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Properties and Kinematics in OMC1 with N_2H^+ Observations

Yu-Hsuan Teng and Naomi Hirano

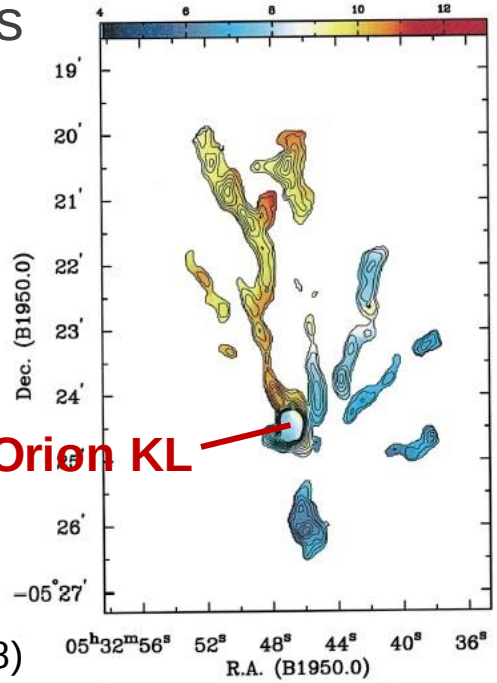
Outline

- Introduction
- Non-LTE Analysis
  - Large scale
  - High resolution
- Filamentary Structure
  - Filament identification
  - Gas motion in filaments
- Conclusions

Motivation

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

Myers (2009)

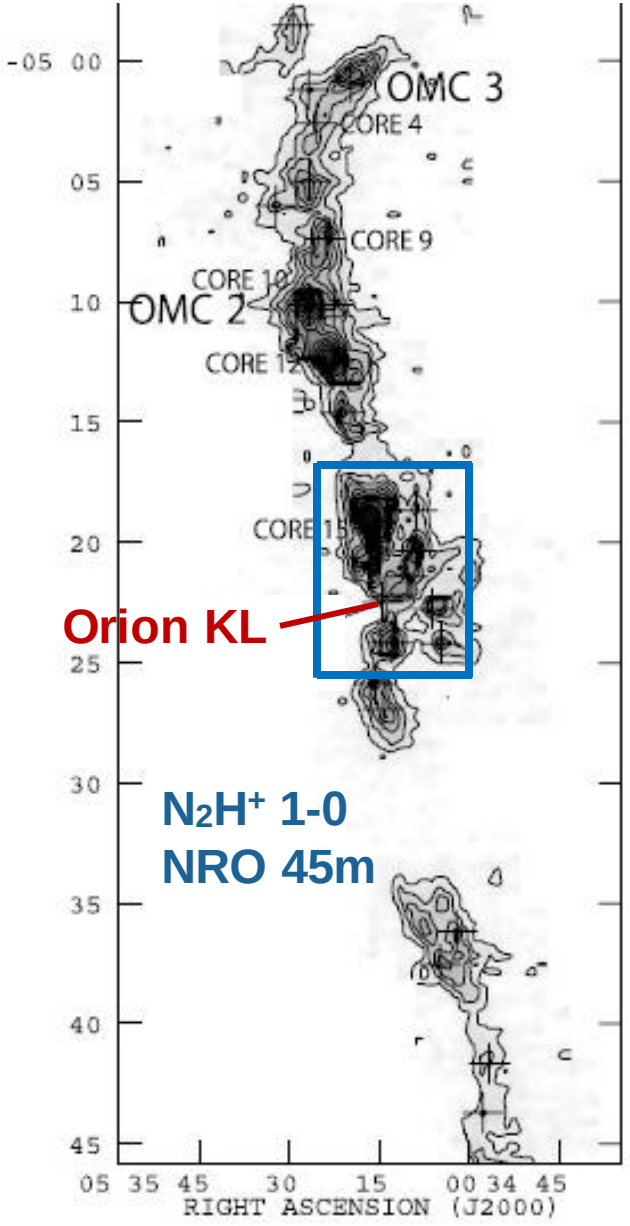


NH_3 (1,1)
VLA
8" resolution

Wiseman and Ho (1998)

Observations

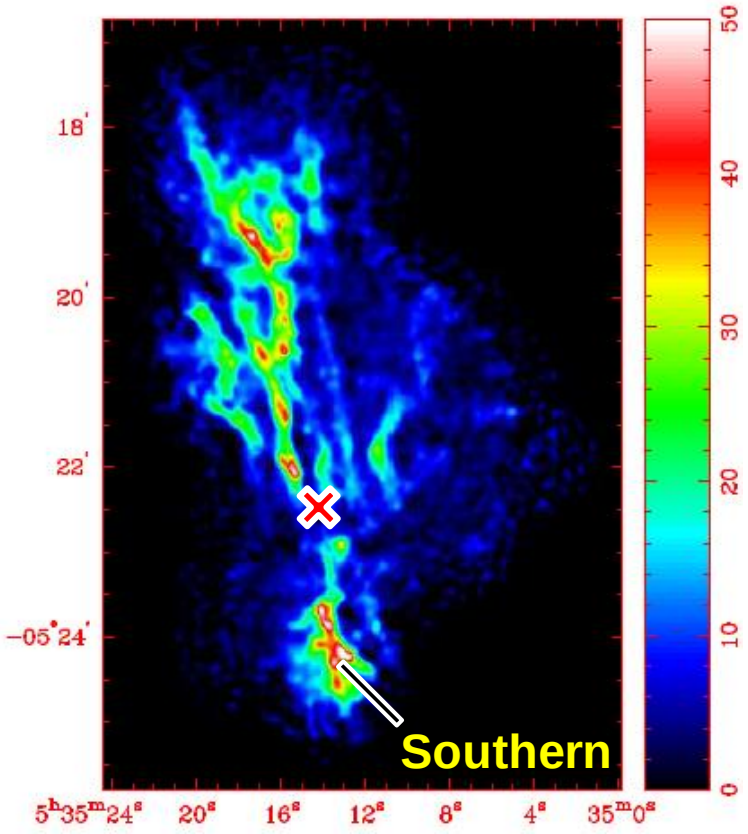
- **Orion molecular cloud 1 (OMC-1)**
  - Distance: 414 pc
  - Nearest high mass star forming region
- **N2H+ J=3-2**
  - Critical density ~ $10^6\ cm^{-3}$
  - SMA: 144 pointing mosaic
  - CSO: OTF mapping
  - **Combine SMA and CSO data**



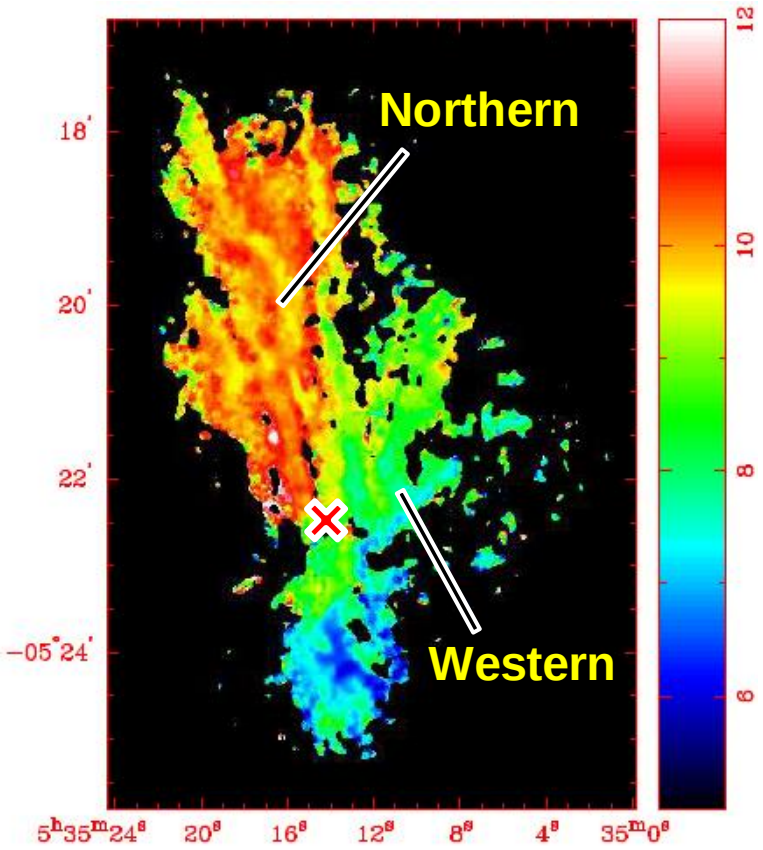
Tatematsu et al. (2008)

SMA + CSO Results

Moment 0 (~5.4")



Moment 1



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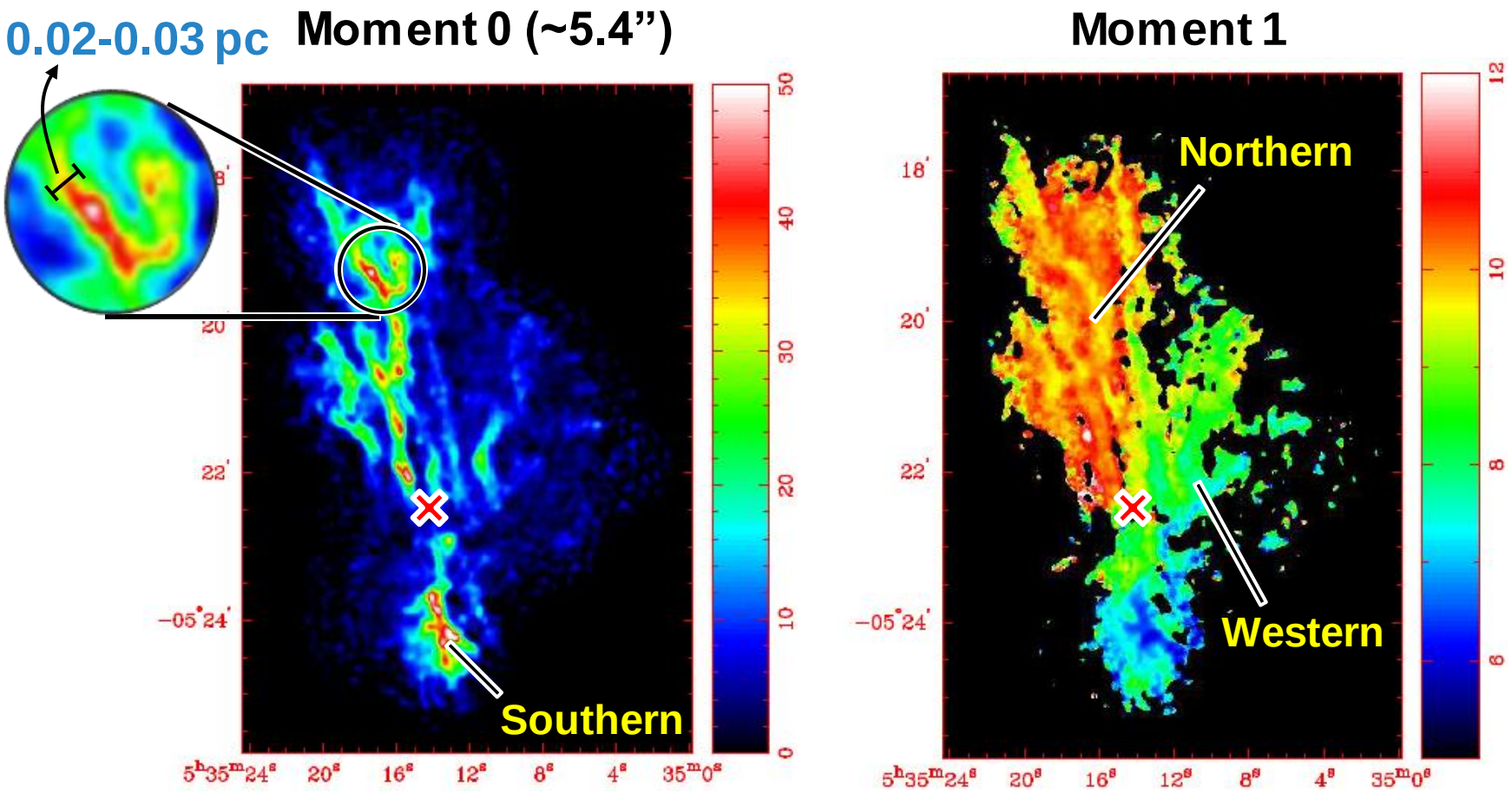
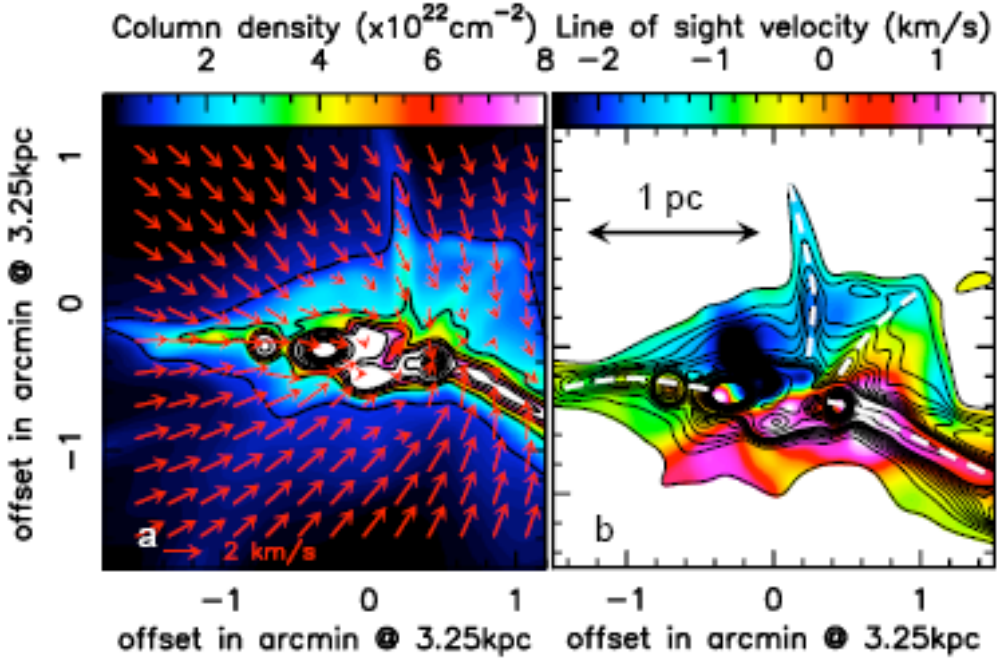
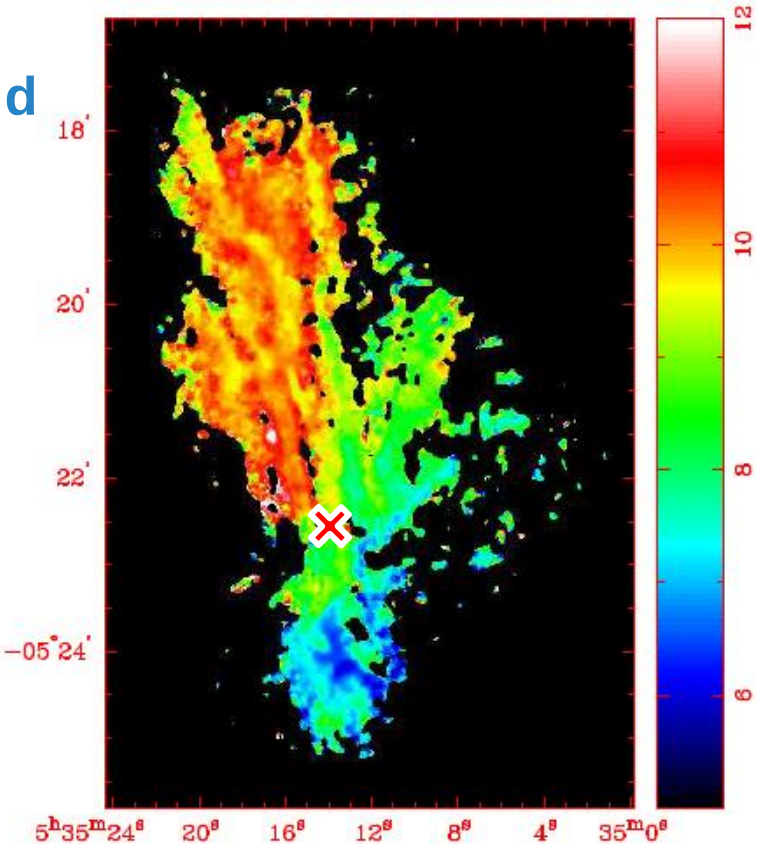


