Gravity, Turbulence, and Magnetic Fields

With
Alexei Kritsuk (UCSD)
Wolfram Schmidt (over there)
Paolo Padoan (Univ. Barcelona)
Michael Norman (UCSD)
Hui Li (LANL)

David C. Collins (Right here)
Metropolis Postdoctoral Fellow
Los Alamos National Lab
"The low-metallicity ISM: chemistry, turbulence and magnetic fields"
2012-10-11

Star Formation:

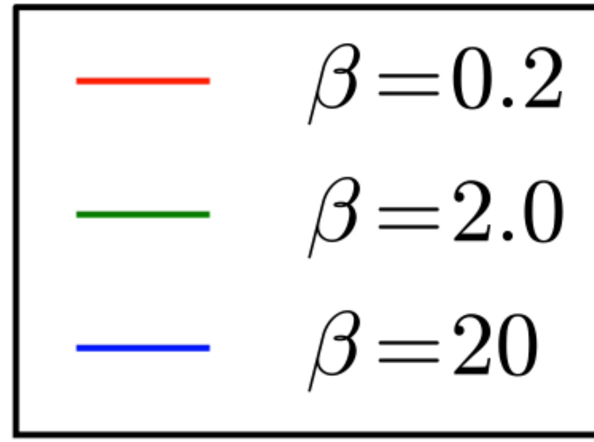
- Turbulence $E(k) \propto k^{-5/3}$
  - Supersonic $V(\rho) = lognormal$, $\rho^{1/3}v$
- Magnetic Fields $V(B) =?$ $B^2(k) \propto k^?$
- Self Gravity ???
- ~~Cooling~~
- ~~Feedback~~

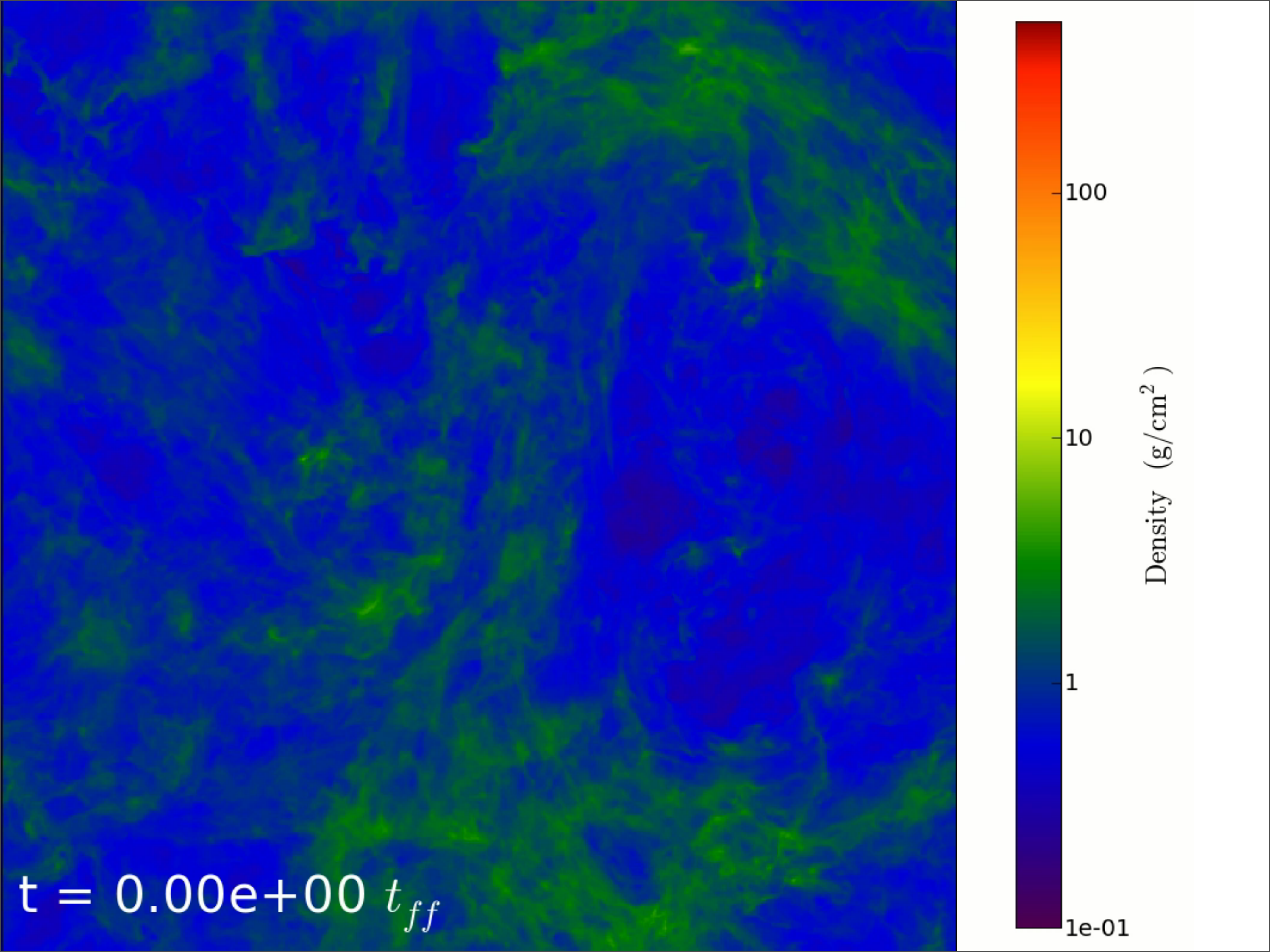
Outline

- Statistical properties of self-gravitating magnetized turbulence.
- Discuss contribution to collapse from kinetic, thermal, magnetic, and gravitational energies

Three Simulations

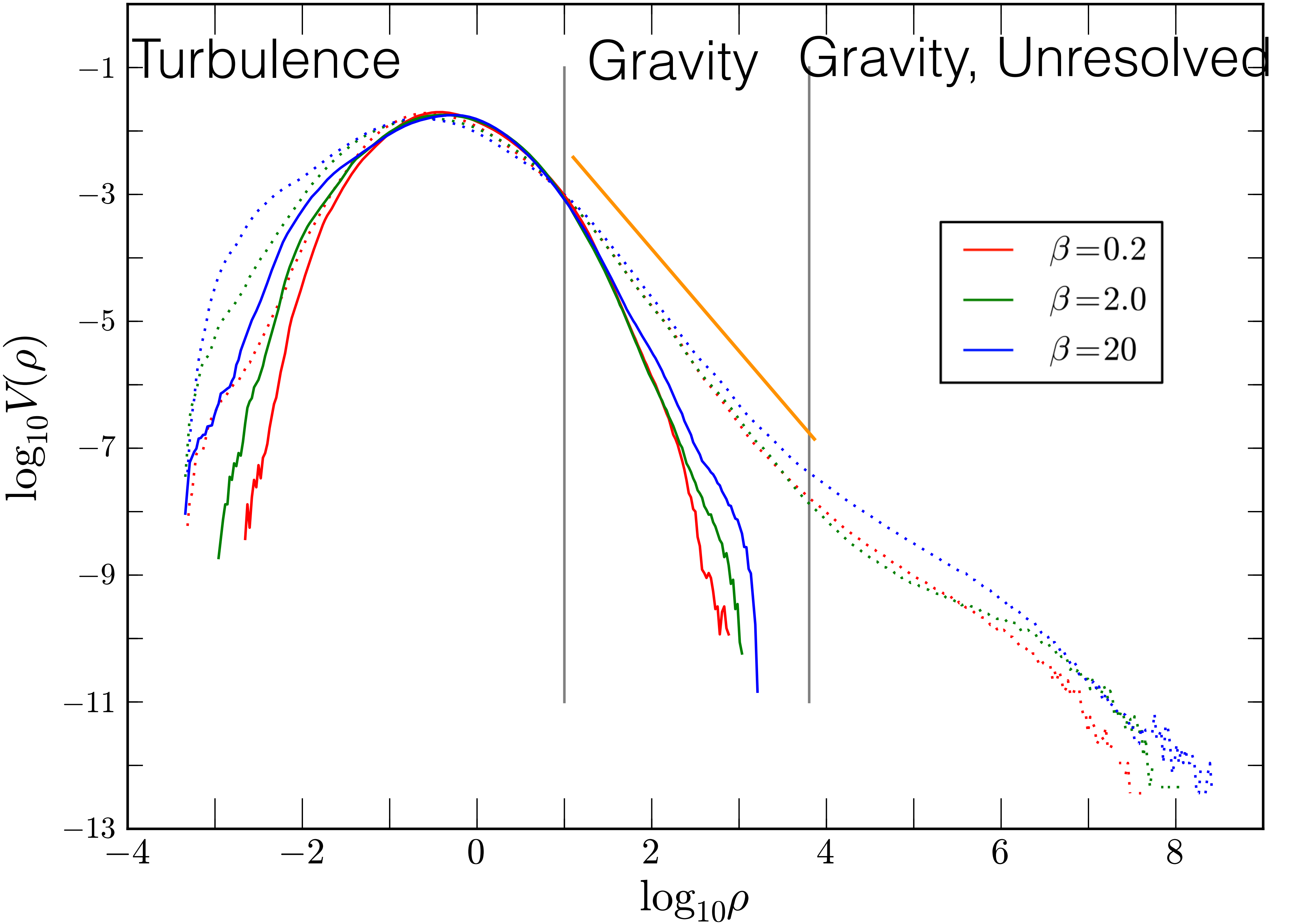
- Mach 10
- Isothermal Ideal MHD
- Gravity
- AMR+MHD (512+4 levels)
- Enzo:(Collins+'10, Balsara+01, Gardiner+05,Li+08) enzo-project.org
- Results (Collins+2011, Collins+2012)
- yt (yt-project.org)
- Kraken





t = 0.00e+00 t_{ff}
100
10
1
1e-01
Density $(\mathrm{g/cm^2})$

Density PDF



Turbulence
Gravity
Gravity, Unresolved
$\beta = 0.2$
$\beta = 2.0$
$\beta = 20$
$\log_{10} V(\rho)$
$\log_{10} \rho$
−1
−3
−5
−7
−9
−11
−13
−4
−2
0
2
4
6
8

