ULM Cores and Protostars in Turbulent Clouds

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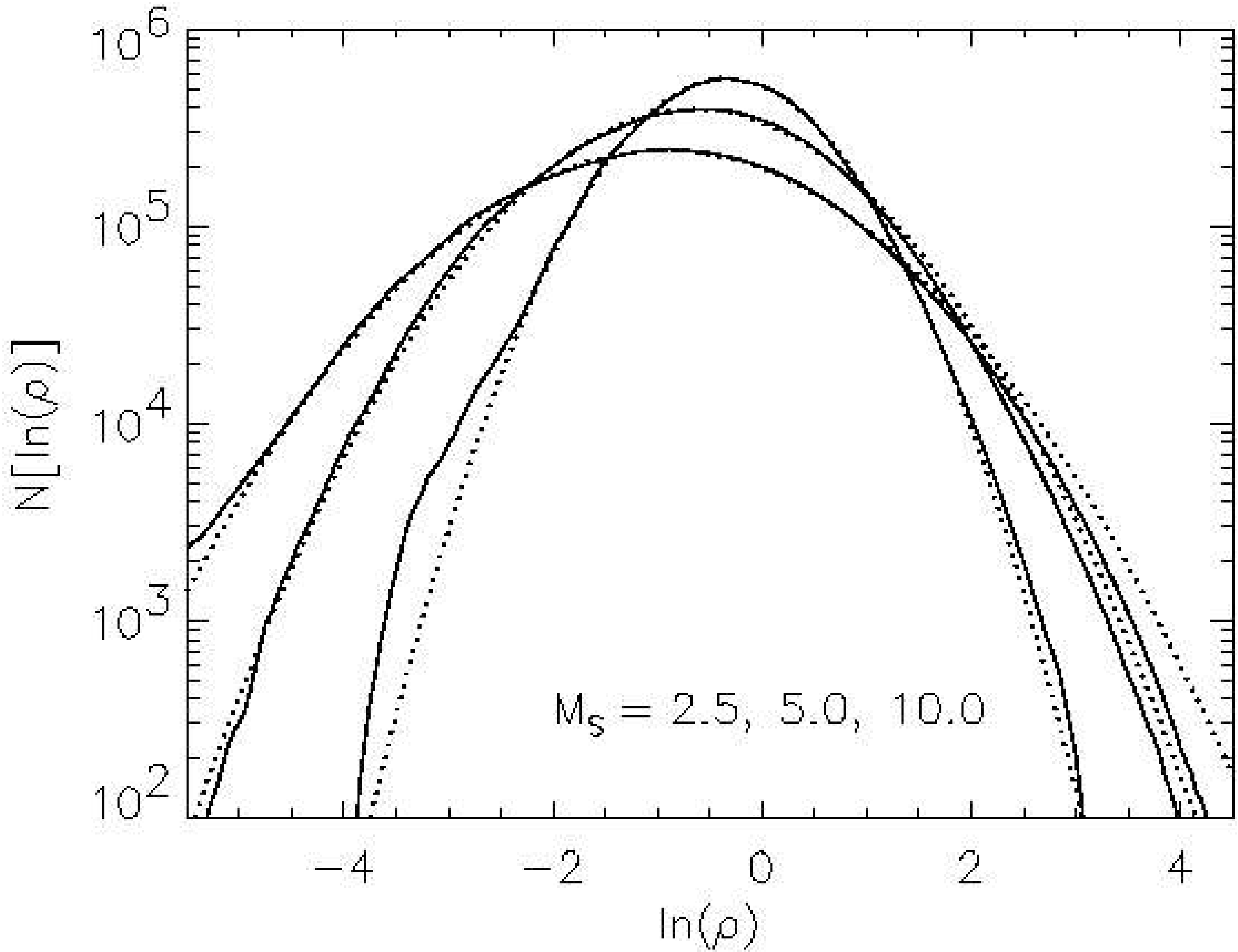
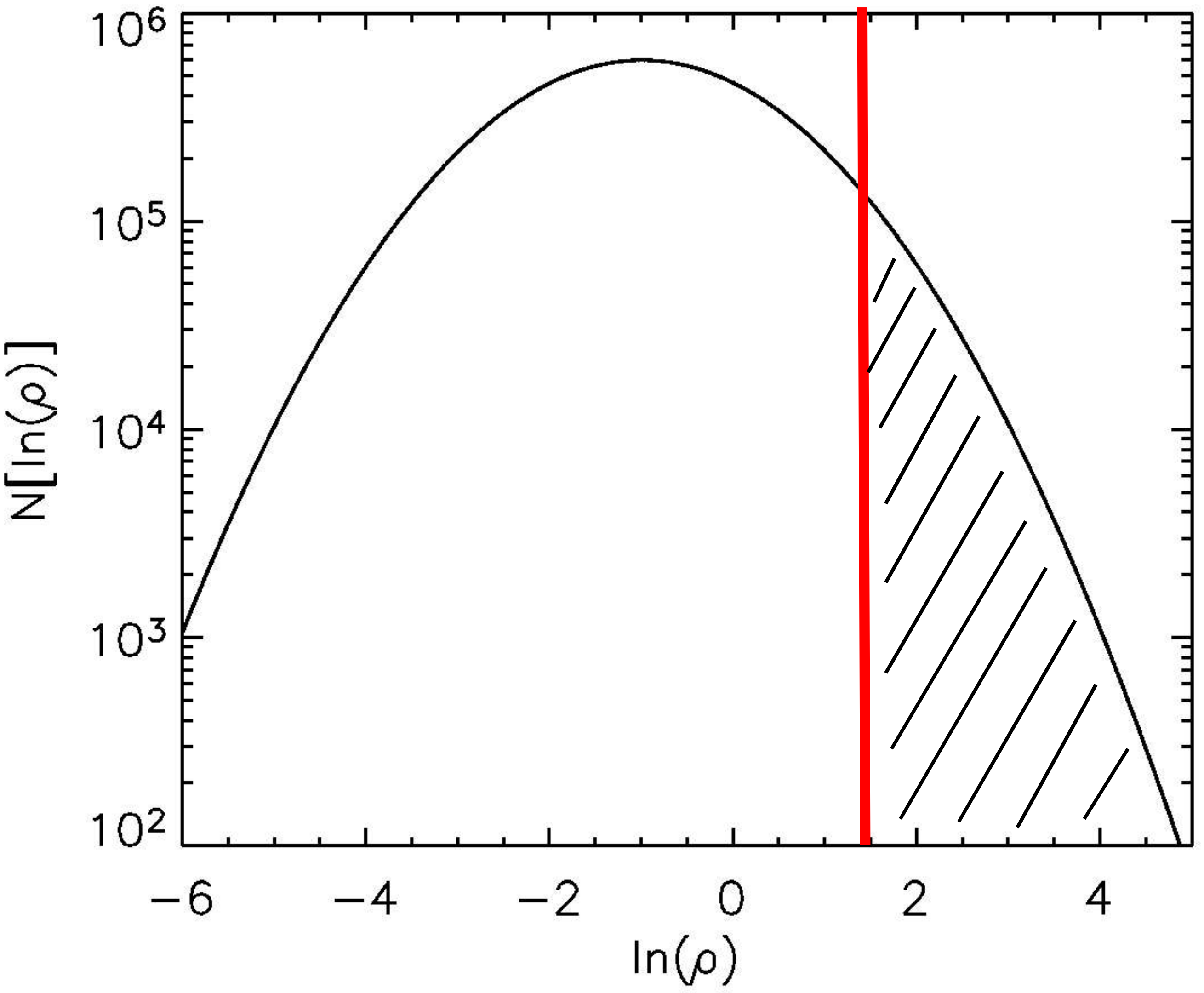
Isothermal supersonic turbulent flows:

