Galactic Center Rotation Curve and Mass

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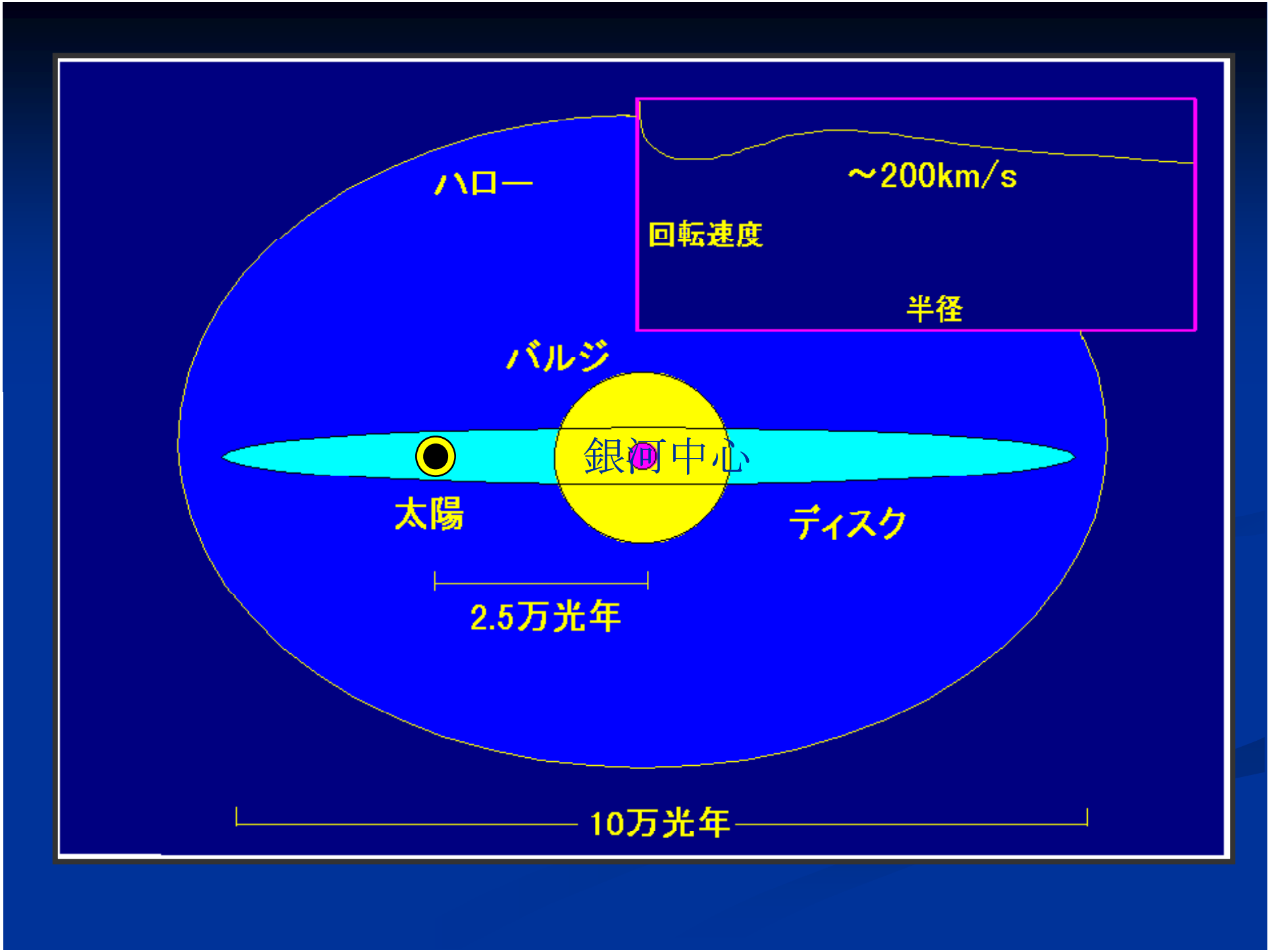
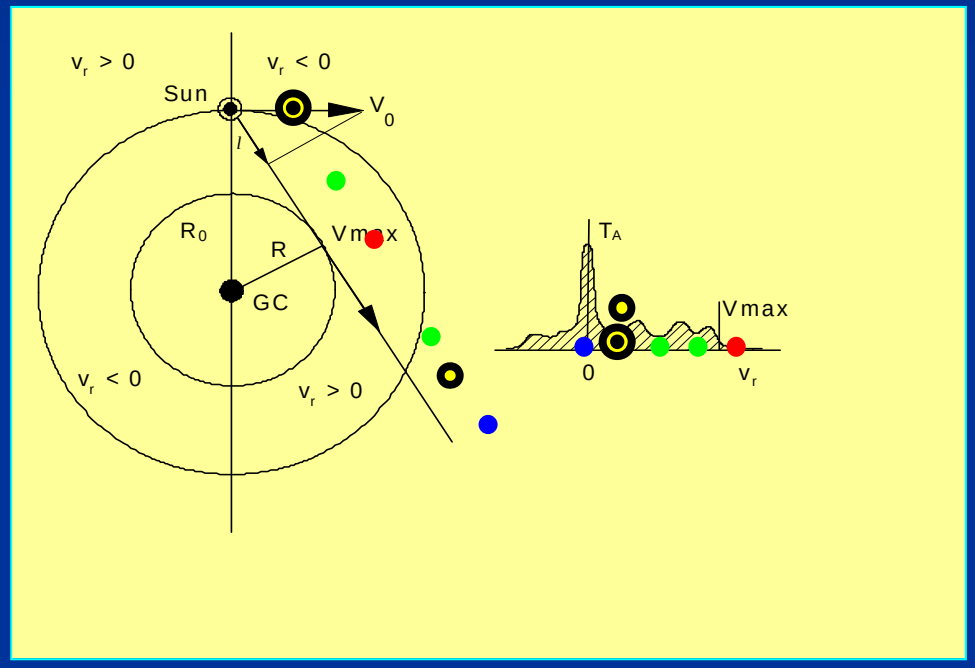
2013 03 28 @ Nagoya University

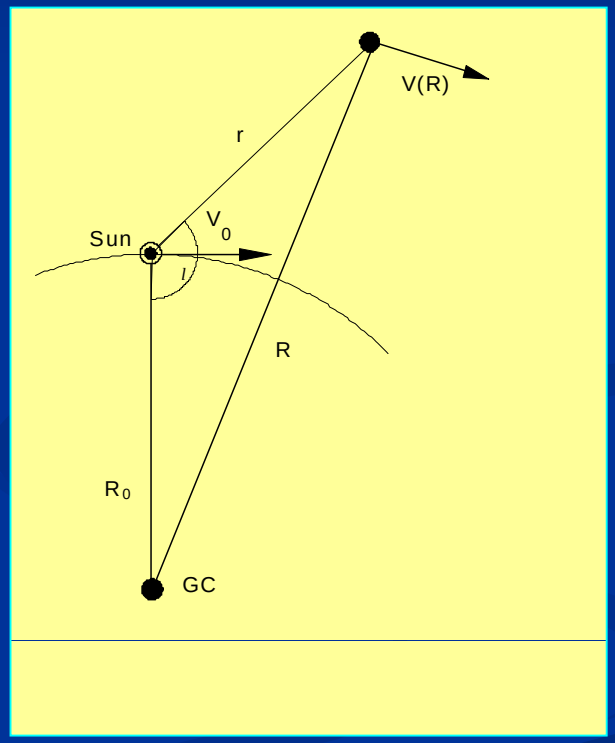
1. Log Rotation Curve
2. Mass models
3. Galactic Center RC
4. BH - Bulge – Disk -DH

