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Filamentary Structure and Star Formation in OMC-1

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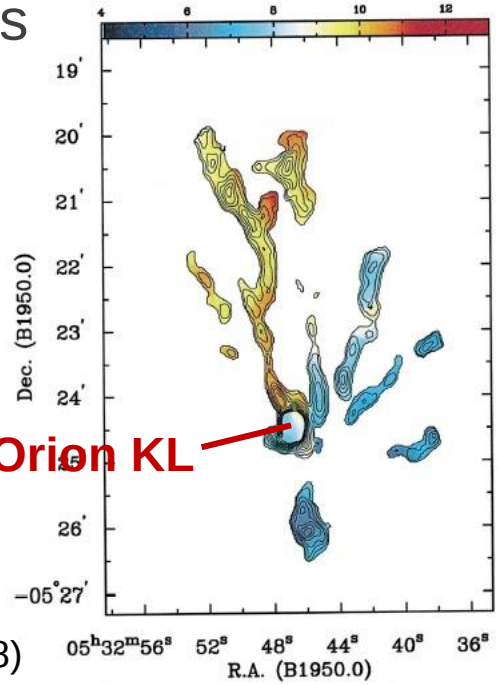
Motivation

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

Myers (2009)

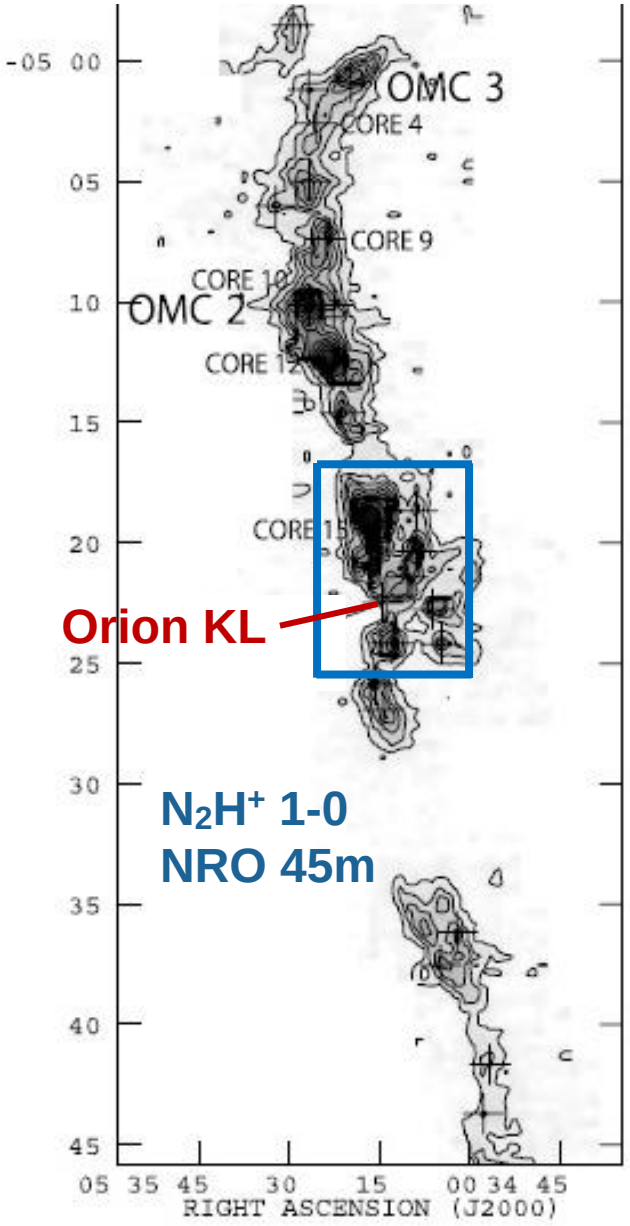


NH_3 (1,1)
VLA
8” resolution

Wiseman and Ho (1998)

Observations

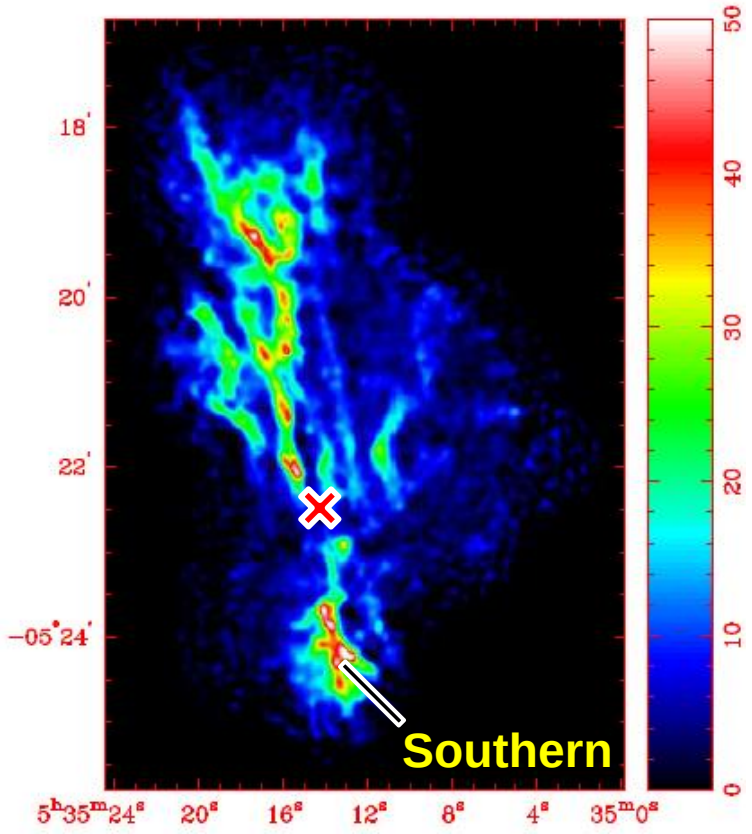
- **Orion molecular cloud 1 (OMC-1)**
  - Distance: 414 pc
  - Nearest high mass star forming region
- **N2H+ J=3-2**
  - Critical density ~ $10^6\ cm^{-3}$
  - SMA: 144 pointing mosaic
  - CSO: OTF mapping
  - **Combine SMA and CSO data**



