Surveying the Dense Gas in Barnard 1 and NGC 1333 from Cloud to Core Scales

CARMA Combined Array for Research in Millimeter-Wave Astronomy

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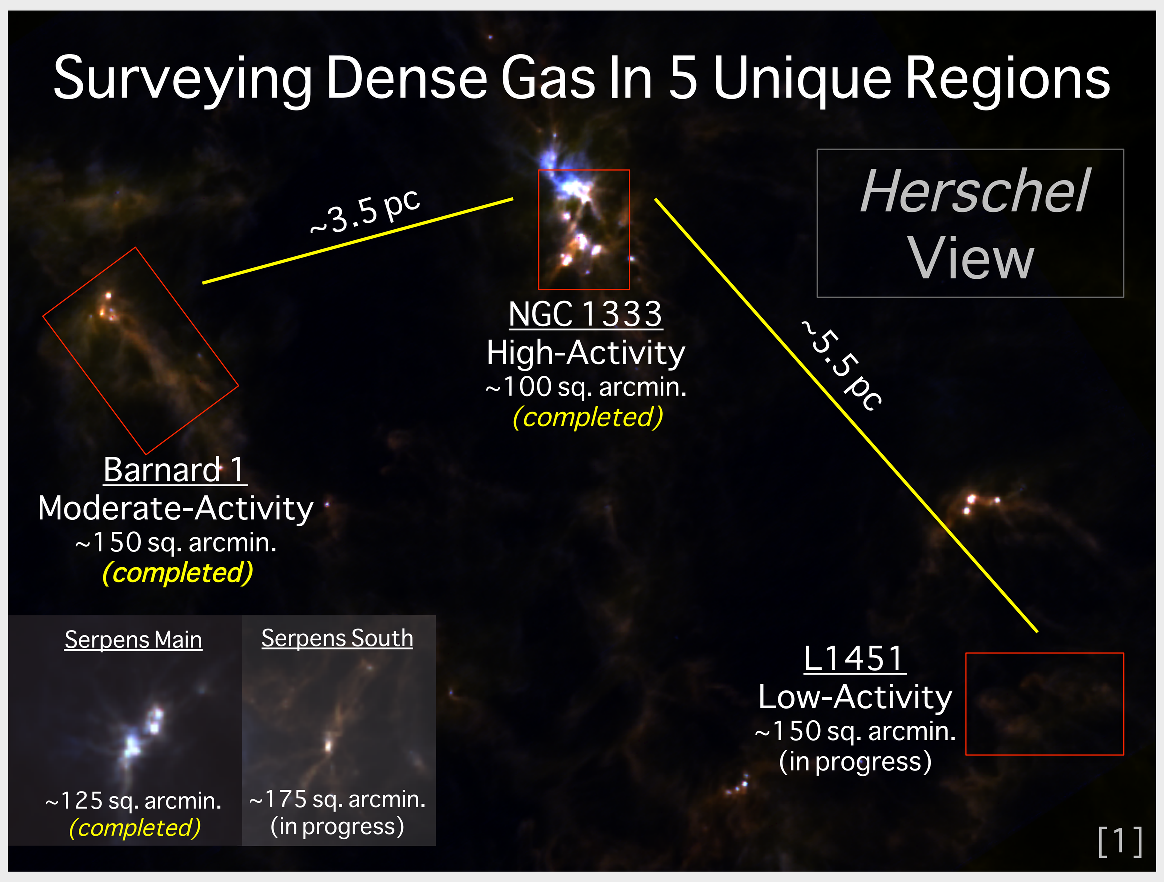
POSTER OVERVIEW

We present an analysis of the turbulent properties of dense gas structures within the Barnard 1 (B1) and NGC 1333 star forming regions, which are two of the five areas being observed in the CARMA Large Area Star formation Survey (CLASSy). CLASSy is mapping large portions of the Perseus and Serpens Molecular Clouds from ~thousand AU to parsec scales using dense gas molecular tracers, thereby probing the gas actively involved in star formation. The focus of this poster is to: (1; left side) Provide an overview of the completed CLASSy fields, and (2; right side) Identify small- and large-scale dense gas structures within B1 and NGC 1333 using a modified dendrogram technique, and then characterize the velocity field within those structures to evaluate their turbulence properties. By probing dense gas turbulence across spatial scales within a single cloud and across clouds at different stages of evolution, we can evaluate the importance of certain turbulence drivers, and test theoretical predictions of turbulence driven filament and core formation.

