Disk Substructures of AS 209 from Dust Continuum and 12CO Emission Line

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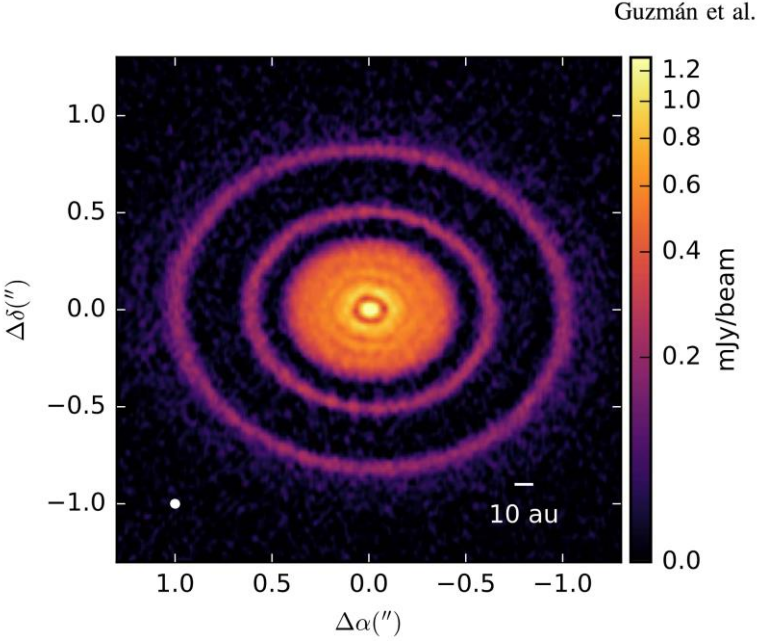
Introduction

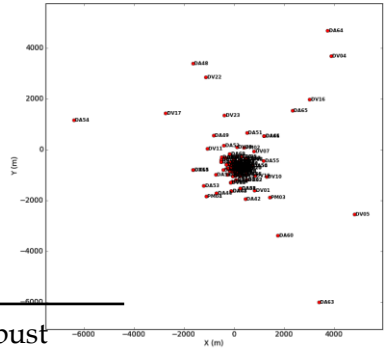
AS 209

- Ophiuchus, 121 ± 2 pc
- Spectral type K5
- Mass ~ 0.9 Msun
- Age ~ 1.6 Myr
- Mdisk ~ 0.028 Msun
- Inclination ~ 40 deg
- Position angle ~ 85.8 deg



Dust continuum emission map

AS 209 dust continuum



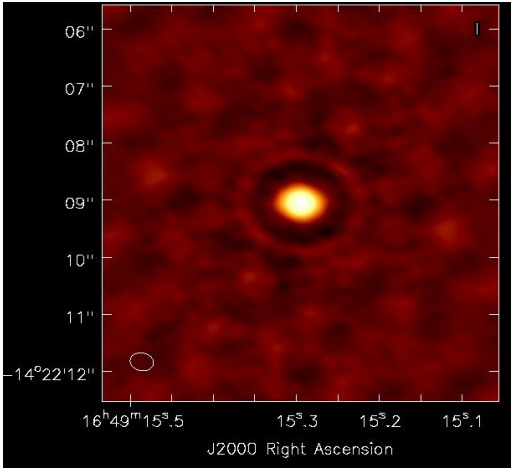
Dust continuum Band 6 (230 GHz), 157 antennas

Spectral window 0 ~ 8 (P.I. Oberg)
Weighting function natural, uniform, robust(Briggs)

Statistics	Natural	Uniform	Robust
Beam size (maj./min.) [″]	0.55 / 0.49	0.42 / 0.37	0.46 / 0.45
Total flux density [Jy]	0.274	0.25	0.27
Peak flux density [Jy]	0.08	0.056	0.07
Mean rms [mJy/beam]	0.18	0.5	0.2

Statistics	Oberg	Fedele	Andrew	Total
Angular resolution [″]	~ 0.5	~ 0.1	~ 0.03	~ 0.03
Beam size (maj./min.) [″]	0.46 / 0.45	0.17 / 0.16	0.06 / 0.04	0.06 / 0.04
Total flux density [Jy]	0.27	0.29	0.43	0.5
Peak flux density [Jy]	0.07	0.014	0.003	0.003
Mean rms [mJy/beam]	0.2	0.05	0.03	0.02

AS 209 dust continuum



self_calibration trial

spw [0~ 8] split -> phase.caltable , amp.caltable
spw [9~13] split -> phase.caltable , amp.caltable

