ASHES

The **A**LMA **S**urvey of 70 μm-dark **H**igh-mass clumps in **E**arly **S**tages

Insights from ASHES: Core Characteristics in 70 μm Dark High-mass Clumps

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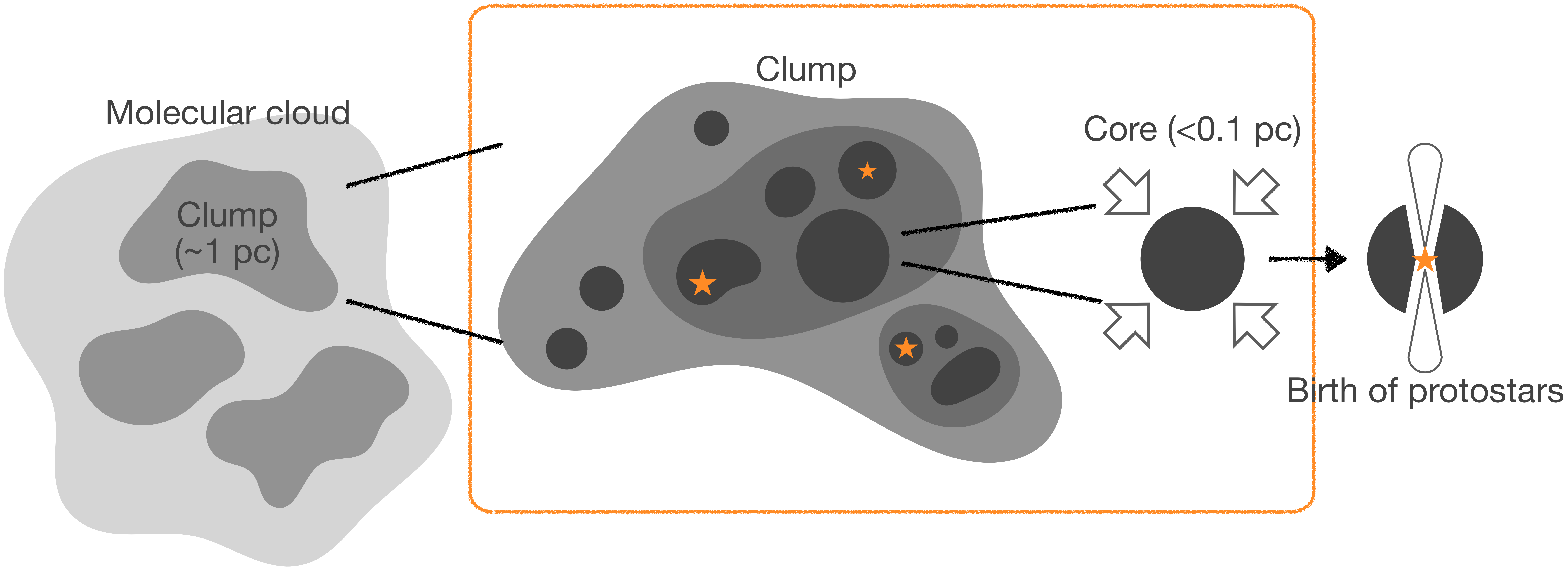
Hierarchical Star Formation



High-mass Star Formation Scenario

Molecular cloud
(1-10 pc)

Clump

Birth of a high-mass prestellar core

McKee and Tan 2002, 2003

$M \gtrsim 30\,M_\odot$

?

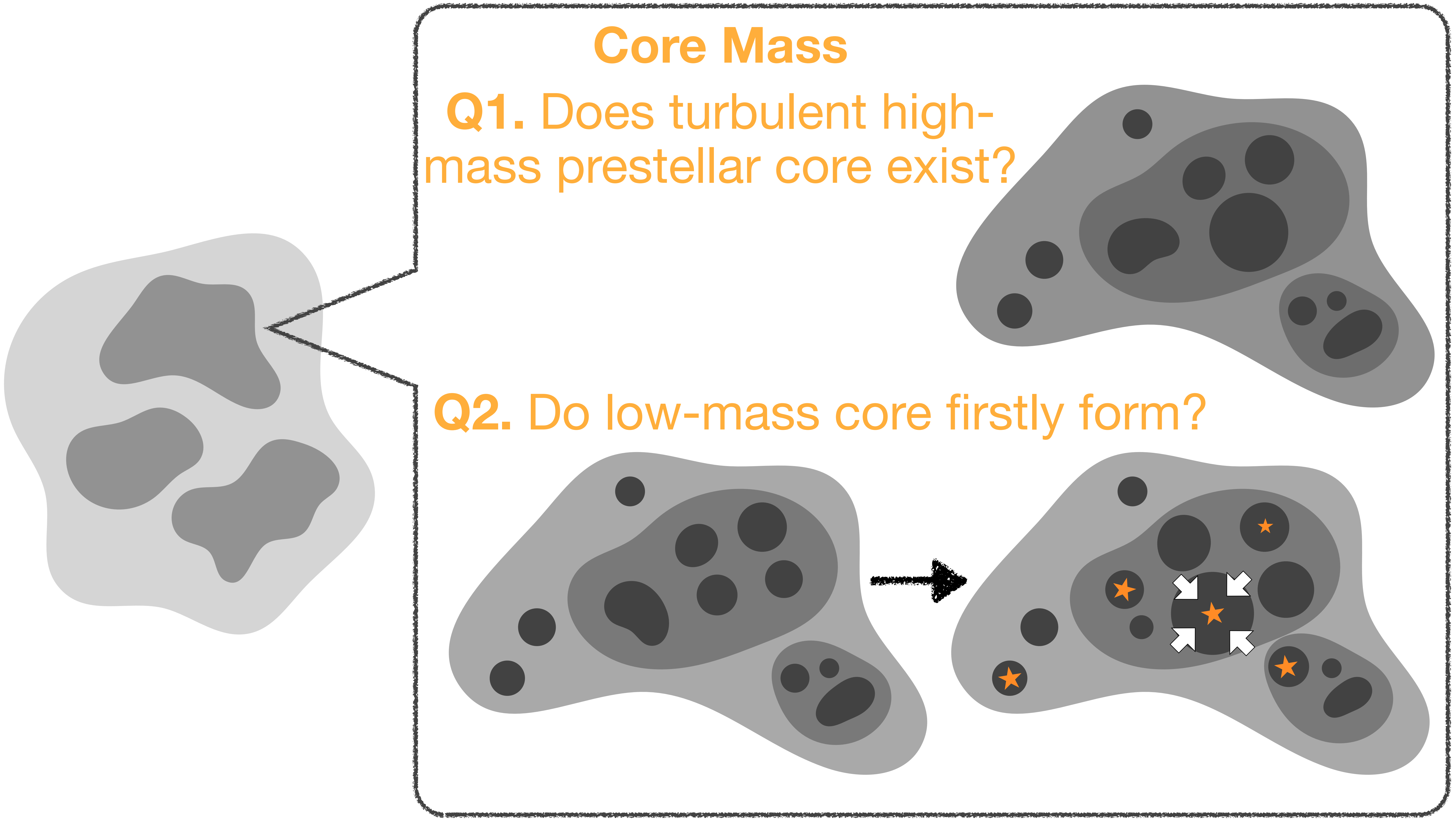
A cluster of low-mass cores

Core growth

Bonnell et al. 2001, Vázquez-Semadeni et al. 2019

Core
<0.1 pc

Questions to be Addressed



Core Mass

Q1. Does turbulent high-mass prestellar core exist?

Q2. Do low-mass core firstly form?

Core stability

Q3. Supported by turbulence or B-fields?

Q4. Gravitationally unstable?

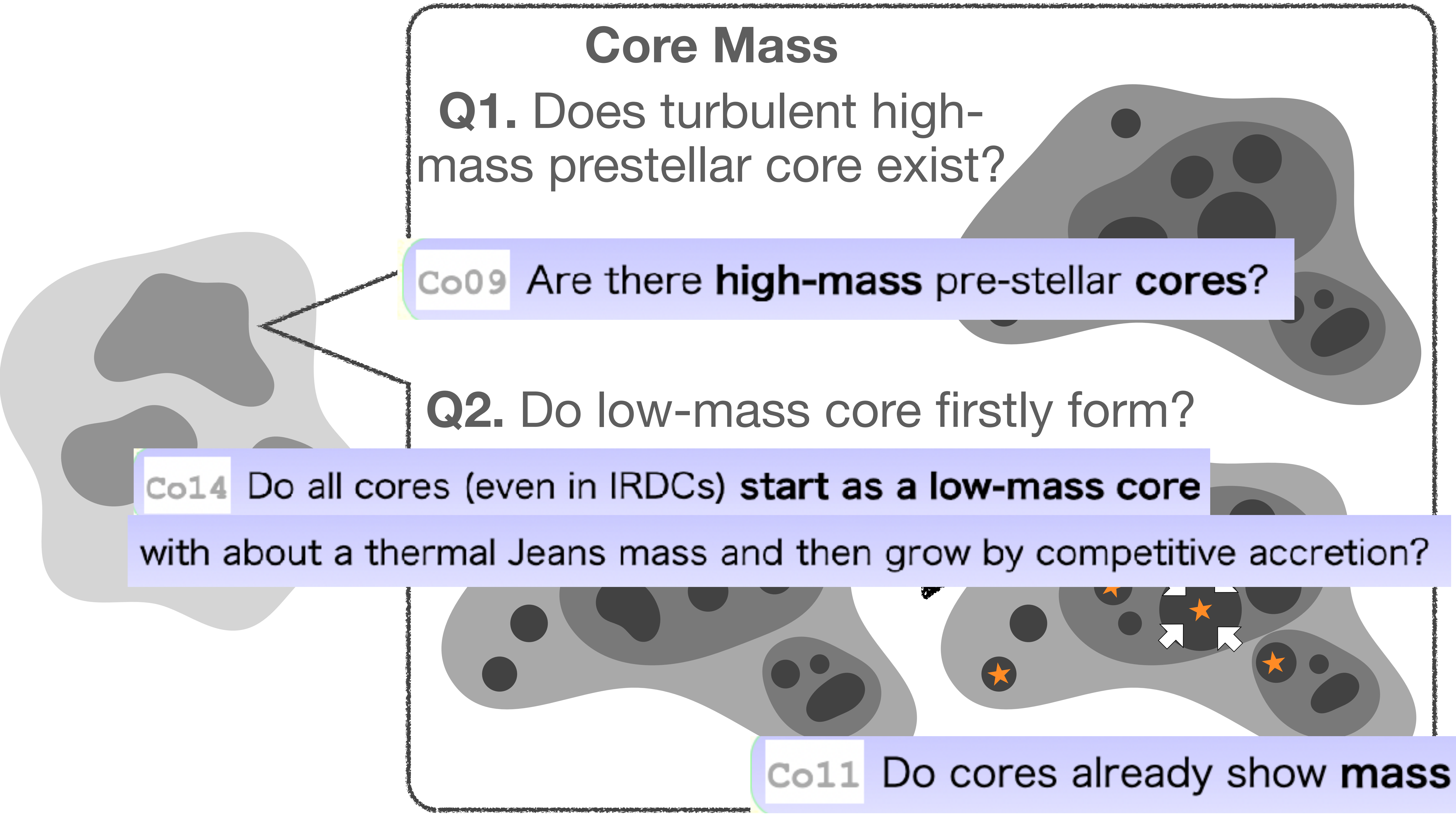
Distribution

Q5. Is there any preferred location of more massive objects?

Gas dynamics **Q6.** Is there any sign of gas feeding around core?

Questions to be Addressed

Ge01 Are **low-mass** stars formed by a **different** physical process than **high-mass** stars?



Core Mass

Q1. Does turbulent high-mass prestellar core exist?

Co09 Are there **high-mass** pre-stellar **cores?**

Q2. Do low-mass core firstly form?

Co14 Do all cores (even in IRDCs) **start as a low-mass core** with about a thermal Jeans mass and then grow by competitive accretion?

Core stability

Q3. Supported by turbulence or B-fields?

Q4. Gravitationally unstable?

Distribution

Q5. Is there any preferred location of more massive objects?

Co11 Do cores already show **mass segregation** within young stellar clusters?

Gas dynamics

Q6. Is there any sign of gas feeding around core?

The **A**LMA **S**urvey of 70 μm dark **H**igh-mass clumps in **E**arly **S**tages

PI: Patricio Sanhueza (NAOJ)

Targets: 39 high-mass prestellar clump candidates

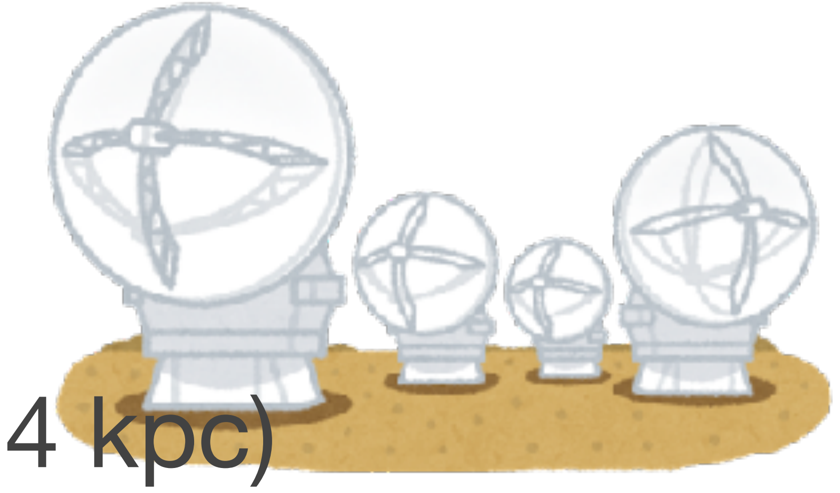
No point source bright at 24 μm and 70 μm, $T < 25\,\mathrm{K}$

