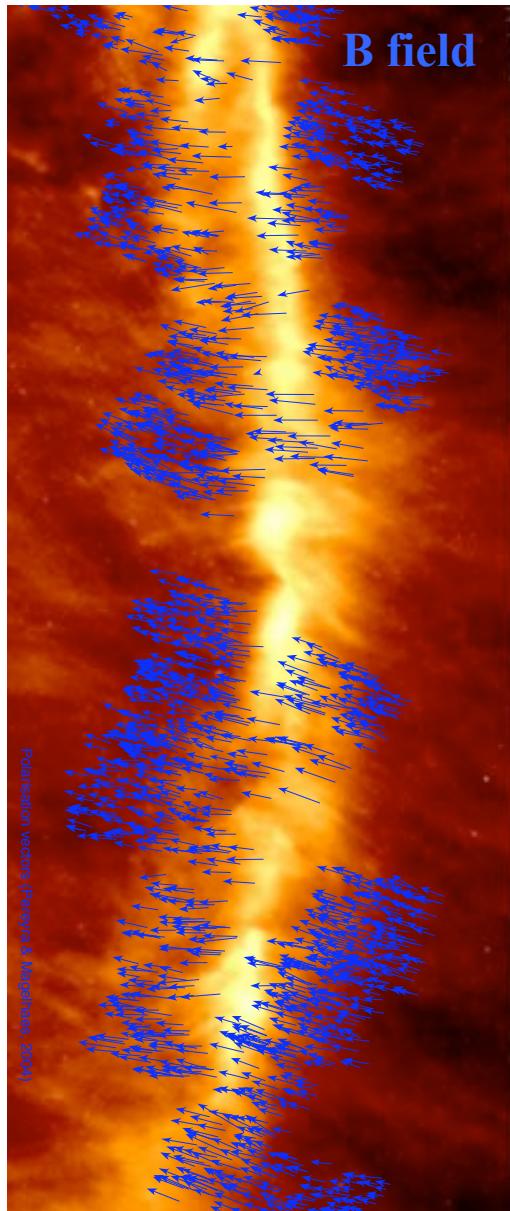
Radial intensity profile
of NGC6334 filament



- Deconvolved FWHM width and diameter of flat inner plateau: $\sim 0.1\text{-}0.2$ pc
- Linear resolution: < 0.07 pc

Role of magnetic fields ?

- Bimodal distribution of filament vs. B-field orientations (see also H.-b. Li+2013 + Planck polar. results J. Soler et al.)