Global Collapse

MHD simulation of a global collapsing cloud





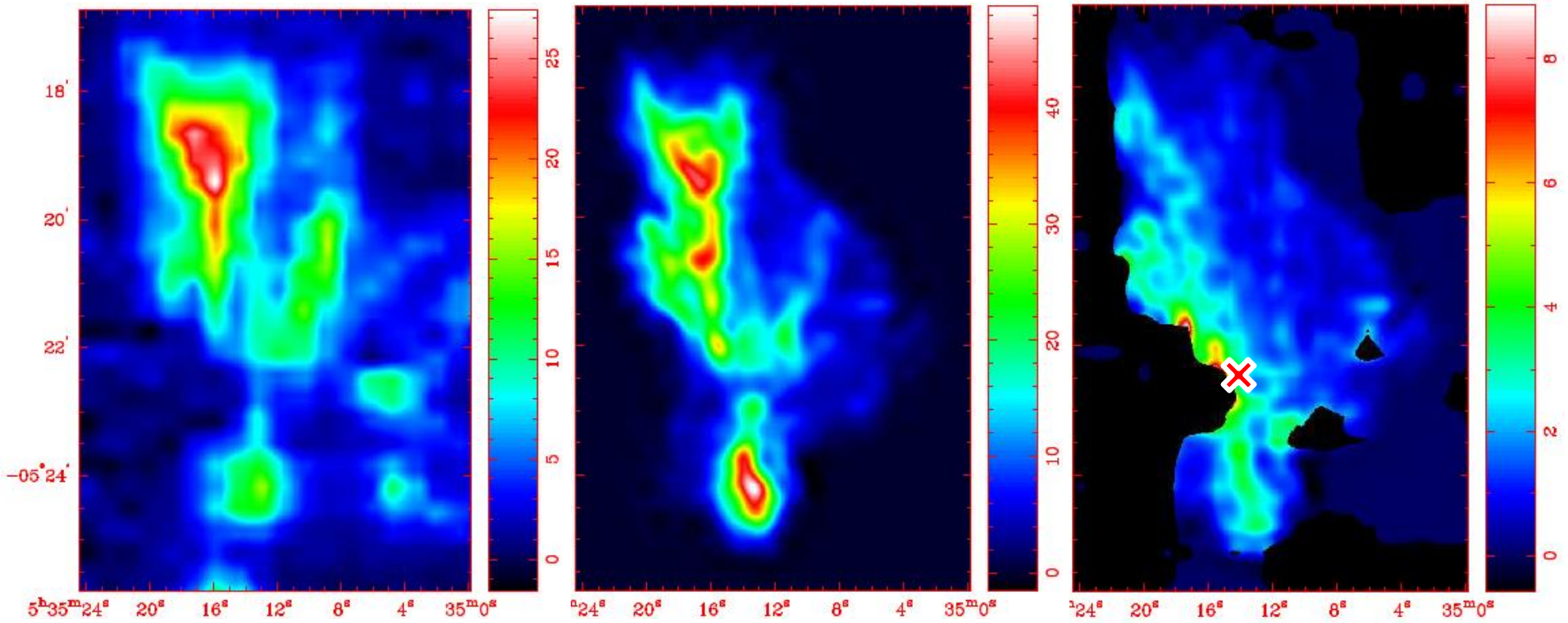
Peretto et al. (2013)

Large Scale Analysis

NRO 45m (1-0)

SMA+CSO (3-2)

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



17.8” resolution

(convolved)

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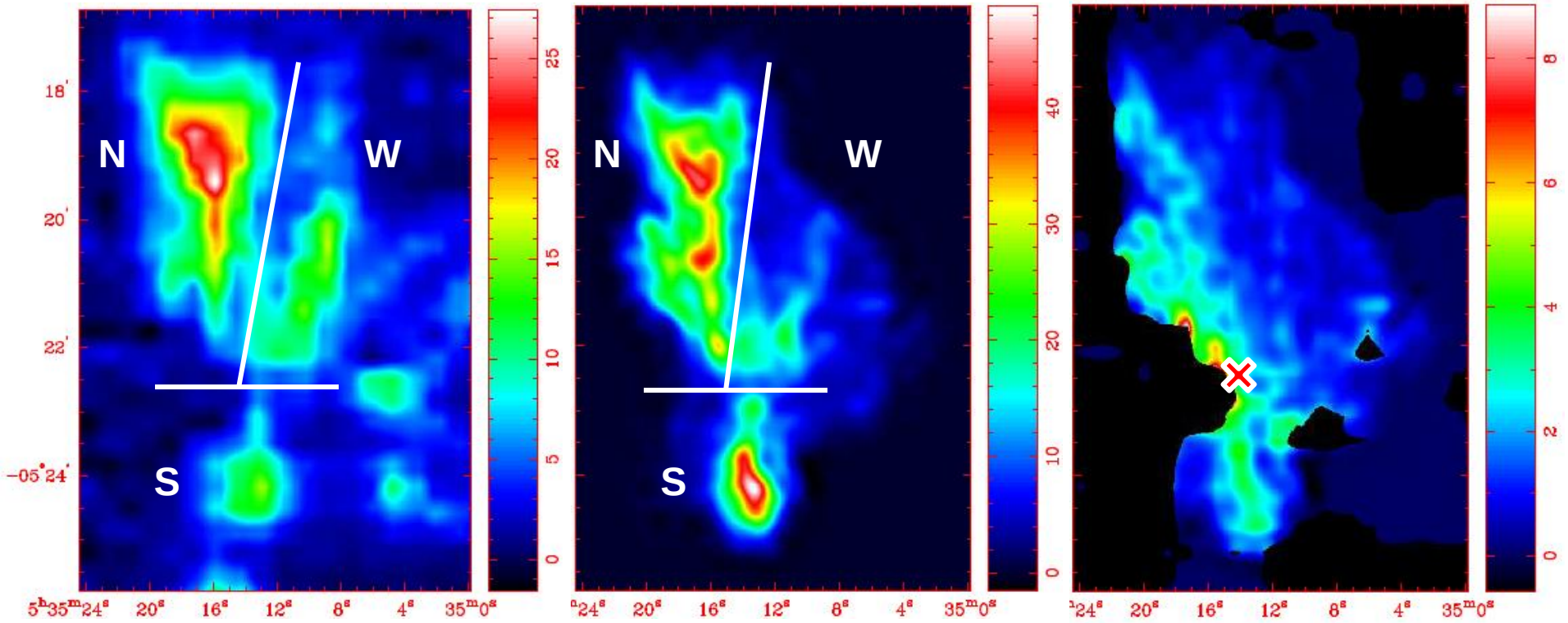

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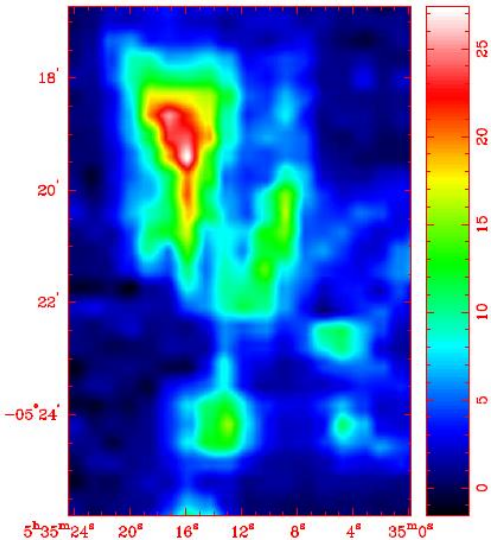

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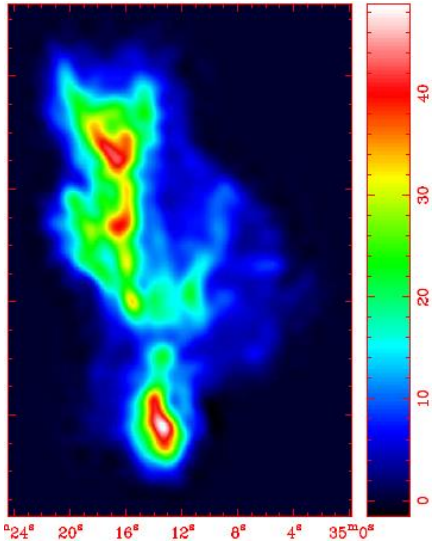

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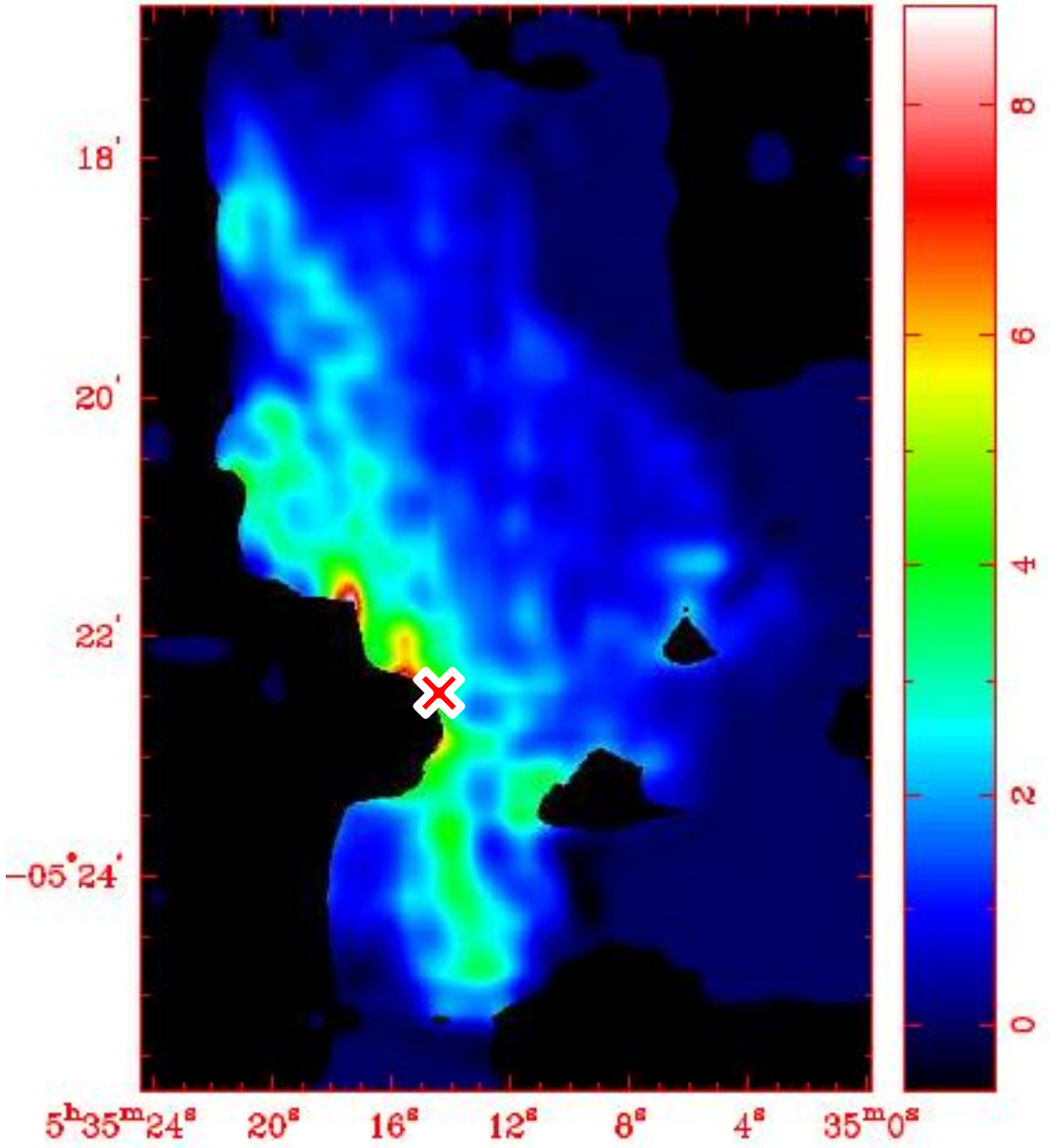

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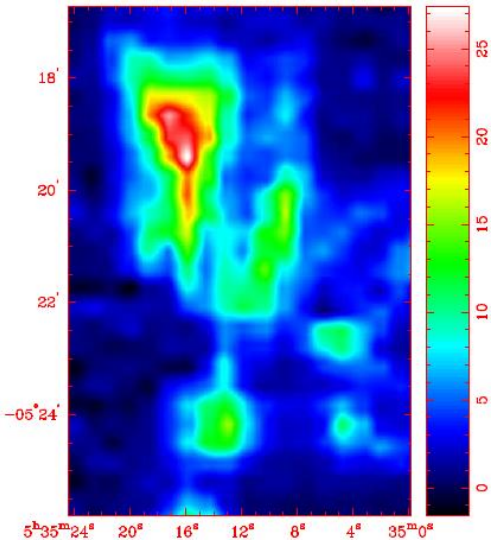

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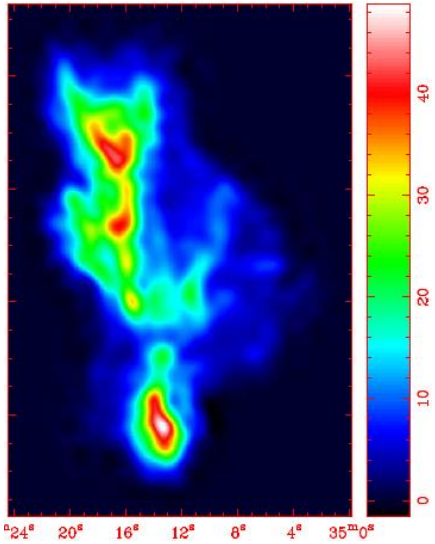

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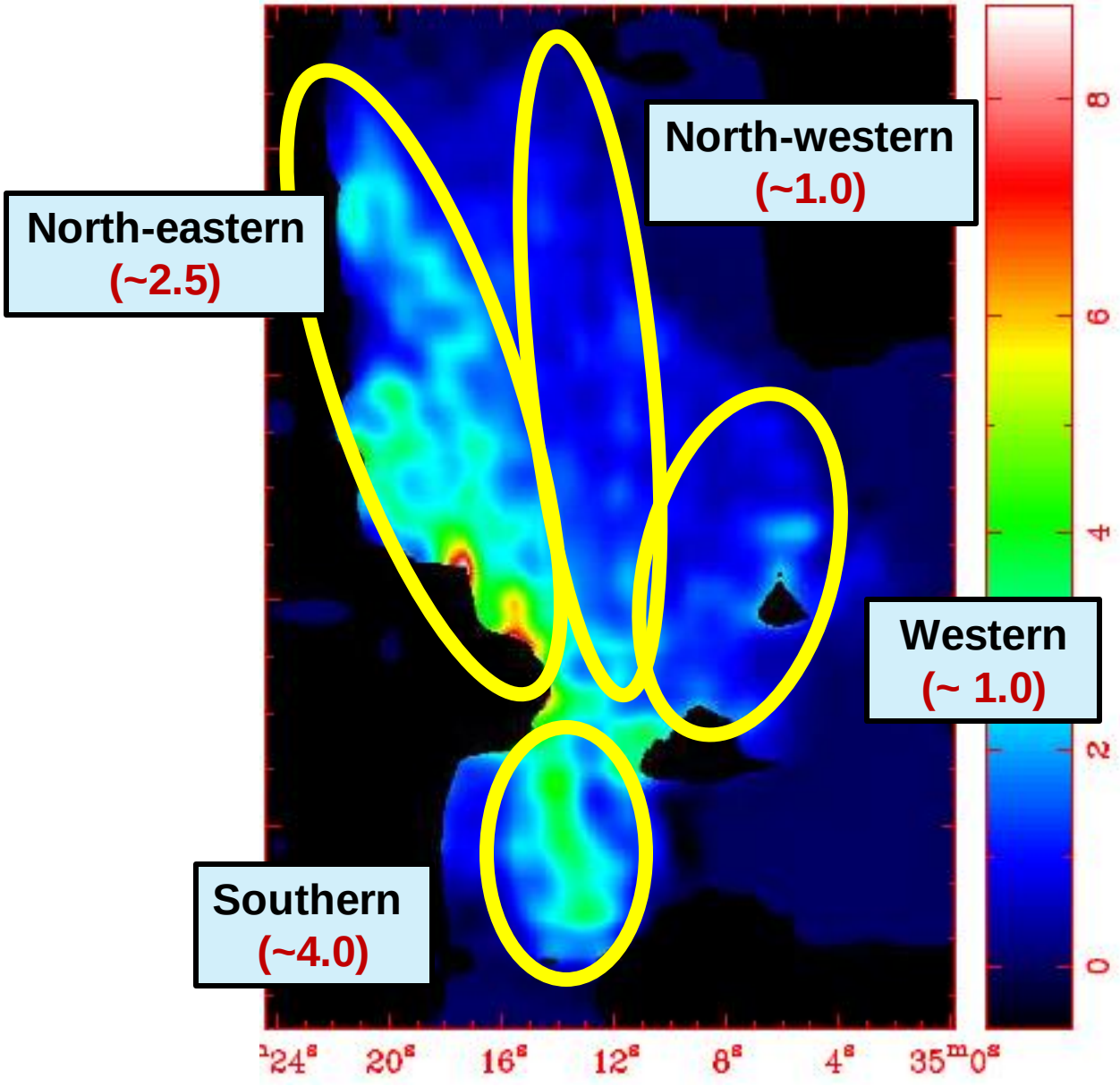


