CARMA Surveys of Nearby Clouds

CARMA Large Area Star-formation Survey

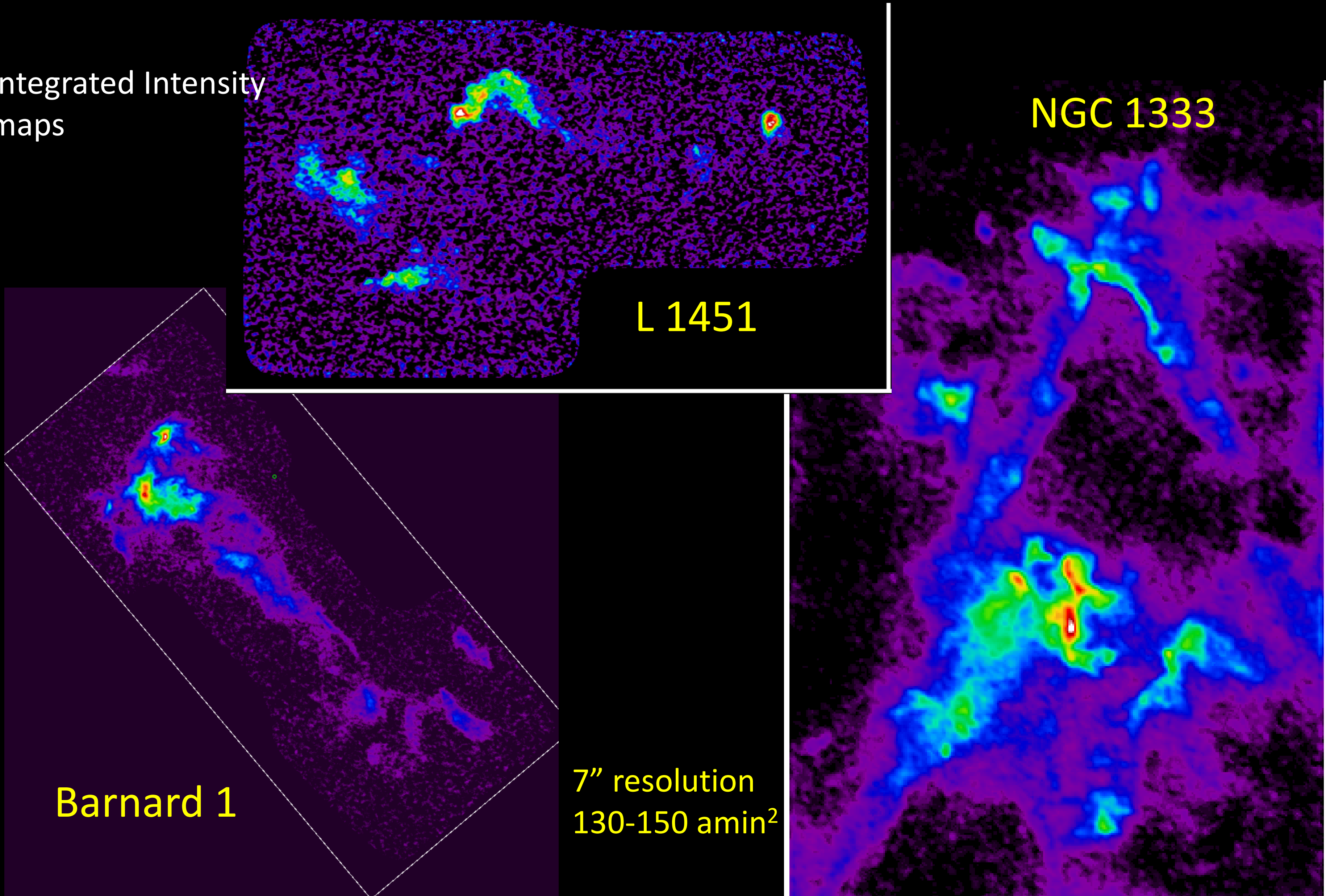
CLASSy Primary Team Members:

- Lee Mundy, Shaye Storm, Peter Teuben, Katherine Lee, Che-Yu Chen (U. Maryland)
- Leslie Looney, Manuel Fernandez-Lopez, Dominique Segura-Cox (U. Illinois)
- Hector Arce, Adele Plunkett (Yale)
- Erik Rosolowsky (U. Alberta)
- Eve Ostriker (Princeton)
- John Tobin (NRAO/Leiden)
- Yancy Shirley (U. Arizona)
- Andrea Isella (Caltech)

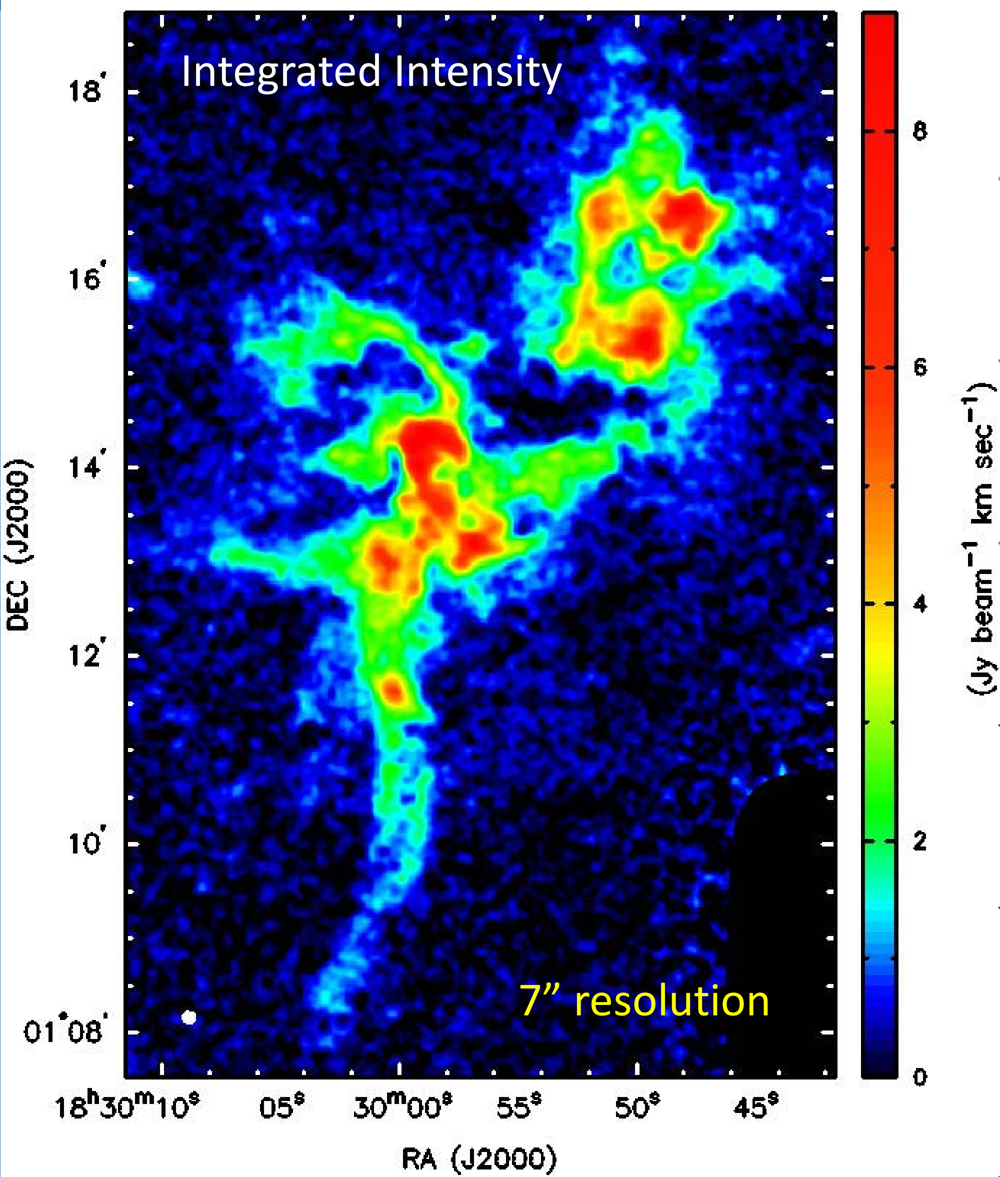
http://carma.astro.umd.edu/classy

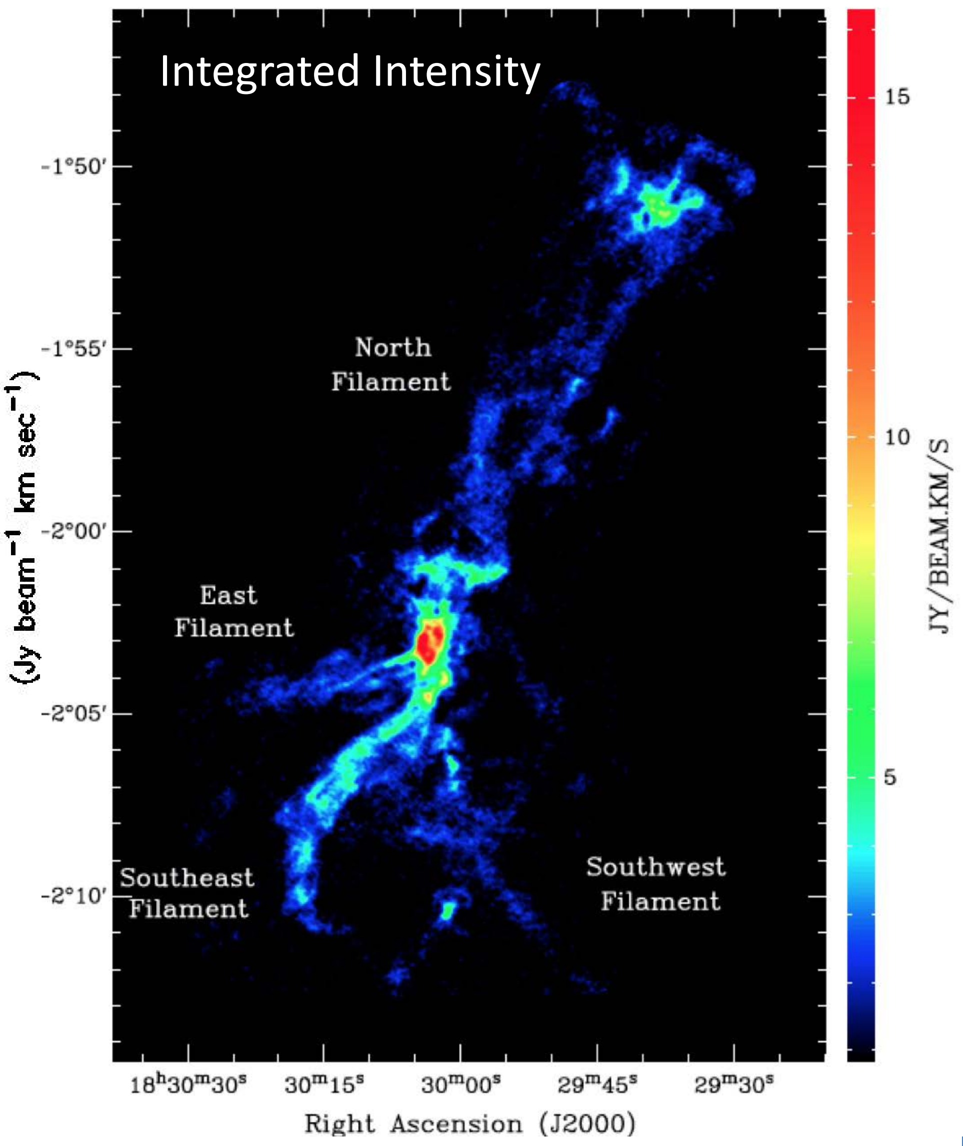
NGC 1333, B1, and L1451 in Perseus Regions in N_2H^+

