Kinematics analysis for MACS1149-JD1 at ALMA

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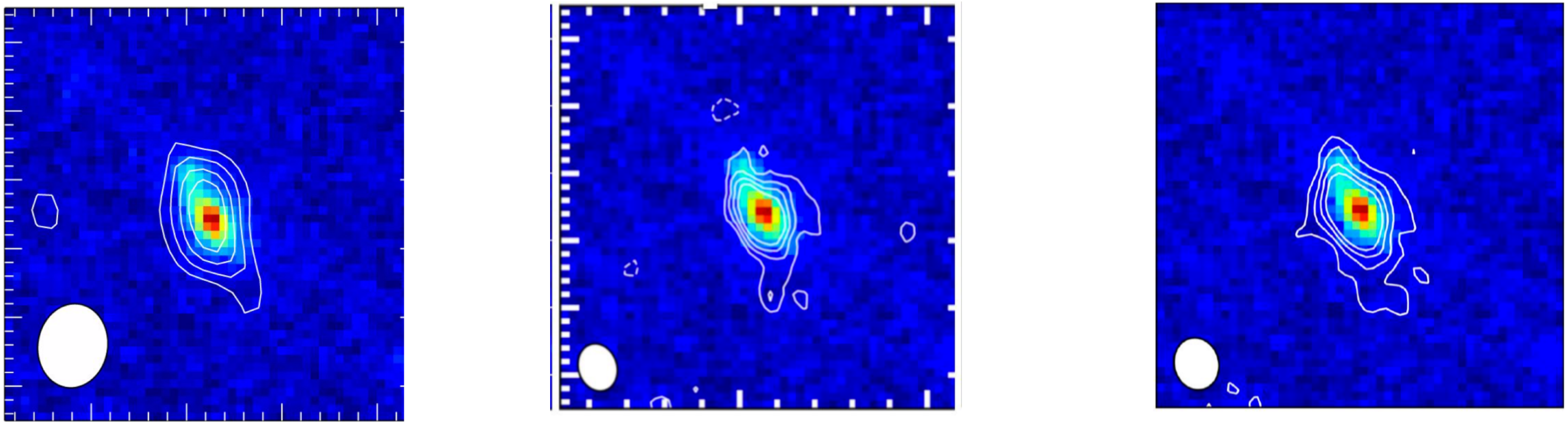
Table of Contents

Background

UV+ [OIII] contour

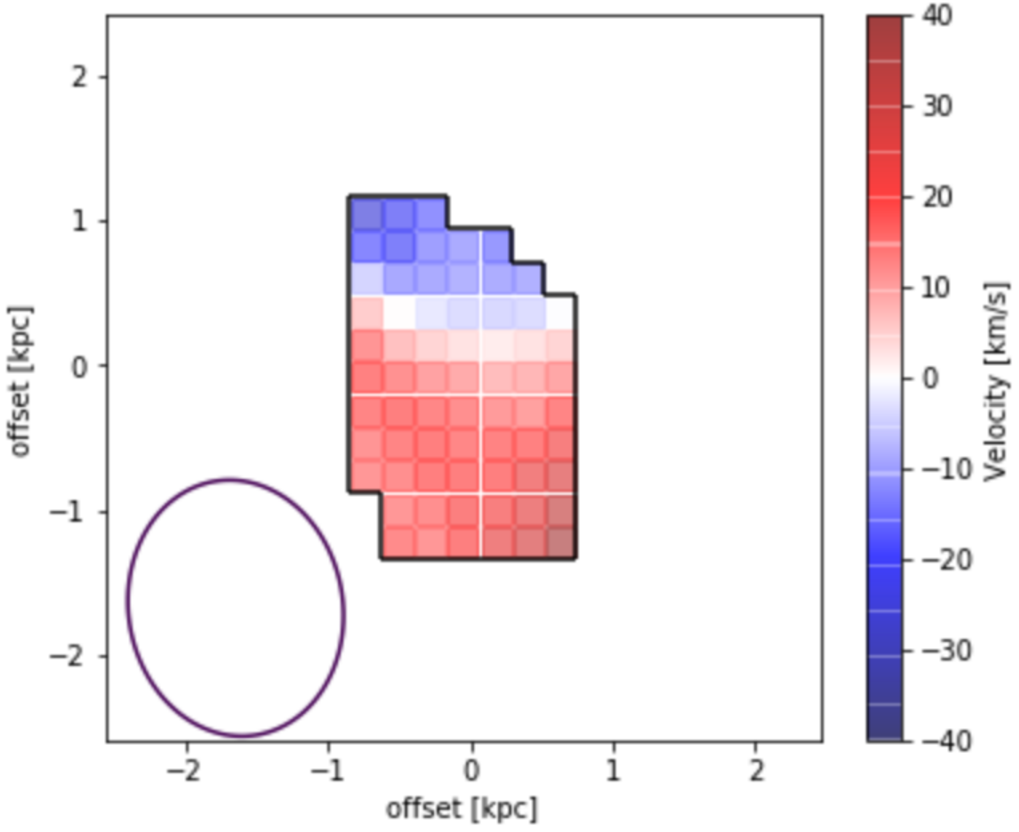


Cy3+4 Cy6 Cy3+4+6

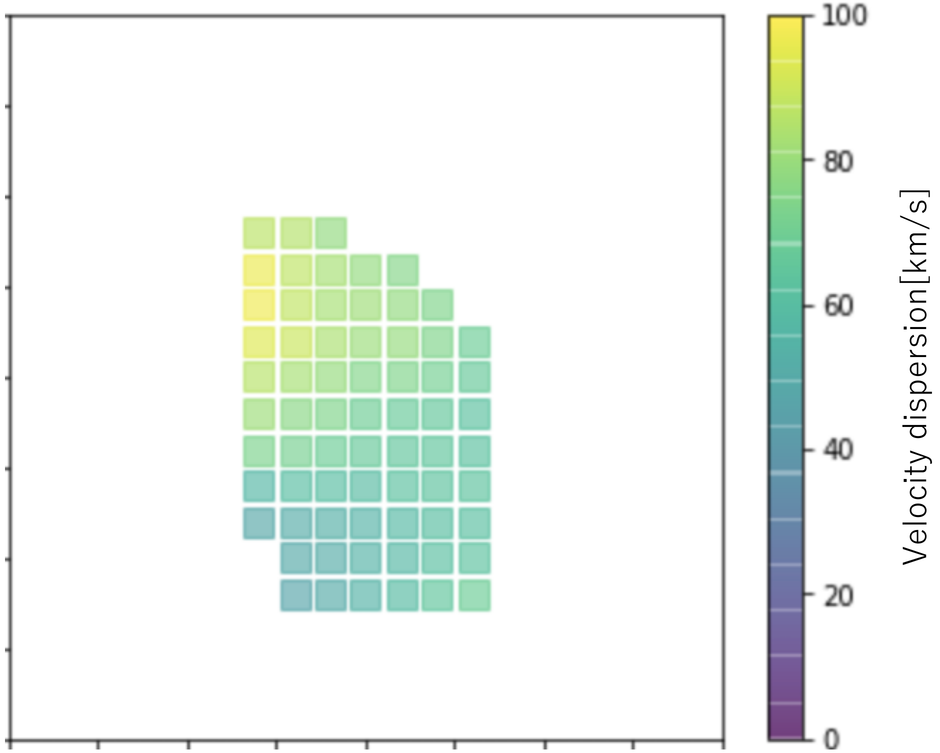
- Observation of MACS1149-JD1 was performed at ALMA(Cy4), targeting [OIII] 88 μ m line, and detected it at a redshift $z = 9.1096 \pm 0.0006$ (Hashimoto et al. 2018).
- The [OIII] emission was confirmed independently in a Cy6 program, and a clear velocity structure was found from Cy3+4+6 combined data.

