New Paradigm and Scenarios for the Dark Matter Phenomenon

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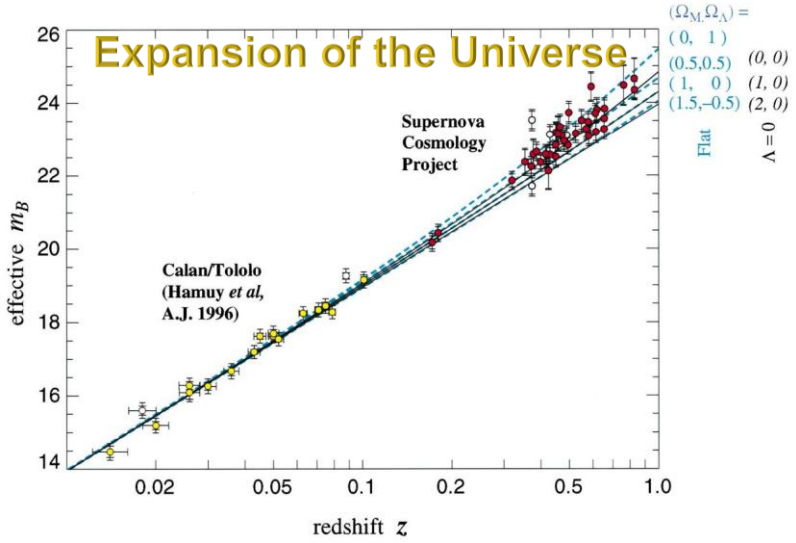
This talk is about

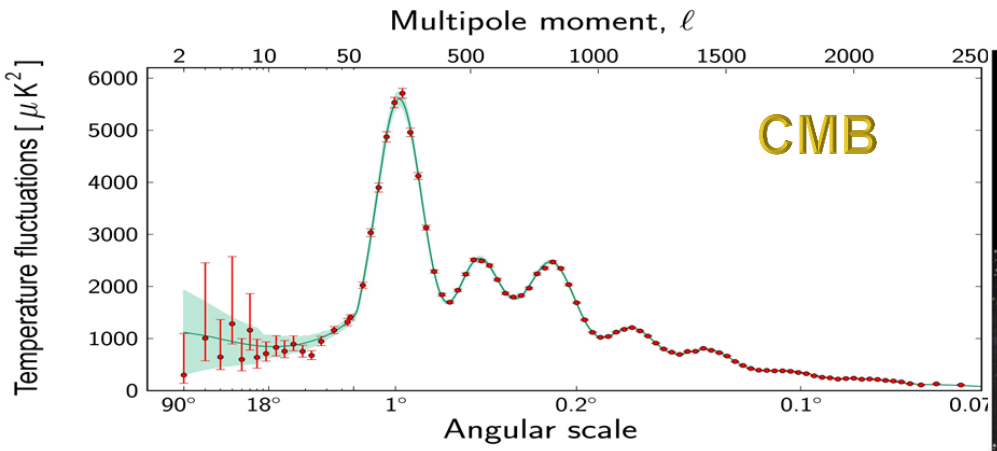
-proposal a new approach the DM mystery, motivated by the observational properties emerged in the past 20 years.

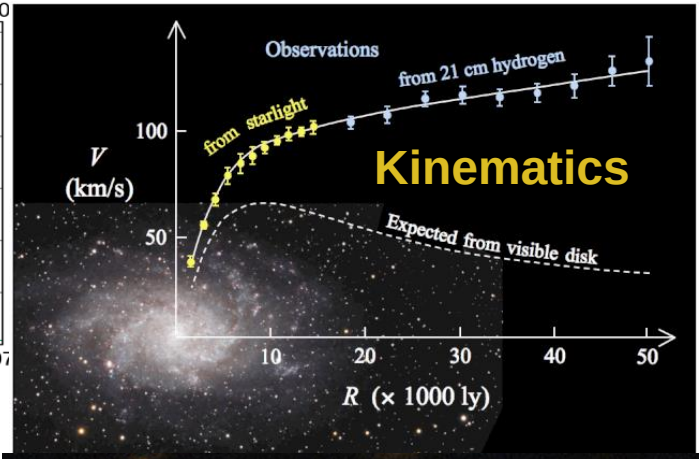
Given the Dark Matter Phenomenon(2024) we need, in the search for the actual explaining Scenario, to adopt a new and suitable generating Paradigm.

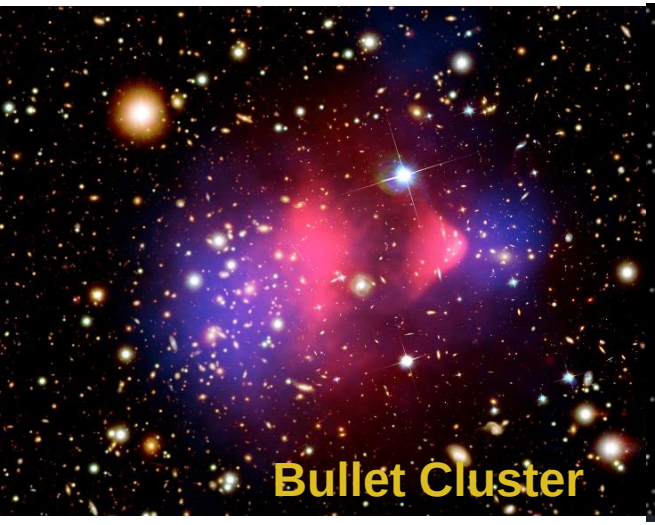
The results, I will show, published (30-2 years ago) have been used to test scenarios.

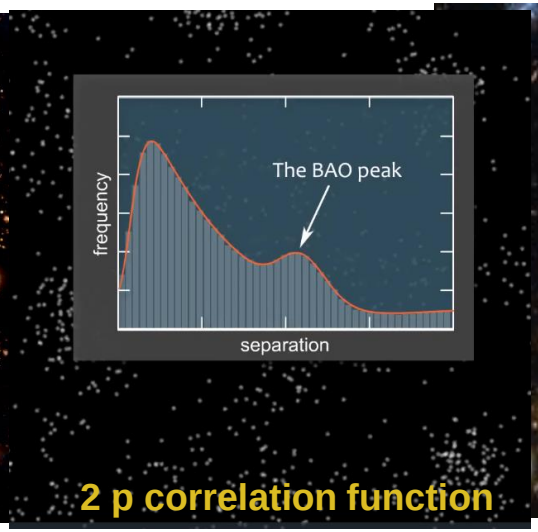
Dark Matter emerges to account for effects that appear to be the result of invisible mass











DM PHENOMENON

DM **IS:**

-a phenomenon. Multiple evidence at different scales of the Universe unexplained without postulating the existence of a dark massive BSM component.

-DMP(year): it has rapidly increased with time in quantity and in complexity.

Dark Matter

The (true) theorethical scenario
emerges from a suitable Paradigm

Since 1990: the Apollonian Paradigm for DM

The true scenario for the DM particles the most beautiful one

It does this:

1) it connects the **new** Dark Matter physics with the **known** physics of the Early Universe.
2) it sheds light on open issues of the Standard Model particle physics or, even long standing big issues of Physics
3) it has a (unique) underlying dark particle, detectable by experiments and observations with near future technology
4) the dark particle is introduced in a natural and simple way and its interactions with the Standard model particles are related with the cosmological matter density.
5) it is mathematically described by a very small number of parameters and has unique and known initial conditions
6) It has a strong predictive power on the evolution of the structures of the Universe, that can be fully followed by suitable numerical simulations.

BEAUTY= SIMPLICITY, NATURALNESS, USEFULNESS, ACHIEVING EXPECTATIONS, HARMONICALLY EXTENDING OUR KNOWLEDGE

From the Apollonian DM Paradigm:

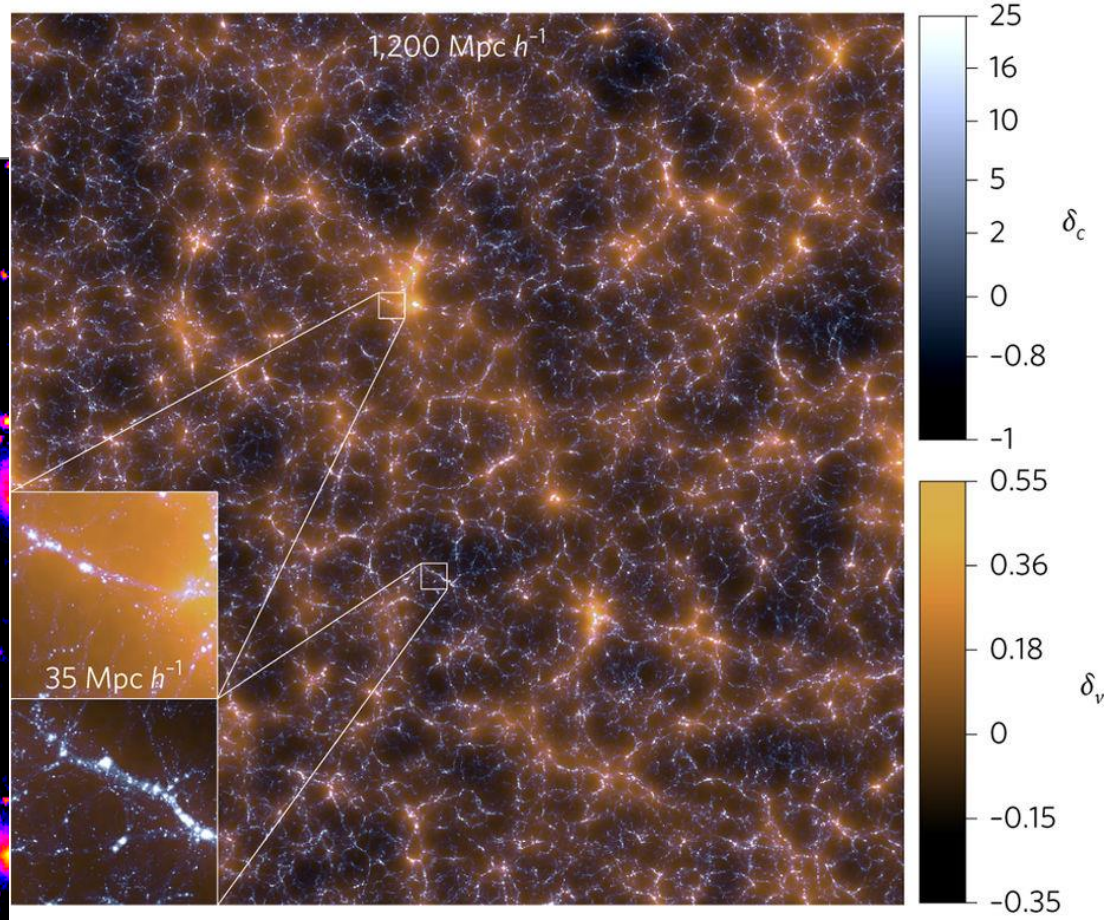
a specific scenario emerged that was also the reverse engineering of the DMP(1990)

