Why cosmologically-relevant particle dark matter cannot exist

28.09.2016

Multi-Spin Galaxies 2016

Nizhnij Arkhyz (Russia)

26-30 September 2016

In celebration of the 50th anniversary of the
Special Astrophysical Observatory of the Russian Academy of Sciences

Pavel Kroupa

Helmholtz-Institute for Radiation und Nuclear Physics (HISKP)
University of Bonn

Astronomical Institute,
Charles University in Prague

c/o Argelander-Institut für Astronomie
University of Bonn

The Standard Modell of Cosmology (SMoC) :

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

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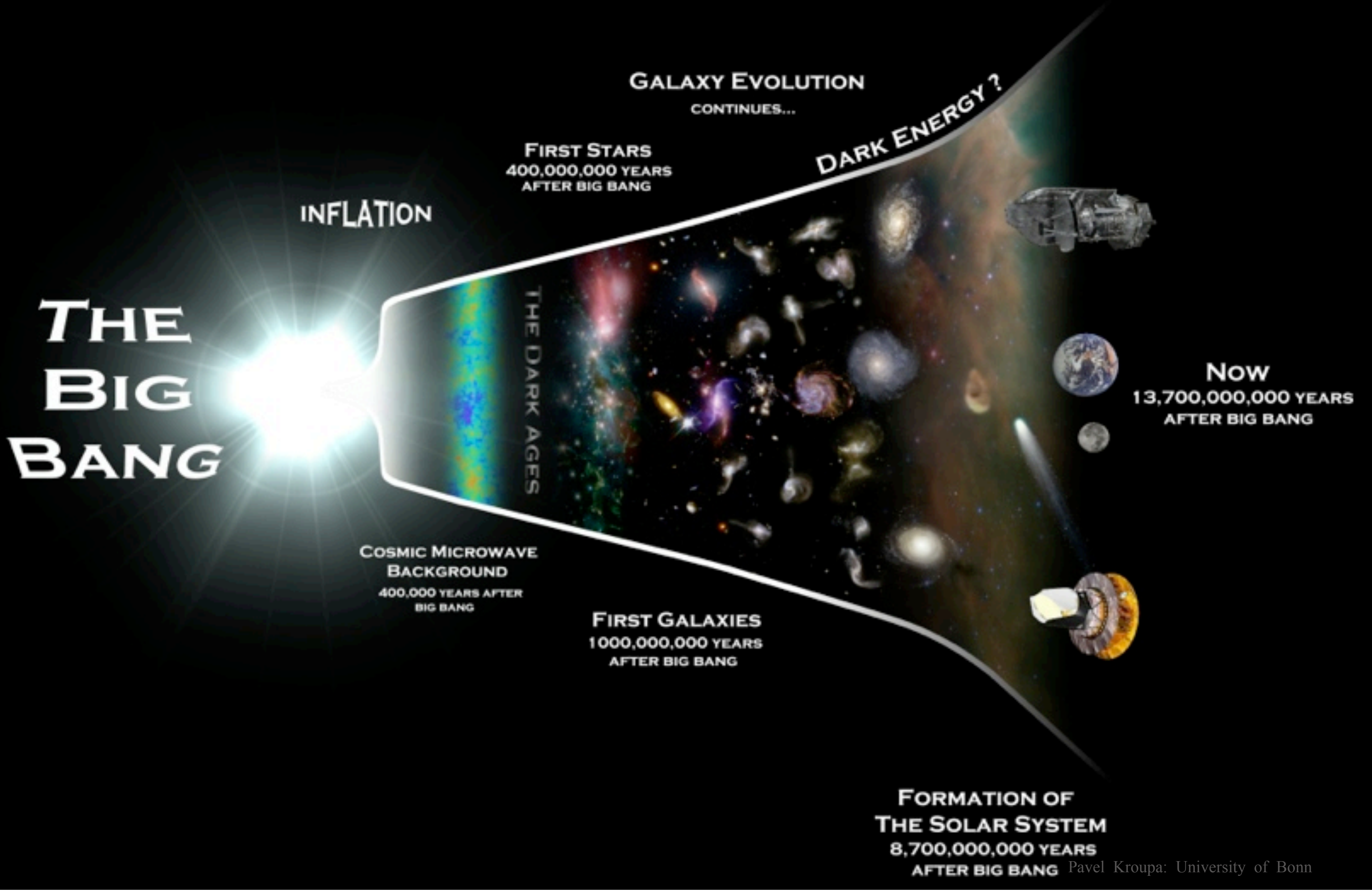

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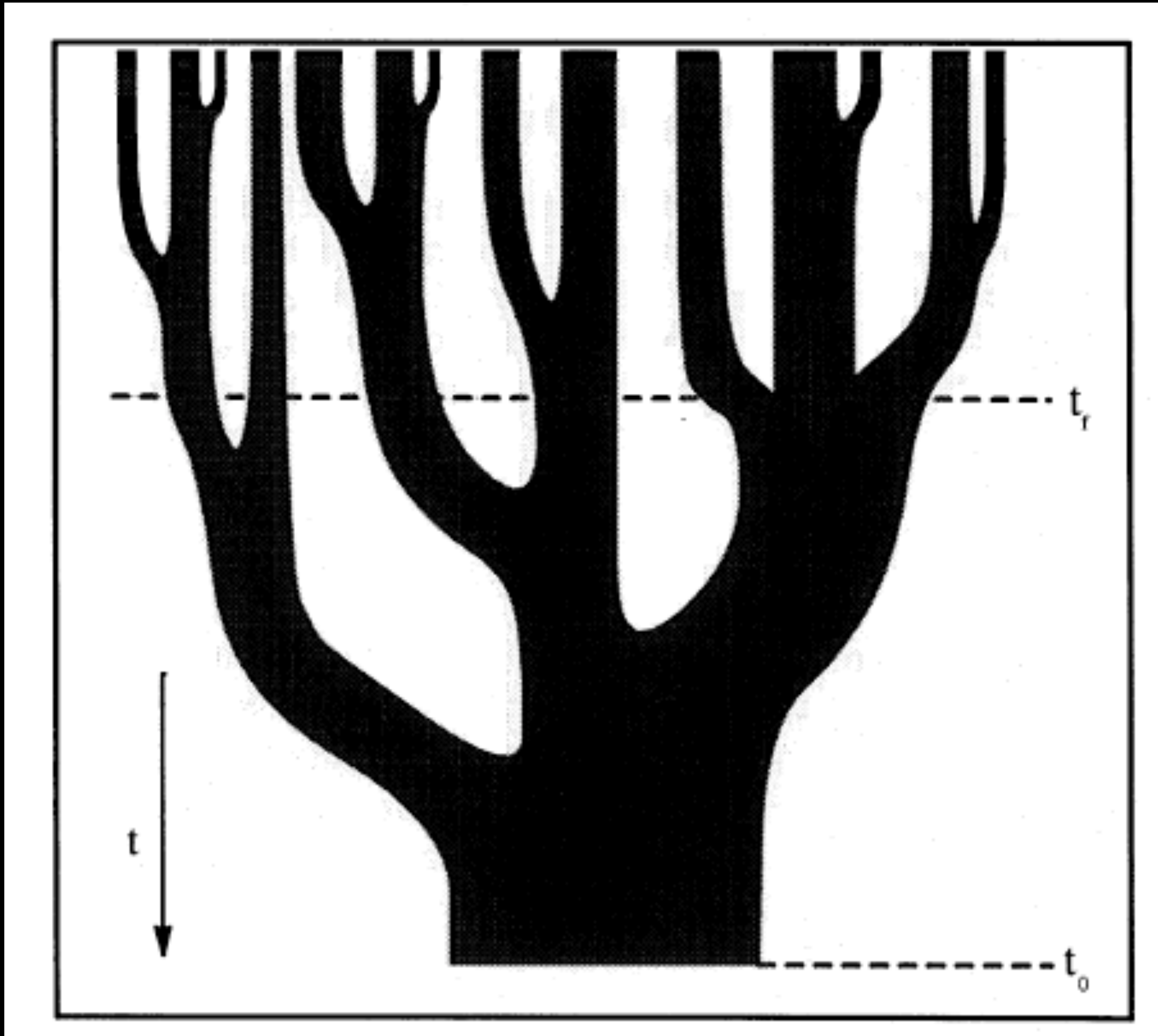
The SMoC leads to the wrong arrangement of matter on virtually all accessible scales

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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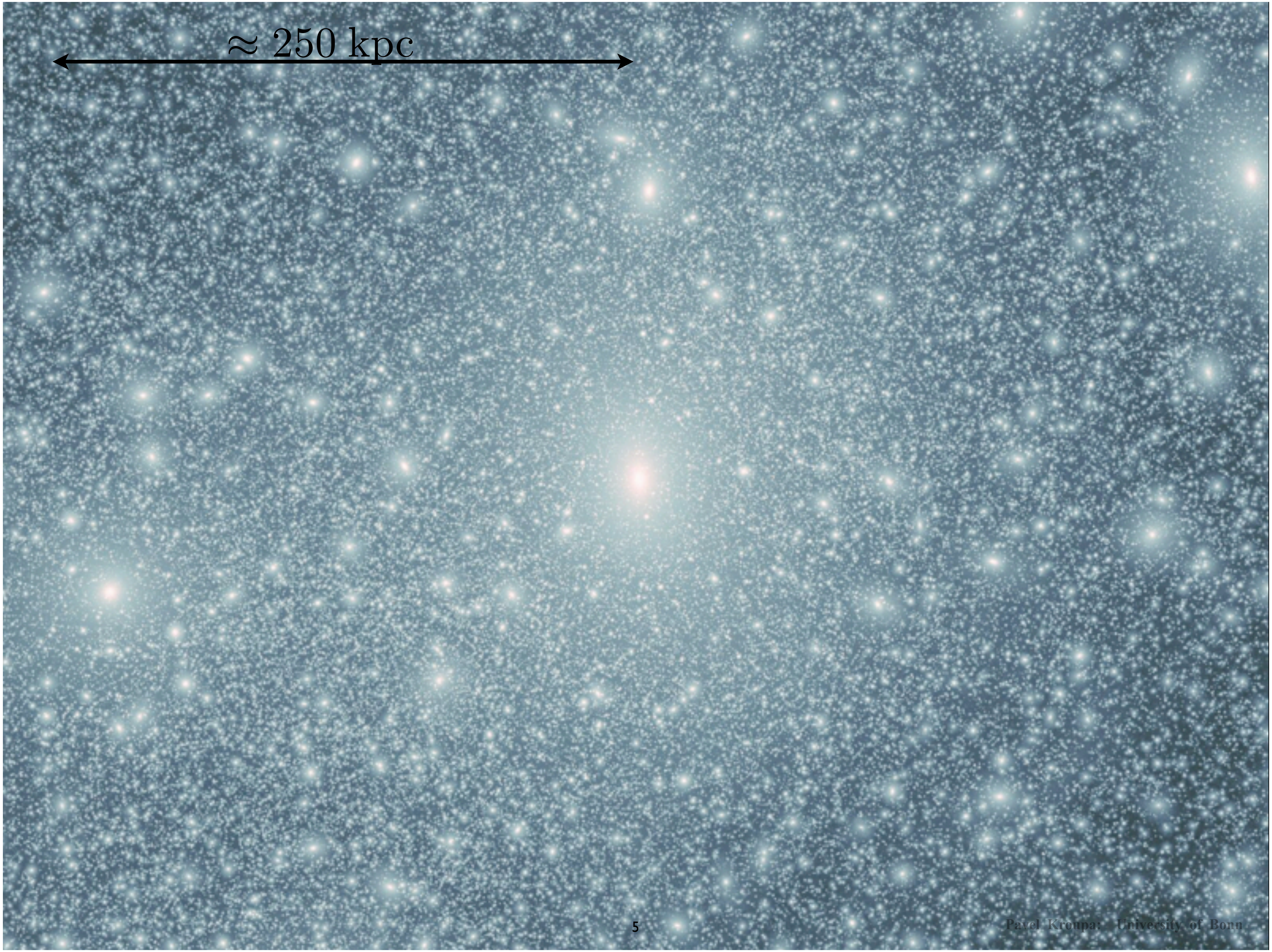
≈ 250 kpc
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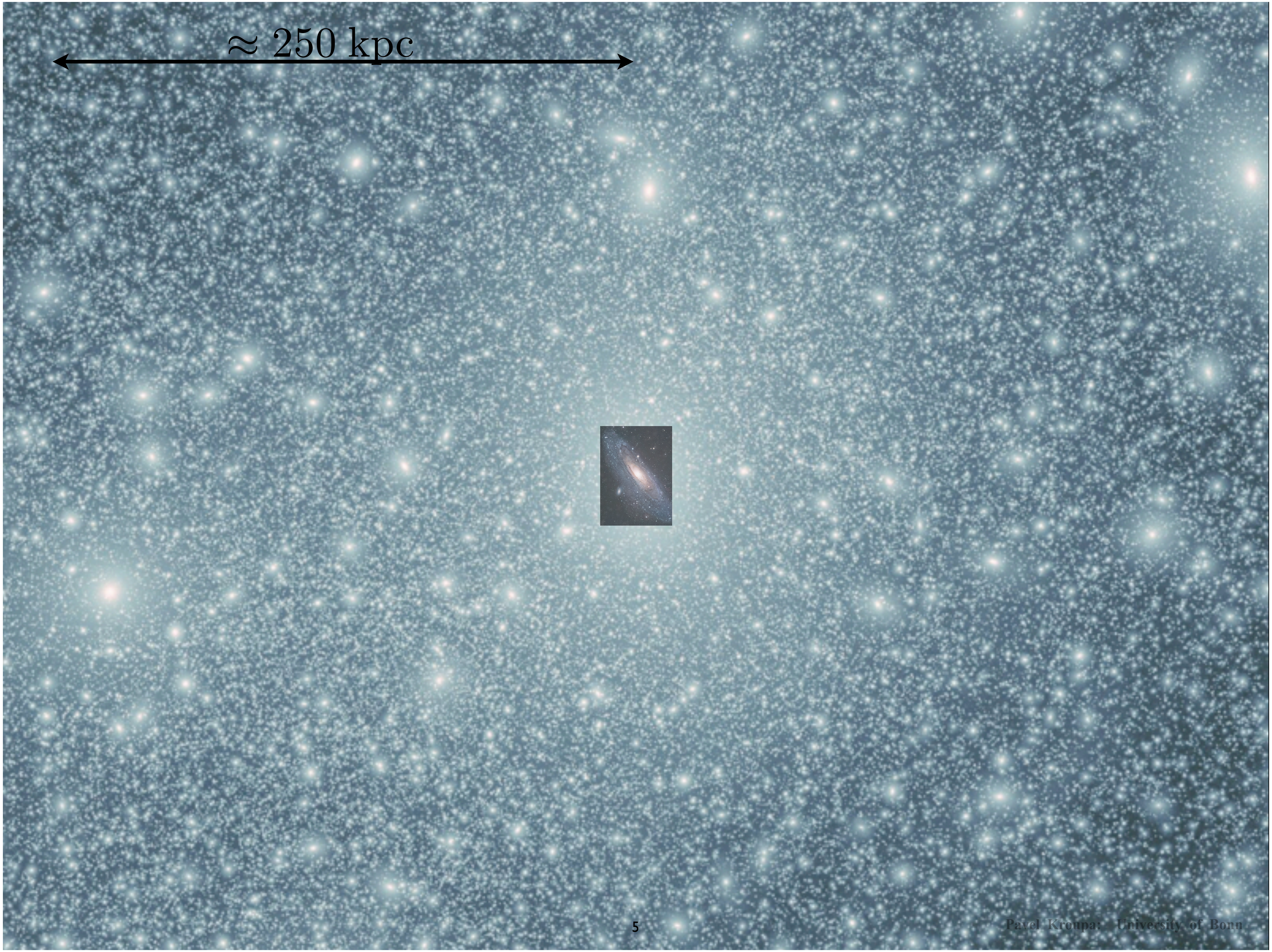
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(Kroupa et al. 2005; Pawlowski, Pflamm-Altenburg & Kroupa 2012, Ibata et al. 2013
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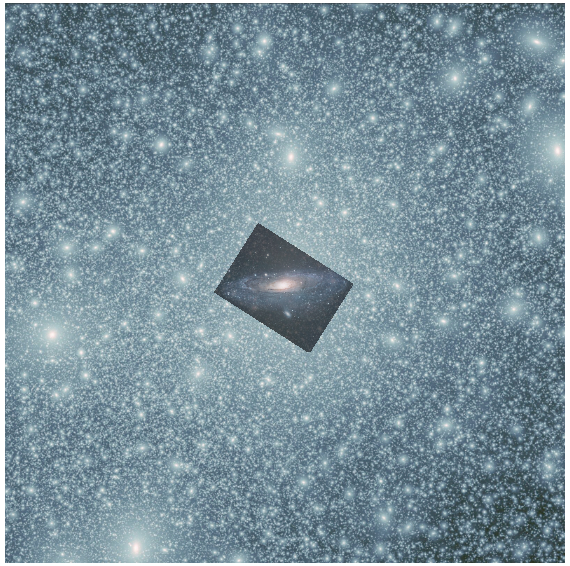
Everything we know about the Local Group today



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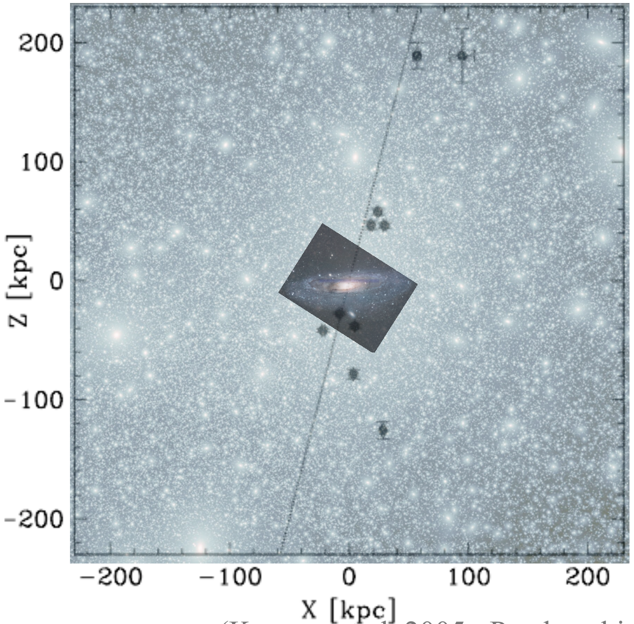

