What is a Filament?

Di Li

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FAST

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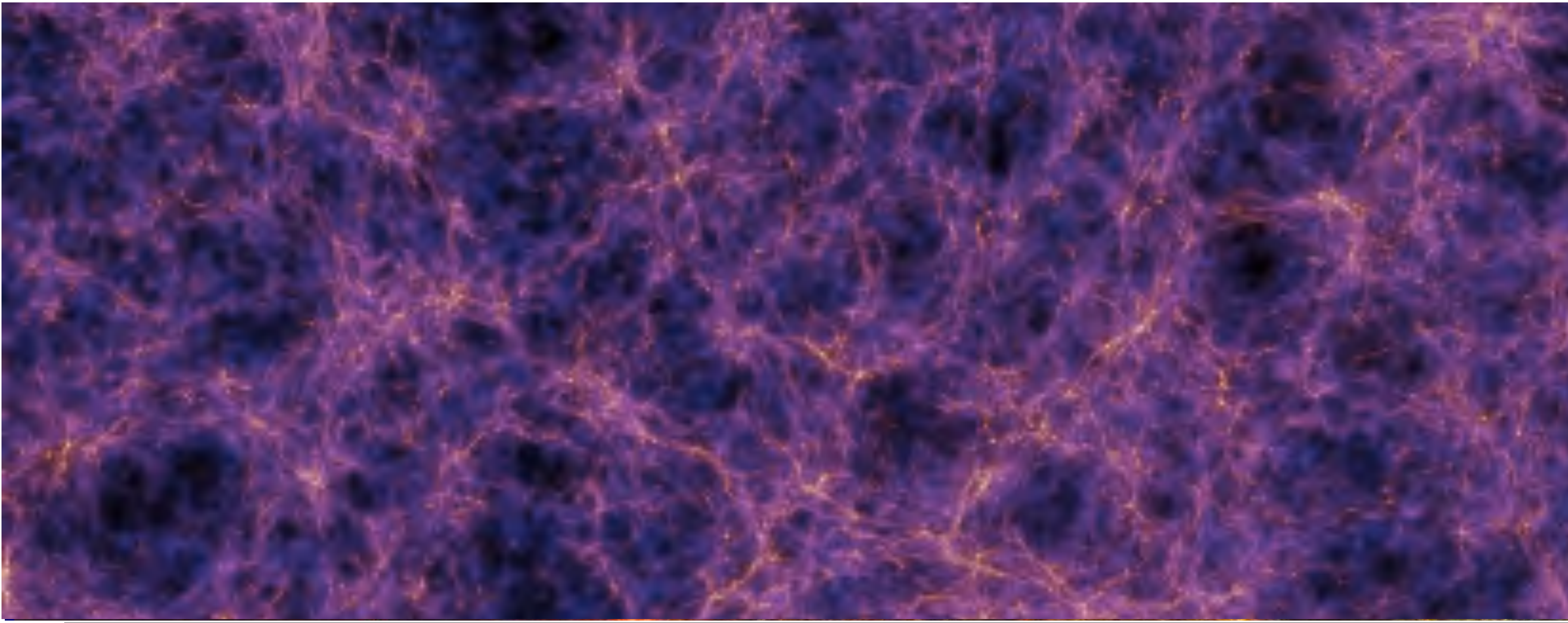
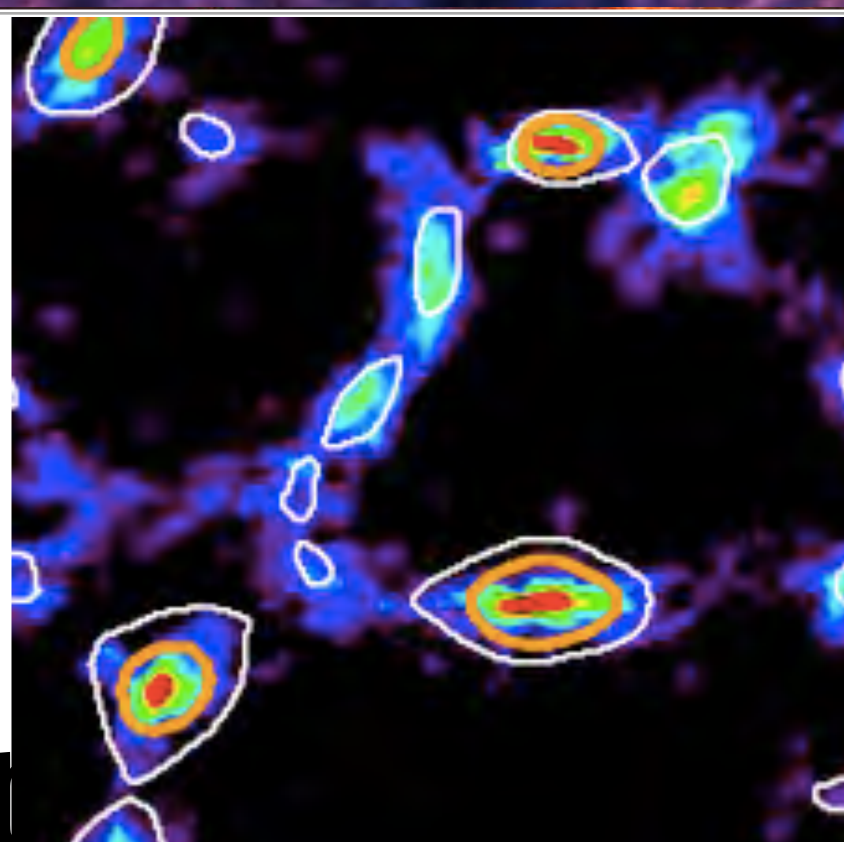
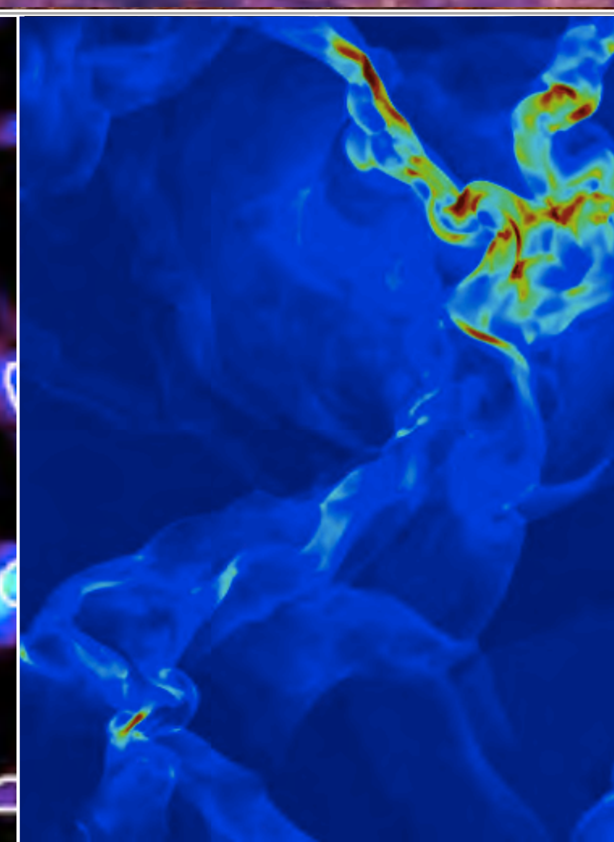
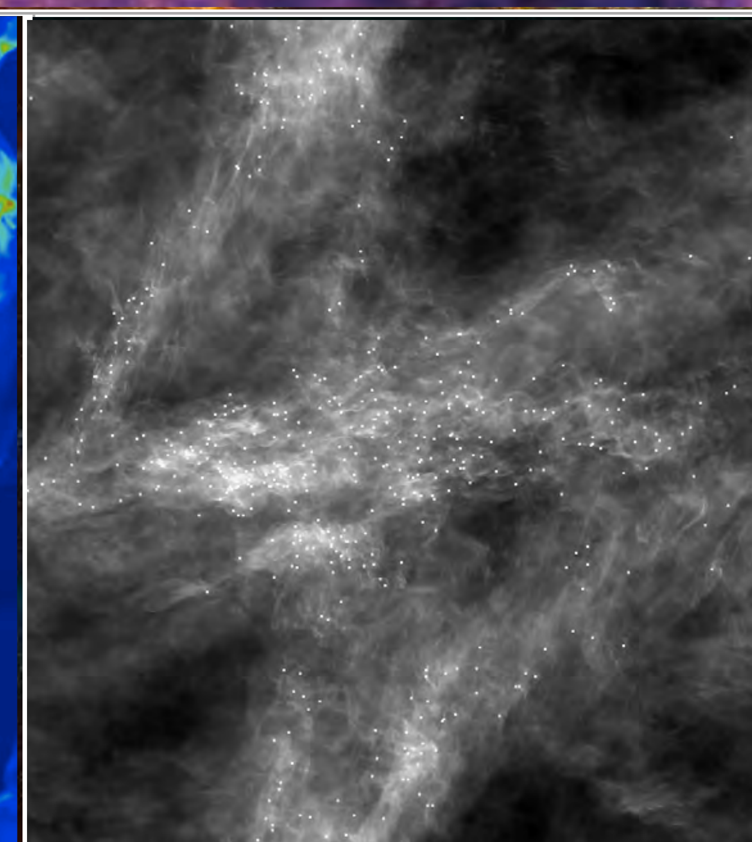








Filar

SF Physics - Energy Balance

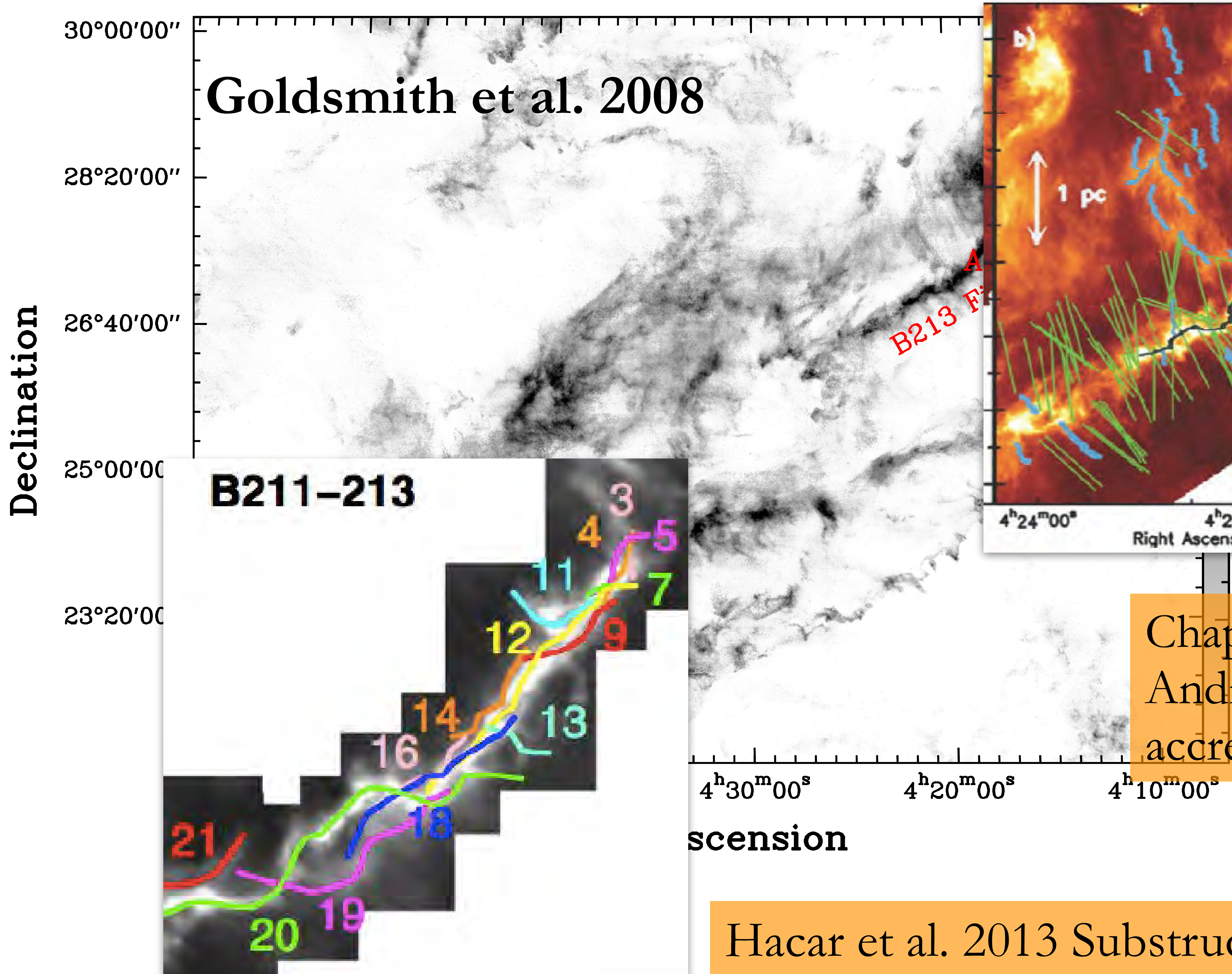
- Gravity: $E_G = -\frac{3}{5}\alpha\frac{GM^2}{r}$
- Pressure: $E_P = \frac{3}{2}\int \rho(\sigma_t^2 + \sigma_{nt}^2)dV$
- Magnetic field: $E_B = \frac{1}{8\pi}\int B dV$
- Turbulence, Fluid Dynamics

