CHANGING DIRECTION

IT IS TIME FOR WDM

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CIAS 2014 6 June

DARK MATTER IN GALAXIES
CDM PARADIGM

- We know the simple observational scenario we need to know.
- A new elementary dark particle from a particular extension of the Standard Model of Elementary Particles provides the Universe with the required collision less massive particle behind the Dark Matter Phenomenon.
- the particle has left its imprint in the baryonic content of the Universe; we can predict its astrophysical impact by means of simulations and analytical modelling
- we can verify this by means of properly suited observations
- we will find out the dark particle by means of accelerator measurements or in non-accelerator detectors by direct or indirect ways.

After 30 years since the Dark Matter Phenomenon has emerged

Progresses in detecting the searched particle have been very few, if any.

No dark particle has been “produced” or "seen" at CERN

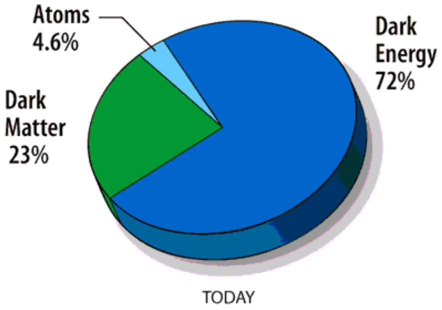
no dark particle has been detected in the many underground dark matter experiments

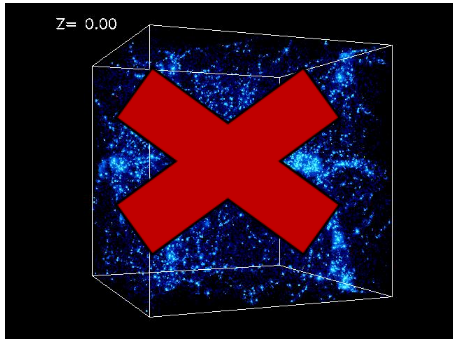
no dark particle has exposed itself by emitting radiation while annihilating with its antiparticle in the centers of Earth, Sun and Galaxy.

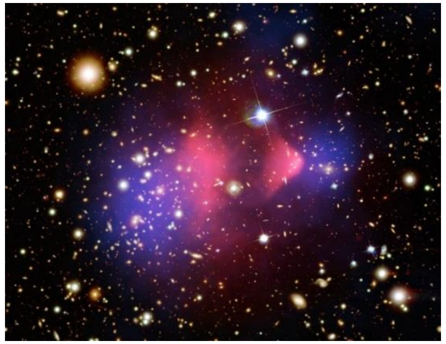
the number of dark halos and their density profiles are very different with respect to those that are predicted within the CDM paradigm.

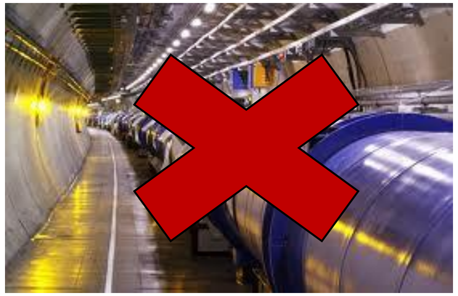
- very serious lack of the "prova regina" that a collision less COLD elementary particle runs the Universe.

Dark Matter is the main protagonist in the Universe





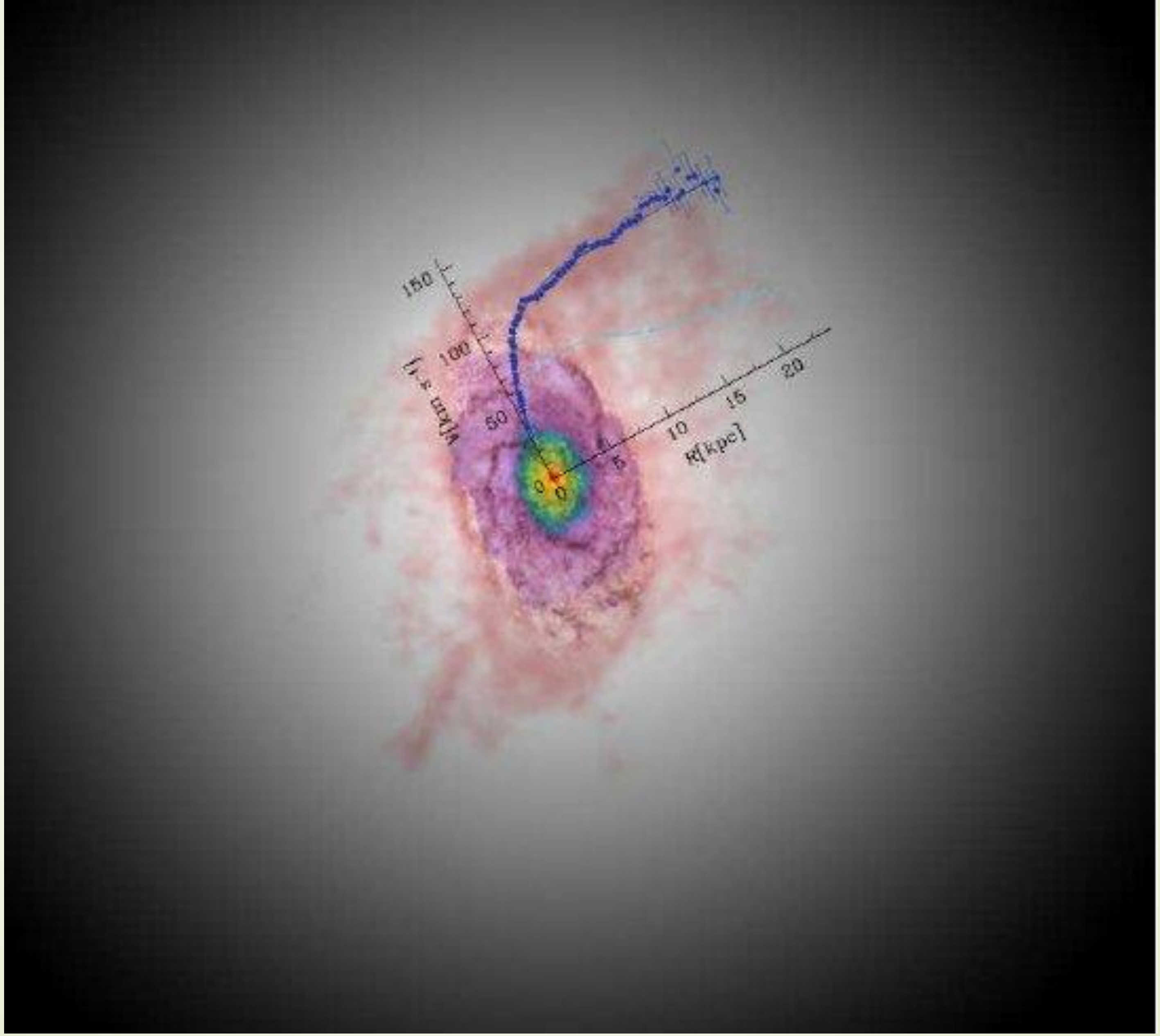




CHANGING PARADIGM: WDM is Dark Matter in Galaxies

Dark Matter in Spirals, Ellipticals, dSphs
Dark and Luminous Matter in galaxies. Global properties.
Phenomenology of the mass distribution in Galaxies.

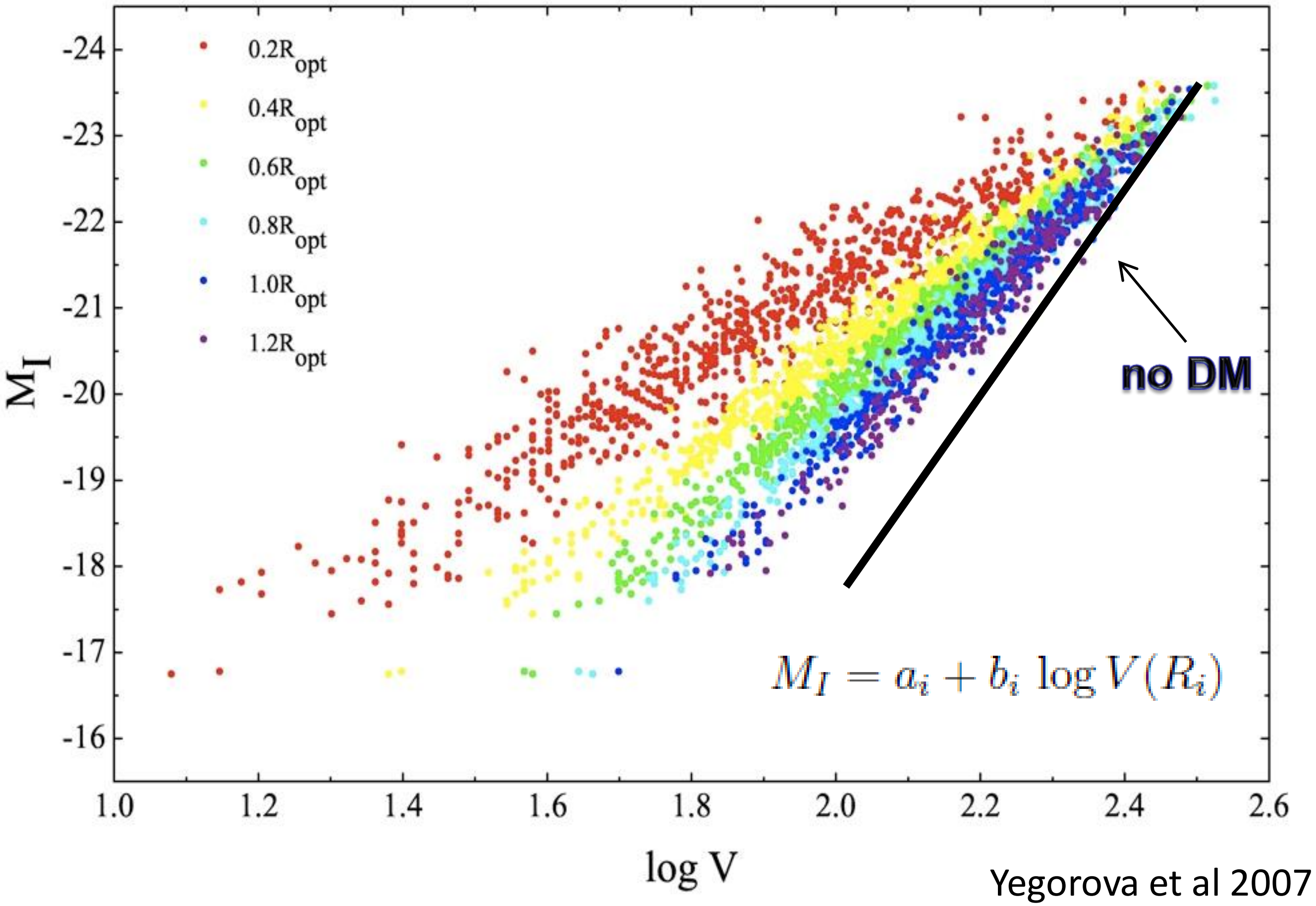
kinematics



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)