---> Universal Log-Normal PDF of gas density



Mass fraction above a critical density



Critical density

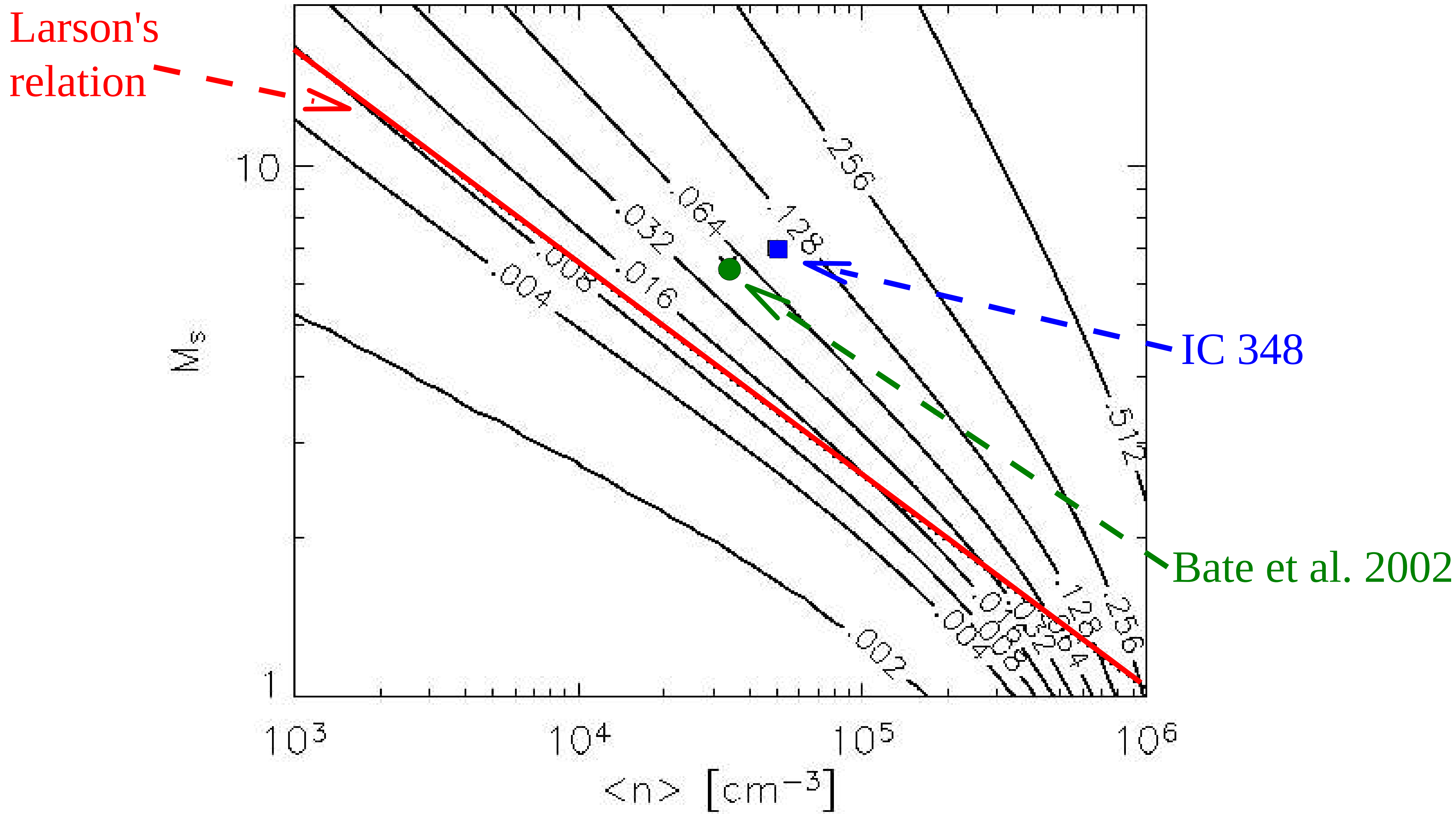
$$m_{BE} = 3.3\,M_{SUN}\left(\frac{T}{10\,K}\right)^{3/2}\left(\frac{n}{10^3\,cm^{-3}}\right)^{-1/2}$$

Bonnor-Ebert mass < 0.075 solar masses

$$n_{cr} = 2\times10^6\,cm^{-3}\left(\frac{T}{10\,K}\right)^3$$

Mass fraction ***available*** to form BDs:
1% in molecular clouds, 10% in clusters (T~10K)

(Padoan & Nordlund 2004)



Mass distribution of density peaks

$$N(m) \propto m^{-S} \propto m^{-3/(4-\beta)}$$

$$\text{for} \quad \beta = 1.8 \quad \Rightarrow \quad N(m) \propto m^{-1.36}$$

Mass range of density peaks in typical clouds:

$$m_{\rm min} \sim 3 \times 10^{-4}\,\mathrm{m_{sun}}, \quad m_{\rm max} \sim 100\,\mathrm{m_{sun}}$$

Turbulent seeds ---> Stars & BDs

Low mass peaks

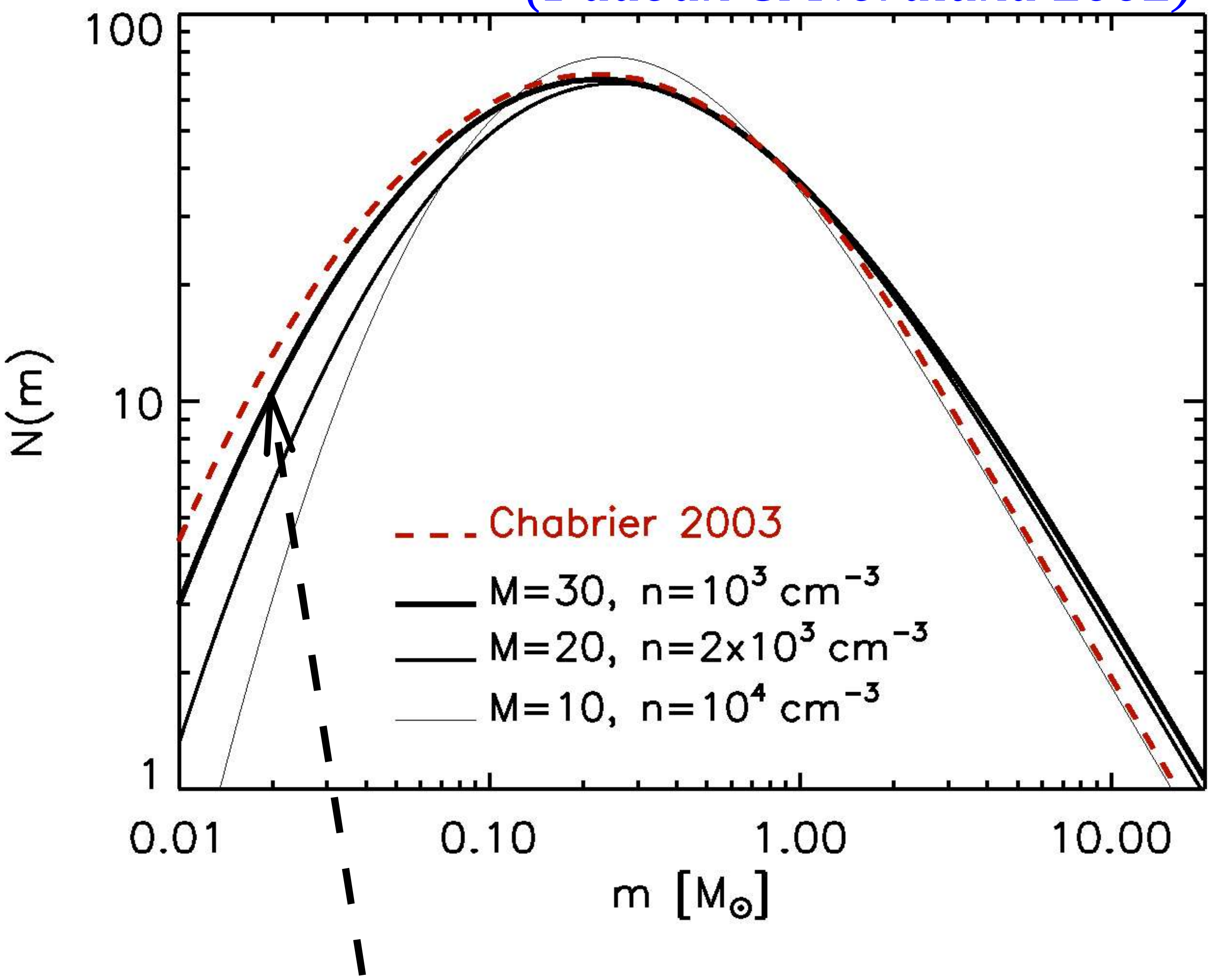
Assumptions for the statistics of mass and density of peaks:

- Mass and density are statistically independent.
- Density follows the Log-Normal turbulent PDF.