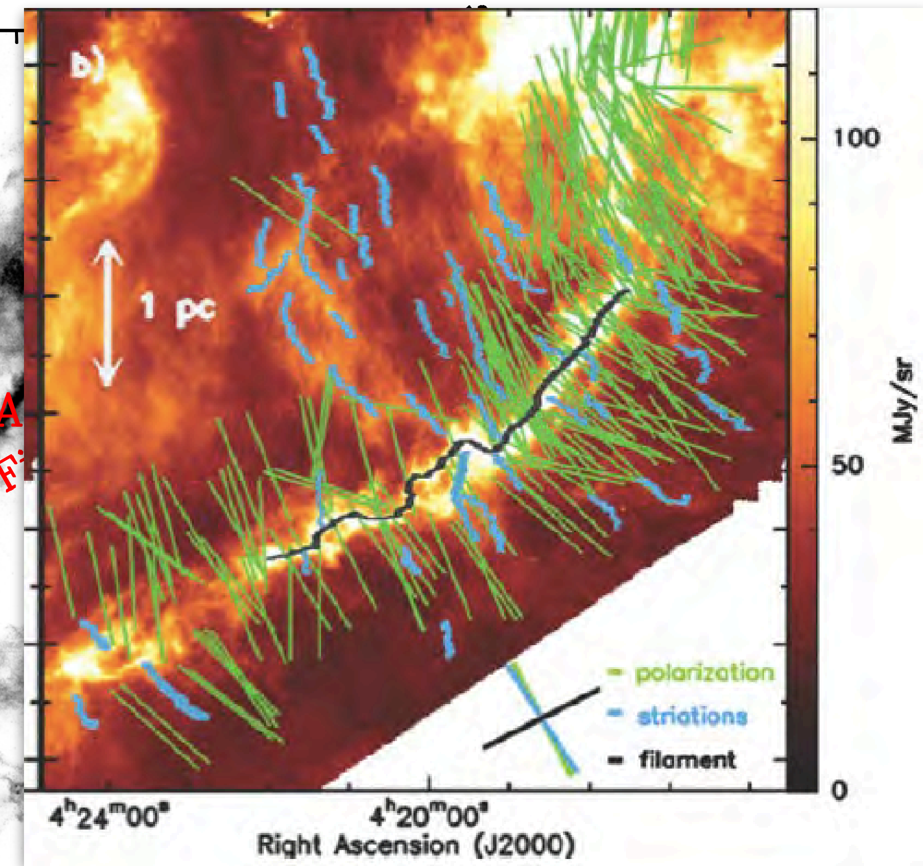
$$dV^2 \sim \mathbf{L^{0.5}}$$

$$M_J = \left(\frac{4\pi}{3}\right)\rho R_J^3 = \left(\frac{\pi}{6}\right)\frac{c_s^3}{G^{3/2}\rho^{1/2}} \simeq (2\ \mathrm{M_\odot})\left(\frac{c_s}{0.2\ \mathrm{km\ s^{-1}}}\right)^3\left(\frac{n}{10^3\ \mathrm{cm^{-3}}}\right)^{-1/2}$$

- Feedback: Supernova, outflow, bubbles …

Sheet or Cylinder?

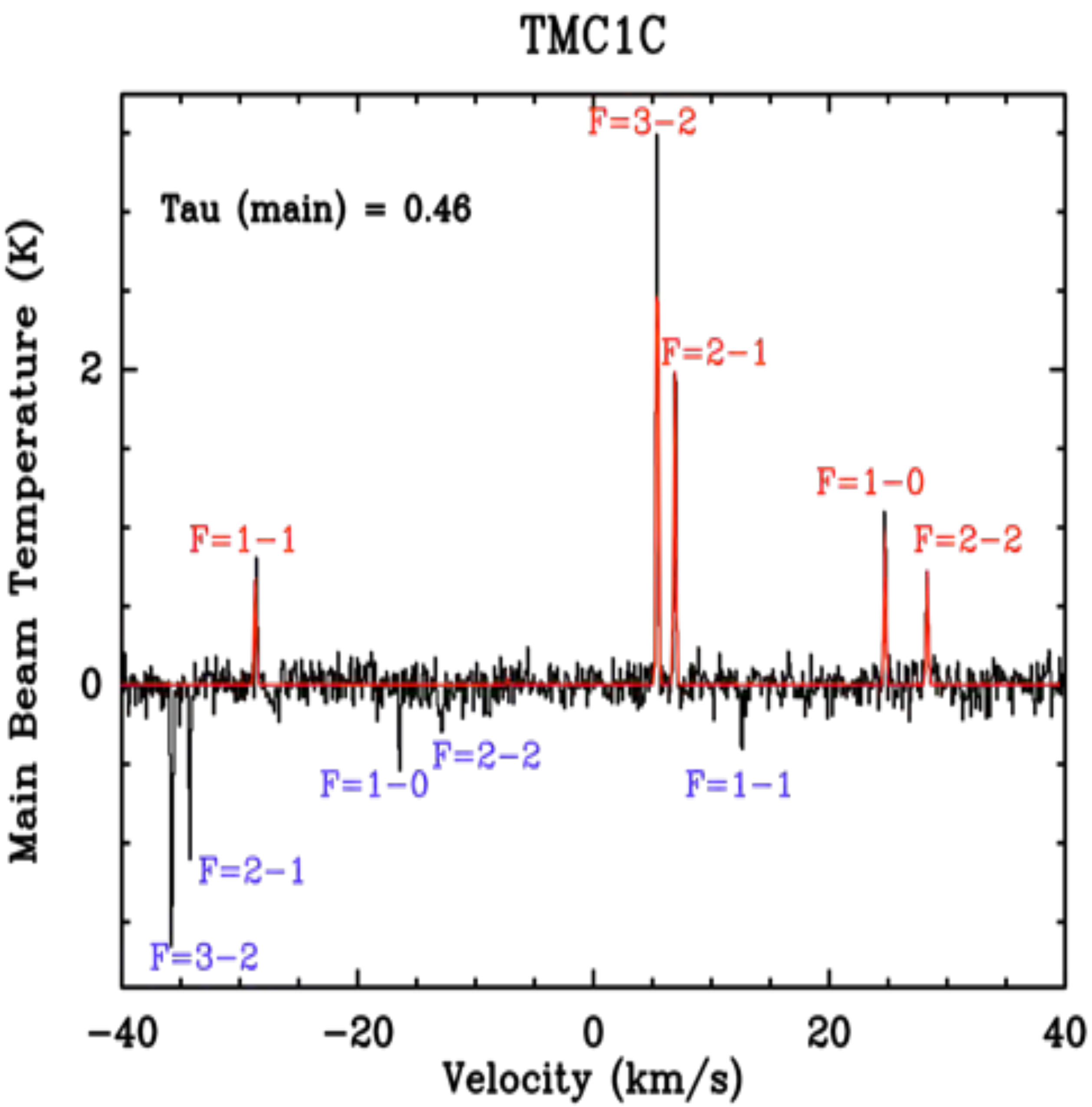




Chapman et al. 2011
Andre et al. 2012
accretion?

Hacar et al. 2013 Substructures?

Cyanopolyyne - HC_3N



Li & Goldsmith 2012, ApJ

HC_3N

2-1 18.2 GHz

…

5-4 45.5 GHz

…

10-9 91.0 GHz

A&A 553, A119 (2013)
DOI: 10.1051/0004-6361/201220822

Astronomy & Astrophysics

Formation and evolution of interstellar filaments

Hints from velocity dispersion measurements⋆,⋆⋆

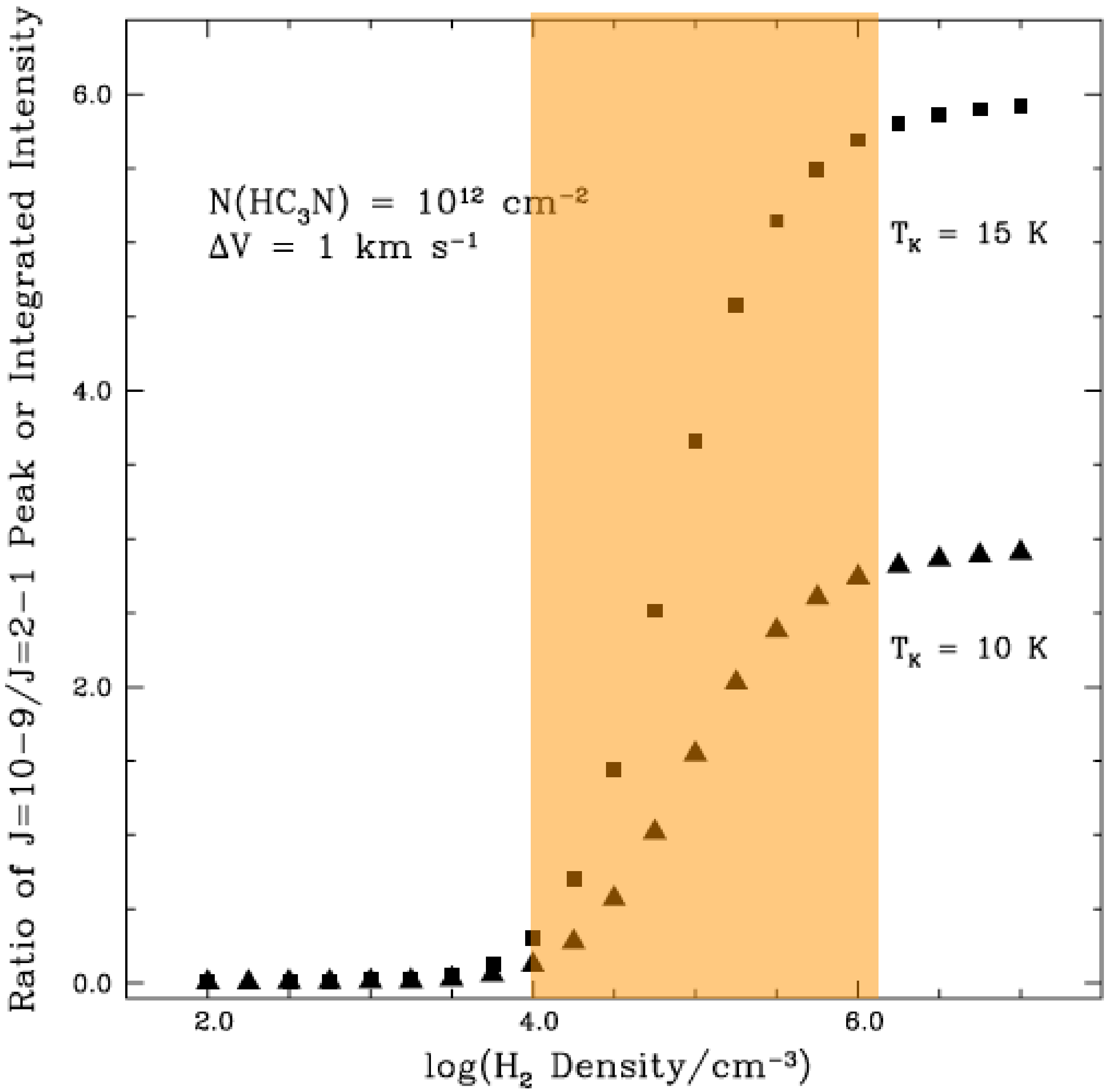
D. Arzoumanian[1,2], Ph. André[1], N. Peretto[1], and V. Könyves[1,2]

