Dark matter in merging galaxies

2017/09/01
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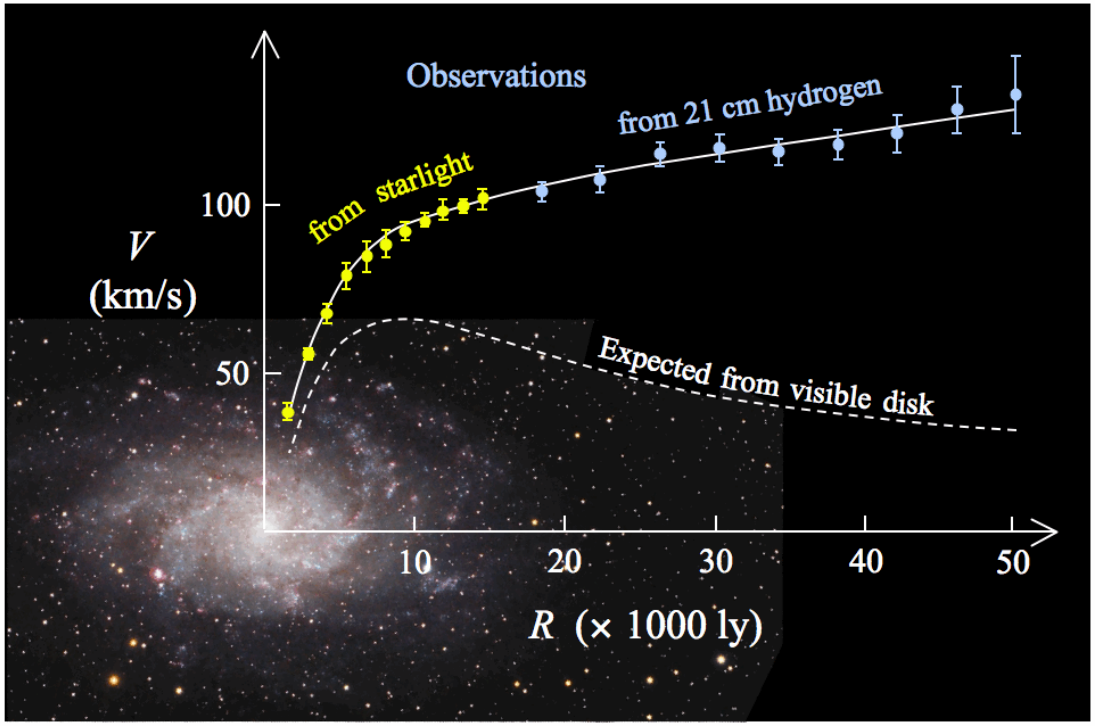
Outline

- Introduction
- Method
- Analysis
- Summary

Introduction

- Unexpected rotation curve of spiral galaxies



From:wiki

How to explain?

- 1.Dark matter!
- 2.Modified Newtonian Dynamics(MOND)

Purpose

- Investigate whether there exist dark matter in the nucleus of merging galaxies

- Why merging galaxies? Why the nucleus?

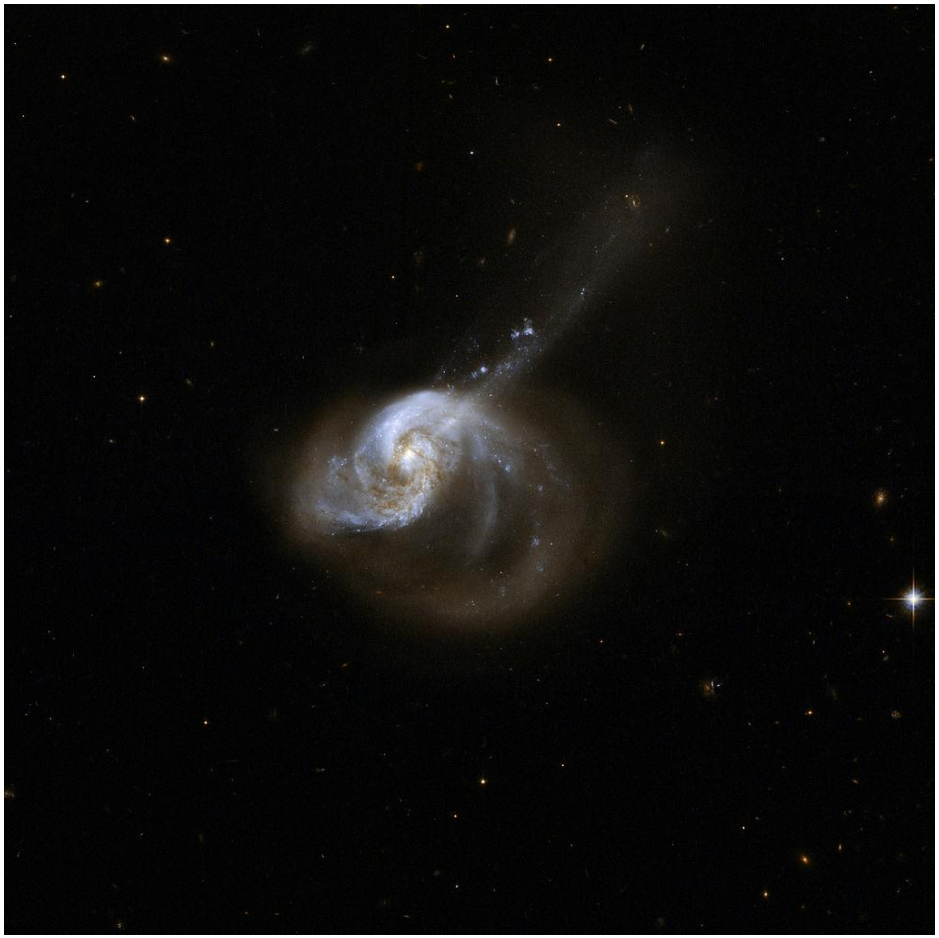
Method: how to do?

- Find the rotation curve of the nucleus by analysis the data of CO(1-0) emission line
- →Find the total dynamical mass

$$\mathrm{M_{dyn}} = \mathrm{M_{mol}} + \mathrm{M_{stellar}} + \mathrm{M_{dust}} + \mathrm{M_{dark}}$$

