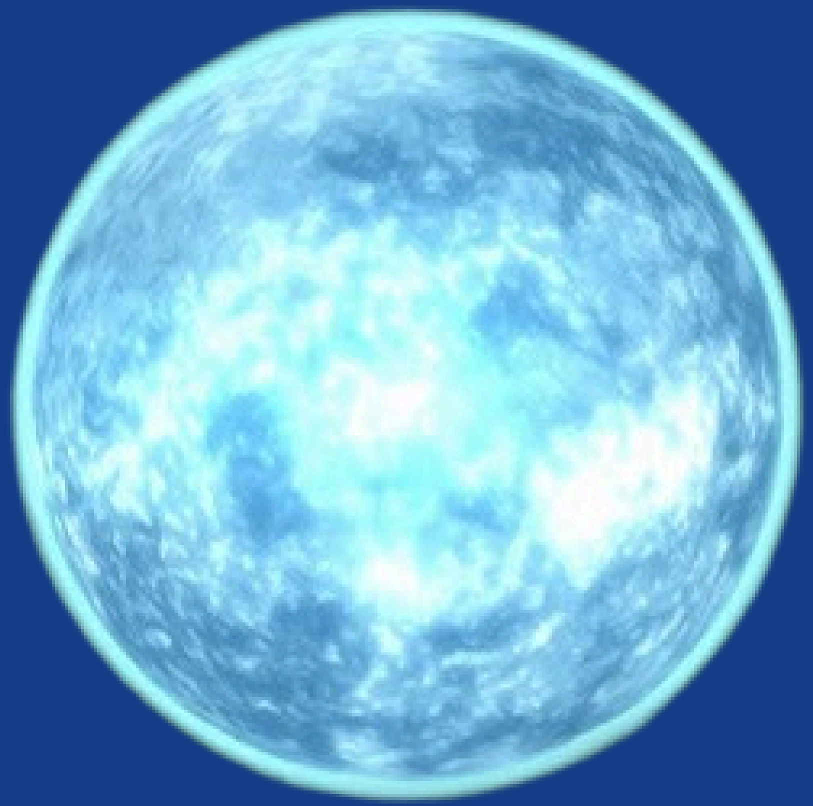

SEARCHING FOR EVIDENCE OF ACCRETION TO MASSIVE PROTOSTARS BEYOND THE CLASSICAL FEEDBACK LIMIT

Presented by:

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Supervised by:

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Yichen Zhang (University of Virginia)
Germán Chaparro (Universidad de Antioquia)

November, 2024

CICO VICO CHALMERS & VIRGINIA Initiatives on Cosmic Origins

NRAO

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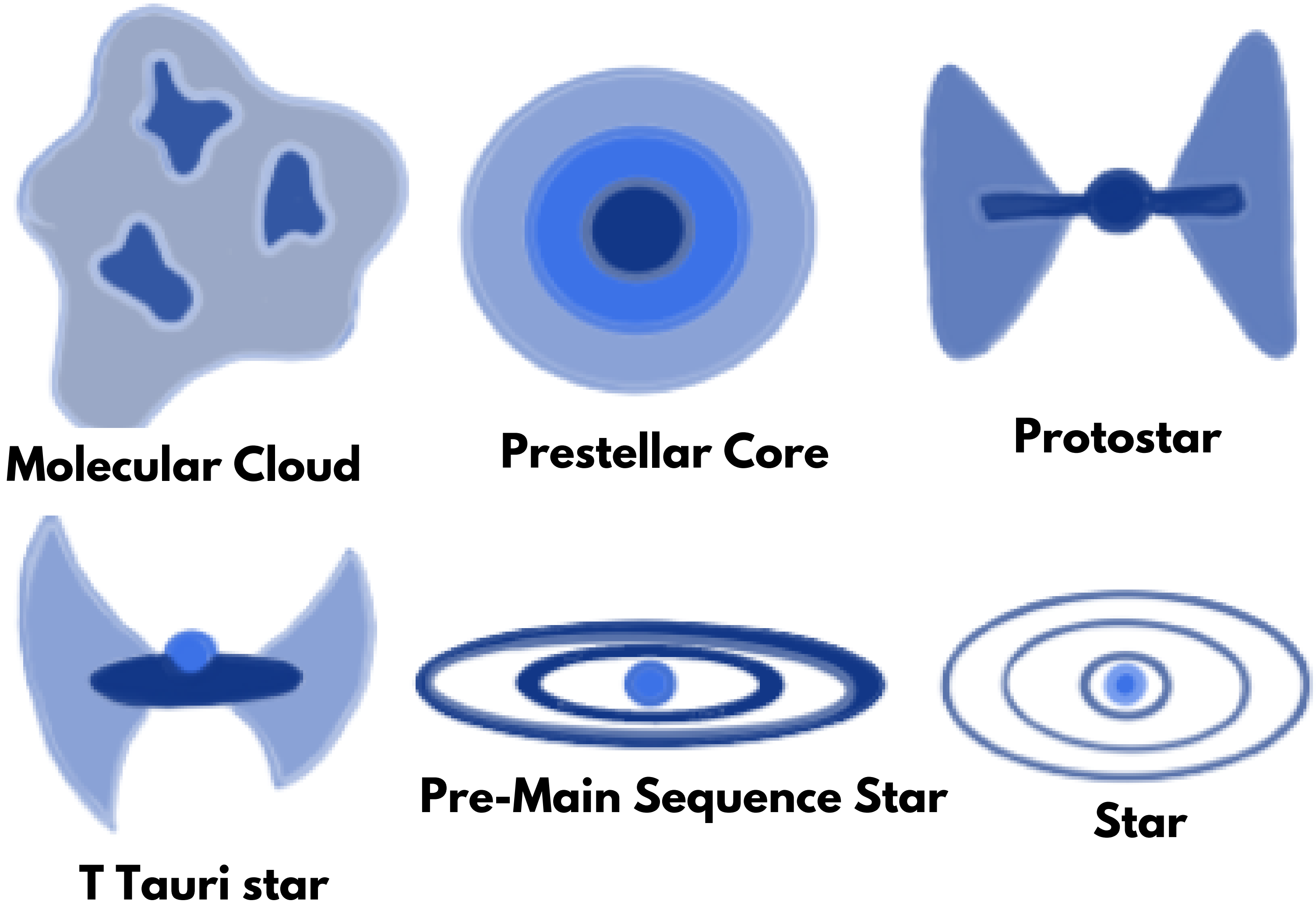
Stellar formation process



1

Low mass systems

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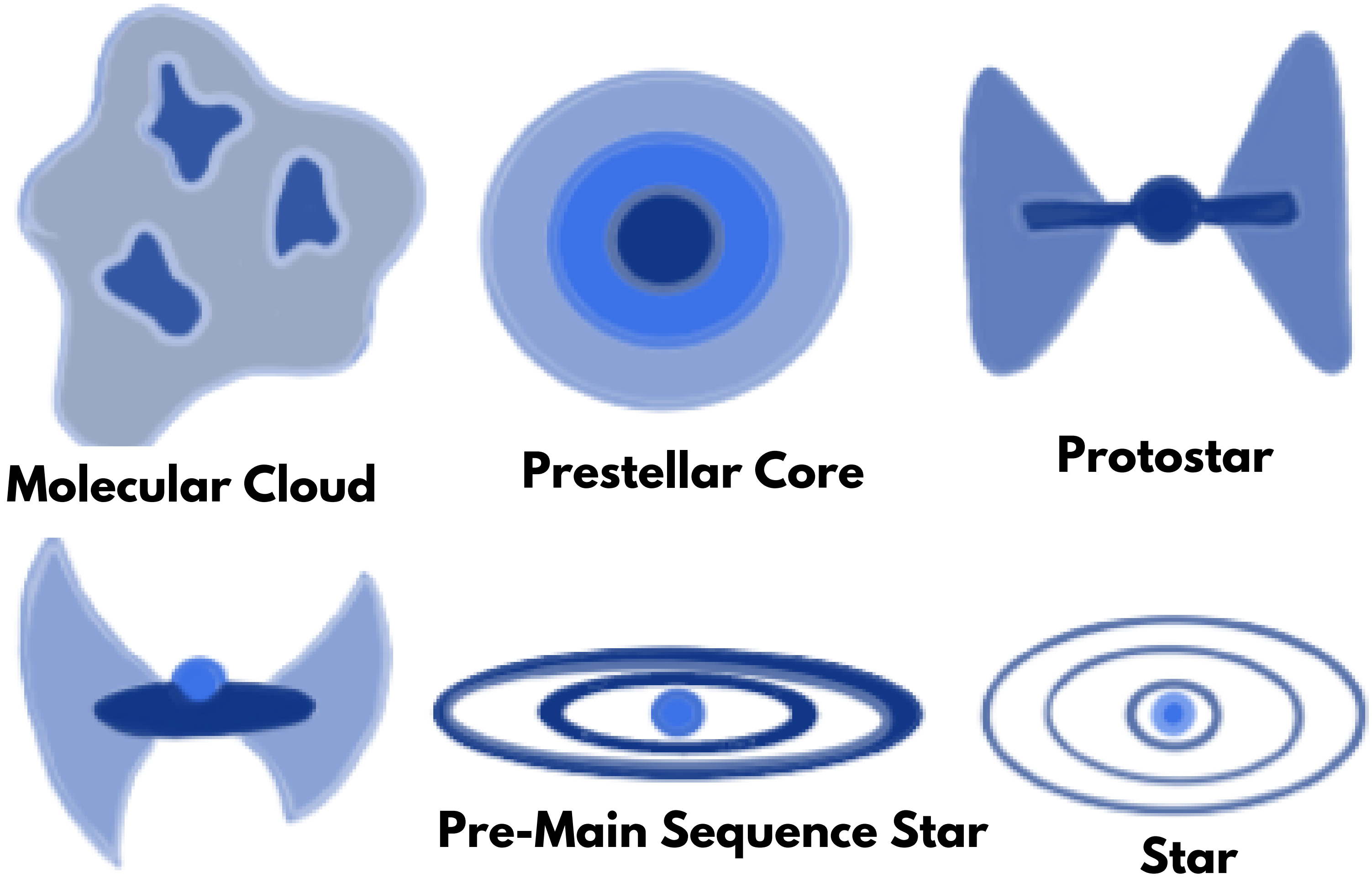
sofia.marulanda2@udea.edu.co

Stellar formation process



Low mass systems

Type B and O stars form, we observe them, but how?

Accretion vs Radiative Feedback problem!

$M \geq 40\ M_\odot$
Acretion Rates $> 3X10^{-3} M_\odot\ yr^{-1}$
$R > 100\ R_\odot$

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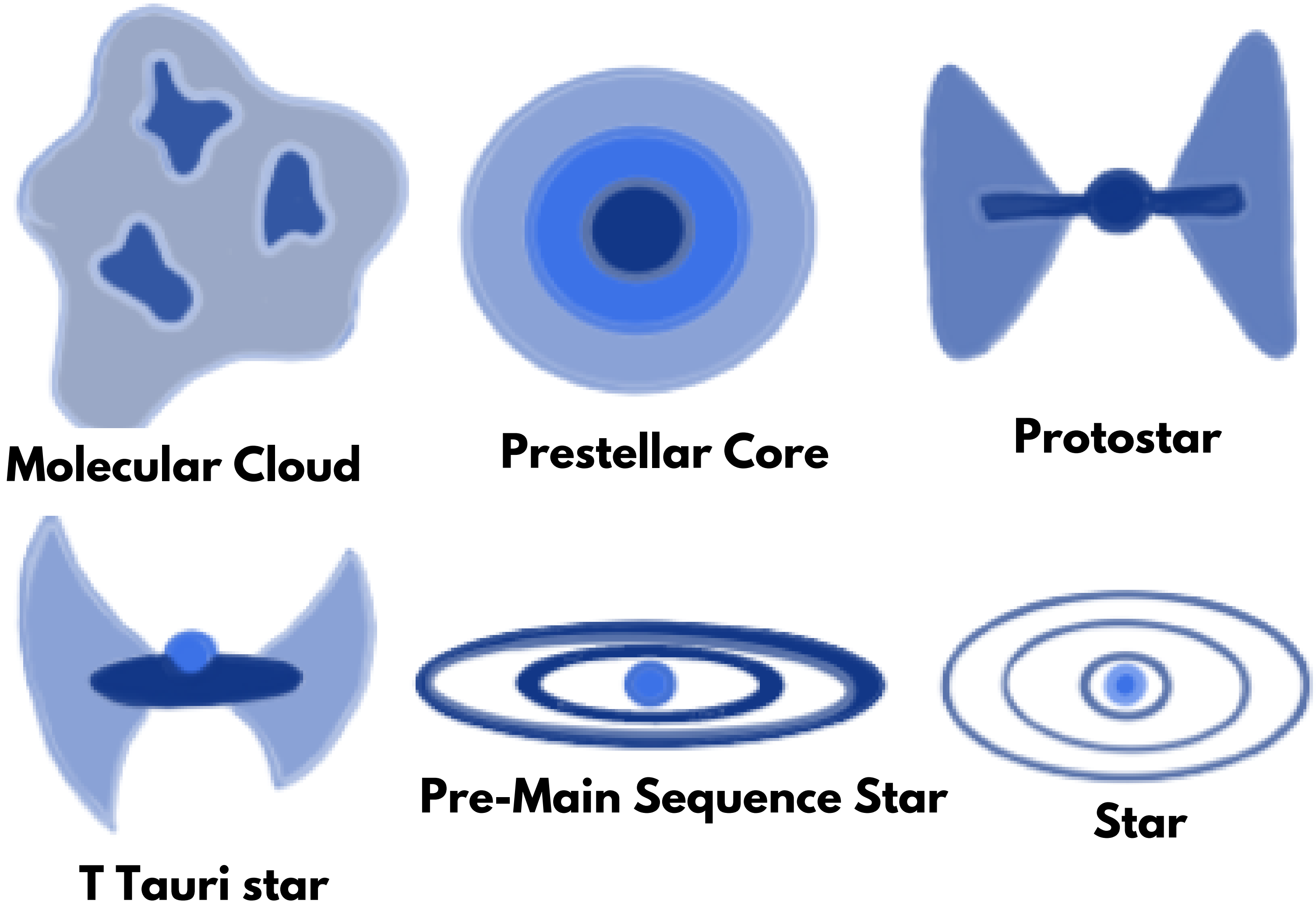
Stellar formation process



Low mass systems

Type B and O stars form, we observe them, but how?

Core accretion

Competitive accretion

Protostellar collisions

Accretion vs Radiative Feedback problem!

No direct observational evidence so far!

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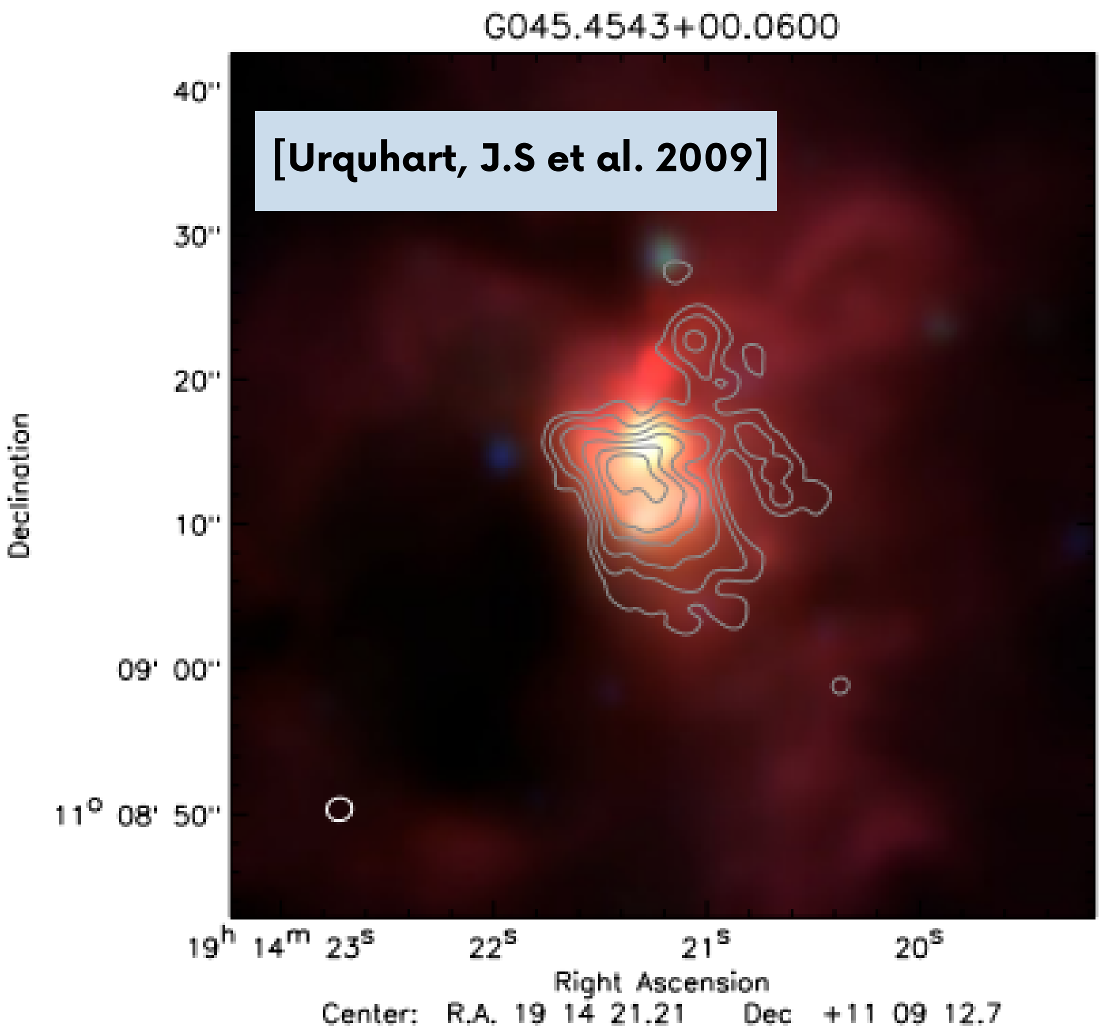
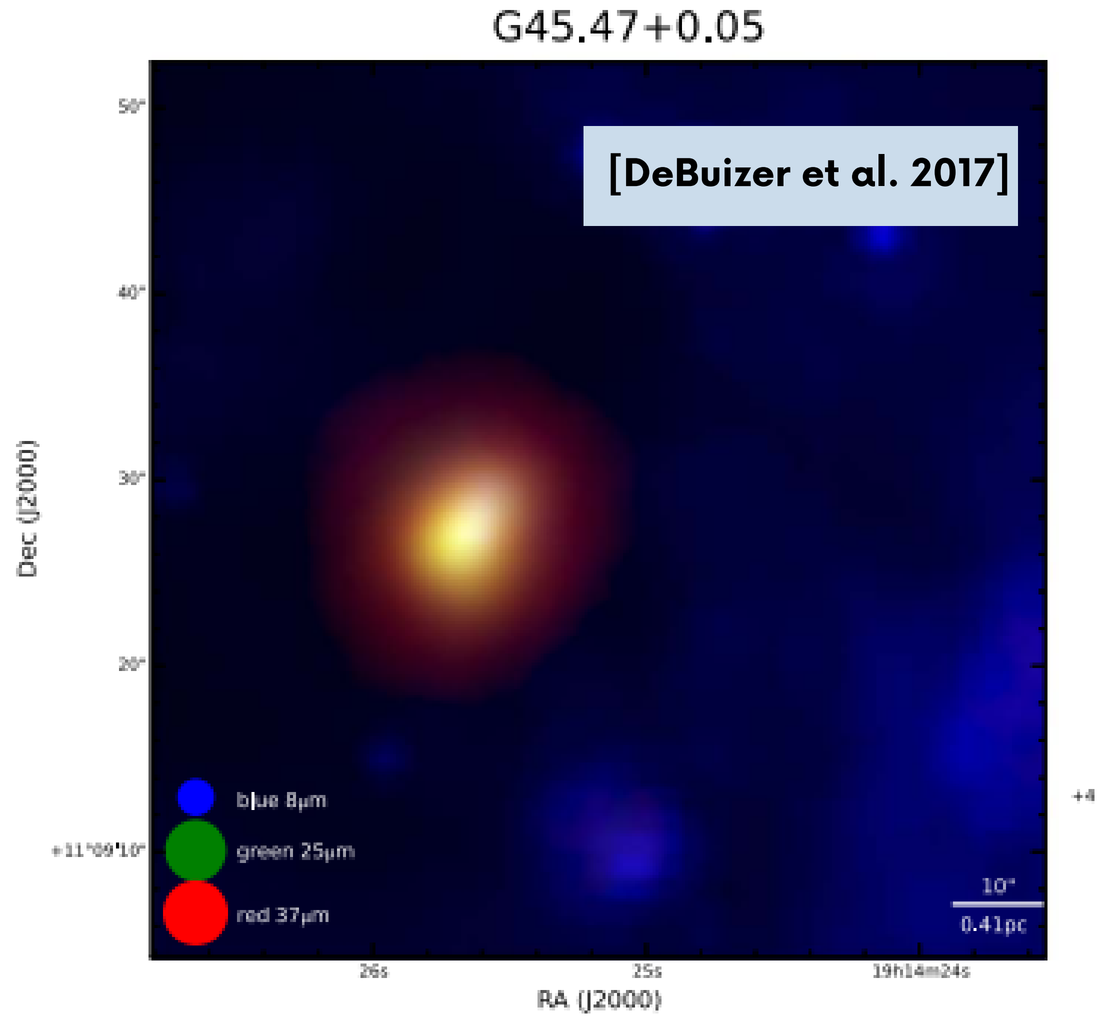
Observing massive sources is difficult!



