ALMA Summer School 2026

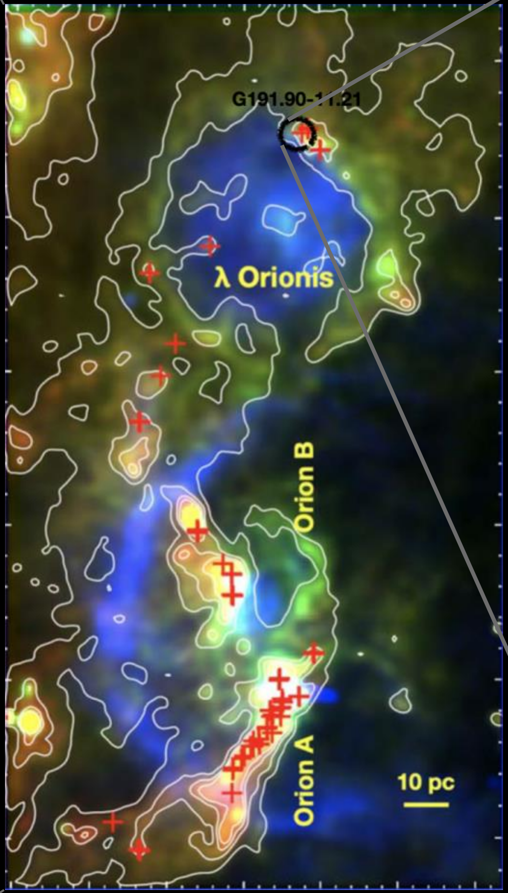
GROUP 2 - Spectral Line 2

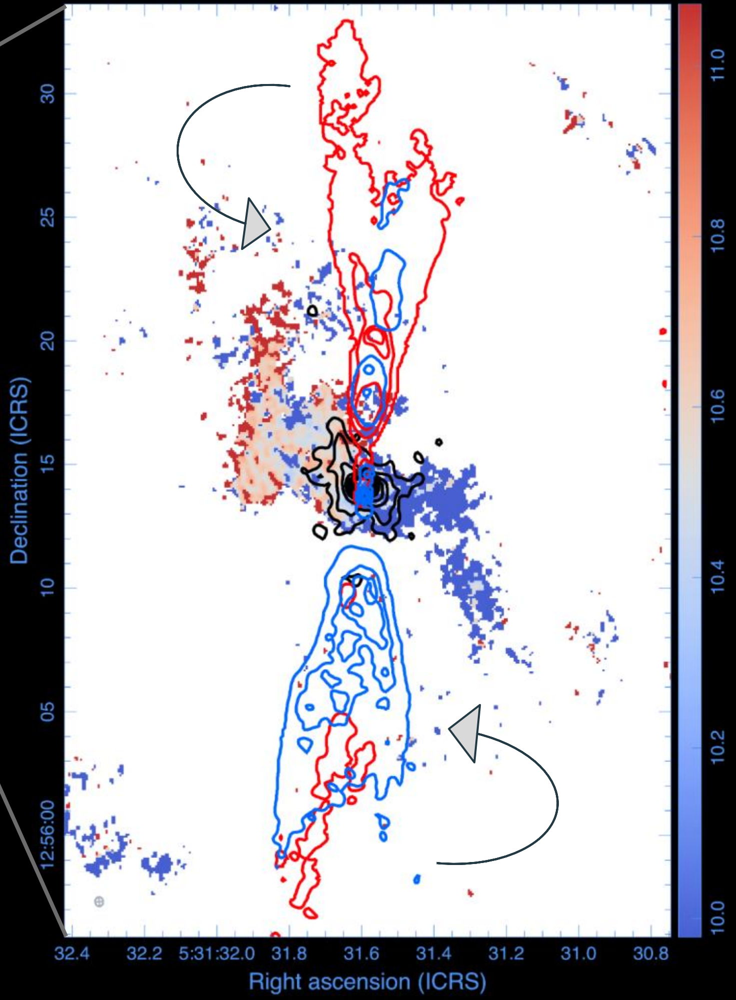
Mentors: Drs. Hee-Weon Lee,
Jihyun Kang

Members: Sohyeon Ahn, Bianca Els,
Rupam Kundu

Contents

Part 1: The Introduction





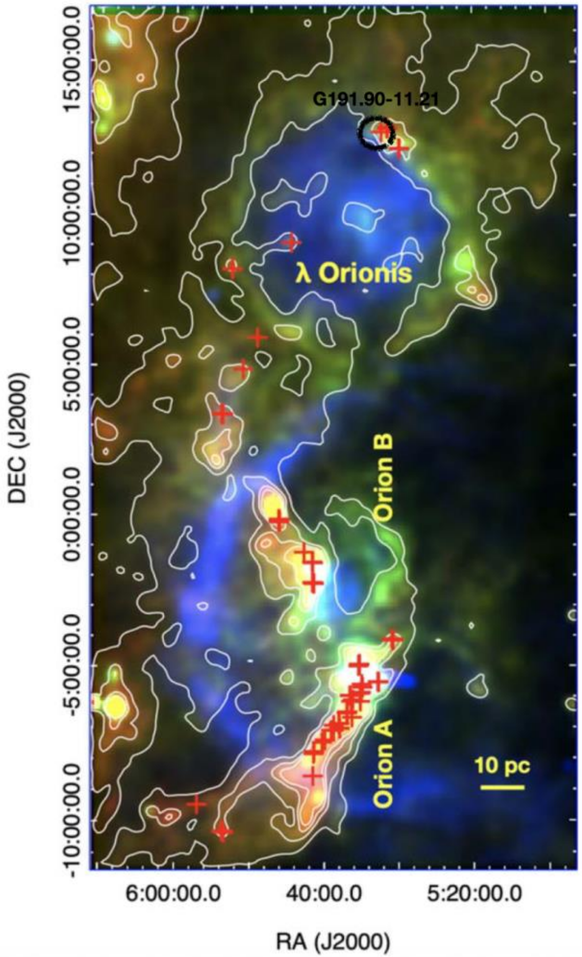
ORION NEBULA

G191.90-11.21S

Information on **G191.90-11.21S**

Coordinate 05:31:31.60 +12:56:14.15
Distance 404±4 pc
Vsys 10.87 km/s
Tbol 60±13 K
Lbol 0.1±0.1 $L_\odot$
Classification Class 0
Mass 0.079±0.034 $M_\odot$

Dutta et al. 2020



What Does ALMA actually see?

ALMA **does not** work like a Giant Camera.

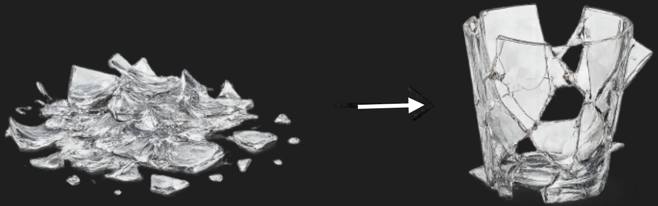
With some scattered Antennas on the ground,

it measures FEW parts, pieces of information (**Fourier Components**) of a source in the sky: **<u>Visibilities</u>. (It can't measure all the components)**

WE,

try to collect those few parts of the image together and try to reconstruct the image of the source in the sky:

Dirty Image.

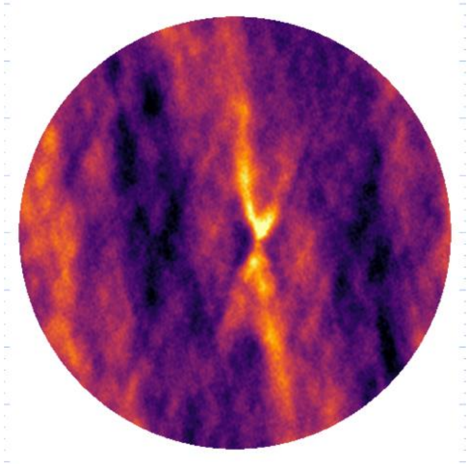


But, the Dirty Image, is **<u>NOT</u>** <u>the true image</u> of the source in the sky.

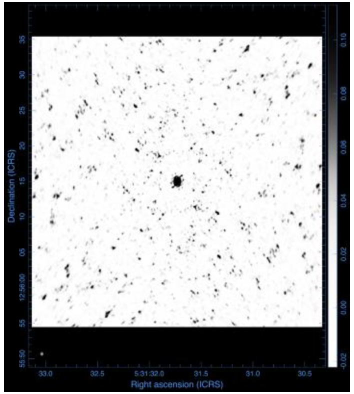
It contains <u>the effect of our INCOMPLETE ANTENNA COVERAGE</u>: the dirty beam and its sidelobes!

So,

WE CLEAN!



Dirty Image



Dirty Beam

Step 1:

Deconvolution measures where the real emission is and removes the pattern due to incomplete antenna coverage (the **Dirty Beam pattern**)!

