Detecting dark matter

13.05.2019

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Based on :

2019arXiv190503258H Galaxies lacking dark matter in the Illustris simulation

- Haslbauer, Moritz; Dabringhausen, Joerg; Kroupa, Pavel; Javanmardi, Behnam; Banik, Indranil

1	2016arXiv161003854K Kroupa, Pavel	1.000	10/2016	A X R U	The observed spatial distribution of matter on scales ranging from 100kpc to 1Gpc is inconsistent with the standard dark-matter-based cosmological models
2	2015CaJPh..93..169K Kroupa, Pavel	1.000	02/2015	A E X R C U	Galaxies as simple dynamical systems: observational data disfavor dark matter and stochastic star formation
3	2015llg..book..337K Kroupa, Pavel	1.000	00/2015	A E X R C U	Lessons from the Local Group (and Beyond) on Dark Matter
4	2014ASPC..486..183K Kroupa, P.	1.000	05/2014	A E F G T R	The Planar Satellite Distributions around Andromeda, the Milky Way and Other Galaxies, and Their Implications for Fundamental Physics
5	2012IJMPD..2130003K Kroupa, Pavel; Pawlowski, Marcel; Milgrom, Mordehai	1.000	12/2012	A E F X R C U	The Failures of the Standard Model of Cosmology Require a New Paradigm
6	2012PASA...29..395K Kroupa, P.	1.000	06/2012	A E X R C S U	The Dark Matter Crisis: Falsification of the Current Standard Model of Cosmology
7	2010A&A...523A..32K Kroupa, P.; Famaey, B.; de Boer, K. S.; Dabringhausen, J.; Pawlowski, M. S.; Boily, C. M.; Jerjen, H.; Forbes, D.; Hensler, G.; Metz, M.	1.000	11/2010	A E F X R C S N U	Local-Group tests of dark-matter concordance cosmology . Towards a new paradigm for structure formation
8	2005A&A...431..517K Kroupa, P.; Theis, C.; Boily, C. M.	1.000	02/2005	A E F X R C S N O U	The great disk of Milky-Way satellites and cosmological sub-structures
9	1997NewA....2..139K Kroupa, Pavel	1.000	07/1997	A E R C S O U	Dwarf spheroidal satellite galaxies without dark matter

Note :

Standard model of particle physics (SMoPP)
==> no path to additional long-lived elementary particles

None of the experiments (eg. LHC) find anything beyond the SMoPP

LHC constrains extensions of the SMoPP (notably supersymmetry) which would contain dark matter particles.

"The beautiful theoretical ideas underlying supersymmetry have not been seen in Nature – at least, not in the simplest form we expected."
(George Redlinger and Paul de Jong, 8th December 2017;

The *only* argument for dark matter :

Extrapolate the empirical law of gravitation (derived using Solar-system data by Newton and Einstein) to galaxies and beyond.

Failure of this extrapolation by many orders of magnitude

==> invoke dark matter

If it had not been for
post-Einsteinian
astronomy-dynamics observations
on galaxy and larger scales,

we would not know about dark matter.

Pavel Kroupa: University of Bonn

Pro dark matter :

- Well-developed (Einsteinian) theory of gravitation which is “believed” by the majority to be correct.

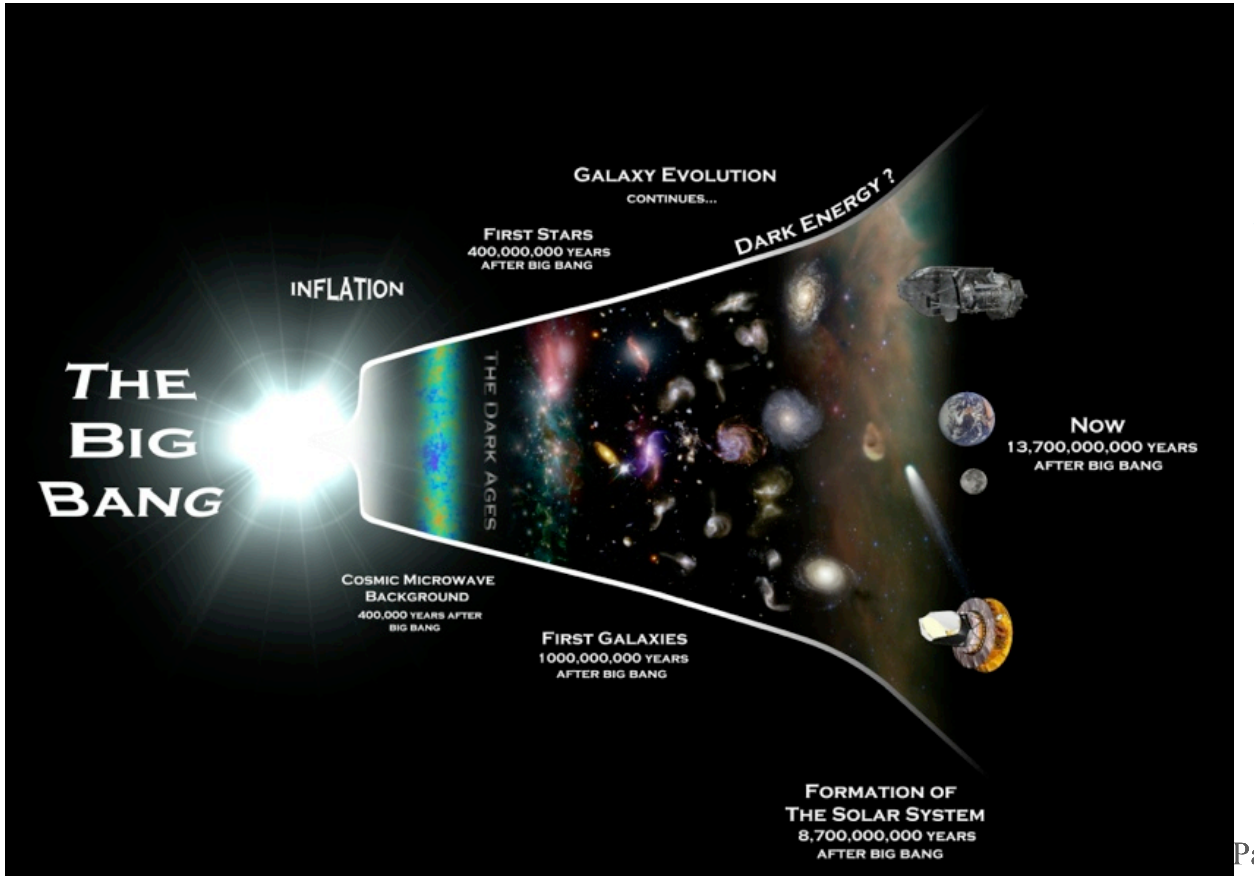
- Rotation curves of galaxies are flat, needing additional matter within this theory.

- The velocity dispersion of stars in satellite galaxies needs much additional matter in this theory.

- The mass of the Local Group of galaxies is much larger than the visible mass in this theory.

- The velocity dispersion of galaxies in galaxy clusters and gravitational lensing, need extra mass within this theory.

- The cosmological model, based on this theory, needs extra matter to account for
  - observed quick structure formation needing dark matter in this theory,
  - the cosmic microwave background radiation is explained by this theory.



The Standard Modell of Cosmology (SMoC) :

1. Einstein is valid
2. All matter created at Big Bang

inflation
+
dark matter needed
+
dark energy

The Standard / Concordance Cosmological Model

dark energy : 70%

the implied dark energy density is so small that it is unstable to quantum correction (Shanks 2005); energy creation

dark matter : 25 %

despite much search hitherto unknown stuff

baryons : 5%

only 40% of these found
- the *missing baryon problem*

Pavel Kroupa: University of Bonn

Uncomfortable :

- the dark matter particles, needed in the above theory, are not part of the standard model of particle physics, and no experimentally verified extension of the standard model of particle physics exists.

- the dark matter particles have not been found despite an incredibly huge effort by many research teams.

Contra :

- ***Dynamical friction*** due to the dark matter halos that should exist in the above theory is not detected.

- Most galaxies are large, thin, disk galaxies and too many galaxies do not have bulges, contradicting a violent merging past which is however predicted in the above theory.

- The distribution and motion of satellite galaxies around major galaxies is in extremely strong disagreement with the above theory.

- The spatial structure of the Local Group of galaxies is completely inconsistent with the above theory.

- The measured rotation curves of galaxies cannot be reproduced within the above theory.

- The observed baryonic Tully-Fisher Relation cannot be reproduced in the above theory.

- The observed RAR cannot be reproduced in the above theory.

- Tidal tails are too long to be consistent with the above theory.

- Backsplash problem.

- Hickson compact groups do not seem to be merging.

***If dark matter particles do not exist*,**

then the standard model of cosmology (the SMoC)

falls apart entirely, and we have perhaps
***the largest scientific and sociological crisis in physics ever*,**

because then maybe also Einstein's field equation

becomes invalid on galactic and cosmological scales

and we have no means of
transforming high-redshift observations into the local frame.

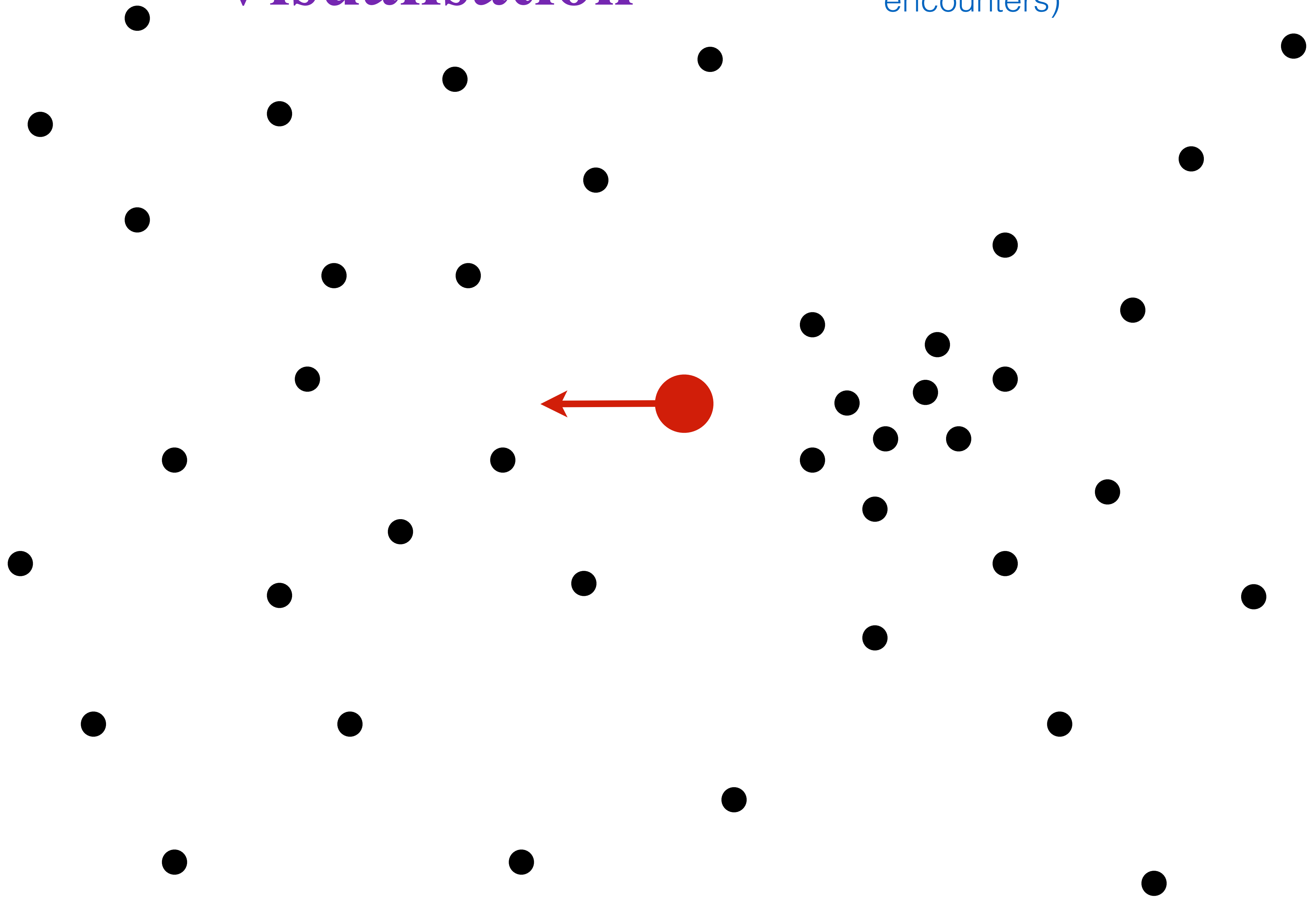
The SMoC is invalid if there is no dark matter.