TAKE AWAY POINTS

- CLASSy is creating a rich dataset of dense molecular gas structure and kinematics in the Perseus and Serpens Molecular Clouds.
- The data will be released to the community upon release of initial papers.
- We derive statistically meaningful samples of gas structures in B1 and NGC 1333 with a new non-binary clustering version of dendrograms.
- Supersonic linewidths in NGC 1333 and the B1 main core, combined with subsonic linewidths in the B1 southern filaments, reveal that turbulence correlates with star formation feedback at spatial scales ~0.01 pc – 0.5 pc.
- The B1 southern filaments are great regions to test the predictions of turbulence driven filament formation and core fragmentation.

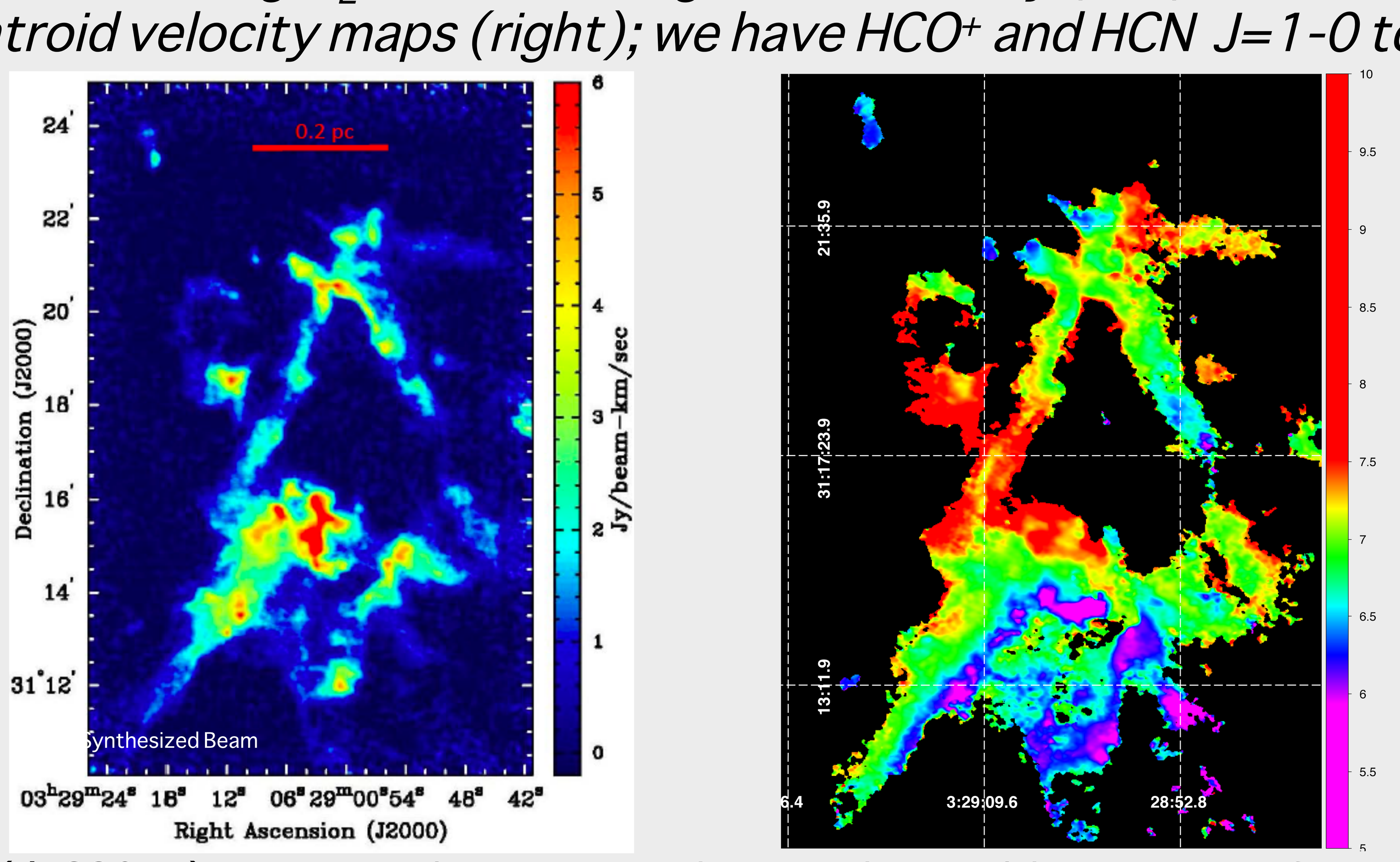
CARMA Large Area Star formation Survey (CLASSy): Overview



