

Anatomy of the Class I protostar L1489 IRS with NOEMA

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**Astronomy
&
Astrophysics**

Anatomy of the Class I protostar L1489 IRS with NOEMA

I. Disk, streamers, outflow(s) and bubbles at 3 mm★

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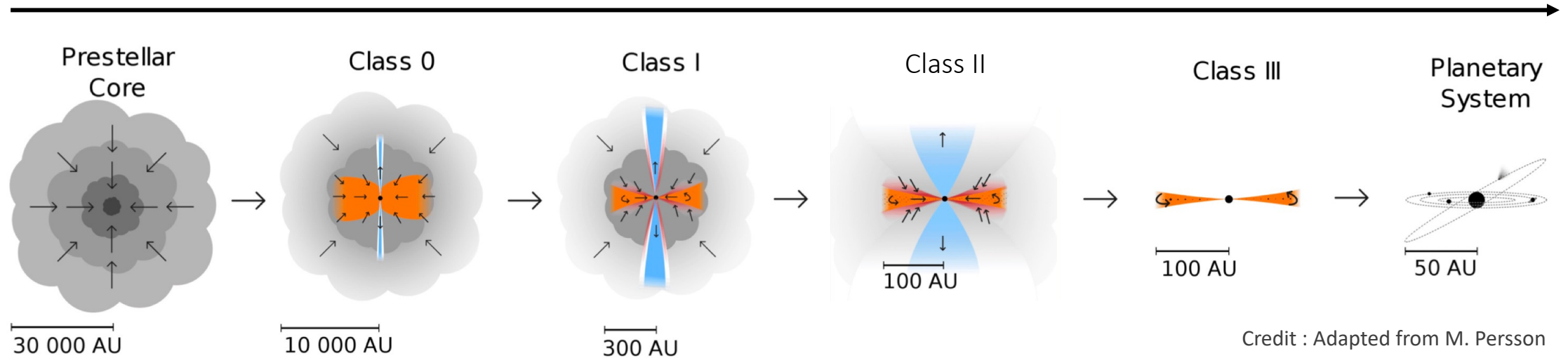
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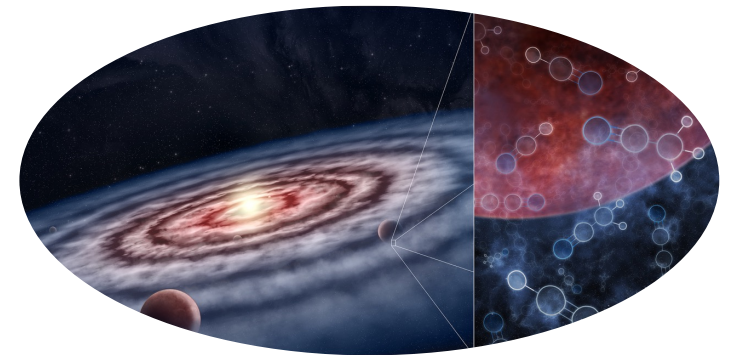
* Tanious et al. 2024 (A&A)

Context

Star formation process

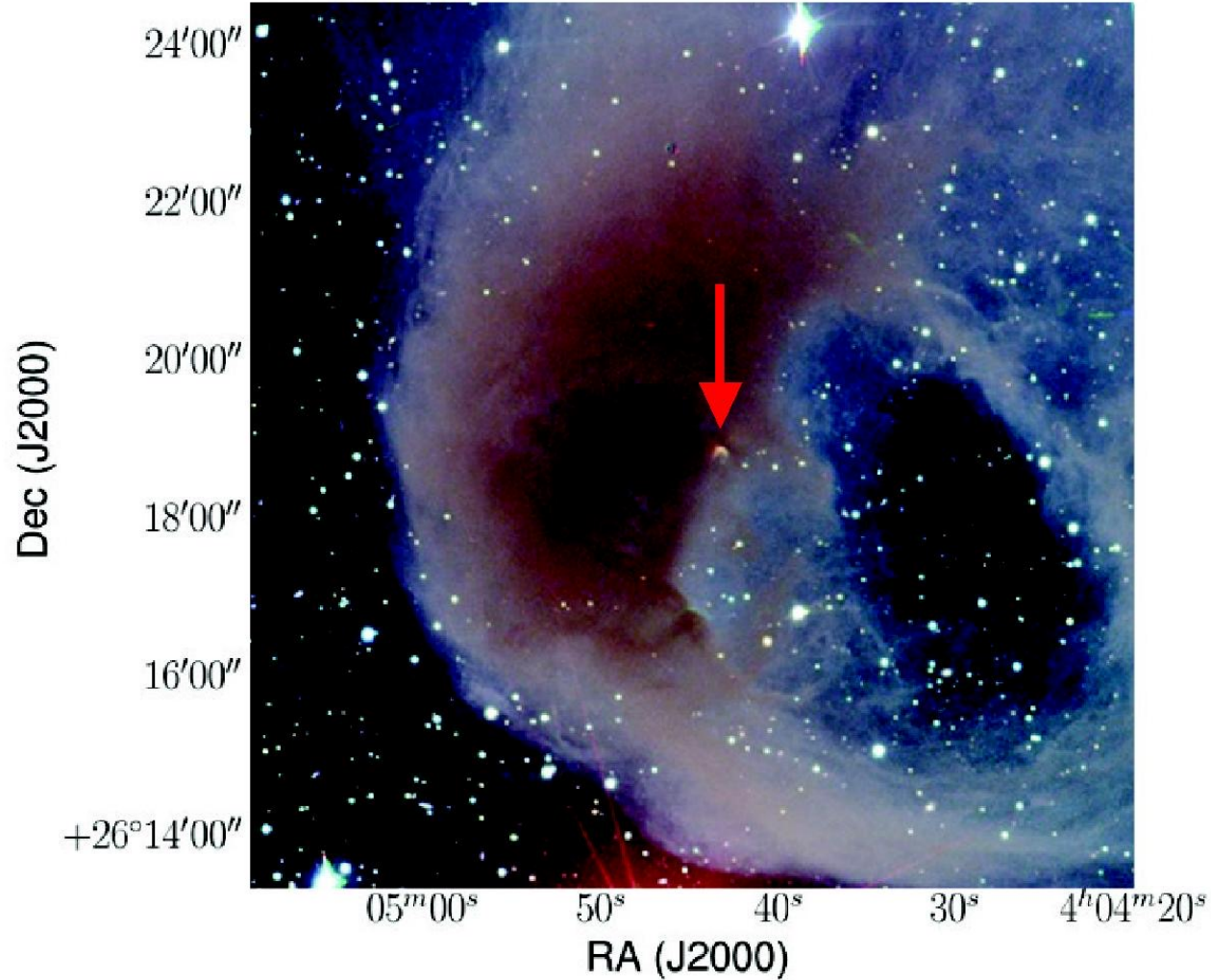


- Rich chemistry in these star forming regions
 - Gas and solid-phase reactions
 - Few studies of young Class I stellar objects
- What is the interstellar legacy or the chemical reset at the Class I stage?



IRAS 04016+2610 / L1489 IRS

$\sim 800'' = 117\,000\text{ AU}$



A. Togi, AN. Witt and DS. John (2017)

Table 1. Properties of L1489 IRS from the literature.

Property	Value	Reference
R.A. (J2000)	04:04:43.071	(1)
Dec. (J2000)	26:18:56.390	(1)
T_{bol}	213 K	(2)
L_{\star}	$3.4 L_{\odot}$	(2)
M_{\star}	$1.7 \pm 0.2 M_{\odot}$	(3)
$M_{\text{Env.}}$	$0.023^{+0.010}_{-0.004} M_{\odot}$	(4)
M_{Disk}	$0.009 \pm 0.001 M_{\odot}$	(4)
$M_{\text{Disk}}/M_{\text{Env.}}$	0.39	(4)
$R_{\text{Env.}}$	$\sim 5\,000\text{ au}$	(5)
R_{Disk}	$\sim 600\text{ au}$	(5)
v_{LSR}	7.37 km s^{-1}	(3)
i	72°	(3)
Distance	$\sim 146\text{ pc}$	(6)

References. (1) [Gaia Collaboration \(2018\)](#), (2) [Ohashi et al. \(2023\)](#), (3) [Yamato et al. \(2023\)](#), (4) [Sheehan & Eisner \(2017\)](#), (5) [Sai et al. \(2020\)](#), (6) [Roccatagliata et al. \(2020\)](#).