Cold, collisionless WIMP (Weakly interacting massive dark particle)

ΛCDM Scenario is fully falsiable by observations, experiments and theorethical arguments
- To set the dark particle nature only DMP(1990) is sufficient.
- is set to reproduce any DMP(XXXX) with the help of “dirty” baryonic physics

35000 published papers based on CDM

N-body simulations



The simple and direct ΛCDM scenario: the density profile

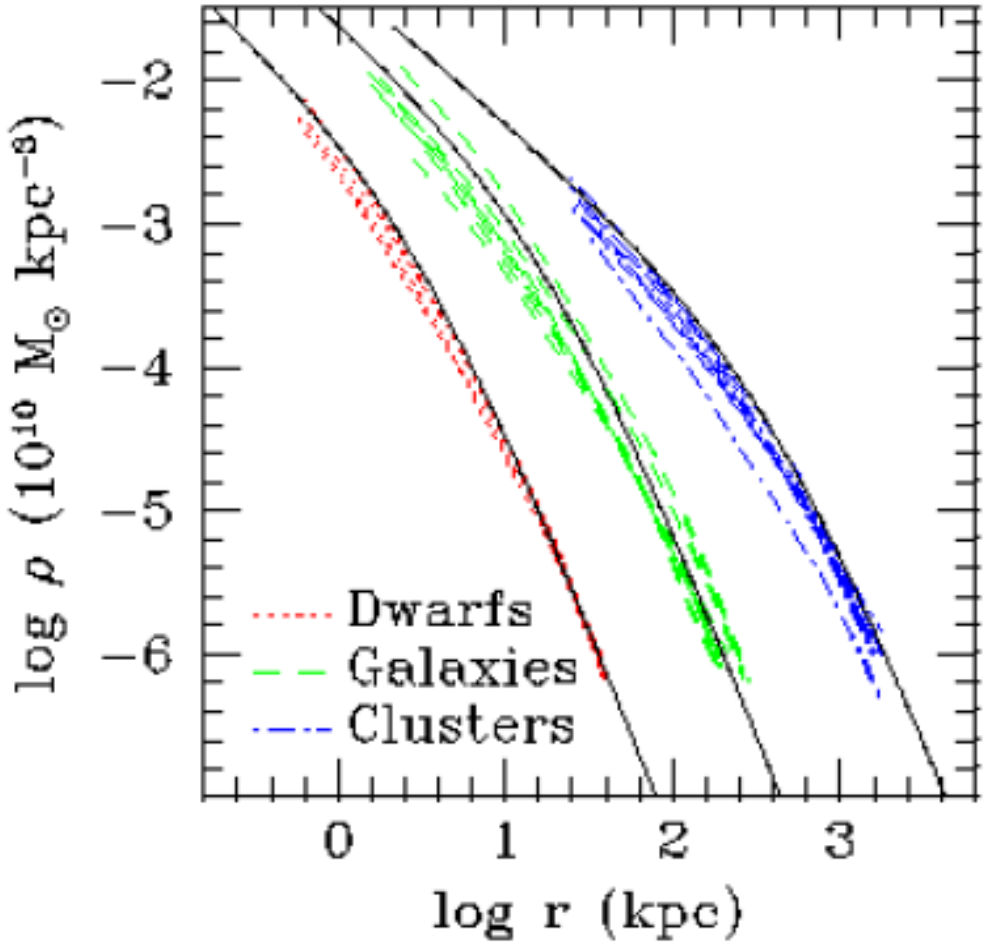
$$\rho_{NFW}(r) = \delta\rho_c \frac{r_s}{r} \frac{1}{(1+r/r_s)^2}$$

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

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

Density Profiles

N-body simulations (1996)

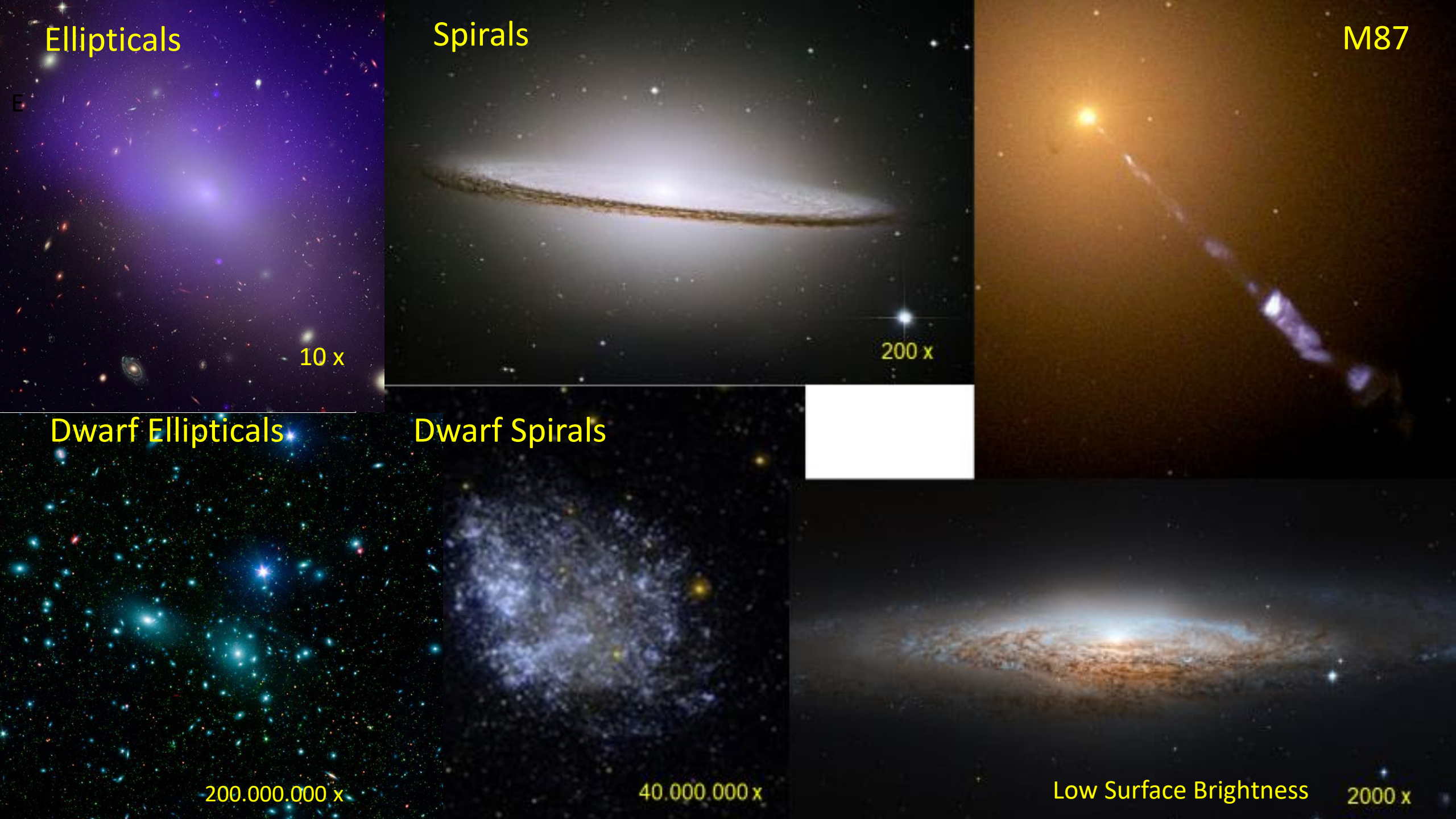


25 YEARS LATER:

Universal structure of dark matter haloes over a mass range of 20 orders of magnitude

J. Wang, S. Bose, C. S. Frenk, L. Gao, A. Jenkins, V. Springel & S. D. M. White

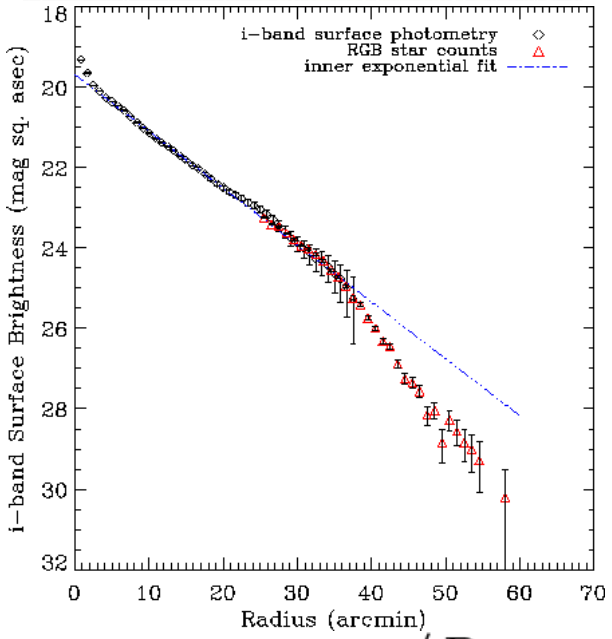
Nature **585**, 39–42 (2020) | Cite this article


Ellipticals
E
10 x
Spirals
200 x
M87
Dwarf Ellipticals
200.000.000 x
Dwarf Spirals
40.000.000 x
Low Surface Brightness
2000 x