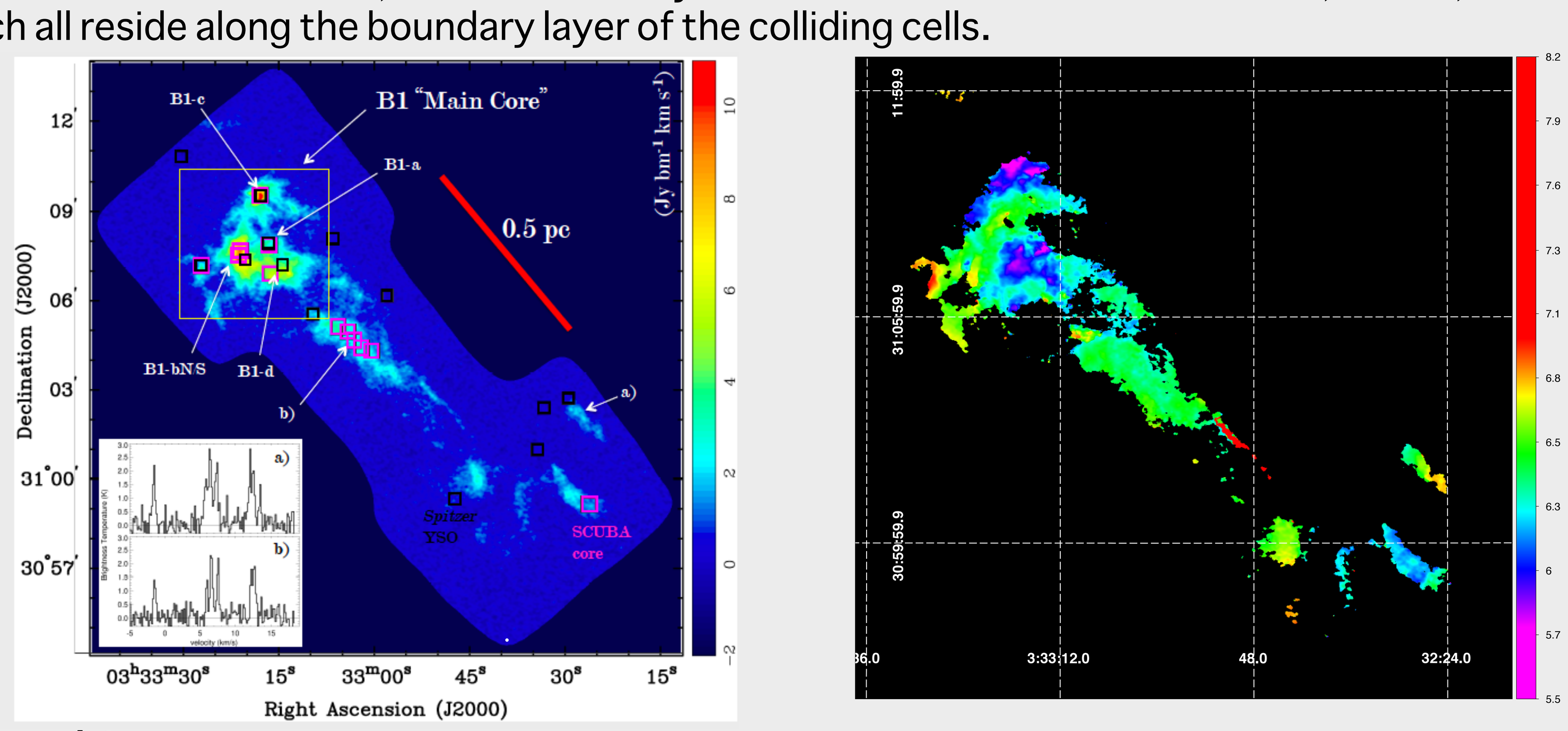
- CARMA D and E arrays
- CARMA 23-dish and single-dish observing
- 700 sq. arcmin. total
- 700 hours total
- Synthesized beam ~6.5'' x 7.5''
- HCN, HCO^+, N_2H^+ J=1-0
- 8 MHz bands; ~0.16 km/s (31 MHz for NGC 1333)
- Sensitivity per channel ~ 130 mJy/bm
- 3 mm continuum
- Sensitivity ~ 1.5 mJy/bm

