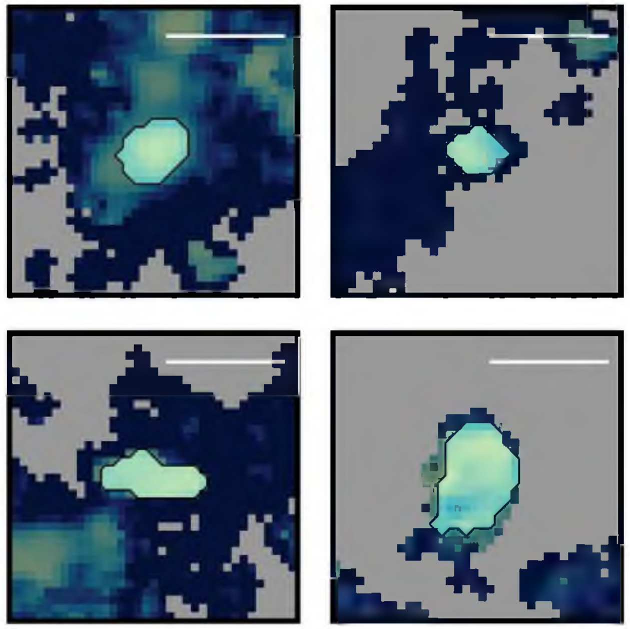


Core Evolution Through A Coherent Phase

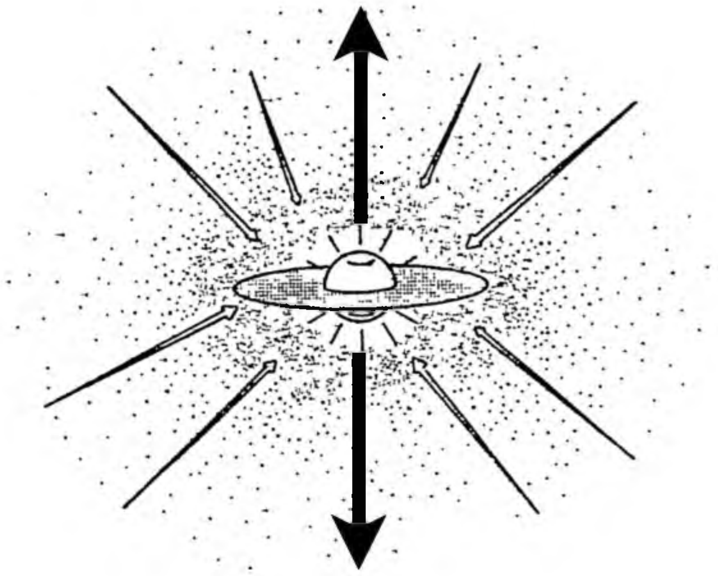
An Updated Core Formation Theory Told By Machine Learning

Hope Chen, Postdoctoral Fellow @ UT Austin

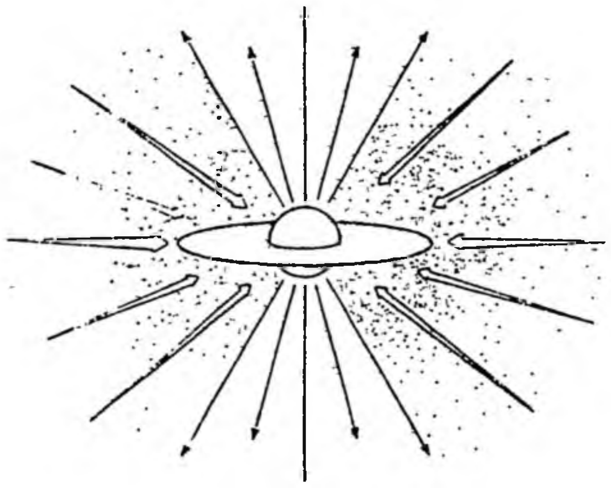
From Gas to Stars, Sept. 17, 2019

I know this is a conference for the formation of massive stars and star clusters, but..

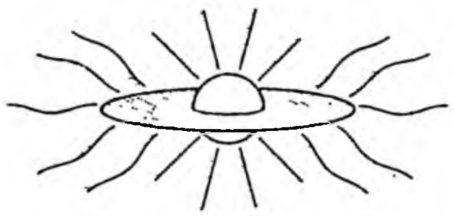
Shu (1987)



Class I

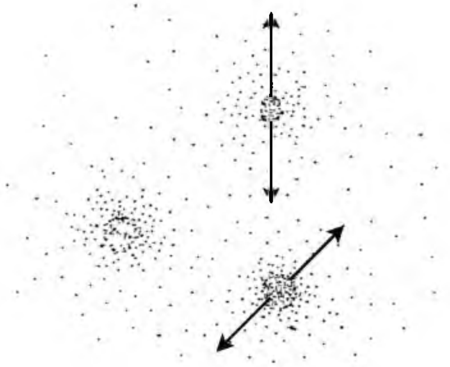


Class II

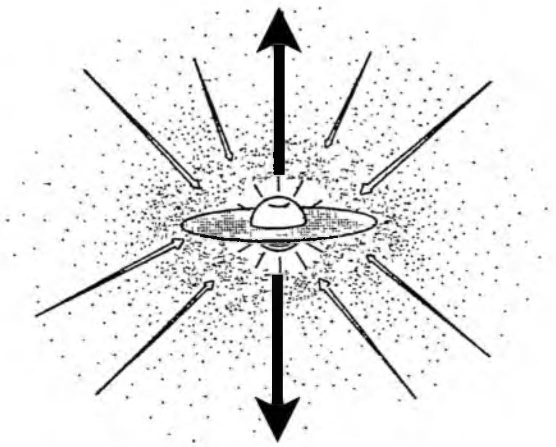


Class III

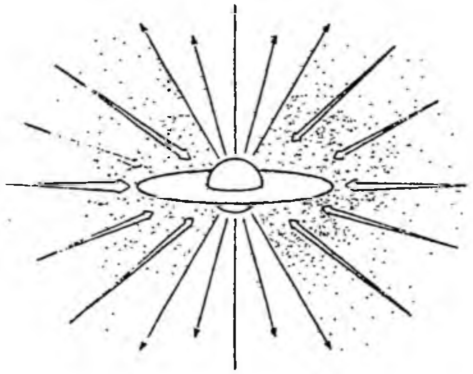
Shu (1987)



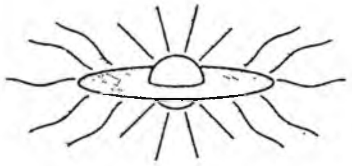
Class 0



Class I



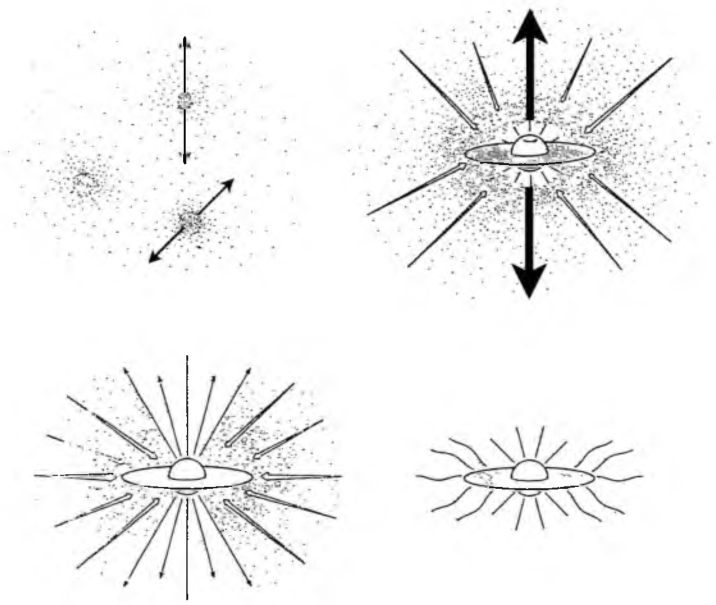
Class II



Class III

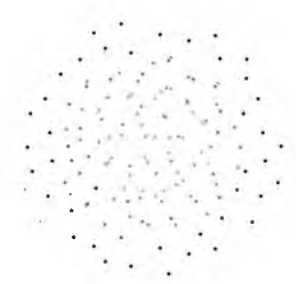
Prestellar Cores

gravitationally bound

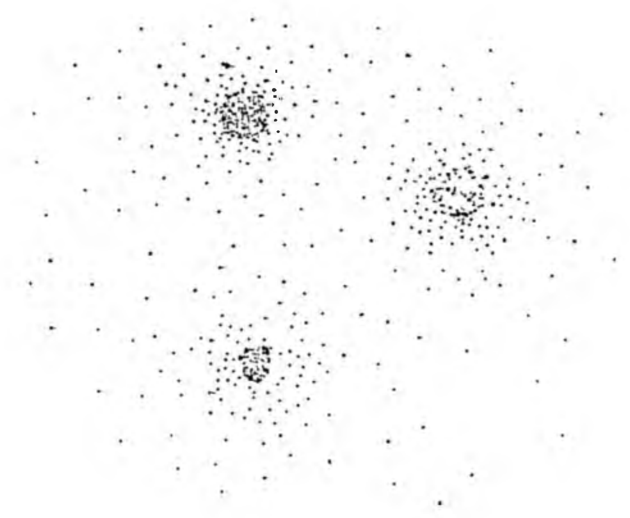


Protostellar Cores/Protostars

assoc. with YSOs

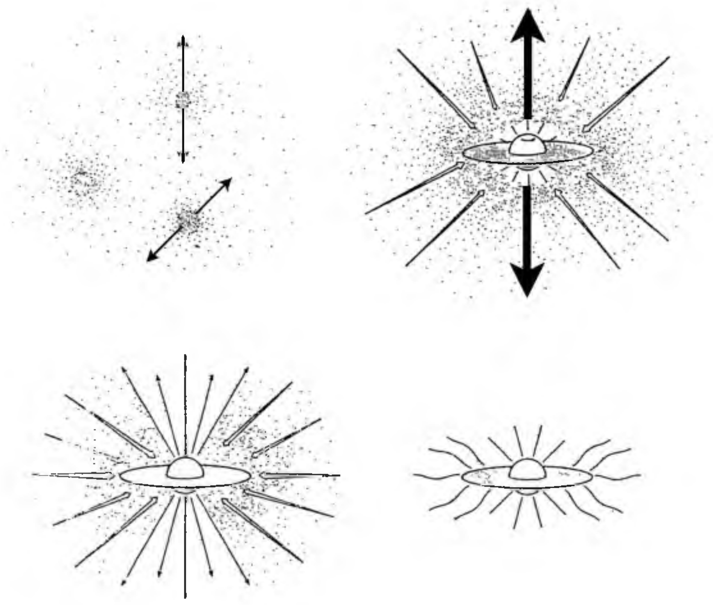


(Starless Cores)



Prestellar Cores

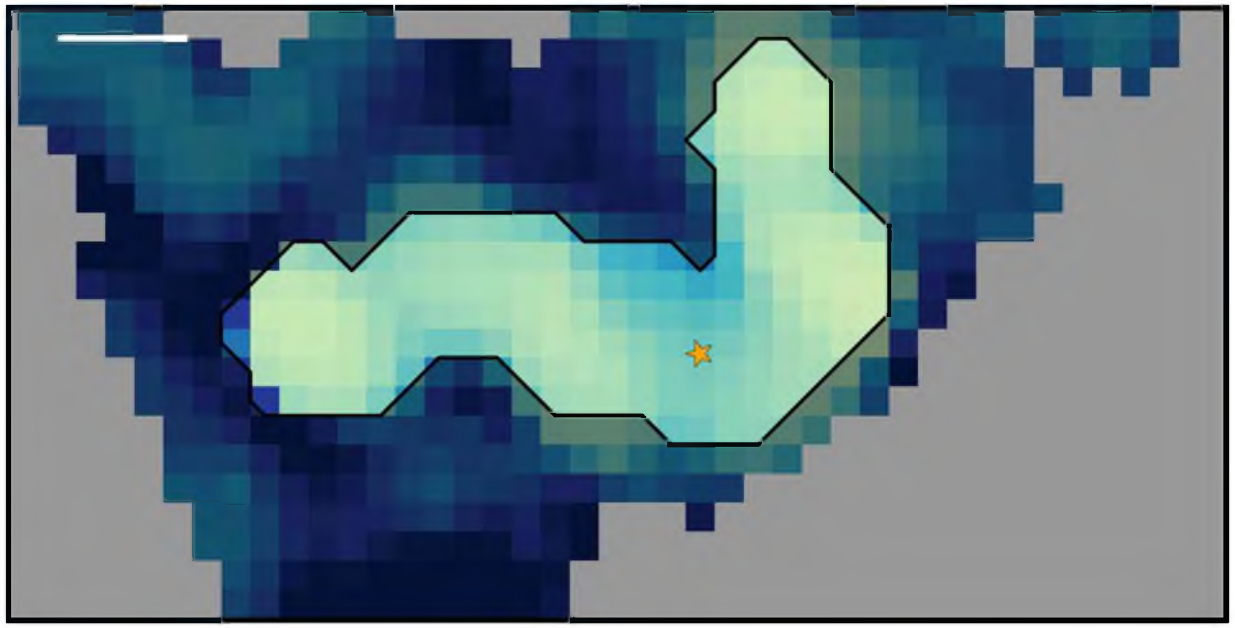
gravitationally bound



Protostellar Cores/Protostars

assoc. with YSOs

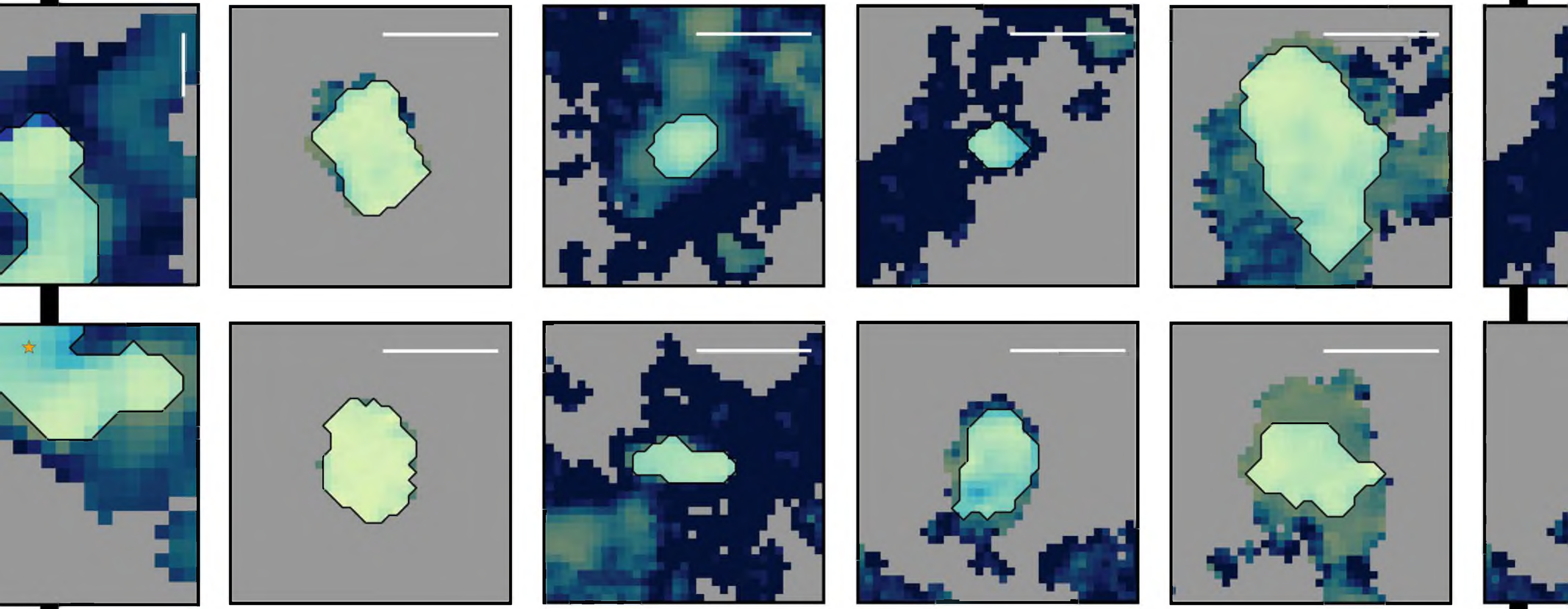
Pineda et al. (2010)