The Distribution of stars in galaxies

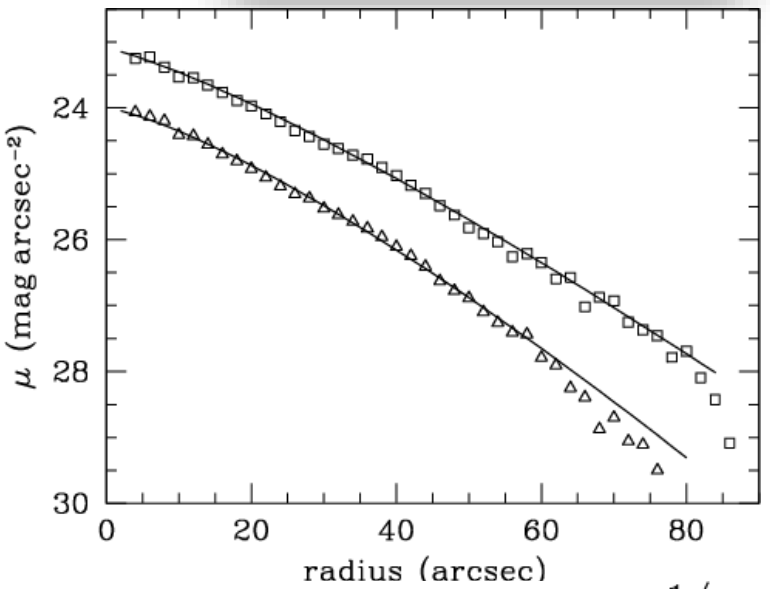
R_D lenght scale of the 2D disk
R_e lenght scale of the 3D spheroid

The distribution of baryons in galaxies



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

Freeman



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

Sersic

From the Gravitational Potential to the mass distribution

$$\phi_{\rm tot} = \phi_b + \phi_{\rm H} + \phi_{\rm disk} + \phi_{\rm HI}$$ Gravitational Potential

$$\nabla^2 \Phi_i = 4\pi G \rho_i$$ Poisson Equation

$$V_{\rm tot}^2(r) = r\frac{\mathrm{d}}{\mathrm{d}r}\phi_{\rm tot} = V_b^2 + V_{\rm H}^2 + V_{\rm disk}^2 + V_{\rm HI}^2.$$ Rotating systems

$$\sigma_r^2(r) = \frac{1}{\nu_\star(r)}\int_r^\infty \nu_\star(r')\left(\frac{r'}{r}\right)^{2\beta}\frac{GM(r')}{r'^2}\,\mathrm{d}r'.$$ Pressure dominated systems

$$\Sigma_{\rm c} = \frac{c^2}{4\pi G}\frac{D_{\rm s}}{D_{\rm l}D_{\rm ls}} \quad \gamma_t(R) = (\bar{\Sigma}(R) - \Sigma(R))/\Sigma_{\rm c}$$ Weak lensing

$$M(<r) = \frac{kT_{\rm g}(r)r}{G\mu\, m_{\rm p}}\left(\frac{\mathrm{d}\,\log\rho_{\rm g}(r)}{\mathrm{d}\,\log r} + \frac{\mathrm{d}\,\log T_{\rm g}(r)}{\mathrm{d}\,\log r}\right)$$ X-Ray emitting gas

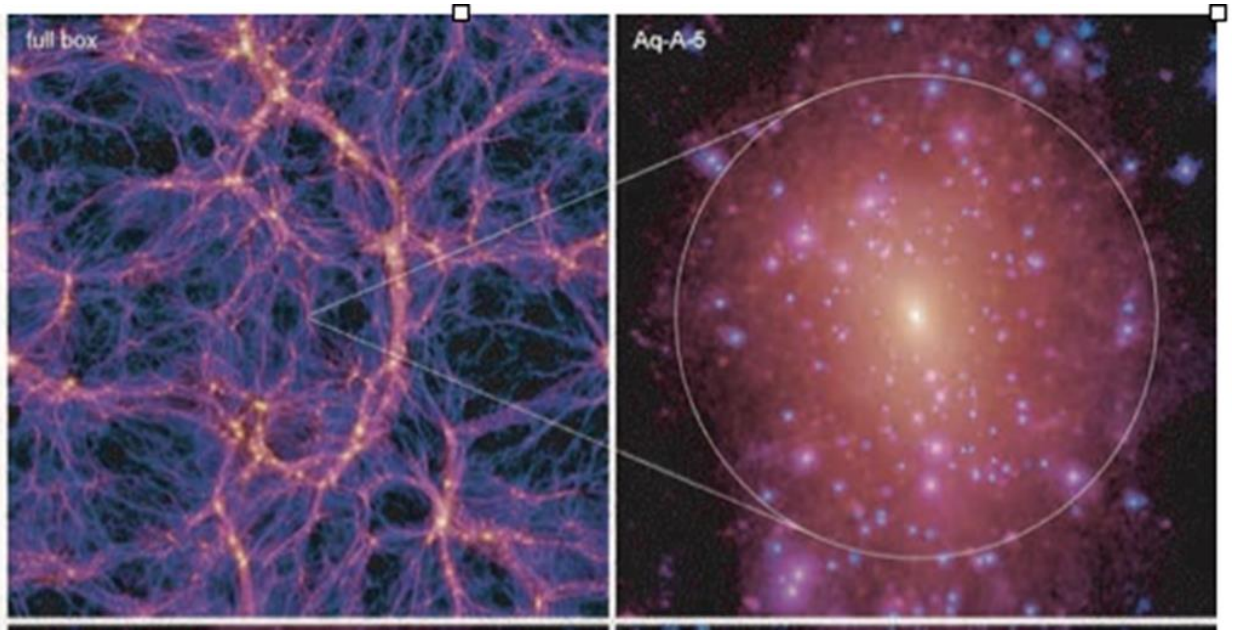
Dark and luminous mass profiles in galaxies

Successful galaxy mass model has 3 free parameters and one free Function:

1p -stellar mass (+ bulge)
2p -halo central density
3p -halo core radius (length-scale)

1f -$\varrho_H(r, 2\ p)$

N-body simulations ΛCDM

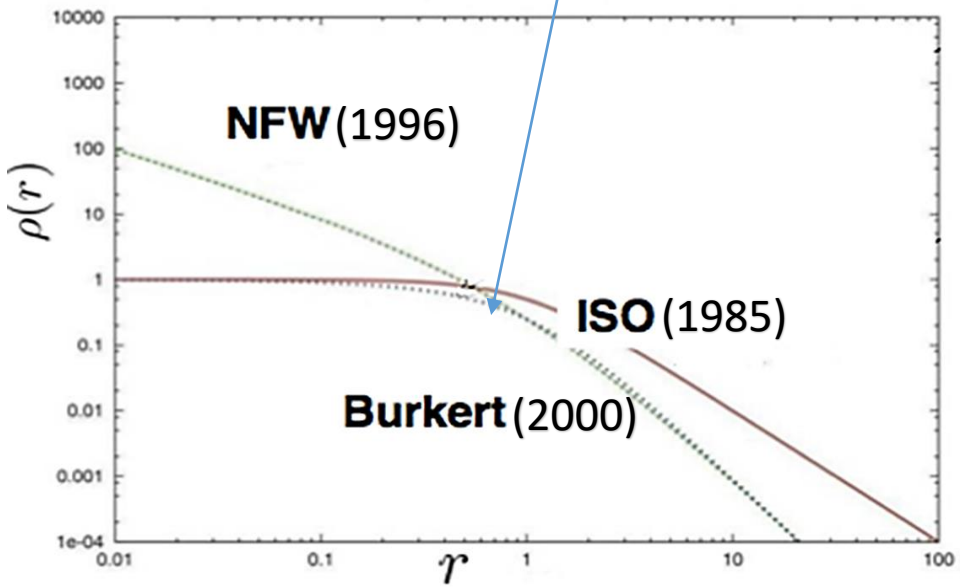


Two new structural parameters, not existing in CDM
But present if matter interacts via EM or Strong forces

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

- ΛCDM → **cusp** $\rho(r) \sim r^{-1}$

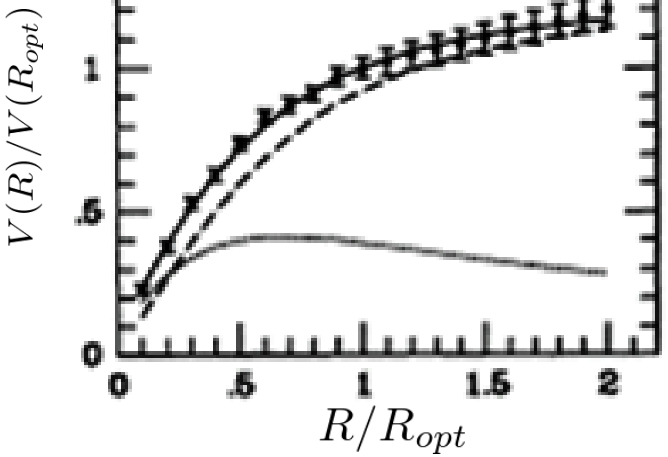
- **Observations** → **core** $\rho(r) = const.$



