The implication of astronomical data on the true nature of gravitation

Astronomical Institute
Charles University in Prague
2nd of December 2015

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Prelude

Standard model of physics :

Computation and prediction of
dynamical structures
(particles and their excited states).

Until now excellent agreement
with experiments
(e.g. LHC).

Standard model of cosmology :

(the SMoC)

Computations and predictions of
dynamical structures
(galaxies and their satellite galaxies).

This talk
and our work in Bonn.

Standard Model of Cosmology :
(the SMoC)

Postulate I : Einstein's field equation is
valid everywhere

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

where $R_{\mu\nu}$ is the Ricci curvature tensor, R the scalar curvature, $g_{\mu\nu}$ the metric tensor, Λ is the cosmological constant, G is Newton's gravitational constant, c the speed of light in vacuum, and $T_{\mu\nu}$ the stress–energy tensor.

Postulate II : Matter is conserved

The SMoC

The model is immediately falsified :
- Prediction of a highly curved highly inhomogeneous universe

Solution:
- Postulate (III) a mathematical trick (*inflation*) not understood

This composite model is immediately falsified :
- Prediction of falling *rotation curves* of galaxies and *structure formation* too slow

Solution:
- Postulate (IV) existence of unknown exotic matter (*dark matter*) not found

This composite model is immediately falsified :
- Universe expands today faster, than it should

Solution: not understood
- Postulate (V) a mathematical trick (*dark energy*)

Problem ? :
- Model (=*Standard Model of Cosmology* = *LCDM*) does **not conserve energy ?** (Baryshev 2006; Lopez-Corredoira 2010)

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End of Prelude

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This SMoC is

not

a satisfactory model **!**

Remember that Einstein constructed his GR to accommodate

Newton's empirical law of universal gravitation

based on observational data limited entirely to the ***Solar System*** on a scale of Mercury to Neptune.

Remember that Einstein constructed his GR to accommodate

Newton's empirical law of universal gravitation

based on observational data limited entirely to the ***Solar System*** on a scale of Mercury to Neptune.

i.e.

over a spatial scale

$$s < 30\,\mathrm{AU} = 10^{-3.8}\,\mathrm{pc}$$

and an acceleration (curvature) scale

$$6 \times 10^{-6}\,\mathrm{m/s^2} < g_\mathrm{N} < 4 \times 10^{-2}\,\mathrm{m/s^2}$$

$>$ 6 orders of magnitude

Galaxies had not yet been discovered and they correspond to scales

$$s > 10^3\,\mathrm{pc}$$

$$g_\mathrm{N} < 10^{-9}\,\mathrm{m/s^2}$$

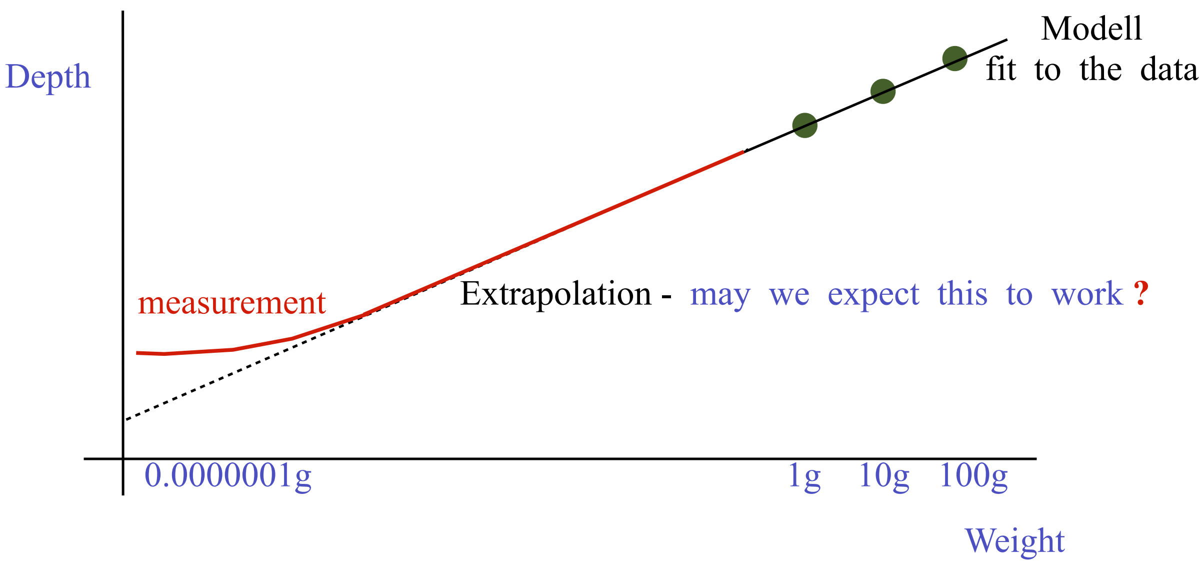
$>$ 4 orders of magnitude

Would you expect an empirical law to hold over an extrapolation of orders of magnitude ?

Gedankenexperiment

by Indranil Banik
(St. Andrews)

Depth of a trampolin with increasing weight :



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Thus the SMoC is

not

a satisfactory model !

But assume it is valid . . .

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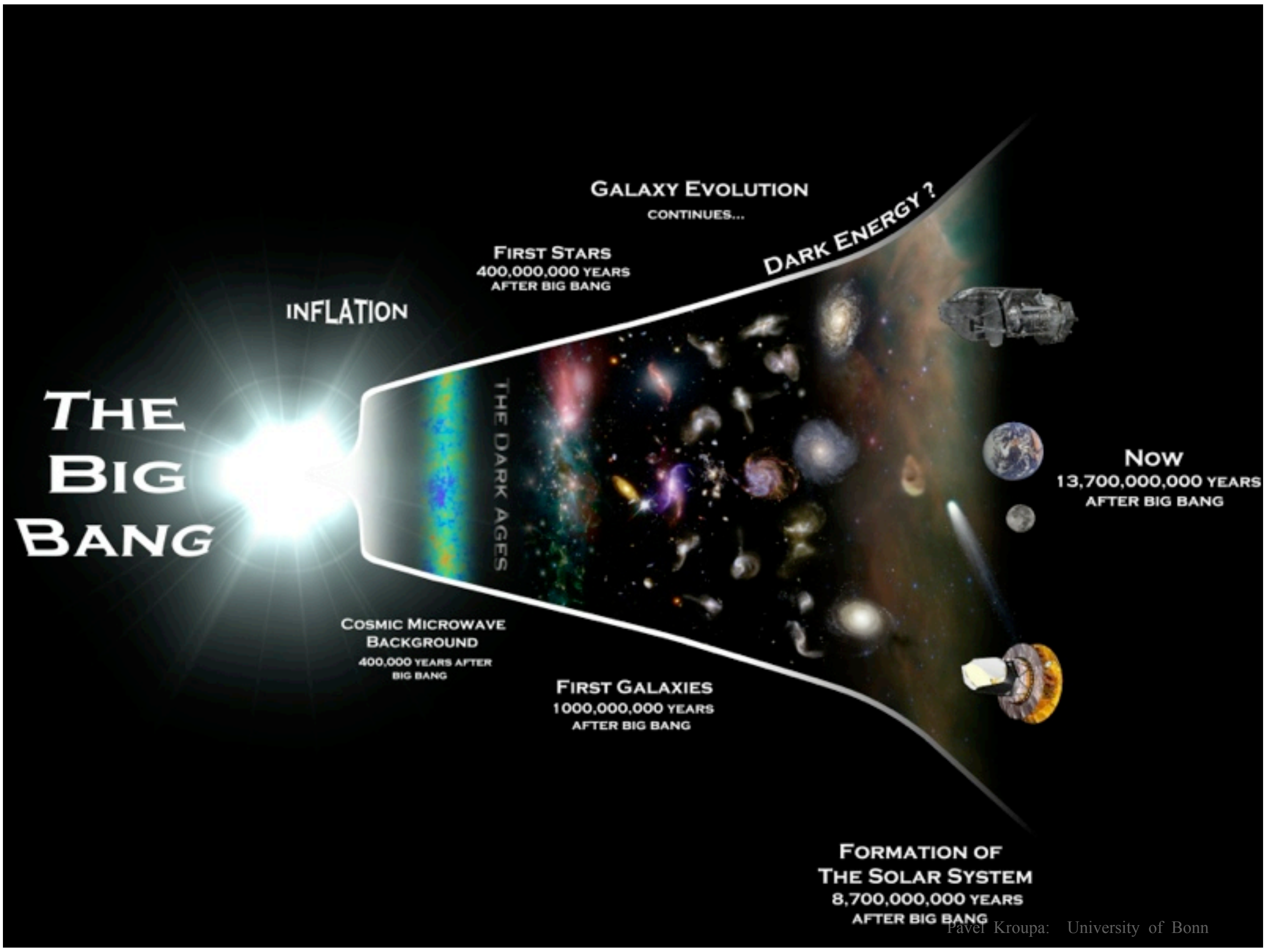


Cosmological structure formation

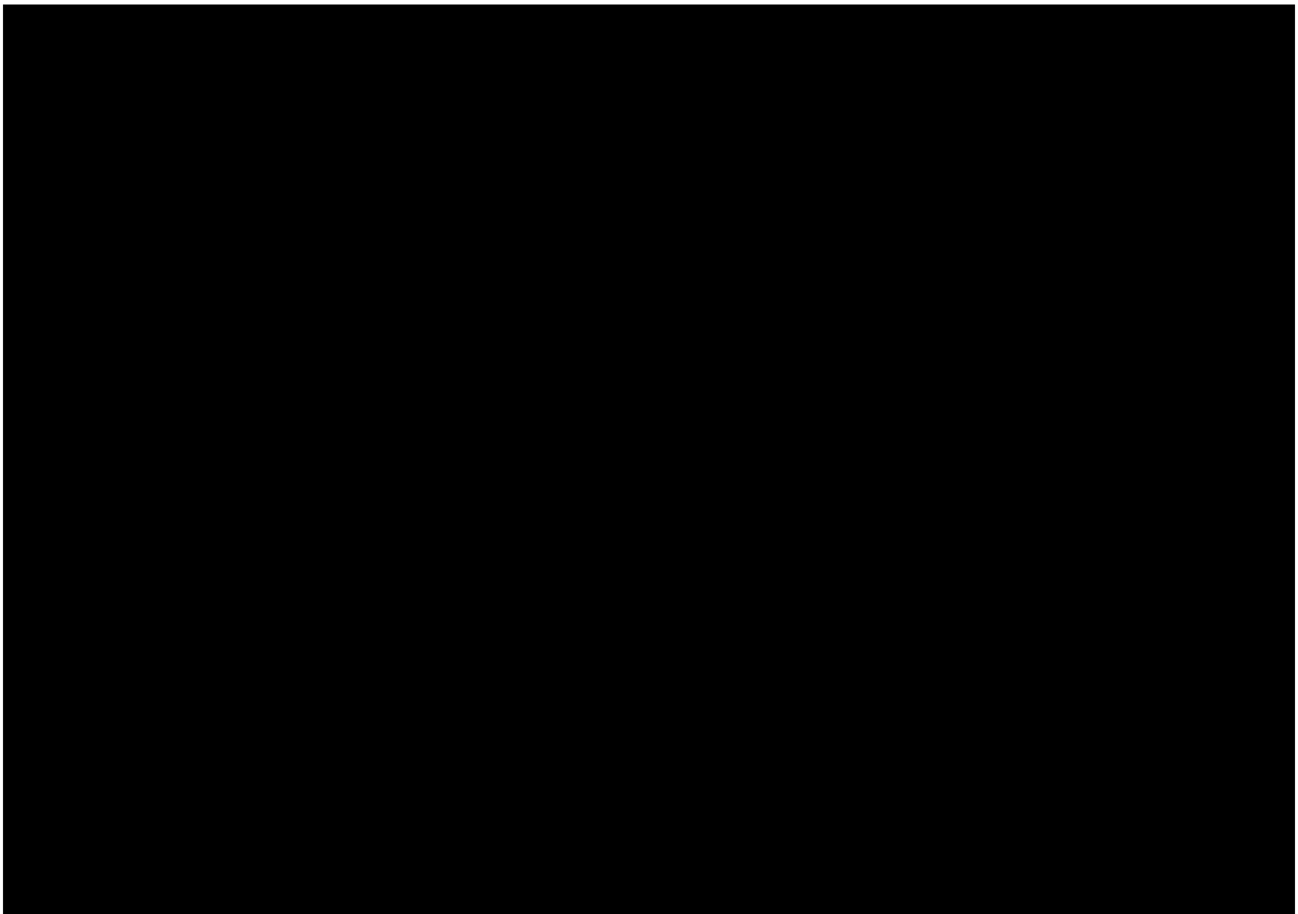
Movie by John Dubinski and Kameel Farah (CITA) of structure formation.

(http://www.cita.utoronto.ca/~dubinski/nbody/)

Cosmic Cruise (1:55)

About 14 billion years ago, the universe began in a Big Bang. In one single instant, all matter and energy were created. Rapid expansion caused the matter to cool and change into atoms and also the mysterious dark matter. At first, the dark matter was spread out evenly but faint echoes of the seething quantum foam that existed at the instant of creation remained like random ripples on the surface of a frozen pond. Gravity took hold of these noisy echoes and caused them to collapse into halos of dark matter that became the seeds of the galaxies.

