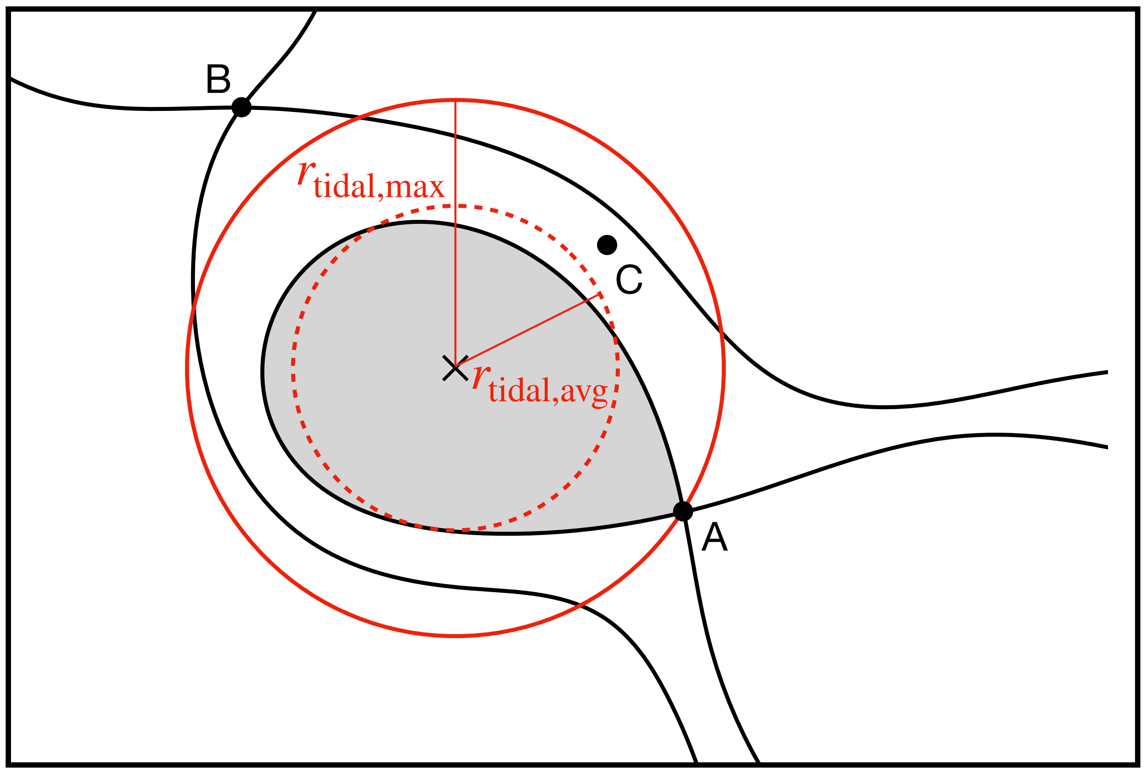
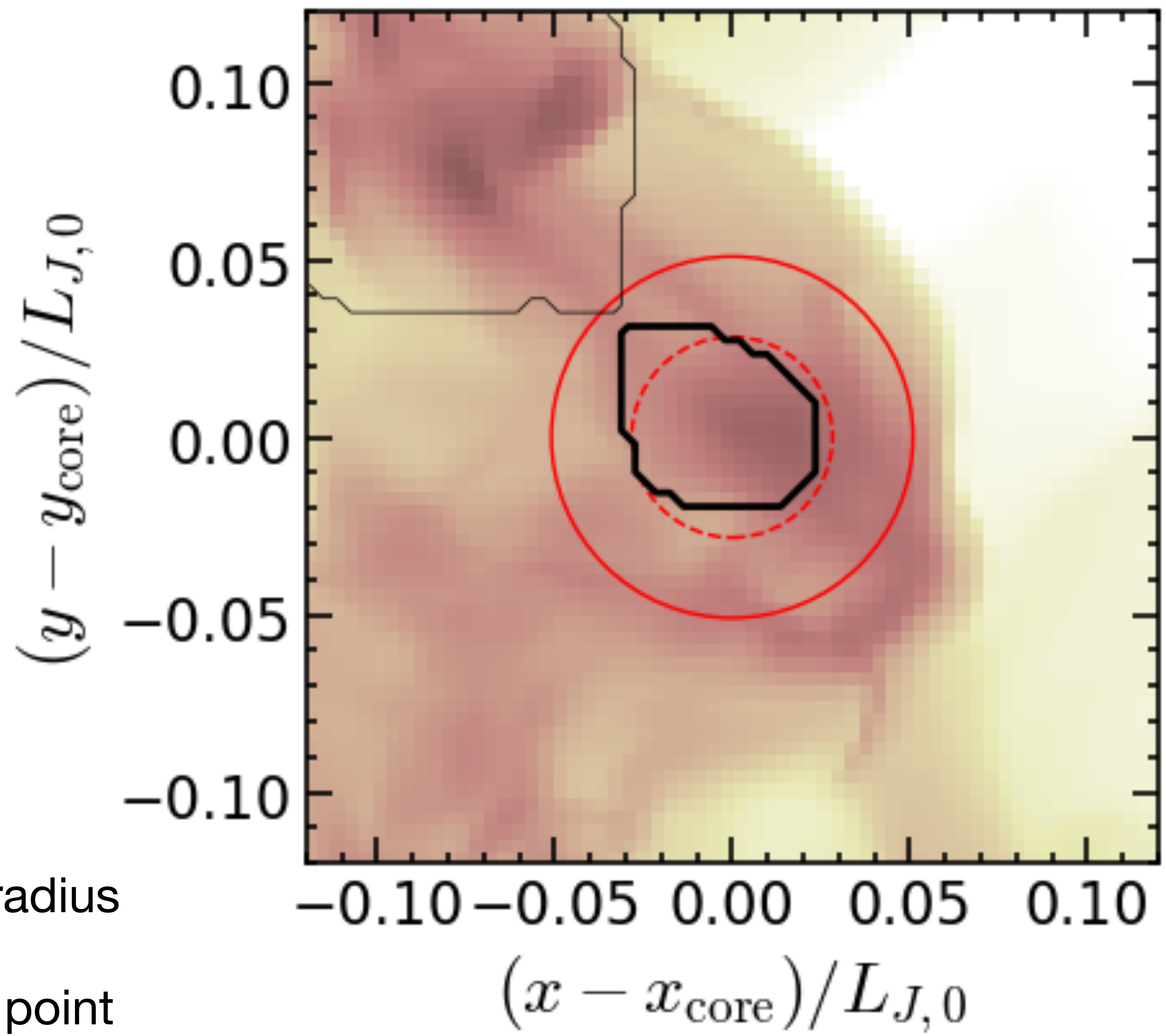
Is there a characteristic mass for star formation? – Part II: Testing theories

Eve Ostriker & **Sanghyuk Moon** (Princeton)

