The disk and the jet of the massive protostar W75N(B)-VLA3

Álvaro Sánchez-Monge

– Institut de Ciències de l'Espai (ICE-CSIC) –

together with

J.F. Gómez – J.M. Torrelles – S. Curiel – J.M. Girart – G. Surcis

C. Carrasco-González – G. Anglada – G.A. Fuller – C. Goddi

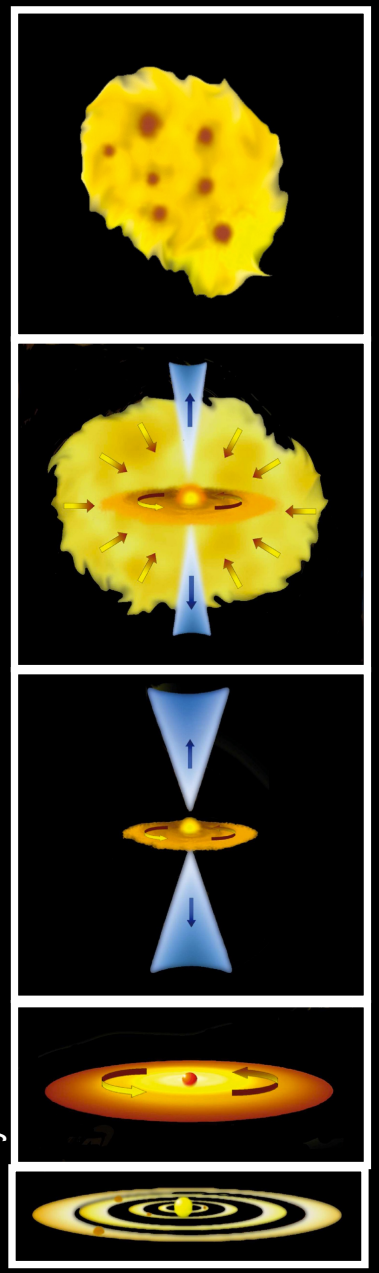
W.H.T. Vlemmings – A.R. Rodríguez-Kamenetzky

H.J. van Langevelde – J.-S. Kim – S.-W. Kim – J. Cantó

CSIC Consejo Superior de Investigaciones Científicas | Institute of Space Sciences 25th Anniversary | Excelencia María de Maeztu | Ministerio de Ciencia e Innovación | Financiado por la Unión Europea NextGenerationEU | Plan de Recuperación, Transformación y Resiliencia | Agencia Estatal de Investigación

low-mass

high-mass



Courtesy of L.Carbonaro and M.T. Beltrán

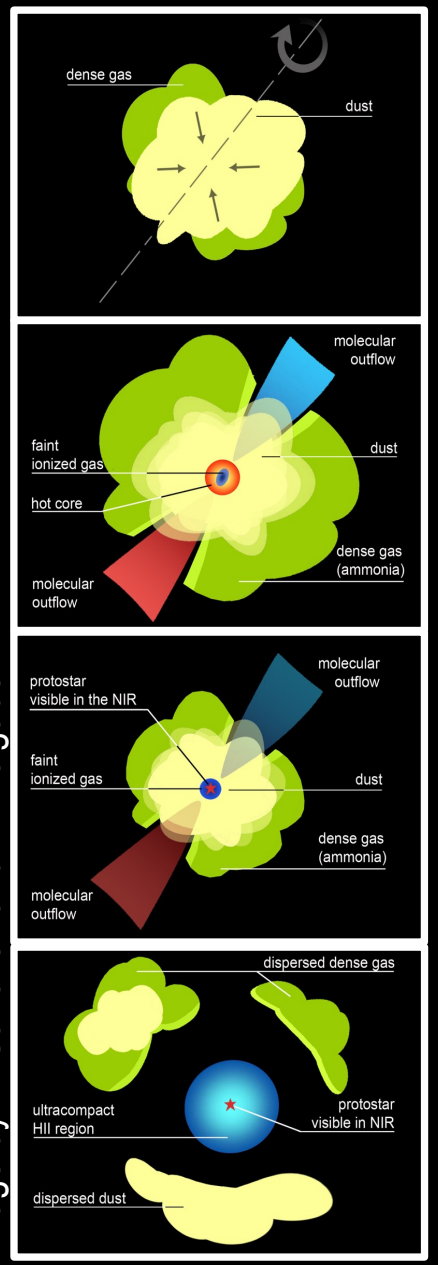


Image by B. Sánchez and R. Delgado

starless IRDCs, massive quiescent clumps, dense cores (lines and dust), disks?
opt / NIR / MIR / FIR / submm / mm / cm

protostellar dense cores, disks, masers, outflows and jets
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final star massive star or cluster, HII regions
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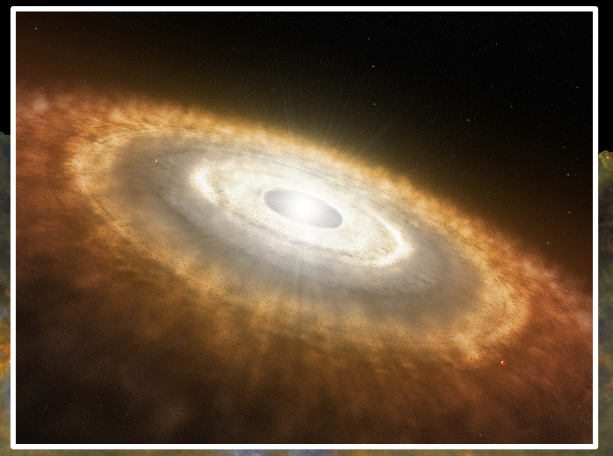
Going back to 2006 …

Robert Estalella

Interstellar medium is cool… there are clouds and high-mass stars are weird, how do they form?



Which topic for a PhD in astrophysics?

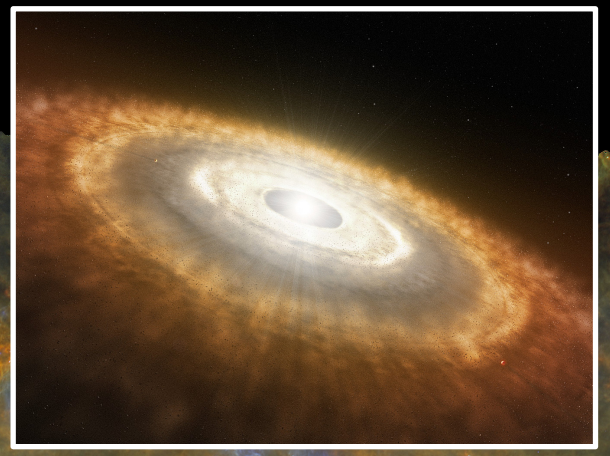
Josep M. Paredes

Micro-quasars, accretion disks, stars eating stars … really high energy events!

PhD thesis 2007 - 2010

Robert Estalella

Interstellar medium is cool… there are clouds and high-mass stars are weird, how do they form?

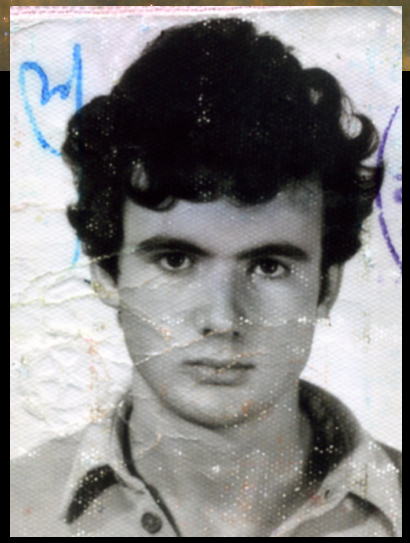


Stan Kurtz

Aina Palau

Luis Felipe Rodríguez

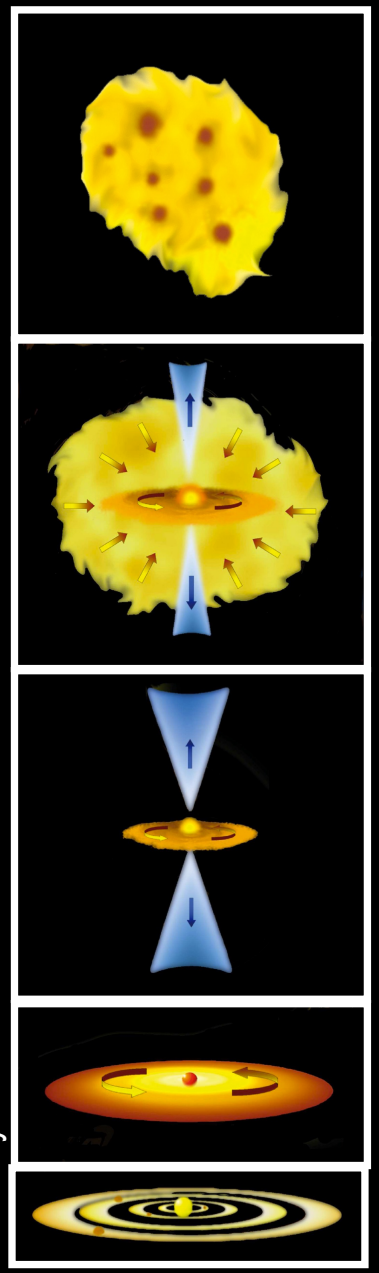
Josep Miquel Girart



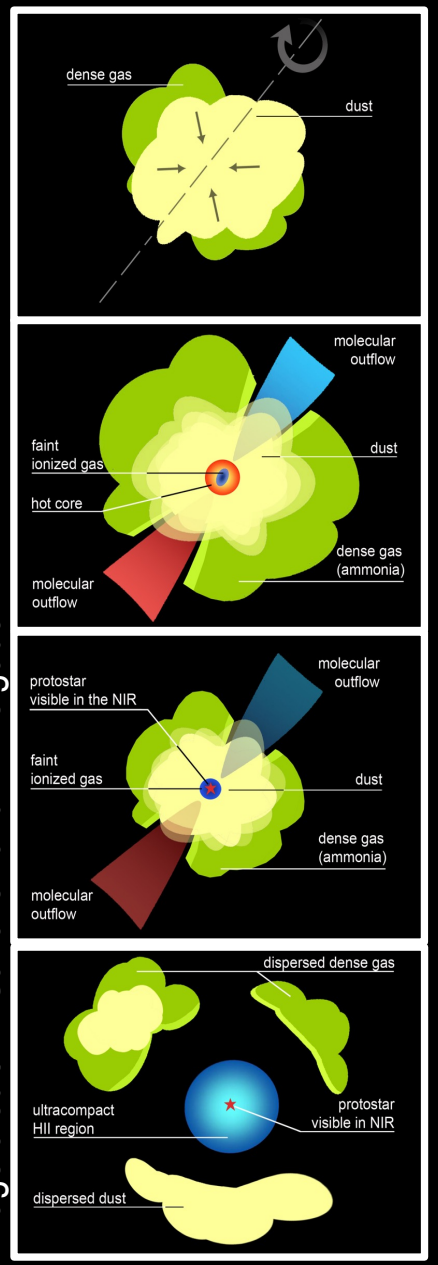
Riccardo a.k.a. “il Cesa”

low-mass

high-mass



Courtesy of L.Carbonaro and M.T. Beltrán



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final star massive star or cluster, HII regions
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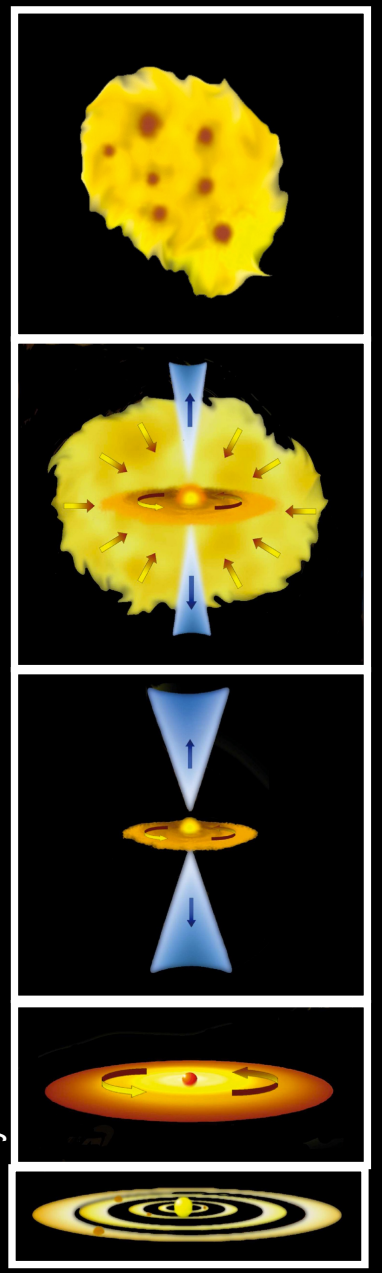
low-mass

high-mass



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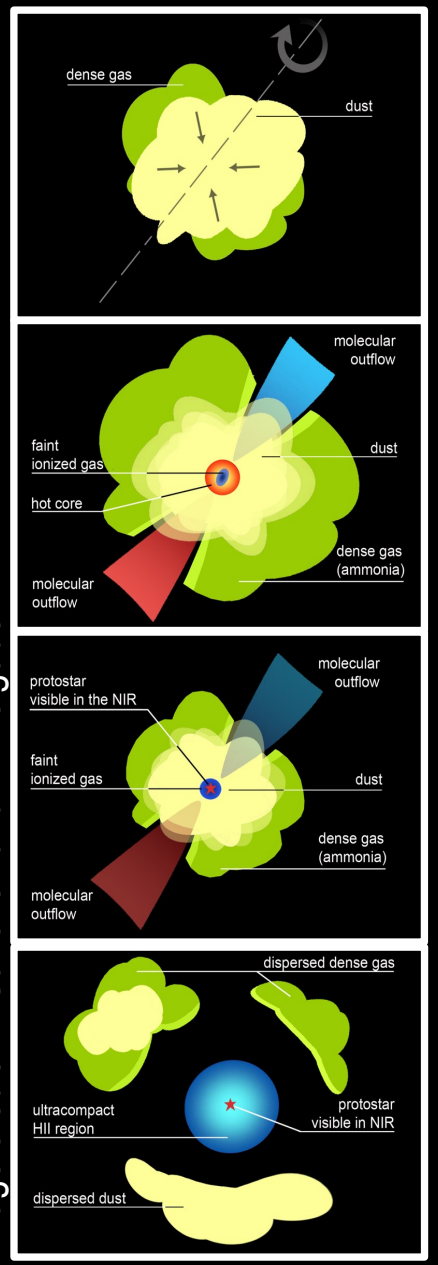

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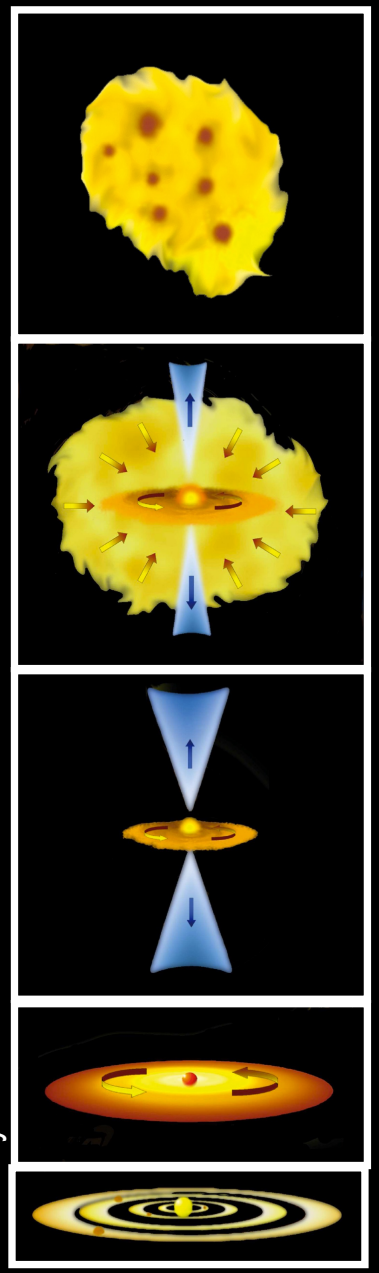

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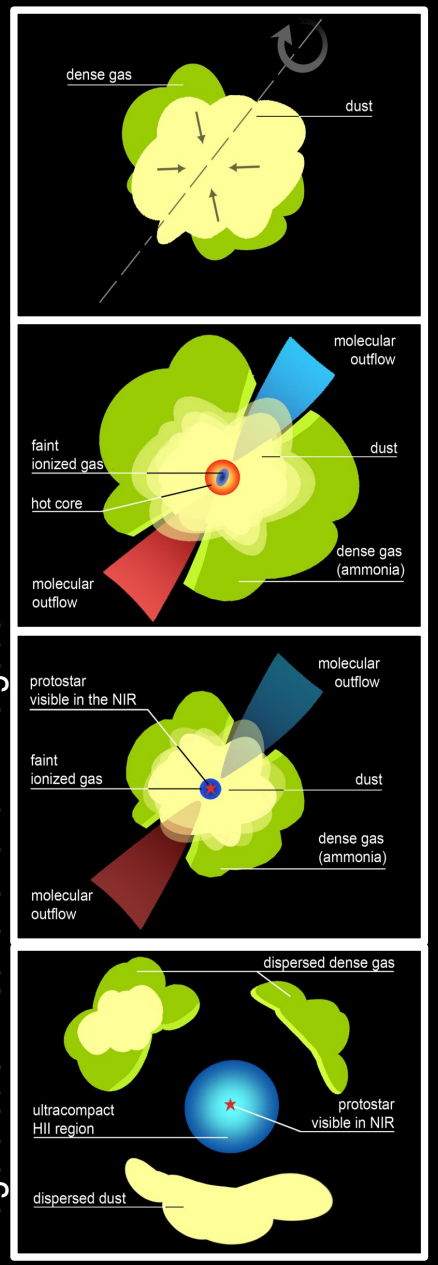

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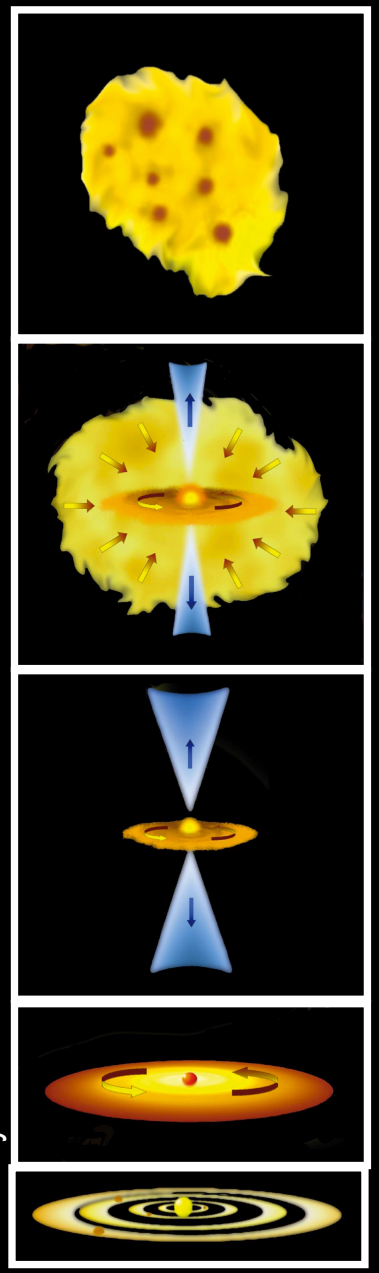

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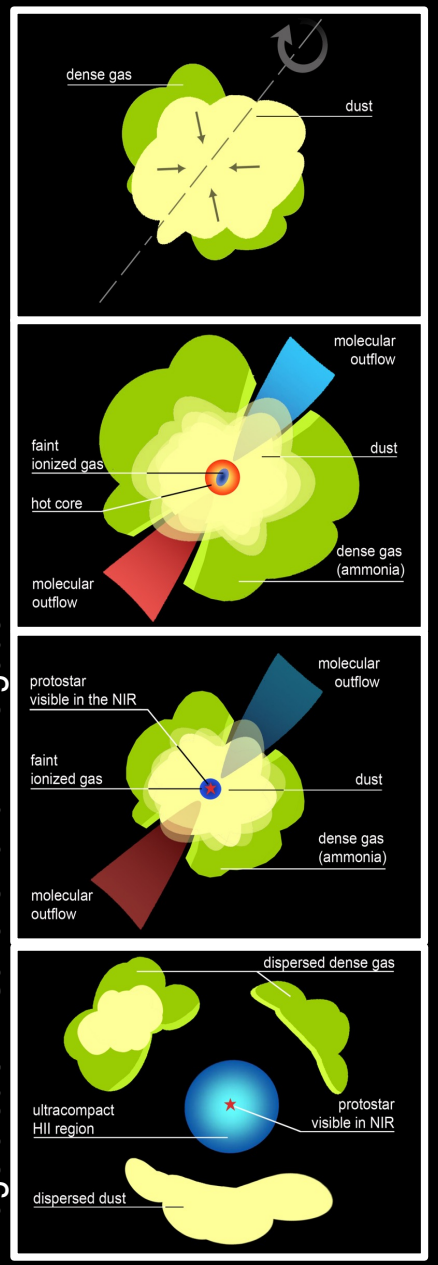

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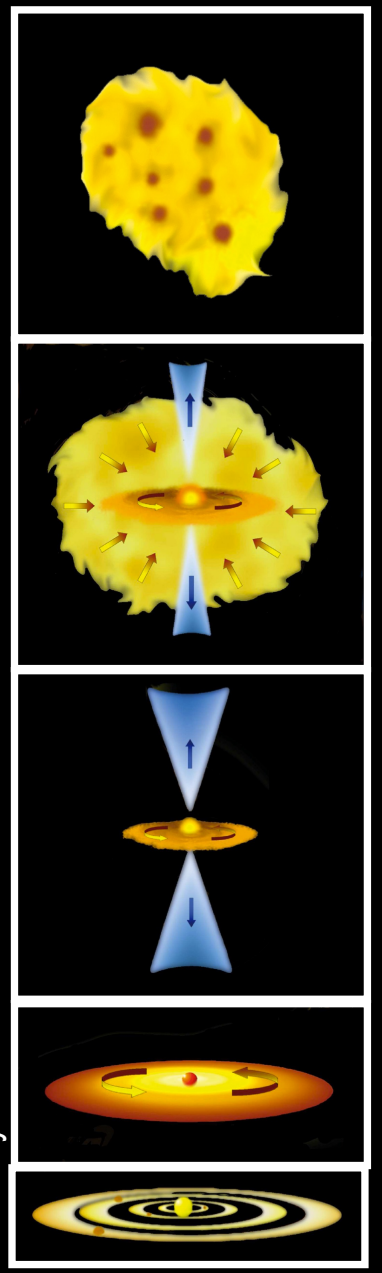

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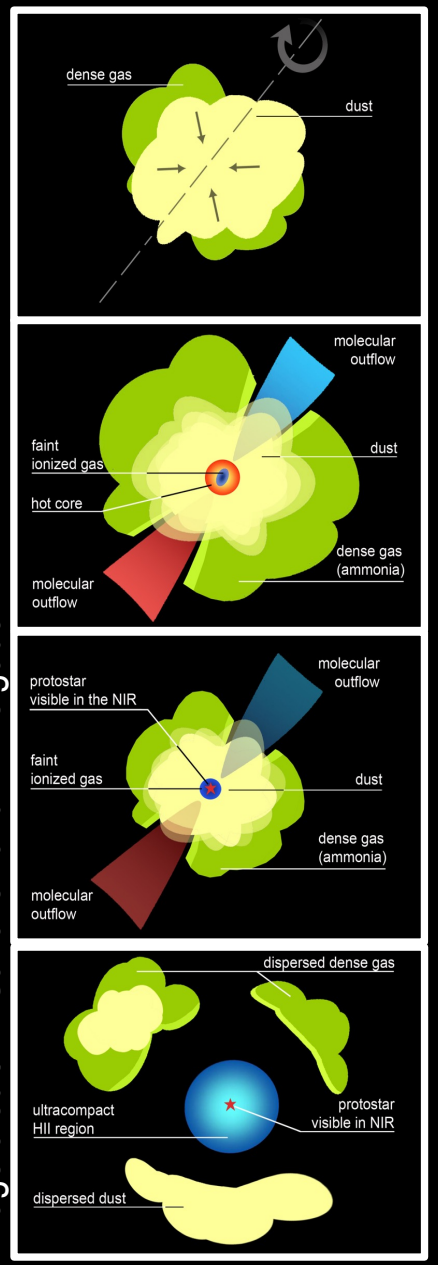

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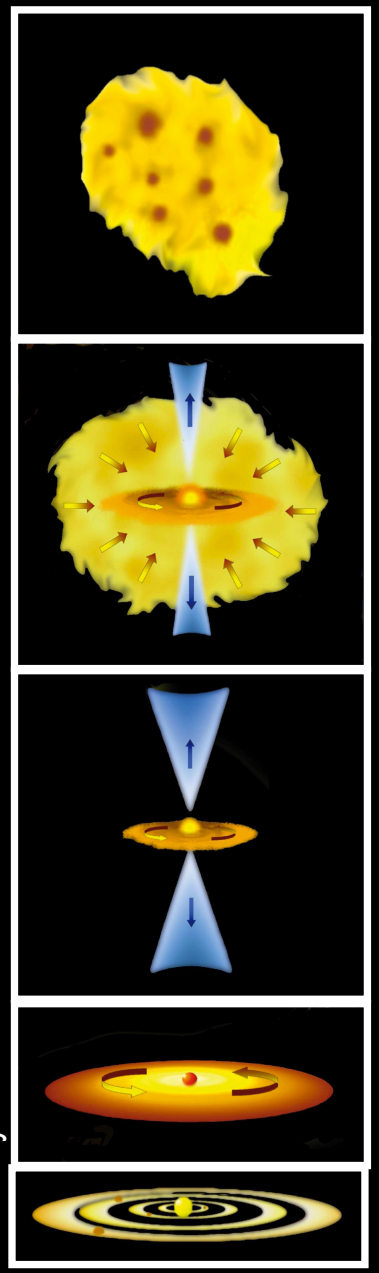