--> The low mass IMF depends on ρ, T, v_{rms} , B.

High Mach number + High density
---> Observed BD abundance

(Padoan & Nordlund 2002)



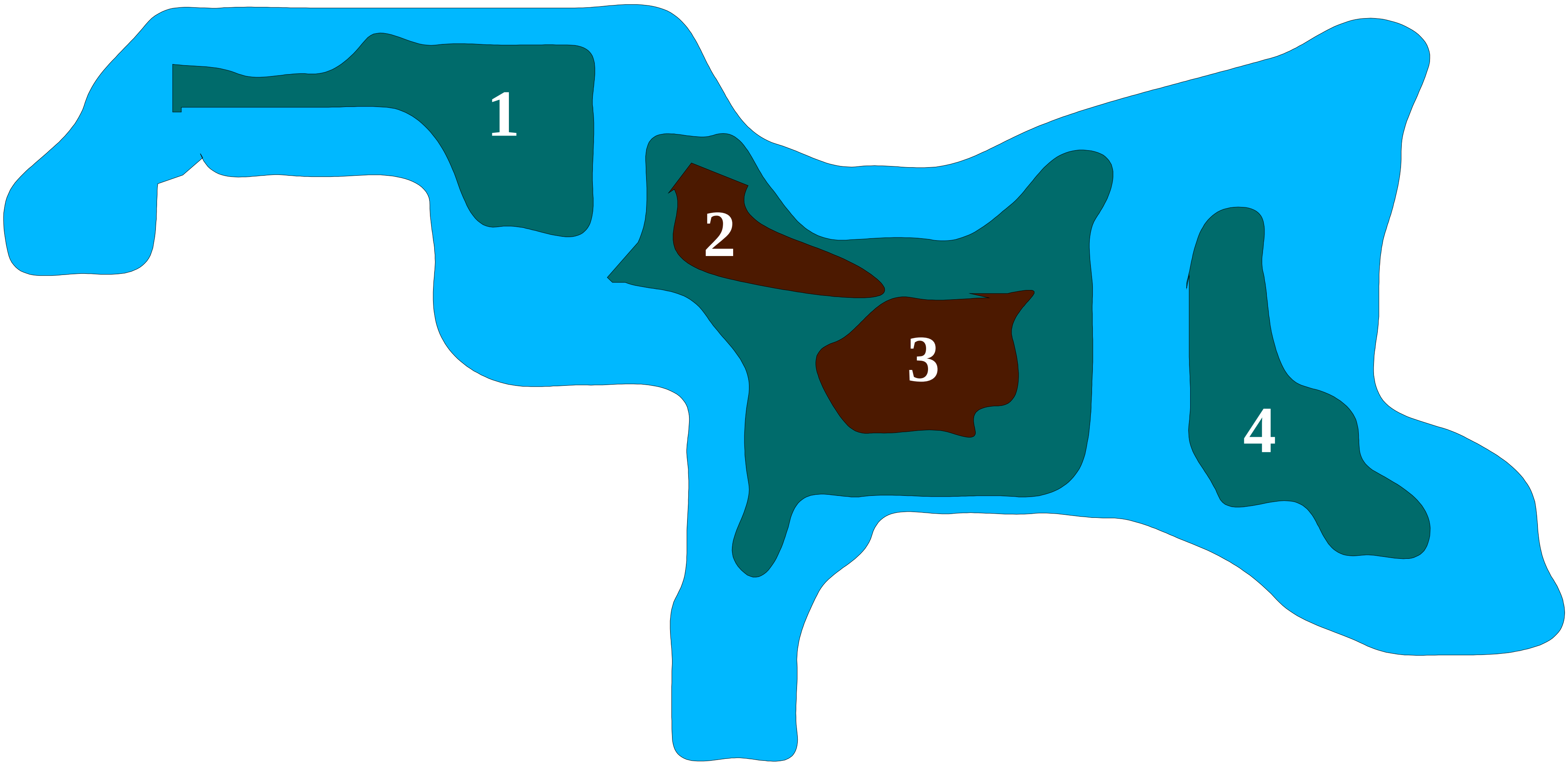
Gravitational fragmentation (binaries)?

Selection of gravitationally unstable density peaks in simulations of supersonic turbulence

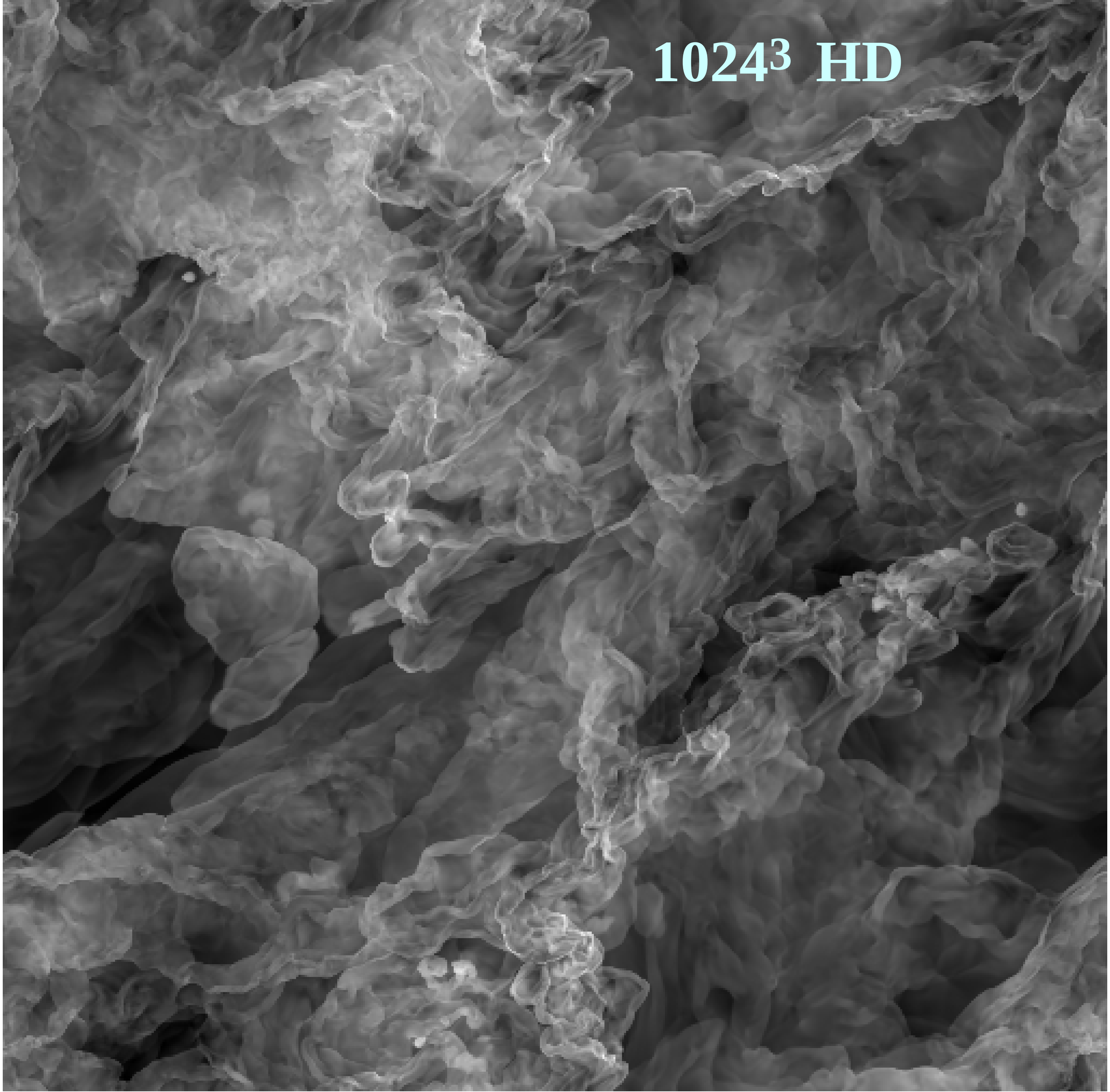
Why not just count sink particles?