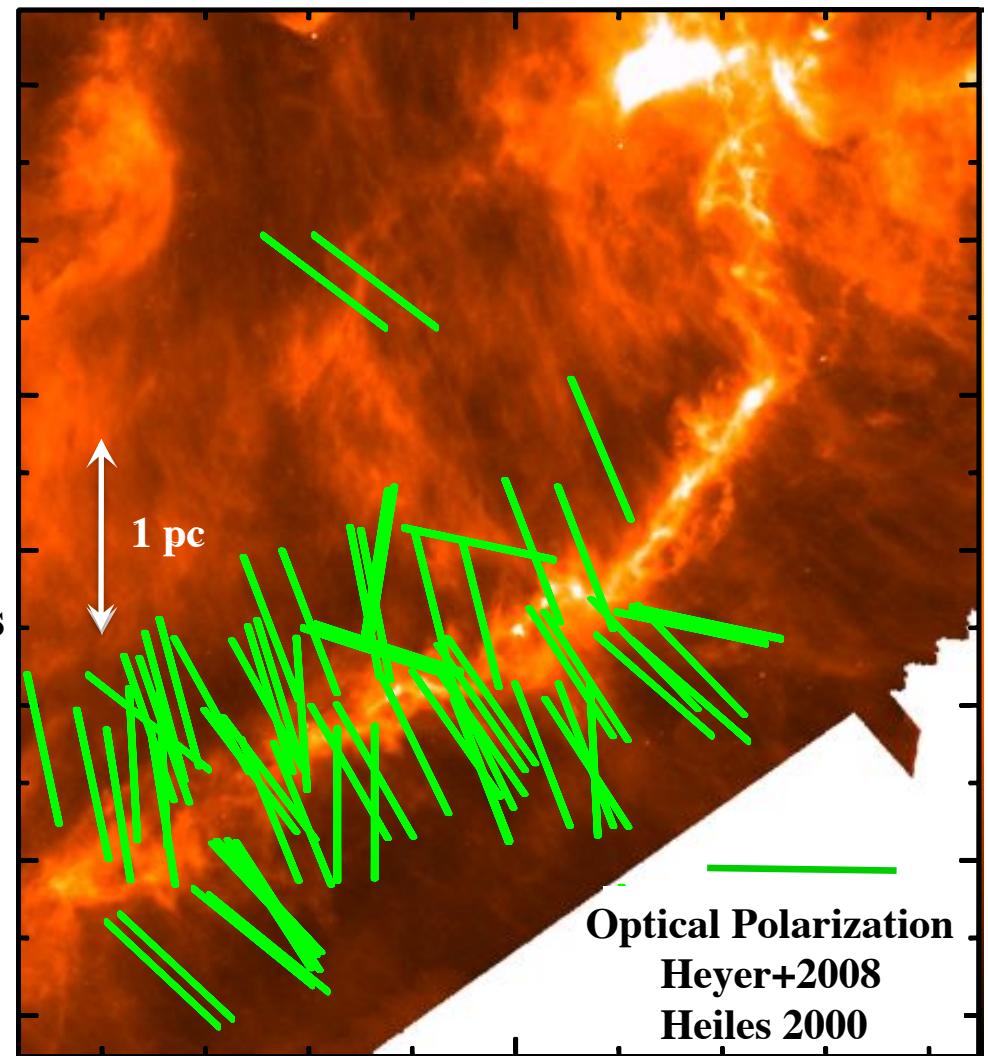


Polarization
vectors overlaid
on *Herschel* images

Pereyra &
Magelhaes 2004

Ph. André
PCMI AstroRennes2014
Rennes – 27 Oct 2014

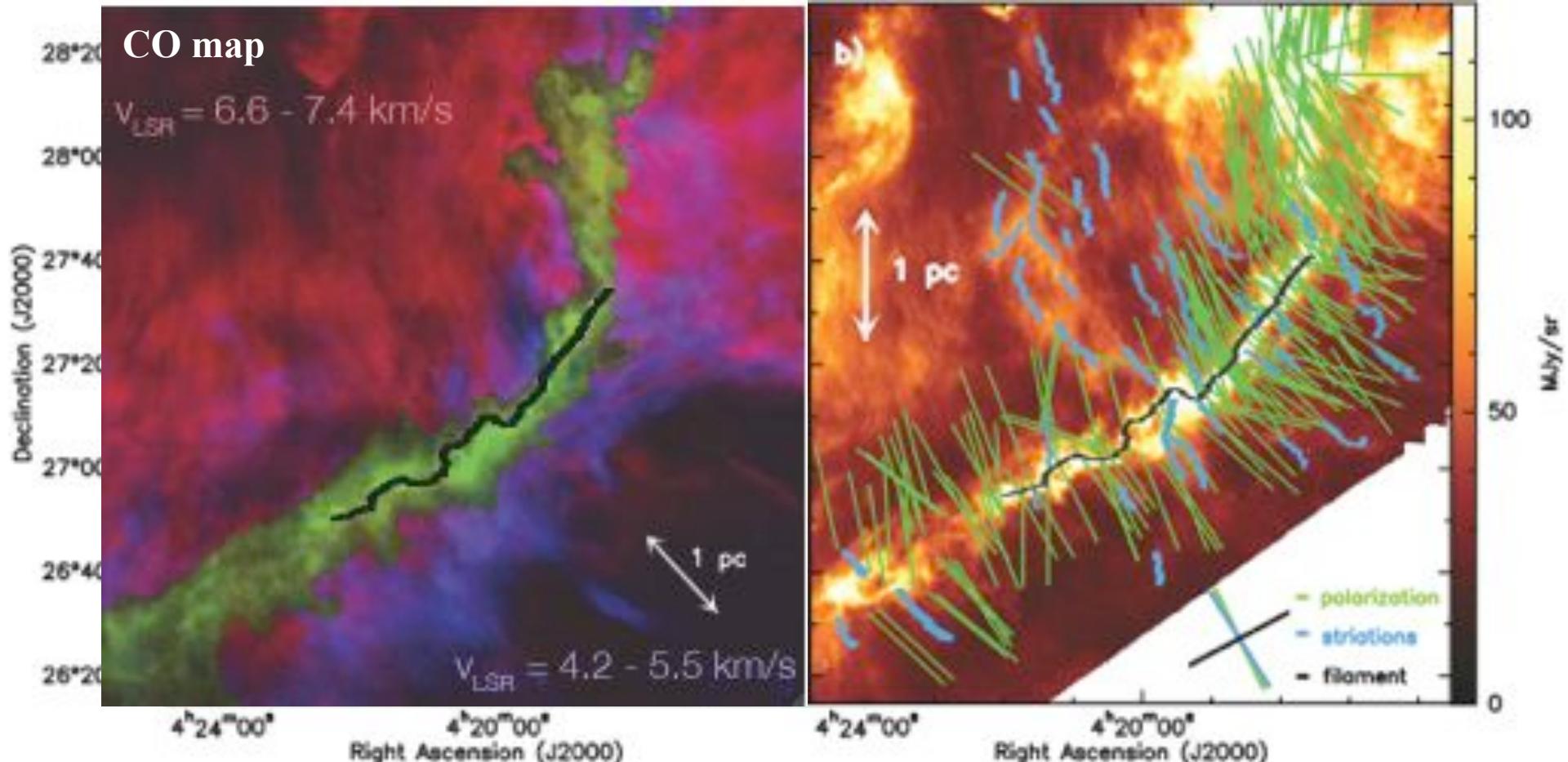