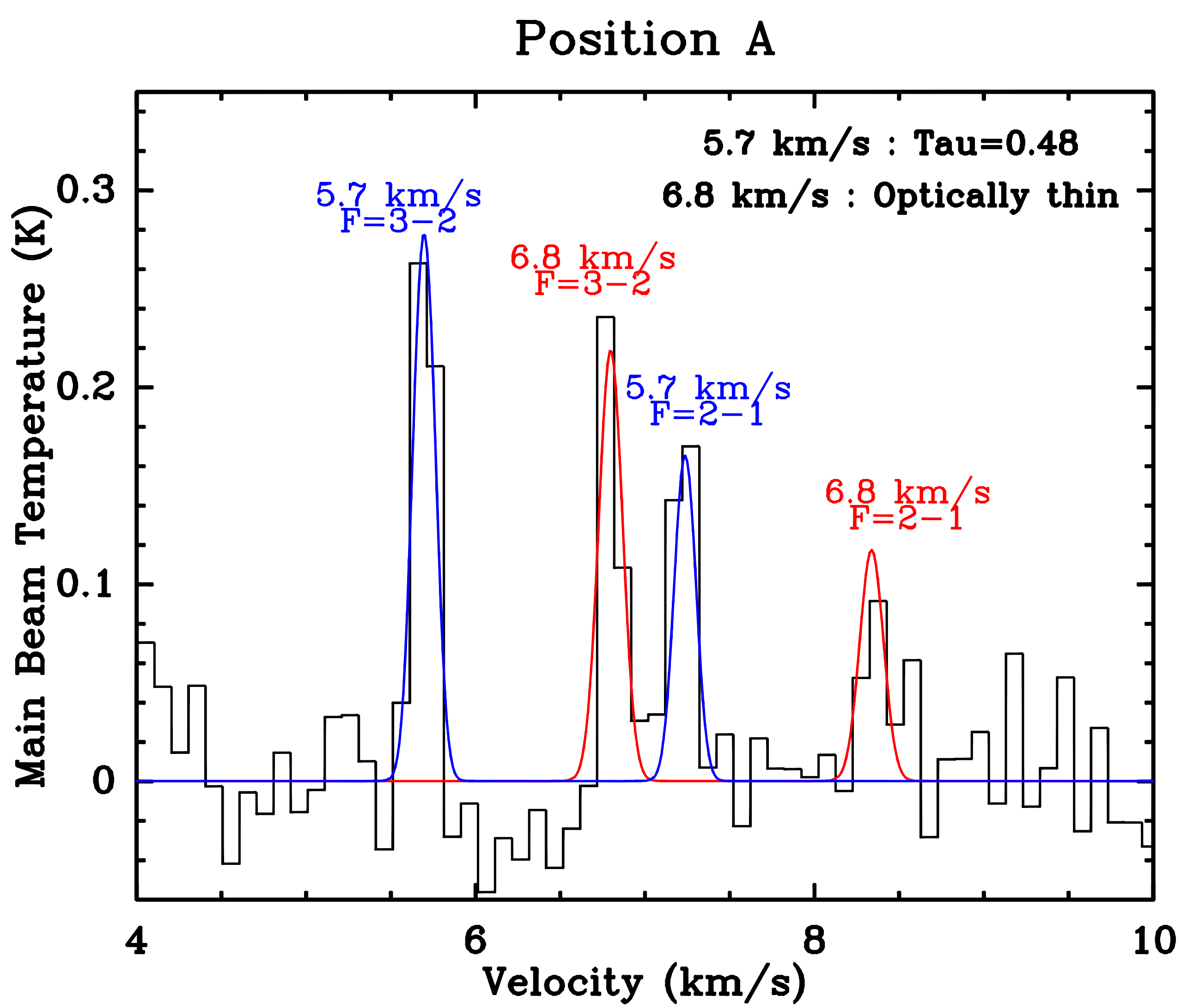
small along the crest of the filament (cf. right panel of Fig. 5), with an average velocity dispersion (0.25 ± 0.03) km s^{-1}. This is consistent with previous observations of a few low-density filaments showing that these structures have velocity dispersions close to the thermal velocity dispersion ~0.2 km s^{-1} for T = 10 K (cf. Hily-Blant 2004; Hily-Blant & Falgarone 2009) and which do not vary much along their length (Hacar & Tafalla 2011; Pineda et al. 2011). Recently, Li & Goldsmith (2012) studied the Taurus B213 filament and found that it is characterized by a coherent velocity dispersion of about ~0.3 km s^{-1}.

These results suggest that the velocity dispersion observed at a single position toward a filament provides a reasonably good estimate of the velocity dispersion of the entire filament[5]. Nevertheless mapping observations of a broader sample

[5] An interstellar filament is an elongated structure characterized by small column density variations along its crest (less than a factor of 3; see Fig. 3-left). Therefore, the velocity dispersion variations induced by the trend $\sigma_{tot} \propto \Sigma_0^{0.5}$ found in Sect. 5 below for supercritical filaments remain small (≪2) along a given filament.

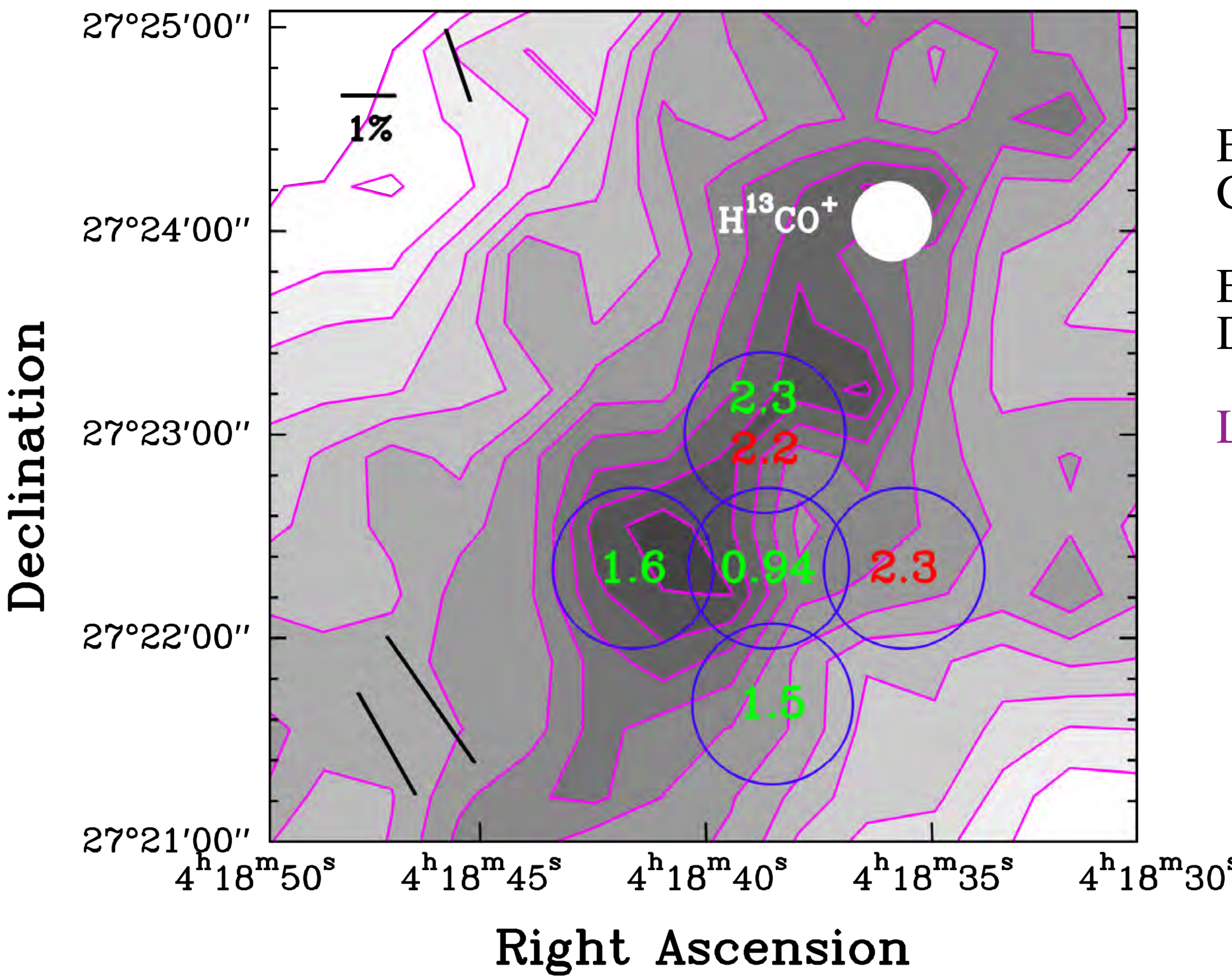
Densitometer





HC3N as densitometer (Li & Goldsmith 2012, ApJ)

