CARMA Surveys of Nearby Clouds

CLASSy Primary Team Members:

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http://carma.astro.umd.edu/classy
NGC 1333, B1, and L1451 in Perseus Regions in $\text{N}_2\text{H}^+$

Integrated Intensity maps

NGC 1333

Barnard 1

L 1451

7” resolution 130-150 amin$^2$
Serpens Main and Serpens South in $\text{N}_2\text{H}^+$

Integrated Intensity

$7''$ resolution
Kinematics of the Gas in NGC 1333

Integrated Intensity

Velocity Centroid

7” resolution
Serpens Main Velocity Centroid and Line width

Integrated Intensity

Velocity Centroid

Lee et. al. 2014
Serpens Main: $N_2H^+$, $HCO^+$, HCN

- $N_2H^+$ most complex and shows the most obvious filamentary structures
- $HCO^+$ and HCN show more extended structures
- $HCO^+$ and HCN most affected by foreground, low-density gas

Lee et. al. 2014
Serpens Main

$N_2H^+$ contours with YSOs from Spitzer c2d catalog

Lee et al. 2014

$N_2H^+$ contours on Herschel 250 microns image

RA (J2000)

DEC (J2000)

Right Ascension (J2000)

Declination (J2000)
CARMA Large Area Star formation Survey (CLASSy)

Three publications this year:

- **Fernandez-Lopez** et al. 2014 ApJL – Serpens South N$_2$H$^+$ J=1-0 filaments

FITS cubes of the data are associated with the paper and available from ApJ links in the on-line papers for Barnard 1 (now) and Serpens Main (when it appears)
Motivation: to follow the structure and kinematics of the gas from parsec to 2,000 AU scales to get a complete picture and see the relationship to star formation.

Science Issues

Connectivity of Cloud-to-Core Structure

3D Structure of Clouds

Filament Formation

Cover enough area and a range of star formation activity to see the pathways to structure formation.
Dense gas cores are more complexly nested in NGC 1333 compared to Barnard 1; L1451 dense gas shows no hierarchical structure.

See Shaye Storm’s Poster
Size-Linewidth Relations Reveal Cloud Depth

Δ\(V_{\text{lsr}}\) vs. Projected Size

\(<\sigma>_{\text{nt}}\) vs. Projected Size

Revealing the 3D structure of clouds

See Shaye Storm’s Poster
Filament Formation

Serpens Main and South: $\text{N}_2\text{H}^+$ Herschel Filaments

See poster by Katherine Lee
$\text{N}_2\text{H}^+$ is correlated with cool filaments
Filament Formation

Serpens South
$N_2H^+$
Integrated Intensity

Herschel contours

Fernandez-Lopez et al. (2014)
Serpens South
$N_2H^+$
Integrated
Intensity

Fernandez-Lopez et al. (2014)
CLASSy has discovered a number of filaments with similar kinematic signature (not all)

NGC 1333
0.32 pc

Serpens South
0.4 pc

L1451
0.15 pc

Serpens South
0.5 pc

Serpens Main
0.2 pc

Barnard 1
0.25 pc
Filament width = 0.08 pc
$V_{lsr}$ difference = 0.3 km/s
Turbulence and gravity create structure on the wide range of scales seen in observations.

Want to observationally capture parsec-scale cloud structure + sub-0.1 pc filament and core structure *along with gas motions*.
Filament Formation

example filaments (with $n \geq 10^5$ cm$^{-3}$)

Chen & Ostriker (2014)
Simulated filament M/L and Dynamics

M/L = 20 M\(_\odot\)/pc

V\(_{\text{lsr}}\) difference across width = 0.1 km/s

Chu-Yu Chen’s talk
Comparing CLASSy and simulated filaments

Can calculate the dimensionless coefficient:

\[ C = \frac{\Delta v_b^2}{G M_R/L} \]

- \( C \sim 1 \) gravity-induced velocity gradient
- \( C \gg 1 \) turbulence-dominated structure
Comparing CLASSy and simulated filaments

Gradient a signature of gravity induced inflow of material from a dense, flattened, post-shock layer in a turbulent cloud.