Integrated Intensity maps

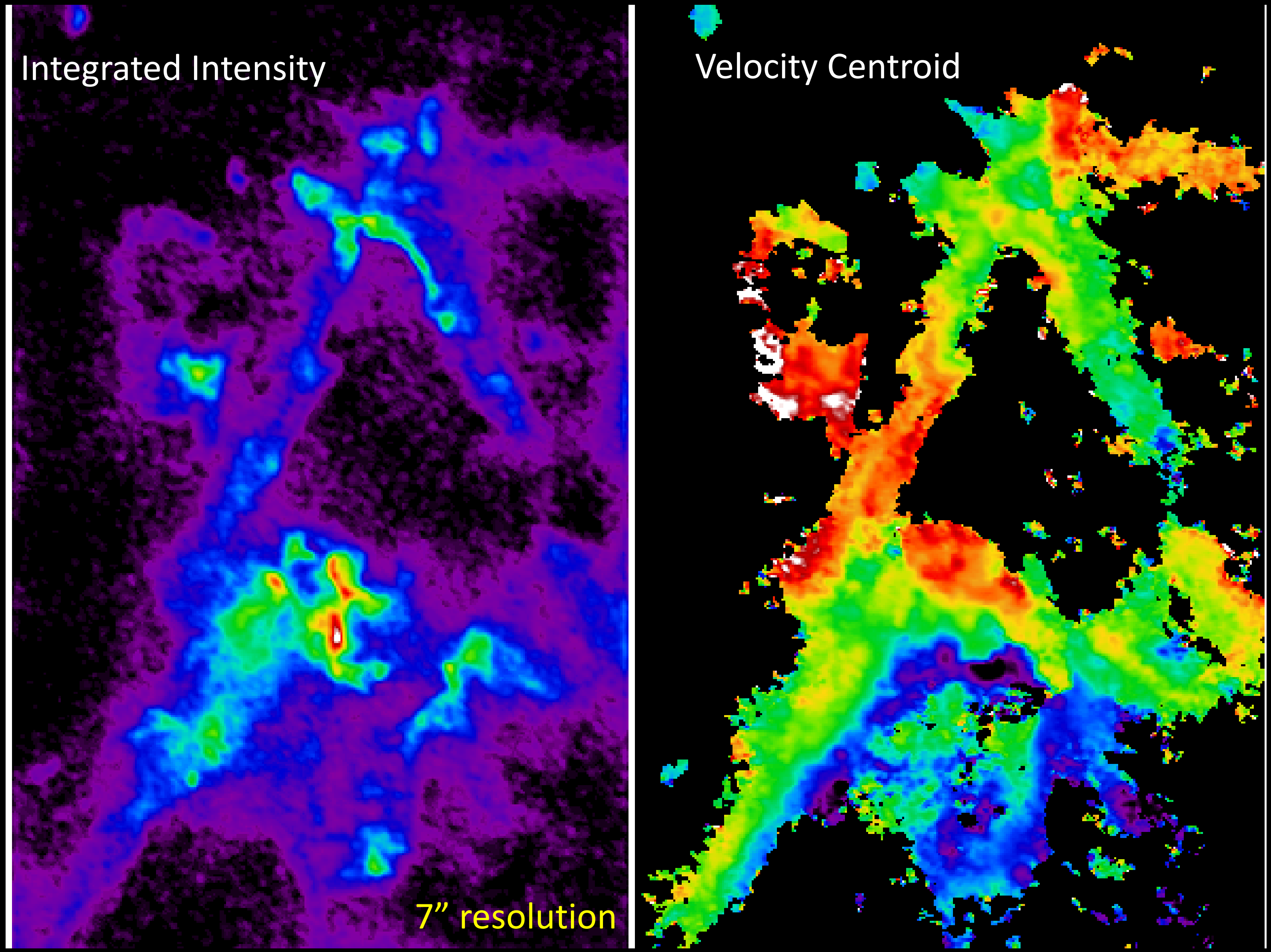


Serpens Main and Serpens South in N_2H^+

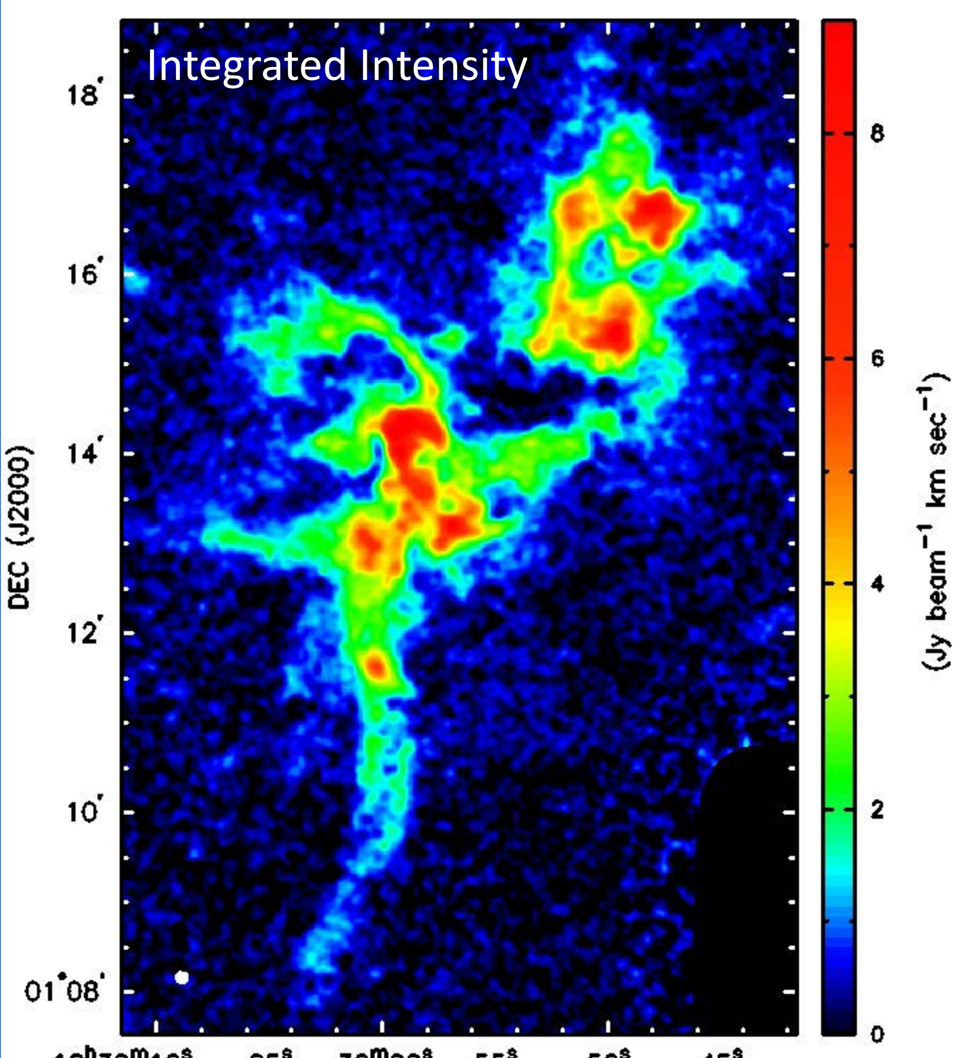


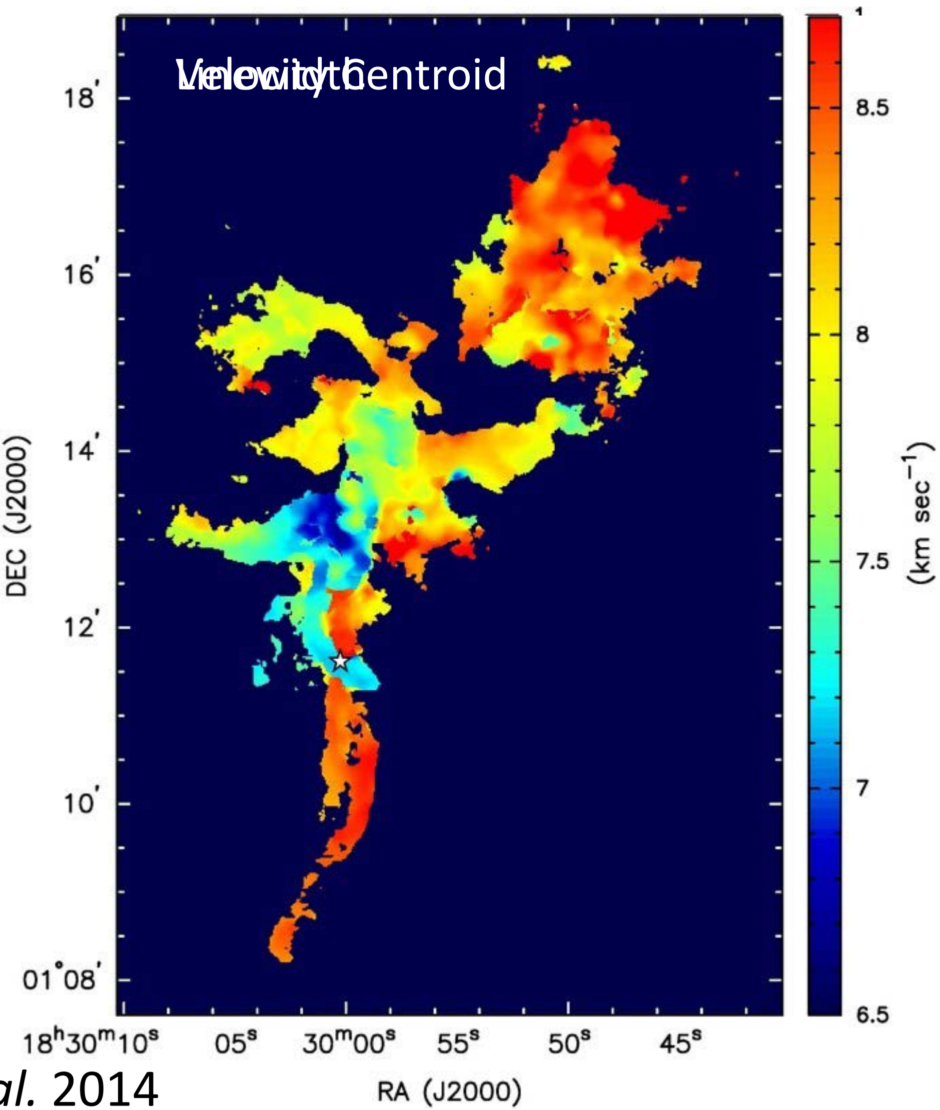


Kinematics of the Gas in NGC 1333



Serpens Main Velocity Centroid and Line width

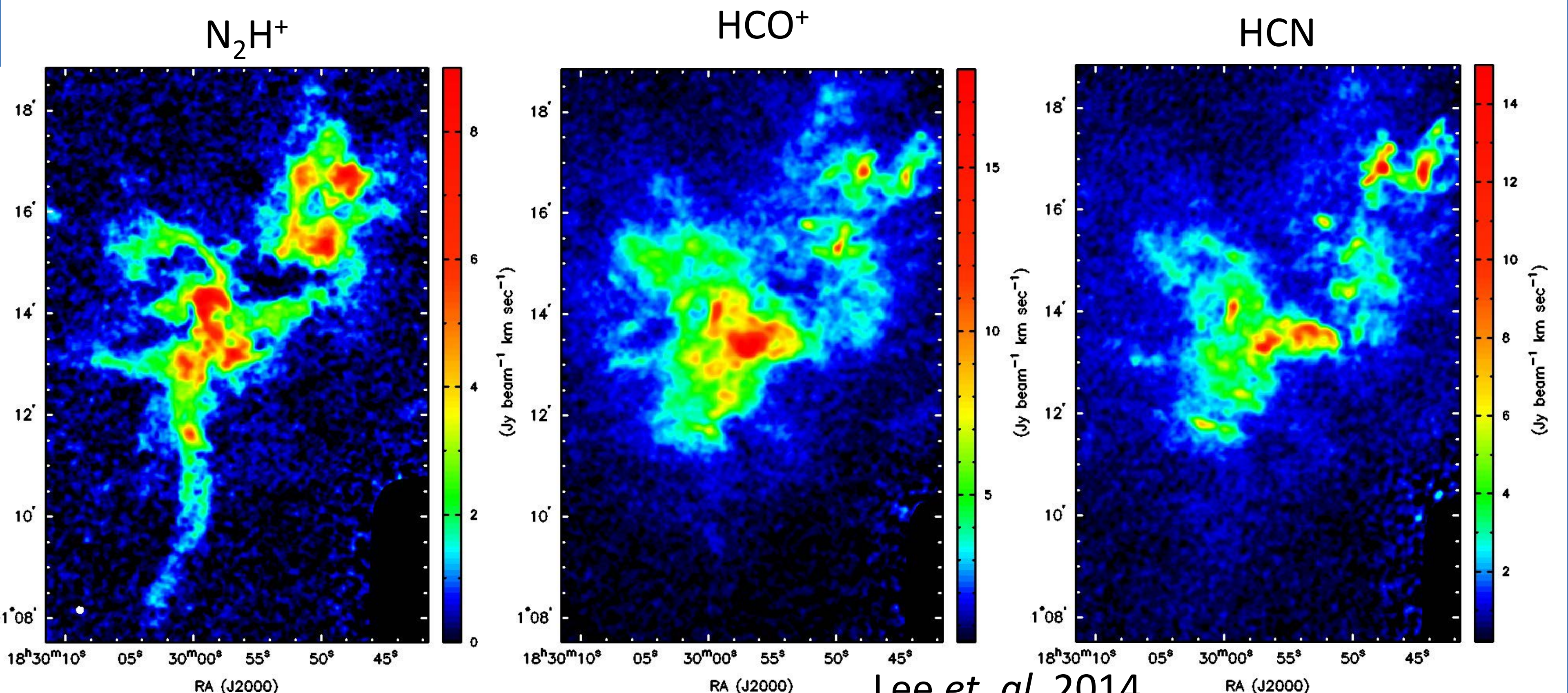




Lee *et. al.* 2014

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



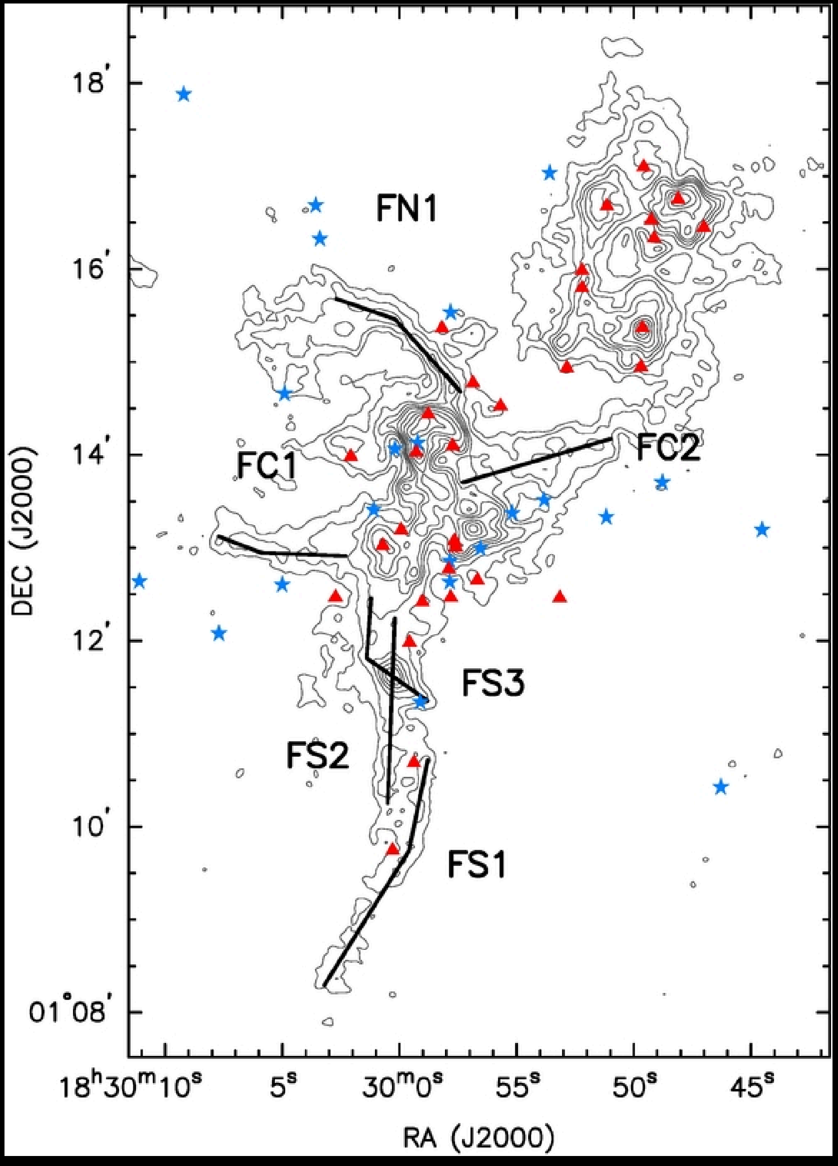
Lee *et. al.* 2014

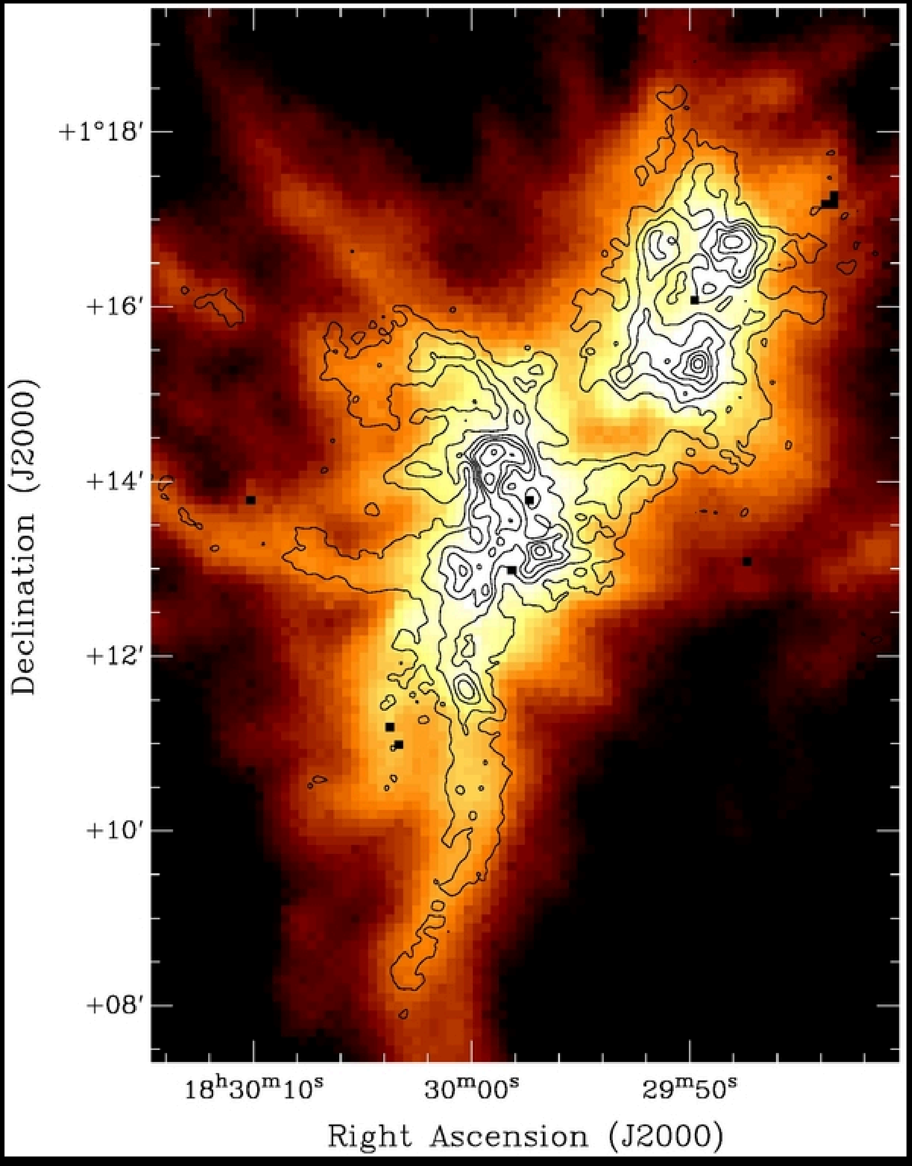
Serpens Main

N_2H^+ contours with YSOs from Spitzer c2d catalog

Lee *et. al.* 2014

N_2H^+ contours on Herschel 250 microns image





CARMA Large Area Star formation Survey (CLASSy)

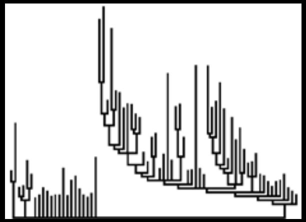
Three publications this year:

- Storm et al. 2014, ApJ (to appear soon) – Project Overview + Barnard 1
- Fernandez-Lopez et al. 2014 ApJL – Serpens South N_2H^+ J=1-0 filaments
- Lee et al. 2014 ApJ – Serpens Main (accepted)

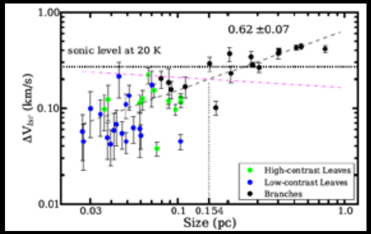
FITS cubes of the data are associated with the paper and available from ApJ links in the on-line papers for Barnard 1 (now) and Serpens Main (when it appears)

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

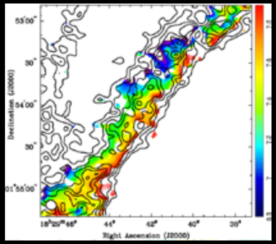
Science Issues



Connectivity of Cloud-to-Core Structure



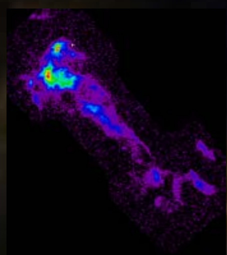
3D Structure of Clouds

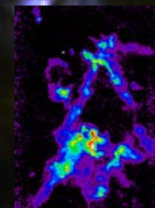


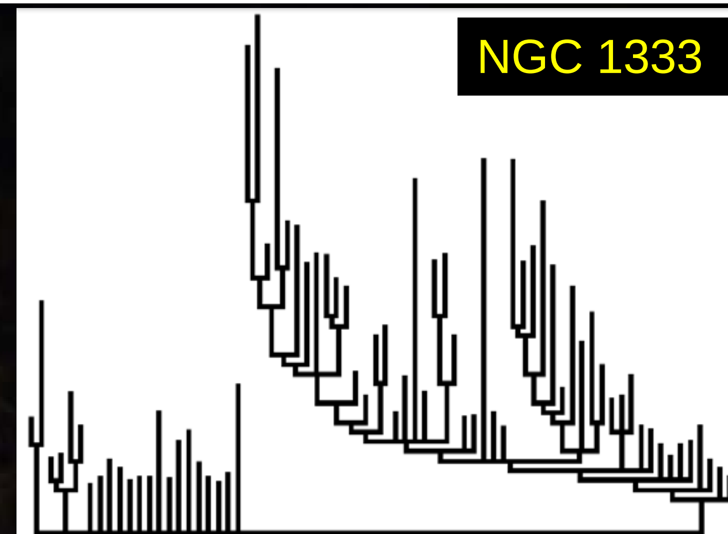
Filament Formation

Cover enough area and a range of star formation activity to see the pathways to structure formation

N_2H^+ Non-binary Dendrograms Across Perseus





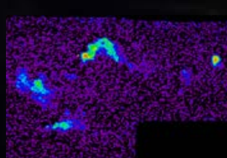


16-Level Hierarchy

4-Level Hierarchy

Dense gas cores are more complexly nested in NGC 1333 compared to Barnard 1; L1451 dense gas shows no hierarchical structure.

