CARMA Large Area Star formation Survey: NGC 1333 SVS-13 Region

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The CARMA Large Area Star-formation Survey Key Project

The CARMA Large Area Star-formation Survey (CLASSy) is a CARMA Key Project which is mapping 5 fields covering more than 100 square-arcminutes each in the Perseus (3 fields) and Serpens (2 fields) Molecular Clouds. The fields were selected to cover the full range of star formation activity in these clouds: from the very active NGC 1333 SVS-13 and Serpens Main regions to the intermediate and very low activity regions of Perseus B1-S and L1451, and Serpens South. The observations are acquired in CARMA 23-element mode with interferometric and autocorrelation data to create fully reconstructed image cubes of the dense molecular gas in the HCN J-1-0, HCO+ J-1-0, and N_2H^+ J-1-0 lines at 7-8 arcsecond resolution.

These data provide a unified, large-area view of the structure and kinematics of the dense gas over regions where many tens of young stars are forming now or may be forming in the future. The multiple transitions create a rich dataset for elucidating connection between the cloud structure/activity, and star formation.

The main goals of CLASSy are to test the predictions of turbulence-driven star formation, to clarify the relationship between the dense gas and young stellar content of clouds, and to study core evolution.

Three of the five regions have completed observations. The other two will be completed by Summer 2013. The image cubes will be made available to the community as the initial data papers are published.