A Coherent Core
(Perseus B5)

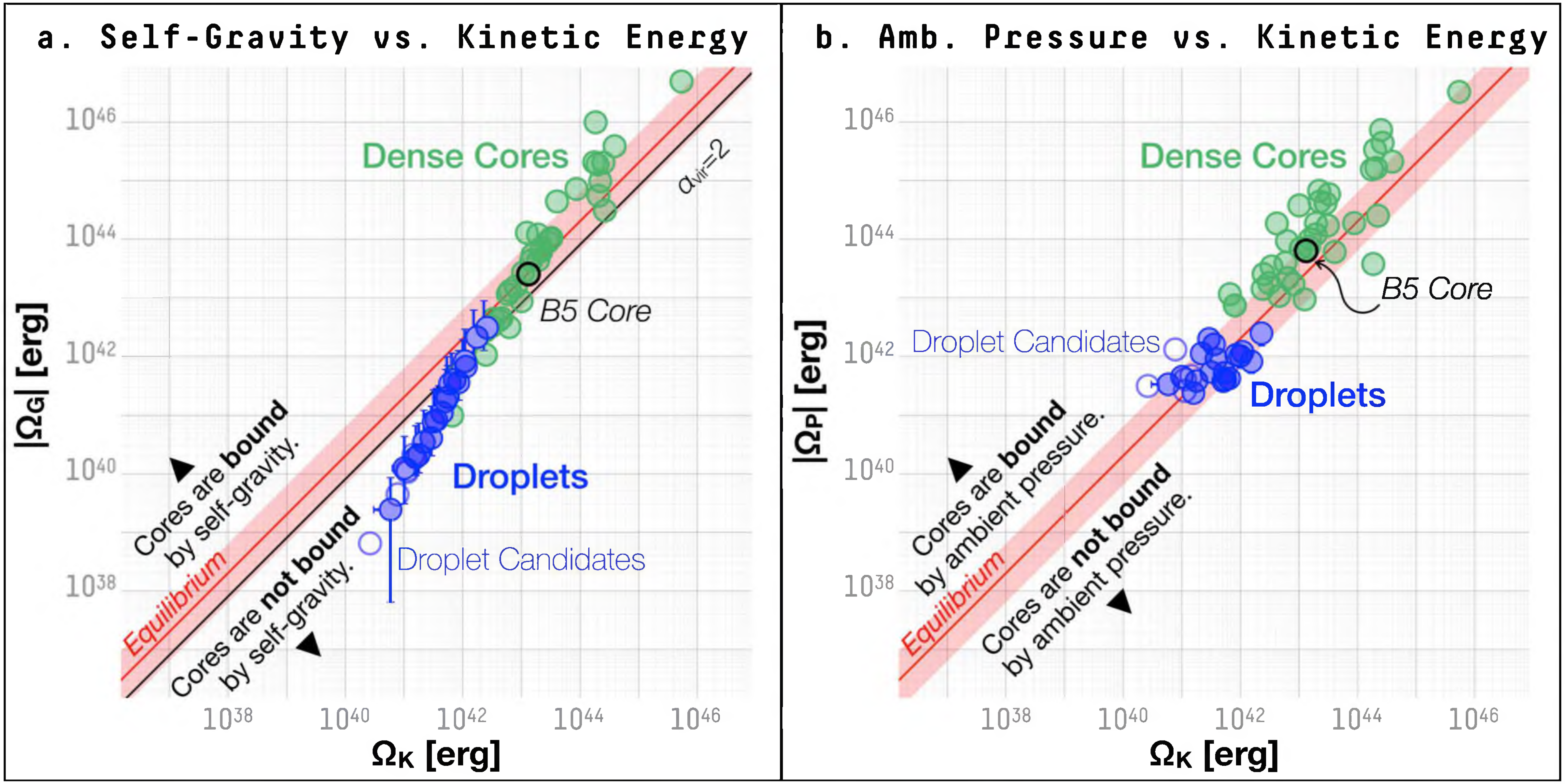
transition to coherence/
Per B5 is gravitationally bound

Chen et al. (2019)



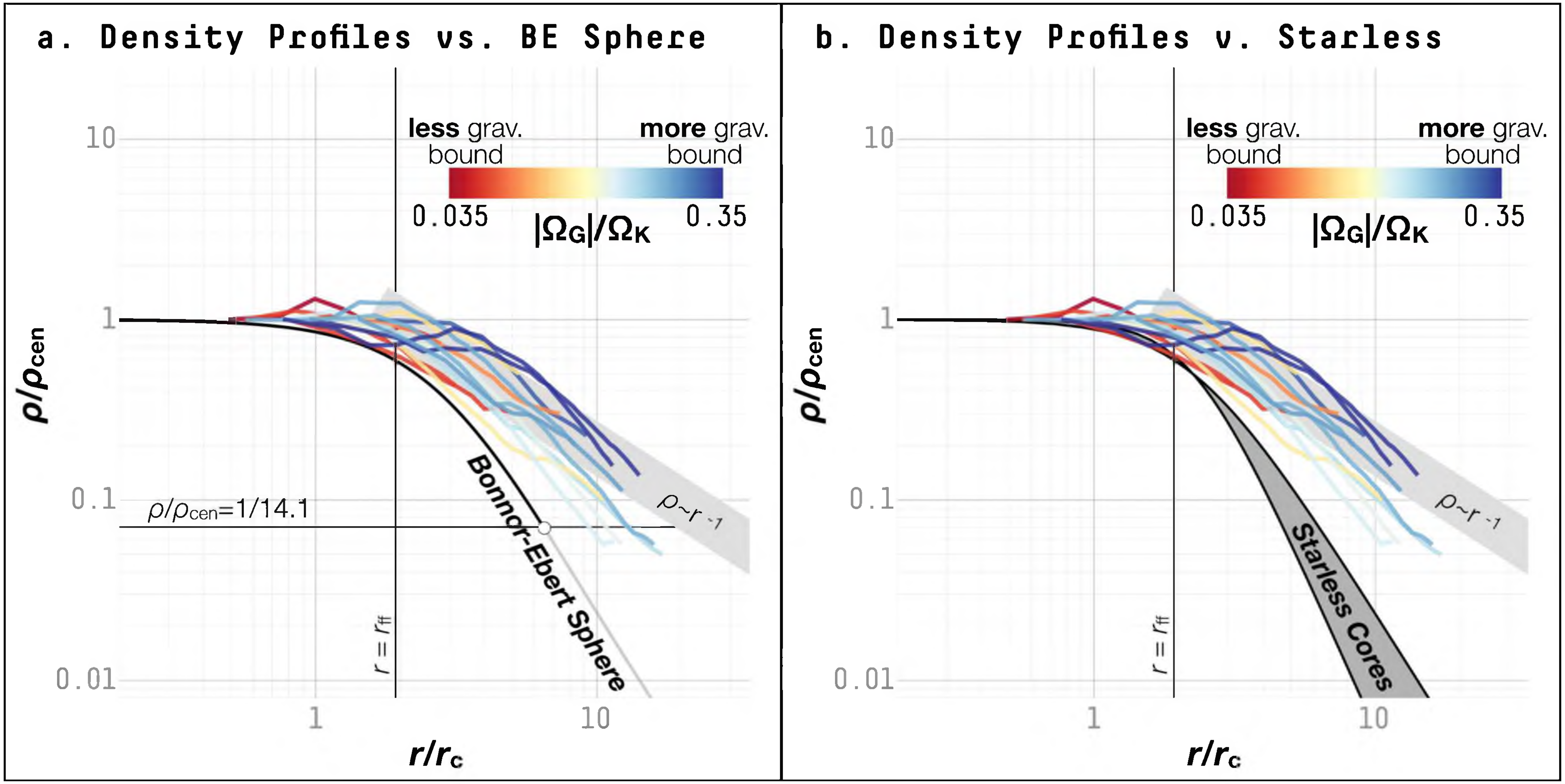
Chen et al. (2019) identify **at least another 18 coherent coherent structures** in NH3 emission. Most of these structures are **not bound by self-gravity**.

Chen et al. (2019)



Chen et al. find that many of these coherent structures are predominantly **confined by the pressure** provided by the ambient gas motions. They also have shallow density profiles.

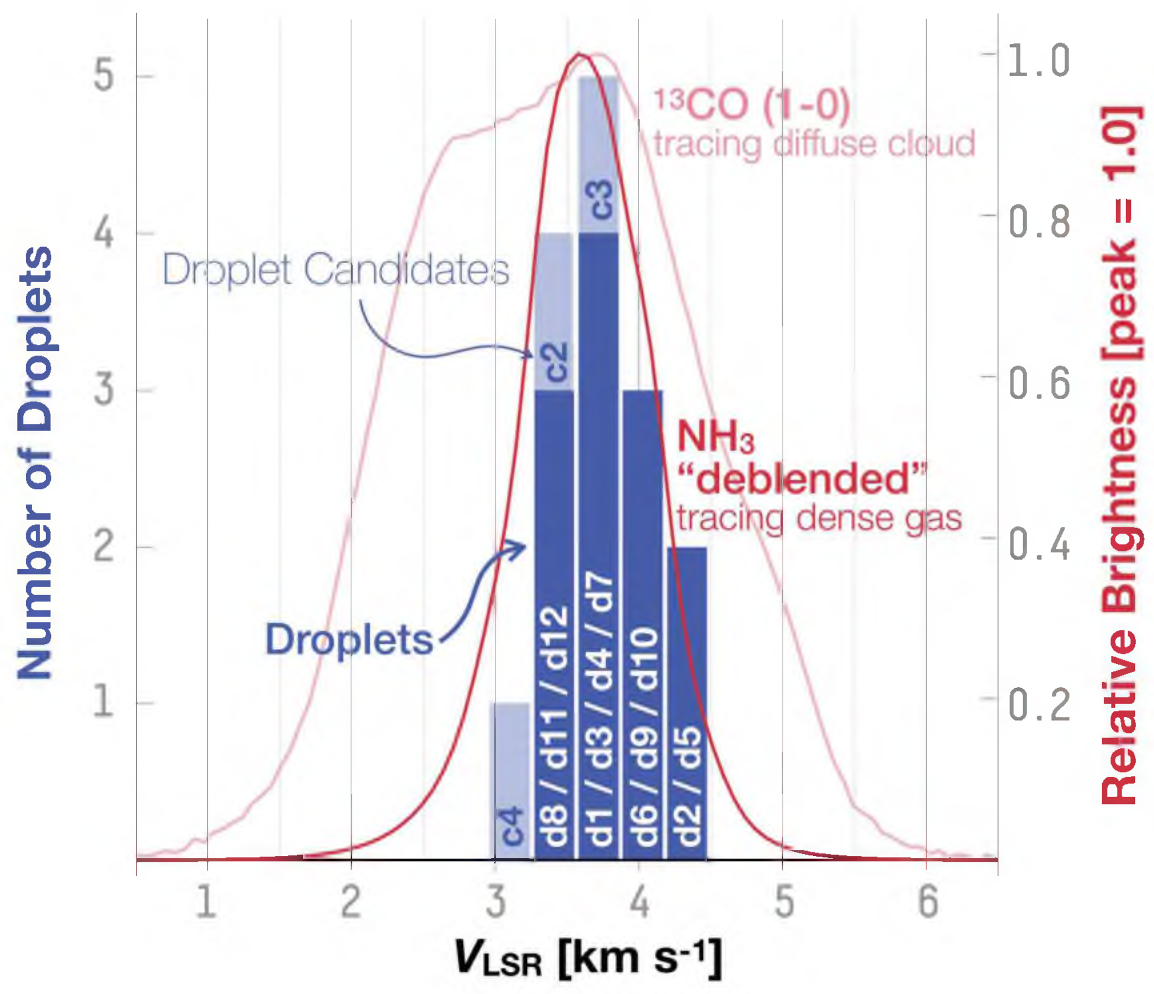
Chen et al. (2019)



Chen et al. find that many of these coherent structures are predominantly confined by the pressure provided by the ambient gas motions. They also have **shallow density profiles**.

