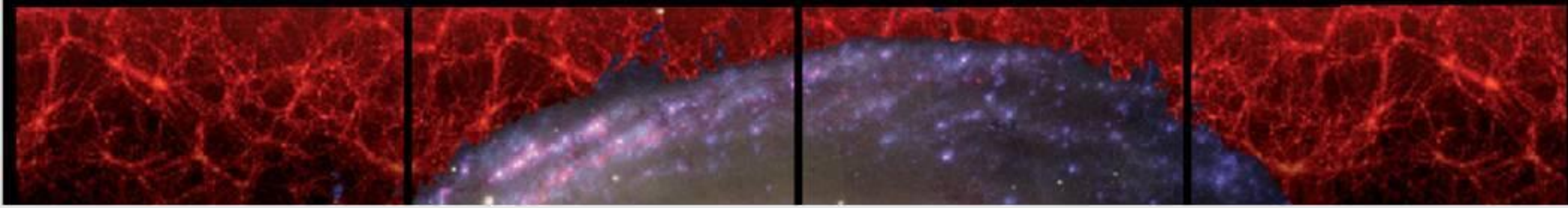


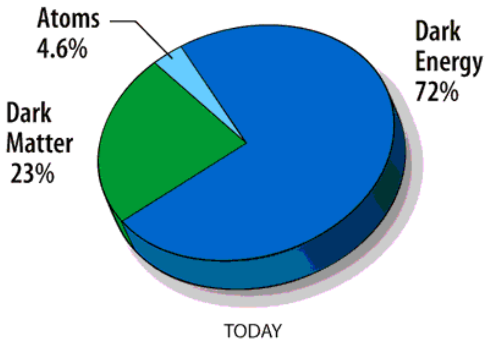
DARK MATTER IN GALAXIES

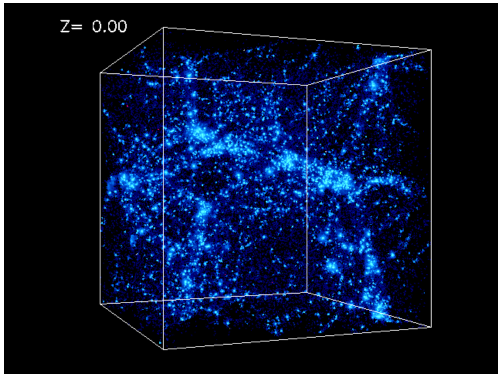
PAOLO SALUCCI

SISSA

Outline of the Review

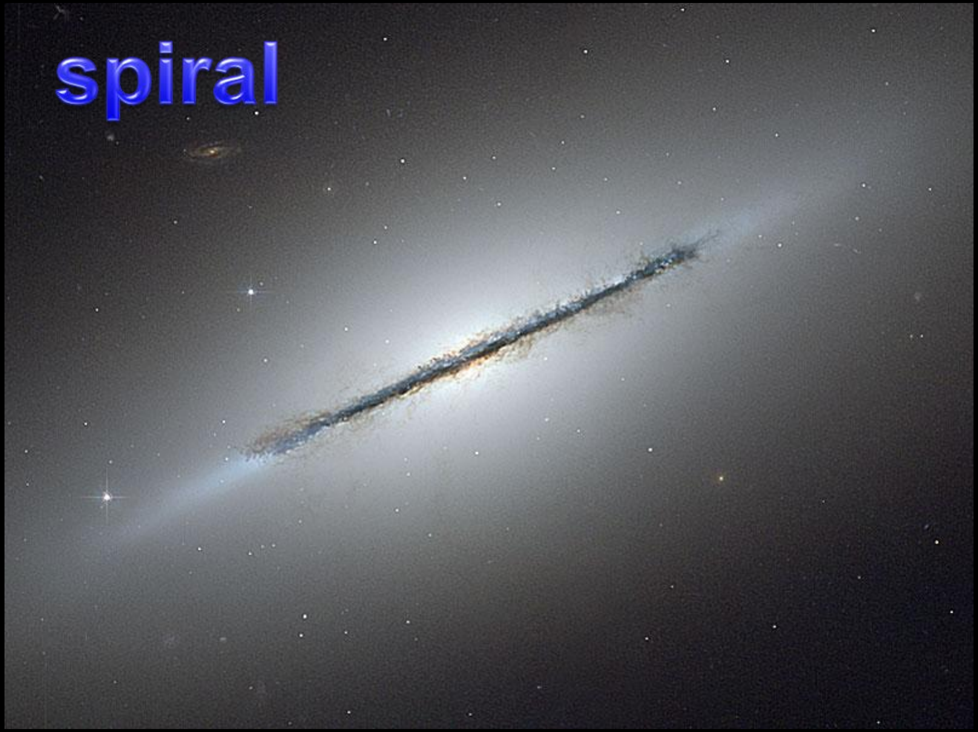
Dark Matter is main protagonist in the Universe





This review focus: Dark Matter in Galaxies

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

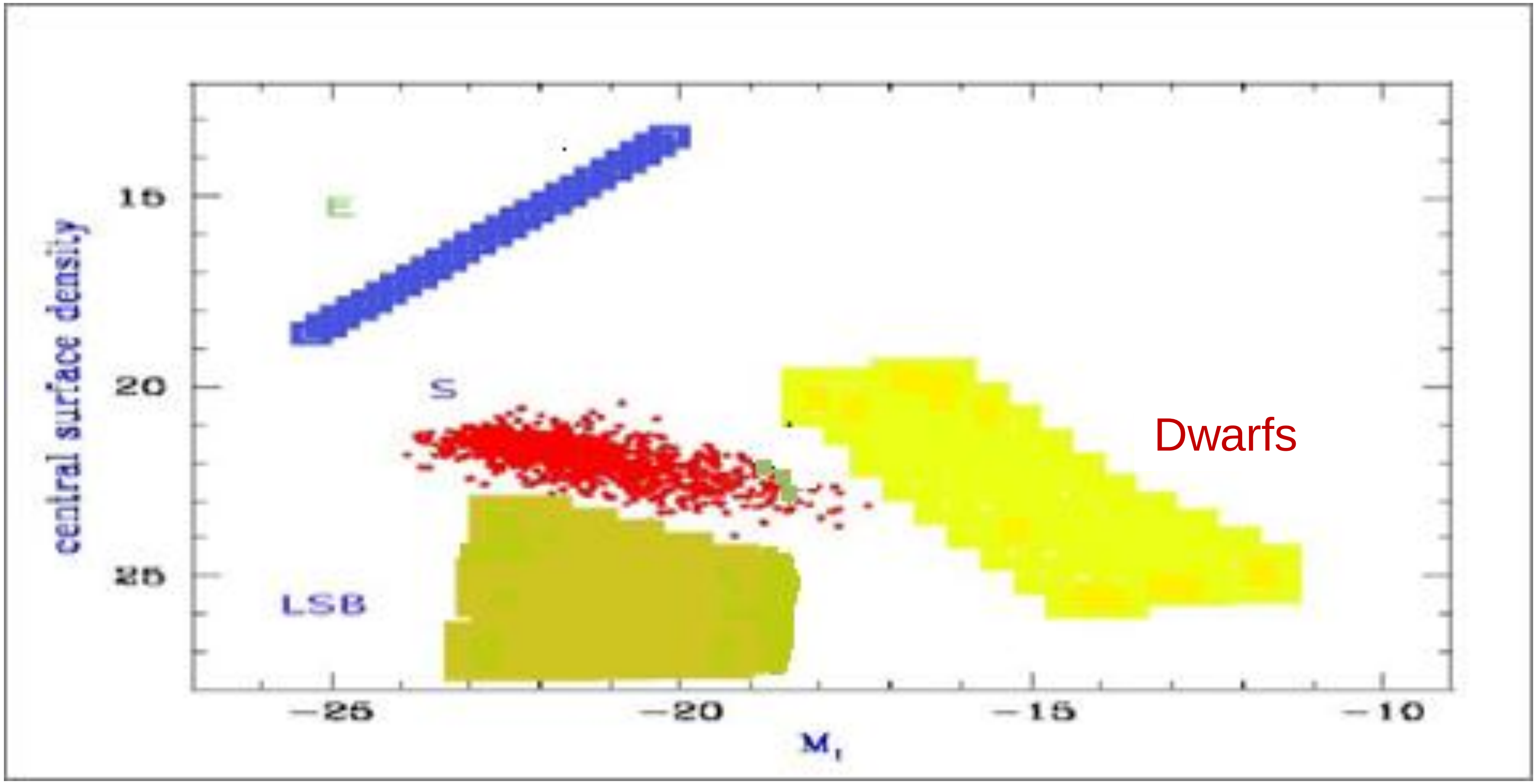


3 MAJOR TYPES OF GALAXIES

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:

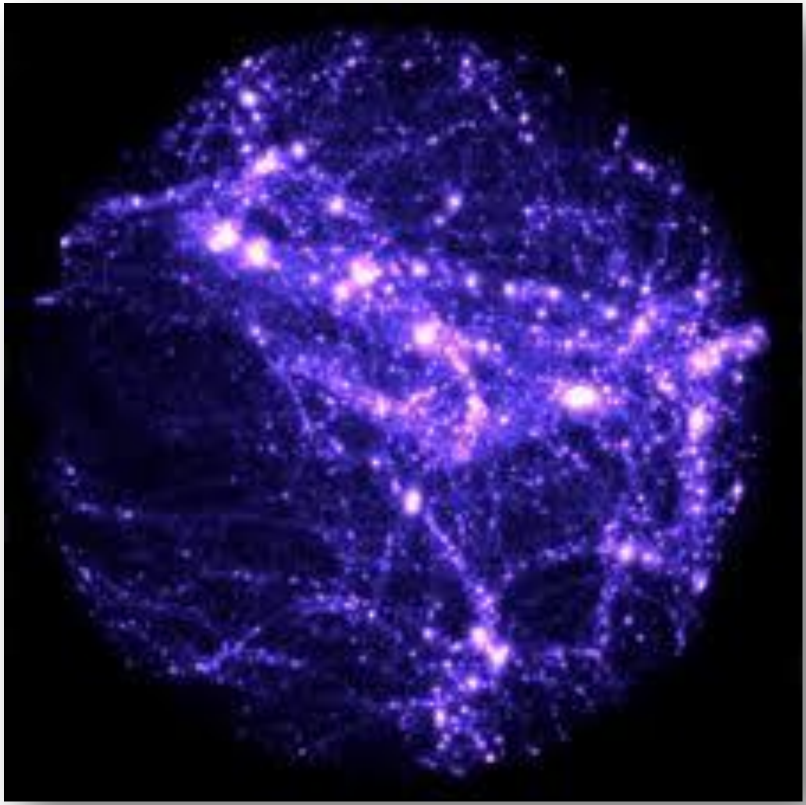
$$\frac{d\log M(r)}{d\log r} = \frac{M_L(r)}{M(r)}\frac{d\log M_L(r)}{d\log r} + \frac{M_H(r)}{M(r)}\frac{d\log M_H(r)}{d\log r}$$

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

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

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

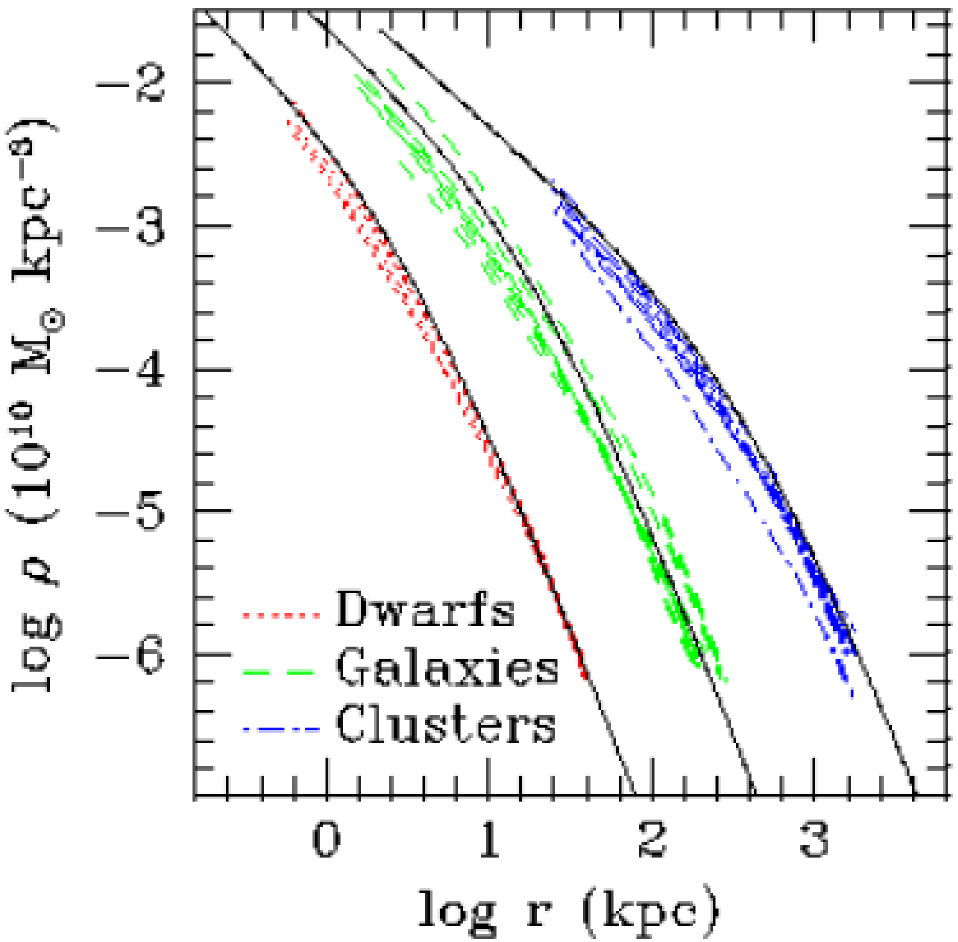
More massive halos and those formed earlier have larger overdensities

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



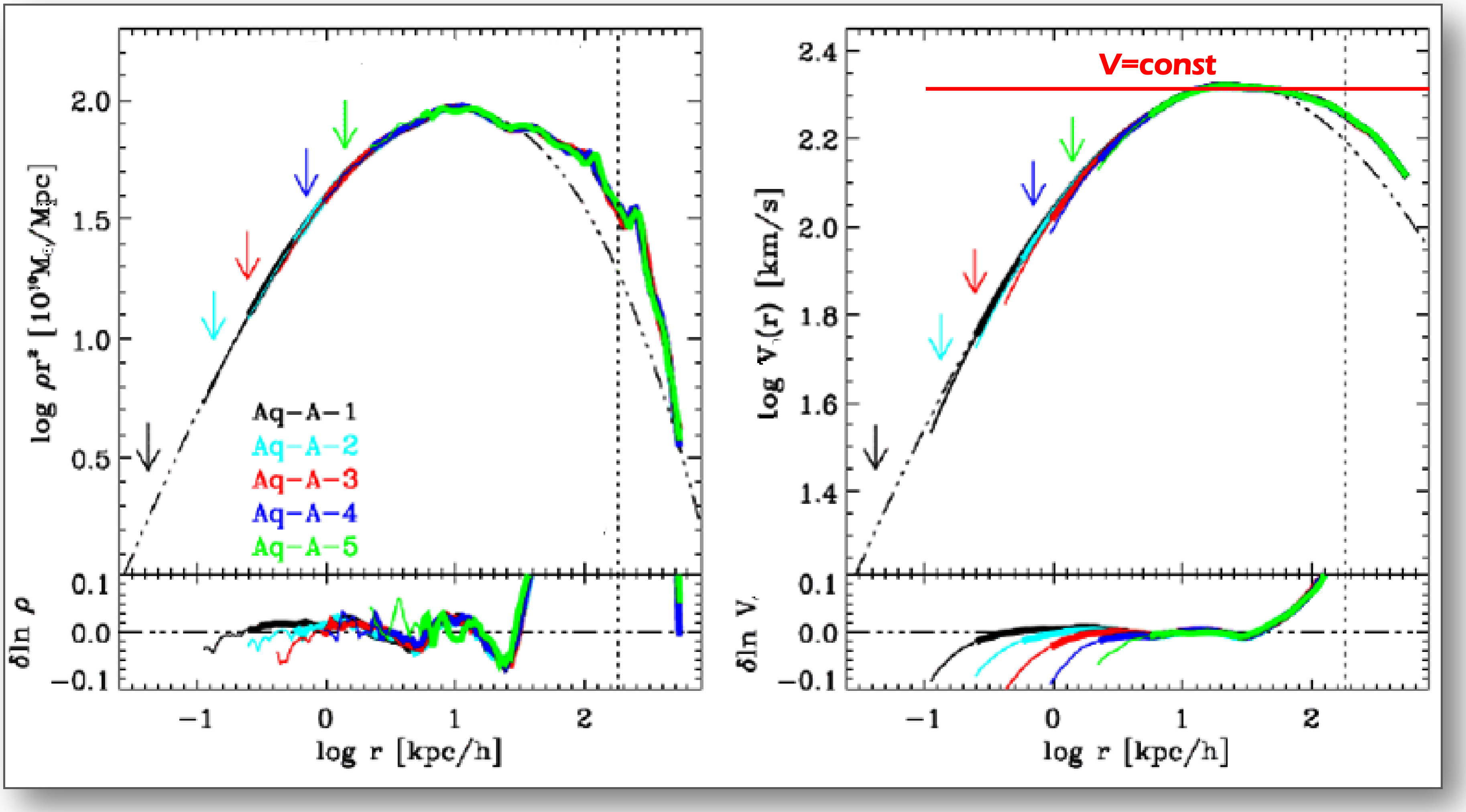
Aquarius N-Body simulations, highest mass resolution to date.

Density distribution: the Einasto Law indistinguishable by NFW

Navarro et al +10

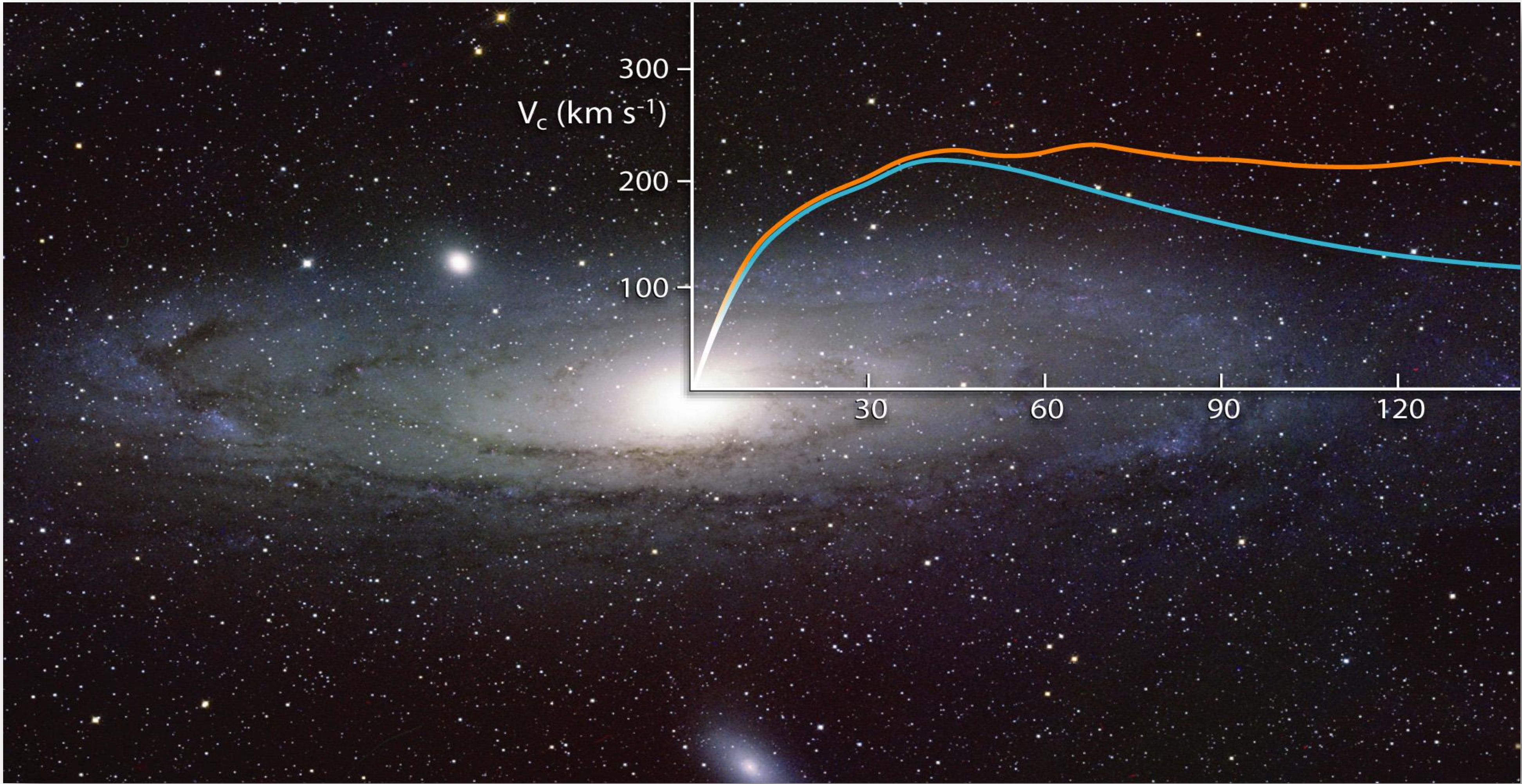
density

circular velocity



How halos form and evolve

SPIRALS



Stellar Disks

M33 disk very smooth,
truncated at 4 scale-lengths

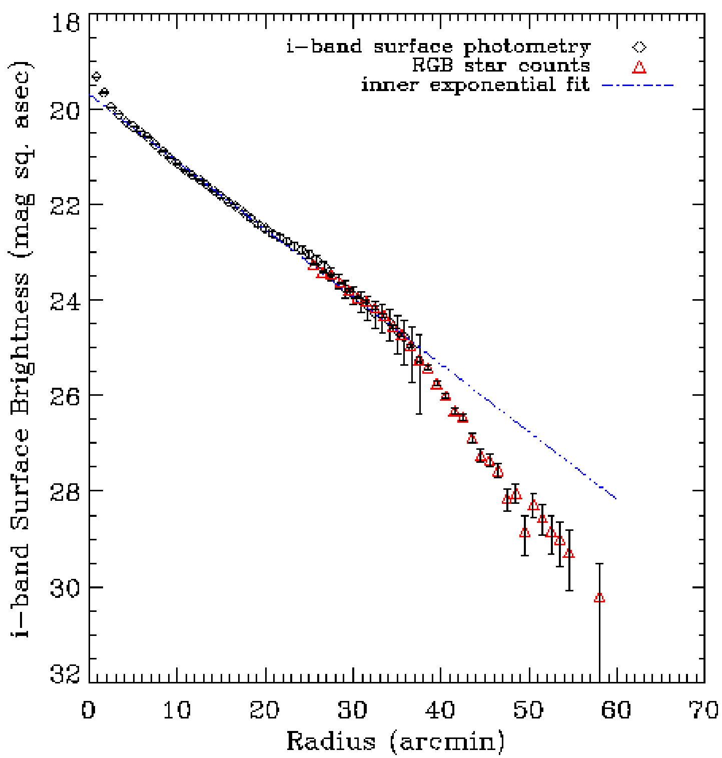
NGC 300 exponential disk
for at least 10 scale-lengths

Spiral Galaxy NGC 300
(MPG/ESO 2.2-m + WFI)

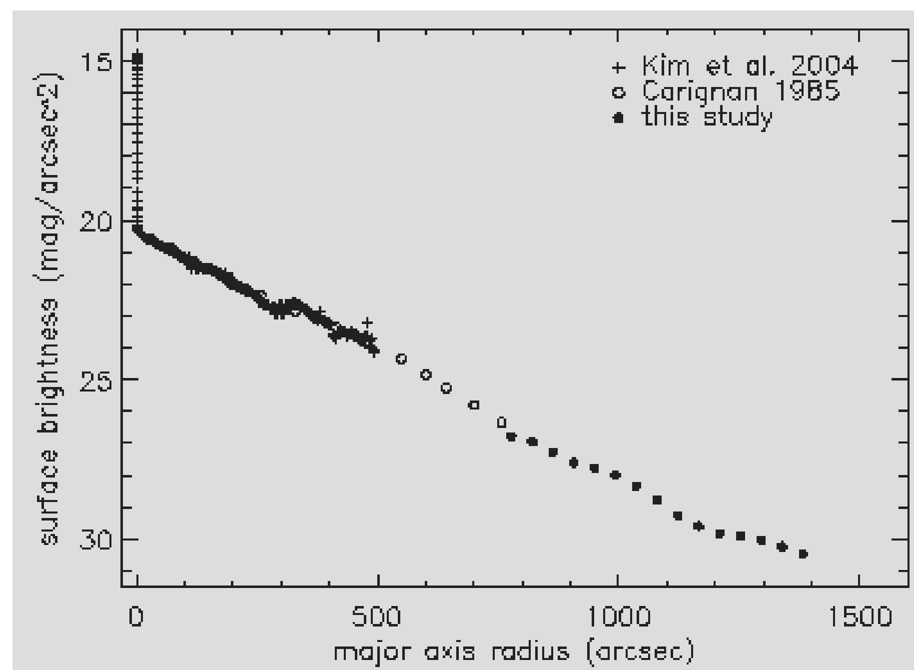
$$I(r) = I_0 e^{-r/R_D}$$

R_D lenght scale of the disk

Freeman, 1970



Ferguson et al 2003



Bland-Hawthorn et al 2005

Gas surface densities

HI

Flattish radial distribution

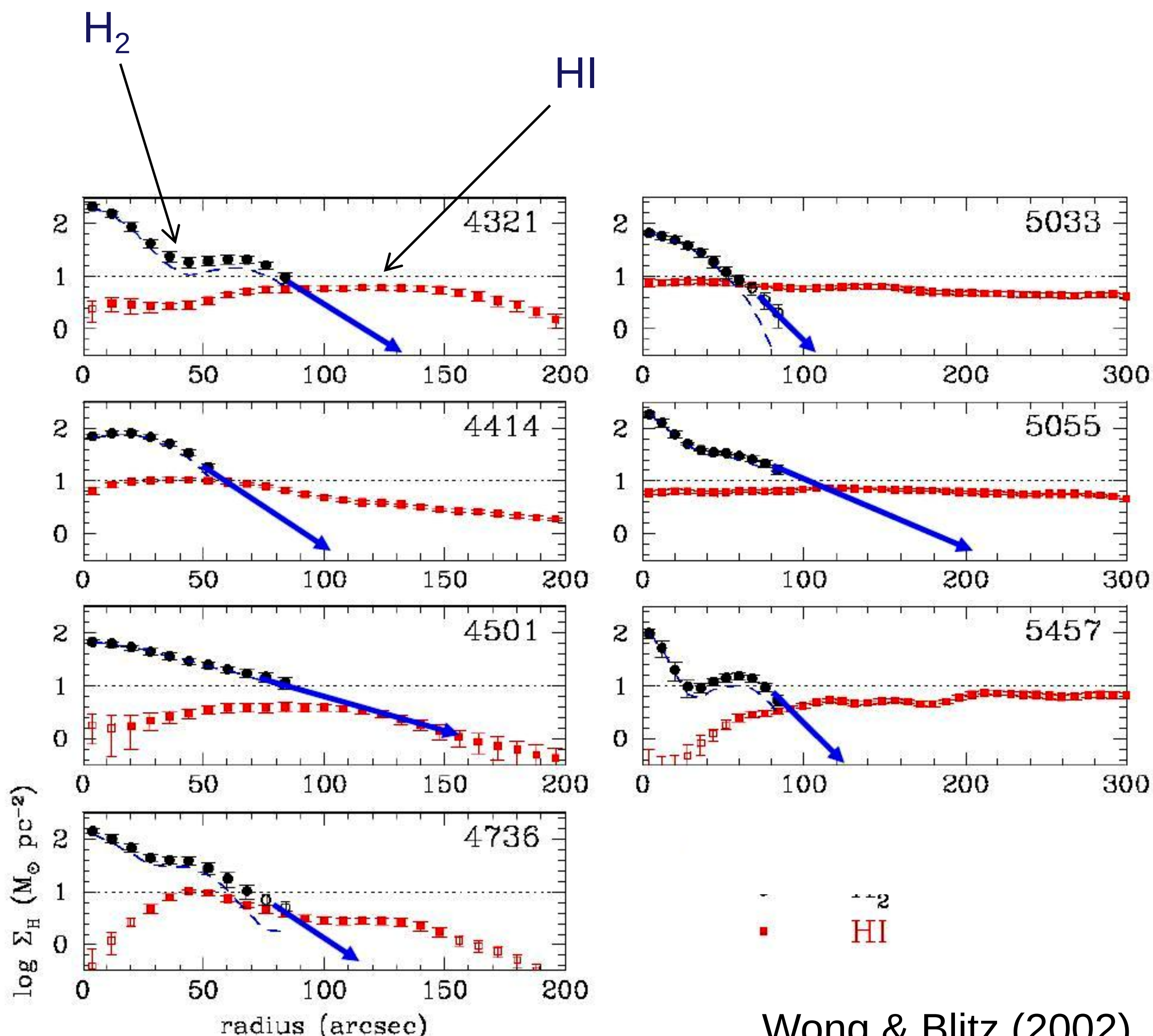
Deficiency in the centre

Extended to (8 – 40) R_D

H_2

Follows the stellar disk

Negligible



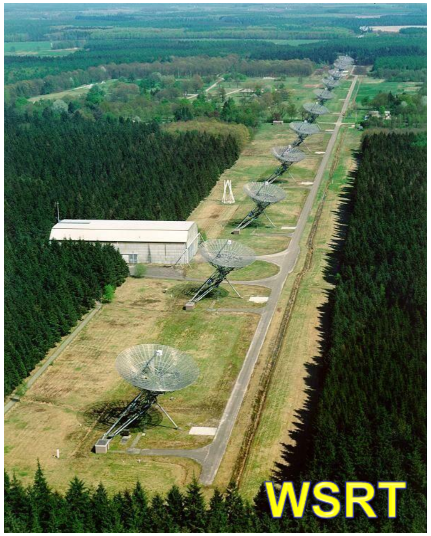
Wong & Blitz (2002)

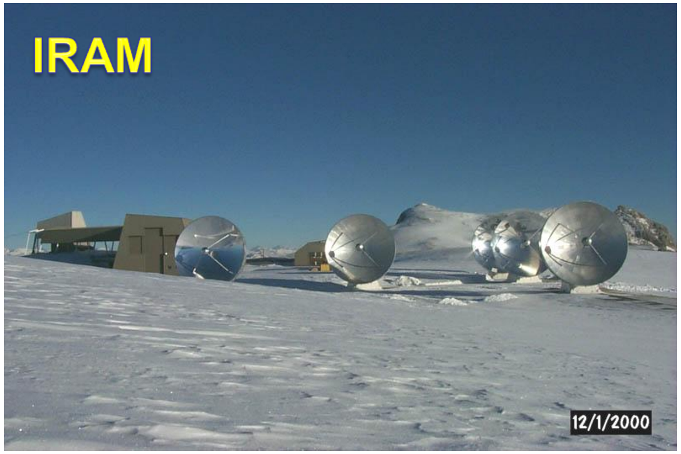
Circular velocities from spectroscopy

- Optical emission lines (Hα, Na)