Step 2:

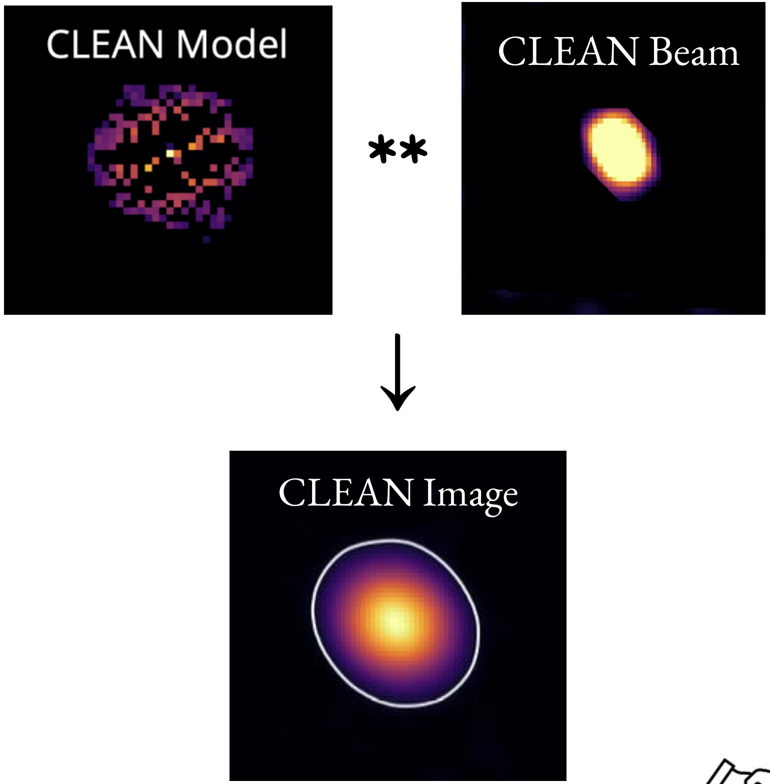
Deconvolution also identifies the real emission step by step and build an estimated representation of the source: **The CLEAN Model.**

Step 3:

But the CLEAN Model is just idealized components of the real image.

So, we convolve the model with a Gaussian beam: **The Gaussian Restoration.**

And, we get ourselves the Final Image.



MINDMAP:

Source

F.T ↓

Receiver (antenna)

(Visibilities)

→

I.F.T.

Dirty Image

↑ CLEAN method

Clean Image

~

Part 1 : The Introduction

We start with Visibility data from ALMA.

For a band of frequency, it has data in different channels: **Multifrequency data.**

We can see, emission from certain molecules in some of the channels/ frequencies in the data: **Line Data.**

The remaining line-free channels mainly contain **continuum emission**. By combining these channels, we create a continuum image, which primarily traces thermal emission from dust in structures such as the protostellar envelope and disk.

So, from the same visibility dataset, we can extract two complementary views:

- **Continuum:** Where is the dust?
- **Spectral lines:** Where is the gas, and how is it moving?

In these procedures, we can carefully transfer our visibility data to scientifically useful images...

Upcoming: Methodology...

Part 2: Overview of Methodology

Overview of Methodology

Identifying and **inspecting spectral-line emission**

Performing **continuum subtraction**

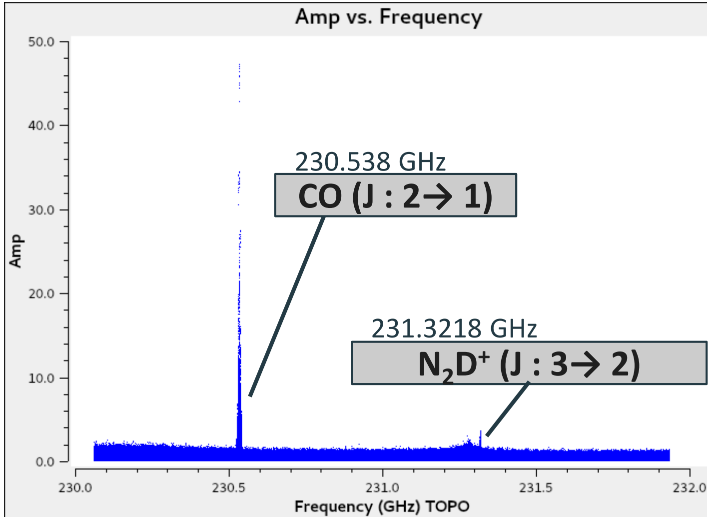
Generating **dirty image**

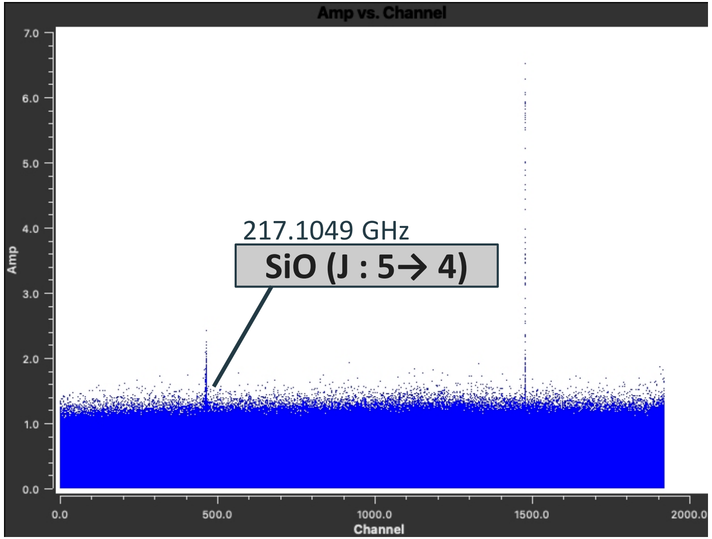
Running the **CLEAN** algorithm

Exploring different imaging and CLEAN **parameter**

Producing preliminary **moment maps** to investigate the kinematic structure of the source

1. Identifying and Inspecting spectral-line emission

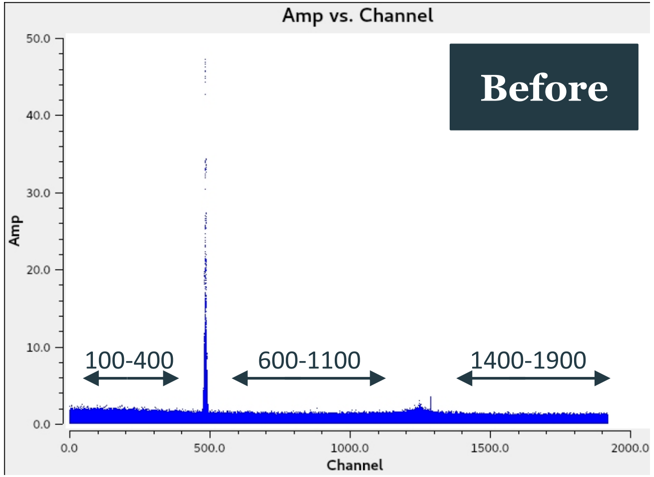


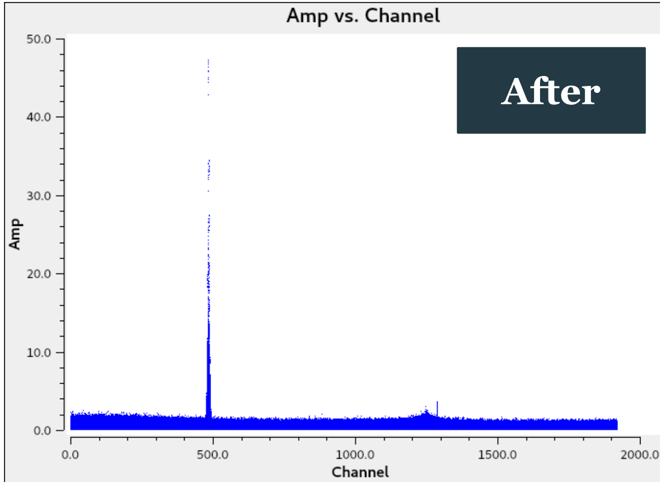


Multi-molecular line analysis

CO, N_2D^+, and SiO emissions to characterize the protostellar environment.

2. Performing continuum subtraction

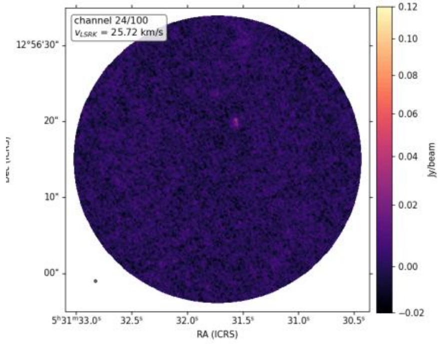




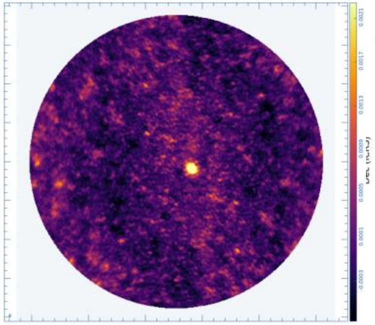
While visual differences in visibility amplitude are subtle,
the final image spectrum confirms a **baseline nearby 0 Jy/beam**.

3. Generating dirty image

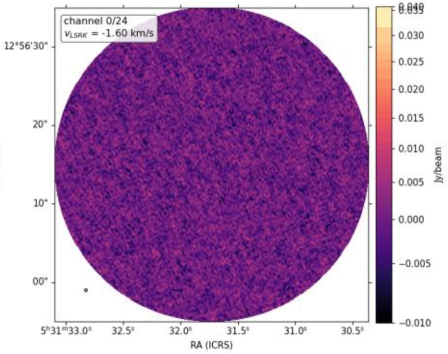
CO



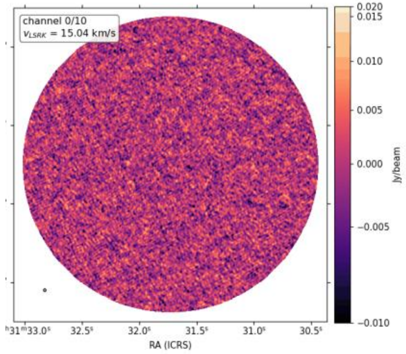
Dust Continuum



SiO



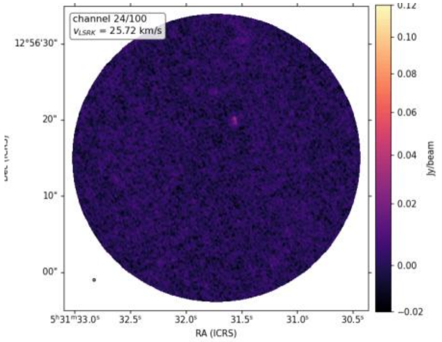
N_2D^+



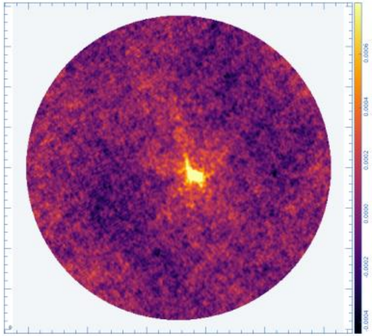
Initial images before deconvolution, essential for estimating RMS noise and determining the appropriate CLEAN threshold.