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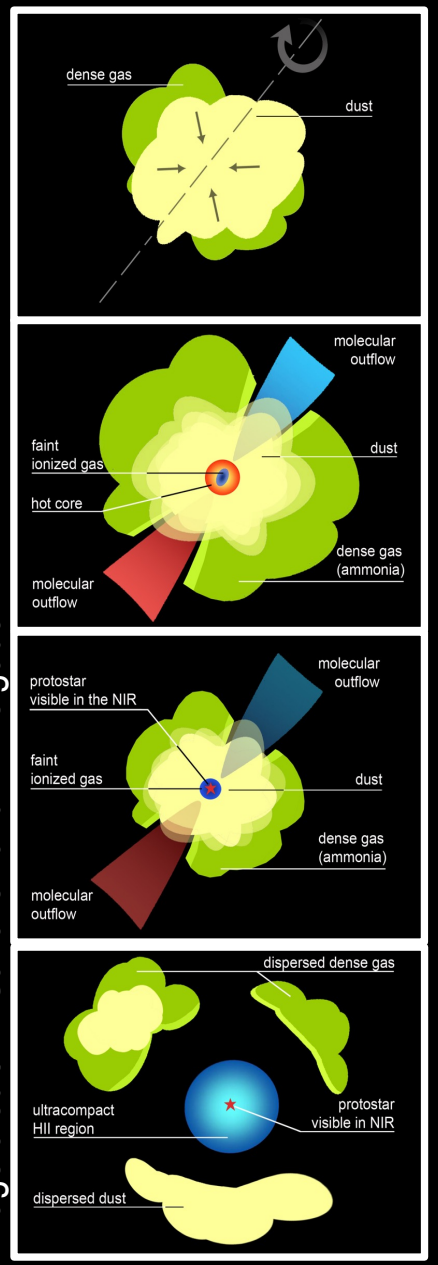

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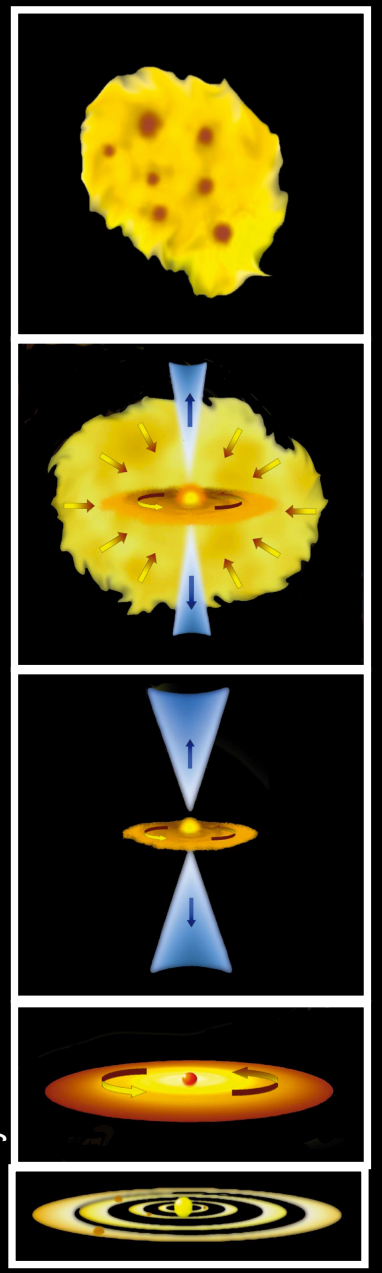

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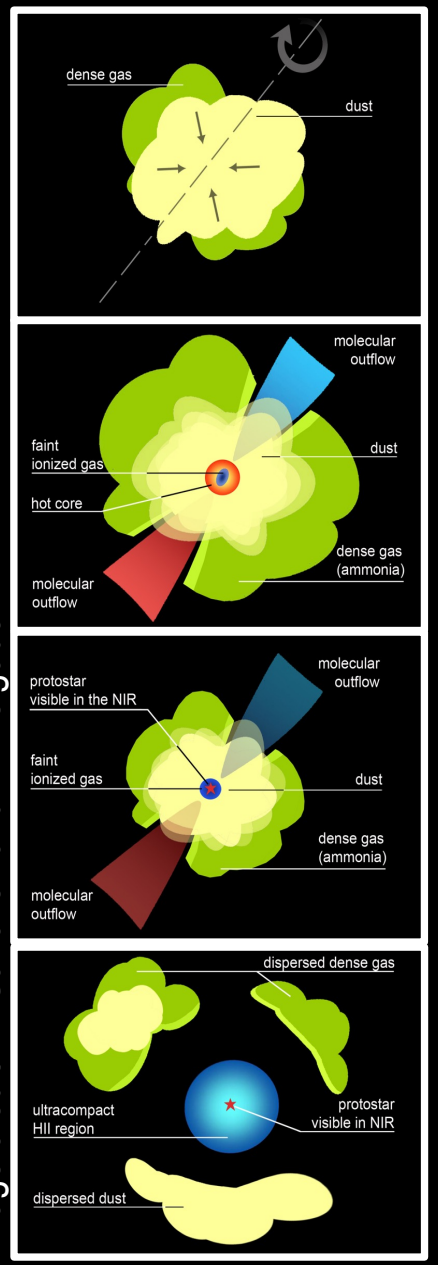

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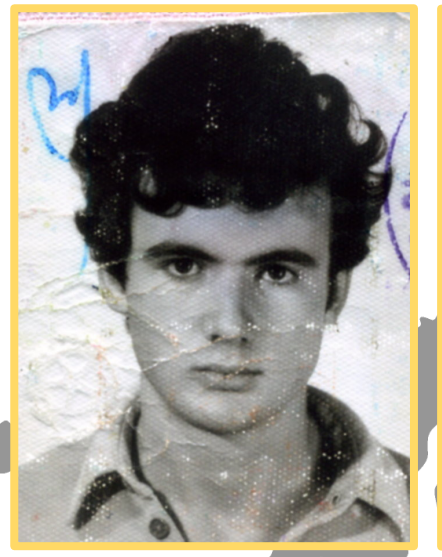
March 2011 – starting my postdoc at Arcetri



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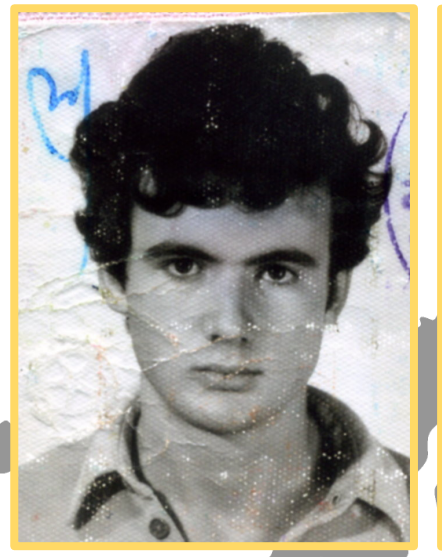
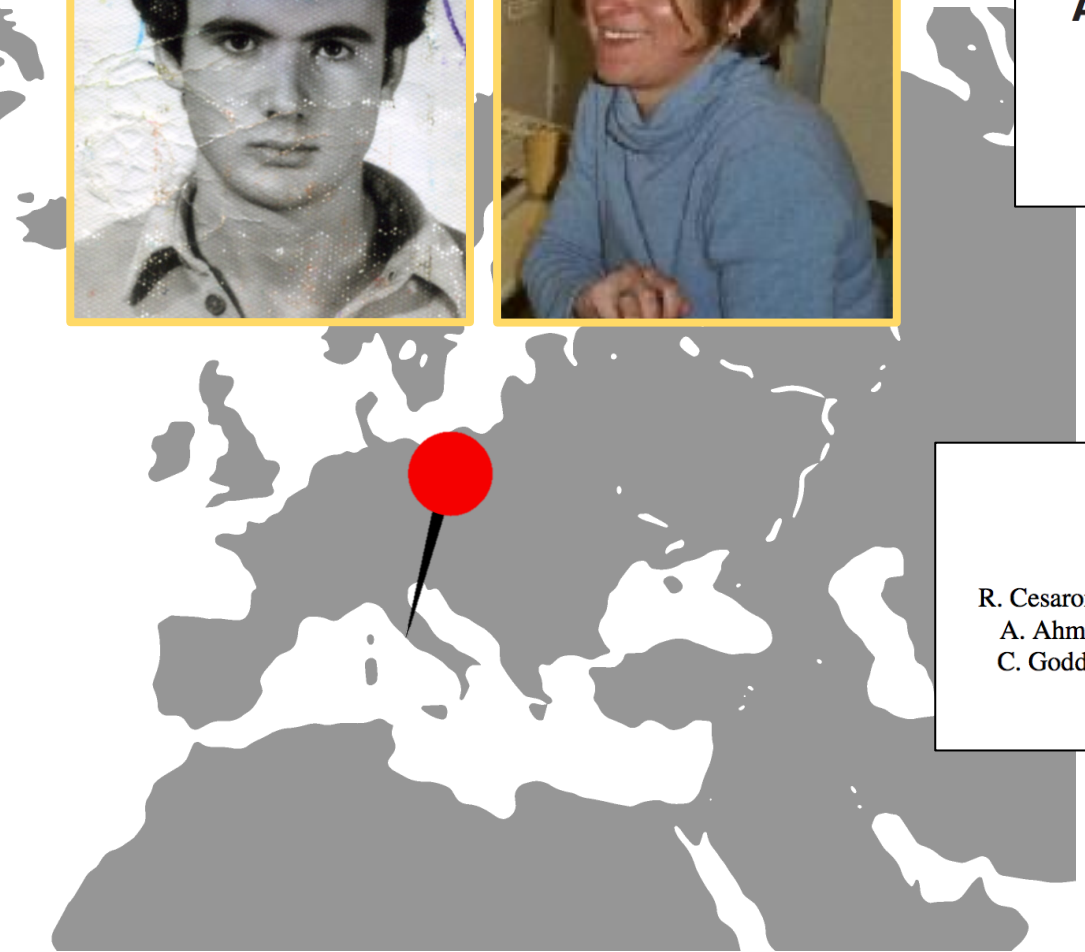




A candidate circumbinary Keplerian disk in G35.20–0.74 N: A study with ALMA

Á. Sánchez-Monge[1], R. Cesaroni[1], M. T. Beltrán[1], M. S. N. Kumar[2], T. Stanke[3], H. Zinnecker[4], S. Etoka[5,6], D. Galli[1], C. A. Hummel[3], L. Moscadelli[1], T. Preibisch[7], T. Ratzka[7], F. F. S. van der Tak[8,9], S. Vig[10], C. M. Walmsley[1,11], and K.-S. Wang[12]

A necklace of dense cores in the high-mass star forming region G35.20–0.74 N: ALMA observations★,★★

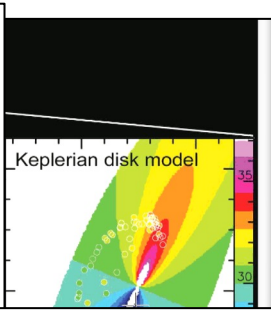
Á. Sánchez-Monge[1,2], M. T. Beltrán[2], R. Cesaroni[2], S. Etoka[3,4], D. Galli[2], M. S. N. Kumar[5], L. Moscadelli[2], T. Stanke[6], F. F. S. van der Tak[7,8], S. Vig[9], C. M. Walmsley[2,10], K.-S. Wang[11], H. Zinnecker[12], D. Elia[13], S. Molinari[13], and E. Schisano[14]

Filamentary structure and Keplerian rotation in the high-mass star-forming region G35.03+0.35 imaged with ALMA★

M. T. Beltrán[1], Á. Sánchez-Monge[1,2], R. Cesaroni[1], M. S. N. Kumar[3], D. Galli[1], C. M. Walmsley[1,4], S. Etoka[5,6], R. S. Furuya[7], L. Moscadelli[1], T. Stanke[8], F. F. S. van der Tak[9,10], S. Vig[11], K.-S. Wang[12,13], H. Zinnecker[14], D. Elia[15], and E. Schisano[16]

Chasing discs around O-type (proto)stars: Evidence from ALMA observations

R. Cesaroni[1], Á. Sánchez-Monge[2], M. T. Beltrán[1], K. G. Johnston[3], L. T. Maud[4], L. Moscadelli[1], J. C. Mottram[5], A. Ahmadi[5], V. Allen[6], H. Beuther[5], T. Csengeri[7], S. Etoka[8], G. A. Fuller[9,10], D. Galli[1], R. Galván-Madrid[11], C. Goddi[12,4], T. Henning[5], M. G. Hoare[13], P. D. Klaassen[14], R. Kuiper[15], M. S. N. Kumar[16,17], S. Lumsden[18], T. Peters[19], V. M. Rivilla[1], P. Schilke[2], L. Testi[20,1], F. van der Tak[21,6], S. Vig[22], C. M. Walmsley[23,1], and H. Zinnecker[24]

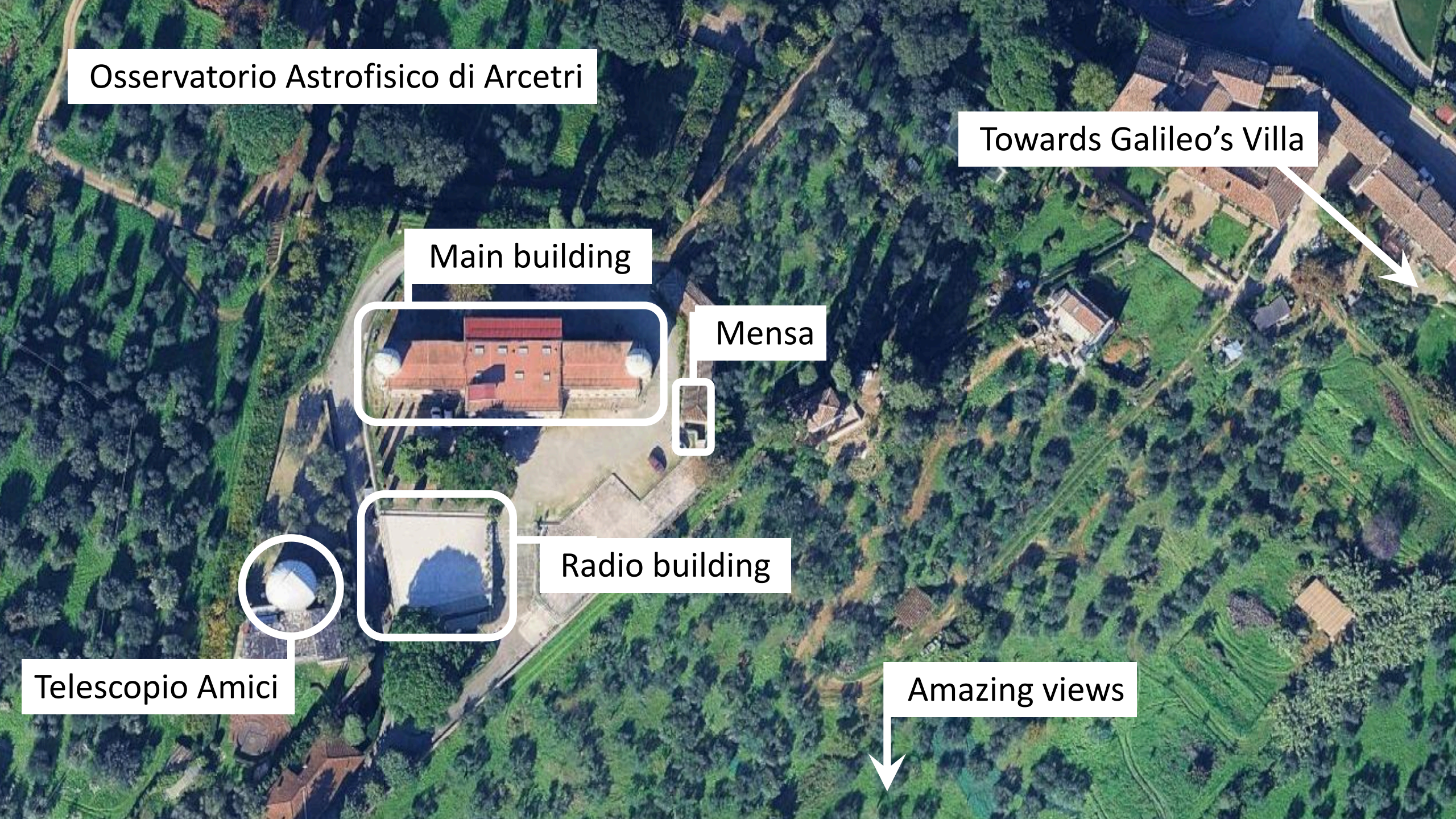


Revealing the dynamics of Class 0 protostellar discs with ALMA

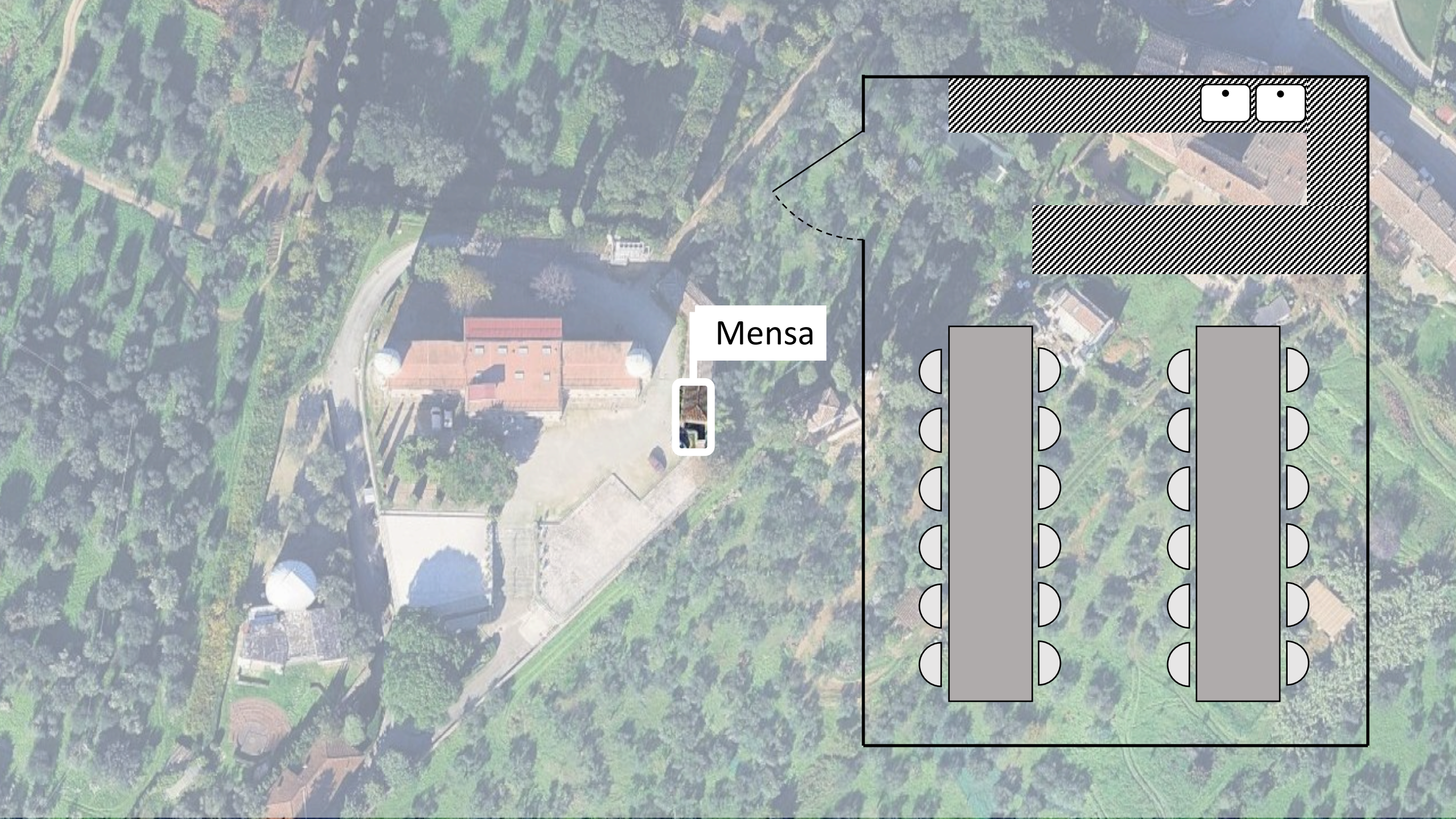
D. Seifried,[1,2★] Á. Sánchez-Monge,[1] S. Walch[1] and R. Banerjee[2]

[1]*I. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany*

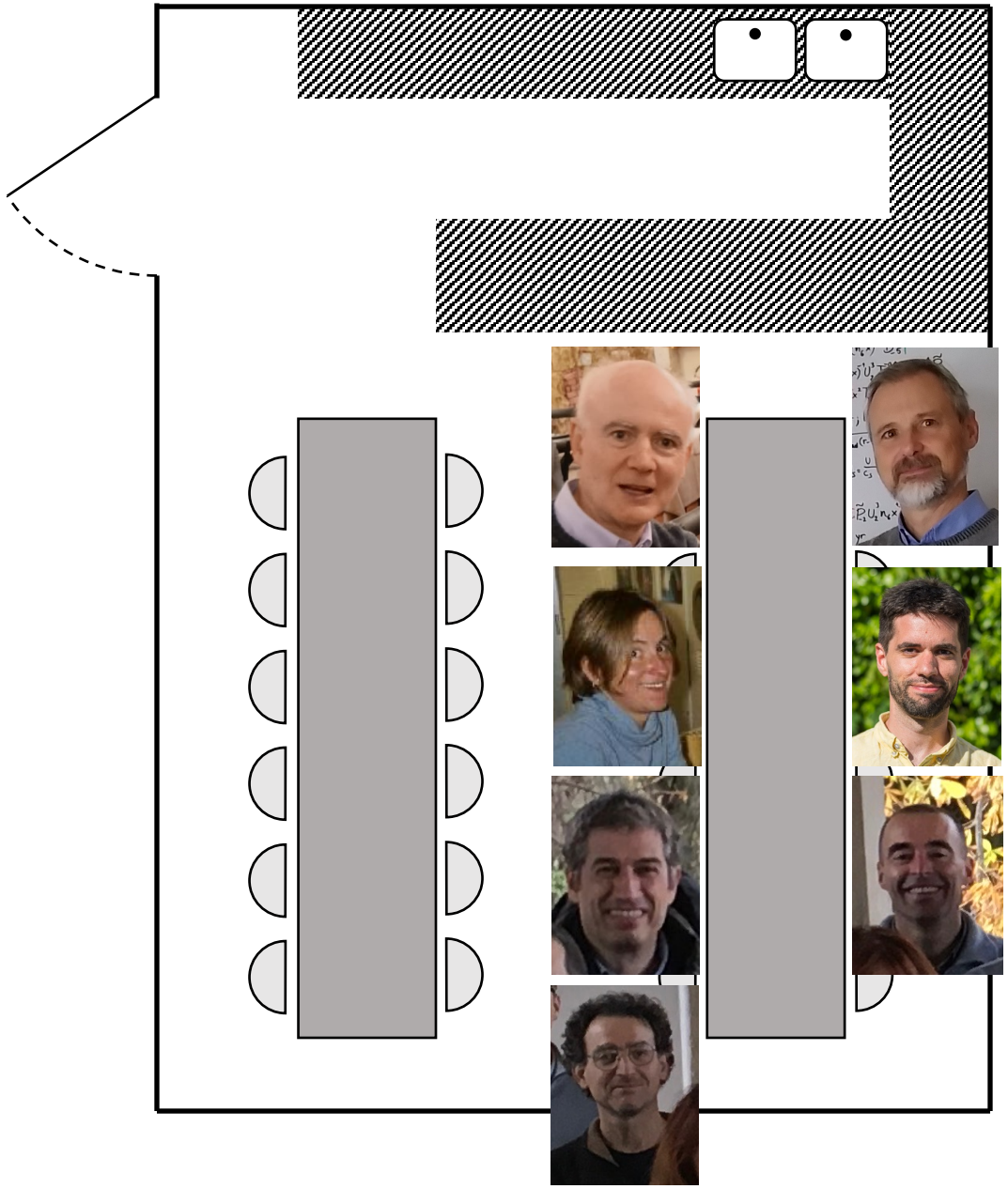
Some memories from my stay in Arcetri (with Riccardo)…


Osservatorio Astrofisico di Arcetri
Towards Galileo's Villa
Main building
Mensa
Radio building
Telescopio Amici
Amazing views


Mensa


Mensa

13:00



13:00


Freshly Dead
A Muscle Dead


MONDIALI 1990
1982
ITALY

PRATIEGHI
frazione di Badia Tedalda
50


PRINCIPE


EMILIA-R
LIGURIA
Massa-Carrara
Monte Prado
Alpi Apuane
Carrara
Massa
Serchio
Lucca
Pistola
Pistoia
Viareggio
Montalbano
Prato
Arno
Pisa
Monte Pisano
Gorgona
Livorno
Chianti
TUSCANY
Siena
Colline Metallifere
Ombrone
Amiata
Grosseto
Golfo di Follonica
Elba
Capraia
MARCHE
UMBRIA
Pisa
Firenze
Siena
Arezzo


DANONE

Some memories from my stay in Arcetri (with Riccardo)…

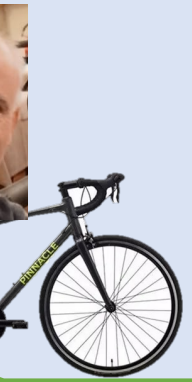
… bicycle tours


STRYDER


PINNACLE

Buff! I am dying.