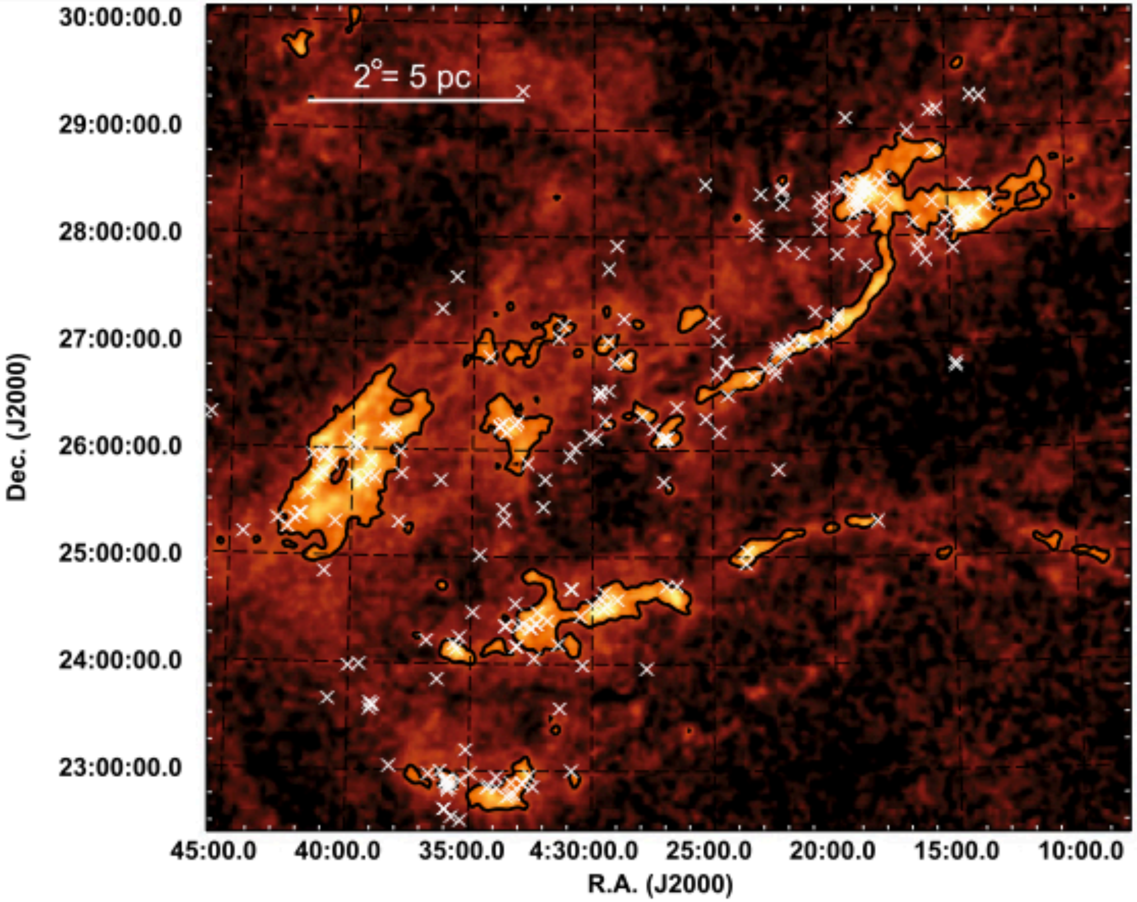
Self Similar Collapse

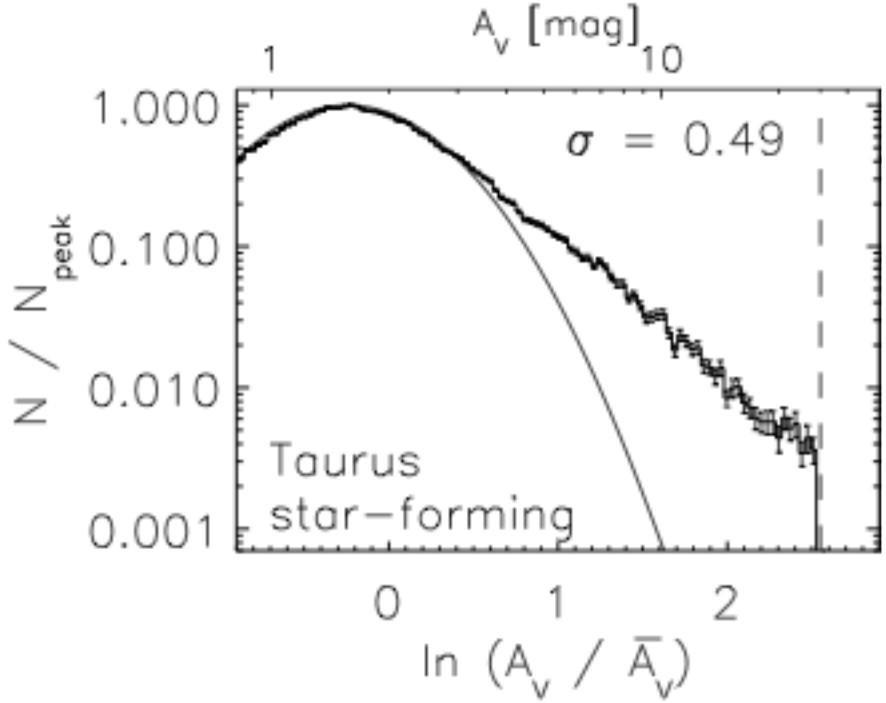
$$\rho \propto r^{-2}$$

$$V(\rho) \propto \rho^{-3/2}$$

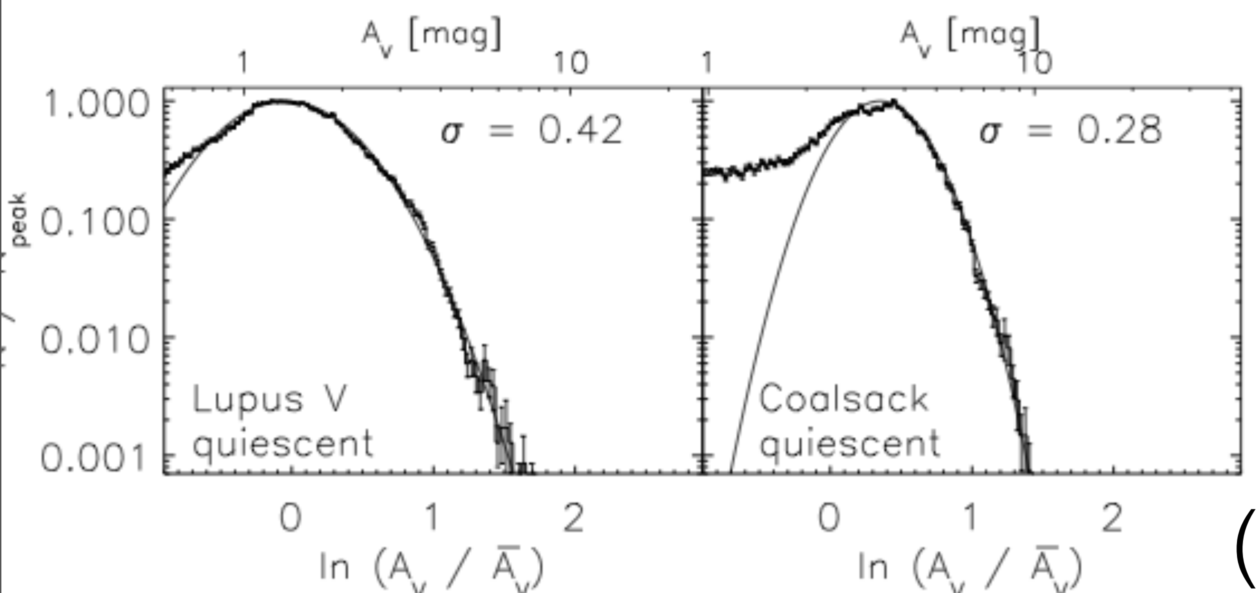
(-1.64 measured. Many self similar spherical solutions. Pressure-Free give -1.7)

(Kritsuk + 2011) (Girichidis + in prep)





Star forming clouds have powerlaw tail!

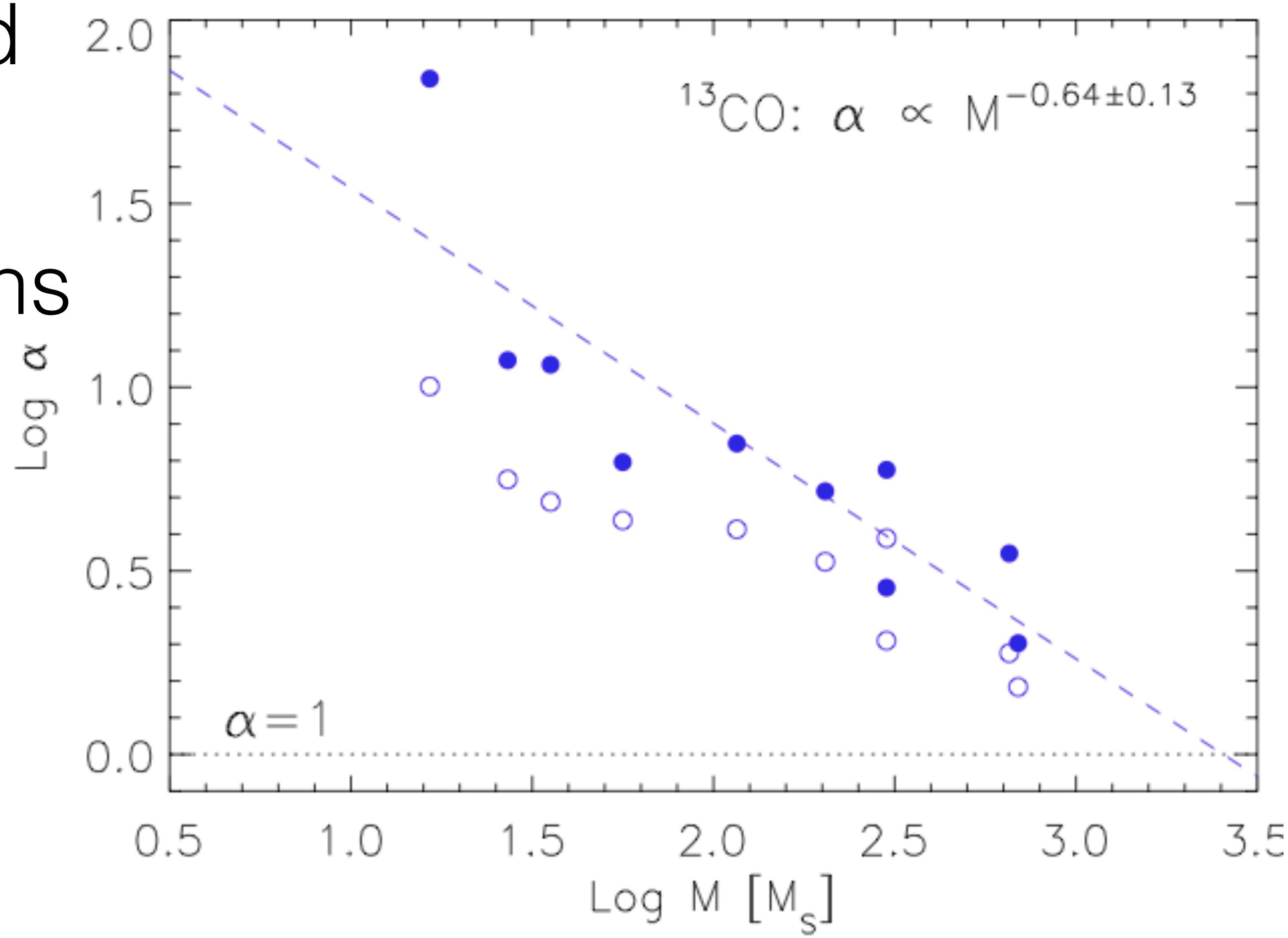


(Kainulainen+ 2009)

