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Physical Conditions and Kinematics of the Filamentary Structure in OMC1

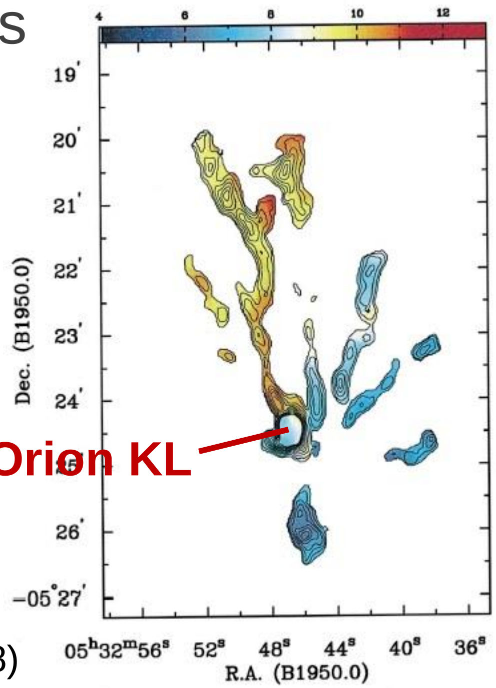
Yu-Hsuan Teng and Naomi Hirano

Motivation

- **Filaments** are commonly observed in star forming clouds
- **Hub-filament structure** in high mass star forming regions

Myers (2009)

NH_3 (1,1)
VLA
8” resolution



Wiseman and Ho (1998)

Friesen et al. (2017)

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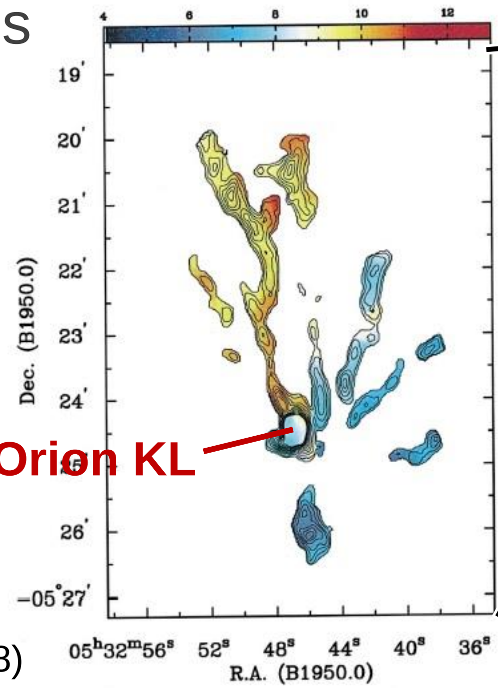

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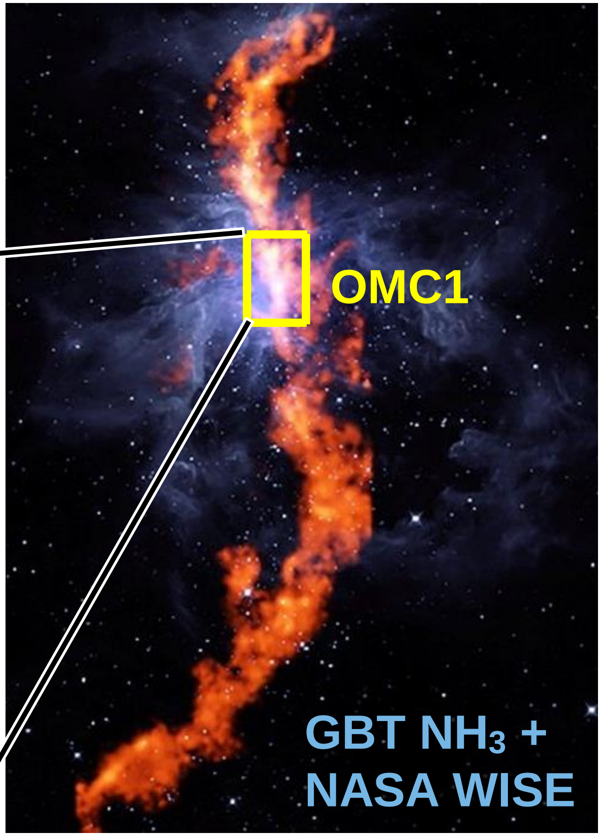
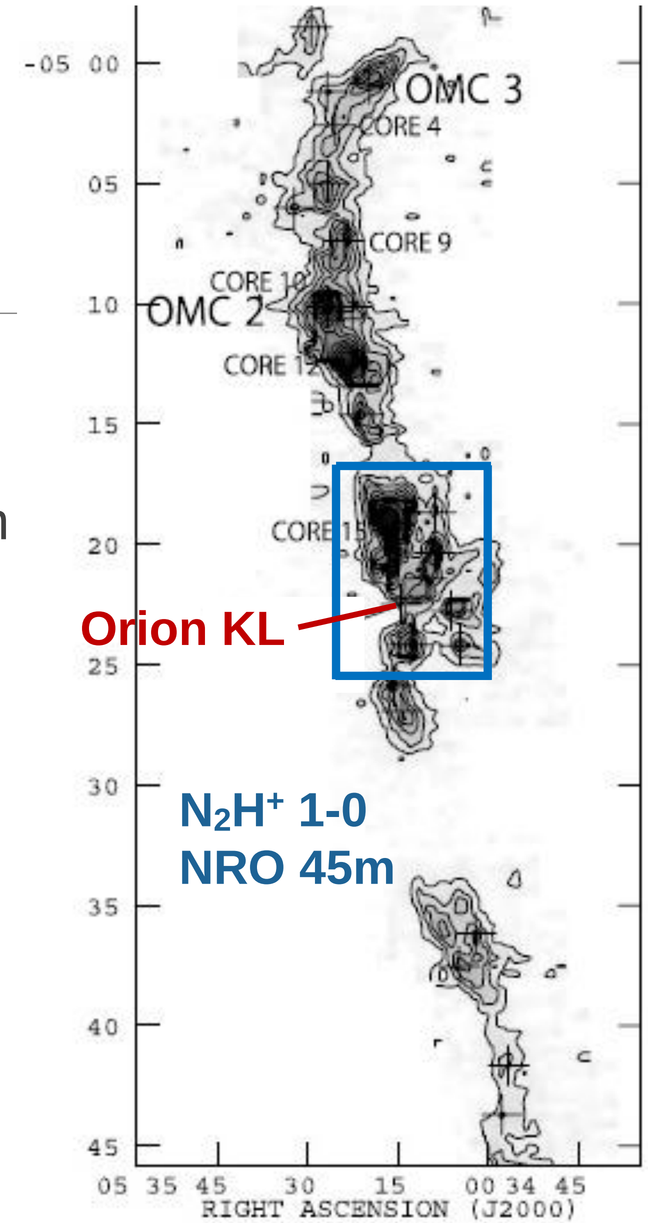


Friesen et al. (2017)

Observations

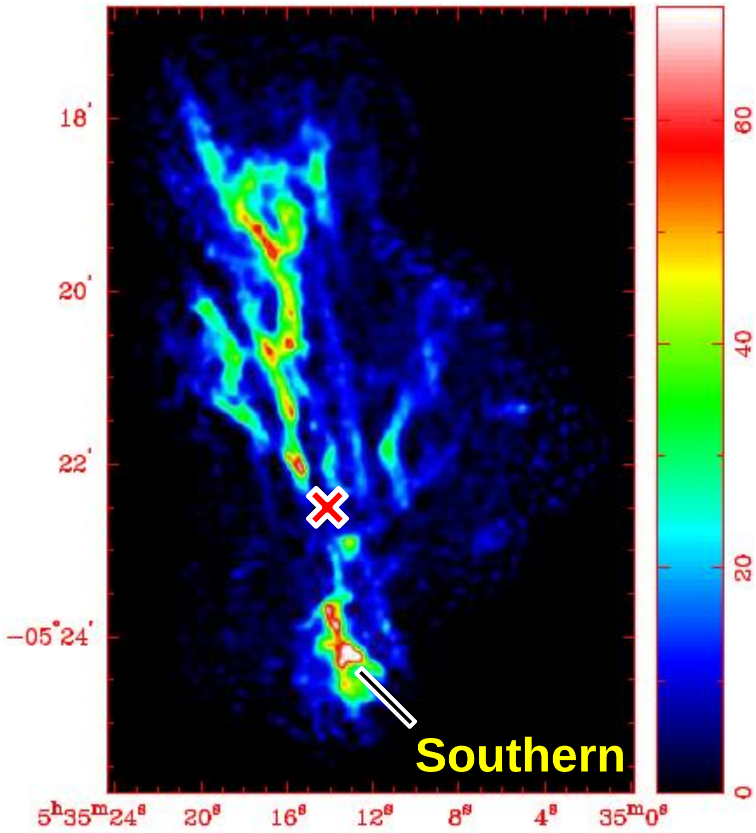
- **Orion molecular cloud 1 (OMC1)**
  - Distance: 414 pc
  - Nearest high mass star forming region
- **N2H+ J=3-2**
  - Critical density ~ $10^6\ cm^{-3}$
  - Abundant in cold regions
- **Combine SMA and SMT data**
  - SMA: 144 pointing mosaic
  - SMT: OTF mapping



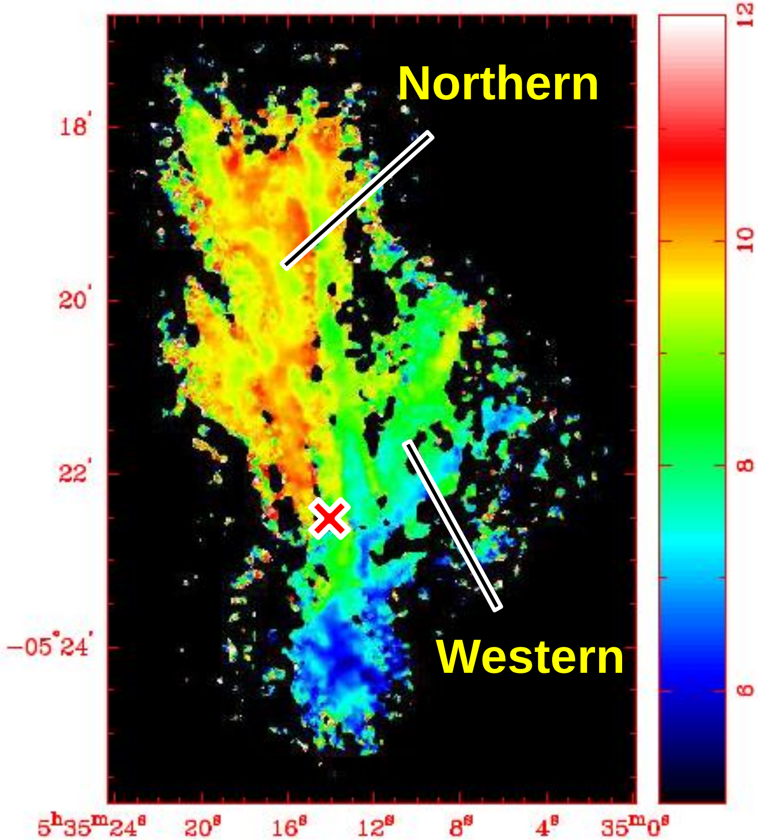
Tatematsu et al. (2008)

SMA + SMT Results

Moment 0 (~5.4”)



