Magnetic Fields, Fragmentation, and the Core Mass Function

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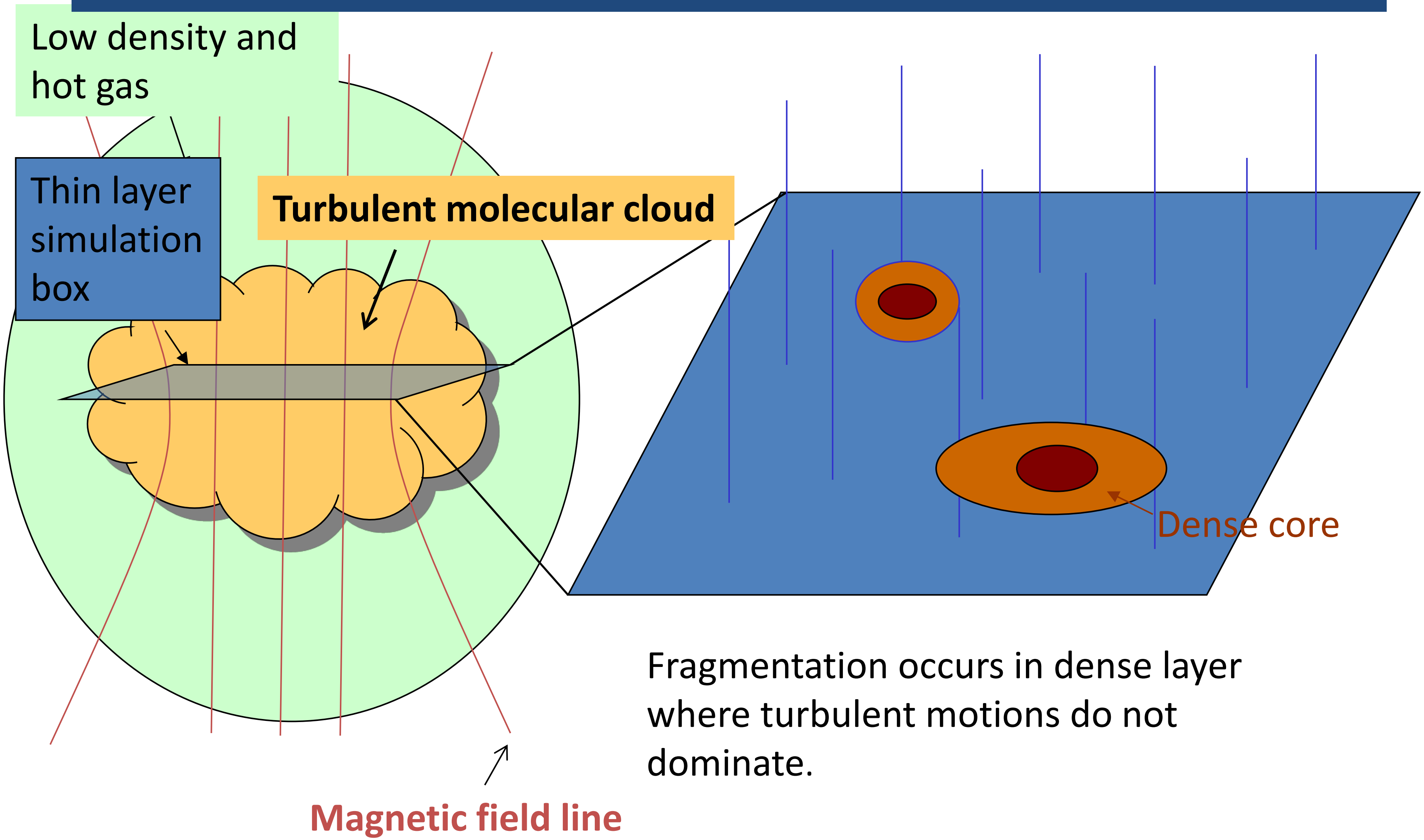
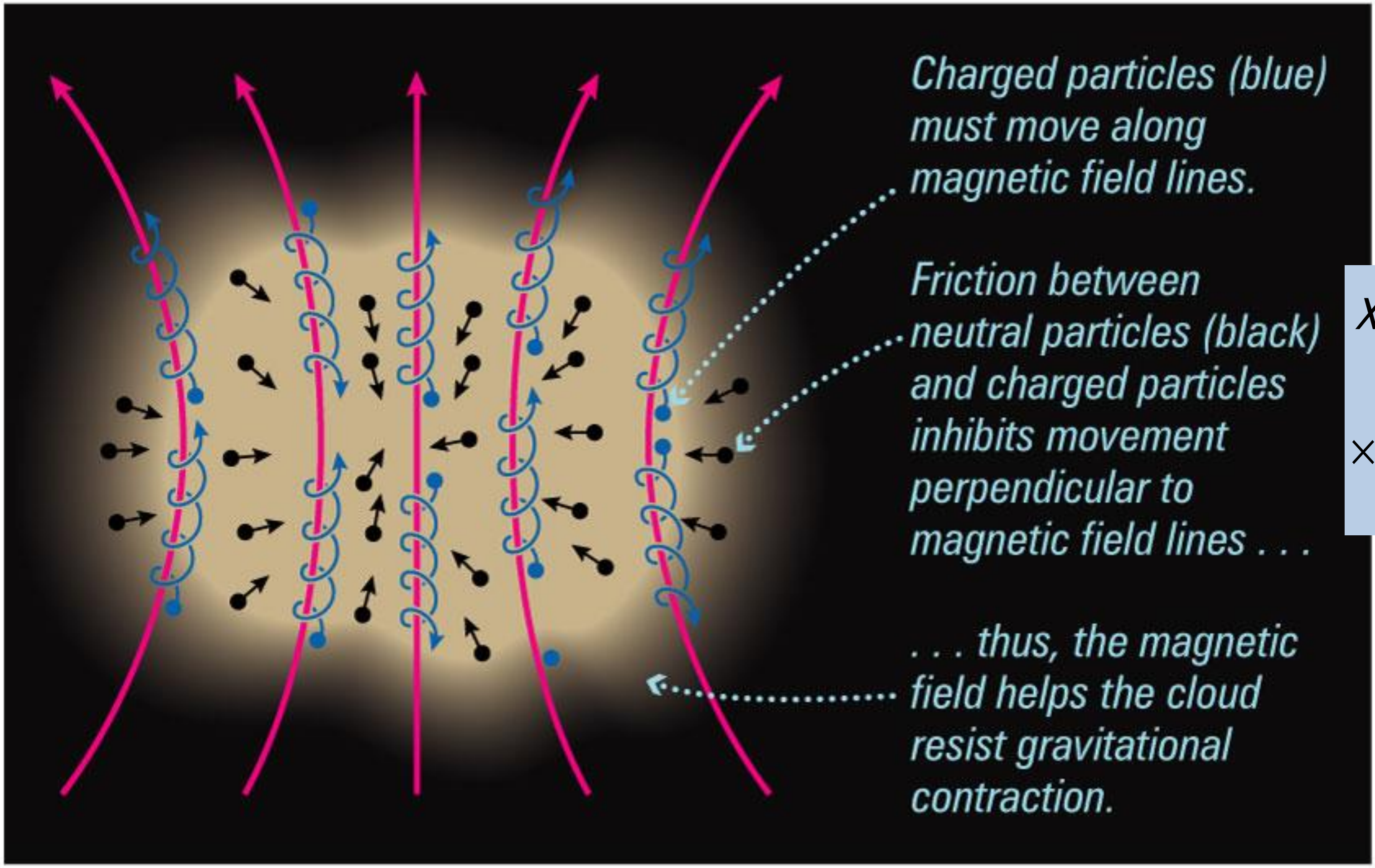
Fragmentation Scenario