Velocity gradient

Referred to R.Smit et al. 2018

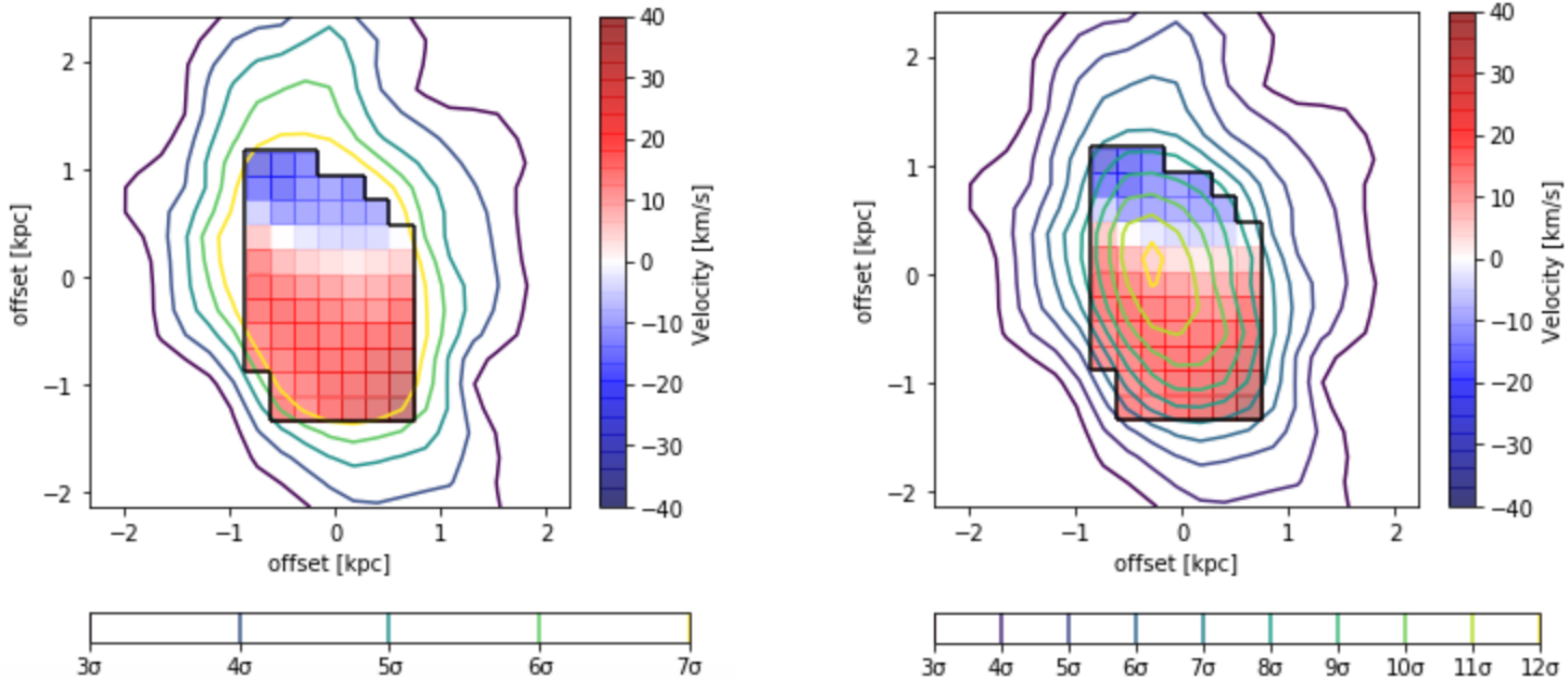


Mean velocity
(at the spatial pixel :the line fit >5 σ)



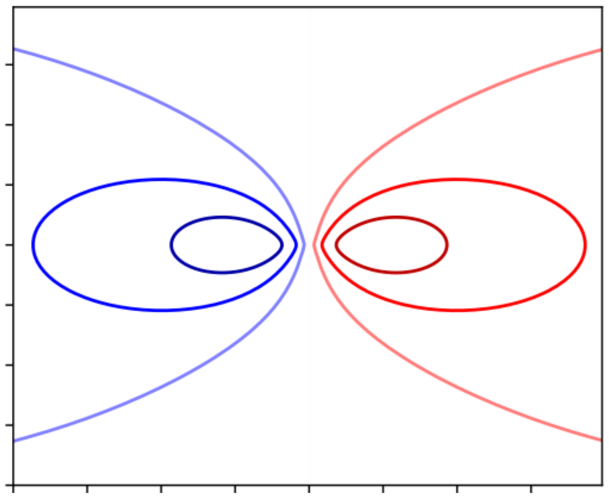
Velocity dispersion
(at the spatial pixel :the line fit >5 σ)

Velocity Map + Moment 0 map contour



Only pixels near the center of the galaxy have been extracted

Content of analysis



Contour of velocity field(model)

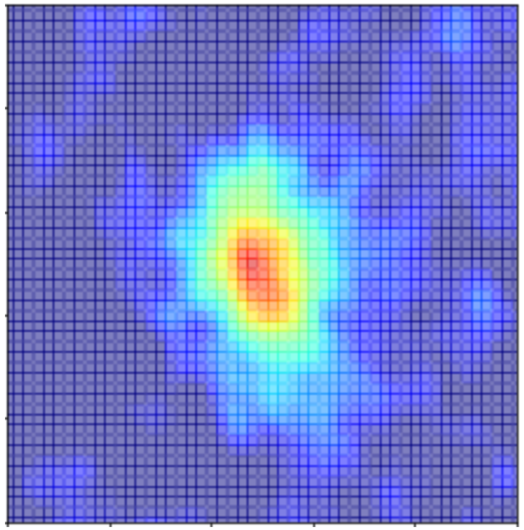
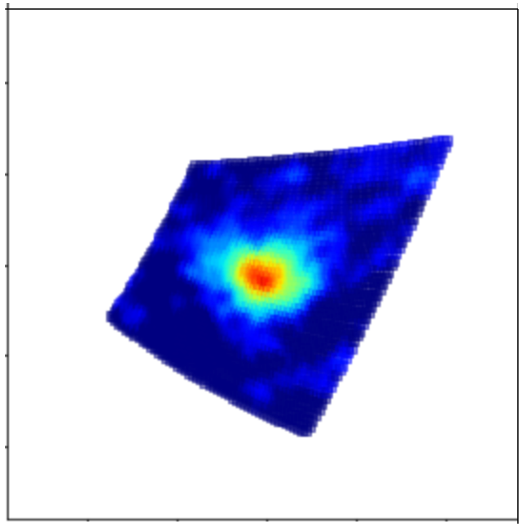


