The line mass power spectrum of interstellar filaments: A possible link to the prestellar CMF

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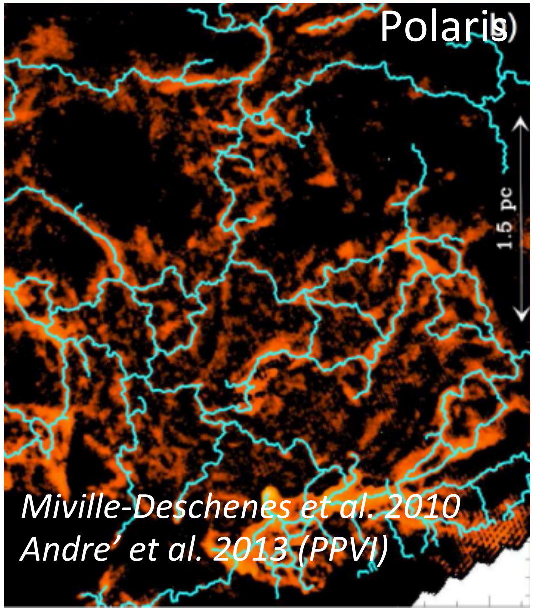
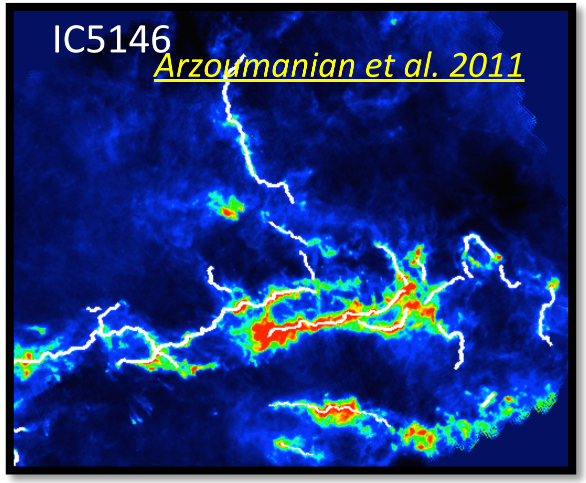
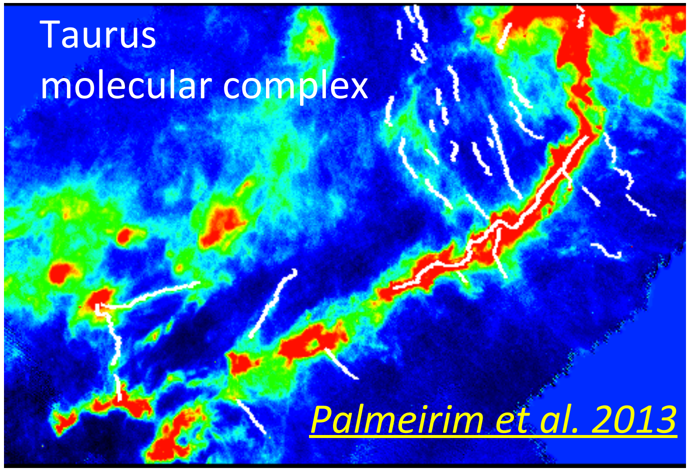
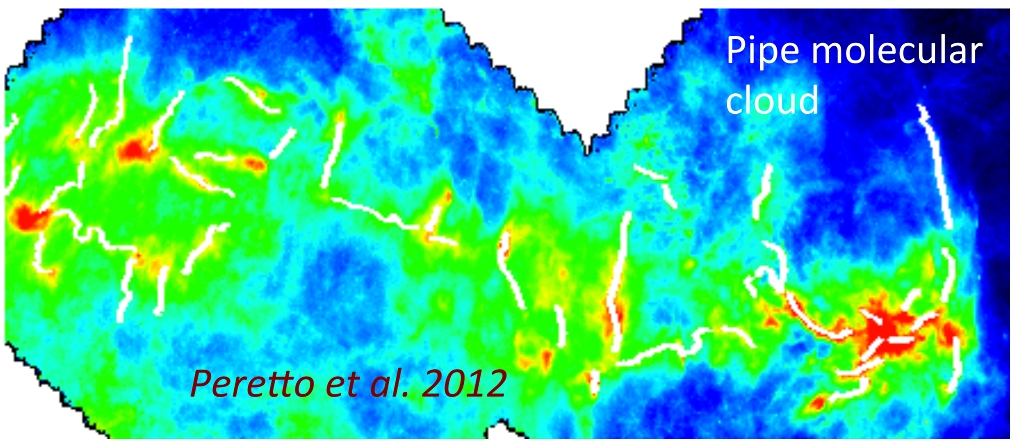
Physical significance of filamentary structures









- Isothermal self gravitating cylinder has an analytical equilibrium solution for density *[Ostriker 1964]*
- $M_{line} > 2c_s^2/G$, thermally unstable *[Inutsuka & Miyama 1997]*
- Quasi-universal sub-parsec width ~ 0.1 pc *[Arzoumanian et al. 2011]*

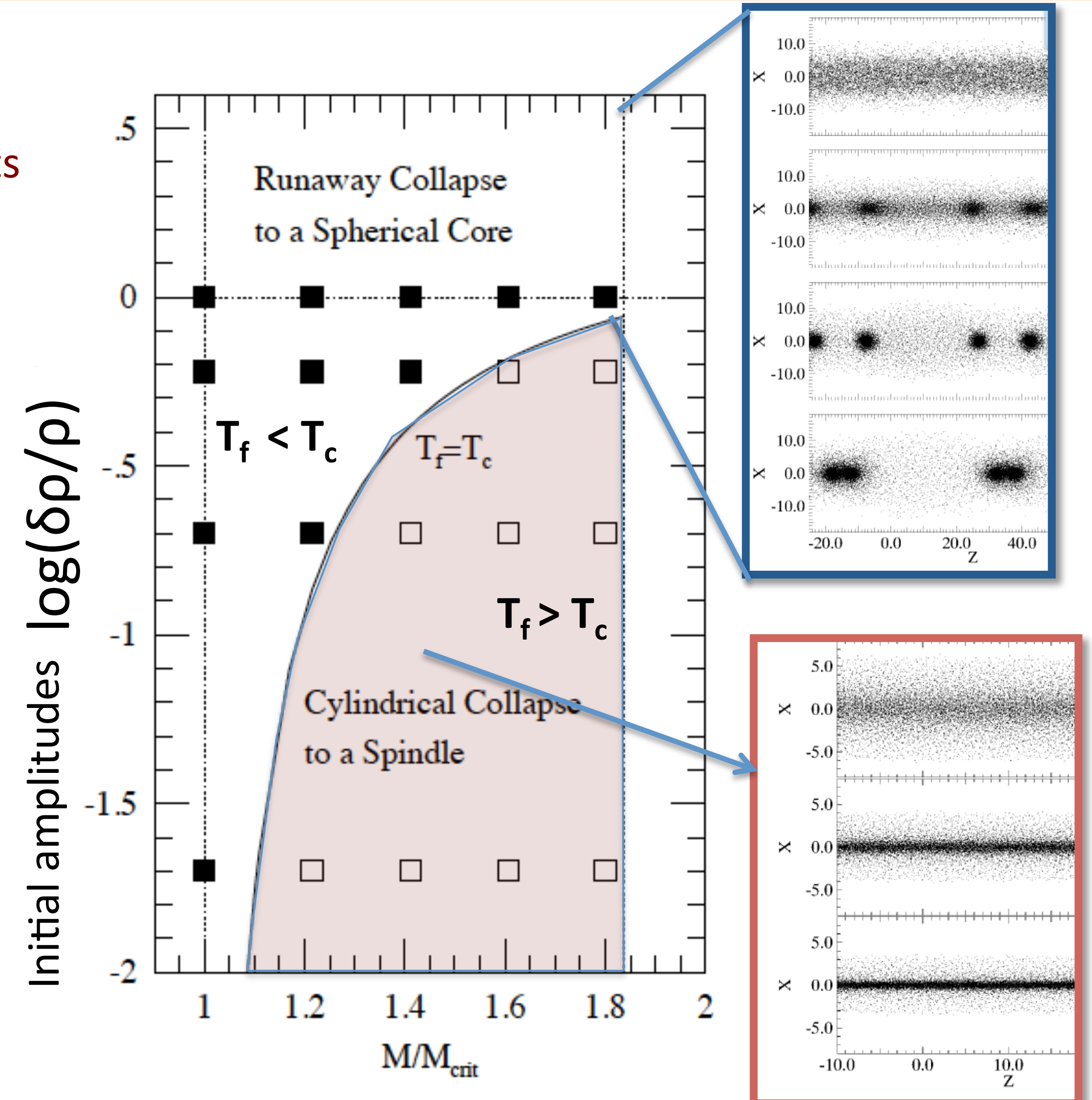
Evolution of perturbation modes in filaments