Tail not self-gravitating?

$$\alpha = \frac{5\sigma^2 R}{GM}$$

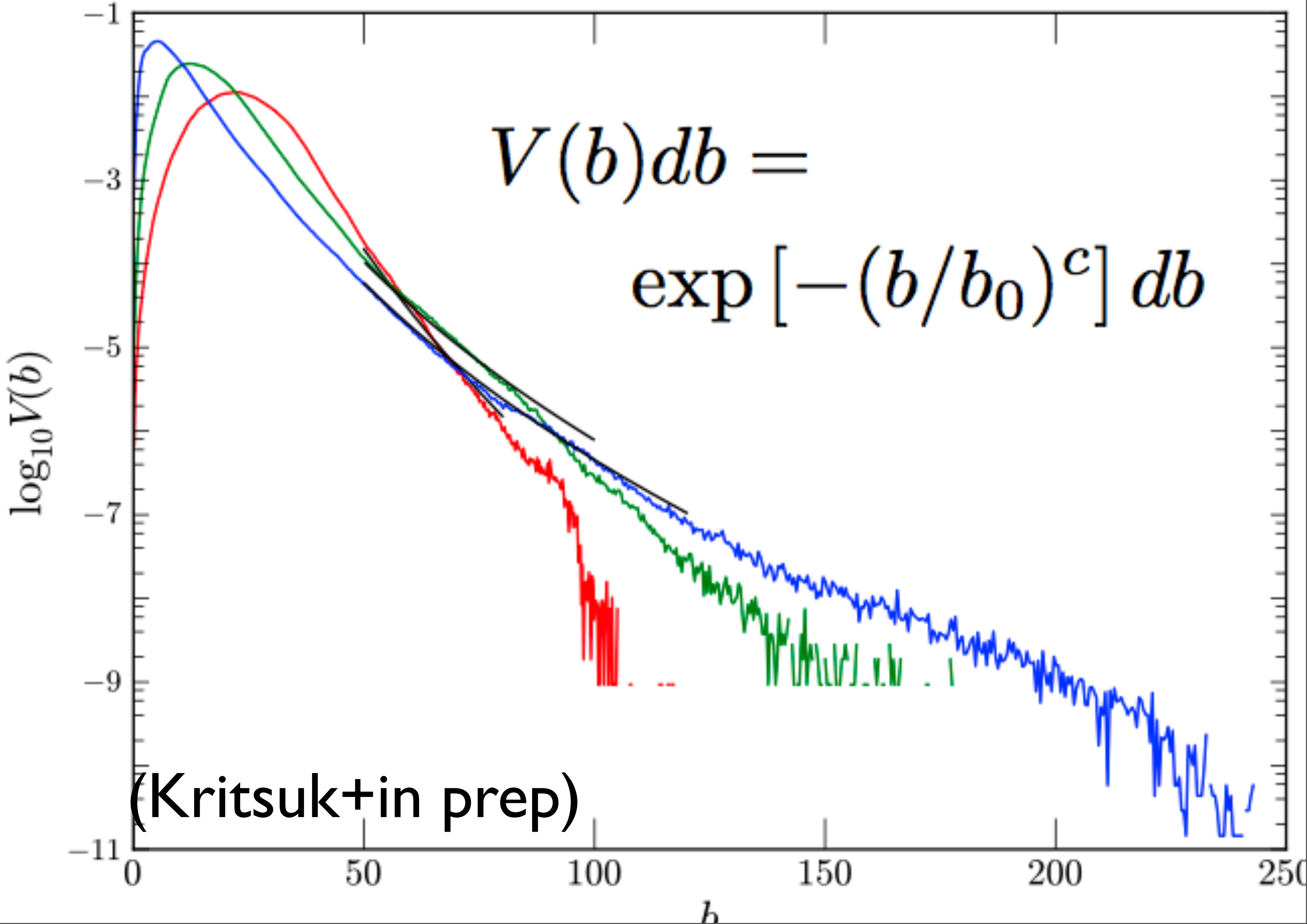
- Consistent with pressure-confined clumps
- How do simulations compare? Need synthetic observations

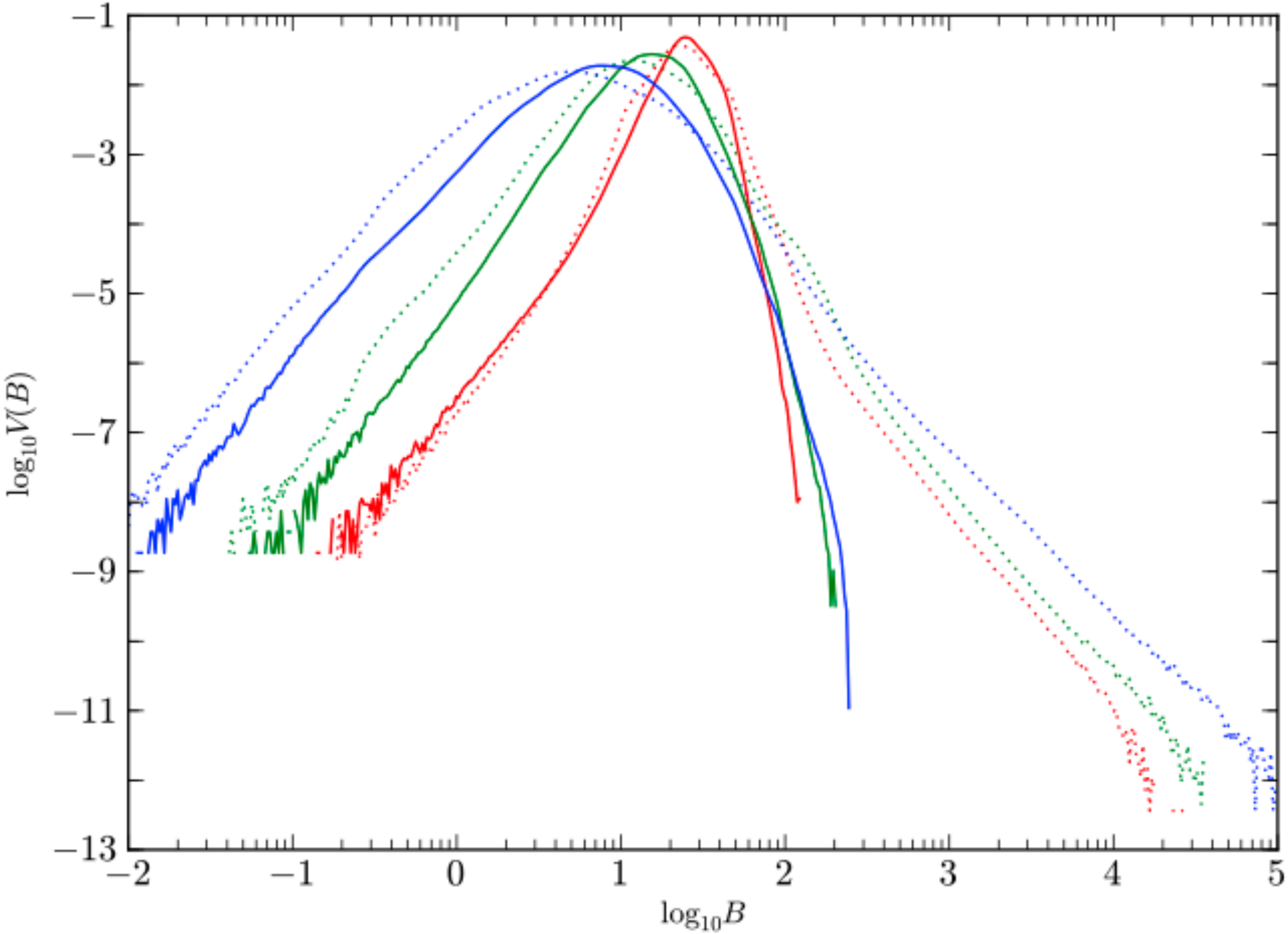


(Kainulainen+ 2011)

