GROUP 3

Evolutionary stage of the protostar SMM3 inspected from morphology, kinematics, and abundance

2020-08-21

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Supervised by Yusuke Aso

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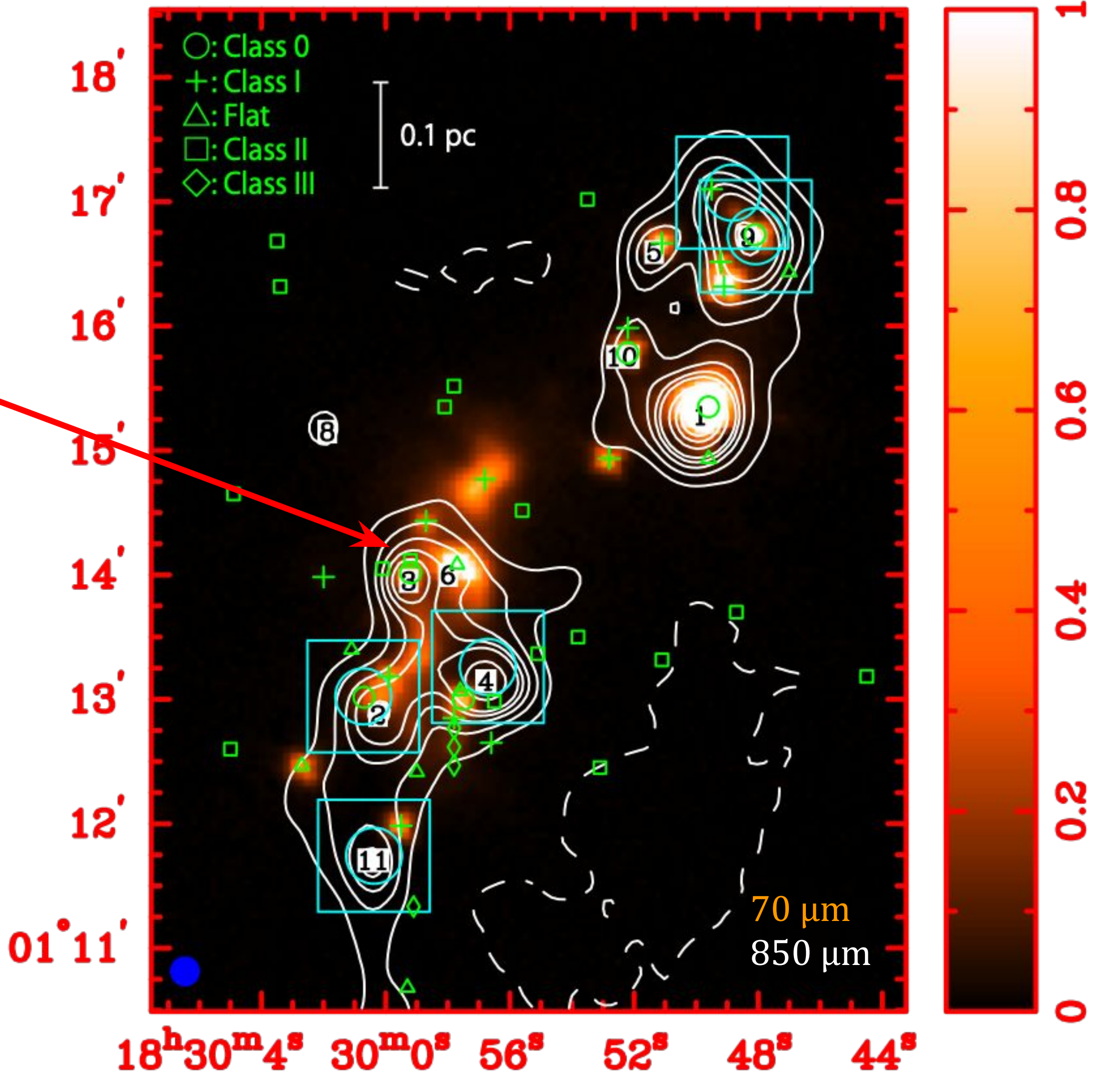
Introduction

SMM3 in Serpens Main (~436 pc)

Class 0/I/II/III



Introduction

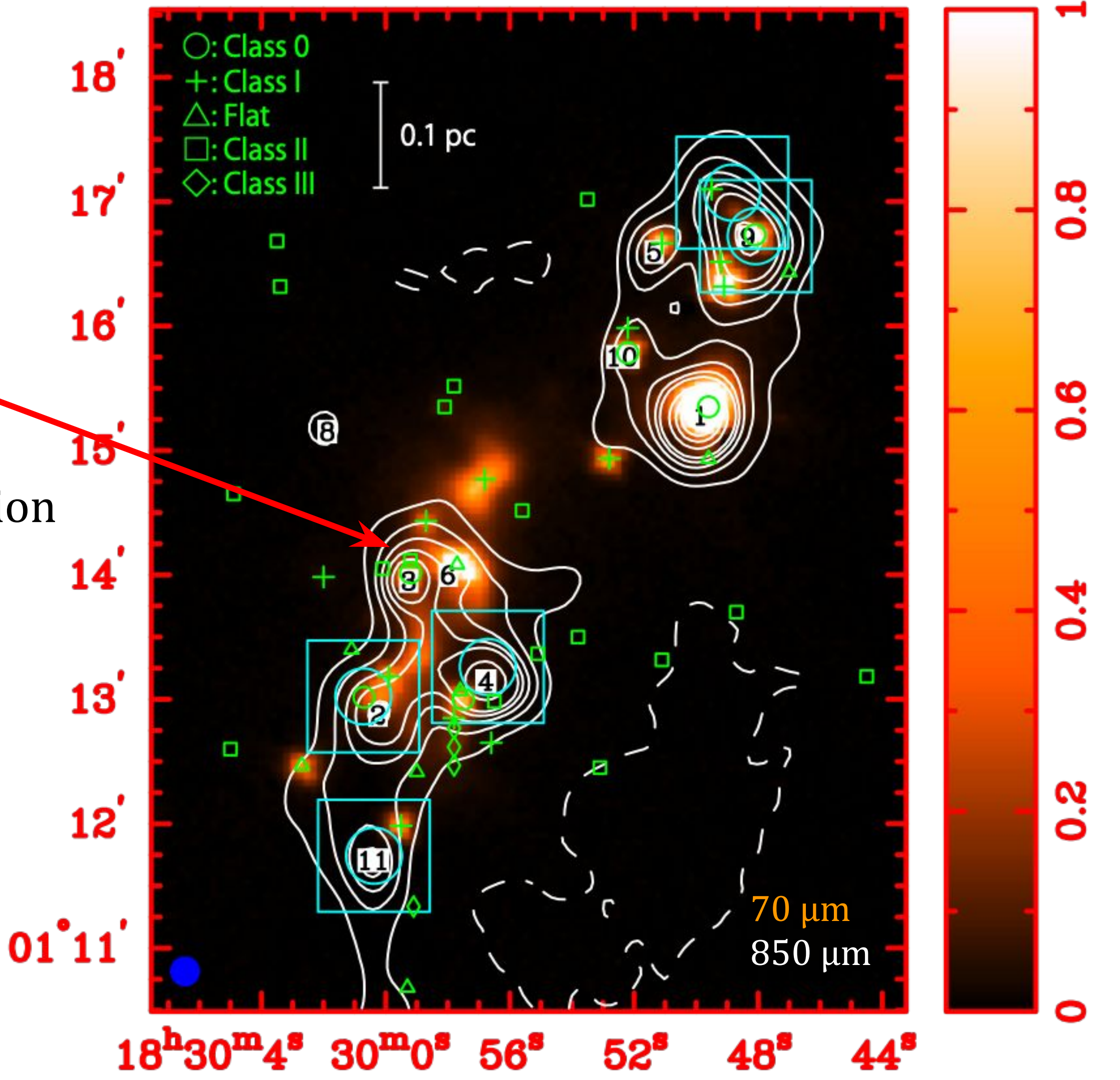
SMM3 in Serpens Main (~436 pc)

Class 0/I/II/III

Youngest phase in star formation

No MIR detection

(sub)mm is required



Introduction

SMM3 in Serpens Main (~436 pc)

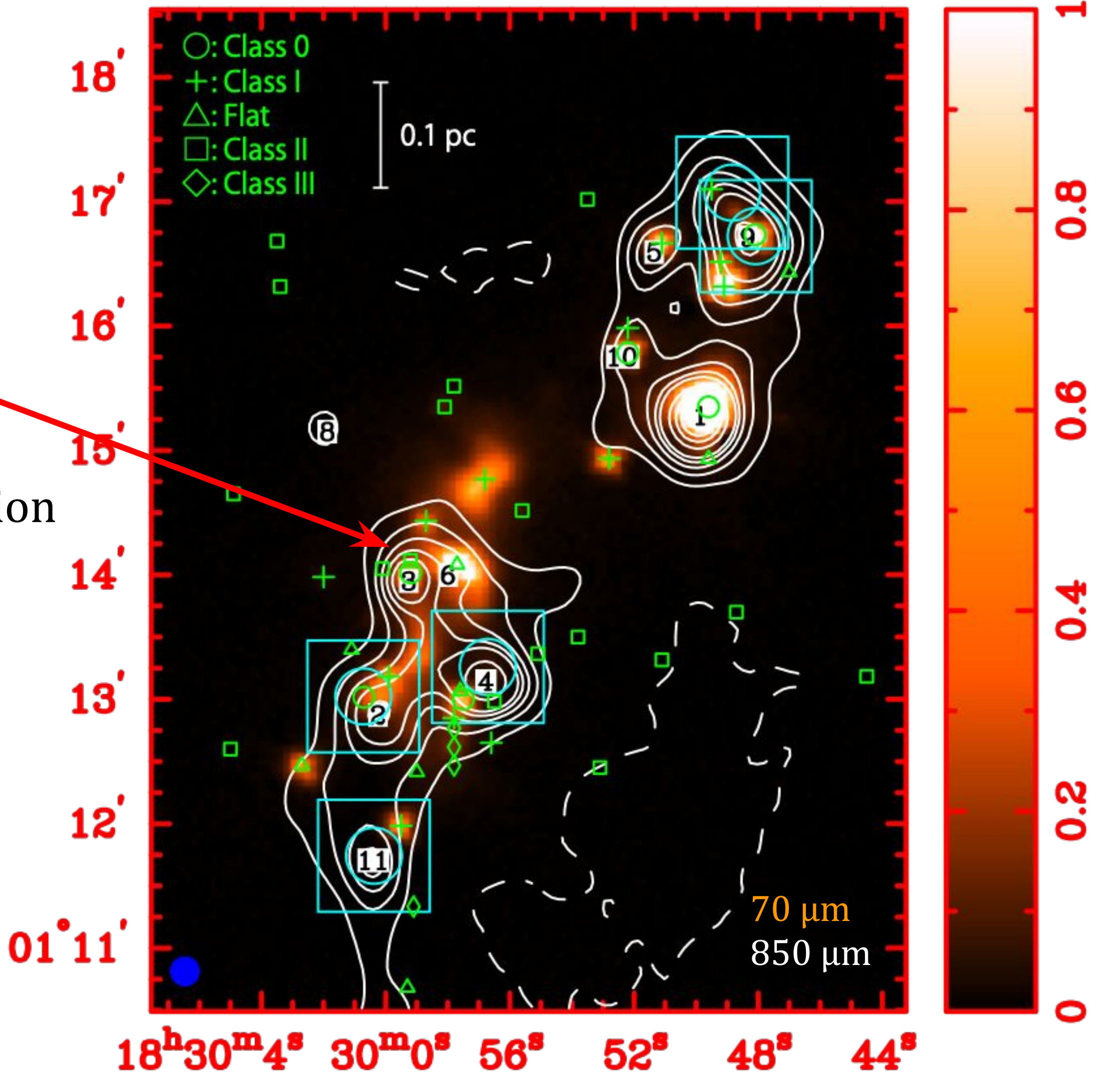
Class **0**/I/II/III

Youngest phase in star formation

No MIR detection

(sub)mm is required

Using ALMA, we attempt to classify Class 0 into subclasses, using
- disk (by continuum)
- kinematics/outflow dynamical time
- element abundances



Observations

ALMA

Cycle 5, 2018-09-16, 45 antennas, ~0.3” resolution, 20 min. on source

Continuum:

Freq = 234 GHz (~1.3 mm), TotBW = 1.875GHz, RMS = 0.3 mJy

lines(CO, ^{13}CO, $C^{18}O$ J=2-1):

ν_{rest} = 230.5 GHz(CO), 220.4 GHz(^{13}CO), 219.5 GHz($C^{18}O$)

velocity resolution ~ 0.63 km/s

<u>Continuum</u>

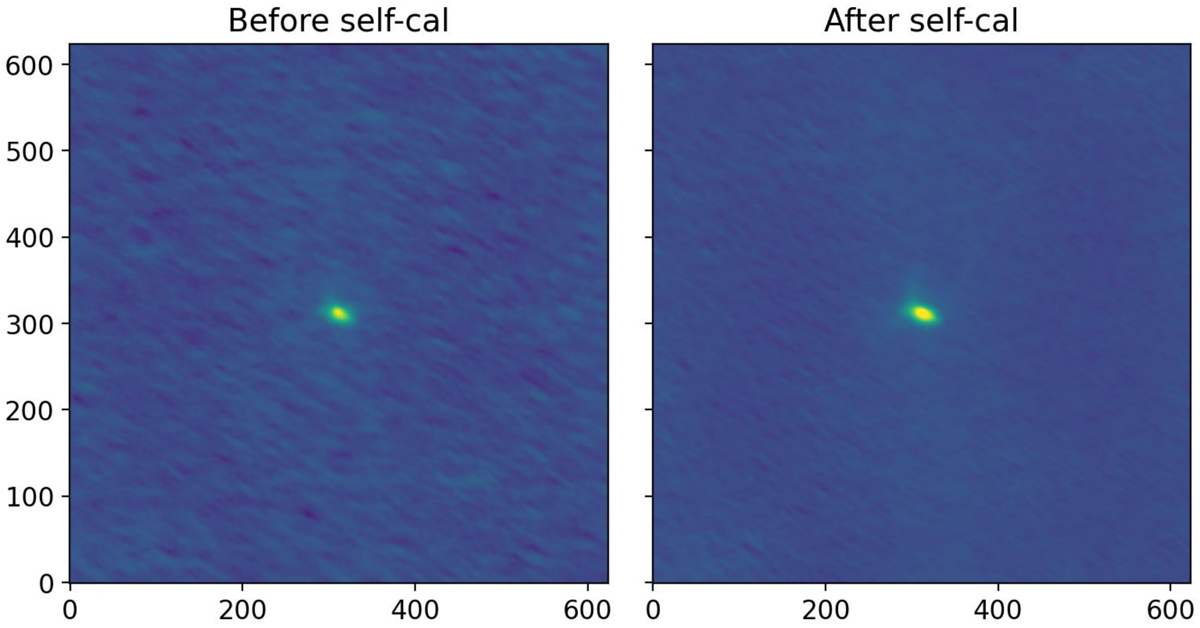
Looking into the disk

Yoonsoo P. Bach

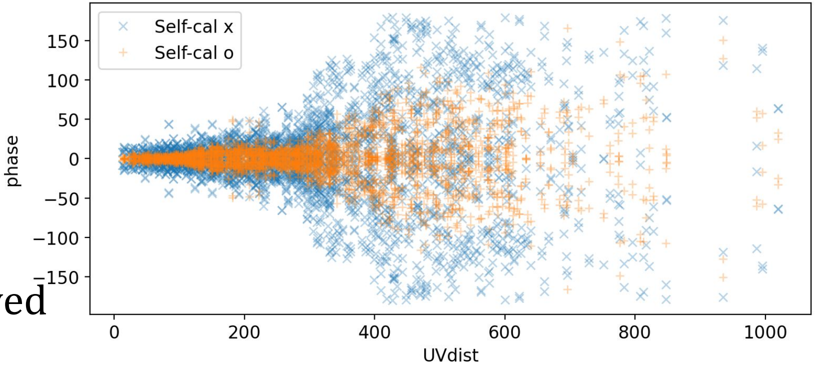
Effect of Self-Calibration (phase)

