Imaging Hot Ammonia in Luminous High-mass Star Forming Regions

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ALMA
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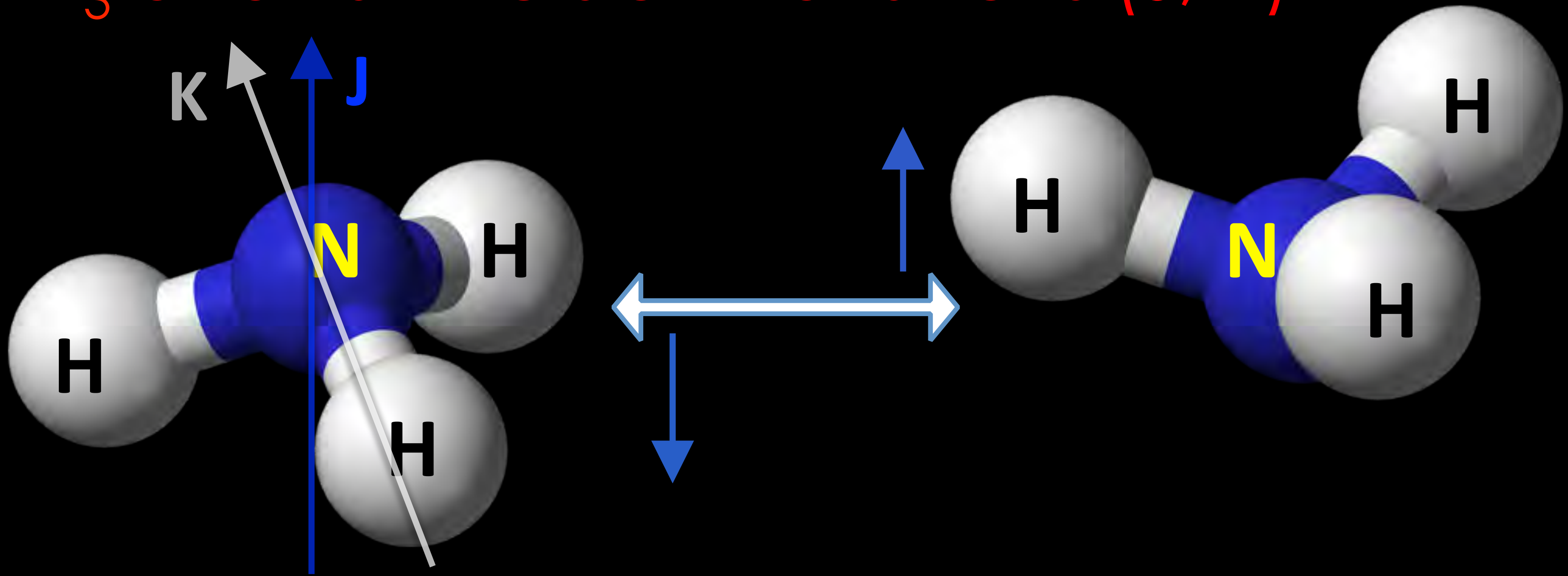
NH_3 and its inversion transitions (J, K)



1. The metastable levels ($J = K$) are collisionally excited, and <u>*multiple*</u> transitions can be used in a Boltzmann energy diagram
   => Excellent thermometer of dense molecular gas

2. Can trace excitation up to E_U~2000 K within 20 – 40 GHz
   => can pick up dense gas at different T in the cloud

Idea:

One could observe multiple NH_3 inversion lines with high excitation temperatures to trace the hottest and densest molecular gas in the vicinity of the central YSO(s)

- ➢ infalling circumstellar envelopes
- ➢ centrifugally-supported accretion disks

Observational constraints on the physics of accretion?

Why not observing (sub)mm lines with ALMA?

Advantages of highly-excited NH_3 inversion lines

With respect to submm spectroscopy (e.g. ALMA)

i. (Sub)mm transitions can probe outer parts of disks/ envelopes where dust opacity is low, but cannot penetrate the innermost regions, where dust emission can dominate over molecular emission at a given frequency
=> cm lines can penetrate the innermost disk/env. regions

ii. Measuring infall is easier in cm lines, because the molecular gas can be seen in absorption against bright HII regions (emission lines would be submerged by noise)
=> gas kinematics at very small scales with interferometers

iii. The detection of faint lines of high-density tracers in the (sub)mm spectrum can be severely affected by blending with stronger transitions from other species (line forest)
=> cm lines not affected by confusion

