Evolution of N_2H^+ and N_2D^+ in the Protostellar Phase

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Background Chemistry

$$H_3^+ + HD \rightleftharpoons H_2D^+ + H_2 + \Delta E$$

(~230 K)

Begins to reverse ~ 20K

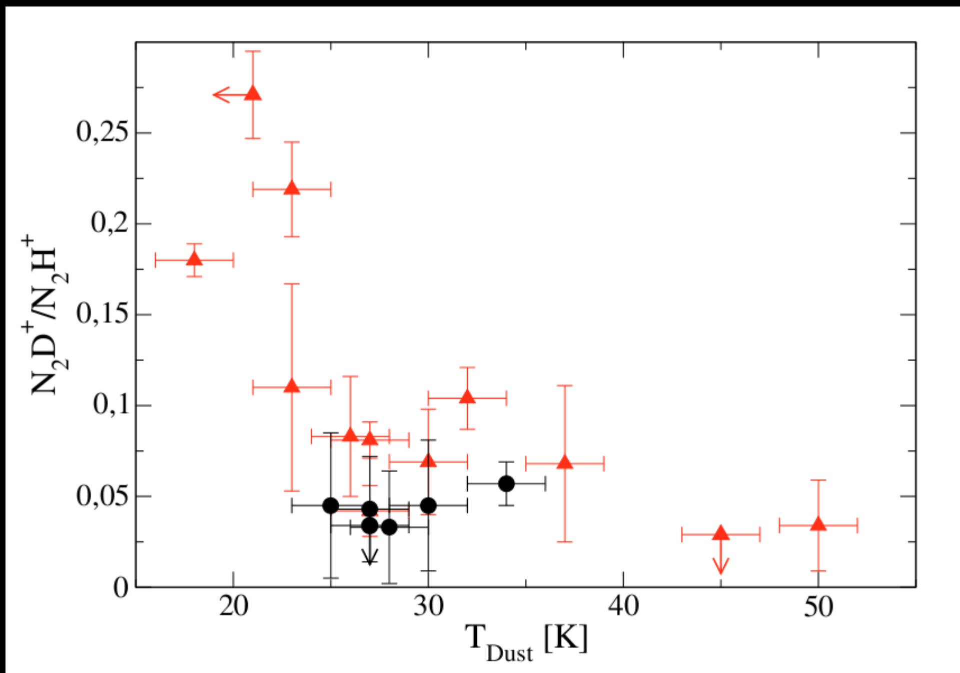
$$N_2 + H_3^+ \rightarrow N_2H^+ + H_2$$

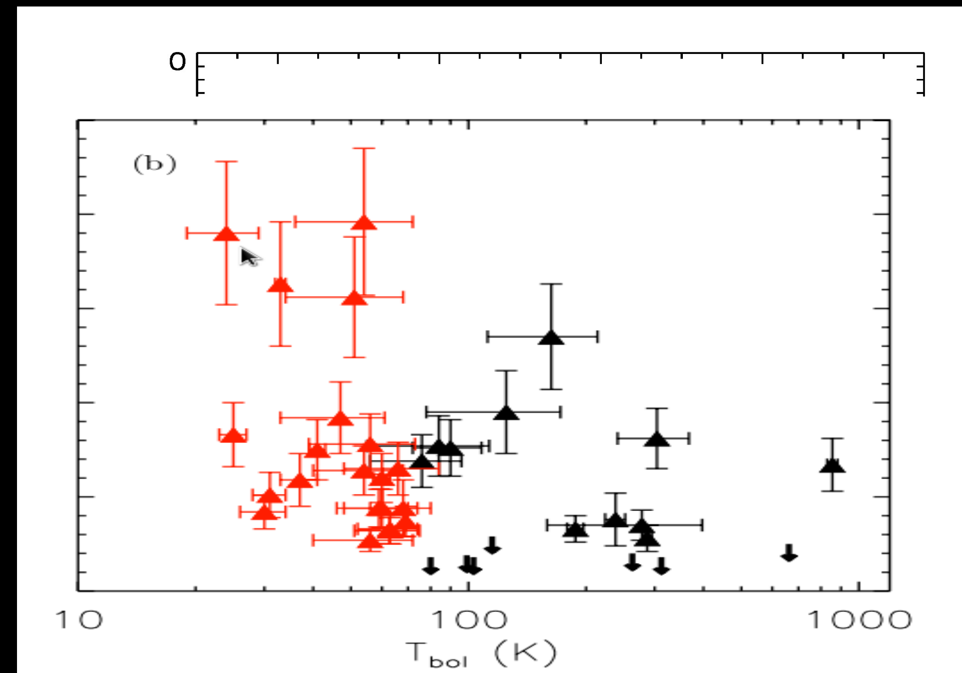
$$N_2 + H_2D^+ \rightarrow N_2D^+ + H_2$$

$$N_2 + D_2H^+ \rightarrow N_2D^+ + HD$$

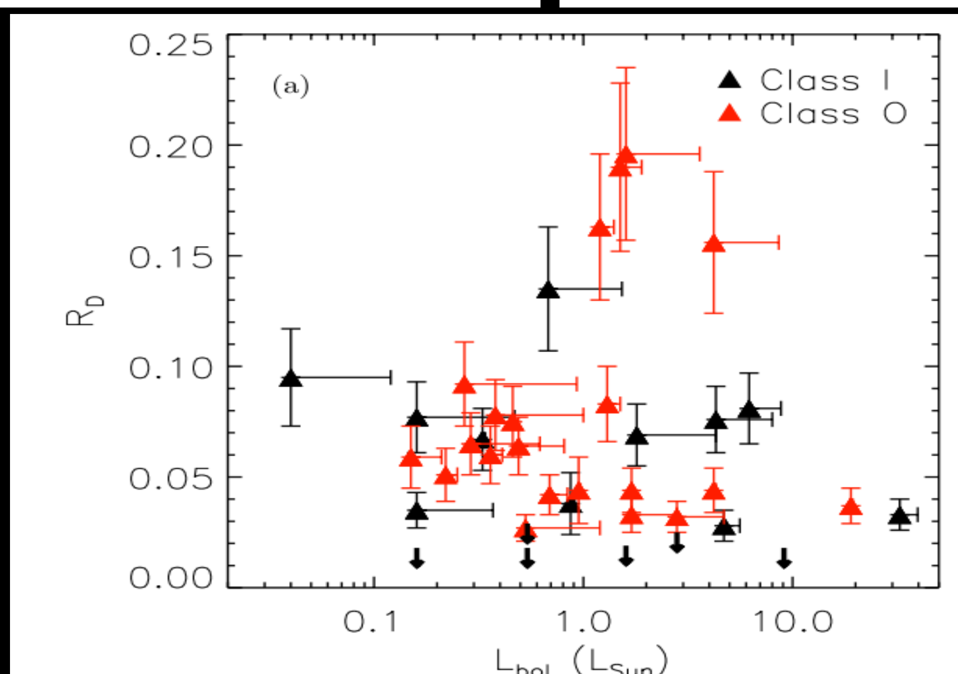
$$N_2 + D_3^+ \rightarrow N_2D^+ + D_2$$