The capability of forming high-mass stars

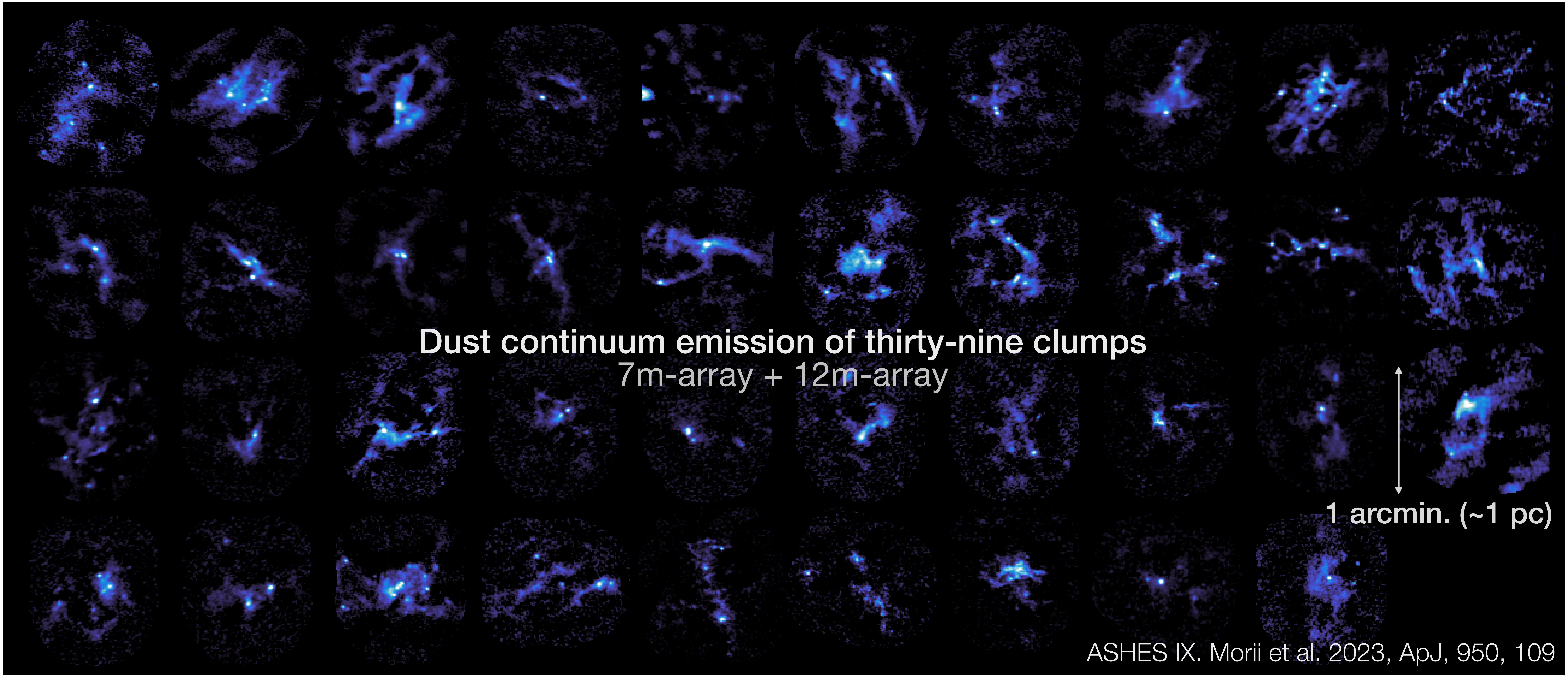
$(\Sigma > 0.1\,\mathrm{g\,cm^{-2}},\, M > 300\,M_\odot)$

ASHES IX. Morii et al. 2023, ApJ, 950, 109

ASHES Project



Observations: ALMA Band 6 mosaics (1.3 mm) with θ~1.2” (0.02 pc/4800 au @4 kpc)



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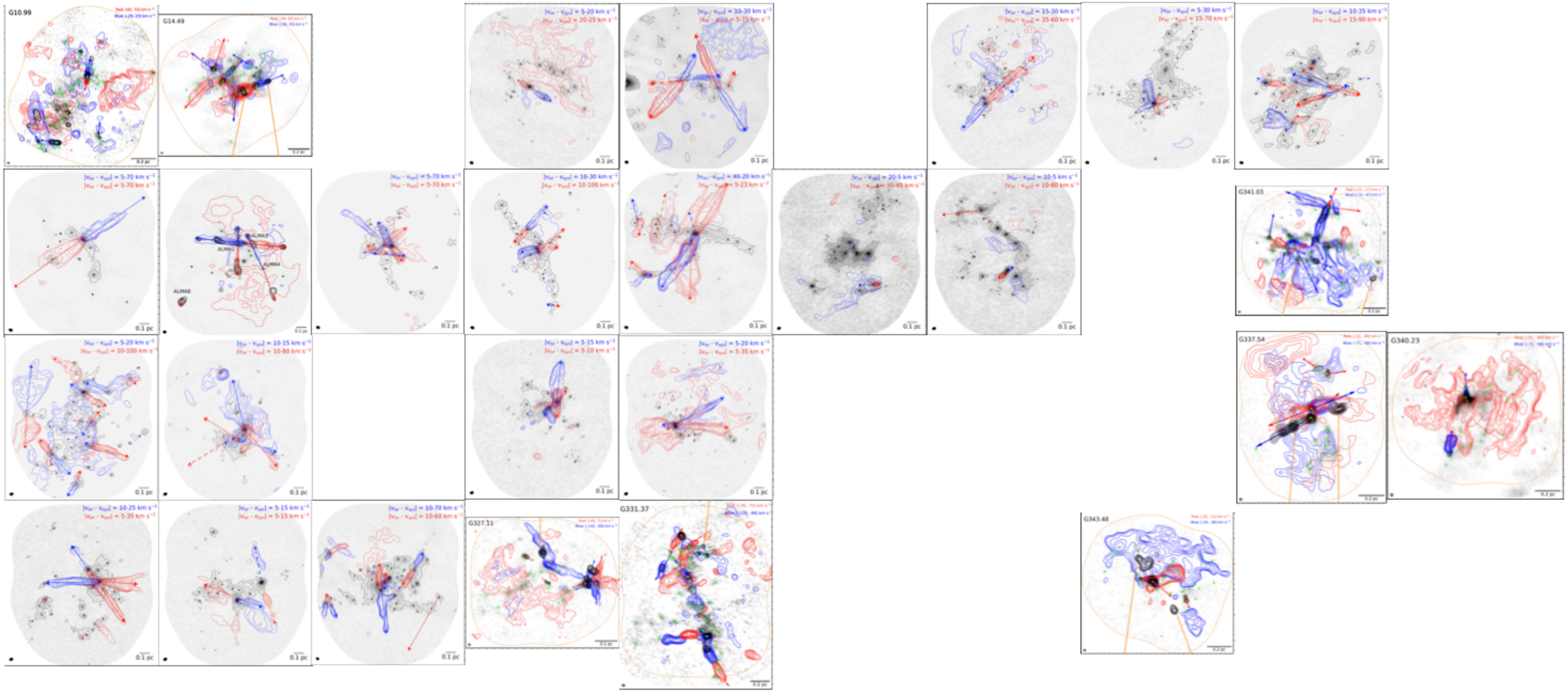
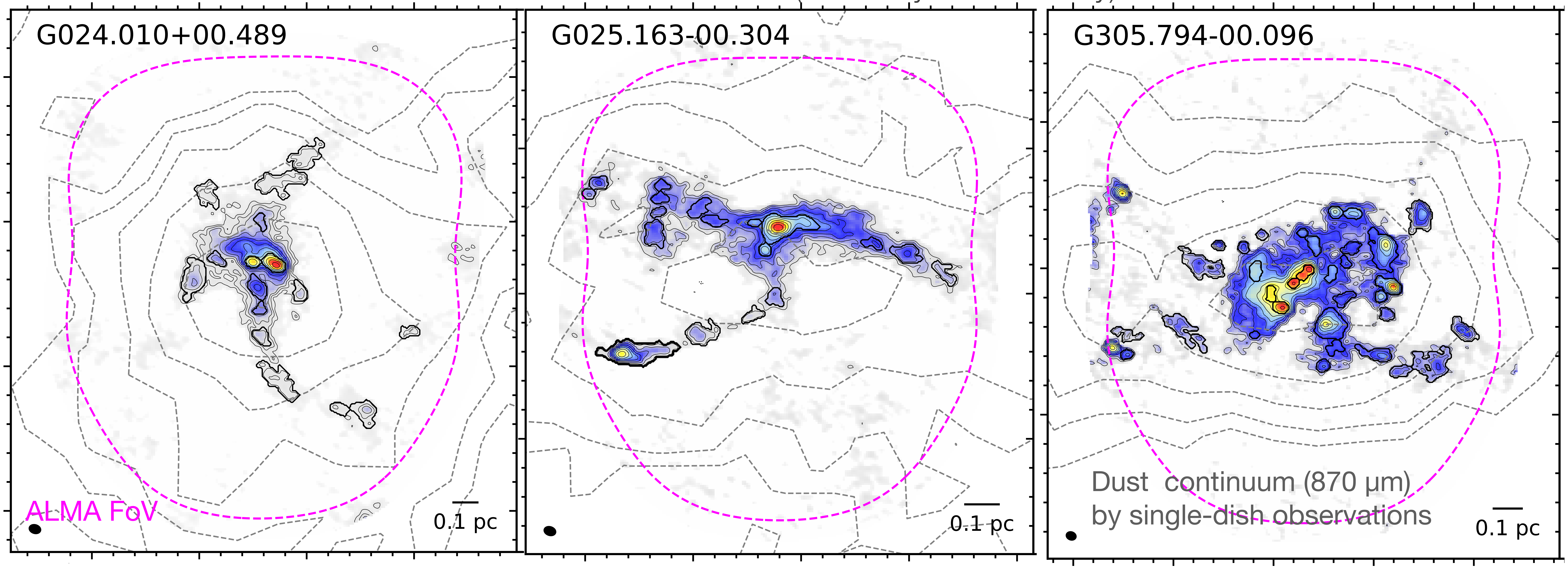
Outflow detection



27/39 clumps host outflows

Core Identification

Dust continuum emission (7m-array + 12m-array)



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dendrogram algorithm → **839** cores

This is the largest sample ever observed in IRDCs

The ALMA Survey of 70 μm dark High-mass clumps in Early Stages (ASHES)

Pilot survey (12 clumps)

~300 cores

I. Clump fragmentation Sanhueza et al. (2019)

II. Outflow Li et al. (2020) CO (J=2-1), SiO (J=5-4)

VI. CO depletion Giovanni et al. (2022) $C^{18}O$ (J=2-1)

VII. Chemistry Li et al. (2022)
N_2D^+ (J=3-2), DCO^+ (J=3-2), DCN (J=3-2) ,
H_2CO (J=3-2), CH_3OH(J_K=4_2-3_1)

VIII. Dynamics Li et al. (2023)
N_2D^+ (J=3-2), DCO^+ (J=3-2), $C^{18}O$ (J=2-1)

X. Hot gas Izumi et al. (2024)
H_2CO (J=3-2), HC_3N J=24-23, OCS J=18-17

Case study

III. Outflow driven by a decelerating jet in G10.99 Tafoya et al. (2021)
CO (J=2-1), SiO (J=5-4)

V. Deuterated molecules in G14.49 Sakai et al. (2021)
N_2D^+ (J=3-2), DCO+ (J=3-2), DCN (J=3-2)

IV. First star formation signatures in G23.47 Morii et al. (2021)
CO (J=2-1), SiO (J=5-4), N_2D^+ (J=3-2), DCO^+ (J=3-2), H_2CO (J=3-2), CH_3OH(J_K=4_2-3_1)

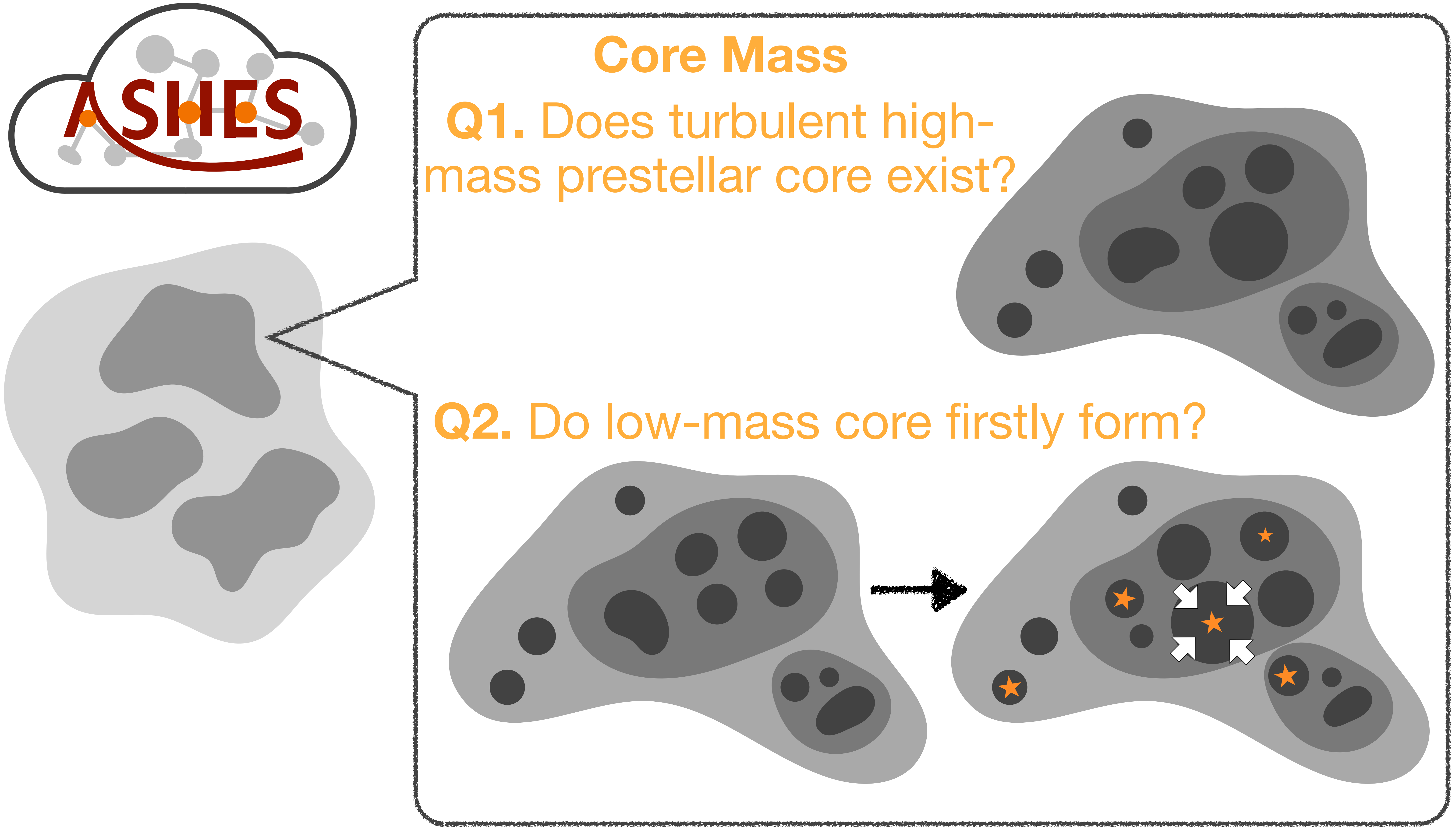
Full sample (39 clumps)

839 cores

IX. Core physical properties and spatial distribution Morii et al. (2023)

XI. Fragmentation Morii et al. (2024)

Questions to be Addressed



Core Mass

Q1. Does turbulent high-mass prestellar core exist?

Q2. Do low-mass core firstly form?

Core stability

Q3. Supported by turbulence or B-fields?

Q4. Gravitationally unstable?

Distribution

Q5. Is there any preferred location of more massive objects?