-> apply them to spw[0~24] , but it didn't work

spw[0~24] -> phase.caltable, amp.caltable : self_calibration

-> beam size = 0.41", 0.31" (before 0.064", 0.039")
-> rms noise ~ 30 mJy/beam

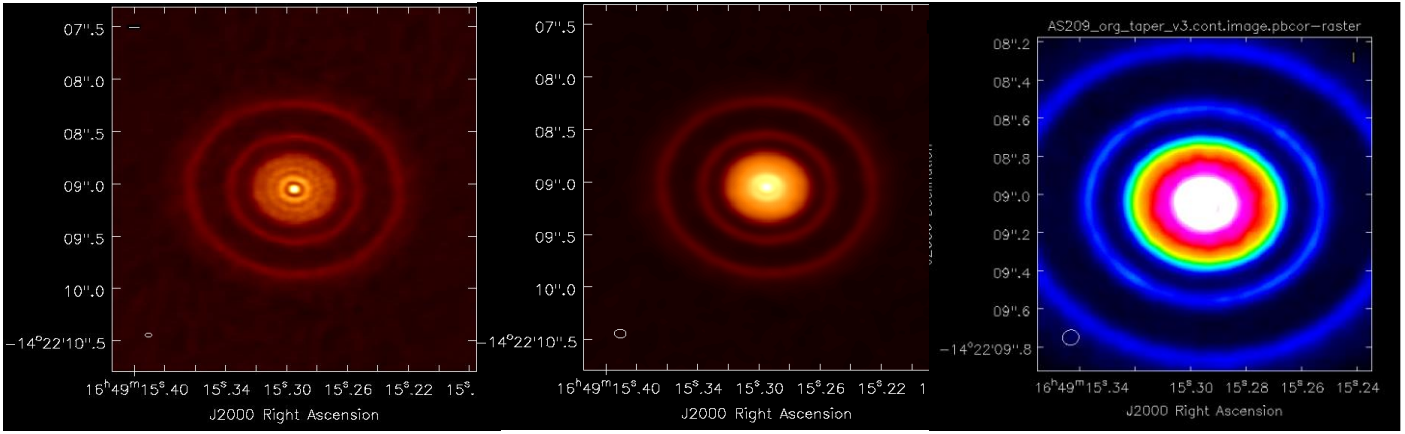
AS 209 dust continuum

After cleaning : beam : 0.064”, 0.041”, 85.3 deg

uvtaper = [‘0.064arcsec’,’0.064arcsec’,’0deg’]
=> beam size : 0.11” , 0.081” , 85.5 deg

uvtaper = ['0.065arcsec', '0.025arcsec', '-5deg’]
=> beam size : 0.086” , 0.079”, -73.2 deg

restoring beam = [‘0.064arcsec’]
=> beam size : 0.064” , 0.039”



AS 209 dust continuum

Estimating disk mass

κ_λ (gas + dust) is taken to be $0.01(1.3\ \mathrm{mm}/\lambda)\ \mathrm{cm^2\ g^{-1}}$ from Ossenkopf & Henning (1994) and assumes $M_{\mathrm{gas}}/M_{\mathrm{dust}} = 100$. The disk mass (gas + dust) is then given by

$$M_{\mathrm{disk}} = 0.06\ M_\odot \frac{F_\lambda}{1\ \mathrm{Jy}} \left(\frac{d}{100\ \mathrm{pc}}\right)^2 \frac{50\ \mathrm{K}}{\langle T \rangle} \frac{0.01\ \mathrm{cm^2\ g^{-1}}}{\kappa_{1.3\ \mathrm{mm}}}, \quad (6)$$

where F_ν is the observed flux at 1.3 mm in Jy. The observational data and resulting masses are summarized in Table 7. The errors in the observed fluxes are taken to be ~30%.

(Thi+2001)

adopting $T_{dust} = 20K$

$$M_{dust} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_{dust})} = 1.25 \times 10^{-6} M_\odot \left(\frac{F_{230GHz}}{1mJy}\right)\left(\frac{d}{121pc}\right)^2$$

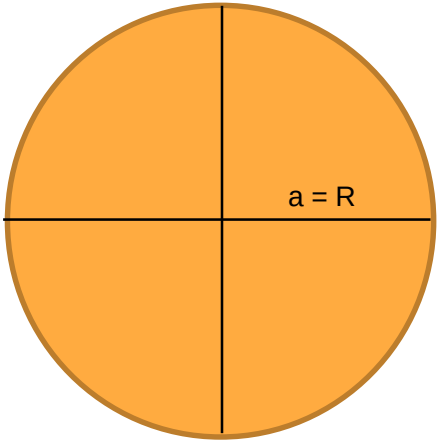
$F_{230GHz} = 386mJy$ → $M_{dust} = 4.8 \times 10^{-4} M_\odot$

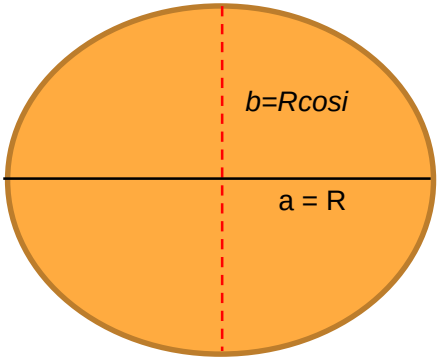
(using all spwIDs)

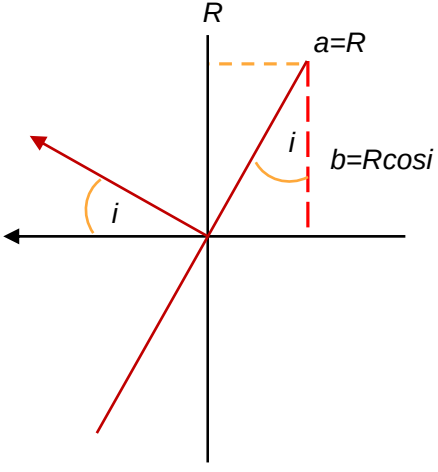
$M_{gas+dust} = 4.8 \times 10^{-2} M_\odot$