Taurus B211 filament: M/L $\sim 50 M_{\odot}/pc$
P. Palmeirim et al. 2013



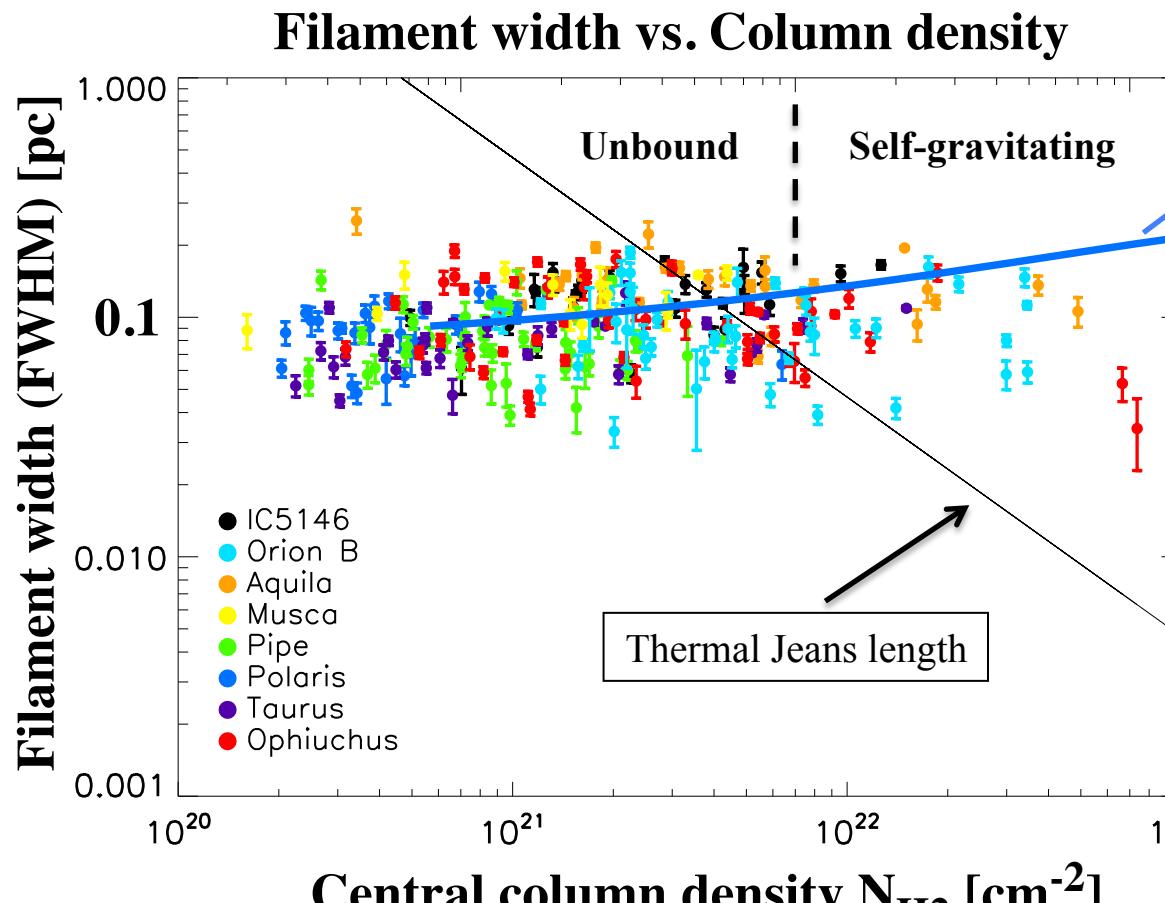
Evidence of accretion of background material (striations) along field lines onto self-gravitating filaments