Image plane

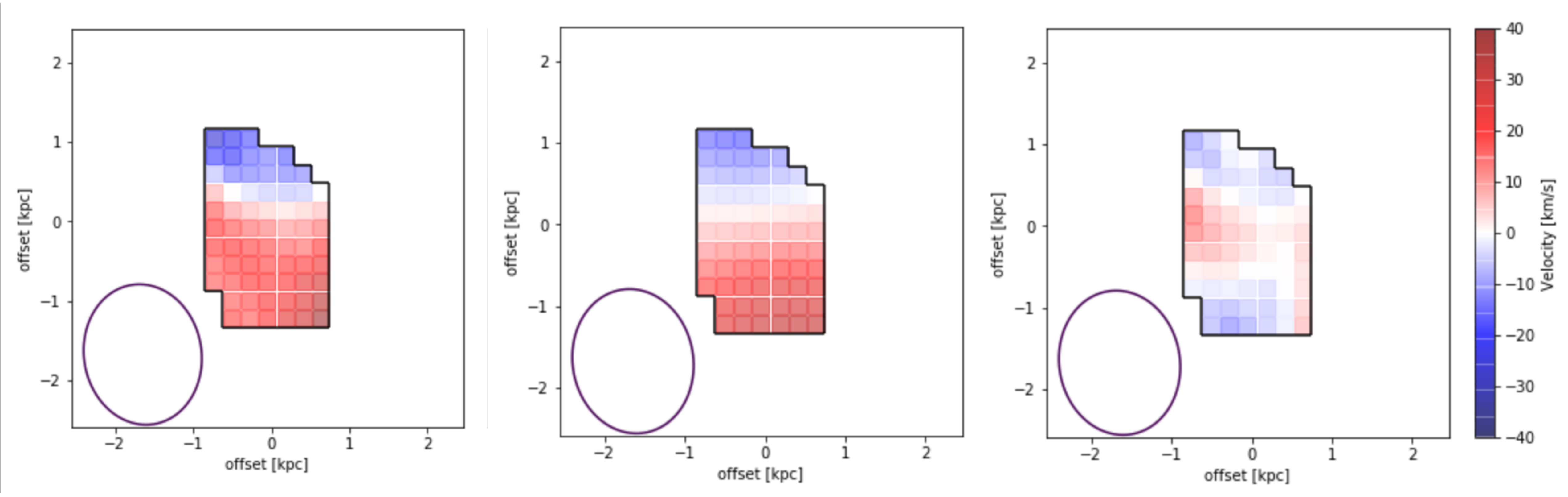
G.L
Kawamata
model



Source plane

- Modeling the velocity field, assuming that the gas is rotating in a circularly symmetric thin disk, and the gravitational potential depends only on the disk mass and surface mass density distribution follow an exponential distribution .
- Free parameters of model are the inclination of the disk, the position angle of the major axis of the disk, the systemic velocity of the galaxy, the scale length of disk and disk mass.
- Considering the gravitational lensing effect.

Velocity fitting



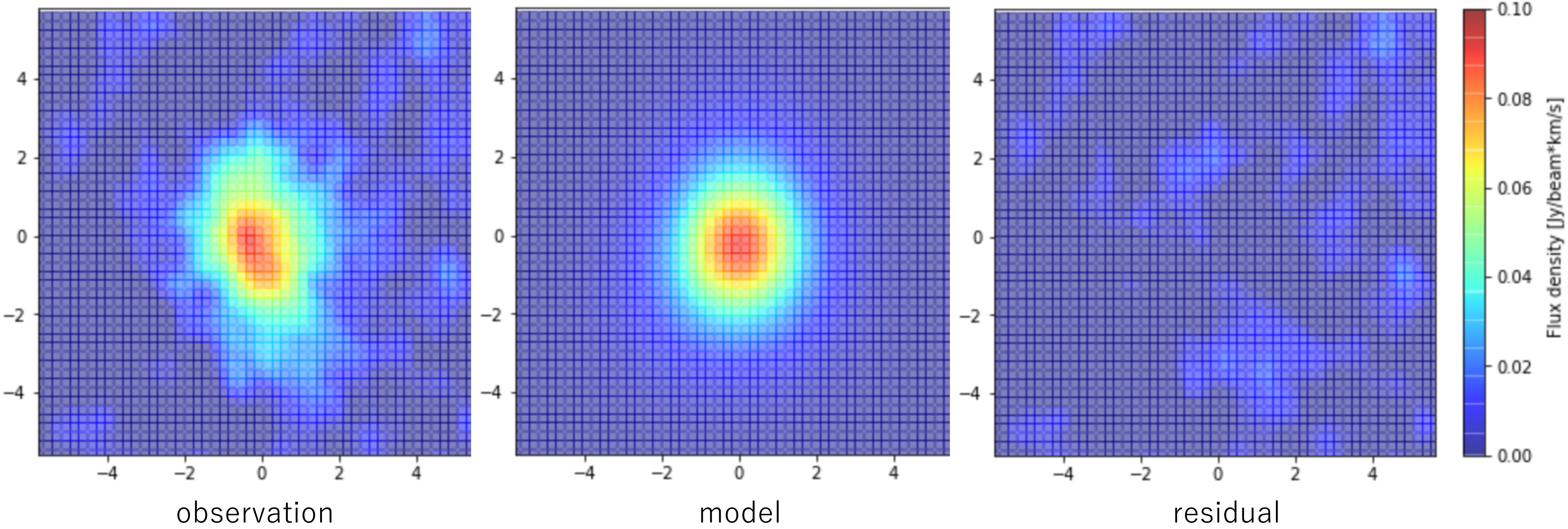
observation model residual

Inclination 65.8° ,disk mass $0.31\times10^{\wedge}9M_{\odot}$,scale length 0.22 kpc, position angle 149.4°

↔Stellar mass $1.08^{+0.53}_{-0.18}\times(10/\mu)\times10^{\wedge}9M_{\odot}$, line size $1.2\pm0.4\times\sqrt{10/\mu}$ kpc.(Hashimoto et al. 2018)

Moment0 Map fitting

G.L(kawamata model)



Assuming that flux density follow an exponential distribution(~exp(-r/h).
Free parameters are inclination, scale length, position angle and center pixel.