Gas Structure and Kinematics for Completed CLASSy Regions

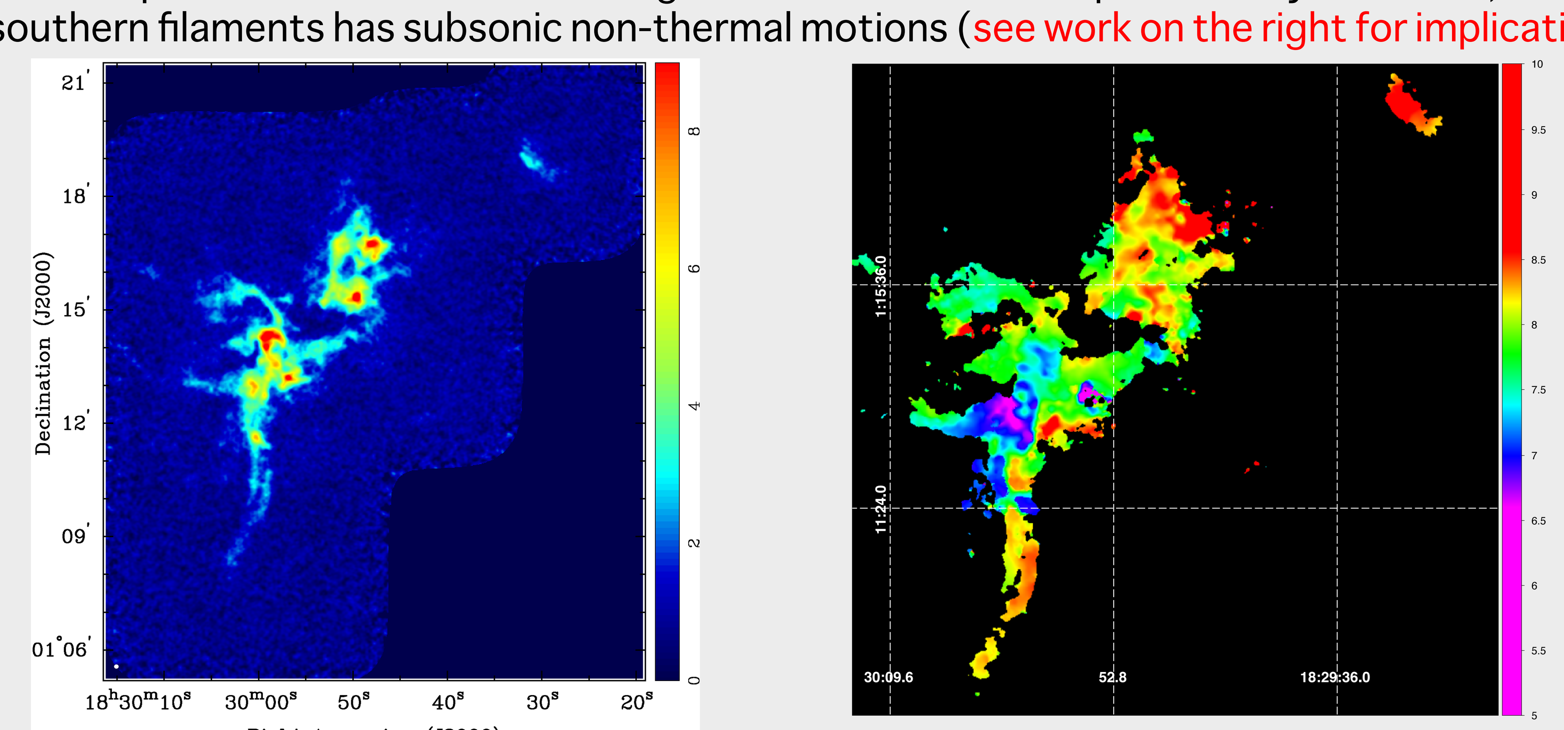
Showing N_2H^+ J=1-0 integrated intensity (left) and centroid velocity maps (right); we have HCO^+ and HCN J=1-0 too!



