
Dark Matter on Galactic Scales
(and the Lack Thereof)
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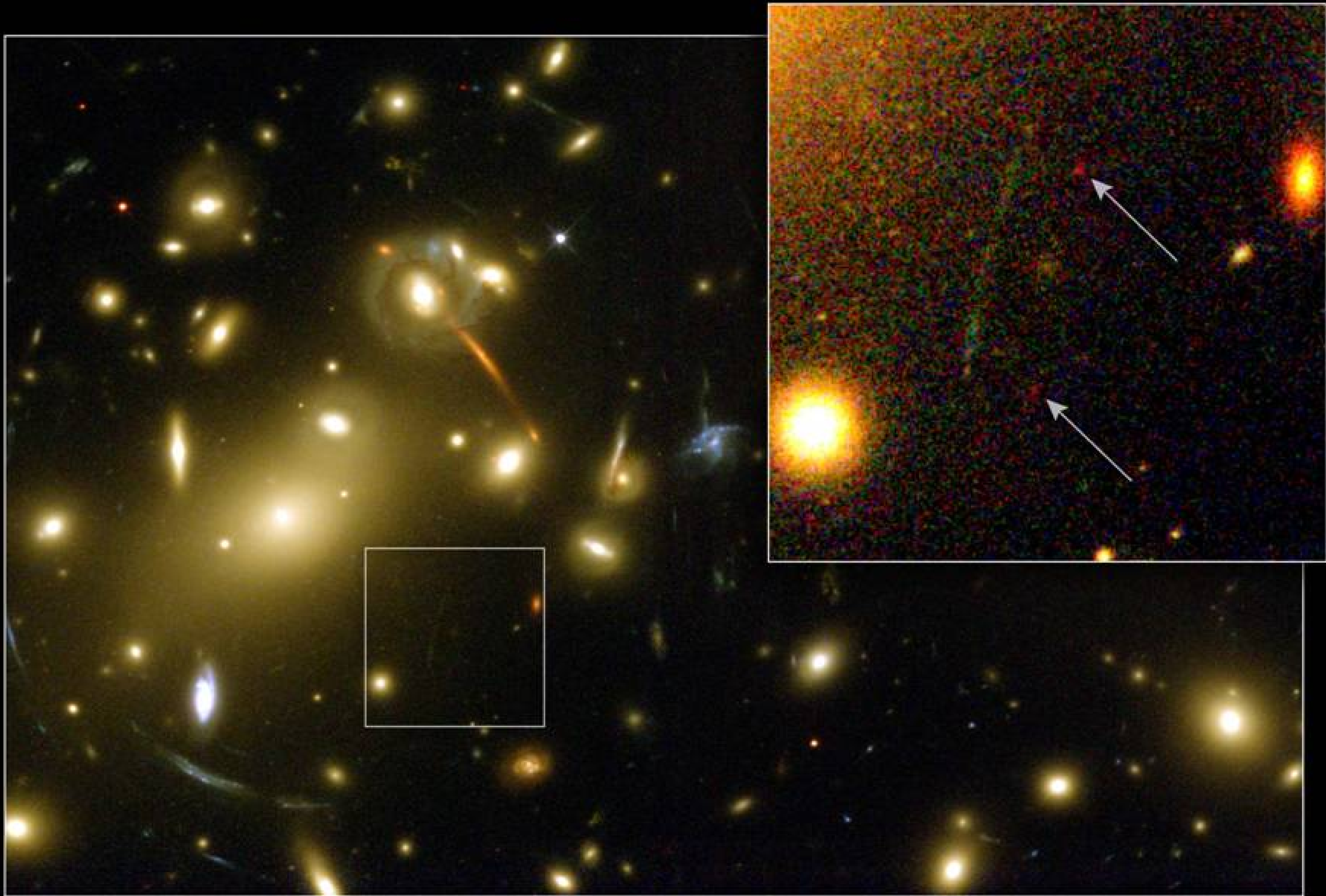
$$2KE + PE = \frac{1}{2}\frac{d^2 I}{dt^2}$$



Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218

Hubble Space Telescope • WFPC2

NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32

NGC 3198

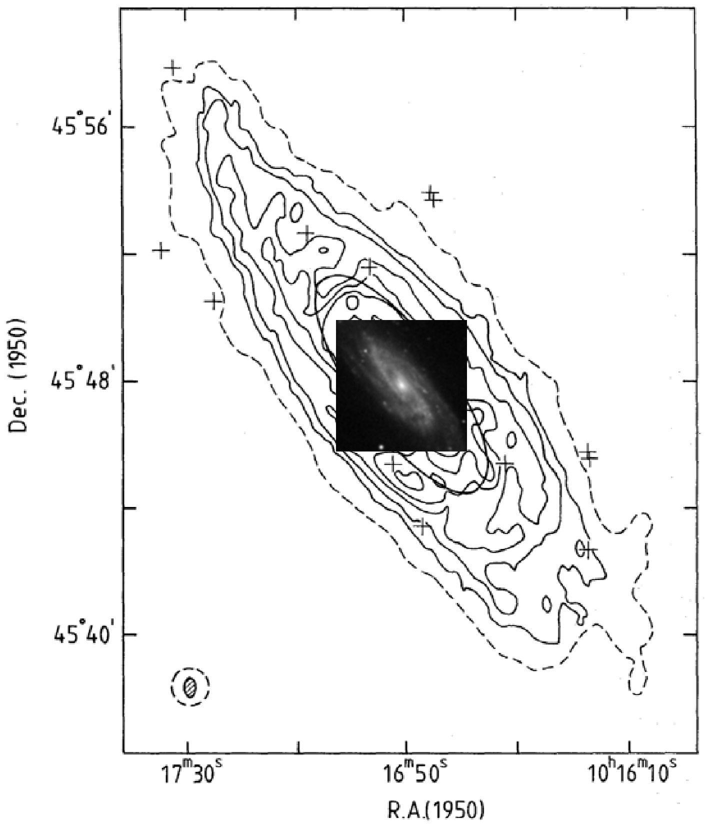


Fig. 4. Map of the H I column density distribution. The dashed contour is from low resolution data (70″ × 70″), the others from full resolution data (25″ × 35″). Contour levels are: 0.5 (3σ, low resolution), 1 (1σ, full resolution), 4, 8, 12, 16, 24, 28 10^{20} atom cm^{-2}. This map has been corrected for primary beam attenuation. The ellipse indicates the 25th mag $arcsec^{-2}$ isophote (de Vaucouleurs et al., 1976). Tickmarks indicate local minima

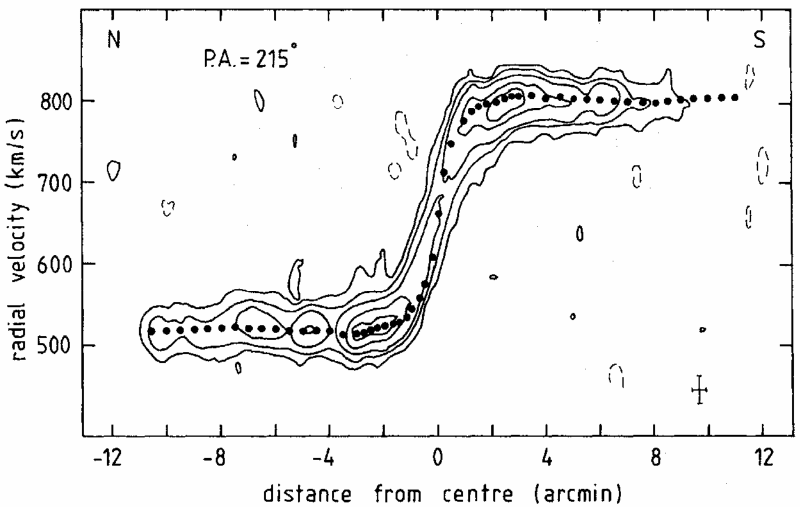
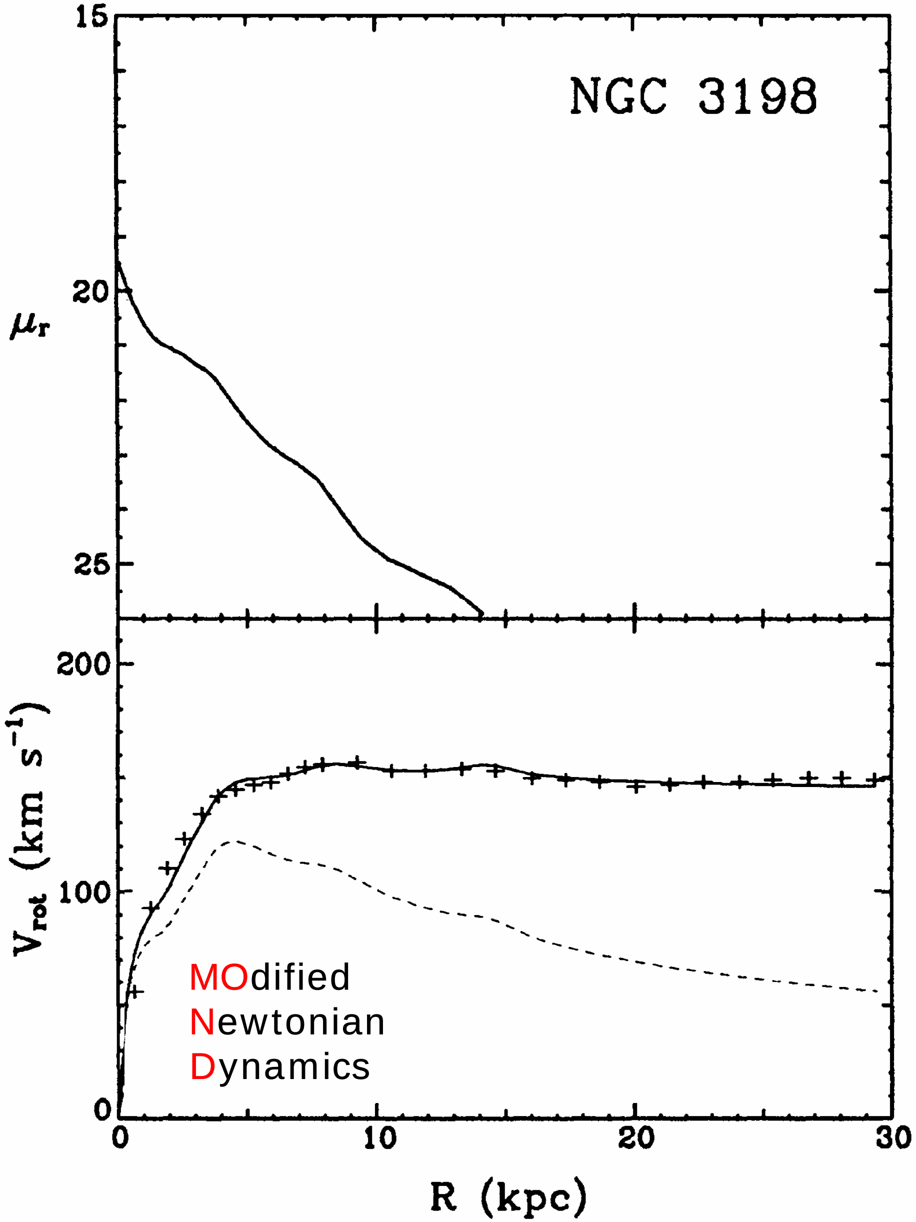