0-Level Hierarchy

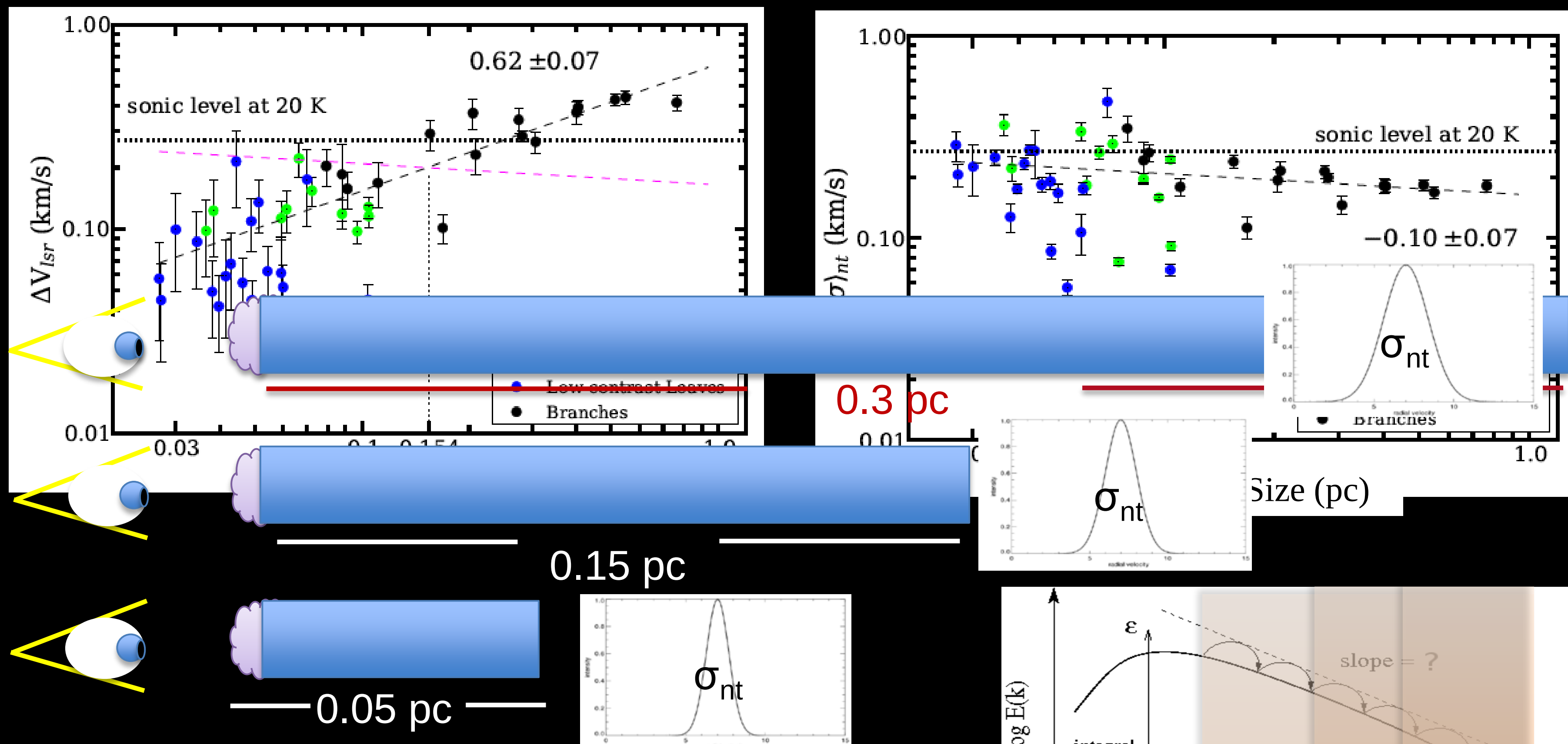


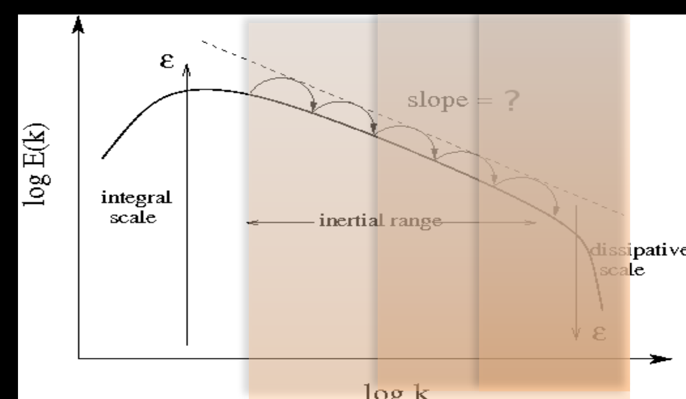
See Shaye Storm's Poster

Size-Linewidth Relations Reveal Cloud Depth

ΔV_{lsr} vs. Projected Size

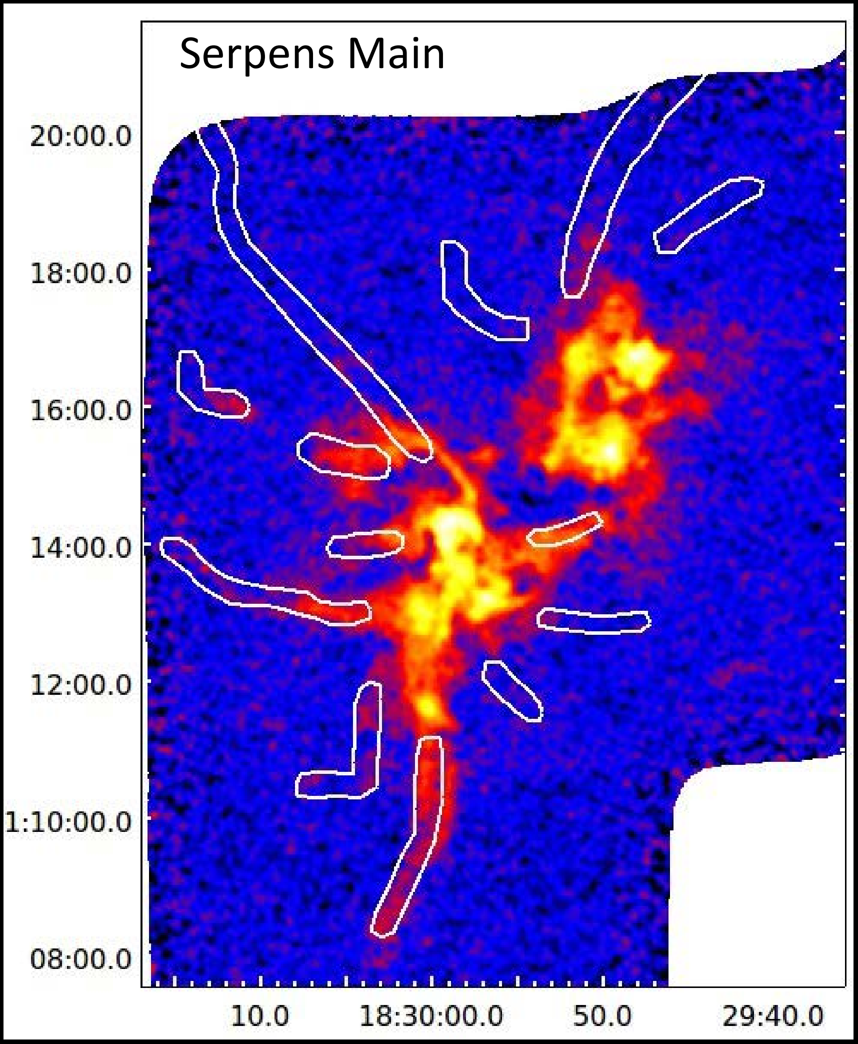
$\langle\sigma\rangle_{nt}$ vs. Projected Size