Method:My target

- NGC1614
- distance:64.7Mpc
- 1" = 341pc

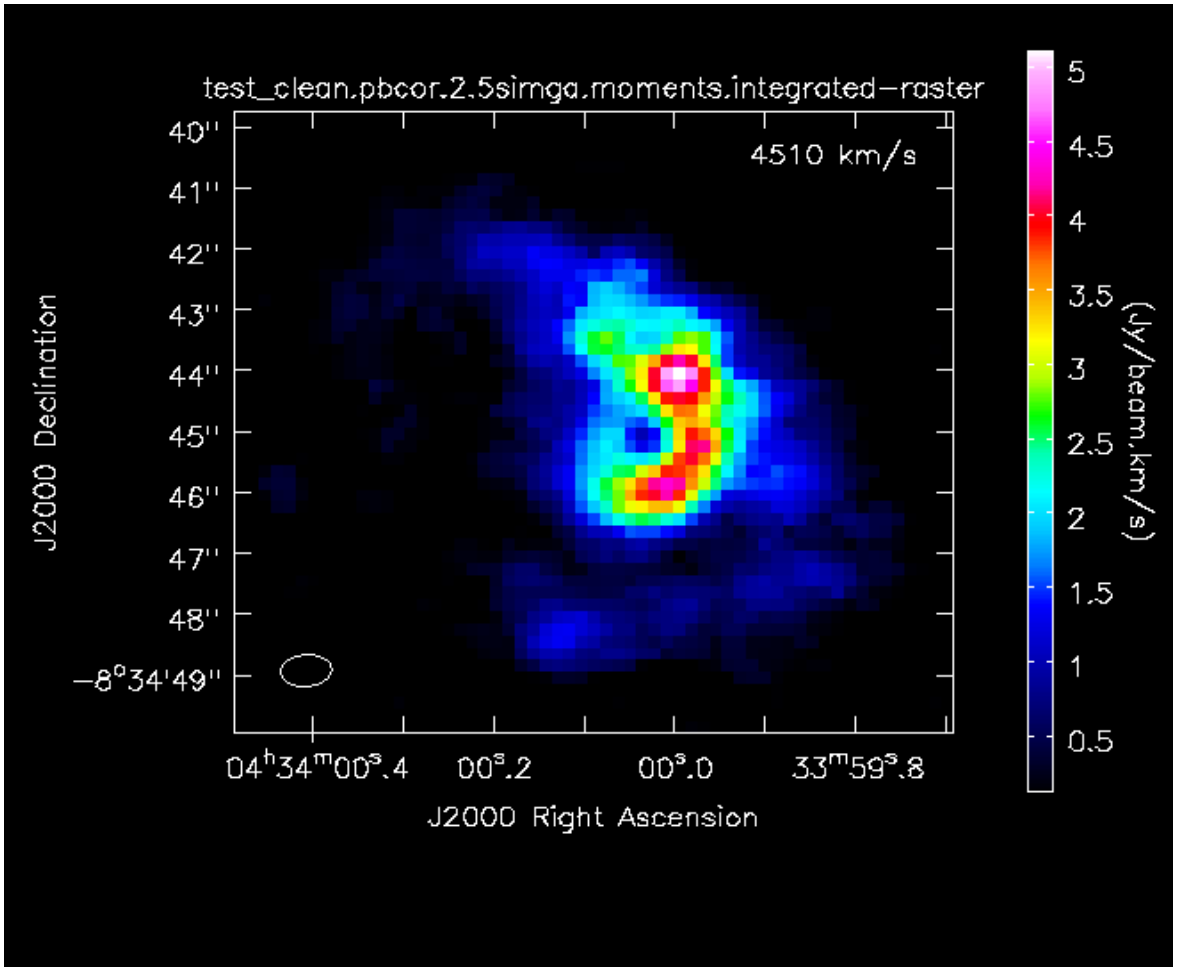


From:NED

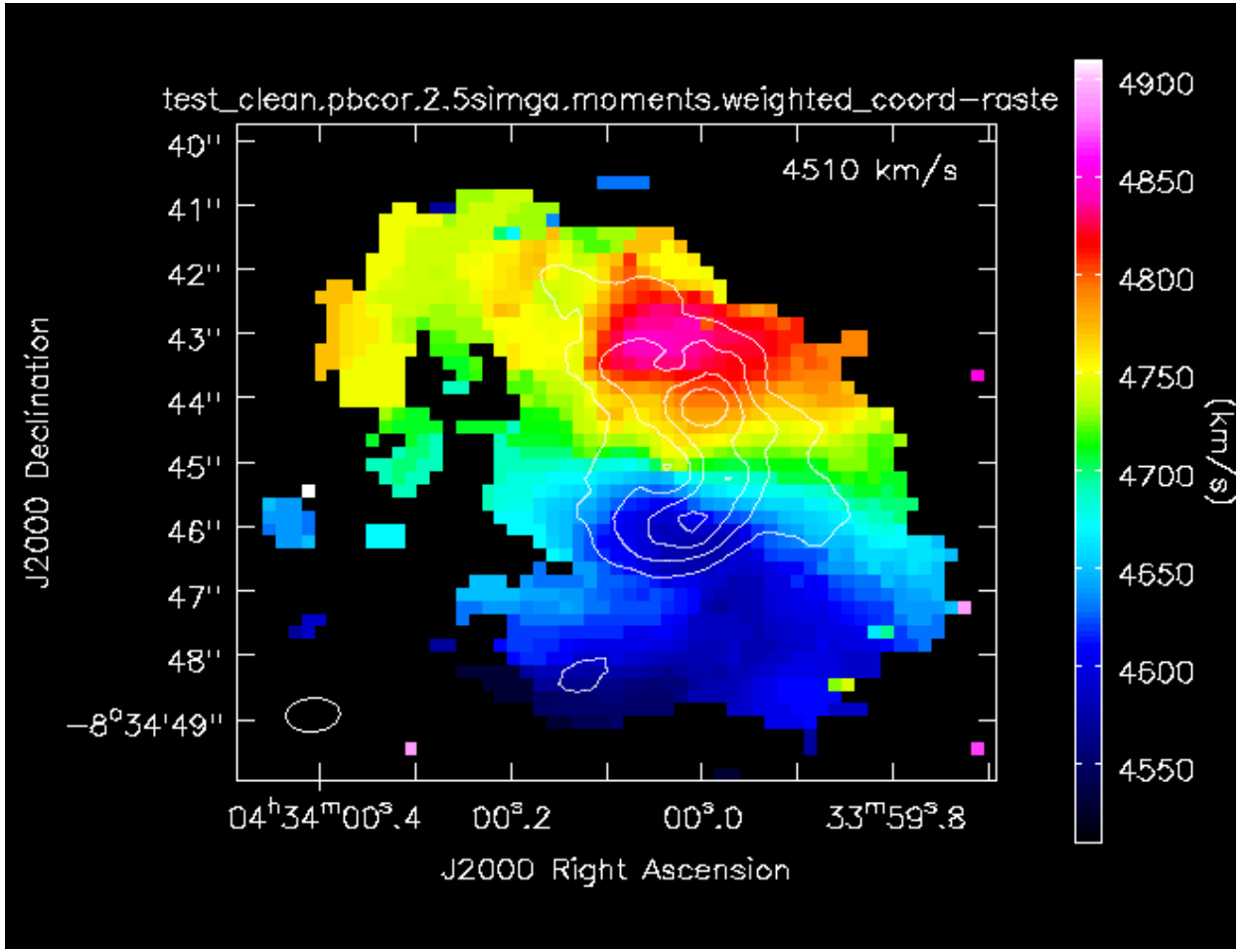
Method:Data

- From ALMA archive
- Project code:2013.1.01172.s(Cycle2,Band3)

Moment 0


test_clean.pbcor.2.5simga.moments.integrated−raster
4510 km/s
40''
41''
42''
43''
44''
45''
46''
47''
48''
−8°34'49''
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
(Jy/beam.km/s)

Moment 1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4510 km/s
40''
41''
42''
43''
44''
45''
46''
47''
48''
−8°34'49''
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension
4900
4850
4800
4750
4700
4650
4600
4550
(km/s)

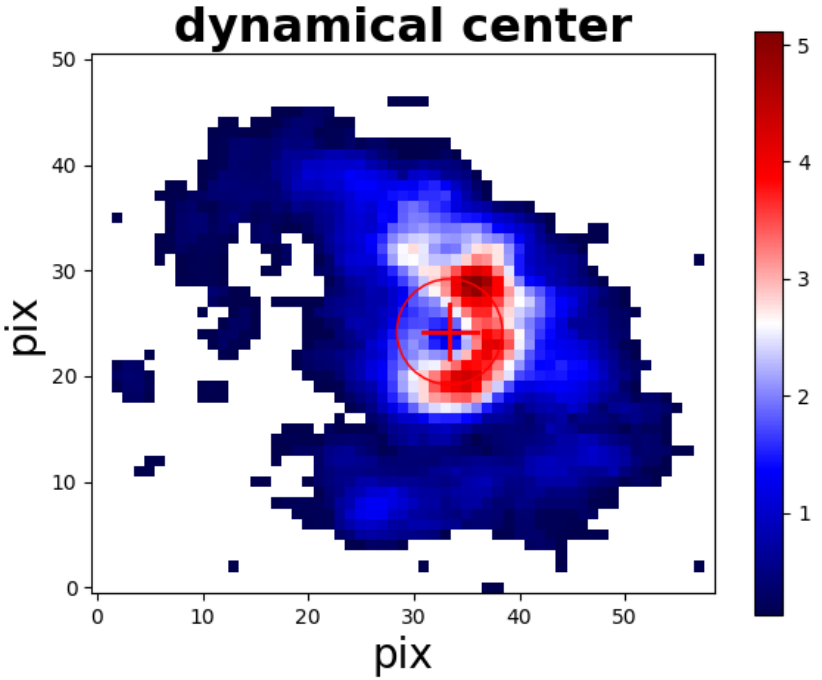
About the disk

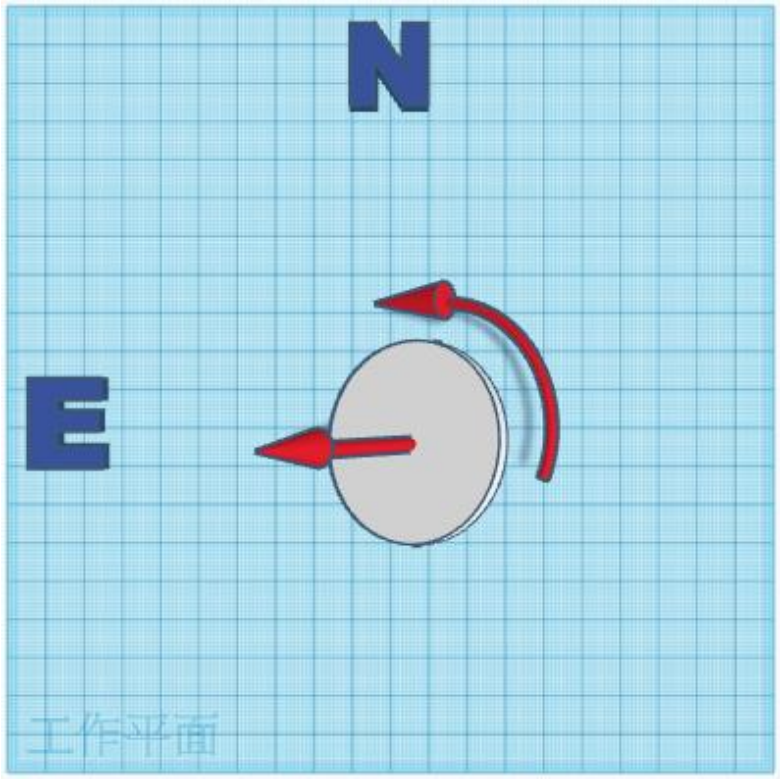
- Declination:36°
- Position angle:352°
- Dynamical center:

  $\alpha 2000 = 04h34m00.03s, \delta 2000 = -08^{\circ}34'45.01''$

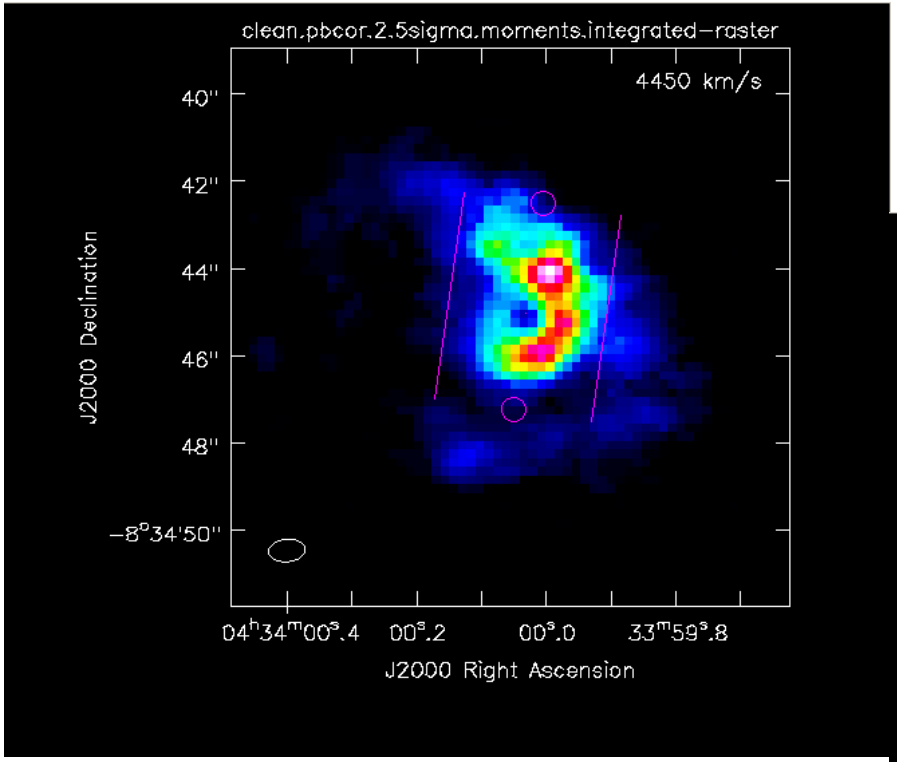
From:Viti, S., García-Burillo, S., Fuente, A., et al. 2014, A&A, 570, A28