Fig. 9. The mean rotation curve for northern and southern half projected on a position-velocity map at a position angle of 215°. Contour levels are −1, 1, 3, 6, 13, 19 K. This map has not been corrected for primary beam attenuation

(Begeman 1989)



$$a_n = \frac{GM(r)}{r^2} = \frac{v^2}{r}$$

$$a_n = a \times \mu(|a|/a_0)$$

$$\mu(x) = \begin{cases} 1 & x >> 1 \\ x & x << 1 \end{cases}$$

(Milgrom 1983)

(Kent 1987)

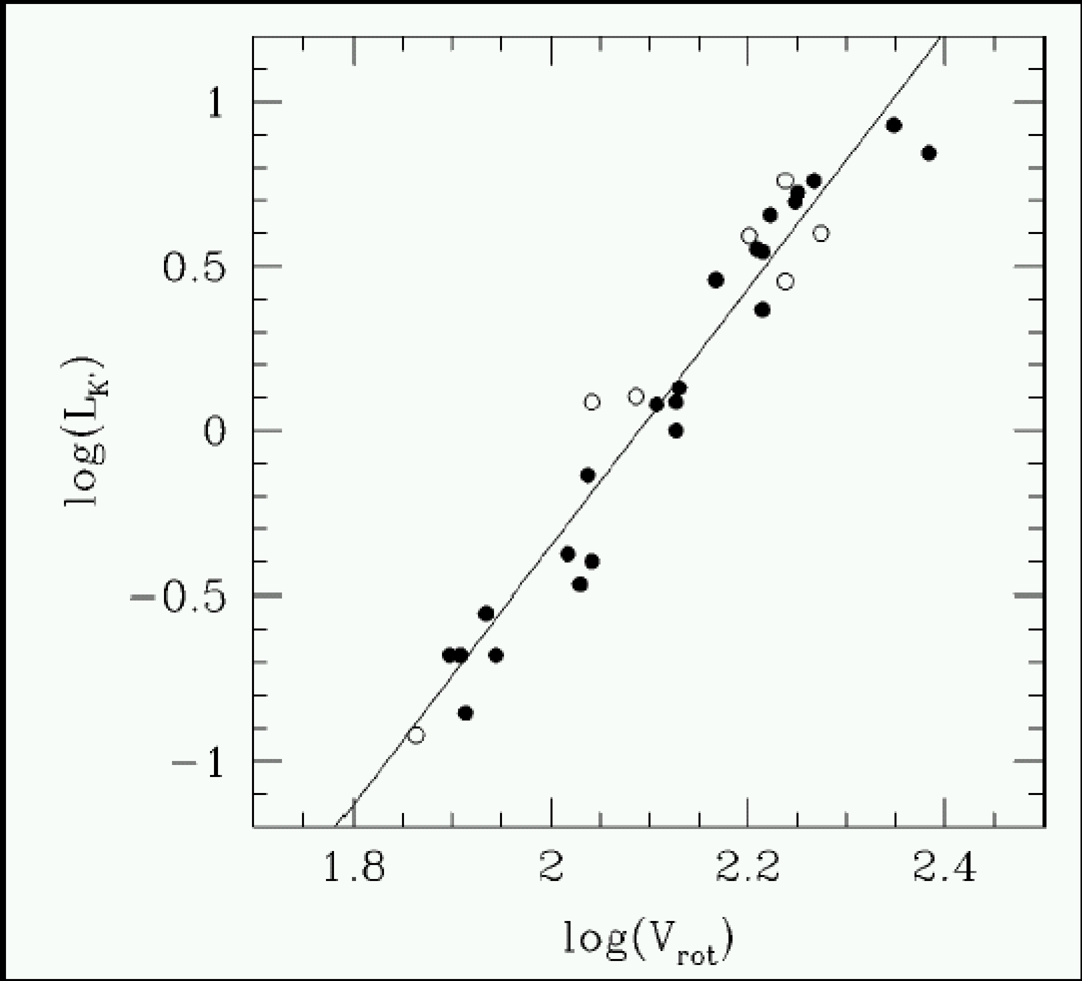
The Tully Fisher Relation

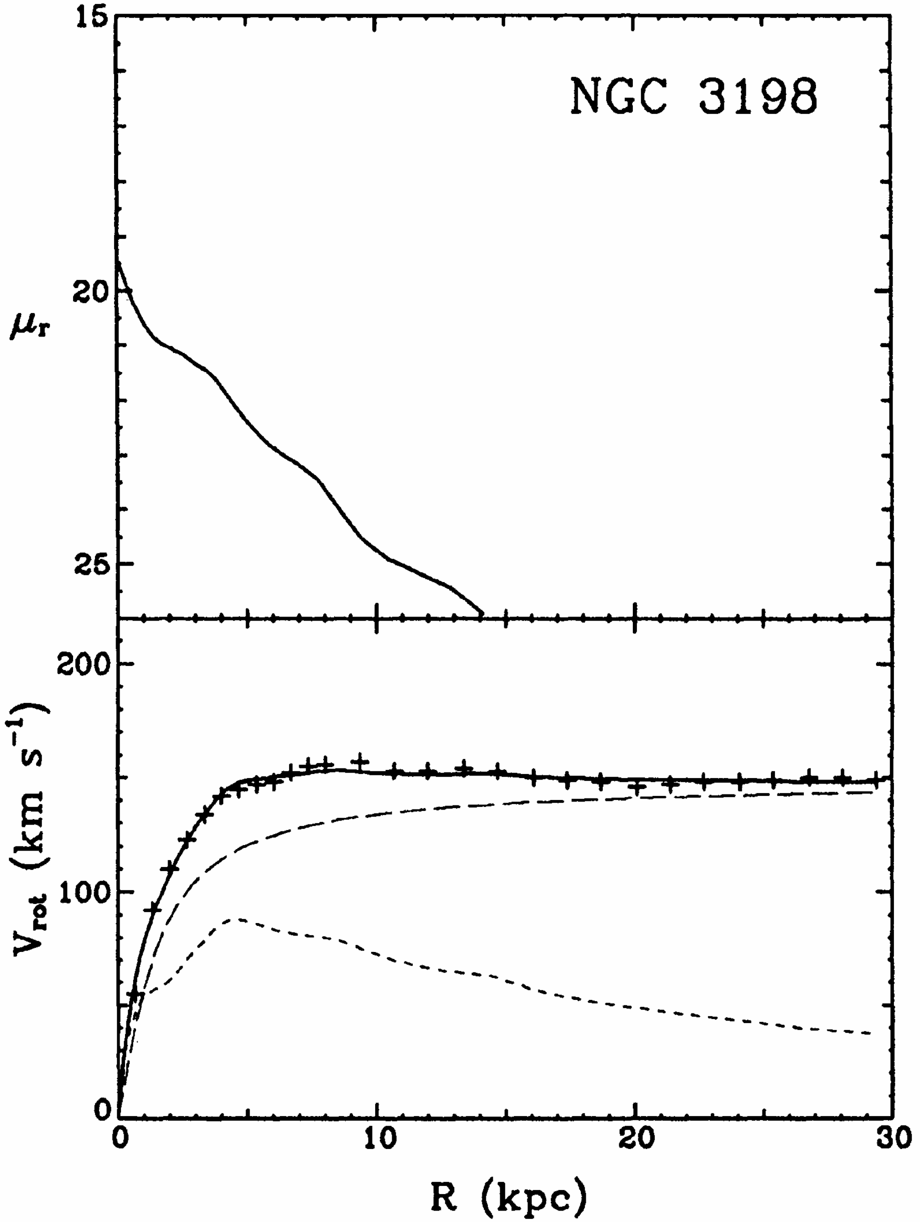
In "deep MOND,"

$$a = \sqrt{a_n a_0}$$

$$\Rightarrow \frac{v^2}{r} = \sqrt{\frac{GM}{r^2} a_0}$$

$$\Rightarrow L \propto M \propto v^4$$





$$a_n = \frac{GM(r)}{r^2} = \frac{v^2}{r}$$

$$\Rightarrow M(r) \propto r$$

$$\Rightarrow \rho(r) \propto r^{-2}$$

(Kent 1987)