- The striations are suggestive of accretion flows into the star-forming filaments

Example of the B211/3 filament in Taurus ($M_{\text{line}} \sim 50 M_{\odot}/\text{pc}$) – Palmeirim+2013

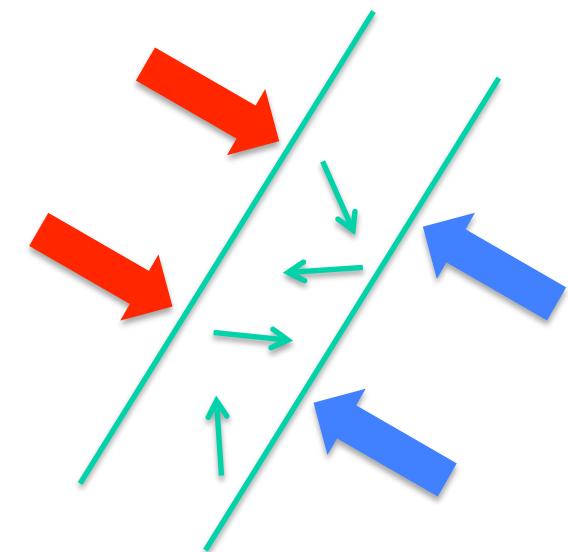


Accretion-driven MHD turbulence can prevent the radial contraction of dense filaments