Previous interferometric observations

- OVRO (beam $\sim 5''$) :
 - Hogerheijde+1997 : HCO^+ 1-0, 3-2, 4-3
 - Hogerheijde+1998 : ^{13}CO 1-0, C^{18}O 1-0
 - Hogerheijde+2001 : HCN 1-0
- SMA : Brinch+2007, HCO^+ 3-2
- SMA : Yen+2013, C^{18}O 2-1
- ALMA : Yen+2014, CO 2-1, C^{18}O 2-1, SO 5_6-4_5
- ALMA : van't Hoff+2020, C^{17}O 2-1, H_2CO $3_{1,2}-2_{1,1}$
- ALMA : Sai+2020, ^{13}CO 2-1, C^{18}O 2-1
- ALMA : Tychoniec+2021 : H_2CS $7_{0,7}-6_{0,6}$, CN 2-1
- ALMA : Yamato+2023, ^{13}CO 2-1, C^{18}O 2-1, SO 5_6-4_5
- ACA : Sai+2022, C^{18}O 2-1

3mm observations
CO or isotopologues

Previous interferometric observations

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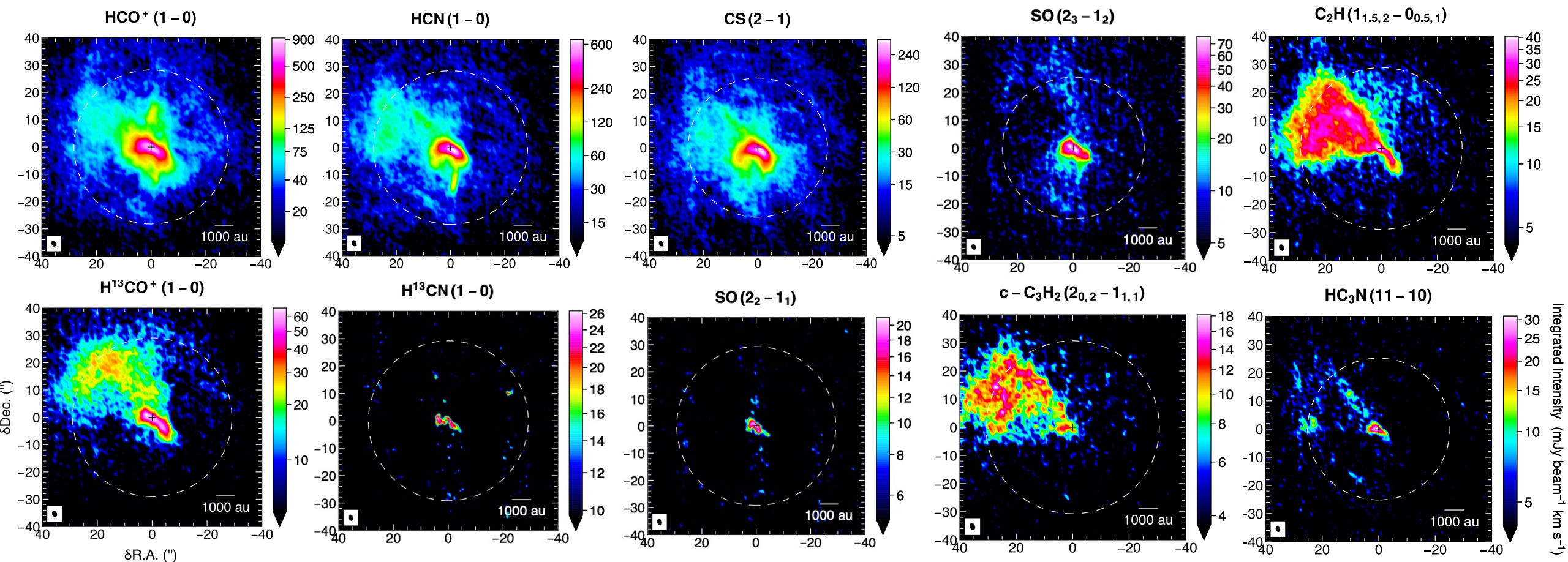
3mm observations
CO or isotopologues



NOEMA + IRAM-30m Observations (2020-2021)
@ 3mm, molecular survey, 62.5 kHz (0.2 km/s), 1.8''

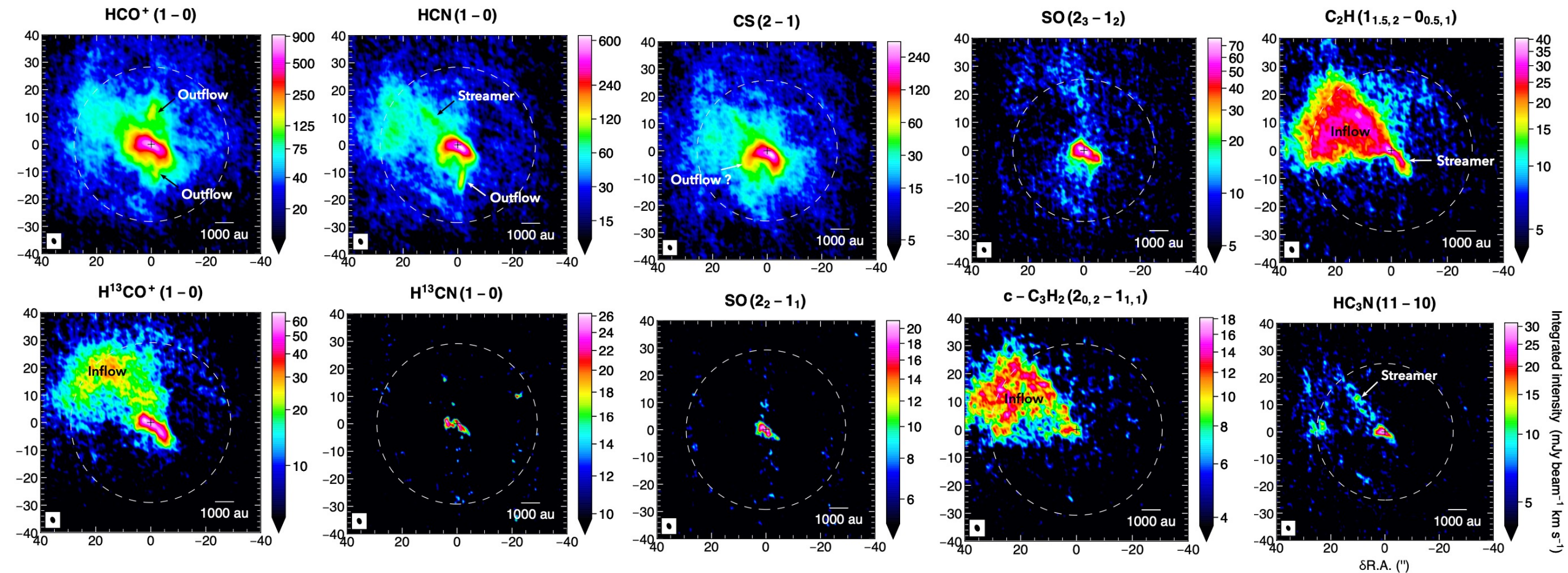
Transition	E_{up} (K)	Rest frequency (GHz)	$\theta_{\text{maj}} \times \theta_{\text{min}}$ (PA) (" × ", °)	Per-channel rms ^(†) (mJy beam ⁻¹)	Velocity range ^(*) (km s ⁻¹)	Integrated intensity (mJy km s ⁻¹)
HCO^+ (1 – 0)	4.3	89.188525	2.05×1.43 (23.1)	1.48	[-7.89, 20.75]	$\geq 112\,785$ ^(a)
H^{13}CO^+ (1 – 0)	4.2	86.754288	2.13×1.48 (22.5)	1.47	[4.01, 10.79]	$\geq 22\,315$ ^(a)
HCN (1 – 0)	4.3	88.631602	2.10×1.46 (22.9)	1.60	[-5.60, 18.54]	$\geq 86\,295$ ^(a,b)
H^{13}CN (1 – 0)	4.1	86.339921	2.16×1.49 (21.6)	1.59	[-3.24, 17.76]	230 ± 23 ^(b)
HC_3N (11 – 10)	28.8	100.07639	1.82×1.30 (24.4)	1.45	[4.75, 9.49]	$\geq 7\,210$ ^(a)
C_2H ($1_{1,5,2} - 0_{0,5,1}$)	4.2	87.316898	2.12×1.47 (22.4)	1.39	[5.01, 9.72]	$\geq 21\,135$ ^(a,c)
c- C_3H_2 ($2_{0,2} - 1_{1,1}$)	6.4	82.093544	2.31×1.58 (22.1)	1.68	[5.91, 8.10]	$\geq 9\,590$ ^(a)
CS (2 – 1)	7.1	97.980953	1.85×1.32 (24.6)	1.44	[4.44, 10.65]	$\geq 49\,470$ ^(a)
SO ($2_3 - 1_2$)	9.2	99.299870	1.83×1.31 (24.5)	1.42	[3.45, 10.77]	$\geq 20\,770$ ^(a)
SO ($2_2 - 1_1$)	19.3	86.093950	2.17×1.49 (21.6)	1.45	[4.25, 10.87]	156 ± 16