Fragmentation occurs in dense layer where turbulent motions do not dominate.

MHD Fragmentation Theory must account for Ambipolar Diffusion

Surface density of neutral gas, Σ, can grow with lesser increase of magnetic field strength *B*.



Cosmic ray ionization

$$x_i = 10^{-7} \times \left(\frac{n_n}{10^4 \text{ cm}^{-3}} \right)^{-1/2}$$

Transcritical (μ ≈ 1) is interesting

$$\mu = \frac{\Sigma_0}{B_0} 2\pi G^{1/2}$$

fragmentation length scale

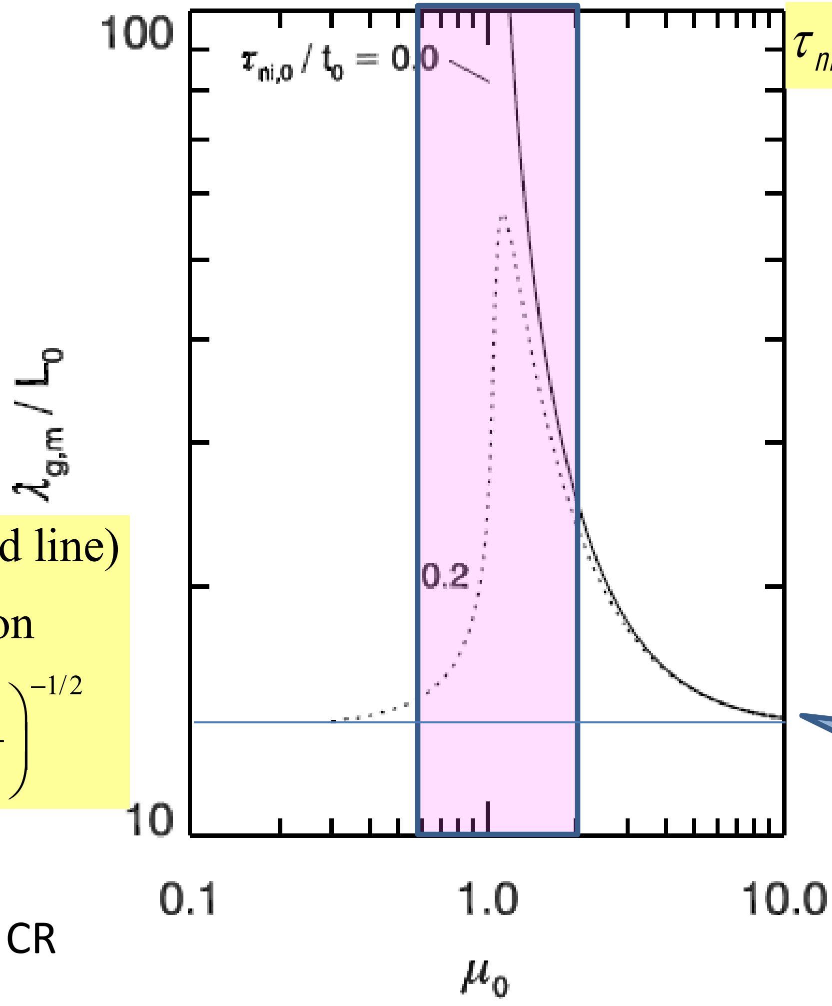
$$L_0 = \frac{c_s^2}{2\pi G \Sigma}$$

$\tau_{ni,0} / t_0 = 0.2$ (dotted line)