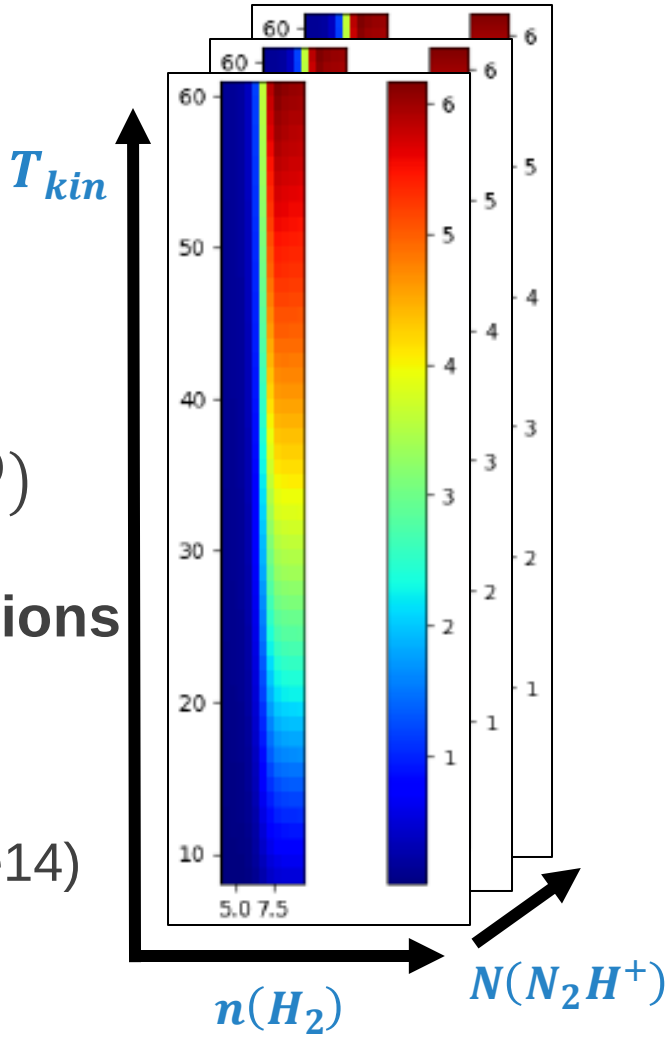
Non-LTE Analysis

- Using *RADEX*
- N_2H^+ (3-2) 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	$\sim 3 \times 10^6$ $(\geq 10^7)$	3×10^6	3×10^7
$\mathbf{T_{kin}}$ $(\boldsymbol{K})$	$35 - 42$	$17 - 19$ $(12 - 14)$	$9 - 13$	$31 - 37$
$\mathbf{N(N_2H^+)}$ $(\boldsymbol{cm^{-2}})$	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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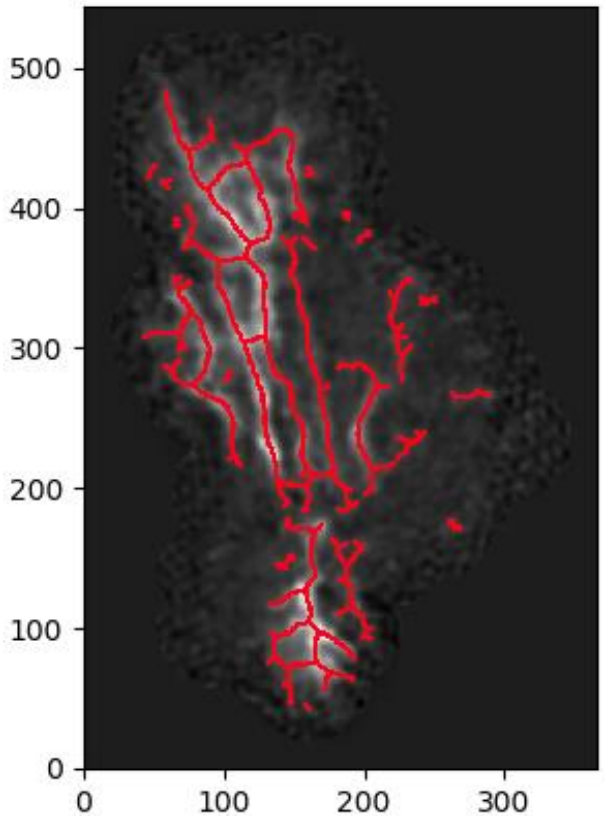
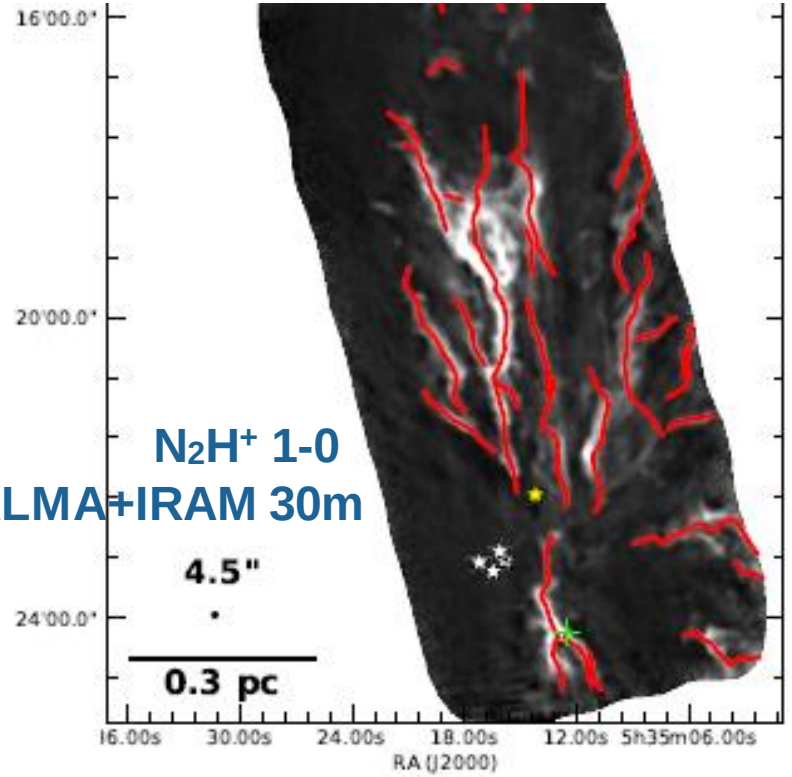
Filament Identification

FilFinder 2D identification



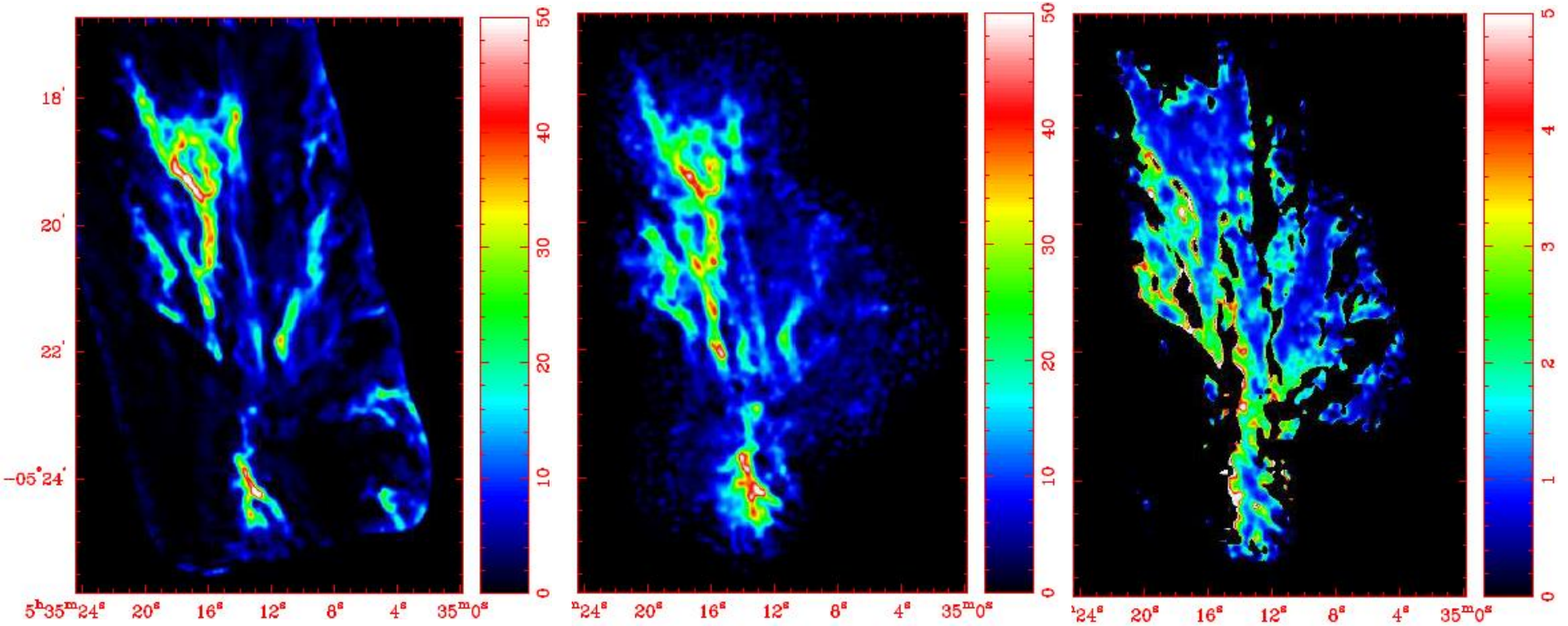
HiFIVE 3D identification



Hacar et al. (2018)

High Resolution Analysis

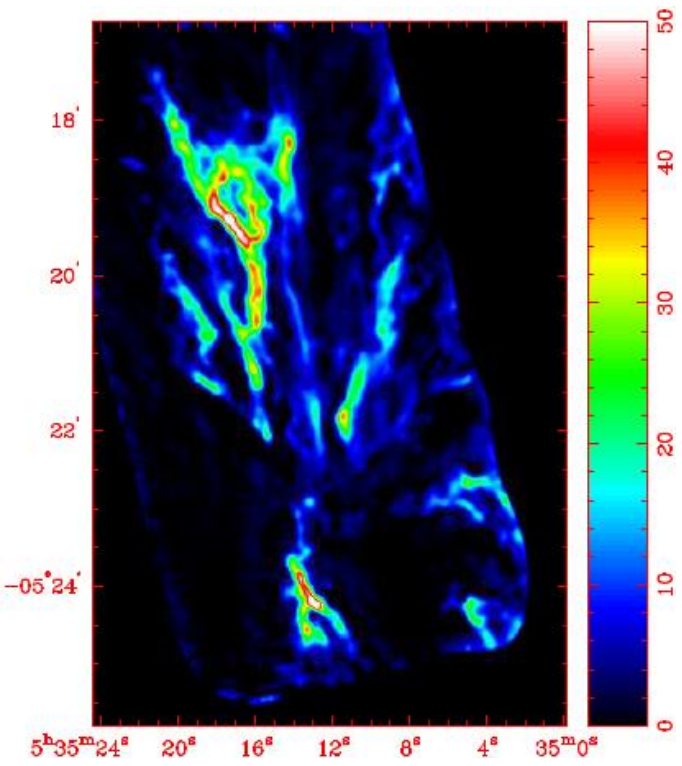
ALMA+IRAM 30m (1-0) SMA+CSO (3-2) **(3-2) / (1-0) ratio**



(convolved) 5.53”×5.25” resolution

High Resolution Analysis

ALMA+IRAM 30m (1-0)



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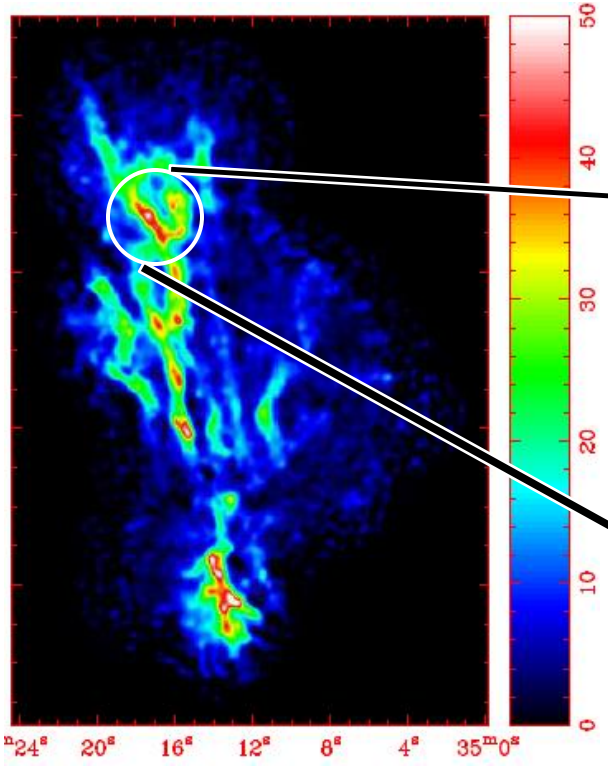

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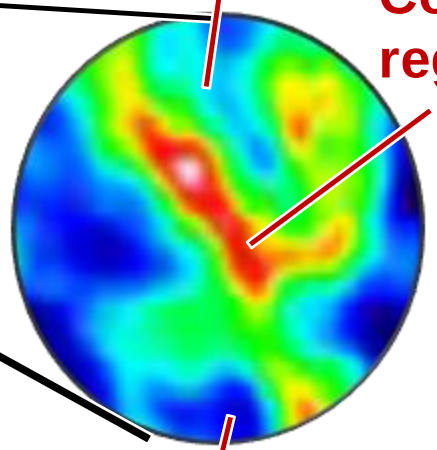
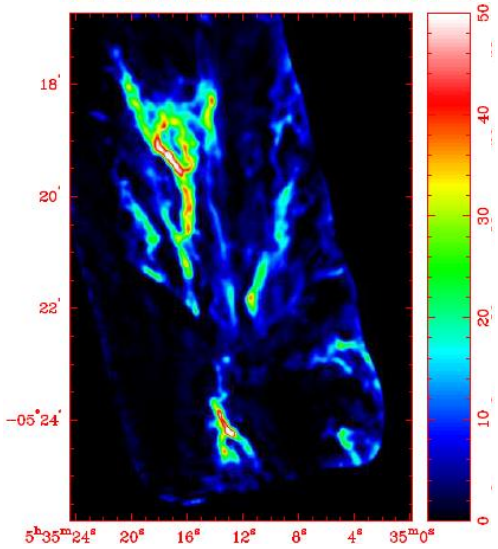


Low intensity regions

Core regions

Non-filament regions

ALMA+IRAM (1-0)



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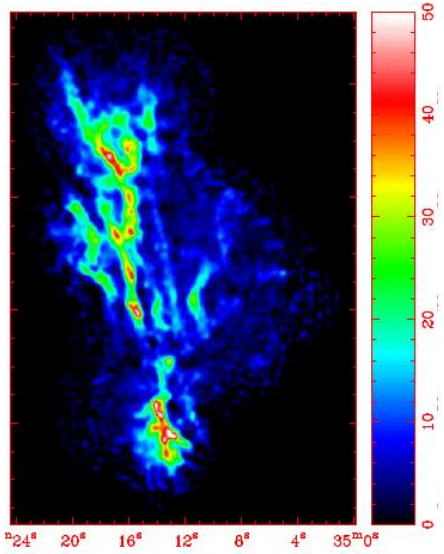