$M_{gas+dust} = 2.8 \times 10^{-2} M_\odot$ (Andrews+2009)

Inclination angle *i*







line of sight

$$i = \cos^{-1}\left(\frac{b}{a}\right)$$

a = 2.73”
b = 2.12”

$$i = \cos^{-1}\left(\frac{2.12}{2.73}\right) \approx 40°$$

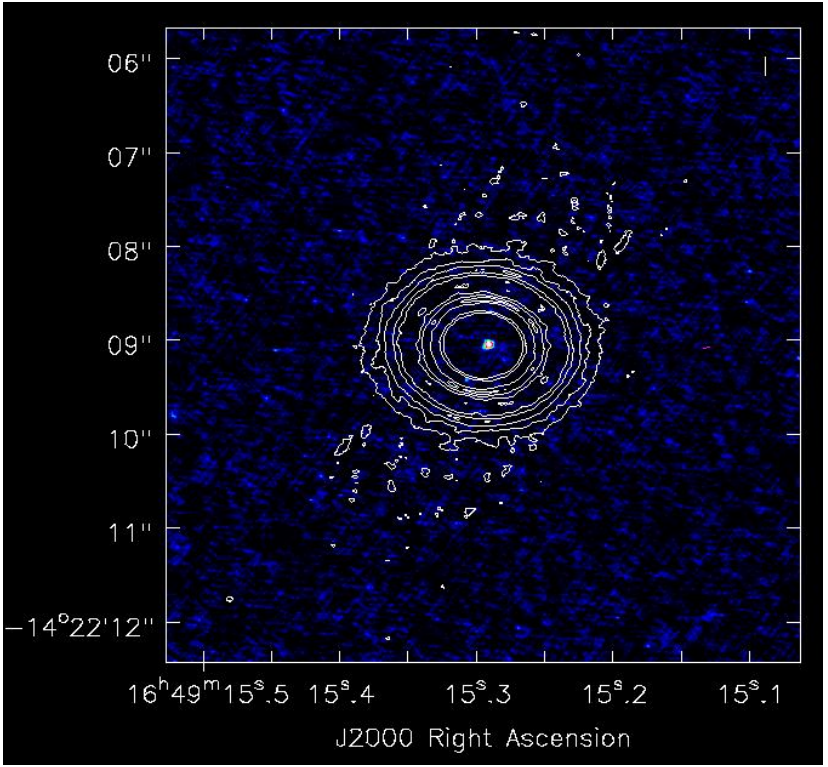
$i = 34.9°$ (Guzmann+2019)