Image and phase improved

Identical stretch & limit (Jy/beam)



Effect of Self-Calibration (phase)



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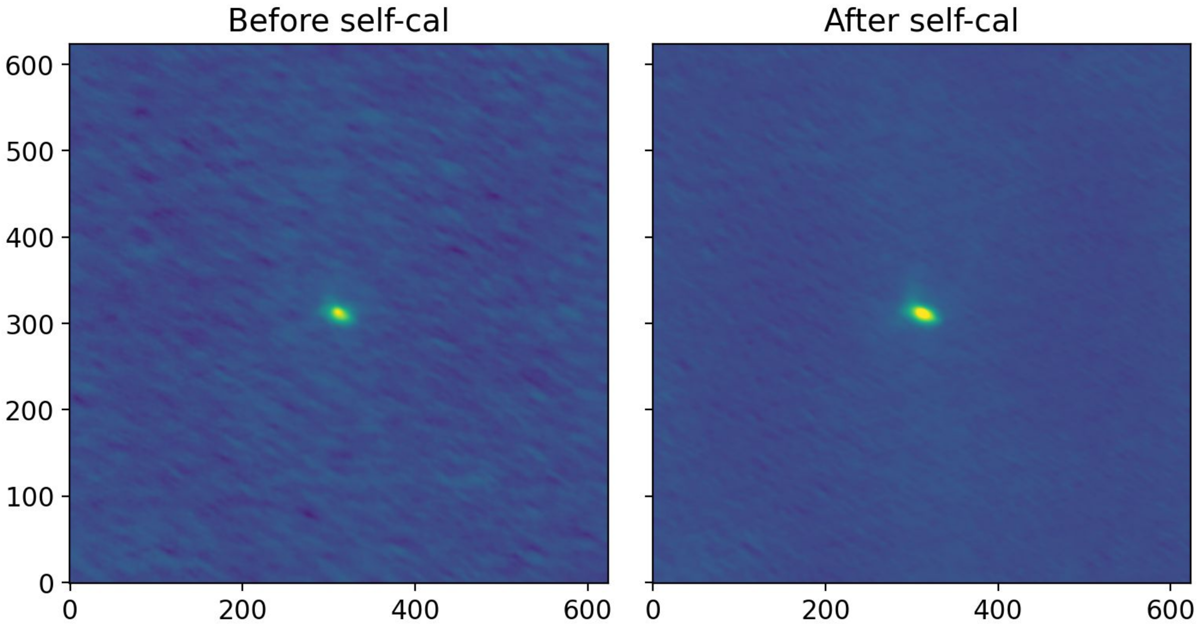
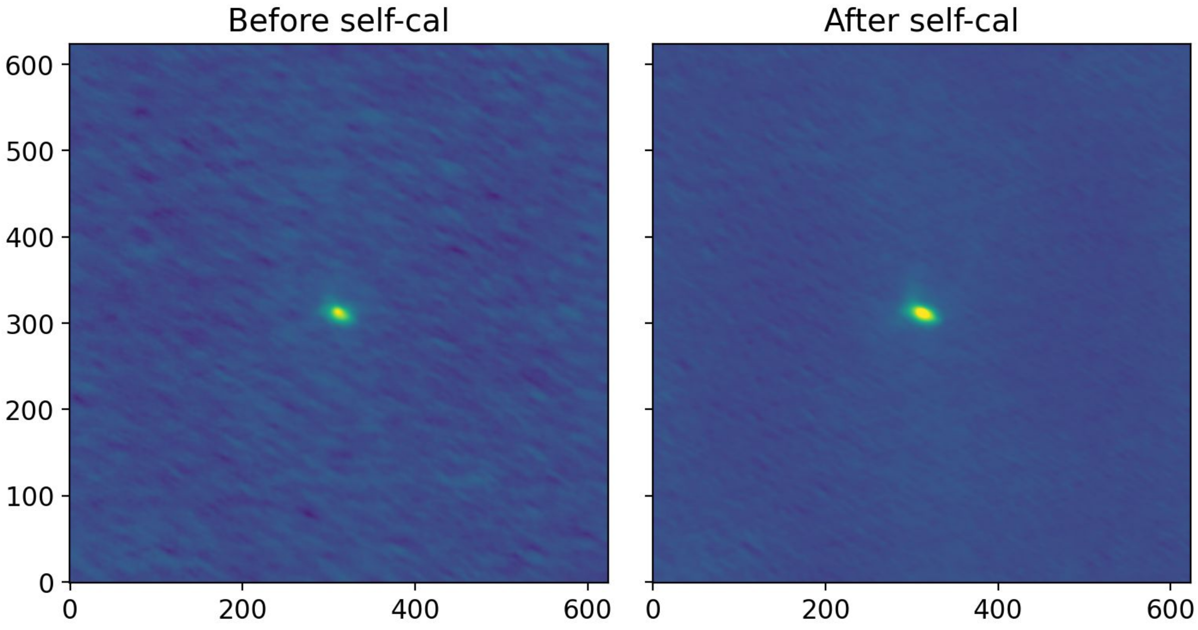
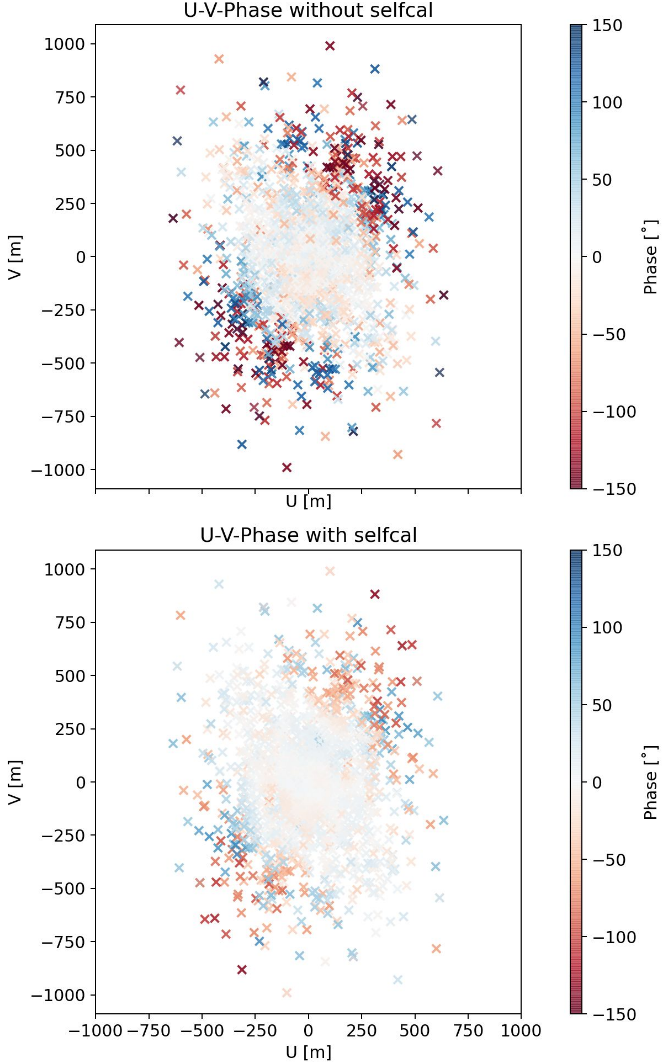


Effect of Self-Calibration (phase)

Image and phase improved

Identical stretch & limit (Jy/beam)





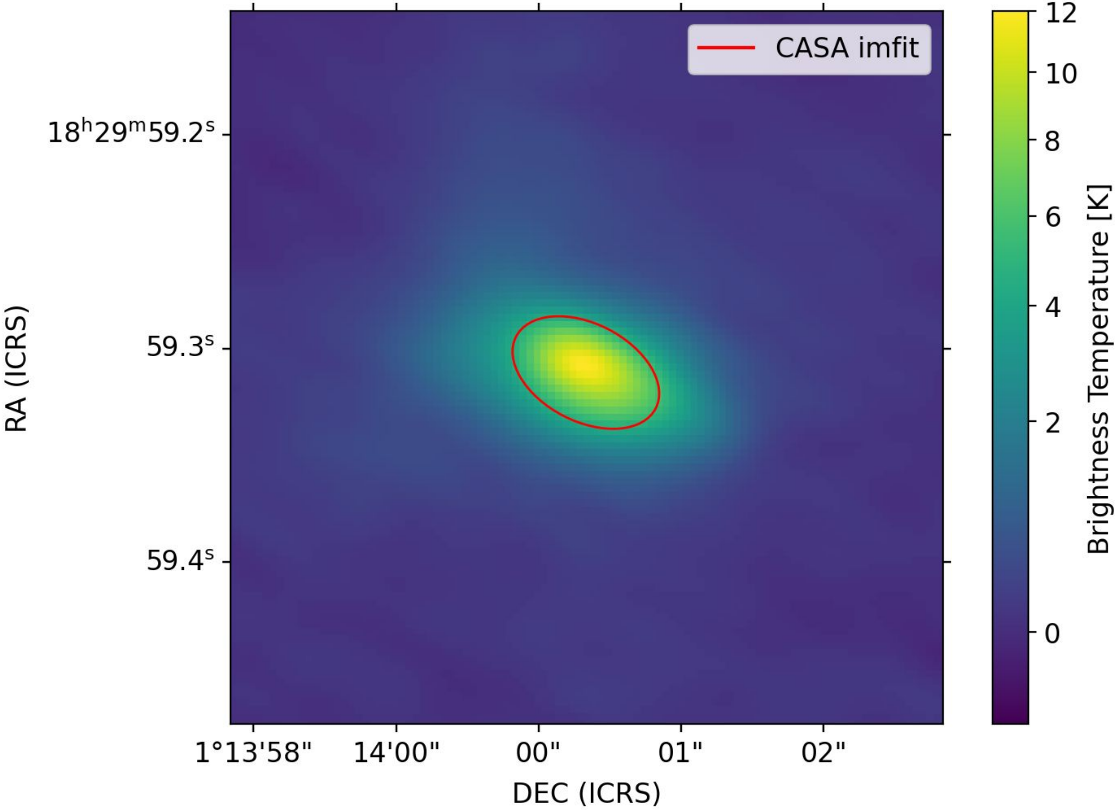
Disk Shape

Continuum

1 mJy threshold clean

phase self-cal

Convert Jy/beam → K ($T_{brightness}$)



Disk Shape

Continuum

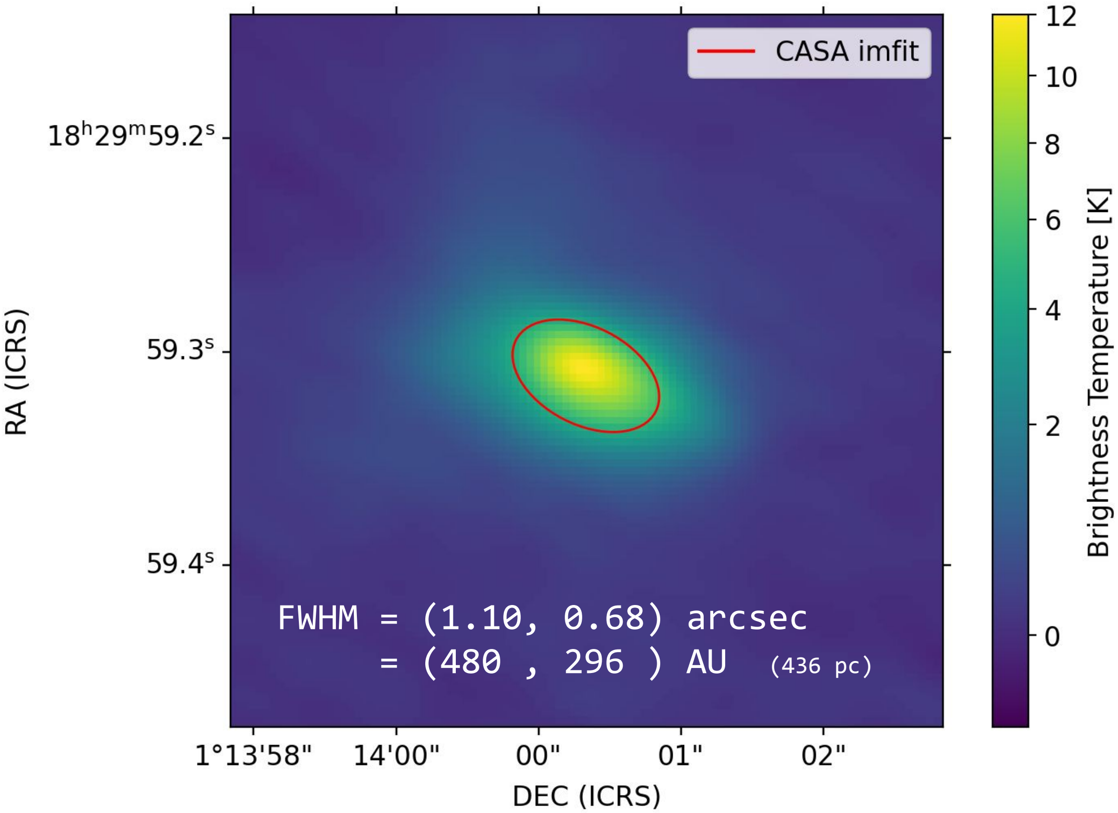
1 mJy threshold clean

phase self-cal

Convert Jy/beam → K ($T_{brightness}$)

PA = 65.5°

Inclination angle ~ 51-52°



$$T = \frac{h\nu}{k_B}\left[\ln\left(1 + \frac{2h\nu^3}{c^2 B_\nu(\nu;T)}\right)\right]$$