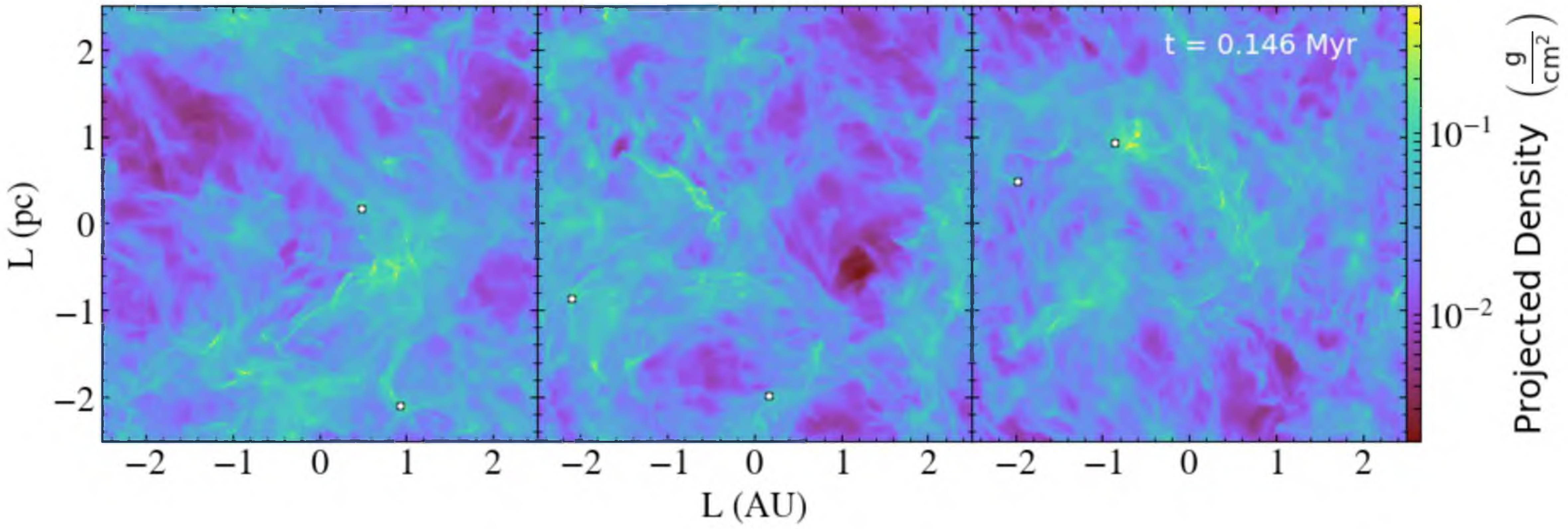
Chen et al. (2019)

Distribution of Velocities (L1688)



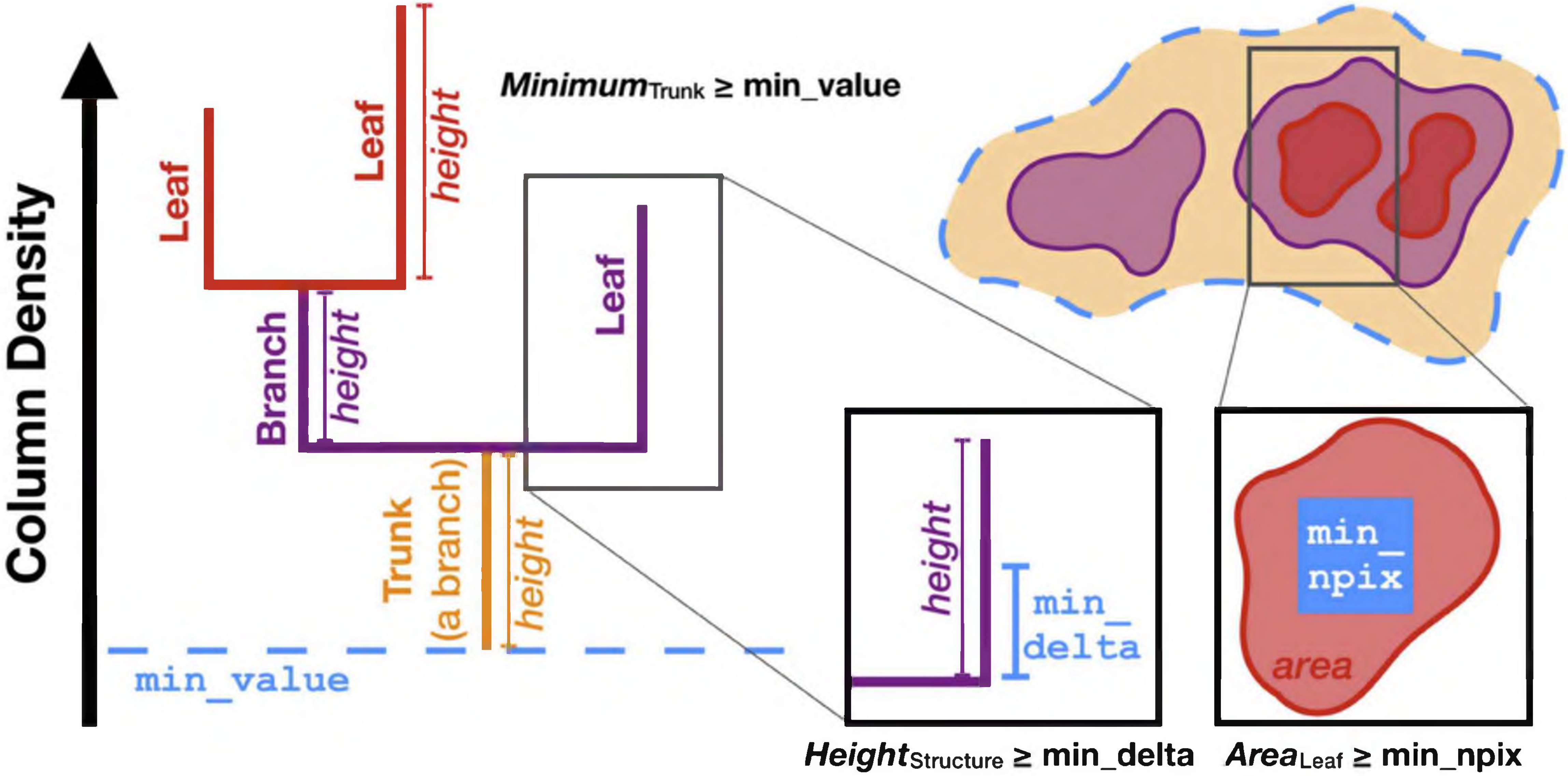
It consistently appears that these structures are
closely associated with the turbulent motions
in the molecular clouds.

Smullen et al. (in prep); Offner et al. (2015)



Here we aim to use a magnetohydrodynamic (MHD) simulation to understand **the origin of coherent structures** and the role they play in **the evolution of cores** and the subsequent **star formation**.

Chen et al. (2018); Rosolowsky et al. (2007)



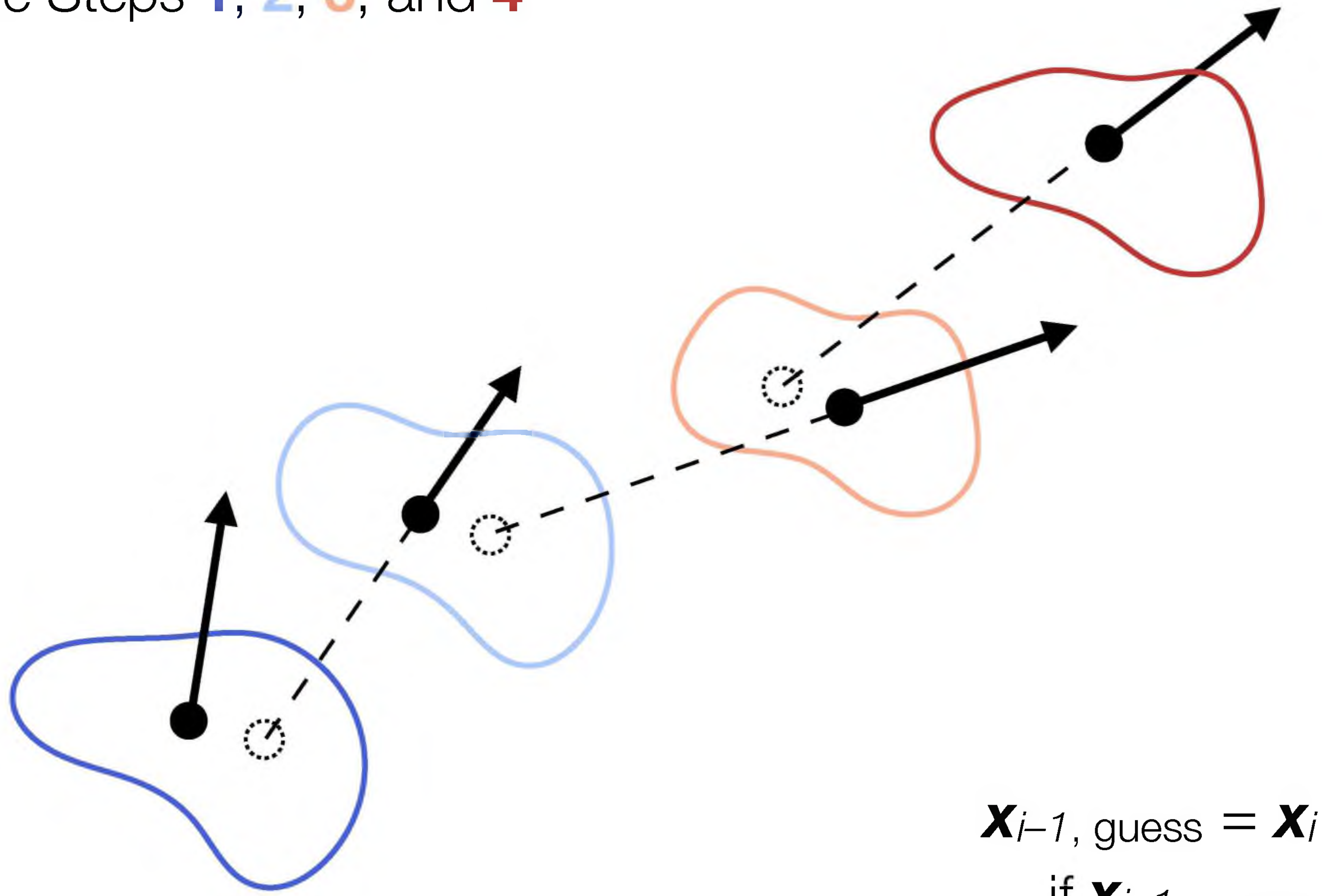
Minimum$_{\text{Trunk}}$ ≥ min_value

Height$_{\text{Structure}}$ ≥ min_delta

Area$_{\text{Leaf}}$ ≥ min_npix

Dendrogram
(structure identification)

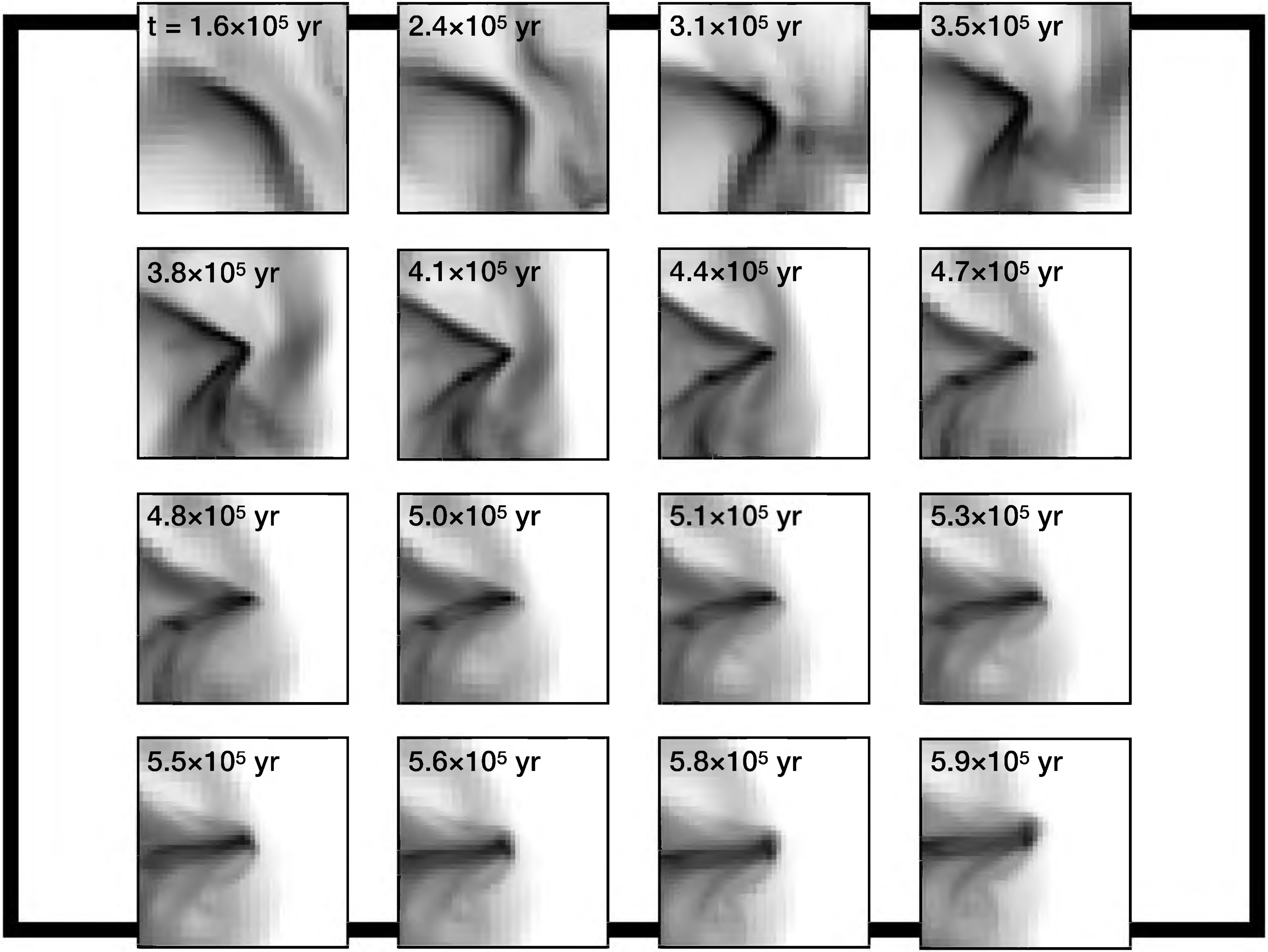
Dendrogram Leaves at Time Steps **1**, **2**, **3**, and **4**