Moment 1



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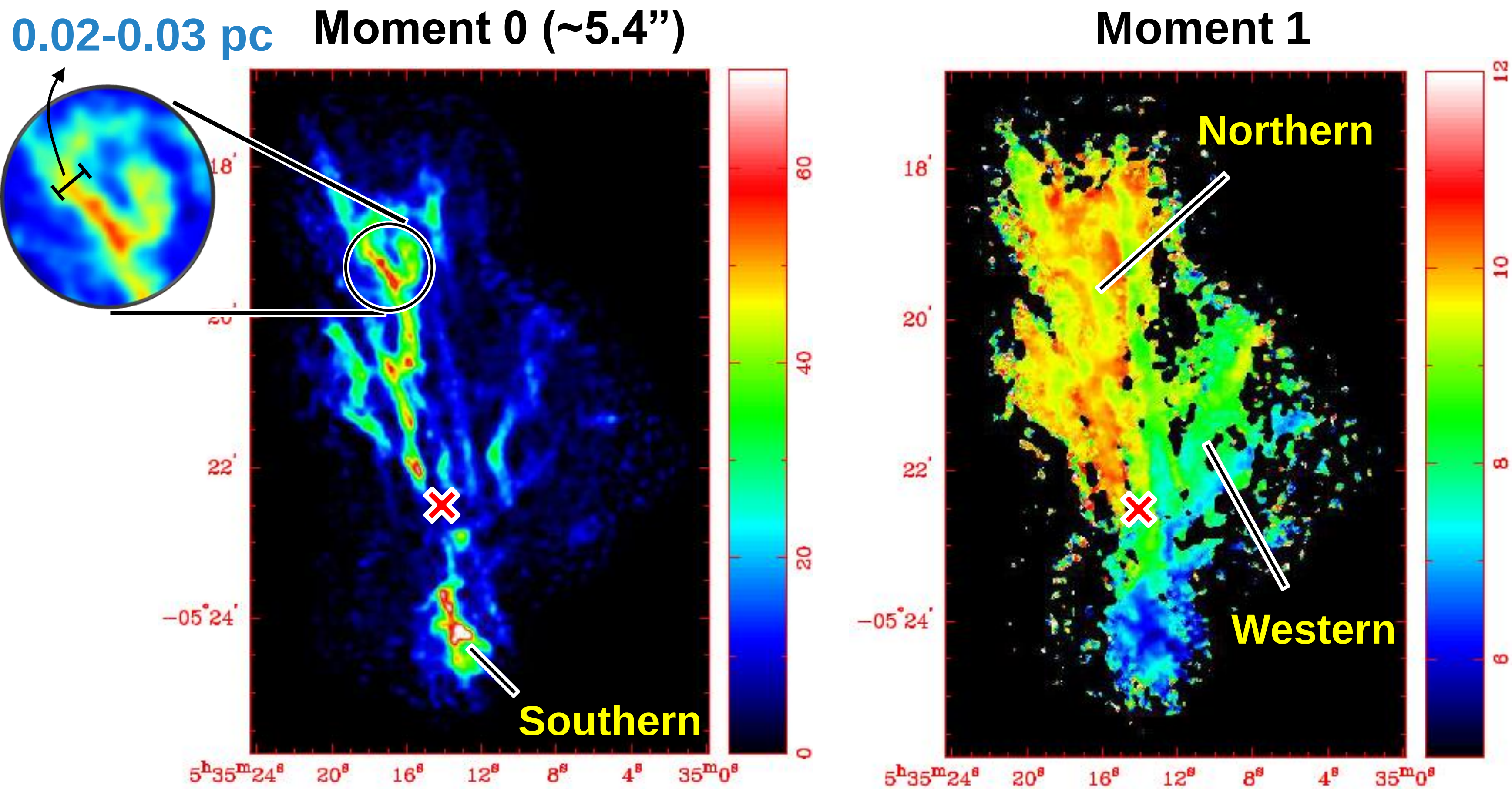
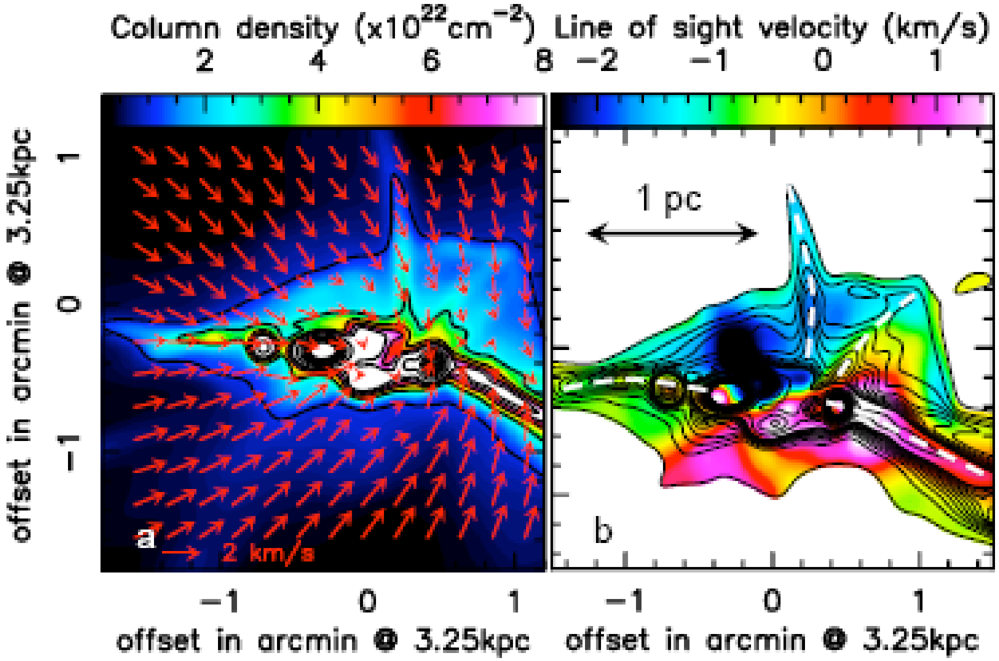
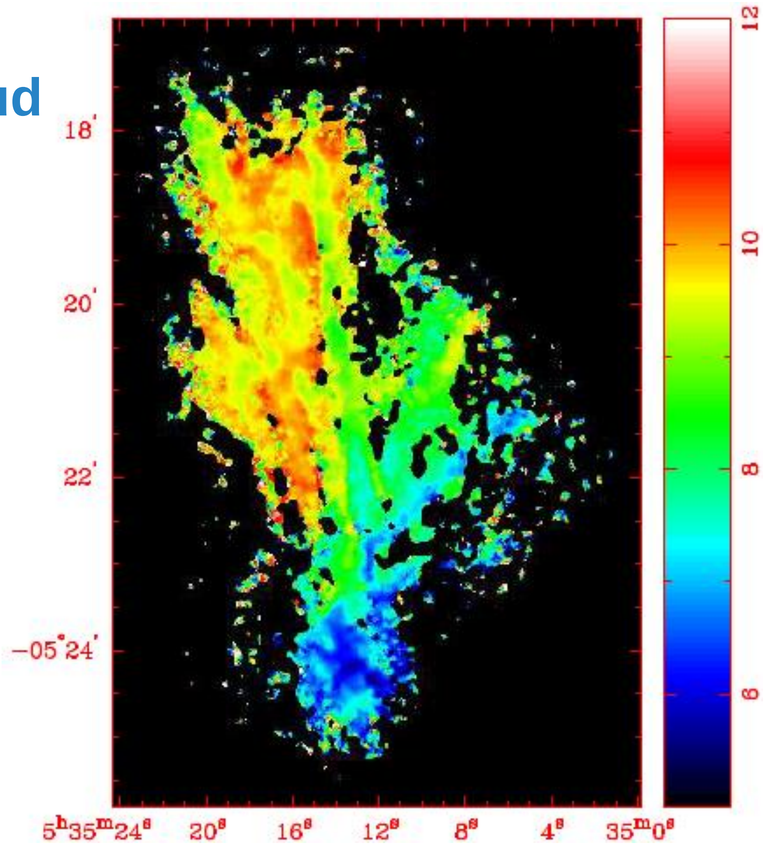


Global Collapse

MHD simulation of a global collapsing cloud

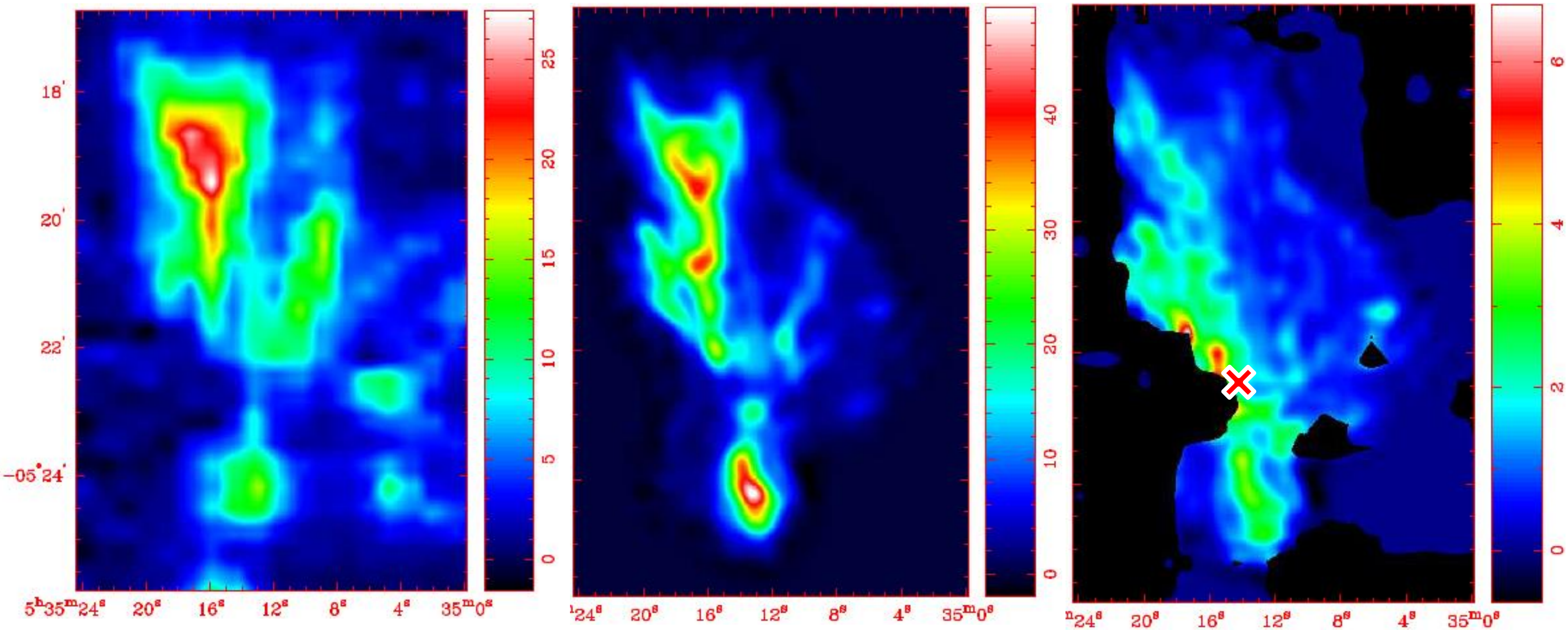




Peretto et al. (2013)

Large Scale Analysis

NRO 45m (1-0) SMA+SMT (3-2) **(3-2) / (1-0) ratio**



17.8" resolution (convolved)

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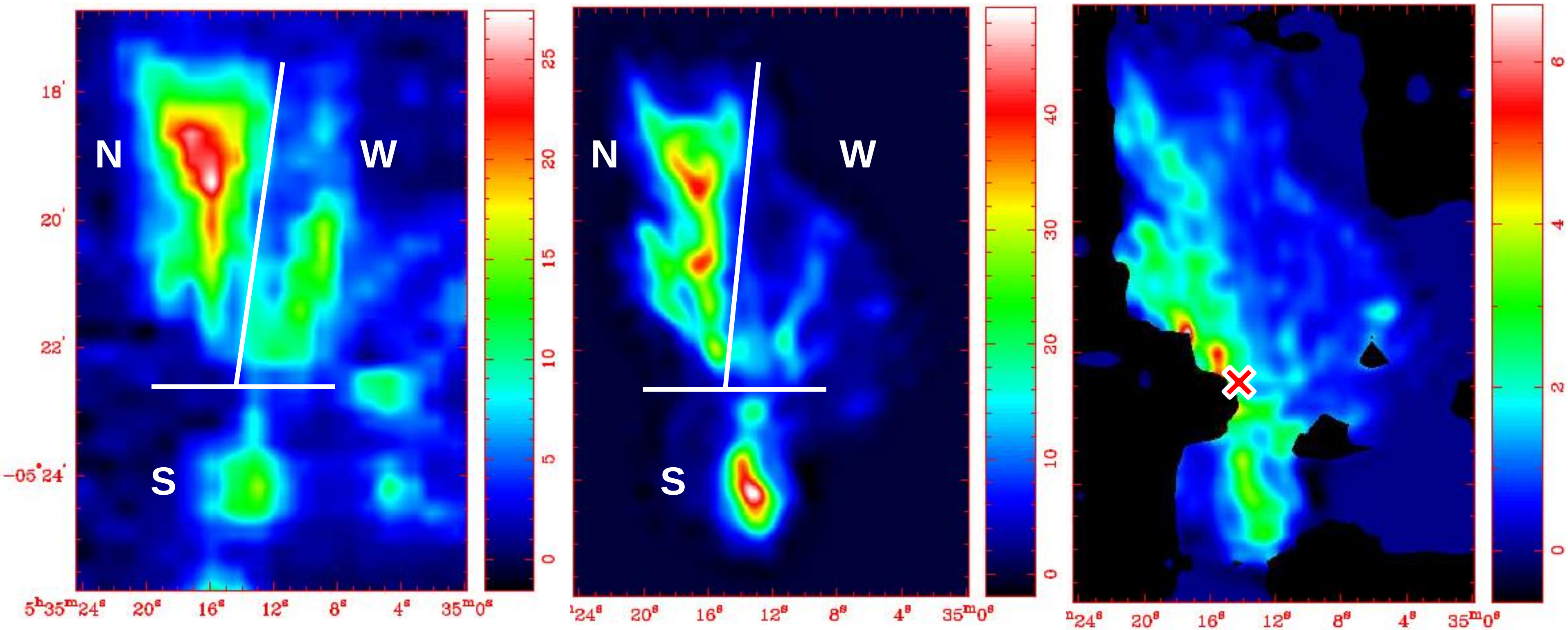

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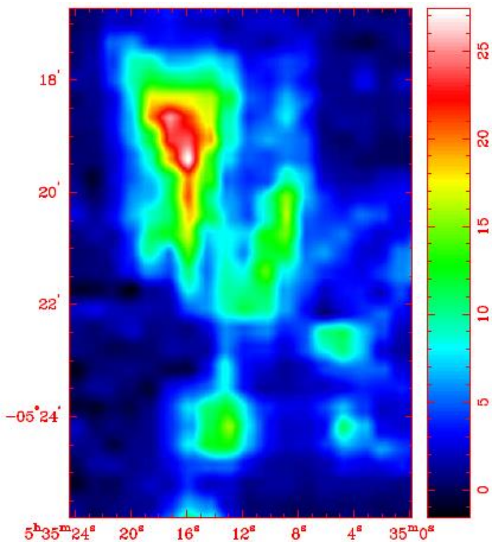

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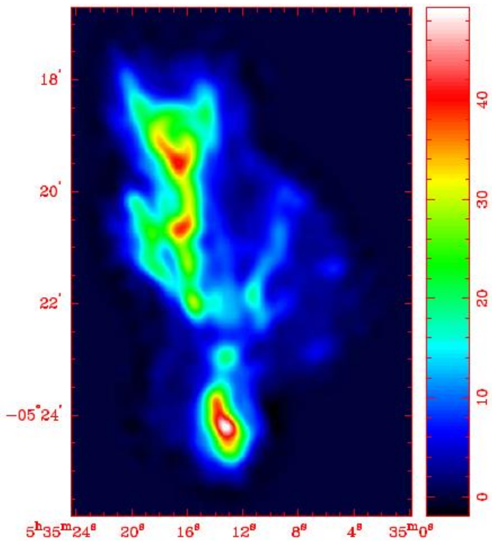