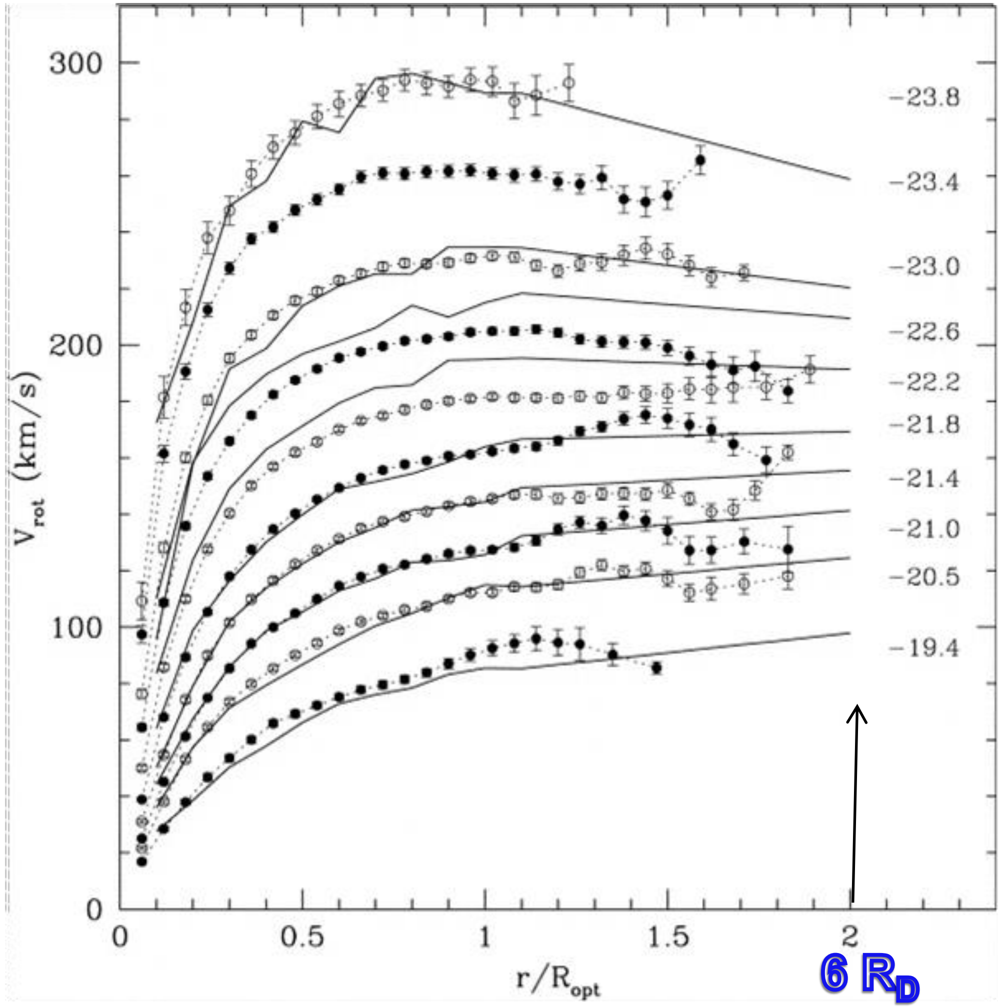


$$M_I = a_i + b_i \log V(R_i)$$

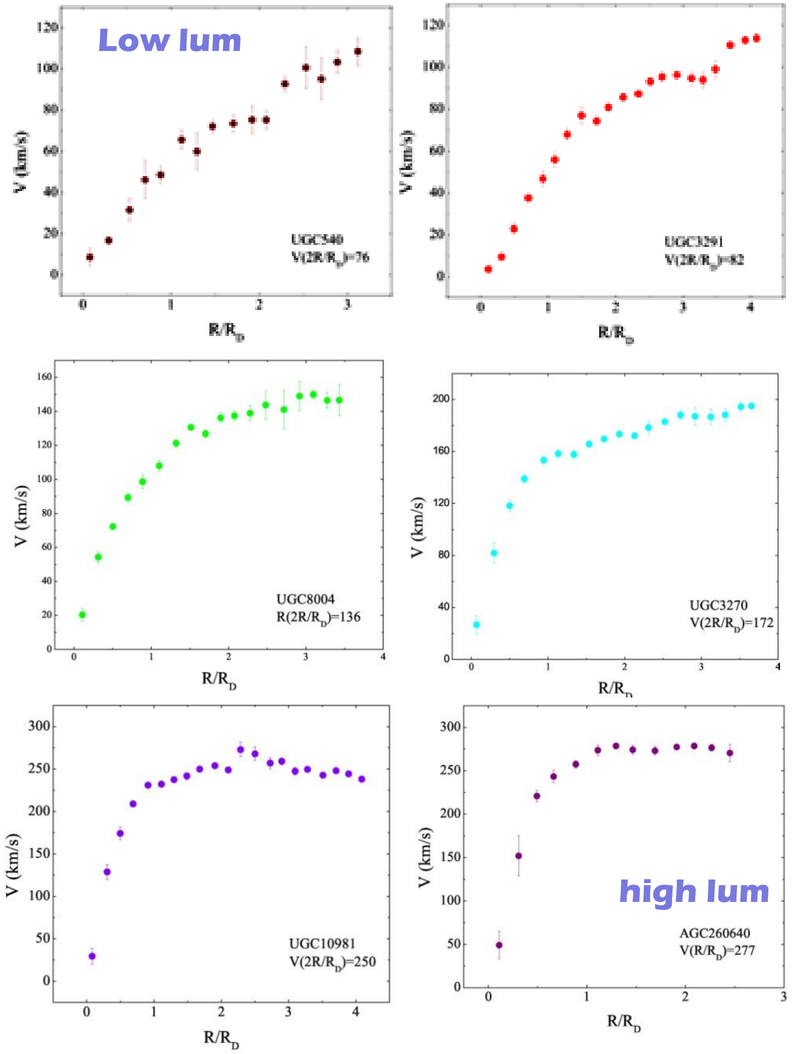
Yegorova et al 2007

Rotation Curves

Coadded from 3200 individual RCs

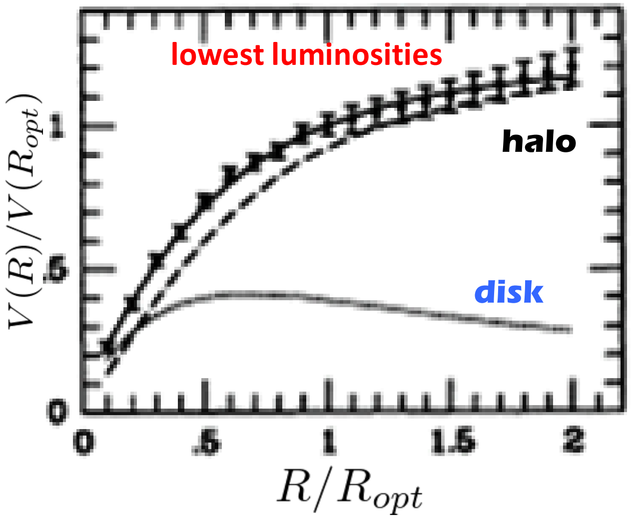


TYPICAL INDIVIDUAL RCs SHOWN BY INCREASING LUMINOSITY

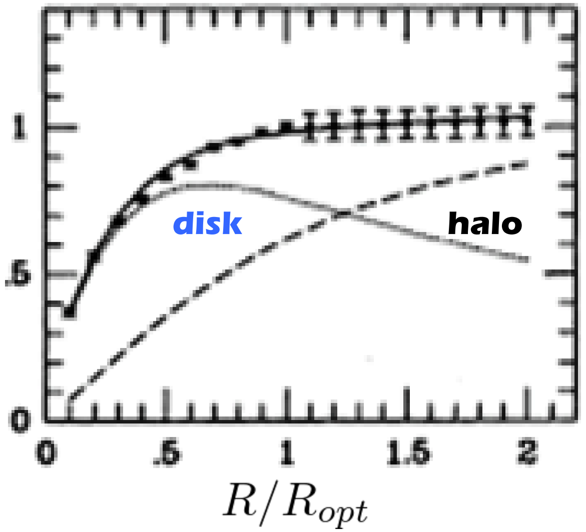


MASS MODELLING RESULTS

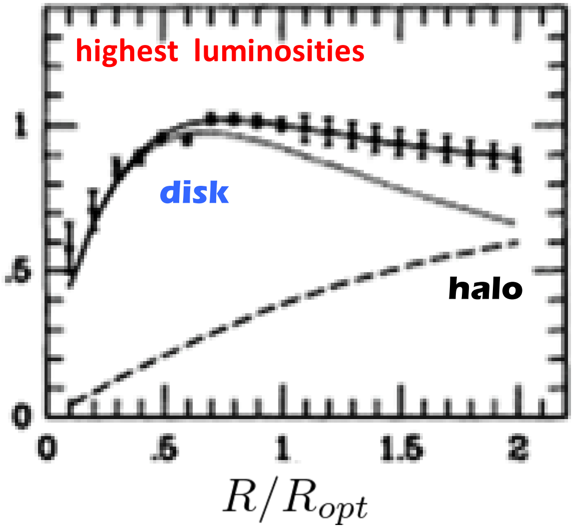
$M_I = -18$



$M_I = -21$

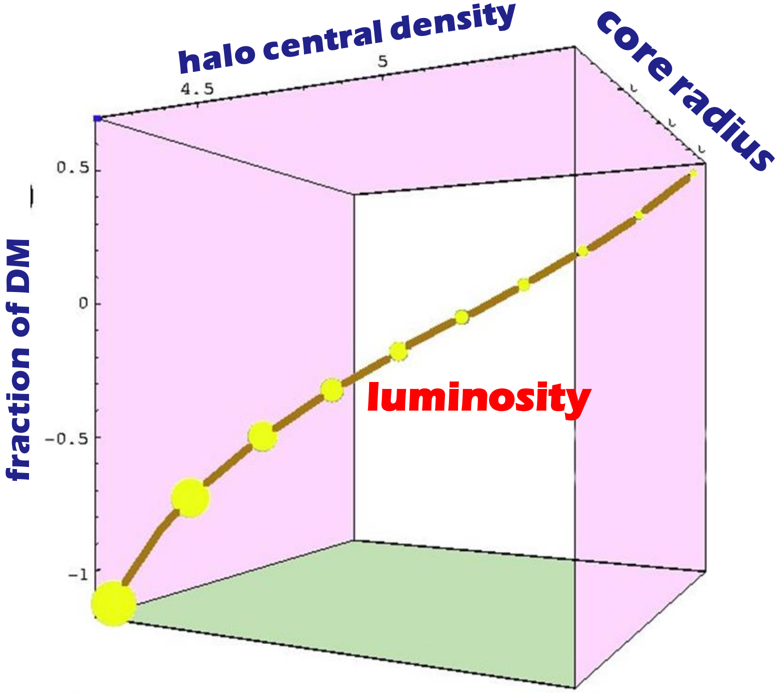