- Neutral hydrogen (HI)-carbon monoxide (CO)

Tracer	angular resolution	spectral resolution
HI	7" … 30"	2 … 10 km s^{-1}
CO	1.5" … 8"	2 … 10 km s^{-1}
Hα, …	0.5" … 1.5"	10 … 30 km s^{-1}

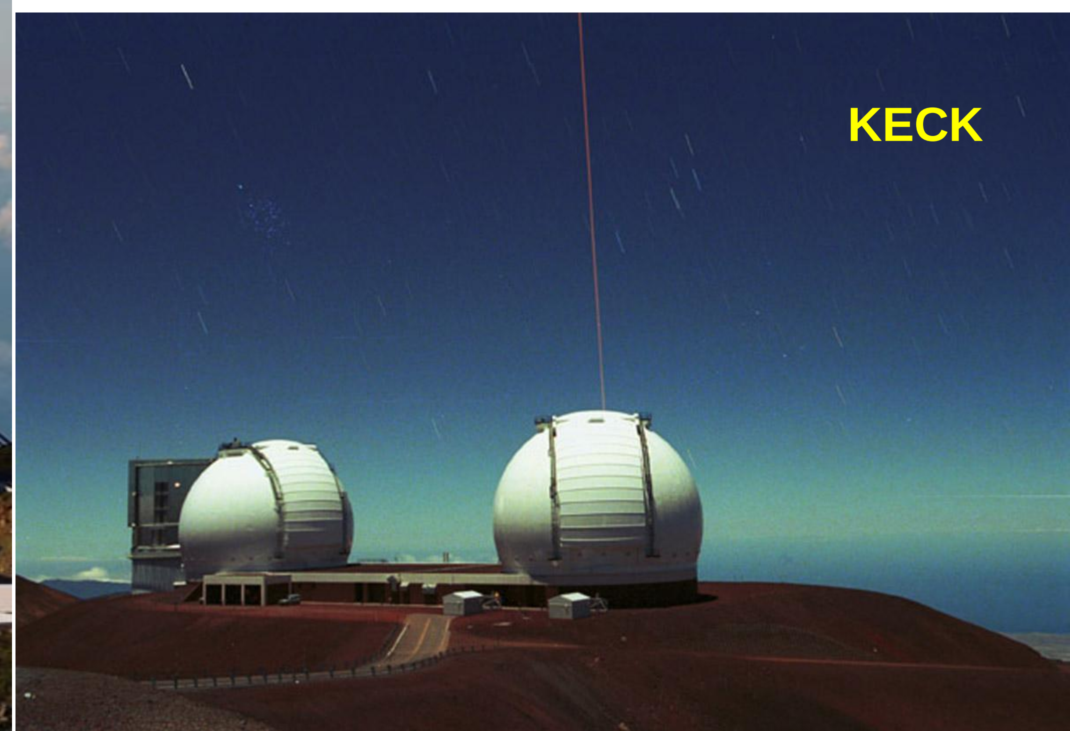





VLT

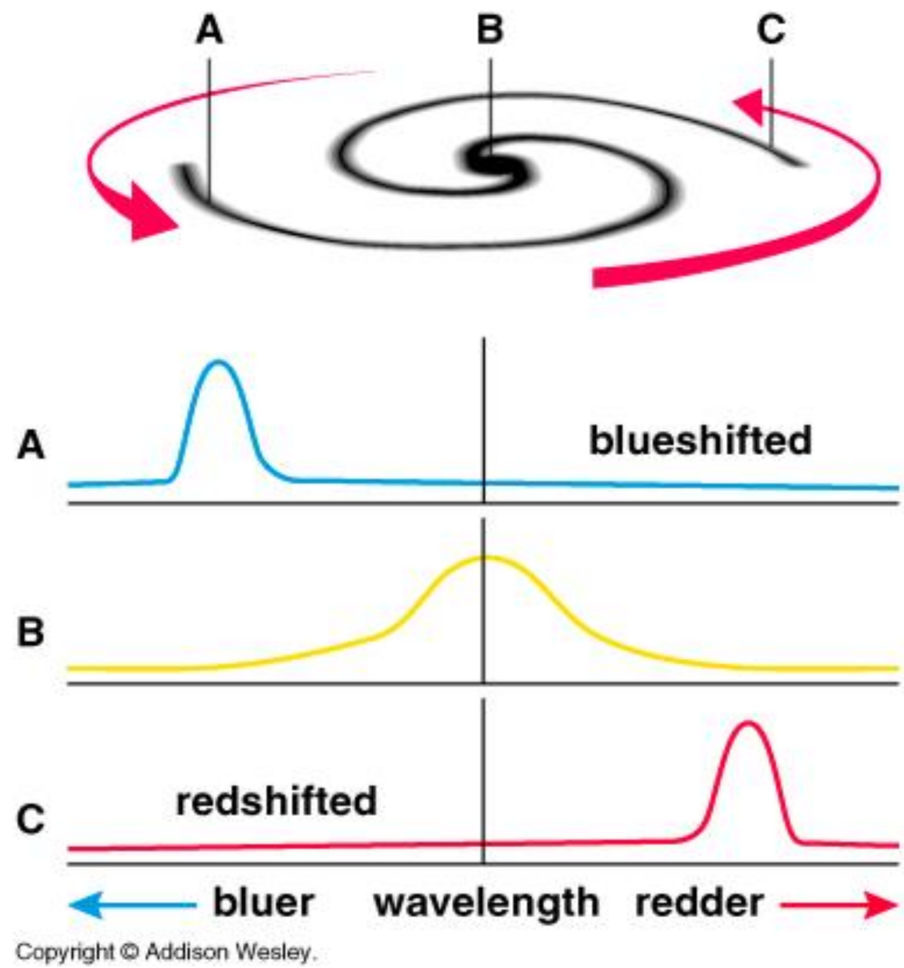

LBT

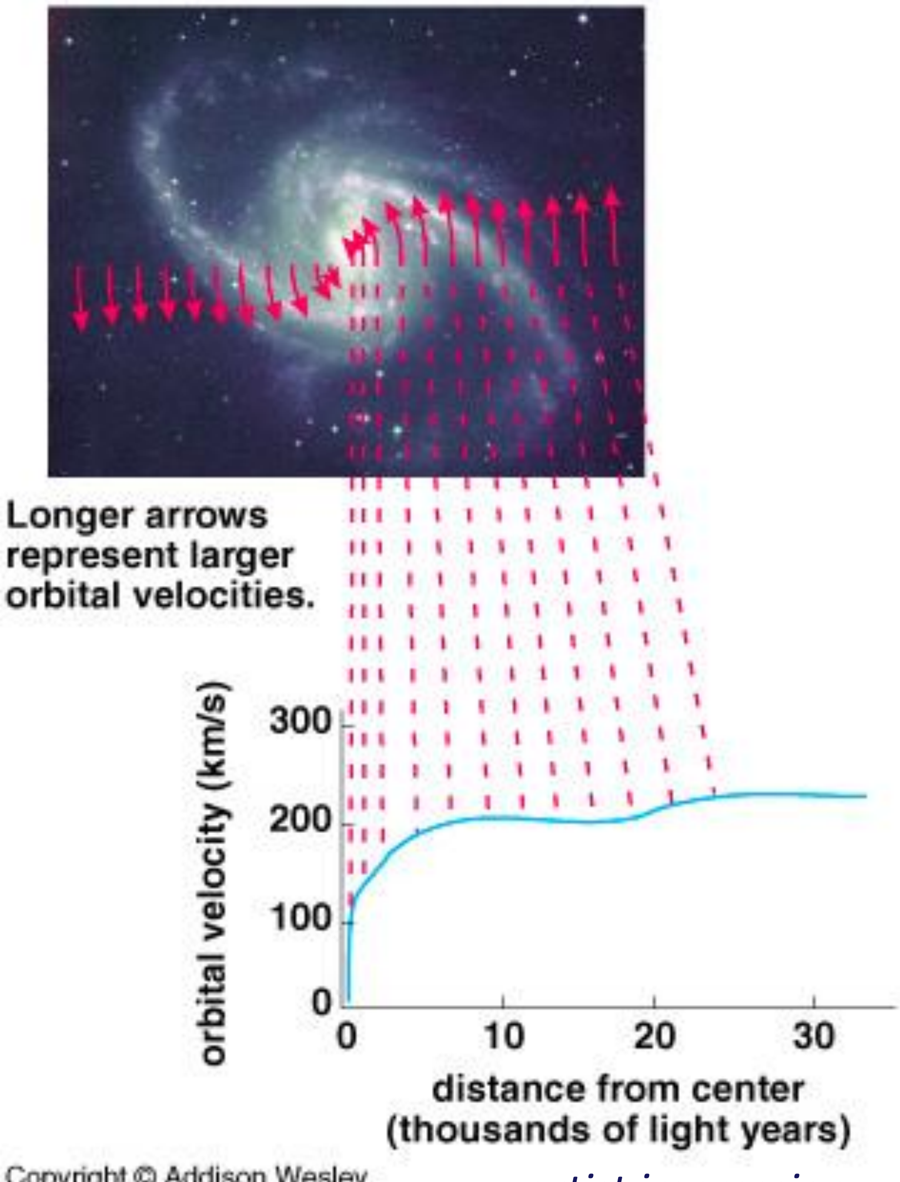

GTC


KECK

ROTATION CURVES

artist impression

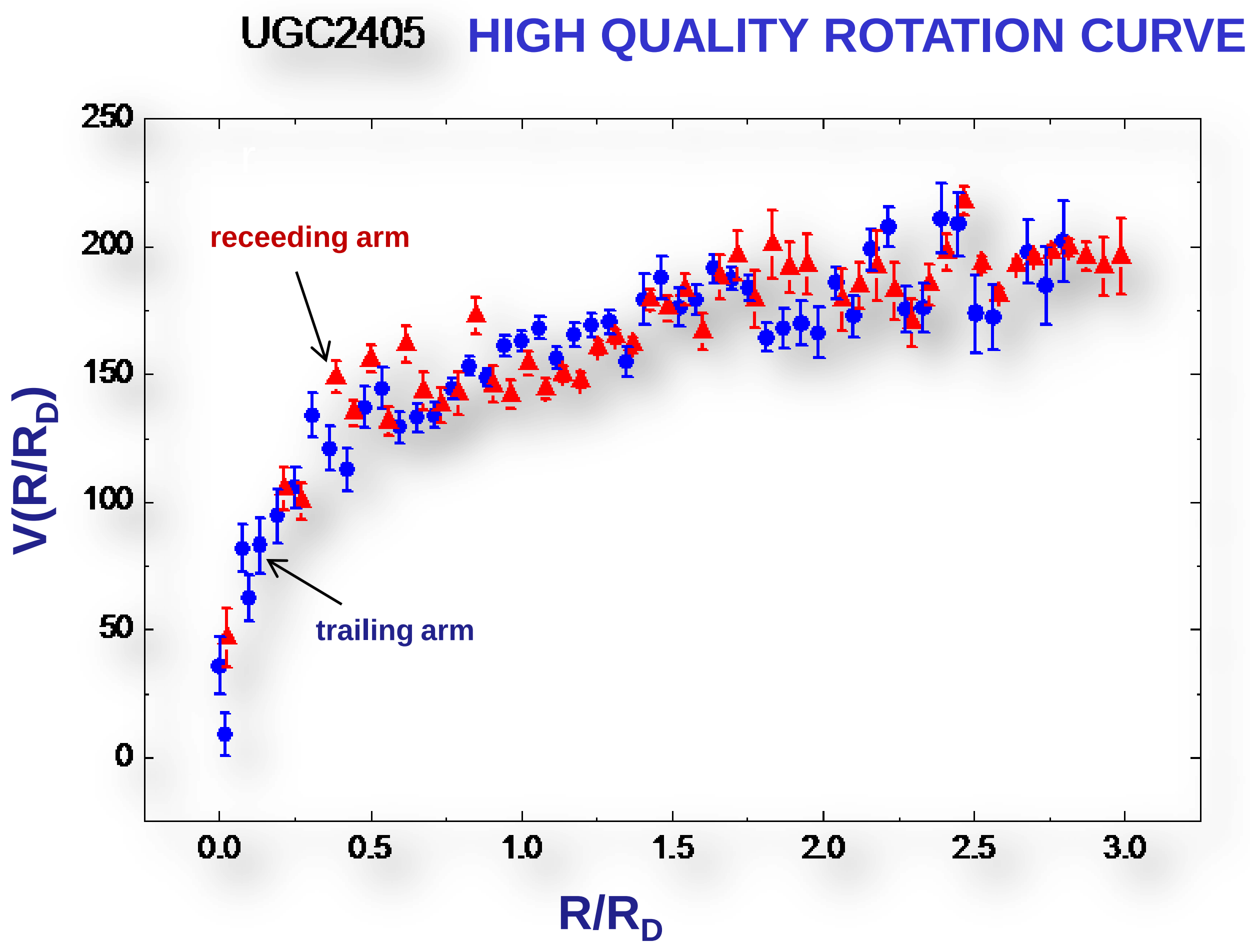




artist impression

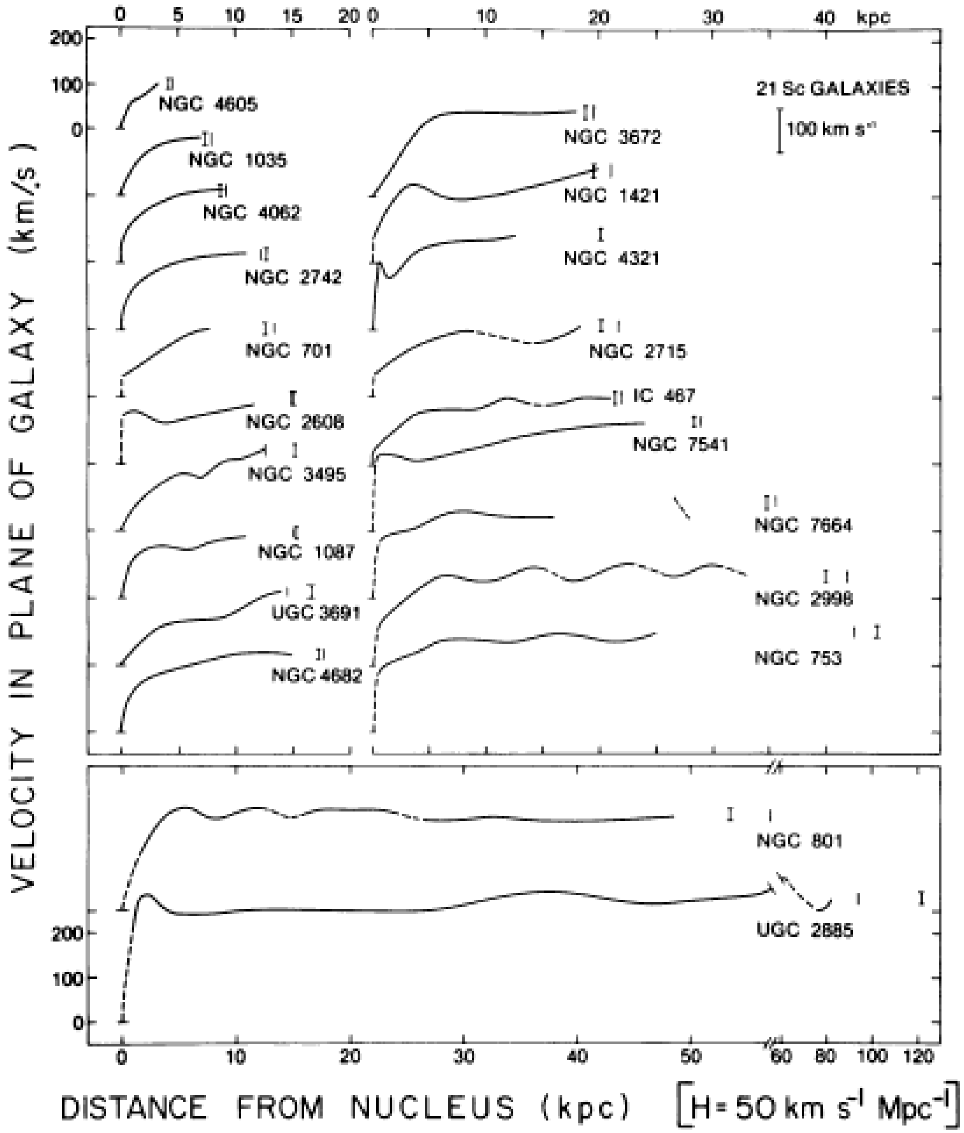
Symmetric circular rotation of a disk characterized by

- Sky coordinates of the galaxy centre
- Systemic velocity V_{sys}
- Circular velocity $V(R)$
- Inclination angle

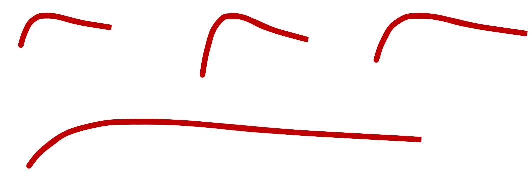


Early discovery from optical and HI RCs

RC DO NOT FOLLOWS THE DISK VELOCITY PROFILE



disk RC profiles of different lenght scale and amplitude



Rubin et al 1980

MASS DISCREPANCY AT OUTER RADII

HI rotation curves beyond the optical image

Bosma, 1978, 1981a,b

R_{opt}

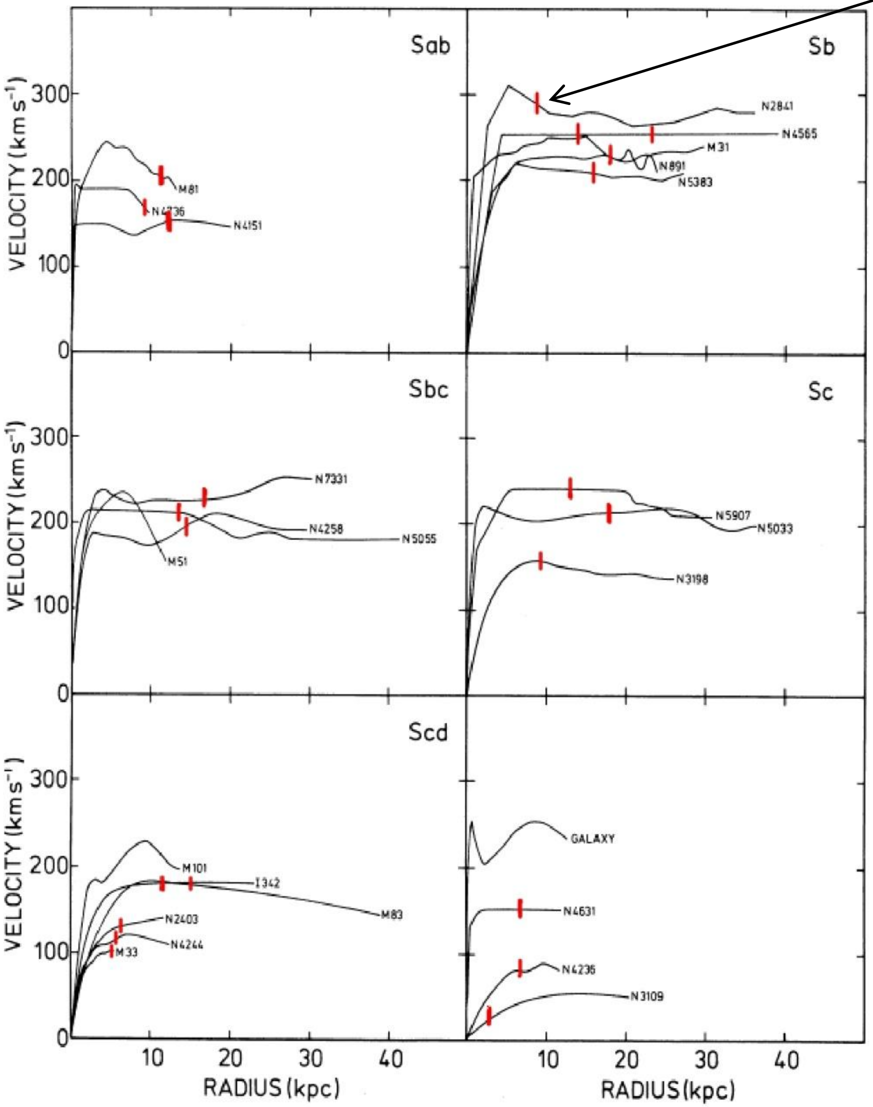
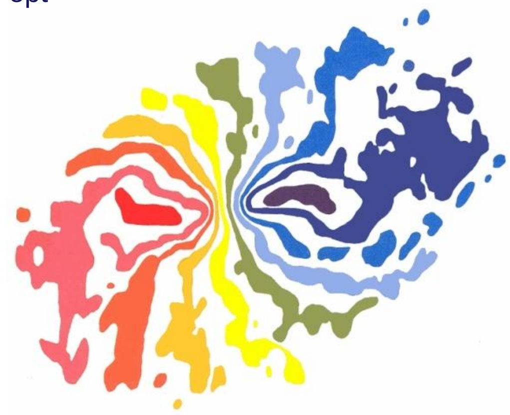
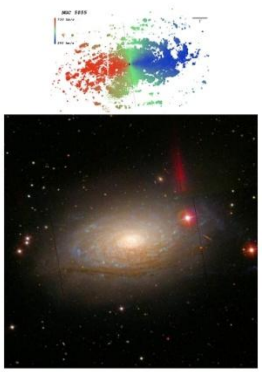
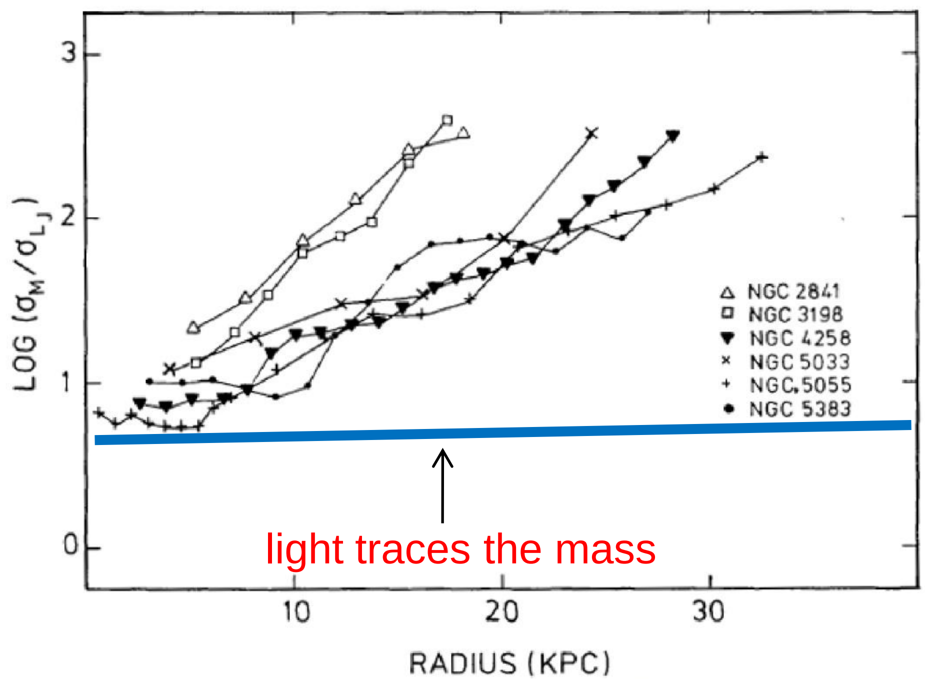


FIG. 3. Rotation curves of 25 galaxies of various Hubble types.





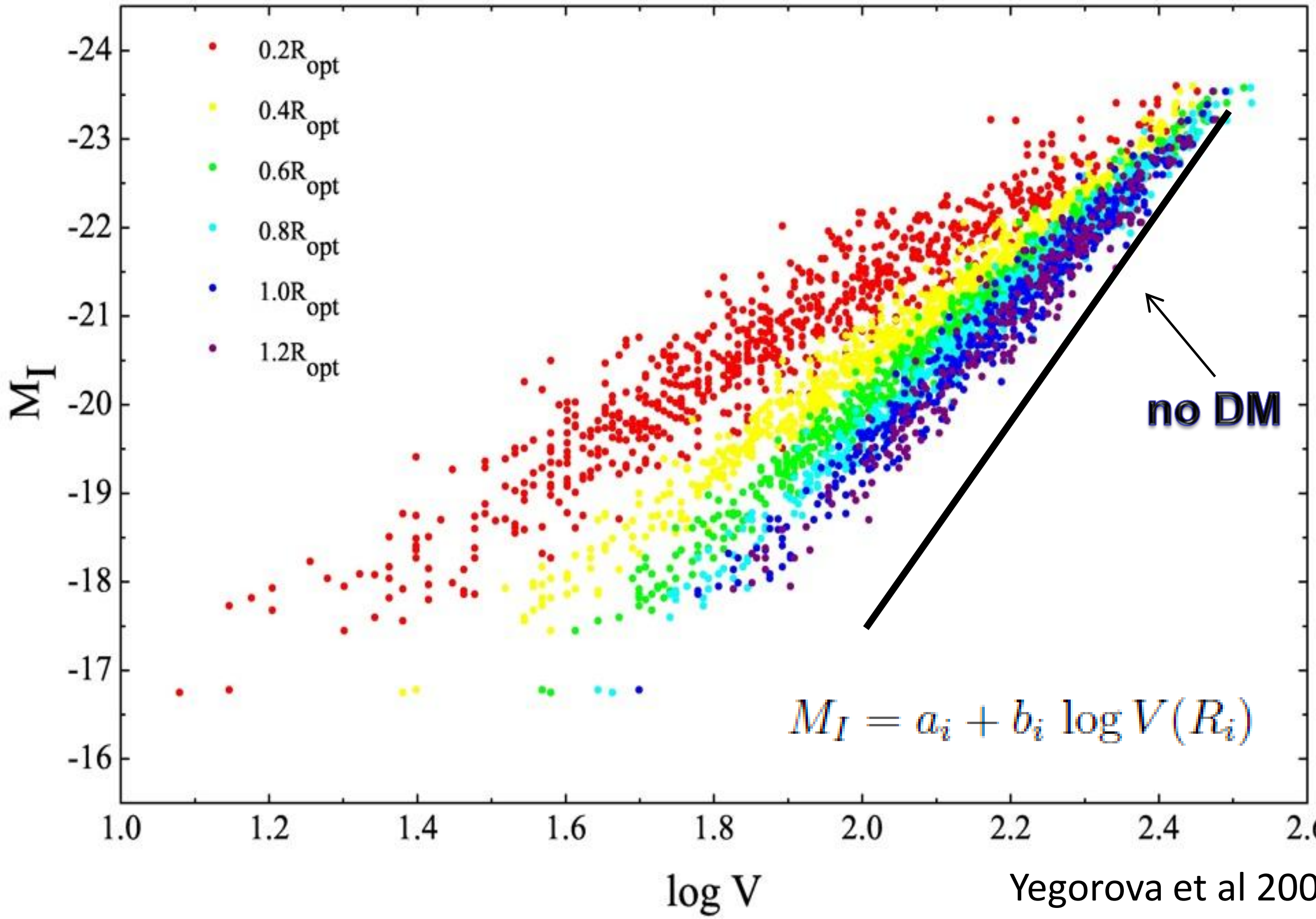


Bosma 1978, Bosma & Van der Kruit 1979

Evidence for a Mass Discrepancy in Galaxies

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

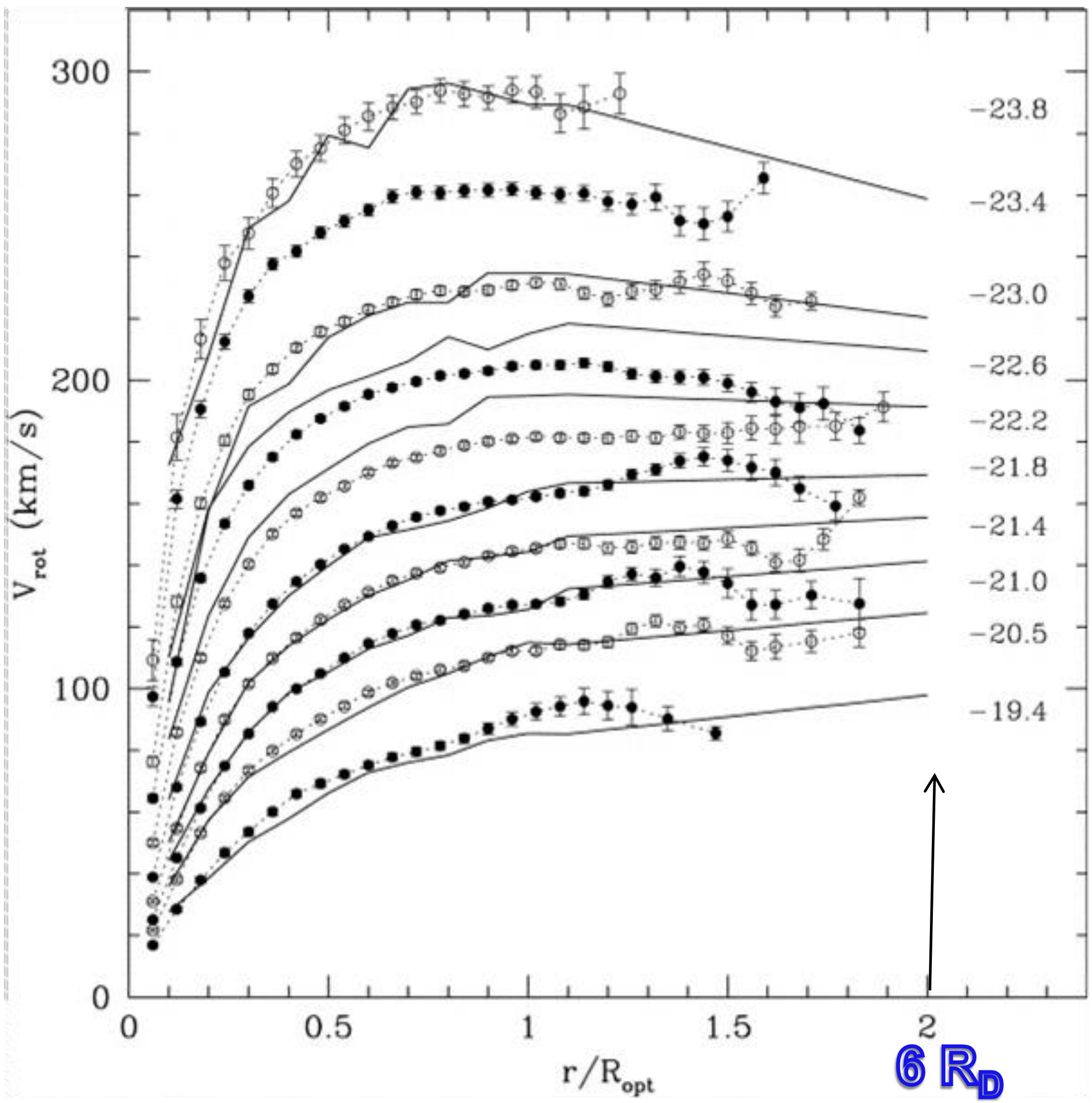
Tully-Fisher relation exists at local level (radii R_i)



