The Local Group Satellite Galaxies:

Testing Fundamental Physics

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If
- virial equilibrium
- spherical symmetry
- isotropic velocity dispersion

then apply *virial theorem* to estimate $\frac{M}{L}$

$$E_{\rm kin} = -E_{\rm tot} \longrightarrow \sigma^2 = G\,\frac{M}{R}$$

Luminosity $L = \pi\, R^2\, I$ | I = surf.lumin.

$$\longrightarrow \frac{M}{L} = \frac{1}{G\,\pi}\,\frac{\sigma^2}{R\,I}$$

Background

$$S \quad + \; d1 \quad + \; d2 \quad + \; \dots \quad + d_n$$

$$n \approx 30\,, \quad d \lesssim 250\,\mathrm{kpc}$$

$$\frac{M}{L} = \frac{1}{G\,\pi}\,\frac{\sigma^2}{R\,I} = \frac{1}{G}\,\frac{\sigma^2 R}{L}$$

Globular clusters :

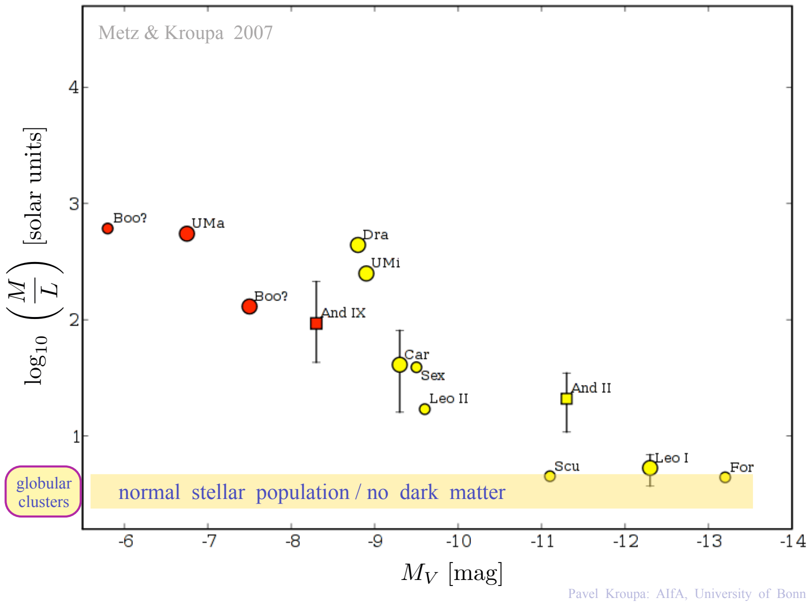
$$R \approx 10\,\mathrm{pc}\,, \quad \sigma \approx 10\,\mathrm{km/s}\,, \quad L \approx 10^5\,L_\odot$$

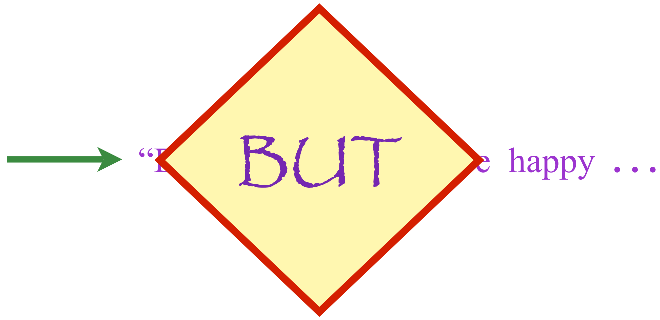
$$\longrightarrow \frac{M}{L} \approx 1$$

Dwarf spheroidal (dSph) satellite galaxies :

$$R \approx 200\,\mathrm{pc}\,, \quad \sigma \approx 10\,\mathrm{km/s}\,, \quad L \approx 10^5\,L_\odot$$

$$\longrightarrow \frac{M}{L} \approx 20$$





Standard / most-popular interpretation :

The *dwarf-spheroidal* (dSph) satellite galaxies
are heavily *dark-matter dominated*;

they are part of the
cosmological sub-strucure
surrounding
the Milky-Way.

