First High-Resolution ALMA Observations of the Protostellar Jet HH 212 in SiO J = 16–15

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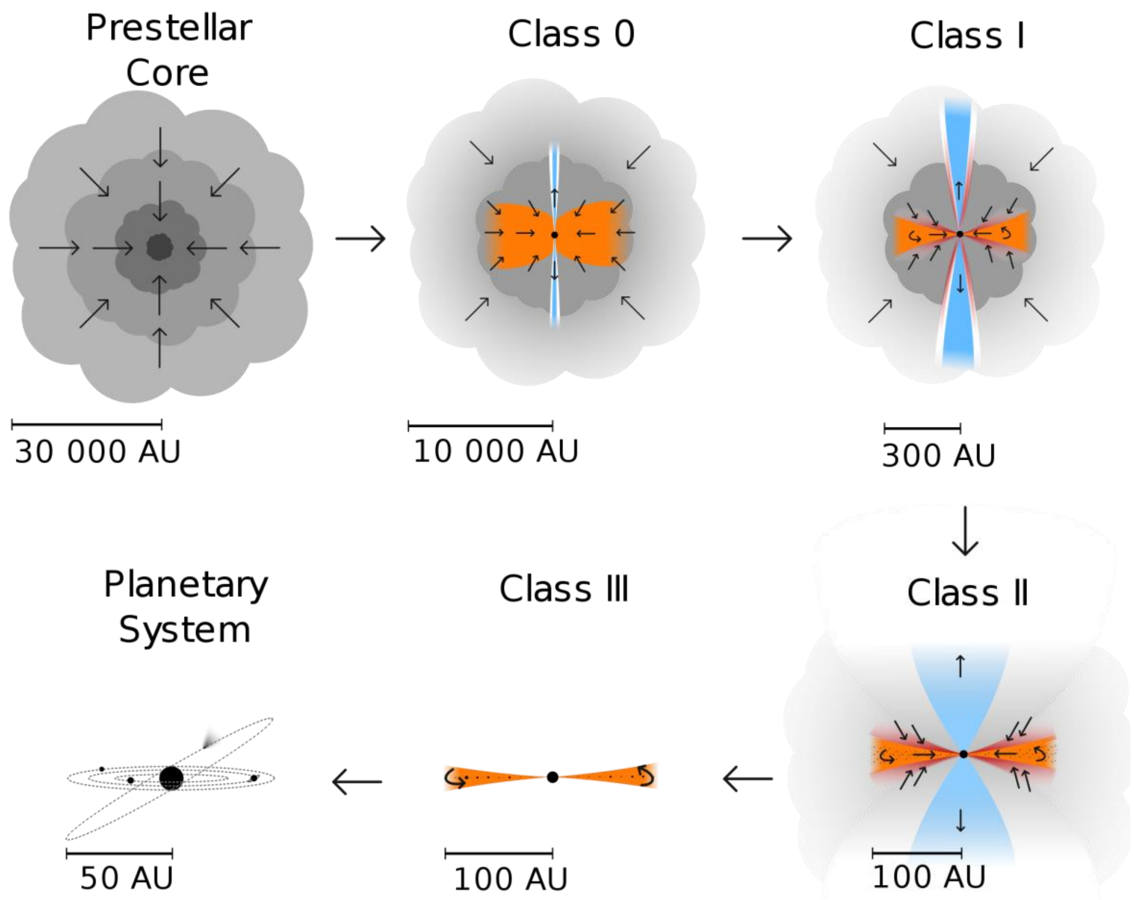
Protostellar Jet in Radio

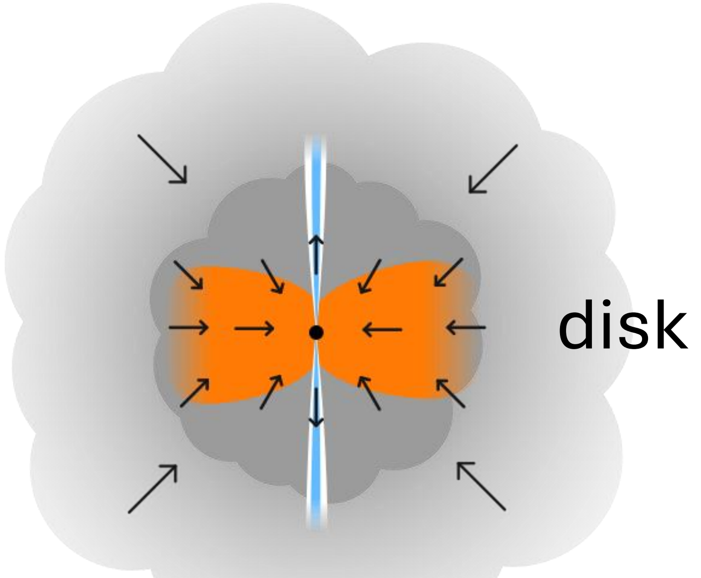
- Class 0 & 1 protostars
- Hidden by gas and dust
- Radio (ALMA) to probe the **innermost** parts



Magnus Vilhelm Persson (2014)

Important Role of Protostellar Jet

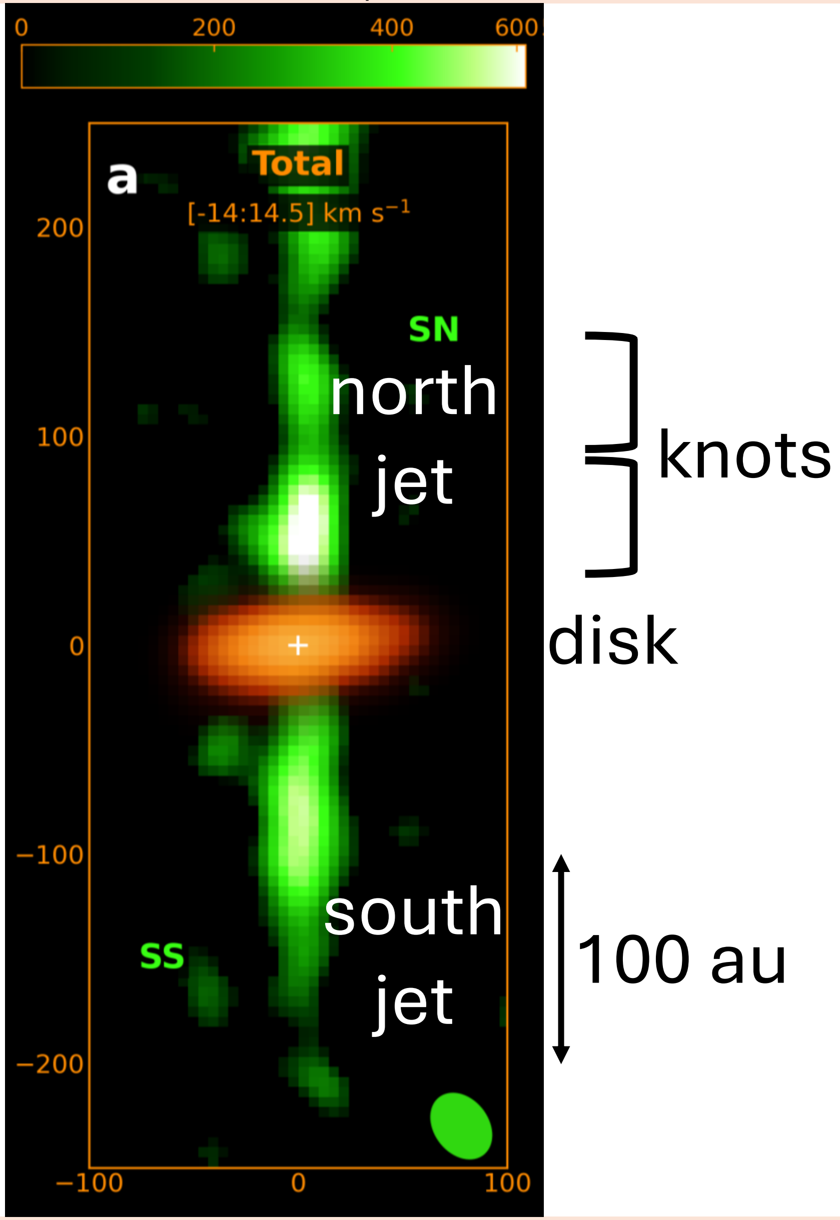
- Remove angular momentum to keep the system growing
- Understand how material is launched, accelerated, and heated



Magnus Vilhelm Persson (2014)

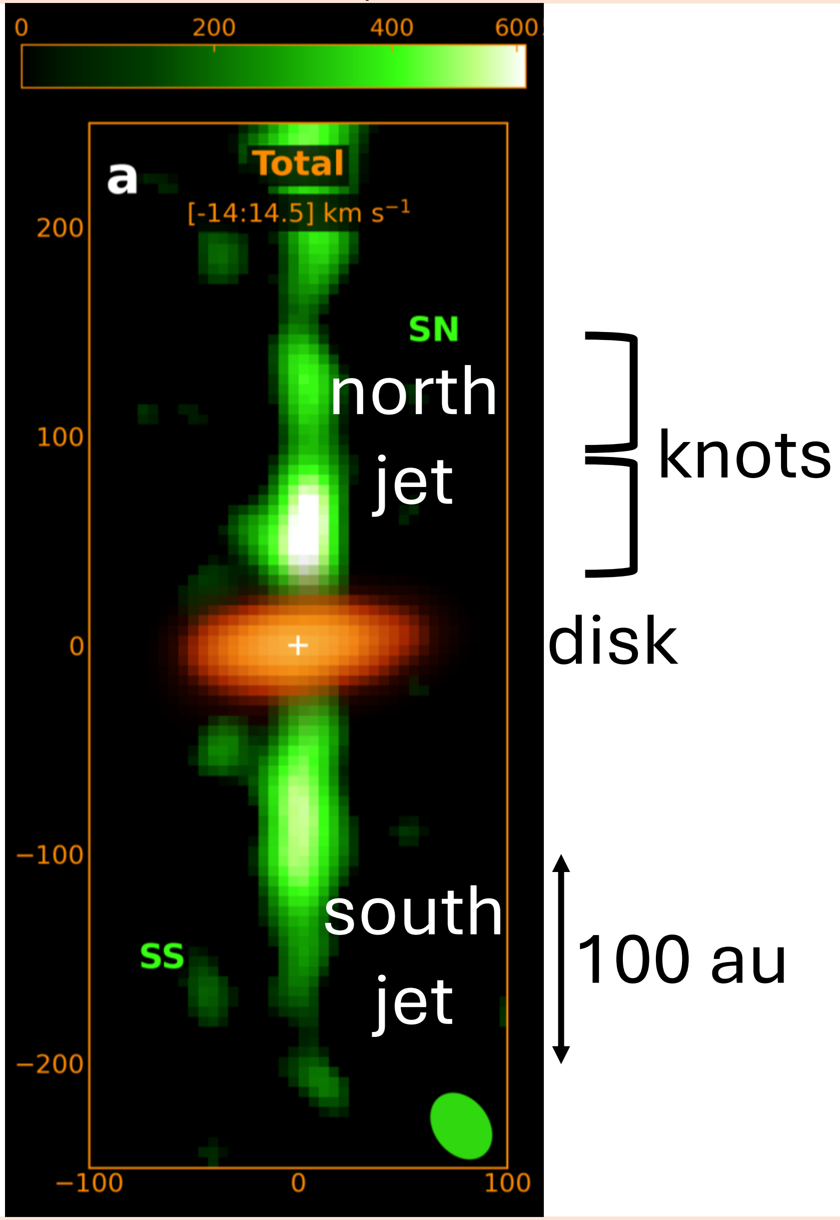
Benchmark HH212

- Edge-on geometry
- Highly symmetric bipolar jets
- Has been studied by many molecular lines (CO, SO, SiO...)