$\Leftrightarrow$ partial ionization

$$x_i = 10^{-7} \left(\frac{n}{10^4 \text{ cm}^{-3}} \right)^{-1/2}$$

Standard value for CR ionized region



$\tau_{ni,0} / t_0 = 0 \Leftrightarrow$ flux freezing

fragmentation mass

$$M_{g,m} = \frac{\pi^2}{4} \Sigma \lambda_{g,m}^2$$

can vary dramatically within narrow range of μ_0.

$$\lambda_{g,m} = 2\pi Z_0$$

$$Z_0 \cong \frac{c_s^2}{\pi G \Sigma_0}$$

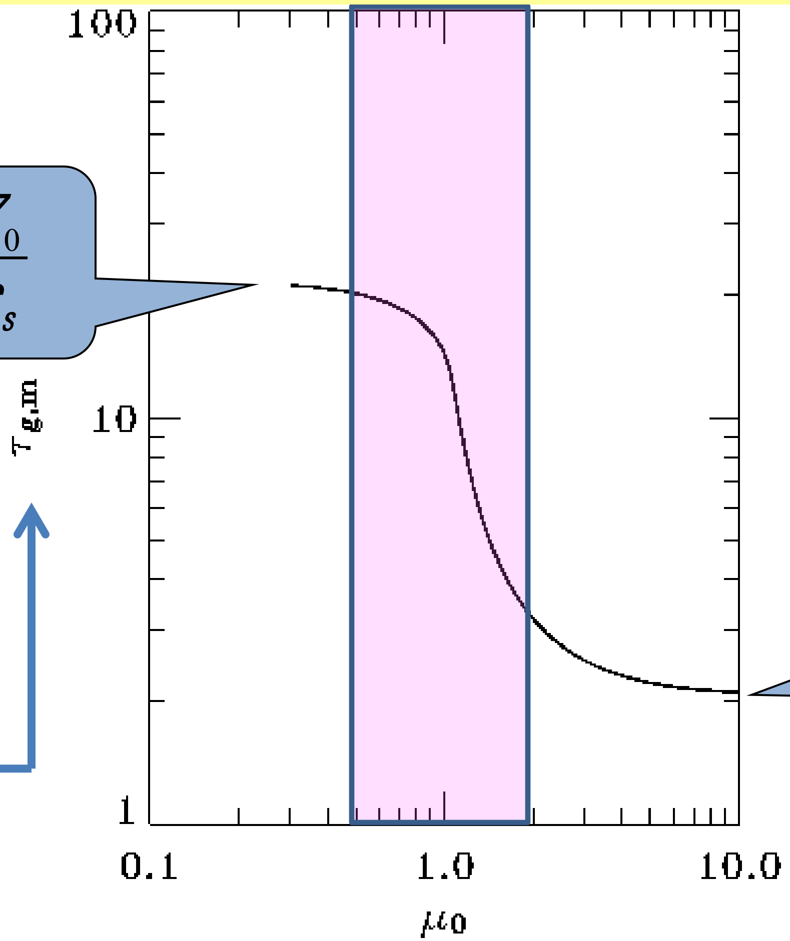
standard Jeans scale

Ciolek & Basu (2006), see also Bailey & Basu (2012)

Transcritical ($\mu \approx 1$) is interesting

For partially ionized sheet, with half thickness Z_0.

$$\mu = \frac{\Sigma_0}{B_0} 2\pi G^{1/2}$$



$$\tau_{g,m} \cong 10 \frac{Z_0}{c_s}$$

τ_{AD}

ambipolar diffusion time

fragmentation time scale

$$x_i = 10^{-7} \left(n_n / 10^4 \text{ cm}^{-3} \right)^{-1/2}$$

cosmic ray ionization

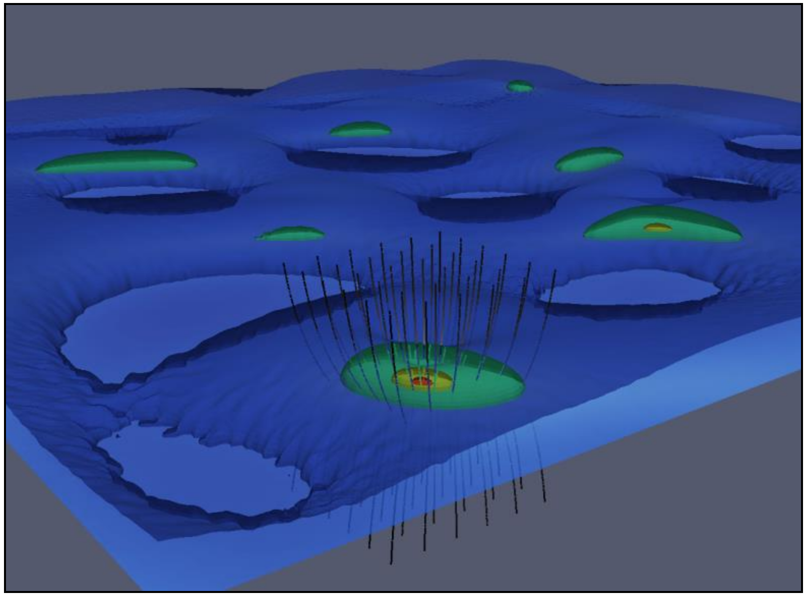
$$Z_0 \cong \frac{c_s^2}{\pi G \Sigma_0}$$

$$\tau_{g,m} = \frac{Z_0}{c_s}$$

dynamical time

Ciolek & Basu (2006) and Bailey & Basu (2012) - a complete linear stability analysis of sheet instability including ambipolar diffusion.