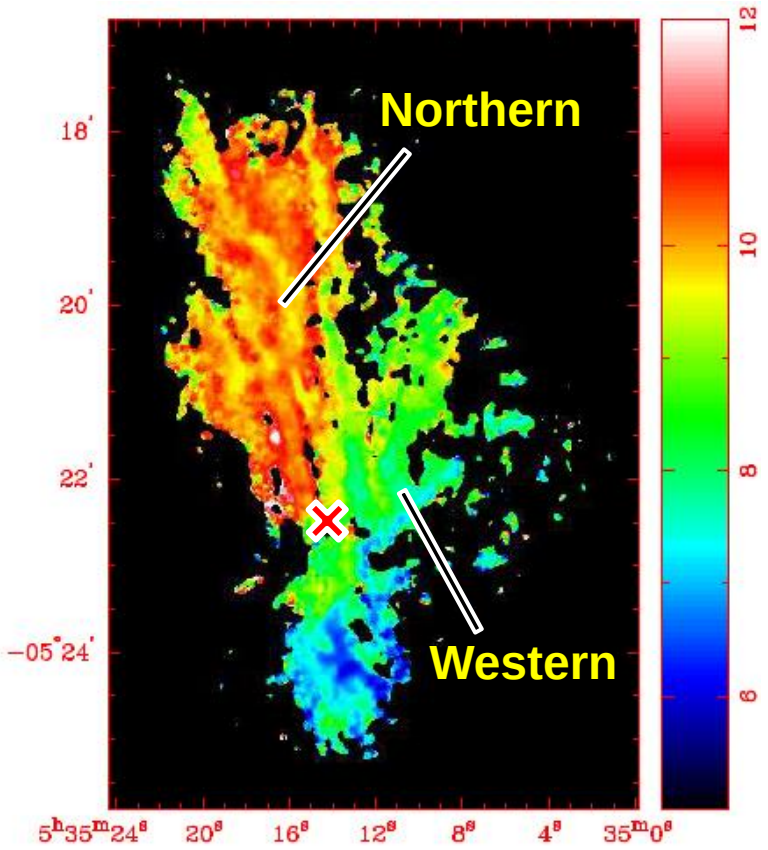
Tatematsu et al. (2008)

SMA + CSO Results

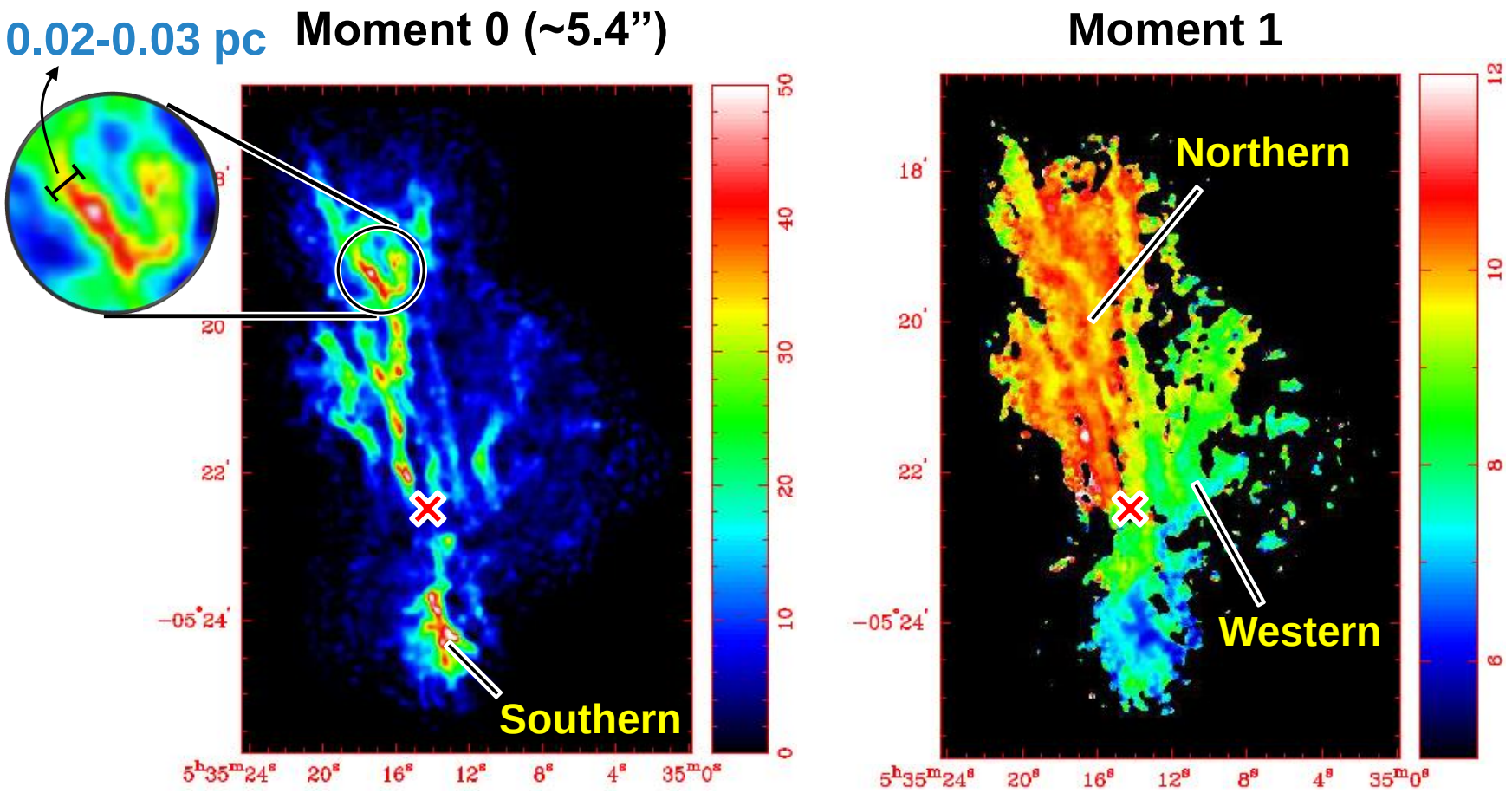
Moment 0 (~5.4")