Puzzles of star formation II @ Ringberg castle, 2025

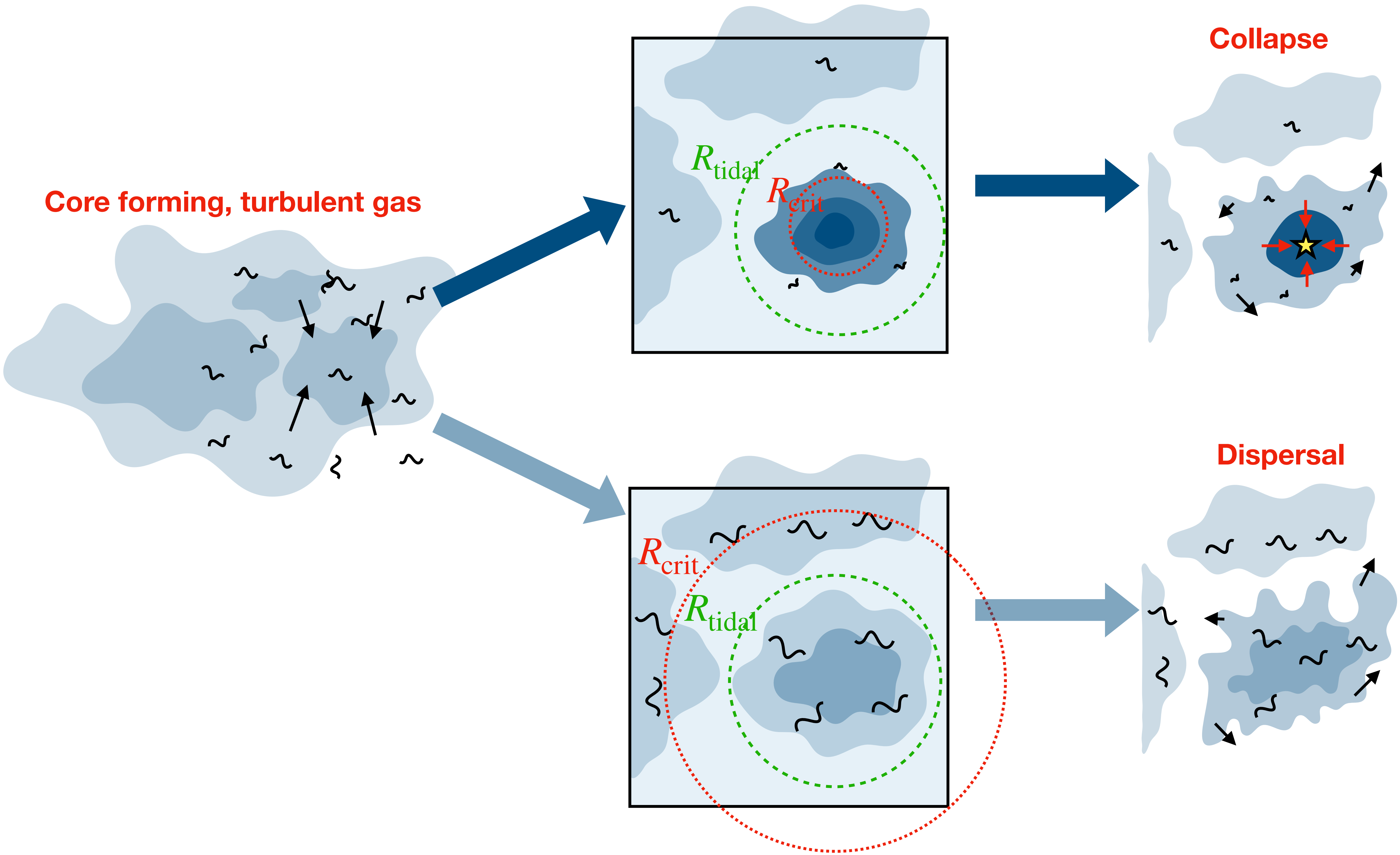
Tidal Radius and Collapse Scenario





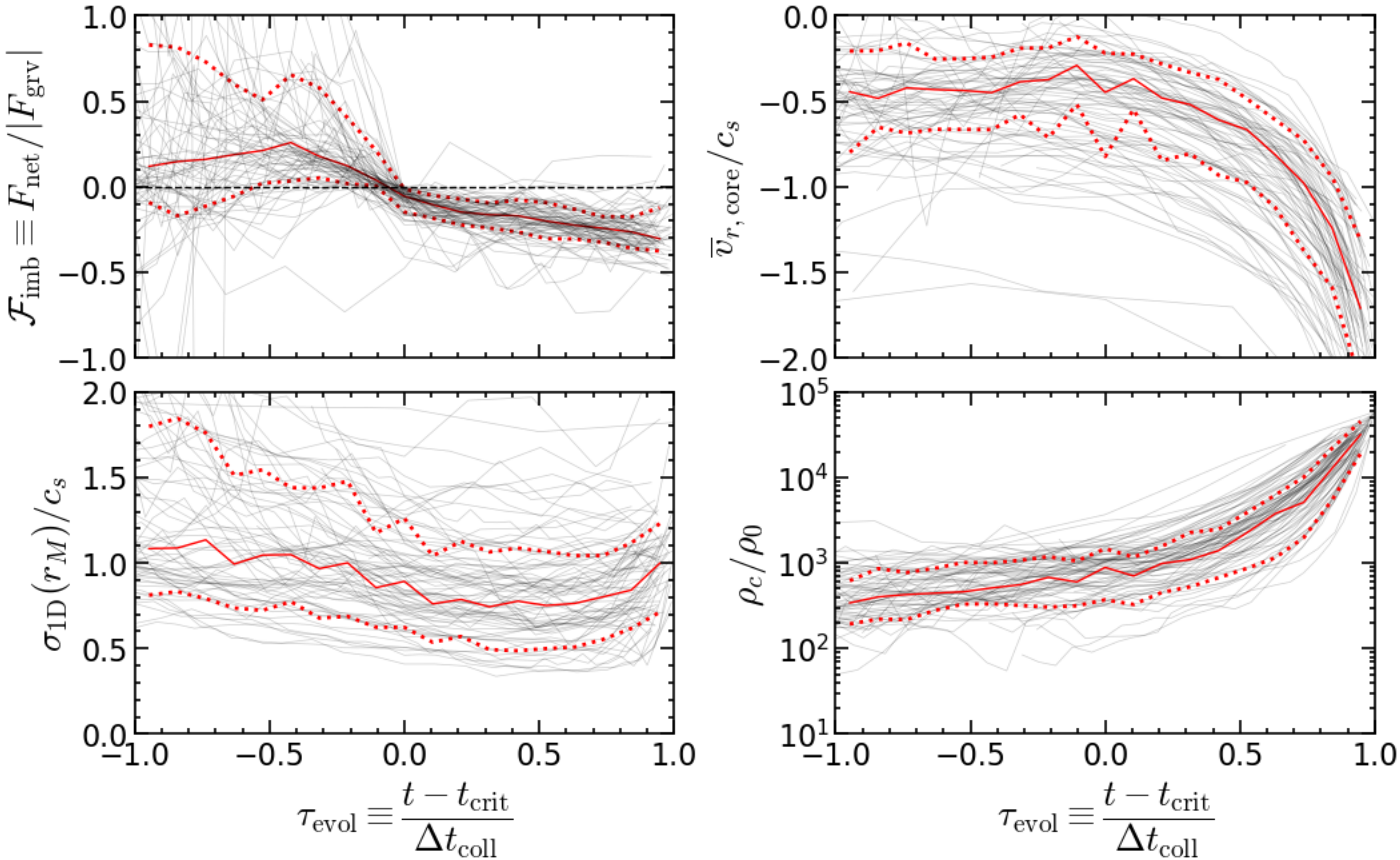
- Cores have no sharp boundary.
- However, they are not isolated → Tidal radius
- $r_{\mathrm{tidal,max}}$: distance to the nearest saddle point
- $r_{\mathrm{tidal,avg}}$: effective radius of the Φ contour touching the saddle point

