2017 UCAT SUMMER STUDENT PROGRAM FINAL PRESENTATION

Digging in the ALMA data archive: Magnetic Fields around protostars

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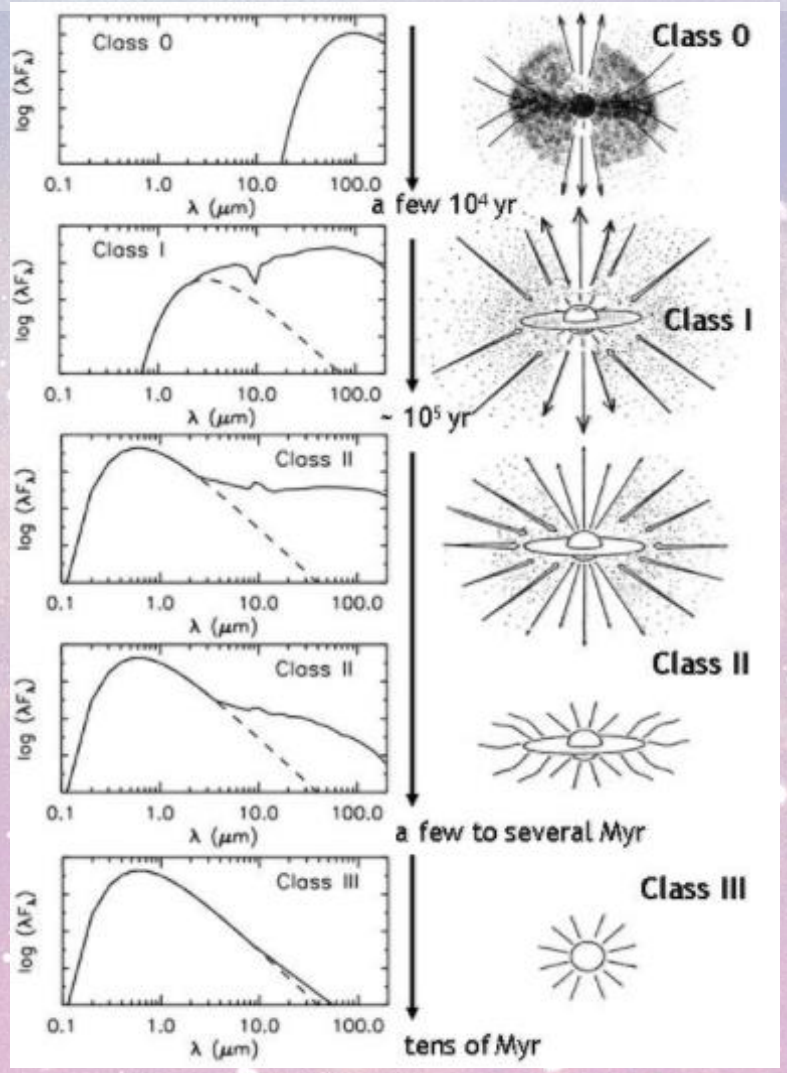
2017/08

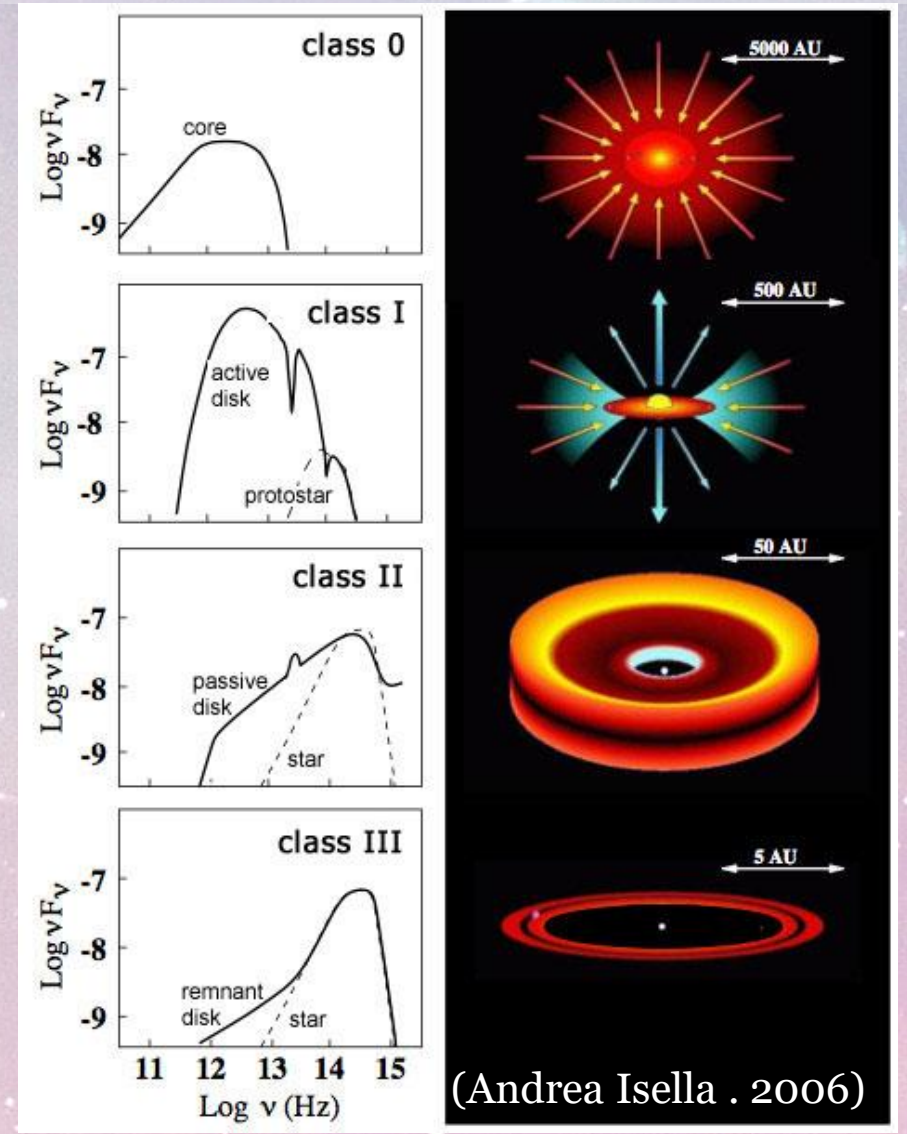
Outline

- Introduction
  - Protostar formation
- Works
  - Target
  - Moment maps
  - Polarization maps
- Conclusions

The formation of star

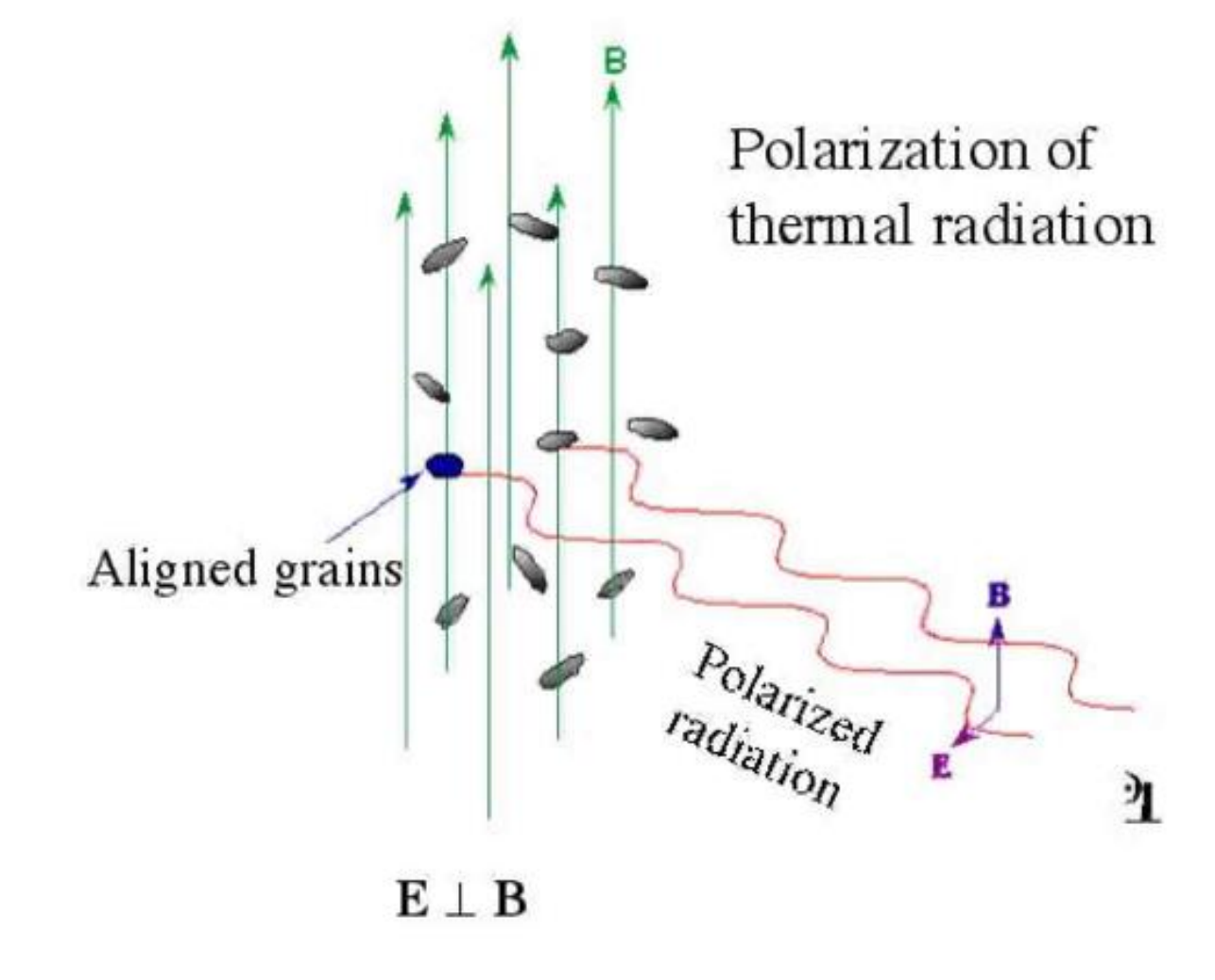


Evolution of Young Stellar Objects



- Class 0:
  - Youngest
  - Most embedded
- Class 1:
  - Starting to shed envelope
- Class 2:
  - Barely any emvelope left
- Class 3:
  - Tenuous disk left

Polarization

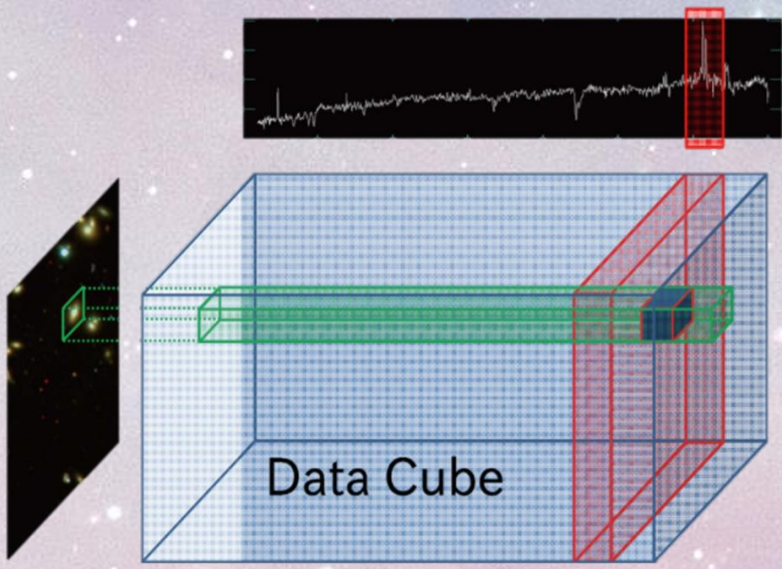


Polarization of radiation from a optically thin cloud of aligned dust grains.
The direction of polarization is perpendicular to the plane of the sky direction of magnetic field.

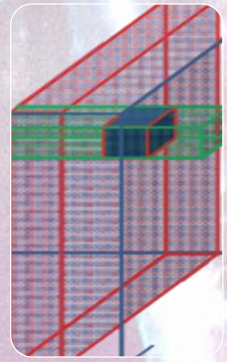
(http://bgandersson.net/the-long-and-the-short-of-itgrain-alignment)

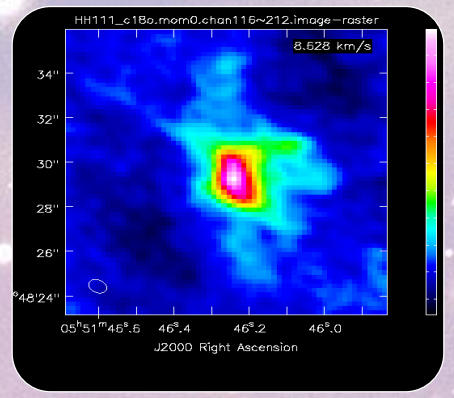
(https://inspirehep.net/record/801796/plots)

Analysis



(http://iopscience.iop.org/article/10.1086/671105)





Data cube

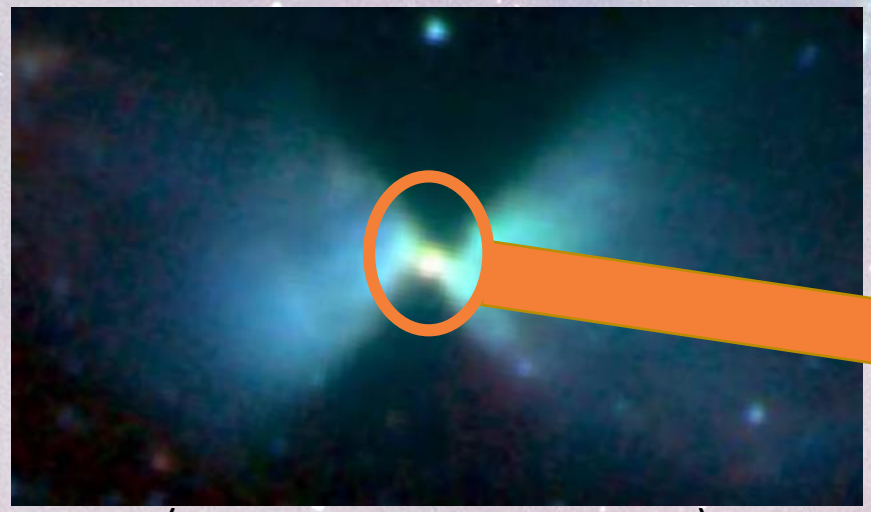
Select frequency range

Moment Map

targets

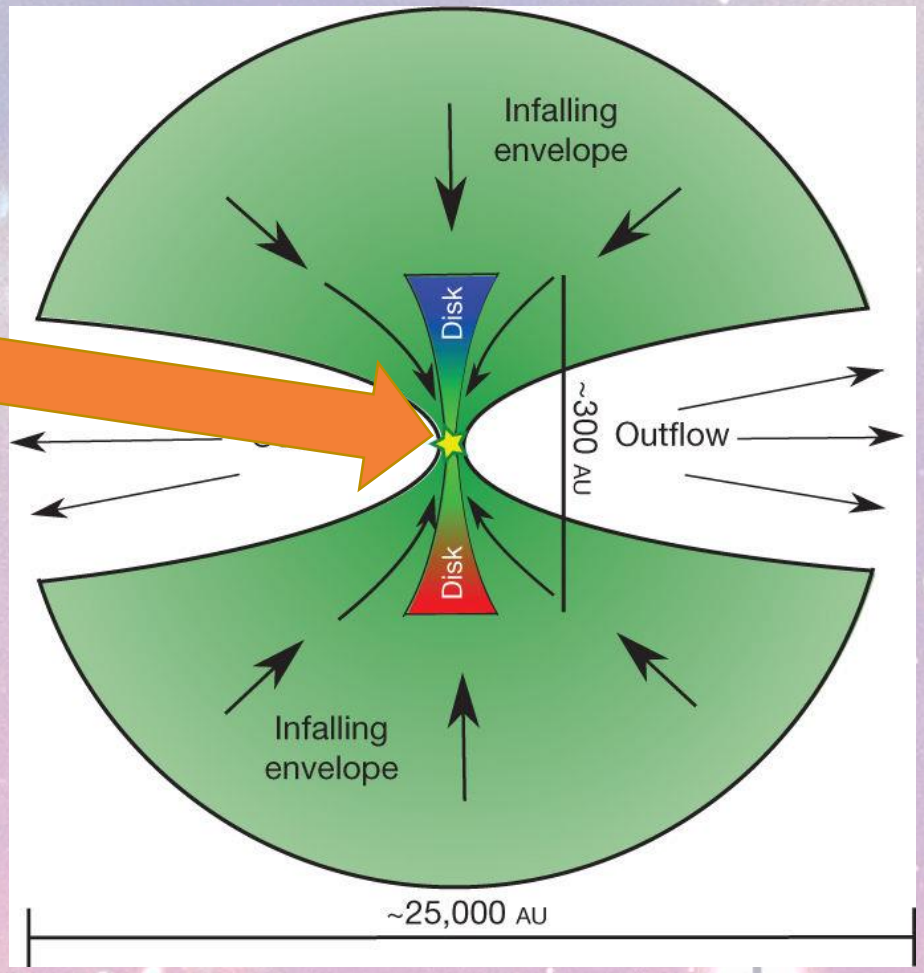
star	stage
L1527	Class I
HH111	Class I
TMC-1A	Class I
L1489 IRS	Class I
Serp_smm2	Class 0
Serp_smm11	Class 0
Serpens_Emb8	Class 0
Serpens_Emb8N	Class 0
Serpens_Emb6	Class 0
BHB07-01	Class 0
BHB07-11	Class I

L1527 protostellar system



(alma.mtk.nao.ac.jp/e/index.html)

Constellation	Taurus
Distance	~140pc
RA(J2000)	04h39m53*s*.9
Dec(J2000)	+26° 03’9’’.72
Stage	Class 0

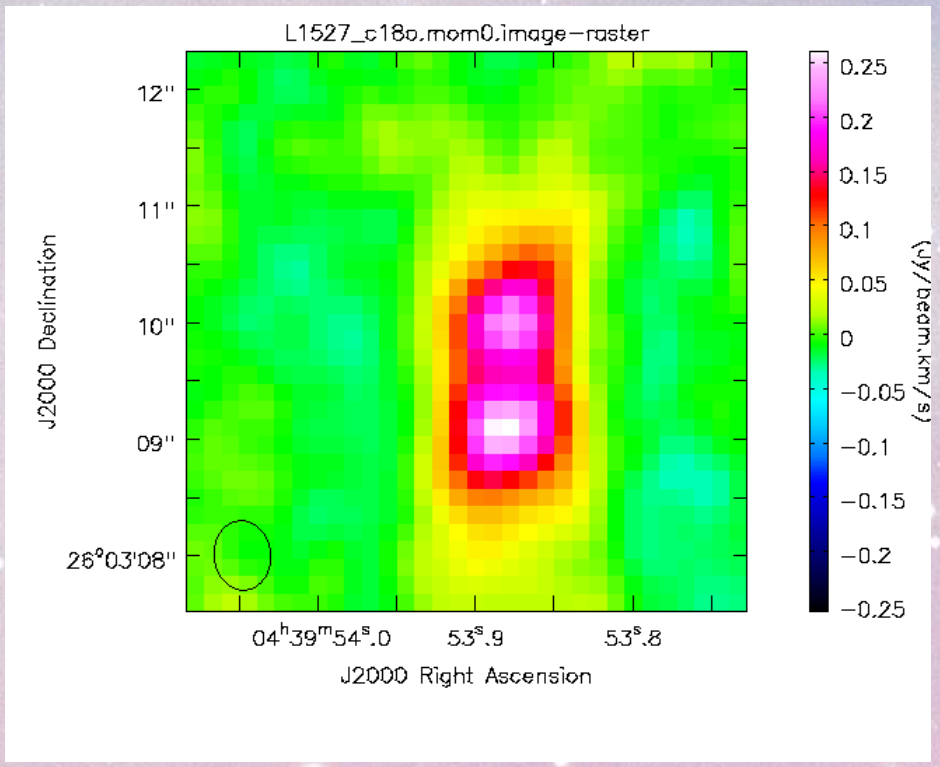


(Tobin et al .2012)

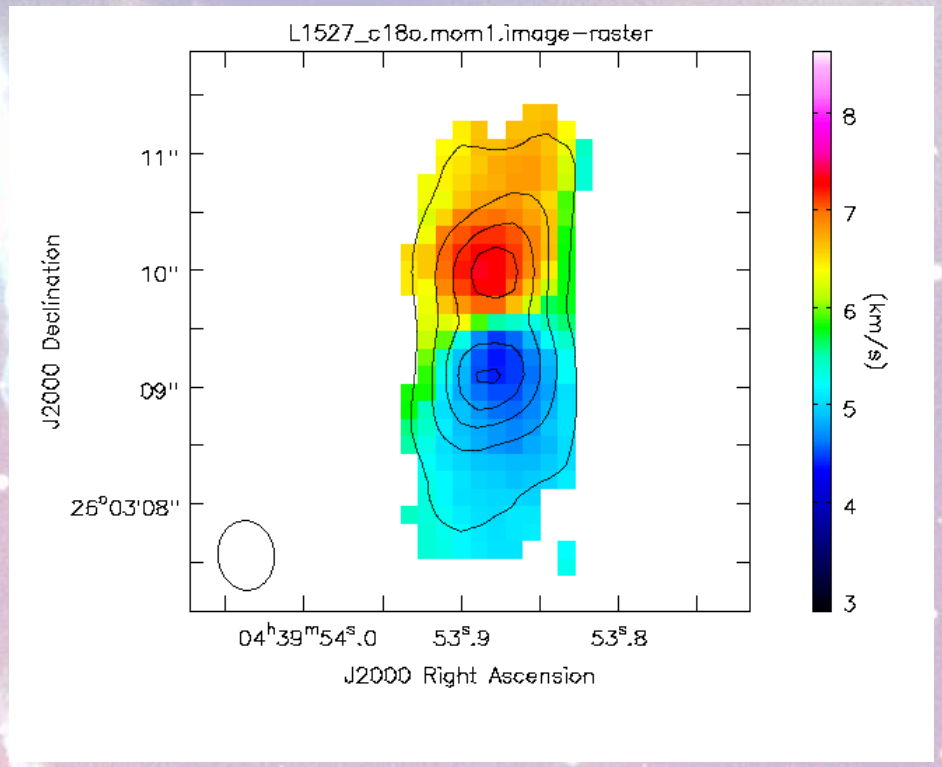
L1527 Moment Map of $C^{18}O(J = 2 - 1)$

Rest frequency=219.56035 GHz

ALMA Archive Band6
219.549 -- 219.560 GHz



Moment 0



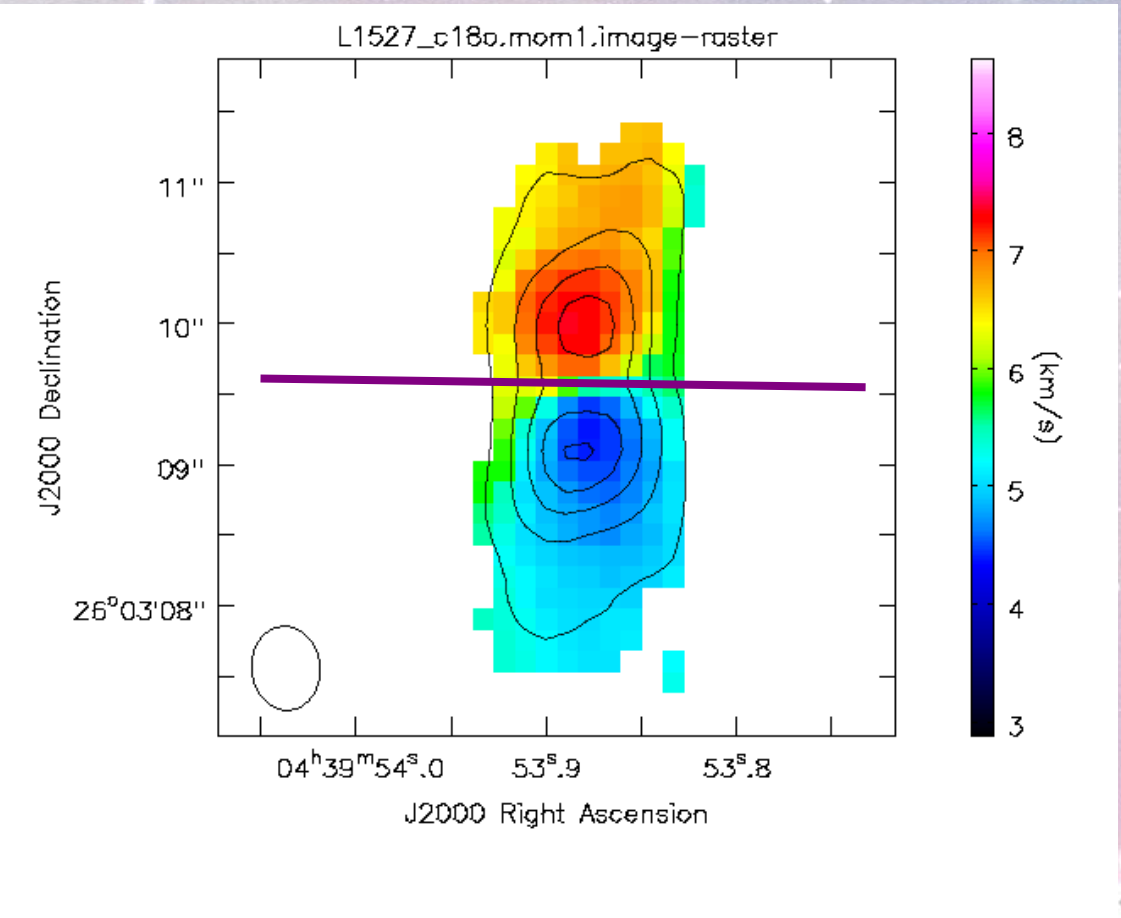
Moment 1

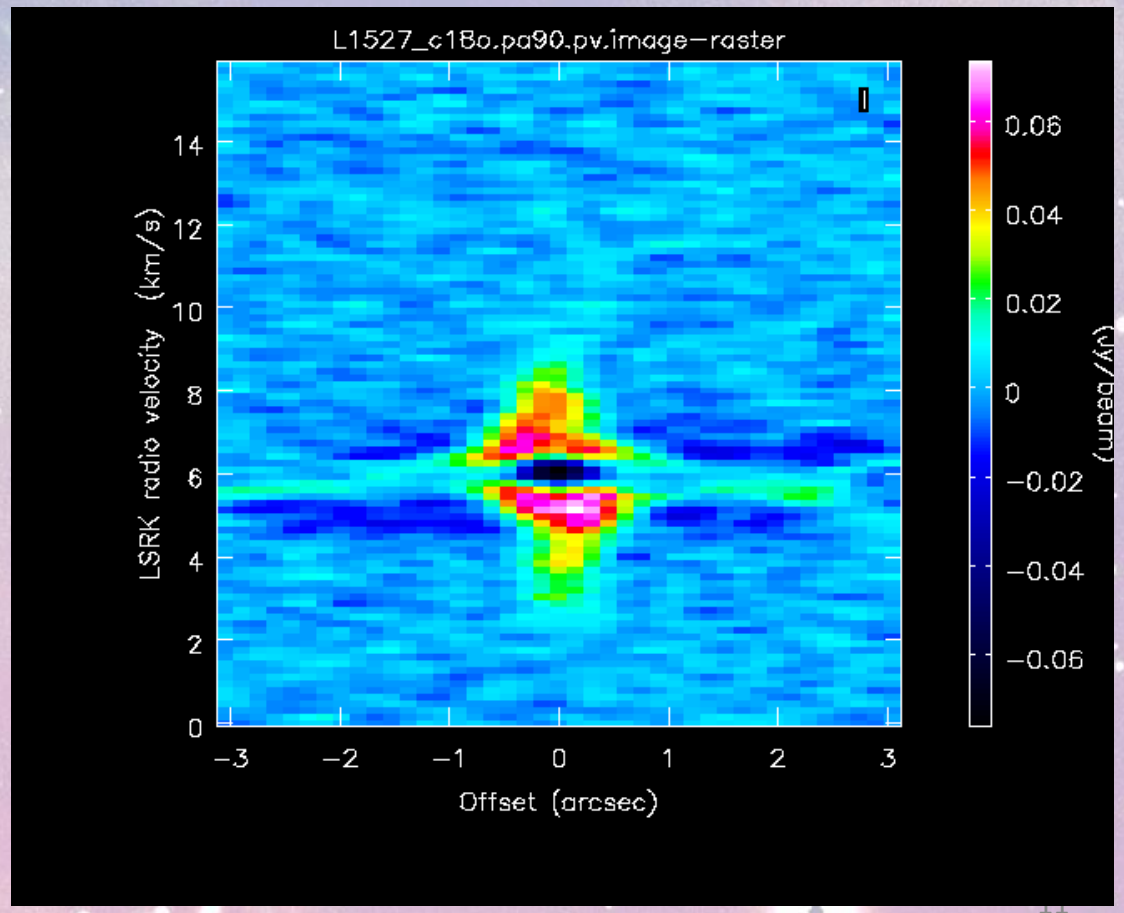
Position-Velocity diagram

http://www.appledaily.com.tw/appledaily/article/forum/20040713/1078943/

L1527 Position-Velocity diagram
$C^{18}O(J = 2 - 1)$

Minor axes(pa=90°)

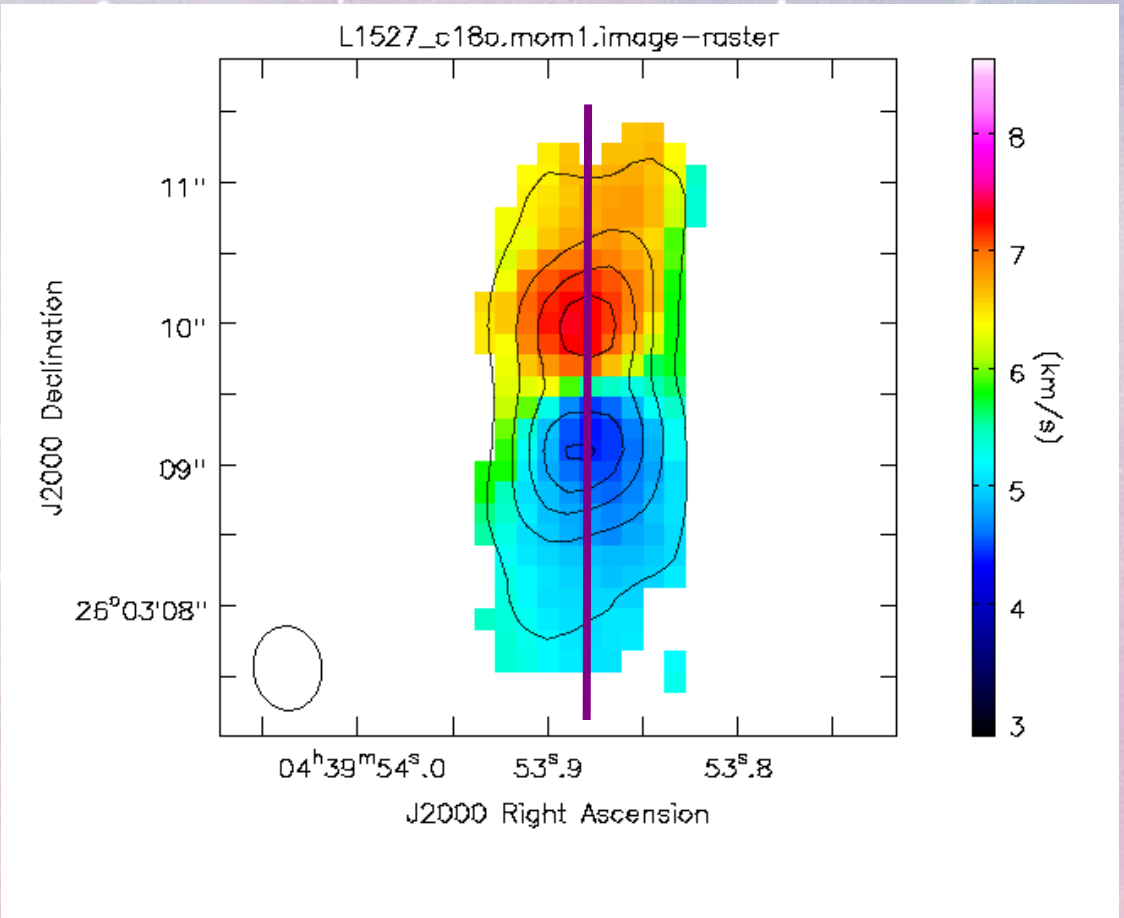


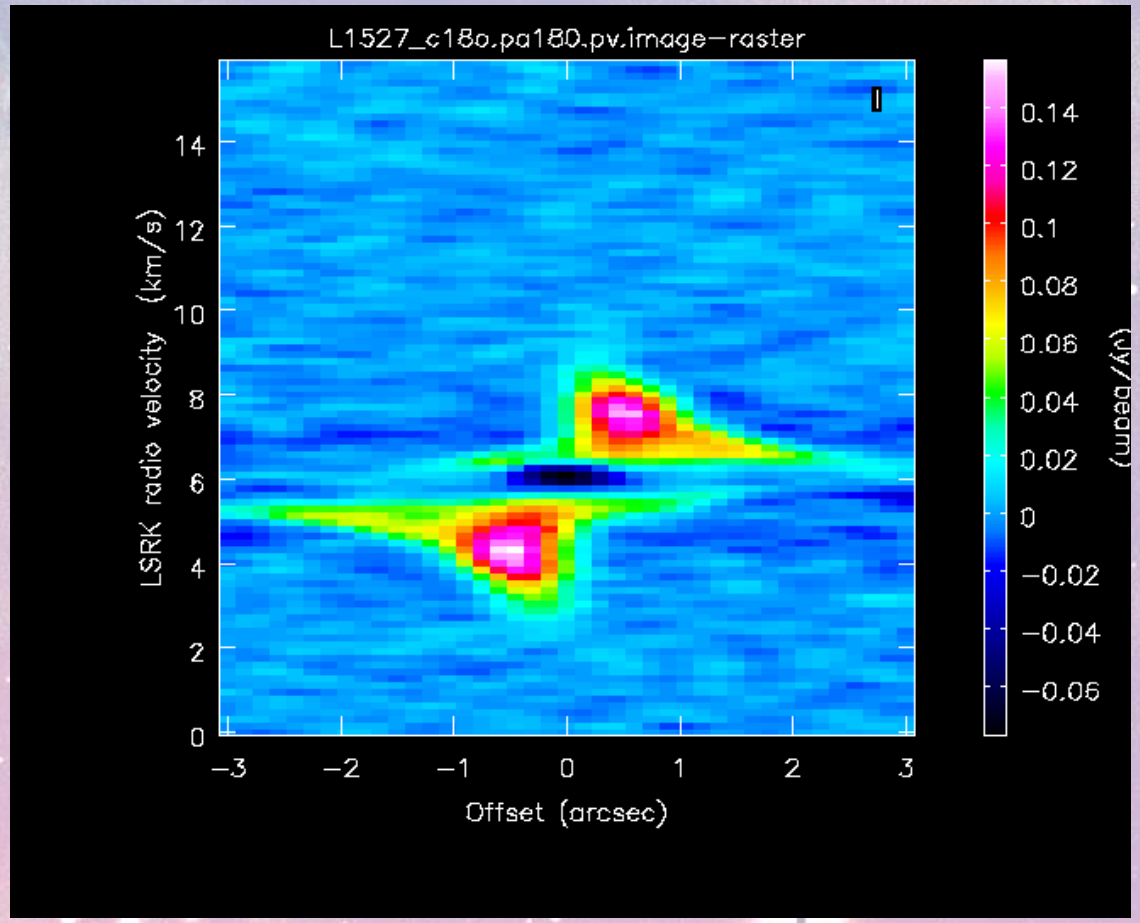


L1527 Position-Velocity diagram

$C^{18}O(J = 2 - 1)$

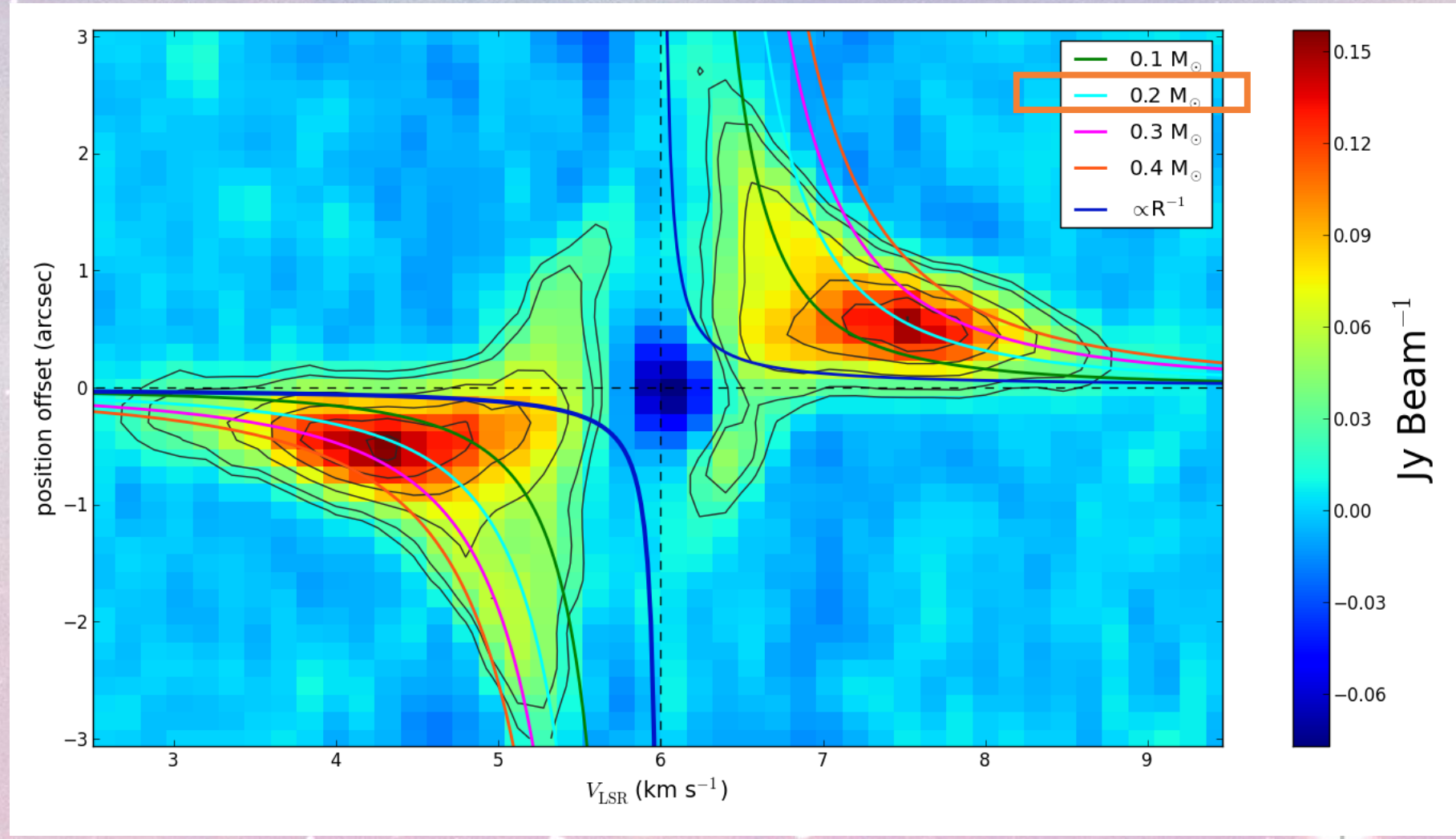
Major axes(pa=180°)