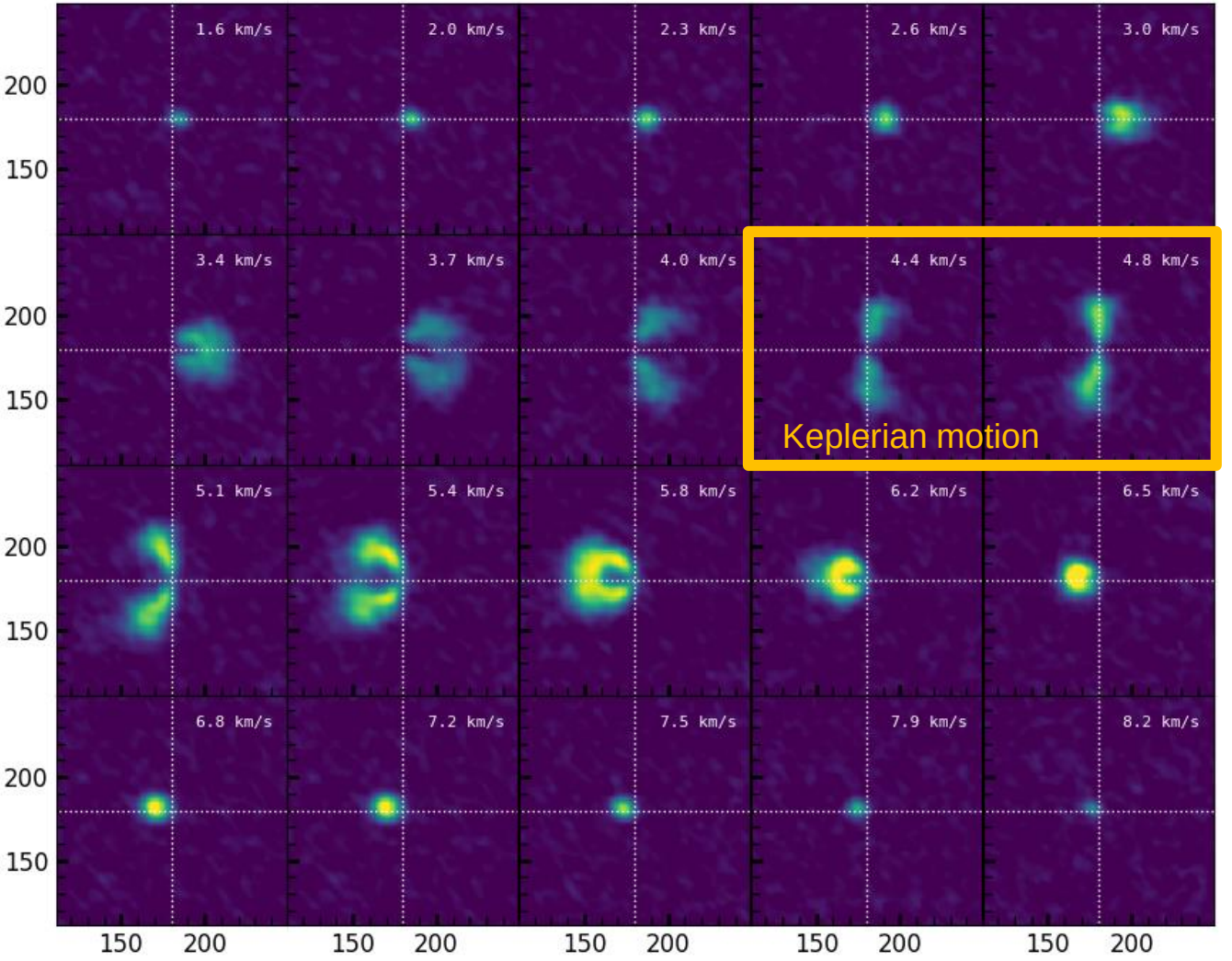
AS 209 12CO emission line

12CO line emission

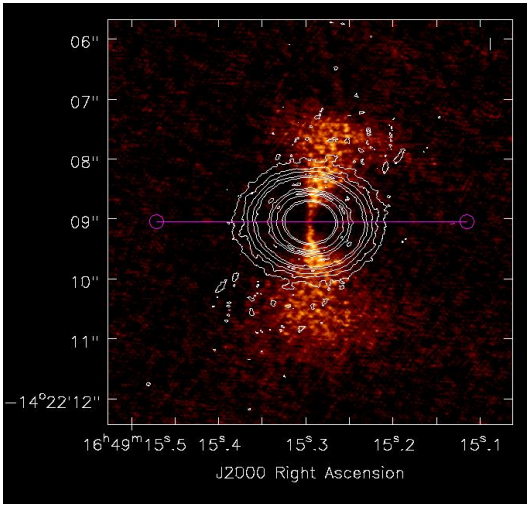
spw [0~2]
ChanWid : 269.147kHz
CtrFreq : 230.533 GHz

vel ~ 0.35 km/s




1.6 km/s
2.0 km/s
2.3 km/s
2.6 km/s
3.0 km/s
3.4 km/s
3.7 km/s
4.0 km/s
4.4 km/s
4.8 km/s
Keplerian motion
5.1 km/s
5.4 km/s
5.8 km/s
6.2 km/s
6.5 km/s
6.8 km/s
7.2 km/s
7.5 km/s
7.9 km/s
8.2 km/s
200
150
150
200

AS 209 12CO emission line



PV diagram

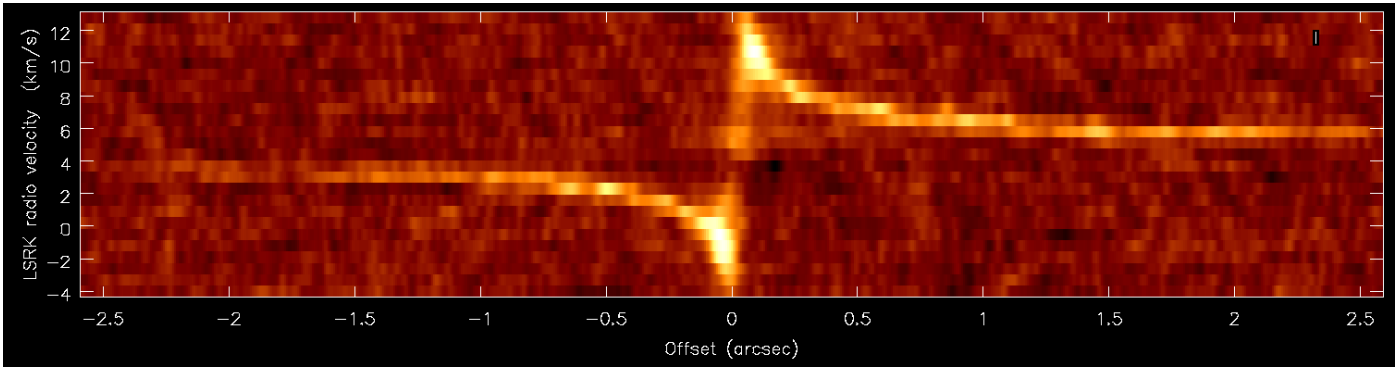
$$\frac{mv^2}{r} = \frac{GM_{\bigstar}m}{r^2}$$