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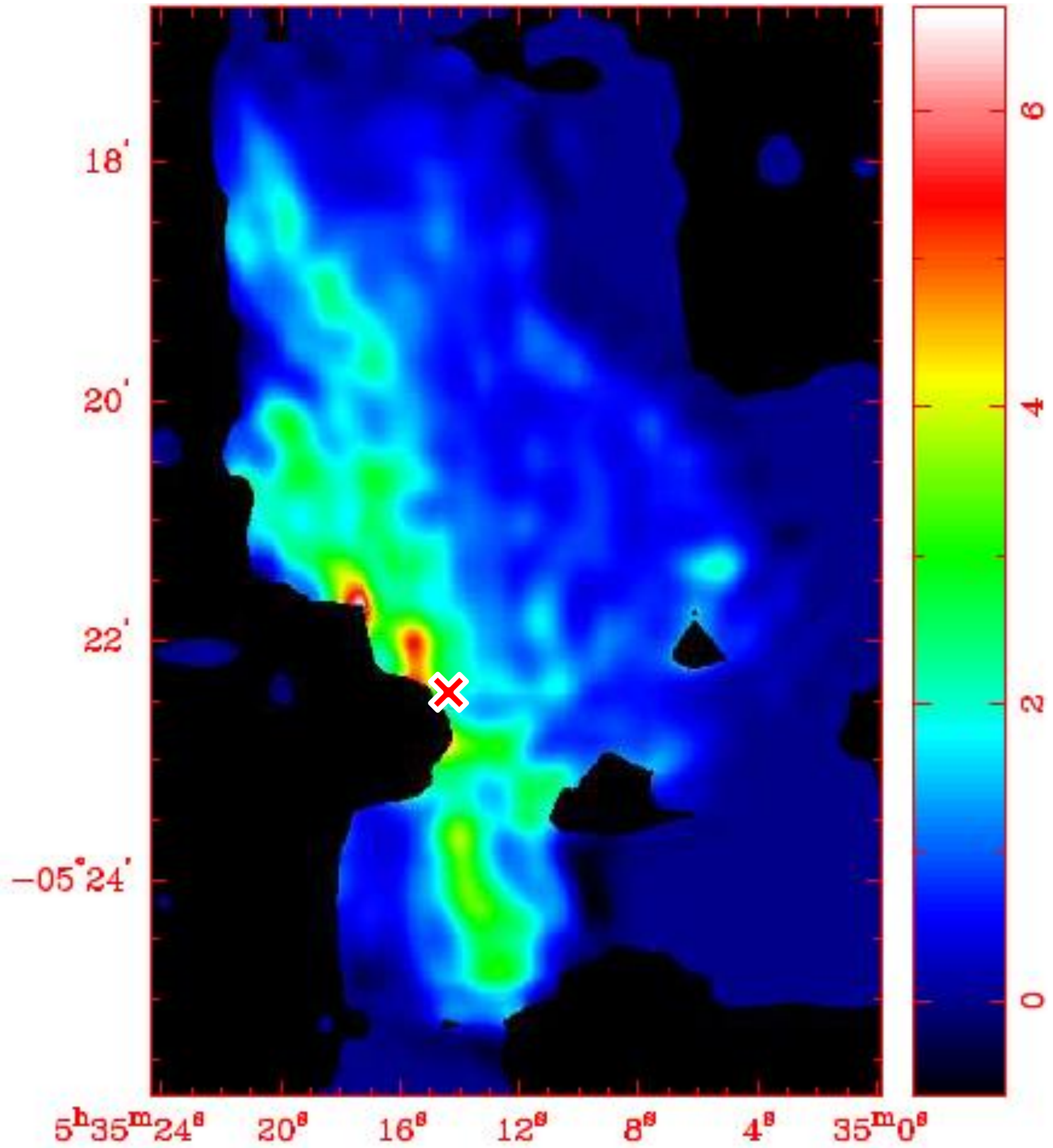

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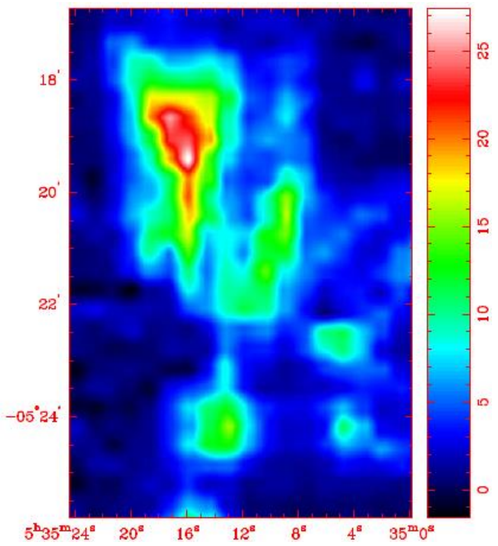

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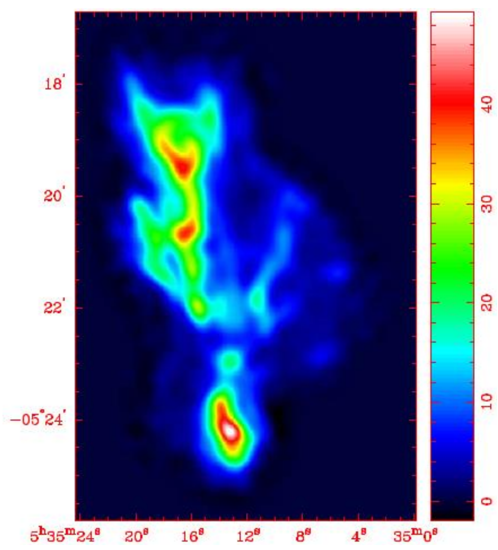

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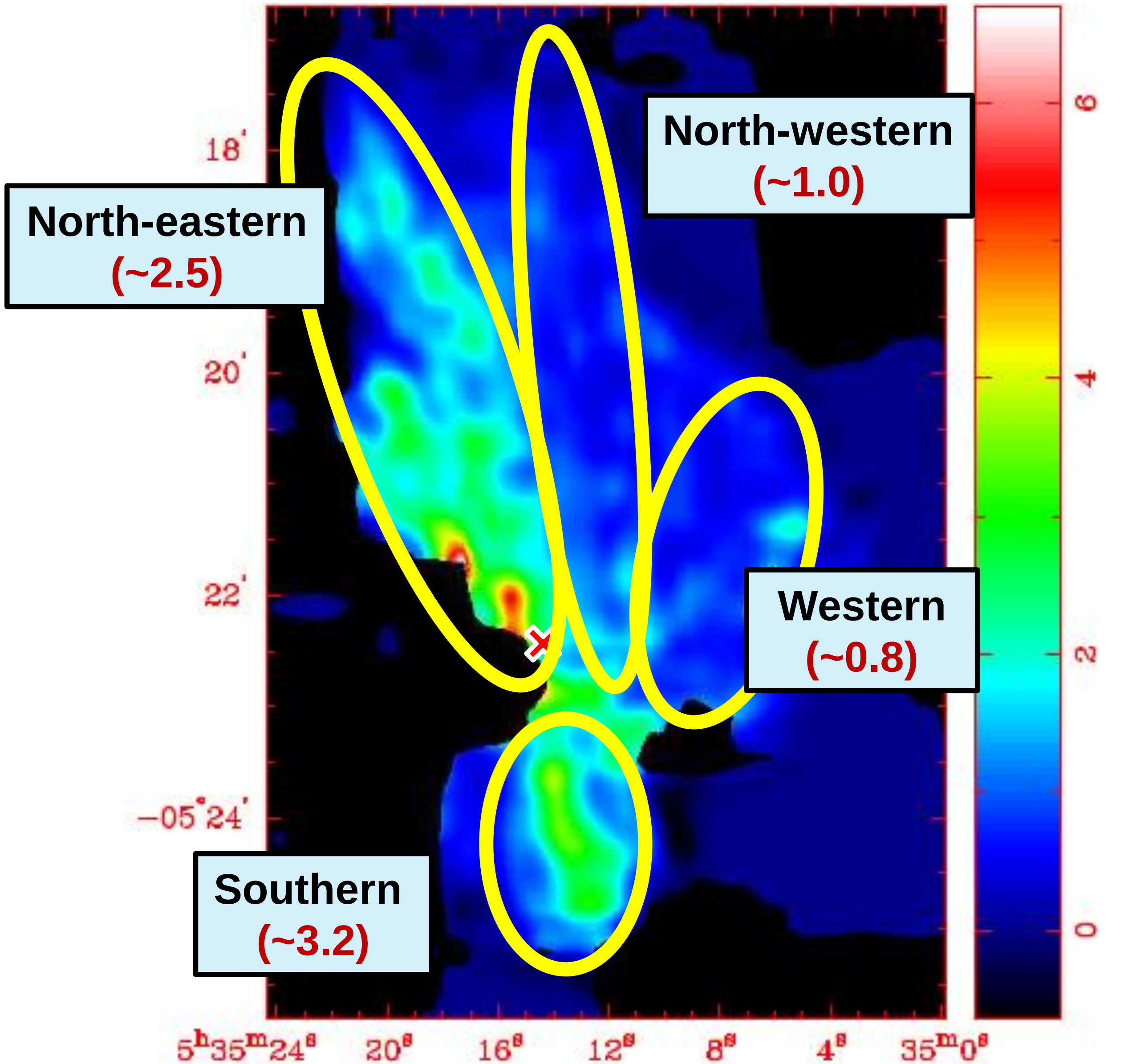
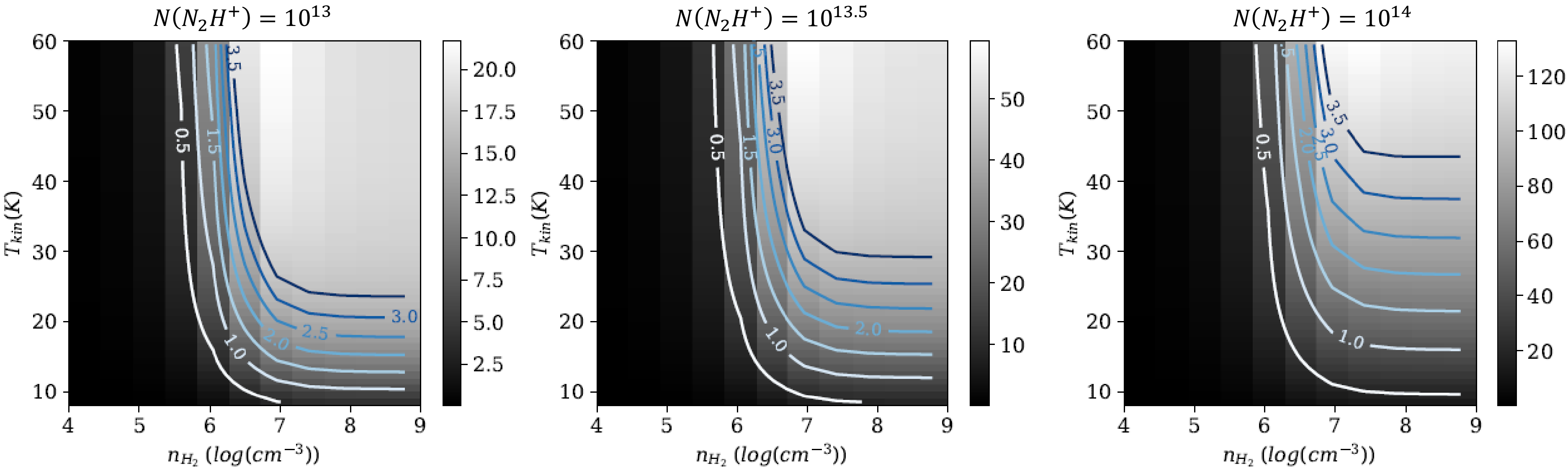


Non-LTE Analysis

- Using *RADEX*
- N_2H^+ (3-2) intensity model and (3-2) / (1-0) line ratio model
- Compare the models with observations

  → constrain the physical parameters: $\boldsymbol{n(H_2), T_{kin}}$ and $\boldsymbol{N(N_2H^+)}$



Physical Conditions

- Radiation from south-east (Orion KL)

	North (Eastern)	North (Western)	Western	Southern
$\mathbf{n(H_2)\ (\boldsymbol{cm^{-3}})}$	3×10^6	$\sim 3 \times 10^6\ (\geq 10^7)$	3×10^6	3×10^7
$\mathbf{T_{\boldsymbol{kin}}\ (\boldsymbol{K})}$	$34 - 43$	$15 - 21\ (11 - 15)$	$12 - 16$	$37 - 45$
$\mathbf{N(N_2\boldsymbol{H}^+)\ (\boldsymbol{cm^{-2}})}$	3×10^{13}	3×10^{13}	10^{13}	10^{14}
Typical Ratio	2.5 ± 0.3	1 ± 0.3	0.8 ± 0.3	3.2 ± 0.4

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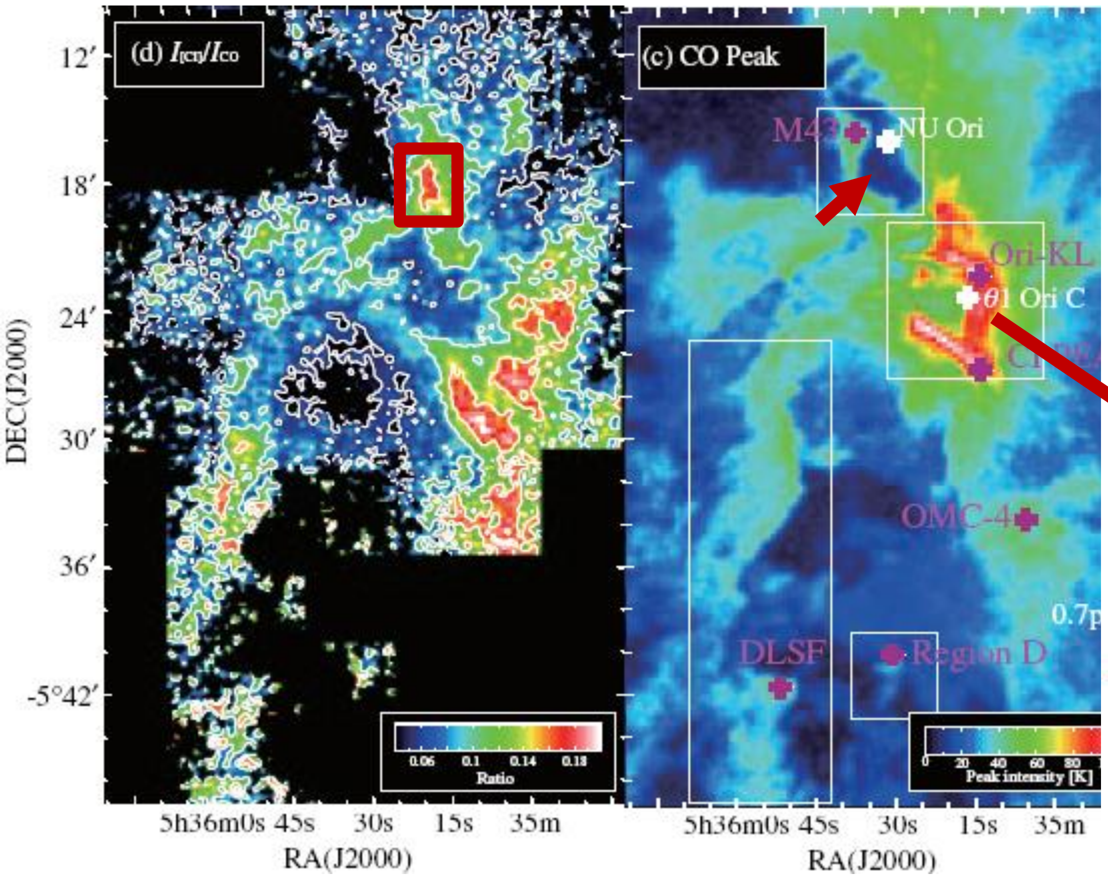
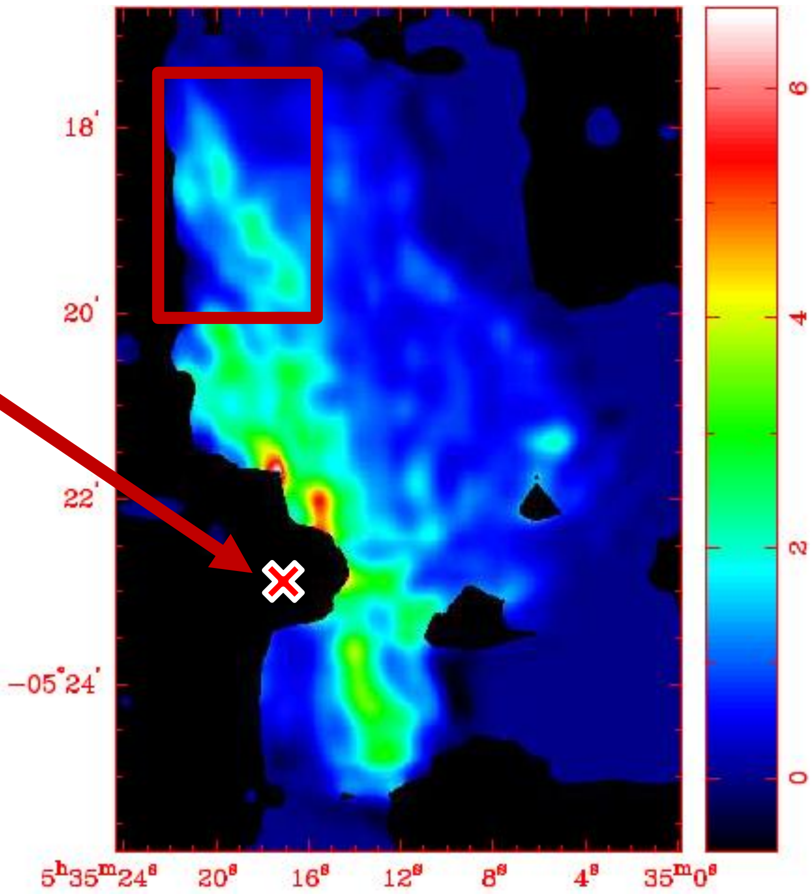
External UV Heating