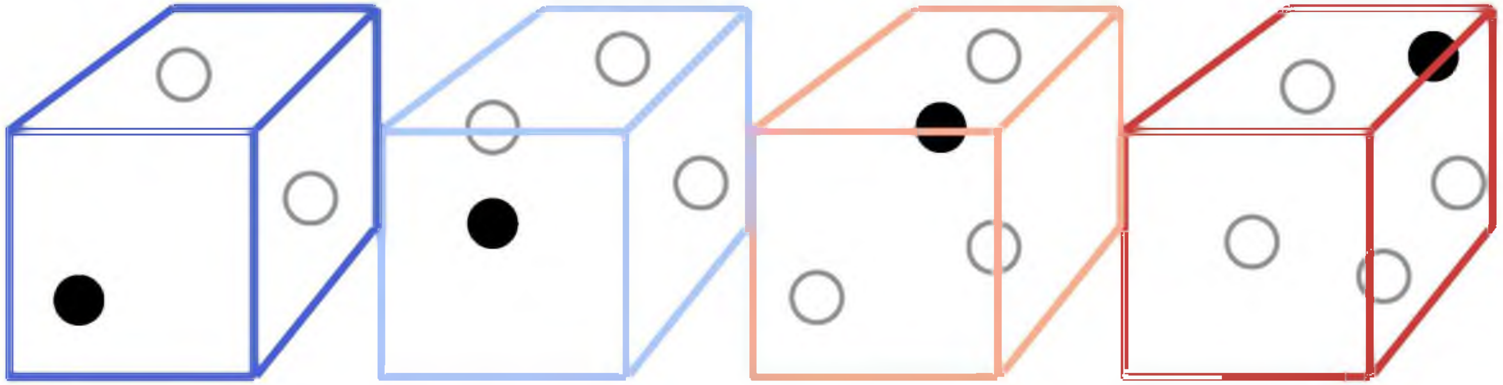
$$\boldsymbol{x}_{i-1,\ \text{guess}} = \boldsymbol{x}_i - \boldsymbol{v}_i \times \Delta\boldsymbol{t}$$

if $\boldsymbol{x}_{i-1,\ \text{guess}}$ is in a leaf:

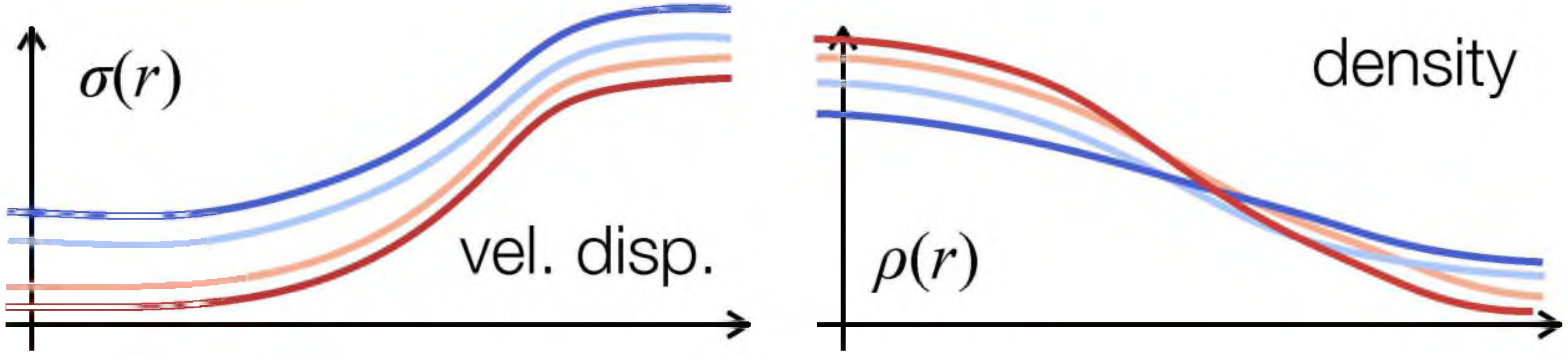
$\boldsymbol{x}_{i-1}$ = (density peak in the leaf)


t = 1.6×10⁵ yr
2.4×10⁵ yr
3.1×10⁵ yr
3.5×10⁵ yr
3.8×10⁵ yr
4.1×10⁵ yr
4.4×10⁵ yr
4.7×10⁵ yr
4.8×10⁵ yr
5.0×10⁵ yr
5.1×10⁵ yr
5.3×10⁵ yr
5.5×10⁵ yr
5.6×10⁵ yr
5.8×10⁵ yr
5.9×10⁵ yr

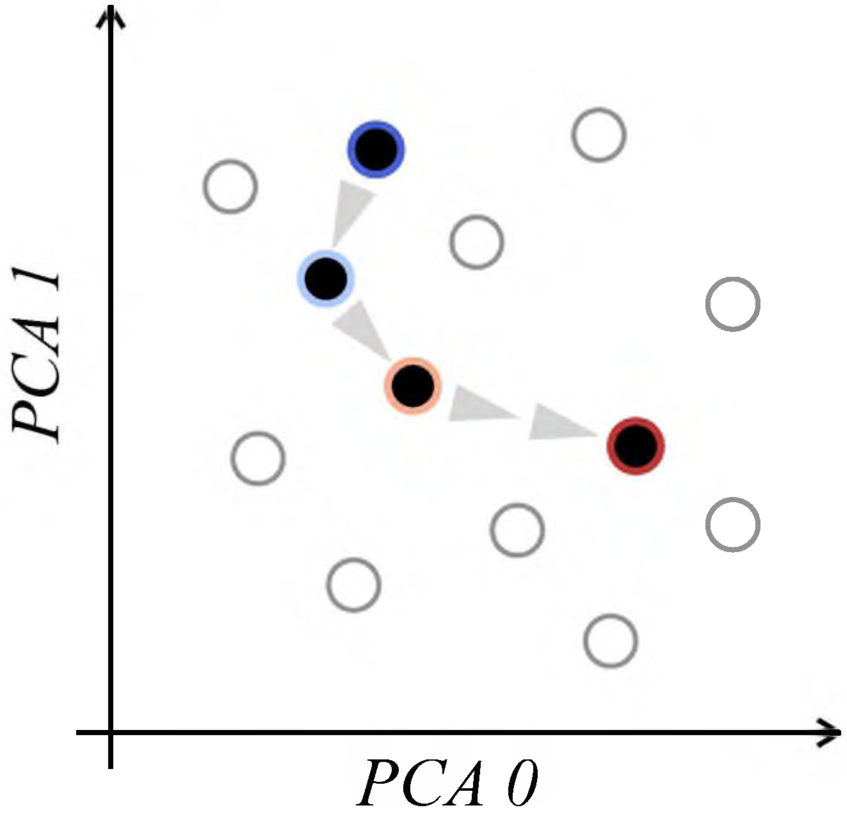
structure
tracking



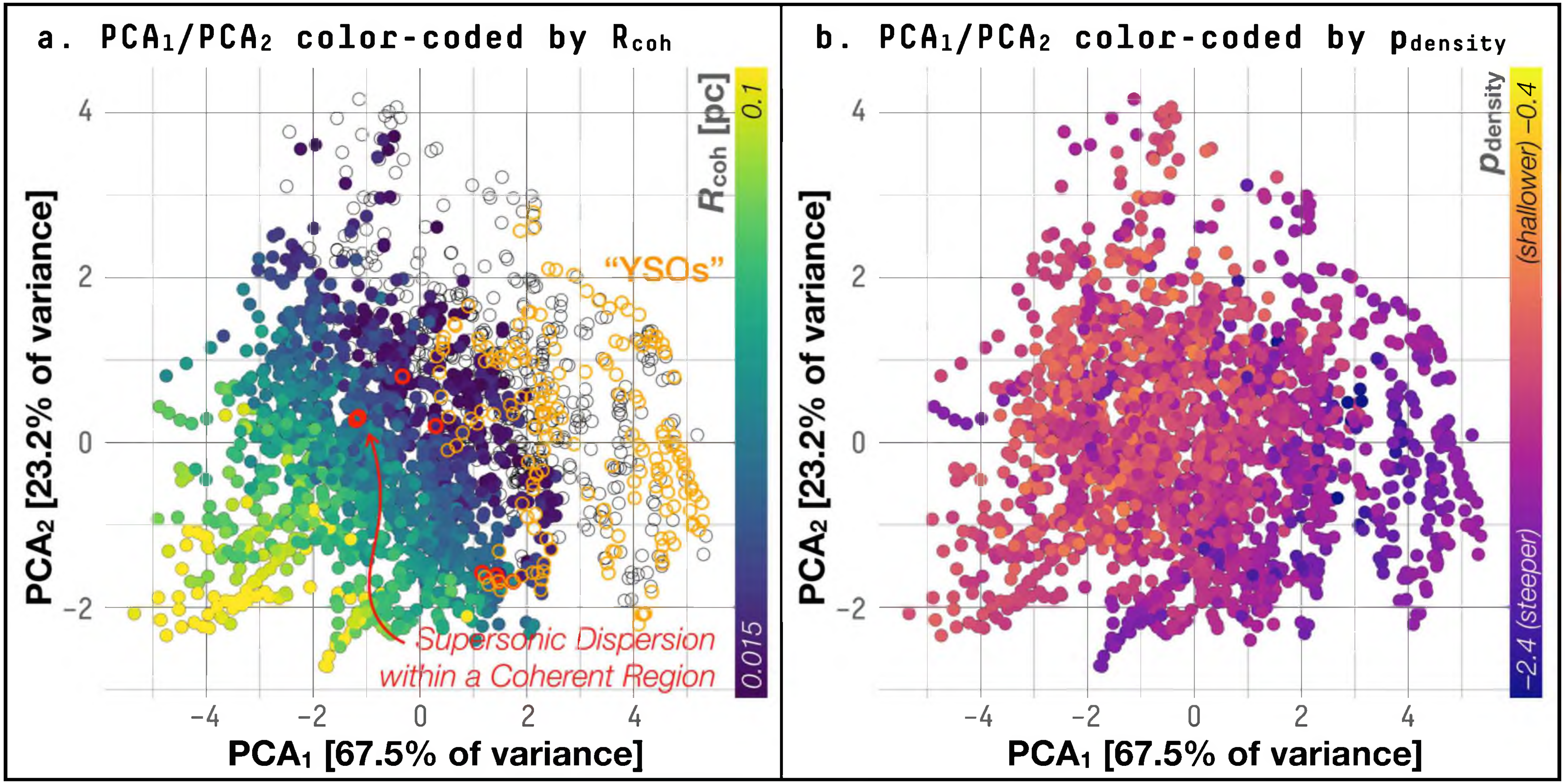
extraction of
radial profiles



PCA analysis of
the radial profiles



PCA.

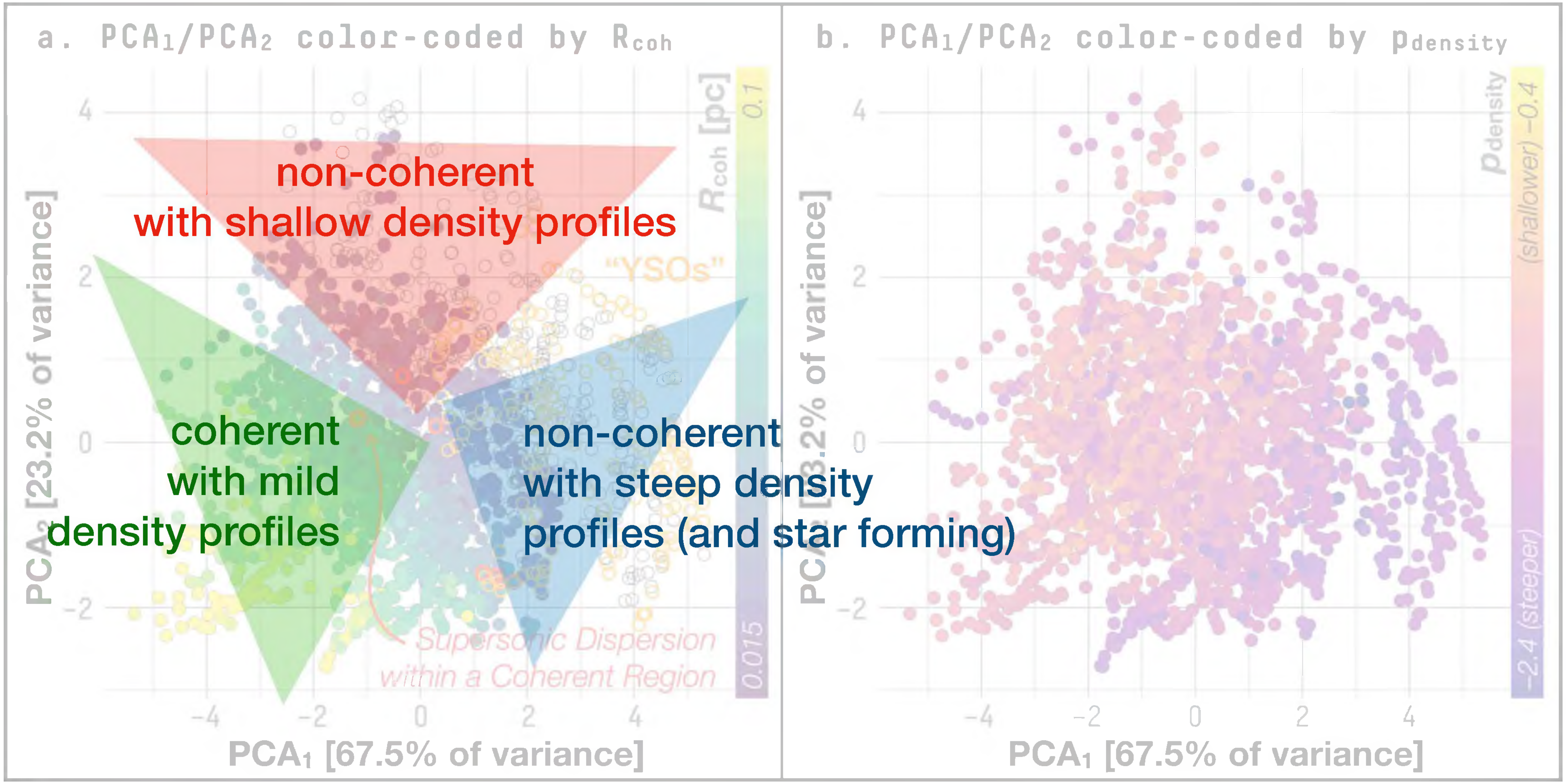


a. $\mathrm{PCA}_1/\mathrm{PCA}_2$ color-coded by R_{coh}

b. $\mathrm{PCA}_1/\mathrm{PCA}_2$ color-coded by $p_{density}$

A total of **~91% of variance** in density and velocity dispersion profiles can be explained the first two PCA components.