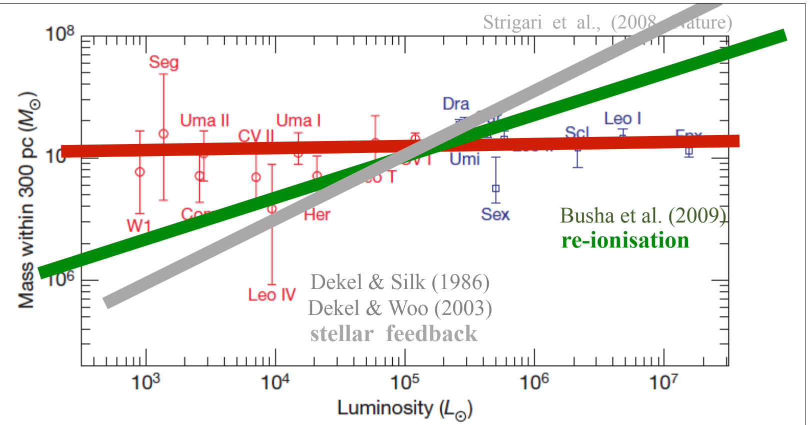


Figure 1 | The integrated mass of the Milky Way dwarf satellites, in units of solar masses, within their inner 0.3 kpc as a function of their total luminosity, in units of solar luminosities. The circle (red) points on the left refer to the newly discovered SDSS satellites, whereas the square (blue) points refer to the classical dwarf satellites discovered pre-SDSS. The error bars reflect the points where the likelihood function falls off to 60.6% of its peak value.

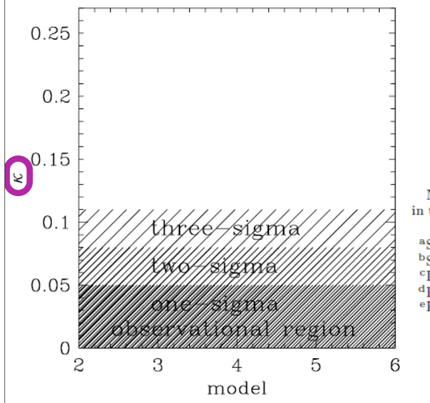


Fig. 1.— The trend κ (eq. 2) for the different models listed in Table 1.

TABLE 1
Fitted parameters for equ 2.

data/model	κ	η	$M_{03} \times 10^{-7}/M_\odot$
1[a]	0.02 ± 0.03		1.02 ± 0.39
2[b]	0.02 ± 0.03		1.01 ± 0.40
3[c]	0.21	1.67	–
4[d]	0.15 ± 0.02		0.24 ± 0.06
5[e]	0.17 ± 0.01		0.18 ± 0.02

Note. — $\eta = 0.35/\kappa$; data 1–2 are observational values derived in this paper, data 3–5 are theoretical values fitted here.

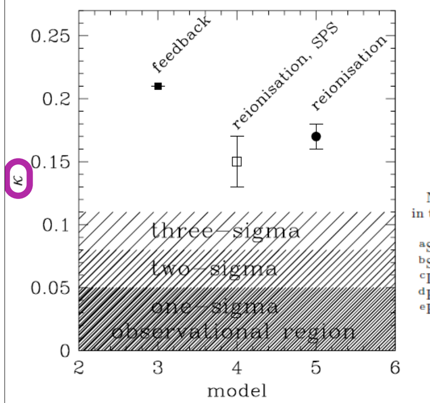
[a] Strigari et al. (2008);
[b] Strigari et al. (2008) without faintest satellite;
[c] Dekel & Silk (1986); Dekel & Woo (2003), stellar feedback (eq. 1);
[d] Busha et al. (2009), their SPS model;
[e] Busha et al. (2009), in-homogeneous re-ionisation model.

$$\log_{20}(M_{0.3\,\mathrm{kpc}}/M_\odot) = \log_{10}(M_{03}/M_\odot) + \kappa \log_{10}(L_V/L_{V,\odot})$$

Conservation of energy

it is increasingly difficulty to remove sub-parts of bound systems with their increasing binding energy.