About the disk





PV diagram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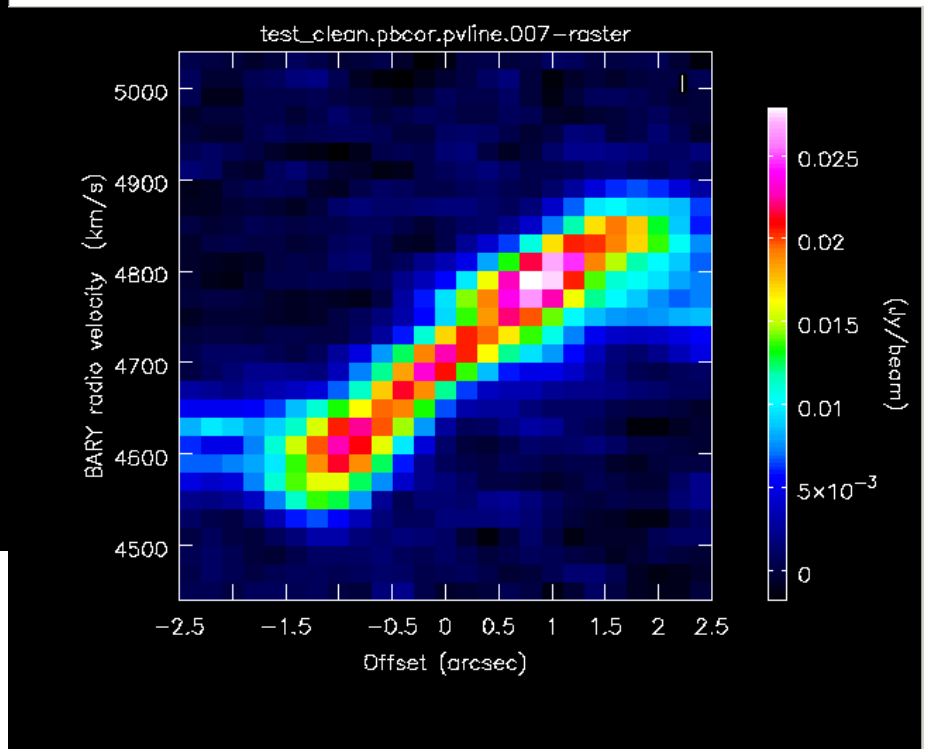
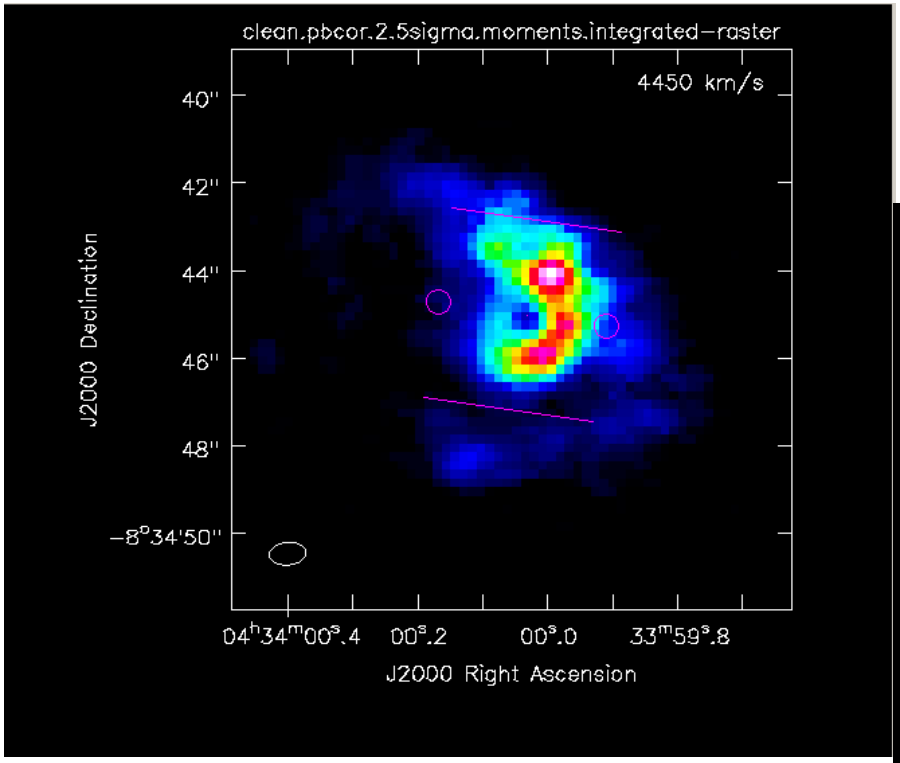
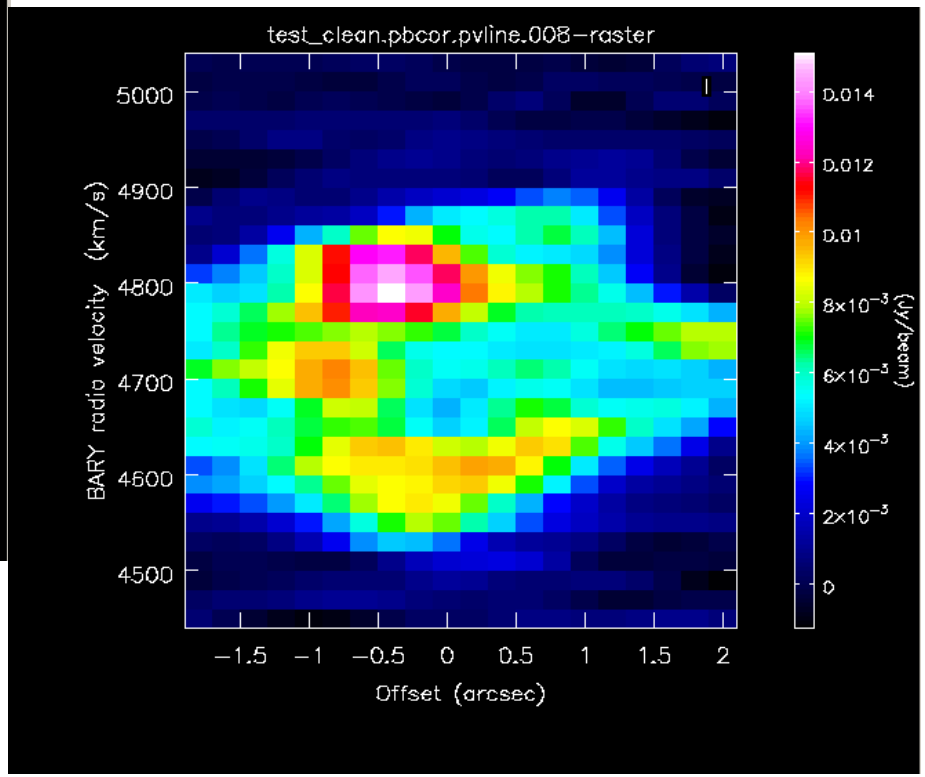
4450 km/s
40"
42"
44"
46"
48"
−8°34'50"
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension


test_clean.pbcor.pvline.007−raster
5000
4900
4800
4700
4600
4500
BARY radio velocity (km/s)
−2.5
−1.5
−0.5
0
0.5
1
1.5
2
2.5
Offset (arcsec)
0.025
0.02
0.015
0.01
5x10−3
0
(Jy/beam)