PCA.



a. PCA_1/PCA_2 color-coded by R_{coh}

b. PCA_1/PCA_2 color-coded by $p_{density}$

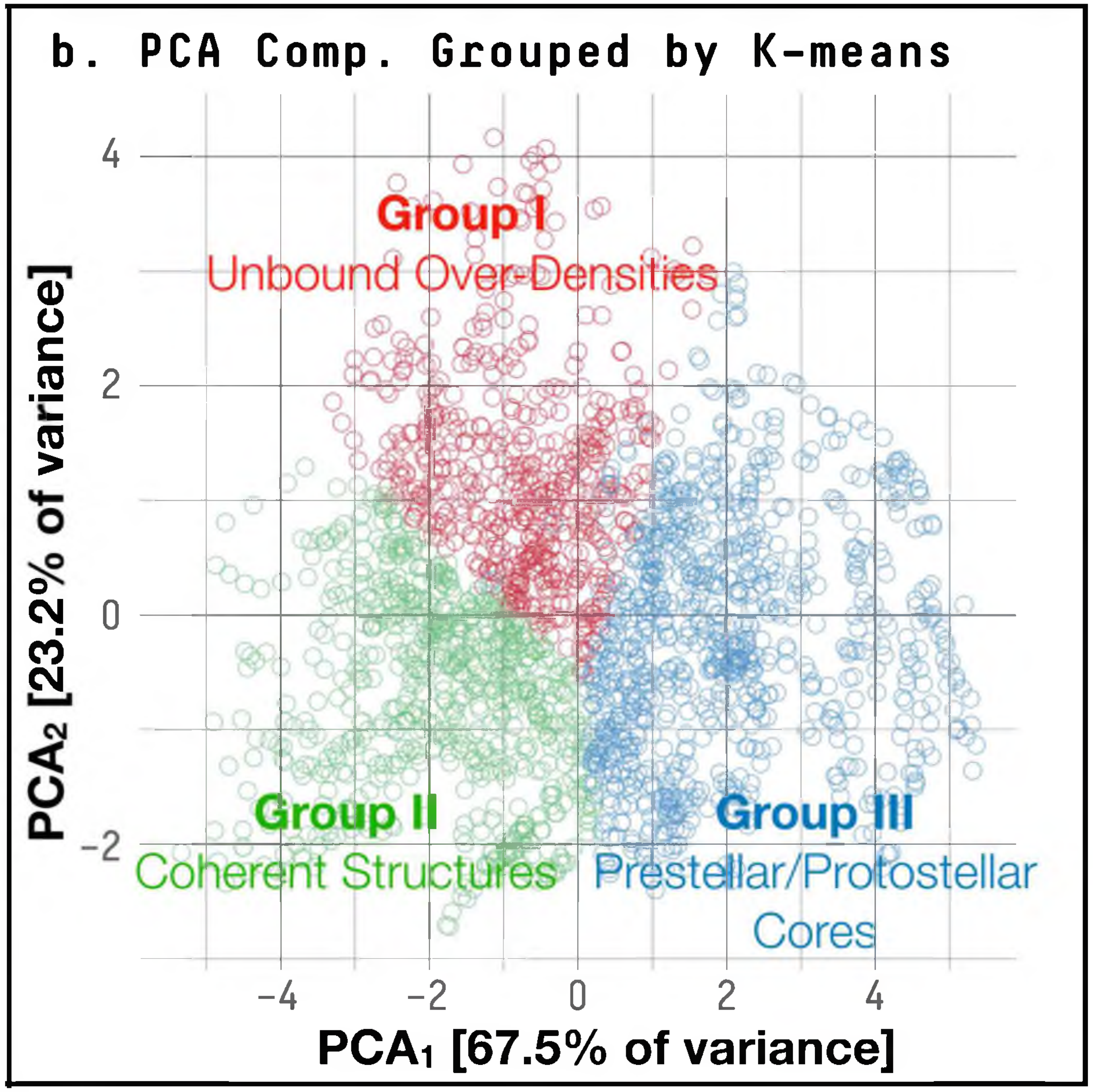
non-coherent
with shallow density profiles

coherent
with mild
density profiles

non-coherent
with steep density
profiles (and star forming)

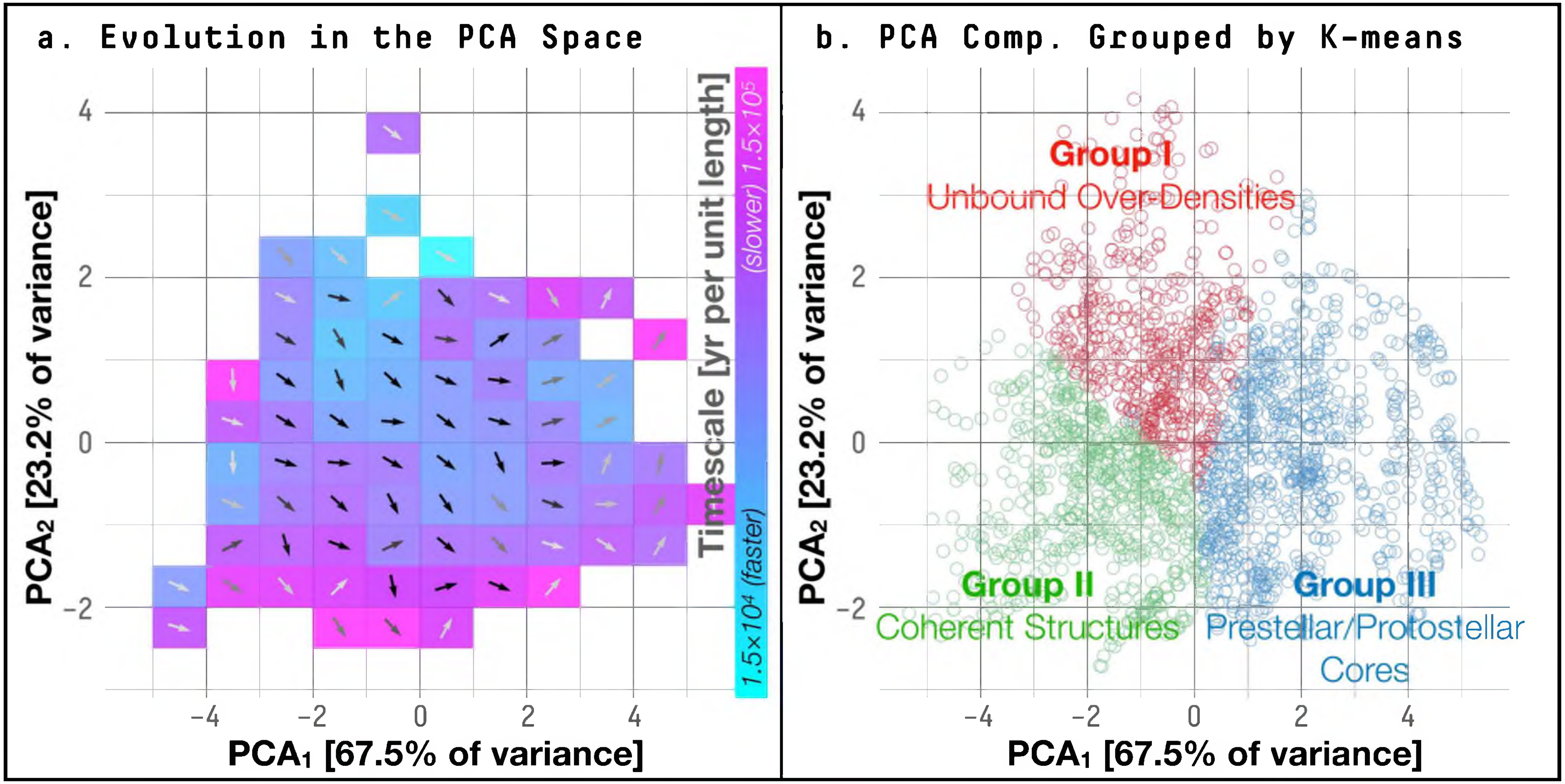
The three corners of the distribution in the PCA space appear to represent three different stages in evolution.

PCA+clustering.



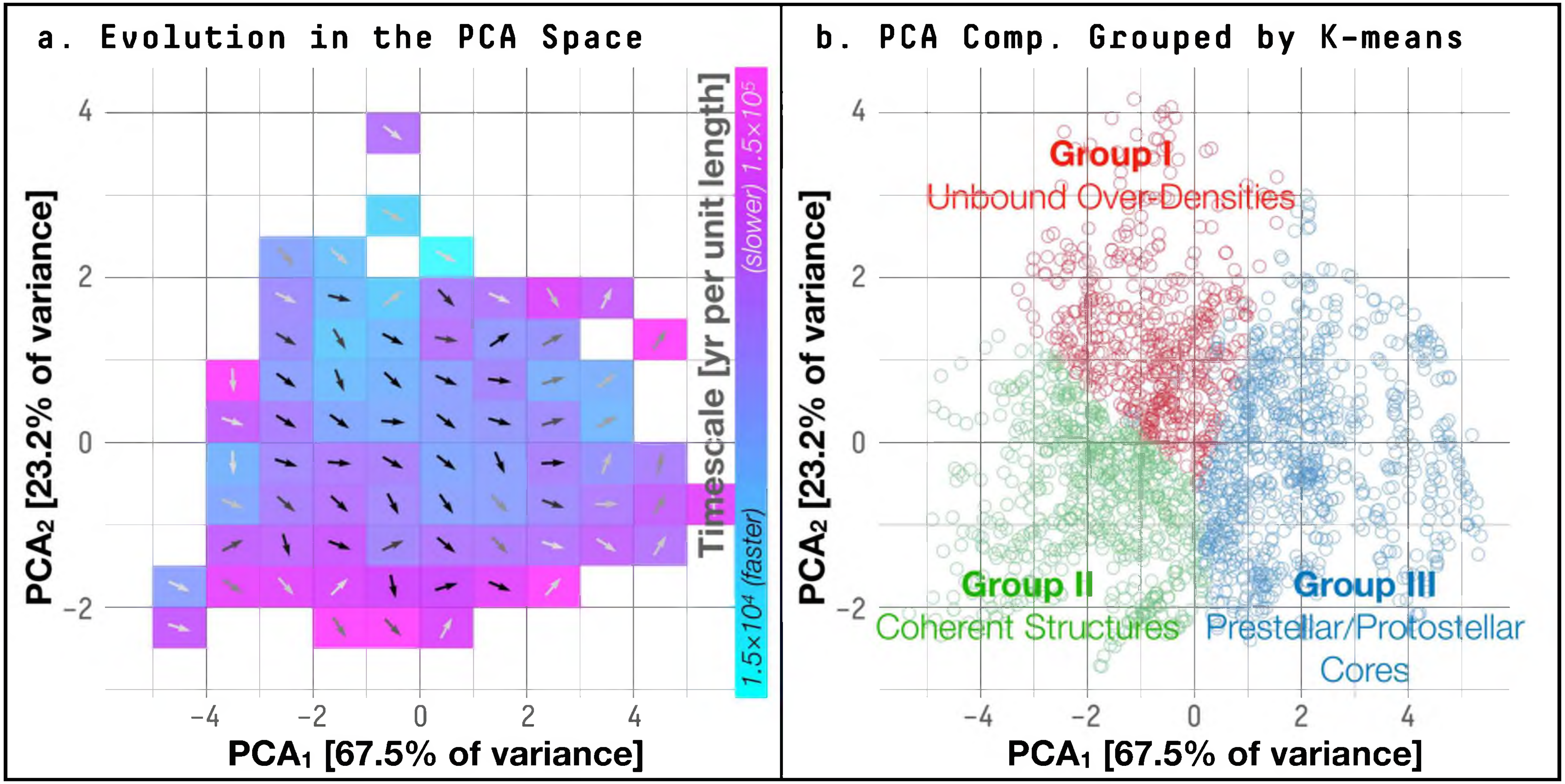
The distribution in the PCA space can be clustered into three groups, which are connected by “tracks” derived from the tracking.

PCA+clustering+tracking.



The three groups represent **the unbound over-densities**, **the coherent structures**, and **the prestellar/protostellar cores**, respectively.

PCA+clustering+tracking.