The existence of a *theoretical* mass-luminosity relation ($\kappa > 0$)



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$$\log_{20}(M_{0.3\,\mathrm{kpc}}/M_\odot) = \log_{10}(M_{03}/M_\odot) + \kappa \log_{10}(L_V/L_{V,\odot})$$

Conservation of energy

it is increasingly difficulty to remove sub-parts of bound systems with their increasing binding energy.

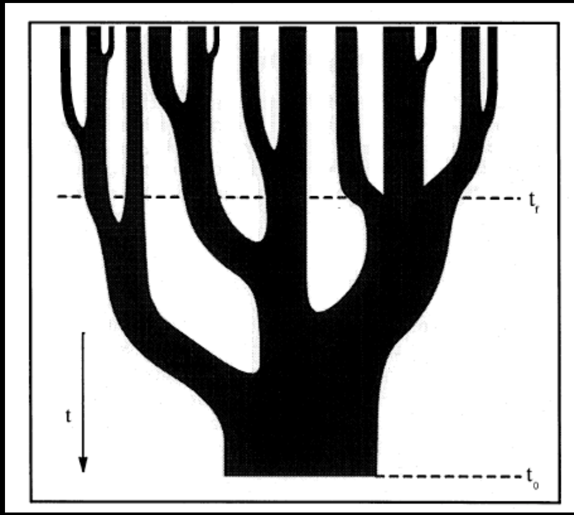
The *lack* of an *observed* mass-luminosity relation ($\kappa \approx 0$)

nature apparently does not care about the existence of the putative dark matter halo.

Thus, the *concept* of dark-matter halos appears to be *unphysical*

The structure of CDM halos

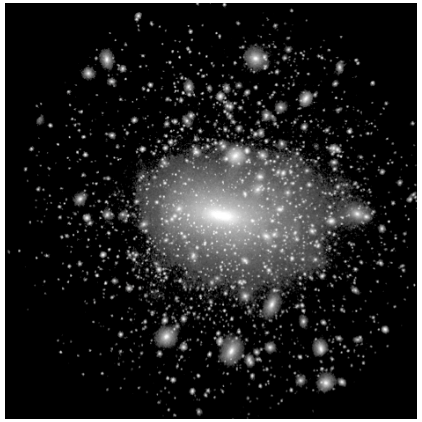
Lacey & Cole (1993)



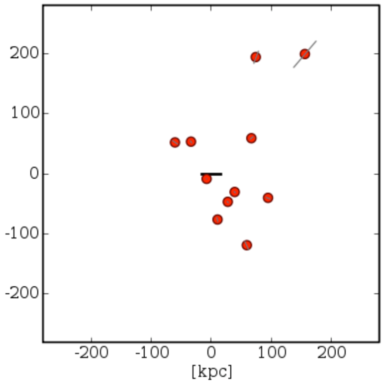
the beginning

today

The spatial distribution of the MW satellites



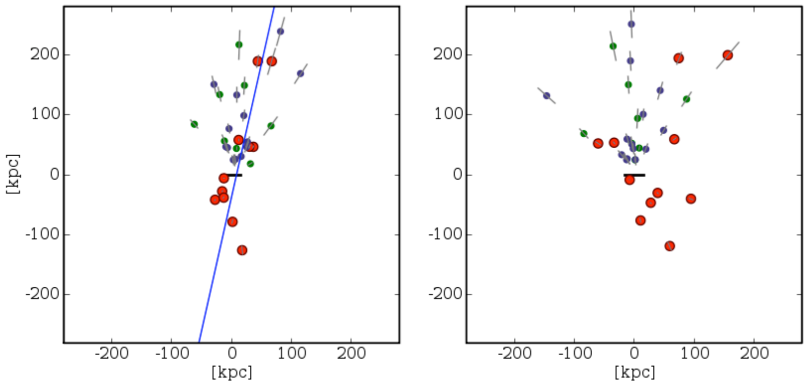
- the 11 "classical" (brightest) satellites