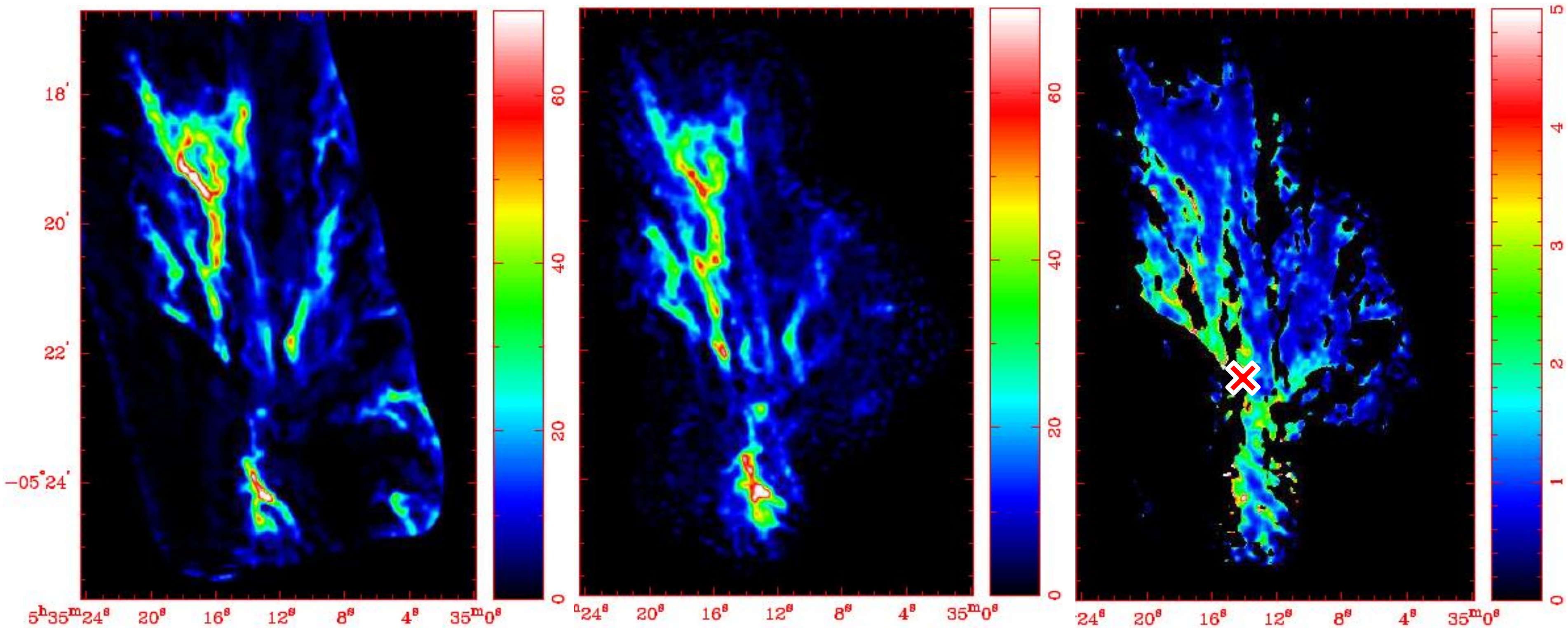


Shimajiri et al. (2013)



High Resolution Analysis

ALMA+IRAM 30m (1-0) SMA+SMT (3-2) **(3-2) / (1-0) ratio**



(convolved) 5.53”×5.25” resolution

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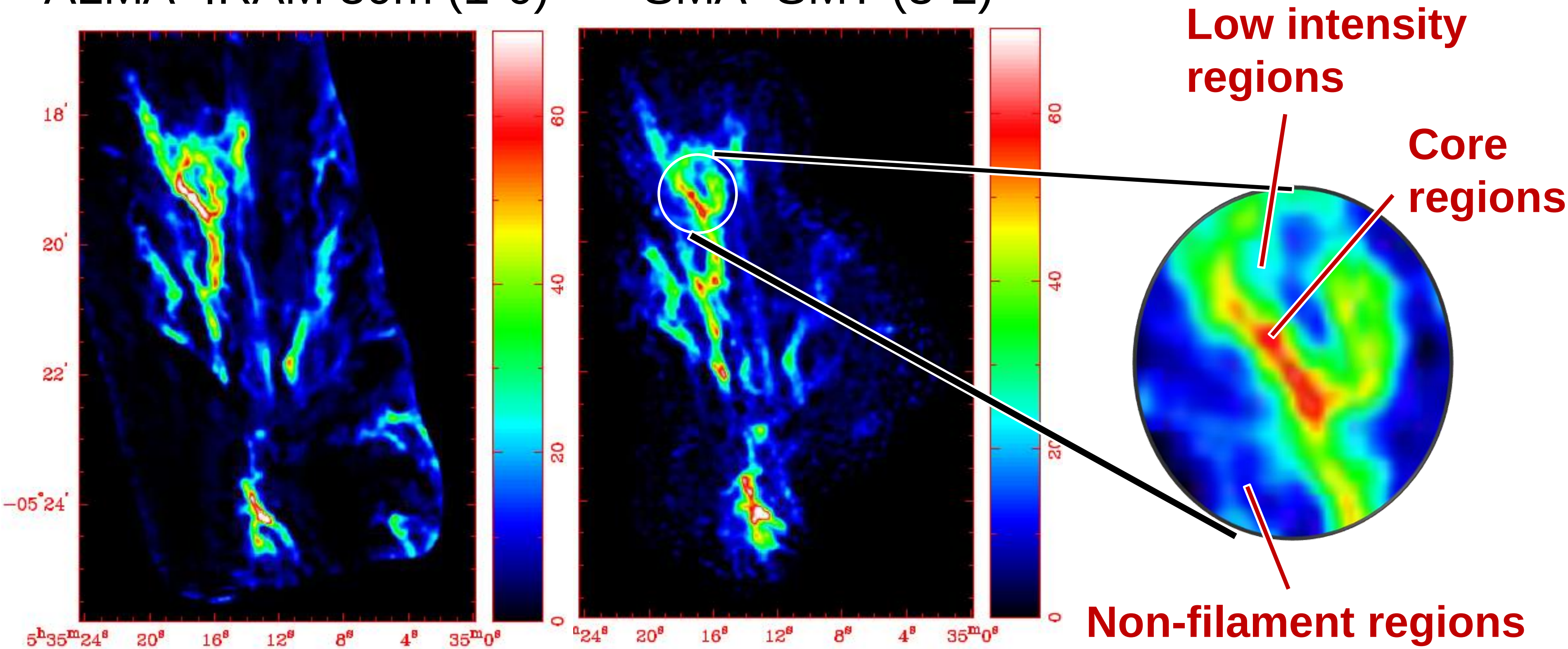

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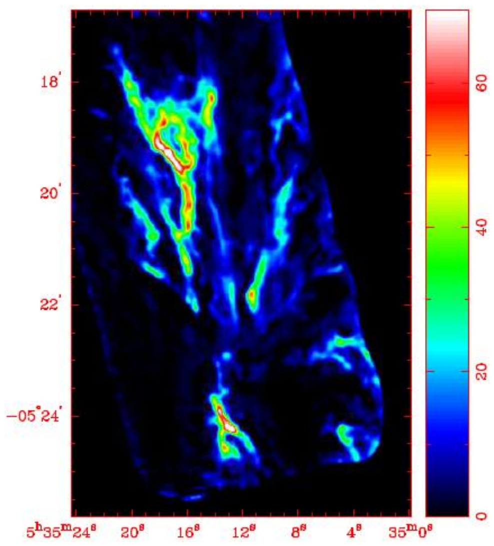

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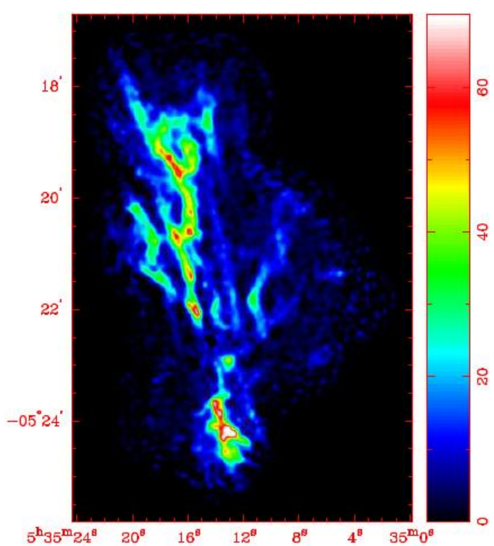

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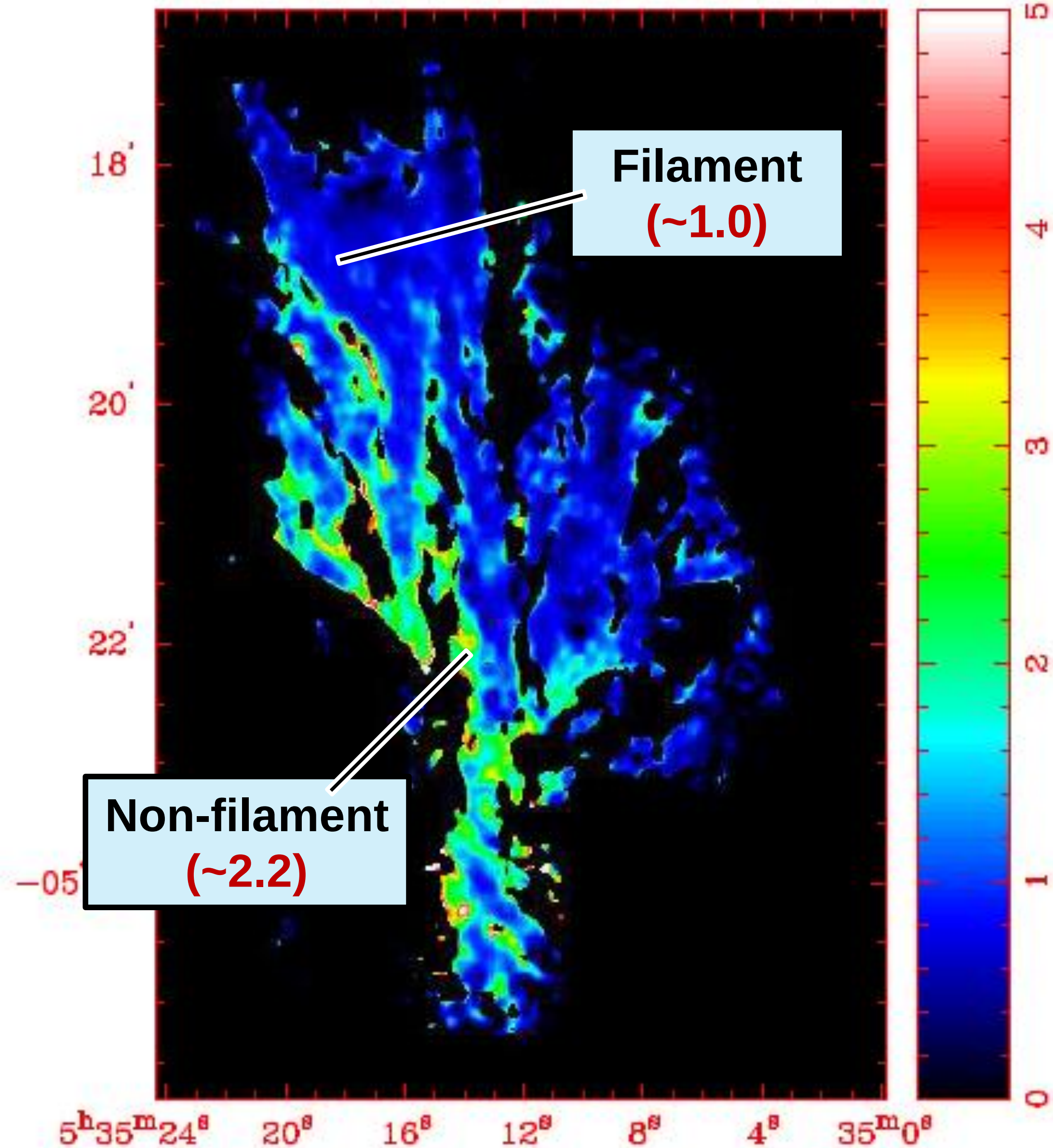