1. Rotation Curve

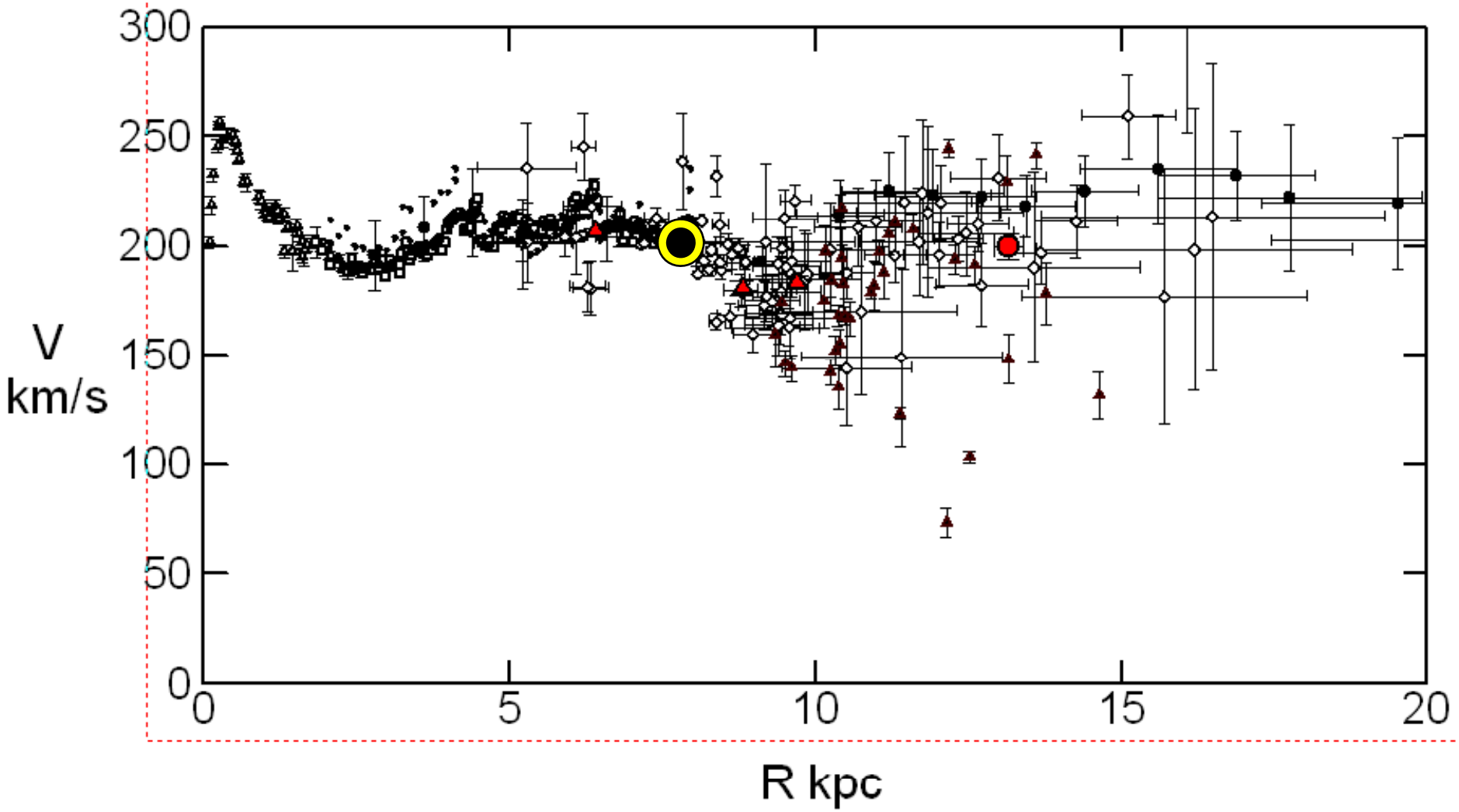

ハロー
～200km/s
回転速度
半径
バルジ
銀河中心
太陽
ディスク
2.5万光年
10万光年

Rotation velocities inside/outside Solar Circle





Solar Circular Velocity V_0=200 km/s @ R_0=8kpc



2. Mass Model

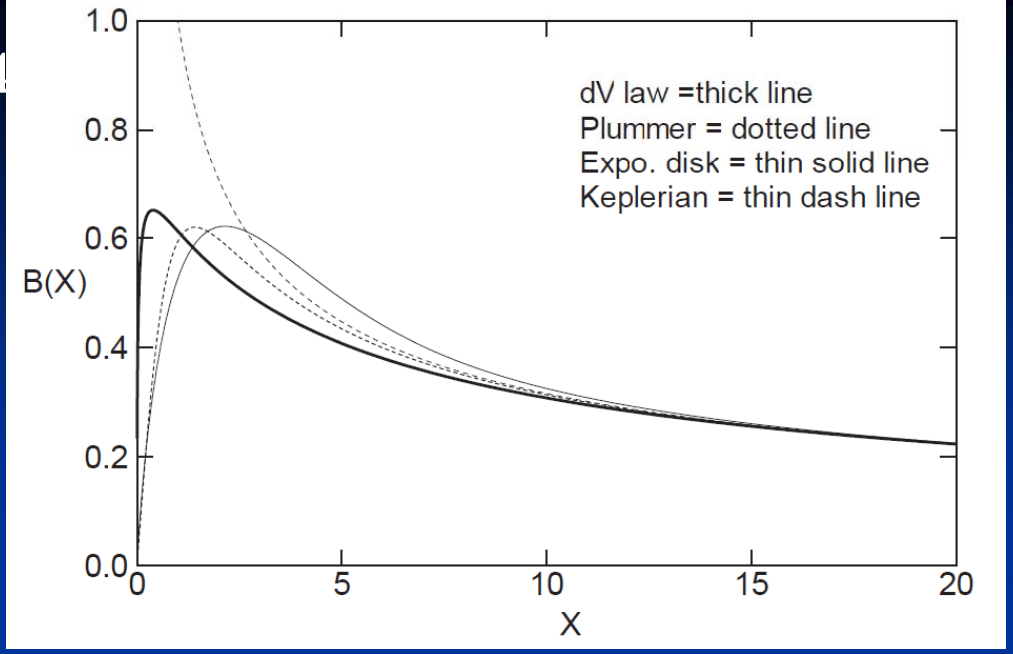
RC Fitting by

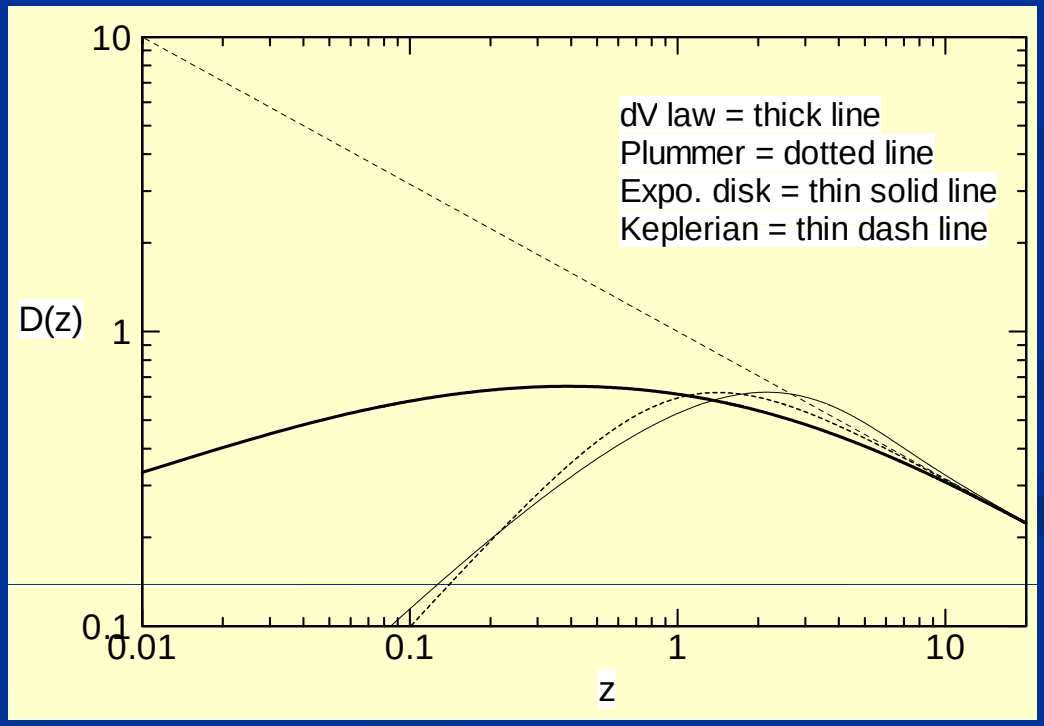
(1) Bulge: de Vaucouleurs Law

(2) Disk: Exponential

(3) Dark Halo: NFW

de V ∝ exp(-r$^{1/4}$)
Expo.
Plummer
Kepler





(1) Bulge de Vaucouleurs: $\exp(-r^{1/4})$

$$\Sigma_b(r) = \lambda_b B_b(r) = \Sigma_{be} \exp\left[-\kappa\left(\left(\frac{r}{R_b}\right)^{1/4} - 1\right)\right]$$

$$\rho(r) = \frac{1}{\pi}\int_r^\infty \frac{d\Sigma_b(x)}{dx}\frac{1}{\sqrt{x^2 - r^2}}dx$$

$$M_b(R) = 4\pi \int_0^R r^2 \rho(r) dr.$$

$$V_b(R) = \sqrt{\frac{GM_b(R)}{R}}.$$

(2) Disk: Exponential

$$V_{\rm d}(R) = \sqrt{\frac{GM_{\rm d}}{a_{\rm d}}}\mathscr{D}(X),$$

where $X = R/a_{\rm d}$, and

$$\mathscr{D}(X) = (X/\sqrt{2}) \times$$

$$\times \left[\{I_0(X/2)K_0(X/2) - I_1(X/2)K_1(X/2)\}\right]^{1/2}$$

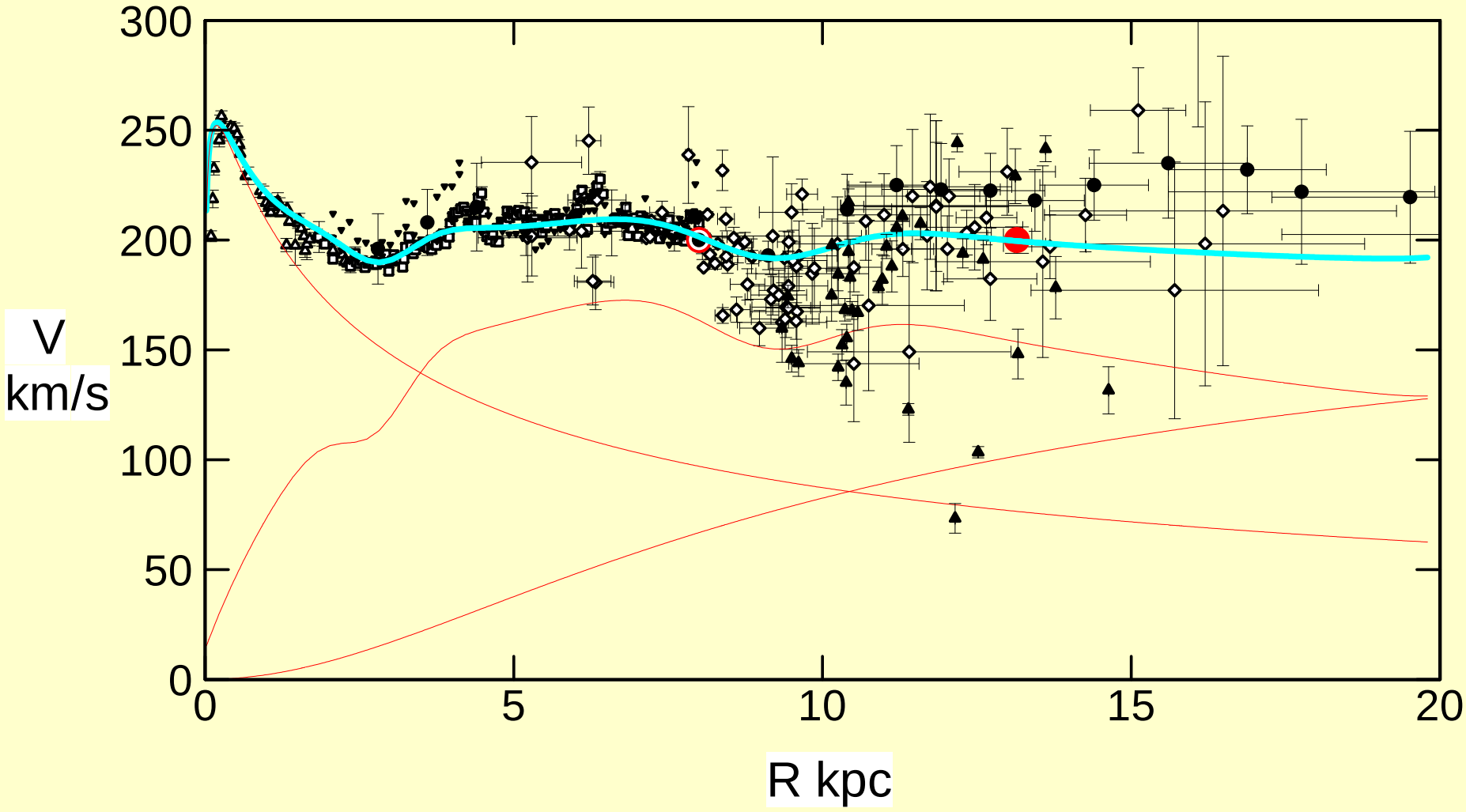
(3) Dark Halo NFW Density Profile

$$X = R/h$$

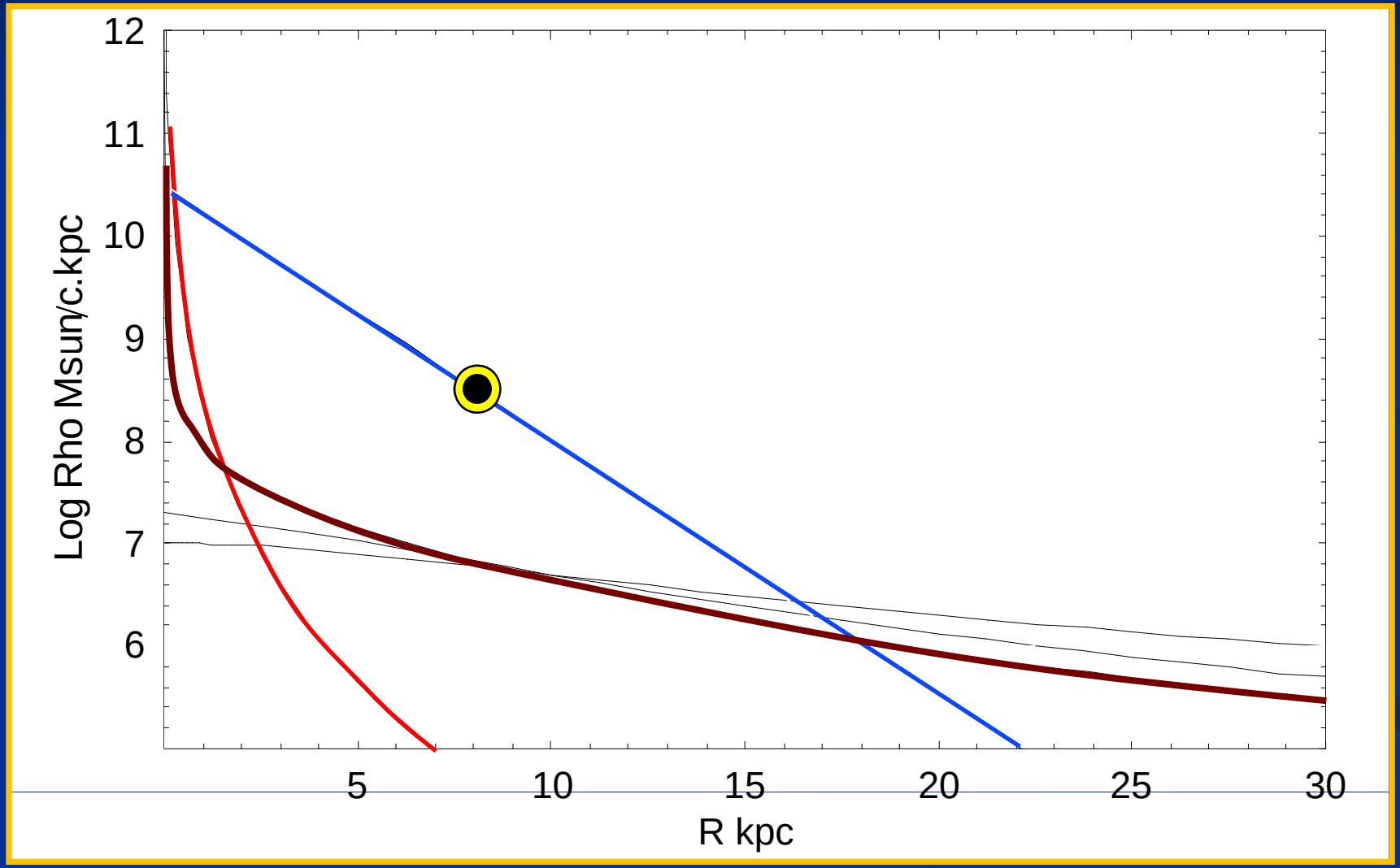
$$\rho(R) = \frac{\rho_0}{X\,(1+X)^2},$$