Real temperature from Planck ≠ $T_{brightness}$

Disk Shape

Continuum

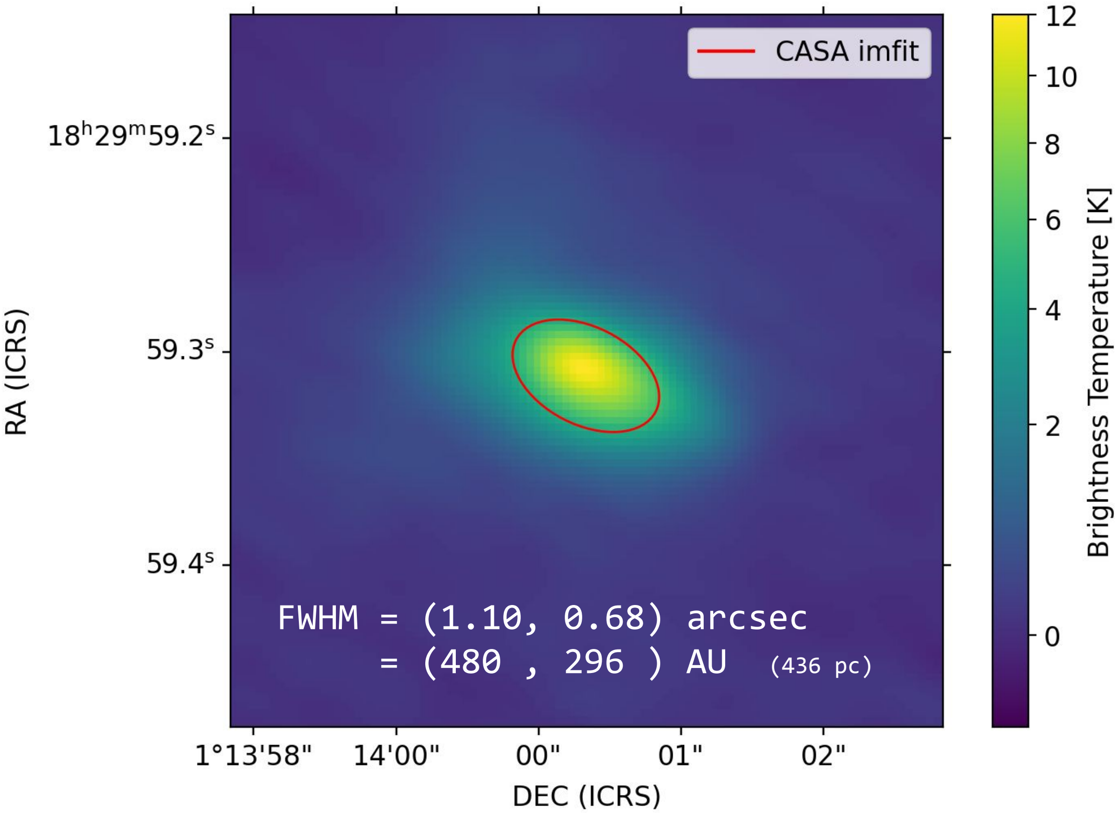
1 mJy threshold clean

phase self-cal

Convert Jy/beam → K ($T_{brightness}$)

PA = 65.5°

Inclination angle ~ 51-52°



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Real temperature from Planck ≠ $T_{brightness}$

Disk Shape

True peak temperature ~ 18K
(previous single dish CO observation reported ~ 20K)

Continuum

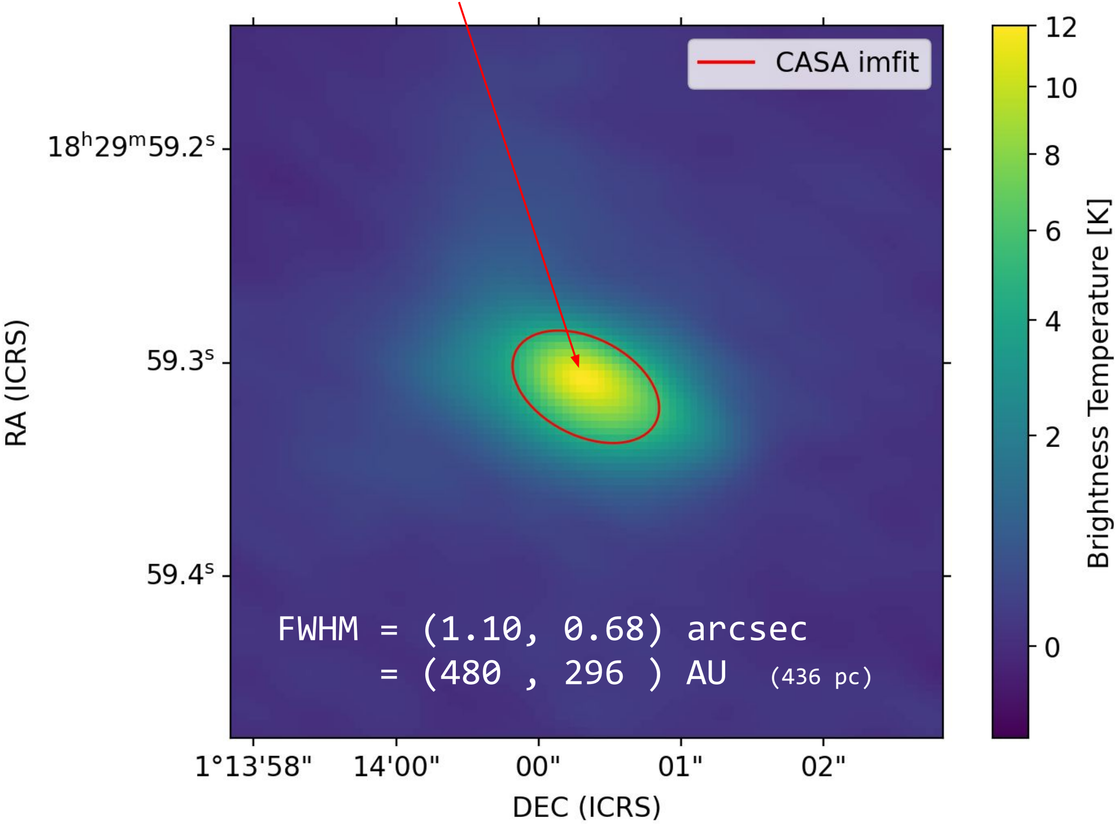
1 mJy threshold clean

phase self-cal

Convert Jy/beam → K ($T_{brightness}$)

PA = 65.5°

Inclination angle ~ 51-52°



$$T = \frac{h\nu}{k_B}\left[\ln\left(1 + \frac{2h\nu^3}{c^2 B_\nu(\nu;T)}\right)\right]$$

Disk Shape

Continuum

1 mJy threshold clean

phase self-cal

Convert Jy/beam → K ($T_{brightness}$)

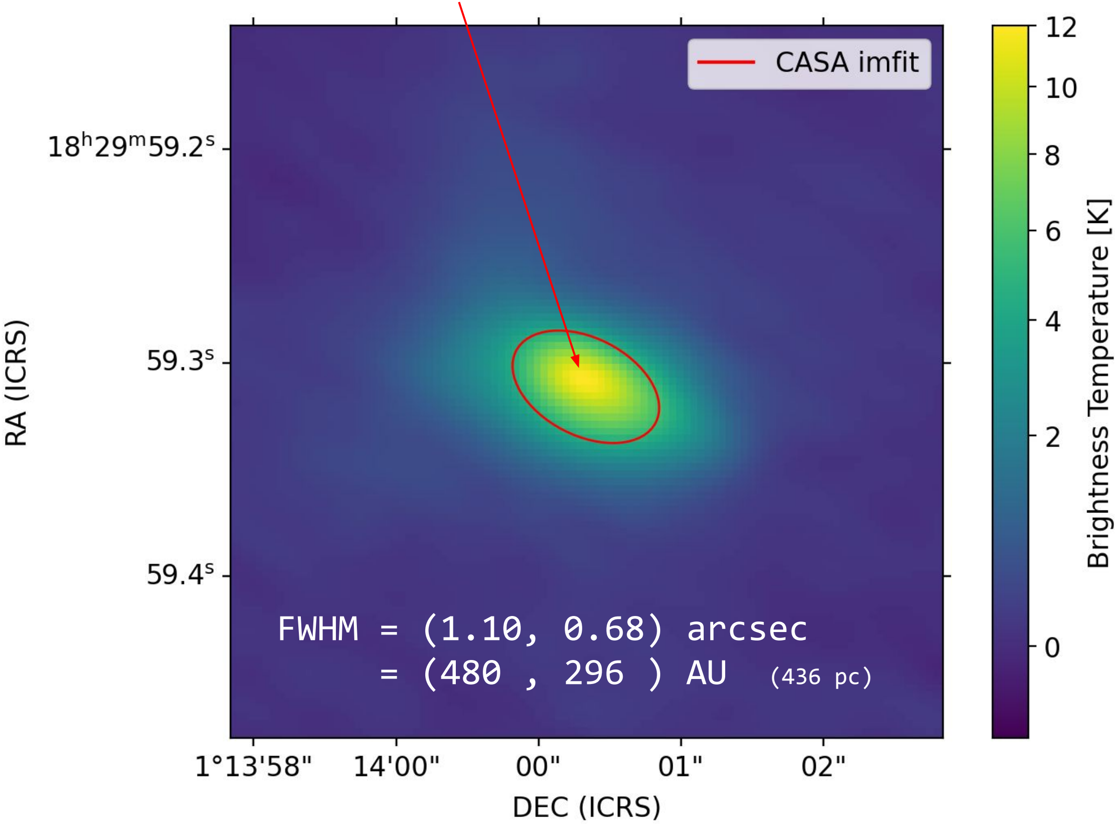
PA = 65.5°

Inclination angle ~ 51-52°

Real temperature from Planck ≠ $T_{brightness}$

True peak temperature ~ 18K → **optically thick**

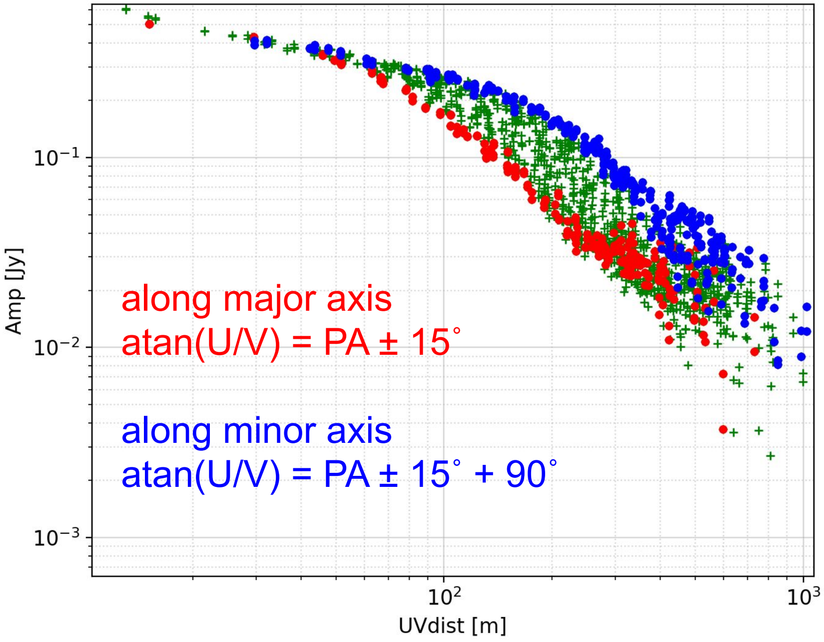
(previous single dish CO observation reported ~ 20K)

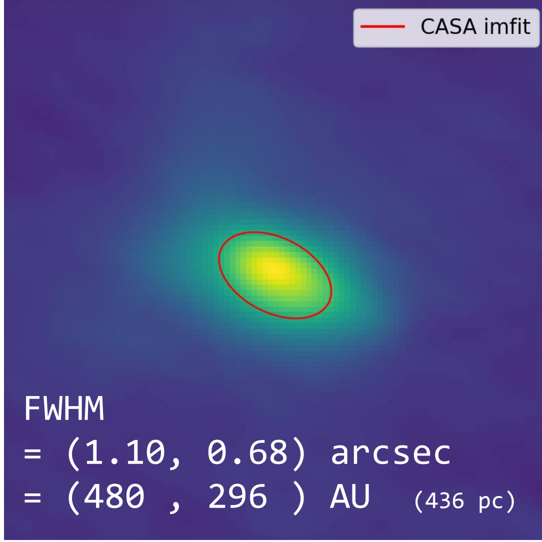


Visibility Profile

in image domain

Large scale ← Small scale





Visibility Profile

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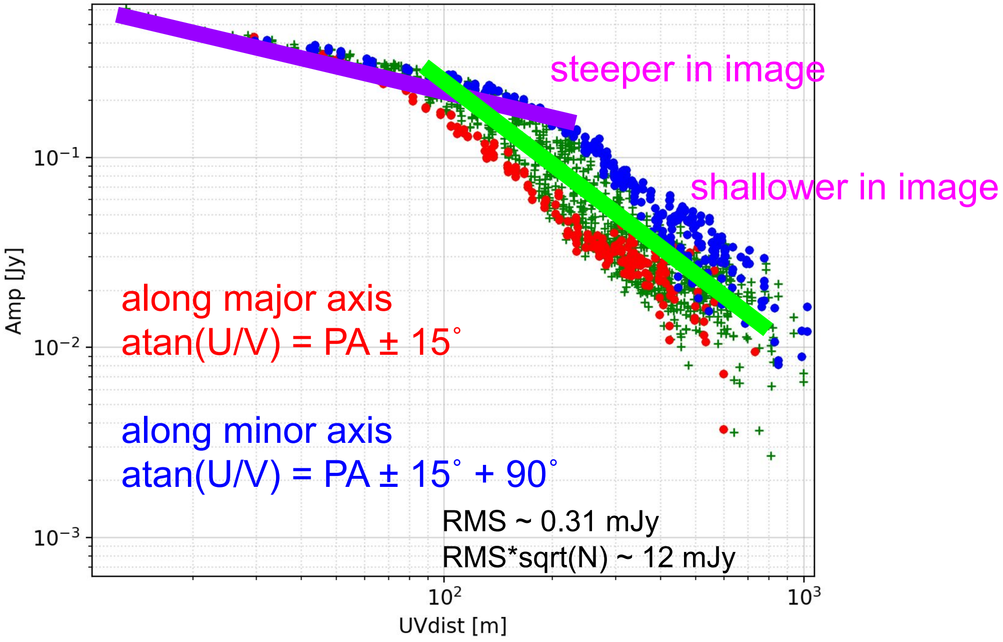
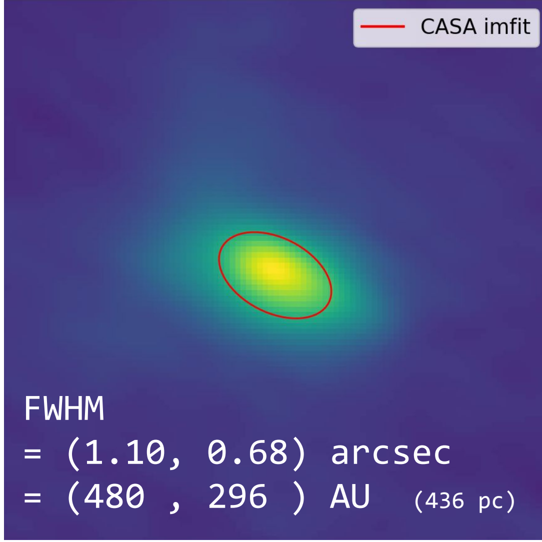
Large scale