Inclination 55.5° ,scale length 0.43 kpc, position angle 21.3°

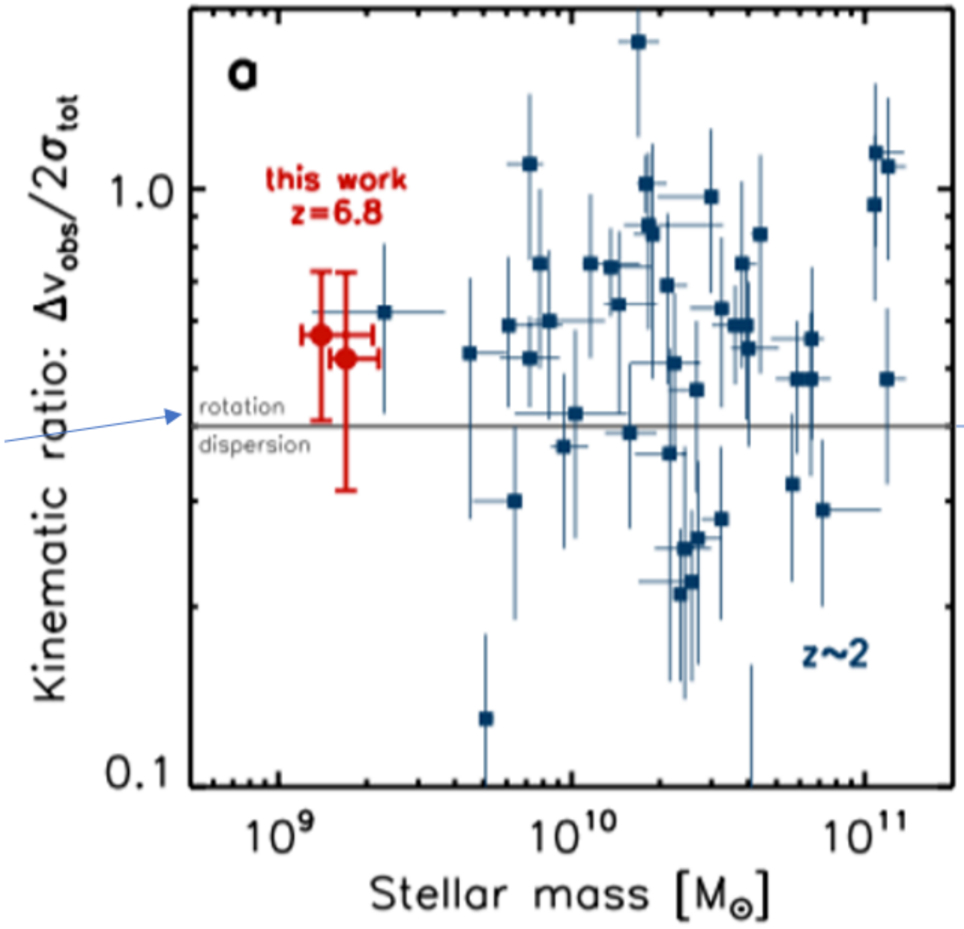
Summary

- We found the velocity structure and fit it, modeling the velocity field and considering the gravitational lensing effect.

- Currently, I am writing code to fit Moment0 map and Velocity map at the same time.

Kinematic Ratio

0.4



(R.Smit et al 2018)

Rotation dominated

Dispersion dominated

observational criterion

Red point: z~6 [CII](0.57 ± 0.16 , 0.52 ± 0.21)

Blue point: the SINS sample of H α emitting galaxies at $z \sim 2$

JD1 result 0.45(>0.4)
→Rotation dominated

(Förster Schreiber, N. M. et al. 2009)

Velocity field of rotation galaxy

- The relation between **velocity field** V_{obs} and rotation velocity $V(r)$

$$V_{obs}(r,\phi) = V_{sys} + V(r)cos\phi\,\sin(i)$$

((r,ϕ): Position on the galactic disk (polar coordinates)、 V_{sys}: Velocity in line-of-sight direction + backward velocity due to motion peculiar to the galaxy、

i:inclination of the disk ($i = 0°$:face on、 $i = 90°$:edge on)

(シリーズ現代の天文学, 4 銀河I,銀河と宇宙の階層構造)

- When gas rotates a rotationally symmetric thin disk, the gravitational potential depends only on the mass of the disk, and the areal density distribution is expressed by an exponential function ($\mu_0 e^{-r/h}$), The rotation speed is expressed as

$$V^2(y) = 4\pi G\mu_0 h y^2[I_0(y)K_0(y) - I_1(y)K_1(y)],\ y = \frac{r}{2h}$$

(I_n,K_n: "$nth - order\ modified\ Bessel\ function\ of\ the\ 1st\ kind\ and\ the\ 2nd\ kind$)

(K.Freeman et al 1970)

How to make the velocity map

I obtain velocity distribution by referring to R.Smit et al. 2018.

First, I write the spectrum for each pixel.

And I obtain the mean velocity and velocity dispersion to fit this with Gaussian ($\sim\exp\left(-\frac{(V-V_{mean})^2}{2\sigma^2}\right)$).

Then, in order to choose the pixels that follow the Gaussian distribution as much as possible,

do the following

$$\chi_{straight}{}^2 - \chi_{gaussfit}{}^2 \geq 25$$

$$\chi_{straight}{}^2 = \sum_{\nu_{start}}^{\nu_{end}} \frac{\left(F_{obs} - F_{straight\ line}\right)^2}{\sigma^2}, \chi_{\mathrm{gauss}fit}{}^2 = \sum_{\nu_{start}}^{\nu_{end}} \frac{\left(F_{obs} - F_{gauss}\right)^2}{\sigma^2}$$

However, to perform fitting with a Gaussian function, the original function must follow a Gaussian distribution.

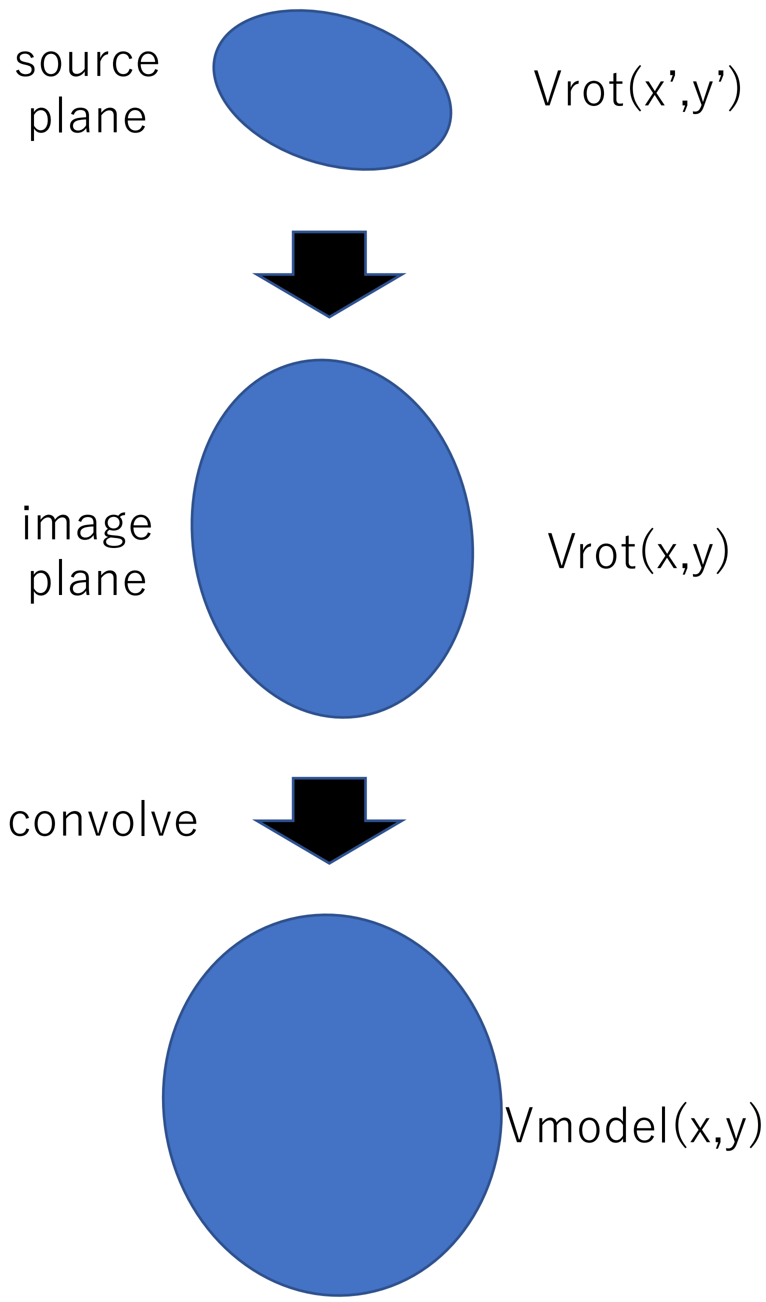
How to fit the velocity structure

①Set spatial pixels in the image plane (x,y) in a sufficient range, and map to the source plane (x',y’).