Results: large diversity of structures



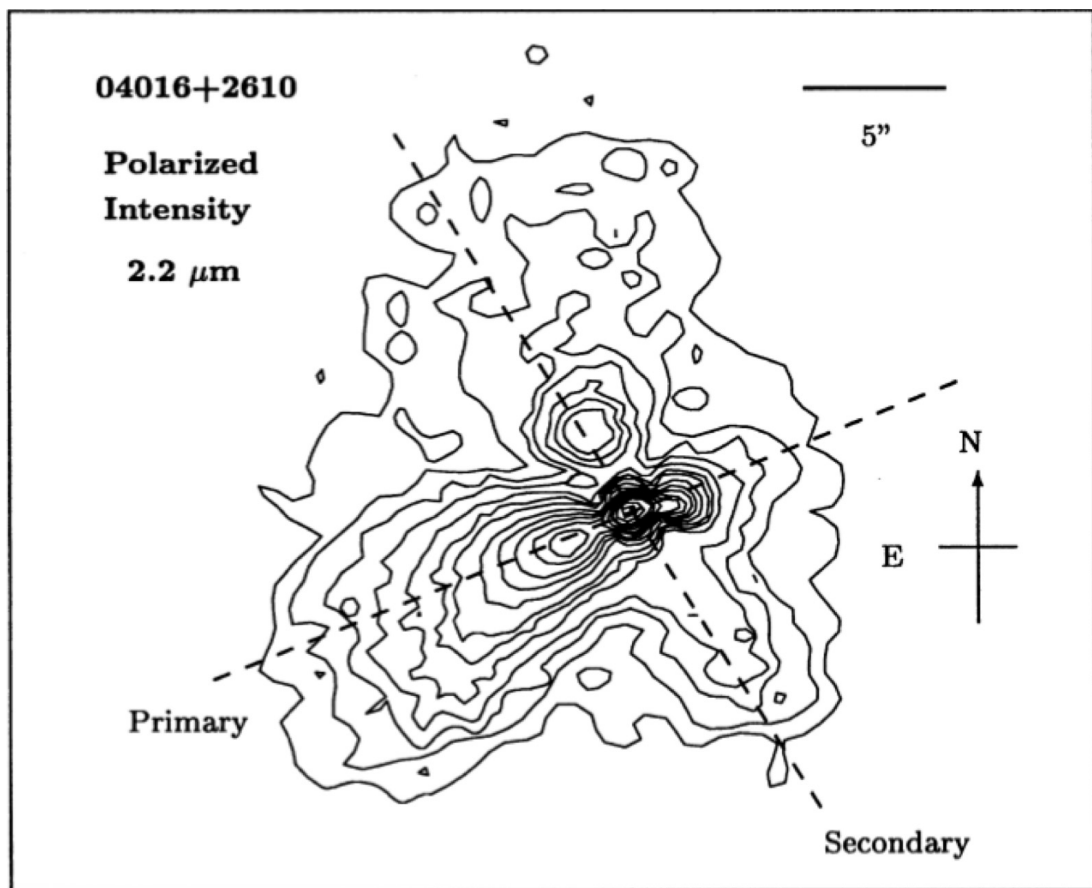
What's going on? Which molecule traces what?

Results: large diversity of structures

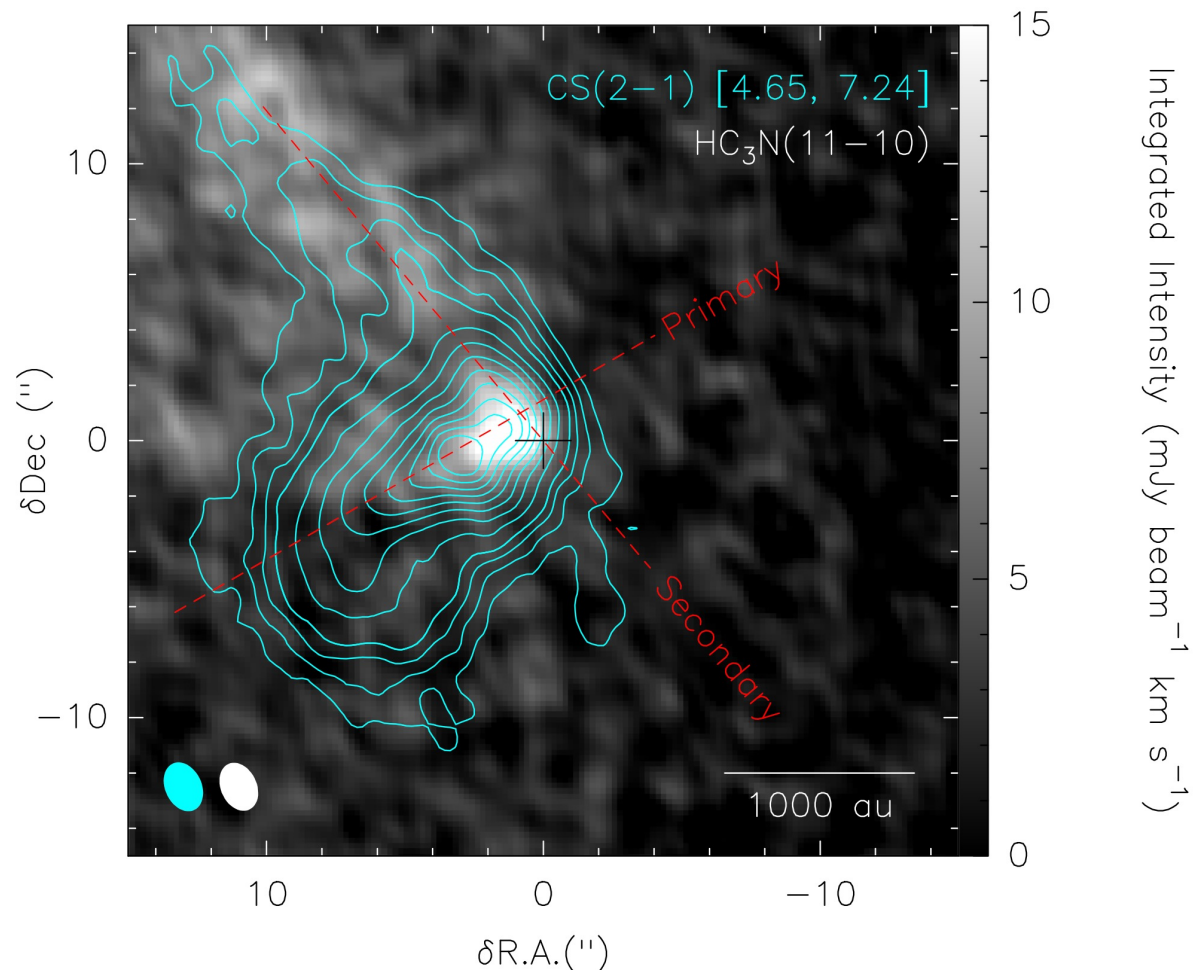


Dense envelope, outflows, inflows, **streamer**, disk...

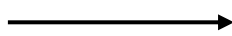
Nature of the quadrupolar flow ?



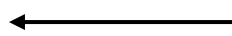
Lucas+2000 (MERLIN + VLA + UKIRT)



Outflows...



Model

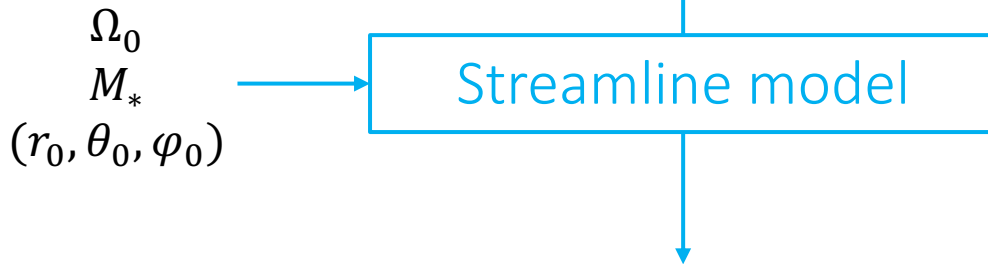


... but HC₃N generally traces infalls/streamers

Results: Streamline model (Pineda+2020)