MASS MODELLING

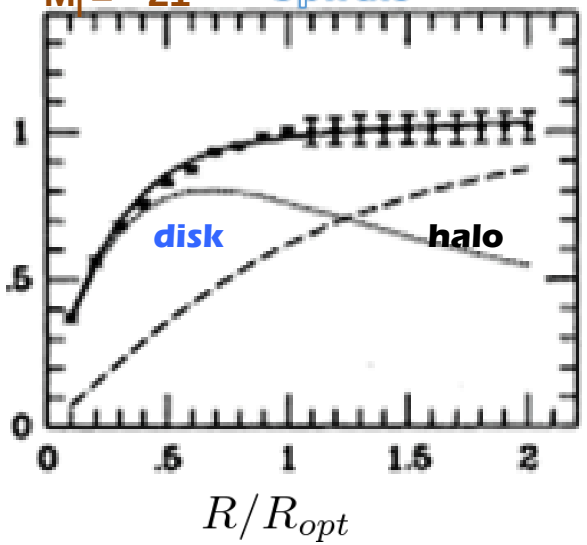
Spirals

M_I = -18



Spirals

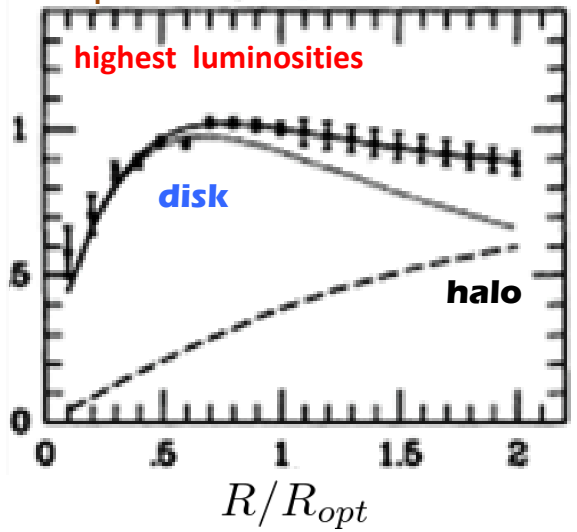
M_I = - 21



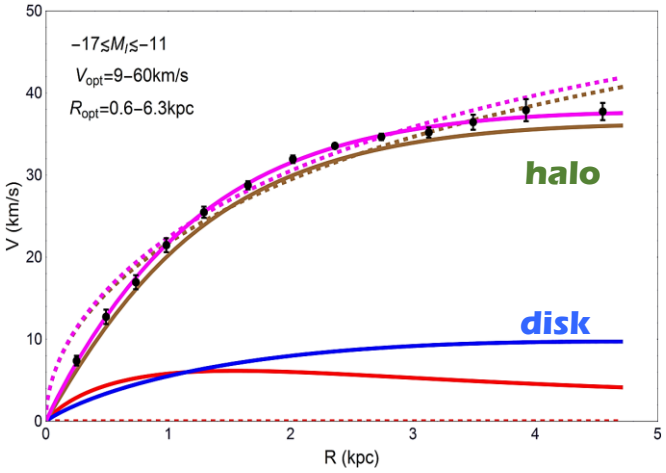
Spirals

M_I = - 23

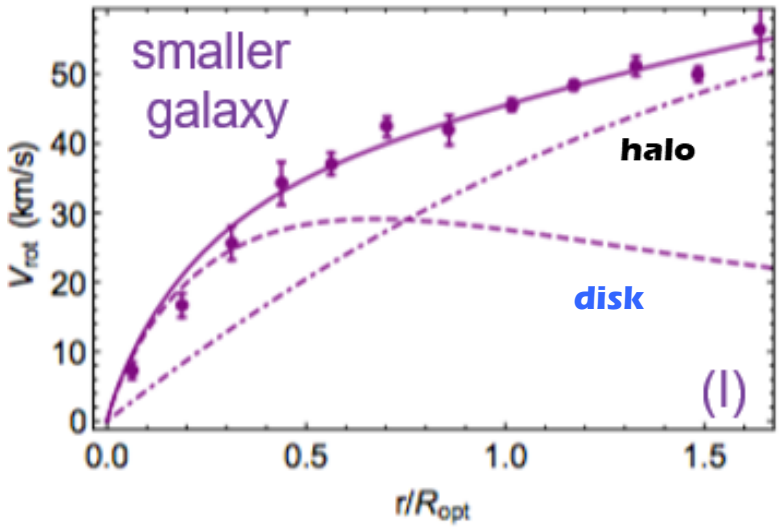
highest luminosities



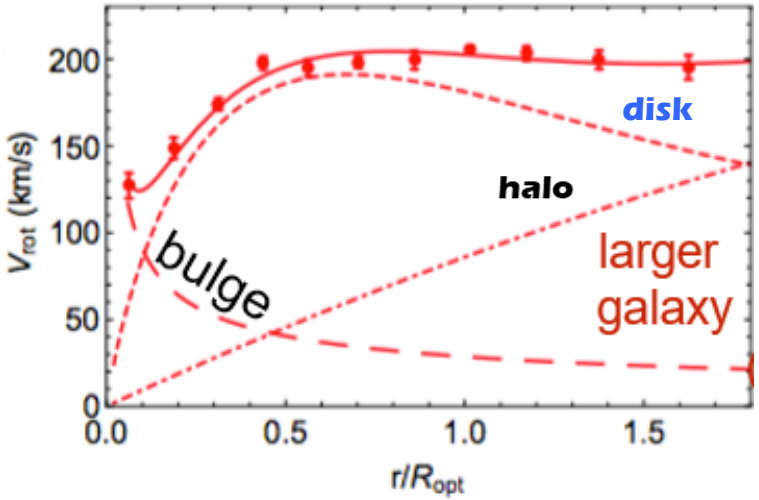
Dwarf Spirals



Low Surface Brightness

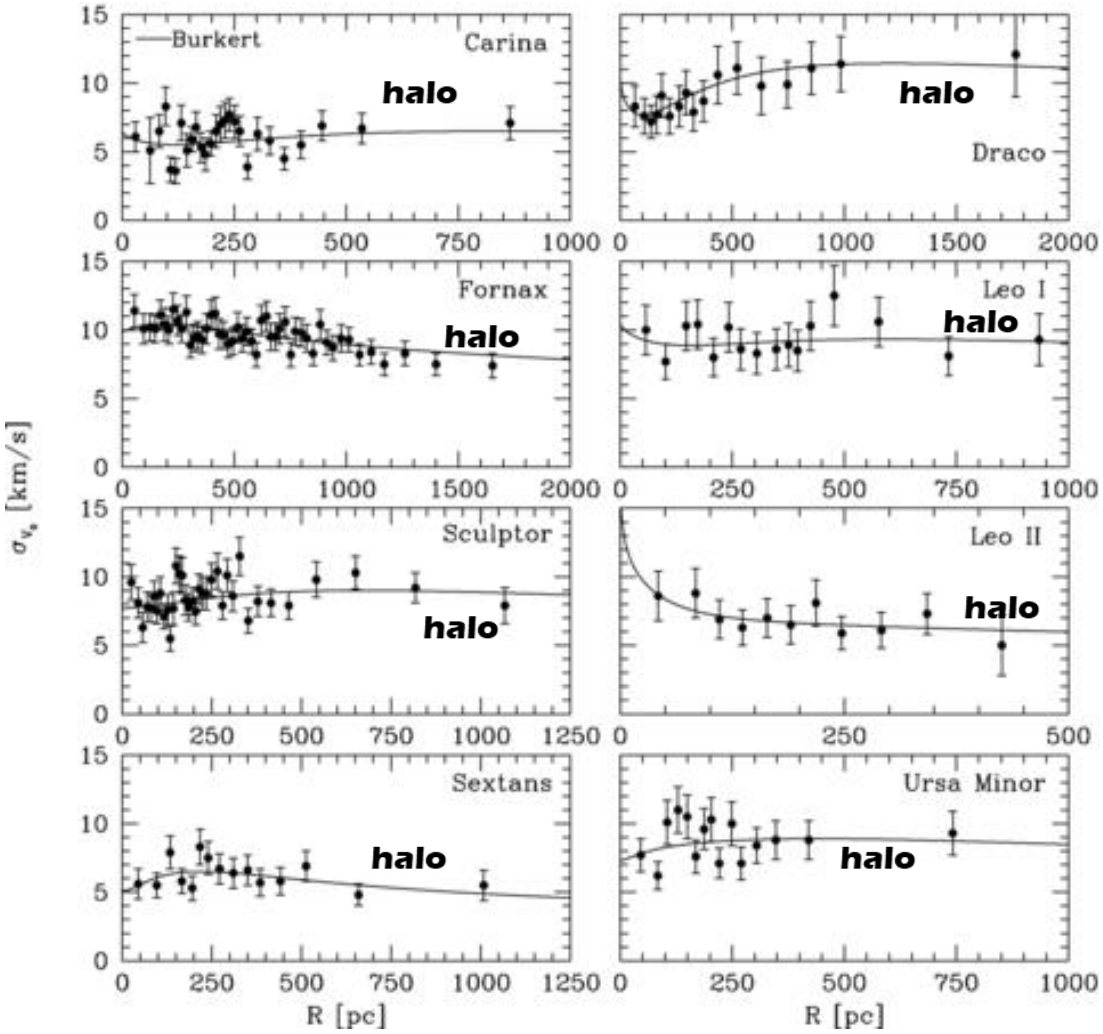


Low Surface Brightness

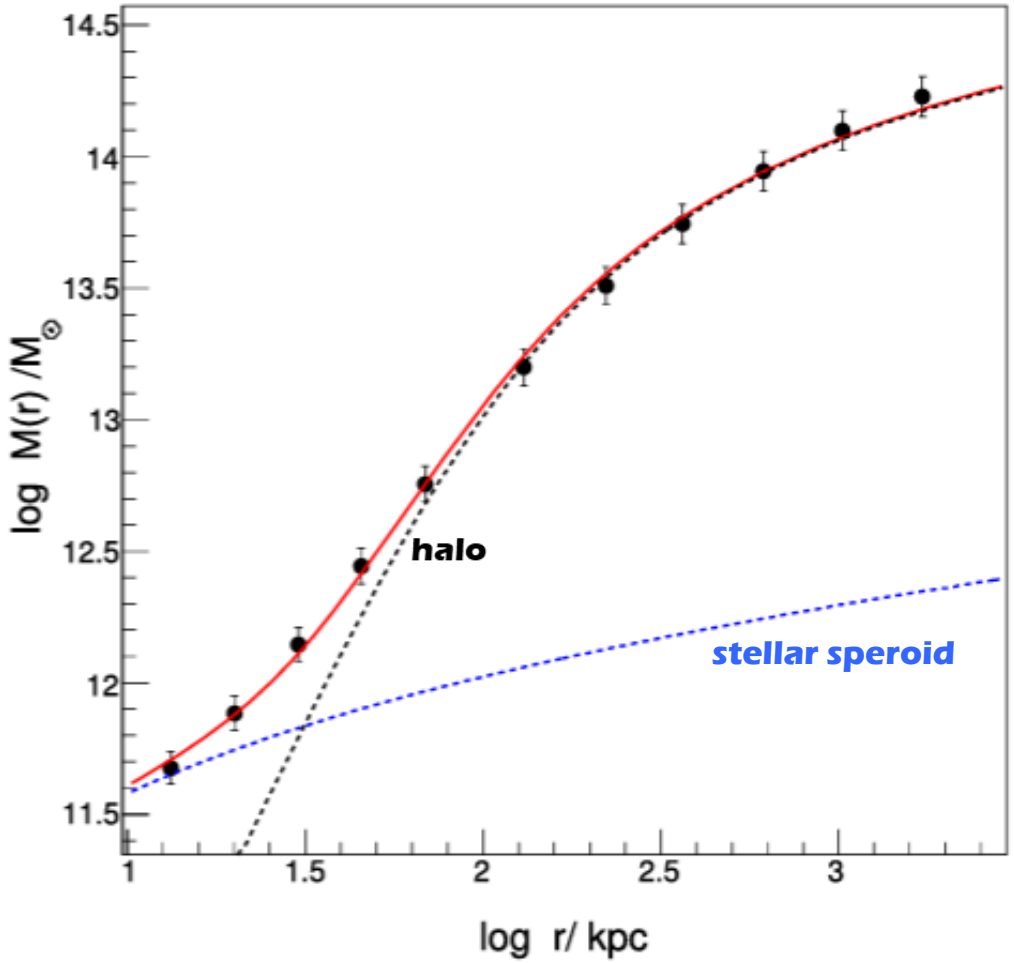