Velocity deprojection using inclination

0.5 arcsec → 1.2 Msun

1.0 arcsec → 0.88 Msun

2.0 arcsec → 0.95 Msun

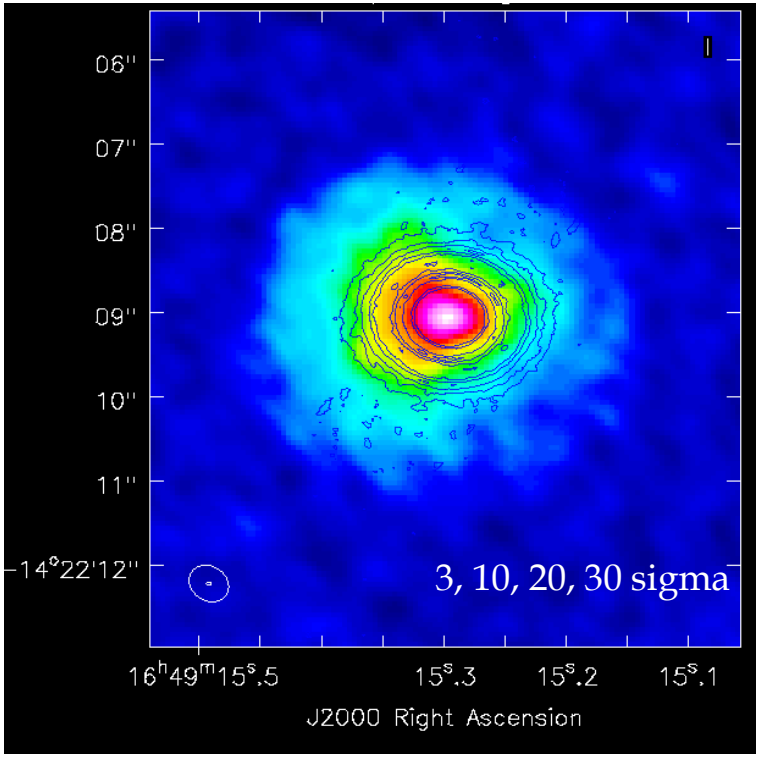


AS 209 12CO emission line

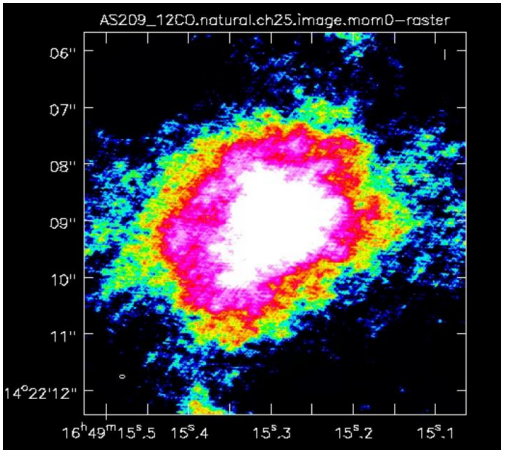
Moment map

Spectral window 0 ~ 2

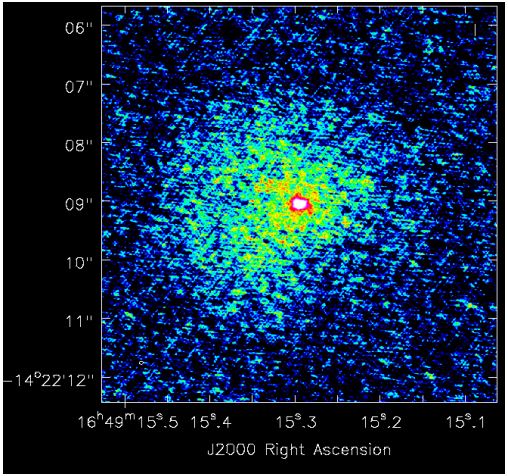
Gas disk is more extended toward NE direction than the dust disk



