

The Role of Hierarchy in Galactic Molecular Clouds: Observational Tests of the Global Hierarchical Collapse

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1. INTRODUCTION

Massive stars form within multiscale gas structures
— **but where is the gas reservoir for their mass set?**

The models disagree:

- A single core — turbulent core (McKee & Tan 2002, 2003)
- The larger hosting structures — competitive accretion (Bonnell+2001, 2004), global hierarchical collapse (GHC; Vázquez-Semadeni+2009, 2019), conveyor belt (Padoan+2020)

The models predict different ways for gas to move and gather across scales.

Tracing how structure and kinematics change across the hierarchy can give observational input on these competing models of massive star formation.

In 13 Galactic star-forming regions, we extract the hierarchy and compare physical properties and star formation activity by position within it.

2. METHOD

Data

¹²CO / ¹³CO (J = 1–0) from FUGIN (Umemoto+2017) for 13 Galactic star-forming regions, smoothed to a common physical resolution of ~1 pc.

Class I/II YSOs from SPICY (Kuhn+2021) and dense clumps from Hi-GAL (Elia+2017, 2021) are used to trace low-mass and high-mass star formation, respectively.

Analysis Method

Dendrogram algorithm (Rosolowsky+2008) is applied to the position-position-velocity cubes, classifying structures (Figure 1.) into:

- Trunk — outermost parental structure
- Branch — intermediate structure (not analyzed here)
- Leaf — densest substructure nested within a trunk
- Isolated — structure with no internal hierarchy

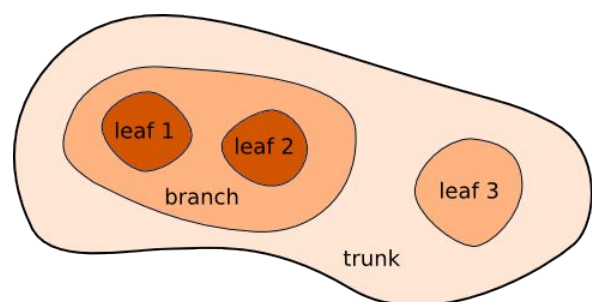


Fig. 1. Hierarchical structure with dendrograms (<https://dendrograms.readthedocs.io>)

Radius, mass, volume density and virial parameter are derived for each, and point sources falling within the projected footprint of a structure are counted as associated.

Type II ANOVA compares the structural categories while controlling for region-to-region differences; the adjusted values in Figs. 4–6 have this regional baseline removed.