Physical Properties of Filaments

(Filament regions)

	Core Regions (High Intensity) (> 50 K•km/s)	**Low Intensity Regions** (< 50 K•km/s)	**Non-filament regions**
$\mathbf{n(H_2)}\ (\boldsymbol{cm^{-3}})$	3×10^7 or 10^7	3×10^6 or 10^7	10^6 or 3×10^6
$\mathbf{T}_{\boldsymbol{kin}}\ (\boldsymbol{K})$	19– 23 or 18– 20	17– 22 or 13– 16	>45 or 21– 30
$\mathbf{N(N_2}\boldsymbol{H^+})\ (\boldsymbol{cm^{-2}})$	10^{14}	3×10^{13}	10^{13}
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Table 2   High-resolution Parameters

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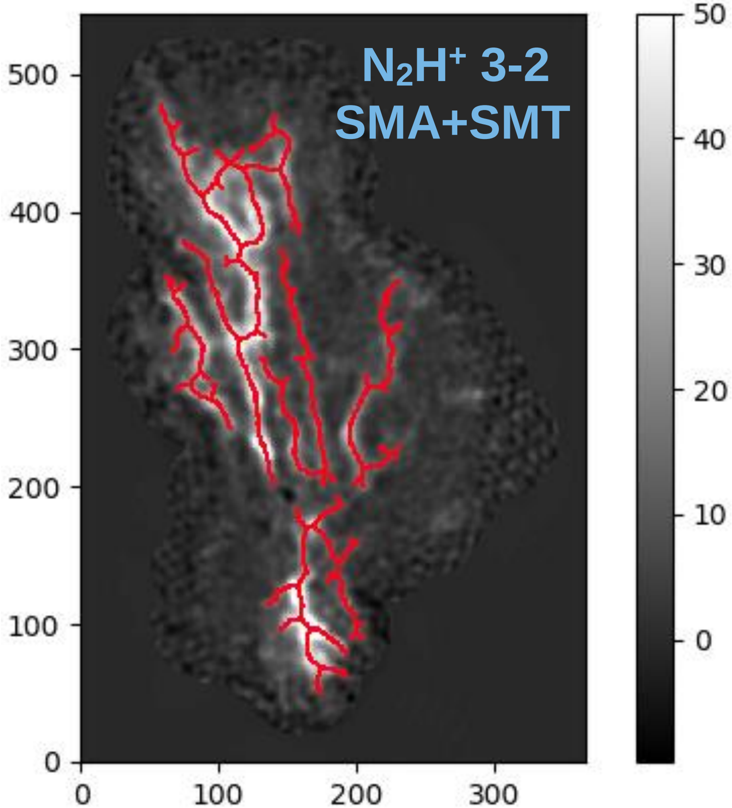
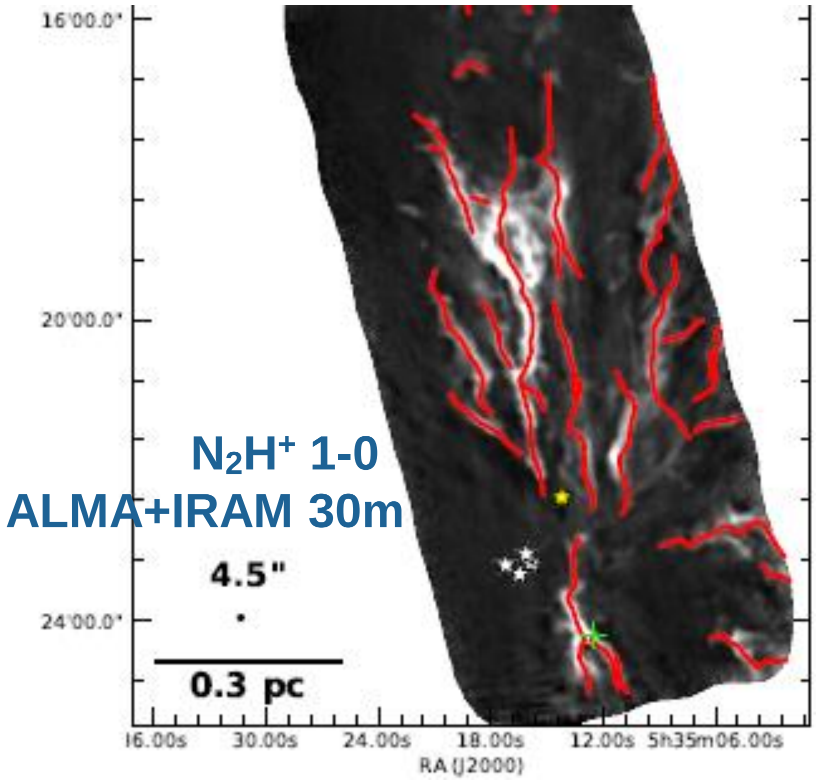
Filament Identification

FilFinder 2D identification

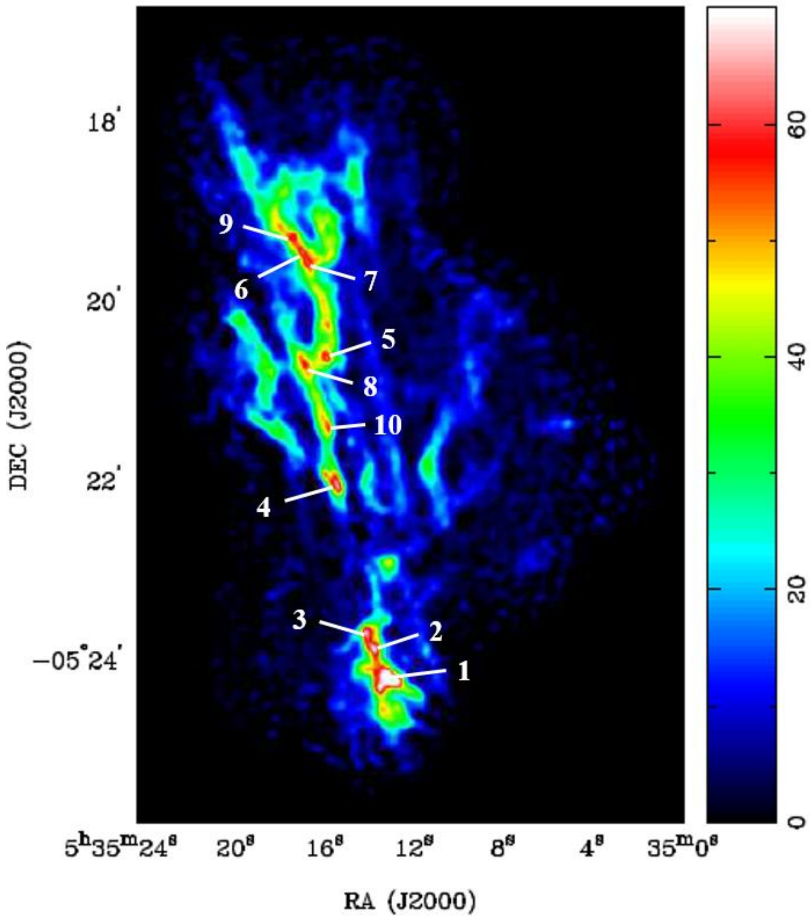


HiFIVE 3D identification



Hacar et al. (2018)

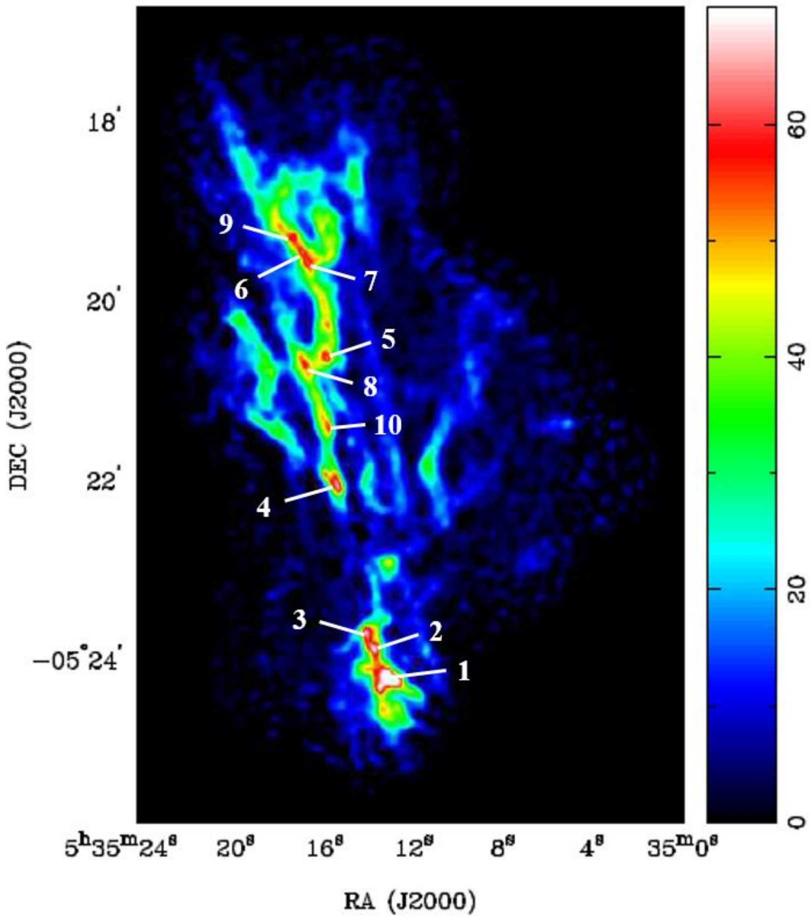
Core Identification

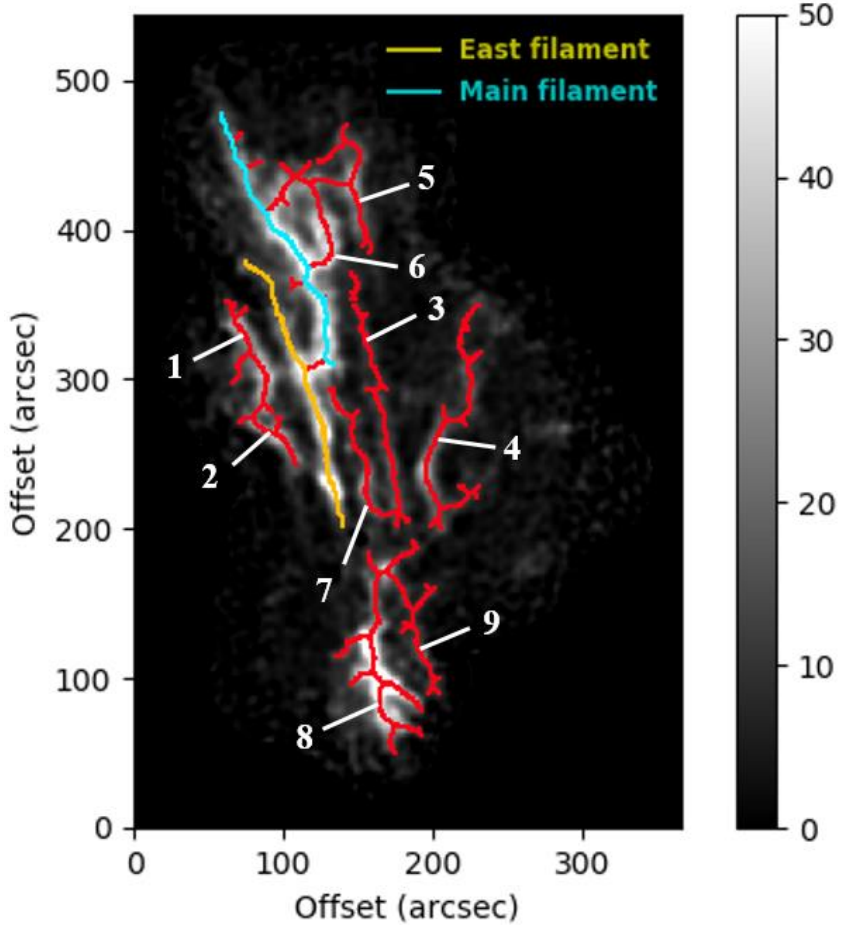


Typical core size: 4.2'' (~0.017 pc)

Core	Δv (km s^{-1})	M ($M_\odot$)	M_{vir} ($M_\odot$)
1	3.5	3.34–10.57	46.08
2	2.8	0.71–2.25	18.51
3	1.6	0.39–1.24	5.01
4	2.0	0.91–2.89	8.50
5	0.9	0.16–0.52	1.20
6	–	0.35–1.11	–
7	–	0.33–1.03	–
8	2.2	0.24–0.76	7.35
9	–	0.36–1.15	–
10	1.1	0.06–0.19	1.32

Cores in the Filaments





Filament Properties

Filament	M_{lin} ($M_\odot$ pc^{-1})	Δv (km s^{-1})	M_{crit} ($M_\odot$ pc^{-1})	M_{lin}/M_{crit}
Main	94.2–101.7	1.0 ± 0.2	119.7	0.79–0.85
East	78.5–85.6	0.9 ± 0.3	103.8	0.76–0.83
1	84.0	0.6 ± 0.2	66.0	1.27
2	76.2	0.7 ± 0.3	76.9	0.99
3	42.5	1.3 ± 0.6	177.6	0.24
4	61.8	1.1 ± 0.3	137.3	0.45
5	84.0	1.0 ± 0.5	119.7	0.70
6	166.3	1.1 ± 0.3	137.3	1.21
7	68.9	1.0 ± 0.4	119.7	0.58
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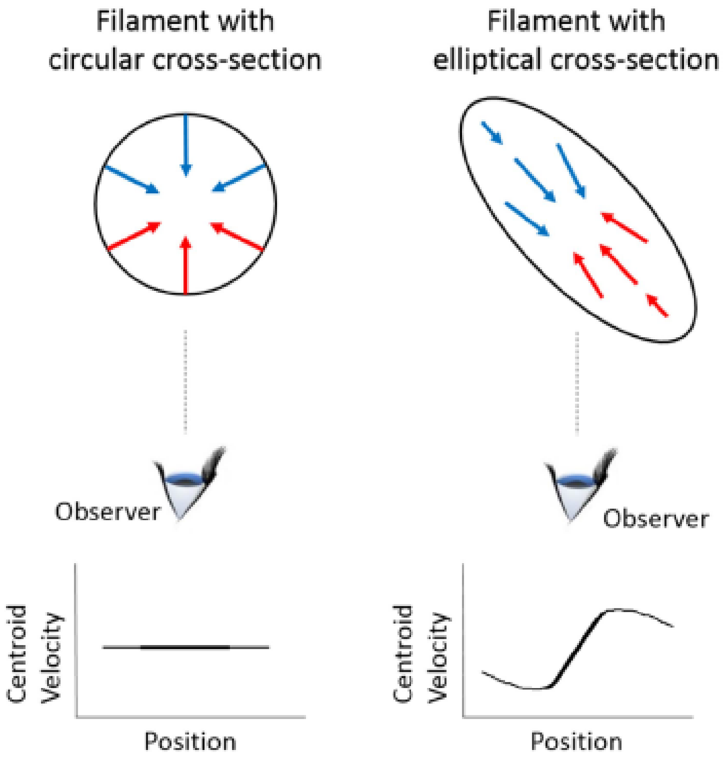
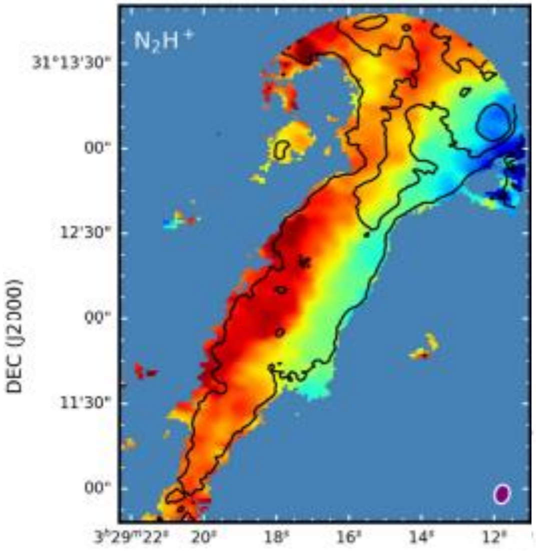
Minor-Axis Analysis