PV diagram


clean.pbcor.2.5sigma.moments.integrated−raster
4450 km/s
40''
42''
44''
46''
48''
−8°34'50''
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension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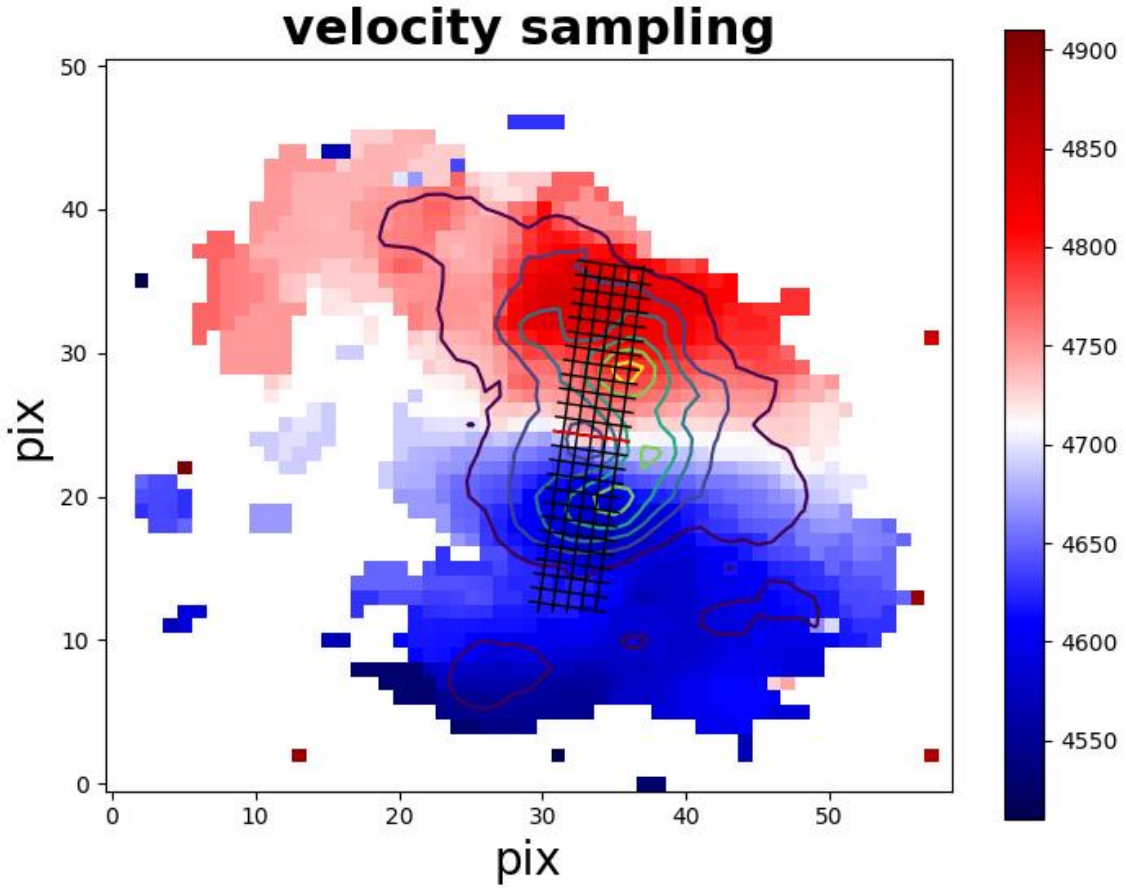
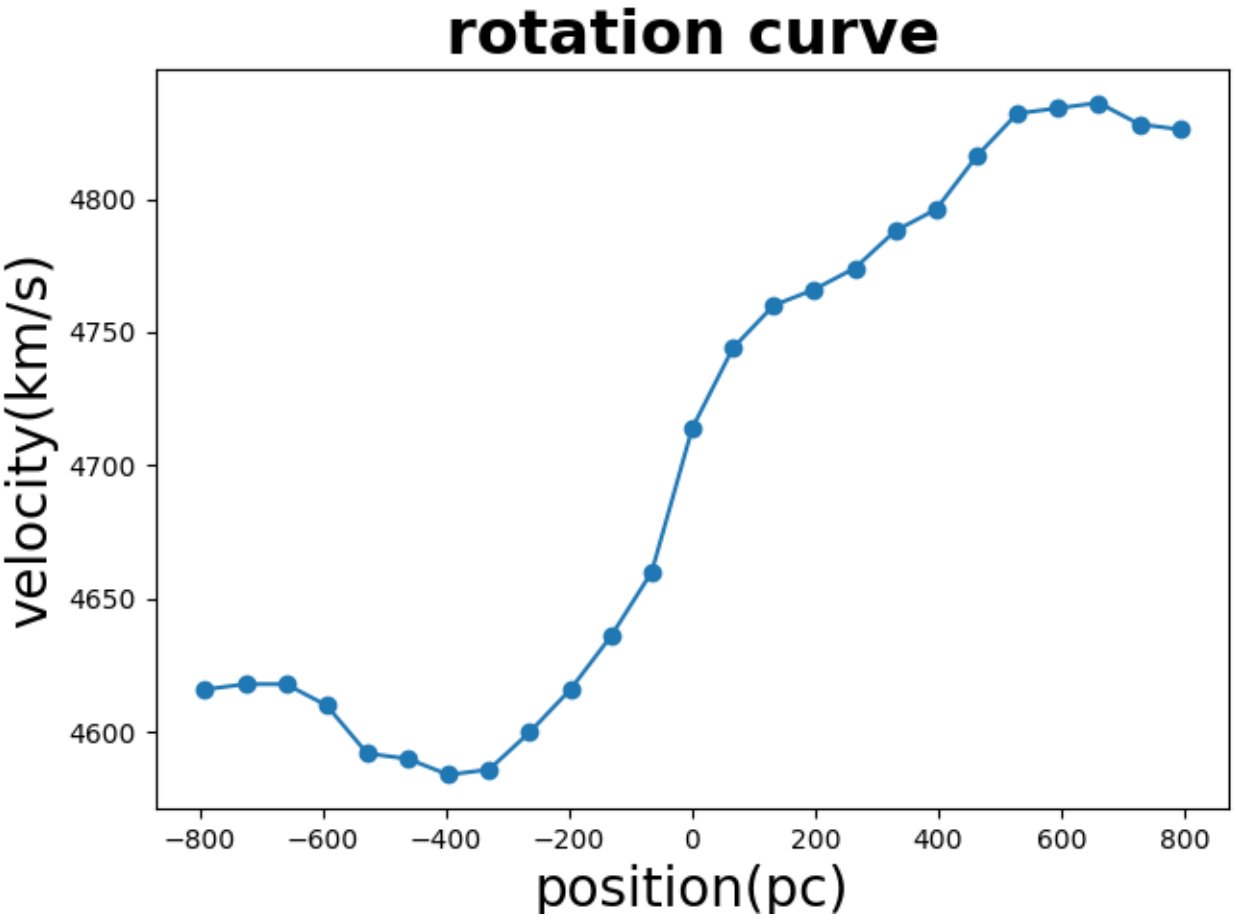
5000
4900
4800
4700
4600
4500
BARY radio velocity (km/s)
−1.5
−1
−0.5
0
0.5
1
1.5
2
Offset (arcsec)
0.014
0.012
0.01
8x10−3
6x10−3
4x10−3
2x10−3
0
(Jy/beam)

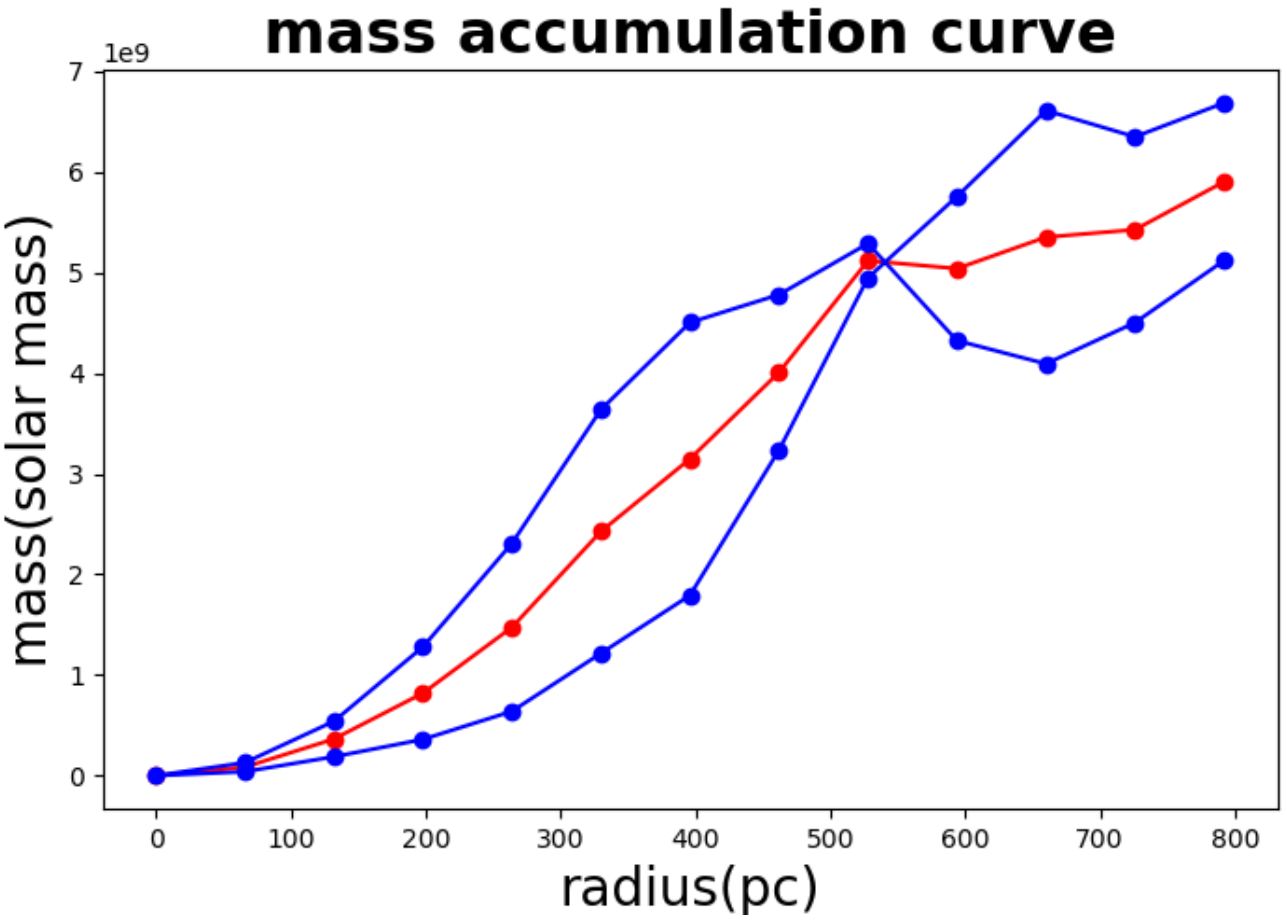
Velocity sampling



Rotation curve



Mass accumulation curve



Now we have

$$\boxed{M_{dyn}} = M_{mol} + M_{stellar} + M_{dust} + M_{dark}$$

Next

$$M_{dyn} = \boxed{M_{mol}} + M_{stellar} + M_{dust} + M_{dark}$$

Molecular gas mass

$$M_{mol} = 2453 \times \alpha_{CO} \times S_{CO}\Delta v \times \frac{D_L^2}{1+z}$$