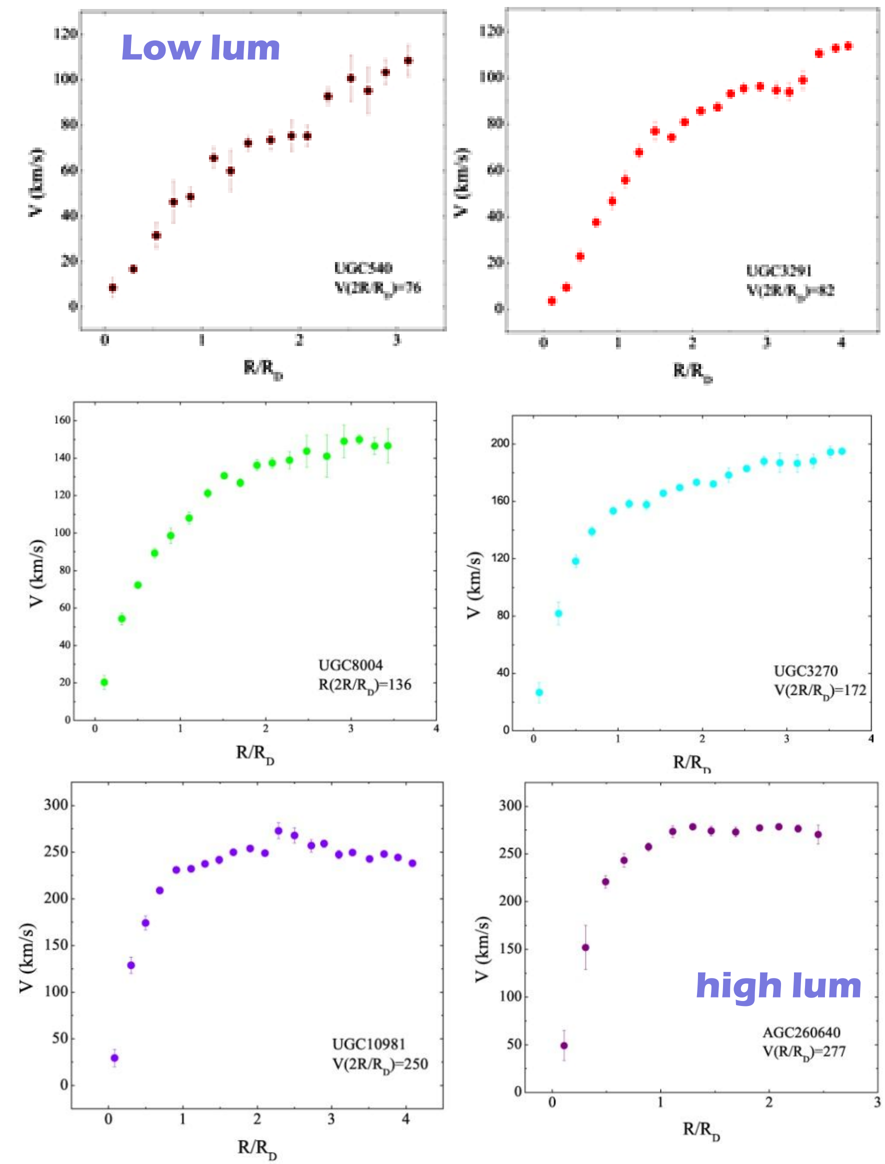
Yegorova et al 2007

Rotation Curves

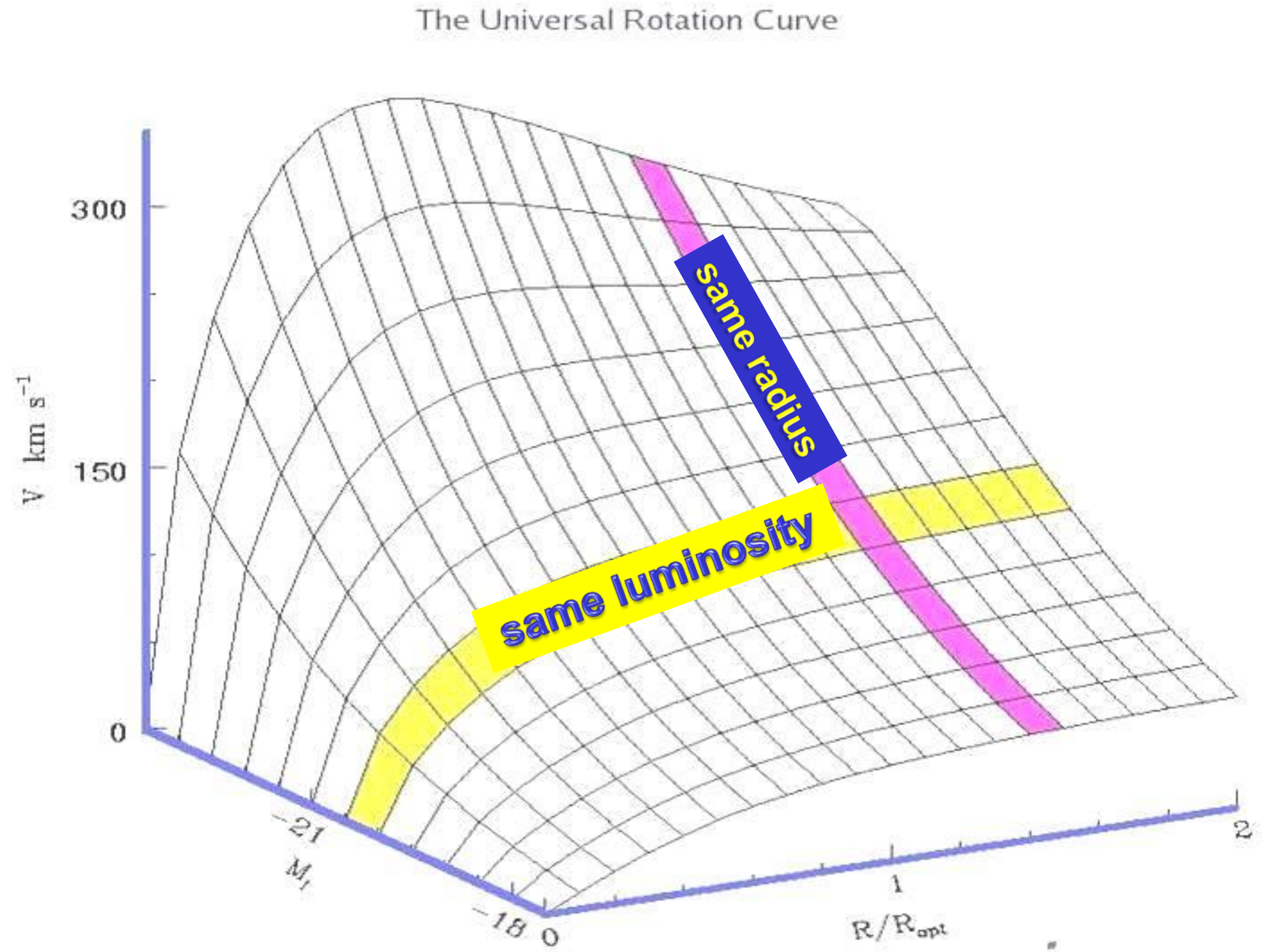
Coadded from 3200 individual RCs



TYPICAL INDIVIDUAL RCs OF INCREASING LUMINOSITY

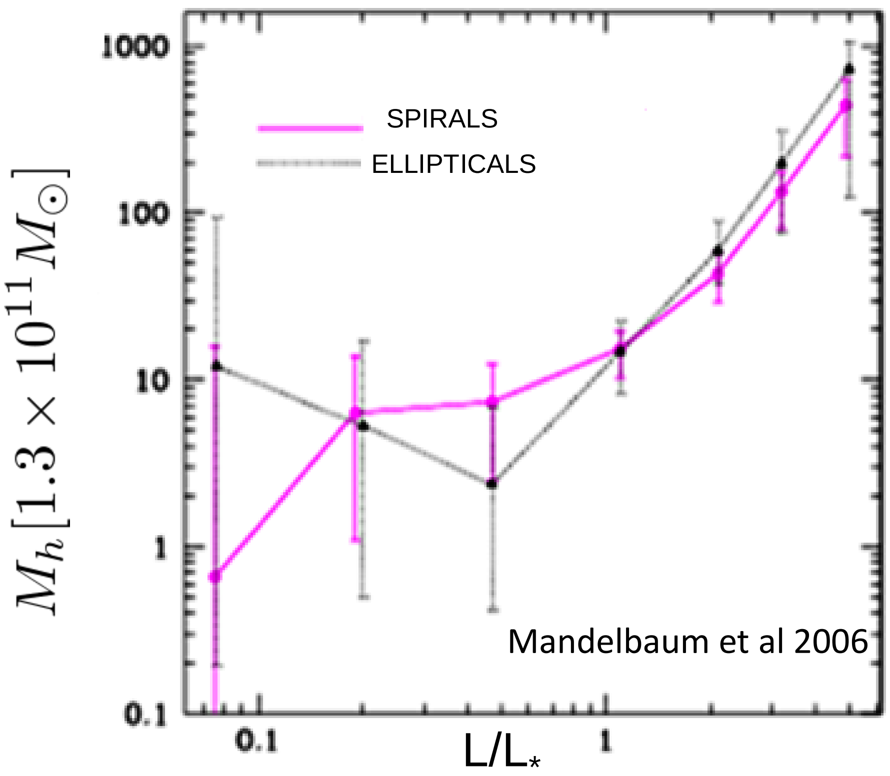


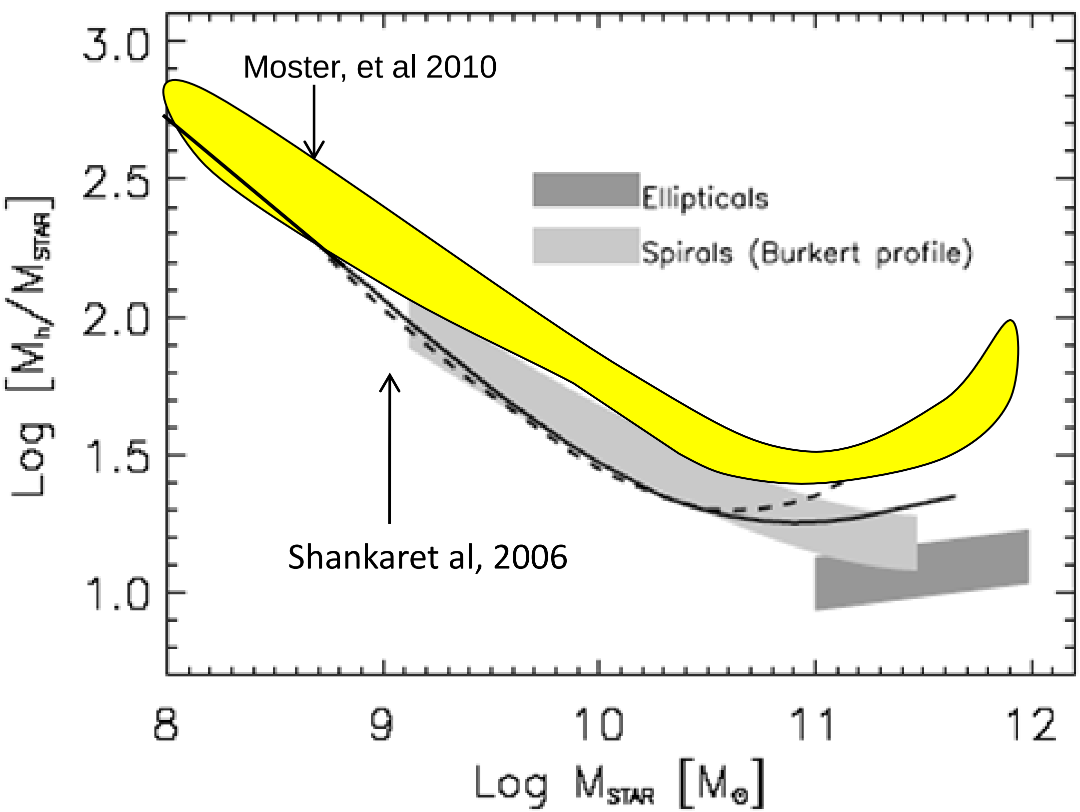
The Cosmic Variance of V measured in galaxies of same luminosity L at the same radius x=R/R_D is negligible compared to the variations that V shows as x and L varies.



Universal Rotation Curve out to the Virial Radius

Method: inner kinematics + independent determinations of halo virial masses



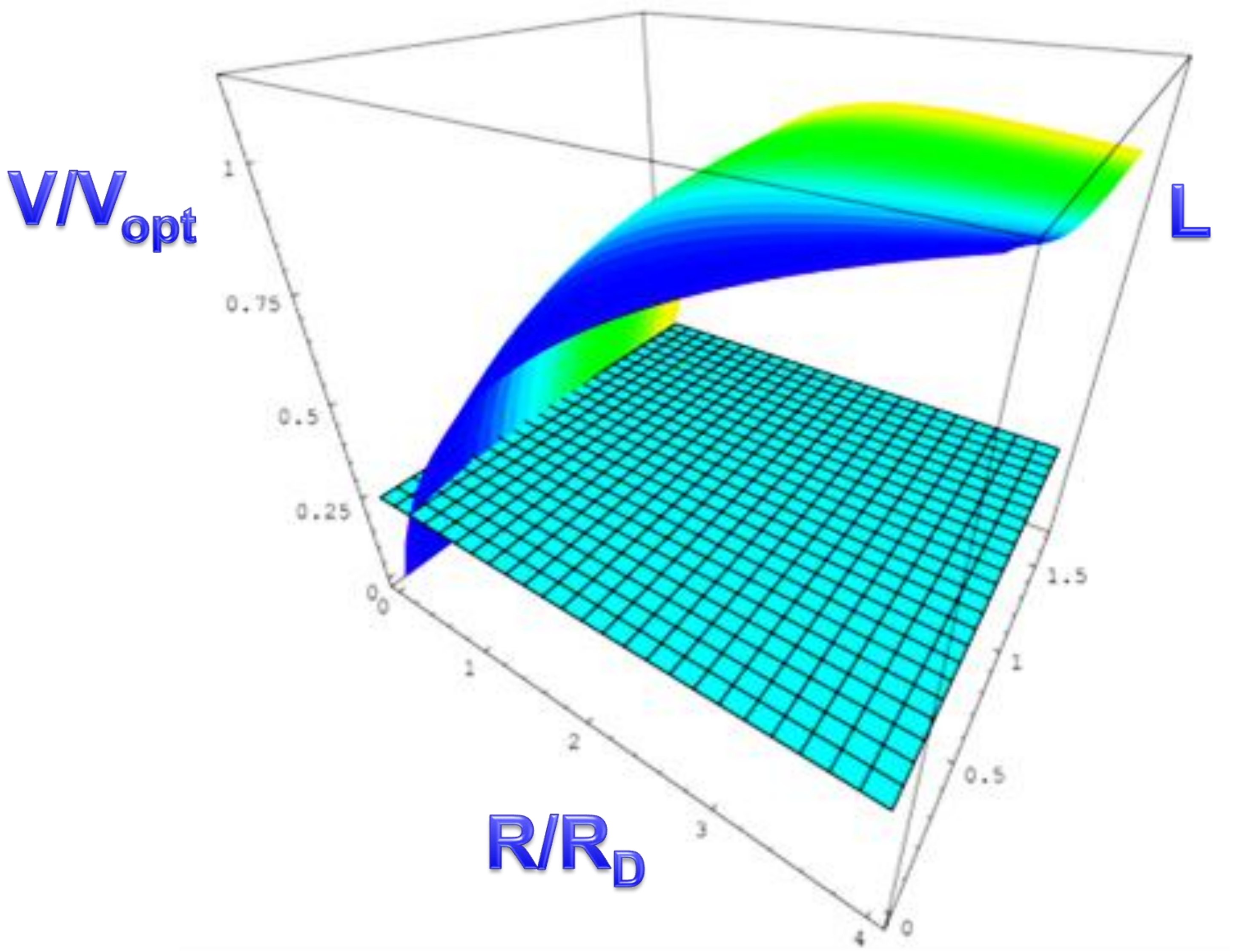


Virial masses M_h of halos around galaxies with stellar mass M_{STAR} (or luminosity L) are obtained

- directly by weak-lensing analysis *(left)*
- indirectly by correlating *dN/dL* with theoretical DM halo *dN/dM (right)*

The Concept of the Universal Rotation Curve (URC)

Every RC can be represented by: V(x,L)   x=R/R_D



The URC out to 6 R_D is derived directly from observations
Extrapolation of URC out to virial radius by using V(R_{vir})

-> Movie 2

Rotation curve analysis

From data to mass models

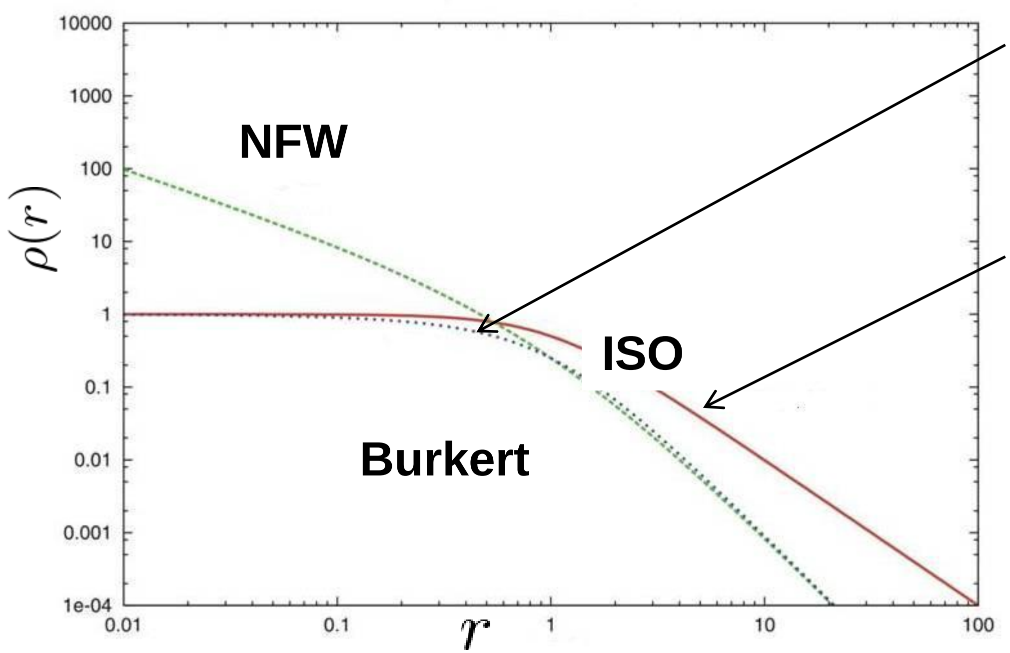
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

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)

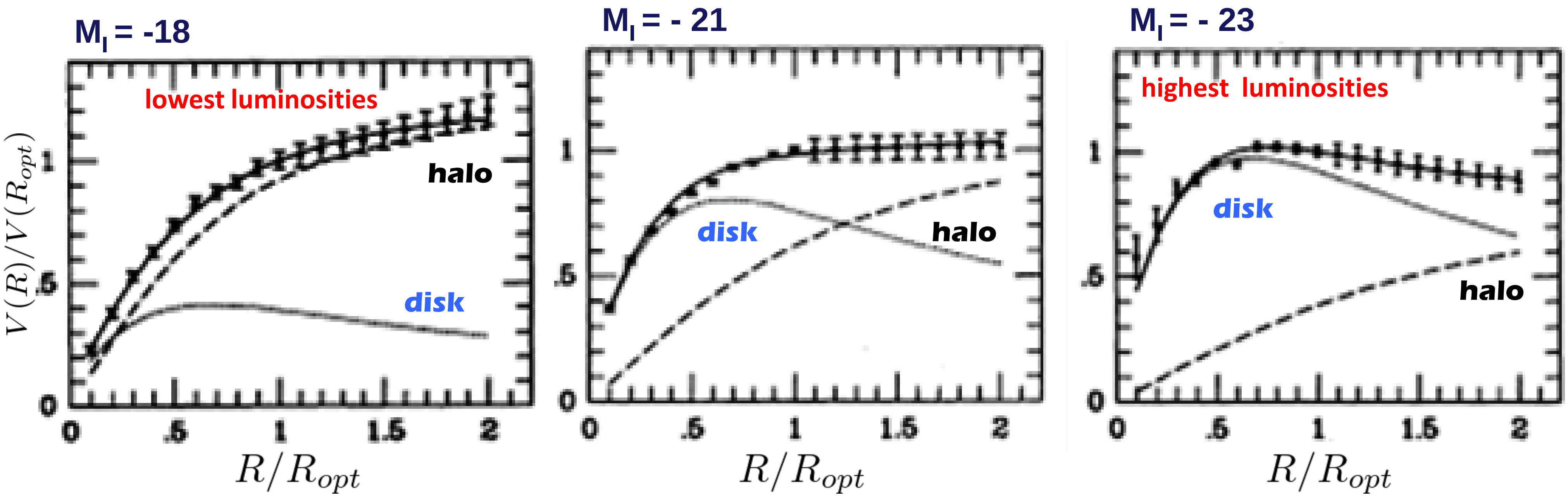


$$\rho(r) = \frac{\rho_0}{(1 + r/r_0)(1 + (r/r_0)^2)}$$

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

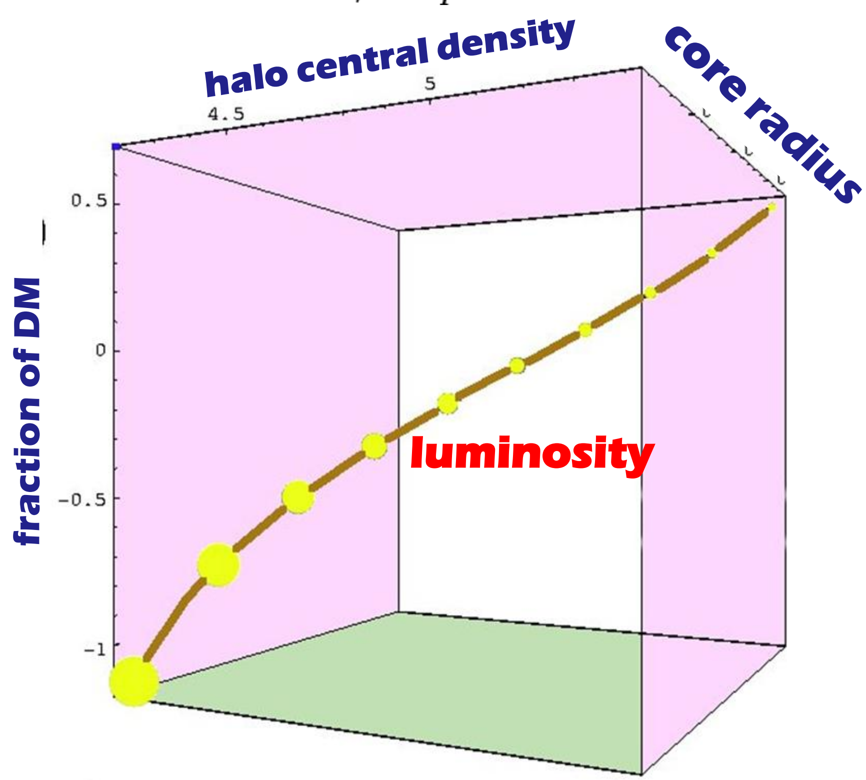
The mass model has 3 free parameters:
disk mass
halo central density
Halo core radius (length-scale)
Obtained by best fitting method

MASS MODELLING RESULTS



All structural DM and LM parameters are related with luminosity.

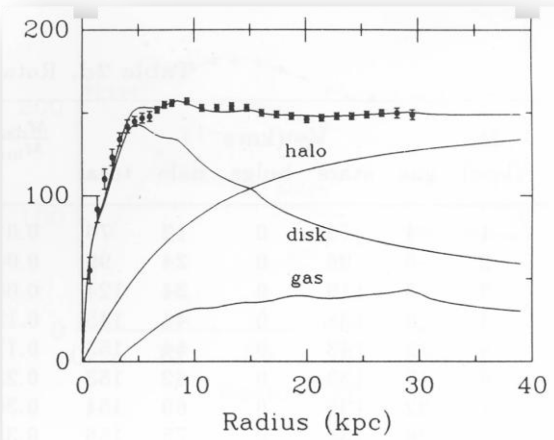
Smaller galaxies are denser and have a higher proportion of dark matter.



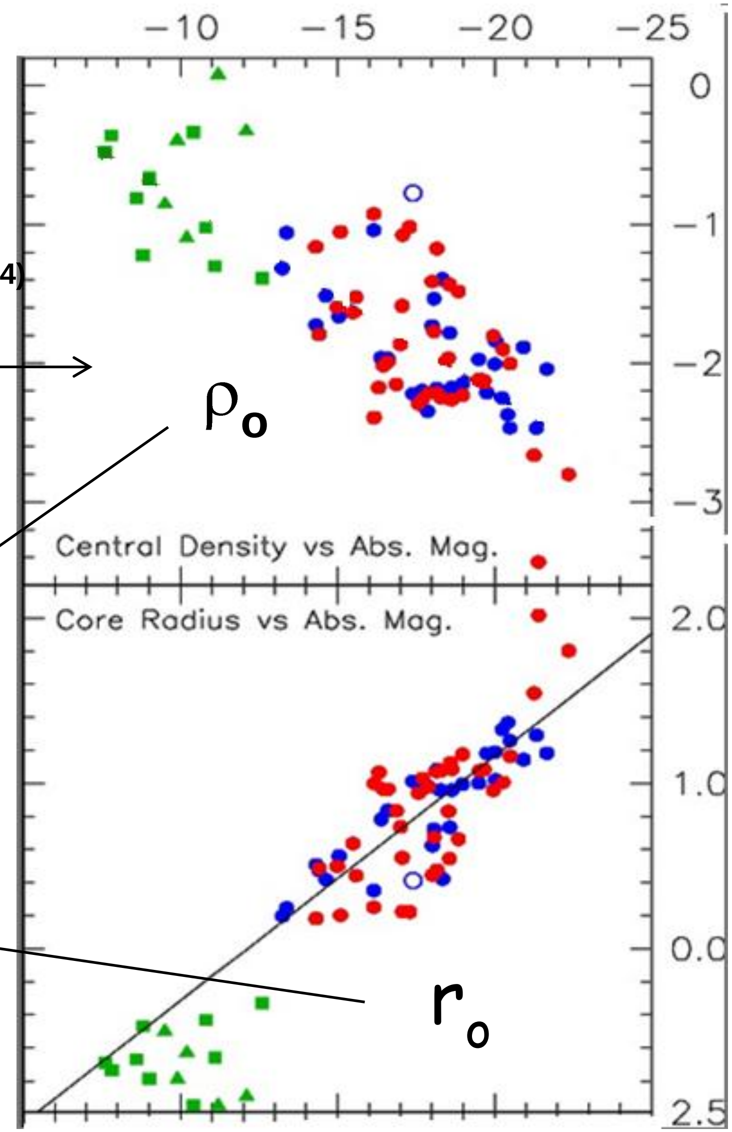
Dark Halo Scaling Laws in Spirals

Careful investigation of relationships between halo structural parameters and luminosity.
via mass modelling of individual galaxies (ρ_0, r_0)

- **Assumption: Maximun Disk, 30 objects**
- **the central <u>slope</u> of the halo rotation curve gives the halo core density**
- **extended RCs provide an estimate of halo core radius r_0**



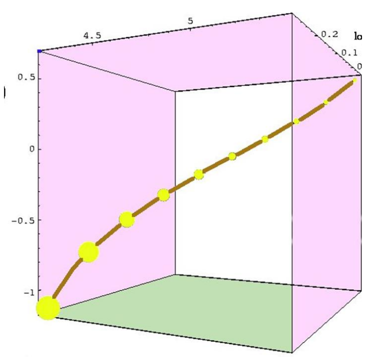
Kormendy & Freeman (2004)