Fate of supercritical filaments depends on:

Amplitudes of perturbation modes + line mass

Inutsuka & Miyama 1997

c.f., Andre' et al., 2014, PPVI

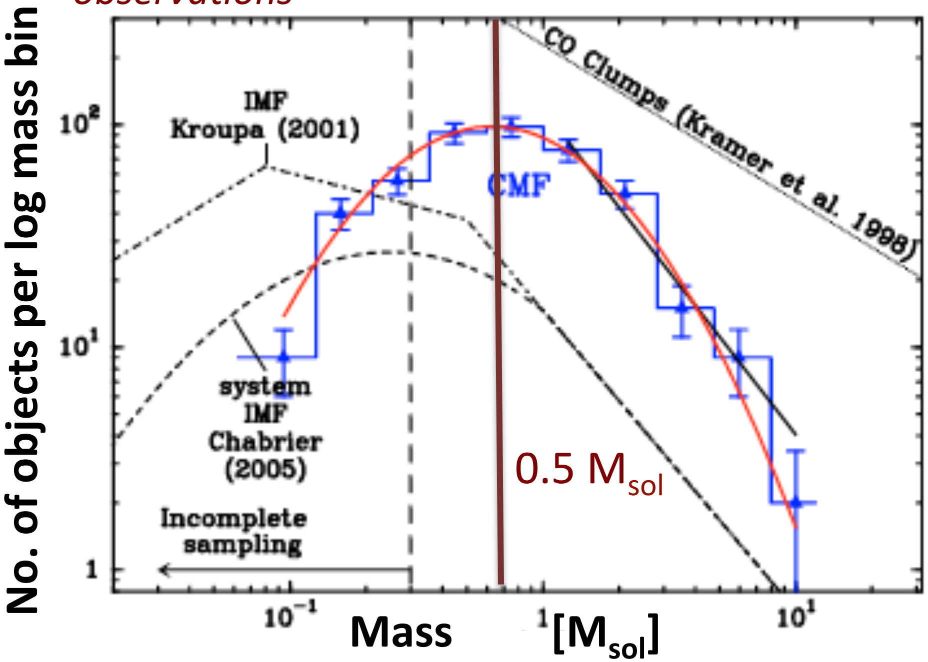


The isothermal fragmentation leads to a characteristic mass scale

Isothermal fragmentation of filaments

The isothermal fragmentation leads to a characteristic mass scale

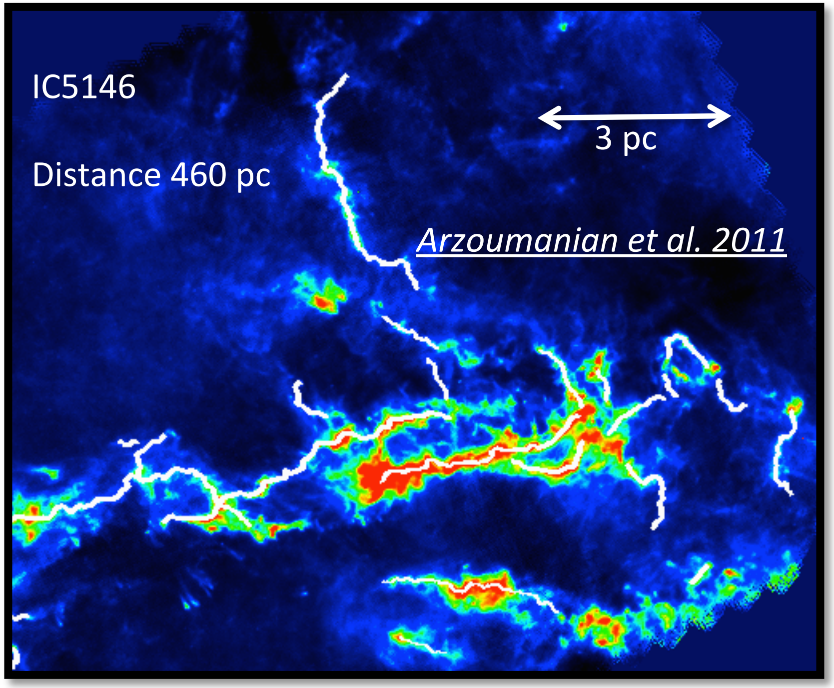
Prestellar core mass function from Herschel observations

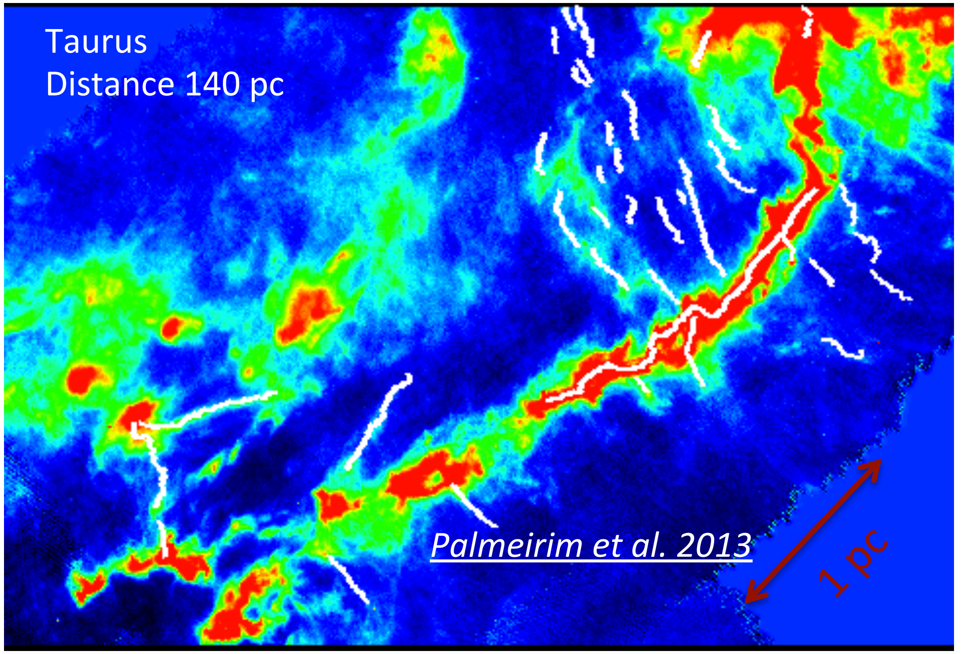


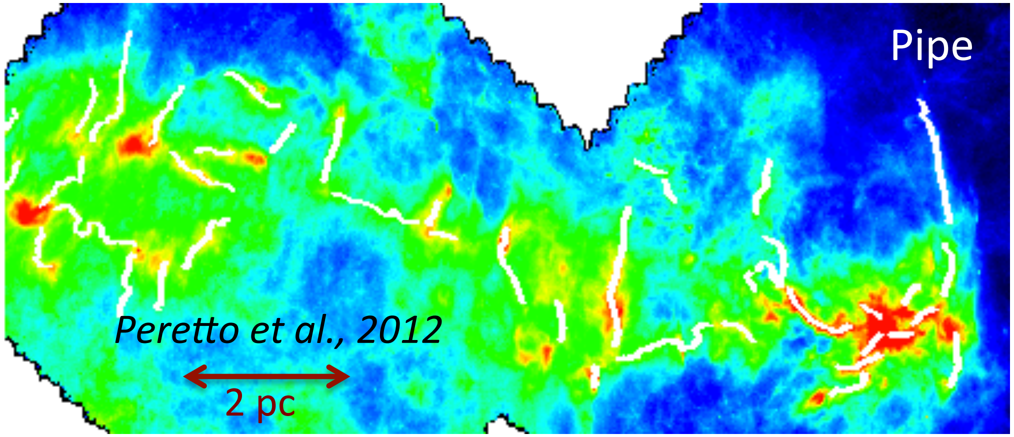
Peak of the CMF coincides with the gravitational fragmentation scale ~ 0.6 M_{sol} with a width of a factor of 2