Filament - Cylinder



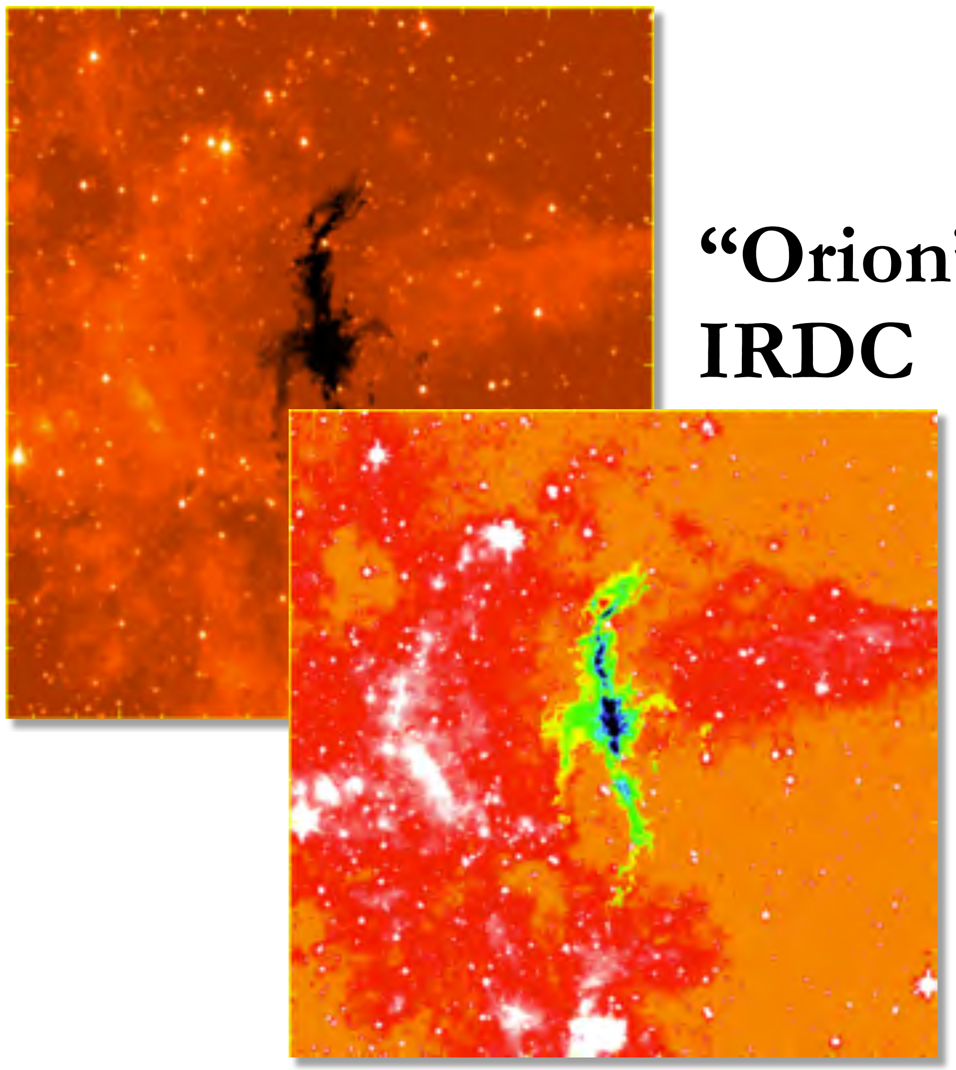
Taurus B213 Filament

Elongation: 1d ~ 2.4 pc
Cross : 3' ~ 0.12 pc

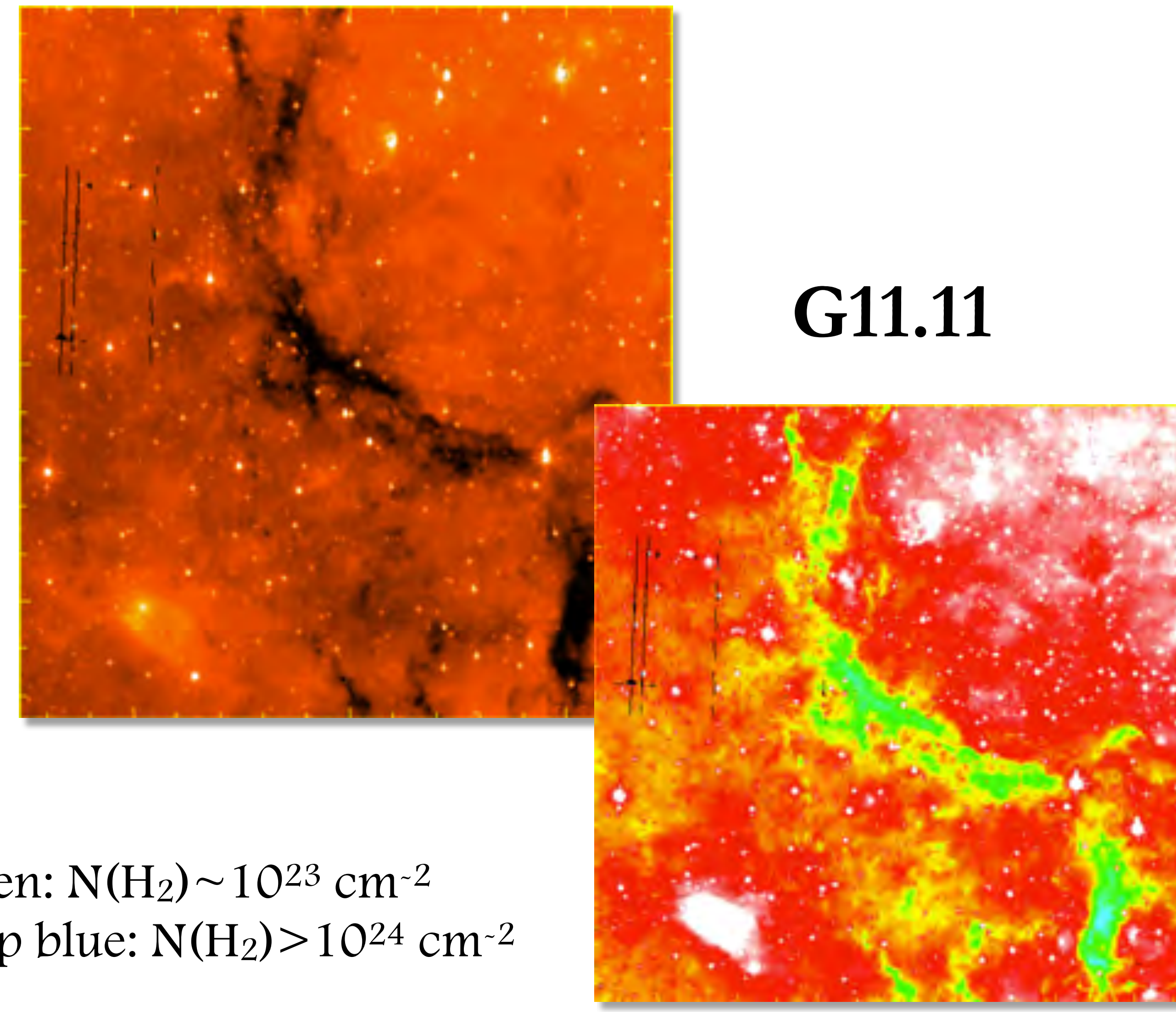
Extinction: Av =10 ~ 10^{22} cm^{-2}
Density: n = 10^4 cm^{-3}

LOS Dimension: 0.33 pc ~ 2.7'

IRDC ?



“Orion” IRDC



G11.11

Green: $N(H_2) \sim 10^{23}$ cm^{-2}
Deep blue: $N(H_2) > 10^{24}$ cm^{-2}

$$\tau_{8\,\mu m} = \kappa_{8\,\mu m}\Sigma = 7.5\left(\frac{\Sigma}{\text{g cm}^{-2}}\right).$$

$$I_{\nu,1} = e^{-\tau_\nu}\ I_{\nu,0},$$

- (Butler & Tan 2013)

Simulated observation shows how Orion A looks like in front of a bright infrared back ground. Denser and more compact absorption feature. (Ren et al. 2015 in prep.)

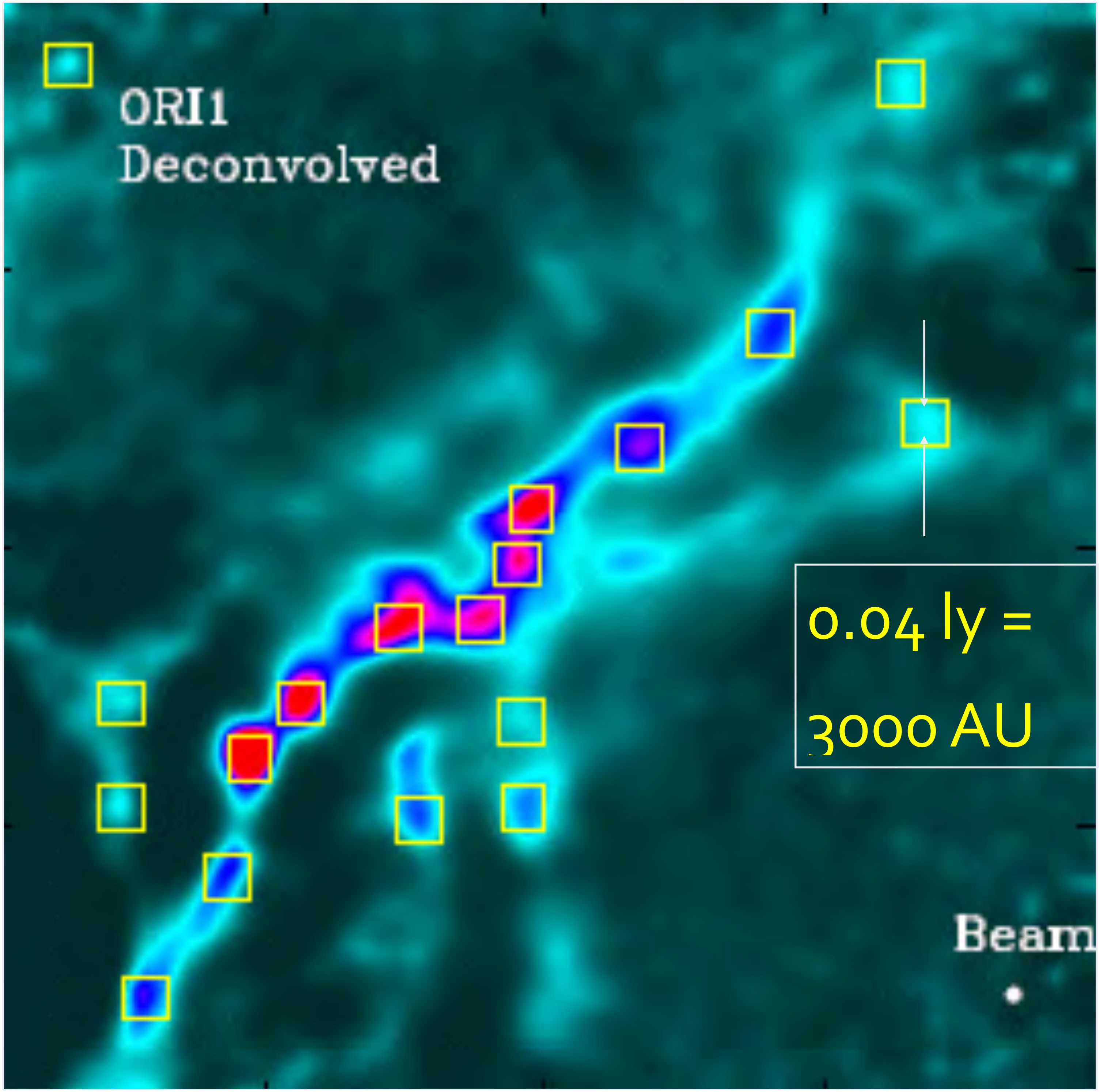
“Pearls on a string”

Cores in Orion

1 to 30 M_{sun}

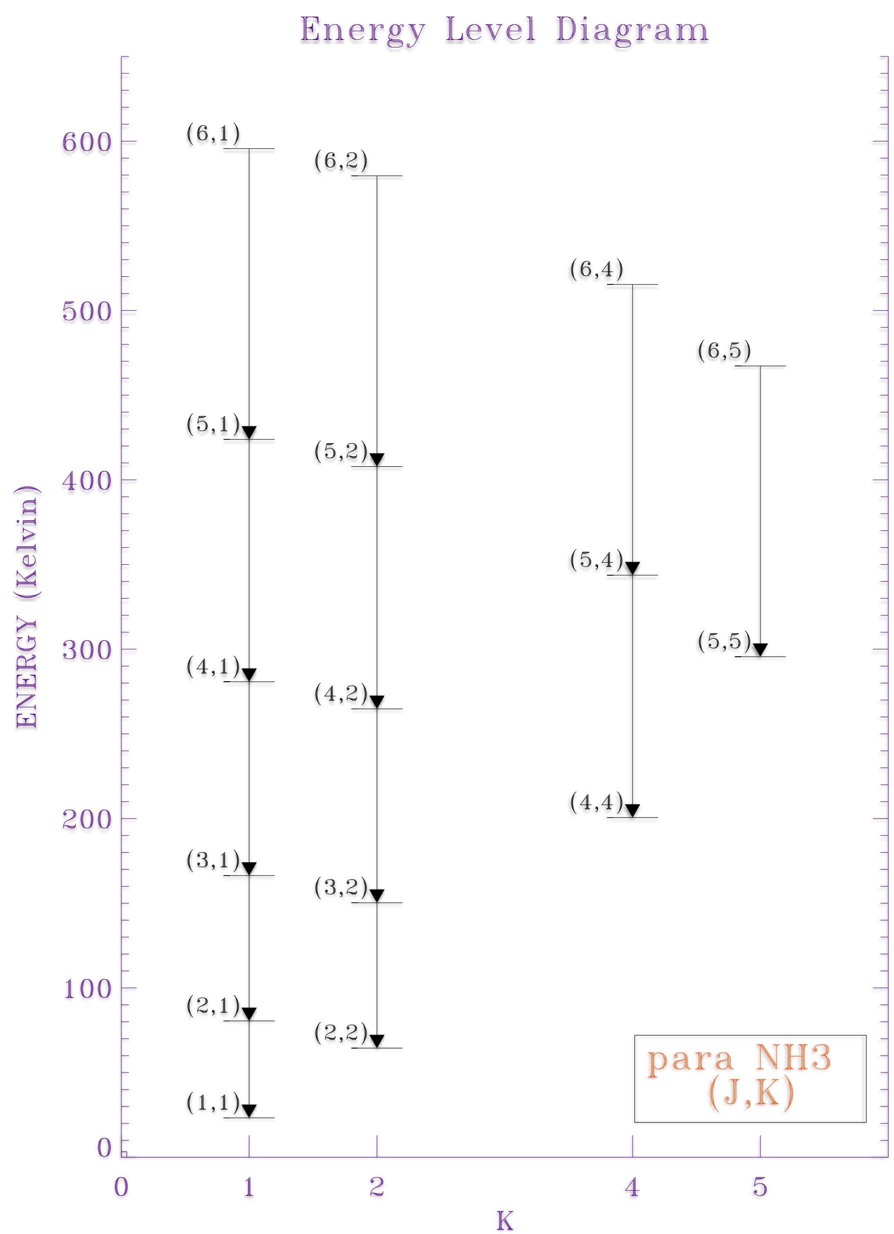
Appear to be unstable against gravitational collapse