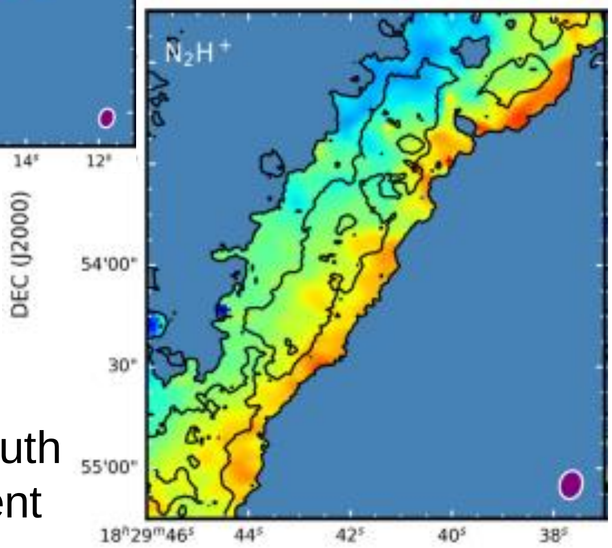
Filament formation model



*All figures are from Dhabal et al. (2018)

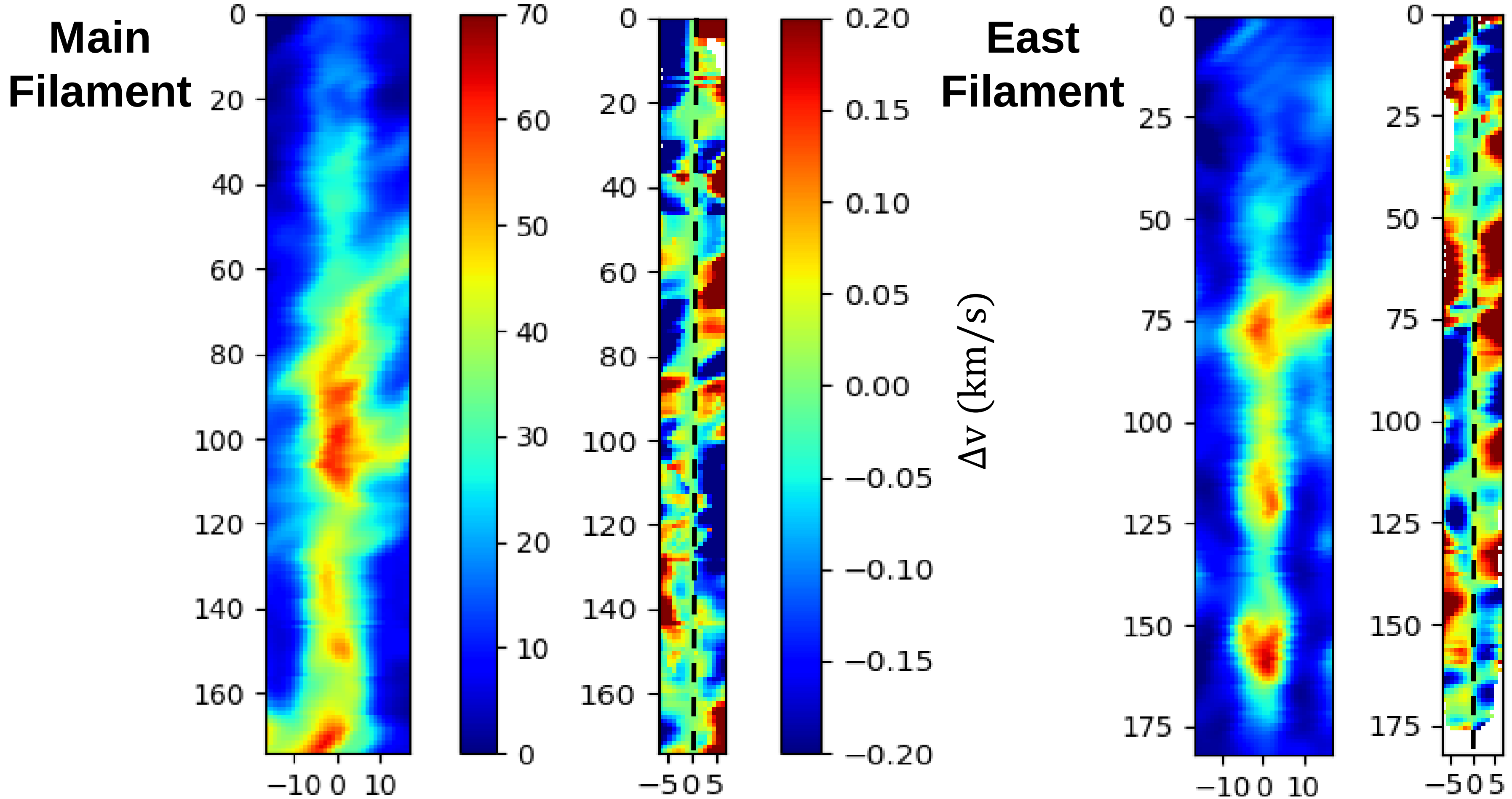


NGC1333
SE region



Serpens South
NW filament

Minor-Axis Analysis



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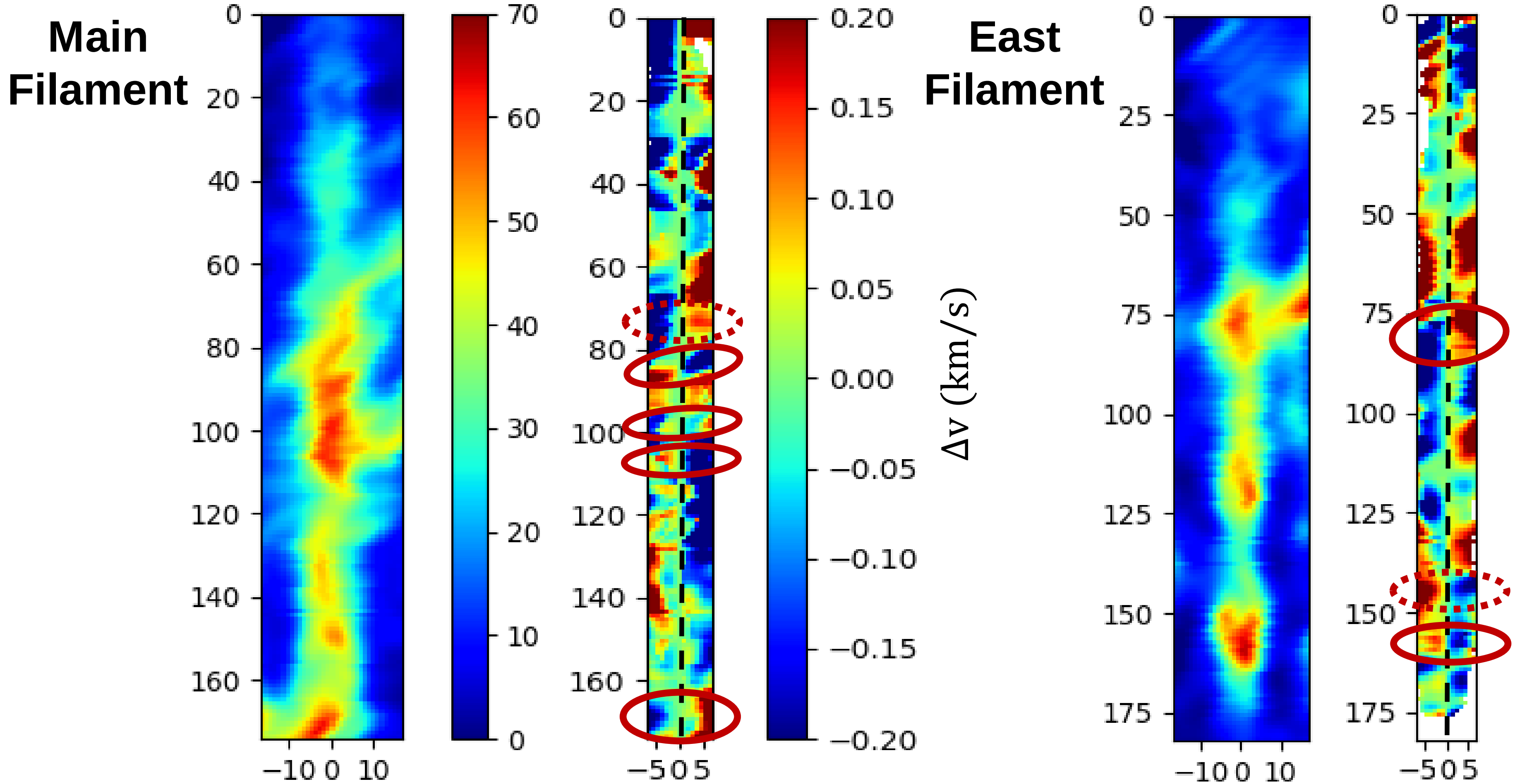

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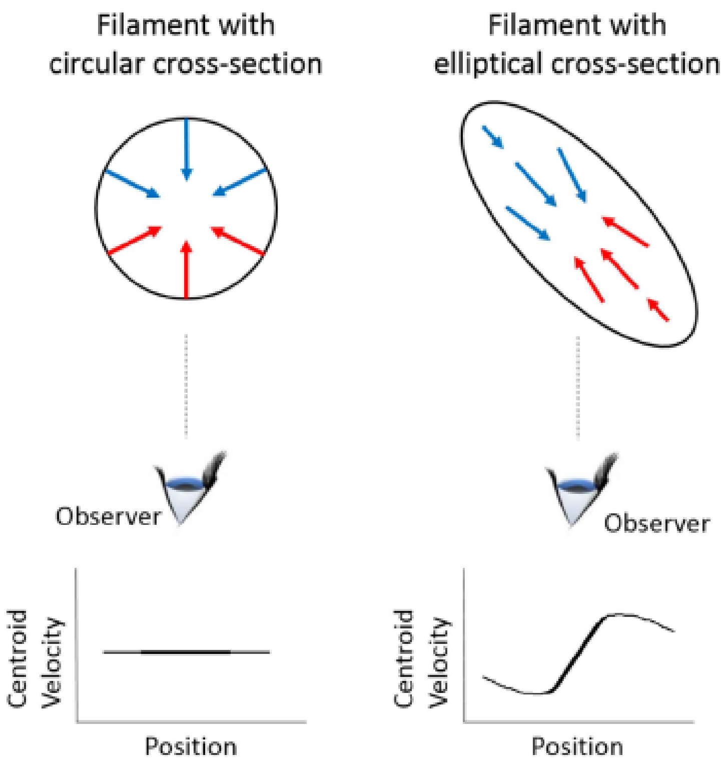
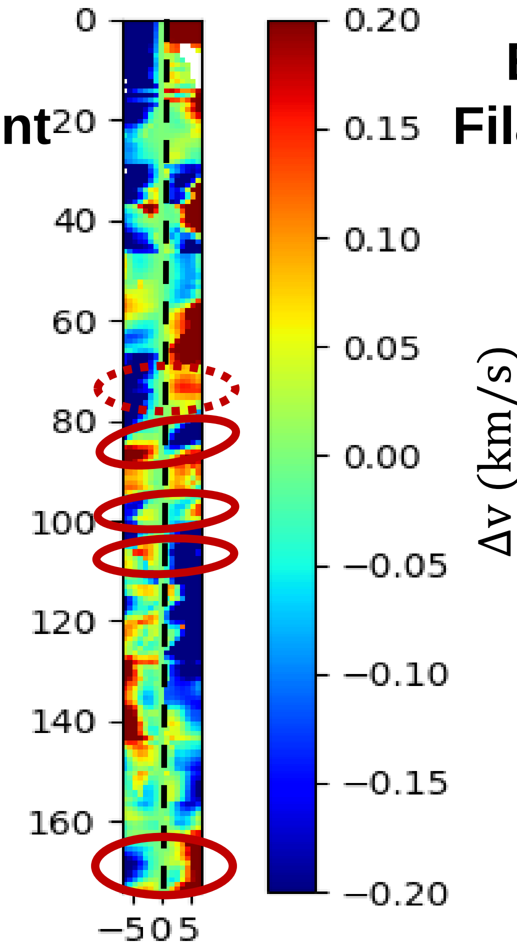
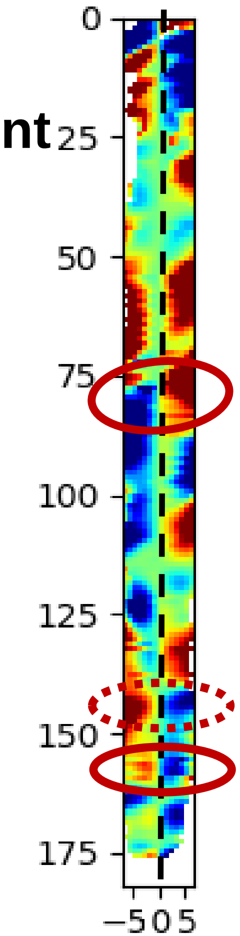