GLIMPSE Spitzer IR in 3.6, 4.5 and 8.0 μm bands (blue, green and red) overlaid with contours of the 6cm radio emission

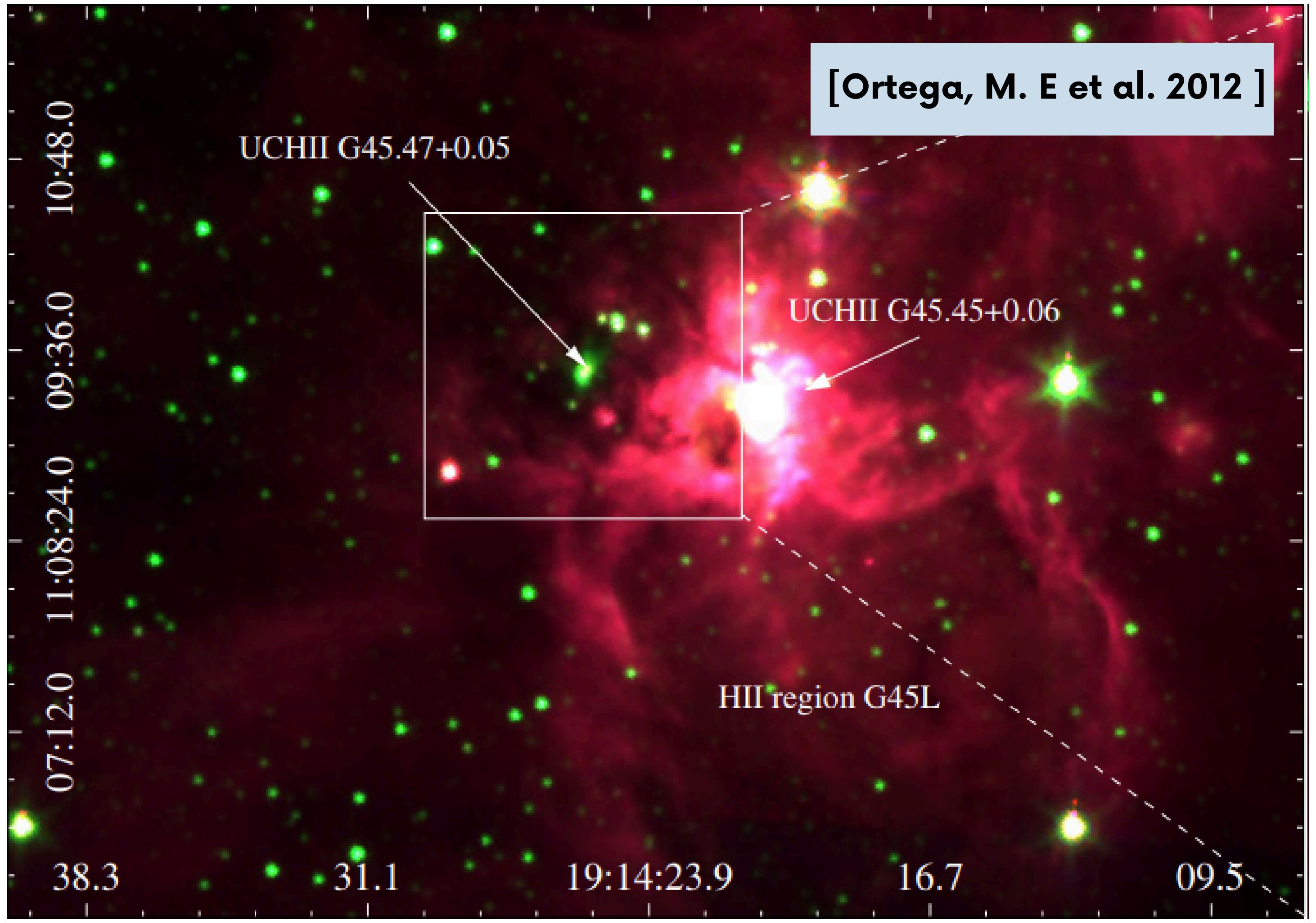


RGB images IR Spitzer

How do we detect them then?

Started being associated with a UCHII region → Wilner et al. 1996, Wood & Churchwell 1989

H2O and HO masers → Forster & Caswell 1989



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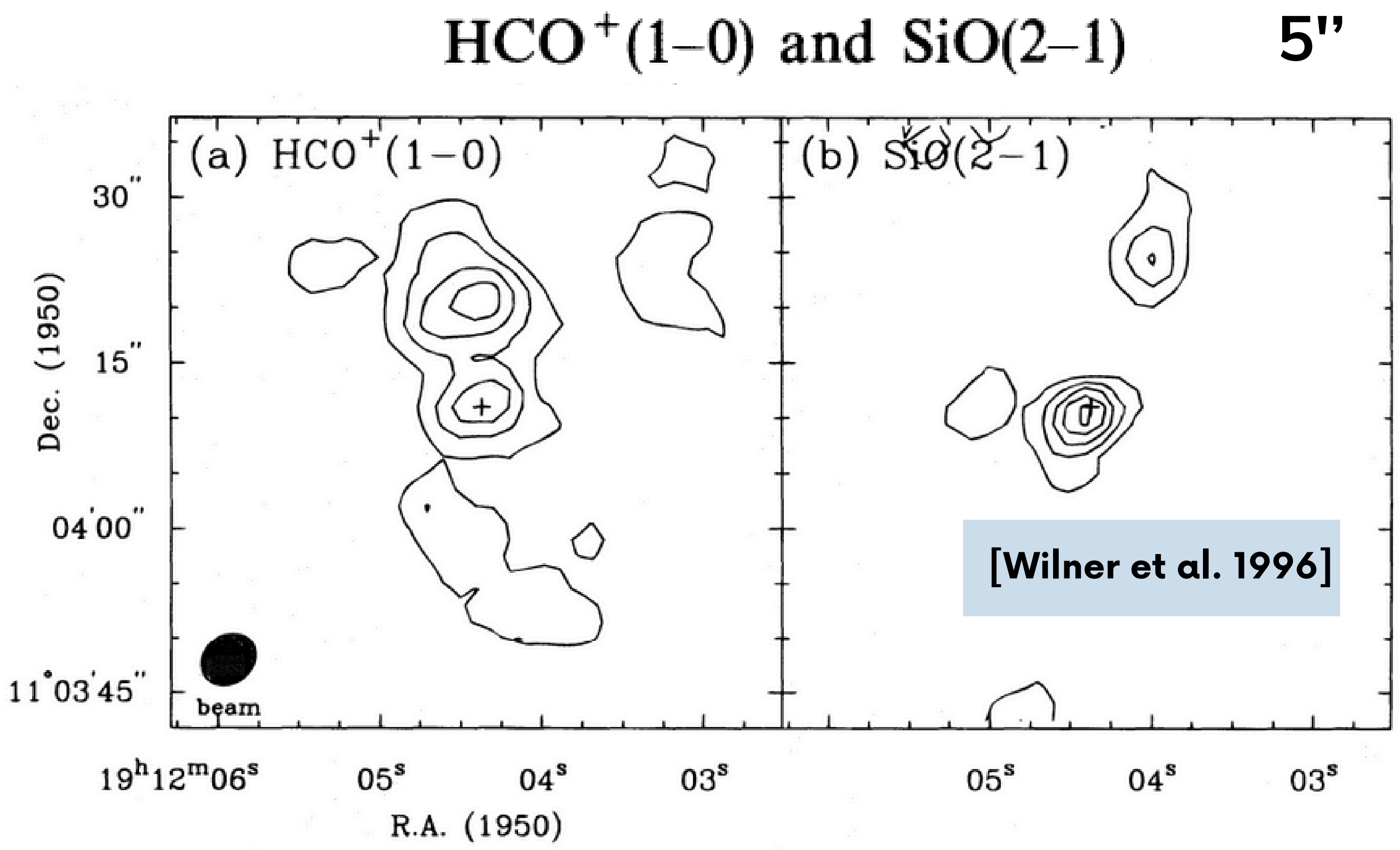
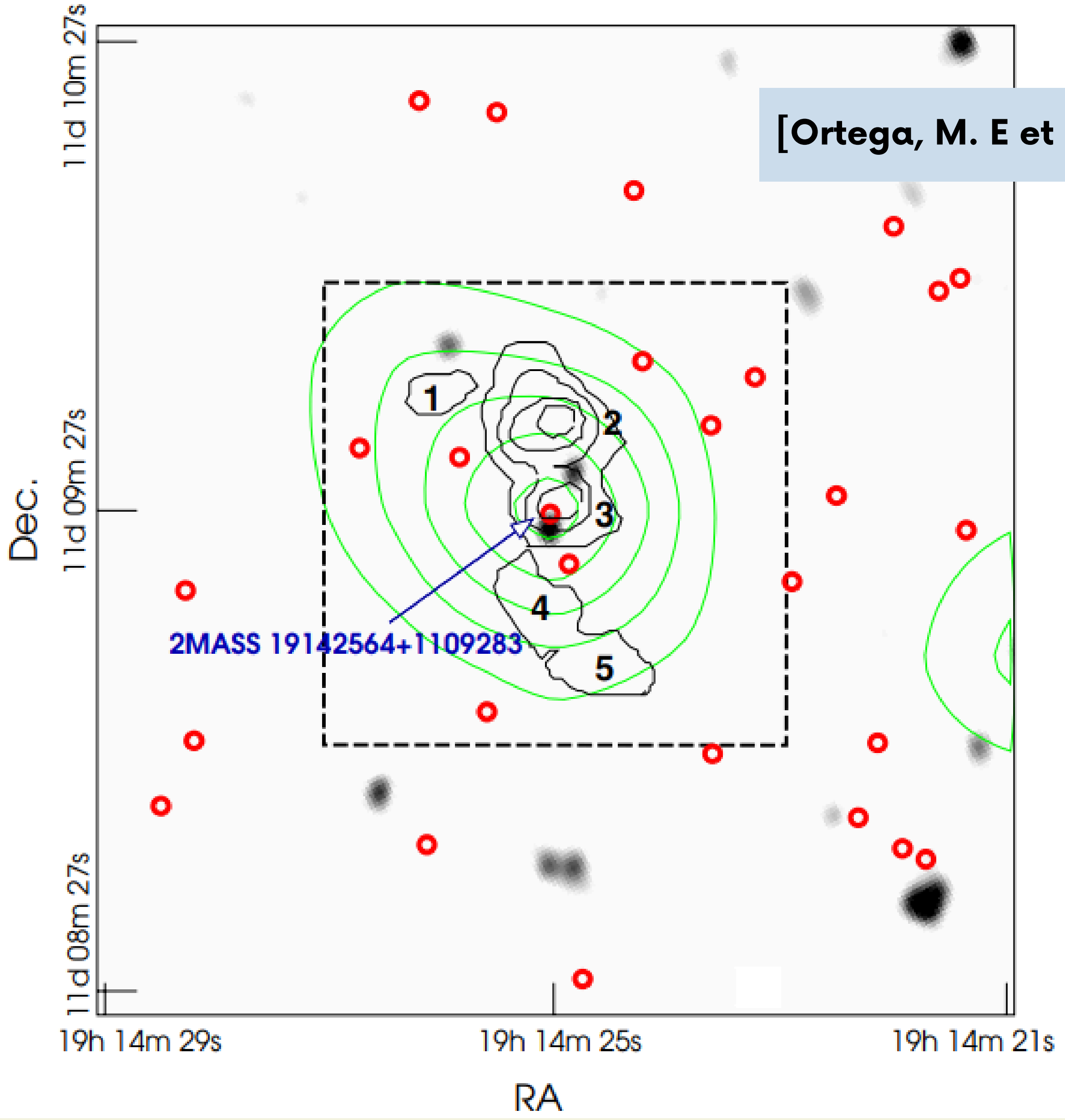
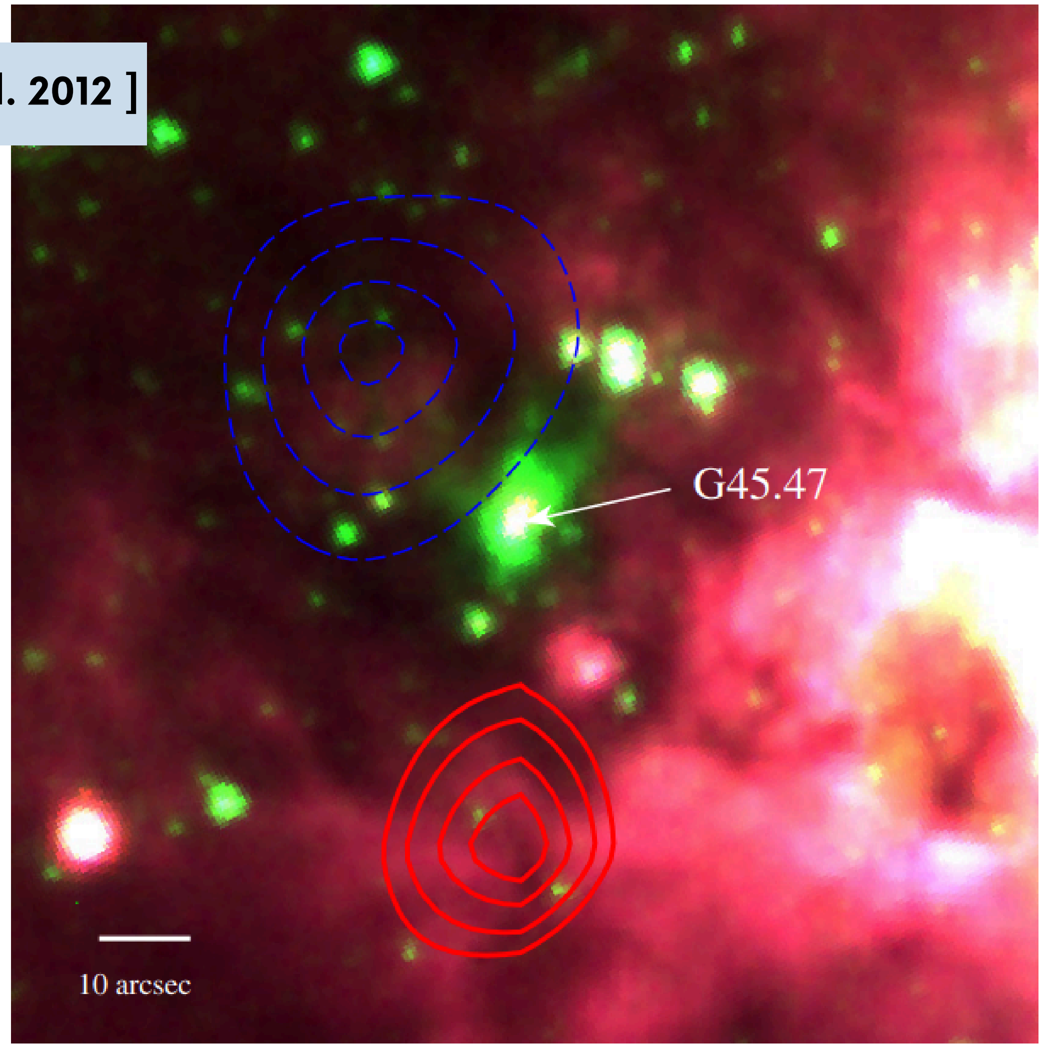
Large scale structure

Searching for infall signatures on the source







Unable to observe an inverse P Cygni profile that indicates infall of material

Green contours are HCO+ J= 4-3
Radio continuum at 6 cm mapped using ASTE
1-5 HCO+ J= 1-0 clumps region is highly fragmented and consists of dense pockets of gas