$M_I = -23$

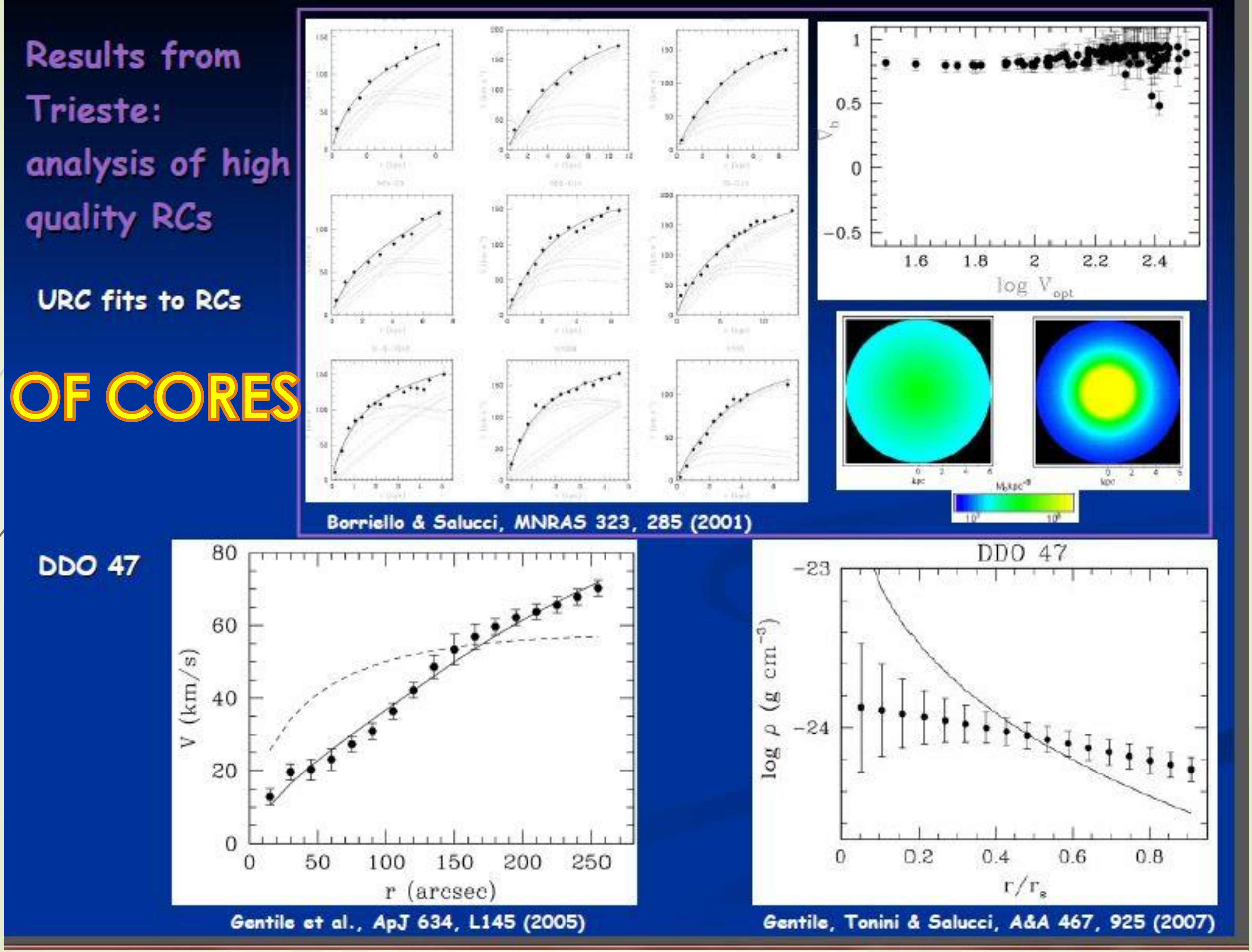


All structural DM and LM parameters are related with luminosity.

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



PROOFS OF CORES



Results from Trieste: analysis of high quality RCs

URC fits to RCs

Borriello & Salucci, MNRAS 323, 285 (2001)

DDO 47

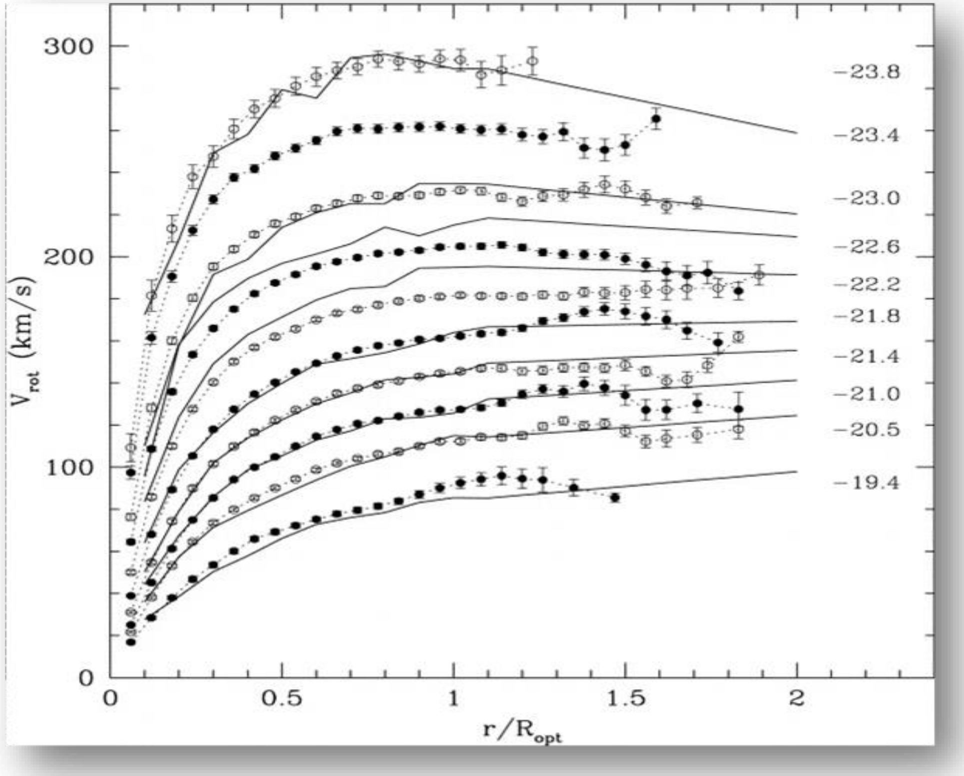
Gentile et al., ApJ 634, L145 (2005)

Gentile, Tonini & Salucci, A&A 467, 925 (2007)