Small scale





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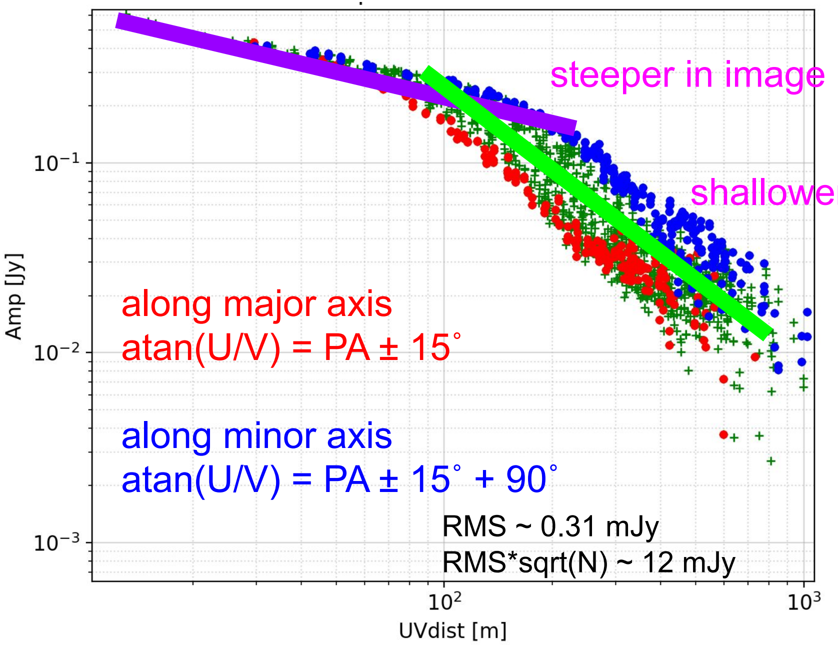
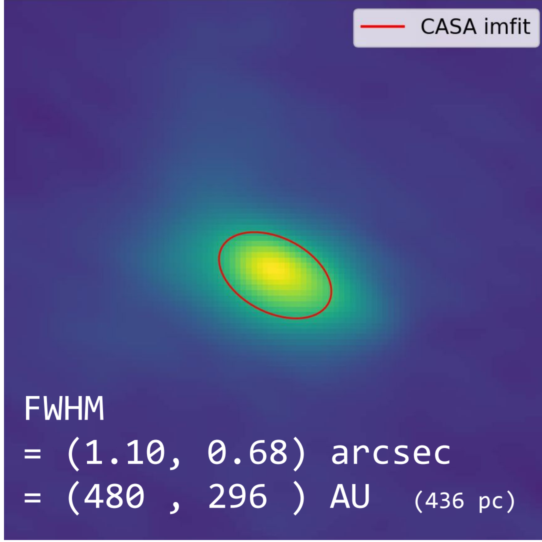
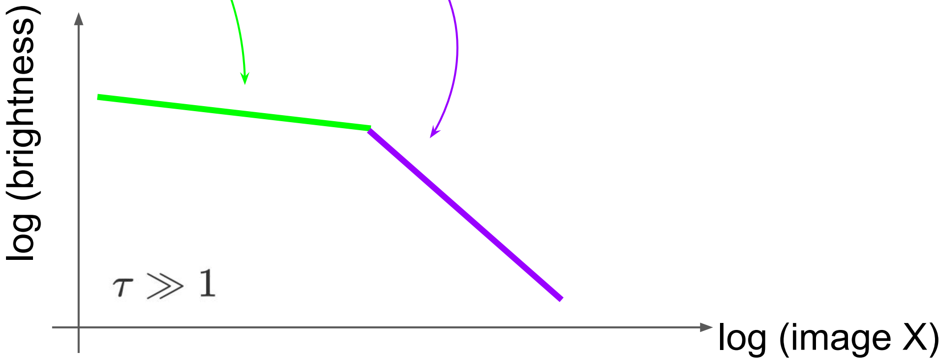


steeper in image

shallower in image





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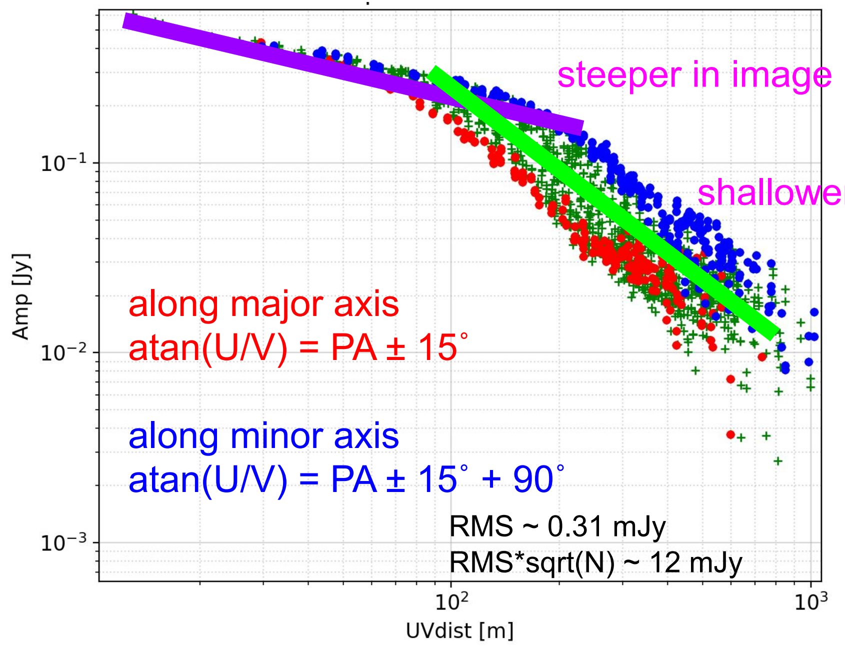

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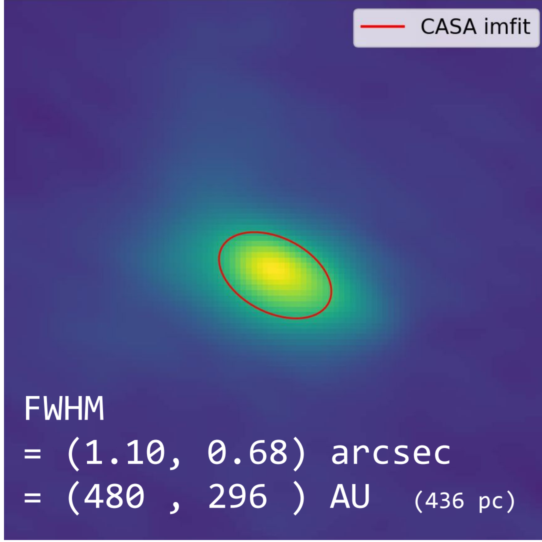
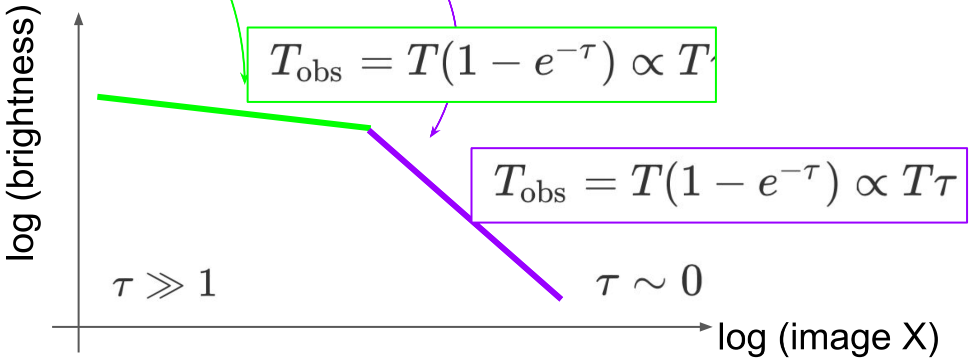




Visibility Profile

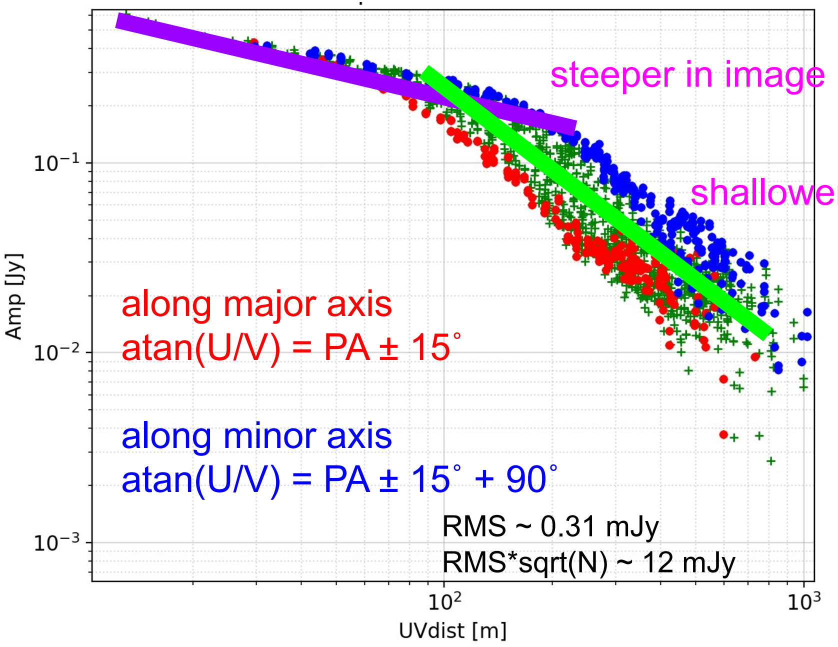
<u>Short intermittent summary</u>

2-components

Optically thick center
& optically thin envelope

in image domain

Large scale   Small scale



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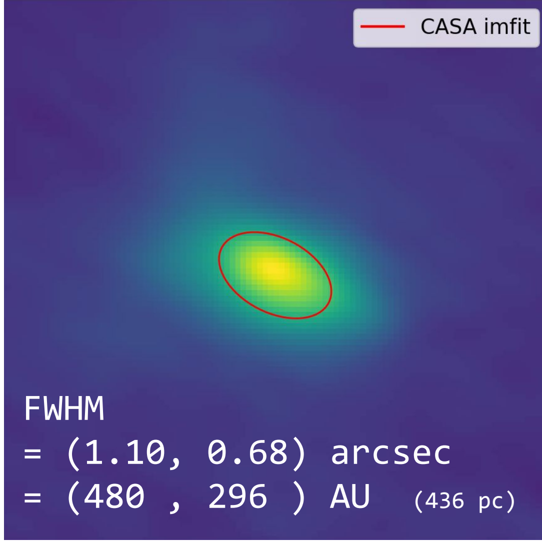

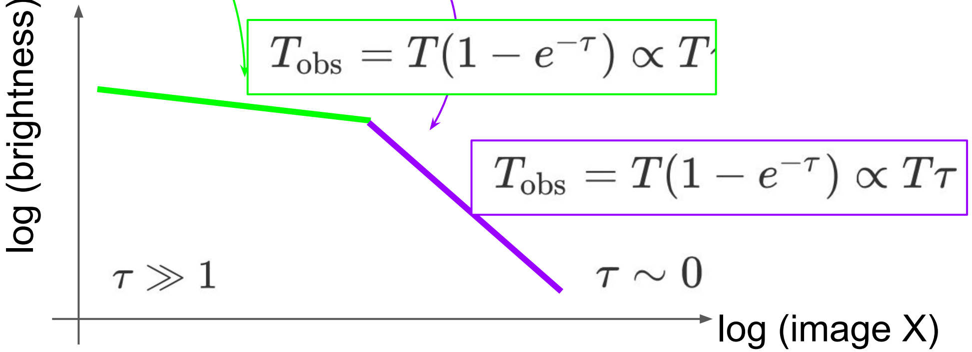

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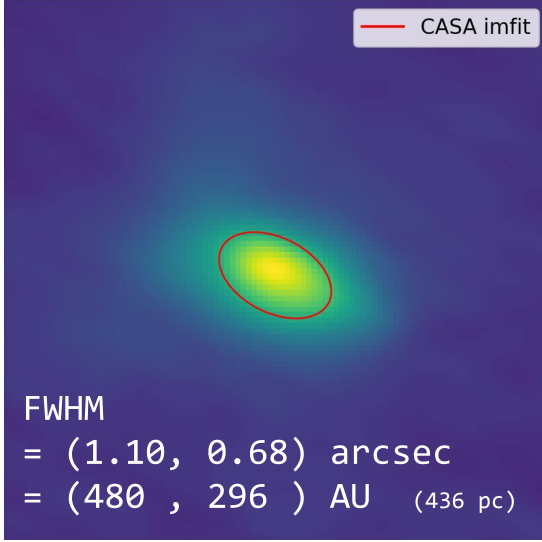
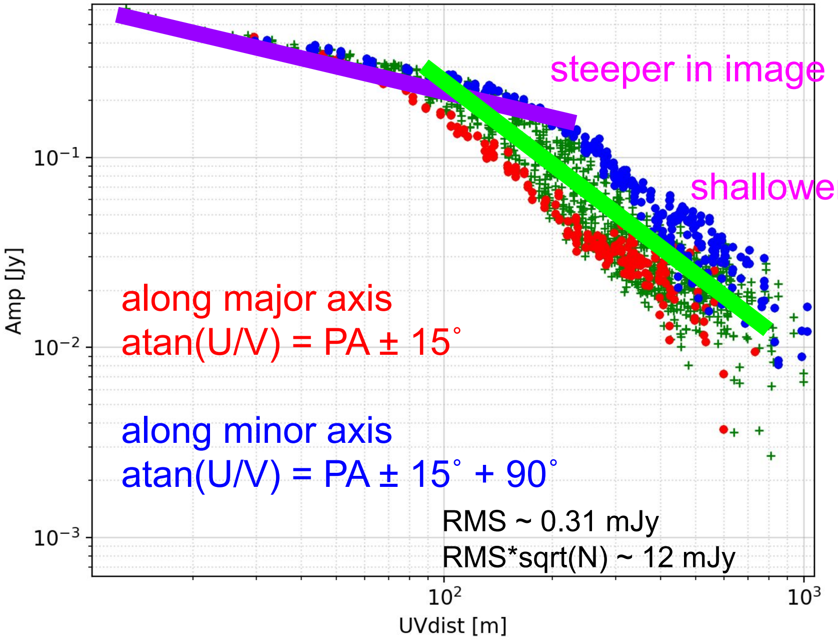


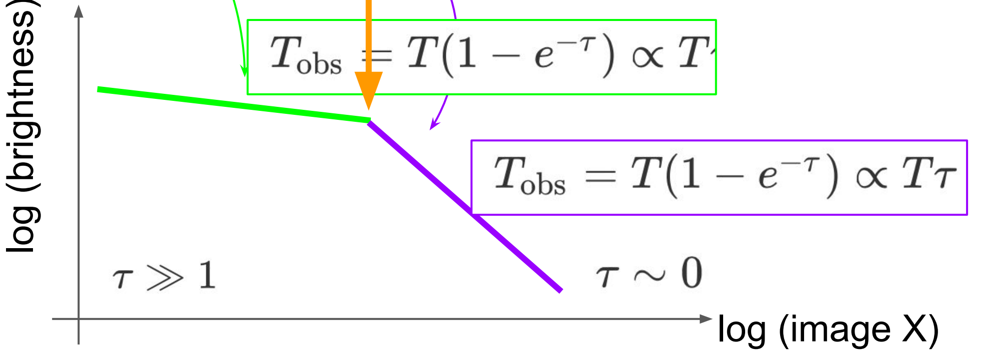
in image domain

Large scale

Small scale



BUT At which X?