CS J = 7–6 transition reveals the presence of warm and dense gas

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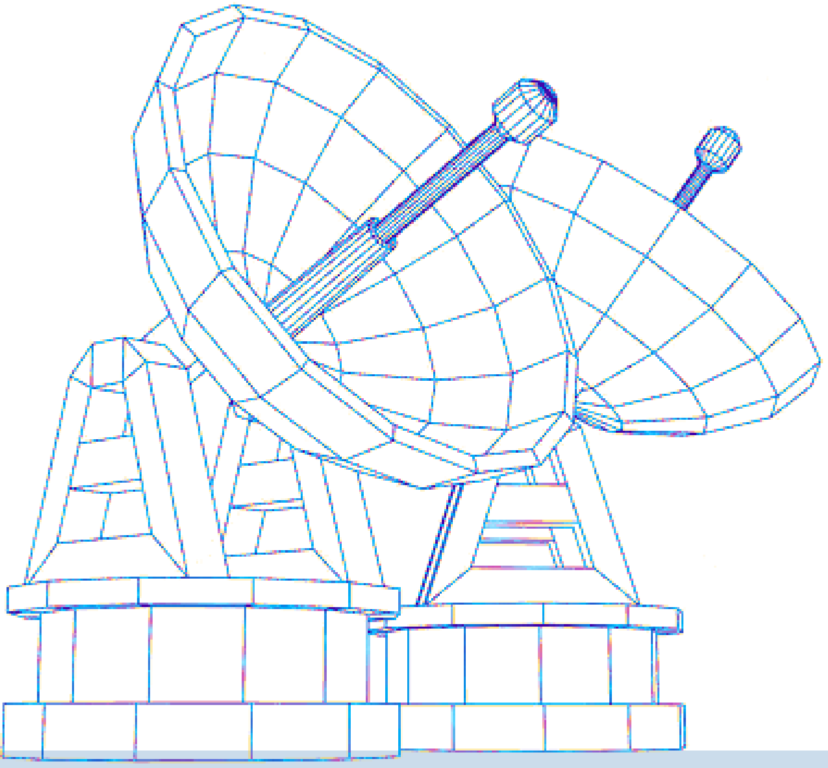
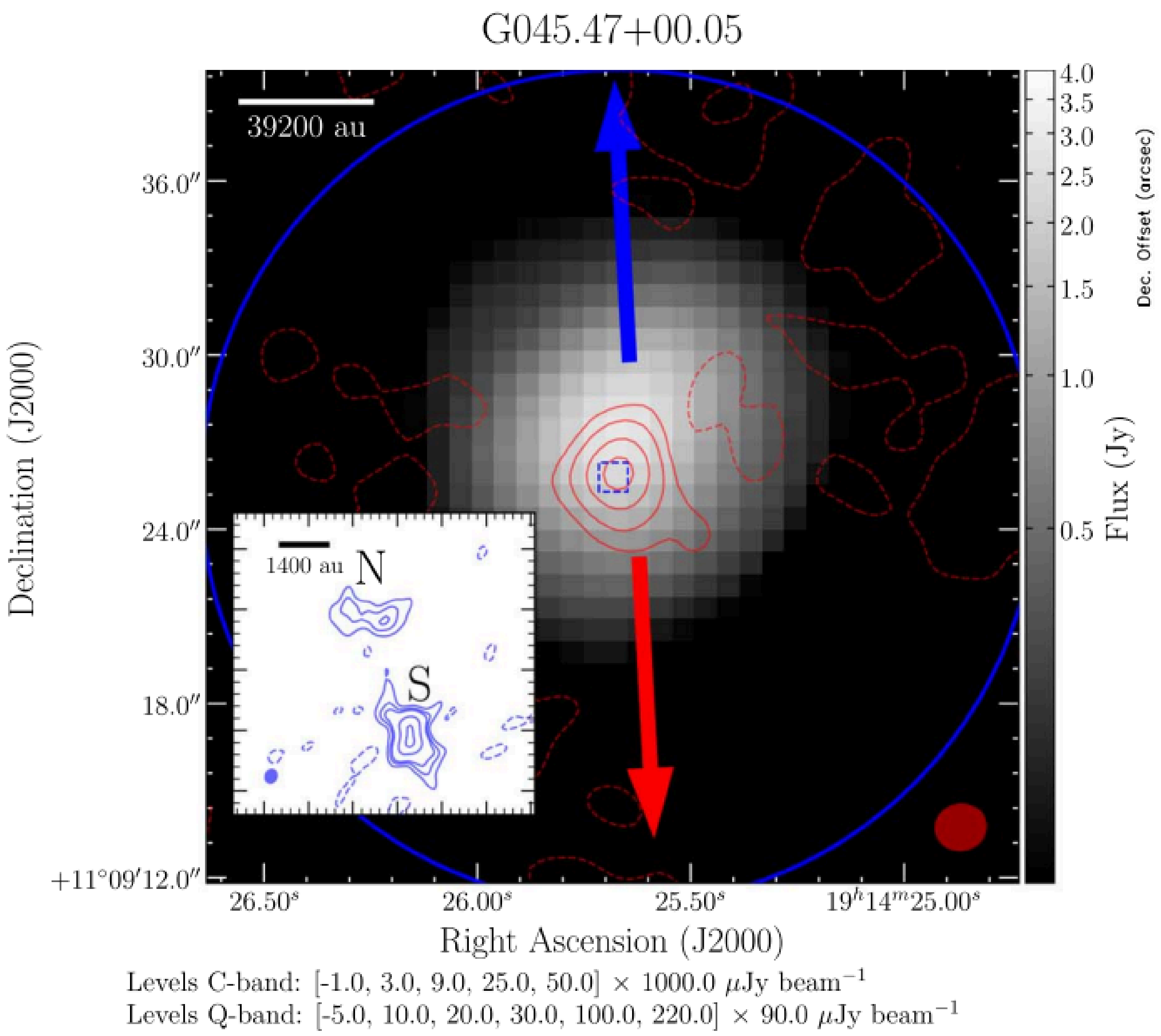
Improved sensitivity

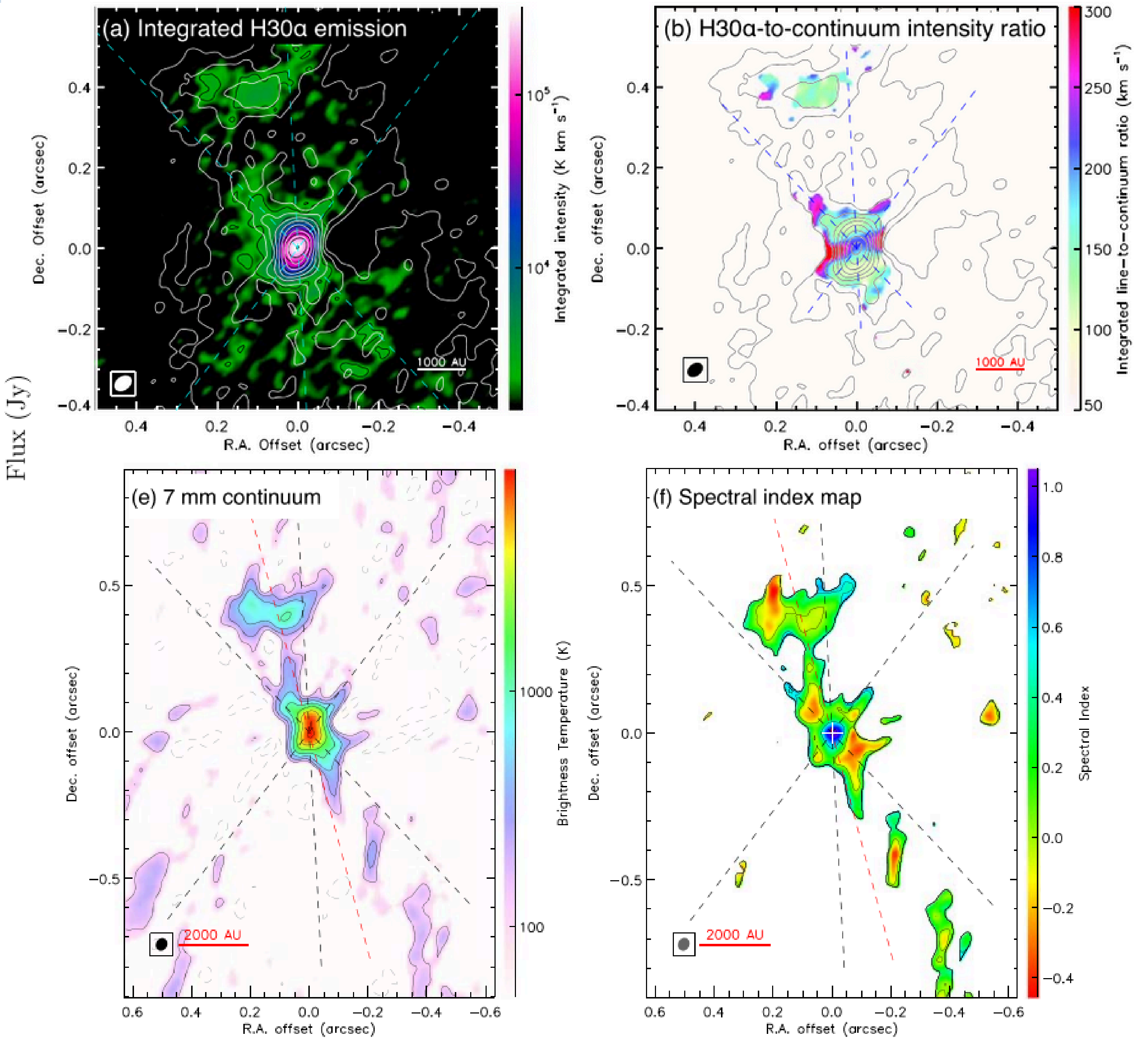
The SOFIA Massive (SOMA) Star Formation Surveys



[Rosero, V et al 2019]



[Zhang, Y et al 2019]



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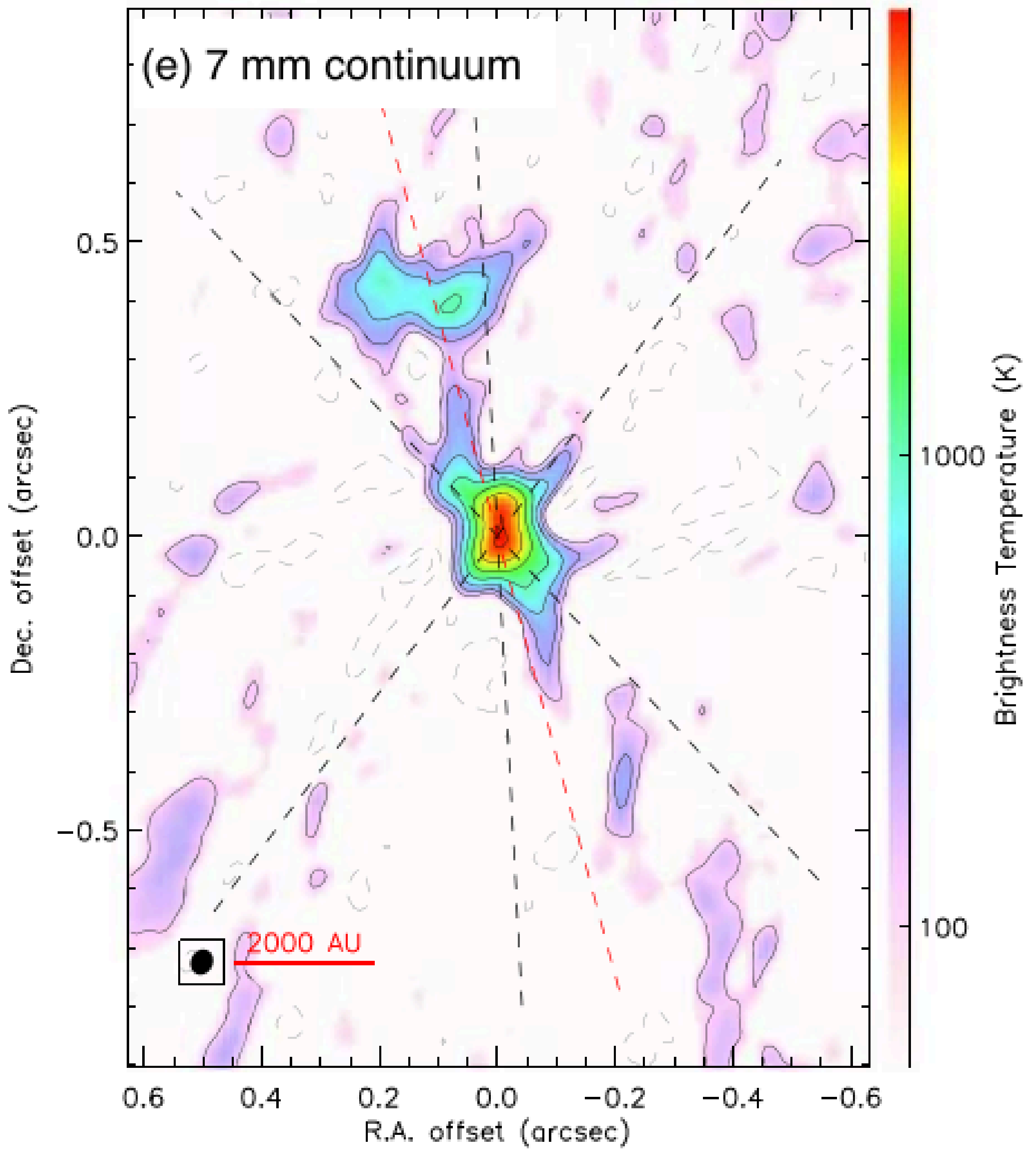
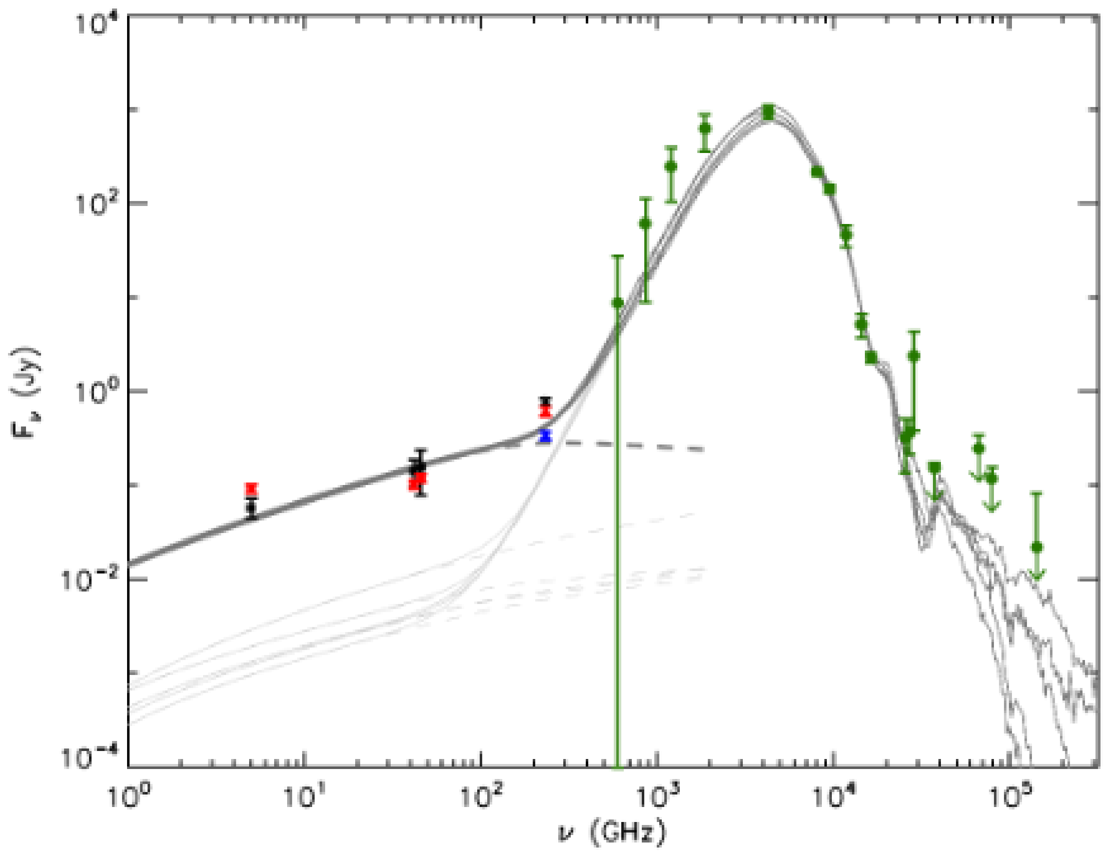
G45.47+0.05

[Zhang, Y et al 2019]



Observed with	Alma Band6 / VLA BandQ
Mass	50M⊙
Distance	8.4 kpc
Birth Region	UHCII

Spectral Energy Distribution



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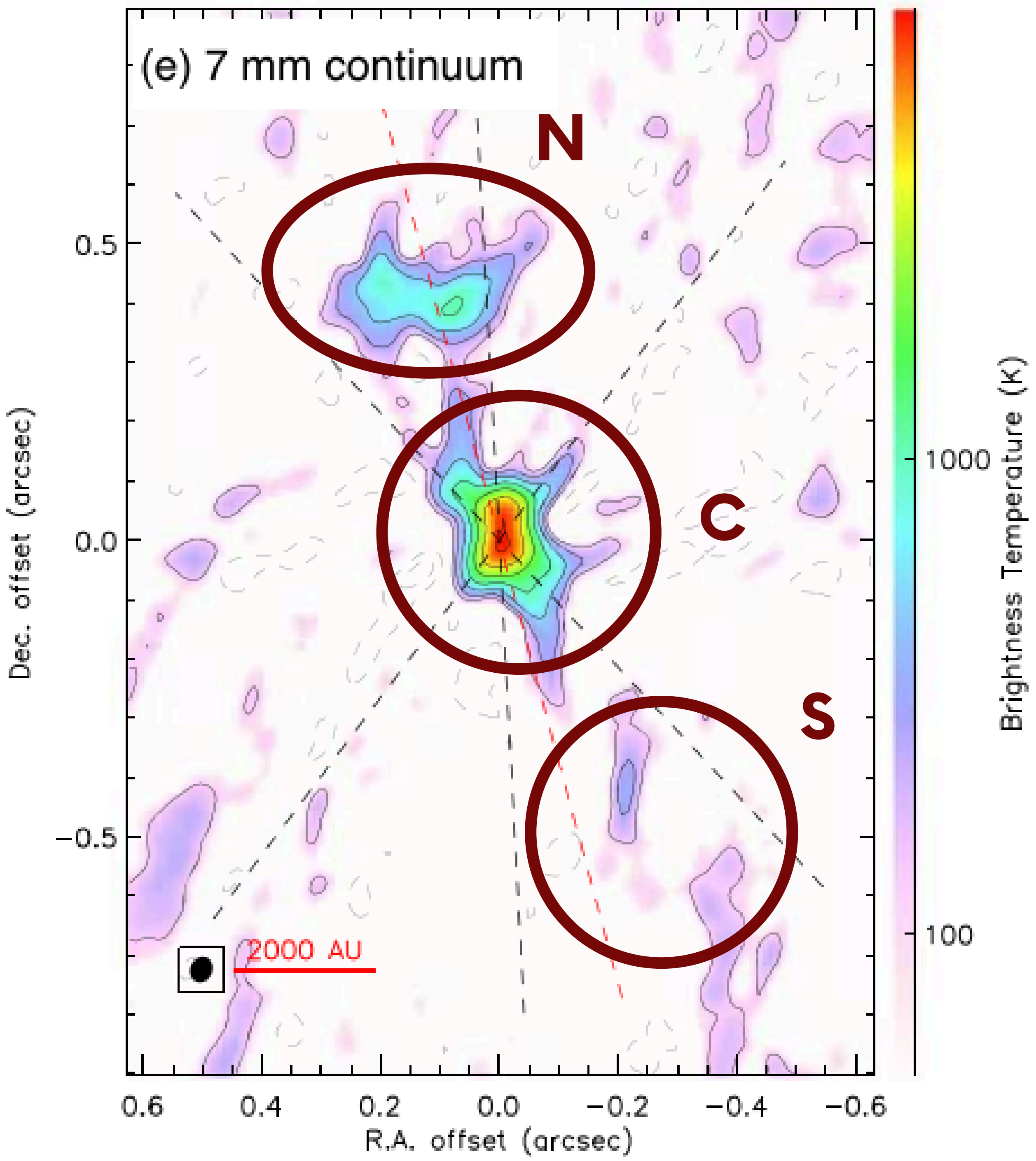
G45.47+0.05

[Zhang, Y et al 2019]