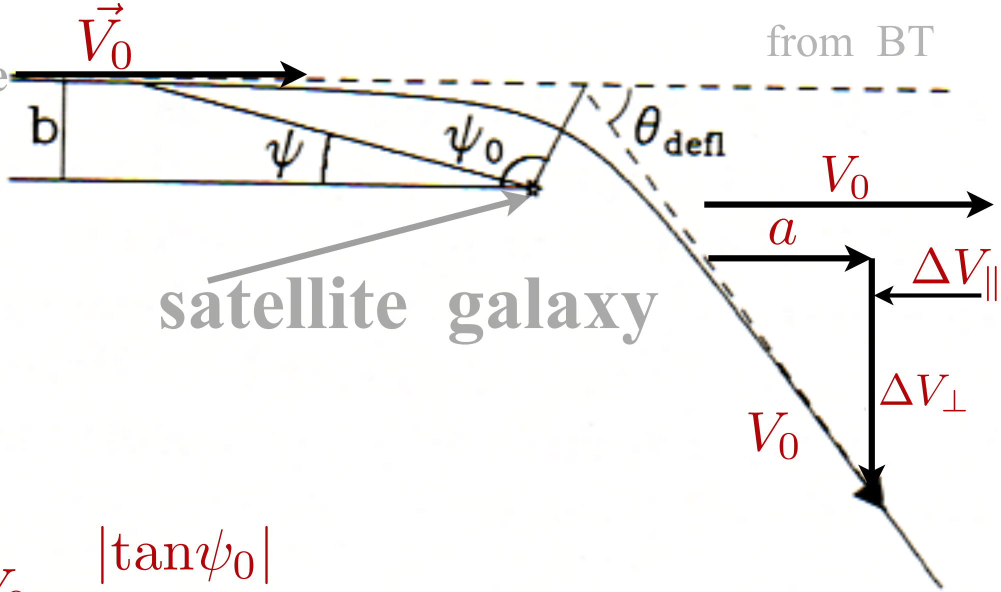
A direct test for the existence of dark matter particles :

Chandrasekhar Dynamical Friction

Visualisation

(integrate over all satellite--DM-particle encounters)





Conservation of energy implies that the relative speed before and after the encounter is equal to V_0.

$$|\Delta \vec{V}_\perp| = V_0 \sin\theta_{\rm defl} = V_0\,|\sin 2\,\psi_0| = 2\,V_0\,\frac{|\tan\psi_0|}{1+\tan^2\psi_0}$$

$$= \frac{2\,b\,V_0^3}{G\,(M+m)}\left[1+\frac{b^2\,V_0^4}{G^2\,(M+m)^2}\right]^{-1}$$

$$|\Delta \vec{V}_{||}| = V_0 - a = V_0\,(1-\cos\theta_{\rm defl}) = V_0\,(1+\cos 2\psi_0) = 2\,V_0\,\frac{1}{1+\tan^2\psi_0}$$

$$= 2\,V_0\,\left[1+\frac{b^2\,V_0^4}{G^2\,(M+m)^2}\right]^{-1}$$

Note that $\Delta\vec{V}_{||}$ points opposite to $\vec{V}_0$.

$$\frac{d\vec{v}_M}{dt} = -\frac{4\,\pi \ln\Lambda\, G^2\,(M+m)\,\rho_0\, m}{v_M^3}\left[\mathrm{erf}(X) - \frac{2\,X}{\sqrt{\pi}}\,e^{-X^2}\right]\,\vec{v}_M$$

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When M is on a *circular orbit* within the host, $v_M = v_c(r)$, then dynamical friction exerts a torque,

$$\vec{T} = \vec{r}\times\vec{F}_{\mathrm{DF}} = \frac{d\vec{L}}{dt}$$

where

$$\vec{F}_{\mathrm{DF}} = M\,\frac{d\vec{v}_M}{dt}$$

$$\vec{L} = M\,\vec{v}_c(r)\times\vec{r}, \qquad |\,|L| = M\,v_c\,r$$

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$$\vec{L} = M\,\vec{v}_c(r)\times\vec{r}, \qquad |\,|L| = M\,v_c\,r$$

$$\frac{dL}{dt} = r\,F_{\mathrm{DF}}(r) = r\;[F_{\mathrm{DF}}(r)]$$

$$= r\left[M\,\frac{dv_M}{dt}\right]$$

$$t_{\rm msgr} = \frac{0.95}{G\,\ln\Lambda}\,\frac{r_i^2}{M}\,\sigma$$

This is approximately the time which a satellite galaxy with mass M (baryonic + dark matter halo !) needs to spiral to the centre of the host halo starting at initial radius r_i

Dark matter halo properties (see next slides)

Maccio et al. 2007, 2008
Bullock et al. 2001;
see Kroupa et al. 2010
for formulae

$G = 0.0045\ {\rm pc}^3\ M_\odot^{-1}\ {\rm Myr}^{-2}$

$\ln\Lambda \approx 3$

Binney & Tremaine (1987, p. 427)

Galaxies merge once they approach within distances comparable to the diameters of their dark matter halos !

t_{msgr} [Myr]	M [M_{sun}]	r_i [kpc]	σ [pc/Myr]
$10^{3.75} \approx 1$ Gyr	10^{11}	200	200

Simulations with stellar feedback, star formation and gas dynamics

Sales, Navarro et al. 2017, MNRAS, "The low-mass end of the baryonic Tully–Fisher relation" (EAGLE simulation)

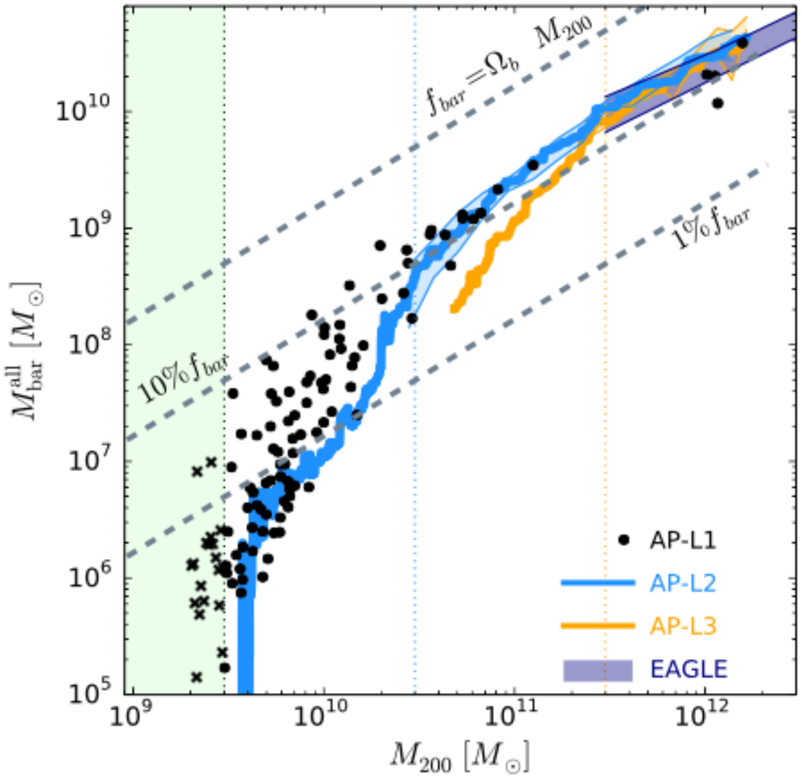


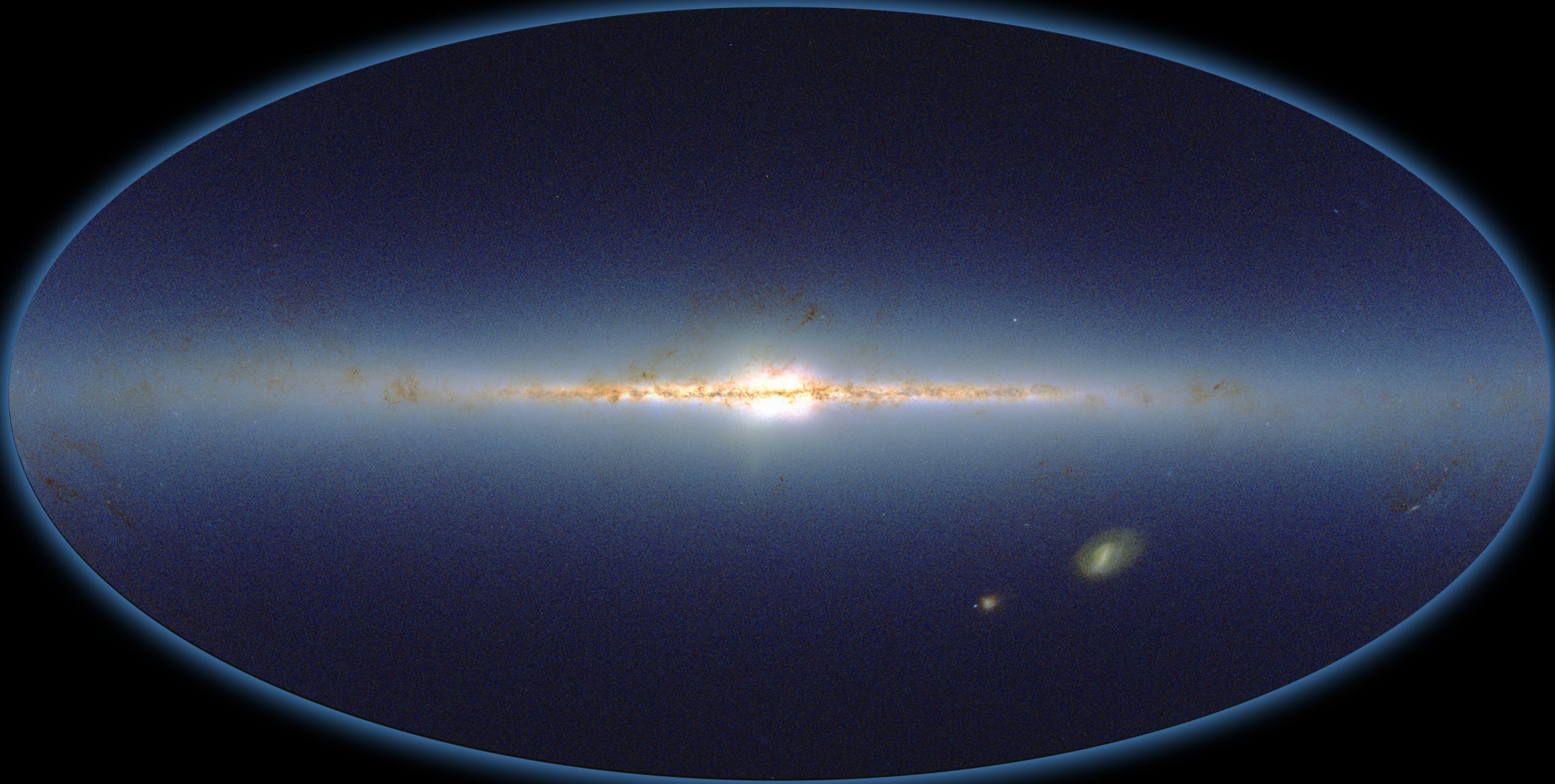
Figure 1. Left: galaxy baryonic mass ($M_{\rm bar}^{\rm all} = M_{\rm gas}^{\rm all} + M_{\rm str}$) versus virial mass ($M_{200}$) in our simulated galaxy sample. Shaded regions indicate the interquartile baryonic mass range at given M_{200} and highlight the virial mass range over which the simulation results are insensitive of resolution. Vertical dotted lines indicate the minimum converged virial mass for each resolution level. Thick lines of matching colour indicate the median trend for each simulation set, as specified in the legend, and extend to virial masses below the minimum needed for convergence. Dashed grey lines indicate various fractions of all baryons within the virial radius. Note the steep decline in 'galaxy formation efficiency' with decreasing virial mass. Dark filled circles indicate the results of individual AP-L1 galaxies. A light green shaded region highlights non-converged systems in our highest resolution runs. Crosses are used to indicate galaxies in haloes considered 'not converged' numerically. Right: stellar half-mass radius, $r_{\rm h}^{\rm str}$, as a function of virial mass for simulated galaxies. Symbols, shading, and colour coding are as in the left-hand panel. Limited resolution sets a minimum size for galaxies in poorly resolved haloes. The same minimum mass needed to ensure convergence in baryonic mass seems enough to ensure convergence in galaxy size, except, perhaps, for AP-L1, for which we adopt a minimum converged virial mass of $6 \times 10^9\ M_\odot$. The values adopted for the minimum virial mass are listed in Table 1.