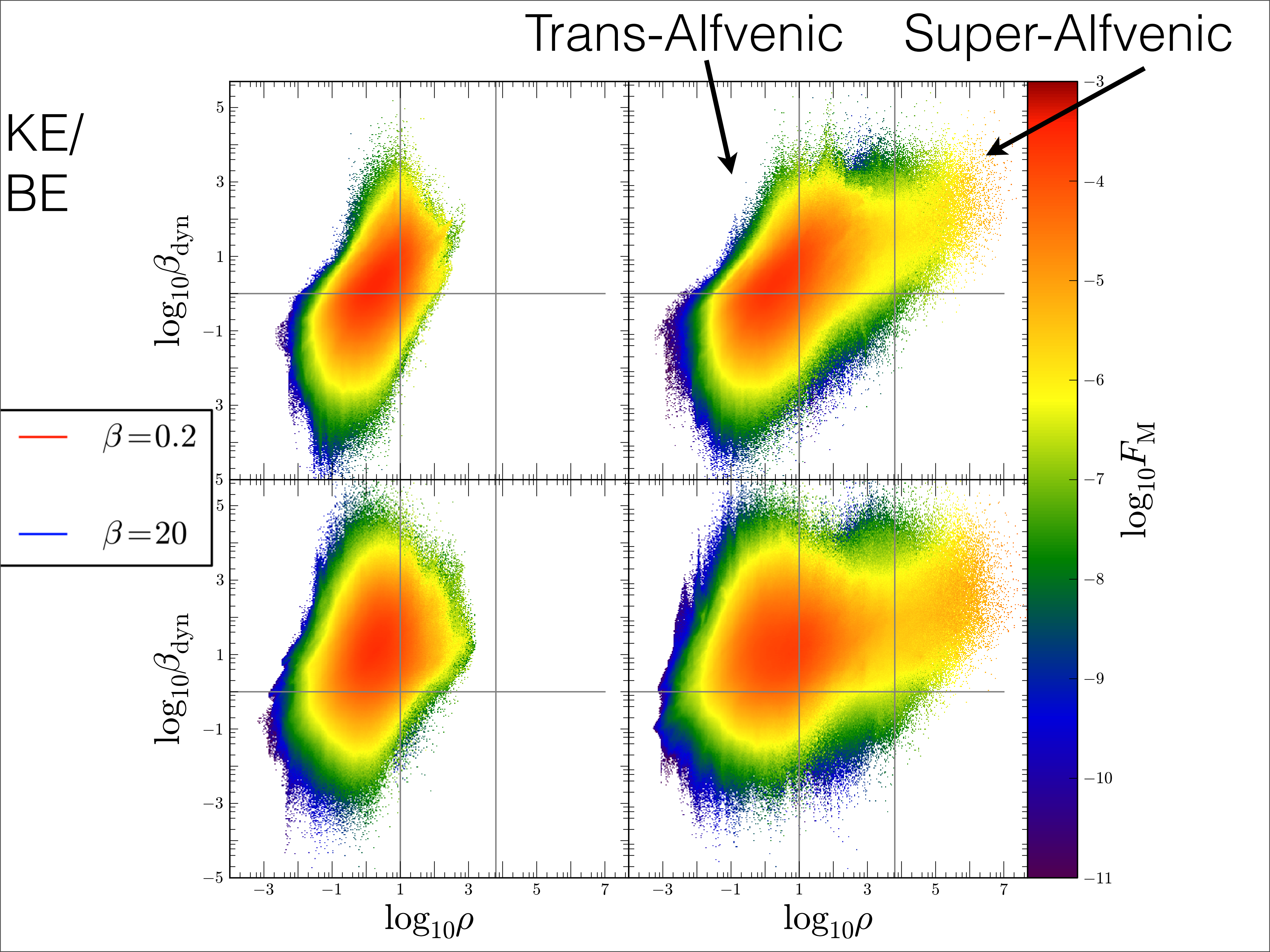
Turbulent Magnetic PDF

Non Monotonic!