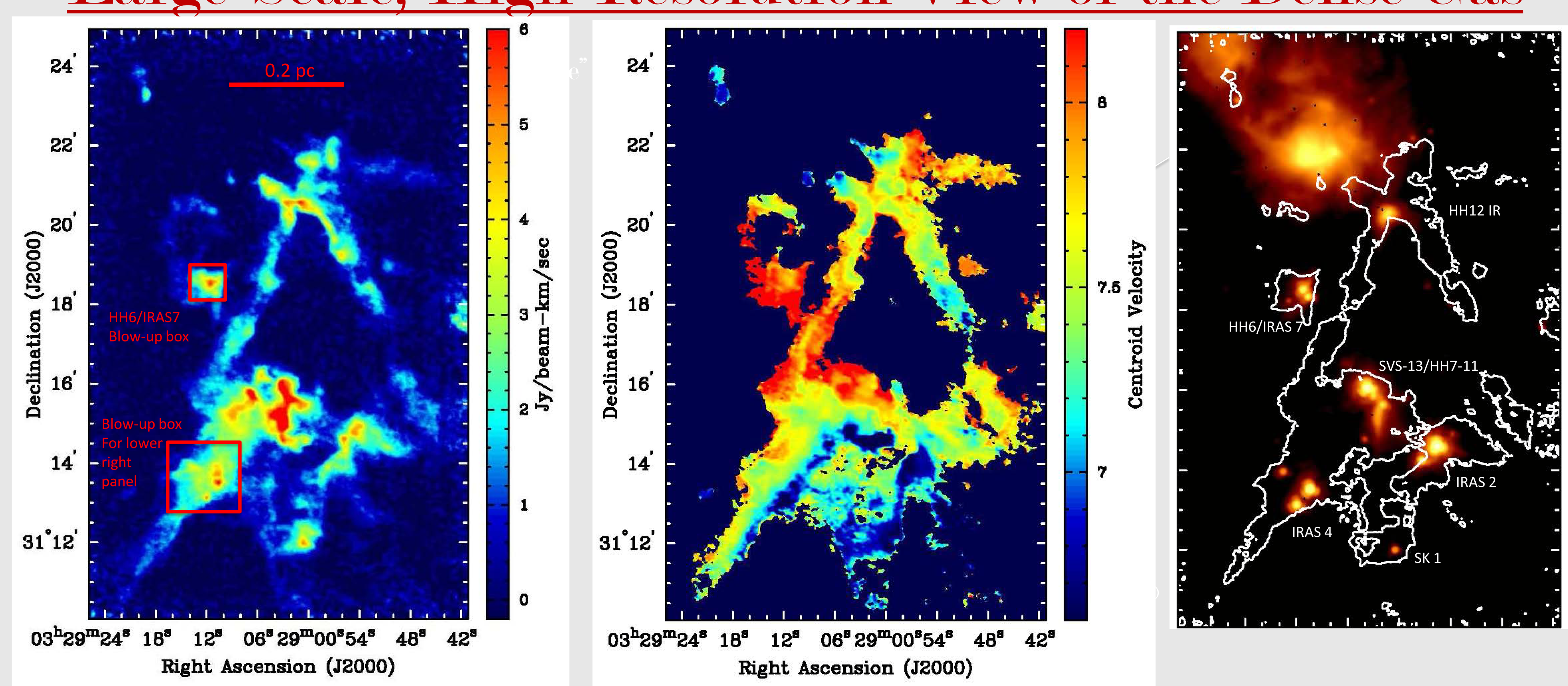
OBSERVATIONS

- CARMA D and E array
- 23-element interferometric and single-dish *(full spatial imaging of molecular lines)*
- Mosaics covering ~ 130 square arcminutes
- Synthesized beam: 8.1" x 6.3"
  - 1700 AU linear resolution at 235 pc
- HCN, HCO^+, N_2H^+ J=1-0
  - 32 MHz bands: ~0.62 km/s resolution
  - Sensitivity per channel ~ 85 mJy/bm
- 3 mm continuum sensitivity ~ 1.5 mJy/bm
- Maximum Entropy Reconstructions