E.g. a 10^8 Msun pre-infall satellite ought to have had a DM halo mass > 10^{10} Msun such that its orbital decay time would be short.

see also Matthee, Schaye et al., 2017, MNRAS, "The origin of scatter in the stellar mass-halo mass relation of central galaxies in the EAGLE simulation"
http://adsabs.harvard.edu/abs/2017MNRAS.465.2381M

The Large Magellanic Cloud

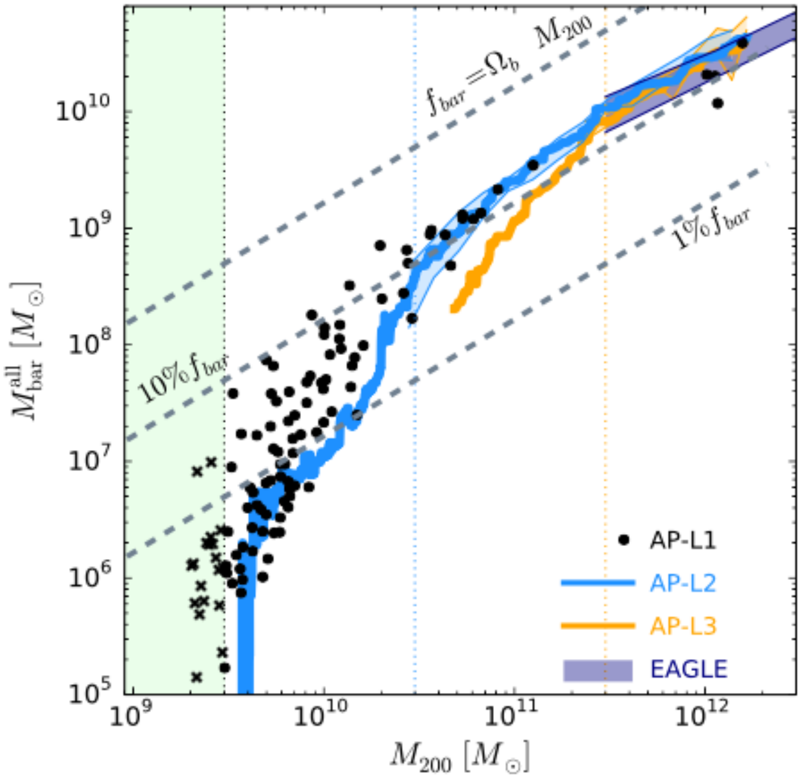
racing past our MW at a distance of 50kpc



2MASS sky atlas

Simulations with stellar feedback, star formation and gas dynamics

Sales, Navarro et al. 2017, MNRAS, "The low-mass end of the baryonic Tully–Fisher relation" (EAGLE simulation)



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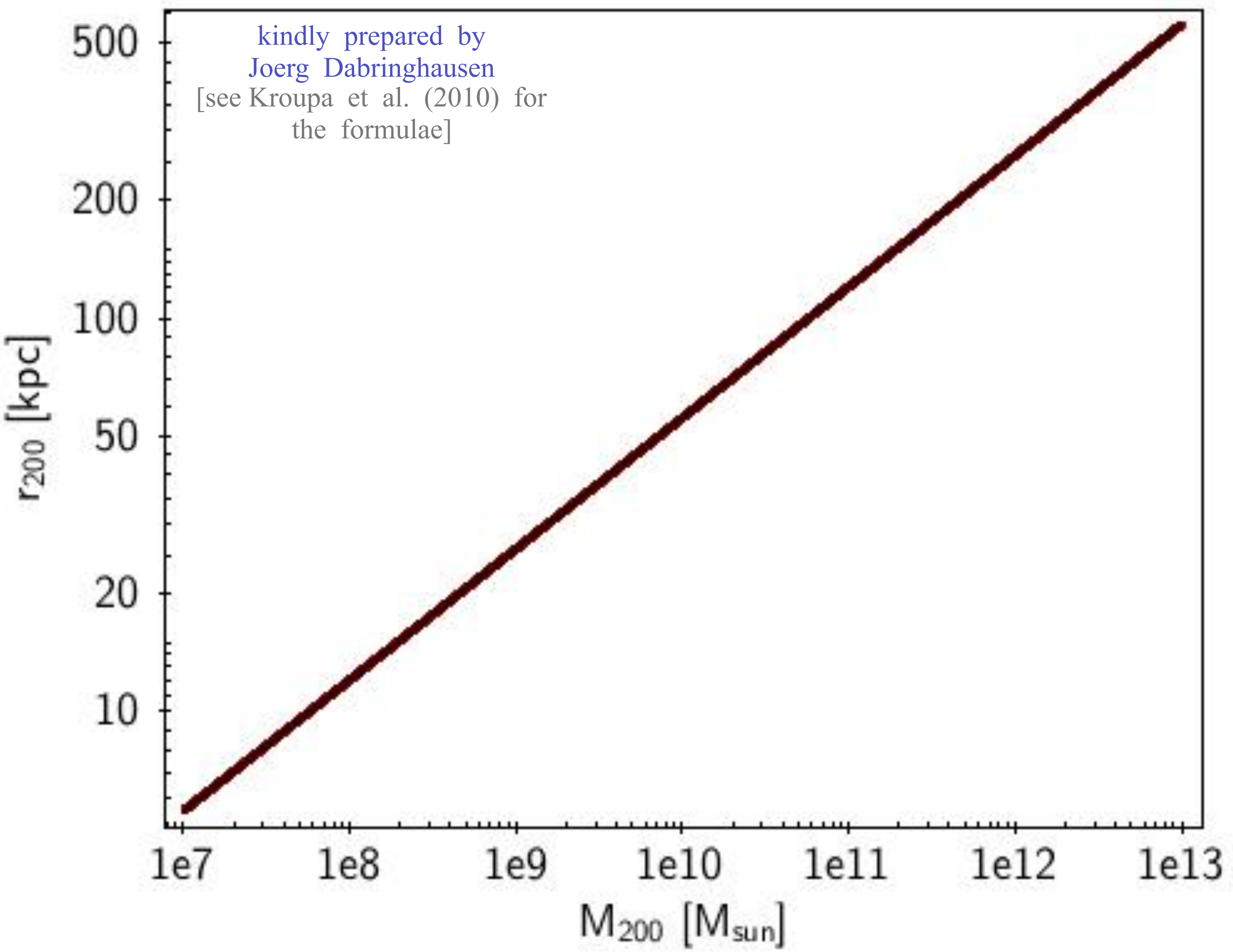
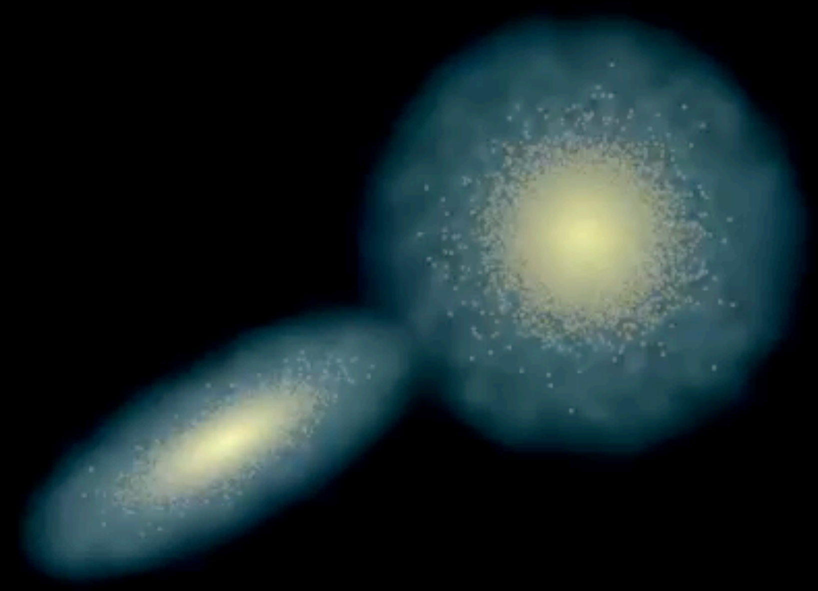
A pre-infall (z=0) DM halo has a virialised radius :

Within r_{200} is the mass M_{200} and a density 200 times larger than the critical cosmological density; r_{200} is approximately the virialised radius.



DM halos are, in a sense, like spider's webs : once two DM halos approach within the sum of their radii they begin to merge, if their relative velocity is comparable to the velocity dispersion of the larger halo.

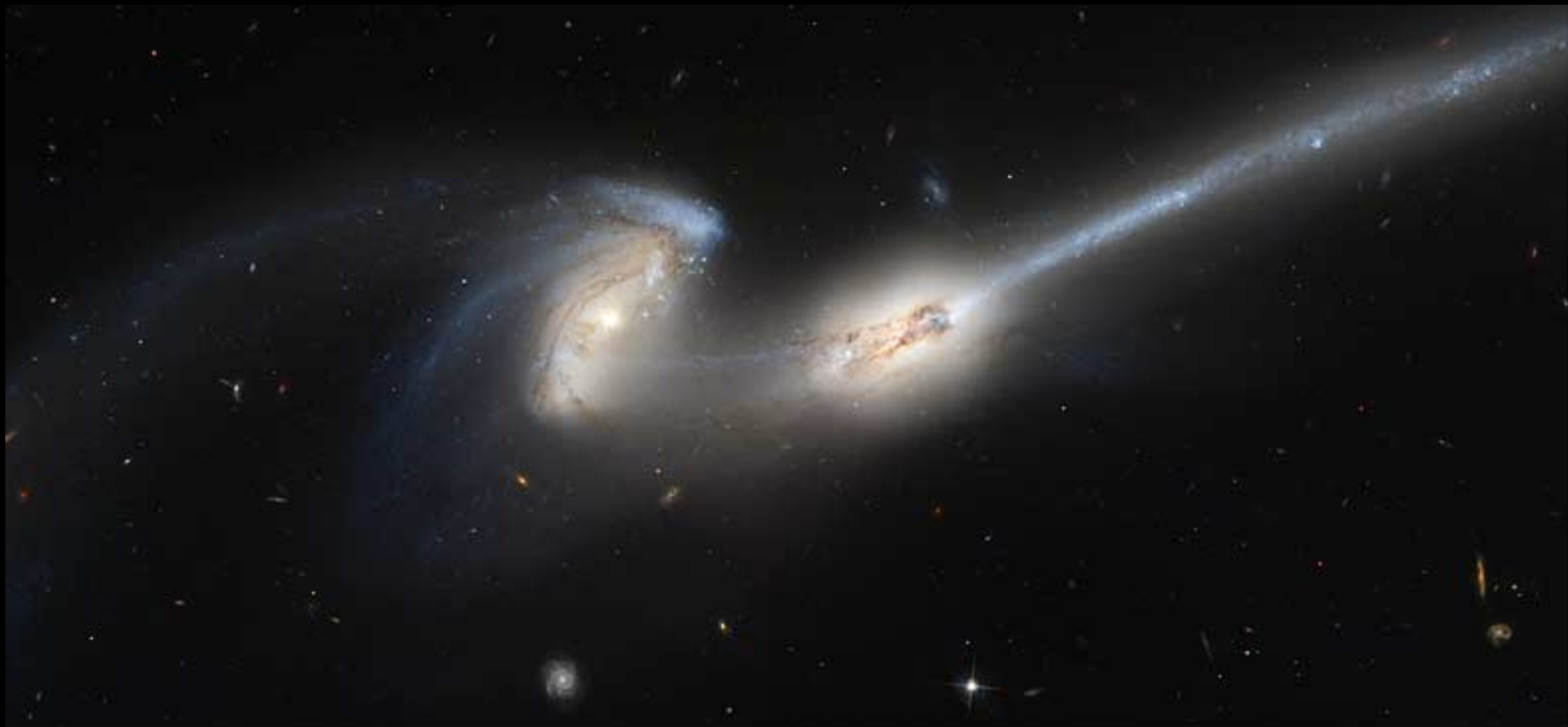
Relevance : The collision of two disks at high redshift