Global Evolution





Emprechtinger+2009



Tobin+2013

Friesen+2013

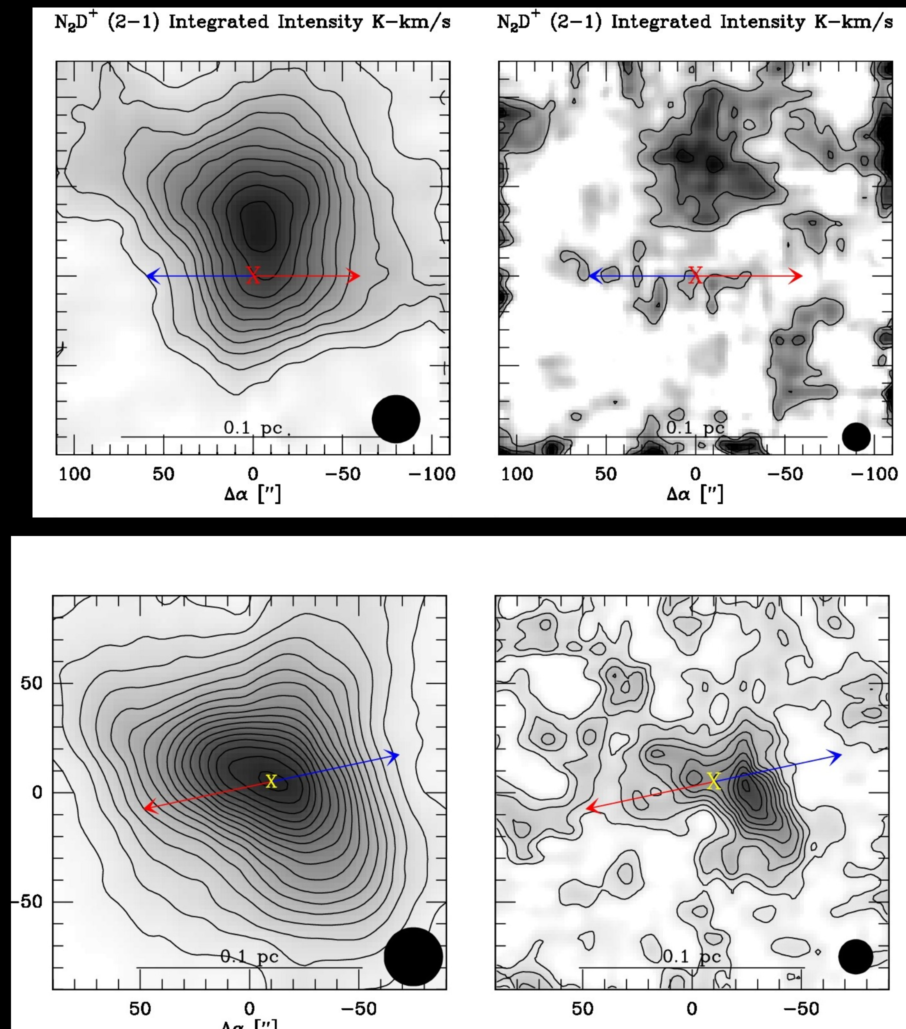
Resolved Observations

Class 0 Protostars

N_2H^+ (J=1-0) N_2D^+ (J=2-1)

L1527

L483



IRAM 30m

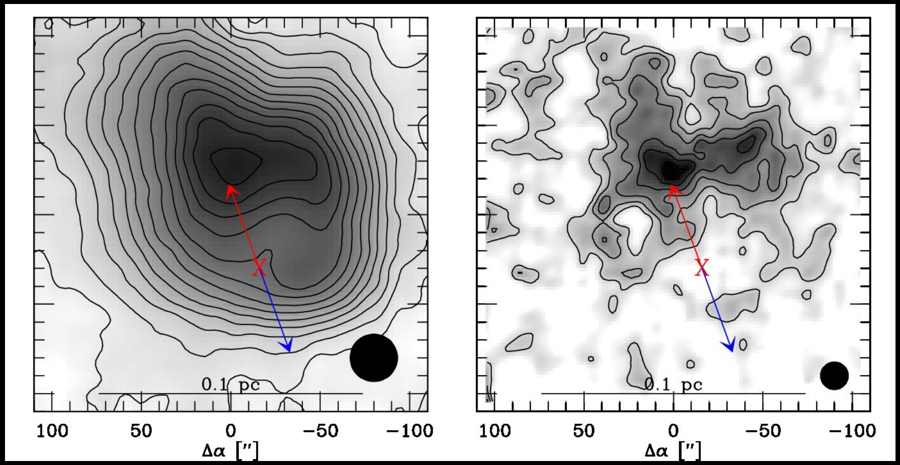
Tobin+2013

Resolved Observations

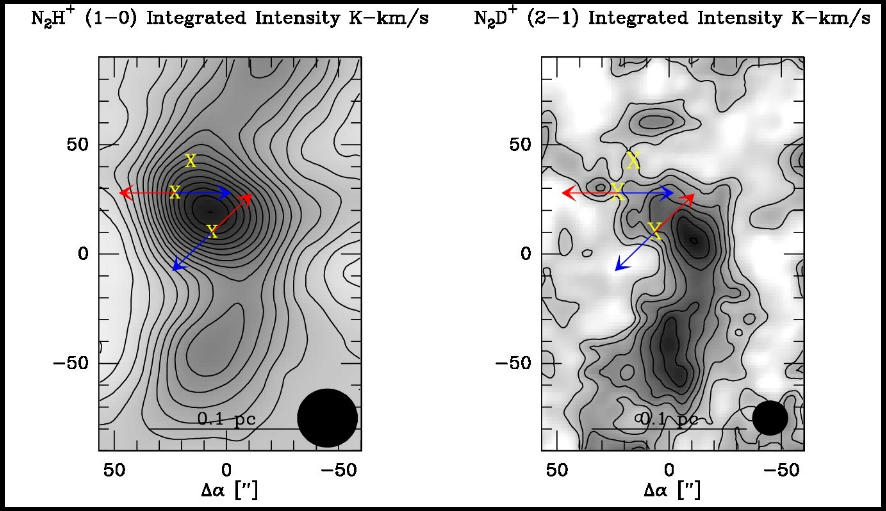
Class I Protostars

N_2H^+ (J=1-0) N_2D^+ (J=2-1)

