

# BEFORE FRAGMENTATION: FROM UNIFORM CLOUDS TO STELLAR CLUSTERS

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Mexico

# The Birth of Star Clusters: A Story of Fragmentation

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Clusters are born within  
massive, dense gas clumps

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Clusters are born within massive, dense gas clumps

How does one massive clump turn into many stars?

# Fragmentation: The Key to Star Formation

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## **The Process:**

Clumps fragment into smaller, denser cores

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## The Battle:

Fragmentation is a battle between gravity, which pulls matter inward, and other forces resisting the collapse

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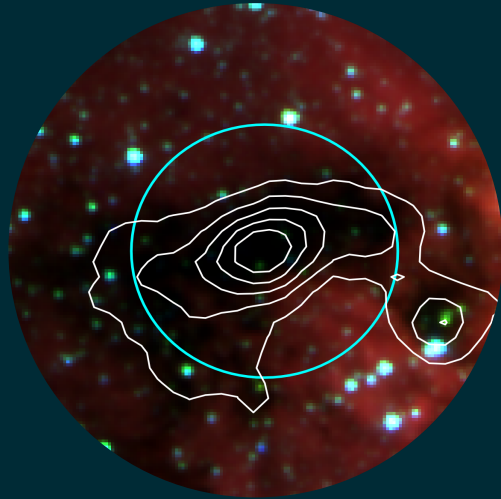
Fragmentation is a battle between gravity, which pulls matter inward, and other forces resisting the collapse

## The Outcome:

These cores collapse into individual stars, eventually forming a star cluster

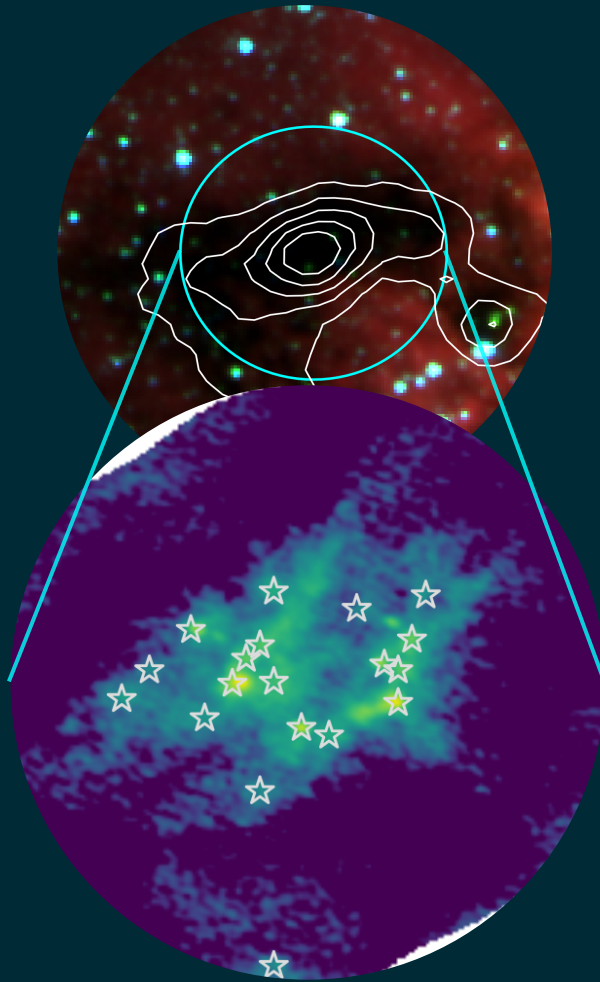
# The Fragmented Nursery

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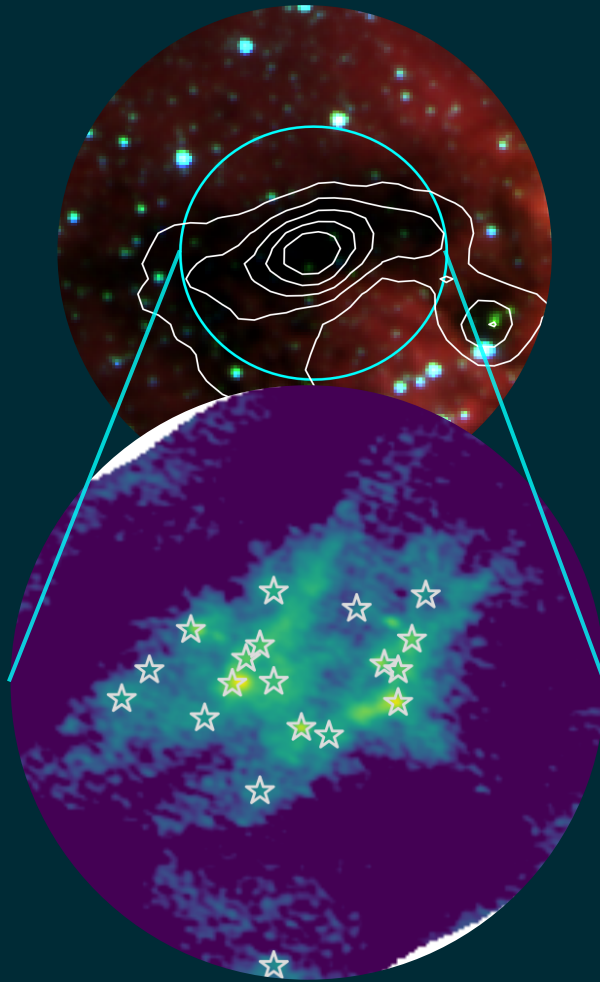
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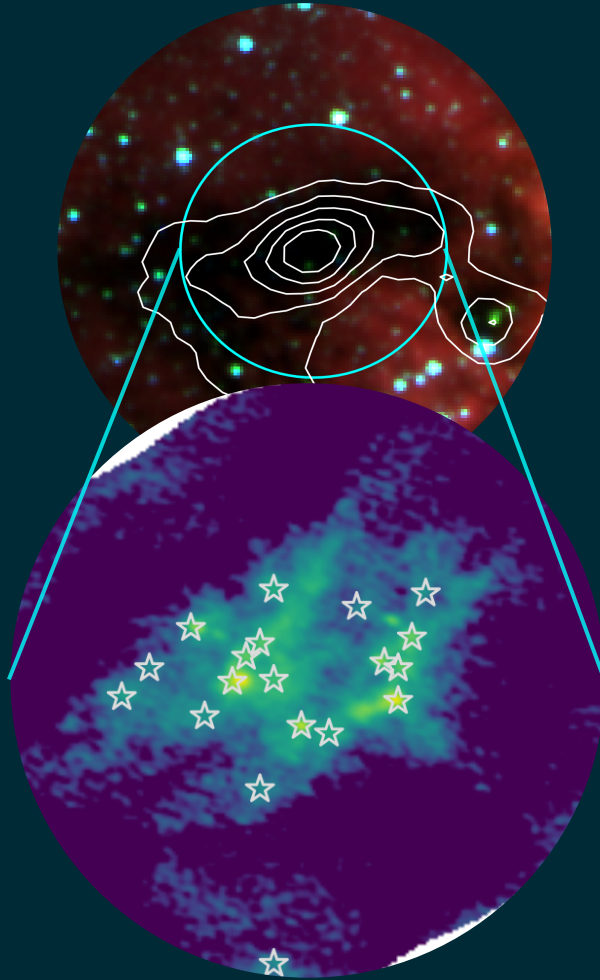
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Fragmentation: reflect  
initial conditions

# The Fragmented Nursery

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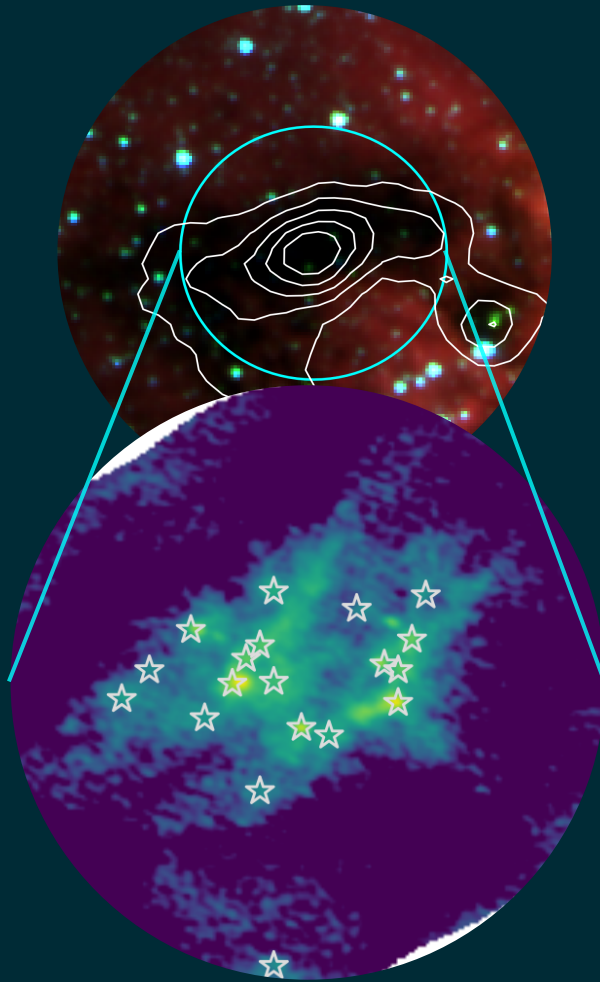


Fragmentation: reflect  
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Consistent investigation

