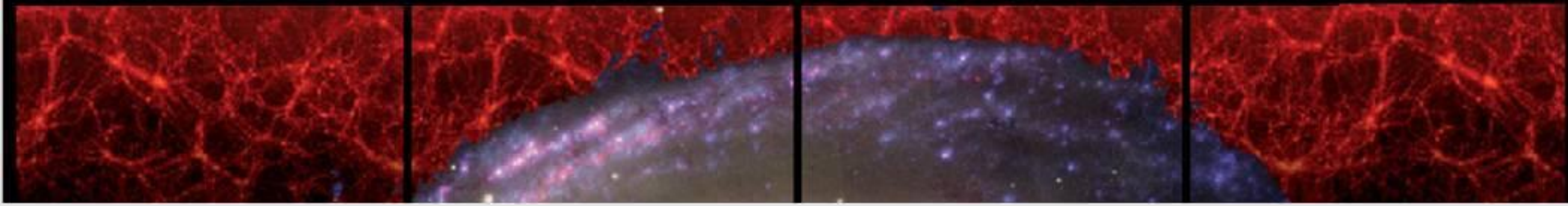


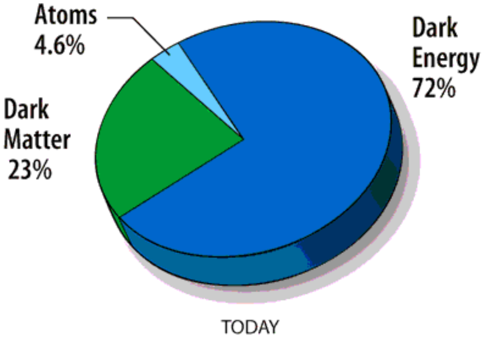
DARK MATTER IN DSPH

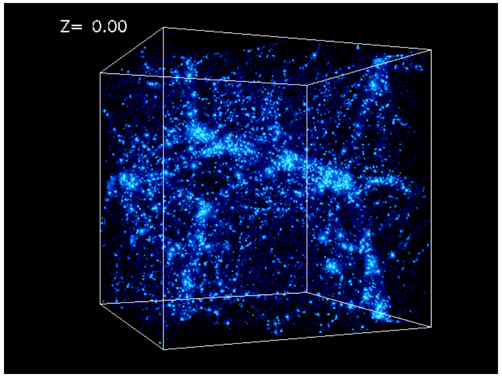
Paolo Salucci (& G. Gilmore)

SISSA (Oxford)

Outline of the Review

Dark Matter is main protagonist in the Universe





This review focus: Dark Matter in dSph

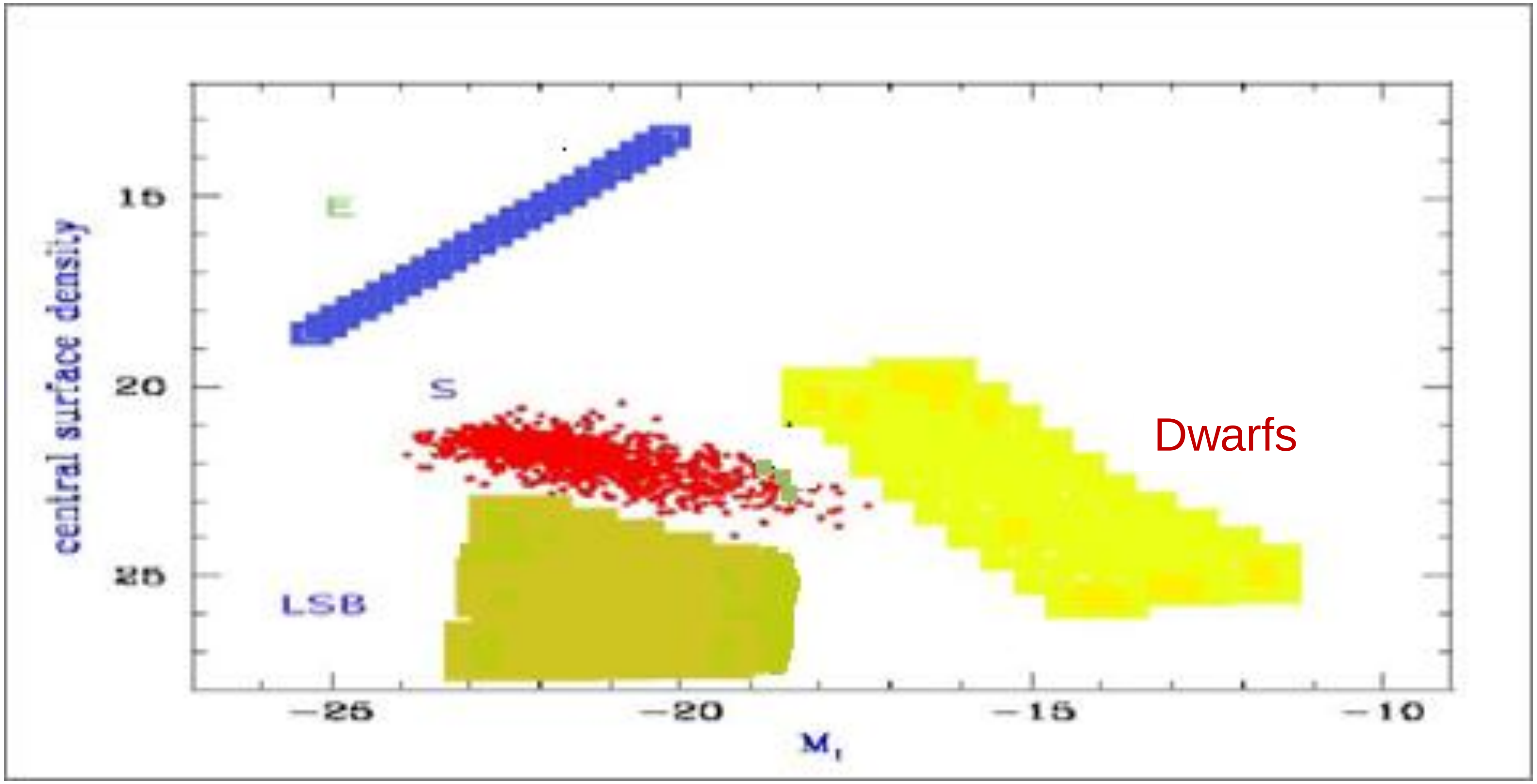
The concept of Dark Matter in virialized objects
Dark Matter in Spirals, Ellipticals, dSphs
Dark and Luminous Matter in dSph. Global properties.
Phenomenology of the mass distribution in Galaxies.
Implications for Direct and Indirect Searches

3 MAJOR TYPES OF GALAXIES

The Realm of Galaxies

The range of galaxies in magnitudes, types and central surface densities : 15 mag, 4 types, 16 mag arsec^{-2}

Central surface brightness vs galaxy magnitude



The distribution of luminous matter :

Spirals : stellar disk +bulge +HI disk

Ellipticals & dwarfs E: stellar spheroid

What is Dark Matter ?

In a galaxy, the radial profile of the gravitating matter M(r) does not match that of the luminous component $M_L(r)$.

A MASSIVE DARK COMPONENT is then introduced to account for the disagreement:

Its profile $M_H(r)$ must obey:

$$\frac{d\log M(r)}{d\log r} = \frac{M_L(r)}{M(r)}\frac{d\log M_L(r)}{d\log r} + \frac{M_H(r)}{M(r)}\frac{d\log M_H(r)}{d\log r}$$

$M(r)$, $M_L(r)$, $d\log M_L(r)/d\log r$ **observed**

The DM phenomenon can be investigated only if we **accurately** meausure the distribution of:

Luminous matter $M_L(r)$.
Gravitating matter $M(r)$

THEORY AND SIMULATIONS

ΛCDM Dark Matter Density Profiles from N-body simulations

The density of virialized DM halos of any mass is empirically described at all times by an Universal profile (Navarro+96, 97, NFW).

$$\rho_{NFW}(r) = \delta\rho_c \frac{r_s}{r} \frac{1}{(1+r/r_s)^2}$$

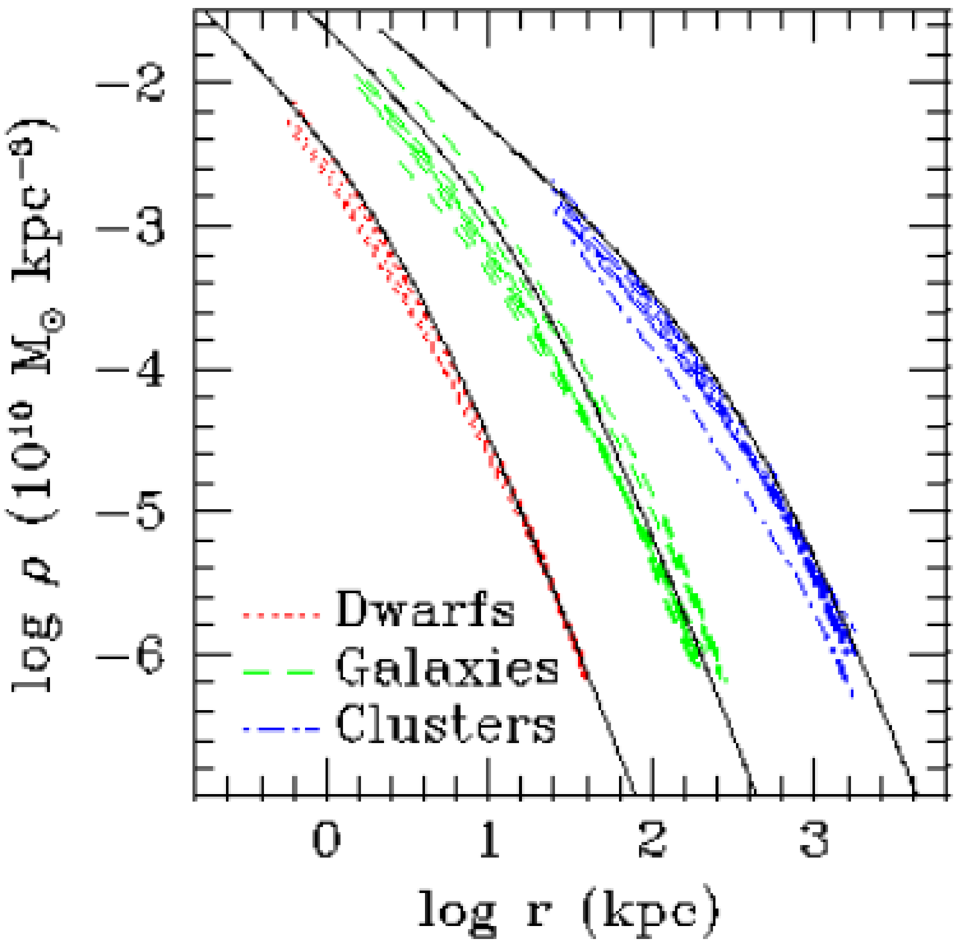
$$c = \frac{R_{vir}}{r_s} \quad R_{vir} = 260 \left(\frac{M_{vir}}{10^{12}\, M_\odot}\right)^{1/3} kpc$$