IRAS 04325+2402



L673

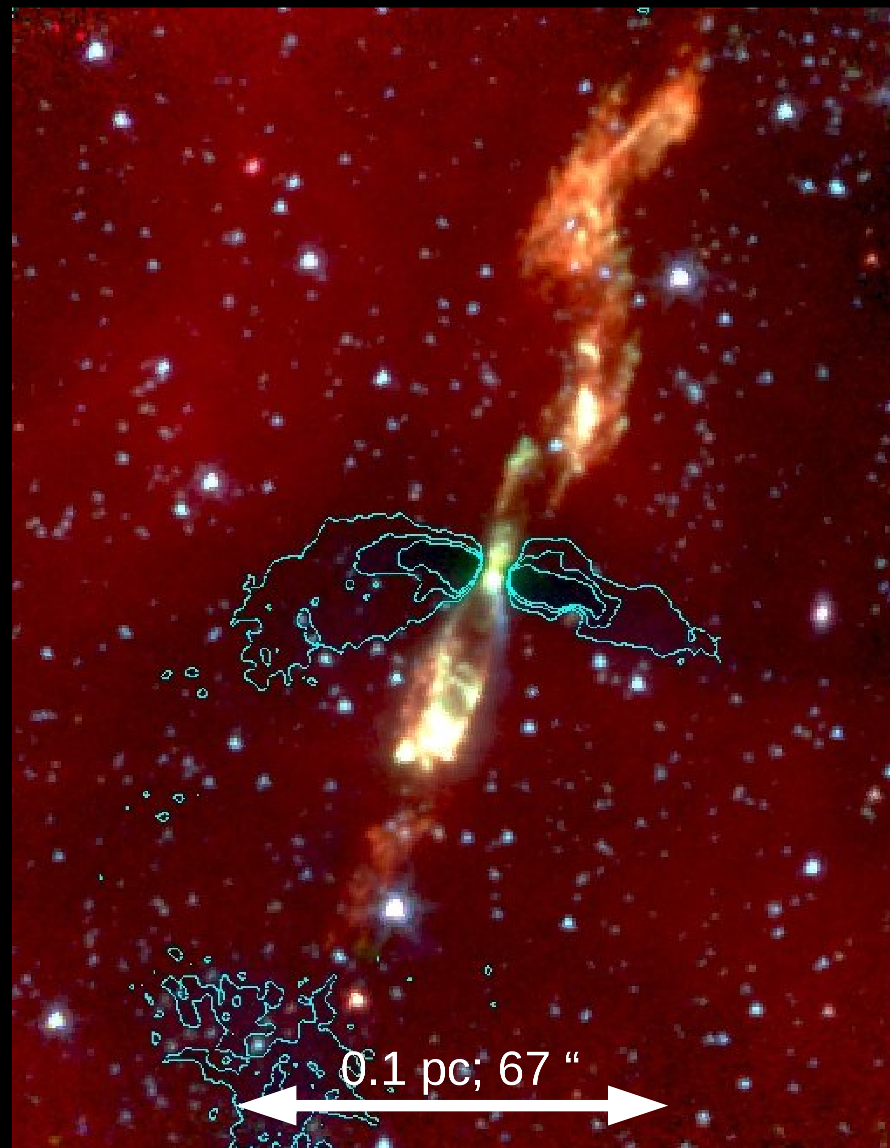


IRAM 30m

Tobin+2013

Detailed Observations

L1157



Contours: A_V =15, 22.5, 30

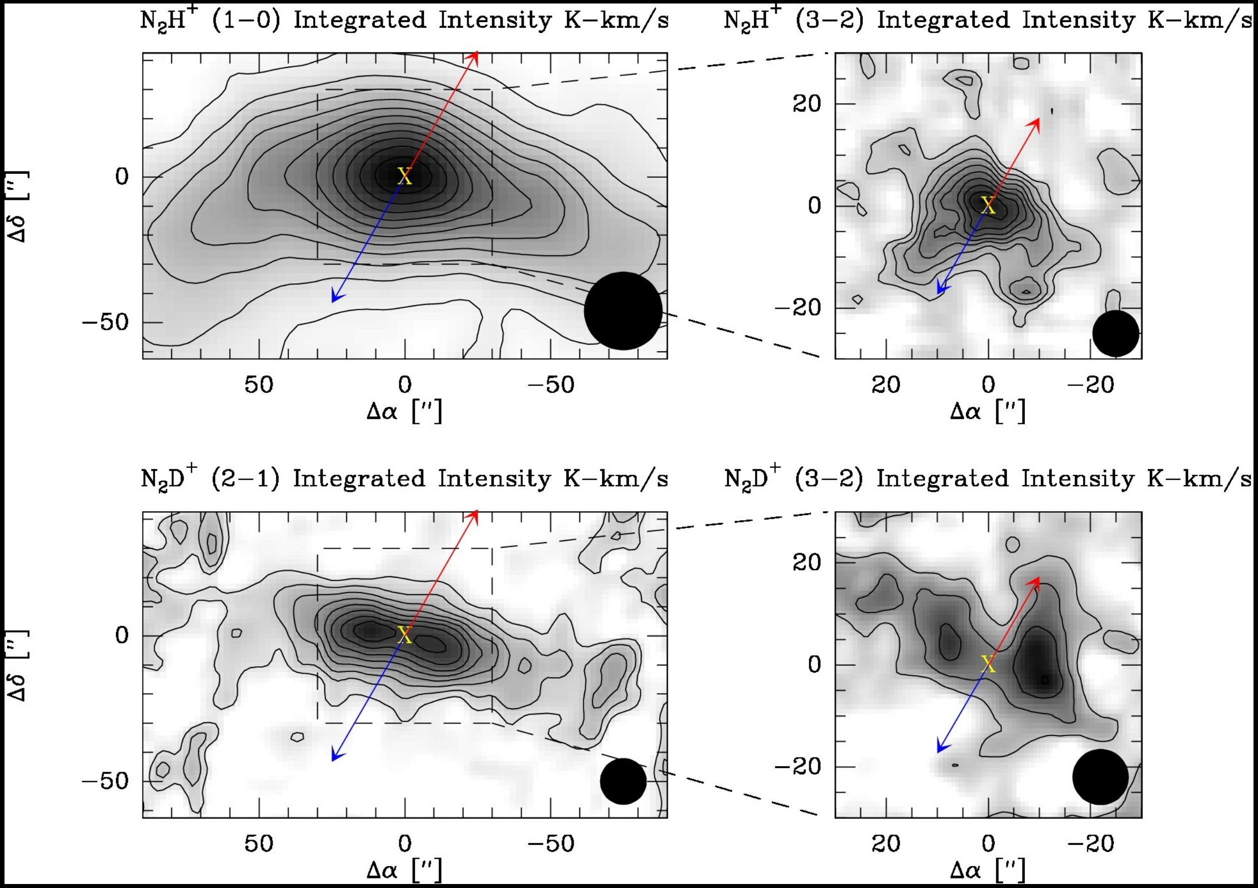
Looney et al. (2007)
Tobin et al. (2010)

Single-Dish Observations

L1157

N_2H^+

N_2D+



IRAM 30m

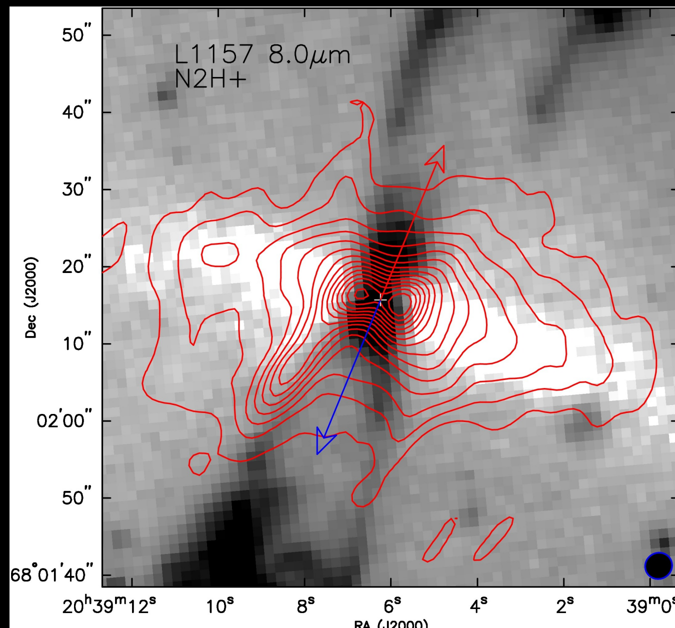
Tobin+2013

Interferometer Observations

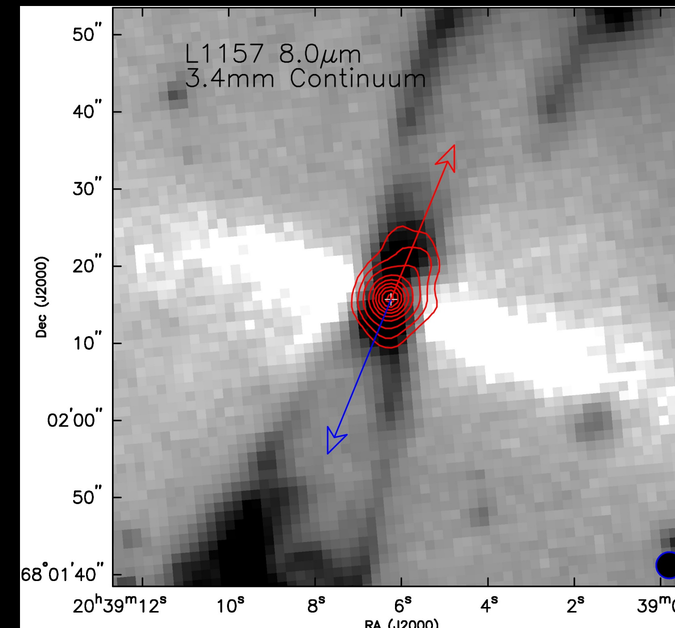
L1157

N_2H^+

(PdBI)