Moment 1

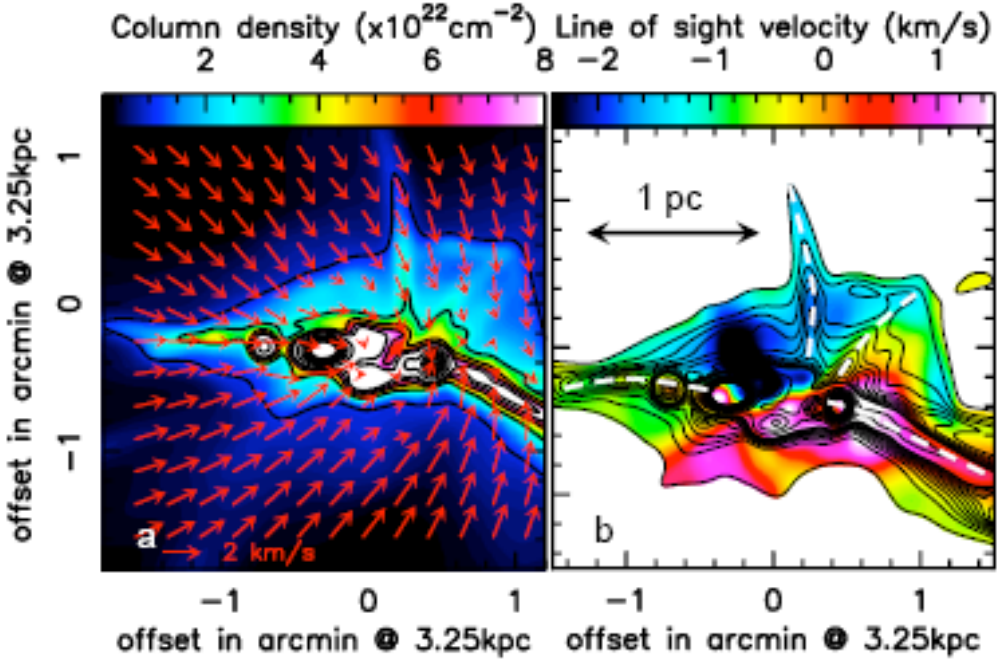


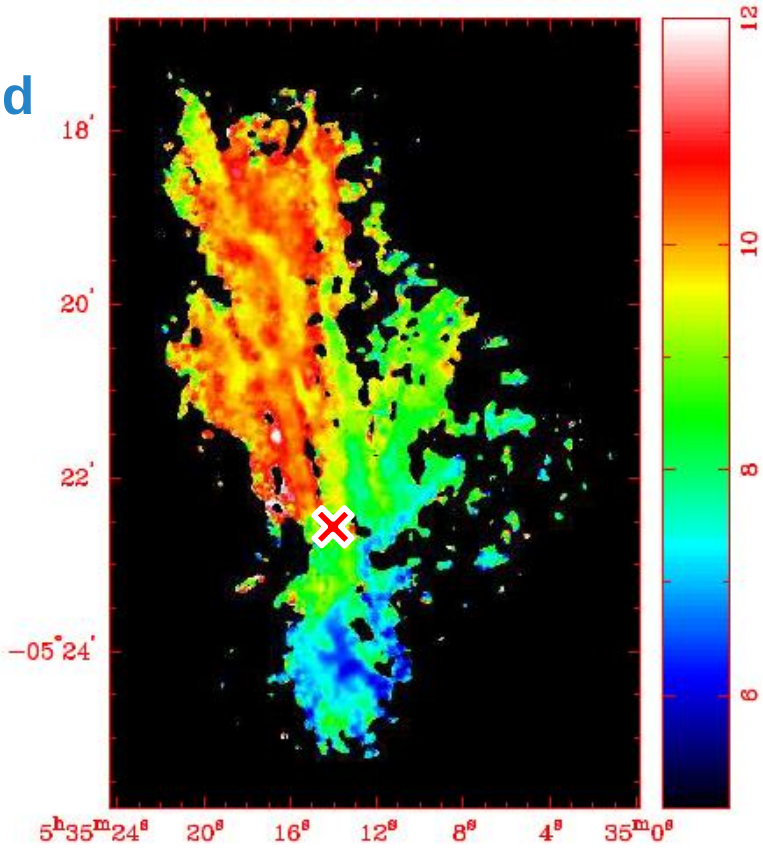
SMA + CSO Results



Global Collapse

MHD simulation of a global collapsing cloud





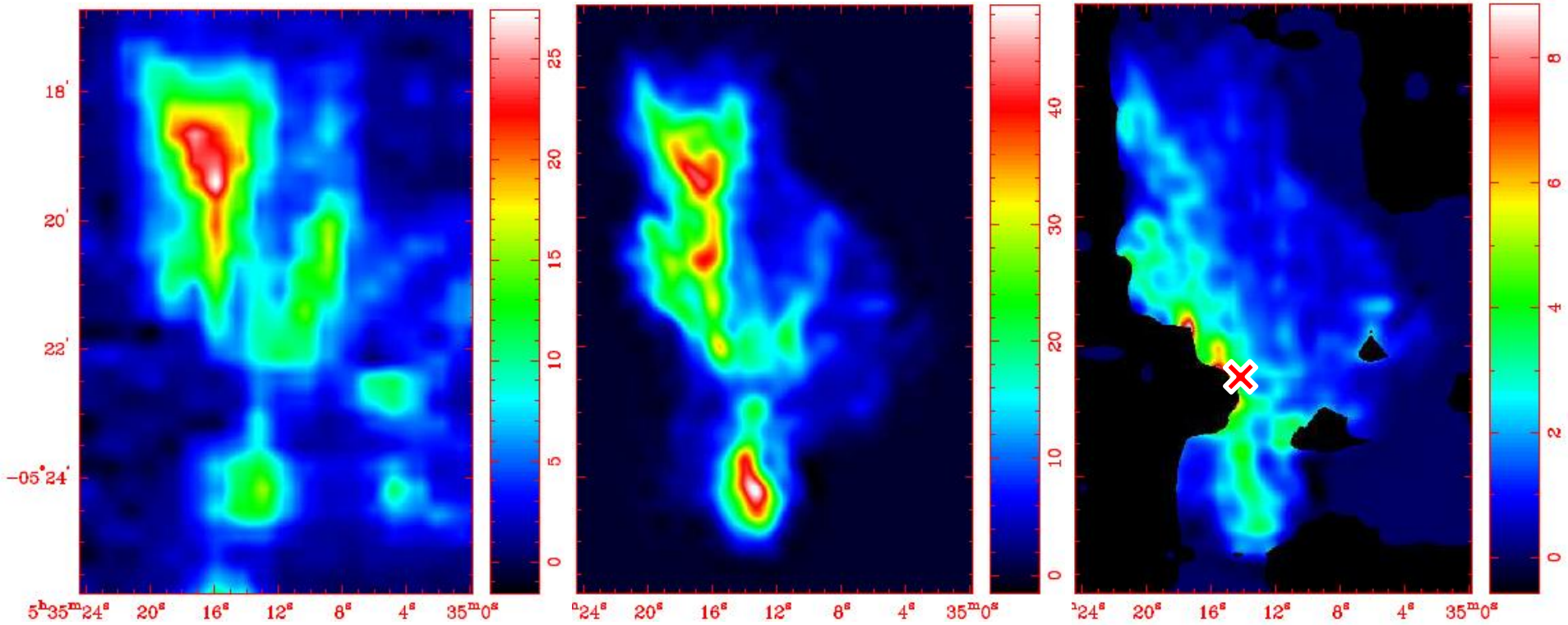
Peretto et al. (2013)