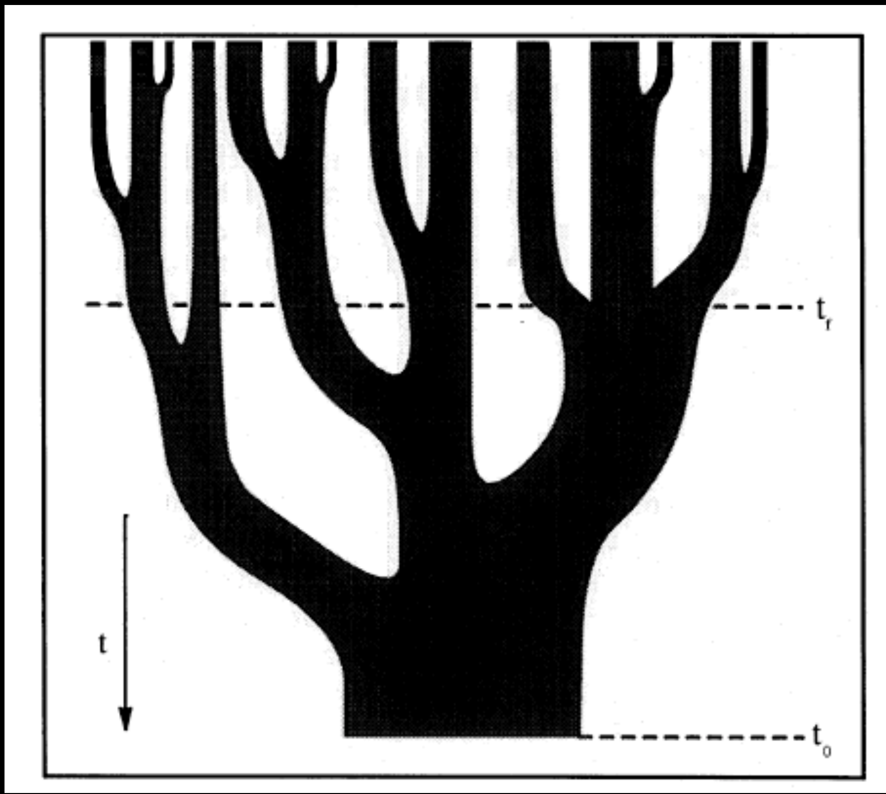
In this animation, we fly straight through a 130 million particle simulation of dark matter travelling hundreds of millions light years over 14 billion years. We illuminate the dark matter particles so that we can watch the formation of the cosmic web - the foundation of all structure in the prevailing model of cosmology. At the start, the regular grid of particles reflects the featureless nature of the universe at the beginning. As the flight continues, we witness the formation of the first structures through the collapse of density fluctuations. These merge with other structures and grow into the dark halos of sizes varying from galaxies to galaxy clusters.



Cosmic structure formation

Structures form according to the cosmological merger tree

Lacey & Cole (1993)



the beginning Big Bang

DM sub-structures form first and coalesce to larger structures

today

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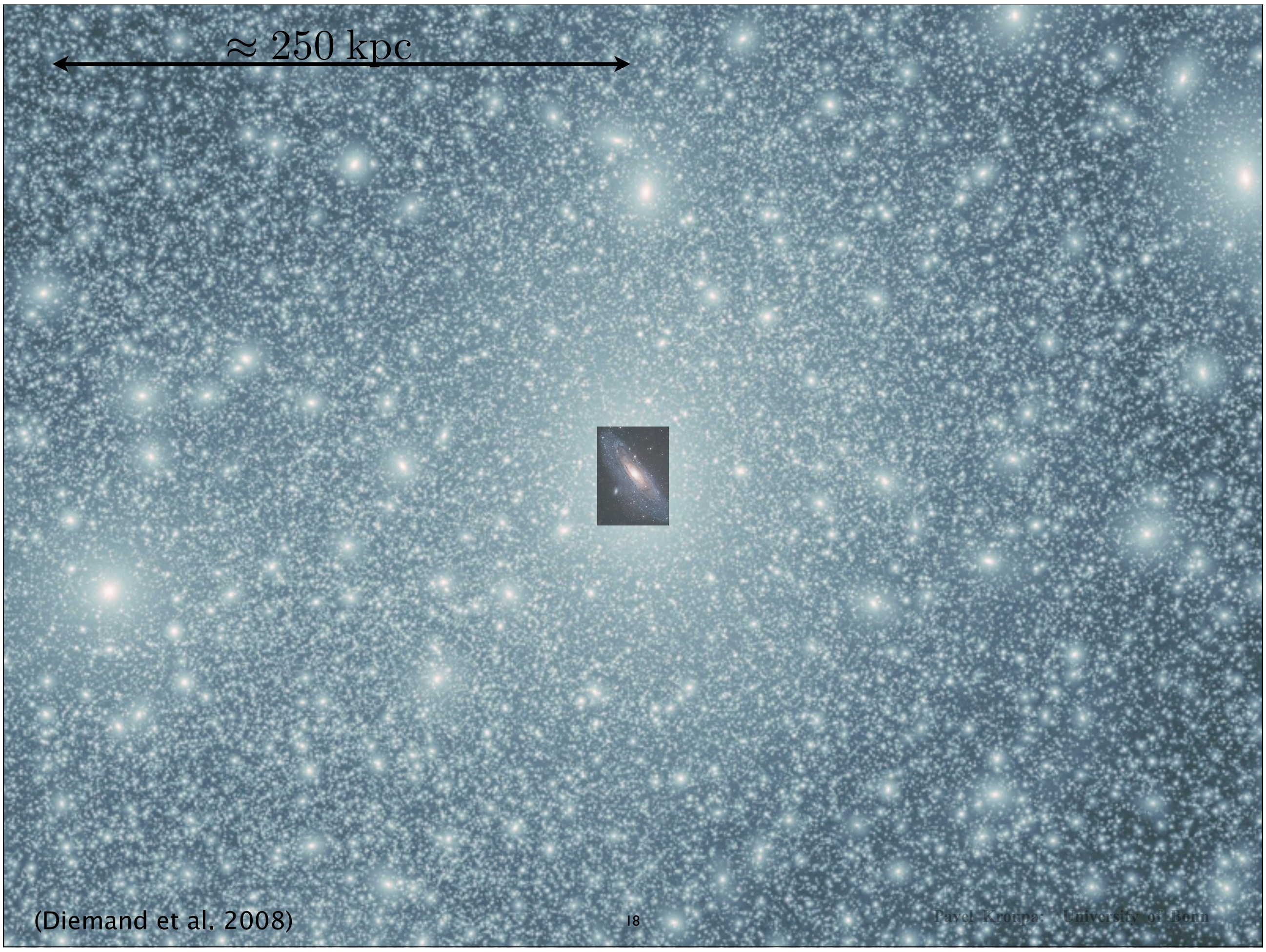


In the SMoC,

each and every galaxy

evolves through a sequence

of stochastic mergers

between sub-halos, each with its own independent merger history.

The *dynamical-friction-induced*

merging sub-halos are very largely

uncorrelated.

Galaxy assembly is thus characterized by

stochastic low-specific angular momentum mergers.

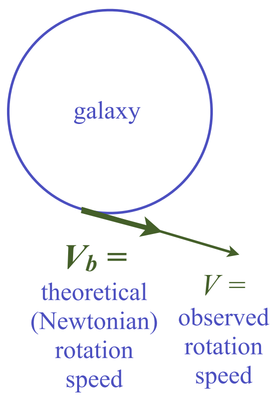
Some tests of the SMoC . . .

Rotation curves and fine tuning

Mass-Discrepancy correlation with acceleration

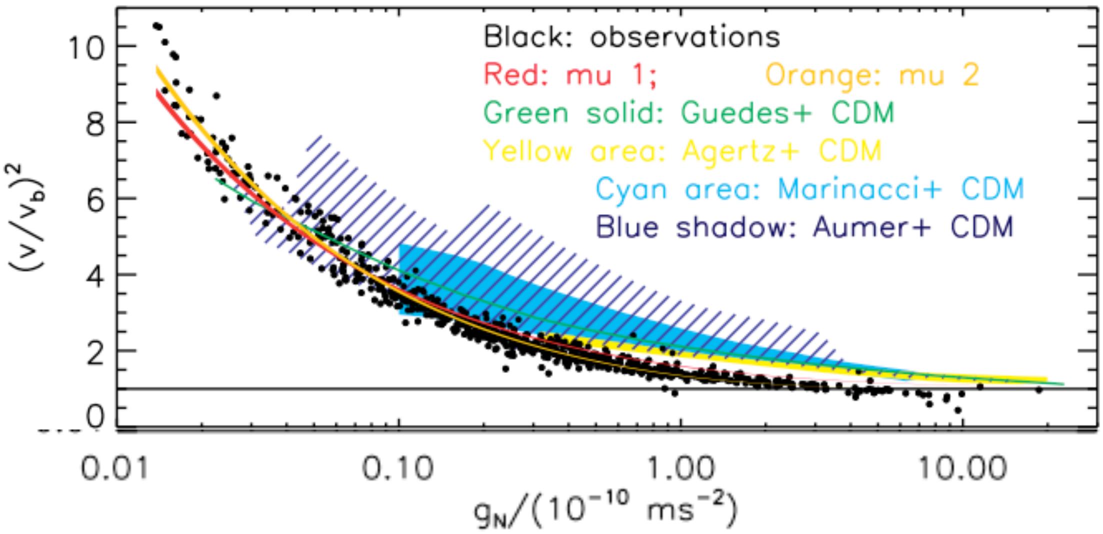
The Sanders-McGaugh correlation

Sanders 1990; McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012



Rotation curves
OR
mass-discrepancy -- acceleration correlation

Wu & Kroupa 2015



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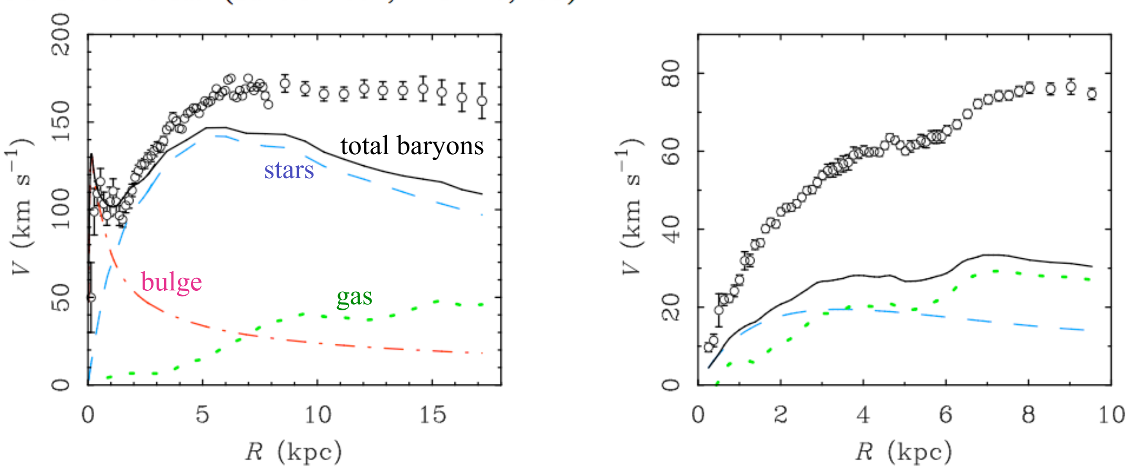
Renzo's rule

Renzo's Rule: "For any feature in the luminosity profile there is a corresponding feature in the rotation curve and vice versa." (Sancisi 2004, IAU 220, 233)



Tuesday, February 28, 2012 Stacy McGaugh, Univ. Maryland KITP DwarfGal

"What is distinctly unnatural is for the baryons to have a perceptible impact where dark matter must clearly dominate." (c.f. LSBs vs HSBs)

Famaey & McGaugh 2012

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No increase in number ratio of E to other galaxies

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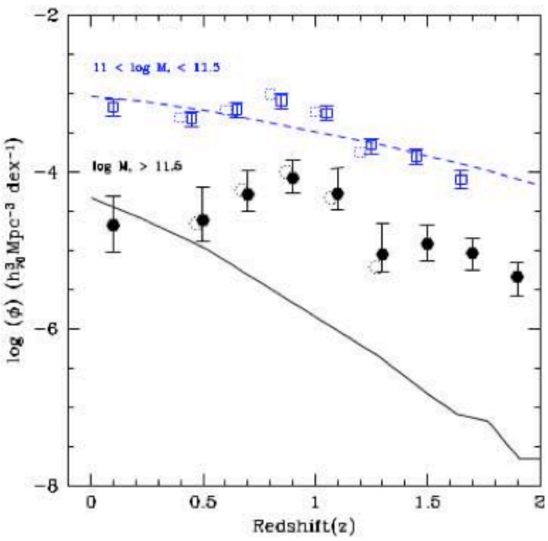
Ratio of massive to less-massive galaxies does not evolve, in conflict with LCDM expectations

Conselice 2012



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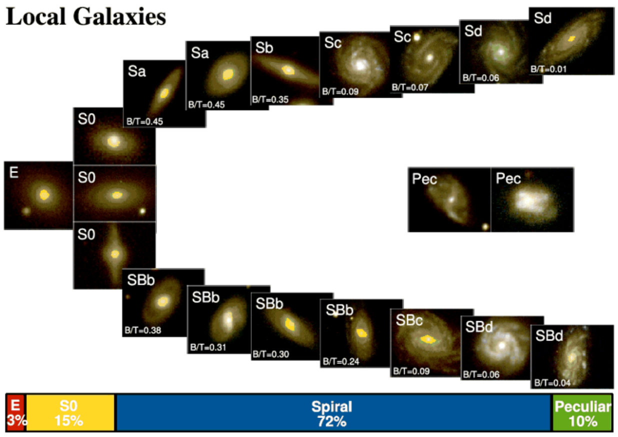
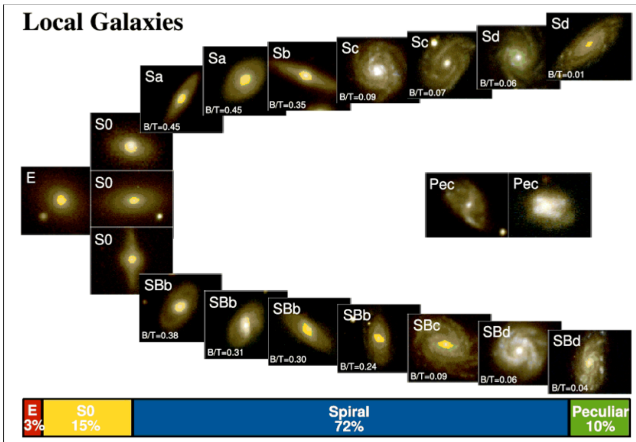


Ratio of E to other galaxies unchanging ?