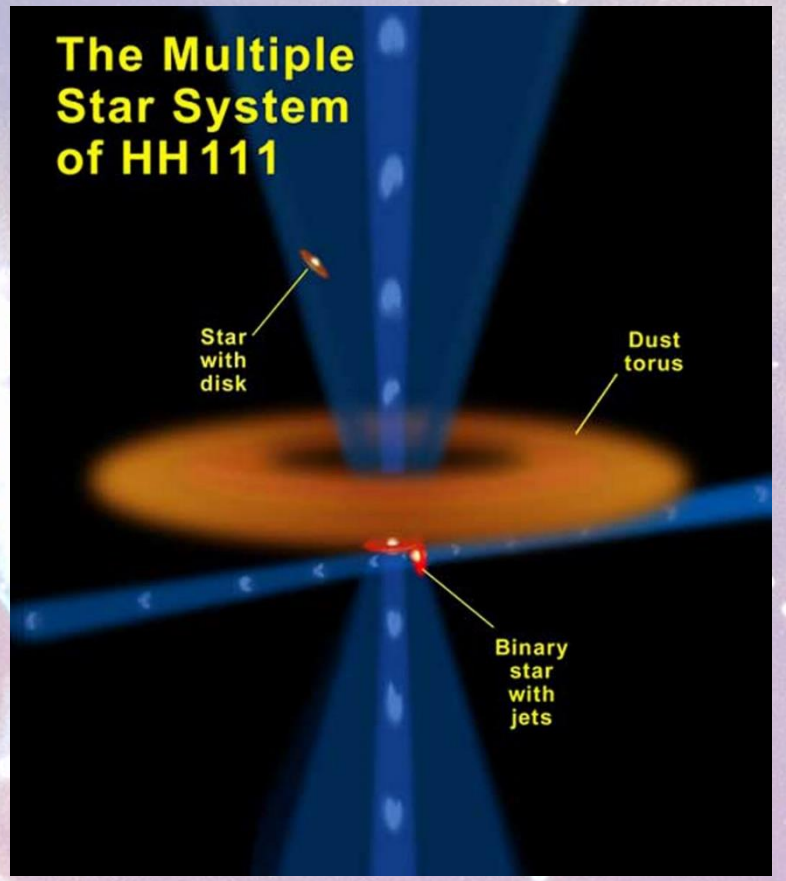
L1527 Position-Velocity diagram

$C^{18}O(J = 2 - 1)$



HH111 protostellar system

Constellation	Orion
Distance	~400pc
RA(J2000)	05h51m46s.254
Dec(J2000)	+02° 48’29’’.65
Stage	Class I

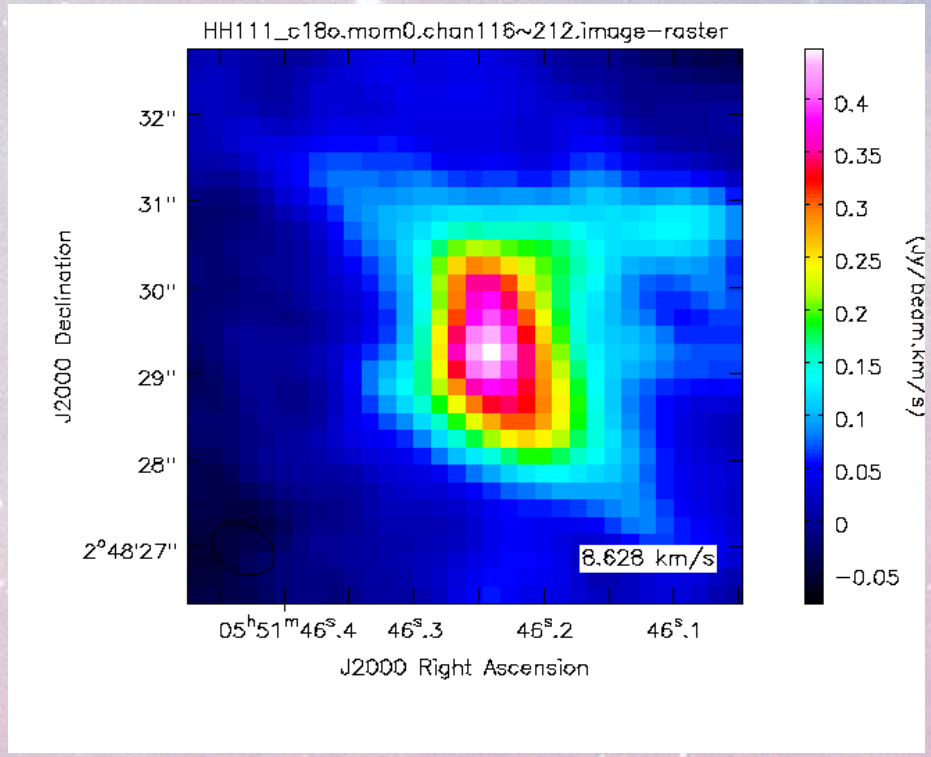


(https://www.spacetelescope.org/images/opo0005b/)

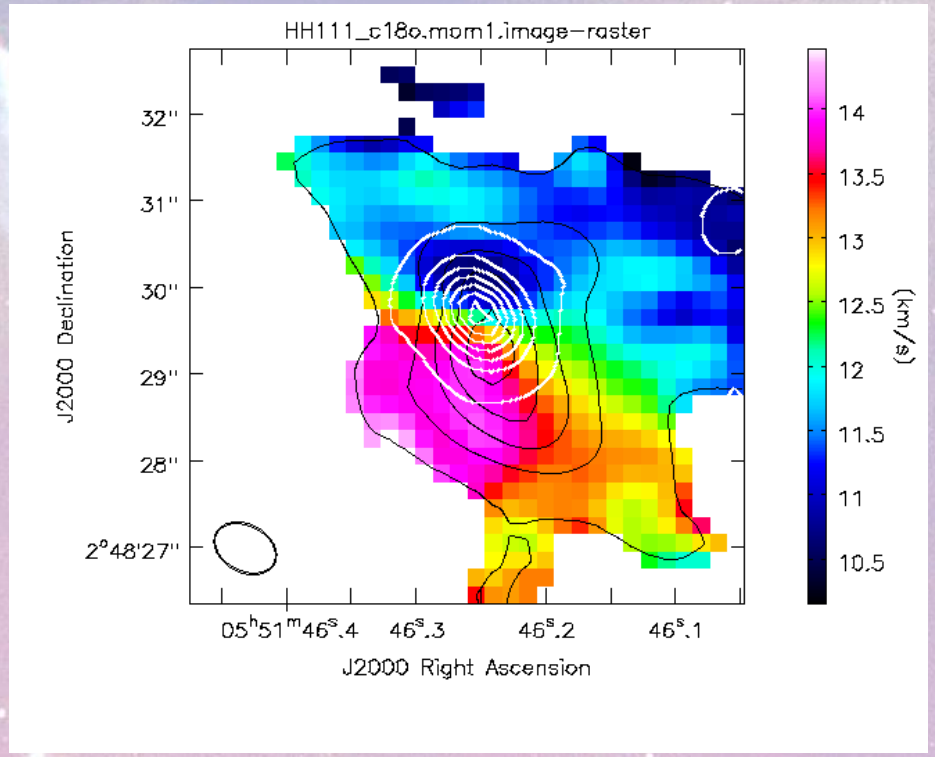
HH111 Moment Map
$C^{18}O(J = 2 - 1)$

ALMA Archive Band6

219.546 -- 219.561 GHZ

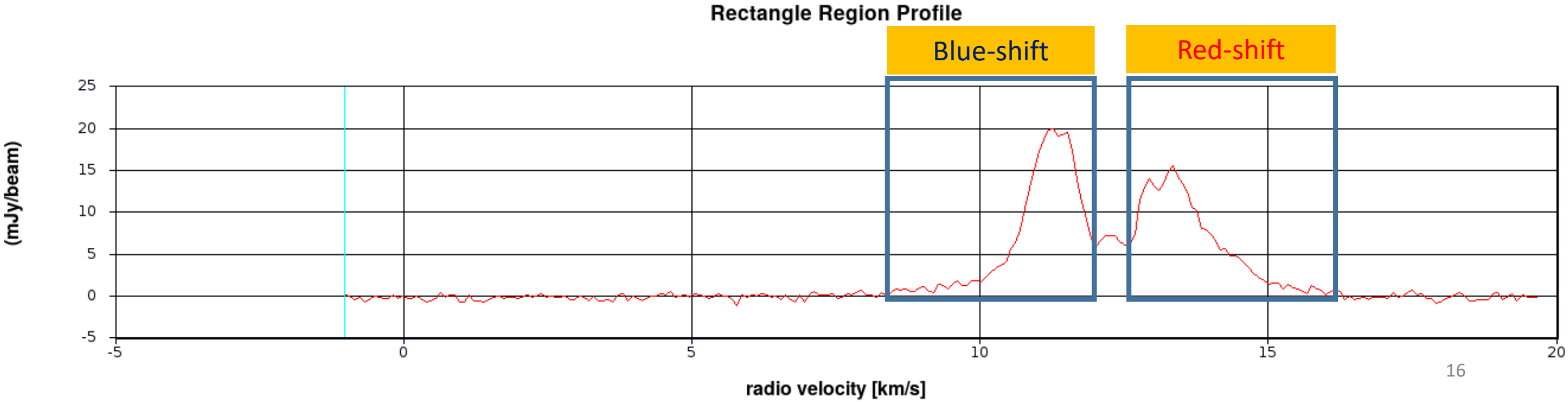


Moment 0



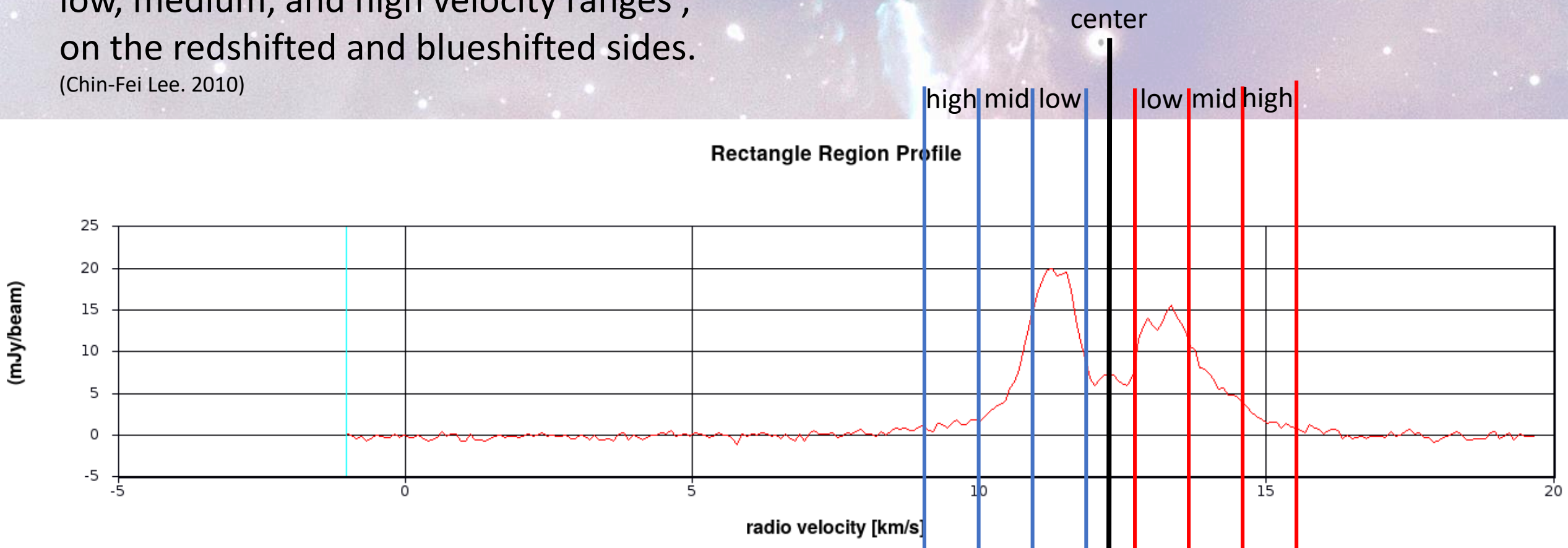
Moment 1

HH111 Spectral Profile



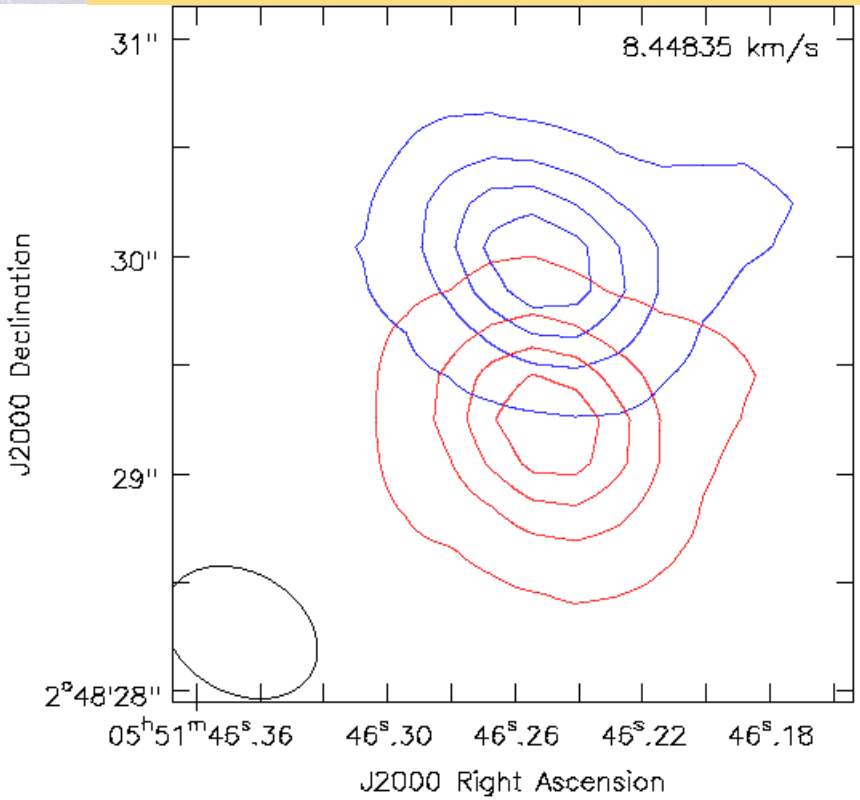
HH111 Disk and Envelope Structure

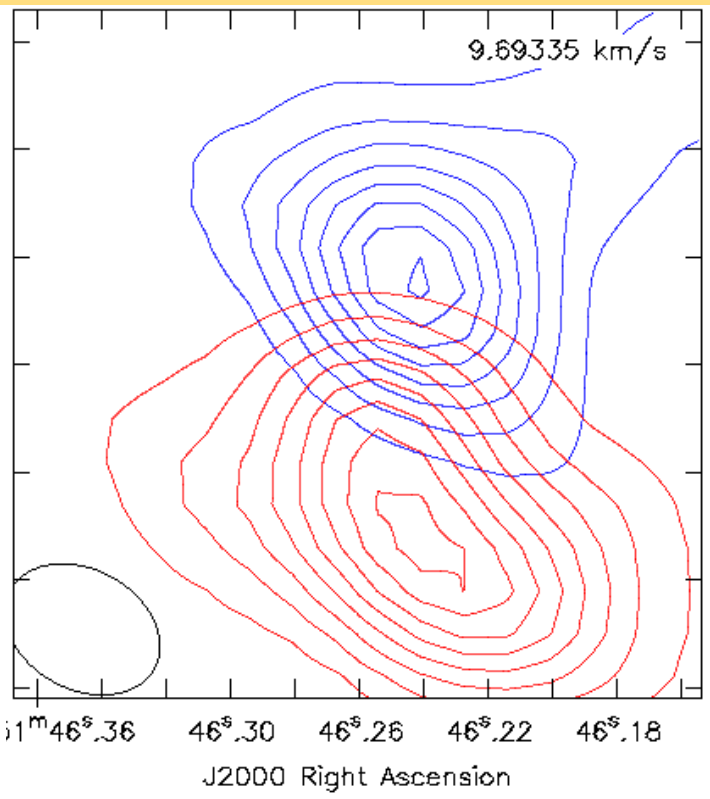
In order to see how the structure changes with velocity,
the line emission is divided into three ranges:
low, medium, and high velocity ranges ,
on the redshifted and blueshifted sides.
(Chin-Fei Lee. 2010)

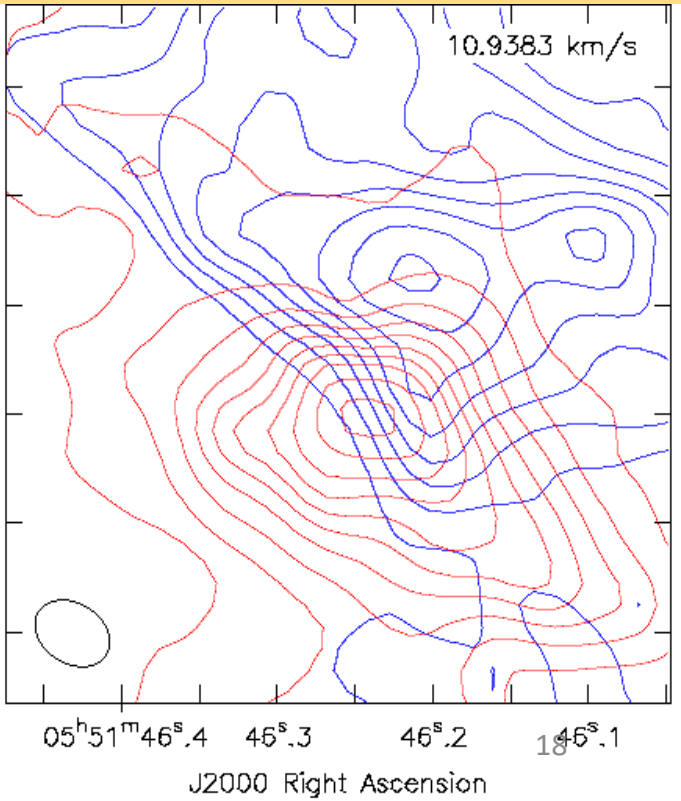


HH111 Disk and Envelope

High	Medium	Low
velocity=8.4~9.6 km/s velocity=15.0~16.2 km/s	velocity=9.6~10.9 km/s velocity=13.7~15.0 km/s	velocity=10.9~12.1 km/s velocity=12.5~13.7 km/s

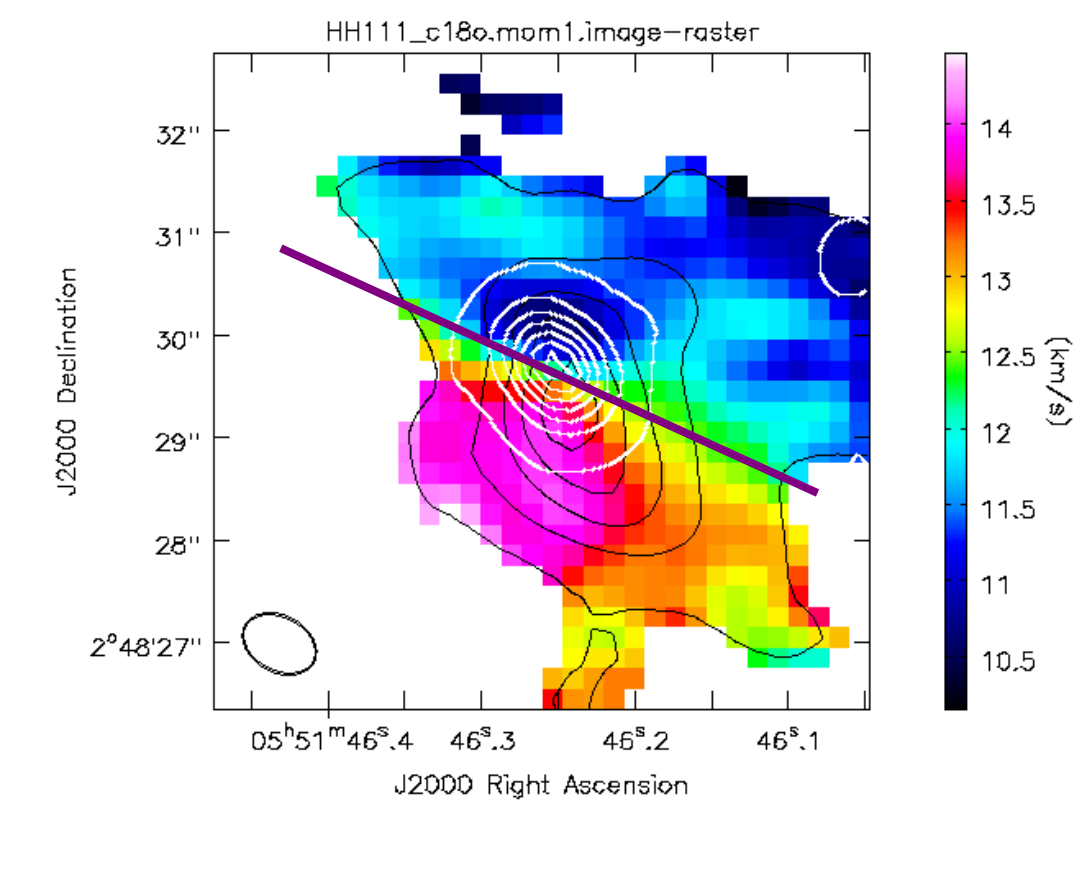


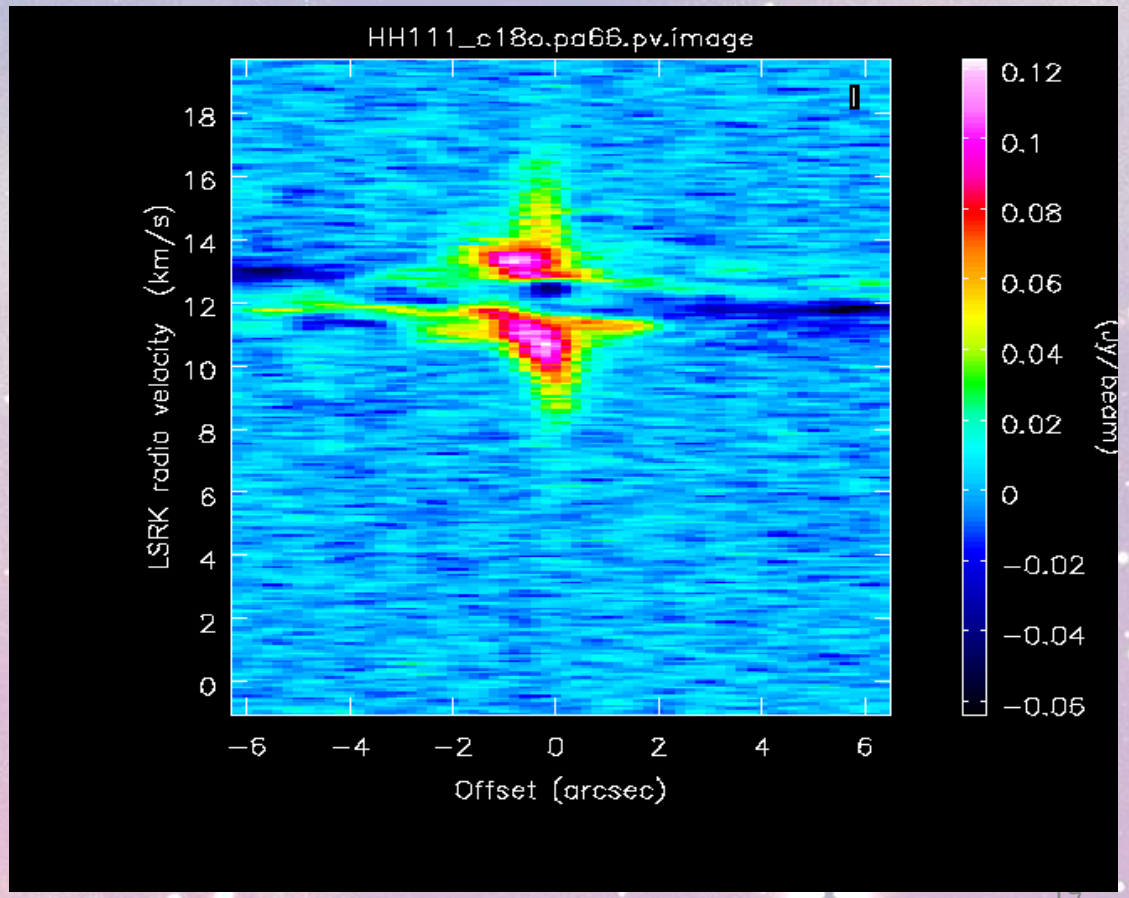




HH111 Position-Velocity diagram
$C^{18}O(J = 2 - 1)$

Minor axes(pa=66°)

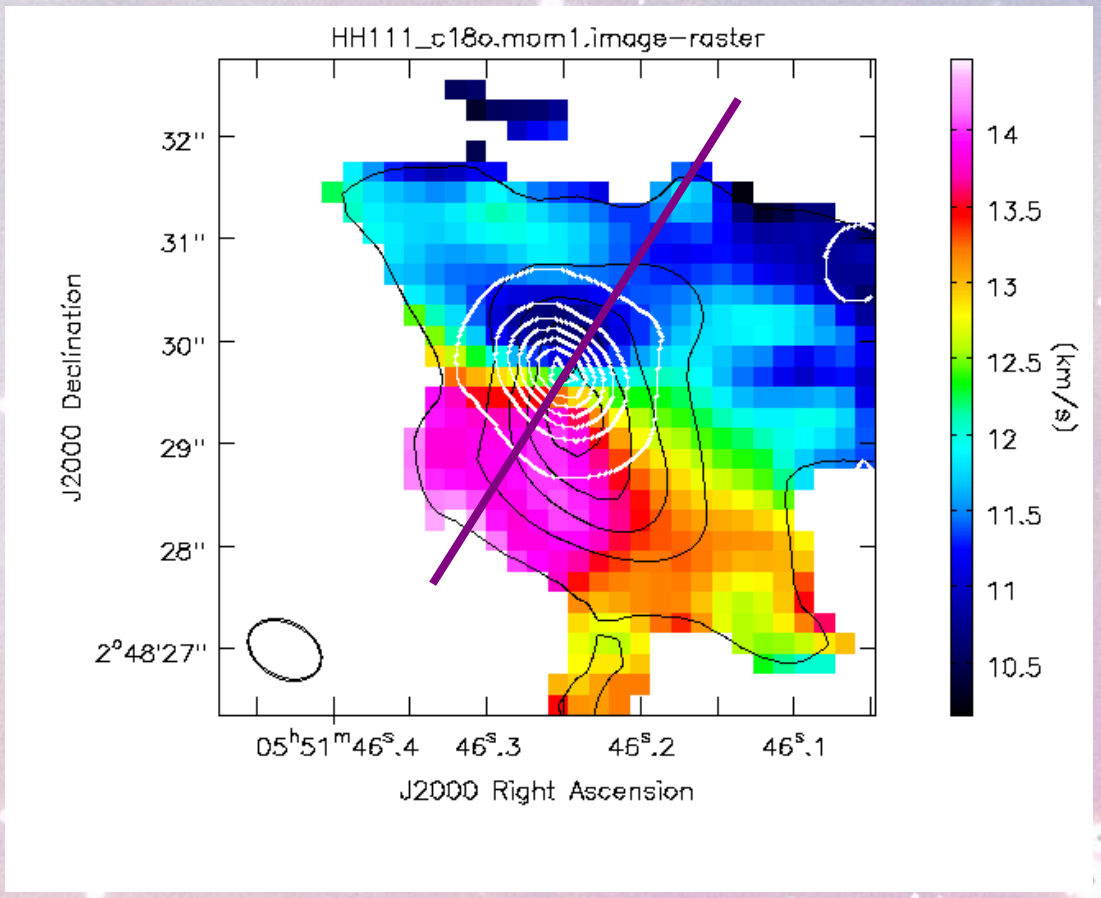


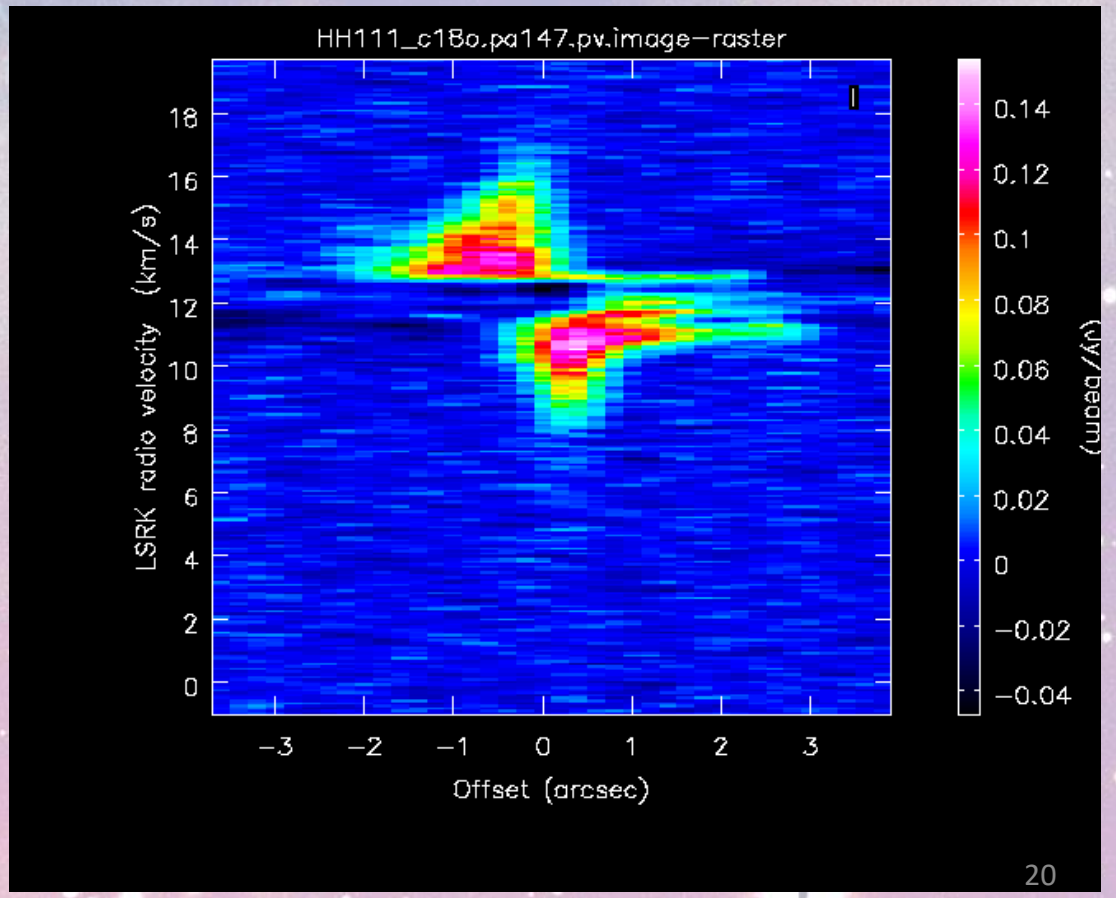


HH111 Position-Velocity diagram

$C^{18}O(J = 2 - 1)$

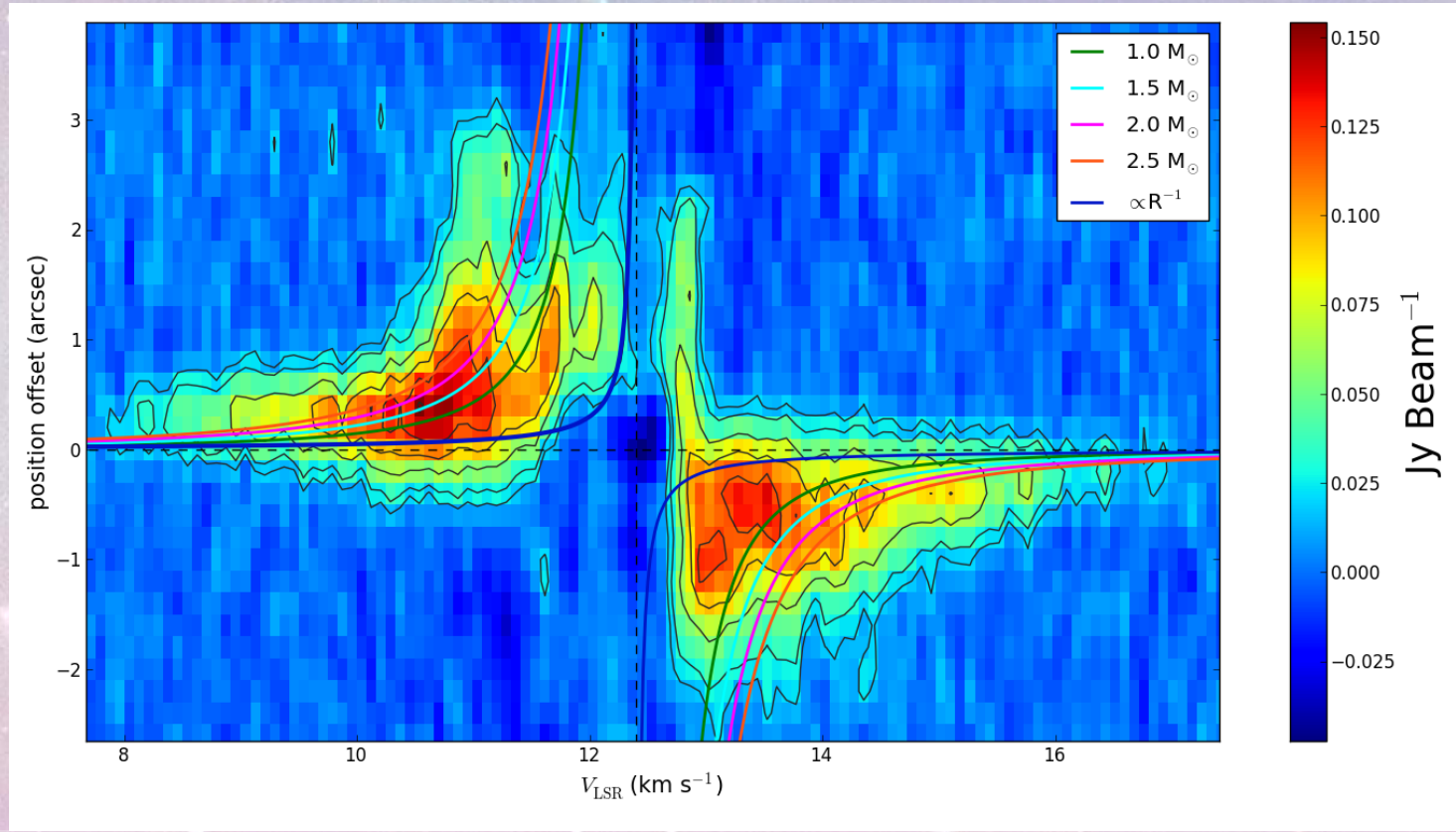
Major axes(pa=147°)





