Rotation of The Andromeda Nebula From a Spectroscopic Survey of Emissions

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Overview

- Velocity observations of HII regions (emission) of the Andromeda Galaxy
- What do we expect to see (implications of mass from rotational velocities)
- Observations – what they did
- Analysis:
  - Rotation curves
- Implications
  - Flat curve at large R: Implications for Galaxy Mass
  - M/L increases => Mass that does not emit light!

Expected Rotational Velocity Curves

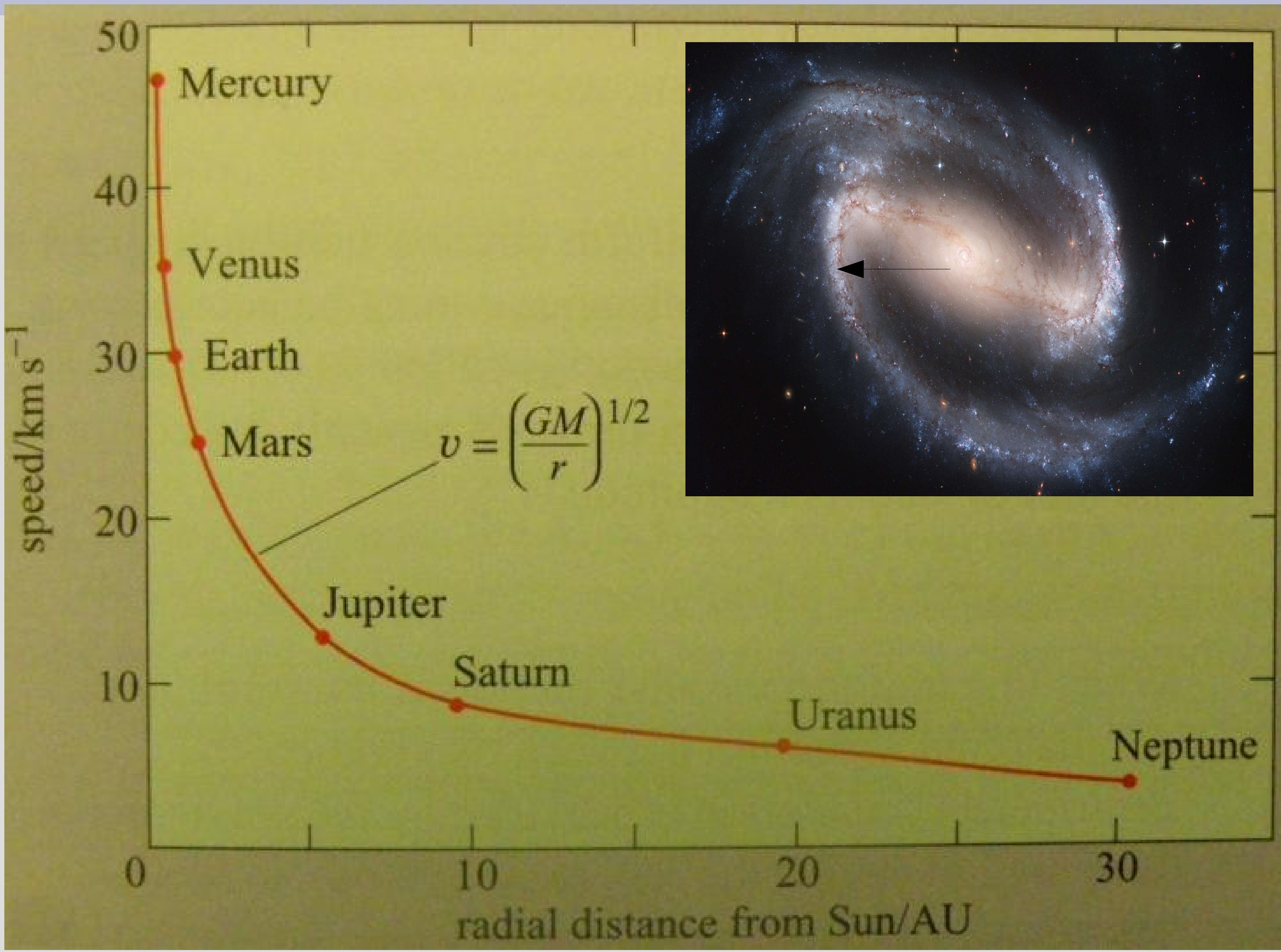
$$a_{\mathrm{cen}} = a_{\mathrm{g},m}$$

$$v^2/r = GM/r^2$$

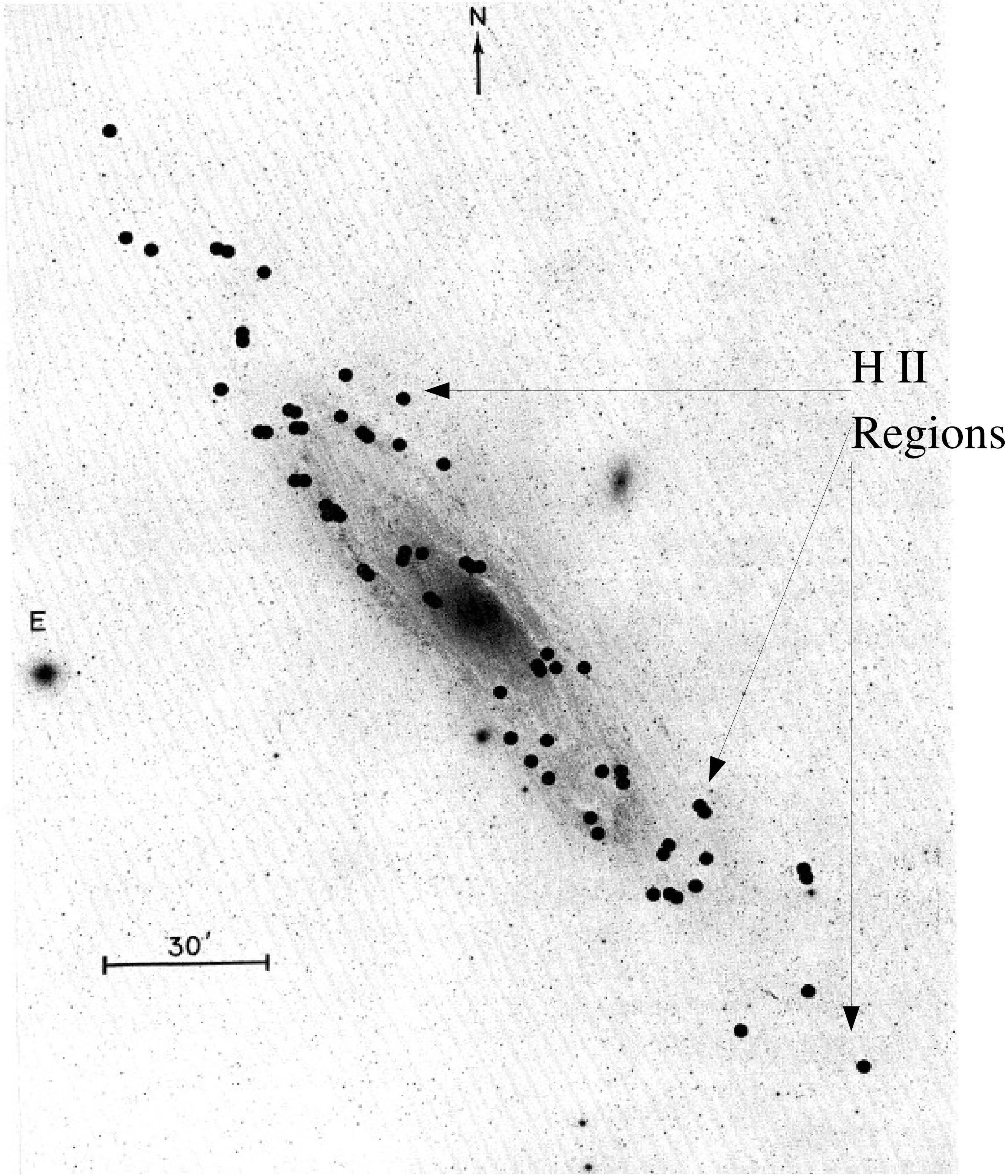
$$M = v^2 r/G$$