Delgado-Serrano et al. (2010)

Galaxy mass in baryons
$> 1.5 \times 10^{10}$ Msun

6 Gyr ago



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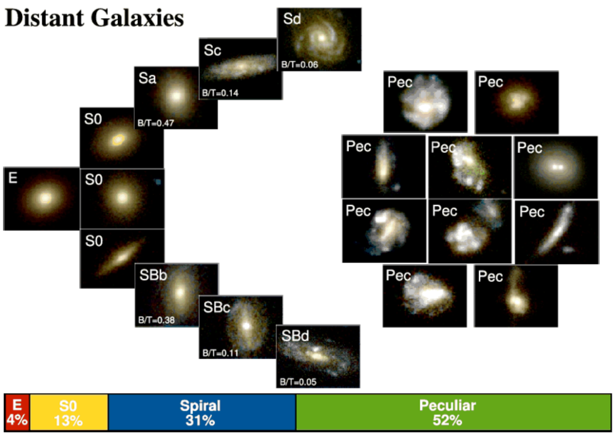

28

6 Gyr ago

Dynamical Friction

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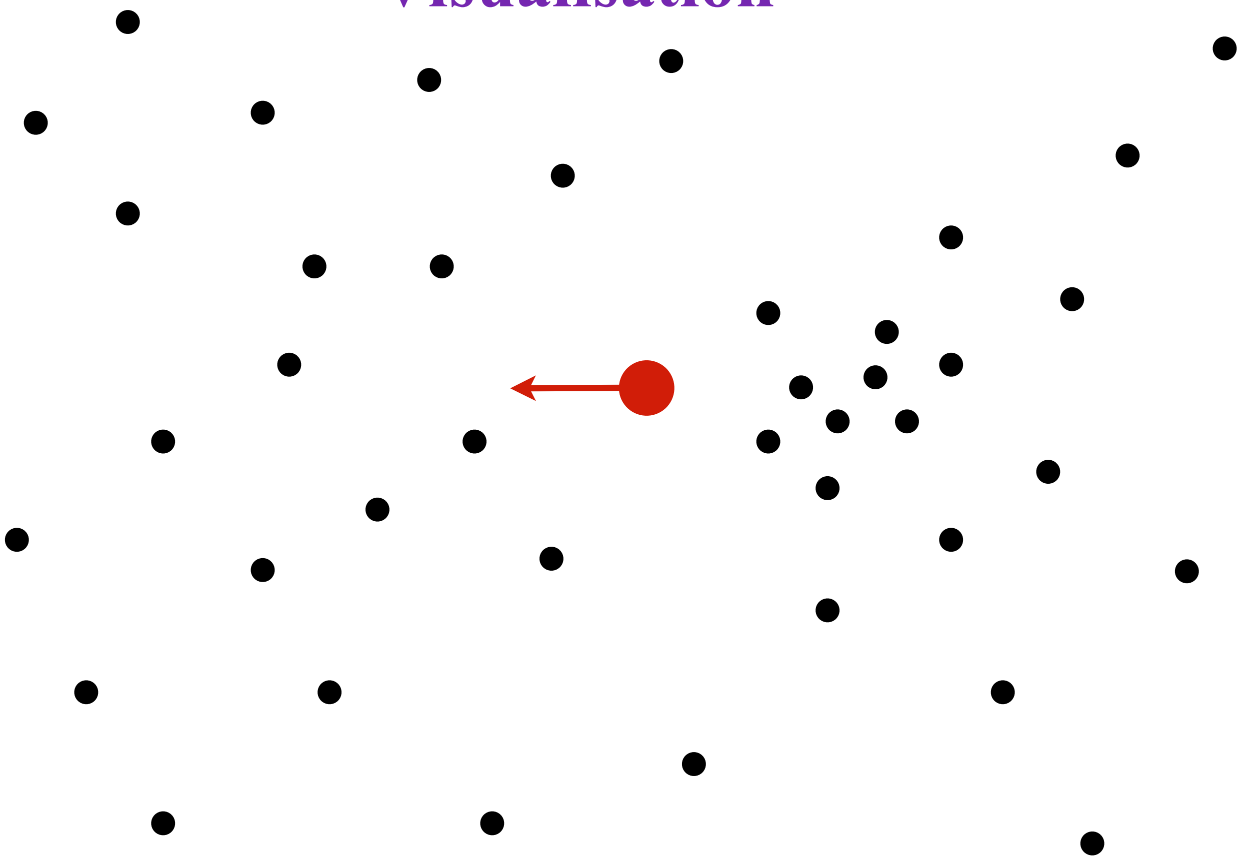
Visualisation



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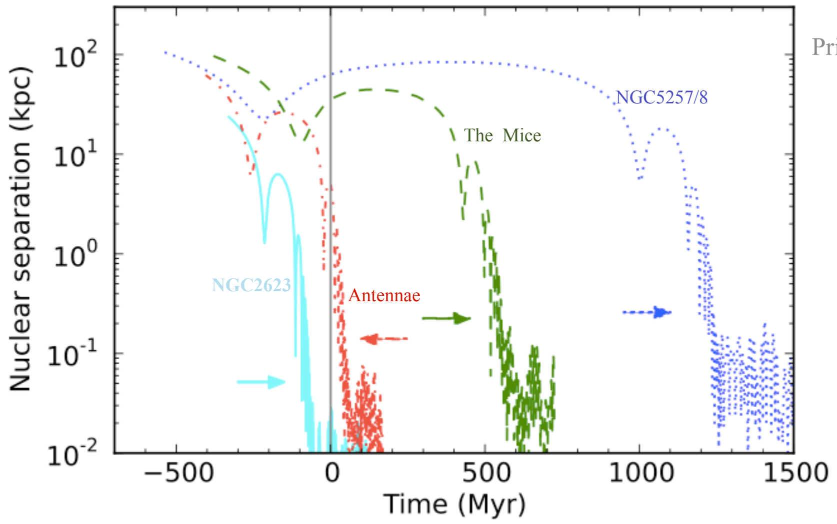
Dynamical friction?? : galaxy mergers - are they really common?

Galaxy encounters with mass ratio = 1 : mergers within 0.5-3 Gyr



Privon, Barnes et al. 2013

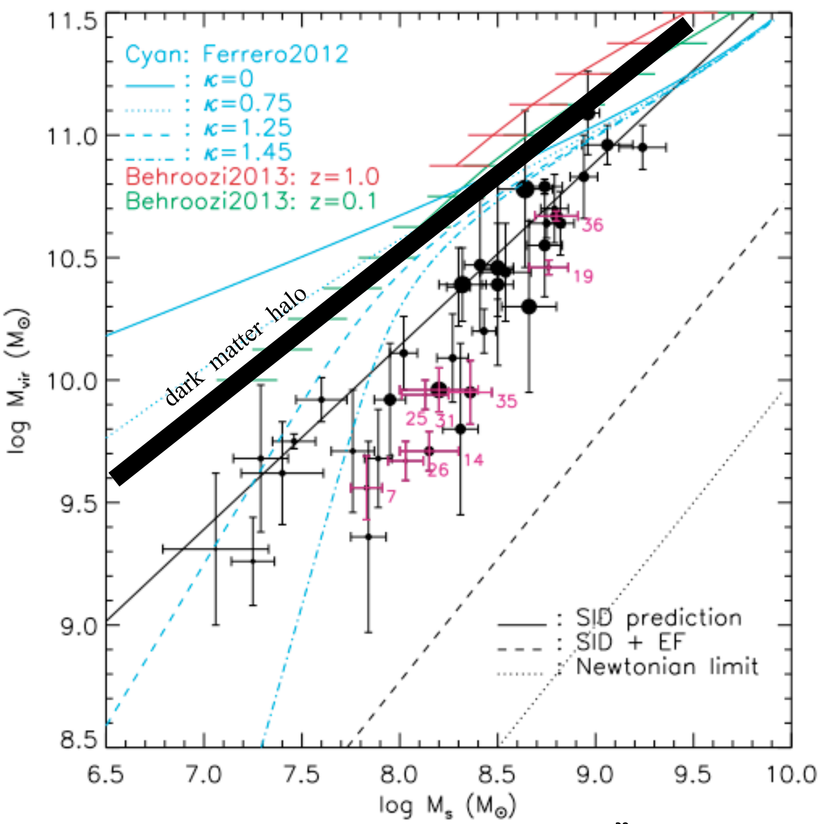
Figure 1. True nuclear separation as a function of time for NGC 5257/8 (dotted blue line), The Mice (dashed green), Antennae (dash-dot red), and NGC 2623 (solid cyan). Time of zero is the current viewing time (solid gray vertical line). The time since first passages for these systems is 175 – 260 Myr (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."

Pavel Kroupa: University of Bonn

Each MW satellite has a pre-infall DM halo :



Wu & Kroupa 2015, MNRAS

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.

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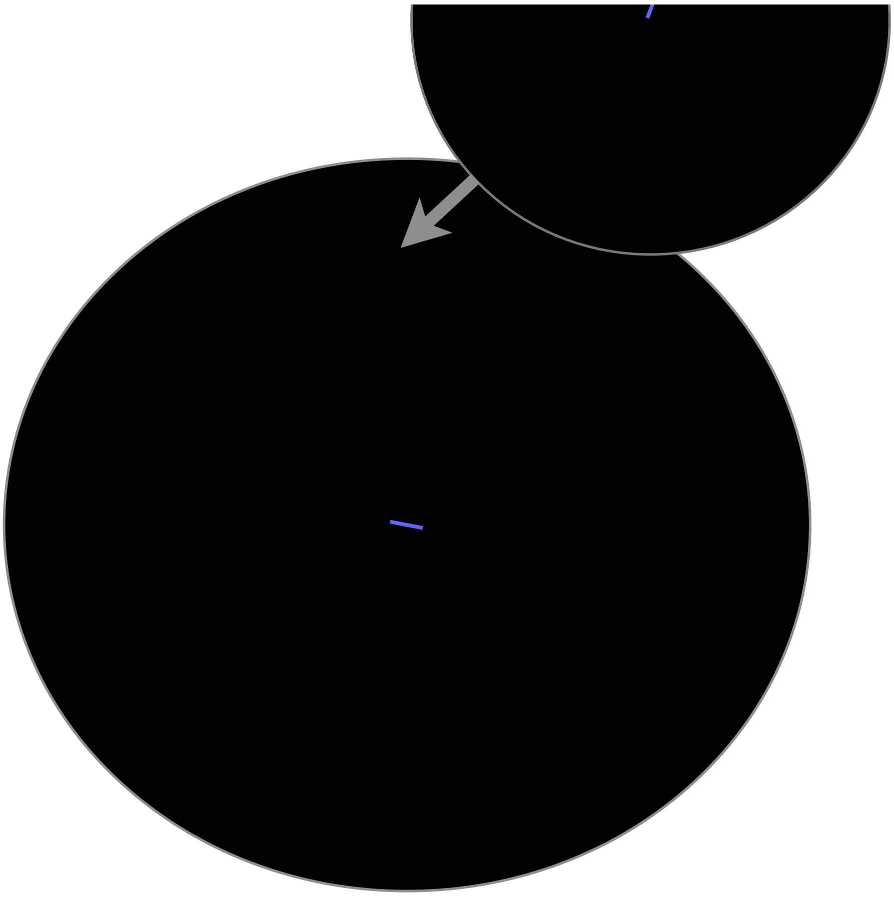