More massive halos and those formed earlier have larger overdensities

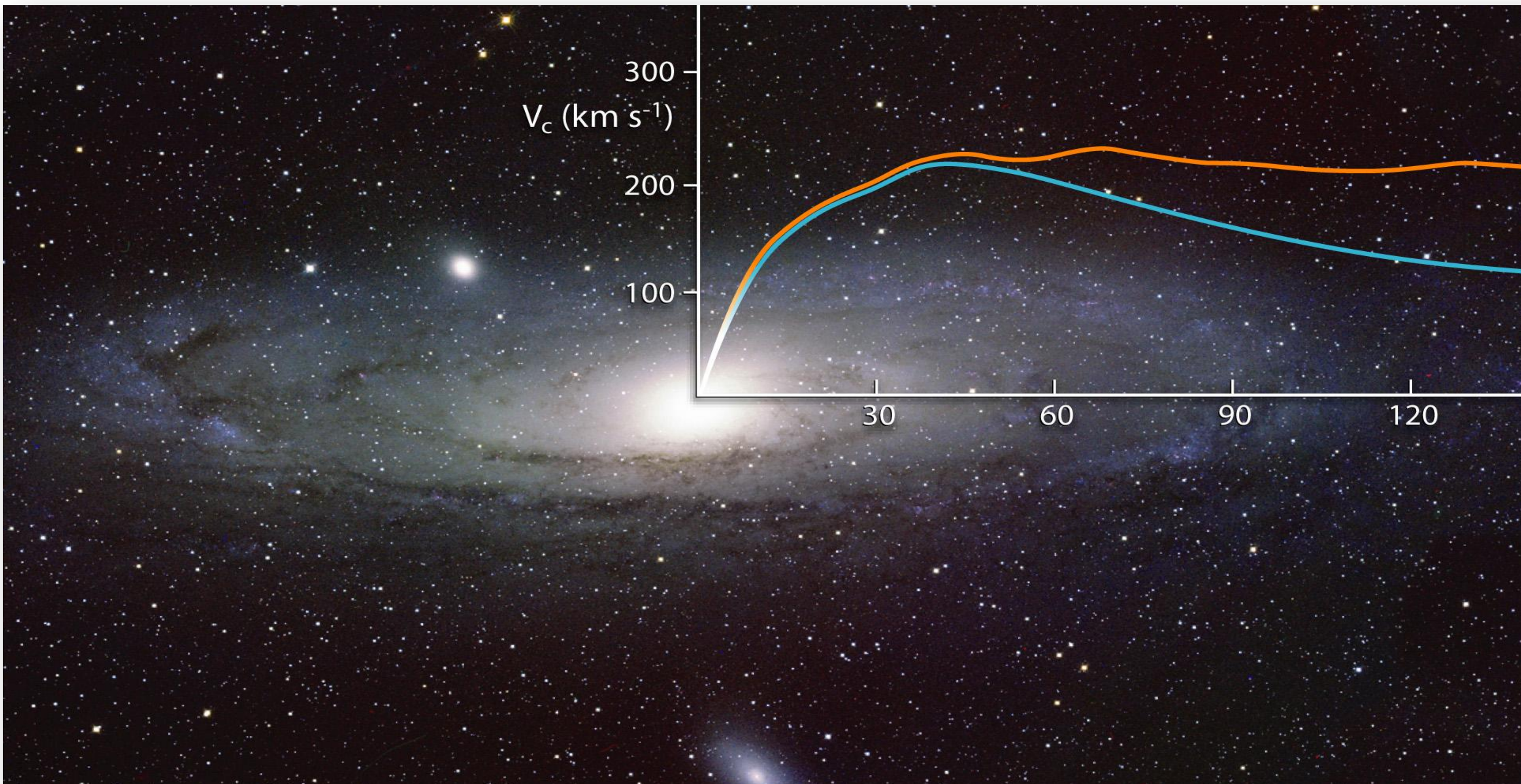
Today mean halo density inside R_{vir} = 100 ϱ_c

$$c(M_{vir}) = 9.35 \left(\frac{M_{vir}}{10^{12}\, M_\odot}\right)^{-0.09}$$

Klypin, 2010



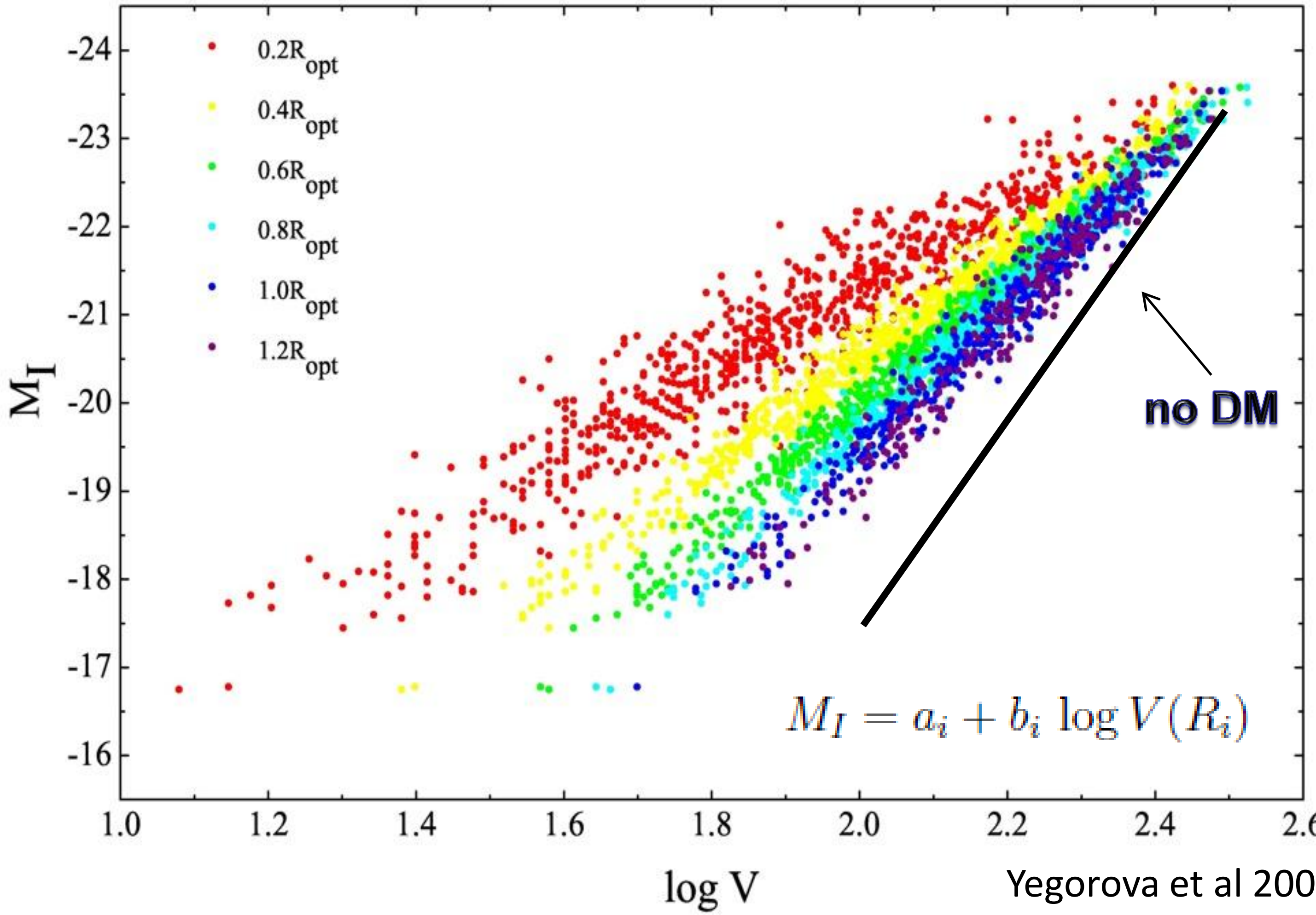
SPIRALS



Evidence for a Mass Discrepancy in Galaxies

The distribution of gravitating matter, unlike the luminous one, is luminosity dependent.

Tully-Fisher relation exists at local level (radii R_i)



Yegorova et al 2007

Rotation curve analysis

From data to mass models

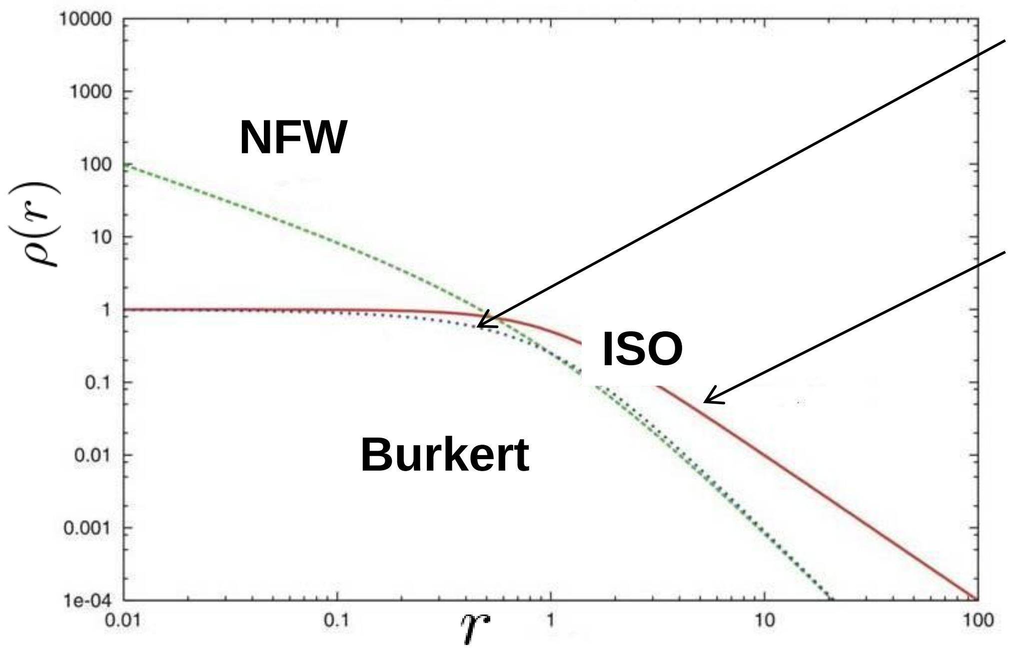
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

observations = model

- V^2_{disk} **from I-band photometry**
- V^2_{HI} **from HI observations**
- V^2_{halo} **different choices for the DM halo density**

Dark halos with central constant density (Burkert, Isothermal)

Dark halos with central cusps (NFW, Einasto)