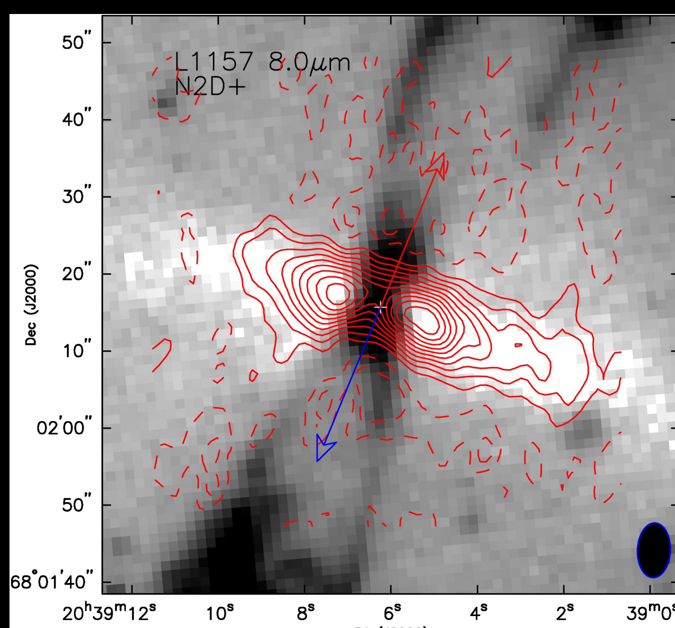


3 mm cont

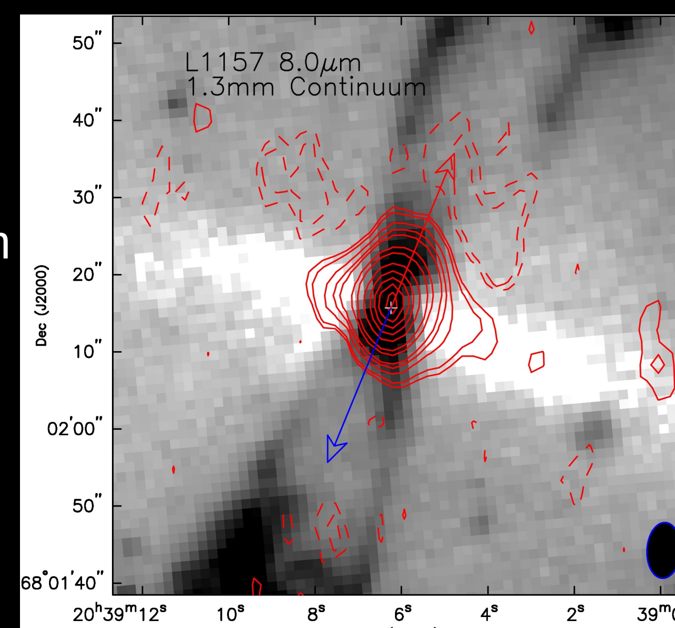


N_2D+

(SMA)



1.3 mm cont



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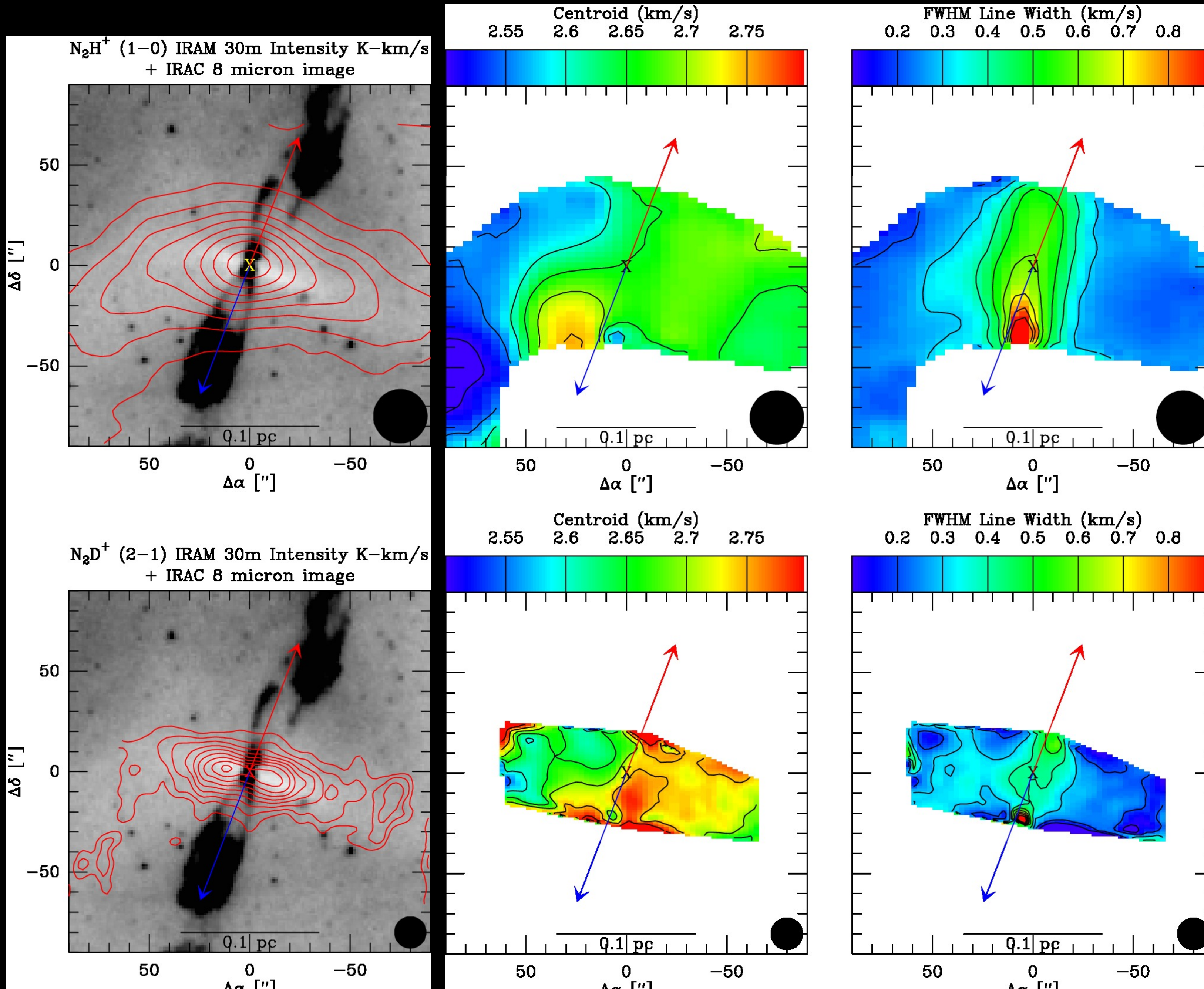
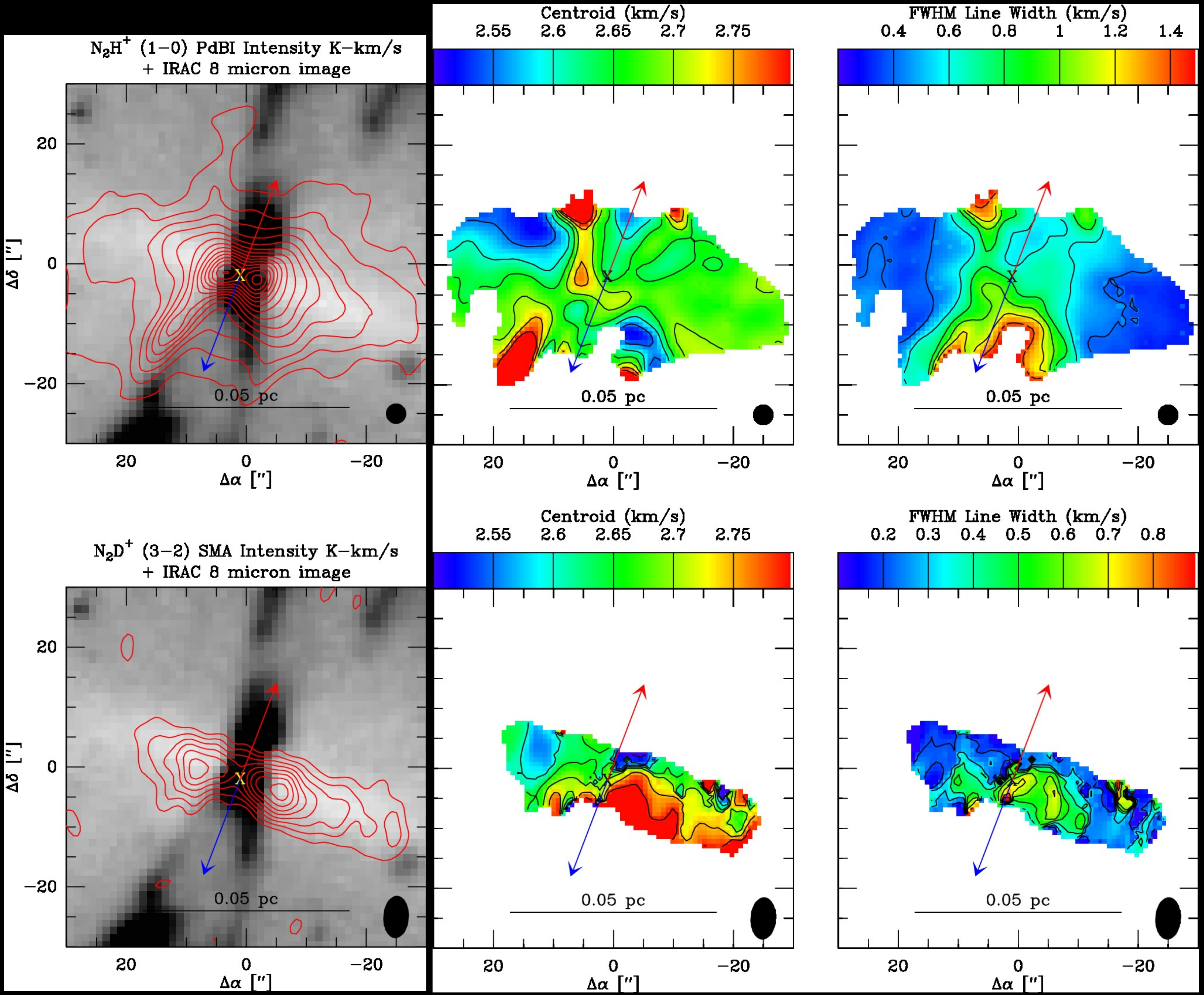
N2D+/N2H+ Kinematics