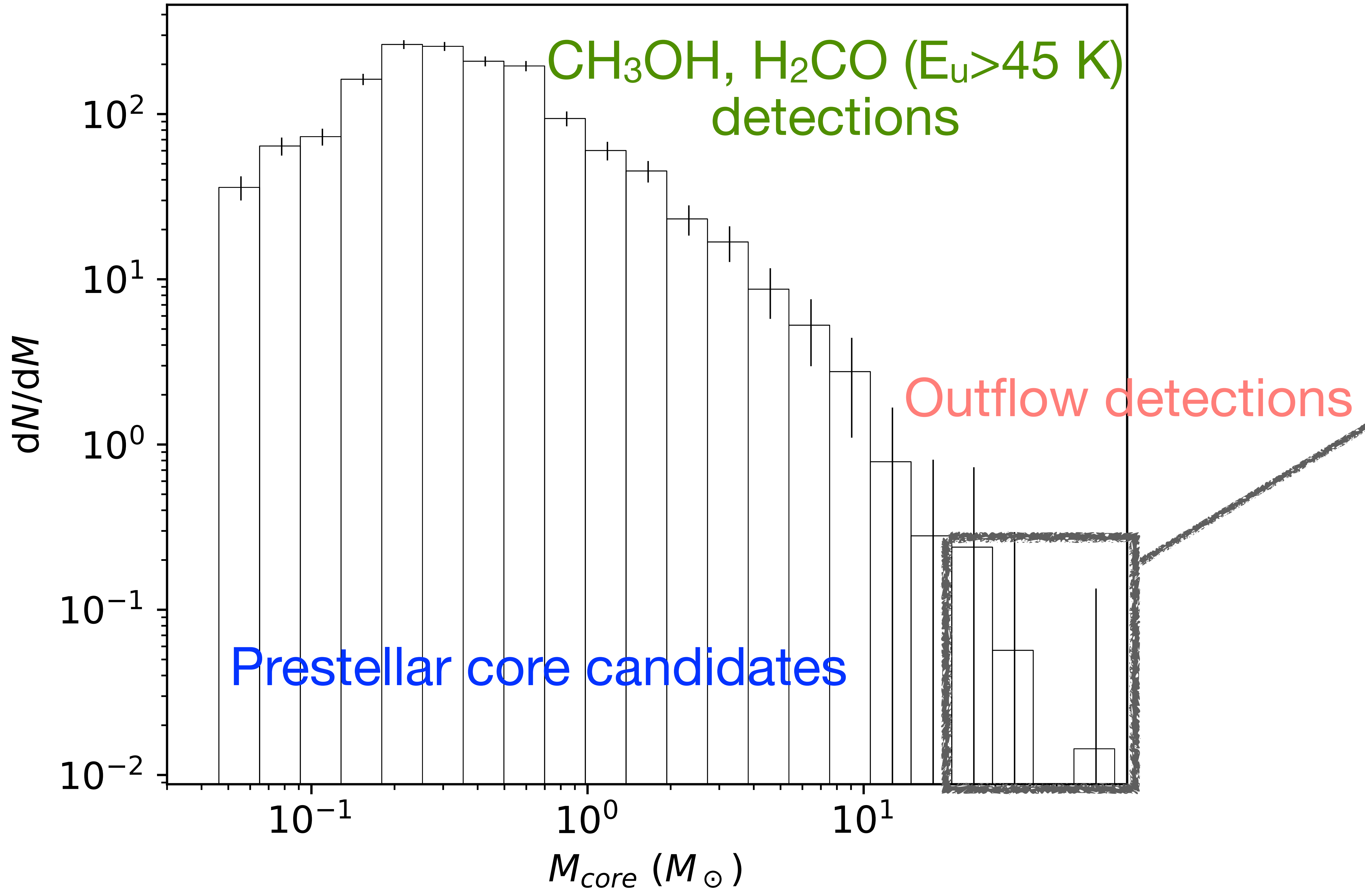
Gas dynamics **Q6.** Is there any sign of gas feeding around core?

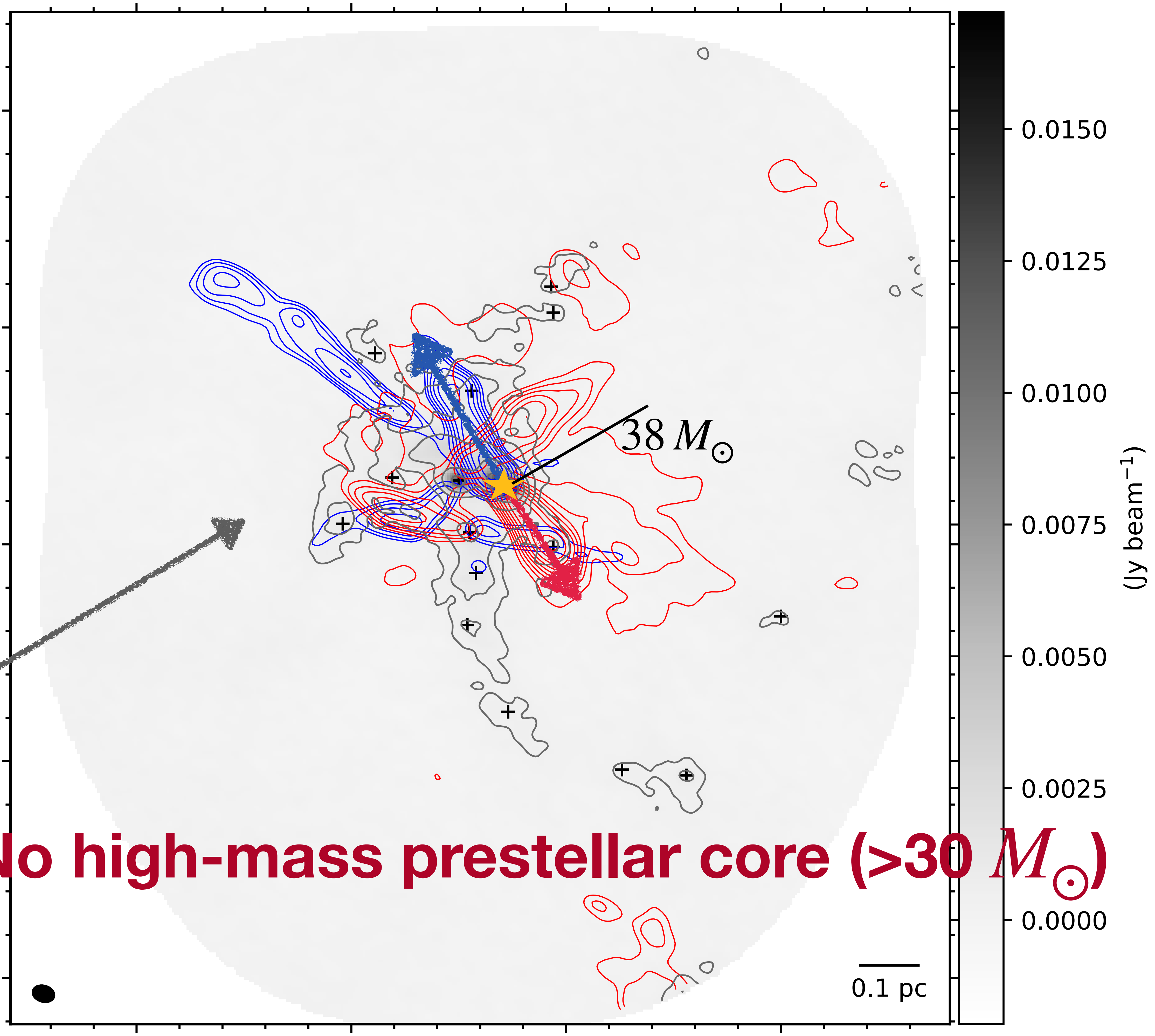
Core Mass

$$M_{\mathrm{core}} = \mathbb{R}\frac{F_{1.3\,\mathrm{mm}}\,d^2}{\kappa_{1.3\,\mathrm{mm}}\,B(T_{\mathrm{dust}})}$$

Core mass ranges from $0.06\,M_{\odot}$ to $81\,M_{\odot}$.

Seven cores (<1%) are $\gtrsim 30\,M_{\odot}$.





No high-mass prestellar core (>30 $M_{\odot}$)

ASHES IX. Morii et al. 2023, ApJ, 950, 109

The most massive cores

Larson’s relation (Larson 2003)

$$m^*_{\rm max} = 16 \left(\frac{\varepsilon_{\rm SFE}}{0.3} \frac{M_{\rm clump}}{10^3\,M_\odot} \right)^{0.45} M_\odot$$

Kroupa’s IMF

$$m^*_{\rm max} = \left(\frac{0.3}{\varepsilon_{\rm SFE}} \frac{21\,M_\odot}{M_{\rm clump}} + 1.5 \times 10^{-3} \right)^{-0.77} M_\odot$$

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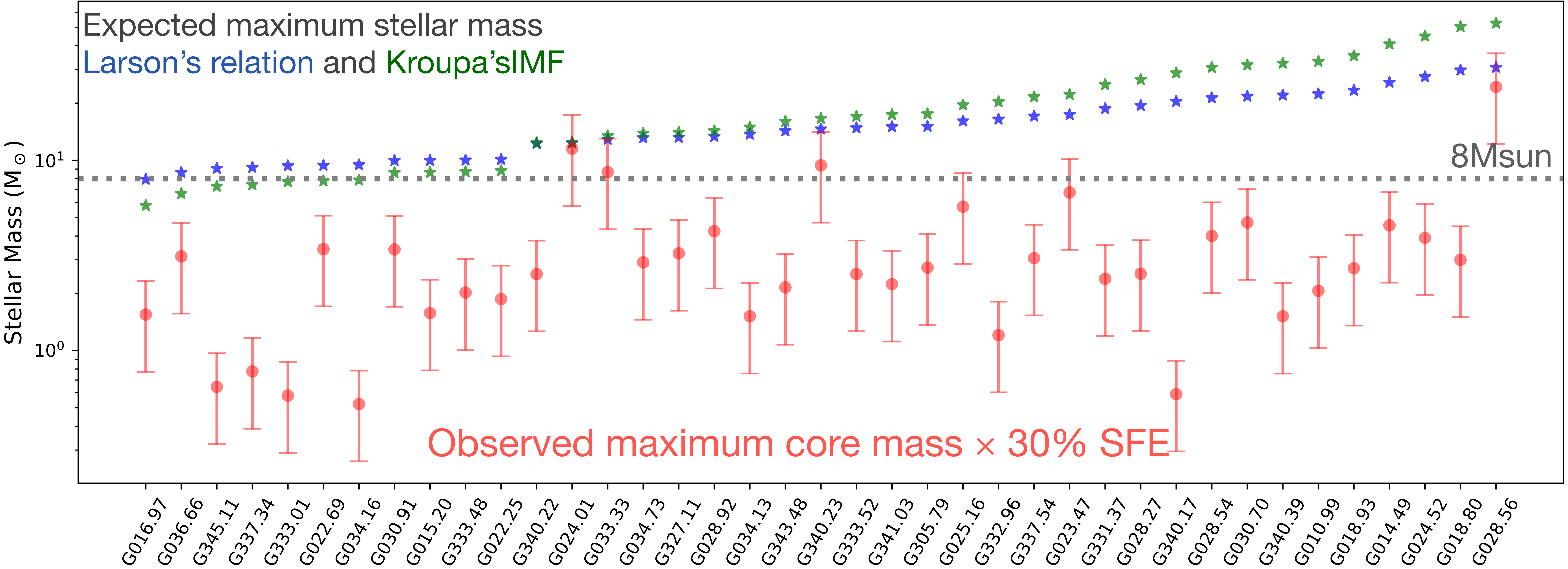
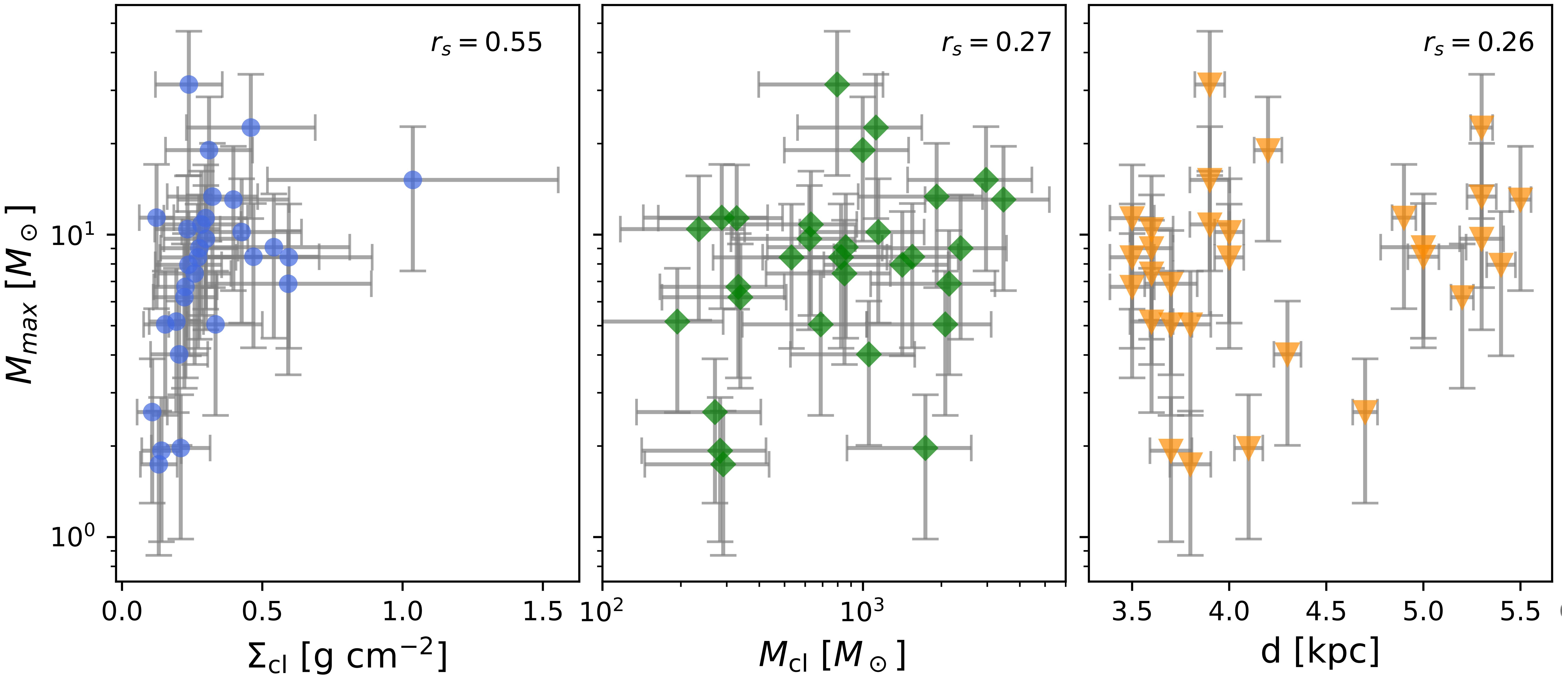


The majority of the clumps hosts only low- to intermediate-mass cores.

The most massive cores

The maximum core mass has a stronger correlation with **clump surface density** than with clump mass.