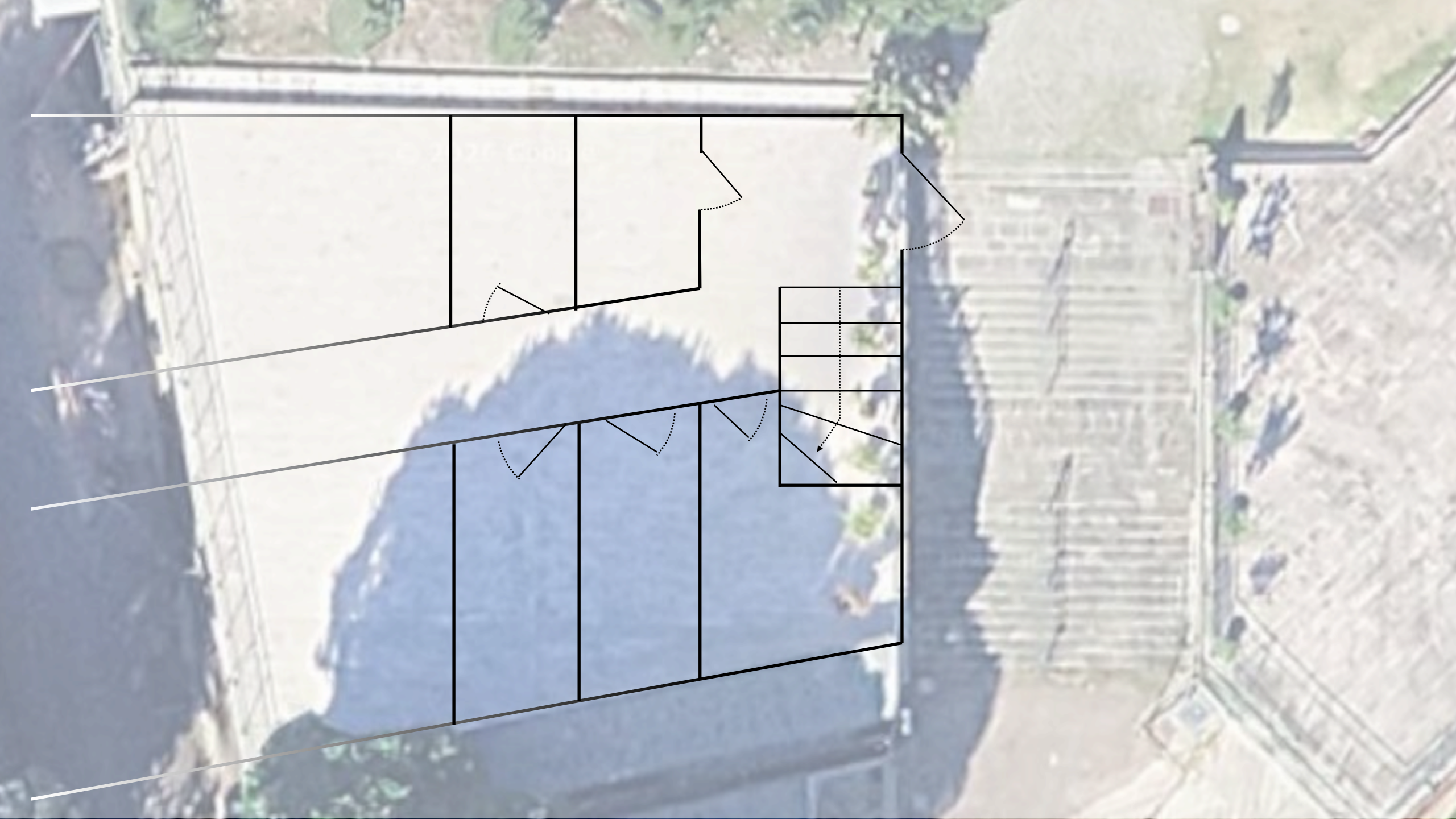
Tomorrow, I will not be able to move

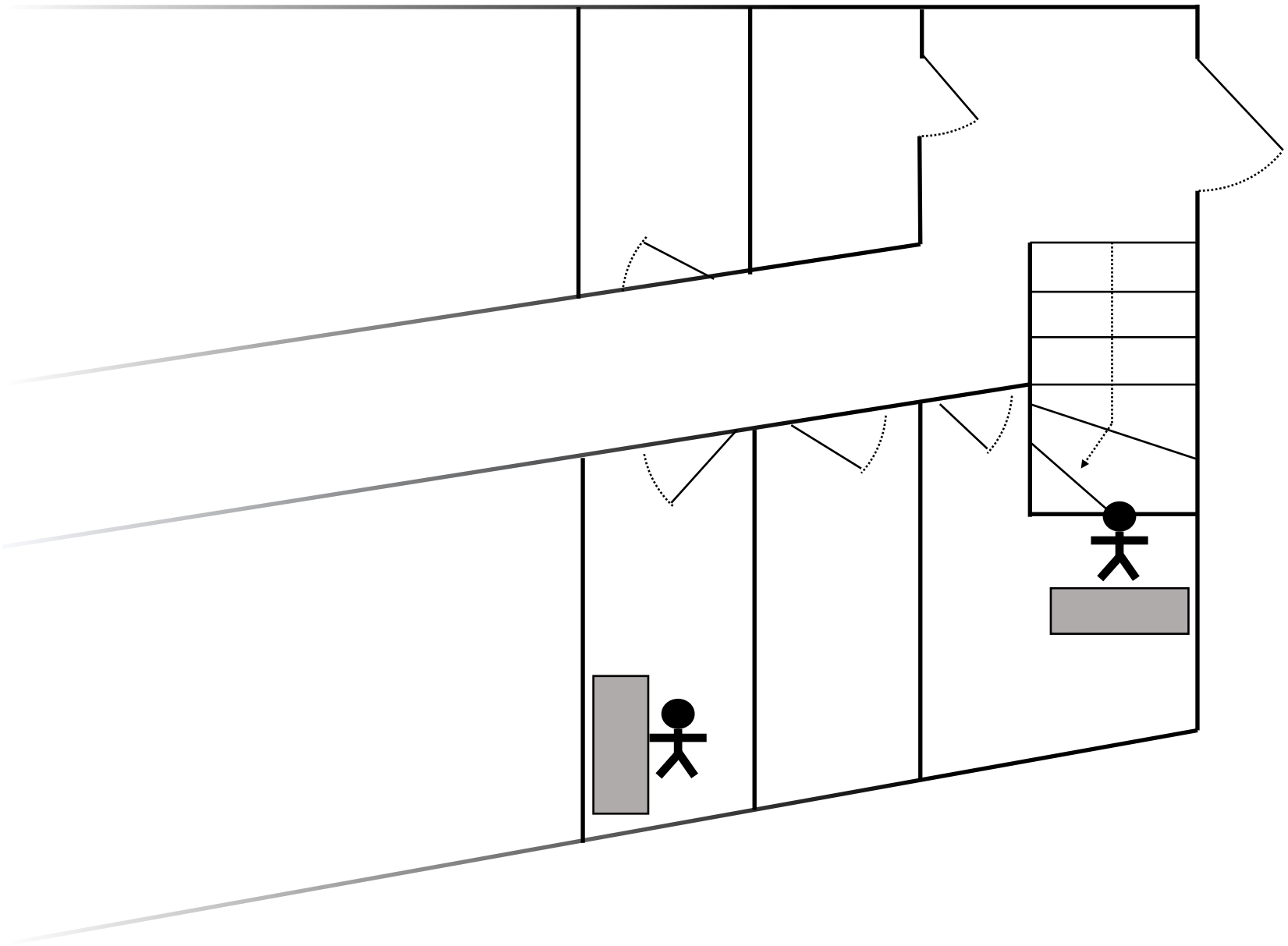


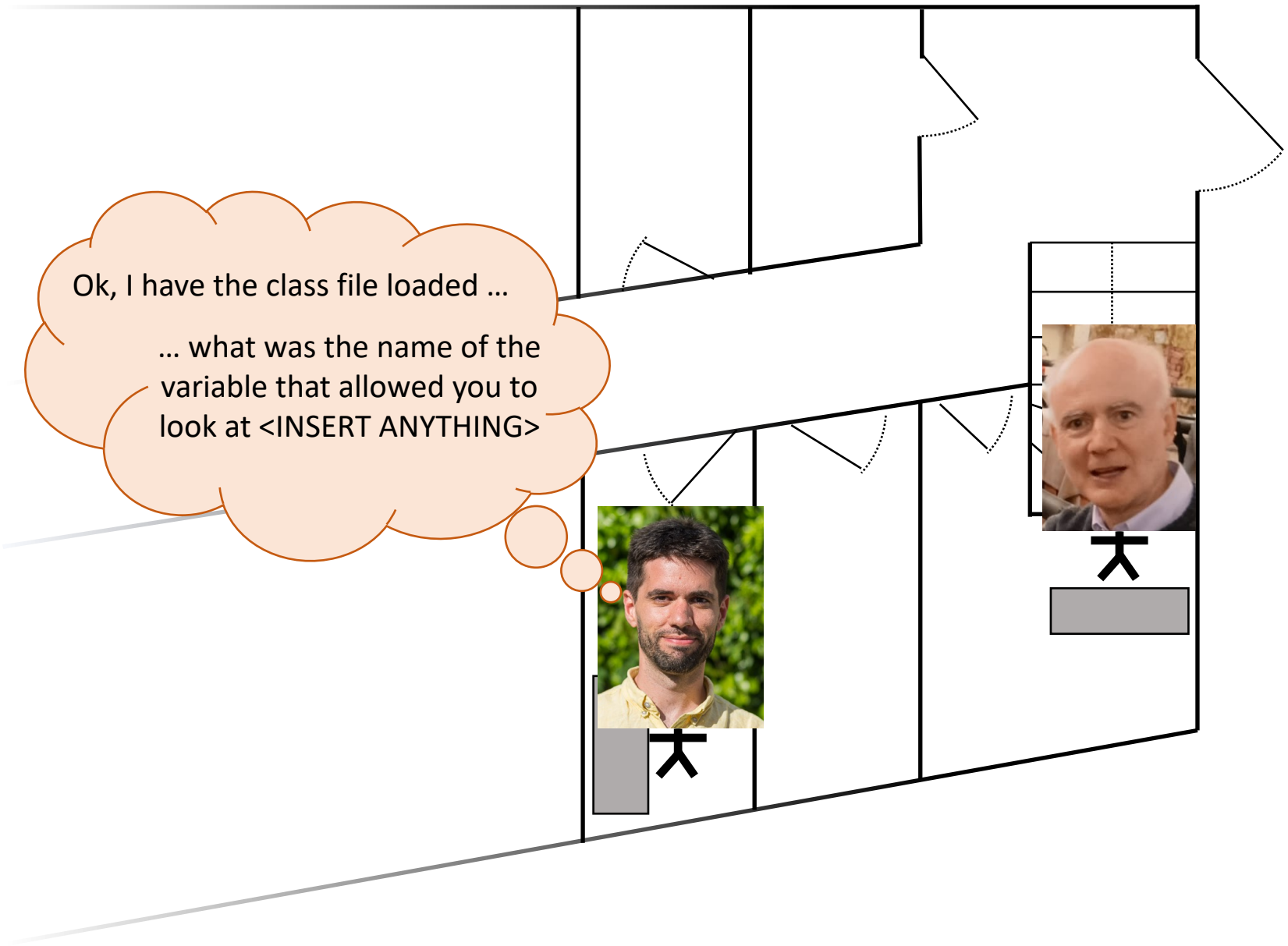
Some memories from my stay in Arcetri (with Riccardo)…

… working time

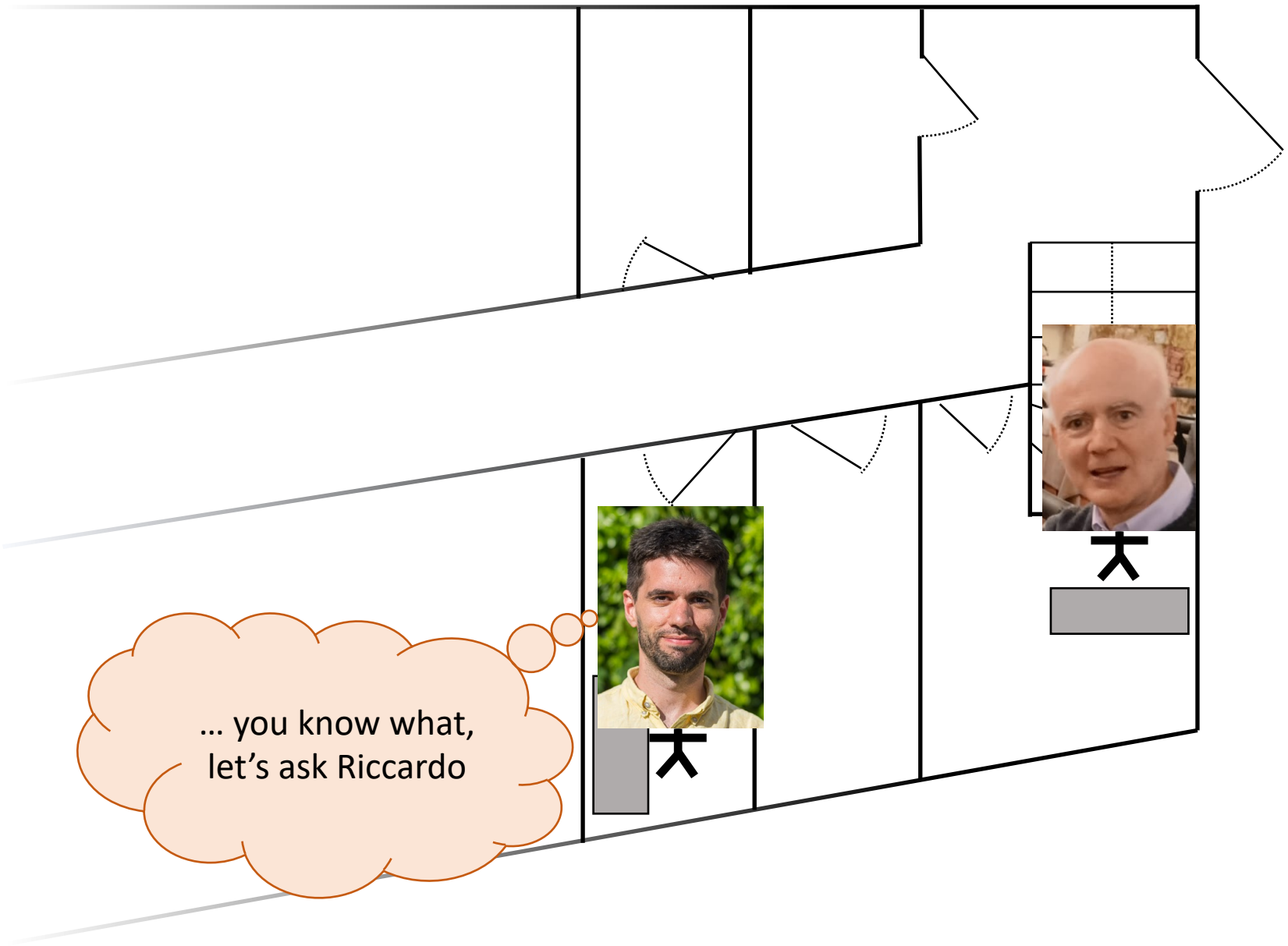
Radio building



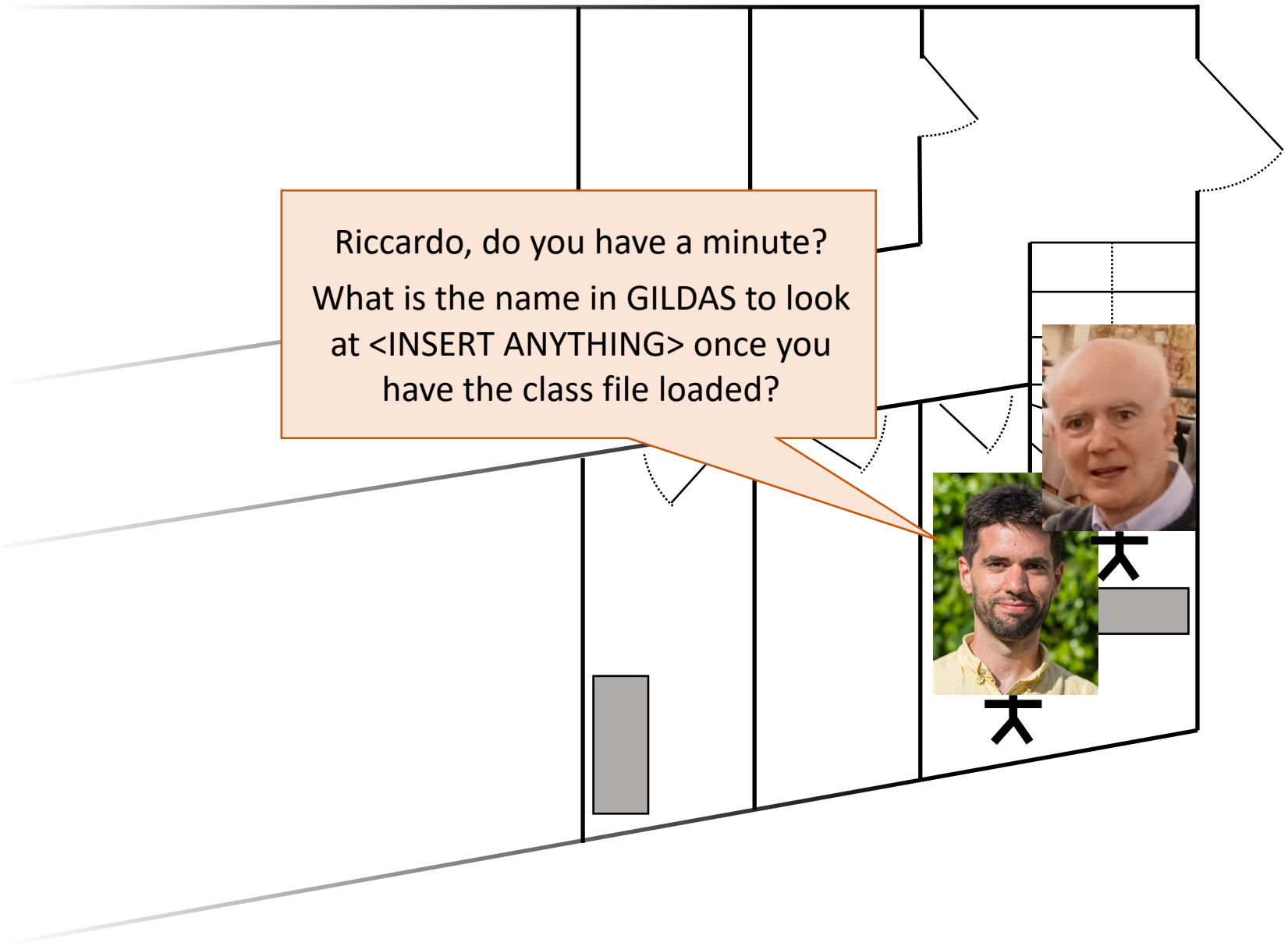



Ok, I have the class file loaded …
… what was the name of the variable that allowed you to look at <INSERT ANYTHING>

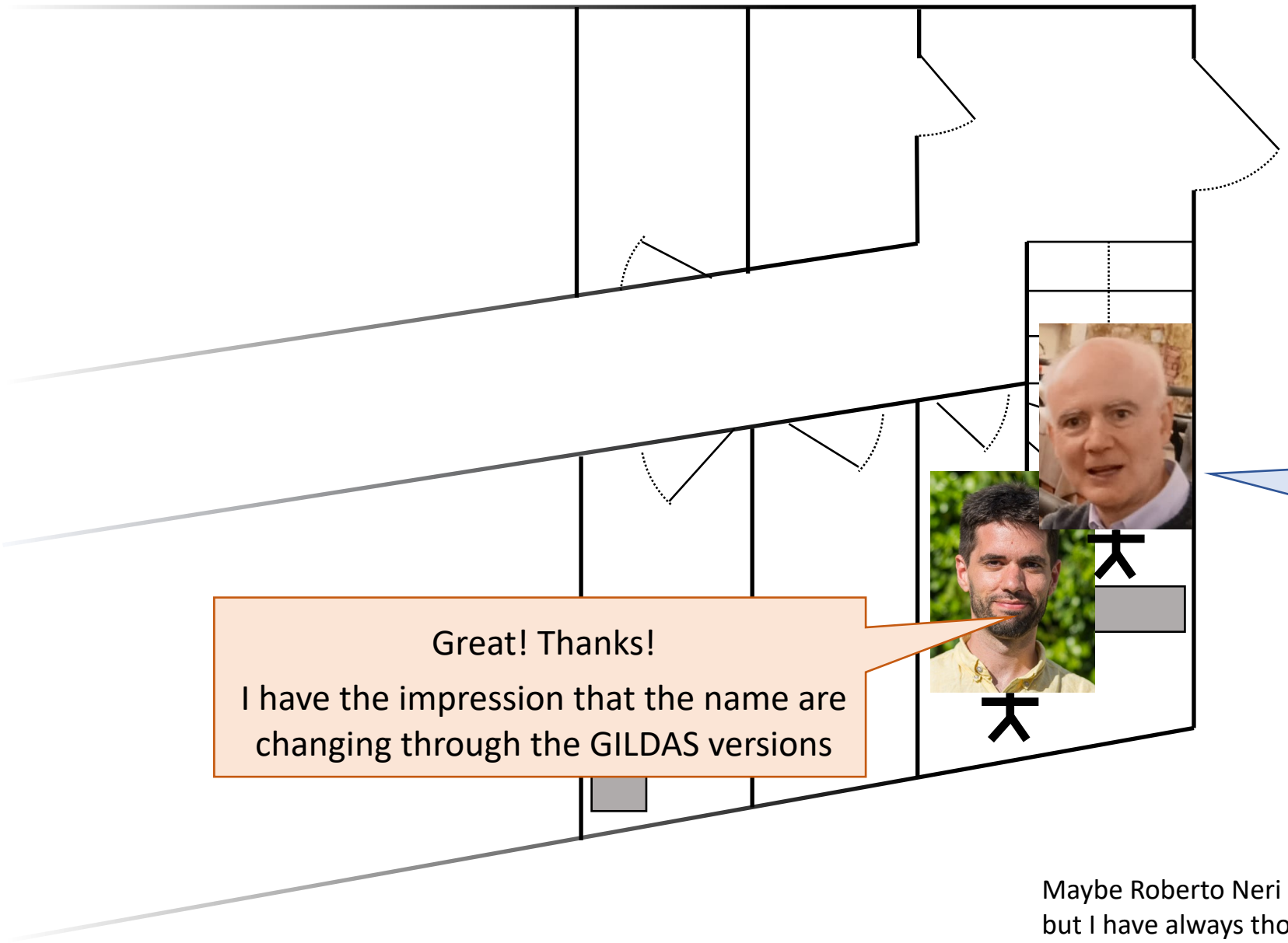
15:52



15:52


Riccardo, do you have a minute?
What is the name in GILDAS to look at <INSERT ANYTHING> once you have the class file loaded?

15:53



Sure! Come in

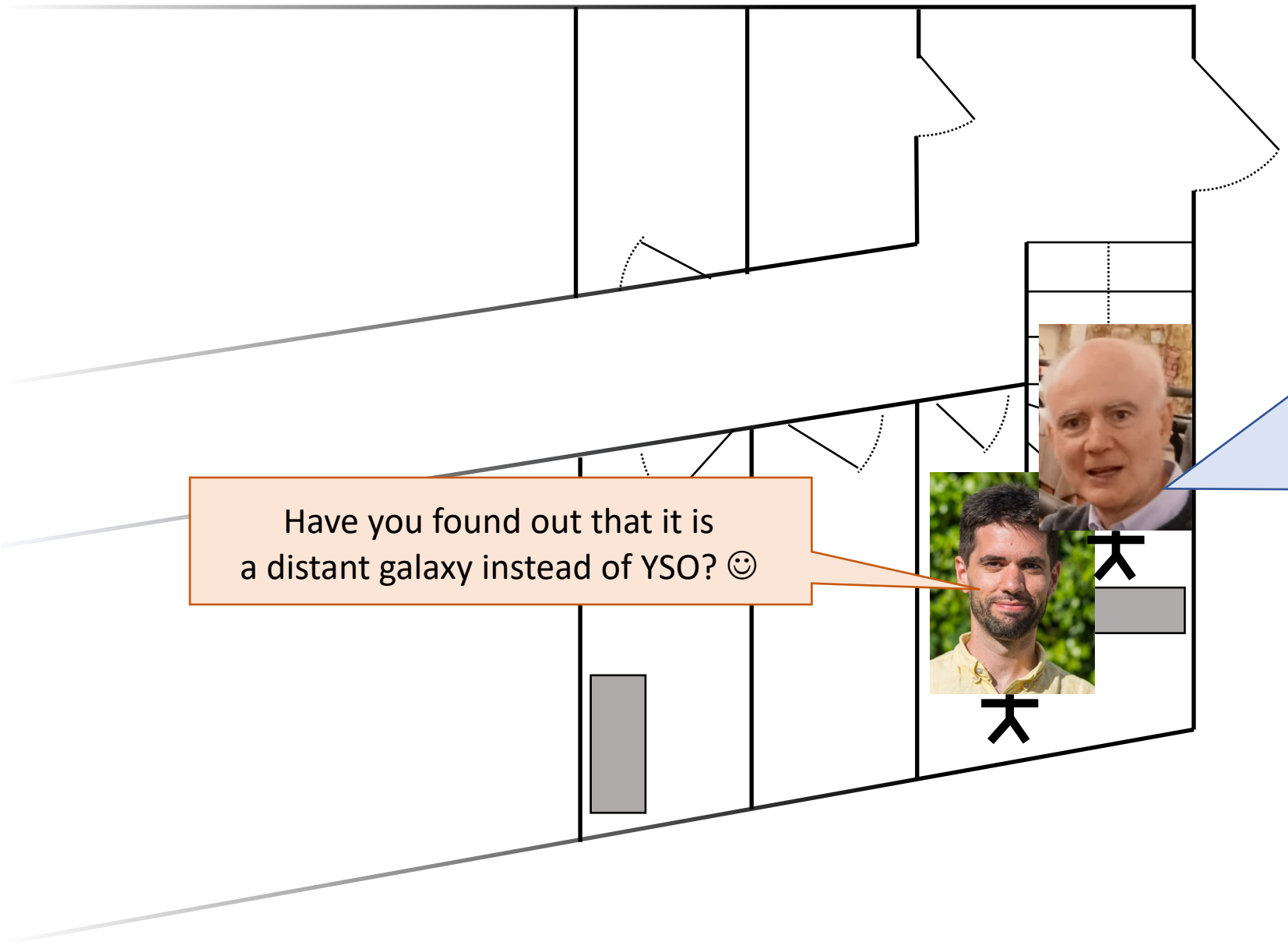
The name of the variable is
<INSERT CORRECT ANSWER>

Great! Thanks!