Andre' et al., 2010, Könyves et al., 2010
c.f., Andre' et al., 2014, PPVI

Selection of region & filaments detection



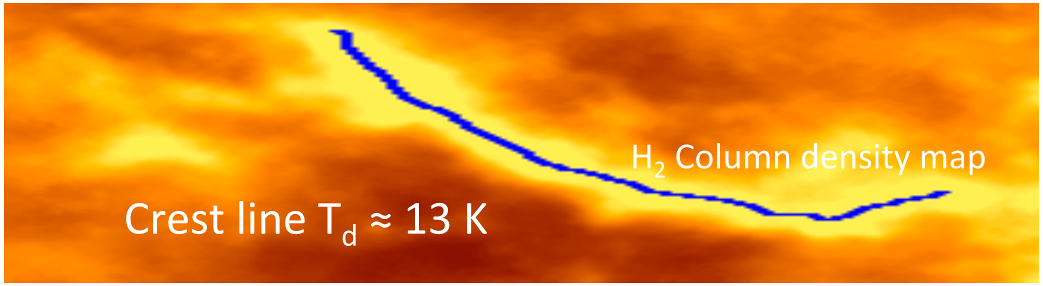




Filament identification

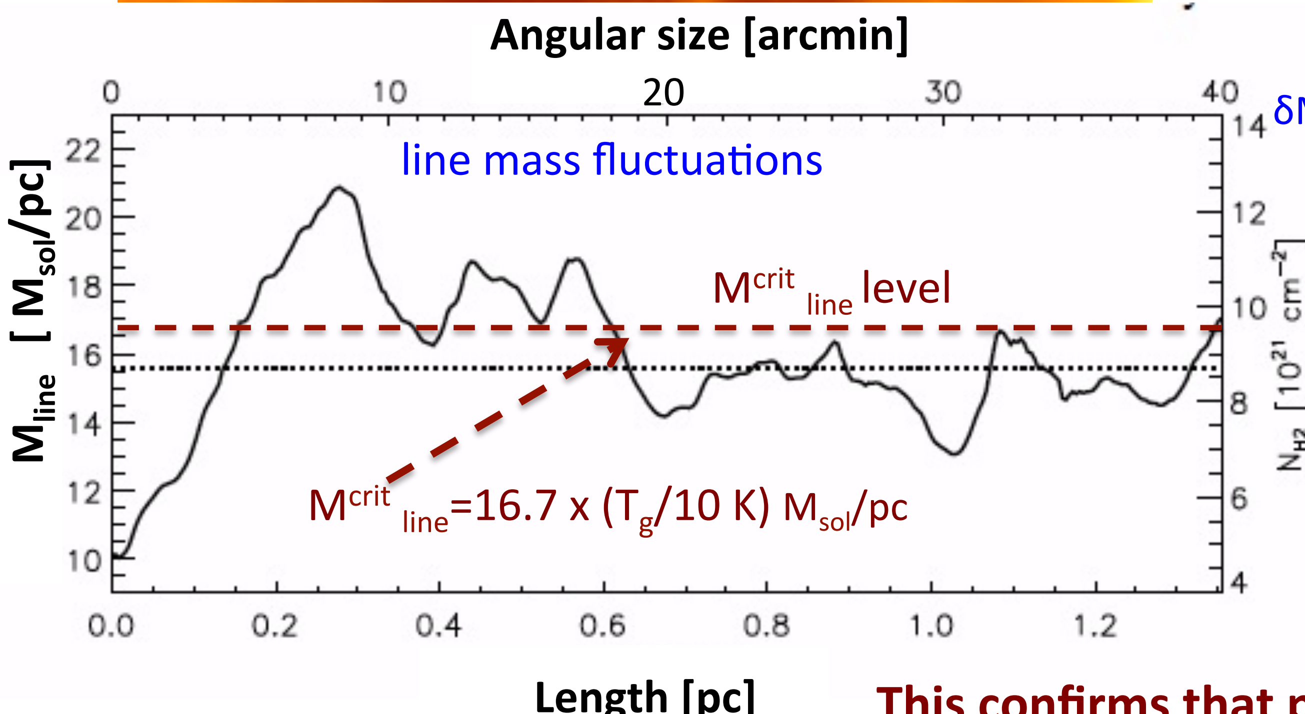
- Morphological component analysis (MCA) → decomposes into wavelet and curvelet basis *[Starck et al., 2003]*
- DisPerSE algorithm on curvelet image to trace crest line along filament *[Sousbie et al., 2011, Arzoumanian et al., 2011]*

Line mass fluctuations along the long axis of a filament



$M_{line}(z) = N_{H2}(z) \times w$ (w is the quasi-universal filament width of 0.1 pc)

Arzoumanian et al., 2011



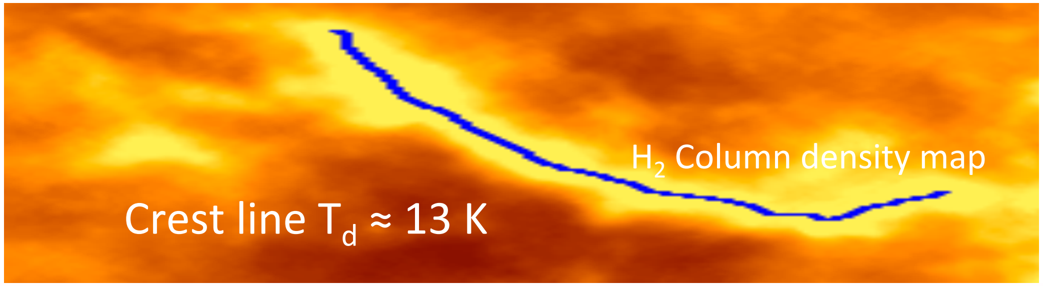
Relative amplitude of line mass perturbations

$\delta M_{line}/ M_{line} = [M_{line} - \langle M_{line} \rangle]/\langle M_{line} \rangle$

$[\delta M_{line}/ M_{line}]_{max} \approx 0.3 < 1$

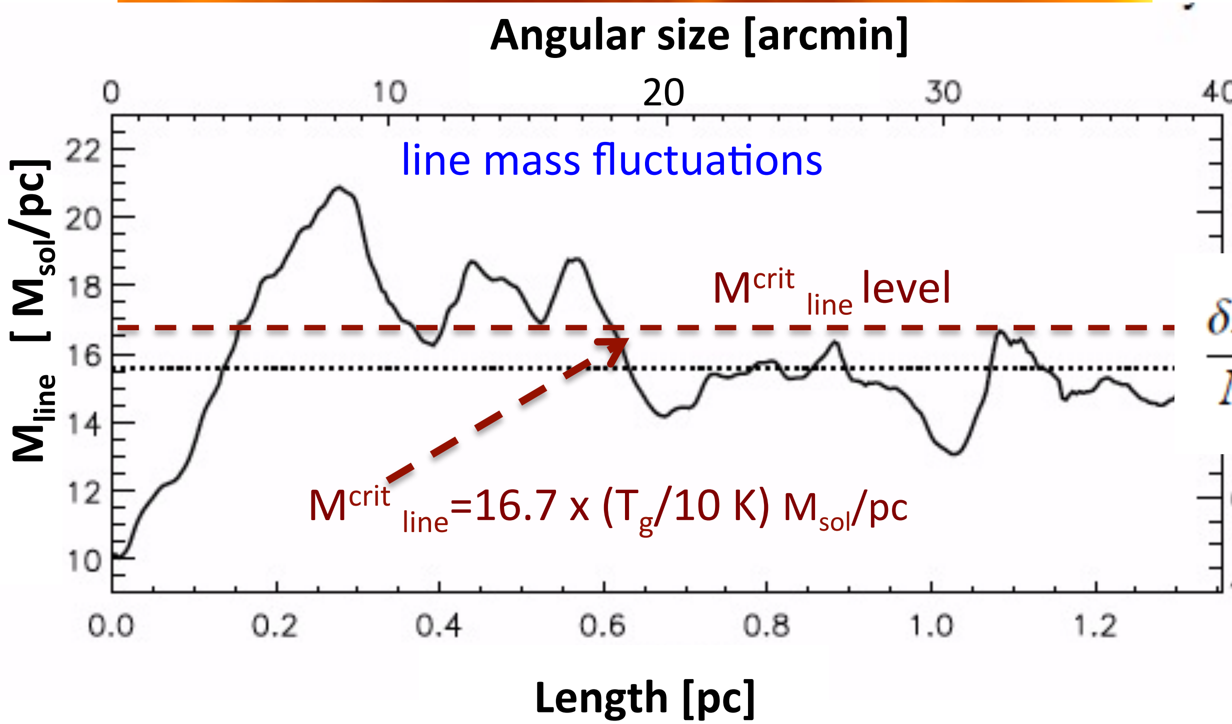
This confirms that perturbation modes are in linear regime