Maybe forming next generation of stars

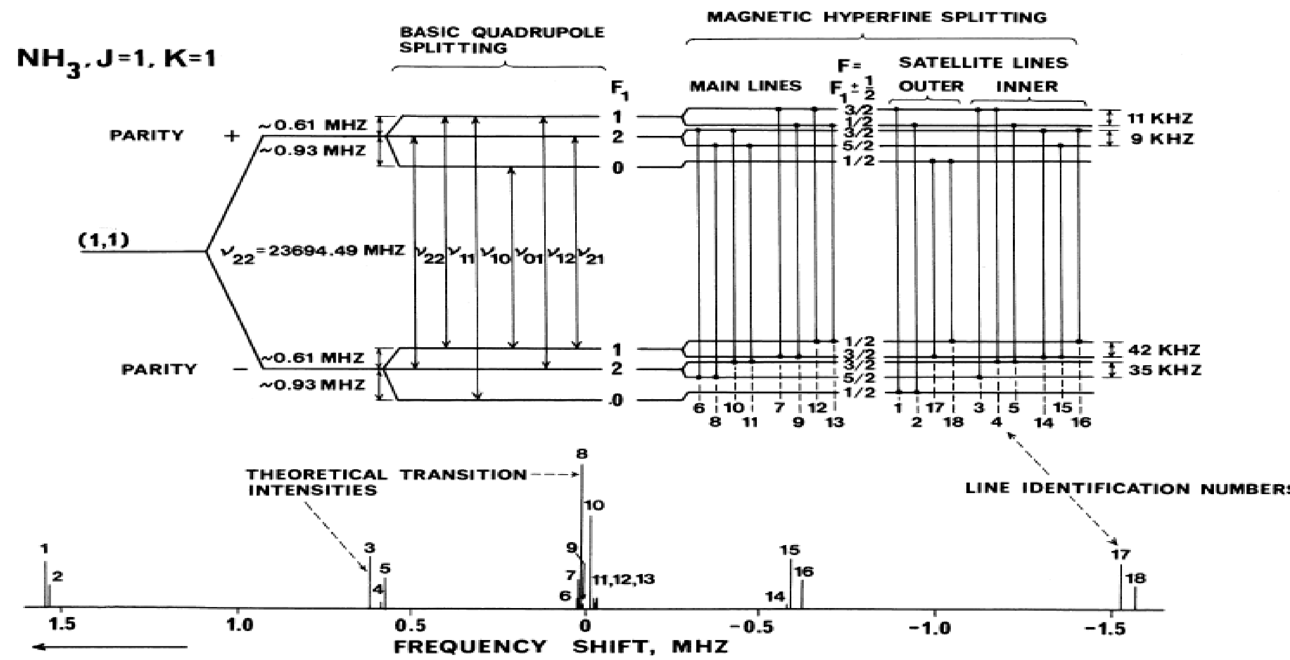


Li, Velusamy, Goldsmith, & Langer 2007

The Magic of NH_3



Li et al. 2013



Rydbeck 1977

$$T_R = 41.5\,\mathrm{K}/\ln[1.06 \times \mathcal{C}(1,\ 1) \times R^{12}], \qquad (1)$$

where $\mathcal{C}(1,\ 1)$ is a numerical factor determined as

$$\mathcal{C}(1,\ 1) = 0.003 + 2.26\,\mathcal{R}^{\mathrm{sm}} + 0.00032\,e^{5.38\,\mathcal{R}^{\mathrm{sm}}}, \qquad (2)$$

which is based on fitting the simulated NH_3 (1, 1) spectra based on a grid of opacities and line width. The kinetic temperature is then (Paper I)

$$T_k = 3.67 + 0.307 \times T_R + 0.0357 \times T_R^2. \qquad (3)$$

“SuperCitical” ?

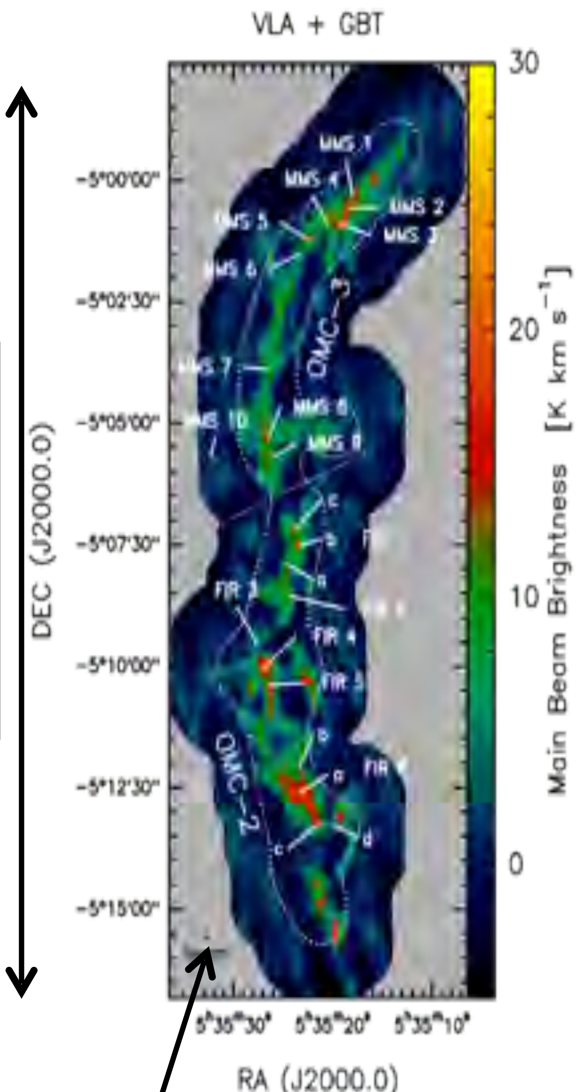
VLA+GBT

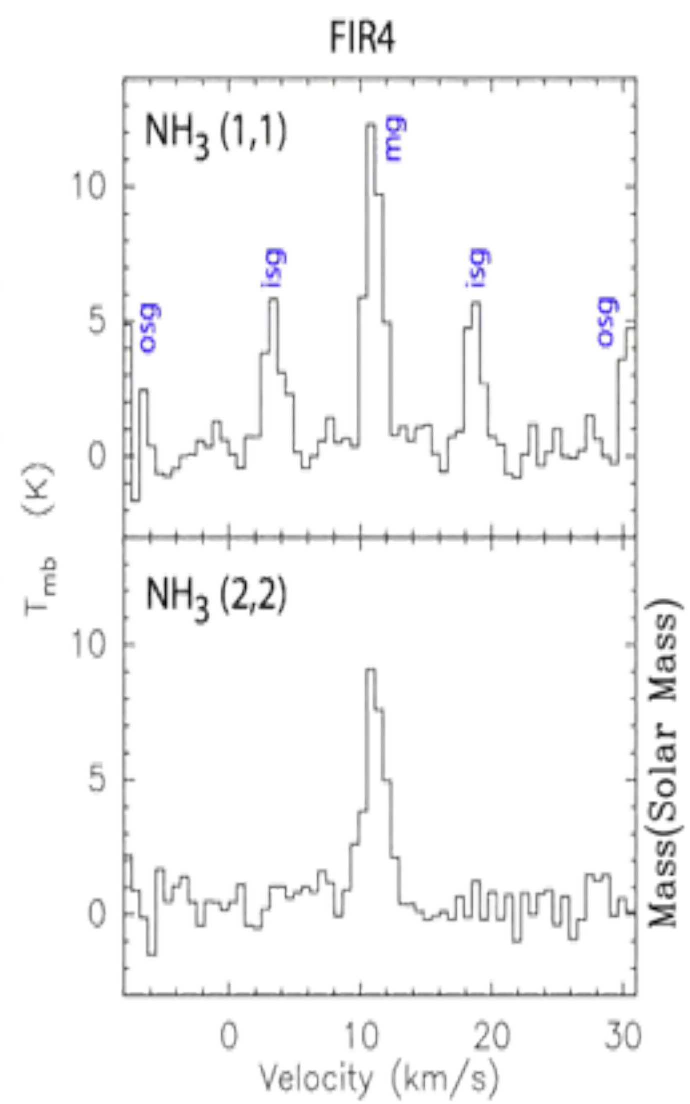
High Res. Ammonia Images

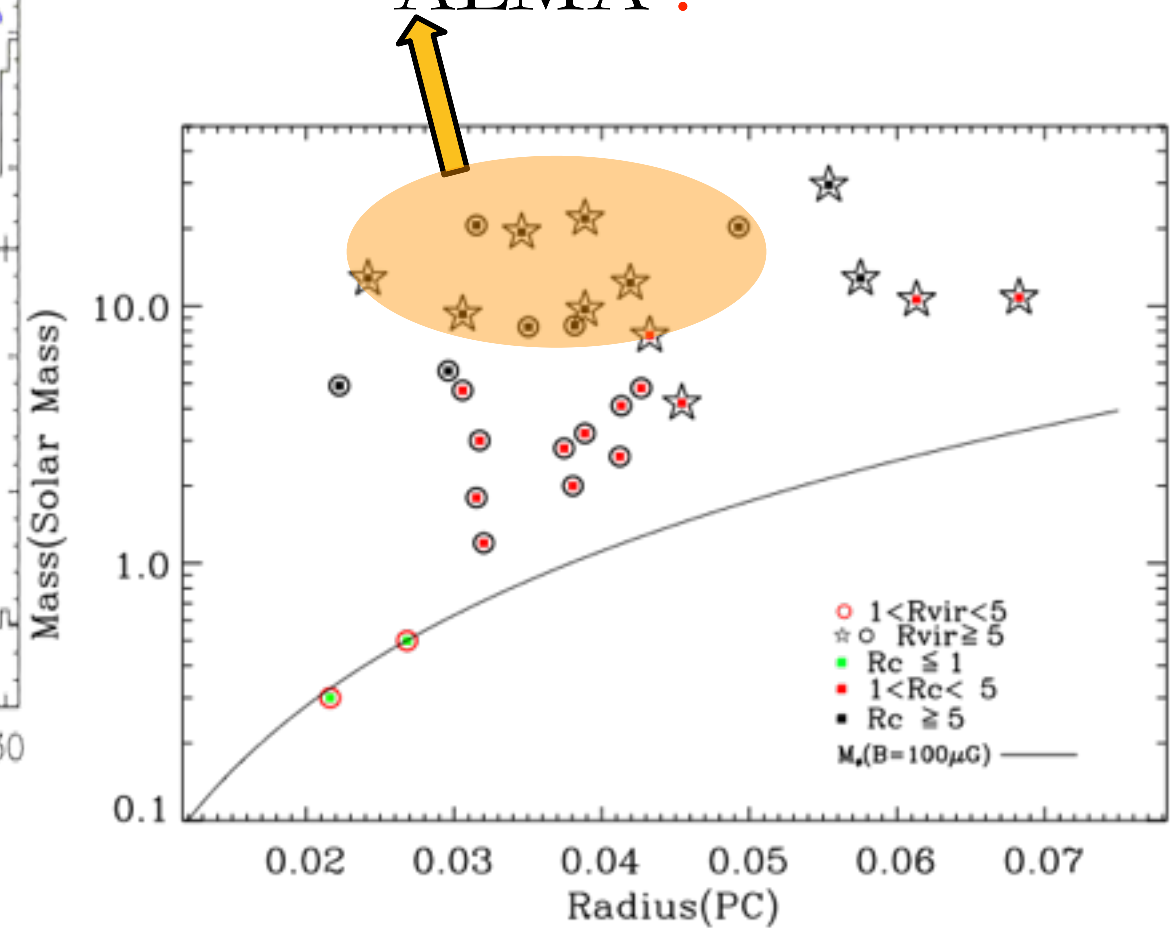
T, V, and dV

ALMA ?

