Core Evolution Through A Coherent Phase
An Updated Core Formation Theory Told By Machine Learning

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

Class II

Class III

Shu (1987)
Prestellar Cores

gravitationally bound

Protostellar Cores/Protostars

assoc. with YSOs
(Starless Cores)

Prestellar Cores
gravitationally bound

Protostellar Cores/Protostars
assoc. with YSOs
A Coherent Core
(Perseus B5)

transition to coherence/
Per B5 is gravitationally bound
Chen et al. (2019) identify at least another 18 coherent structures in NH3 emission. Most of these structures are not bound by self-gravity.
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. 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.
It consistently appears that these structures are closely associated with the turbulent motions in the molecular clouds.
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.
Dendrogram
(structure identification)
Dendrogram Leaves at Time Steps 1, 2, 3, and 4

\[ x_{i-1, \text{guess}} = x_i - v_i \times \Delta t \]

if \( x_{i-1, \text{guess}} \) is in a leaf:

\[ x_{i-1} = (\text{density peak in the leaf}) \]
structure tracking

extraction of radial profiles

PCA analysis of the radial profiles
A total of \( \sim 91\% \) of variance in density and velocity dispersion profiles can be explained by the first two PCA components.
PCA.

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.
Based on the results, we derive a typical timescale of the coherent phase of $\sim 2.9$ to $4.2 \times 10^5$ 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

- **Group I**: Unbound Over-Densities
- **Group II**: Coherent Structures
- **Group III**: Prestellar/Protostellar Cores

(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.
Questions?
Why NH$_3$?

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 NH₃?

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 NH₃ emission.