NGC 1333 (d=230 pc) represents the prototypical active, clustered, low-mass star forming region. One of many interesting features is the southeastern filament that is being created by the collision of large-scale turbulent cells; this collision may have driven the formation of IRAS 4, IRAS 2, and SVS-13, which all reside along the boundary layer of the colliding cells.



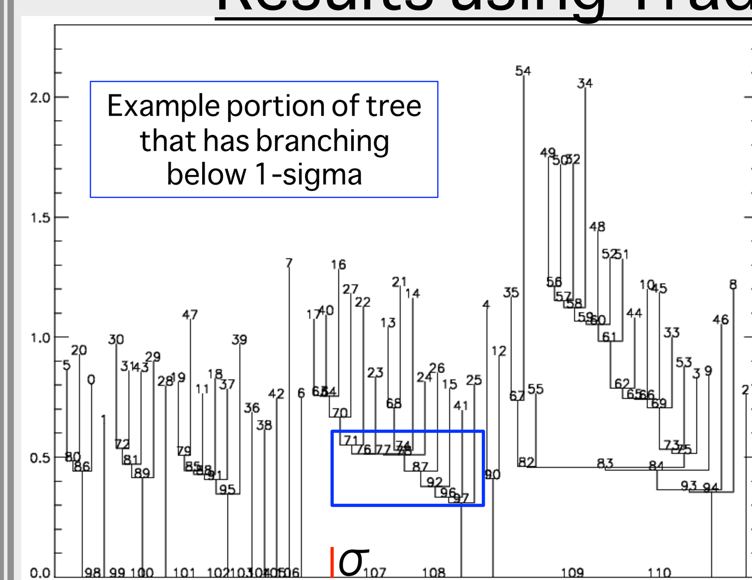
Barnard 1 (d=230 pc) provides the opportunity to study star formation along a gradient of evolutionary stages in a single region of Perseus. The "main core" contains several continuum clumps of cool dust, outflows, and shock activity, while the gas and dust southwest of the main core is much less active. Our spectral data reveals that the gas in the main core is supersonically turbulent, while the gas in the southern filaments has subsonic non-thermal motions (see work on the right for implications).



Serpens Main (d=415 pc) is an active low- to intermediate-mass star forming region. We resolve complex, overlapping filamentary gas structures. We also identify 20 continuum cores, which in combination with the gas structure and kinematics, provide a great test-bed for understanding how the cores may have formed. We can compare to NGC 1333 for a cross-cloud comparison of active regions.

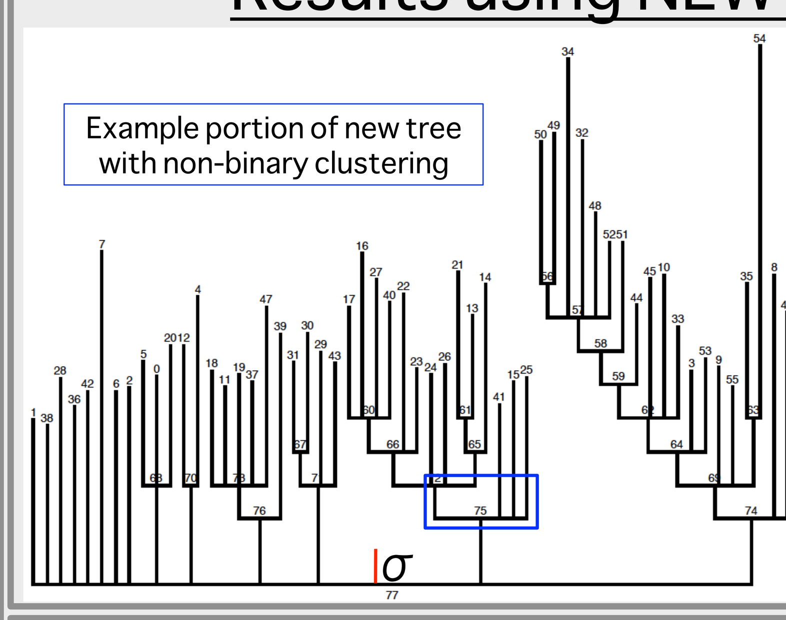
B1 Dense Gas Object Identification Using Dendrograms

Results using Traditional Binary Clustering Code



- A dendrogram decomposition [2,3,4] is the most appropriate method to identify gas structures in nearby molecular clouds with dense, blended hierarchical gas. It captures large- and small-scales, avoiding the small-scale segmentation of a clumpfind-type approach, facilitating an analysis of turbulence across spatial scales.
- However, the standard implementation results in tree branching well below the 1-sigma sensitivity of the data in order to enforce a binary clustering requirement (see left).
- The forcing of binary clustering results in "phantom" branching where > 2 structures should merge considering the noise limitations of real data, and we end up with a collection of branching structures that is not statistically meaningful.