4. Running the CLEAN algorithm

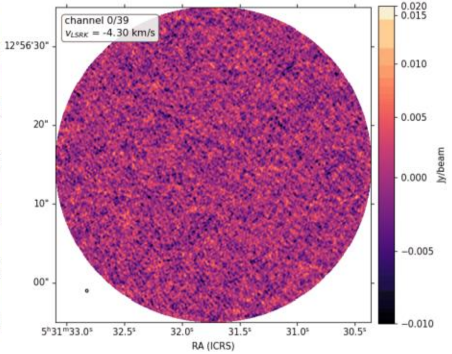
CO



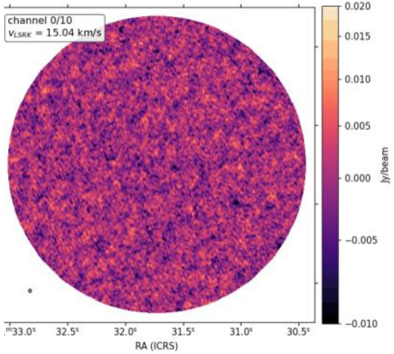
Dust Continuum



SiO



N_2D^+



CLEAN deconvolves the instrumental PSF, restores the model with a Gaussian beam, and adds the residual emission.

5. Exploring different imaging and CLEAN parameter

Table of Standard Values

The values presented in this table are the standard values that the pipeline uses when it performs automasking and have been extensively tested. The values listed for combined data in the last column are tentative and should serve as a starting point for your analysis. This table can be found in the Pipeline User's Guide section 9.39 (hif_makeimages).

Parameter	7m (continnum/line)	12m (b75 < 300m)	12m (300m < b75 < 400m)	12m (b75 > 400m)	12m + 7m combined *TENTATIVE*
noisethreshold	5.0	**4.25**	5.0	5.0	4.25
sidelobethreshold	1.25	**2.0**	2.0	2.5	2.0
lownoisethreshold	2.0	**1.5**	1.5	1.5	1.5
minbeamfrac	0.1	**0.3**	0.3	0.3	0.3
negativethreshold	0.0	**0.0 (continuum) 15.0 (line)**	0.0 (continuum) 7.0 (line)	0.0 (continuum) 7.0 (line)	[illegible]
fastnoise	False	**False**	False	True	[illegible]

https://casaguides.nrao.edu/index.php?title=Automasking_Guide_CASA_6.5.4

Key parameters adjusted based on the standard values for the 12m array (b75 > 400m)

threshold

usemask

weighting

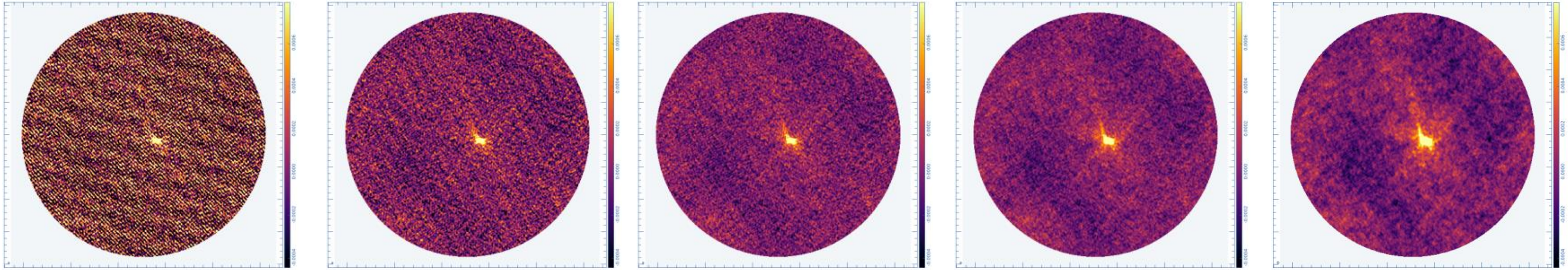
Uniform / Briggs / Natural

robust

-0.5 / 0 / 0.5

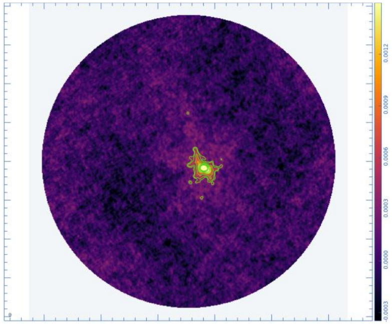
Key parameters adjusted for imaging

5. Exploring different imaging and CLEAN parameter



Uniform | Briggs (-0.5) | Briggs (0) | Briggs (+0.5) | **Natural**

Good spatial resolution ⟷ Good sensitivity



Natural weighting was selected for the dust continuum to maximize sensitivity and reveal the extended emission

5. Exploring different imaging and CLEAN parameter

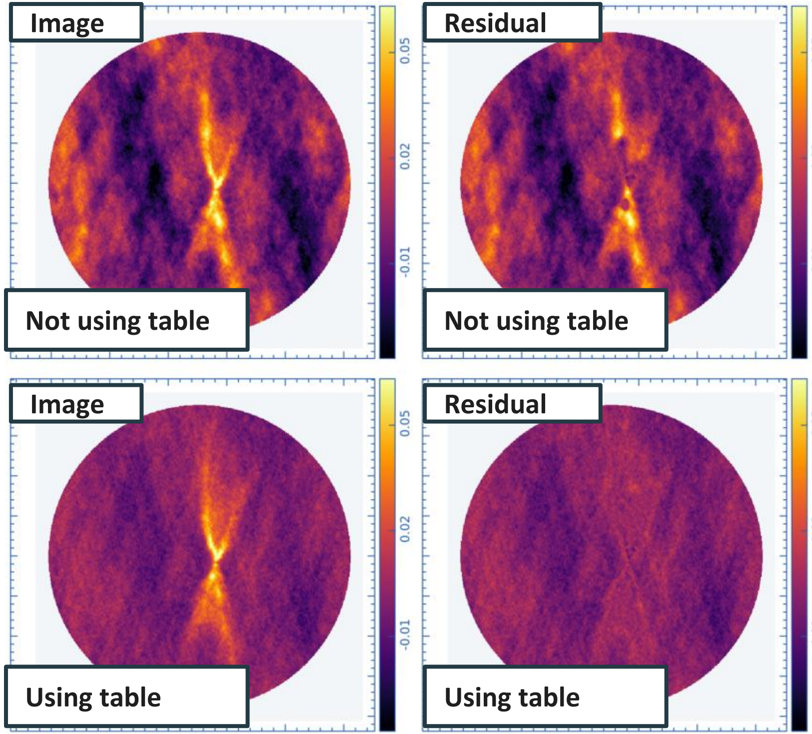


Table of Standard Values

The values presented in this table are the standard values that the pipeline uses when it performs automasking and have been extensively tested. The values listed for combined data in the last column are tentative and should serve as a starting point for your analysis. This table can be found in the Pipeline User's Guide section 9.39 (hif_makeimages).

Parameter	7m (continnum/line)	12m (b75 < 300m)	12m (300m < b75 < 400m)	12m (b75 > 400m)	12m + 7m combined *TENTATIVE*
noisethreshold	5.0	**4.25**	5.0	5.0	4.25
sidelobethreshold	1.25	**2.0**	2.0	2.5	2.0
lownoisethreshold	2.0	**1.5**	1.5	1.5	1.5
minbeamfrac	0.1	**0.3**	0.3	0.3	0.3
negativethreshold	0.0	**0.0 (continuum)** **15.0 (line)**	0.0 (continuum) 7.0 (line)	0.0 (continuum) 7.0 (line)	0.0
fastnoise	False	**False**	False	True	False

Applying the **standard parameters** significantly reduces the uncleaned flux in the residuals of specific channels.