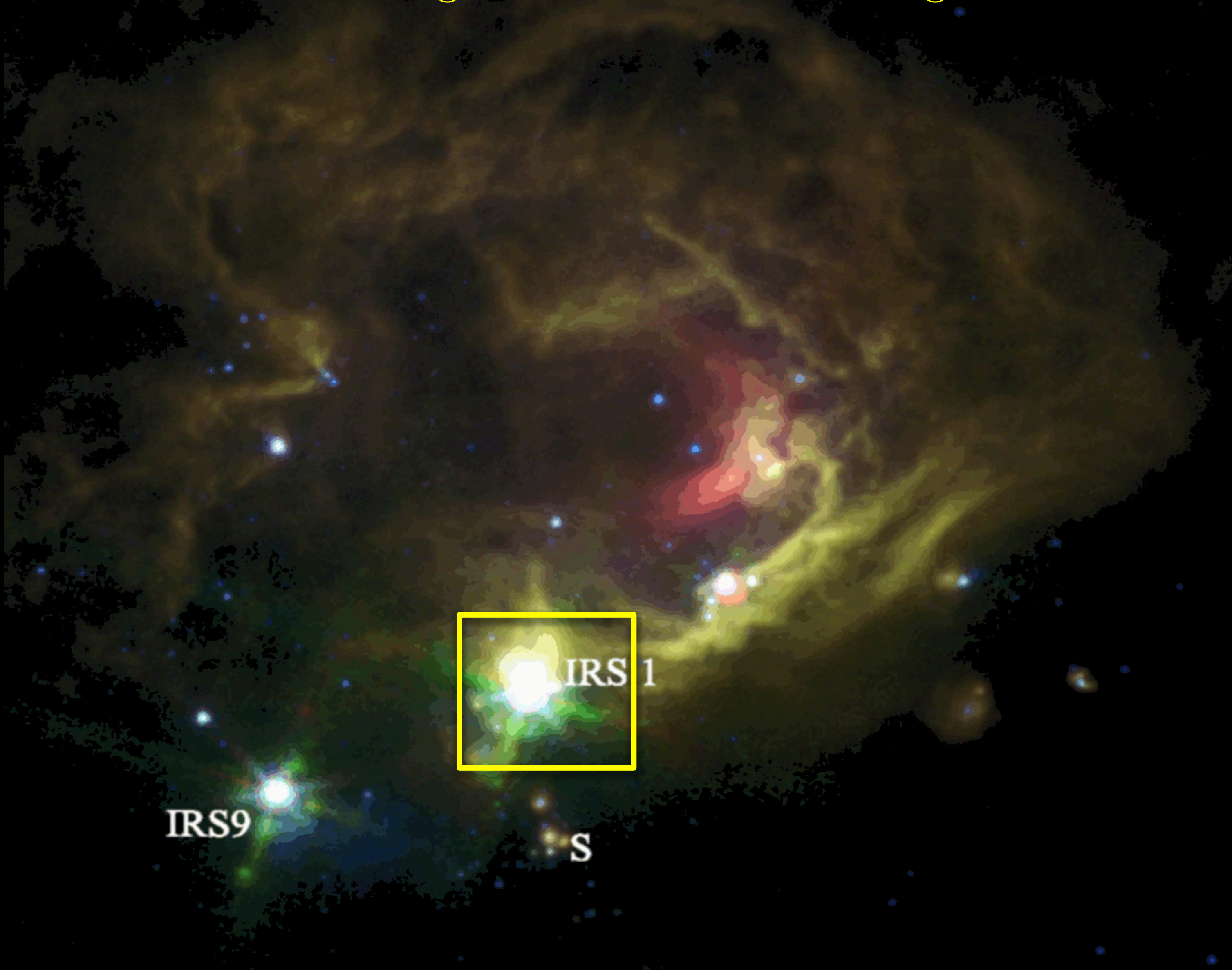
Transition [a] (J,K)	ν_{rest} (MHz)	E_l/k (K)	JVLA Receiver
(6,6)	25055.96	408	K
(7,7)	25715.14	538	K
(9,9)	27477.94	852	Ka
(10,10)	28604.75	1035	Ka
(12,12)	31424.94	1455	Ka
(13,13)	33156.84	1691	Ka
(14,14)	35134.28	1945	Ka

Observations details:

- Array: B or C-configuration
- Linear resolution: O(500 AU)
- RMS on ch. maps: O(1 mJy)
- Channel width: 0.4 km/s
- Correlator: Progressively more lines observed simultaneously
- Targets: Orion-KL, NGC7538, W51, W3OH, DR21OH, G10.62, SgB2, W49N, G34.26….

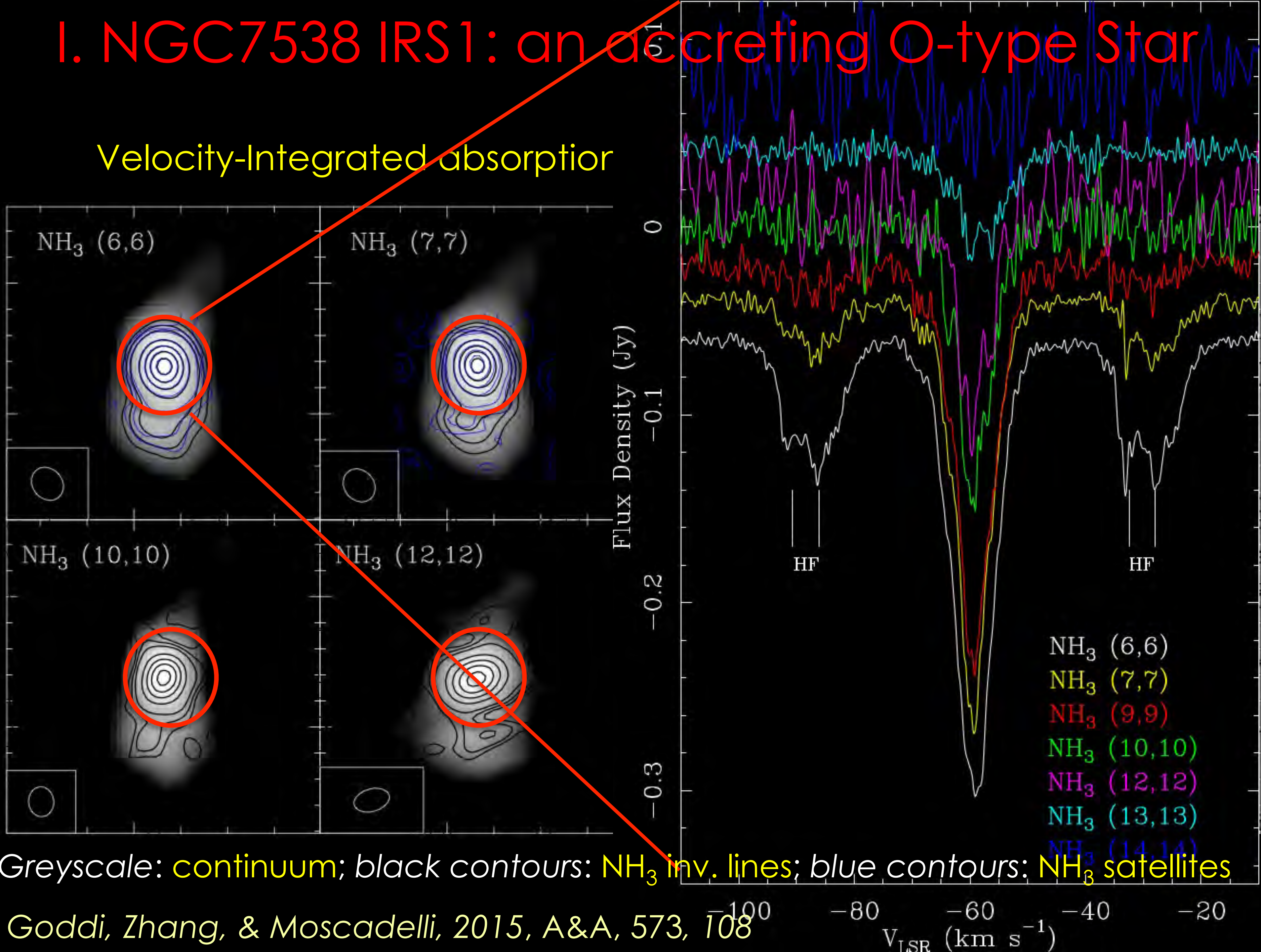
I. NGC7538 IRS1: an accreting O-type Star