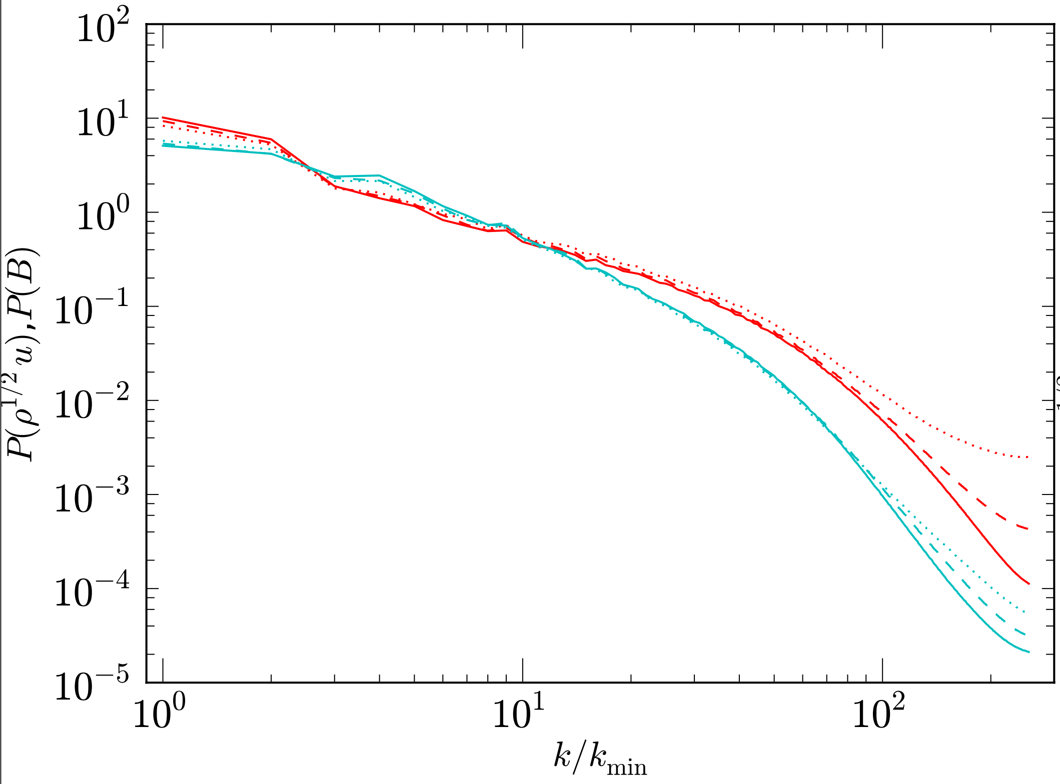


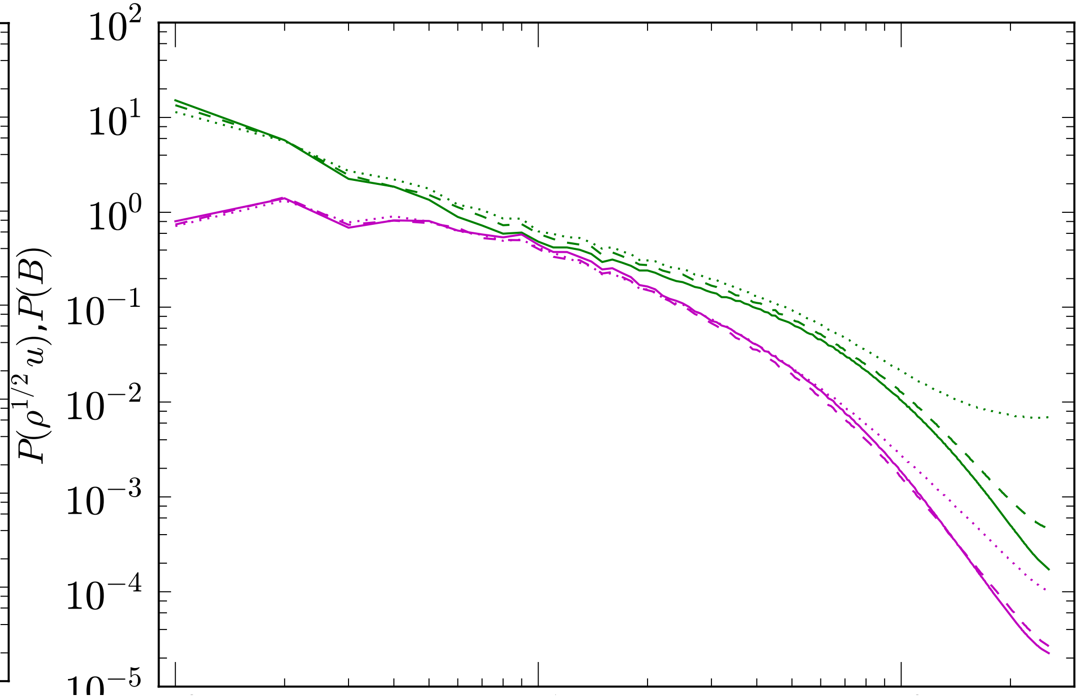


−1
−3
−5
−7
−9
−11
−13
−2
−1
0
1
2
3
4
5
$\log_{10} V(B)$
$\log_{10} B$

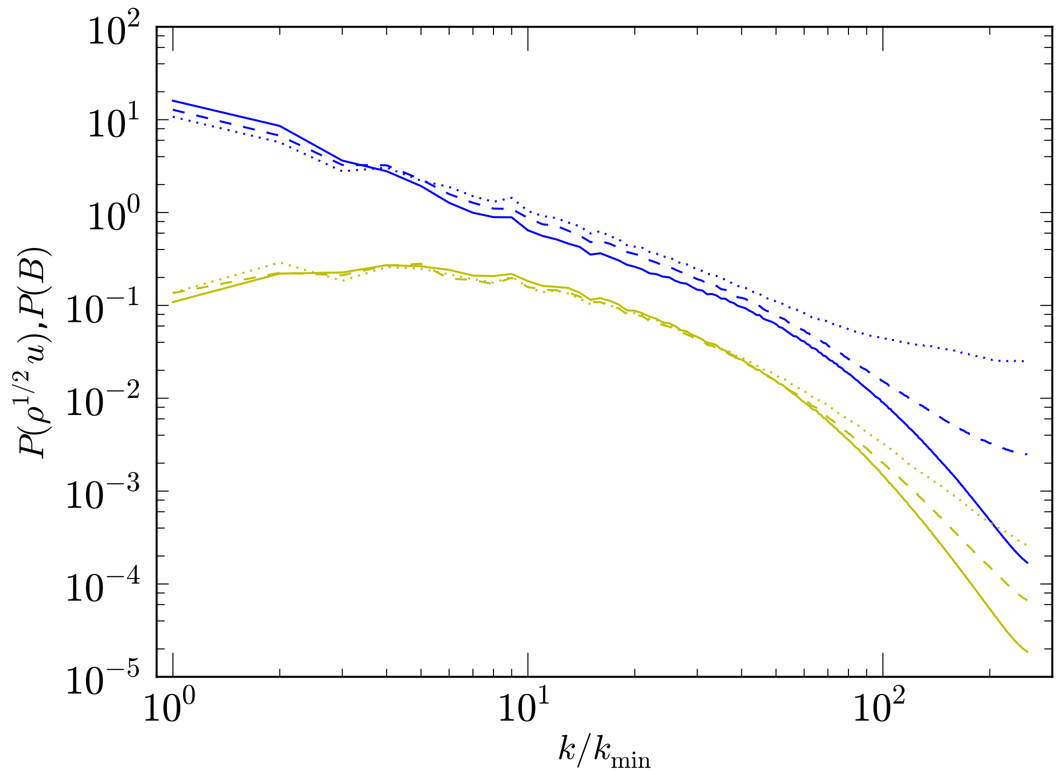


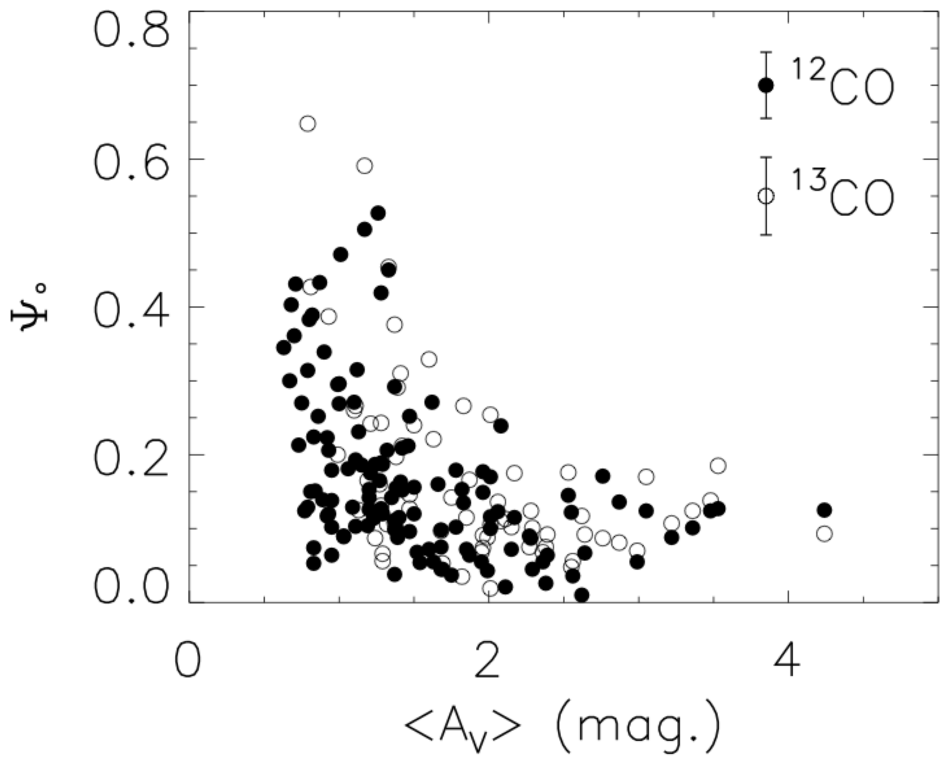
Trans-Alfvenic
Super-Alfvenic
KE/BE
$\beta = 0.2$
$\beta = 20$
$\log_{10}\beta_{\mathrm{dyn}}$
$\log_{10}\rho$
$\log_{10} F_{\mathrm{M}}$
−3 −4 −5 −6 −7 −8 −9 −10 −11

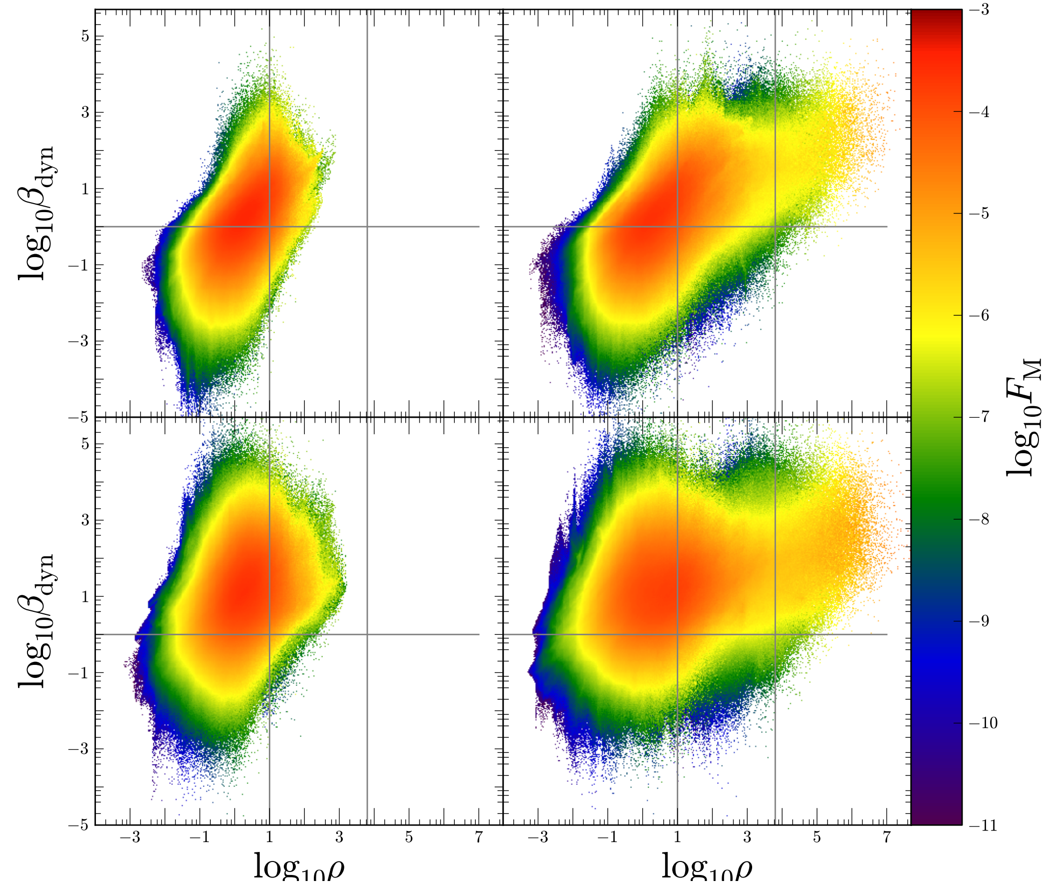


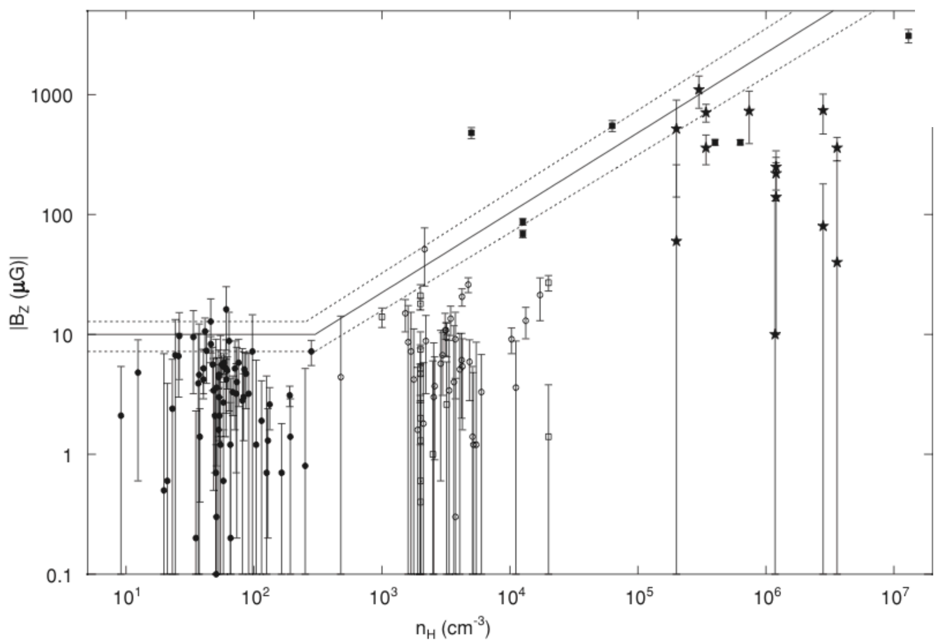


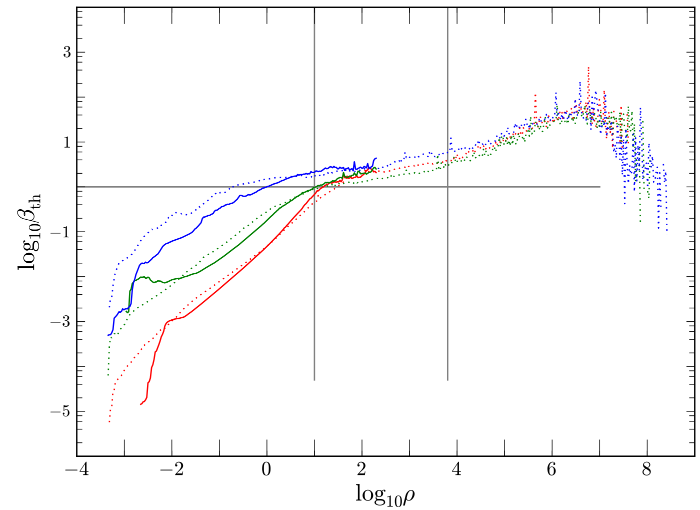
- Saturation depends on scale and mean field
- Gravity flattens spectra











Turbulence + Magnetic Fields + Gravity: Sale dependance?

Local Support against Gravity in magneto turbulent fluids.

Schmidt, Collins, & Kritsuk (2012?) in prep

Outline

- Statistical properties of self-gravitating turbulence.
- Discuss contribution to collapse from kinetic, thermal, magnetic, and gravitational energies

Typically

$$\sigma^2 = c_s^2 + v_{\rm rms}^2 + v_A^2$$

Goal

- Examine stability of cloud via velocity divergence.

$$d = \nabla \cdot \mathbf{v}$$

Goal

- Examine stability of cloud via velocity divergence.

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v} \otimes \mathbf{v}) = -\nabla P + \frac{1}{c}(\mathbf{J} \times \mathbf{B}) - \rho \nabla \phi.$$

Goal

- Examine stability of cloud via velocity divergence.

$$-\frac{\mathrm{D}d}{\mathrm{D}t} = 4\pi G\rho_0\delta - \Lambda$$

$$\Lambda = \Lambda_{\mathrm{turb}} + \Lambda_{\mathrm{therm}} + \Lambda_{\mathrm{magn}}$$

$$\Lambda_+ > 0 \quad \Lambda_- < 0$$

Easy!

$$\Lambda_{\text{therm}} = -\frac{1}{\rho}\frac{\partial^2 P}{\partial x_i \partial x_i} + \frac{1}{\rho^2}\frac{\partial \rho}{\partial x_i}\frac{\partial P}{\partial x_i} = -c_0^2 \nabla^2 \ln \rho$$

$$\Lambda_{\text{turb}} = \frac{1}{2}\left(\omega^2 - |S|^2\right)$$

$$\Lambda_{\text{magn}} = \frac{1}{4\pi\rho}\left[-\frac{\partial^2}{\partial x_i \partial x_i}\left(\frac{1}{2}B^2\right) + \frac{\partial B_i}{\partial x_j}\frac{\partial B_j}{\partial x_i}\right]$$