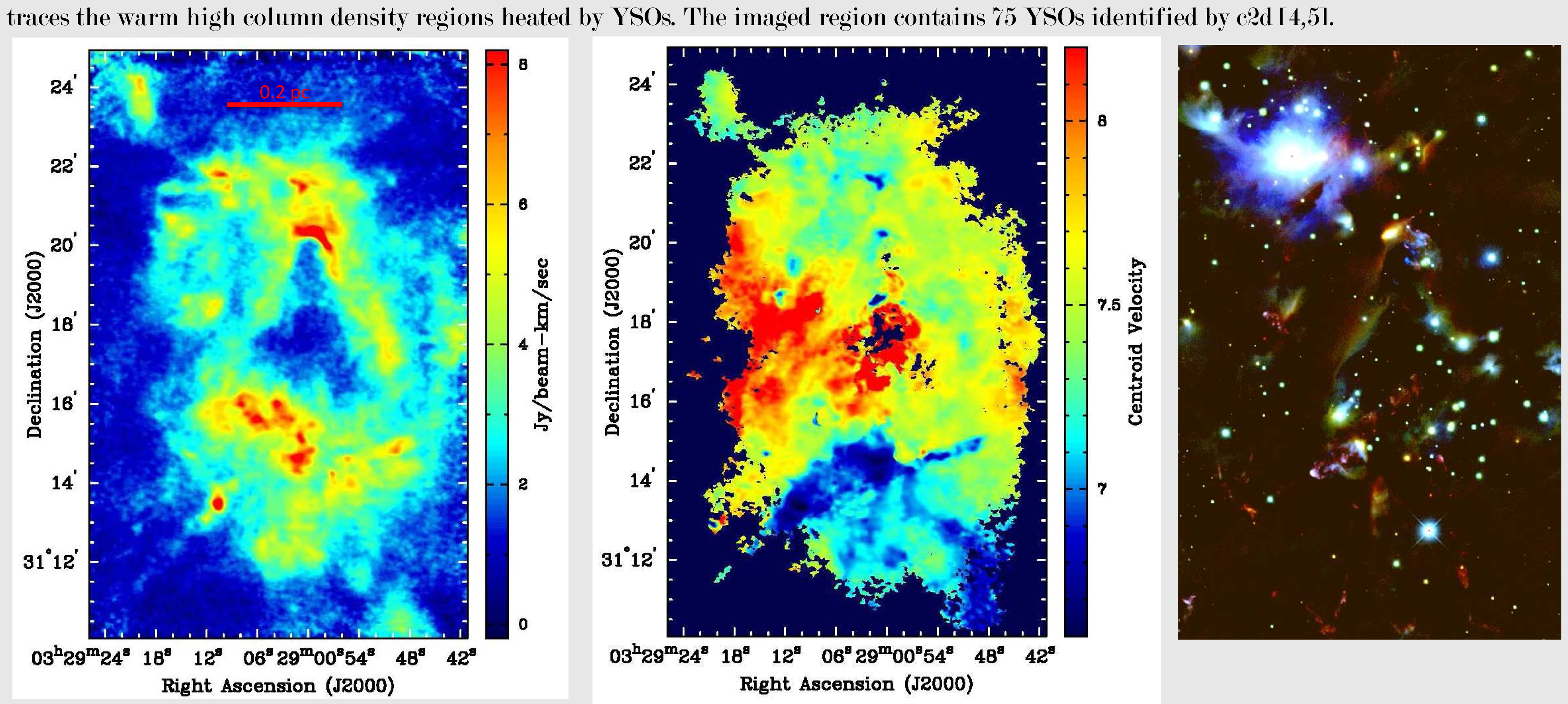
TAKE AWAY POINTS

- The CLASSy is imaging a total of roughly 600 arcminutes in the nearby Perseus and Serpens molecular clouds in the N_2H^+, HCN, and HCO^+ J-1-0 lines which trace the dense gas. The five fields under study span the full range of star formation activity in these clouds. The resulting data cubes provide information on cloud structure and kinematics and the relationship of the dense gas to star formation on the scales from parsec to 2,000 AU: from individual cores to the overall region where many 10's of YSO's are forming.
- We highlighted the HH6/IRAS 7/Per-emb21 core in this poster as an example of the work that can be done on the kinematics of individual cores. The N_2H^+ line, a tracer of cold dense core gas, outlines the core structure and its turbulent nature on the scale of 3,000 AU.
- All three molecules studied here show kinematic structures associated with a prominent filament extending to the southeast from the SVS-13 region which are indicative of a collision which maybe responsible for the filament and the creation of IRAS 4, IRAS 2, and SVS-13.