ρ_o

r_o

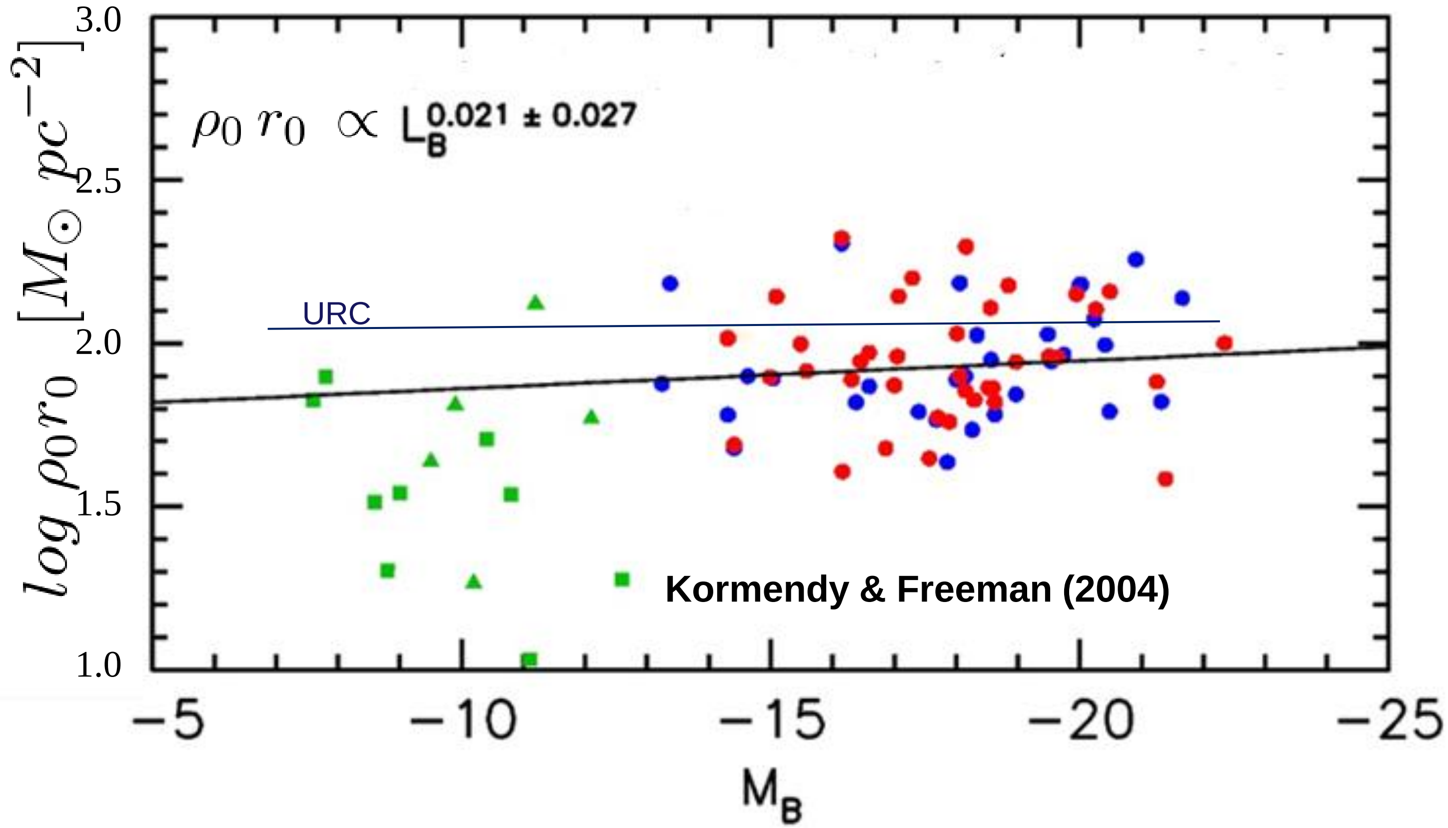
URC



$$\rho_o \sim L_I^{-0.7} \qquad \rho_o \sim L_B^{-0.6}$$

$$r_o \sim L_I^{0.7} \qquad r_o \sim L_B^{0.6}$$

The halo central surface density $\rho_0 r_0$: constant in Spirals

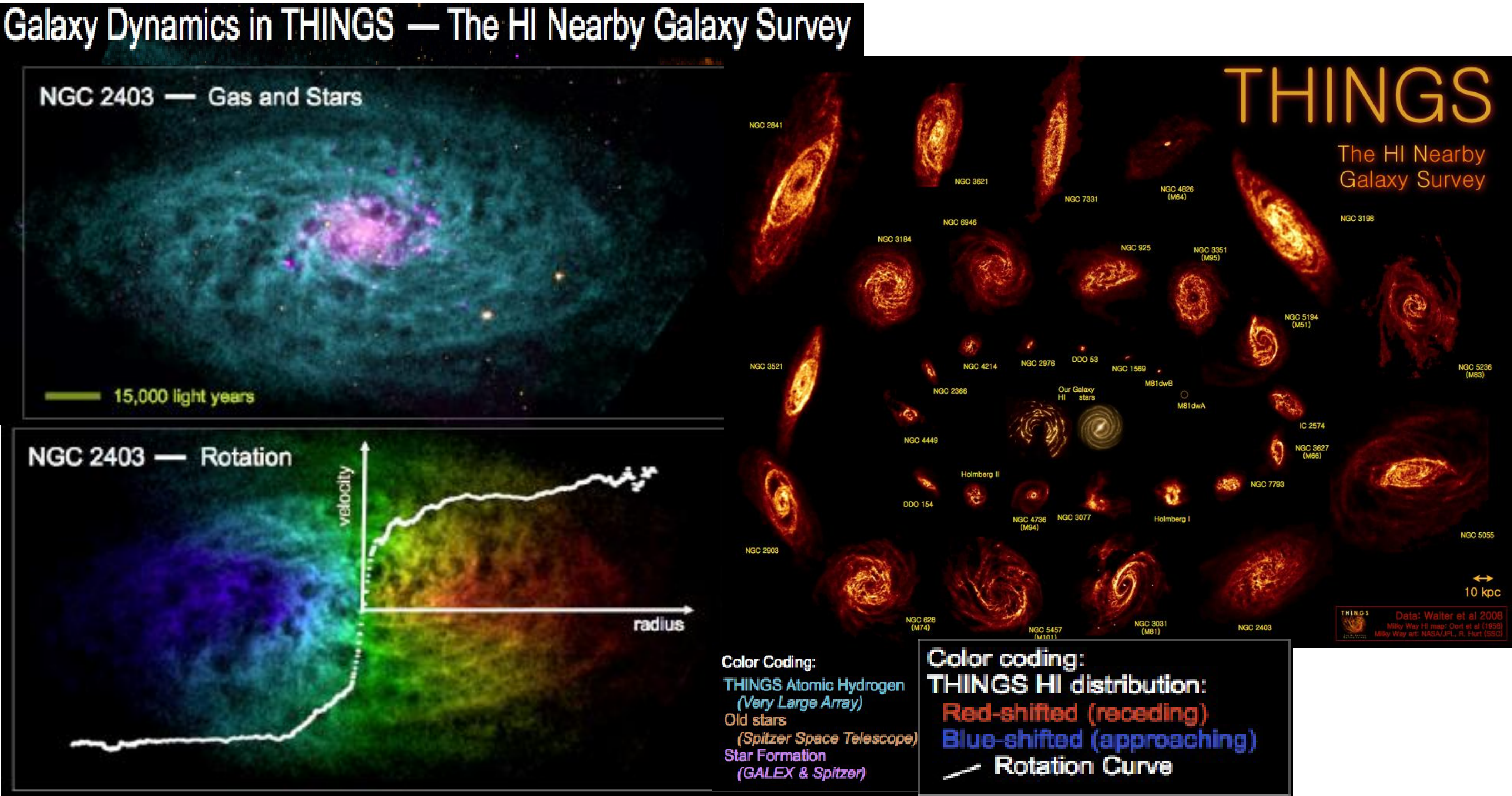


Kormendy & Freeman (2004)

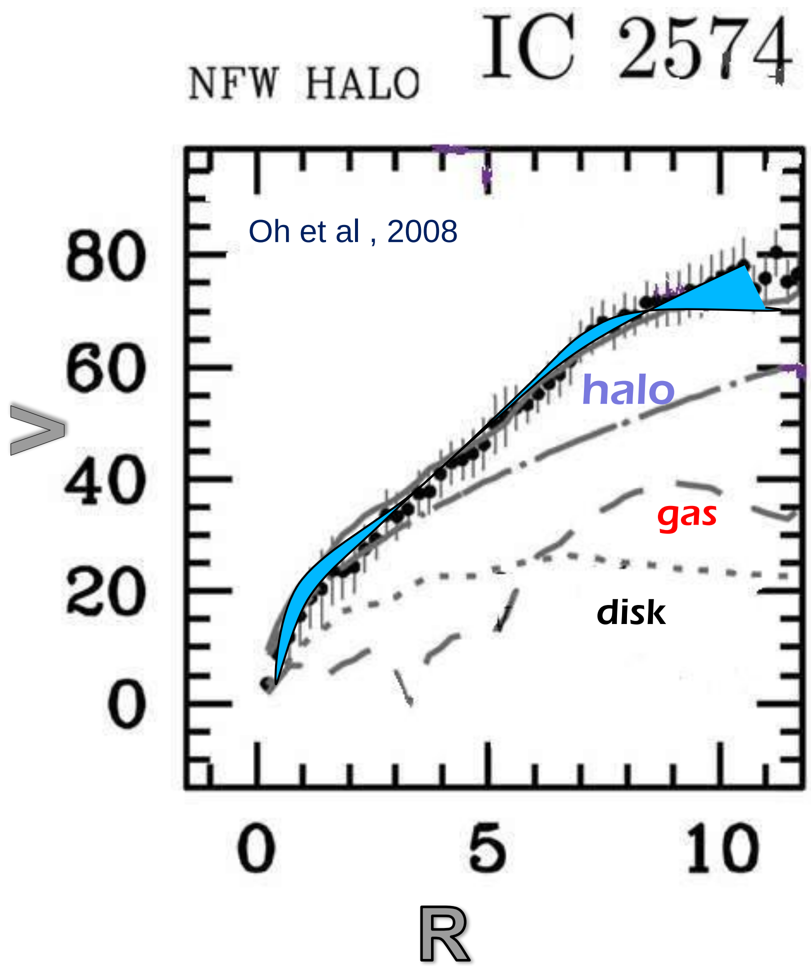
The distribution of DM around spirals

Using individual galaxies **Gentile+ 2004, de Blok+ 2008 Kuzio de Naray+ 2008, Oh+ 2008, Spano+ 2008, Trachternach+ 2008, Donato+,2009**

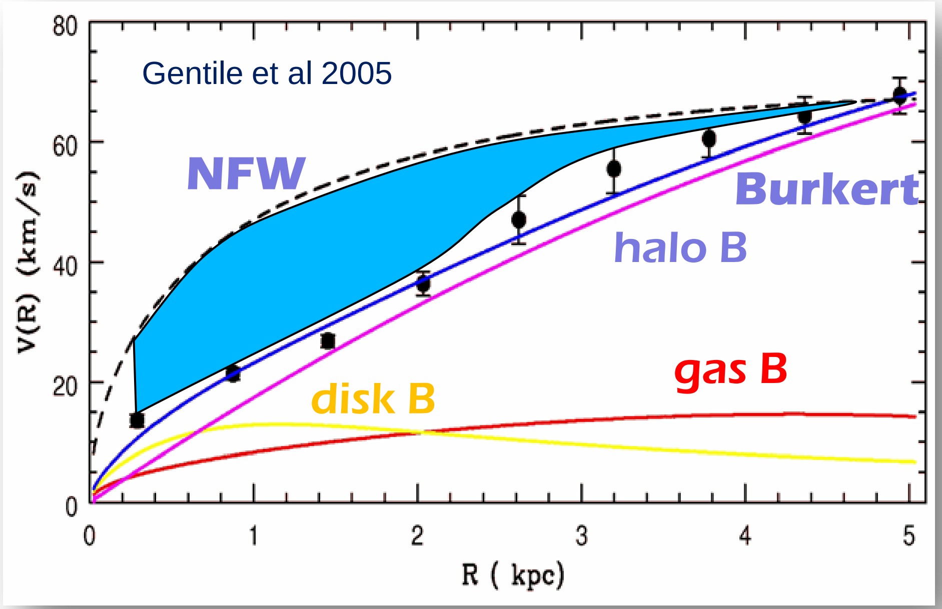
A detailed investigation: high quality data and model independent analysis



EXAMPLES



DDO 47



General results from several samples e.g. THINGS

- ***Non-circular motions are small.***
- ***DM halo spherical***
- ***ISO/Burkert halos much more preferred over NFW***

- **Tri-axiality and non-circular motions cannot explain the CDM/NFW cusp/core discrepancy**

SPIRALS: WHAT WE KNOW

AN UNIVERSAL CURVE REPRESENTS ALL INDIVIDUAL RCs
MORE PROPORTION OF DARK MATTER IN SMALLER SYSTEMS
THE RADIUS IN WHICH THE DM SETS IN IS A FUNCTION OF LUMINOSITY
THE MASS PROFILE AT LARGER RADII IS COMPATIBLE WITH NFW
DARK HALO DENSITY SHOWS A CENTRAL CORE OF SIZE 2 R_D

ELLIPTICALS

The Stellar Spheroid

Surface brightness of ellipticals follows a Sersic (de Vaucouleurs) law

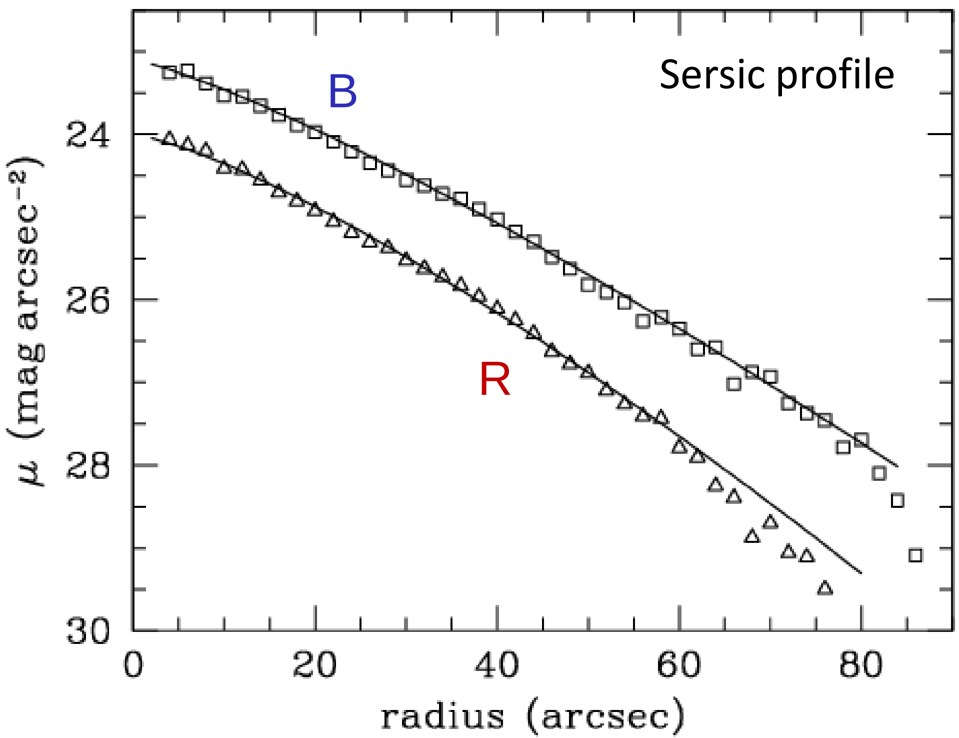
$$I(R) = I_e e^{-b_n[(R/R_e)^{1/n}-1]}$$

R_e : the radius enclosing half of the projected light.

By deprojecting I(R) we obtain the luminosity density *j(r)*:

$$I(R) = \int_{-\infty}^{+\infty} j(r)\,dz = 2\int_{R}^{+\infty} \frac{j(r)\,r\,dr}{\sqrt{r^2 - R^2}} \qquad \rho_{sph}(r) = (M/L)_\star\, j(r)$$

ESO 540-032



Modelling Ellipticals

Measure the light profile = stellar mass profile $(M_*/L)^{-1}$

Derive the total mass profile M(r) from:

Dispersion velocities of stars or of Planetary Nebulae

X-ray properties of the emitting hot gas

Weak and/or strong lensing data

Disentangle M(r) into its dark and the stellar components

In ellipticals gravity is balanced by pressure gradients -> Jeans Equation

anisotropy of the orbits

$$\frac{\mathrm{d}}{\mathrm{d}r}(j\sigma_r^2) + \frac{2\beta}{r} j\sigma_r^2 = -j\frac{\mathrm{d}\Phi}{\mathrm{d}r}$$

grav. potential

dispersion velocities

Kinematics of ellipticals: Jeans modelling of radial, projected and aperture velocity dispersions

$$M(r) = M_{sph}(r) + M_h(r).$$

$$\sigma_r^2(r) = \frac{G}{\rho_{sph}(r)} \int_r^\infty \frac{\rho_{sph}(r')M(r')}{r'^2}\, dr'$$ radial

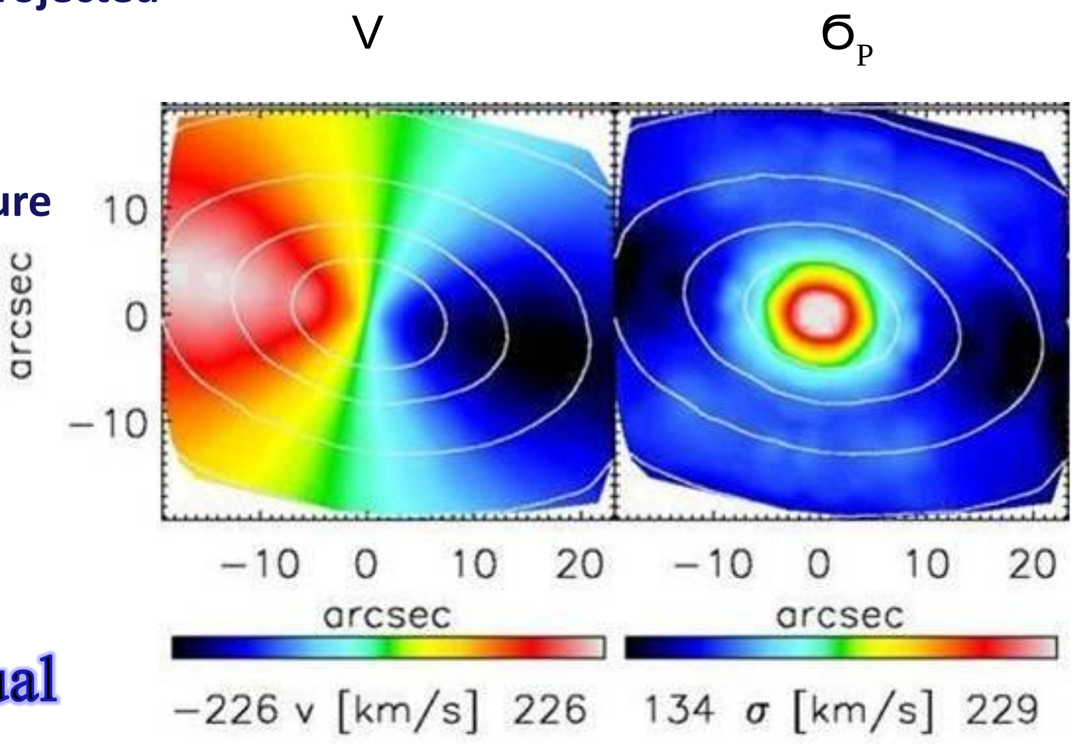
$$\sigma_P^2(R) = \frac{2}{I(R)} \int_R^\infty \frac{\rho_{sph}(r)\ \sigma_r^2(r)\ r}{\sqrt{r^2 - R^2}}\, dr$$ projected

$$\sigma_A^2(R_A) = \frac{2\pi}{L(R_A)} \int_0^{R_A} \sigma_P^2(R)\ I(R)\ R\, dR$$ aperture

$$L(R) = 2\pi \int I(R)\ R\, dR$$

measure I(R), σ_P(R)

derive $M_h(r)$, $M_{sph}(r)$

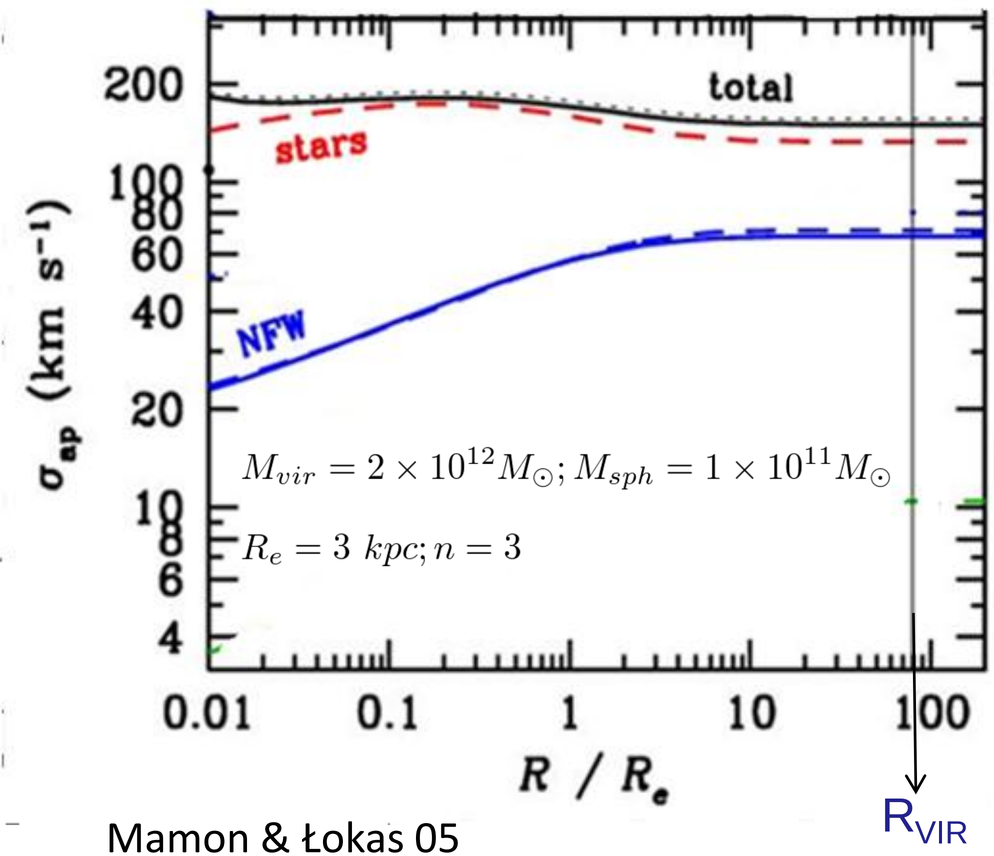


SAURON data of N 2974

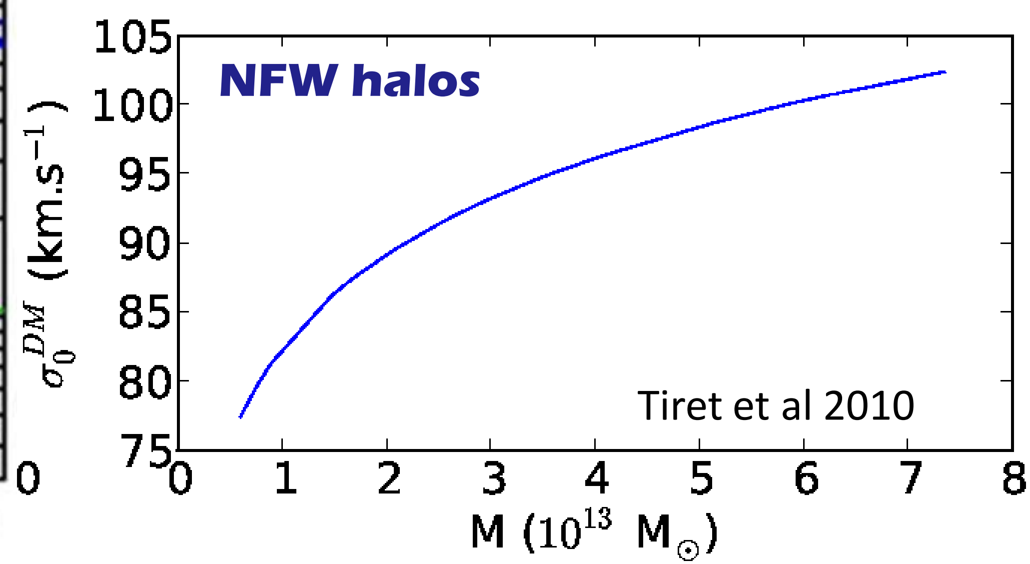
-Rotation is not always negligible
-σ_r (R) is a direct probe of grav potential but it is not observable
-σ_P (R) is observable when individual star measures are available
-σ_{AP} is the standard observable

Warning: mass decomposition of dispersion velocities not unique.

Exemple: NFW halo + Sersic spheroid. Orbit isotropy.



Mamon & Łokas 05

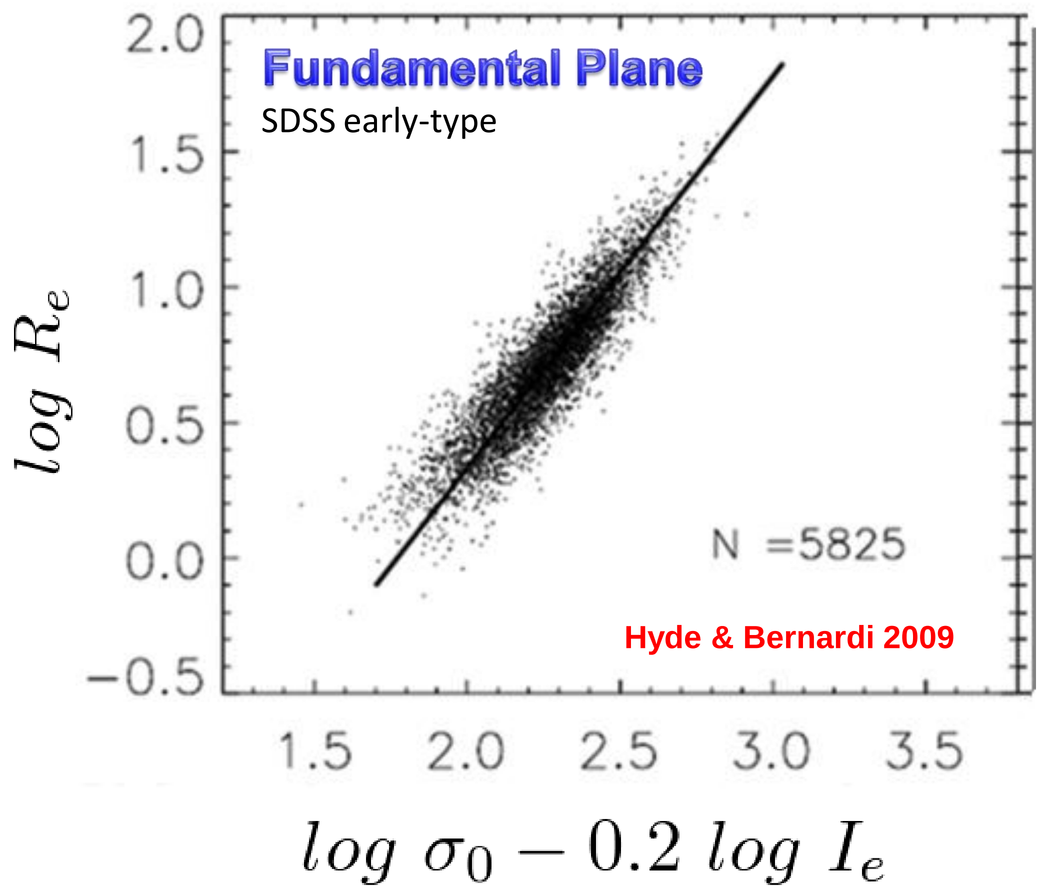


The spheroid determines the values of the aperture dispersion velocity

The contribution of the DM halo to the central dispersion velocity is lesser than 100 km/s

Inside R_e the dark matter profile is intrinsically unresolvable

The Fundamental Plane: the **values** of the central dispersion velocity, half light radius and central surface brightness are strongly related

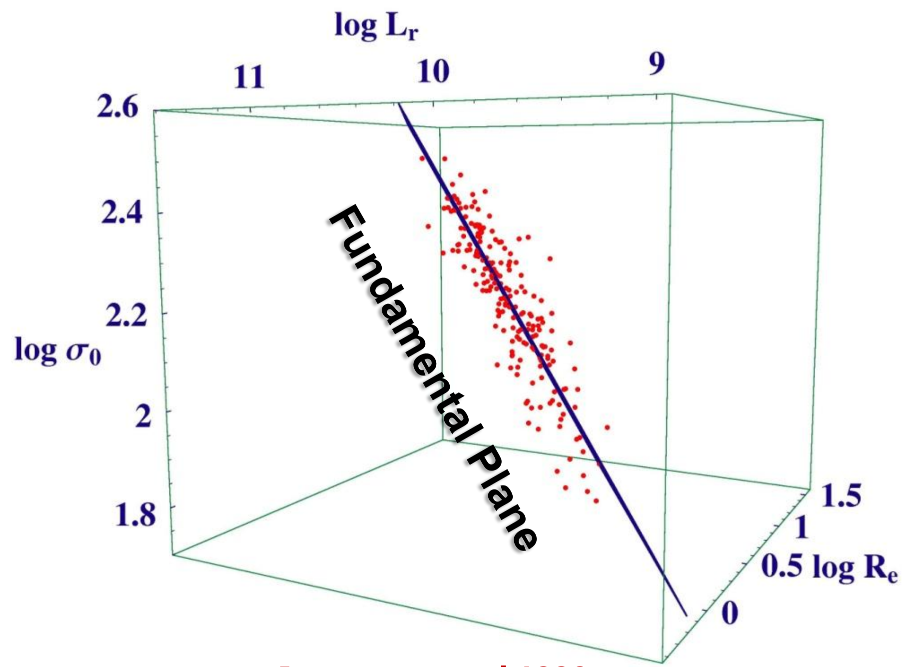


FP "tilt" due to variations with σ_0 of:
Stellar populations among E

From **virial theorem**

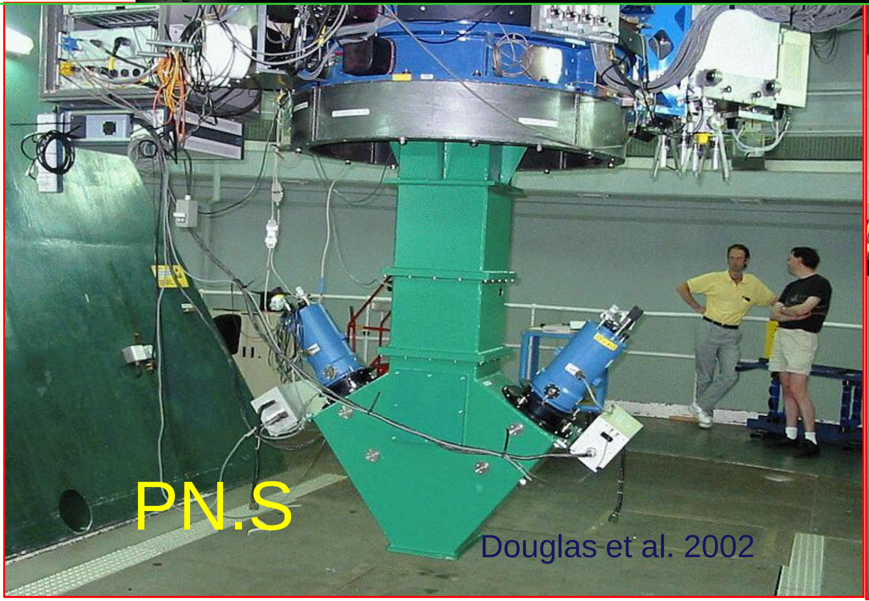
$$\sigma^2 \propto \frac{M}{r} \propto \left(\frac{M}{L}\right)\left(\frac{L}{r}\right) \propto \left(\frac{M}{L}\right)\left(\frac{L}{r^2}\right) r$$