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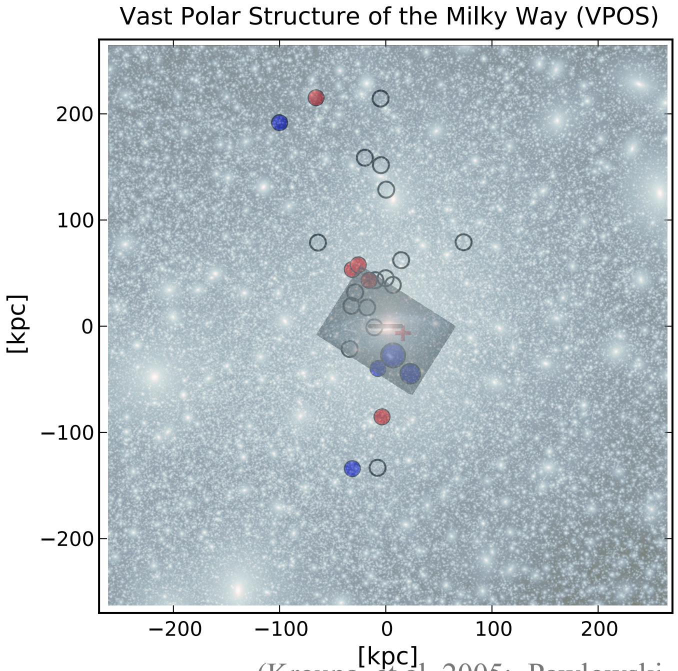

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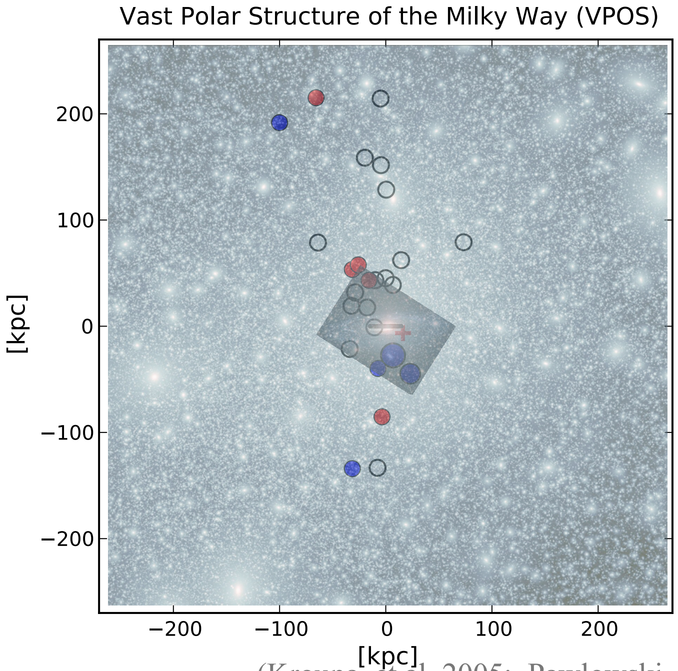

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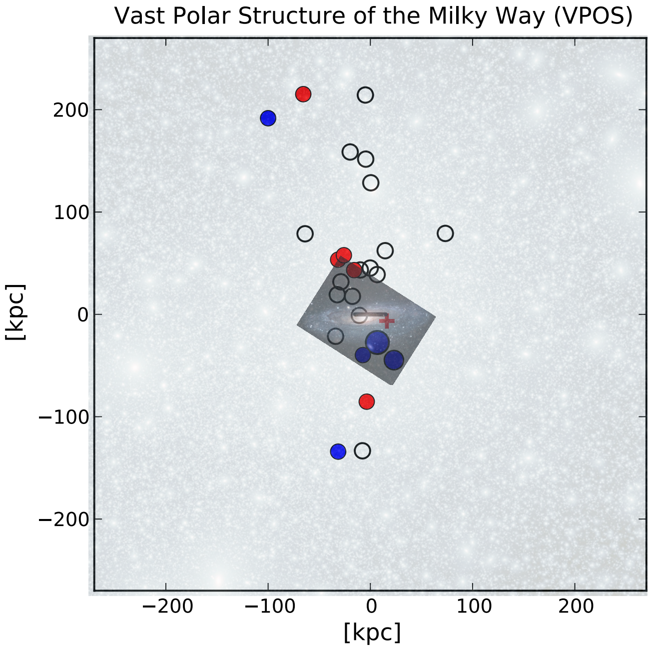

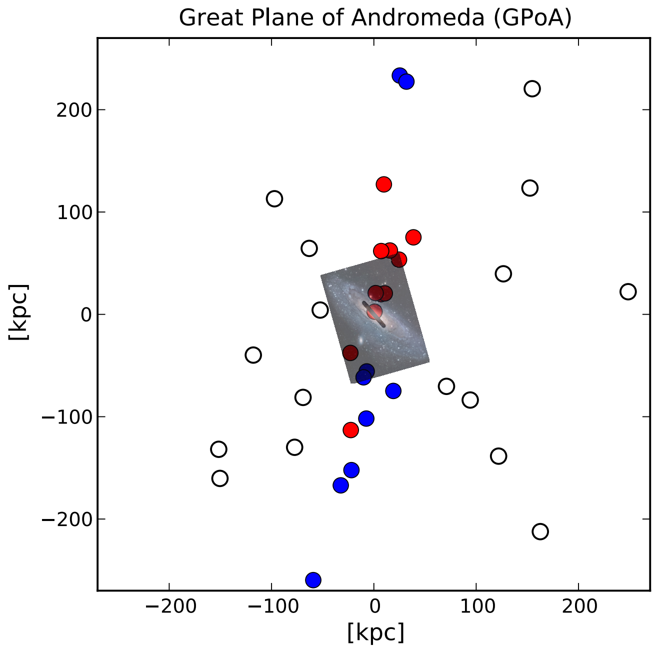

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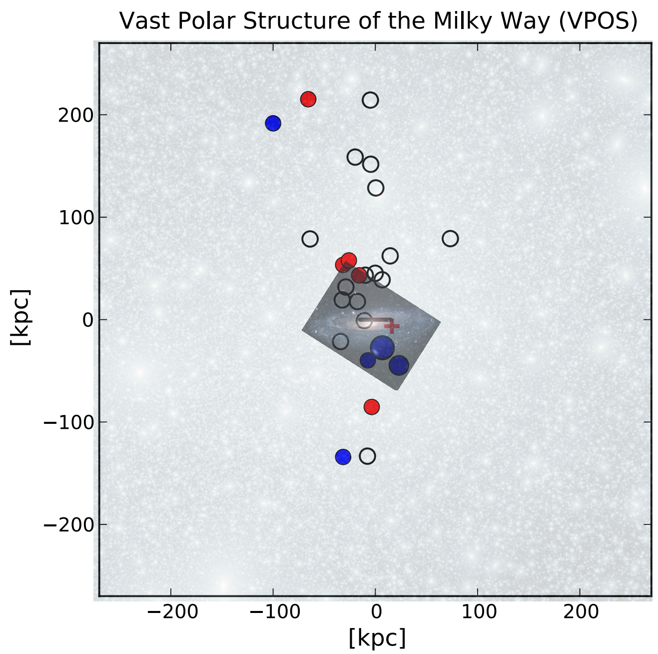

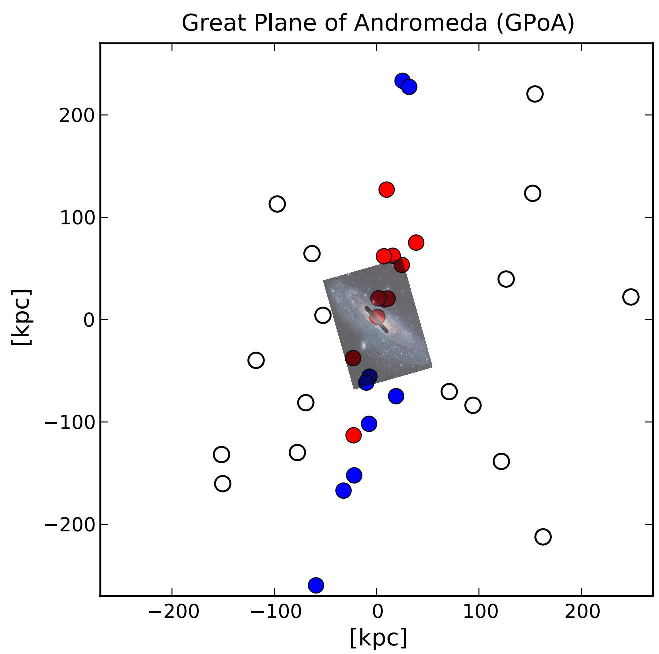

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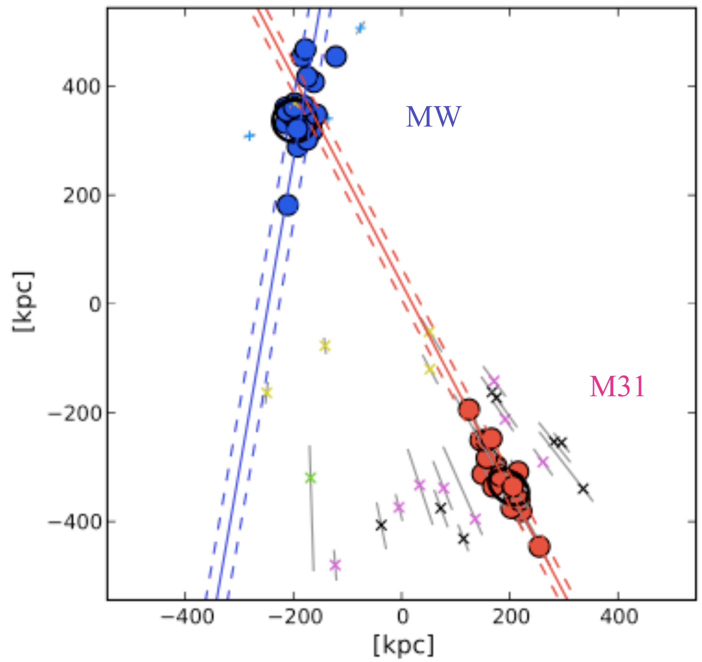

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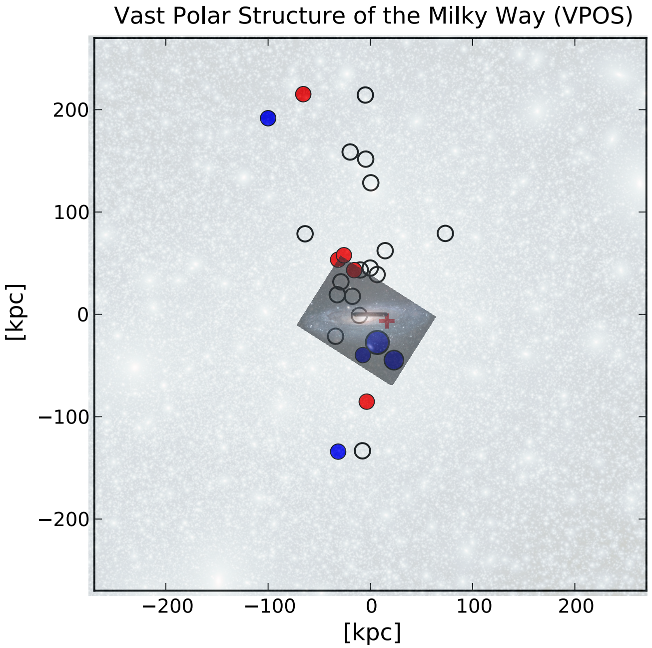

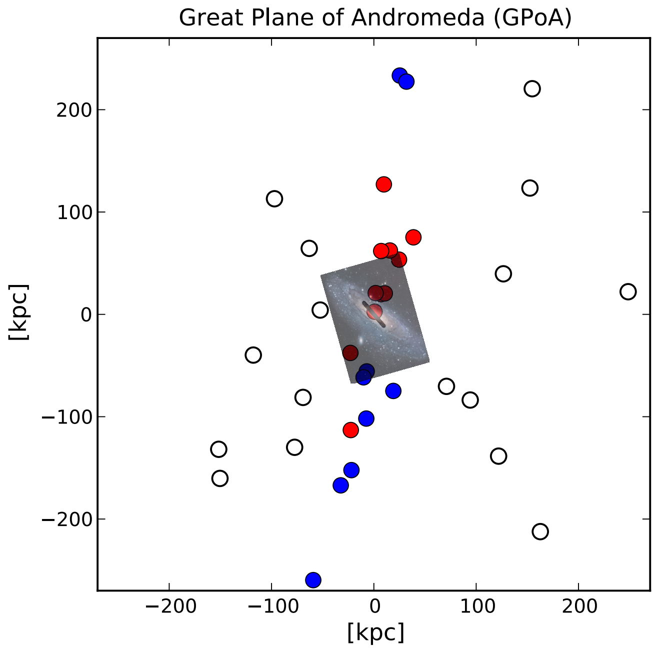

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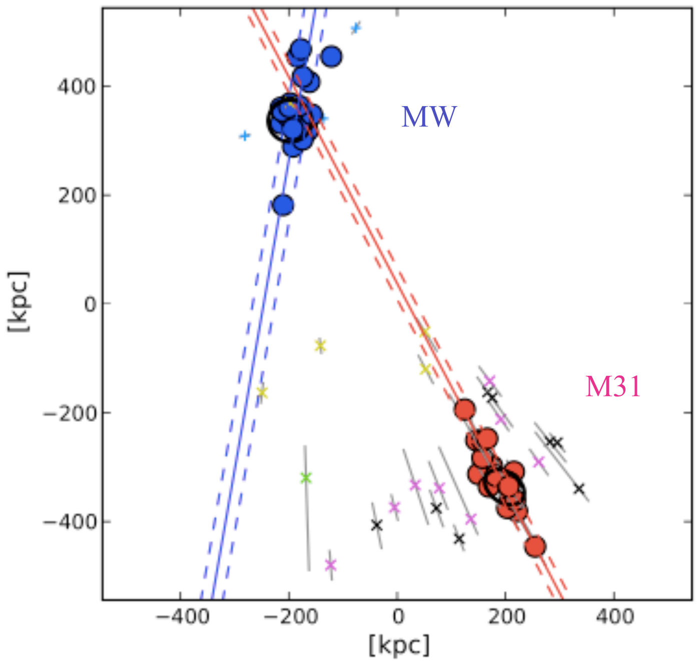