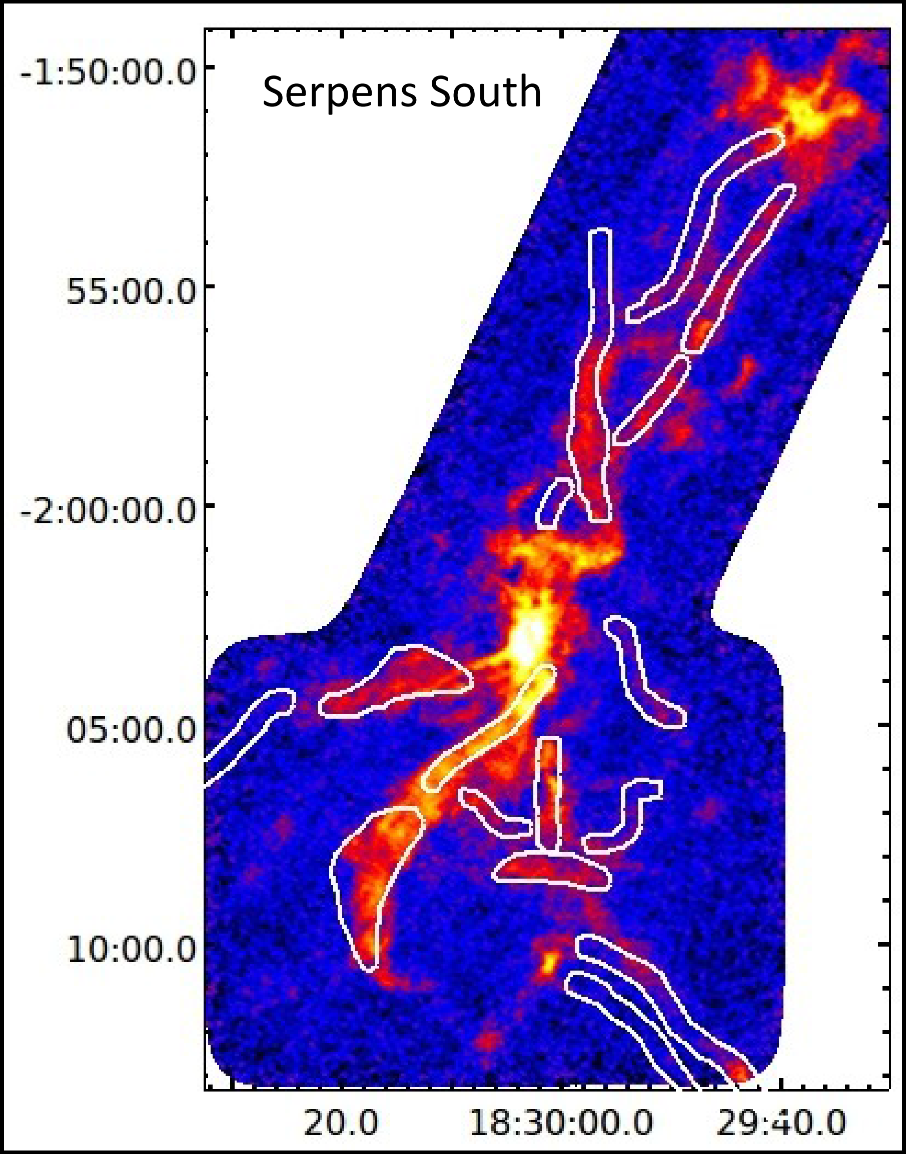




See Shaye Storm's Poster

Serpens Main and South: N_2H^+ Herschel Filaments

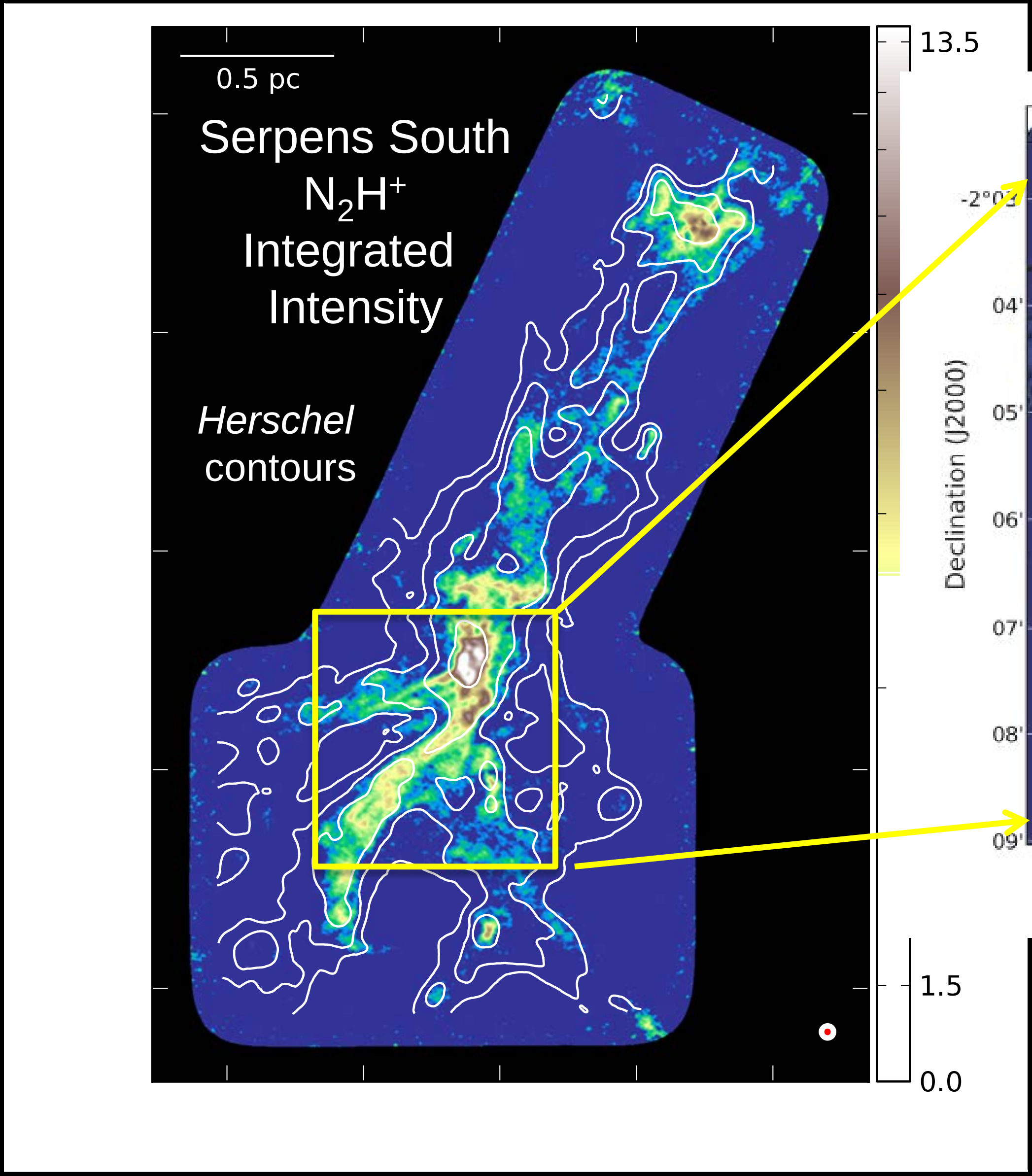


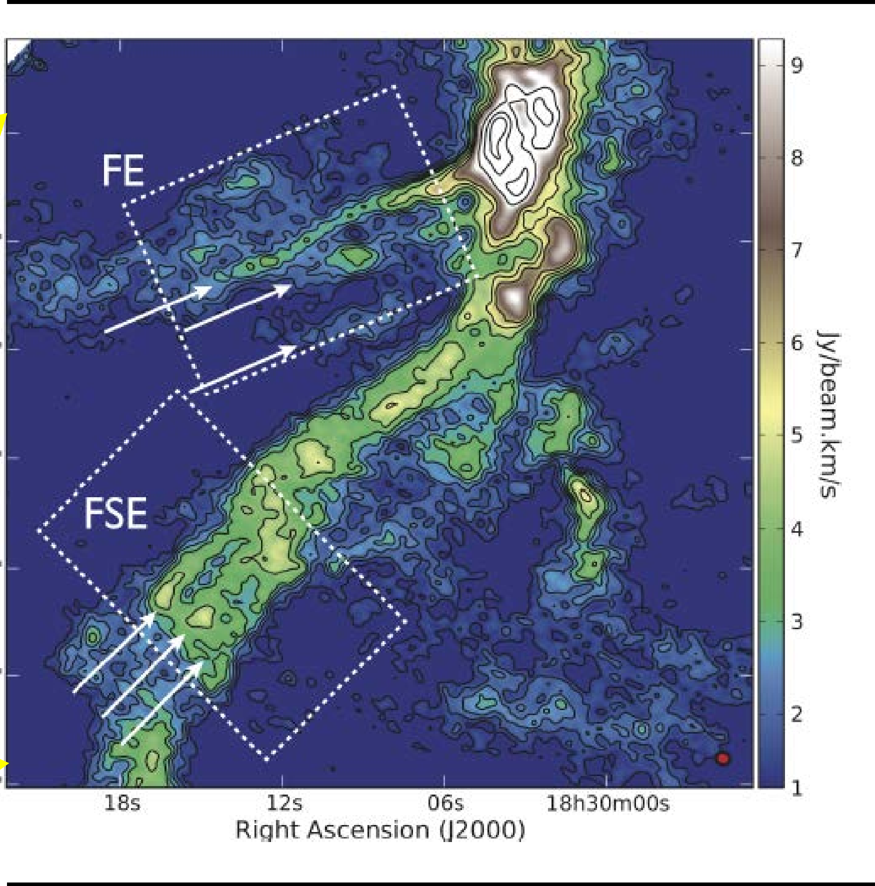


See poster by Katherine Lee

N_2H^+ is correlated with cool filaments

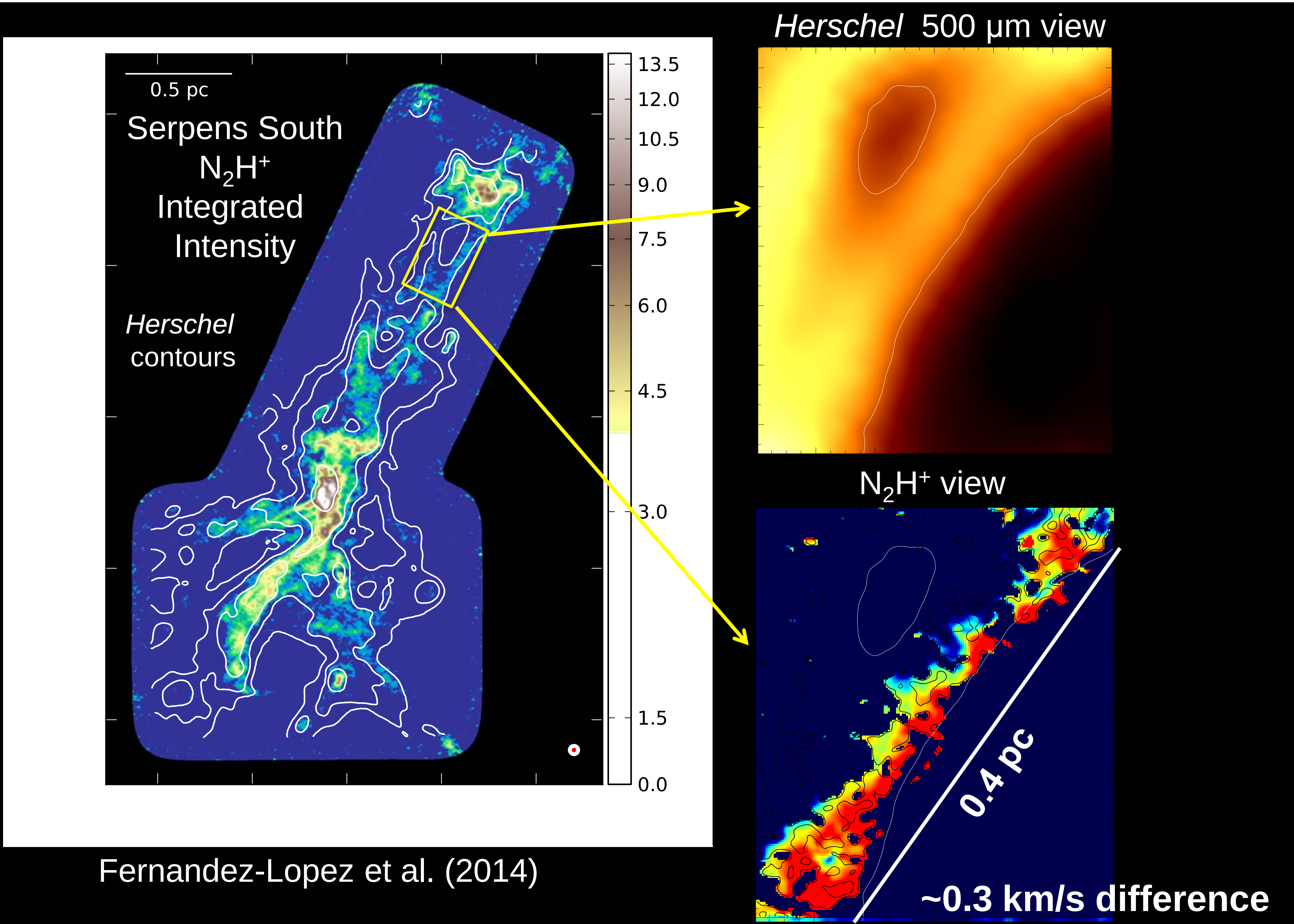
Filament Formation





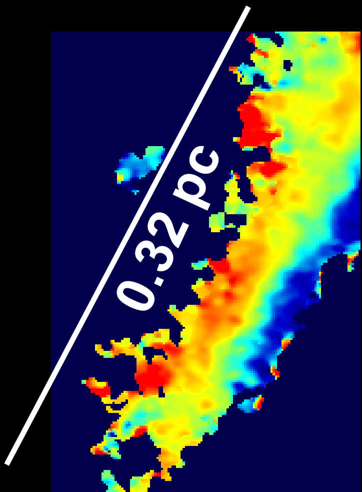
Fernandez-Lopez et al. (2014)

Filament Formation

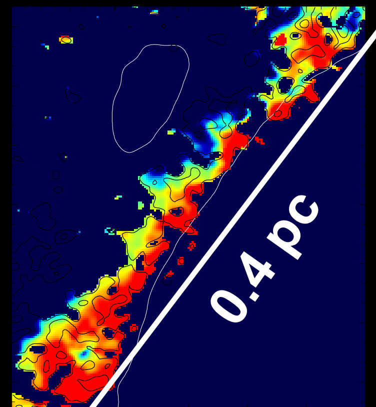


Fernandez-Lopez et al. (2014)