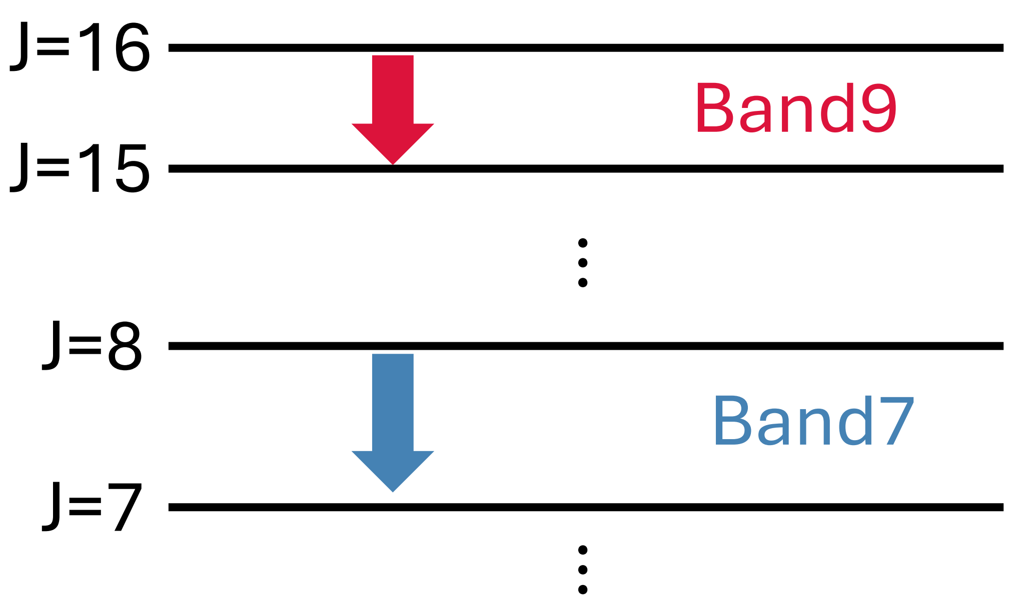


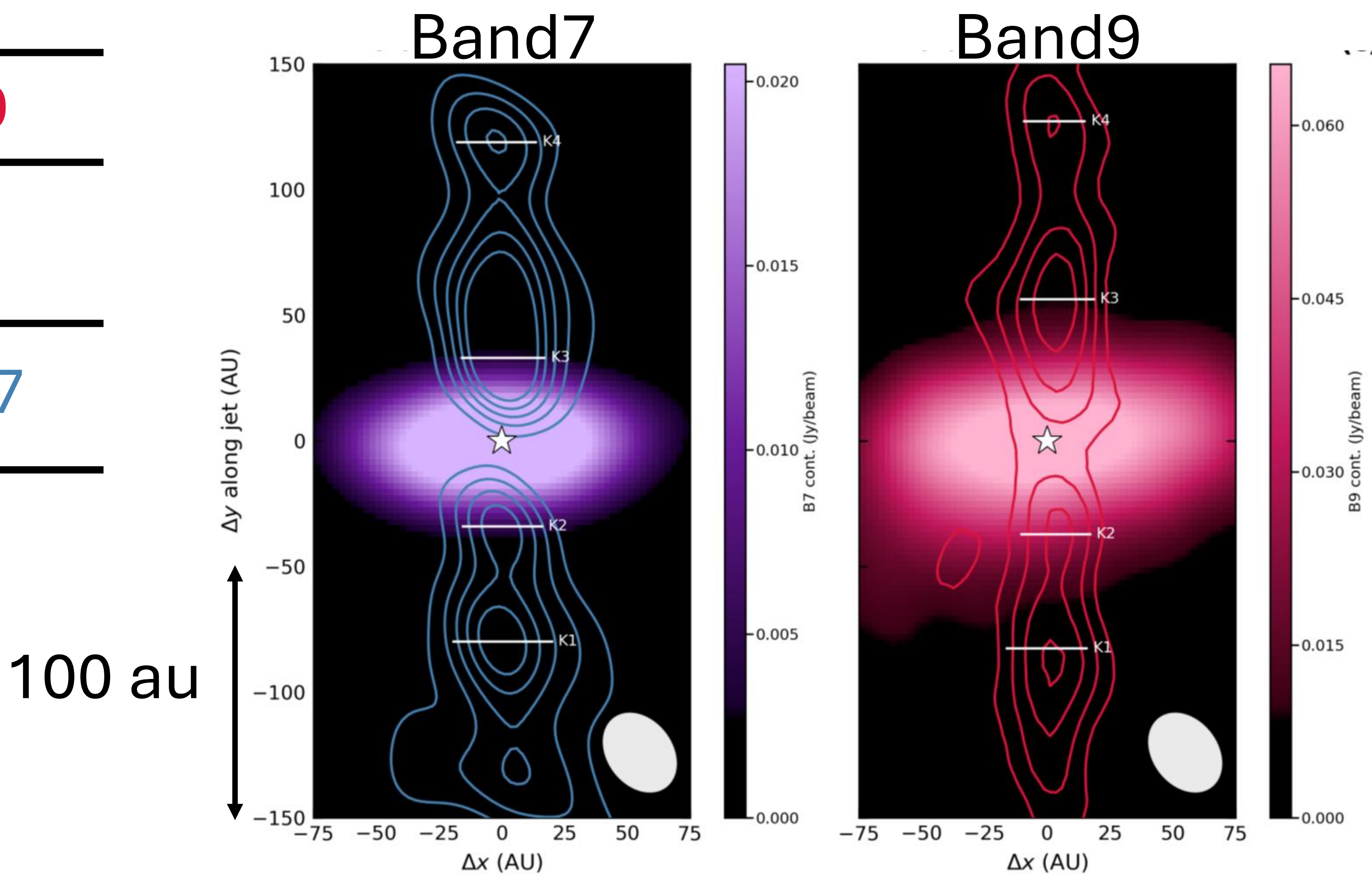
Benchmark HH212

- Edge-on geometry
- Highly symmetric bipolar jets
- Has been studied by many molecular lines (CO, SO, SiO…)
- Our target is the SiO emission



ALMA Band7 (SiO J=8-7) & Band9 (J=16-15)





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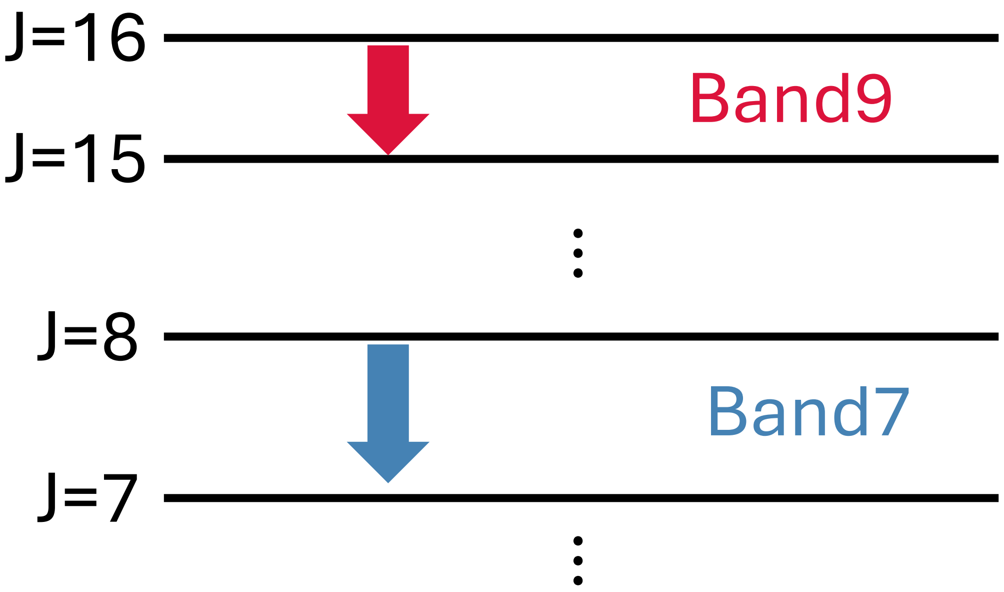
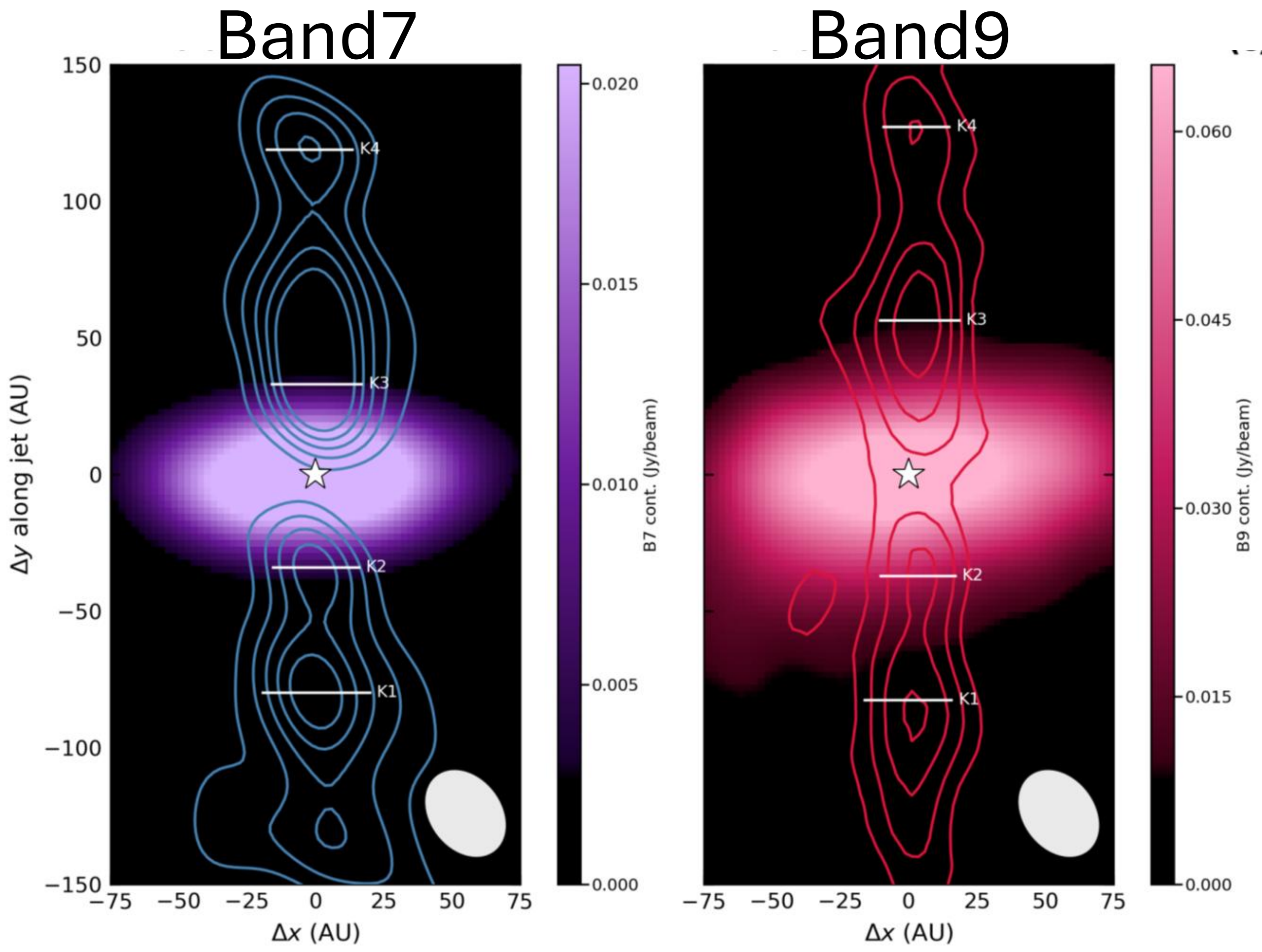
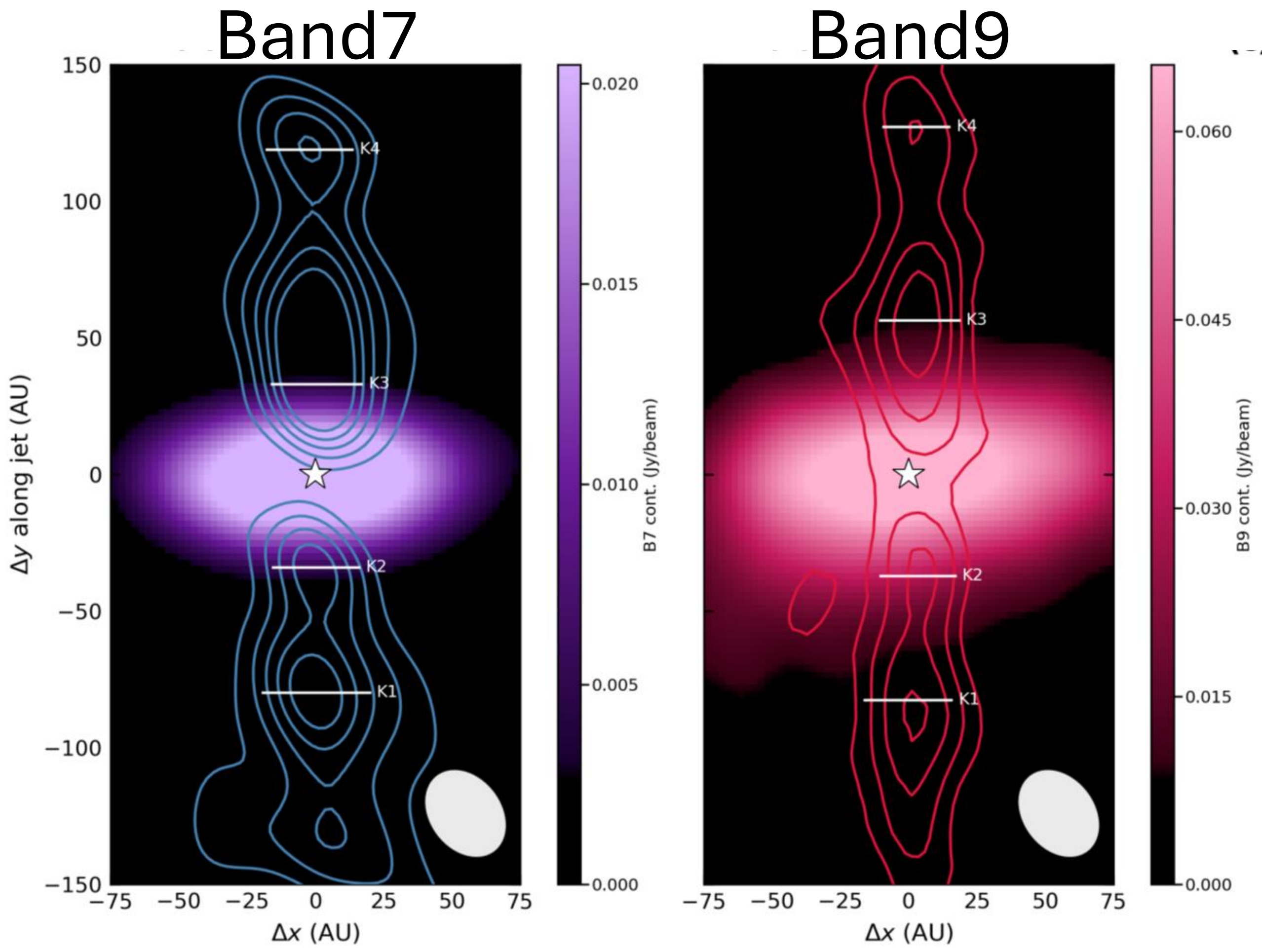