② The rotation disk is placed on the source plane (x',y'), and the rotation speed Vrot(x',y') is obtained.

③ Convolve Vrot (x,y) with the beam in the image plane.

④ Fitting is performed so that
$\chi^2([(Vobs(x,y)-Vmodel(x,y))/Verror]^2)$ is minimized.



Gravitational lensing

$$\begin{pmatrix}\delta\beta_1\\ \delta\beta_2\end{pmatrix} = \begin{pmatrix}1-\kappa-\gamma_1 & -\gamma_2\\ -\gamma_2 & 1-\kappa+\gamma_1\end{pmatrix}\begin{pmatrix}\delta\theta_1\\ \delta\theta_2\end{pmatrix}$$

$$\kappa = \frac{1}{2}(\psi_{11}+\psi_{22})$$

$$\gamma_1 = \frac{1}{2}(\psi_{11}-\psi_{22})$$

$$\gamma_2 = \psi_{12}$$

$\delta\vec{\beta}$: source plane

$\overrightarrow{\delta\theta}$: image plane

$$\psi_{ij} = \frac{\partial^2\psi}{\partial\theta_i\partial\theta_j}$$

(ψ:gravitational potential of cluster)

- coordinate transformation (image plane→ source plane),using κ, γ_1 and γ_2 of HFF gravitational lens model.
- $\overrightarrow{\delta\theta}$ is the position vector around the center pixel

Velocity fit result

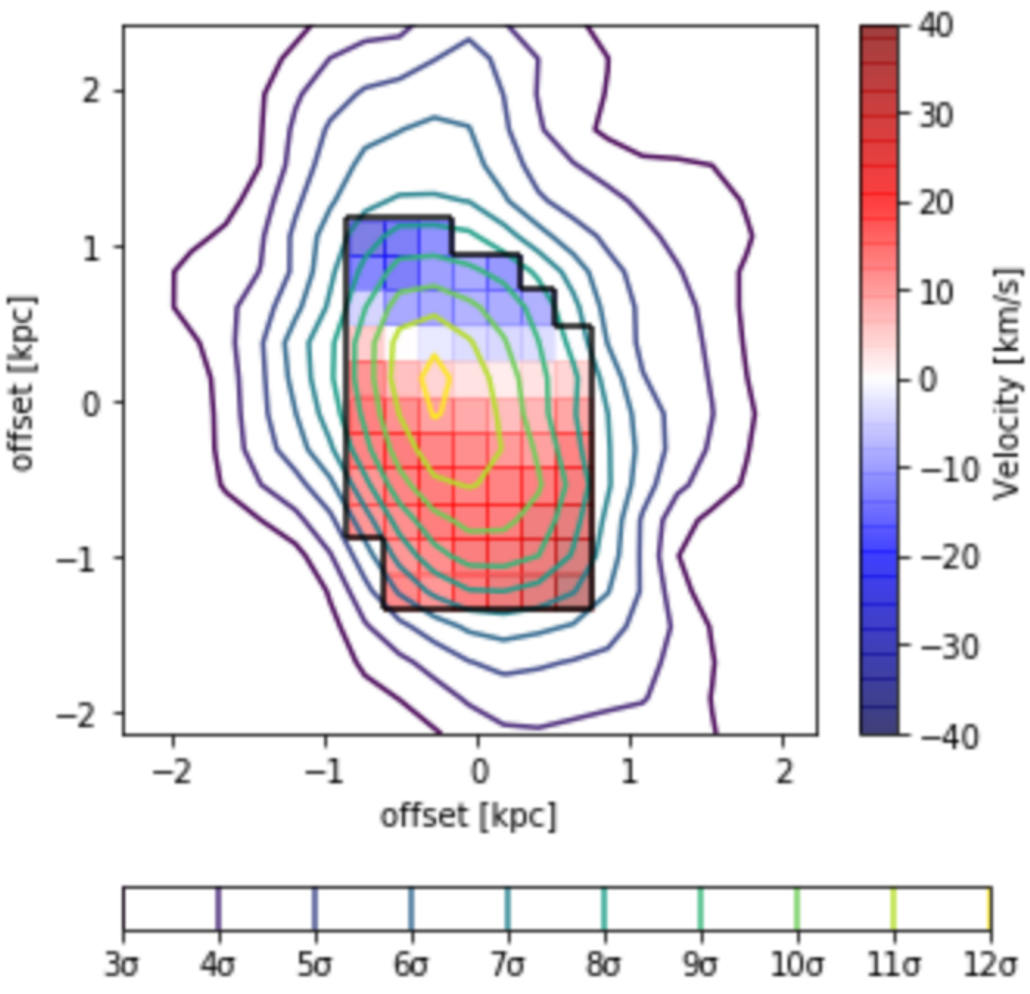
	inclination[°]	Mdisk10^9Mo]	Scale radius[kpc]	Position angle[°]
kawamata	65.8	0.31	0.22	149.4
bradac_v1	59.5	0.79	0.23	145.0
merten_v1	70.3	0.61	0.20	278.1
sharon_v2.1	87.3	39.76	1.51	205.7
sharon_v4	84.0	2.69	0.29	203.1
sharon_v4cor	89.3	1.45	0.20	229.0
sharon_v4orig	84.0	2.69	0.29	203.1
williams_v1	54.2	460	4.93	21.0
williams_v4	1.7	42437	5.22	9.0
zitrin-ltm_v1	70.4	0.59	0.29	164.5
zitrin-ltm-gauss_v1	84.3	12.75	0.87	191.9