D~2.7 kpc, $L \sim 10^5 L_\odot$, O6-7 star of 30 $M_\odot$



I. NGC7538 IRS1: an accreting O-type Star

Velocity-Integrated absorptior

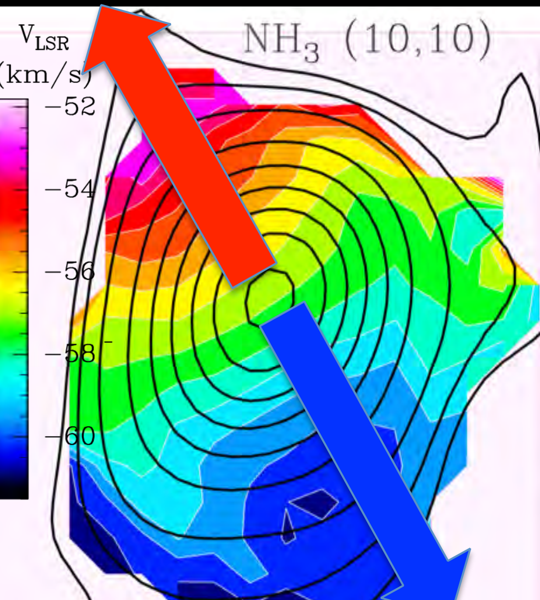


Greyscale: continuum; *black contours*: NH_3 inv. lines; *blue contours*: NH_3 satellites

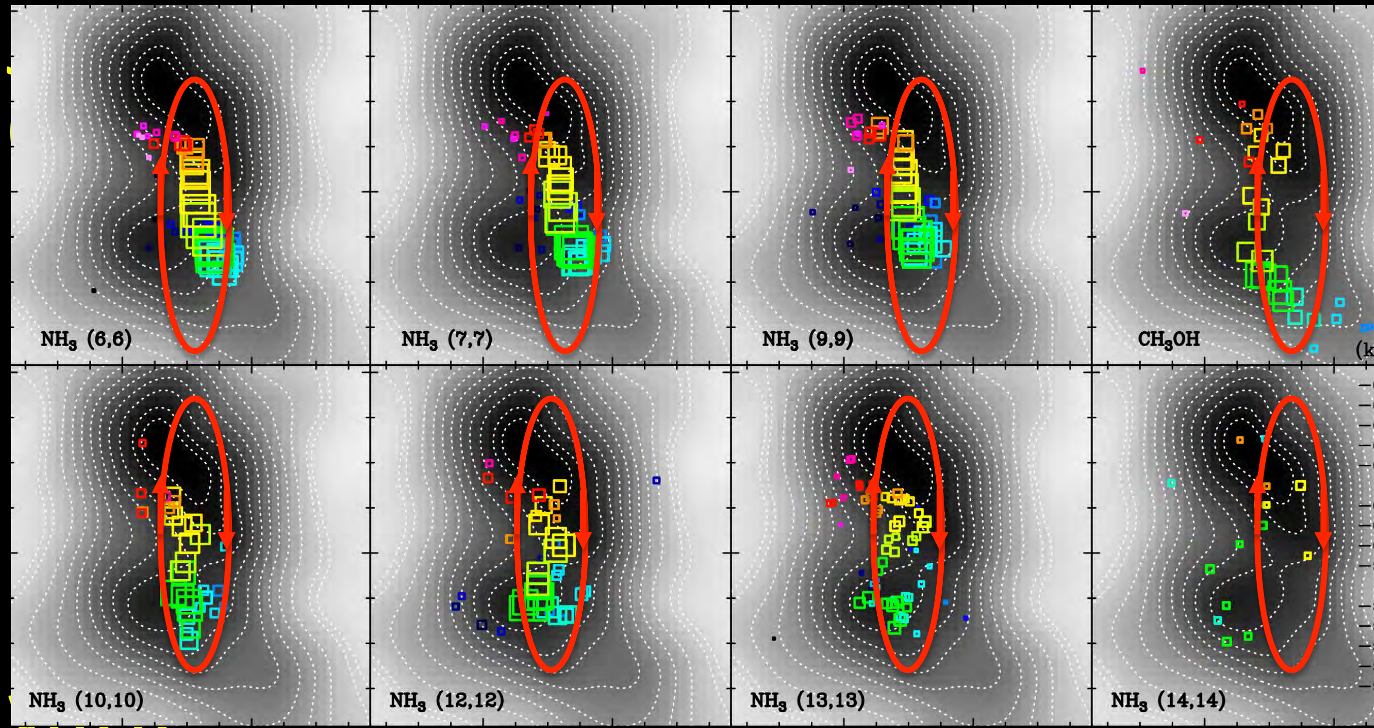
Goddi, Zhang, & Moscadelli, 2015, A&A, 573, 108