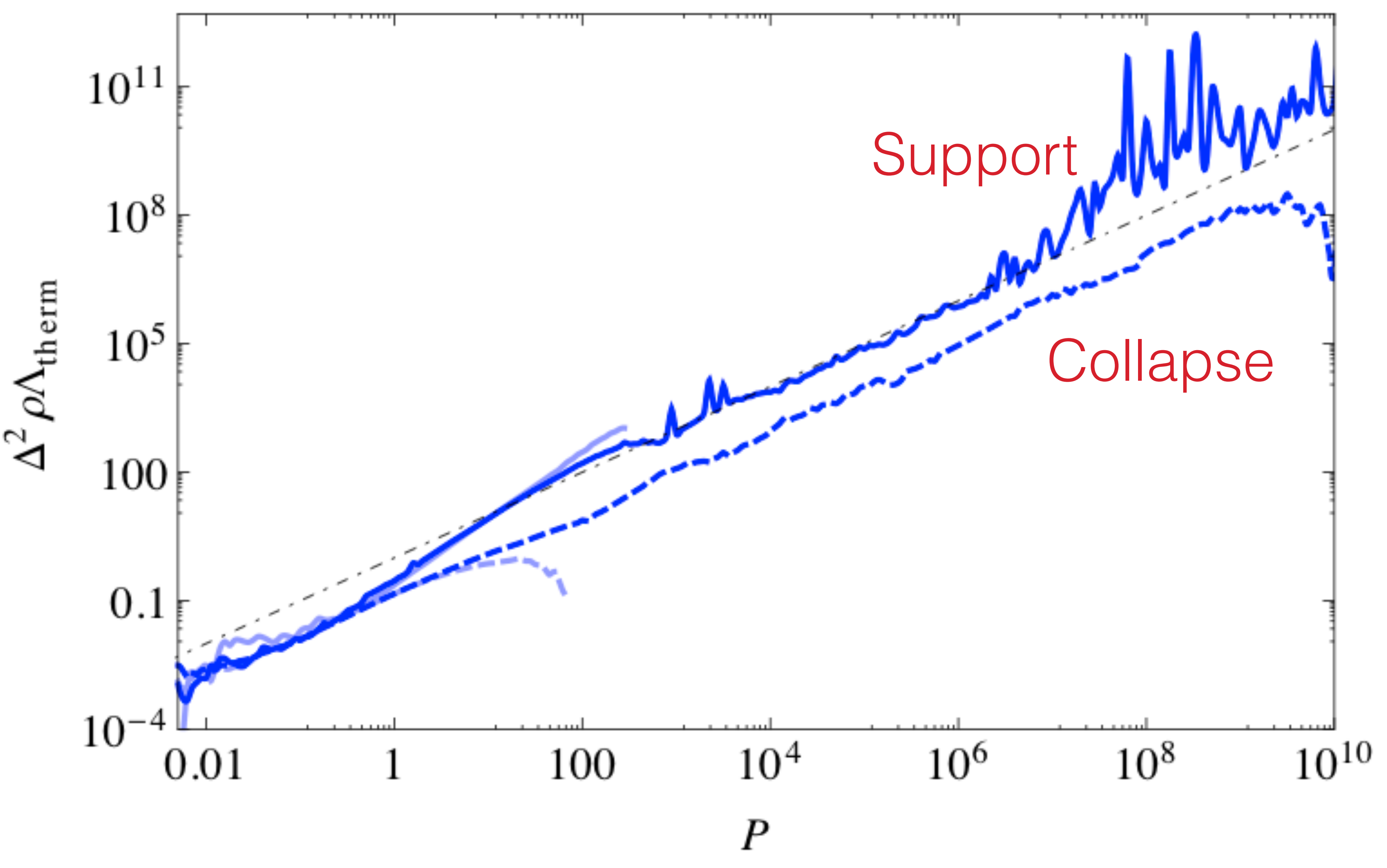
$$+\frac{1}{4\pi\rho^2}\frac{\partial \rho}{\partial x_i}\left[\frac{\partial}{\partial x_i}\left(\frac{1}{2}B^2\right) - B_j \frac{\partial B_i}{\partial x_j}\right]$$

Simulations

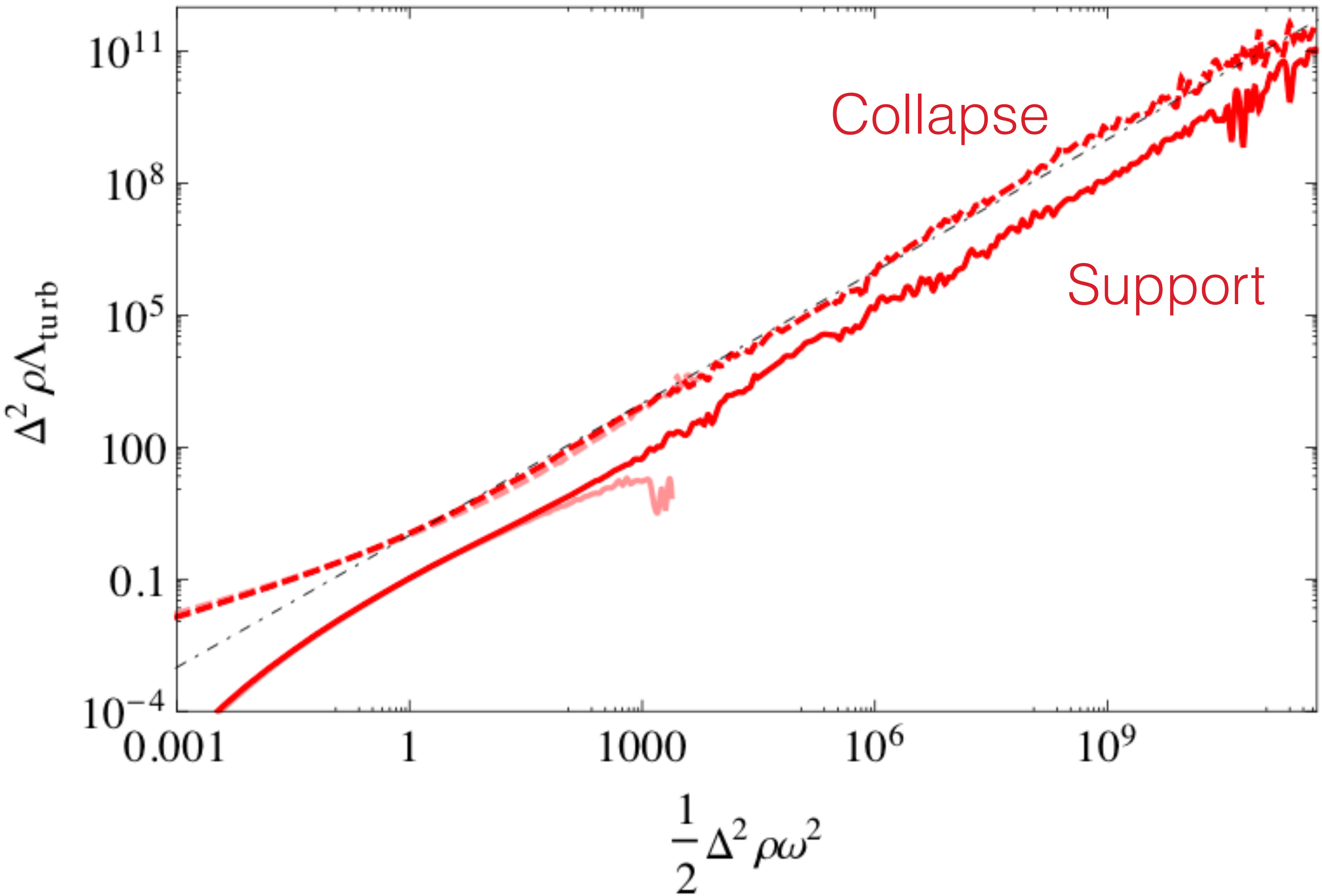
- As before, plus:
- AMR Hydro (512 + 5x4), Mach 6
- Kritsuk + 2011

Results

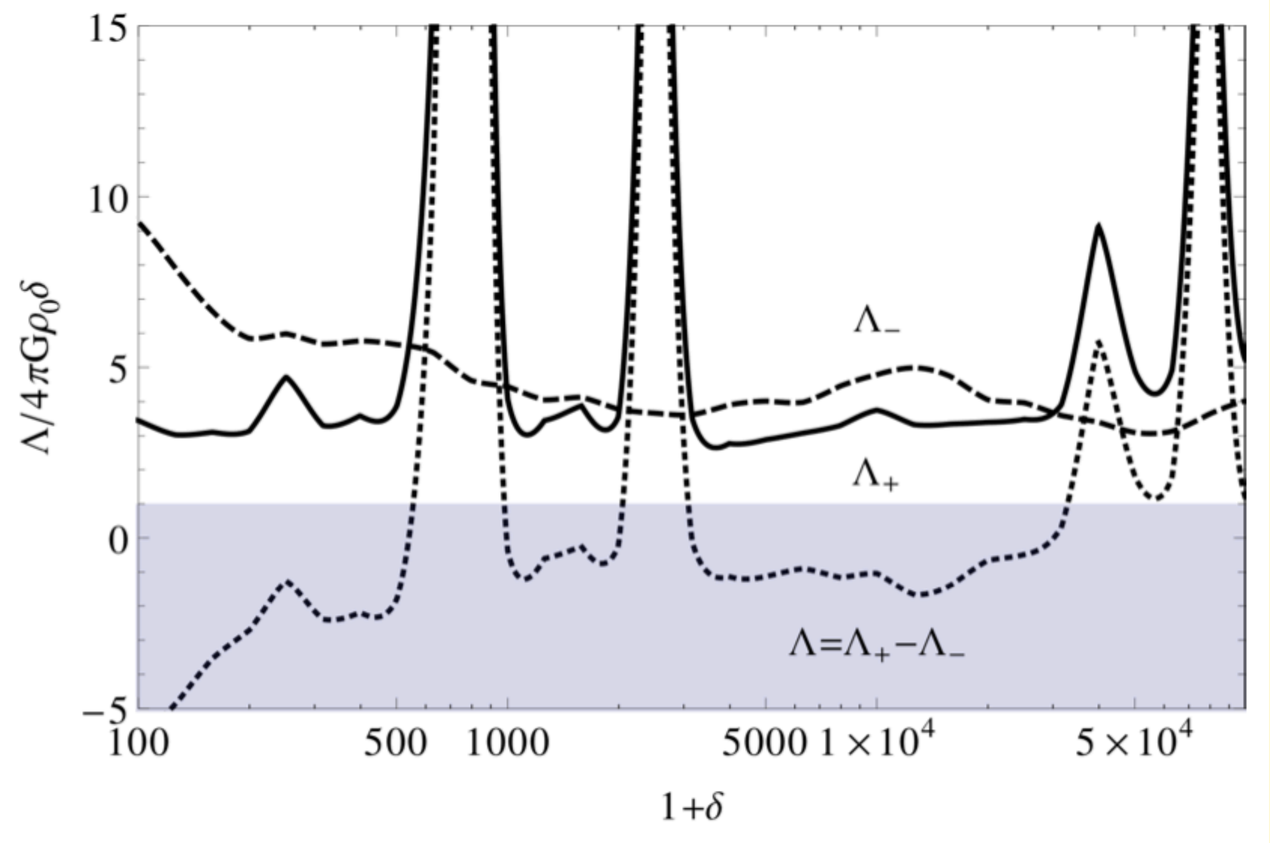
- Gravity provides collapse (duh) $4\pi G\rho_0\delta$
- Pressure gradients support $\Lambda_{\rm therm}$
    - Mach 10!
- Turbulence causes compression $\Lambda_{\rm turb}$
    - "Turbulent Pressure?"
- Weak fields experience more amplification, support than strong. $\Lambda_{\rm magn}$