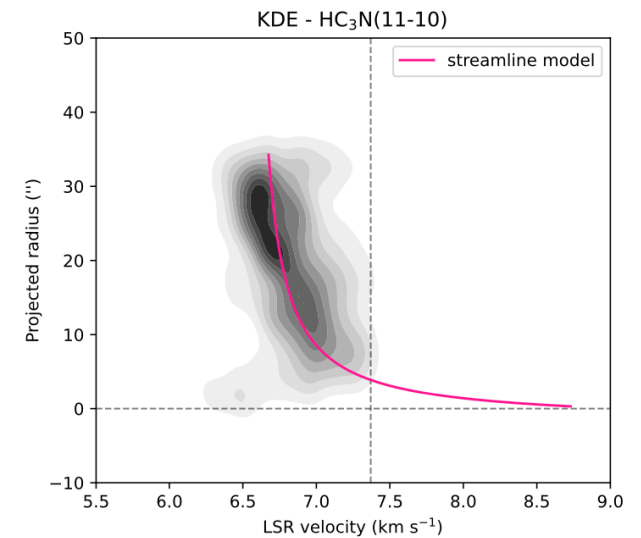
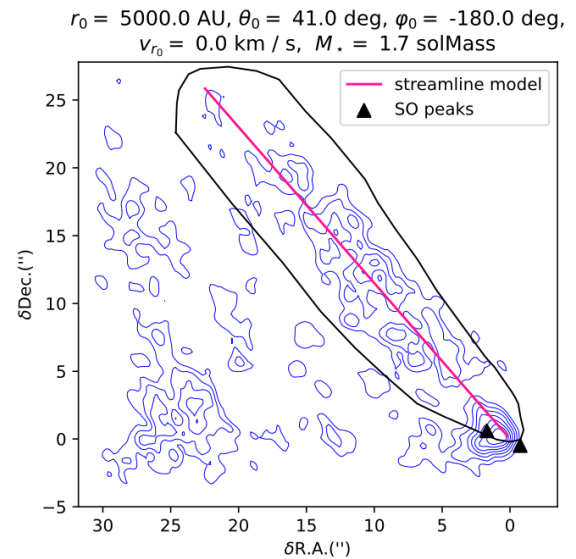
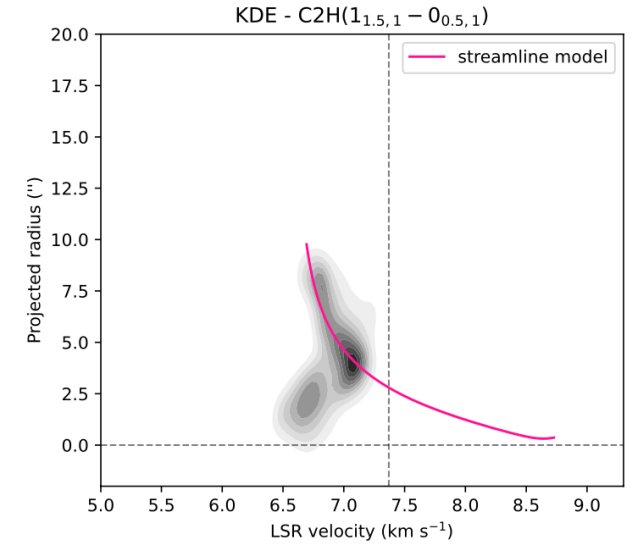
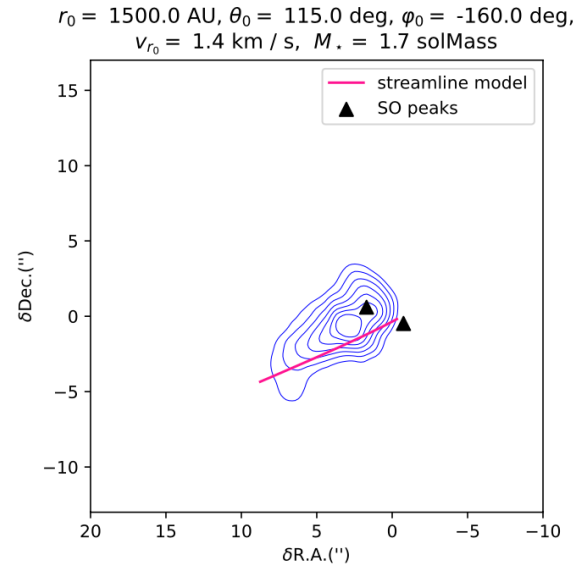
Primary axis:

- Troubles to find parameters that fit both emission and velocity profile
- **Unlikely to be a streamer**
- An outflow ? Blue lobe of CO ?



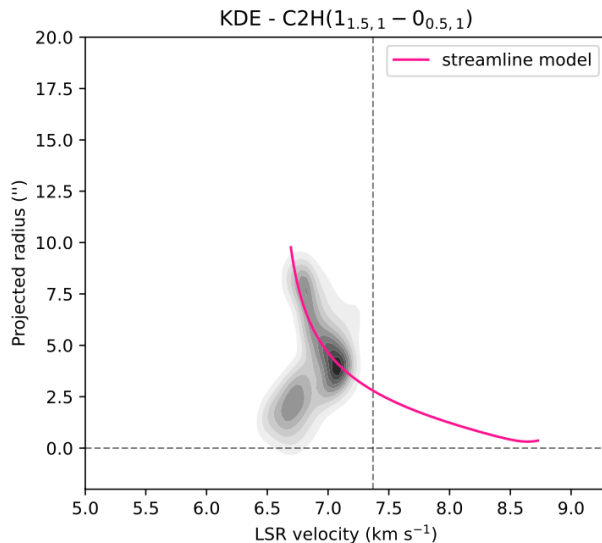
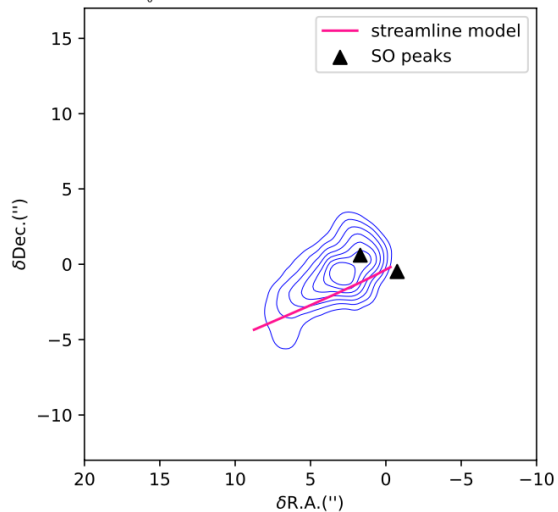
Secondary axis:

- Multiple parameters fit the observations
- **Likely to be a streamer**

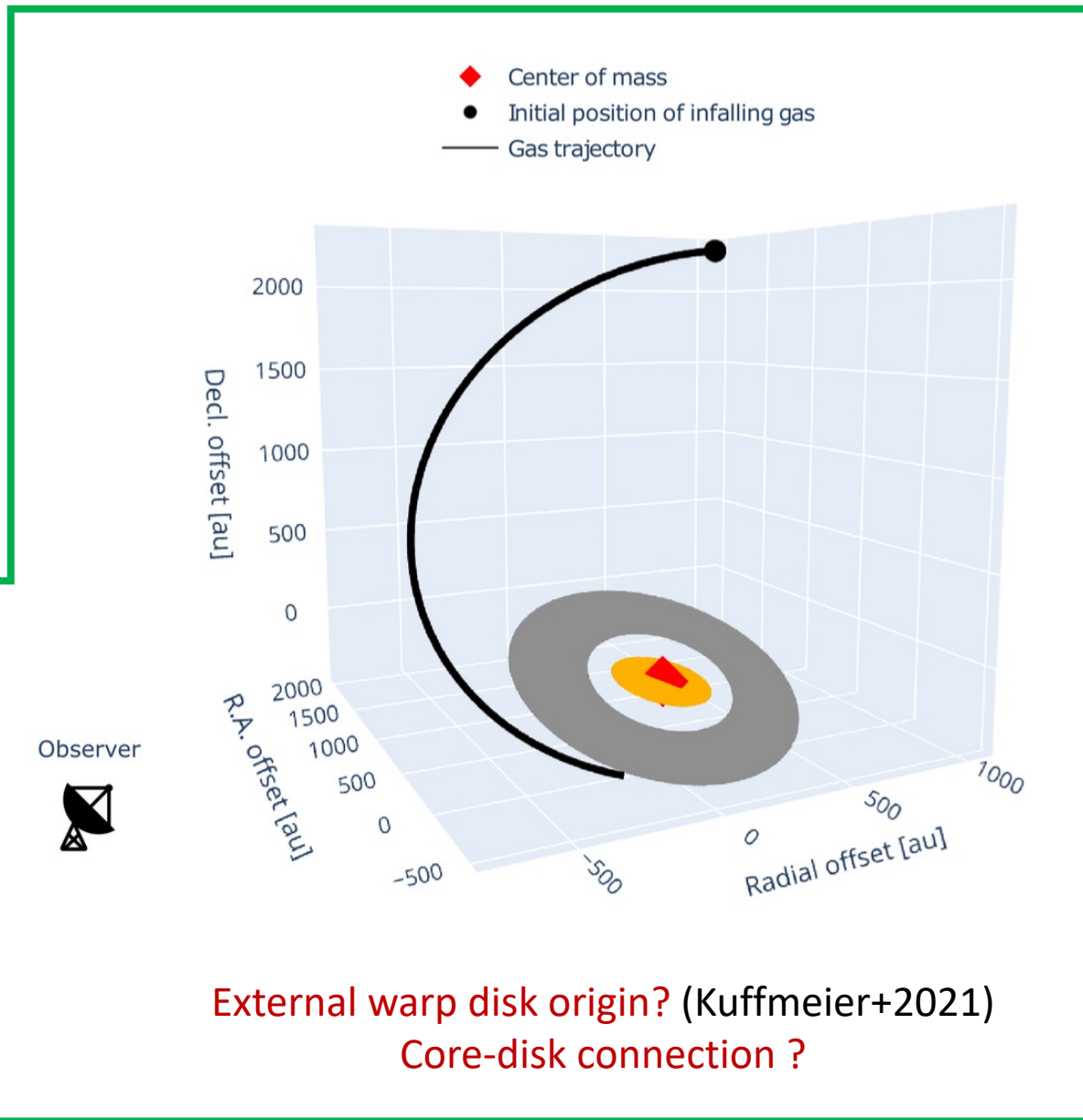
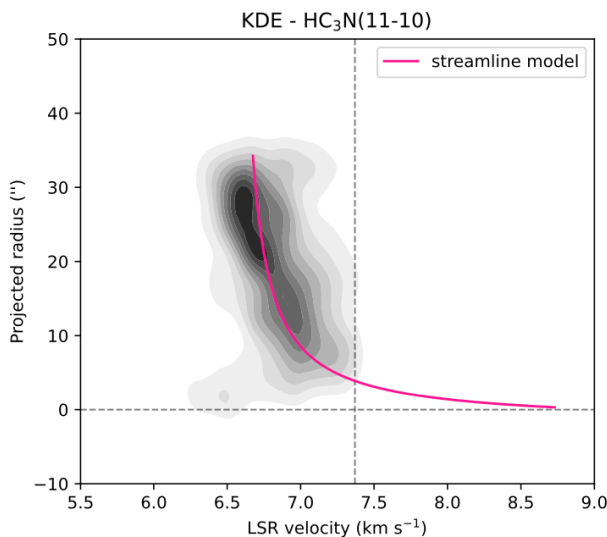
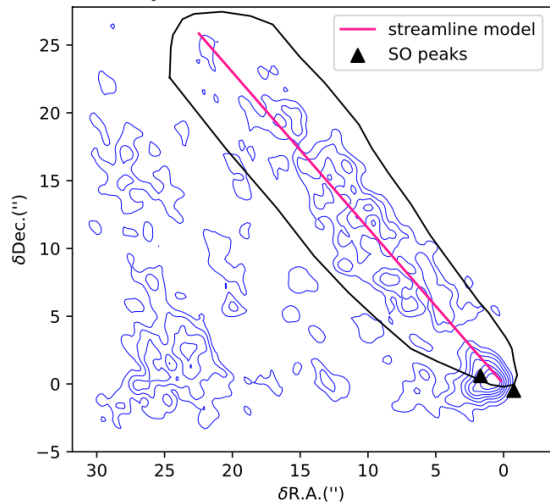