expected $R_e \propto \sigma_0^a I_e^b$, with a=2 and b=1
found: a=1.8, b=0.8

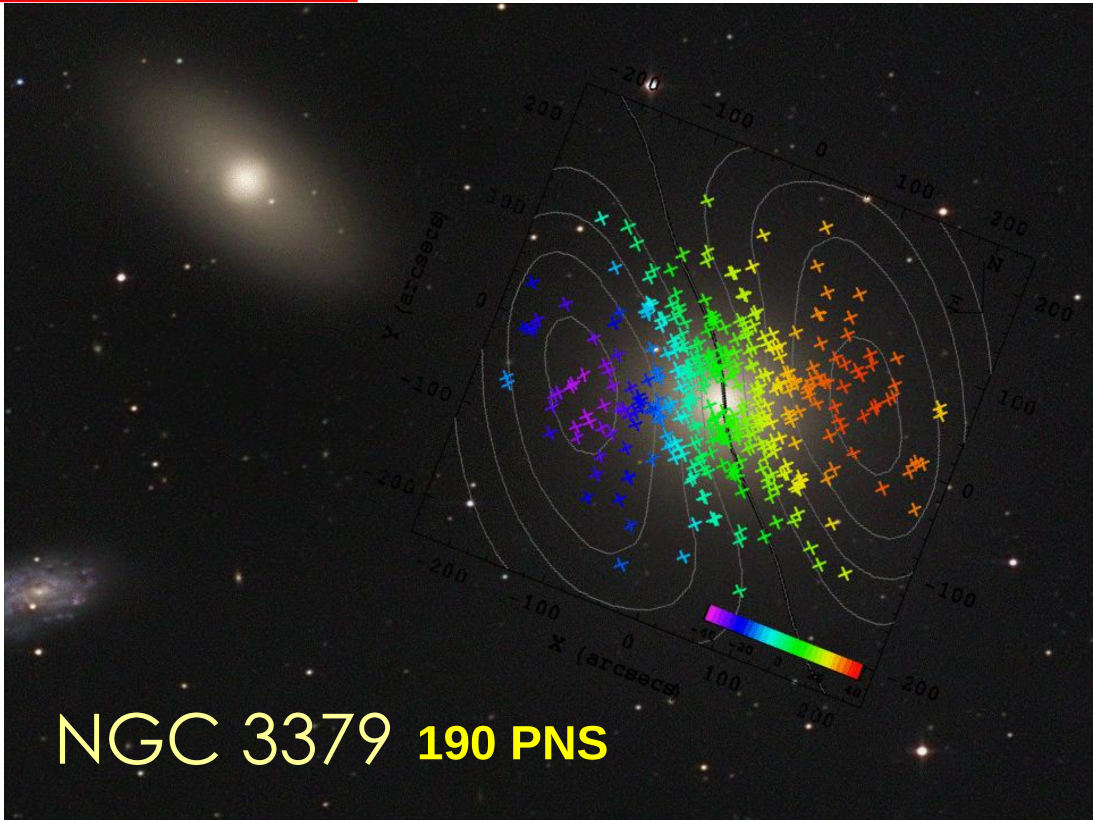


Jørgensen et al 1996

The Planetary Nebula Spectrograph

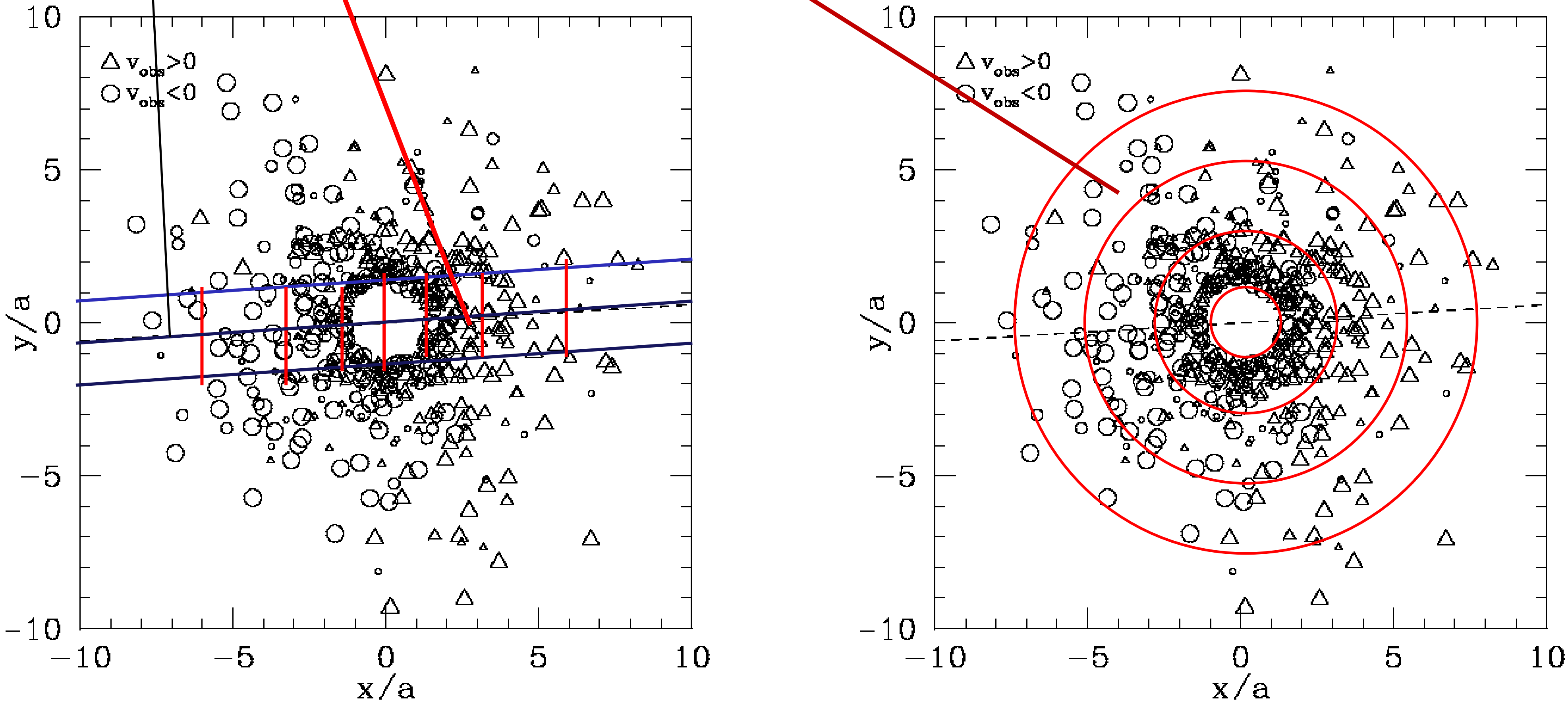


Extended kinematics of elliptical galaxies obtained with the Planetary Nebula Spectrograph



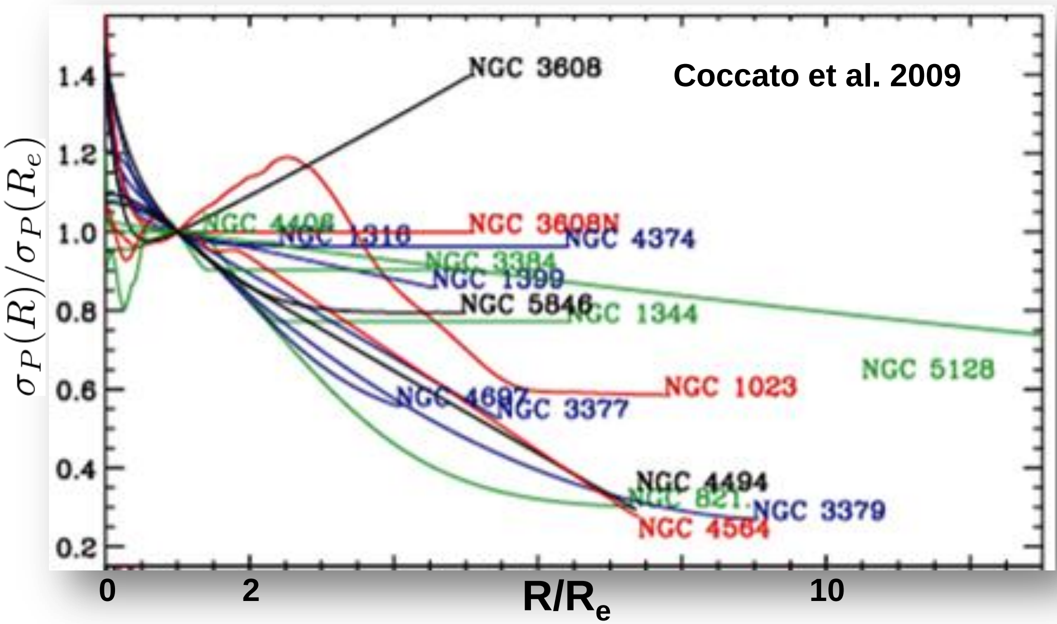
Major/minor axis or radial binning of the data

$$\sigma_p = \frac{1}{N-1}\sum_{i=1}^{N}(v_i - v)^2$$

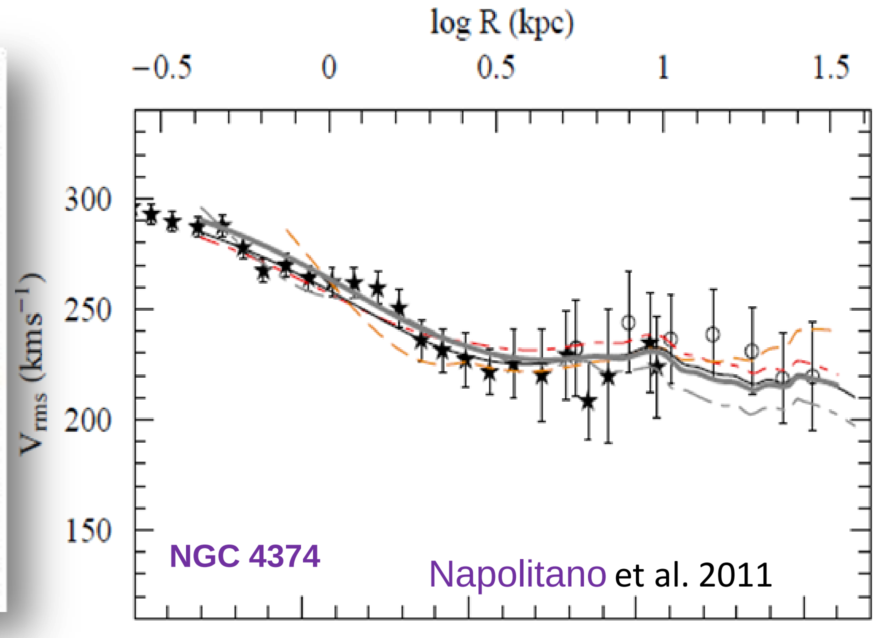


PN data

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



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



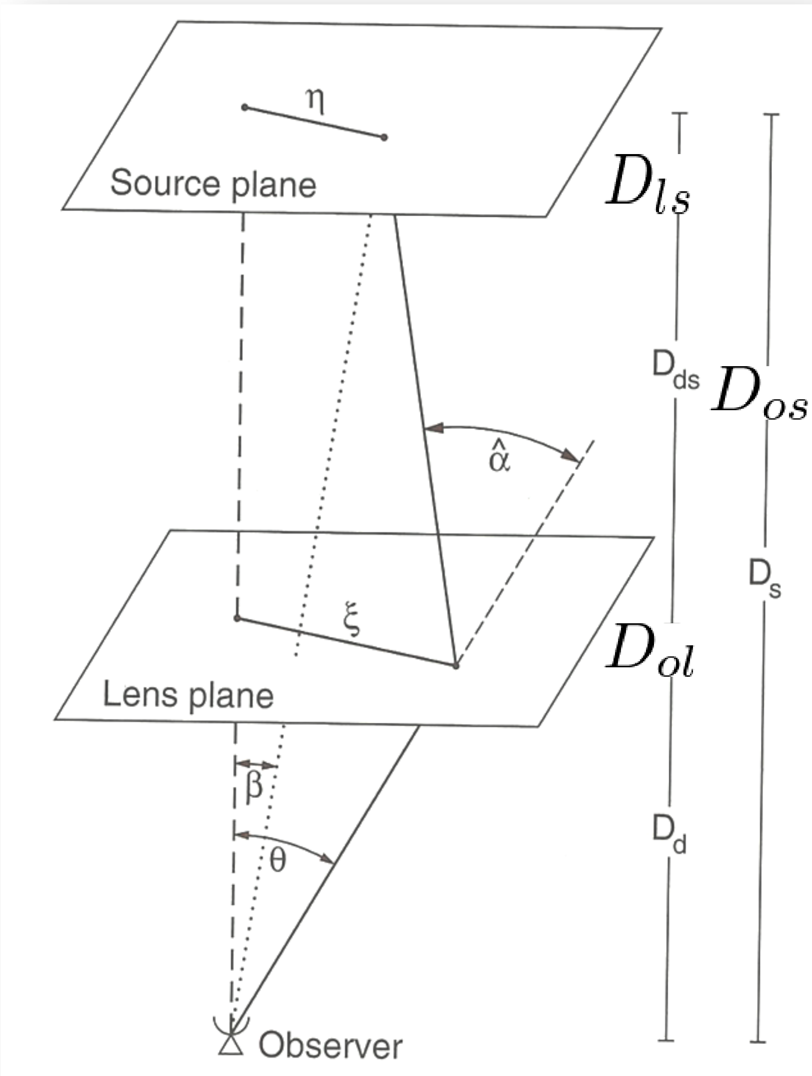
$$M(r) = -\frac{\sigma_r^2\, r}{G}\left(\frac{d\ln j_*}{d\ln r} + \frac{d\ln \sigma_r^2}{d\ln r} + 2\beta\right)$$

JEANS ANALYSIS

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

MORE DATA

Mass profiles from weak lensing



Lensing equation for the observed tangential shear

e.g. Schneider,1996

$$\langle \gamma_t \rangle \equiv \frac{\overline{\Sigma}(R) - \Sigma(R)}{\Sigma_c(R)}$$

$$\bar{\Sigma} = \frac{M(R)}{4\pi R^2}$$

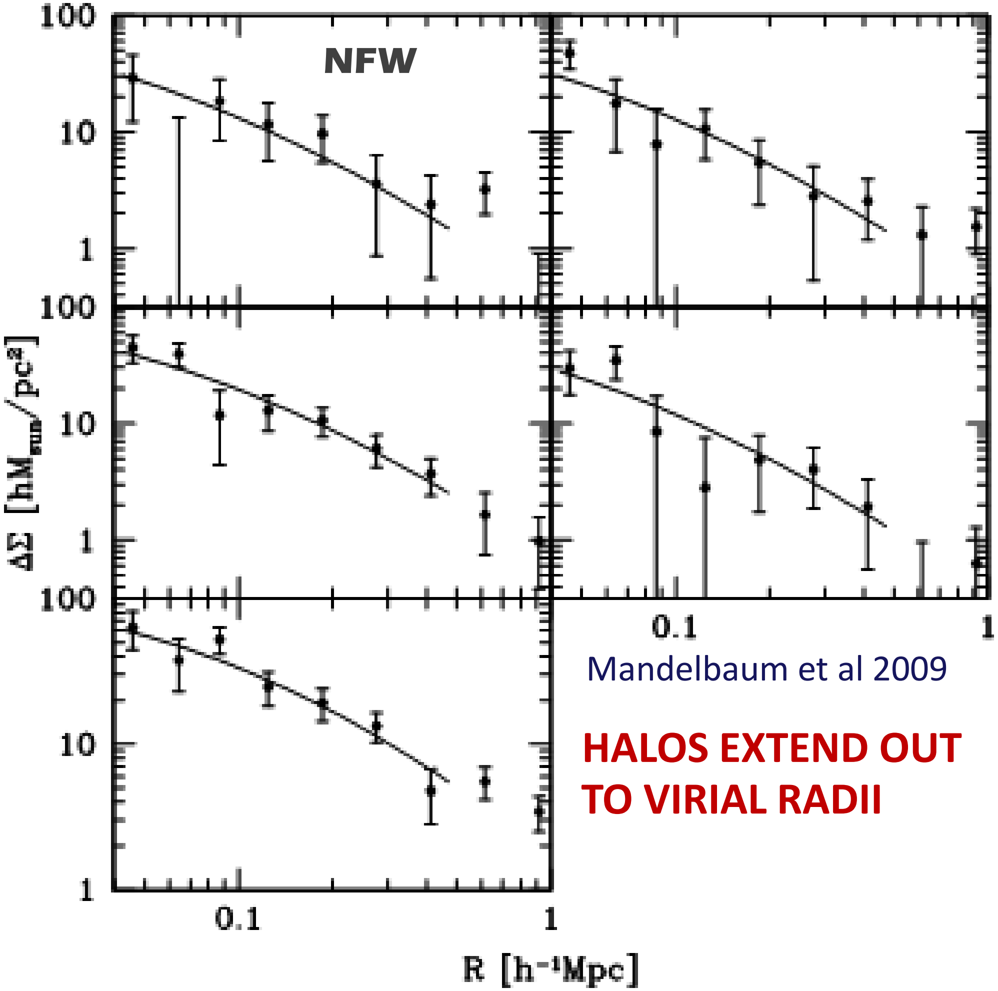
$$R = \theta D_{ol}$$

$$\Sigma_c = \frac{c^2}{4\pi G} \frac{D_{os}}{D_{ol} D_{ls}}$$

MODELLING WEAK LENSING SIGNALS

Lenses: 170 000 isolated galaxies, sources: 3 10^7 SDSS galaxies

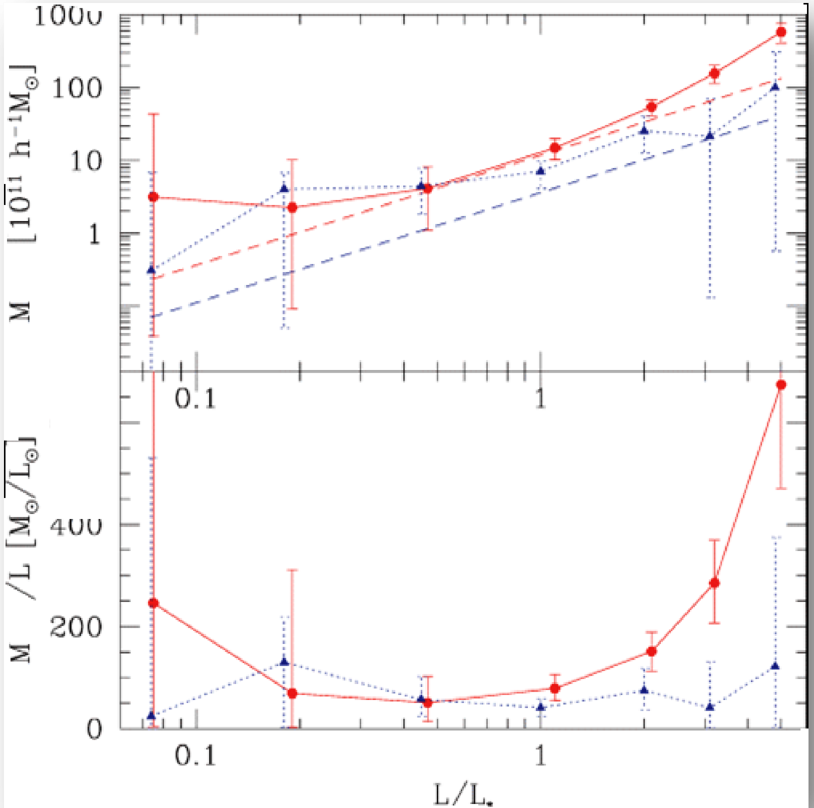
Lower luminosity ellipticals (left) and spirals (right)



Mandelbaum et al 2009

HALOS EXTEND OUT TO VIRIAL RADII

Mandelbaum et al 2006



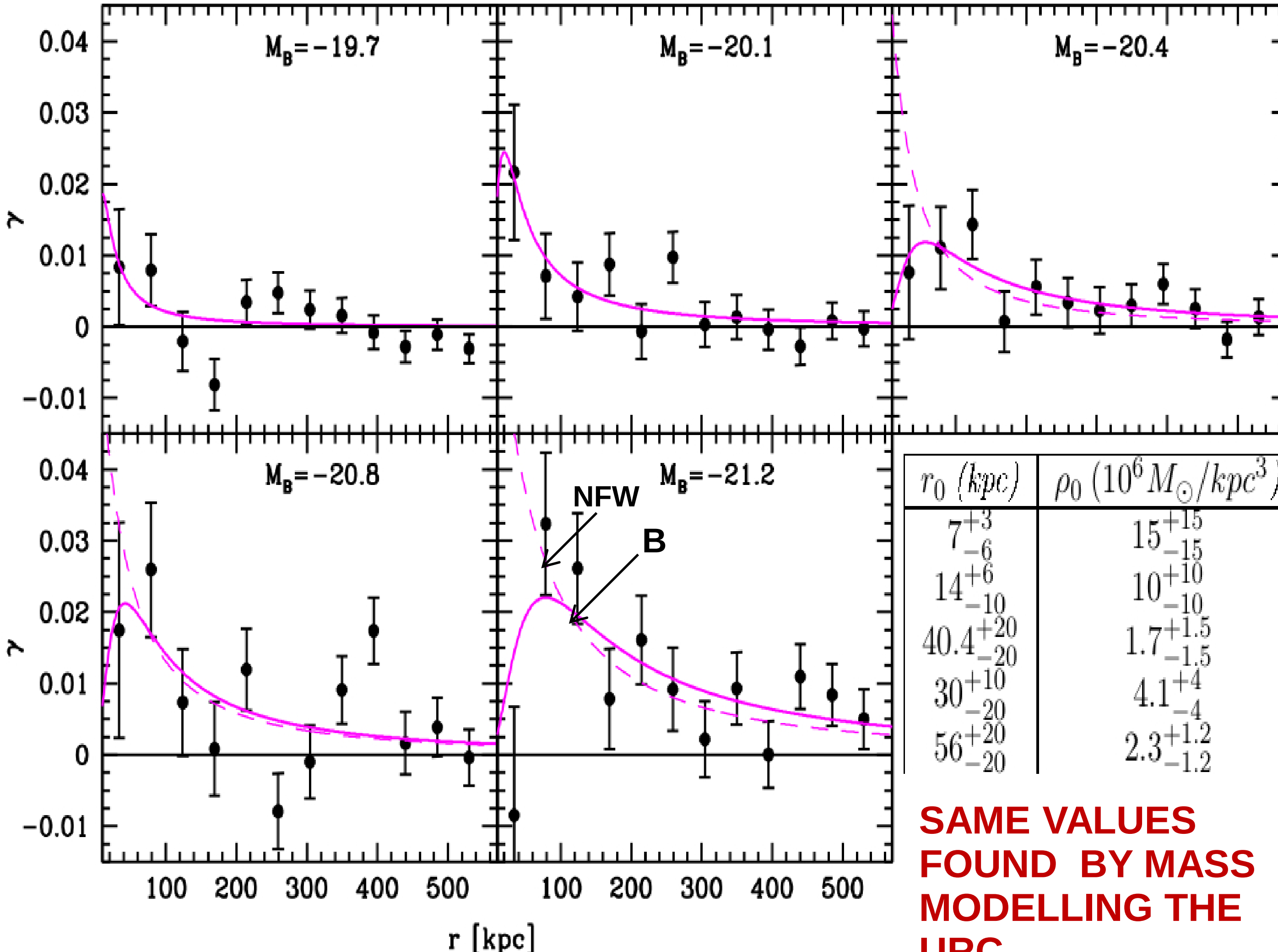
VIRIAL MASS FUNCTION OF GALAXY LUMINOSITY

Halo masses exceed the masses in baryons by much more than the cosmological factor of 7.

Halo and baryonic masses correlate.

OUTER DM HALOS: NFW/BURKERT PROFILE FIT THEM EQUALLY WELL

Donato et al 2009



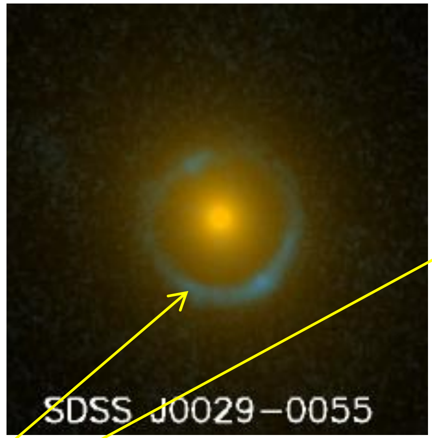
r_0 (kpc)	ρ_0 ($10^6 M_\odot/kpc^3$)
7^{+3}_{-6}	15^{+15}_{-15}
14^{+6}_{-10}	10^{+10}_{-10}
40.4^{+20}_{-20}	$1.7^{+1.5}_{-1.5}$
30^{+10}_{-20}	4.1^{+4}_{-4}
56^{+20}_{-20}	$2.3^{+1.2}_{-1.2}$

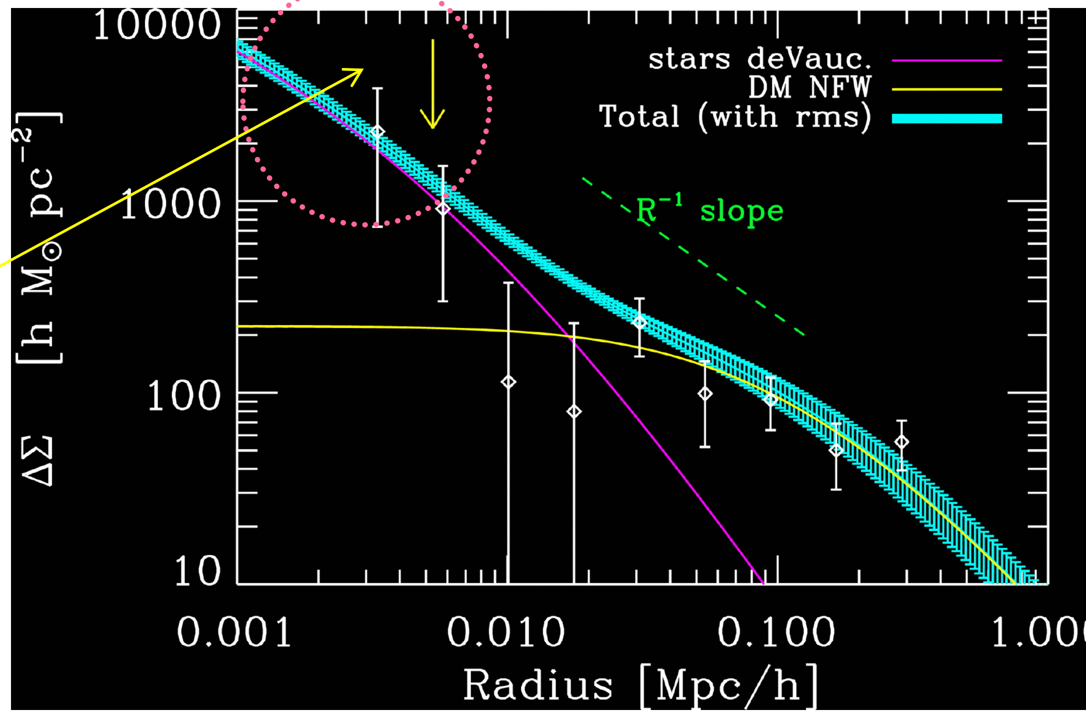
SAME VALUES FOUND BY MASS MODELLING THE URC

Weak and strong lensing

SLACS: Gavazzi et al. 2007)

strong lensing measures the **total** mass inside the Einstein ring





AN EINSTEIN RING AT $\mathbf{R_{einst}}$ IMPLIES THERE A CRITICAL SURFACE DENSITY:

$$\Sigma(R_{Einst}) = \frac{0.35}{D\ (Gpc)}\ g/cm^2$$

$$D = \frac{D_{\rm os}}{D_{\rm ol}D_{\rm ls}}$$

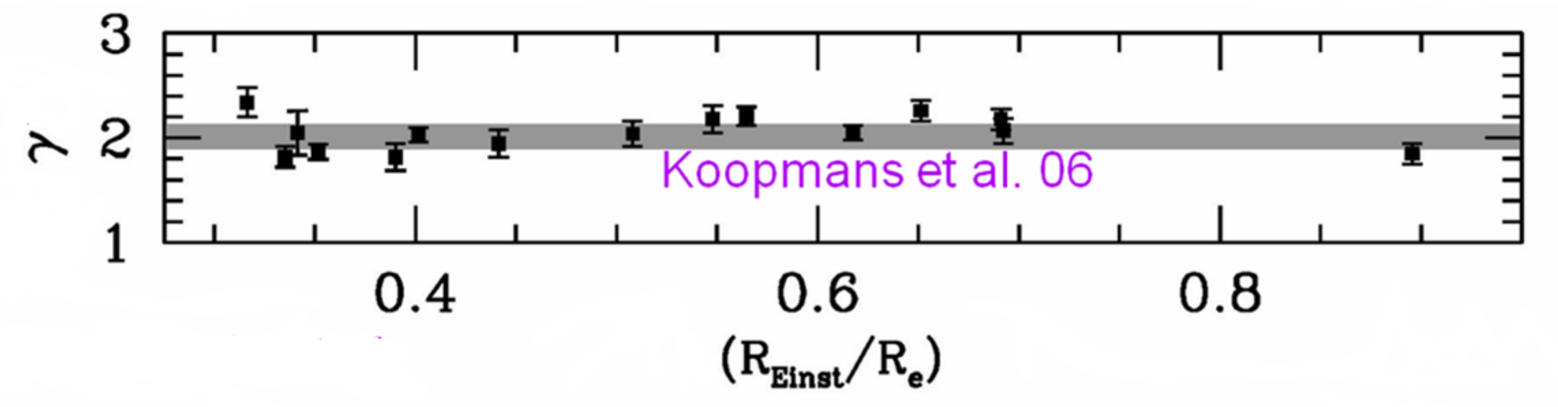
,

Strong lensing and galaxy kinematics

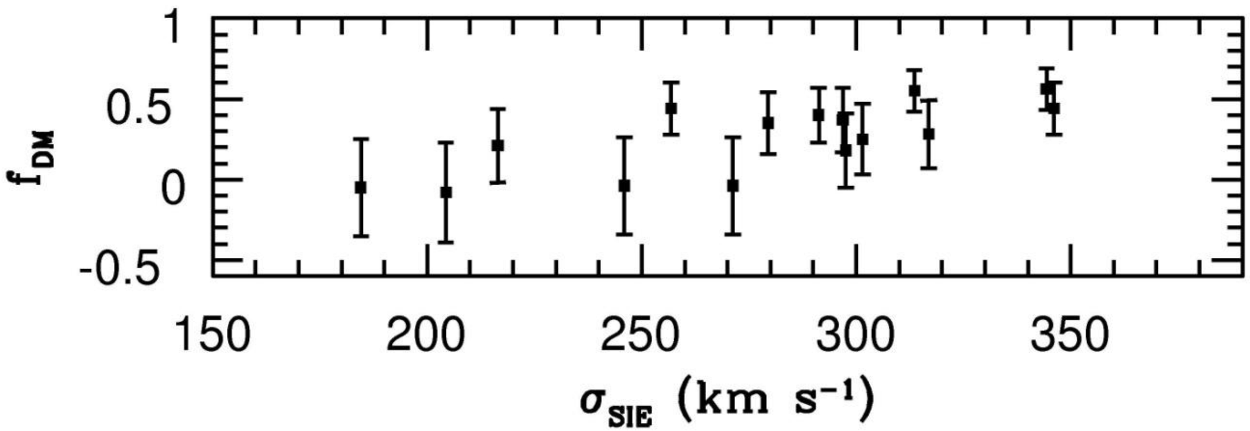
Koopmans, 2006

Assume $\rho_{tot}(r) = \rho_0(r/r_0)^{\gamma}$ $\rho_{sph}(r) = \frac{M_{sph}}{4\pi}\frac{R_e}{r(r+R_e/1.8)^3}$