# The Fragmented Nursery

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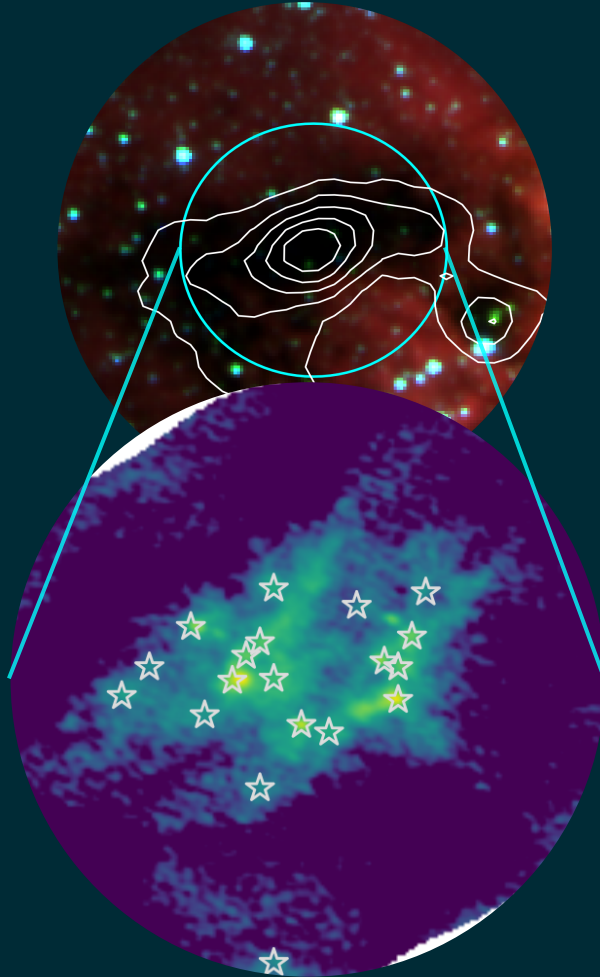
Fragmentation: reflect  
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Mechanisms driving  
fragmentation?

# The Core Debate – Turbulence vs. Gravity

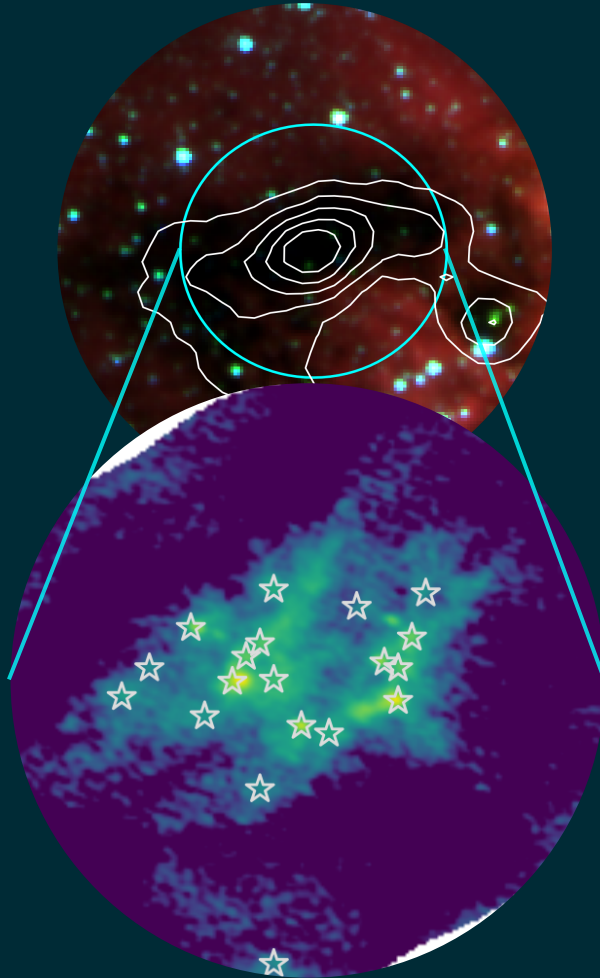
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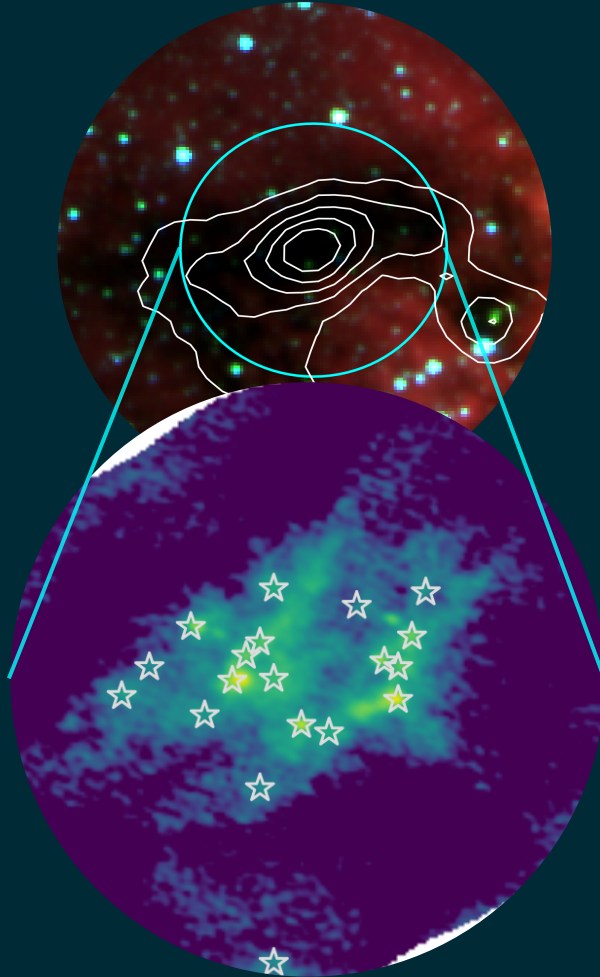
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Turbulence and/or gravity?



# The Core Debate – Turbulence vs. Gravity

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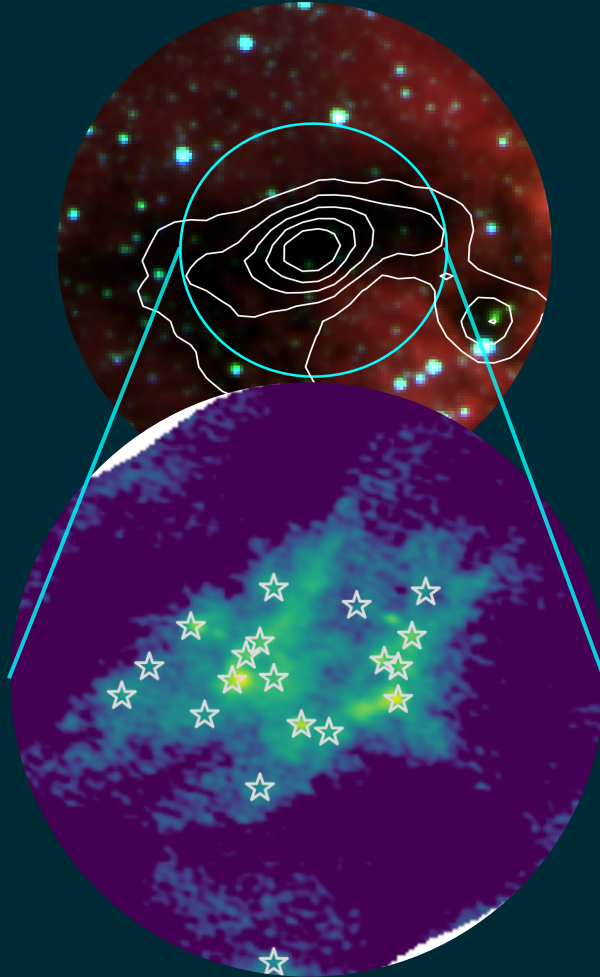


Turbulence and/or gravity?

Focus on the brightest  
sources

# The Core Debate – Turbulence vs. Gravity

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Turbulence and/or gravity?

Focus on the brightest  
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The unasked question: are  
we looking at the earliest  
phases?

# The CoCoA Survey - Our Unbiased Sample

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CoCoA (Cold Cores with ALMA) survey:

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No selection  
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Three  
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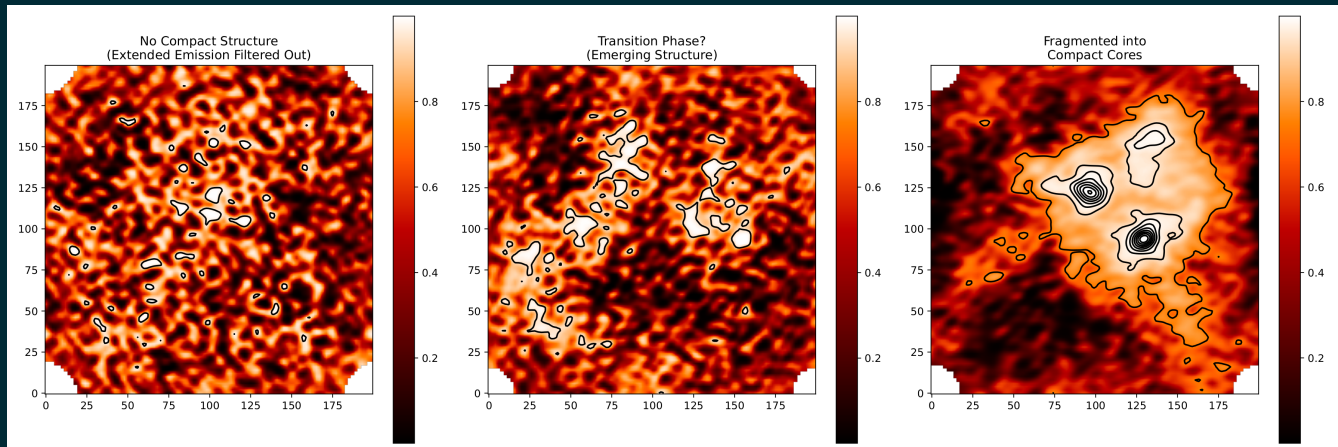
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Three  
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**WHERE HAS THE VAST RESERVOIR OF MATERIAL VISIBLE  
AT PC-SCALE VANISHED TO?**