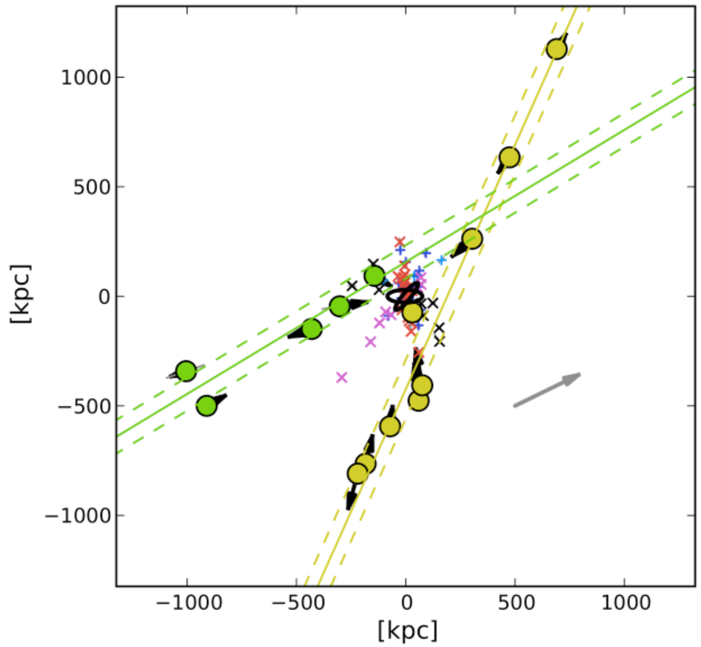

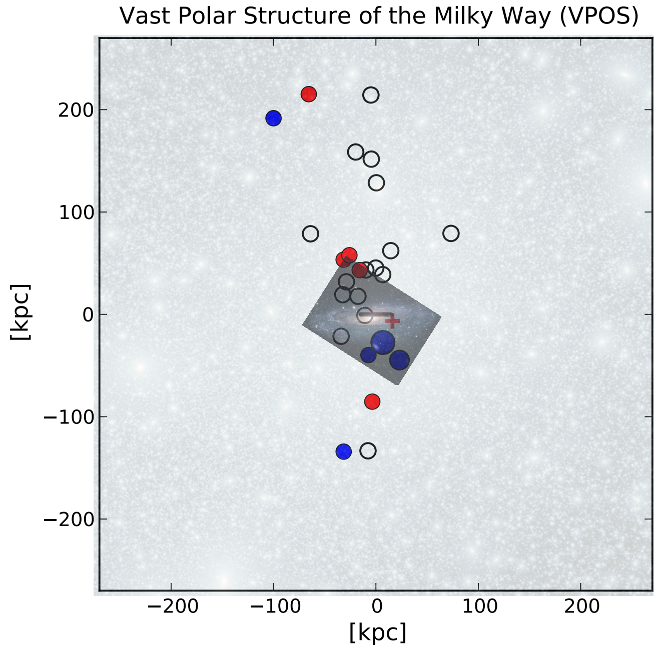

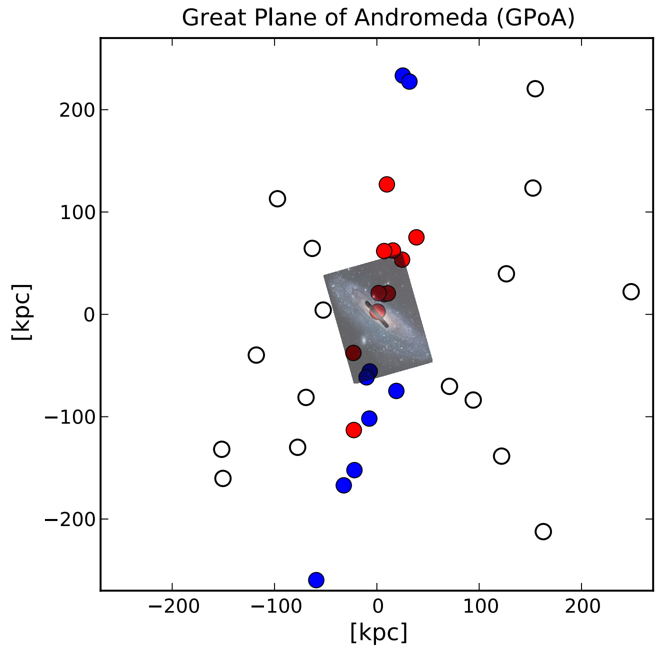

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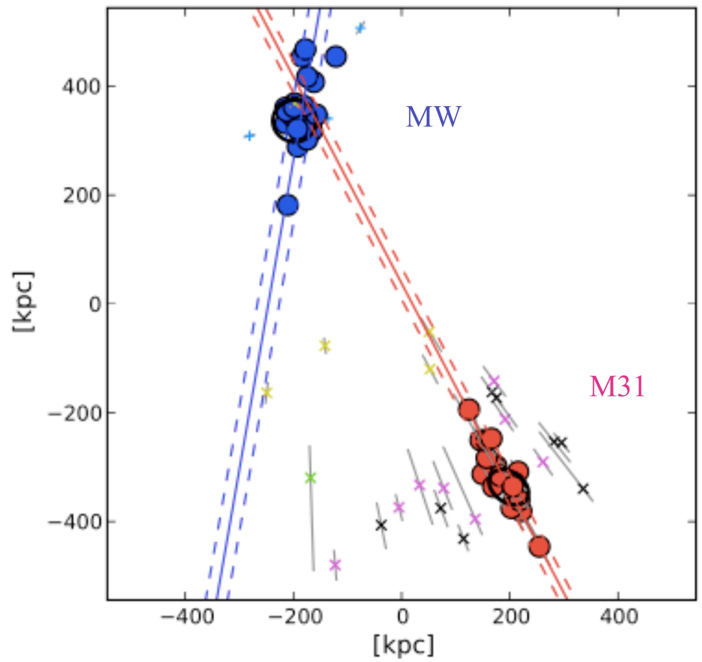
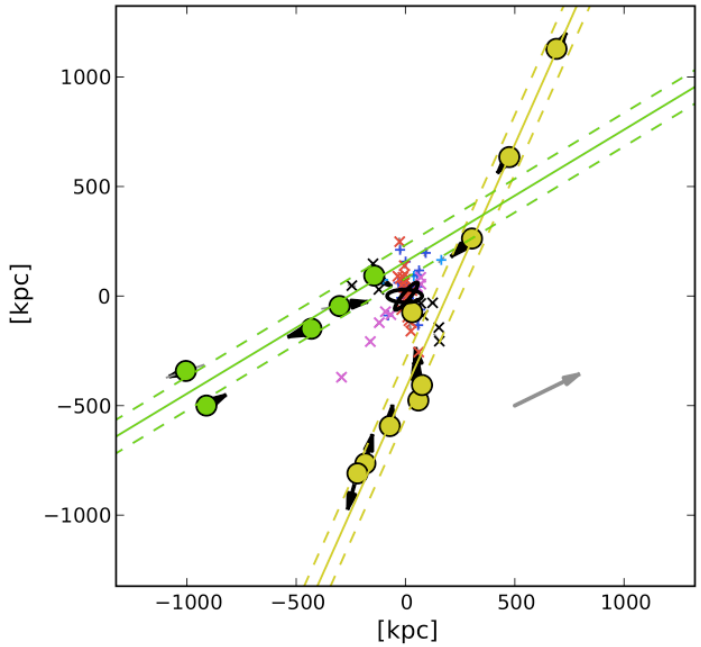
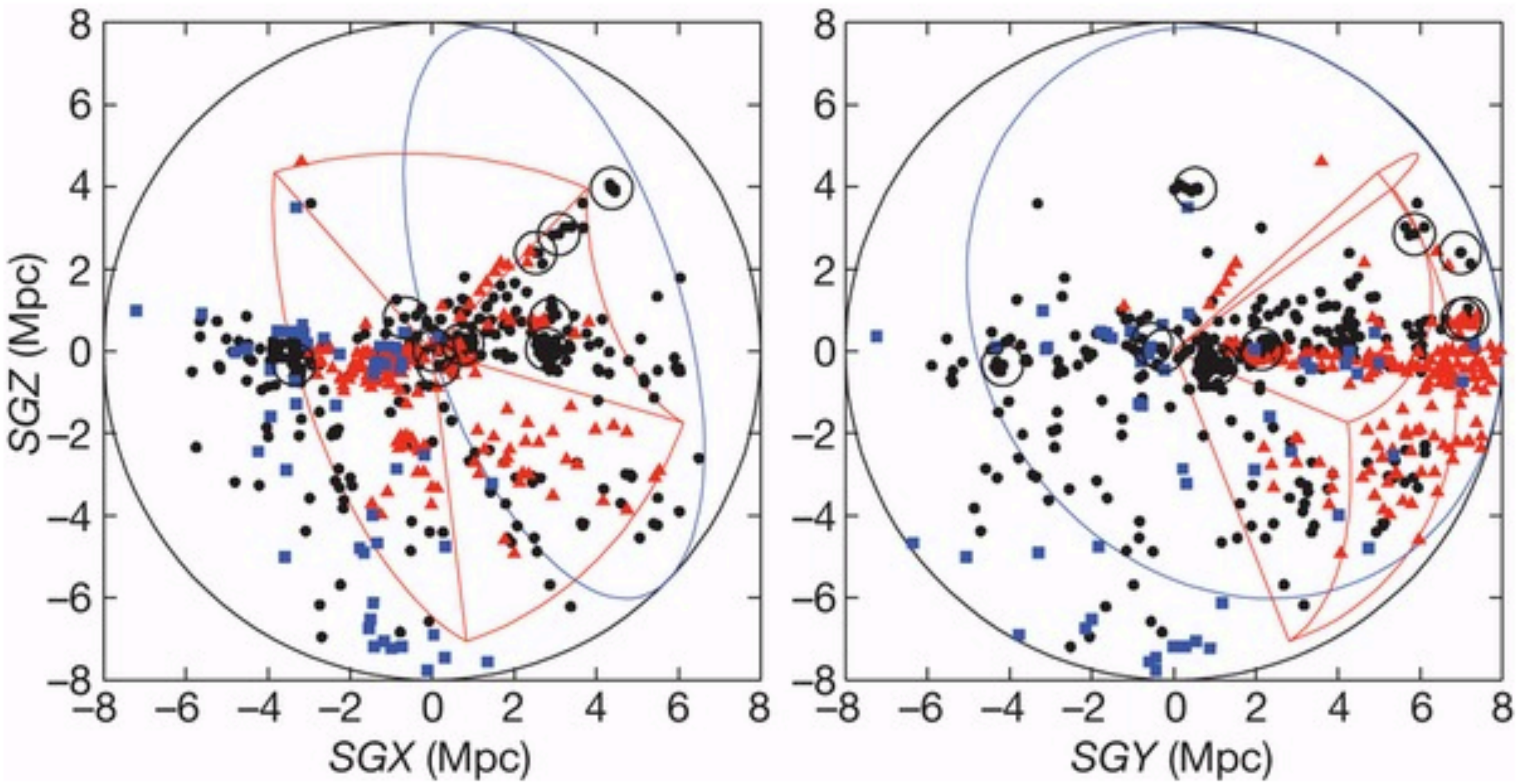




a frightening symmetry !

Figure 1: Galaxies at radial distances 1 < *D* < 8 Mpc from the centre of the Local Group of galaxies.



Peebles & Nusser 2010, Nature

The Local Sheet is the concentration along the centre plane, and the Local Void is the region on the upper left in the left-hand projection. The ten most luminous galaxies (including M31 and the Milky Way at *D* < 1 Mpc) are indicated by the open circles. The orthogonal projections are plotted in supergalactic coordinates. Black filled circles: 337 galaxies largely discovered on photographic plates and with well-measured distances. Red triangles: 172 galaxies added by the Sloan Digital Sky Survey (SDSS), with redshift errors of less than 50 km s^{-1}. Blue squares: 53 galaxies discovered by the H i Parkes All Sky Survey (HIPASS) from 21-cm emission by atomic hydrogen. SDSS and HIPASS have less secure redshift distances and cover only the parts of the sky roughly indicated by the red and blue curves, respectively. There are many more dwarf galaxies to be discovered at this distance.

Peebles & Nusser 2010, Nature :

Local void is too empty => "We conclude that there is a good case for *inconsistency between the theory and our observations* of galaxies in the Local Void."

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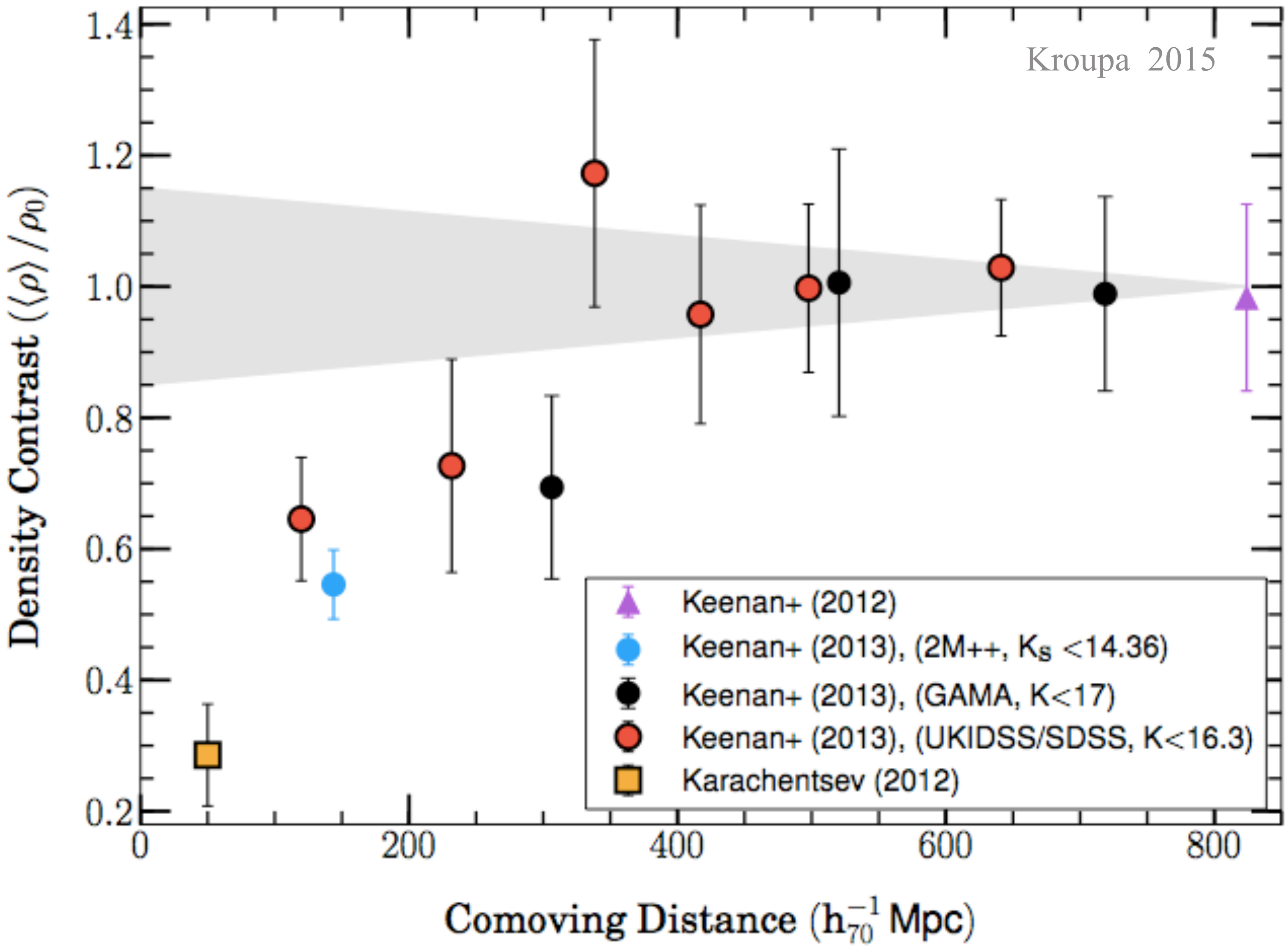
Large / massive galaxies too far from sheet **:**

"Among the ten most luminous galaxies in Fig. 1, the spirals **M51**, **M101** and **NGC 6946** are respectively 2.4, 2.8 and 4.0 Mpc above the centre plane of the Local Sheet. They are in an uncrowded region: of the 562 known galaxies with 1 < D < 8 Mpc, only 5.0% are more than 2 Mpc above the Local Sheet (whereas 73% of the known galaxies are within 2 Mpc of the plane and the rest are below the plane). However, 30% of the largest galaxies are more than 2 Mpc above the Local Sheet. *If galaxy luminosities were randomly assigned, this situation would have a 1% probability, but the probability is less than this in the standard picture of the cosmic web, in which more-luminous galaxies avoid less dense regions.* These three could not be dwarfs masquerading as large galaxies; their circular velocities indicate the central masses of large galaxies. That is, the presence of these three large galaxies in the uncrowded region above the Local Sheet is real, and at well below 1% probability *it is an unlikely consequence of standard ideas*."

Measured matter density as a function of distance



12

. . . wherever we look
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. . . there is more structure with
more regularities . . .

As an aside:
evidence for anisotropic cosmic expansion
(a possible violation of the *cosmological principle*)

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Subdivide SN1a sky
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Alignment with CMB anomalies !!

Javanmardi et al. (2015, ApJ)

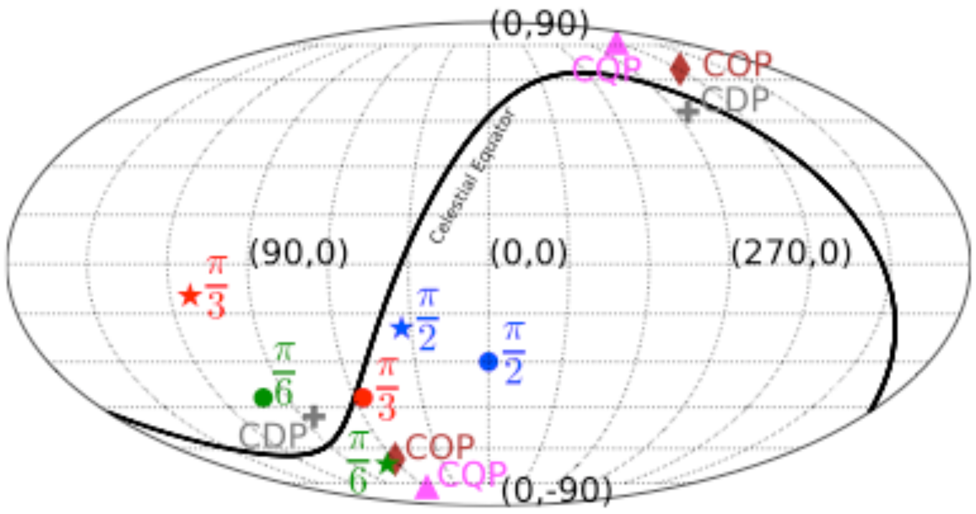

Figure 6. Most (star) and second-most (circle) discrepant directions in the magnitude–redshift relation of SNe Ia (for three cone opening angles $\theta = \frac{\pi}{2}, \frac{\pi}{3}$, and $\frac{\pi}{6}$) obtained in this work are compared with the directions of the CMB dipole (CDP), quadrupole (CQP), and octopole (COP) from the Planck Collaboration et al. (2014a). The black solid curve denotes the celestial equator.