Large Scale Analysis

NRO 45m (1-0)

SMA+CSO (3-2)

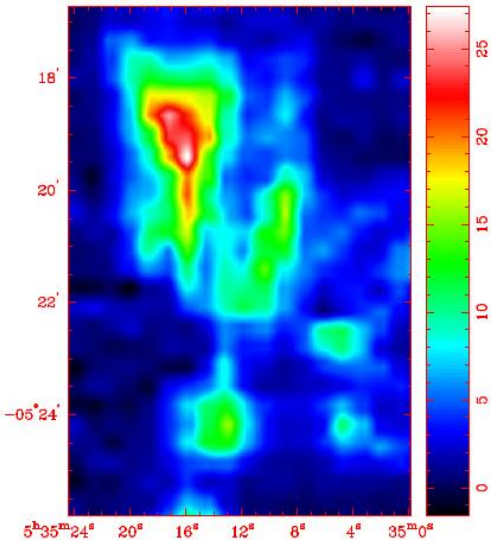
(3-2) / (1-0) ratio



17.8” resolution

(convolved)

NRO 45m (1-0)



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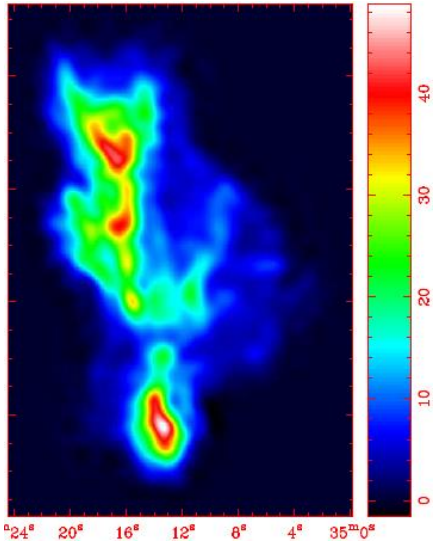

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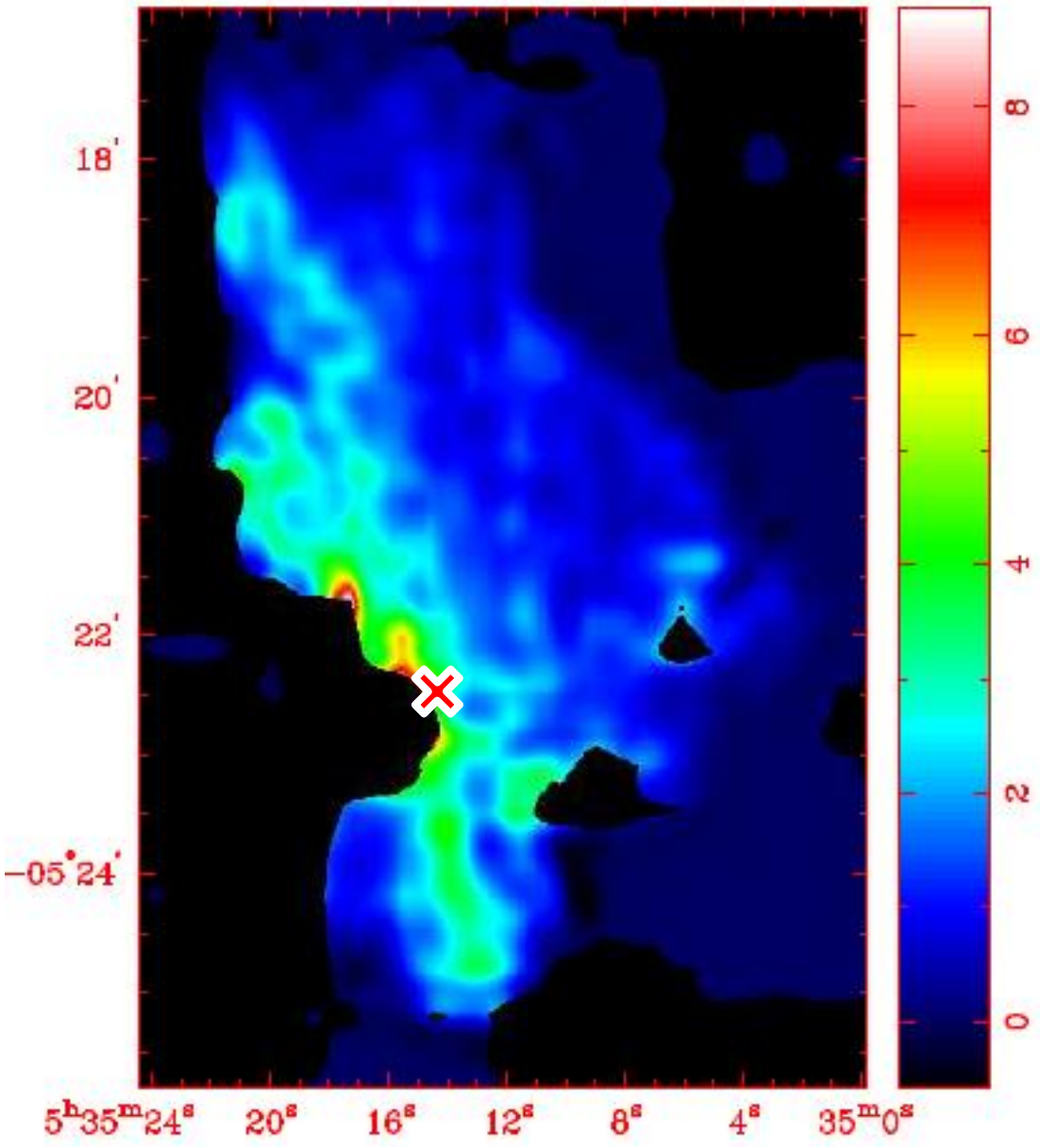