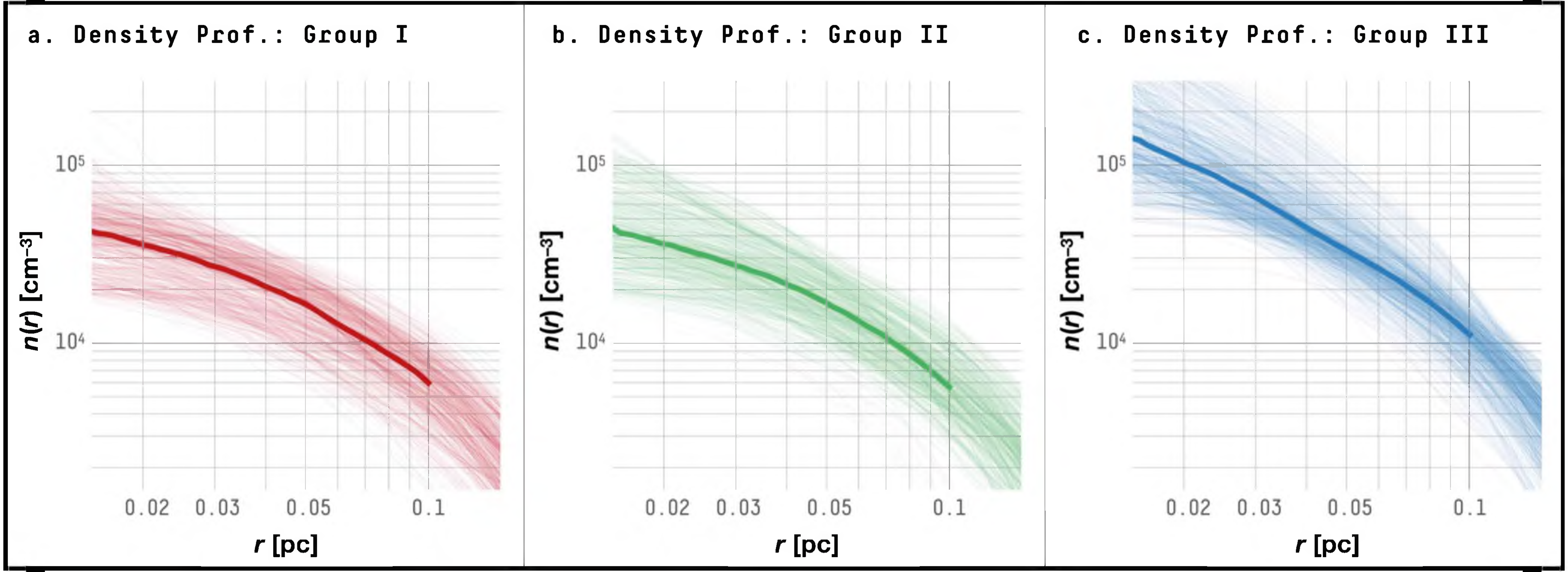


a. Evolution in the PCA Space

b. PCA Comp. Grouped by K-means

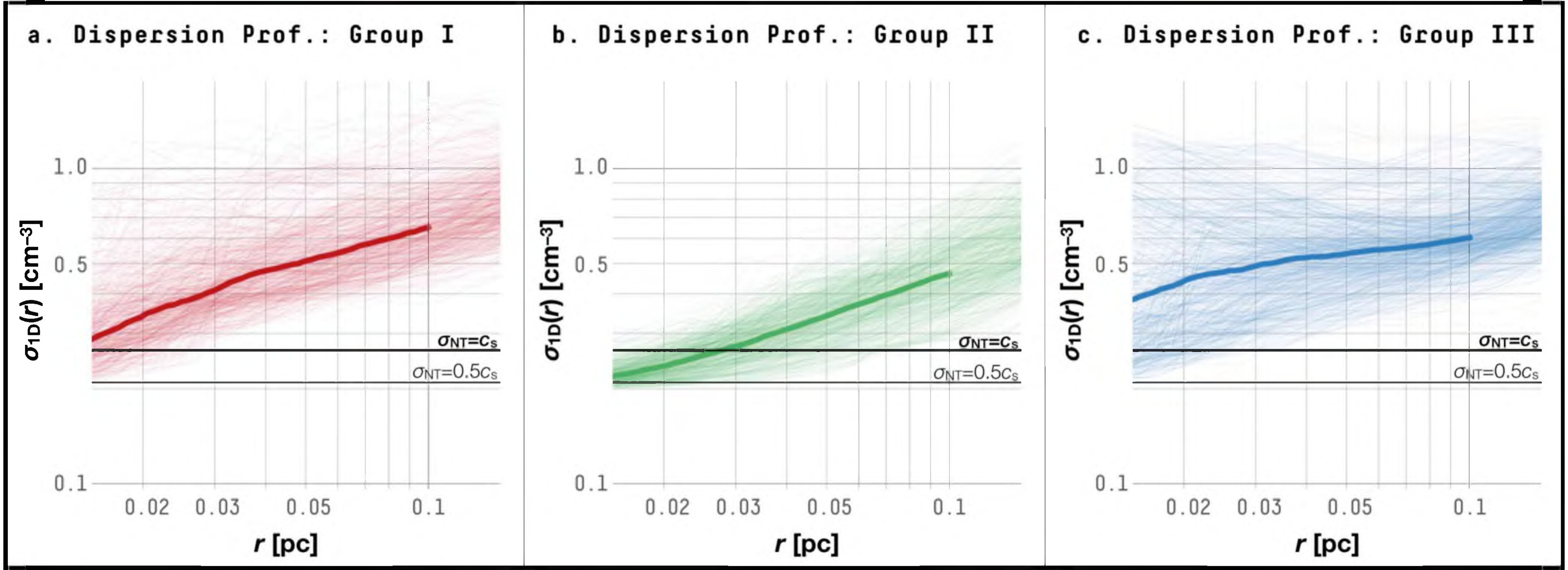
Based on the results, we derive a typical timescale of the coherent phase of ~2.9 to 4.2×10^5 years.

Radial Profiles of Density.



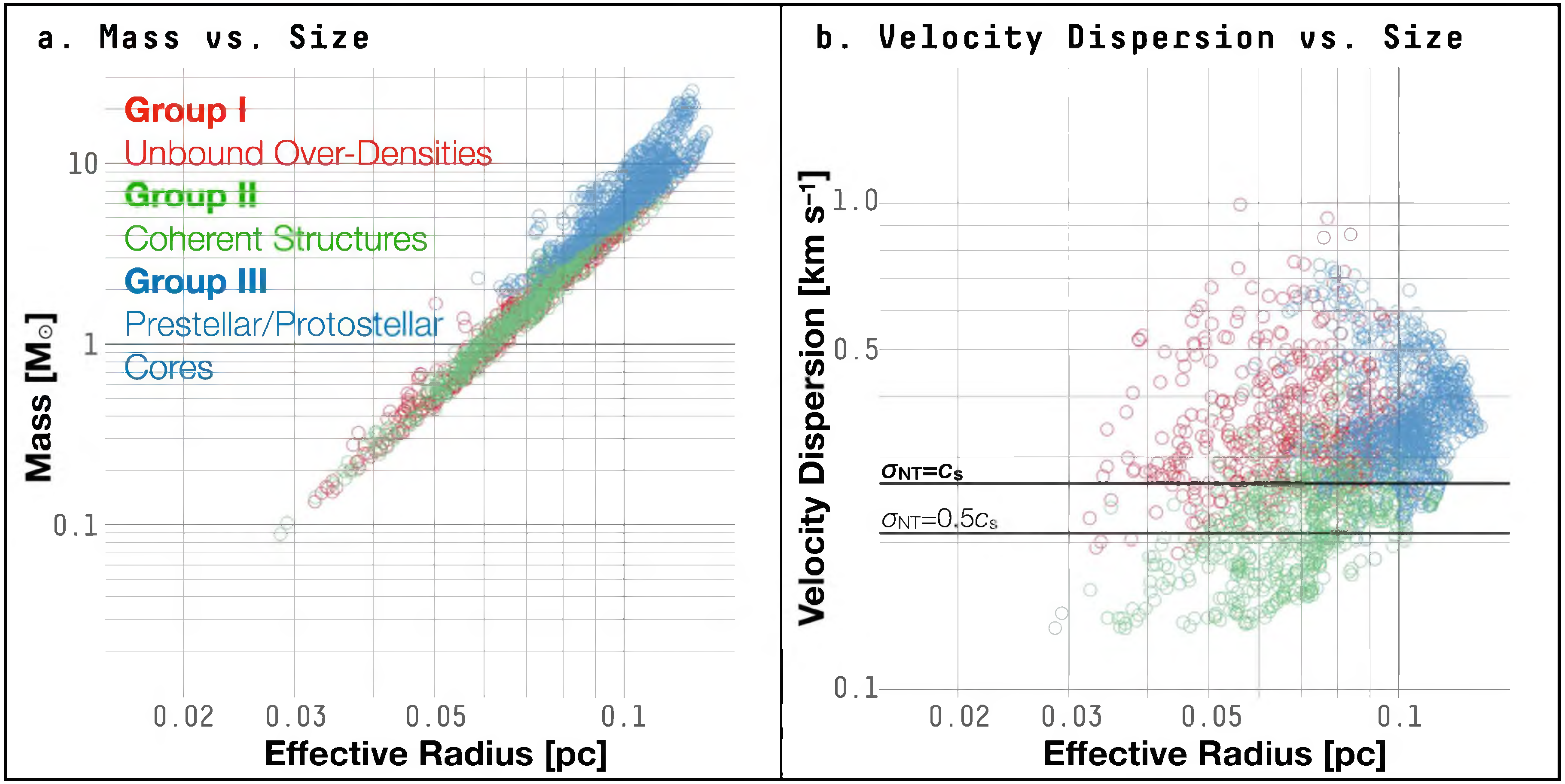
The evolution of the **density** and velocity dispersion profiles reflect the evolution along the proposed evolutionary route.

Radial Profiles of Velocity Dispersion.



The evolution of the density and **velocity dispersion** profiles reflect the evolution along the proposed evolutionary route.

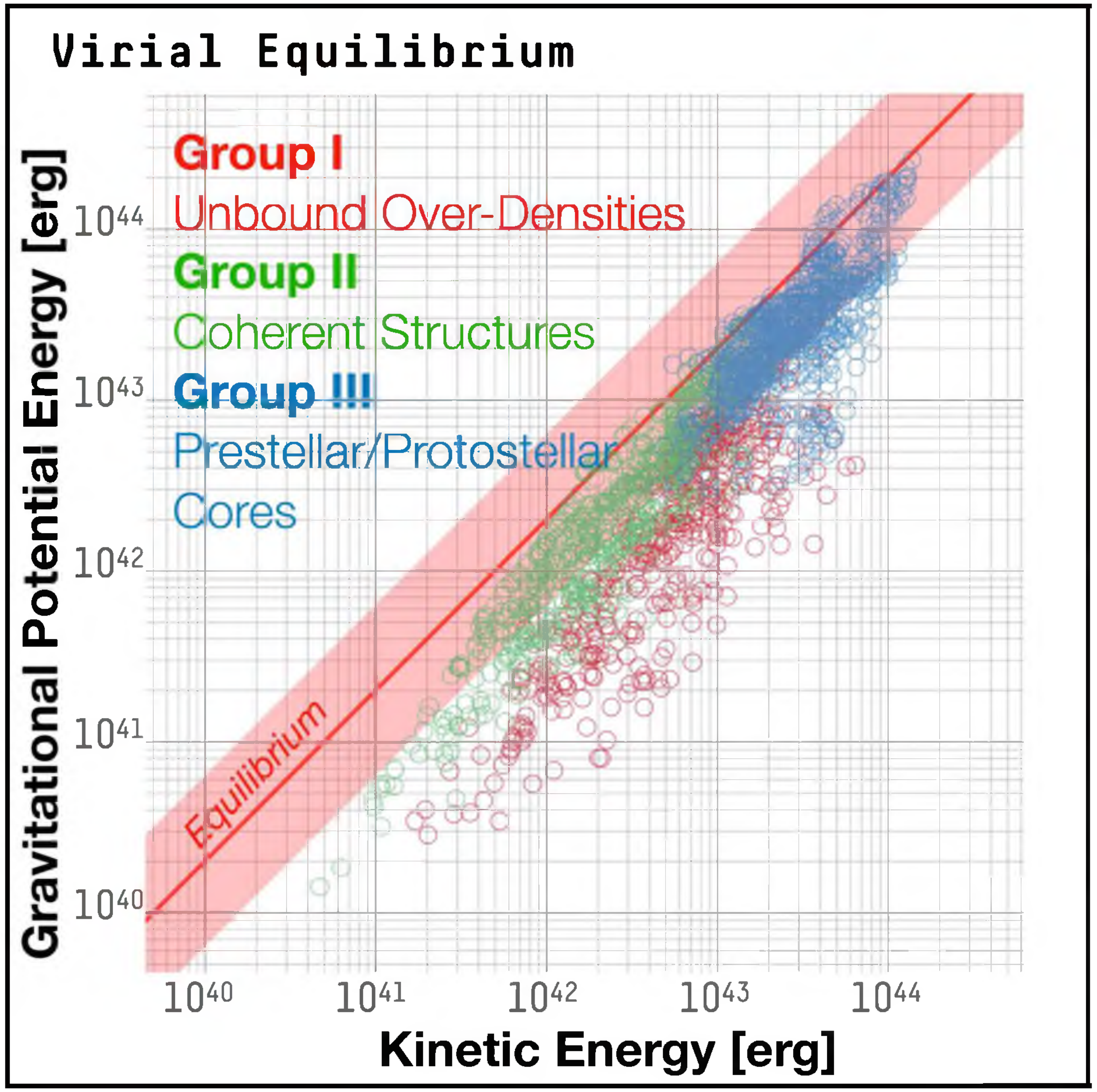
Physical Properties.


a. Mass vs. Size

b. Velocity Dispersion vs. Size

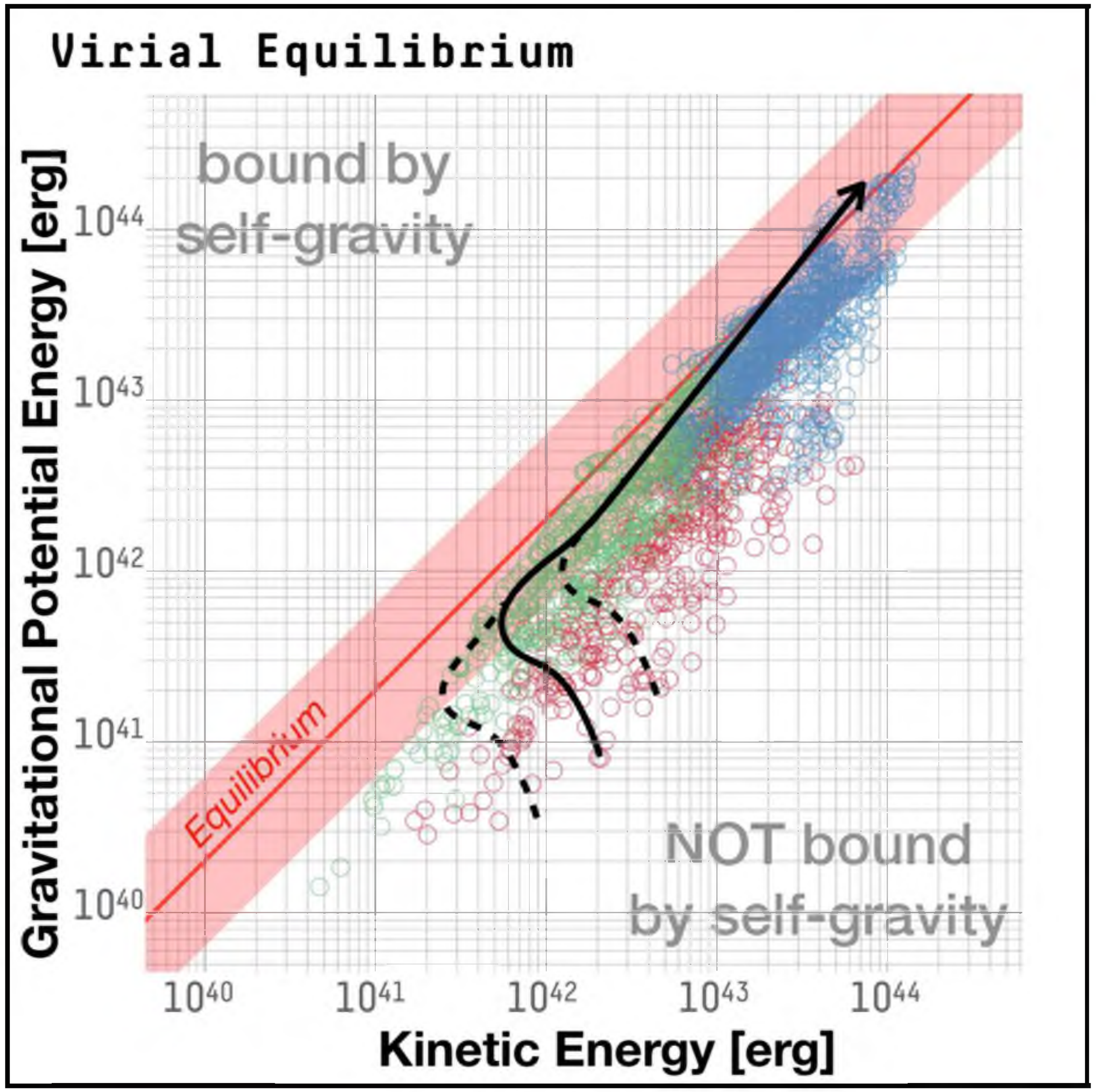
The three groups occupy different parts of the parameter space.