A direct test for the existence of dark matter particles :

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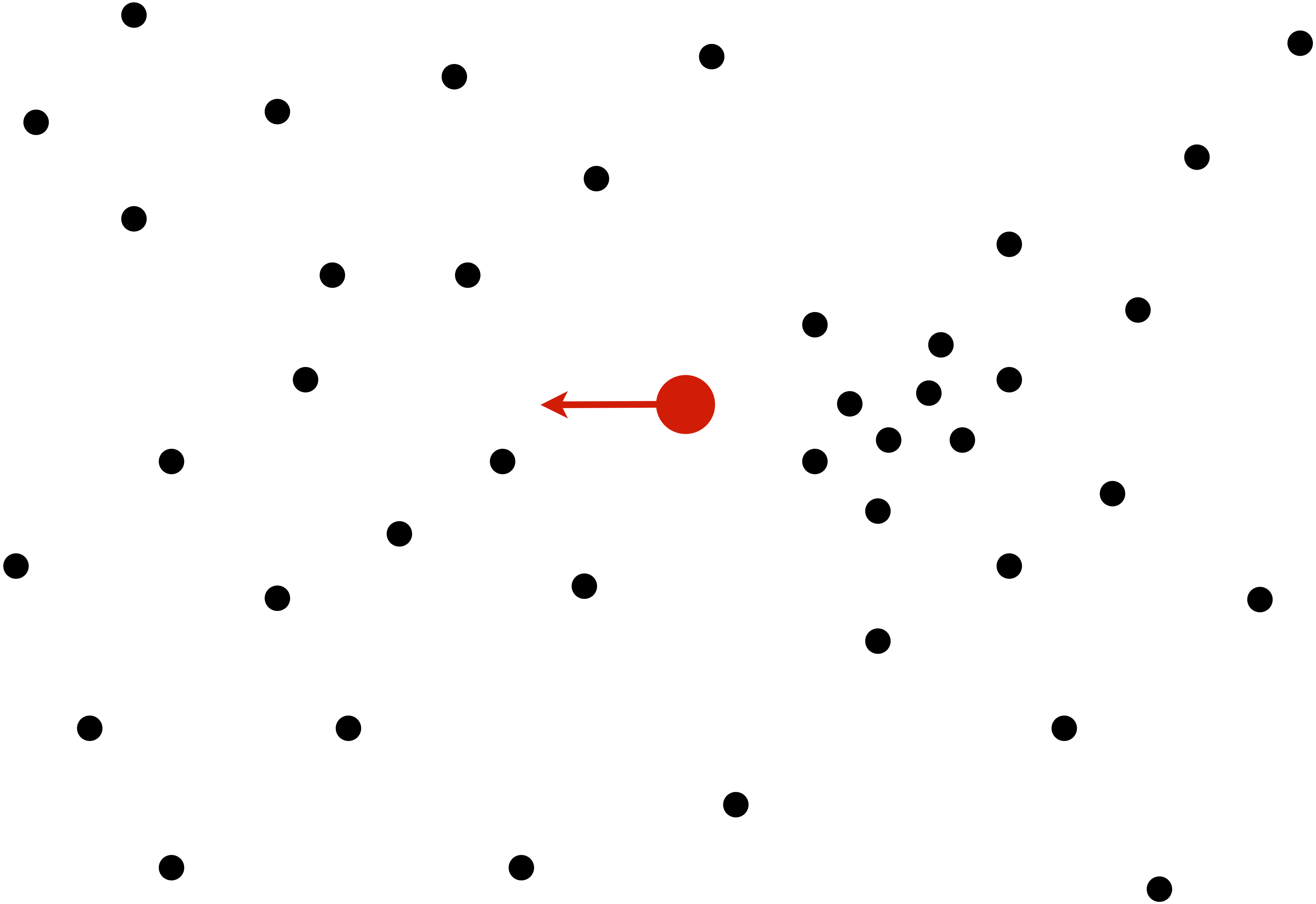
Dynamical Friction

Visualisation



This implies . . .

Dynamical friction : galaxy mergers - must be common

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

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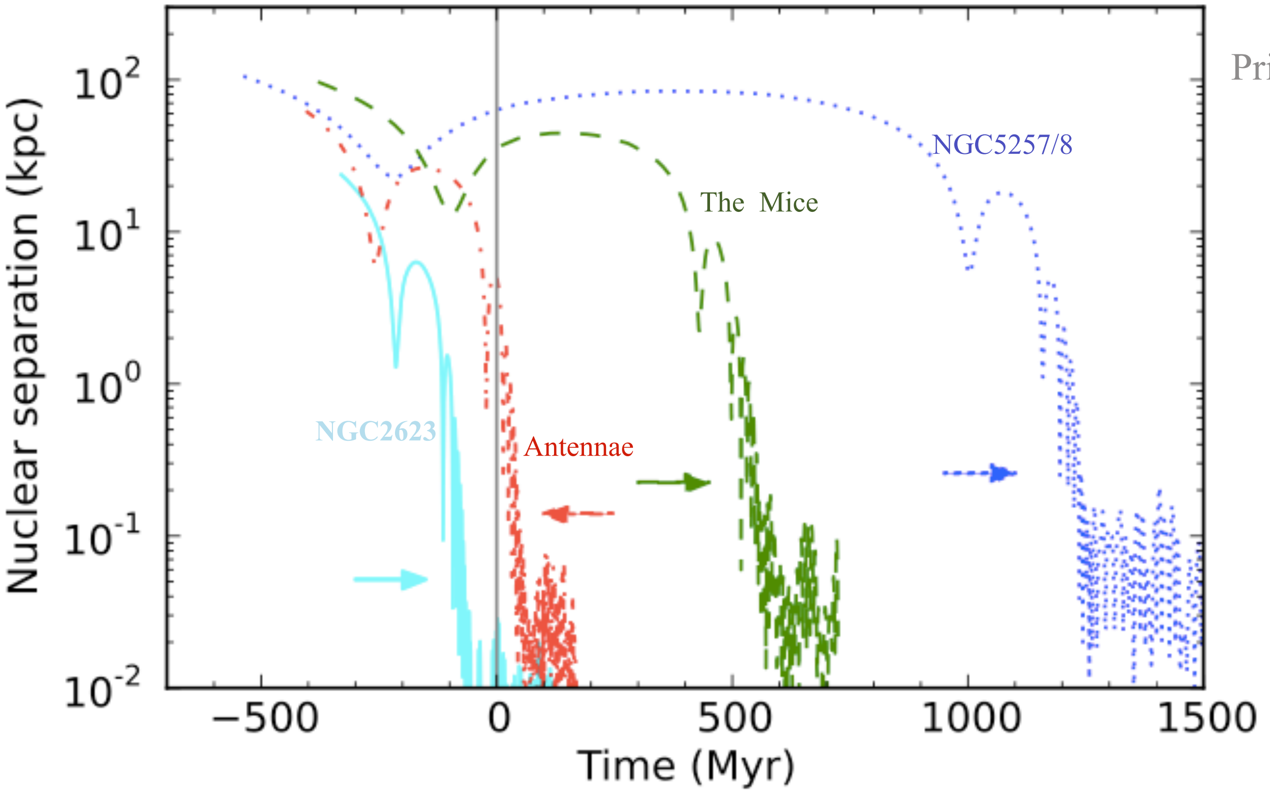

Privon, Barnes et al. 2013

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.

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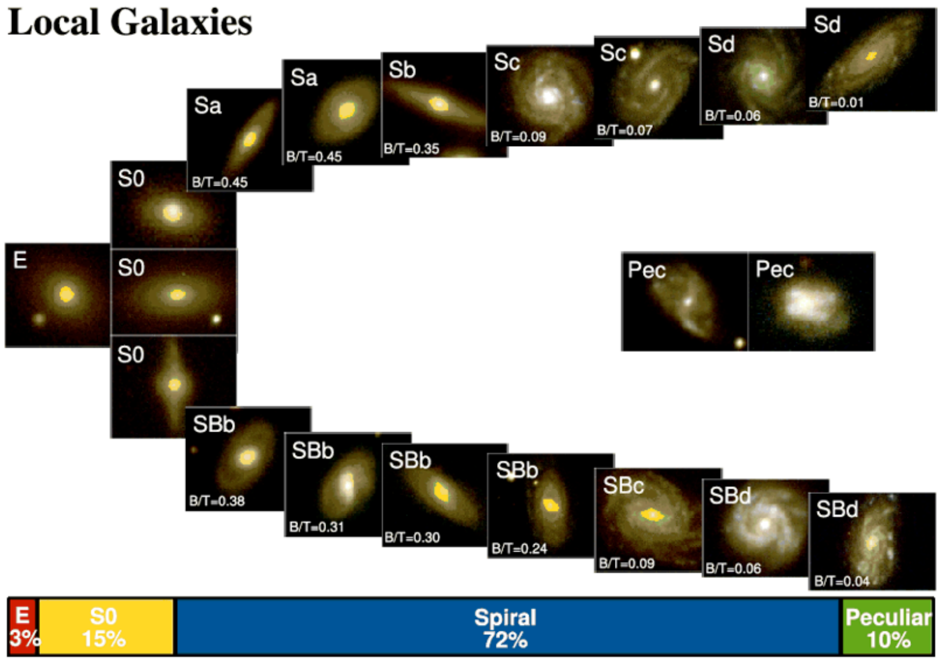
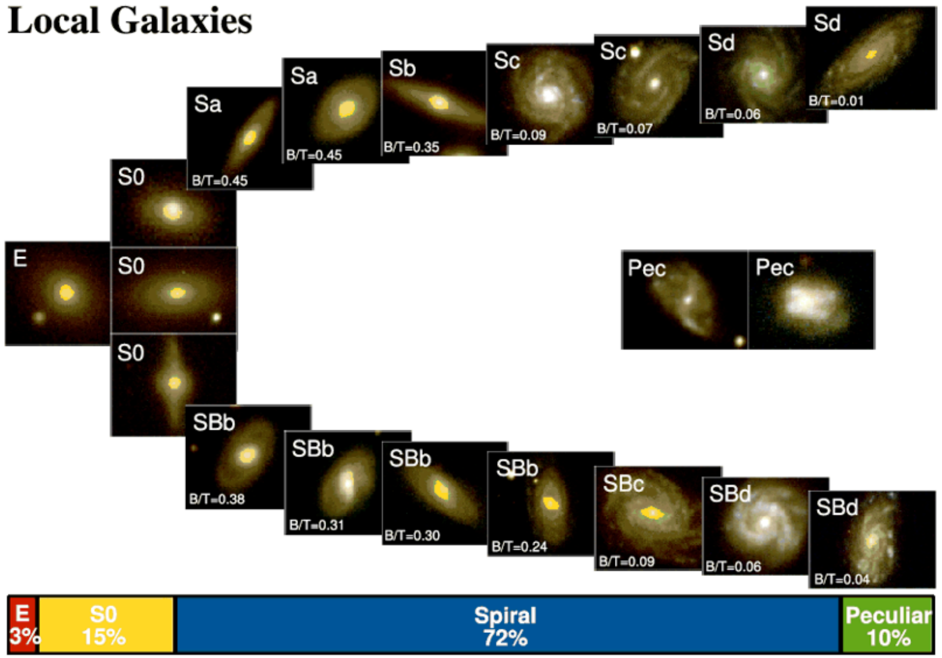


Ratio of E to other galaxies unchanging ?

Delgado-Serrano et al. (2010)

Galaxy mass in baryons
> 1.5×10^{10} Msun

6 Gyr ago



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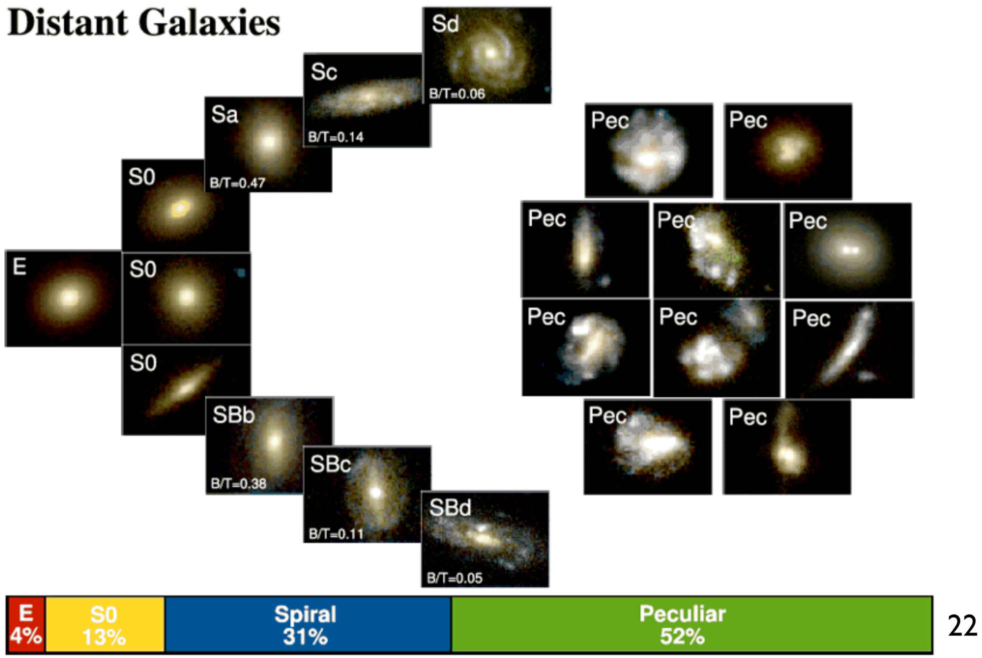

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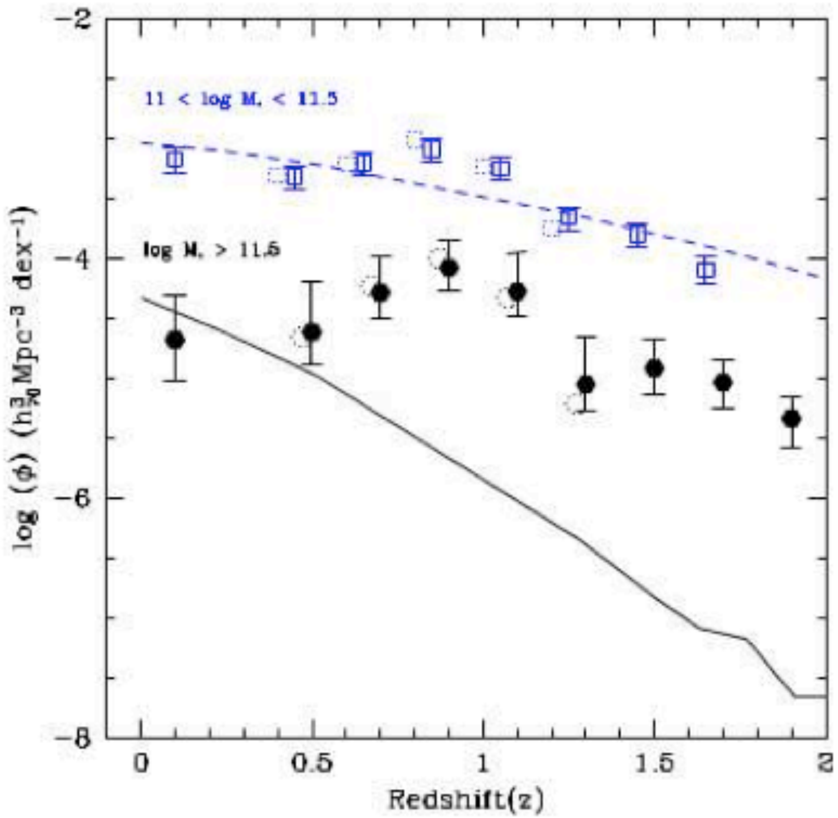
Conselice 2012



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

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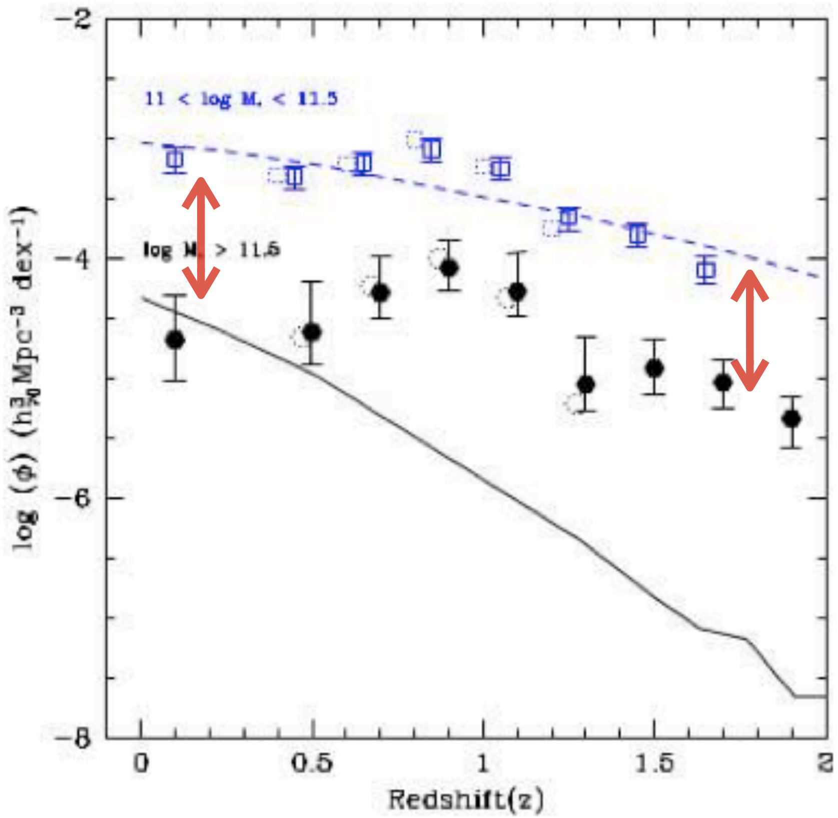

observations

23

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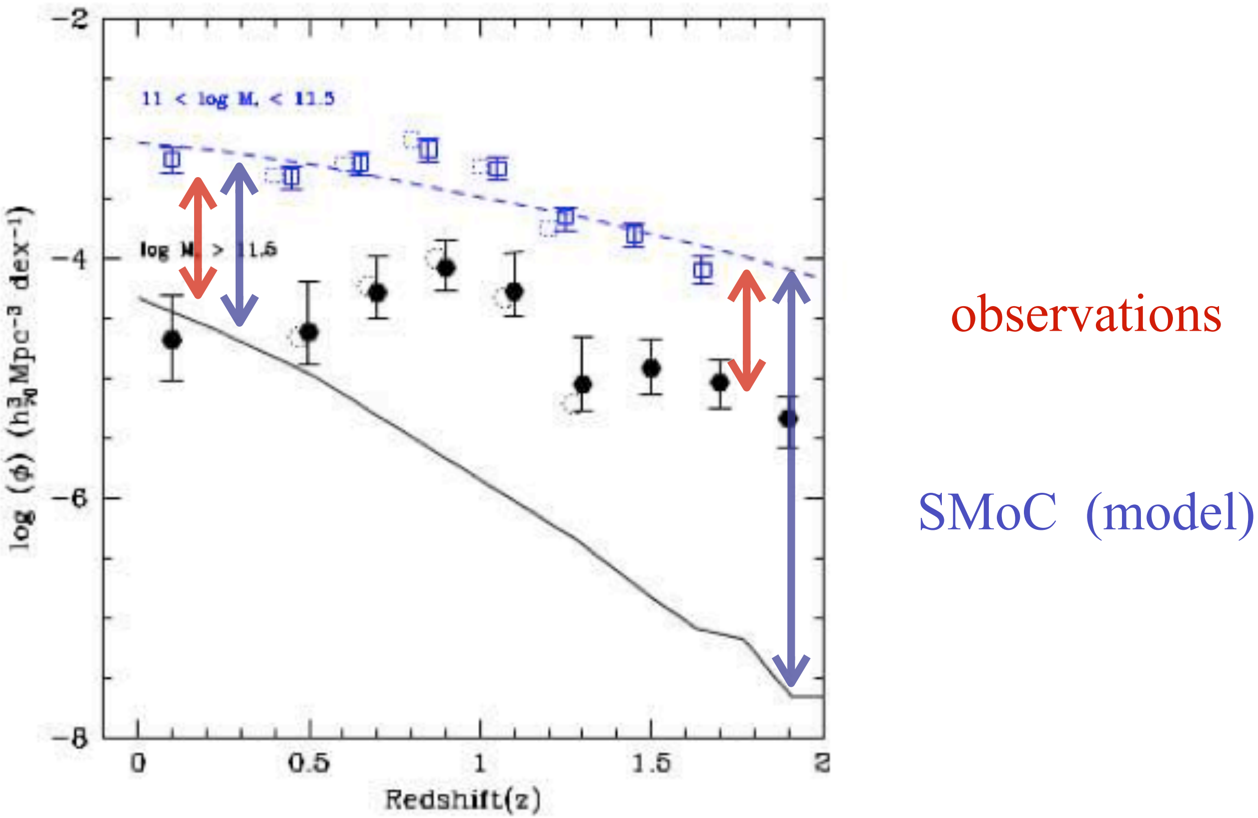