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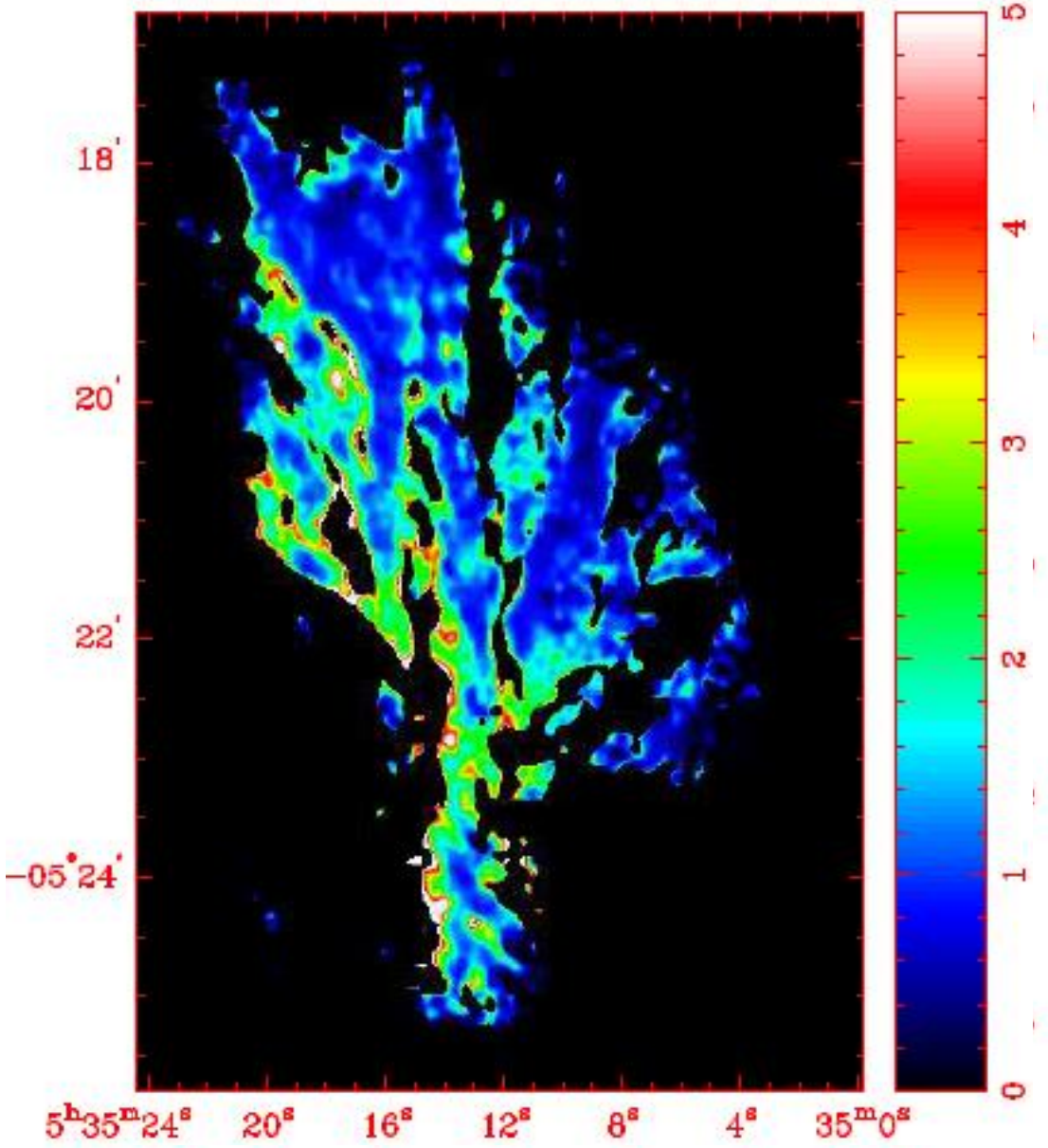

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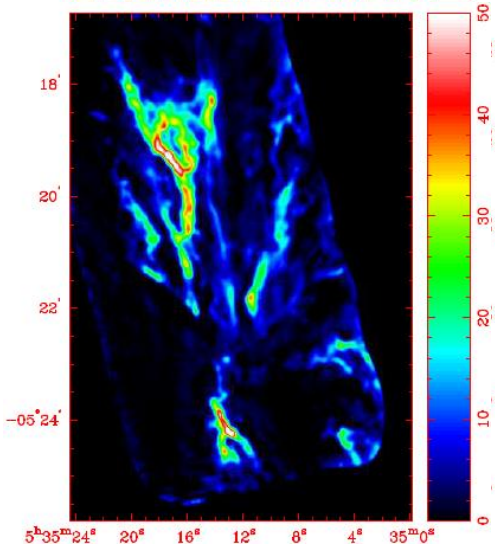

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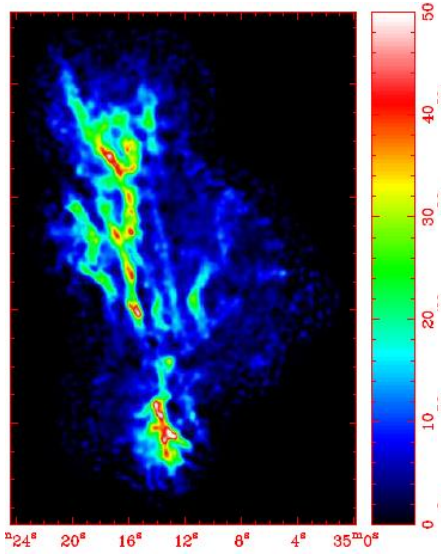

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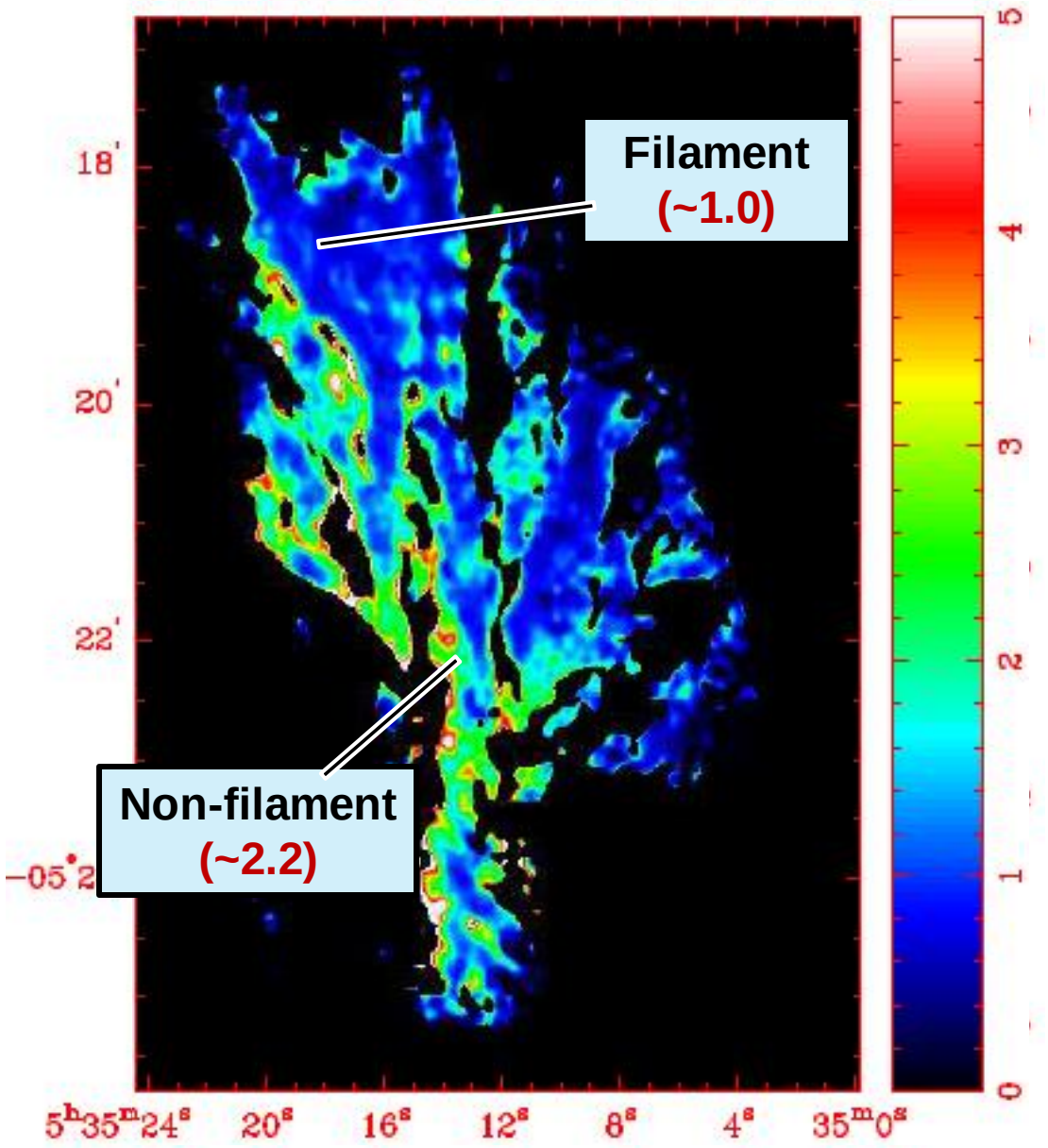

Physical Properties of Filaments

(Filament regions)

	Core Regions (High Intensity) (> 34 K•km/s)	**Low Intensity Regions** (14-20 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
$\mathbf{T_{kin}}$ $(\boldsymbol{K})$	15– 19 or 16– 20	15– 18 or 11– 14	>40 or 20– 25
$\mathbf{N(N_2H^+)}$ $(\boldsymbol{cm^{-2}})$	10^{14}	3×10^{13}	10^{13}
Typical Ratio	1 ± 0.2	1 ± 0.2	2.2 ± 0.8

Table 2 High-resolution Parameters

Physical Properties of Filaments

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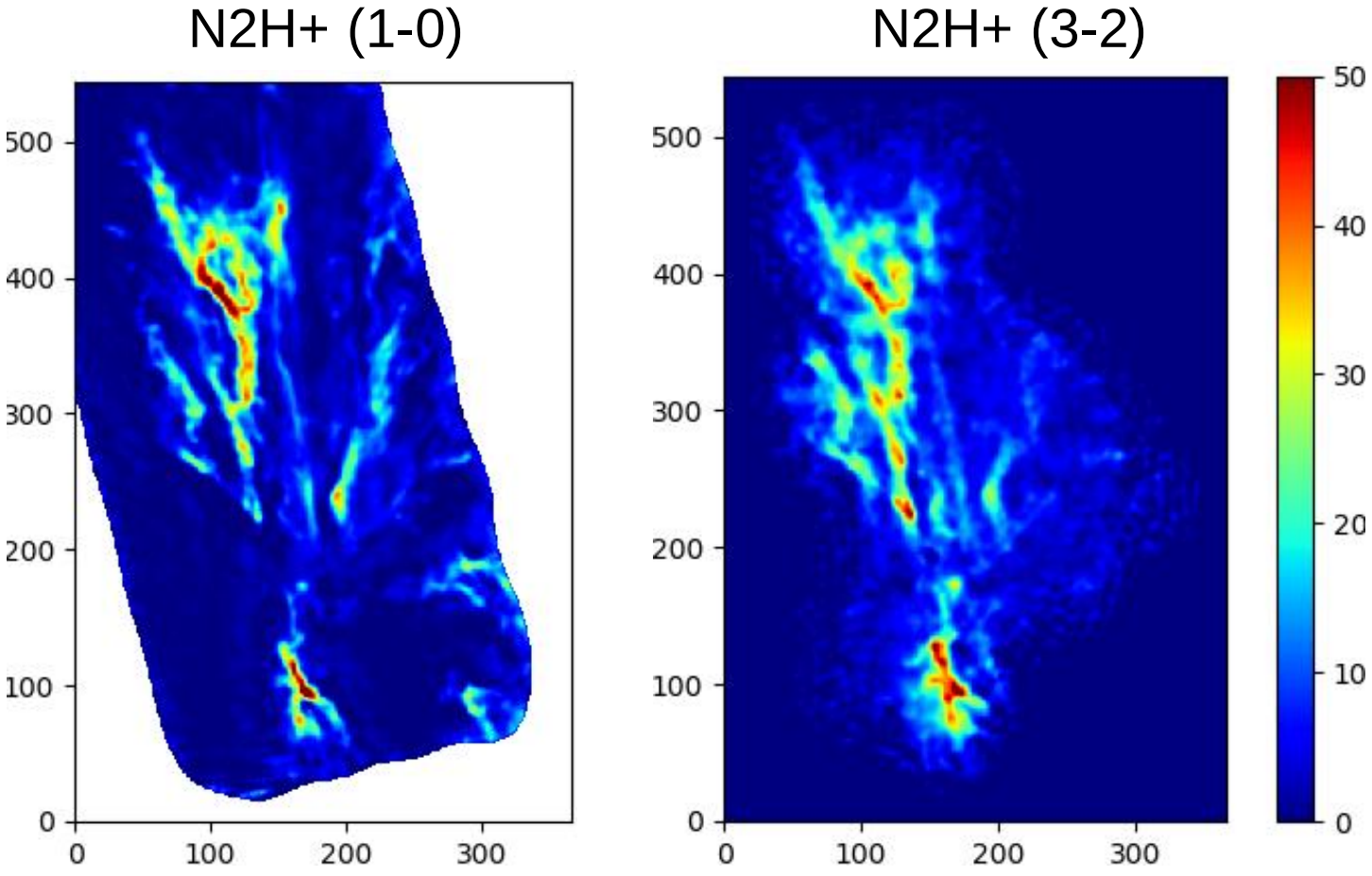
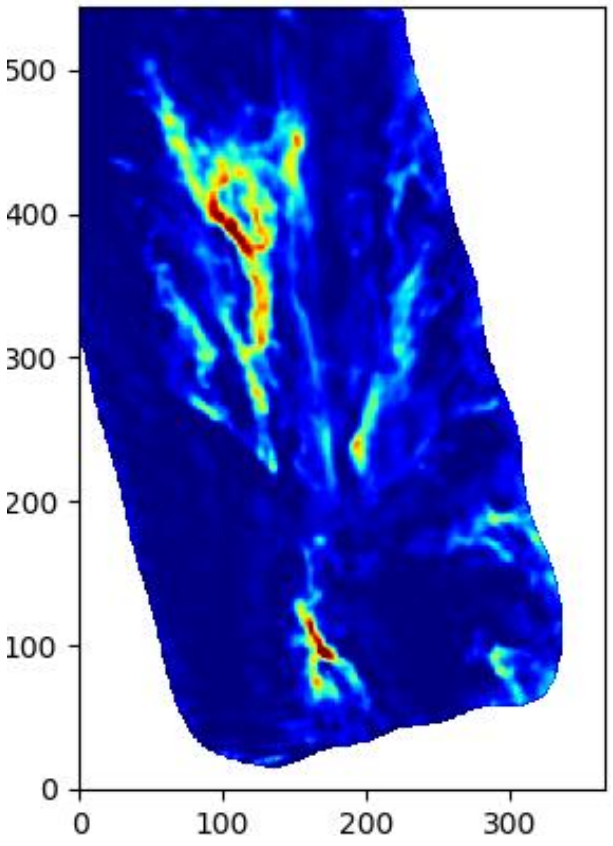


Cores in the Filaments

N2H+ (1-0)