In Situ Measurements

In the Solar neighbourhood, we have:

$\Sigma_{1.1} \approx 70\ M_a\ \mathrm{pc}^{-2}$ — Total mass within 1.1 kpc of the Galactic plane (Kuijken & Gilmore 1991)

$\Sigma_{1.1}^{\mathrm{bar}} \approx 50\ M_a\ \mathrm{pc}^{-2}$ — Census of mass in baryons within 1.1 kpc of the Galactic plane (Olling & Merrifield 2001)

$\Sigma_{1.1}^{\mathrm{DM}} \approx 20\ M_a\ \mathrm{pc}^{-2}$

$\approx 0.4\ \Sigma_{1.1}^{\mathrm{bar}}$

whereas more globally in the Milky Way:

$M(R_0) \approx 9.5 \times 10^{10}\ M_a$ — Total dynamical mass within the Solar circle

$M^{\mathrm{bar}}(R_0) \approx 5.5 \times 10^{10}\ M_a$ — Census of mass in baryons within the Solar circle (Olling & Merrifield 2001)

$M^{\mathrm{DM}}(R_0) \approx 4.0 \times 10^{10}\ M_a$

$\approx 0.7\ M^{\mathrm{bar}}(R_0)$

Dark matter more spherically distributed than baryons

Measuring Halo Shape

One measure of the shape of the halo can be made using the thickness of a galaxy's gas layer, assuming that it is in hydrostatic equilibrium:

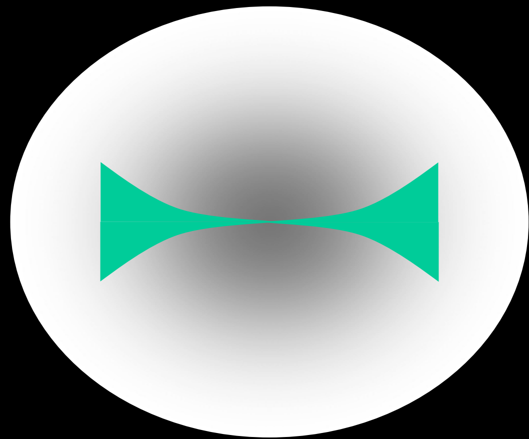
Flatter
halo

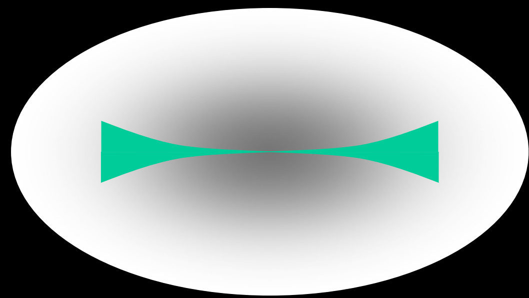
⇓

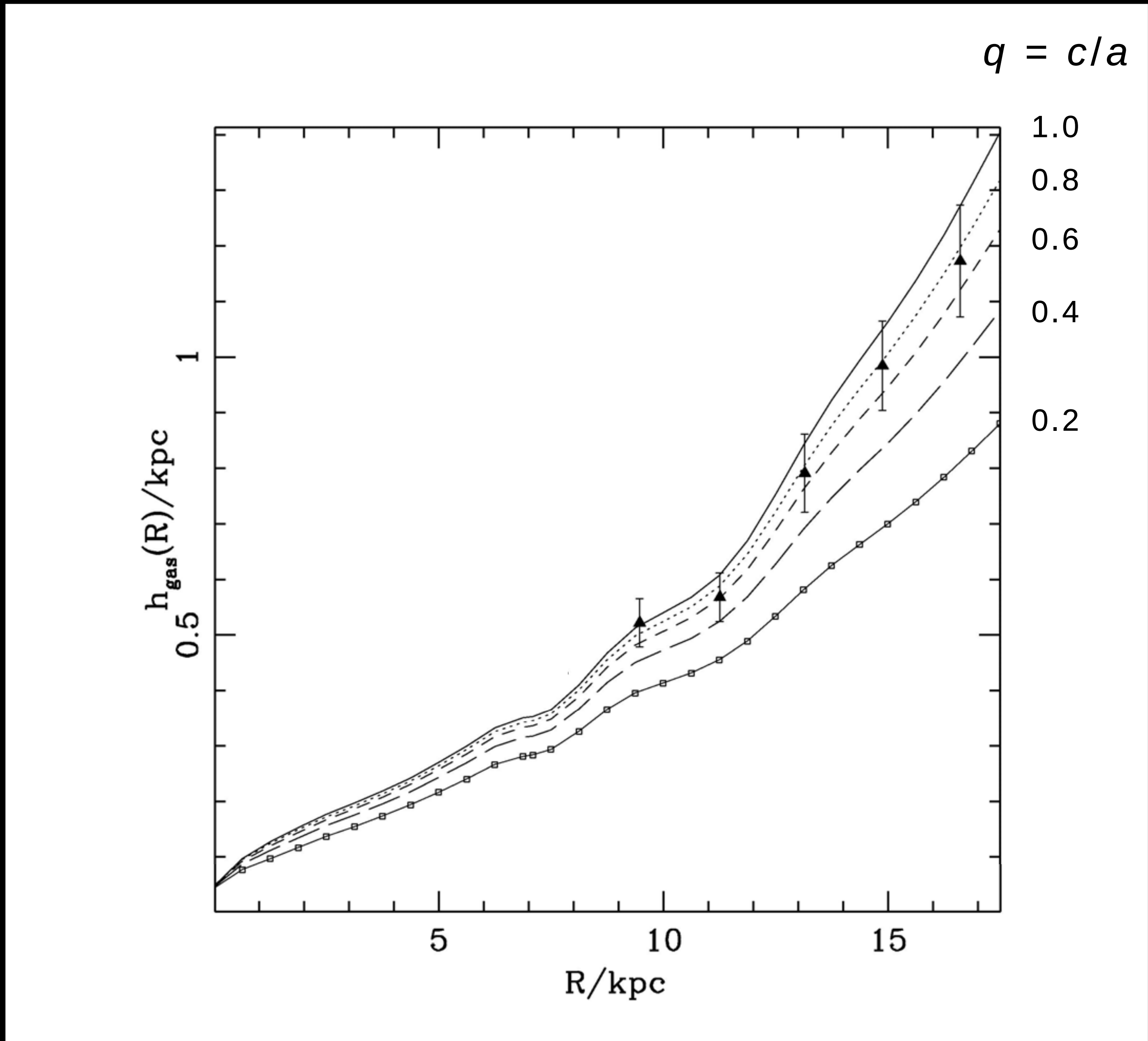
dark matter concentrated
closer to plane

⇓

Vertical gravitational pull
reduces scaleheight of gas layer

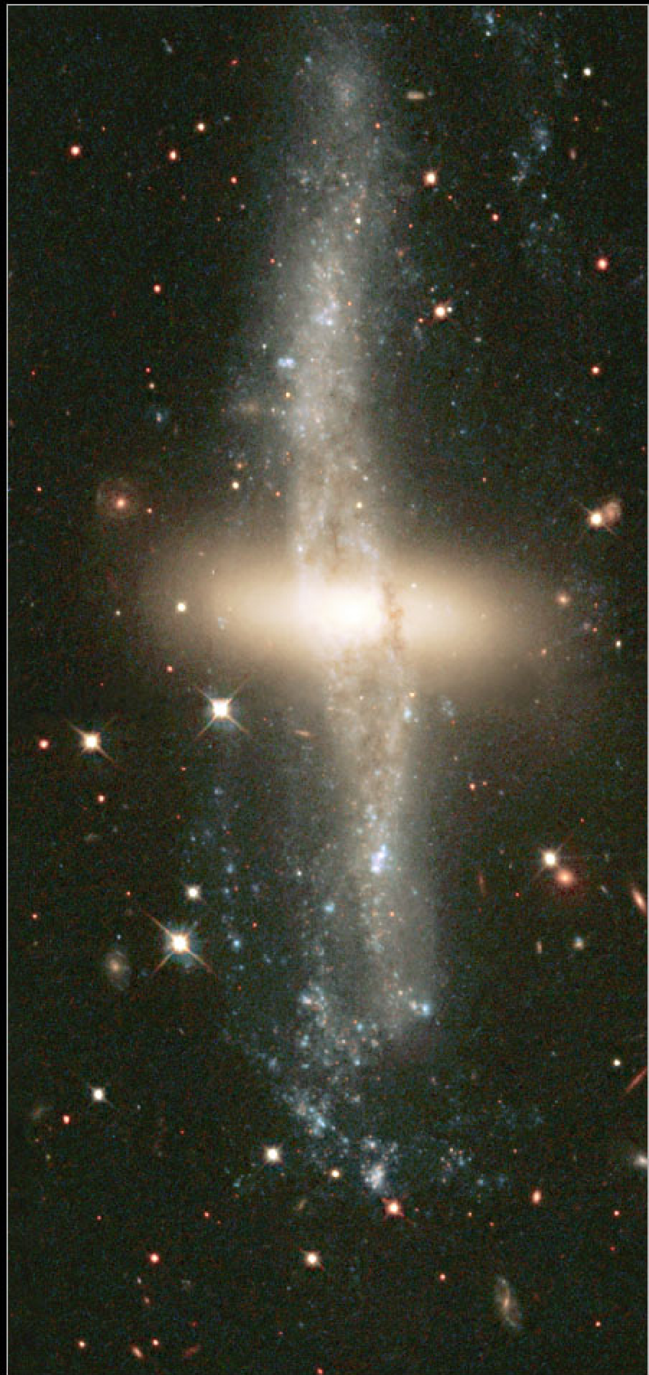






(Olling & Merrifield 2000)