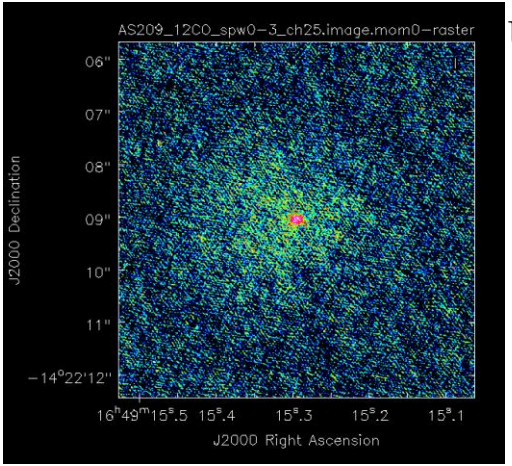
12CO line momen-0 map



Natural weighting

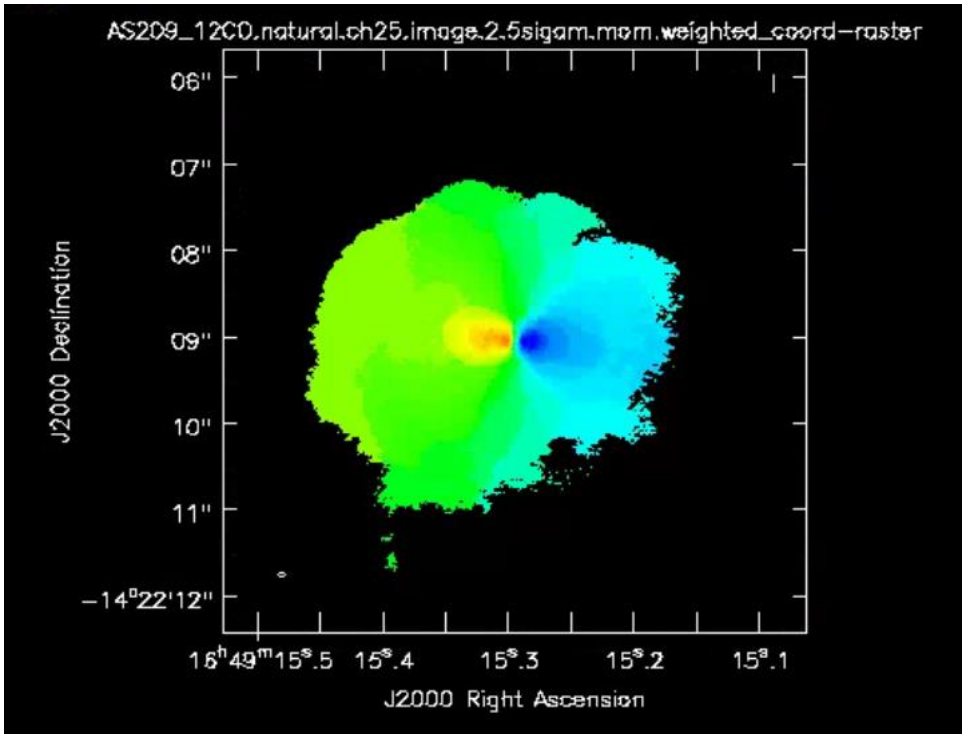


Robust weighting



Uniform weighting

Natural weighting 12CO line momen-1 map

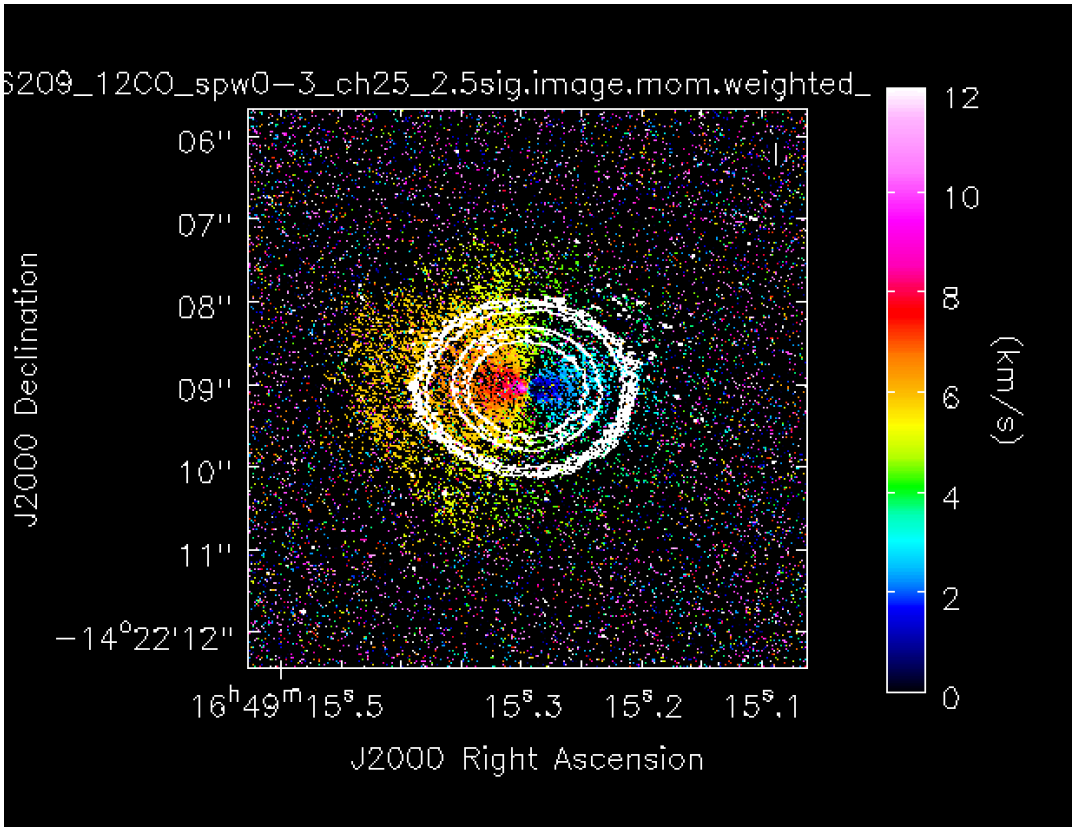