I. NGC7538 IRS1: an accreting O-type Star

NH_3 Absorption Velocity

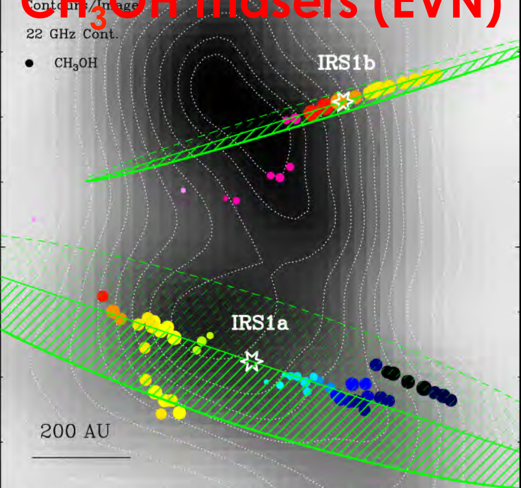


Velocity-channel centroid NH_3 maps



1.3 cm continuum

CH_3OH masers (EVN)

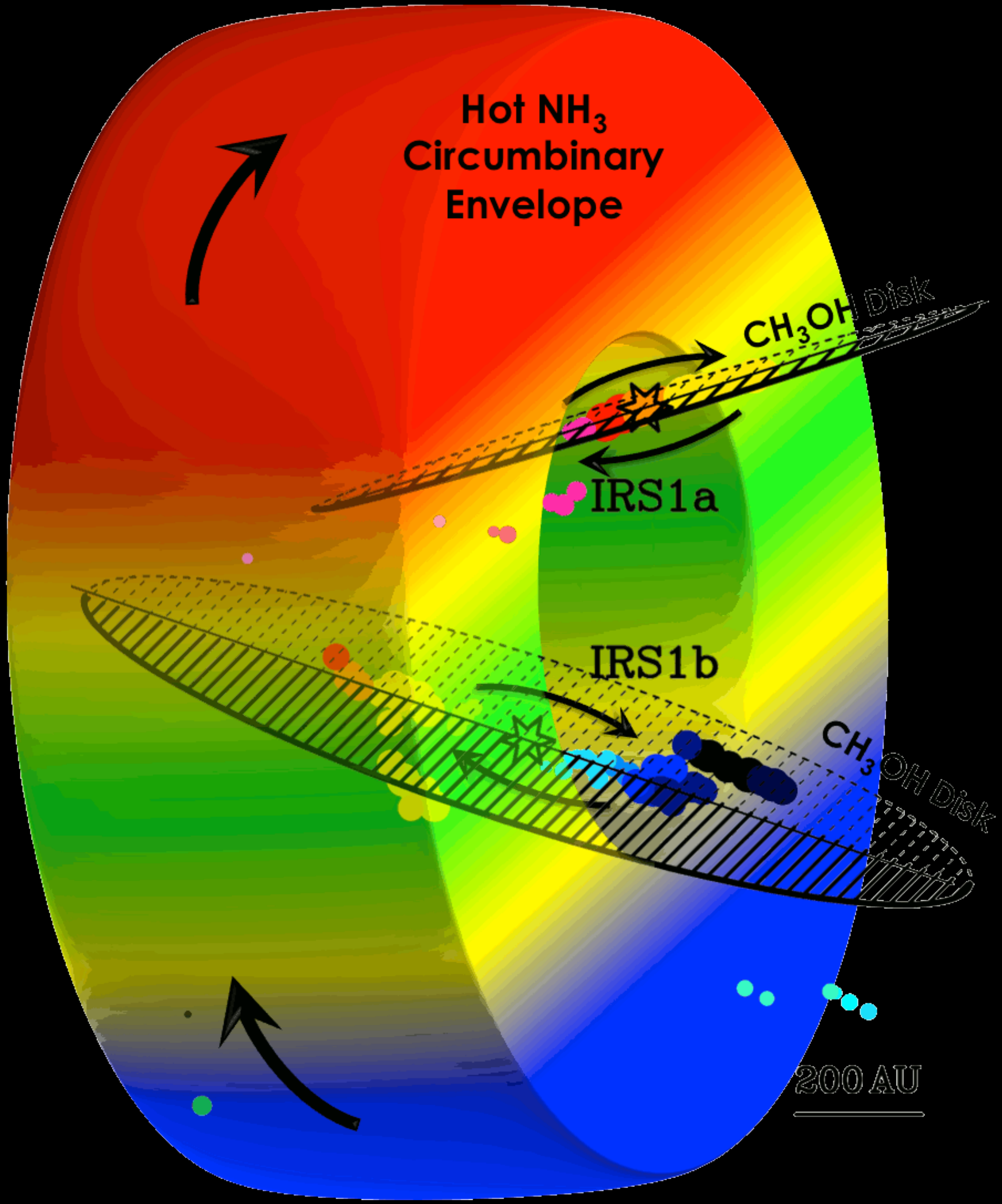


(θ=0.08”)

- *<u>Two</u> rotating (quasi-edge-on) disks in individual YSOs (from CH_3OH)*
- *North-South Rotation of the Hot Thermal Gas (from NH_3)*