Polar-Ring Galaxy NGC 4650A



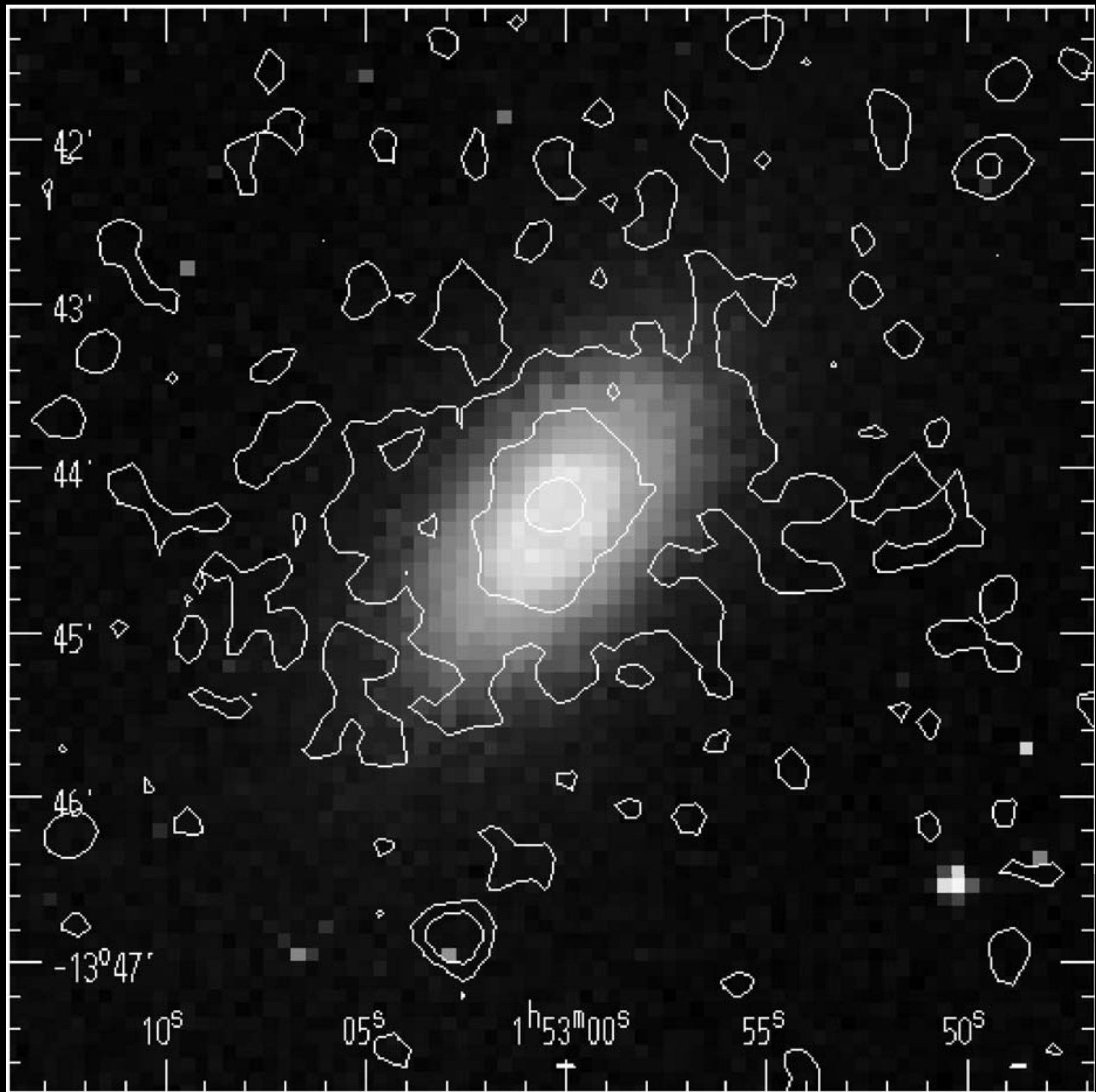
PRC99-12

Space Telescope Science Institute

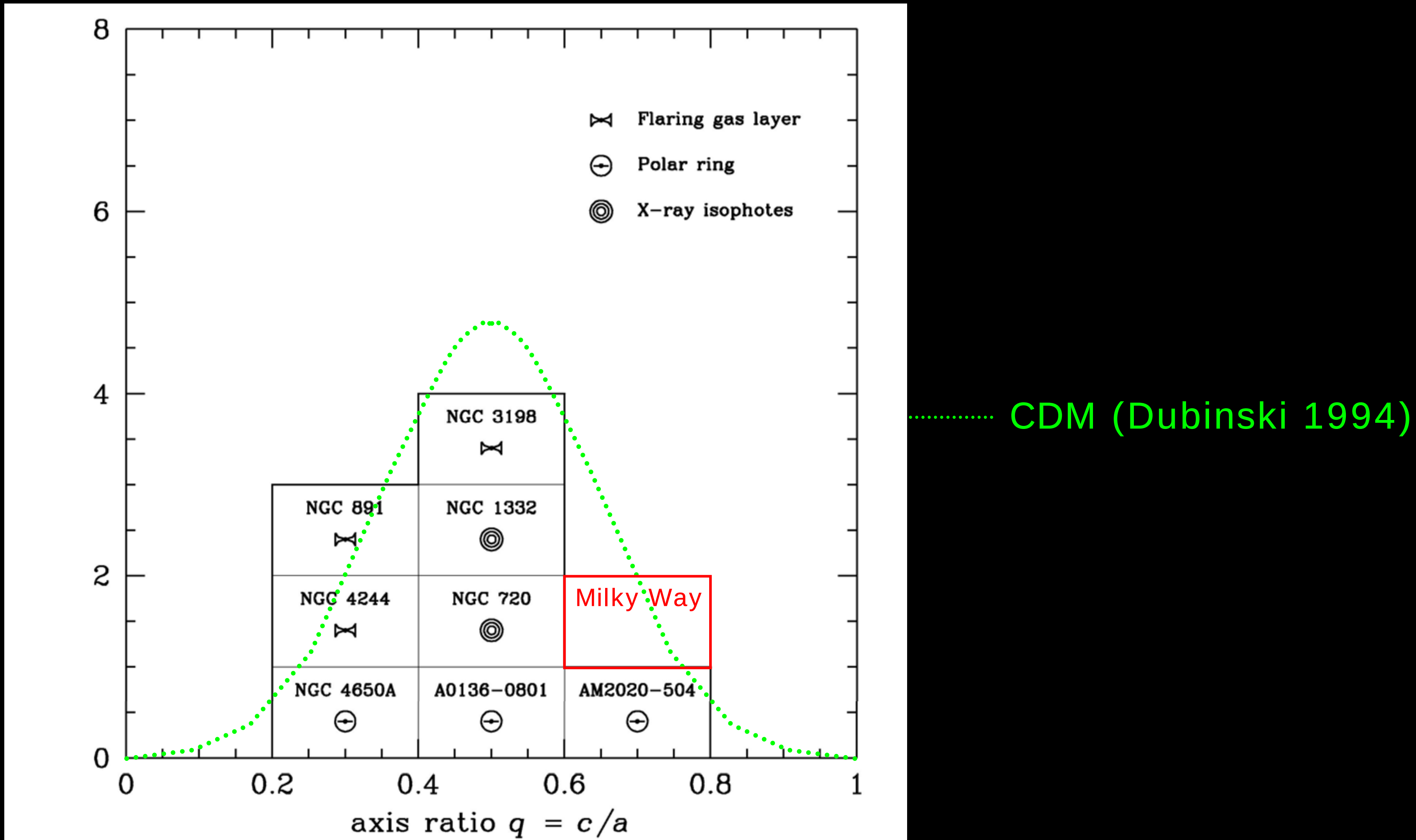
Hubble Heritage Team (AURA/STScI/NASA)

