Molecular Cloud Fragmentation and the IMF

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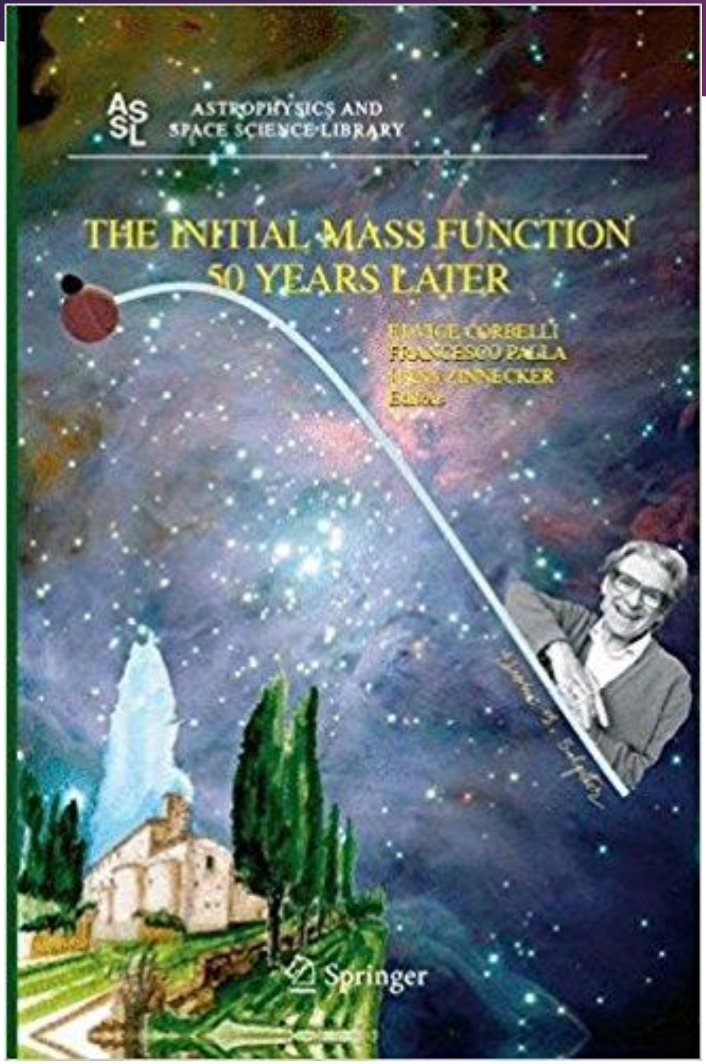
Francesco Palla



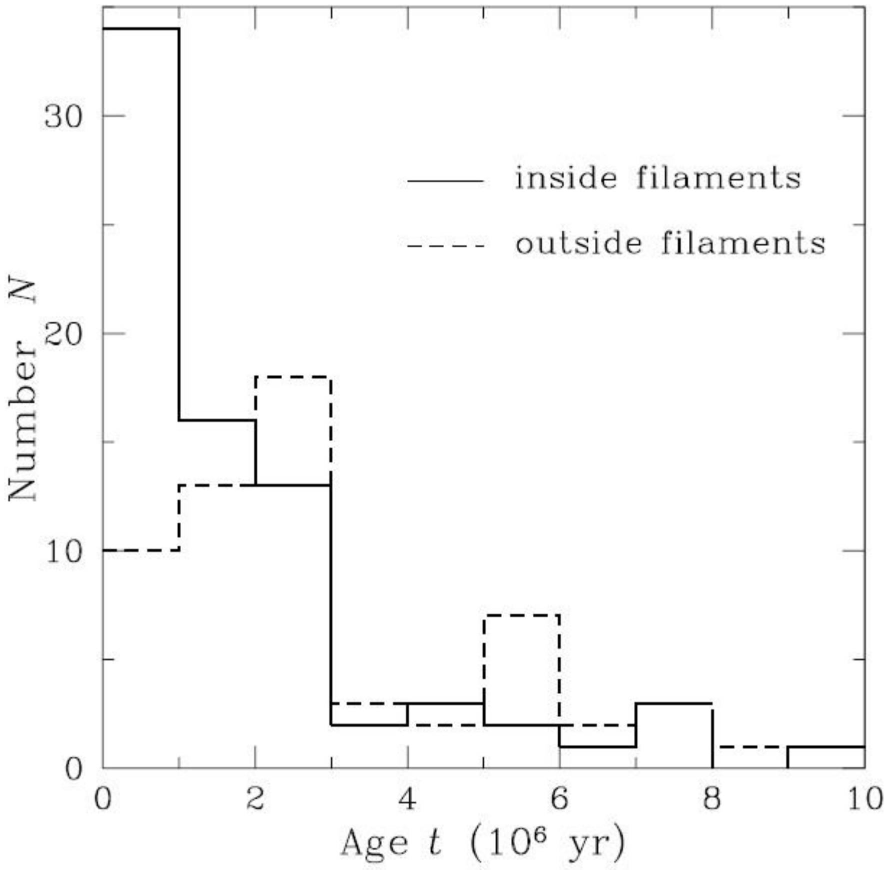
IMF@50,
SFR@50,
IGM@50

- Star formation rate and history in a molecular cloud
- Molecular cloud lifetimes
- The initial mass function
- The first stars

Key Steps

- Fragmentation of cloud into large scale structures (filaments/ribbons, etc.)
- Formation of dense cores within larger structures
- Core collapse to form hydrostatic protostar
- Disk formation, multiplicity, BDs, planets