Observed with	**Alma Band6 / VLA BandQ**
Mass	**50M☉**
Distance	**8.4 kpc**
Birth Region	**UHCII**

Disk confirmed throught kinematics

Photoionised bipolar outflow

Spectral index
$\alpha > 0$ Dominant free-free emission
Some regions $\alpha < -0.5$ indicate non-thermal emission

Inside the ionized outflow: Non-thermal jet candidate

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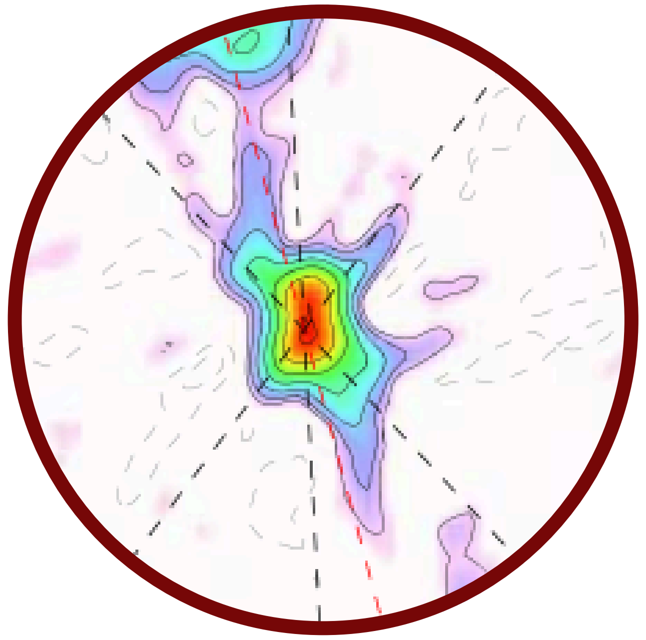
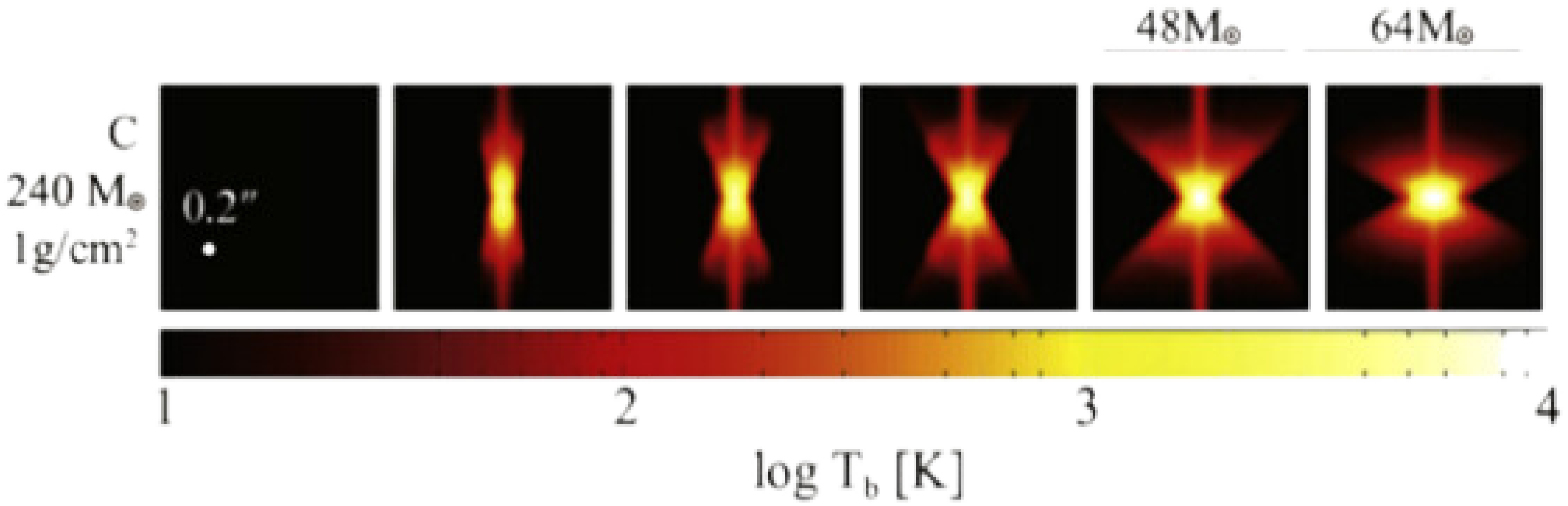
G45.47+0.05

Why is it so special?



Morphologically, it coincides well with the model



[Tanaka, K.E.I., Tan, J.C., Zhang, Y., 2016]

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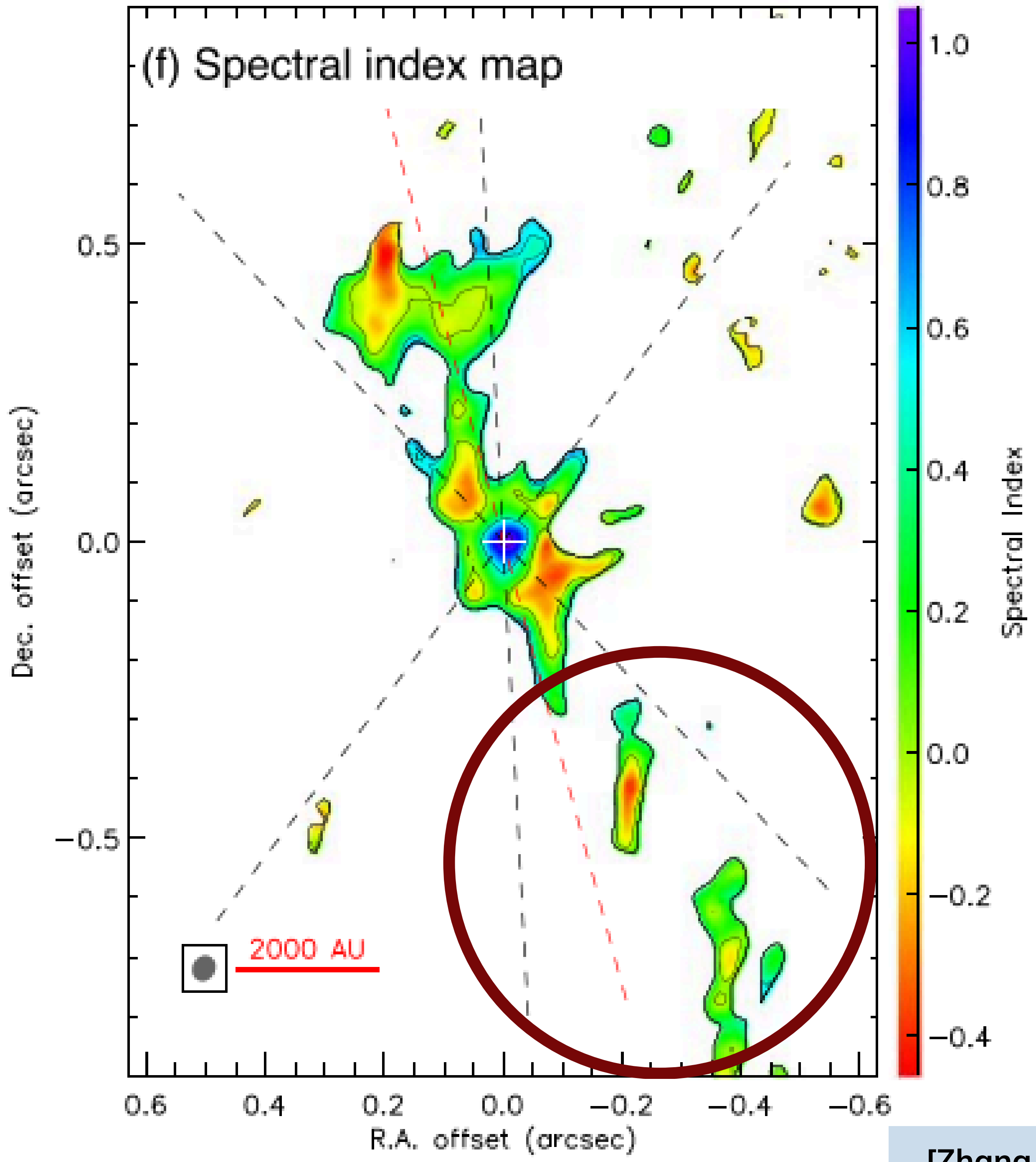
G45.47+0.05

Very challenging source!



Artifact or detection?

[Zhang, Y et al 2019]

Observed with	**Alma Band6 / VLA BandQ**
Mass	**50M⊙**
Distance	**8.4 kpc**
Birth Region	**UHCII**

Disk confirmed throught kinematics

Photoionised bipolar outflow

Spectral index
α > 0 Dominant free-free emission
Some regions **α < -0.5 indicate non-thermal emission**

Inside the ionized outflow: Non-thermal jet candidate

Demonstrating its presence would make G45 the first confirmed observational evidence of disk accretion

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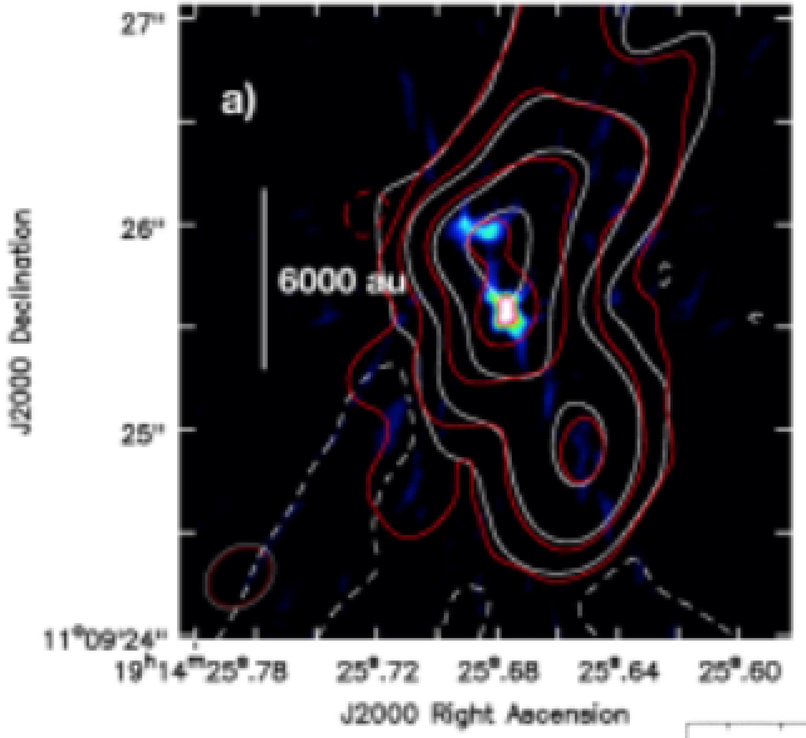
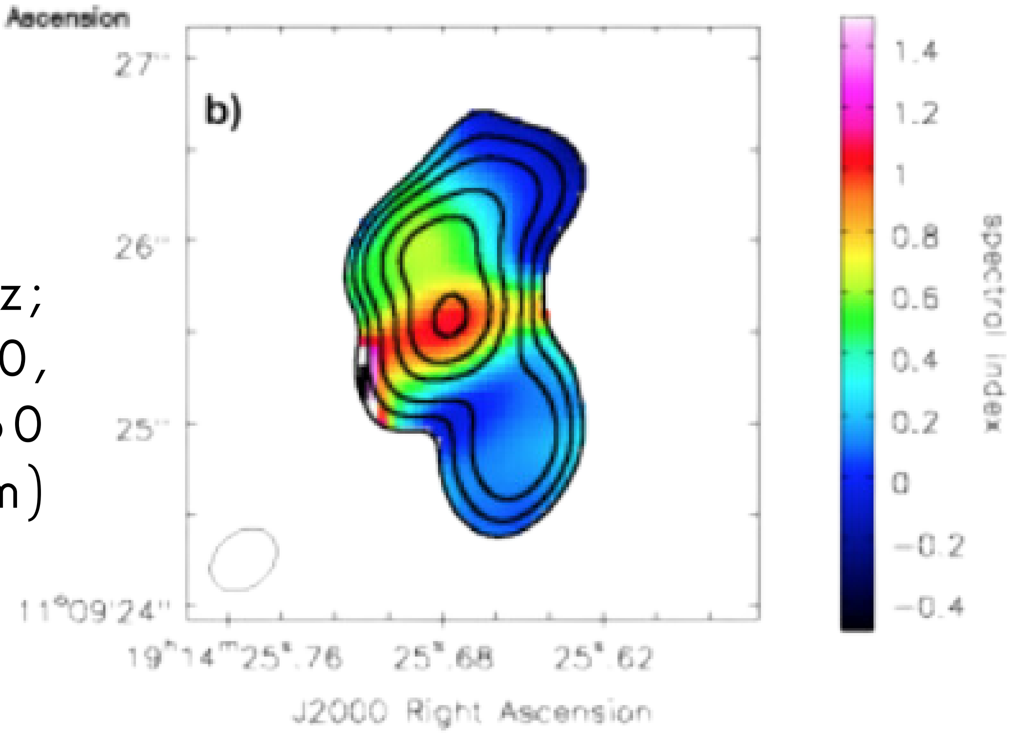
The Observations



Q-band (44 GHz) with overlaid white contours at C-band (6 GHz; levels: [−3, 3, 20, 70, 150, 200)× 94 μJy/beam])



K-band (22 GHz; red; (−3, 3, 20, 120, 500)× 60 μJy/beam)

	Band	Frequency (GHz)	Central Frequency (GHz)	L (cm)
ALMA	6	211 – 275	234	0.13
VLA	Q	40 – 50	44	0.7
	Ka	26.5-40	33	1
	K	18 – 26.5	22.2	1.3
	Ku	12 - 18	15	2
	C	4 – 8	6.7	6

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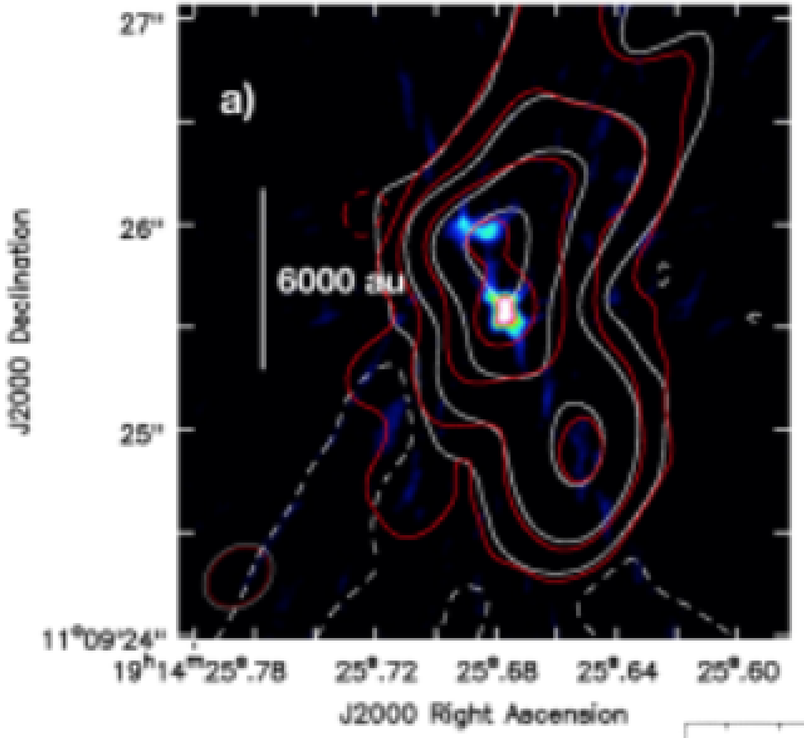
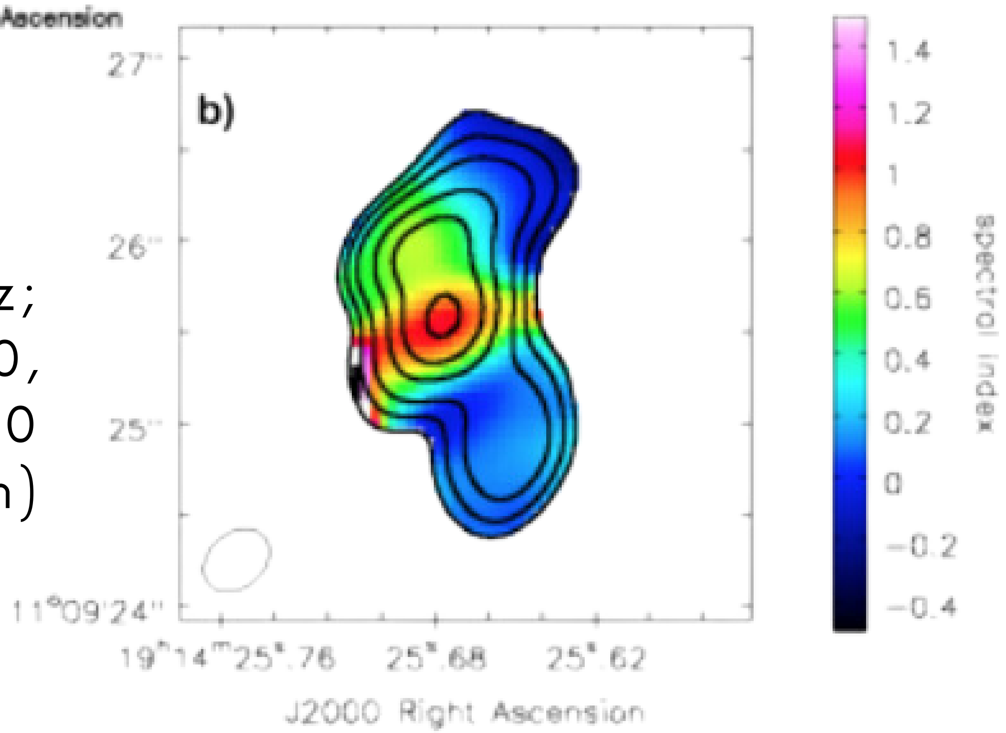
The Observations



Q-band (44 GHz) with overlaid white contours at C-band (6 GHz; levels: [−3, 3, 20, 70, 150, 200)× 94 μJy/beam])



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	Ka	26.5-40	33	1	NEW!
	K	18 – 26.5	22.2	1.3	
	Ku	12 - 18	15	2	
	C	4 – 8	6.7	6	NEW!

Wide Multiband Approach!