Kroupa, Theis & Boily (2005)
Metz, Kroupa, Jerjen (2006)

MW satellites are in a disk-like configuration:

- the 11 "classical" (brightest) satellites
- new candidate (faint) satellites
- current new candidates (faint) satellites



Walsh, Jerjen & Willman (2007)

MW satellites are in a disk-like configuration:

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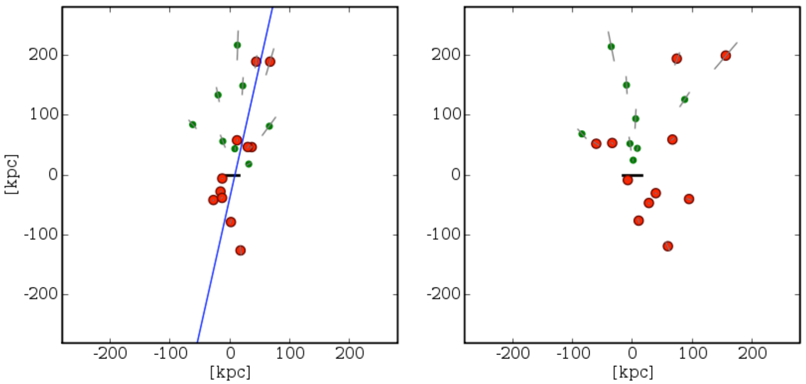
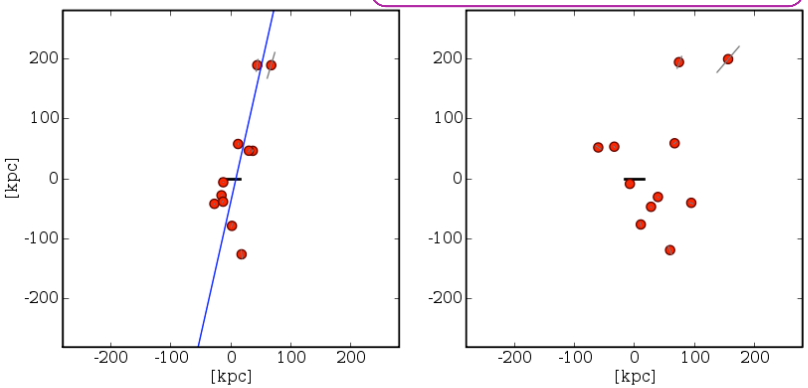


Belokurov et al. (2005);
Zucker et al. (2005)

Disk of Satellites

➡ ***a rotational structure ?***

- the 11 "classical" (brightest) satellites



Kroupa, Theis & Boily (2005)
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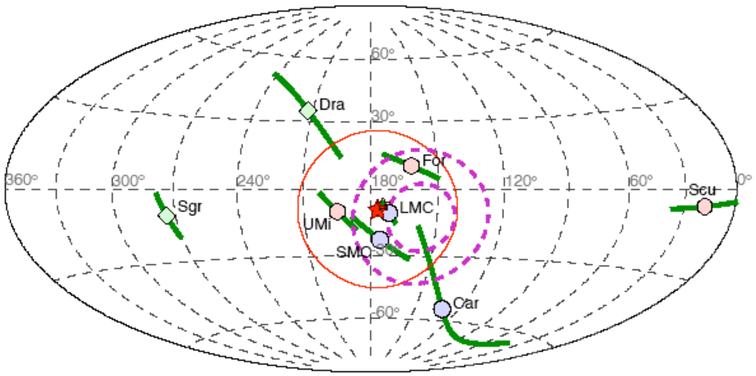
Directions of orbital angular momenta of MW satellites

Metz, Kroupa & Libeskind (2008)



This
correlated phase-space
population
is *inconsistent* with
the satellites being
dark-matter sub-haloes
that fell into the MW halo
individually.