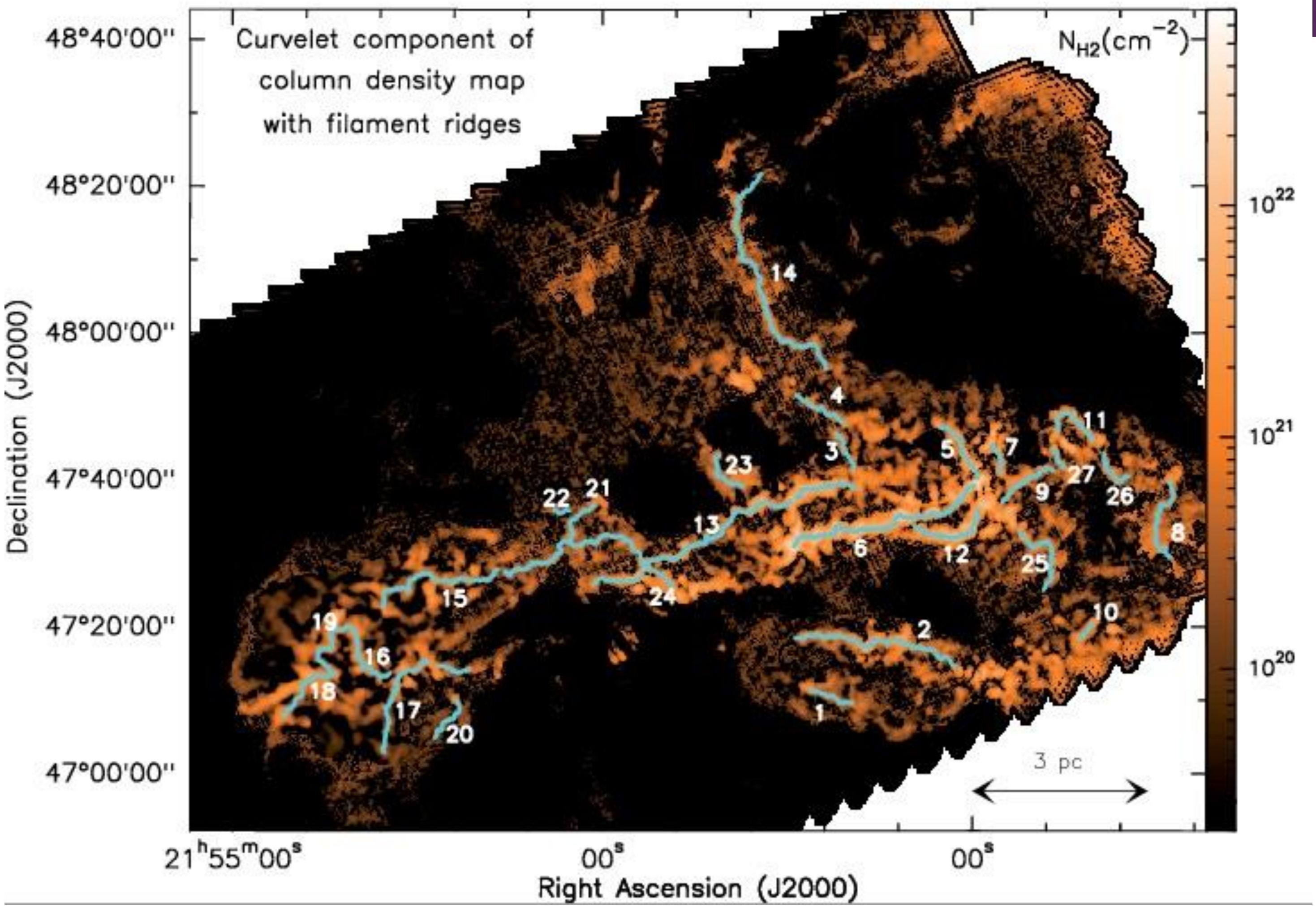
Time Spread of Star Formation



Palla and Stahler (1999, 2000, 2002)

- Inferred YSO age distribution in Taurus at left
- Can the age spread be linked to spatial locations and/or masses of the stars?