$$M_{\rm h}(R) = 4\pi\rho_0 h^3 \left\{ \ln(1+X) - \frac{X}{1+X} \right\}.$$

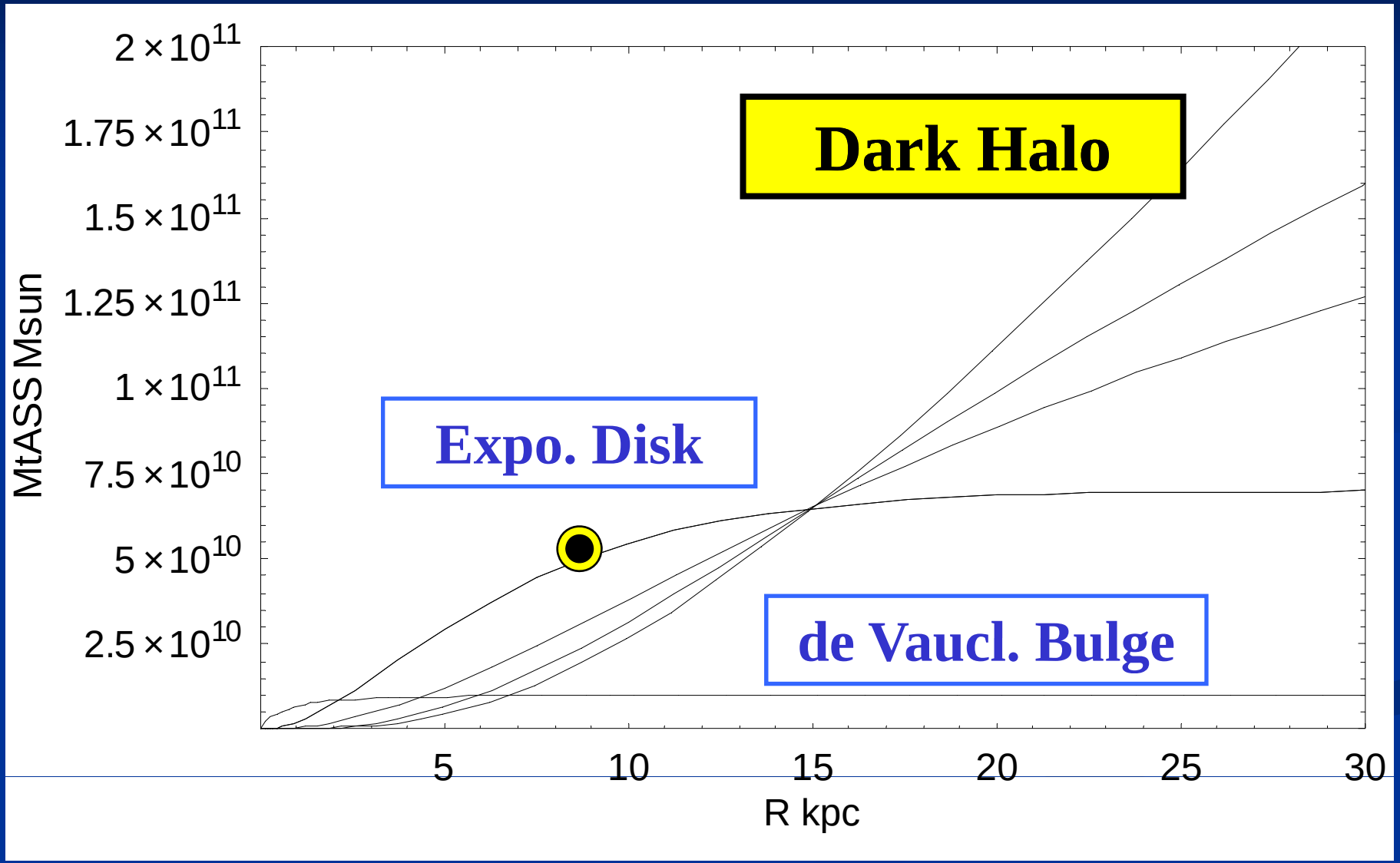
Sofue, Honma, Omodaka 2009



Volume Densities for Bulge, Disk, and Halo (Isoth, NFW, Burkert)

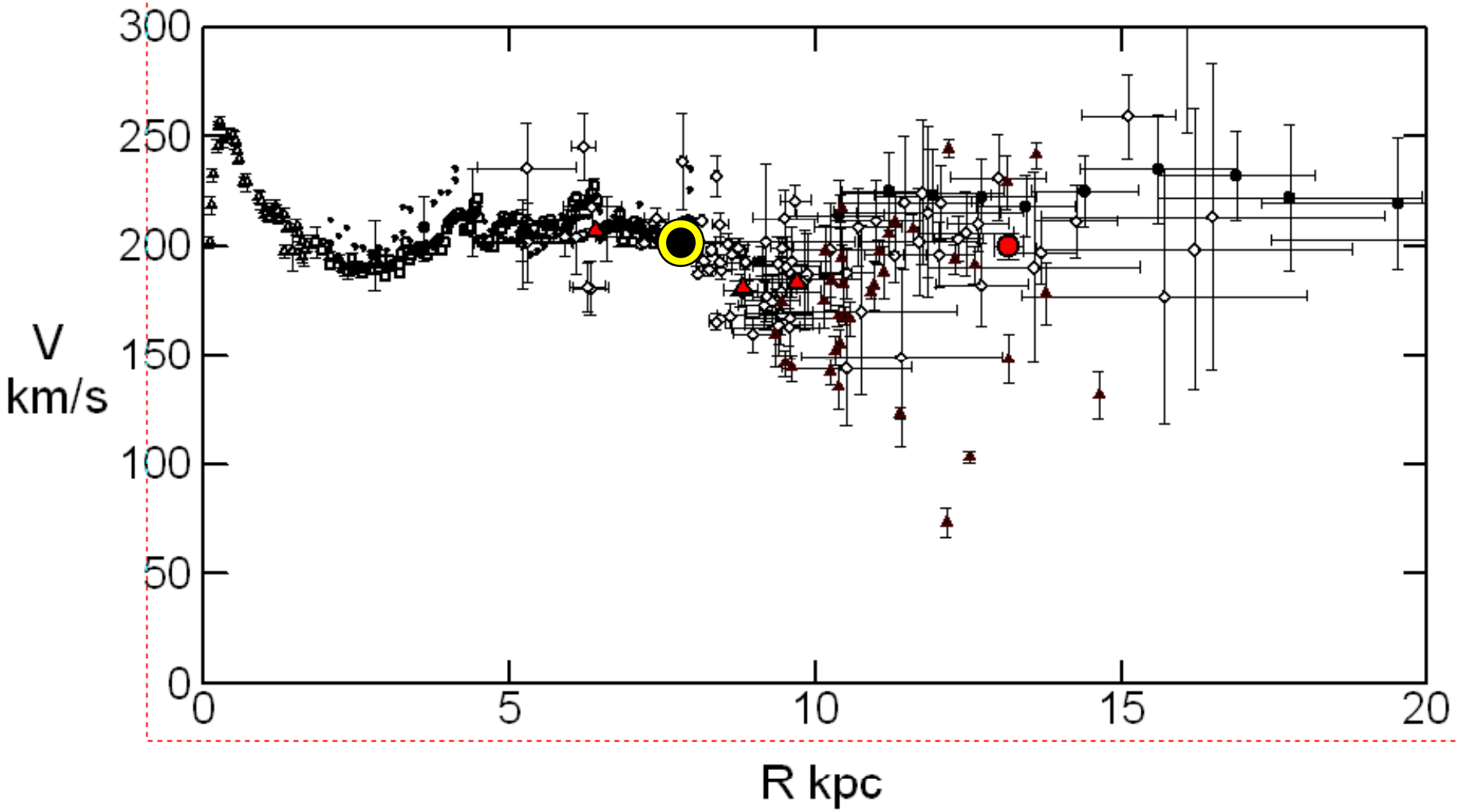


Total Masses



3. Grand Rotation Curve

Solar Circular Velocity V_0=200 km/s @ R_0=8kpc



Rotation curve at R>30 kpc assuming random motion of satellite galaxies

Define:

$$V_{rot} = V_{virial} \fallingdotseq \sqrt{2}\, V_{GC}$$

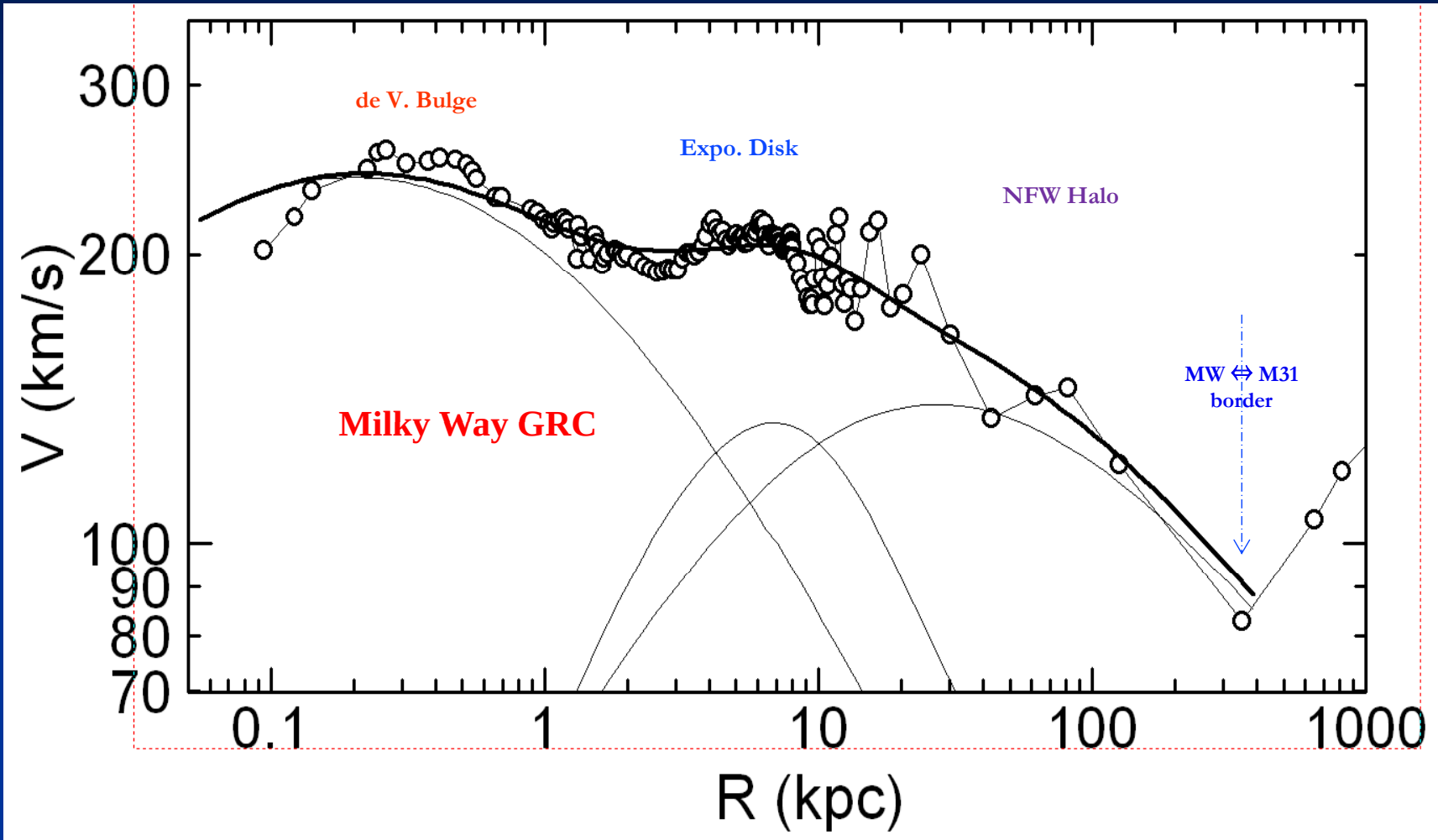
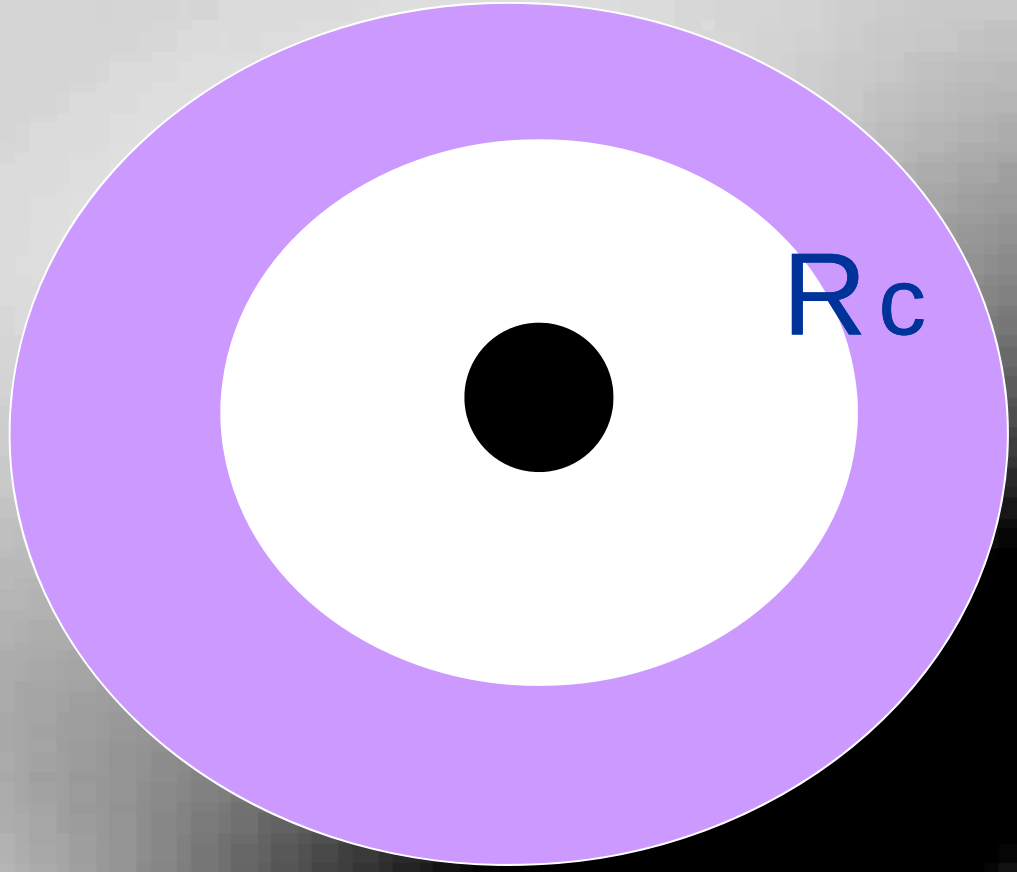