The MW satellite *DoS* is defined mostly by the *outer satellites*;
but the *angular momenta* of the *inner satellites*
are aligned to the pole of the DoS

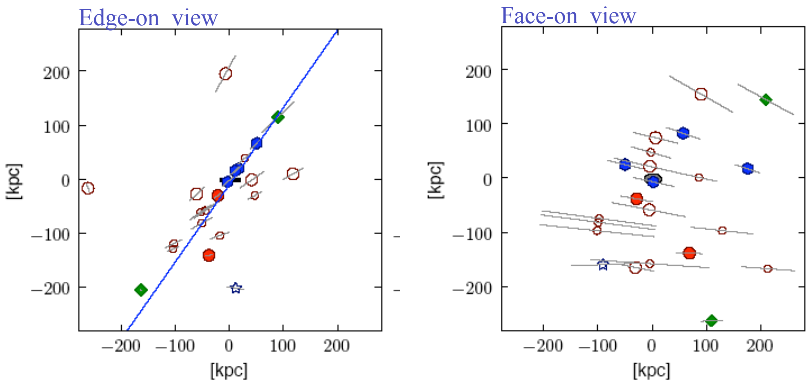
the DoS is rotationally supported :
the satellites form a
highly correlated
phase-space population

Andromeda

Andromeda

(Metz, Kroupa, Jerjen 2006)

- ● dSph
- ◆ dEs, cEs
- ■ dIrrs, dIrr/dSph



Tidal-dwarf satellite galaxies

(TDGs)

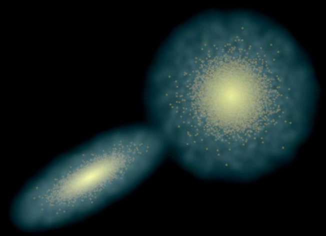
(Mirabel, Dottori & Lutz 1992; Duc & Mirabel 1994)

An inherent part of any hierarchical structure formation theory,
and a conservative, *classical approach* to the problem of dSph satellites.

From α to Ω

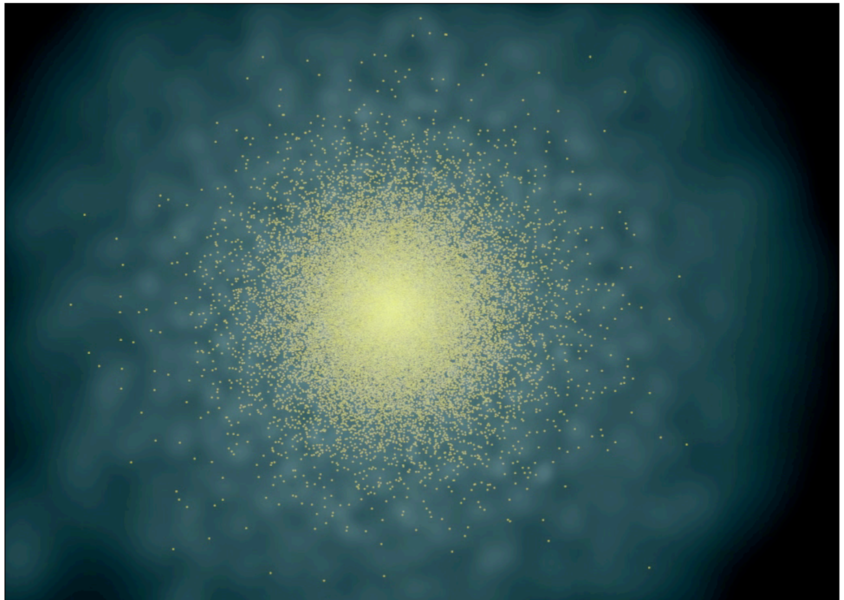
On their origin.