Line mass fluctuations along the long axis of a filament



$M_{line}(z) = N_{H2}(z)$ X w (w is the quasi universal filament width of 0.1 pc)

Arzoumanian et al., 2011



Proportionality of observables in cylindrical symmetry :

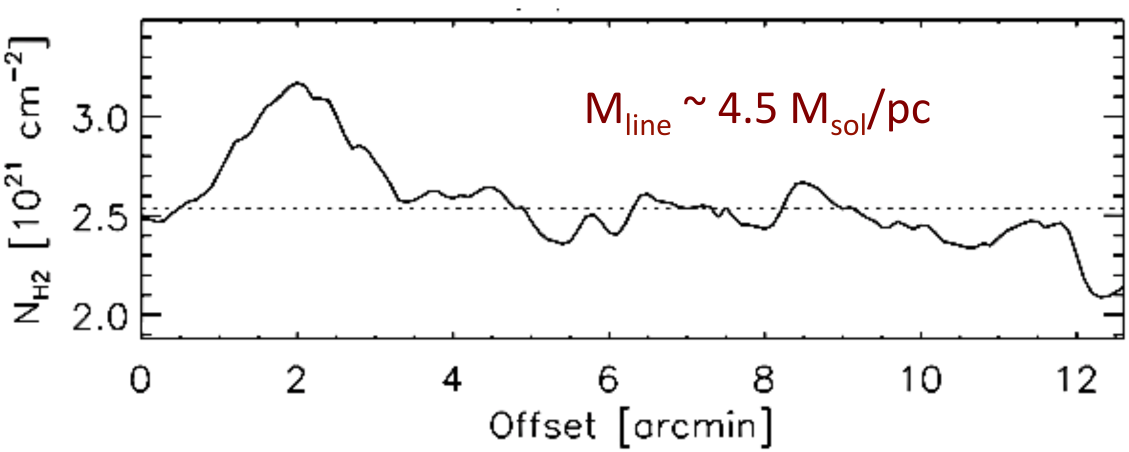
$$\frac{\delta N_{H_2}}{N_{H_2}} \propto \frac{\delta N_{H_2} \times w}{N_{H_2} \times w} \propto \frac{\delta M_{\rm line}}{M_{\rm line}} \propto \frac{\delta \rho}{\rho}$$

Line mass fluctuations along the long axis of a filament

Roy, Andre', Arzoumanian et. al 2014, to be submitted

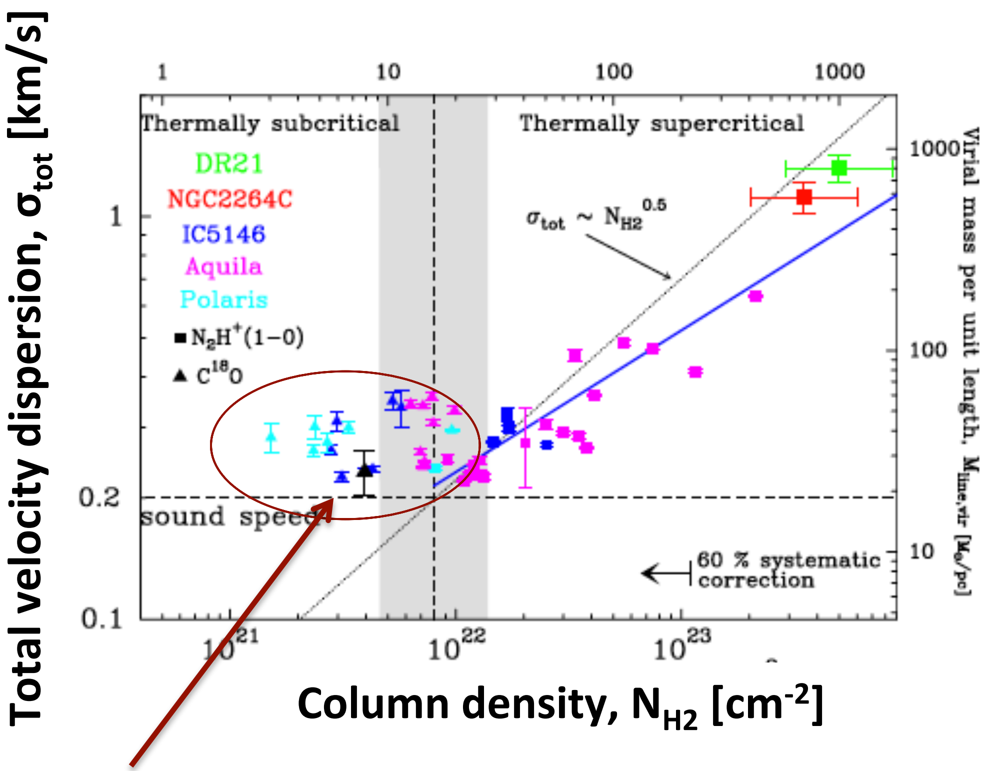
An example of subcritical filament

Column density fluctuations along z axis



$[\delta M_{line} / M_{line}]_{max} \approx 0.2$

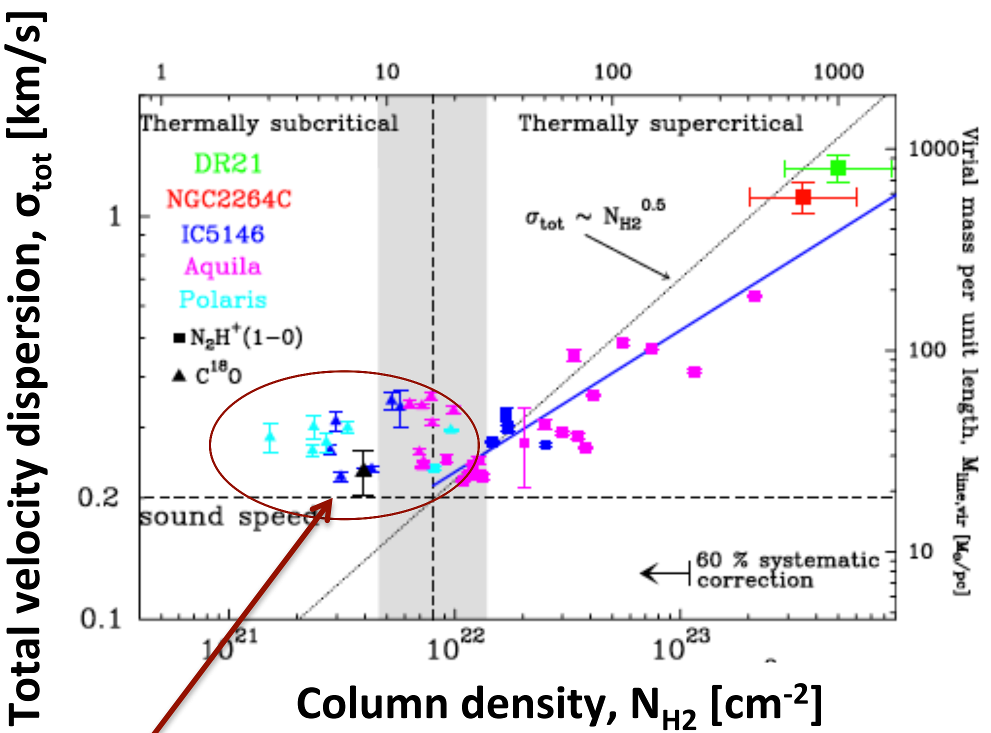
Nature of velocity and density perturbations in filaments



Subcritical or marginally supercritical filaments have subsonic to transonic velocity dispersion