Magnetic Model (Thin Disk Approx.)

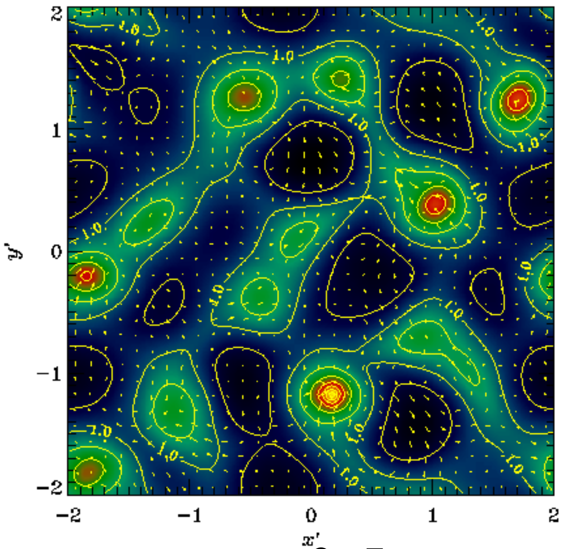


Simulations with thin sheet non-ideal MHD code. Vertical (z) structure assumed to be in hydrostatic equilibrium. External magnetic field effects included.

Code described by Basu & Ciolek (2004), Ciolek & Basu (2006), Basu, Ciolek, & Wurster (2009). Partially ionized gas in which ambipolar diffusion can occur.

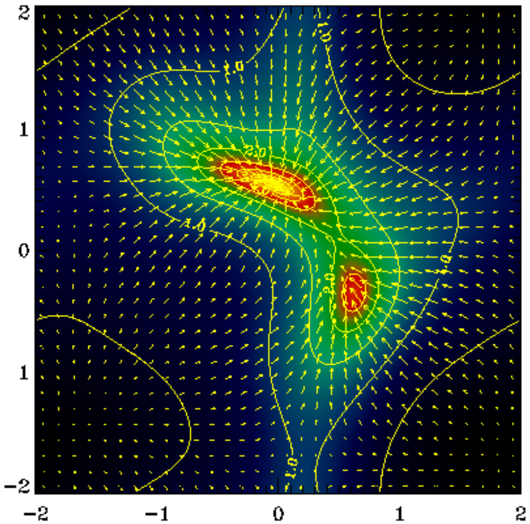
Magnetic Fields and Origin of the CMF

Basu, Ciolek & Wurster (2009, NewA, 14, 221)



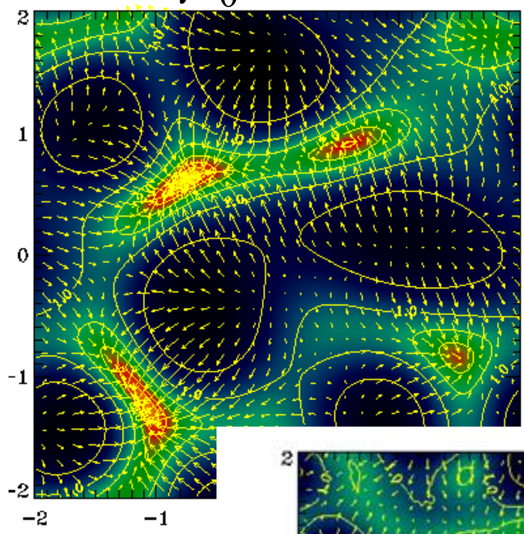
$\mu_0 = 0.5$

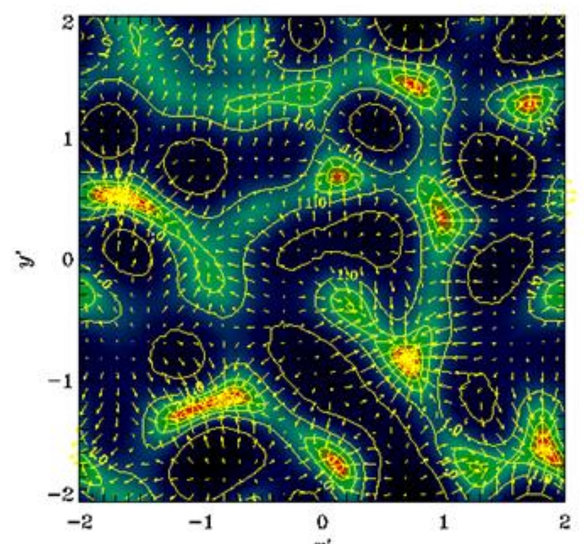
$x' = x/(2\pi Z_0)$, etc.



$\mu_0 = 1.1$

$\mu_0 = 2.0$





$\mu_0 = 10$

Periodic isothermal thin-sheet model. Initial small amplitude perturbations. B is initially normal to sheet.