# Is Fragmentation a Sign of Evolution?

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**Gravity:**



# Is Fragmentation a Sign of Evolution?

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**Gravity:**



Density  $\uparrow$  with time

# Is Fragmentation a Sign of Evolution?

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Less fragmented clumps  
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Fragmentation linked to  
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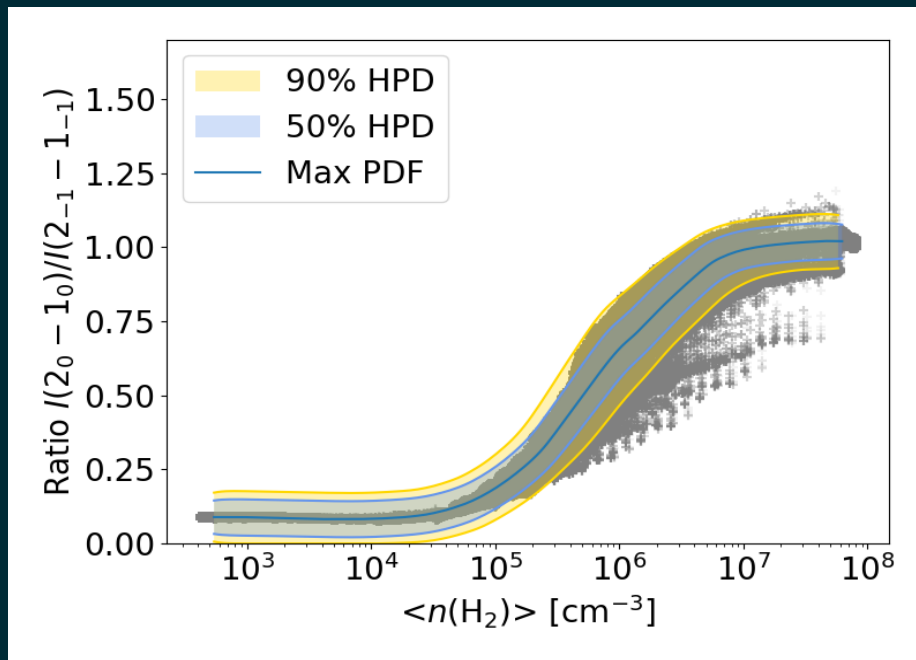
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# CH<sub>3</sub>OH Line Ratios as the Ultimate Density probe

Reliable and robust  
volume density  
probe...

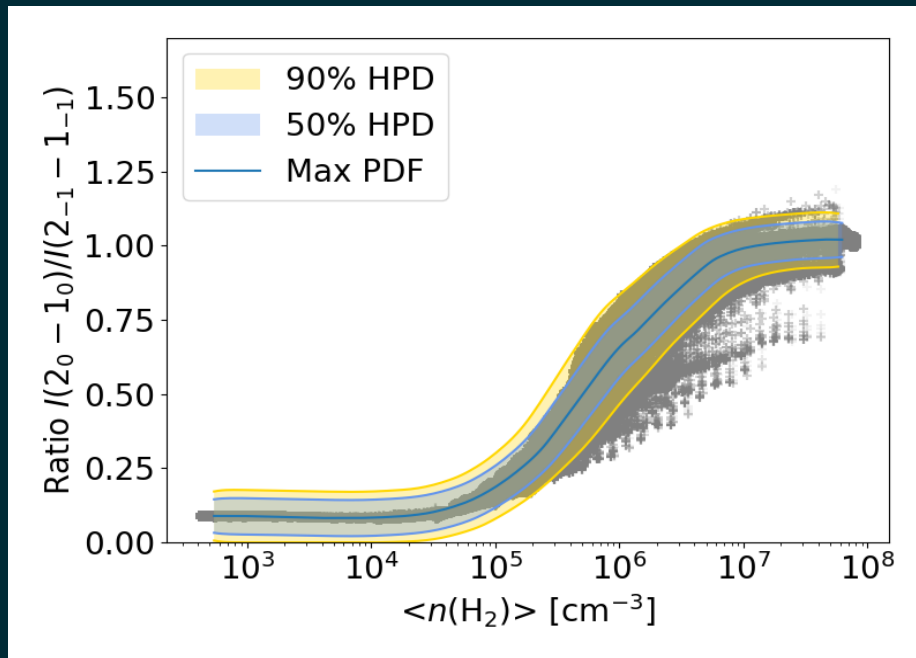


Giannetti et al. 2025

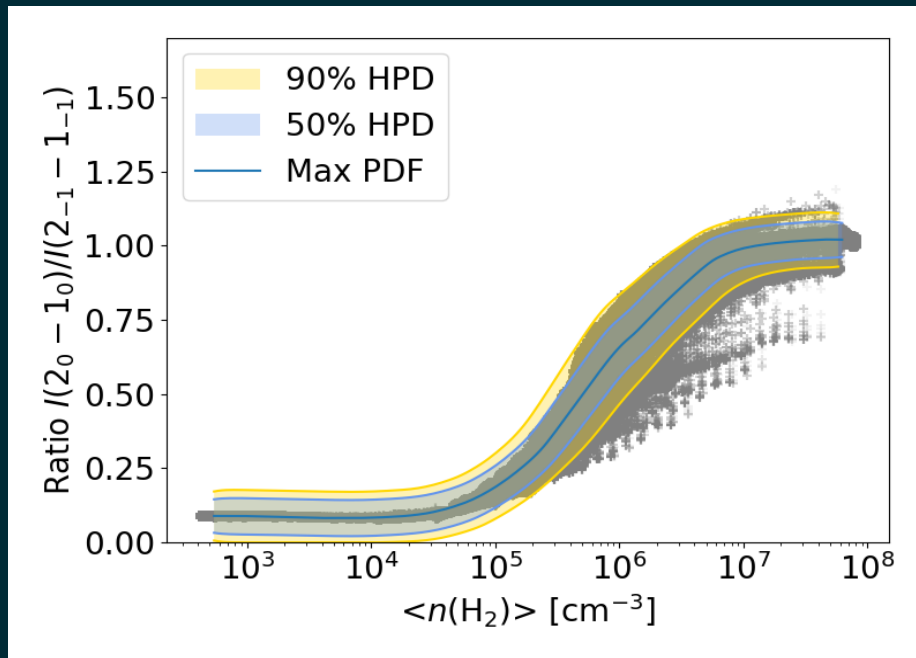
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Giannetti et al. 2025

Reliable and robust  
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... Over multiple  
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Are we really looking at pre-cores clumps?

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Increase MRS

# Are we really looking at pre-cores clumps?

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Increase MRS



Density estimates

# Are we really looking at pre-cores clumps?

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Increase MRS



Density estimates



Cold gas

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**Turbulence or gravity? Dissecting early fragmentation in massive cluster progenitors**

2025.1.00538.S

## ABSTRACT

The ALMA CoCoA survey of massive starless clumps revealed many sources surprisingly devoid of detectable core substructure in dust continuum. This raises a fundamental question: where is the significant mass reservoir observed at pc-scales in these cluster progenitors gone to? We address this by selecting a sample of CoCoA clumps, including these 'unfragmented' sources and a control sample, and we propose ALMA 3mm CH<sub>3</sub>OH and N<sub>2</sub>H<sup>+</sup> lines observations to distinguish between turbulence and gravity-dominated fragmentation. We quantify fragmentation across scales via 3D dendrograms and measure gas volume density PDFs using CH<sub>3</sub>OH line ratios, the most powerful density diagnostics available to date. Comparing fragment number and density PDFs to theoretical models allows us to discern what drives the earliest fragmentation phases. Solving this mystery will reveal how massive clumps prepare for star and cluster formation.

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Increase MRS



Density estimates



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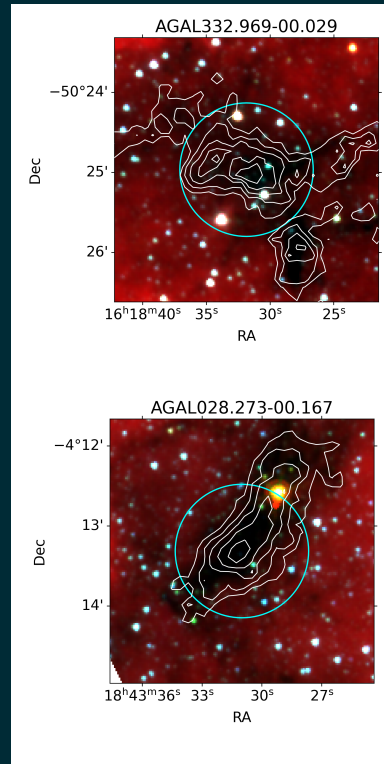
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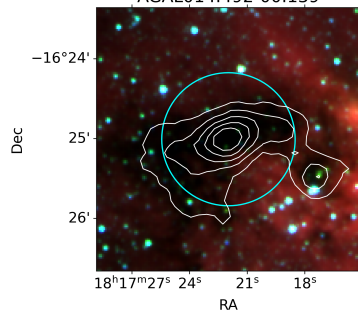
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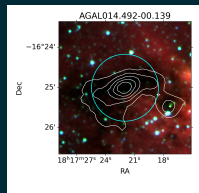
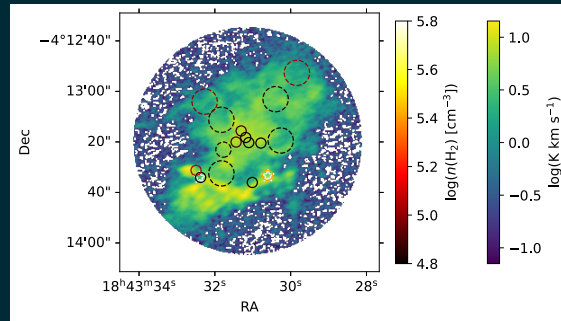
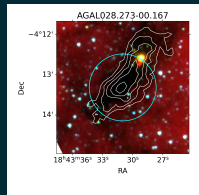
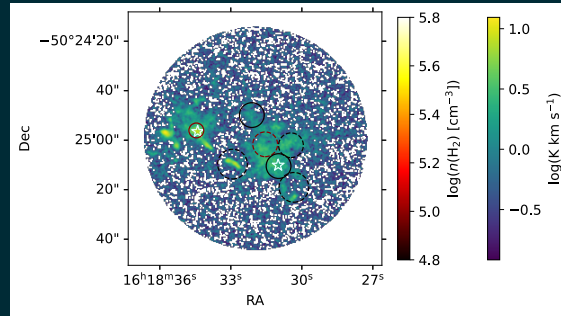
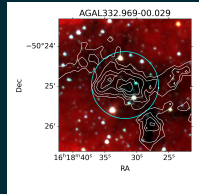
# An Underrepresented Phase