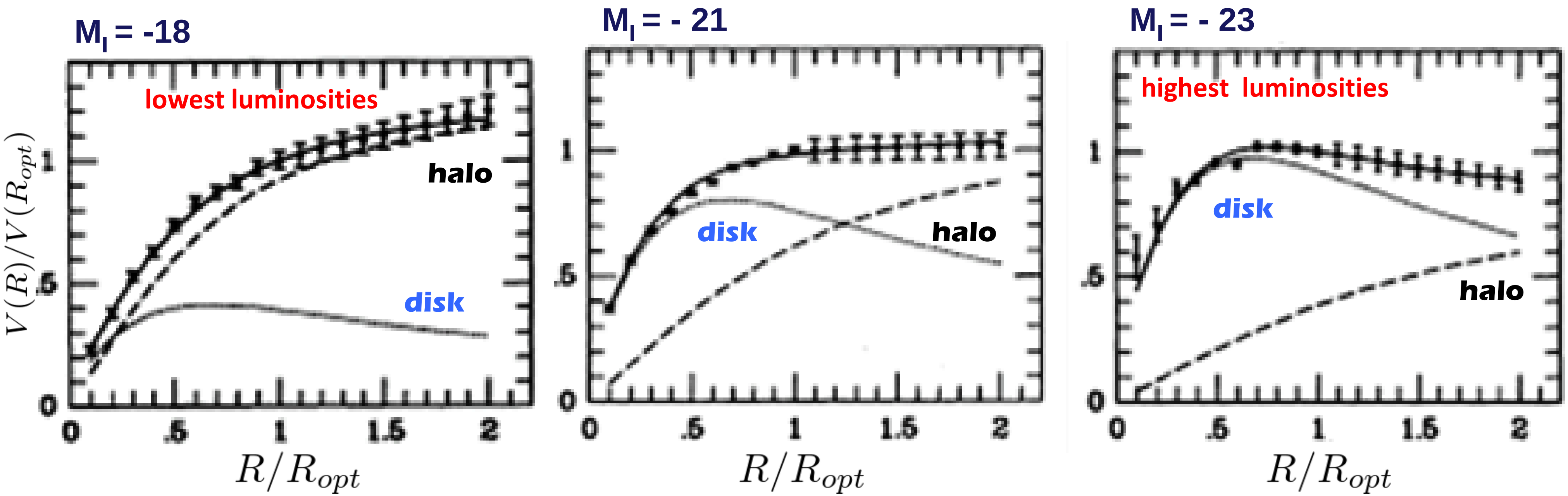


$$\rho(r) = \frac{\rho_0}{(1 + r/r_0)(1 + (r/r_0)^2)}$$

$$\rho(r) = \frac{\rho_0}{1 + (r/r_0)^2}$$

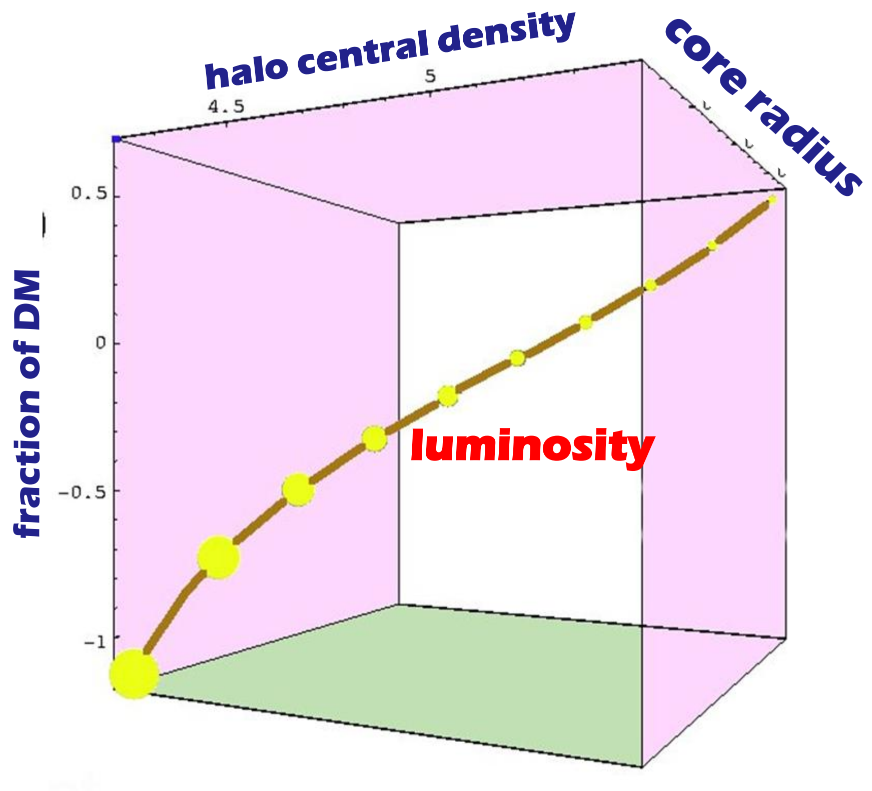
The mass model has 3 free parameters:
disk mass
halo central density
Halo core radius (length-scale)
Obtained by best fitting method

MASS MODELLING RESULTS



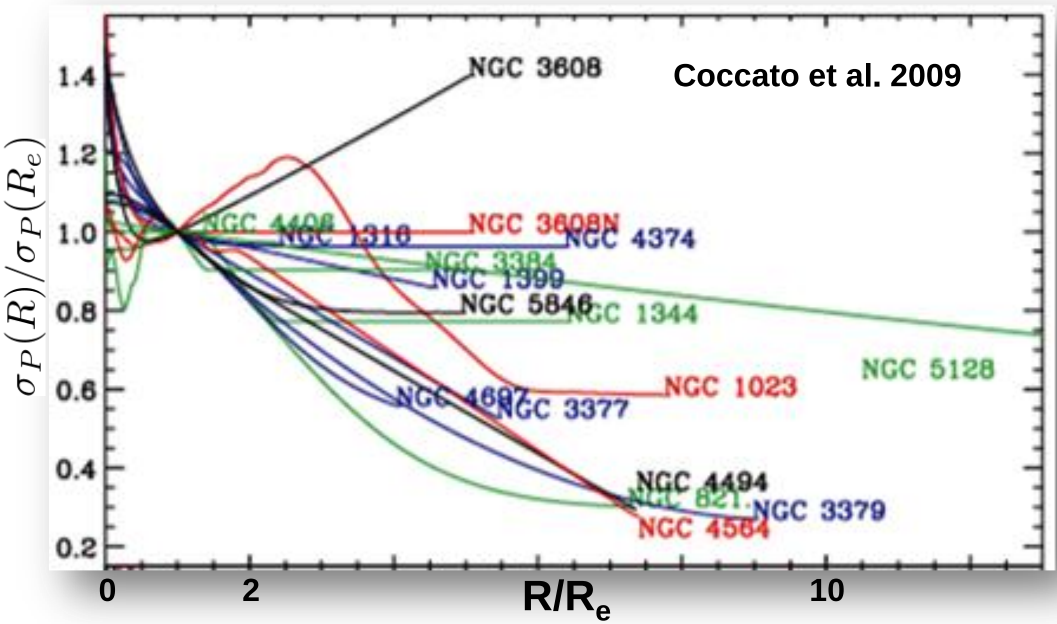
All structural DM and LM parameters are related with luminosity.

Smaller galaxies are denser and have a higher proportion of dark matter.

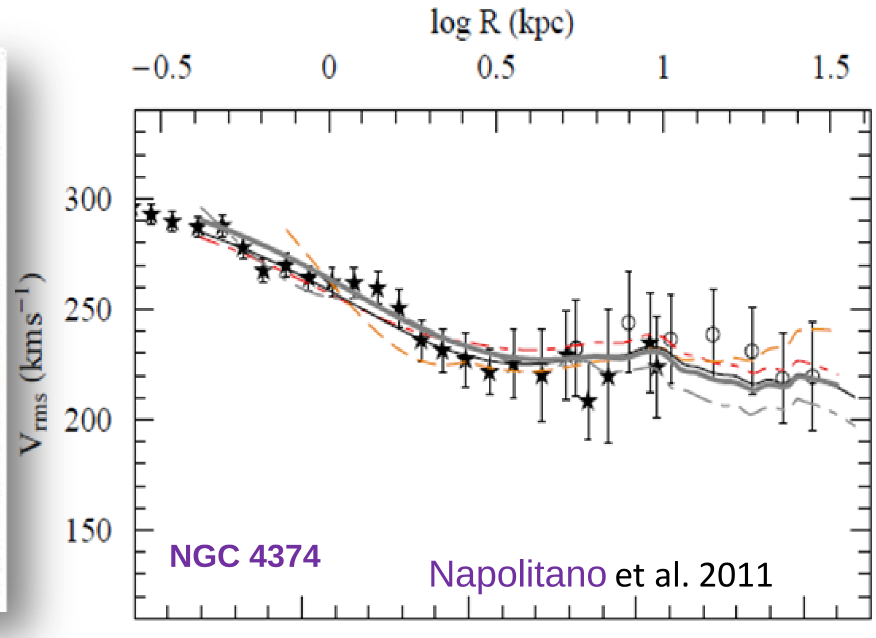


ELLIPTICALS

Jeans modelling of PN data with a stellar spheroid + NFW dark halo



Velocity dispersion are flat or strongly decreasing outside ~2R$_e$



$$M(r) = -\frac{\sigma_r^2\, r}{G}\left(\frac{d\ln j_*}{d\ln r} + \frac{d\ln \sigma_r^2}{d\ln r} + 2\beta\right)$$