Hubble Heritage

NGC 720

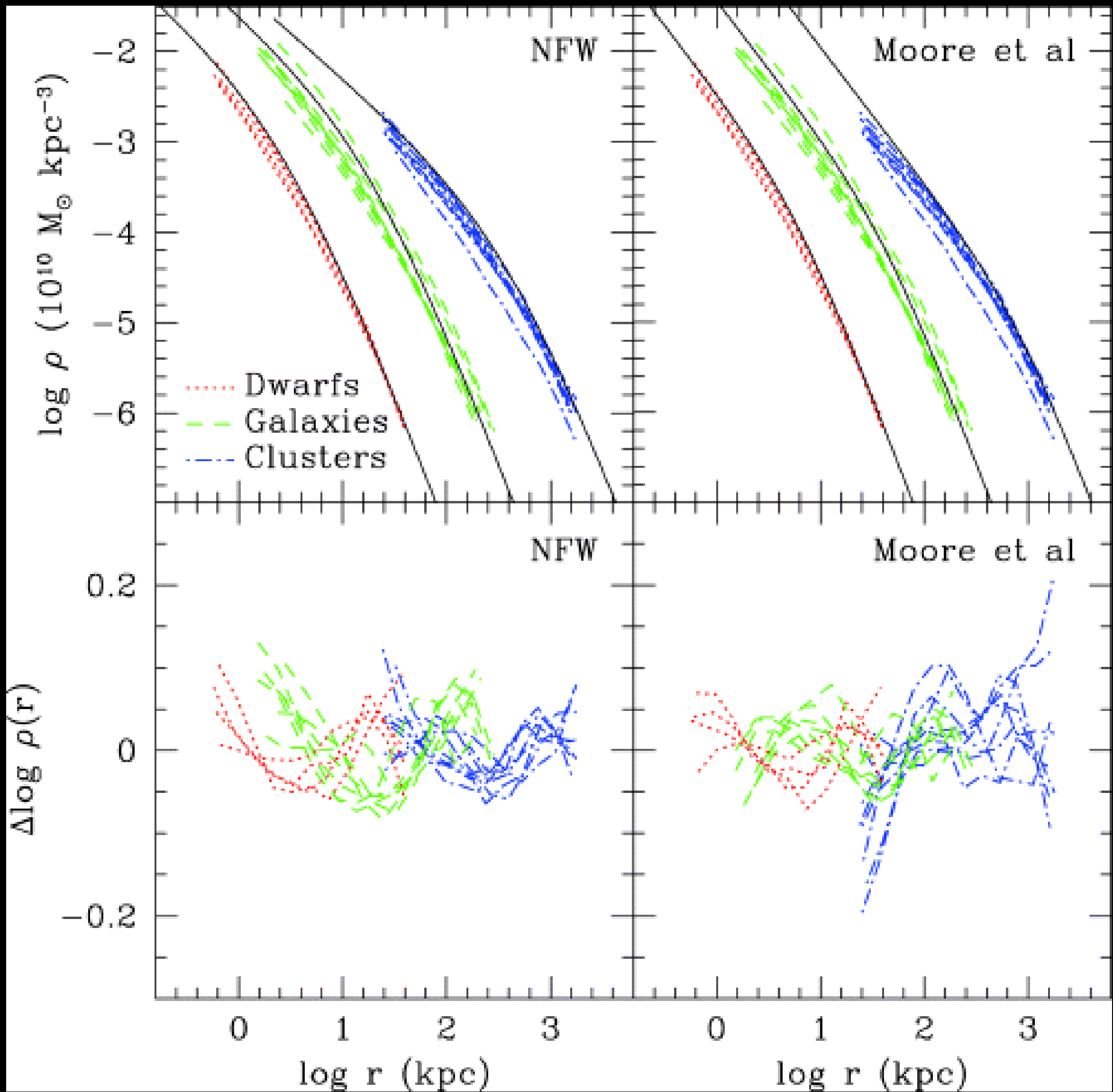


(Buote & Canizares 1996)



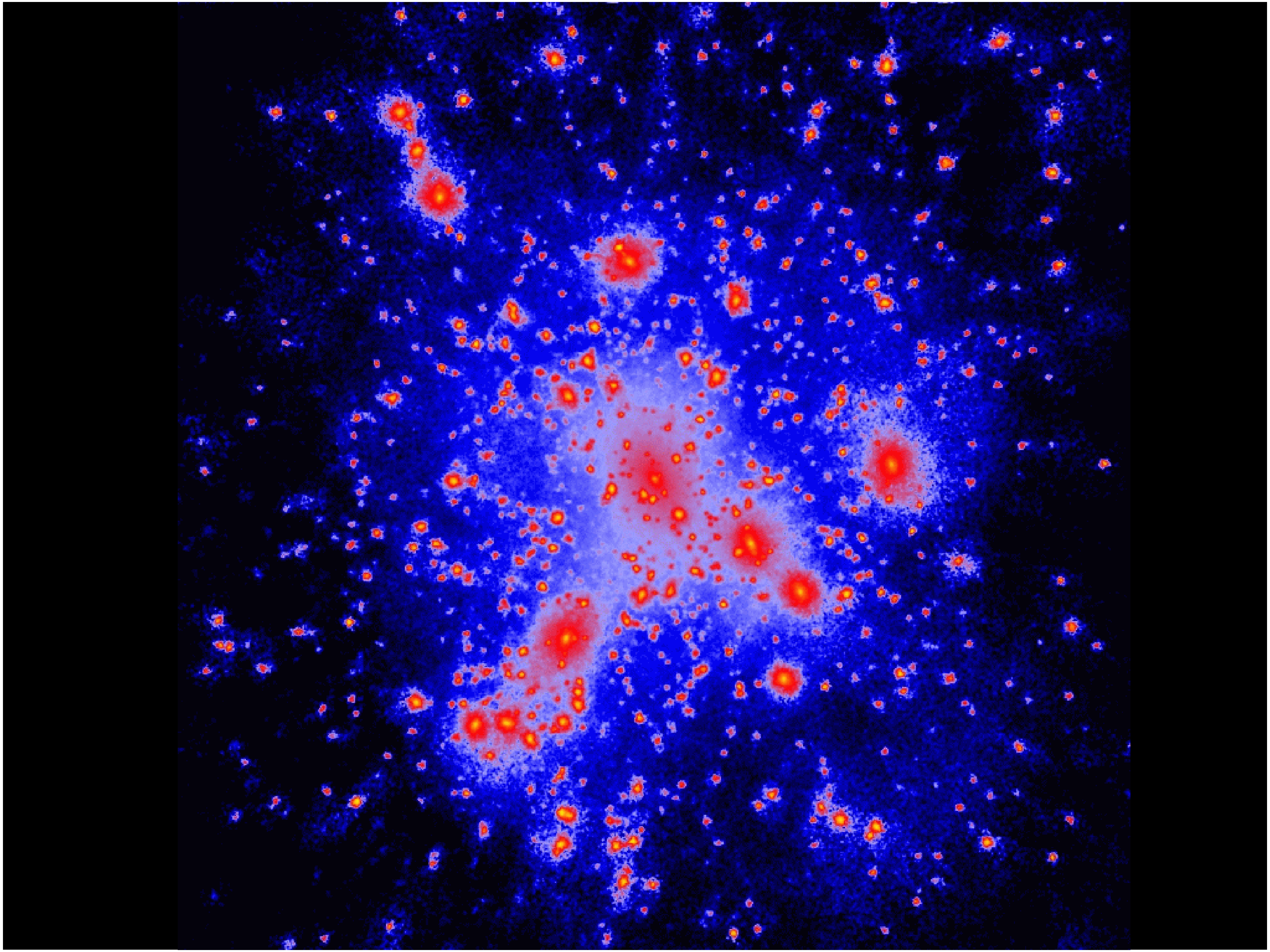
Flaring gas layer
Polar ring
X-ray isophotes
NGC 3198
NGC 891
NGC 1332
NGC 4244
NGC 720
Milky Way
NGC 4650A
A0136−0801
AM2020−504
0
2
4
6
8
0
0.2
0.4
0.6
0.8
1
axis ratio $q = c/a$
CDM (Dubinski 1994)

Moore *et al.* (2003)