HH111 Position-Velocity diagram

$C^{18}O(J = 2 - 1)$



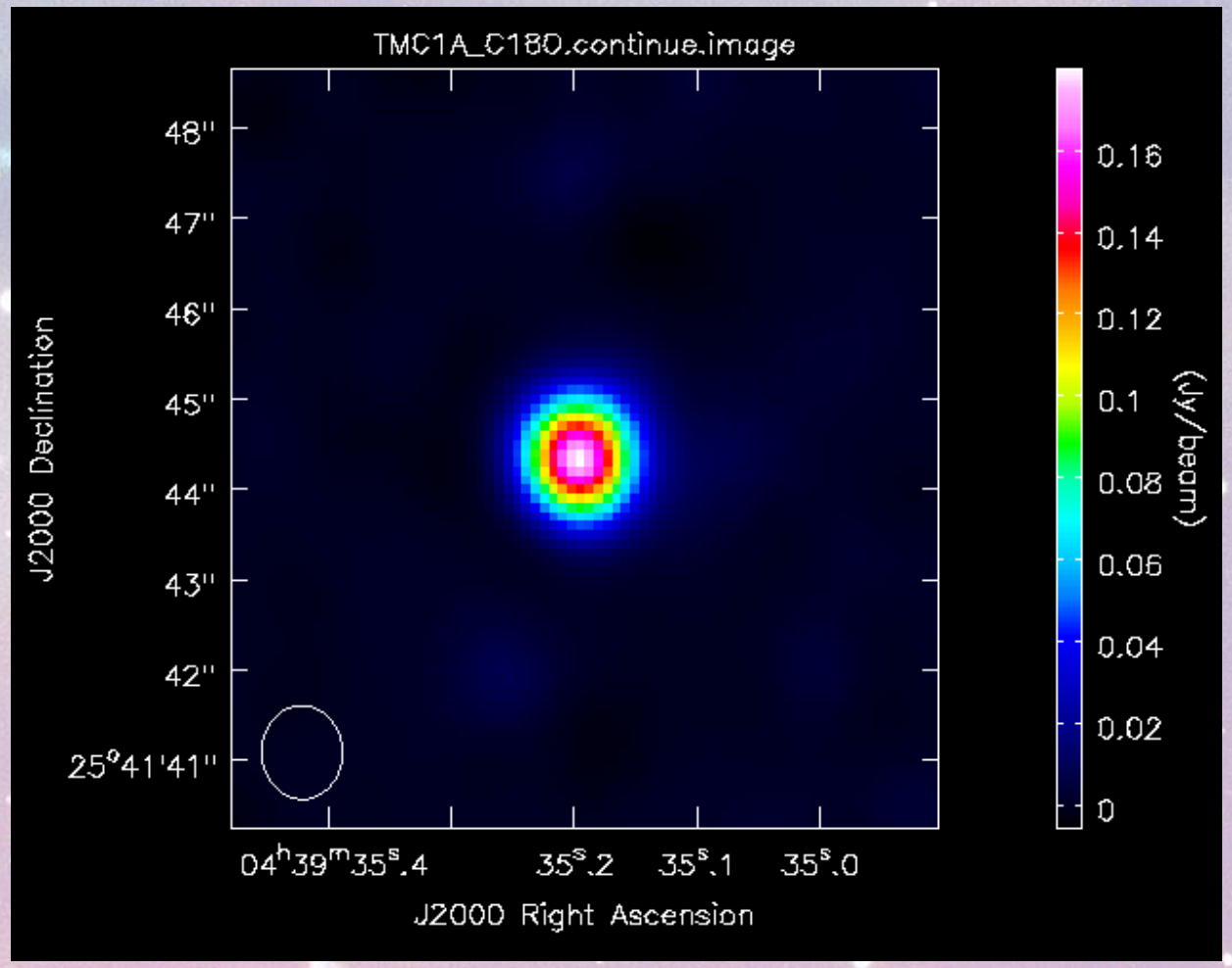
The mass that supports the Keplerian rotation :$\sim 1.38 M_{\odot}$

(Chin-Fei Lee .2010)

TMC-1A protostellar system

Constellation	Taurus
Distance	~137pc
RA(J2000)	04h39m35*s*.195
Dec(J2000)	+25° 41’44’’.344
Stage	Class I

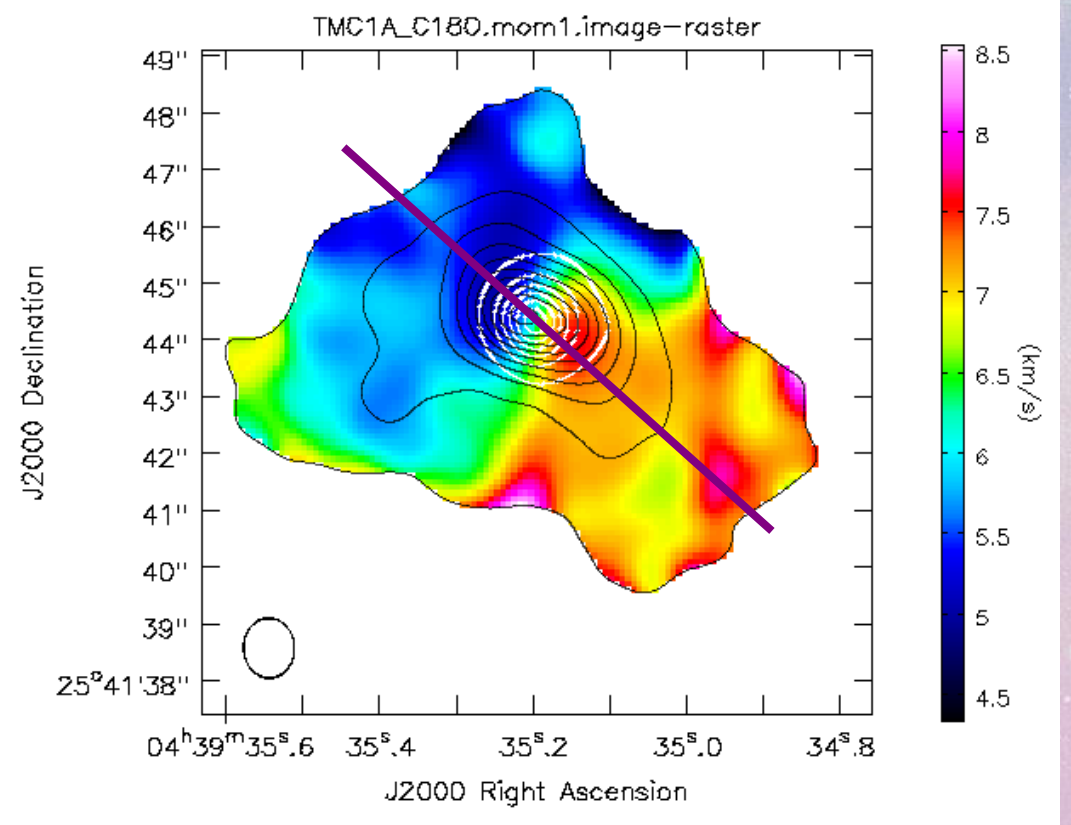
TMC-1A is located in the Heiles Cloud 2 (Torres et al. 2007), where the carbon-chain-molecule rich starless core TMC-1 and the warm-carbon-chain-chemistry (WCCC) source L1527 (Sakai et al. 2008) are associated.



continuum map
Frequency range:219.439 ~ 230.650GHz

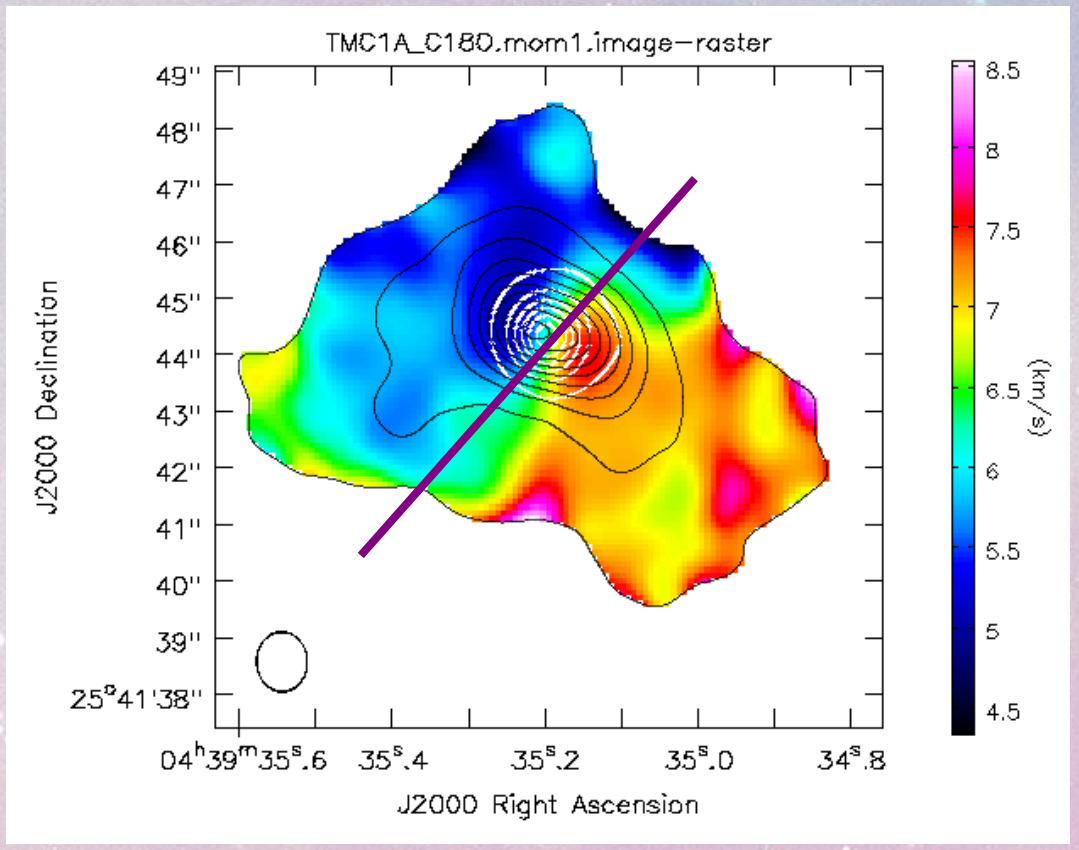
TMC-1A Moment Map
$C^{18}O(J = 2 - 1)$

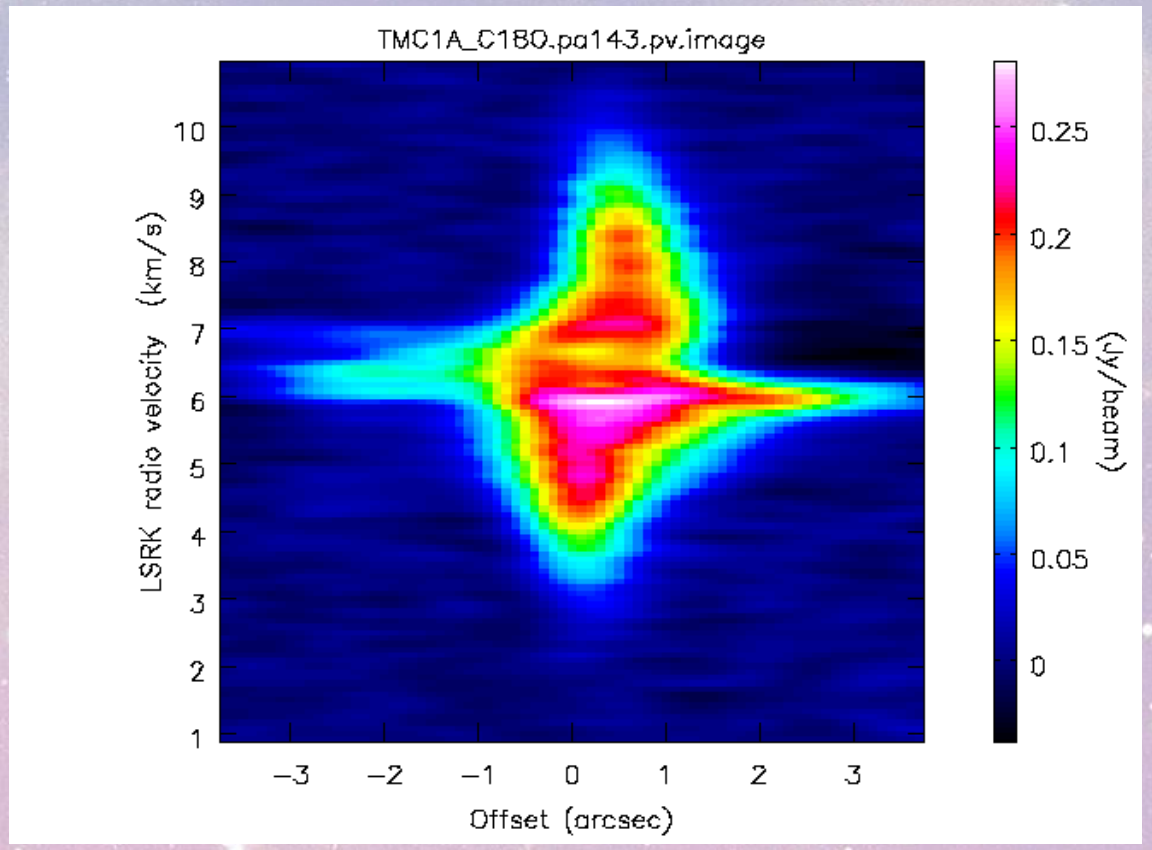
ALMA Archive Band6
219.546 ~ 219.561 GHZ



The figure shows continuum(white contours), intensity (black contours) and velocity (color-scale) integrated map of $C^{18}O(J = 2 - 1)$.
White contour levels are from 15σ to 265σ in steps of 50σ, where 1σ is 0.61Jy beam^{-1} km s^{-1}.
Black contour levels are from 3σ to 93σ in steps of 10σ, where 1σ is 12mJy beam^{-1} km s^{-1}.

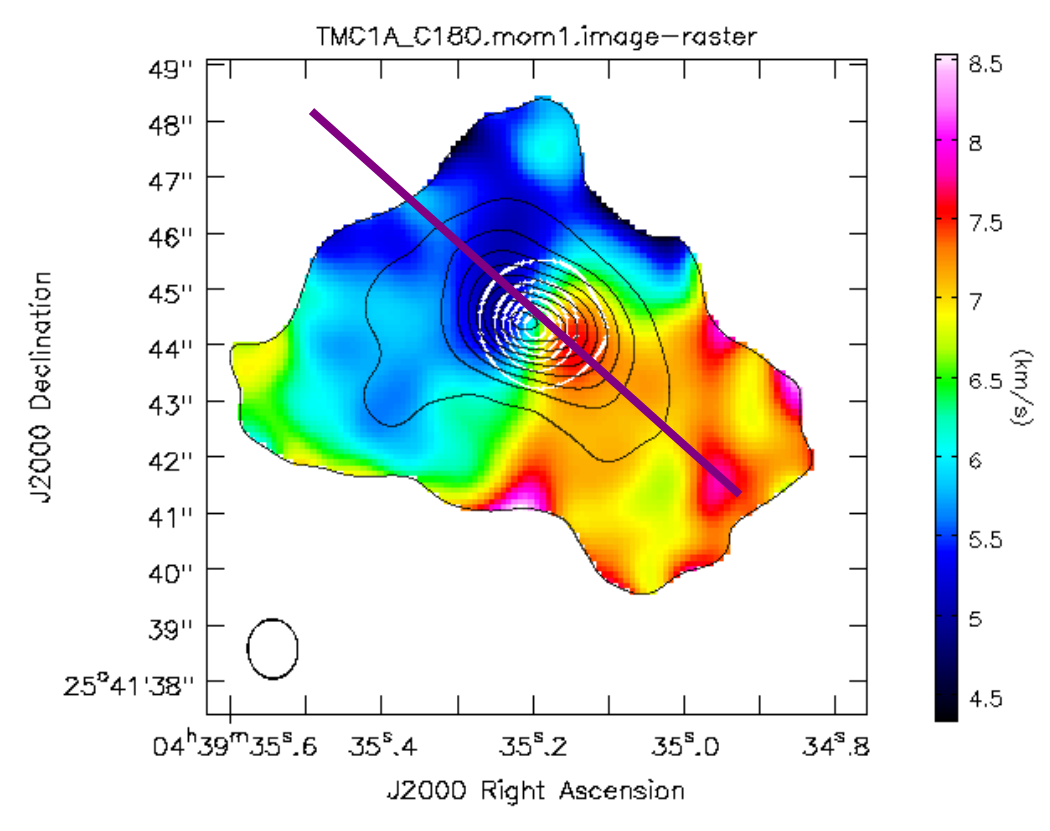
TMC-1A Position-Velocity diagram
$C^{18}O(J=2-1)$

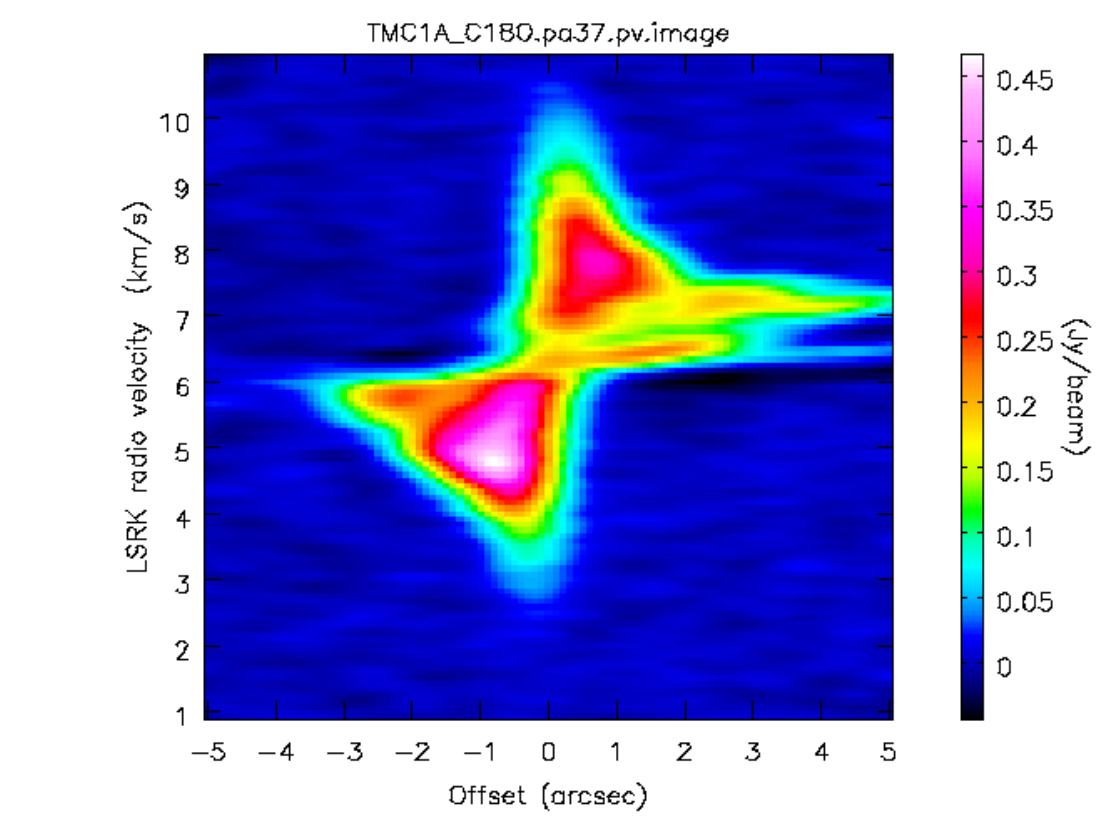




PV diagram of $C^{18}O$ along the disk minor axes(pa=143°)

TMC-1A Position-Velocity diagram
$C^{18}O(J = 2 - 1)$

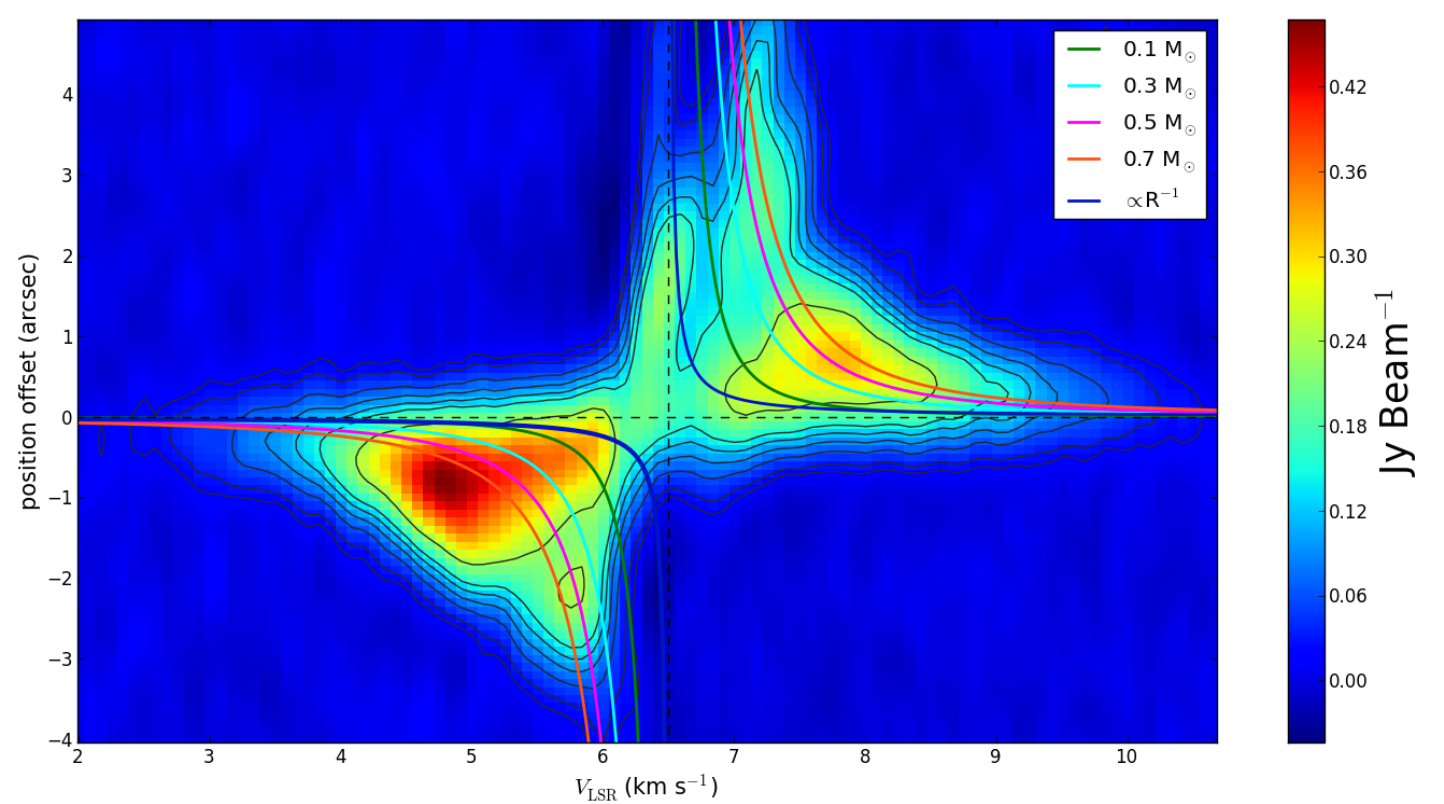




P-V diagram of $C^{18}O$ along the disk major axis (PA = 37°)

TMC-1A Position-Velocity diagram

$C^{18}O(J = 2 - 1)$



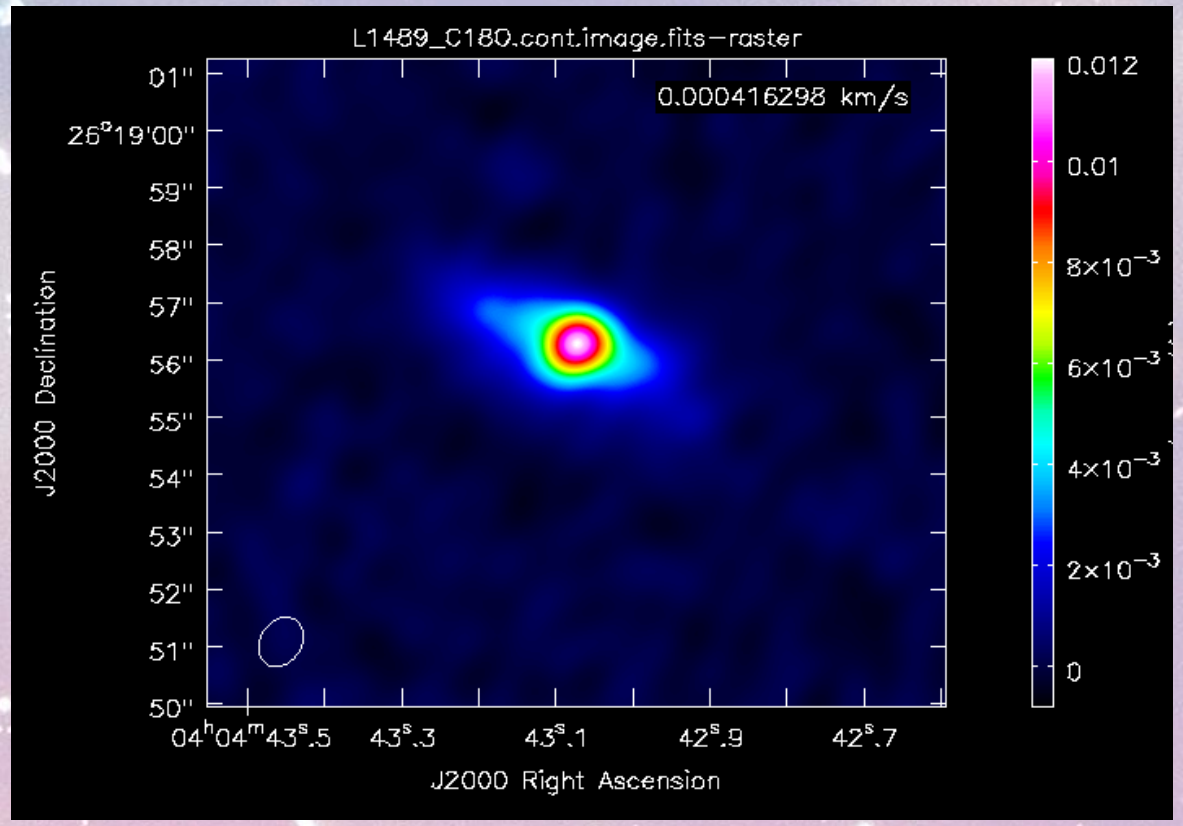
Contour levels are in steps of $3,5,10,15,20,25,39\sigma$,
where σ =6mJy/beam
curves: the kepler's third law, different colors represent different masses of the proto-star.(except blue line: infall)
Inclination angle=55°

The protostellar mass is $0.68M_{\odot}$
(Yusuke Aso et al. 2015)

L1489 IRS

Constellation	Taurus
Distance	~140pc
RA(J2000)	04h04m43*s*.075
Dec(J2000)	+26° 18’56’’.300
Stage	Class I

L1489 IRS : a Class I protostar surrounded by a Keplerian disk and an infalling envelope. (Hsi-Wei Yen et al. 2015)

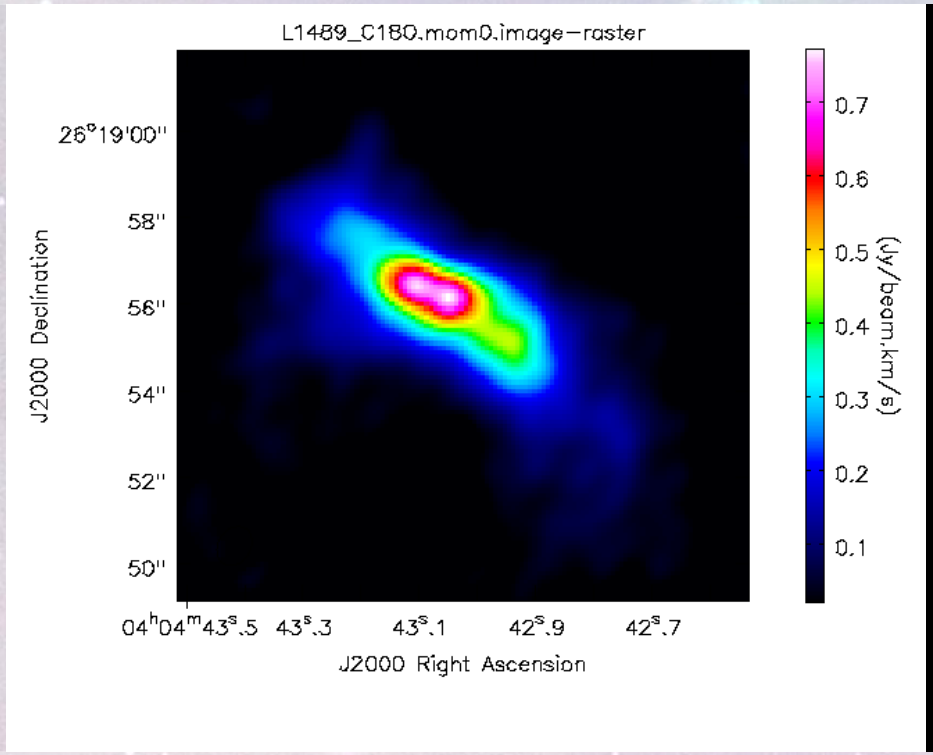


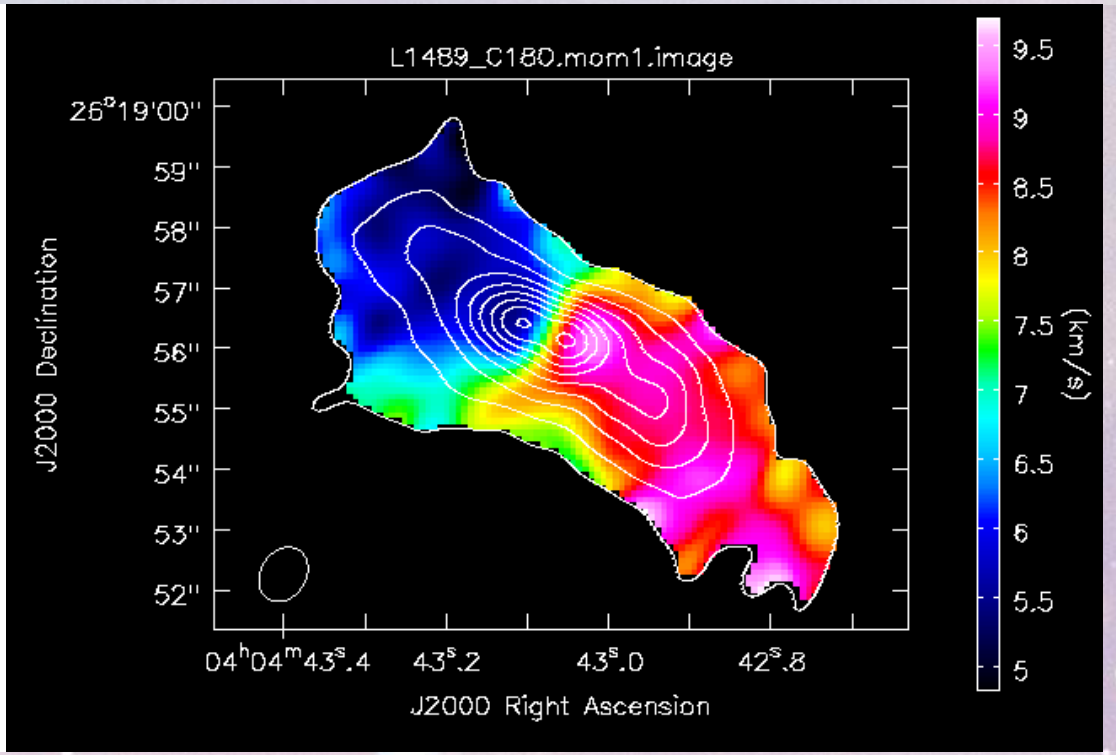
continuum map
Frequency range:219.445 -- 230.642GHz

L1489 IRS Moment Map

$C^{18}O(J = 2 - 1)$

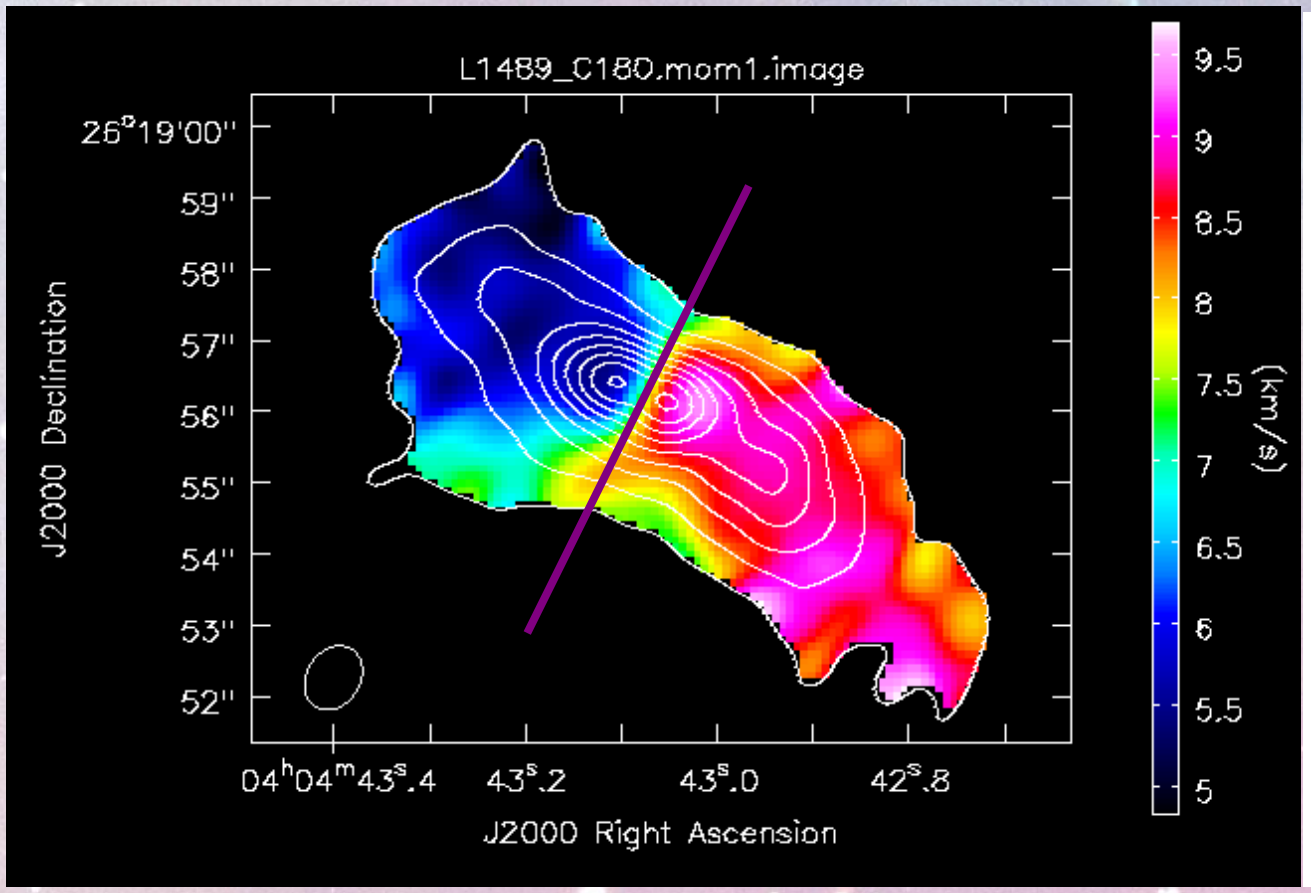
ALMA Archive Band6
219.550 -- 219.559 GHZ

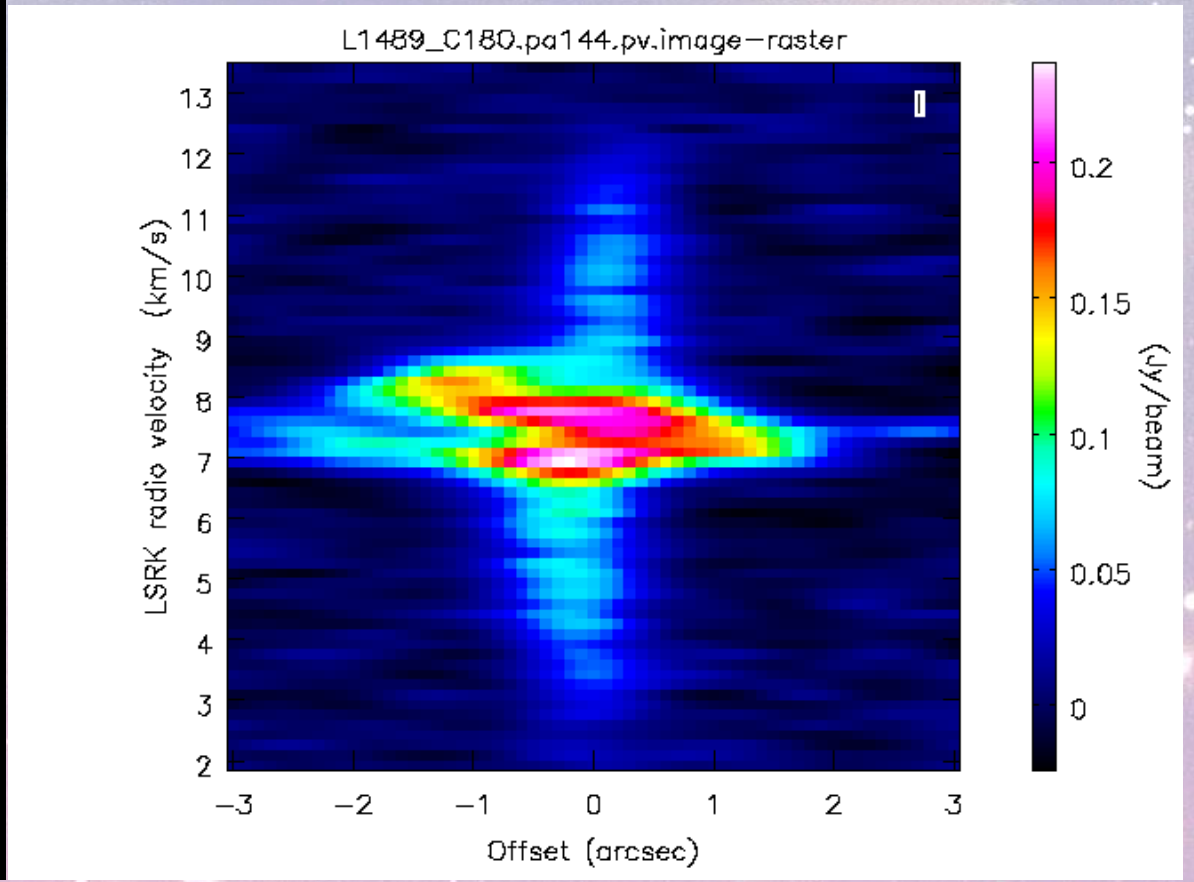




Left figure shows Moment 0 map of the $C^{18}O(J = 2 - 1)$
Right figure shows Moment 0 map (contour) overlaid on the moment 1 map (color) of the $C^{18}O(J = 2 - 1)$emission in L1489 IRS. Contour levels are from 3σ to 27σ in steps of 3σ, where 1σ is 28mJy beam^{-1} km s^{-1}. Black contour levels are from 3σ to 93σ in steps of 10σ, where 1σ is 12mJy beam^{-1} km s^{-1}. Moment 1