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Morii et al. 2023

Thermal vs Turbulent Jeans fragmentation

Thermal

$$\lambda_J^{\rm th} = c_s\sqrt{\frac{\pi}{G\rho}} \quad \left(c_s = \sqrt{\frac{k_{\rm B}T}{\mu m_{\rm H}}}\right)$$

$$M_J^{\rm th} = \frac{4\pi\rho}{3}\left(\frac{\lambda_J^{\rm th}}{2}\right)^3 = 1.5\left(\frac{T}{15\,K}\right)^{3/2}\left(\frac{n({\rm H_2})}{10^5\,{\rm cm^{-3}}}\right)^{3/2} M_\odot$$

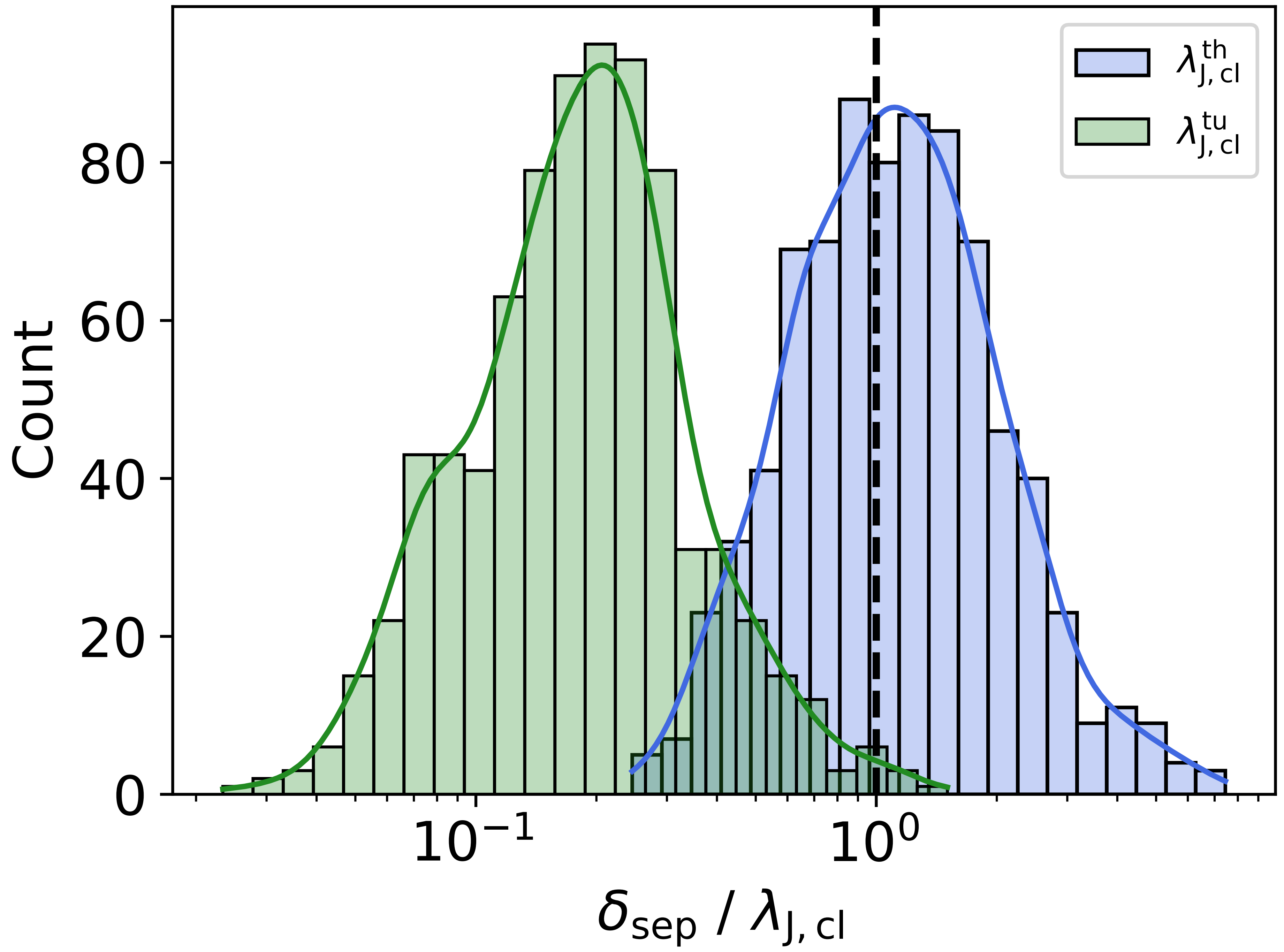
Turbulent

$$\lambda_J^{\rm tu} = \sigma\sqrt{\frac{\pi}{G\rho}}$$

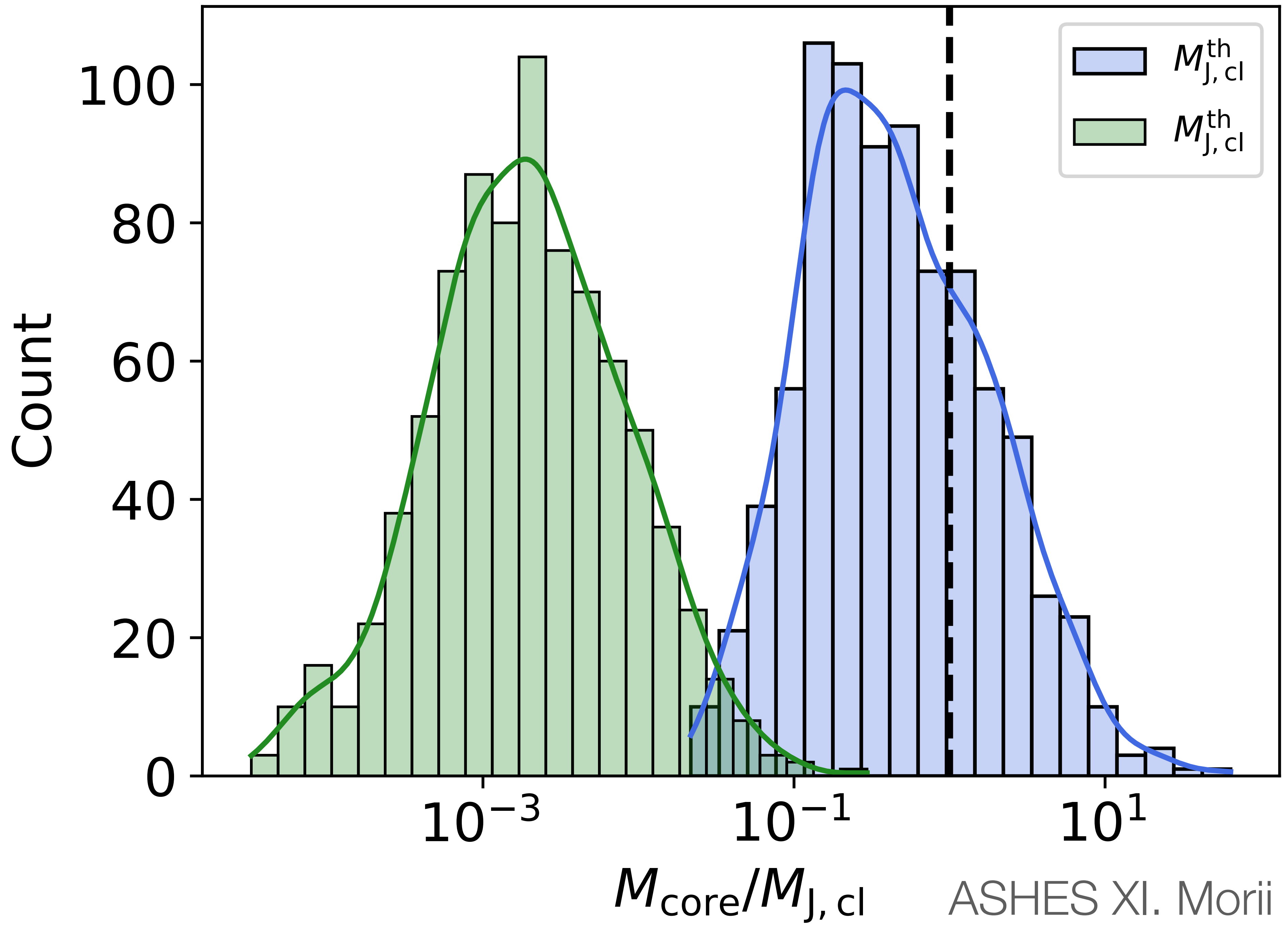
σ：velocity dispersion from $C^{18}O$ (2-1) TP data

$$M_J^{\rm tu} = \frac{4\pi\rho}{3}\left(\frac{\lambda_J^{\rm tu}}{2}\right)^3 = 210\left(\frac{\sigma}{1.2\,{\rm km\,s^{-1}}}\right)^3\left(\frac{n({\rm H_2})}{10^5\,{\rm cm^{-3}}}\right)^{3/2} M_\odot$$

Separation



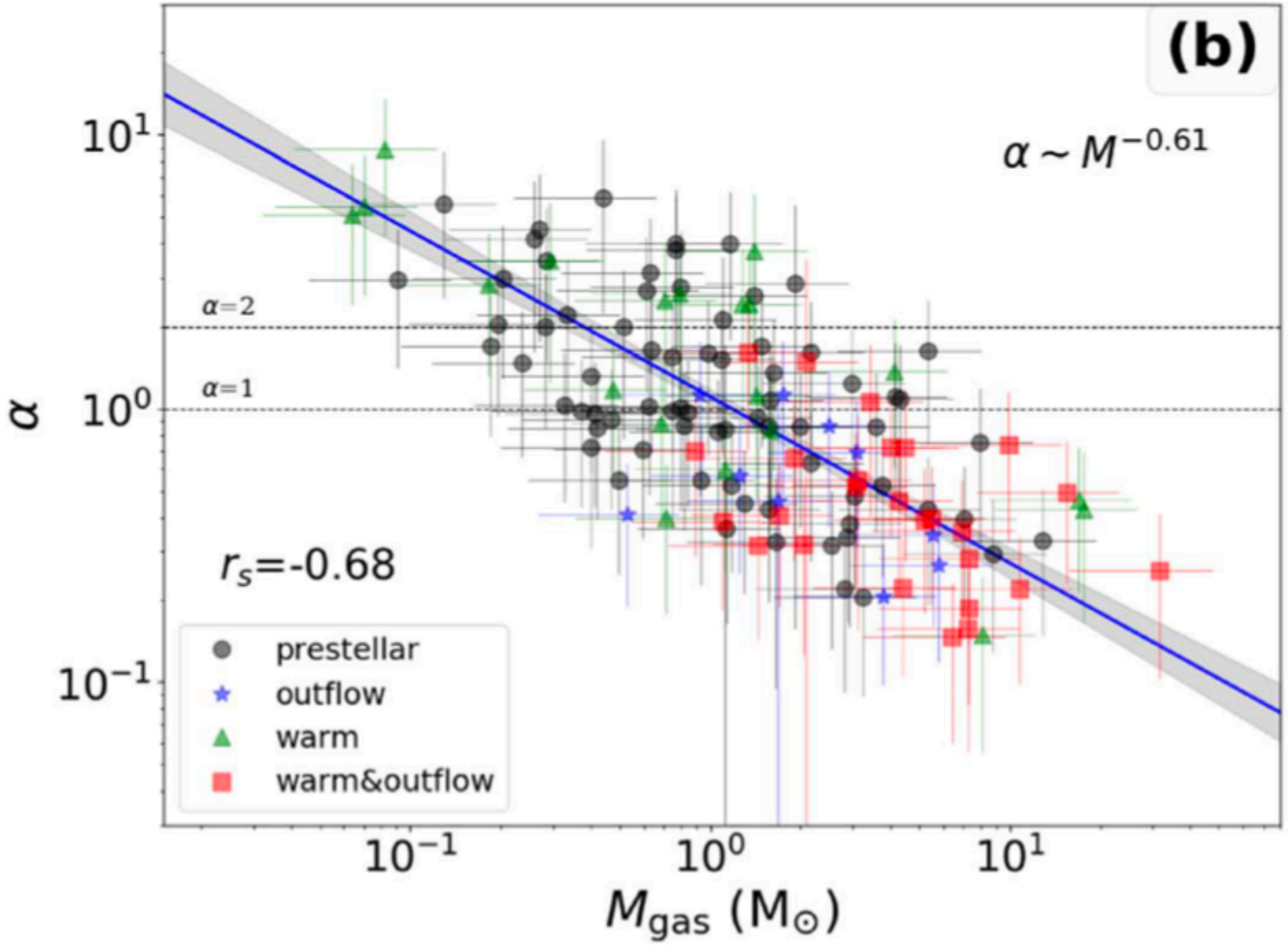
Mass



ASHES XI. Morii et al. 2024, ApJ, 966, 171

Virial Analysis

ASHES VIII. Li et al. 2023, ApJ, 949, 109

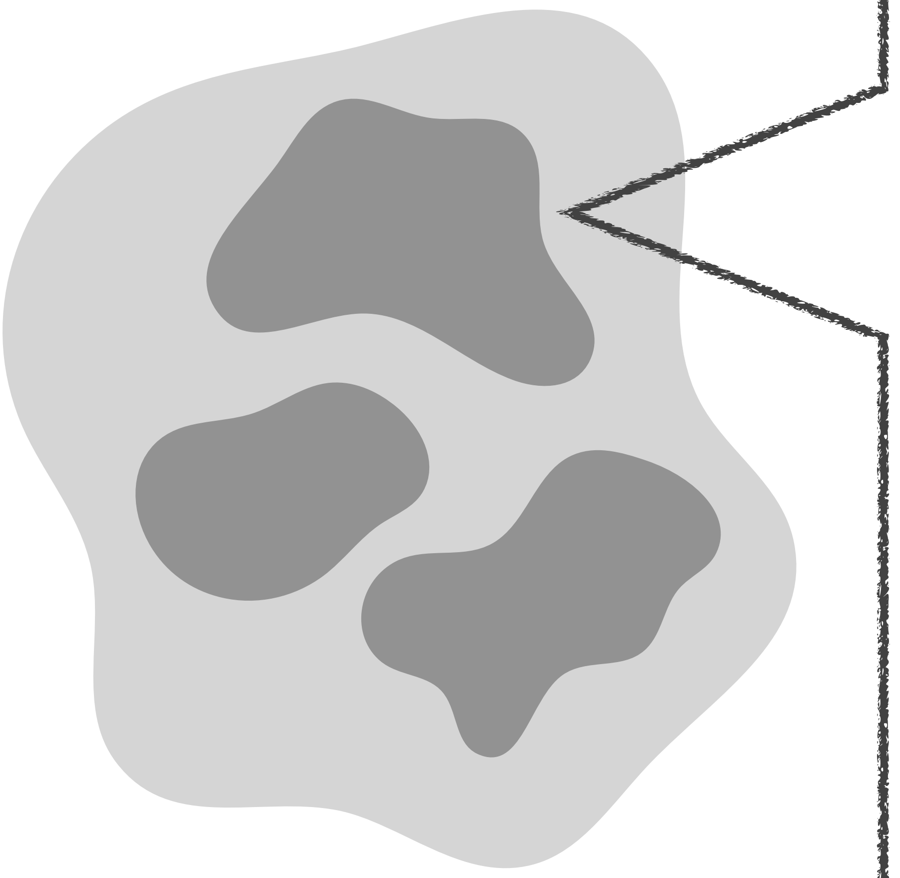


Virial mass $M_{\rm vir} = \frac{3(5-2a)}{3-a}\frac{R\sigma_{\rm tot}^2}{G}$ $\left(\sigma_{\rm tot}^2 = \frac{kT}{\mu_{\rm p} m_{\rm H}} + \sigma_{\rm nt}^2\right)$

Virial parameter $\alpha = M_{\rm vir}/M_{\rm core}$

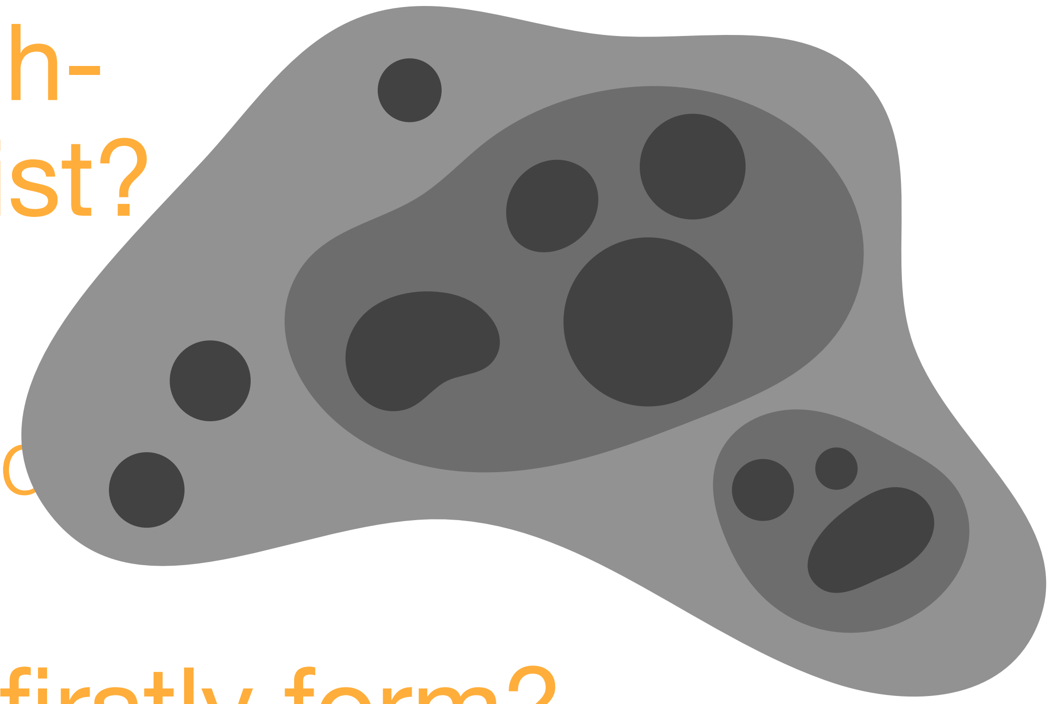
The majority of cores have α<2,
and in the **non-equilibrium state**.