Chu-Yu Chen’s talk
Serpens South Northwest Filament
J=1-0
vs.
J=3-2

- Assume uniform density cylinder with: \( n \sim 1.8 \times 10^5 \text{ cm}^{-3} \), \( r=0.04 \text{ pc} \)
  \[ M/L = 61 \text{ M}_\odot/\text{pc} \]

\( \text{N}_2\text{H}^+ \) J=3-2 observations with the ARO 10-m
Comparing CLASSy and simulated filaments

\[ C = \frac{(0.1 \text{ km/s})^2}{G \times 20 \, M_\odot/\text{pc}} \approx 0.1 \]

\[ C = \frac{(0.3 \text{ km/s})^2}{G \times 61 \, M_\odot/\text{pc}} \approx 0.4 \]

\[ C \leq 1 \text{ for both observed and simulated filaments} \]

Can calculate the dimensionless coefficient:

\[ C = \frac{\Delta v_h^2}{GM_R/L} \]

- \( C \sim 1 \) gravity-induced velocity gradient
- \( C \gg 1 \) turbulence-dominated structure
Role of Filaments in Core/Star Formation

Filaments are growing in mass and density by inflow dominately from a 2-D dense layer.

Filaments with observed gradients are generally growing in mass and should become unstable to local gravitational collapse to form protostars.
CLASSy 2 – Follow-up Isotopic Work

Focussed on filaments -- 250 hours of CARMA time – just started

- $^1$H$^{13}$CO$^+$, $^1$H$^{13}$CN, HNC J=1-0
- C$^{18}$O J=1-0, $^{13}$CO J=1-0, HC$_3$N J=12-11
- Plan to map 5-7 filaments

Lee et. al. 2014
CLASSy 2 – Results on First Filament

$^\text{13}\text{C}^+\text{O}^+$ shows very similar kinematics to $\text{N}_2\text{H}^+$

Serpens Main – East Filament

Integrated Intensity

Velocity Centroid

$^\text{13}\text{C}^+\text{O}^+$

Integrated Intensity

Velocity Centroid

$\text{N}_2\text{H}^+$
CARMA Orion and North American Neb

Goal: To follow the cloud structure from 6-8 pc to 0.012 pc in:
- the diffuse molecular gas (12CO and 13CO)
- warm dense gas (CS and C180)
- the cold dense gas (CN)

People: John Bally (Colorado), John Carpenter (Caltech, PI), Rachel Friesen (Toronto), Adam Ginsburg (Colorado), Paul Goldsmith (Caltech/JPL), Chihomi Hara (NAOJ), Andrea Isella (Caltech), Doug Johnstone (NRC), Jens Kauffmann (Caltech), Ryoheki Kawabe (NAOJ), Ralf Klessen (Heidelberg), Darek Lis (Caltech), Peregrine McGehee (Caltech/IPAC), Fumitaka Nakamura (NAOJ), Volker Ossenkopf (Cologne), Paolo Padoan (Bacelona), Thushara Pillai (Caltech), Jorge Pineda (Caltech/JPL), Rene Plume (Calgary), Peter Schilke (Cologne), Yoshito Shimajiri (NAOJ), Jon Swift (Caltech)
Summary

**CLASSy**

Papers and data are being published. FITS data cubes linked to published papers. 7” resolution information on the dense gas distribution and kinematics – including filaments!

**Cloud Structure and kinematics**

Dendrograms provide a useful methodology for characterizing the structure in the dense gas, and reveal new insights into clouds.

See poster by Shaye Storm

**$\text{N}_2\text{H}^+$ and filaments**

$\text{N}_2\text{H}^+$ is a good tracer of the dense gas structure and of cold filaments. $\text{N}_2\text{H}^+$ kinematics shows cross-filament velocity gradients in a number of filaments.

See posters by Shaye Storm and Katherine Lee

**Evidence for turbulent formation of filaments**

Simulations of turbulent clouds form filaments which show kinematics similar to those of observed filaments. The conclusion is that at least some filaments form in 2-D dense layers and accrete material mainly from the dense layer.

Upcoming talk by Che-Yu Chen