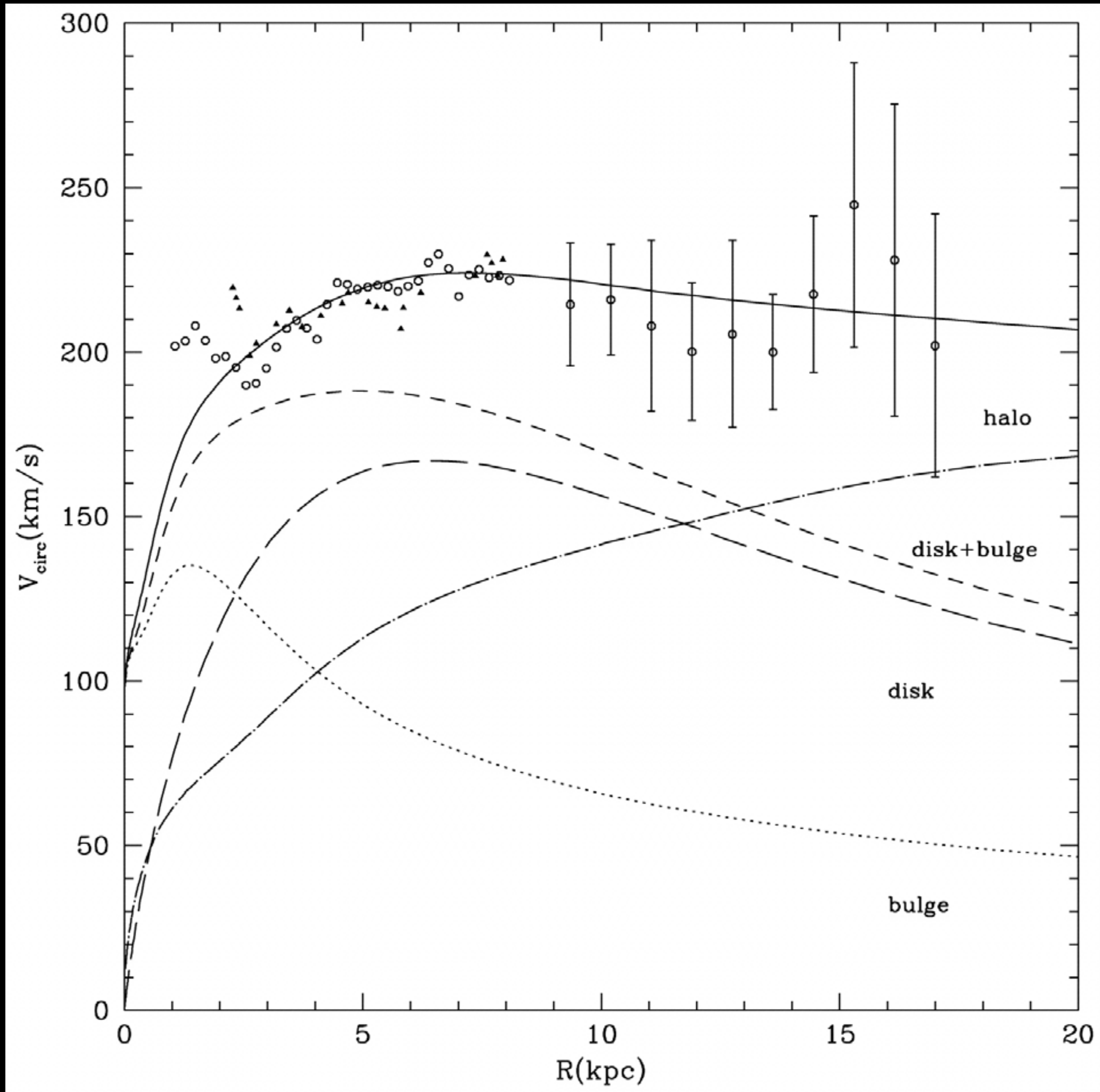


$$\rho_{NFW}(r) = \frac{\rho_s}{(r/r_s)\left[1+(r/r_s)\right]^2} \qquad \rho_M(r) = \frac{\rho_M}{(r/r_M)^{1.5}\left[1+(r/r_M)^{1.5}\right]}$$

Navarro *et al.* (2004)

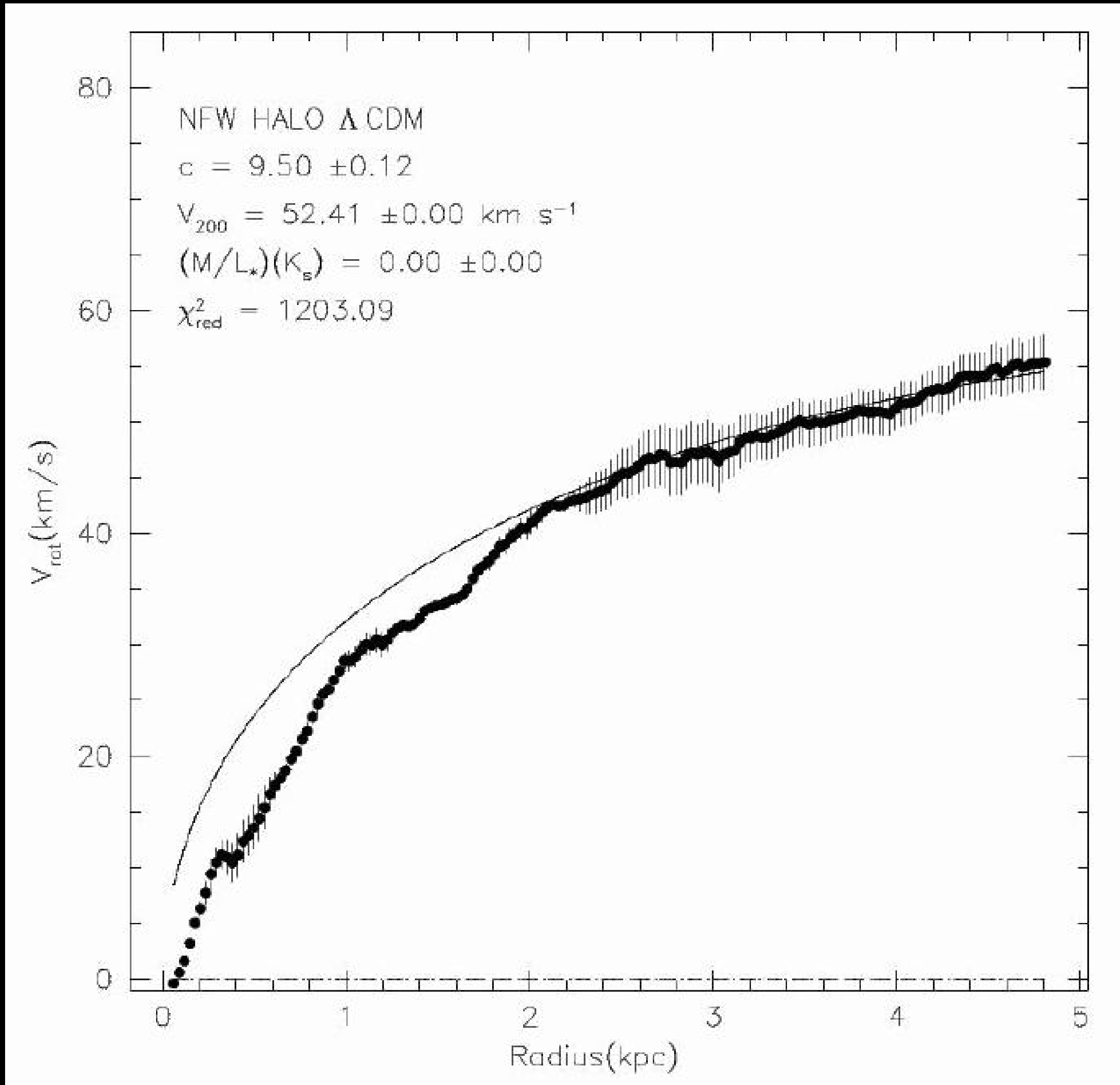


The Milky Way Rotation Curve in CDM



(Klypin, Zhao & Somerville 2002)

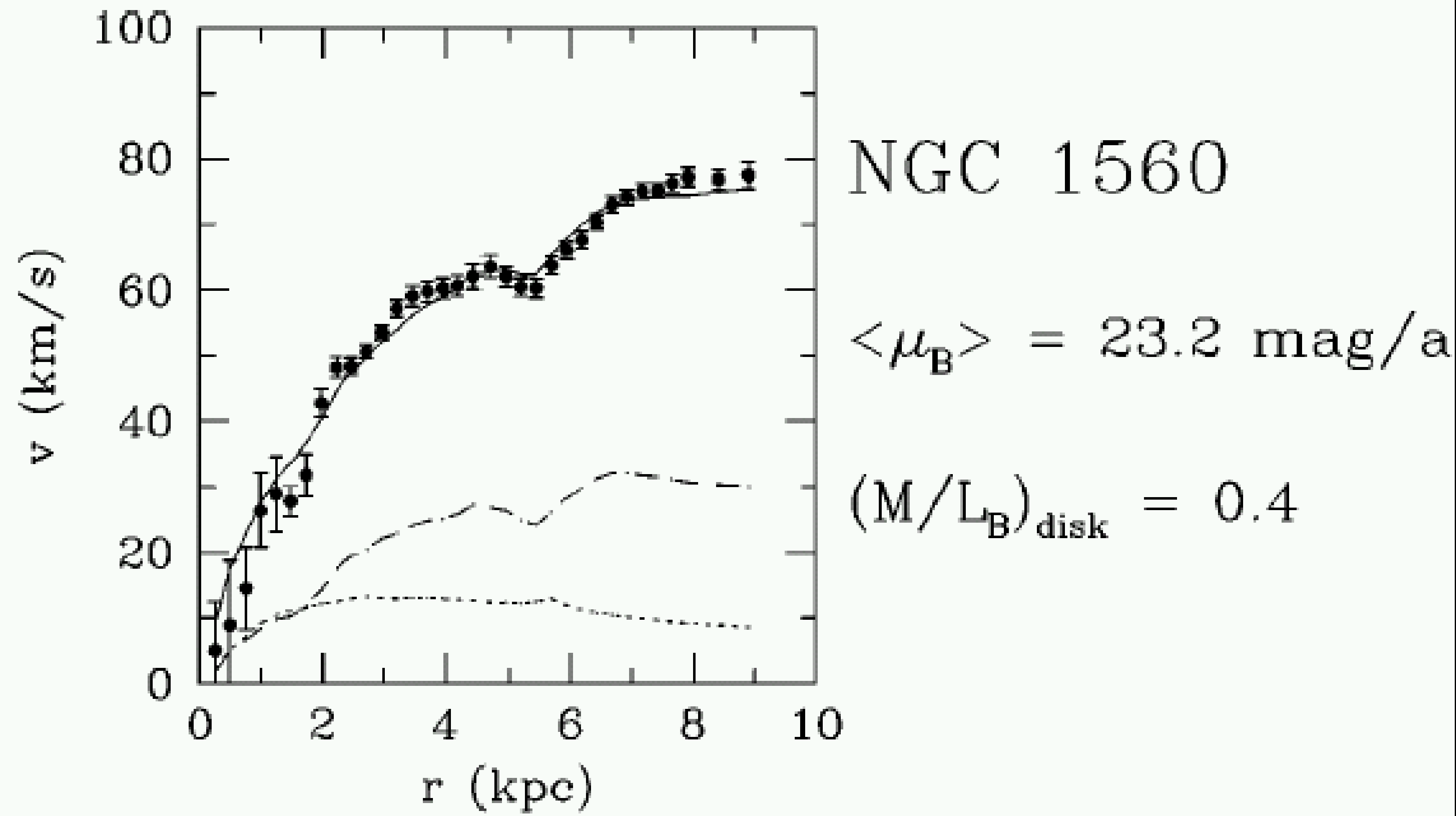
NGC 6822



NFW HALO Λ CDM
c = 9.50 ±0.12
V200 = 52.41 ±0.00 km s-1
(M/L*)(Ks) = 0.00 ±0.00
χ²red = 1203.09
Vrot(km/s)
Radius(kpc)
0
20
40
60
80
0
1
2
3
4
5