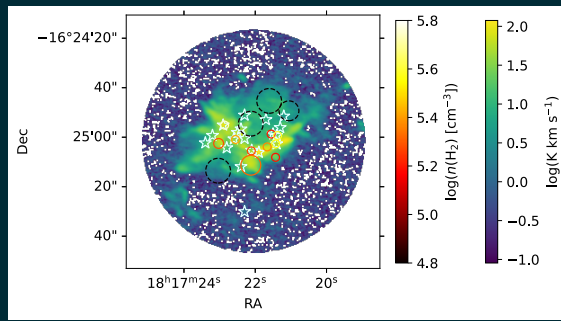


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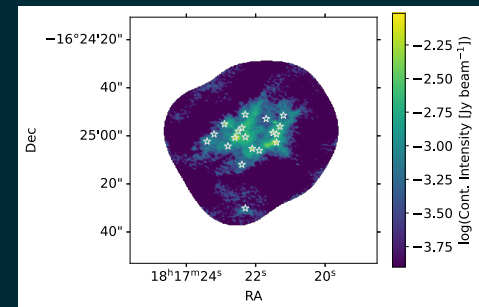
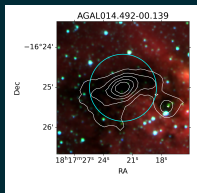
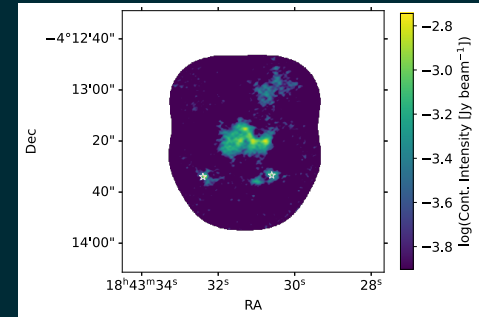
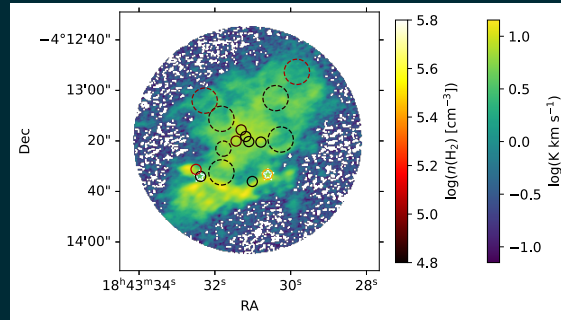
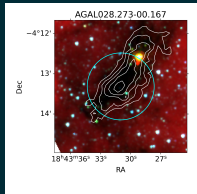
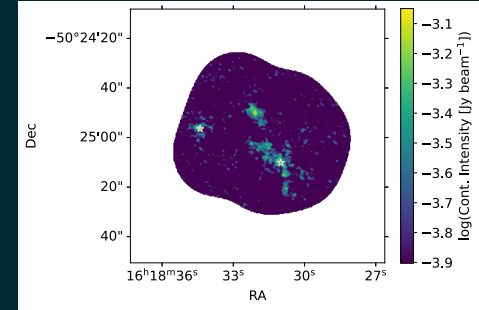
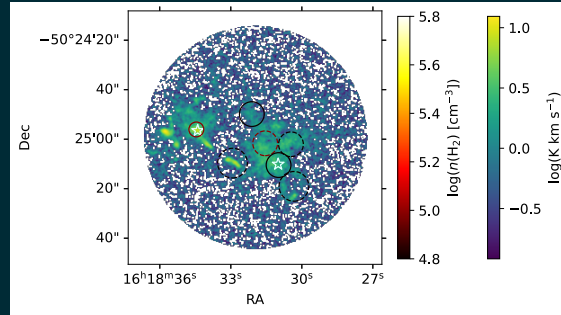
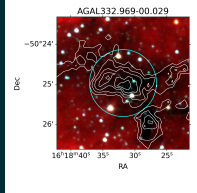


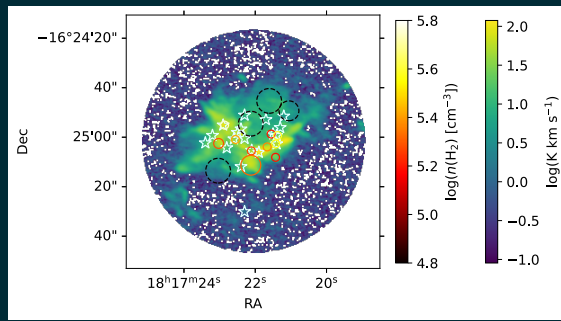
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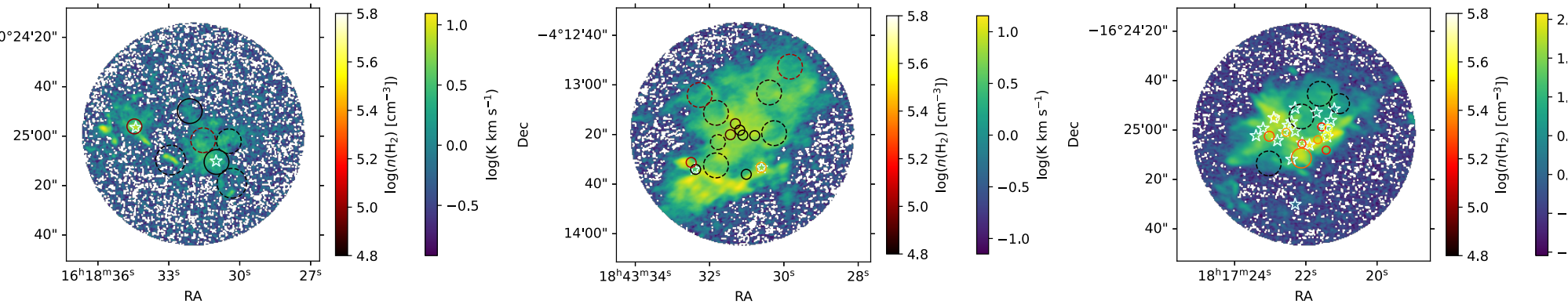


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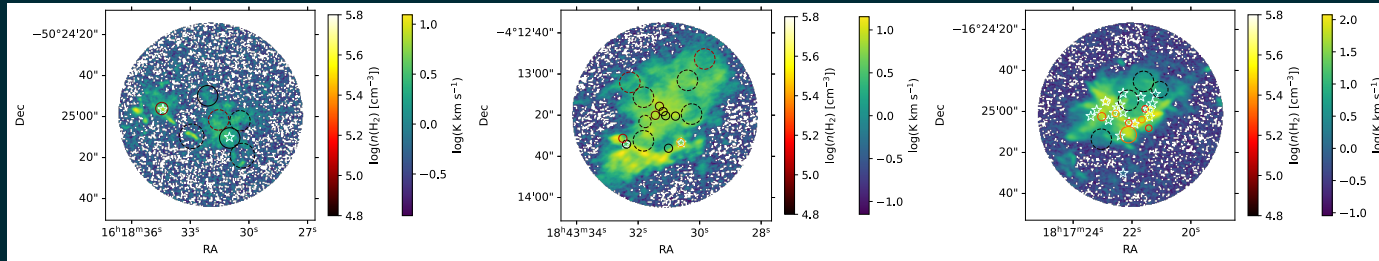




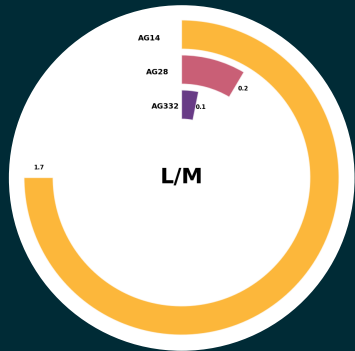
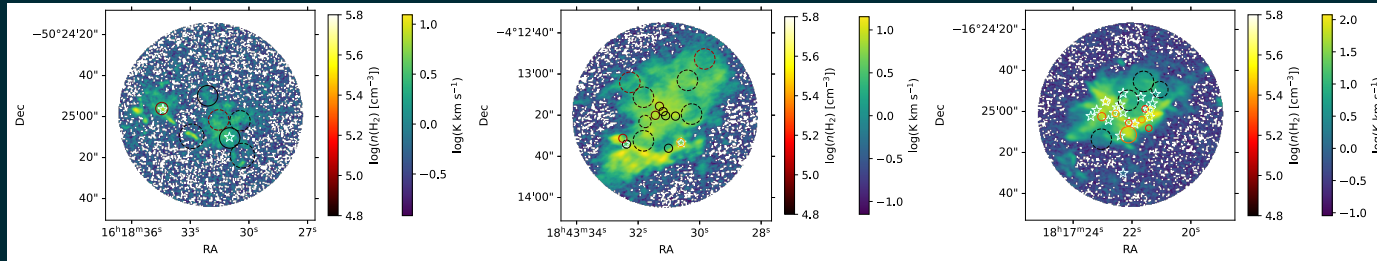
# Quantifying the Difference