IRAM 30m

Tobin+2013

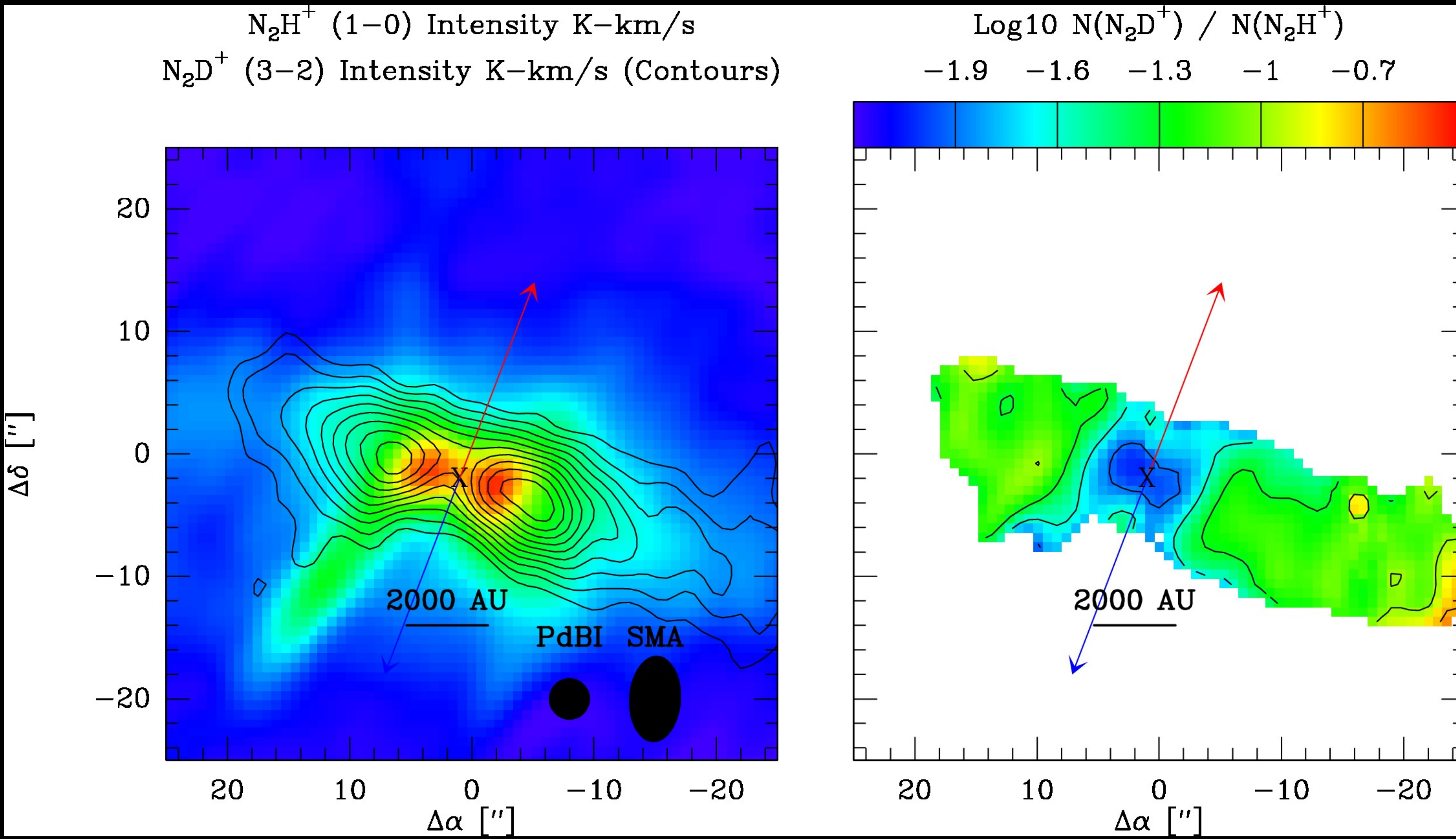
N2D+/N2H+ Kinematics



PdBI/SMA

Tobin+2013

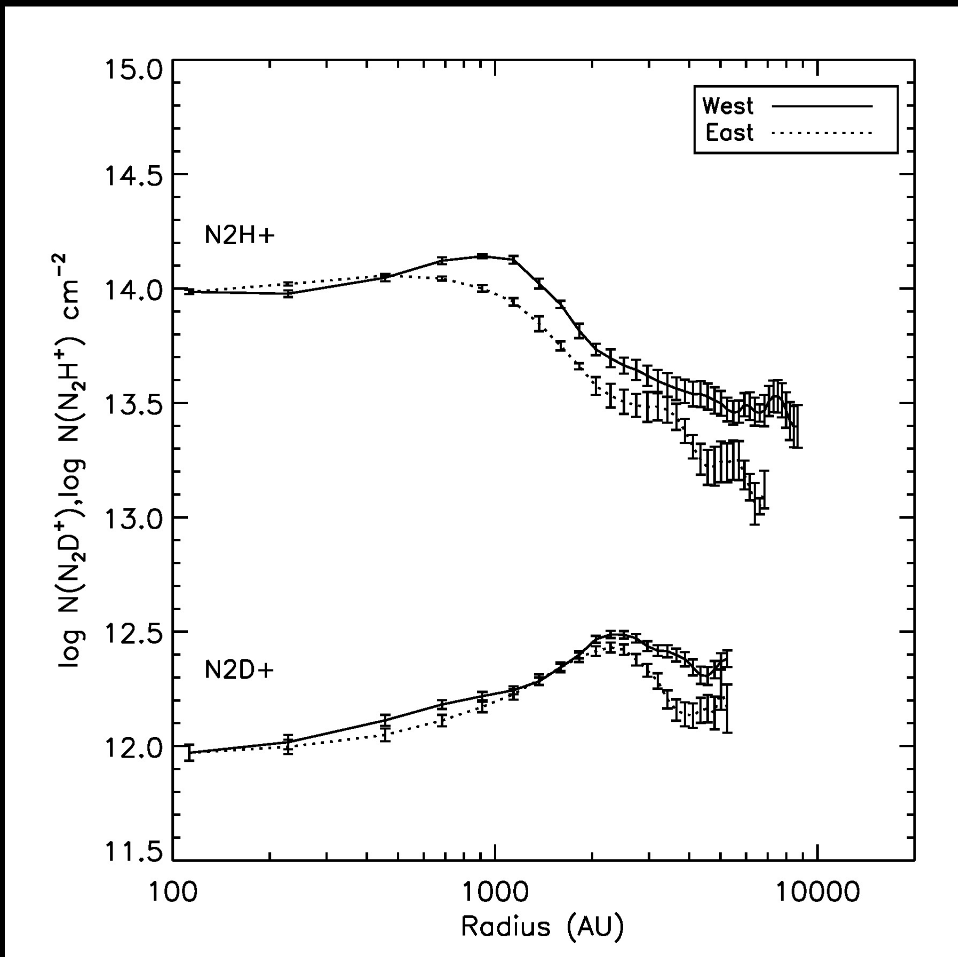
Resolved N2D+/N2H+ Ratio



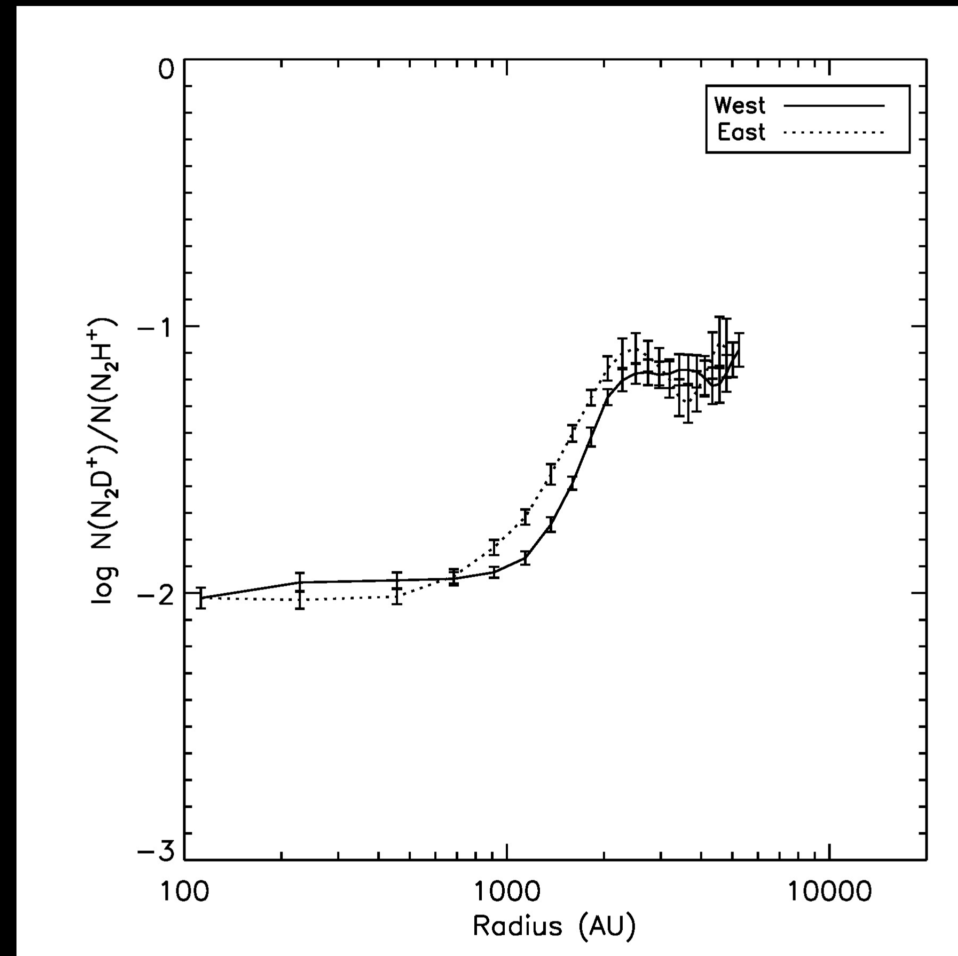
Tobin+2013