Herschel Observations

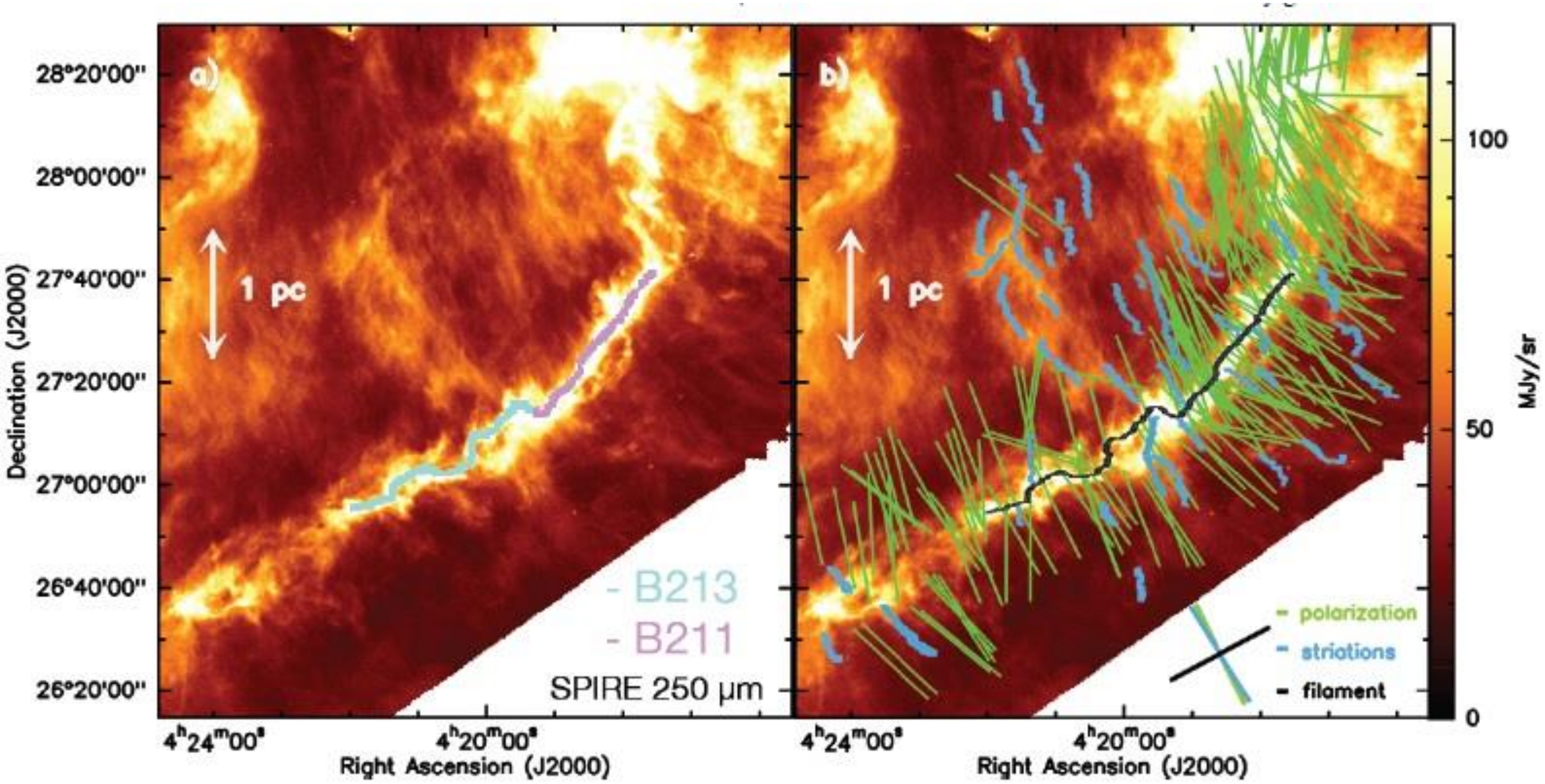


IC 5146
Arzoumanian et al. (2011)

Avg. observed filament width L ~ 0.1 pc over a wide range of column densities.

Also a hint that spacing between filaments L_0 ~ 1 pc.

Magnetic Fields and Filaments

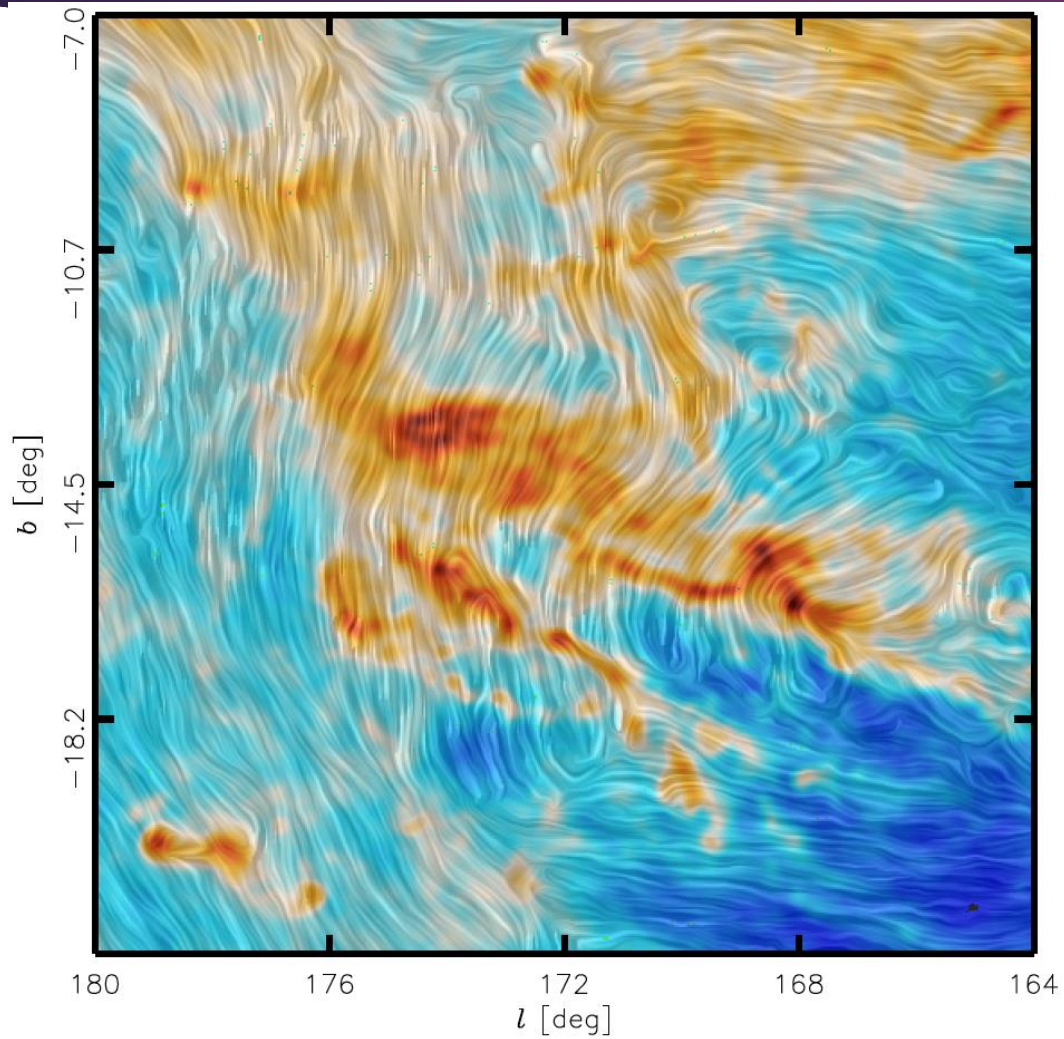


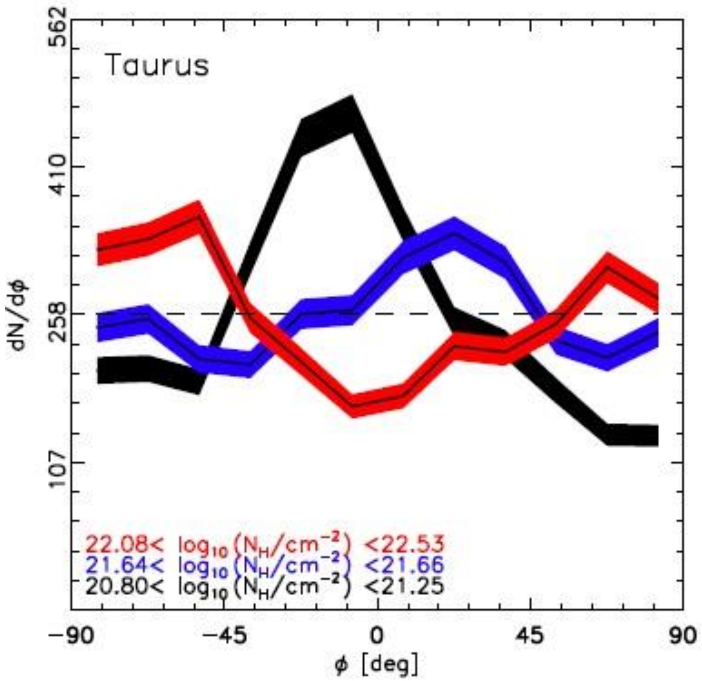
Palmeirim et al. (2012)

Inferred *B* directions in green.