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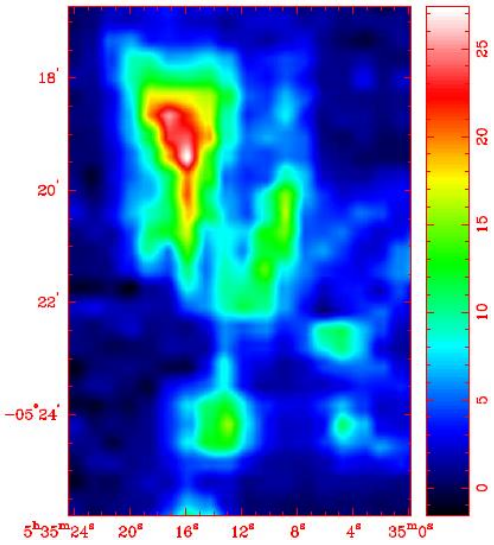

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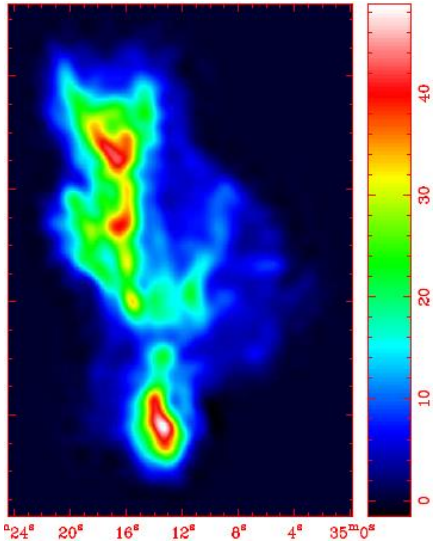

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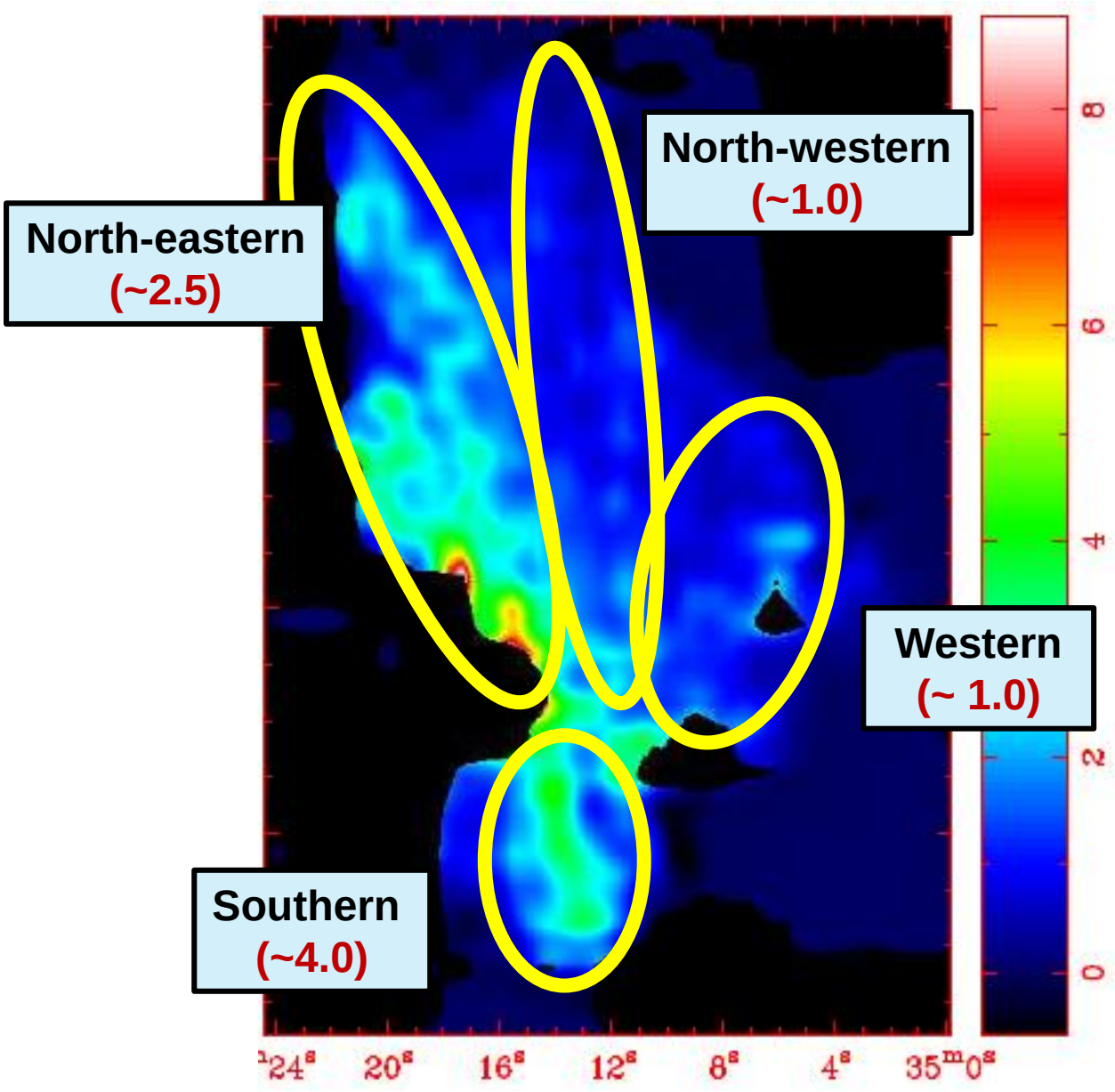