3. RESULT: Individual Regions

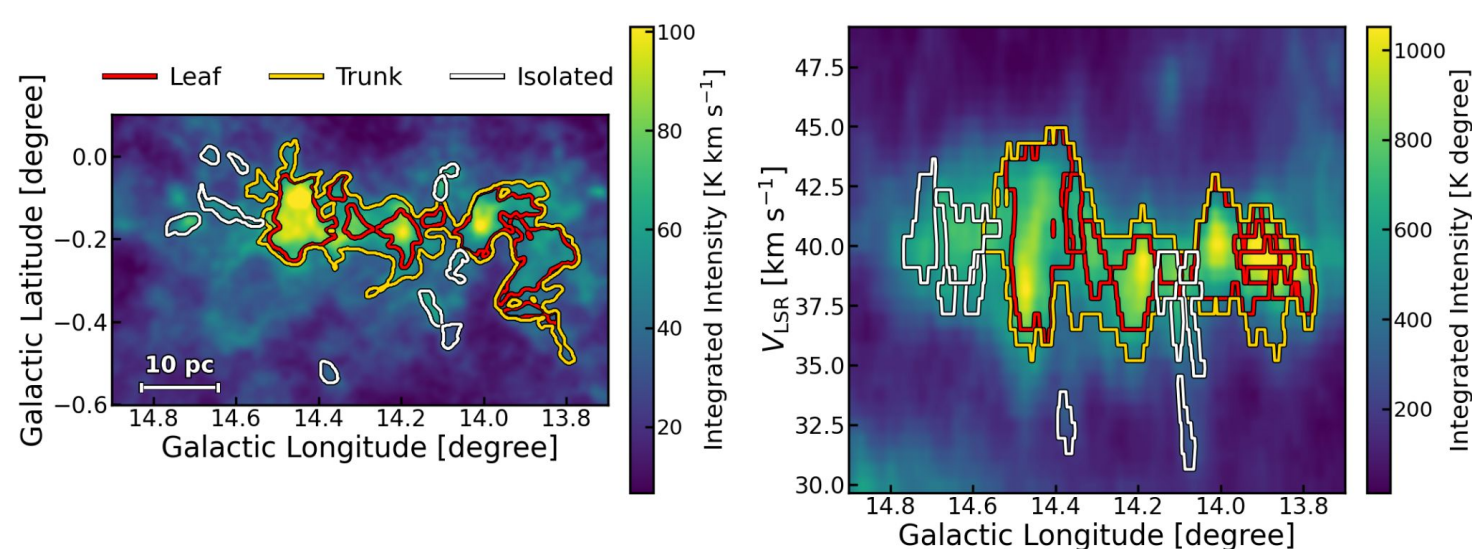


Fig. 2. Position-position (left) and position-velocity (right) diagrams of N14 in ¹³CO(1–0), overlaid with dendrogram structures: trunks (yellow) enclose leaves (red), their densest substructures; isolated structures (white) have no hierarchy

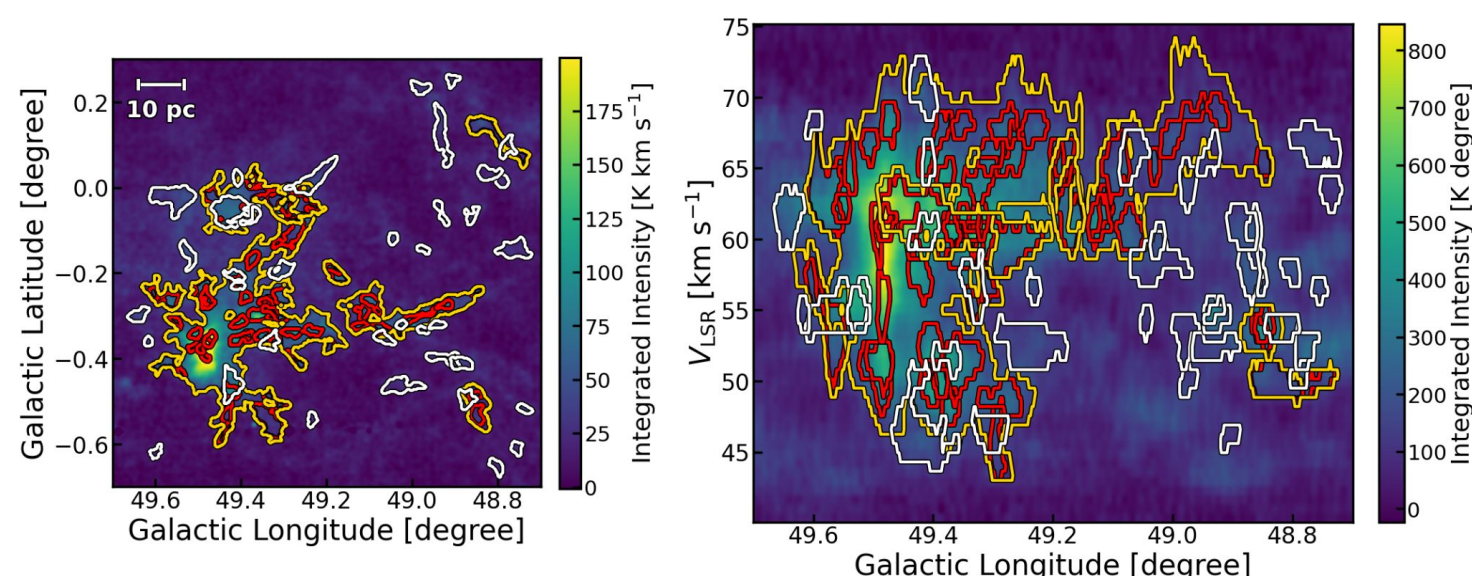


Fig. 3. Same as Fig. 2, but for W51 A

N14 (Figure 2.) — **Trunk traces the filament; leaves sit at the peaks of its oscillatory velocity pattern**, attributed to hierarchical contraction (Dewangan+2020).

W51 A (Figure 3.) — **Trunk spans multiple velocity components joined by a broad bridge**, attributed to a cloud–cloud collision (Fujita+2021); **leaves are scattered across them**.