Moscadelli & Goddi, 2014, A&A, 566, 150

I. NGC7538 IRS1: an accreting O-type Star



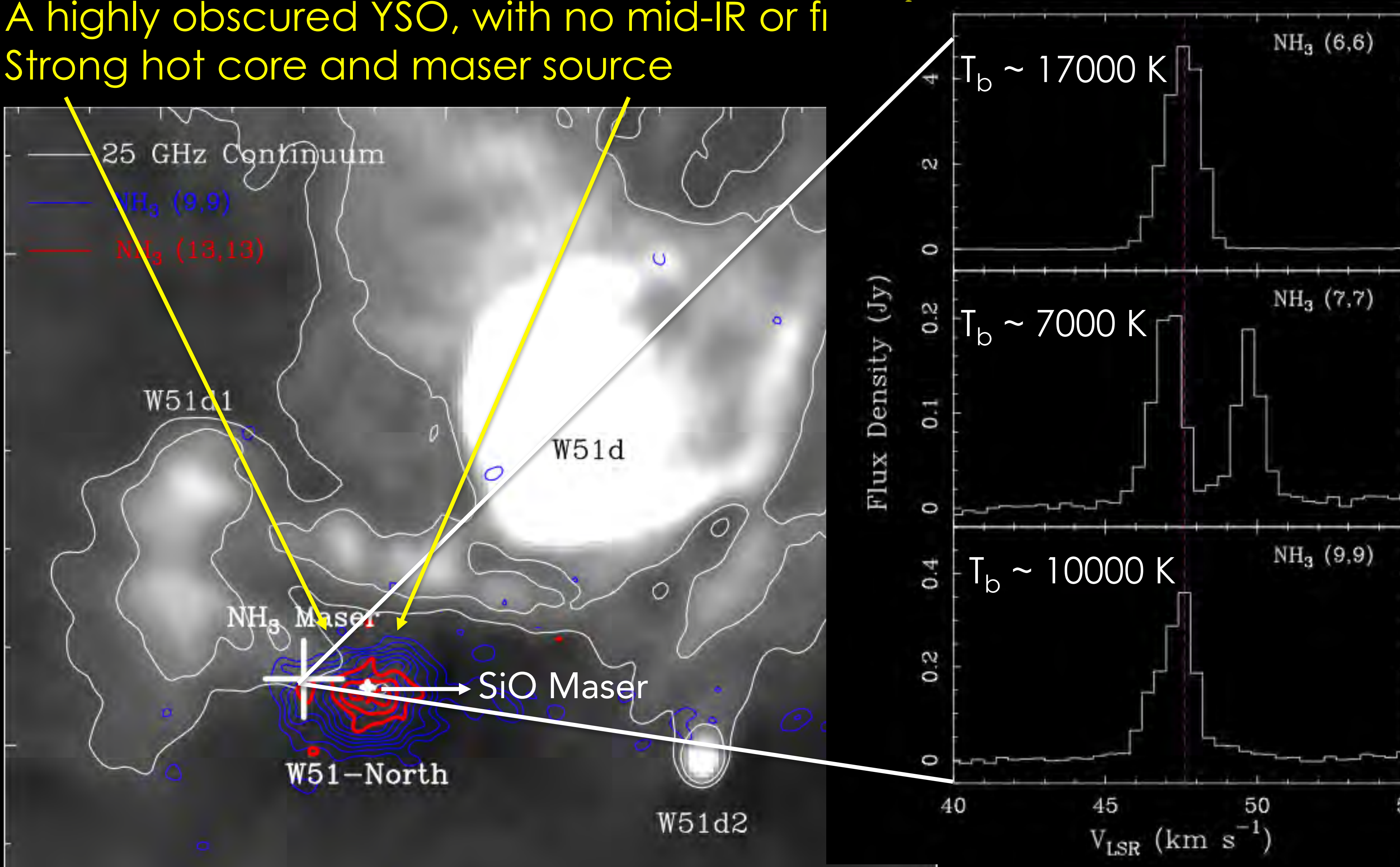
Two accretion disks around two massive YSOs in the cavity of a rotating circumbinary envelope