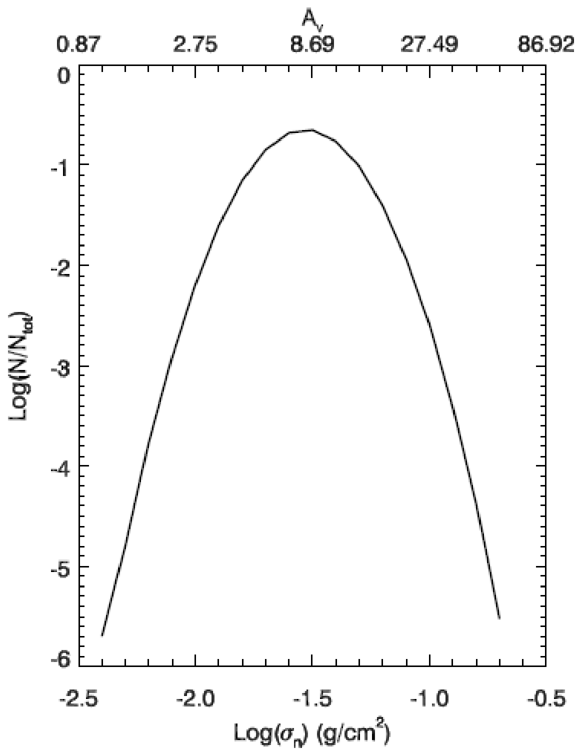
Column density and velocity vectors (unit 0.5 c_s)
Note irregular shapes with no strong turbulence.

Random Sampling Approach to CMF

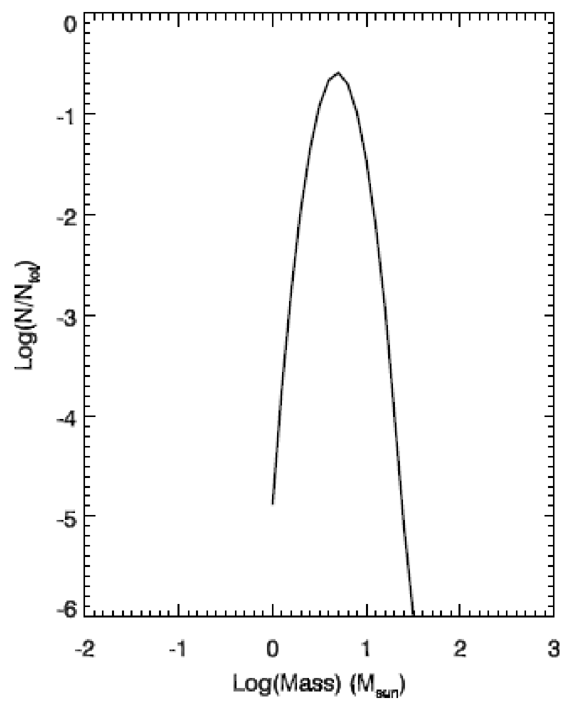
- Extrapolate from (uniform background Σ, μ) simulation results using a Monte Carlo approach
- Expect a distribution of column densities of regions where fragmentation occurs
- Expect a distribution of mass-to-flux ratios of regions where fragmentation occurs
- Ionization fraction will vary amongst star forming regions, due to dependence on column density (ignore intrinsic variations in this study)

Core Mass Function

Hydrodynamic case



$$\lambda_{g,m} = \frac{2c_s^2}{G\Sigma}$$



Lognormal column density pdf

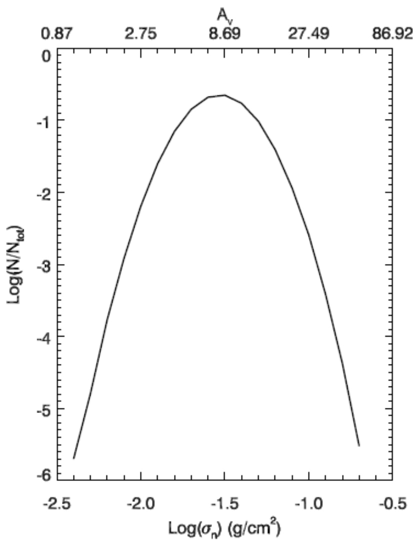
e.g., Kainulainen et al. (2009) fits to data

Lognormal core mass function

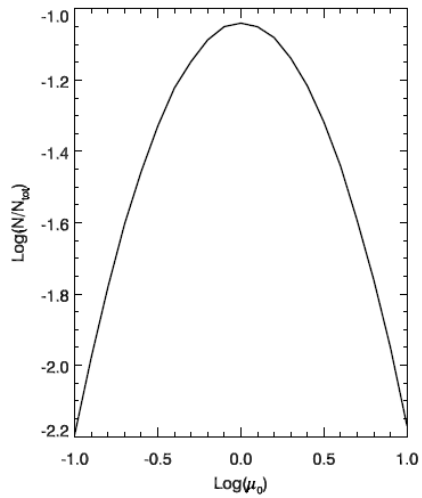
Bailey & Basu (2013, ApJ, 766, 27)