- We want to understand the role of turbulence and initial conditions
- Uncertainty of the definition, accretion and merging of sink particles

Cloud-in-Cloud problem (Peak clustering)



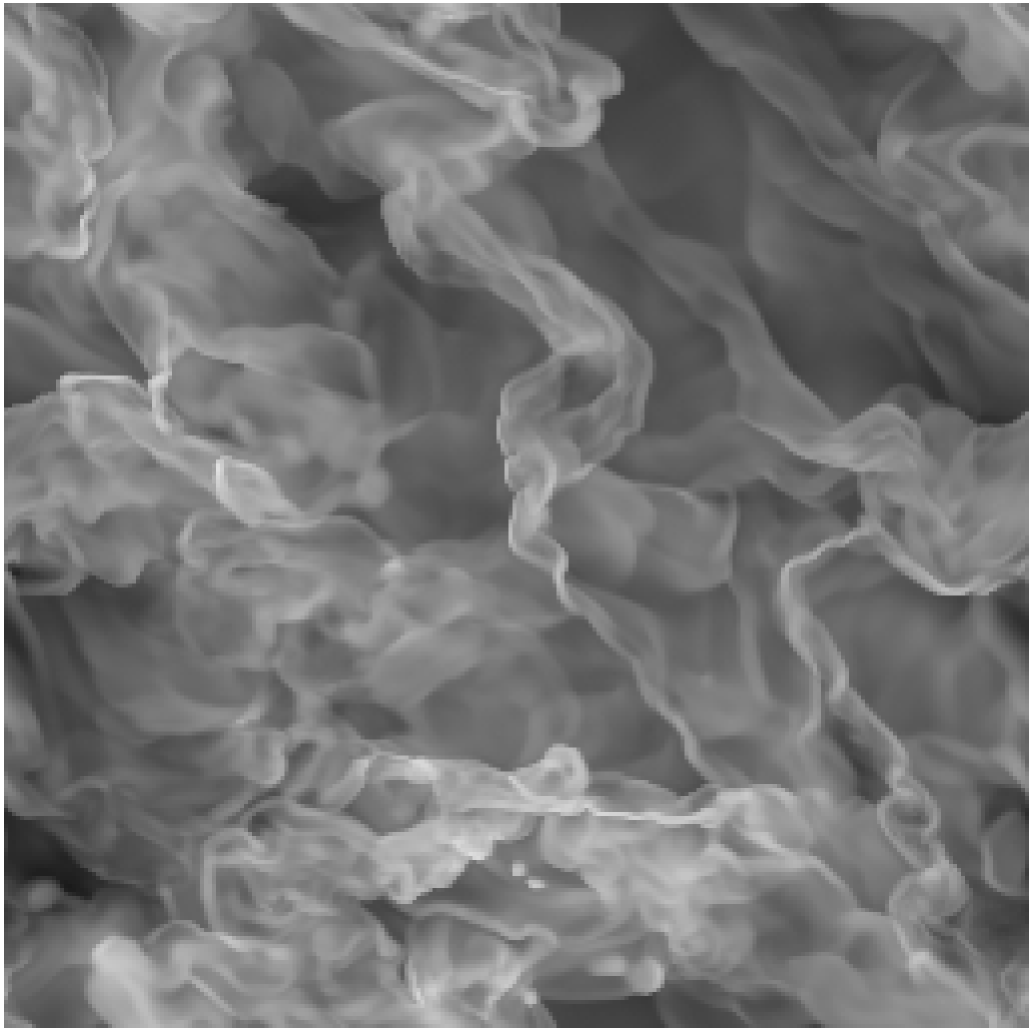
---> The peakfind algorithm selects 4 cores
(if all larger than their Bonnor-Ebert mass)