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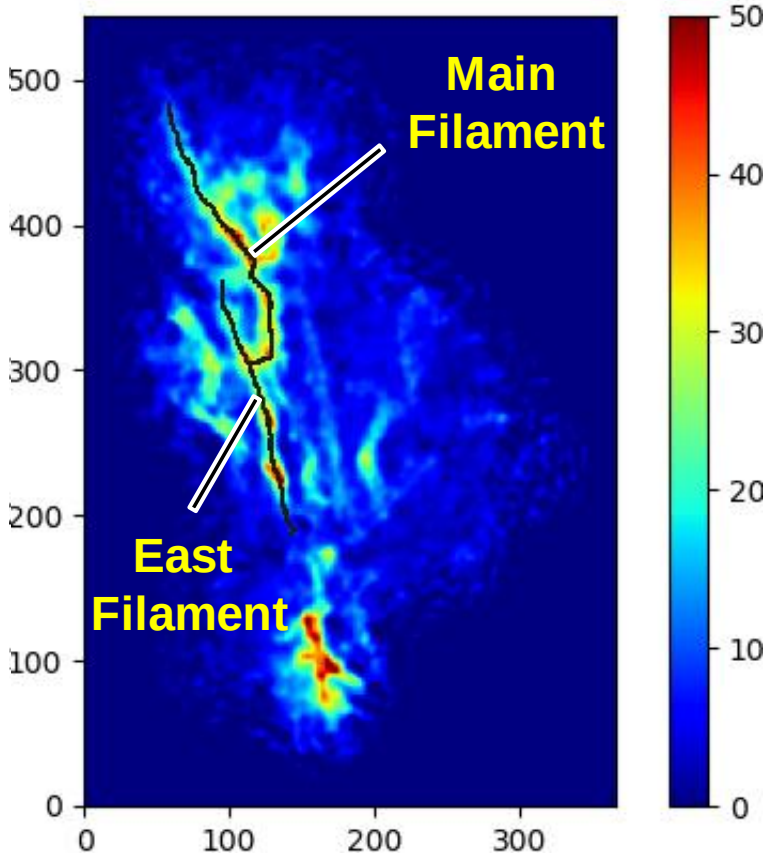


Cores in the Filaments

Main Filament

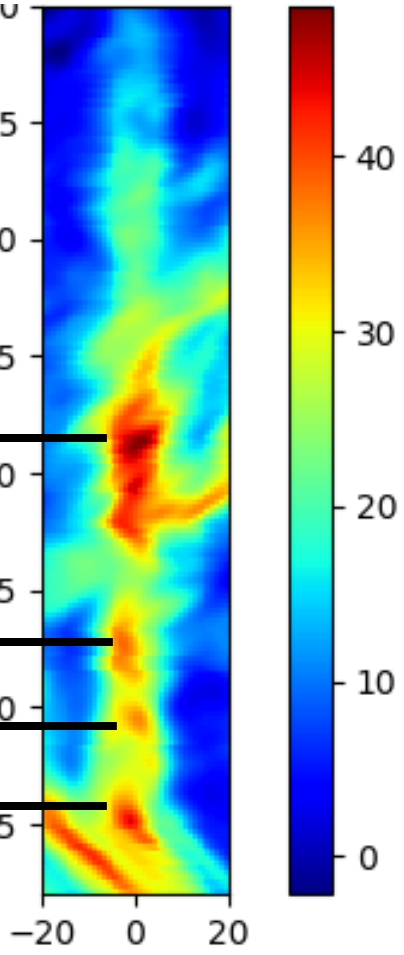
Line density:
$125.5 - 209.2\ M_\odot/pc$

$12.1 - 38.2\ M_\odot$

$0.49 - 1.54\ M_\odot$

$0.20 - 0.64\ M_\odot$

$1.00 - 3.15\ M_\odot$



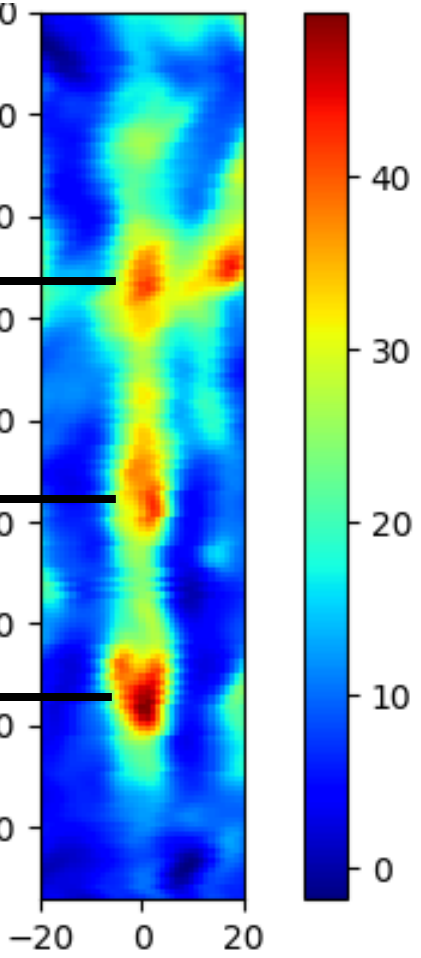
East Filament

$1.29 - 4.08\ M_\odot$

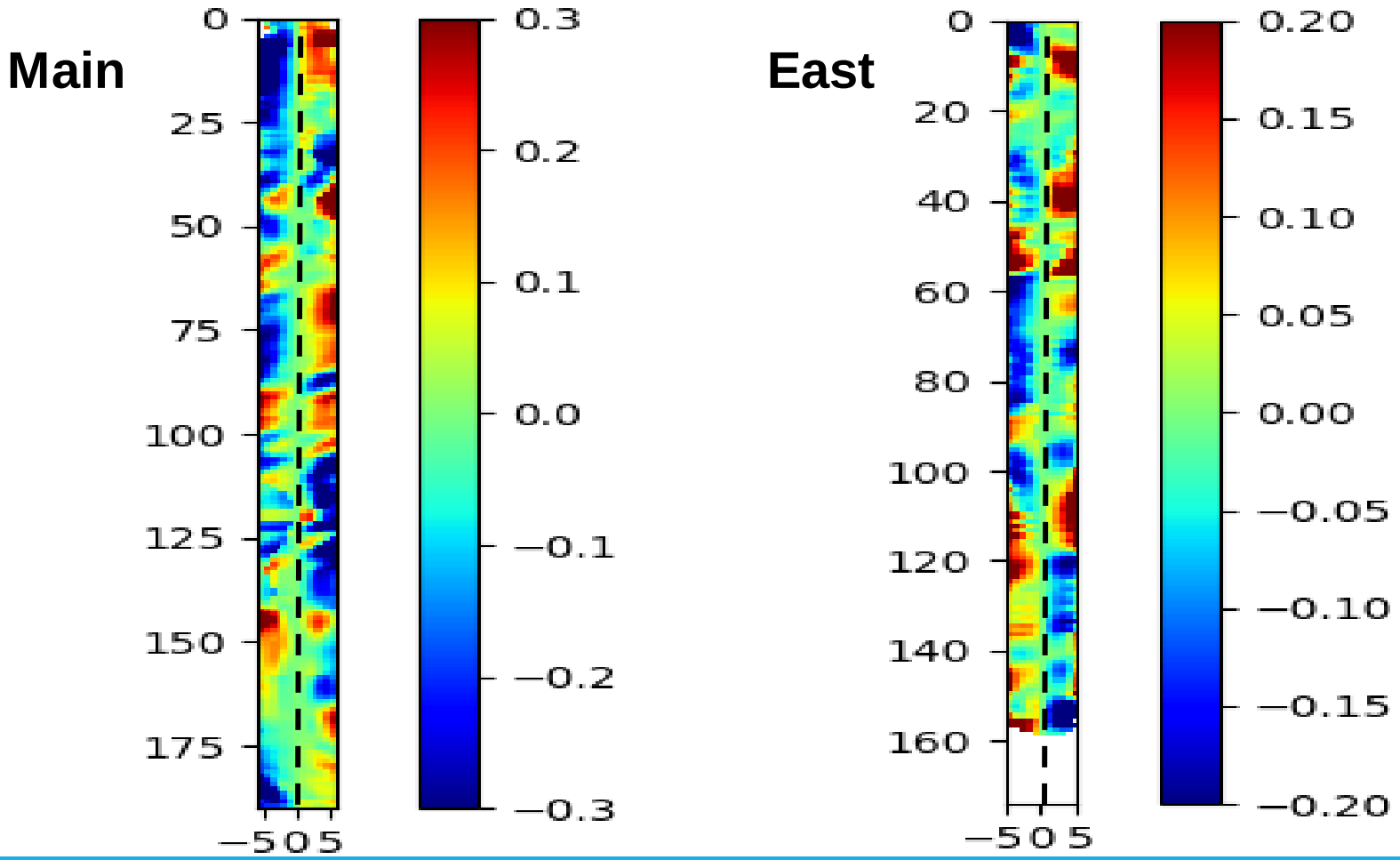
$1.46 - 4.63\ M_\odot$

$2.11 - 6.69\ M_\odot$

Line density:
$109.2 - 141.1\ M_\odot/pc$



Minor-Axis Analysis



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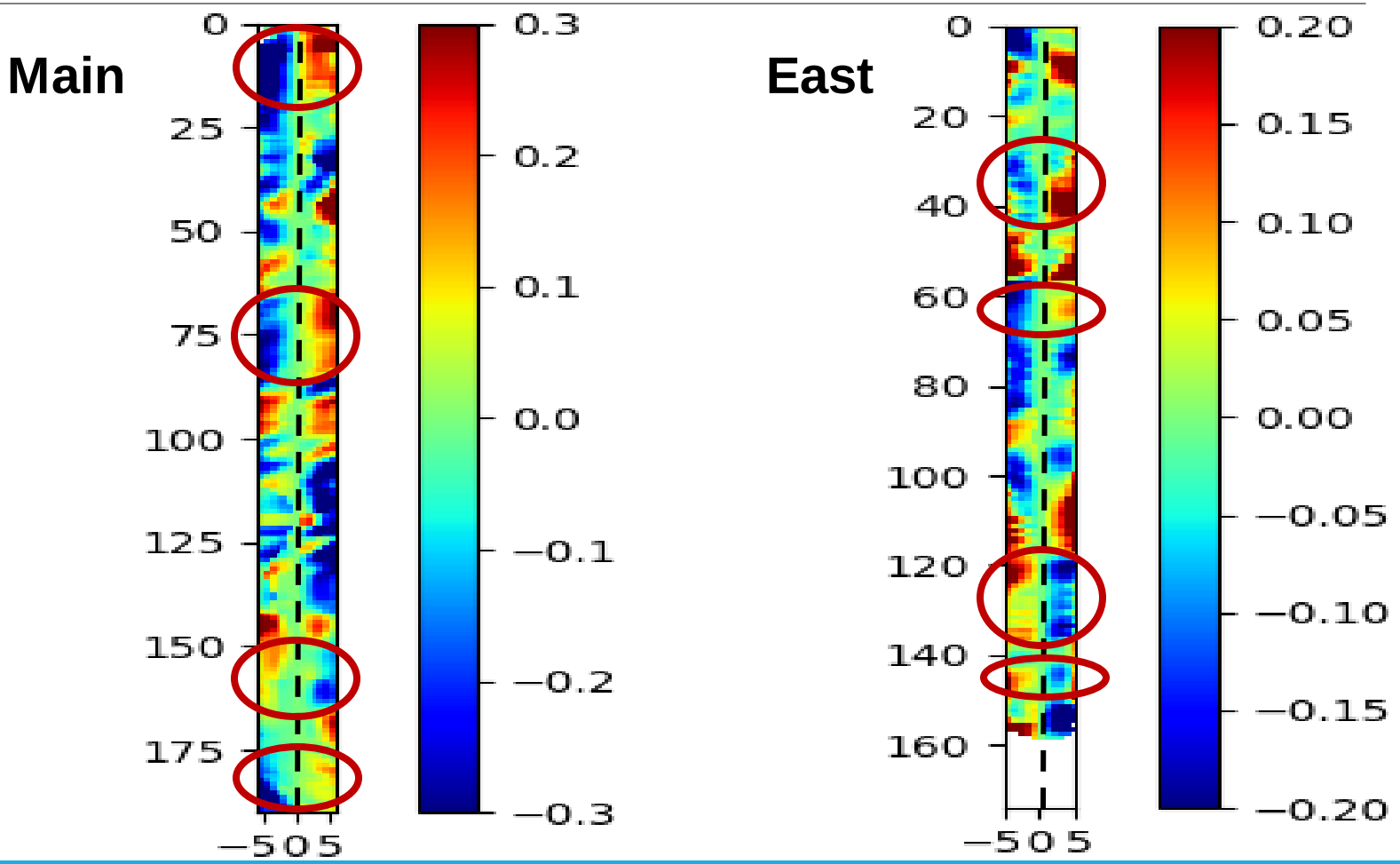

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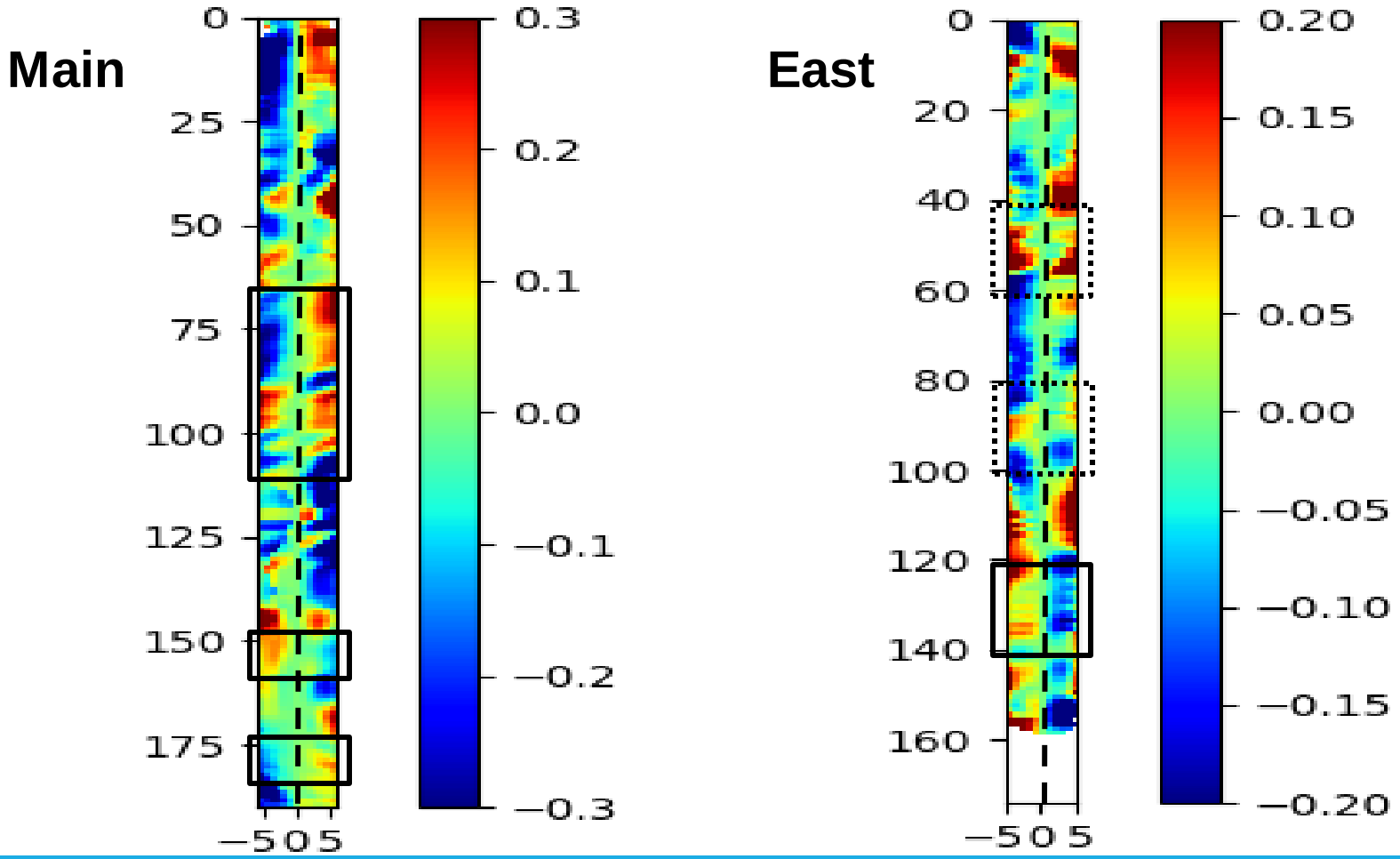