Higher transition (high-J) needs warmer / denser gas to excite

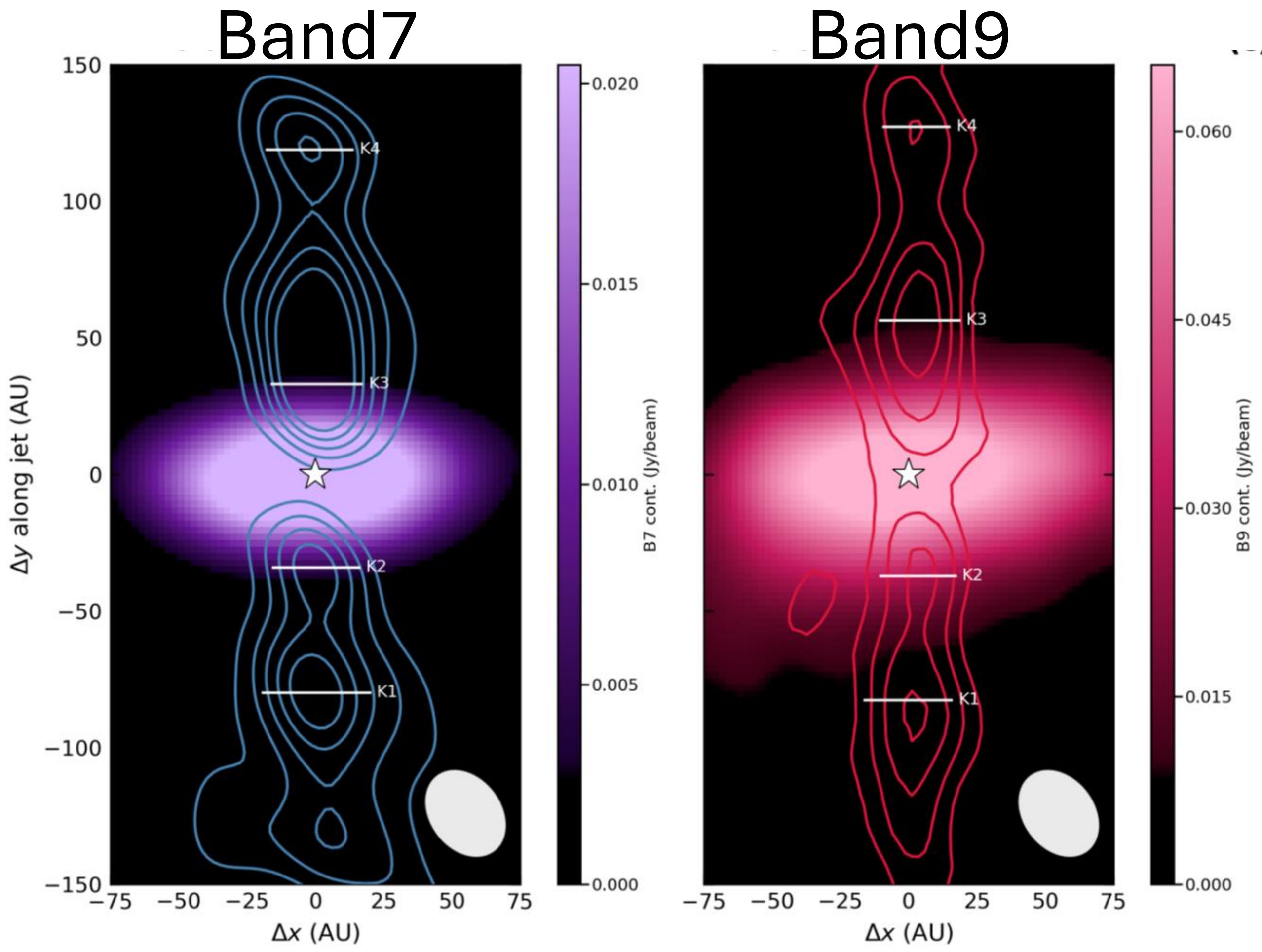
ALMA Band7 (SiO J=8-7) & Band9 (J=16-15)

- Higher transition (high-J) traces warmer and denser gas



ALMA Band7 (SiO J=8-7) & Band9 (J=16-15)

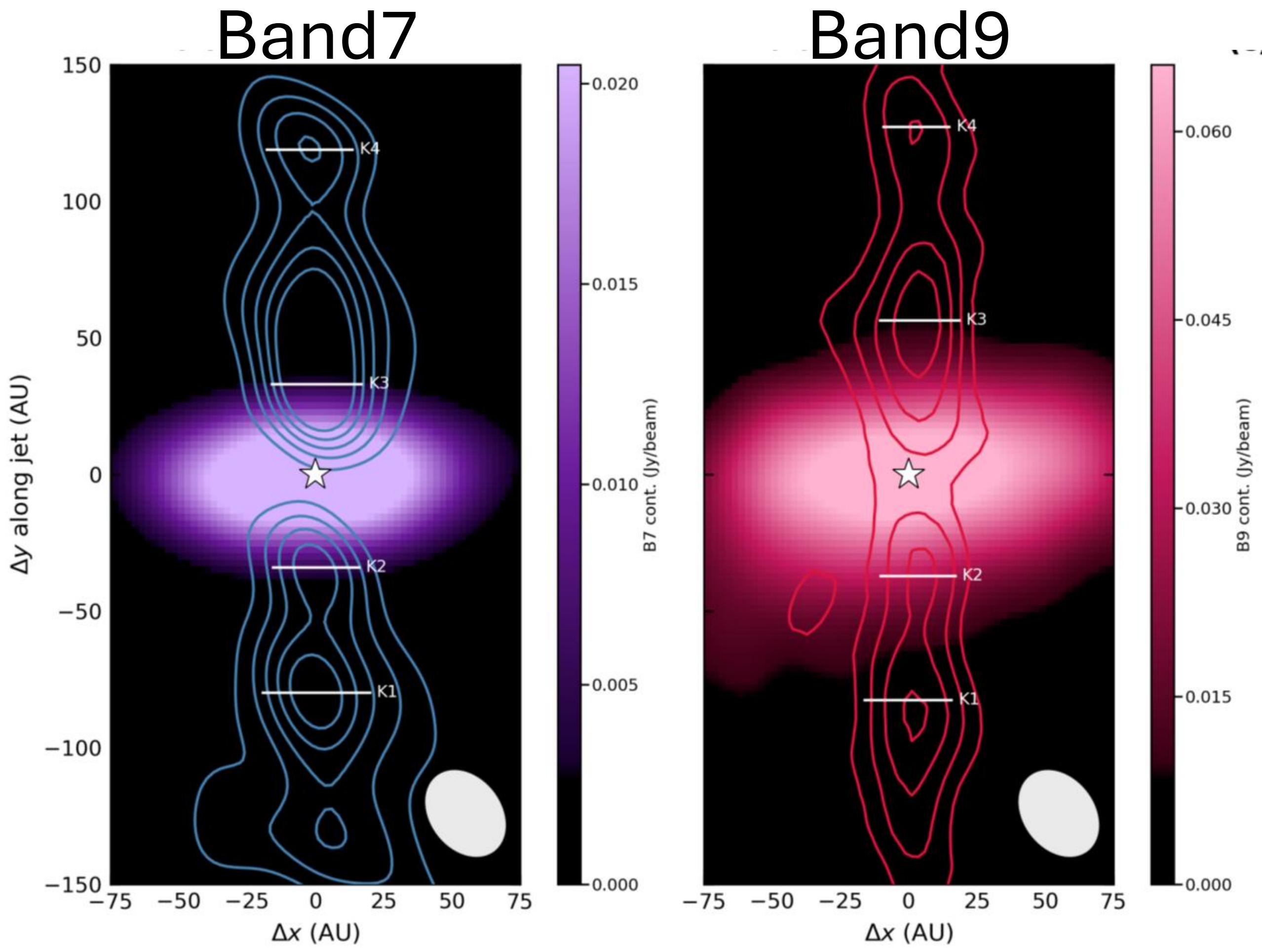
- Higher transition (high-J) traces warmer and denser gas
- The only other data with such resolution is Band 7
- **Goal: understand the Band9 features, comparing to Band7**