Uniform weighting

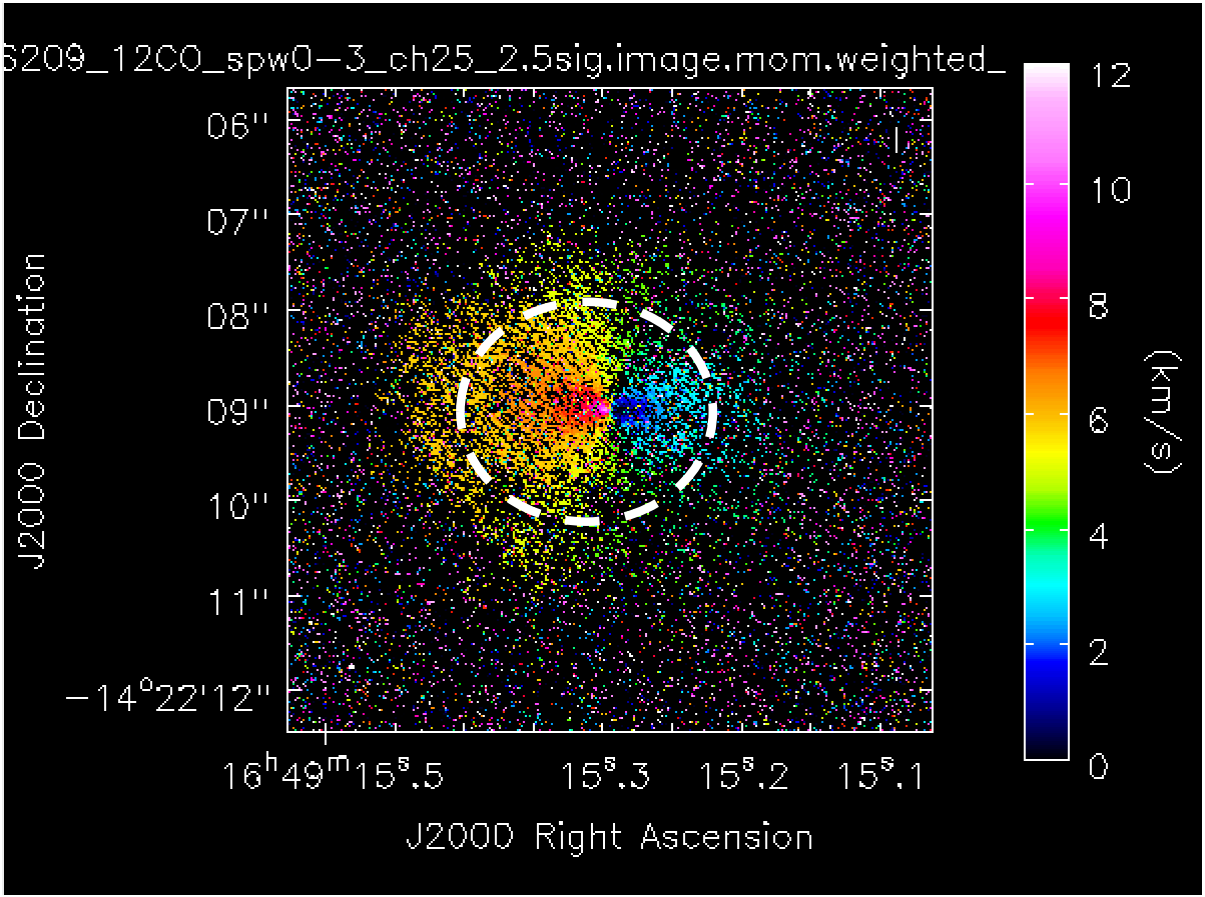
moment 1 vs continuum

moment 1
ch2-ch23
include pixel > 0.00375 Jy/beam (2.5sigma)

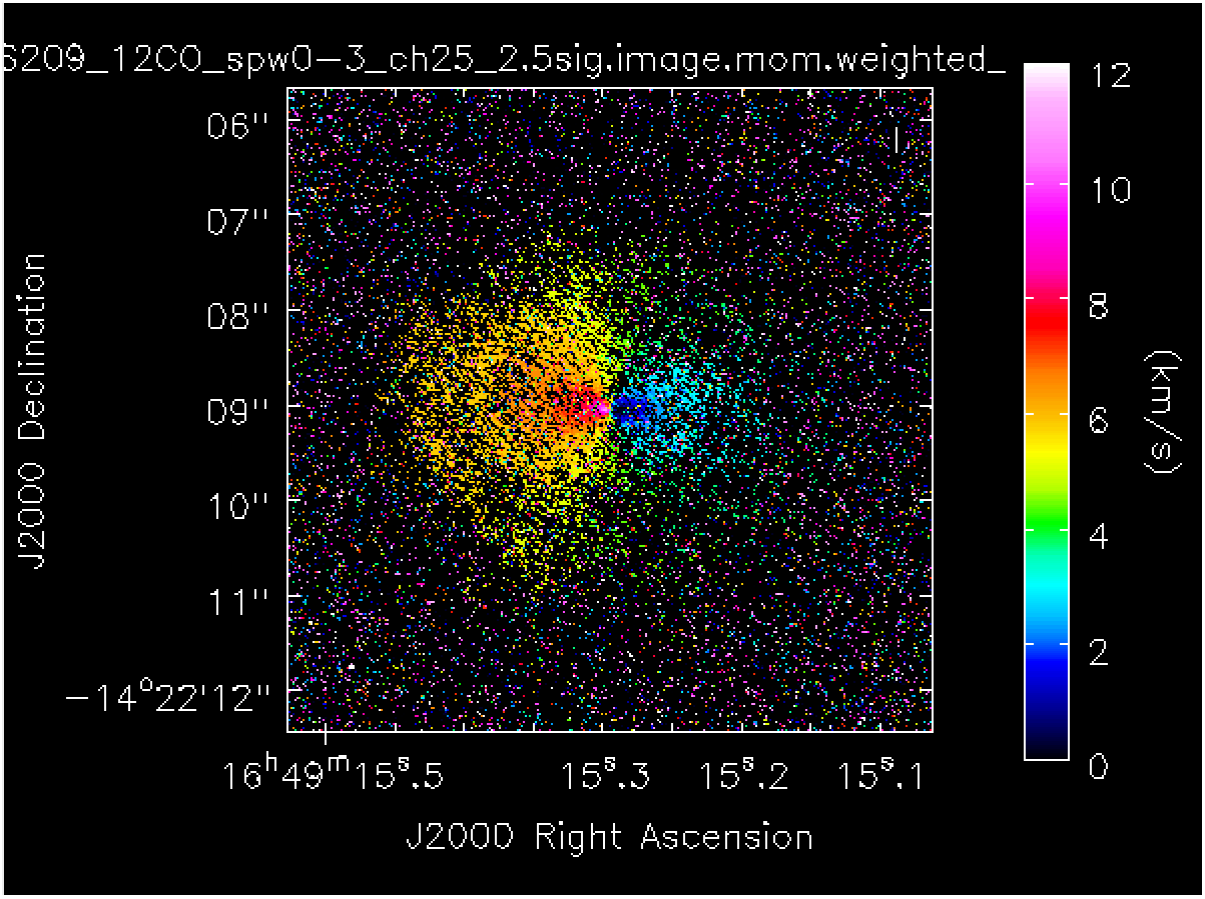
contour: dust continuum.
3, 5, 9-sigmas
(1sig = 1.35e-5Jy/beam)