α_{CO}: H_2 to CO conversion factor

$S_{CO}\Delta v$: integrated line flux density

D_L: luminosity distance

z: redshift

From: Alberto D. Bolatto, Mark Wolfire, Adam K. Leroy, 2013

But wait

CO Line	$\nu_{\rm rest}$ (GHz)	$E_{\rm u}/k$ (K)	Band	MRS ($''$)	uv-weight	Beam Size ($''$)	rms (mJy b^{-1})	$S_{\rm CO}\Delta v$ (Jy km s^{-1})	Recovered Flux (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$J = 1$–0 (ACA+12 m)	115.271	5.53	B3	17.6	briggs	1.0×0.6	1.4	295.3 ± 1.8	113 ± 26
$J = 1$–0 (12 m)	115.271	5.53	B3	4.6	briggs	1.0×1.0	1.6	69.3 ± 1.1	27 ± 5

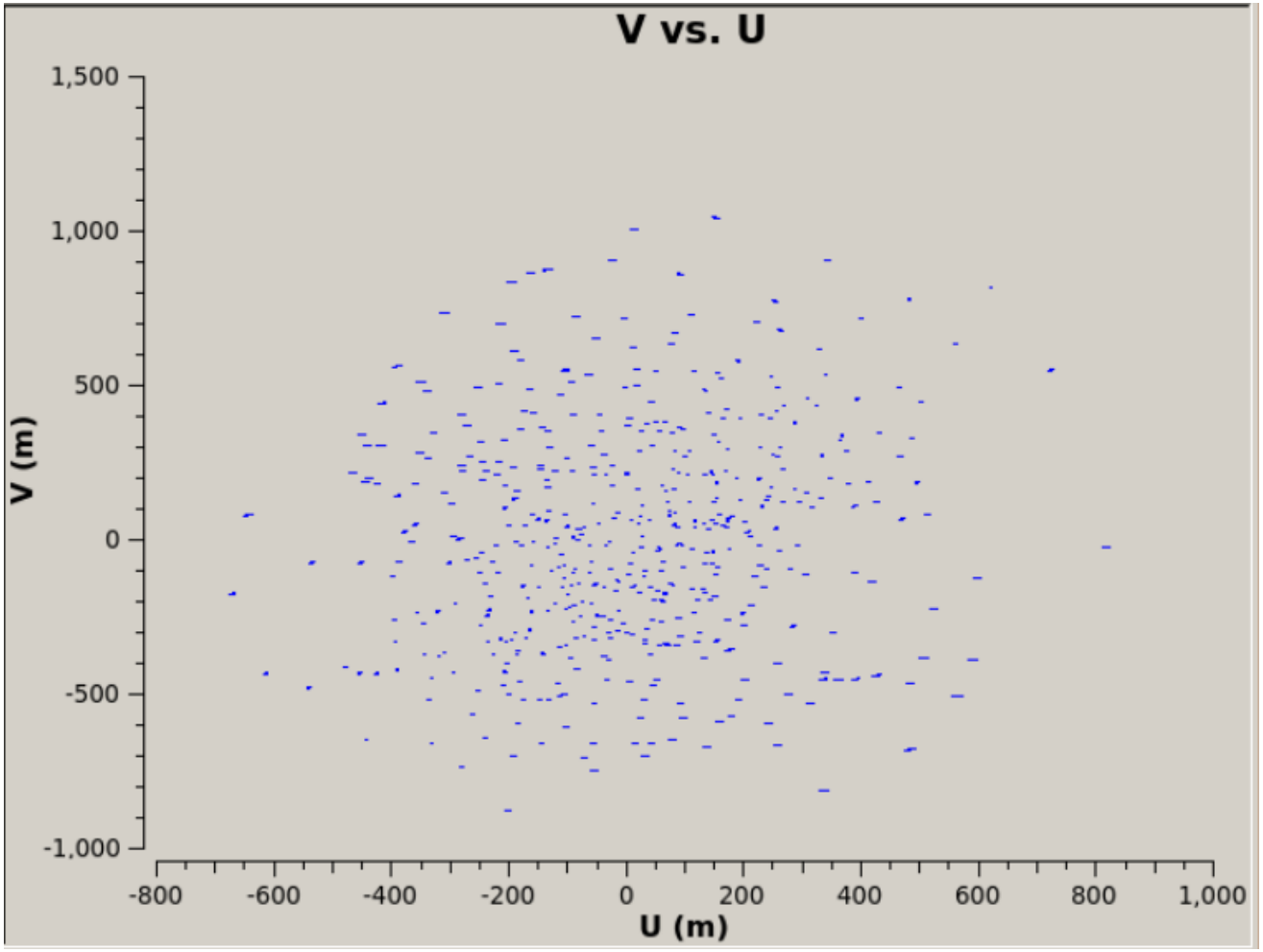
Too many missing flux!

From:Toshiki Saito, Daisuke Iono ,et al. 2017,ApJ,835,174

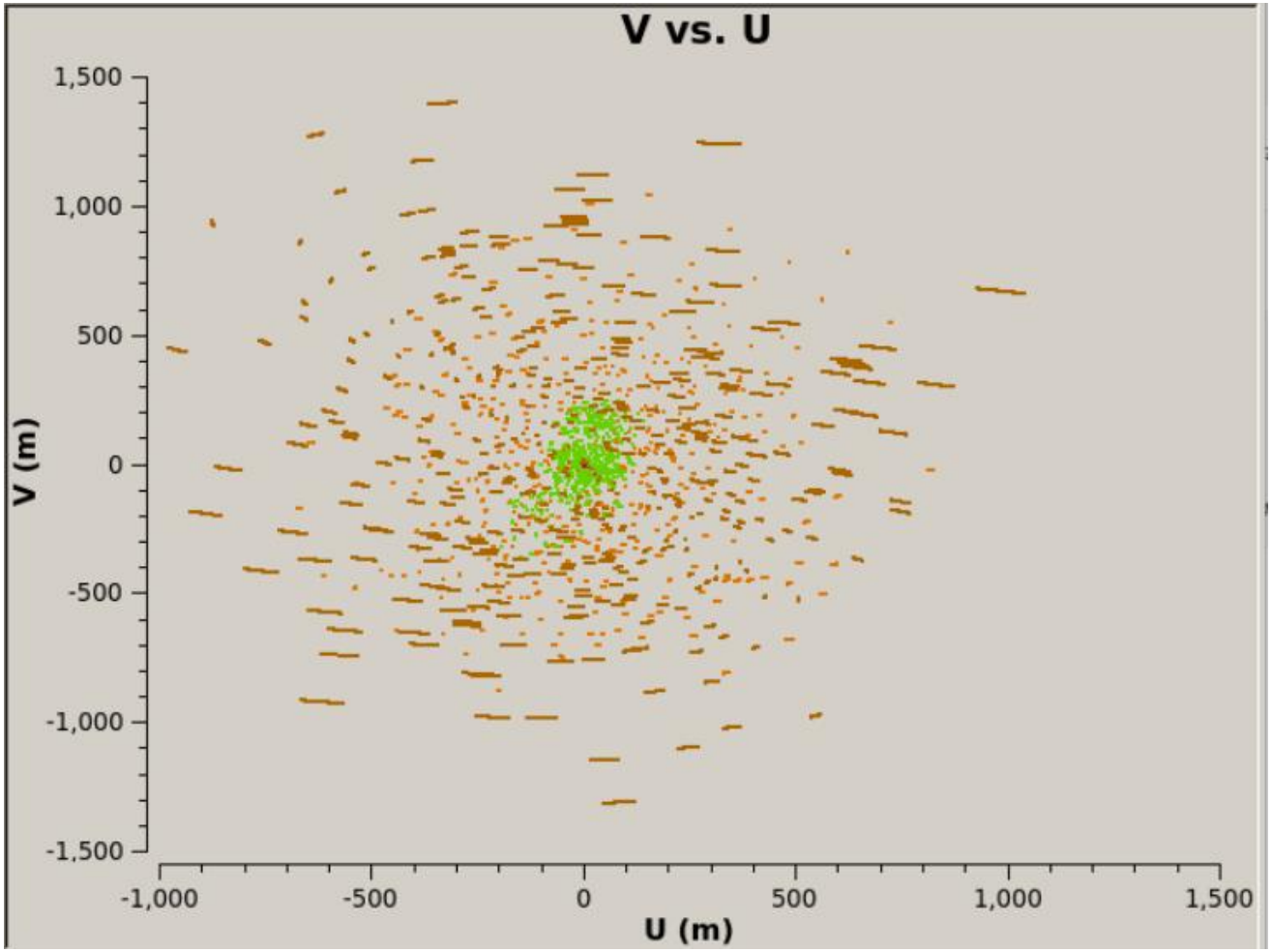
Combine data!