Goddi, Zhang, & Moscadelli, 2015, A&A, 573, 108

II. W51-North: Rare NH_3 Masers

A highly obscured YSO, with no mid-IR or fi

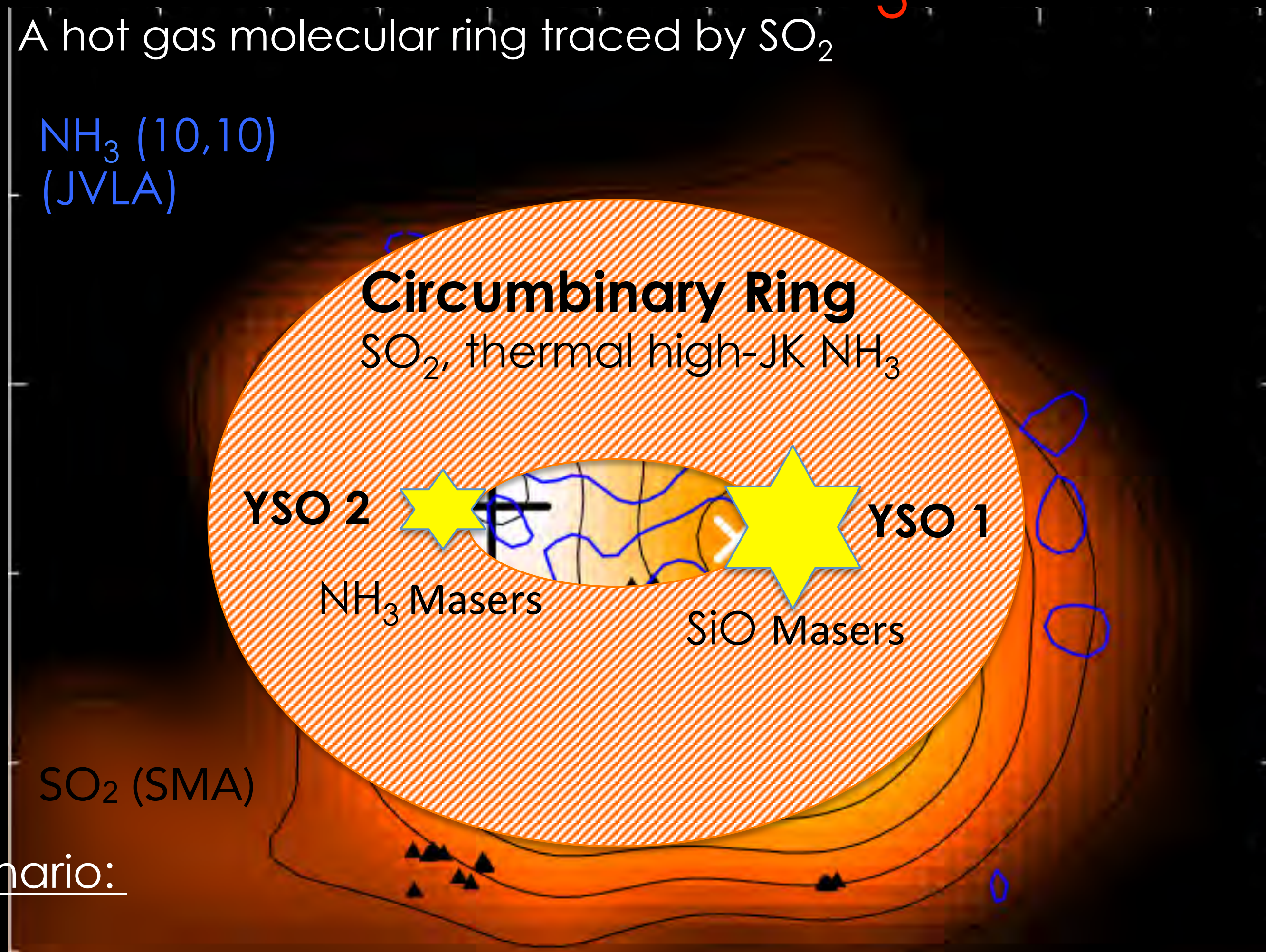
Strong hot core and maser source



Q: Are the rare SiO and NH_3 masers related?

Goddi, Henkel, Zhang, Zapata, & Wilson, 2015, A&A, 573, 109

II. W51-North: Rare NH_3 Masers



Proposed scenario:

The SO_2 ring is a **circumbinary disk** surrounding two high-mass YSOs (3500 AU separation):
- W51-North (exciting the SiO masers)
- a nearby companion (exciting the NH_3 masers)

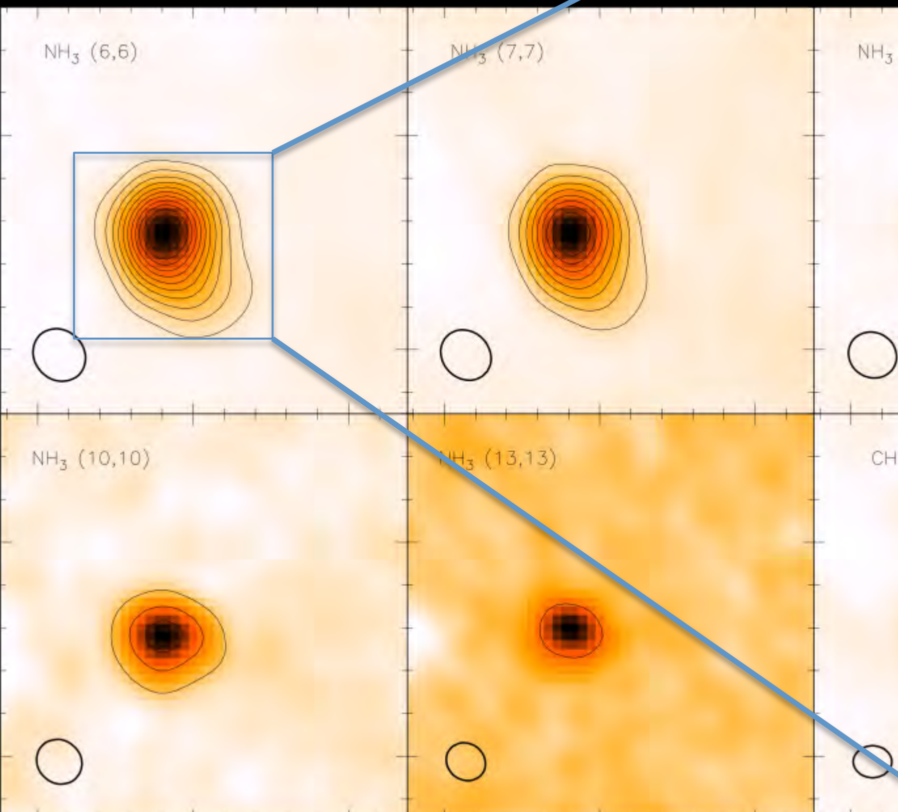
Goddi, Henkel, Zhang, Zapata, & Wilson, 2015, A&A, 573, 109