4. RESULT: Statistical Trends

Physical Properties of Structures

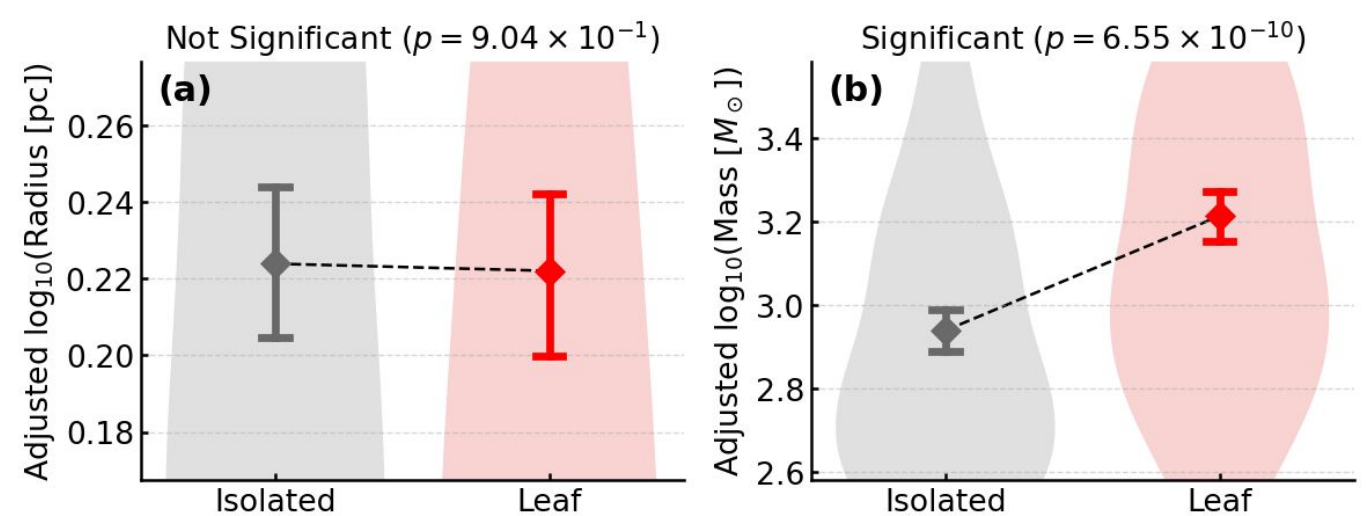


Fig. 4. Adjusted distributions of (left) effective radius and (right) mass for isolated structures and leaves in 13 regions. Violins show the distributions after removing the regional baseline; diamonds and error bars denote the means and their 95% bootstrap confidence intervals.

Leaves and isolated structures share the same radius, **but leaves are more massive and more tightly bound (Figure 4.)**

The trunks hosting them are **larger, more massive and more bound still**.

Number of YSOs / Hi-GAL clumps

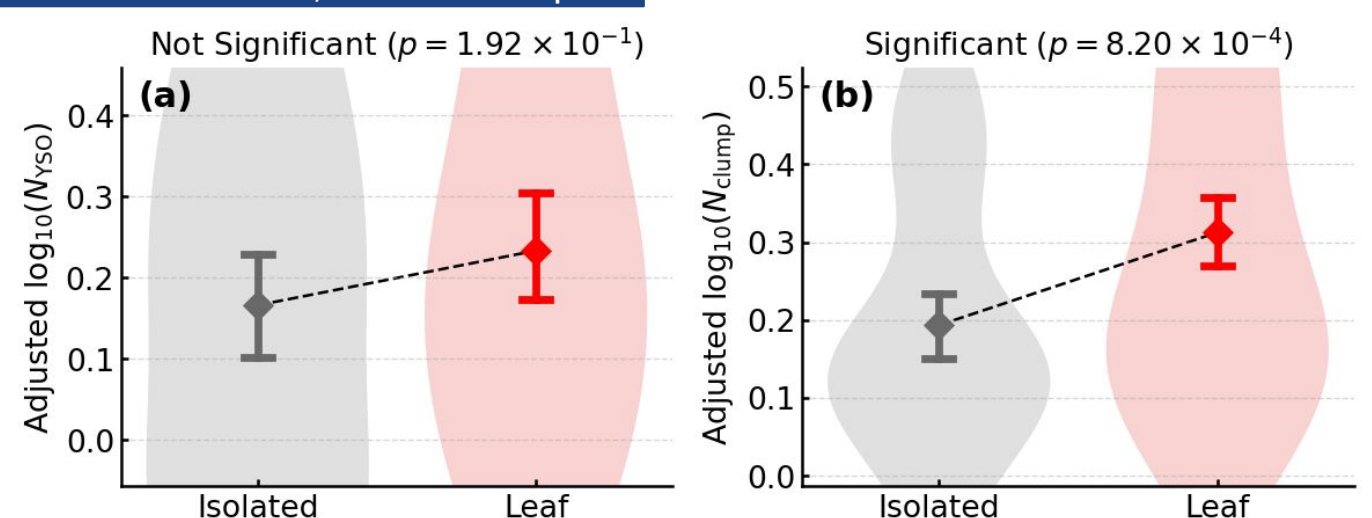


Fig. 5. Same as Fig. 4, but for (left) the number of associated YSOs and (right) Hi-GAL clumps