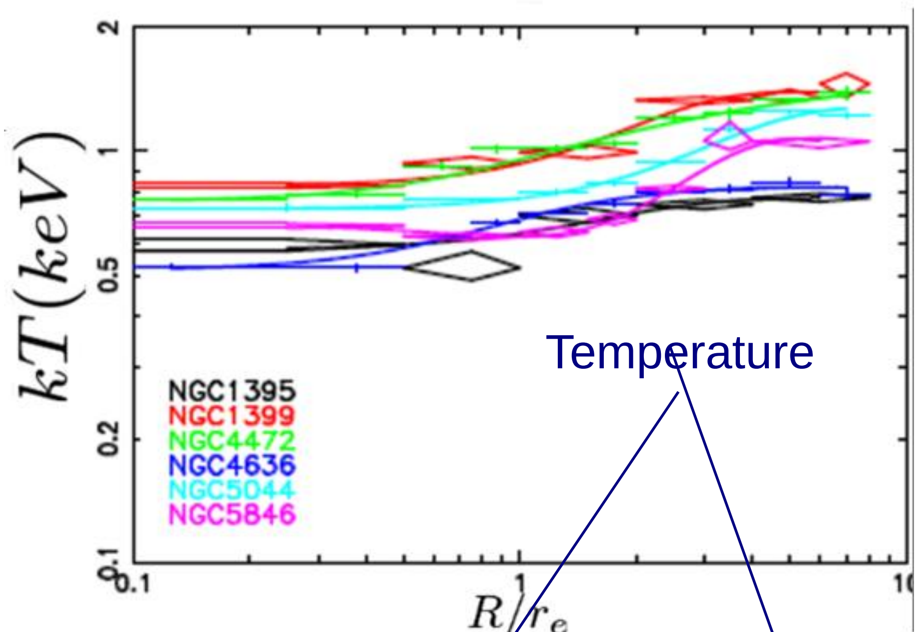
JEANS ANALYSIS

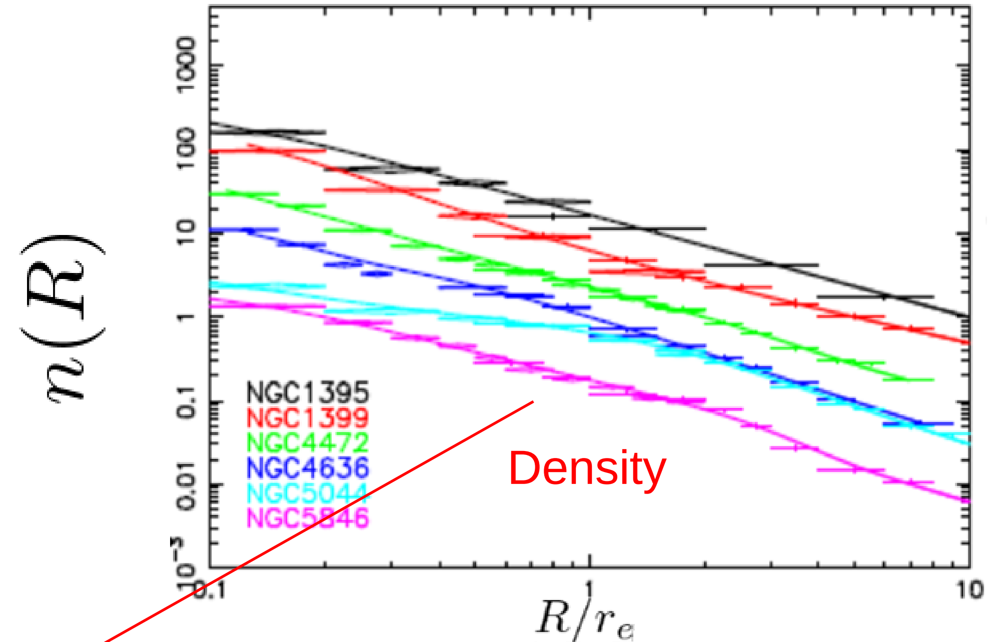
There exist big DM halos around Ellipticals, Cored and cuspy DM profiles are both possible.

MORE DATA

Mass Profiles from X-ray

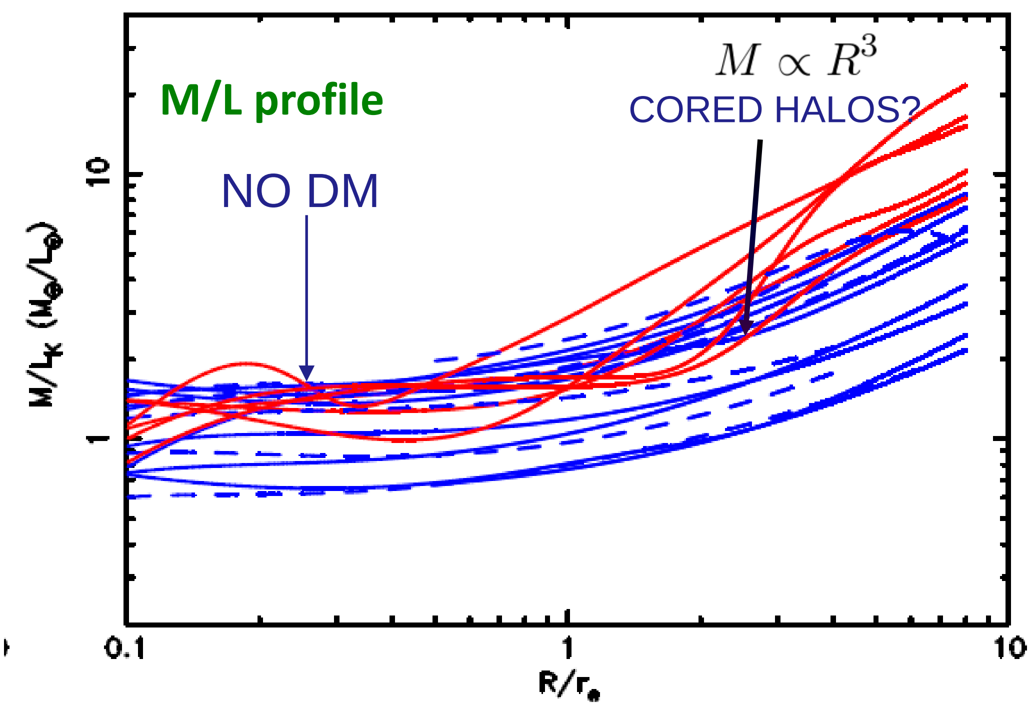
Nigishita et al 2009



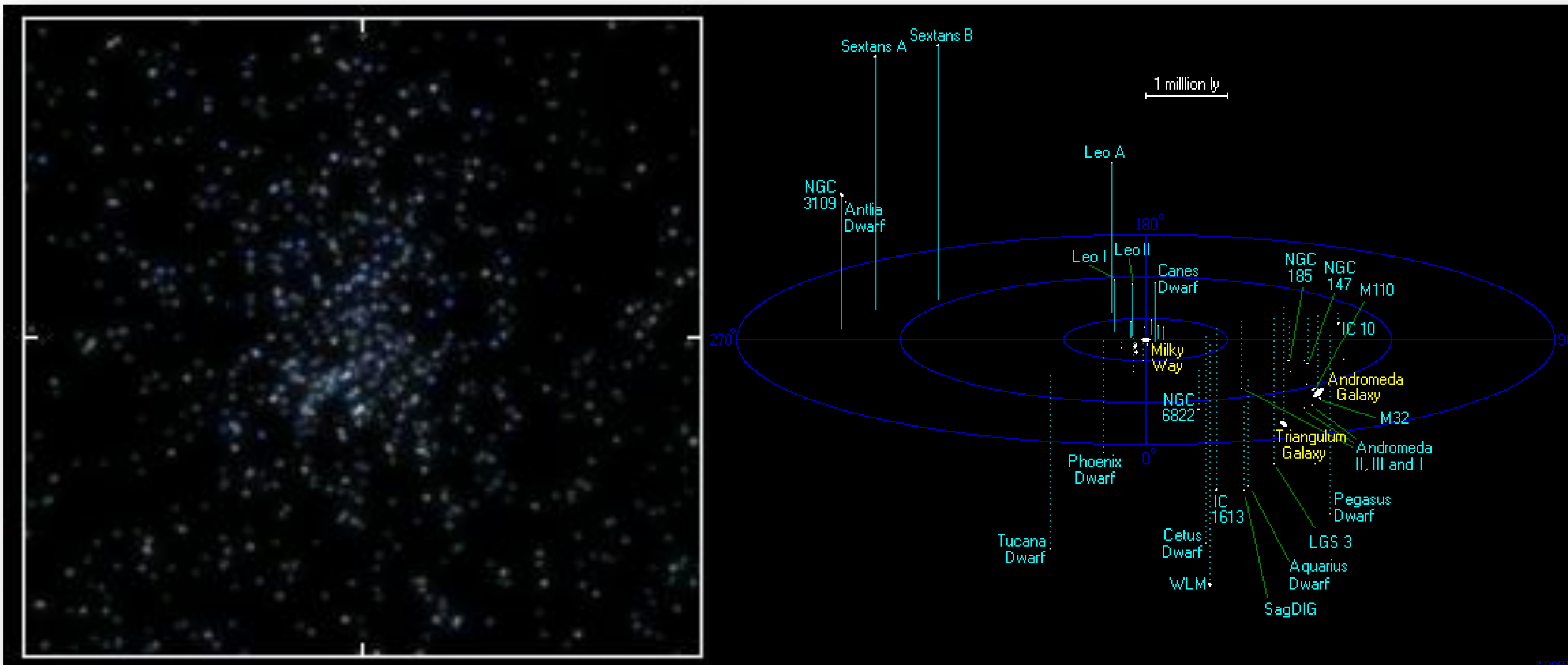


$$M(R) = -\frac{kT(R)\cdot R}{G\mu m_p}\left(\frac{d\ln n(R)}{d\ln R} + \frac{d\ln T(R)}{d\ln R}\right)$$

Hydrostatic Equilibrium



dSphs

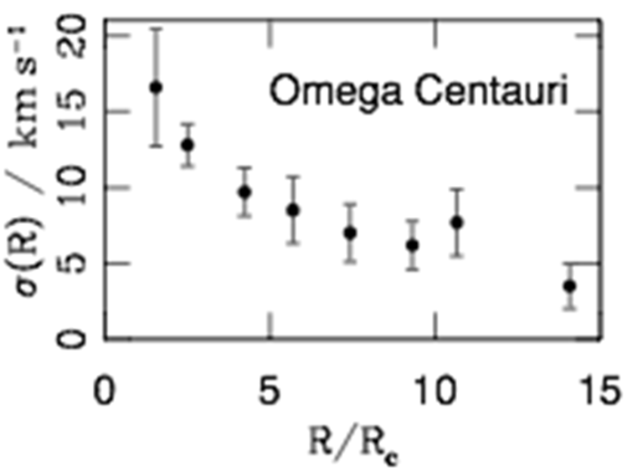


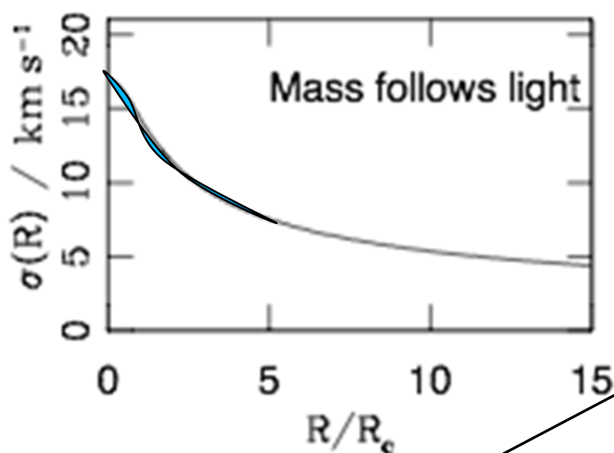
Sextans A
Sextans B
1 million ly
Leo A
NGC 3109
Antlia Dwarf
180°
Leo I
Leo II
Canes Dwarf
NGC 185
NGC 147
M110
IC 10
270°
90°
Milky Way
Andromeda Galaxy
NGC 6822
M32
Triangulum Galaxy
Andromeda II, III and I
Phoenix Dwarf
0°
IC 1613
Pegasus Dwarf
Tucana Dwarf
Cetus Dwarf
LGS 3
Aquarius Dwarf
WLM
SagDIG
r.powell