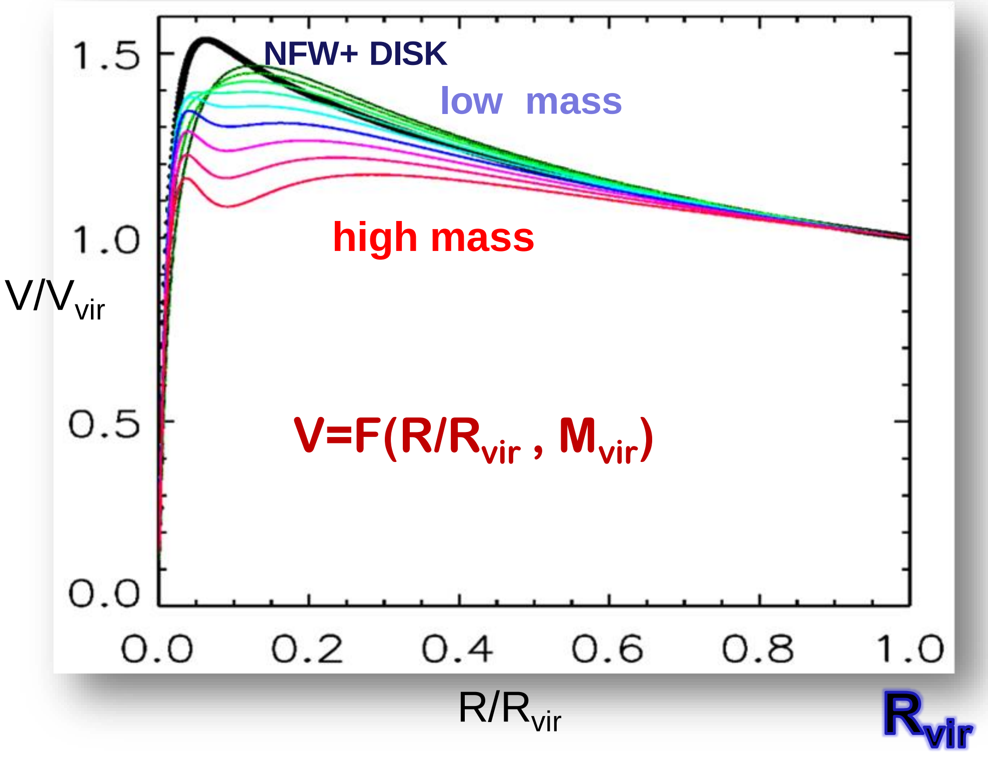
Universal Mass Distribution

URC

$V=F(R/R_D\,,\,M_I)$



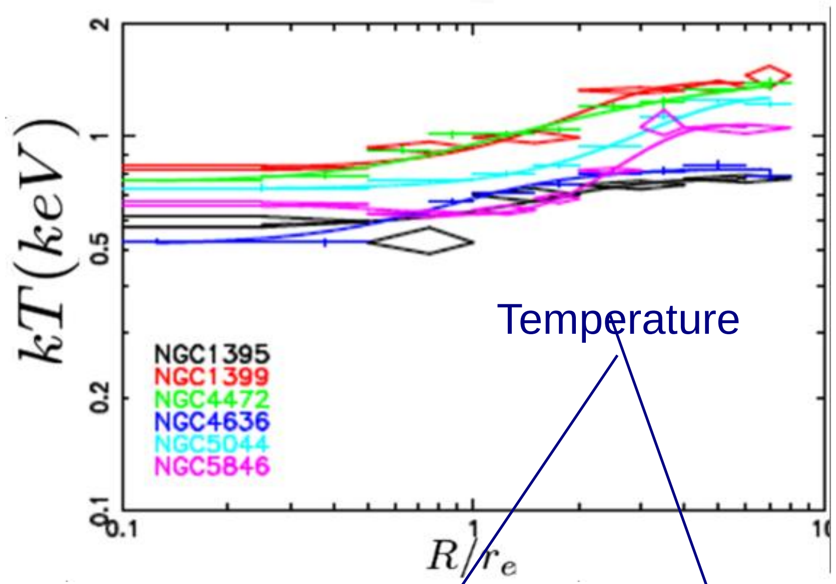
URC out to R_{vir} and ΛCDM model



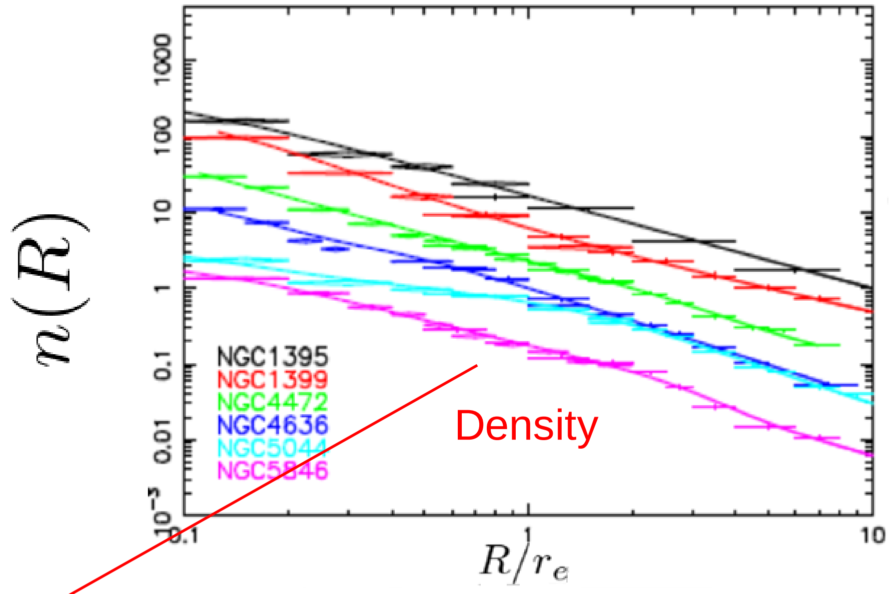
$V=F(R/R_{vir}\,,\,M_{vir})$

Mass Profiles from X-ray

Nigishita et al 2009



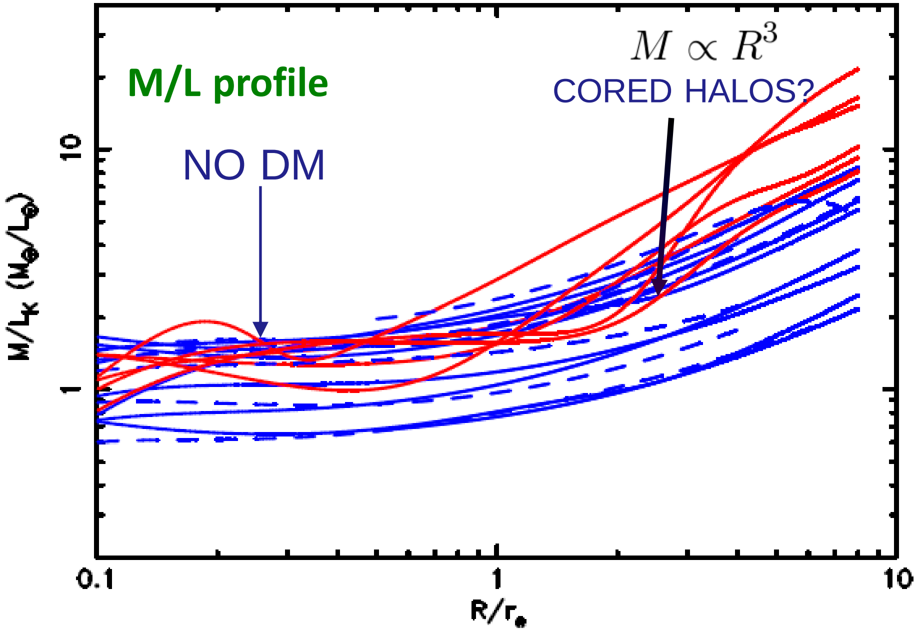
Temperature



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



M/L profile

NO DM

$M \propto R^3$

CORED HALOS?

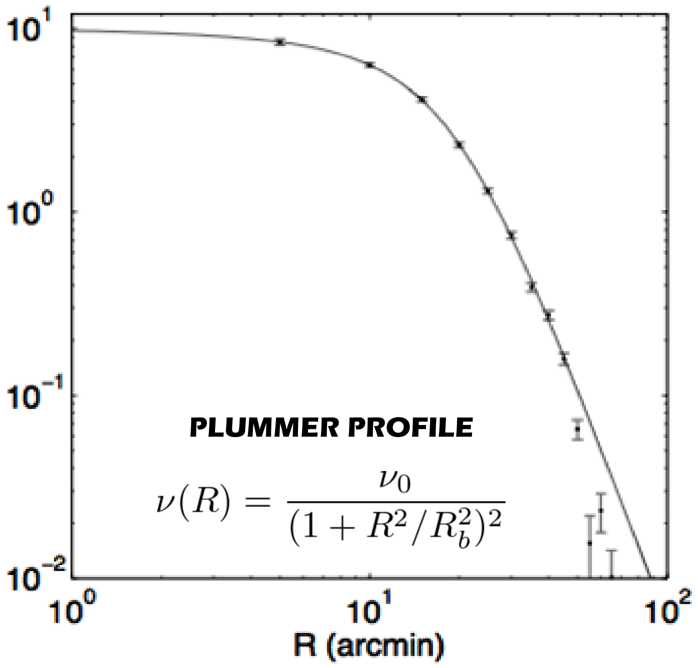
Mass profiles of dSphs

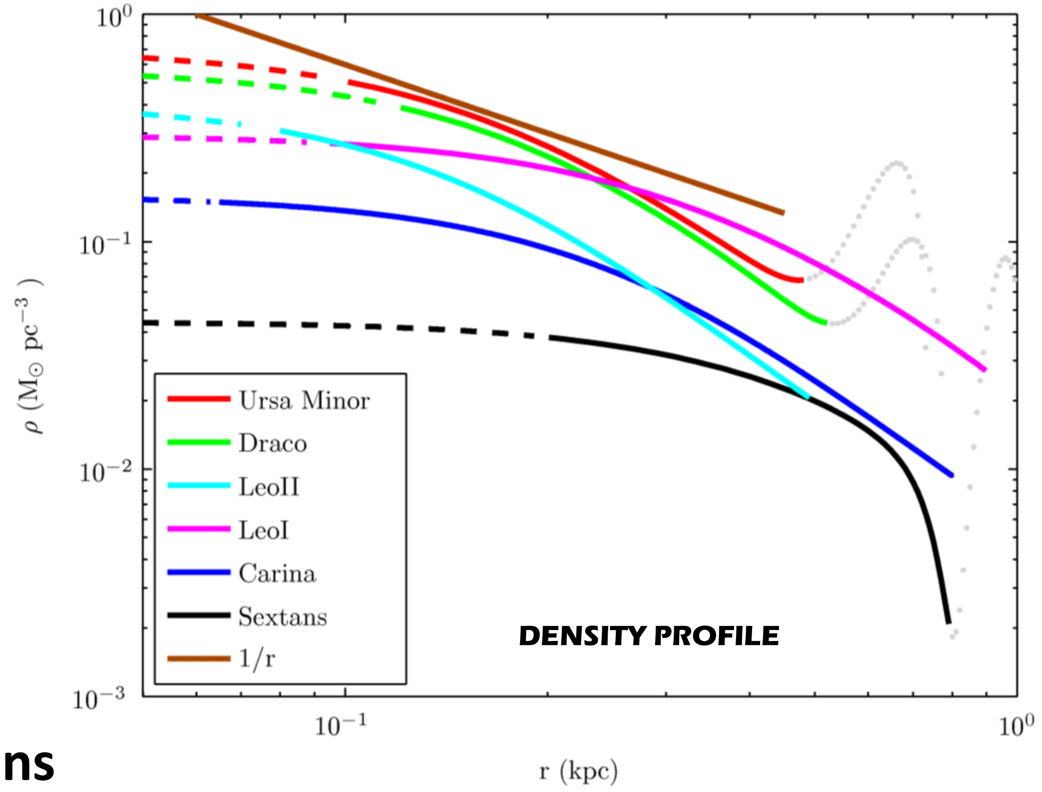
$$M(r) = -\frac{r^2}{G}\left(\frac{1}{\nu}\frac{\mathrm{d}\,\nu\sigma_r^2}{\mathrm{d}\,r} + 2\,\frac{\beta\sigma_r^2}{r}\right)$$

Jeans' models provide the most objective sample comparison

Jeans equation relates kinematics, light and underlying mass distribution

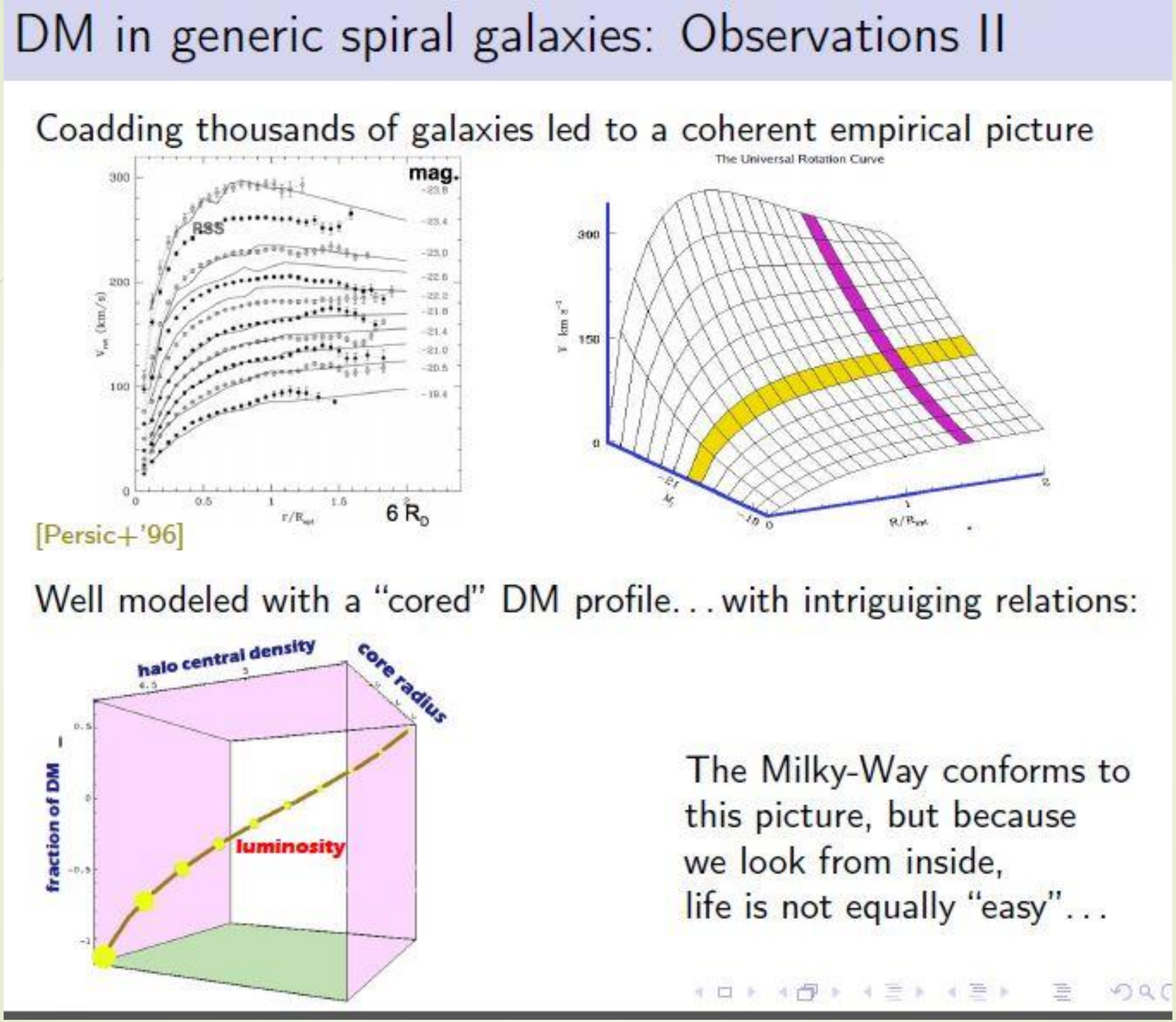
Make assumptions on the velocity anisotropy and then fit the dispersion profile





Results point to cored distributions

Gilmore et al 2007



DM in generic spiral galaxies: Observations II

Coadding thousands of galaxies led to a coherent empirical picture

[Persic+'96]