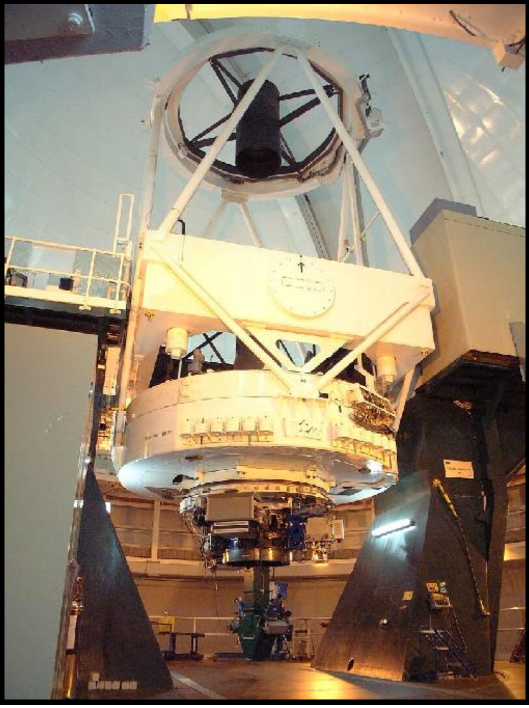
(de Blok 2004)

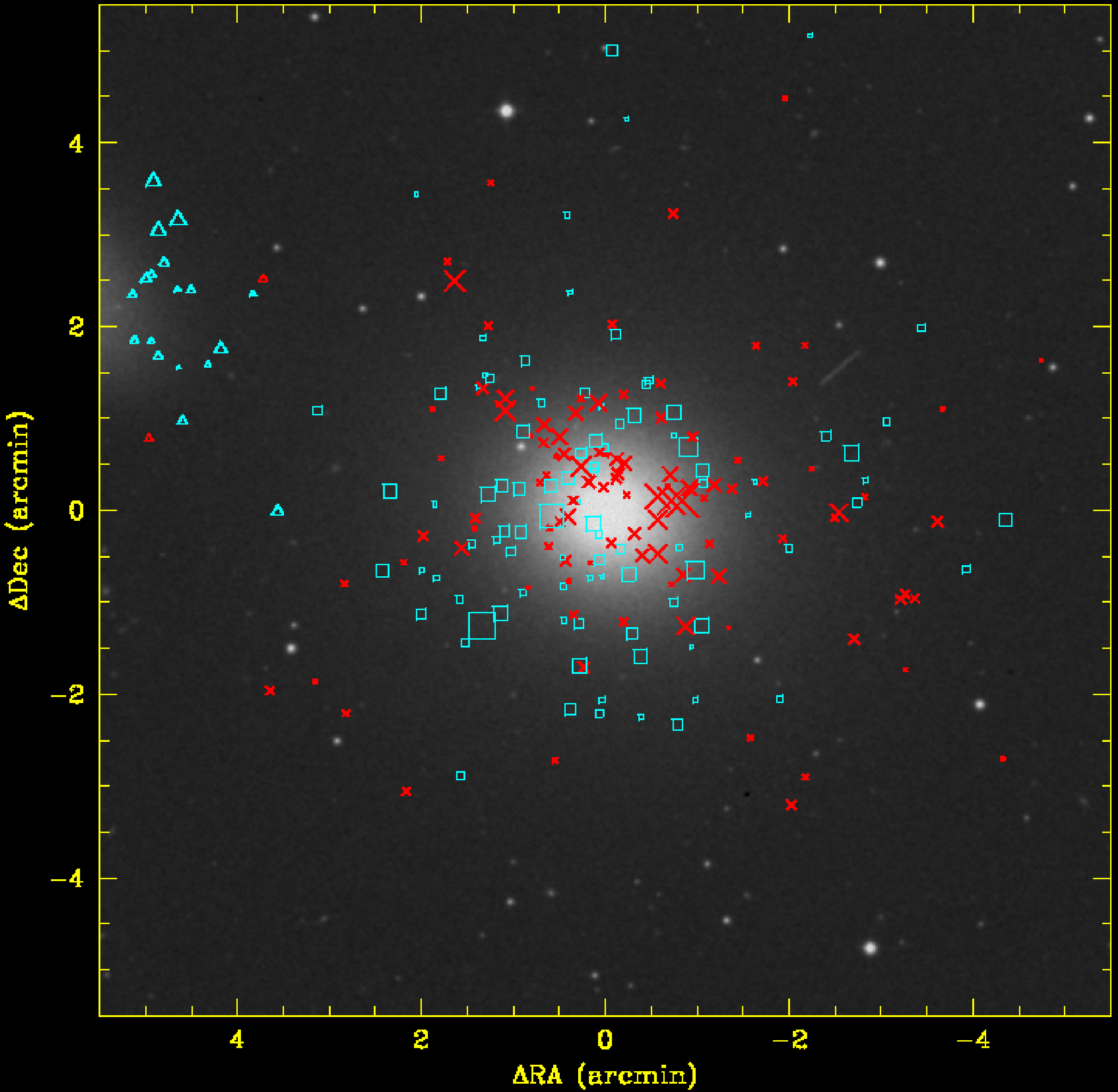
MOND Again



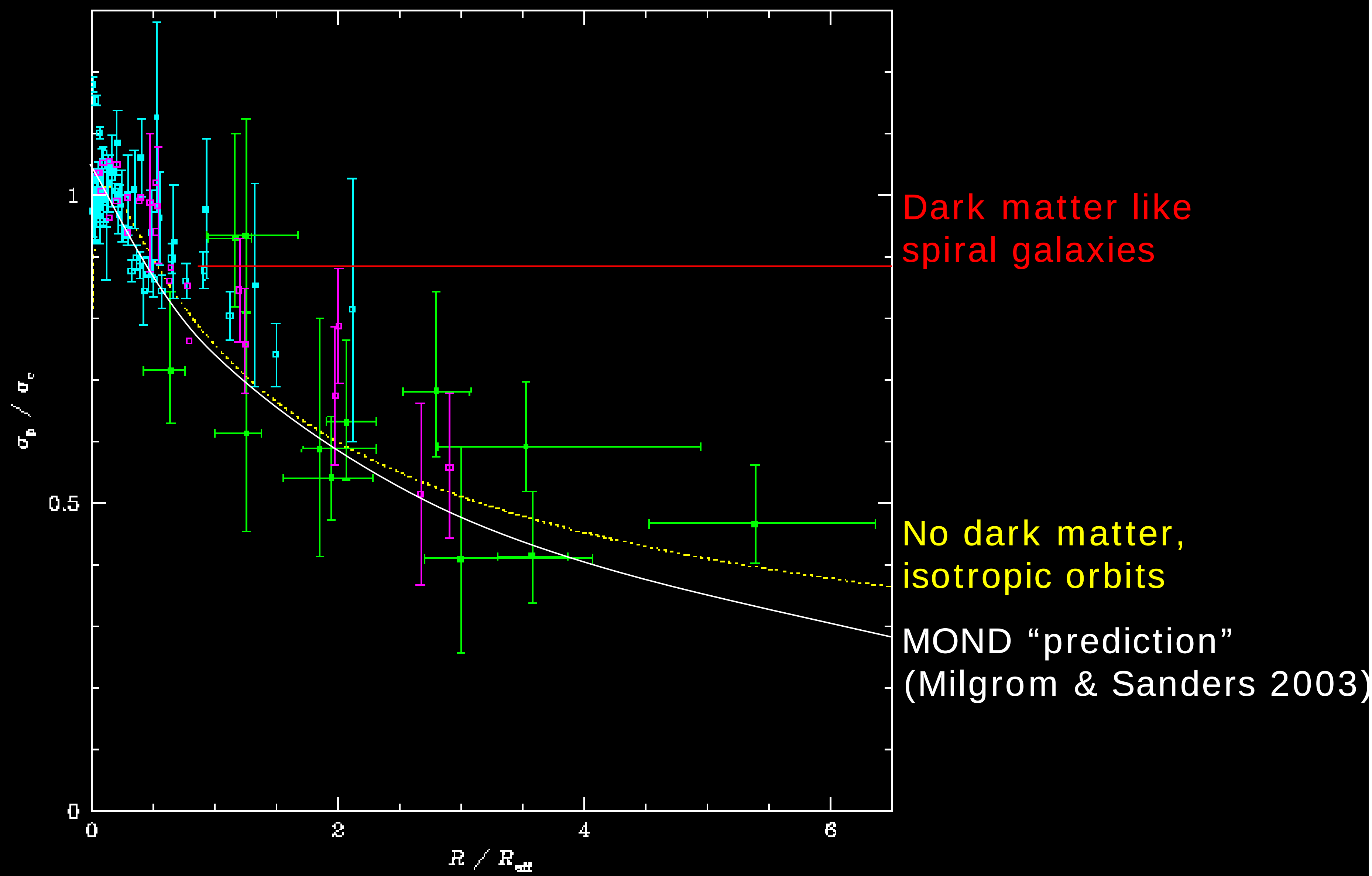
(Sanders & McGaugh 2002)