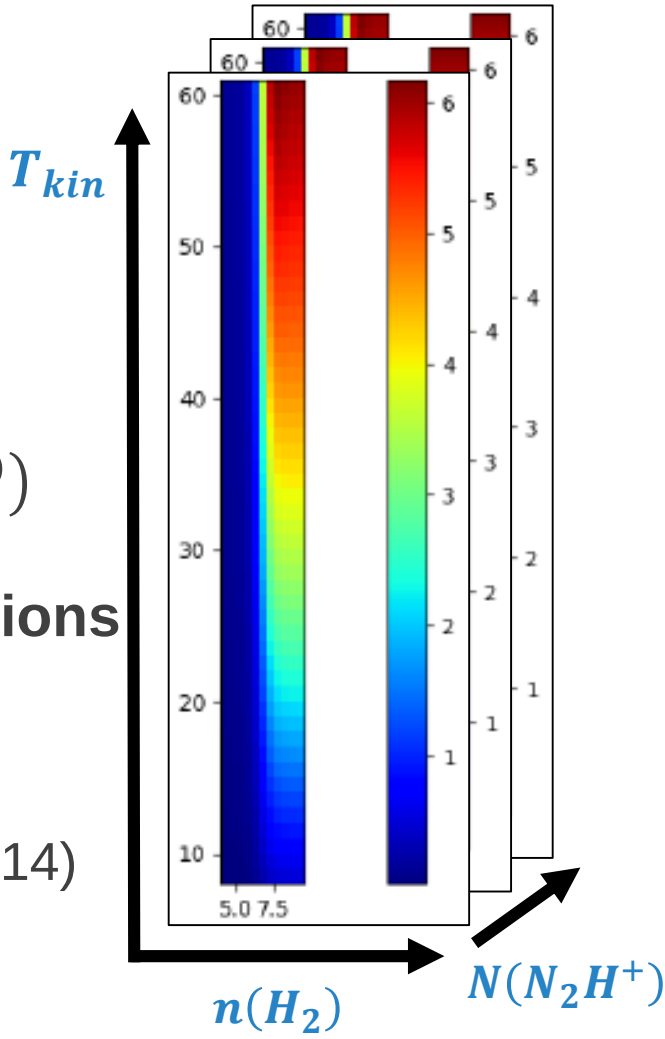
Non-LTE Analysis

- Using *RADEX*
- N_2H^+ (3-2) 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)



Physical Conditions

- Radiation from south-east (Orion KL)

	North		Western	Southern
	(Eastern)	(Western)		
$\mathbf{n(H_2)}$ $(\boldsymbol{cm^{-3}})$	3×10^6	$\sim 10^7$ $(\leq 3 \times 10^6)$	3×10^6	3×10^7
$\mathbf{T_{kin}}$ $(\boldsymbol{K})$	$31 - 37$	$12 - 14$ $(20 - 40)$	$9 - 13$	$35 - 42$
$\mathbf{N(N_2H^+)}$ $(\boldsymbol{cm^{-2}})$	3×10^{13}	3×10^{13}	10^{13}	3×10^{13}
Typical Ratio	2.5 ± 0.25	1 ± 0.1	1 ± 0.4	4 ± 0.4

Table 1 Large-scale Parameters

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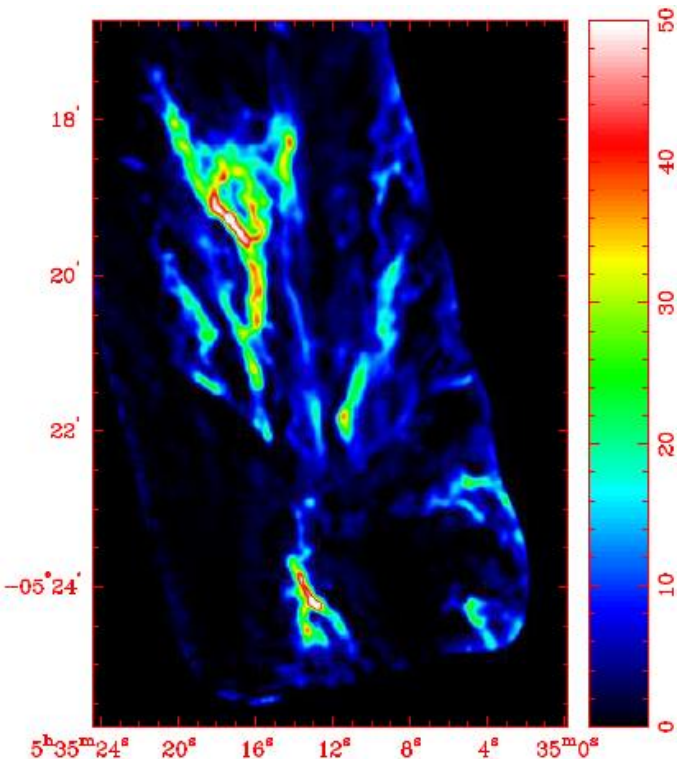
Table 1 Large-scale Parameters