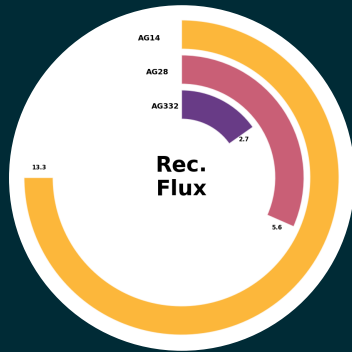
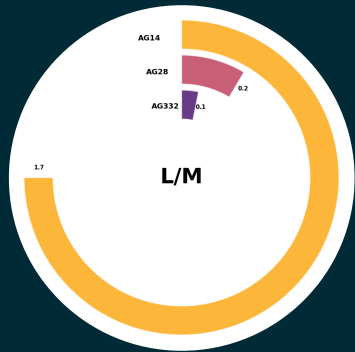
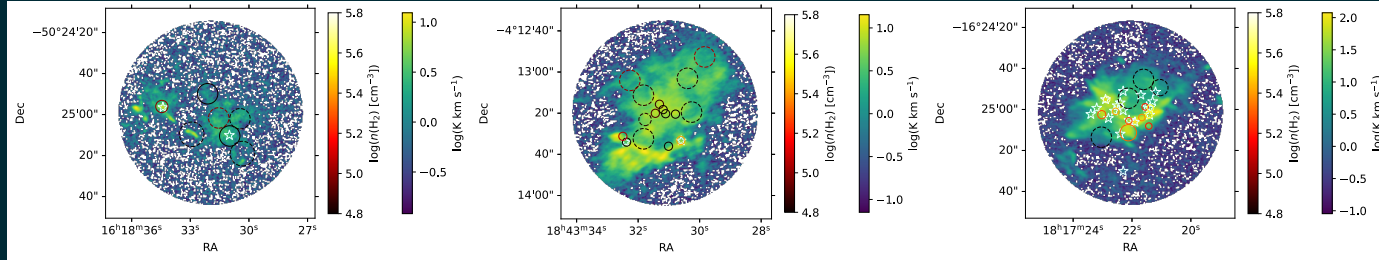
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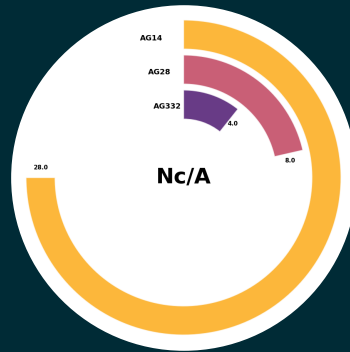
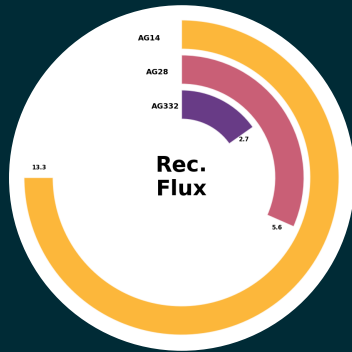
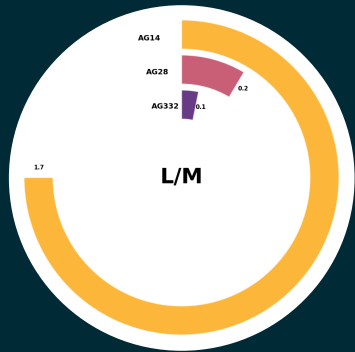
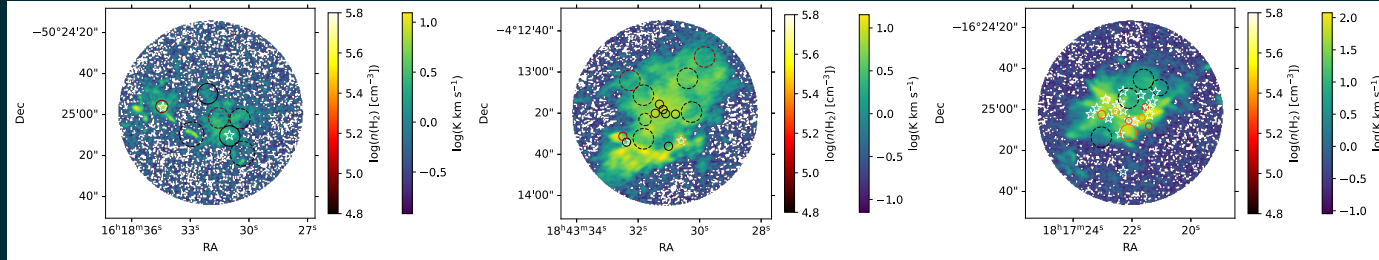
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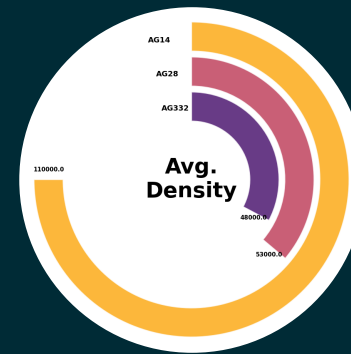
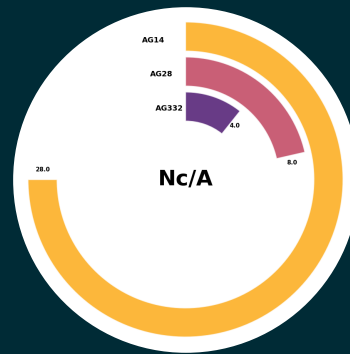
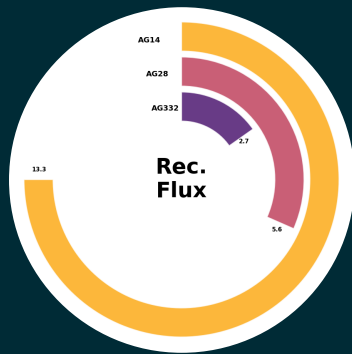
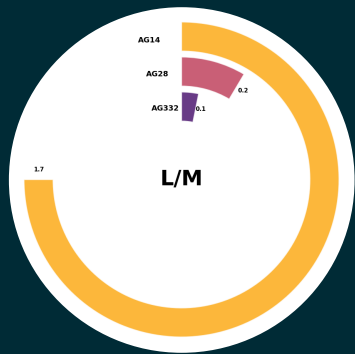
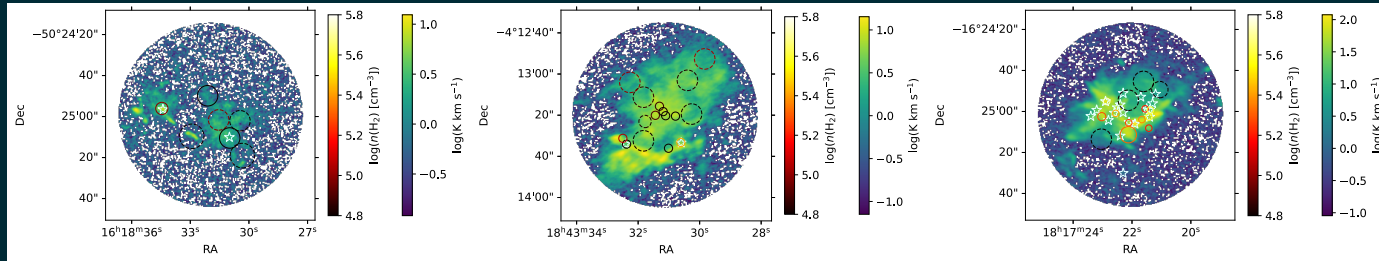
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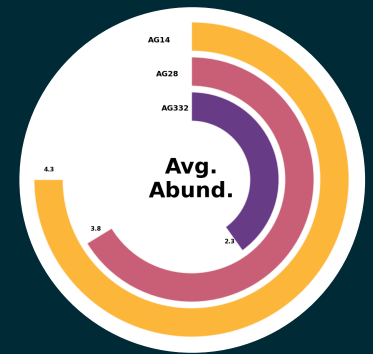
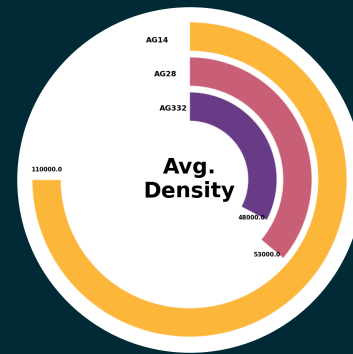
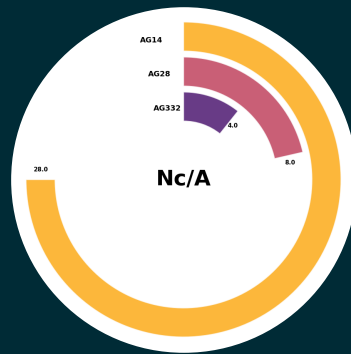
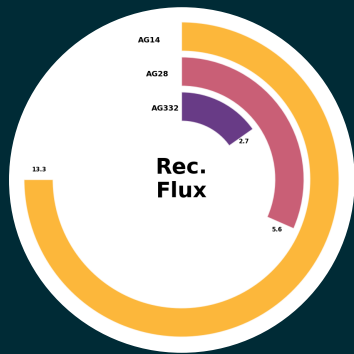
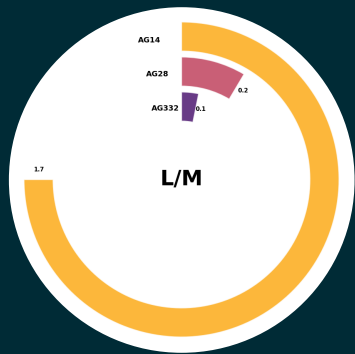
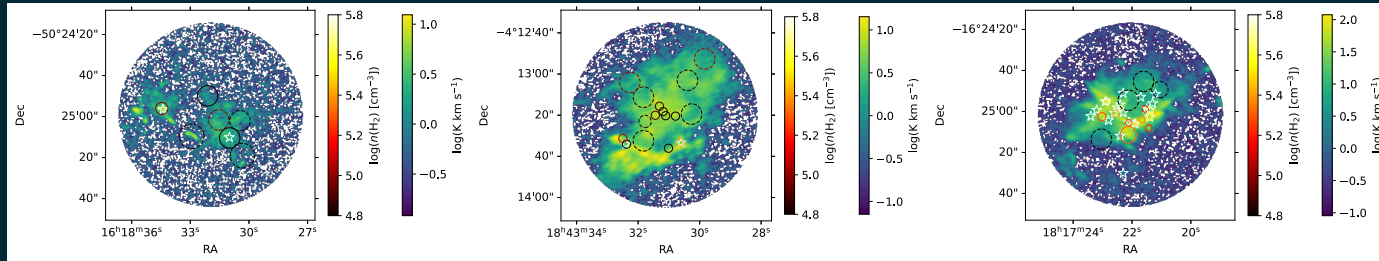