Elliptical Galaxies

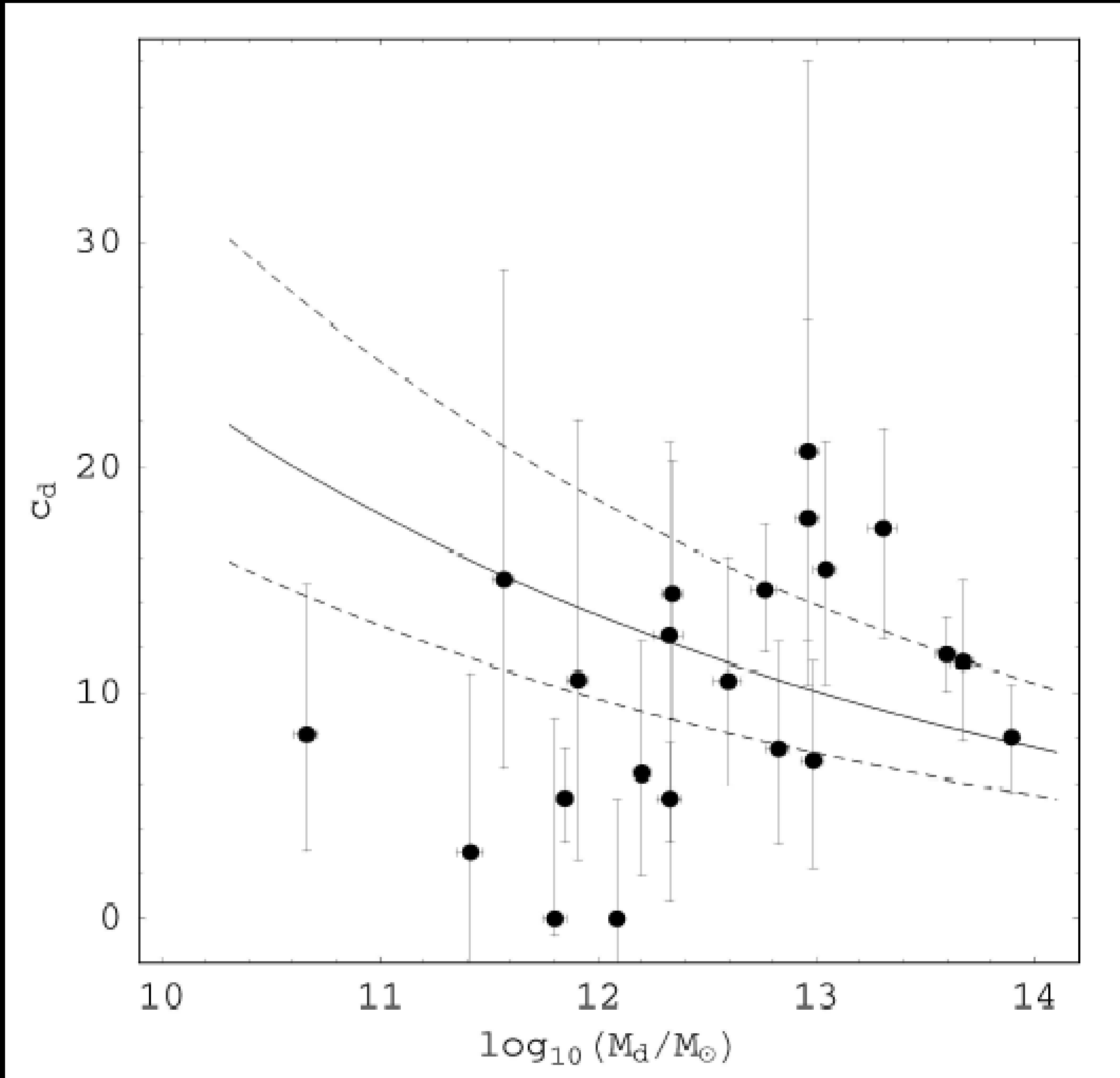




Romanowsky *et al.* (2003)



Romanowsky *et al.* (2003)



Napolitano *et al.* (2004)

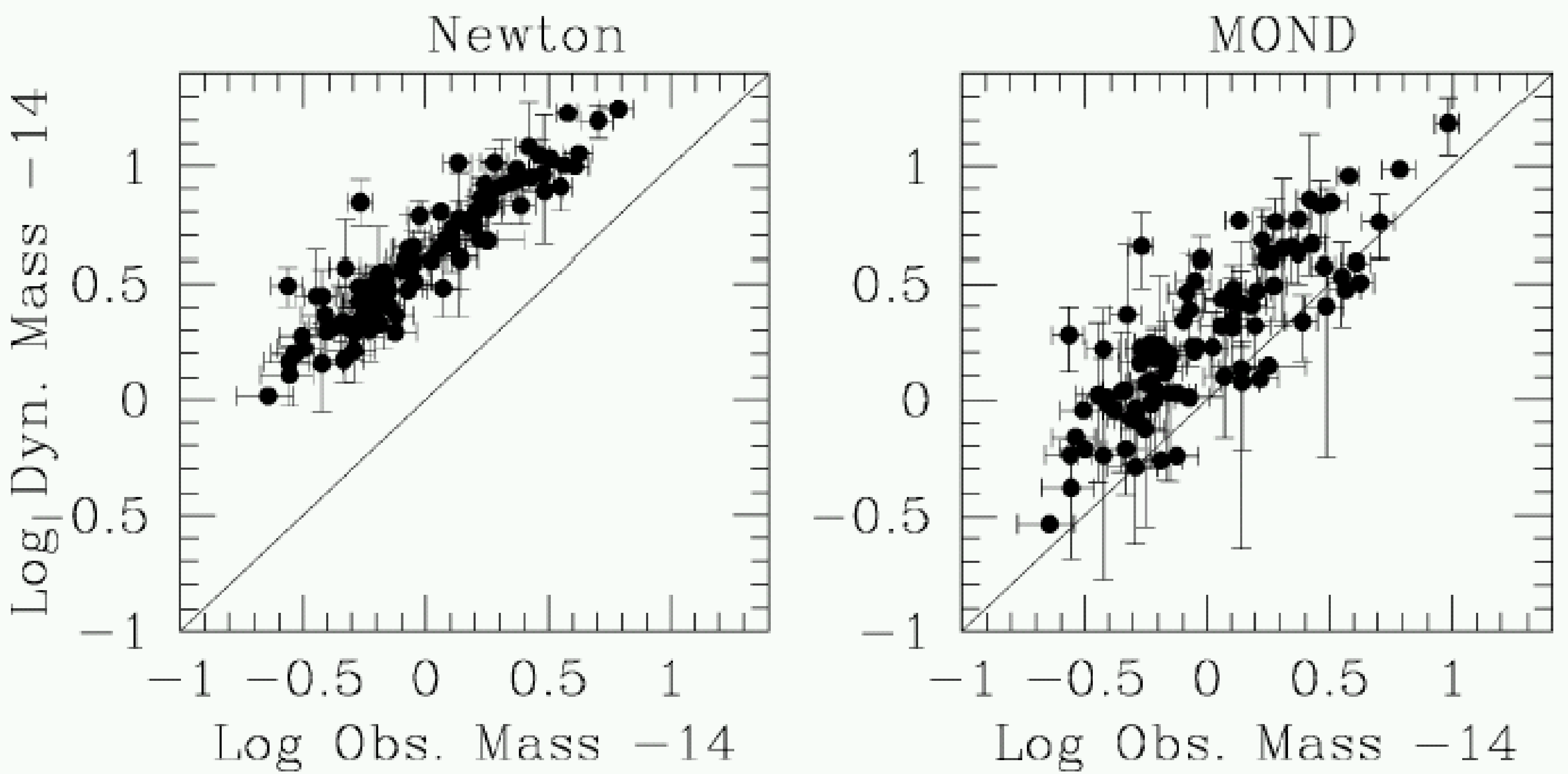
Conclusions

There is overwhelming evidence that, on the scale of galaxies, dynamically-inferred masses exceed the observed baryonic masses

For the last twenty years, the paradigm has been that the deficit is made up by non-baryonic dark matter

It is by no means clear at this point that Occam's Razor supports this interpretation (*c.f.* MOND)

Save the paradigm — detect the dark matter!


Newton
MOND
Log Dyn. Mass −14
Log Obs. Mass −14
−1
−0.5
0
0.5
1