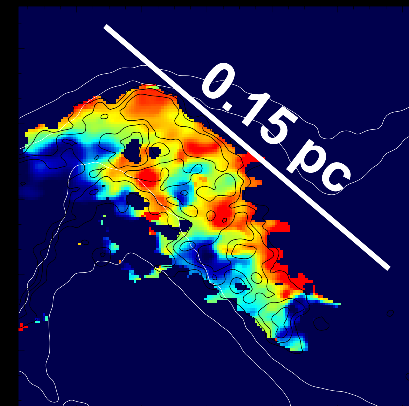
CLASSy has discovered a number of filaments with similar kinematic signature (not all)



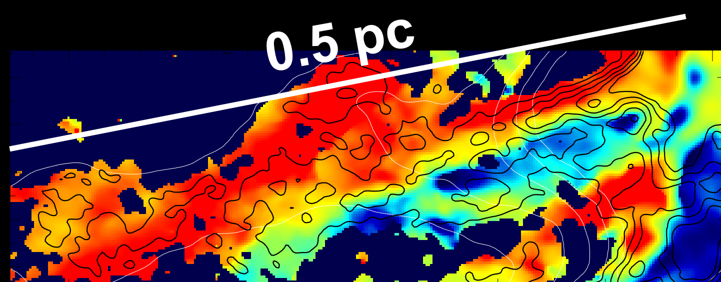
NGC 1333



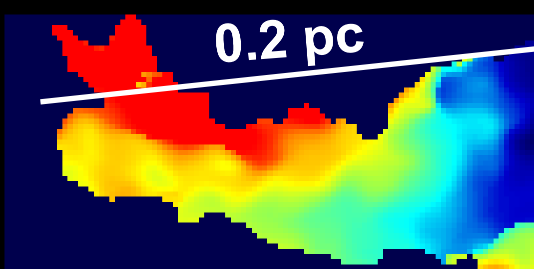
Serpens South



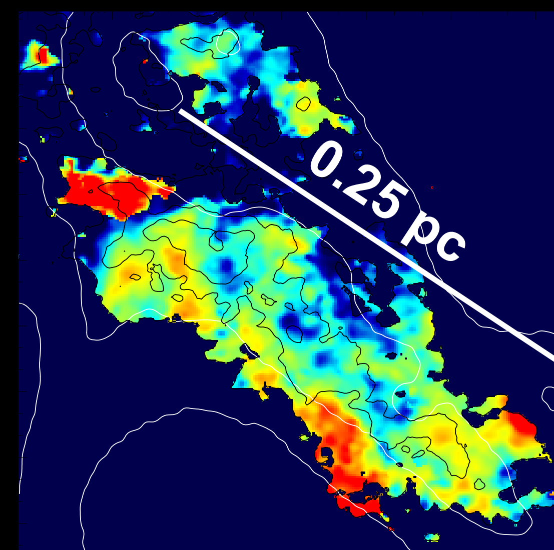
L1451



Serpens South



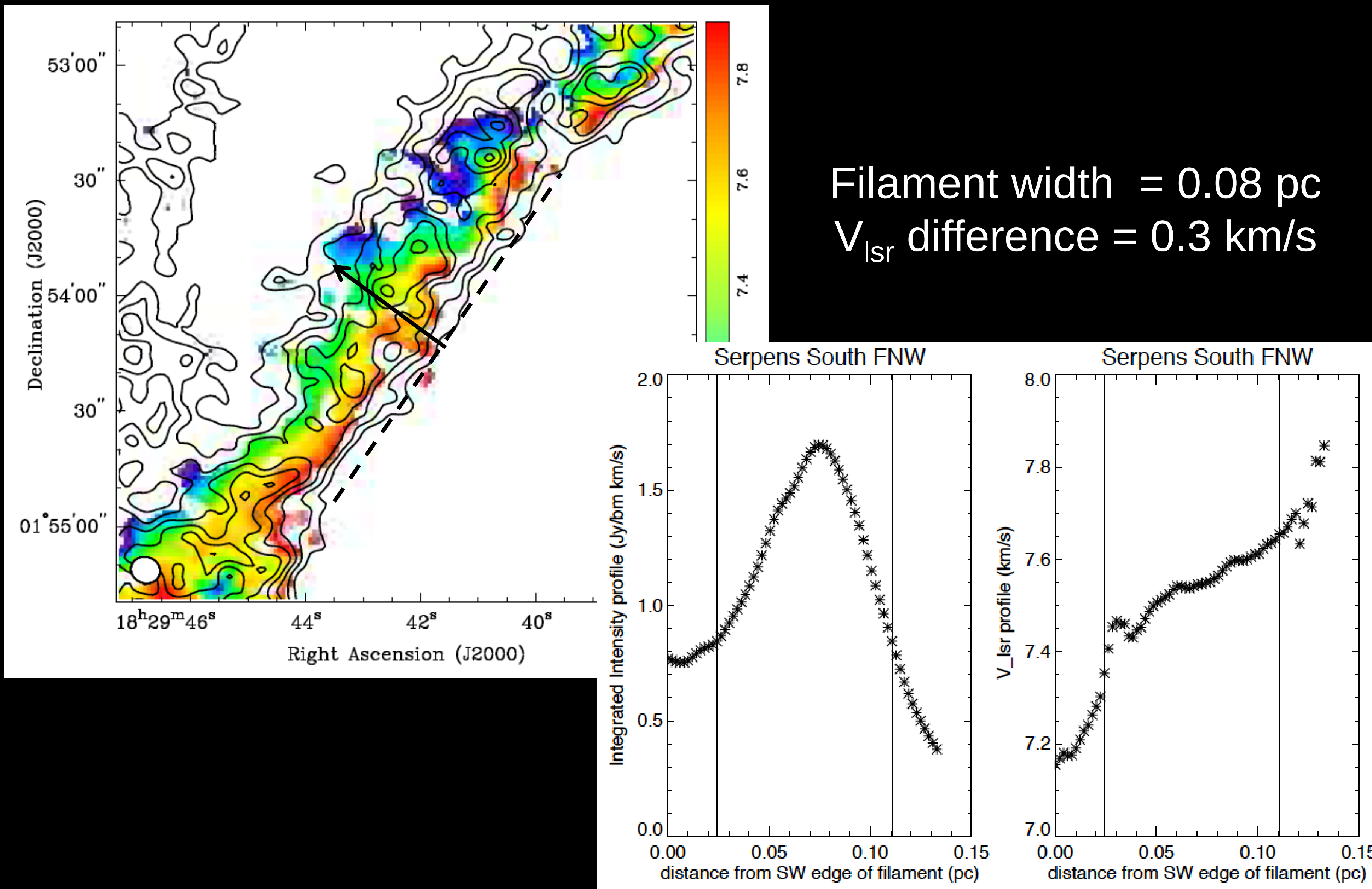
Serpens Main



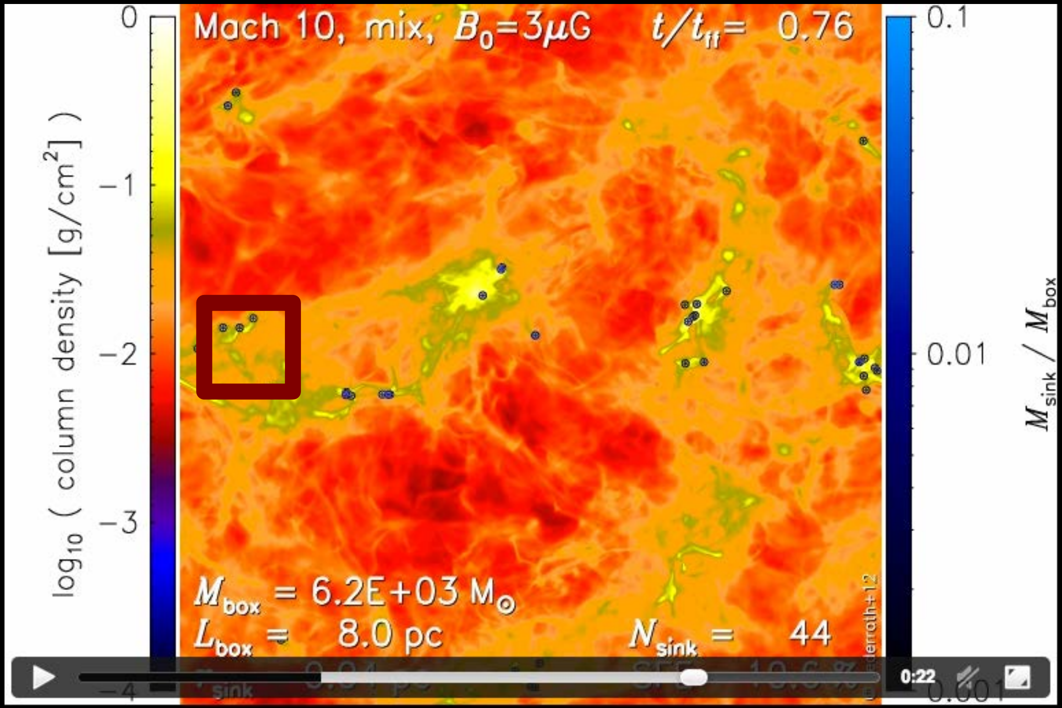
Barnard 1

CLASSy Filament Kinematics

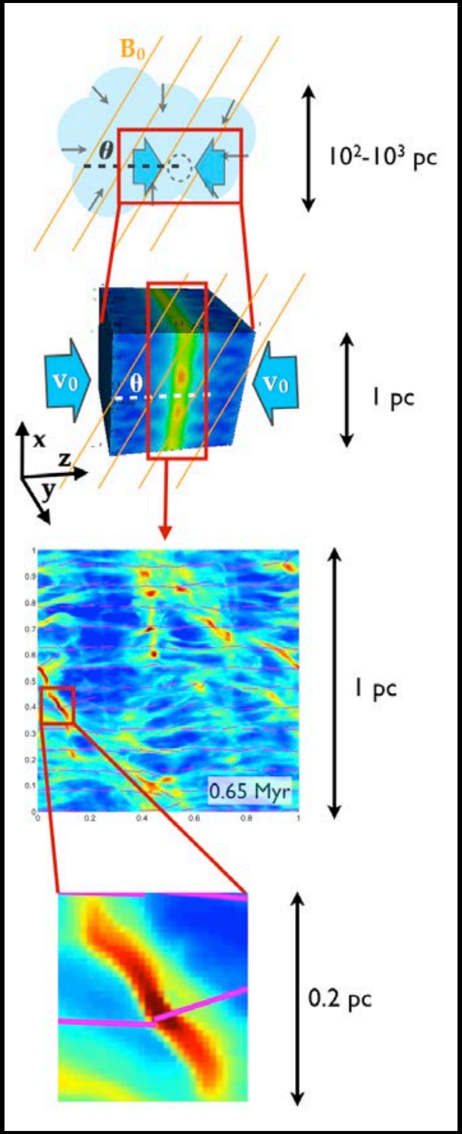
Filament width = 0.08 pc
V_{lsr} difference = 0.3 km/s