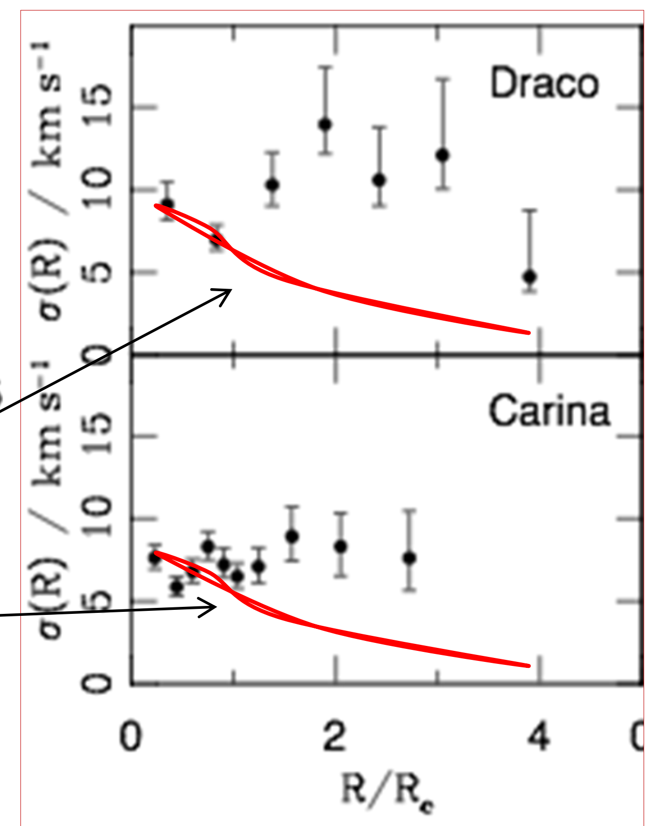
Kinematics of dSph

1983: Aaronson measured velocity dispersion of Draco based on observations of 3 carbon stars - M/L ~ 30
1997: First dispersion velocity profile of Fornax (Mateo)
2000+: Dispersion profiles of all dSphs measured using multi-object spectrographs

2010: full radial coverage in each dSph, with 1000 stars per galaxy

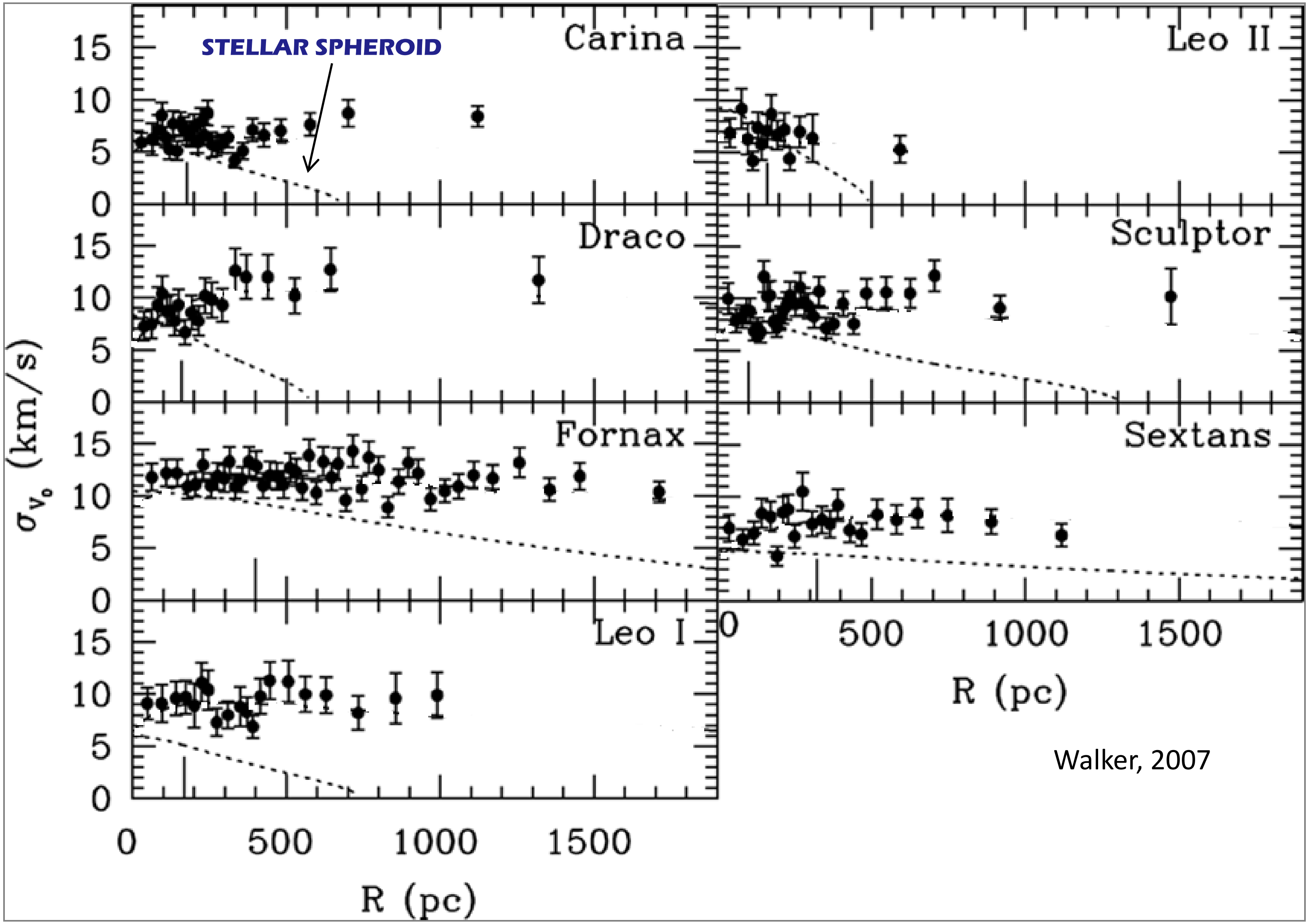






STELLAR SPHEROID

Dispersion velocity profiles



dSph dispersion profiles generally remain flat to large radii
Huge model-independent evidence of mass-to-light discrepancy

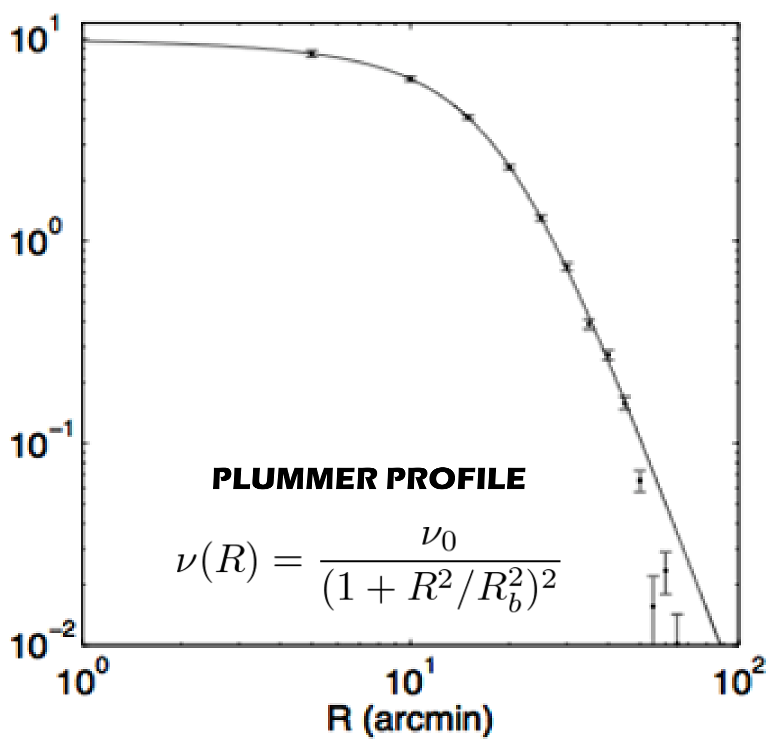
Mass profiles of dSphs

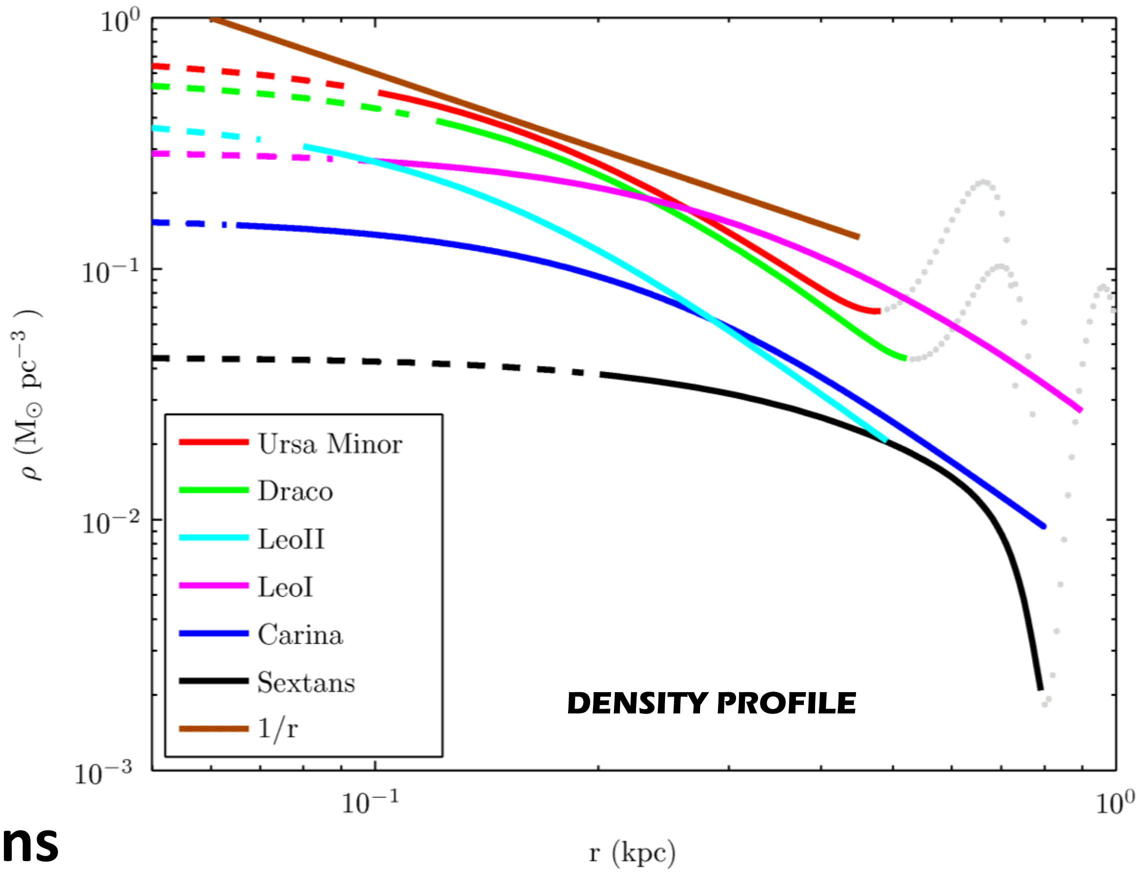
$$M(r) = -\frac{r^2}{G}\left(\frac{1}{\nu}\frac{\mathrm{d}\,\nu\sigma_r^2}{\mathrm{d}\,r} + 2\,\frac{\beta\sigma_r^2}{r}\right)$$