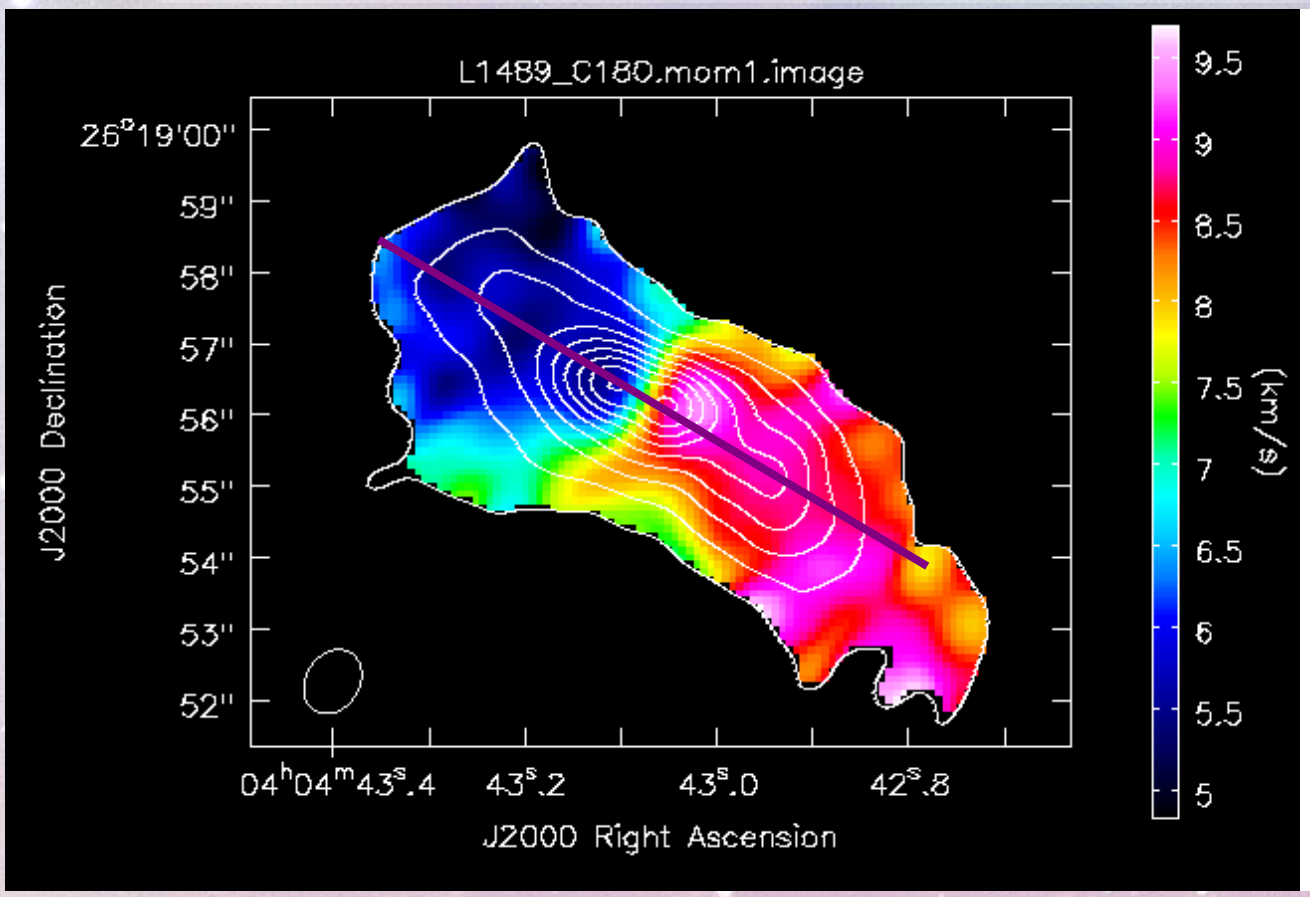
L1489 IRS Position-Velocity diagram
$C^{18}O(J = 2 - 1)$

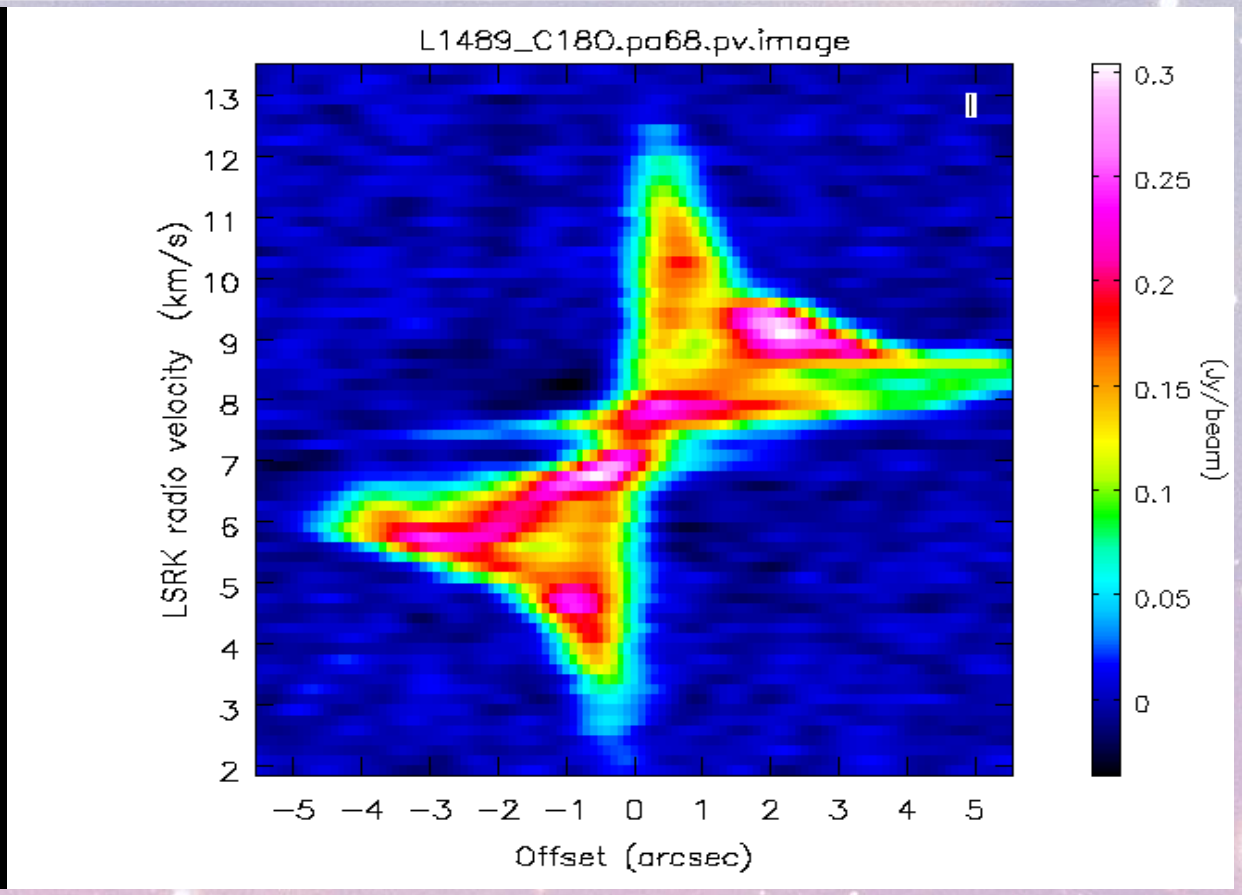




PV diagram of $C^{18}O$ along the disk minor axes(pa=144°)

L1489 Position-Velocity diagram
$C^{18}O(J = 2 - 1)$

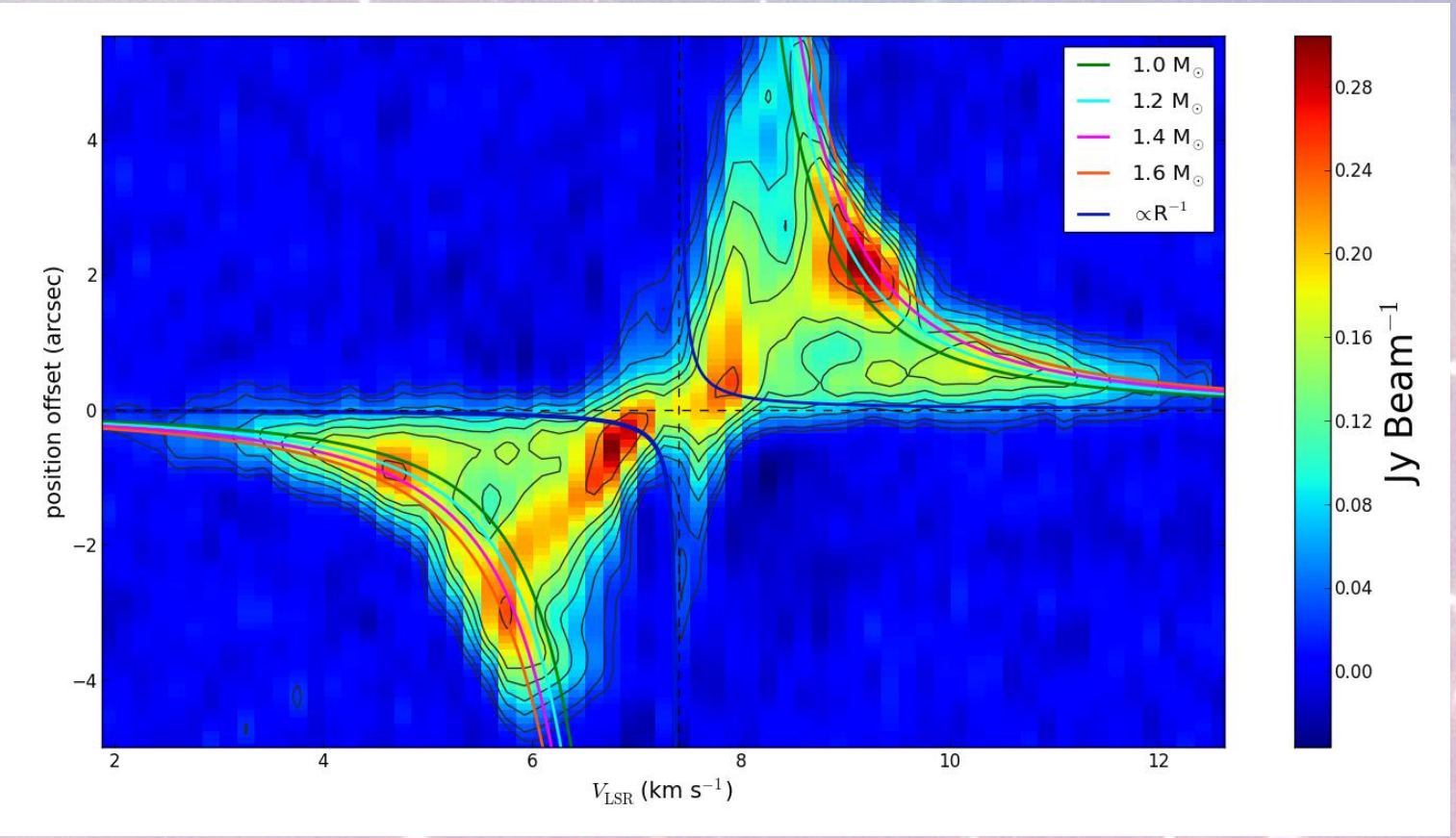




PV diagram of $C^{18}O$ along the disk major axes(pa=168°)

L1489 Position-Velocity diagram

$C^{18}O(J = 2 - 1)$



Contour levels are in steps of 3,5,10,15,20,25,39σ,
where σ =6mJy/beam
curves: the kepler's third law, different colors represent different masses of the proto-star.
(except blue line: infall)
Inclination angle=66°

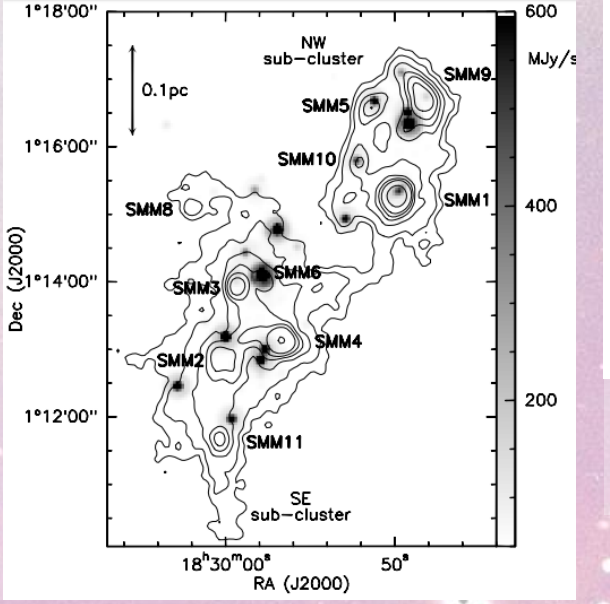
the protostellar mass is estimated to be

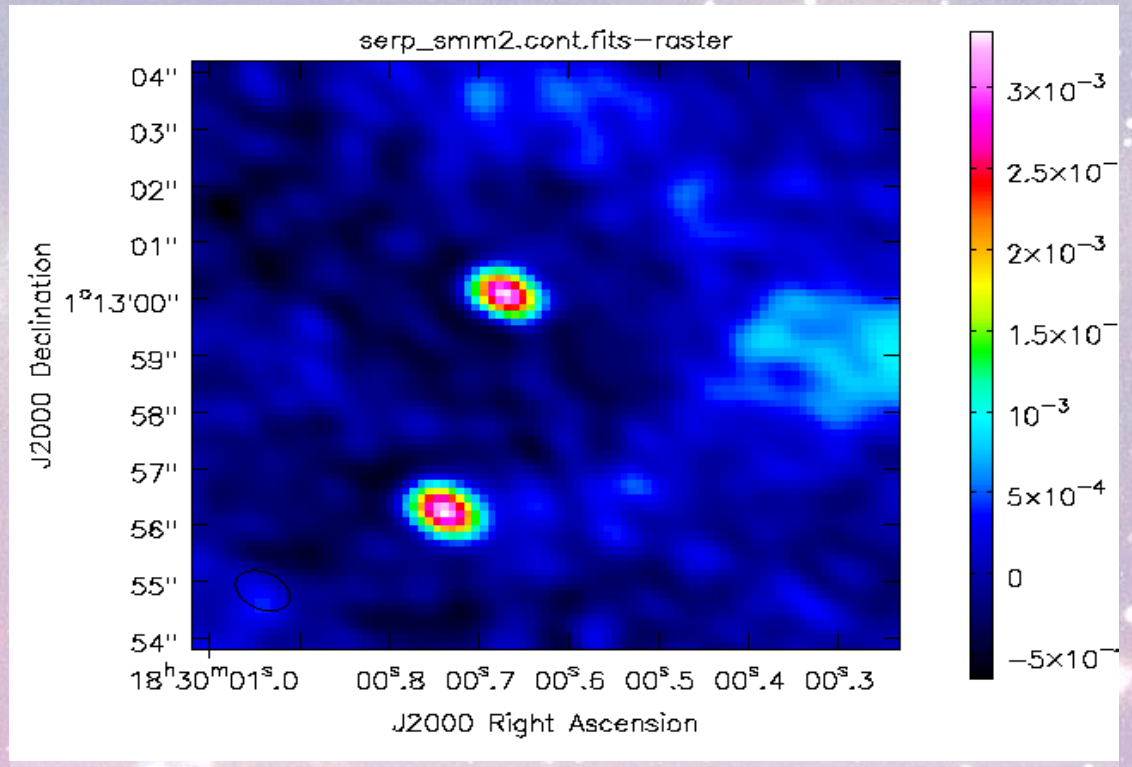
(Hsi-Wei Yen et al. 2015)

Serp_smm2

Constellation	Serpens
RA(J2000)	18h30m00s.7
Dec(J2000)	+01° 13’01’’
Stage	Class 0

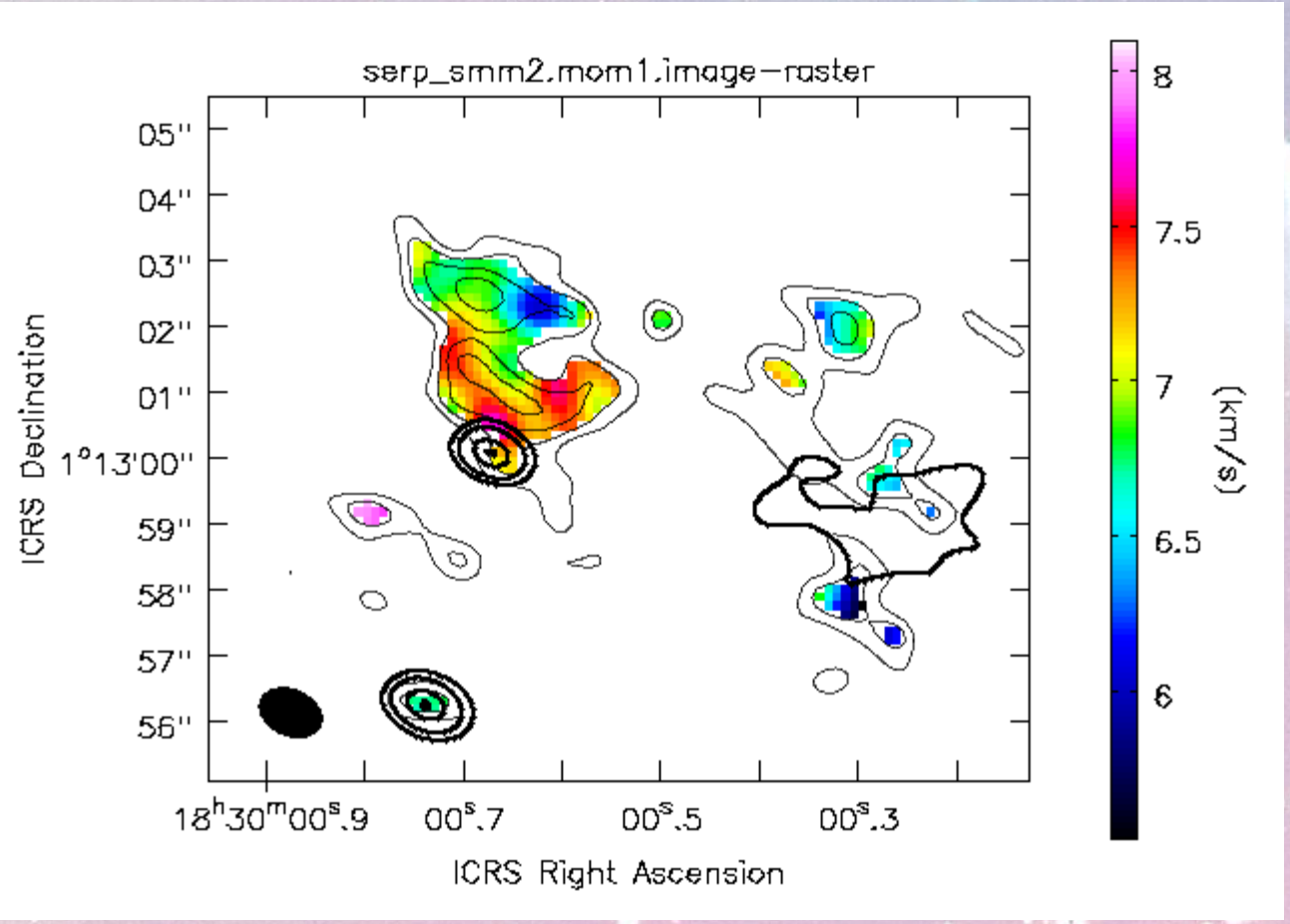
Map of the SCUBA 850 µm continuum emission in contours showing the position of the submillimetre sources (labeled)





continuum map
Frequency range:219.445 -- 230.642GHz

Serp_smm2
$C^{18}O(J = 2 - 1)$



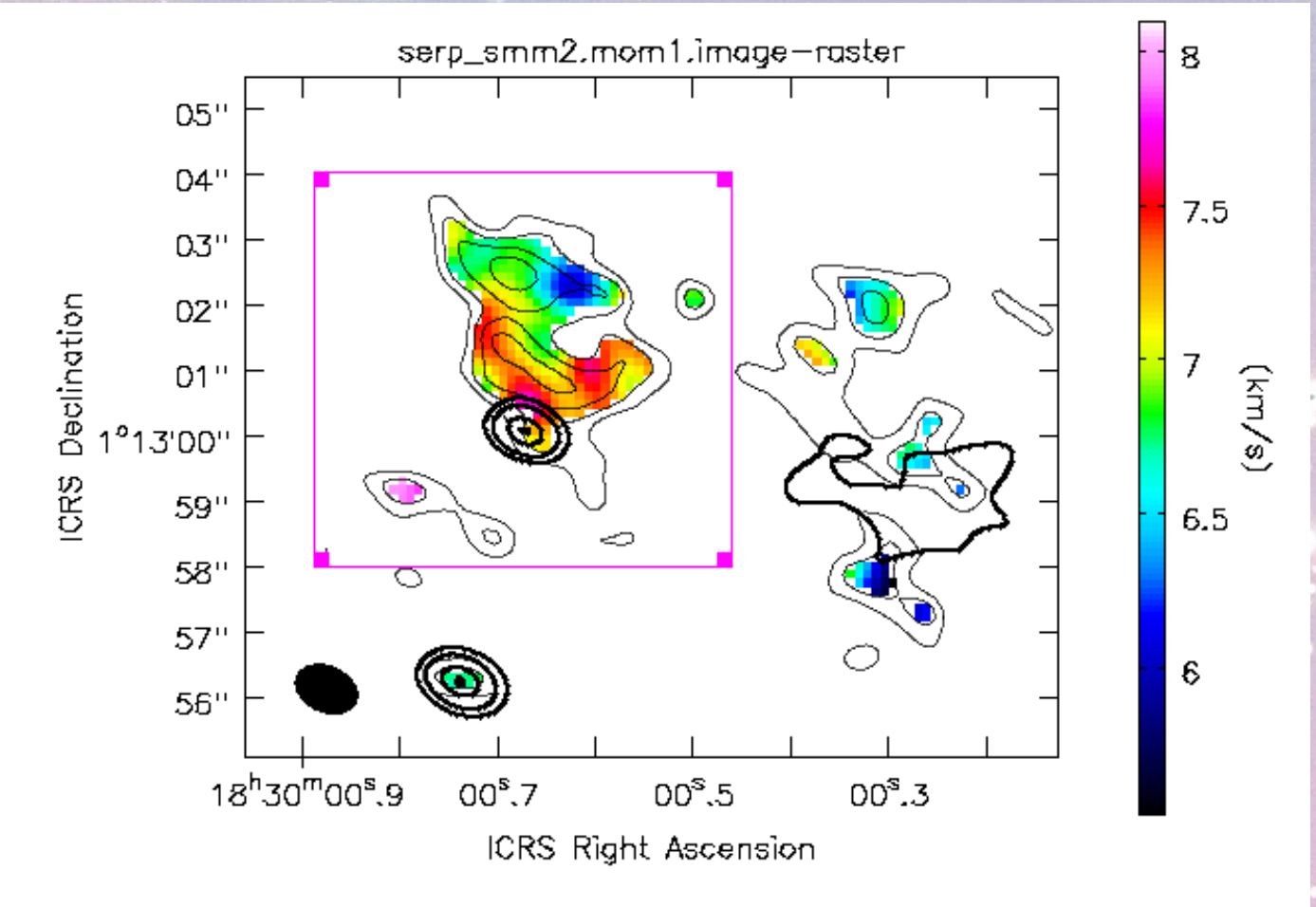
Moment 0 map (light contour) and continue map(heavy contour) overlaid on the moment 1 map (color) of the $C^{18}O$ (2-1) emission in serp_smm2.

A filled ellipse in the bottom right corner of each panel denotes the beam size.

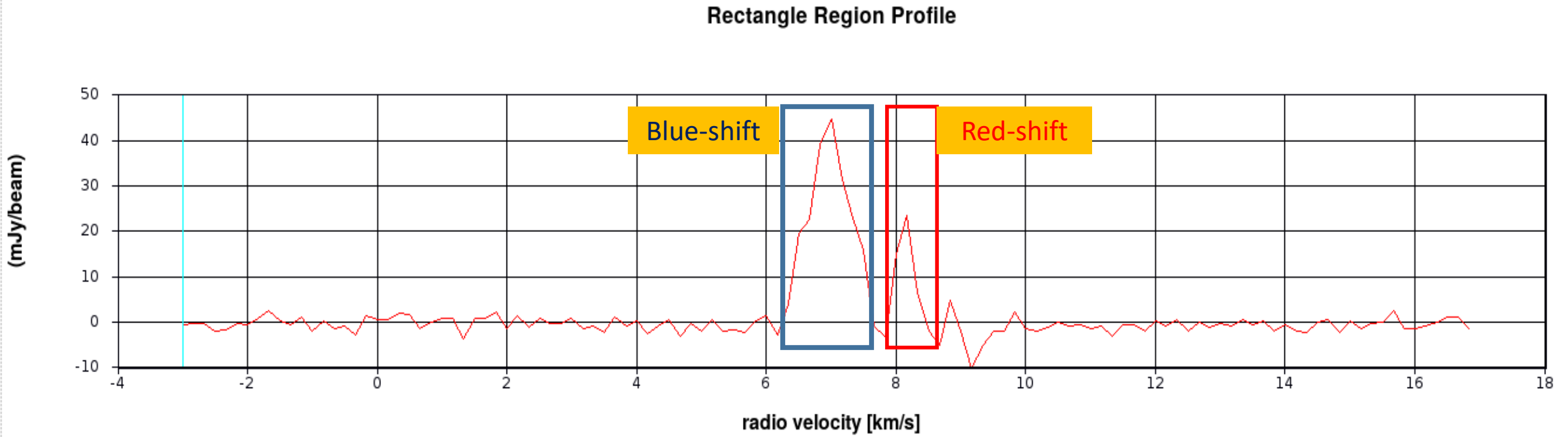
Moment 0 contour levels are from 3σ to 6σ in steps of 1σ, where 1σ is 0.02Jy beam^{-1} km s^{-1}.

Continue map contour levels are from 5σ to 30σ in steps of 5σ, where 1σ is 0.13mJy beam^{-1} km s^{-1} .

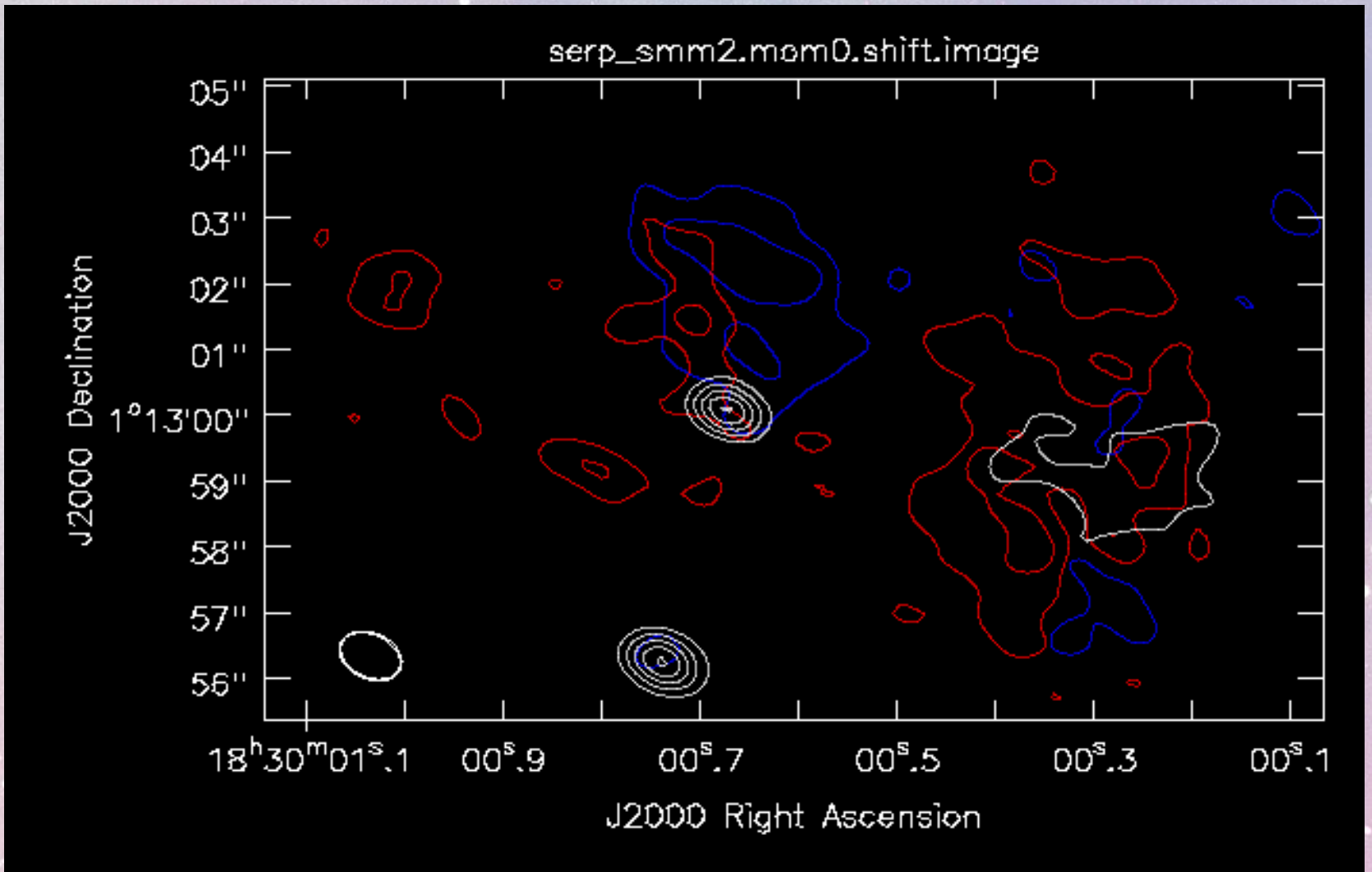
Serp_smm2
$C^{18}O(J = 2 - 1)$



Serp_smm2
$C^{18}O(J = 2 - 1)$



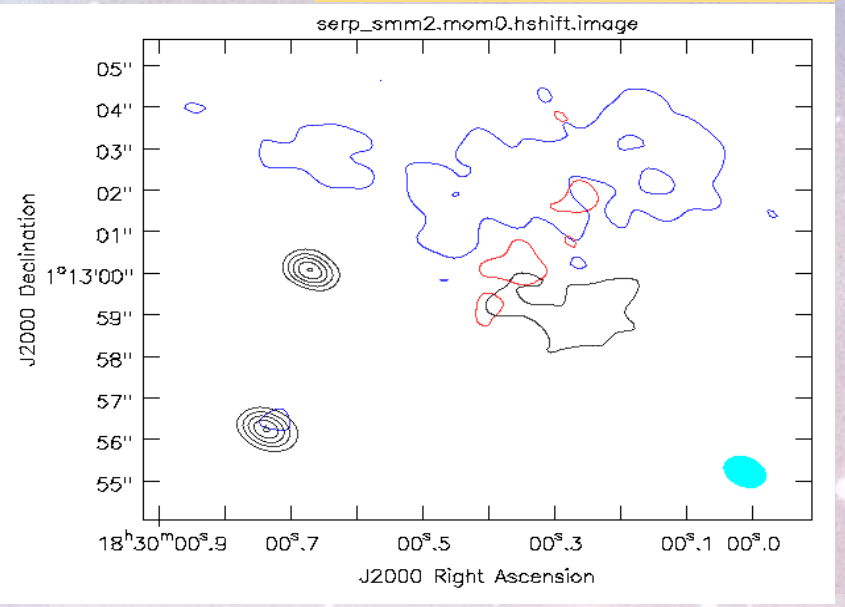
Serp_smm2
$C^{18}O(J=2-1)$



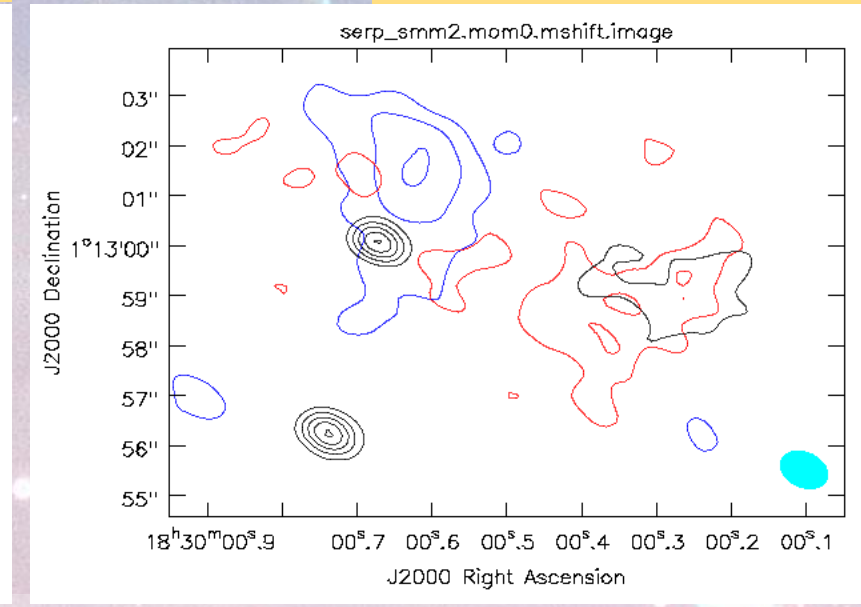
Blue:5.8~7.8km/s
Red:7.8~8.5km/s

Serp_smm2
$C^{18}O(J=2-1)$

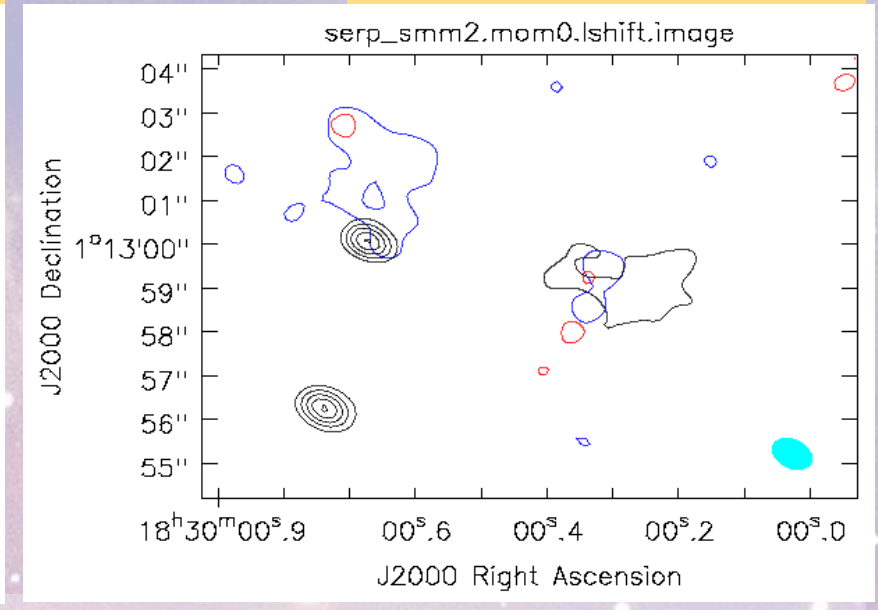
High velocity=6.1~6.6 km/s
velocity=8.3~8.5 km/s



Medium velocity=6.6~7 km/s
velocity=8.0~8. km/s



Low Velocity=7.1~7.6 km/s
velocity=7.6~8.0 km/s



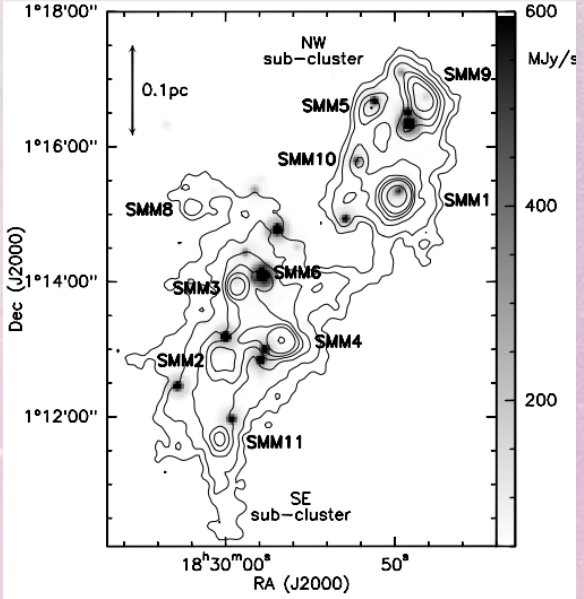
Moment 0 map of the high-velocity, medium-velocity, and low-velocity $C^{18}O$ (2-1) emission in Serp_smm2. The integrated velocity ranges are shown above the relevant panels. A filled ellipse in the bottom right corner of each panel denotes the beam size.