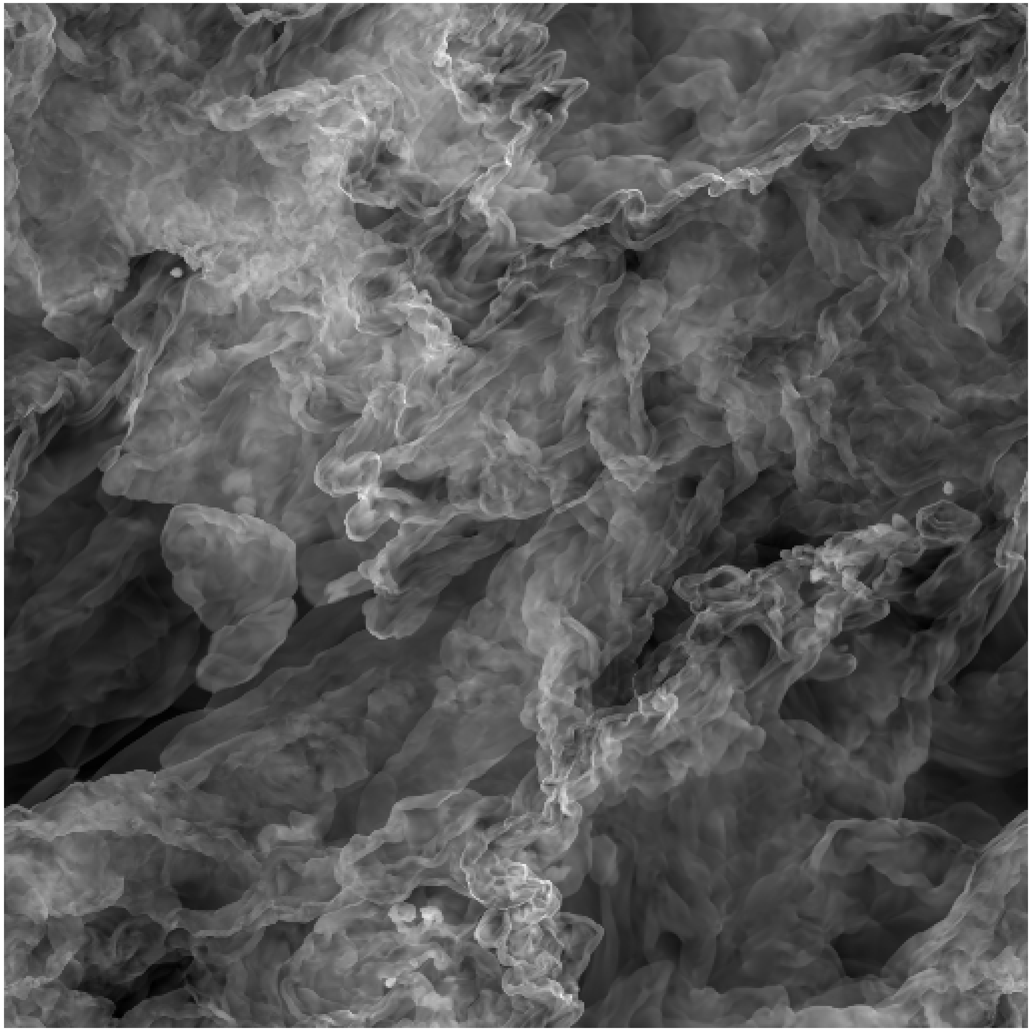
1024^3 HD

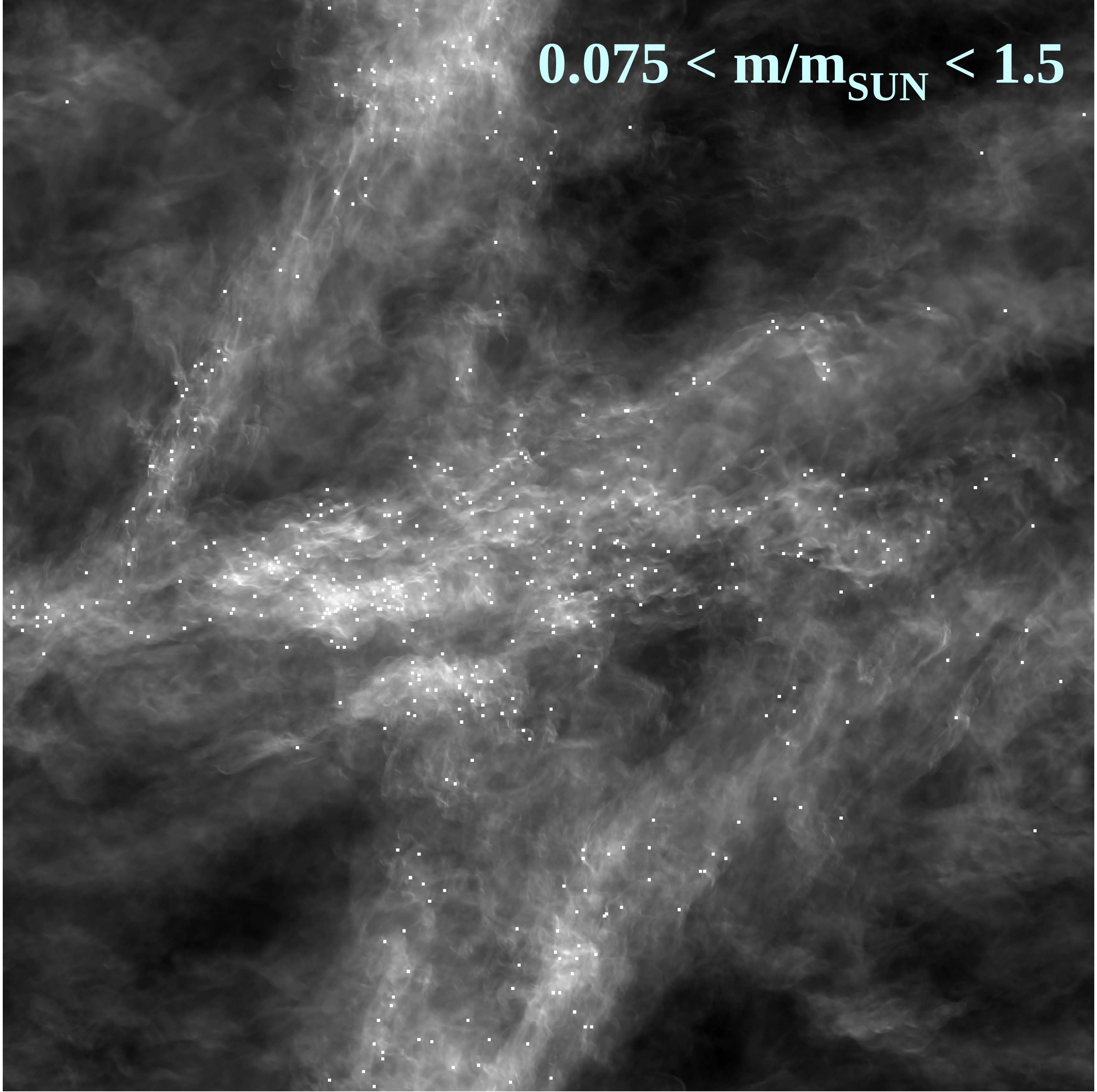
In HD the numerical **resolution** is crucial to capture the instabilities of postshock shear layers.