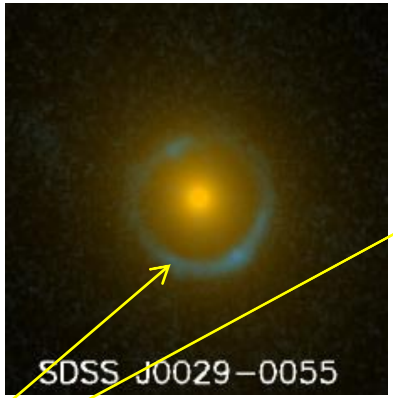
Well modeled with a "cored" DM profile. . . with intriguiging relations:

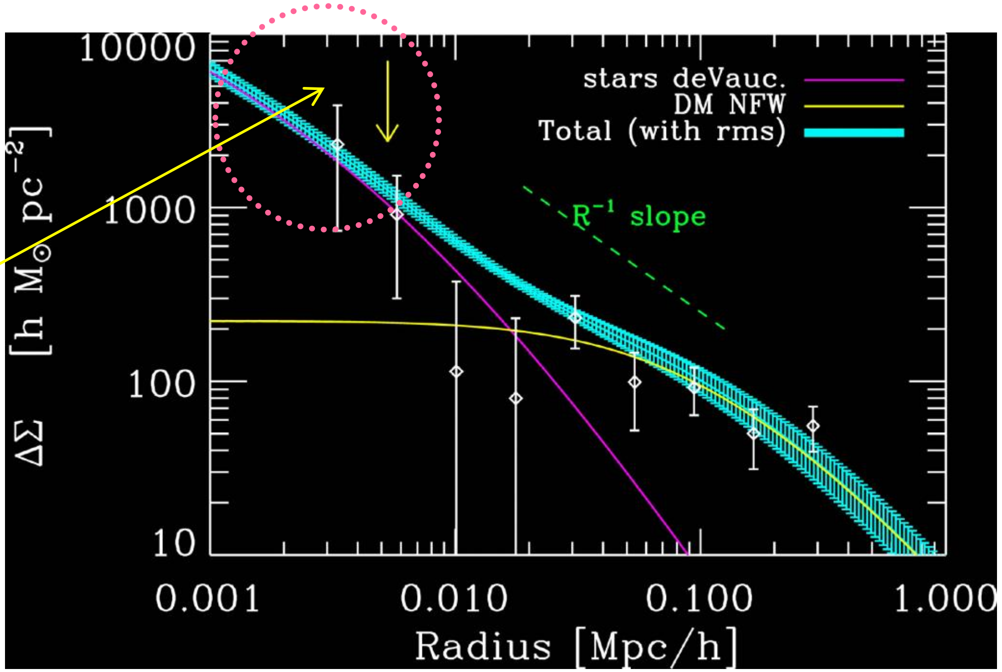
The Milky-Way conforms to
this picture, but because
we look from inside,
life is not equally "easy". . .

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:

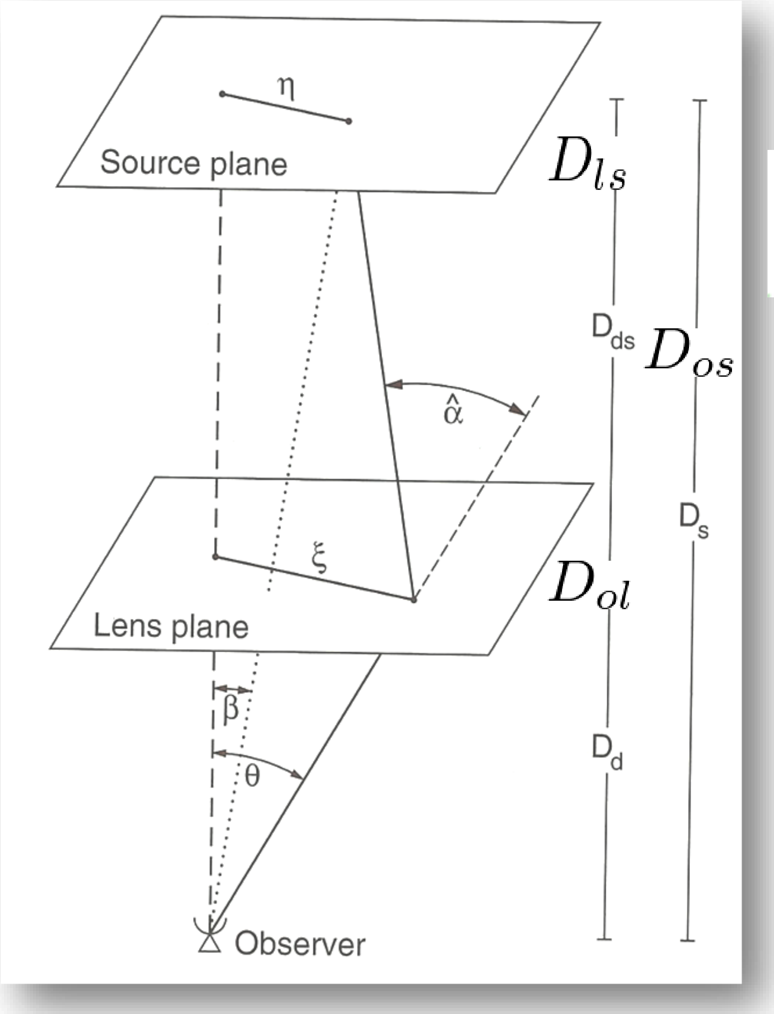
$$\Sigma(R_{Einst}) = \frac{0.35}{D\ (Gpc)}\ g/cm^2$$

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

,

core in an elliptical

Mass profiles from weak lensing



Lensing equation for the observed tangential shear

e.g. Schneider,1996

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

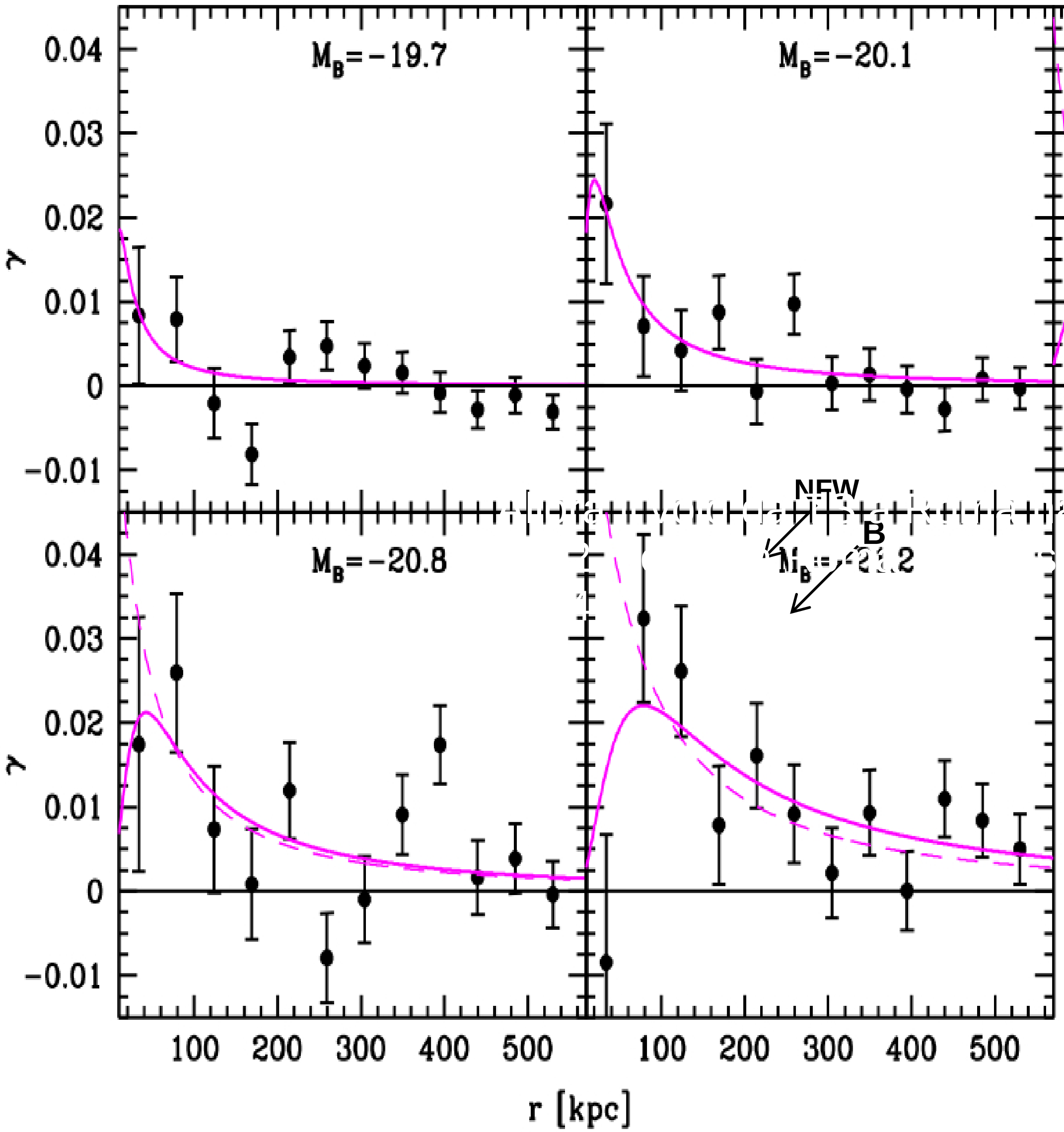
$$\bar{\Sigma} = \frac{M(R)}{4\pi R^2}$$