I have the impression that the name are changing through the GILDAS versions

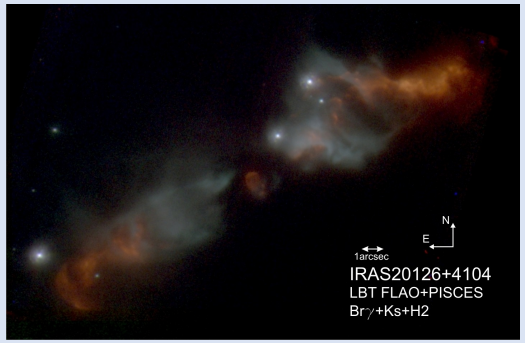
Maybe Roberto Neri can confirm this,
but I have always thought that Riccardo is the secret developer of GILDAS

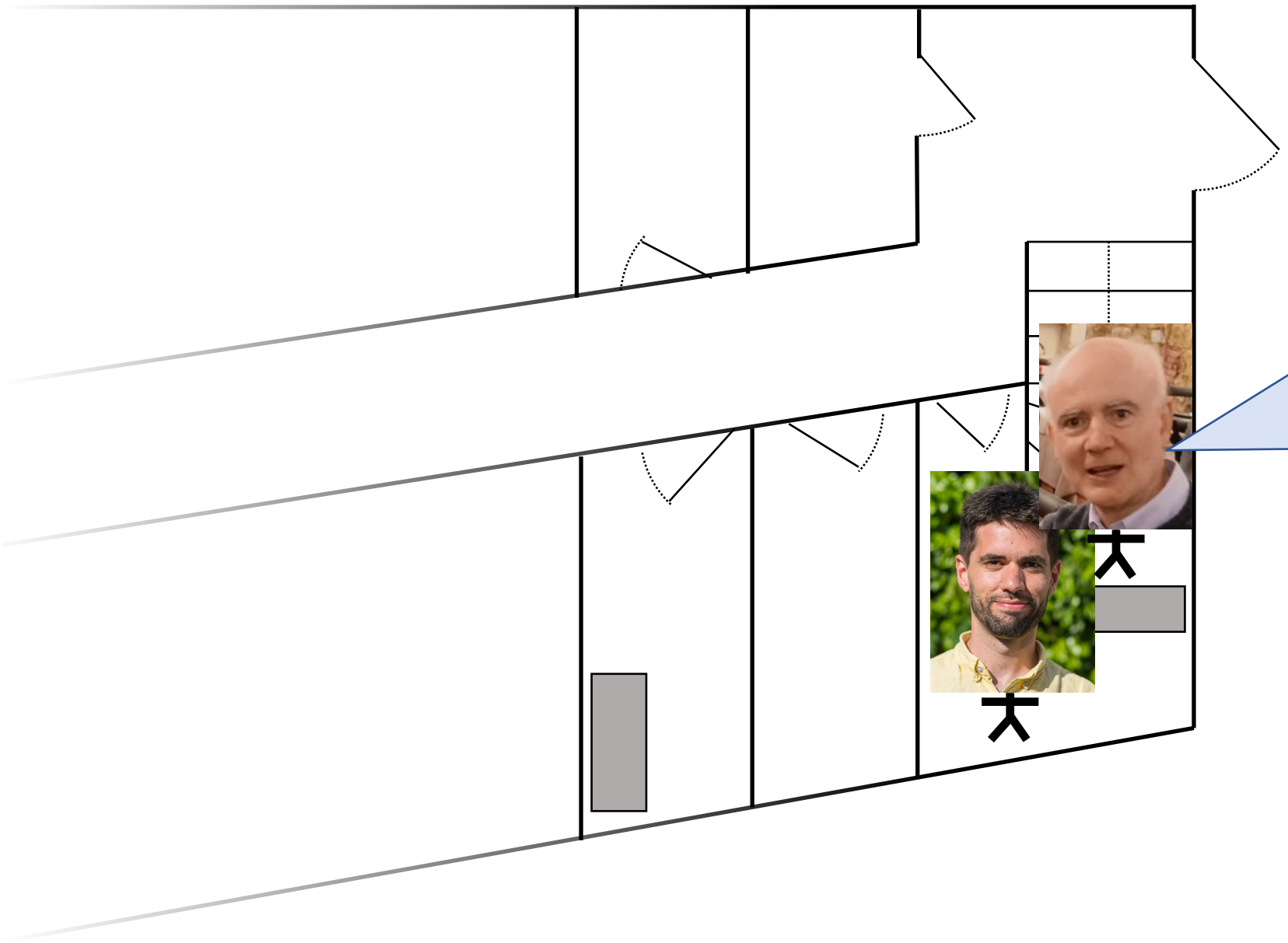
15:54



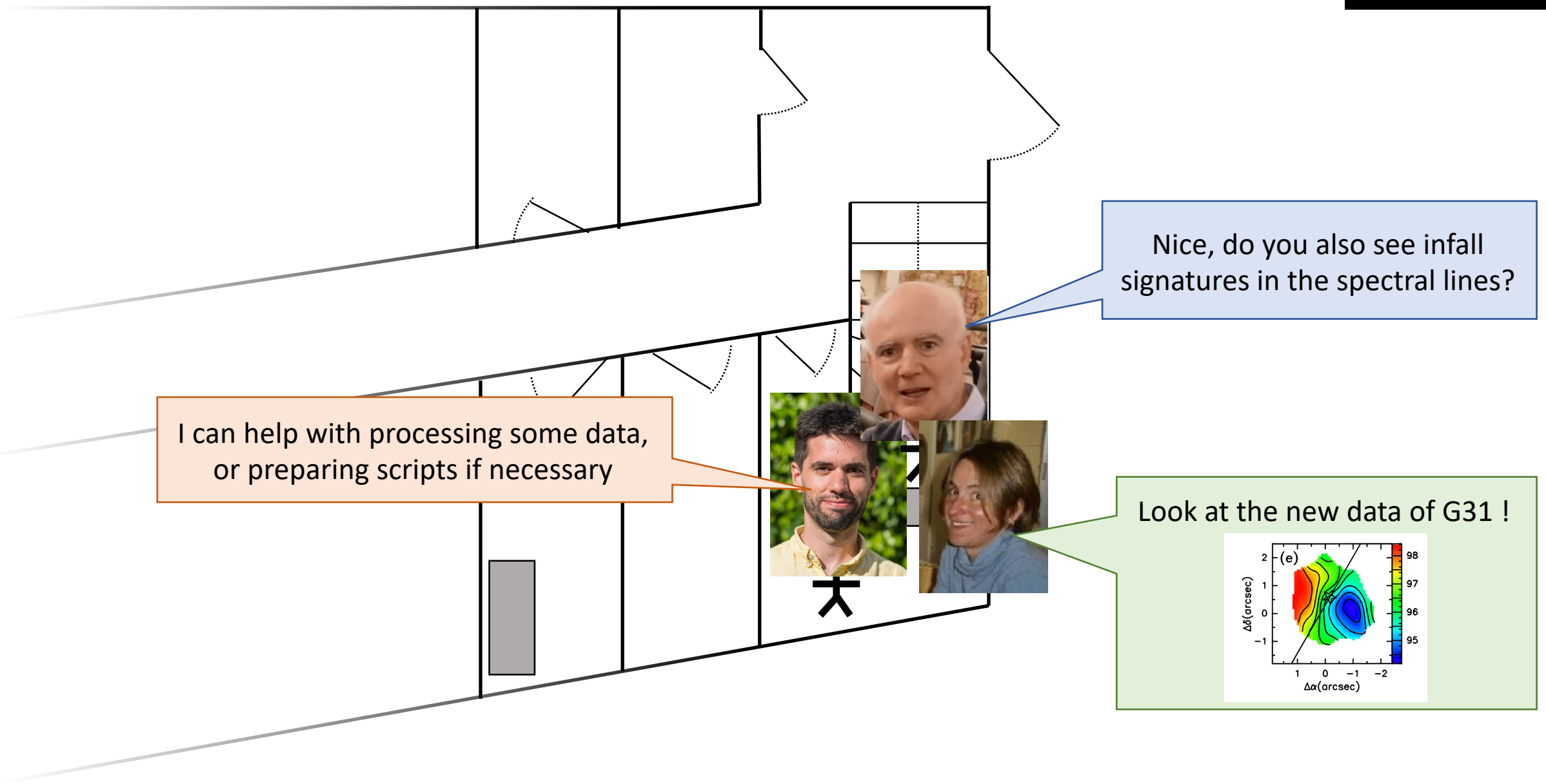
Have you found out that it is
a distant galaxy instead of YSO? ☺

By the way, let me show you
the new images of
IRAS 20126+4104




16: 19
How do you say this word <INSERT WORD> in Spanish?
We do not have to mix AVISPA con OVISPO
Have you seen these <INSERT FUNNY IMAGES/TEXTS>

16:53

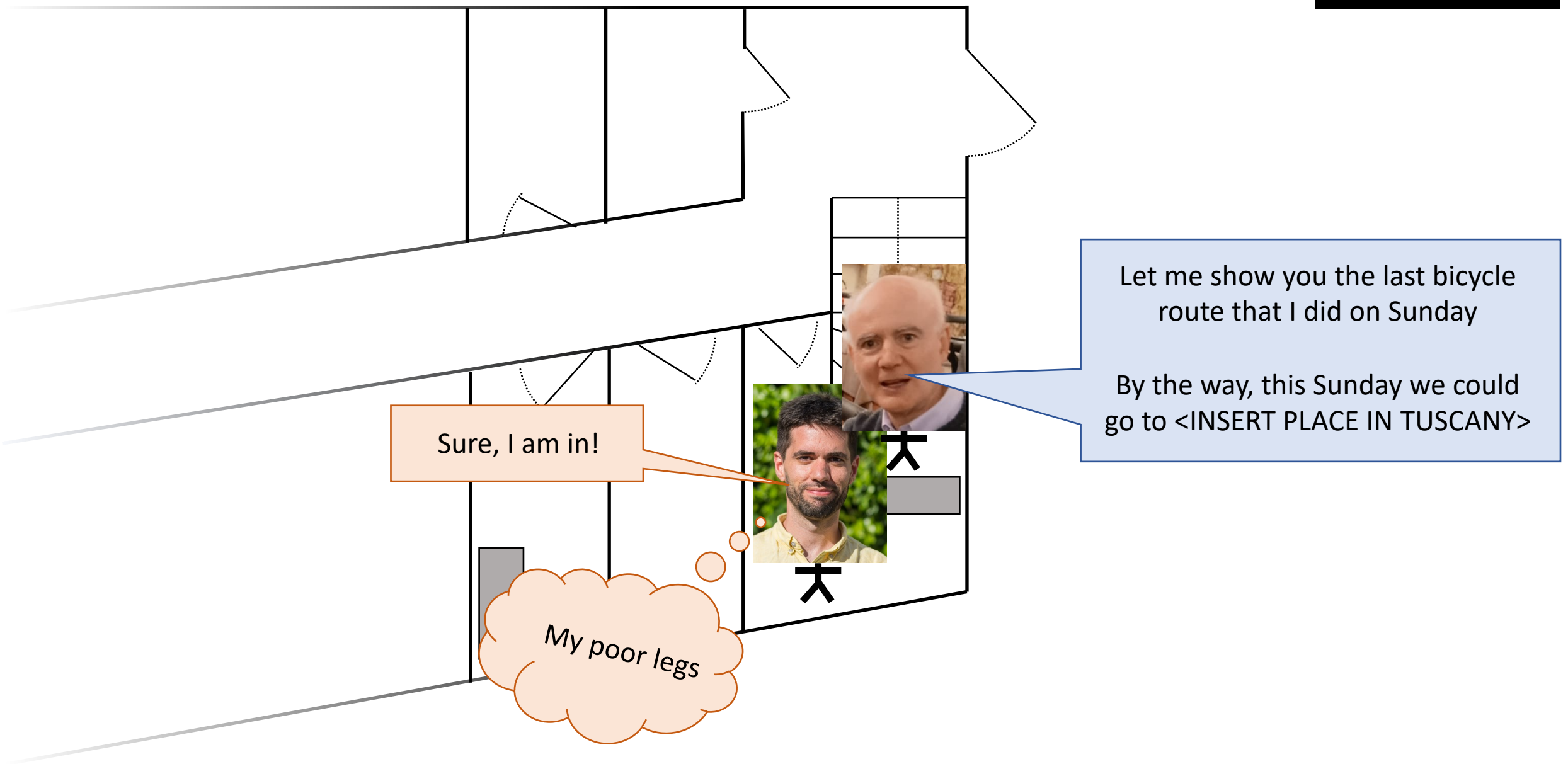


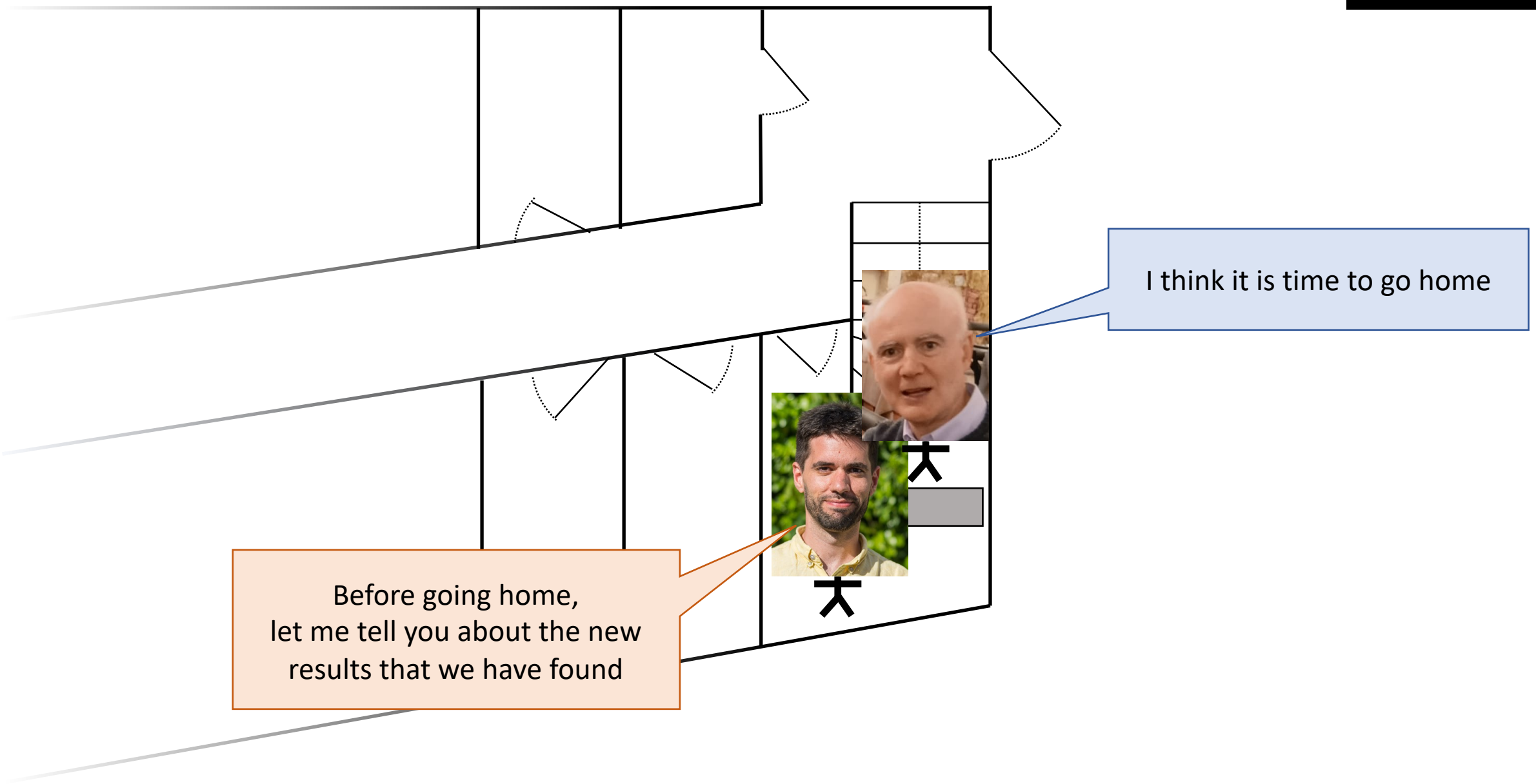
Nice, do you also see infall signatures in the spectral lines?

I can help with processing some data, or preparing scripts if necessary

Look at the new data of G31 !

18:26


Let me show you the last bicycle route that I did on Sunday
By the way, this Sunday we could go to <INSERT PLACE IN TUSCANY>
Sure, I am in!
My poor legs


19:37
I think it is time to go home
Before going home,
let me tell you about the new
results that we have found

The disk and the jet of the massive protostar ~~IRAS 20126+4104~~ W75N(B)-VLA3

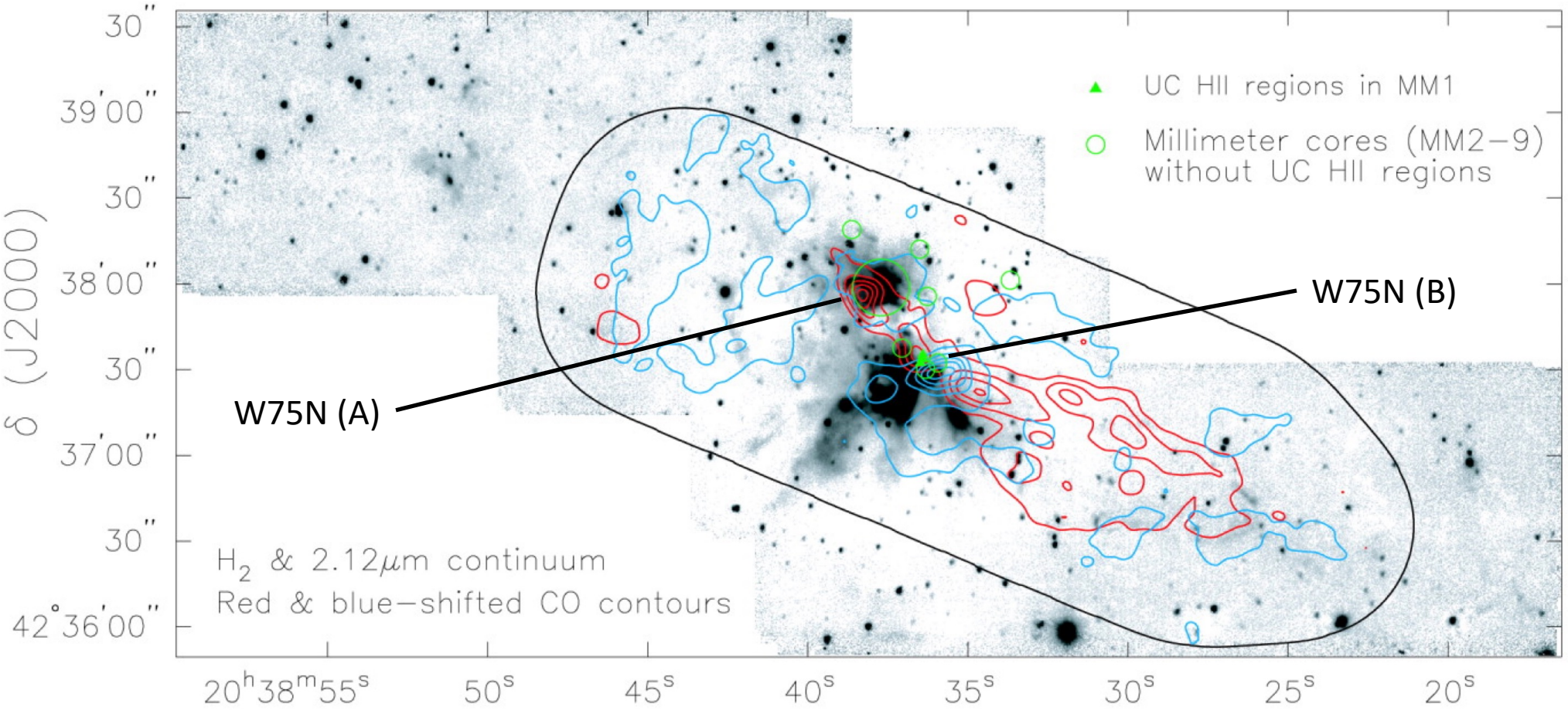
W75N star forming complex

- Distance: 1.3 kpc
- Luminosity: 10^5 $L_\odot$
- Large and massive molecular outflow
- Rich maser activity: H_2O, CH_3OH, OH masers

The properties of W75N are similar to your source

IRAS 20126+4104 is more isolated

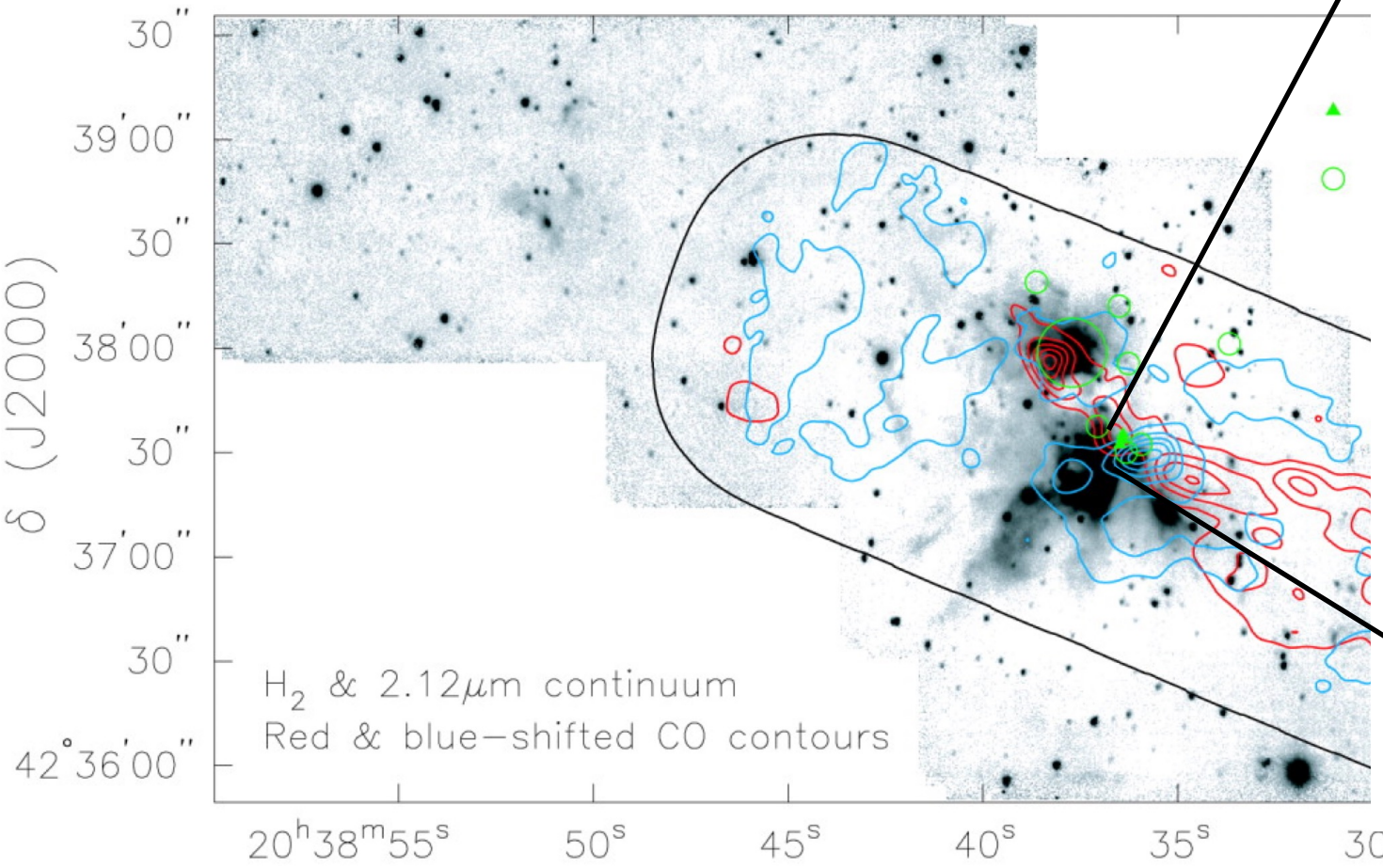
Haschick+1981; Hunter+1994; Torrelles+1997; Minier+2000; Slysh+2002; Hutawarakorn+2002; Shepherd+2003; Persi+2003; Surcis+2009, 2023; Carrasco-Gonzalez+2010; Kim+2013; Rodriguez-Kamenetzky+2020; …