Visibility Profile

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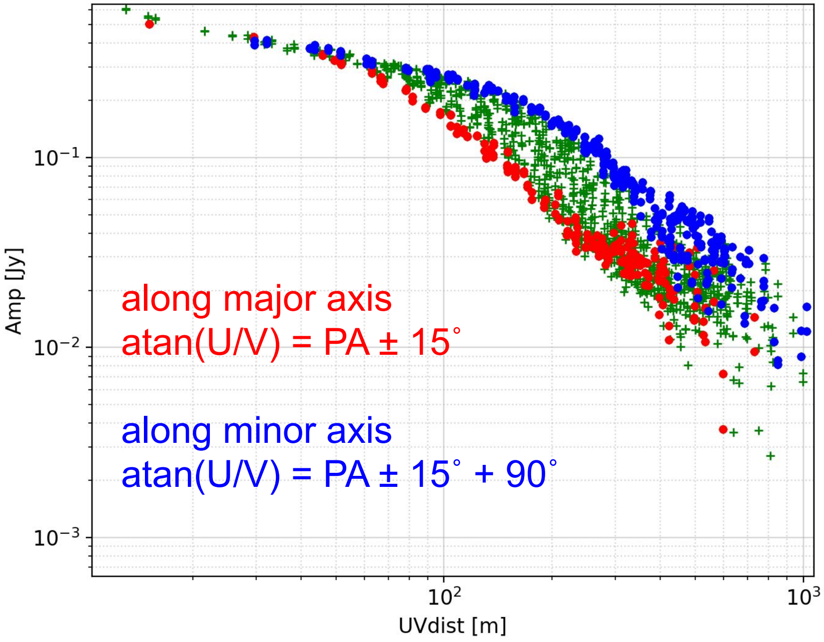
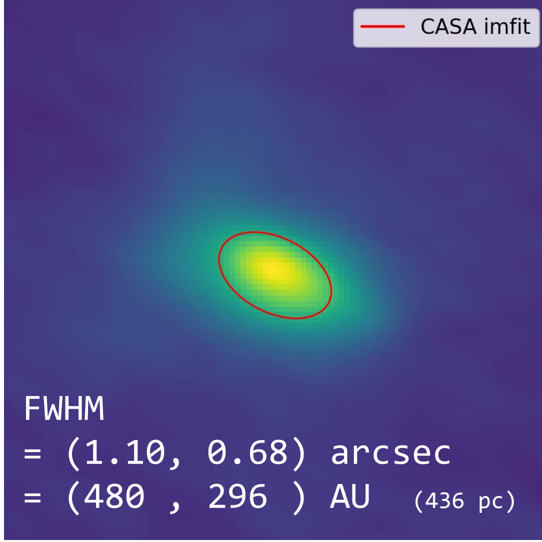
Large scale

Small scale





Visibility Profile

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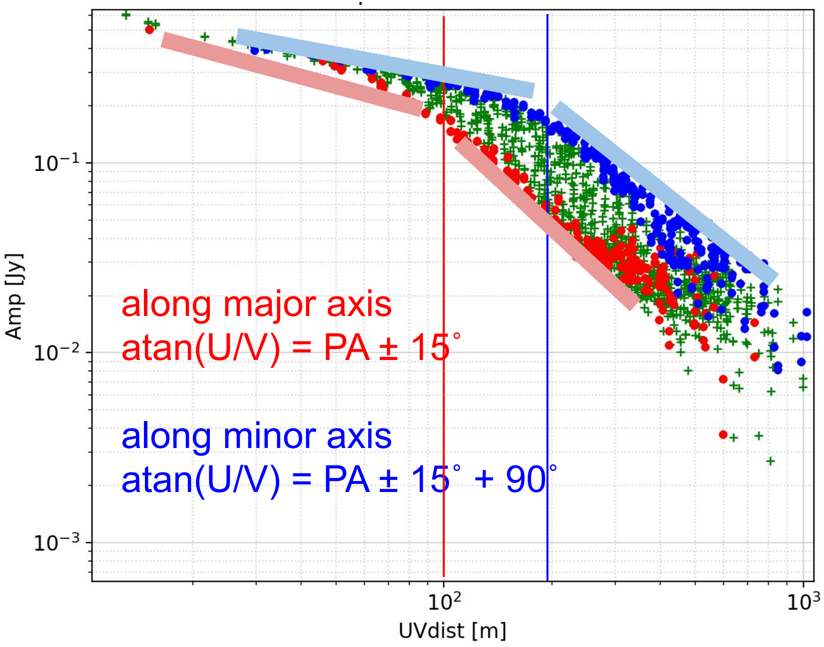

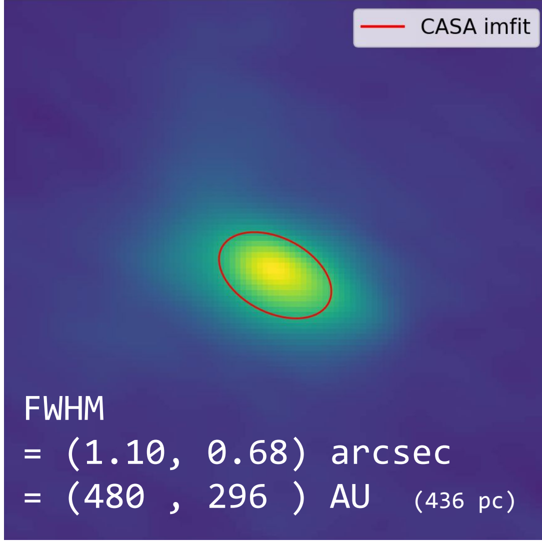

Visibility Profile

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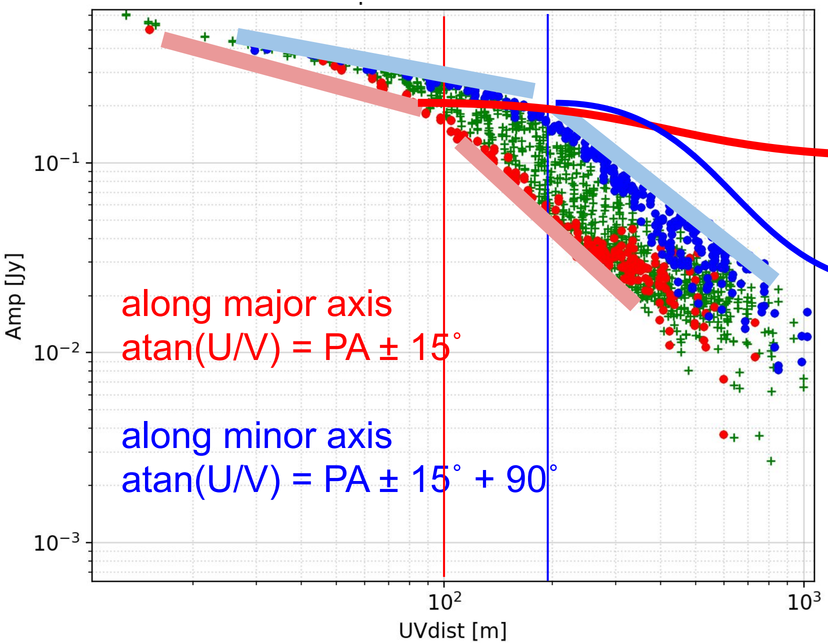
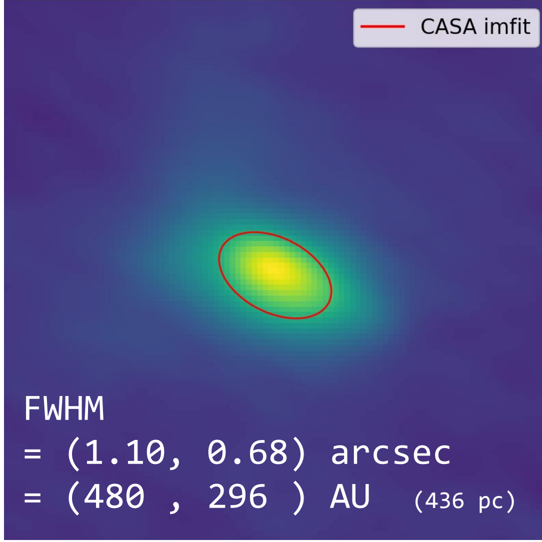
Small scale



Knee at

UVdist ~ 100 m
along major axis

UVdist ~ 200 m
along minor axis

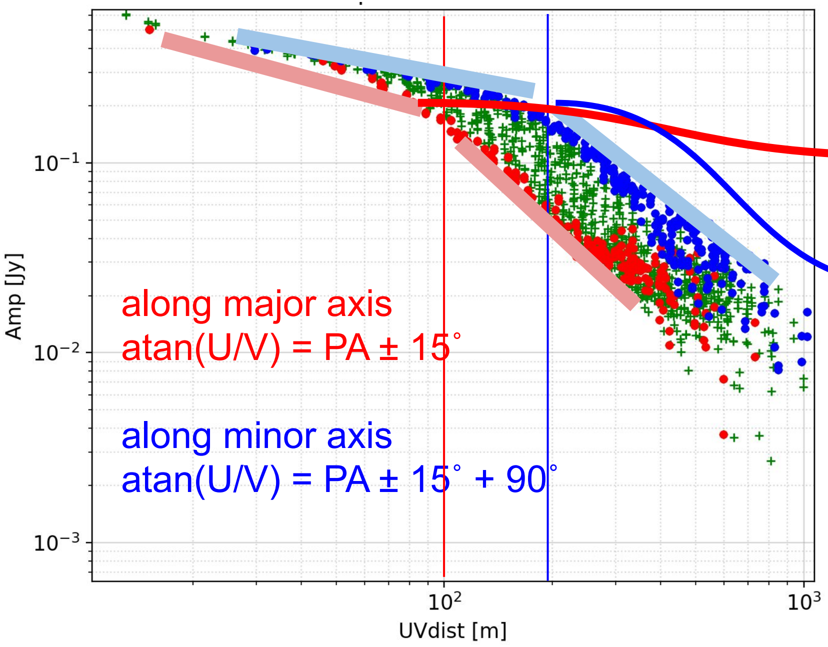


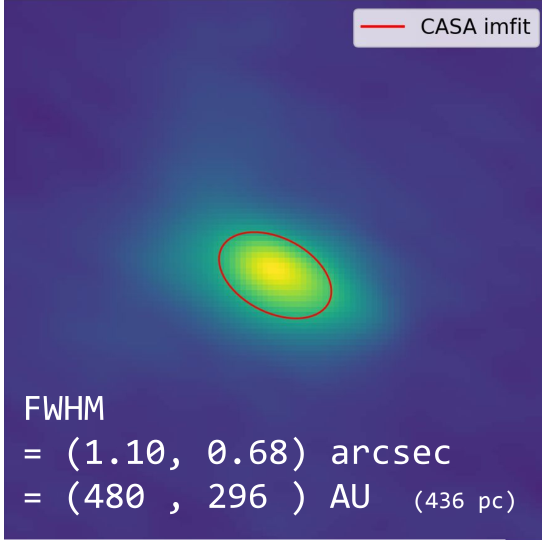
Visibility Profile

in image domain

Large scale

Small scale





Knee at

UVdist ~ 100 m
along major axis

UVdist ~ 200 m
along minor axis

$$V = \int\int I(s) e^{-i(2\pi ul)} d\Omega$$

$$u = \text{Baseline}/\lambda_{\text{obs}}$$

$e^{-i(2\pi u \times l)}$ VS $e^{-i(2\pi/\lambda \times x)}$

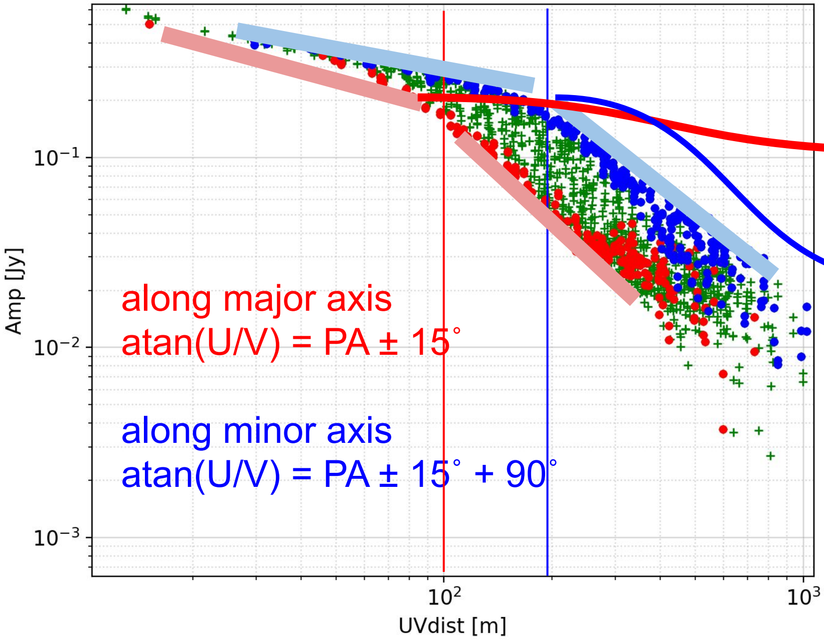
spatial “wavelength”

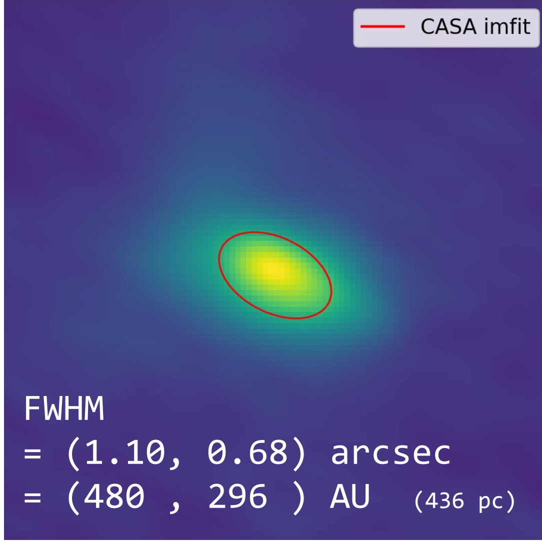
$$\lambda = \frac{1}{u} = \frac{\lambda_{\text{obs}}}{\text{Baseline}} = \frac{c}{\nu_{\text{obs}}\text{Baseline}}$$

Visibility Profile

in image domain

Large scale   Small scale





Knee at

UVdist ~ 100 m along major axis → 1.3 arcsec

UVdist ~ 200 m along minor axis → 0.65 arcsec

spatial "wavelength"