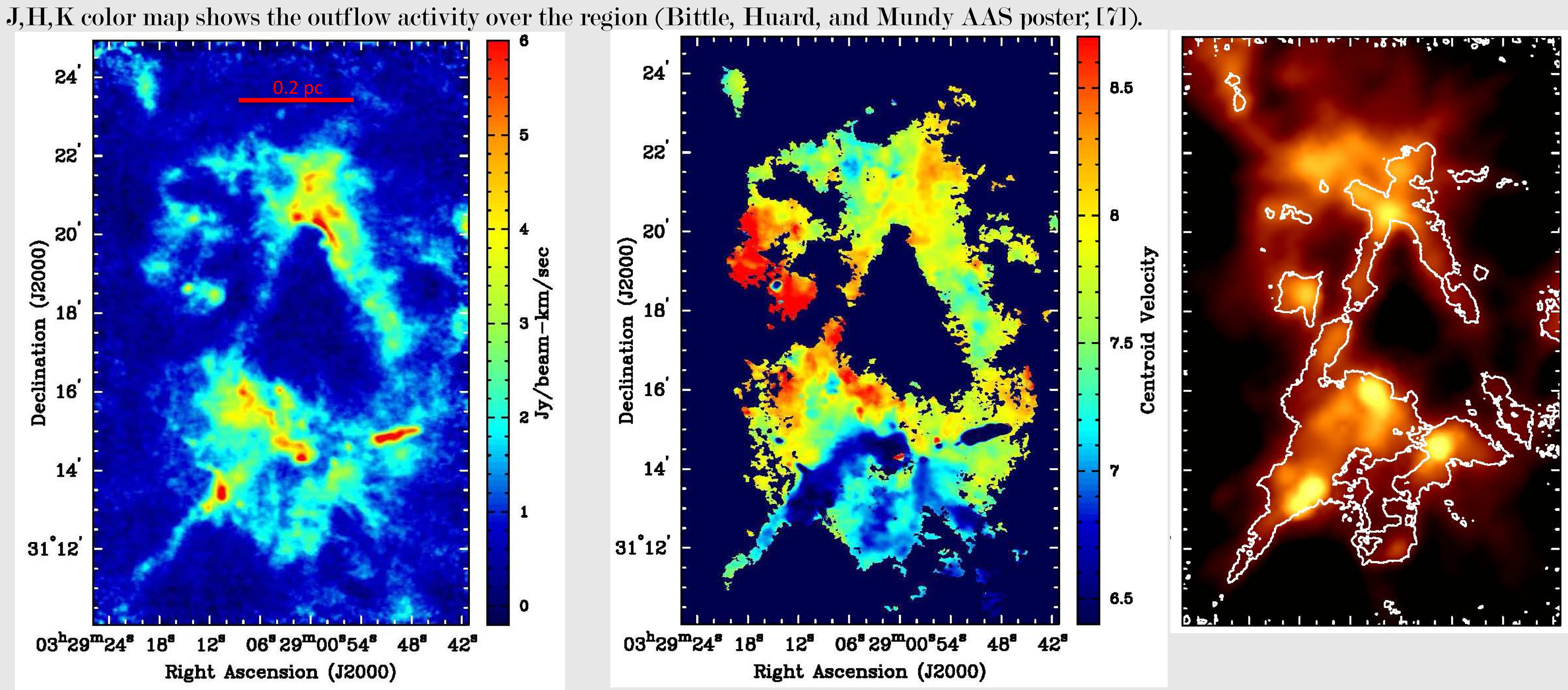
Large-Scale, High-Resolution View of the Dense Gas



N_2H^+ (1-0) Integrated Intensity, Centroid Velocity, and Herschel PACS 100 microns Maps: The left image is the N_2H^+ emission integrated over the main hyperfine component. The center image shows the best-fit centroid velocities; the right image is the Herschel 100 µm emission with 1.5 Jy/beam km/sec contour from the N_2H^+ integrated emission image. N_2H^+ is a tracer of cold dense gas; the 100 µm emission traces the warm high column density regions heated by YSOs. The imaged region contains 75 YSOs identified by c2d [4,5].