Tidal Radius and Collapse Scenario



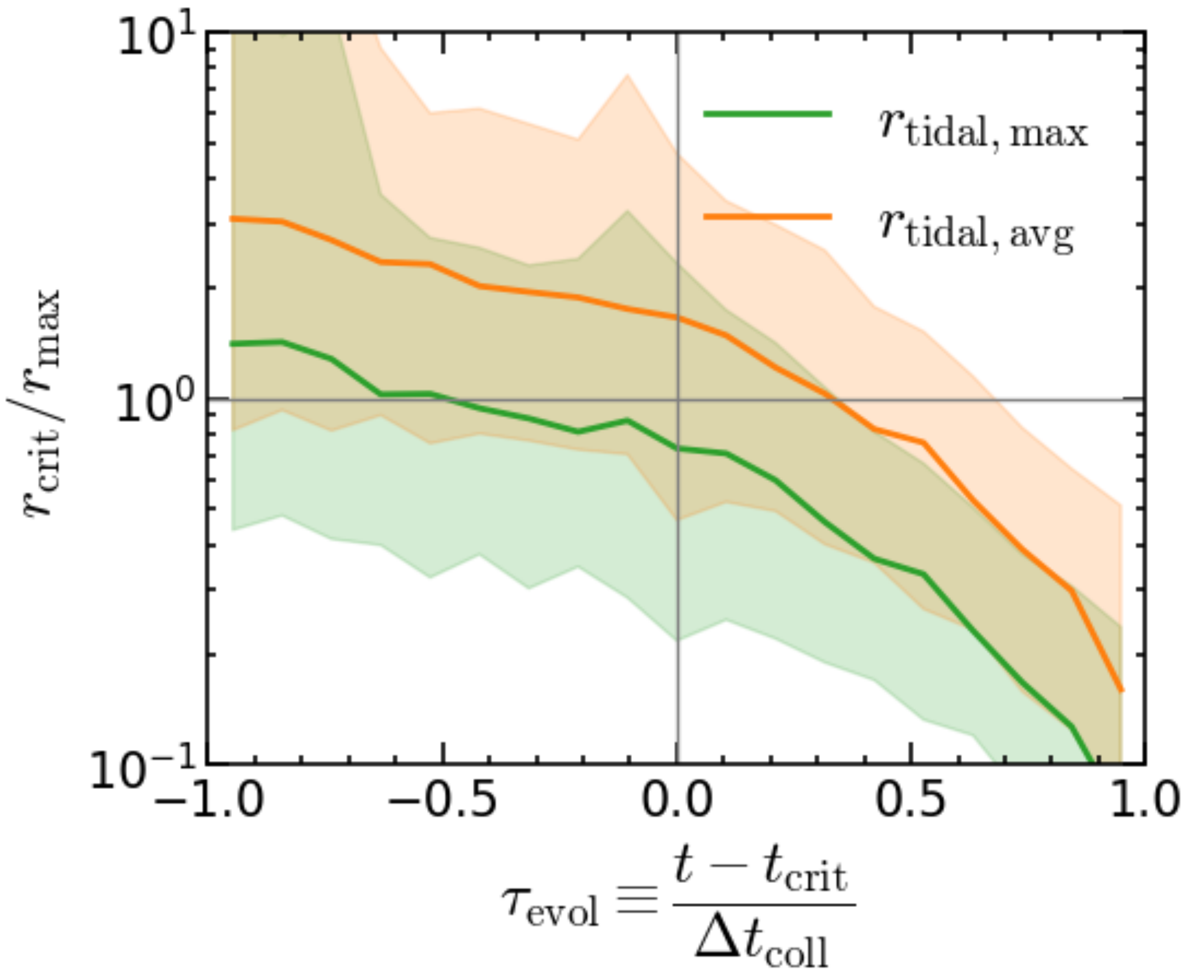
Evolution of Simulated Cores

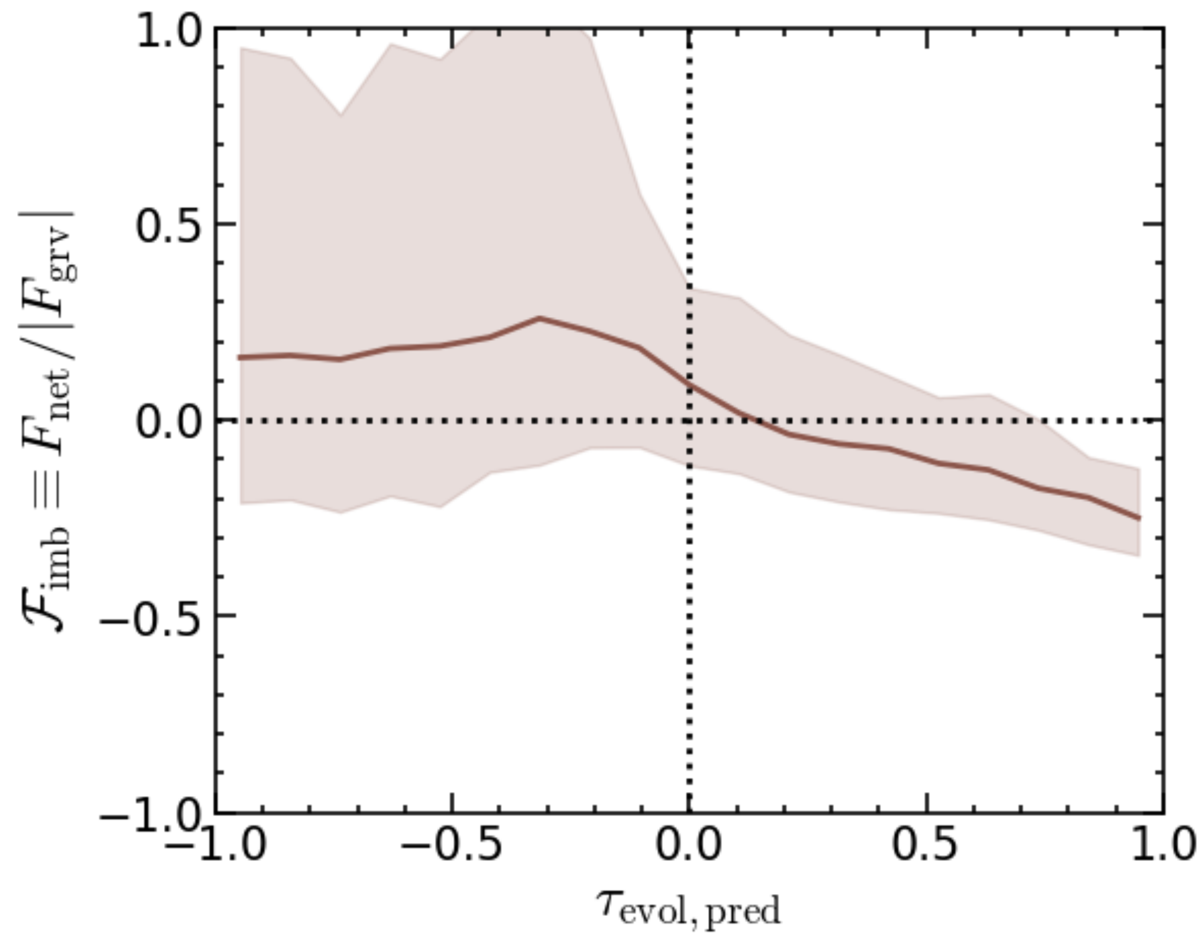
- There is a physically meaningful, **identifiable** moment when the collapse **begins!** **(**Sanghyuk Moon & Eve Ostriker on arXiv; See also David Collins et al. 2024)



Evolution of Simulated Cores

- There is a physically meaningful, **identifiable** moment when the collapse **begins!** **(**Sanghyuk Moon & Eve Ostriker on arXiv; See also David Collins et al. 2024)
- And the critical time identified in the simulations is consistent with the theoretical prediction.





Testing Theories

Statistical properties of supersonic turbulence

— Density PDF
— Power spectrum
— n-point correlation functions
— …

Theory

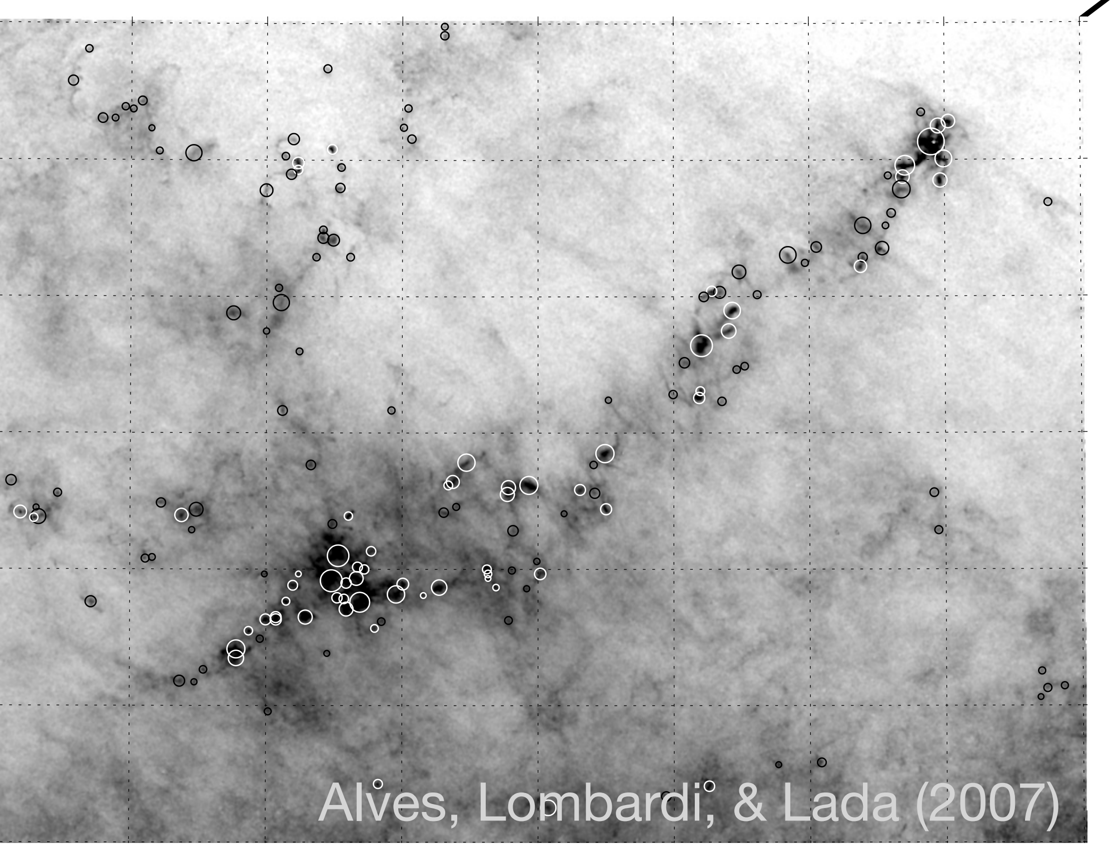
Core mass function

—Definition?

…

1. Observational test

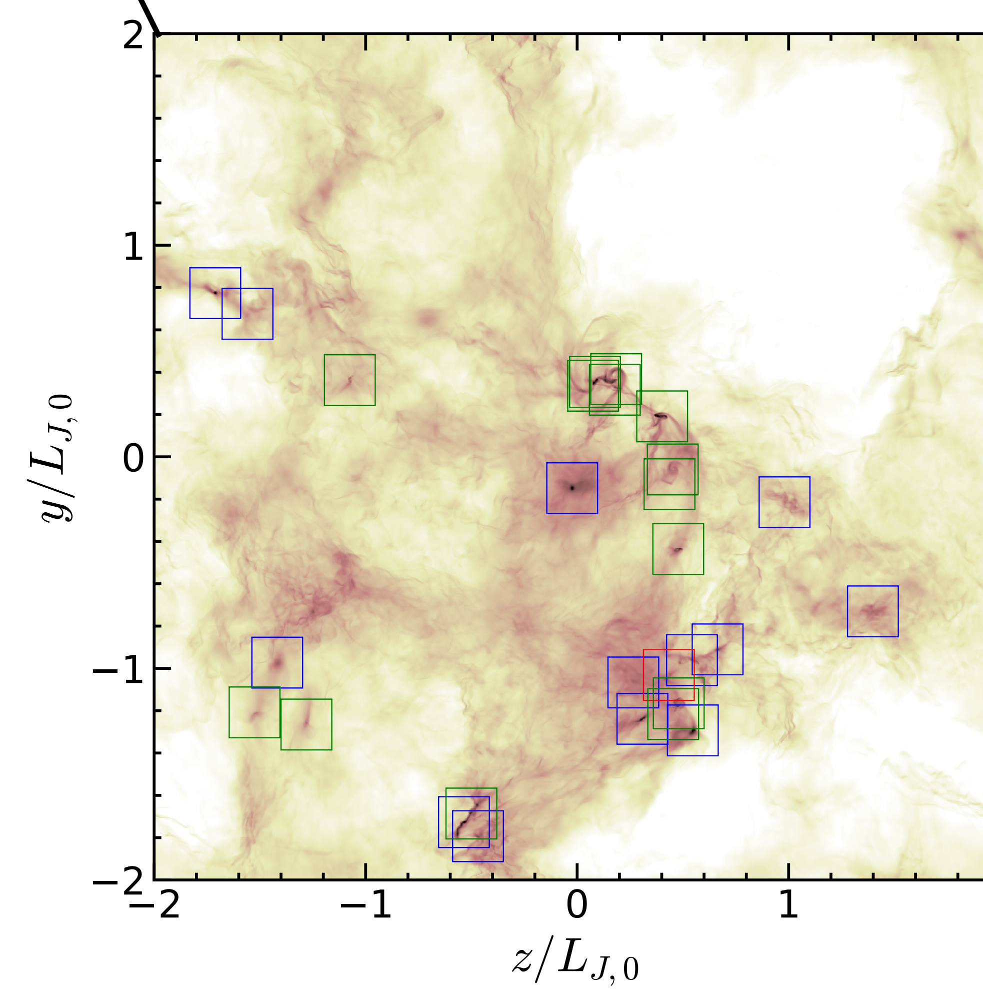
2. Experimental test


Alves, Lombardi, & Lada (2007)