Wetzstein, Naab & Burkert 2007

NGC 5257/8

The Mice

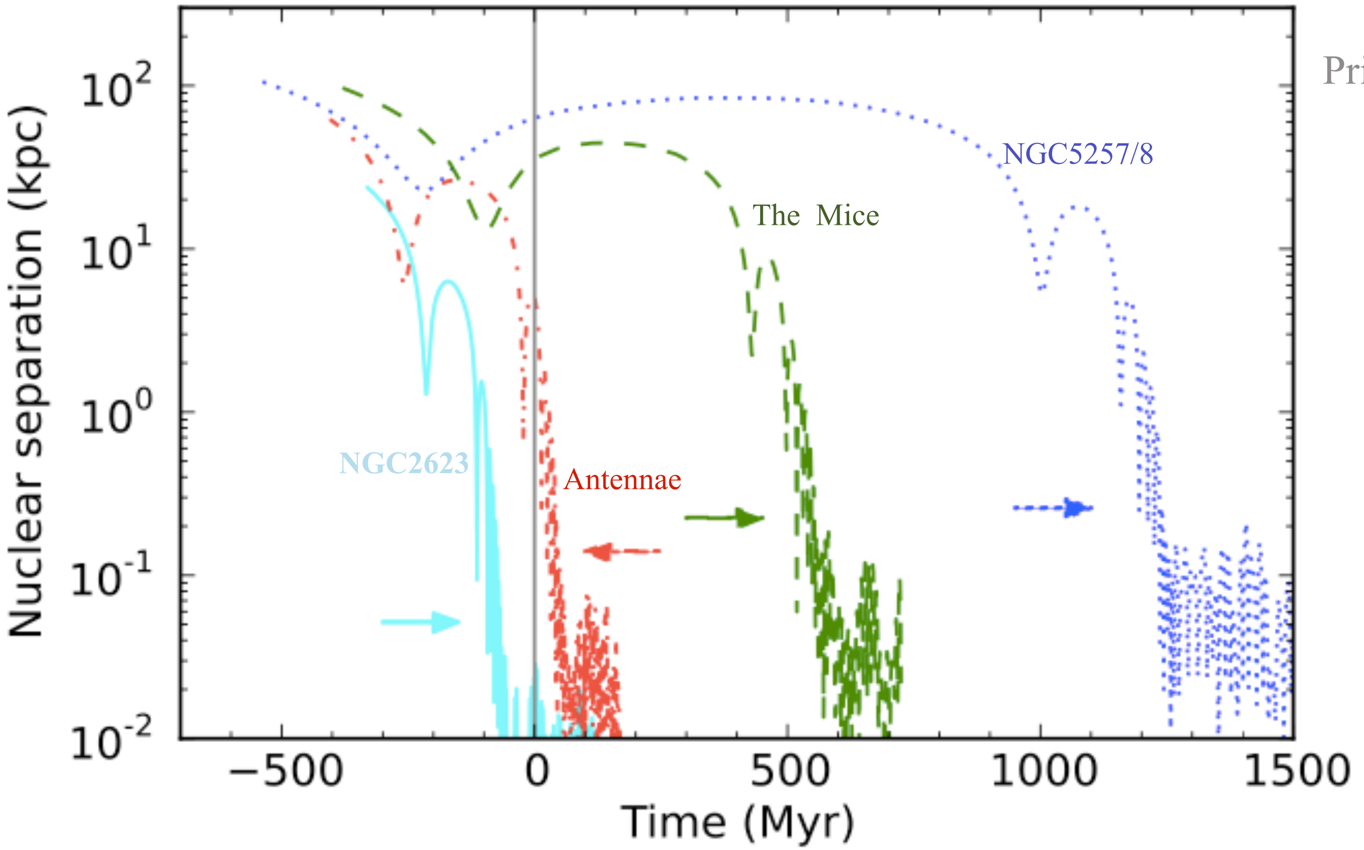


Antennae

NGC 2623

Dynamical friction : galaxy mergers - must be common

Galaxy encounters with mass ratio = 1 : mergers within 0.5-1.8 Gyr



Privon, Barnes et al. 2013

All merge within 0.5-1.8 Gyr, *i.e.* 2 crossing times.

IF there is dark matter

Figure 1. True nuclear separation as a function of time for NGC 5257/8 (dotted blue line), The Mice (dashed green), Antennae (dash-dot red), and NGC 2623 (solid cyan). Time of zero is the current viewing time (solid gray vertical line). The time since first passages for these systems is 175 – 260 Myr (cf. Table 2). Colored arrows mark the smoothing length in kpc for the corresponding system; this is effectively the spatial resolution of our simulations and the behavior of the curves on length scales smaller than the smoothing length is not reliable.

Barnes (1998) in "Dynamics of Galaxy Interactions" :

"Interacting galaxies are well-understood in terms of the effects of gravity on stars and dark matter."

Mon. Not. R. Astron. Soc. **416,** 1401–1409 (2011) doi:10.1111/j.1365-2966.2011.19138.x

Using dwarf satellite proper motions to determine their origin

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ABSTRACT
The highly organized distribution of satellite galaxies surrounding the Milky Way is a serious challenge to the concordance cosmological model. Perhaps the only remaining solution, in this framework, is that the dwarf satellite galaxies fall into the Milky Way's potential along one or two filaments, which may or may not plausibly reproduce the observed distribution. Here we test this scenario by making use of the proper motions of the Fornax, Sculptor, Ursa Minor and Carina dwarf spheroidals, and trace their orbits back through several variations of the Milky Way's potential and account for dynamical friction. The key parameters are the proper motions and total masses of the dwarf galaxies. Using a simple model, we find no tenable set of parameters that can allow Fornax to be consistent with filamentary infall, mainly because the 1σ error on its proper motion is relatively small. The other three must walk a tightrope between requiring a small pericentre (less than 20 kpc) to lose enough orbital energy to dynamical friction and avoiding being tidally disrupted. We then employed a more realistic model with host halo mass accretion and found that the four dwarf galaxies must have fallen in at least 5 Gyr ago. This time-interval is longer than organized distribution is expected to last before being erased by the randomization of the satellite orbits.

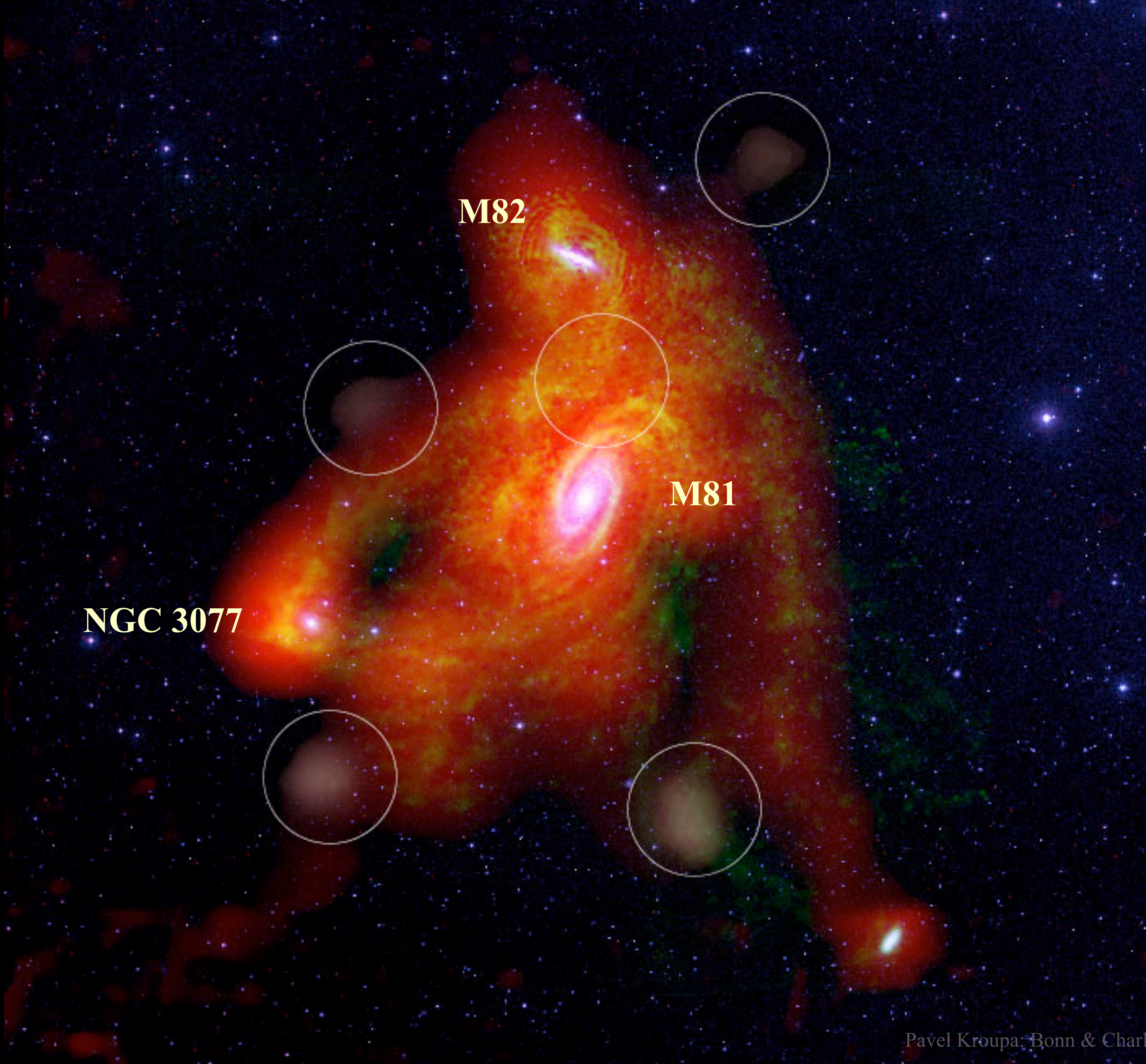
Table 2. Galactocentric distances and velocities of the dSphs. For Fornax, Sculptor and Ursa Minor, our V_{x_0} corresponds to Piatek et al. (2003, 2005, 2006, 2007a) V_r and our V_{y_0} to their V_t. For Carina, the proper motion comes directly from Pasetto et al. (2011). Distances come from Mateo (1998).

dSph	r_0 (kpc)	V_{x_0} (km s^{-1})	V_{y_0} (km s^{-1})
Fornax	138 ± 8	-31.8 ± 1.7	196 ± 29
Sculptor	87 ± 4	79 ± 6	198 ± 50
Ursa Minor	76 ± 4	-75 ± 44	144 ± 50
Carina	101 ± 5	113 ± 52	46 ± 54

The M81 group of galaxies

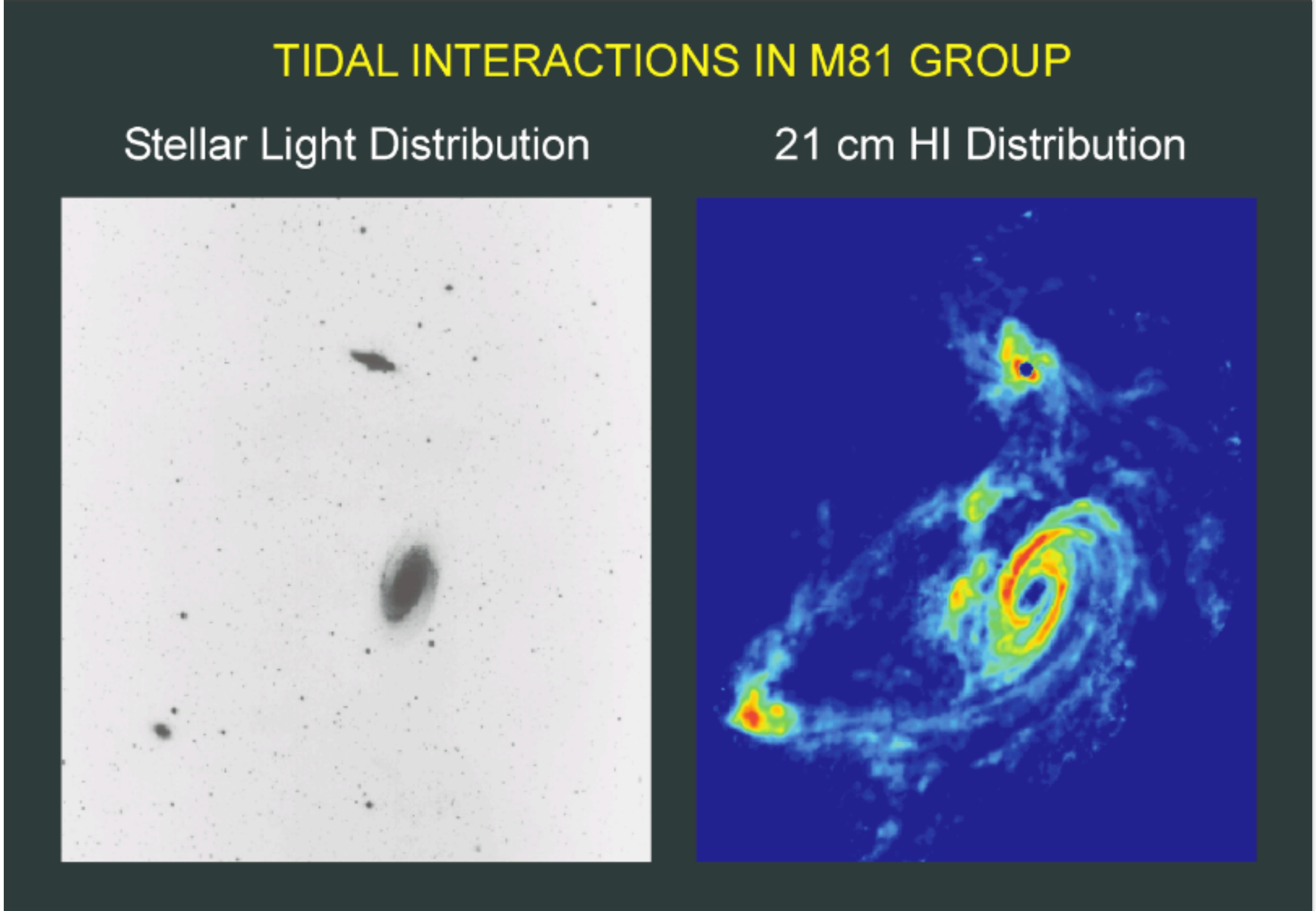
~ an analogue to the Local Group at 3.6 Mpc