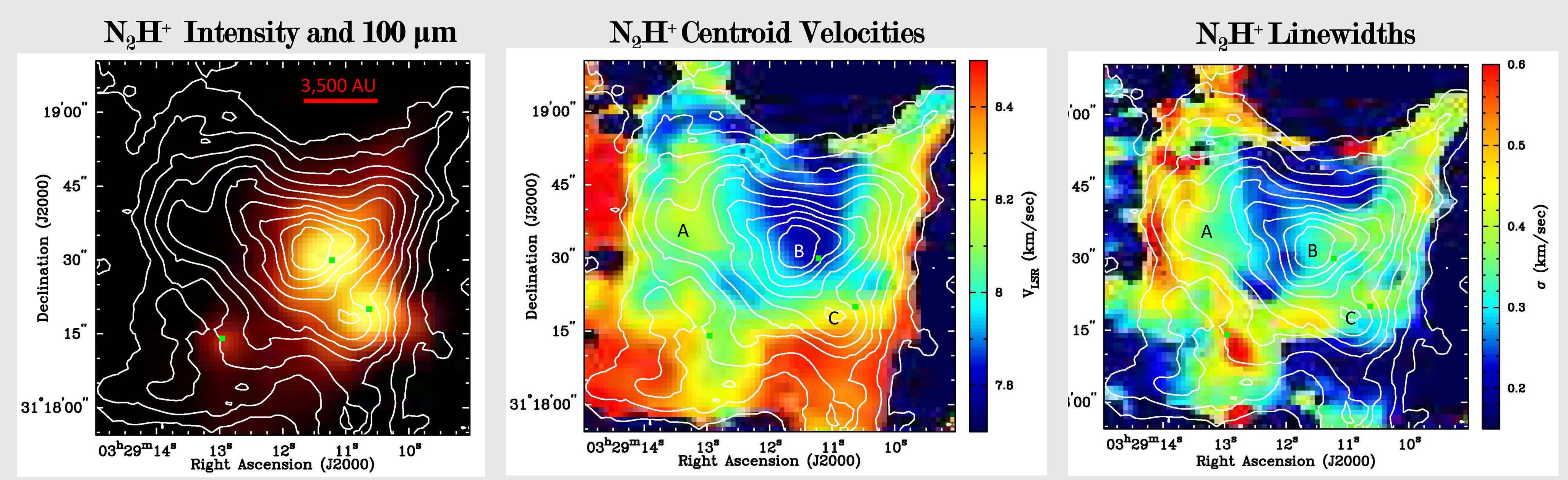


HCO^+ (1-0) Integrated Intensity ,Velocity Centroid, and J,H,K 3-Color Maps: The HCO^+ (left) integrated emission and velocity centroid (center) maps are shown; we exclude outflow channels here. The HCO^+ is more extended but shows similar structure and kinematics to N_2H^+. The J,H,K color map shows the outflow activity over the region (Bittle, Huard, and Mundy AAS poster, [7]).



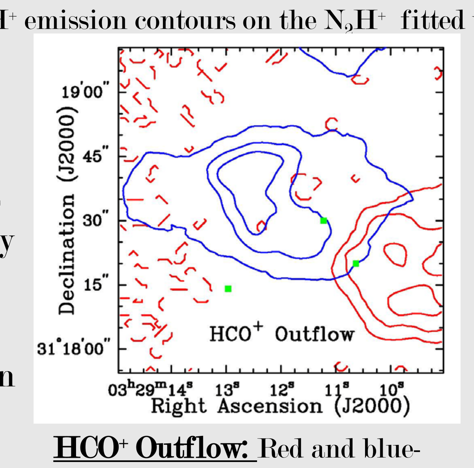
HCN (1-0) Integrated Intensity Velocity Centroid, and Herschel SPIRE 350 µm Maps: The left figure is the HCN integrated emission over the core of the main hyperfine component. The center figure is the fitted central velocity. The right figure is the Herschel 350 µm emission with a N_2H^+ contour overlaid for comparison. The HCN emission in intermediate in extent compared to HCO^+ and N_2H^+; the brightest emission features are associated with outflows. The 350 µm traces the cool dust and gas with the brightest emission toward YSO heated regions.

Studying the Dense Gas in Cores: HH6/IRAS 7

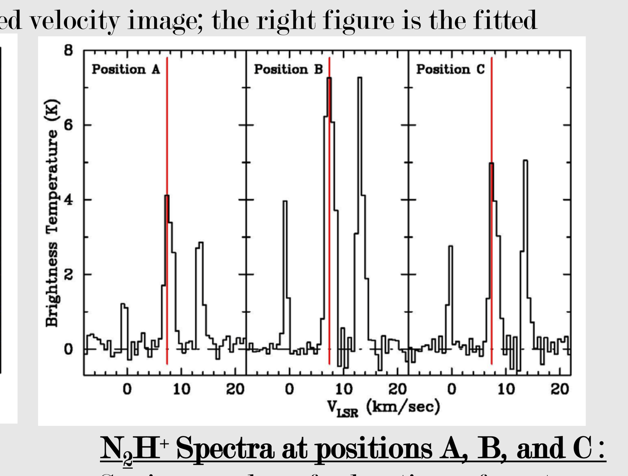


HH6/IRAS7/Per-emb21 Core: The left image is an overlay of N_2H^+ integrated emission contours on the Herschel 100 µm image. The green squares are the YSO locations based on 24 – 160 µm data. The center image is an overlay of the N_2H^+ emission contours on the N_2H^+ fitted velocity image; the right figure is the fitted velocity width expressed as the Gaussian σ (not FWHM).