Fit $M_{tot}(R_{Einst}), \sigma_{ap}(R)$



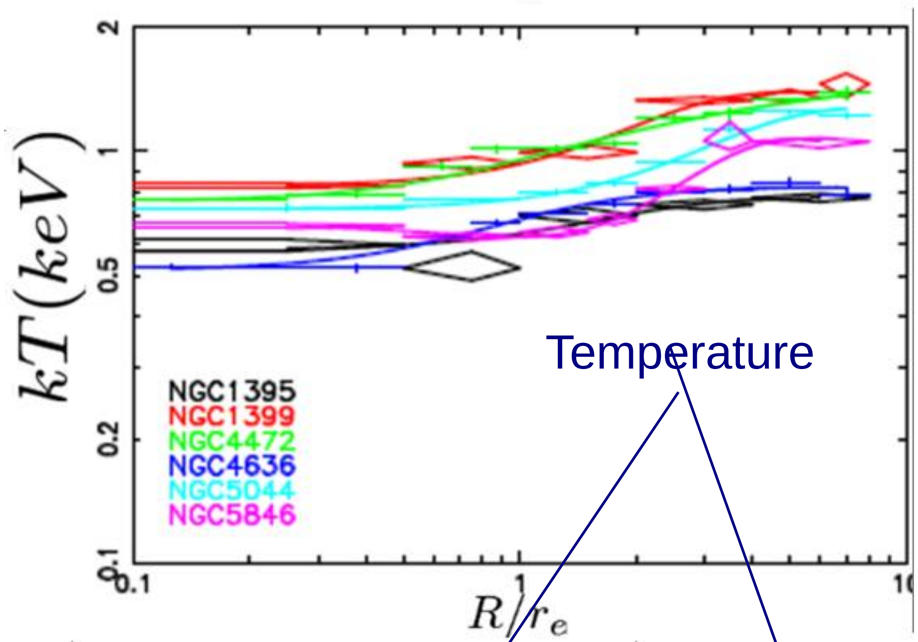
Inside R_{Einst} the total (spheroid + dark halo) mass increase proportionally with radius



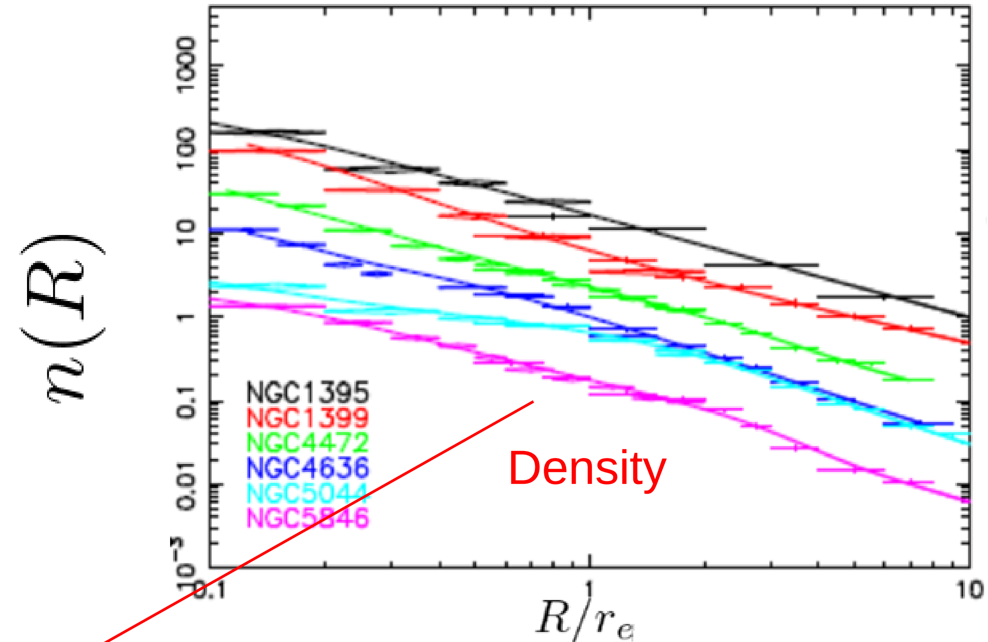
Inside R_{Einst} the total the fraction of dark matter is small

Mass Profiles from X-ray

Nigishita et al 2009



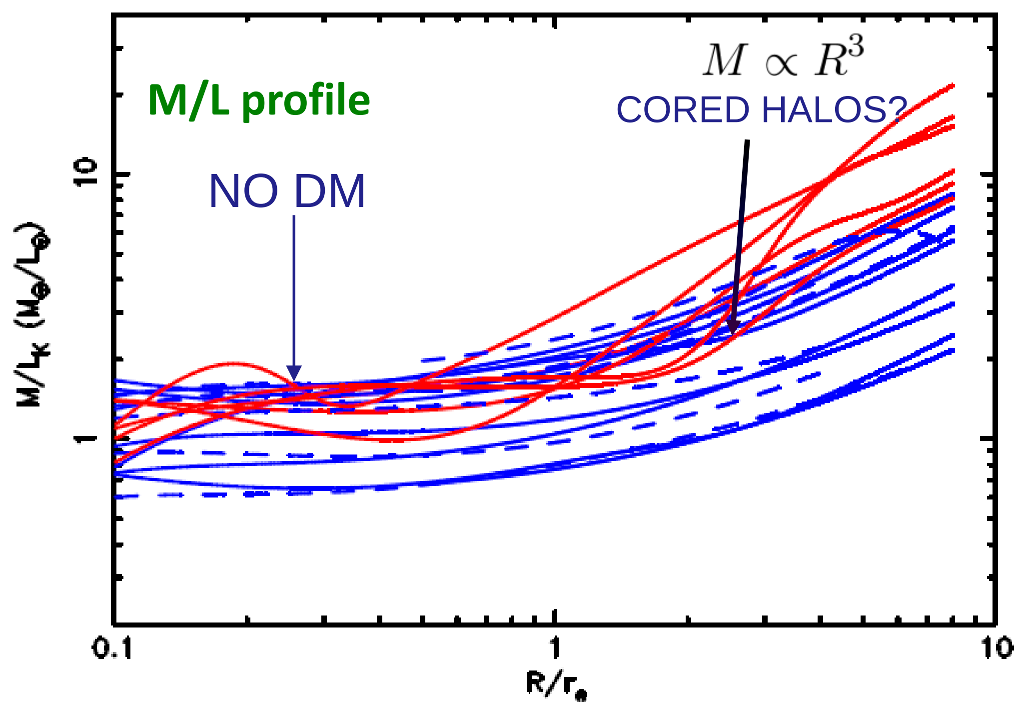
Temperature



Density

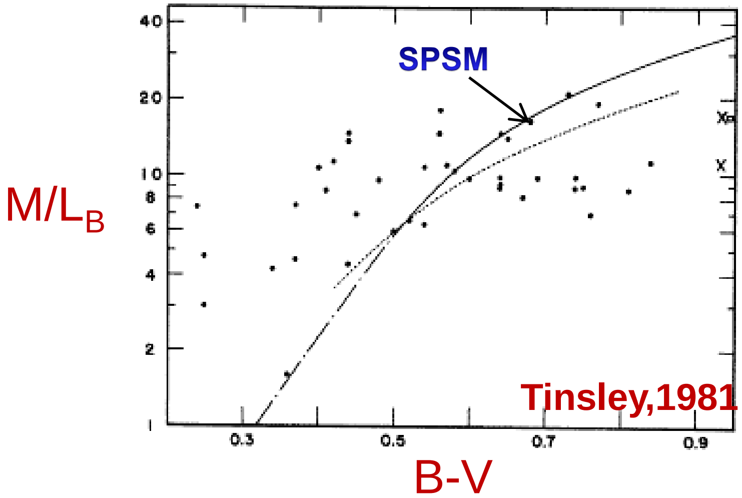
$$M(R) = -\frac{kT(R)\cdot R}{G\mu m_p}\left(\frac{d\ln n(R)}{d\ln R} + \frac{d\ln T(R)}{d\ln R}\right)$$

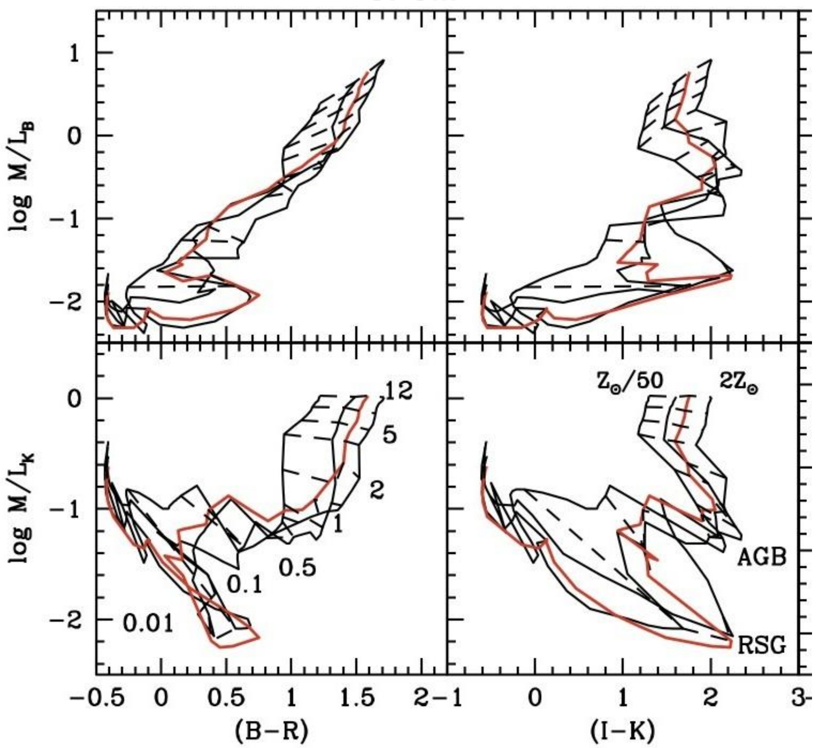
Hydrostatic Equilibrium



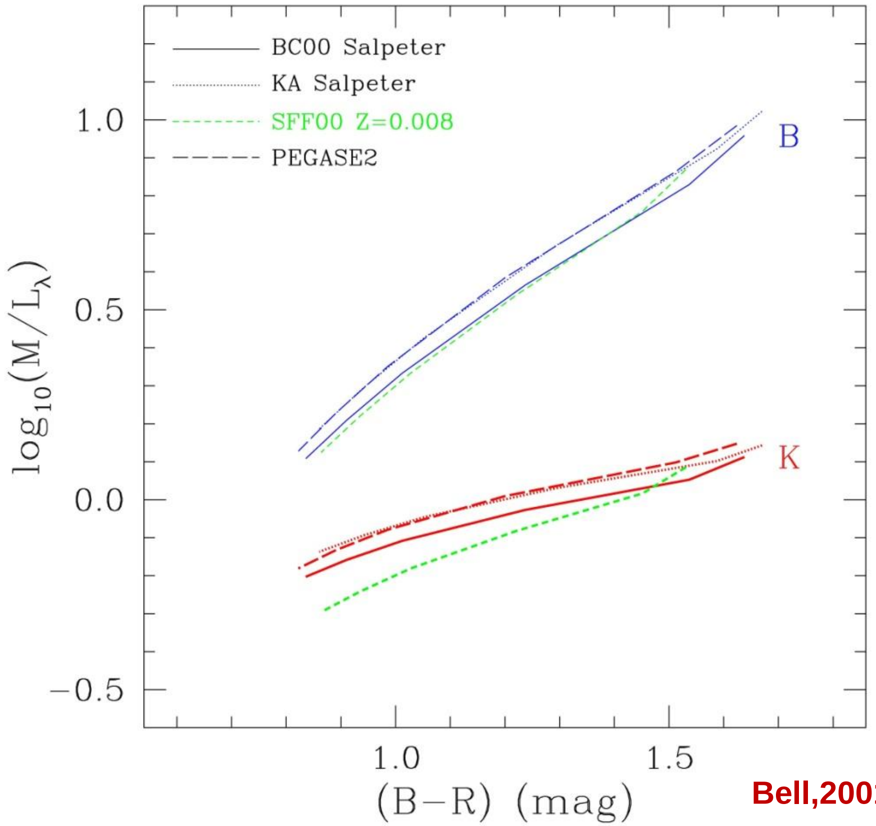
The mass in stars in galaxies

Stellar mass of a galaxy can be obtained via Stellar Population Synthesis Models by its colors and SED





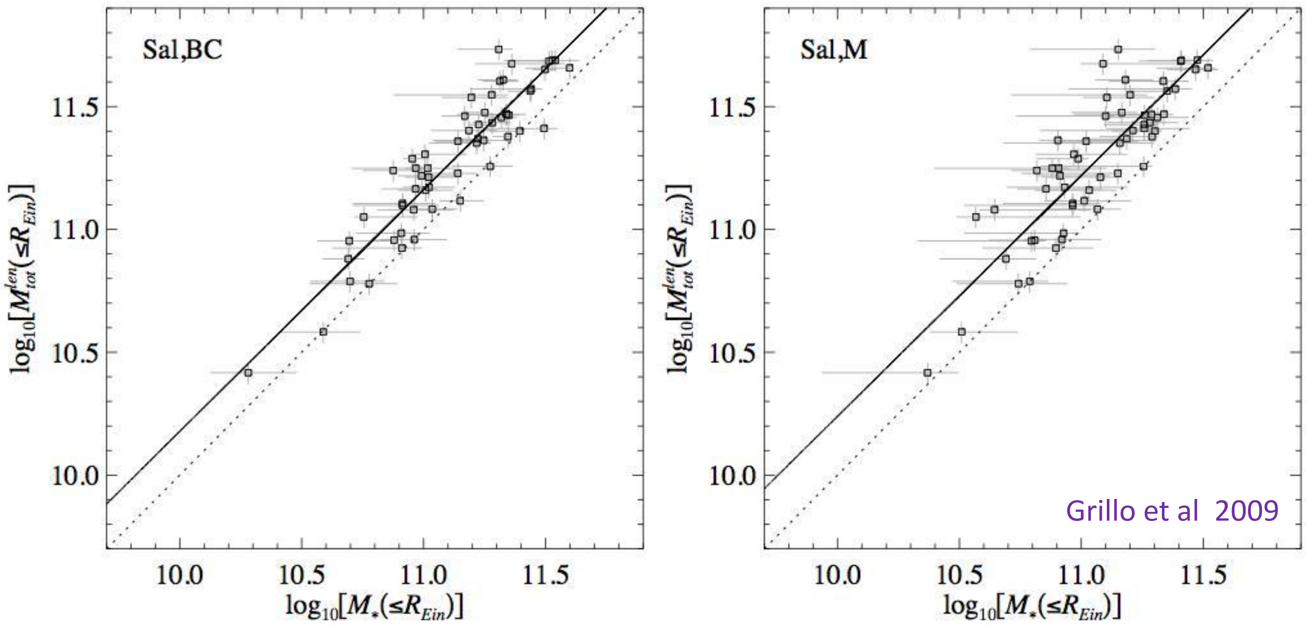
Maraston et al , 2009



Bell,2001

Log (mass-to-light) = a + b (color)

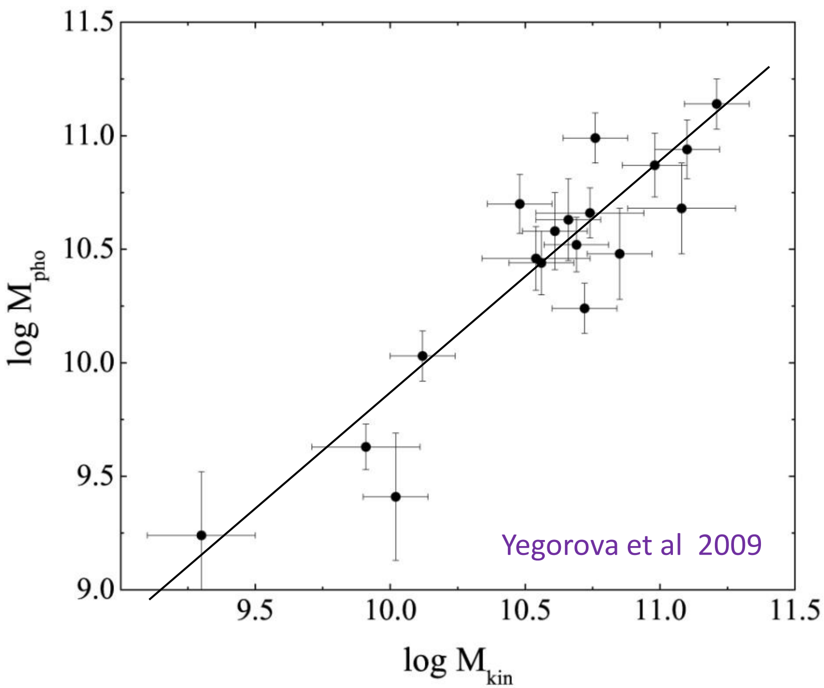
Dynamical and photometric estimates of the galaxy stellar mass agree

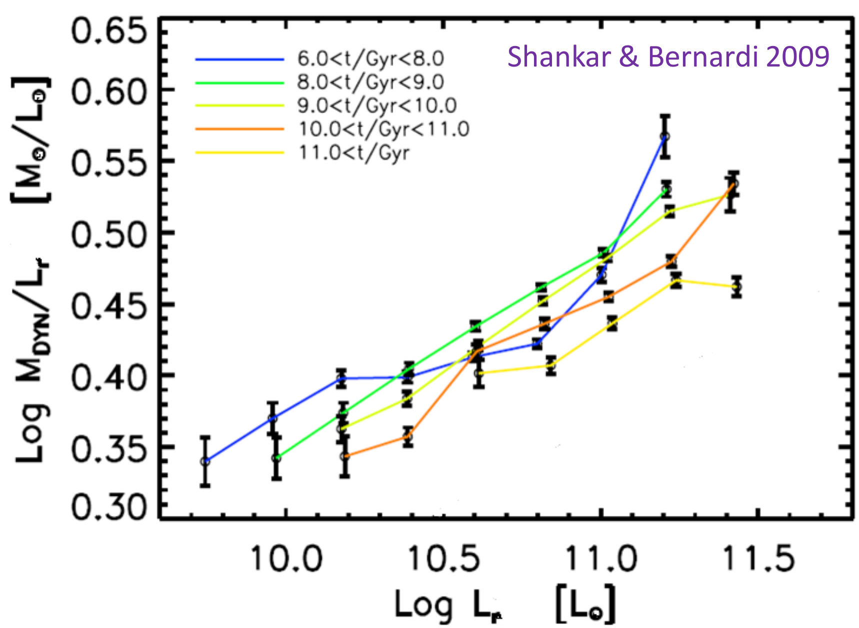


Discrepancy 0.15 dex

small for cosmological applications

Large for mass modelling

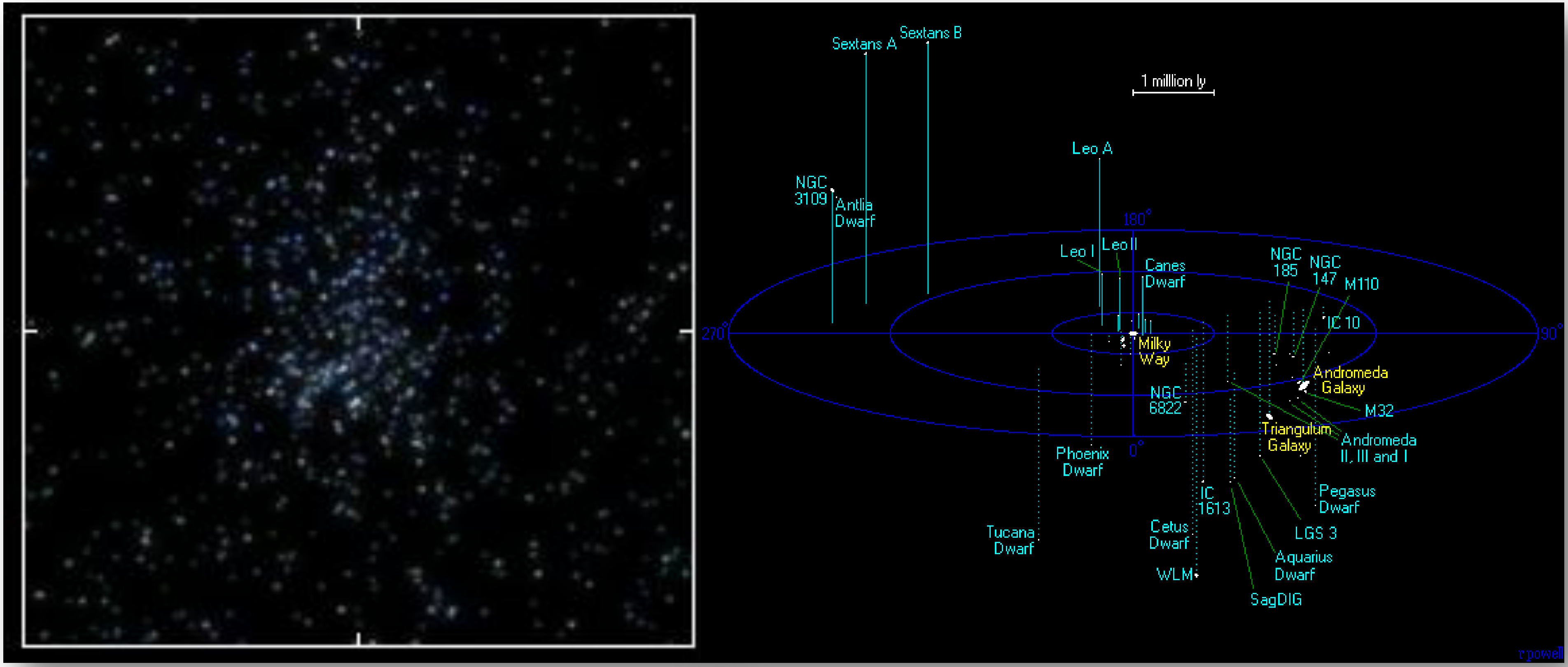




ELLIPTICALS: WHAT WE KNOW

A LINK AMONG THE STRUCTURAL PROPERTIES OF STELLAR SPHEROID
SMALL AMOUNT OF DM INSIDE R_E
MASS PROFILE COMPATIBLE WITH NFW AND BURKERT
DARK MATTER DIRECTLY TRACED OUT TO R_{VIR}

dSphs



Sextans A
Sextans B
1 milllion 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

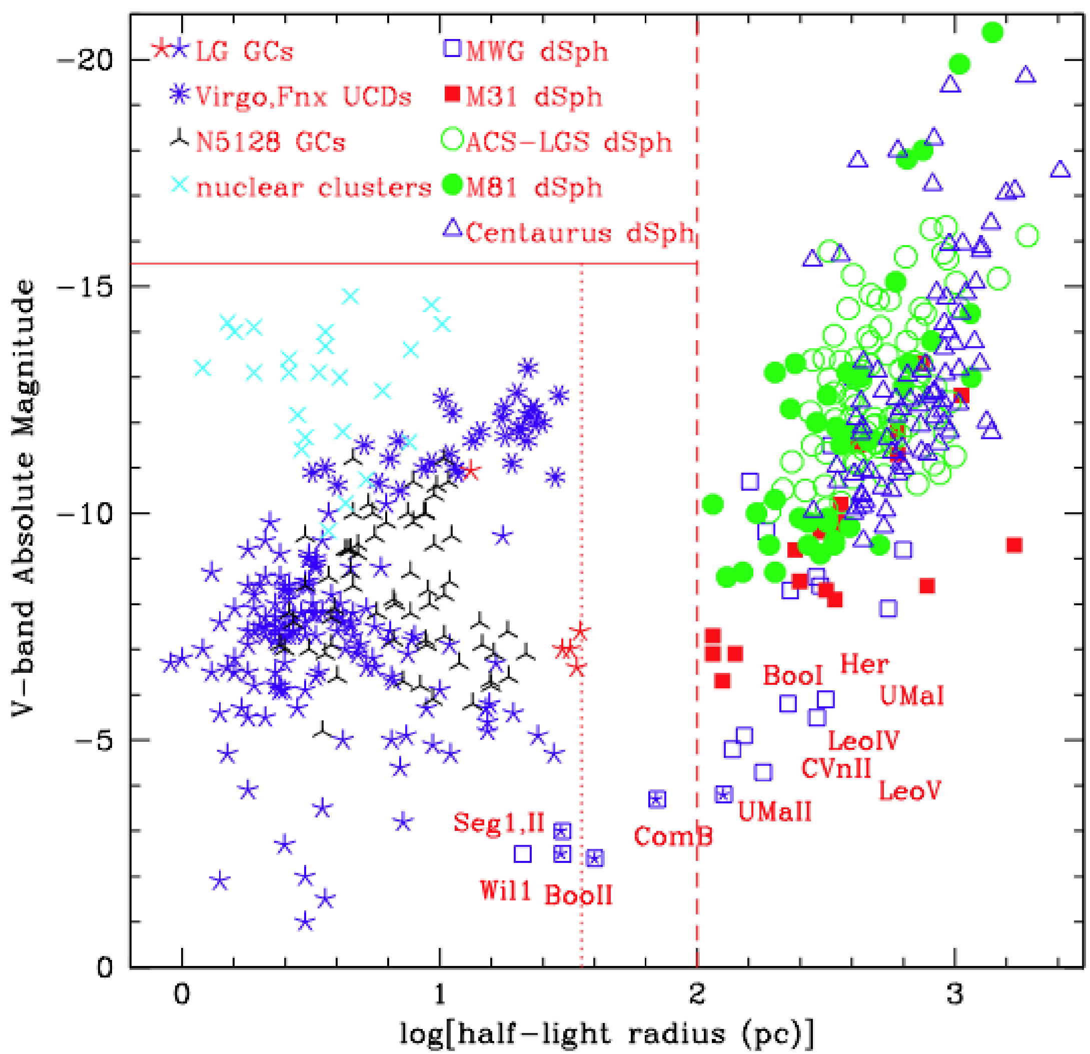
Dwarf spheroidals: basic properties

The smallest objects in the Universe, benchmark for theory

$$L = 2\times10^3 L_\odot - 2\times10^7 L_\odot \quad \sigma_0 \sim 7 - 12\,\mathrm{km\,s^{-1}} \quad r_0 \approx 130 - 500\,\mathrm{pc}$$