Dynamical friction?? : the M81 group of galaxies



by
Chynoweth,
Langston,
Yun,
Lockman,
Scoles

Dynamical friction?? : the M81 group of galaxies



Last publications (conference proceedings only) :

Yun 1999
=> no solutions with dark matter : system merges

Thomson, Laine & Turnbull 1999
=> no solutions with dark matter : system merges

Oehm et al. (2017)
Oehm & Kroupa (2018)

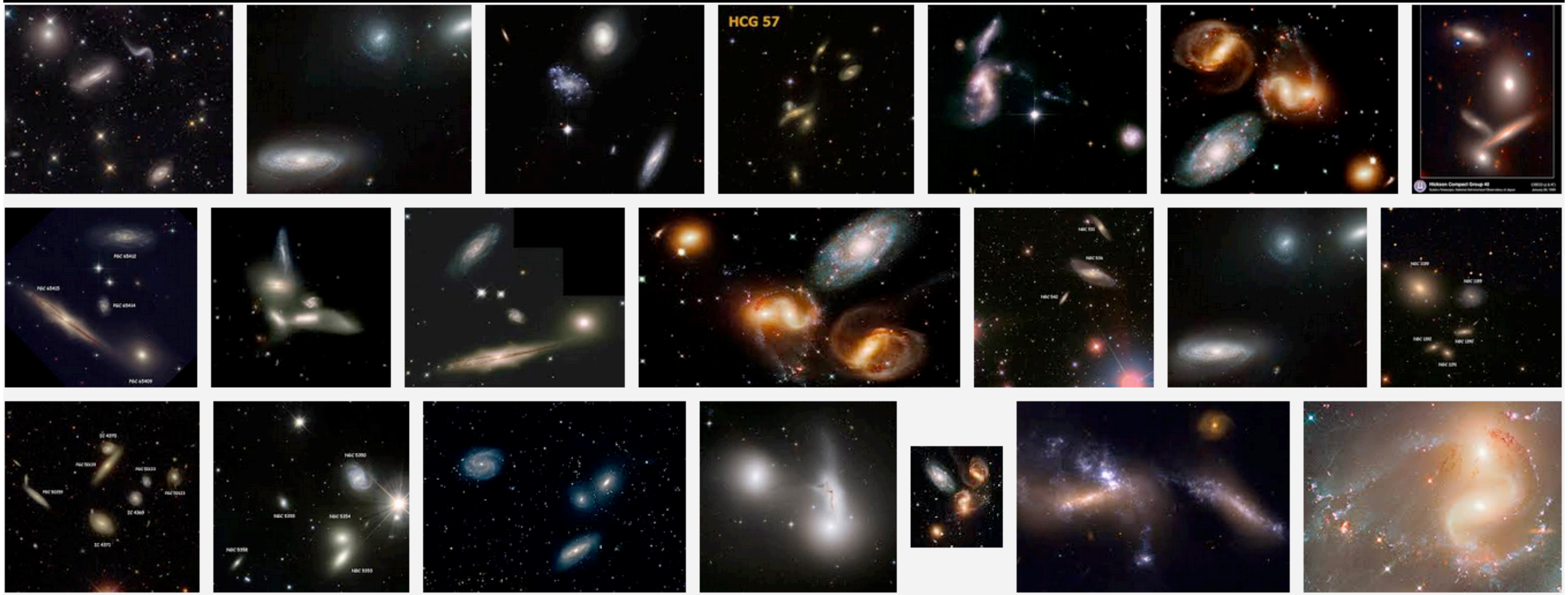
. . . basically, all members of the M81 group would have to have fallen in synchronously from large distances and have a peri-galactic encounter with M81 at nearly the same time without having merged yet.

This is arbitrarily unlikely.

AND, there are many other similar groups.

The *Hickson compact groups* are are particularly troubling for LCDM, because they all must have assembled during the past 1-3 Gyr with all members magically coming together for about one synchronised perigalactic passage, while the remnants (field E galaxies with low alpha element abundances from previously such formed groups) do not appear to exist in sufficient numbers.

silkscape.com


HCG 57

Therefore . . .

The present-day motions and distances of MW satellites preclude them to have fallen-in from a filament if they have dark-matter halos. M81 group should not be there.

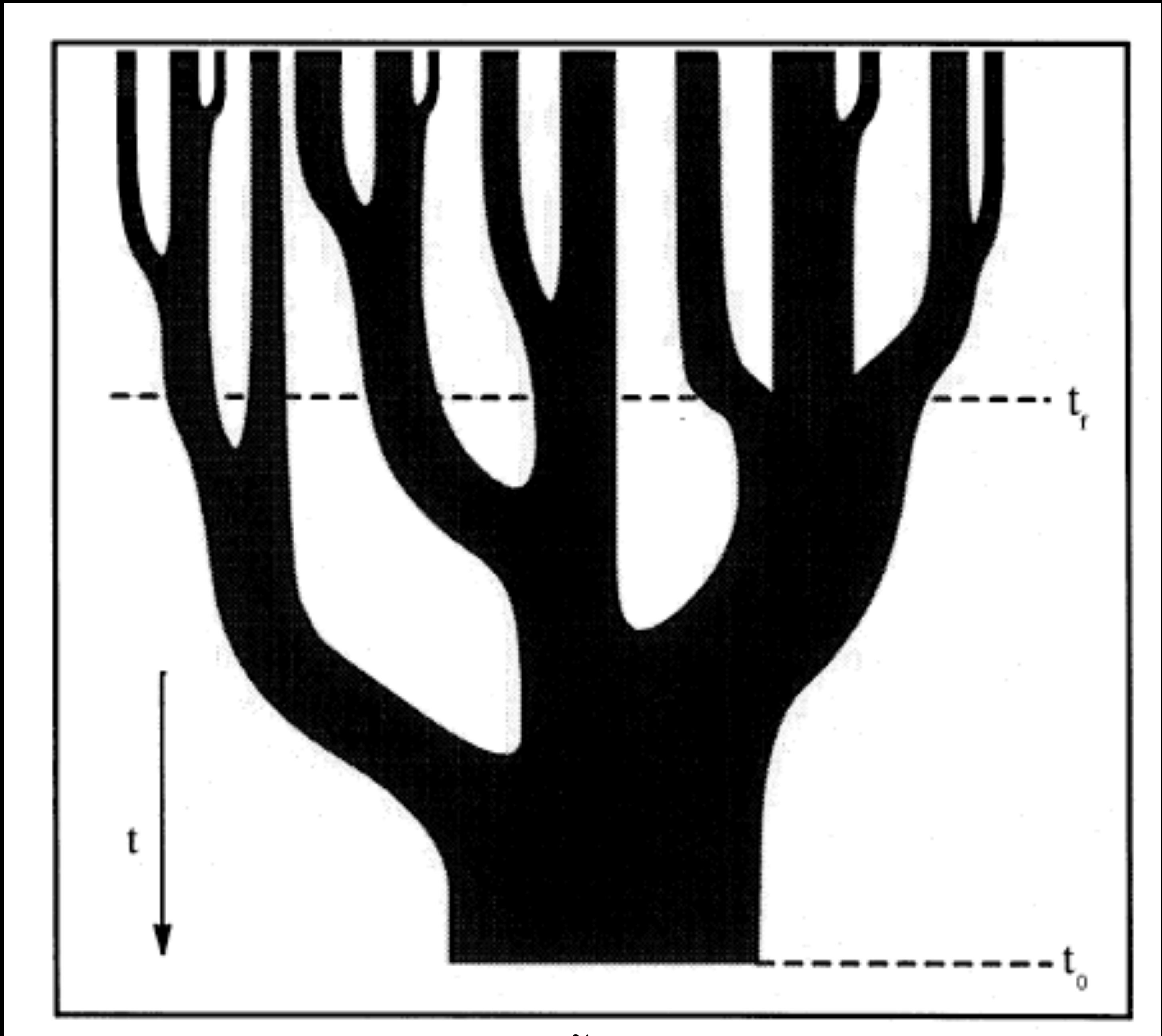
→ no dynamical friction due to dark matter halos

→ no dark matter halos

Phase-space distribution of matter

Structures form according to the cosmological merger tree

Lacey & Cole (1993)



the beginning Big Bang

low-mass DM halos form first and coalesce to larger structures

today

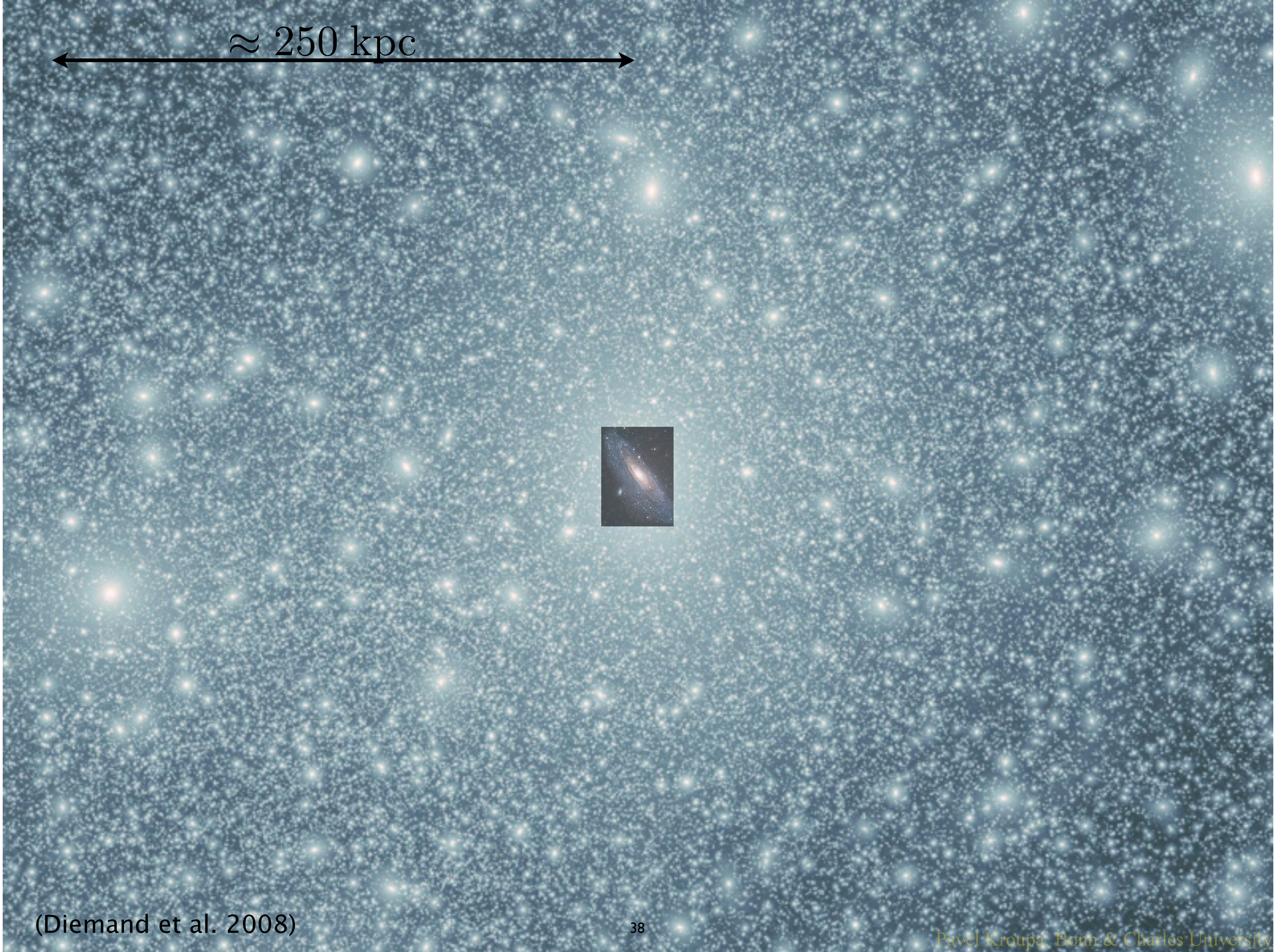
Is there independent evidence for this conclusion ?