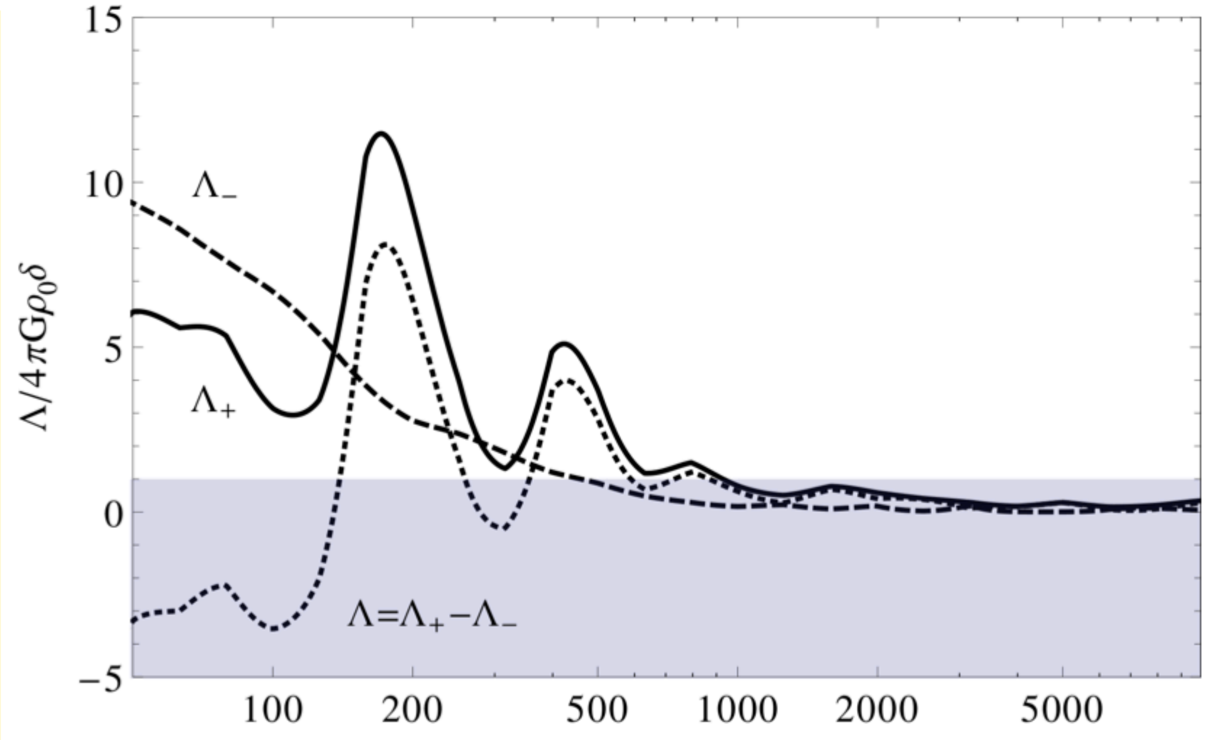
Support
Collapse
$\Delta^2 \rho \Lambda_{\mathrm{therm}}$
10^{11}
10^8
10^5
100
0.1
10^{-4}
0.01
1
100
10^4
10^6
10^8
10^{10}
P



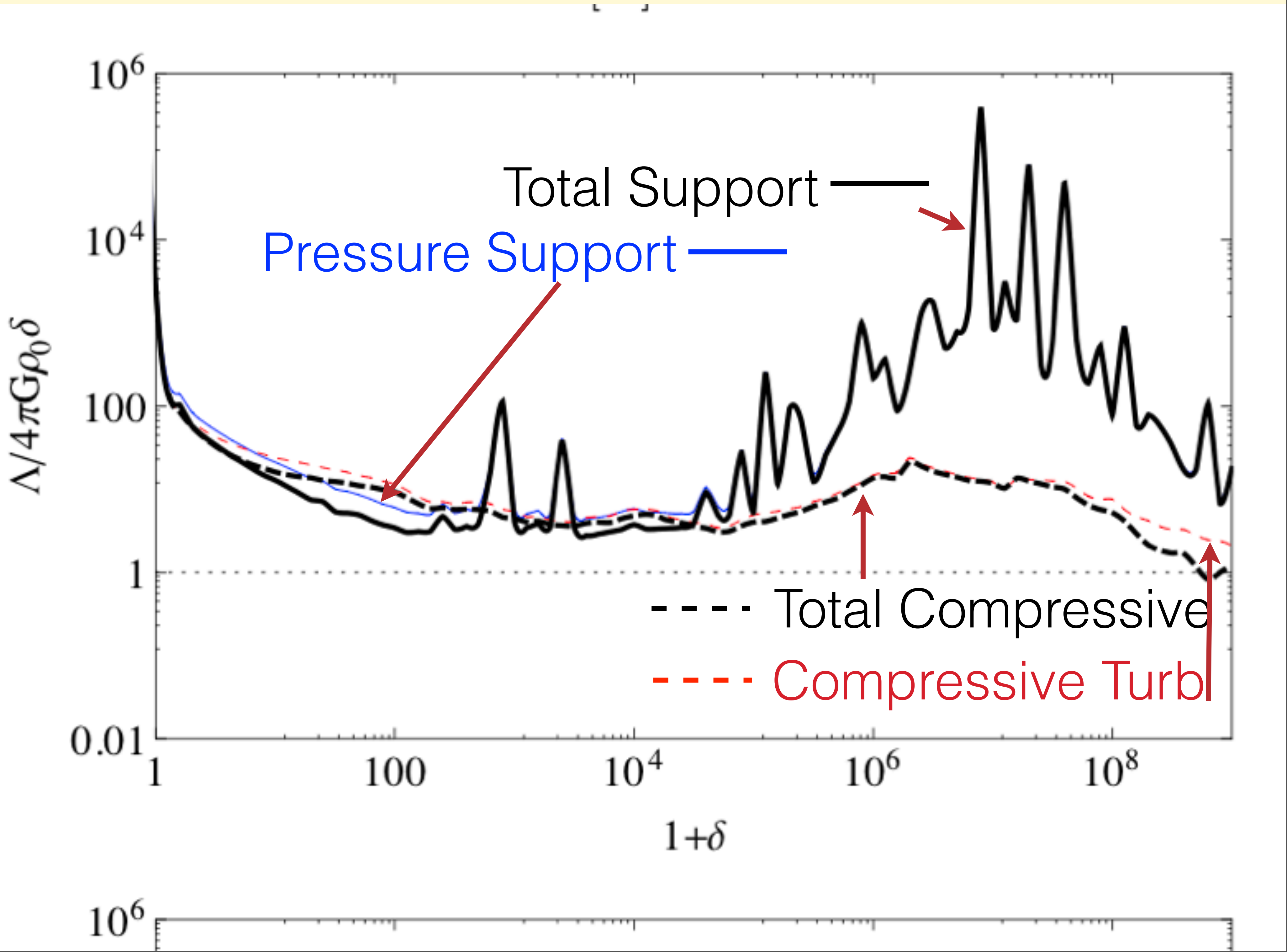
Collapse
Support
10^{11}
10^8
10^5
100
0.1
10^{-4}
0.001
1
1000
10^6
10^9
$\Delta^2 \rho \Lambda_{\mathrm{turb}}$
$\frac{1}{2}\Delta^2 \rho \omega^2$



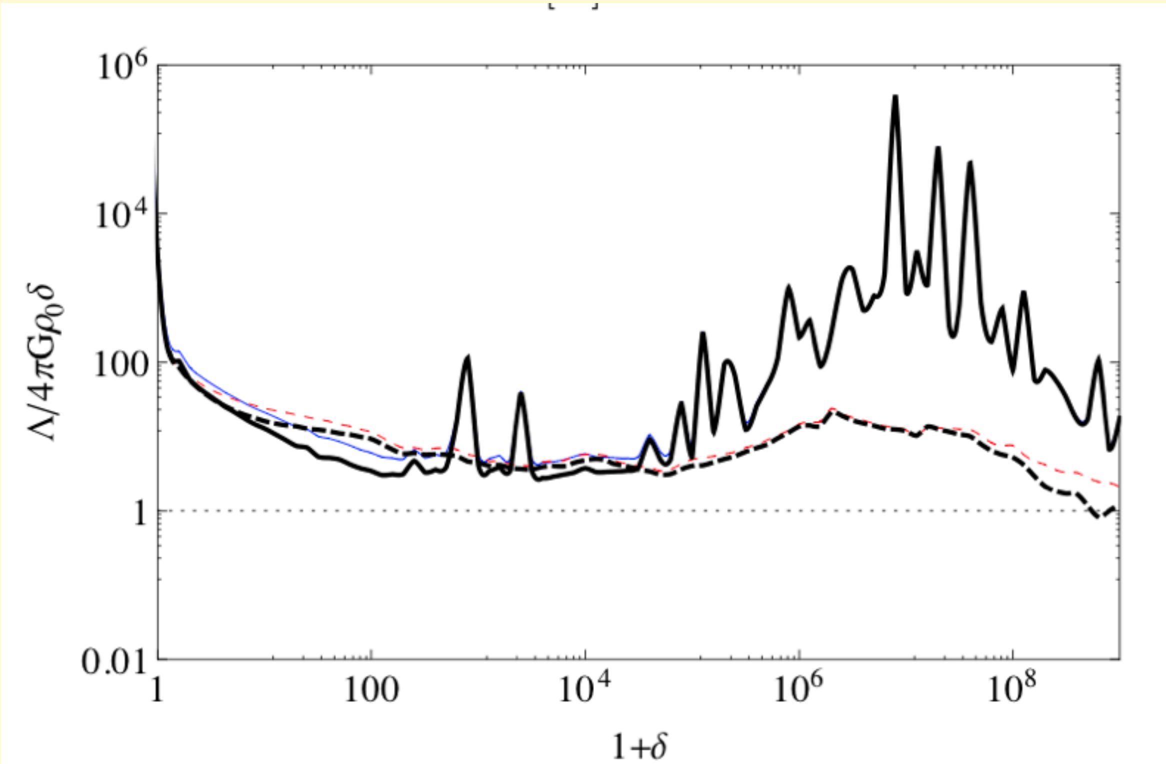
All AMR
Super Gravity.