de V. Bulge
Expo. Disk
NFW Halo
MW ⇔ M31
border
Milky Way GRC
V (km/s)
300
200
100
90
80
70
0.1
1
10
100
1000
R (kpc)

Table 1. Best-fit parameters for the mass components of the Galaxy

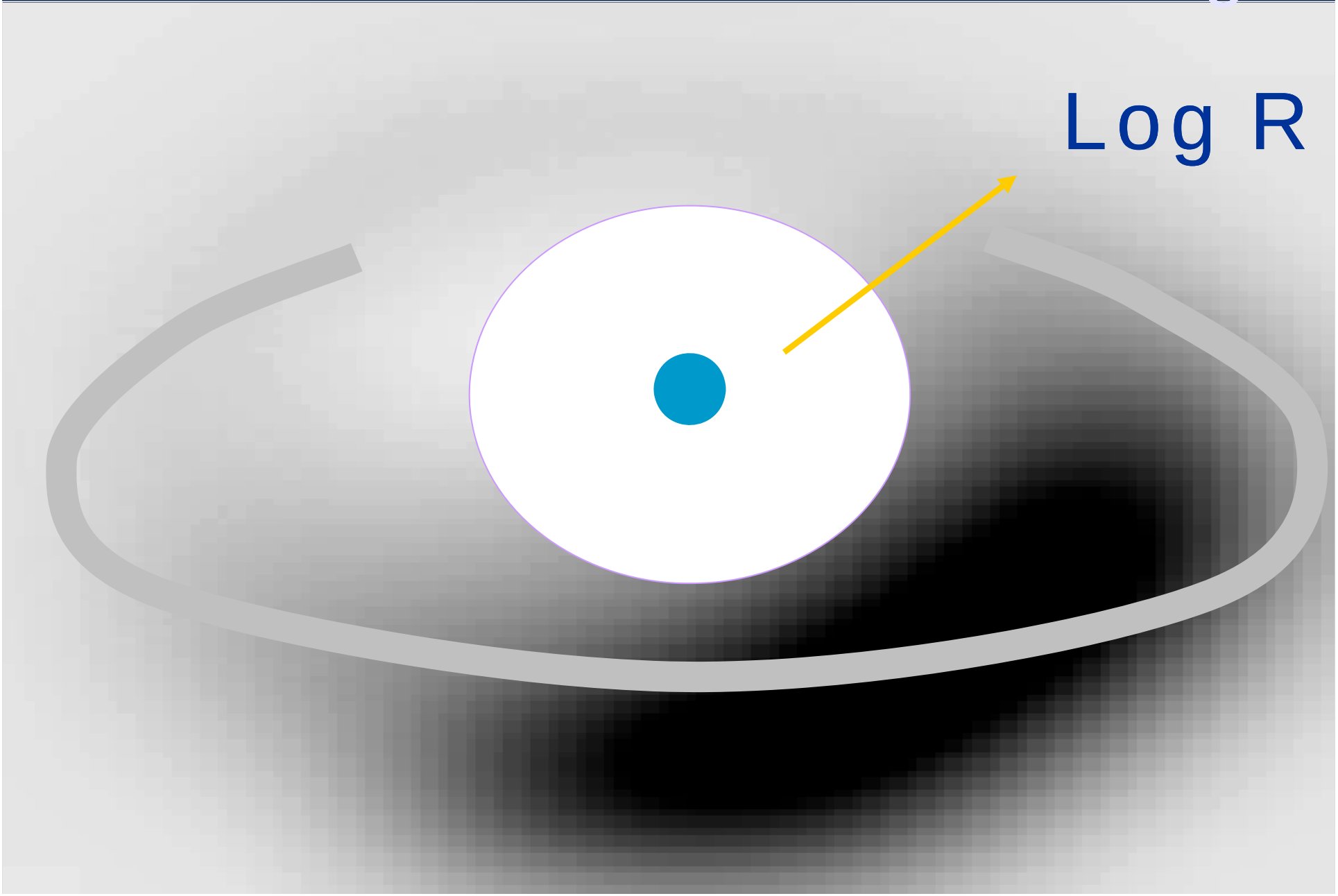
Mass component	Mass; Density	Scale Radius
Bulge param.	$M_{\rm b} = (1.652 \pm 0.083) \times 10^{10} M_\odot$	$a_{\rm b} = 0.522 \pm 0.037$ kpc
Disk param.	$M_{\rm d} = (3.41 \pm 0.41) \times 10^{10} M_\odot$	$a_{\rm d} = 3.19 \pm 0.35$ kpc
B+D Mass	$M_{\rm b+d} = (5.06 \pm 0.97) \times 10^{10} M_\odot$	
B/D ratio	$M_{\rm b}/M_{\rm d} = 0.48 \pm 0.09$	
DH param.	$\rho_0 = (1.06 \pm 0.14) \times 10^{-2} M_\odot {\rm pc}^{-3}$	$h = 12.53 \pm 0.88$ kpc
	$= 0.403 \pm 0.051$ GeV cm^{-3}	
Local DM dens.	$\rho_0^\odot = (6.12 \pm 0.80) \times 10^{-3} M_\odot {\rm pc}^{-3}$	
at $R_0 = 8$ kpc	$= 0.235 \pm 0.030$ GeV cm^{-3}	
DH Mass[‡]	$M_{\rm h}(R \leq 8{\rm kpc}) = (2.71 \pm 0.42) \times 10^{10} M_\odot$	
	$M_{\rm h}^*(\leq h) = (5.05 \pm 0.78) \times 10^{10} M_\odot$	
	$M_{\rm h}(\leq 20{\rm kpc}) = (8.87 \pm 1.37) \times 10^{10} M_\odot$	
	$M_{\rm h}(\leq 385{\rm kpc}) = (6.52 \pm 1.01) \times 10^{11} M_\odot$	
Galaxy Mass	$M_{\rm b+d+h} = (7.03 \pm 1.01) \times 10^{11} M_\odot$	$(R \leq 385$ kpc$)$
Baryon Fraction	$M_{\rm b+d}/(M_{\rm b+d+h}) =$ **0.072 ± 0.018**	