Results: TIPS Y model (Gupta+2024)

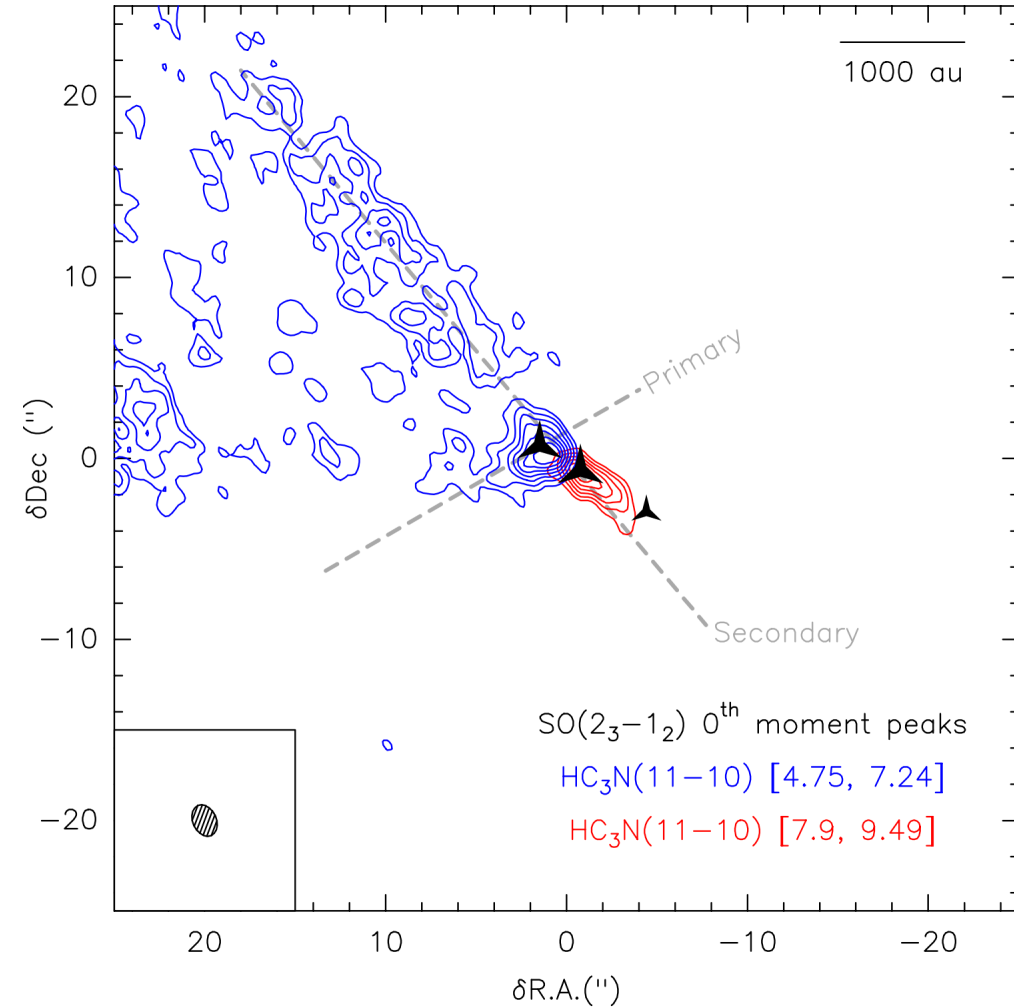
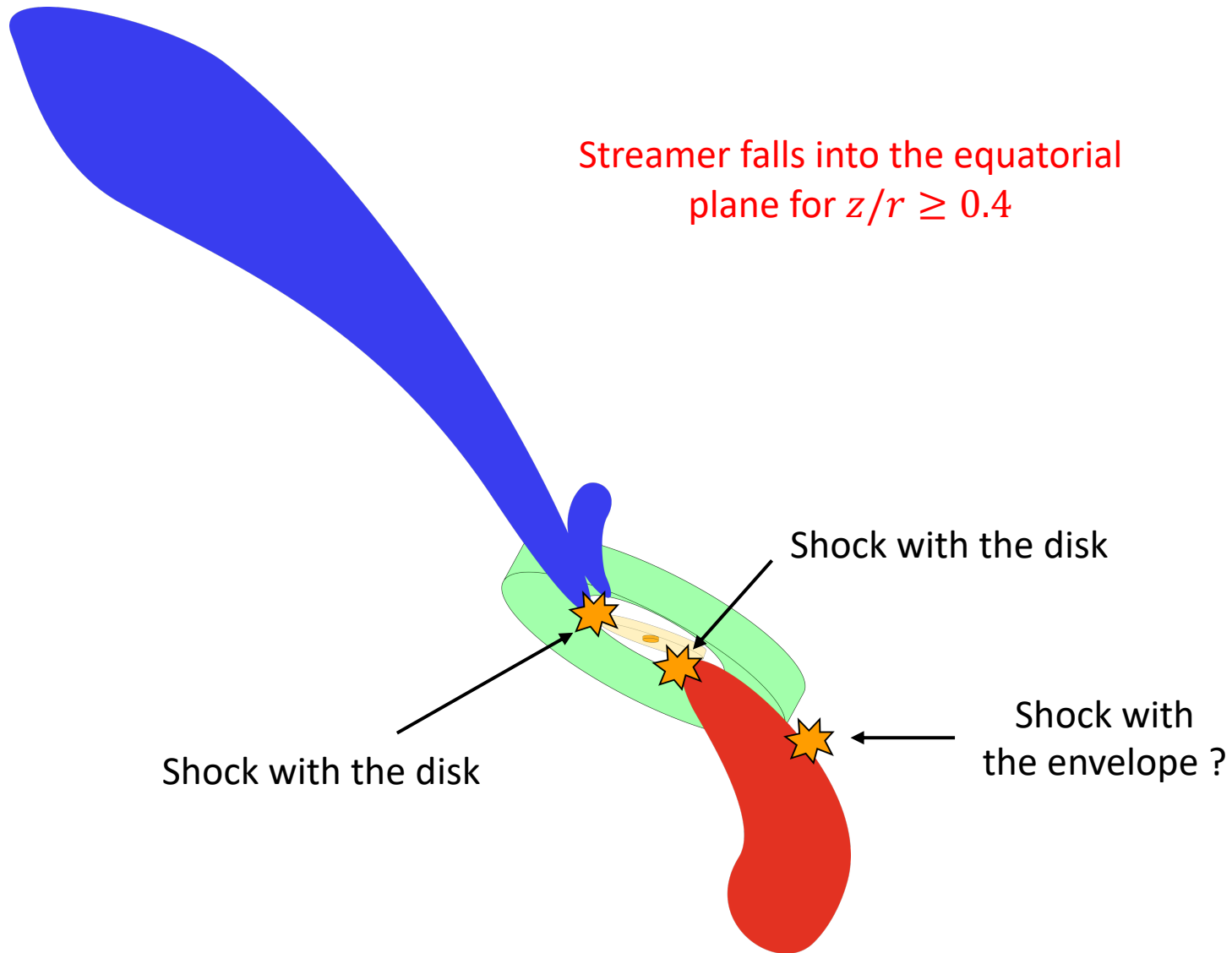
$r_0 = 1500.0$ AU, $\theta_0 = 115.0$ deg, $\phi_0 = -160.0$ deg,
 $v_{r0} = 1.4$ km / s, $M_* = 1.7$ solMass