Core Mass Function

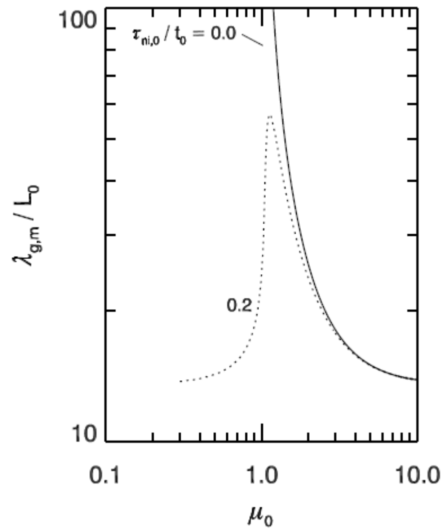
Ideal MHD



Lognormal Σ pdf

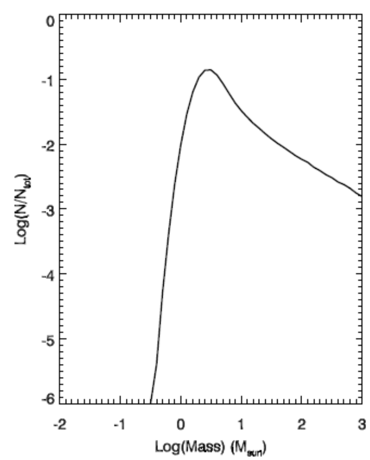


Lognormal μ pdf



Fragmentation scale (solid line)

$$L_0 = \frac{c_s^2}{2\pi G\Sigma}$$



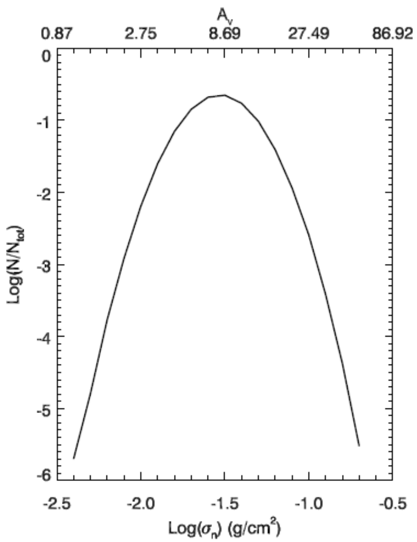
Synthetic core mass function

Shallow power law

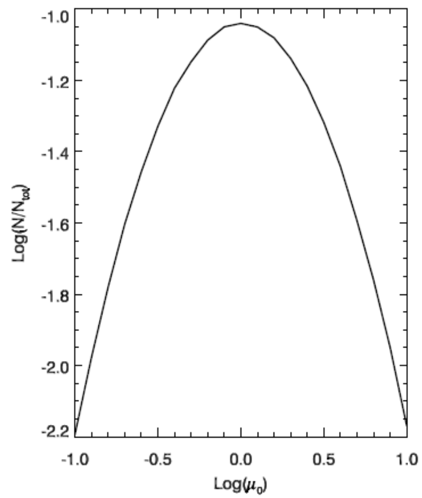
Bailey & Basu (2013, ApJ, 766, 27)

Core Mass Function

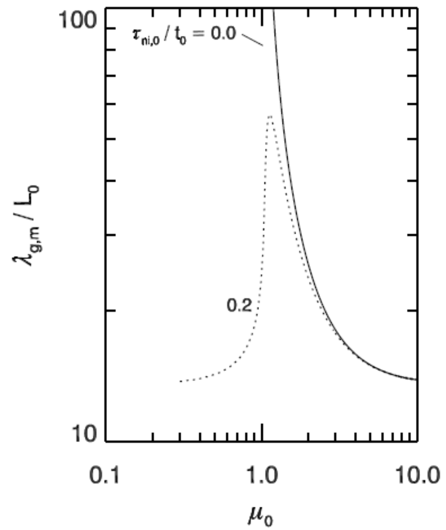
Non-ideal MHD



Lognormal Σ pdf

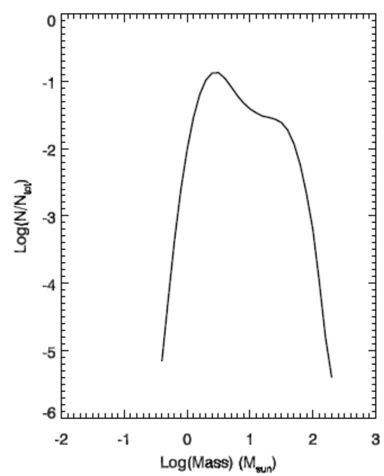


Lognormal μ pdf



Fragmentation scale (dotted line)