$$M(R) = \frac{2}{G\pi}\int_0^R \frac{V^2(a)\,a\,da}{(R^2 - a^2)^{1/2}}\,.$$

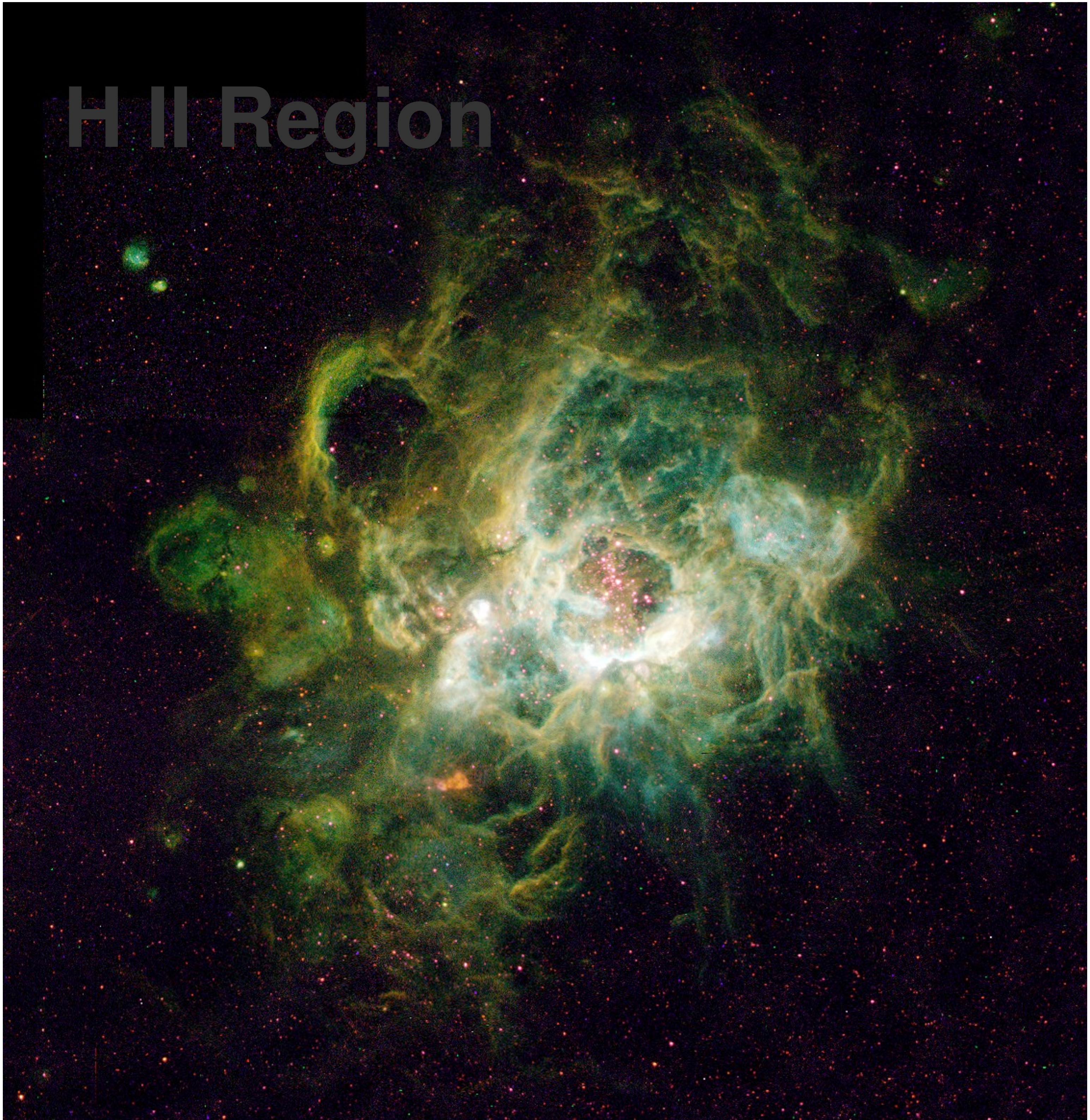
Expected Rotational Velocity Curves

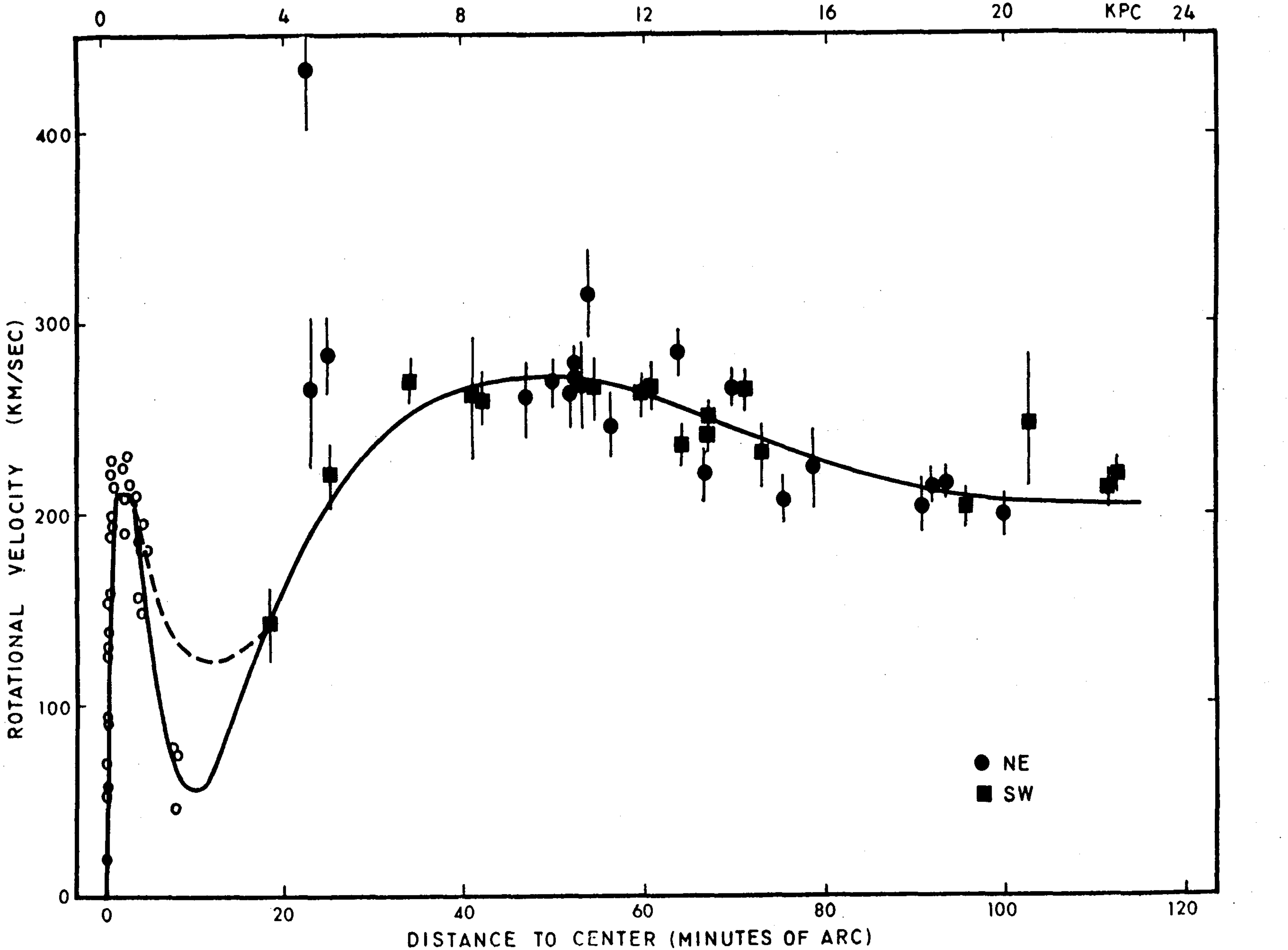


Andromeda



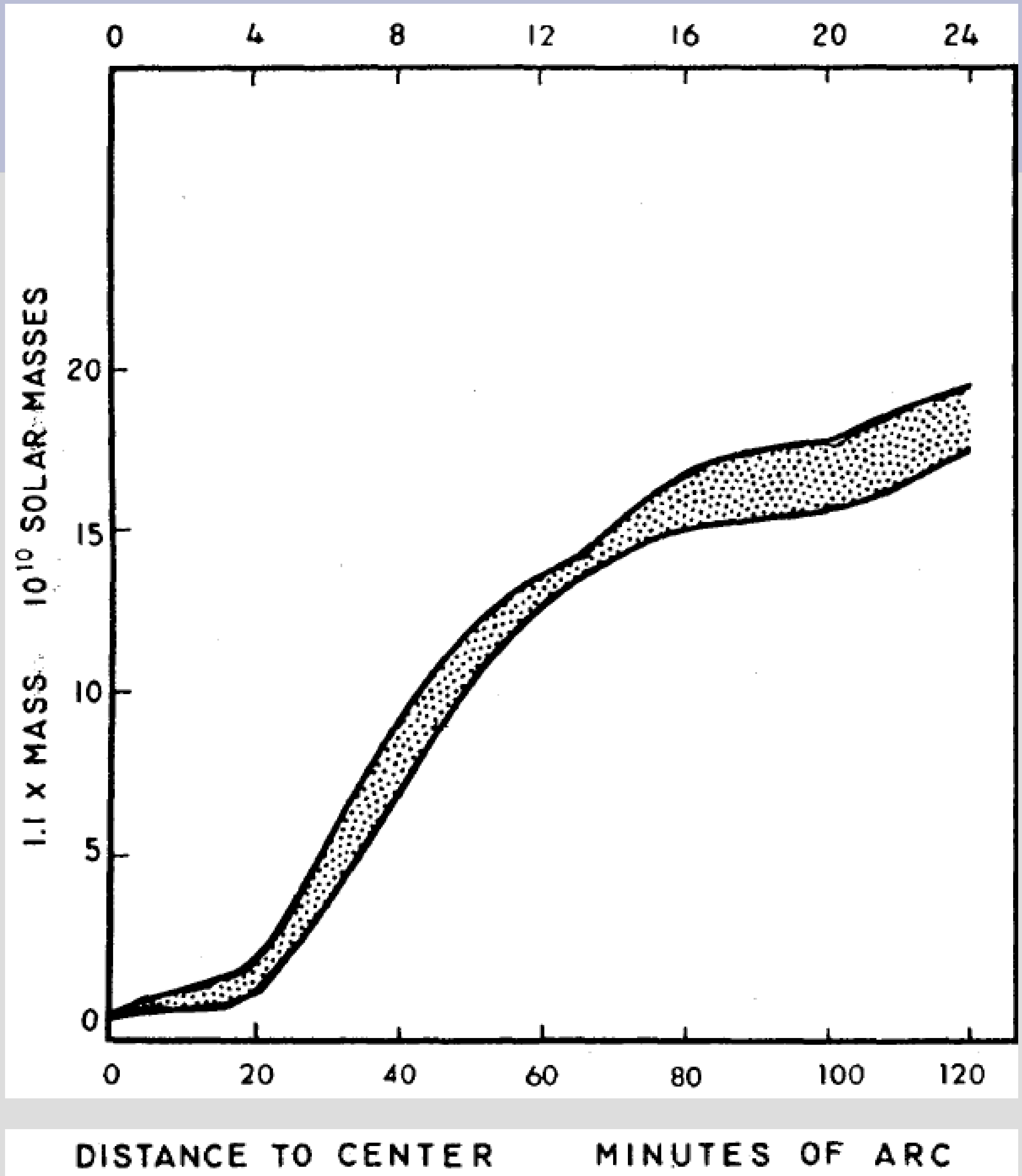
H II Region





0
4
8
12
16
20
KPC
24
400
300
200
100
0
ROTATIONAL VELOCITY (KM/SEC)
NE
SW
0
20
40
60
80
100
120
DISTANCE TO CENTER (MINUTES OF ARC)

M(R)



0
4
8
12
16
20
24
1.1 x MASS 10^10 SOLAR MASSES
20
15
10
5
0
0
20
40
60
80
100
120
DISTANCE TO CENTER
MINUTES OF ARC

TABLE 5

MASS-LUMINOSITY RATIOS FOR M31

R (min. of arc) (1)	R (kpc) (2)	$\int M$ to R ($10^{10} M_\odot$) (3)	$\int L$ to R ($10^{10} L_\odot$) (4)	$\int M/L$ to R (5)
15.....	3	0.416±0.4*	0.42	1.0±1†
30.....	6	3.64 ±0.8	0.64	5.7±1
45.....	9	8.73 ±0.9	0.83	10 ±1
60.....	12	12.7 ±0.5	0.99	13 ±0.5
90.....	18	15.9 ±1	1.30	12 ±0.8
120.....	24	18.3 ±1	1.37	13 +0.7

De Vaucouleur's Law

$$I(R) = I_e \exp\left\{-7.67\left[\left(\frac{R}{R_e}\right)^{0.25} - 1\right]\right\}$$