$r_0 = 5000.0$ AU, $\theta_0 = 41.0$ deg, $\phi_0 = -180.0$ deg,
 $v_{r0} = 0.0$ km / s, $M_* = 1.7$ solMass

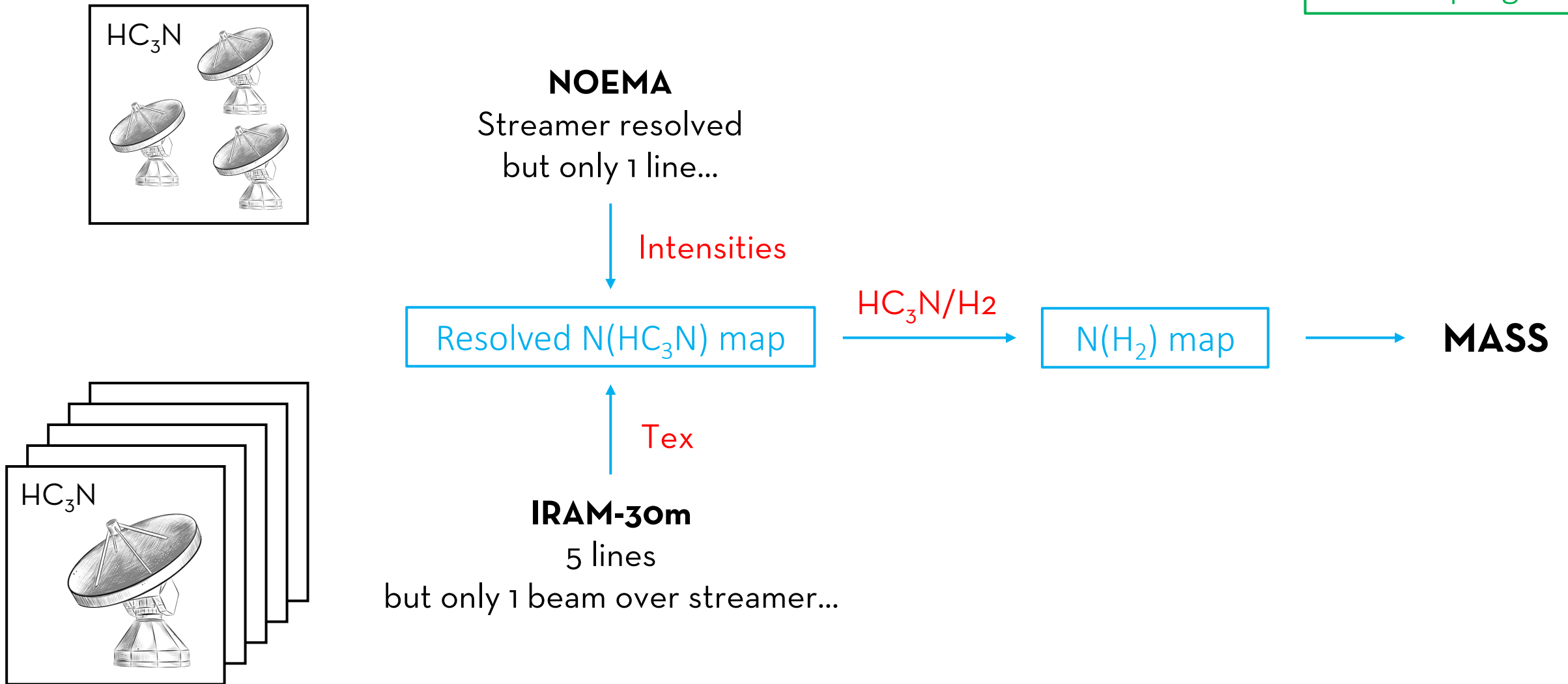


Results: shocks due to infalls ?



Streamer mass? Methodology

Work in progress

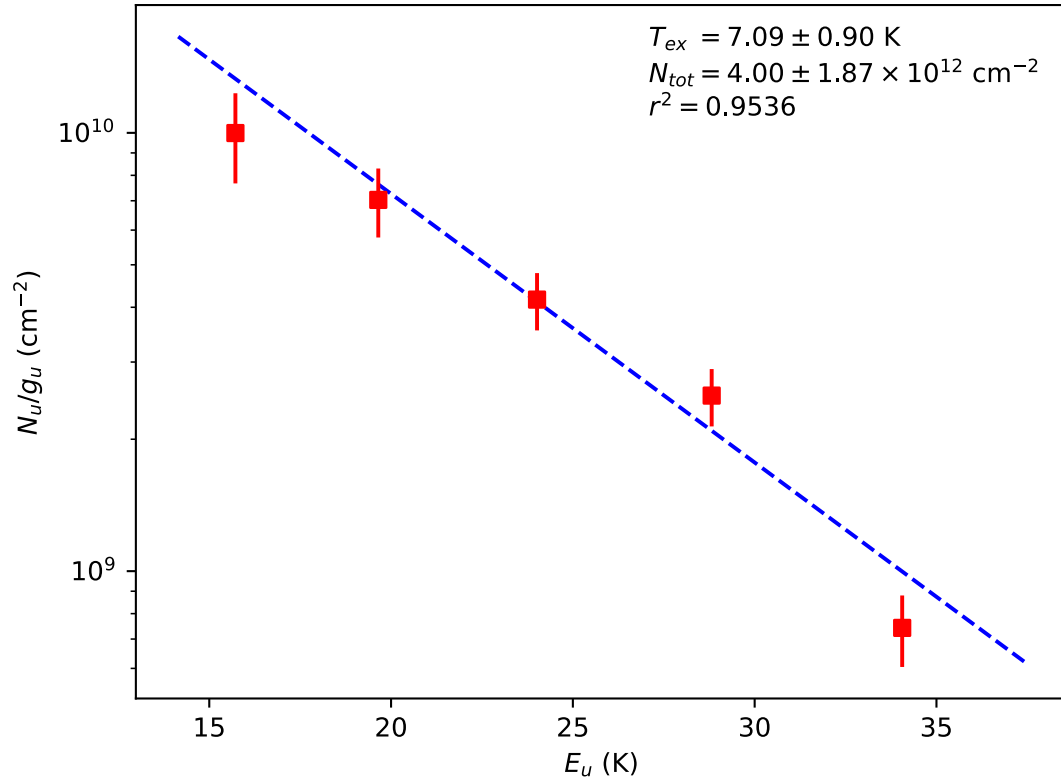


Tanious et al, in prep.