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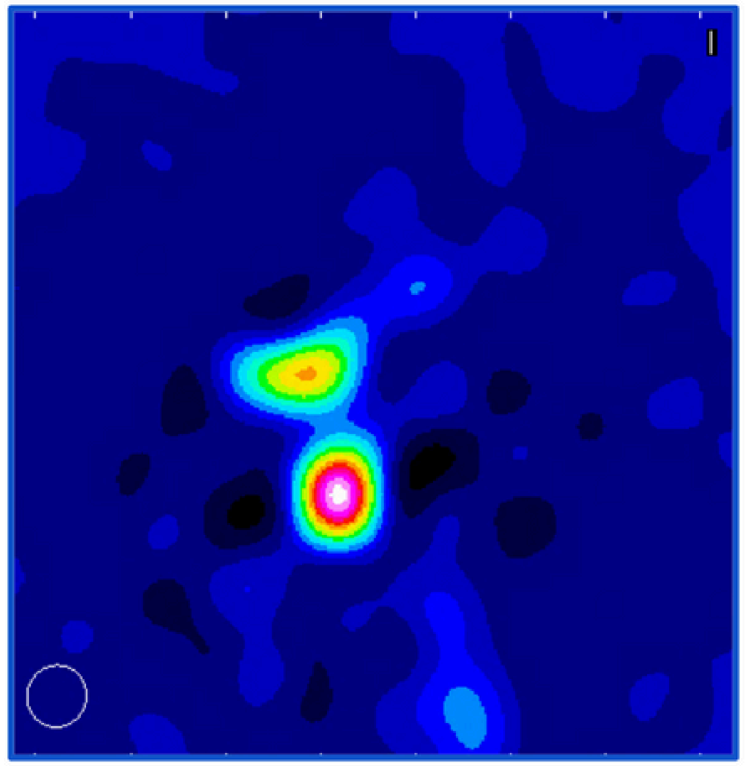
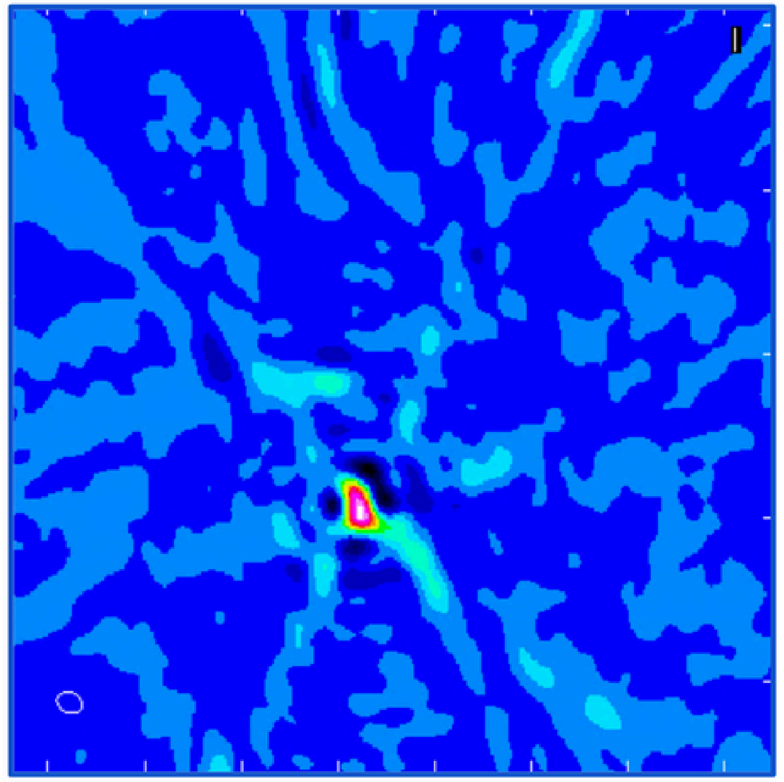
Continuum Imaging Process

High and low resolution approach





CASA
Common Astronomy Software Applications

Iterative cleaning

Combine bands

Resolve compact emissions

Enhance sensitivity without sacrificing resolution

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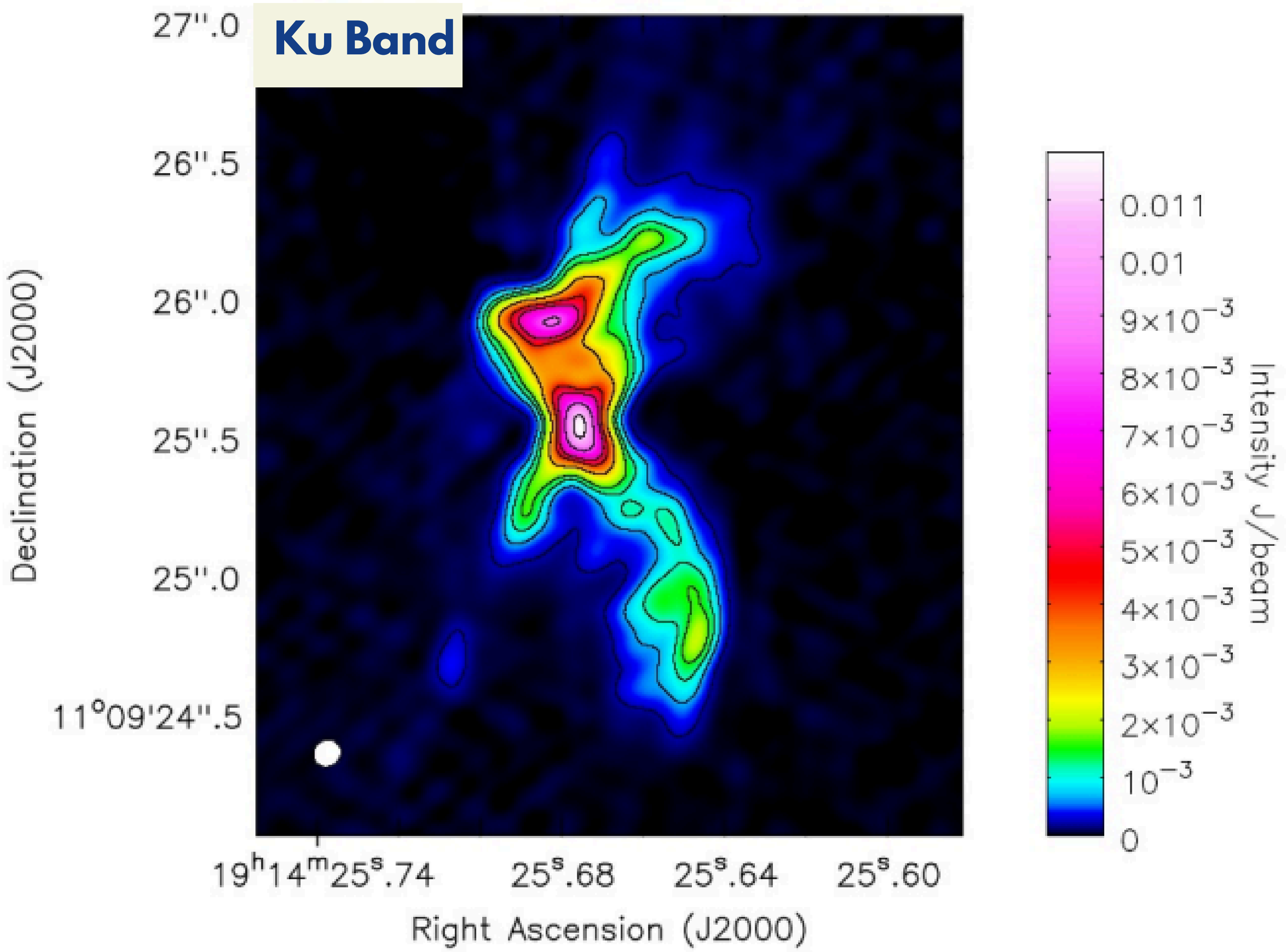
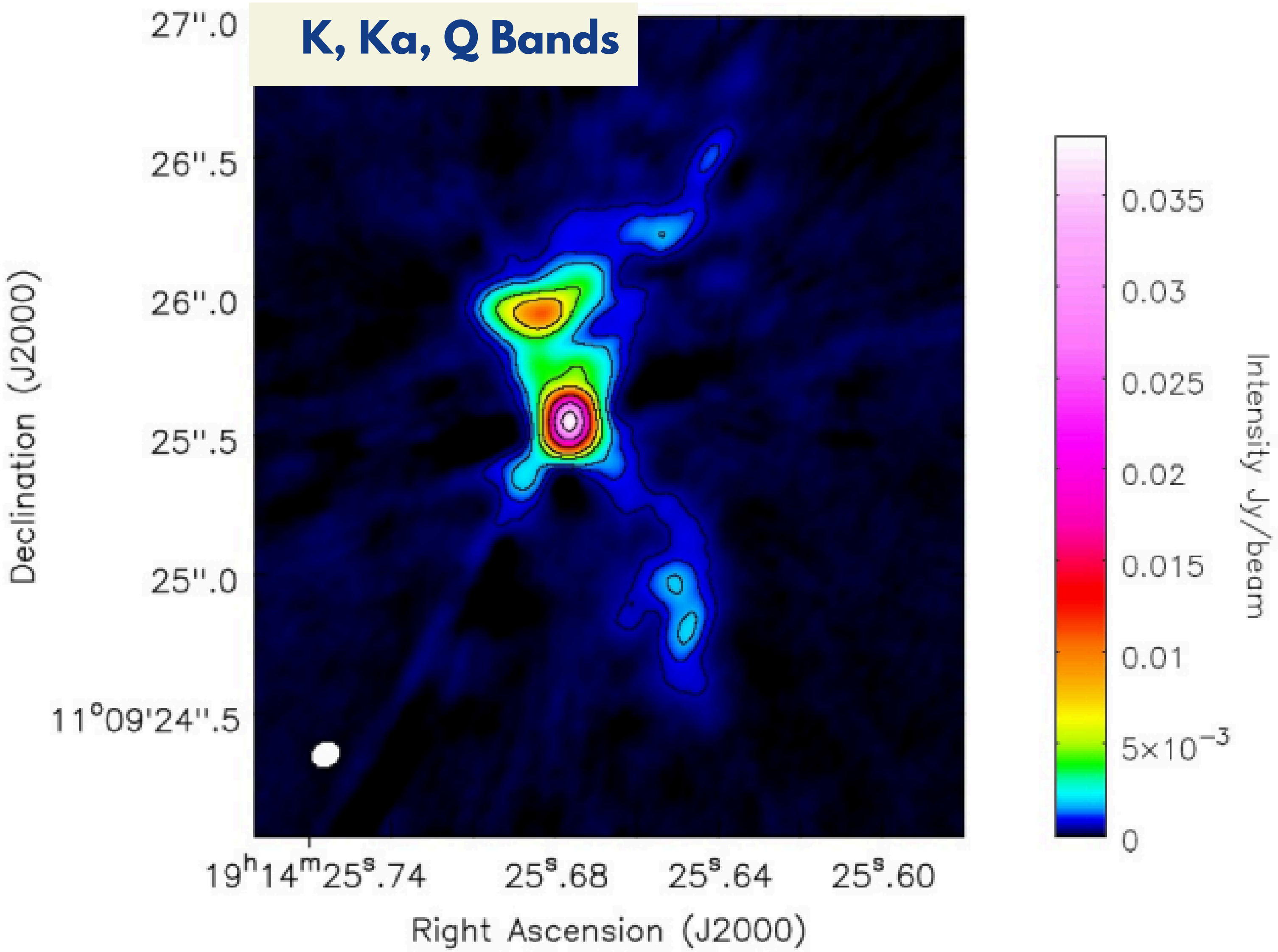
Radio continuum results

C.F 15 GHz 0.11" 0.022 mJy beam−1 **C.F 33.2 GHz 0.06" 0.048 mJy beam−1**

3σ detection significance



[−3, 10, 30, 50, 70, 130, 200, 250, 370, 500] × 0.022mJy beam−1



[−3, 10, 20, 35, 90, 150, 300, 480, 700] × 0.048mJy beam−1

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Radio continuum results

C.F 15 GHz 0.11" 0.022 mJy beam−1

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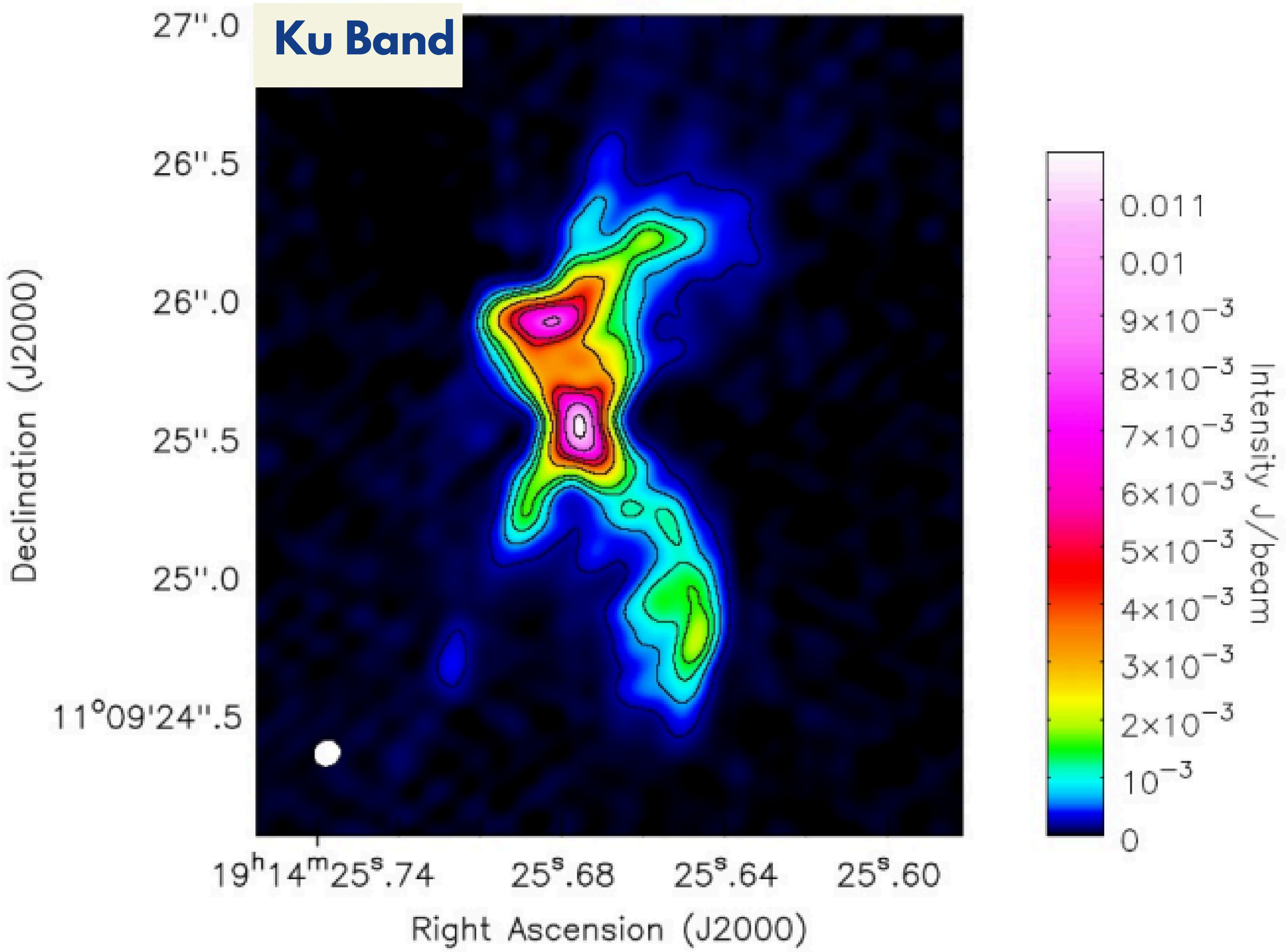

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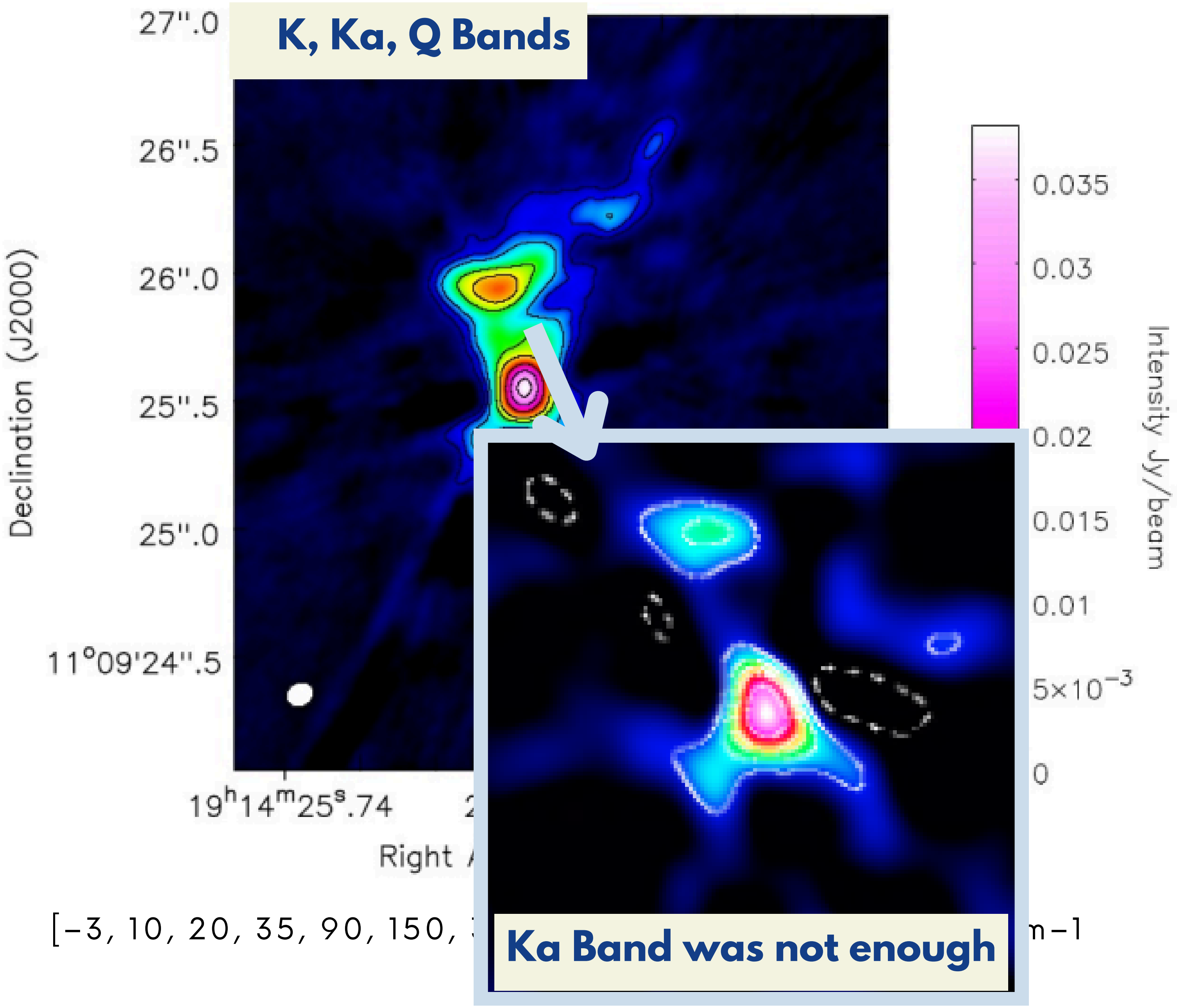