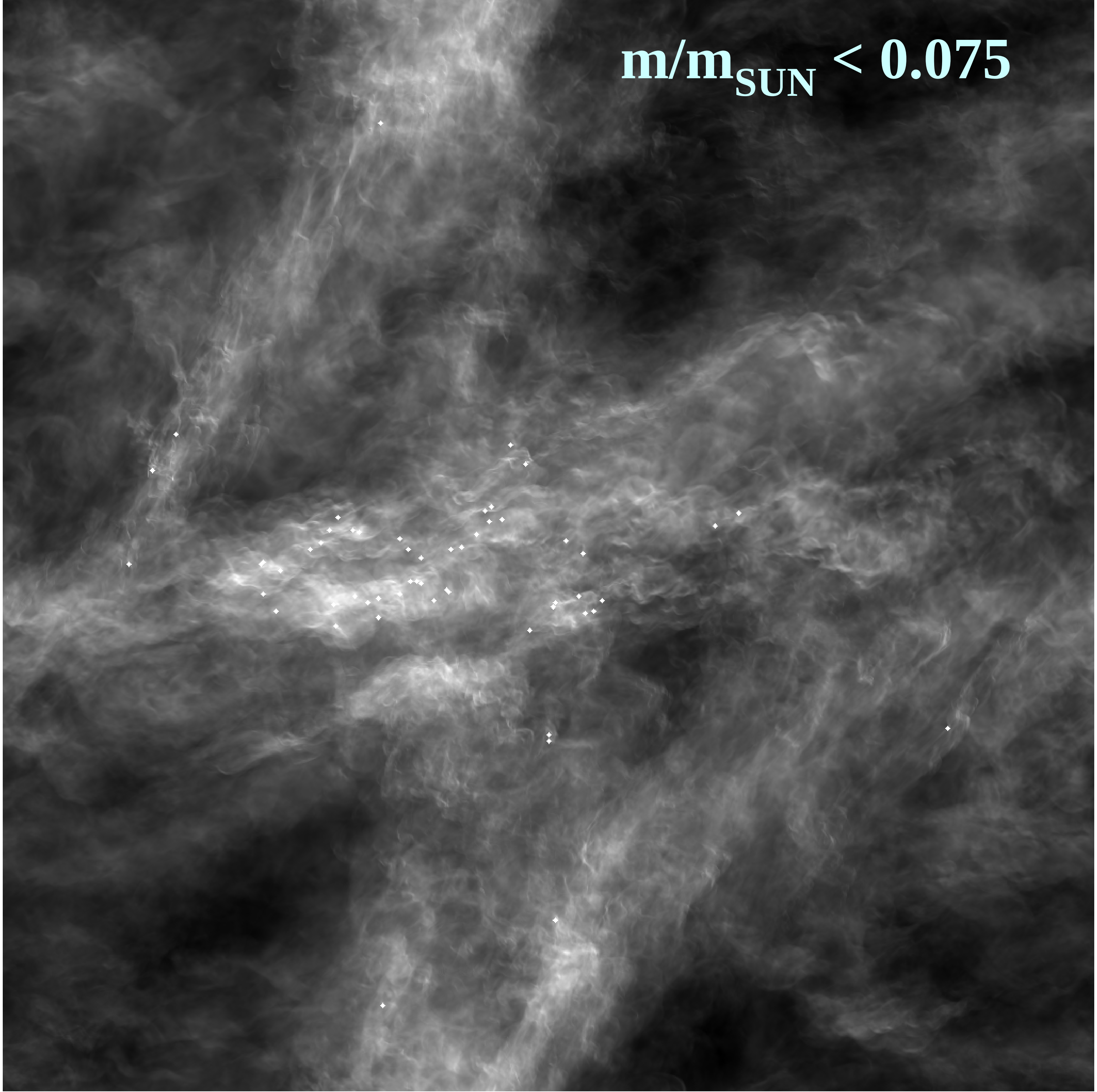
256^3

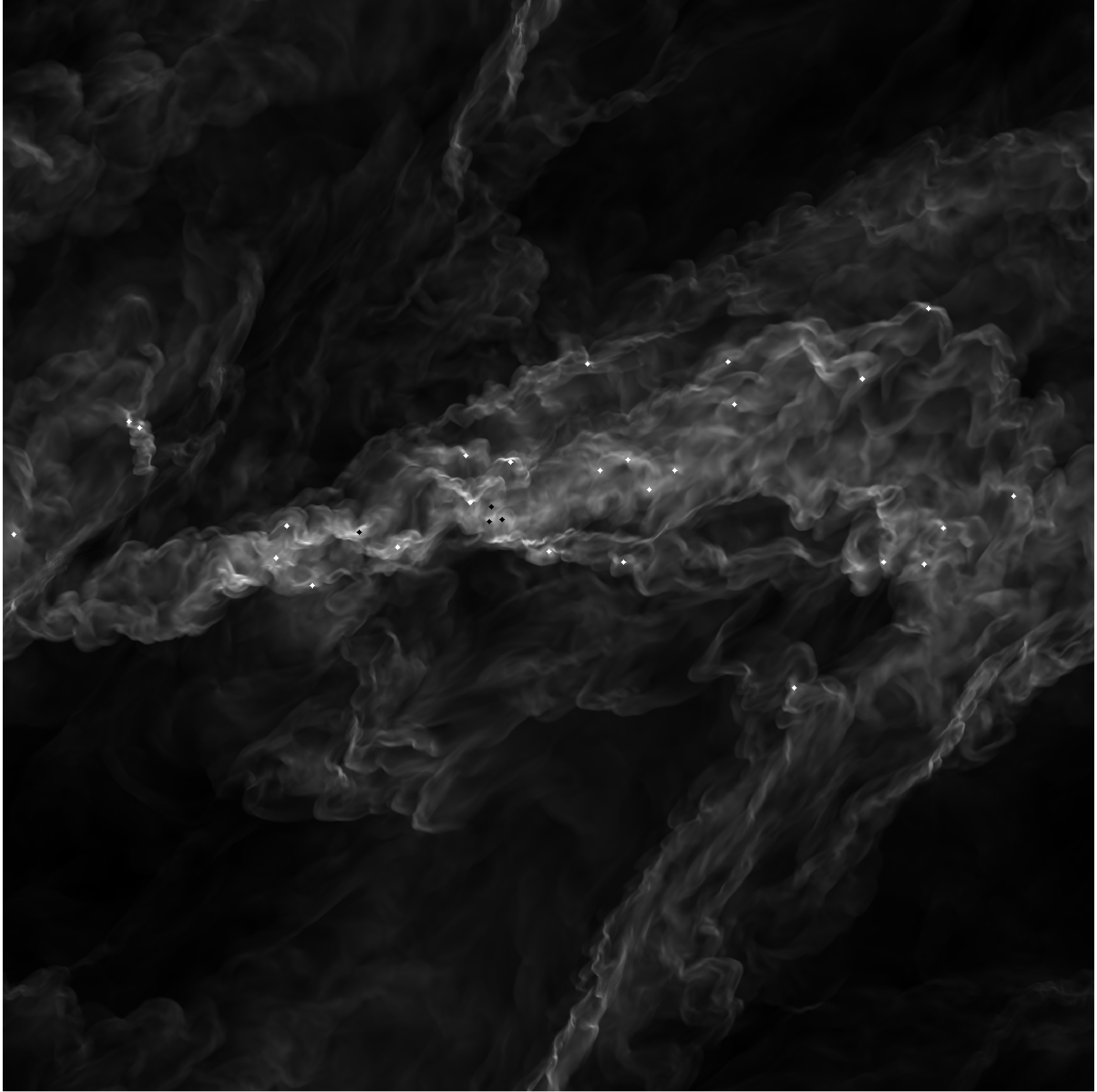


1024^3

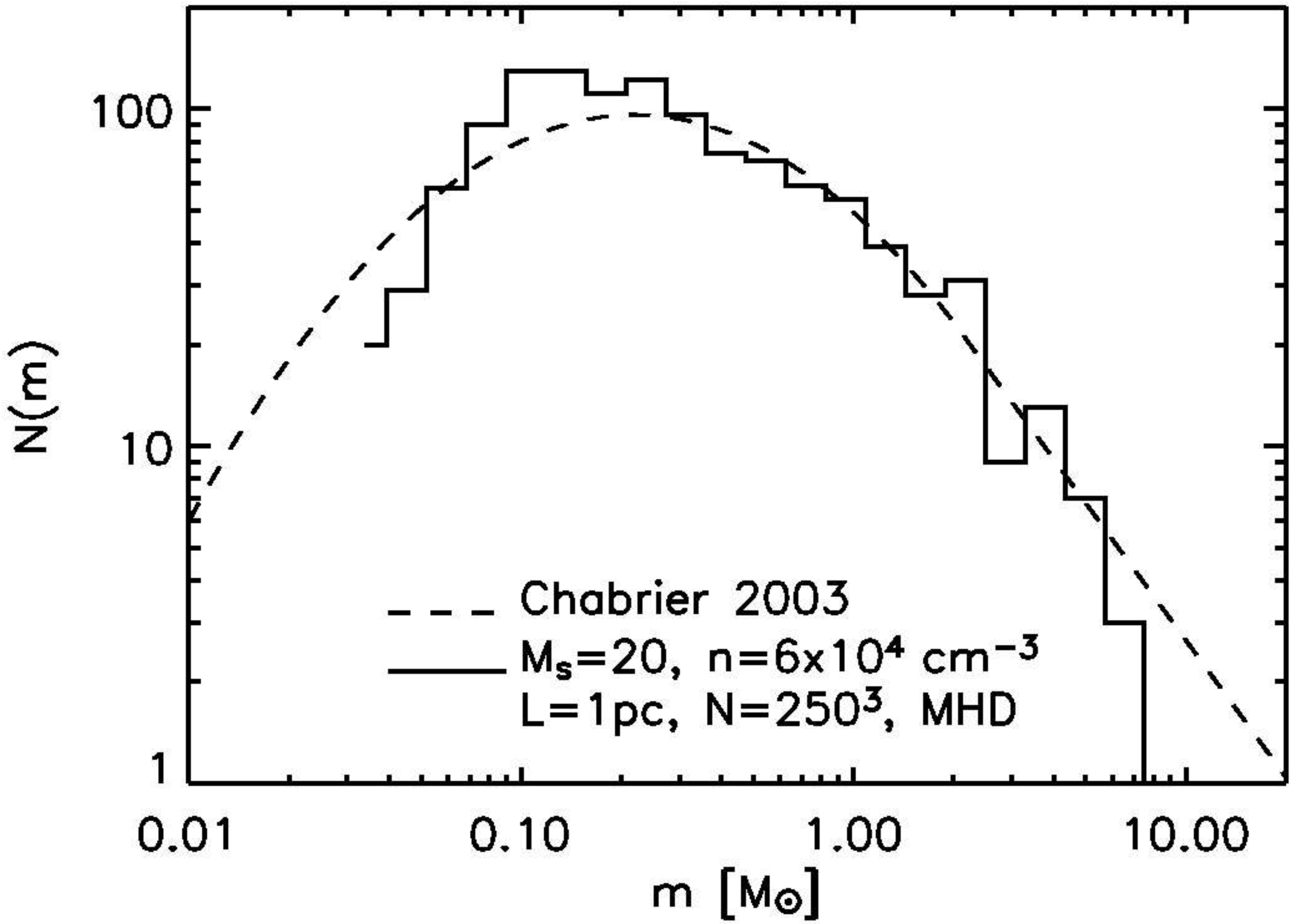



$0.075 < m/m_{SUN} < 1.5$


$m/m_{SUN} < 0.075$