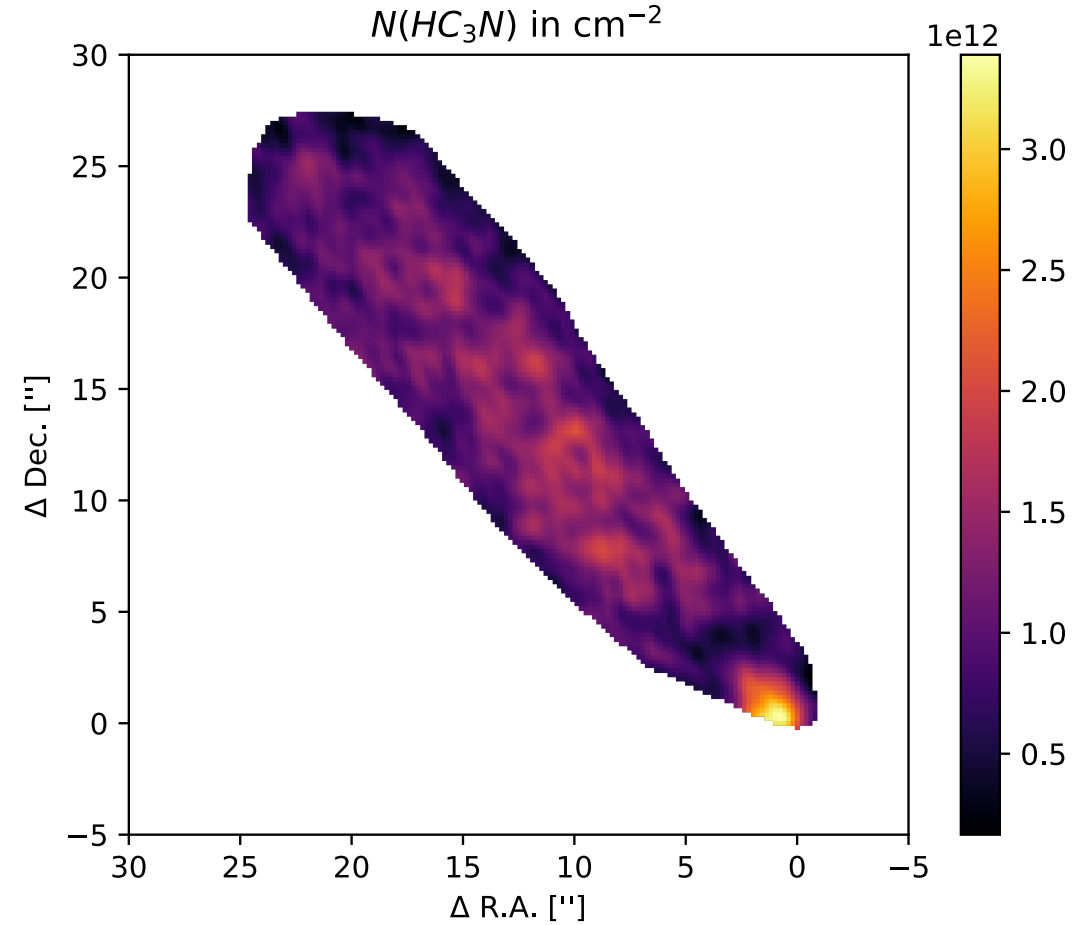
HC₃N column density map

Work in progress

Rotational diagram of HC₃N using IRAM-30m data



Tex



$T_{ex} = 7.09 \pm 0.9$ K
 $N(\text{HC}_3\text{N}) = 4.00 \pm 1.87 \times 10^{12}$ cm⁻²

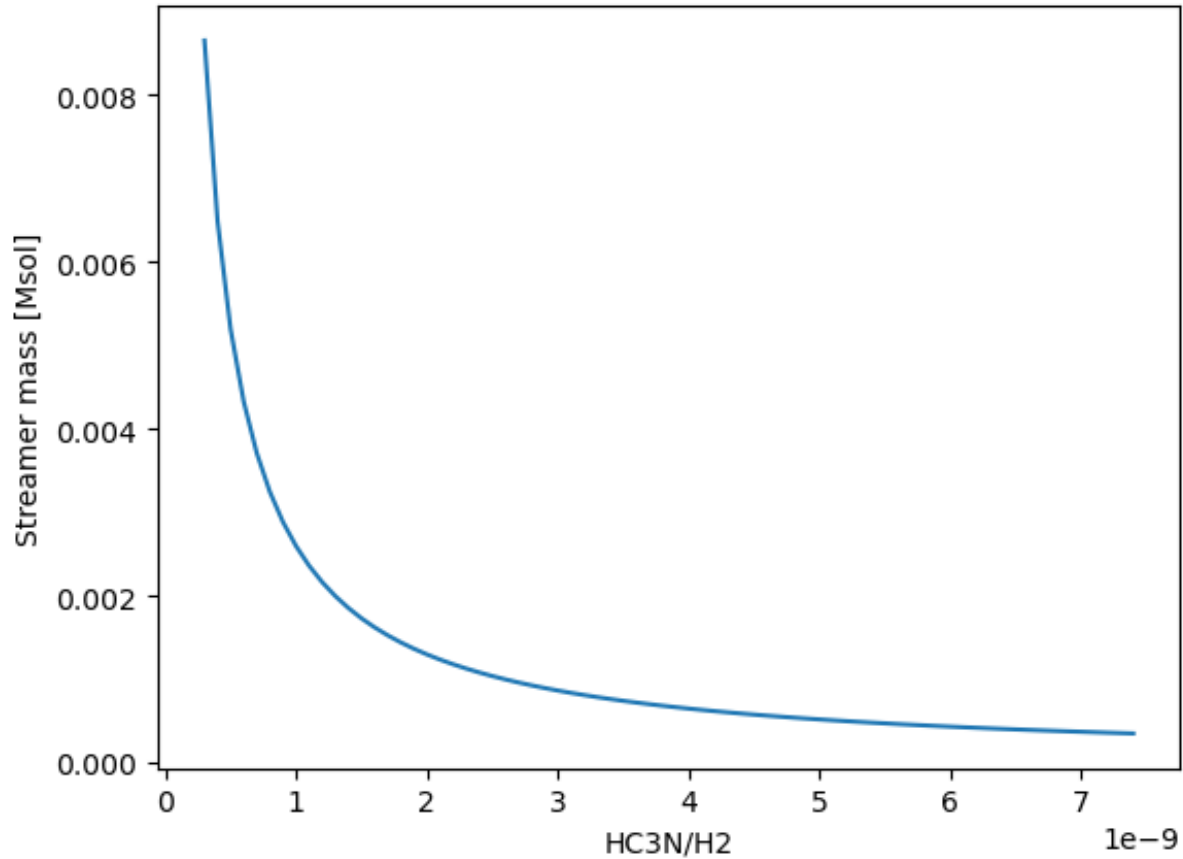
Assuming LTE

Tanious et al, in prep.

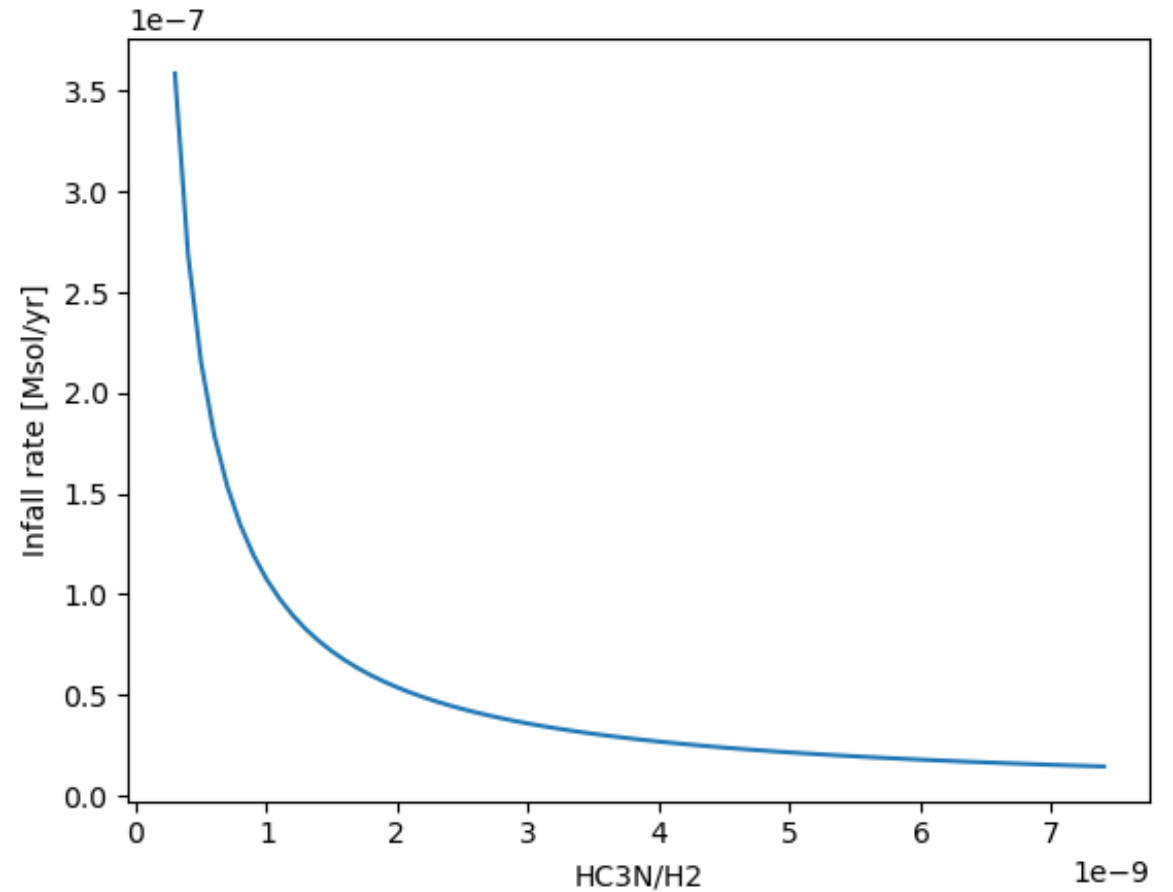
Influence of abundance on Streamer mass

Work in progress

Streamer mass



Infall rate



HC₃N abundance: a critical parameter

Tanious et al, in prep.