The Size And Mass of Galaxies, And The Mass of The Universe

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Overview

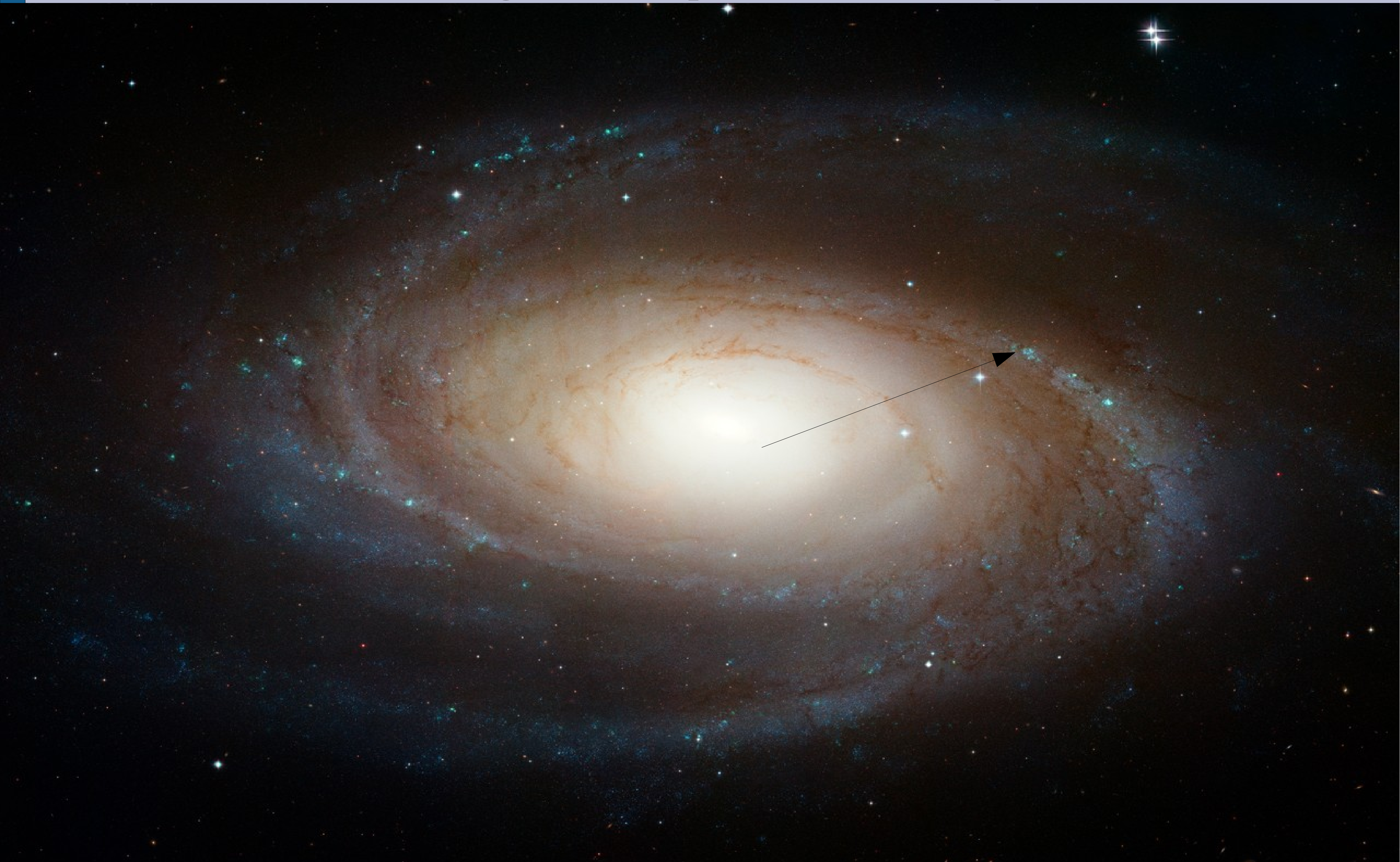
- What is $\Omega = \rho/\rho\_crit$? Measured at 0.01, expected (desired) to be 1
- Argue underestimated masses => underestimated ρ
- Re-assess ρ by assembling well measured masses
- Newly estimated ρ still yields a low Ω of 0.2, within a factor of 3 (however much larger than 0.01)
- In accounting for still missing the mark of $\Omega = 1$, propose idea of **Dark Halo**

Miss-Measured Mass(?)

- Expect total mass to be off by factor of 10
- M/L ratio to measure mass = BAD IDEA
- Gravitational interaction – only reliable way of measuring mass.
- However, gravitational interaction does not give us complete picture.