An Evolutionary Track?



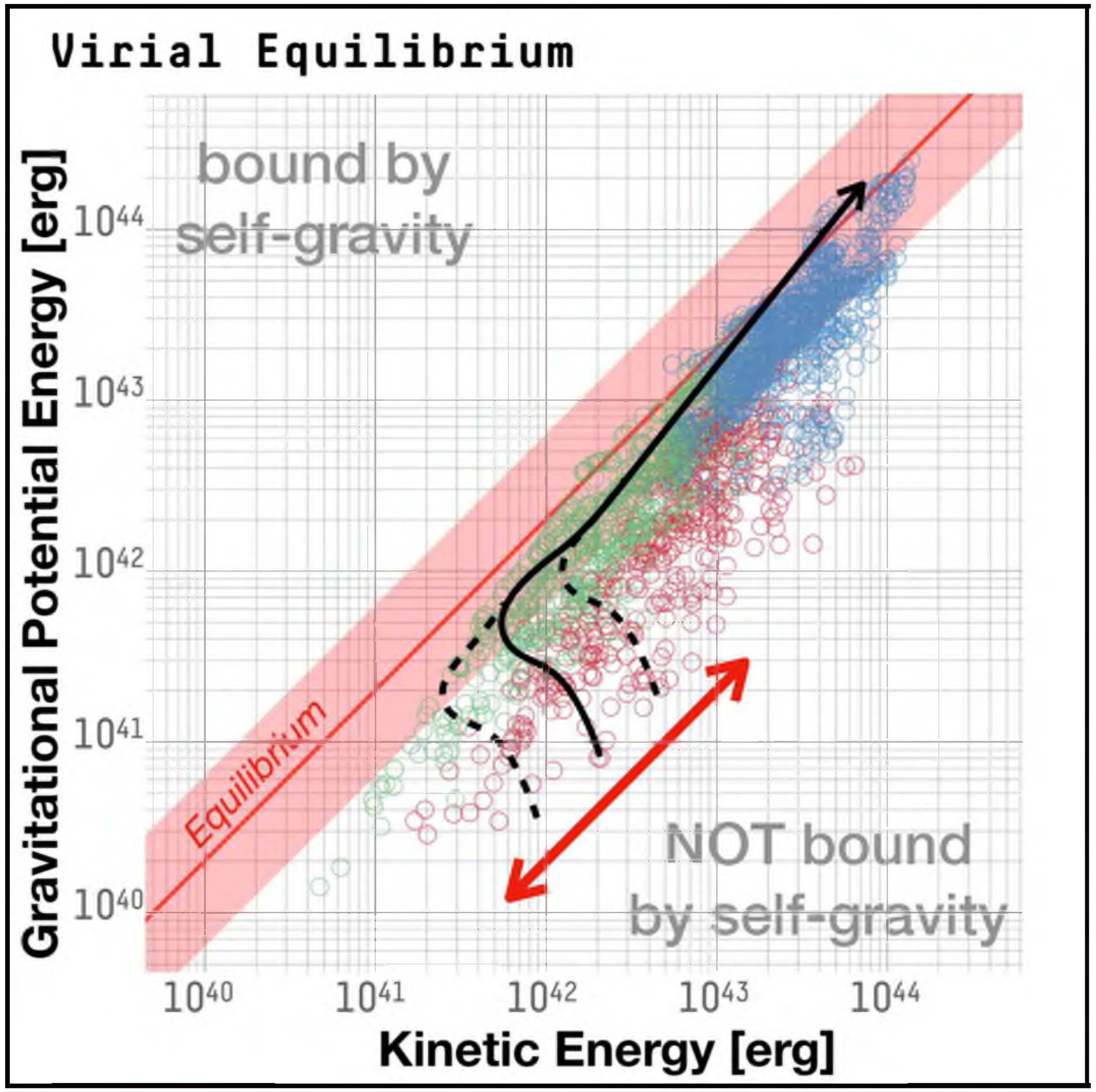
Consequently, they occupy different parts of the parameter space of the kinetic and gravitational potential energies.

An Evolutionary Track?



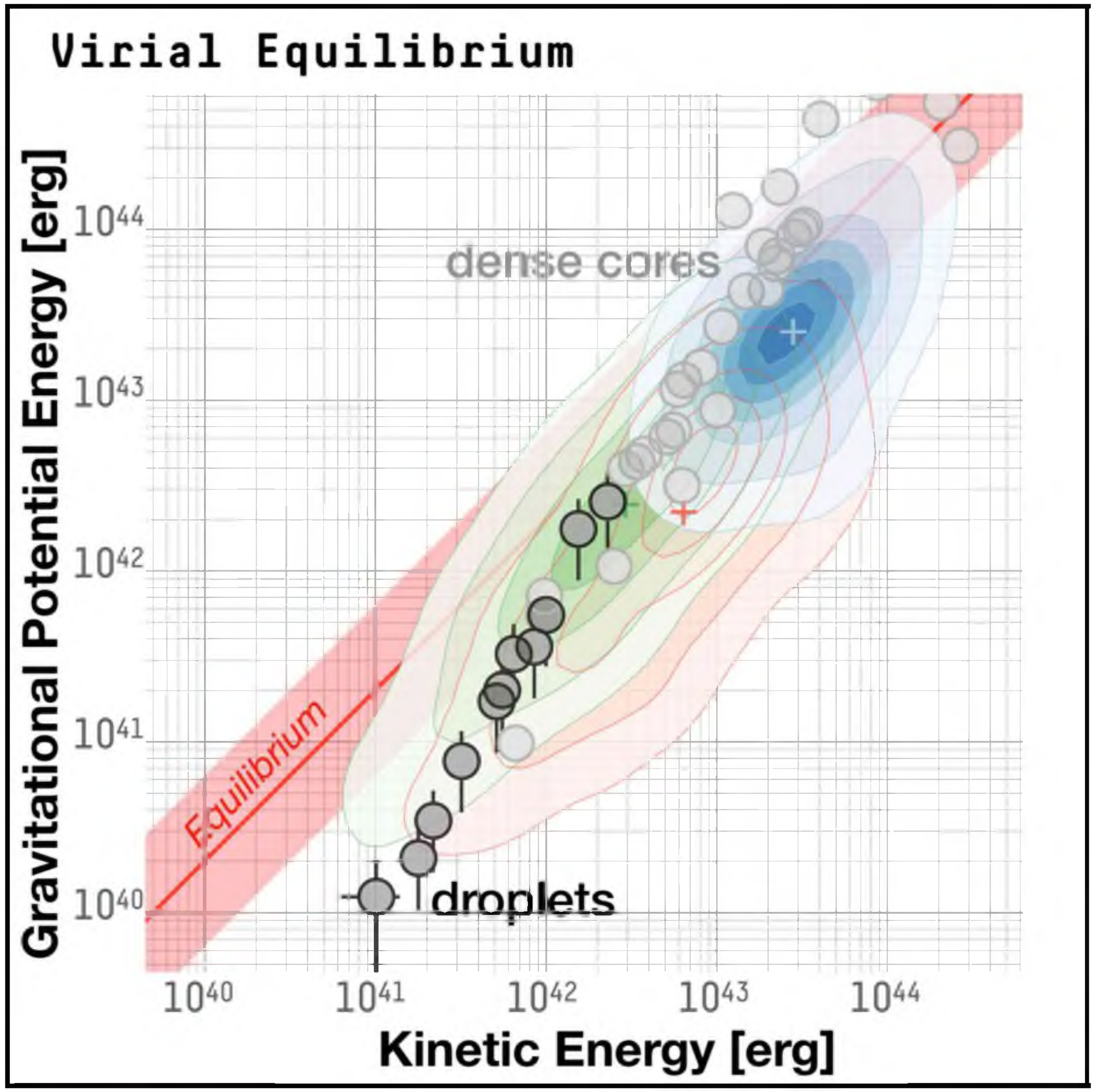
Their distributions of kinetic and gravitational potential energies may suggest an evolutionary route that **starts with the depletion of turbulence** and **continues with growth nearly along a virial equilibrium**.

An Evolutionary Track?



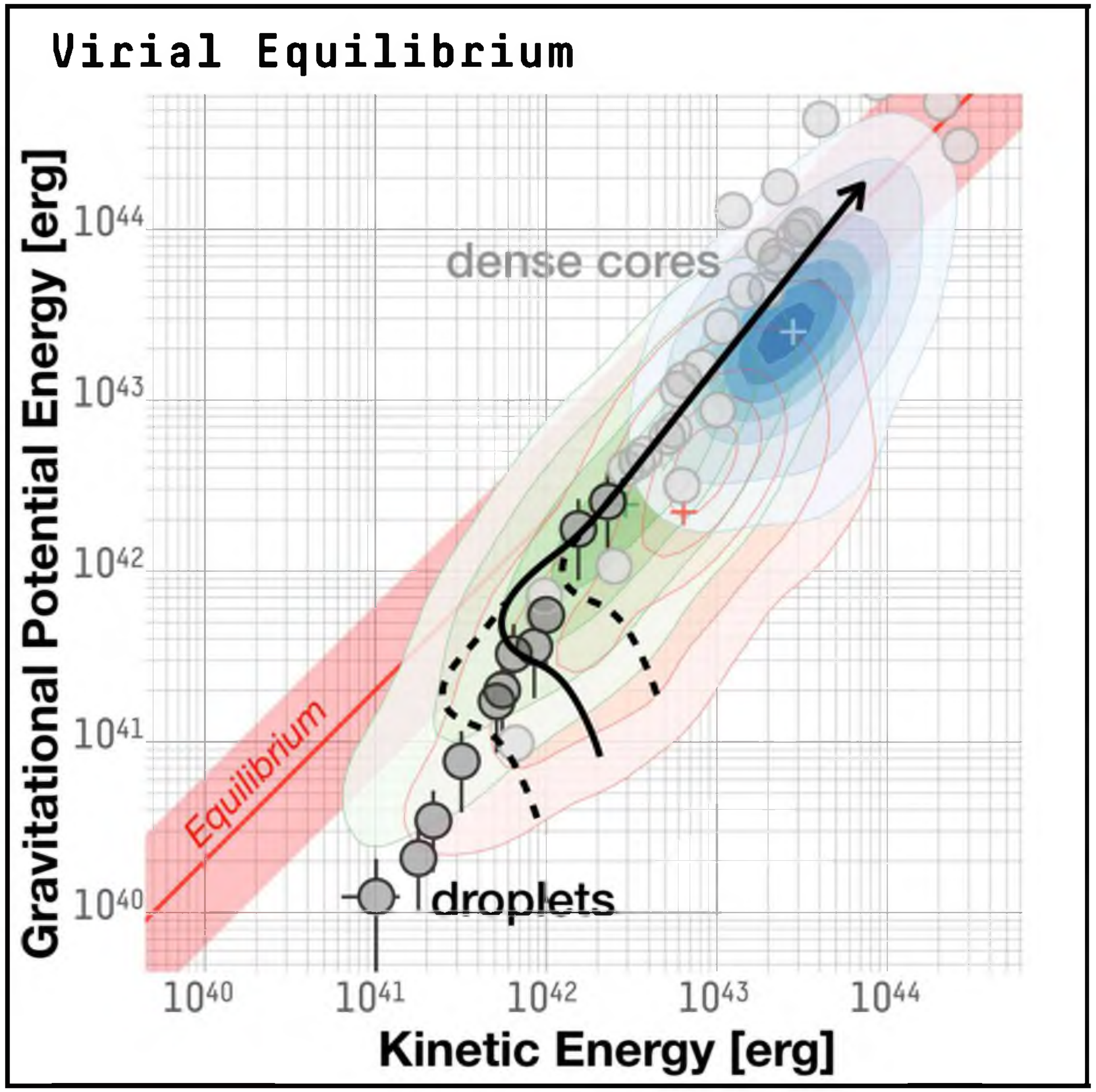
The variation near the starting point of the evolutionary route may be explained by the **different sizes of the initial "seeds."**

An Evolutionary Track?



The droplets and the dense cores appear to represent different stages along the proposed evolutionary route.

An Evolutionary Track?