[−3, 10, 20, 35, 90, 150, … m−1

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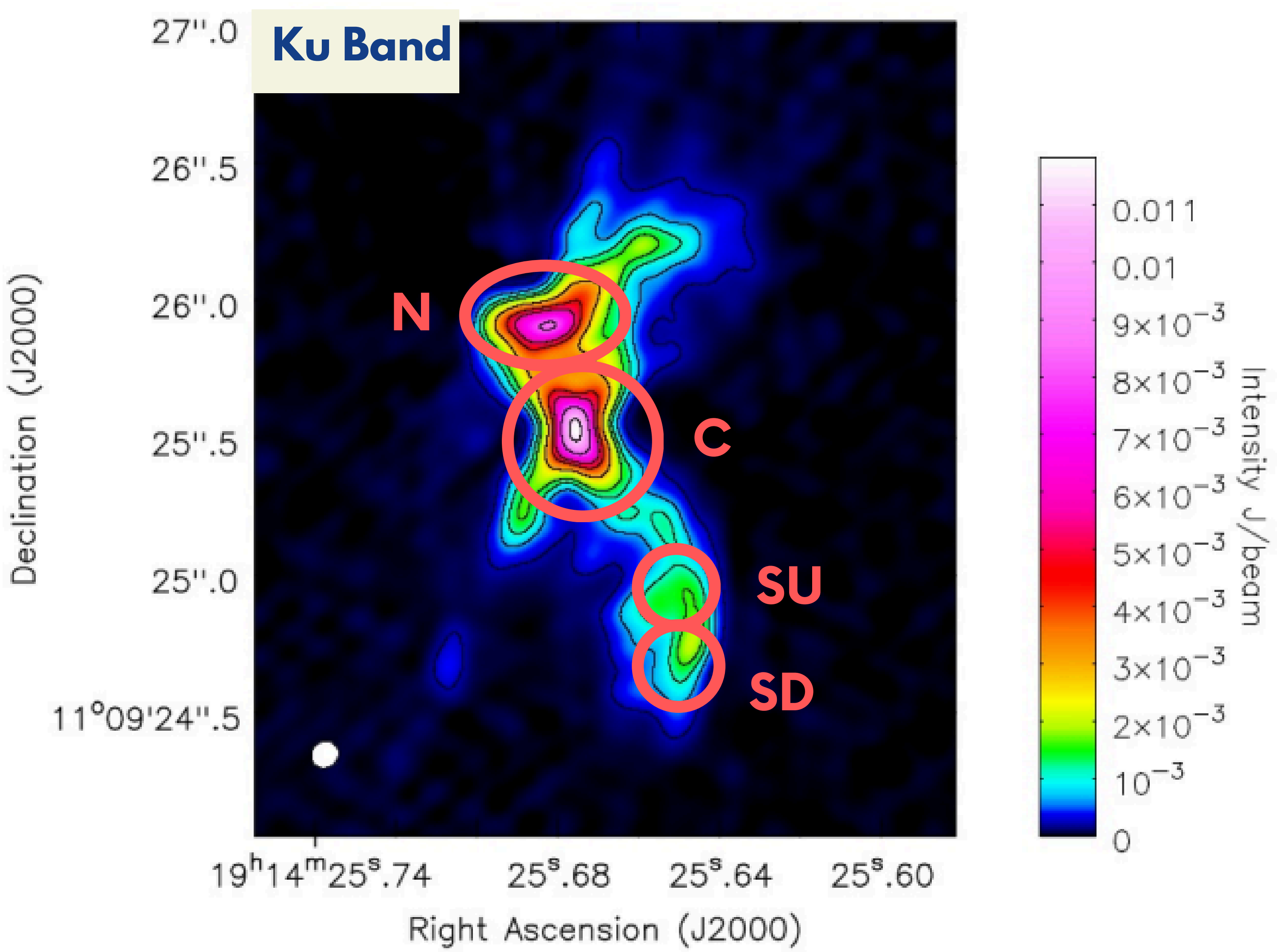
Radio continuum results

How does the emission change with frequency?

C.F 15 GHz 0.11" 0.022 mJy beam−1



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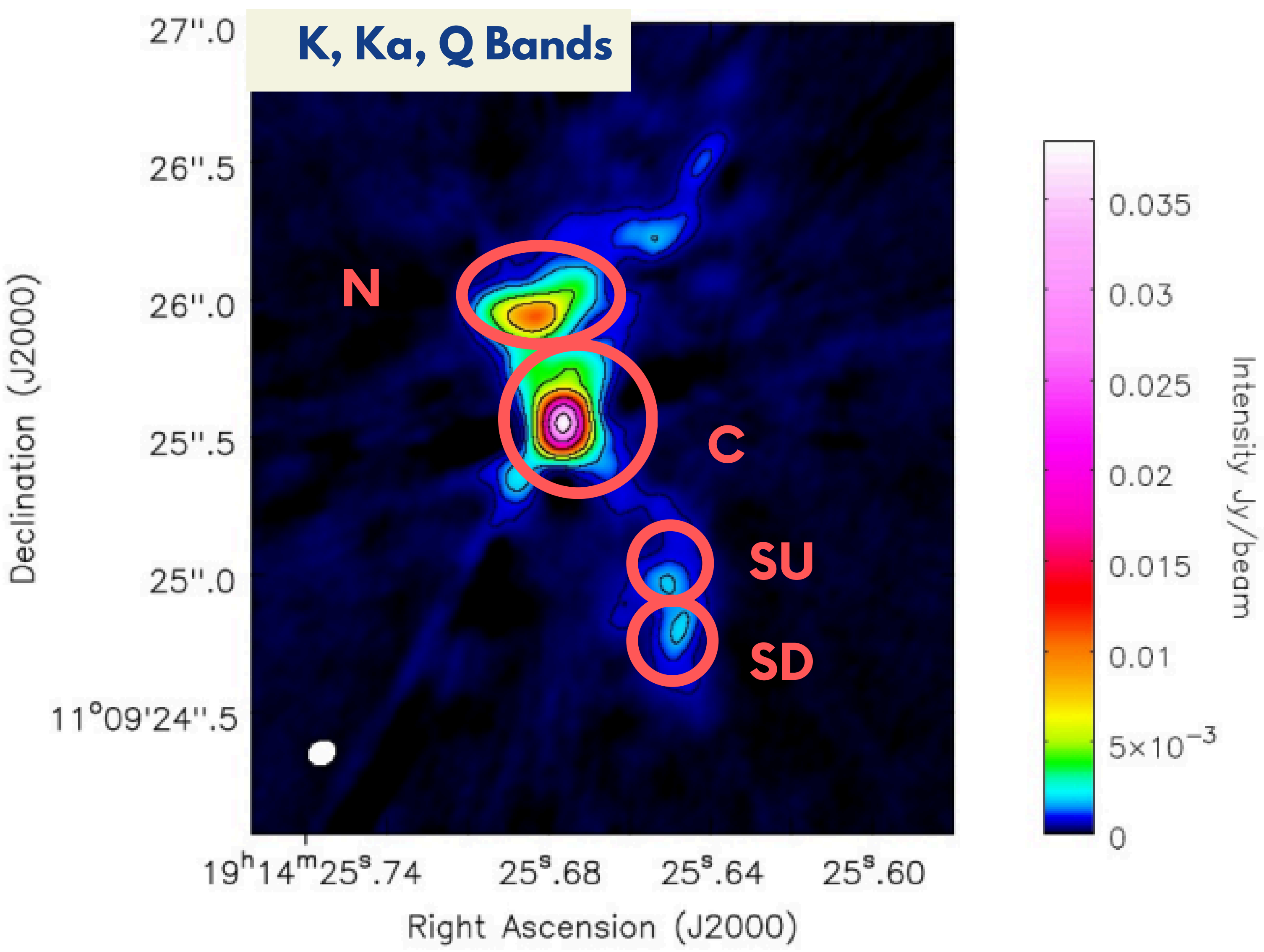

[−3, 10, 20, 35, 90, 150, 300, 480, 700] × 0.048mJy beam−1

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Spectral Index α

$$S(\nu) \propto \nu^{\alpha}$$

We can use this to characterize the compact emissions in the source

$$\alpha = \frac{\log\left(\frac{I_{\nu_1}}{I_{\nu_2}}\right)}{\log\left(\frac{\nu_1}{\nu_2}\right)} \qquad \nu_1 = 15\,\text{GHz} \quad \nu_2 = 33.2\,\text{GHz}$$

α Range	Emitting Source	Typical Emission Mechanism
α < 0	Non-thermal sources	Synchrotron radiation, AGN, supernova remnants
0 < α < 1	Ionized gas (thermal)	Free-free emission (H II regions)
1 < α < 2	Dust (thermal)	Thermal dust emission
α ≈ 2	Very cool thermal sources	Blackbody radiation (cool stars, cold dust)
α > 2	Very cold sources	Extremely cold dust or molecular clouds

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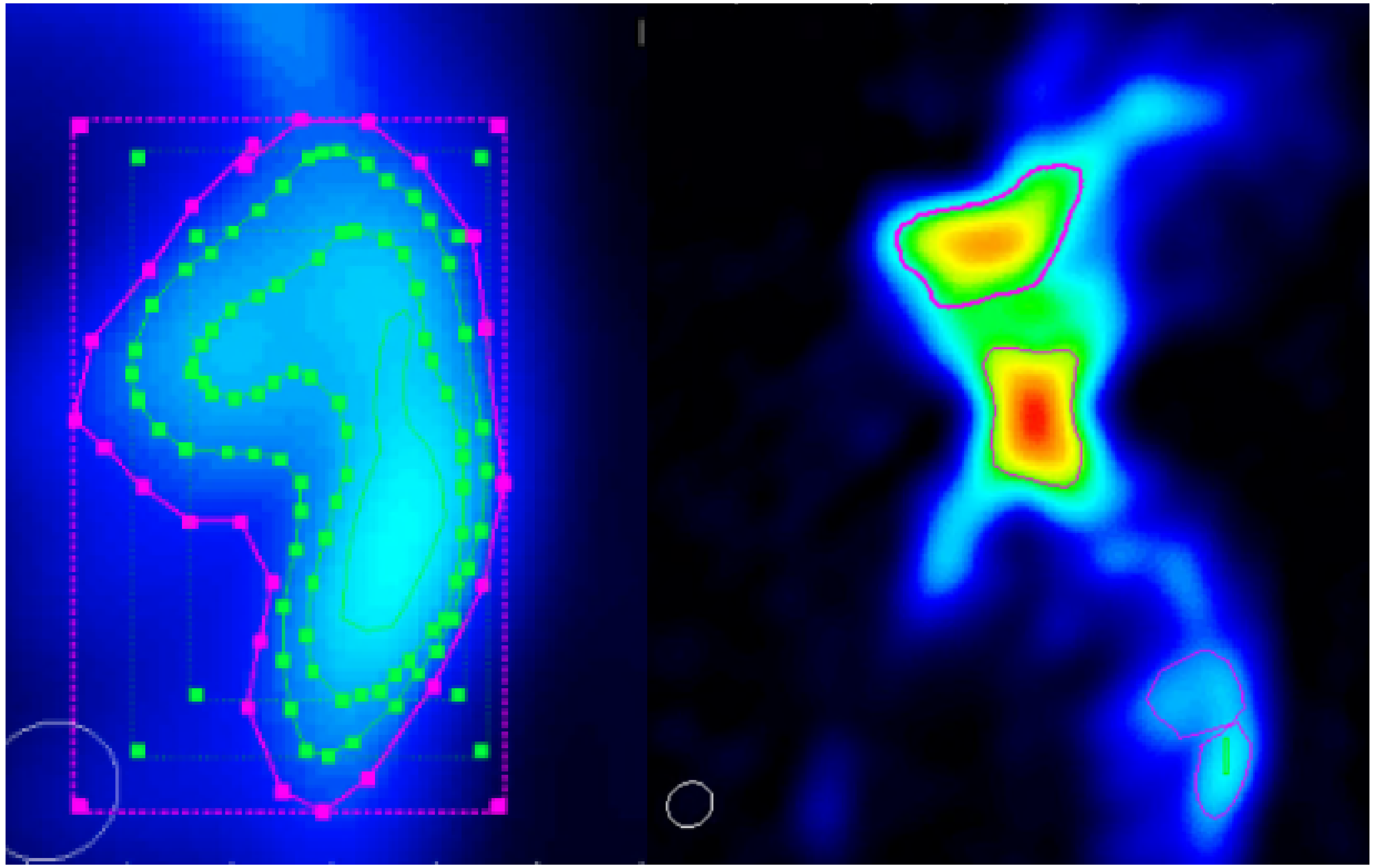
Spectral Index α: flux extraction



imfit task could not resolve the compact sources, unreliable flux outcomes

Manual enclosing of sources based on contour levels

Same regions used on both Ku and KKaQ images

Flux densities extracted from the viewer

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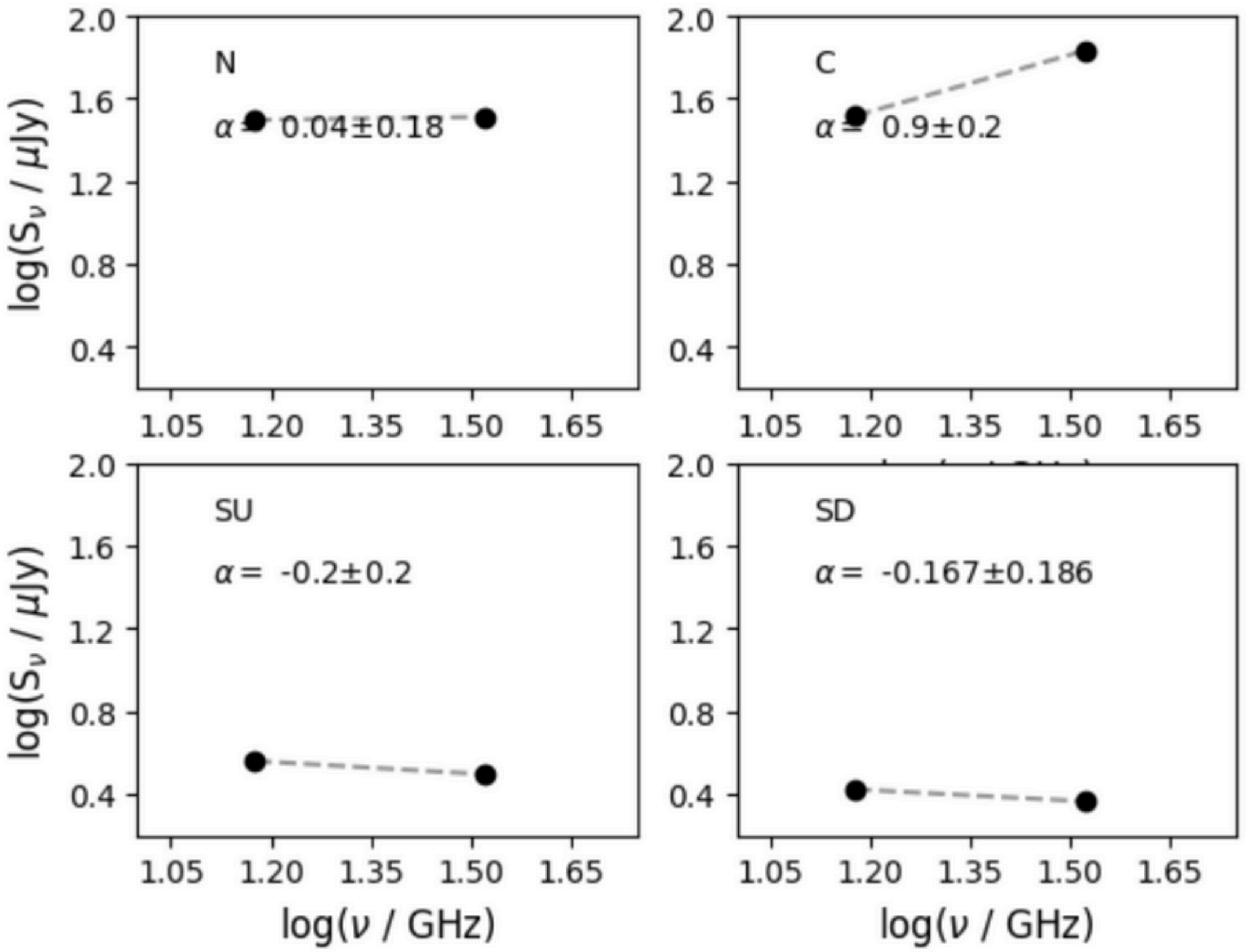
Spectral Index α: flux extraction

α < 0	Non-thermal sources
0 < α < 1	Ionized gas (thermal)



Source	R.A. (J2000)	Decl. (J2000)	Size (″×″)	$S_{\nu 15GHz}(mJy)$	$S_{\nu 33.2GHz}(mJy)$	α
G45N	19:14:25.682	11.09.25.986	0.4 ×0.22	31.40 ±0.06	32.50 ±0.12	0.04 ±0.18
G45C	19:14:25.676	11.09.25.552	0.28 ×0.18	32.80 ±0.05	67.80 ±0.10	0.90 ±0.2
G45SU	19:14:25.650	11.09.24.969	0.20 ×0.19	3.63 ±0.04	3.13 ±0.08	-0.2 ±0.2
G45SD	19:14:25.648	11.09.24.804	0.19 ×0.11	2.65 ±0.03	2.32 ±0.06	-0.17 ±0.18

Flux density uncertainity

$$\sigma_{S_\nu} = \sigma_{\text{image}} \times \left(\frac{\text{npts}}{\text{beam area}}\right)^{0.5}$$

Added in quadrature with an assumed 10% error in callibration

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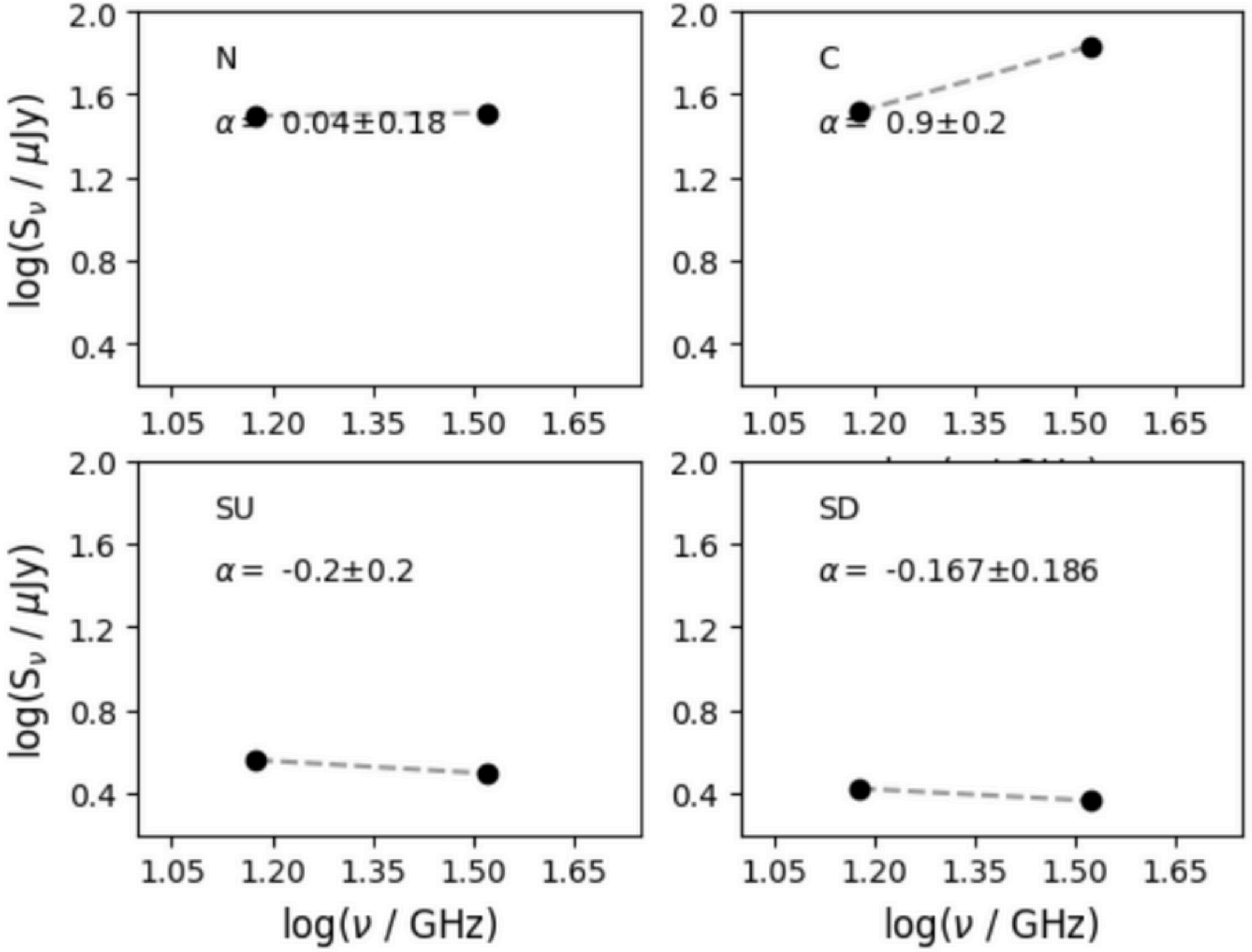
Instituto de Física - Universidad de Antioquia