Arzoumanian et al. 2013

Nature of velocity and density perturbations in filaments



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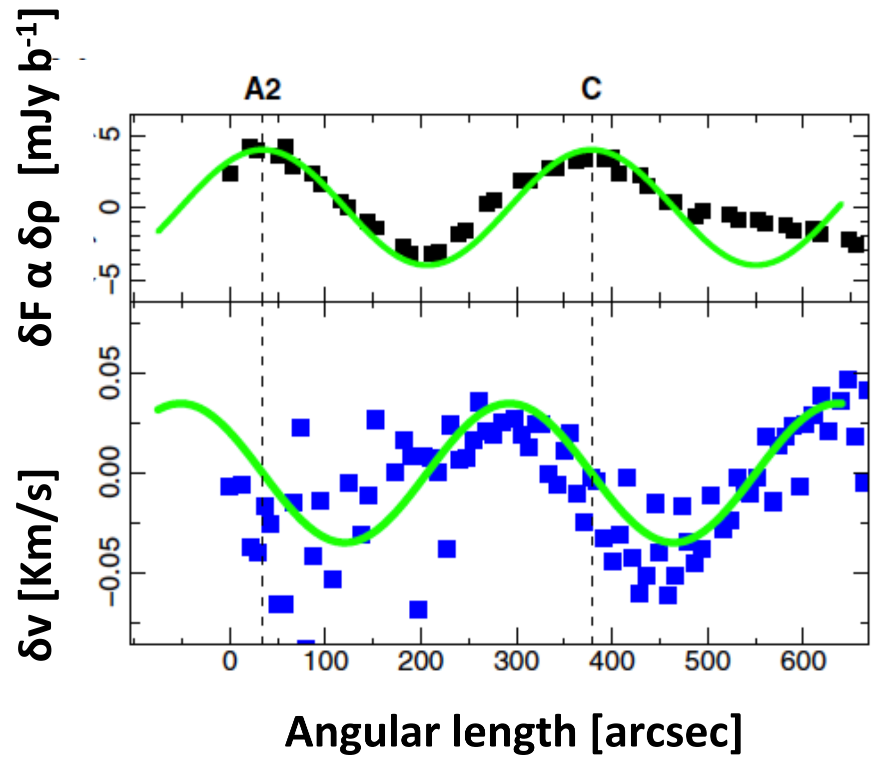
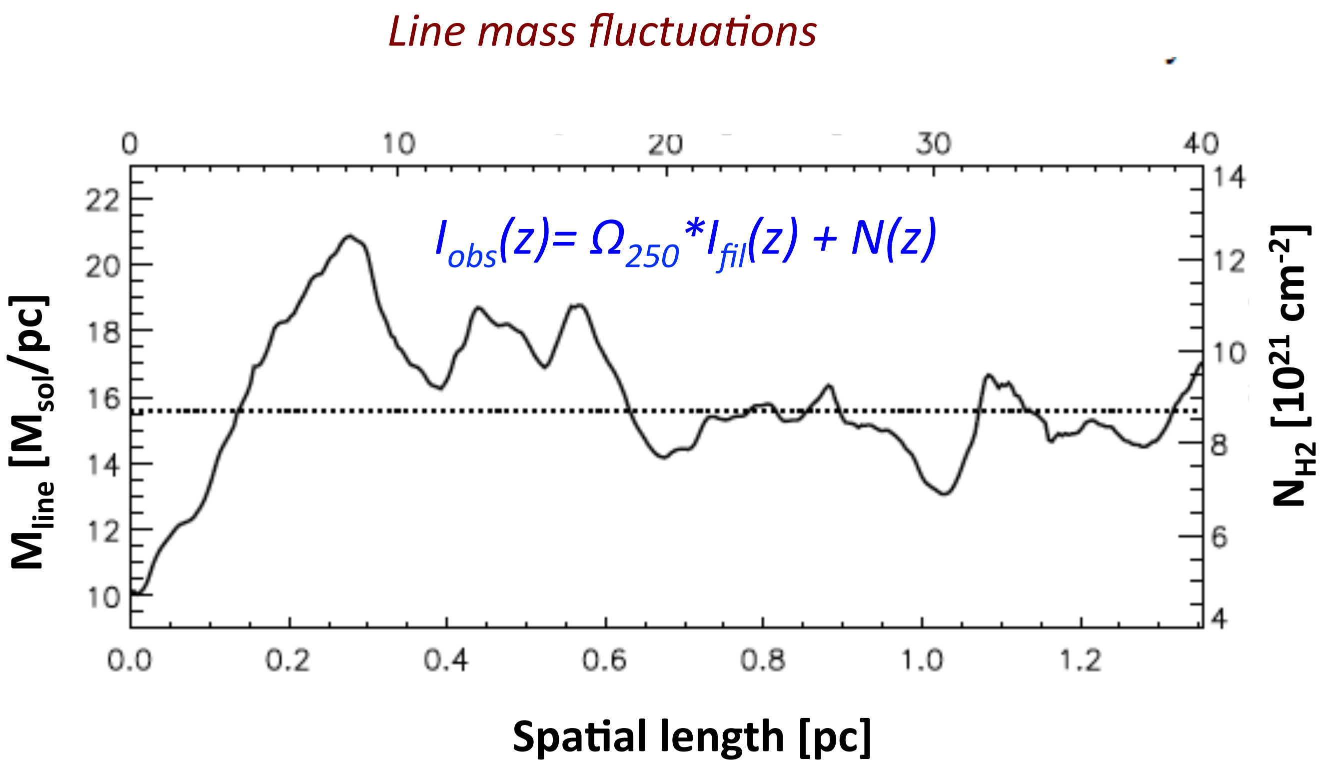


From linear perturbation analysis, density perturbations are proportional to velocity perturbations

Hacar et al. 2011

$$(\delta v/c_s) \propto (\delta\rho/\rho)$$

Statistical properties of line mass fluctuations



Power spectrum (PS): $P(s) = \langle I(s) I^*(s) \rangle$

Statistical properties of line mass fluctuations

Power spectrum along a filament

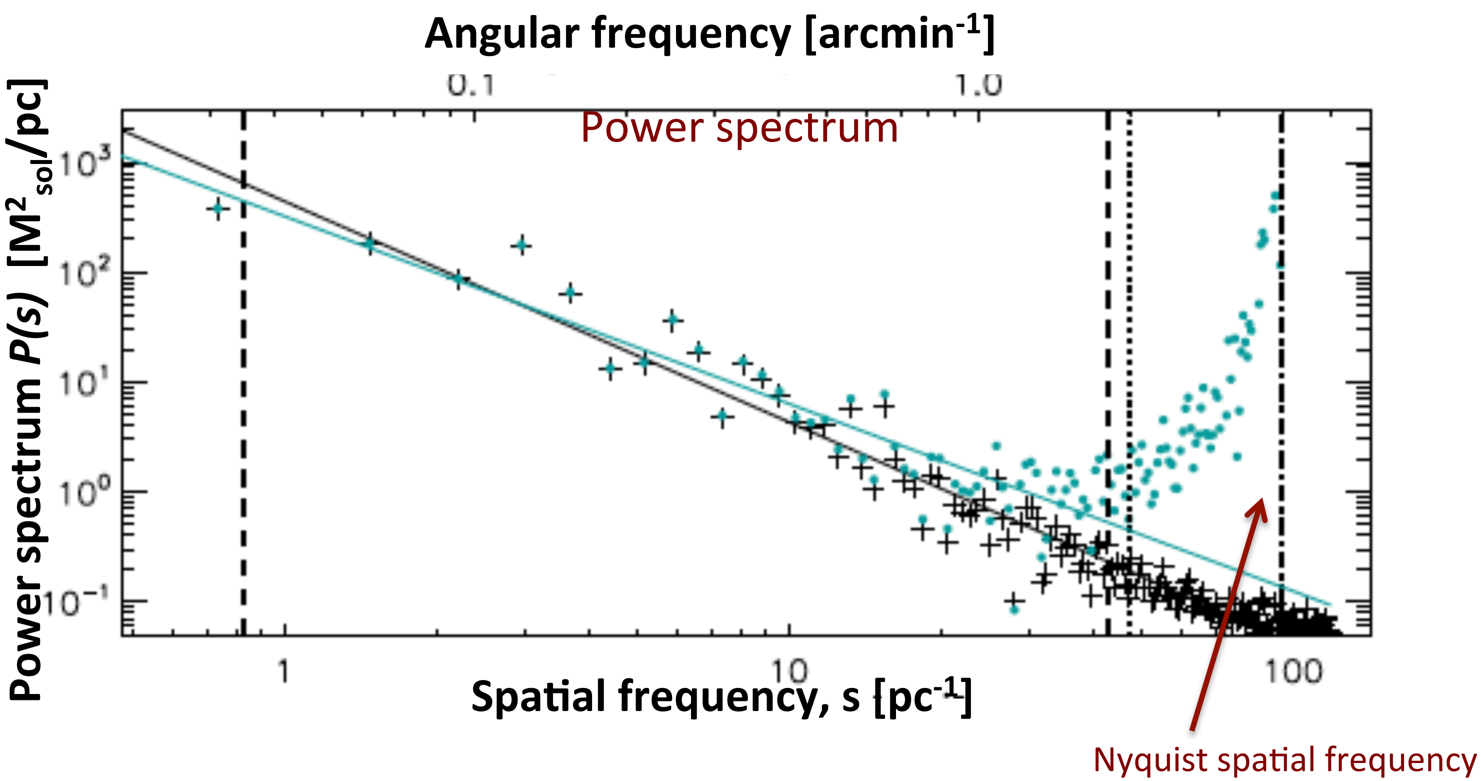
Roy, Andre', Arzoumanian et. al 2014, to be submitted