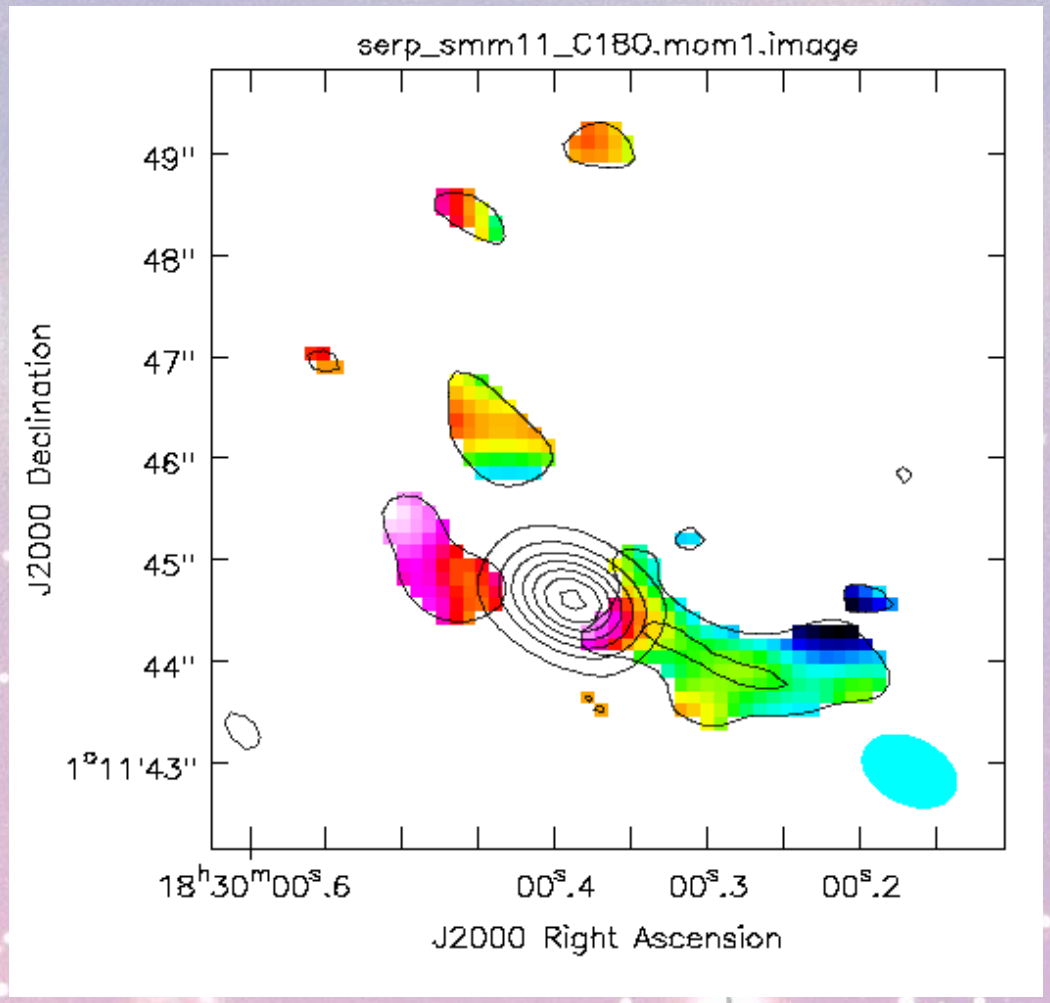
Contour levels are from 3σ in steps of 1σ in the high-velocity、the medium-velocity and low-velocity maps. Here 1σ is 11, 5.8,12, 6.1, 10, and 6.9 mJy beam^{-1} km s^{-1}in the high-velocity blueshifted, high-velocity redshifted, medium-velocity blueshifted, medium-velocity redshifted, low-velocity blueshifted, and low-velocity redshifted maps, respectively.

Serp_smm11

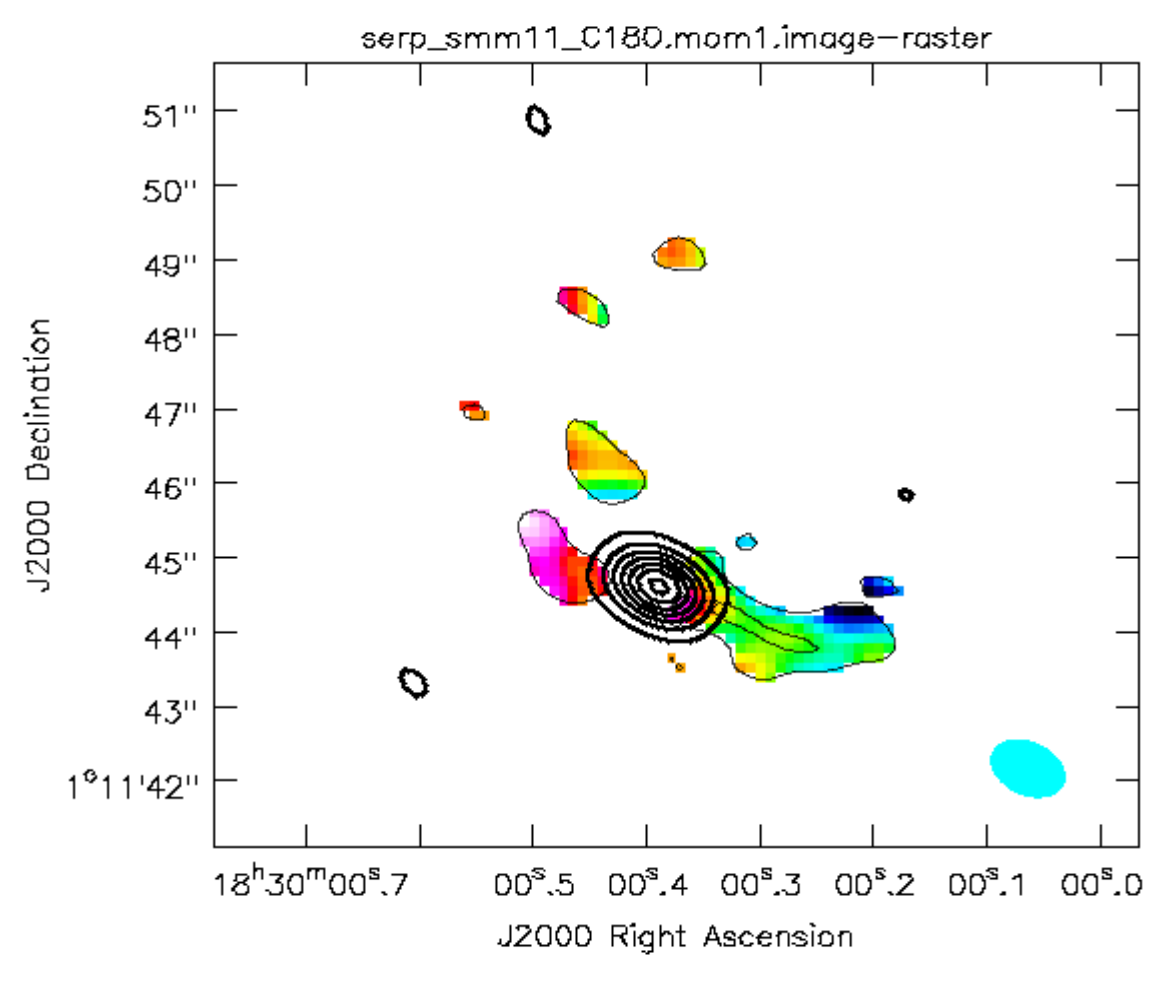
Constellation	Serpens
RA(J2000)	18h30m00.3
Dec(J2000)	+01d11m44
Stage	Class 0

Map of the SCUBA 850 µm continuum emission in contours showing the position of the submillimetre sources (labeled)





Serp_smm11



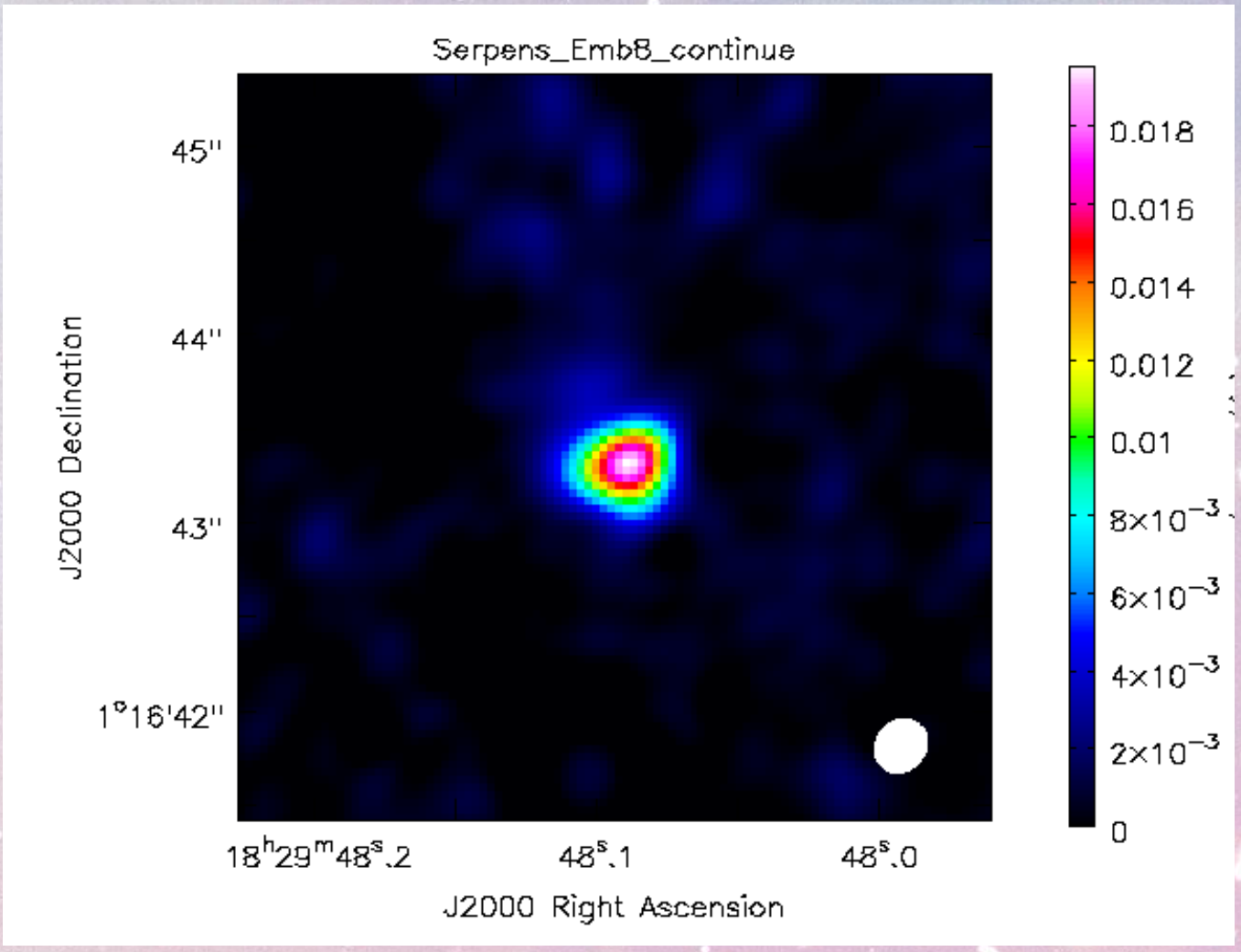
Moment 0 map (light contour) and continue map(heavy contour) overlaid on the moment 1 map (color) of the $C^{18}O$ (2-1) emission in serp_smm2.

A filled ellipse in the bottom right corner of each panel denotes the beam size.

Moment 0 contour levels are from 3σ to 6σ in steps of 1σ, where 1σ is 0.02Jy beam^{-1} km s^{-1}.

Continue map contour levels are from 5σ to 30σ in steps of 5σ, where 1σ is 0.13mJy beam^{-1} km s^{-1} .

Serpens_Emb8



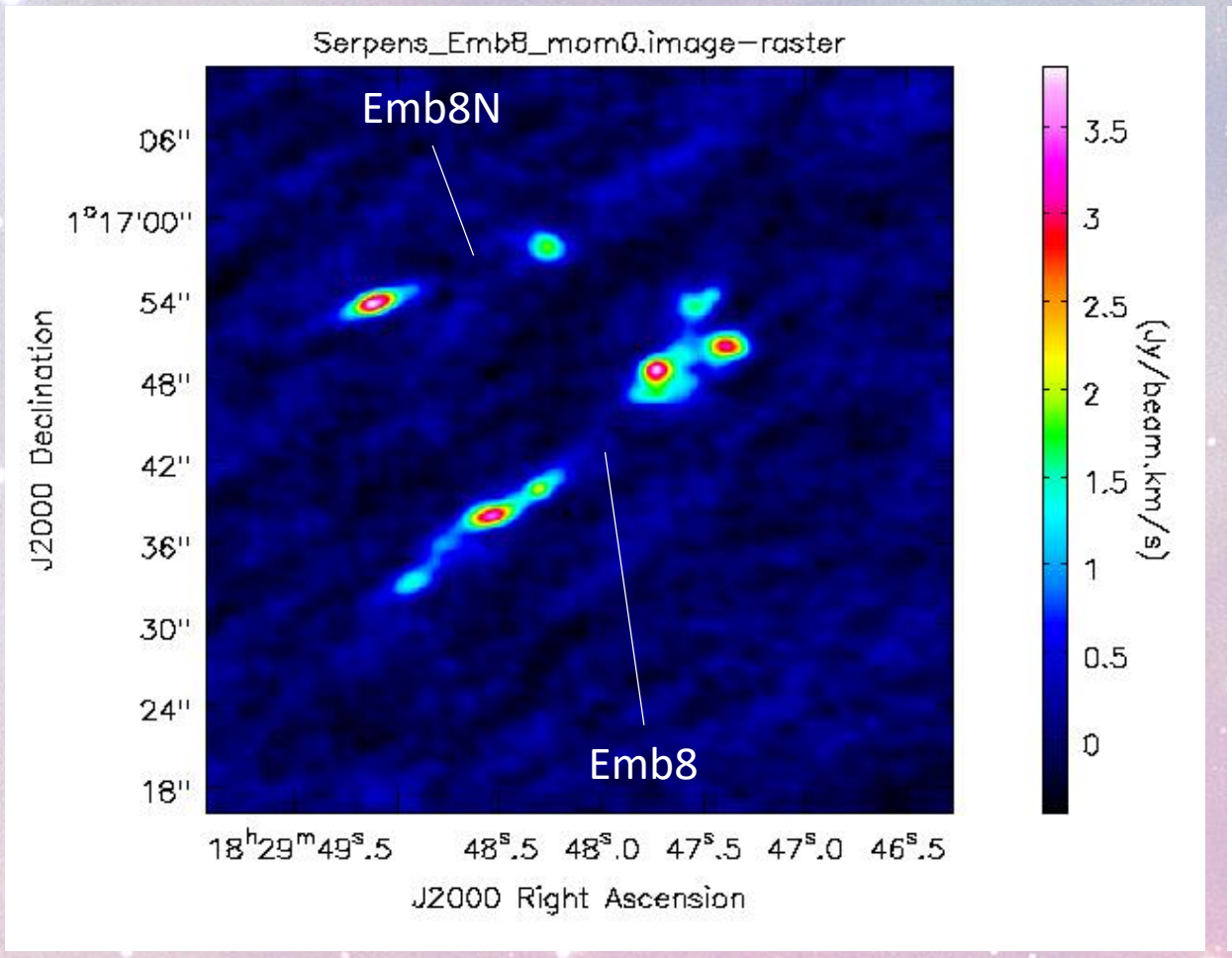
ALMA Archive Band6
216.080~232.164GHz
Continuum map

Constellation	Serpens
Distance	415 pc (Dzib et al. 2010)
stage	Class 0 (Hull et al .2016)
RA(J2000)	18h29m48.10
Dec(J2000)	+01d16m43.54

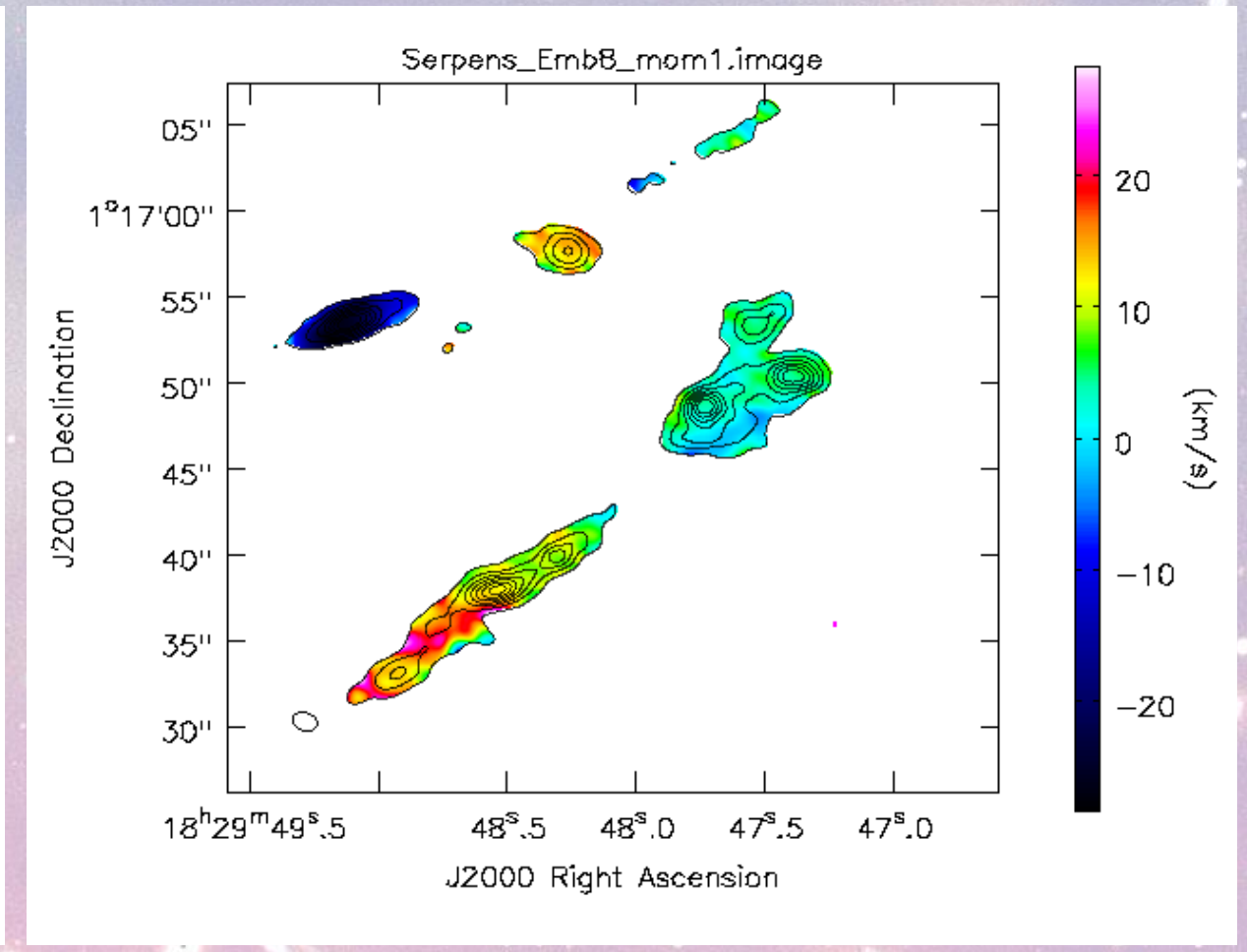
Ser-emb 8 has been known by many names including Serpens SMM9

Serpens_Emb8
Moment Map of SiO(J=5-4)

ALMA Archive Band6 217.084 -- 217.149GHz

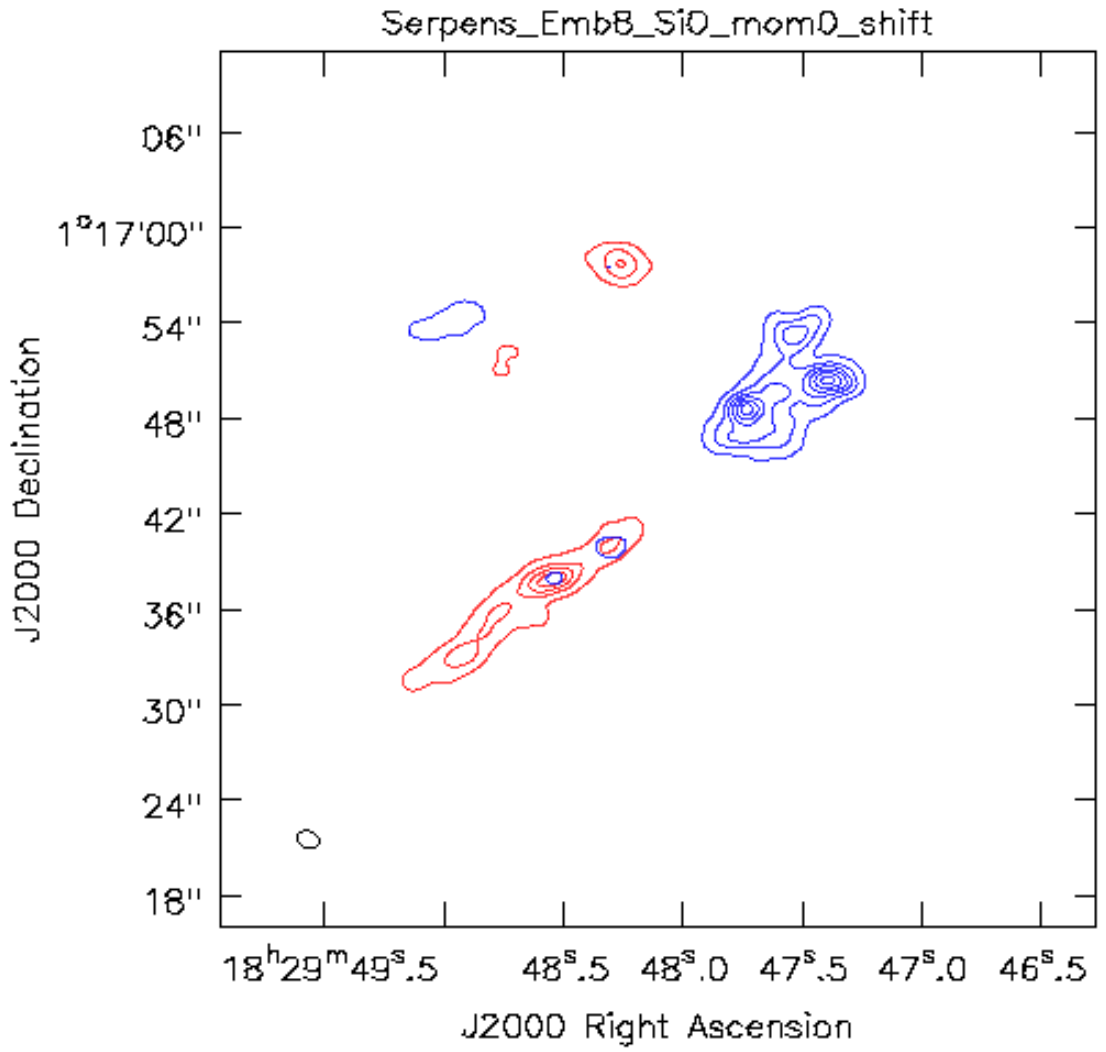


Moment 0 map



Moment 0 map(contour)
Moment 1 map(colar scale)

Serpens_Emb8
Moment Map of SiO(J=5-4)



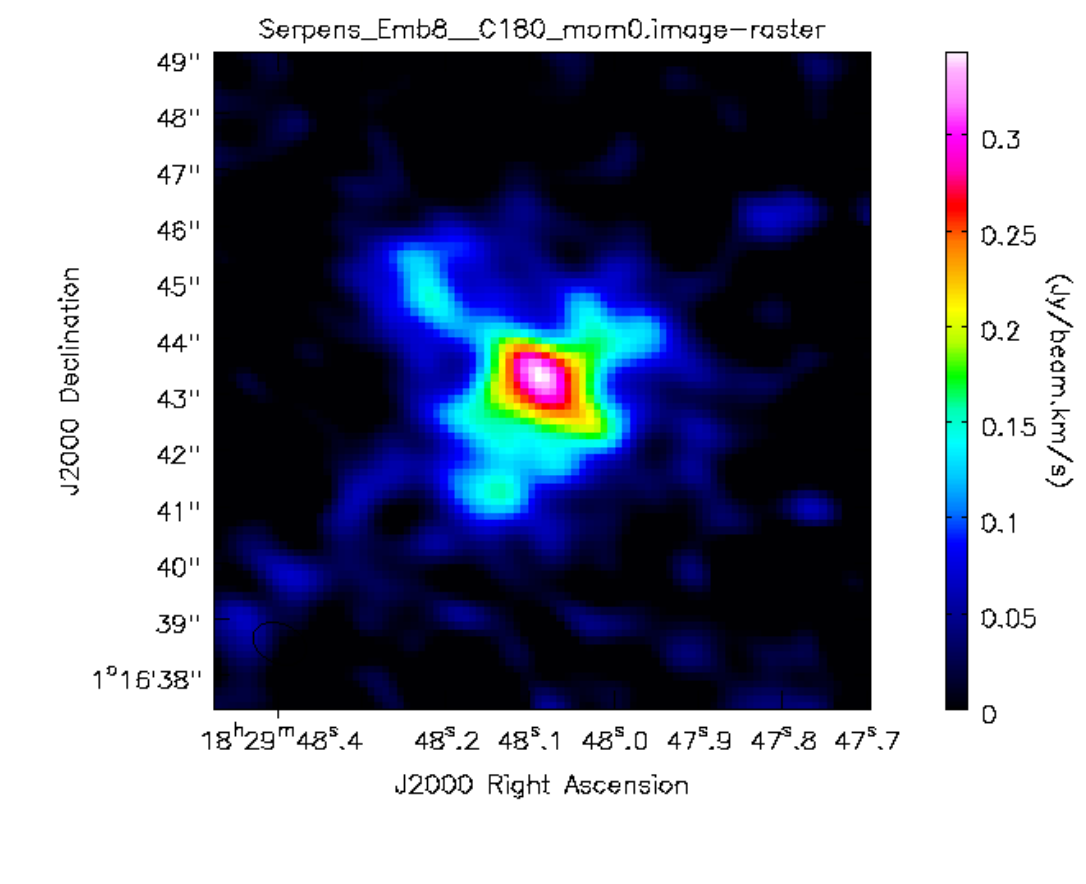
Serpens-emb 8 and 8(N)

The velocity ranges of the SiO(J = 5-4) line wing emission are 22 to 10 km/s (redshifted) and 7 to −7 km/s (blueshifted).

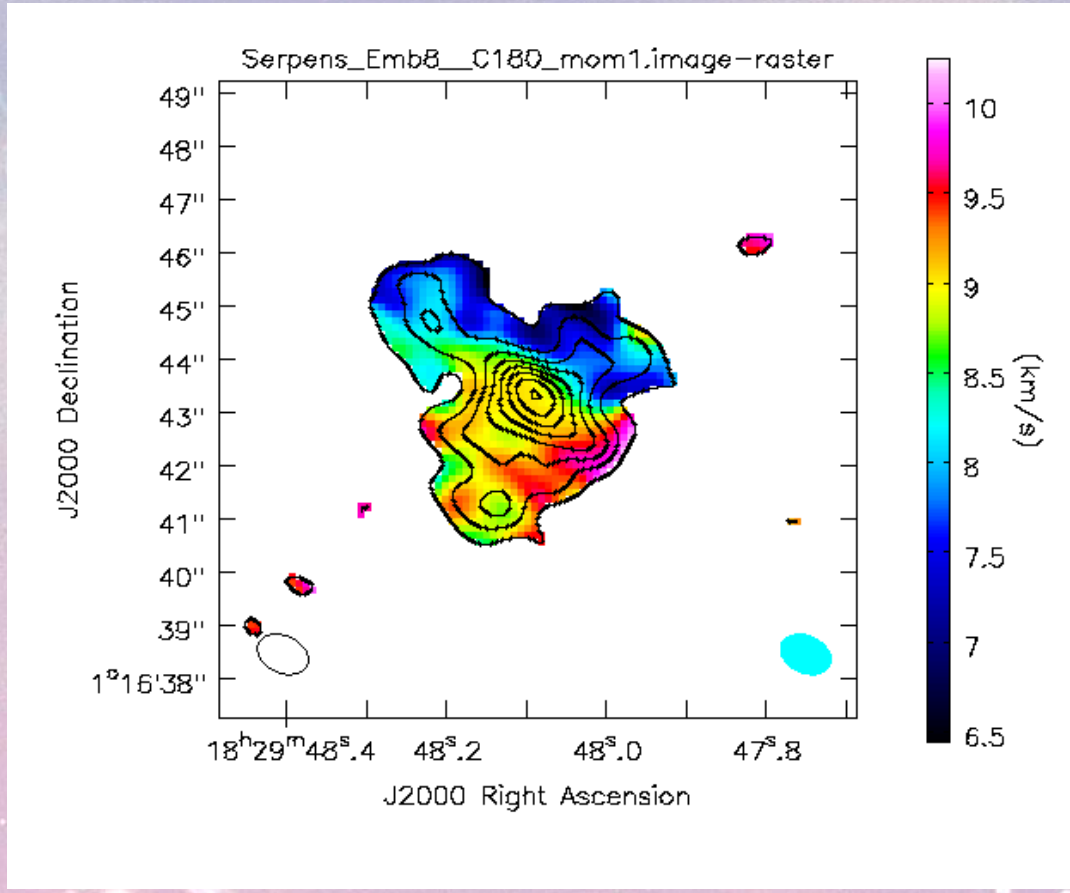
σ= 0.06 Km/s

Serpens_Emb8 Moment Map of $C^{18}O(J = 2 - 1)$

ALMA Archive Band6 219.548 ~219.563GHz

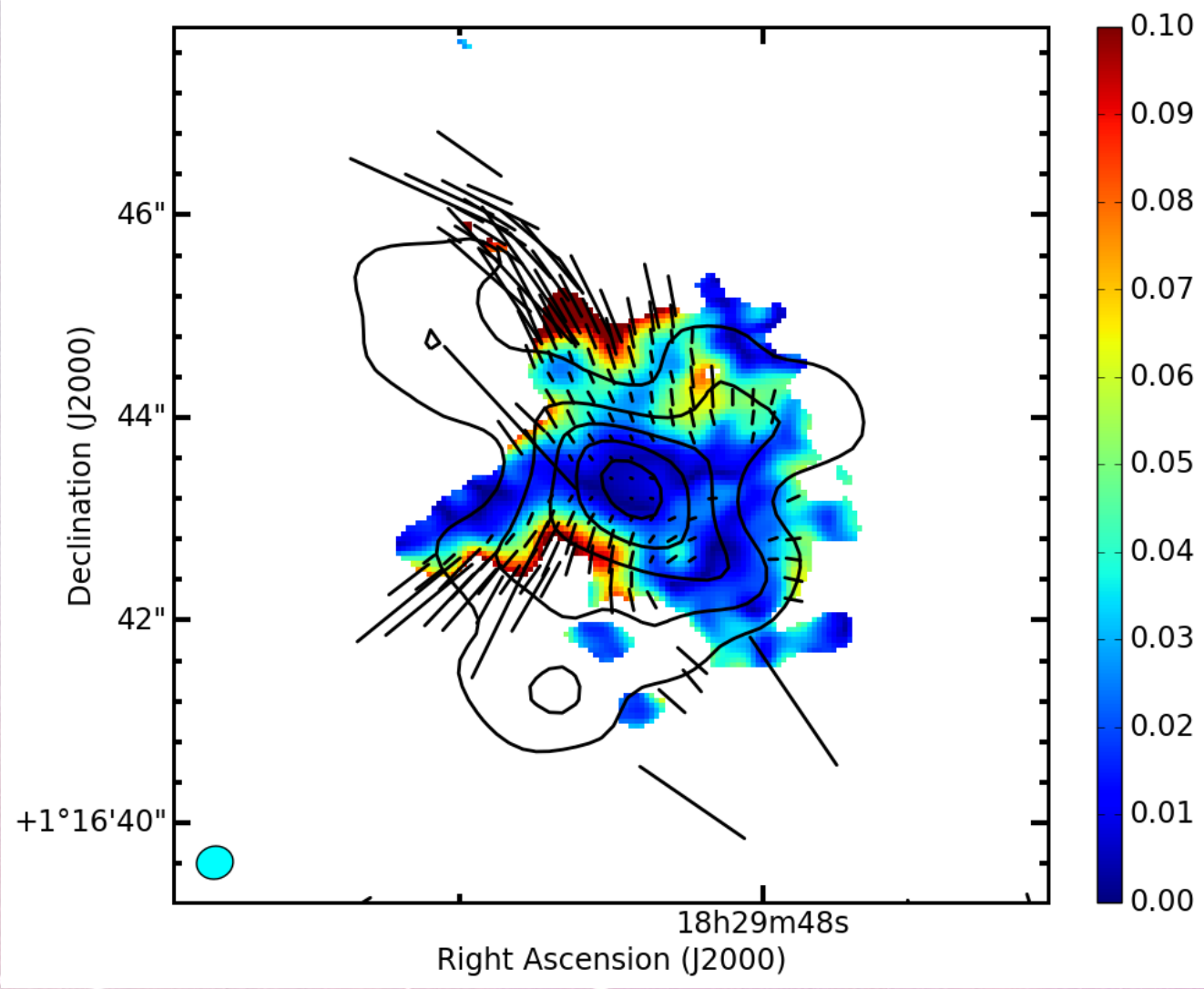


Moment 0 map



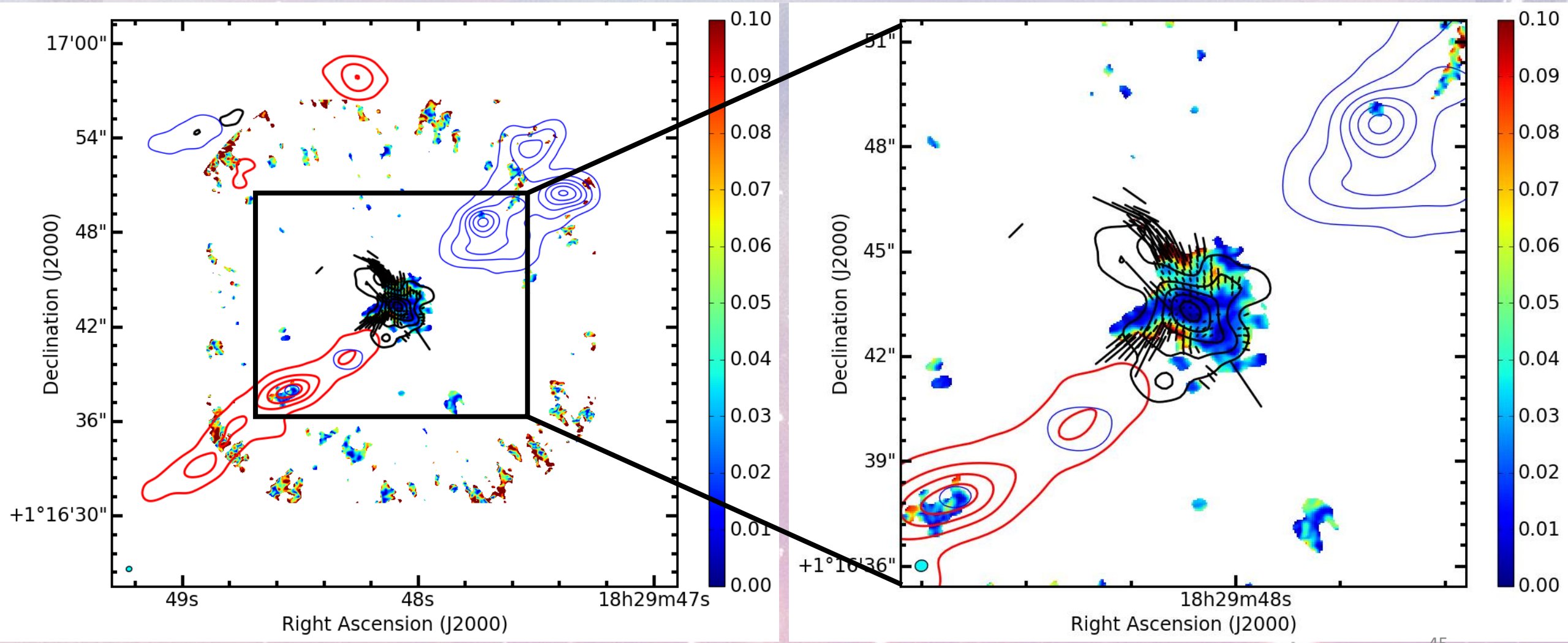
Moment 0 map(contour)
Moment 1 map(colar scale)

Serpens_Emb8
Moment Map of $C^{18}O$ (J=2-1) and Polarization Map

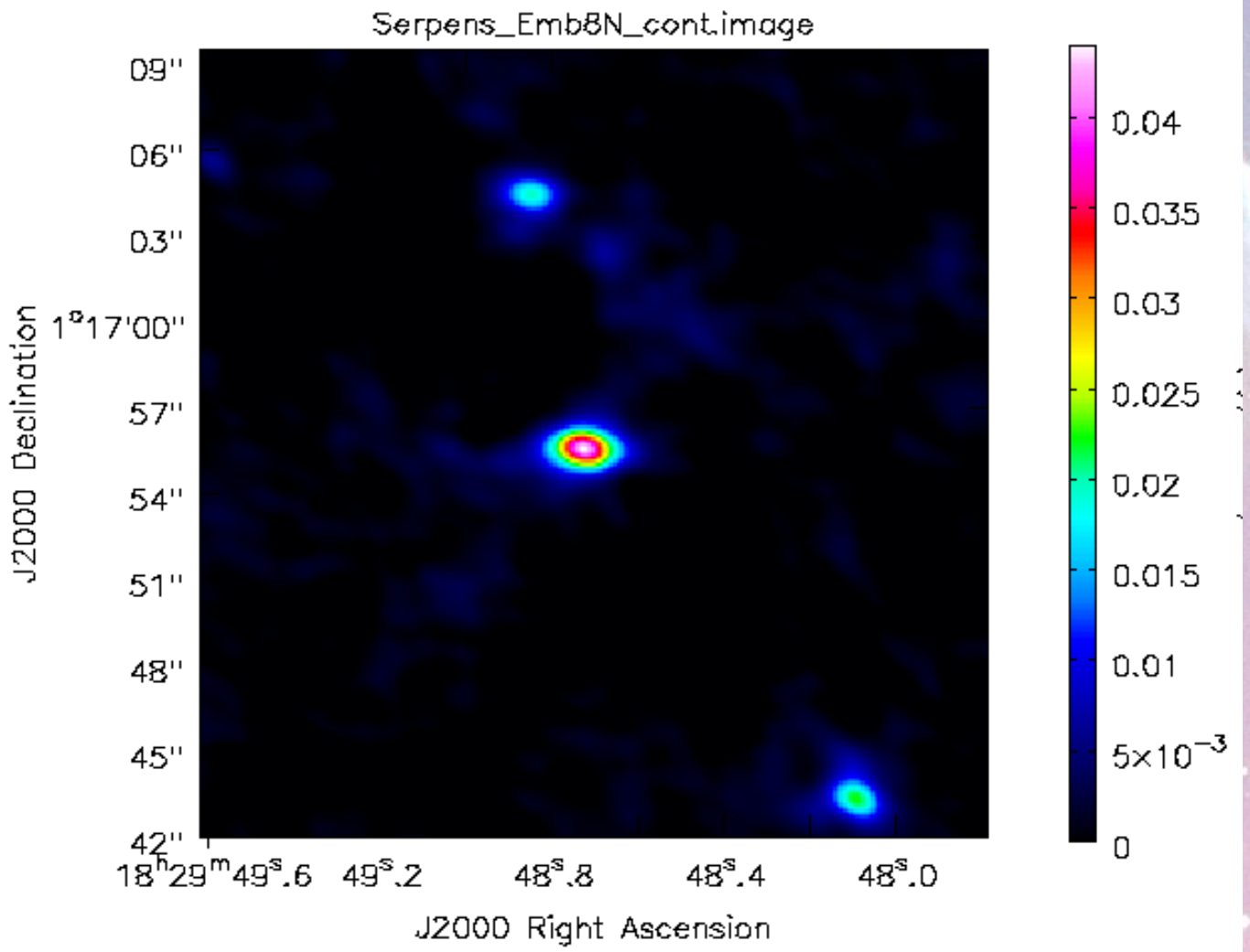


- $C^{18}O$ moment 0 map(contour)
- Polarization degree(color scale)
- Polarization angle(line)