Questions to be Addressed



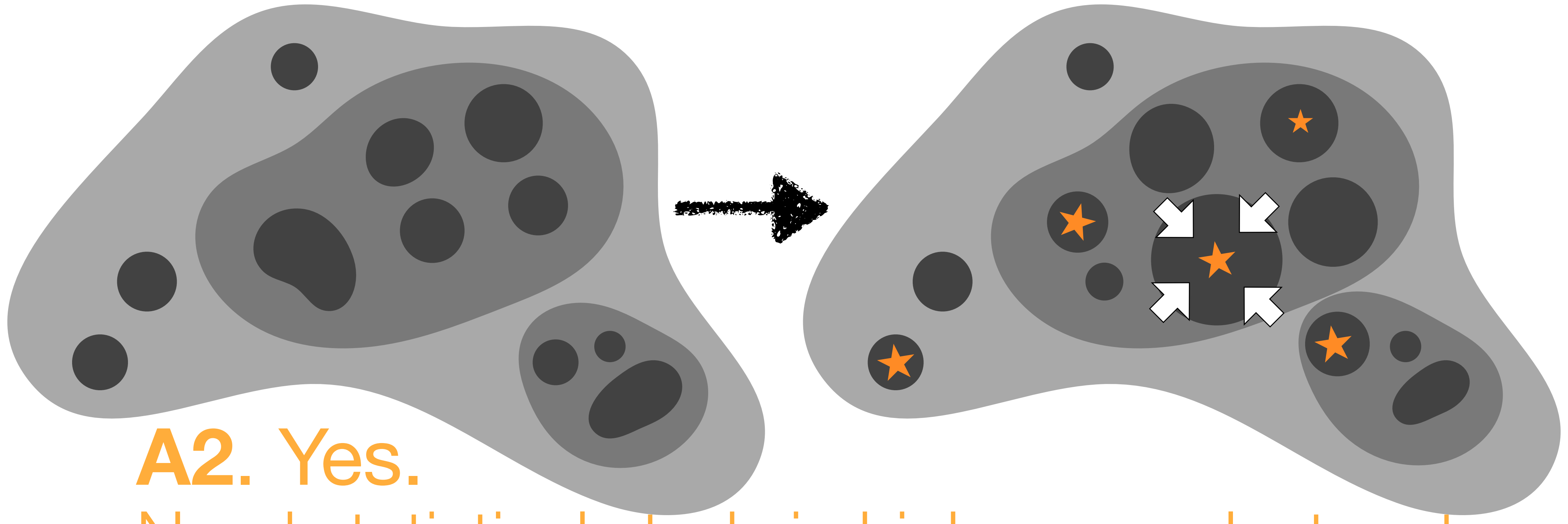
Core Mass

Q1. Does turbulent high-mass prestellar core exist?



A1. No
(at least in 70 µm-dark clouc

Q2. Do low-mass core firstly form?



A2. Yes.
Need statistical study in high-mass clusters too.

Core stability

Q3. Supported by turbulence or B-fields?

A3. Not yet clear

Q4. Gravitationally unstable?

A4. Yes (especially for more massive cores)

Distribution

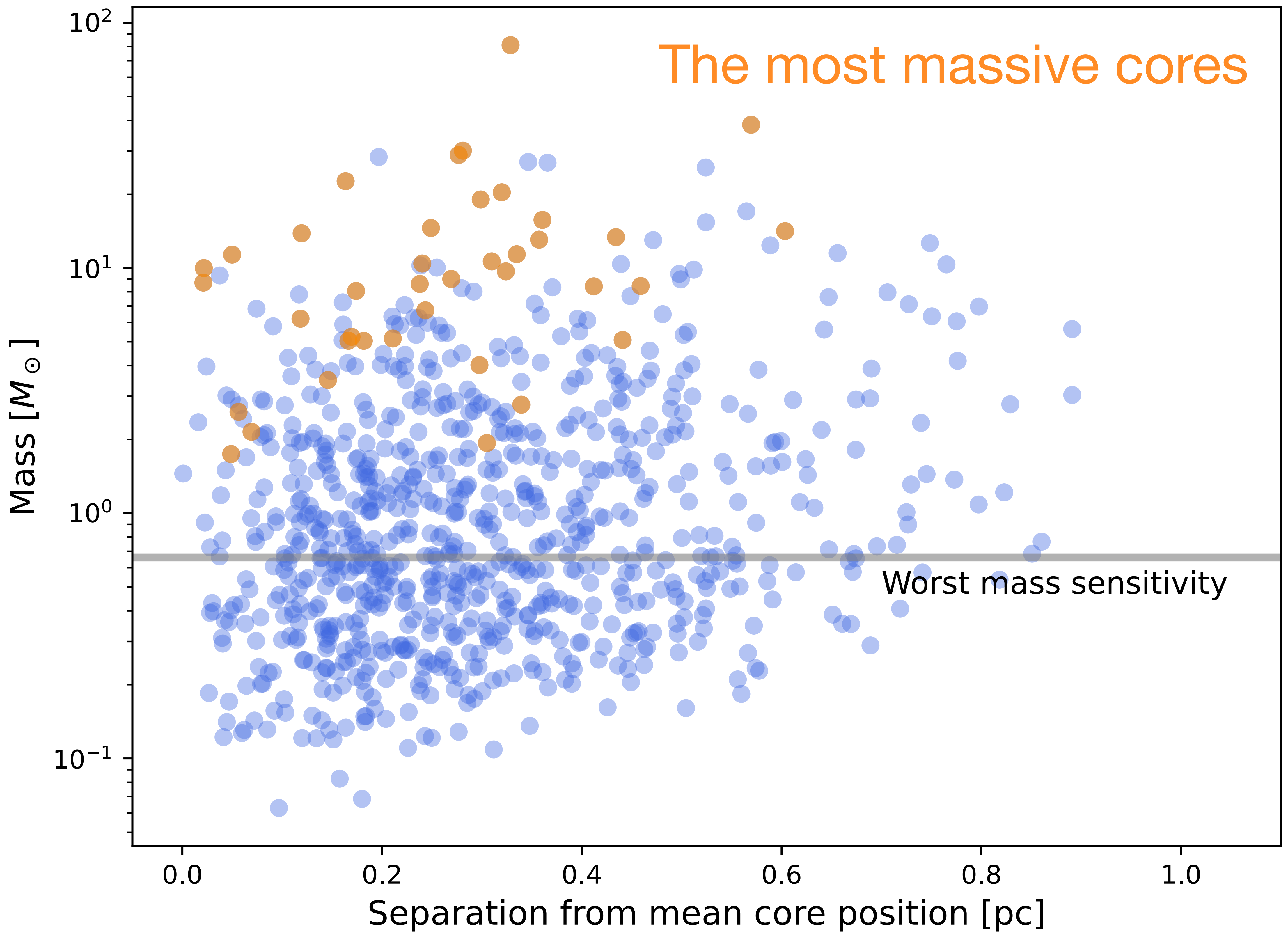
Q5. Is there any preferred location of more massive objects?

Gas dynamics

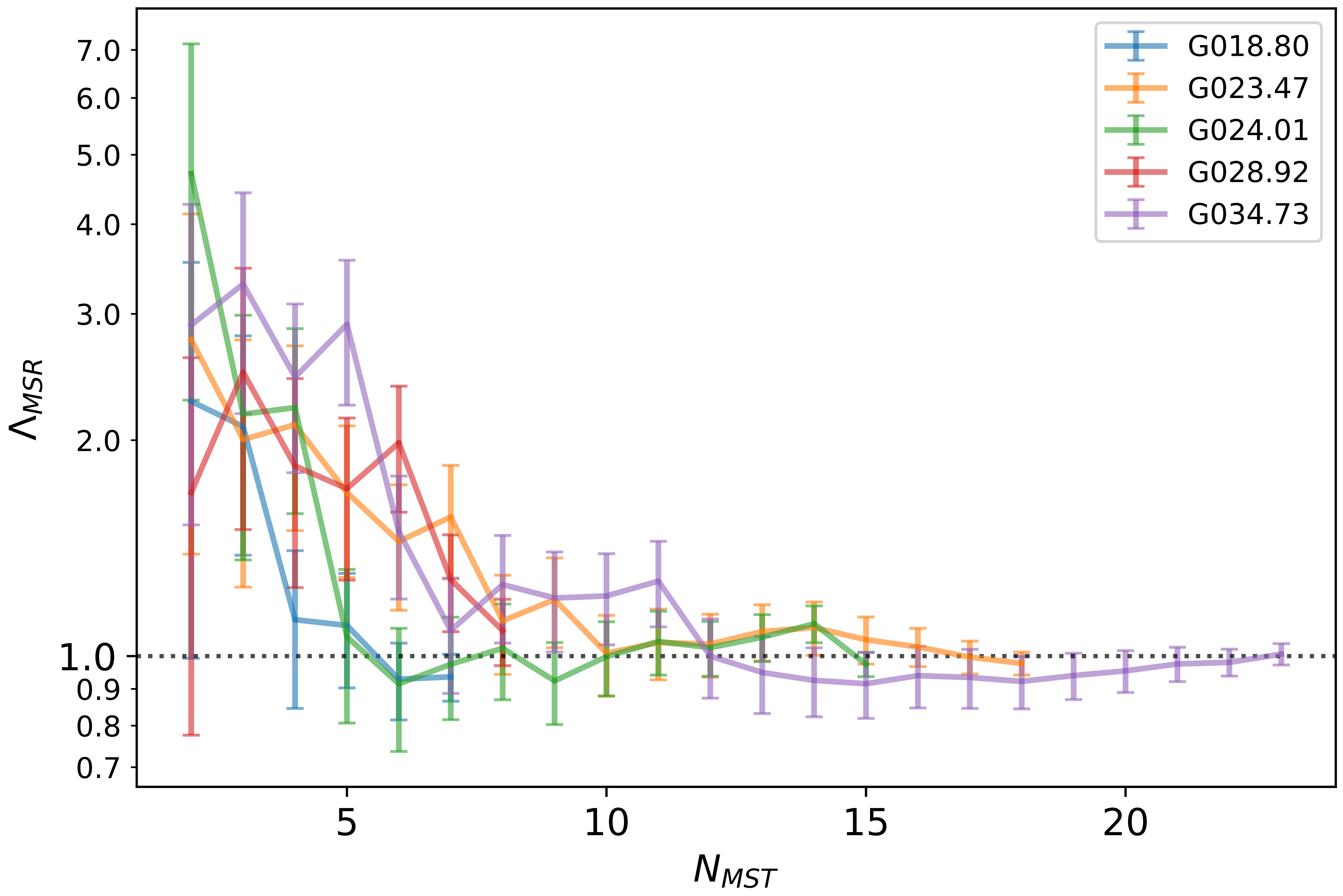
Q6. Is there any sign of gas feeding around core?

Core Spatial Distribution

Q Is there any preferred location of (relatively) high-mass cores?



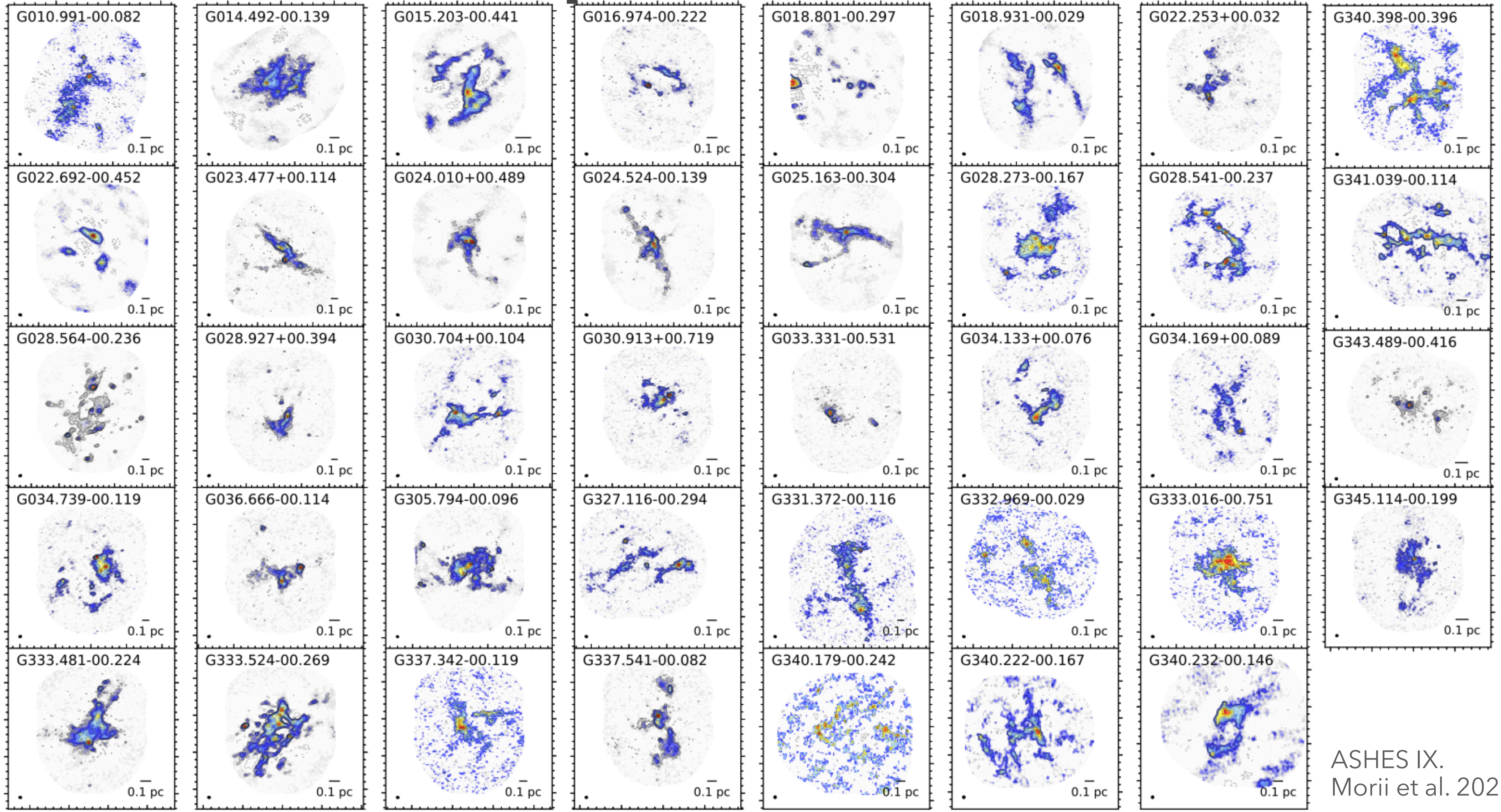
Λ_{MSR} plot for the clumps showing Λ_{MSR}>2



No clear sign that the most massive cores locate near the clump center and mass segregation.