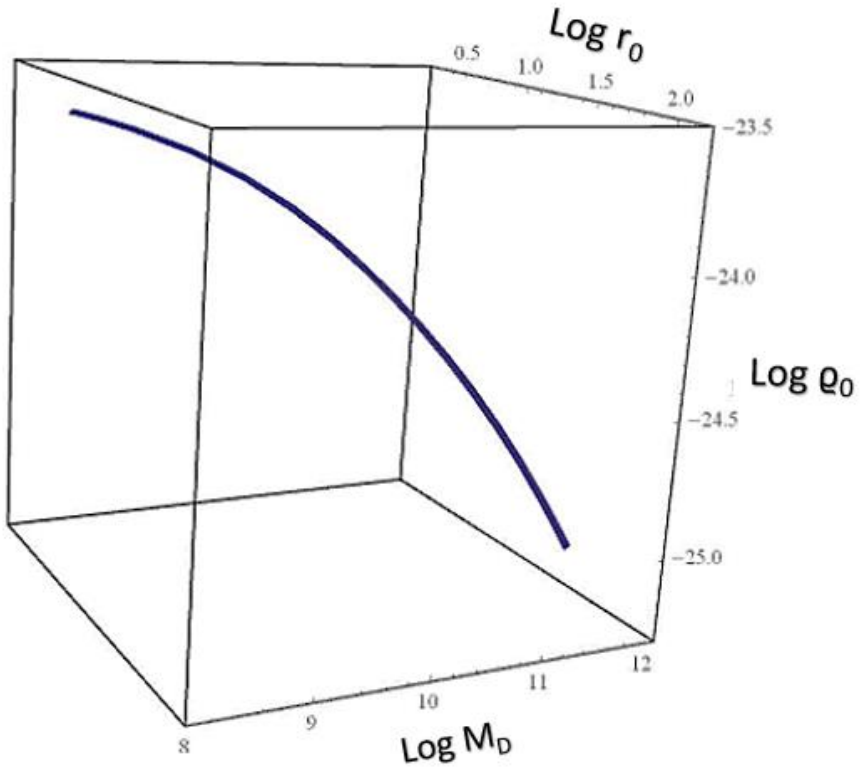
MASS MODELLING-2

Dwarf Ellipticals



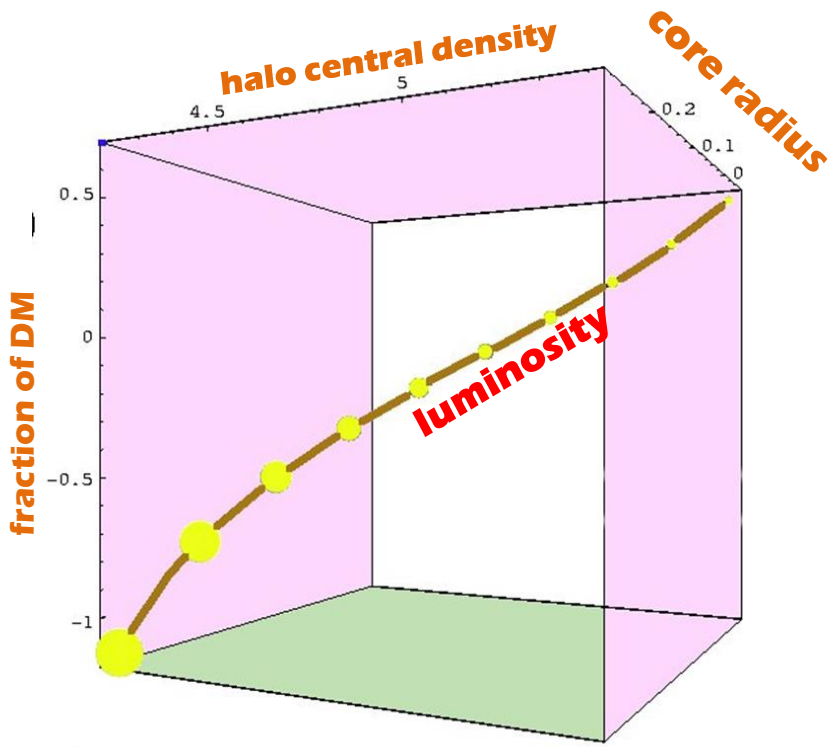
M 87



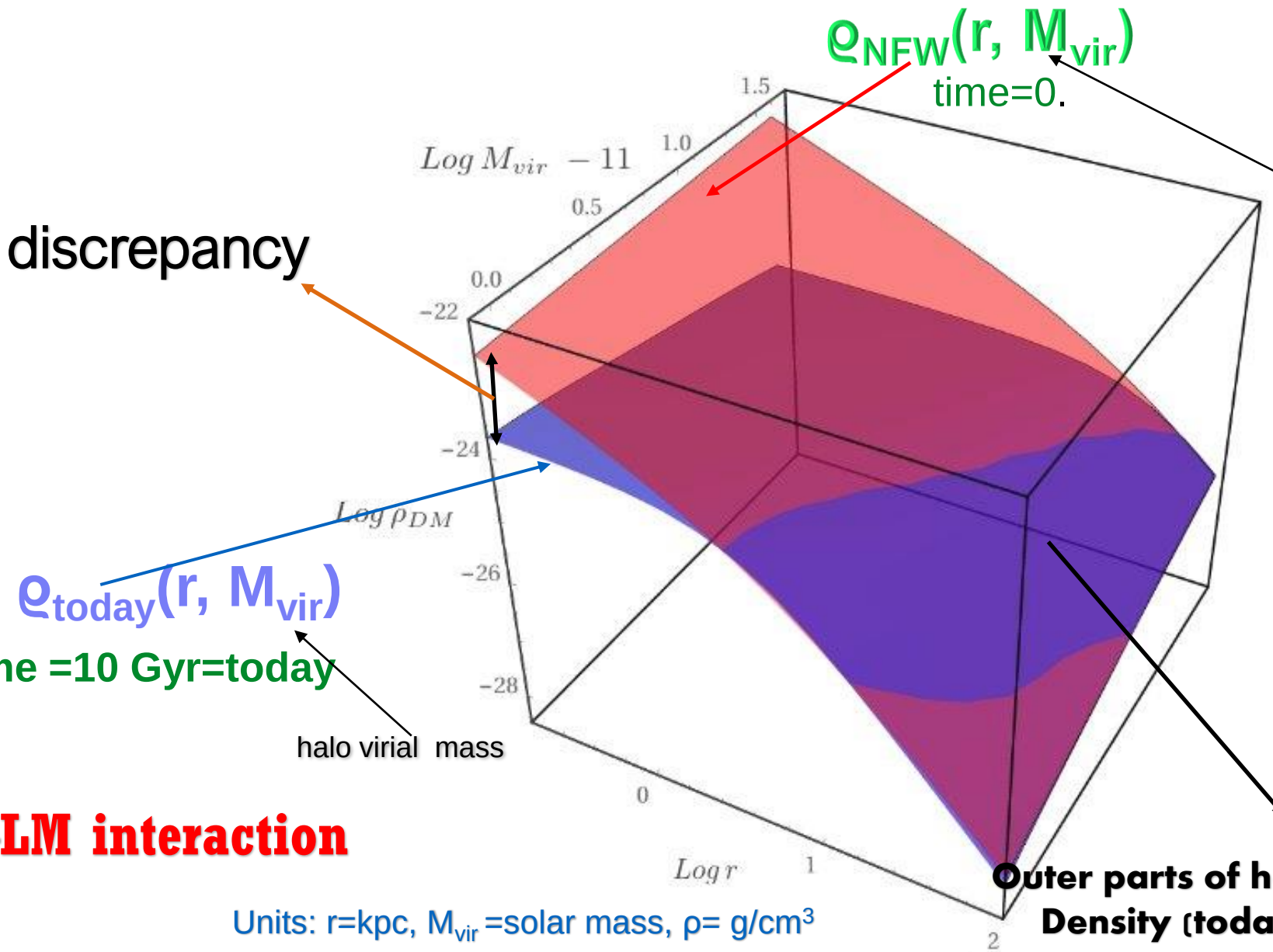


The structural DM and LM parameters are related among themselves and with luminosity.

-Baryonic feedback: cores maybe, relations not.
-no explanation (inside the Apollonian DM Paradigm)



Outer halo radii: initial = present day DM density profiles.