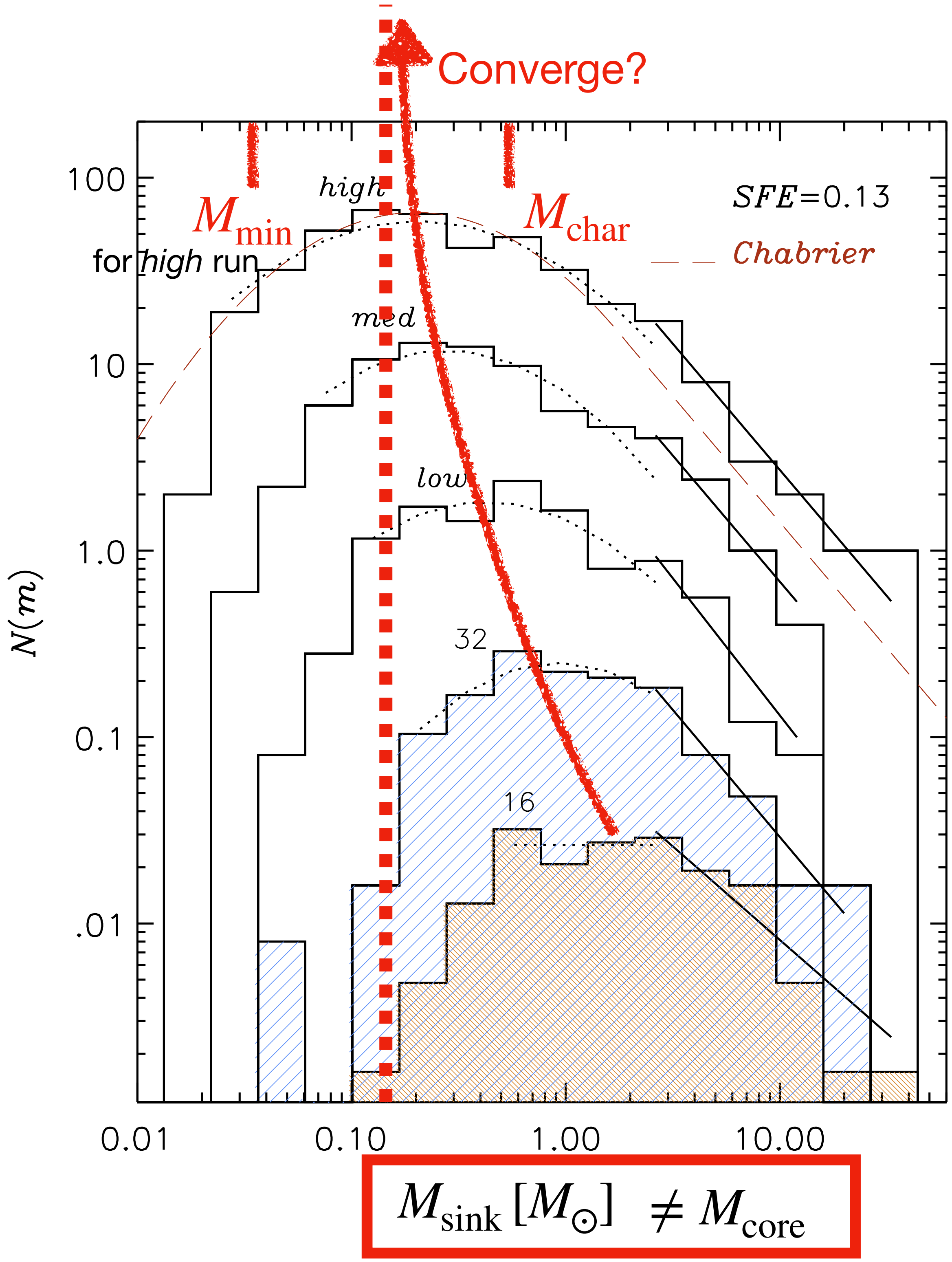
Are we comparing apples to apples?

What is the required resolution to achieve convergence?

Are all elements of theories – including their assumptions – being tested?



Resolving the Peak of the CMF



Annotated, from Haugbølle et al. (2018)

1

Theoretically anticipated peak mass

$$M_{\rm peak} = \text{(order unity factor)} \times M_{\rm char}$$

where

$$M_{\rm char} \equiv M_{\rm BE}(\rho_{\rm ps})$$

is the Bonnor-Ebert mass evaluated at typical "post-shock" density $\rho_{\rm ps} \equiv \mathscr{M}_{\rm 3D}^2 \rho_0$

2

The mass of the smallest Bonnor-Ebert sphere that is "resolved" is

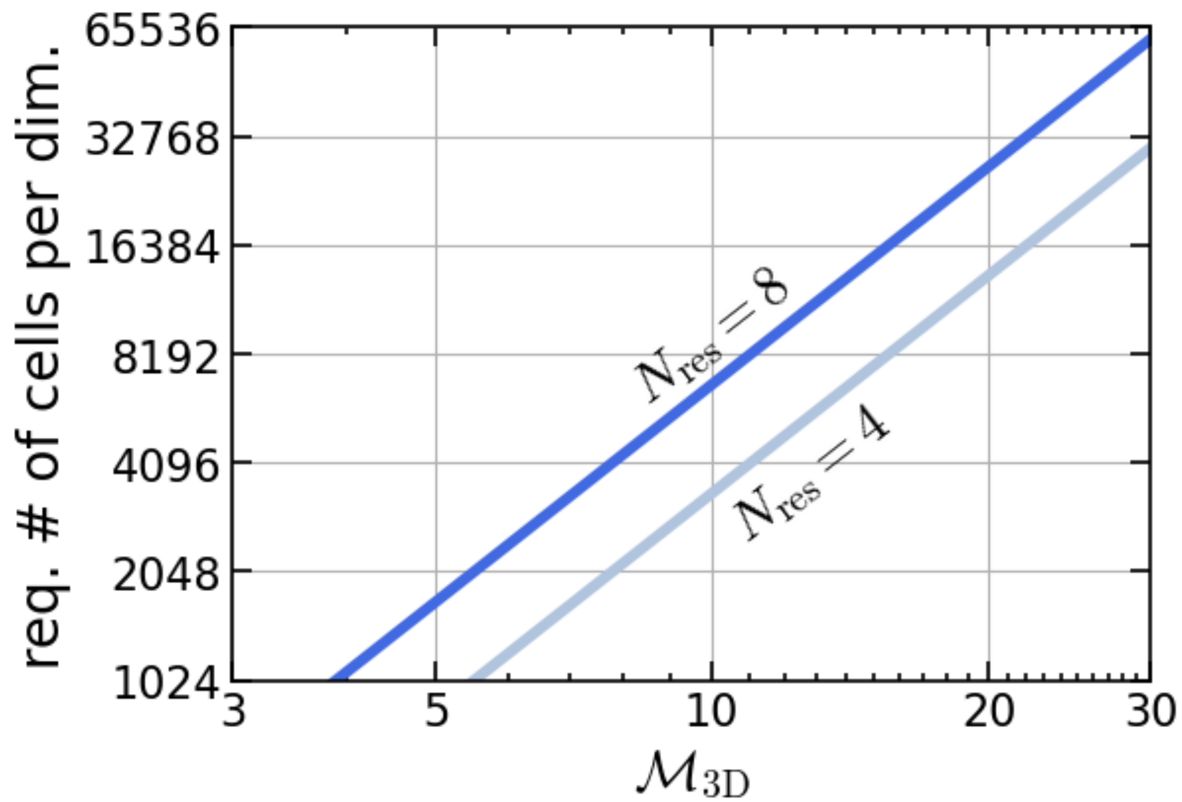
$$M_{\rm min} \equiv 2.4 \frac{c_s^2}{G}(N_{\rm res}\Delta x); \qquad N_{\rm res} \gtrsim 8$$