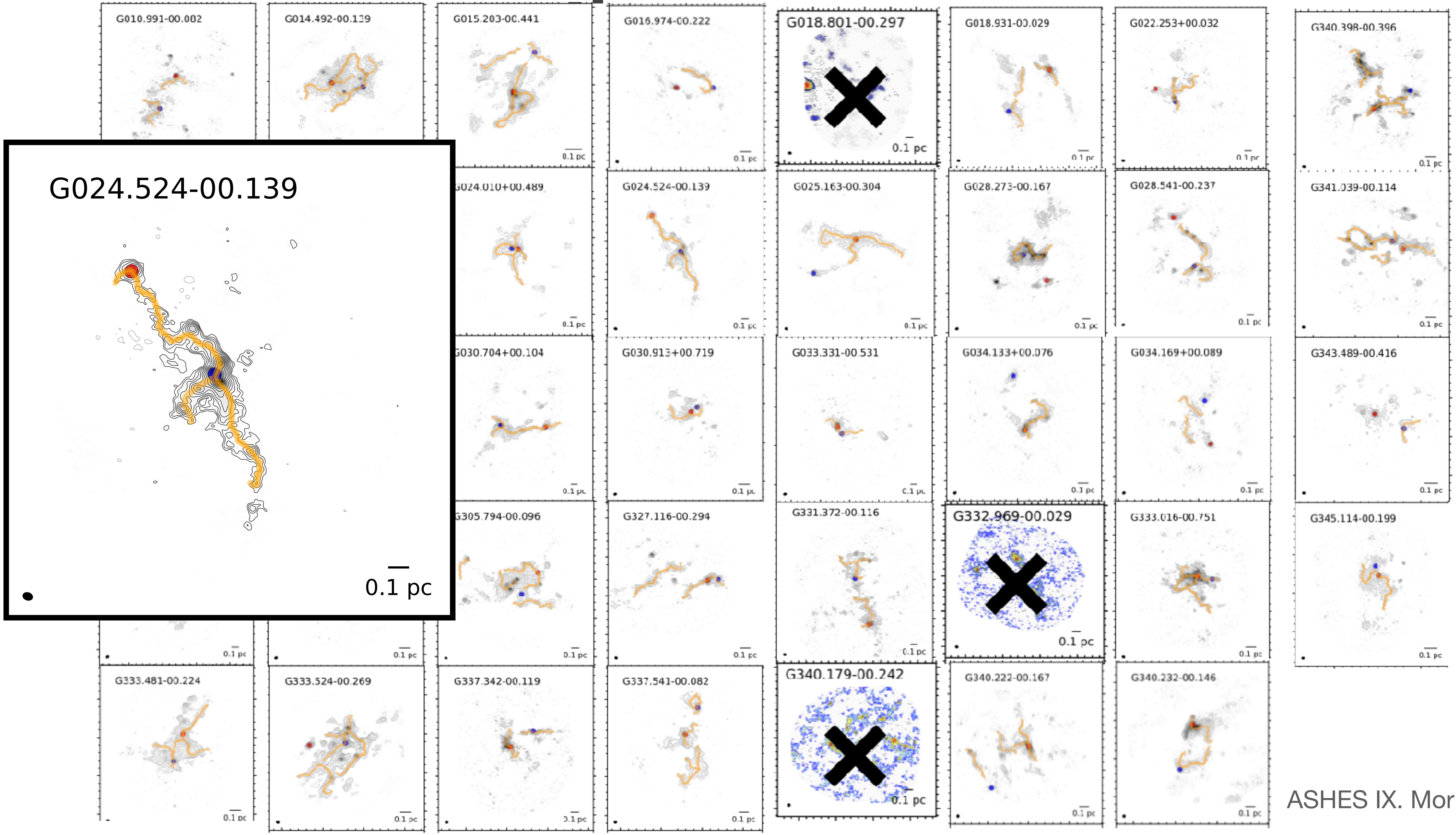
ASHES IX. Morii et al. 2023, ApJ, 950, 109

Core Spatial Distribution



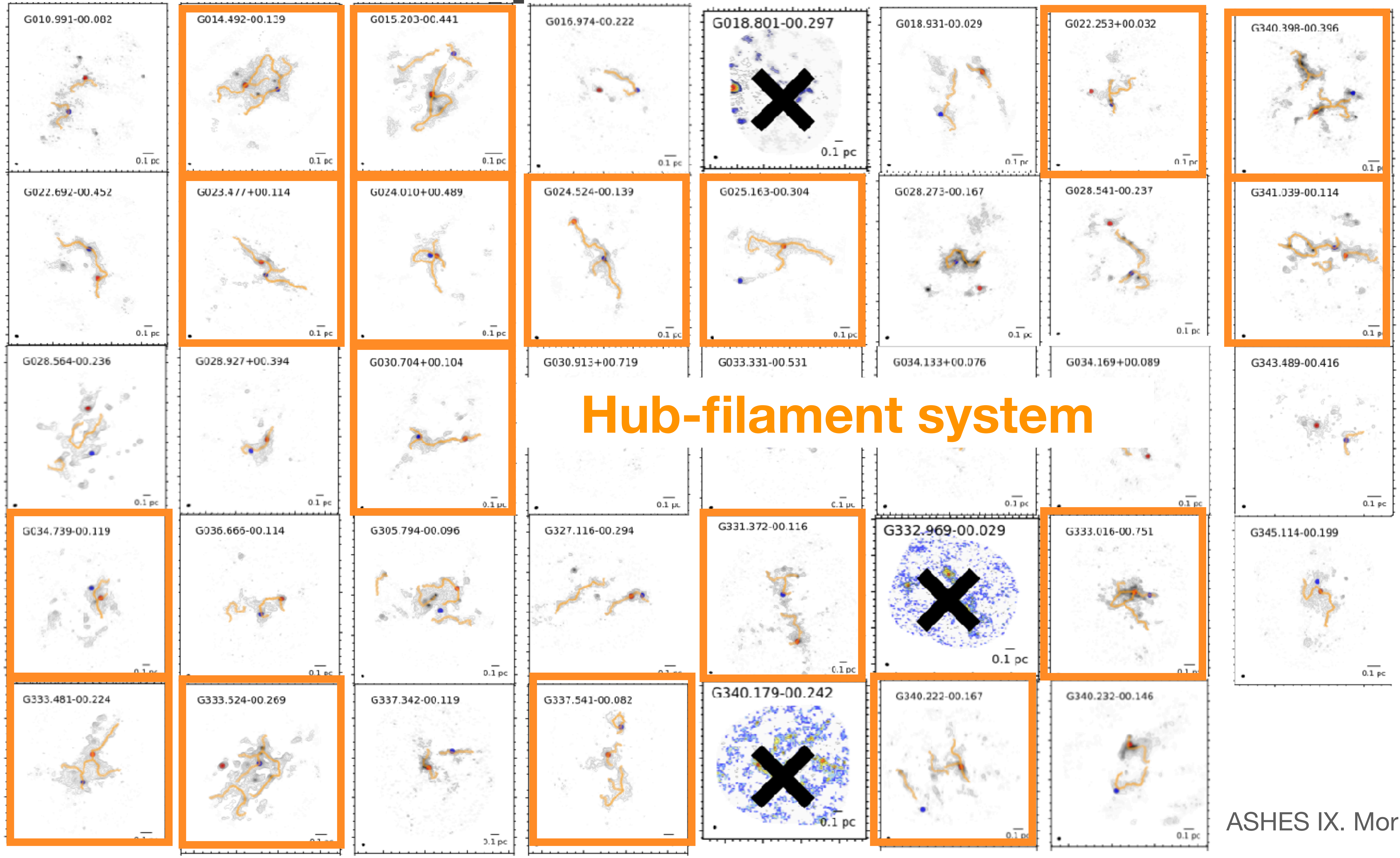
ASHES IX.
Morii et al. 2023

Core Spatial Distribution



ASHES IX. Morii et al. 2023

Core Spatial Distribution



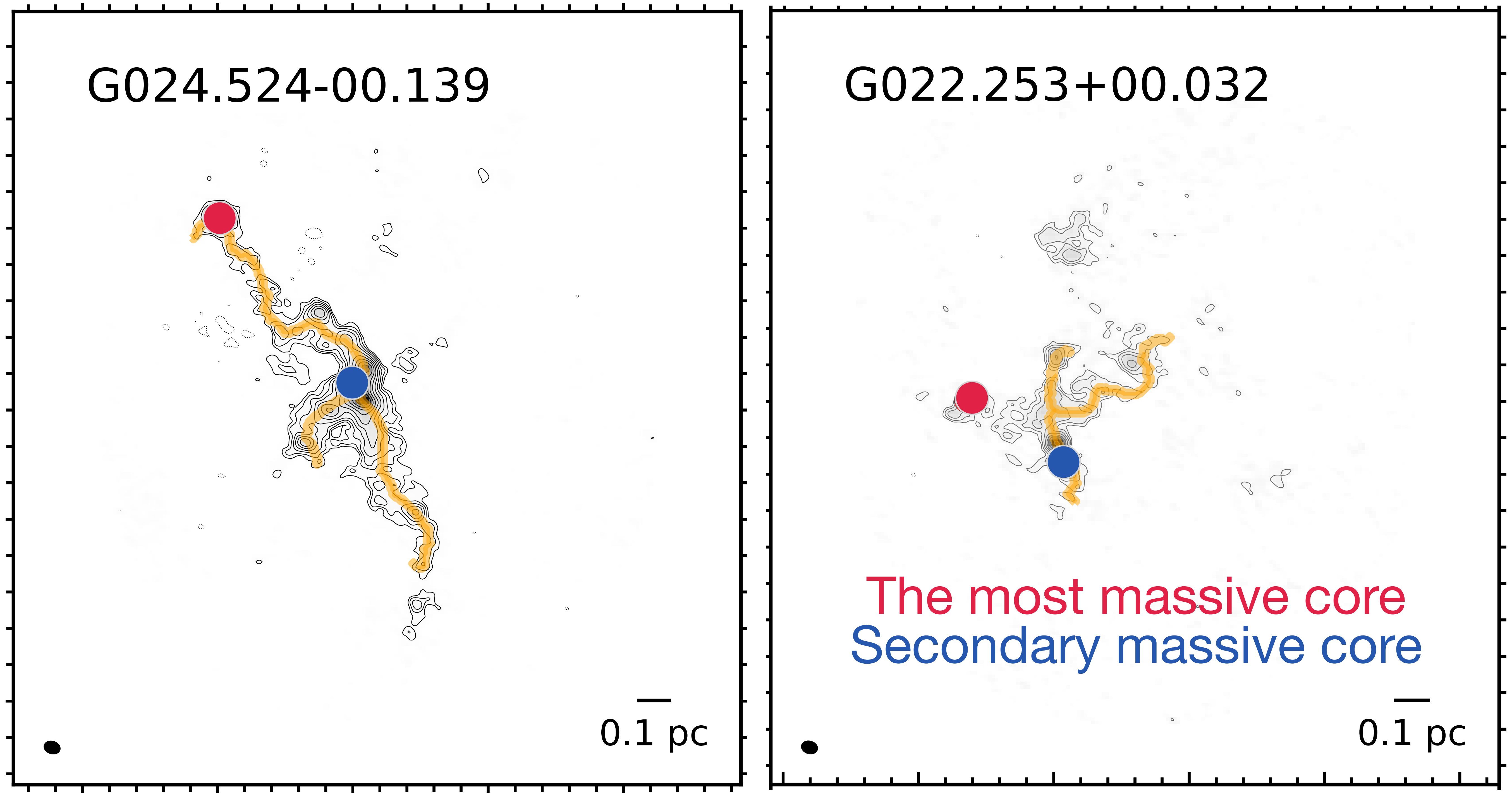
Hub-filament system

ASHES IX. Morii et al. 2023

Core Spatial Distribution

Q Are (relatively) high-mass cores formed at the hub-filament system?