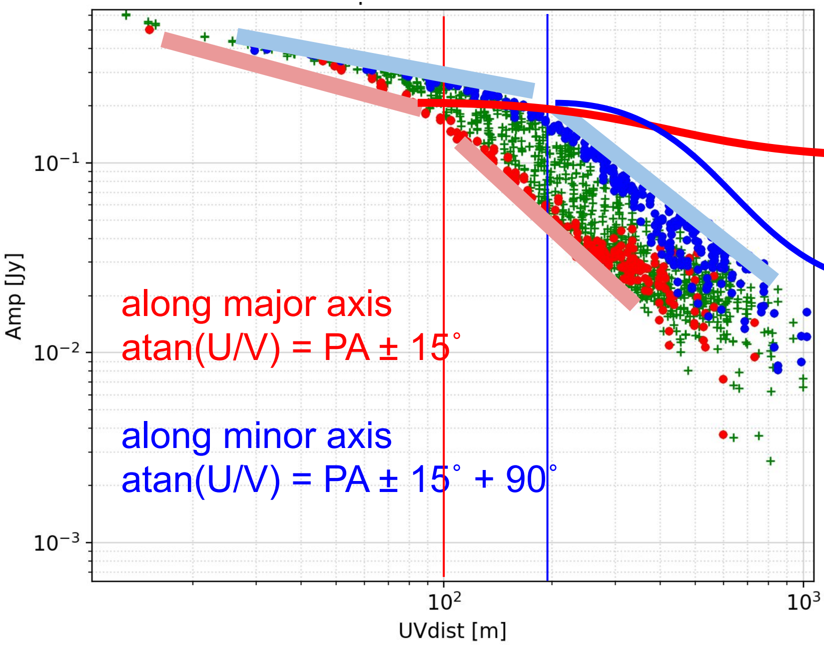
$$\lambda = \frac{1}{u} = \frac{\lambda_{\rm obs}}{\rm Baseline} = \frac{c}{\nu_{\rm obs}\,{\rm Baseline}}$$

Visibility Profile

in image domain

Large scale

Small scale



Knee at

UVdist ~ 100 m
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spatial "wavelength"

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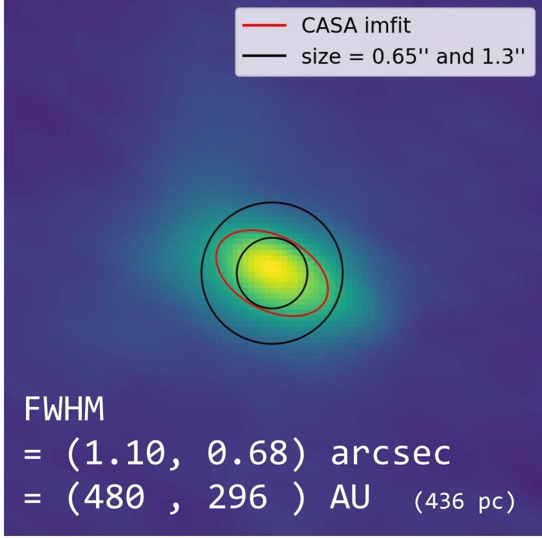
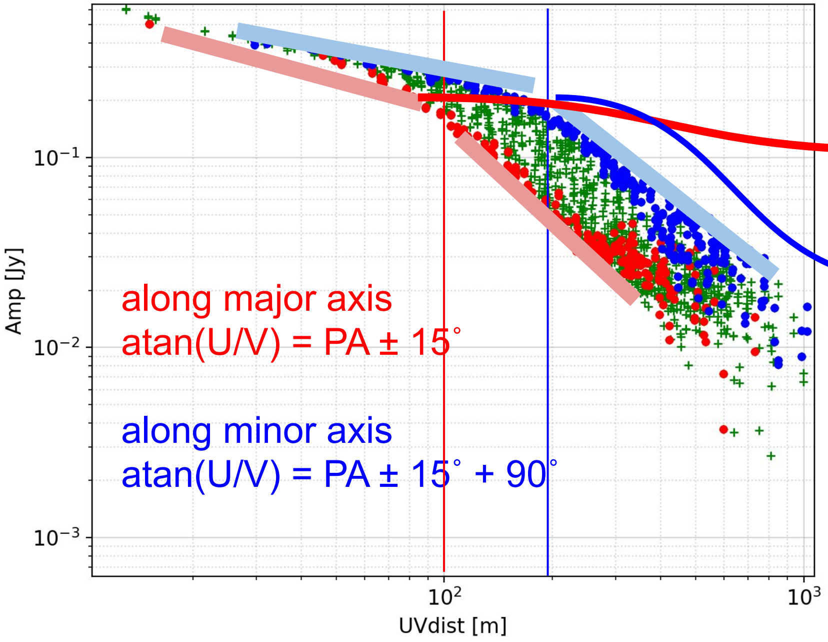


Visibility Profile

in image domain

Large scale

Small scale



Knee at

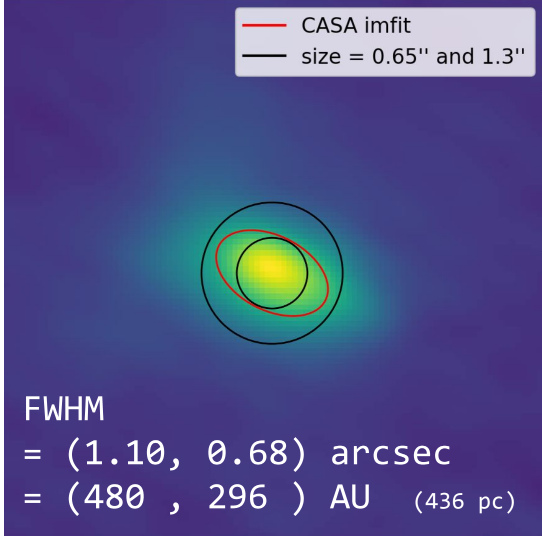
UVdist ~ 100 m
along major axis

UVdist ~ 200 m
along minor axis

1.3 arcsec

0.65 arcsec

~ellipse FWHM

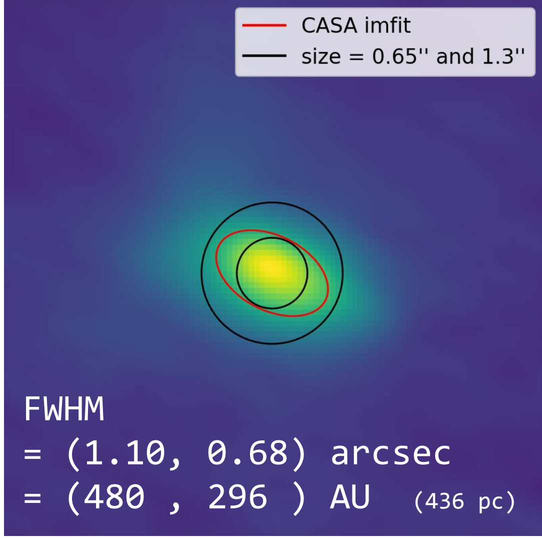


spatial “wavelength”

$$\lambda = \frac{1}{u} = \frac{\lambda_{\rm obs}}{\rm Baseline} = \frac{c}{\nu_{\rm obs}\,{\rm Baseline}}$$

Visibility Profile

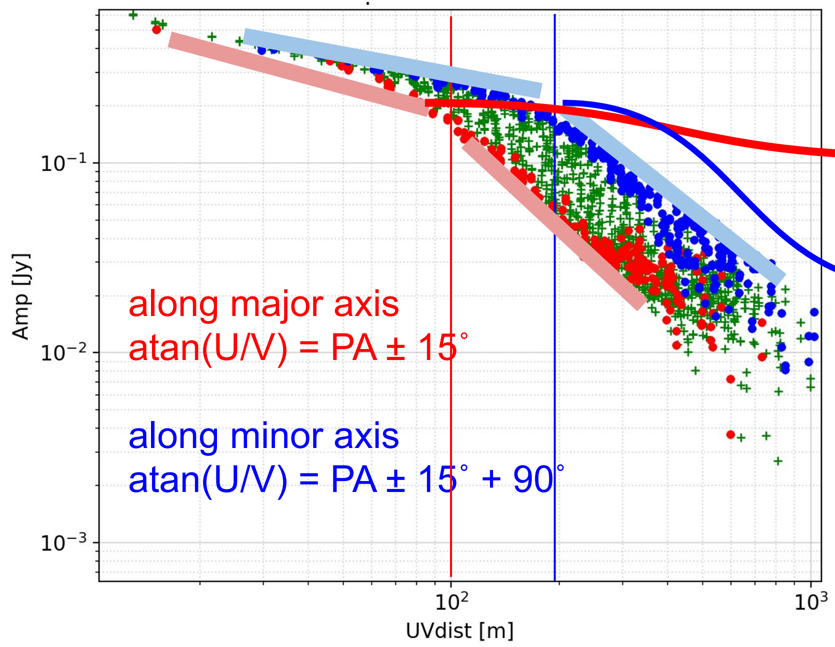
1. **Two-component**
   a. Optically thick center
   b. Optically thin envelope
2. **boundary ~ FWHM (>200 AU)**
3. **size > 200 AU: *evolved* class 0**



in image domain

Large scale

Small scale



Knee at

UVdist ~ 100 m along major axis → **1.3 arcsec**

UVdist ~ 200 m along minor axis → **0.65 arcsec**

~ellipse FWHM

spatial "wavelength"

$$\lambda = \frac{1}{u} = \frac{\lambda_{\rm obs}}{\rm Baseline} = \frac{c}{\nu_{\rm obs}\,{\rm Baseline}}$$

Kinematics of SMM3

Seulgi Kim

Components of YSOs

According to kinematic model of YSOs,

infalling gas, disk, outflows

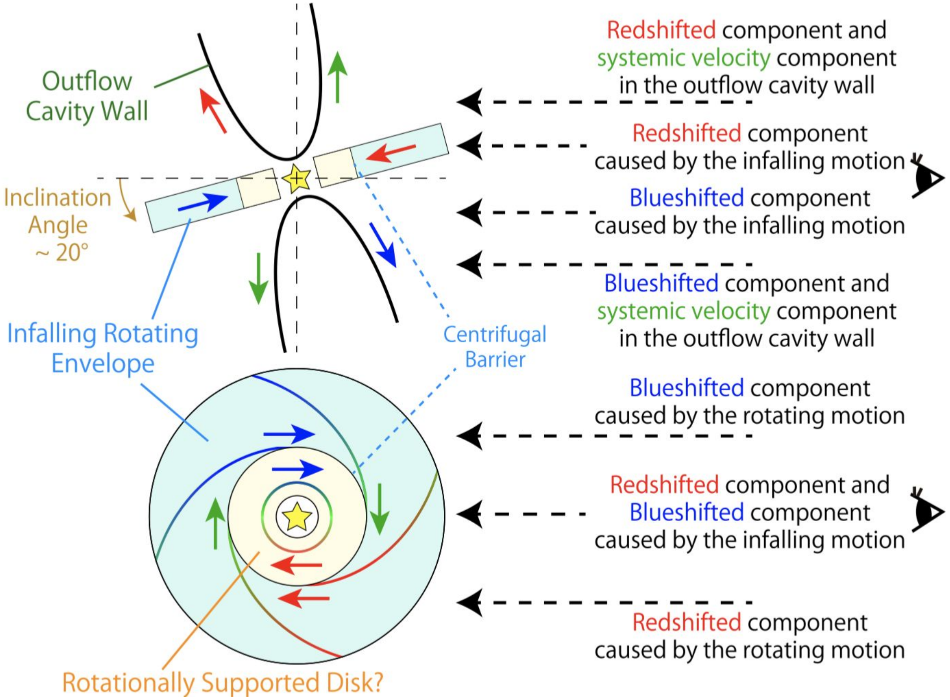
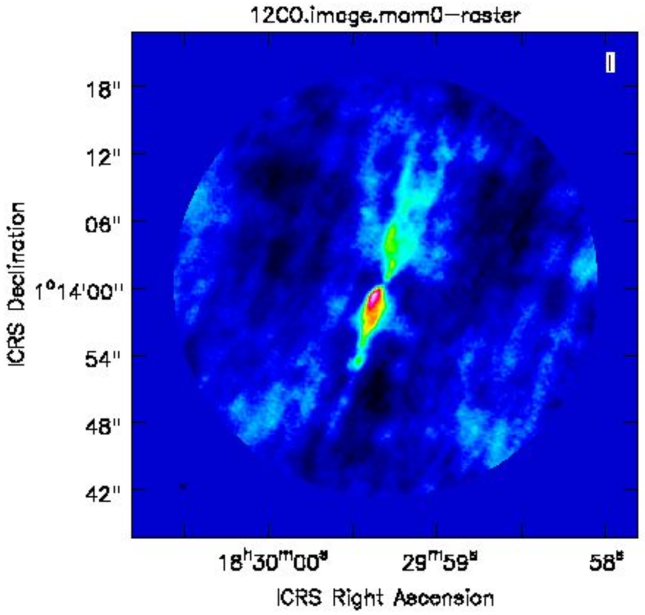


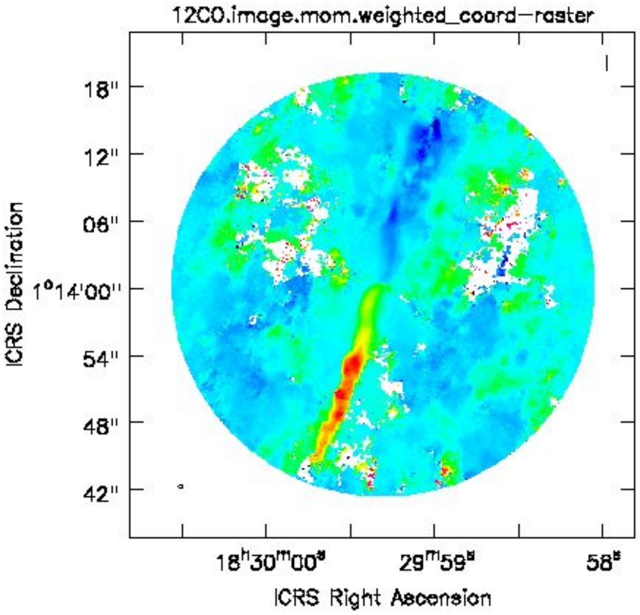
Figure adopted from OyaY+2014, ApJ, 795, 152