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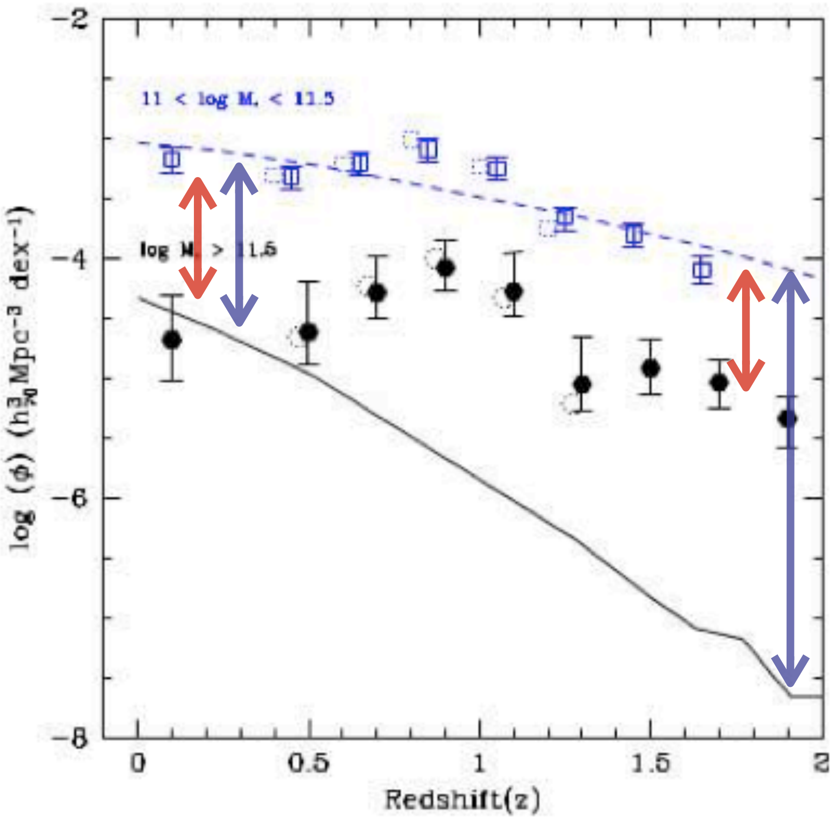
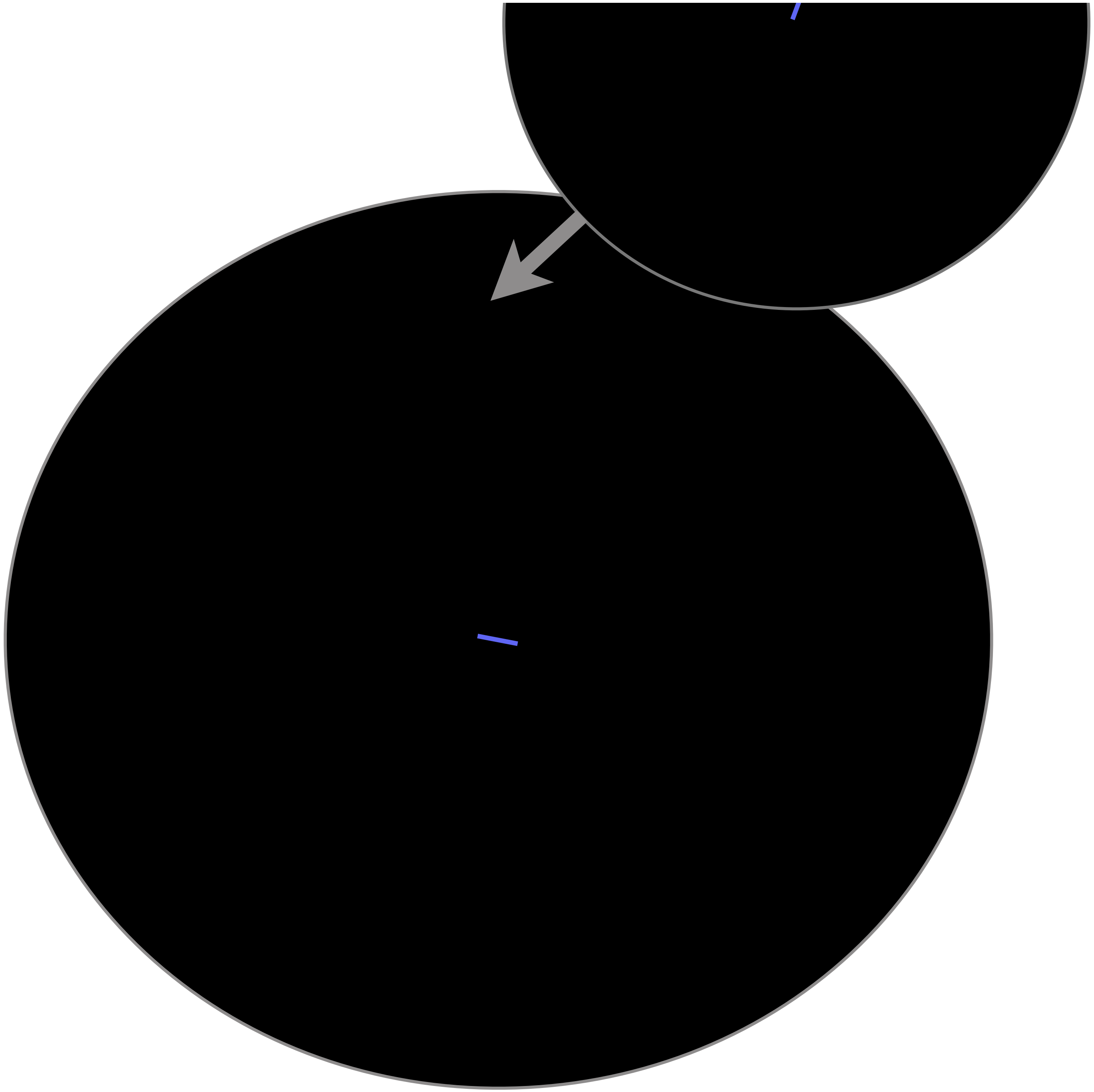


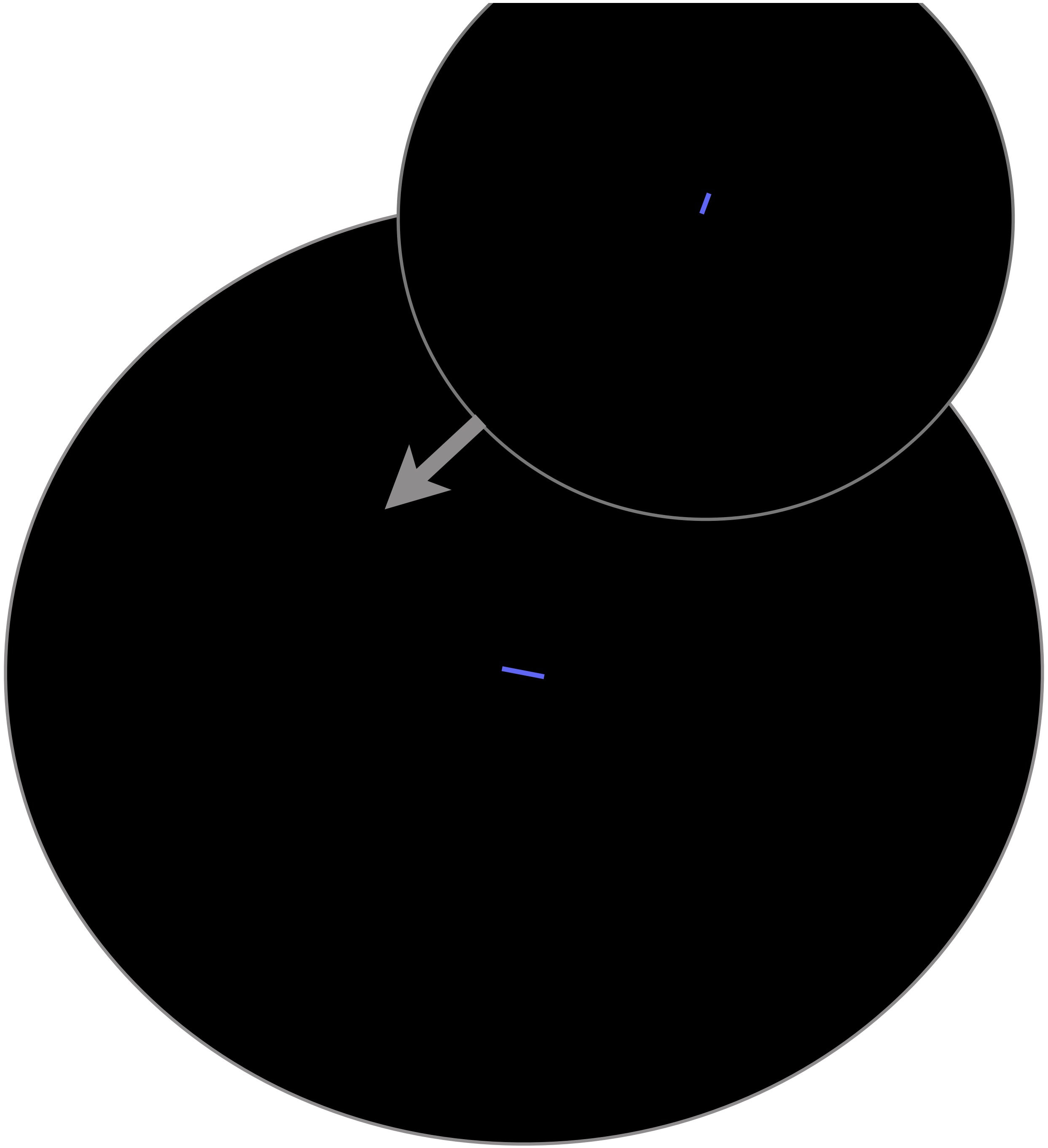
observations

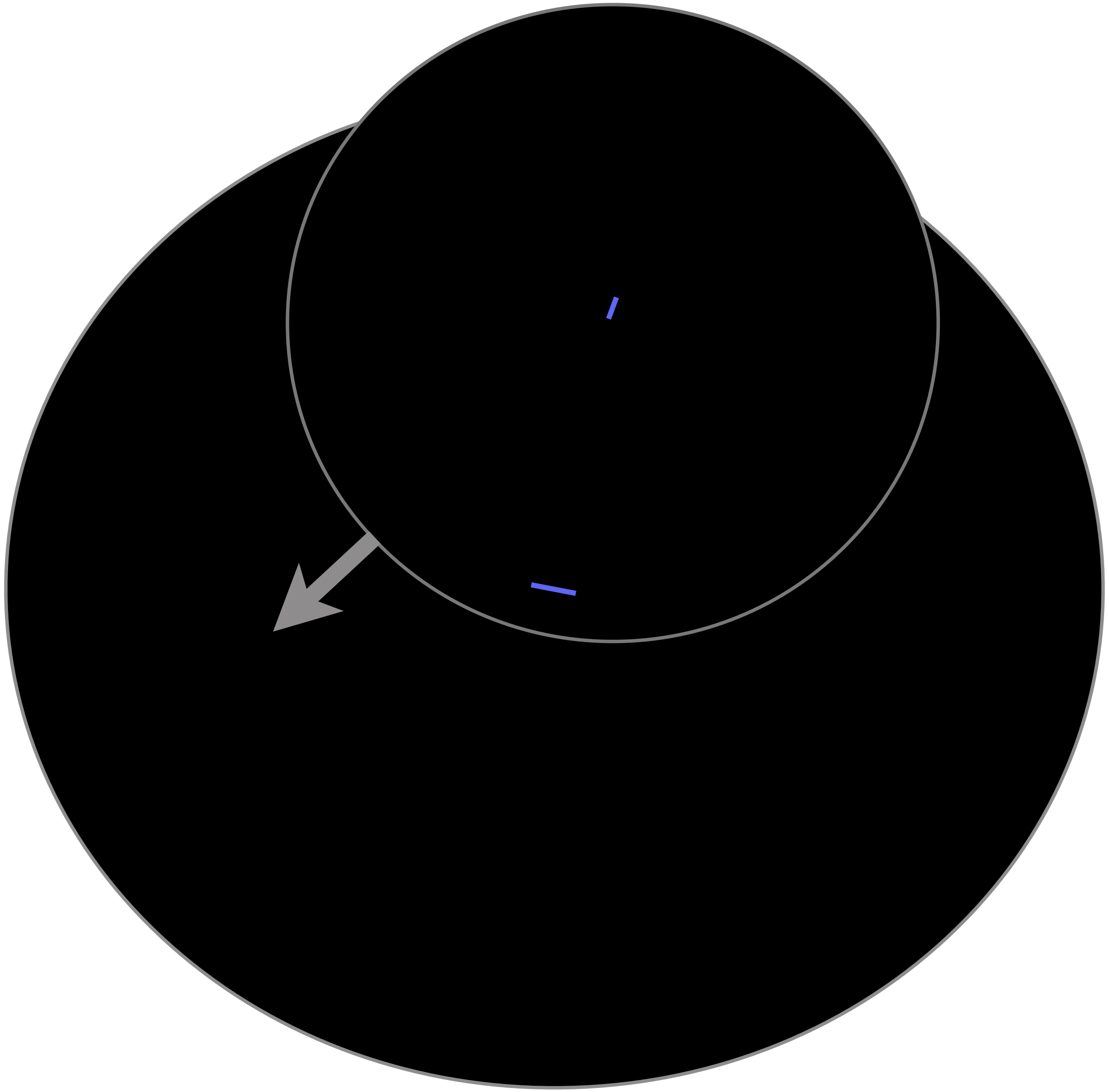
SMoC (model)

No evidence for growth of galaxies through mergers.

Pavel Kroupa: University of Bonn







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

G. W. Angus,[1,2,3]★ Antonaldo Diaferio[2,3,4] and Pavel Kroupa[5]

[1] *Astrophysics, Cosmology & Gravity Centre, University of Cape Town, Private Bag X3, Rondebosch 7700, South Africa*
[2] *Dipartimento di Fisica Generale 'Amedeo Avogadro', Università degli studi di Torino, Via P. Giuria 1, I-10125 Torino, Italy*
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[4] *Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA*
[5] *Argelander Institute for Astronomy, University of Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany*

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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.

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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

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[5]*Argelander Institute for Astronomy, University of Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany*

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.

Therefore . . .

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The present-day motions and distances of MW satellites preclude them to have fallen-in from a filament if they have dark-matter halos.

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.