D. Arzoumanian et al. 2011 + PhD thesis
+ Hennebelle & André 2013

Model of accreting filaments



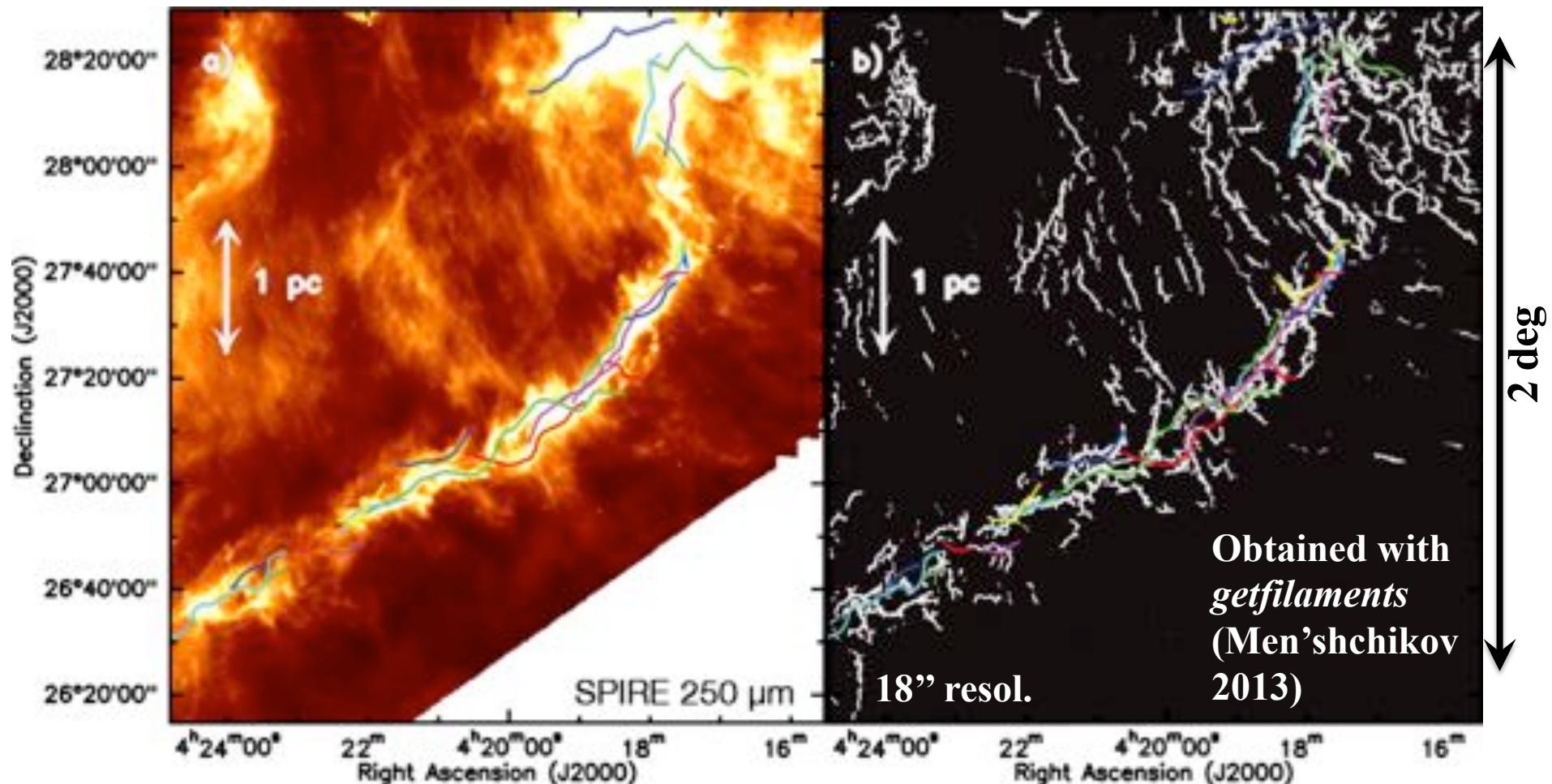
Balance between accretion-driven turbulence (Klessen & Hennebelle 2010) and dissipation of MHD turbulence due to ion-neutral friction

« Dynamical » equilibrium with $\langle \text{width} \rangle \sim 0.1$ pc

‘Fibers’: A possible manifestation of accretion-driven MHD turbulence ?

Hacar et al. (2013)’s C¹⁸O « fibers » overlaid on Herschel 250 μm image (Palmeirim et al. 2013)

Filtered 250 μm image showing the fine structure of the Taurus B211/3 filament



Possible future tests of this picture with high-resolution dust polarimetric imaging at 1.2mm with NIKA2



IRAM30m

➤ Goal: Probe the geometry of the B-field *within* dense, star-forming filaments and the role of B in channeling matter from filaments to prestellar cores ($\sim 0.01\text{-}0.1$ pc scales)