Scale: 25’



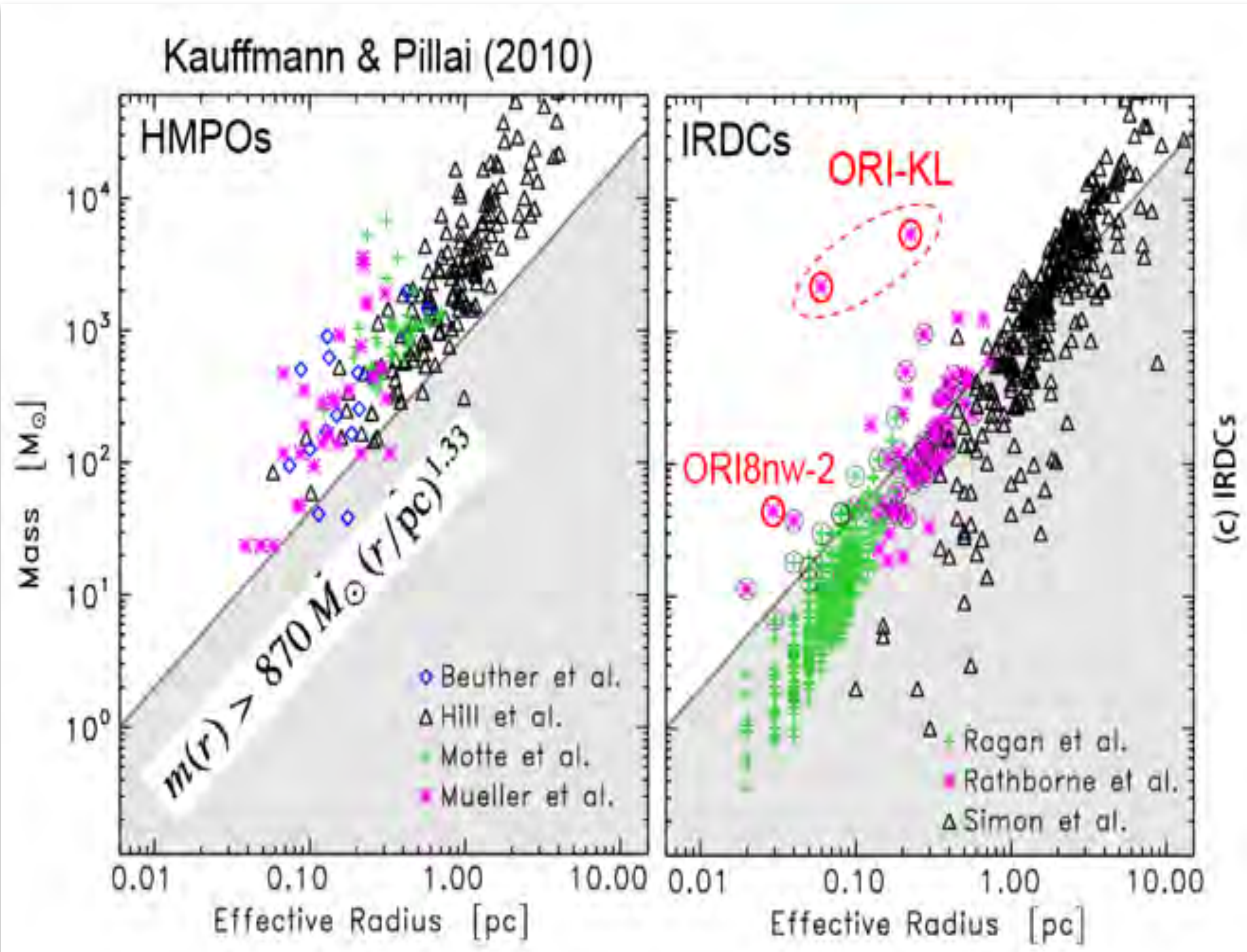




Beam : 3”

Li, Kauffmann, Zhang, Chen, 2013, ApJL

Is Orion a HMSF?

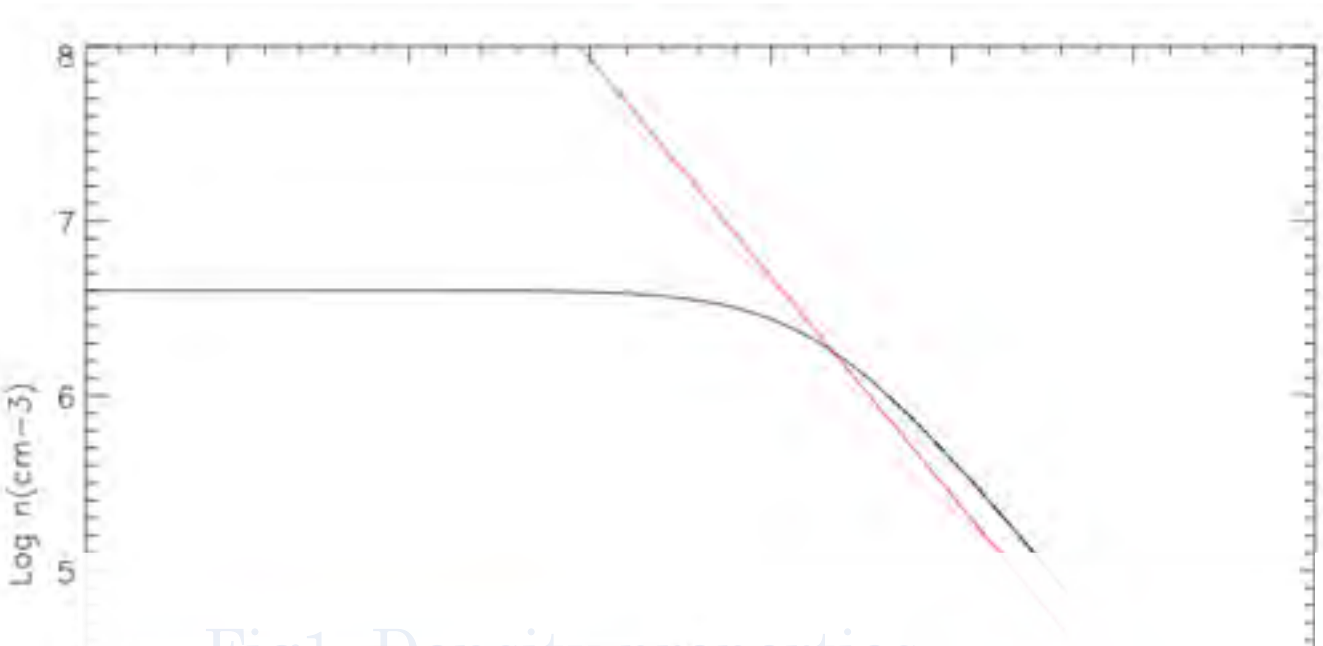


Zapata et al. 2011
Ren & Li 2014, 2015

The locations of the Orion cores on the Mass-Radius diagram for the young stellar cores(Kauffmann & Pillai 2010): high-mass prestellar objects (HMPOs, left panel) and IRDCs (right). The cores above the gray shadowed area may have potential to form high-mass stars.

It shows that the two Orion KL cores are high above the trend for the IRDCs, indicating the probability of becoming HMPOs. It also shows that the young high-mass cores in IRDCs (dark region) are scarce.