Beam *PS*

Intrinsic filament *PS*

$$P_{\mathrm{obs}}(s) = \gamma(s) \times P_{\mathrm{fil}}(s) + P_{\mathrm{N}}(s),$$

Noise *PS*

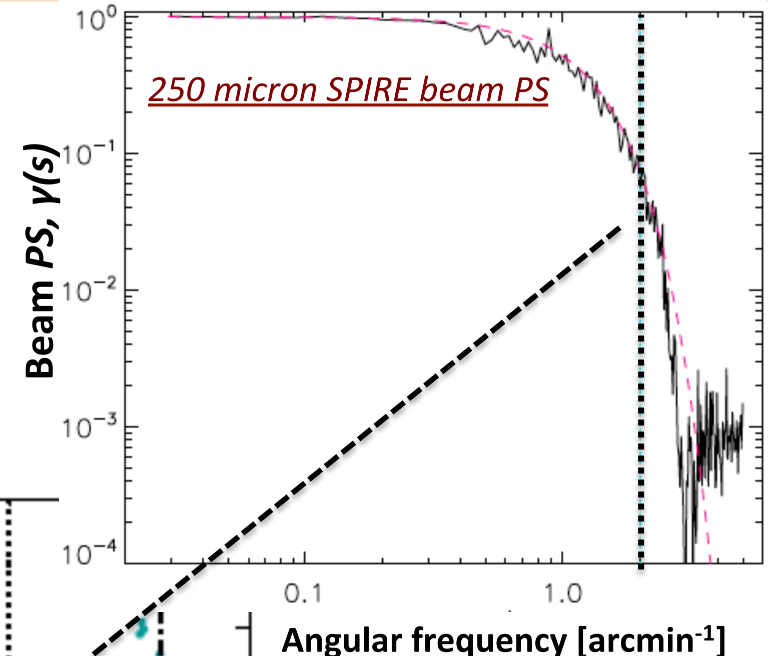


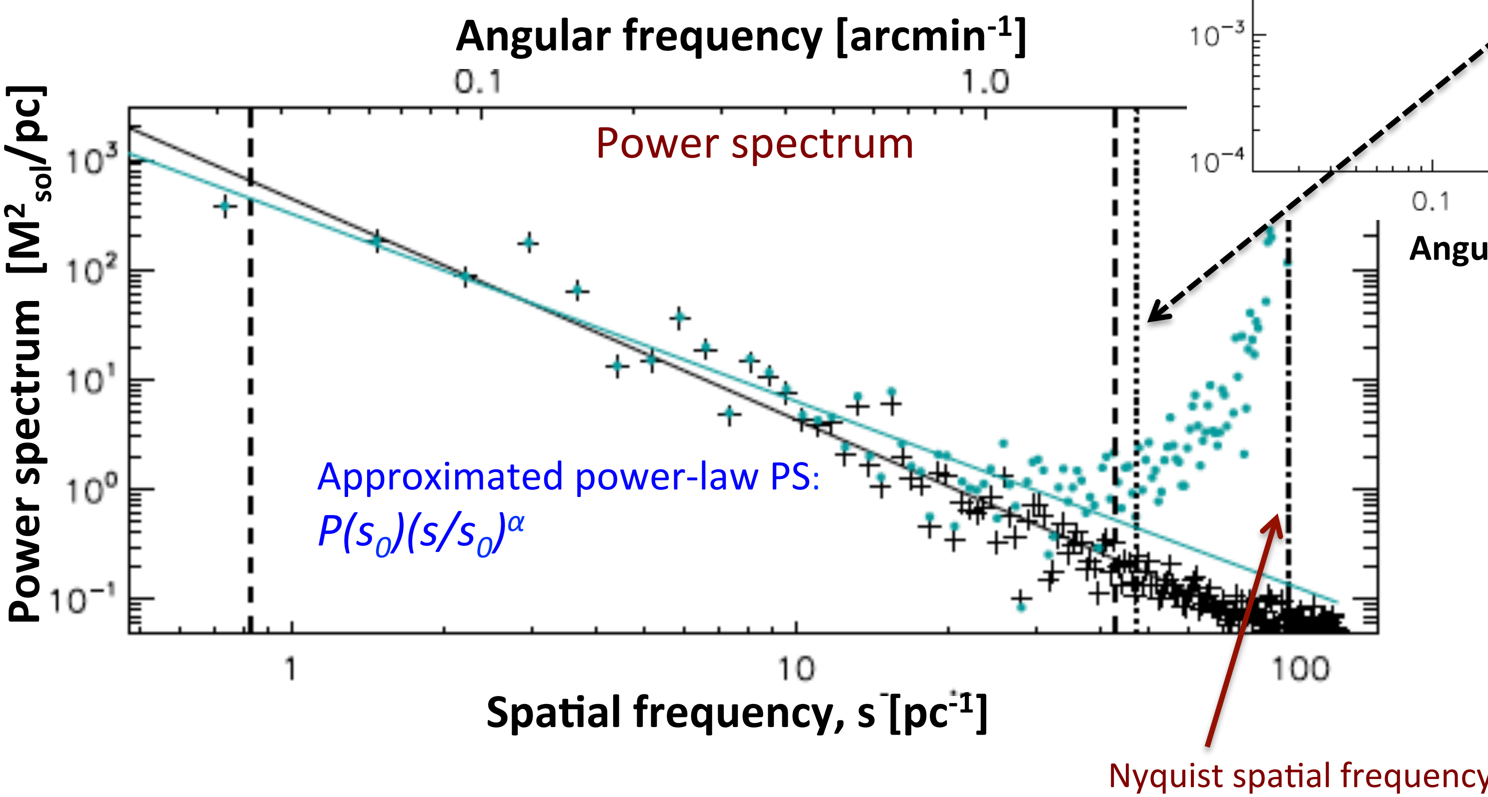
Statistical properties of line mass fluctuations

Power spectrum along a filament

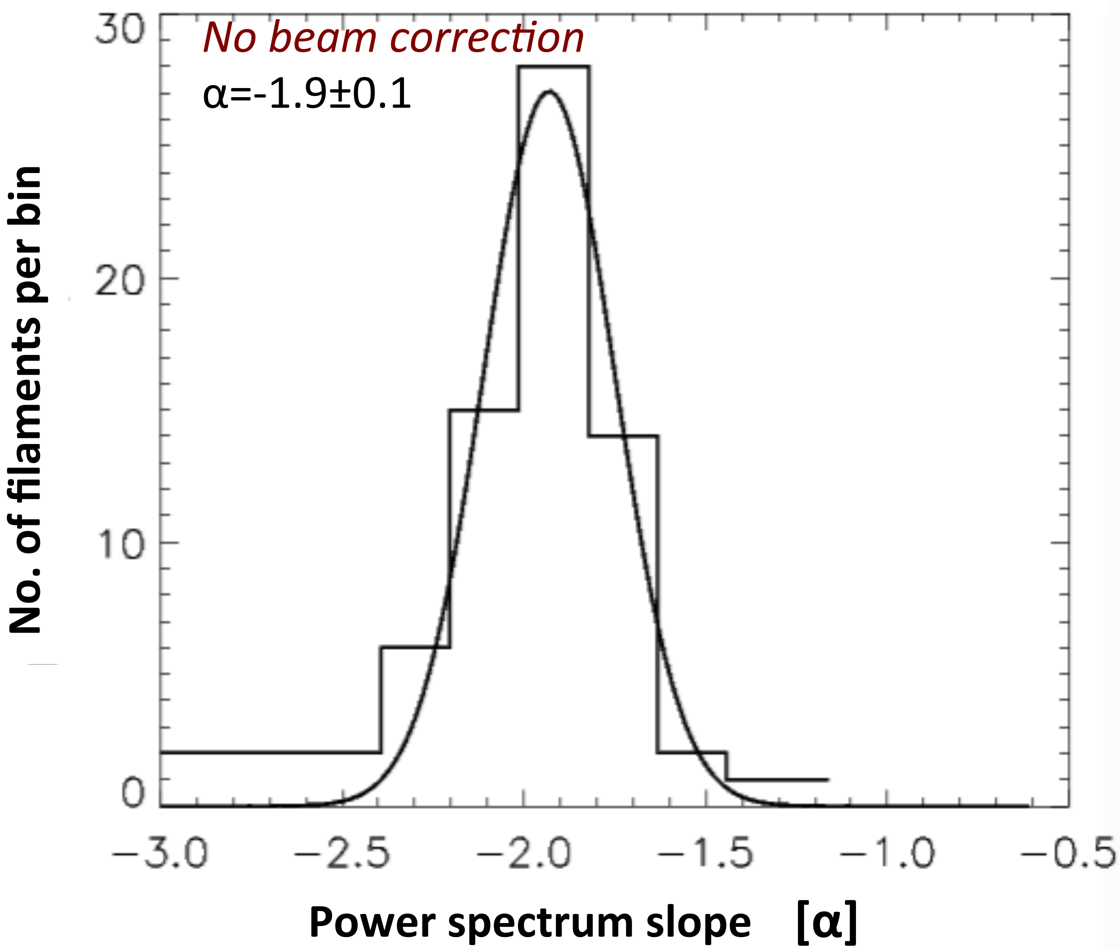
Beam *PS* — Intrinsic filament *PS* — Noise *PS*