Limits In Mass Measurement And Why Keep Looking

M81-Hubble

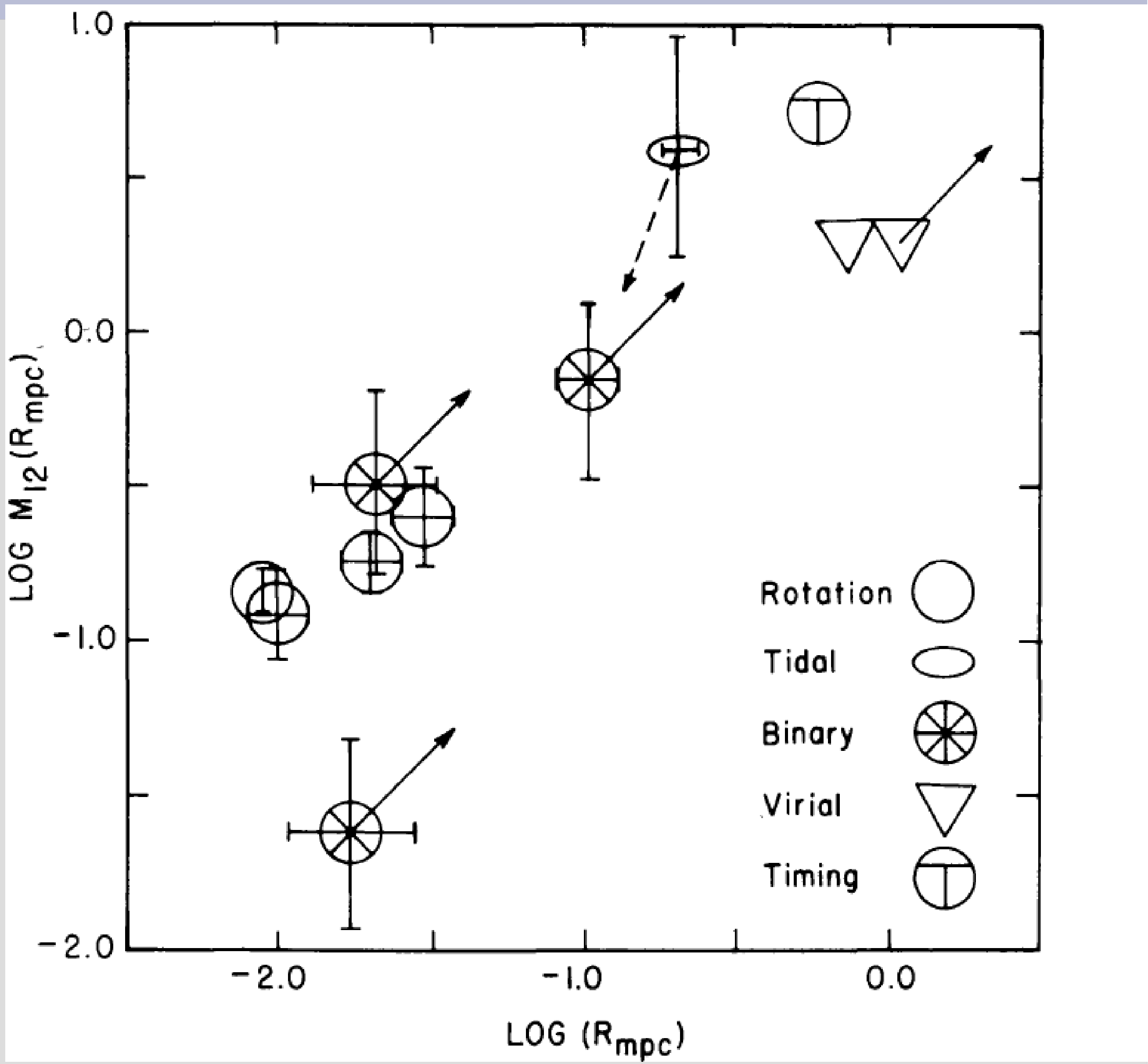


Attempt To Better Estimate Ω

- Use various techniques to better estimate mass
  - Hydrogen rotation ($r<10$ kpc)
  - Binary (2 galaxies – Virial theorem)
  - Tidal (observed local dwarf galaxies)
  - Virial (for group of galaxies)

Linear Trend

- Find linear trend in mass with increasing R
- M81 Group (factor of 10 error if outliers are excluded.
- Note Error Bars



W Calculation

$$\Omega_{\rm gal} = (\rho_{\rm gal}/\rho_{\rm crit})$$

$$\rho_{\rm gal} = f_{\rm sp} j_{\rm sp} + f_{\rm el} j_{\rm el}$$

$$= 4.0 \times 10^{-30} h^1 t_{10}{}^{-1} + 0.4 \times 10^{-30}\, h^2 \,\rm g\, cm^{-3}\,, \quad (2)$$