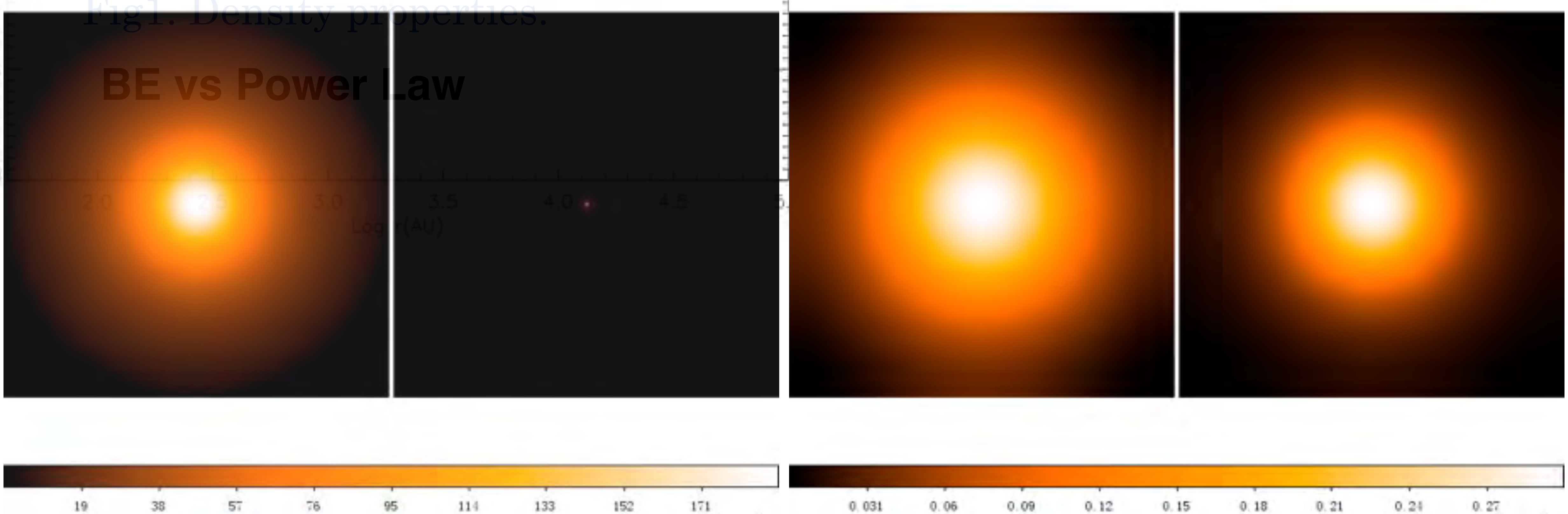
Core Physics: Resolution



A massive core in Orion

d=417pc
D=0.04pc 20”
m=50 M_{sun}

Temperature profile
T=10K constant value

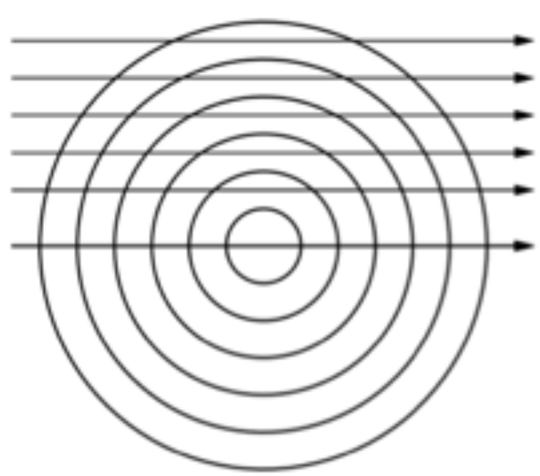


COREFIT

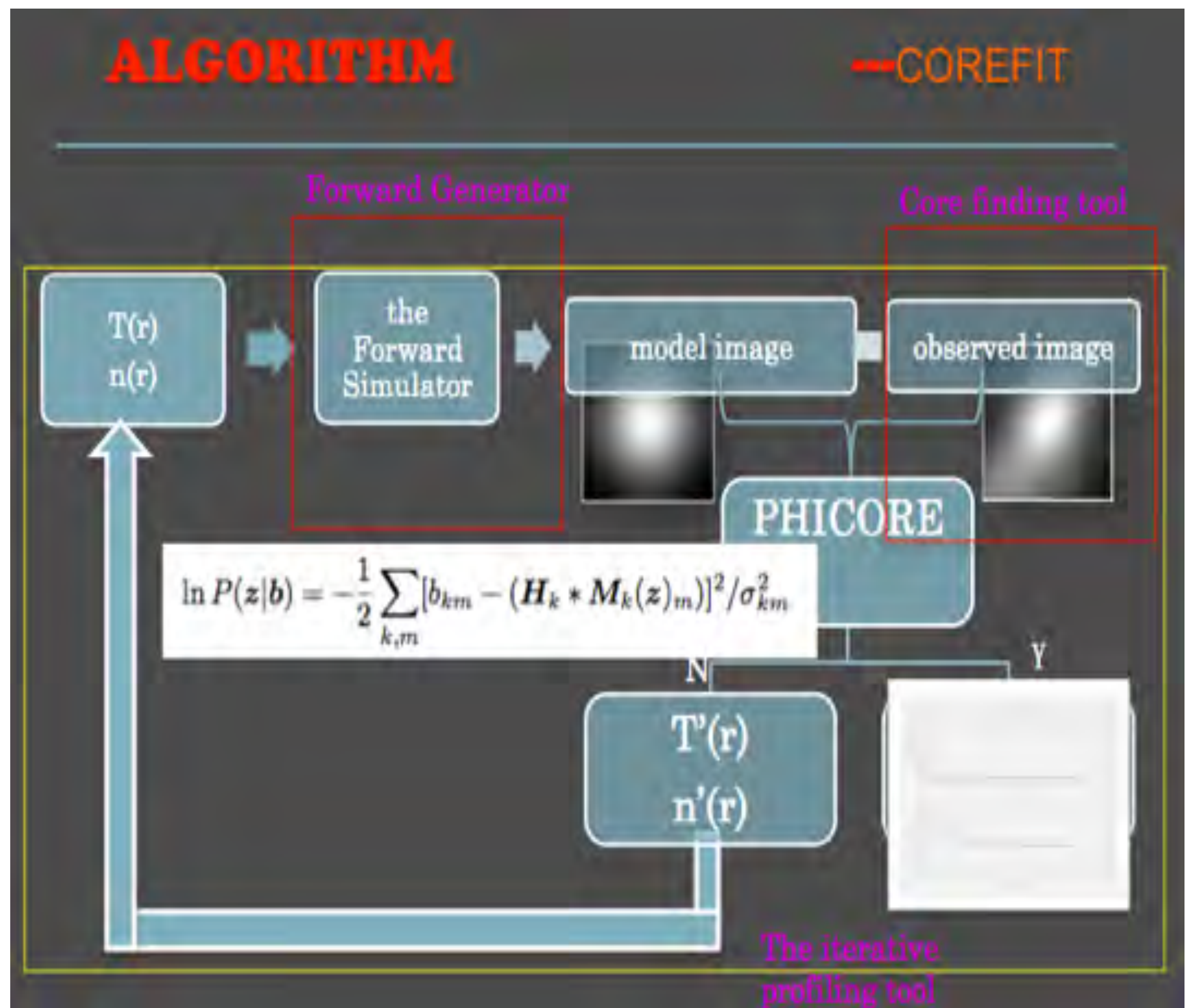
- ➡ Iterative inversion of multi-wave length data and SED data, providing estimates of density and temperature structure of a cold core. Three Components: The forward generator + A core finding tool + The iterative profiling tool . (Yue, Li, Marsh, Chapman 2015 in prep.)

$$T(r) = T_1 + \frac{T_0 - T_1}{1 + (\frac{r}{r_t})^2}$$

$$n_{H_2}(r) = \frac{n_{H_2}(0)}{1 + (\frac{r}{r_0})^\alpha}$$



$$I_\nu^i = I_\nu^{i-1} e^{-\tau_\nu^i} + B_\nu^i(T^i)(1 - e^{-\tau_\nu^i}).$$



COREFIT

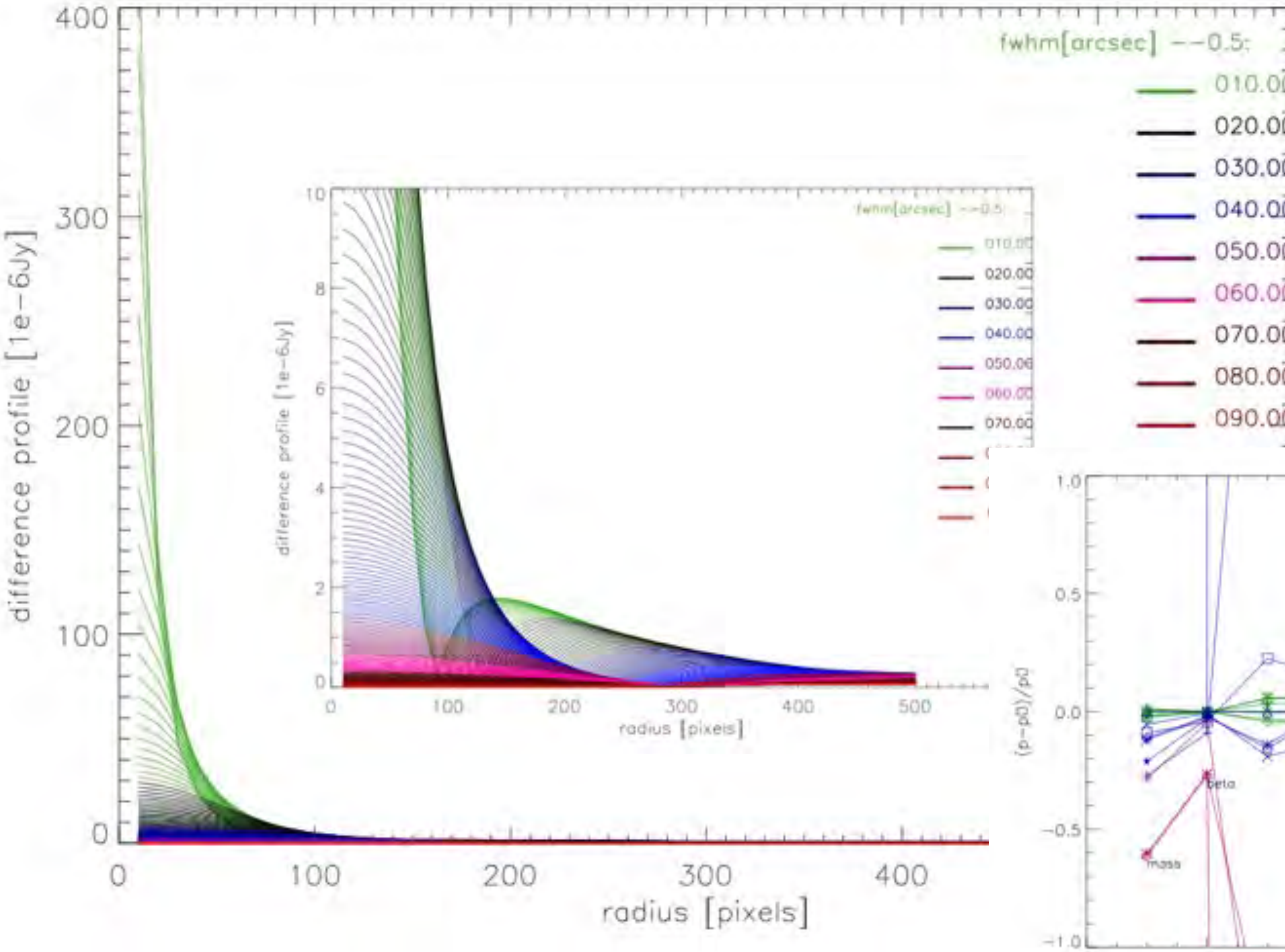
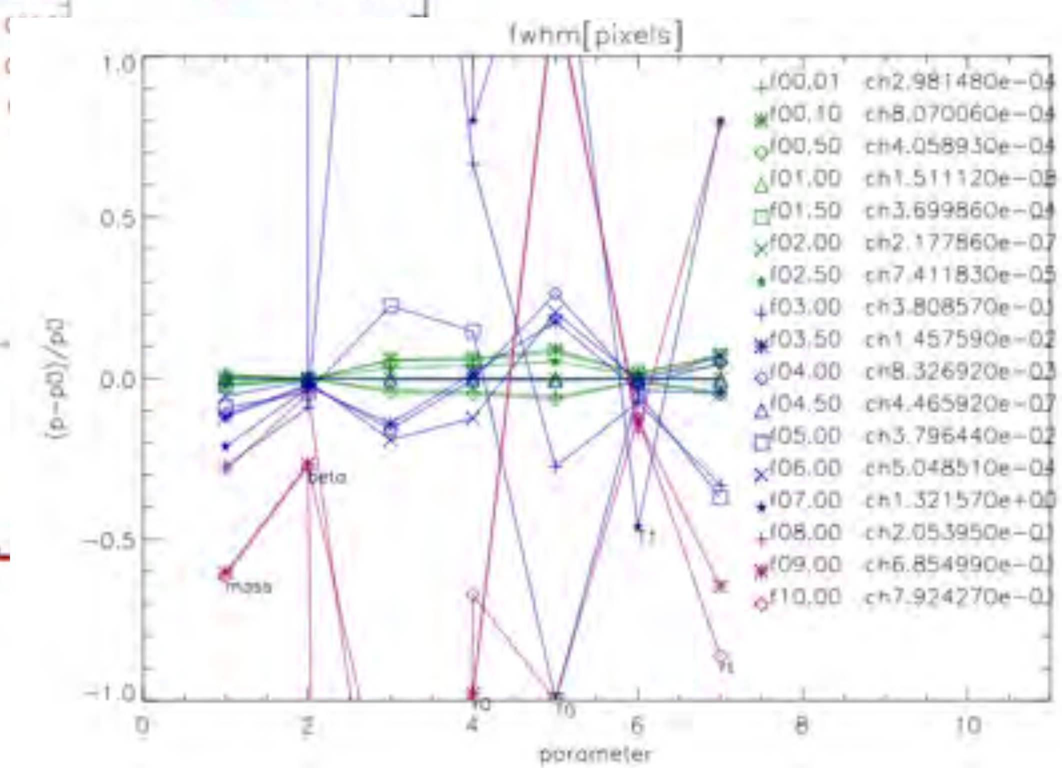
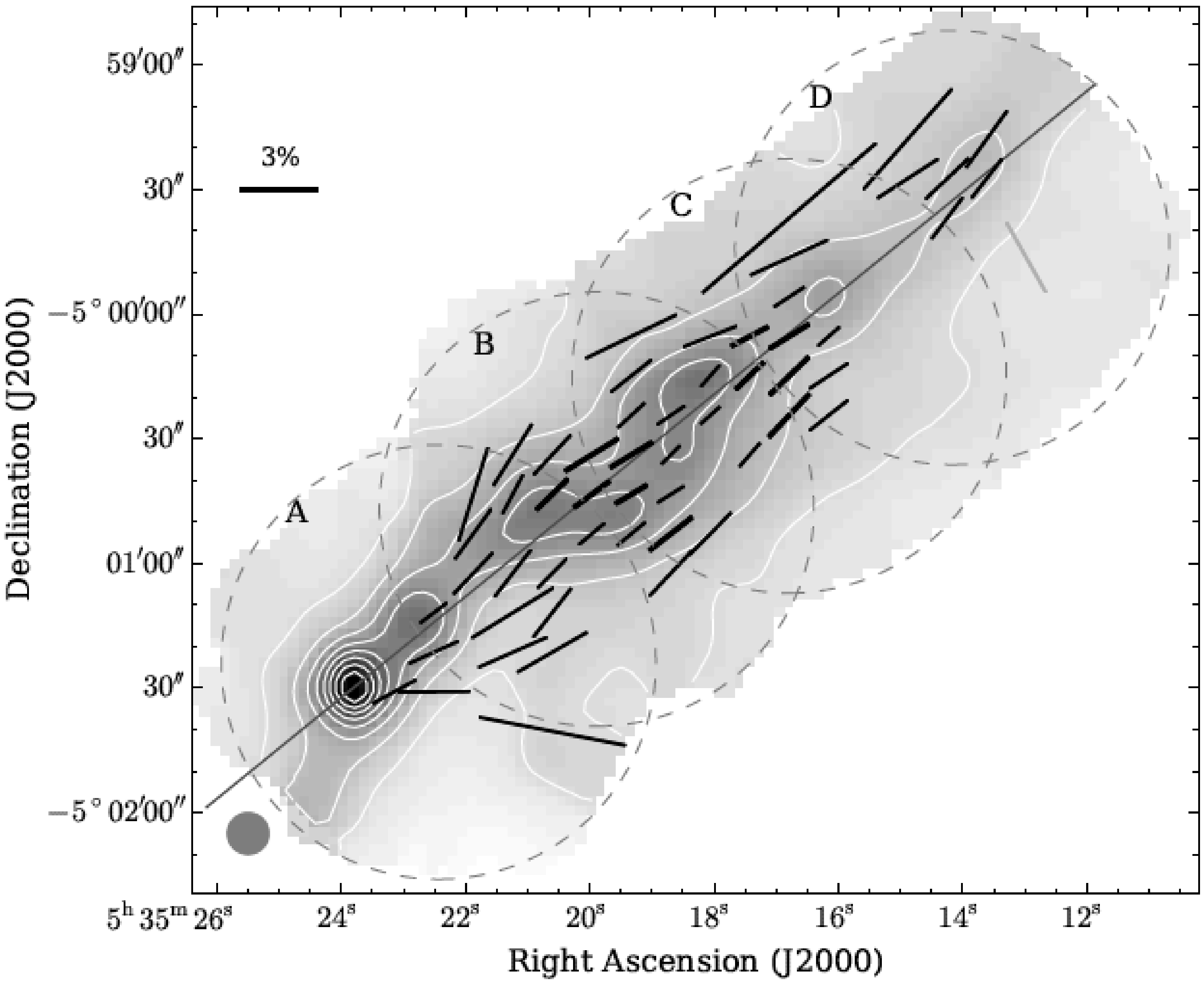