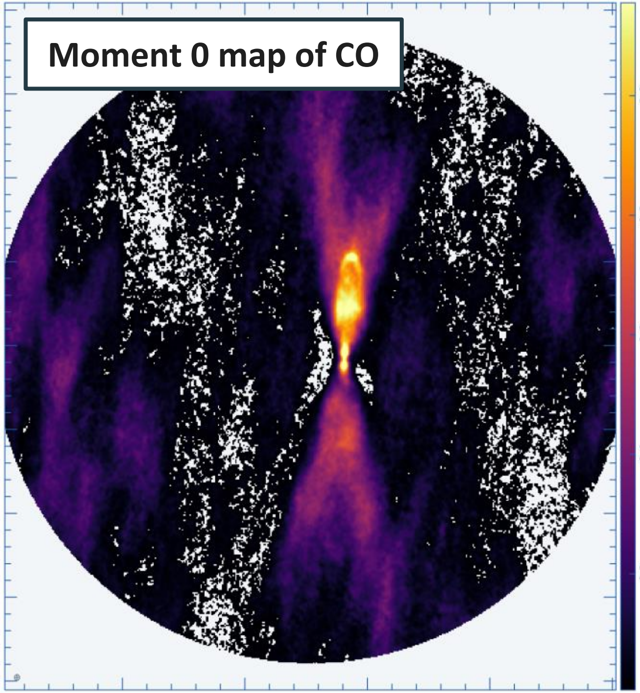
6. Producing preliminary moment maps

Moment Map Generation

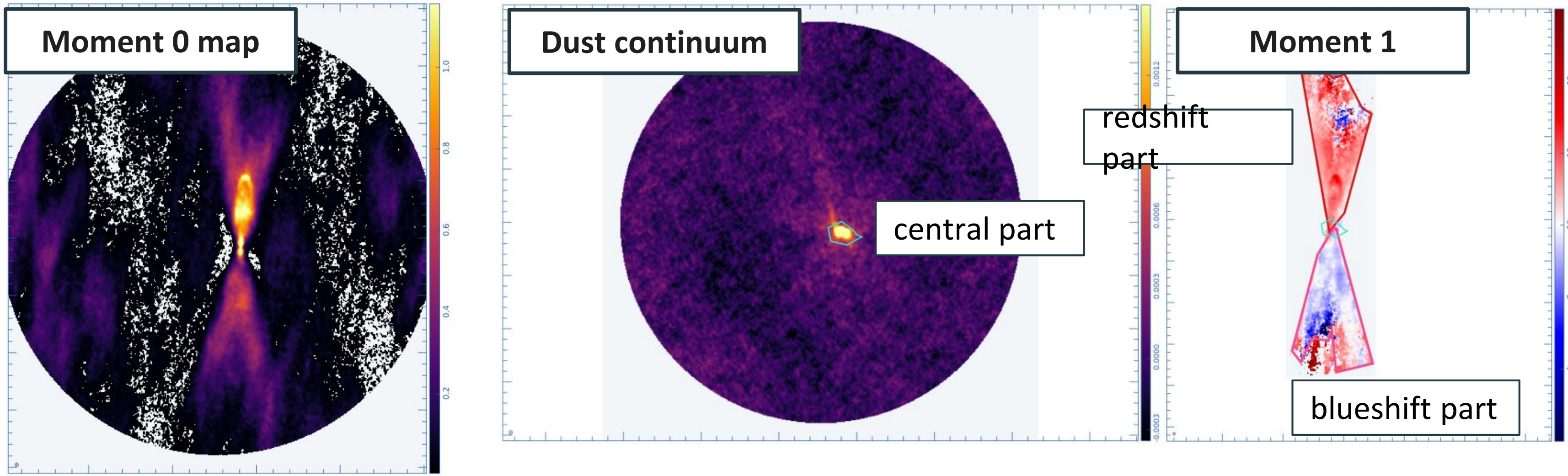
- **Channel Selection**: Integrated velocity channels showing significant line emission.
- **Noise Clipping**: Applied a 3-5σ pixel clipping threshold based on the RMS noise level.

Moment Map

- **Moment 0 map**: Intensity
- **Moment 1 map**: Velocity
- **Moment 2 map**: Velocity Dispersion

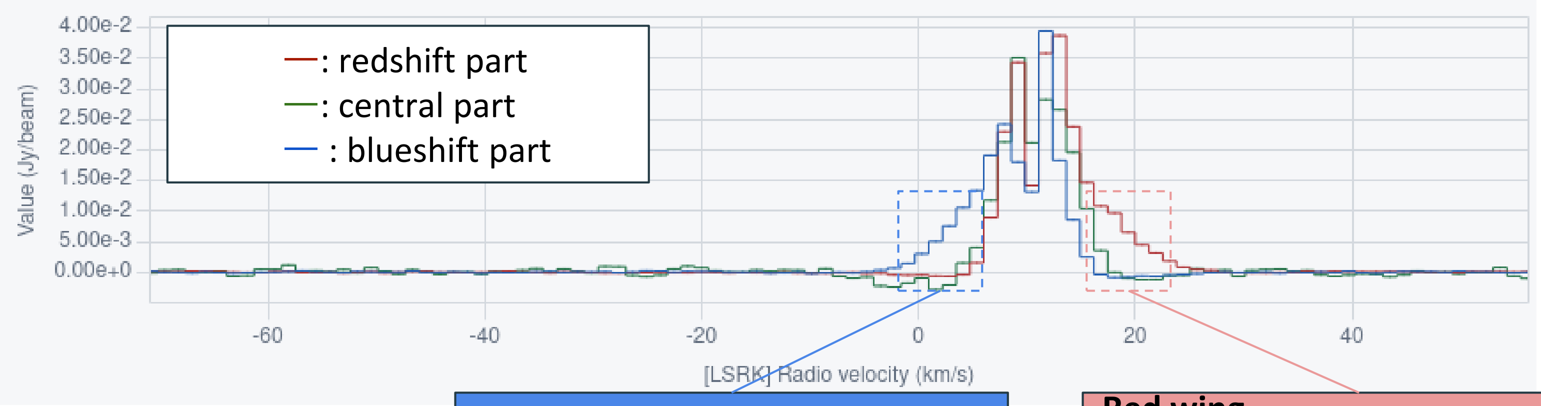


Defining Kinematic Regions for Spectral Extraction



We have to extract spectra of these three parts

Defining Velocity Ranges for CO Outflows

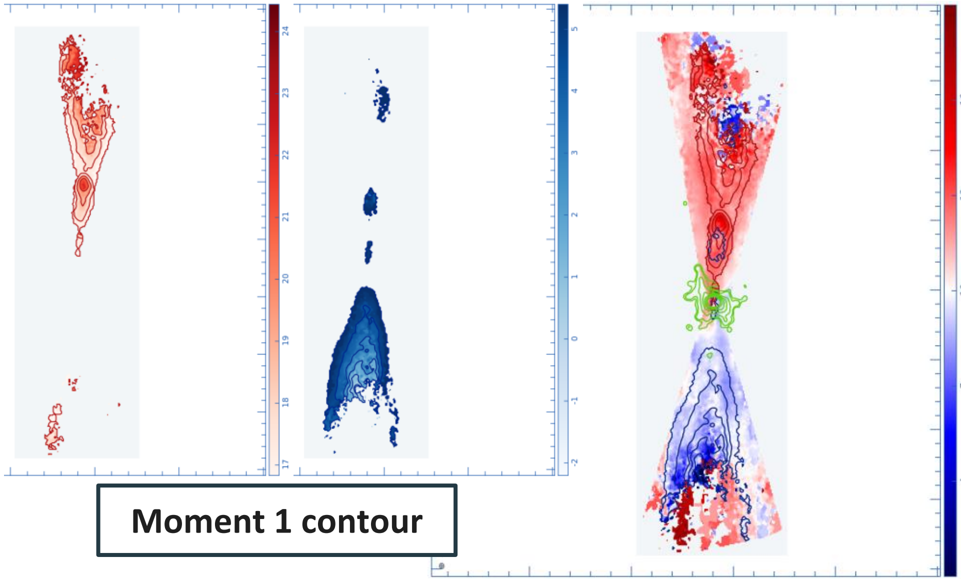


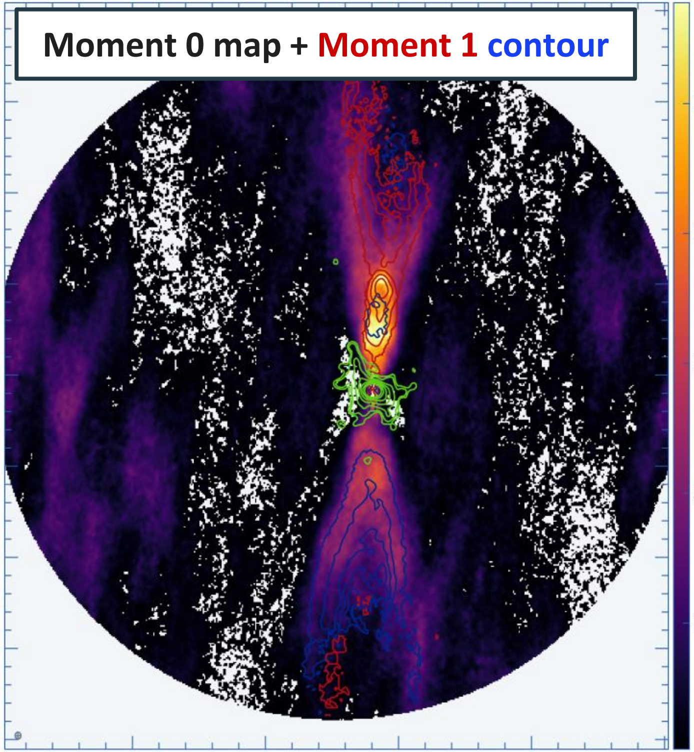
Blue wing
Velocity : -2.2178 ~ 5.4816 km/s

Red wing
Velocity : 16.8306 ~ 24.4500 km/s

Outflow wings are defined as the velocity ranges where the shifted emission strictly dominates