$$L_0 = \frac{c_s^2}{2\pi G\Sigma}$$

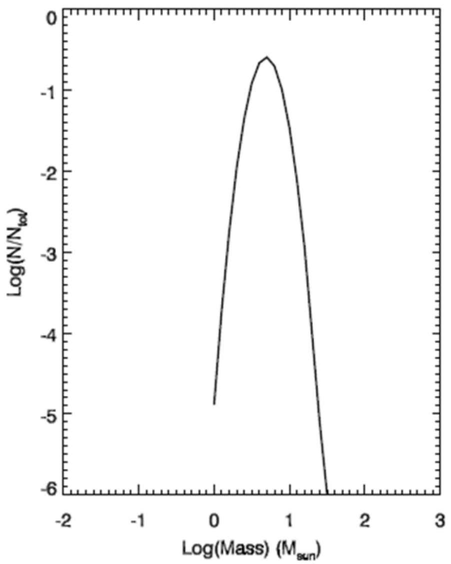


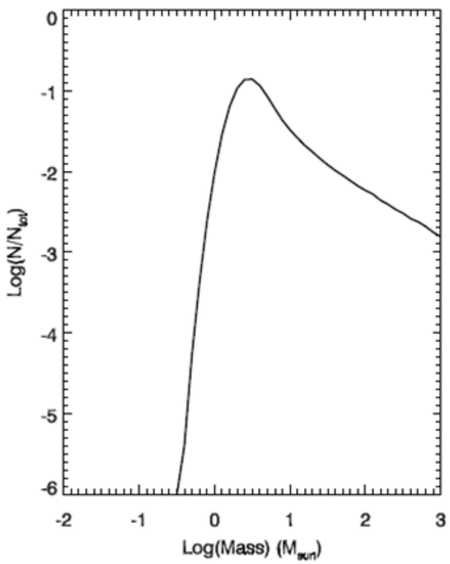
Synthetic core mass function

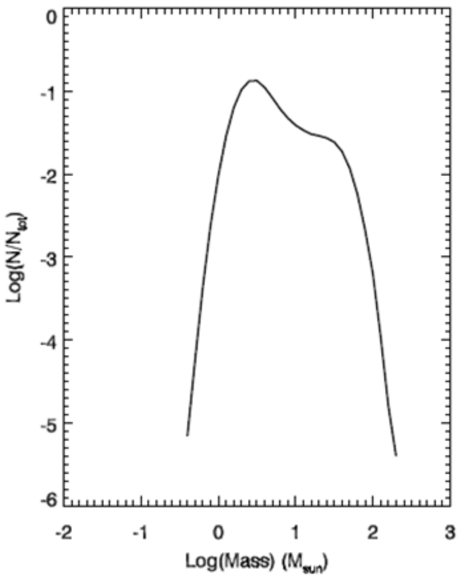
Broad and truncated

Bailey & Basu (2013, ApJ, 766, 27)

Core Mass Function





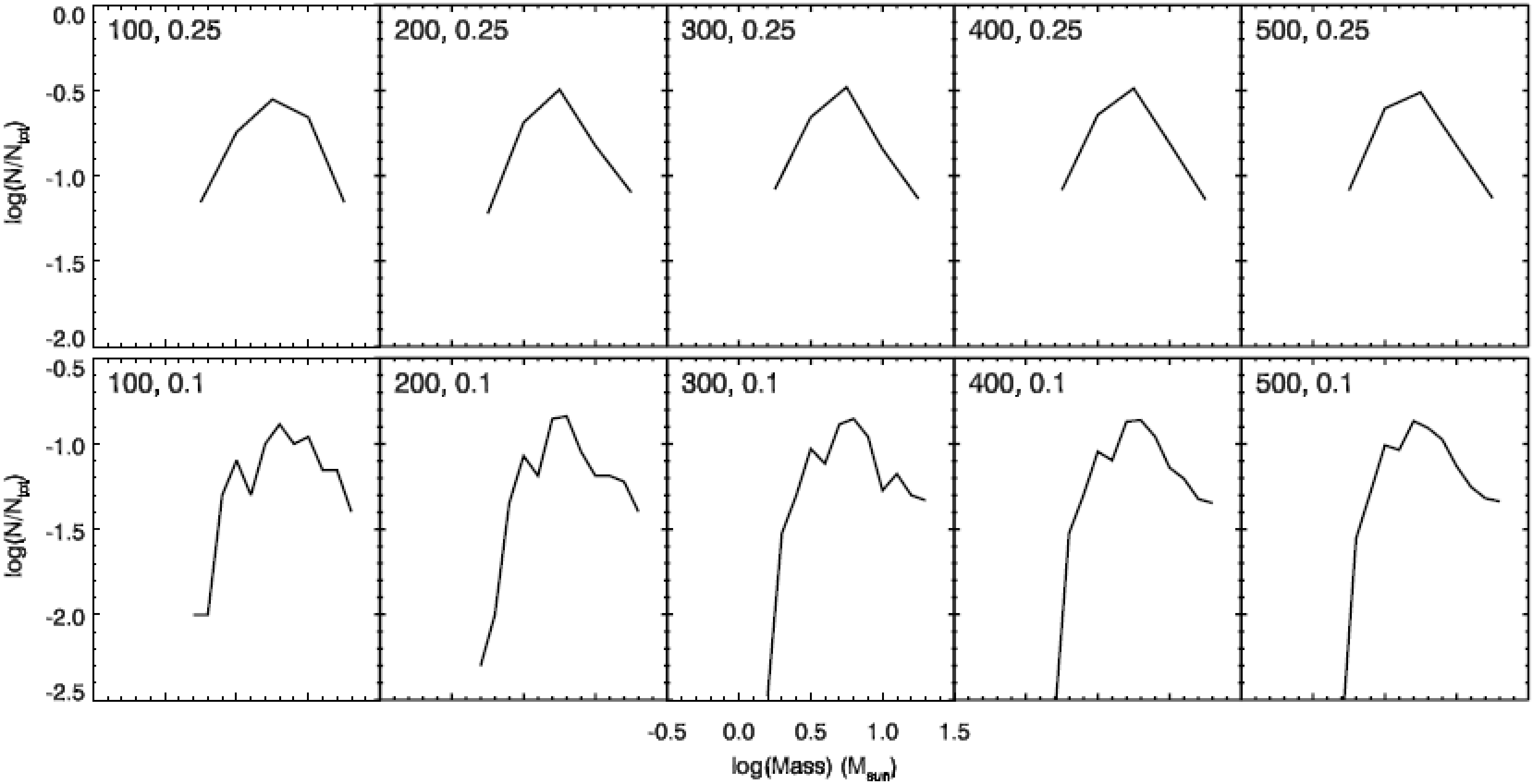


Hydrodynamic | Ideal MHD | Non-ideal MHD

lognormal | broad shallow tail | high mass truncation

Bailey & Basu (2013)