Herschel observations of B211 and B213 in Taurus Molecular Cloud.

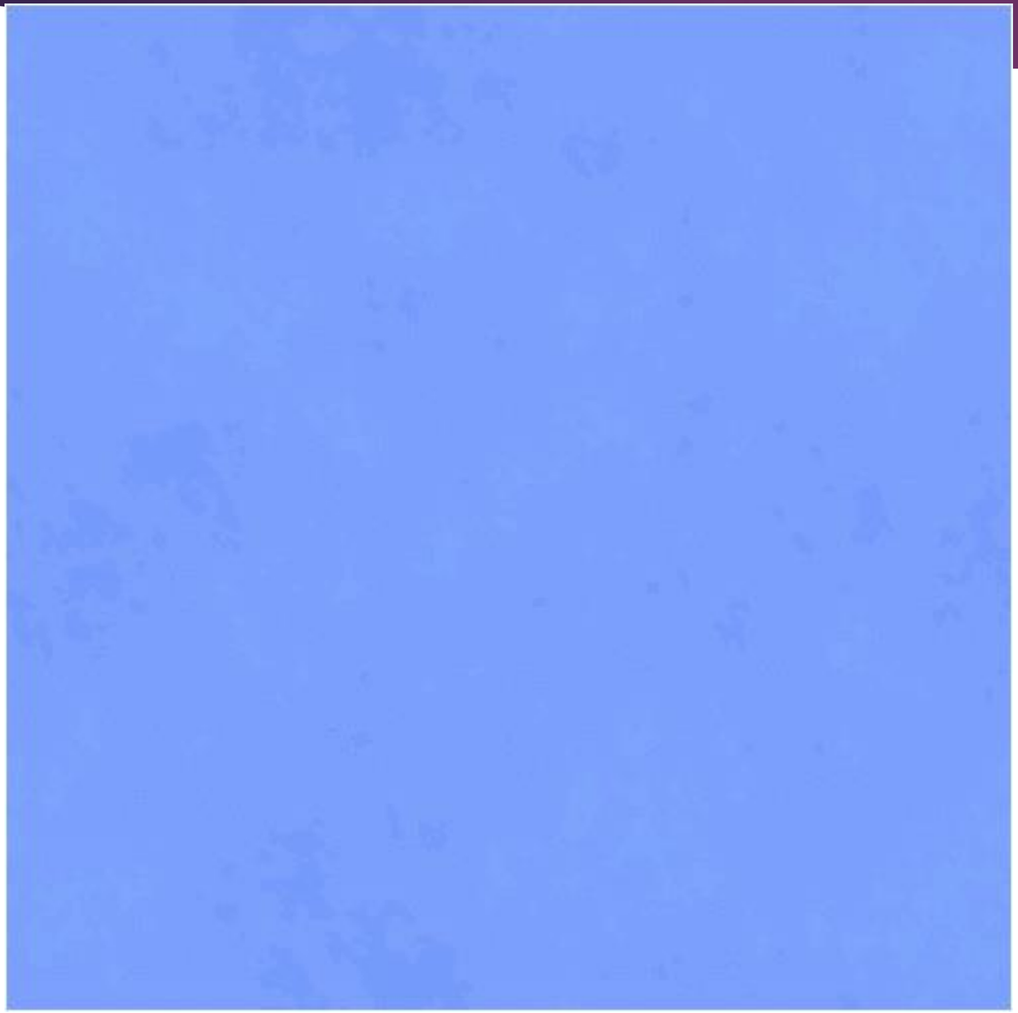
Planck Collaboration Map of Taurus





Planck collaboration XXXV et al. (2016)

Subcritical turbulent cloud with ambipolar diffusion (neutral-ion drift)



Partial ionization due to cosmic rays in this model.