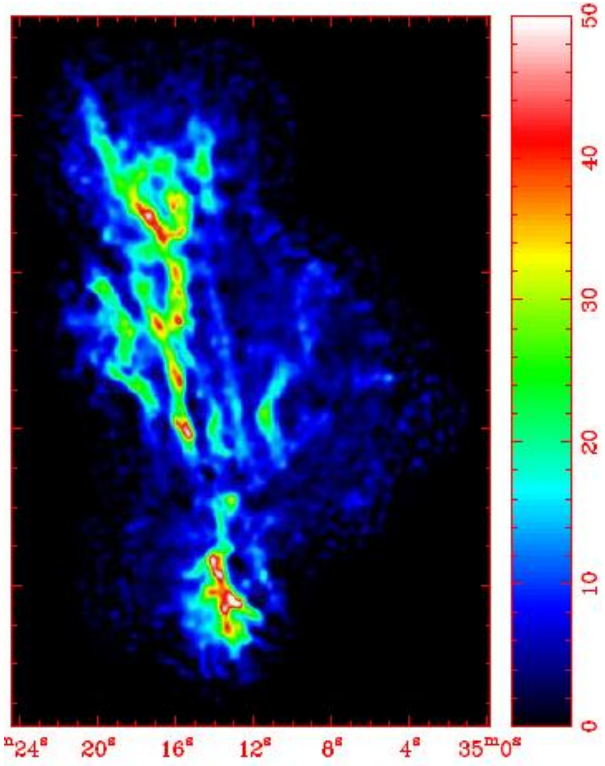
High Resolution Analysis

ALMA+IRAM 30m (1-0)



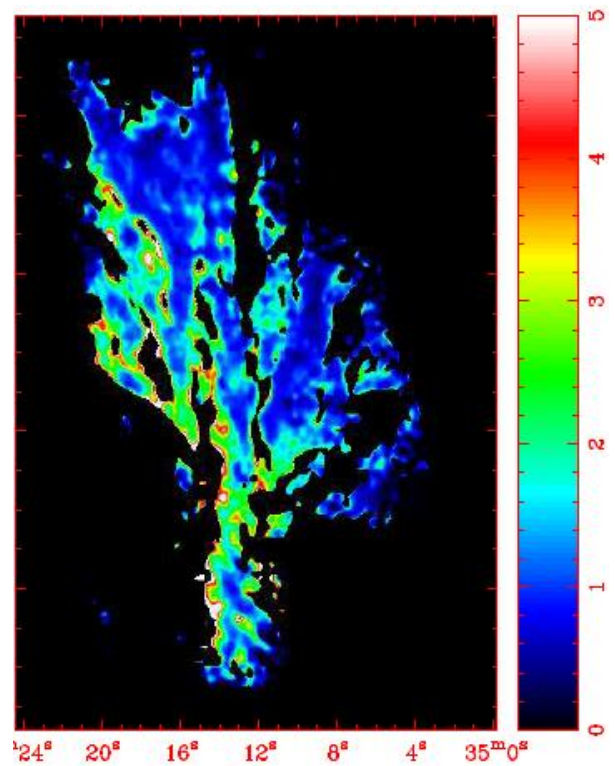
(convolved)

SMA+CSO (3-2)



5.53”×5.25” resolution

(3-2) / (1-0) ratio



Physical Properties of Filaments

(Filament regions)

	Core Regions (High Intensity) (> 40 K•km/s)	**Low Intensity Regions** (14-20 K•km/s)	**Non-filament regions**
$\mathbf{n(H_2)}\ (\boldsymbol{cm^{-3}})$	10^7	10^7	3×10^6
$\mathbf{T_{kin}}\ (\boldsymbol{K})$	$16 - 20$	$11 - 14$	~ 35
$\mathbf{N(N_2H^+)}\ (\boldsymbol{cm^{-2}})$	10^{14}	3×10^{13}	3×10^{13}
Typical Ratio	1 ± 0.2	1 ± 0.2	2.5 ± 0.5

Table 2 High-resolution Parameters

Physical Properties of Filaments

(Filament regions)

	Core Regions (High Intensity) (> 40 K•km/s)	**Low Intensity Regions** (14-20 K•km/s)	**Non-filament regions**
$\mathbf{n(H_2)}\ (\boldsymbol{cm^{-3}})$	10^7	10^7	3×10^6
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Table 2 High-resolution Parameters

Physical Properties of Filaments

(Filament regions)

	Core Regions (High Intensity) (> 40 K•km/s)	**Low Intensity Regions** (14-20 K•km/s)	**Non-filament regions**	**North-Western**
$\mathbf{n(H_2)}$ $(\boldsymbol{cm^{-3}})$	10^7	10^7	3×10^6	$\sim 10^7$ ~~$(\leq 3 \times 10^6)$~~
$\mathbf{T_{kin}}$ $(\boldsymbol{K})$	$16 - 20$	$11 - 14$	~ 35	$12 - 14$ ~~$(20 - 40)$~~
$\mathbf{N(N_2H^+)}$ $(\boldsymbol{cm^{-2}})$	10^{14}	3×10^{13}	3×10^{13}	3×10^{13}
Typical Ratio	1 ± 0.2	1 ± 0.2	2.5 ± 0.5	1 ± 0.1