Three Analysis Understanding High-J SiO

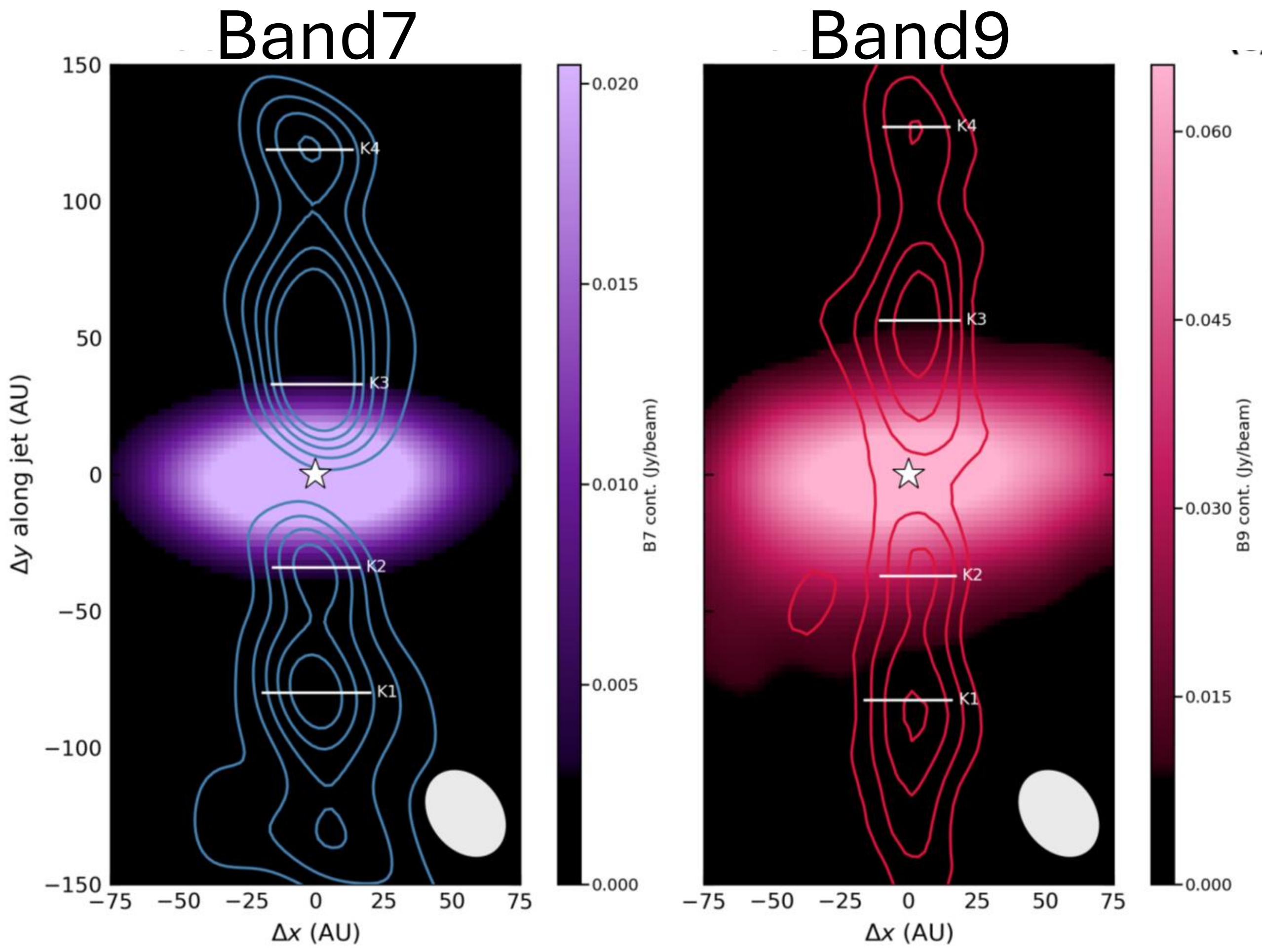
- **Integrated intensity map:**

  total emission & morphology



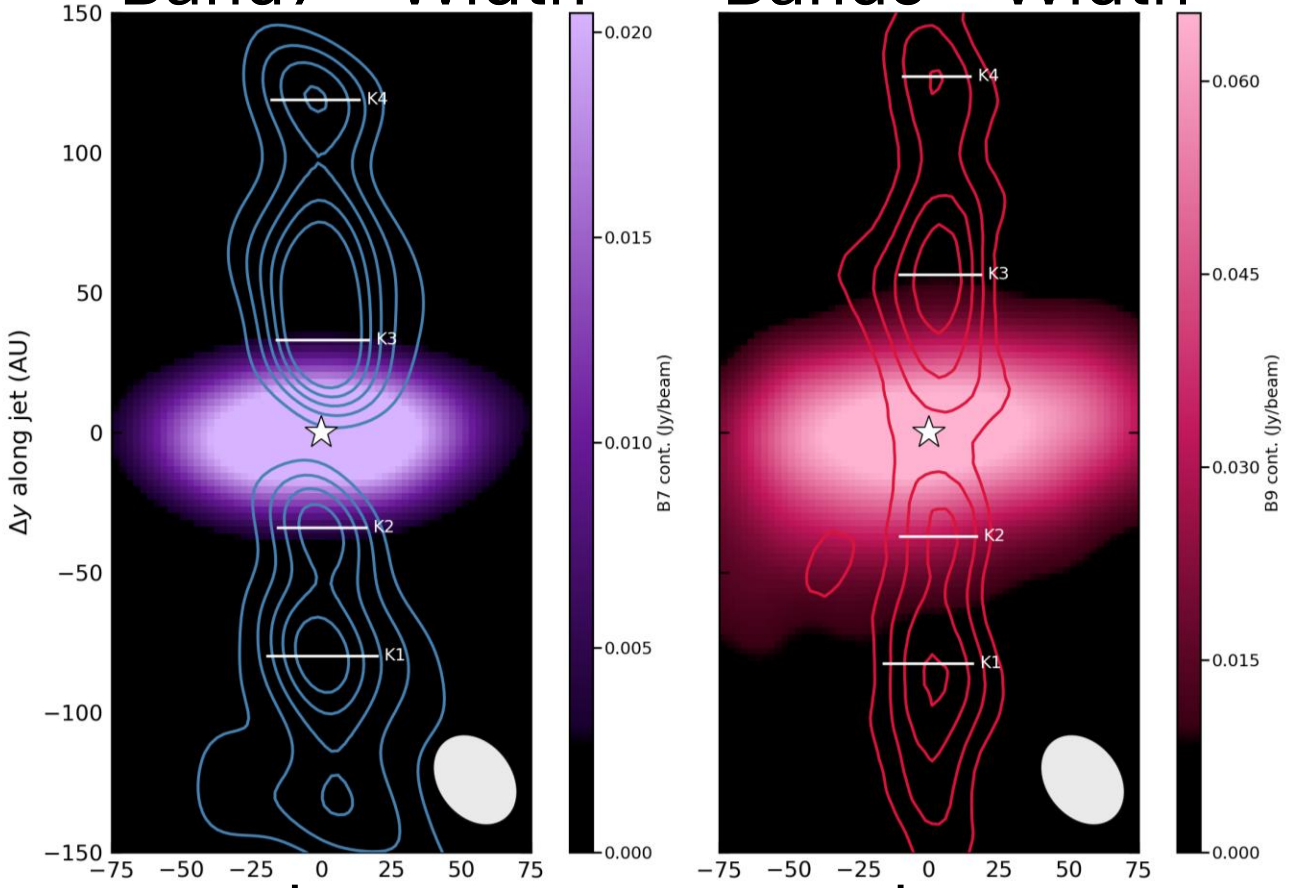
Three Analysis Understanding High-J SiO

- **Integrated intensity map:**
  total emission & morphology
- **Spectra of jets:**
  kinematic features & line ratios
- **Non-LTE (non local thermal equilibrium) radiative transfer**