Effect on 1-2 % of the halo mass

Inner DM–LM interaction

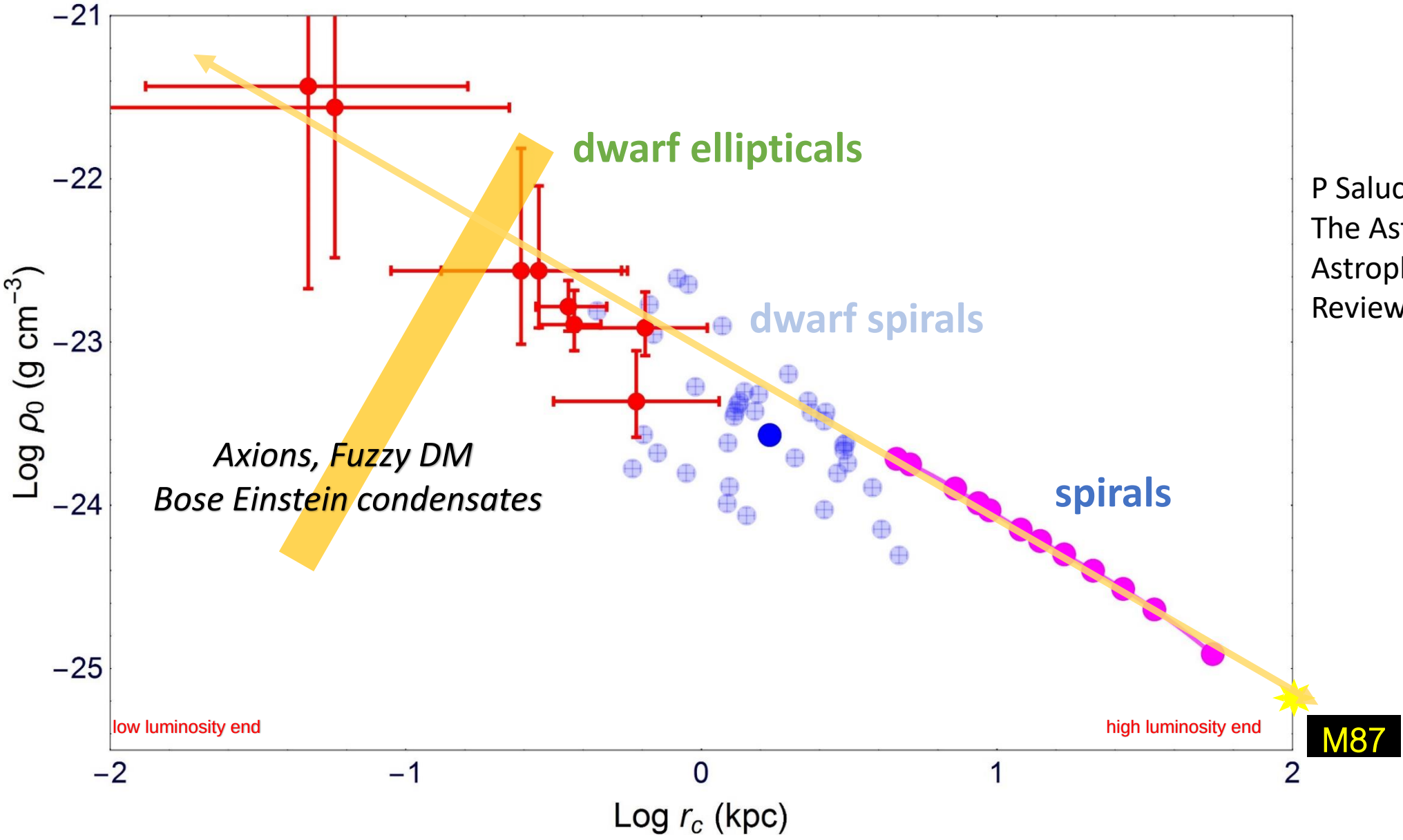
Units: r=kpc, M_{vir} =solar mass, ρ= g/cm^3

Outer parts of halos are collisionless
Density (today)=Density (initial)
Struct. Param.: no those from simulations

ΛCDM -8

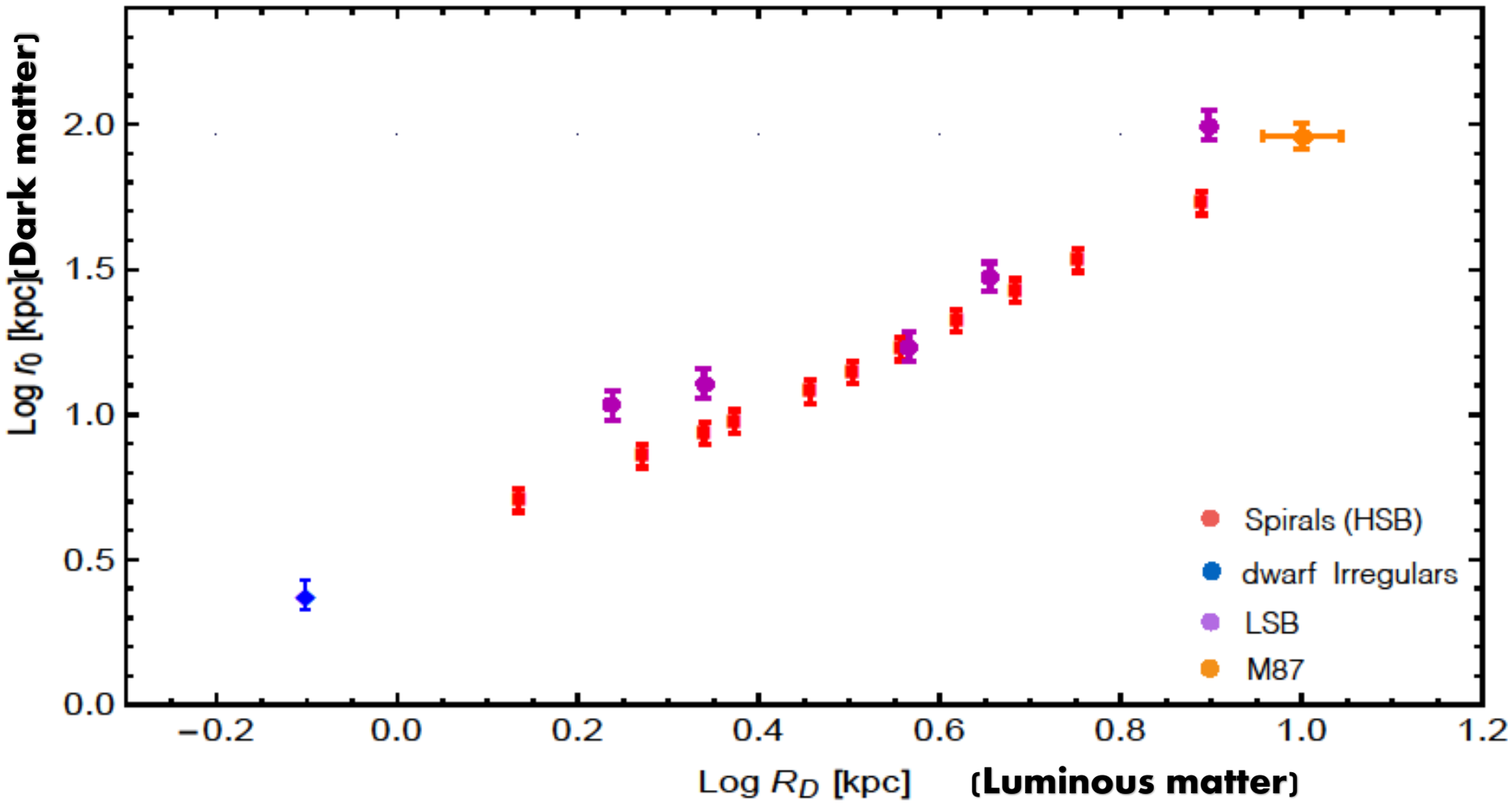
-8

Central DM halo density vs. core radius



P Salucci, 2018
The Astron and Astrophysics Review 27, 1-60

Stellar (disk) length scales vs halo core radii



The log derivative of the stellar surface density vs. that of the dark halo 3D density