Spectral Index α: flux extraction

α < 0	Non-thermal sources
0 < α < 1	Ionized gas (thermal)



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Source	α
G45N	0.04 ±0.18
G45C	0.90 ±0.2
G45SU	-0.2 ±0.2
G45SD	-0.17 ±0.18

Agrees with initial characterization by Zhang et al. 2019

Not conclusive enough

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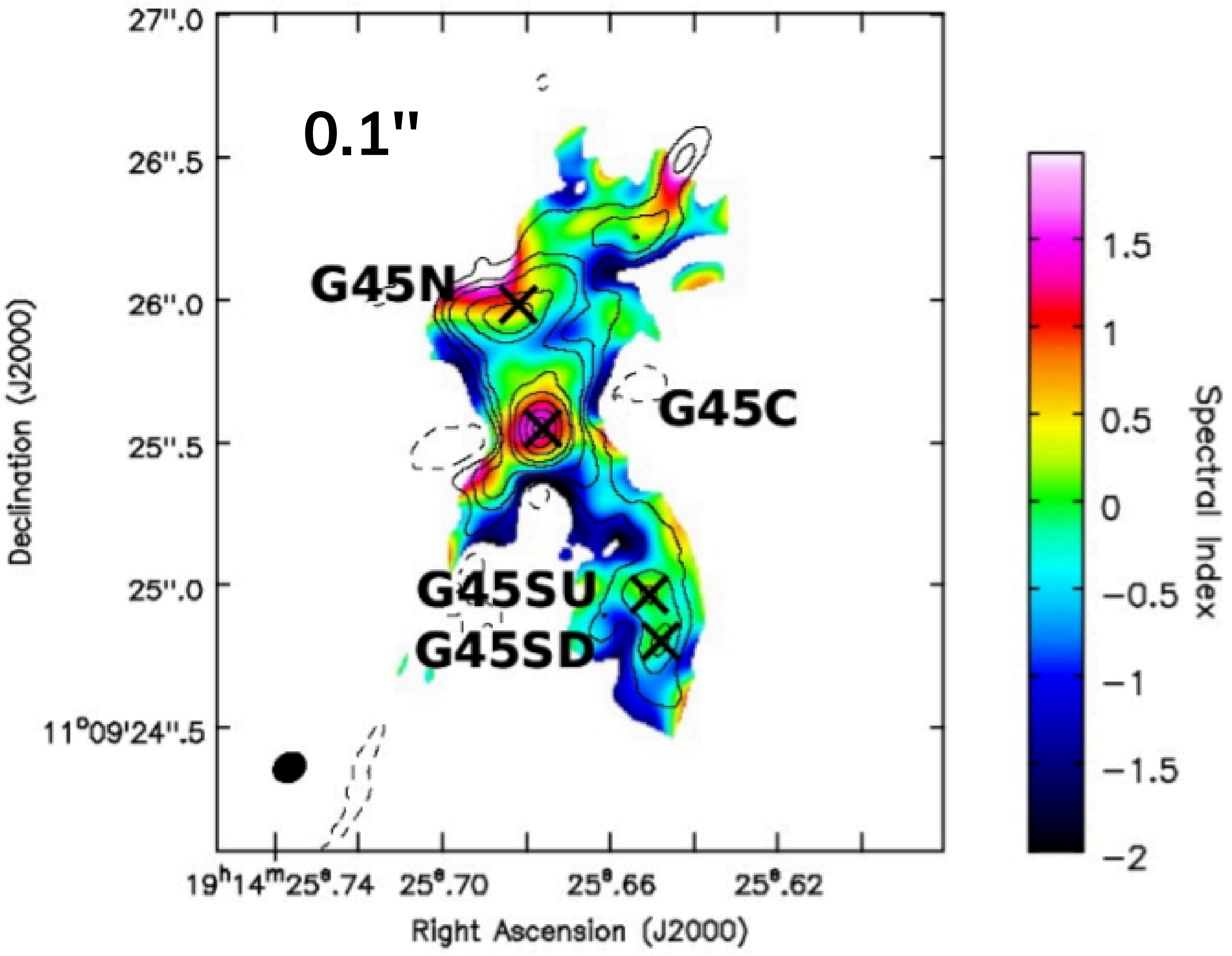
Spectral Index α: mapping

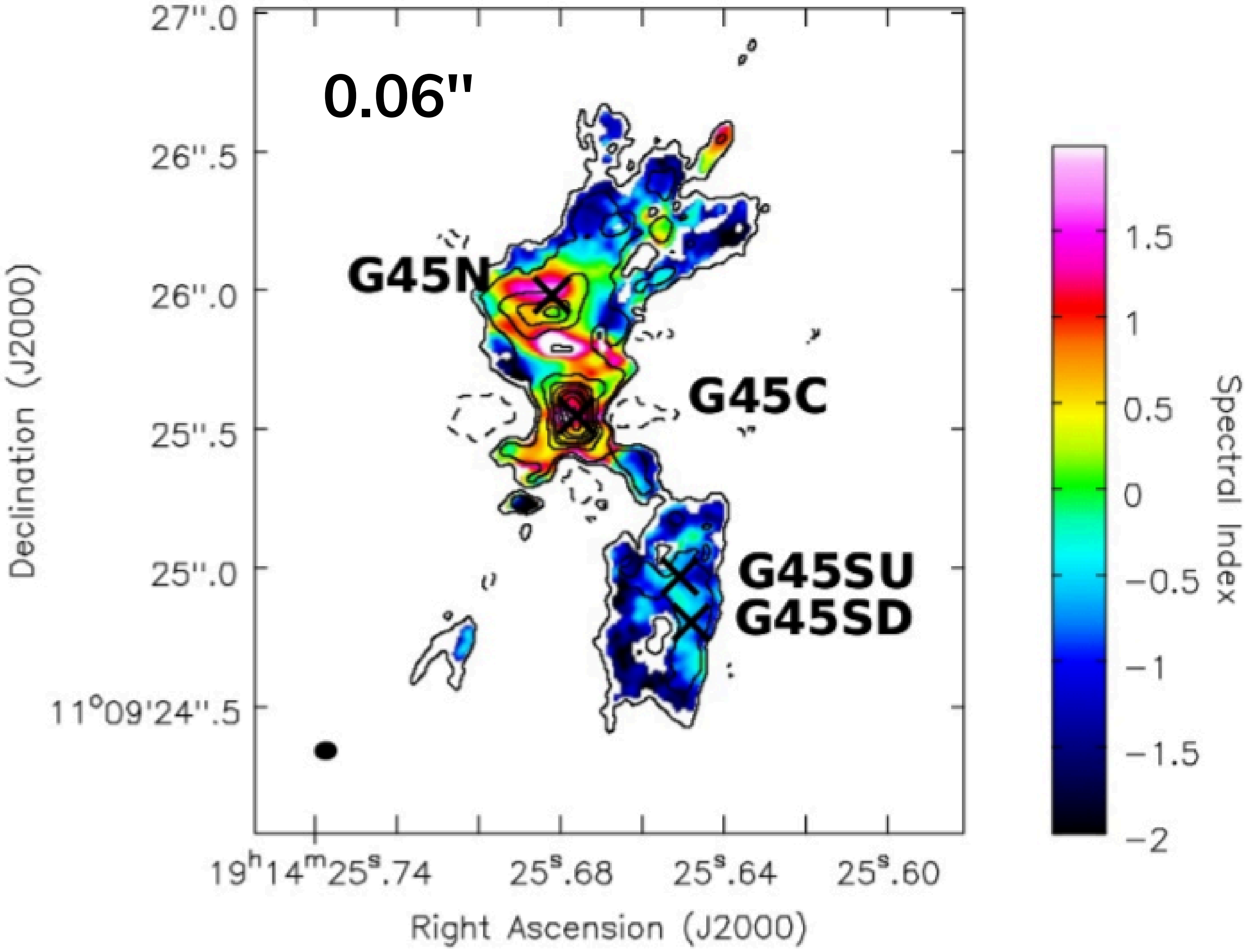
Pixel-by-pixel map
Ku Band - KKaQ Image

12-50 GHz 0.048 mJy beam−1



In-band wideband map
CKuKKaQ Bands

4-50 GHz 0.048 mJy beam−1



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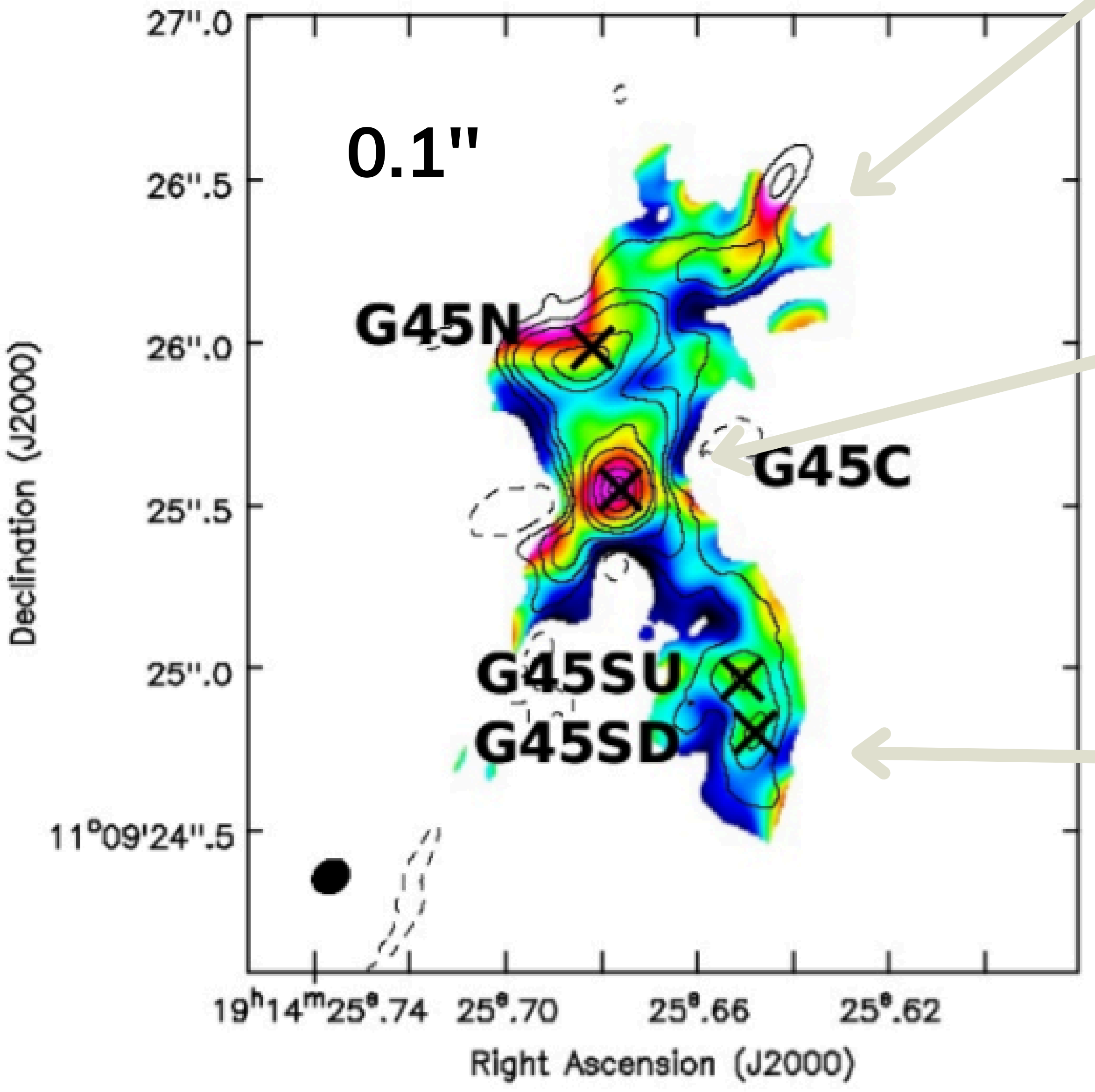
Spectral Index α: mapping