Mom0 fit result

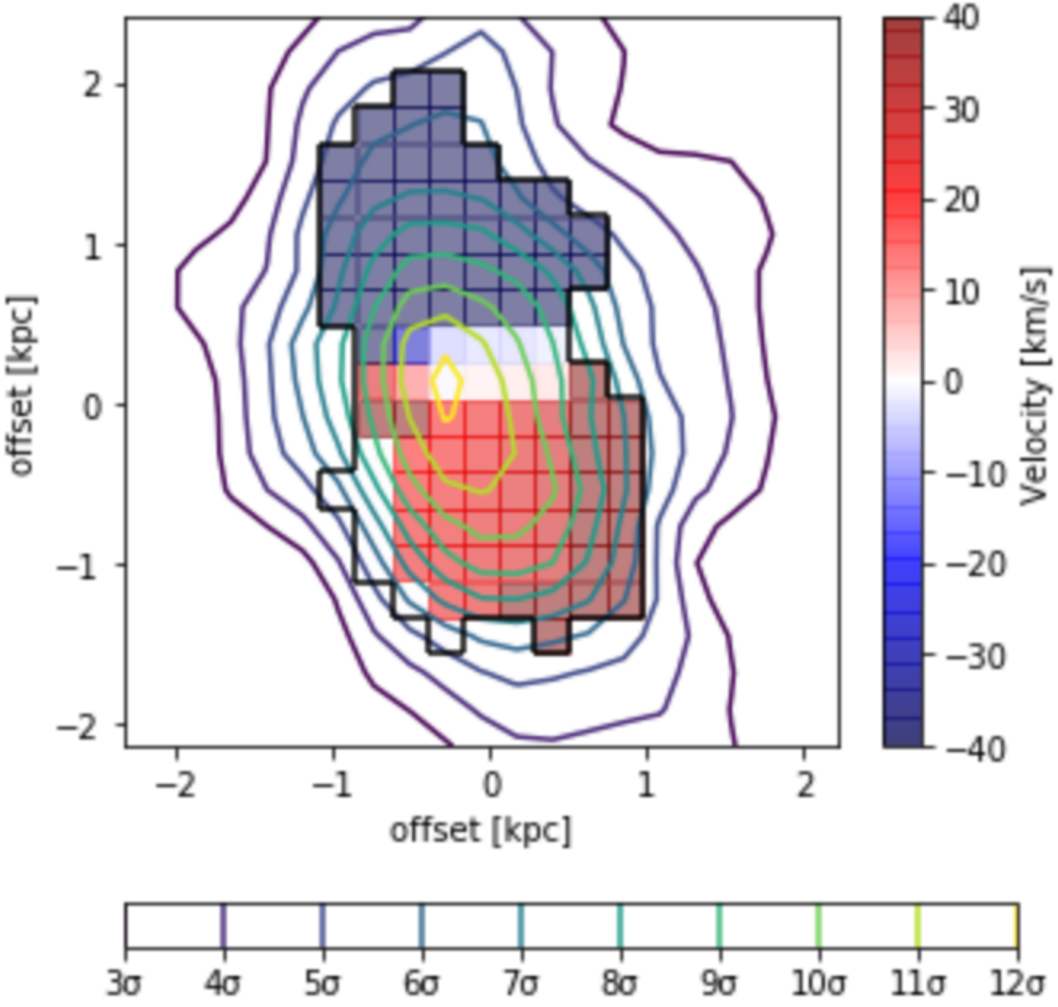
The red letters don't seem to fit well

	inclination[°]	Center pixel[pix]	Scale radius[kpc]	Position angle[°]
kawamata	55.5	255.3,254.4	0.43	21.3
bradac_v1	75.2	255.6,253.6	0.34	29.9
merten_v1	68.2	255.4,254.3	0.44	121.8
sharon_v2.1	80.0	255.3,254.4	0.51	49.6
sharon_v4	83.9	255.5,254.1	0.44	133.1
sharon_v4cor	90.0	260.9,259.1	4.76	51.4
sharon_v4orig	83.9	255.5,254.1	0.44	133.1
williams_v1	89.7	255.7,254.3	1.15	57.2
williams_v4	75.6	255.4,254.1	0.78	144.1
zitrin-ltm_v1	58.9	255.4,254.4	0.61	170.1
zitrin-ltm-gauss_v1	80.8	255.4,254.3	0.74	43.7

Mom0contour+Velocity map

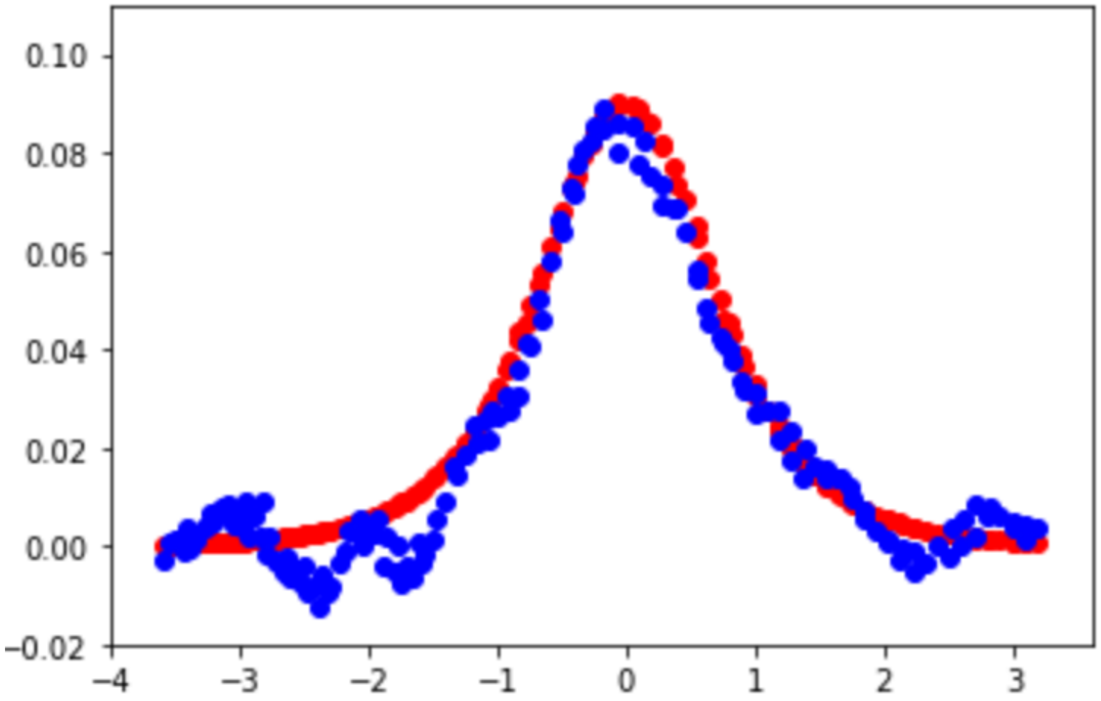


Mean velocity (at the spatial pixel :the line fit >5 σ)