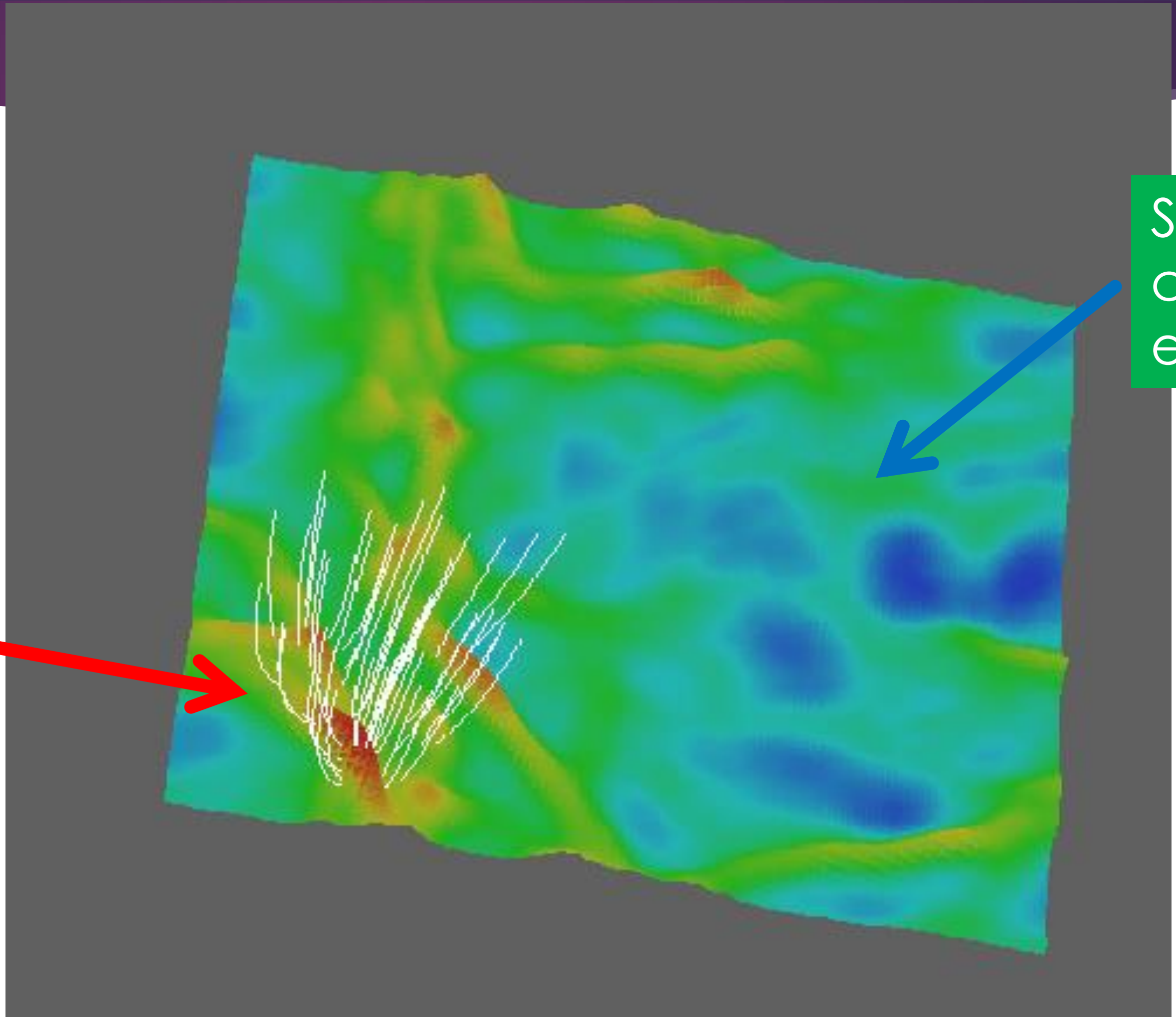
Mass-to-flux ratio

$$\mu_0 \equiv 2\pi G^{1/2} \frac{\Sigma_0}{B_0}$$

$$= 0.5$$

Animation available at
Basu & Dapp (2010, ApJ, 716, 427)

Molecular Cloud Scenario

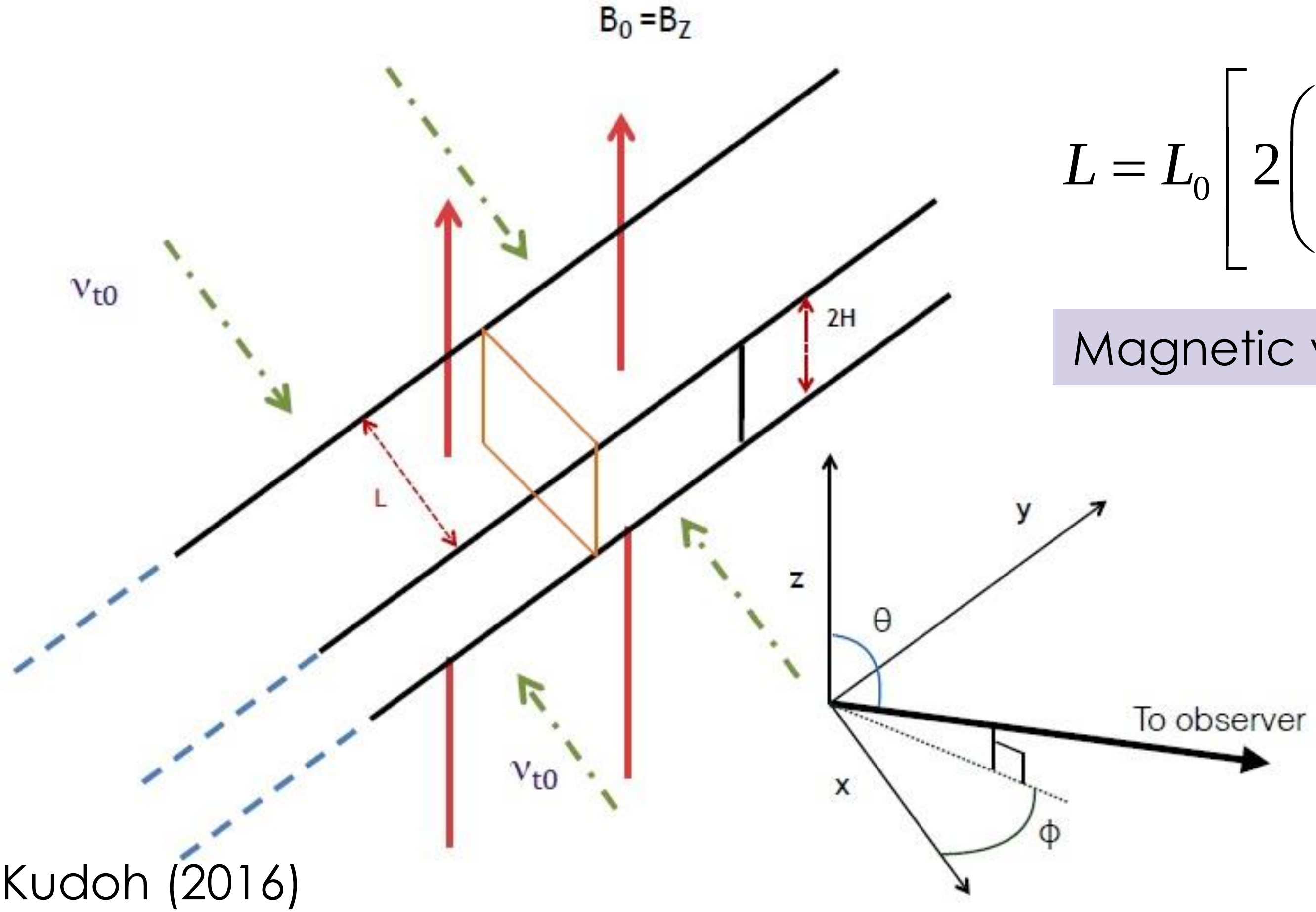


Subcritical common envelope

Supercritical high-density regions assembled by large scale flows/turbulence

cf. Nakamura & Li (2005), Elmegreen (2007), Kudoh & Basu (2008), Nakamura & Li (2008), Basu , Ciolek, Dapp, & Wurster (2009; model shown here).