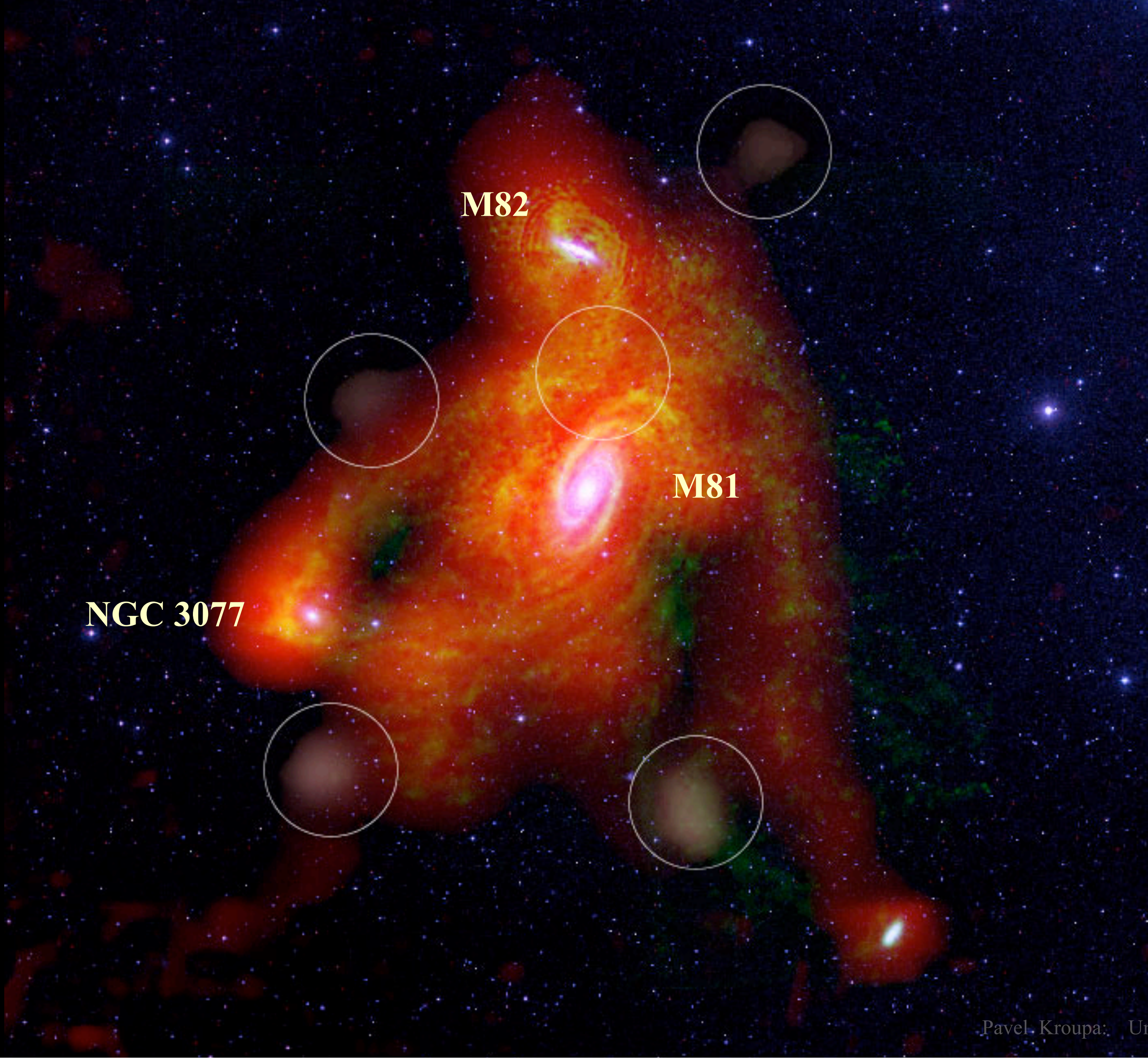
→ inconsistency with dark-matter

Other Consequences

The M81 group of galaxies

- an analogue to the Local Group at 3.6 Mpc

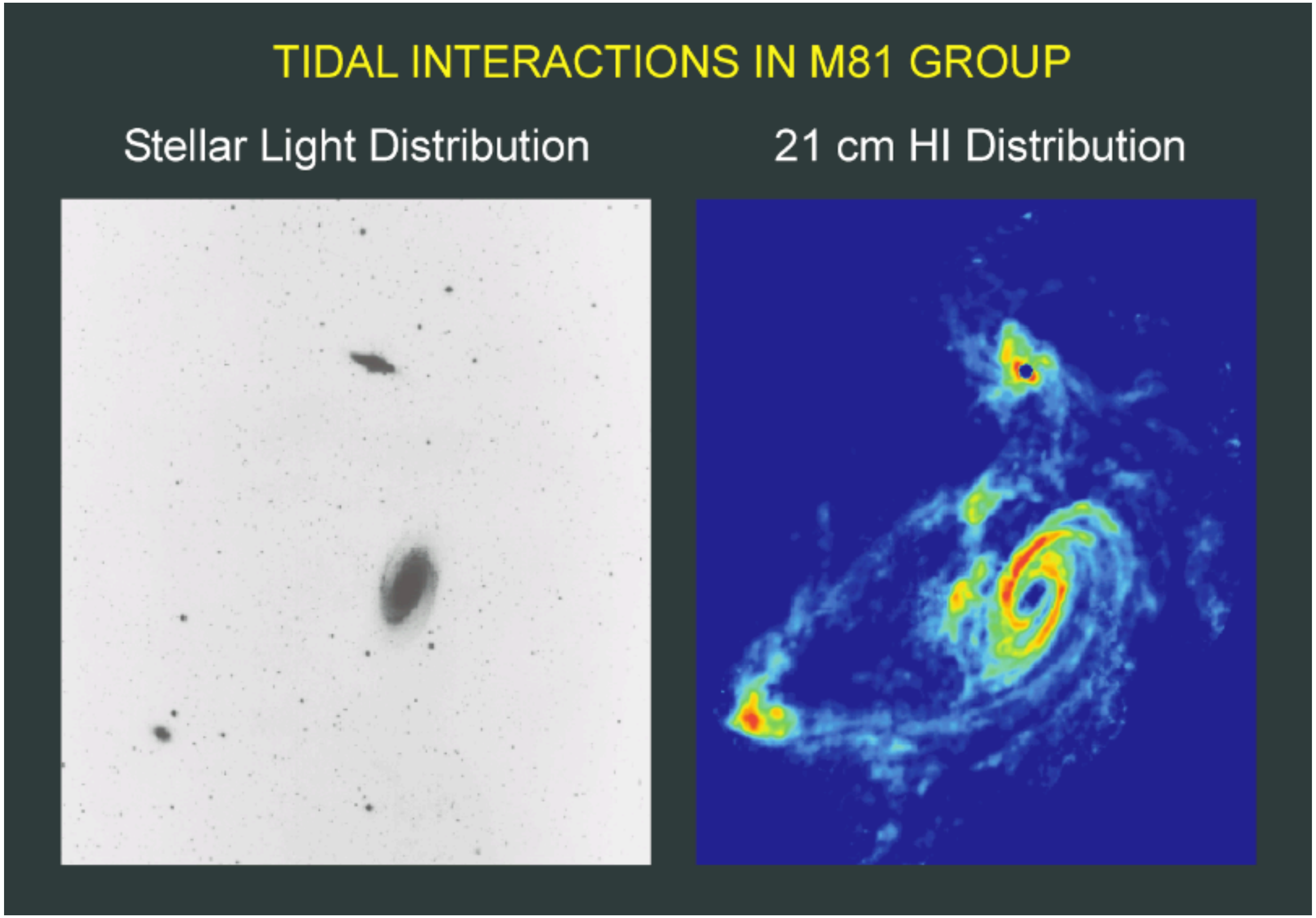
Dynamical friction?? : the M81 group of galaxies



by
Chynoweth,
Langston,
Yun,
Lockman,
Scoles

Pavel Kroupa: University of Bonn

Dynamical friction?? : the M81 group of galaxies



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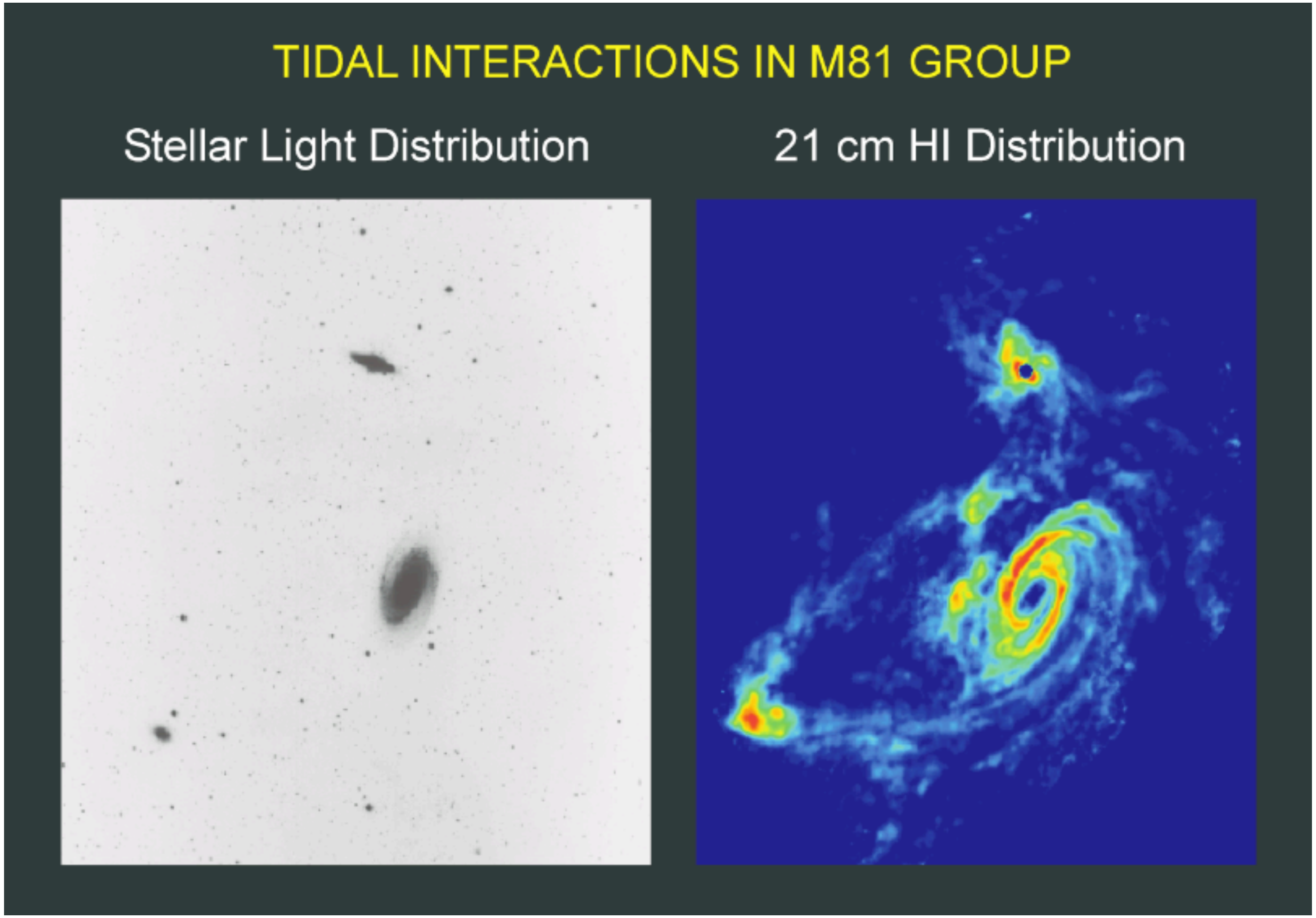

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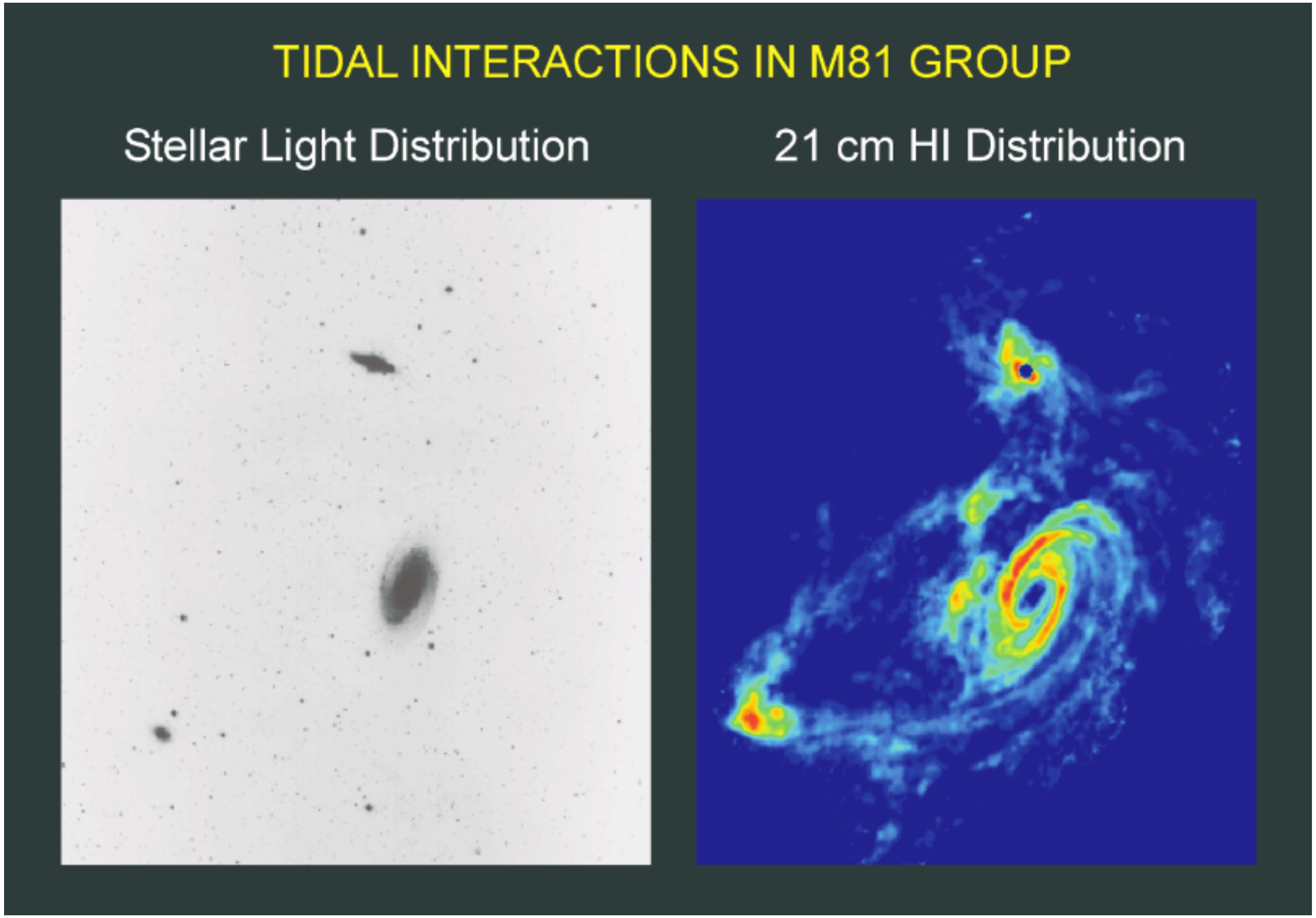

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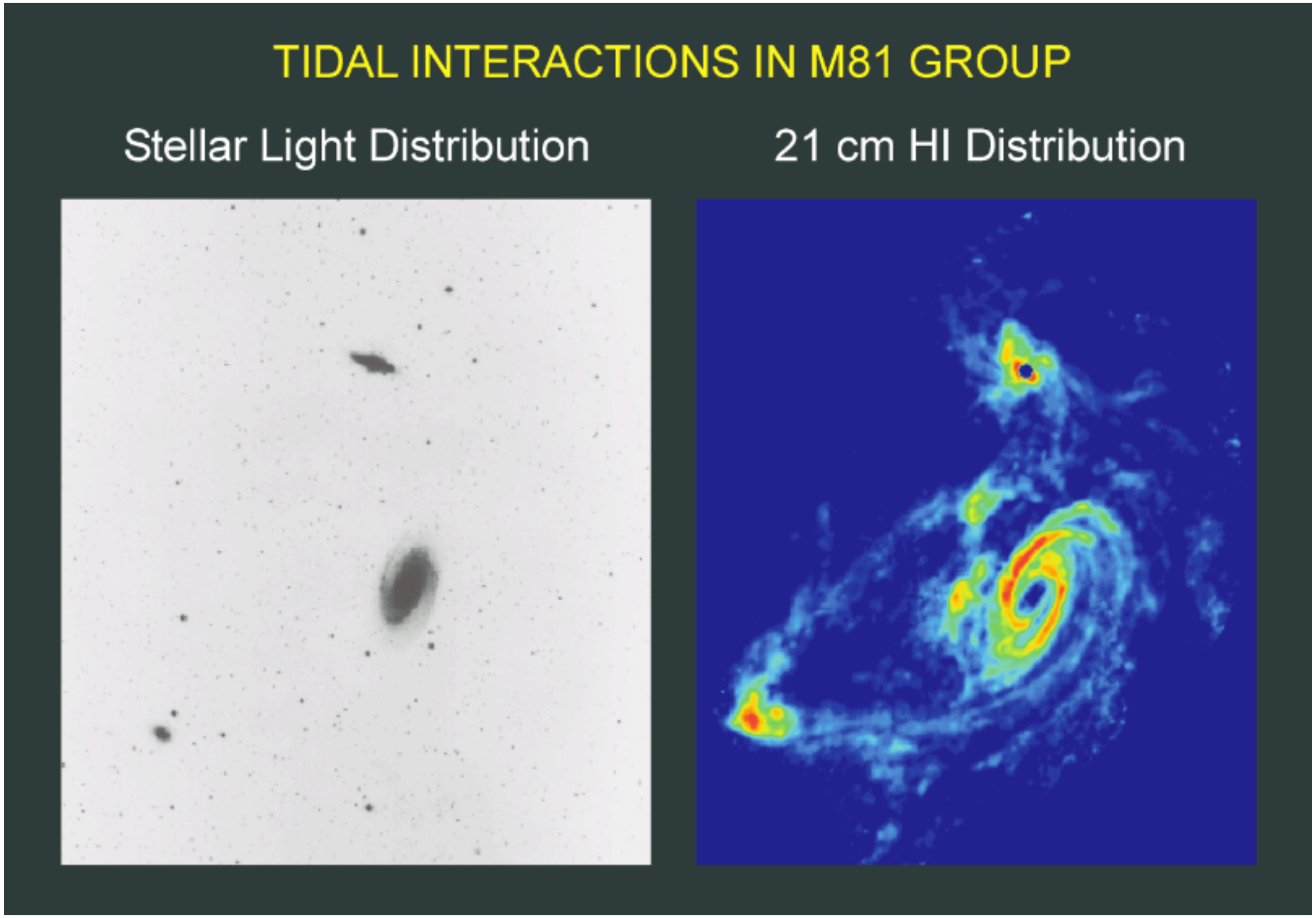