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

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

OUTER DM HALOS

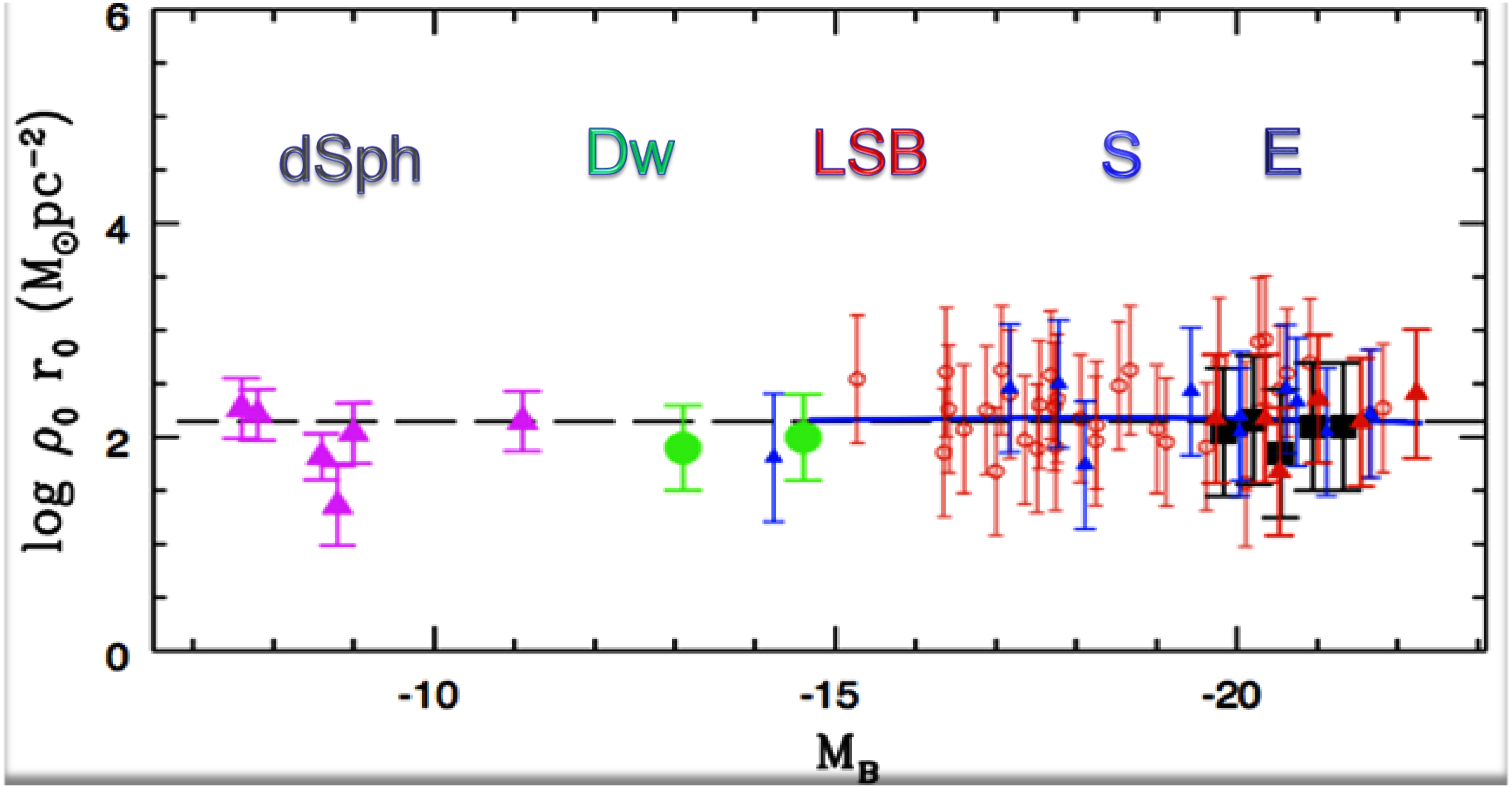
Donato et al 2009



r_0 (kpc)	$\rho_0\ (10^6 M_\odot/kpc^3)$
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

GALAXY HALOS: AN UNIFIED VISION

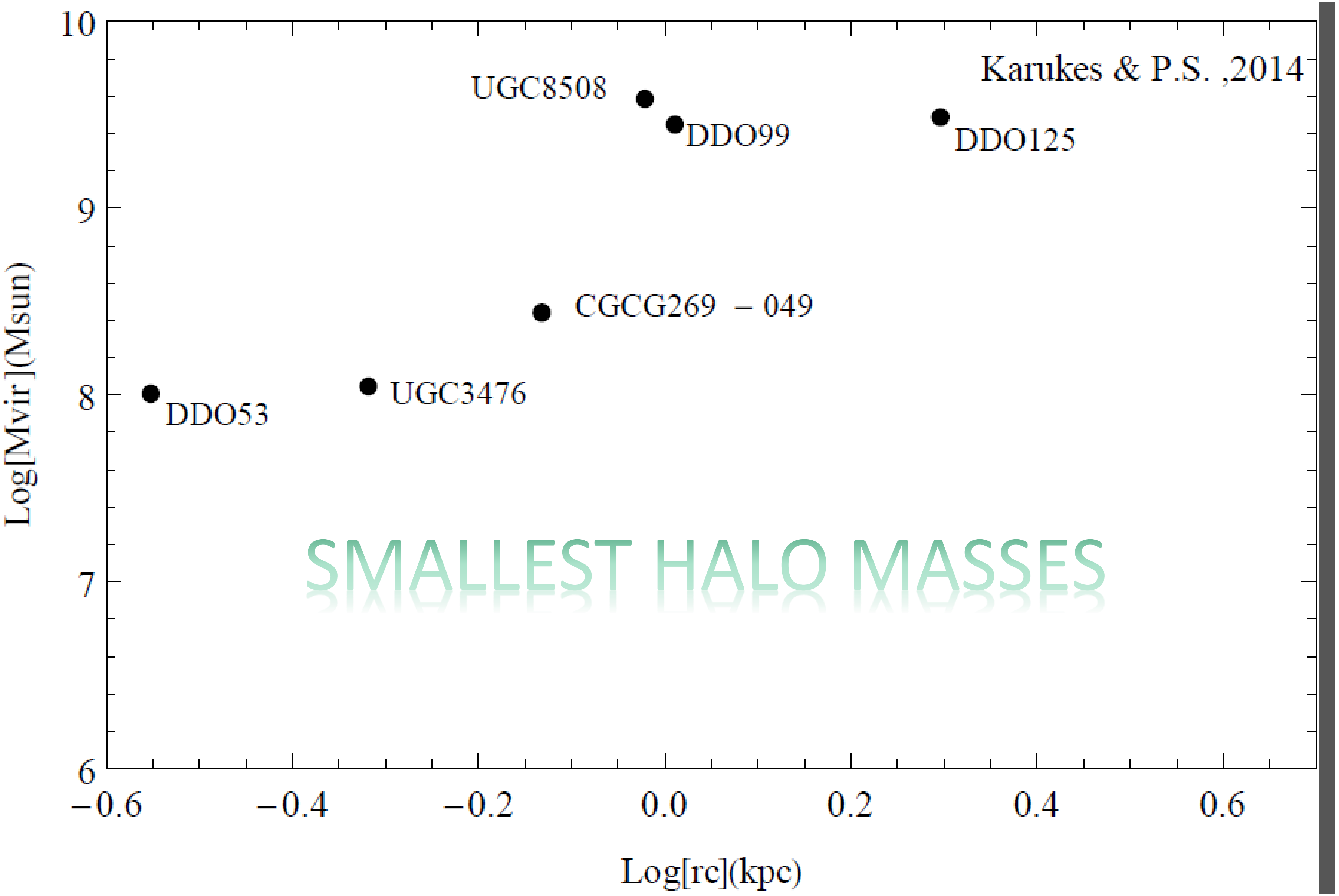


Universal Density Profile

$$\log(\rho_0/g\ cm^{-3}) = -23.773 - 0.547 \log\left(\frac{M_{vir}}{10^{11} M_\odot}\right)$$

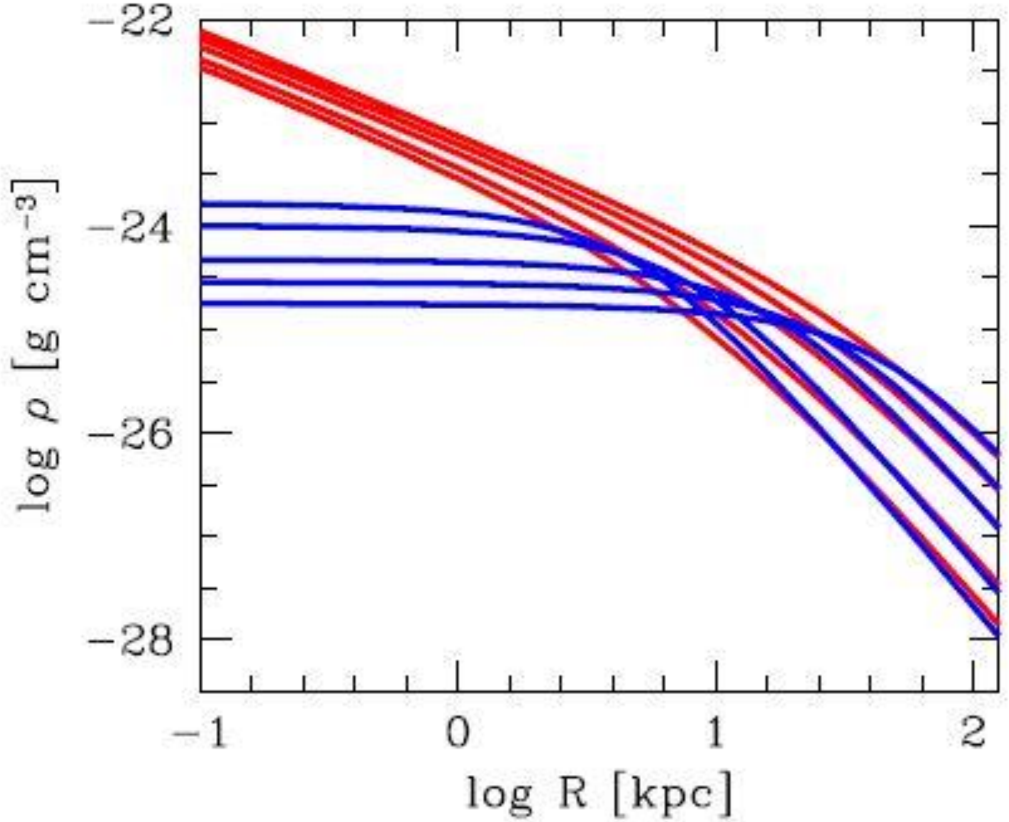
$$\log(r_0/kpc) = 0.71 + 0.547 \log\left(\frac{M_{vir}}{10^{11} M_\odot}\right),$$

$$M_D(M_{vir}) = \frac{2.4 \times 10^{10} \left(\frac{M_{vir}}{3\times 10^{11}}\right)^{2.73}}{1.5 + \left(\frac{M_{vir}}{3\times 10^{11}}\right)^{1.9}},$$