Outflows

^{12}CO moment 0 map



^{12}CO moment 1 map



strongly collimated

dynamical time ~ 1000 yr, older than other Class 0s

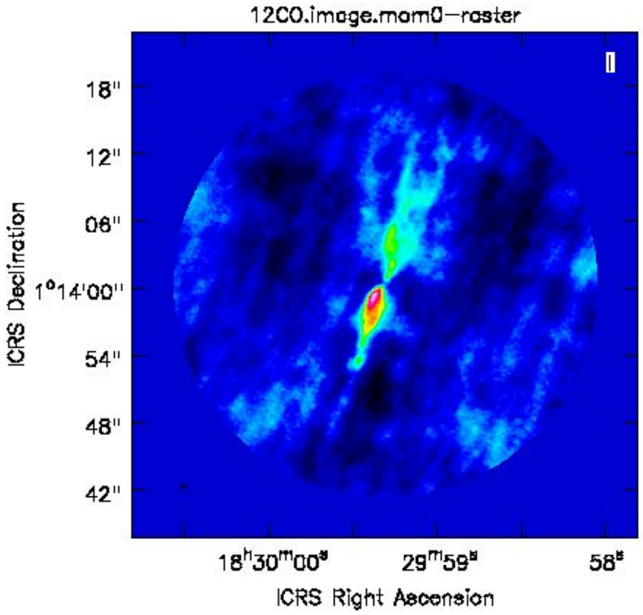
$$t_{dy} = \frac{d}{v}$$

d_{proj}~10”, rv=34 km/s

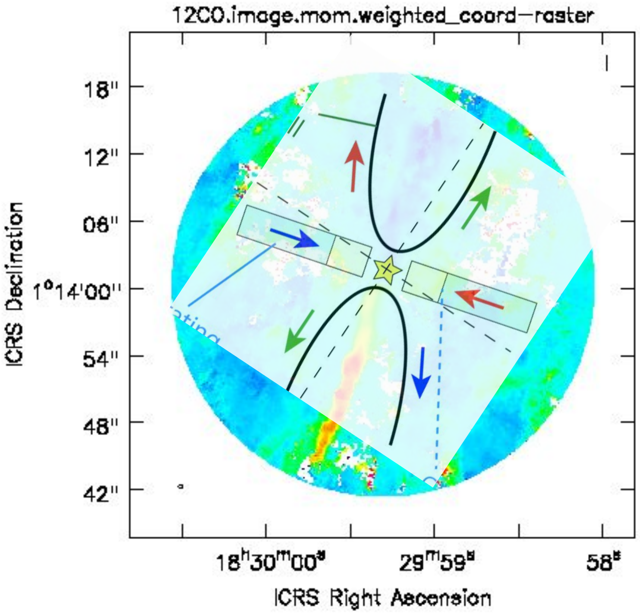
$$d = d_{proj}/\cos i,\ v = rv/\sin i$$

Outflows

^{12}CO moment 0 map



^{12}CO moment 1 map



strongly collimated

dynamical time ~ 1000 yr, older than other Class 0s

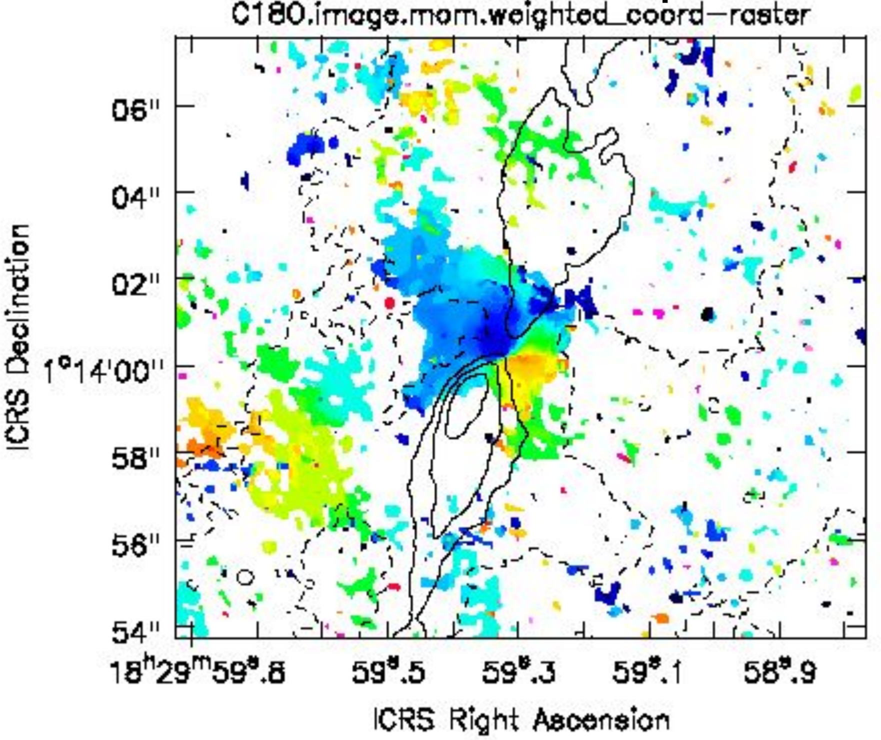
$$t_{dy} = \frac{d}{v}$$

d_{proj}~10”, rv=34 km/s

$$d = d_{proj}/\cos i,\ v = rv/\sin i$$

Rotating materials

$C^{18}O$ moment 1 map



perpendicular to outflow > presence of disk

distribution of $C^{18}O$ is extended along with disk > relatively old

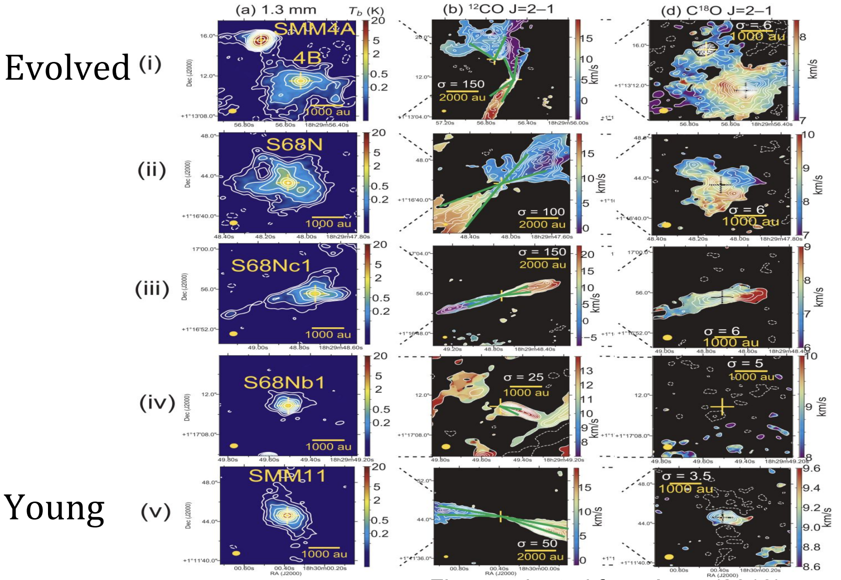
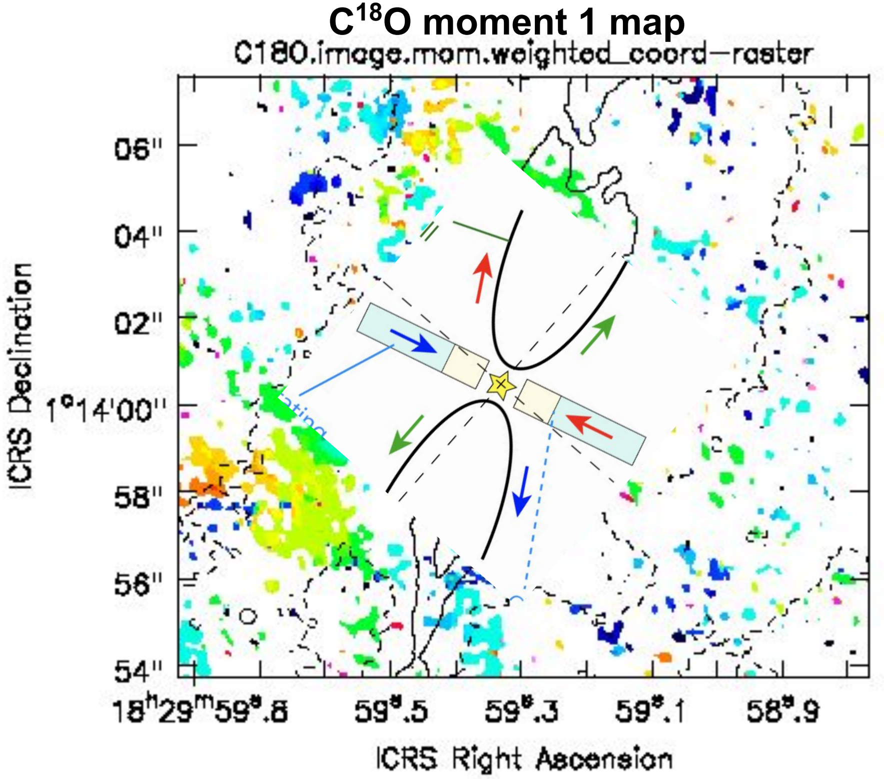


Figure adopted from Aso+ (2019)

Rotating materials



perpendicular to outflow > presence of disk

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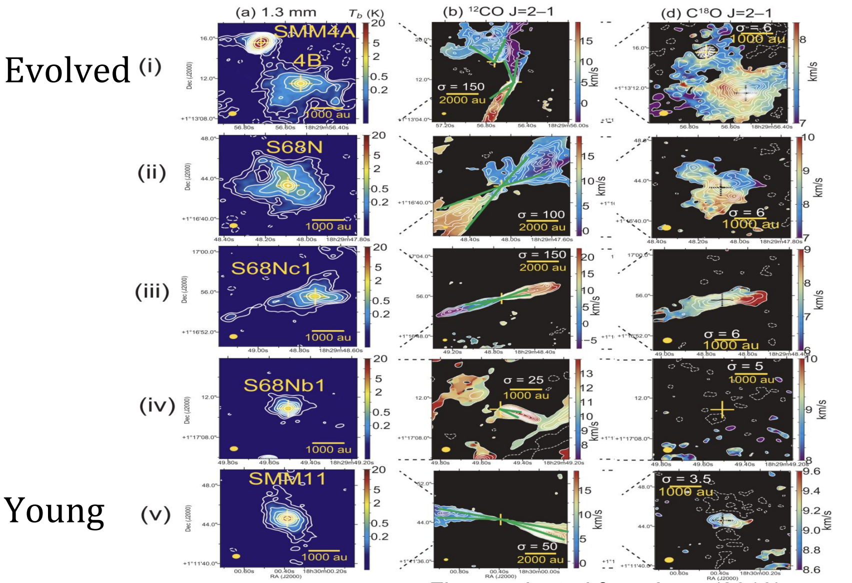
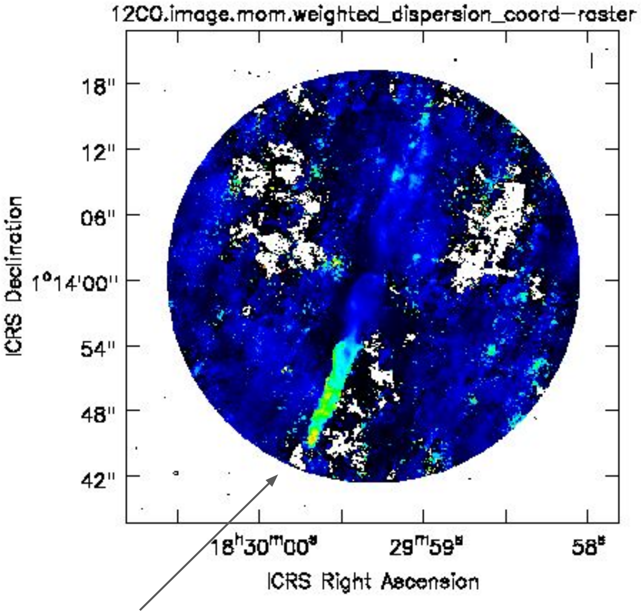


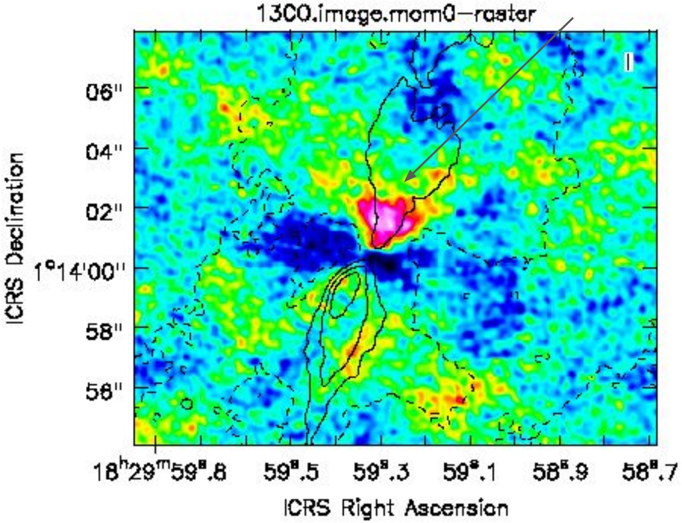
Figure adopted from Aso+ (2019)

Asymmetry of outflows

^{12}CO moment 2 map



^{13}CO moment 0 map



northern -

scattered in ^{12}CO

bright in ^{13}CO

southern -

bright in ^{12}CO

↑ velocity dispersion in ^{12}CO

$C^{18}O$ and ^{13}CO Abundance in SMM3

Ilseung Han

Continuum image

$$I_\nu = (B_\nu(T_{dust}) - B_\nu(T_{CMB}))(1 - e^{-\tau})$$

$$\tau = \kappa\Sigma_{gas} = \kappa m_{H_2} N_{H_2}$$

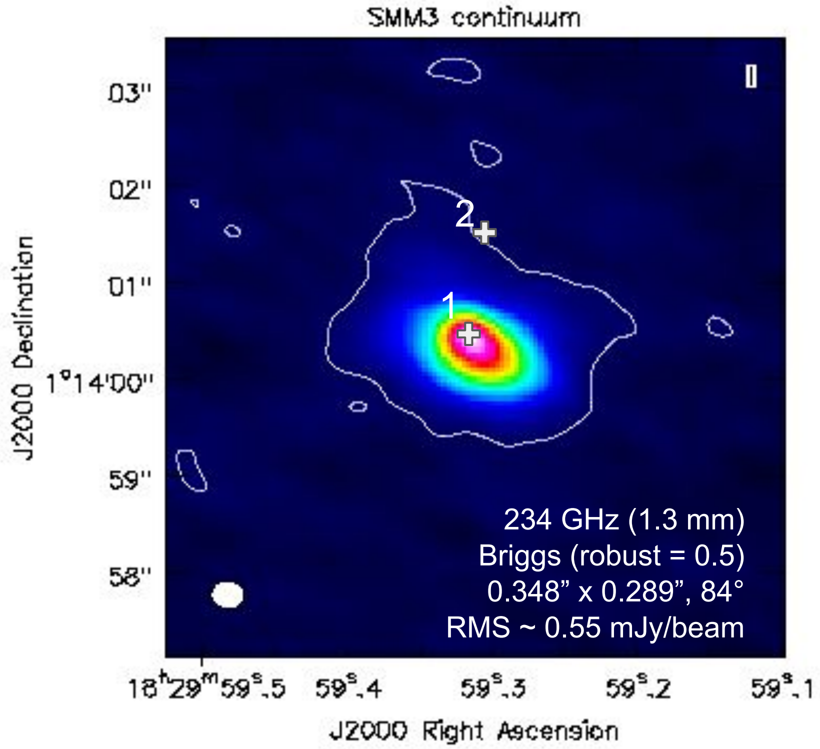
T_{dust} = 20 K (Lee+14), T_{CMB} = 2.7 K

opacity(κ) = 2.3 cm^2/g (Andrews&Williams05)

$I_{cont,\,1}$ = 50 mJy/beam, $I_{cont,\,2}$ = 1.5 mJy/beam

$\tau_{cont,\,1}$ = 1.4, $\tau_{cont,\,2}$ = 0.02

$N_{H2,\,1}$ = 1.8e+25 cm^{-2}, $N_{H2,\,2}$ = 2.9e+23 cm^{-2}



$C^{18}O$ moment 0 map

$$I_\nu = (B_\nu(T_{dust}) - B_\nu(T_{CMB}))(1 - e^{-\tau})$$

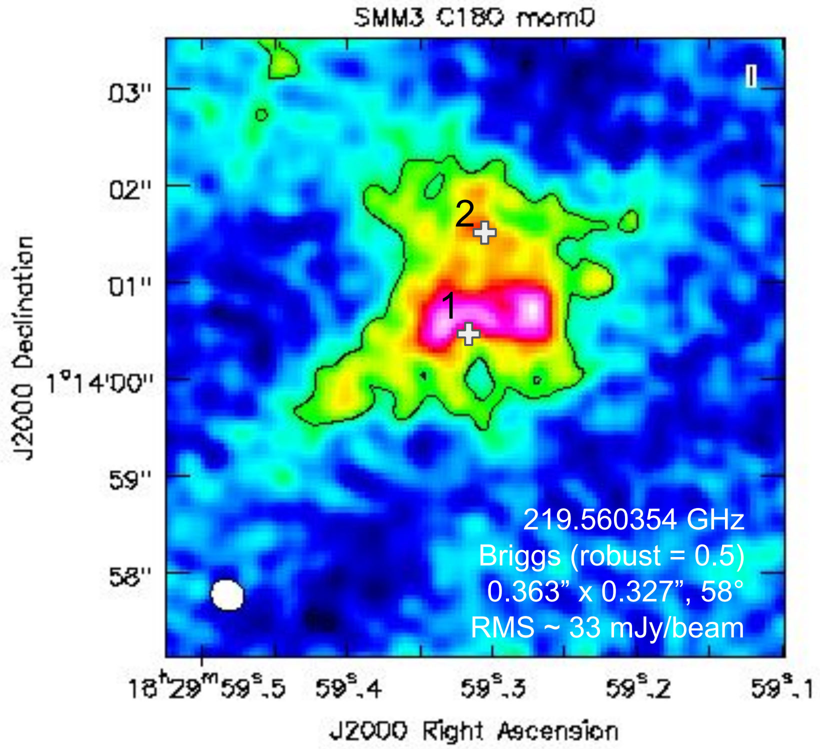
$$\tau = \frac{hc}{4\pi}\frac{A_{21}}{B_\nu(T_{gas})}\frac{g_2}{Z}e^{-\frac{E_2}{k_B T}}\frac{N}{\Delta\nu}$$

$T_{dust} = T_{gas}$ = 20 K, LAMDA: A_{21}, g_2, Z, E_2, ...