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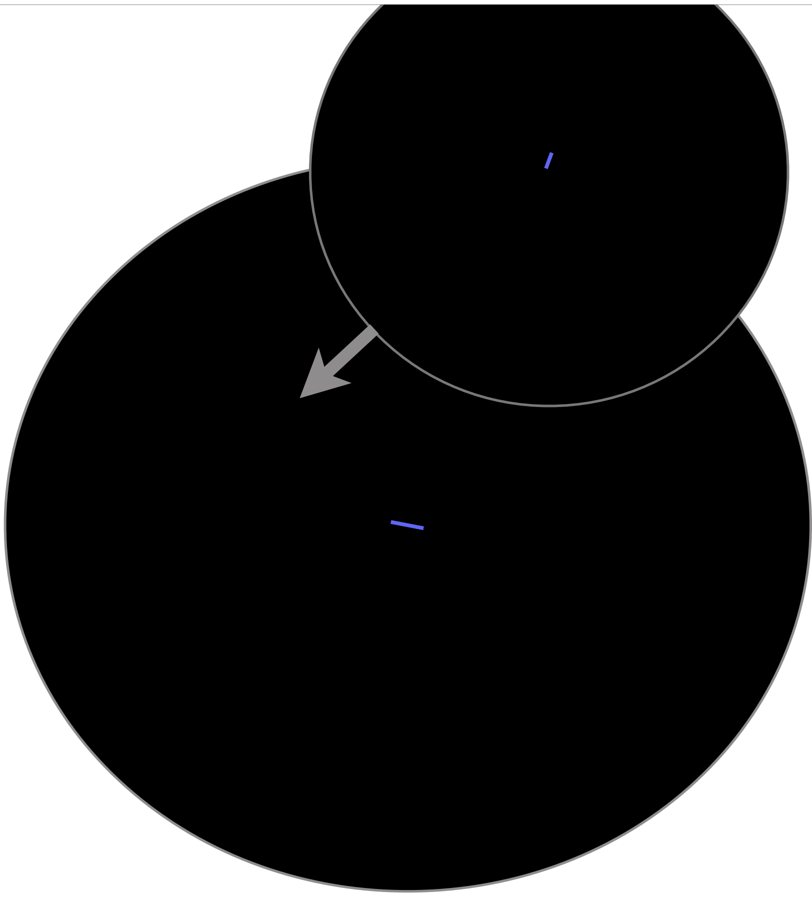
Pavel Kroupa: University of Bonn



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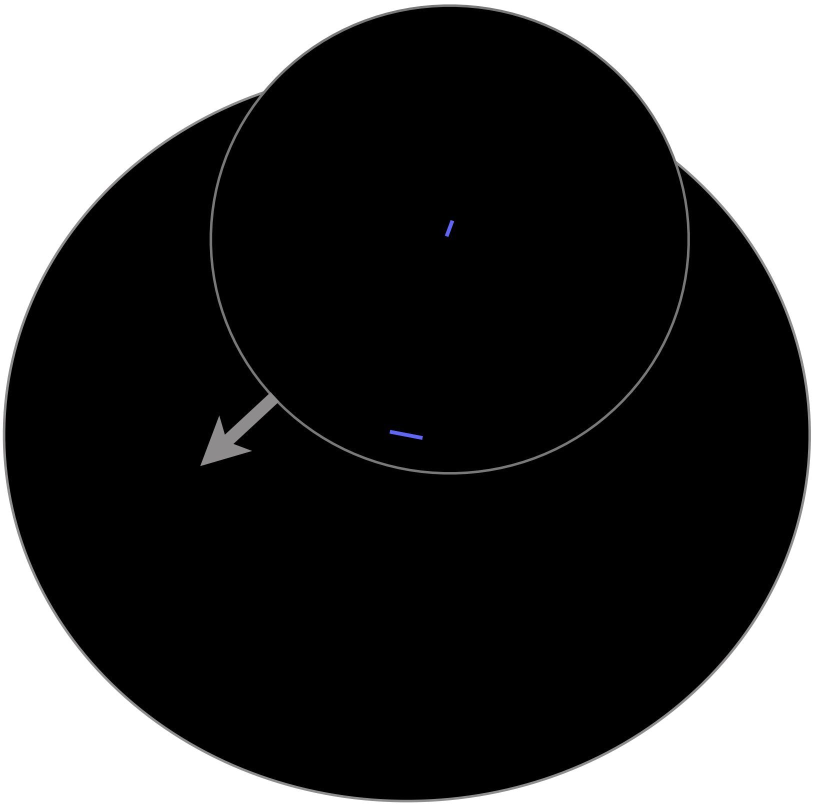

Mon. Not. R. Astron. Soc. **416,** 1401–1409 (2011) doi:10.1111/j.1365-2966.2011.19138.x

Using dwarf satellite proper motions to determine their origin

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Accepted 2011 May 25. Received 2011 May 25; in original form 2010 September 14

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

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.

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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.

→ inconsistency with the dark-matter model

Sagittarius: on a high-energy orbit but still not merged **?**
LMC/SMC: In DoS so cannot be on first-passage **?**

Other Consequences

The M81 group of galaxies

- an analogue to the Local Group

Constraints on the existence of dark matter halos by the galaxy group M81

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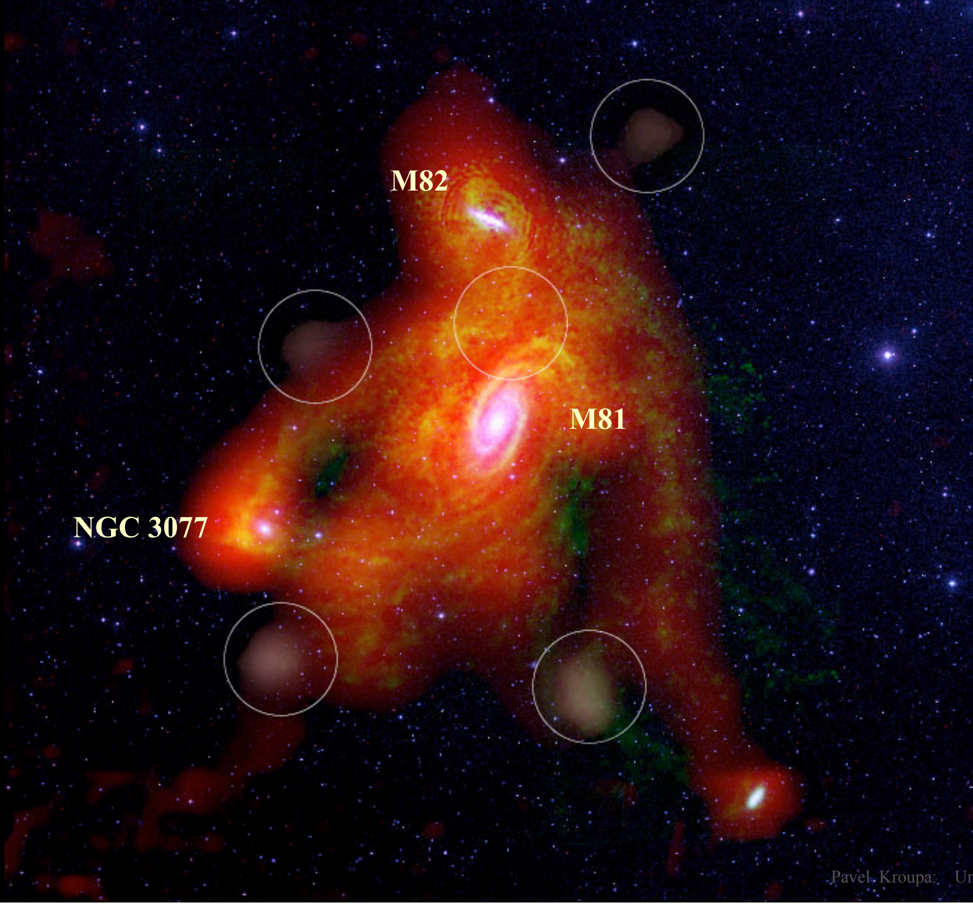
8 May 2015

ABSTRACT
According to the standard model of cosmology, galaxies are embedded in dark matter halos, thus extending the mass and the size of the visible baryonic matter by one or two orders of magnitude. By means of this hypothesis, which claims an extension to the standard model of particle physics, observed deviations from Newtonian dynamics in galactic dynamical processes find, at a first glance, their appropriate explanation. However, incorporating the influence of dynamical friction established by Chandrasekhar, we obtain the result for the inner M81 group of galaxies that the existence of dark matter halos appears to be implausible. To be precise, the inner M81 group merges too rapidly making the initial pre-interaction phase-space configuration extremely unlikely. This result is derived by the employment of two separate and independent statistical methods, namely a Markov chain Monte Carlo method and the genetic algorithm. Without any exception, all numerical computations have been performed by means of SAP's *ABAP* development workbench, thus facilitating a program development time at least two or three times faster compared to the development environments of *FORTRAN* or *C++*. The conclusions reached here are discussed in view of independent evidence for dark-matter-induced dynamical friction being a relevant process in galaxy evolution.

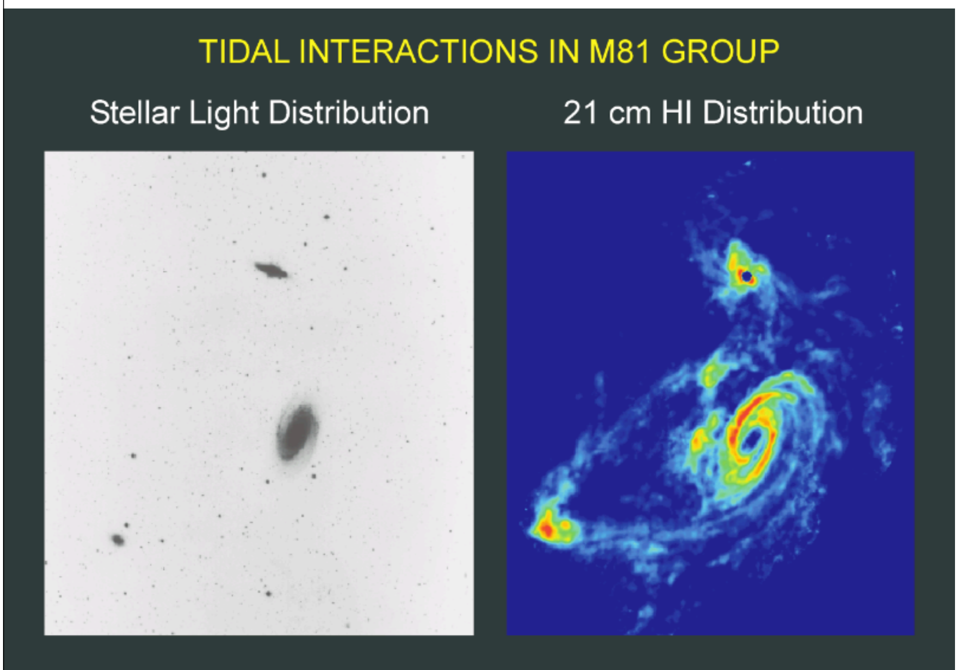
Key words: galactic dynamics - dark matter - standard model of cosmology - computational methods

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

Results

The results arrived at here strongly exclude the process of dynamical friction having played a role in the M81 group of galaxies: if the extensive and massive DM halos were present, then for the M81 system of galaxies to exist in its current pre-merger configuration is extremely unlikely.

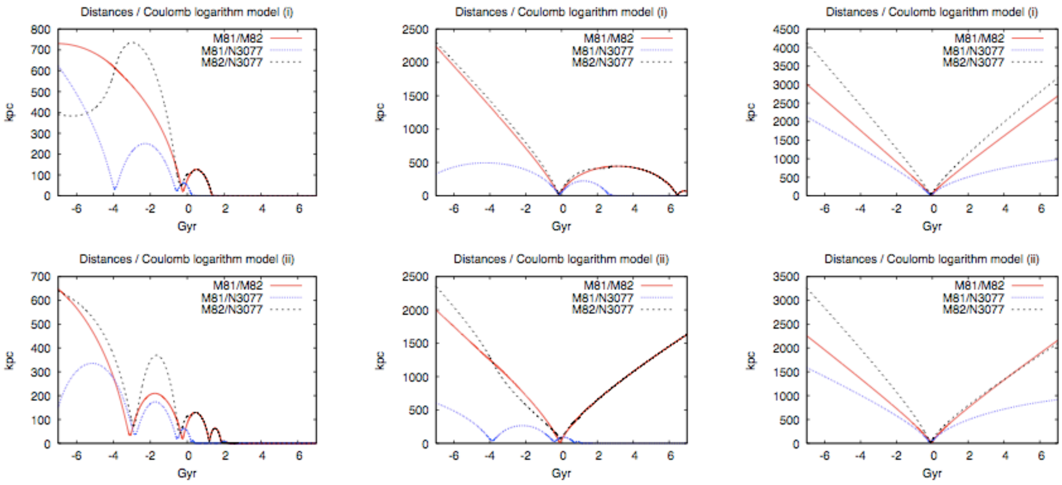


Figure 8. GA: Typical solutions for the three-body orbits presented as distances between the galaxies in the time interval from − 7 Gyr to 7 Gyr. For each Coulomb logarithm model (*(i)* at top, *(ii)* at bottom) we selected examples with merging galaxies, as well as an example for each model, where the companions both arrive from a far distance and no merger process occurs (see Table 5 and Appendix D for an assessment).

. . . 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.