The Per-emb21 core, associated with HH6 and IRAS 7, is estimated to have 3 solar masses of gas/dust and contains three Class 0 YSOs (green squares) [2]. The northern YSO is the reddest and appears at the center of the HCO^+ outflow; the total luminosity of the core is ~3 solar luminosities. The spectra (right), for the three locations indicated on the center and right figures, show the narrow line widths and velocity shifts of up to 0.5 km/sec as seen in the velocity centroid map (center). The velocity variation indicate supersonic turbulence and perhaps asymmetric accretion [6].



HCO^+ Outflow: Red and blue-shifted lobes of low velocity outflow.



N_2H^+ Spectra at positions A, B, and C: See images above for locations of spectra.

Investigating the Cascade of Structure

A primary goal of the CLASSy project is to capture simultaneously large scale and small scale structure and kinematics of the cloud in order to follow the origins and evolution of structure from parsec to 2,000 AU scale. The SVS-13 region has been studied extensively (e.g. [1,8]) but the CLASSy data provide a unique new view.

The fitted velocity maps (middle figure in panel to the left) show a large scale velocity structure along the lower 1/3 of the image in each molecule. Several of the prominent Class 0 YSO groups, IRAS2, IRAS4, and SVS-13, fall along this velocity transition region.

The images to the right show blow-ups (lower red box in the N_2H^+ velocity figure in the panel to the left) of the fitted V_{LSR} and σ Gaussian velocity width for the N_2H^+, HCO^+, and HCN emission across this velocity feature.

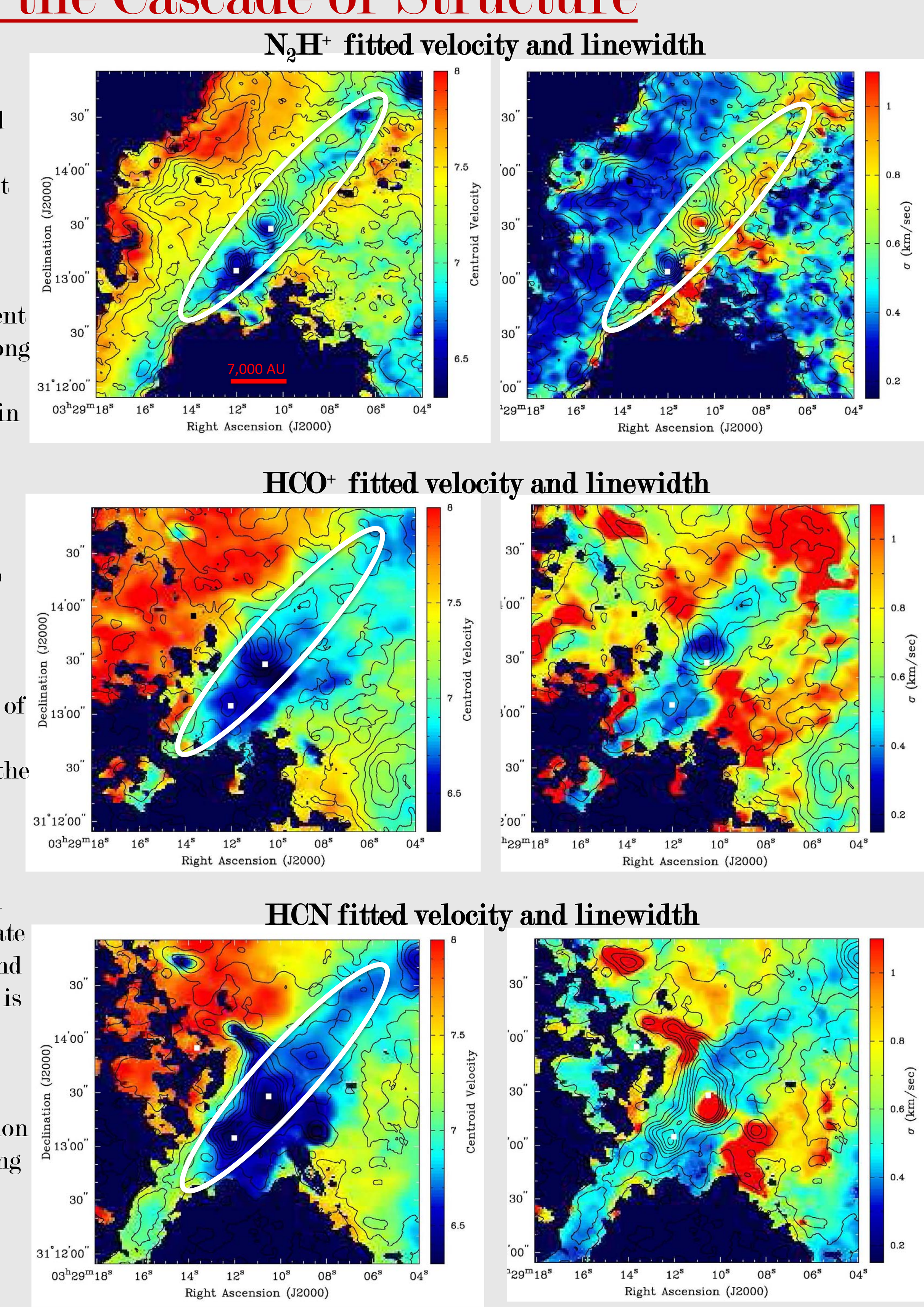
The three lines show a common velocity pattern:
- a diagonal swath of 6.8-6.9 km/sec (white ellipse)
- velocities of 7.3 km.sec below that swath
- velocities of 7.5-8.0 km/sec above the swath.