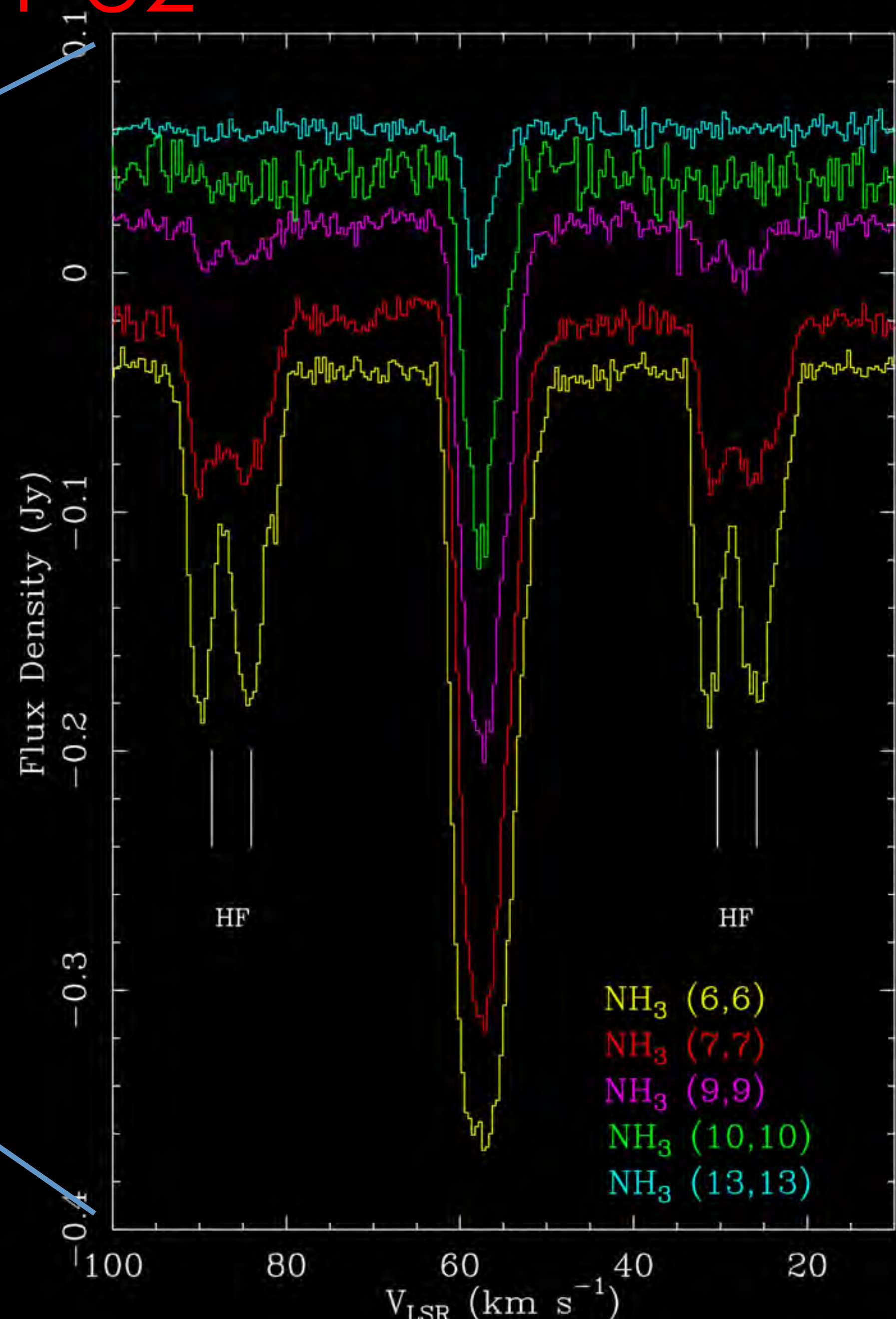
III. W51-e2

D~5.4 kpc, L~10^6 $L_\odot$

Strong hot core, HC-HII region

Velocity-Integrated Absorptic

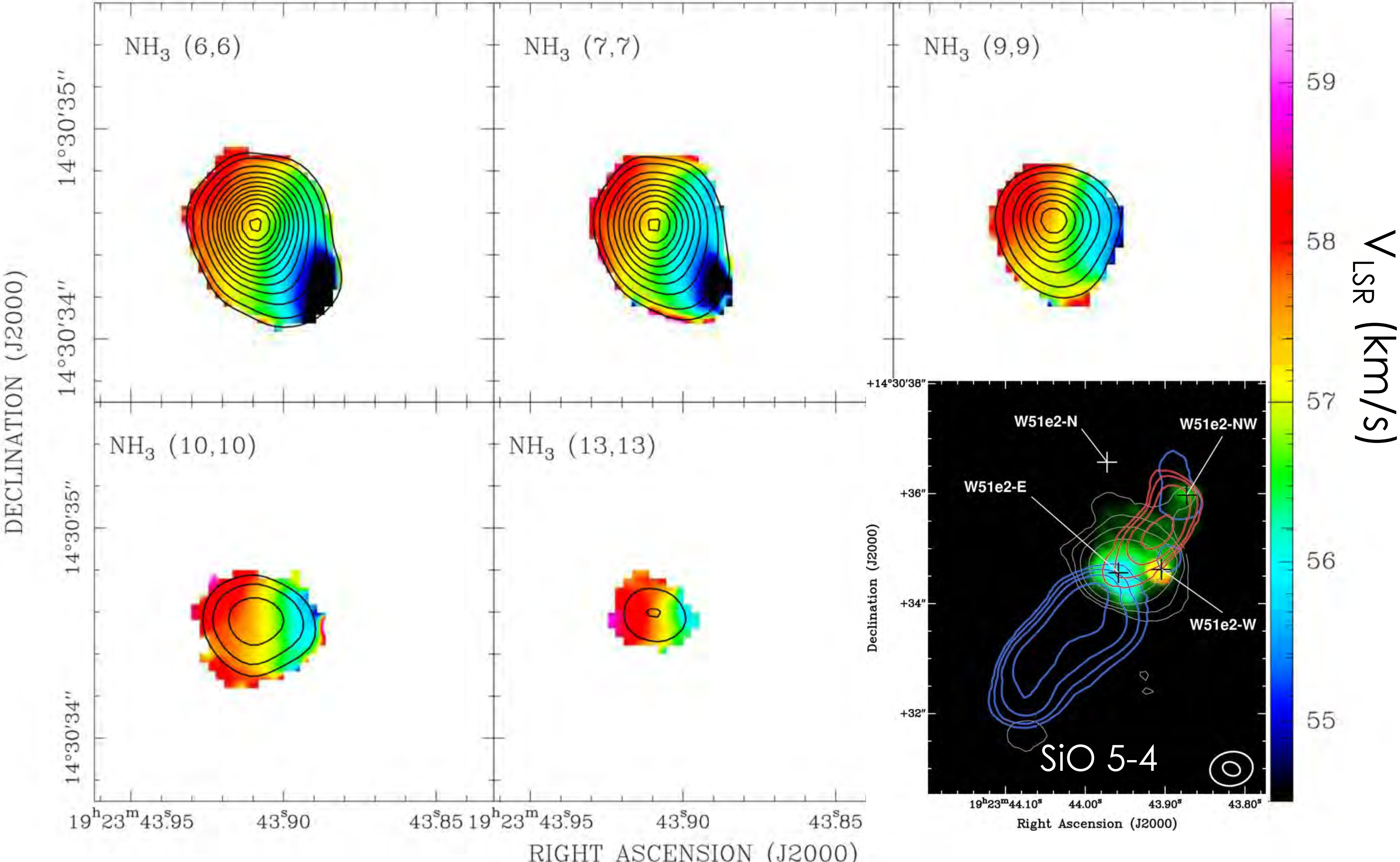




Goddi & Zhang, in prep.