Relative disk mass due to infall

Work in progress

	$\text{HC}_3\text{N}/\text{H}_2$	Streamer mass (M_\odot)	Infall rate (M_\odot/yr)	Relative disk's mass due to infall [5]
[1]	3×10^{-10} (L134N)	8.7×10^{-3}	3.6×10^{-7}	303 %
[2]	2.8×10^{-9} (TMC-1)	9.3×10^{-4}	3.8×10^{-8}	33 %
[3]	7.4×10^{-9} (Per-emb-2)	3.5×10^{-4}	1.5×10^{-8}	12 %
[4]	1.3×10^{-9} (RADEX model)	2.1×10^{-3}	8.6×10^{-8}	73 %

[1] Dickens et al (2000)

[2] Loomis et al (2016)

[3] Pineda et al (2020)

[4] Using $n_{\text{H}_2} = 4 \times 10^5 \text{ cm}^{-3}$ and cylindrical streamer ($D = 6.4''$)

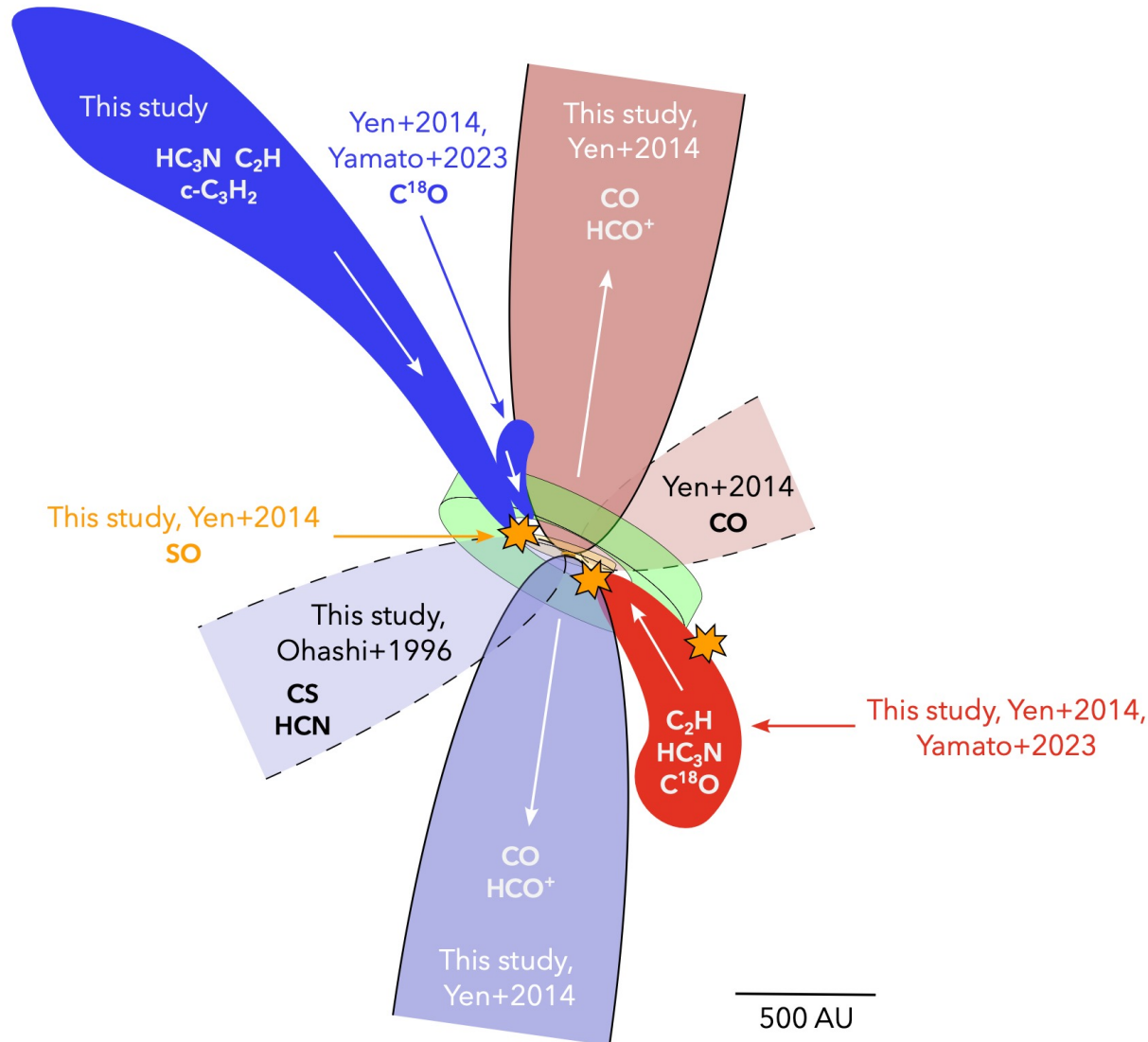
[5] Based on disk's mass and age from Sai+2022's model

A significant part of the disk's mass could come from the streamer, **supporting a warp disk's origin**

Stay Tuned...

Tanious et al, in prep.

Take-home messages



1. New ≥ 3000 AU streamer identified in HC₃N (and C₂H, c-C₃H₂, HCN, CS, H¹³CO⁺)
2. Likely connects the nearby core to the protostar through a gas bridge
3. Likely at the origin of the external warped disk
4. Potential second outflow: confirmation of the binarity in this system?

Prospects

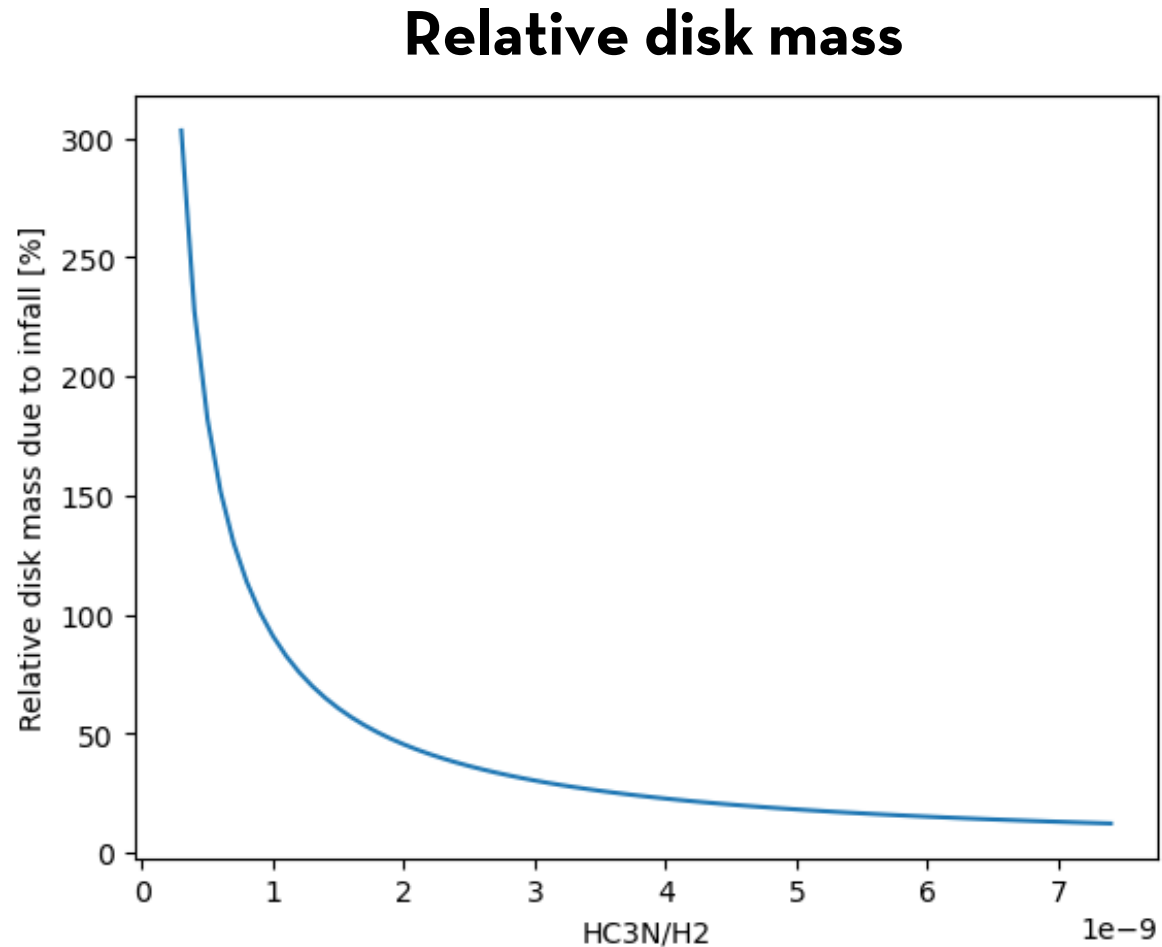
1. Mosaic observations (on-going)
2. Chemistry and excitation in these structures (on-going)



Thank you!

Influence of abundance on relative disk mass

Work in progress



HC₃N abundance: a critical parameter

Tanious et al, in prep.