# Quantifying the Difference



Fraction of dense gas  
increases

# Quantifying the Difference

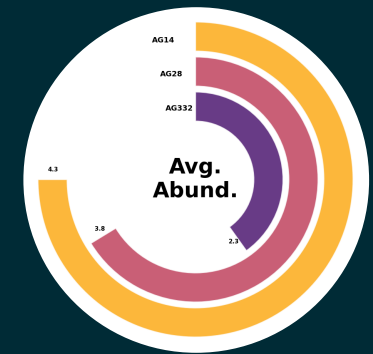
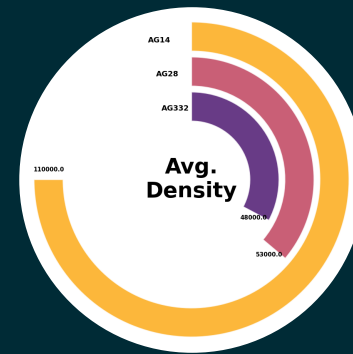
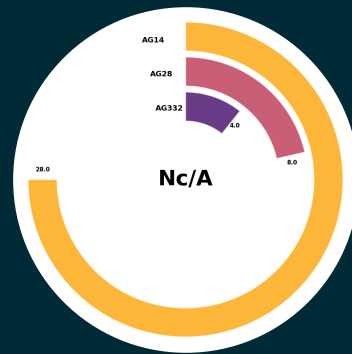
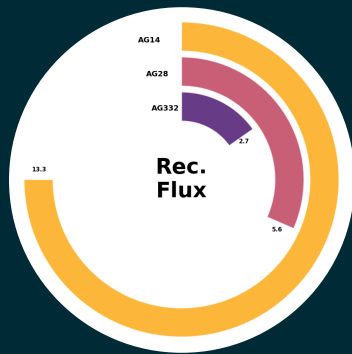
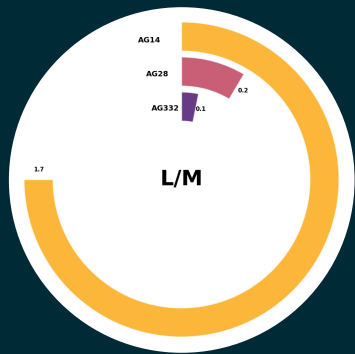
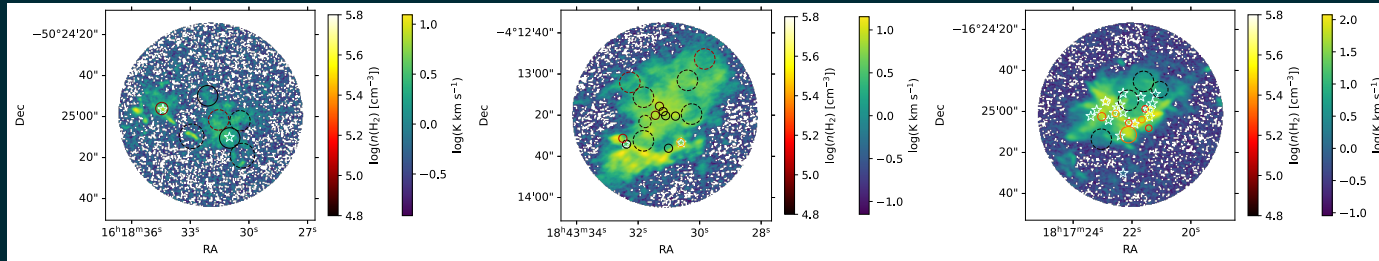


Fraction of dense gas  
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Abundance  
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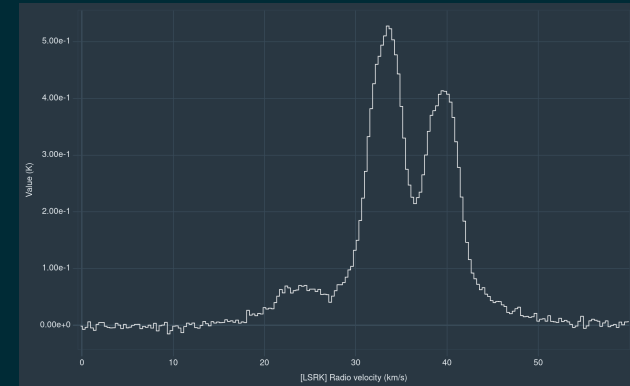
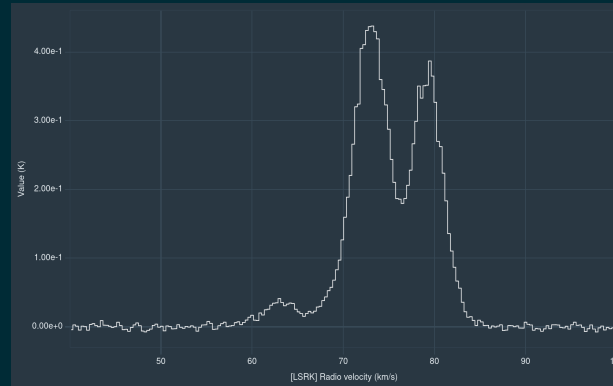
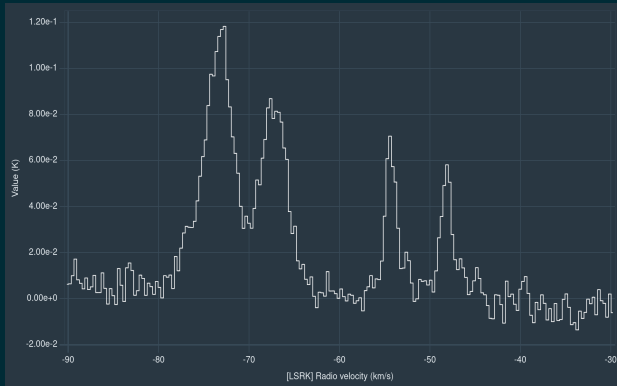


Abundance  
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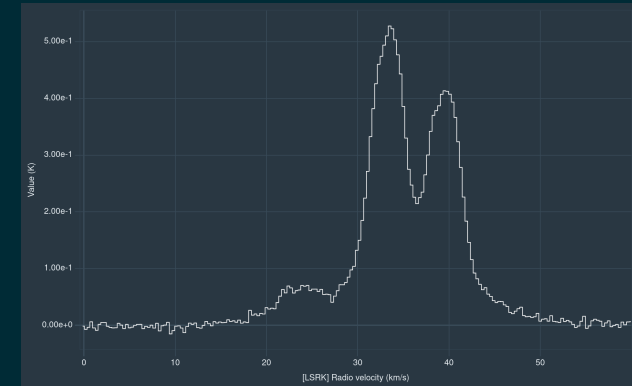
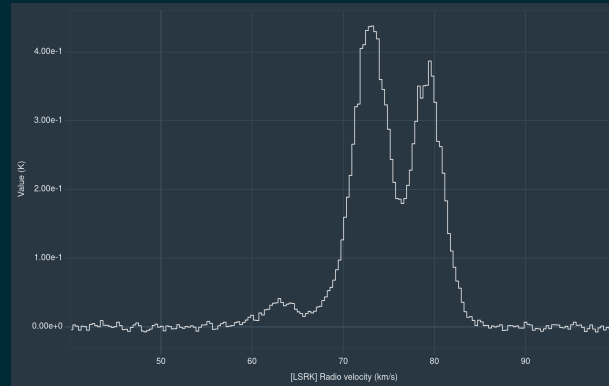
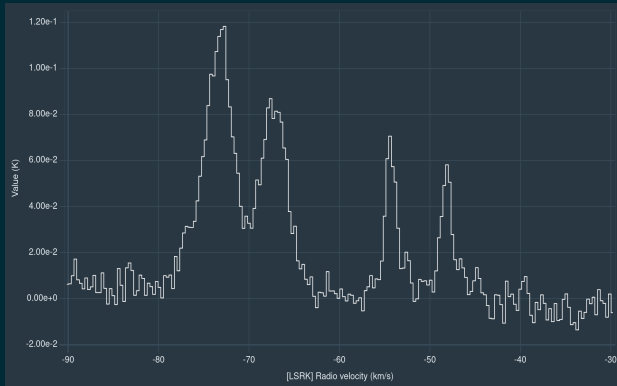