Band9 is Narrower and Fainter

Band7 + Width   Band9 + Width

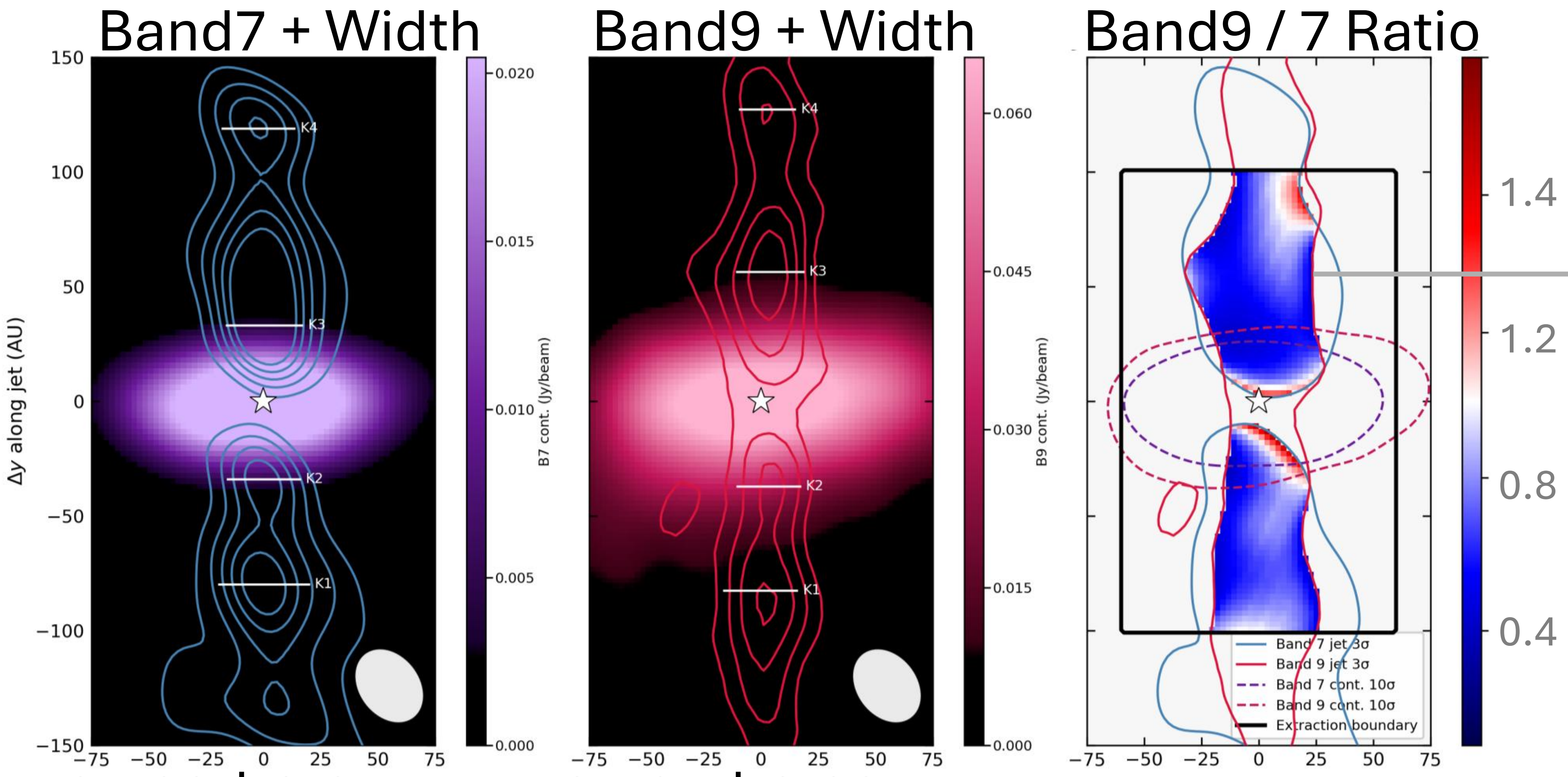


35.82 ± 2.61 au   **31.01 ± 3.08 au**

Band9 jet width < Band7 jet width

The first dataset resolves innermost jet and find difference

Band9 is Narrower and Fainter

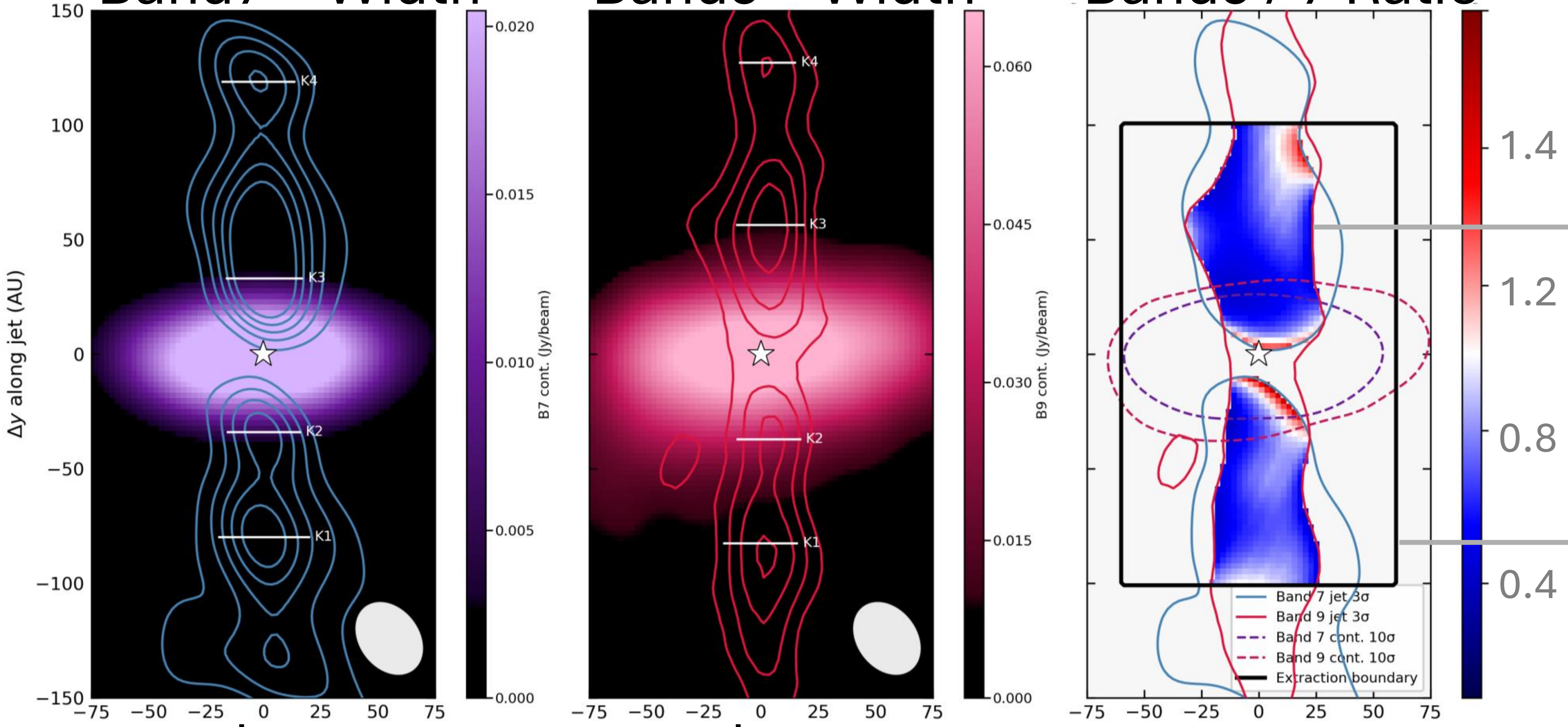


35.82 ± 2.61 au **31.01 ± 3.08 au**

Ratio overall <1
→ Band9 is fainter

Band9 is Narrower and Fainter

Band7 + Width | Band9 + Width | Band9 / 7 Ratio

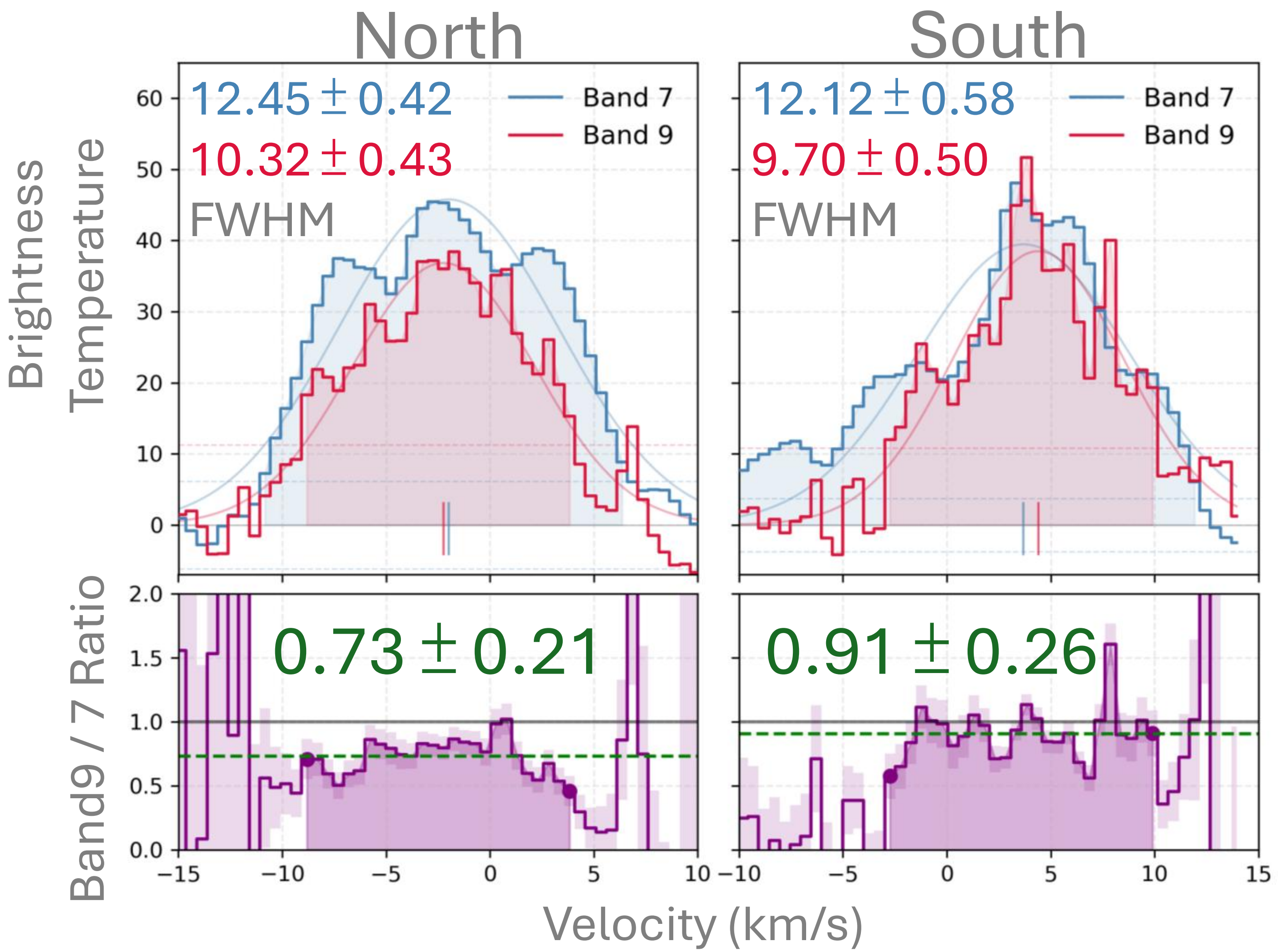


35.82 ± 2.61 au | **31.01 ± 3.08 au**

Ratio overall <1
→ Band9 is darker

spectrum extraction north/south

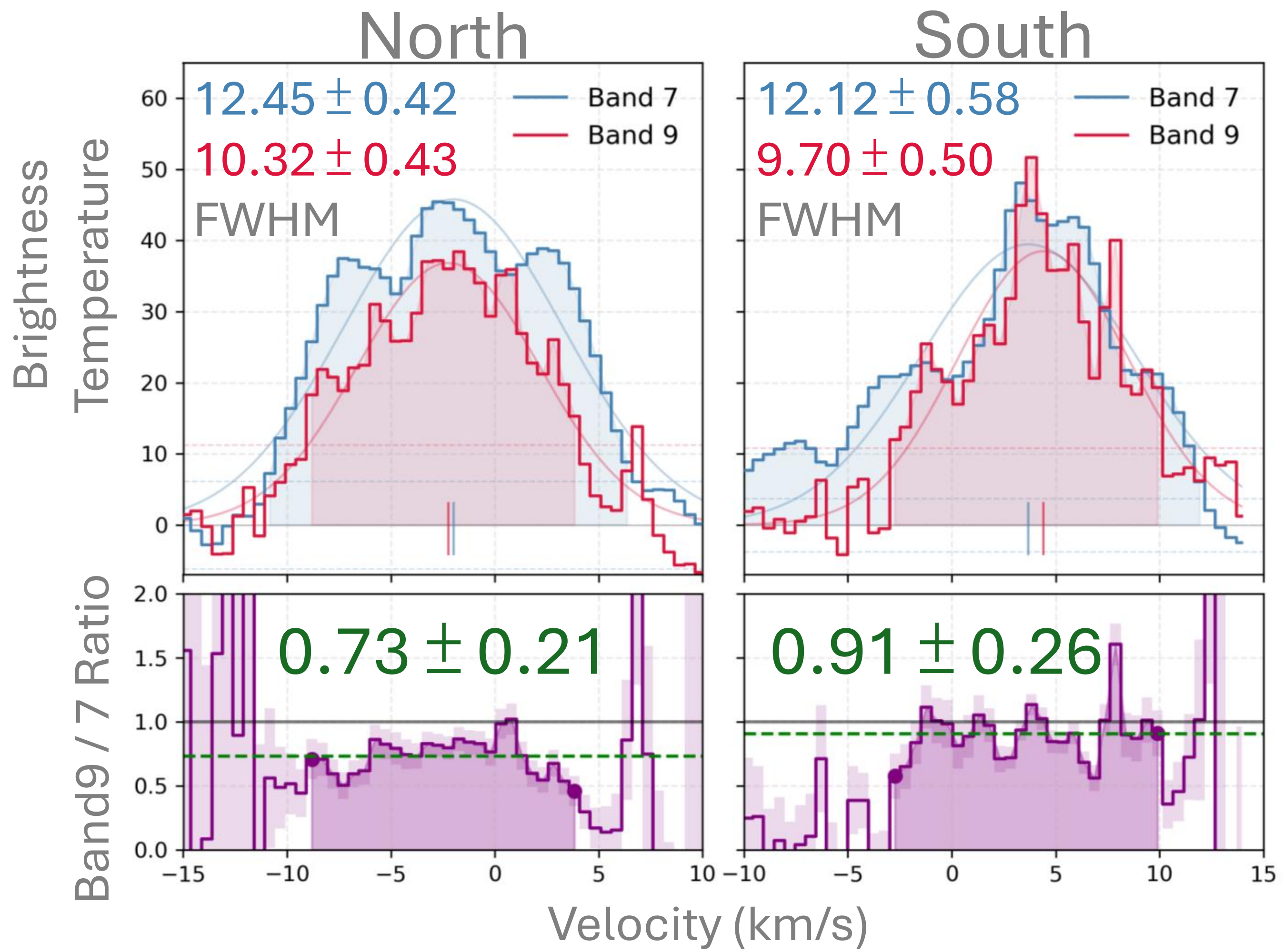
Band9 Spectrum is Narrower and Fainter



spectrum

spectrum ratio (Band9/Band7)