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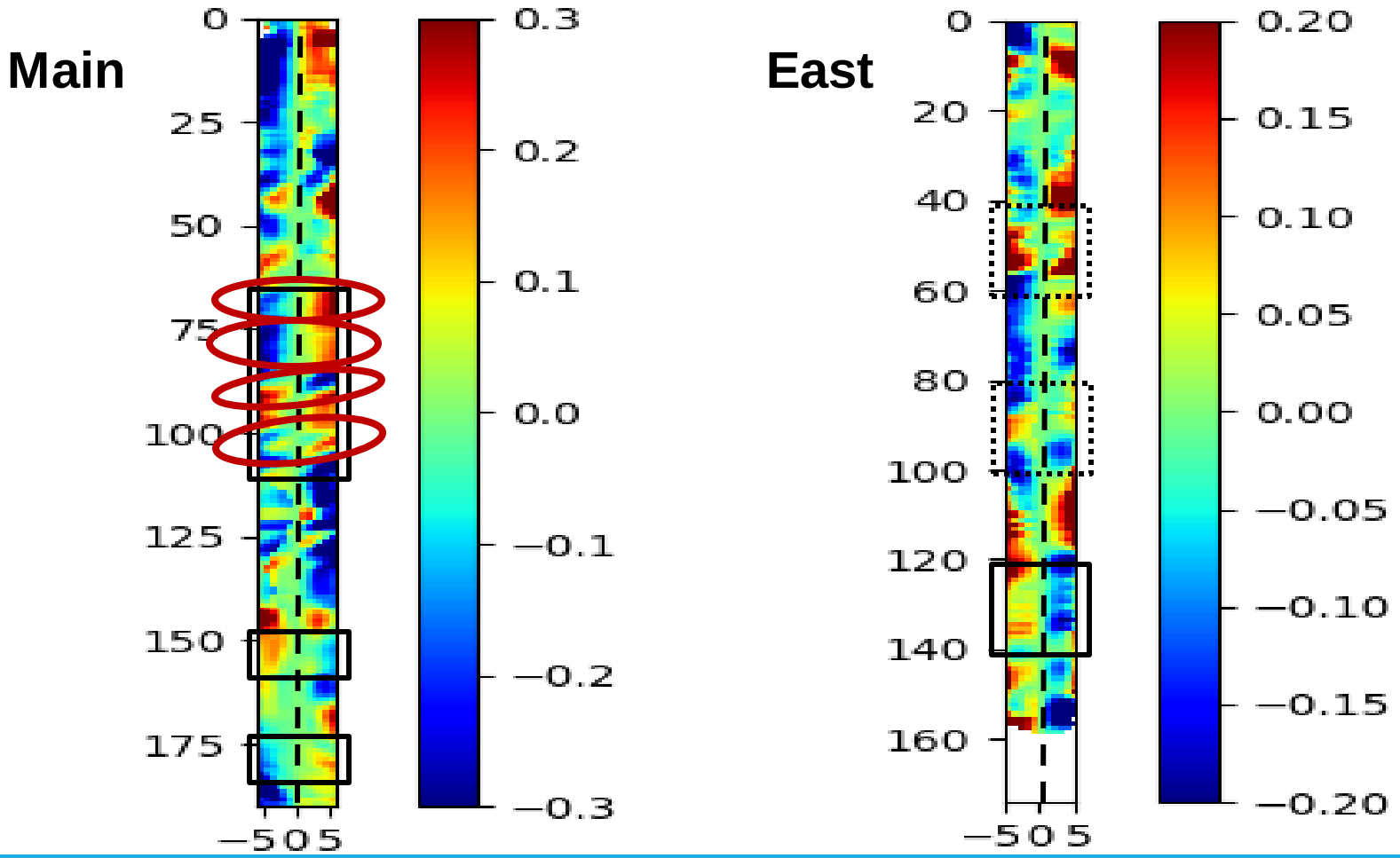

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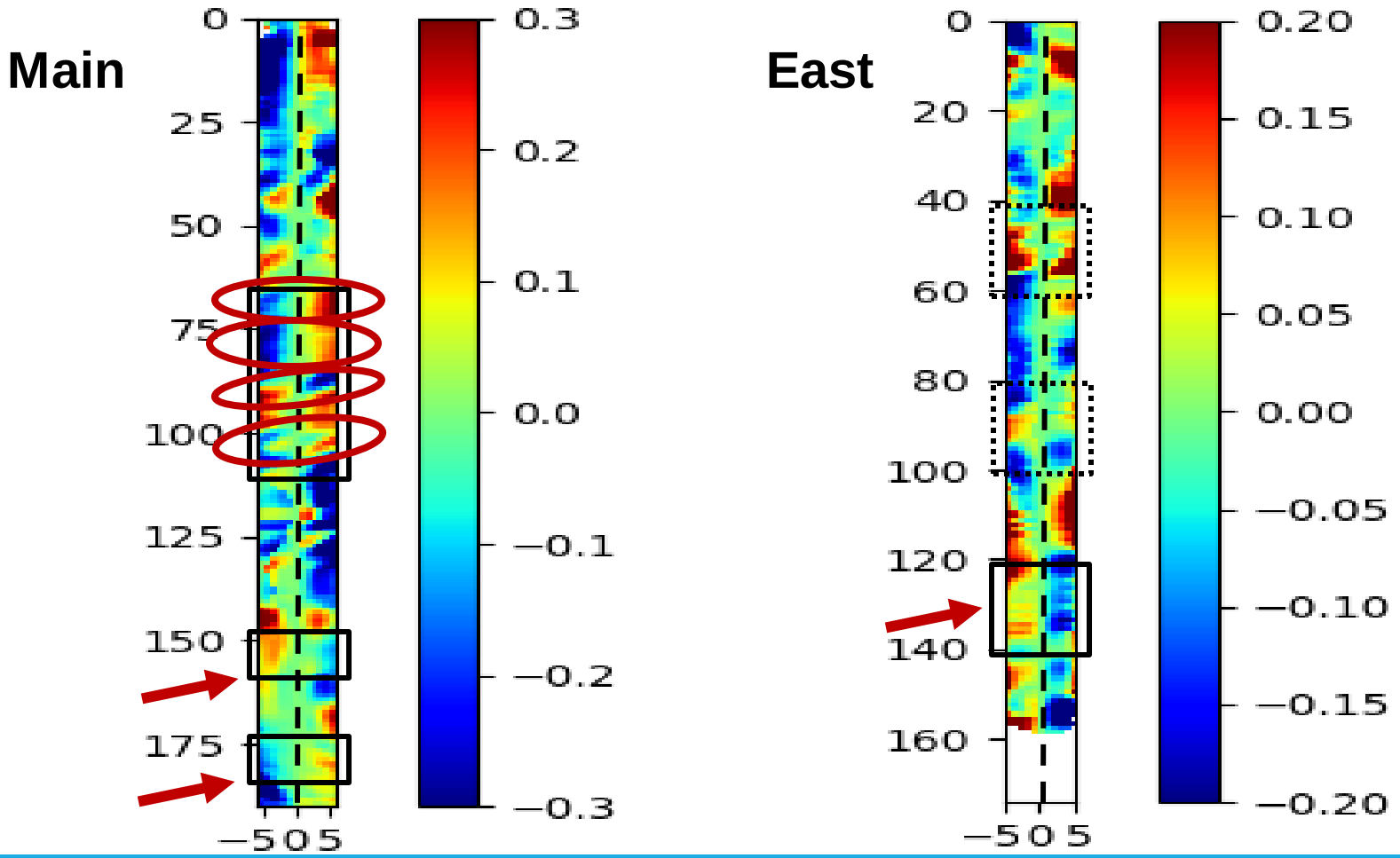

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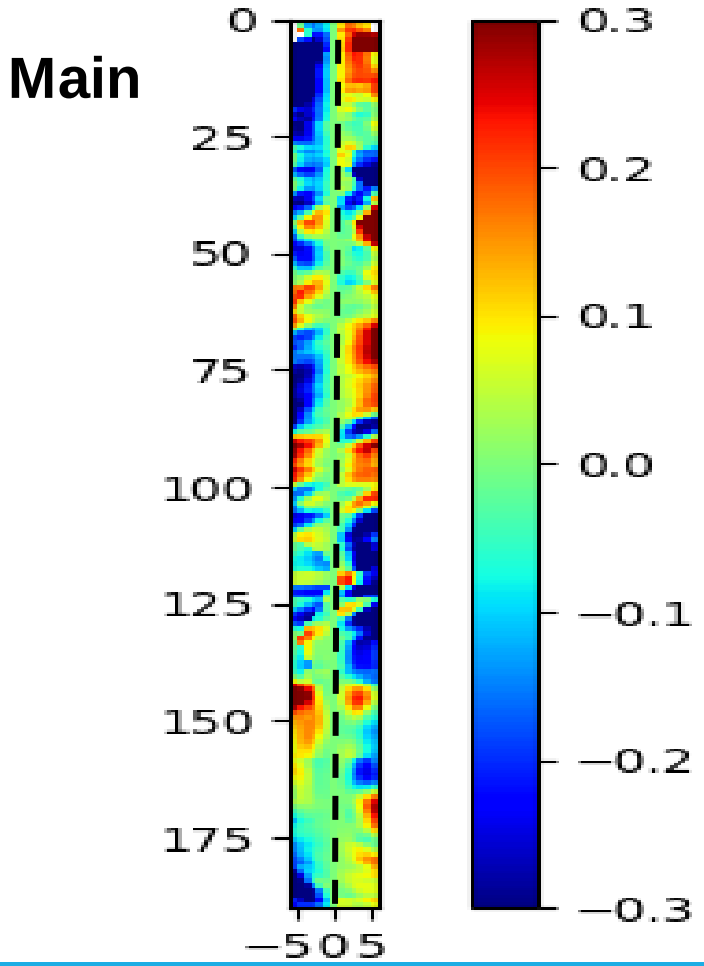

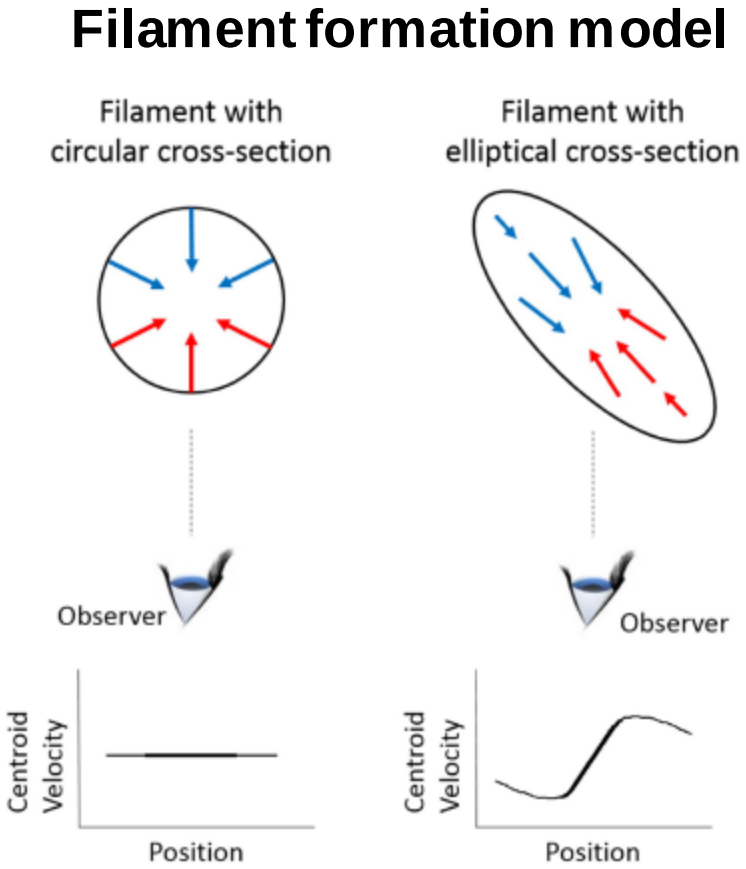

Dhabal et al. (2018)

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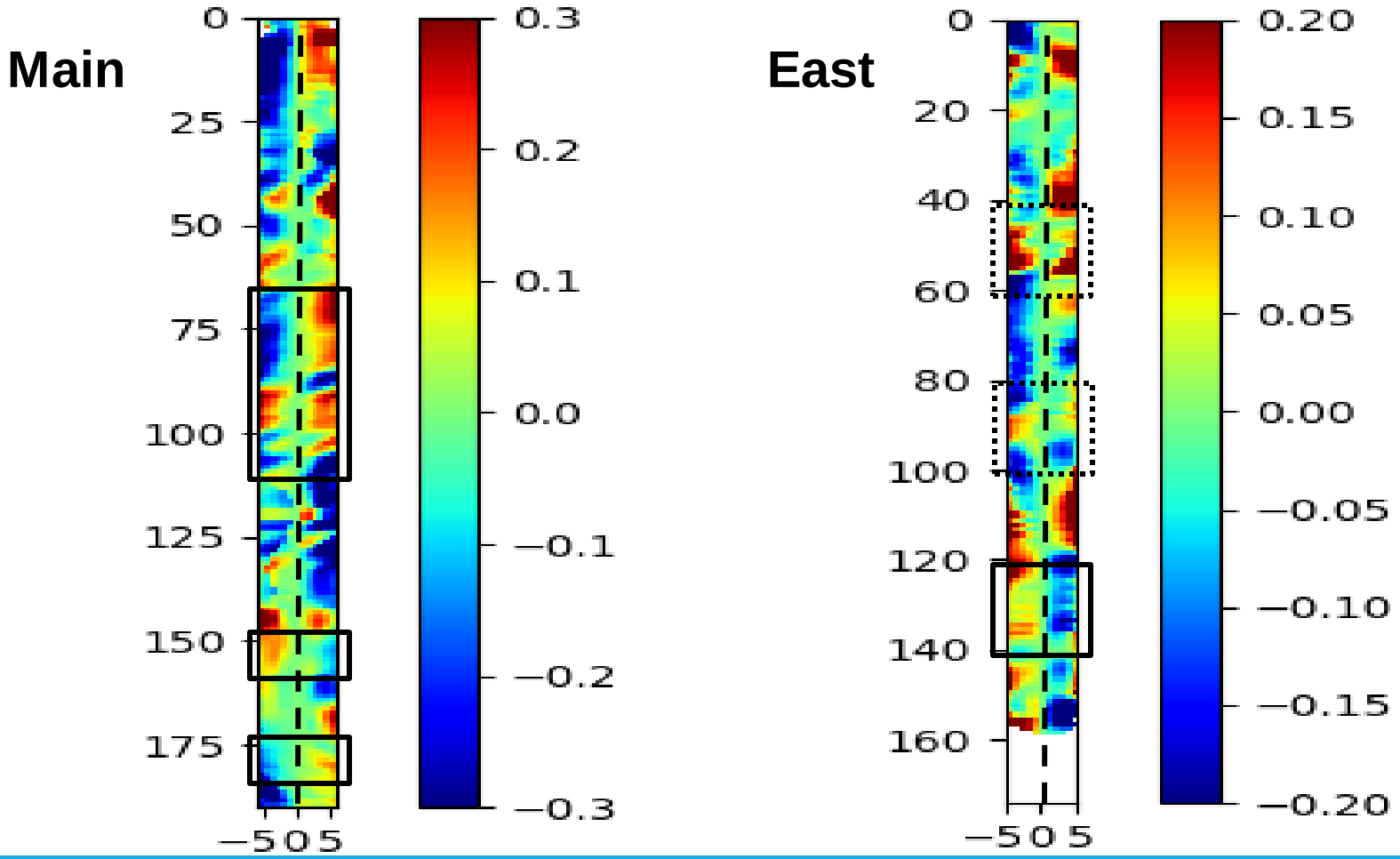
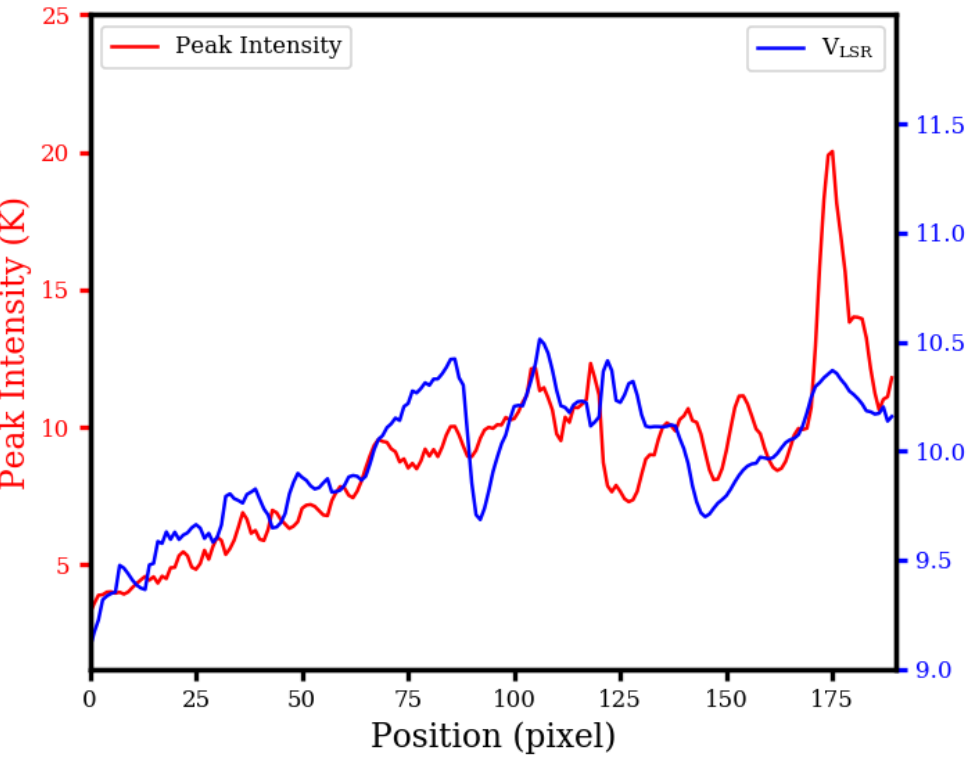
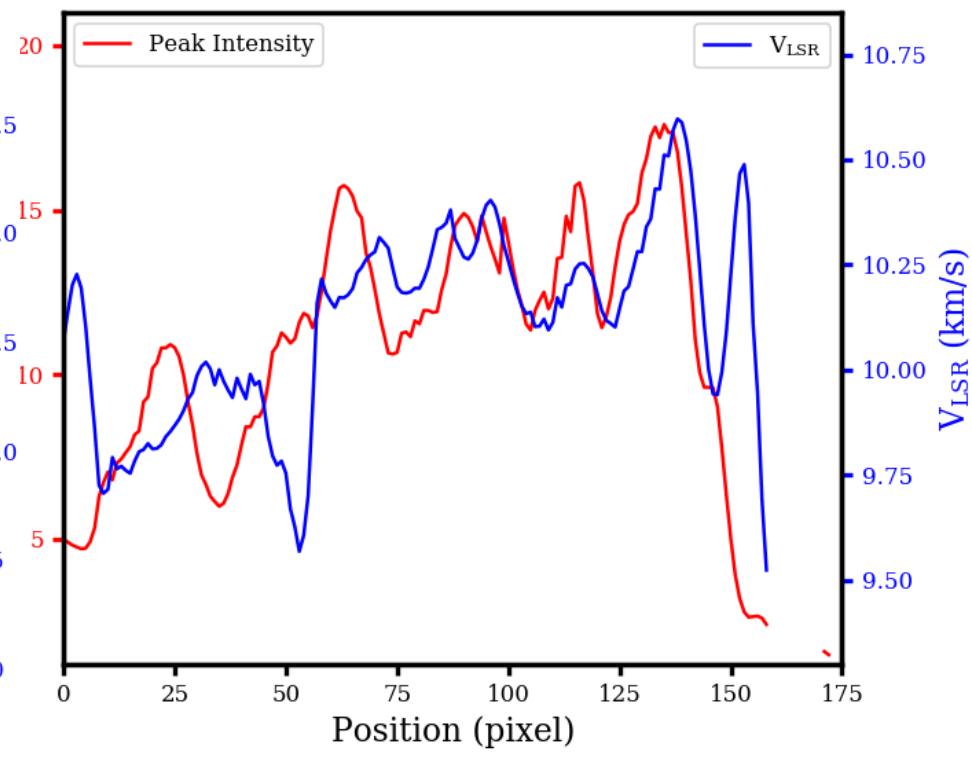