3

In order to clearly identify the anticipated peak, we need

$$M_{\rm min} \ll M_{\rm char}$$

Resolving the Peak of the CMF



$$N_{cells} = \frac{L_{box}}{\Delta x}$$

$$= 6745 \left(\frac{N_{core,res}}{8}\right) \left(\frac{M_{min}/M_{char}}{0.1}\right)^{-1}$$

$$\times \left(\frac{\alpha_{vir}}{2}\right)^{-1/2} \left(\frac{\mathscr{M}_{3D}}{10}\right)^{2}$$

1

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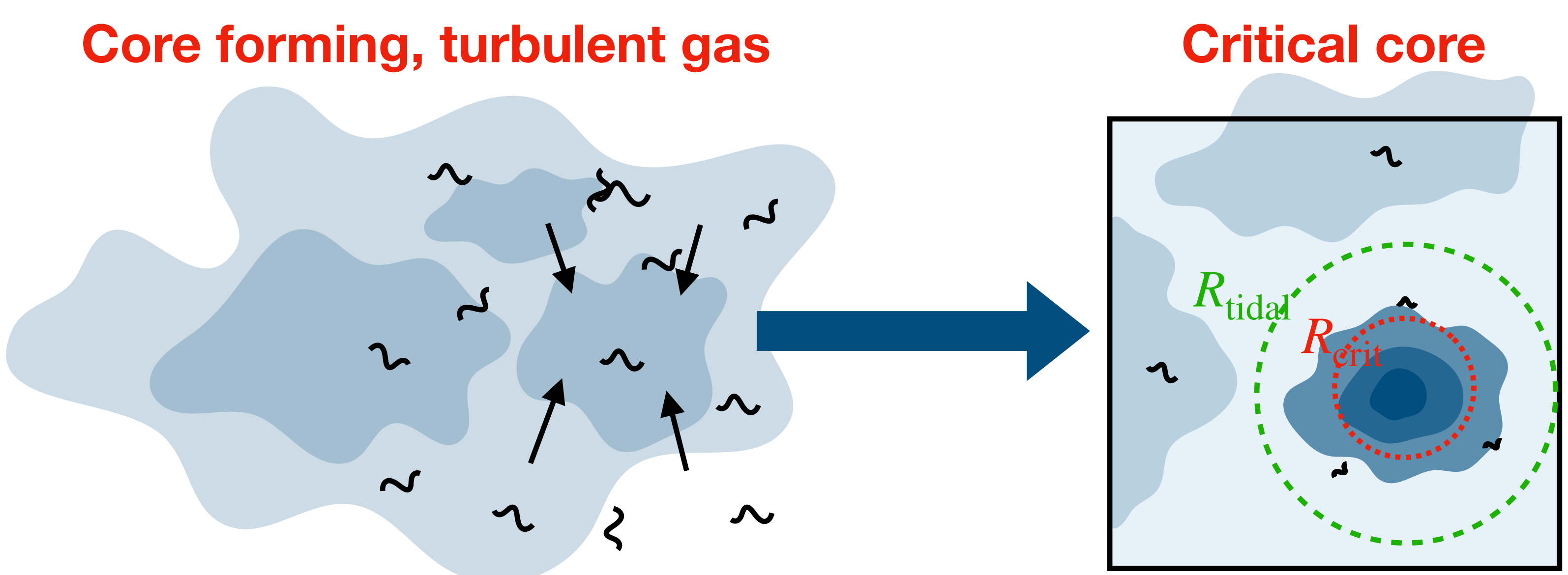
What do we need to resolve?