Band9 Spectrum is Narrower and Fainter



- Band9 spectrum width < Band7 spectrum width
- Band9/7 ratio ~ 0.73 — 0.91 < 1

The first spectrum set from the innermost part of jet and find difference

This dataset provides the **first direct observational evidence** that

the innermost jet contains

different structural and spectral features

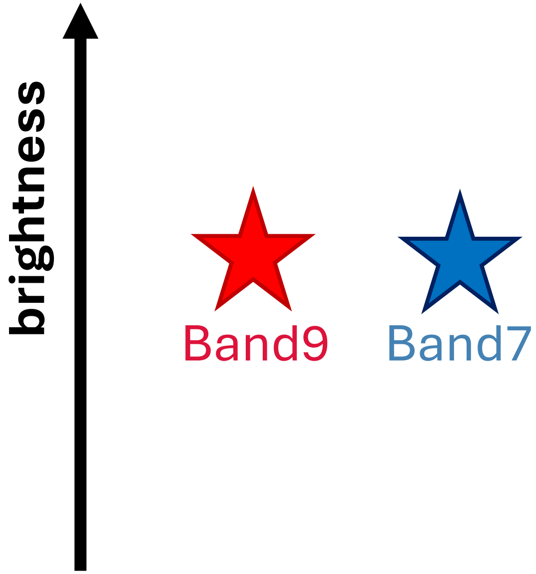
In Band9 (higher transition):

(1) the jet's width is narrower

(2) the brightness is less

(3) the spectrum is narrower

A Solution: Non-LTE + Density Gradient



- **Assume** there are emissions in Band9 and Band7 with same brightness
- A possible scenario is that **Band9 comes from a denser region**

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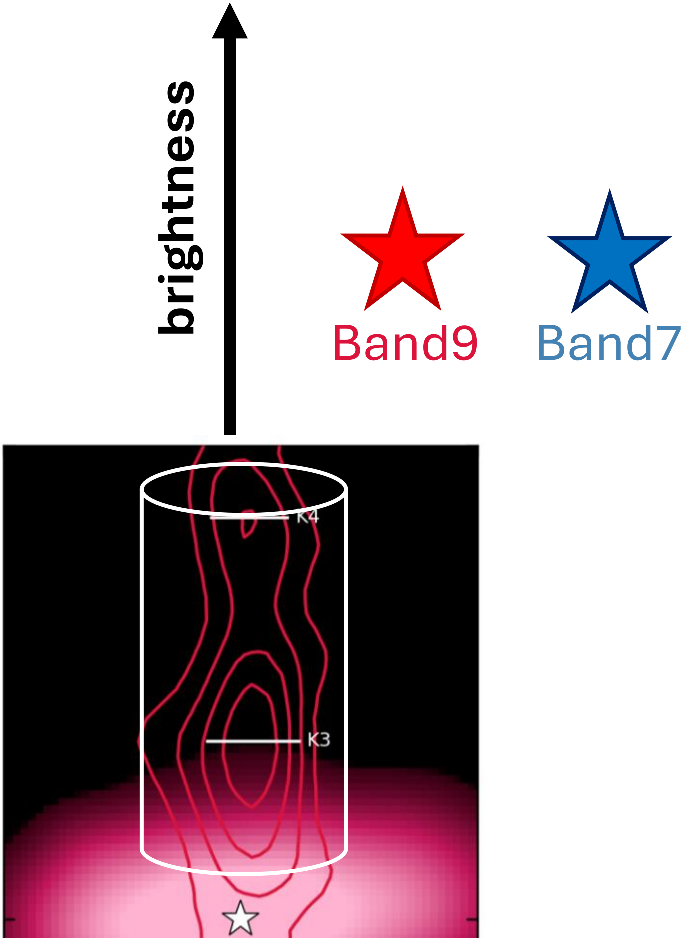

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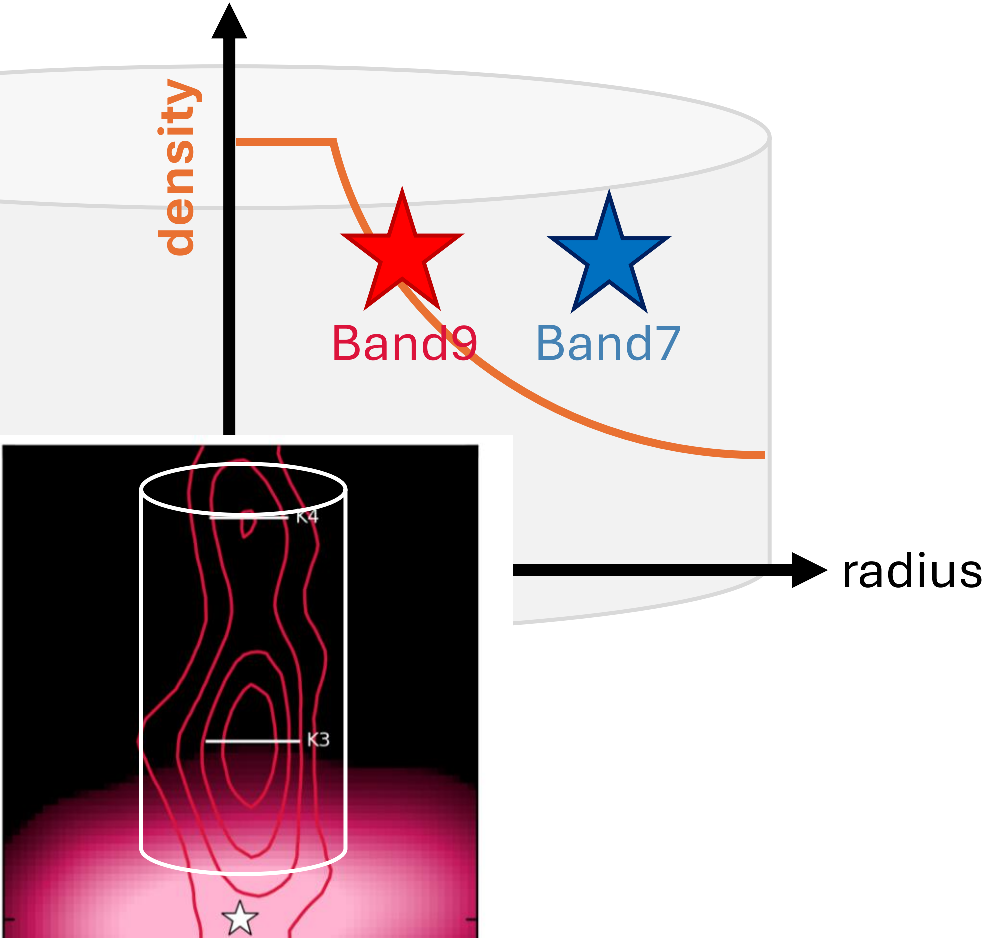

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- A density profile radially decreasing

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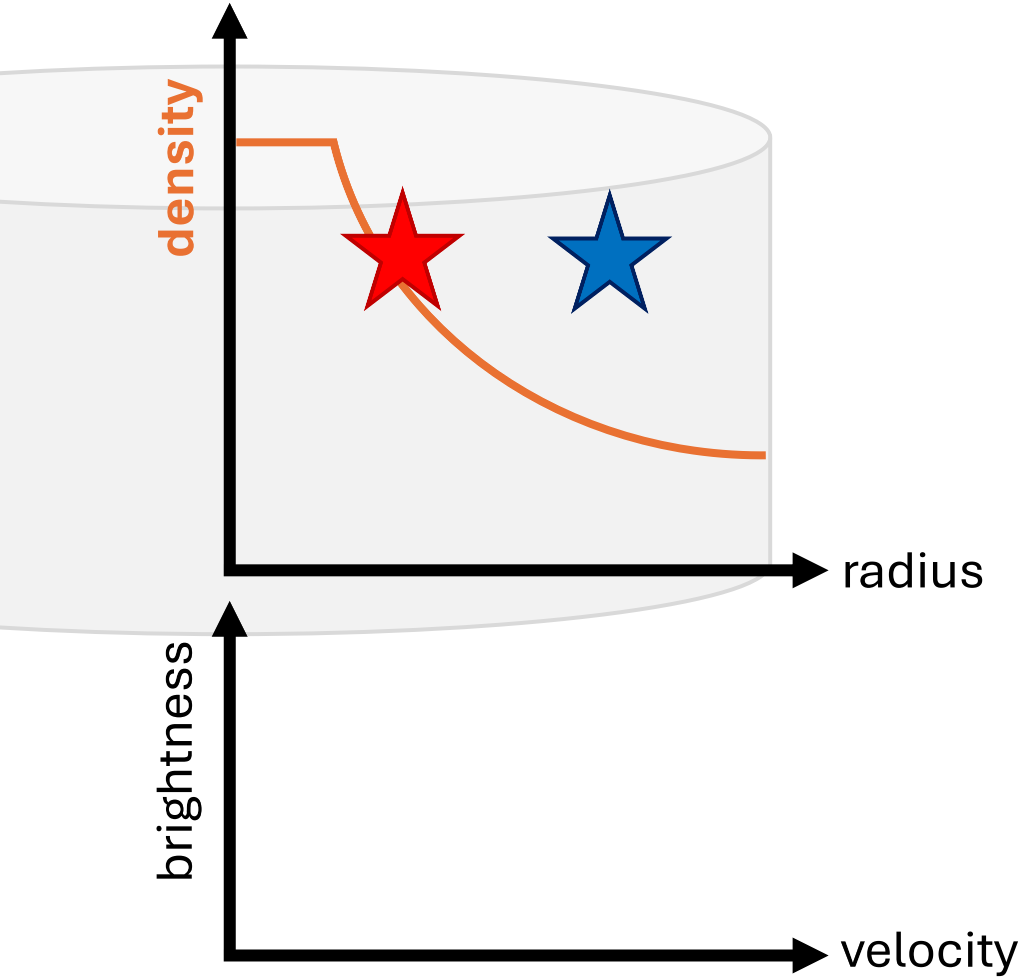
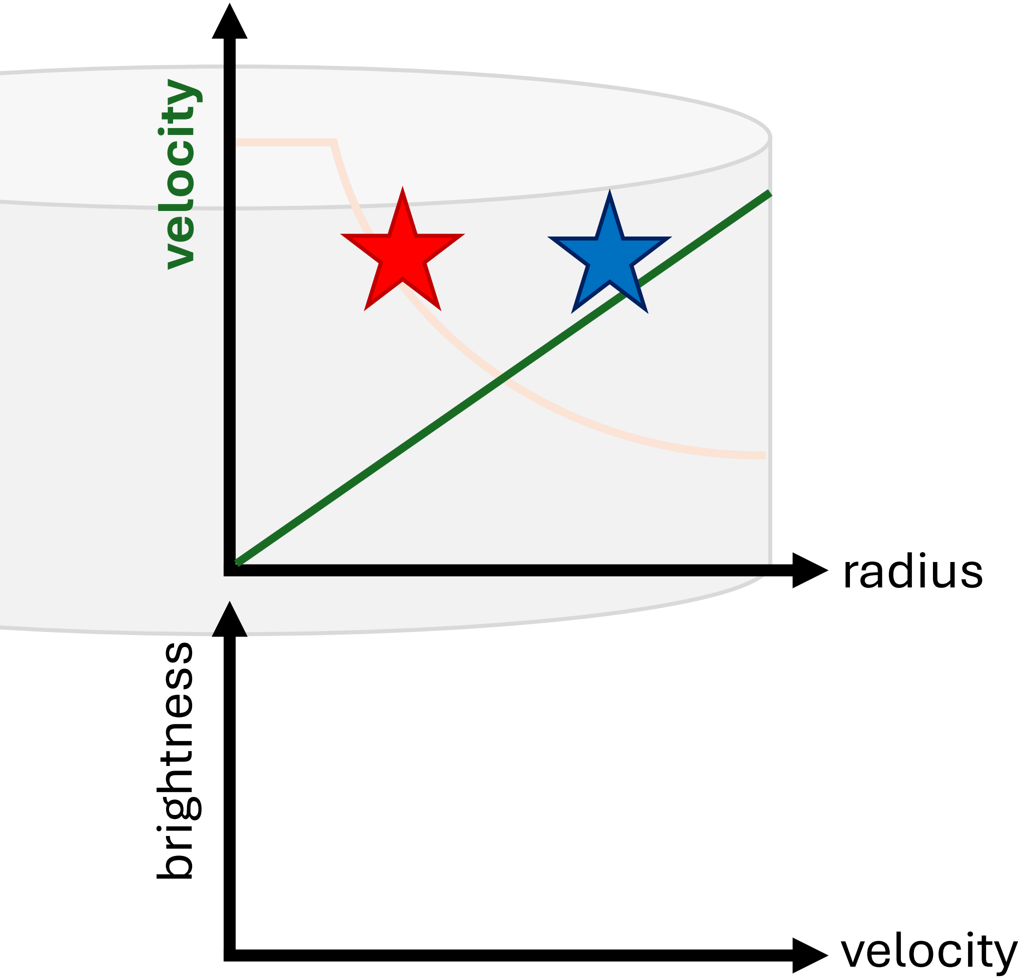