- Project code:2013.1.00991.s
- One ACA dataset, and two 12m dataset

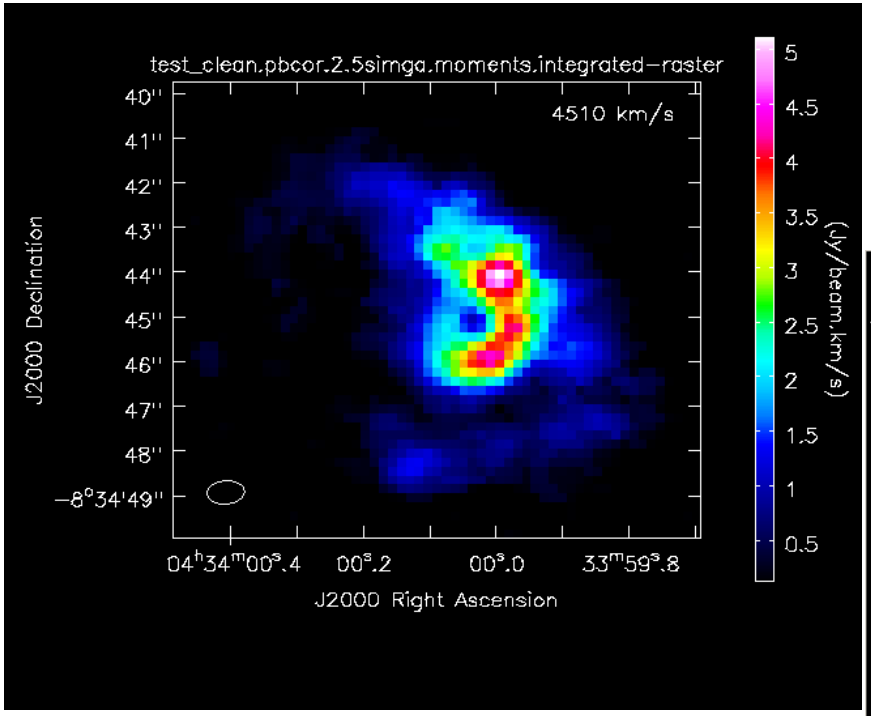
UV coverage


V vs. U
V (m)
U (m)
1,500
1,000
500
0
-500
-1,000
-800
-600
-400
-200
0
200
400
600
800
1,000

UV coverage

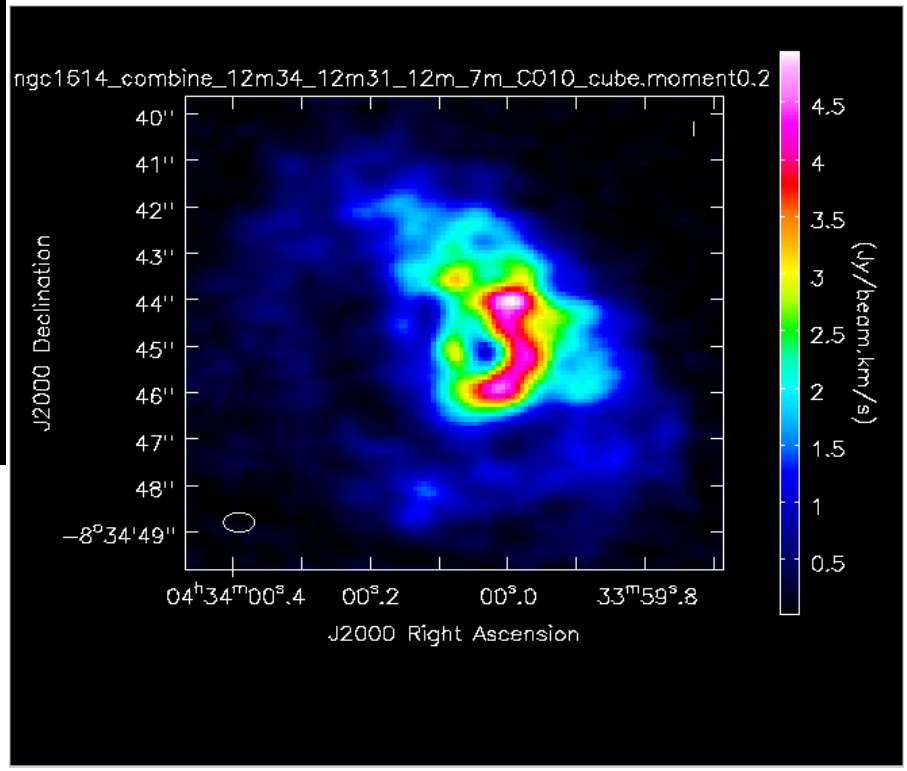

V vs. U
1,500
1,000
500
0
-500
-1,000
-1,500
V (m)
-1,000
-500
0
500
1,000
1,500
U (m)

Moment 0

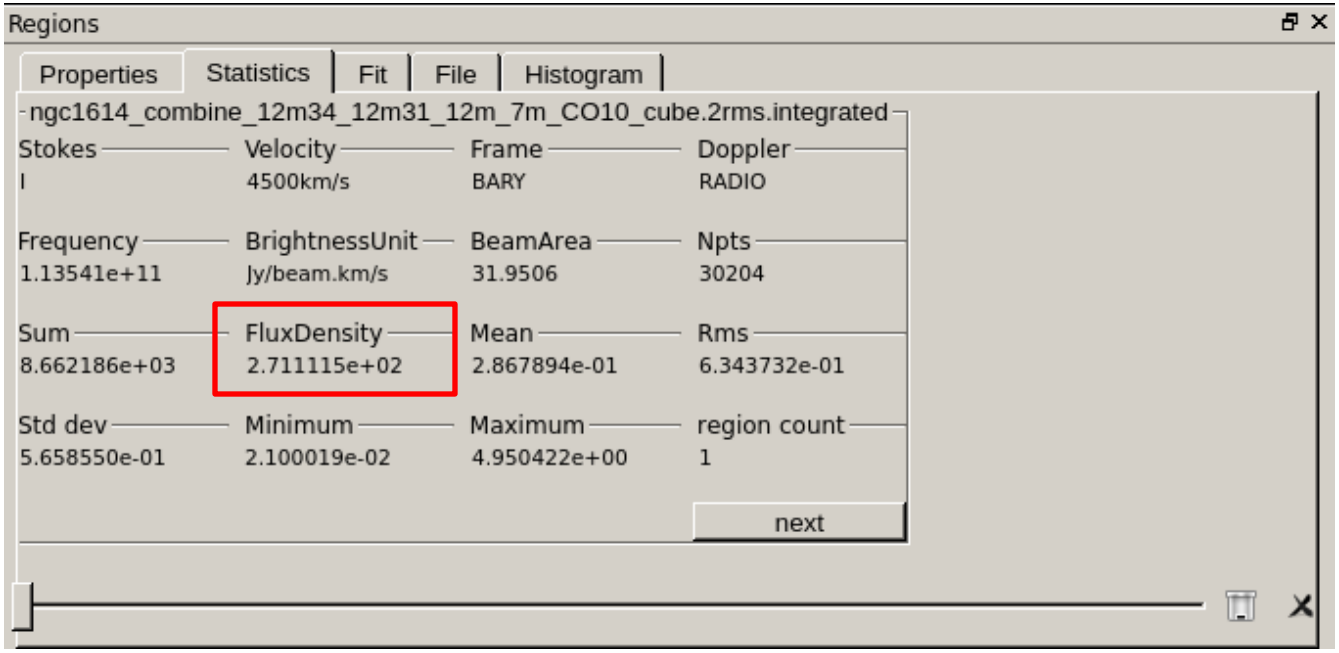


Before combination

After combination

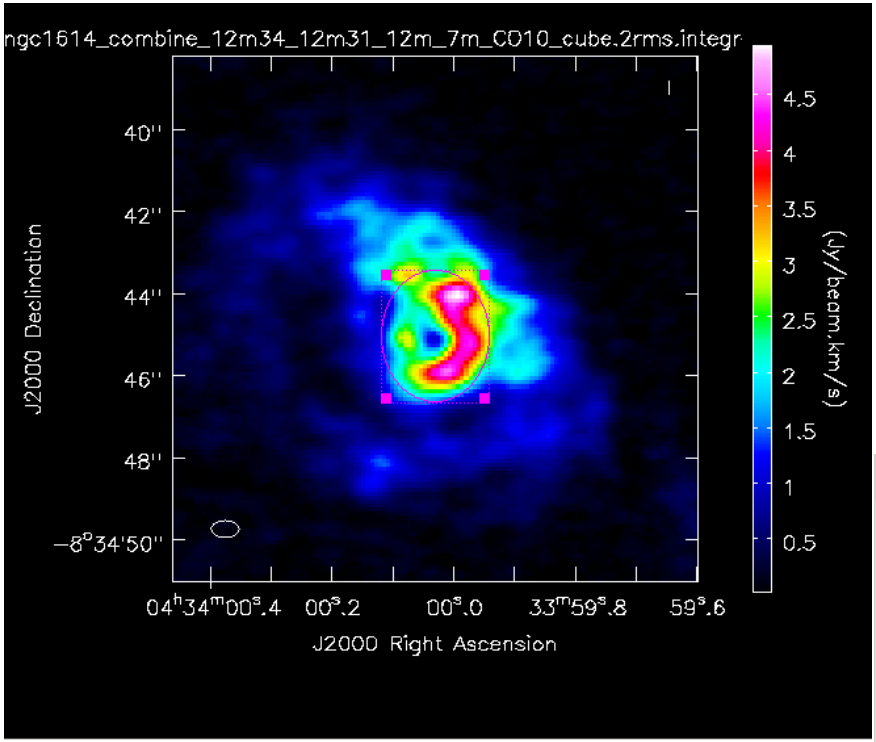


Recovered flux



$S_{CO}\Delta v$ (Jy km s^{-1}) (9)	Recovered Flux (%) (10)
295.3 ± 1.8	113 ± 26

Molecular gas mass



Properties | Statistics | Fit | File | Histogram

ngc1614_combine_12m34_12m31_12m_7m_CO10_cube.2rms.integrated

Stokes	Velocity	Frame	Doppler
I	4500km/s	BARY	RADIO
Frequency	**BrightnessUnit**	**BeamArea**	**Npts**
1.13541e+11	Jy/beam.km/s	31.9506	654
Sum	**FluxDensity**	**Mean**	**Rms**
1.886051e+03	5.903014e+01	2.883870e+00	3.029051e+00
Std dev	**Minimum**	**Maximum**	**region count**
9.272319e-01	9.856611e-01	4.950422e+00	1