Jeans' models provide the most objective sample comparison

Jeans equation relates kinematics, light and underlying mass distribution

Make assumptions on the velocity anisotropy and then fit the dispersion profile



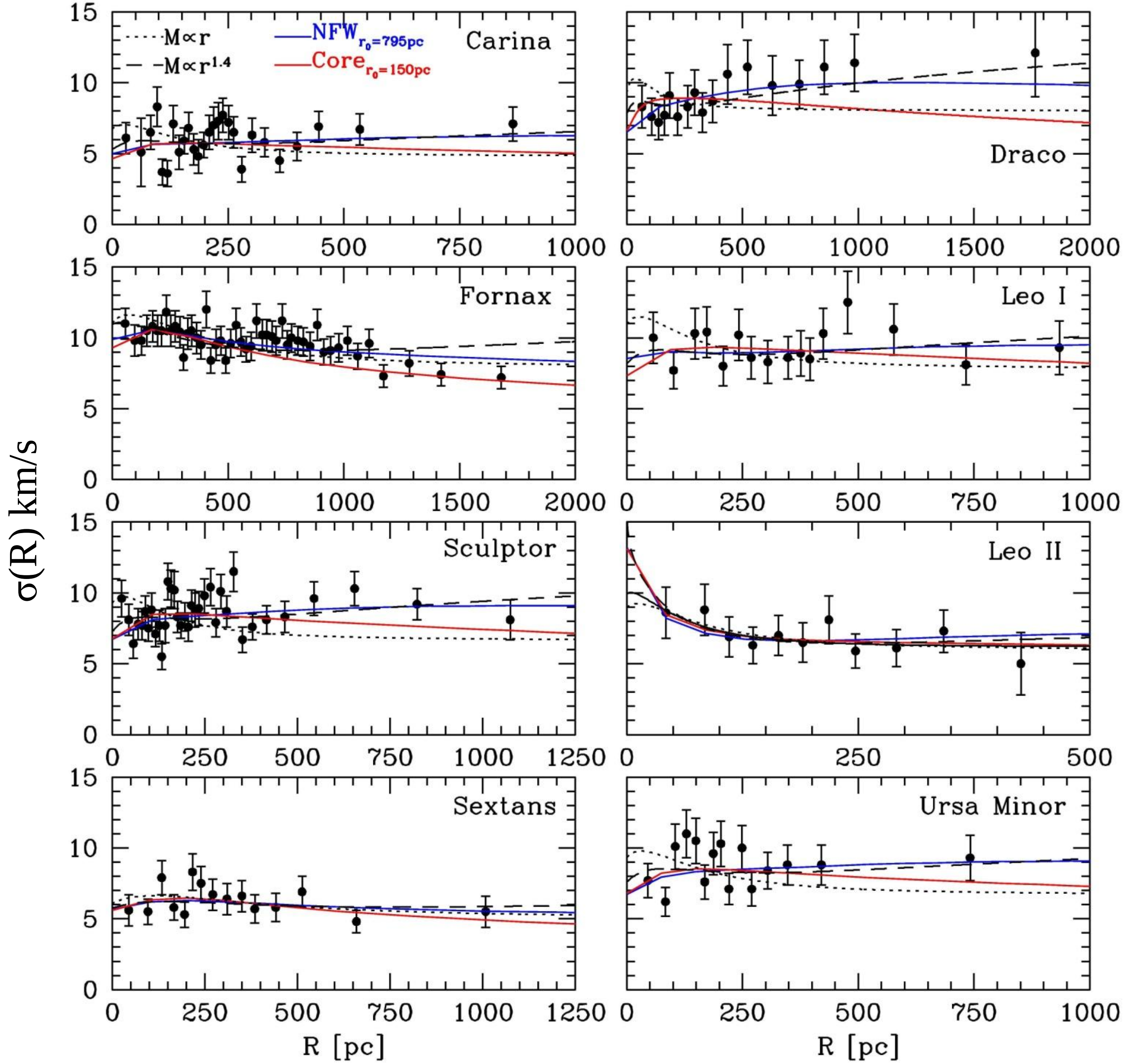


Results point to cored distributions

Gilmore et al 2007

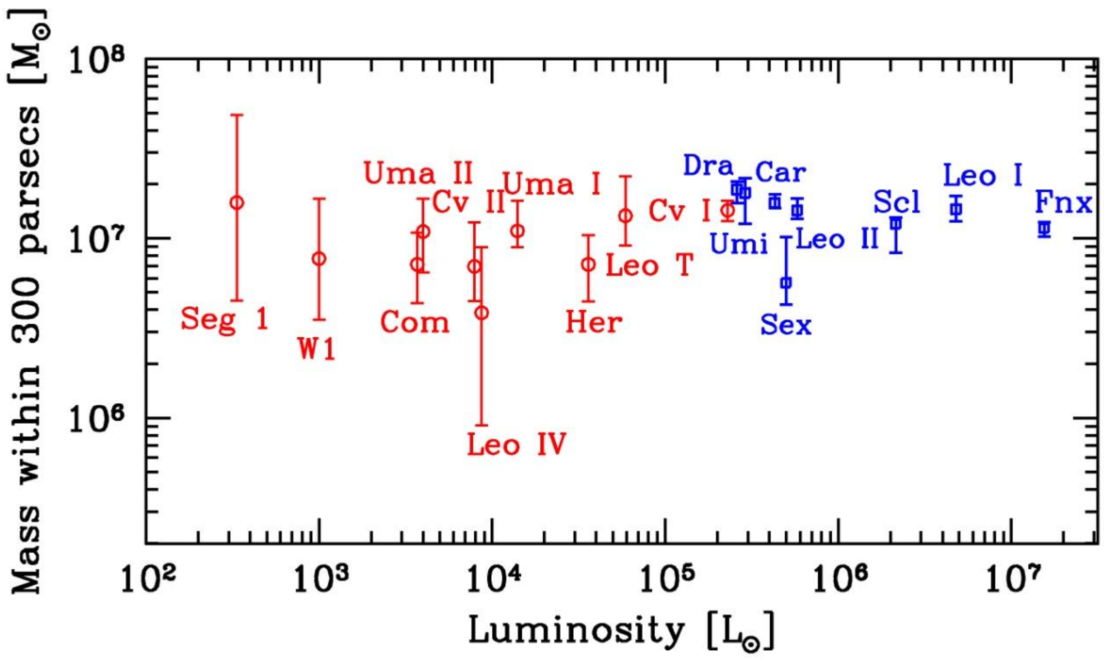
Degeneracy between DM mass profile and velocity anisotropy

Cored and cusped halos with orbit anisotropy fit dispersion profiles equally well



Walker et al 2009

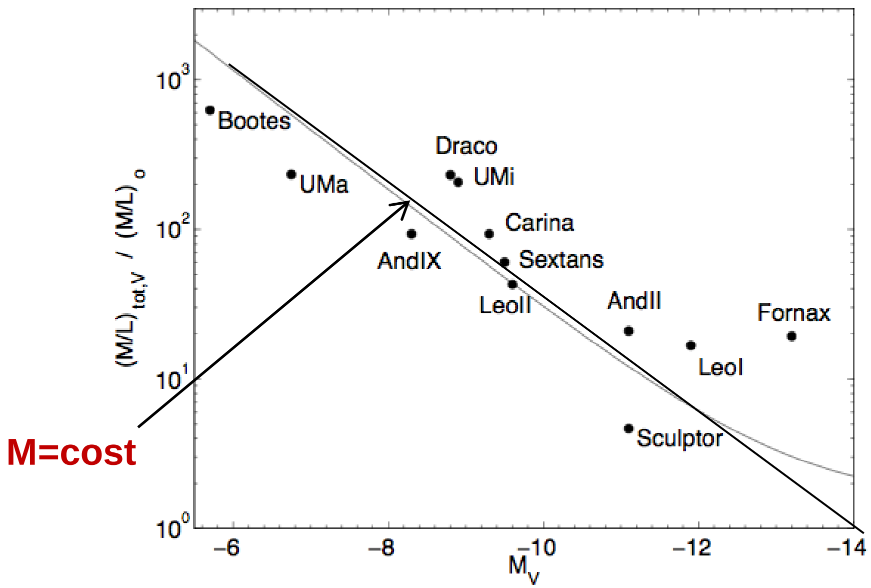
Global trend of dSph haloes



Mateo et al 1998

Strigari et al 2008

M_{VIR} ~ THE SAME IN ALL DWARF SPHEROIDALS?