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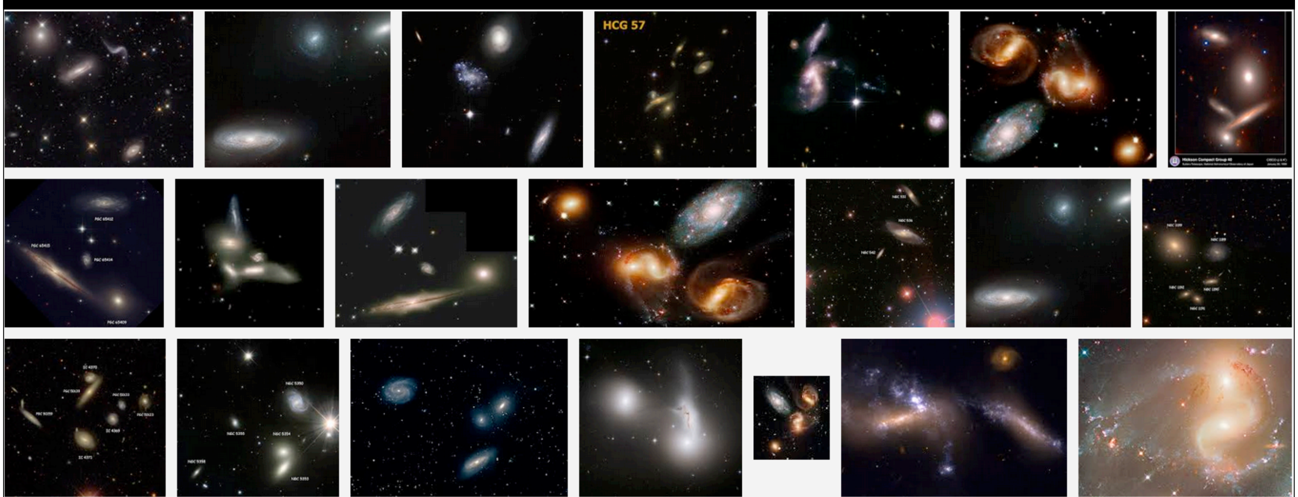

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silkscape.com

From various surveys (Delgado-Serrano et al. 2010; Conselice 2012) we know that the co-moving volume number ratio (E/S galaxies) does not evolve with redshift.

Abundances and ages of most field E galaxies and of fossil group E galaxies are very similar to Es in clusters (Pompei & Iovino 2012).

citing from COSMOS - The SAO Encyclopedia of Astronomy on Hickson Compact groups:

"The velocities measured for galaxies in compact groups are quite low (~200 km/s), making these environments highly conducive to interactions and mergers between galaxies.

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However, this makes the formation of compact groups something of a mystery, as the close proximity of the galaxies means that they should merge into a single galaxy in a short time, leaving only a fossil group.

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This would mean that compact groups are a shorted-lived phase of group evolution, and we would expect them to be extremely rare.

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This would mean that compact groups are a shorted-lived phase of group evolution, and we would expect them to be extremely rare.

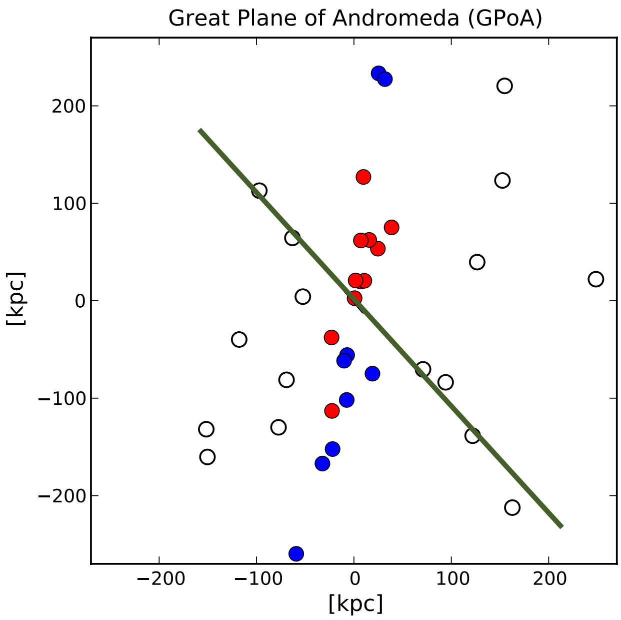
Instead, we find a significant number of compact groups in the nearby Universe, with well over 100 identified."

DoS / VPOS / GPoA

and

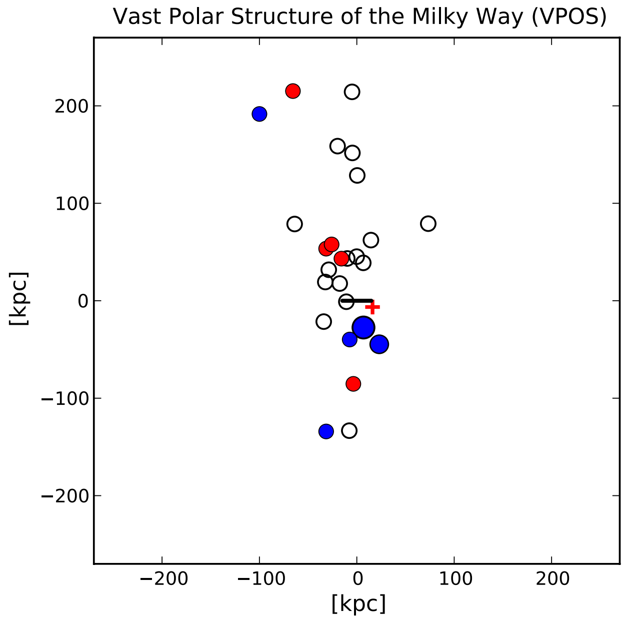
the frightening symmetry of the Local Group

Andromeda



Ibata et al. 2013, 2014

Milky Way



Kroupa et al. 2005;
Pawlowski & Kroupa 2013

Pawlowski, Kroupa & Jerjen (2013 MNRAS)

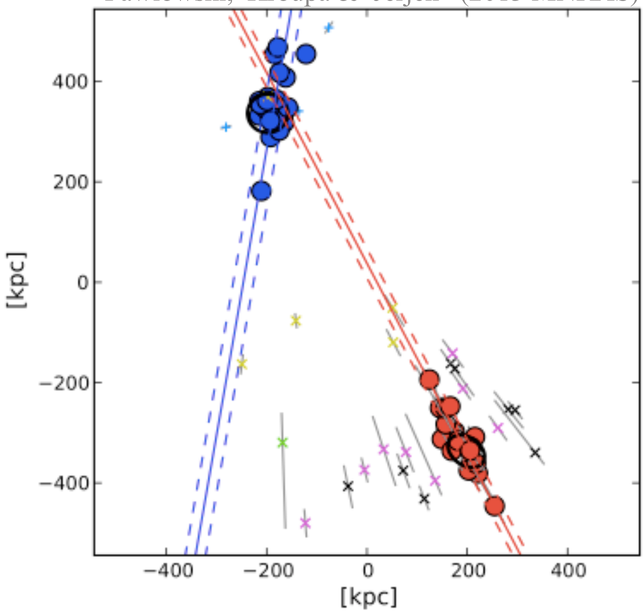


Figure 16. Edge-on view of the satellite galaxy planes around the MW and M31, similar to Fig. 9 for the LG planes. As before, galaxies which are

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

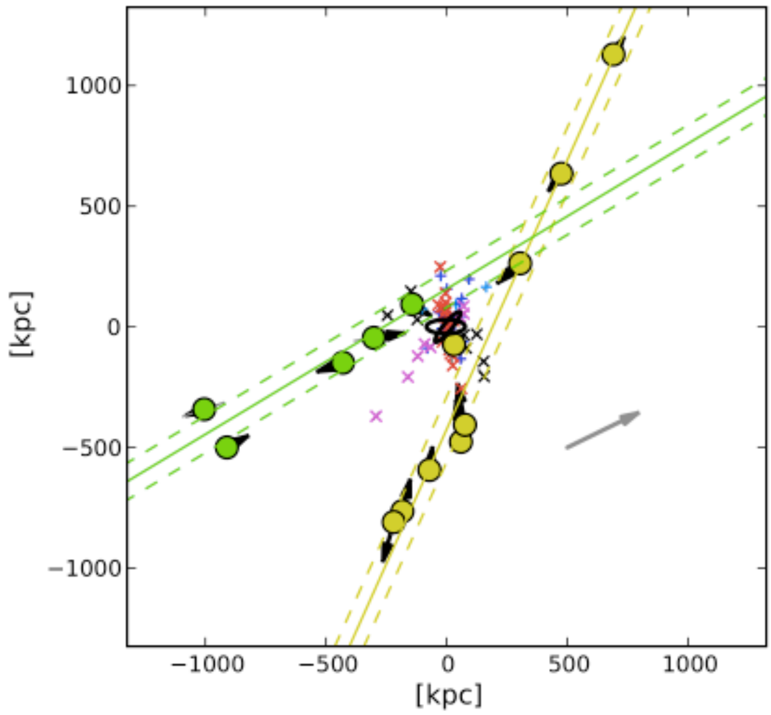


Figure 9. Edge-on view of both LG planes. The orientation of the MW and M31 are indicted as black ellipses in the centre. Members of the LGP1 are plotted as yellow points, those of LGP2 as green points. MW galaxies are plotted as plus signs (+), all other galaxies as crosses (×), the colours code their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

Pawlowski, Kroupa & Jerjen (2013 MNRAS)

"The discovery of symmetric structures in the Local Group"

A frightening symmetry

. . . the arrangement of matter in the Local Group is

totally incompatible

with the dark-matter-dominated structures.

The symmetry of the Local Group constrains the motion of

M31 relative to MW.

A not-so local under-density

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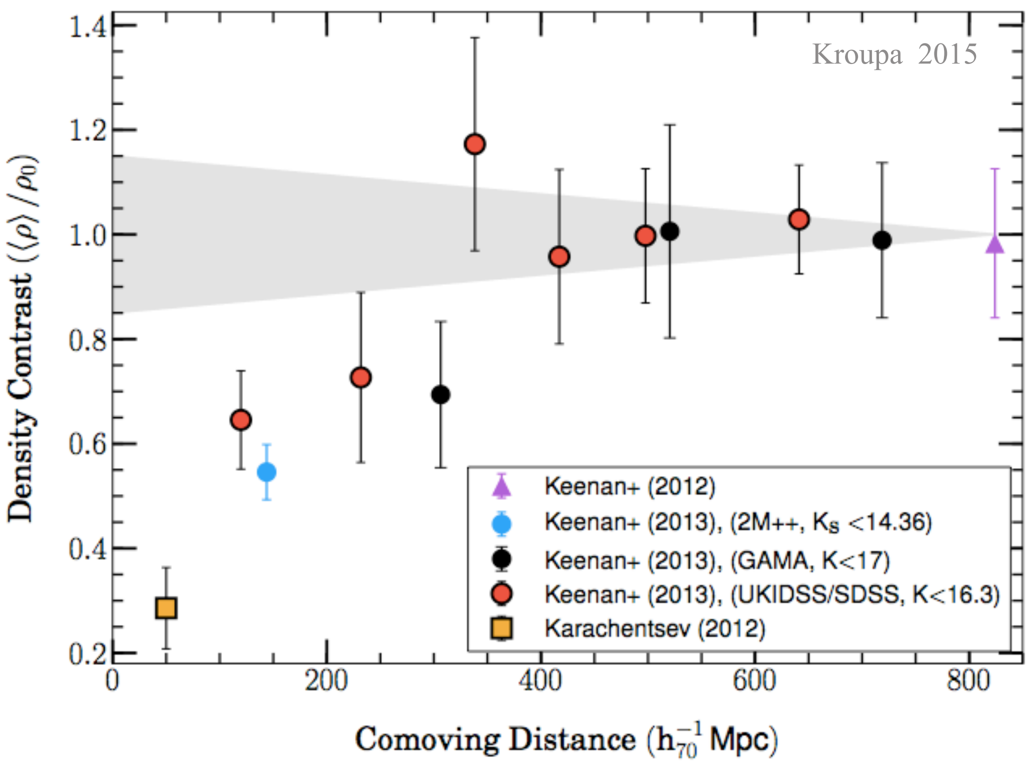
Pavel Kroupa: University of Bonn

Measured matter density as a function of distance



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The way forward :

beyond particle dark matter

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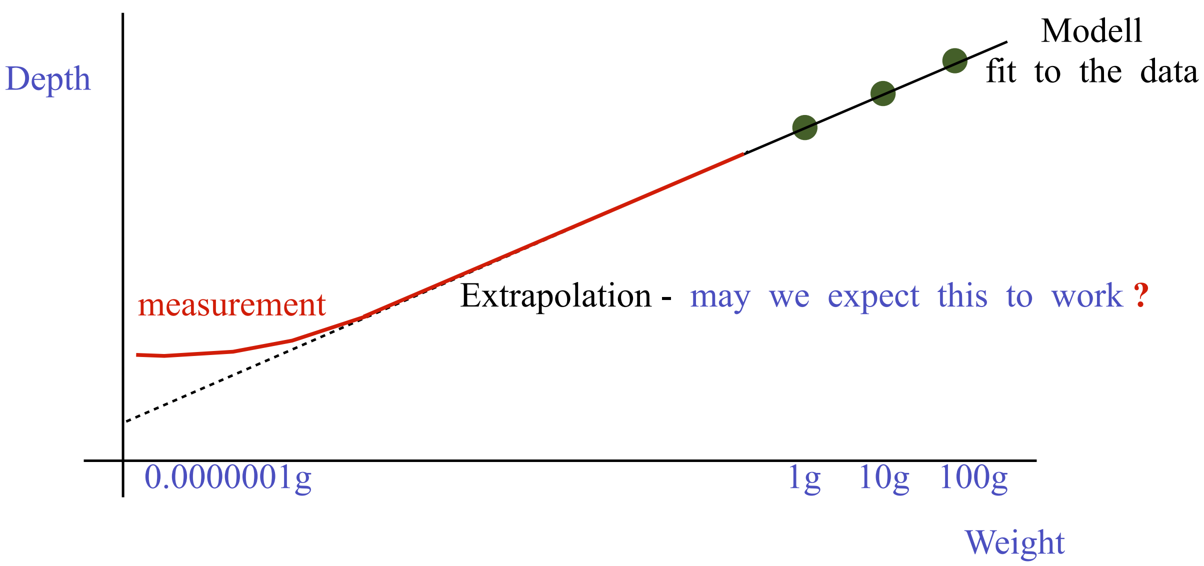
Remember : ***Gedankenexperiment***

by Indranil Banik (St. Andrews)

Depth of a trampolin with increasing weight :



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Do galaxies

contain clues

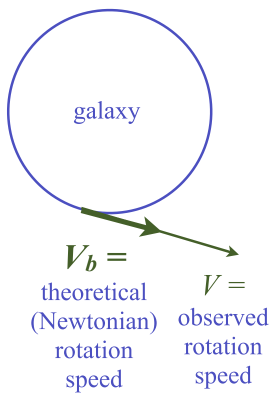
that perhaps the extrapolation of Einstein / Newton

fails ?