$$P_{\rm obs}(s) = \gamma(s) \times P_{\rm fil}(s) + P_{\rm N}(s).$$



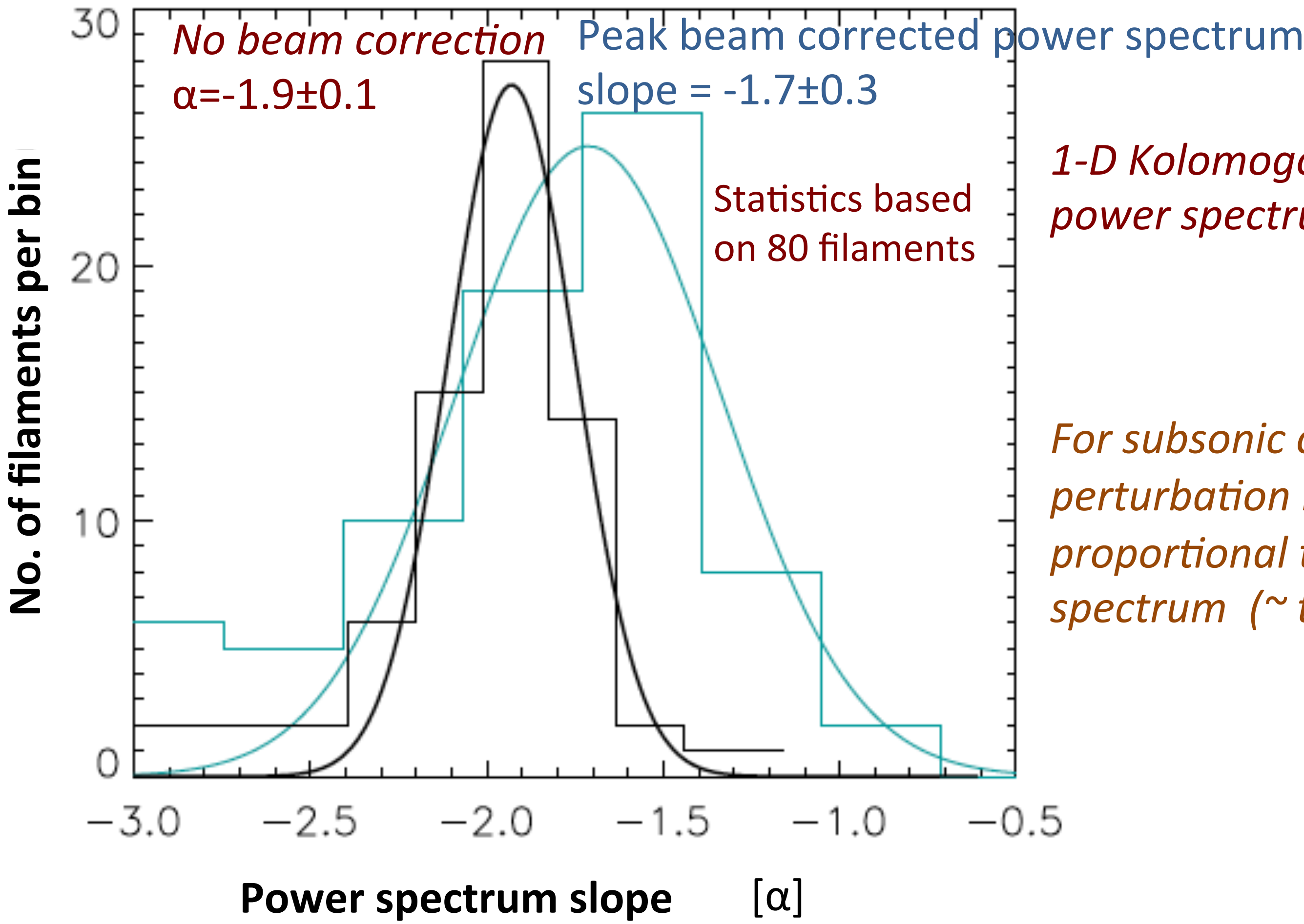


Characteristic power spectrum slope for filaments



Roy, Andre', Arzoumanian et al. 2014 to be submitted

Characteristic power spectrum slope for filaments



1-D Kolomogorov energy/velocity power spectrum slope is -5/3 = -1.67

For subsonic case density perturbation is approximately proportional to velocity power spectrum (~ to linear order)

Roy, Andre', Arzoumanian et al. 2014 to be submitted

Link to prestellar core mass function ?

Perturbed M_{line} field characterized by

$P(s)\ \alpha\ s^{\alpha}$

Variance: $$\sigma_M^2 = \frac{1}{L}\int |\delta_M(x)|^2 dx = \frac{L}{2\pi}\int_{-k_M}^{k_M} |\delta_k(k')|^2 dk'$$

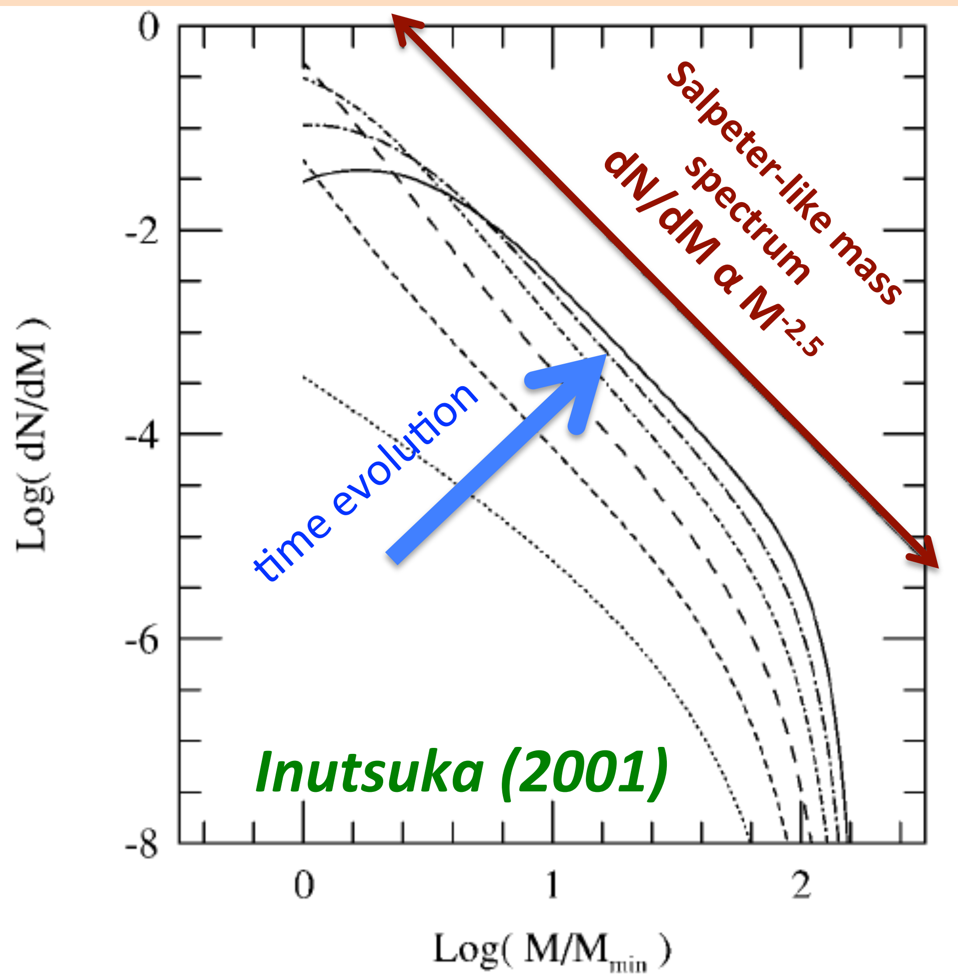
Pdf: $$f(M,\ \delta > \delta_c) = \int_{\delta_c}^{\infty} \frac{1}{\sqrt{2\pi\sigma_M^2}} \exp\left(-\frac{\delta^2}{2\sigma_M^2}\right) d\delta$$