Evolutionary  
sequence

# Kinematic Clues – Gravity's Signature

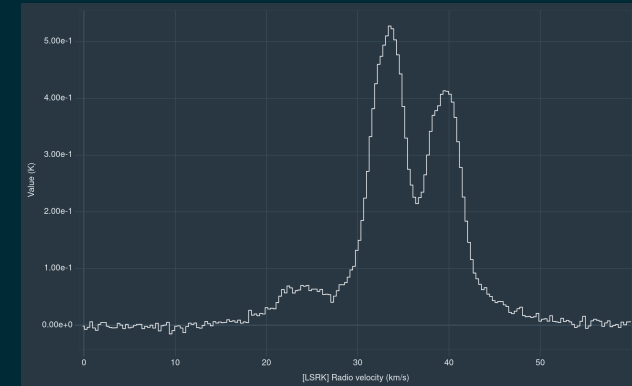
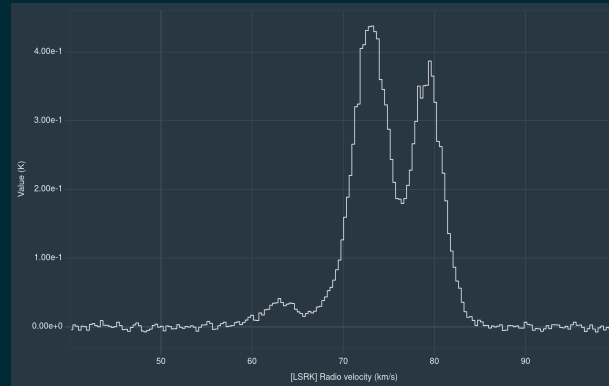
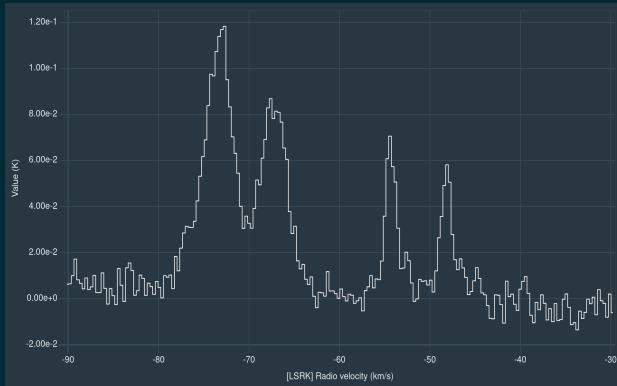


# Kinematic Clues – Gravity's Signature



High mach  
number: strong  
and similar  
fragmentation

# Kinematic Clues – Gravity's Signature

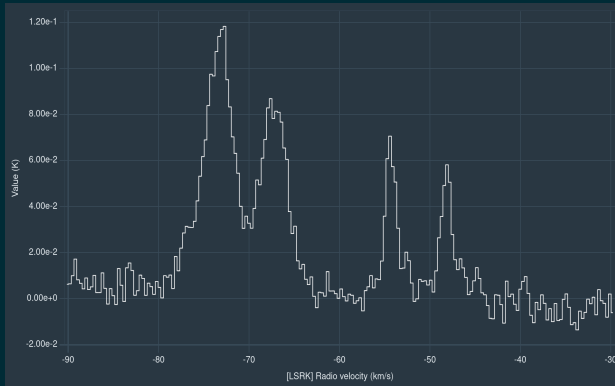


High mach  
number: strong  
and similar  
fragmentation

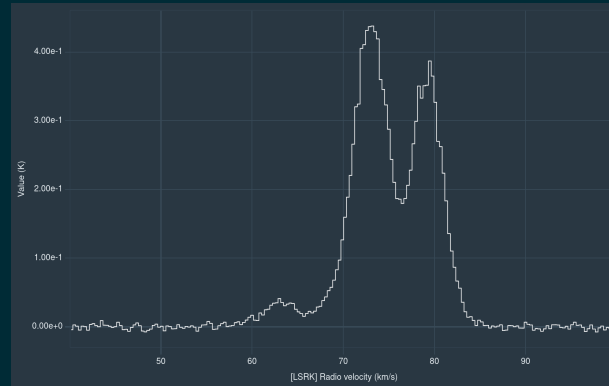


Large velocity  
gradients

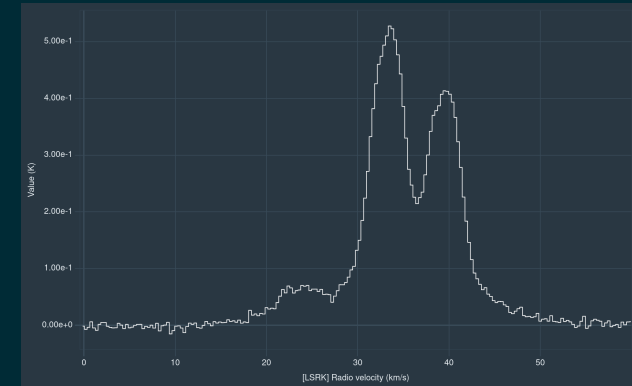
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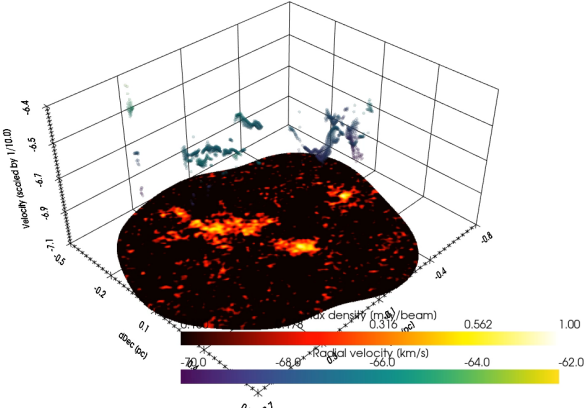
Large velocity  
gradients



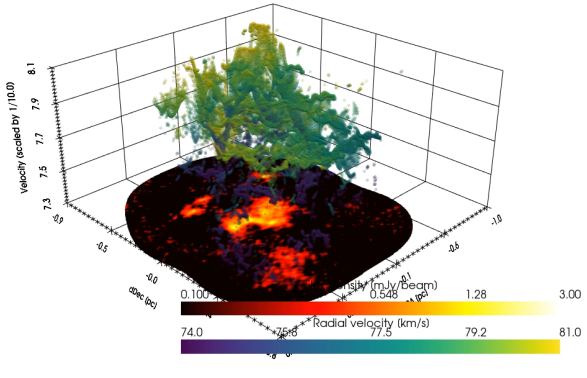
Comparable to  
observed  
linewidths

# Gravity's Dominance – Collapse & Infall

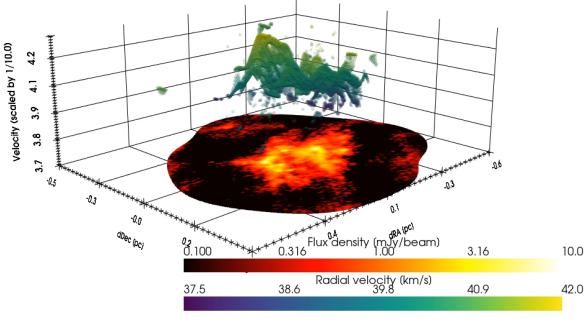
G332.96 3D Velocity Field



G28 3D Velocity Field

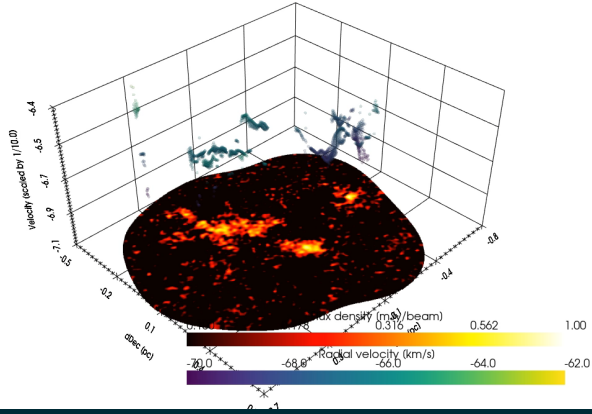


G14 3D Velocity Field

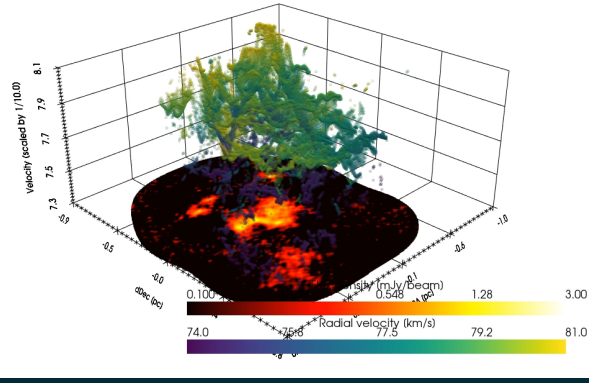


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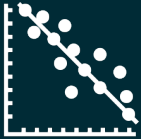
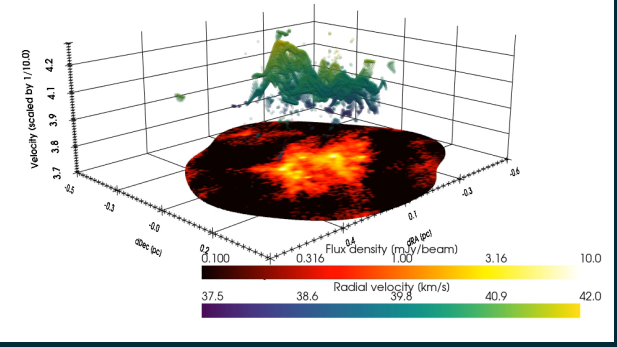
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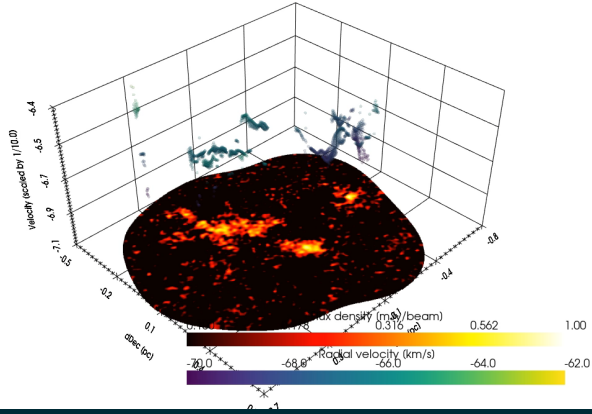
G14 3D Velocity Field