4. Galactic Center & BH

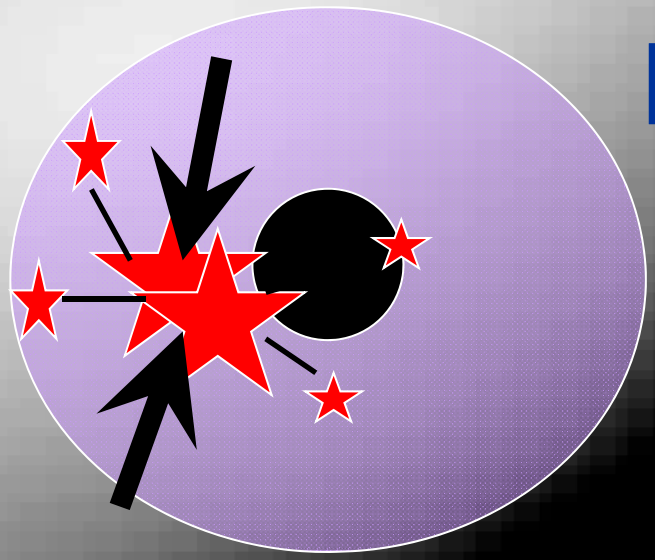
質量空白域 or DM cusp



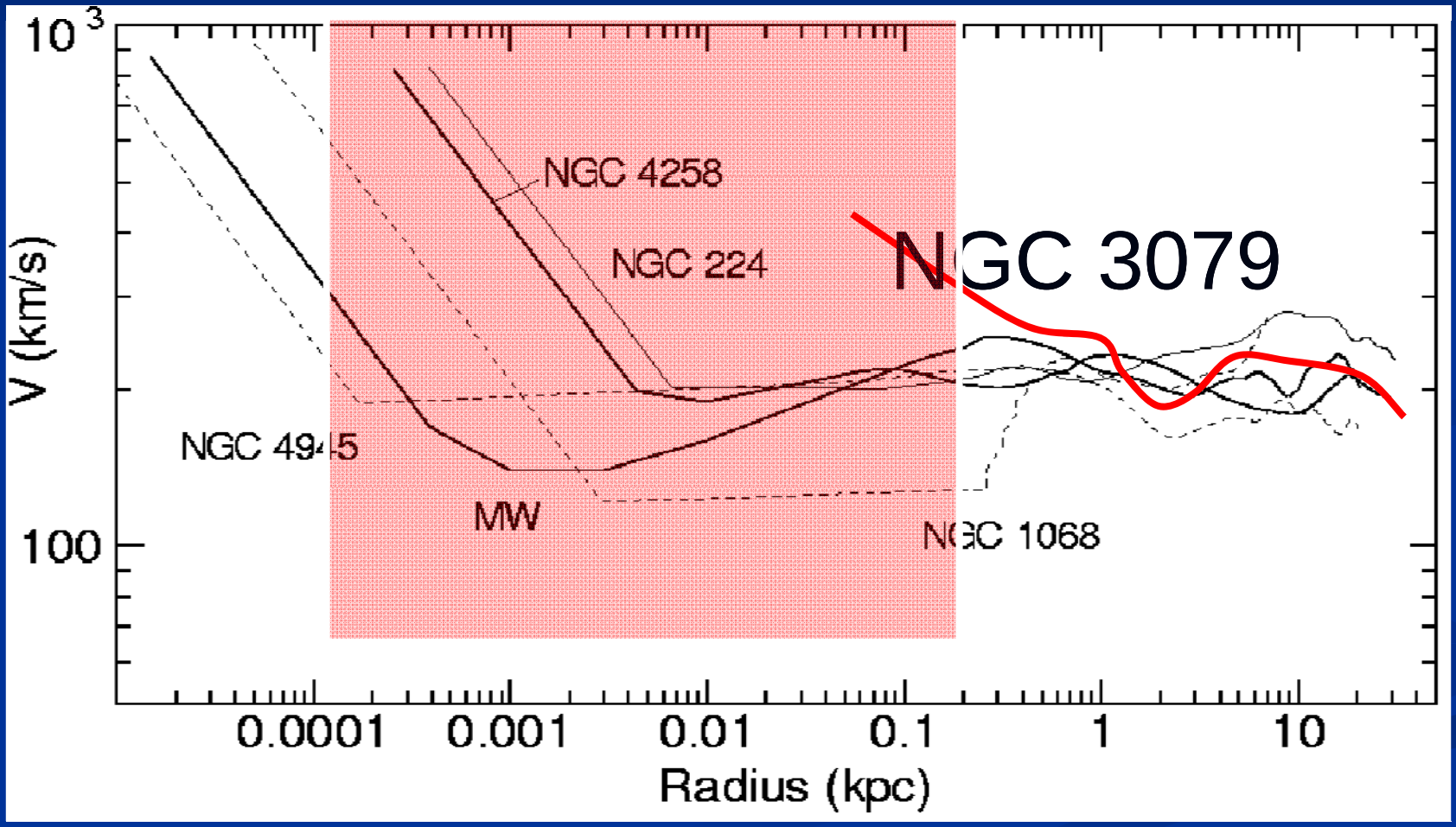
銀河質量研究の空白領域 BH - Bulge



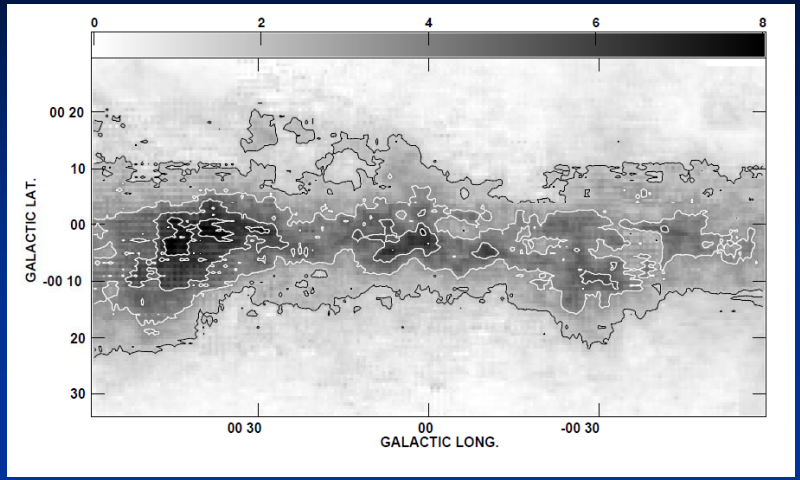
BH formation in core/cusp

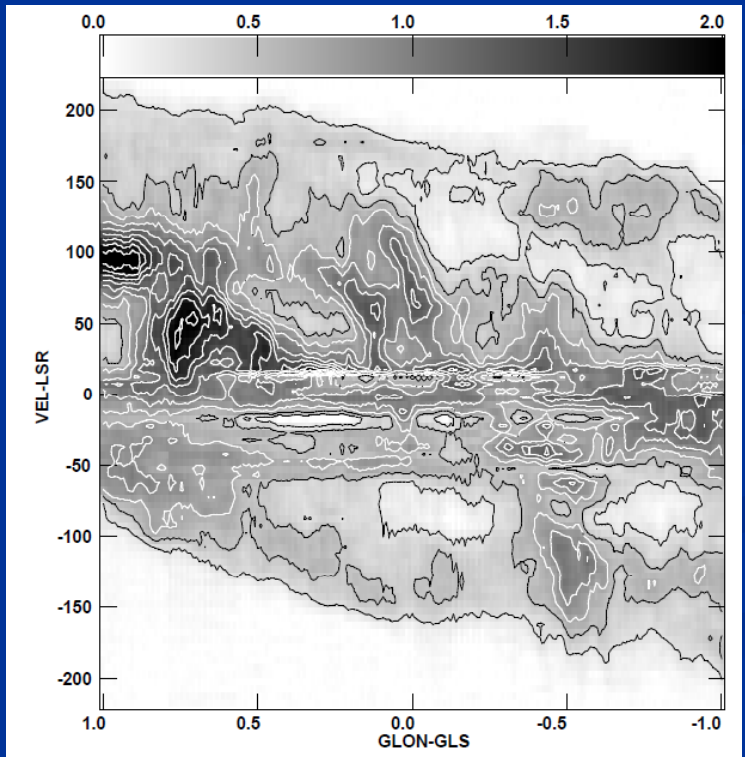


BH – Bulge – Disk

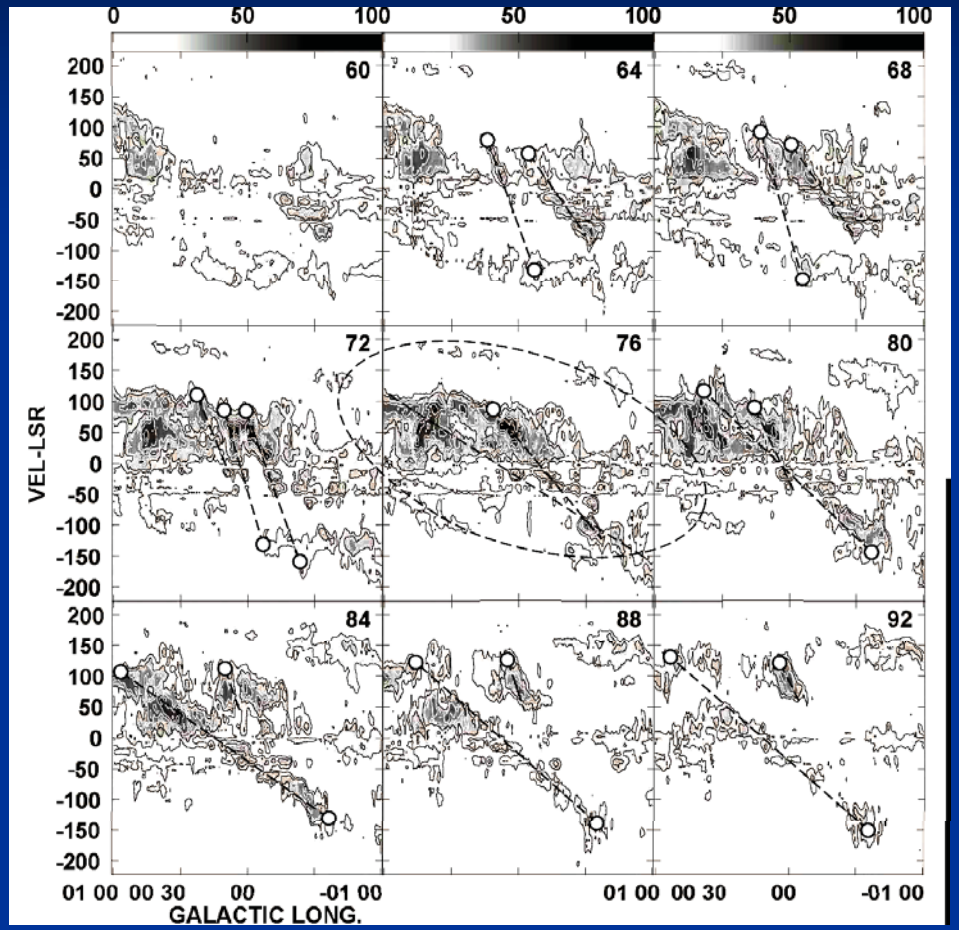


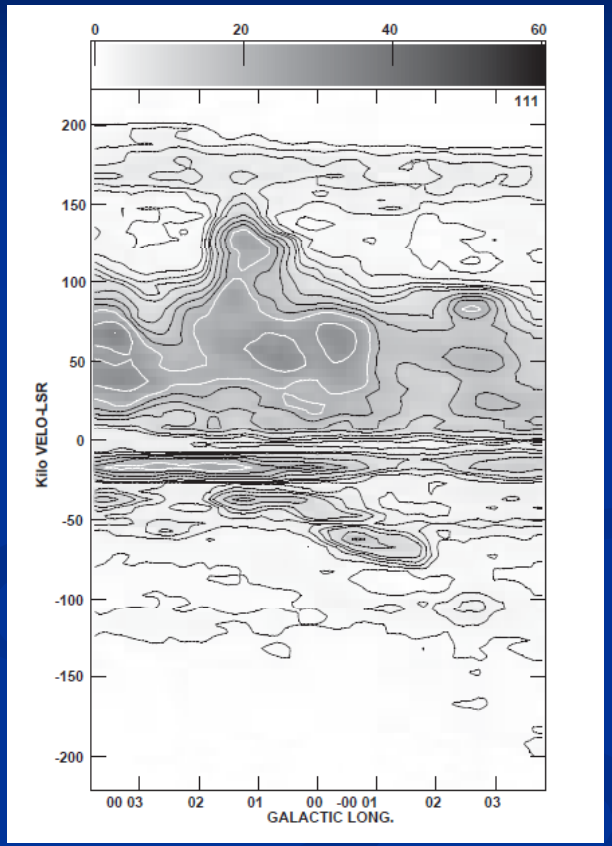
GC CO map & LV diagrams



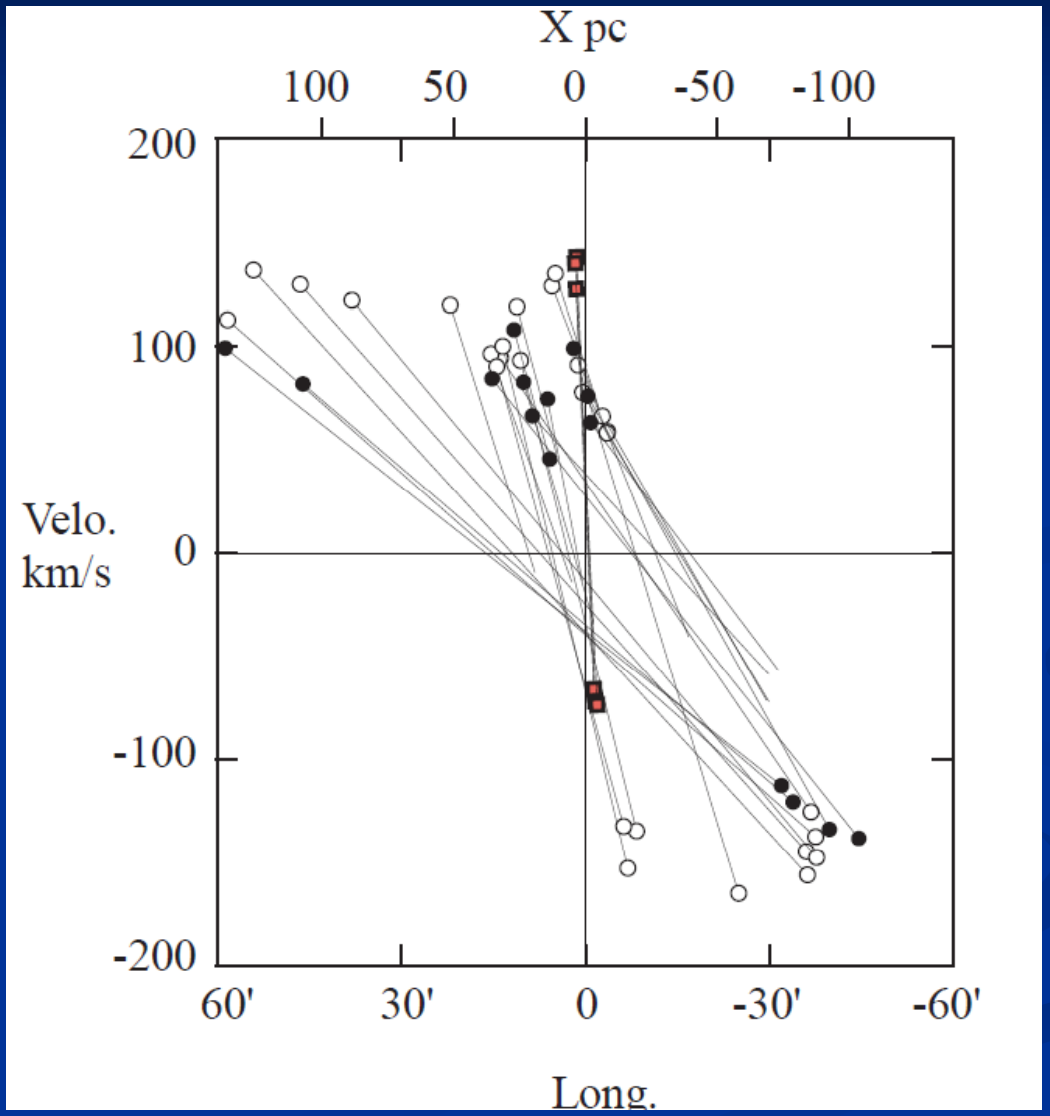


CO LV diagrams

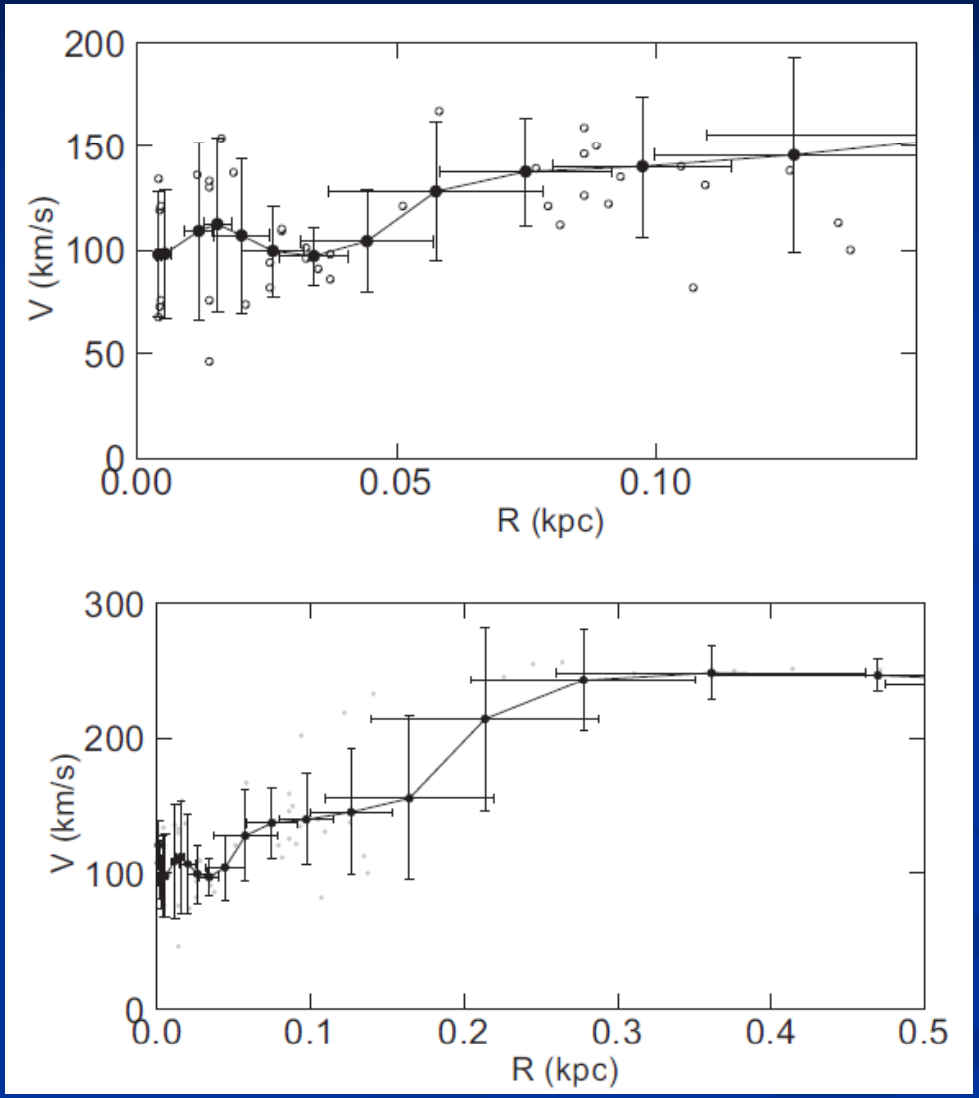




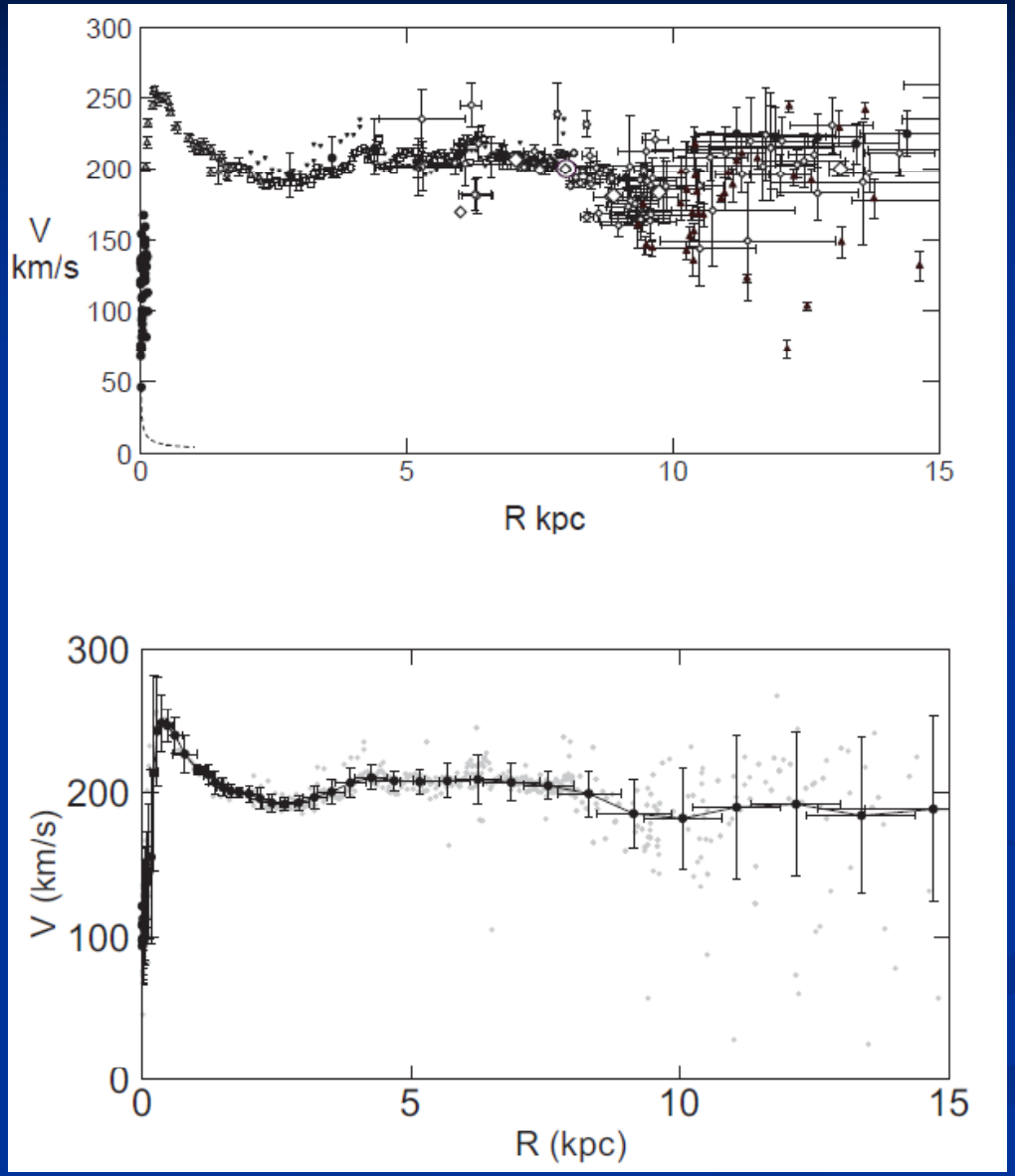
Terminal Velocities



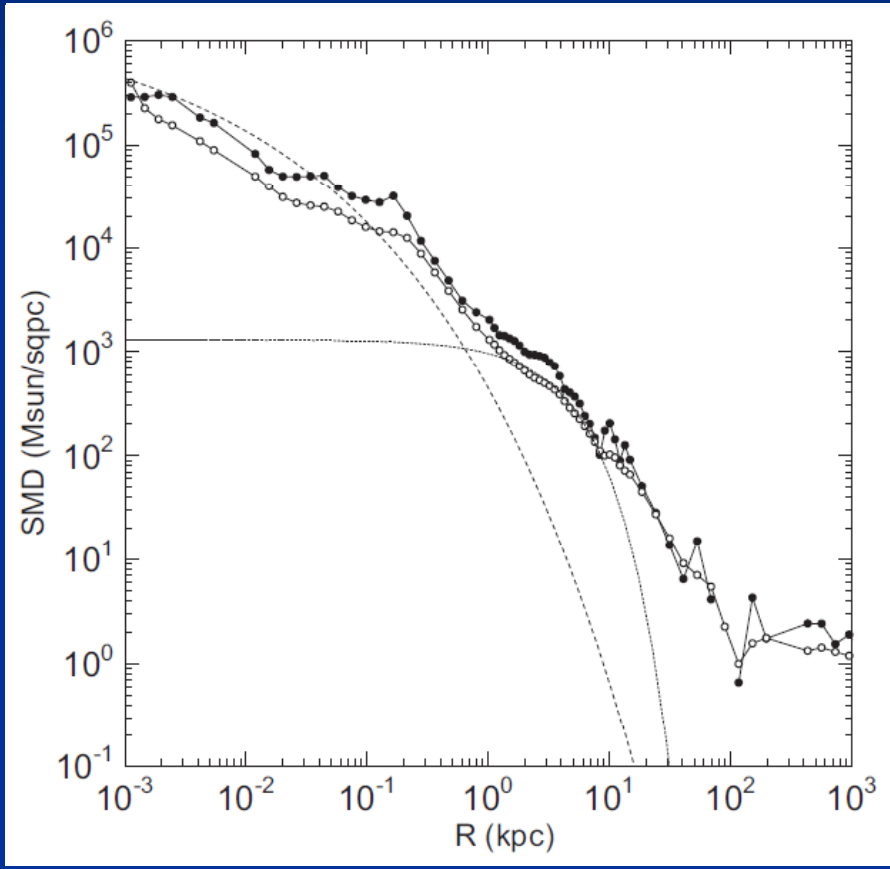