Mass function (Press-Schechter formalism):

$$\frac{dN}{dM} = -2\frac{M_{\rm line}}{M}\frac{df(M,\ \delta > \delta_c)}{dM}$$
$$= -\frac{M_{\rm line}}{M}\frac{\delta_c}{\sqrt{\pi}}\exp\left(-\frac{\delta_c^2}{2\sigma_M^2}\right)\frac{1}{\sigma_M^3}\frac{d\sigma_M^2}{dM}$$

Adopted power spectrum slope of-1.5

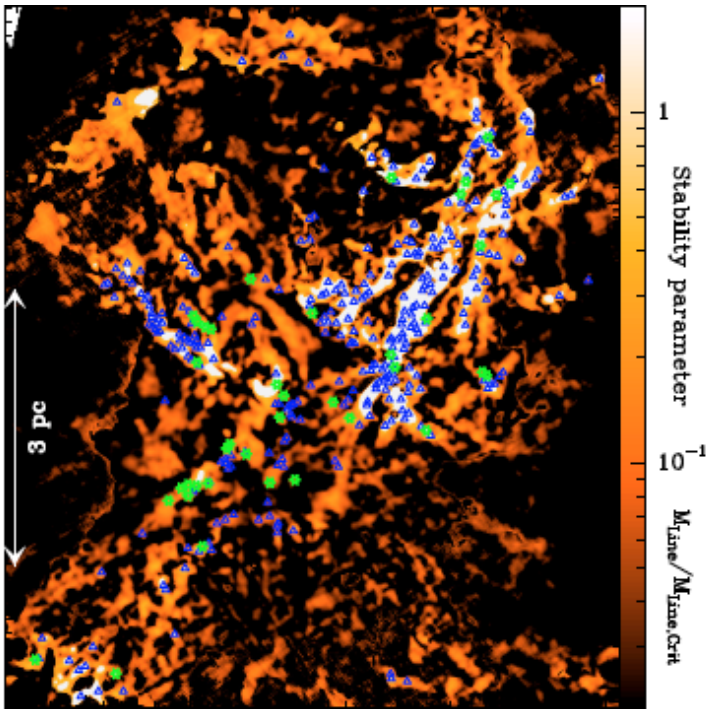
$dN/dM \longrightarrow M^{-2.5}$



c.f., Hennebelle & Chabrier 2008

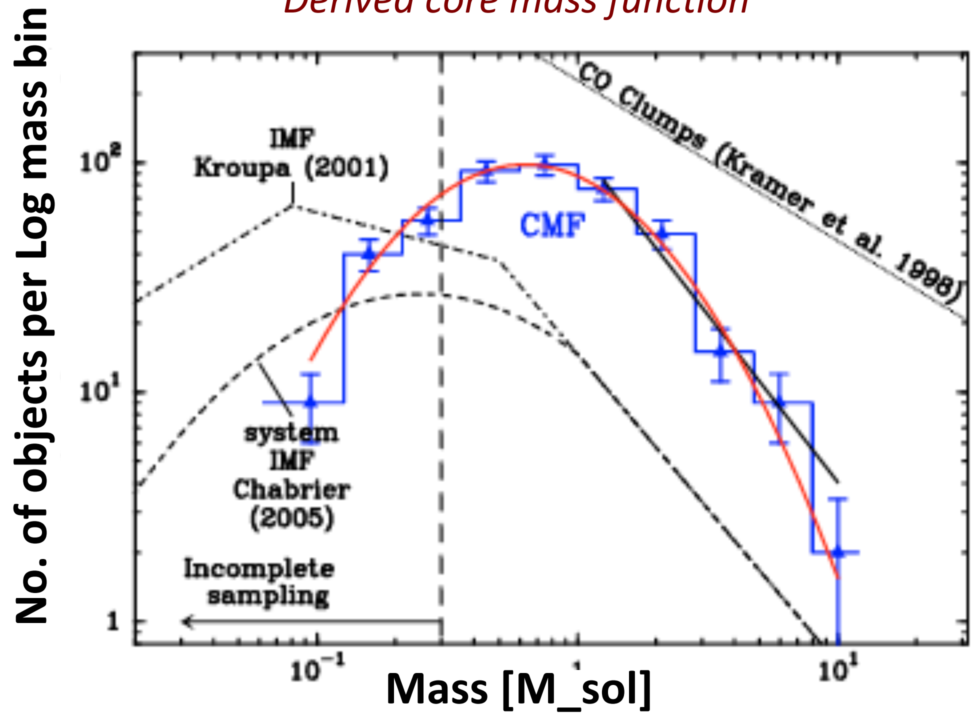
How this scenario fits with observations?

~75% of the prestellar cores are along supercritical filaments in Aquila



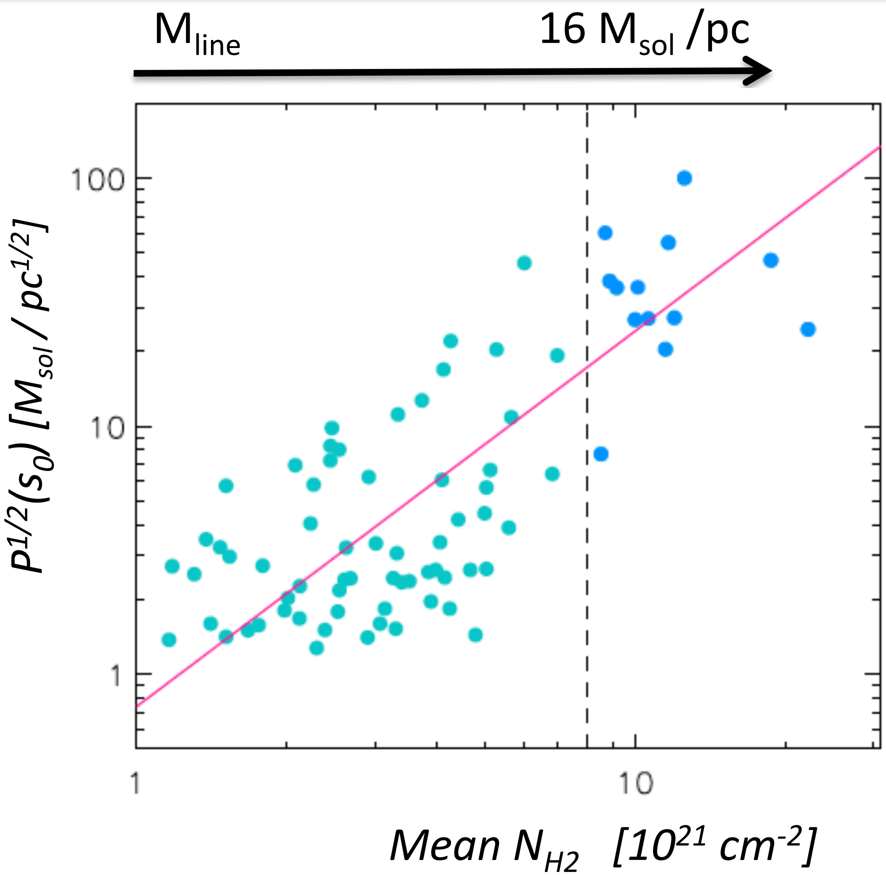
Andre' et al., 2010 & Konyves et al., 2010 more to come from Konyves et al., 2014

Derived core mass function



- *Possibly, supercritical filaments in Aquila back in time (few 10^4 years) were seeded with hierarchical density perturbations due to transonic turbulence*
- *Initial memory retained in the later part of the evolution*

Standard deviation of line-mass fluctuations



$P^{0.5}(s_0) \propto N_{H2}^{1.5\pm0.1}$

Conclusions

- Power spectrum slope of line mass fluctuations has a characteristic value around 1.7
- Interstellar turbulence seeds the initial line mass fluctuations along filaments
- Suggests that supercritical filaments collapse into a population of cores that has a mass spectrum similar to the Salpeter at the high mass end
- Possibility that the density perturbations due to turbulence is prerequisite for generating a Salpeter-like mass function