Pixel-by-pixel map
Ku Band - KKaQ Image

12-50 GHz 0.048 mJy beam−1



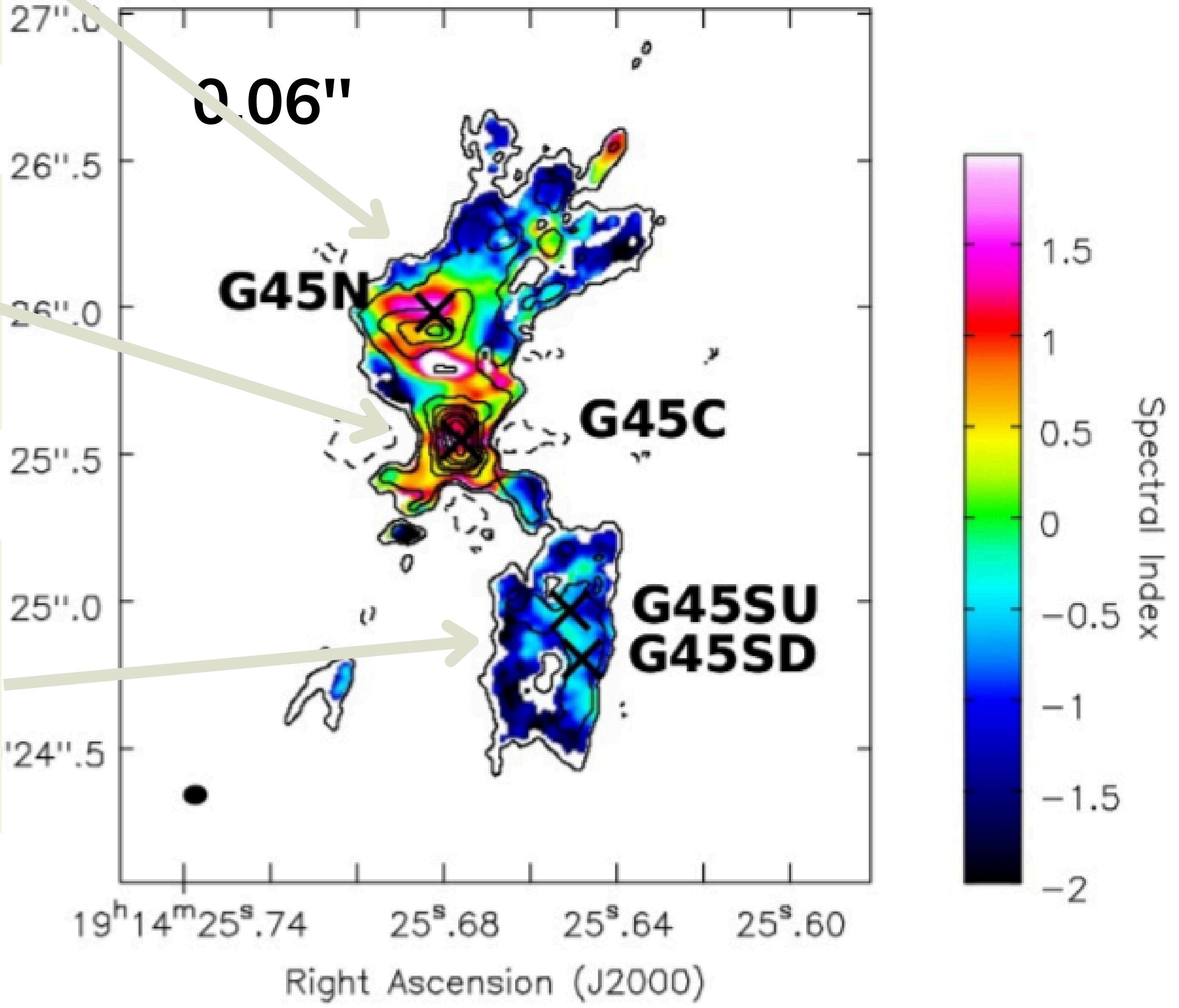
Steep values to the north

Agreement with initial characterization

Supports previous α results with a decreasing trend

In-band wideband map
CKuKKaQ Bands

4-50 GHz 0.022 mJy beam−1



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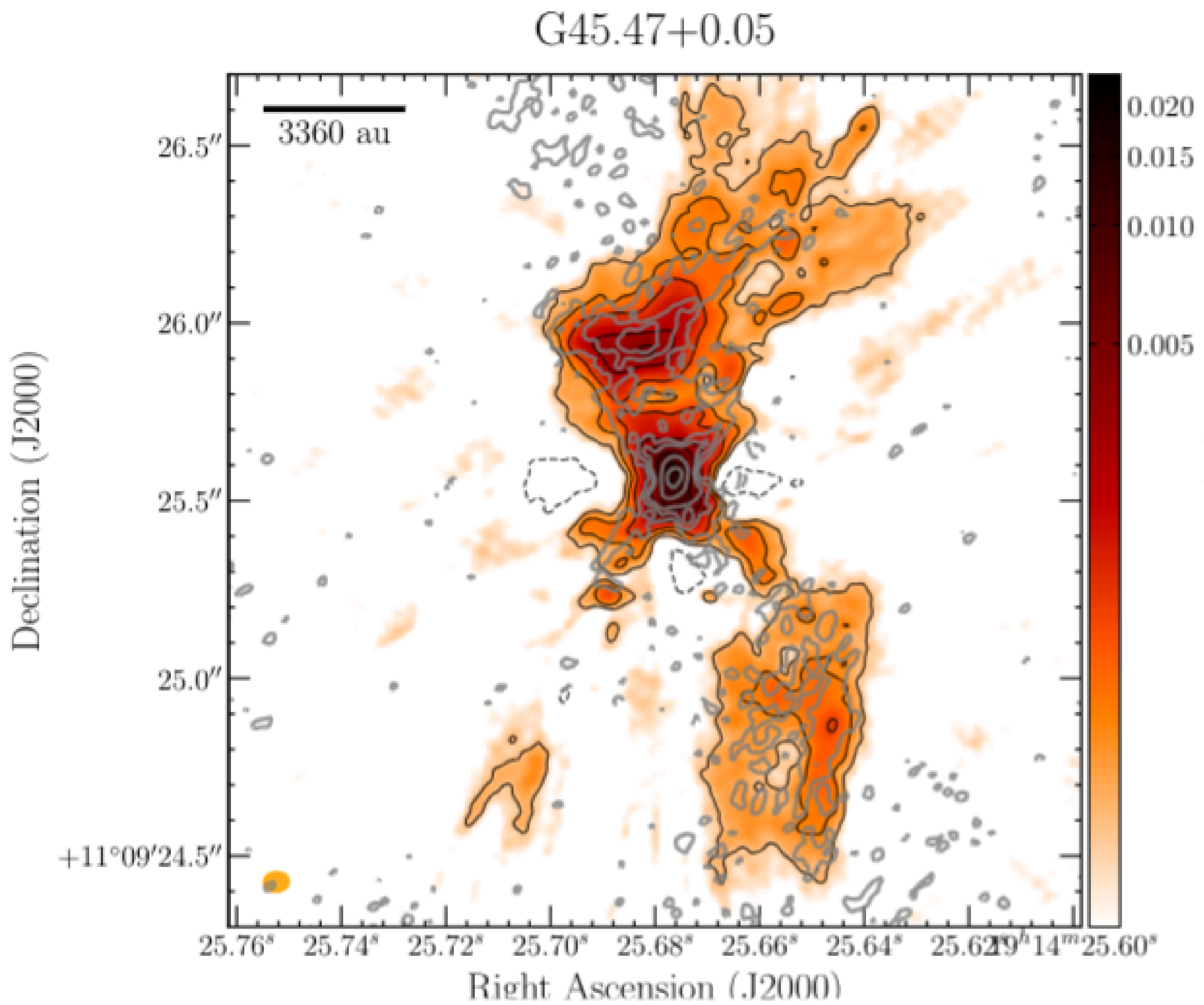
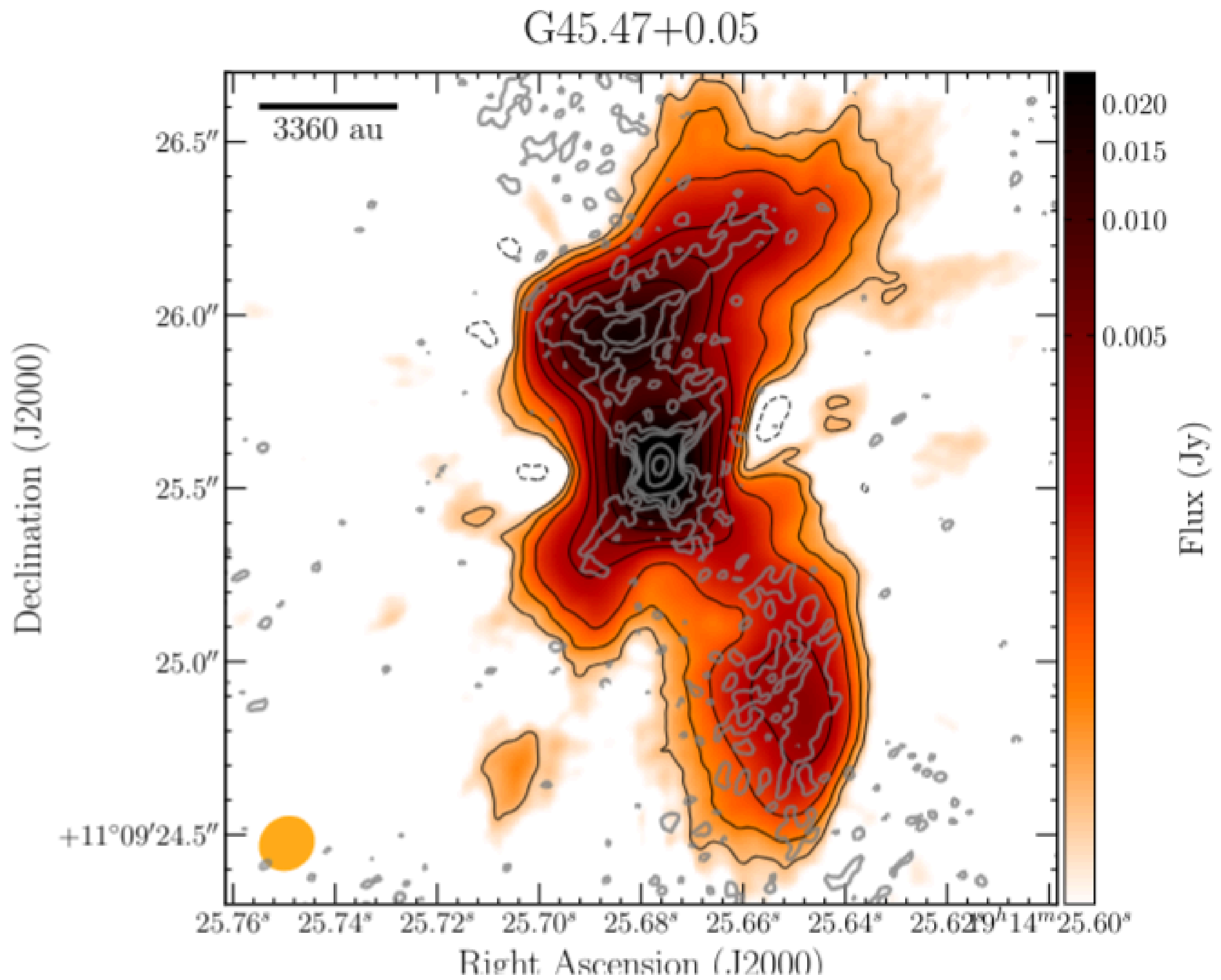
ALMA vs VLA

ALMA 1.3 mm [−5, 3, 10, 20, 200, 1000] × 0.047mJy beam−1 grey contours

Compare mm dust emission with submm ionization





● VLA 0.06'' ● ALMA 0.03''

● VLA 0.1'' ● ALMA 0.03''

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Possible scenarios

Photoionized Dust Clumps

Dense Material Hosting an Embedded Jet

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Possible scenarios

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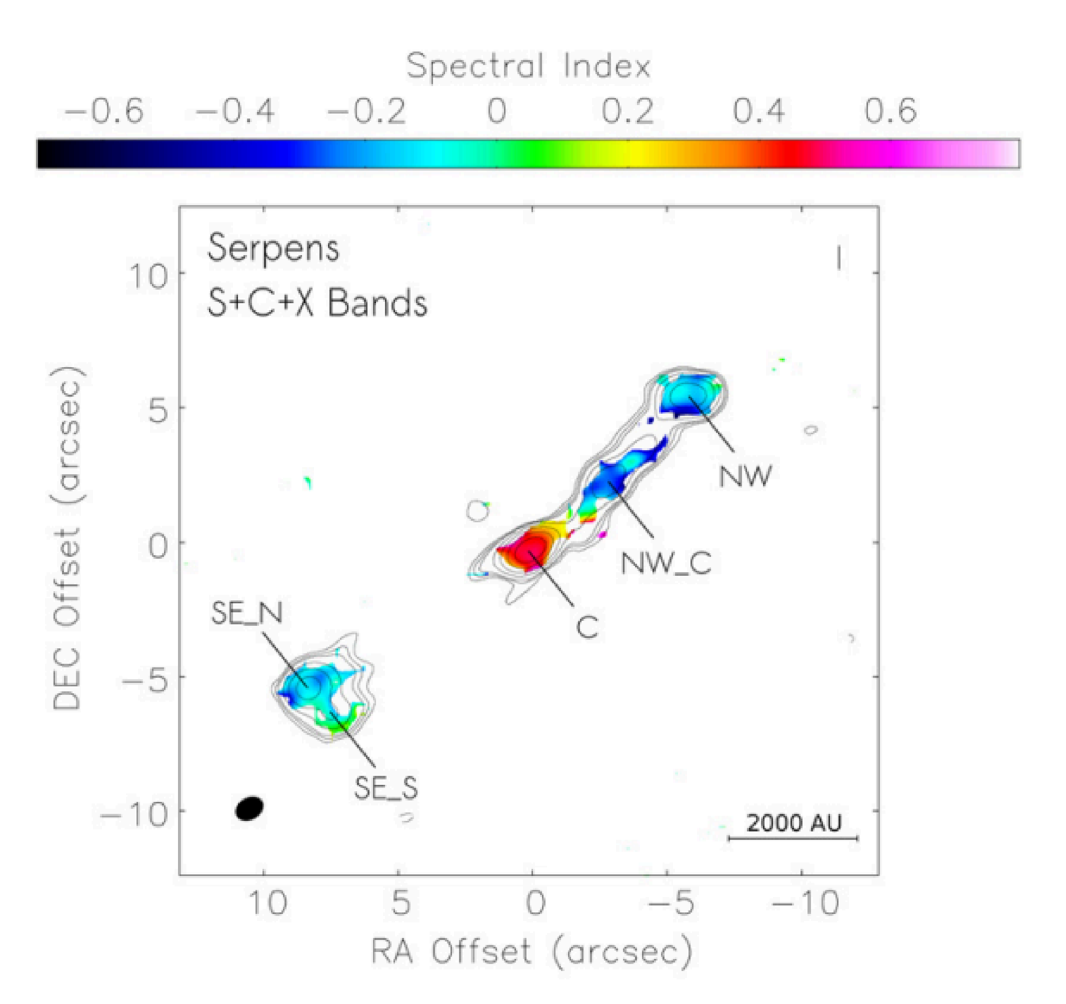
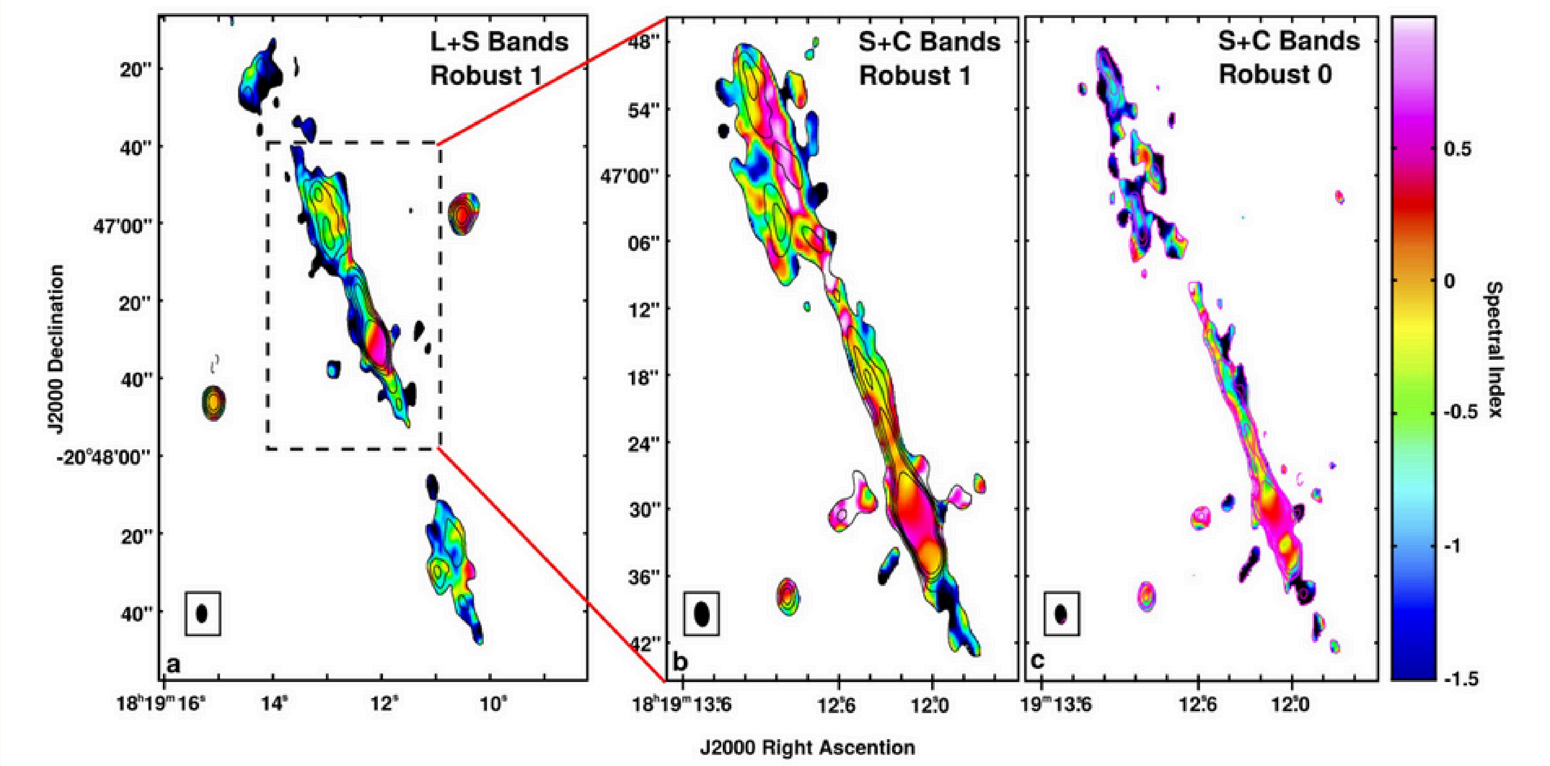


Triple source in serpens

Intermediate mass source
Direct observation



HH 80-81

Detection of linearly polarized radio emission

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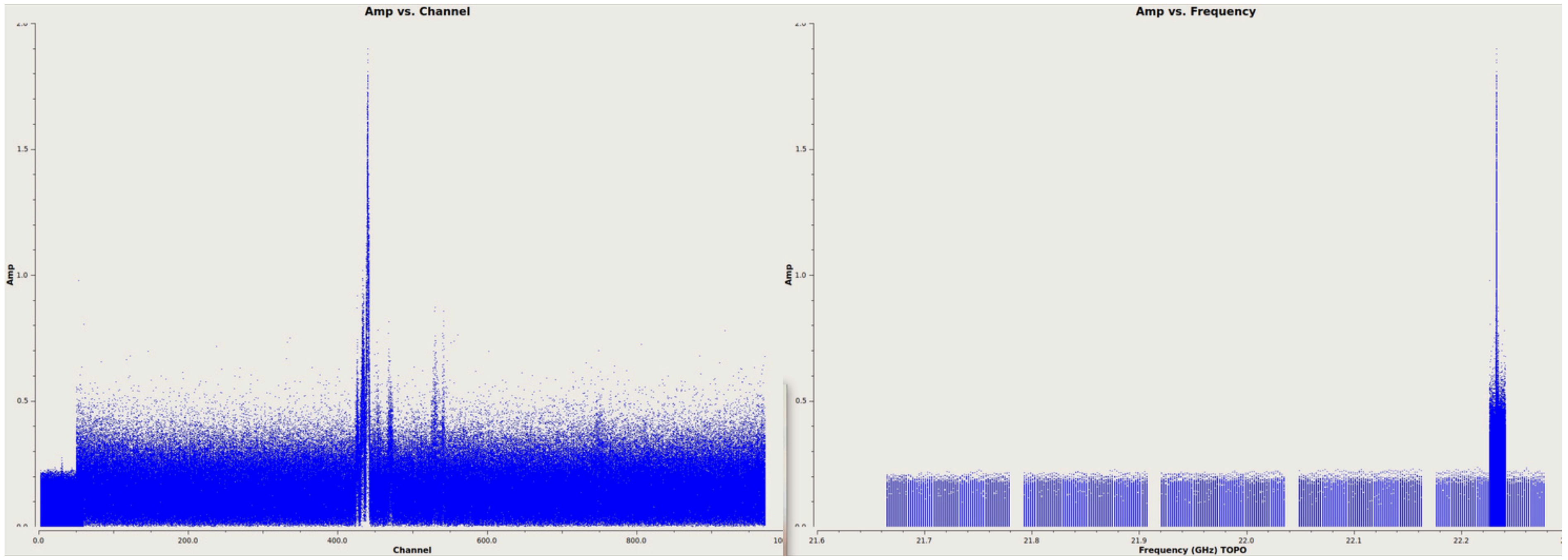
Possible scenarios

Photoionized Dust Clumps

Dense Material Hosting an Embedded Jet

22 GHz Water Maser

K Band	Bandwith 18 – 26.5	C.F 22.2	l (cm) 1.3



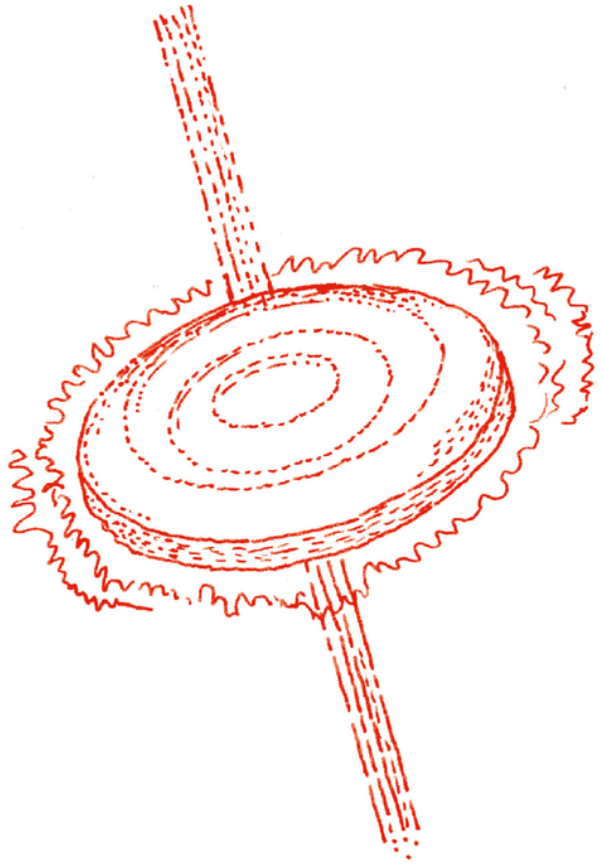
Proper Motion

Relative velocity of the jet

0.06'' resolution

Observational proposal

$$V_{\rm PM}({\rm km\ s^{-1}}) = 4.74\ D_{\rm kpc}\ {\rm PM}({\rm mas\ yr^{-1}}),$$



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Conclusions

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Conclusions

Weak emission is detected on the southern lobe and isolated from upper sources

The wideband image (4-50 GHz) significantly improved the sensitivity

Although the nature of the emission from the region cannot be conclusively determined, we have restricted the emission from the candidate jet to two possible scenarios that align with large-scale structures and the evolutionary phase indicated by the feedback effects of the sources.

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THANK YOU!

Thanks to

CICO VICO CHALMERS & VIRGINIA Initiatives on Cosmic Origins
NRAO
INTERNSHIP RECA
RECA Red Estudiantes Colombianos Astronomia
UNIVERSIDAD DE ANTIOQUIA 1803
FACom Grupo de Física y Astrofísica Computacional Instituto de Física - Universidad de Antioquia

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THANK YOU!

Thanks to

Viviana Rosero (Caltech)
Joshua Marvil (NRAO)
Kei Tanaka (Tokio Tech)
Yichen Zhang (University of Virginia)
Germán Chaparro (Universidad de Antioquia)

Red de Estudiantes Colombianos de Astronomía
National Radio Astronomy Observatory
Grupo de Fisica y Astrofisica Observacional UdeA

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