moment 1


S209_12CO_spw0-3_ch25_2.5sig.image.mom.weighted_
06''
07''
08''
09''
10''
11''
−14°22'12"
J2000 Declination
16h49m15s.5
15s.3
15s.2
15s.1
J2000 Right Ascension
12
10
8
6
4
2
0
(km/s)

moment 1


6209_12CO_spw0-3_ch25_2.5sig.image.mom.weighted_
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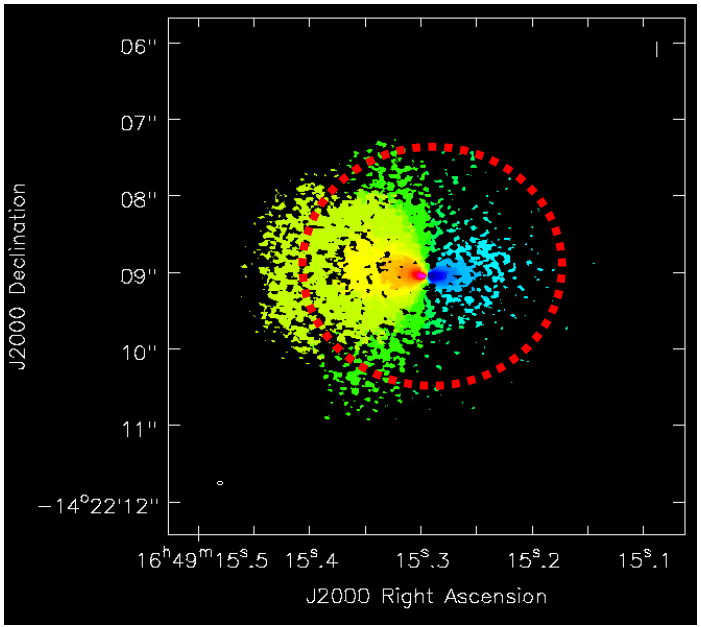
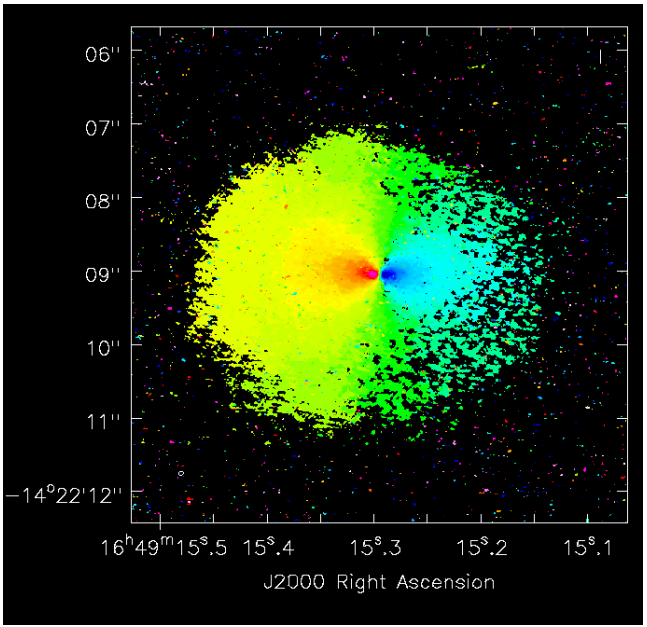
15s.2
15s.1
J2000 Right Ascension
12
10
8
6
4
2
0
(km/s)

Robust weighting 12CO line momen-1 map





5 sigma

2.5 sigma