Major-Axis Analysis

Main Filament

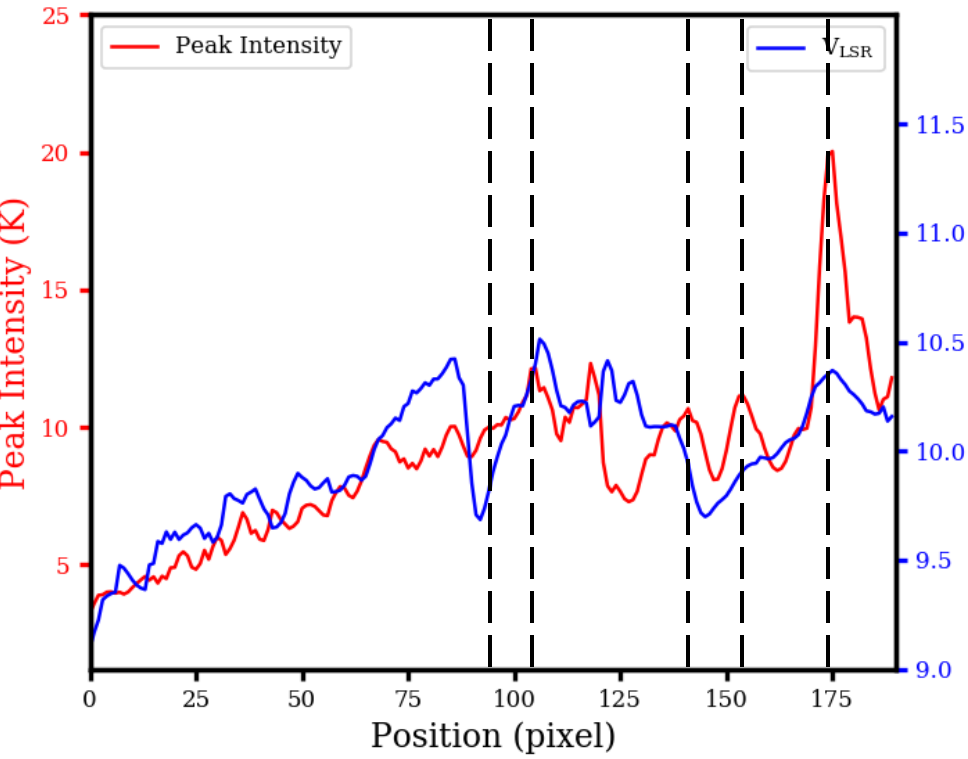


East Filament

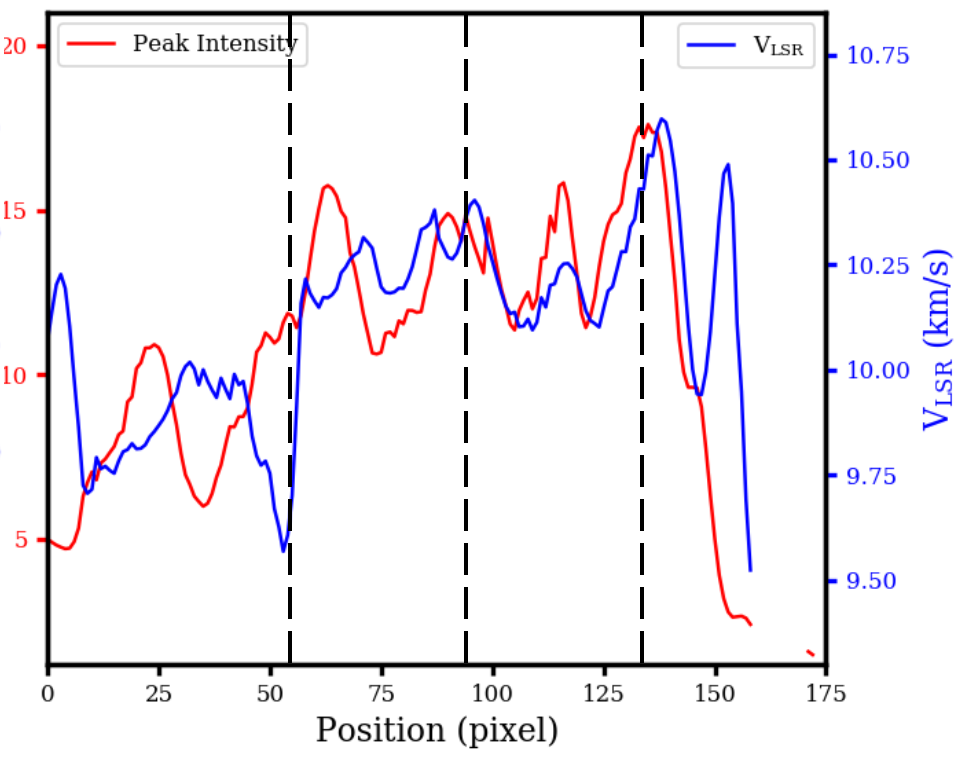


Major-Axis Analysis

Main Filament

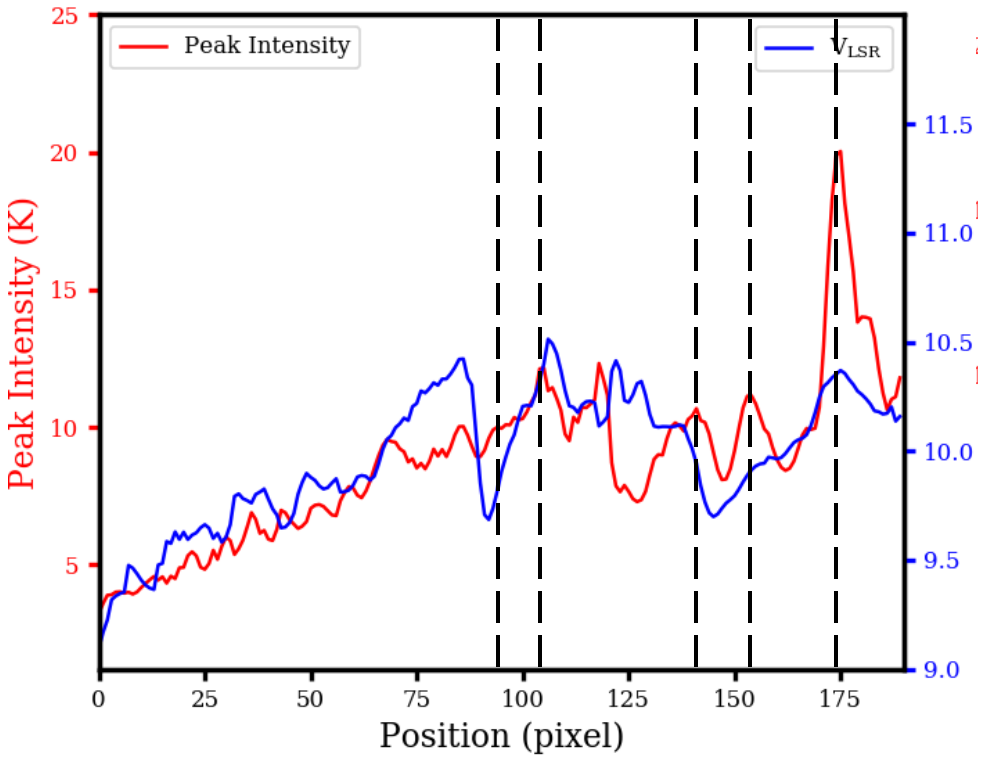


East Filament

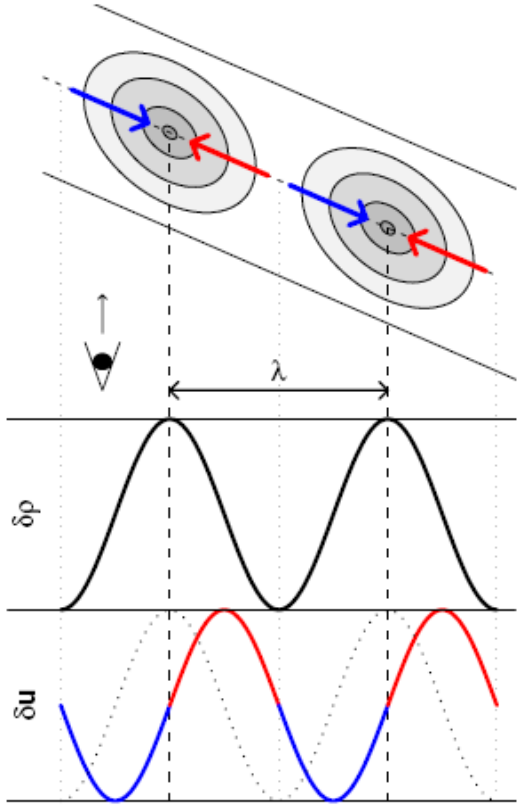


Major-Axis Analysis

Main Filament



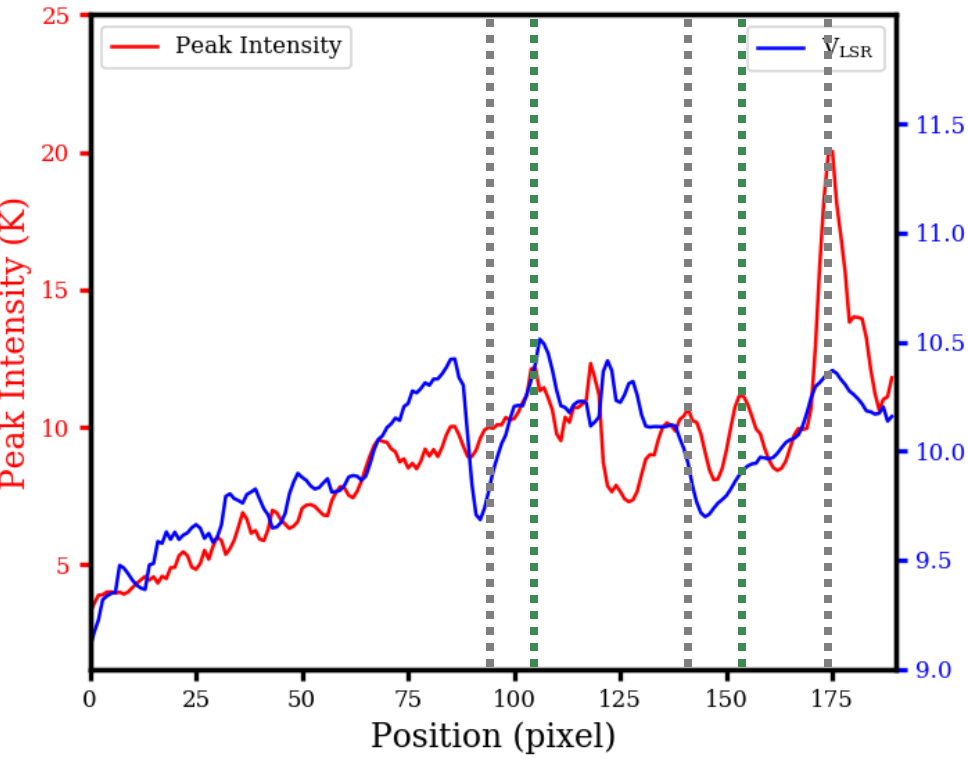
Core formation model



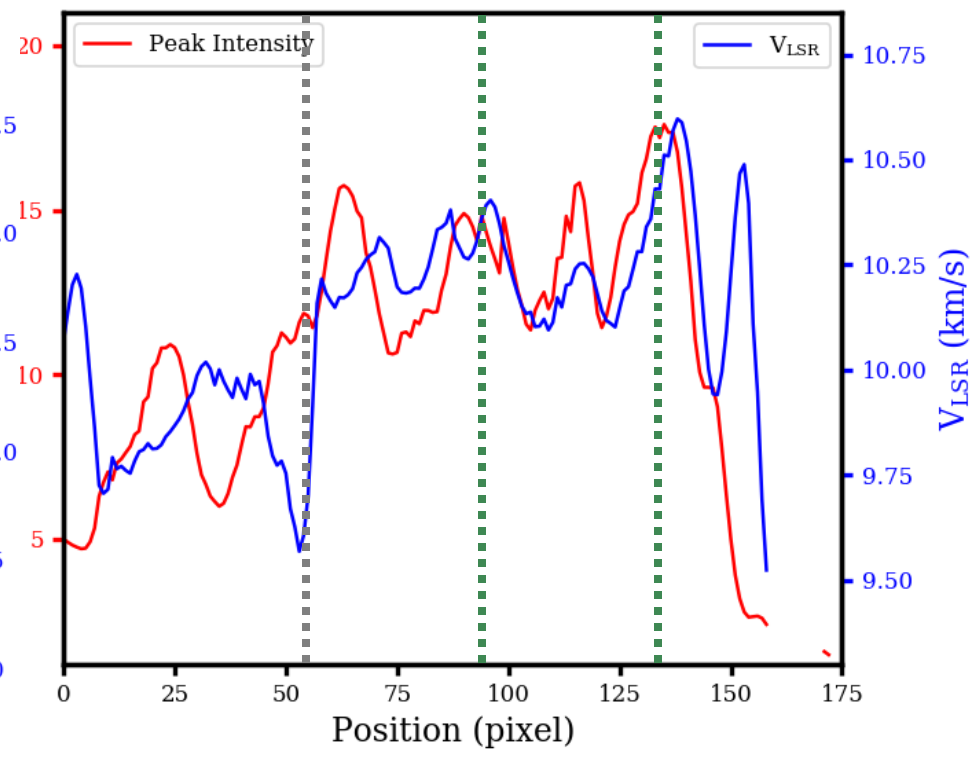
Hacar and Tafalla (2011)