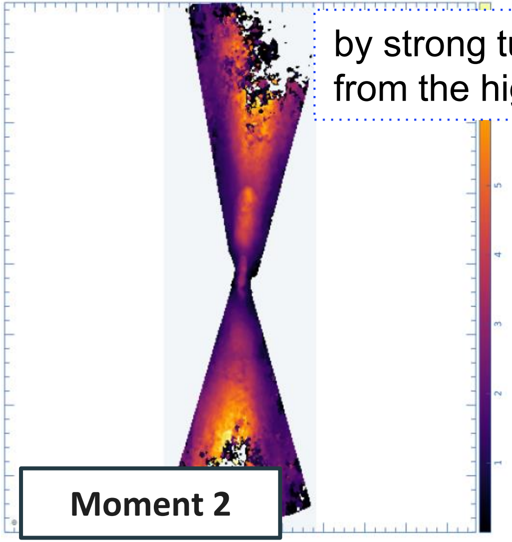
Outflow moment map : CO





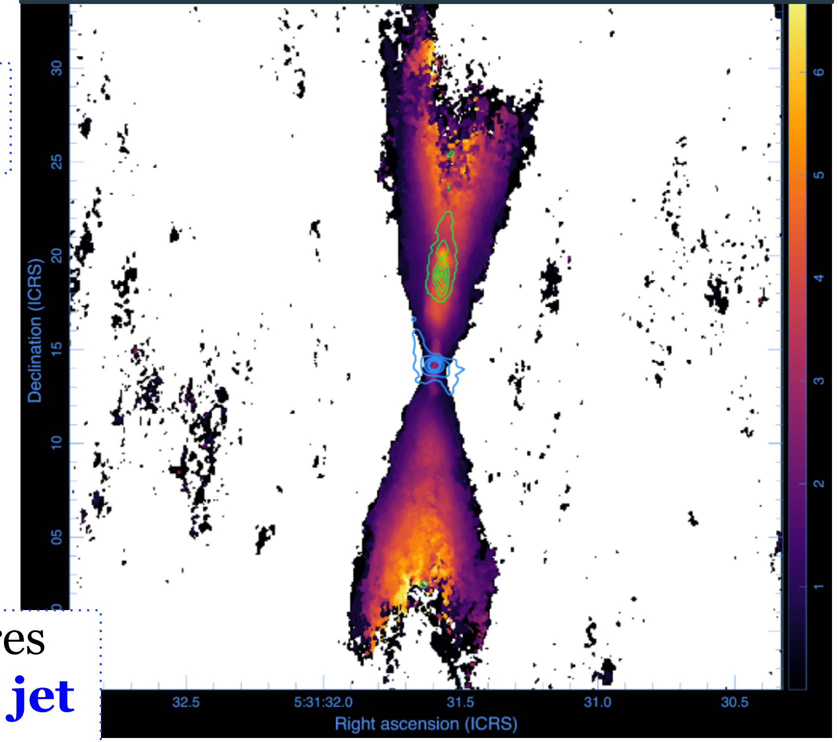
Overlaying Moment 1 contours onto the Moment 0 map to trace the kinematic structure of the **outflow lobes**

Moment 2 map : CO



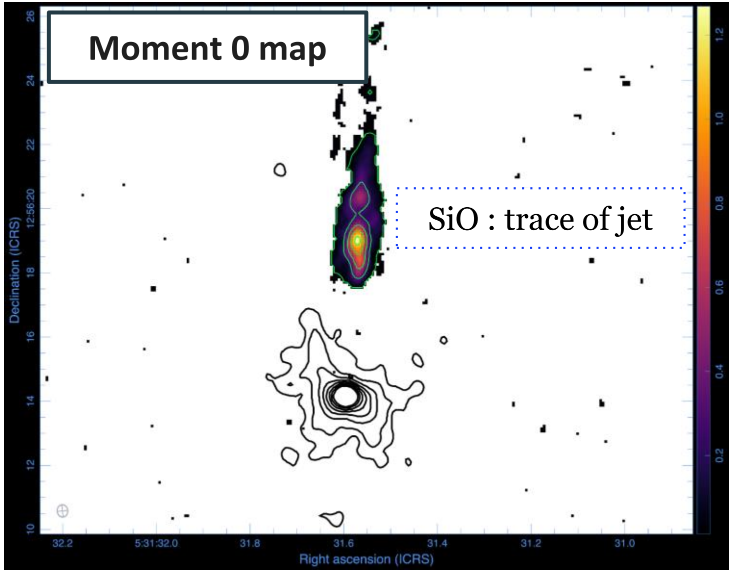
by strong turbulence from the high-speed jet

Moment 2 map of CO + Moment 0 contour of SiO + contour of dust continuum



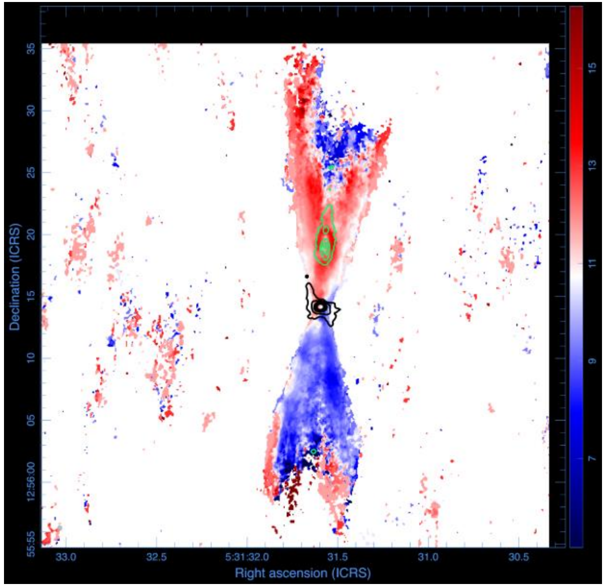
The high-dispersion, knot-like structures along the central axis indicate **episodic jet ejections** driving the outflow

6. Producing preliminary moment maps : SiO

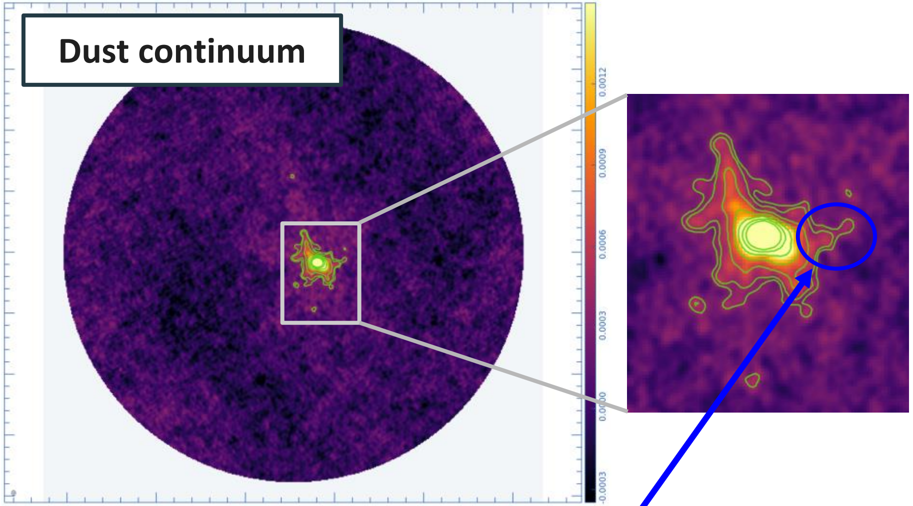


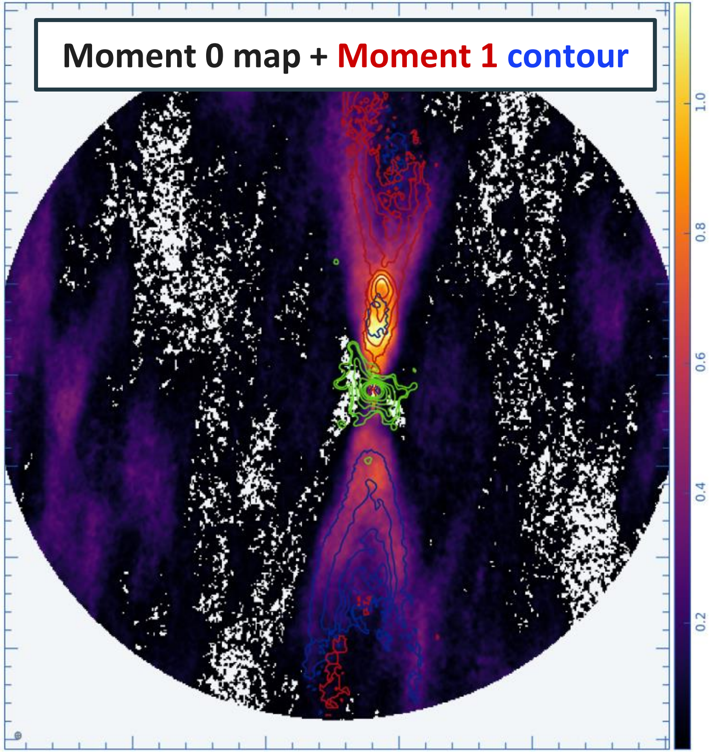
The alignment of SiO contours with the central axis supports the jet-driven nature of the CO outflow

Moment 2 map of CO + Moment 0 contour of SiO + contour of dust continuum



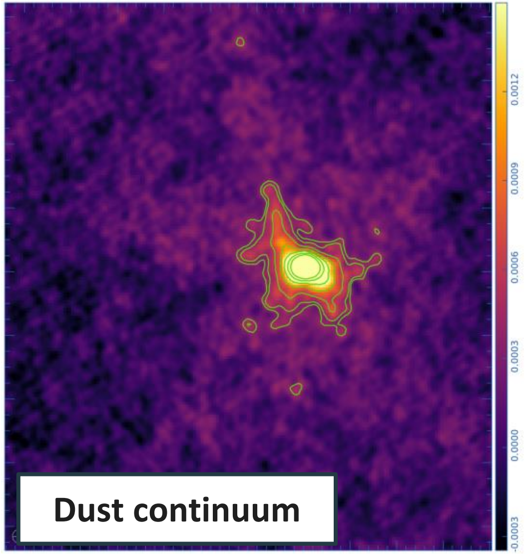
However,



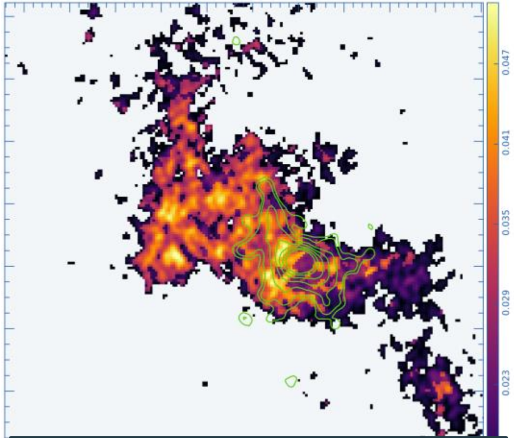


The extended dust continuum shows a morphological mismatch with the outflow axis.