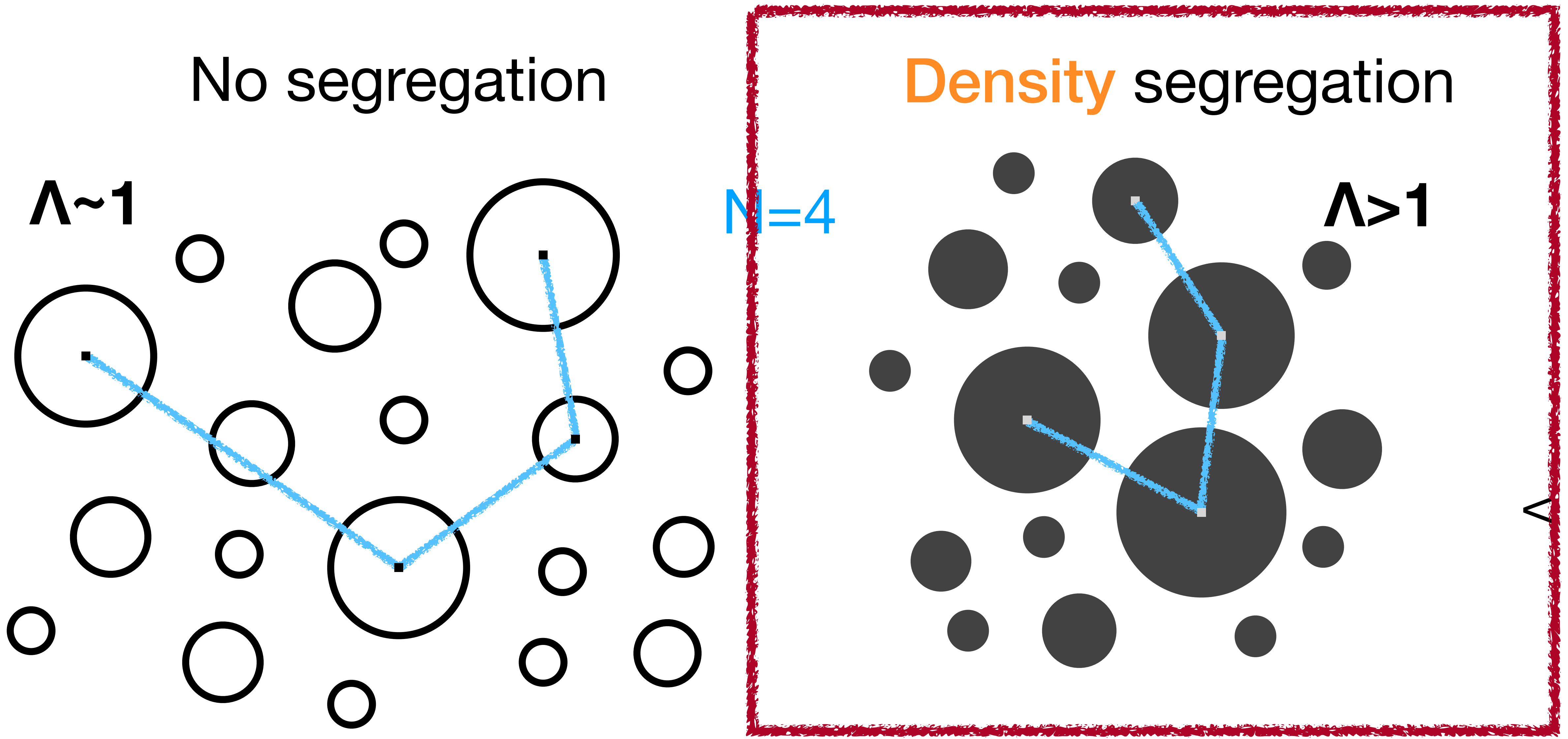
ASHES IX. Morii et al. 2023, ApJ, 950, 109



Most clump host filamentary structure, and half host **hub-filament systems**.
No sign that the most massive cores are preferentially located at **hubs** (7/39, 18%).
→ The hub-filament systems are not yet efficiently contributing to the core accretion.

Core Spatial Distribution

Signs of segregation by density

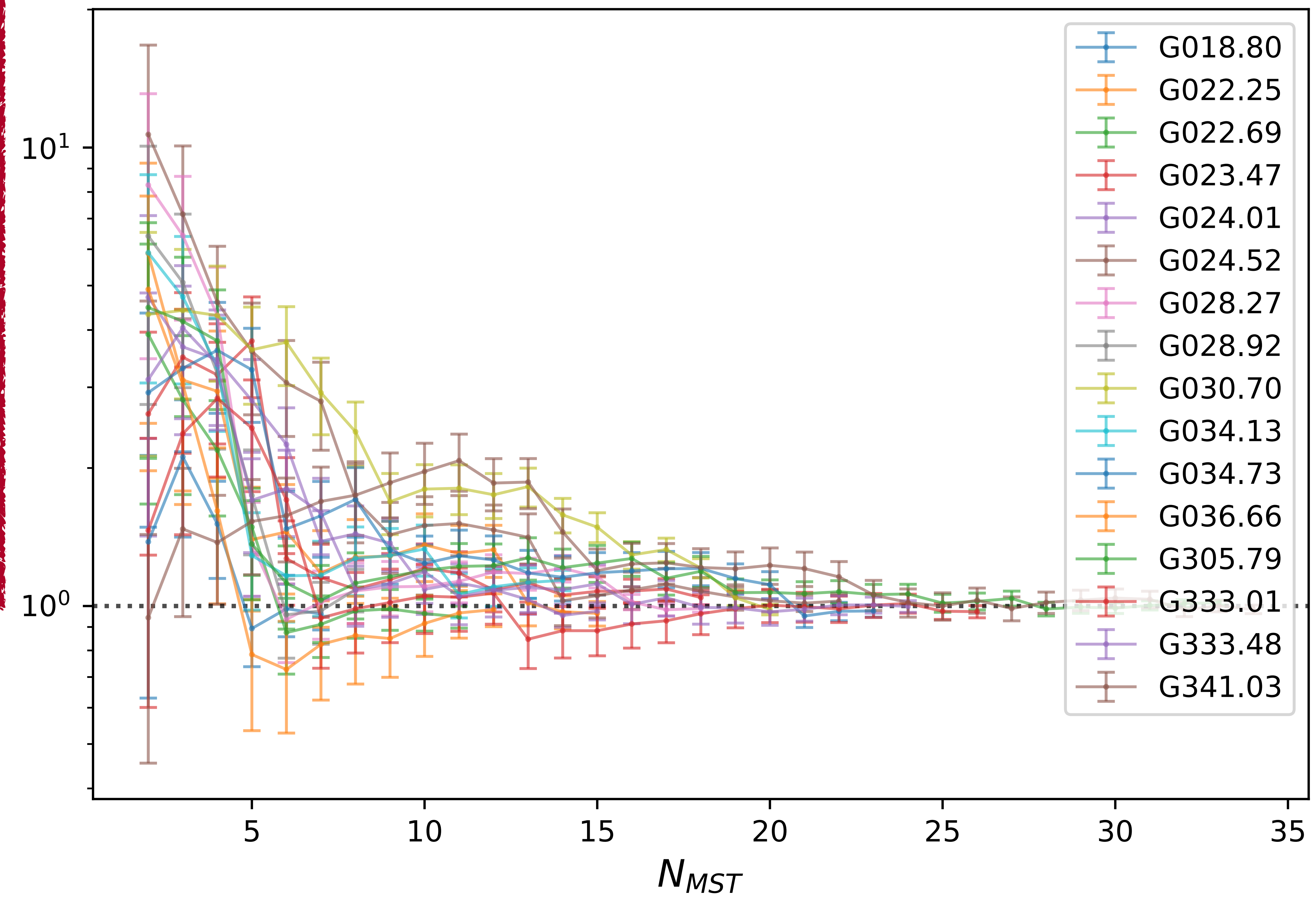


*Circle size represents density

$$\Lambda = \frac{\text{Sum of randomly selected N-core separation}}{\text{Sum of the densest N-cores' separation}}$$

Allison et al. 2009

Λ plot for the clumps showing Λ>2



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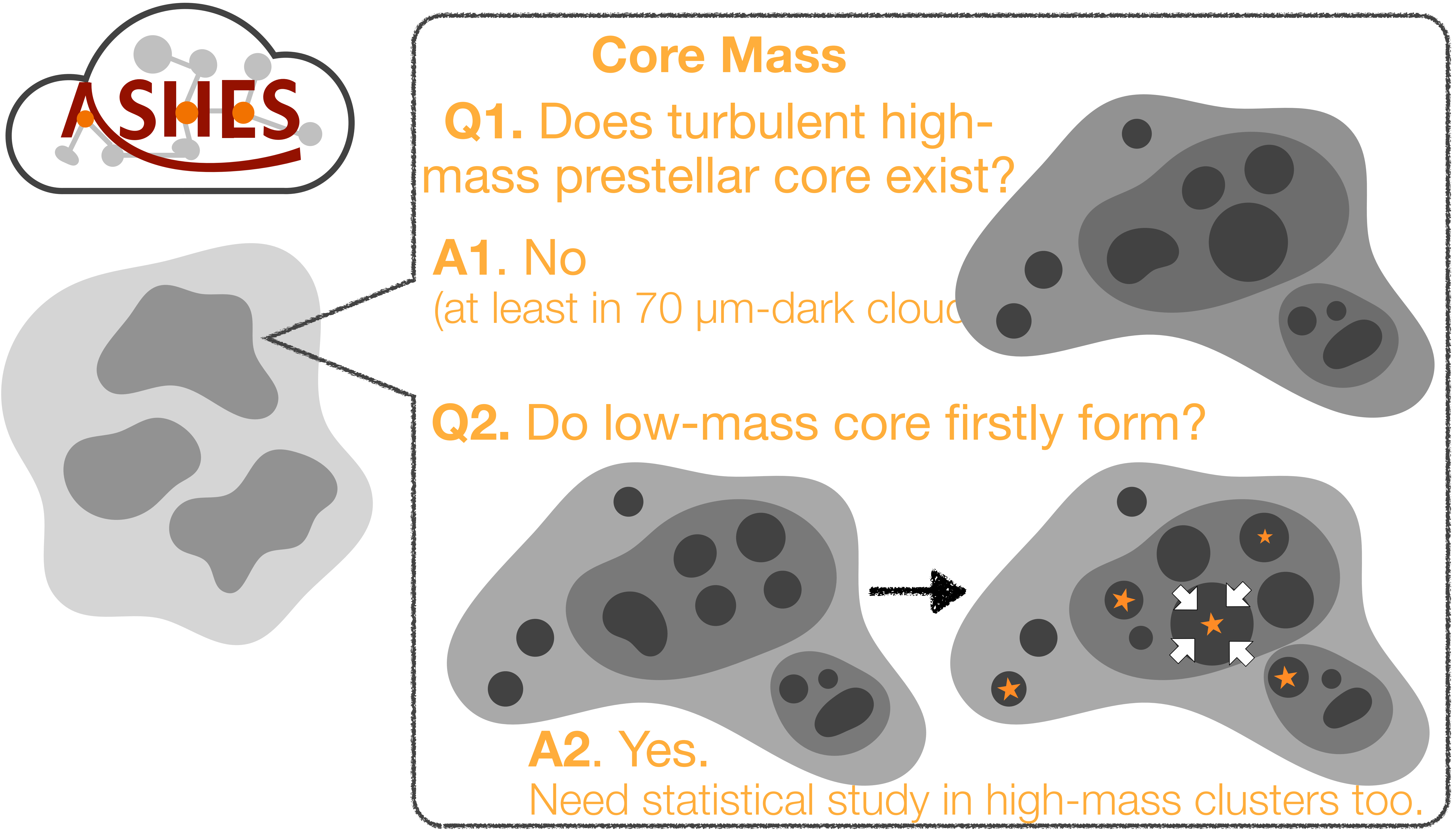
Questions to be Addressed



Core Mass

Q1. Does turbulent high-mass prestellar core exist?

A1. No
(at least in 70 μm-dark clou

Q2. Do low-mass core firstly form?

A2. Yes.
Need statistical study in high-mass clusters too.

Core stability

Q3. Supported by turbulence or B-fields?

A3. Not clear for B-field yet

Q4. Gravitationally unstable?
A4. Yes (especially for more massive cores)

Distribution

Q5. Is there any preferred location of more massive objects?

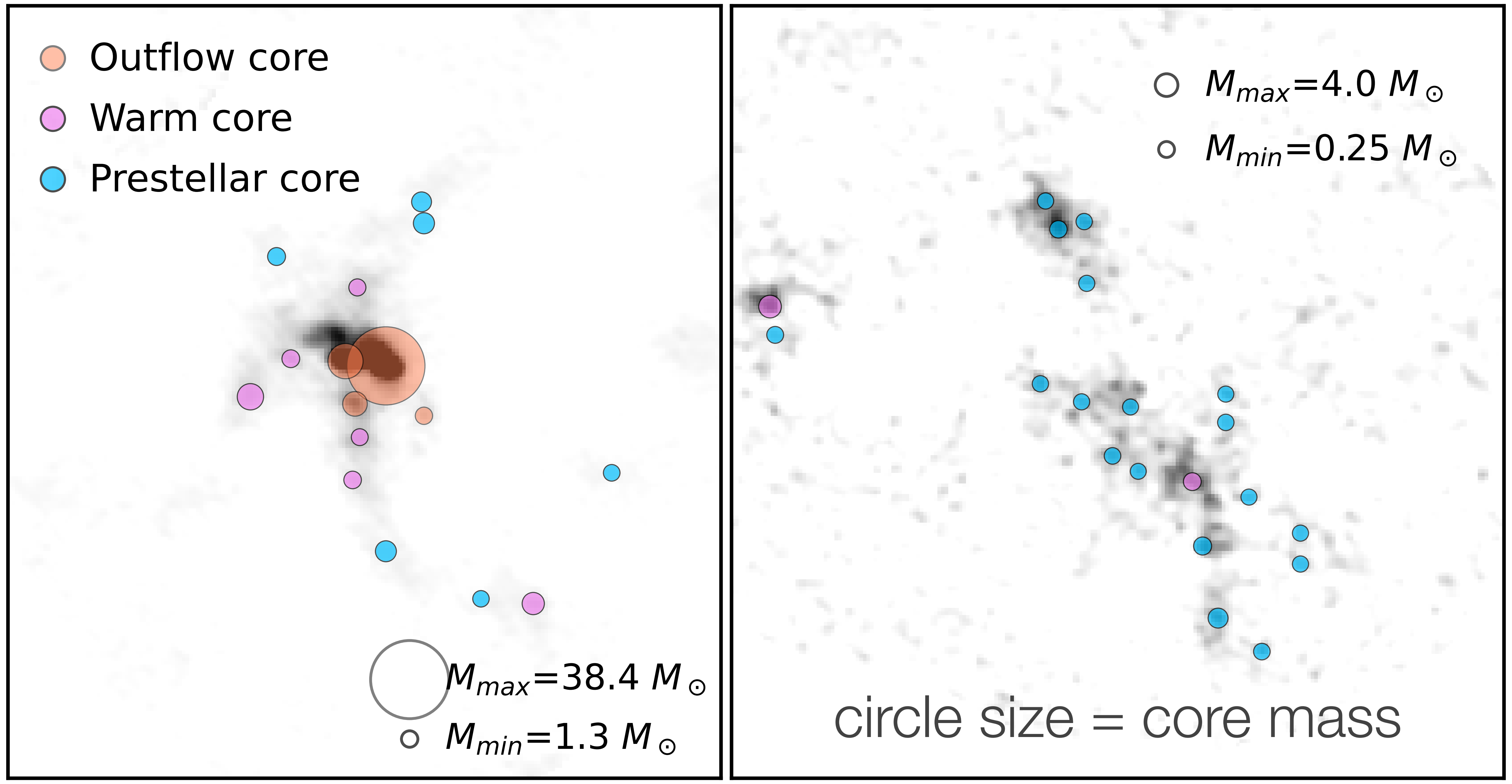
A5. No significant sign detected.