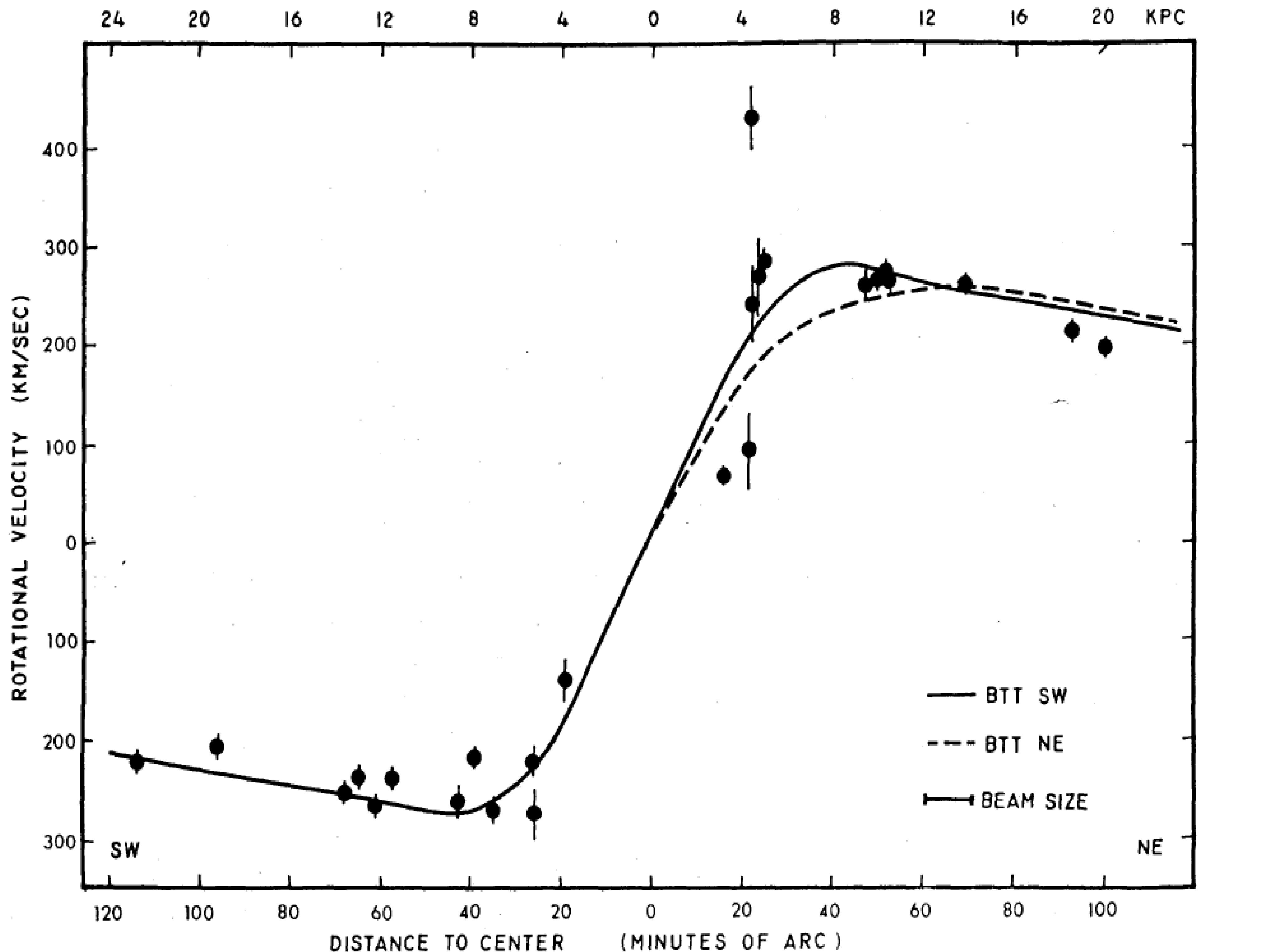
$f_{\rm sp} \equiv (M/L)_{\rm spiral}$ In Solar Units

$f_{\rm sp} \simeq 200 h^0 t_{10}{}^{-1}$ For Local Group and M81 Group

$f_{\rm el} \simeq 300 h^1$

Final Comments on Mass

- Note High M/L ratios for spirals and ellipticals
- 2 Arguments for a faint massive halo
  - Large M/L
  - Dynamical Stabilities (of cold disks)
    - No nonaxisymmetric distrubances (i.e. bars)



24 20 16 12 8 4 0 4 8 12 16 20 KPC
ROTATIONAL VELOCITY (KM/SEC)
400
300
200
100
0
100
200
300
SW
NE
BTT SW
BTT NE
BEAM SIZE
120 100 80 60 40 20 0 20 40 60 80 100
DISTANCE TO CENTER (MINUTES OF ARC)