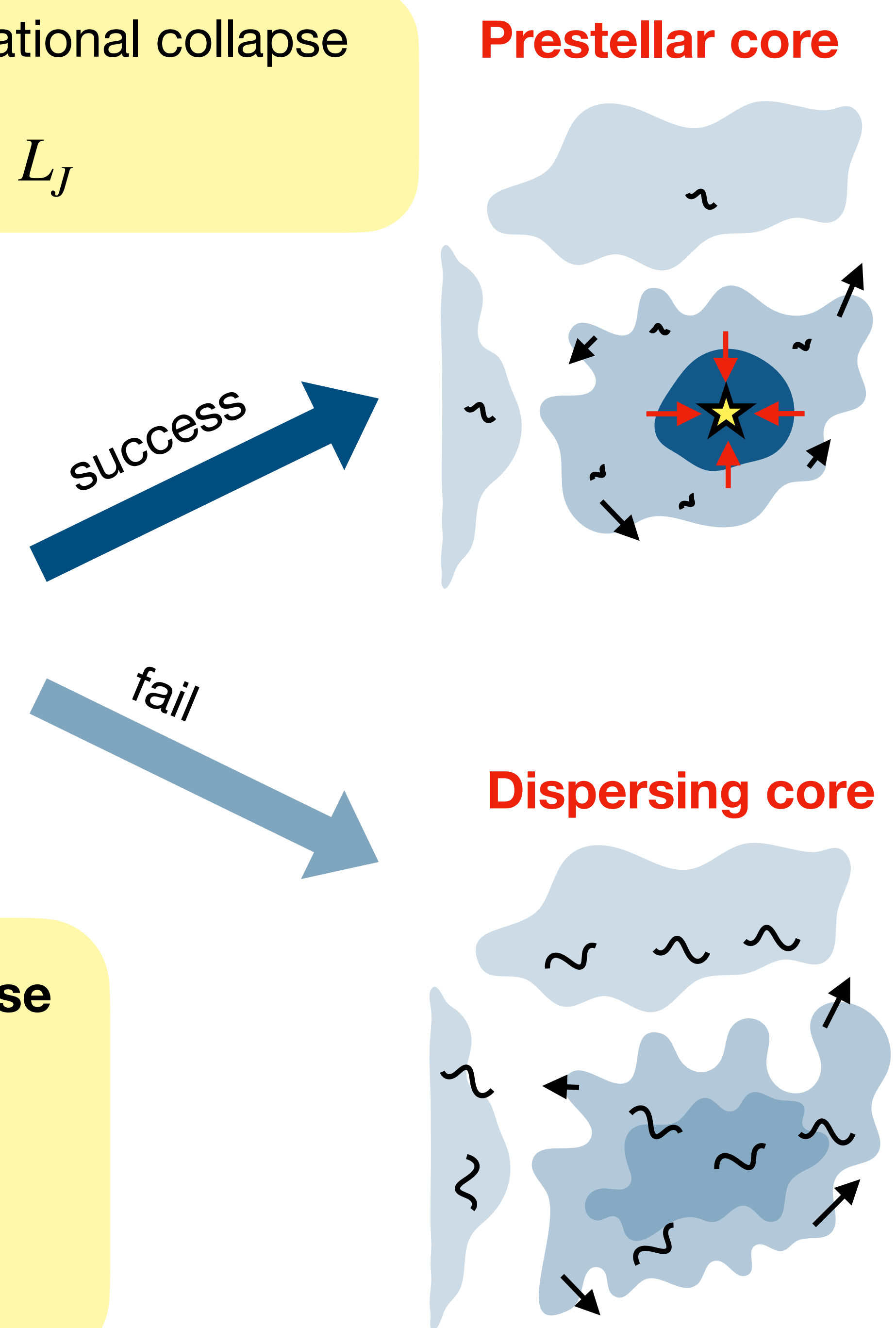
1. Turbulent core formation

$\Delta x \ll \lambda_s$

2. Gravitational collapse

$\Delta x \ll L_J$

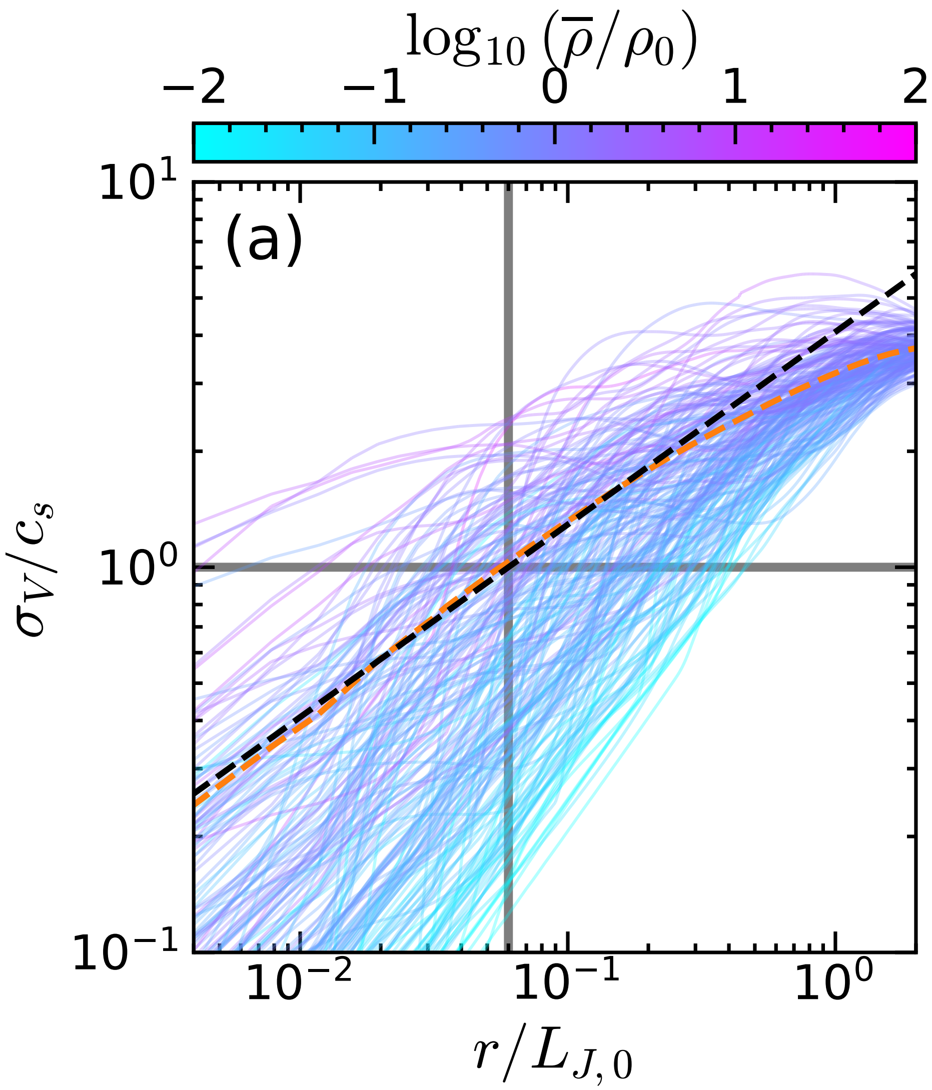


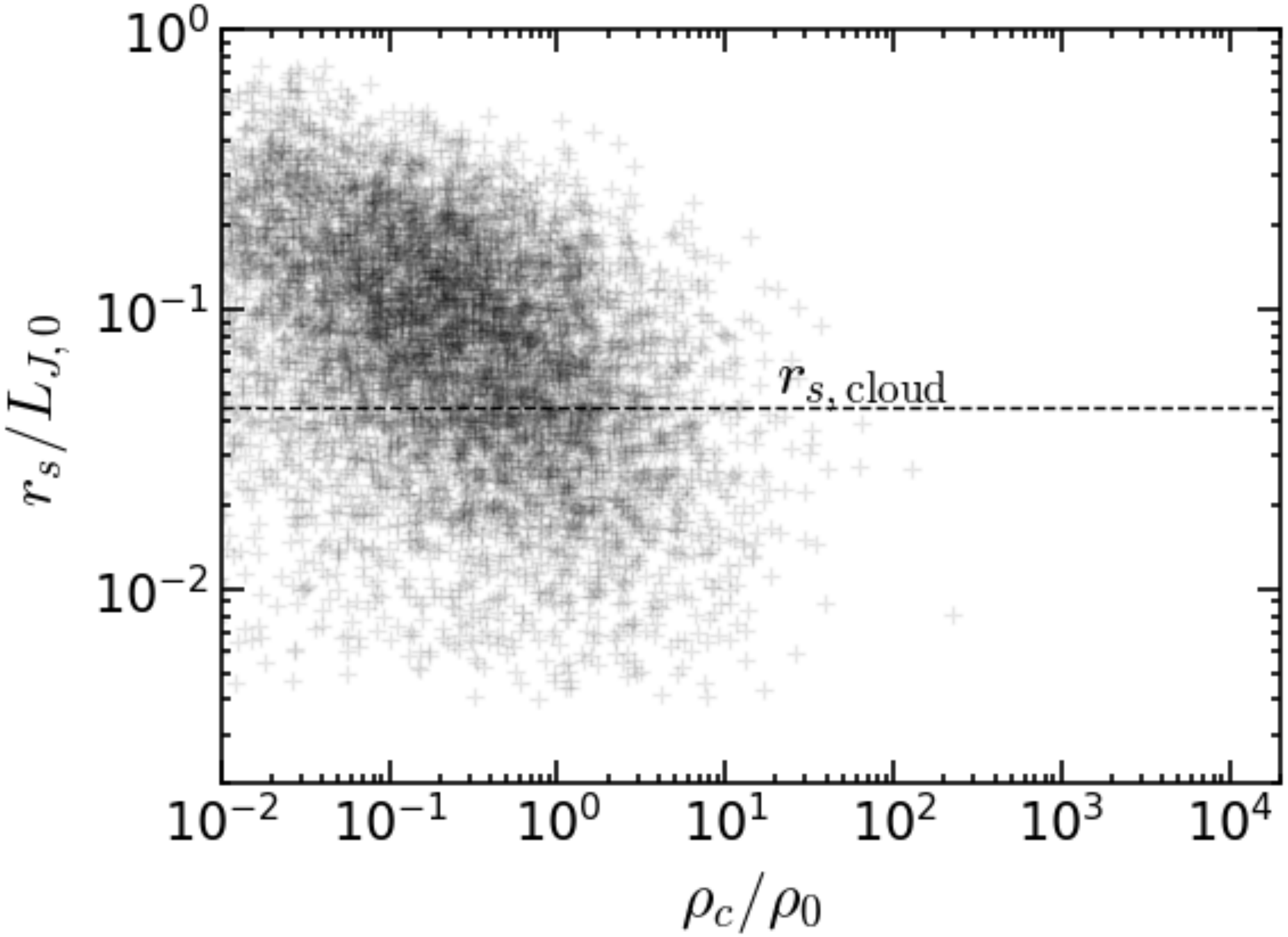


Critical conditions for collapse

- density
- turbulence
- magnetic fields
- …

Resolving Turbulence





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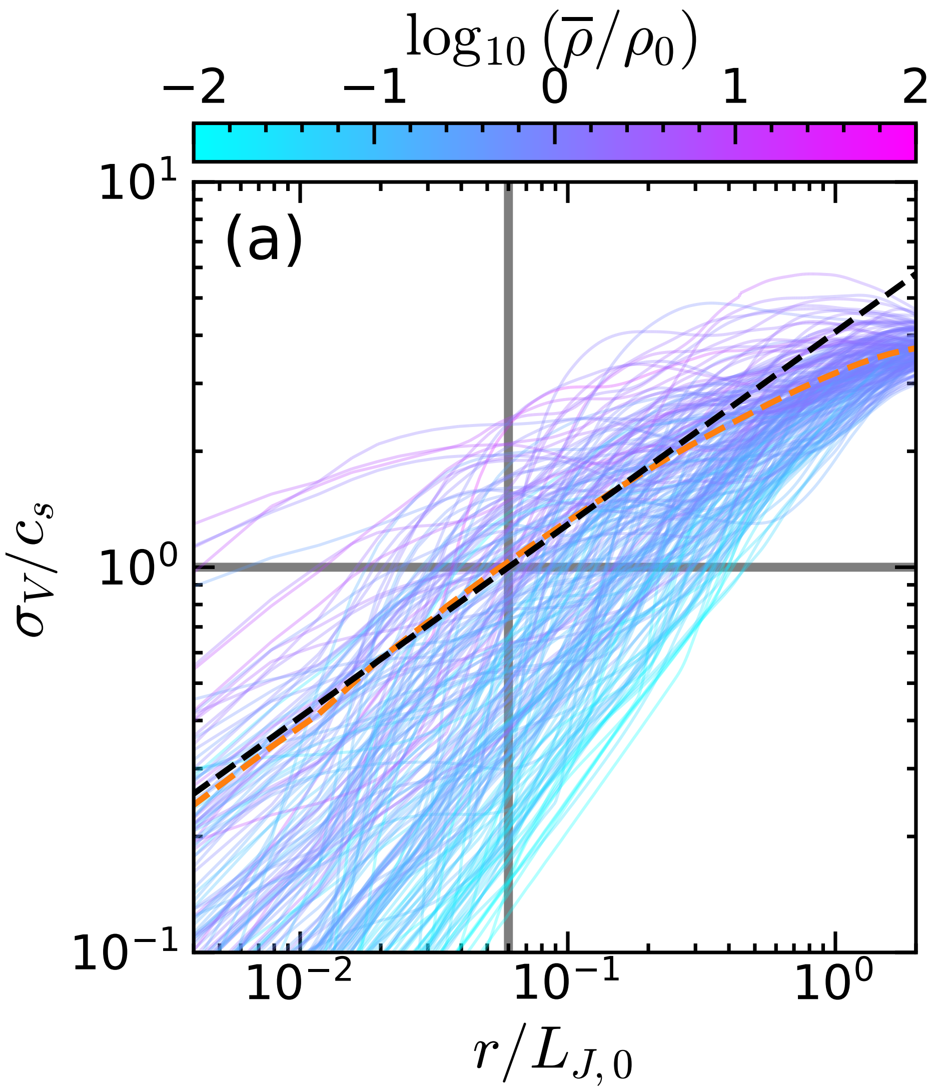