Relevance : The collision of two disks at high redshift



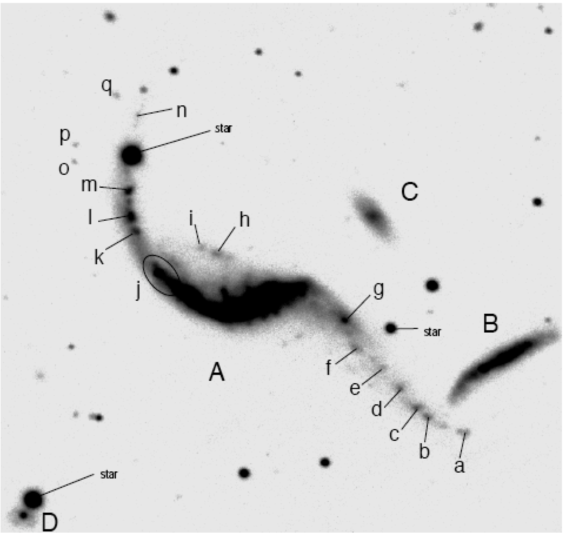
Wetzstein, Naab & Burkert 2007

TDGs are baryon dominated
(Barnes & Hernquist 1992).



Wetzstein, Naab & Burkert 2007

An unsettling
Truth . . .



(Weilbacher et al. 2000)

$N_{\rm TDG} \approx 14$

Fig. 21. Identification chart of field 10 around AM 1353-272.

Okazaki & Taniguchi (2000, ApJ)

"Dwarf galaxy formation induced by galaxy interactions"

TABLE 1

MERGER SCHEME

Scheme	Collision	Parameter	Result
1	Sp + Sp		S0 + k_1 dEs
2	Sp + S0	a	E + k_2 dEs
		$1 - a$	S0 + S0 + k_3 dEs
3	S0 + S0	b	E + k_4 dEs
		$1 - b$	S0 + S0 + k_5 dEs

NOTE.—In this scheme, a merger between two spiral galaxies evolves not into an elliptical galaxy but into an S0 one. The reason for this is as follows: It is widely accepted that elliptical-like products are formed by dissipationless collapse. Mergers between gas-rich spiral galaxies can achieve a similar physical condition in their final phase. However, if the star formation timescale is longer significantly than the dynamical timescale, the remaining gas will settle to a disk and then the end product will not become an elliptical-like galaxy. This is confirmed by analytical and numerical methods.

Based on the above assumption, we obtain a set of kinetic equations for morphological-type evolution as a consequence of galaxy interactions in the following form:

$$\frac{1}{\gamma}\frac{dn_{\rm Sp}}{dt} = -2n_{\rm Sp}^2 - n_{\rm S0}\,n_{\rm Sp}\,, \qquad (1)$$

$$\frac{1}{\gamma}\frac{dn_{\rm S0}}{dt} = n_{\rm Sp}^2 + (1-2a)n_{\rm Sp}\,n_{\rm S0} - 2bn_{\rm S0}^2\,, \qquad (2)$$

$$\frac{1}{\gamma}\frac{dn_{\rm E}}{dt} = bn_{\rm S0}^2 + an_{\rm S0}\,n_{\rm Sp}\,, \qquad (3)$$