Serpens_Emb8
Moment Map of SiO(J=5-4)、$C^{18}O(J=2-1)$ and Polarization Map



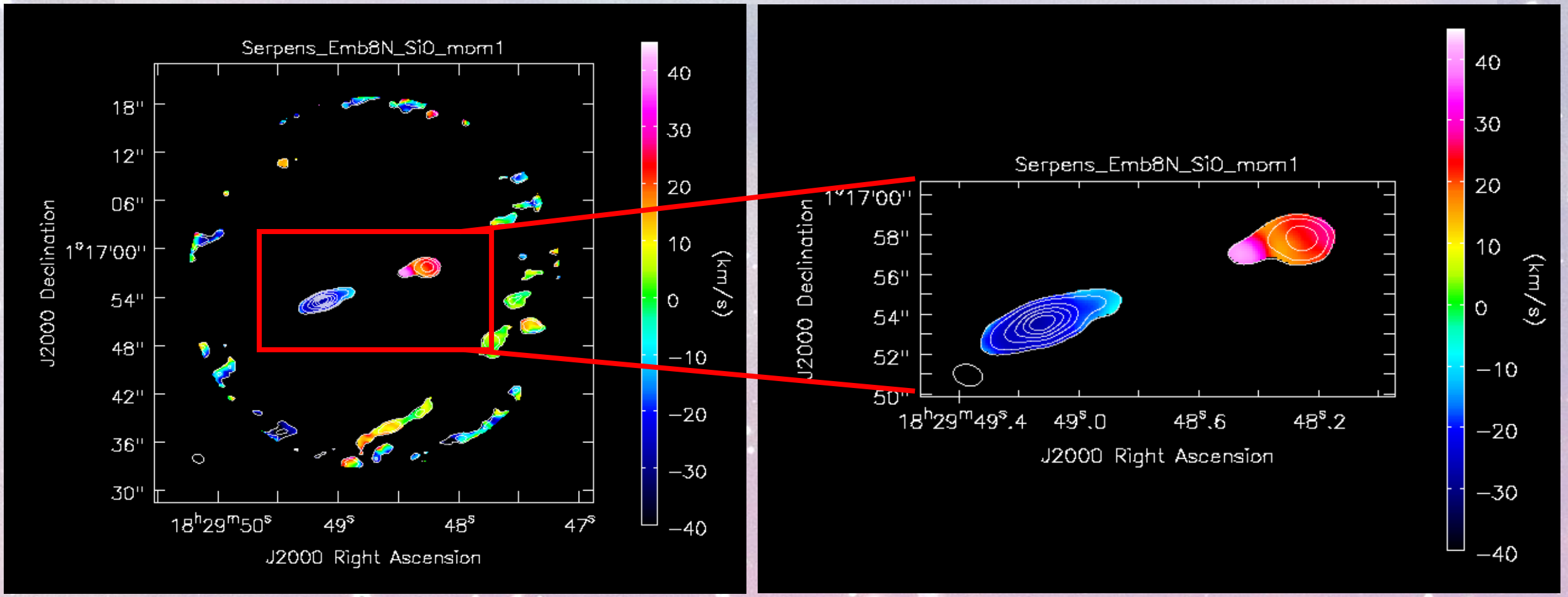
Serpens_Emb8N



ALMA Archive Band6
216.080~232.164 GHz
Continuum map

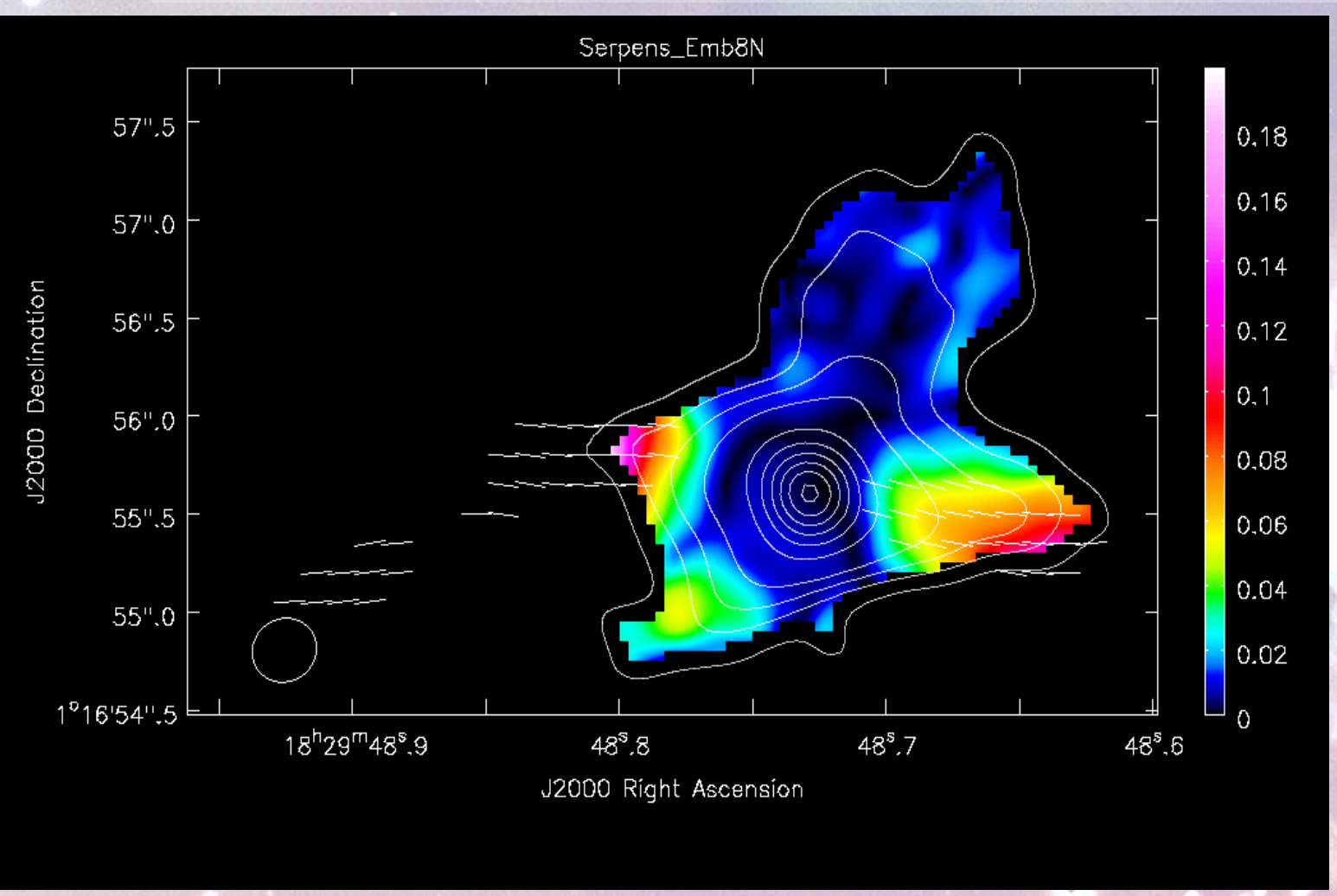
Constellation	Serpens
Distance	415 pc
stage	Class 0
RA(J2000)	18h29m48.7
Dec(J2000)	+01d16m55s

Serpens_Emb8N SiO Moment Map



Moment 1(color scale)
Moment 0(contour)

Serpens_Emb8N Polarization Map

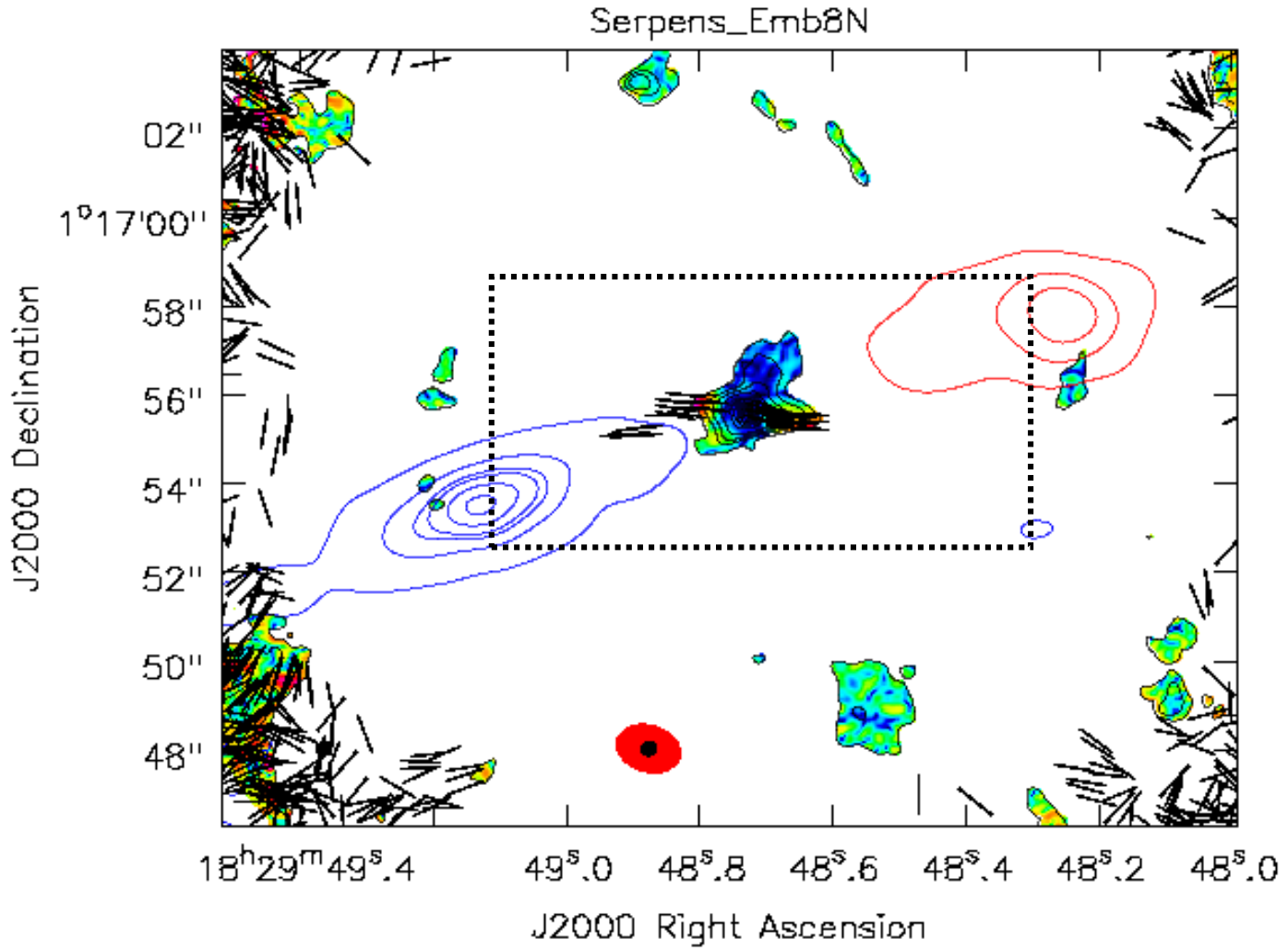


ALMA Archive Band7 335.495 ~351.497GHz

- Polarization degree(color scale)
- Total intensity(contour)
- Polarization angle(line)

A contour ellipse in the bottom left corner denotes the beam size.

Serpens_Emb8N
Moment Map and Polarization Map

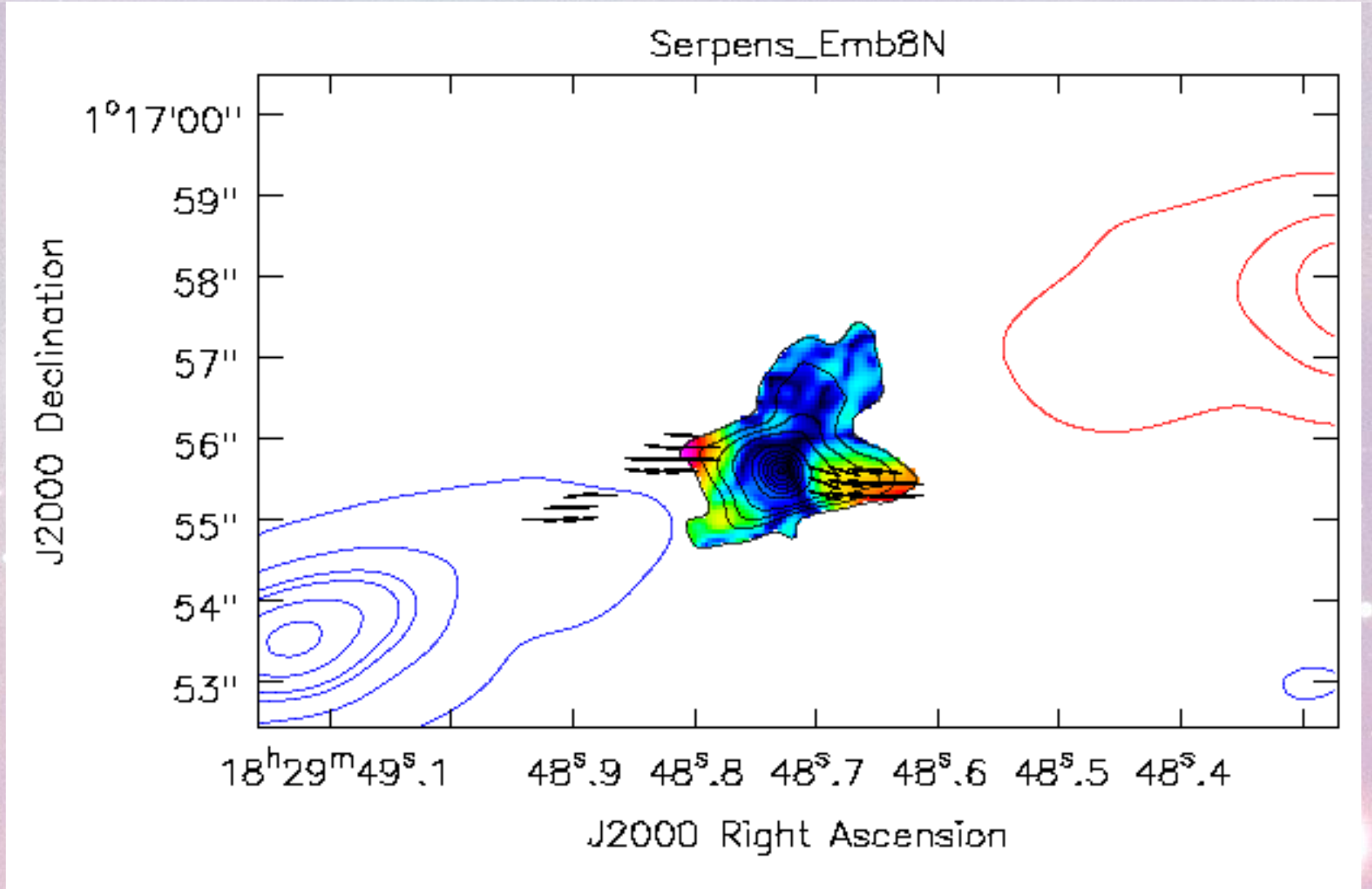


- Polarization degree(color scale)
- Total intensity(light contour)
- direction of polarization(red line)
- Serpens_Emb8N_SiO moment 0 (black contour)

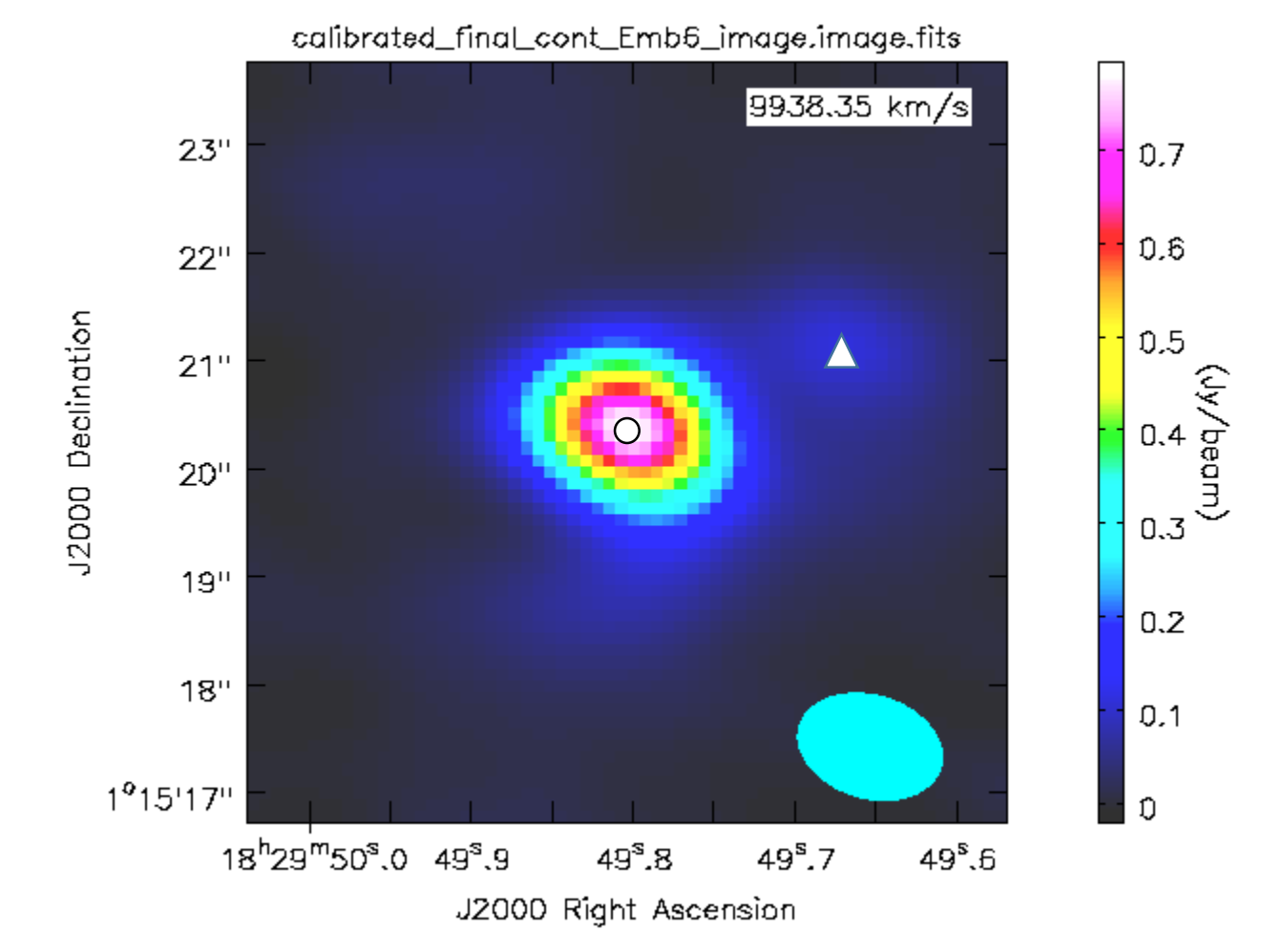
A filled ellipse in the bottom corner denotes the beam size.
(red=SiO, black=polarization map)

The dashed gray zoom box represents the region pictured in the next page.

Serpens_Emb8N
Moment Map and Polarization Map



Serpens_Emb6



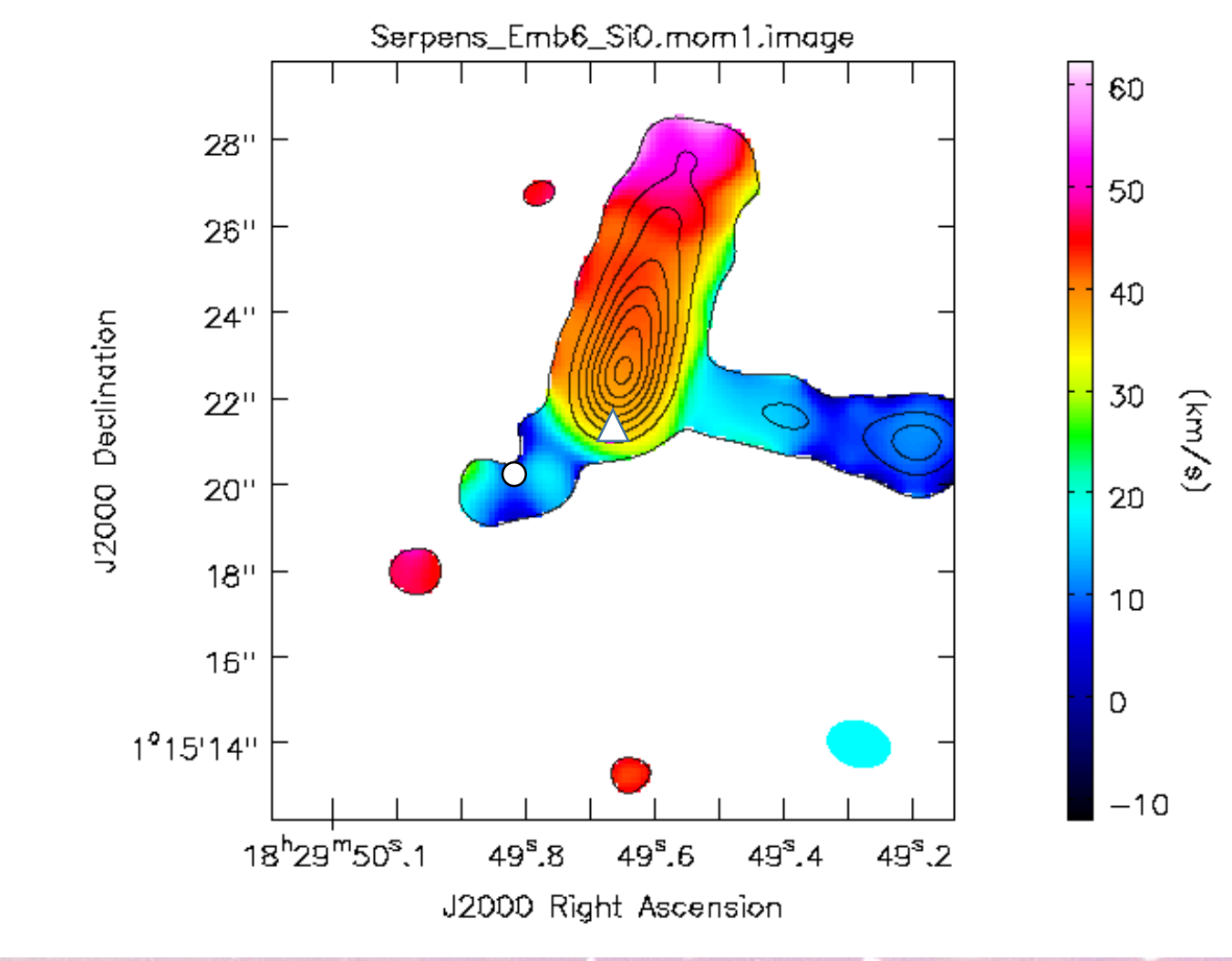
ALMA Archive Band6 216.080~232.164GHz

Constellation	Serpens
RA(J2000)	18h29m49.8
Dec(J2000)	+01d15m20s
Distance	415 pc

Ser-emb 6 (also called Serp-FIR1 and Serp-SMM1) is the brightest (sub)millimeter source in the Serpens Main cluster.

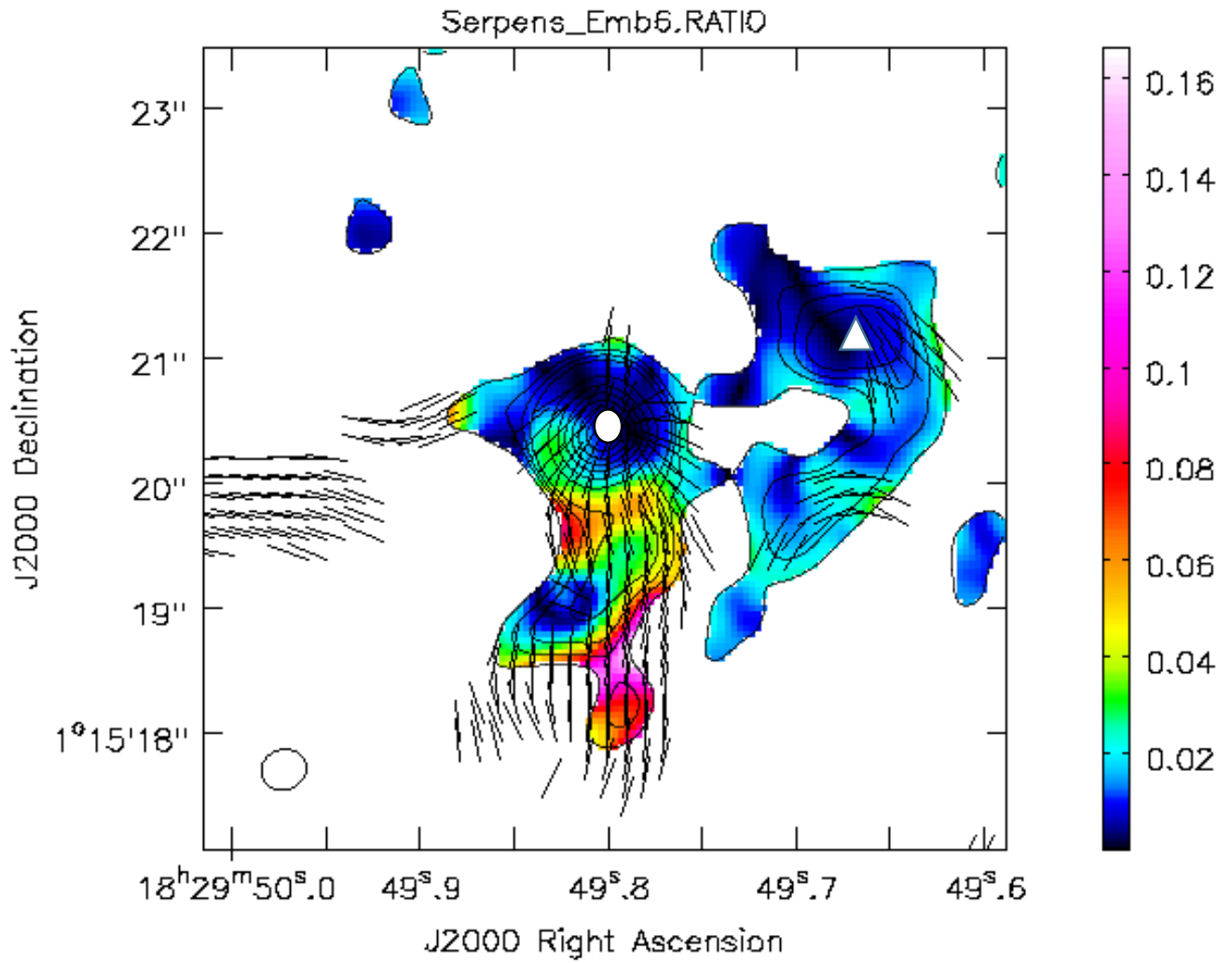
The images are centered on the main source SMM1-a (white circle: J2000 = 18:29:49.81, J2000 = +1:15:20.32); the fainter source 200 to the WNW is SMM1-b (white triangle: J2000 = 18:29:49.67, J2000 = +1:15:21.07).

Serpens_Emb6 Moment Map of SiO(J=5-4)



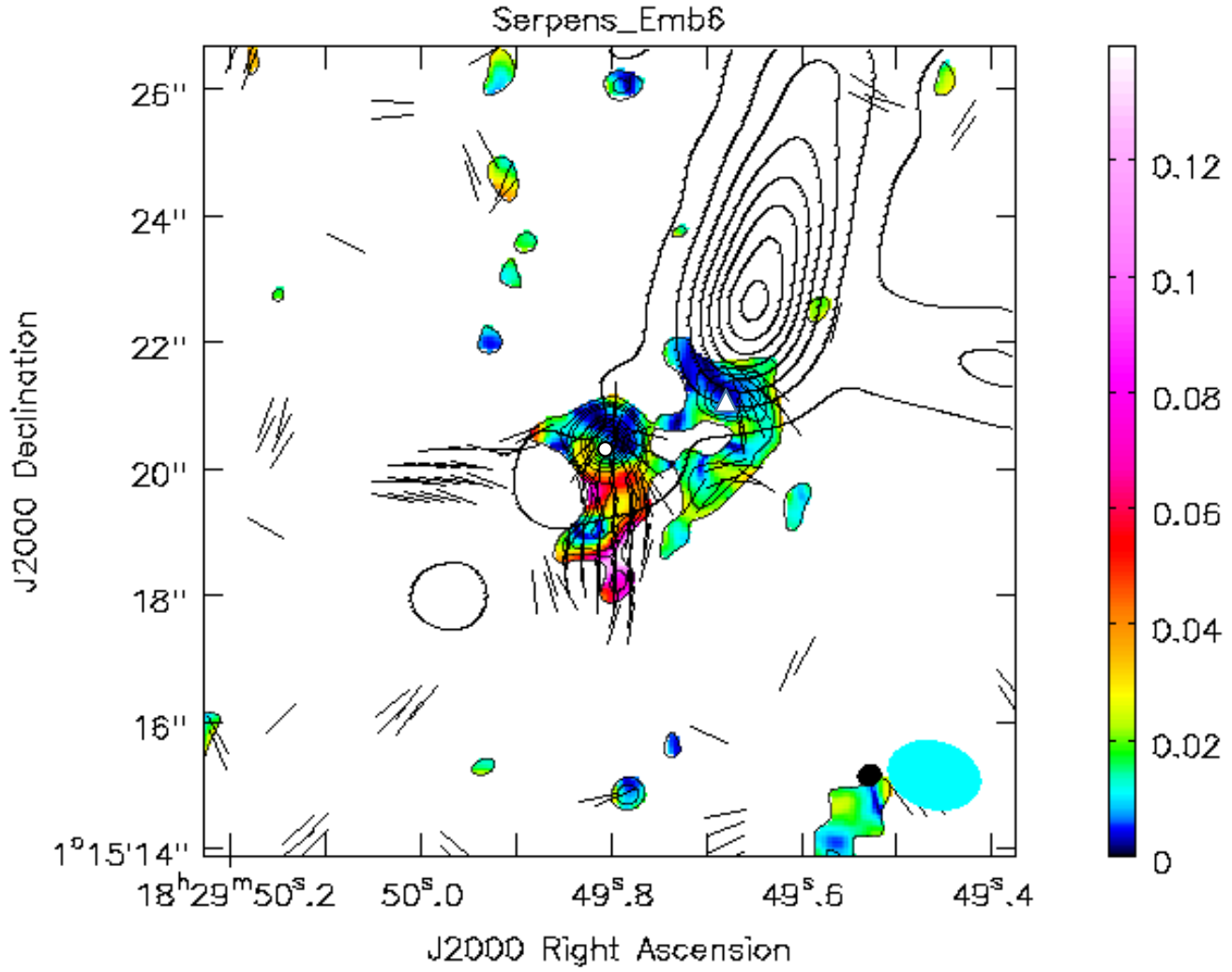
- Moment 0 map(contour)
- Moment 1 map(colar scale)

Serpens_Emb6 Polarization Map



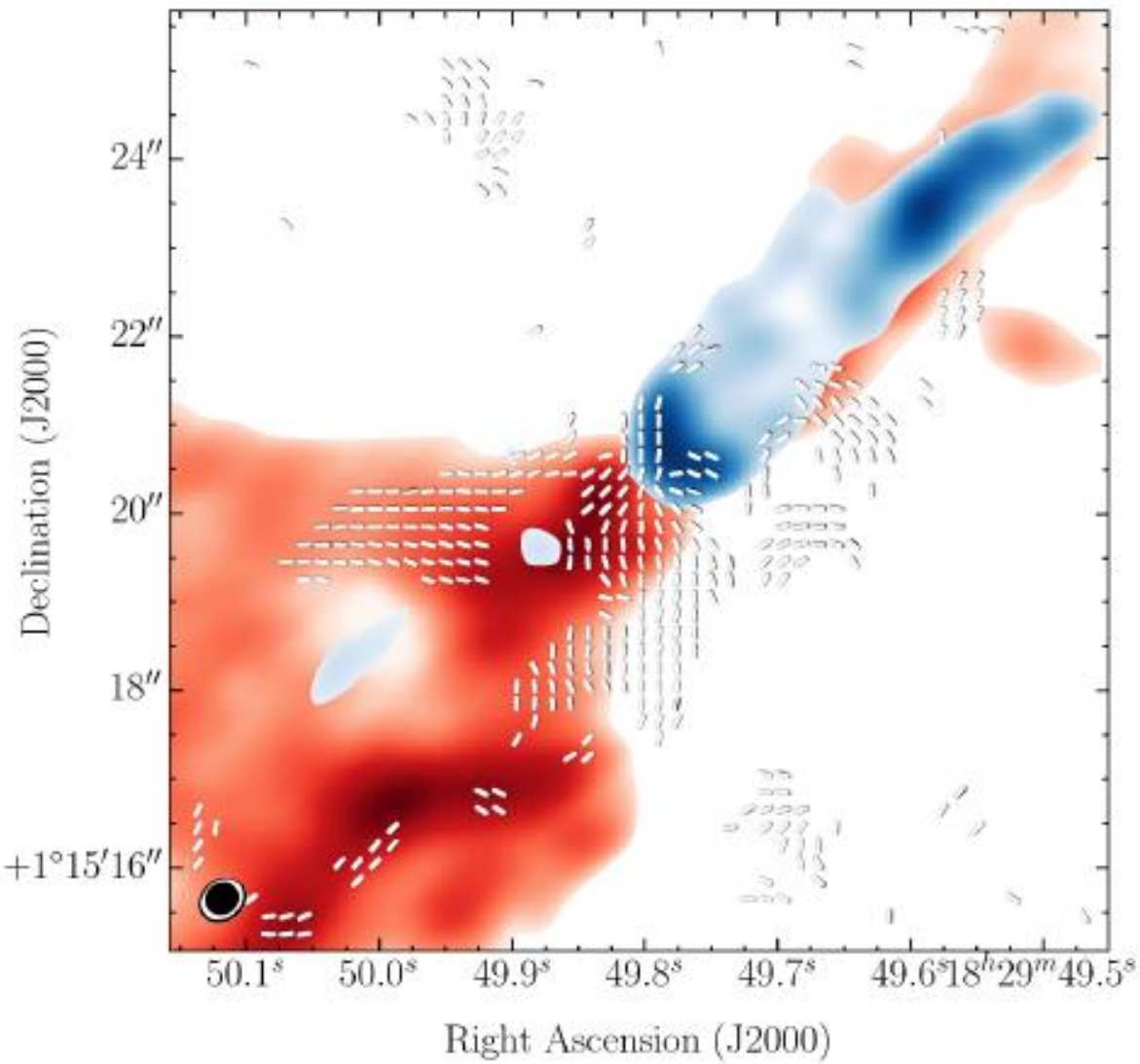
- Polarization degree(color scale)
- Total intensity(contour)
- Polarization angle(line)

Serpens_Emb6
Moment Map of SiO(J=5-4) and Polarization Map



- SiO(J=5-4) Moment 0 map(contour)
- Polarization Map(color scale)
- Position angle(Line segments)

Serpens_Emb6
Moment Map of CO(J=2-1)



Low-velocity red- and blue shifted CO(J =2-1) from the ALMA data (red and blue contours, respectively), The CO velocity ranges are 2 to 15km/s (redshifted) and –20 to –5km/s (blueshifted) relative to the VLSR of SMM1 of 8.5km/s (Lee et al. 2014). Line segments represent the inferred magnetic field orientation