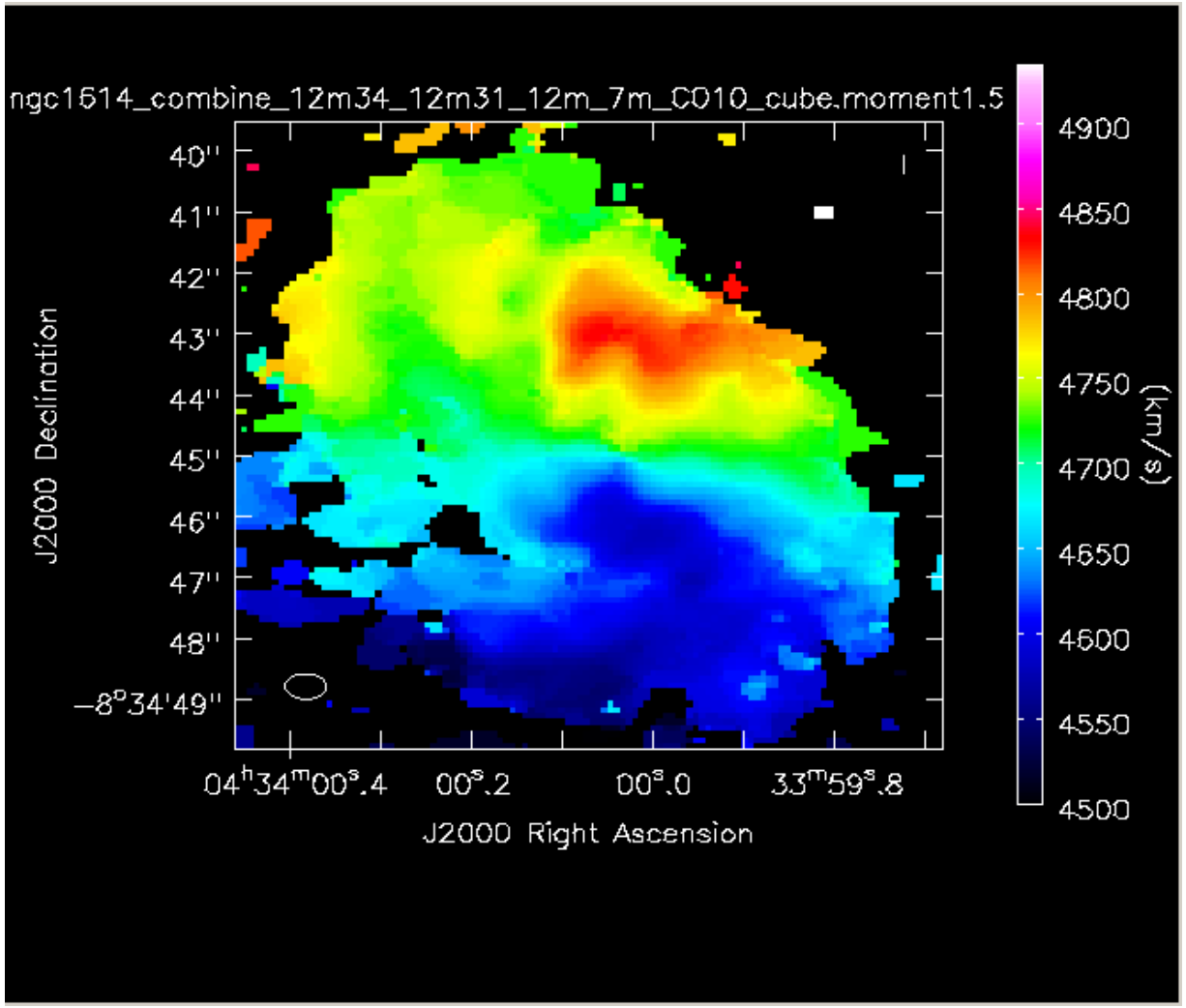
next

Molecular gas mass

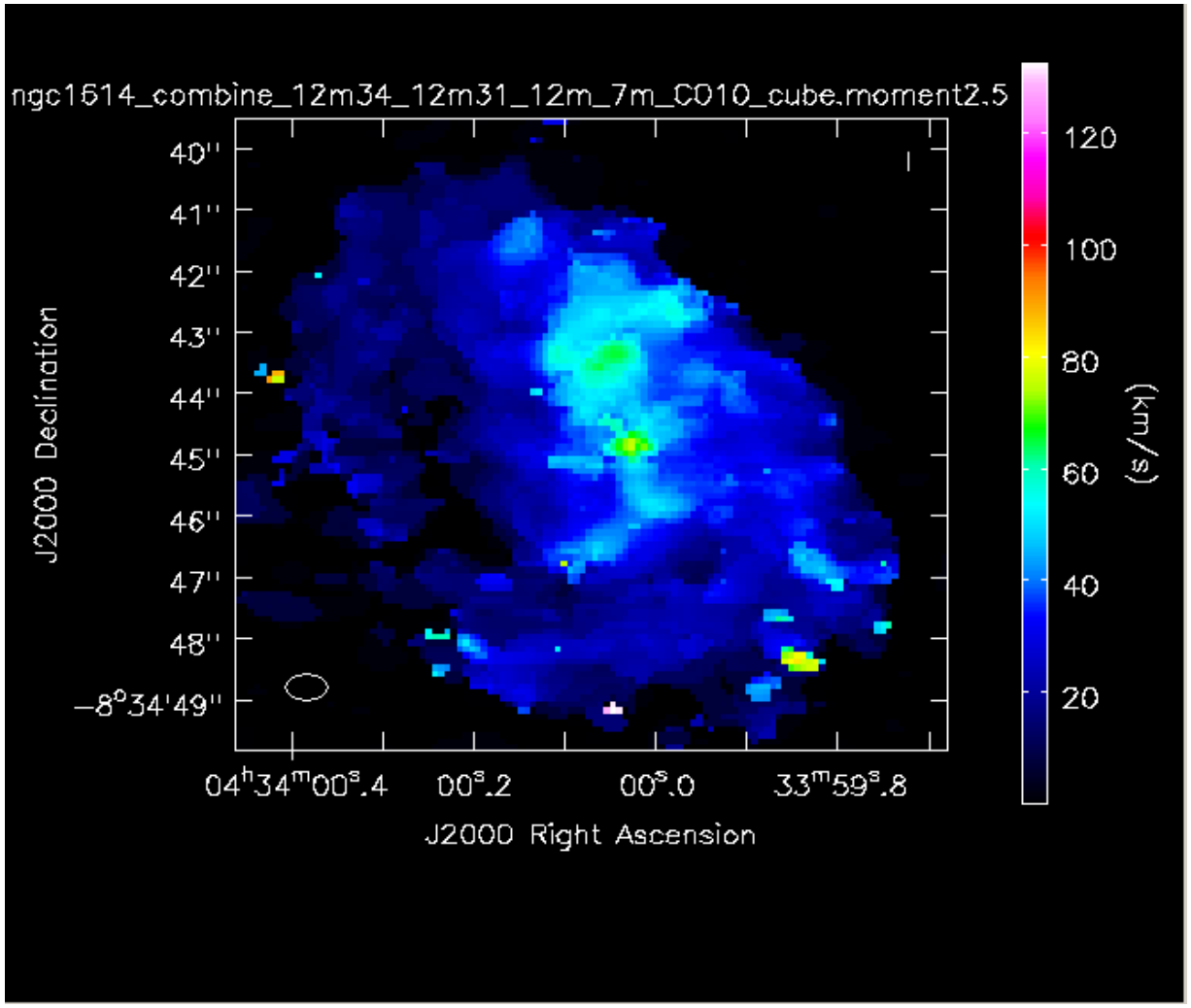
$$M_{mol} = 5.259 \times 10^8 \ M_\odot$$

$$\text{Assuming } \alpha_{CO} = 0.86 \ \frac{M_\odot}{K \cdot {}^{km}/_{s} \cdot pc^2}$$