Resolved N2D+/N2H+ Ratio

N2D+, N2H+ Column Density



N2D+/N2H+ Ratio



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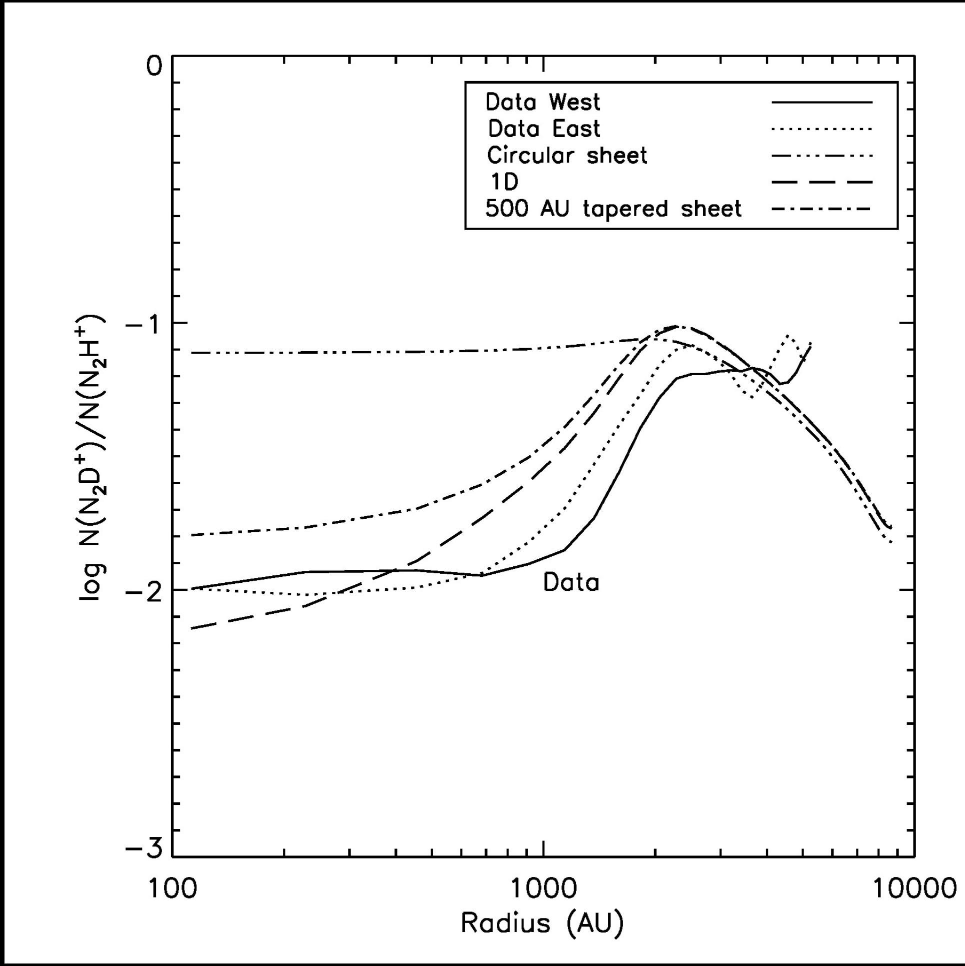
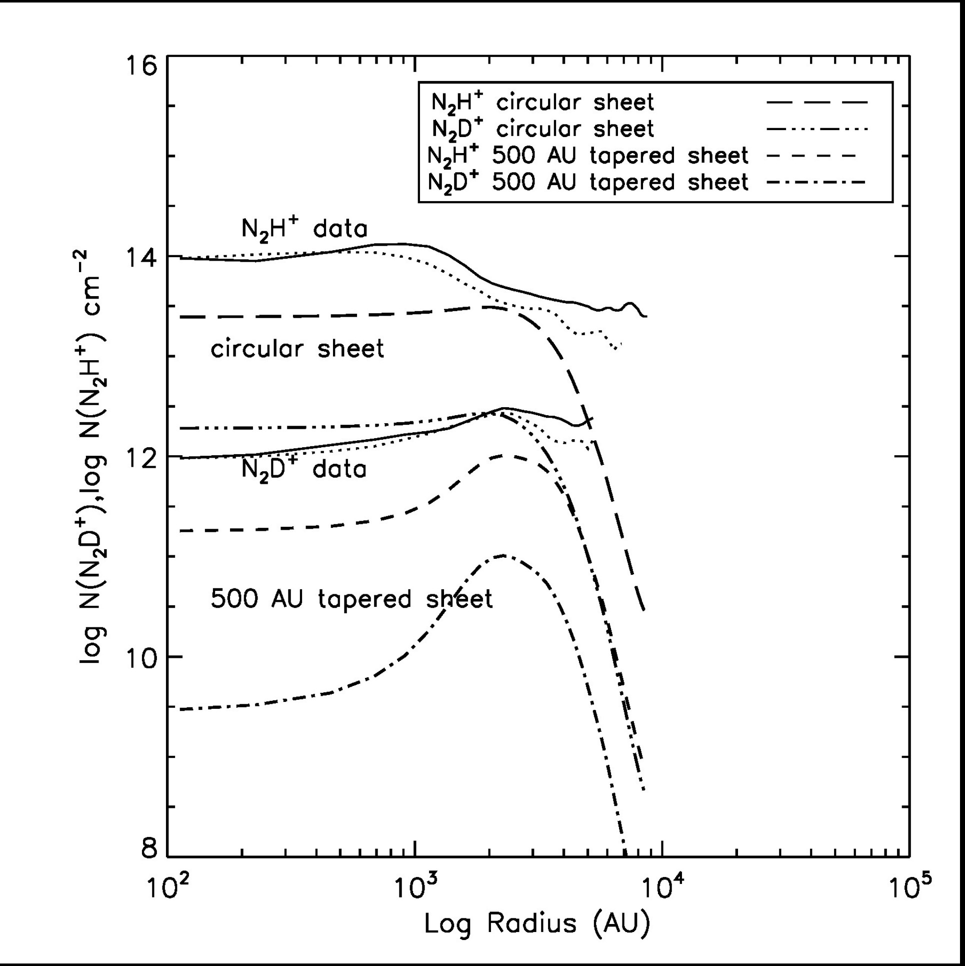
Chemical Model Comparison