GC Rotation Curve

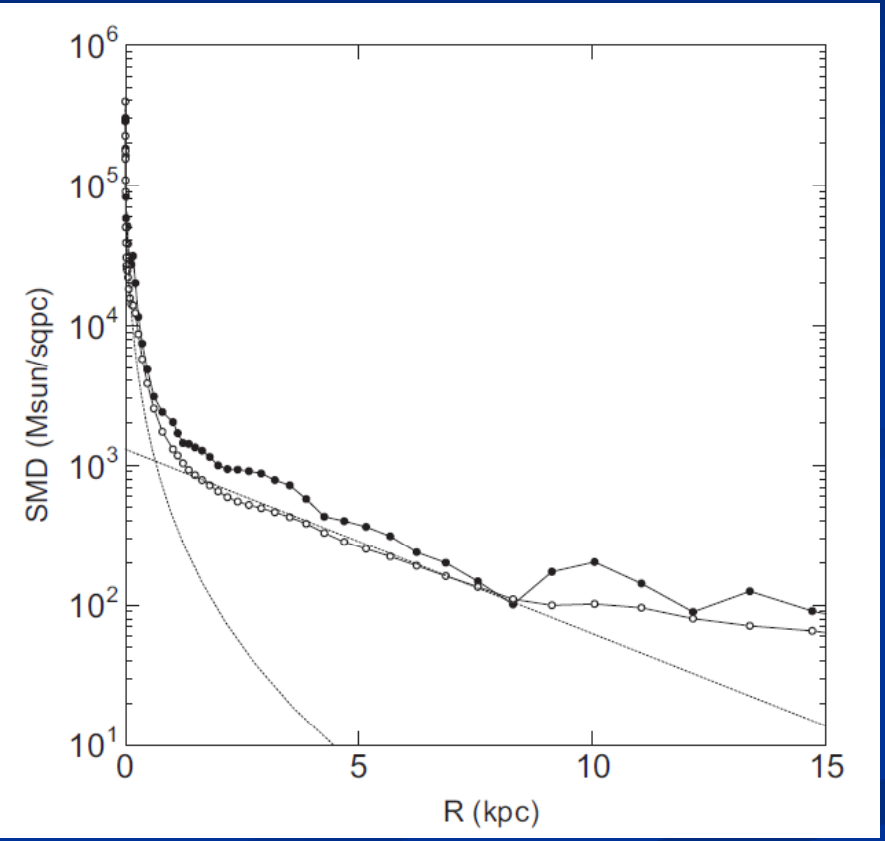


Galaxy Rotation Curve

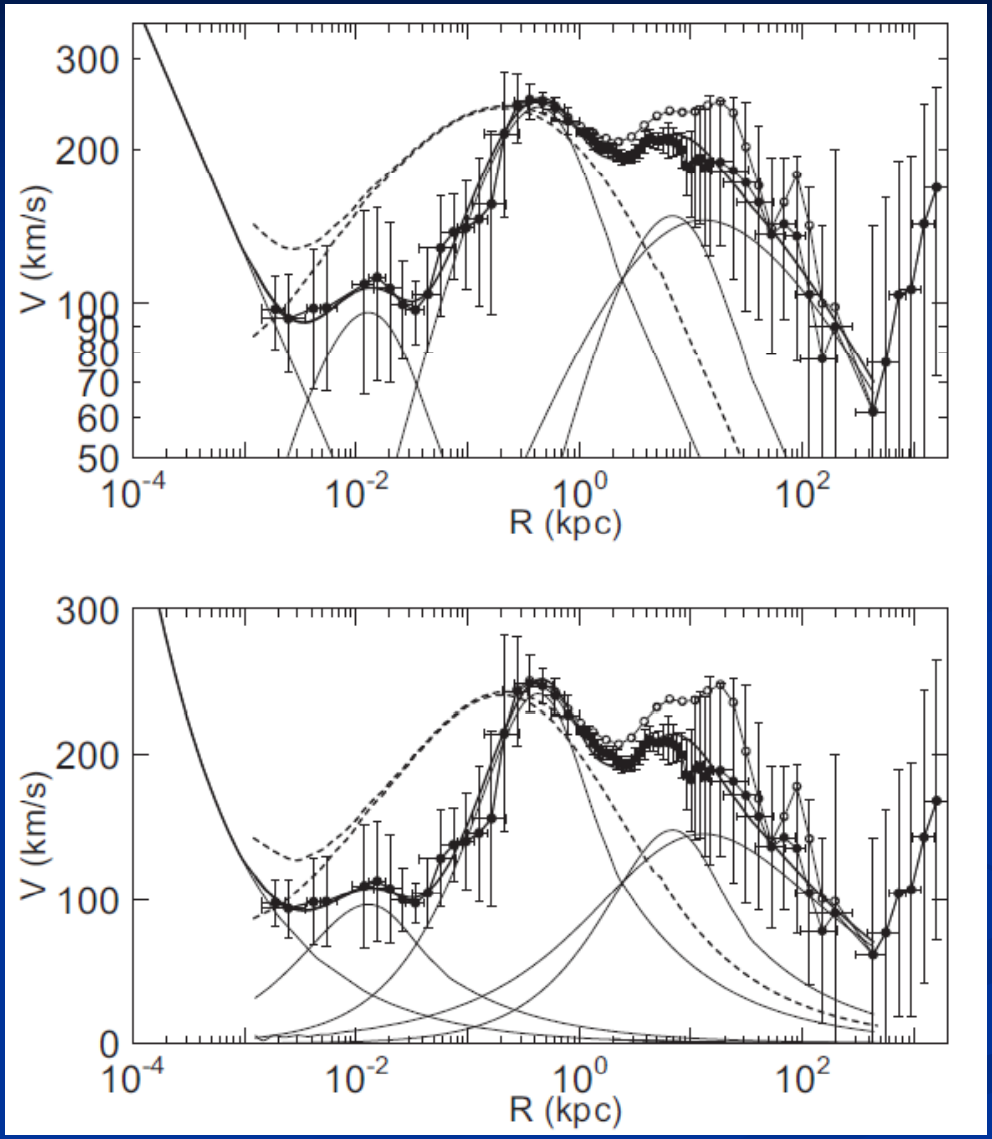


Surface Mass Density

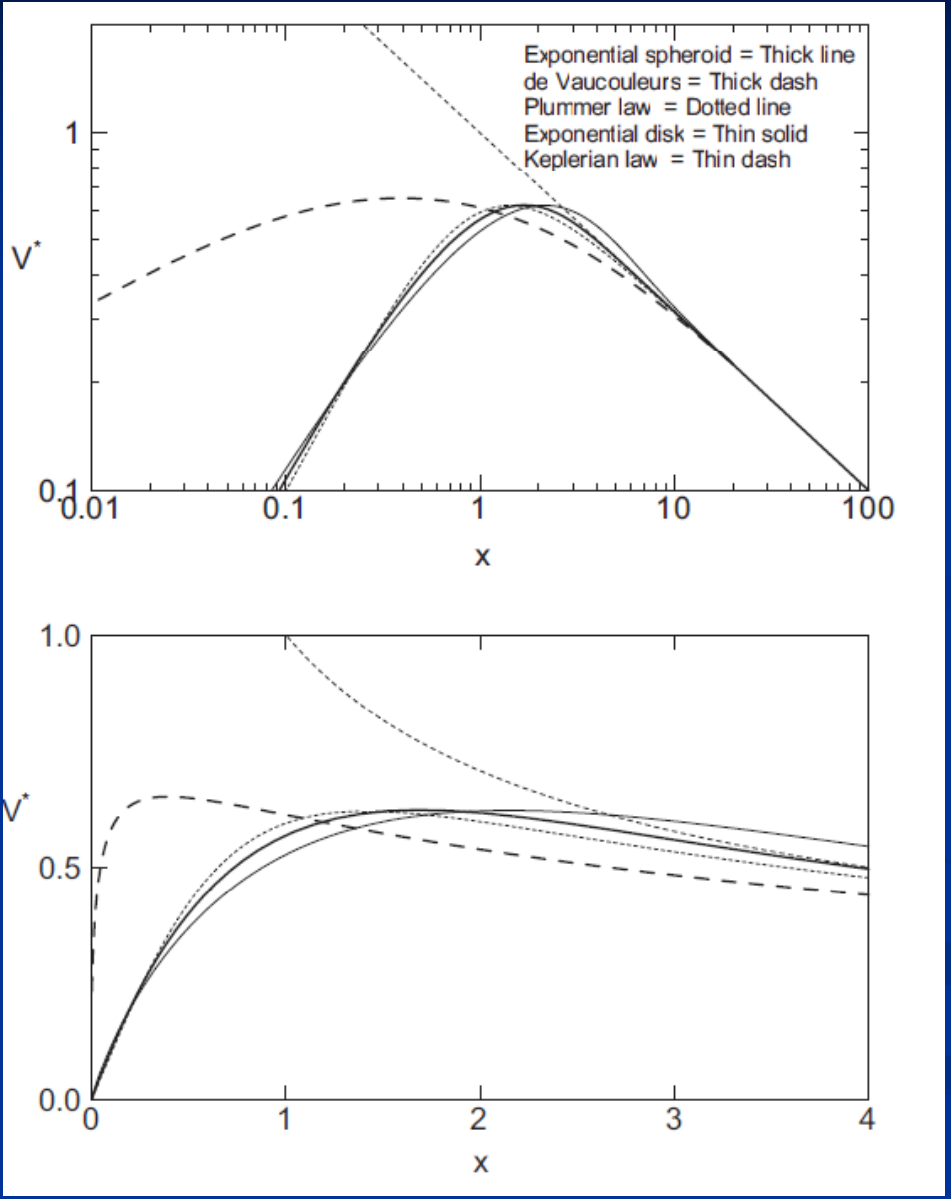




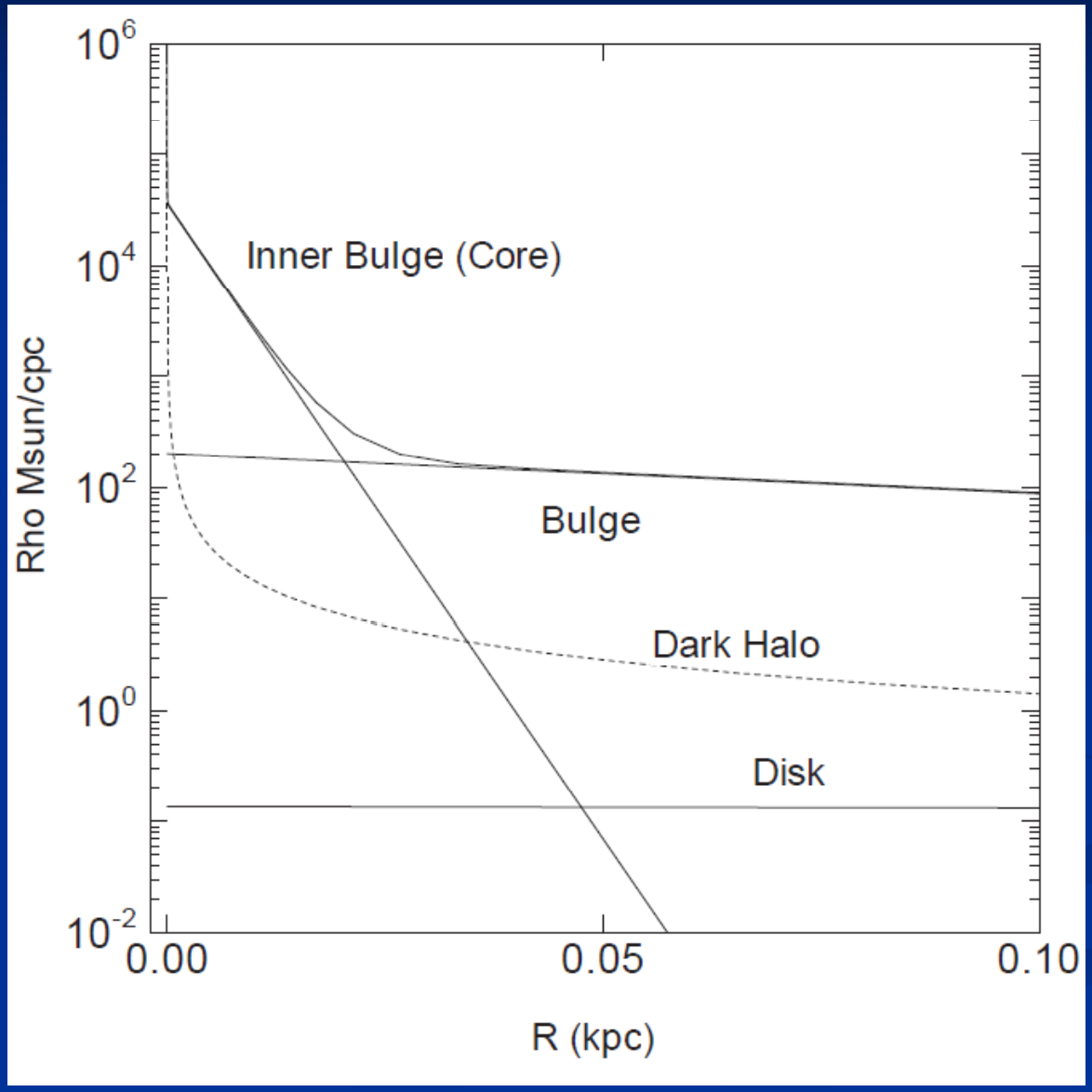
Deconvolution of RC



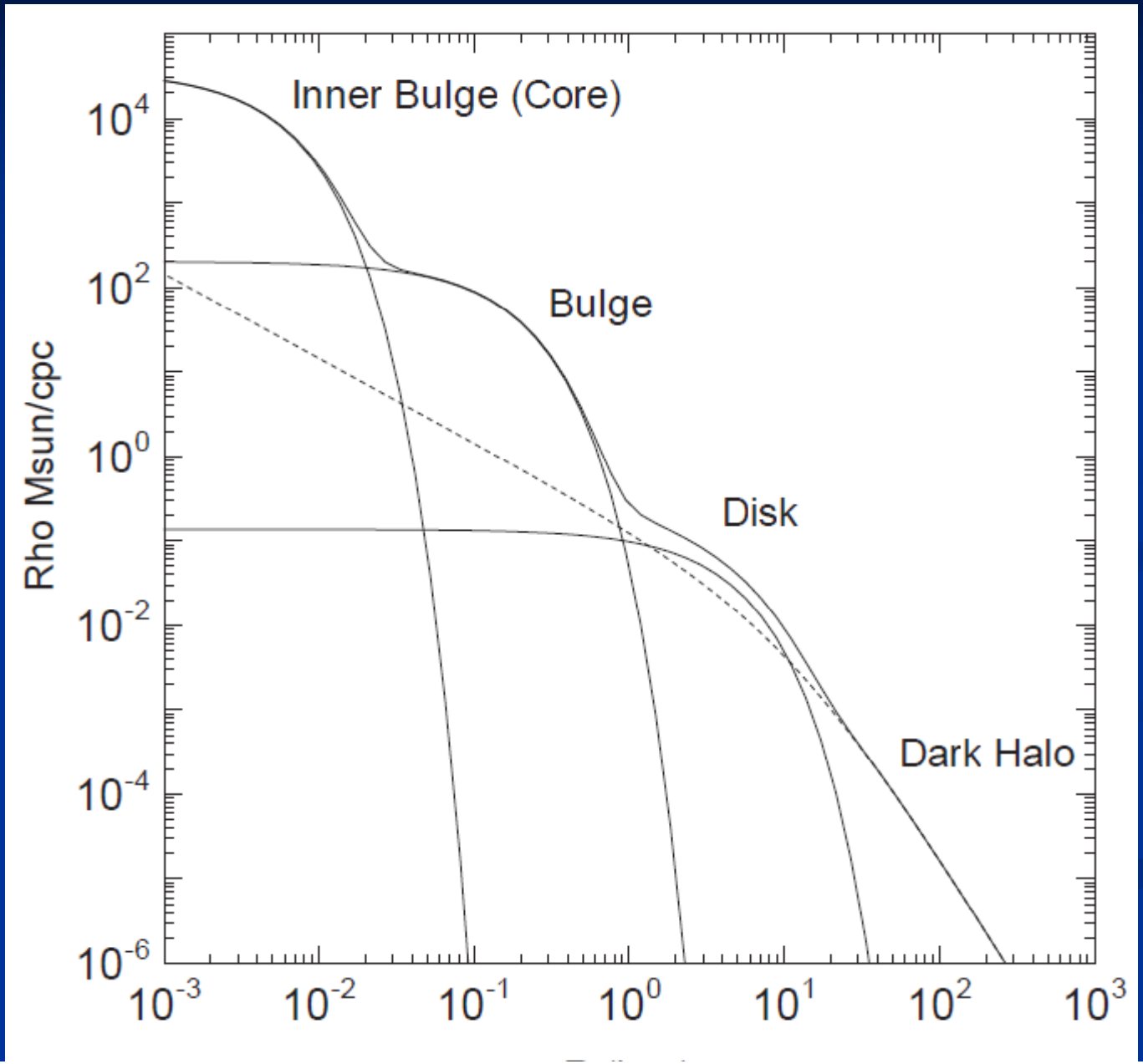
Vaucouleurs vs Exponential



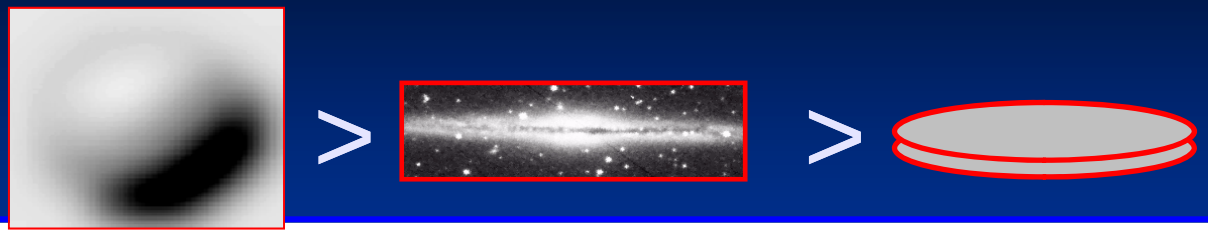
Density (Semi Log)



Density (Log Log)



質量分布ー直接導出



(a) Spherical Mass Distribution:

$$M(r) = \frac{rV(r)^2}{G},$$

$$\rho(r) = \frac{1}{4\pi r^2}\frac{dM(r)}{dr}.$$

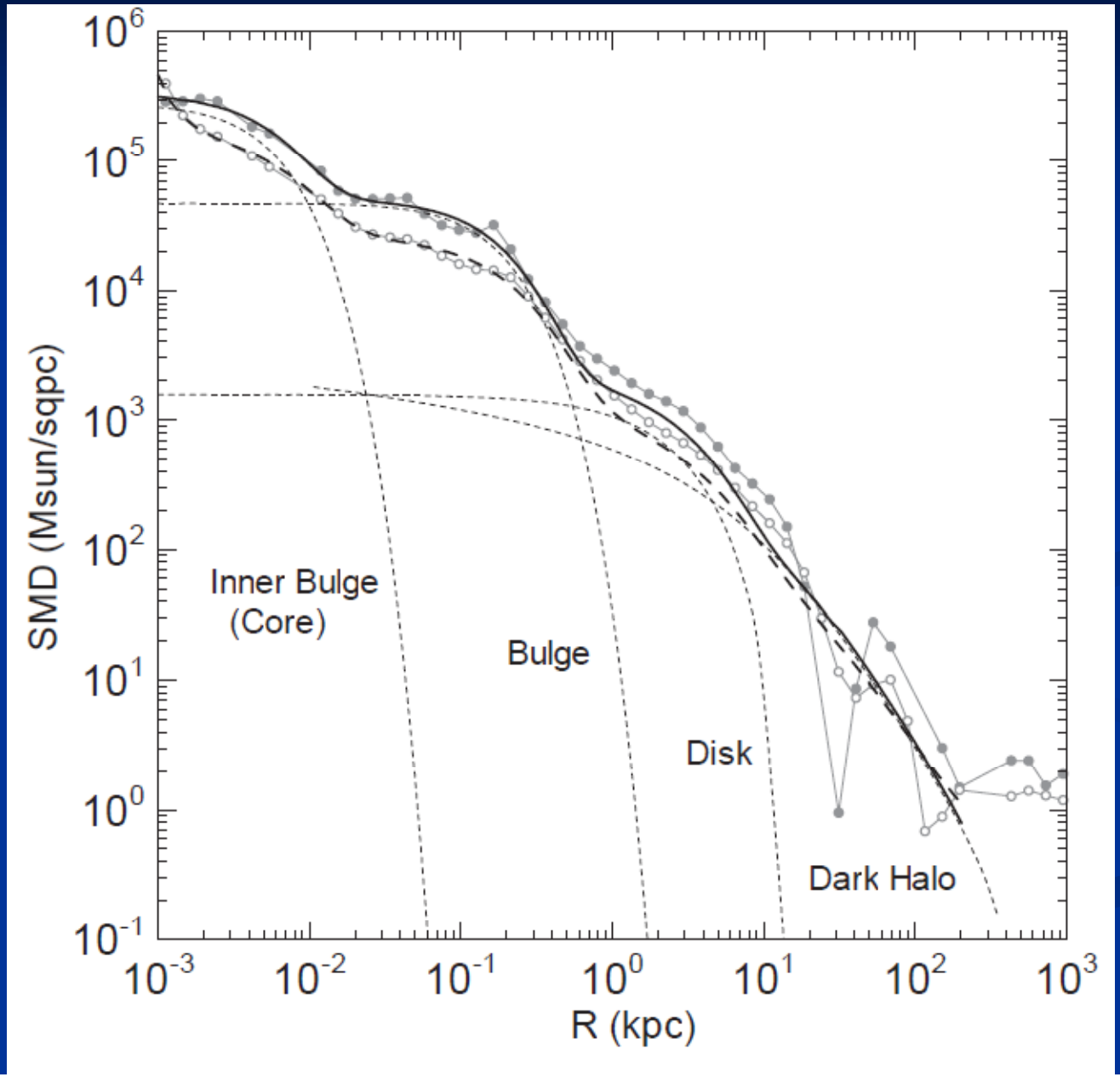