Major-Axis Analysis

Main Filament



East Filament



Conclusions

- 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

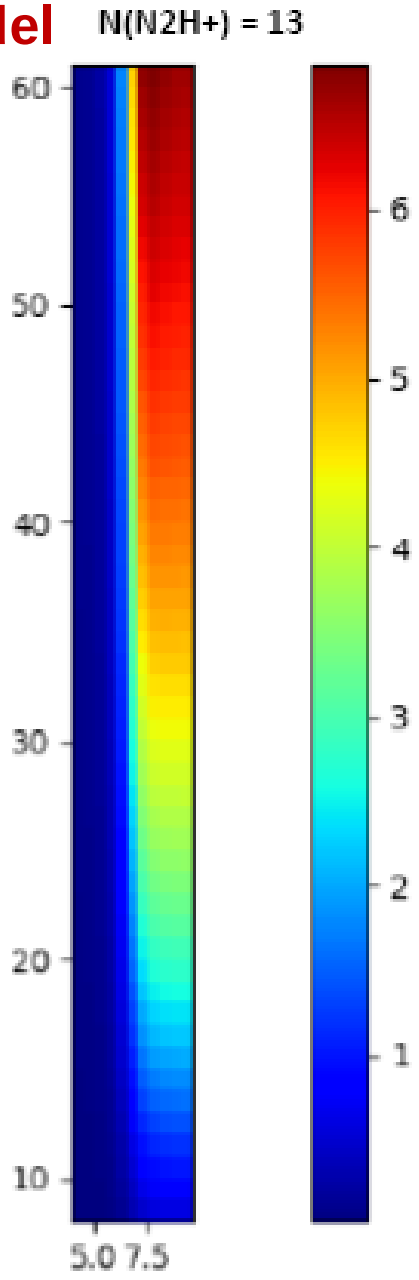
    → External heating (T_{kin}~$31 - 37\ K$)
  - High resolution analysis shows a low ratio in the filaments

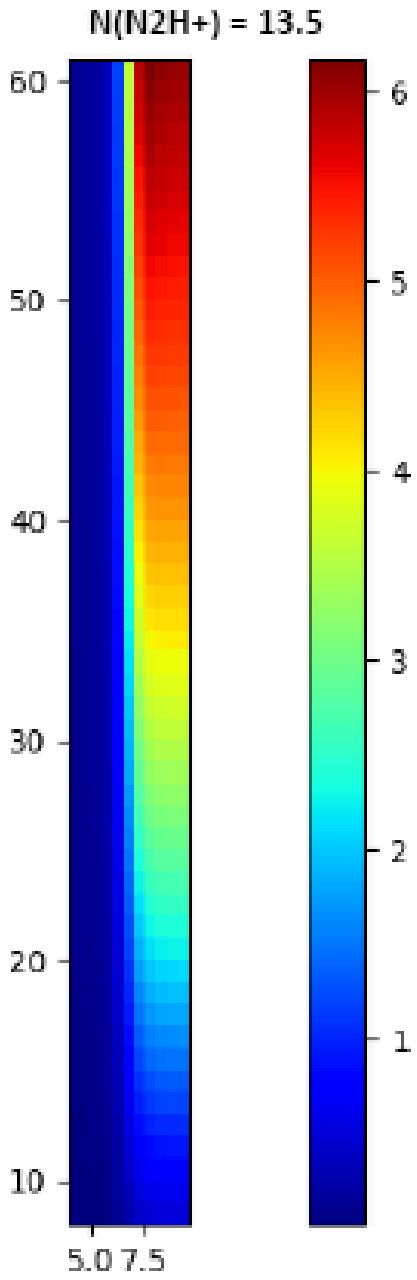
    → High density and low temperature ($n_{H_2} \sim 10^7\ cm^{-3}$ and T_{kin}~$15K$)
- Velocity along the minor-axis of the filaments do not show systematic gradient. Each core has its own rotational axis.
- Major-axis analysis on the filaments may suggest a different core formation mechanism from the ones in typical low-mass regions.

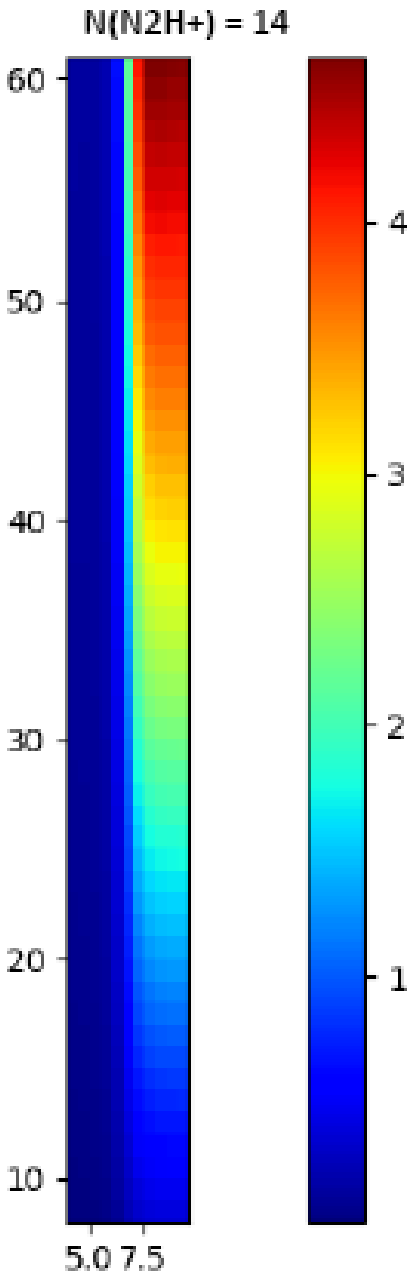
Thank you for your attention!

M42 and Orion KL

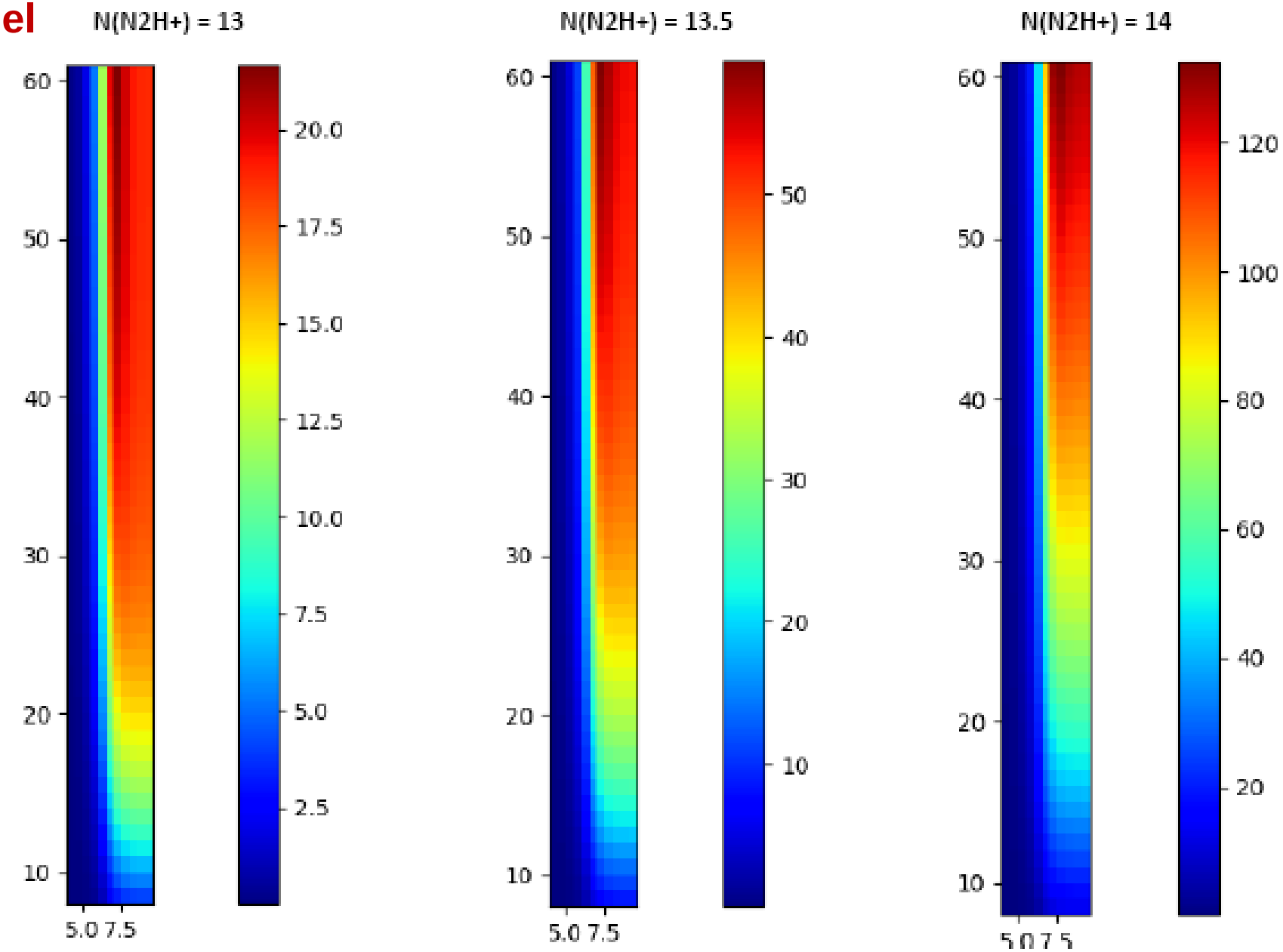
Ratio Model


N(N2H+) = 13
60
50
40
30
20
10
5.0 7.5
6
5
4
3
2
1

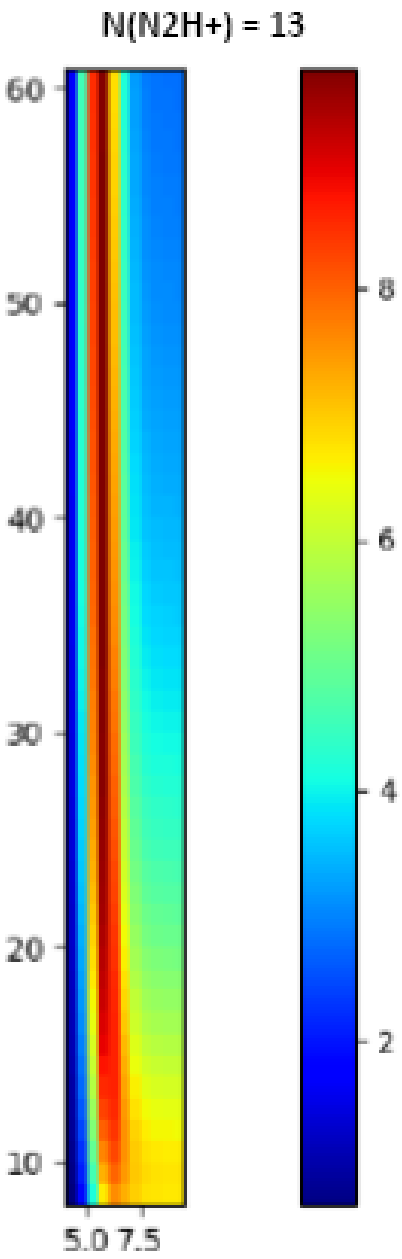

N(N2H+) = 13.5
60
50
40
30
20
10
5.0 7.5
6
5
4
3
2
1

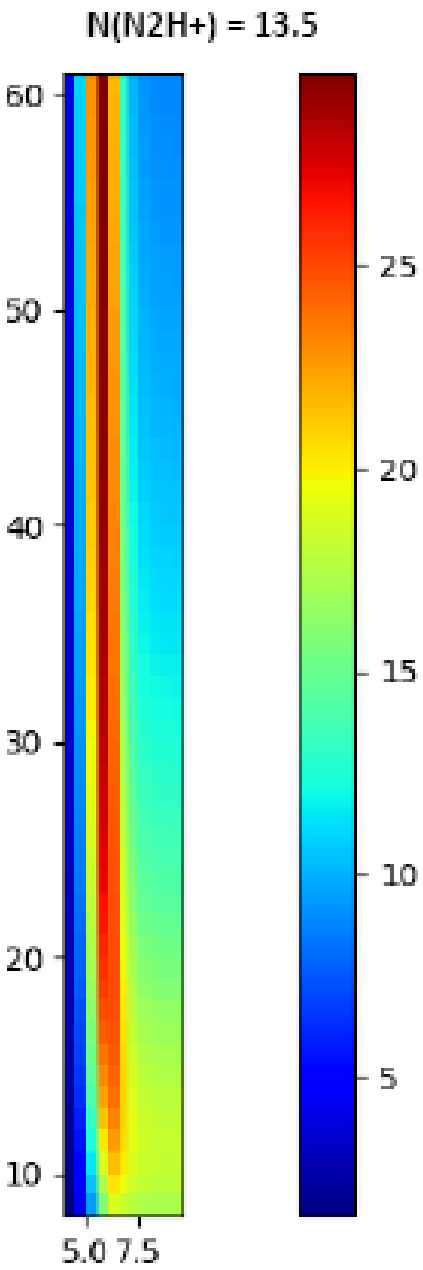

N(N2H+) = 14
60
50
40
30
20
10
5.0 7.5
4
3
2
1

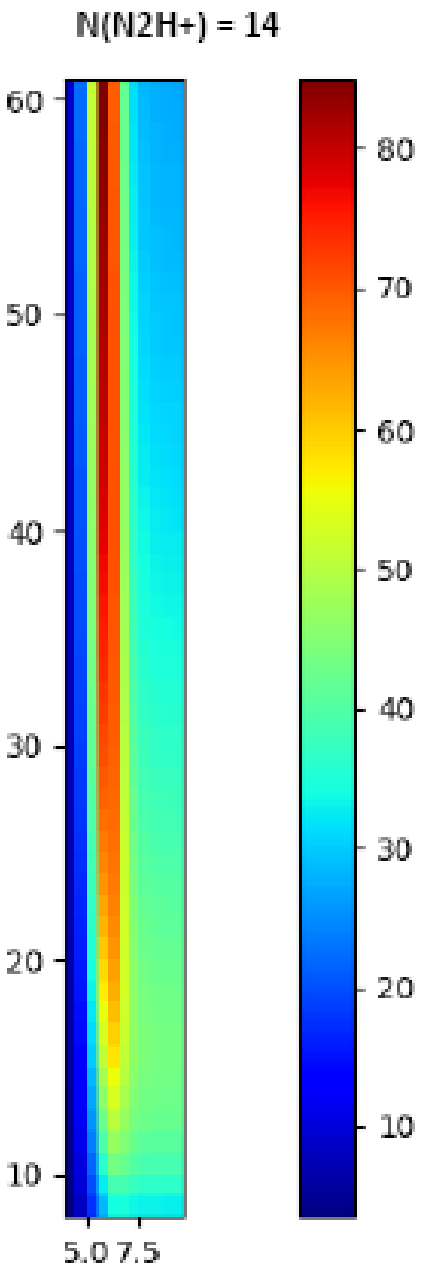
3-2 Model


N(N2H+) = 13
N(N2H+) = 13.5
N(N2H+) = 14
60
50
40
30
20
10
5.0 7.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
50
40
30
20
10
120
100
80
60
40
20

1-0 Model


N(N2H+) = 13
60
50
40
30
20
10
5.0
7.5
8
6
4
2


N(N2H+) = 13.5
60
50
40
30
20
10
5.0
7.5
25
20
15
10
5


N(N2H+) = 14
60
50
40
30
20
10
5.0
7.5
80
70
60
50
40
30
20
10