N2D+/N2H+ Ratio



N2D+, N2H+ Column Density



- Chemical models from Lee+2004
- Models work ok in relative abundance
- Fail for absolute abundance peaks

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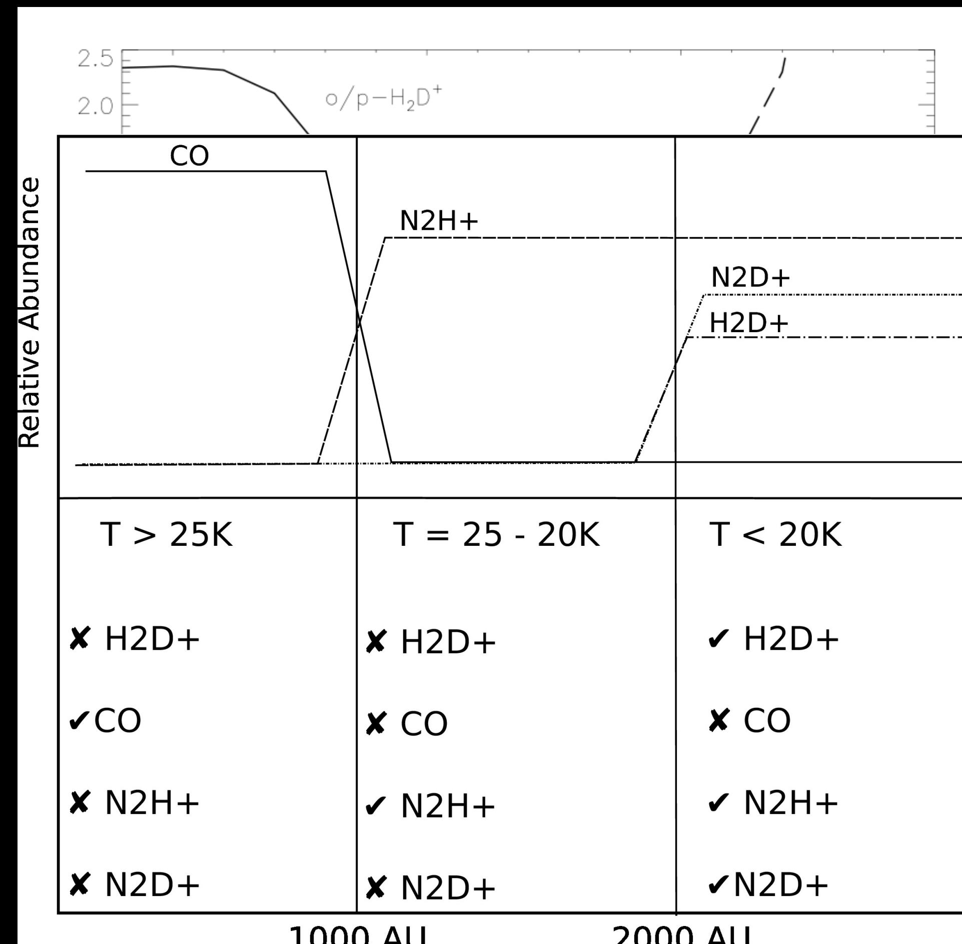
Why Do Models Fail?

- Observations highlight missing chemistry

- Need a region with N_2H^+ but no N_2D^+/N_2H^+
  - H_2D^+ abundance depends on H_2 OPR
  - o-H_2 ground state (J=1; 170 K)
  - OPR gradients could cause N_2D^+ decrease
- CO evaporation Temp > 20 K due to ice mixtures?
  - Creates region with no CO, also no H_2D^+/N_2D^+ due to H_2D^+ destruction

$$H_3^+ + HD \rightleftharpoons H_2D^+ + H_2 + \Delta E$$

(~230 K)