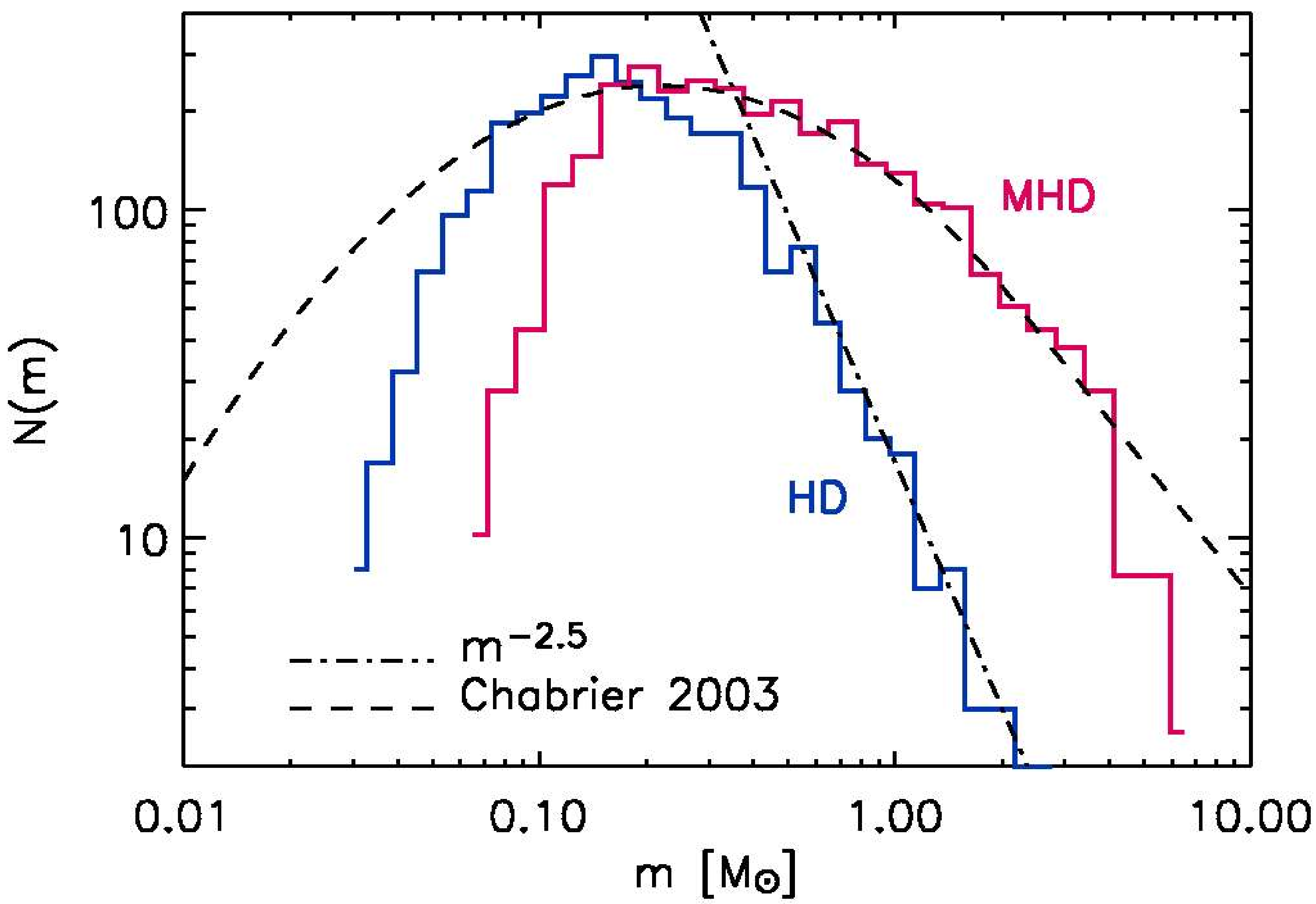


MHD:

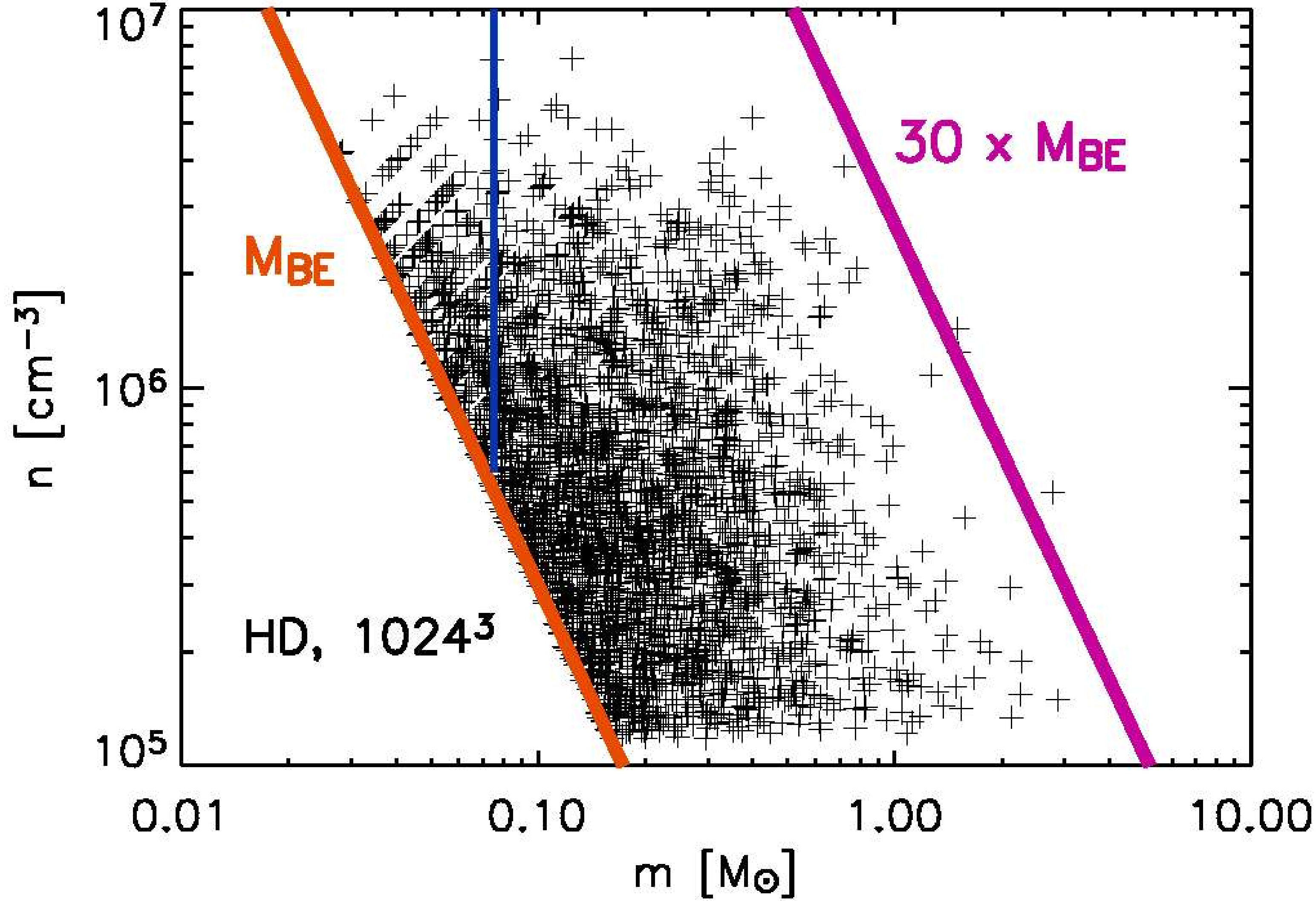


100
10
1
N(m)
0.01
0.10
1.00
10.00
m [M⊙]
Chabrier 2003
Ms=20, n=6x10⁴ cm⁻³
L=1pc, N=250³, MHD