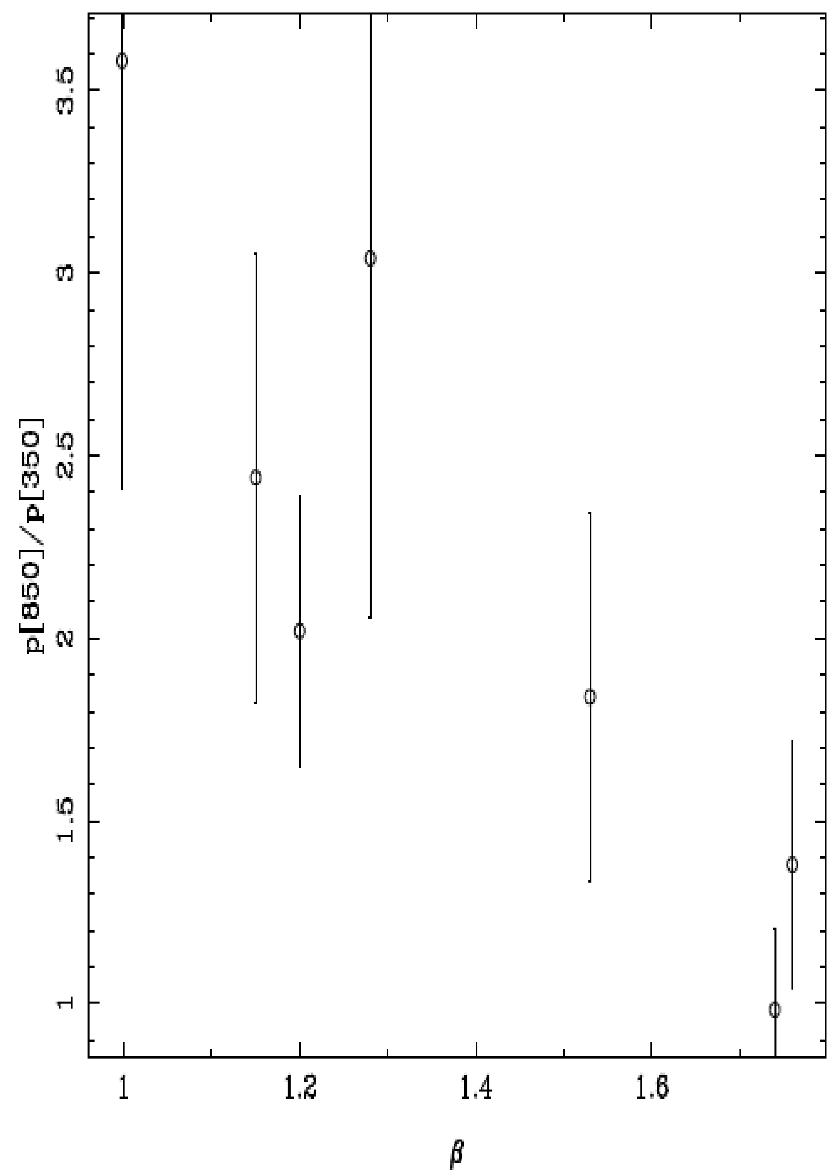
Fig5.The profiles of 1200μn continuum image difference between BE and p.w.l models with different beam sizes.



ALMA: Configuration C34
1’ resolution - S/N > 20

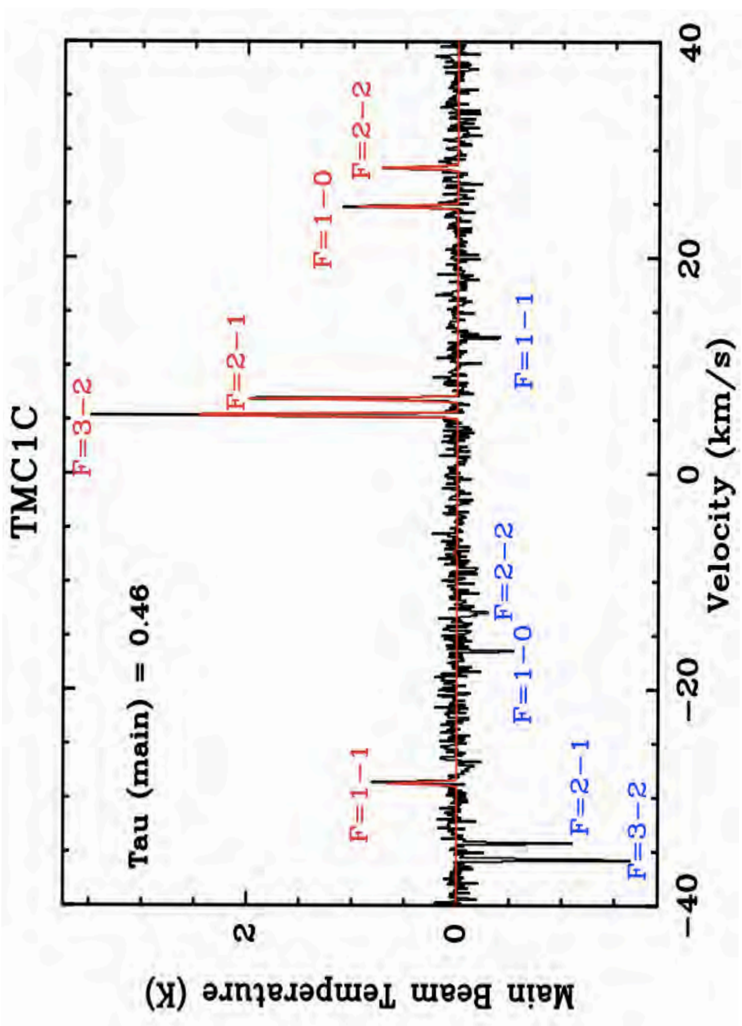
SHARP: 350micron Pol



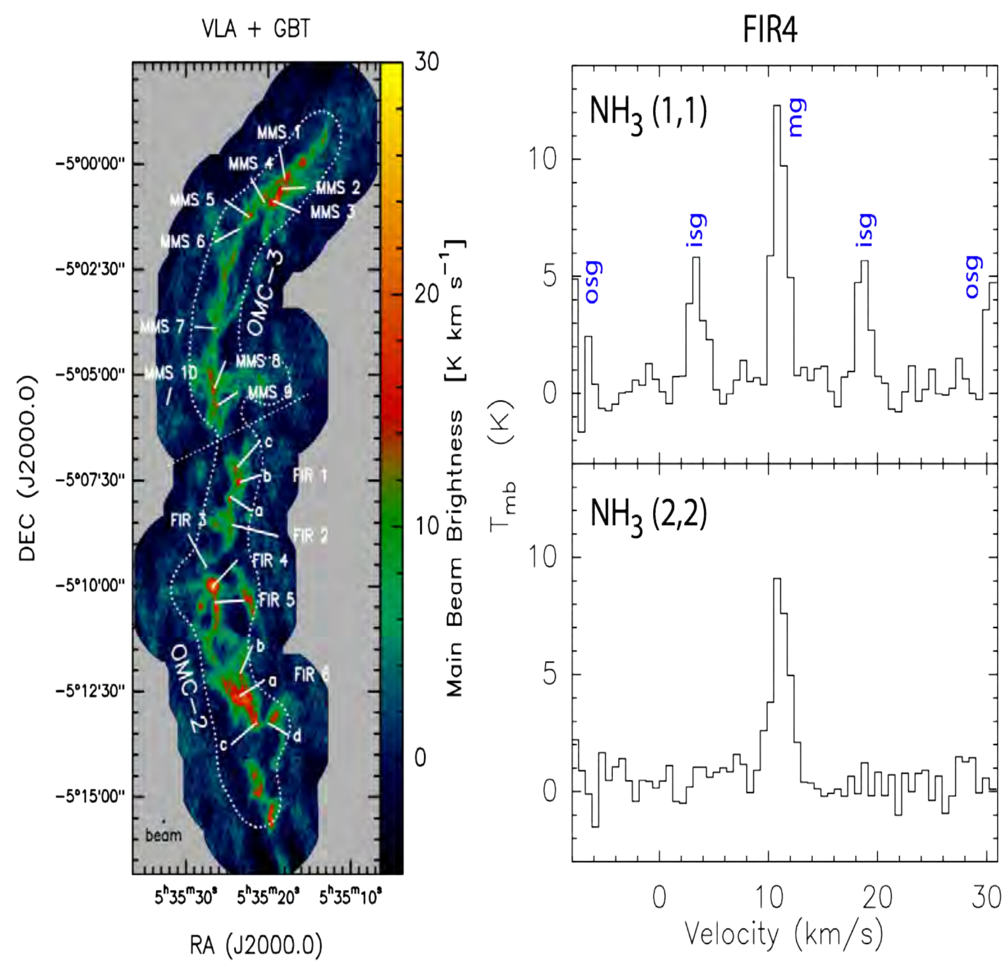


Chapman, Li, Novak, Schnee 2015, in prep

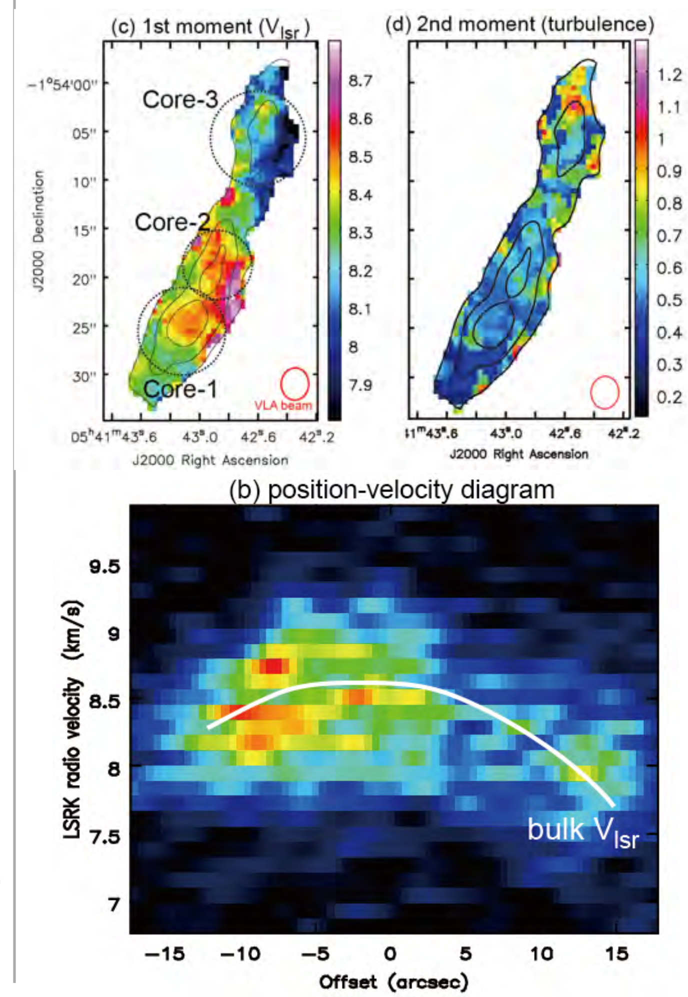
Measuring Filaments



Li & Goldsmith 2012 ApJ



Li et al. 2013 ApJL



Ren et al. 2014

Density

Temperature

Dynamic

“Fila-mental” Questions

- **Characteristic scale**: 0.1pc, Sonic scale from ISM shocks (Padoan & Juvela 2001)?
- **Substructures and superstructures**: fiber, bundle, bones, fork, ridge, hub …
- **Gas Flow and Accretion:** flow along or accrete onto?
- **Magnetic field:** configuration and strength
- **Cores:** HMPO? collapse? (COREFIT …)

more data (B and V) to distinguish physics