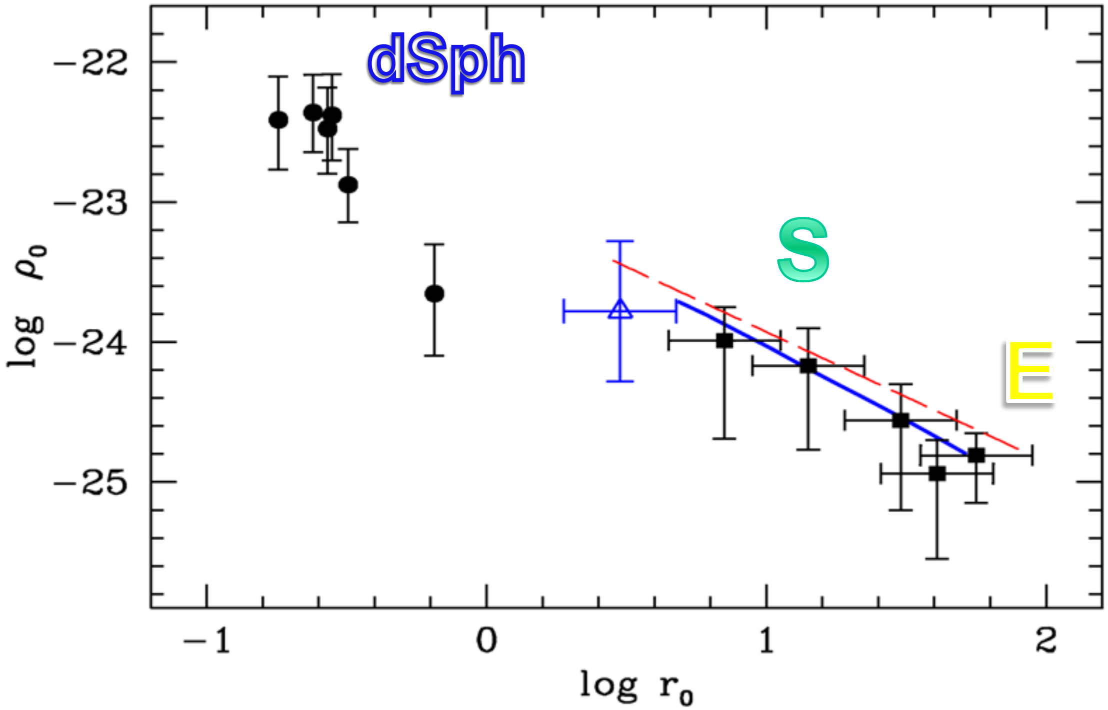


Gilmore et al 2007

dSphs cored halo model

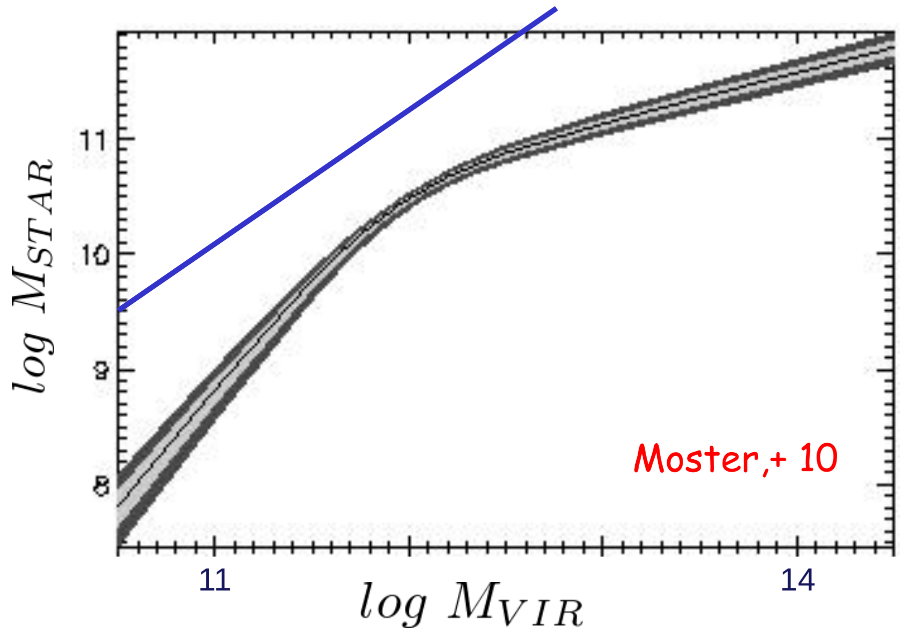
halo central densities correlate with core radius in the same way as Spirals and Ellipticals

$$\rho_0 = 10^{-23} \left(\frac{r_0}{1kpc} \right)^{-1} g/cm^3$$

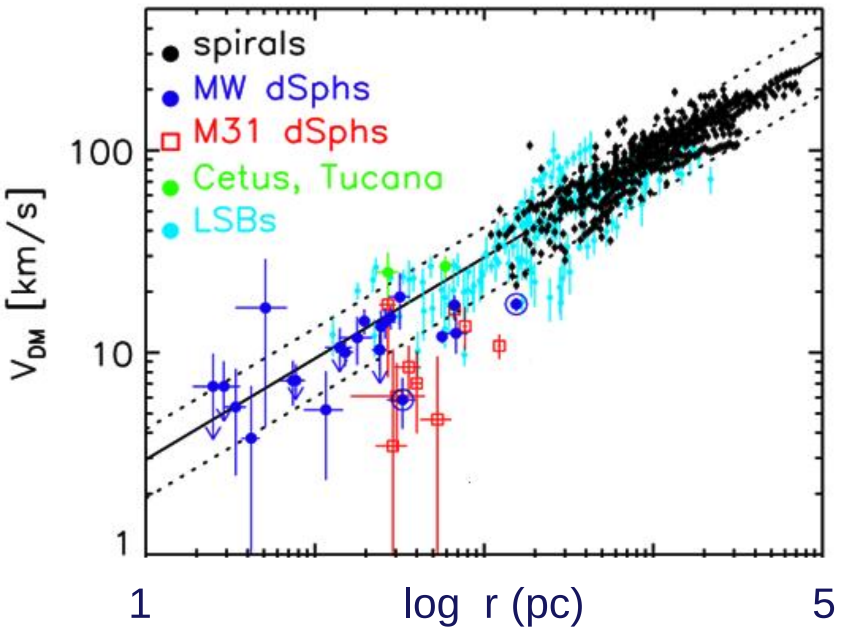


Donato et al 2009

Virial Halo Masses correlate with the Masses of the Stellar Component

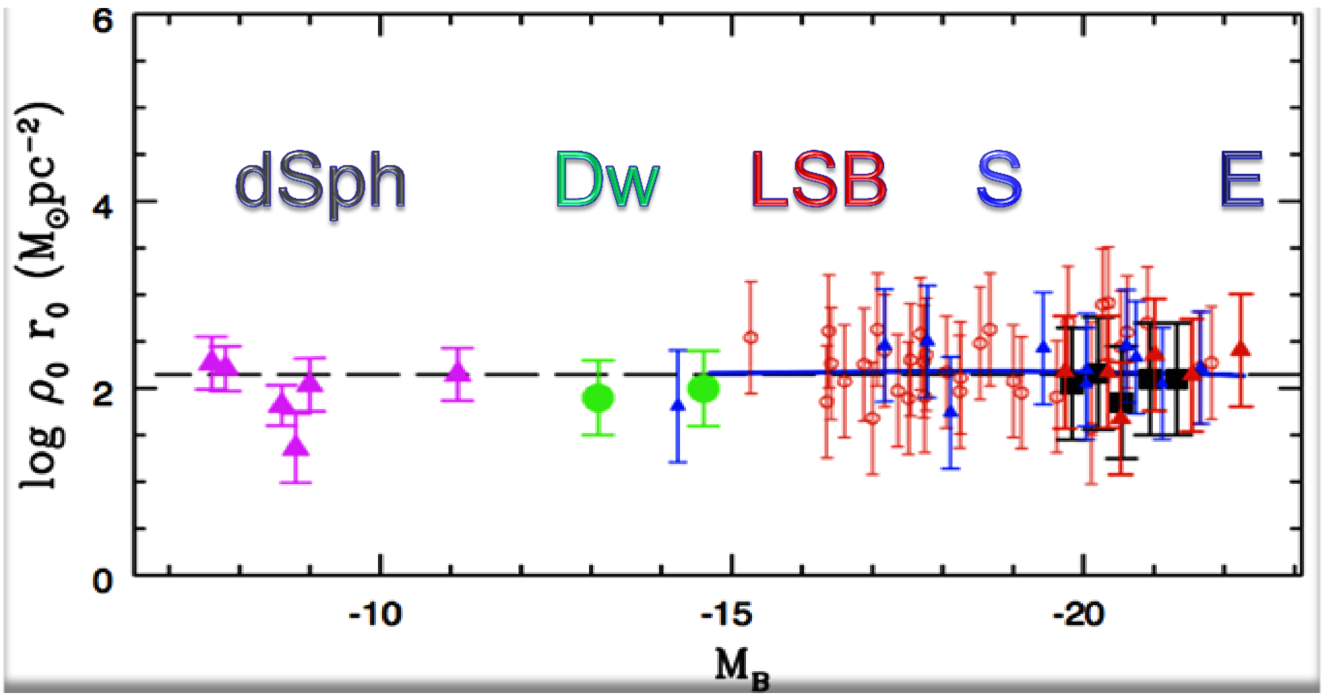


An unique mass profile $M_h(r) = G(r)$?



Walker+ 09, 10

GALAXY HALOS: AN UNIFIED VISION

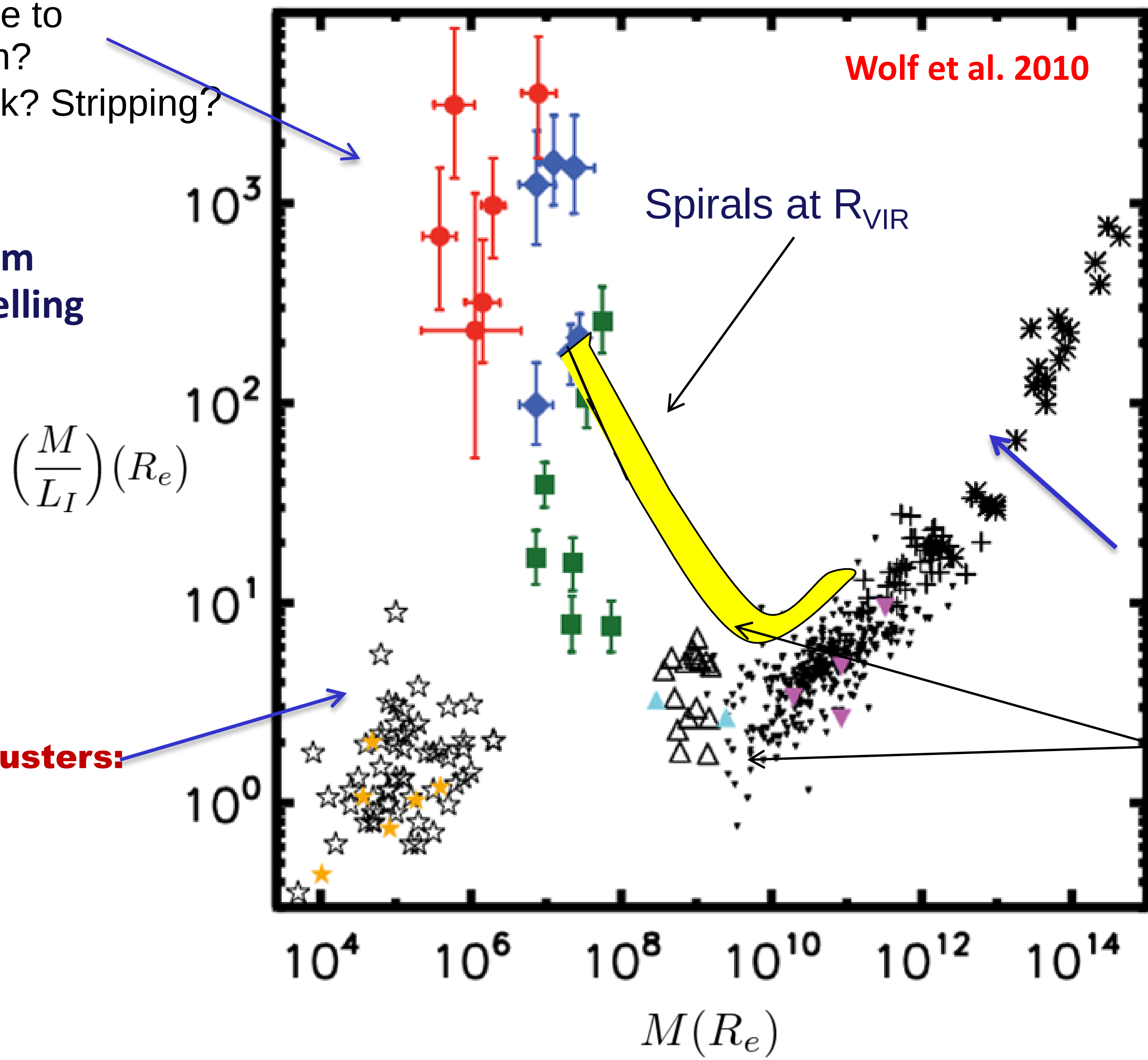


Mass-to-Light ratios at half light radius R_e in virialized objects

Increase due to Reionization? SN feedback? Stripping?