Not Adiabatic Exchange of 4-momentum

DM and LM compactnesses

$M_D(R_D)$, R_D; $M_H(r_0)$, r_0

$$C_\star = \frac{(M_D(R_D)/R_D^2)}{<(M_D(R_D)/R_D^2)>}$$

same $M_D(R_D)$

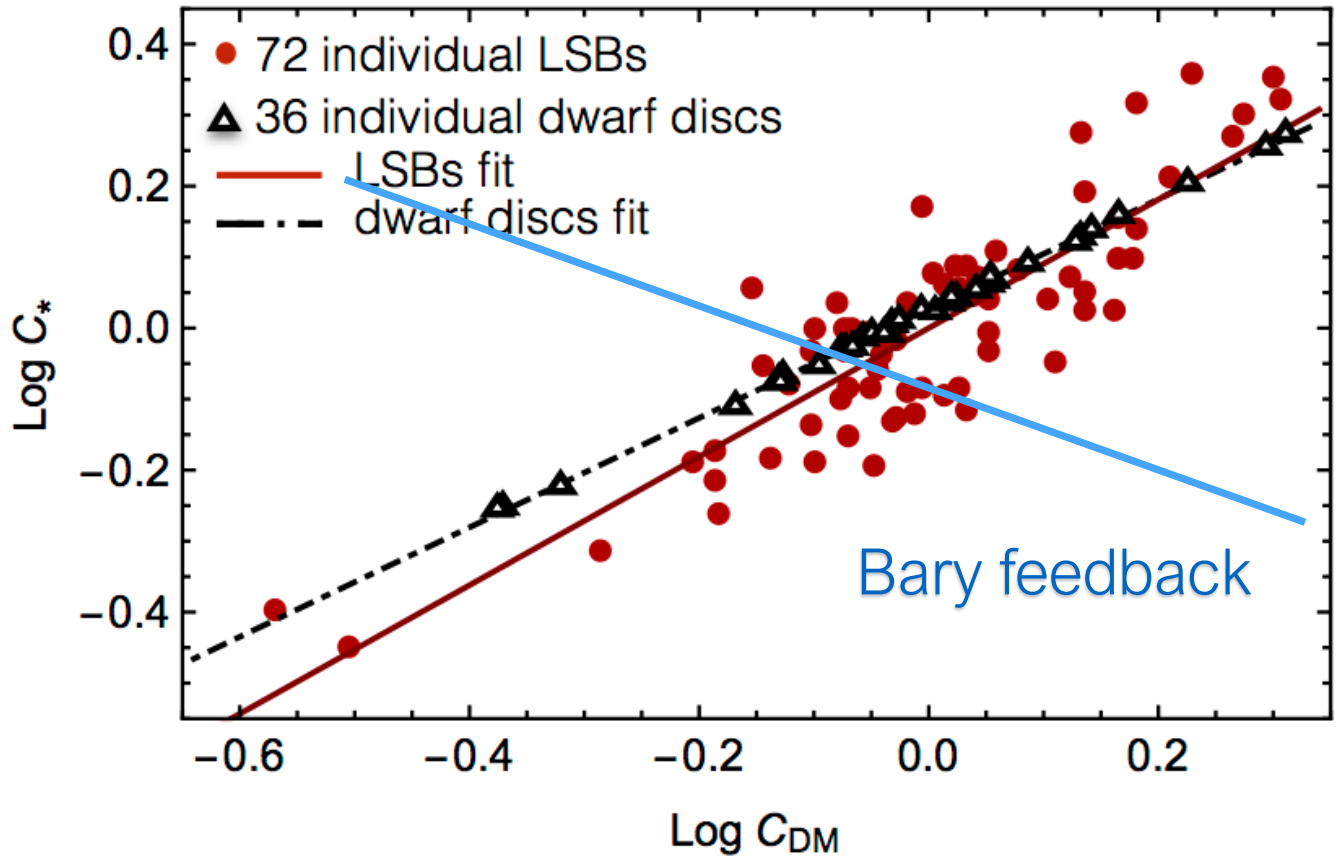
Formation of the stellar disks

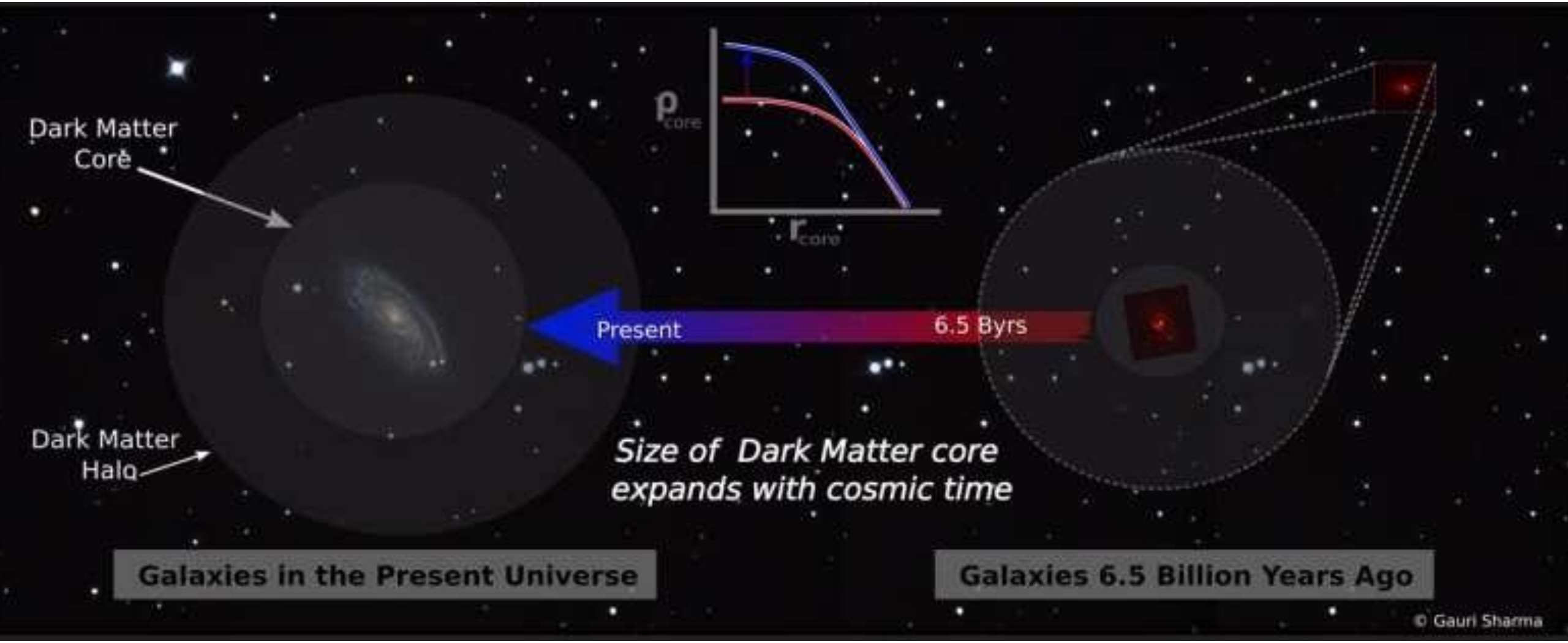
$$C_{DM} = \frac{(M_H(r_0)/r_0^2)}{<(M_H(r_0)/r_0^2)>}$$

same $M_H(R_0)$

Formation of the const density region in dark halos

$$Log\ C_* = 0.00 + 0.90\ Log\ C_{DM}$$



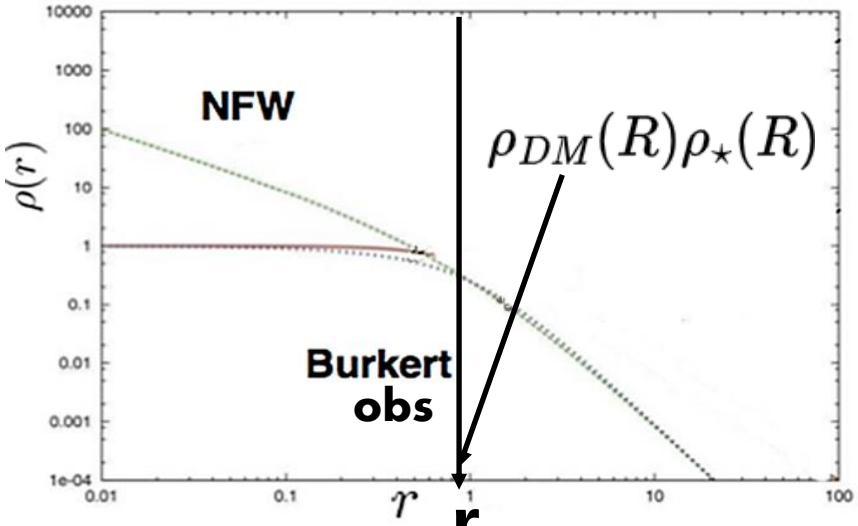

Dark Matter
Core
Dark Matter
Halo
ρ_{core}
r_{core}
Present
6.5 Byrs
Size of Dark Matter core
expands with cosmic time
Galaxies in the Present Universe
Galaxies 6.5 Billion Years Ago
© Gauri Sharma

In galaxies, the quantity: $\rho_{DM}(R)\rho_{\star}(R)$

varies by 10^3 at different radii and among them

BUT IT IS CONSTANT:

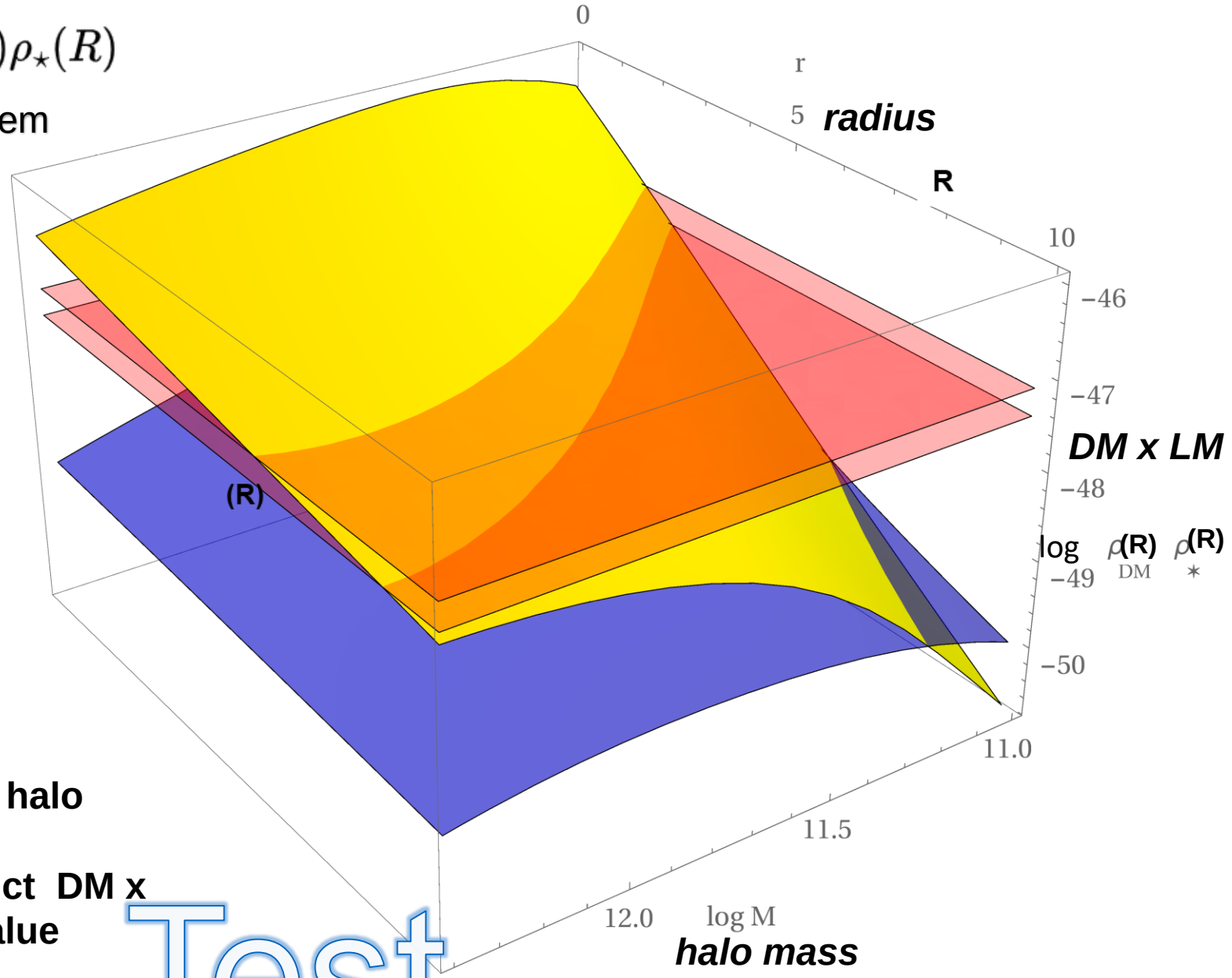
$= 10^{-47.5\pm0.3} g^2 cm^{-6}$ @ **r_0** in any galaxy



r_0 **r_0** ***in all galaxies***

-is the size of the region in which the DM halo density is constant

-marks the radius inside which the product DM x LM densities , in all galaxies, is a fixed value