Mass-Discrepancy correlation with acceleration

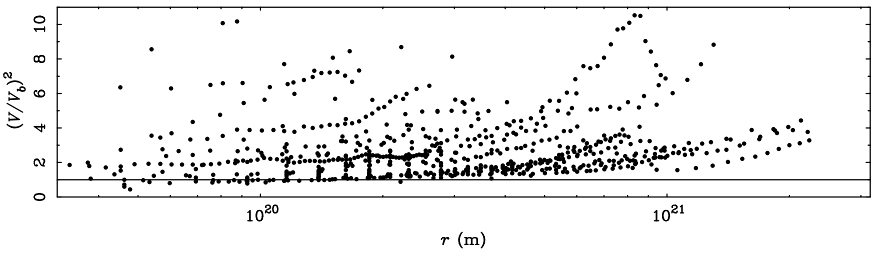
The Sanders-McGaugh correlation

Sanders 1990; McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012

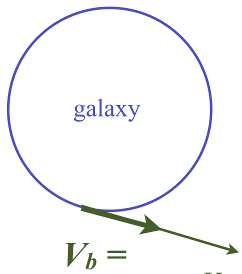


Mass-Discrepancy correlation with acceleration

Sanders 1990; McGaugh 2004
Famaey & McGaugh 2012
(Kroupa 2012, 2015)



$1\ \mathrm{pc} = 31 \times 10^{15}\ \mathrm{m}$ $1\ \mathrm{m} = 3.2 \times 10^{-17}\ \mathrm{pc}$

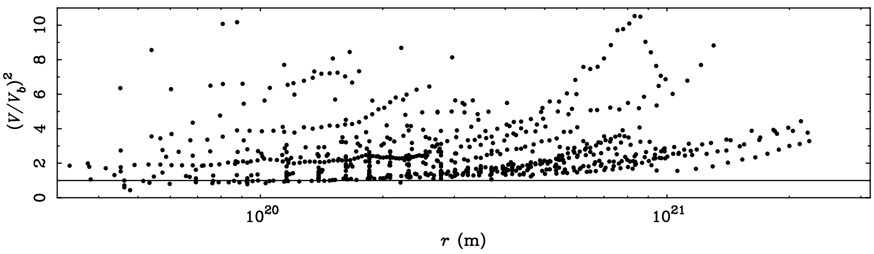


$V_b =$ theoretical (Newtonian) rotation speed

$V =$ observed rotation speed

Mass-Discrepancy correlation with acceleration

Sanders 1990; McGaugh 2004
Famaey & McGaugh 2012
(Kroupa 2012, 2015)



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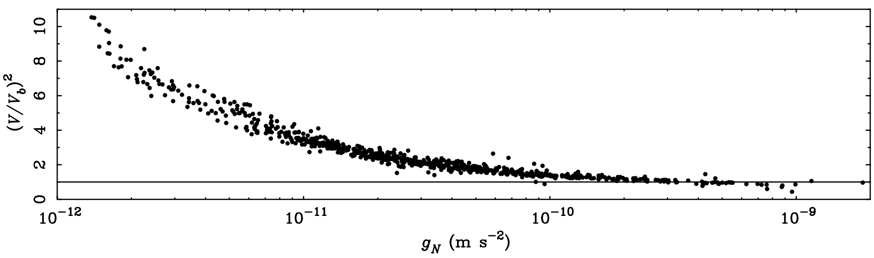

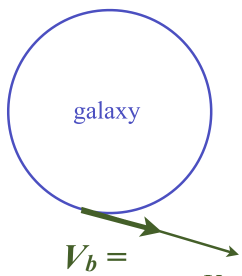

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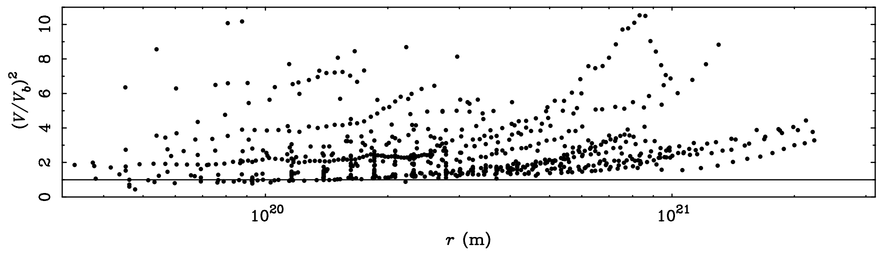

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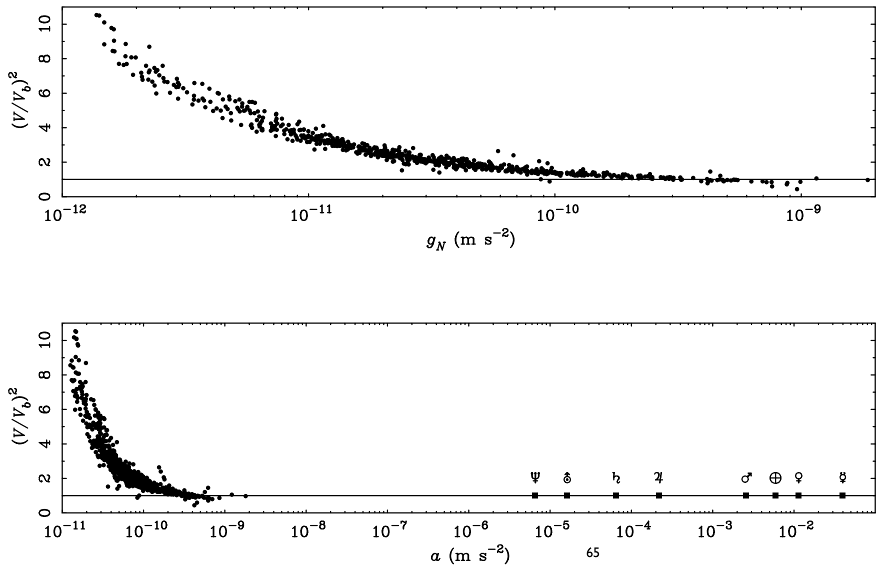

Correlation can't be explained by Dark Matter : DM particle physics is independent of the local acceleration in the SMoC.

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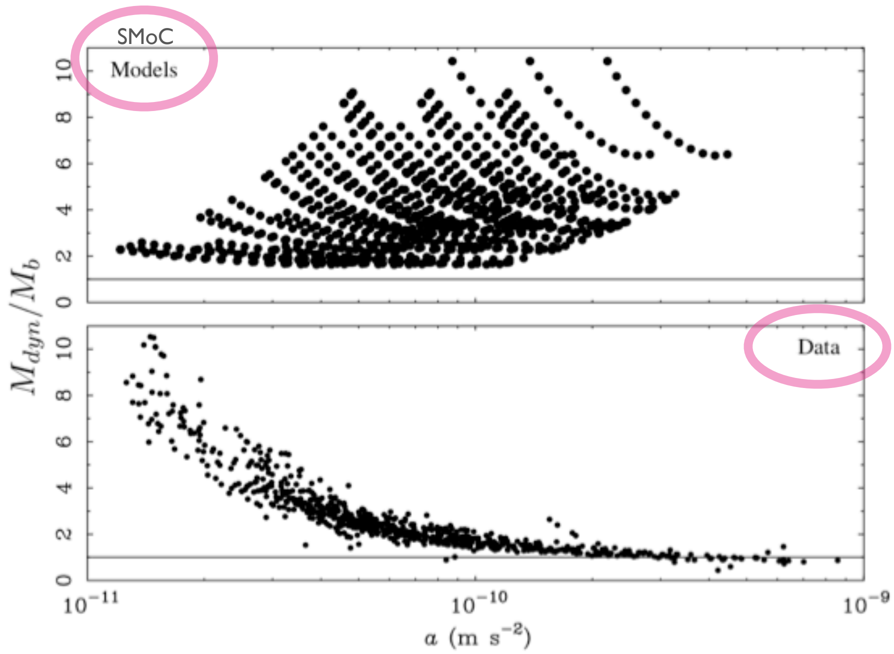
Mass-Discrepancy correlation with acceleration

McGaugh 2014
also
Wu & Kroupa 2015



Correlation can't be explained by Dark Matter : DM particle physics is independent of the local acceleration in the SMoC.

Fig. 3. The mass discrepancy–acceleration relation. The ratio of dynamical to baryonic mass is shown at each point along rotation curves as a function of the centripetal acceleration at that point. The top panel shows model galaxies in ΛCDM (see text). The bottom panel shows data for real galaxies (42). Individual galaxies, of which there are 74 here, do not distinguish themselves in this diagram, though model galaxies clearly do. The organization of the data suggest the action of a single effective force law in disk galaxies. This phenomenon does not emerge naturally from ΛCDM models.

$1 \text{ pc} = 31 \times 10^{15} \text{ m}$ $1 \text{ m} = 3.2 \times 10^{-17} \text{ pc}$

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space-time

scale-invariant

(Milgromian)

dynamics

(SID)

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Mordecai Milgrom
(+PK)
Strasbourg, 29.06.2010.

Ansatz :

(Milgrom 1983, ApJ, 270, 371)

Pavel Kroupa: AIfA, University of Bonn

Consider ***space-time scale invariance*** :

(**Milgrom 2009**; Kroupa, Pawlowski & Milgrom 2012; Kroupa 2014)

If $(t, x, y, z) \rightarrow \lambda(t, x, y, z)$

then, the Newtonian gravitational acceleration, $g_N \propto GM/r^2$,

scales as $g_N \rightarrow \lambda^{-2} g_N$

while the kinematical acceleration, g , scales as $g \rightarrow \lambda^{-1} g$ $\left[\frac{d\dot{x}}{dt}\right]$

For gravitational and kinematical acceleration to also be scale invariant we thus need g to scale as $g_N^{1/2}$

i.e. $g \propto (a_o g_N)^{1/2}$ $g^2 = a_o g_N$ or $a^2 = a_o g_N$

i.e. $\frac{a}{a_o} a = g_N$

space-time scale invariance (from above) :

i.e. $\frac{a}{a_o} a = g_N$, thus $a = \frac{\sqrt{GM}}{r} \sqrt{a_0}$

centrifugal acceleration = centripetal acceleration

$$a = \frac{V^2}{r} = \frac{\sqrt{GMa_0}}{r} \qquad (V \equiv V_c)$$

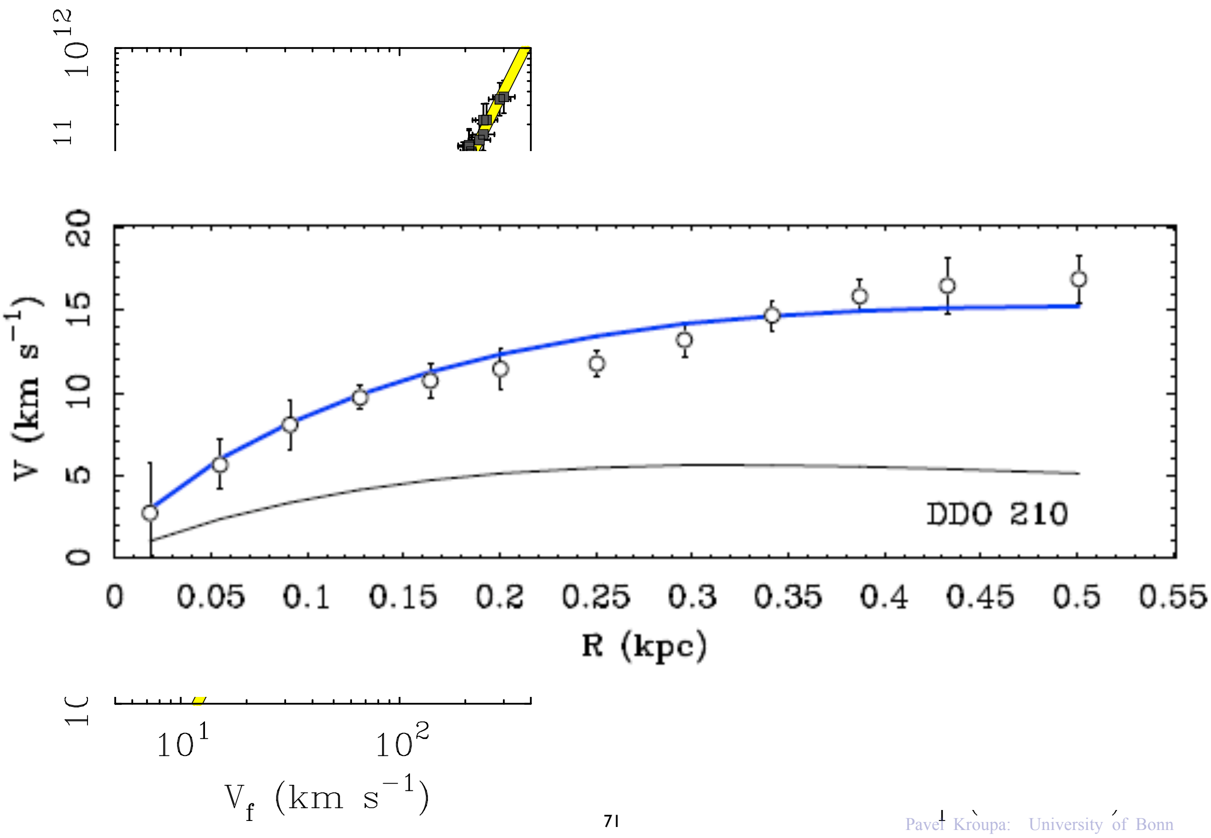
$$V = (GMa_0)^{\frac{1}{4}}$$

the ***Tully-Fisher relation*** !

and ***flat rotation curves*** !