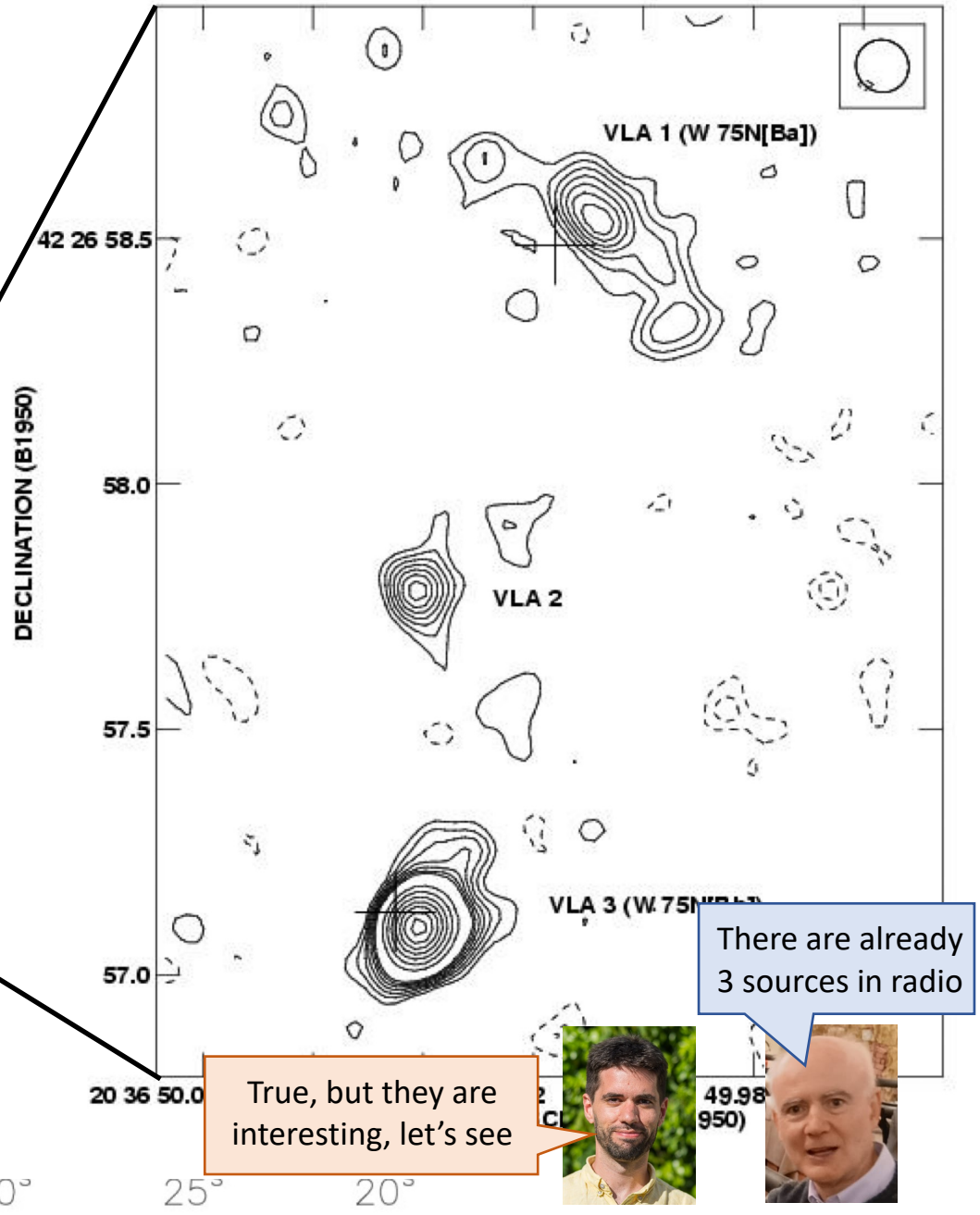
W75N star forming complex

- Distance: 1.4 kpc
- Luminosity: 10^5 $L_\odot$
- Large and massive molecular outflow
- Rich maser activity: H_2O, CH_3OH, OH masers

Haschick+1981; Hunter+1994; Torrelles+1997; Minier+2000; Slysh+2002; Hutaw
Persi+2003; Surcis+2009, 2023; Carrasco-Gonzalez+2010; Kim+2013; Rodriguez-K



W75N (B)



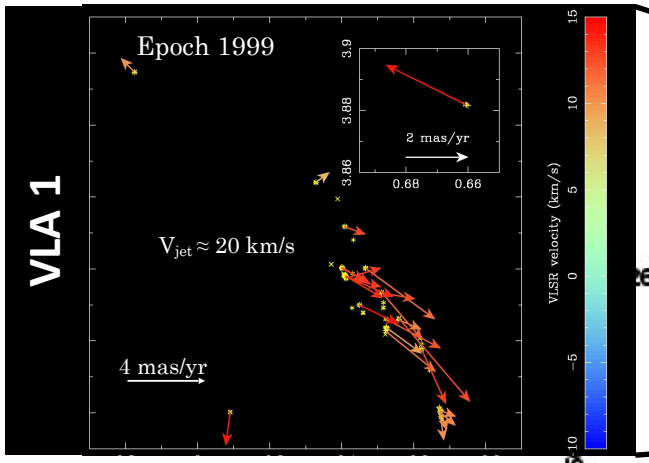
True, but they are interesting, let's see

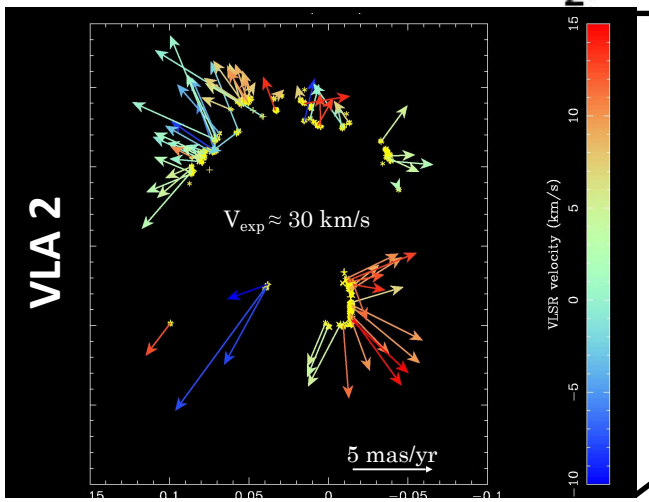
There are already 3 sources in radio

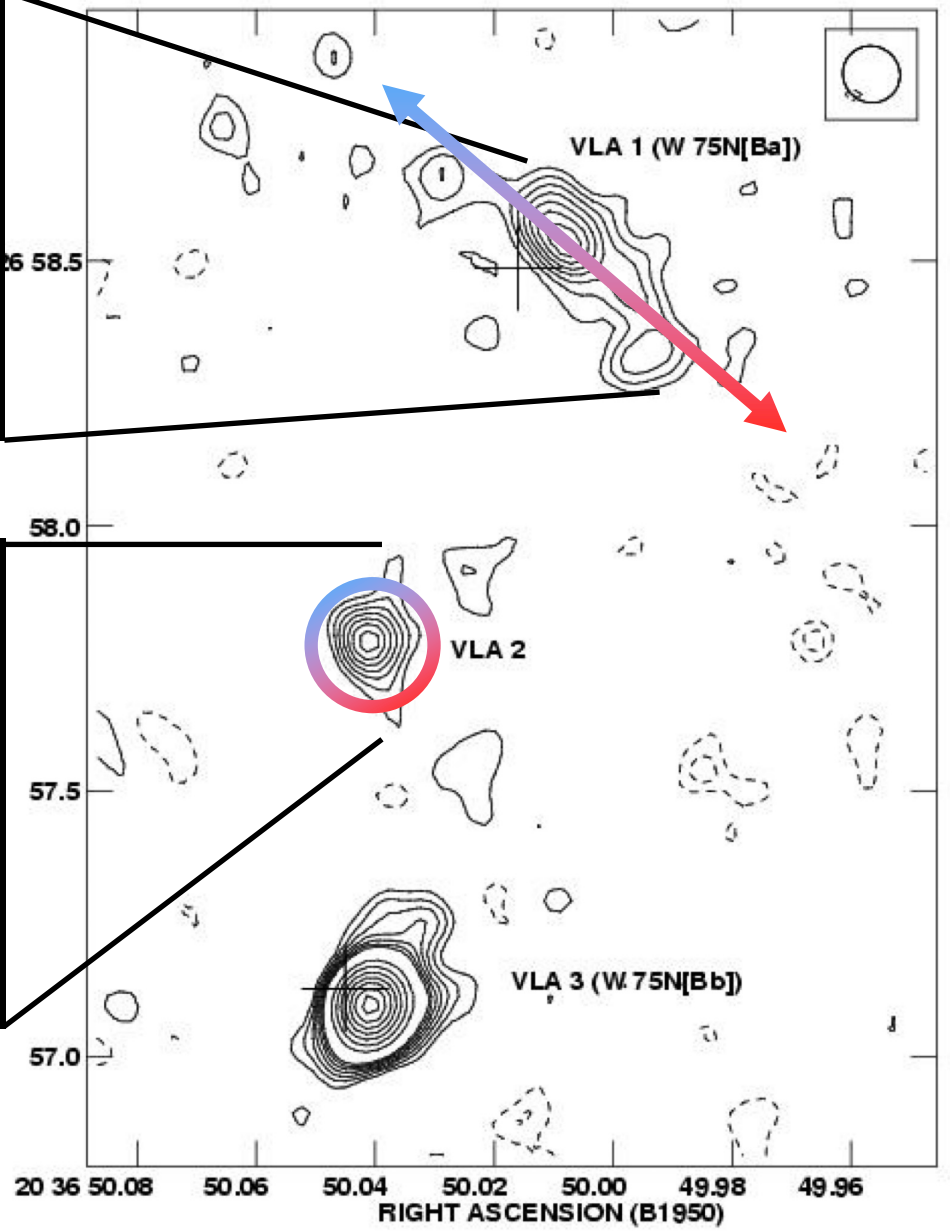
W75N (B)

Interesting maser motions, different for each source

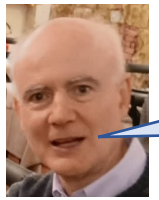
[see Ciriaco's and Chema's talks]





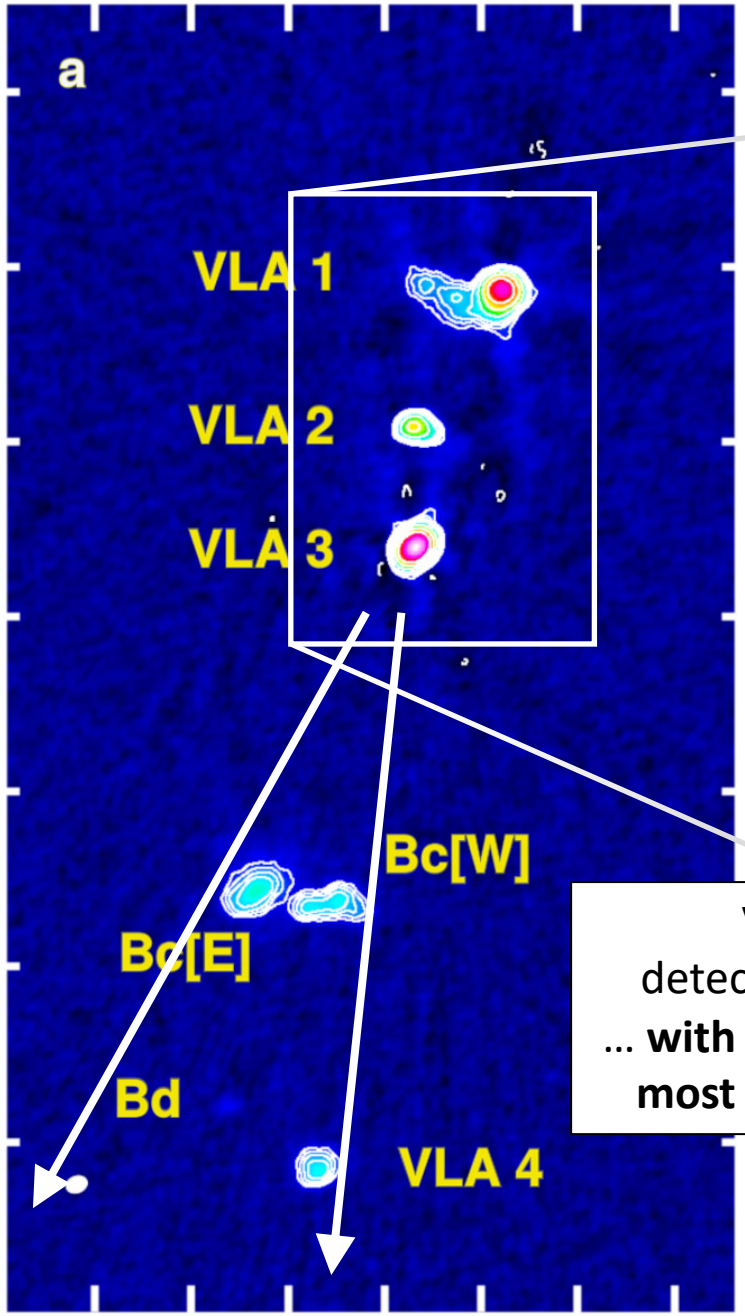


Nice, there are lots of masers!

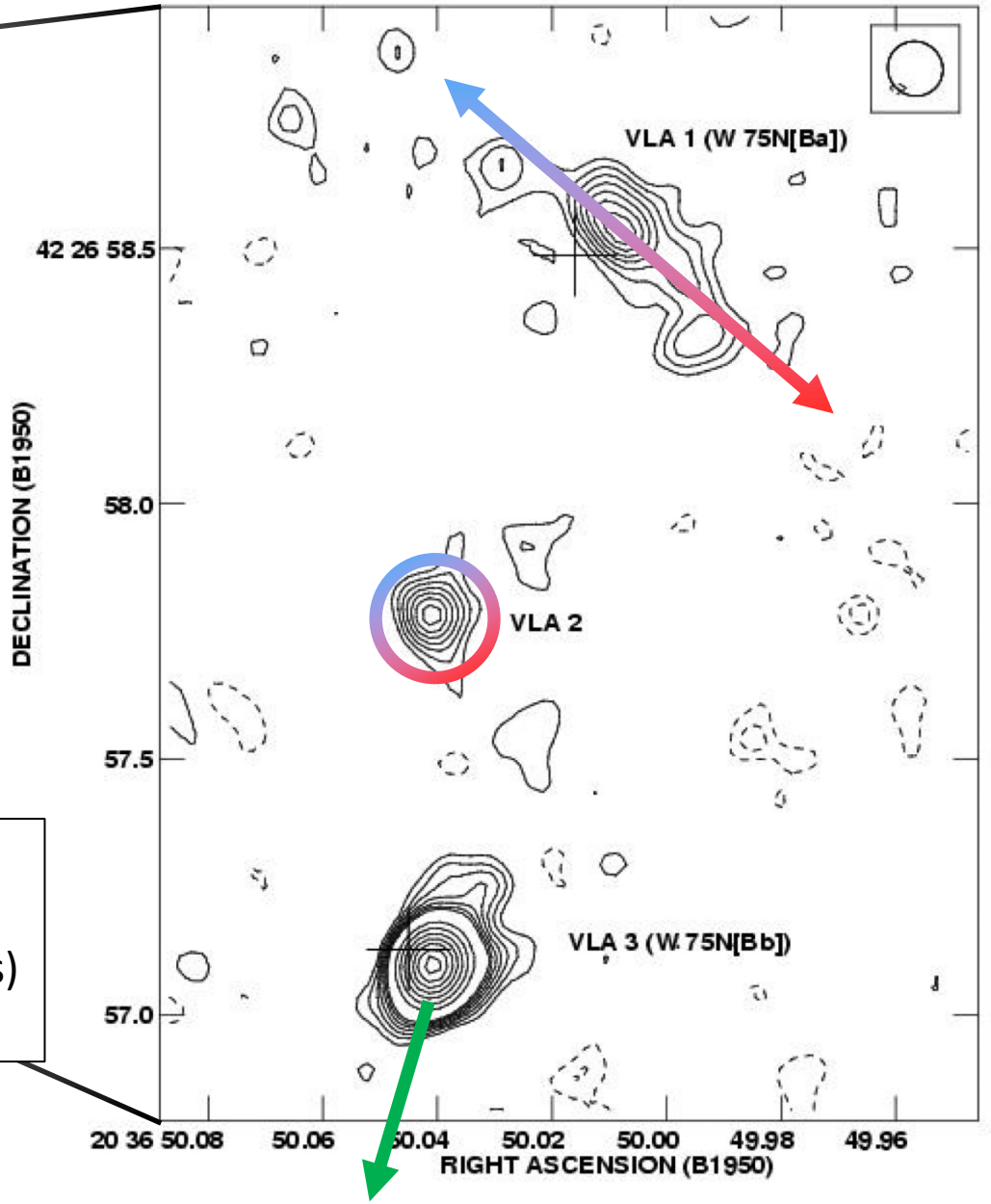


This is for "il Mosca"

Torrelles+1997, 2003; Carrasco-Gonzalez+2010; Rodriguez-Kamenetzky+2020; …

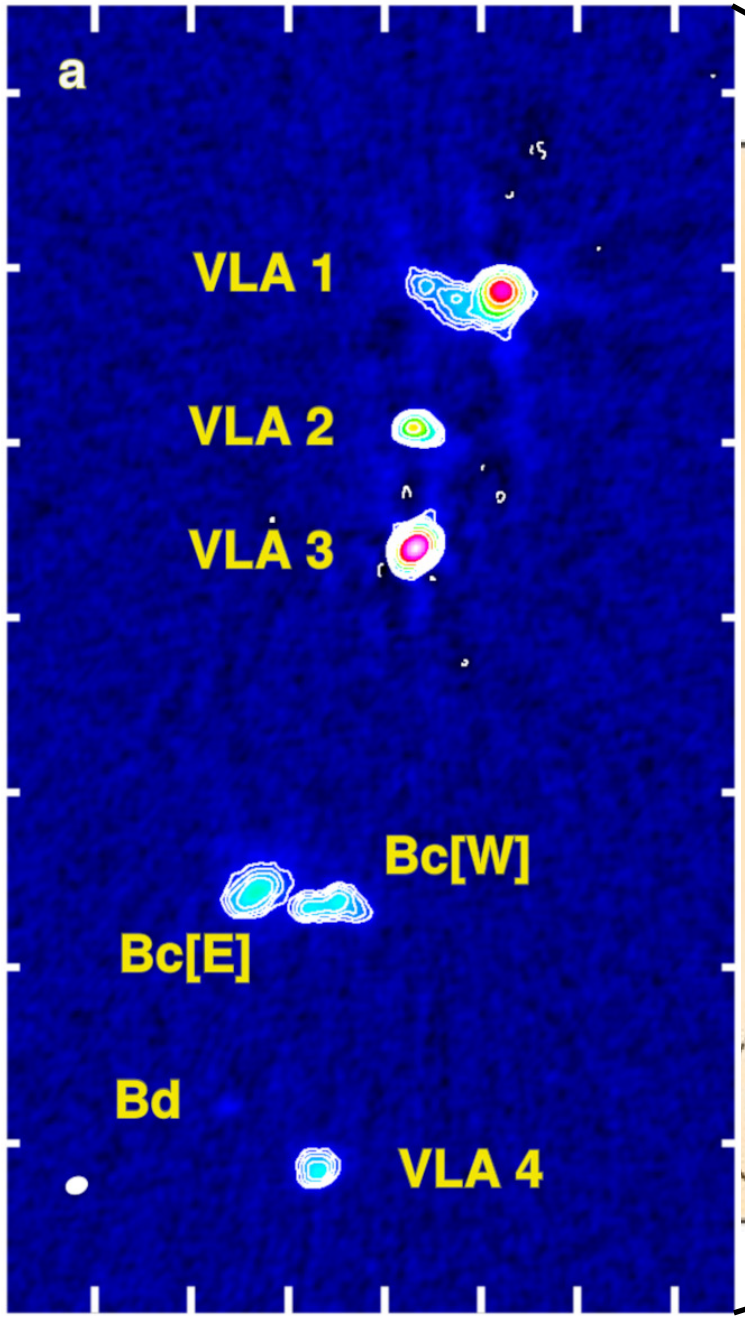


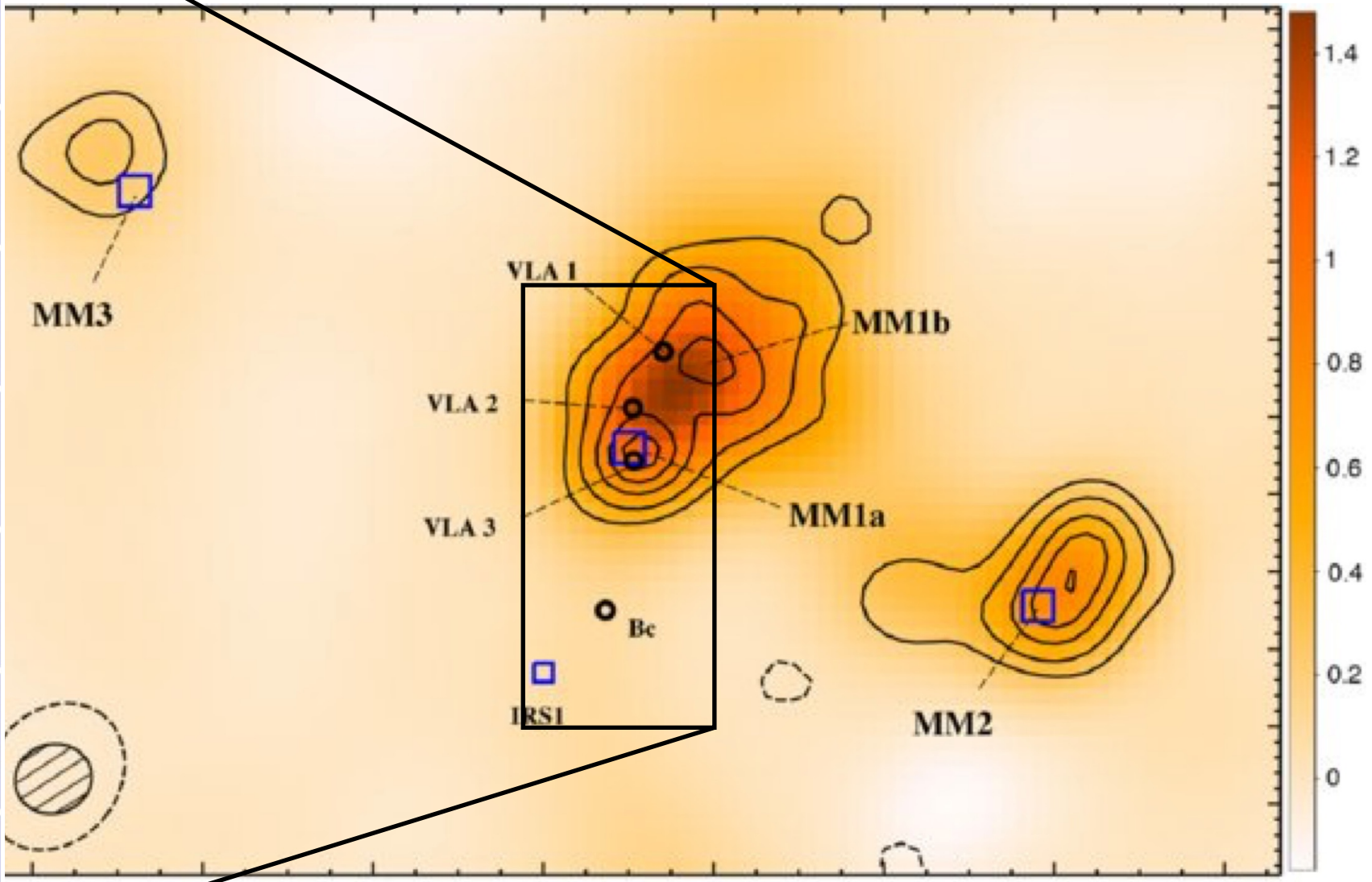
VLA sensitive observations
detected additional compact sources
… **with proper motions** (about 100 km/s)
most likely ejected from VLA3 source