dSph show large M_{grav}/L

Luminosities and sizes of Globular Clusters and dSph are different

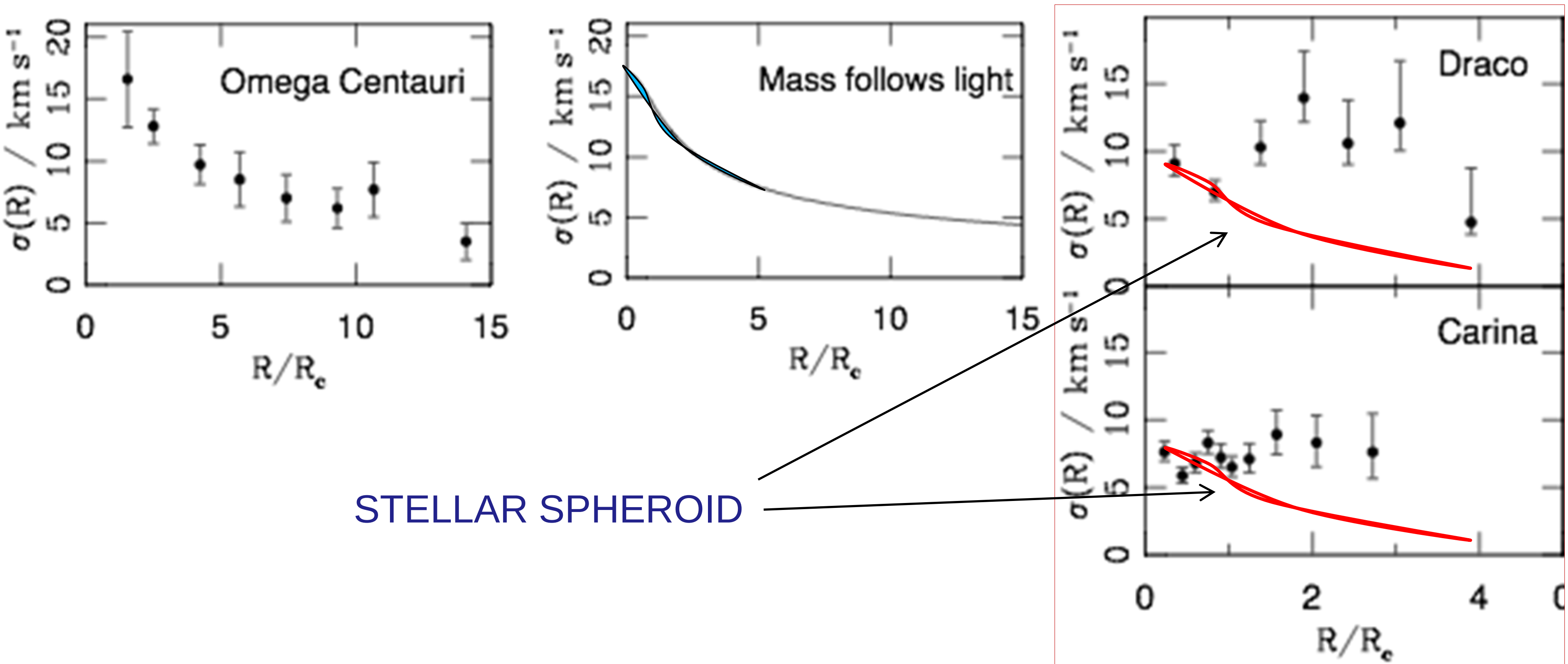


Gilmore et al 2009

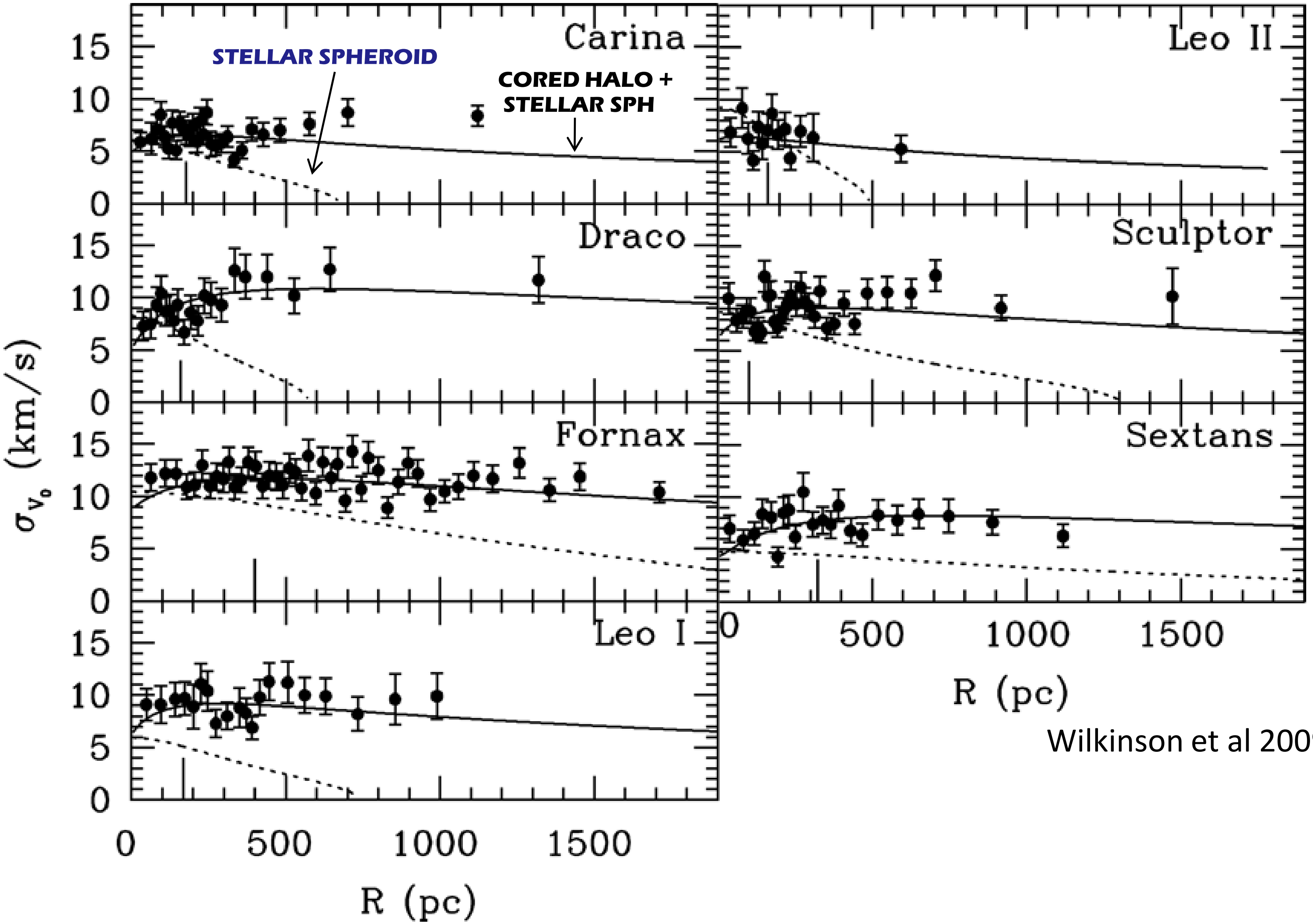
Kinematics of dSph

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



Dispersion velocity profiles



Wilkinson et al 2009

dSph dispersion profiles generally remain flat to large radii

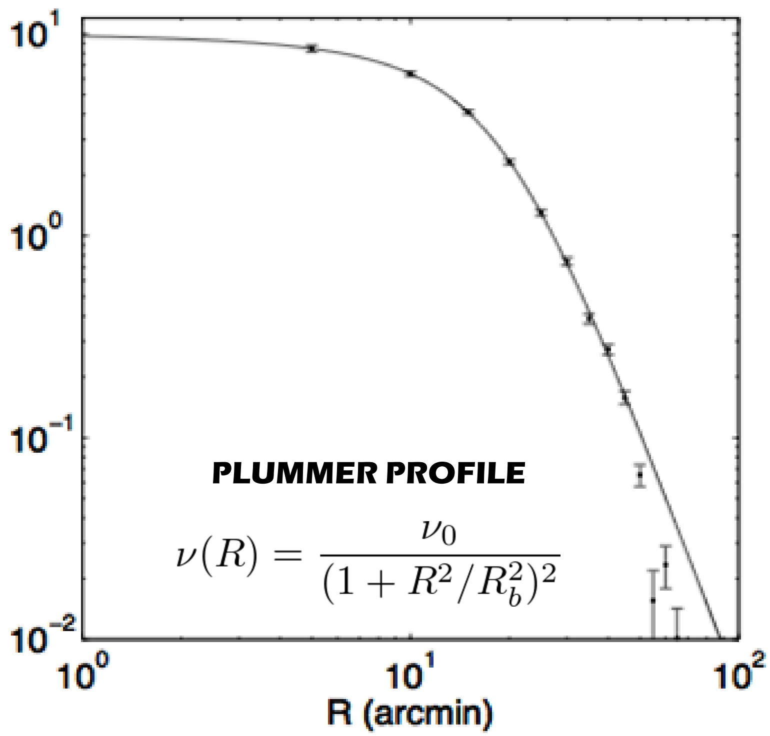
Mass profiles of dSphs

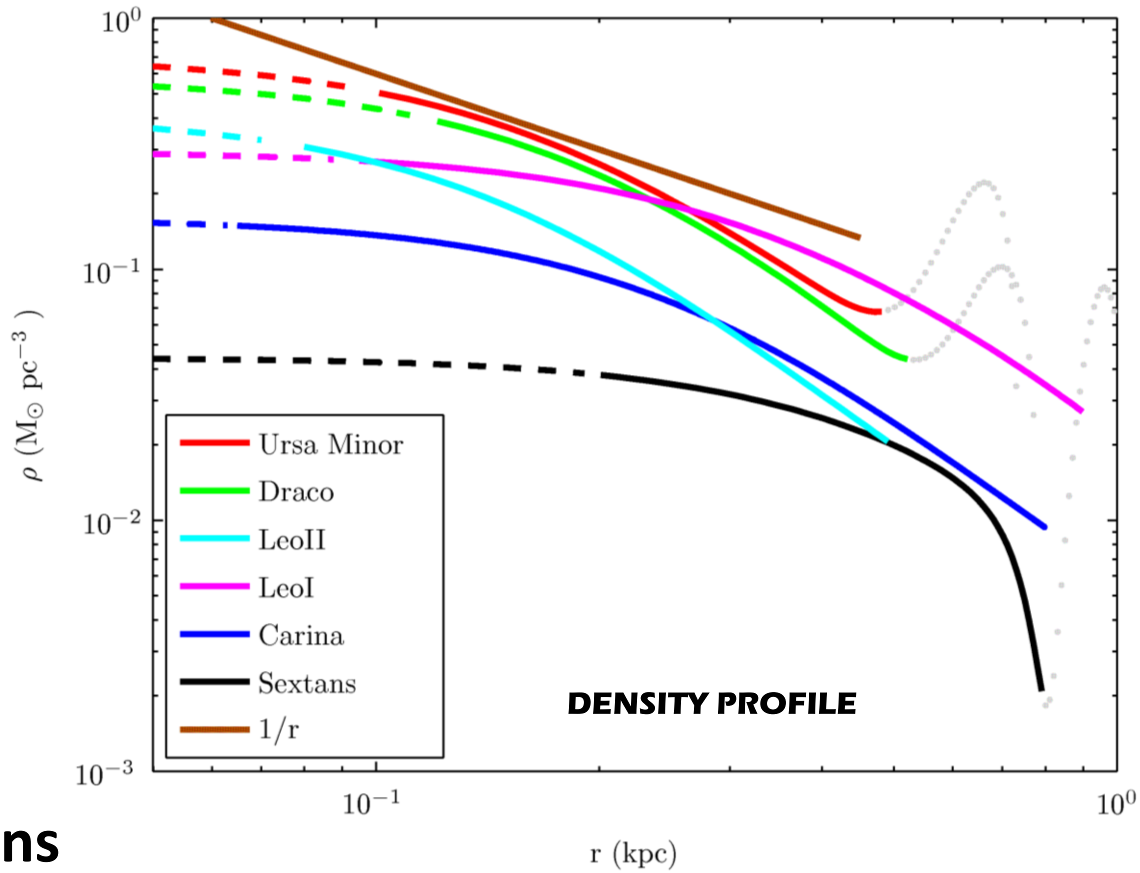
$$M(r) = -\frac{r^2}{G}\left(\frac{1}{\nu}\frac{d\,\nu\sigma_r^2}{d\,r} + 2\,\frac{\beta\sigma_r^2}{r}\right)$$

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



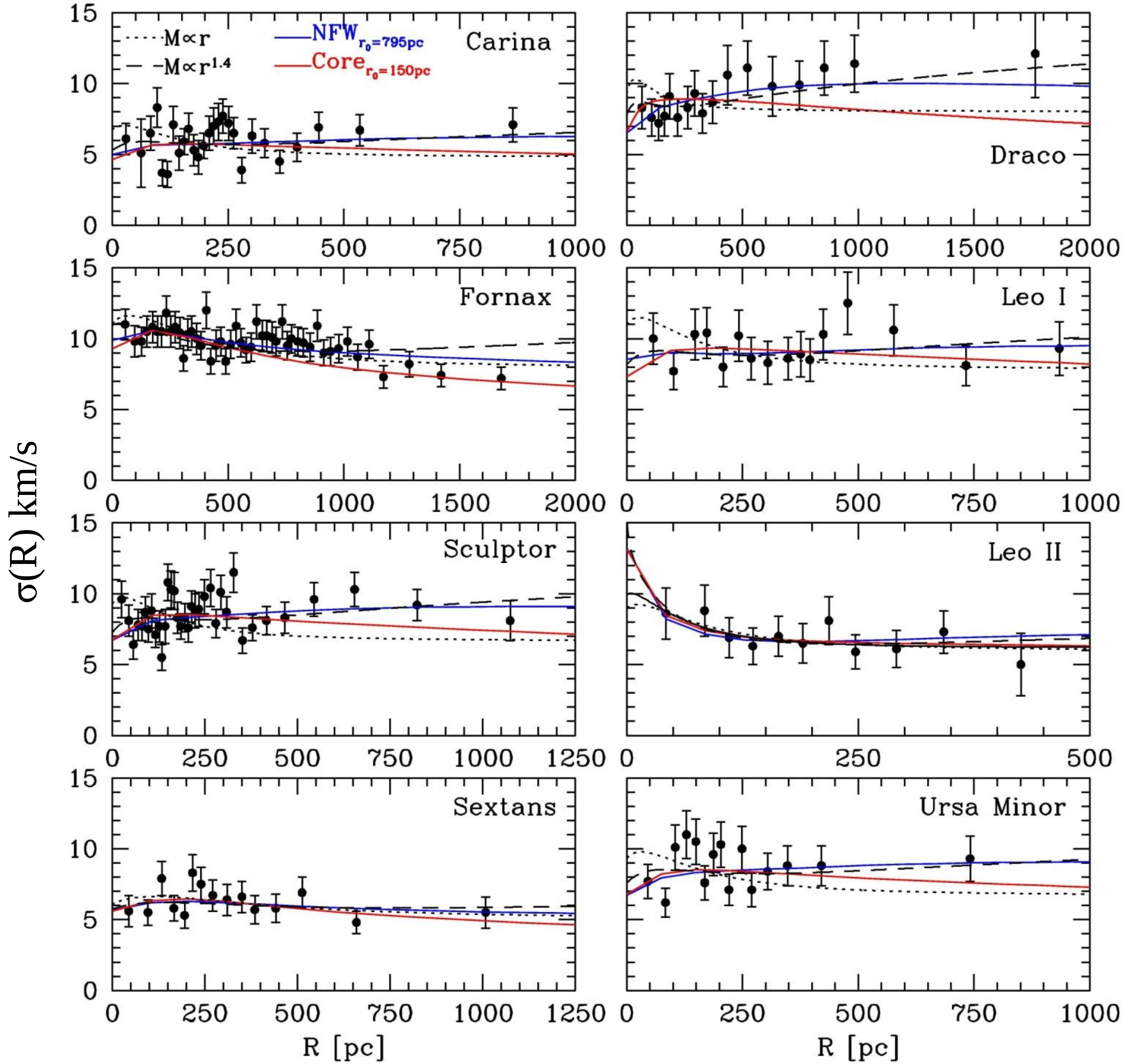


Results point to cored distributions

Gilmore et al 2007

Degeneracy between DM mass profile and velocity anisotropy

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

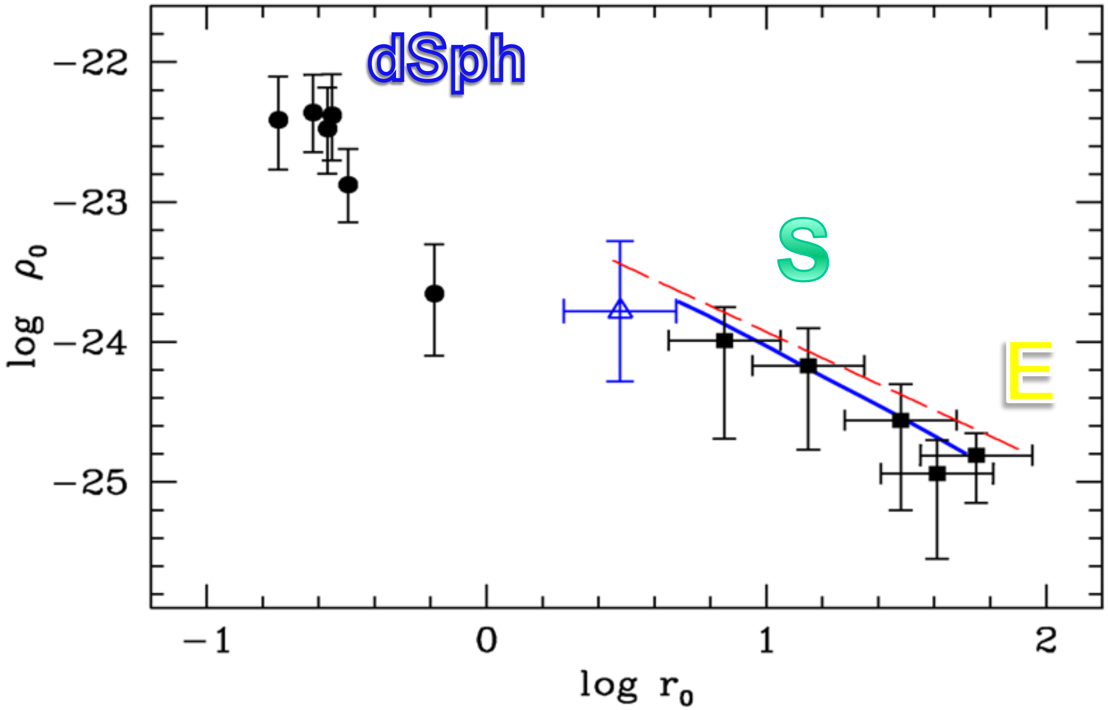


Walker et al 2009

dSphs cored halo model

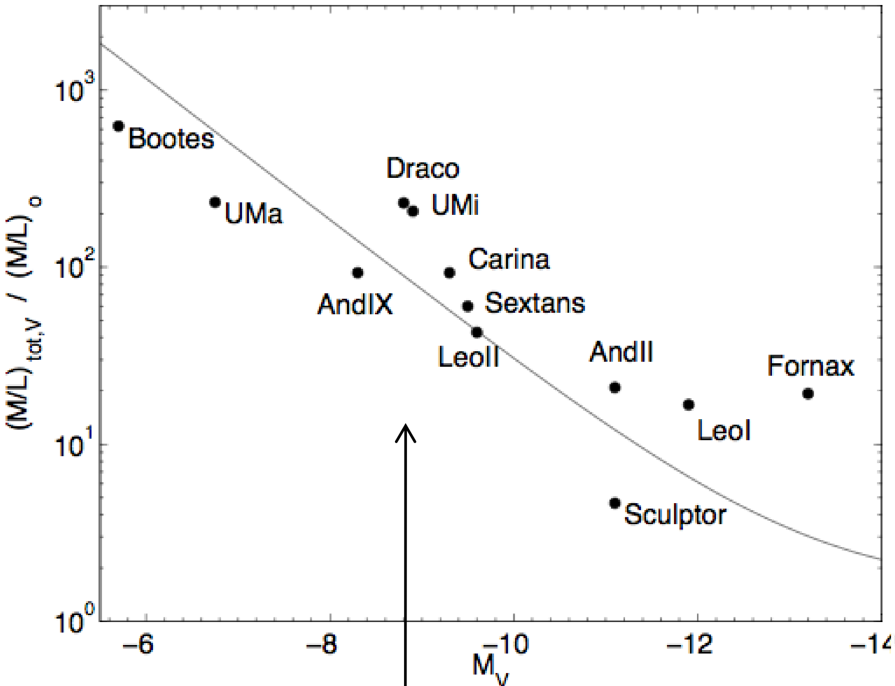
halo central densities correlate with core radius in the same way as Spirals and Ellipticals

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



Donato et al 2009

Global trend of dSph haloes

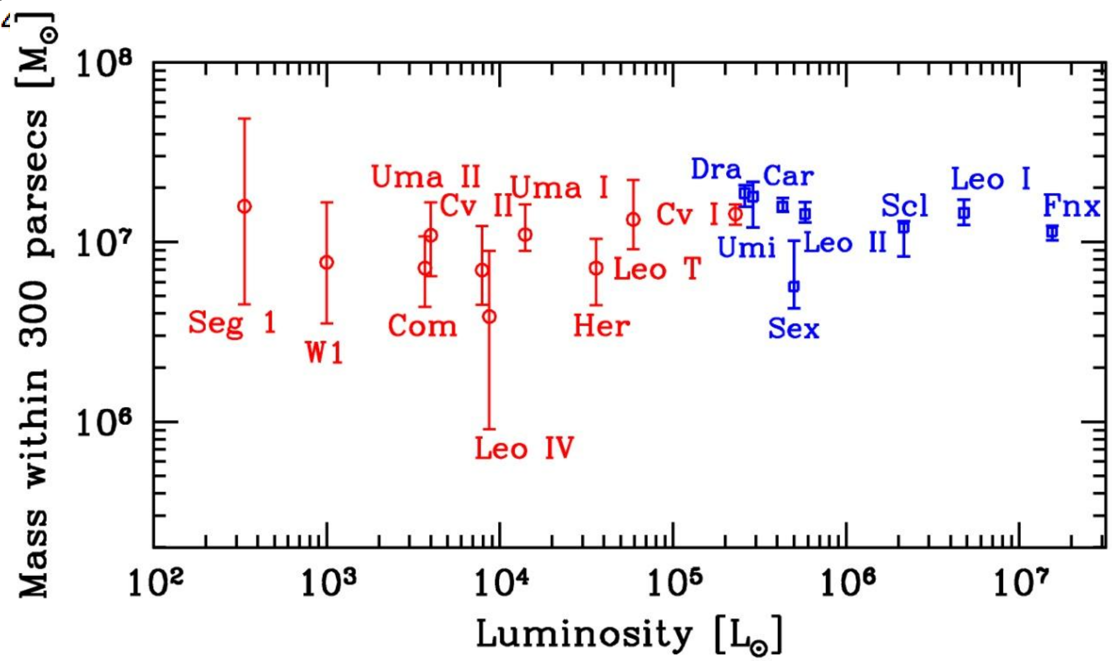


Mateo et al 1998

Gilmore et al 2007

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

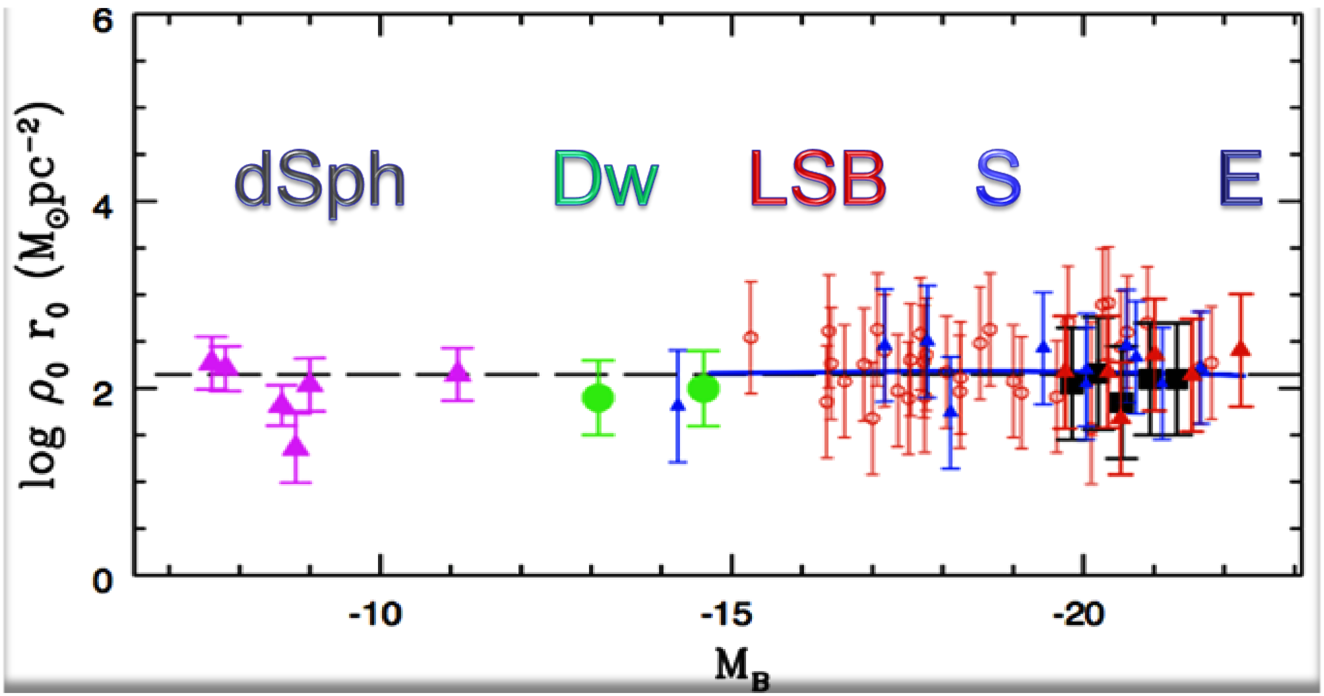
Strigari et al 2008



DSPH: WHAT WE KNOW

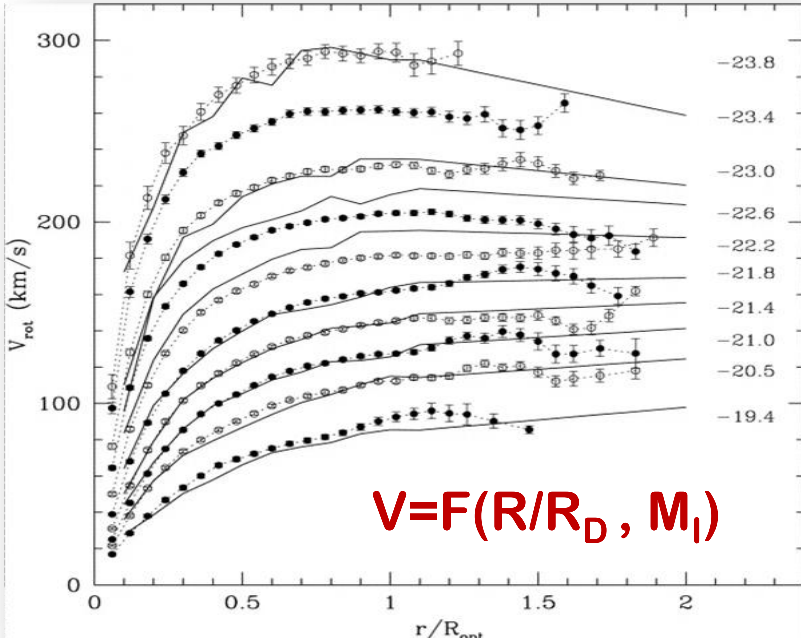
PROVE THE EXISTENCE OF DM HALOS OF 10^{10} M_{SUN} AND ρ_0 =10^{-21} g/cm^3
DOMINATED BY DARK MATTER AT ANY RADIUS
MASS PROFILE CONSISTENT WITH THE EXTRAPOLATION OF THE URC
HINTS FOR THE PRESENCE OF A DENSITY CORE