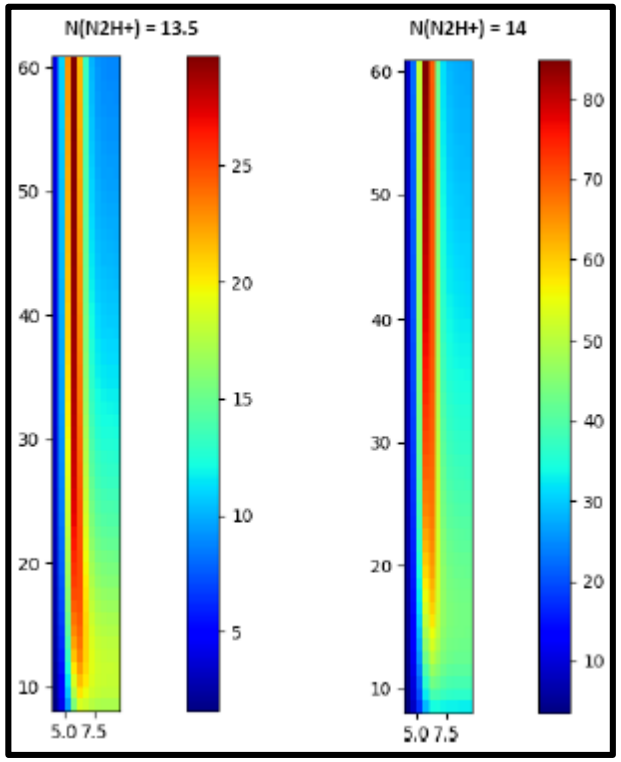
Table 2 High-resolution Parameters

Conclusion

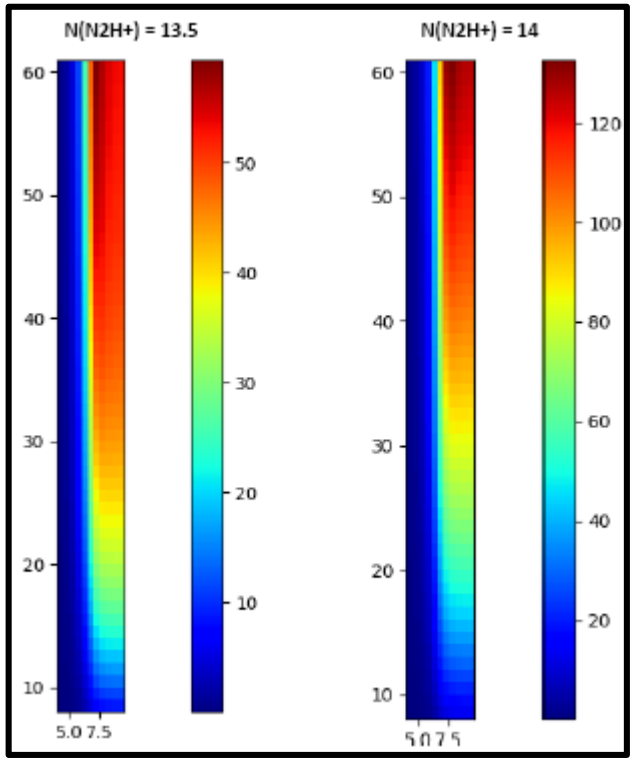
- Moment 0 map in N_2H^+ (3-2) reveals filamentary structure with typical widths of ~0.02 to 0.03 pc.
- Velocity structure in N_2H^+ (3-2) may indicate a global collapse scenario.
- From (3-2)/(1-0) intensity ratio maps,
  - large scale analysis shows a high ratio in the eastern edge → External heating (T_{kin}~$31 - 37\ K$)
  - high resolution analysis shows a low ratio in the filaments → High density and low temperature (n~$10^7\ cm^{-3}$ and T_{kin}~$11 - 20\ K$)

Thank you for your attention!

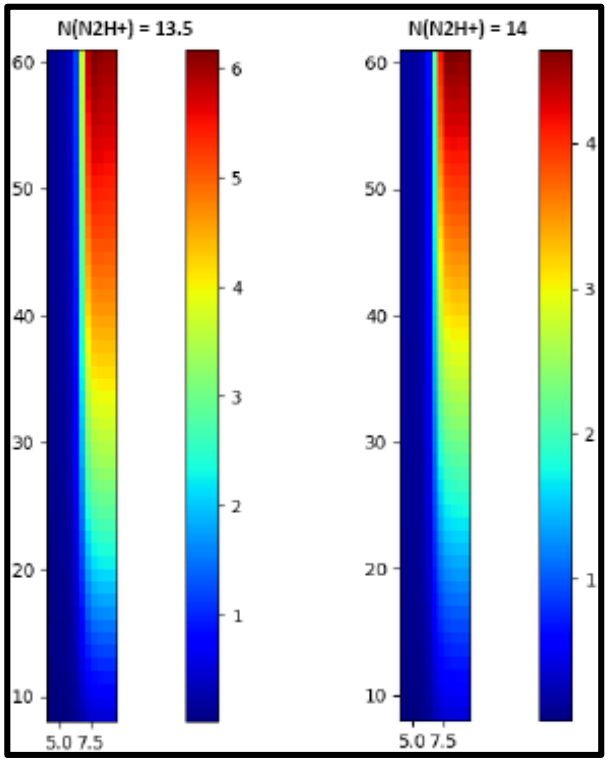
1-0 Model



3-2 Model



Ratio Model



< region = west/bg west/fila north/main fila north/west fila north/east fila south/highT south/lowT >

<ratio = 1±0.4 1±0.2 2.5±0.25---3.5±0.35 1±0.1 3.5±0.46 4±0.4 2.5±0.38 >

<emission = 4~7 15~20 15~45---35~45 15~40 20~30 30~55 10~25 >

	1e6	3.1623e6	1e7	3.1623e7	1e8	3.1626e8	1e9
1e13	18~23K X X	11~13K X 25~32K	9~11K X 18~22K	9~10K X 17~20K	8~10K X 16~19K	8~10K X 16~19K	8~10K X 16~19K
3.1623e13	X 34~36K X---X 40~53K X X X	X 16~17K 35~42K---51K 17~19K X X X	X 12~13K 23~26K---31K 13~14K X X X	X 11~12K X---28~29K 12K X 31~37K X	X 11~12K 21~23K---27~30K 12K X 31~37K X	X 11~12K 20~23K---27~30K 11~12K X 30~37K X	X 11~12K 20~23K---27~30K 11~12K X 30~37K X
1e14	X	X	X	X	X	X	X

< region = filaments non-filaments >

<ratio = 1±0.2 2.5±0.5 >

	1e6	3.1623e6	1e7	3.1623e7	1e8	3.1623e8	1e9
1e13	22~35K X	12~16K 23~34K	9~13K 16~23K	9~12K 15~21K	9~12K 15~21K	8~11K 14~21K	8~11K 14~21K
3.1623e13	33~60K X	15~21K 30~48K	11~15K 20~29K	10~14K 18~26K	10~14K 18~26K	10~13K 18~26K	10~13K 18~26K
1e14	X X	21~32K 54~60K	15~21K 30~44K	13~19K 27~39K	13~19K 26~38K	13~18K 26~38K	13~18K 26~38K

< region = filaments >

< ratio = 1±0.2 >

<intensity = 14~20K 20~30K 40~50K >

	1e6	3.1623e6	1e7	3.1623e7	1e8	3.1623e8	1e9
1e13	X	X	X	X	X	X	X
3.1623e13	X 36~60K	15~18K X	11~14K X	10~13K X	10~13K X	X X	X X
1e14	X	X	16~20K	15~19K	X	X	X

M42 and Orion KL