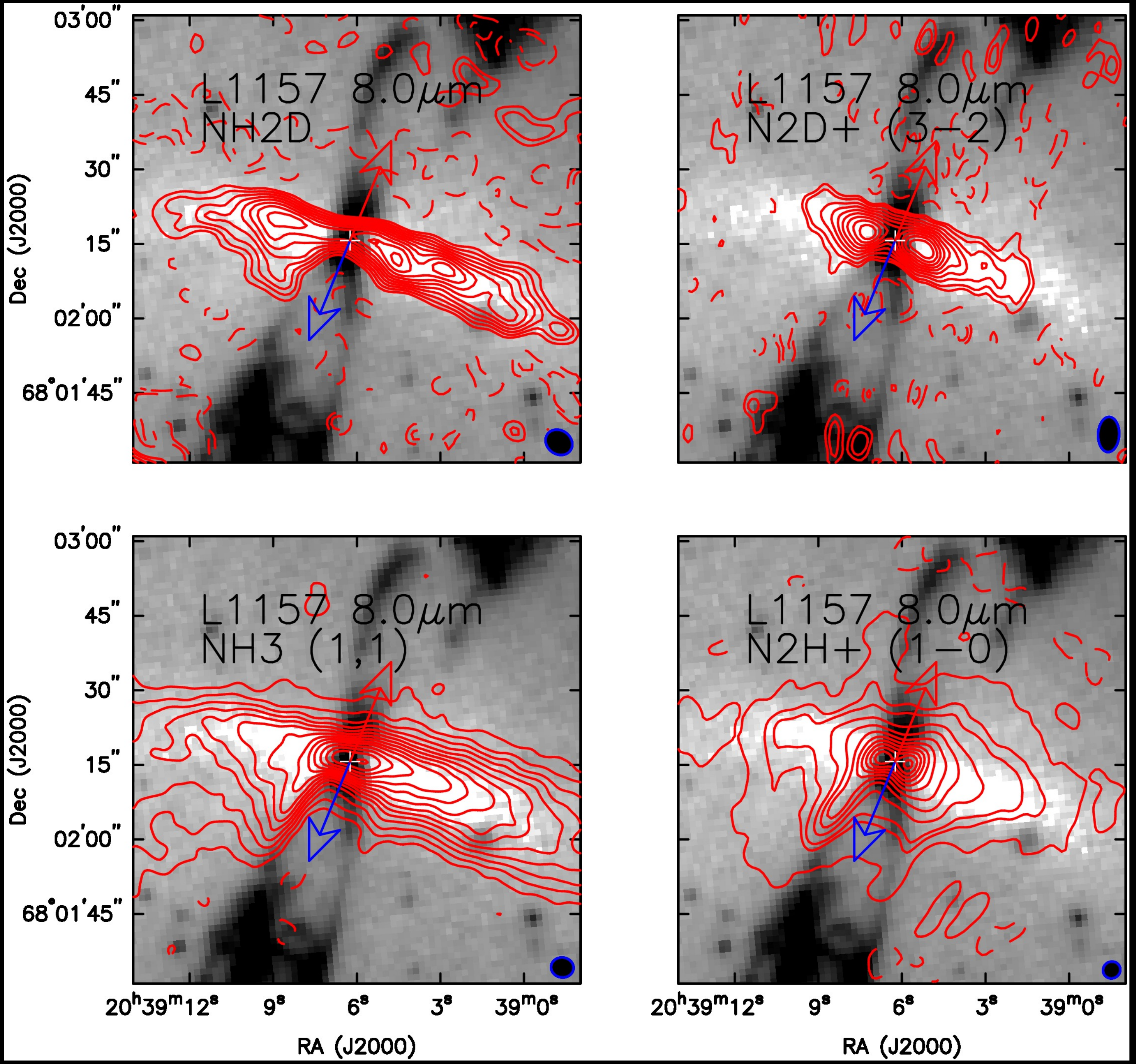
N_2D^+ vs NH_2D Emission

- N_2H^+ and NH_3 tend to trace very similar physical conditions (Johnstone+2011, Tobin+2011)

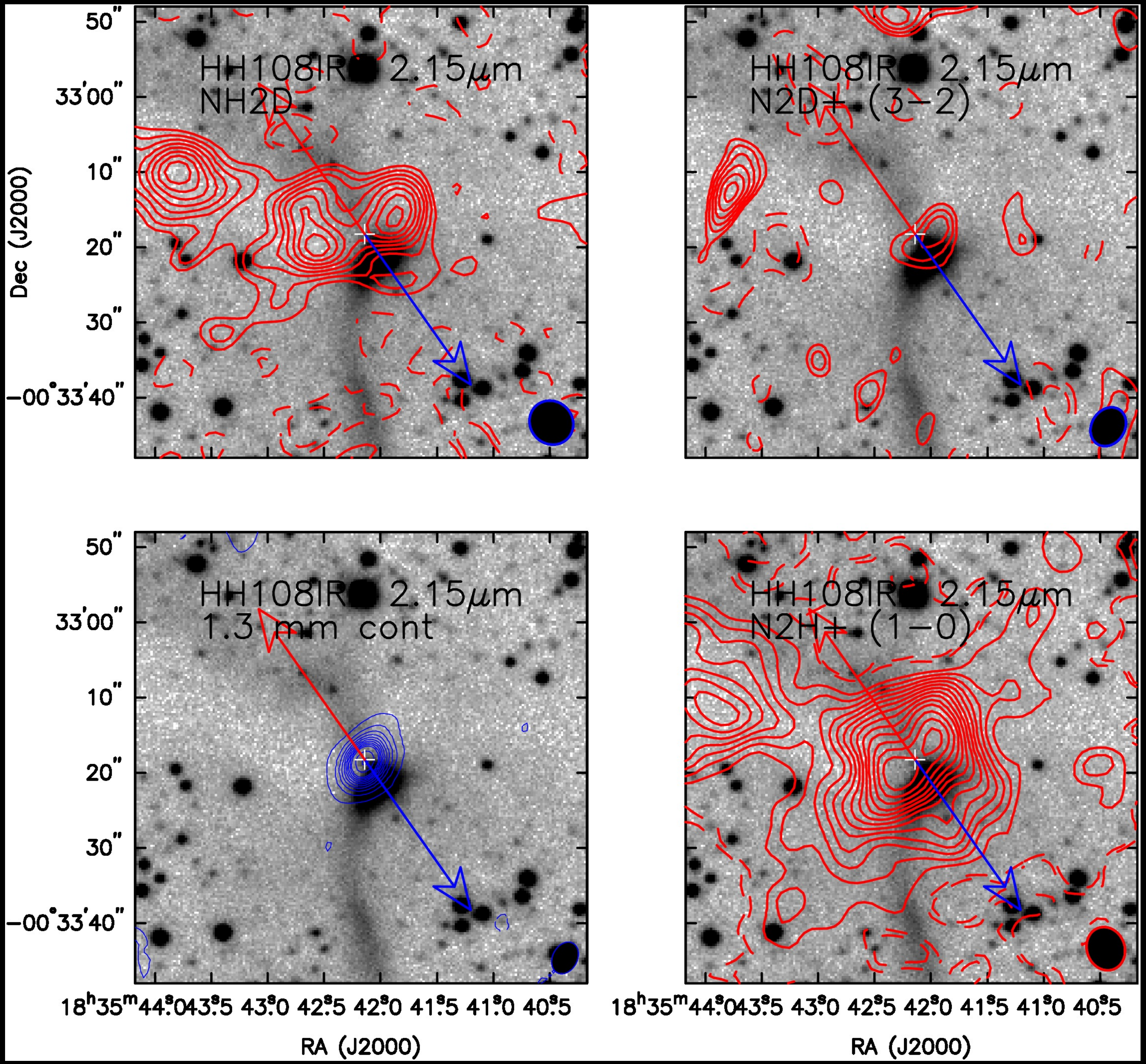
- What about N_2H^+ and NH_2D?

- Band 3 cannot simultaneously observe N_2H^+ and o-NH_2D
    - Band 2 could observe N_2D^+ and o-NH_2D simultaneously and possibly N_2H^+ (w/4-12 GHz IF)

N_2D^+ vs NH_2D Emission



N_2D^+ vs NH_2D Emission



ALMA Band 2

- N_2D^+ (J=1-0) would be best...
- Why?
  - T_{ex} derived from fitting hyperfine components
  - J = 3 – 2 optically thin, T_{ex} unreliable
  - T_{ex}(1-0) = T_{ex}(3-2) assumed

  - Higher excitations more spatially compact, T~10 K gas

  - Similar energies for J = 1 – 0 lines, enabling more fair comparison

  - Unique capability for ALMA, higher excitation transitions fainter, only PdBI currently covers (2-1) line

Transition	Frequency	ALMA Band	Installed?
N2D+ (1-0)	77 GHz	2	
N2H+ (1-0)	93 GHz	3	x
N2D+ (2-1)	154 GHz	4	In progress?
~~N2H+ (2-1)~~	~~186 GHz~~		
N2D+ (3-2)	231 GHz	6	x
N2H+ (3-2)	275 GHz	6/7	x