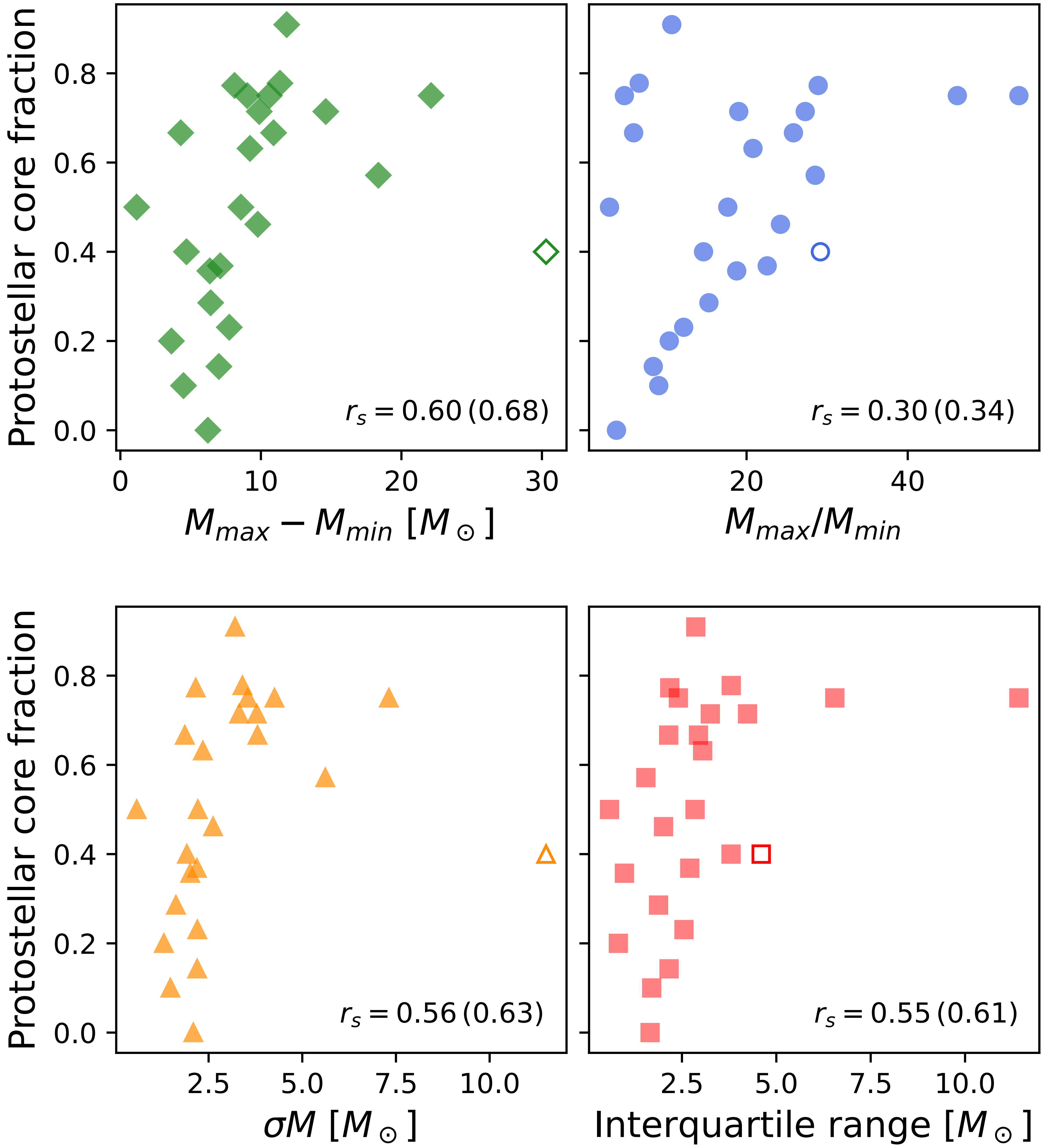
Gas dynamics **Q6.** Is there any sign of gas feeding around core?

Evolution of Mass Dynamic Range

ASHES XI. Morii et al. 2024, ApJ, 966, 171

Large mass dynamic range   Small mass dynamic range



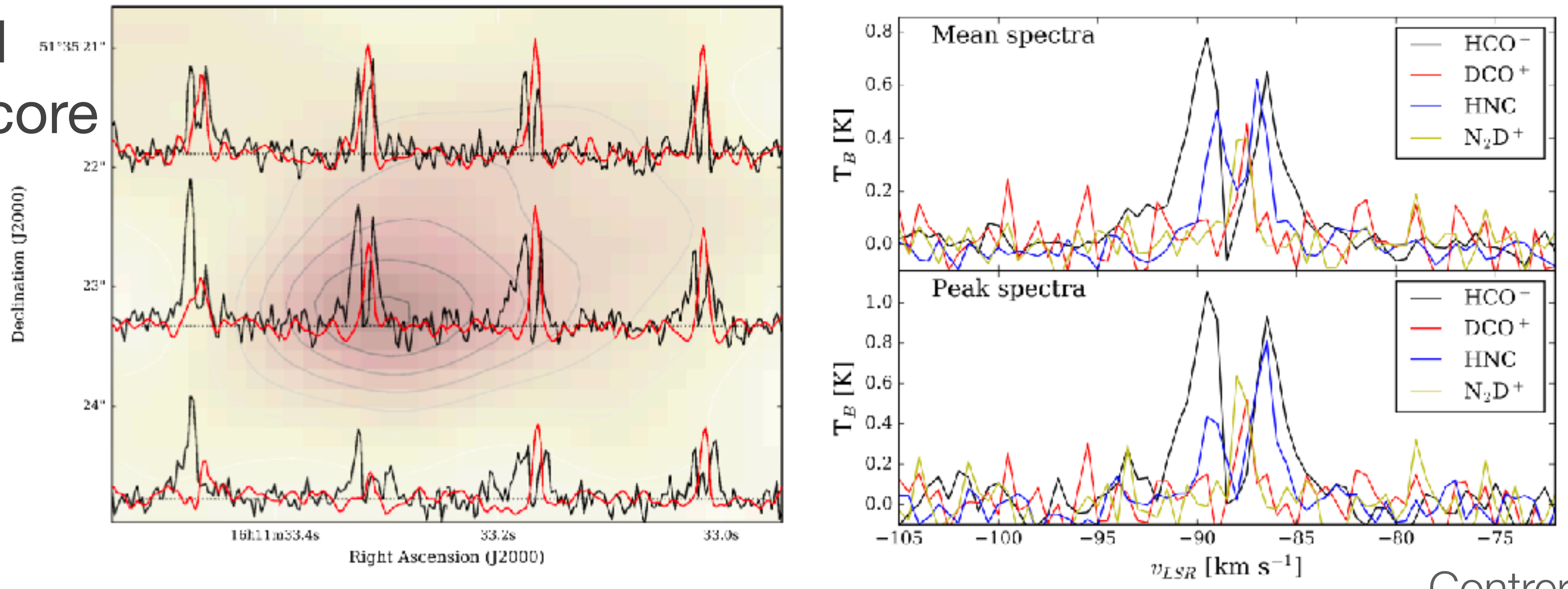


The higher protostellar core fraction, the larger mass dynamic range.

Signs of Gas Infall

Infall motion around an intermediate-mass core

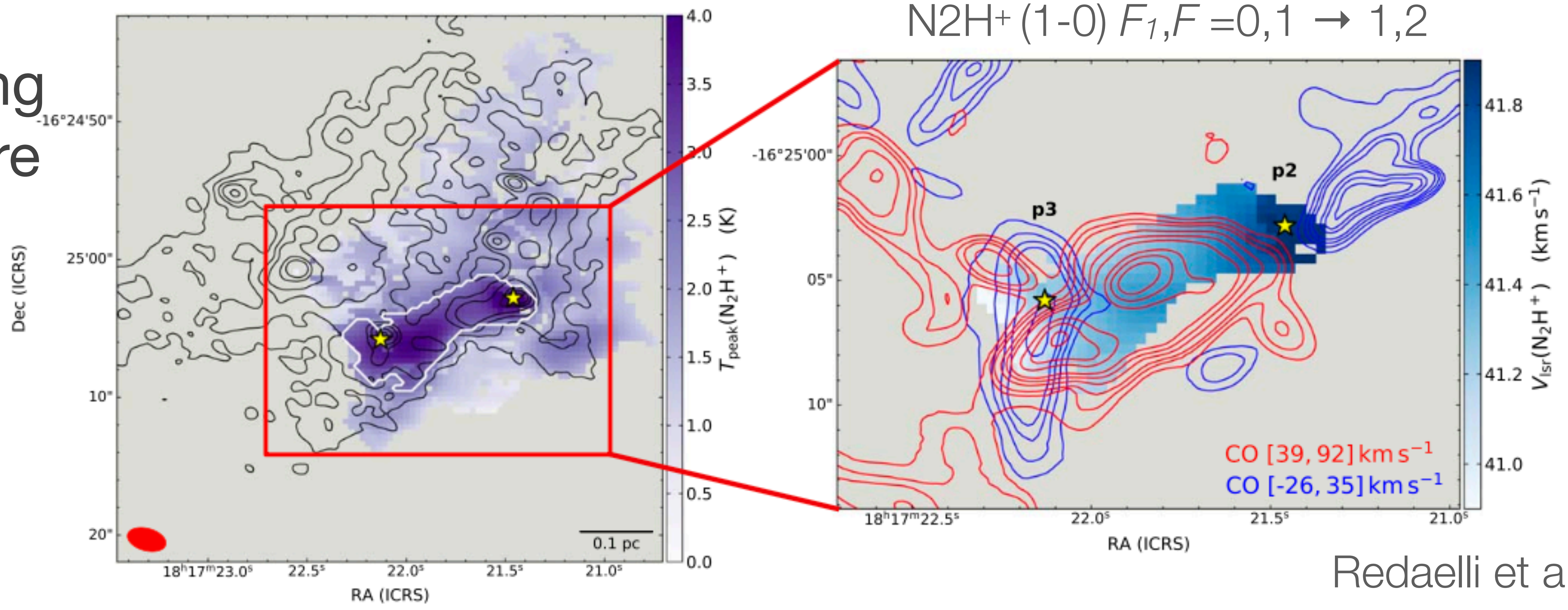
$$\dot{M} \sim 2 \times 10^{-3}\, M_{\odot}\mathrm{yr}^{-1}$$



Contreras et al. 2018, ApJ, 861, 14

Velocity gradient along a filamentary structure

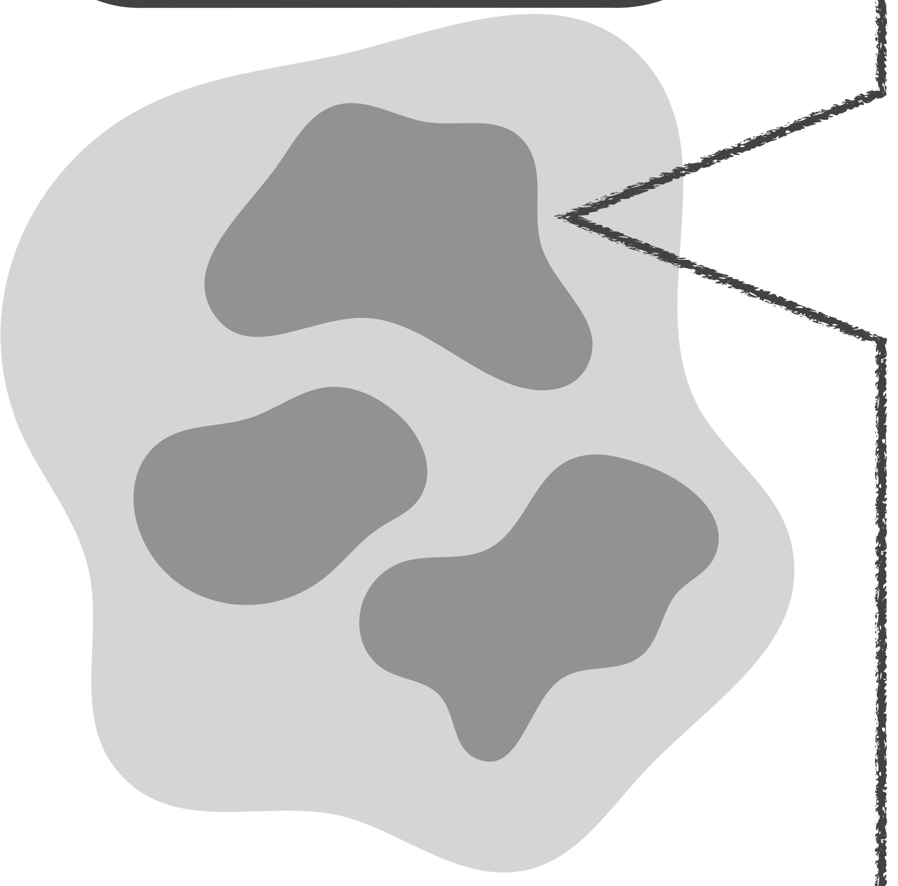
$$\dot{M} \sim 2 \times 10^{-4}\, M_{\odot}\mathrm{yr}^{-1}$$



N2H+ (1-0) *F₁*,*F* =0,1 → 1,2

Redaelli et al. 2022, ApJ, 936, 169

Very Early Evolutionary Stage of High-mass star formation

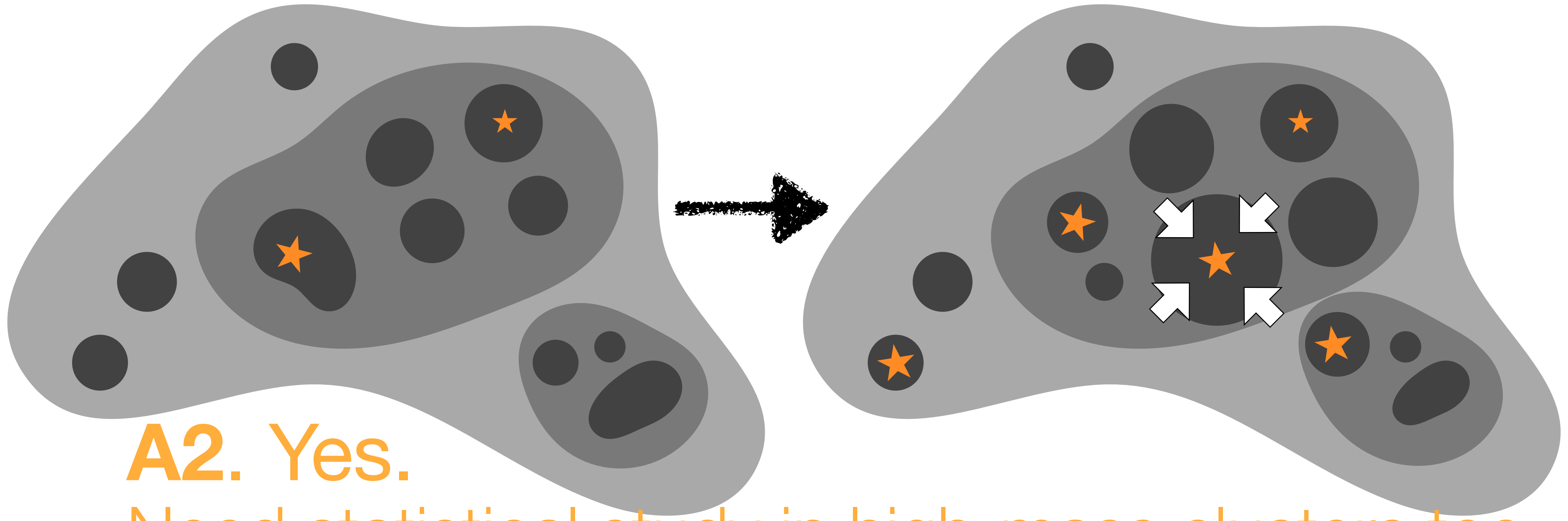


Core Mass

Q1. Do turbulent high-mass prestellar core exists?

A1. No
(at least in 70 μm-dark clouds)

Q2. Low-mass core first?



A2. Yes.
Need statistical study in high-mass clusters too.

Core stability

Q3. Supported by turbulence or B-fields?

A3. Not clear for B-field yet

Q4. Gravitationally unstable?

A4. Yes (especially for more massive cores)

Distribution

Q5. Is there any preferred location of more massive objects?

A5. No significant sign detected.

Gas dynamics

Q6. Is there any sign of gas feeding around core?

A6. Some case studies find them.