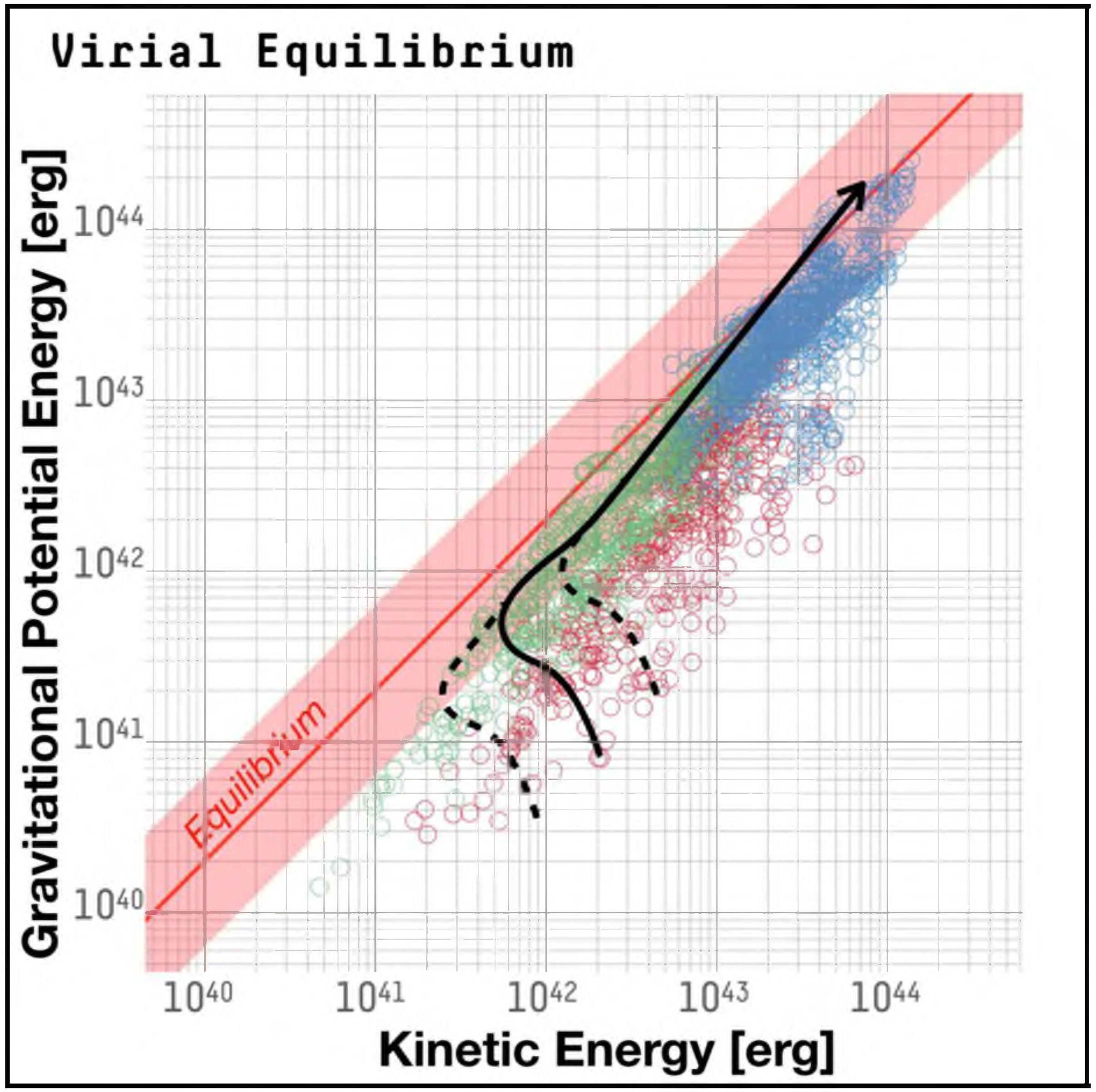
The droplets and the dense cores appear to represent different stages along the proposed evolutionary route.

Massive Stars & Star Clusters?

In the formation of massive stars, when and how does the depletion of turbulence happen?

Massive Stars & Star Clusters?

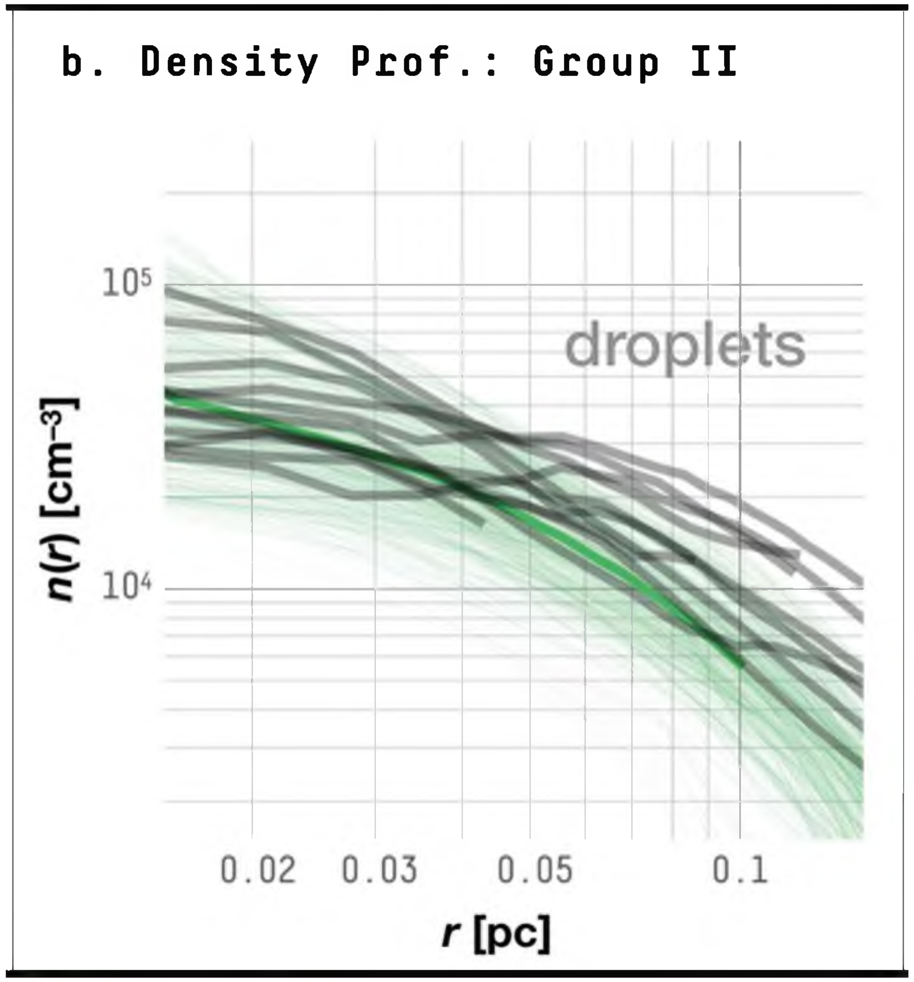
Seeds of cores form first in the turbulent medium, before coming together to form larger-scale structures such as filaments.



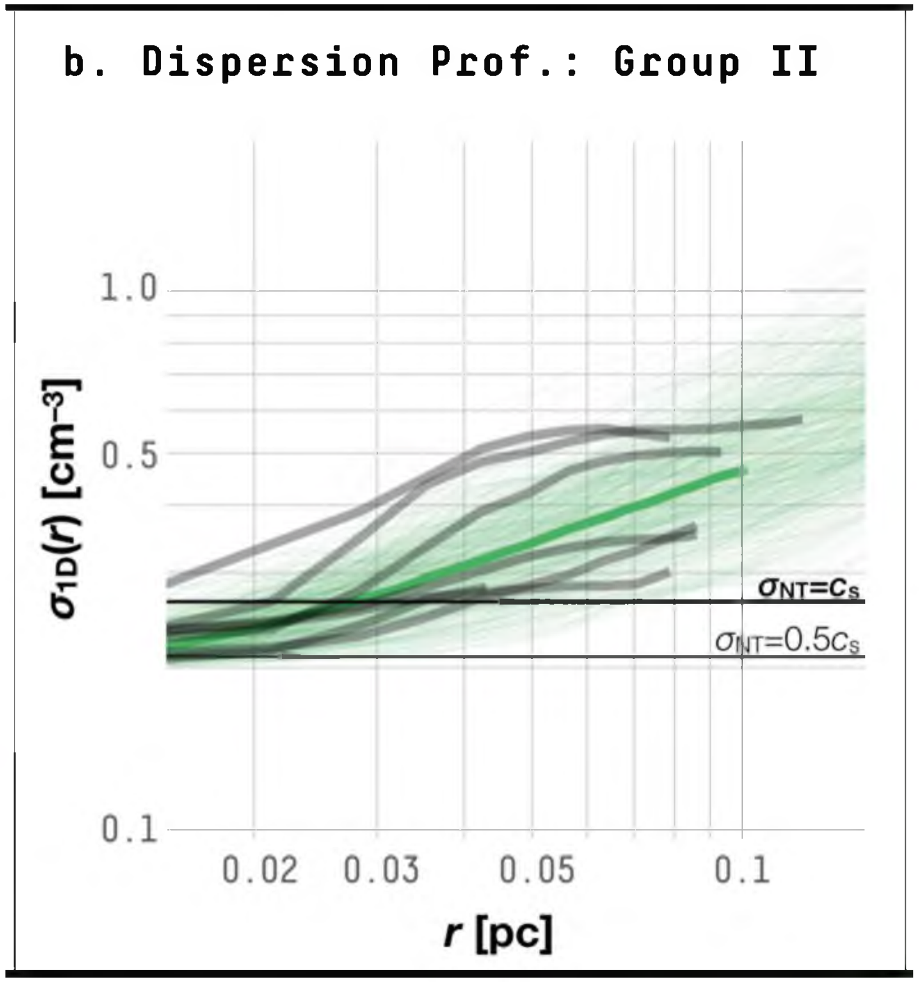
Virial Equilibrium

Questions?

Why NH_3?



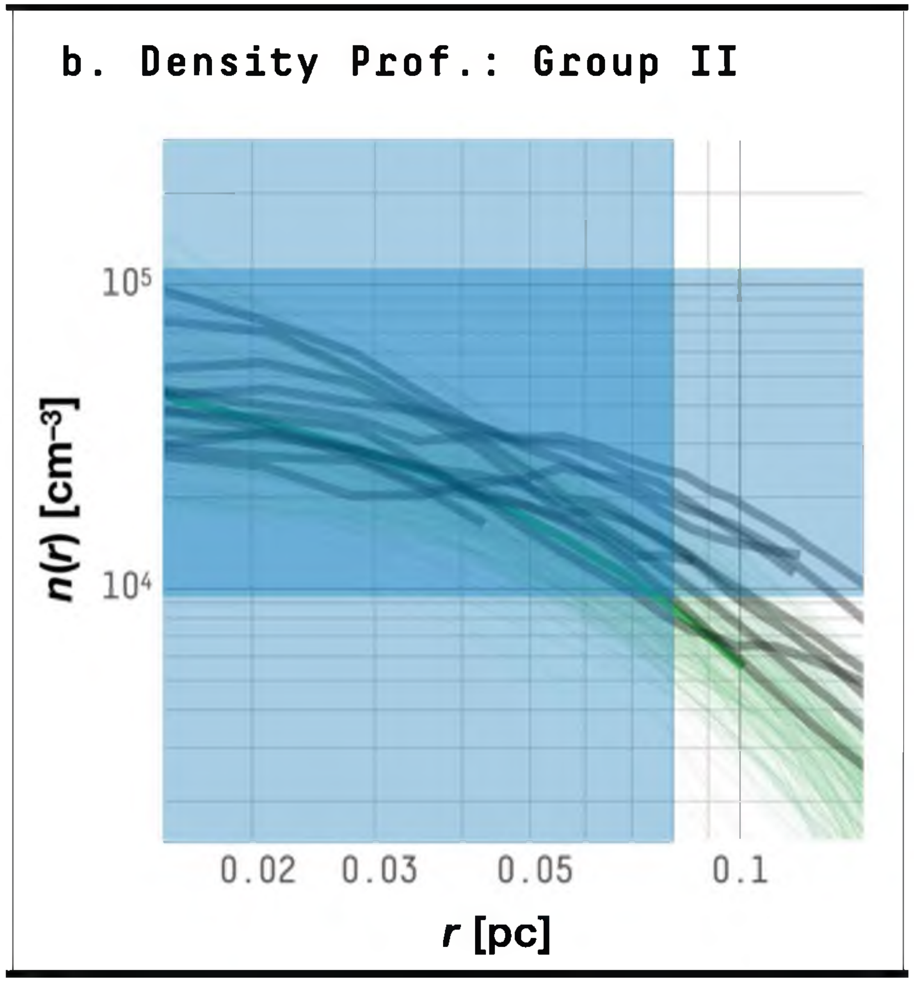
b. Density Prof.: Group II



b. Dispersion Prof.: Group II

The density and velocity dispersion profiles of **Group II structures** also partly explain why the “transition to coherence” has so far only been directly observed in NH_3 emission.

Why NH_3?



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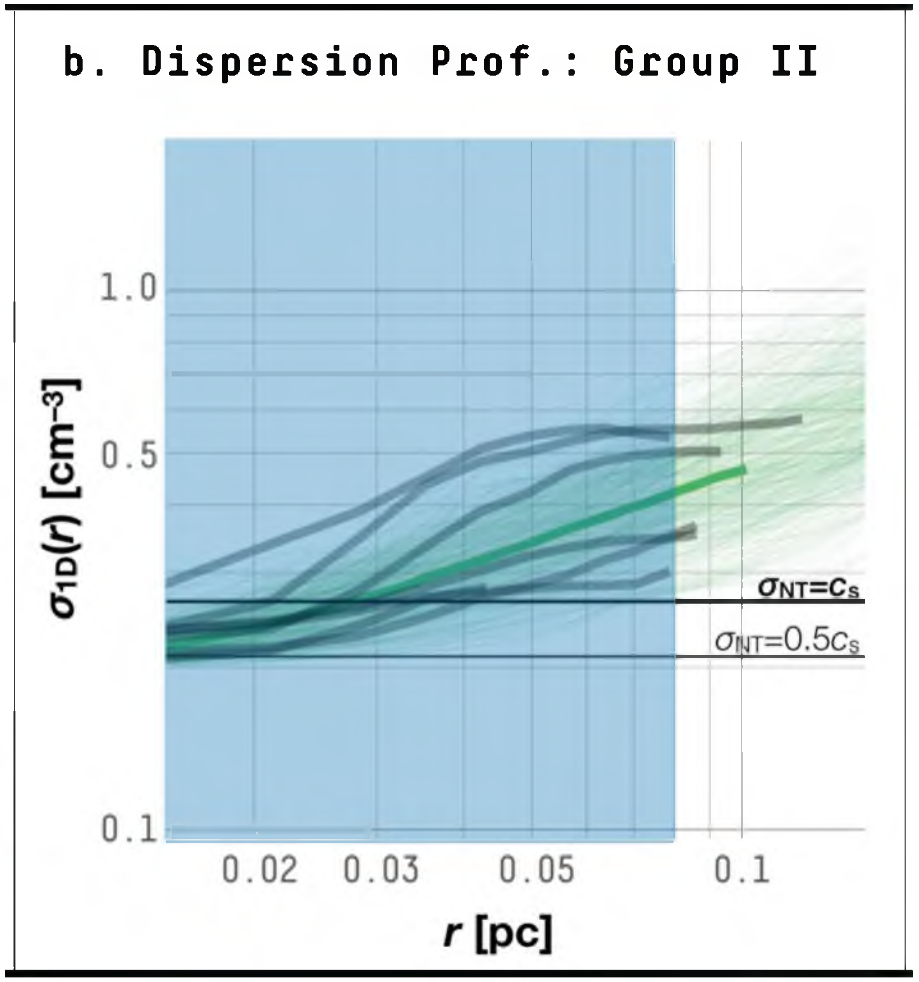

b. Dispersion Prof.: Group II

The density and velocity dispersion profiles of **Group II structures** also partly explain why the “transition to coherence” has so far only been directly observed in NH_3 emission.