The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



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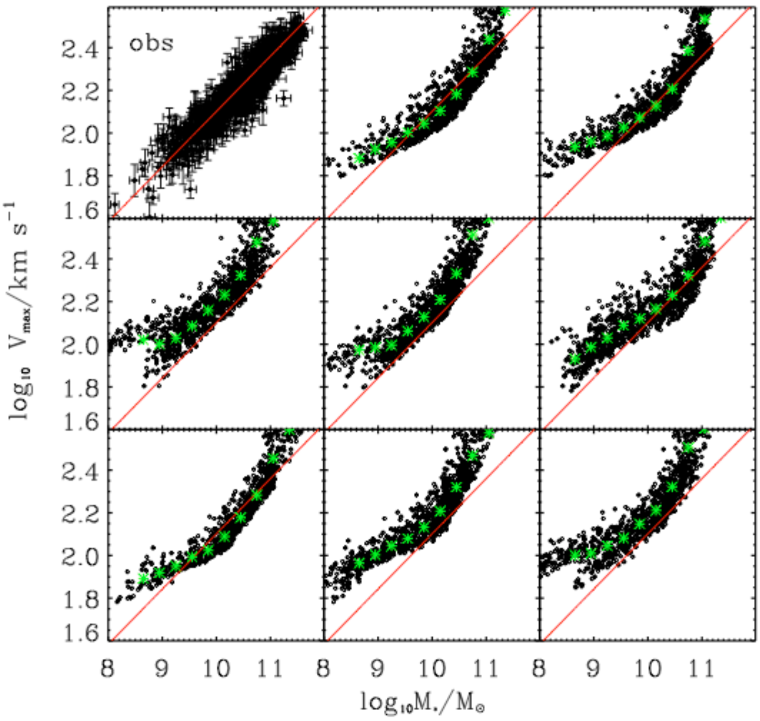
The SMoC Baryonic Tully -Fisher Relation

Bayesian inference from the K-band luminosity function 37



Lu, Mo, Katz & Weinberg 2012

Figure 4. The stellar mass Tully-Fisher relation predicted by 8 models randomly selected from the posterior compared with data from Dutton et al. (2011) shown in the upper-left panel. The red line denotes a fit to the observational data given by Dutton et al. (2011).

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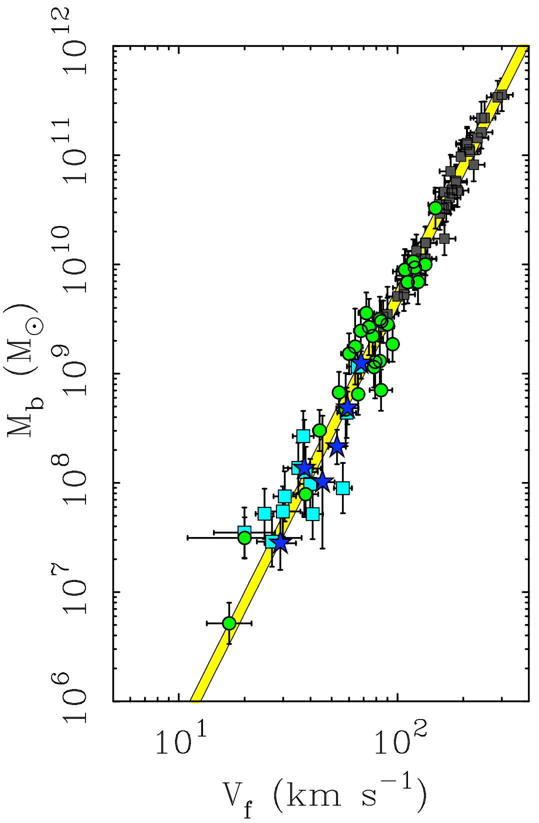
The observational Baryonic Tully-Fisher Relation

Famaey & McGaugh 2012



in Milgrom

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Consider *space-time scale invariance* :

(Milgrom 2009; Kroupa, Pawlowski & Milgrom 2012)

If $(t, x, y, z) \longrightarrow \lambda(t, x, y, z)$

$\Rightarrow$ $g^2 = a_o g_N$ or $a^2 = a_o g_N$

i.e. $\frac{a}{a_o} a = g_N$

Since $V^2 = (G a_0 M)^{\frac{1}{2}}$

$V_b^2 = \frac{GM}{r}$

$$\Rightarrow \left(\frac{V}{V_b}\right)^2 = \frac{(G a_0 M)^{\frac{1}{2}}}{r\frac{GM}{r^2}} = \frac{(G a_0 M)^{\frac{1}{2}}}{ra} = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$$

i.e. $\left(\frac{V}{V_b}\right)^2 = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$

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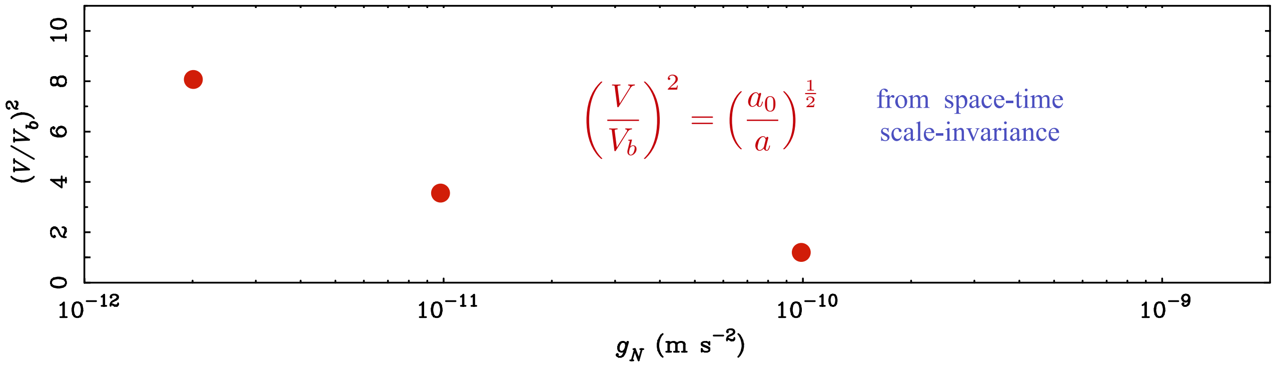
Mass-Discrepancy correlation with acceleration

The Sanders-McGaugh correlation explained



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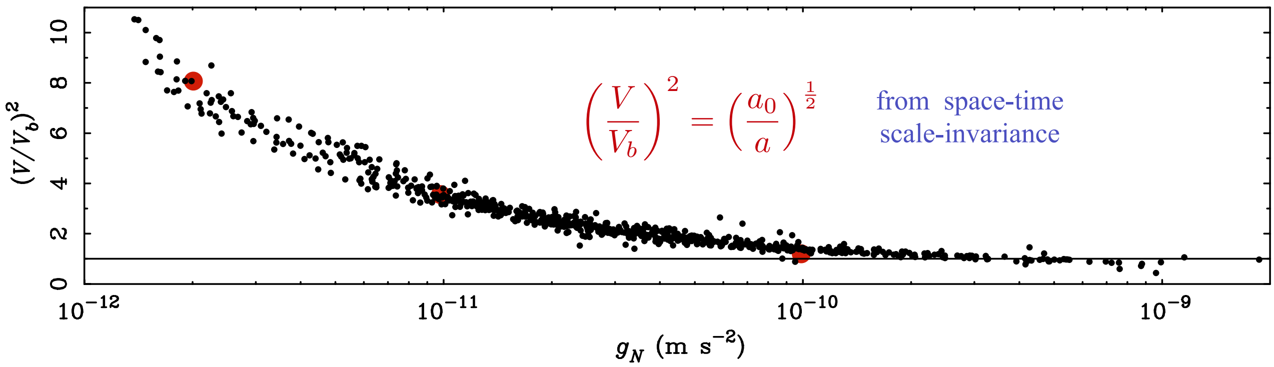
Mass-Discrepancy correlation with acceleration

The Sanders-McGaugh correlation explained



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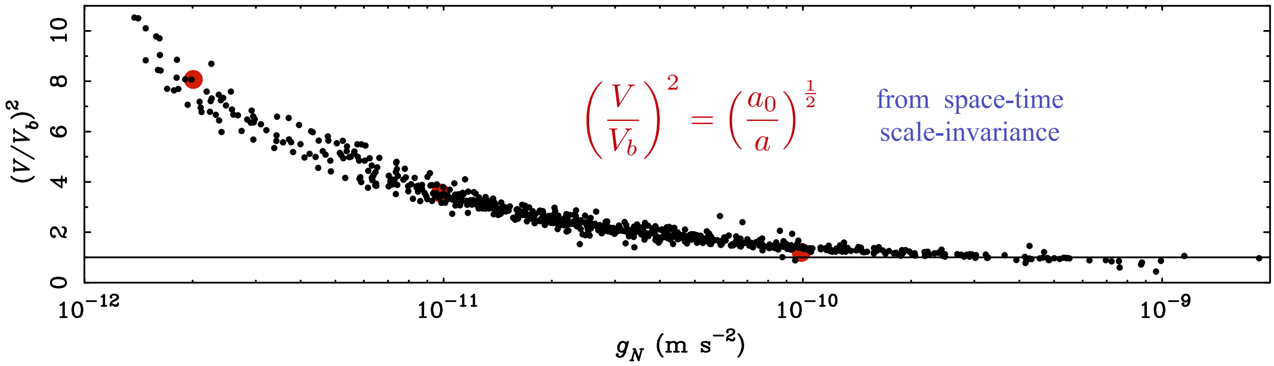
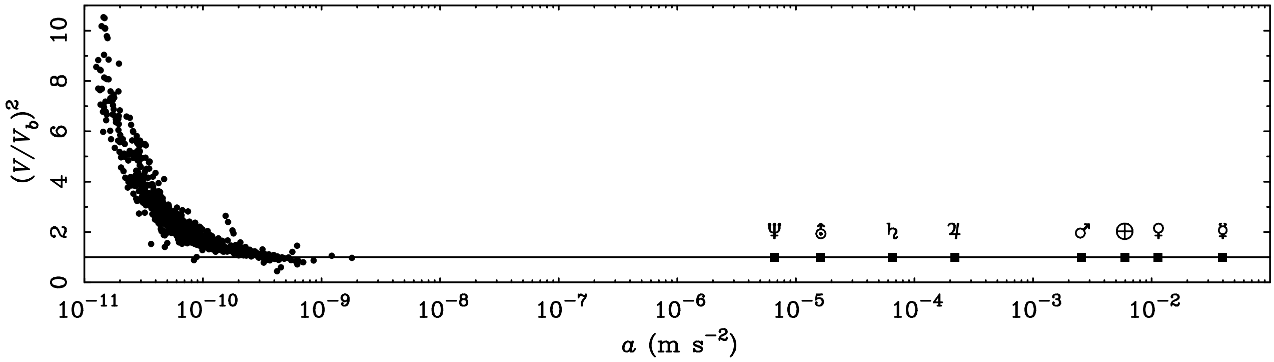
Mass-Discrepancy correlation with acceleration