Torrelles+1997, 2003; Carrasco-Gonzalez+2010; Rodriguez-Kamenetzky+2020; …

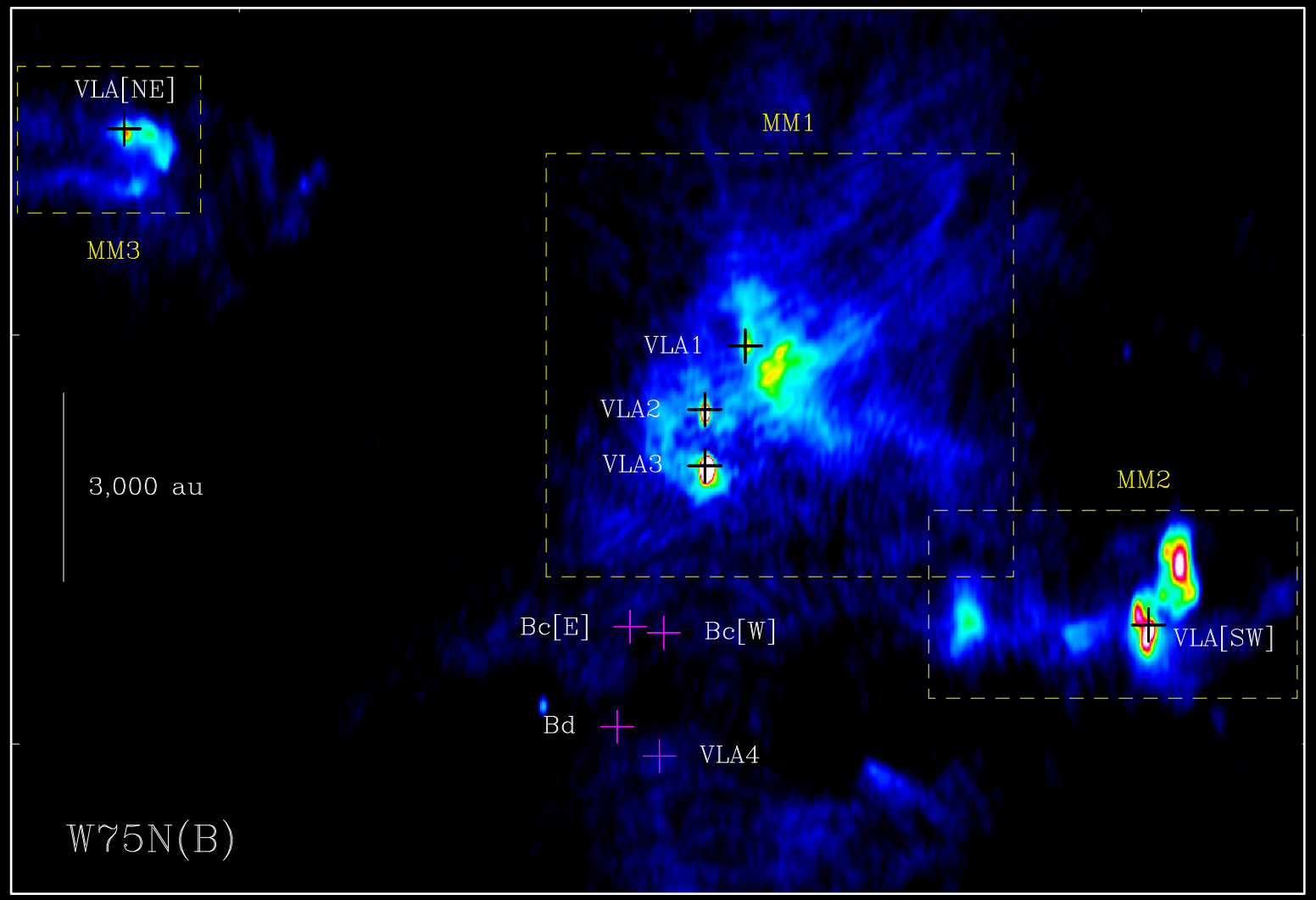
SMA 1 mm continuum observations (at 1.5 arcsec)





Minh, Su, Chen, Liu, Yan, Kim (2010)

ALMA 1 mm continuum emission (at 0.12 arcsec), with SNR > 1000

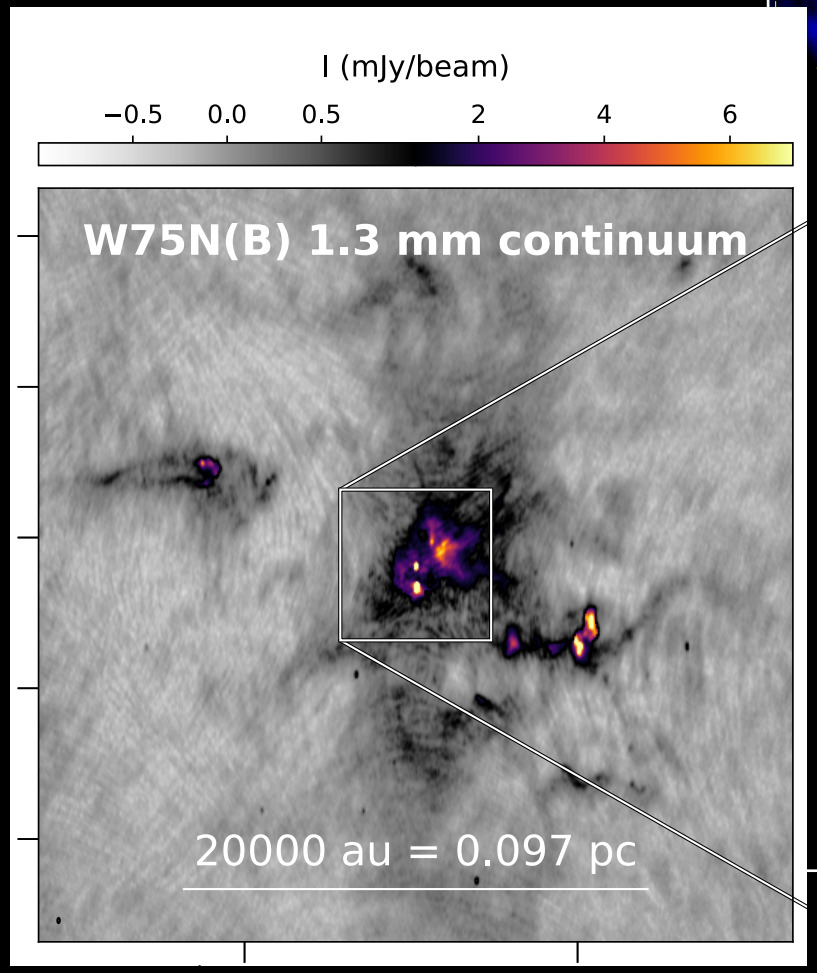


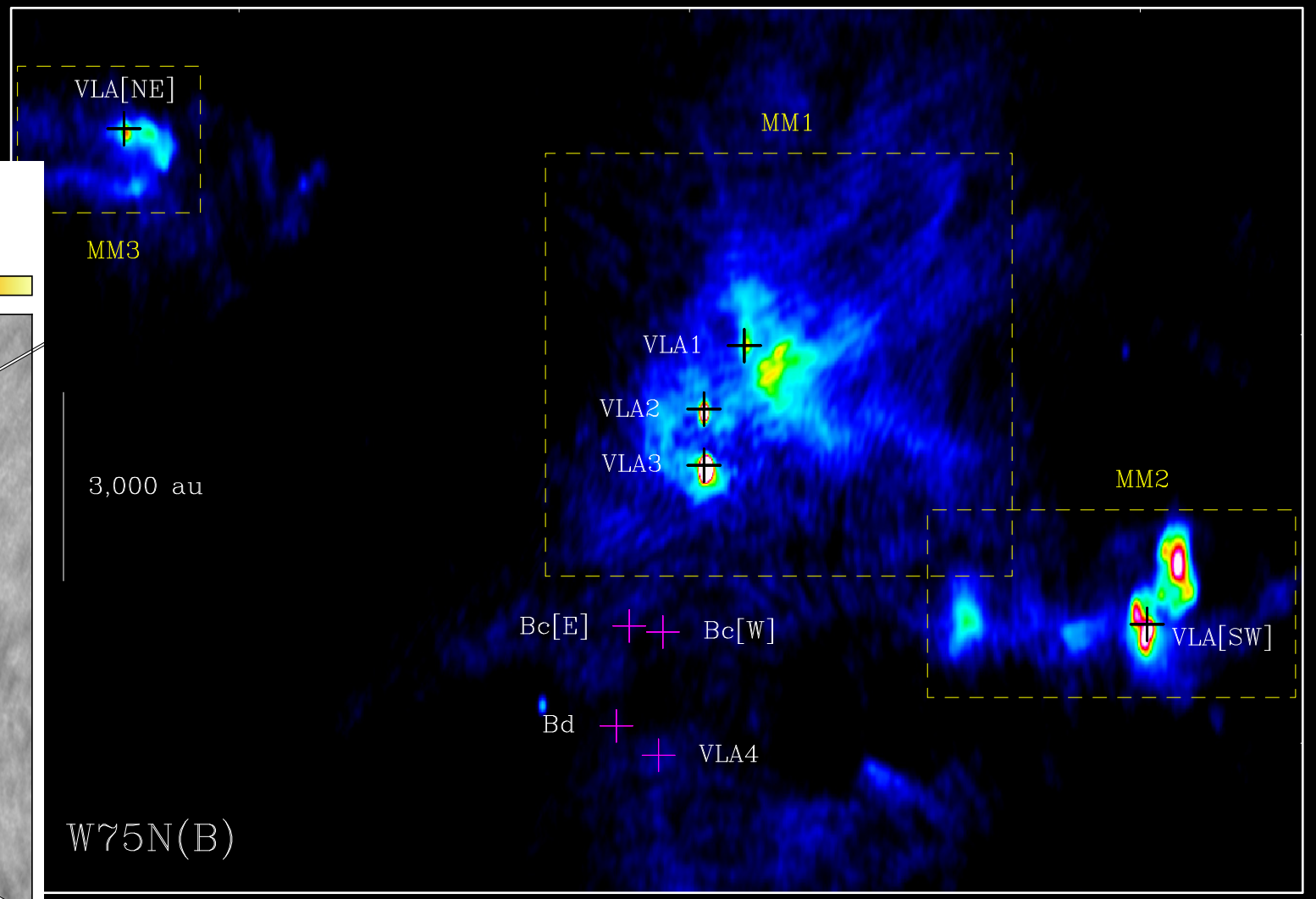
ALMA data revealed:

- Cluster of 40+ compact cores
- Most of them low-mass
- Three main sources coincident with VLA1, VLA2 and VLA3

Gómez, Torrelles, Girart, … Goddi, … Sánchez-Monge (2023)

ALMA 1 mm continuum emission (at 0.12 arcsec), with SNR > 1000

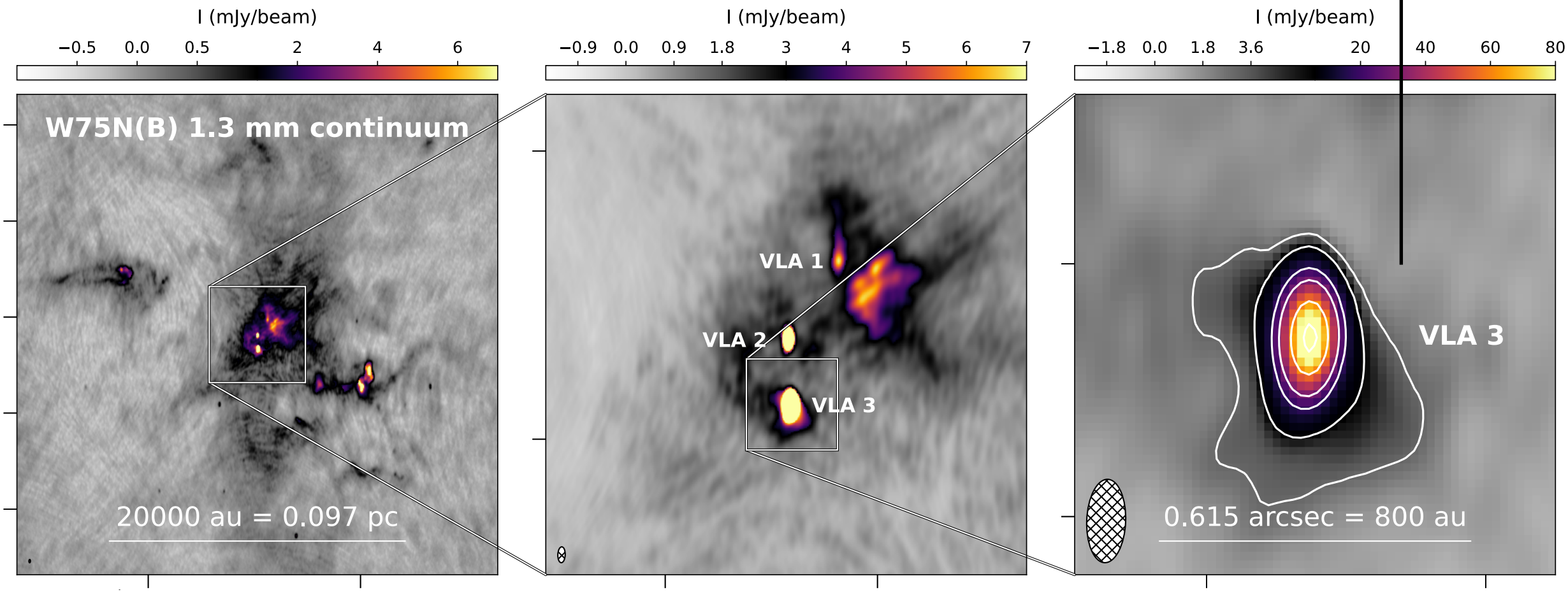




Gómez, Torrelles, Girart, … Goddi, … Sánchez-Monge (2023)

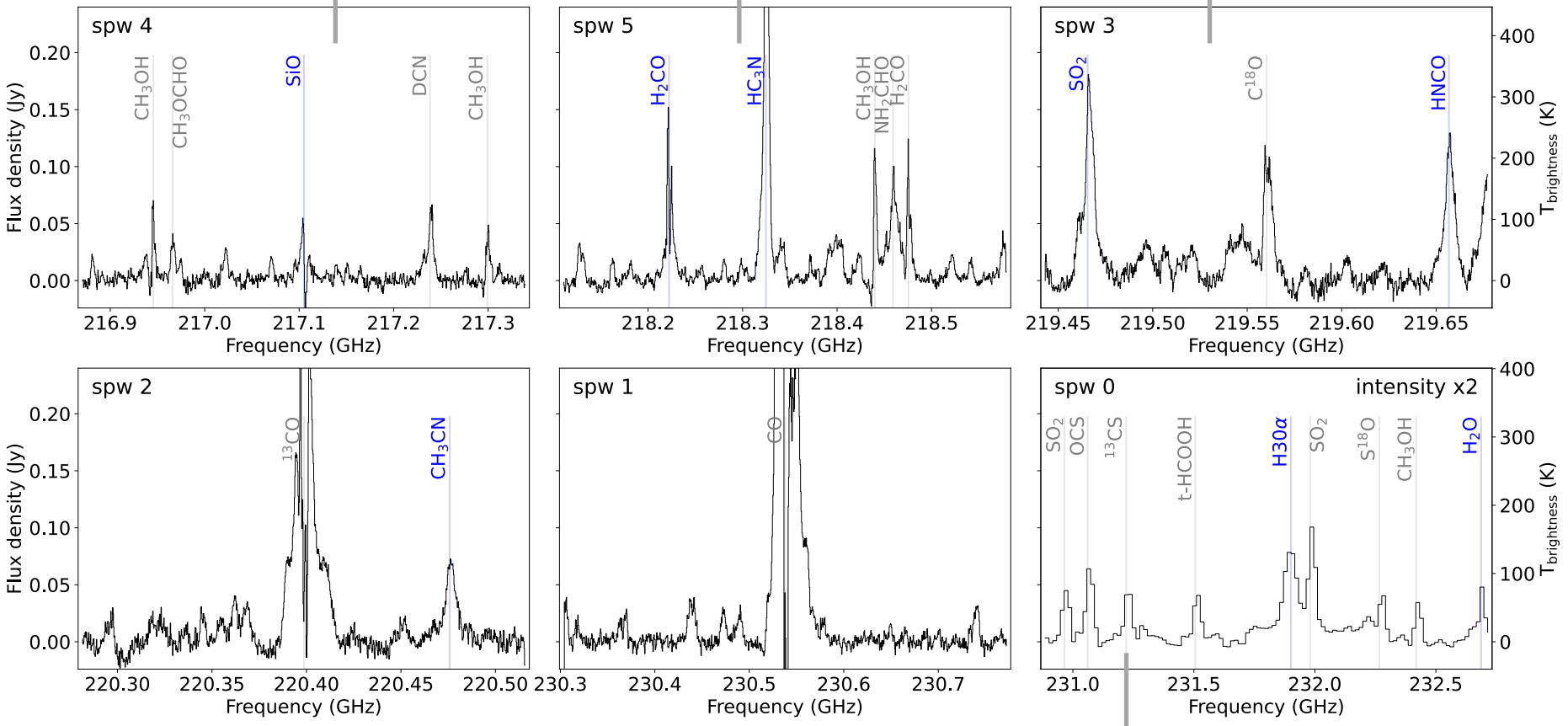
W75N(B)-VLA3 1 mm continuum emission

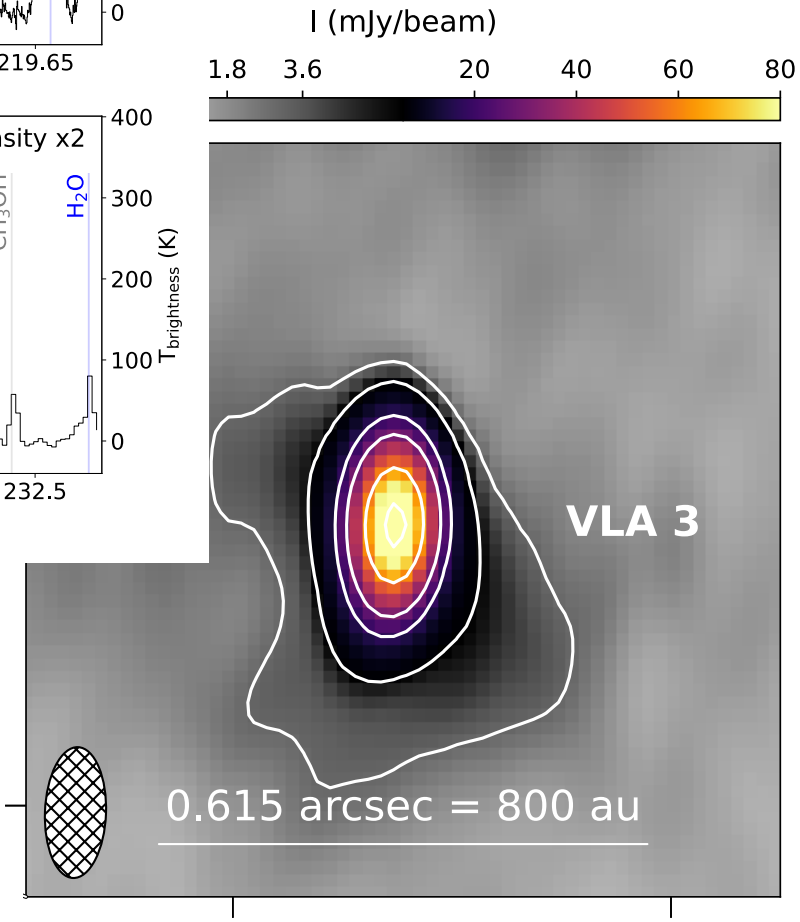
- total flux at 1 mm: about 150 mJy
  - 25 mJy from free-free (extrapolated from radiojet)
  - 125 mJy from dust
- $M_{dust+gas}$ about 0.43 – 1.74 $M_{\odot}$ (assuming 200 – 50 K)
- effective circular radius about 300 au



Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

Blue lines highlight species studied in SM+2025





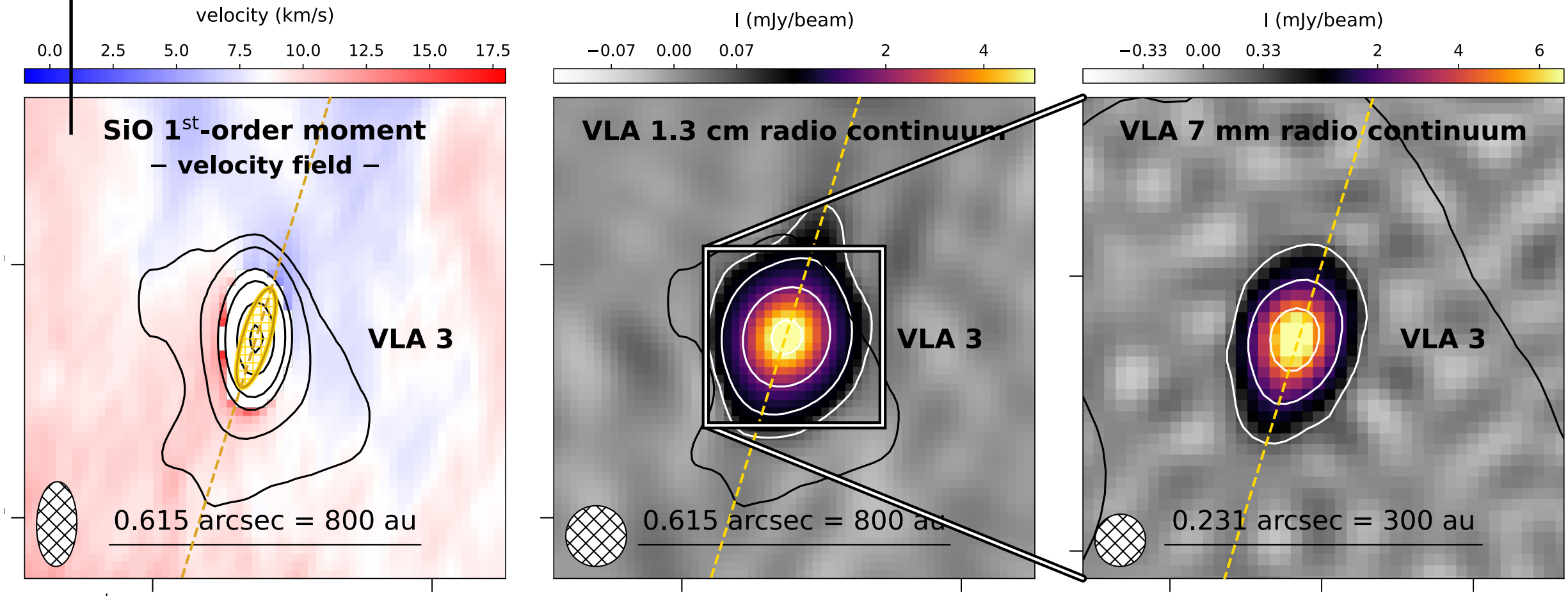
Look! There is even your favorite molecule

… but you have covered only one line of CH_3CN

Broad spectral window (low resolution : 20 km/s)

Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

SiO (5-4) emission : tentative velocity gradient in the direction of the VLA radiojet (and proper motions)

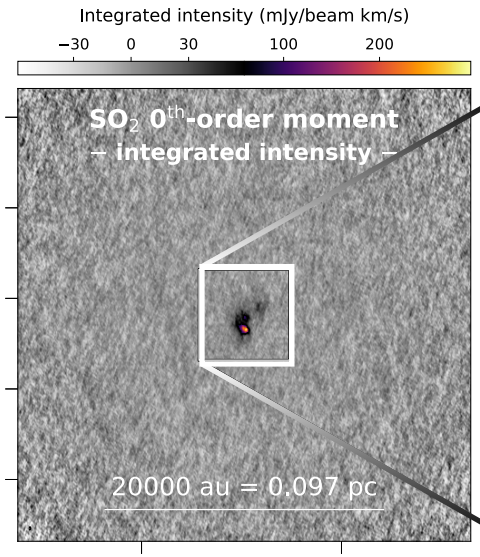


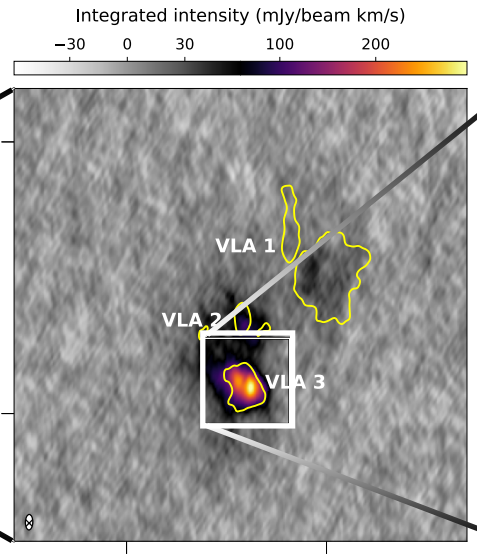
Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

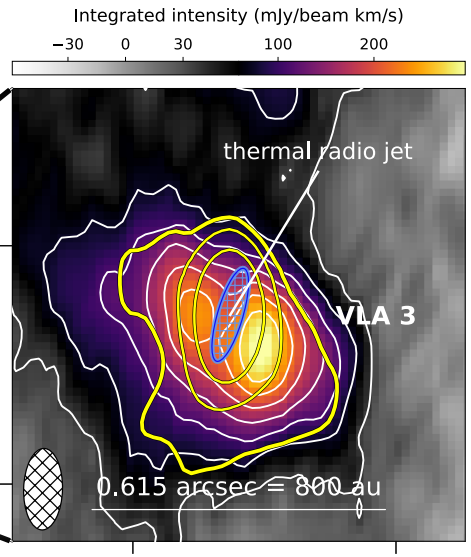
0th moment
(integrated intensity)

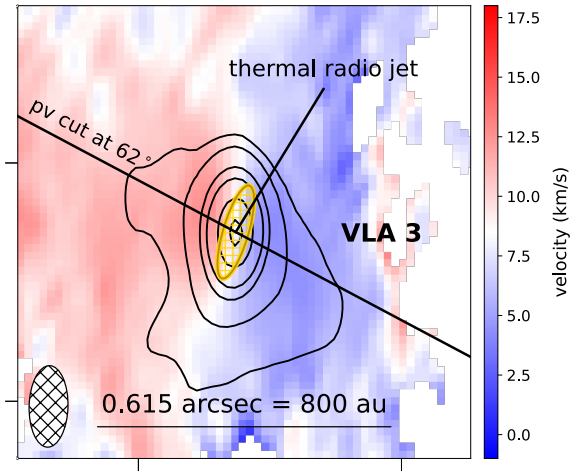
1st moment
(velocity field)

SO_2 v_2=1
(E_{up} = 1012 K)