The standard model of cosmology (SMoC) predicts that each and every galaxy has a history of mergers.

The mergers are random, i.e. every galaxy has a different merger history !

---> DM satellites ought to be distributed spheroidally

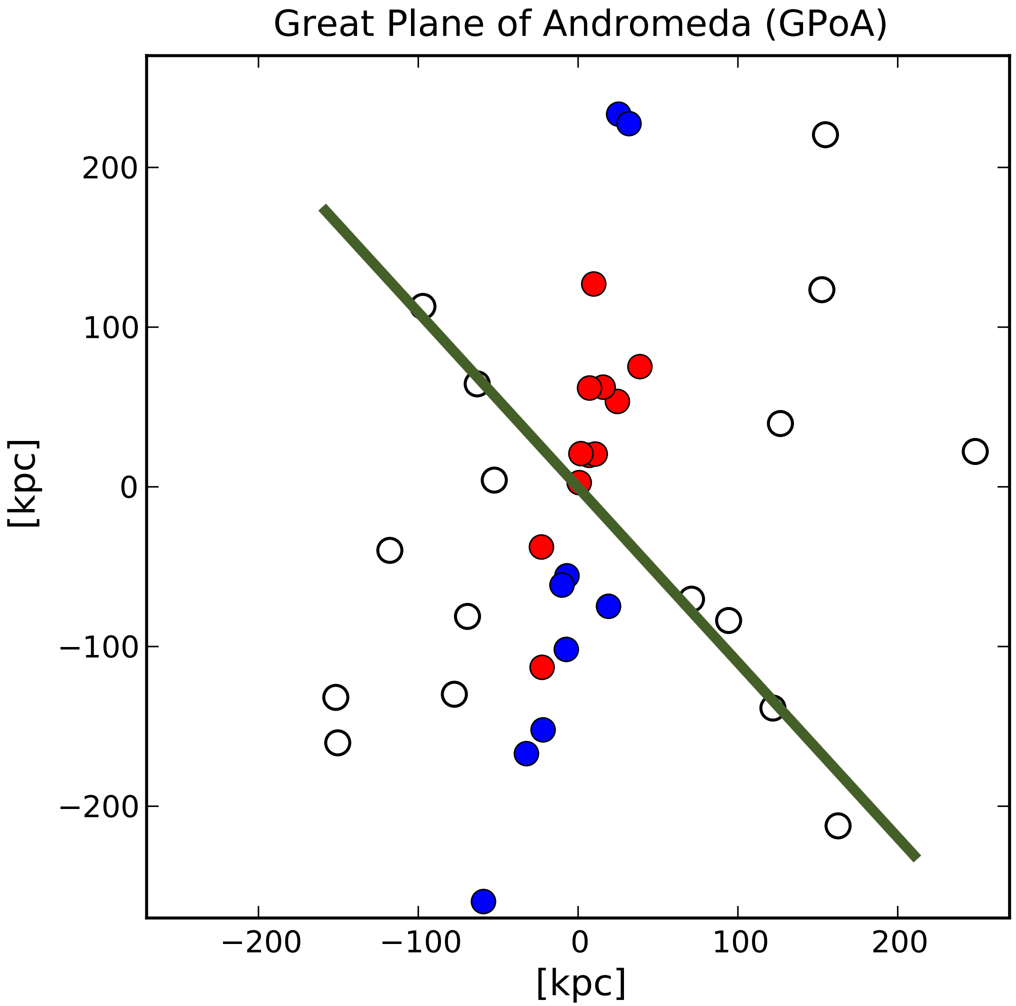
As is well known: they are not

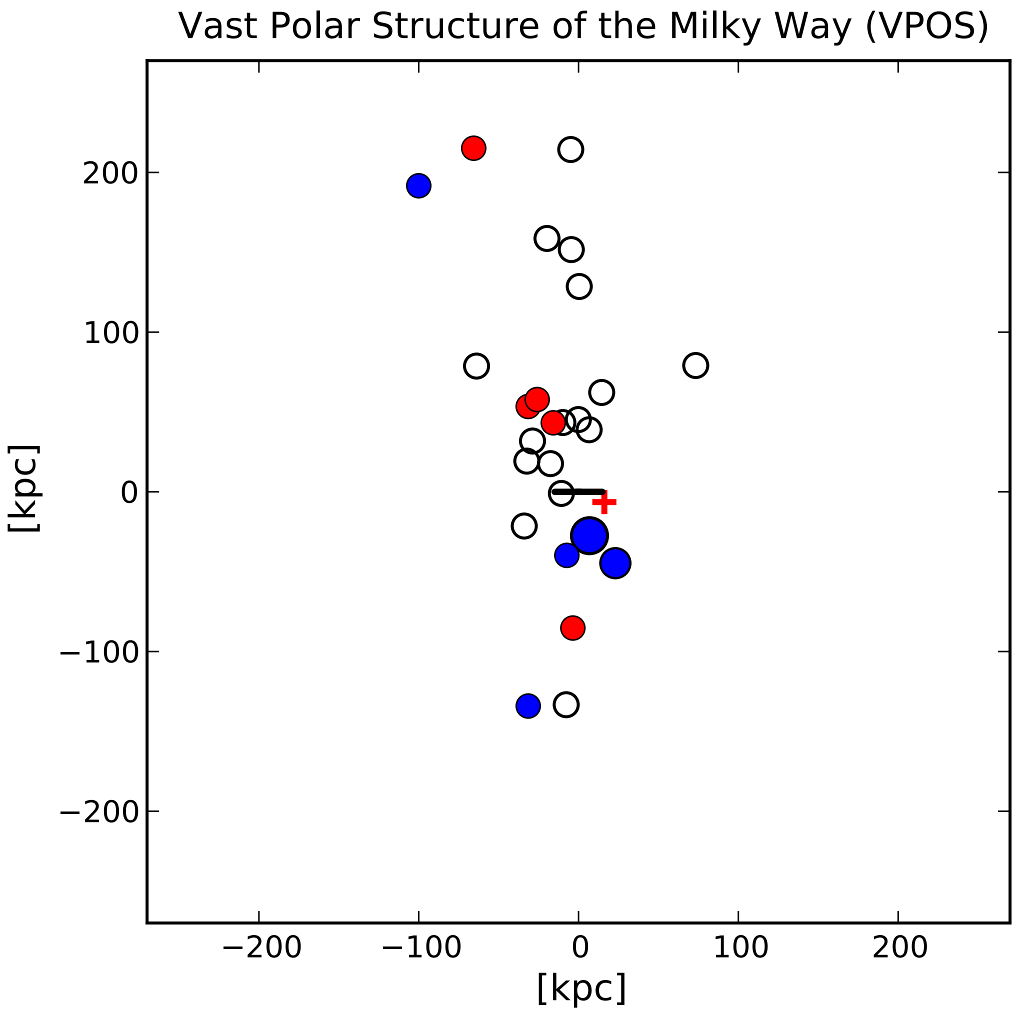


(Diemand et al. 2008)

Andromeda

Milky Way





Ibata et al. 2013, 2014

Pawlowski & Kroupa 2013

Pawlowski, Kroupa & Jerjen (2013 MNRAS)

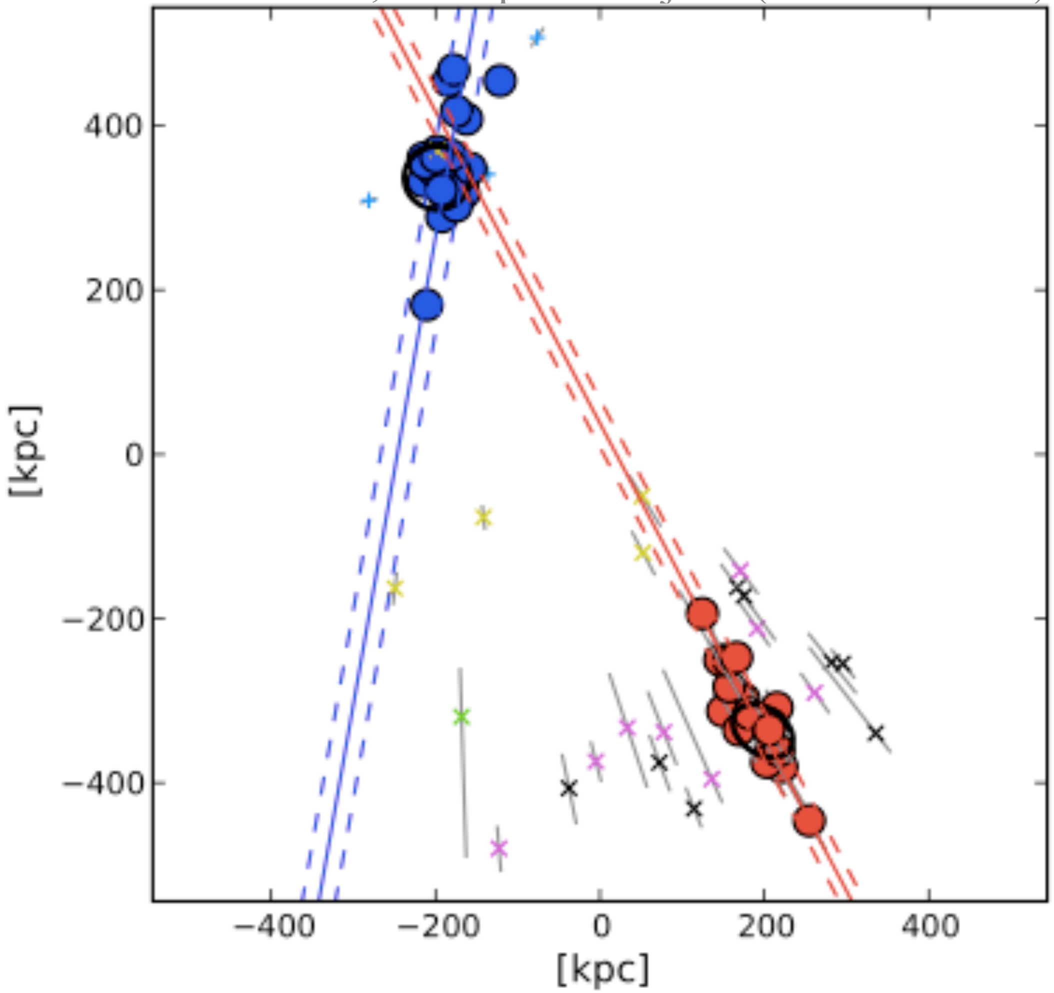


Figure 16. Edge-on view of the satellite galaxy planes around the MW and M31, similar to Fig. 9 for the LG planes. As before, galaxies which are

How can the MW and Andromeda satellite systems be so correlated, if they are sub-halos falling-in individually ?

Mueller, Pawlowski et al. (2018, Science)

MW & M31
plane of satellites
are
not unique !

Probabilities

Assume LCDM structure formation : how often should we find such disks of satellite systems ?