- A density profile radially decreasing
  - Band9 is inner than Band7

A Solution: Non-LTE + Density & Velocity



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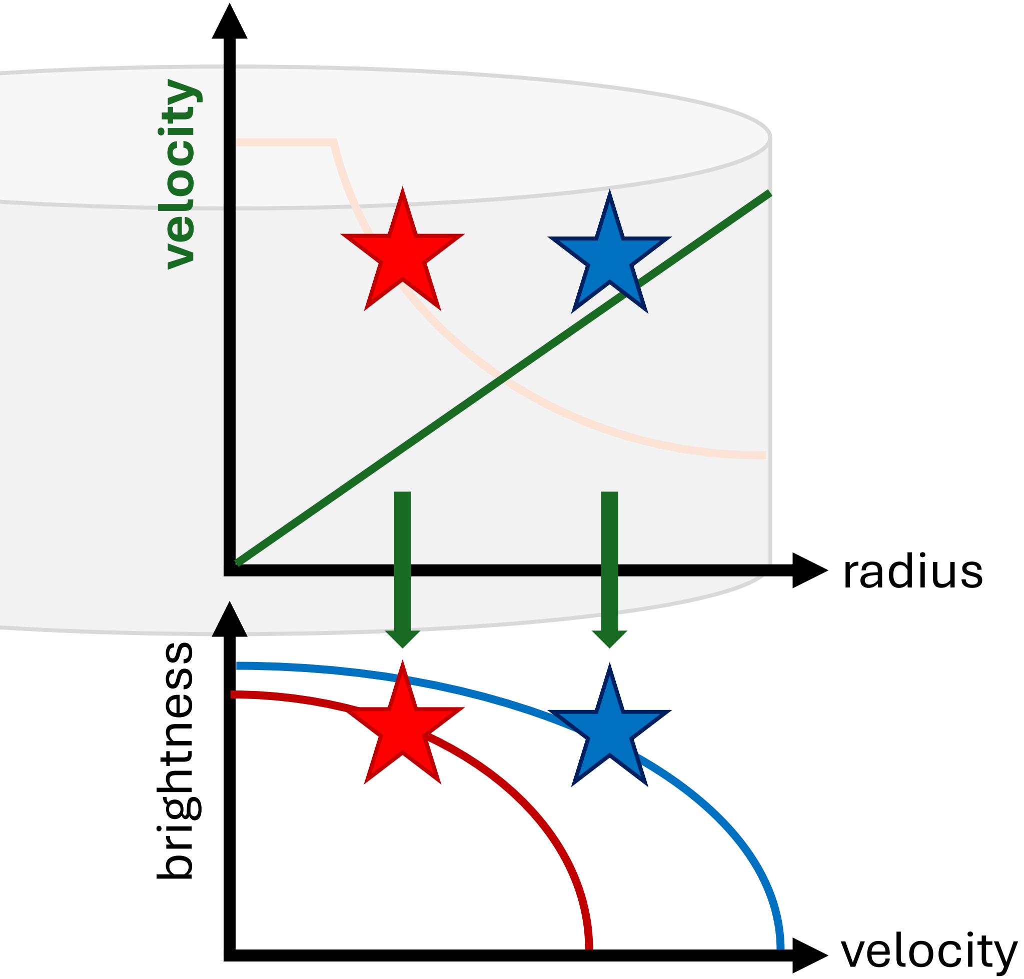

- A density profile radially decreasing
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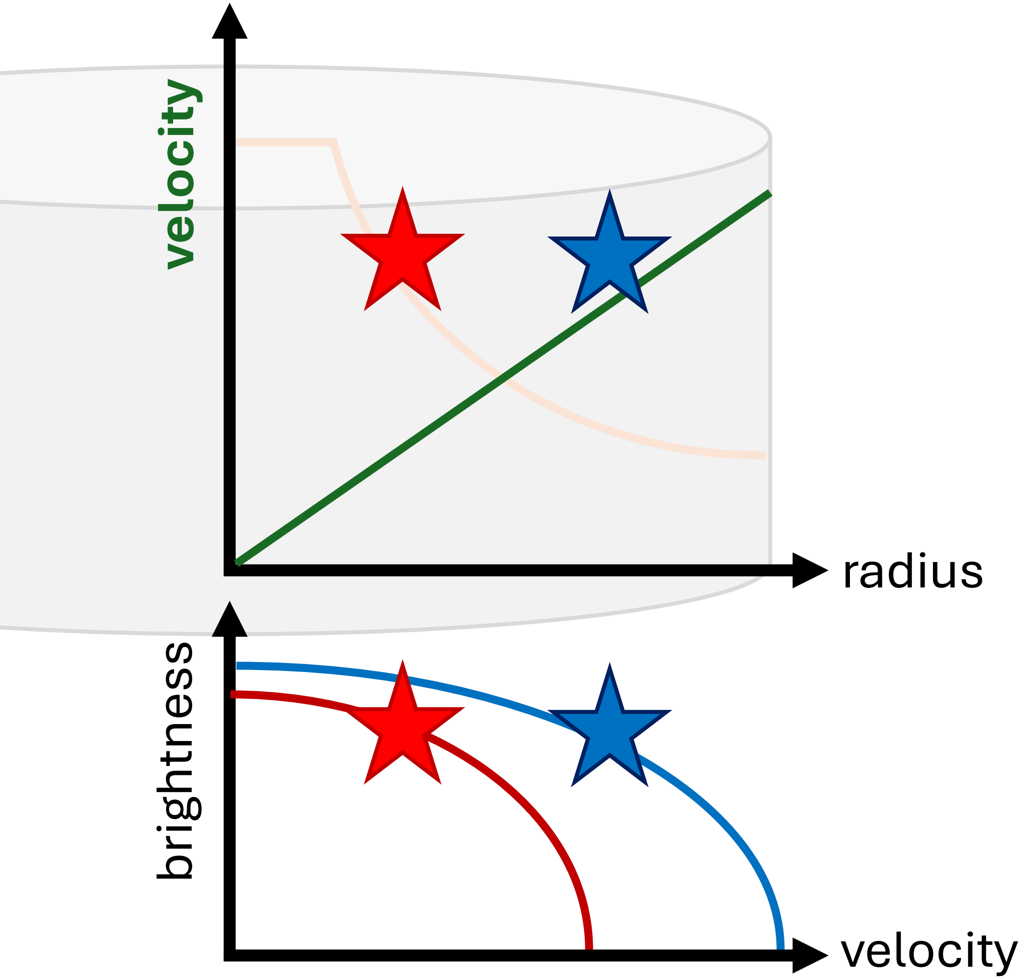

- A density profile radially decreasing
  - Band9 is inner than Band7
- A velocity profile radially increasing
  - At the same brightness, Band9 signals are from the lower velocities

Band9 is inner → width is narrower
→ overall fainter
Band9 spectrum is narrower

Simple Concepts from the X-Wind Model

decreasing density profile

increasing velocity profile

} explanation of observation

[1] Shu and Shang (1995), [2] Lee et al. (2015), [3] Lee et al. (2022)

Simple Concepts from the X-Wind Model

- [1]Inverse-square **decreasing density profile**
- [1]Linearly **increasing velocity profile**
- [1]Uniform temperature

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X-wind model

- [2]Mass-loss rate ~ $1.1 \times 10^{-6}\ \mathrm{M_{\odot}/yr}$
- [3][SiO/H] ~ 3.3×10^{-6}

prior observation

[1] Shu and Shang (1995), [2] Lee et al. (2015), [3] Lee et al. (2022)

Simple Concepts from the X-Wind Model

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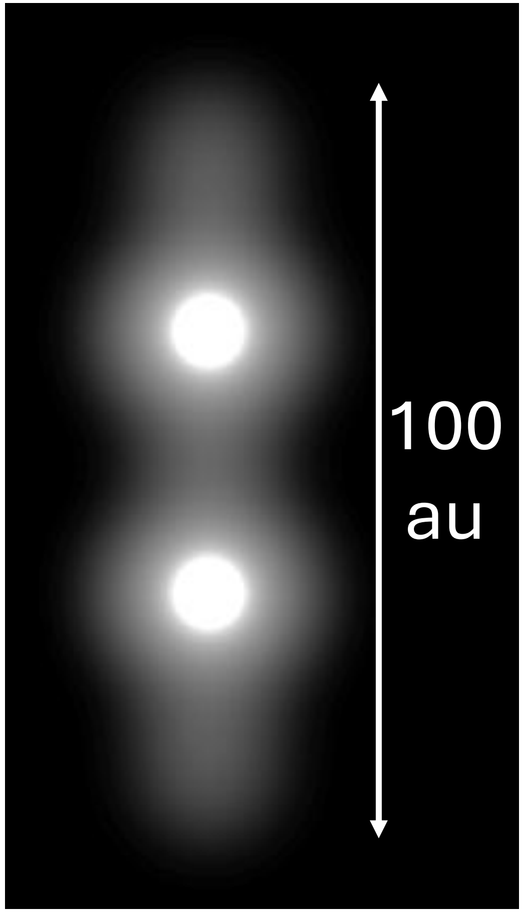
[4]LIME Radiative Transfer Model