Dhabal et al. (2018)

Main Filament



East Filament

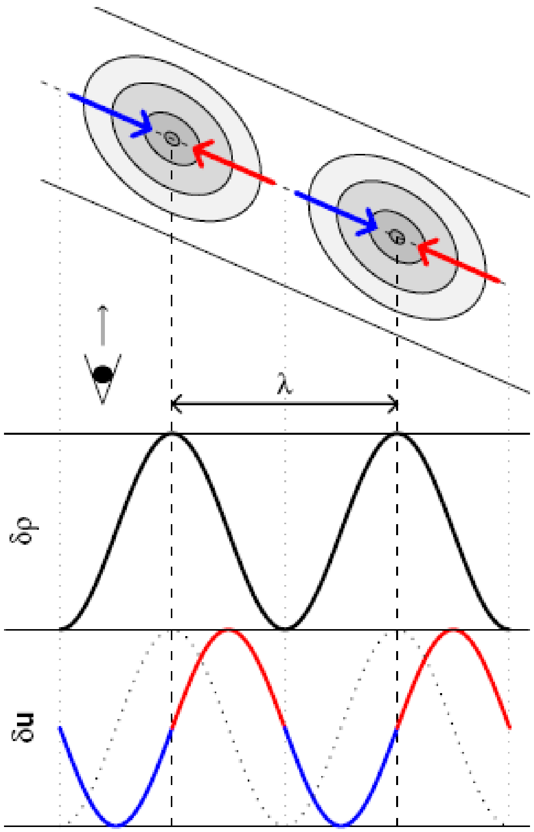


Major-Axis Analysis

Core formation model

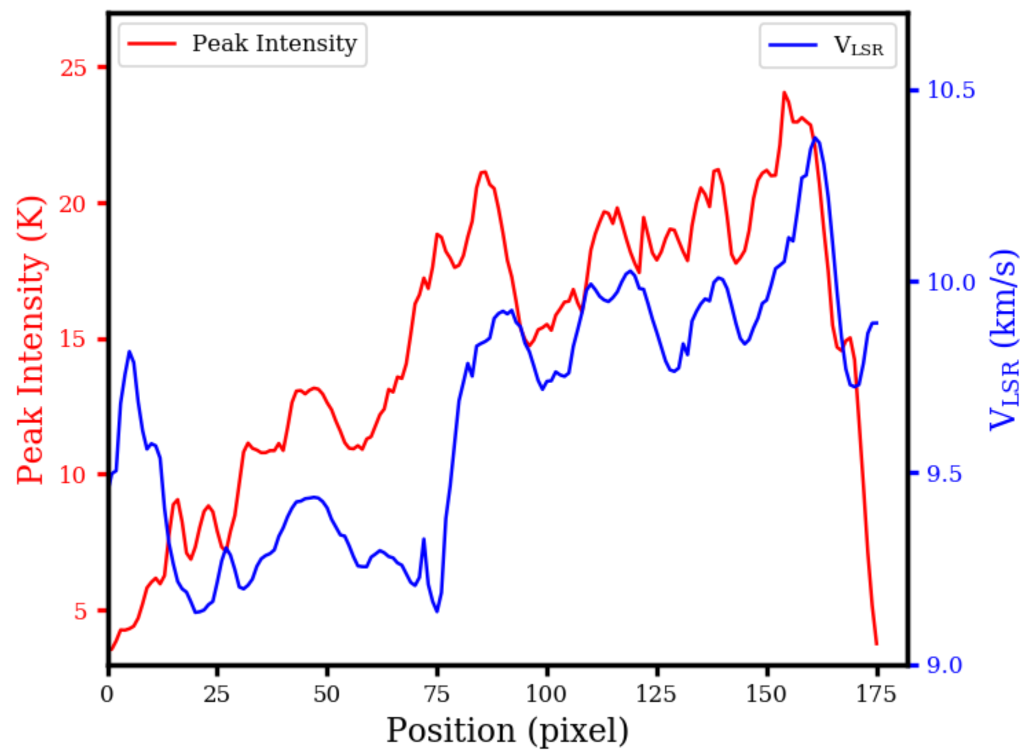
Density
(Intensity)

Velocity



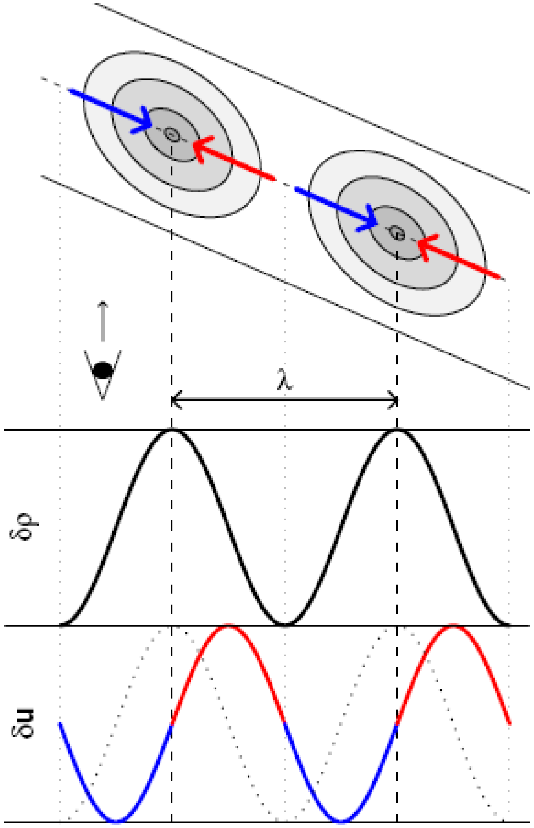
Hacar and Tafalla (2011)

East Filament



Major-Axis Analysis

Core formation model

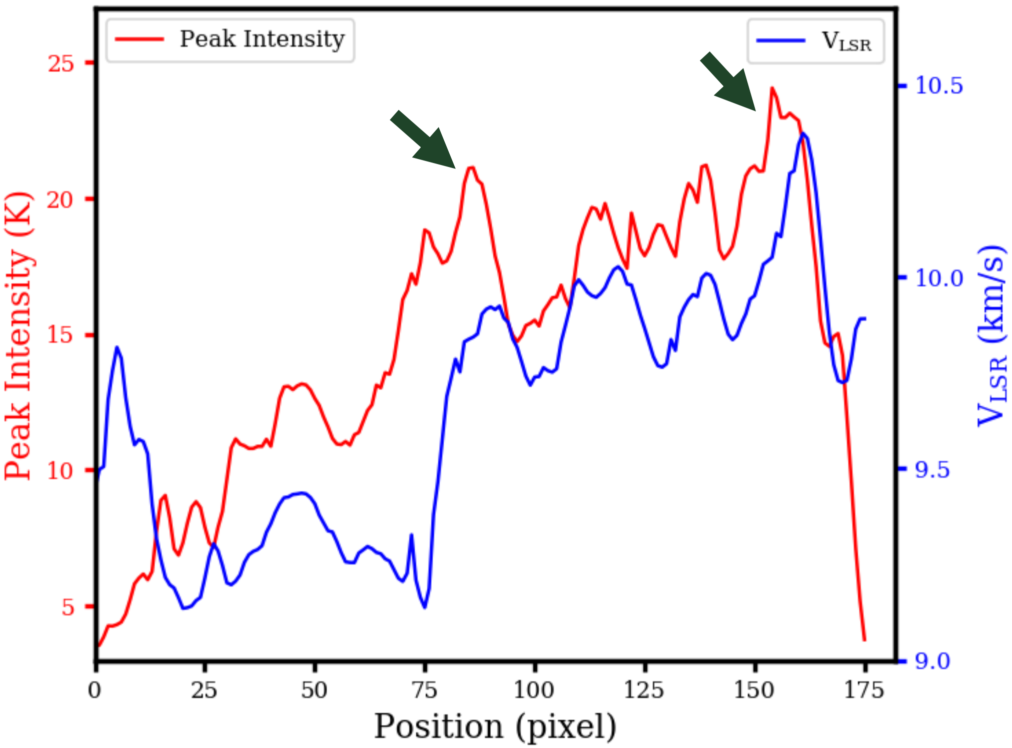


Density (Intensity)

Velocity

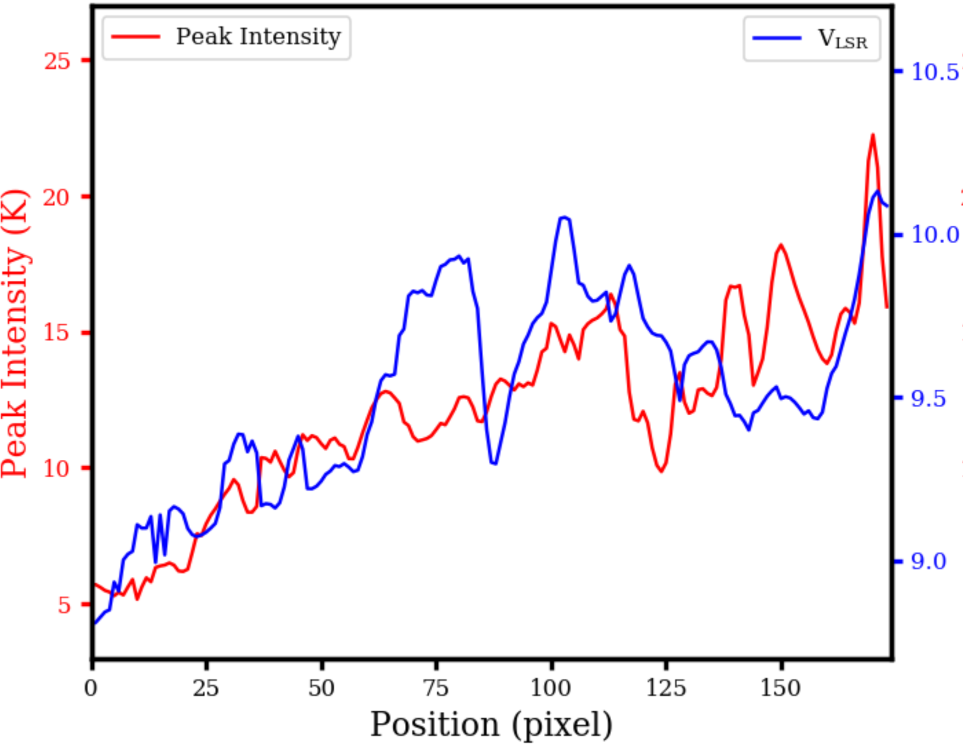
Hacar and Tafalla (2011)

East Filament

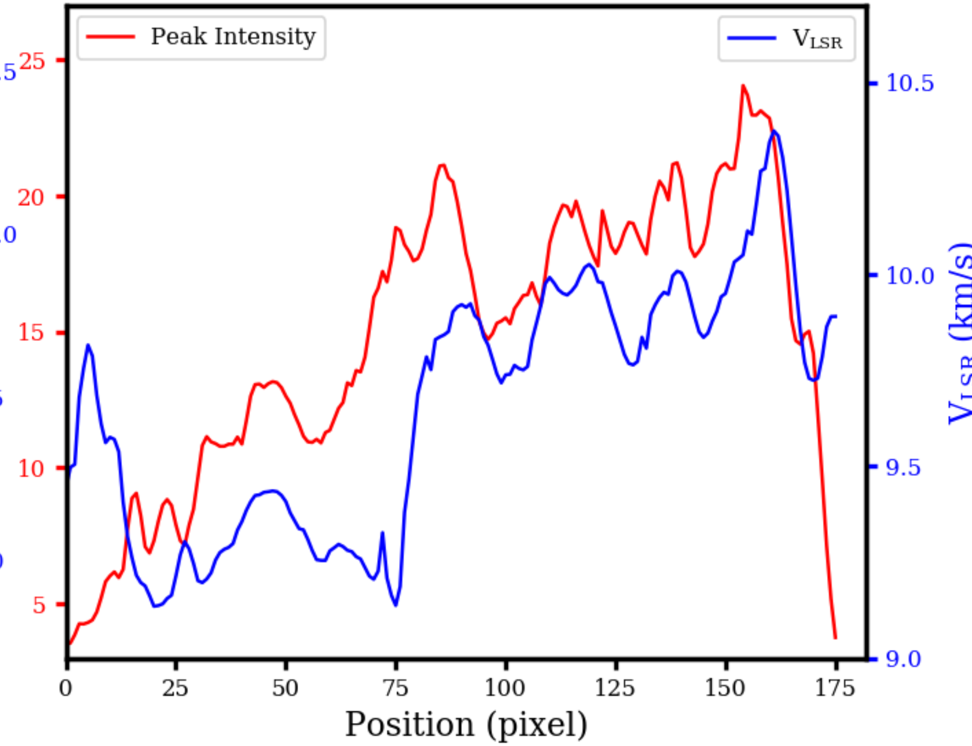


Major-Axis Analysis

Main Filament



East Filament



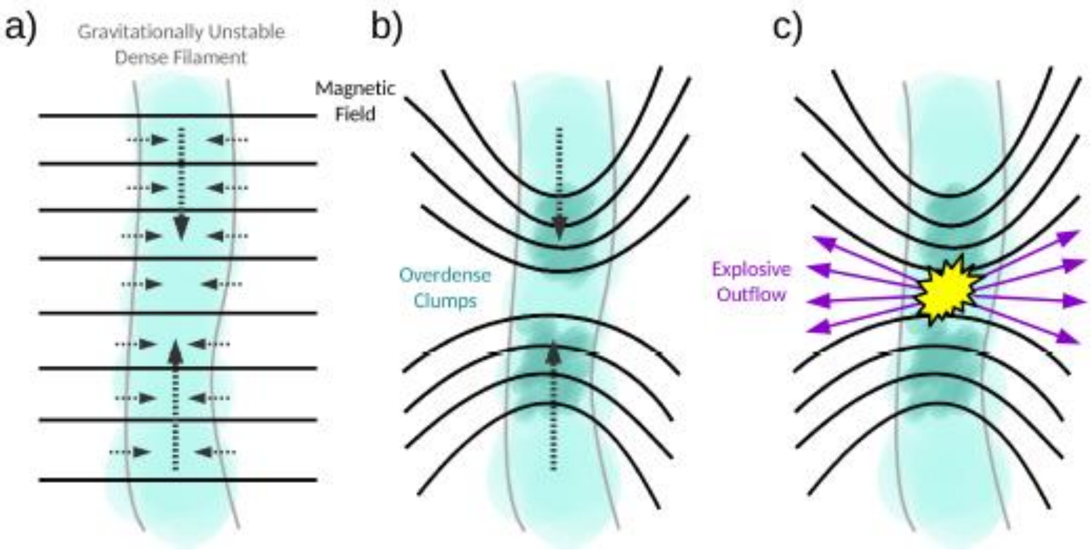
Summary

- We combine single-dish (SMT) and interferometer (SMA) data in N_2H^+ 3-2 and produce the high-resolution image
  → filamentary structure with typical widths of ~0.02 to 0.03 pc
- Velocity structure in N_2H^+ may indicate a global collapse scenario
- We use N_2H^+ 3-2 and 1-0 lines to constrain the physical parameters
  - Large scale analysis shows a high line ratio in the eastern edge
    → External heating (T_{kin}~$34-43\ K$)
  - High resolution analysis shows a low ratio in the filaments
    → High density and low temperature ($n_{H_2} \sim 10^7\ cm^{-3}$ and T_{kin}~$20K$)
- Line densities of the OMC1 filaments are similar to the critical values, and the measured core masses are smaller than the virial masses.
  → non-thermal motions in OMC1 are larger than in low-mass regions
- The formation mechanism of the OMC1 filaments may be different from that in typical low-mass star-forming regions.
- We find signatures of core-forming gas motions in the east filament
  → younger evolutionary phase

Thank you for your attention!