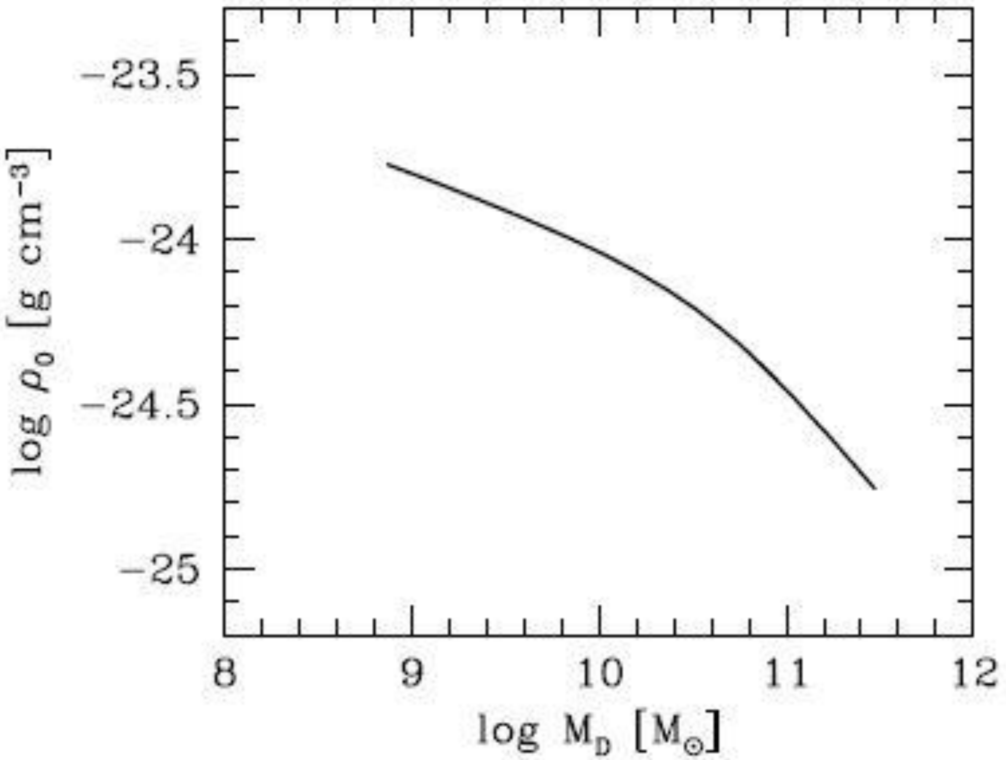


SMALLEST HALO MASSES

DMP



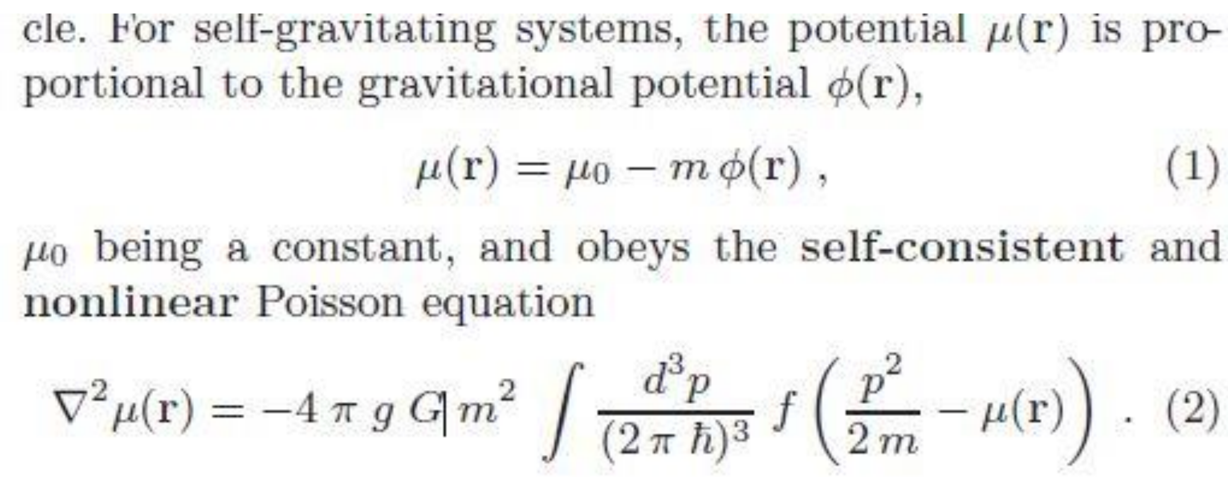
−22
−24
−26
−28
−1
0
1
2
log ρ [g cm^{-3}]
log R [kpc]



−23.5
−24
−24.5
−25
8
9
10
11
12
log ρ_0 [g cm^{-3}]
log M_D [$M_\odot$]

STRUCTURE OF WDM HALOS

DeVega,Sancez and P.S.

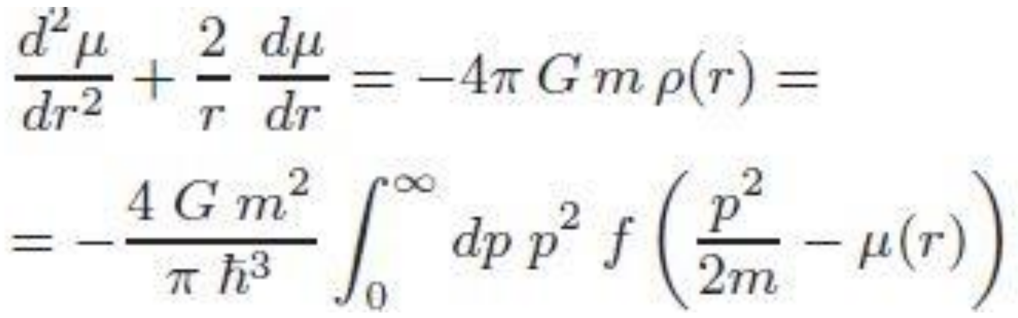


cle. For self-gravitating systems, the potential $\mu(\mathbf{r})$ is proportional to the gravitational potential $\phi(\mathbf{r})$,

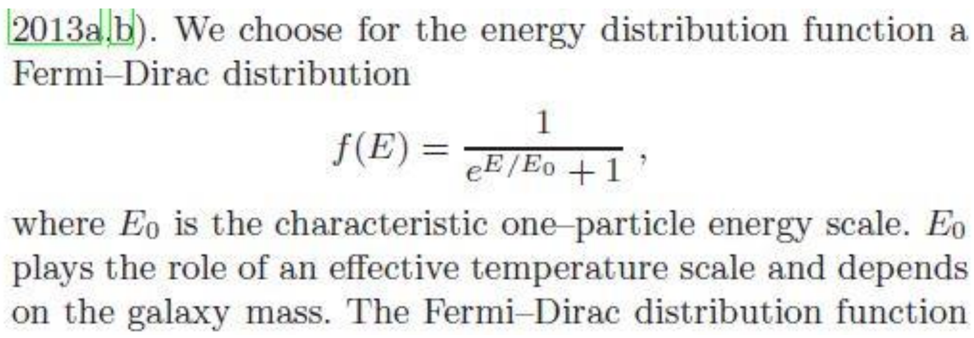
$$\mu(\mathbf{r}) = \mu_0 - m\,\phi(\mathbf{r}) \; , \tag{1}$$

μ_0 being a constant, and obeys the **self-consistent** and **nonlinear** Poisson equation

$$\nabla^2 \mu(\mathbf{r}) = -4\,\pi\,g\,G\,m^2 \int \frac{d^3p}{(2\,\pi\,\hbar)^3}\, f\left(\frac{p^2}{2\,m} - \mu(\mathbf{r})\right) \; . \tag{2}$$



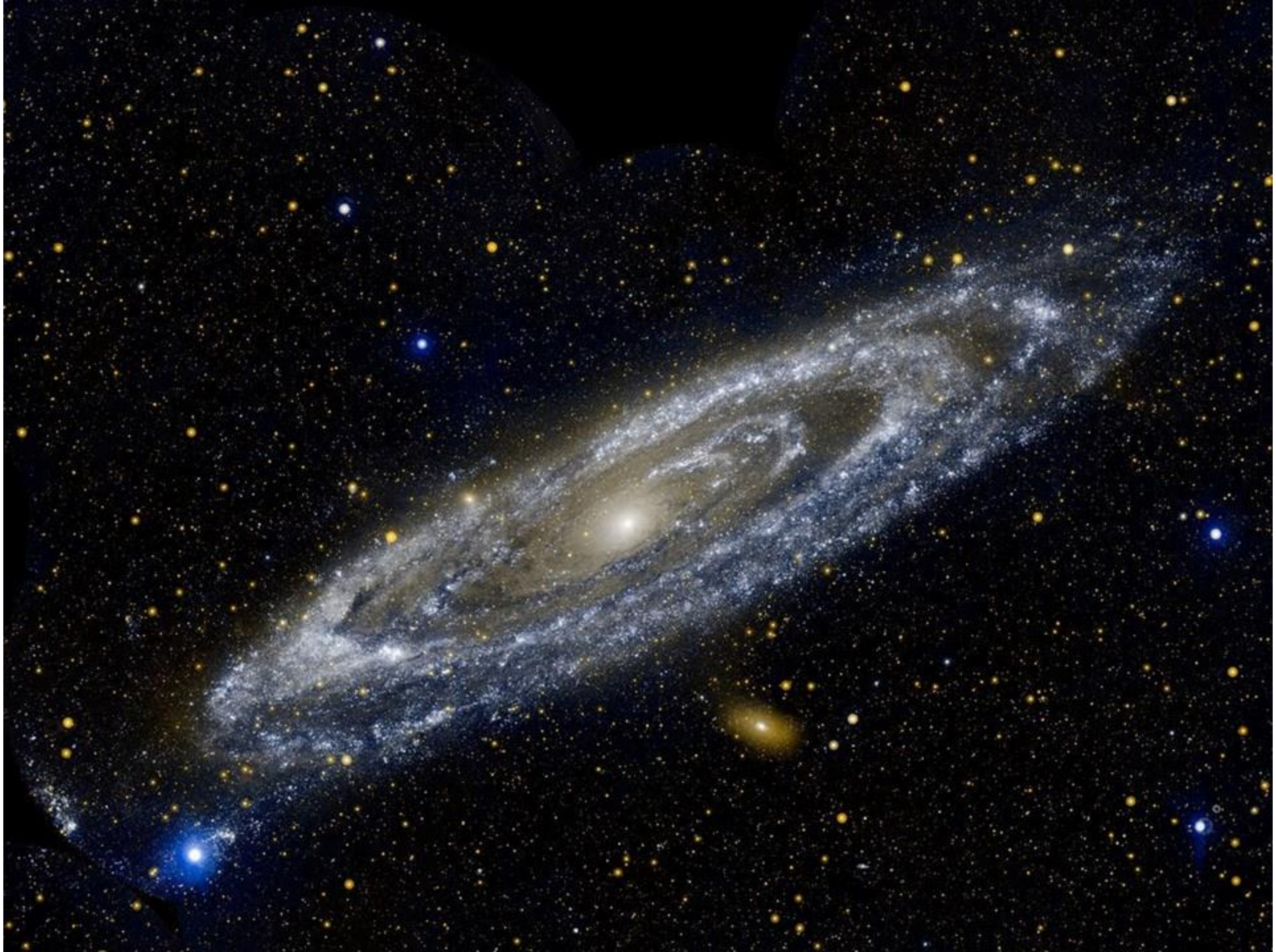
$$\frac{d^2\mu}{dr^2} + \frac{2}{r}\,\frac{d\mu}{dr} = -4\pi\,G\,m\,\rho(r) =$$
$$= -\frac{4\,G\,m^2}{\pi\,\hbar^3} \int_0^\infty dp\,p^2\, f\left(\frac{p^2}{2m} - \mu(r)\right)$$