6. Producing preliminary moment maps : N_2D^+



Dust continuum

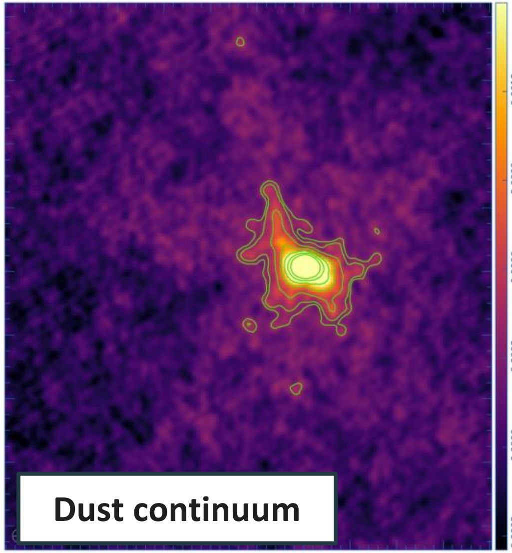


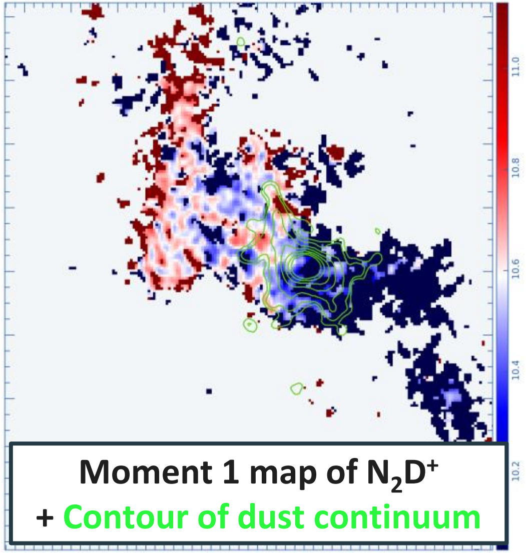
Moment 0 map of N_2D^+
+ Contour of dust continuum

N_2D^+ : Tracer of inner envelope

The asymmetric bump in the dust continuum traces the **disk-envelope interface**, where the dense N_2D^+ envelope interacts with the central disk.

6. Producing preliminary moment maps : N_2D^+





The velocity gradient in N_2D^+ indicates **rotation or helical motion** of the dense inner envelope.

Part 3: Struggle Section

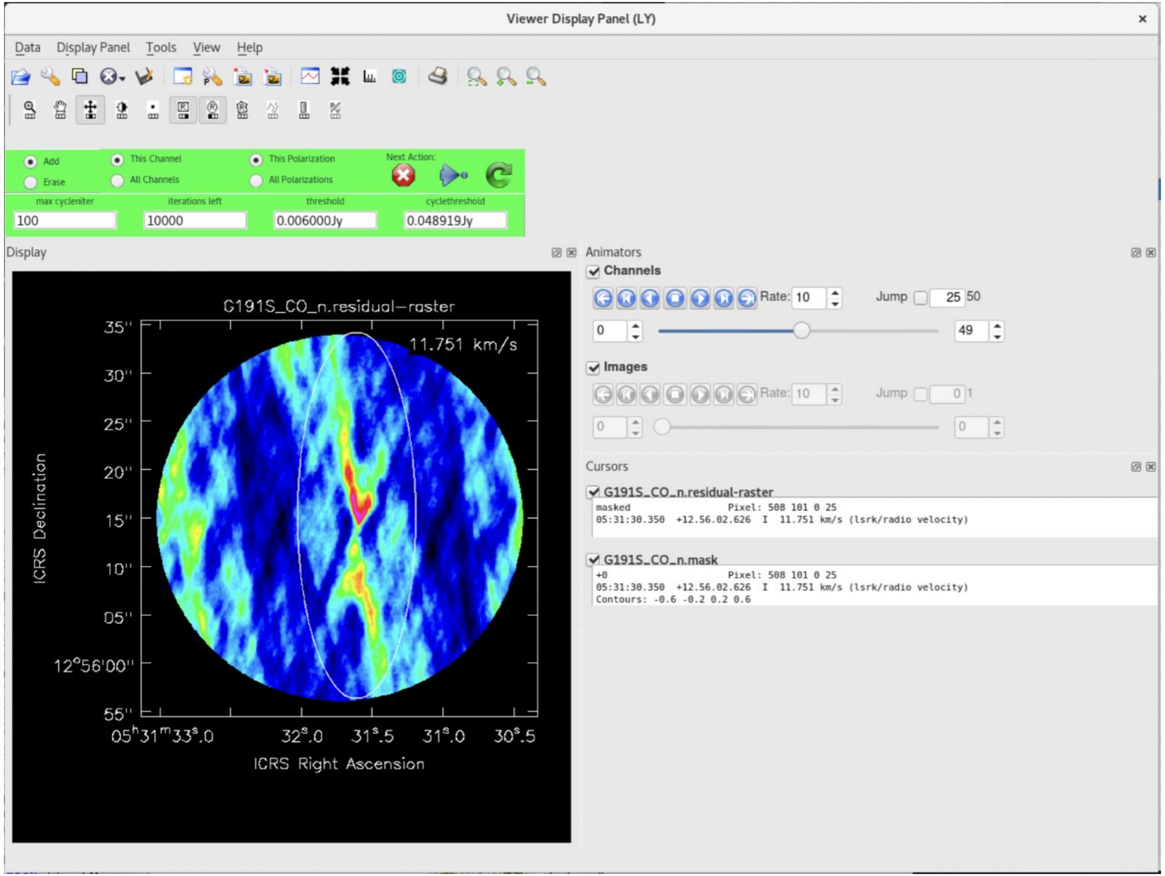
tclean vs. iclean

Task clean = Interactive clean = Form images from visibilities and reconstruct a sky model.

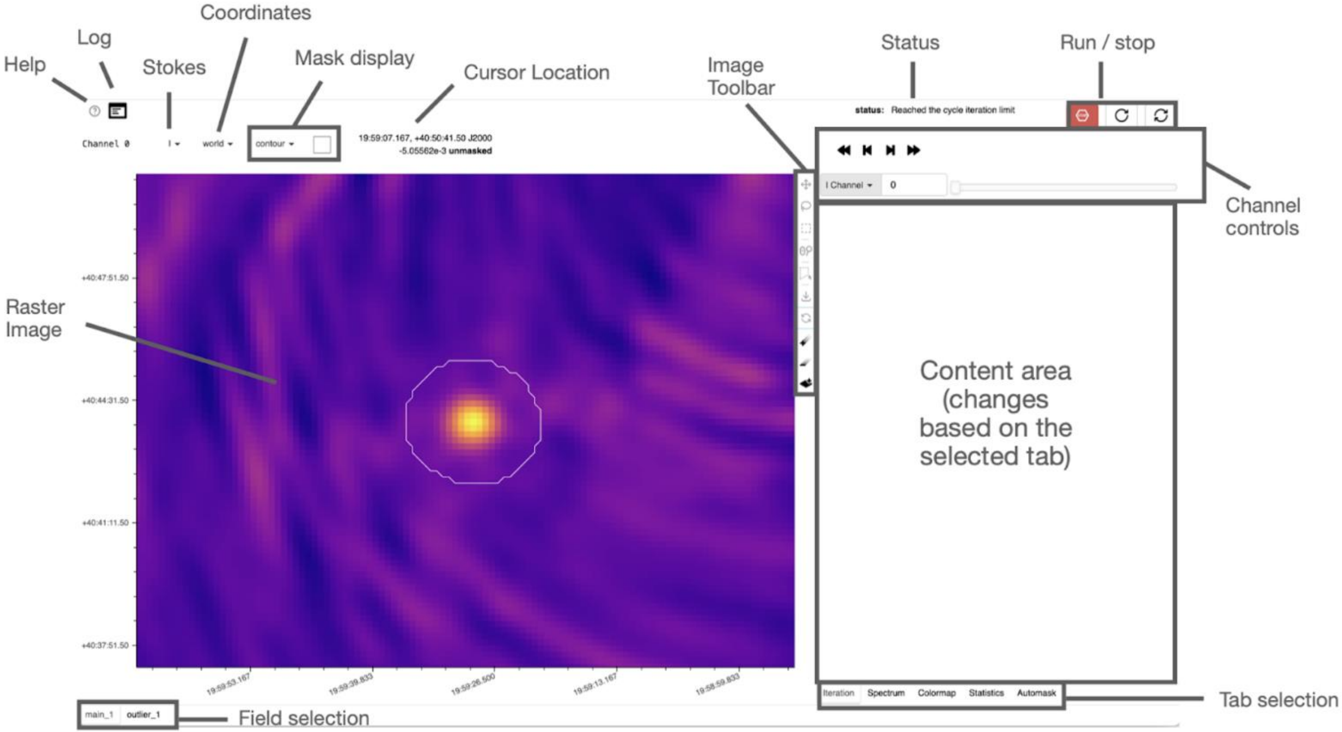
DEF: This task handles continuum images and spectral line cubes, supports outlier fields, contains standard clean based algorithms along with algorithms for multi-scale and wideband image reconstruction, widefield imaging correcting for the w-term, full primary-beam imaging and joint mosaic imaging (with heterogeneous array support for ALMA).