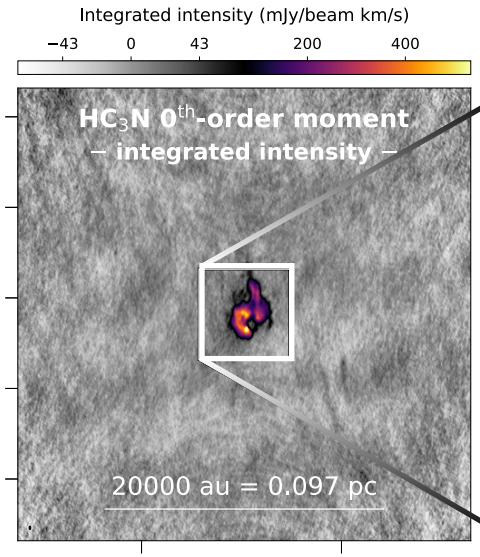


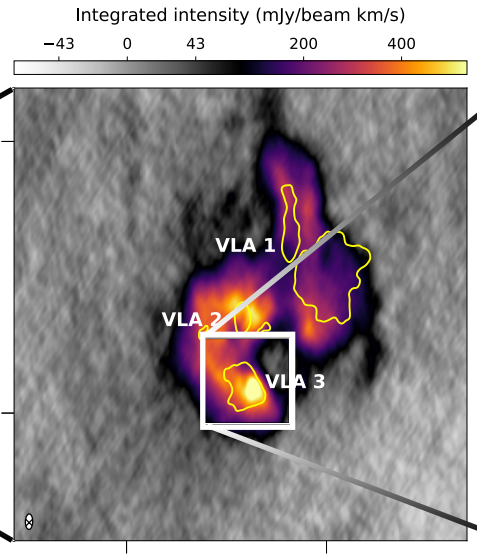


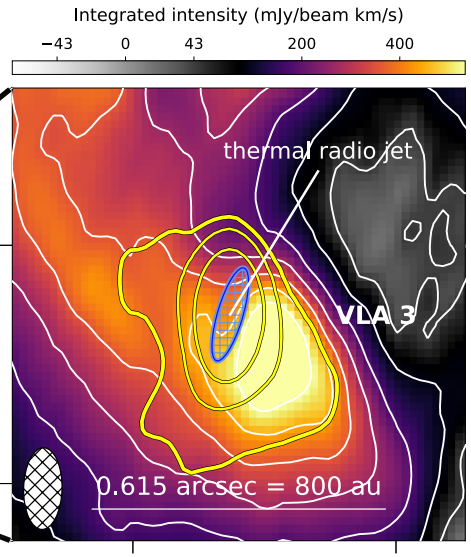


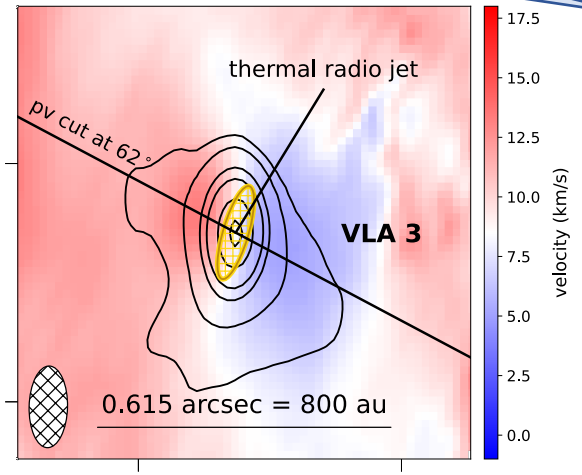


HC_3N
(E_{up} = 130 K)







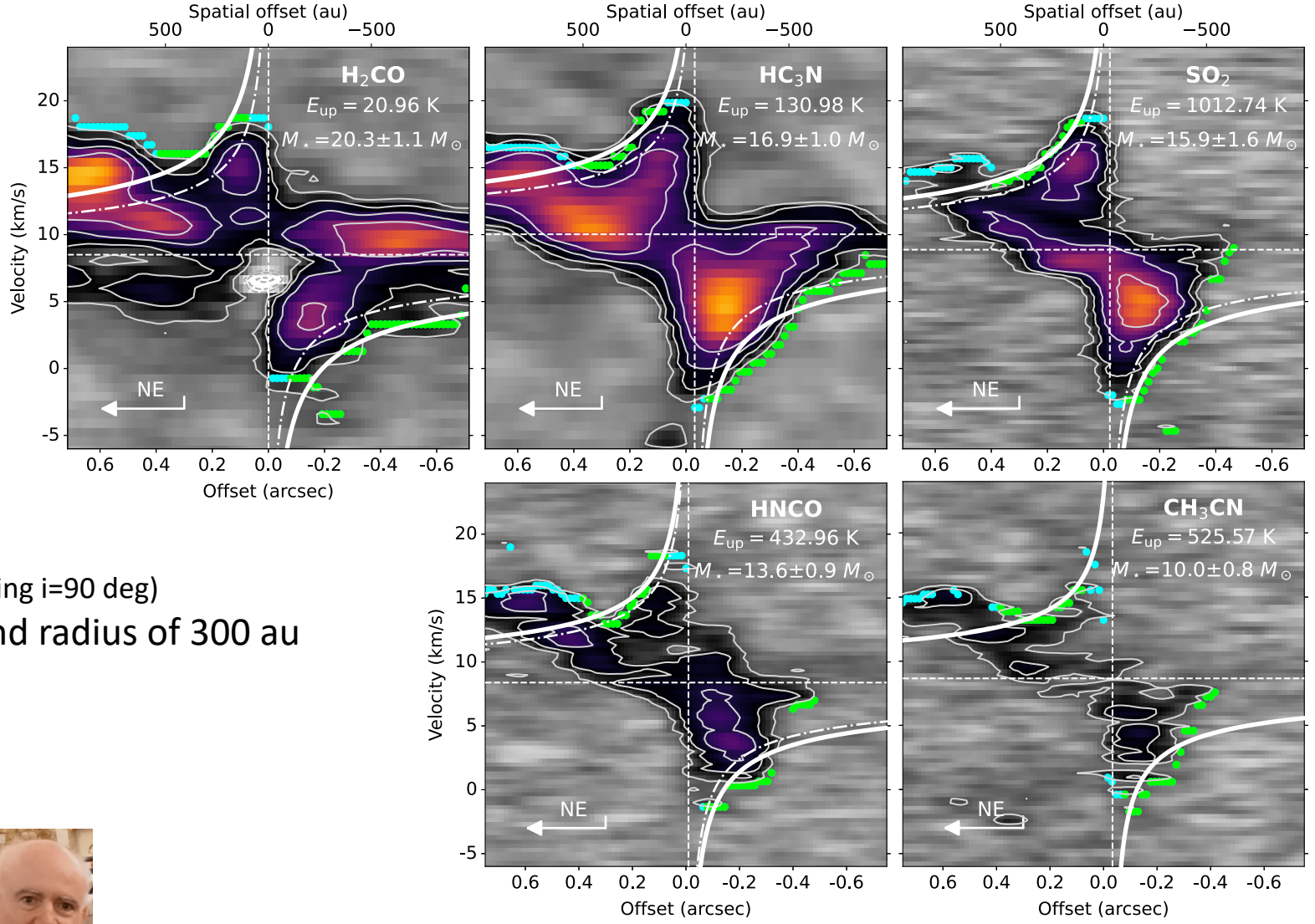


A rotating disk!

Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

Species	$M_{*,\mathrm{fit}}$ ($M_\odot$)	v_0 (km s^{-1})	r_0 (au)	r_0 (arcsec)
H_2CO	20.3 ± 1.2	8.5 ± 0.3	−1 ± 14	−0.001 ± 0.010
HC_3N	16.9 ± 1.0	10.0 ± 0.3	−41 ± 11	−0.032 ± 0.008
SO_2	15.9 ± 1.6	8.9 ± 0.5	−29 ± 22	−0.022 ± 0.017
HNCO	13.6 ± 1.0	8.4 ± 0.4	−12 ± 19	−0.009 ± 0.015
CH_3CN	10.0 ± 0.9	8.7 ± 0.3	−44 ± 15	−0.034 ± 0.012

Notes. The fitted parameters are the central stellar mass $M_{*,\mathrm{fit}} = M_* \sin^2 i$ (in $M_\odot$), the systemic velocity or velocity shift v_0 (in km s^{-1}), and the positional shift r_0 (in au and arcsec) with respect to the center of the PV-cut or location of VLA3, α(J2000) = 20^{h}38^{m}36.^{s}4815 and δ(J2000) = +42°37′33.″355.



M_{star} about 16 ± 4 $M_\odot$ (conservative value assuming i=90 deg)
… compare with $M_{dust+gas}$ = 0.43-1.74 $M_\odot$, and radius of 300 au

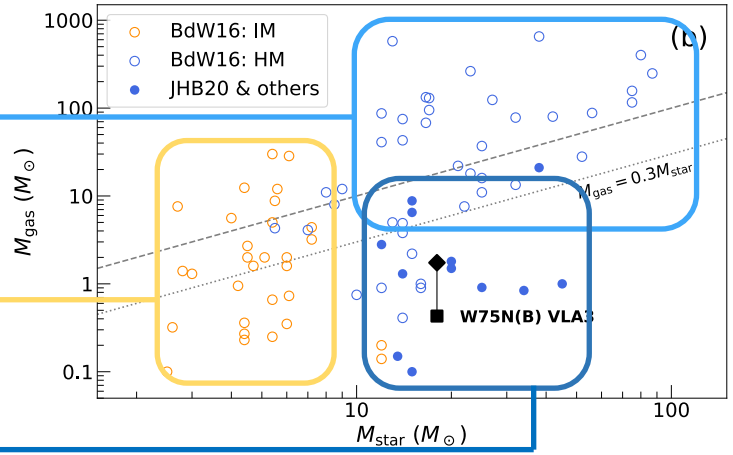
The velocity field is consistent with the “butterfly” pv-plot

Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

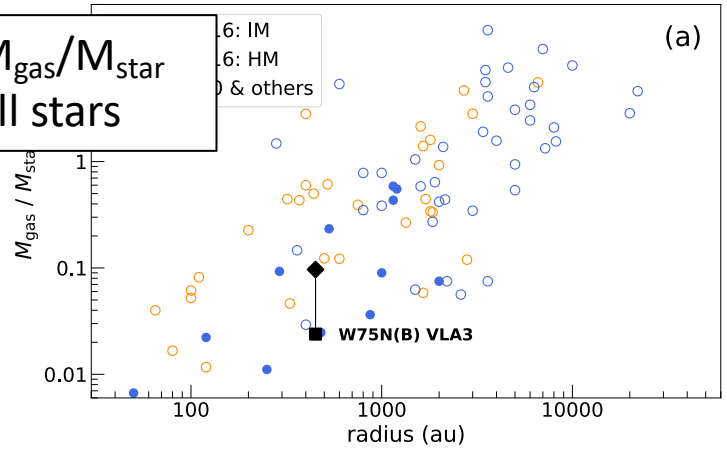
massive toroids

LM / IM disks

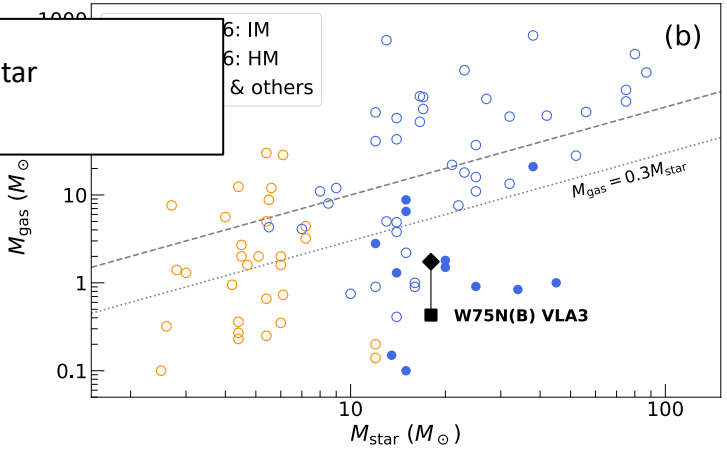
HM disks



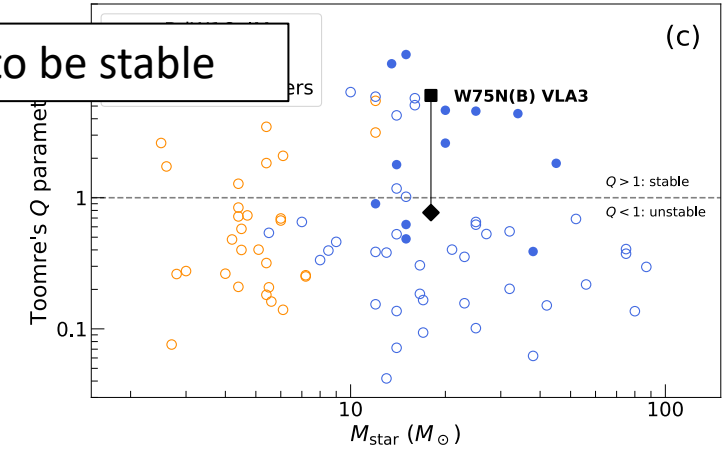
similar radii and M_{gas}/M_{star} for disks around all stars



toroids: $M_{gas} < M_{star}$
disks: $M_{gas} > M_{star}$

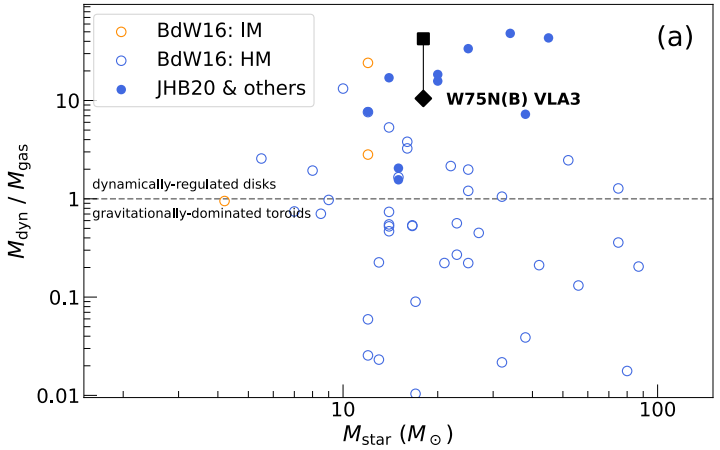


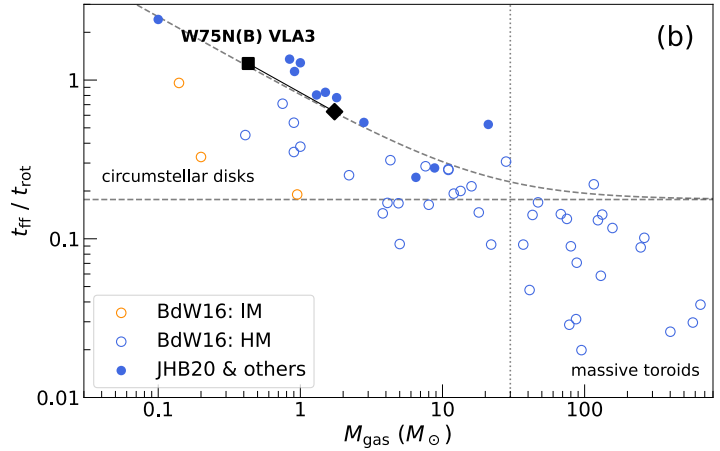
HM disks appear to be stable



recreation of the plots presented in Beltrán & de Wit 2016

adding disks observed at high-resolution around massive protostars

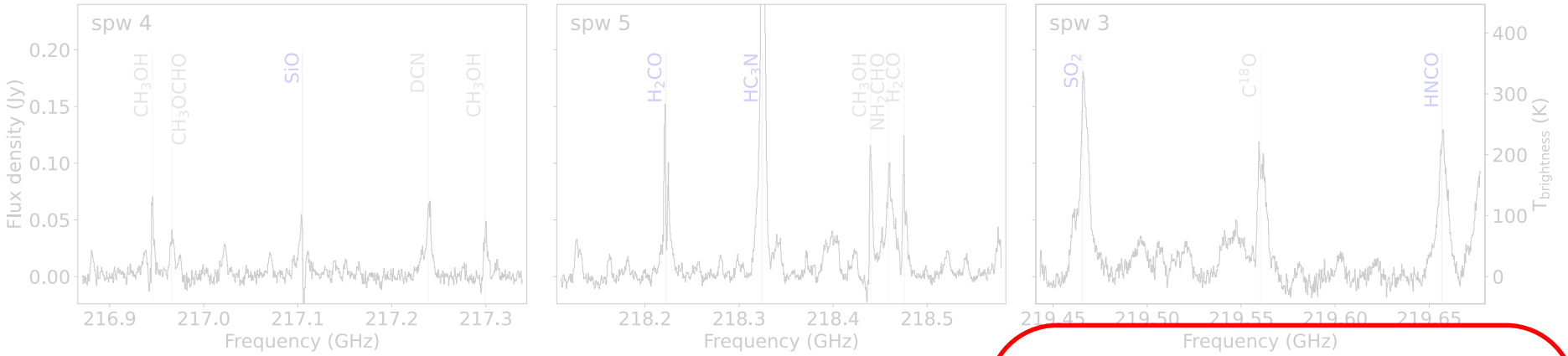


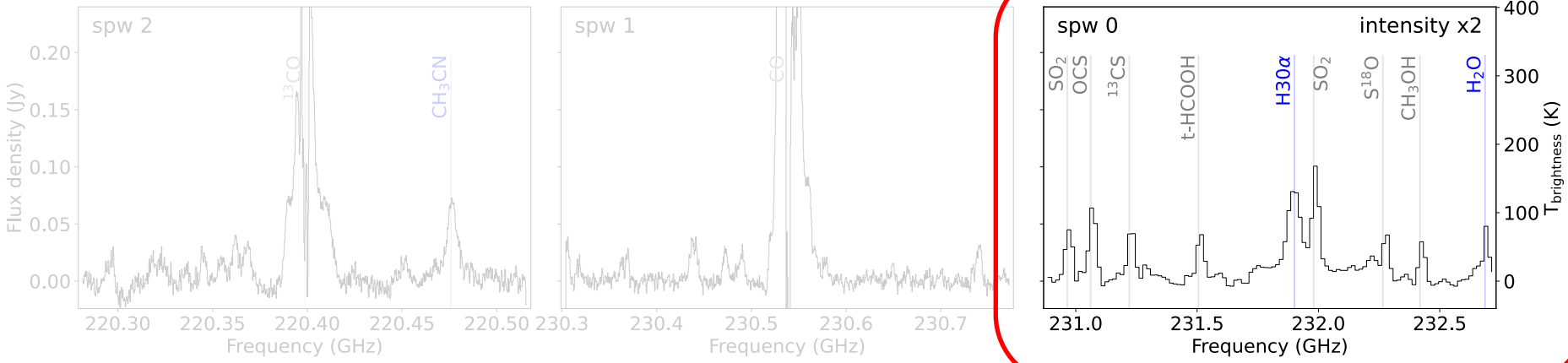


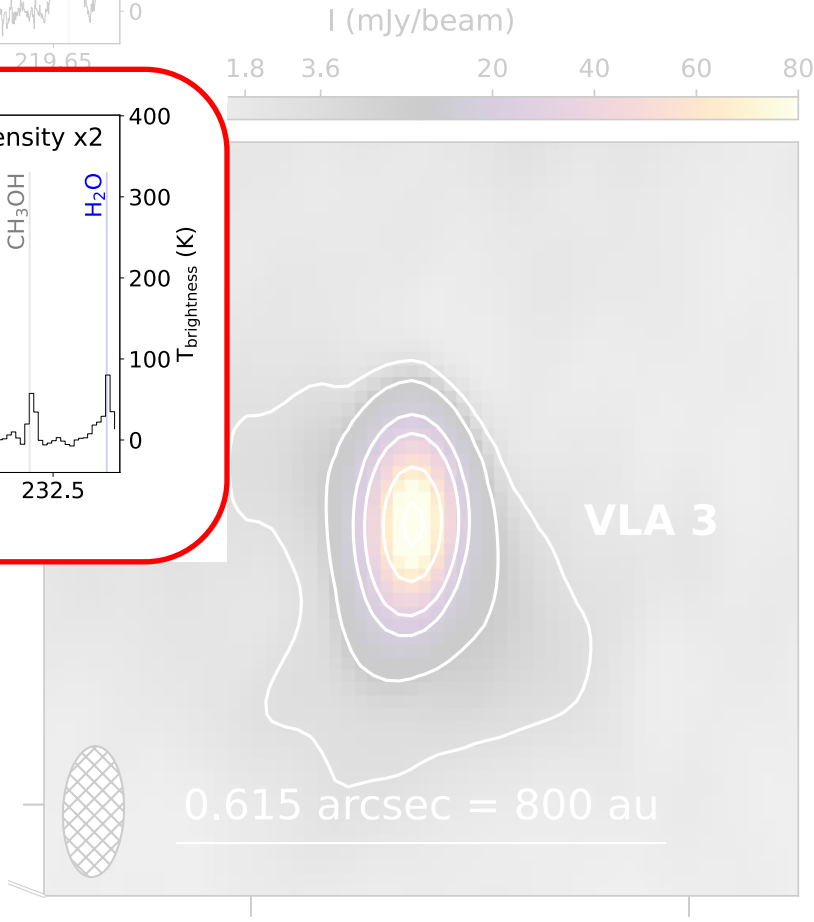
HM disks appear to be dynamically-regulated
(contrary to massive toroids)

High resolution observations show that these disks may be stable

Good choice plots !







Going back to the spectral lines….

Radio recombination lines!

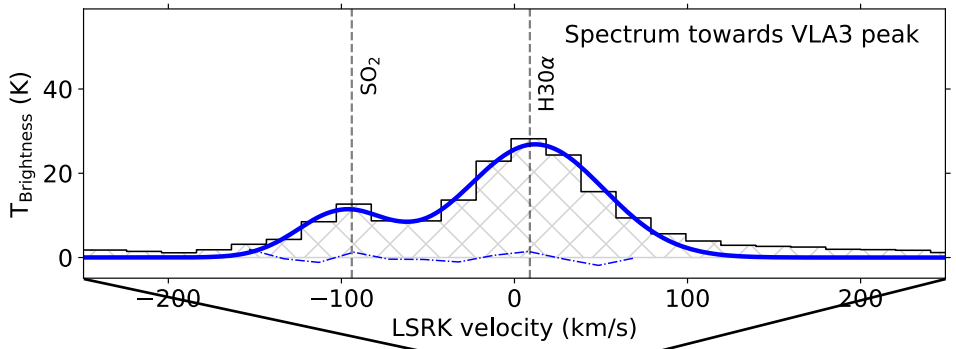
… chemistry ?

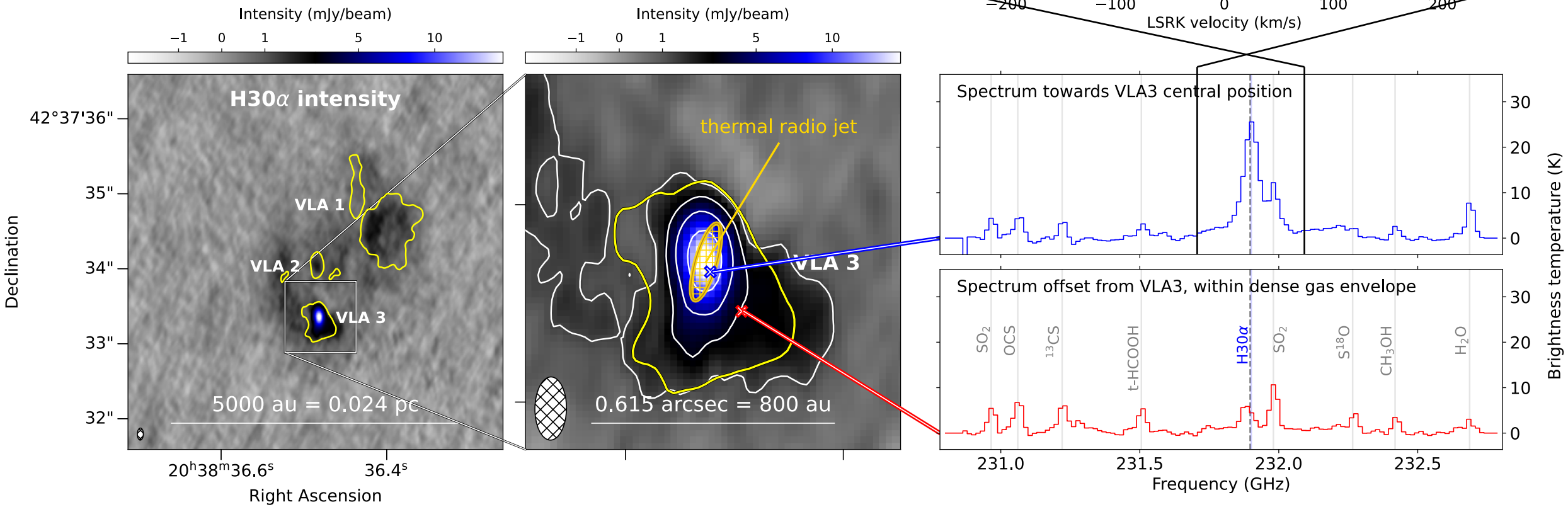
Here comes the interesting part!

Very broad H30α line: FWHM = 98 ± 10 km/s

H30α emission spanning from -150 to +150 km/s

H30α flux density: 36 mJy (after excluding line contamination)





Here comes the interesting part!