GALAXY HALOS: AN UNIFIED VISION

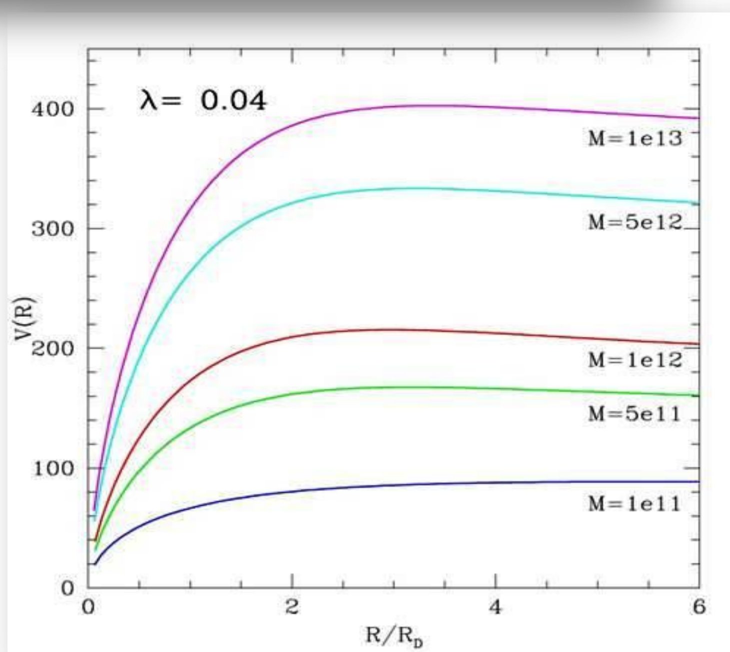


Universal Mass Distribution

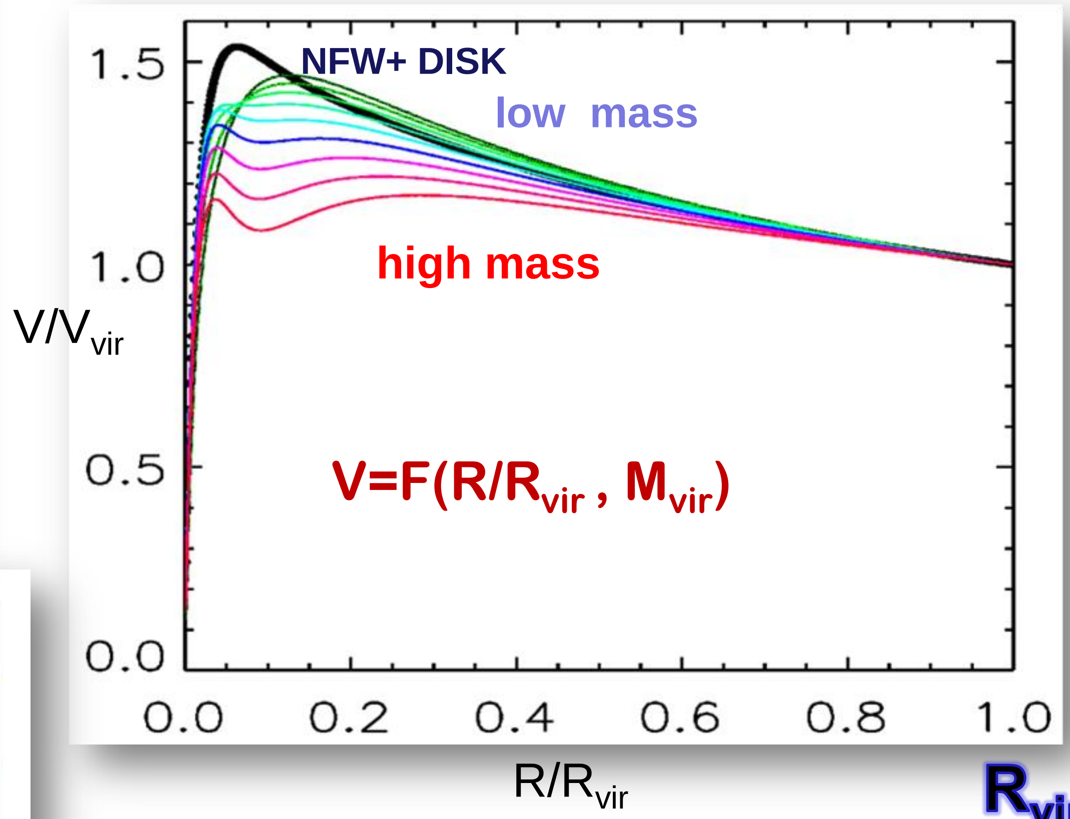
URC



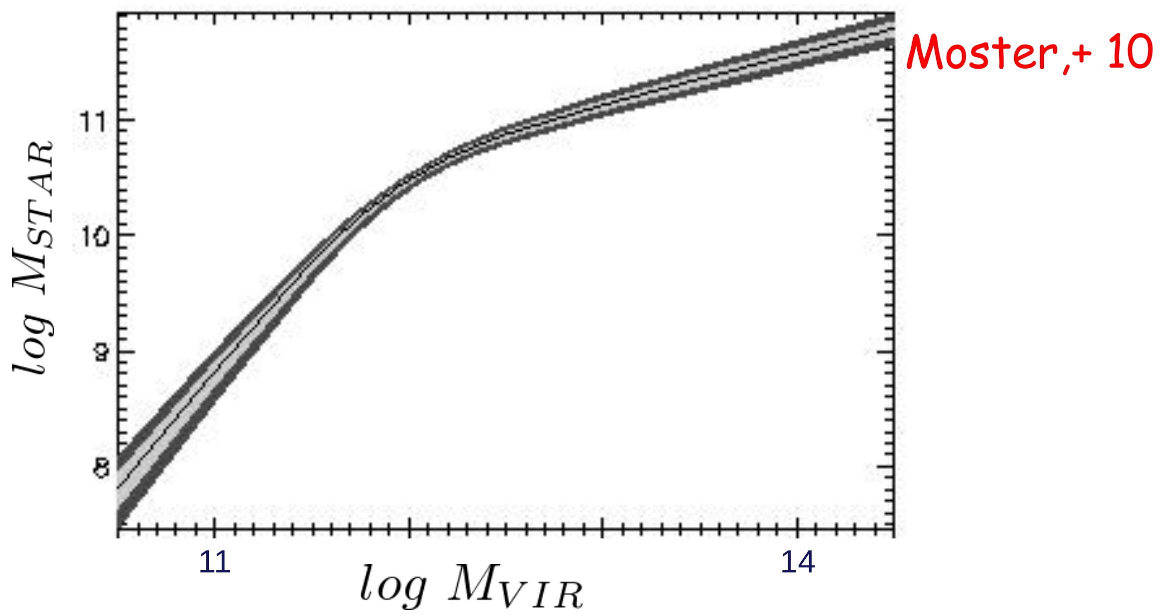
ΛCDM



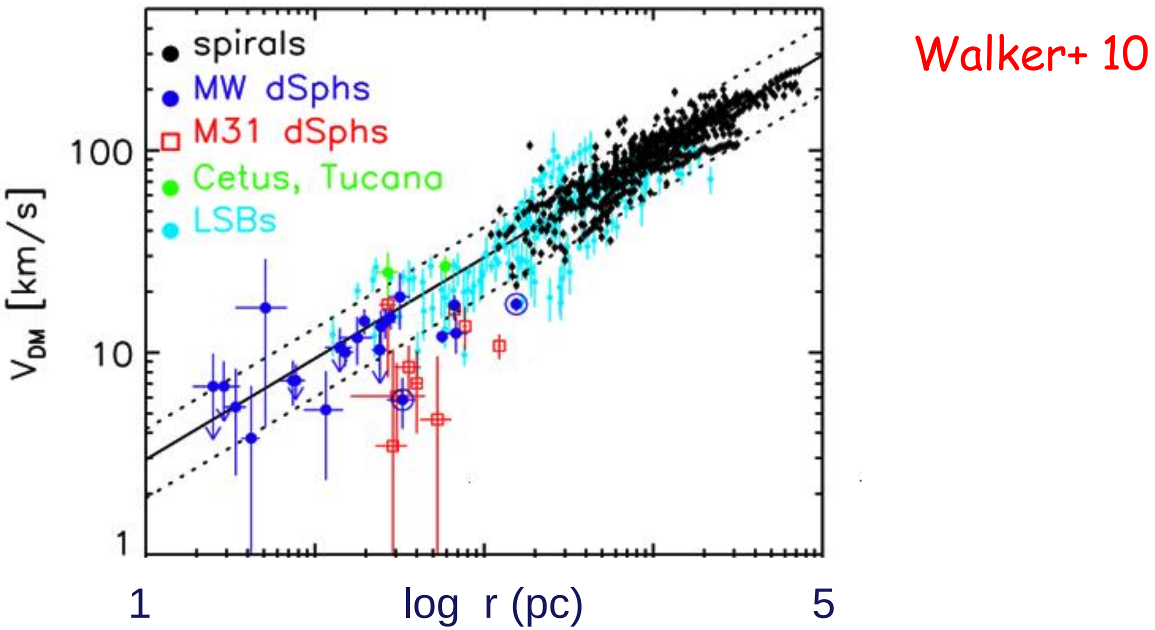
URC out to R_{vir} and ΛCDM model



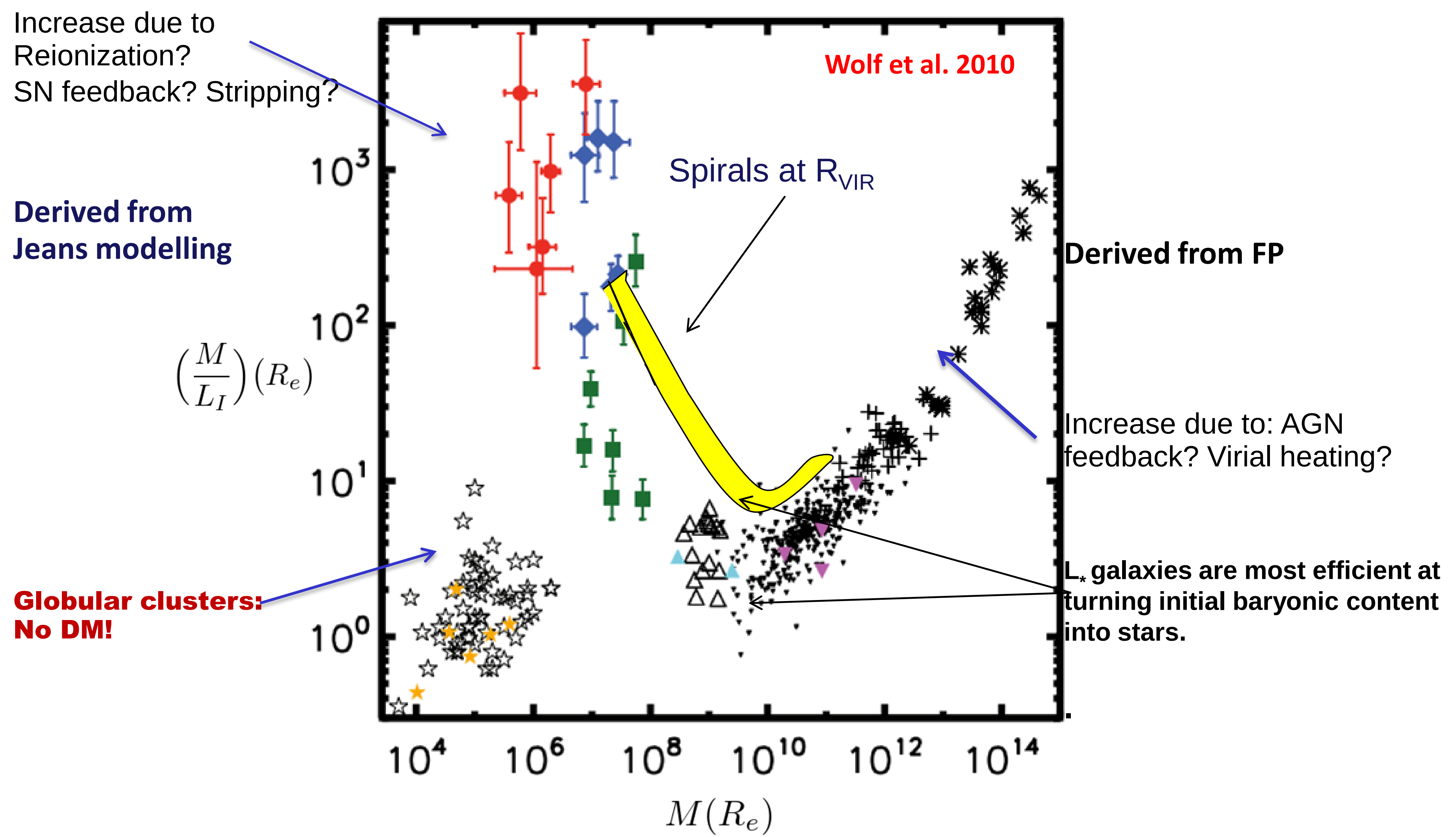
Virial Halo Masses correlate with the Masses of the Stellar Component



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

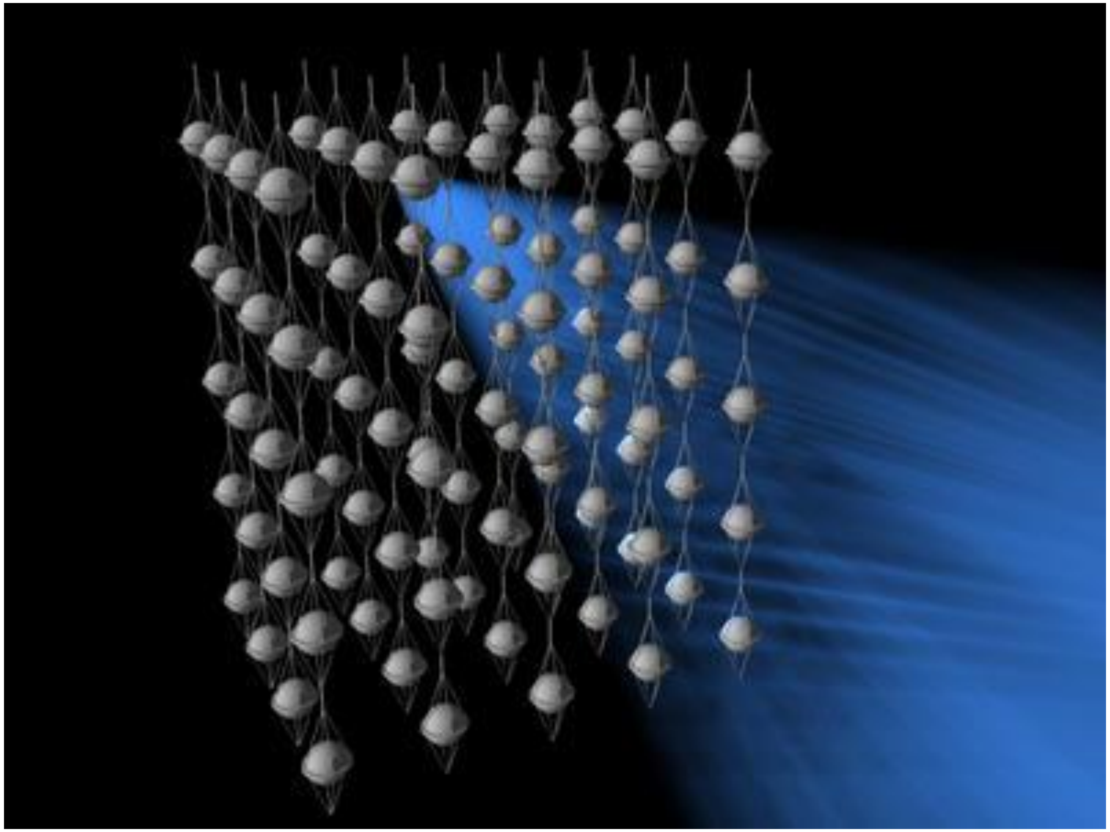


Mass-to-Light ratios at half light radius R_e in virialized objects



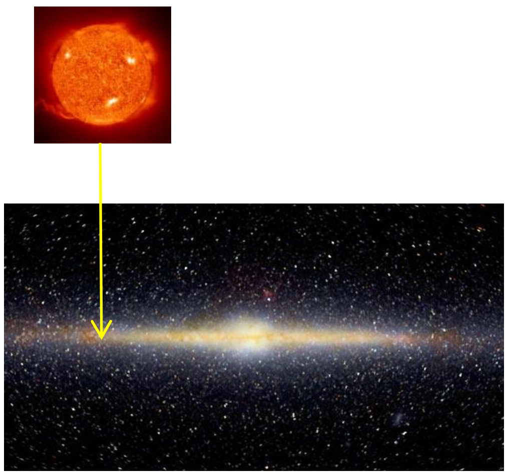
Galaxies are increasingly DM dominated at lower and higher mass

DETECTING DARK MATTER



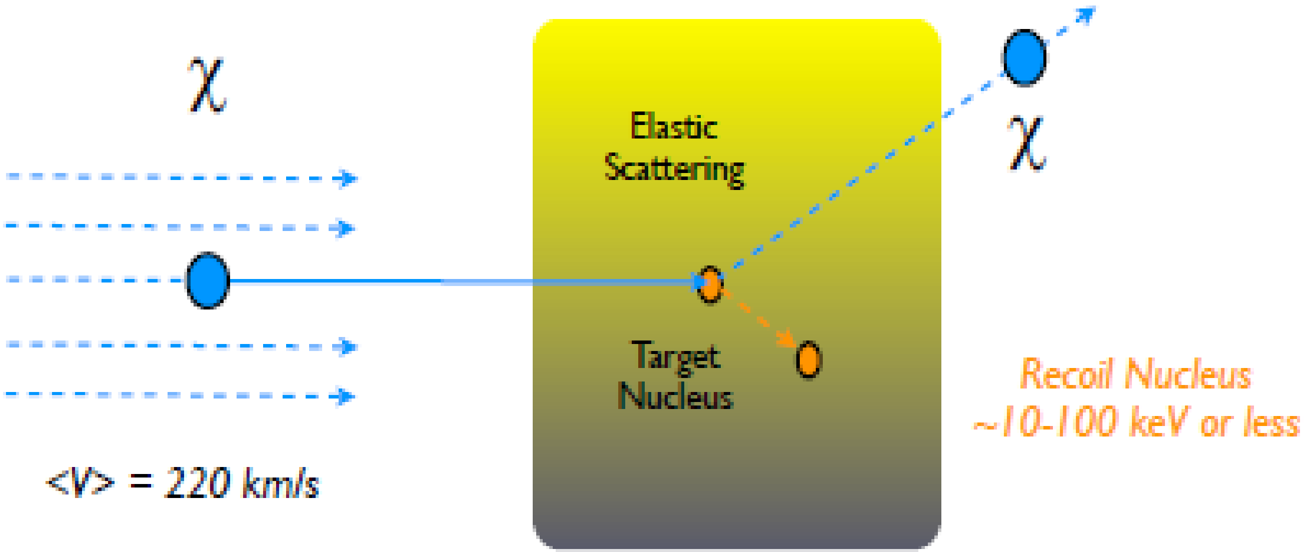
Principle of Direct Detection

Goodman and Witten: coherent scattering of WIMPs off nuclei (1985)



$$\rho_{DM}(R_{\odot}) = 0.4\ GeV/cm^3$$

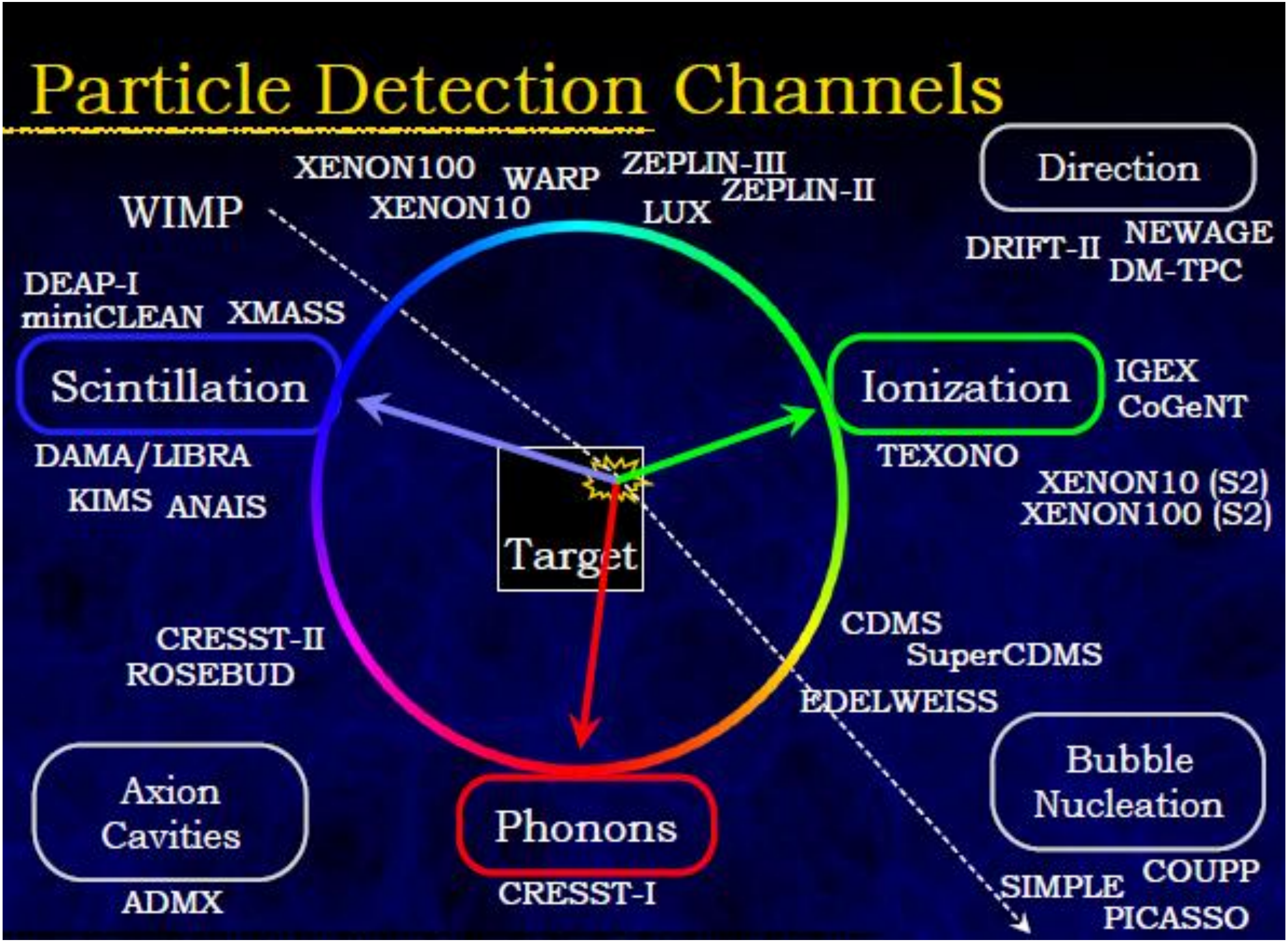
Nesti, 2010



$\sigma_{\chi N}$ probed to-date ~ 10^{-44} cm^2

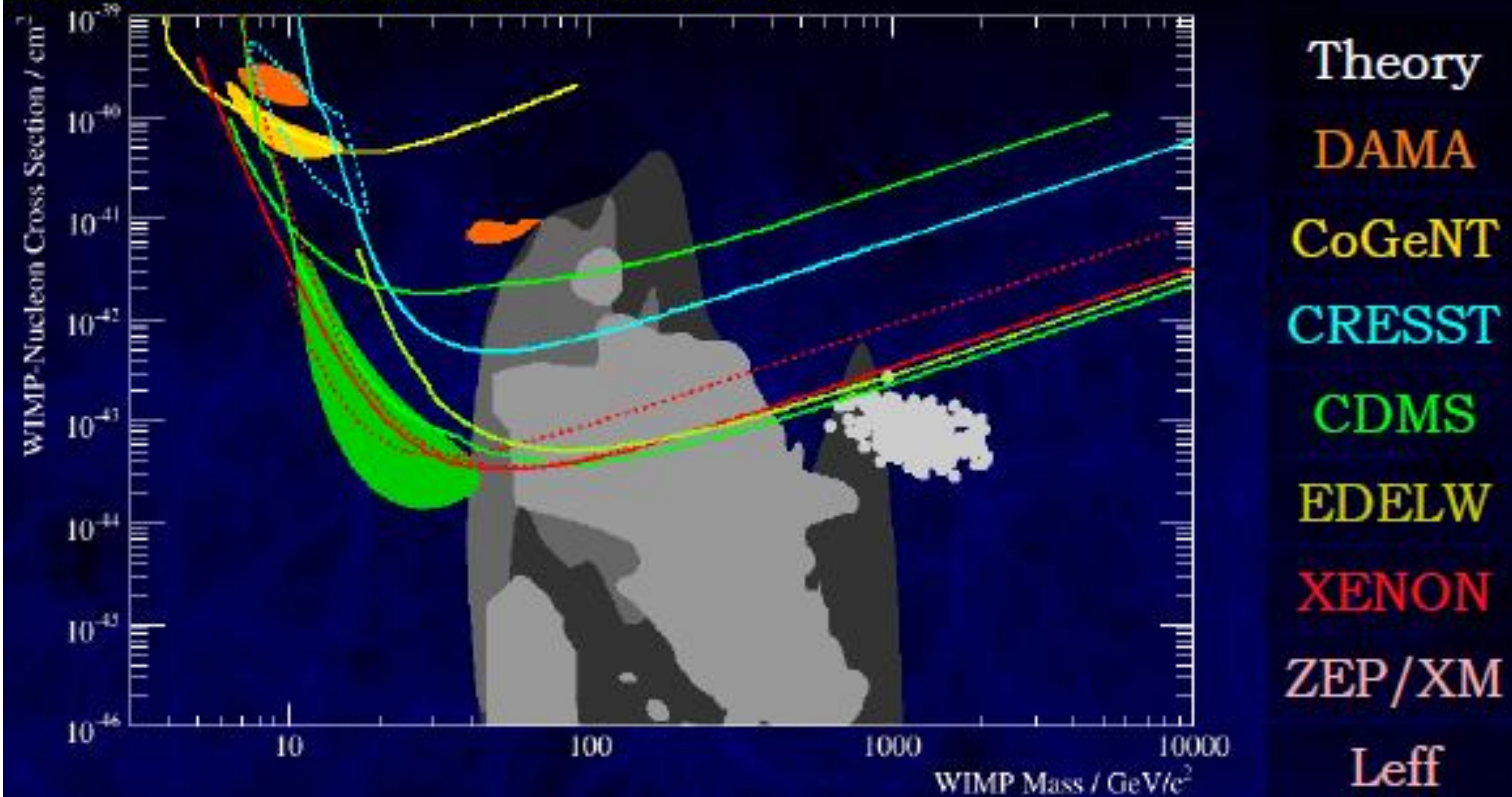
What is measured (with different target nuclei and detectors) : energy of the recoiling nucleus

What are the challenges: very small energy, very large backgrounds and very small rate



Particle Detection Channels
WIMP
XENON100
XENON10
WARP
ZEPLIN-III
ZEPLIN-II
LUX
Direction
DRIFT-II
NEWAGE
DM-TPC
DEAP-I
miniCLEAN
XMASS
Scintillation
DAMA/LIBRA
KIMS
ANAIS
Ionization
IGEX
CoGeNT
TEXONO
XENON10 (S2)
XENON100 (S2)
Target
CRESST-II
ROSEBUD
CDMS
SuperCDMS
EDELWEISS
Bubble Nucleation
COUPP
SIMPLE
PICASSO
Axion Cavities
ADMX
Phonons
CRESST-I

Summary



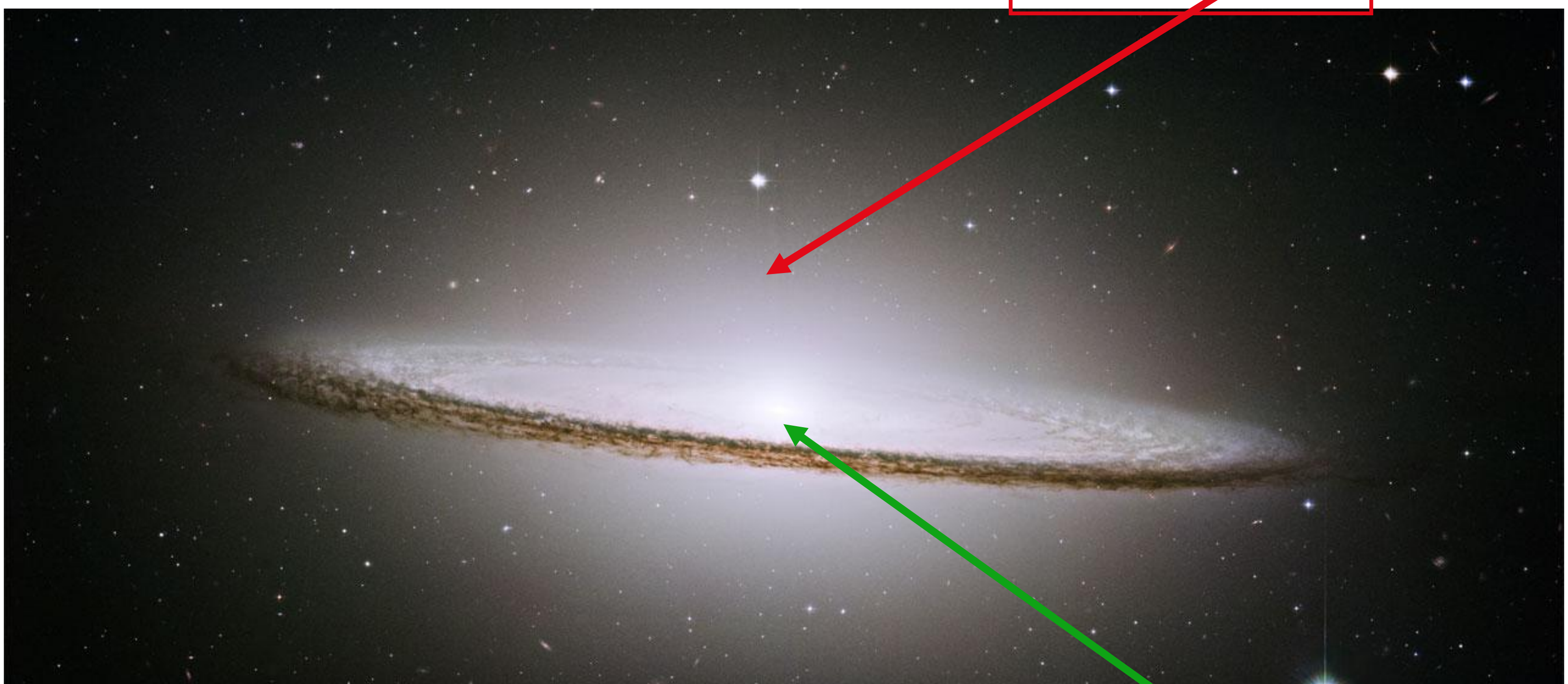
A very active and versatile field of research
many hints to follow up, many promising experiments

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

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



FAKE ASTRO SIGNAL

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

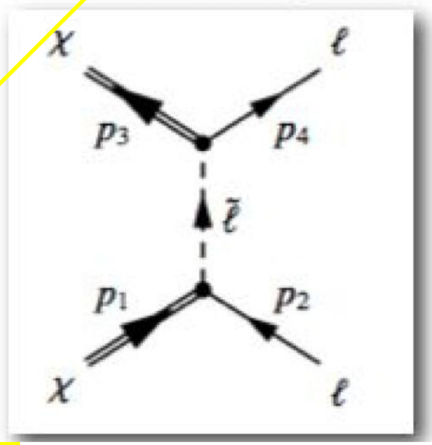
Antimatter is already manufactured inside the galactic disk

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

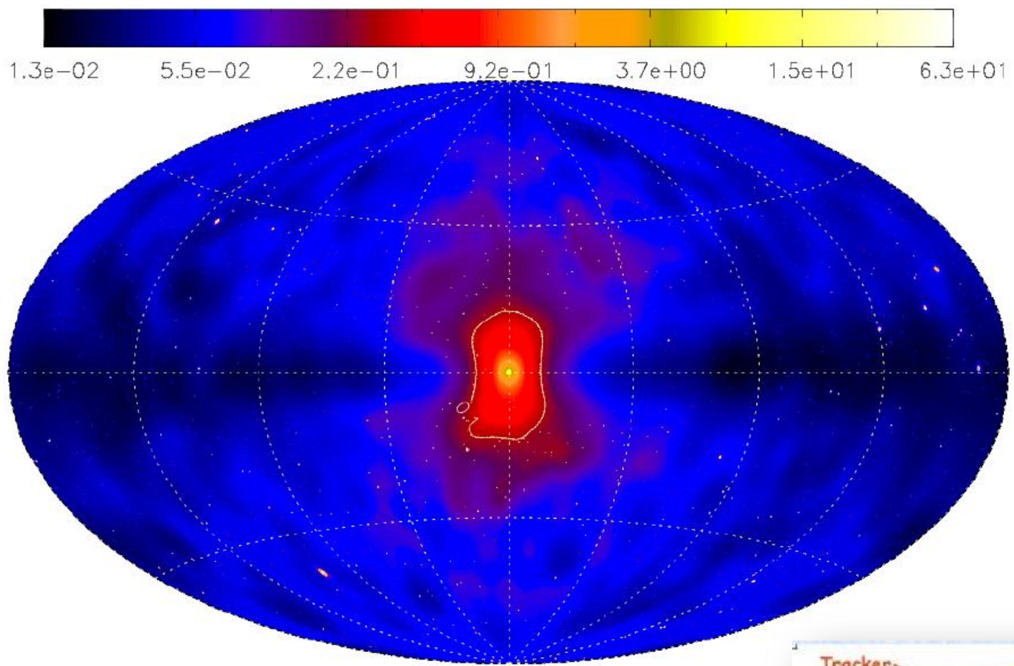


E =photon energy
ΔΨ=detector acceptance
σ =annihilation cross section
v =wimp velocity
m =wimp mass
B =branching ratio
N =photon spectrum in a given channel

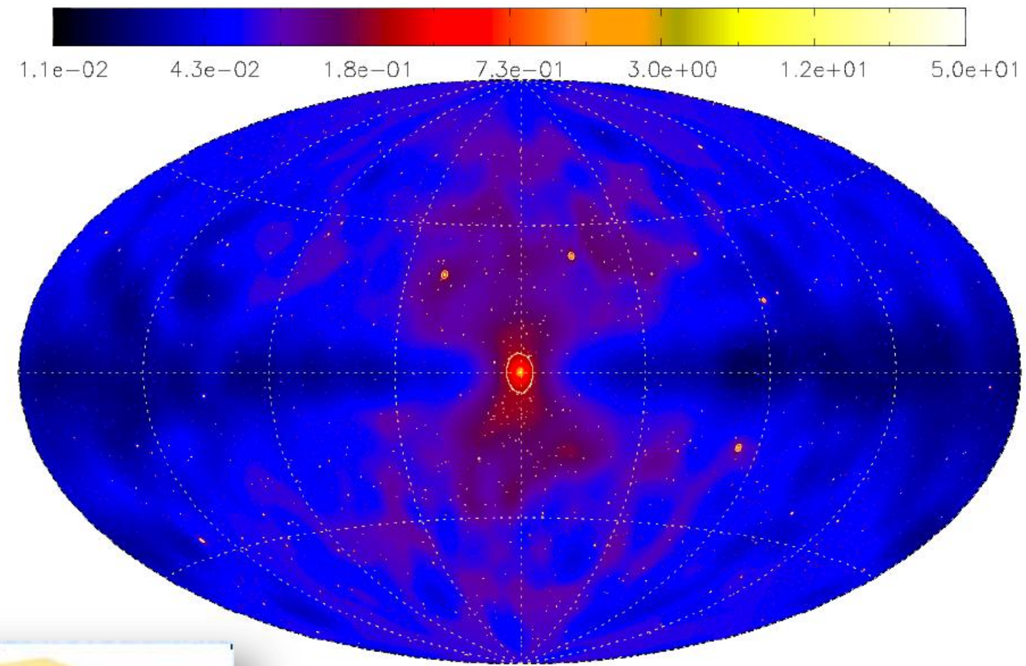
Strong dependence on specific DM halo density profile

DM particles annihilate into high-energy photons

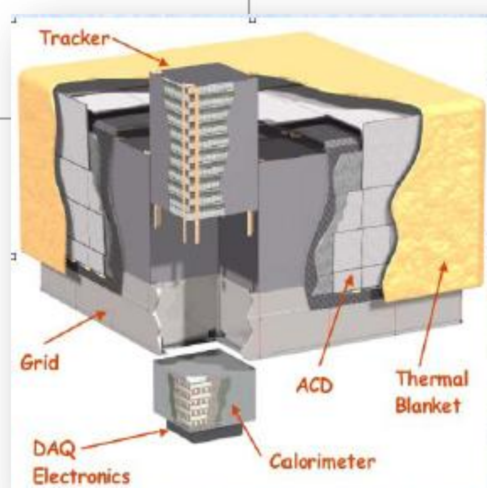
40 GeV neutralino with $b\bar{b}$ annihilation channel



Aquarius



Via Lactea II



Pieri et al 2010

WHAT WE KNOW?

The distribution of DM in halos around galaxies shows a striking and complex phenomenology crucial to understand

The nature of dark matter and the galaxy formation process

Refined simulations should reproduce and the theory should explain:

a shallow DM inner density distribution, a central halo surface density independent of halo mass and a series of relationships between the latter and the i) central halo density, ii) baryonic mass, iii) half-mass baryonic radius and iv) baryonic central surface density

Theory, phenomenology, simulations, experiments are all bound to play a role in the search for dark matter and its cosmological role.

The mass discrepancy in galaxies is a complex function of radius, total baryonic mass, Hubble Type

$$\frac{M_{grav}}{M_b} \sim \frac{1+\gamma_1(M_b,T)r^3}{1+\gamma_2(M_b,T)r^2}$$

Unlikely all this masks a new law of Gravity but certainly it is beyond the present ΛCDM predictive power

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If you play it, it will be also yours!

If you deliver it, it will become yours!

Thanks to everyone!