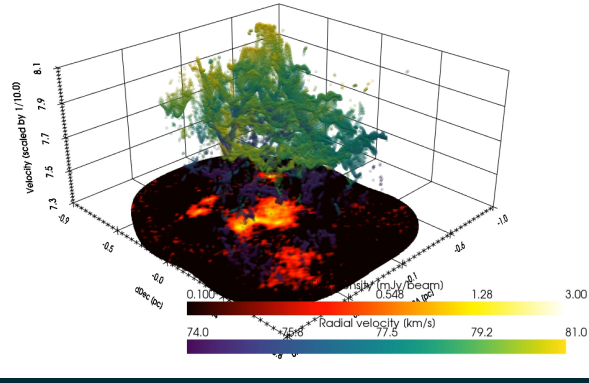
Linear gradients:  
planar accretion

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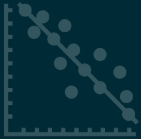
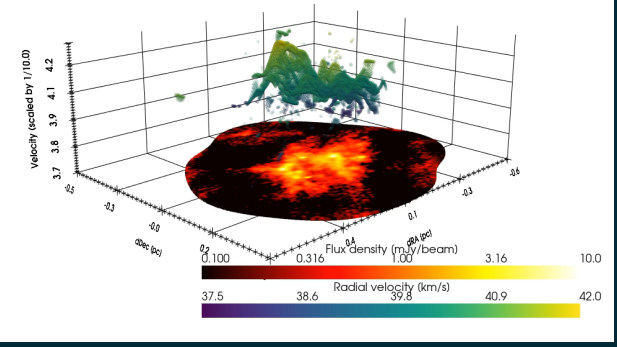
G332.96 3D Velocity Field



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G14 3D Velocity Field

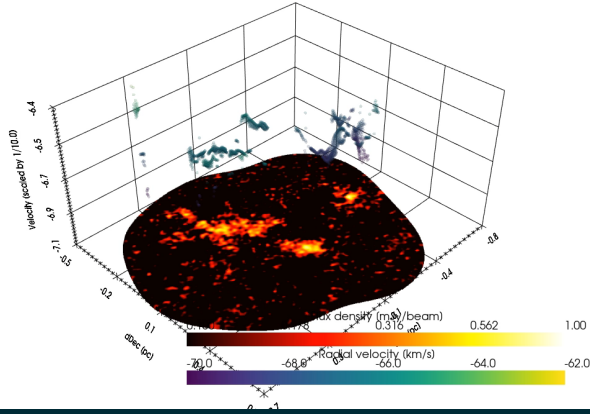


Linear gradients:  
planar accretion

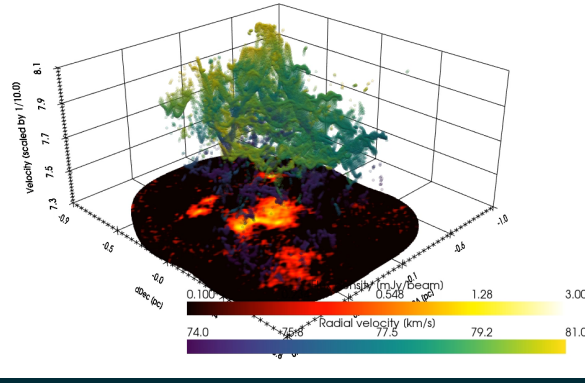
Toy model for  
filamentary infall

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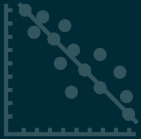
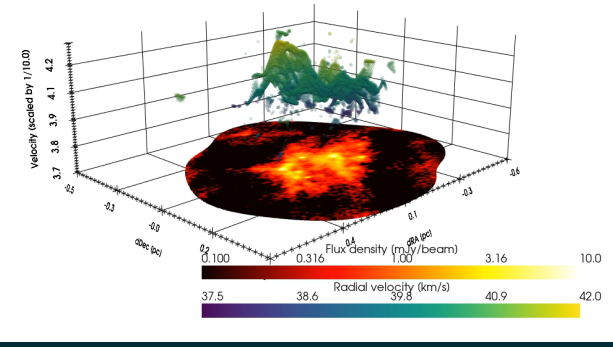
G332.96 3D Velocity Field



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Linear gradients:  
planar accretion

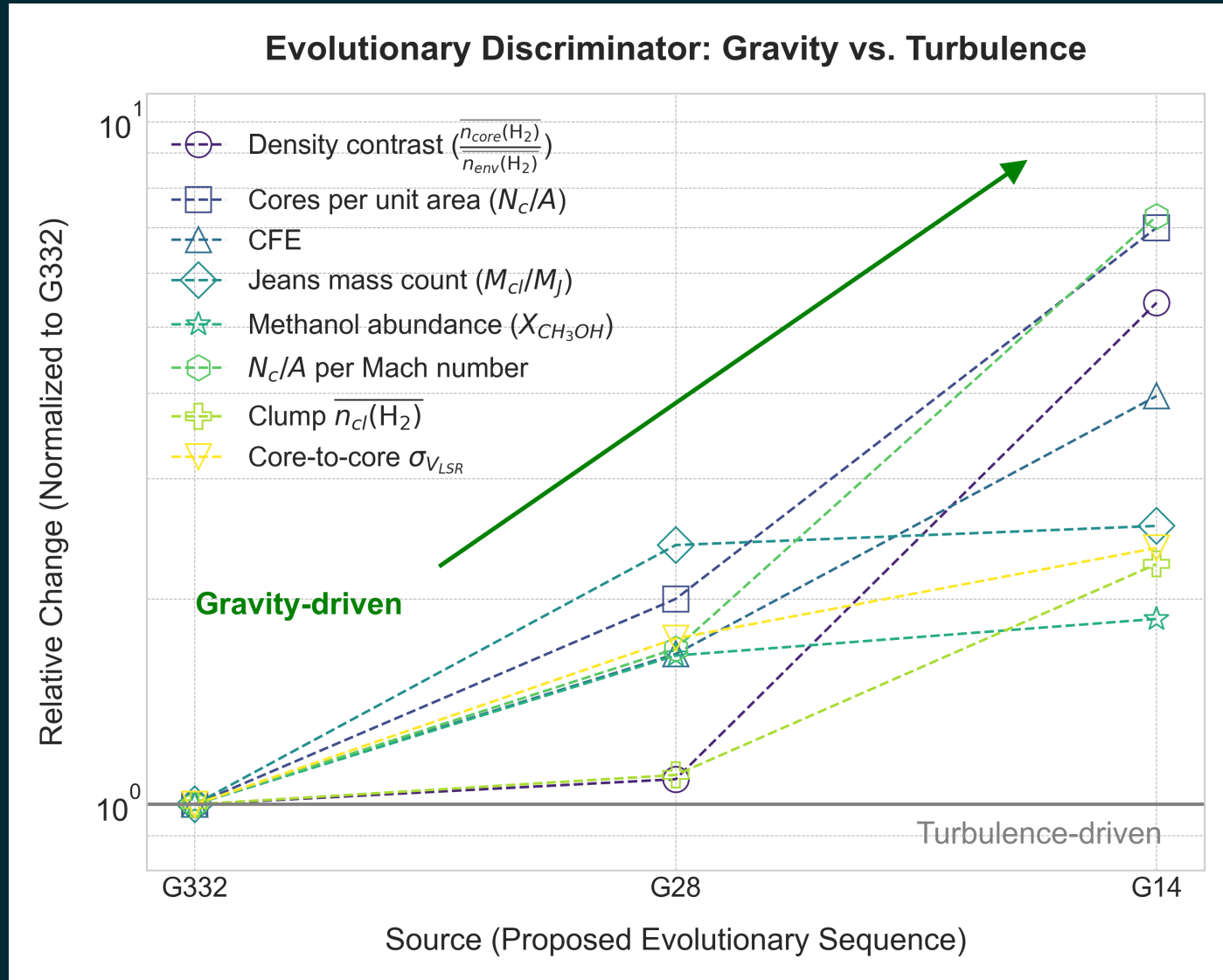


Toy model for  
filamentary infall



Mass  
accumulation  
time ~ chemical  
timescale

# Putting it All Together



Conclusions:

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## **The Discovery:**

Marginally fragmented clumps are more prevalent than previously thought and were overlooked

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### **The Impact:**

These clumps are not 'uninteresting': critical component for understanding initial conditions

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### **The New Paradigm:**

Evidence for gravitational fragmentation; we must expand our observations to get a complete picture

Conclusions:

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Fragmentation  
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gradients are  $\sim$   
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## Conclusions:

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Velocity  
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Abundance  
agrees with  
early formation  
of COMs