Magnetic Ribbon Model



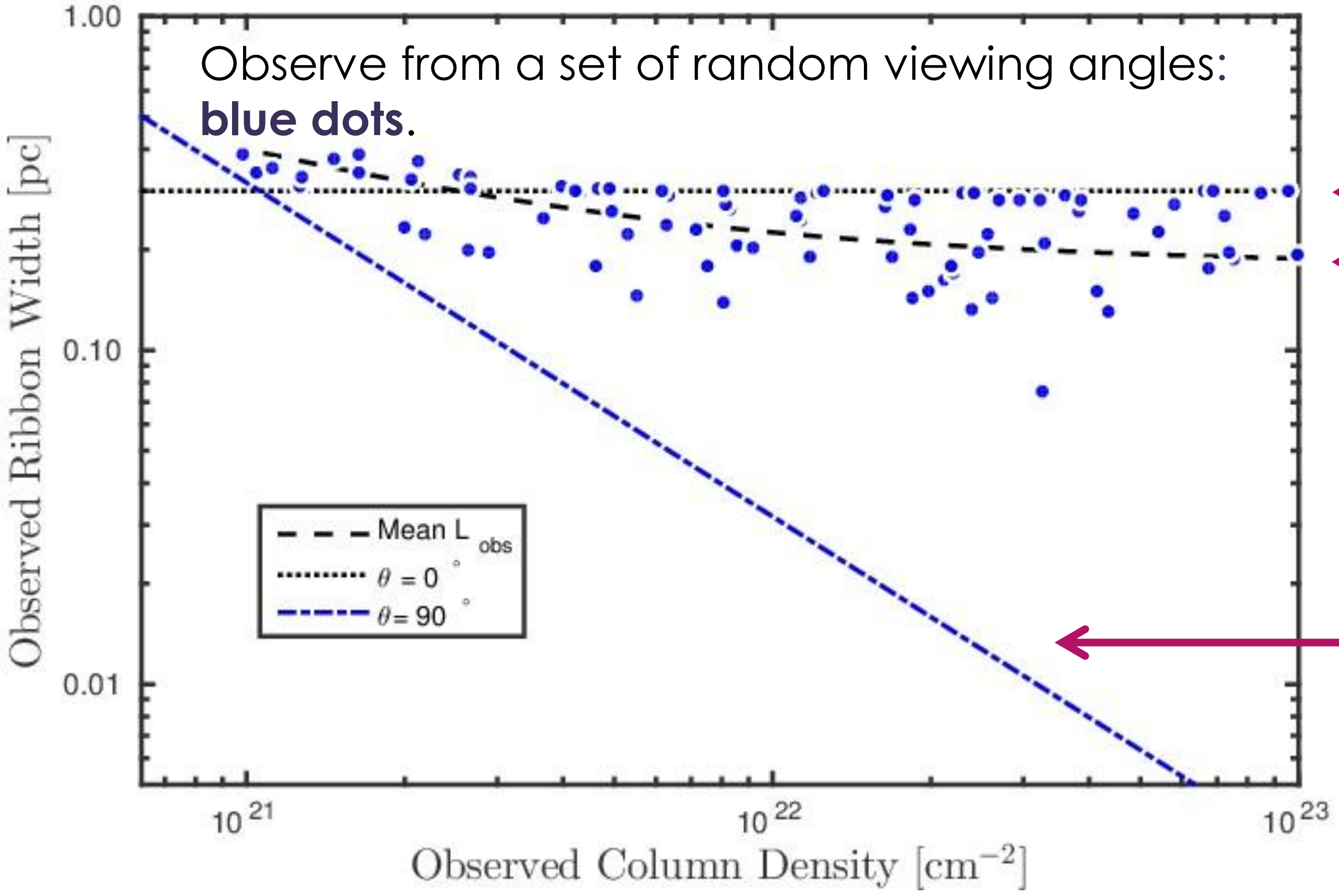
$$L = L_0 \left[2 \left(\frac{v_{t0}}{v_{A0}} \right)^2 + 1 \right]^{-1}$$

Magnetic vs. turbulent pressure

Observed width depends on turbulent compression scale, Aflvénic Mach number, and viewing angle.

Auddy, Basu, & Kudoh (2016)