III. W51-e2

NH_3 Absorption-Integrated Velocity Maps



Goddi & Zhang, in prep.

Summary

High-resolution imaging of highly excited NH_3 lines is well suited to study kinematics and physical conditions of the hottest and densest molecular gas in accretion disks and envelopes around O-type YSOs.

I. NGC7538 IRS1 (HC-HII) hosts a circumbinary rotating envelope, which feeds two circumstellar rotating disks

II. W51-North (pre-HII) may be a wide massive binary exciting rare SiO and NH_3 masers

III. W51-e2 (HC-HII) has an NH_3 disk perpendicular to a collimated CO outflow: analogous to disk/jet systems in solar-like stars?

Edge-on Disk Model

For an edge-on disk in centrifugal equilibrium:

$$V_{rot} = \frac{\sqrt{GM(R)}}{R^{0.5}}$$ Rotation Velocity

$$\Omega = \frac{\sqrt{GM(R)}}{R^{1.5}}$$ Angular Velocity

$$A_c = \frac{GM(R)}{R^2}$$ Centripetal Acceleration

We can express these quantities with just 2 free parameters:

q describes how the mass distributes in the disk

$$M(R) \propto R^q$$

R_0 describes the disk radius at the star position along the l.o.s.

$R=F(R_0,q)$

The best values of R_0 and q are derived by minimizing the $\chi 2$:

$$\chi^2 = \frac{1}{N_{free}} \left(\sum_i \left(\frac{A_z^i - \Upsilon^i}{\Delta \Upsilon^i} \right)^2 + \sum_j \left(\frac{V_s^j - \Lambda^j}{\Delta \Lambda^j} \right)^2 \right)$$

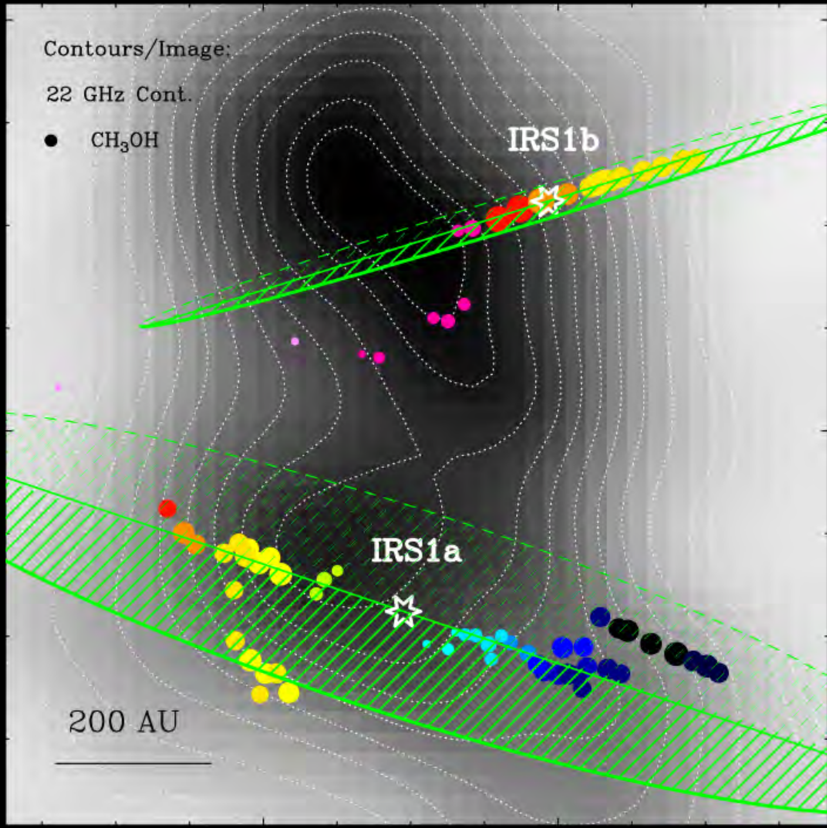
Accelerations 3D Velocities

Parameters of the two Edge-on Disks

Fit to positions, l.o.s. velocities, accelerations, and proper motions of maser spots, gives :

IRS1b
$$\begin{cases} R_0 = 550 \pm 10 \text{ AU} \\ q = 1.9 \pm 0.06 \\ M_0 = 16 \pm 1 \text{ M}_\odot \end{cases}$$

IRS1a
$$\begin{cases} R_0 = 740 \pm 100 \text{ AU} \\ q = 0.8 \pm 0.8 \\ M_0 = 25 \pm 10 \text{ M}_\odot \end{cases}$$



Keplerian disks may exist around massive O-type YSOs after all!

Moscadelli & Goddi, 2014, A&A, 566, 150

Rotation in Edge-on Disks

Five (independent) pieces of evidence strongly suggest edge-on rotation traced by maser clusters:

1. linear or elongated spatial distribution;

2. regular variation of V_{LSR} with position along the major axis of the distribution;

3. proper motions approximately parallel to the elongation axis;

4. average amplitude of proper motions (≈5 km s^{-1}) similar to the variation in V_{LSR} (4–6 km s^{-1}) across the maser cluster;