DoS of MW: $p = 0.6 \times 10^{-3}$ (relative to MilleniumII)

Pawlowski et al. (2014 MNRAS, Sec.3.4)

DoS of M31: $p = 1.4 \times 10^{-3}$ (relative to MilleniumII)

Pawlowski et al. (2014 MNRAS, Sec.2.4)

DoS of Cen A: $p = 1 \times 10^{-3}$ (relative to MilleniumII)

DoS of Cen A: $p = 5 \times 10^{-3}$ (relative to Illustris)

Mueller, Pawlowski et al. (2018 Science)

Combined : $p = pMW \times pM31 \times pCenA = 8.4 \times 10^{-10}$ (relative to MilleniumII)

Combined : $p = pMW \times pM31 \times pCenA \approx 4.2 \times 10^{-9}$ (relative to Illustris)

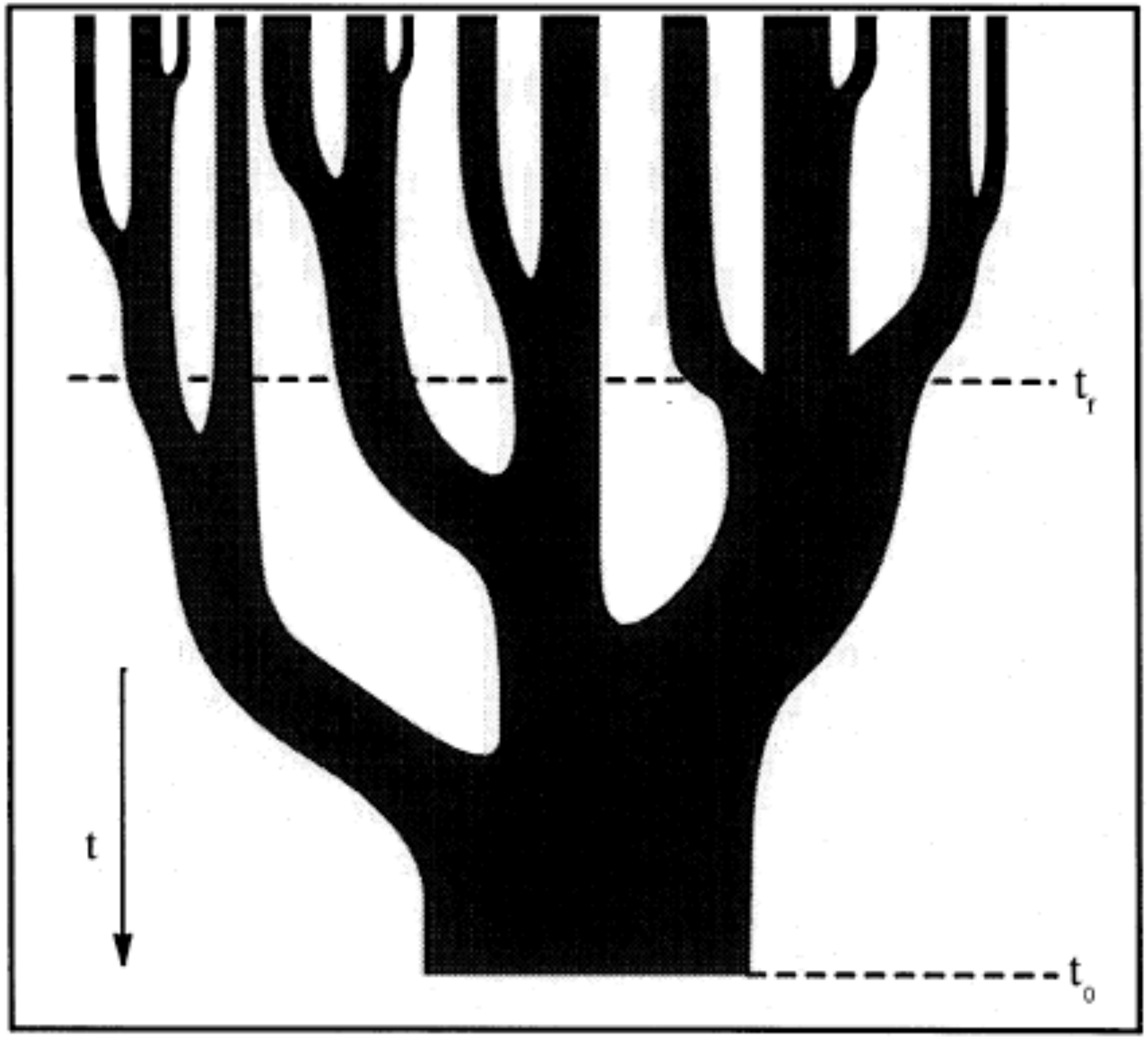
EXPECT 3 DoSs amongst 2.38×10^{8} host galaxies

OBSERVE >3 DoSs amongst the 5 closest L_* - type host galaxies
(MW, M31, M81, M83, CenA -- there are indications that M81 and M83 also contain DoSs)

But a five sigma discrepancy: one in 1744278

The structure of the

Local Group of Galaxies



In the SMoC
structures form
from many independent
(stochastic)
mergers

-->

expect no
ordered
structures

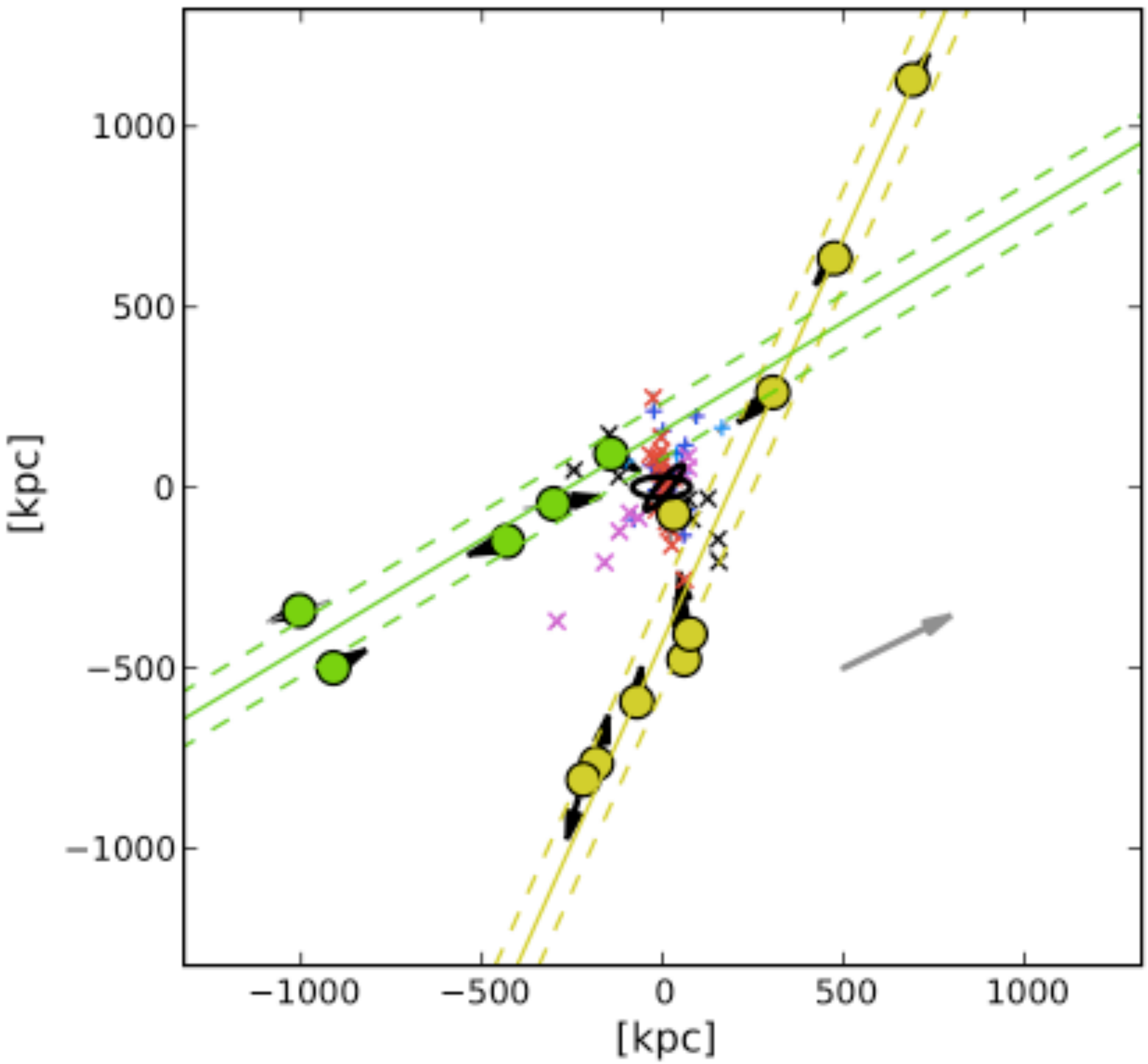


Figure 9. Edge-on view of both LG planes. The orientation of the MW and M31 are indicted as black ellipses in the centre. Members of the LGP1 are plotted as yellow points, those of LGP2 as green points. MW galaxies are plotted as plus signs (+), all other galaxies as crosses (×), the colours code their plane membership as in Fig. 6. The best-fitting planes are plotted as

Everything we know about the Local Group today

Pawlowski, Kroupa & Jerjen (2013 MNRAS)

"The discovery of symmetric structures in the Local Group"