Test

DMP(2023) ≠ DMP(1990)

ΛCDM scenario today suffers by:

- Emergence of a strong DM-LM entanglement
- Inconsistencies on scales < 0.1 Mpc

The disagreement is now so deep and wide that concerns also the paradigm that has generated this scenario

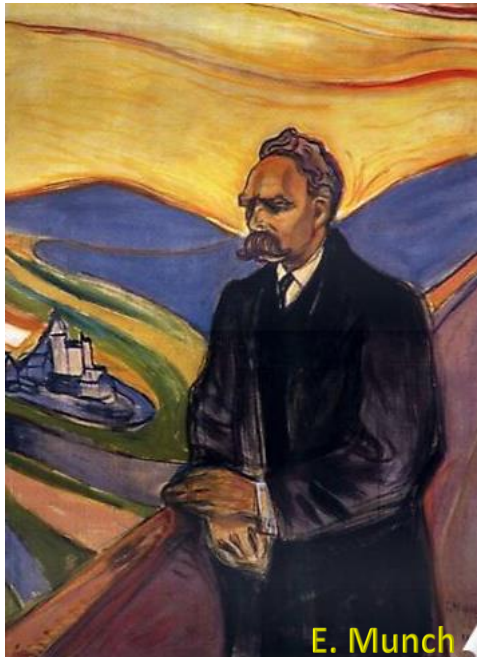
-The failure of the scenario stems from its a-priori adhesion to criteria of scientific beauty in all its various acceptations

The philosopher Nietzsche, not the first, proposed the idea:

Beauty ⟹ Truth

False ⟹ Ugly

NIETZSCHEAN Paradigm for the actual Scenario of DM



The paradigm remains agnostic with respect to the canon of scientific beauty of a scenario.

- It allows scenarios that appear to our “scientific senses” ugly, ad hoc and anti-Occam and that are not helpful in making progresses on presently open issues of Physics.

-The DM scenario is primarily built by iteratively reverse engineering the DMP as this plays out with time.

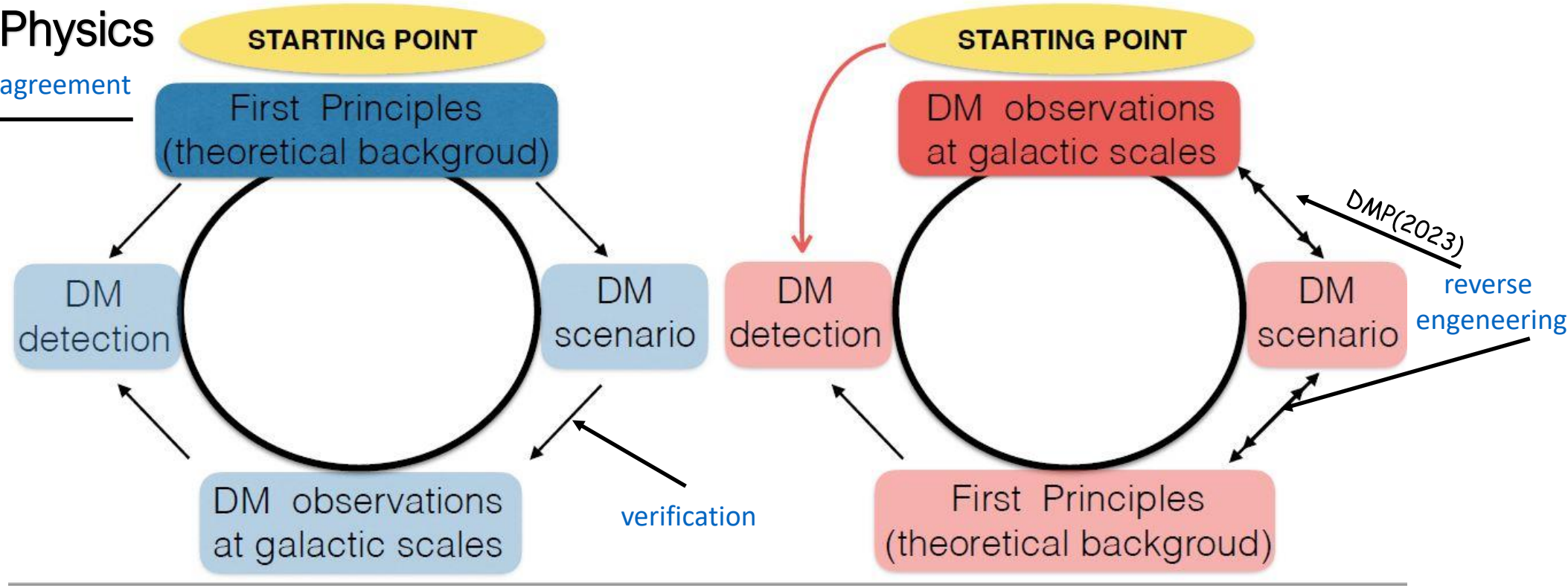
-This paradigm applies for the DM (DE?) (e.g. not for BSM physics)

PARADIGM SHIFT

Apollonian → NIETZSCHEAN

Crucial moment
in the history of Physics

DMP(1990) ← In agreement



Salucci et al Universe, 2020, 6, 118

DMP(2024) → SCENARIOS

A new physical interaction creates the DM cores and the fascinating aspects of the DMP(2024).
At macroscopic Level 1 kpc^3:

$$d\rho_{DM}(r,t)/dt = k < \sigma V_r > \rho_{DM}(r,t)\rho_{LM}(r);\ \ \rho_{DM}(r,0) = \rho_{NFW}(r)$$

explains naturally the formation of cores and the above relationships

Direct DM-SM particle interaction. Scattering, absorption and emission, capture, resonance.
Multiple location of the interactions.
DM-DM interaction enhanced by local baryonic excess

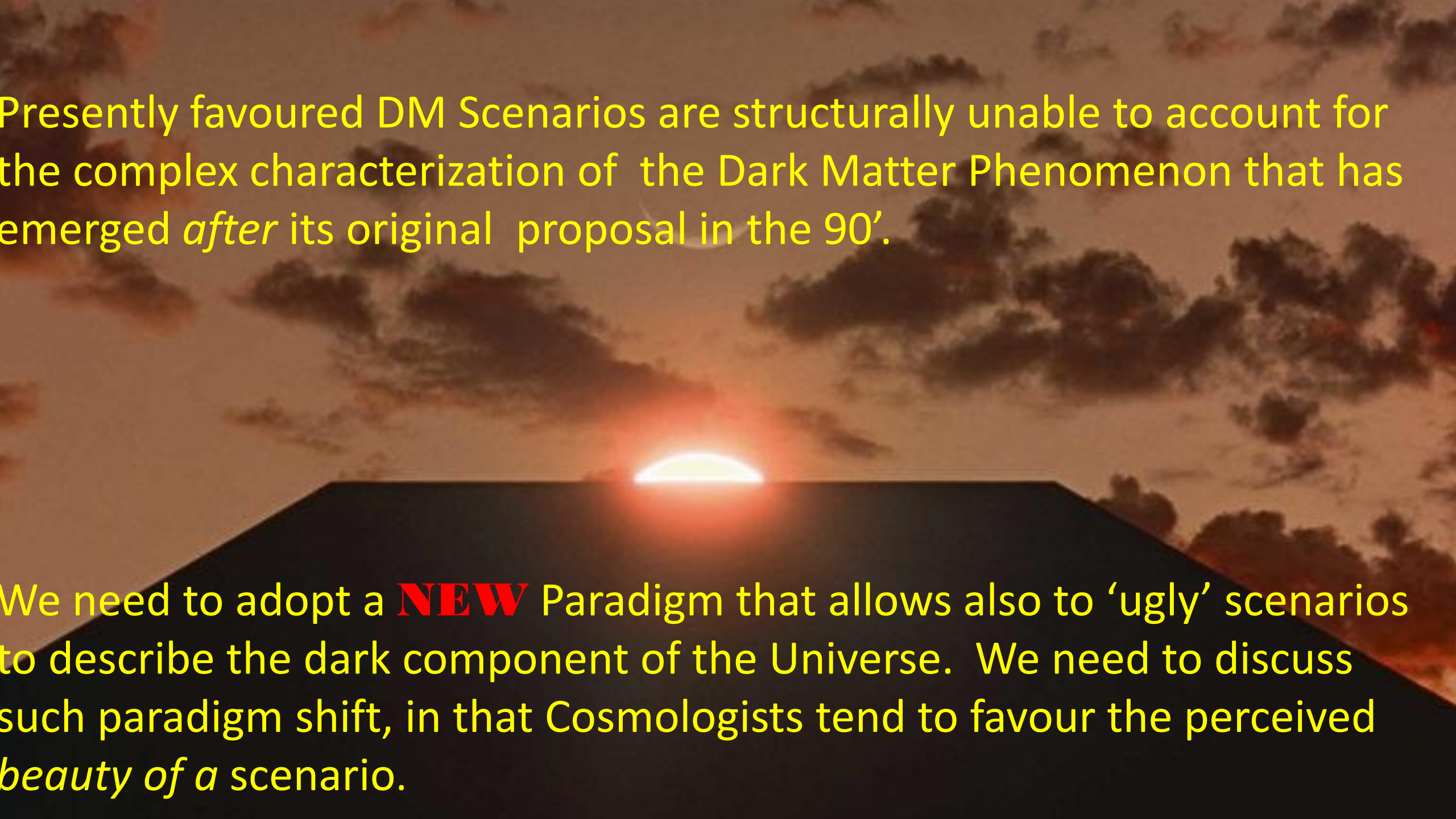
Neutrinos?

Can be the DM particle. Degenerate ~1 kev WDM fermionic neutrino (+self interaction)

Can push out of the DM ‘standard particle’. Neutrino flux from supernovae on DM halo particles.

Can be the witness of the interaction between DM and SM particles (in stars, neutron stars, ecc

Are some neutrino anomalies already suggesting that?



Presently favoured DM Scenarios are structurally unable to account for the complex characterization of the Dark Matter Phenomenon that has emerged *after* its original proposal in the 90'.

We need to adopt a **NEW** Paradigm that allows also to 'ugly' scenarios to describe the dark component of the Universe. We need to discuss such paradigm shift, in that Cosmologists tend to favour the perceived *beauty of a* scenario.