Derived from Jeans modelling

Globular clusters: No DM!



Derived from FP

Increase due to: AGN feedback? Virial heating?

L_* galaxies are most efficient at turning initial baryonic content into stars.

Galaxies are increasingly DM dominated at lower and higher mass

DSPH: WHAT WE KNOW

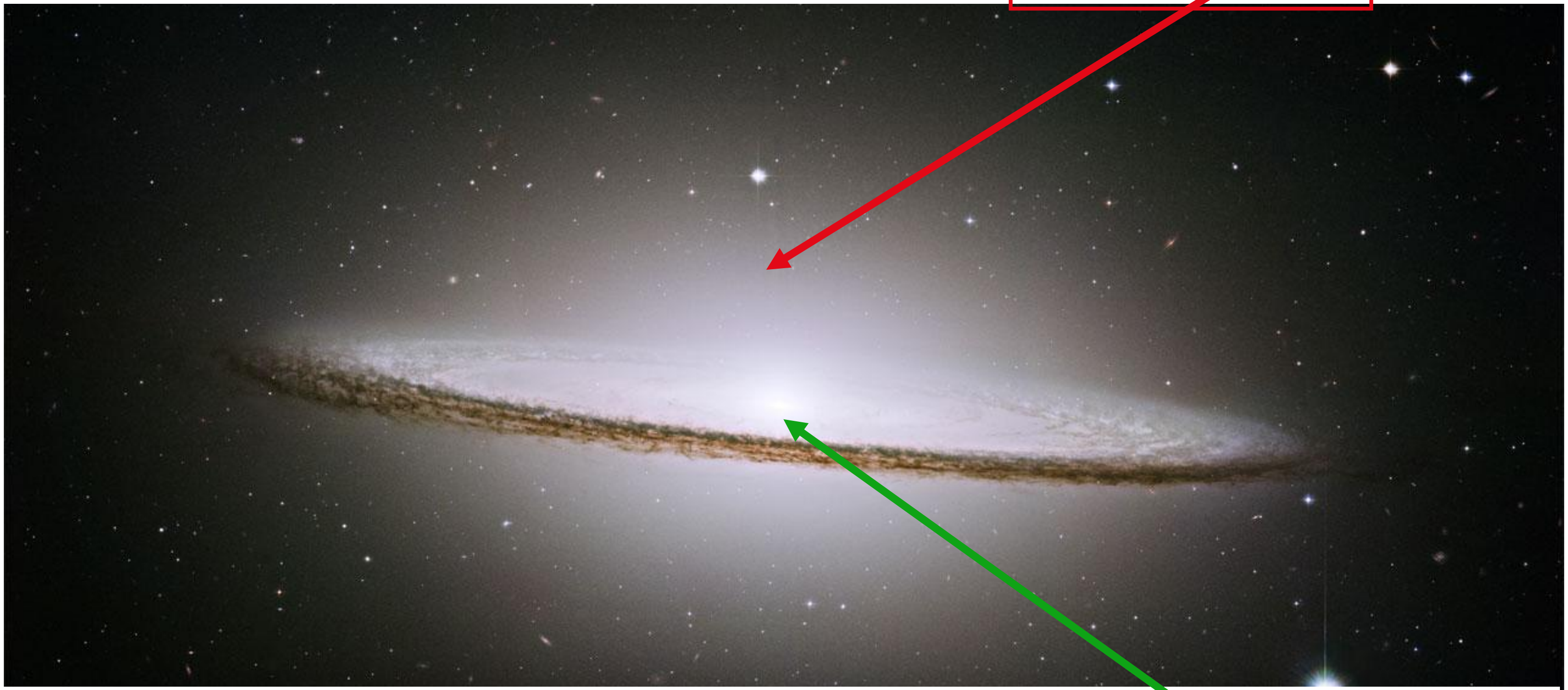
PROVE THE EXISTENCE OF DM HALOS OF 10^{10} M_{SUN} AND ρ_0 =10^{-21} g/cm^3
DOMINATED BY DARK MATTER AT ANY RADIUS
MASS PROFILE CONSISTENT WITH THE EXTRAPOLATION OF THE URC
HINTS FOR THE PRESENCE OF A DENSITY CORE

INDIRECT SIGNATURES OF DM SPECIES

WIMP mutual annihilations of WIMPs in DM halos would produce, on Earth, an indirect signature in a flux of high energy cosmic rays or photons. Sources: galactic center, MW satellites, nearby galaxies, clusters.

TRUE DM SIGNAL

$$\chi + \chi \to q\bar{q}, W^+W^-, \ldots \to \gamma, \bar{p}, \bar{D}, e^+ \;\&\; \nu's$$



$$p \text{ or } \alpha \text{ (CR)} + \text{ISM} \to \bar{p}, \bar{D}, e^+ + X$$

Antimatter is already manufactured inside the galactic disk

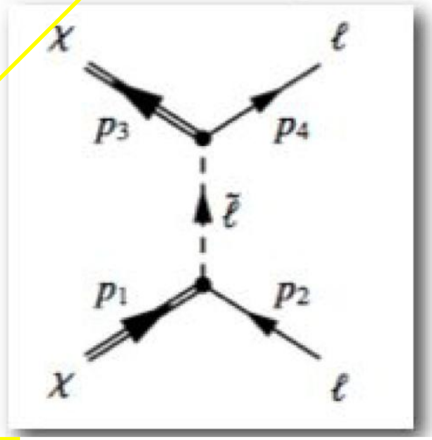
FAKE ASTRO SIGNAL

Gamma ray flux on detector on Earth from DM annihilation in DM halos

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \Delta\psi) = \frac{\langle \sigma v \rangle_{ann}}{4\pi m_\chi^2} \Sigma_f B_f \frac{dN_\gamma^f}{dE_\gamma} \times \frac{1}{2} \int_{\Delta\psi} \frac{d\Omega}{\Delta\psi} \int_{l.o.s.} dl(\psi) \rho_\chi^2(r)$$

Particle Physics

Astrophysics

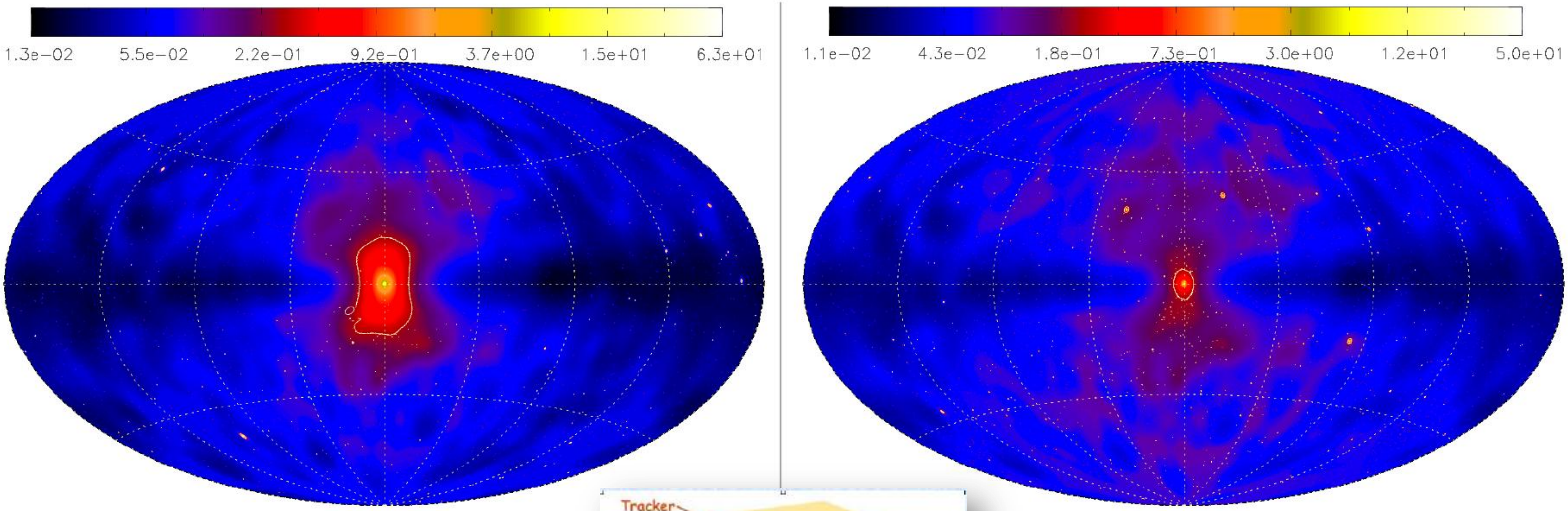


E =photon energy
ΔΨ=detector acceptance
σ =annihilation cross section
v =wimp velocity
m =wimp mass
B =branching ratio
N =photon spectrum in a given channel

Strong dependence on specific DM halo density profile

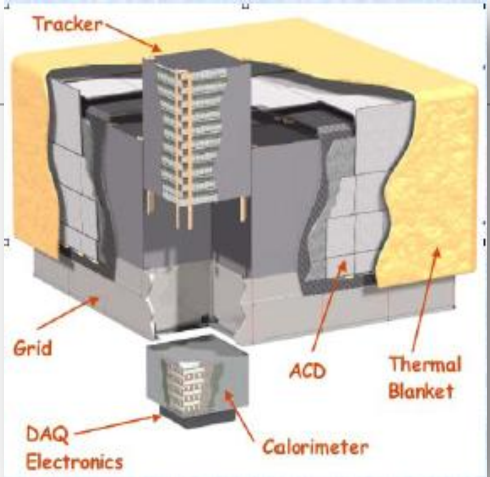
DM particles annihilate into high-energy photons

40 GeV neutralino with $b\bar{b}$ annihilation channel



Aquarius

Via Lactea II



Pieri et al 2010