Numerical simulations of Molecular Clouds



Federrath & Klessen (2012)

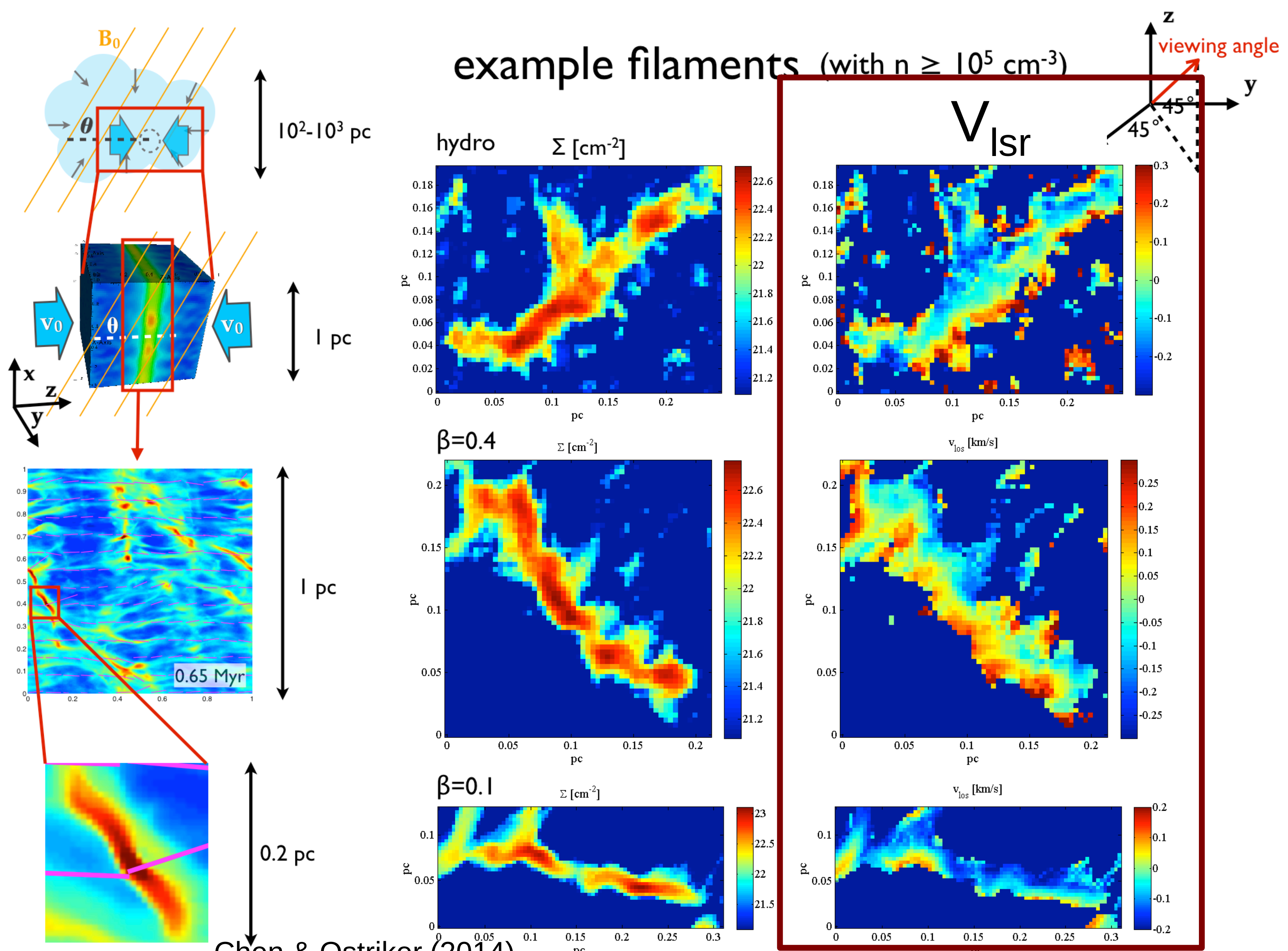


Chen & Ostriker (2014)

- 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*.

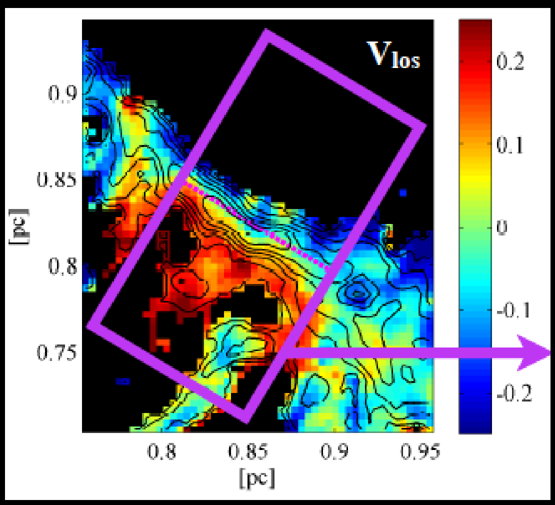
Chu-Yu Chen's talk -- next

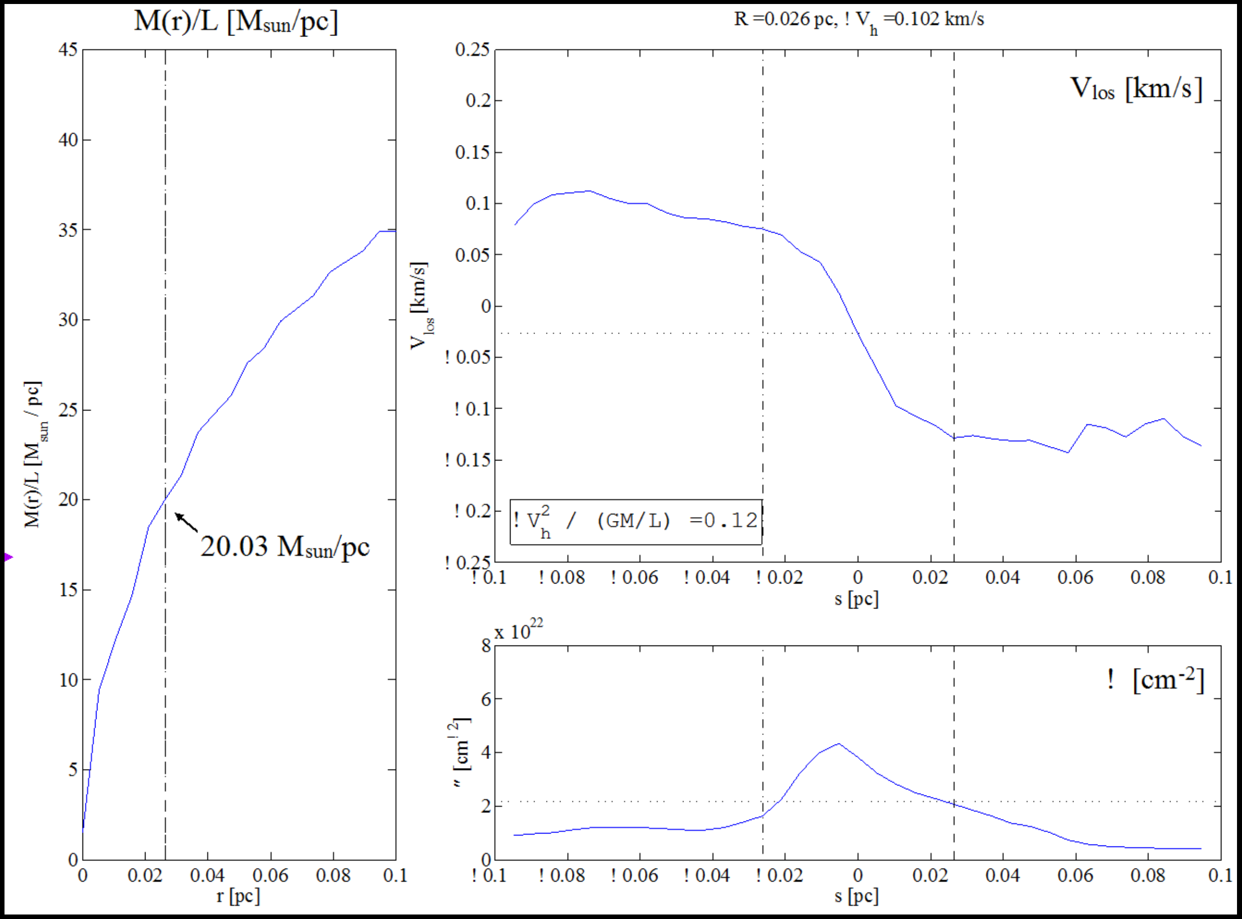
Filament Formation



Chen & Ostriker (2014)

Simulated filament M/L and Dynamics



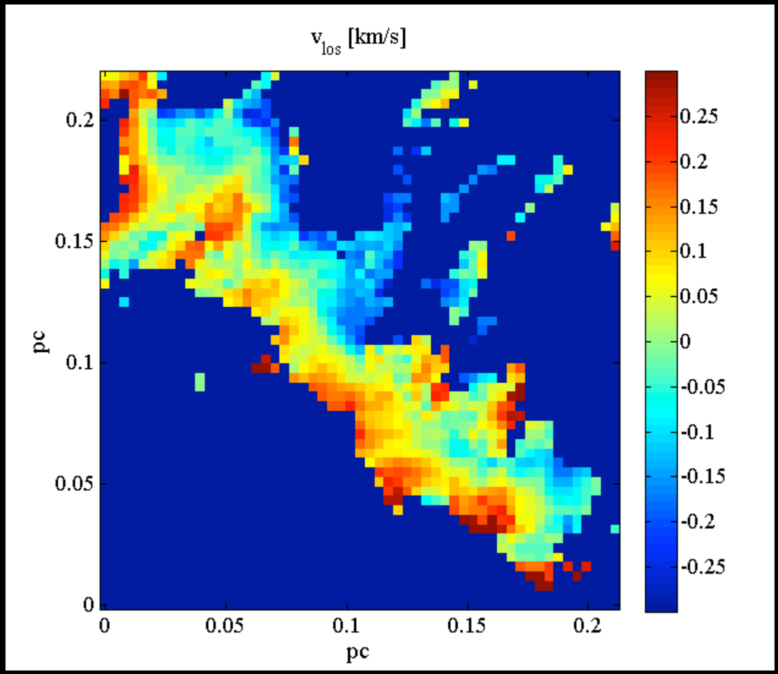


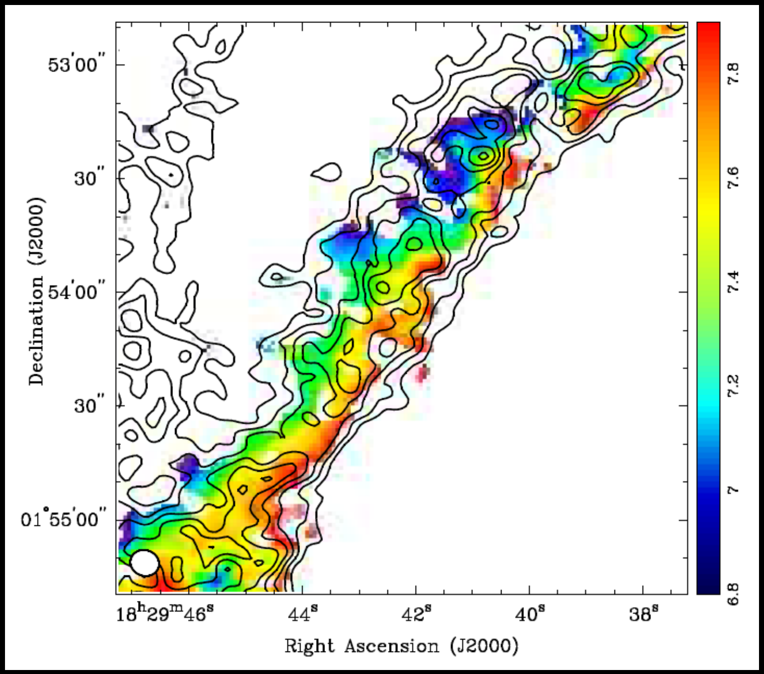
M/L = 20 $M_{\odot}$/pc

V_{lsr} difference across width = 0.1 km/s

Chu-Yu Chen's talk

Comparing CLASSy and simulated filaments





Can calculate the dimensionless coefficient:

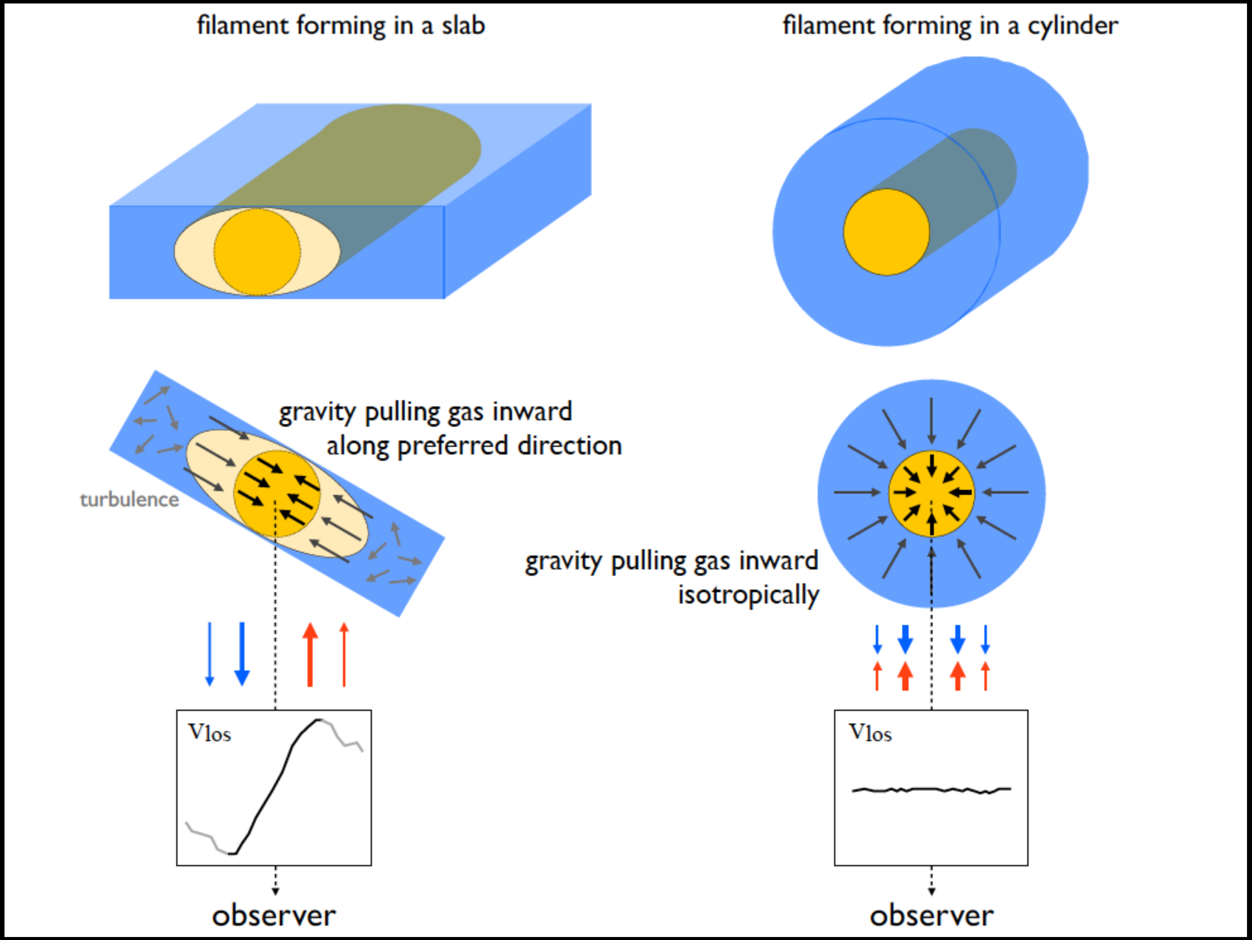
$$C = \frac{\Delta v_h{}^2}{G\overline{M_R/L}}$$

$C \sim 1$ gravity-induced velocity gradient

$C \gg 1$ turbulence-dominated structure

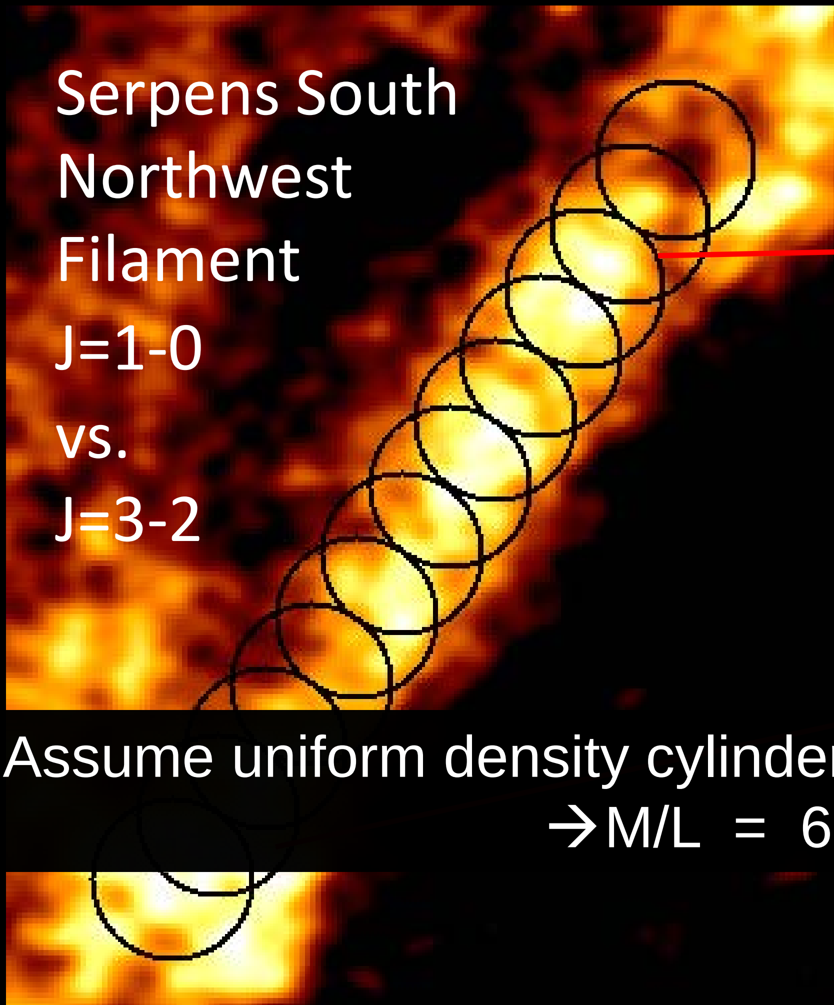
Comparing CLASSy and simulated filaments

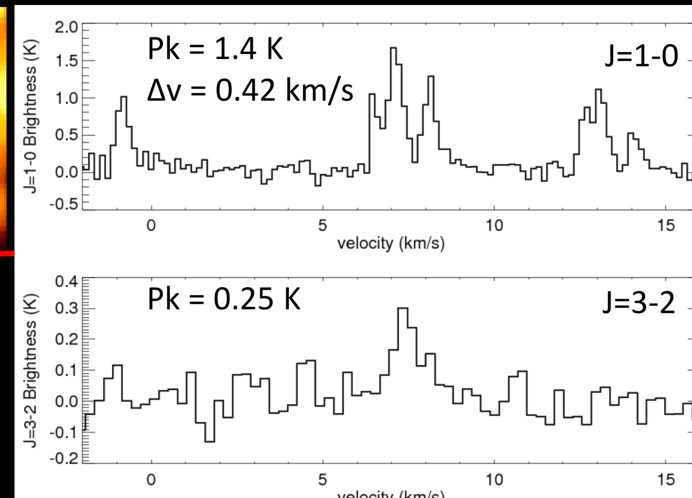
Gradient a signature of gravity induced inflow of material from a dense, flattened, post-shock layer in a turbulent cloud.

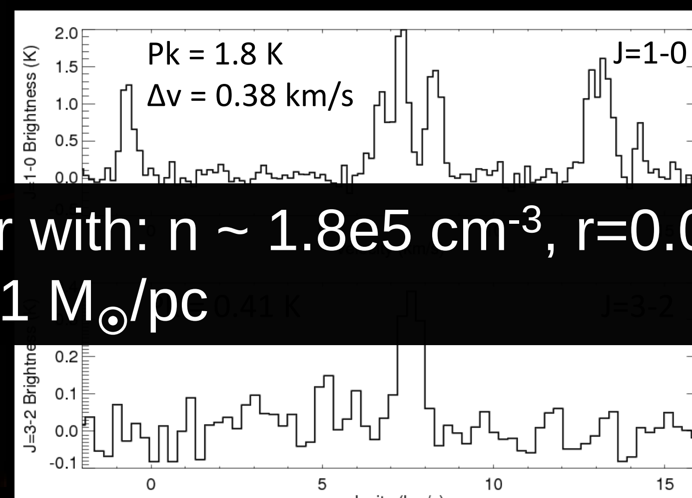


Chu-Yu Chen's talk

CLASSy Filament Density Estimates





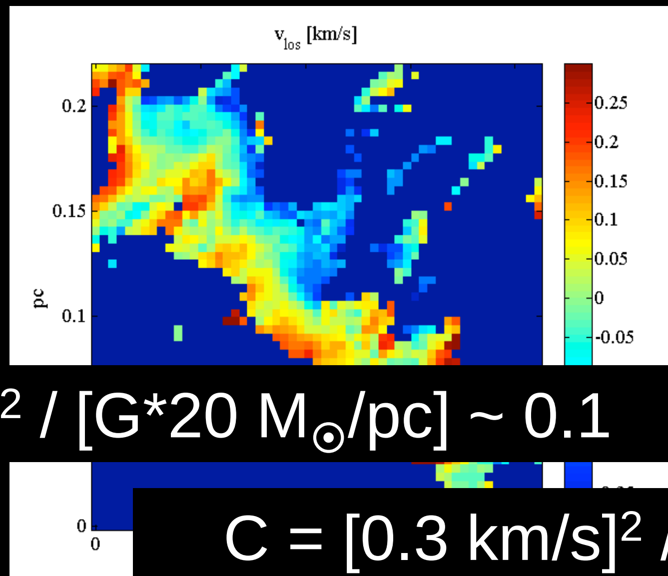


- Assume uniform density cylinder with: n ~ 1.8e5 cm^{-3}, r=0.04 pc

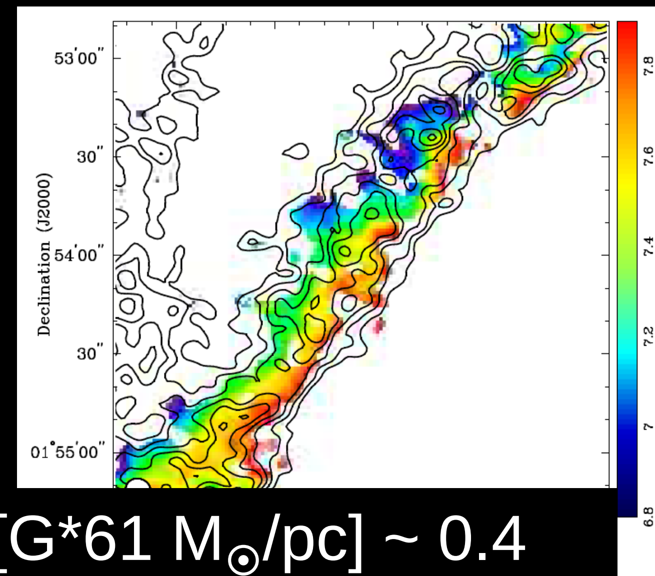
  → M/L = 61 $M_{\odot}$/pc

N_2H^+ J=3-2 observations with the ARO 10-m

Comparing CLASSy and simulated filaments



$C = [0.1\ \mathrm{km/s}]^2 / [G*20\ M_\odot/\mathrm{pc}] \sim 0.1$



$C = [0.3\ \mathrm{km/s}]^2 / [G*61\ M_\odot/\mathrm{pc}] \sim 0.4$

Can calculate the dimensionless coefficient:

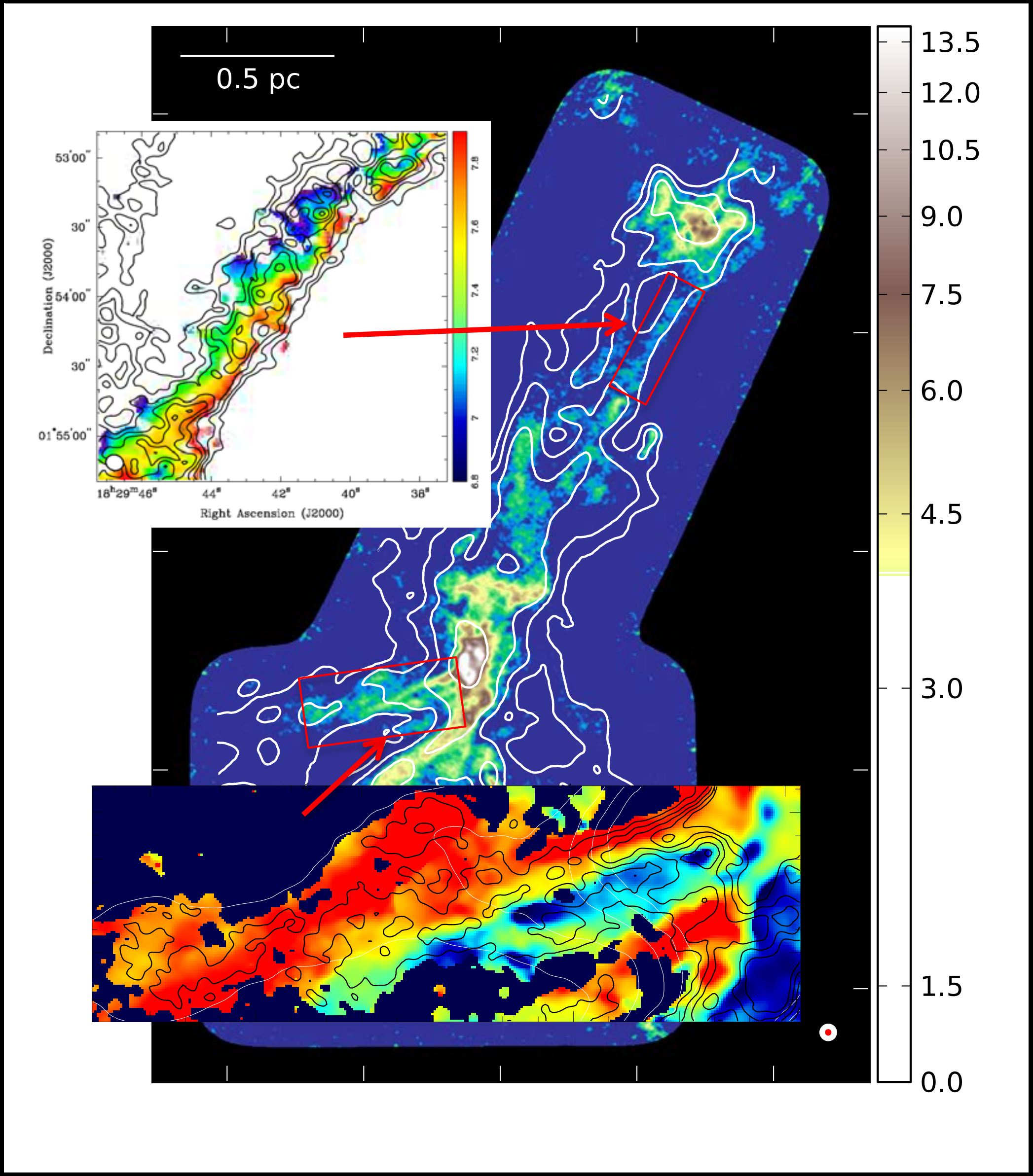
$$C = \frac{{\Delta v_h}^2}{G\overline{M_R/L}}$$