Magnetic Ribbon Model



L

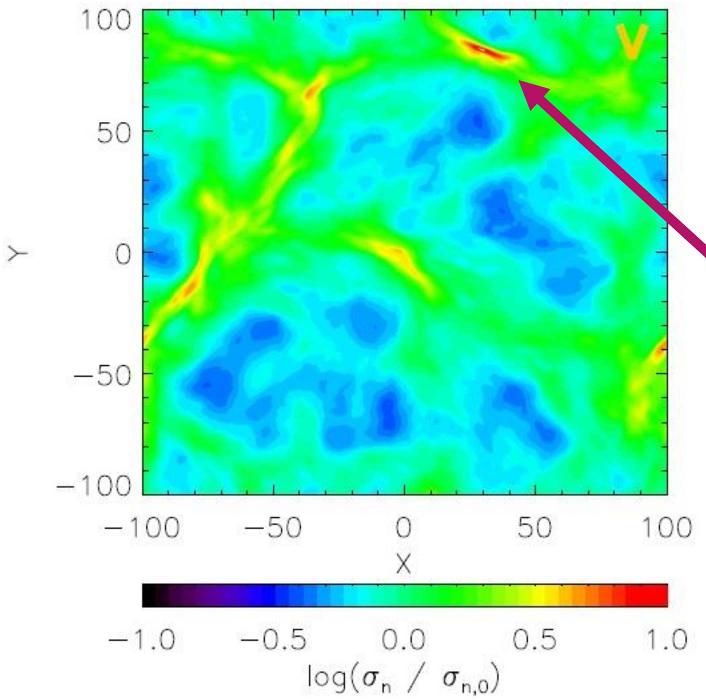
Average over random viewing angles

$2H \approx \lambda_J$

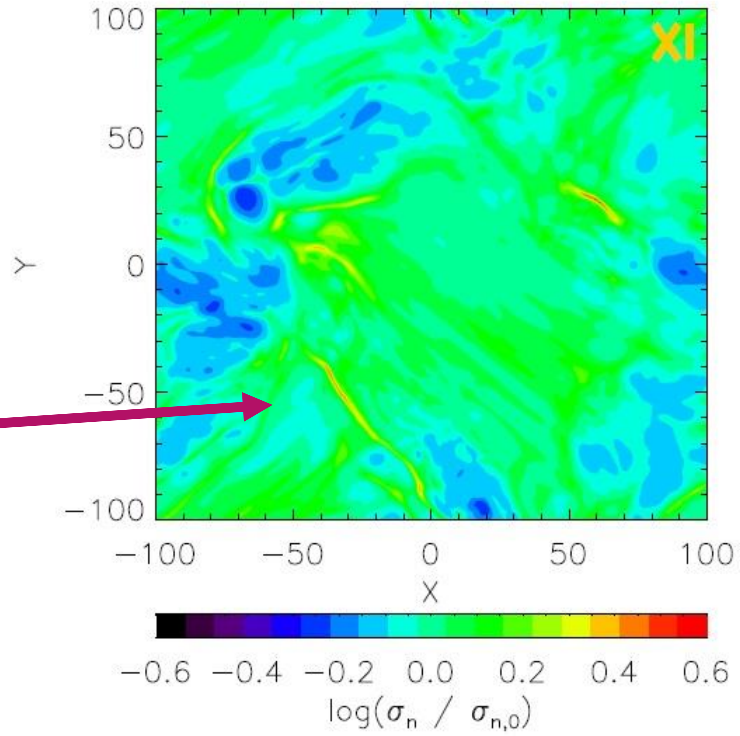
Assuming trans-Alfvénic turbulence and turbulent scale $L_0 \sim 1$ pc.

Auddy, Basu, & Kudoh (2016)

Filaments and Fibers

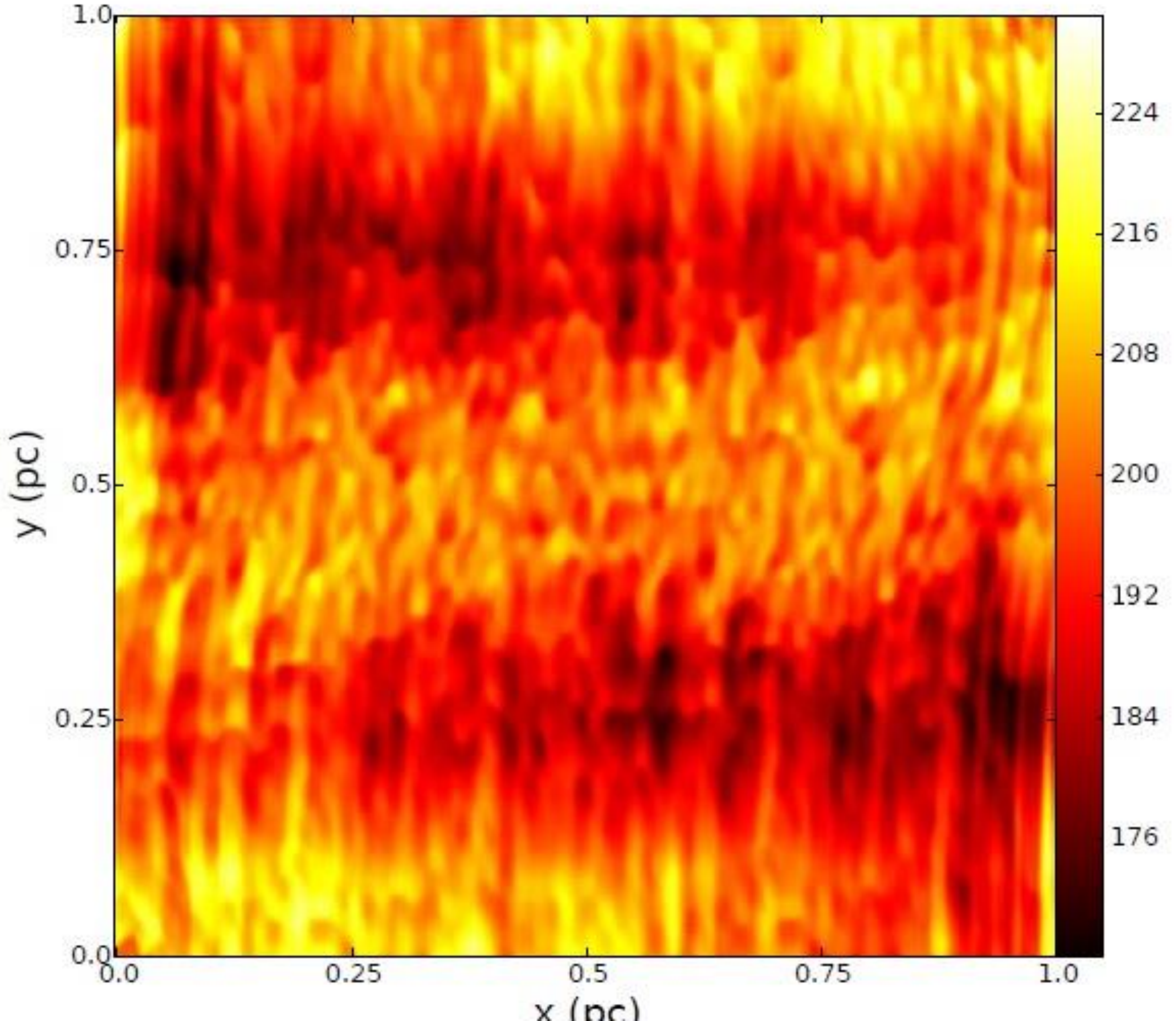


- Filaments as transcritical collapsing magnetized objects
- Sterile fibers as transient subcritical structures



Bailey, Basu and Caselli (2017)