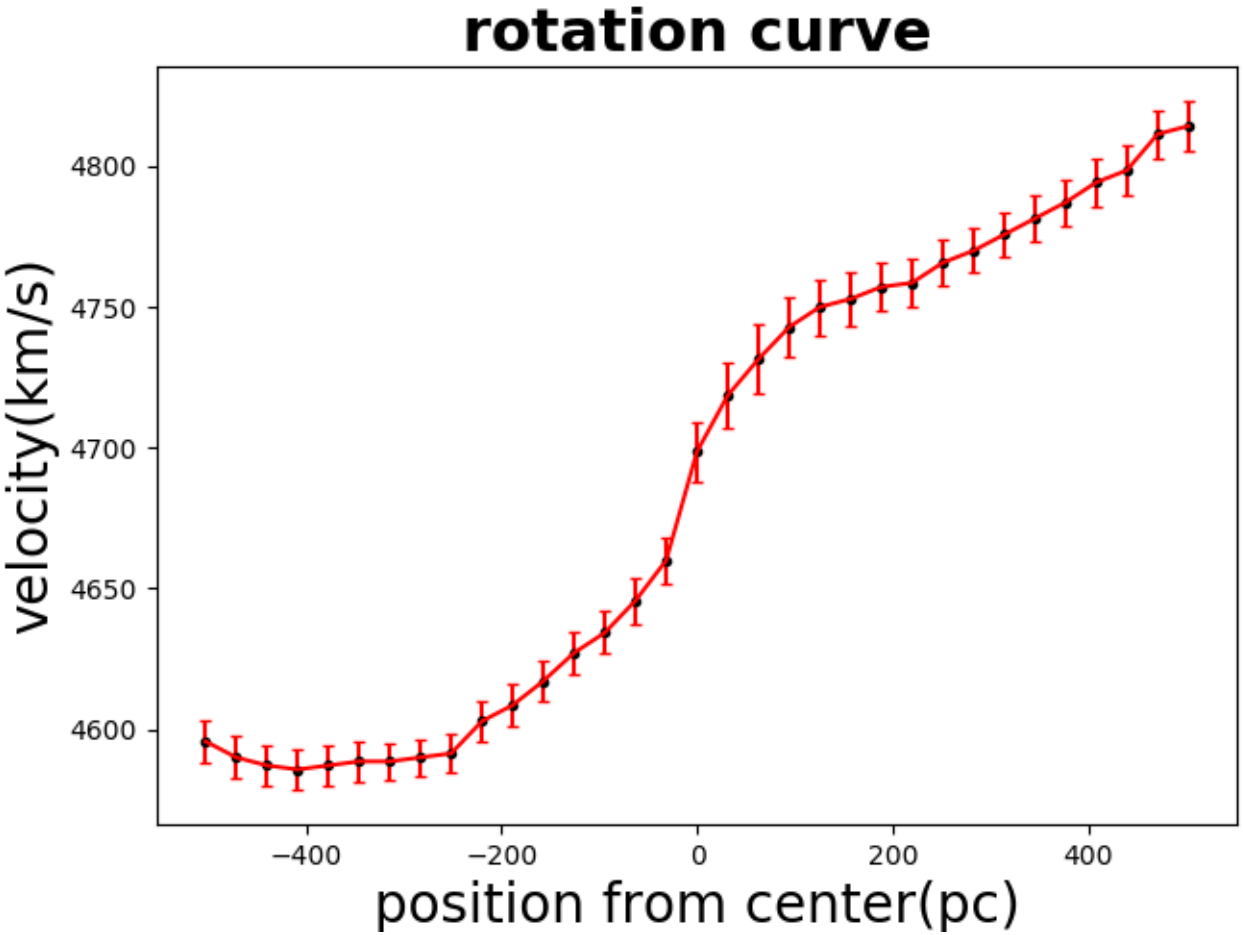
Moment 1


ngc1614_combine_12m34_12m31_12m_7m_CO10_cube.moment1.5
40''
41''
42''
43''
44''
45''
46''
47''
48''
−8°34'49''
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension
4900
4850
4800
4750
4700
4650
4600
4550
4500
(km/s)

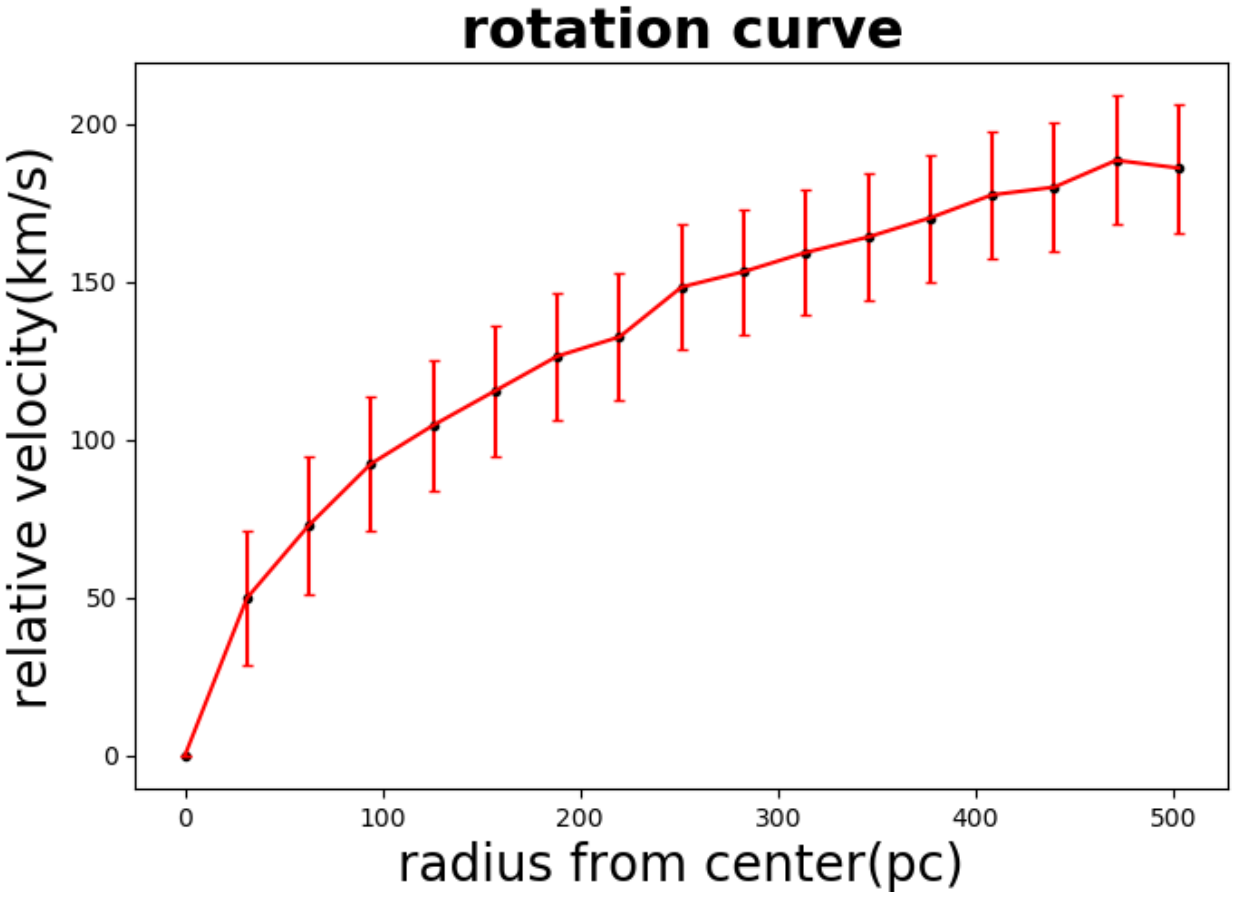
Moment 2


ngc1614_combine_12m34_12m31_12m_7m_CO10_cube.moment2.5
40''
41''
42''
43''
44''
45''
46''
47''
48''
−8°34'49''
J2000 Declination
04h34m00s.4
00s.2
00s.0
33m59s.8
J2000 Right Ascension
120
100
80
60
40
20
(km/s)

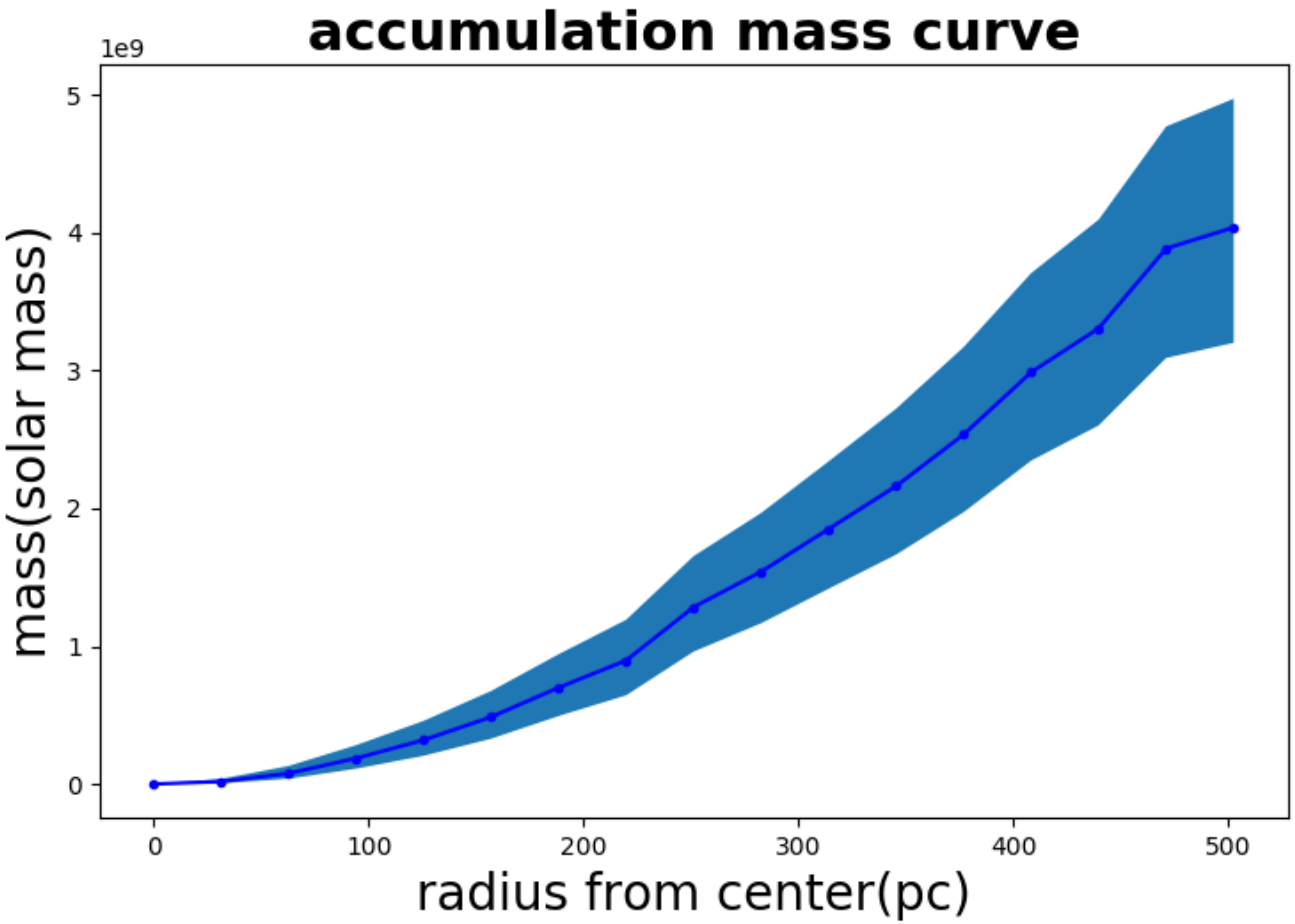
Rotation curve



Rotation curve



Mass accumulation curve



Dynamical mass

$$\mathrm{M_{dyn}} = 4.038 \times 10^{9} \quad \mathrm{M_{\odot}}$$

Summary

- The dynamical mass of the nucleus is 4.038*10^9 solar mass.

- the molecular gas mass of the nucleus is 5.259*10^8 solar mass.

Future

- Estimate the dust mass and the stellar mass.

$$M_{dyn} = M_{mol} + M_{stellar} + M_{dust} + M_{dark}$$

Thank you