Results using NEW Non-binary Clustering Code

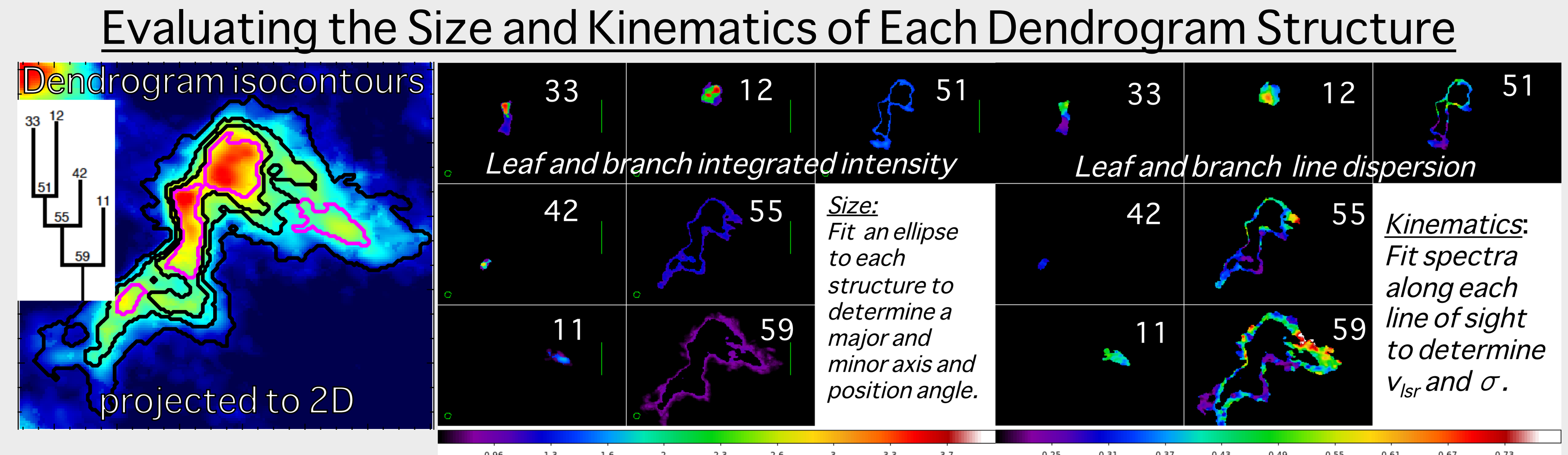


- Our modified code adopts the same single-linkage, agglomerative clustering as before, adding a lot of array gymnastics to keep track of non-binary clustering of tree leaves/branches.
- The new tree (left) represents the observable emission hierarchy within noise limits of our data.
- The result is a more statistically meaningful list of structures not polluted by phantom branching. We use this decomposition below.

(tree drawn with Dendroscope 3 software [5])