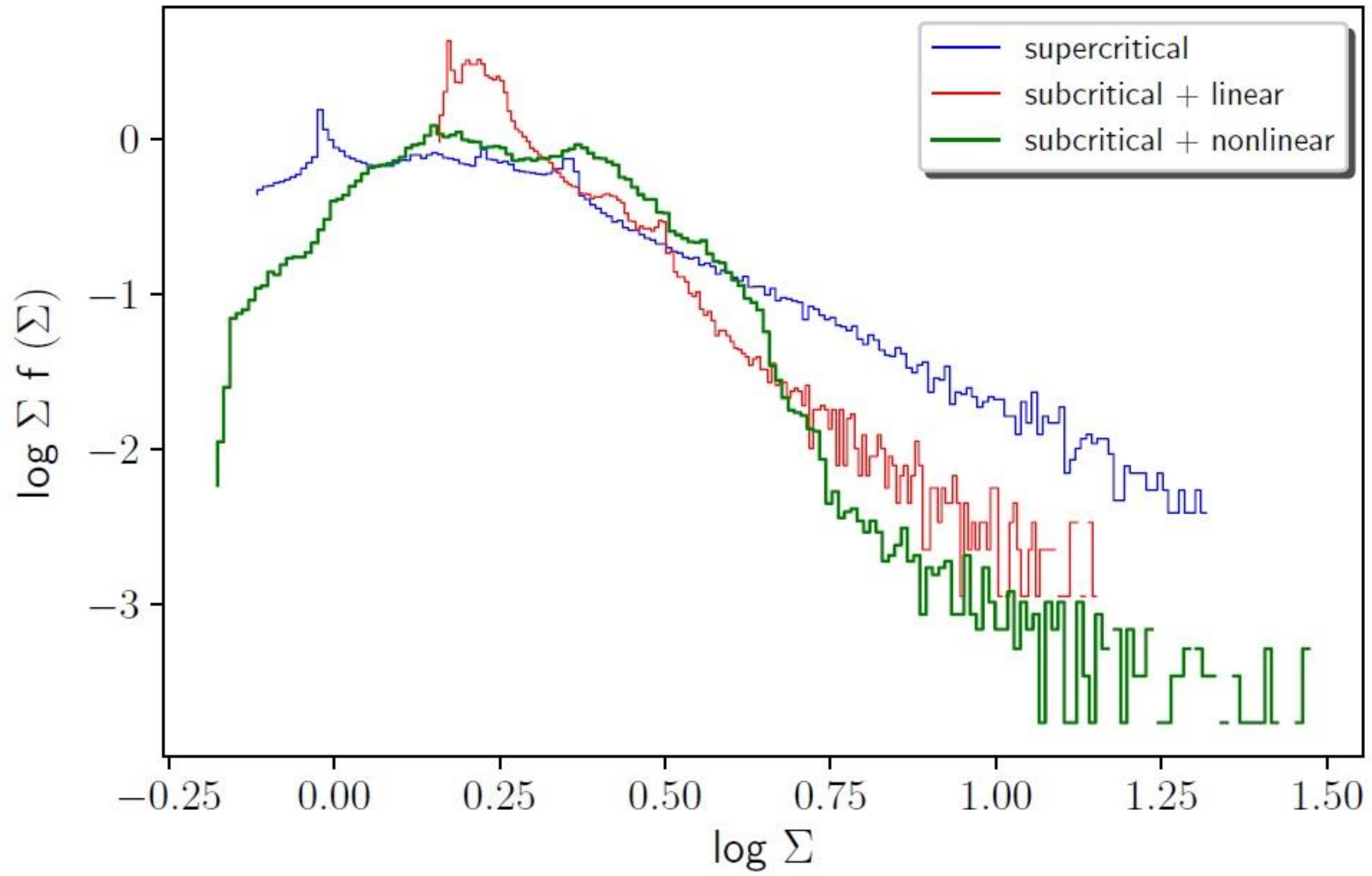
Striations



- Alfvén modes couple to magnetosonic modes
- Density enhancements due to magnetosonic modes

Tritsis and Tassis (2016)

Column Density PDF (ΣPDF/NPDF) from 3D non-ideal MHD simulations



- Supercritical → shallow power-law Npdf consistent with B-E spheres
- Subcritical → steeper power-law from ambipolar diffusion regulated evolution
- Subcritical+turbulence → lognormal plus shallow power law at high column density

Auddy, Basu, & Kudoh (2017)

The Origin of Stellar Masses

- Does the CMF or NPDF have anything to do with the IMF?
- Many low mass substellar objects being discovered
- In ONC, Drass et al. (2016) find evidence for

~ 920 low mass stars
~ 760 brown dwarfs
~ 160 planemos

"Face it—in this town, either you're a star or you're just another brown dwarf."

Fig. 1 Cartoon from Mick Stevens published in the New Yorker magazine issue 01/08/1996 (Reprinted with permission by The Cartoon Bank)

The Low Mass IMF

- A need to avoid a reliance on Jeans mass to obtain arbitrarily low masses
- Alternative: accretion growth starting from first stellar core masses ~ 10^{-3} – 10^{-2} M_{sun} plus a scenario for accretion termination. Parts of this scenario in Zinnecker (1982), Adams & Fatuzzo (1996), Basu & Jones (2004), Bate & Bonnell (2005), Myers (2009)
- Stellar birthline (Stahler 1983) associated with onset of deuterium fusion can play a role – outflows?
- Ejections from multiple systems are a promising avenue especially for lowest mass objects (Stamatellos & Whitworth 2009; Basu & Vorobyov 2012; Vorobyov 2016)

The Intermediate and High Mass IMF

- A power-law in $f(m) = dN/dM \sim m^{-(1+\alpha)}$ naturally arises in an accretion scenario if there is:
- An exponential distribution of accretion lifetimes (equally likely stopping in all intervals). Characteristic time τ_{stop}.
- Exponential growth of mass accretion rate. Note observations e.g., Myers & Fuller (1992) find

$$M/\dot{M} = \tau_{\text{growth}} \approx \text{constant}$$

- Then $\alpha = \tau_{growth}/\tau_{stop}$ (Basu & Jones 2004; Basu et al. 2015). Empirically $\alpha \sim 1$.

Summary of Key Points

- Near-equilibrium filaments, transient fibers and striations emerge naturally from simulations of magnetically dominated molecular clouds
- Column density pdf provides a clear observable distinction in power law profiles between supercritical and subcritical (plus turbulent) core formation
- A distribution of accretion lifetimes due to e.g., ejections and outflows, along with late time accretion growth can in principle explain many features of the IMF