$$\sigma(R)_s = 2\int_0^\infty \rho(r)dz = \frac{1}{2\pi}\int_R^\infty \frac{\left(\frac{dM(r)}{dr}\right)_x}{x\sqrt{x^2-R^2}}dx,$$

(b) Flat-Disk Mass Distribution: Laplace's equation $\Delta\Phi \quad 0$:

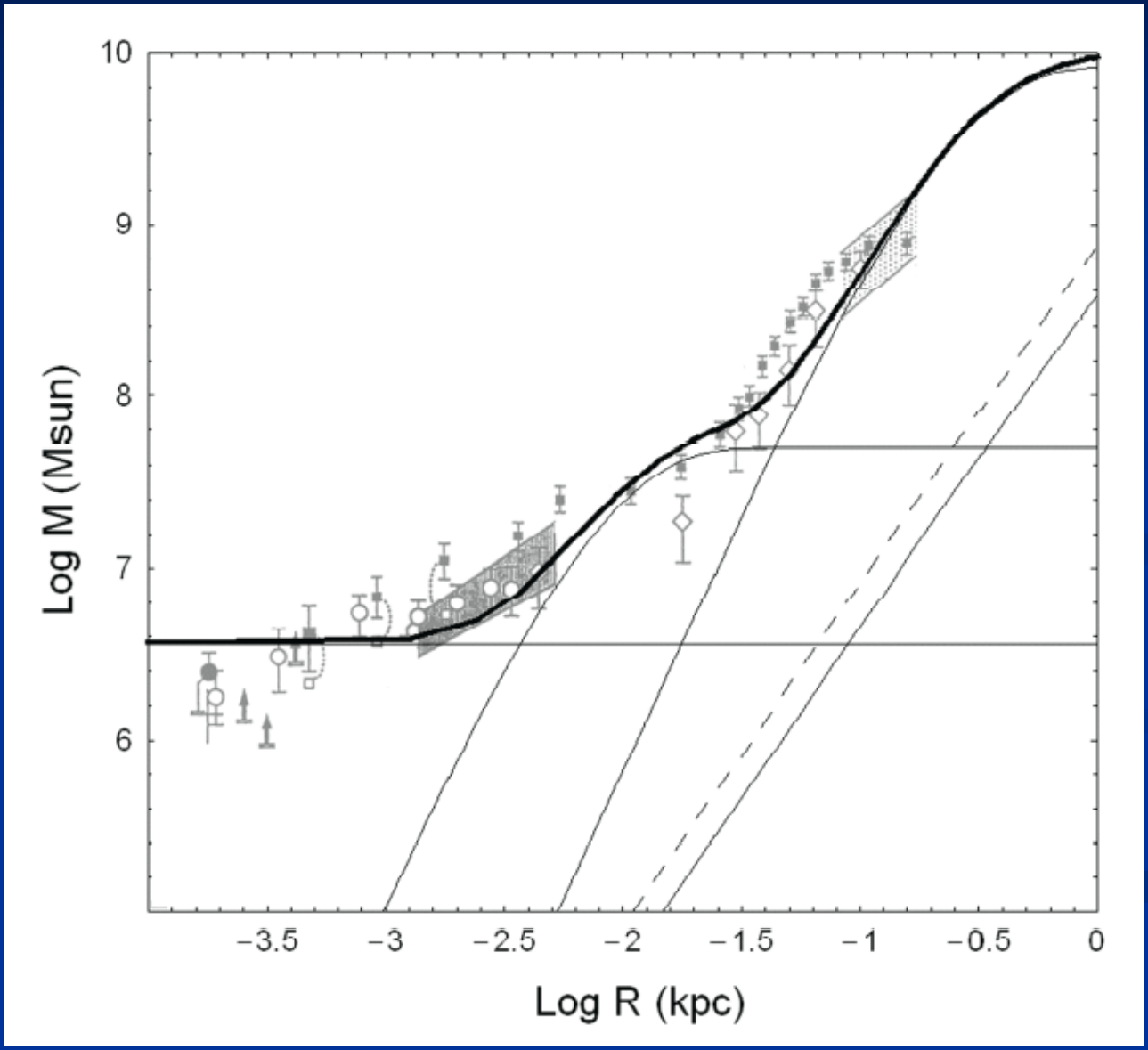
$$\sigma(R)_f = \frac{1}{\pi^2 G}\left[\frac{1}{R}\int_0^R \left(\frac{dV^2}{dr}\right)_x K\left(\frac{x}{R}\right)dx + \int_R^\infty \left(\frac{dV^2}{dr}\right)_x K\left(\frac{R}{x}\right)\frac{dx}{x}\right],$$

where $K(x)$ is the complete elliptic integral(Binney & Tremaine 1987).

SMD : Obs vs Model



Comparison with Genzel et al. 94



RC Fitting Result:

(1) BH

(2) Bulge 1 : Exp. Sphere

(3) Bulge 2: Exp. Sphere

(4) Exp. Flat Disk

(5) NFW Dark Halo

PASJ submitted 2013

PASJ: Publ. Astron. Soc. Japan , 1–??,

Rotation Curve and Mass Distribution in the Galactic Center and Entire Galaxy

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(Received 2013 0; accepted 2013 0)

PASJ: Publ. Astron. Soc. Japan , 1–??,
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Logarithmic Rotation Curve and Multiple Bulges around the Galactic Center

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(Received ; accepted)

Further Analysis of Activity in known Gravity Environment