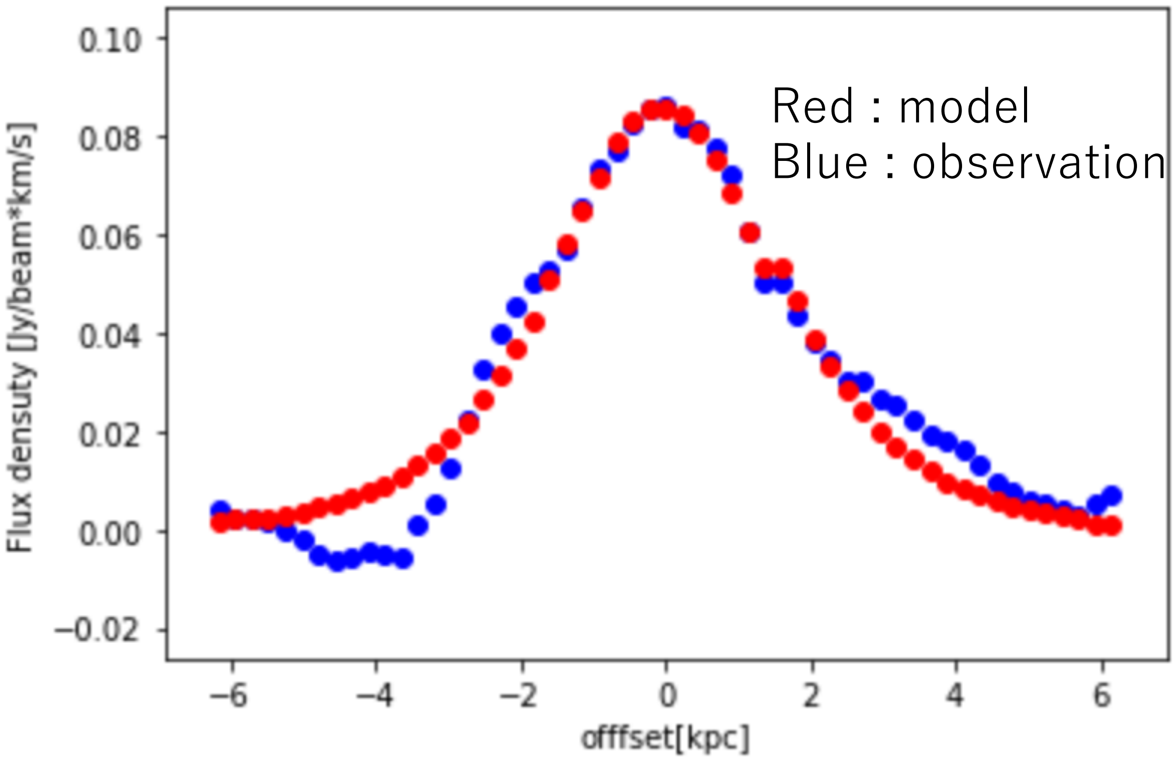


Moment1 map(threshold 5 σ)

Cross section of moment0 map



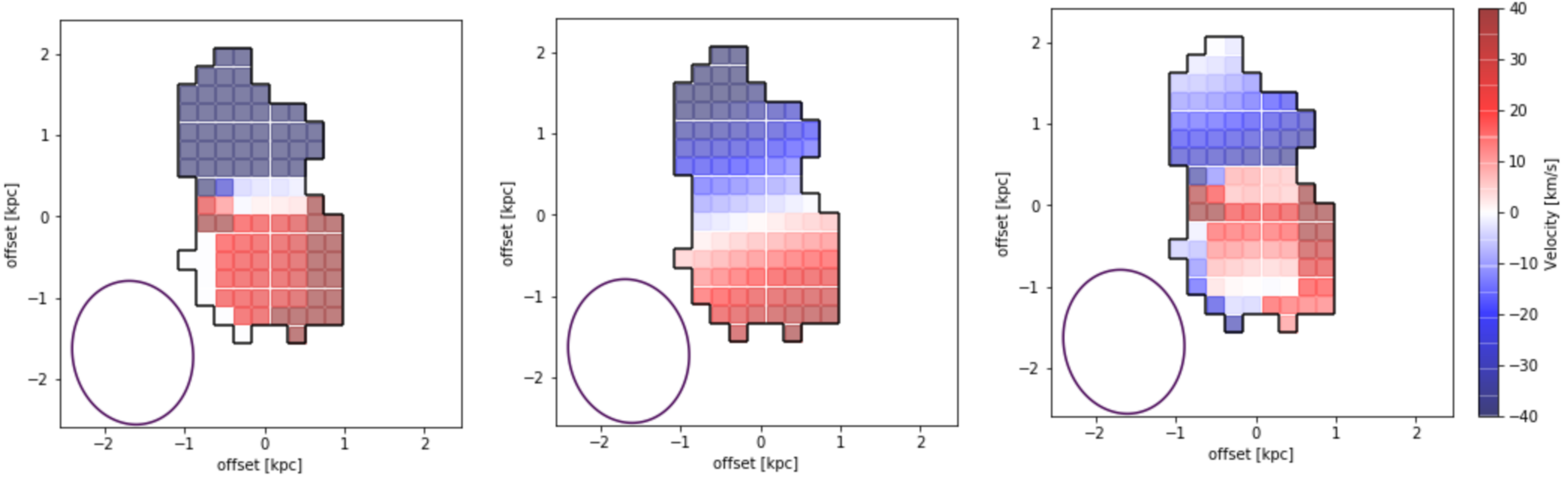
(source plane)



(image plane)