HD fragmentation is different from MHD

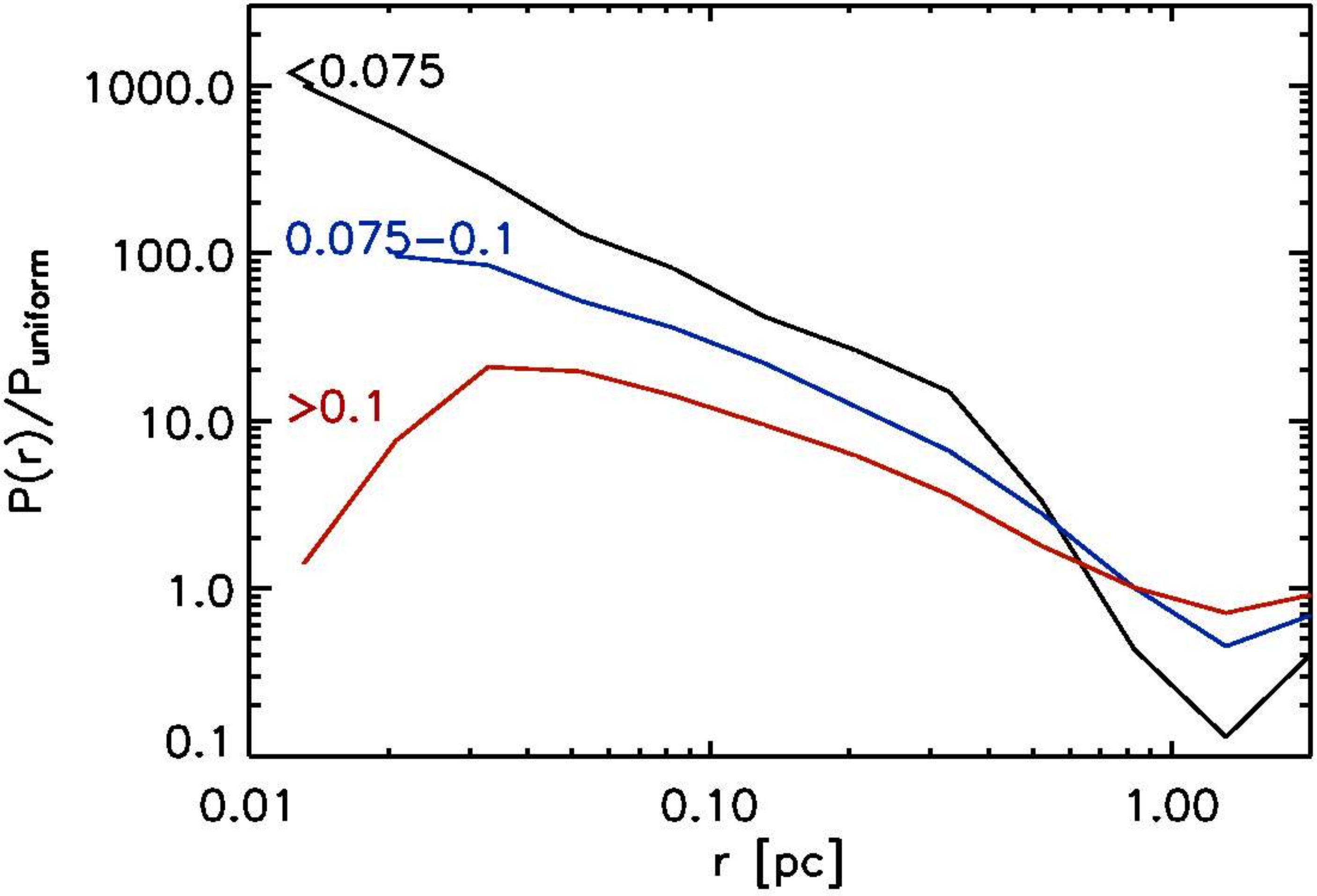


Mean density of unstable peaks versus mass

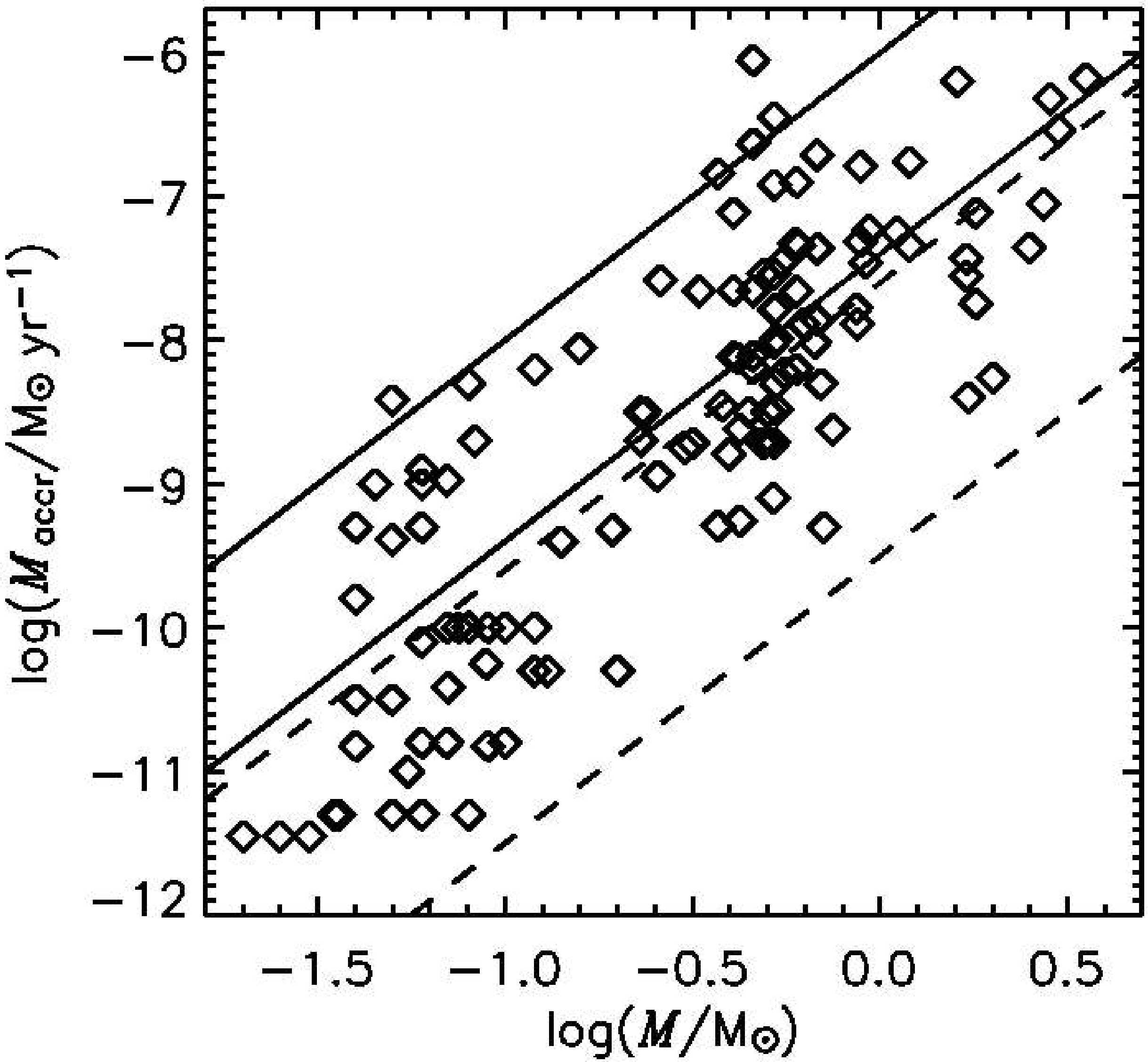


- Turbulence can create local densities much larger than the mean ---> local M_{BE} much larger than the mean M_{BE}
- Turbulence can generate collapsing cores much larger than the local Jeans mass, **but not so large in HD as in MHD.**

The **clustering of density peaks** increases with decreasing peak mass



Bondi-Hoyle accretion: $\dot{M}_{BH} = \frac{4\pi G^2 \rho_\infty}{(c_\infty^2 + v_\infty^2)^{3/2}} M^2$



Conclusions

Turbulent fragmentation plays a role in normal star formation, hence in ultra-low-mass star formation as well.

Turbulence may control the BD abundance (with some role left to traditional gravitational fragmentation, e.g. binary formation).

Many aspects of BD formation are likely to resemble hydrogen burning star formation (disks, accretion rates,...).

Observational Tests

BD abundance (IMF): May be a crucial test, but only once the numerical simulations are proved to be reliable (or at least not known to have artificial fragmentation).

Binarity: May be crucial as well, but hard to simulate because it must be a late stage event (especially for close separations), affected by numerical treatment of sink particles (creation, accretion, merging).

Clustering: Easier numerically and the observational samples are getting larger. It may be a crucial test using very young star-forming regions.