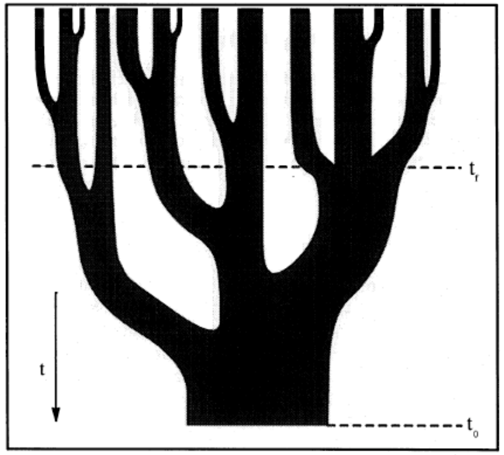
$$\frac{1}{\gamma}\frac{dn_{\rm dE}}{dt} = k_1\,n_{\rm Sp}^2 + [k_2\,a + k_3(1-a)]n_{\rm S0}\,n_{\rm Sp} + [k_4\,b + k_5(1-b)]n_{\rm S0}^2\,, \qquad (4)$$

where $n_{\rm Sp}$, $n_{\rm S0}$, $n_{\rm E}$, and $n_{\rm dE}$ are the number densities of spirals, S0s, ellipticals, and dwarfs, respectively, γ is the mean collision rate, and k_i (i = 1–5) is the number of dwarfs formed by one collision in each case. Note that the first three equations are the same as those in SN81.

Okazaki & Taniguchi (2000) **:**

The galaxy interaction scheme proposed by Silk & Norman (1981)

(Lacey & Cole 1993)



Okazaki & Taniguchi (2000) **:**

The galaxy interaction scheme proposed by Silk & Norman (1981)

"can be *responsible for the observed numbers of dEs* in the various environs from poor groups of galaxies to the usual rich clusters of galaxies. The *formation rate of TDGs* is estimated to be *1–2 in each galaxy interaction*."

i.e. *standard cosmology* predicts ***all dE's*** to be ***TDGs***

But remember, $N_{\rm TDG}$ *scales with gas content* and thus evolutionary status / cosmological epoch of interacting galaxies (*many more formed in the past*).

Within the framework of
standard cosmology,
there is
little room
for
shining cosmological sub-structures
with $< 10^{10}\, M_\odot$ **!**

(taking account of only the TDGs, not even counting “fireballs”)

There are thus 5 essentially independent arguments :

A
contradiction
in standard cosmological theory
thus emerges **:**

theory + observation **:**
a large fraction (if not all) of
observed $\lesssim 10^{10}\, M_\odot$ sub-structures are TDGs

Previous and current attempts to get the
$< 10^{10}\, M_\odot$ dark matter subhaloes
to shine would have been ill-fated **. . .**

1) *Lack* of a *mass-luminosity relation* (binding energy does not play a role)
and
all haloes having the *same mass* is *incompatible* with the individual growth histories inherent to the dark-matter hypothesis.

→ dark-matter halo masses appear to be unphysical.

2) The satellites form a correlated phase-space population.
This is *incompatible* with them being individual haloes that fell into the MW halo independently.

→ dark-matter halo masses appear to be unphysical.

3) The satellites form a *correlated phase-space population*.
This can only really imply they are *ancient tidal-dwarf galaxies* (TDGs).
Their high M/L ratia

→ dark-matter halo masses appear to be unphysical.

4) The *number of TDGs* produced in standard cosmology accounts for all dE galaxies.

→ there is not much room for shining dwarf dark matter haloes.

5) *Young TDGs* are observed to have flat rotation curves. But they cannot contain dark matter

→ "dark matter" appears to be a *manifestation* of *non-Newtonian dynamics*.

The END

The *failure* of the dark-matter ansatz

↓

Newtonian dynamics seems to *fail*
(flat rotation curves and high M/L ratia of dSph satellites).

We therefore have to face the real possibility that we probably live in a *non-Newtonian universe*.

Popular examples of alternative dynamics theories:
MOND, MOG.

M/L_V vs *mass* :

Dabringhausen, Hilker & Kroupa 2008