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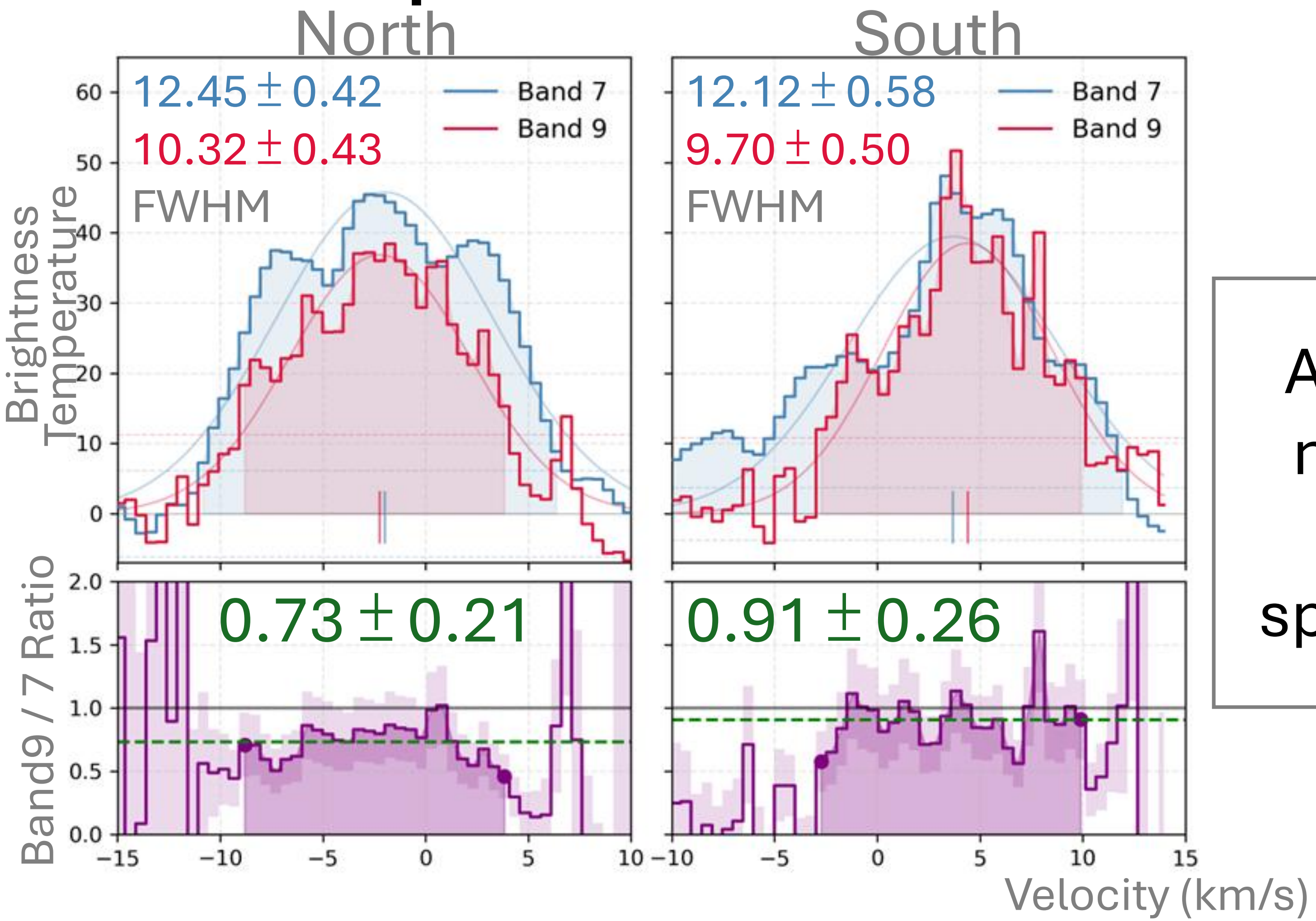
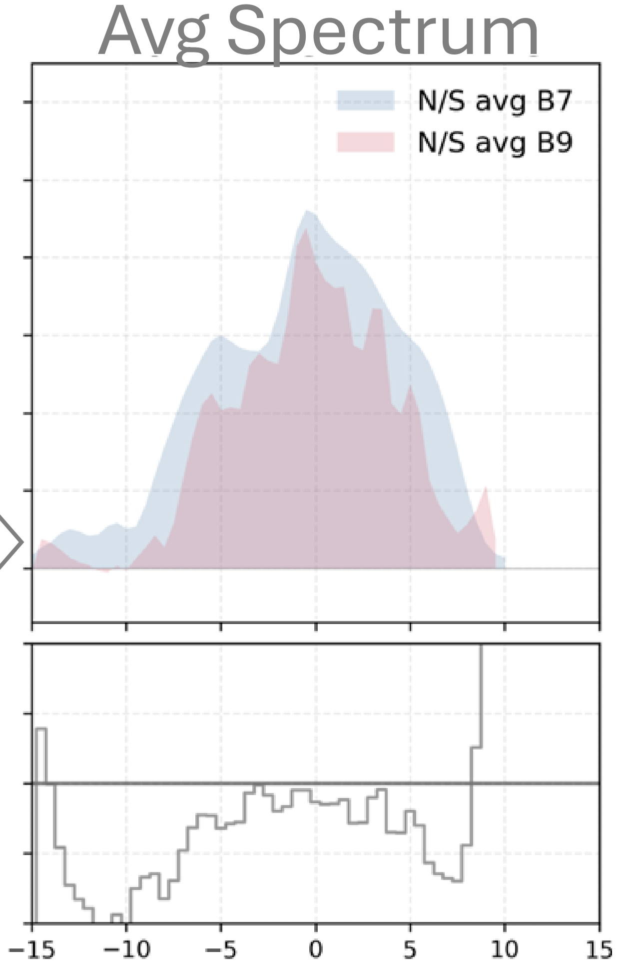
Comparison between Observation & Model



Average north & south spectrum



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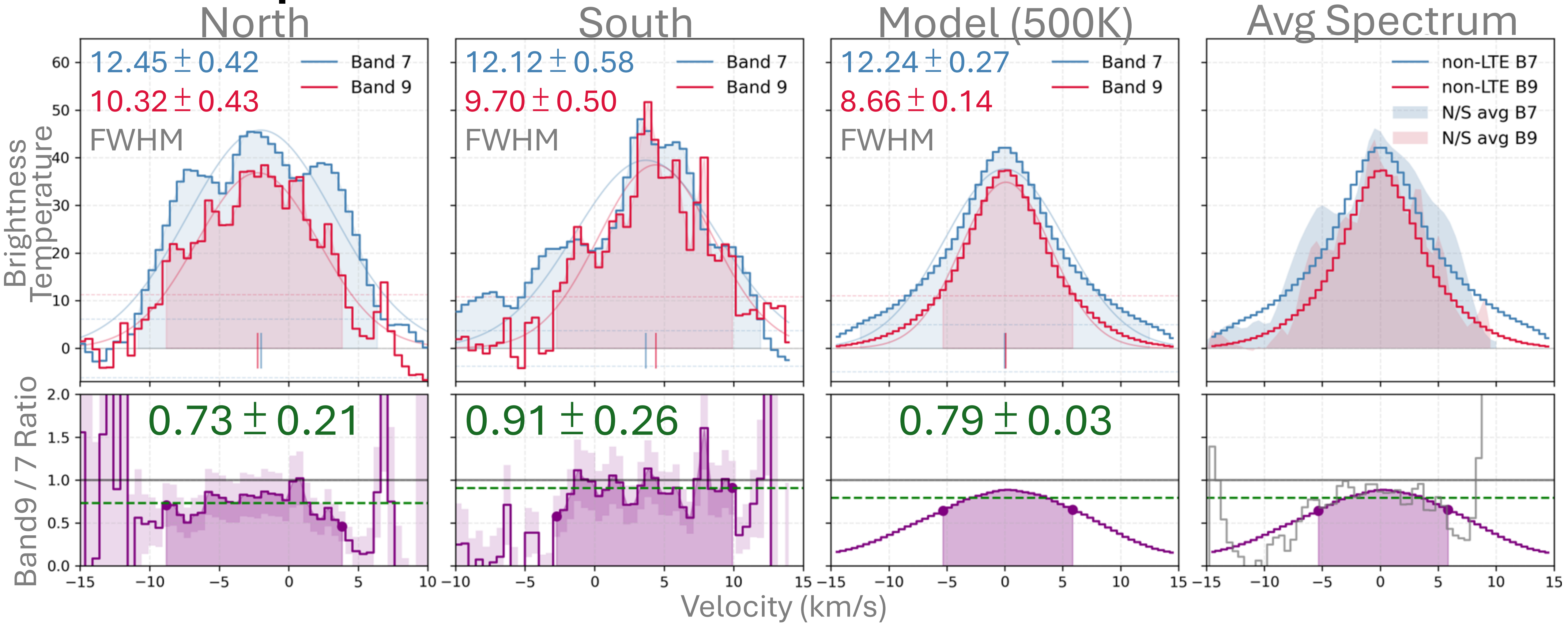

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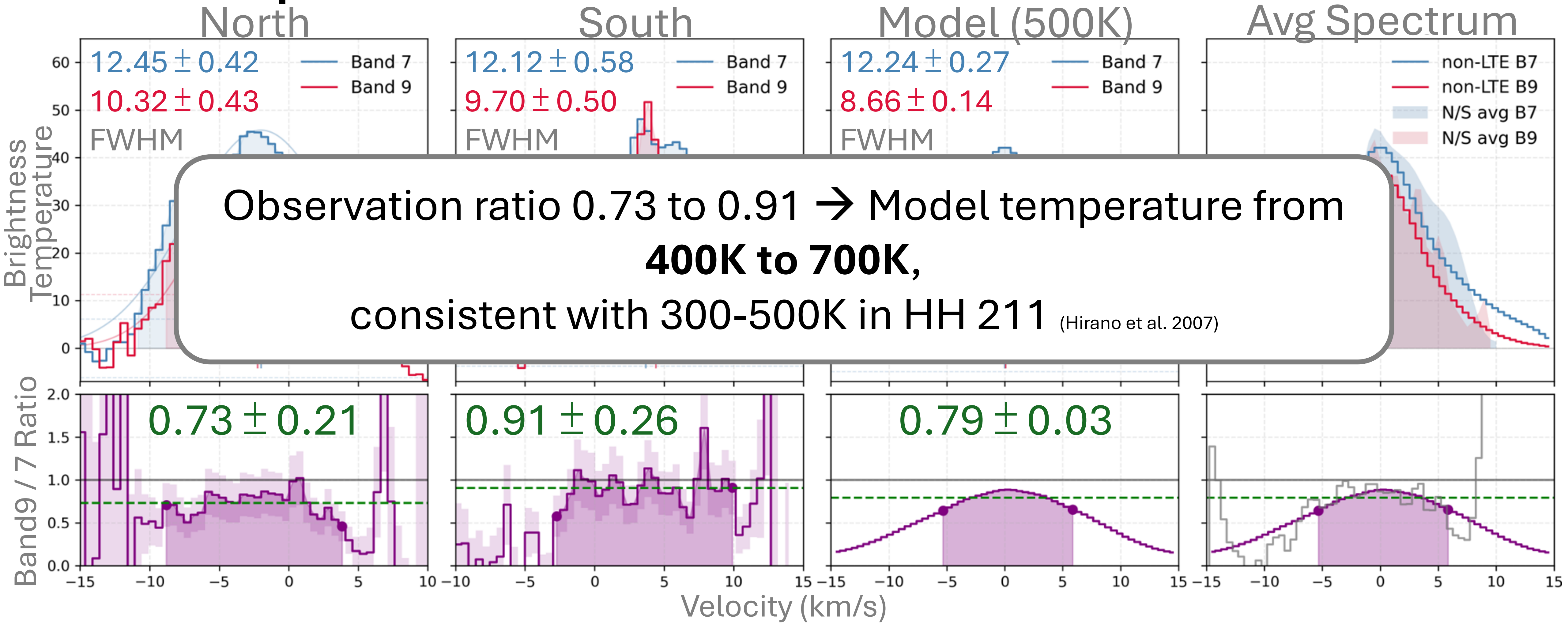

Observation ratio 0.73 to 0.91 → Model temperature from **400K to 700K**, consistent with 300-500K in HH 211 (Hirano et al. 2007)

Conclusion & Summary

- First high-J (J=16-15) SiO observation to the innermost part (100-au-scale), comparing to J=8-7 and find:
  - Jet's width is narrower
  - Jet is overall fainter
  - Jet's spectrum is narrower
- The temperature possibly ranges from 400 to 700K
- We build **the first reference of high transition observation** and provide **further support for the X-wind model** in generating protostellar jets