The Sanders-McGaugh correlation explained





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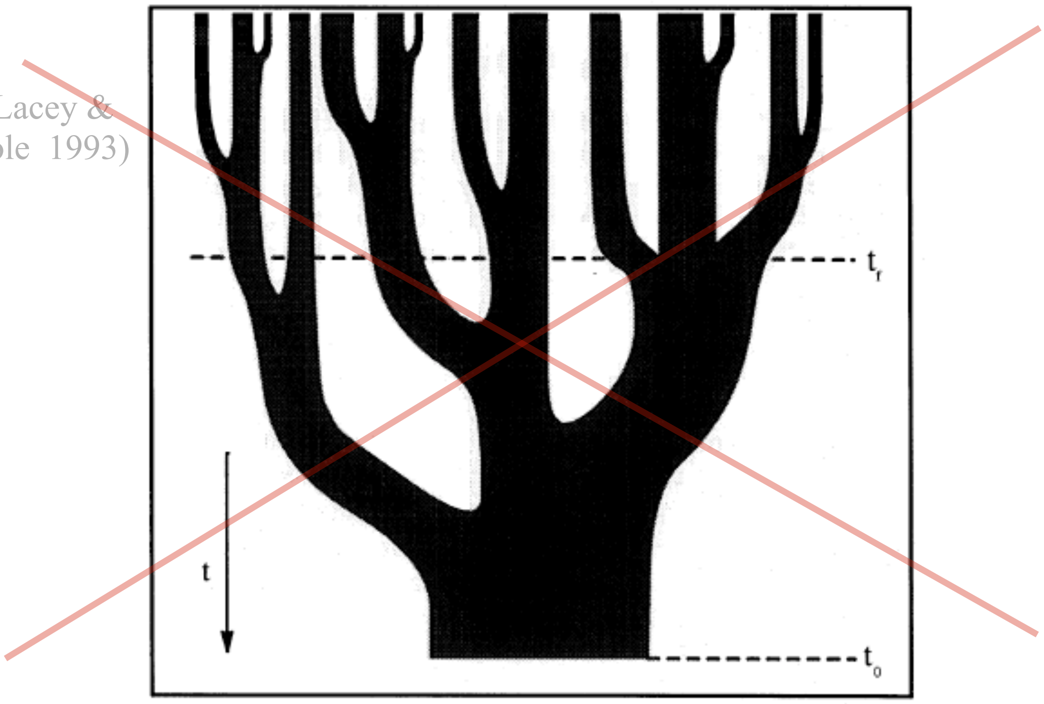
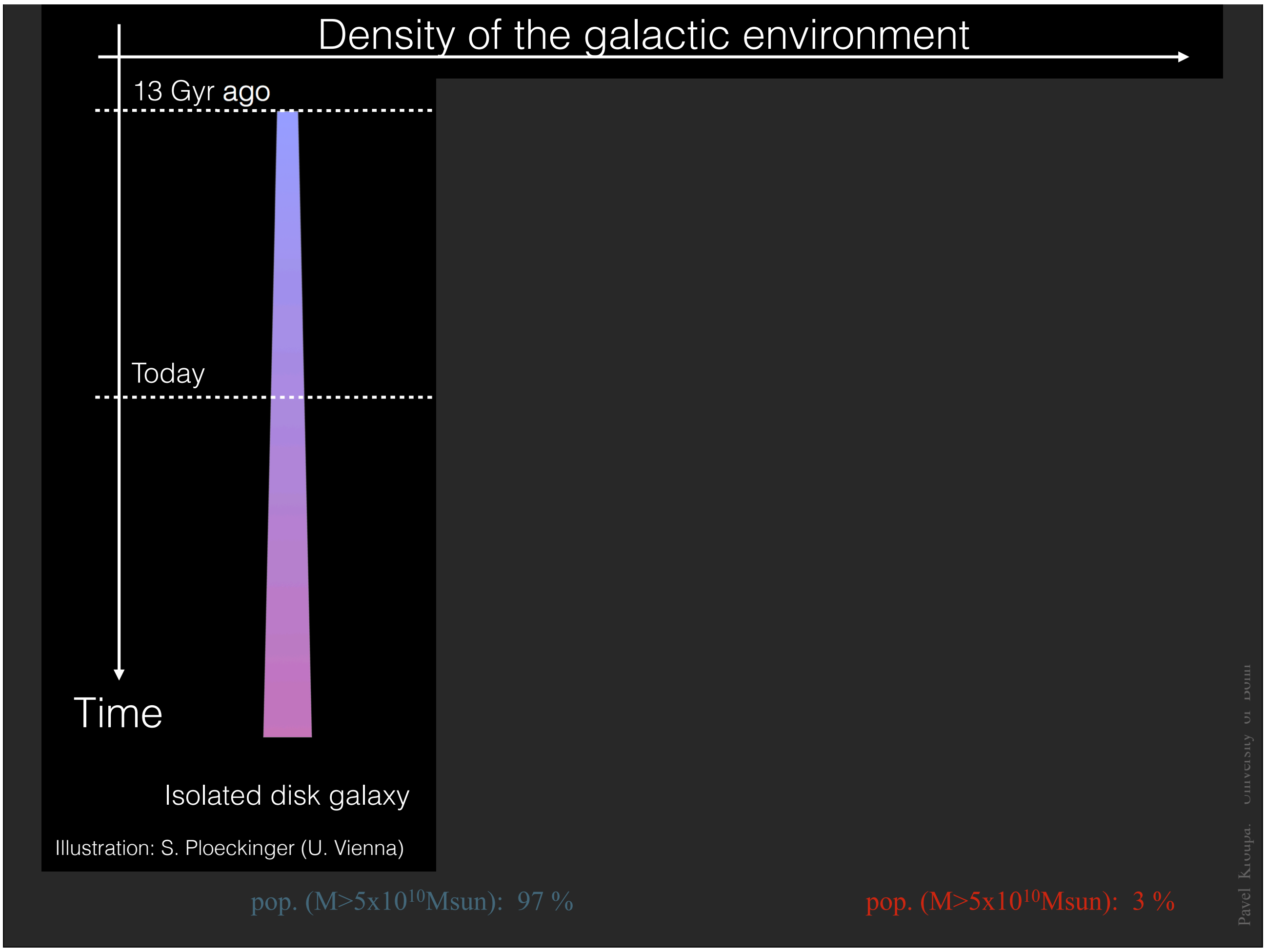
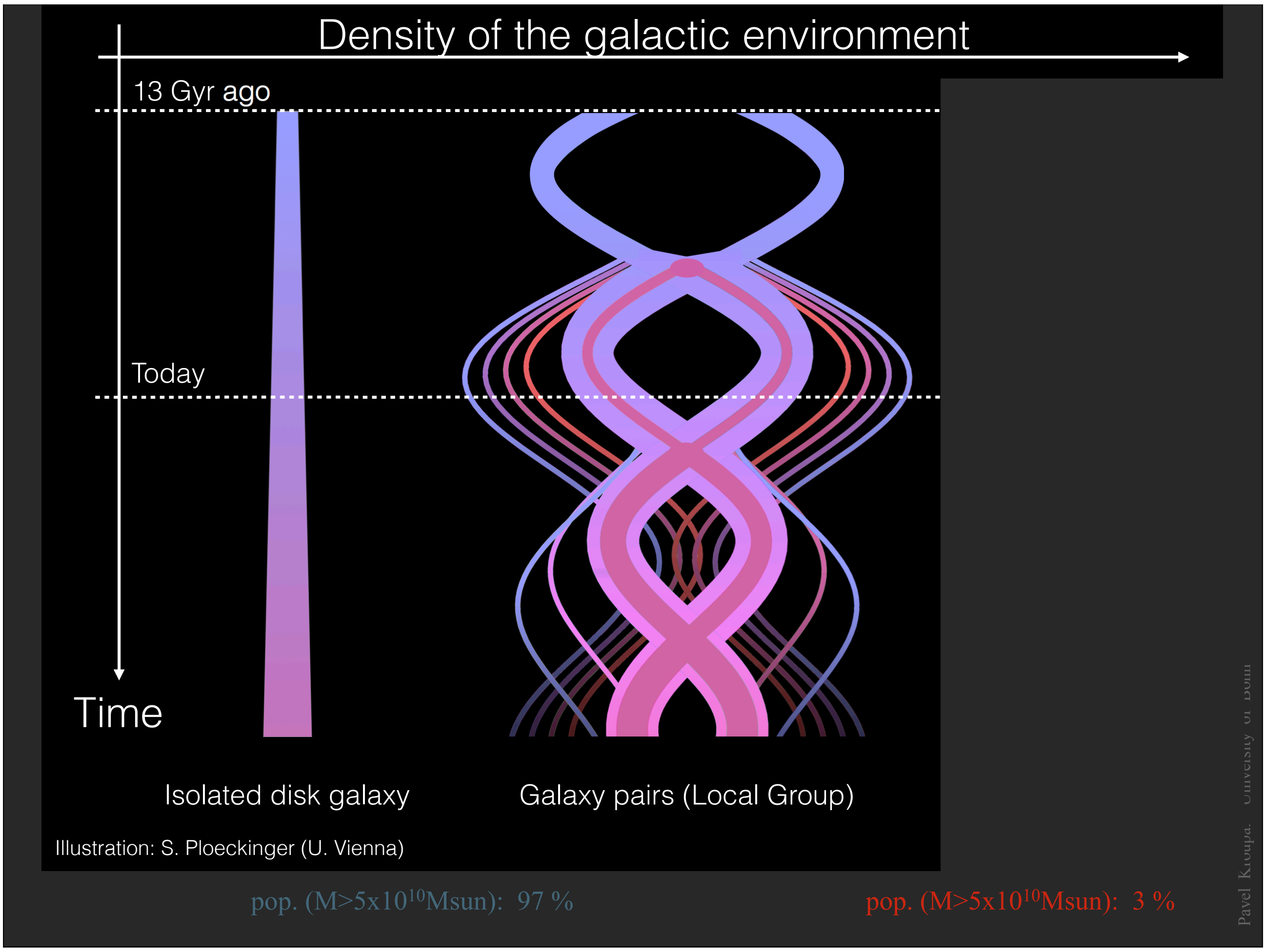
The Standard LCDM Model of Cosmology structure formation tree

(Lacey & Cole 1993)




Density of the galactic environment
13 Gyr ago
Today
Time
Isolated disk galaxy
Illustration: S. Ploeckinger (U. Vienna)
pop. (M>5x10^10Msun): 97 %
pop. (M>5x10^10Msun): 3 %


Density of the galactic environment
13 Gyr ago
Today
Time
Isolated disk galaxy
Galaxy pairs (Local Group)
Illustration: S. Ploeckinger (U. Vienna)
pop. (M>5x10^10Msun): 97 %
pop. (M>5x10^10Msun): 3 %

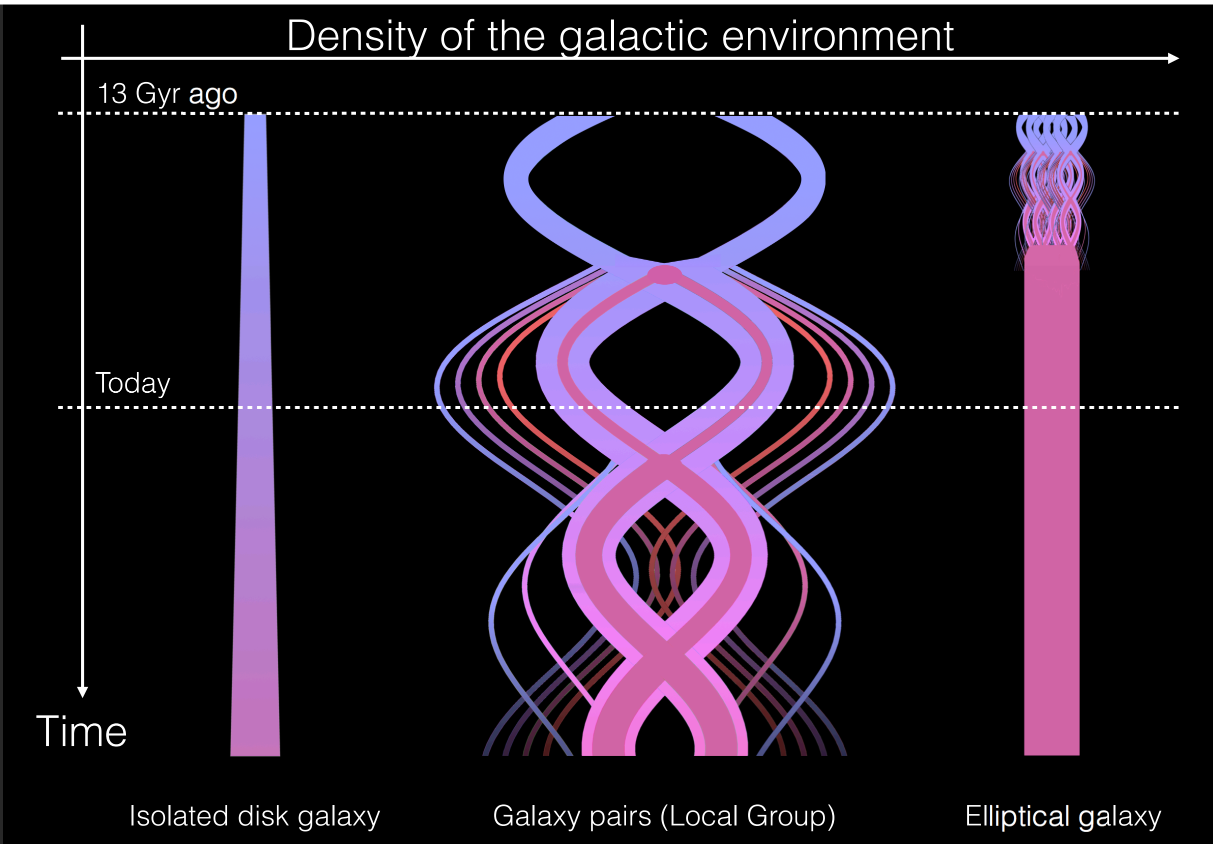


Illustration: S. Ploeckinger (U. Vienna)

pop. (M>5×10^{10}Msun): 97 %

pop. (M>5×10^{10}Msun): 3 %

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Conclusions

The astronomical data rather convincingly indicate that *dark matter particles cannot exist* such that they are dynamically relevant.

They are in any case not part of the SMoPP and they have not been found directly nor indirectly.

No DM ==> SMoC falsified

Therefore: Milgromian dynamics and PoR ...

Essentially all of the above problems are then solved trivially,

except LG symmetry and the "local" under-density.

And galaxies merge rarely .

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