A frightening symmetry

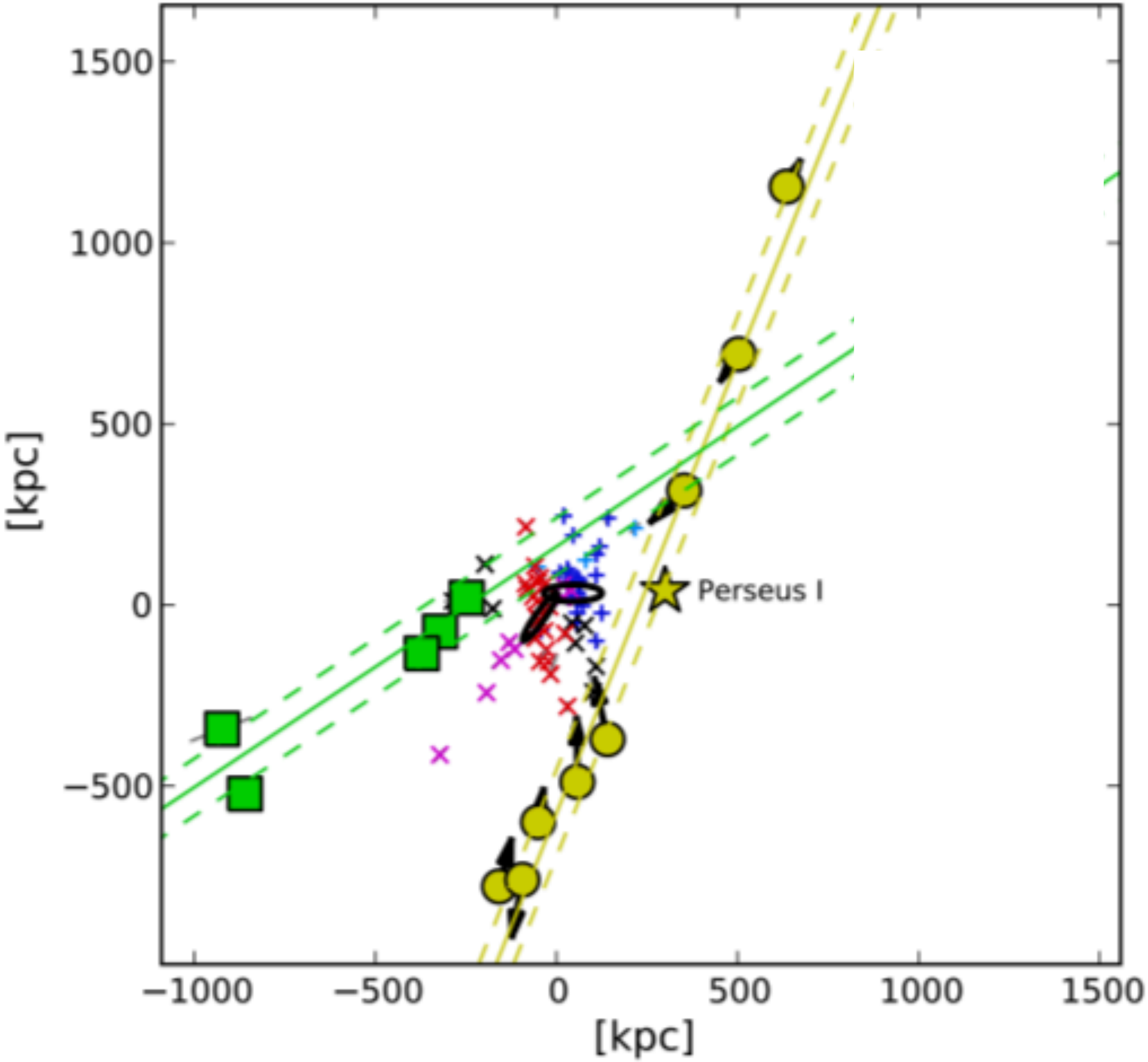
. . . the structure of the

Local Group of Galaxies

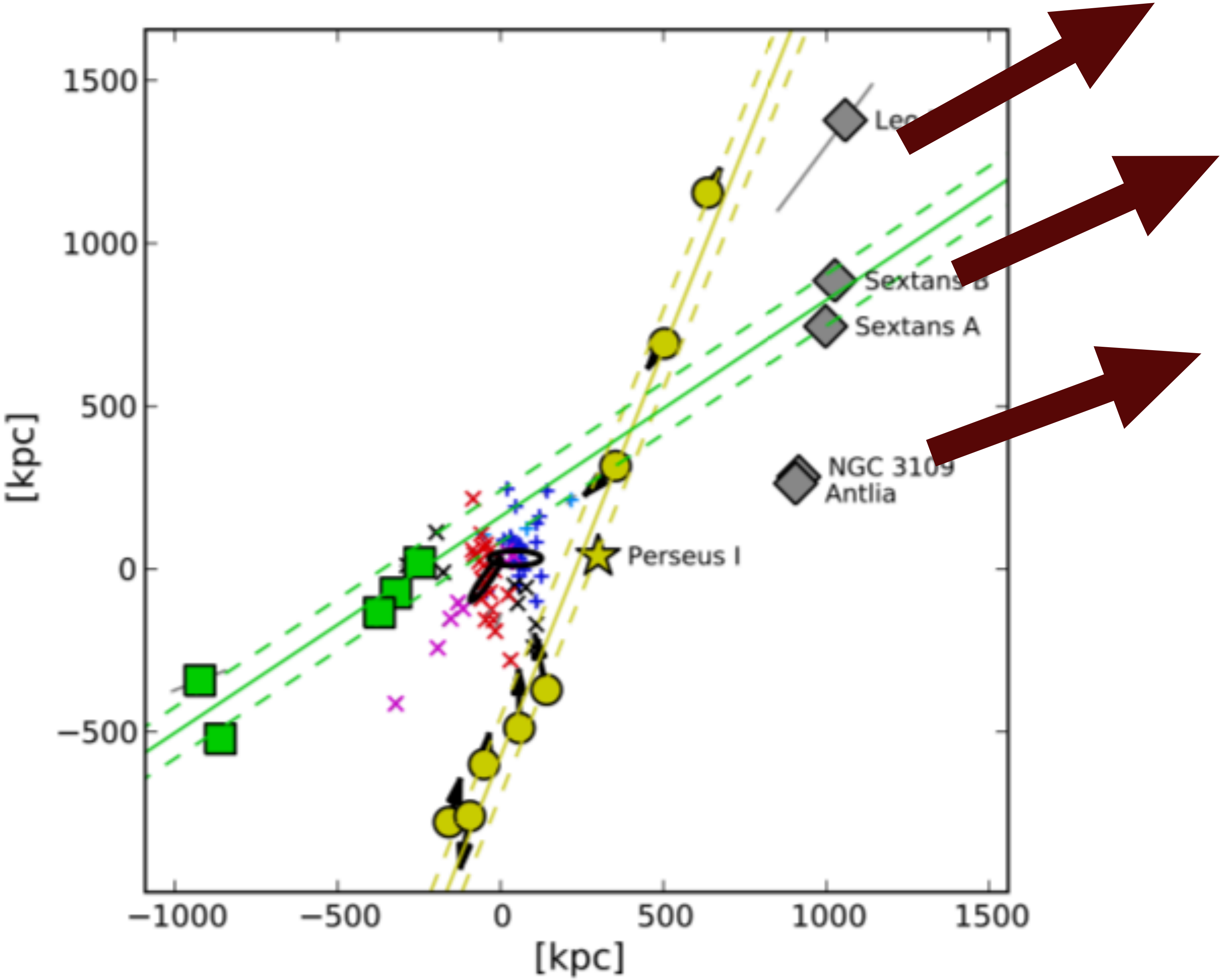
is incompatible

with the SMoC.

Pawlowski & McGaugh (2014) : **the "backsplash problem"**
(see also Banik & McGaugh 2018)



Pawlowski & McGaugh (2014) : **the "backsplash problem"**
(see also Banik & McGaugh 2018)



The "backsplash problem"

→ Too many galaxies are receding
from the Local Group too orderly
(in a plane)
and too fast.

→ This is impossible if the Local Group
has dark matter
(dynamical friction
would slow / capture the galaxies).

Consequences of random mergers :

→ the disagreements concerning
tests relying on dynamical friction
are consistent with each other
and
always and only
point to dynamical friction
not being active.

→ This can only be the case
if
there are no dark matter halos.

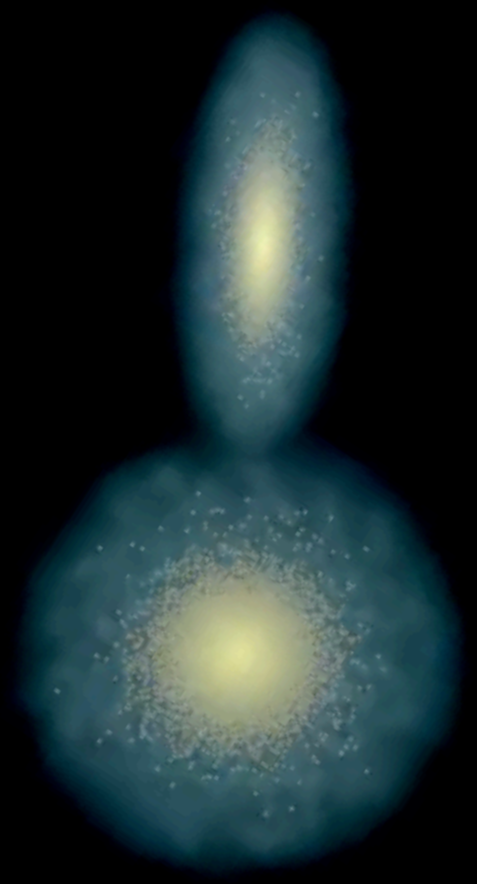
The dual dwarf galaxy theorem

(Kroupa 2012; Haslbauer et al. 2019)

In any cosmological theory there exist primordially formed galaxies and tidal-dwarf galaxies.

In the LCDM model, primordial dwarfs are dominated by dark matter and tidal dwarfs have no dark matter.

Relevance : The collision of two disks at high redshift



Wetzstein, Naab & Burkert 2007

(Weilbacher et al. 2000)

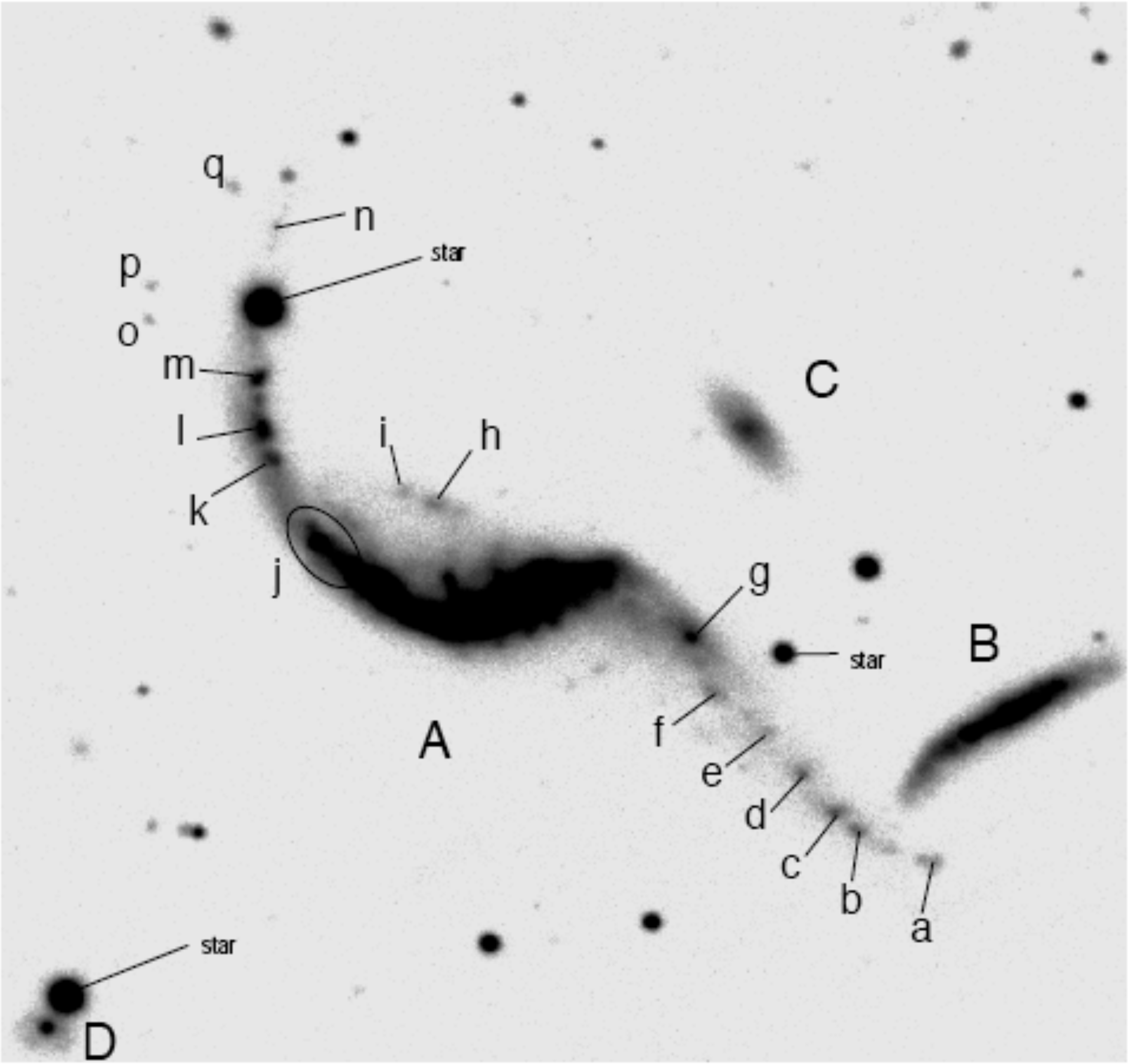


Fig. 21. Identification chart of field 10 around AM 1353-272.

$N_{\mathrm{TDG}} \approx 14$

Wetzstein, Naab & Burkert 2007

The dual dwarf galaxy theorem

(Kroupa 2012; Haslbauer et al. 2019)

In any cosmological theory there exist primordially formed galaxies and tidal-dwarf galaxies.

In the LCDM model, primordial dwarfs are dominated by dark matter and tidal dwarfs have no dark matter.

→ at the same baryonic mass, they must have different radii

→ falsified by data

This independent test verifies the previous conclusion (dark matter does not exist)

Dark matter does not exist ==>

cosmological model ruled out ?

Title: Universe opacity and CMB
Authors: Vavryčuk, Václav
Affiliation: AA(The Czech Academy of Sciences, Boční II, Praha 4, 14100, Czech Republic)
Publication: Monthly Notices of the Royal Astronomical Society, Advance Access (MNRAS Homepage)
Publication Date: 04/2018
Origin: OUP
Astronomy Keywords: cosmic background radiation, dust, extinction, early Universe, galaxies: high redshift, galaxies: ISM, intergalactic medium

DOI: 10.1093/mnras/sty974
Bibliographic Code: 2018MNRAS.tmp..943V

Abstract

A cosmological model, in which the cosmic microwave background (CMB) is a thermal radiation of intergalactic dust instead of a relic radiation of the Big Bang, is revived and revisited. The model suggests that a virtually transparent local Universe becomes considerably opaque at redshifts $z > 2 - 3$. Such opacity is hardly to be detected in the Type Ia supernova data, but confirmed using quasar data. The opacity steeply increases with redshift because of a high proper density of intergalactic dust in the previous epochs. The temperature of intergalactic dust increases as $(1 + z)$ and exactly compensates the change of wavelengths due to redshift, so that the dust radiation looks apparently like the radiation of the blackbody with a single temperature. The predicted dust temperature is $T^D = 2.776$ K, which differs from the CMB temperature by 1.9% only, and the predicted ratio between the total CMB and EBL intensities is 13.4 which is close to 12.5 obtained from observations. The CMB temperature fluctuations are caused by EBL fluctuations produced by galaxy clusters and voids in the Universe. The polarization anomalies of the CMB correlated with temperature anisotropies are caused by the polarized thermal emission of needle-shaped conducting dust grains aligned by large-scale magnetic fields around clusters and voids. A strong decline of the luminosity density for $z > 4$ is interpreted as the result of high opacity of the Universe rather than of a decline of the global stellar mass density at high redshifts.

Conclusions I

It seems, the observed Universe does not contain dark matter (particles).

By implications: the standard LCDM (SMoC) is not the correct description.

The observed Universe appears to be more regulated / have more symmetric structures than expected.