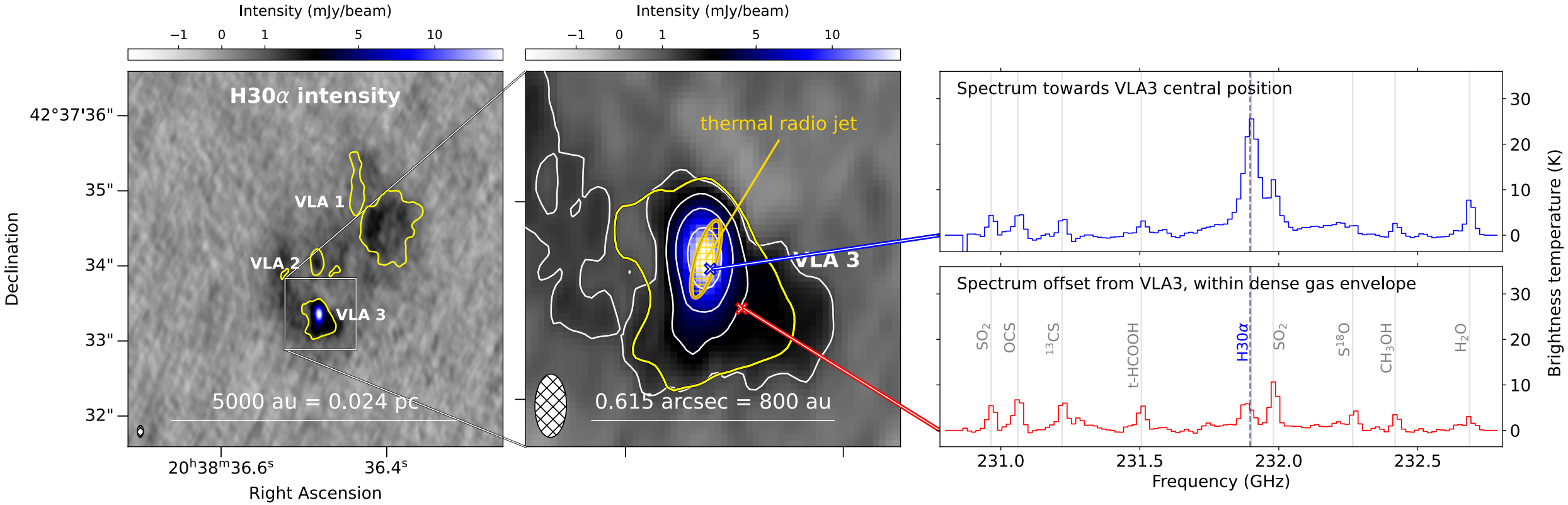
Very broad H30α line: FWHM = 98 ± 10 km/s

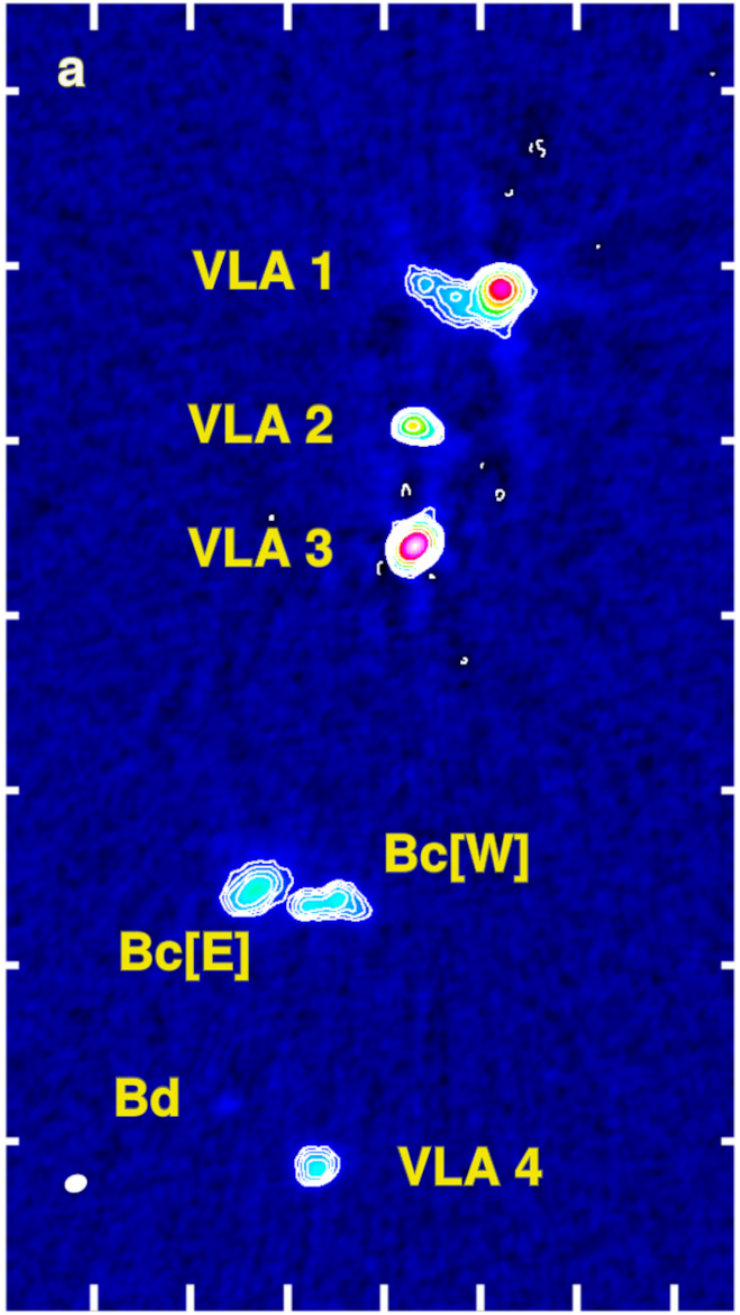
H30α emission spanning from -150 to +150 km/s

H30α flux density: 36 mJy (after excluding line contamination)

How do we create such a broad RRL ?

- ~~HII regions: RRLs have typical widths of 20 km/s~~
- ~~HCHII regions: RRLs have FWHM of 50 km/s at cm~~
  ~~30 km/s at mm~~
- Rotation from an ionized disk
- RRLs from a protostellar jet / wind





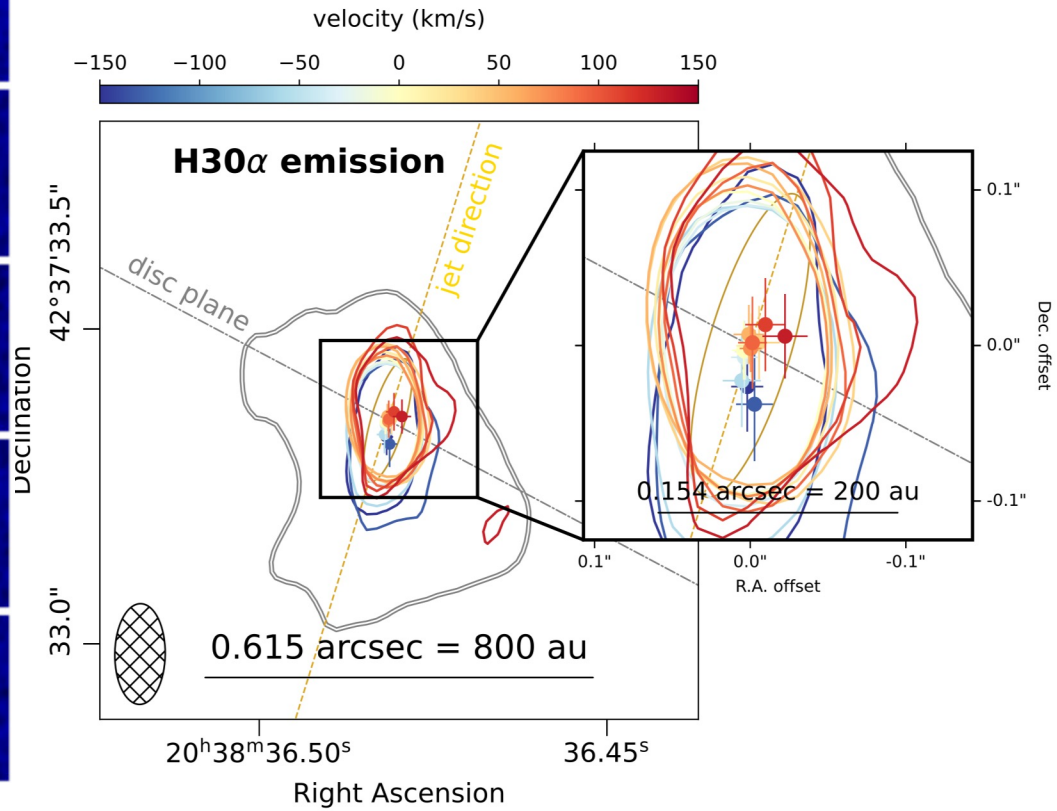
Very broad H30α line: FWHM = 98 ± 10 km/s

H30α emission spanning from -150 to +150 km/s

H30α flux density: 36 mJy (after excluding line contamination)

How do we create such a broad RRL ?

- ~~HII regions: RRLs have typical widths of 20 km/s~~
- ~~HCHII regions: RRLs have FWHM of 50 km/s at cm~~
  ~~30 km/s at mm~~
- ~~Rotation from an ionized disk~~
- RRLs from a protostellar jet / wind



Expected line-to-continuum flux for RRLs from thermal protostellar jets [Anglada et al 2018]:

$$\frac{S_L}{S_C} = \left[0.25 \left(\frac{\nu_L}{\mathrm{GHz}} \right)^{1.1} \left(\frac{T_e}{10^4\ \mathrm{K}} \right)^{-1.1} \left(\frac{\Delta v}{\mathrm{km\ s^{-1}}} \right)^{-1} + 1 \right]^{2/3} - 1$$

25 mJy | 232 GHz | 10^4 K | 100 km/s

Expected H30α flux: 37 mJy

Very broad H30α line: FWHM = 98 ± 10 km/s

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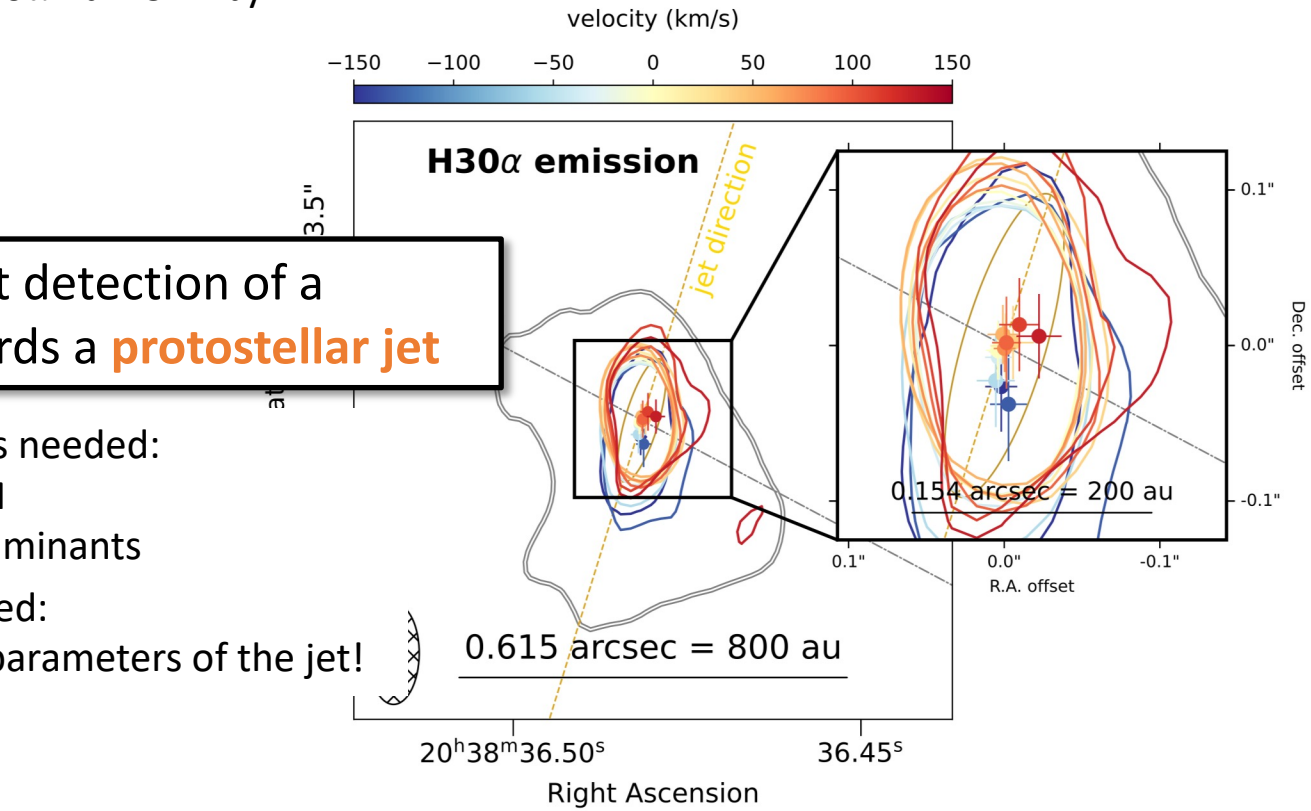
- RRLs from a protostellar jet / wind

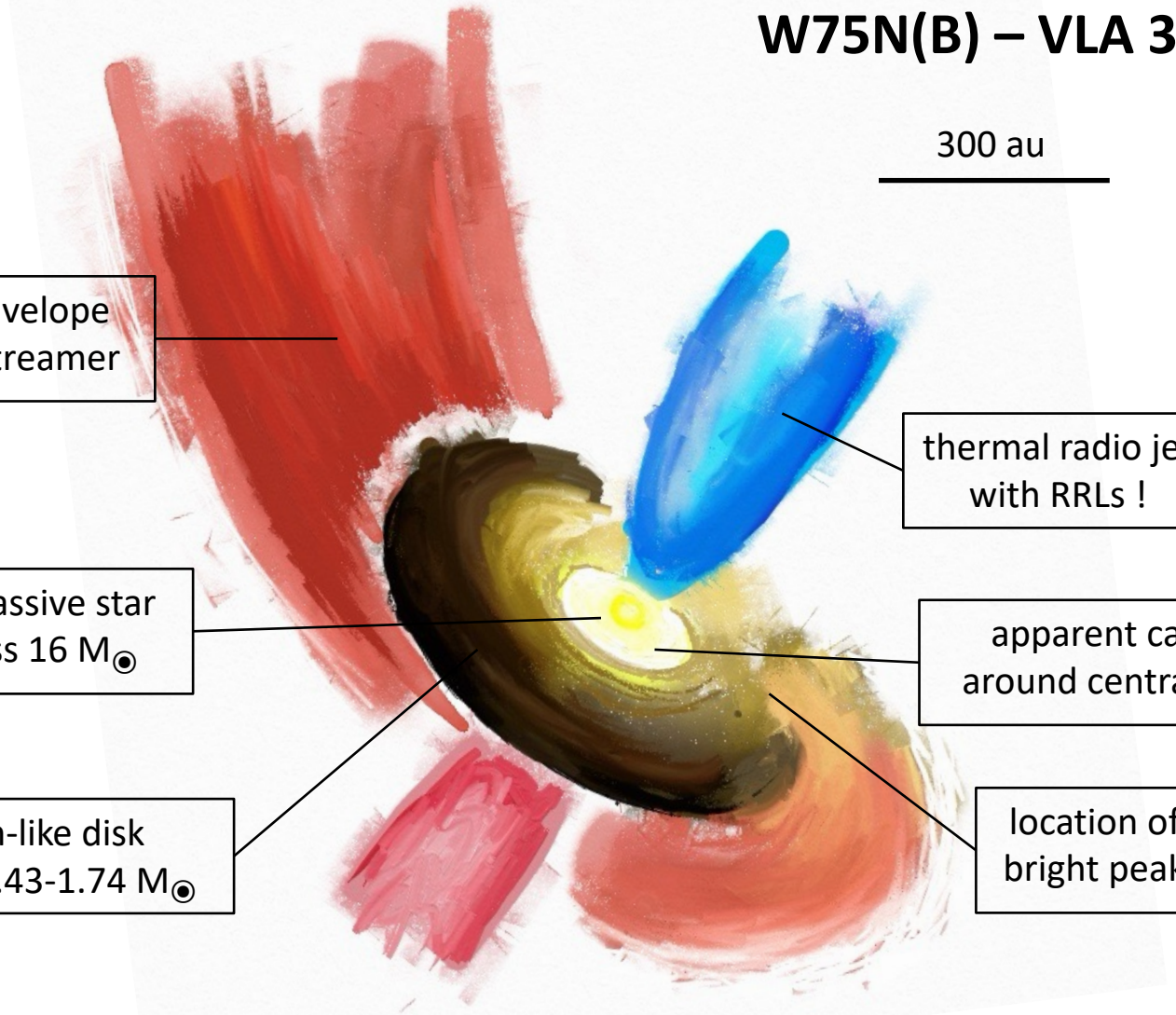
Potential first detection of a thermal RRL towards a protostellar jet

High spectral resolution is needed:
… to confirm large FWHM
… to better remove contaminants

Additional RRLs are needed:
… to determine physical parameters of the jet!

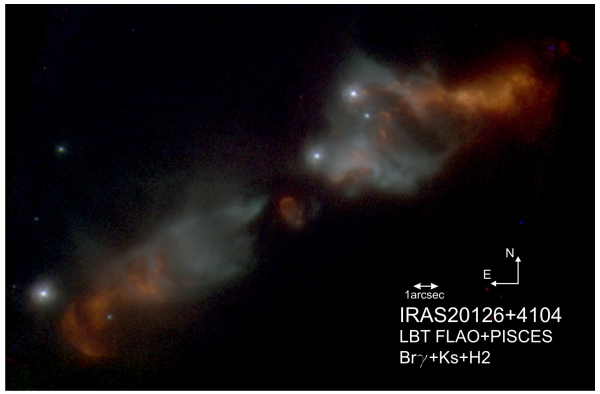


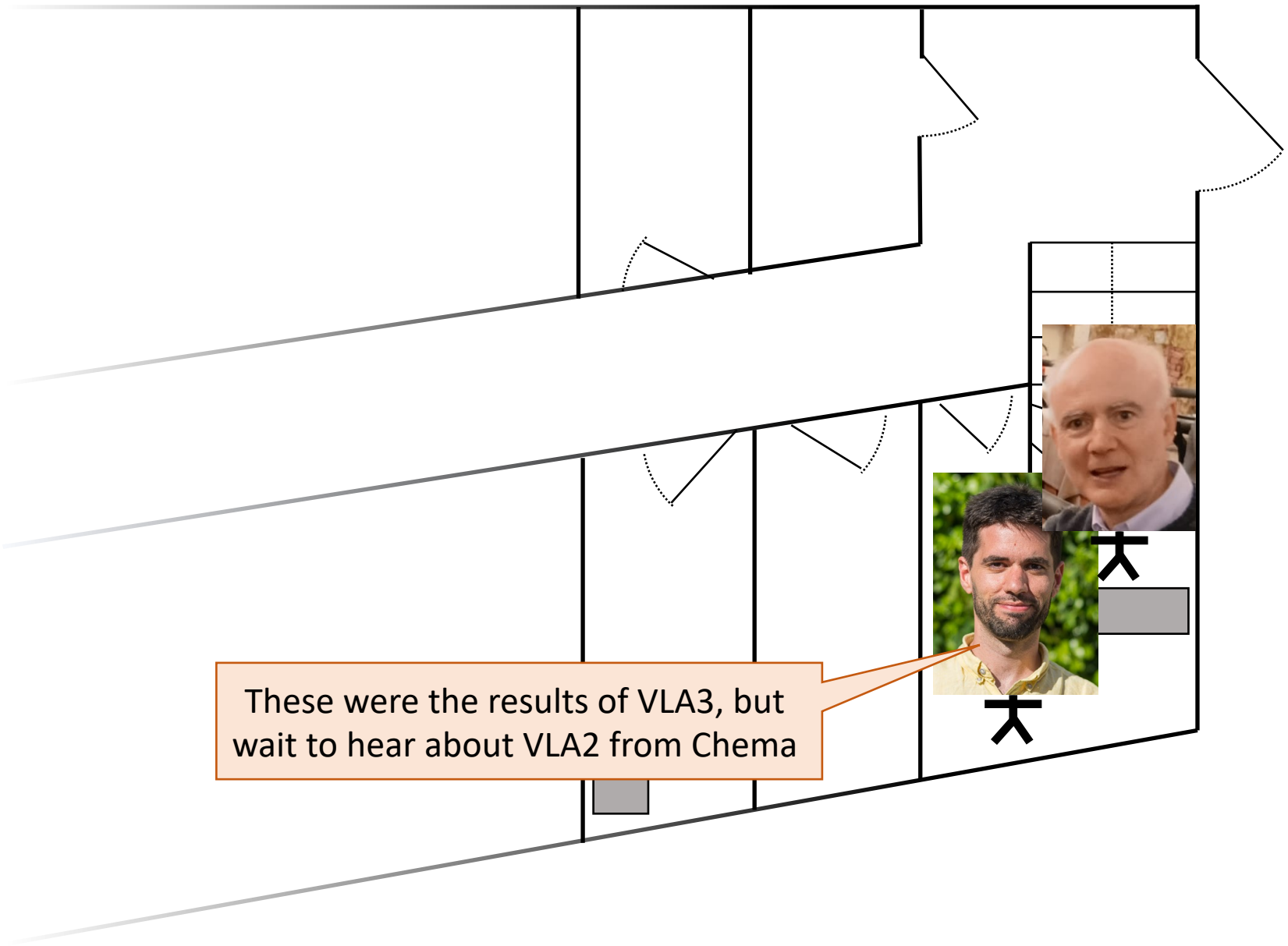
W75N(B) – VLA 3



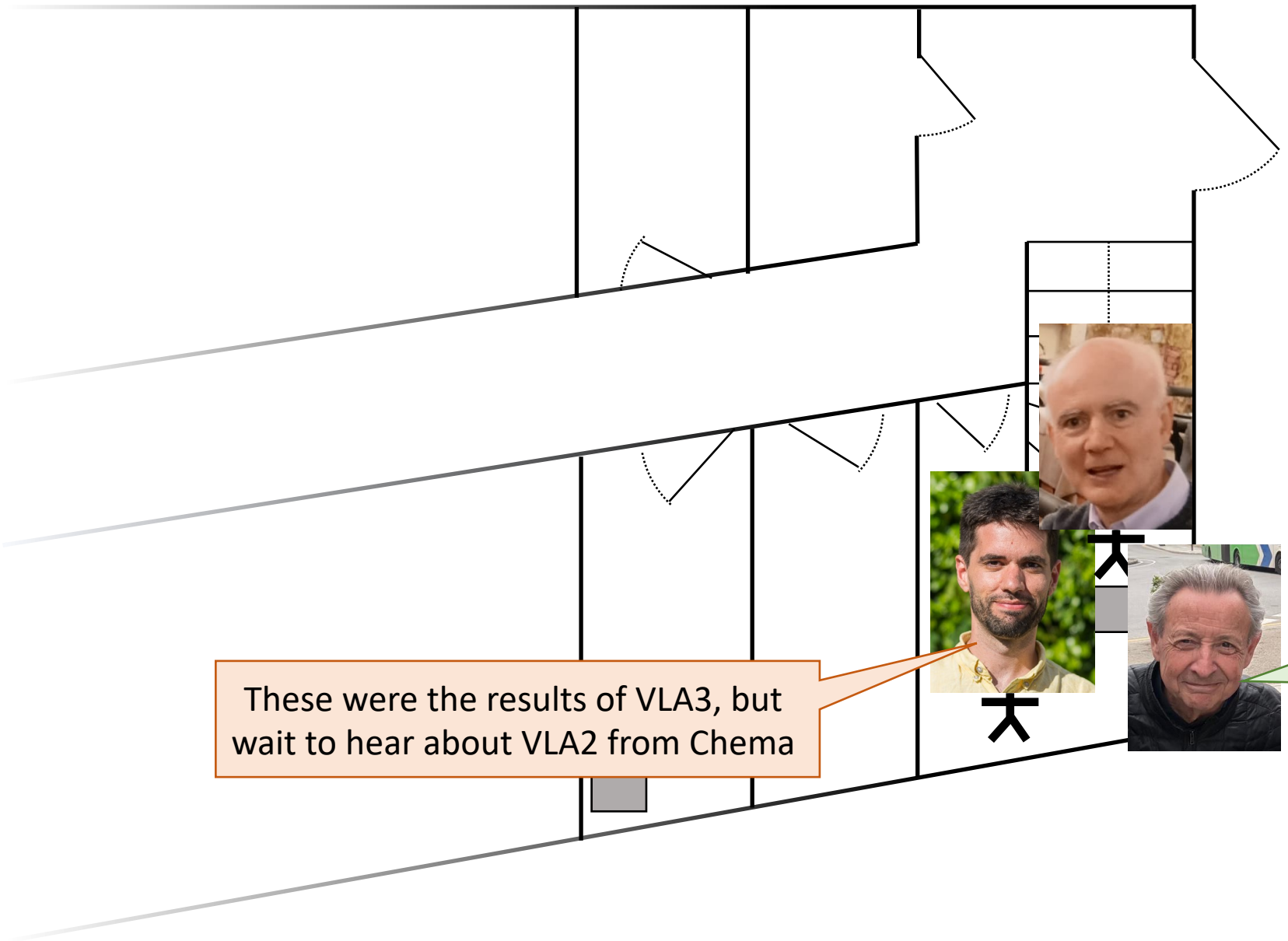
Sánchez-Monge, Gómez, Torrelles, …, Girart, …, Goddi et al (2025)

Interesting source…
but I will keep looking at
IRAS 20126+4104



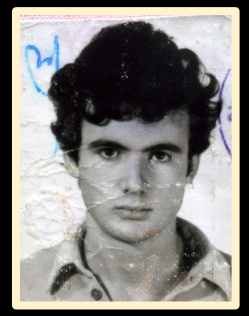

These were the results of VLA3, but wait to hear about VLA2 from Chema

11:30



These were the results of VLA3, but wait to hear about VLA2 from Chema

Ciao Riccardo, in the next talk I will present more nice results from this region



Gracias Ric!

Gracias Cesa!

Gracias Riccardo!

YERAC 1986

YERAC 1998