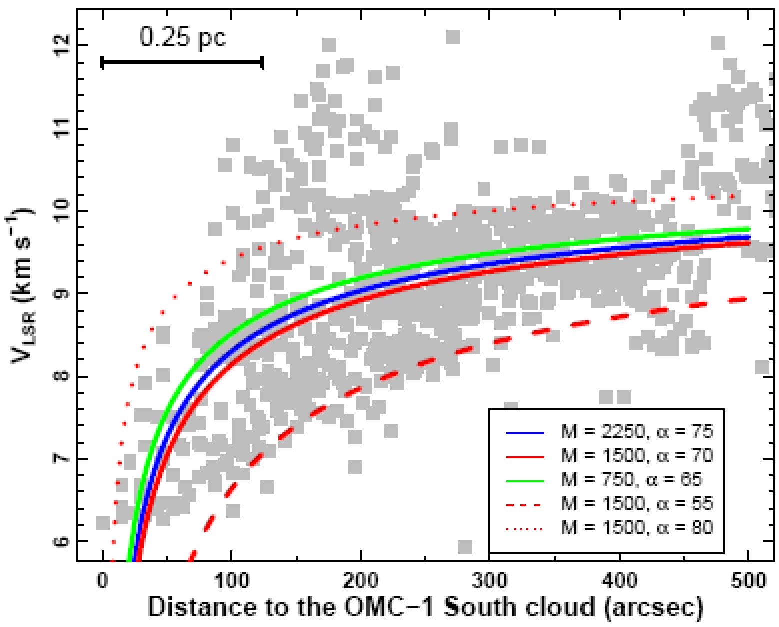
Global Collapse

Hourglass-shaped magnetic field



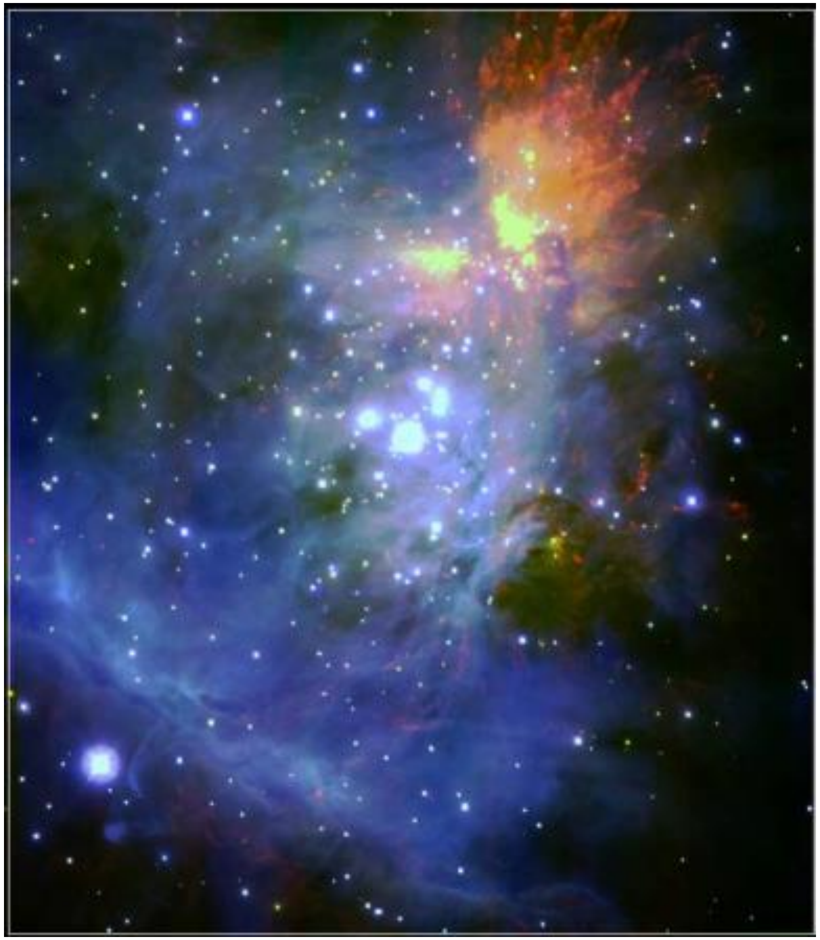
Pattlle et al. (2017)
(JCMT BISTRO Survey)

Accelerated gas motion

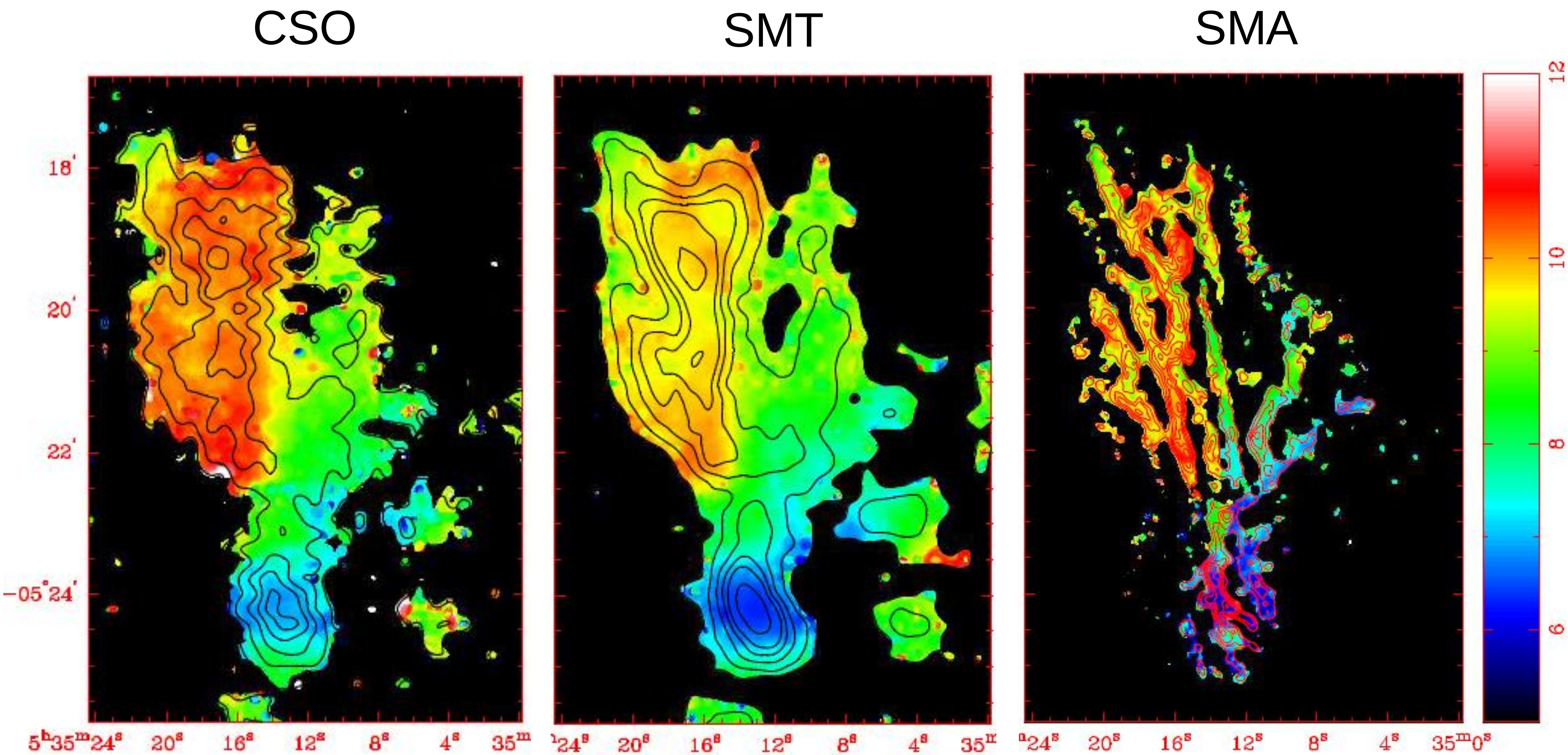


Hacar et al. (2017)

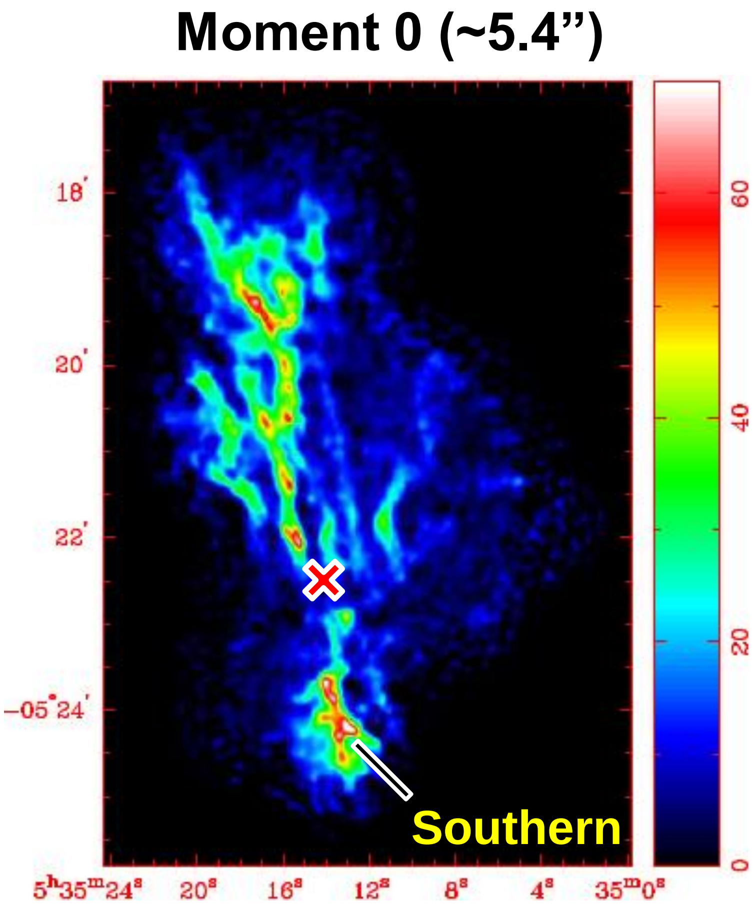
M42 and Orion KL

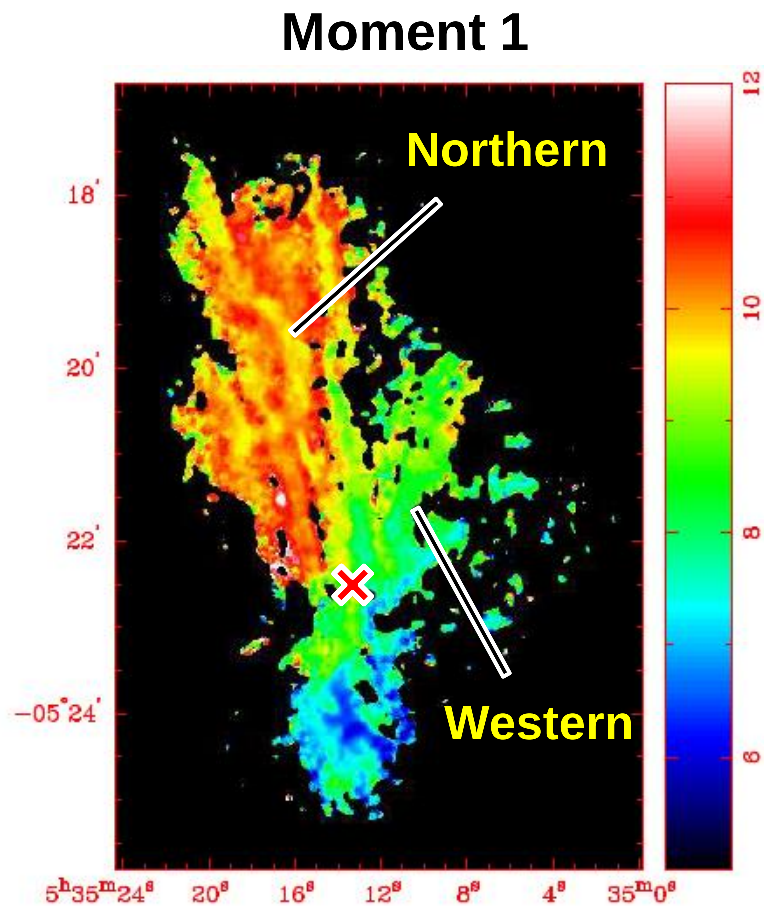


Problems in CSO data



SMA + CSO Results





Non-LTE Analysis

- Using *RADEX*
- N_2H^+ (3-2) and (1-0) spectra model

  → (3-2) / (1-0) intensity ratio model

- $T_{MB}(v) = \left(\frac{\sum J(T_{ex}^{i}) \tau_i(v)}{\sum \tau_i(v)} - J(T_{bg}) \right) \left(1 - e^{-\sum \tau_i(v)}\right)$

- **Compare three models with observations**

  → Derive the physical parameters
  - $\boldsymbol{T_{kin}}$: Kinetic temperature (8-60K)
  - $\boldsymbol{N(N_2H^+)}$: N_2H^+ column density (1e12-1e14)
  - $\boldsymbol{n(H_2)}$: H_2 density (1e4-1e9)