$C \sim 1$ gravity-induced velocity gradient

$C \gg 1$ turbulence-dominated structure

C ≤1 for both observed and simulated filaments

Role of Filaments in Core/Star Formation



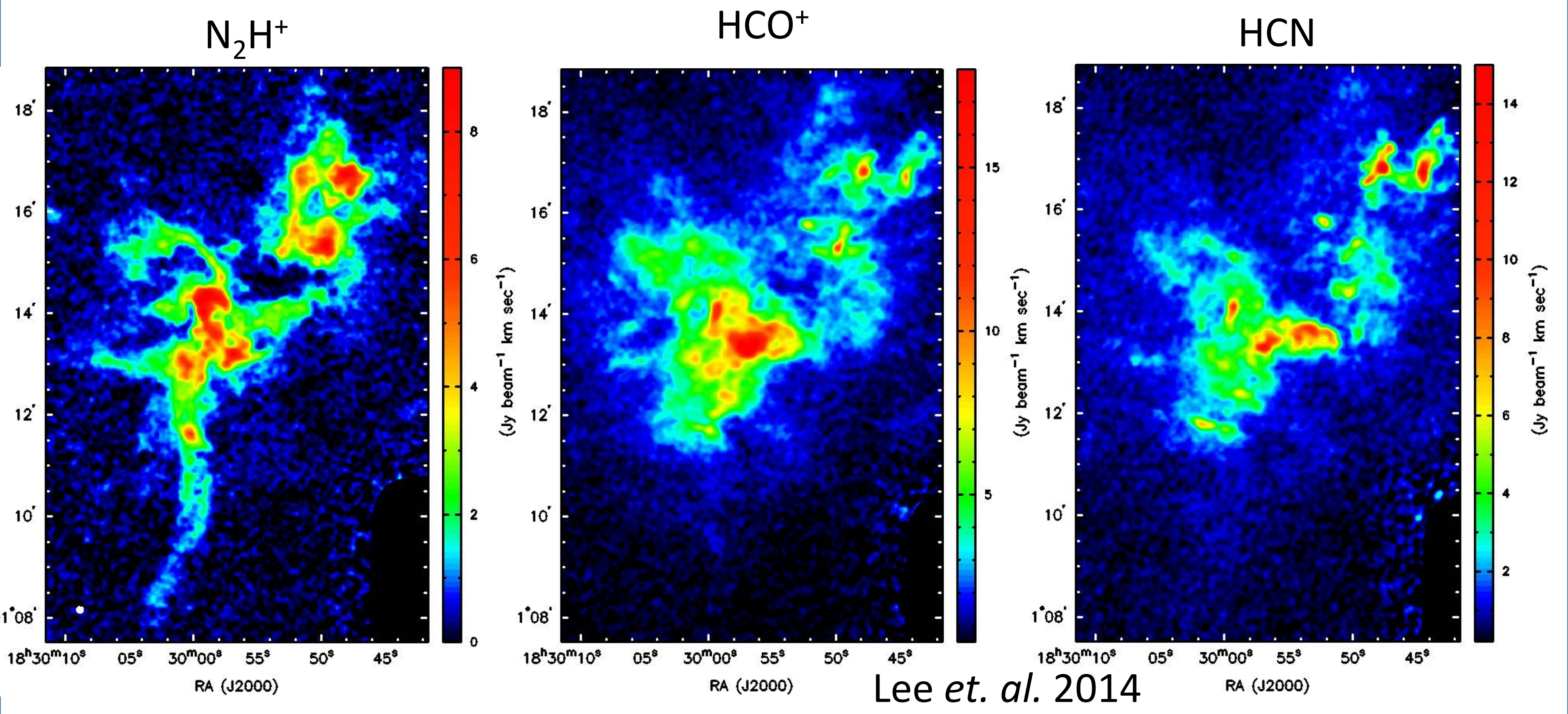
Filaments are growing in mass and density by inflow dominately from a 2-D dense layer.

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

- $H^{13}CO^+$, $H^{13}CN$, HNC J=1-0
- $C^{18}O$ J=1-0, ^{13}CO J=1-0, HC_3N J=12-11
- Plan to map 5-7 filaments

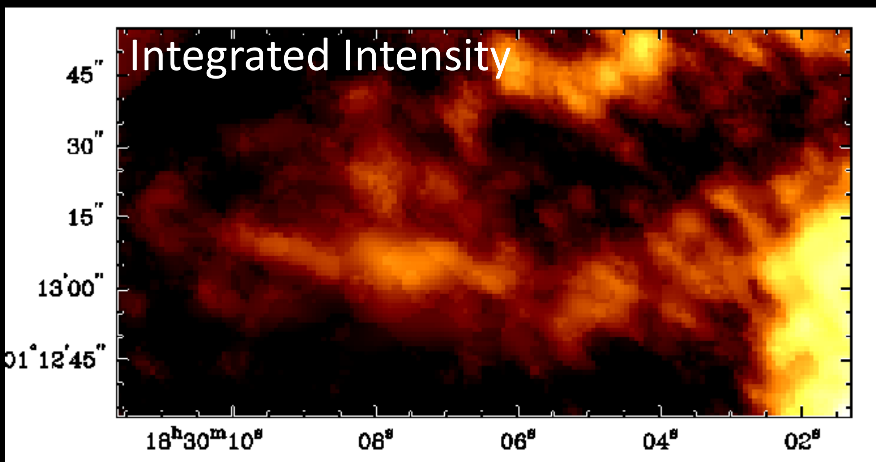


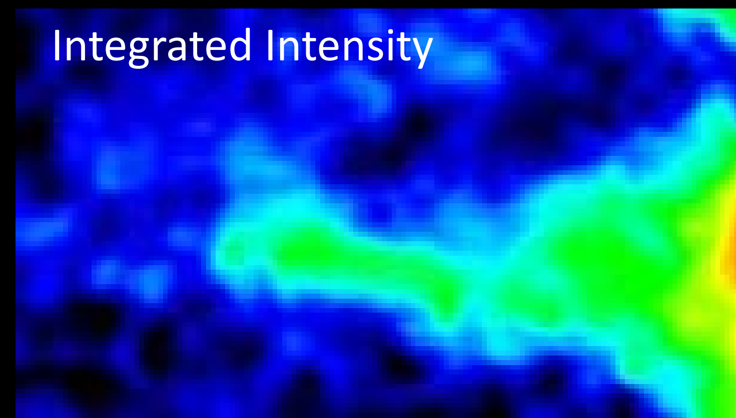
Lee *et. al.* 2014

CLASSy 2 – Results on First Filament

$H^{13}CO^+$ shows very similar kinematics to N_2H^+

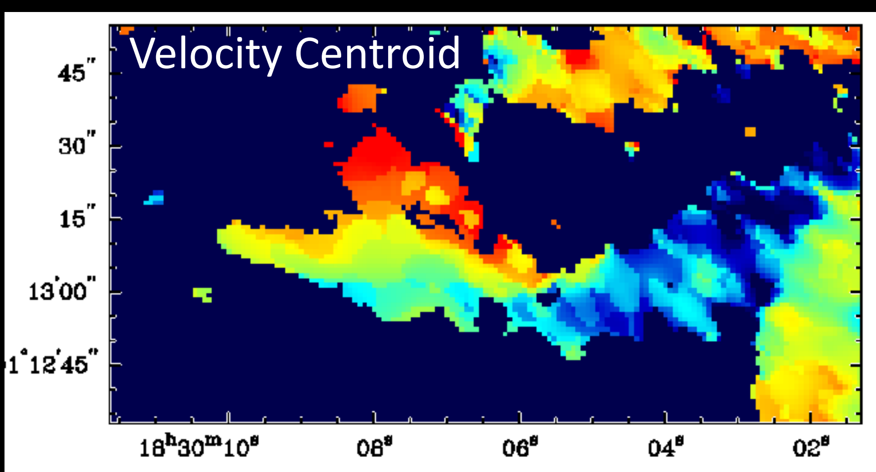
Serpens Main – East Filament

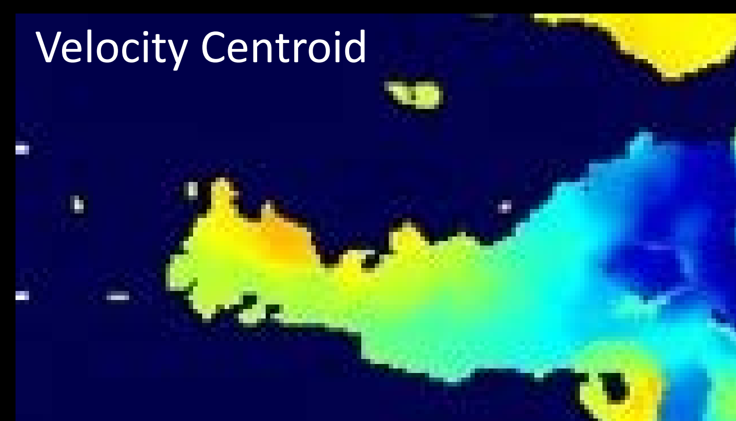




$H^{13}CO^+$

N_2H^+



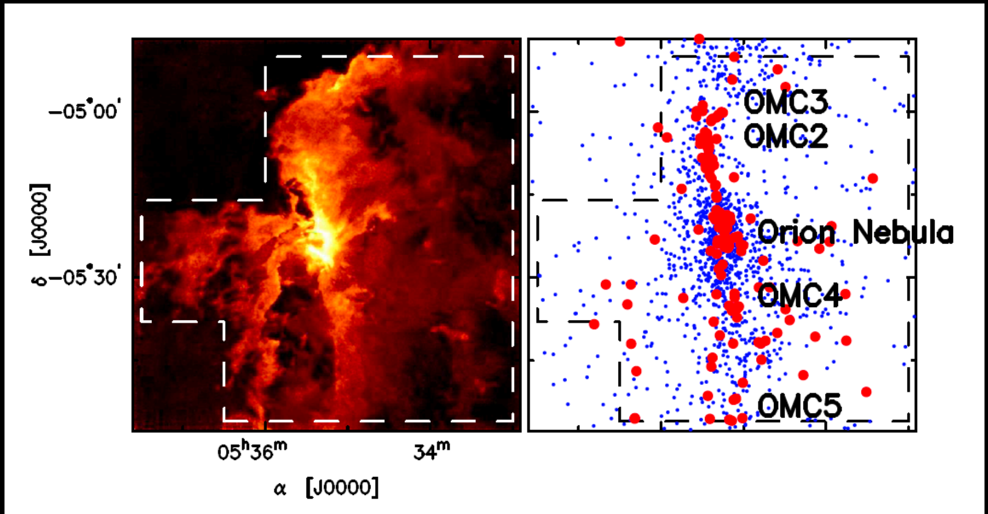


CARMA Orion and North American Neb

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 C18O)
- the cold dense gas (CN)

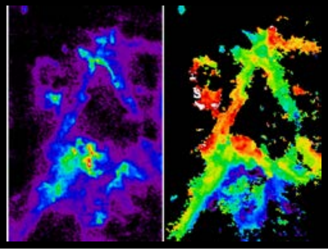
People: John Bally (Colorado), John Carpenter (Caltech, PI), Rachel Friesen (Toronto), Adam Ginsburg (Colorado), Paul Goldsmith (Caltech/JPL) ,Chihomi Hara (NAOJ), Andrea Isella (Caltech), Doug Johnstone (NRC), Jens Kauffmann (Caltech), Ryohei Kawabe (NAOJ), Ralf Klessen (Heidelberg), Darek Lis (Caltech) 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

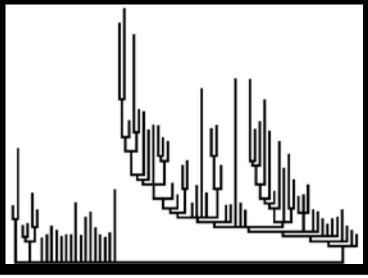
Papers and data are being published.
FITS data cubes linked to published papers.
7” resolution information on the dense gas distribution and kinematics – including filaments!



Cloud Structure and kinematics

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

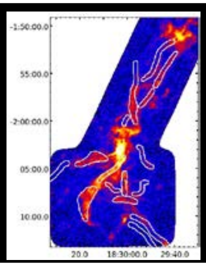
See poster by Shaye Storm



N_2H^+ and filaments

N_2H^+ is a good tracer of the dense gas structure and of cold filaments. N_2H^+ 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