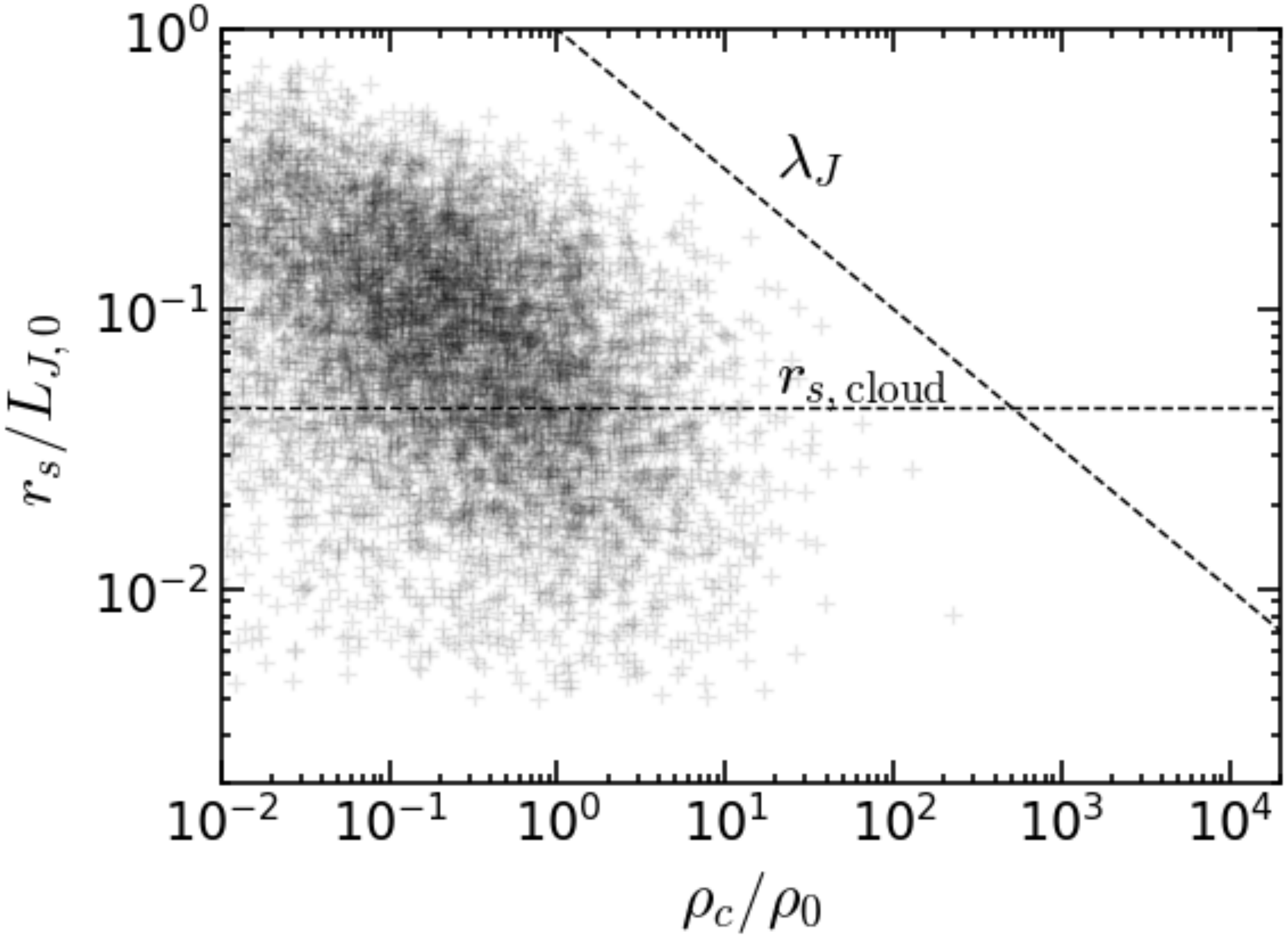

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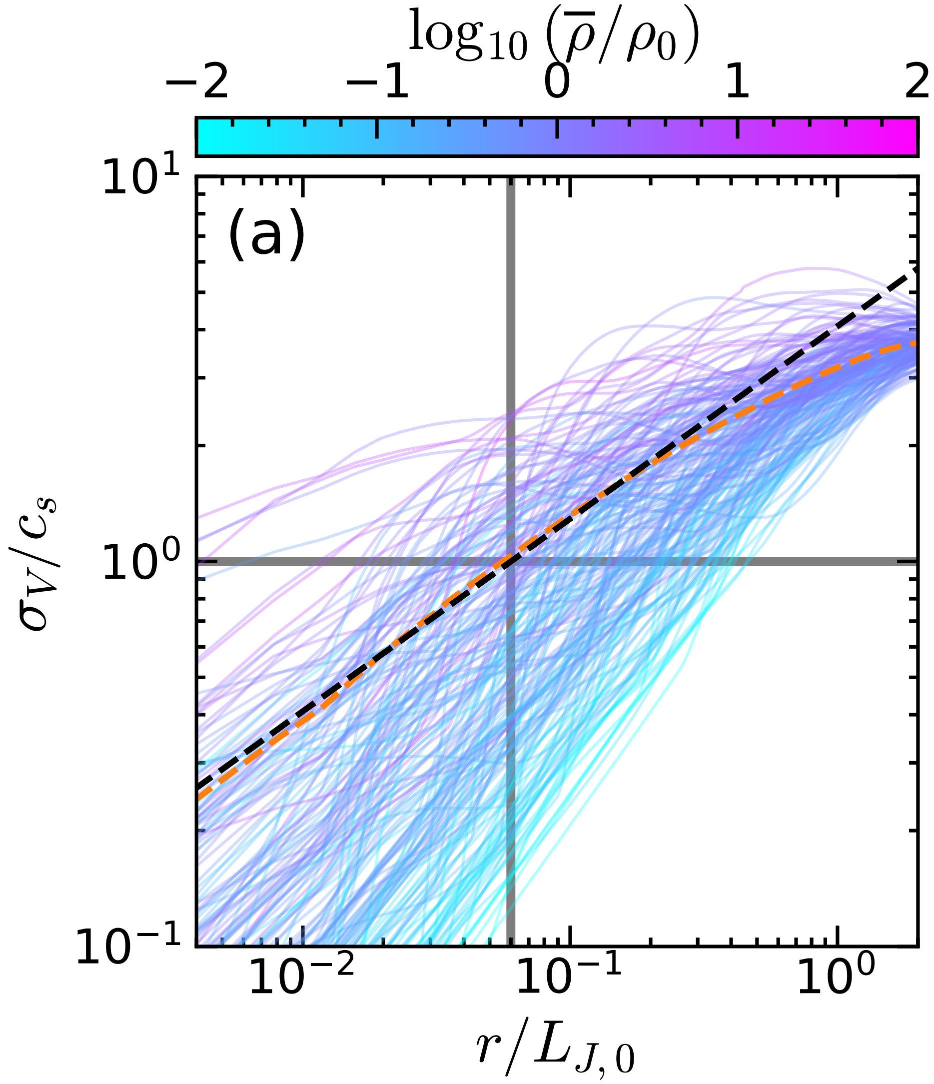
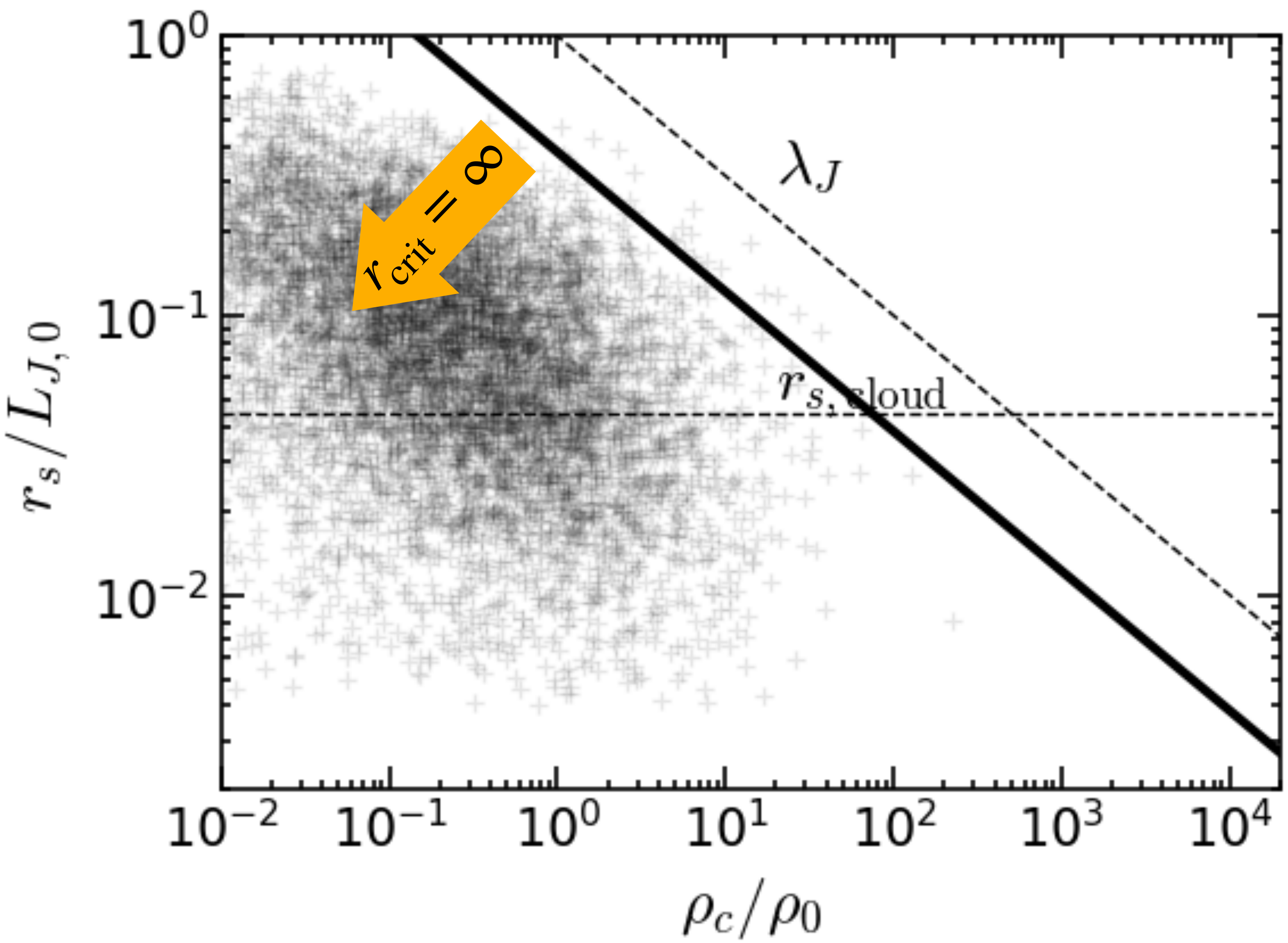
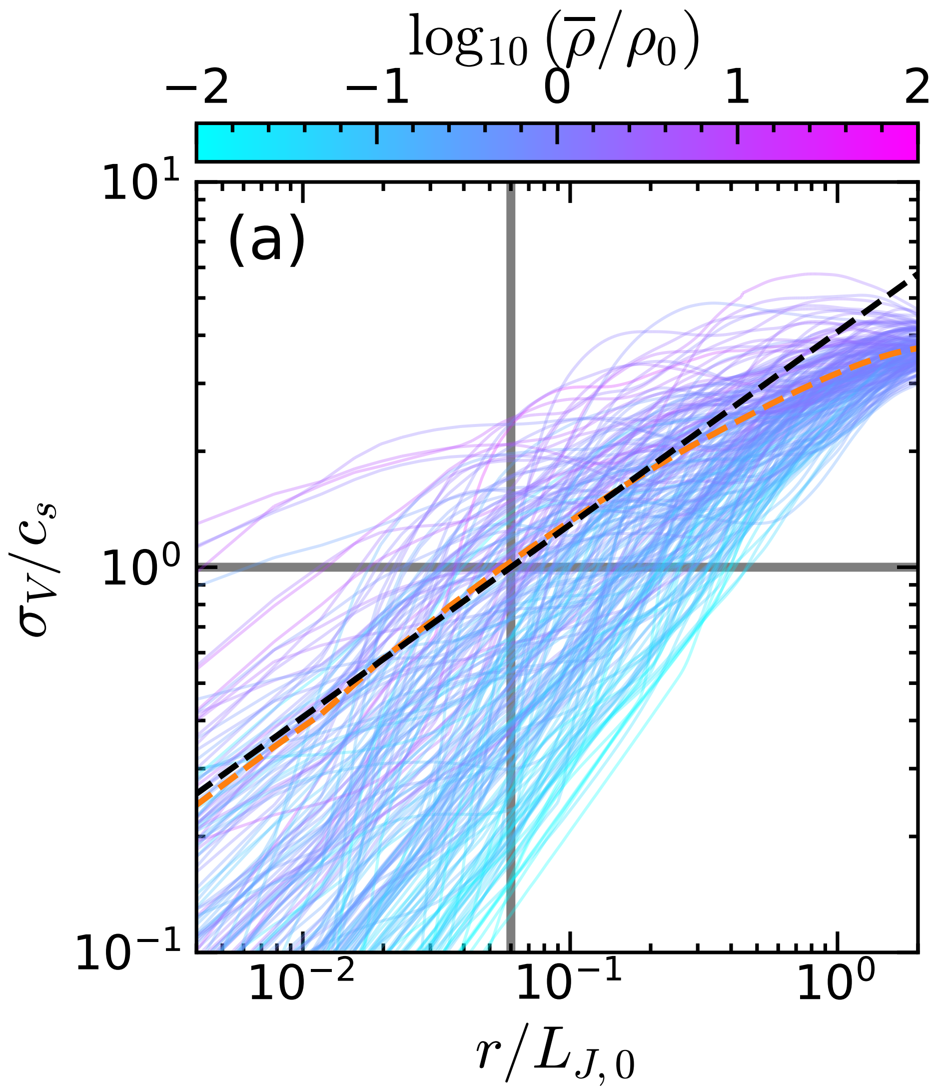
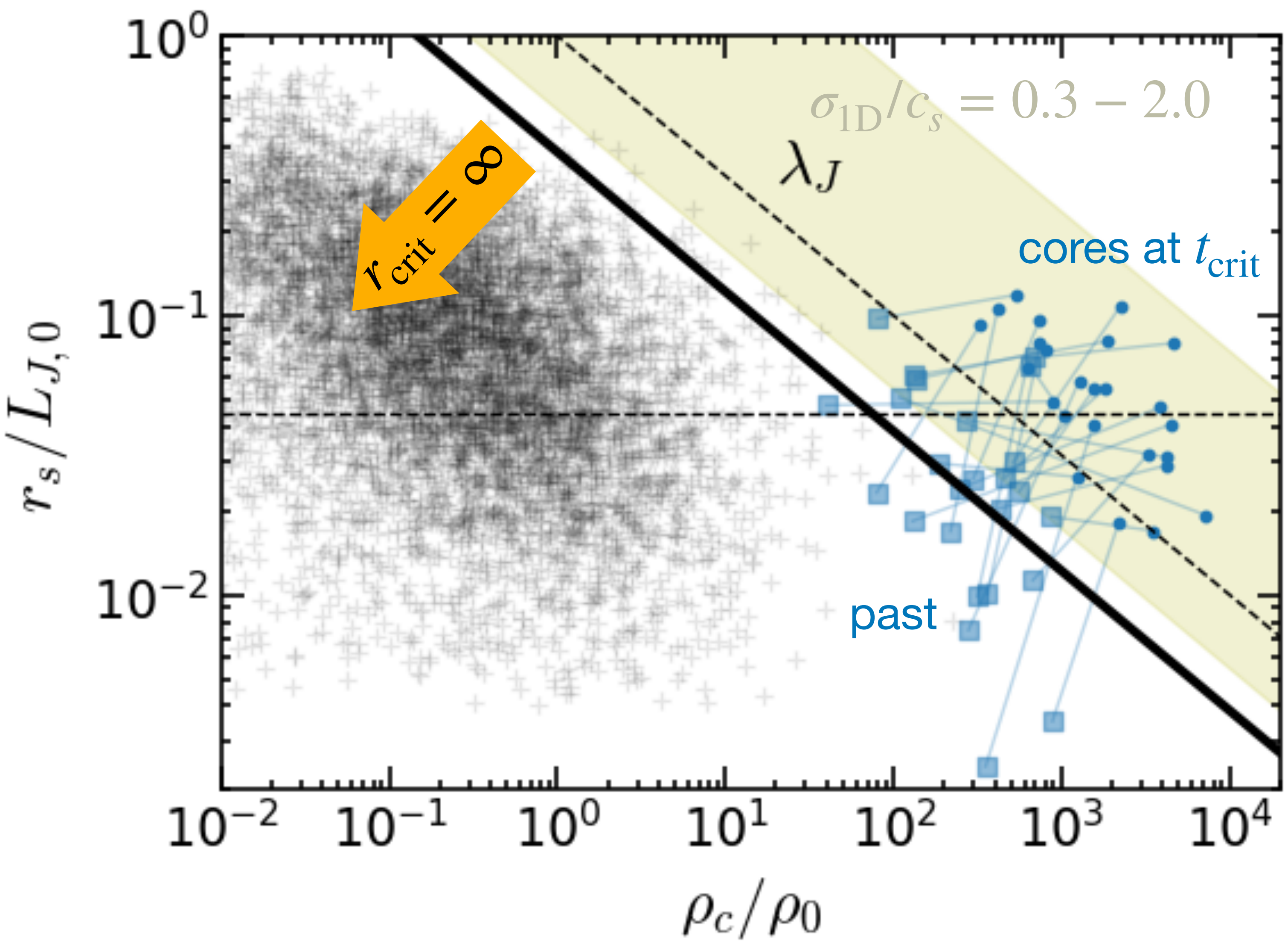




$$n_{\mathrm{H2},c}^{\mathrm{min}} = 2.2 \times 10^4\,\mathrm{cm}^{-3} \left(\frac{T}{10\,\mathrm{K}}\right) \left(\frac{r_s}{0.05\,\mathrm{pc}}\right)^{-2}$$

Resolving Turbulence





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Questions for discussion

- Is it valid to separate control of SF into different stages in numerical simulations (and theory)?
  – Do idealized IC and BC give the same results as realistic IC and BC?
  – Are realistic simulations even possible, given the huge dynamic range in time? (not just space)

- If so, within a given stage,
  – what essential physics must be included?
  – what algorithmic approaches are sufficiently accurate?
  – what are the resolution requirements imposed by the key physical processes?
  – how can we efficiently and systematically explore the large parameter space?

- Is it possible to empirically constrain gravo-magneto-turbulent fragmentation into cores in more extreme environments?
  – Galactic center molecular clouds
  – Cluster-forming clumps within outer-disk GMCs

- Is it possible to identify critical core transition from positive to negative force in observations?

- What kind of new analysis would prove to be useful? Virial analysis? Tracer particles? Neural network? What would be the best strategy to analyze anisotropic evolution when there are magnetic fields?

- What is the correct refinement condition in star formation simulations?