Effect of limited sampling



Δ log m = 0.25

Δ log m = 0.1

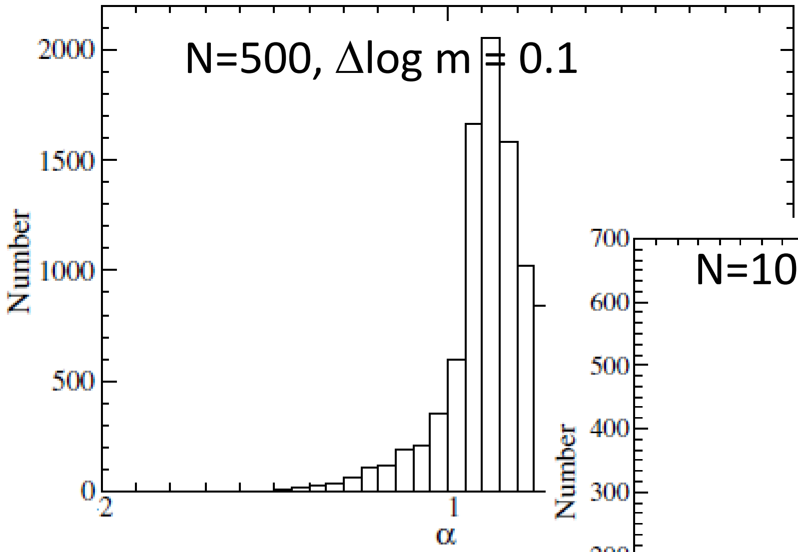
Sample size = 100

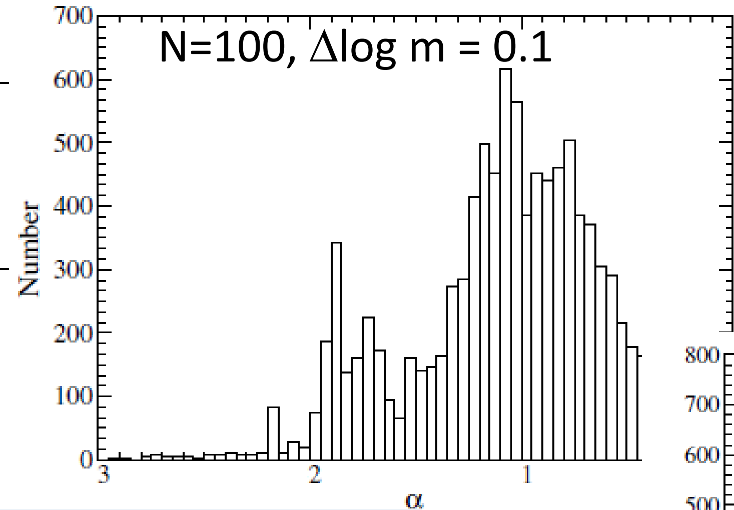
Sample size = 500

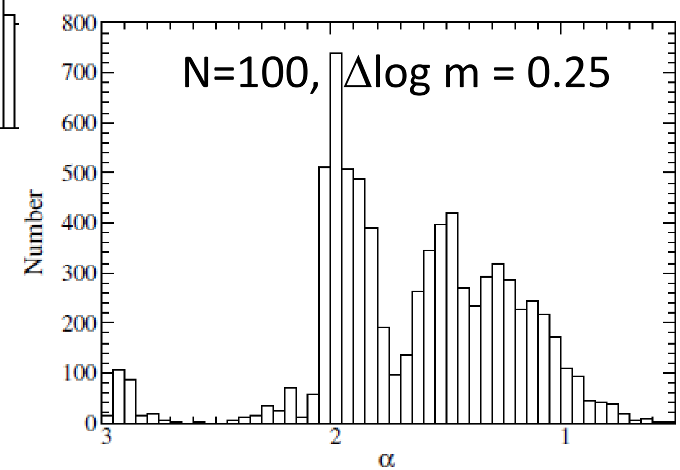
Bailey & Basu (2013)

Slope of high mass tail

High mass slope α calculated from 2000+ realizations. Salpeter α = 1.35. N = sample size. Bin width either 0.1 or 0.25 as labeled.







Analysis of the derived slope from synthetic CMFs shows that the slope of the high-mass tail is systematically steeper for smaller core sample sizes than for larger sample sizes. The average slope is also systematically steeper for larger bin sizes.

Bailey & Basu (2013)

Magnetic Fields and CMF: Conclusions

- Transcritical initial conditions yield massive cores
- Flux frozen fragmentation starting from lognormal column density pdf yields a shallow power law tail
- Ambipolar diffusion introduces a high mass cutoff
- Small number (e.g., hundreds) samples have significant variations. AD induced CMF and empirical CMF can look similar
- Steeper slopes for smaller samples or larger bin sizes