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Thomson, Laine & Turnbull 1999
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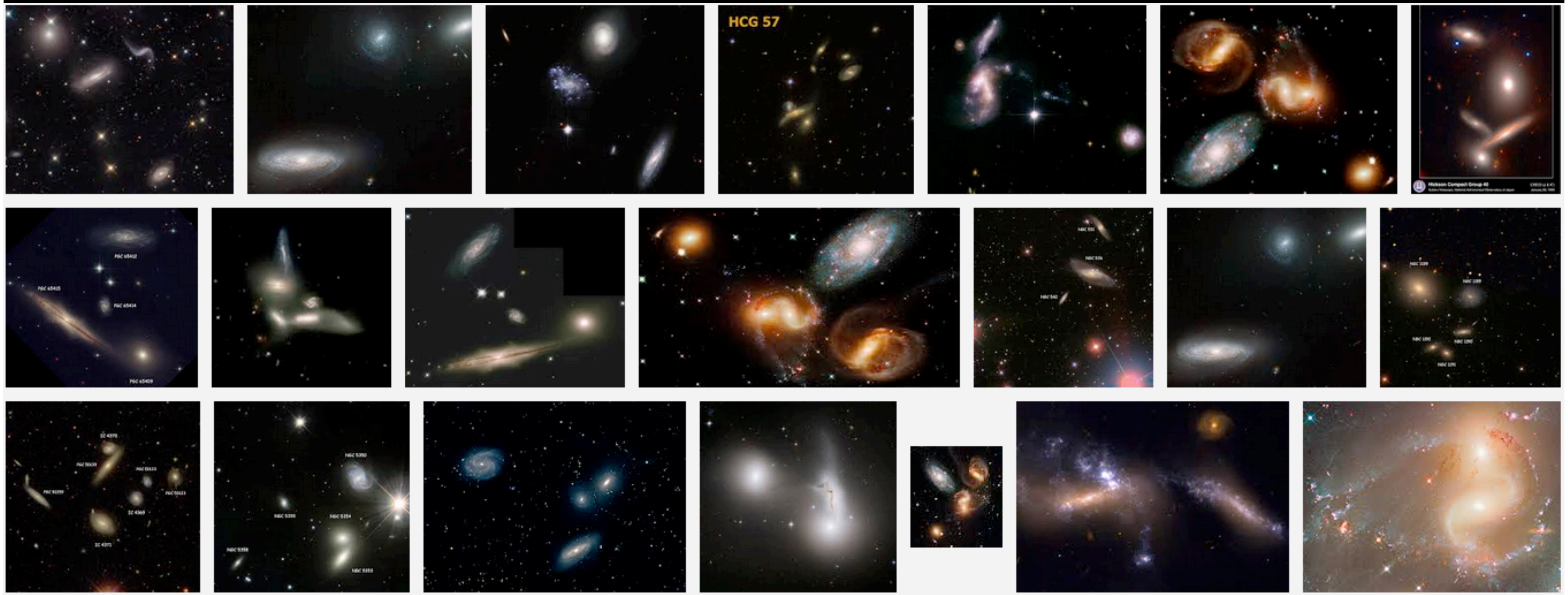
The *Hickson compact groups* are are particularly troubling for LCDM, because they all must have assembled during the past 1-3 Gyr with all members magically coming together for about one synchronised perigalactic passage, while the remnants (field E galaxies with low alpha element abundances from previously such formed groups) do not appear to exist in sufficient numbers.

silkscape.com



Pavel Kroupa: University of Bonn

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

Sohn, Hwang, Geller et al. (2015, JKAS)

. . . thus,

the observational data disfavour the existence of dark matter

(SMoC leads to wrong structures
and lack of dynamical friction
disfavors dark matter particles)

A historical perspective which may give a clue . . .

Remember that Einstein constructed his GR to accommodate

Newton's *empirical* law of universal gravitation

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

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

and an acceleration (space-curvature) scale

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

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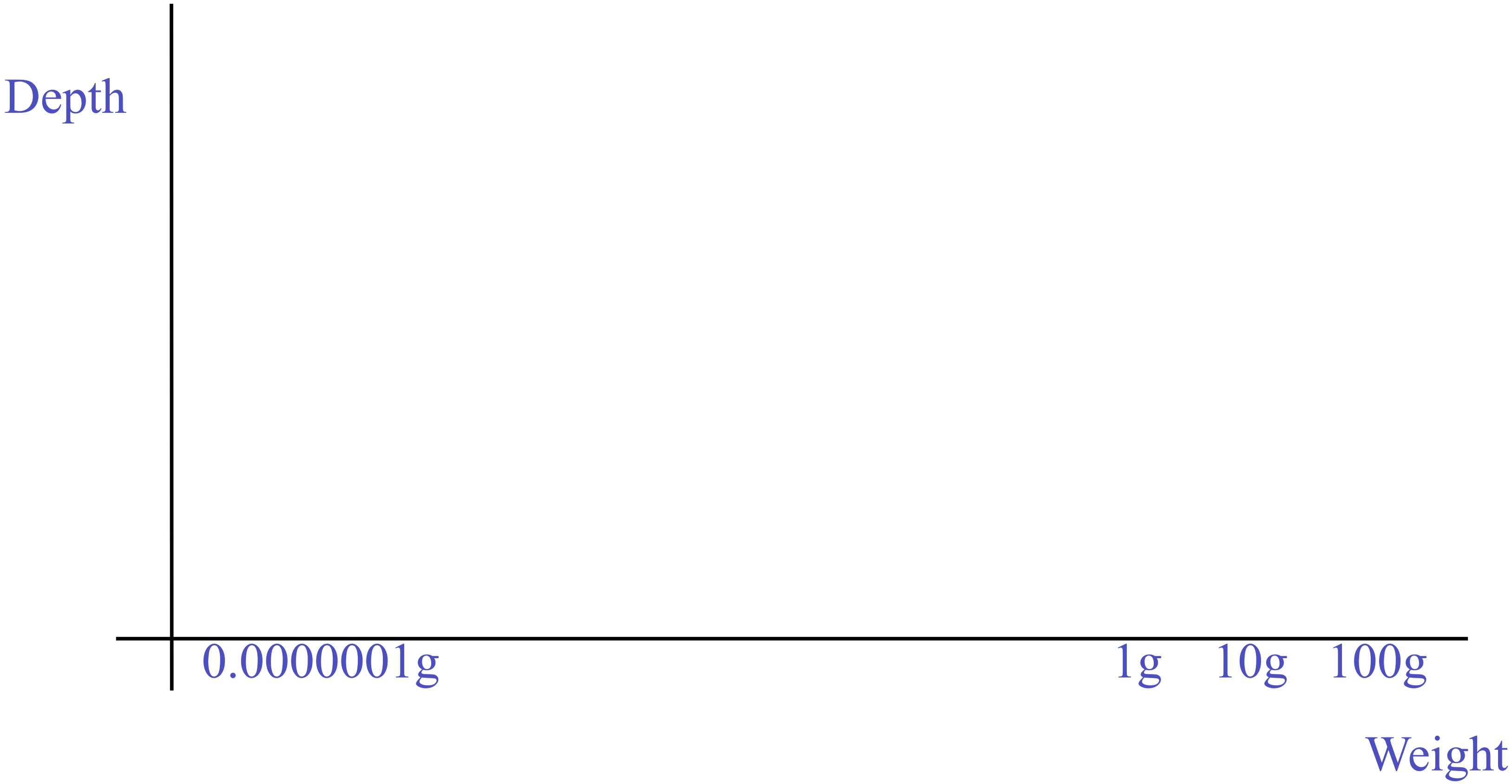
> 4 orders of magnitude

Should one expect an
empirical law to hold

over an extrapolation of
orders of magnitude ?

Gedankenexperiment

by Indranil Banik
(St. Andrews)



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Depth of a trampolin with increasing weight :

Depth

0.0000001g 1g 10g 100g

Weight

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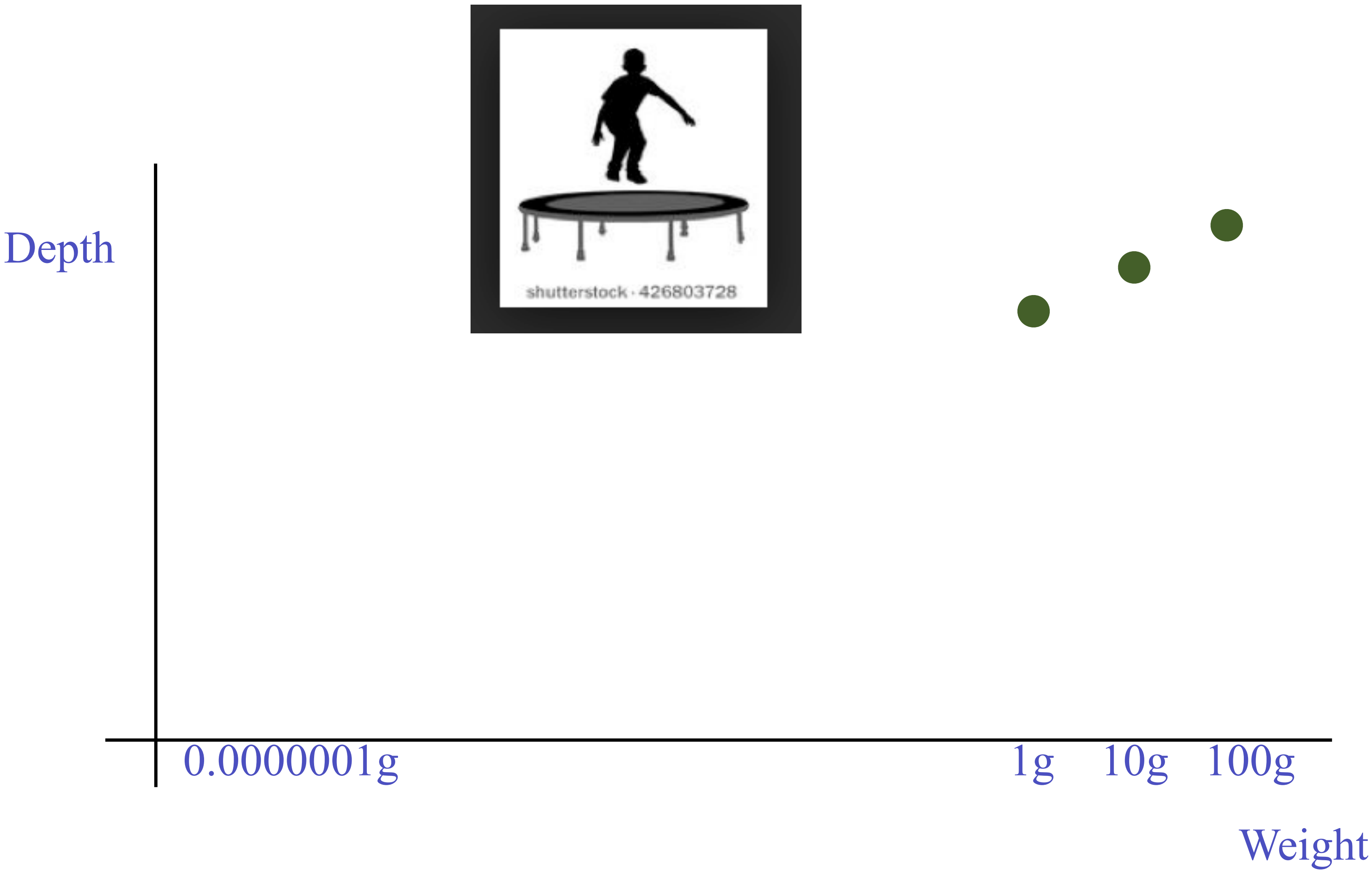

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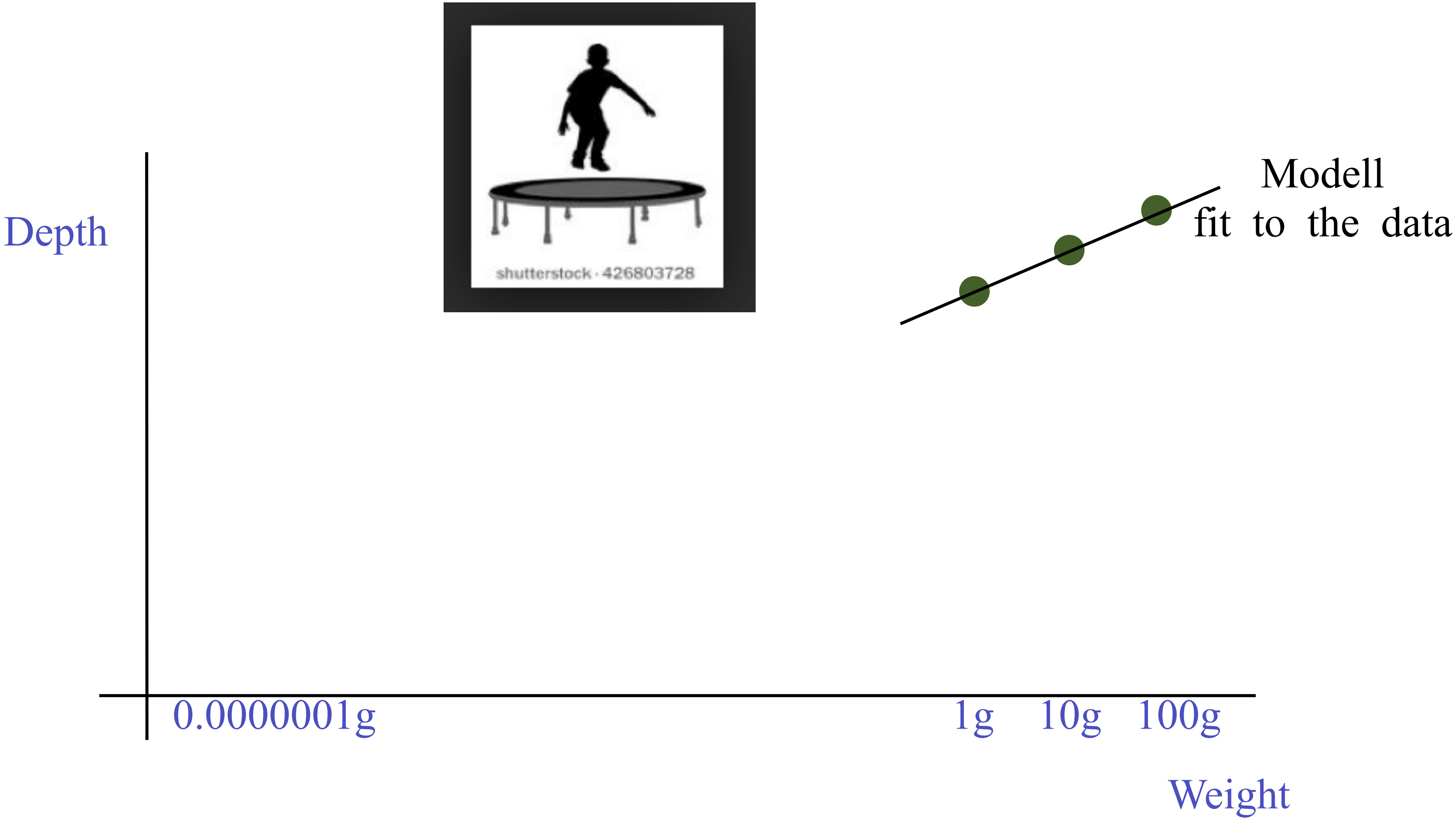

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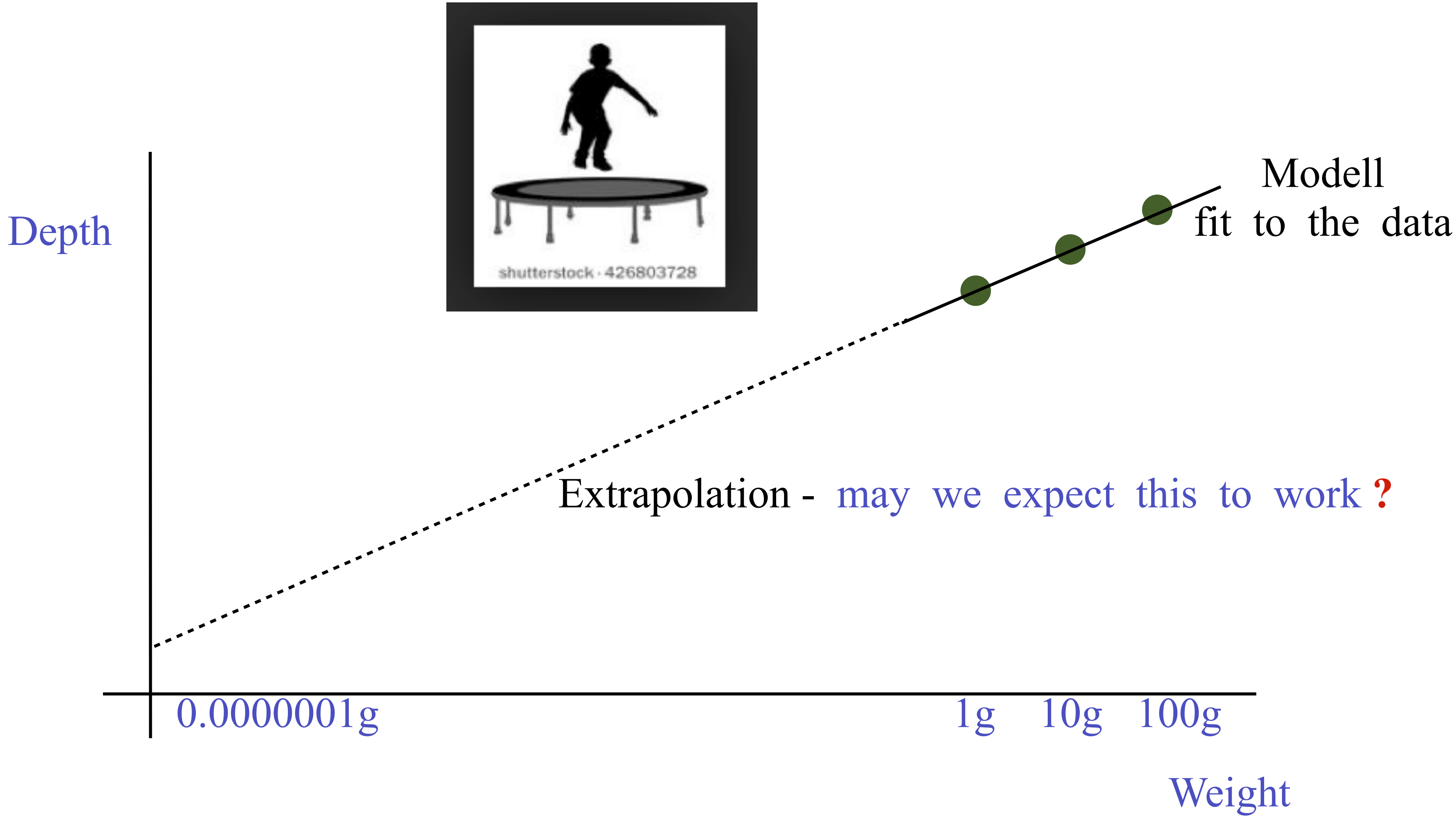