Feature	**`iclean`**	**`tclean`**
Underlying task	Calls `tclean`	Native CASA task
Interactive viewer	Opens automatically	Only if `interactive=True`
Designed for	Interactive imaging/teaching	General imaging (interactive or scripted)
Available in CASA	Only if defined/imported	Always
Imaging algorithm	`tclean`	`tclean`

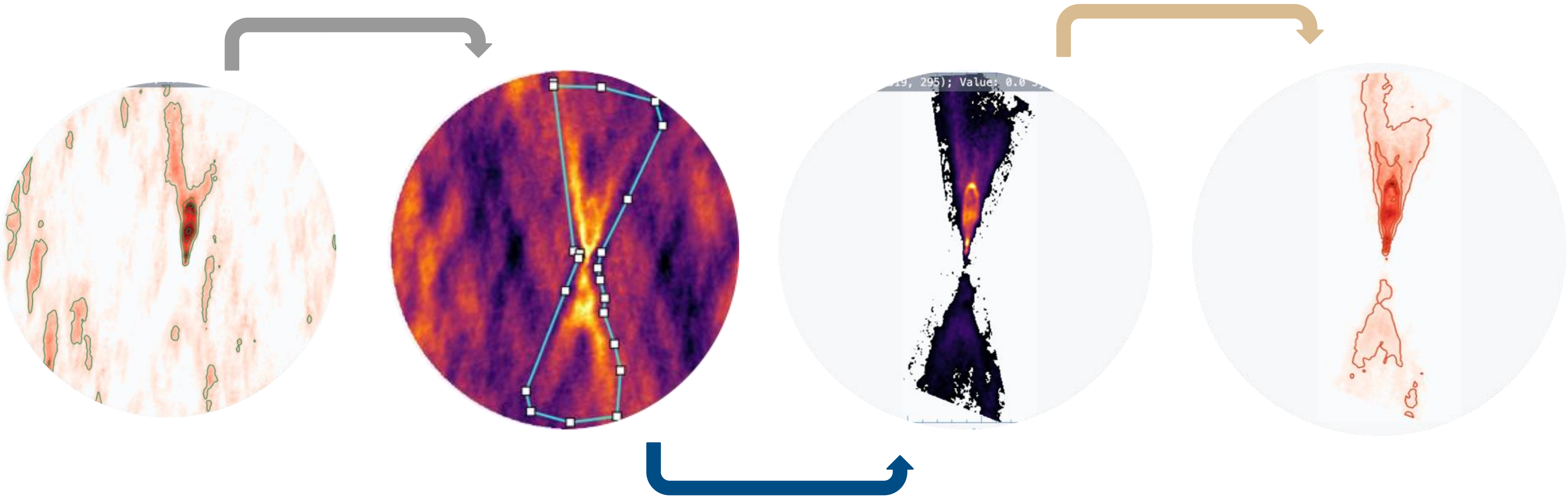
tclean interface



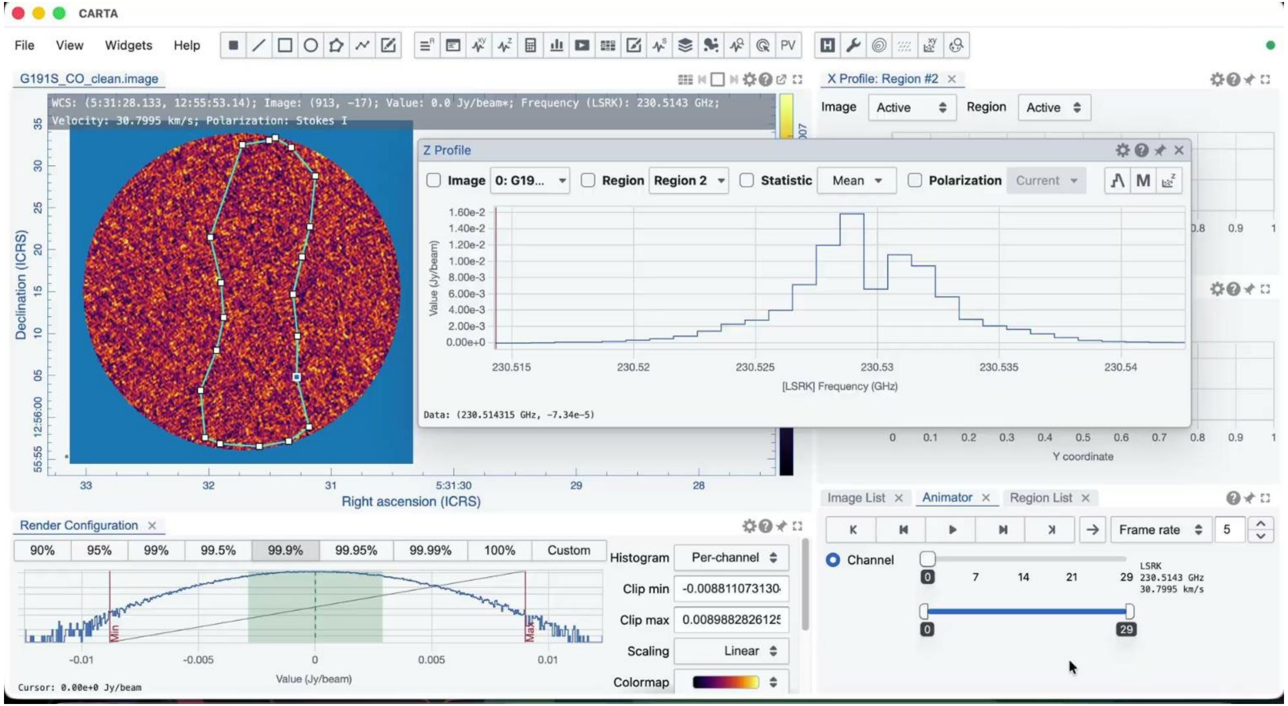
iclean interface



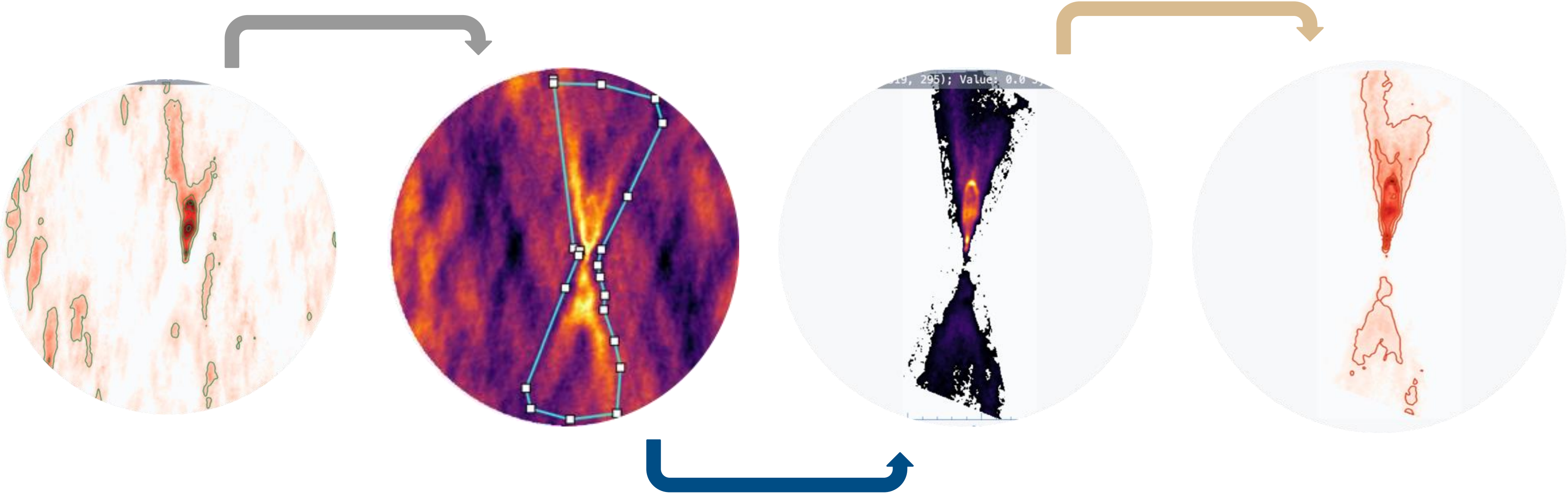
Regions



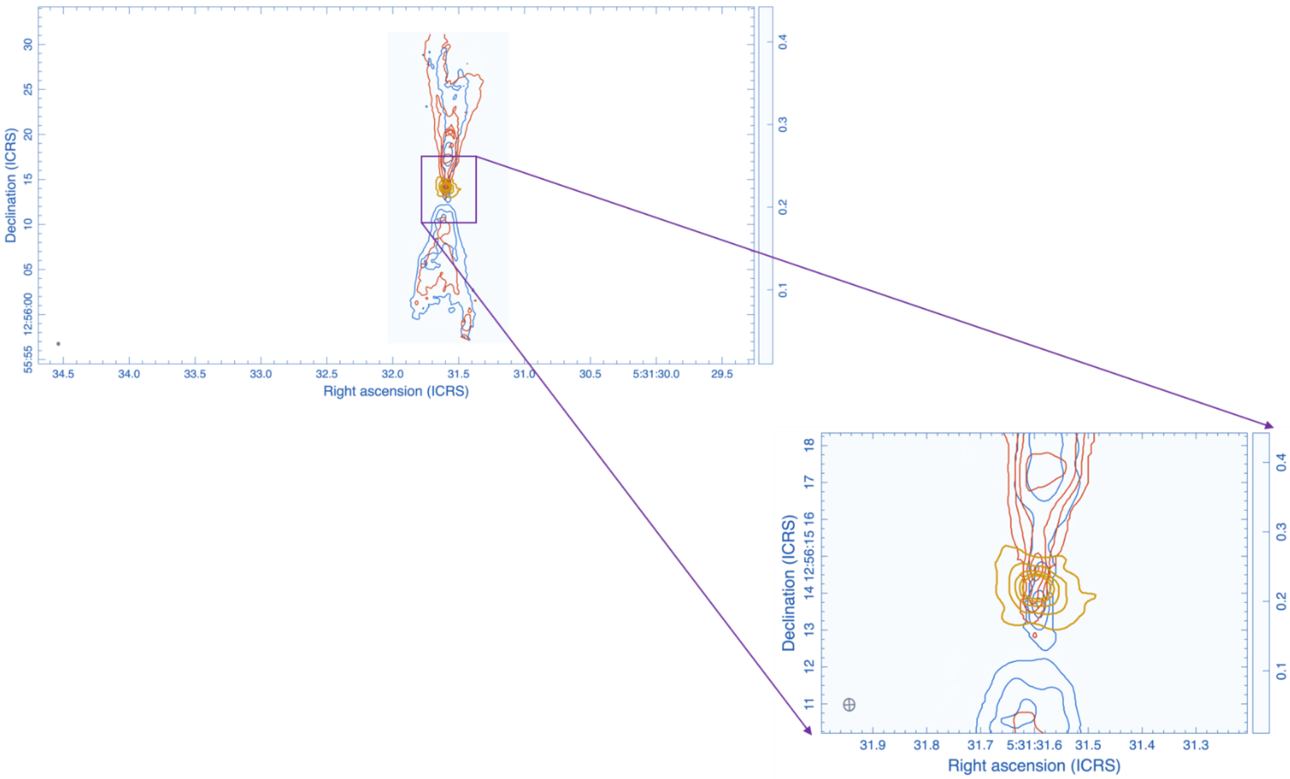
Regions


CARTA
File
View
Widgets
Help
G191S_CO_clean.image
WCS: (5:31:28.133, 12:55:53.14); Image: (913, -17); Value: 0.0 Jy/beam*; Frequency (LSRK): 230.5143 GHz;
Velocity: 30.7995 km/s; Polarization: Stokes I
Declination (ICRS)
Right ascension (ICRS)
X Profile: Region #2
Z Profile
Image
Region
Region 2
Statistic
Mean
Polarization
Current
Value (Jy/beam)
[LSRK] Frequency (GHz)
Data: (230.514315 GHz, -7.34e-5)
Y coordinate
Render Configuration
90%
95%
99%
99.5%
99.9%
99.95%
99.99%
100%
Custom
Histogram
Per-channel
Clip min
-0.008811073130
Clip max
0.008988282612
Scaling
Linear
Colormap
Value (Jy/beam)
Cursor: 0.00e+0 Jy/beam
Image List
Animator
Region List
Frame rate
5
Channel