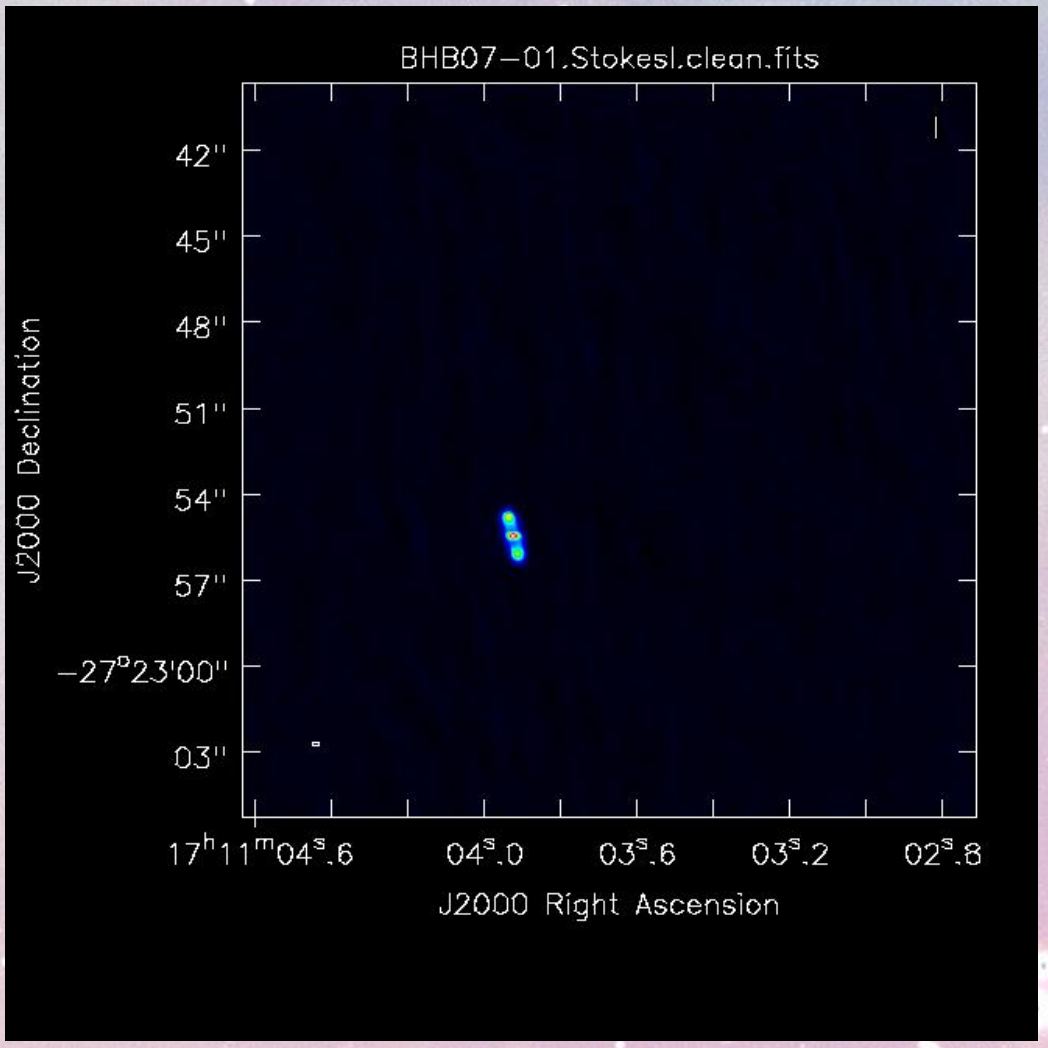
(Hull et al .2017)

Barnard 59

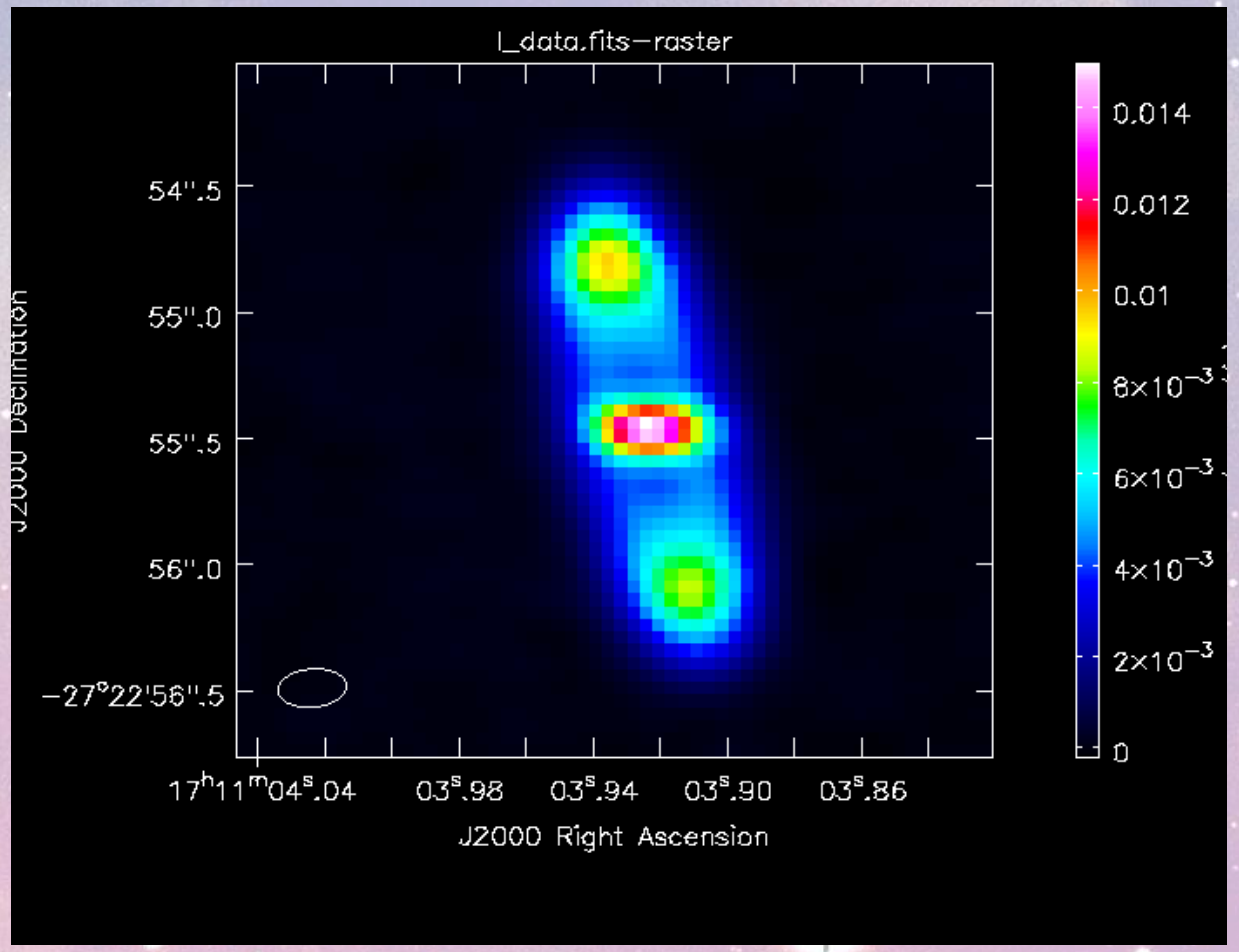
a dark nebula in the Ophiuchus constellation and a part of the Dark Horse Nebula.

https://www.eso.org/public/videos/eso1233b/

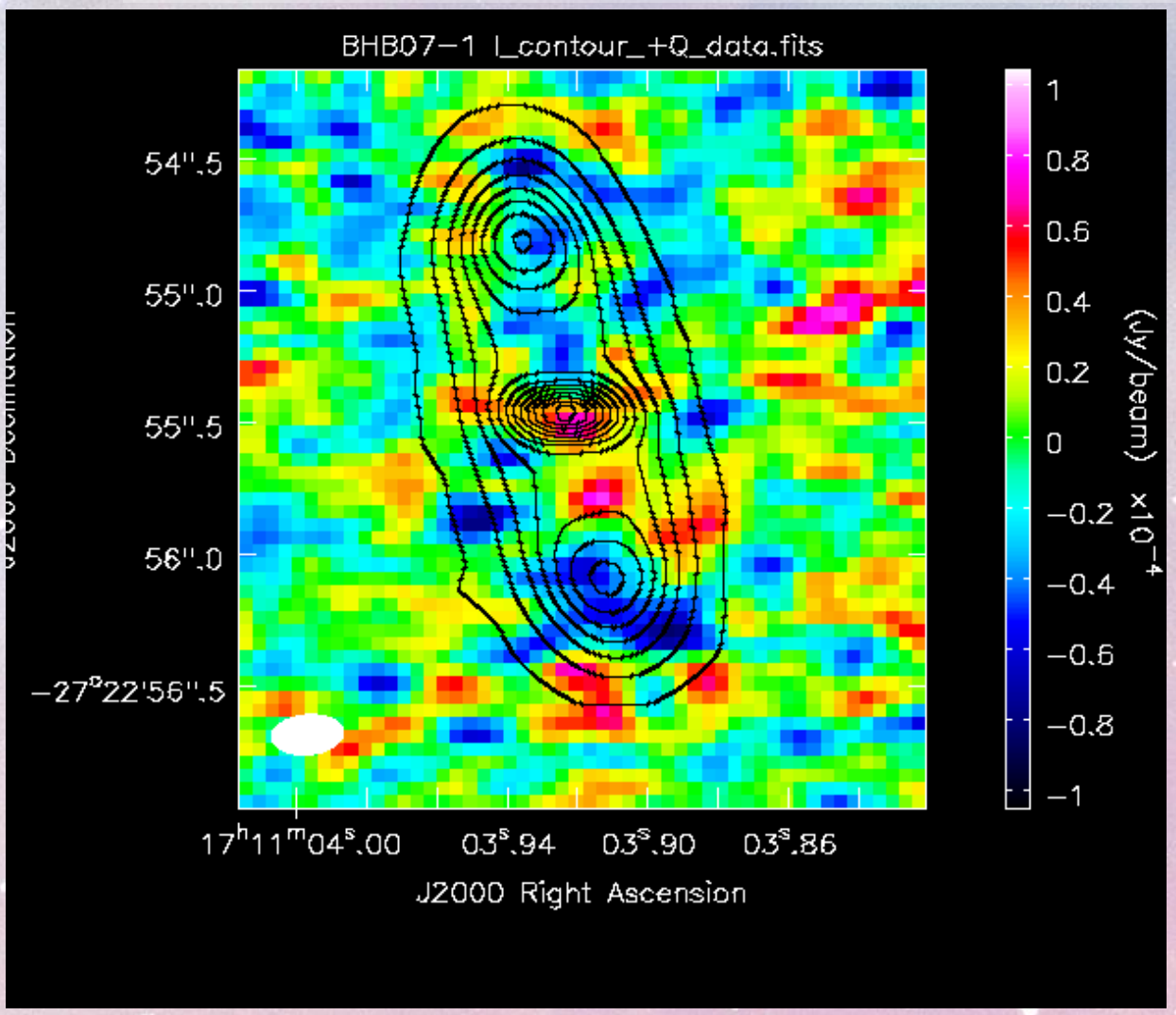
BHB07-01



- Stokes I

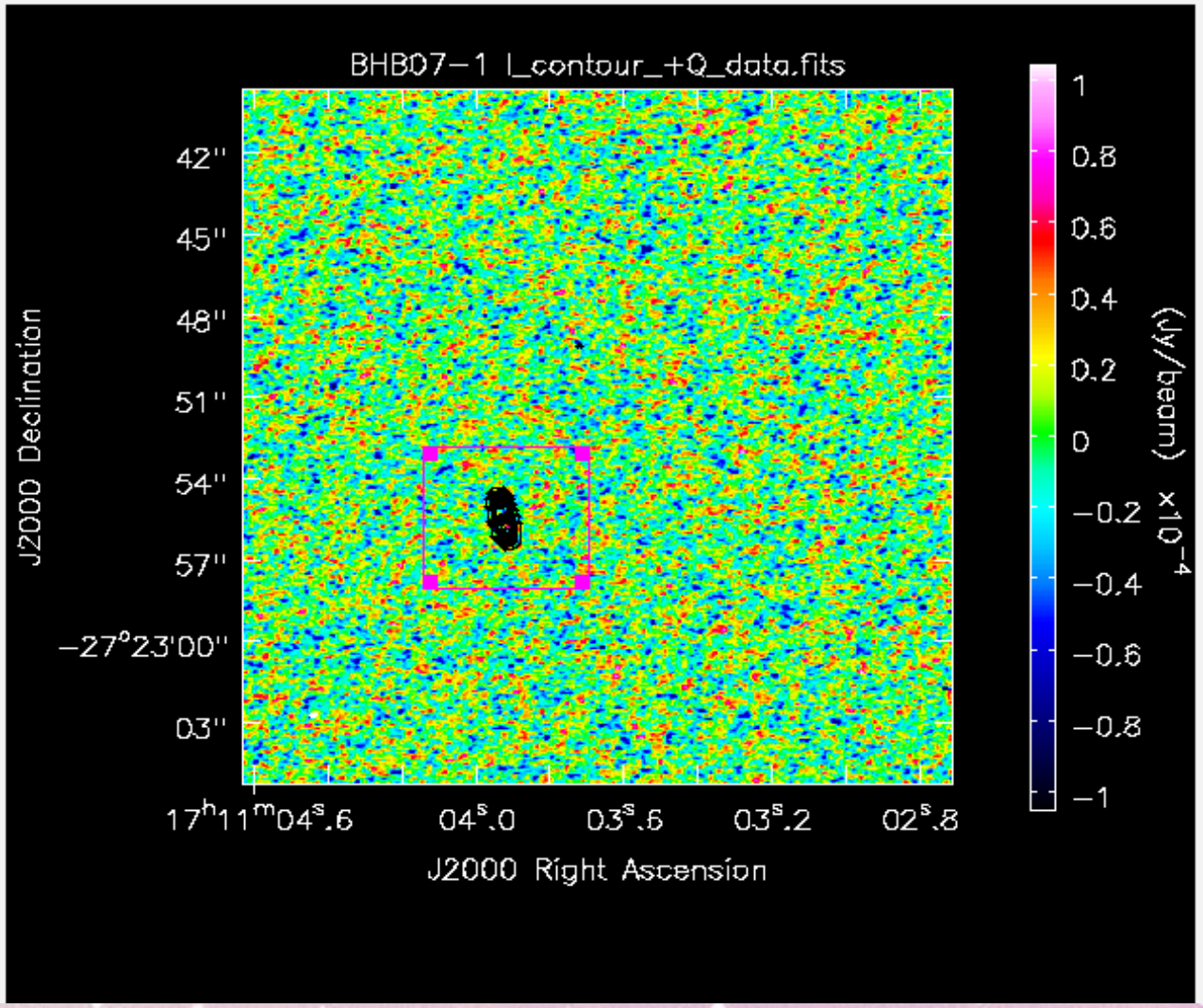


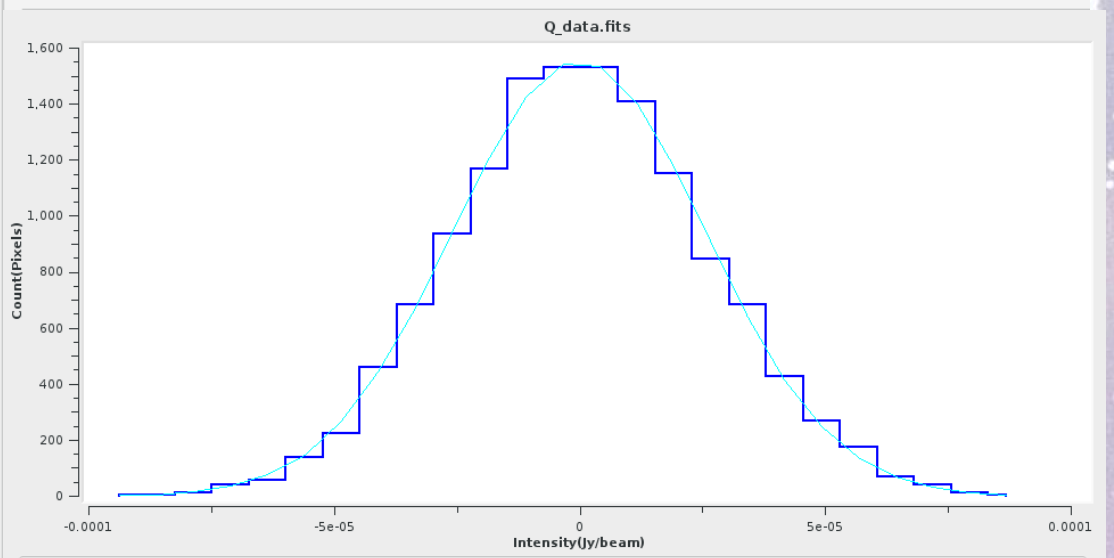
BHB07-01



- Stokes Q
- Stokes I contour

BHB07-01 Stoke Q

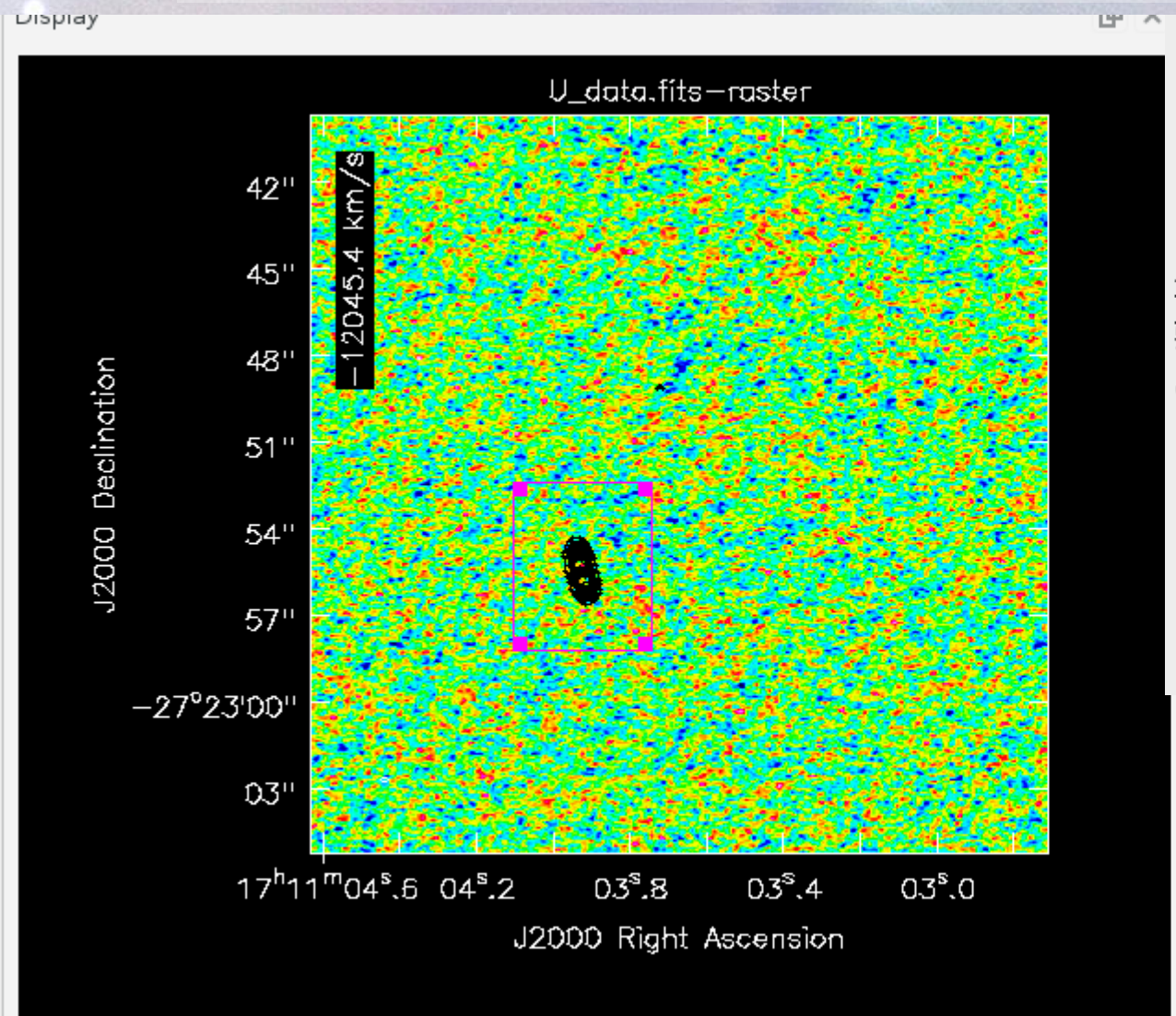


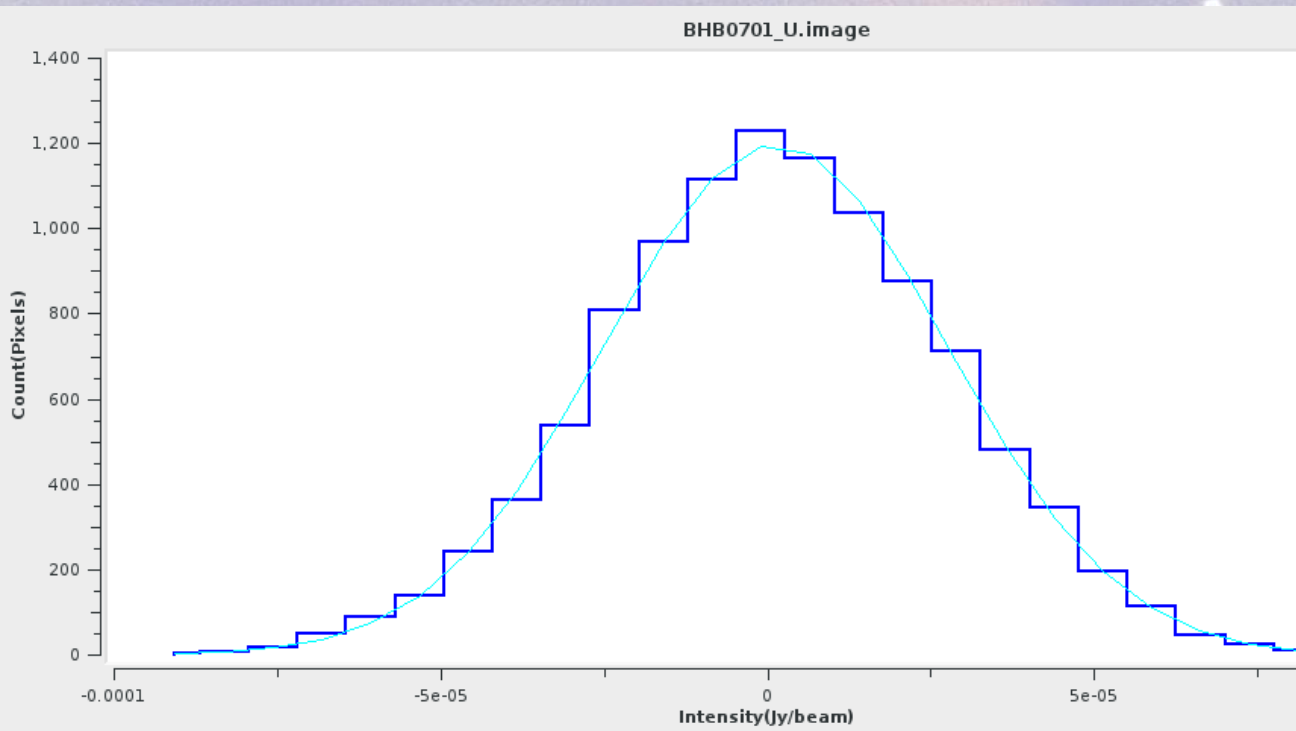


very low signal-to noise ratios
weak signals

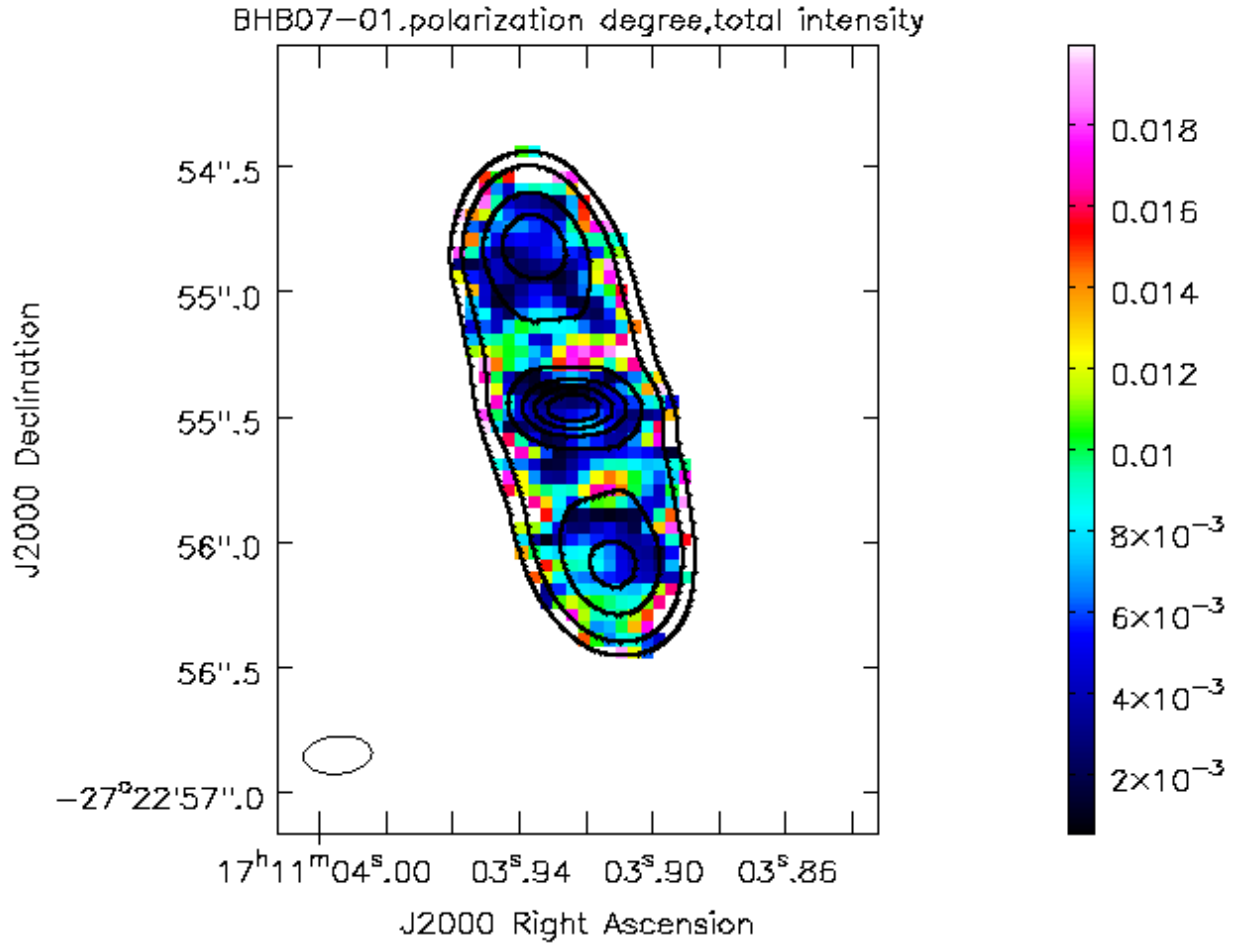
Regions Animators

BHB07-01 Stoke U





BHB07-01

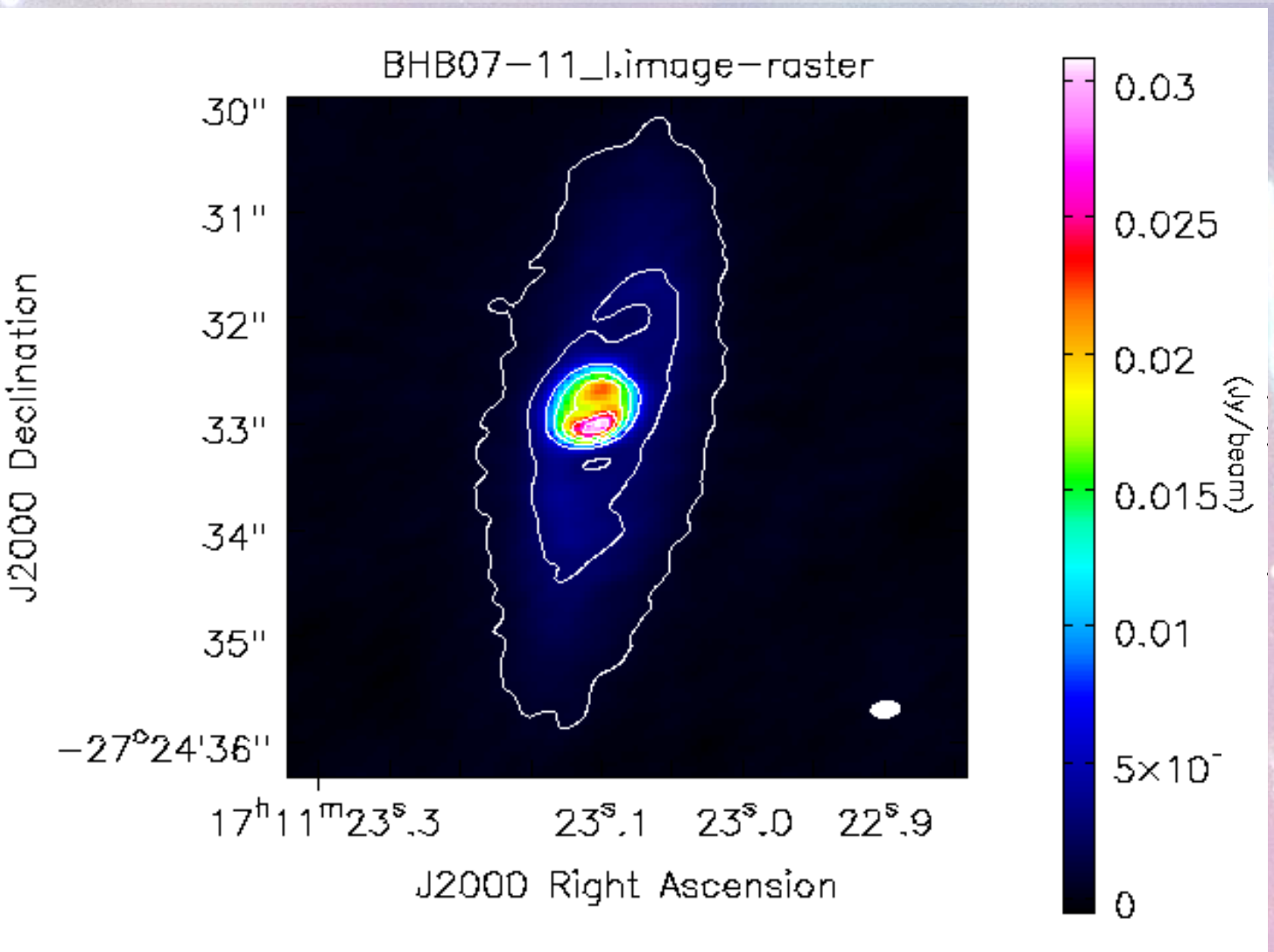


- Polarization percentage(color scale)
- Total intensity(contour)

BHB07-11

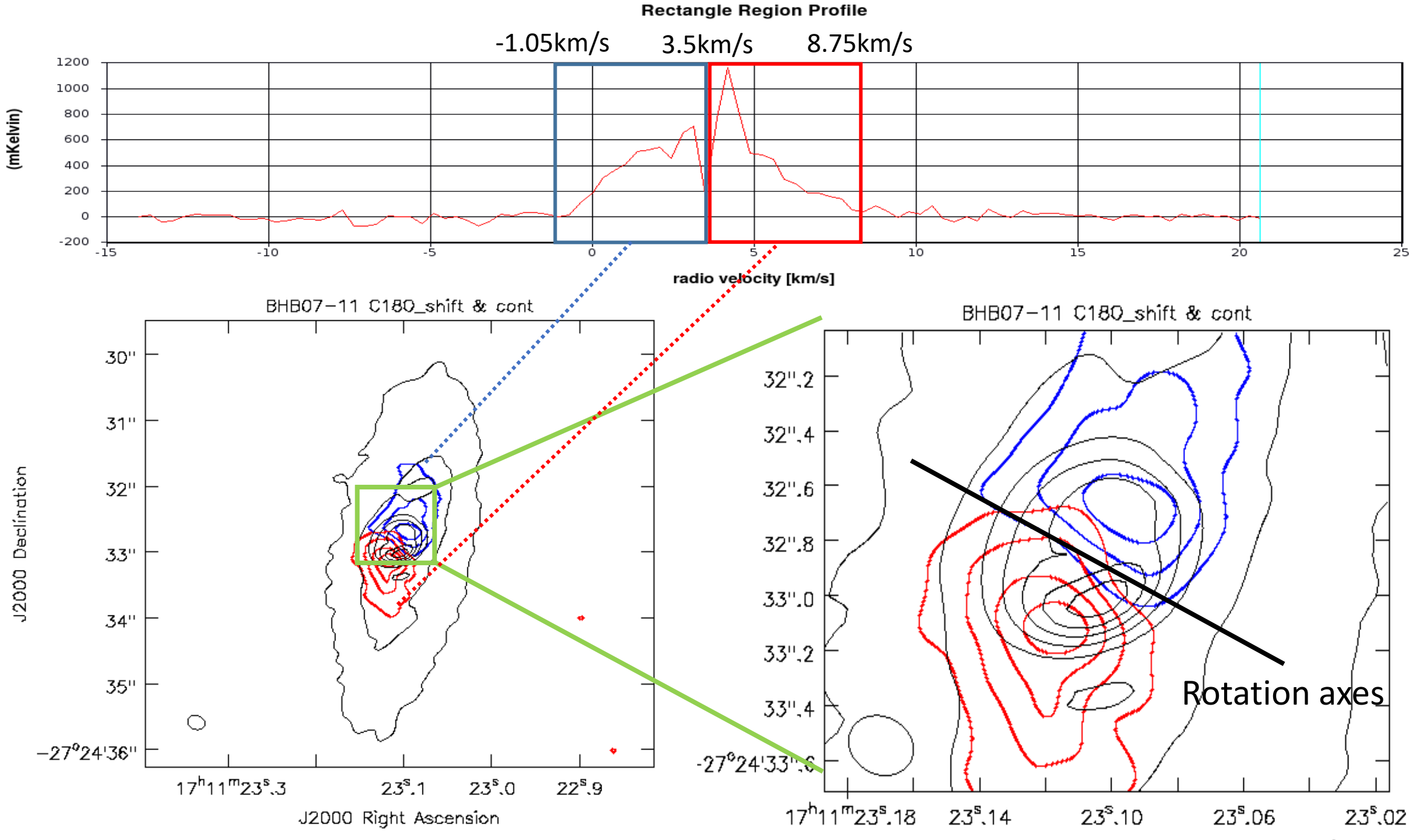
Constellation	Ophiuchus
RA(J2000)	17h11m23.0
Dec(J2000)	-27d24m33
Distance	145 pc
Stage	Class I

BHB07-11



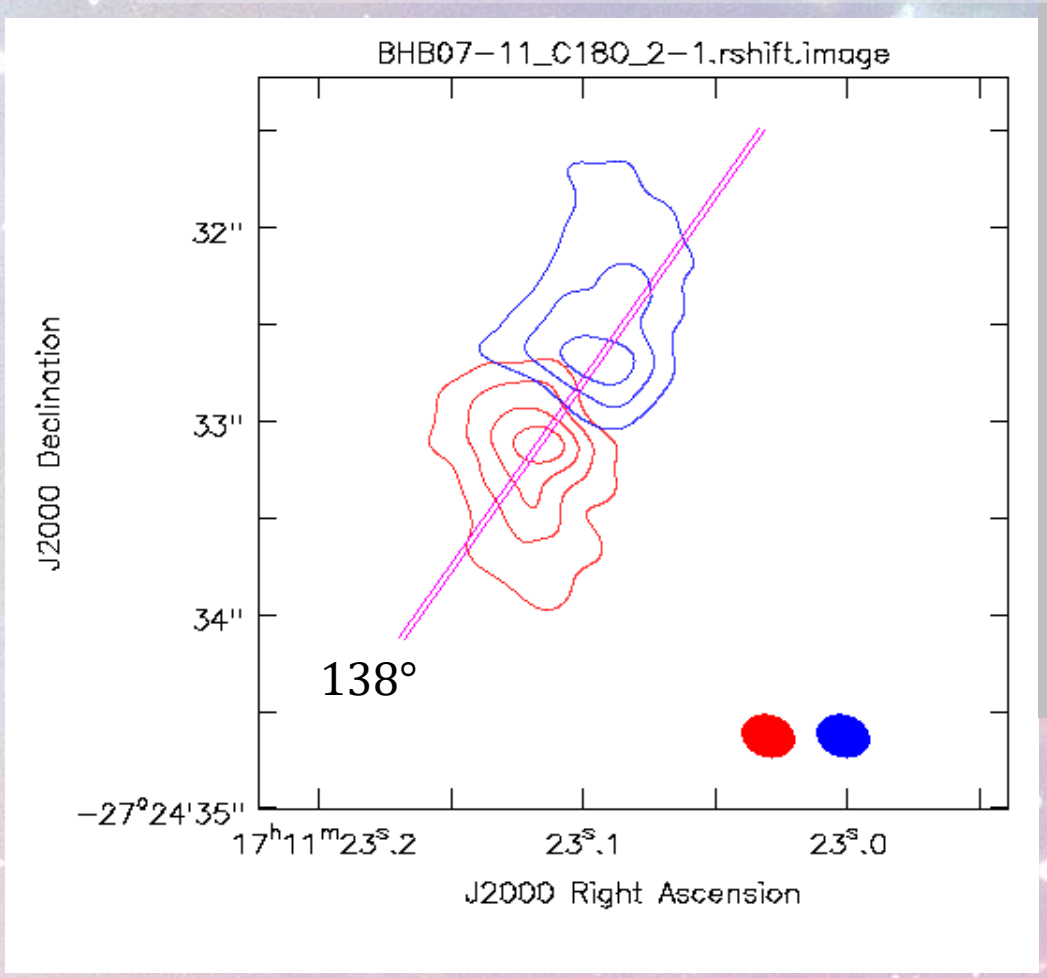
ALMA Archive Band6 223 ~243GHz

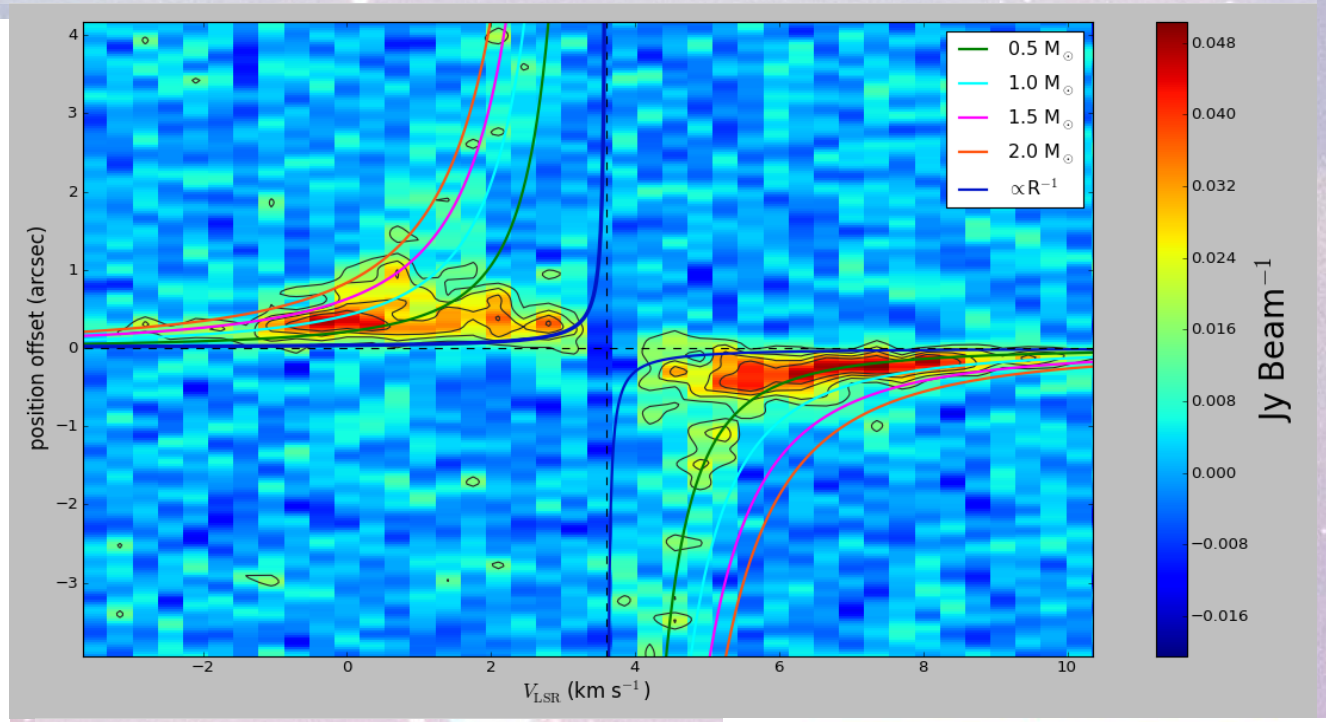
- The intensity contrast between the envelope (and spirals) and the disk is clear.
- Total intensity with contours of 5, 25, 75, 125, 175, 225, 275 and 325 times the noise level (0.1mJy/beam)