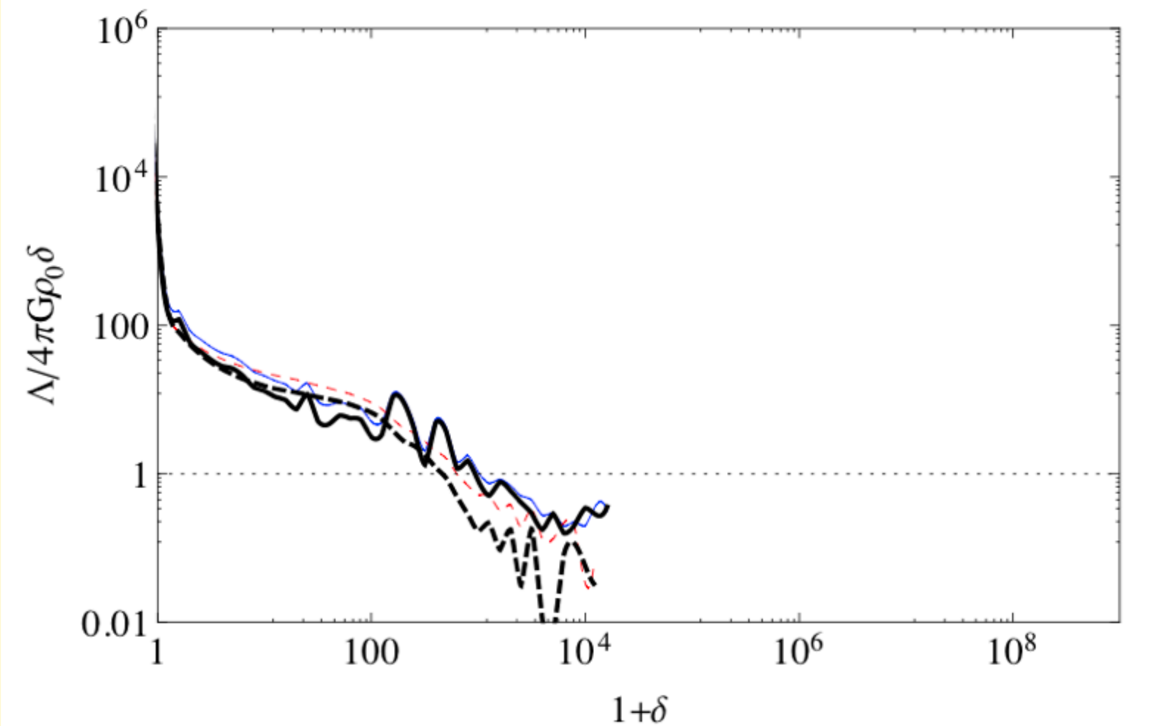
Same snapshot, only root grid. Effective large scale filtering.



Total Support
Pressure Support
Total Compressive
Compressive Turb
$\Lambda/4\pi G\rho_0\delta$
$1+\delta$
10^6
10^4
100
1
0.01
1
100
10^4
10^6
10^8

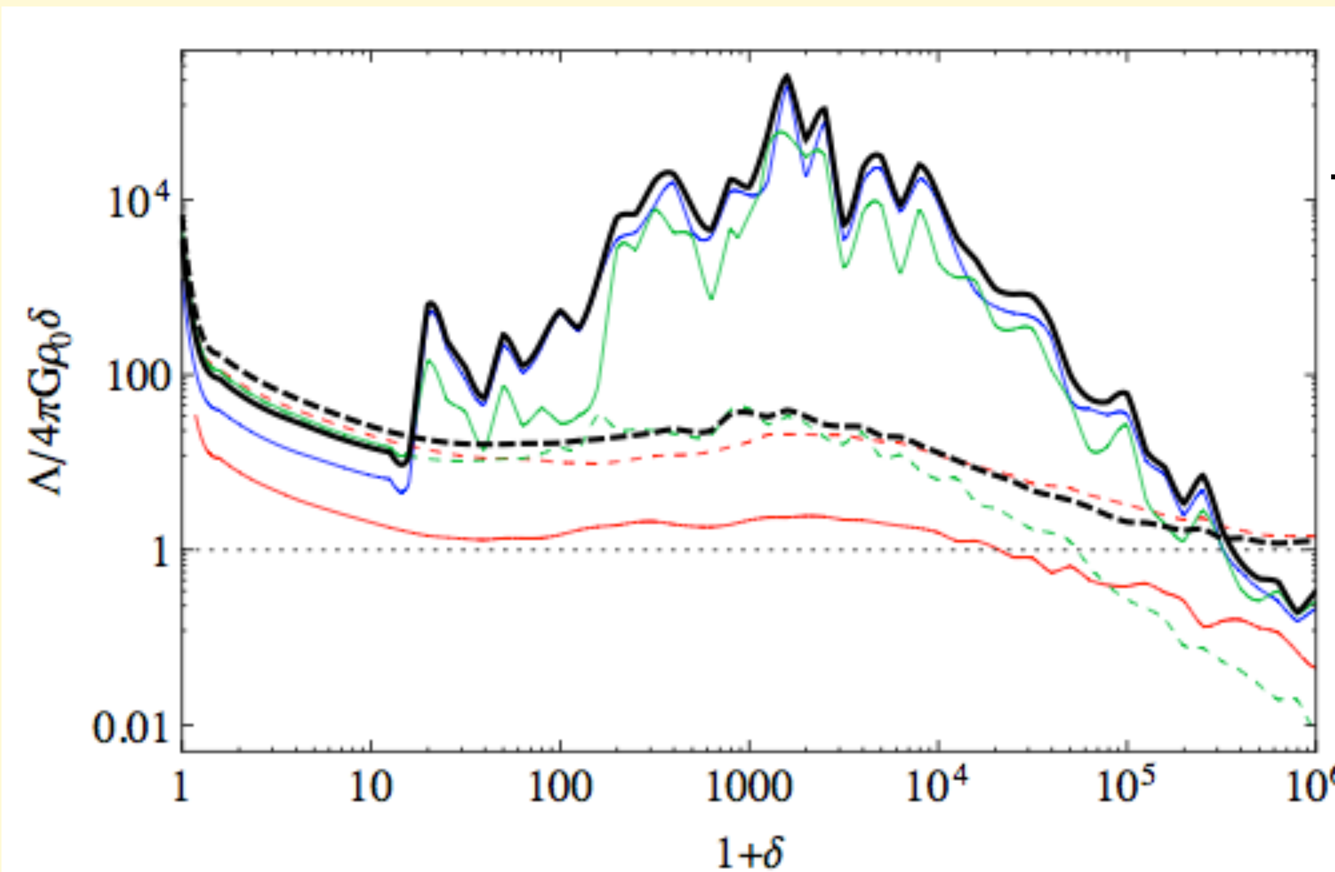


All AMR



Same snapshot, only root grid. Effective large scale filtering.

Magnetic Term: Low Field Run.



Pressure Support

Total Support

Mag Support

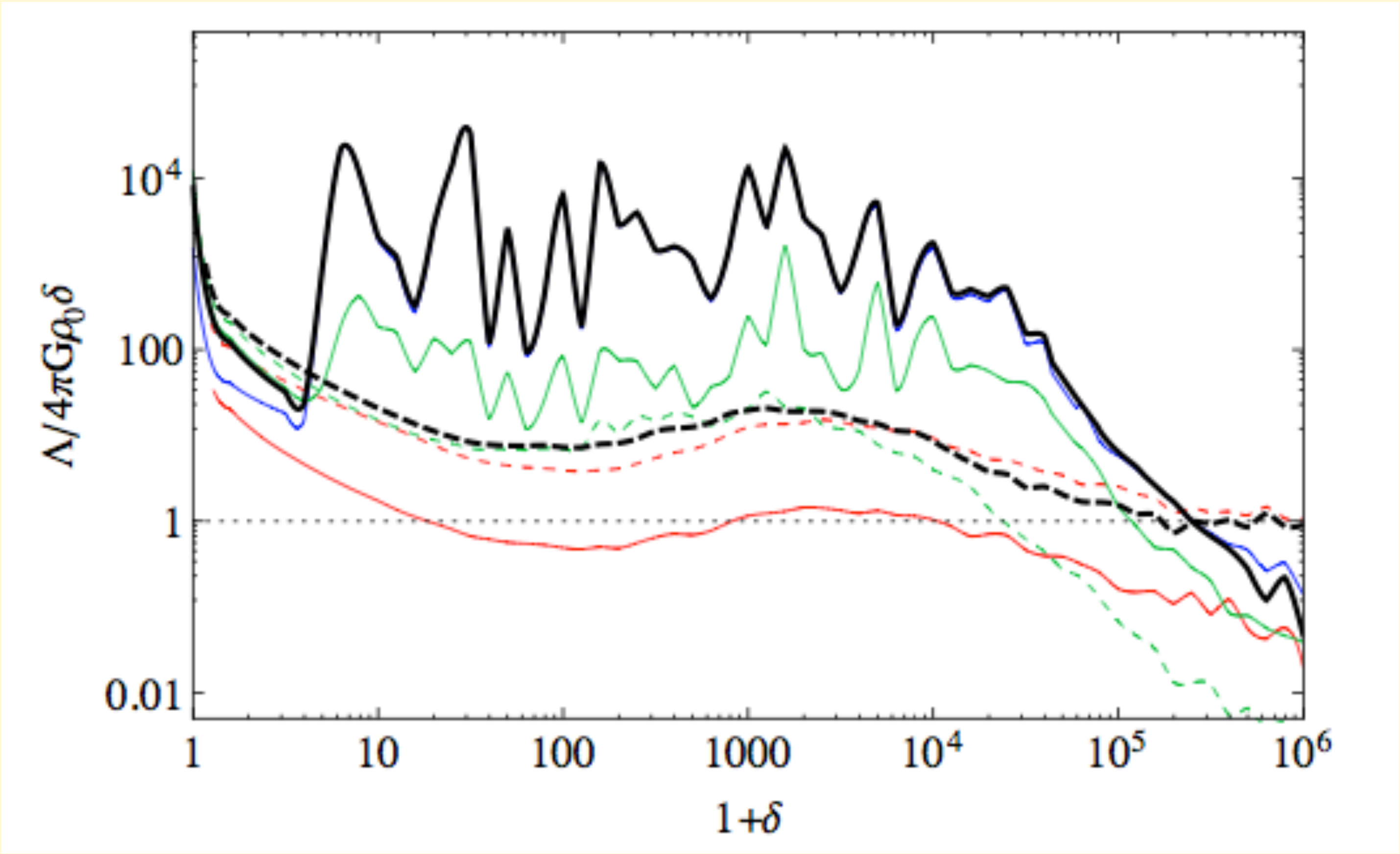
Turb Support

Total Compressive

Turb Compressive

Mag Compressive

Magnetic Term: High Field Run.



Results

- Gravity collapses.
  - Powerlaw tails! (?)
- Pressure gradients support
- Turbulence compression
- Fields? Non monotonic!
- Scale Dependance
- Virial Parameter?