With a lens, it looks more symmetric near the peak than without a lens

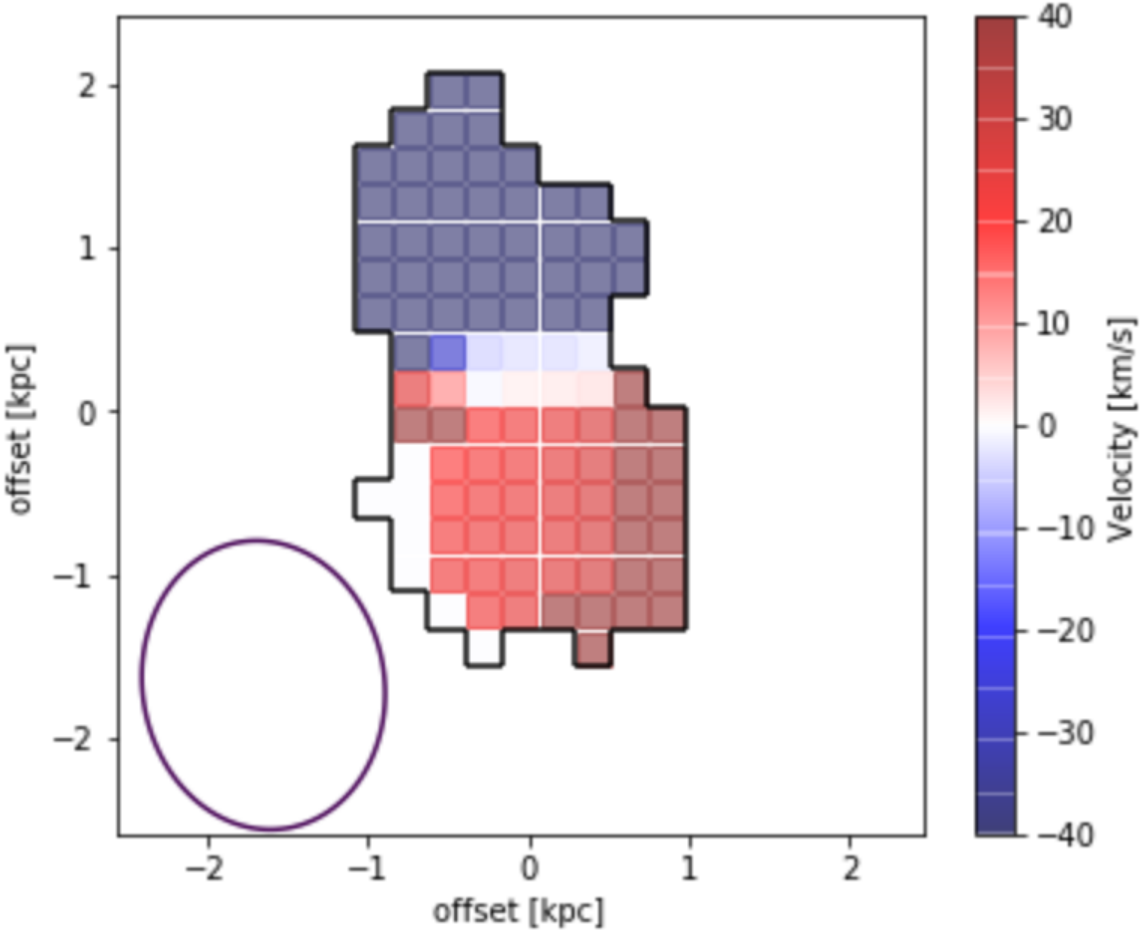
Moment 1 map fitting



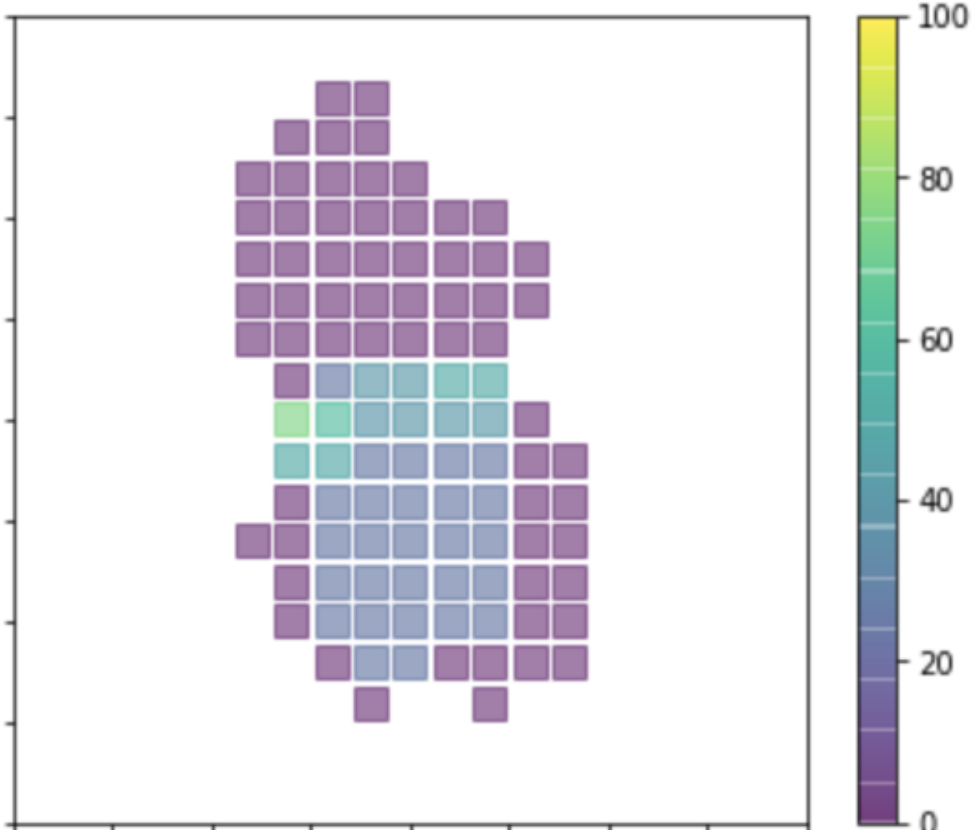
observation　　model　　residual

Inclination 63.6° ,disk mass 7.4×10^9$M_{\odot}$,scale radius 1.3 kpc , position angle 142.8°

Moment 1,2 Map

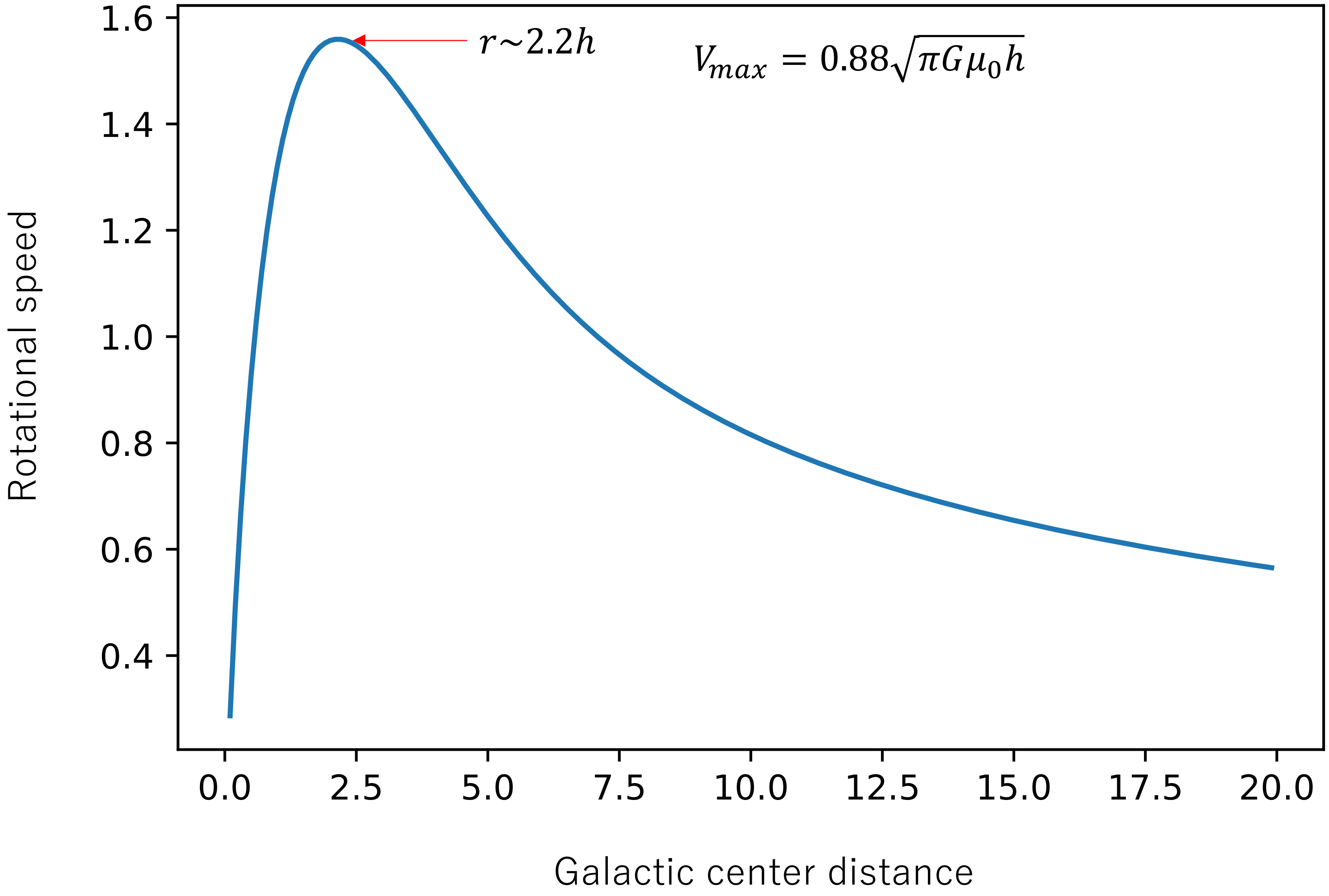


Moment1 map(threshold 5 σ)



Moment2 map(threshold 5 σ)

Rotation curve



Surface density distribution of the galactic disk

$$\mu(r) = \mu_0 \exp\left(-\frac{r}{h}\right)$$