The lines show a different pattern in σ:
- N_2H^+ shows increased linewidth along the swath of low velocity: up from 0.4 to 0.7 km/sec
- HCO^+ and HCN have decreased linewidth along the swath: down from 0.8 to 0.5 km/sec.

The low velocity and high linewidth swath in N_2H^+ follows the southwestern edge of the strong filament of N_2H^+ emission stretching from NW to SE This diagonal filament is not distinct in HCO^+ emission and intermediate strength in HCN emission. The Herschel 350 µm (left) and JCMT SCUBA-2 images [3] clearly show the filament; it is not present in the Herschel 100 µm image. Hatchel et al estimate a dust temperature of 10-12 K.

The similar structure in 350 µm and N_2H^+ emission indicates the filament is a cold, high column density region of dense gas. The N_2H^+ emission reveals the collision along the SW side of the filament which causes the increased linewidth. Moving to NW across the filament, the N_2H^+ linewidth decreases indicating that the highest column density regions of the filament are quiescent.

Bottom line: the filament being created by the collision of large scale turbulent cells; this collision may have driven the formation of IRAS 4, and IRAS2 and SVS-13.



N_2H^+, HCO^+ and HCN Velocity and Gaussian σ: The left figure in the three rows above is the fitted velocity; the right panel is the fitted linewidth. The white ellipse is the swath of low velocity discussed in the text. The white squares are IRAS4 A, B, and C.

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References: [1] Curtis and Richer 2010 MNRAS, 410, 75 · [2] Enoch et al 2007 ApJ, 692, 973 · [3] Hatchel et al 2012 MNRASL · [4] Jorgensen et al. 2006 ApJ 645 1246 · [5] Rebull et al ApJS, 171, 447 · [6] Smith et al. ApJ, 750, 64 · [7] Walawender et al. 2005 ApJ 130 1795 · [8] Walsh et al 2007 ApJ, 655, 958