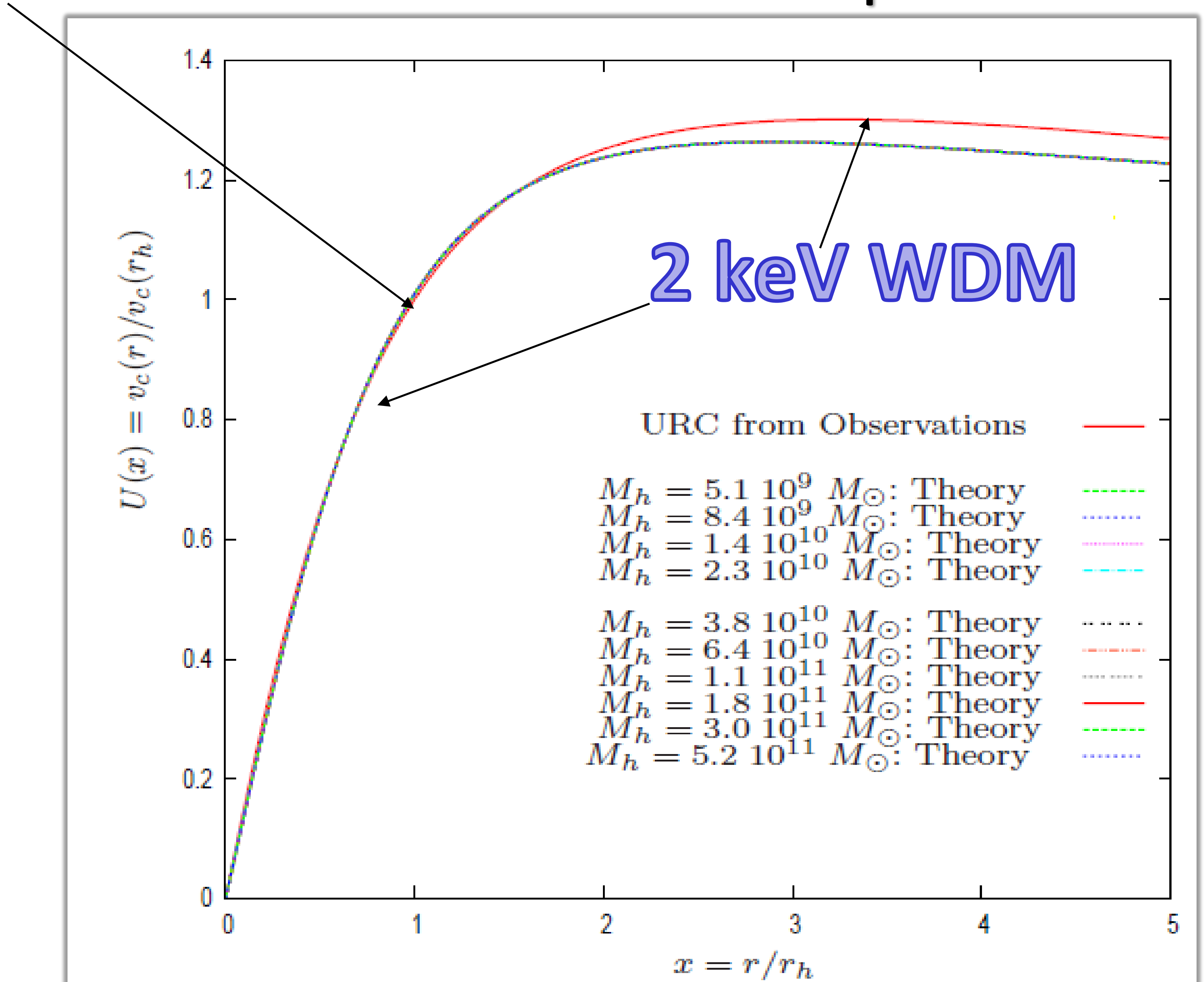
2013a,b). We choose for the energy distribution function a Fermi–Dirac distribution

$$f(E) = \frac{1}{e^{E/E_0} + 1} \; ,$$

where E_0 is the characteristic one–particle energy scale. E_0 plays the role of an effective temperature scale and depends on the galaxy mass. The Fermi–Dirac distribution function

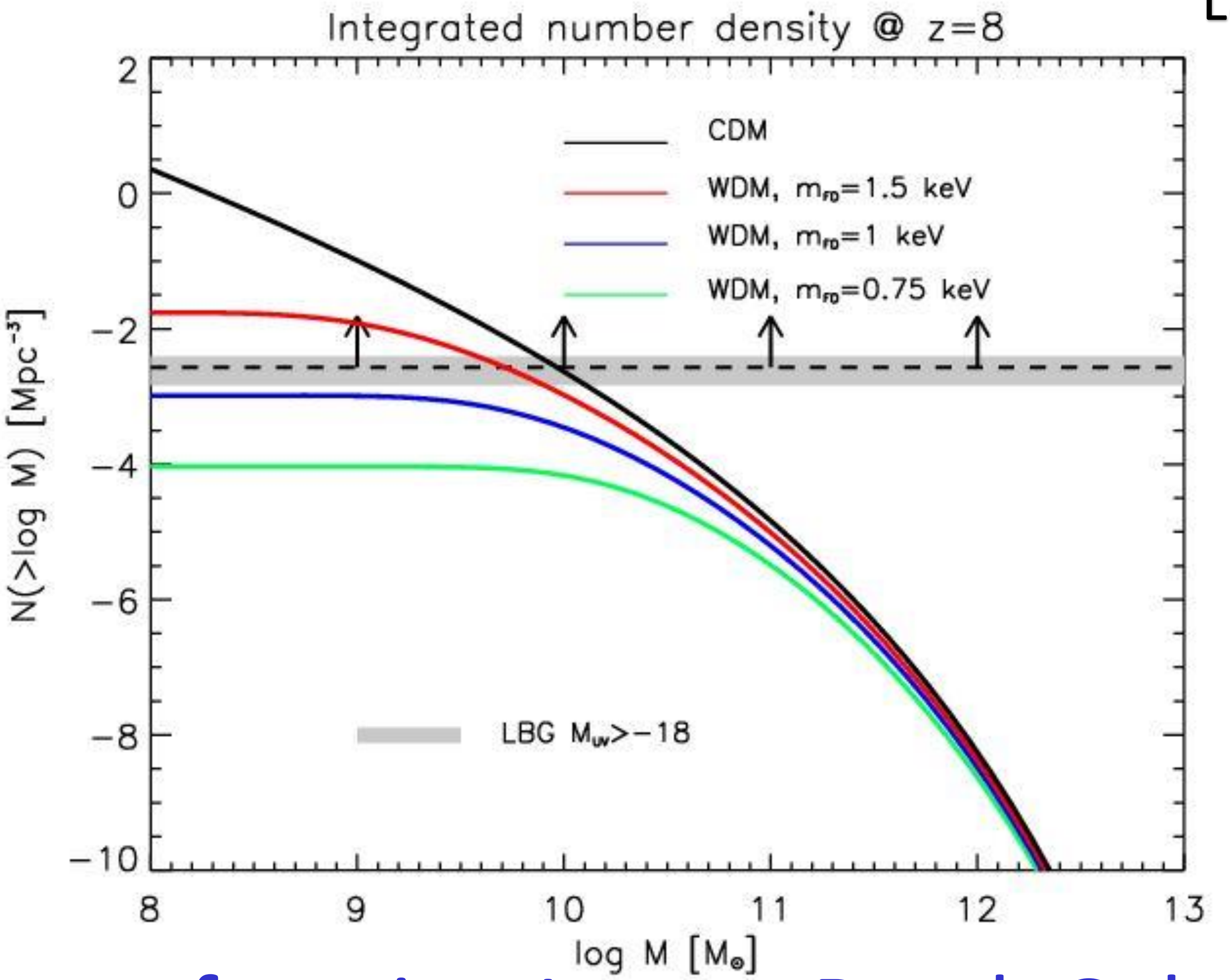


Universal Rotation Curve Halo component

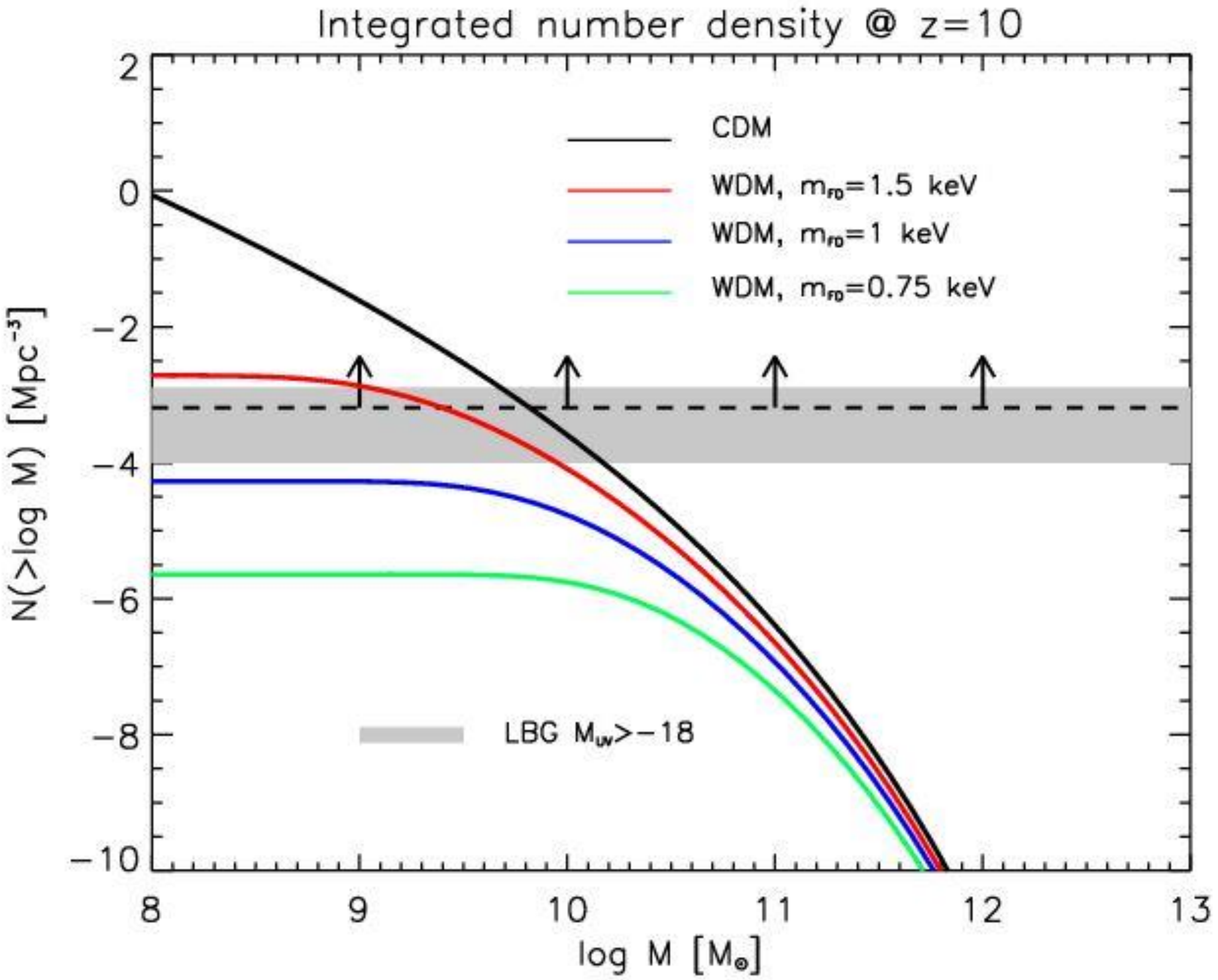


2 keV WDM

Lapi, Salucci,Danese



mass function Lyman Break Galaxies


Integrated number density @ z=10
N(>log M) [Mpc^{-3}]
log M [M$_\odot$]
2
0
−2
−4
−6
−8
−10
8
9
10
11
12
13
CDM
WDM, m_{FD}=1.5 keV
WDM, m_{FD}=1 keV
WDM, m_{FD}=0.75 keV
LBG M_{UV}>−18

CONCLUSIONS

- Dark Matter has a very rich observational phenomenology
- Theories based on strong pre-judices or supposed miracles simply cannot work. Reality is too complex.
- The baggage of observational phenomena that theorists must bring with them in their enterprise of investigating the Universe is a big one
- Theories, like WDM, that consider, seriously from the beninning, the Observational Universe, have a chance to solve the greatest mystery of the