$I_{C18O,1}$ = 37.5 mJy/beam km/s

$I_{C18O,2}$ = 44 mJy/beam km/s

$N_{C18O,1}$ = 4.7e+15 cm^{-2}; $N_{C18O,2}$ = 5.6e+15 cm^{-2}



^{13}CO moment 0 map

$$I_\nu = (B_\nu(T_{dust}) - B_\nu(T_{CMB}))(1 - e^{-\tau})$$

$$\tau = \frac{hc}{4\pi}\frac{A_{21}}{B_\nu(T_{gas})}\frac{g_2}{Z}e^{-\frac{E_2}{k_B T}}\frac{N}{\Delta v}$$

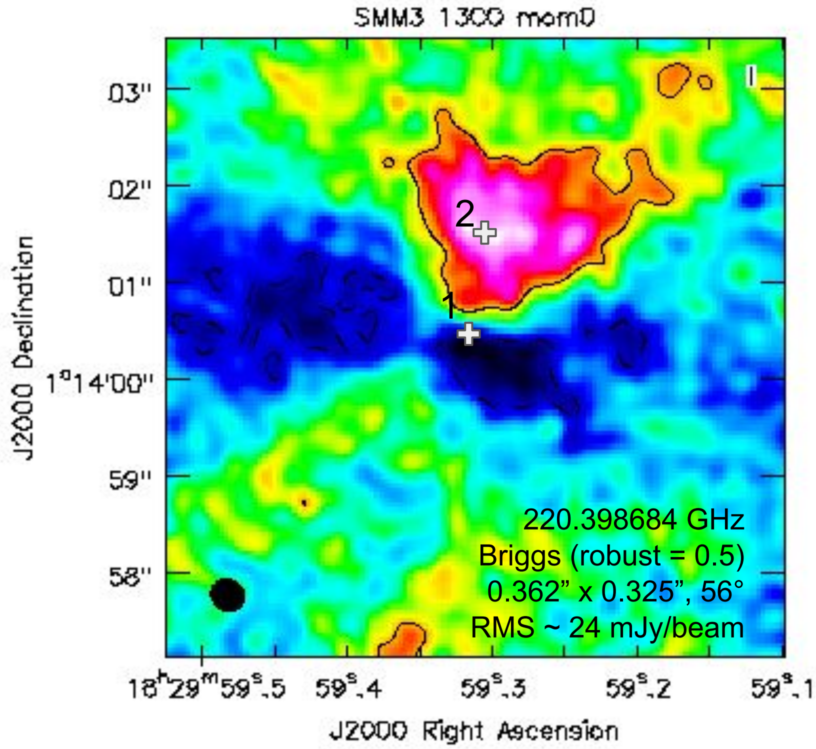
$T_{dust} = T_{gas} = 20$ K

$I_{C18O,\,1} = -120$ mJy/beam km/s

(affected by absorption)

$I_{C18O,\,2} = 171$ mJy/beam km/s

$\mathbf{N_{C18O,\,2} = 2.2e{+}16\ cm^{-2}}$



Abundance (or 2 slides)

X_C18O

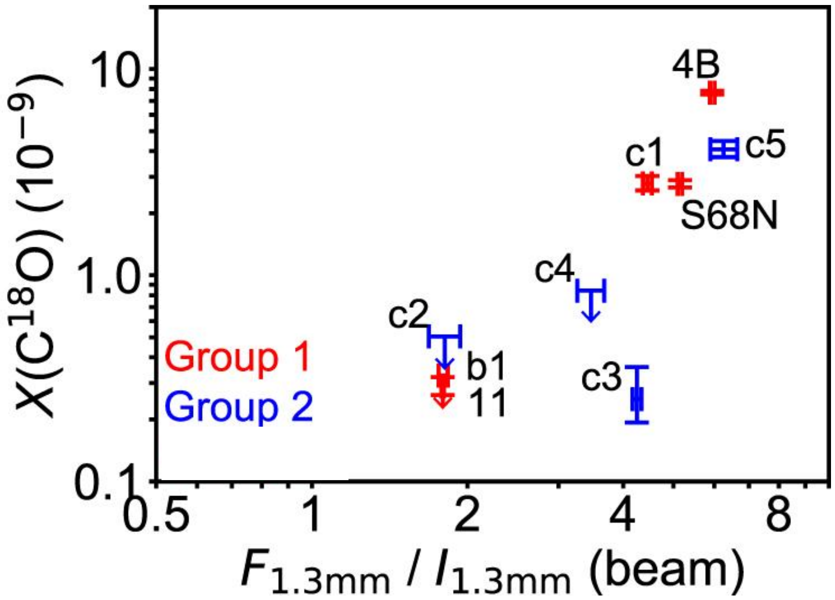


Figure adopted from AsoY+2019, ApJ, 887, 209

X_13CO / X_C18O

$C^{18}O$ abundance at point 2

F_{cont} = 280 mJy; $I_{cont,\,2}$ = 50 mJy/beam

F/I = 5.6

X_{C18O} = 1.9e-08

cf. $<X_{C18O}>$ = 1.9e-08 (Duarte-Cabral+10)

mean abundance in Serpens Main

Older Class 0 in Serpens Main

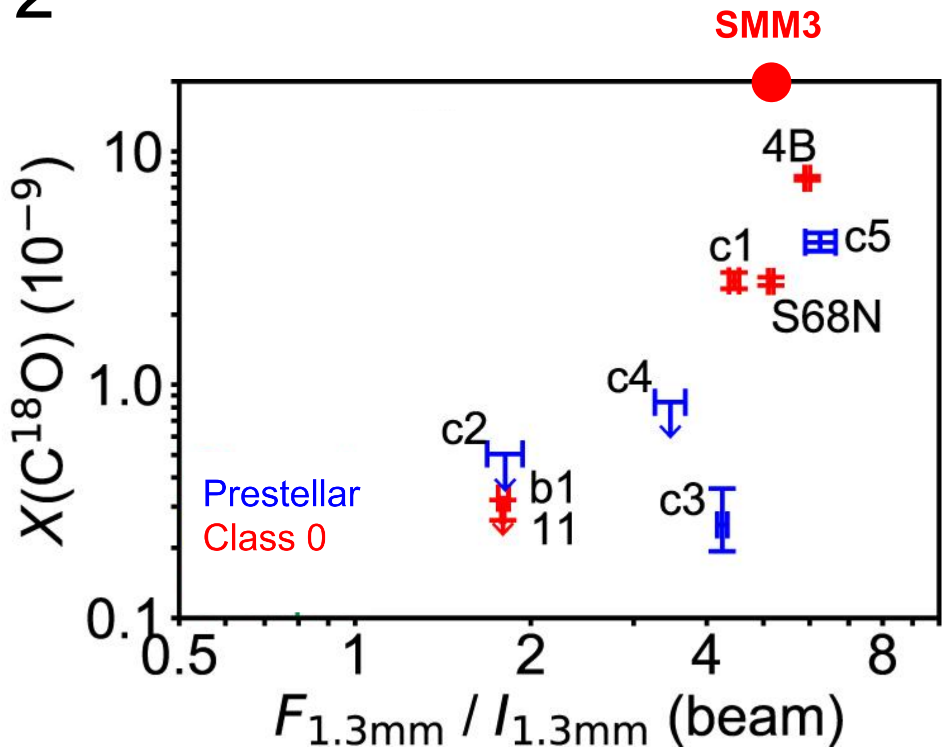


Figure adopted from Aso+19

X_{13CO} / X_{C18O} at Point 2

X_{C18O} = 1.9e-08

X_{13CO} = 7.6e-08: the first result in Serpens Main

X_{13CO} / X_{C18O} = 4.0

cf. X_{13CO} / X_{C18O} = 7.3 in ISM (Wilson&Rood94)

We suggest that

"**X_{13CO} / X_{C18O} is nearly constant regardless of the evolutionary stage**"

because the difference between SMM3 and ISM is less than a factor of 2.

Summary and future work

Summary: SMM3, evolved among Class 0

- 2-components (opt. thick center & thin envelope) in continuum large disk
- Outflow dynamical time $\tau_{\mathrm{dyn}} \sim 1$ kyr evolved outflow
- X_{C18O} similar to X_{C18O} of large scale in Serpens Main evolved chemically
- $\mathrm{X}_{\mathrm{13CO}}$ / $\mathrm{X}_{\mathrm{C18O}}$ is nearly constant regardless of the evolutionary stage.

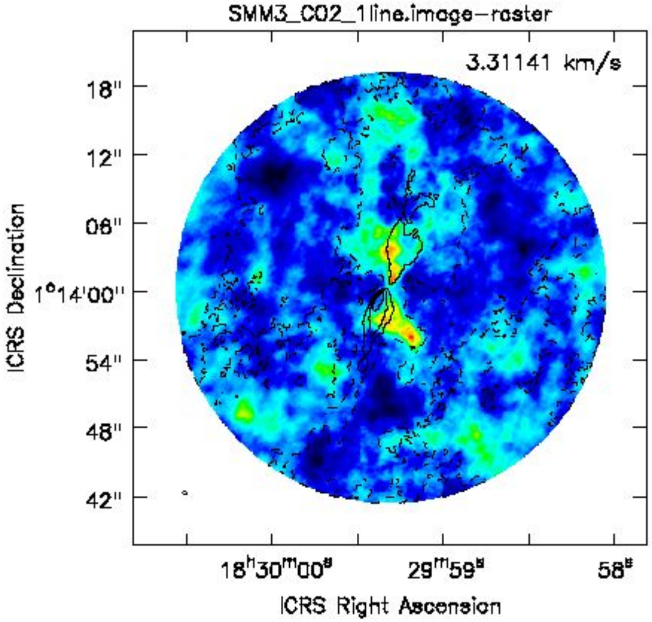
Future work

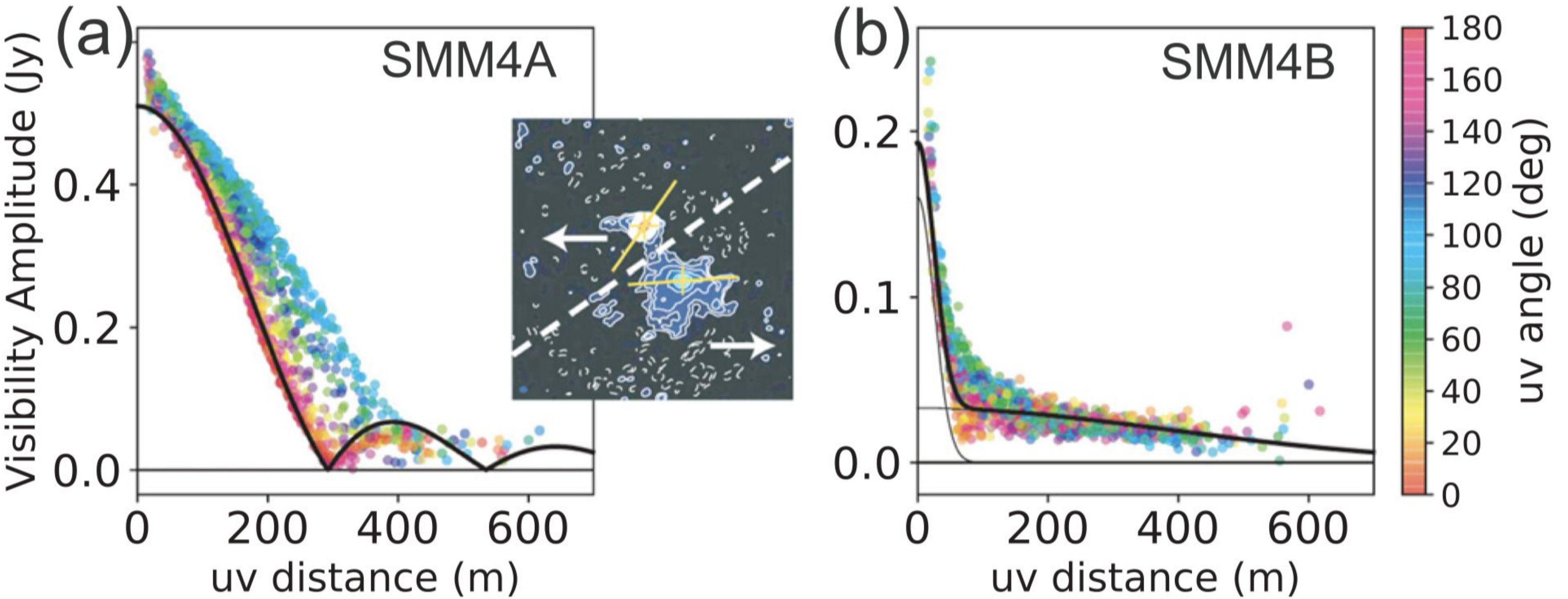
- PV diagram for accretion disk (Keplerian → mass?)
- Use 7m data (and combine 7m and 12m)

Supporting Materials

Additional component

^{12}CO rv = 3.3 km/s channal map




(a)
SMM4A
Visibility Amplitude (Jy)
0.0
0.2
0.4
0
200
400
600
uv distance (m)
(b)
SMM4B
0.0
0.1
0.2
0
200
400
600
uv distance (m)
uv angle (deg)
0
20
40
60
80
100
120
140
160
180

UVrange

Due to insufficient coverage of UV space at short baseline, we put uvrange >30m for tclean when using line data.