Rectangle Region Profile
-1.05km/s
3.5km/s
8.75km/s
(mKelvin)
radio velocity [km/s]
BHB07−11 C18O_shift & cont
J2000 Declination
J2000 Right Ascension
BHB07−11 C18O_shift & cont
Rotation axes

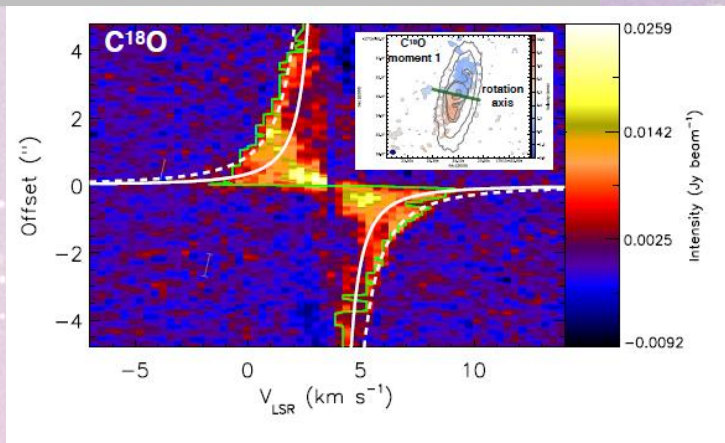
BHB07-11 Position-Velocity diagram

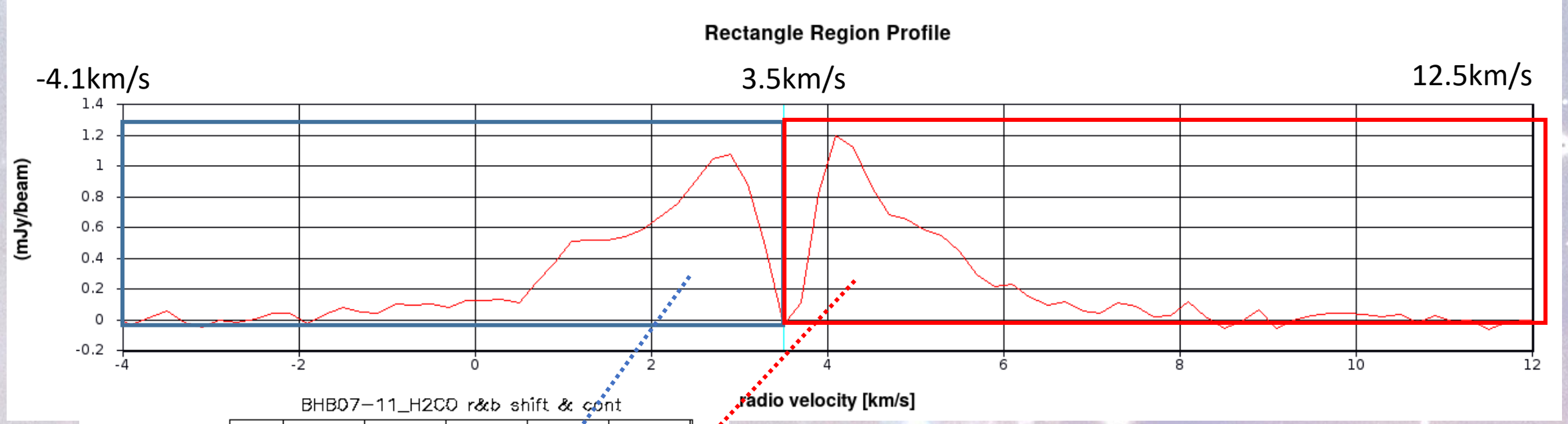
$C^{18}O(J = 2 - 1)$

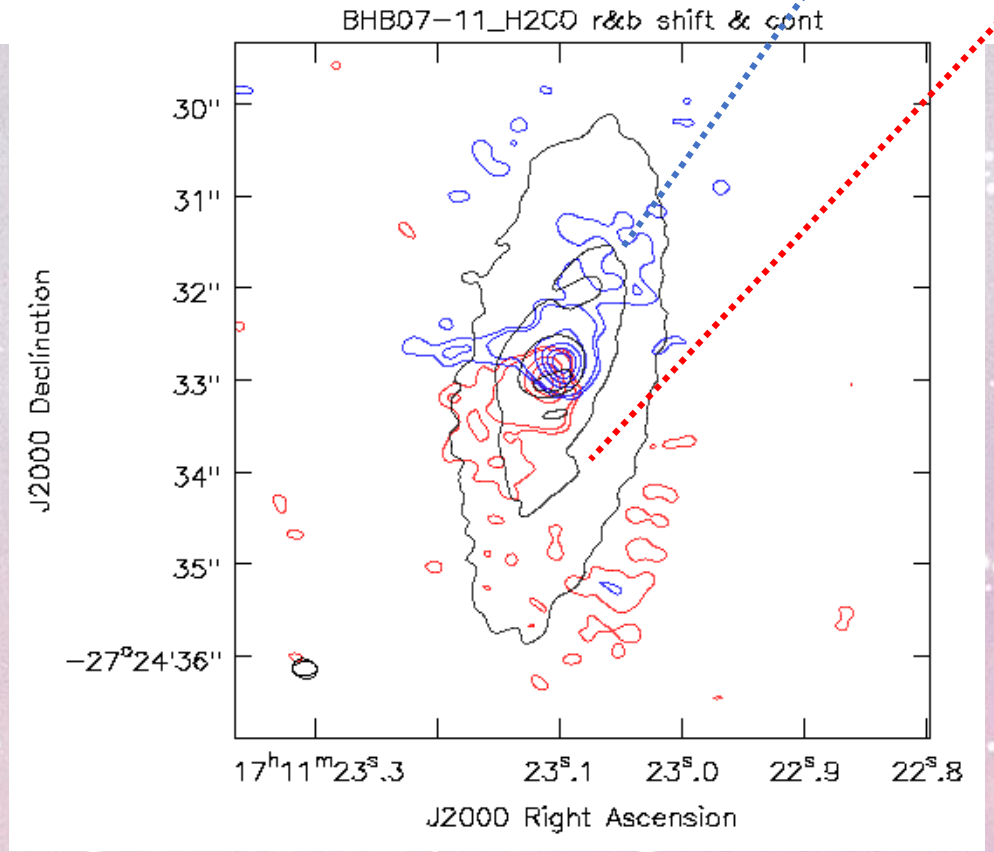




the stellar mass is estimated to be $1.7 \pm 0.4 M_{\odot}$ (F. O. Alves et al. 2017)
Or $0.73 M_{\odot}$ (Hara et al. 2013)





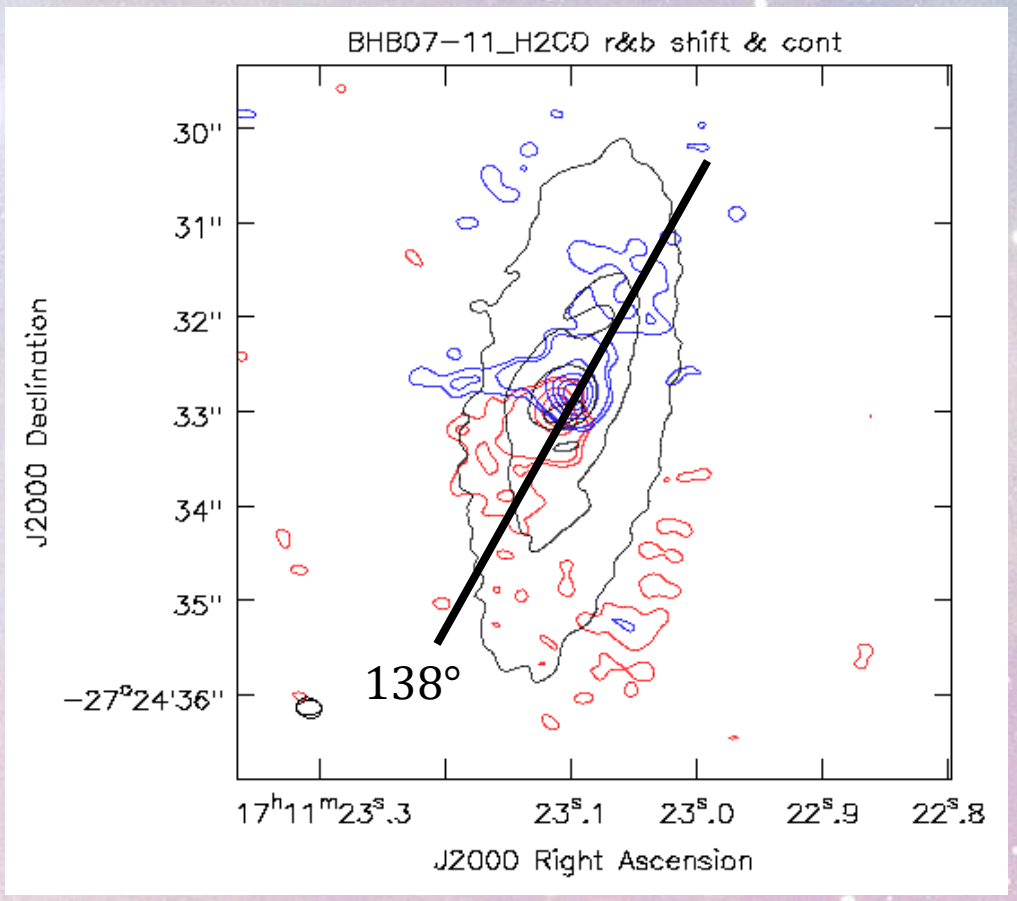


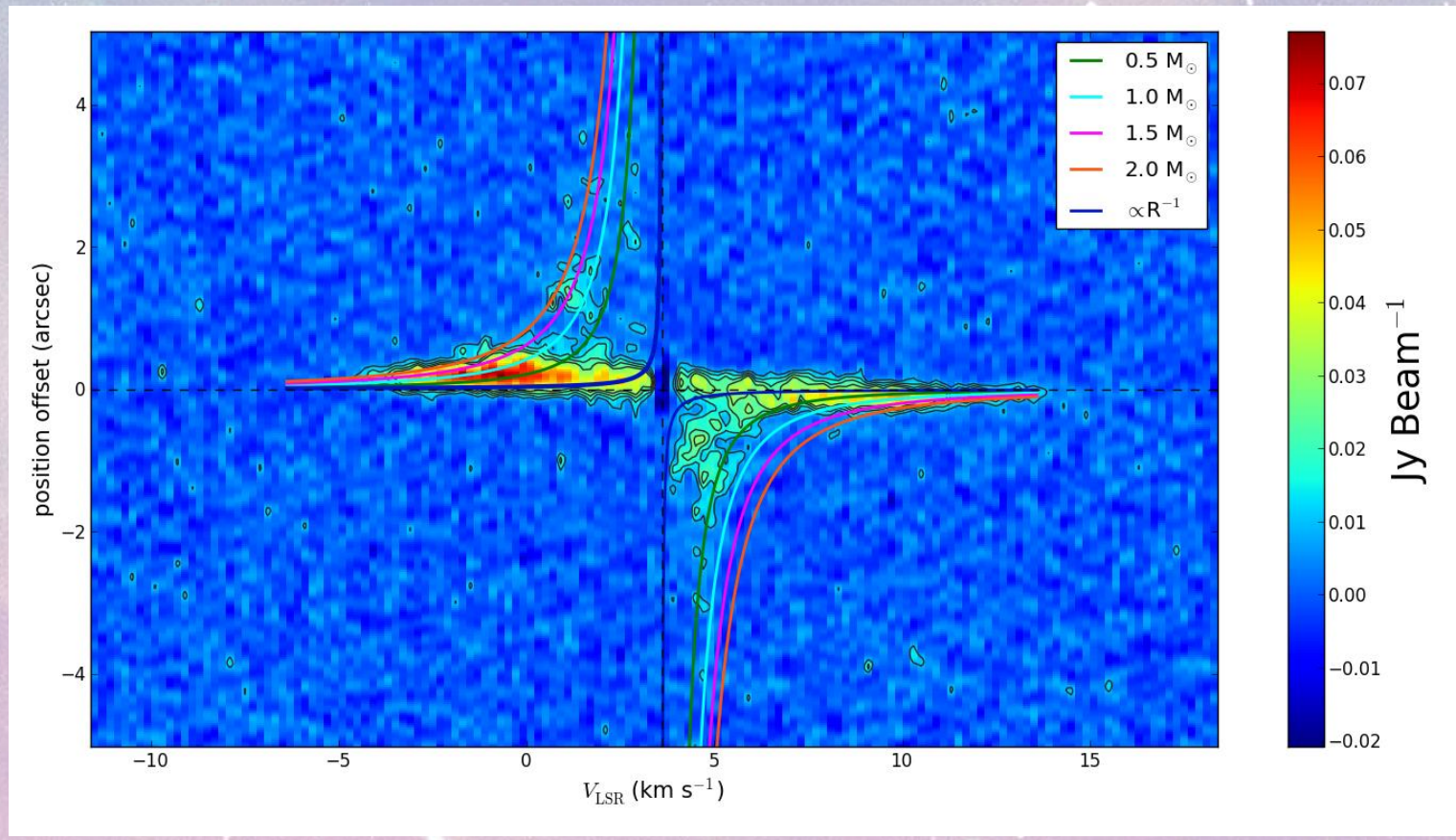
- Blue shift and red shift of H^2CO emission line
- continuum emission(black contours)

BHB07-11 Position-Velocity diagram

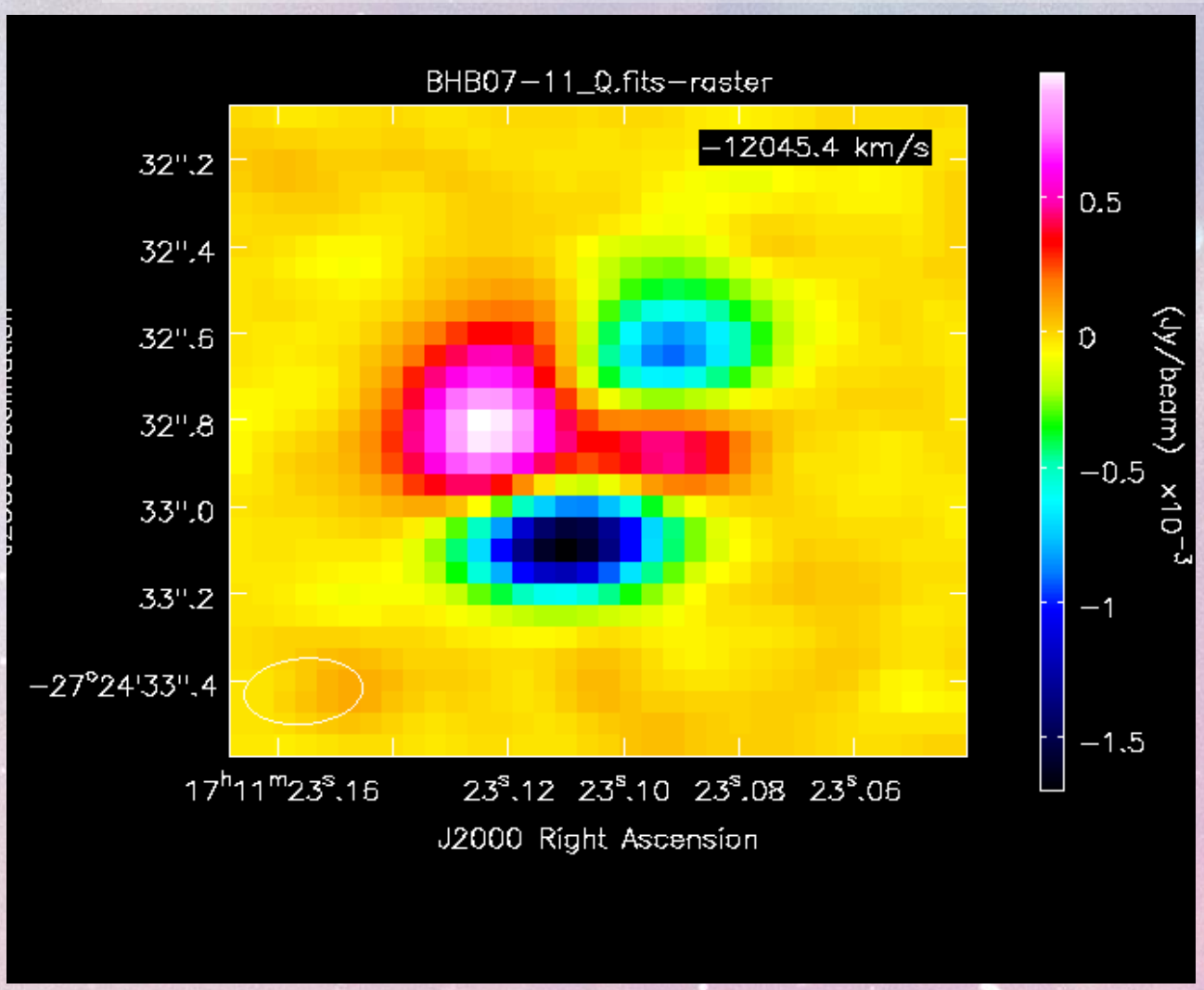
$H^2CO(J = 303 - 202)$

ALMA archive band6 218.209 -- 218.231GHz



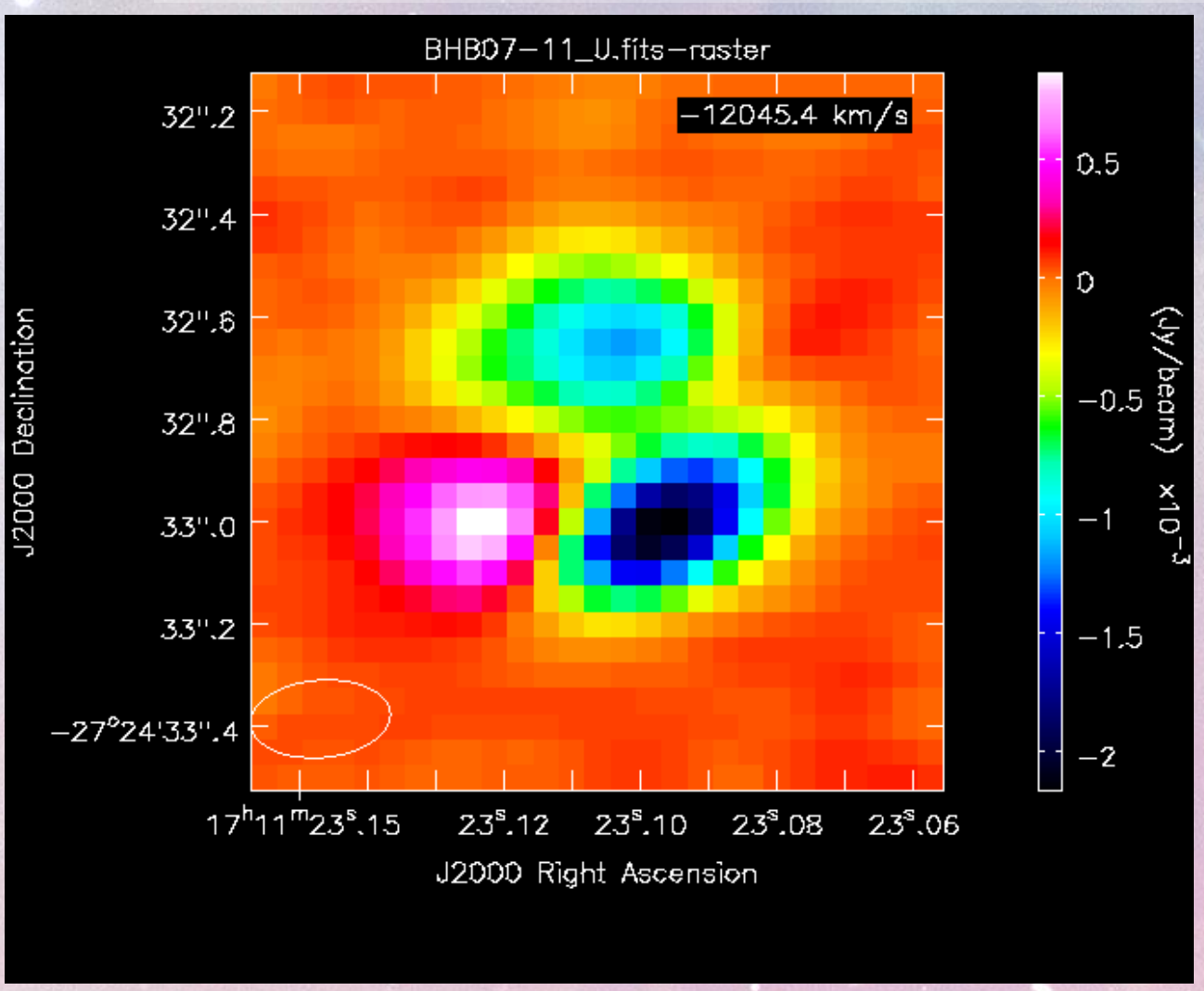


BHB07-11



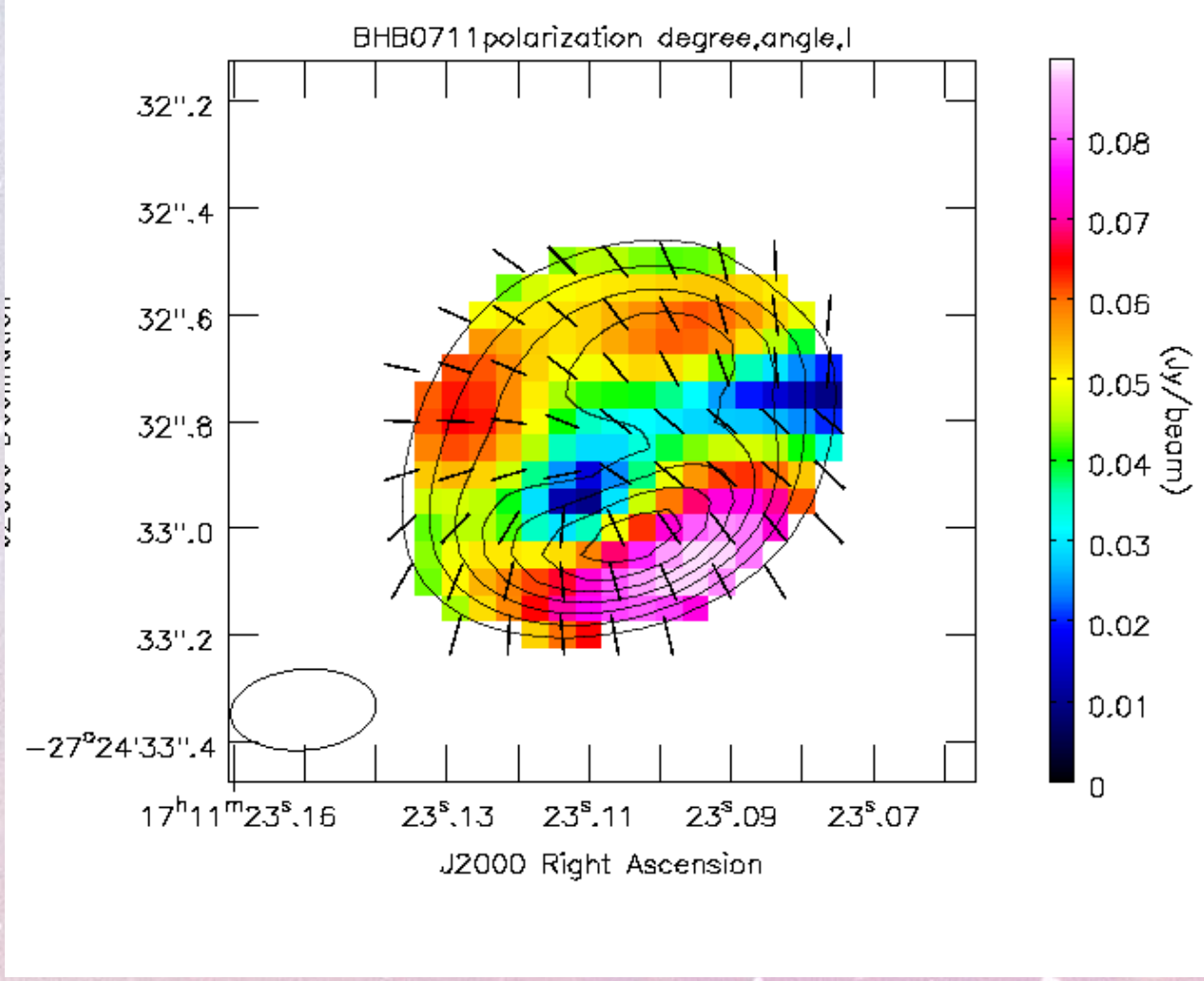
- Stoke Q diagram

BHB07-11



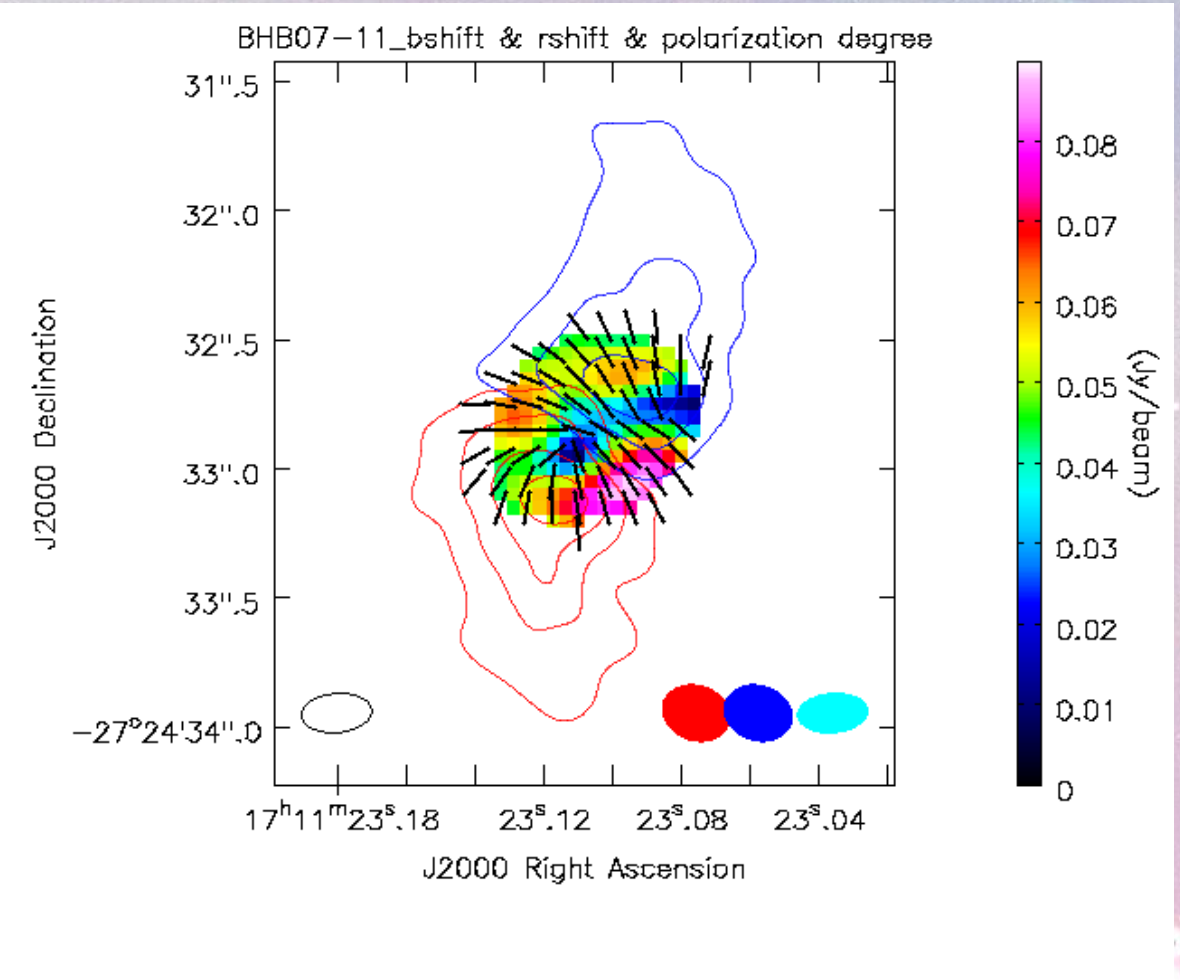
- Stoke Q diagram

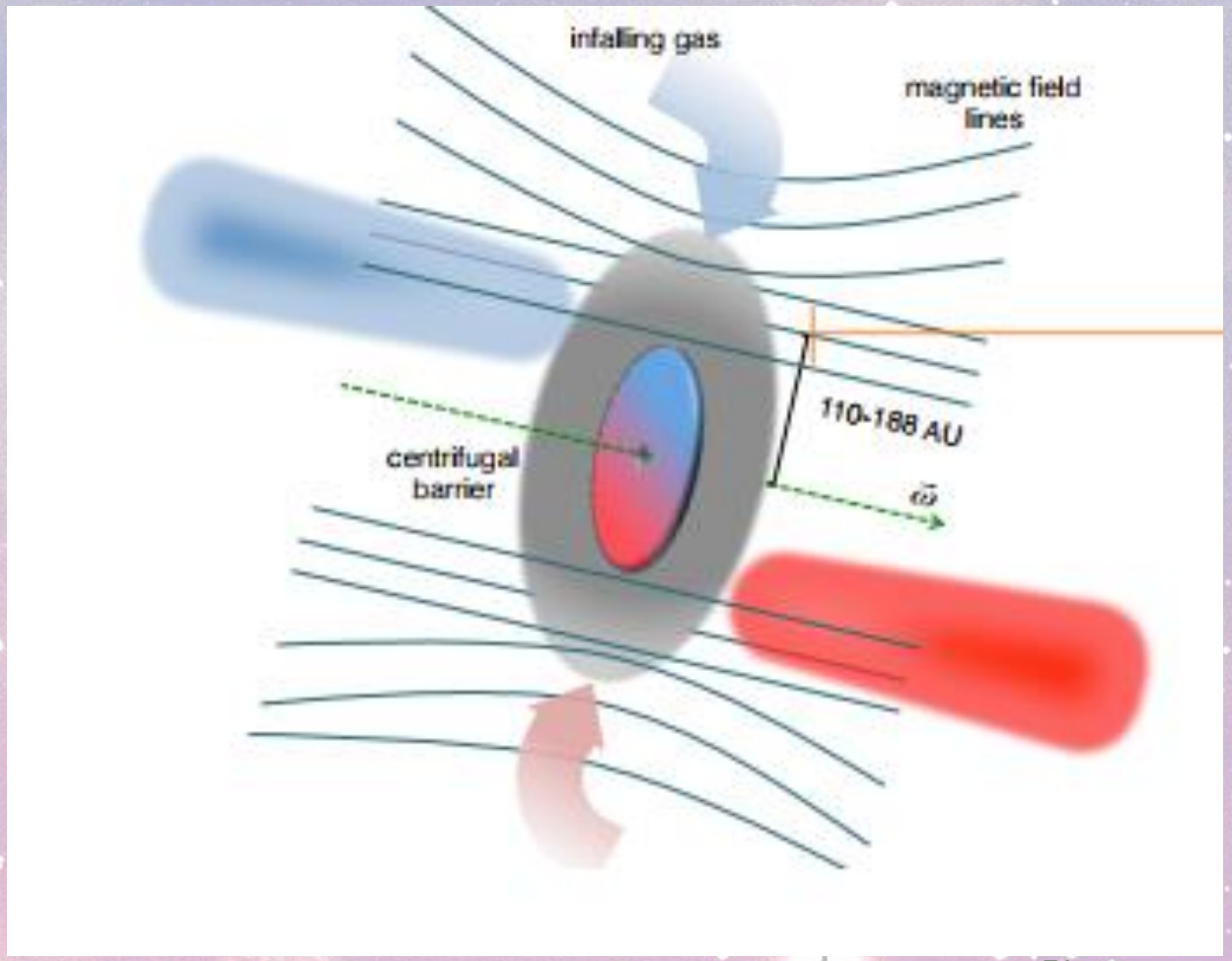
BHB07-11 Polarization Map



- Polarization degree(color scale)
- Total intensity(contour)
- Polarization angle(line)

BHB07-11 Polarization Map





(F. O. Alves .2017)

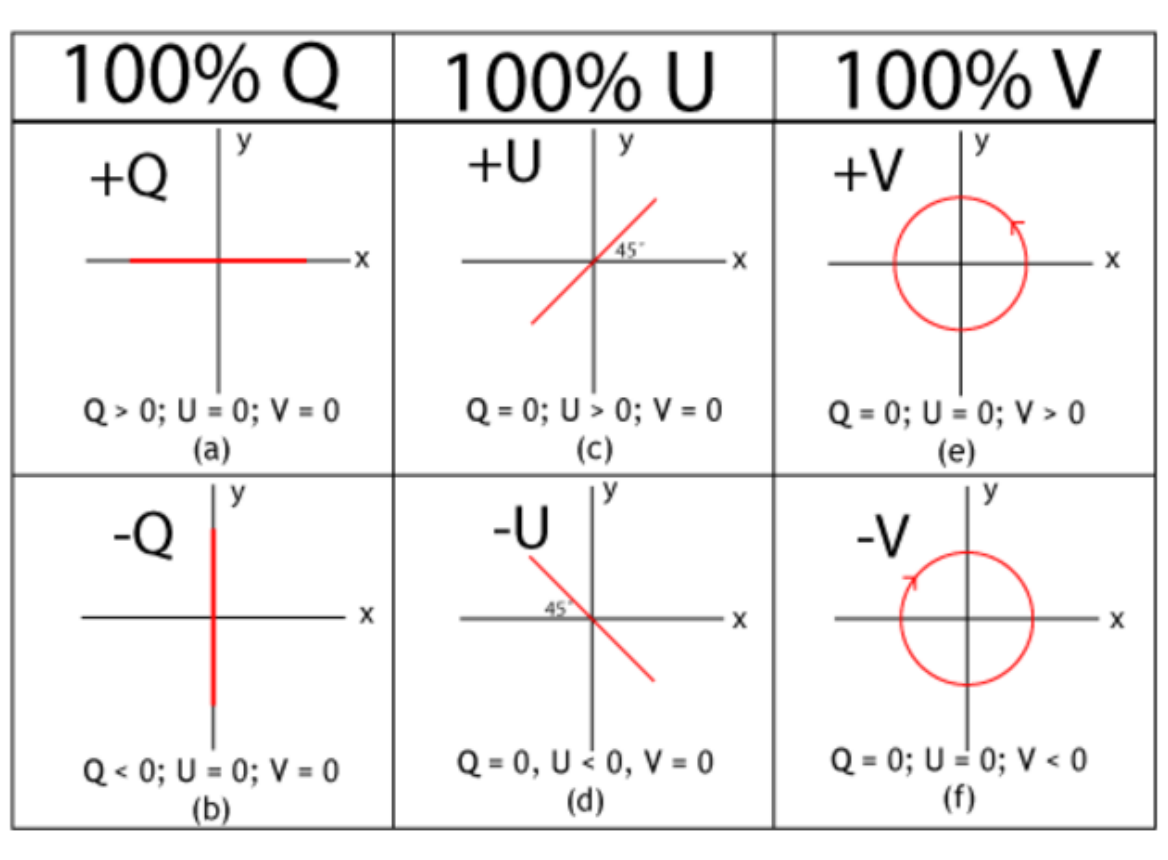
Conclusions

star	stage	Keplarian disk
L1527	Class I	O
HH111	Class I	O
TMC-1A	Class I	O
L1489 IRS	Class I	O
Serp_smm2	Class 0	X
Serp_smm11	Class 0	X
Serpens_Emb8	Class 0	X
Serpens_Emb8N	Class 0	X
Serpens_Emb6	Class 0	X
BHB07-01	Class 0	△
BHB07-11	Class I	O

Thanks for listening

Q&A

Stokes parameters



- Polarized intensity:

$$P = \sqrt{Q^2 + U^2}$$

- Polarization angle:

$$\chi = 0.5 arctan U/Q.$$

(https://en.wikipedia.org/wiki/Stokes_parameters)