The number of associated YSOs shows no significant difference between leaves and isolated structures, whereas **leaves contain significantly more Hi-GAL clumps (Figure 5.) at an indistinguishable CFE = $M_{\text{clump}}/M_{\text{gas}}$ (Figure 6.)**.

Since $M_{\text{clump}} = \text{CFE} \times M_{\text{gas}}$, this reflects **the larger gas reservoirs of the leaves rather than a higher conversion rate**.

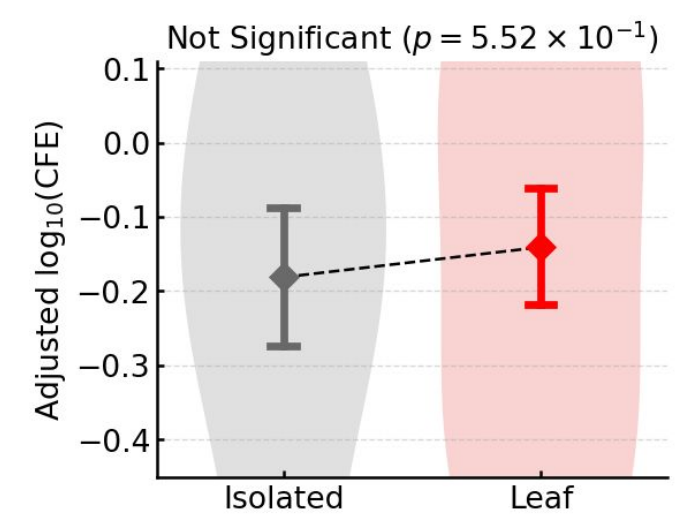


Fig. 6. Same as Fig. 4, but for the clamp CFE.

5. DISCUSSION

Taken together, these contrasts suggest the following scenario (Figure 7):

- **A trunk gathers gas as a large-scale reservoir**, plausibly assembled by arm-driven dynamics such as filament formation and cloud–cloud collisions (e.g. M33; Tokuda+2020). **Within its deep potential, the leaves are fed by inward accretion (e.g. N14, Figure 3) and mutual interaction (e.g. W51 A, Figure 5), growing more massive, denser, and more tightly bound than isolated structures of the same scale (Figure 4).**

- Their densities ($\sim 10^3 \text{ cm}^{-3}$) stay a decade below the star-forming threshold (10^4 cm^{-3} ; Lada+2010), so the YSO count stays flat (Figure 6a); **instead the sustained supply raises the fragmentation mass (Li 2024) and — with CFE unchanged (Figure 6c) — builds massive clumps, not more low-mass stars.**

The leaves differ from isolated structures only in sitting inside a trunk, so the gas reservoir looks like a property of the hierarchy, not the local structure.

This fits the larger-scale-reservoir pictures (competitive accretion, GHC, conveyor-belt) better than the core-scale turbulent-core model.

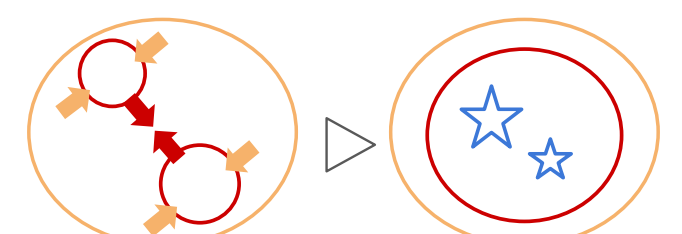


Fig. 7. Schematic of the proposed scenario. The orange ellipse denotes a trunk and the red circles the leaves embedded within it; orange arrows indicate gas inflow onto the leaves, red arrows mutual interactions among them, and blue stars the Hi-GAL clumps.

We offer this as observational input, not a verdict, and each limit points to a next step: at ~1 pc we see where the gas is, not the cores (reaching them would test the turbulent-core picture; Sanhueza+2019); and one epoch cannot tell the larger-scale scenarios apart (multi-tracer velocity diagnostics could; Peretto+2013).

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