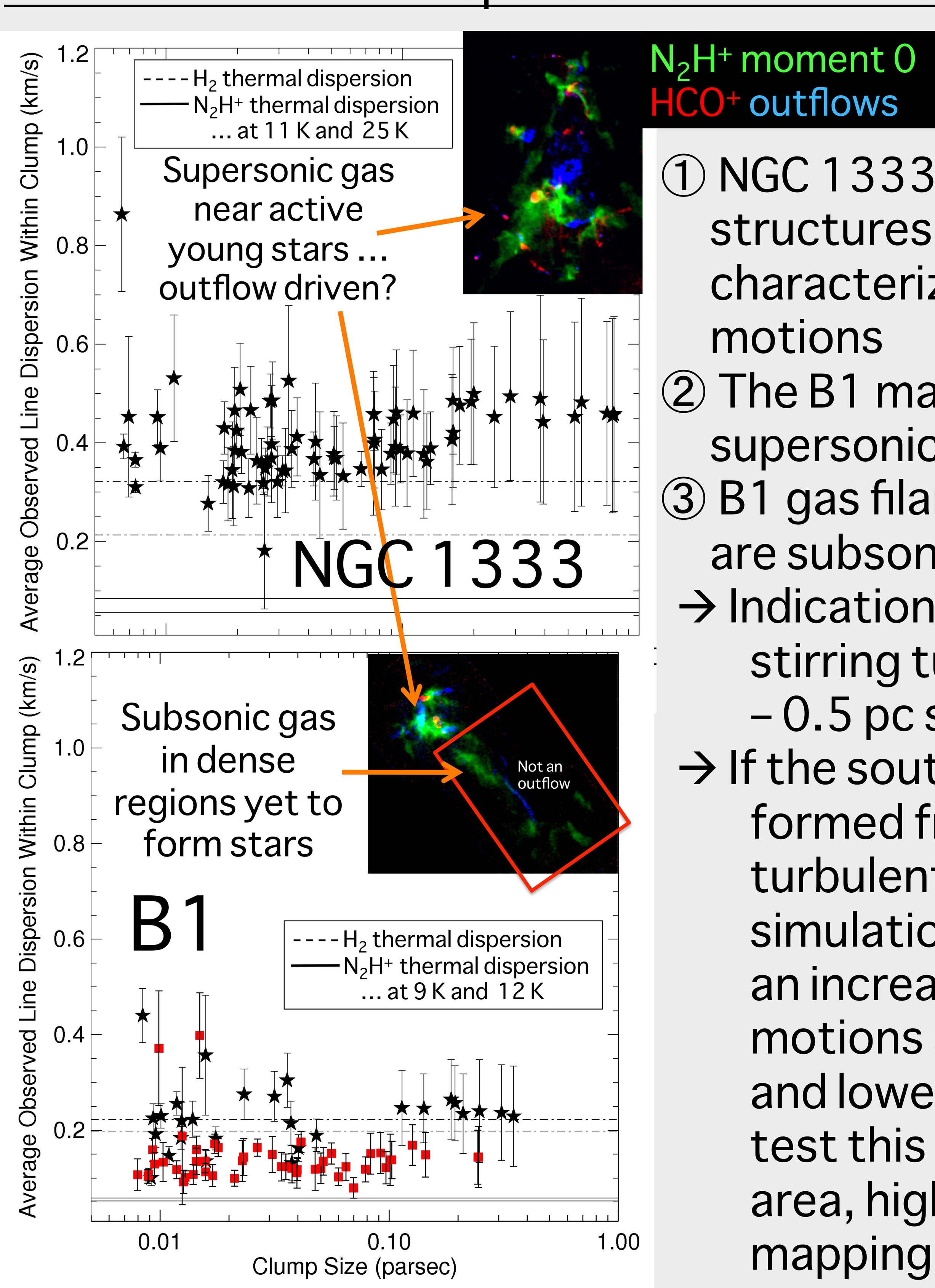
Turbulent Properties of Dendrogram Identified Structures: Comparing B1 and NGC 1333 Dense Gas from ~0.01 – 0.5 pc scales

Evaluating the Size and Kinematics of Each Dendrogram Structure



Above: Illustrating dendrogram structures using the IRAS 2 region of NGC 1333

Results: Mean line dispersion of structure vs. Structure size



① NGC 1333 dense gas structures are nearly all characterized by supersonic motions

② The B1 main core has supersonic gas structures

③ B1 gas filaments to the south are subsonic (red points)

→ Indication that outflows are stirring turbulence on ~0.01 – 0.5 pc scales.

→ If the southern filaments were formed from supersonic turbulent flows, theoretical simulations [e.g., 6] predict an increase of turbulent motions at even larger scales and lower densities ... we will test this with future large-area, high-resolution CARMA mapping projects.

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References: [1] Andre et al. 2010 A&A 518L 102A • [2] Rosolowsky et al. 2008 ApJ 679 1338 • [3] Goodman et al. 2009 Nature 457 • [4] Houlahan & Scalo 1992 ApJ 393 172 • [5] Huson & Scornavacca 2012 Syst Biol 062 • [6] Gong & Ostriker 2011 ApJ 729 120

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