LSRK
230.5143 GHz
30.7995 km/s

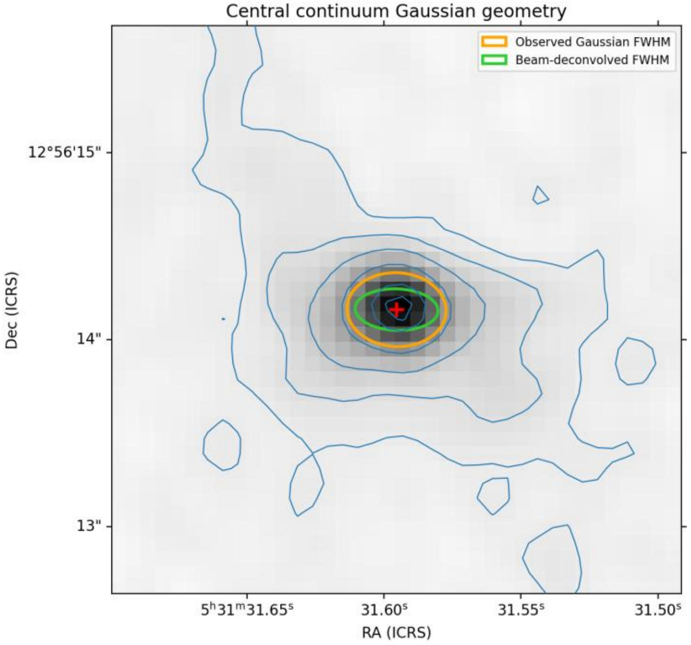
Regions



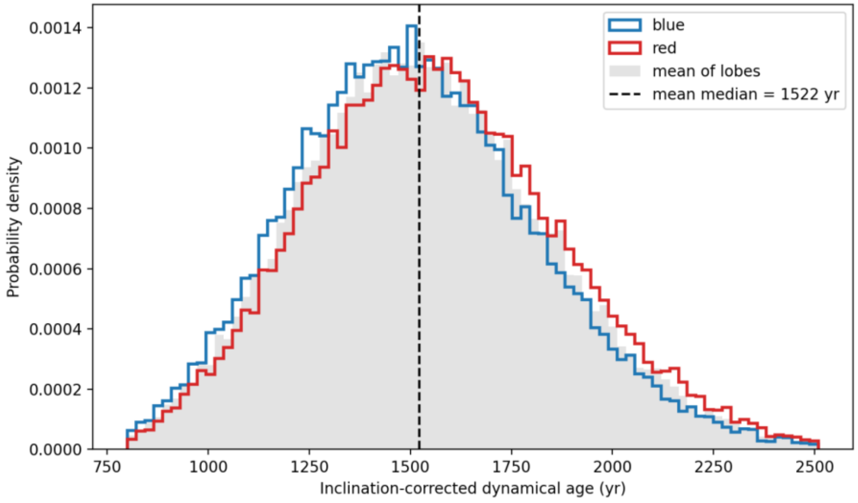
Regions


Declination (ICRS)
30
25
20
15
10
05
12:56:00
55:55
34.5
34.0
33.5
33.0
32.5
32.0
31.5
31.0
30.5
5:31:30.0
29.5
Right ascension (ICRS)
0.4
0.3
0.2
0.1
18
17
12:56:15 16
14
13
12
11
31.9
31.8
31.7
5:31:31.6
31.5
31.4
31.3

Beam size

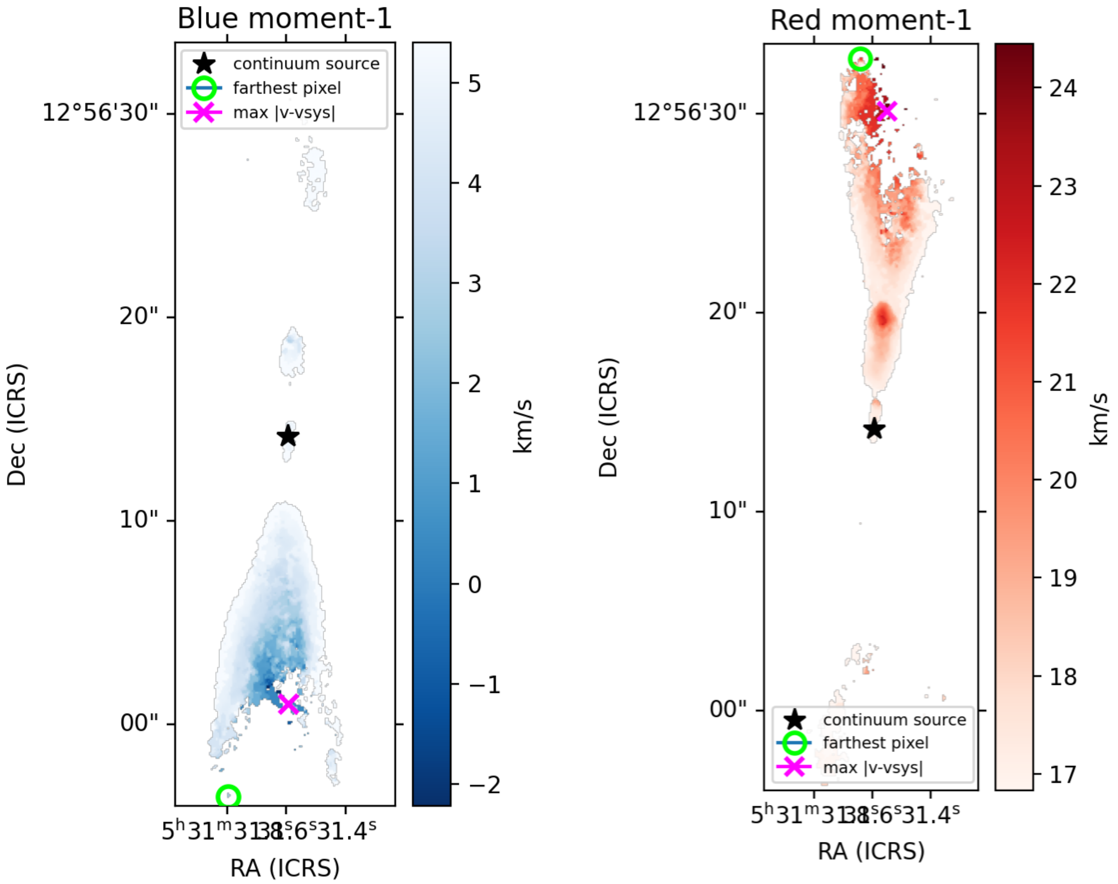


Central continuum Gaussian geometry
Observed Gaussian FWHM
Beam-deconvolved FWHM
12°56'15"
14"
13"
Dec (ICRS)
5h31m31.65s
31.60s
31.55s
31.50s
RA (ICRS)



blue
red
mean of lobes
mean median = 1522 yr
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Probability density
750
1000
1250
1500
1750
2000
2250
2500
Inclination-corrected dynamical age (yr)

Beam size


Blue moment-1
continuum source
farthest pixel
max |v-vsys|
12°56'30"
20"
10"
00"
Dec (ICRS)
RA (ICRS)
km/s
Red moment-1
continuum source
farthest pixel
max |v-vsys|
12°56'30"
20"
10"
00"
Dec (ICRS)
RA (ICRS)
km/s

KEY LEARNING POINTS:

THANK YOU FOR LISTENING!

<u>Rupam:</u>

Love it

or,

Leave it!

<u>Sohyeon:</u>

Weight it

Clean it

If it’s smaller than the beam—leave it!

<u>Bianca:</u>

- Sleep.
- Practice, practice, practice!
- Repeat.