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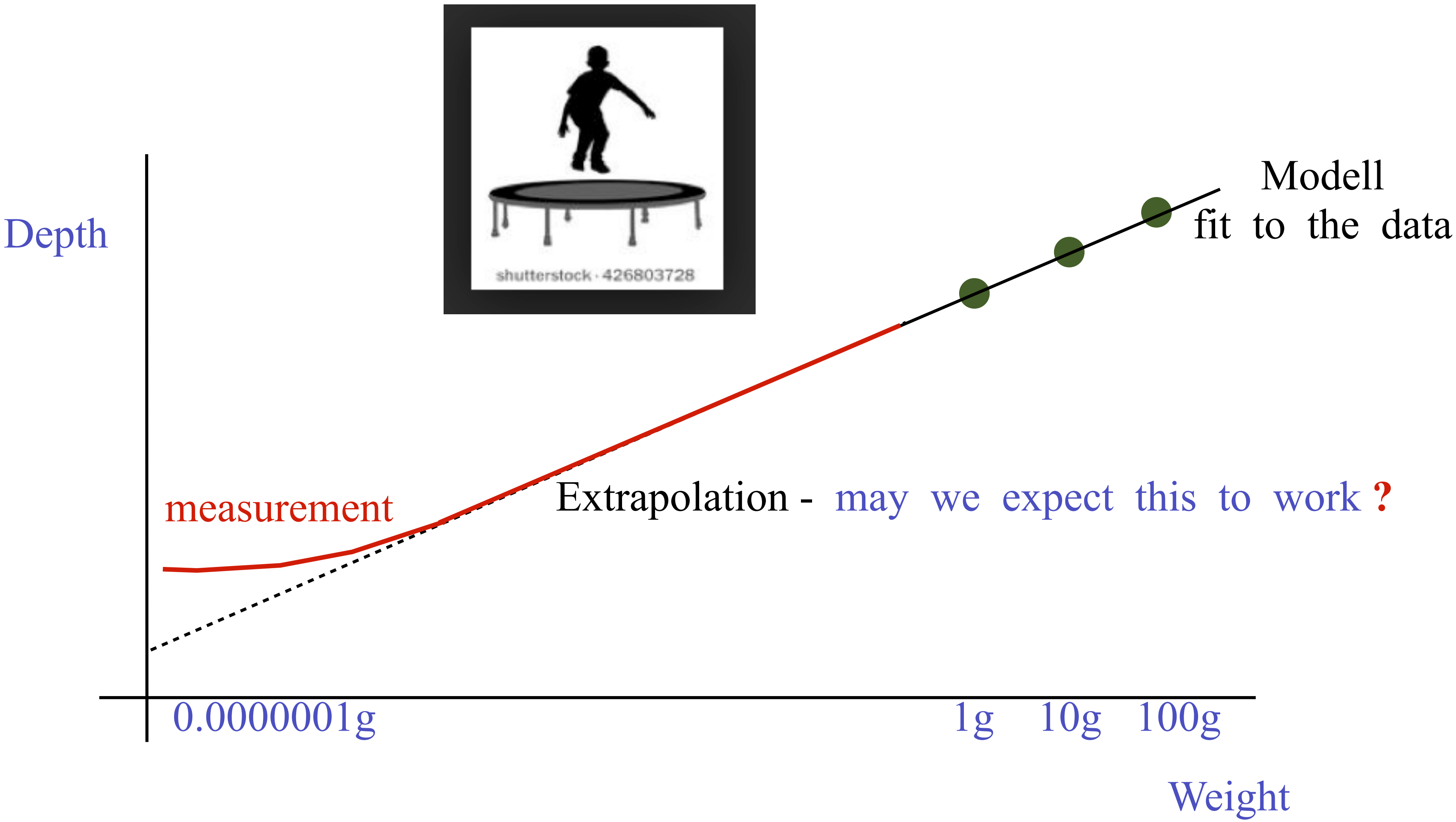


Pavel Kroupa: University of Bonn

How to proceed?

How to proceed ?

A clue is provided

by the

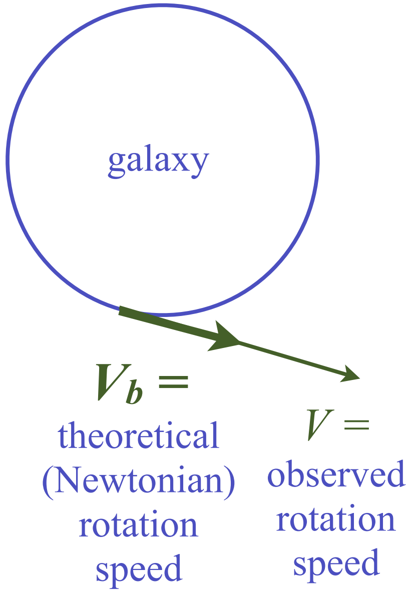
mass-discrepancy--acceleration
data

in galaxies

Mass-Discrepancy correlation with acceleration

The Sanders-McGaugh correlation

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



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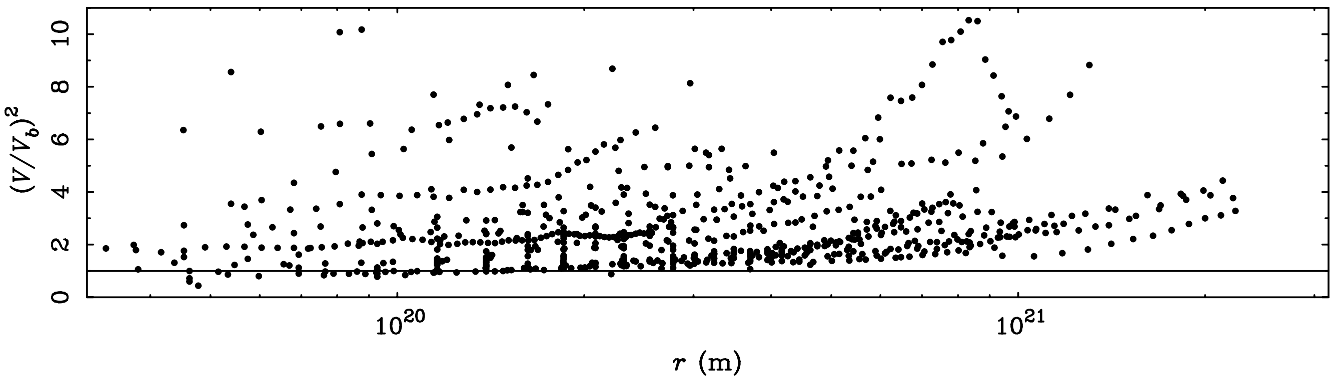

Sanders 1990; McGaugh 2004

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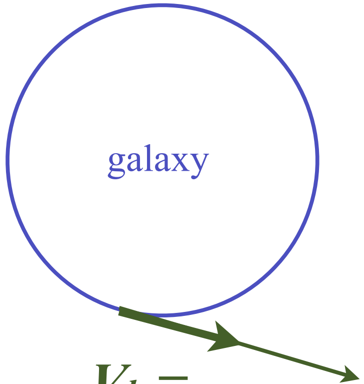

V_b = theoretical (Newtonian) rotation speed

V = observed rotation speed

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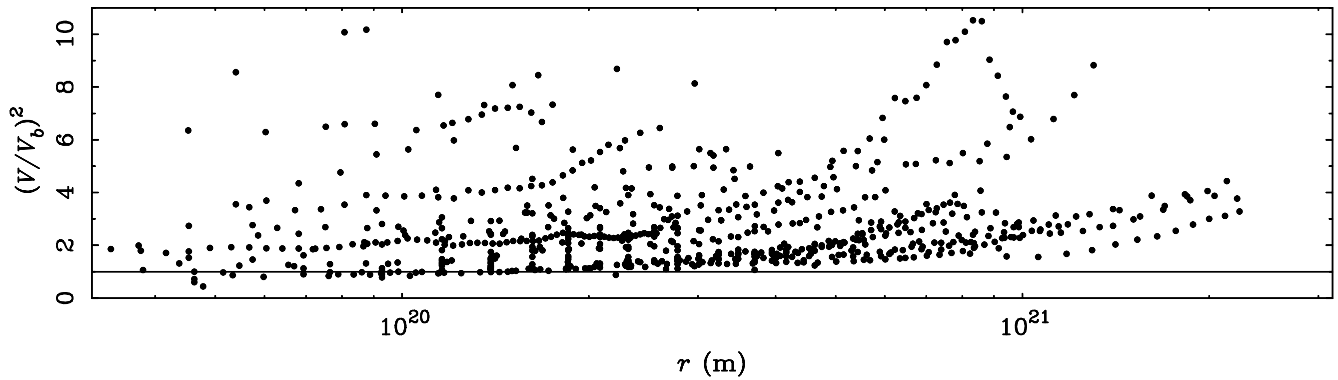

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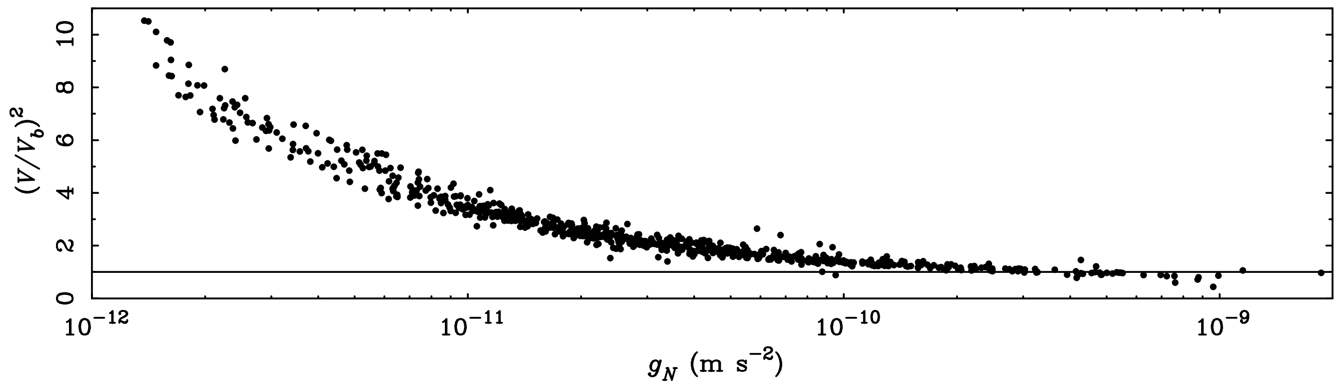

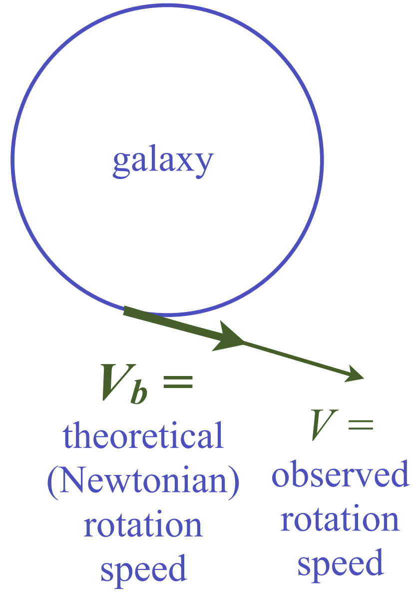

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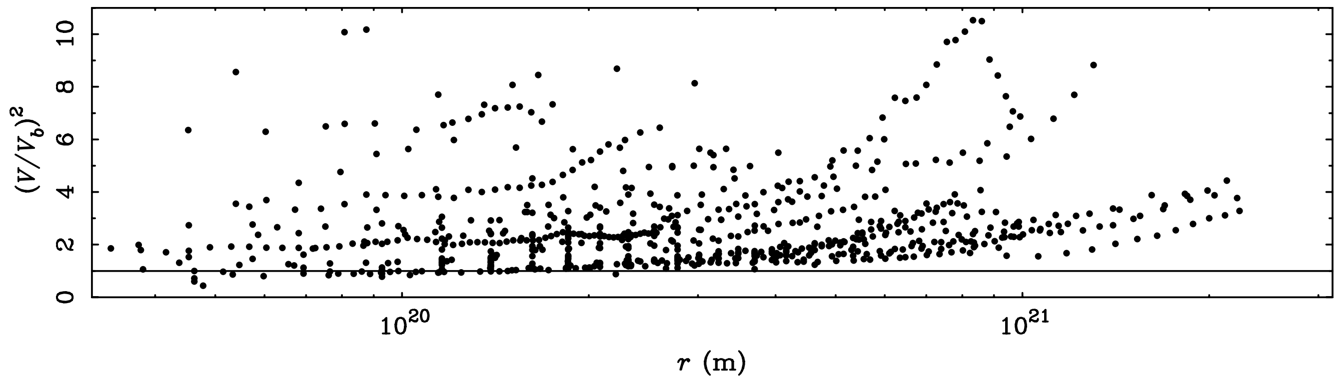

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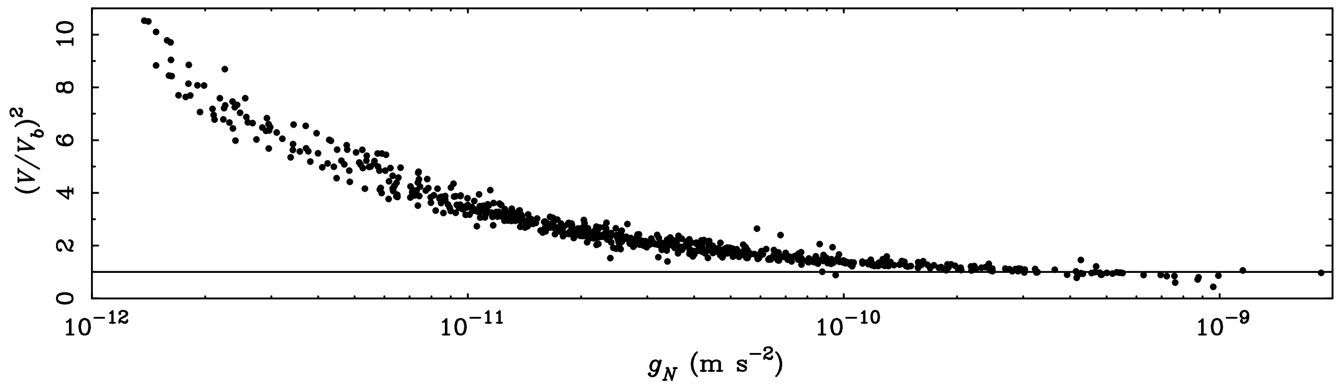

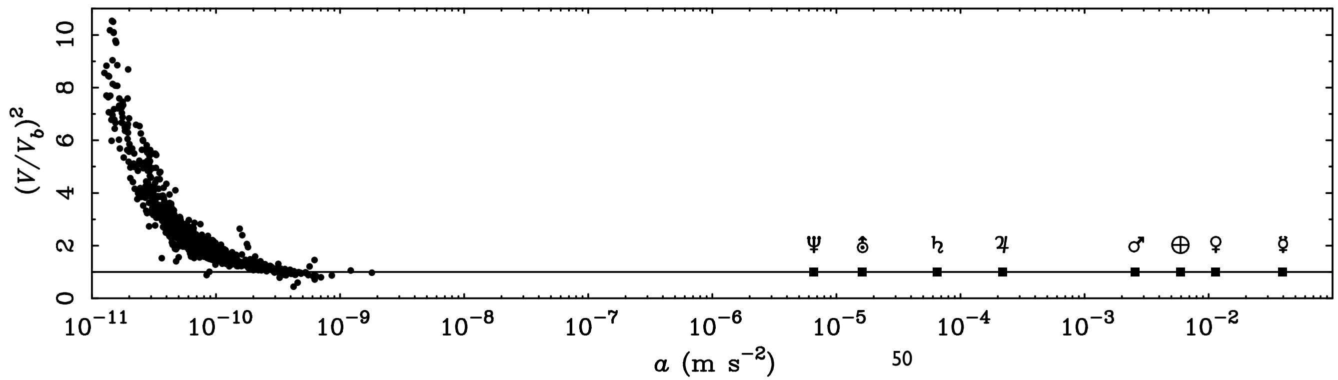

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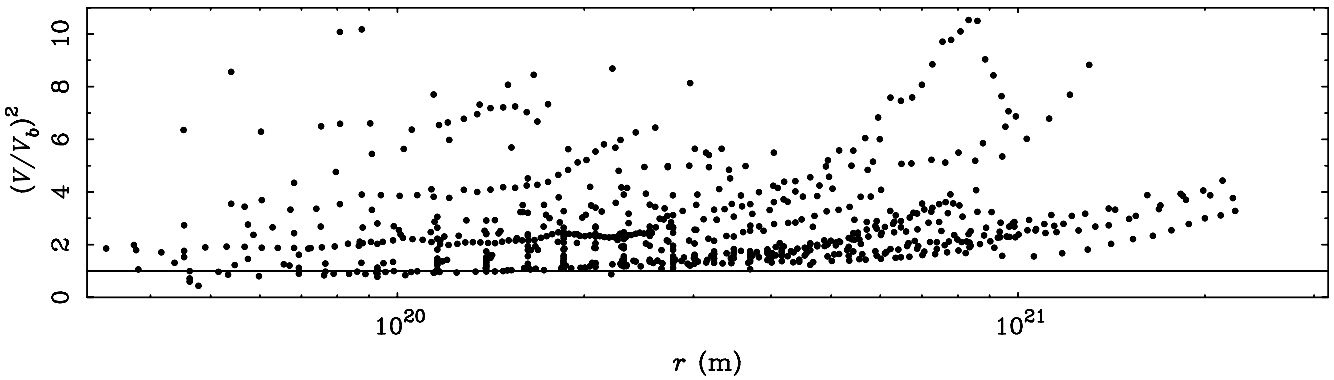

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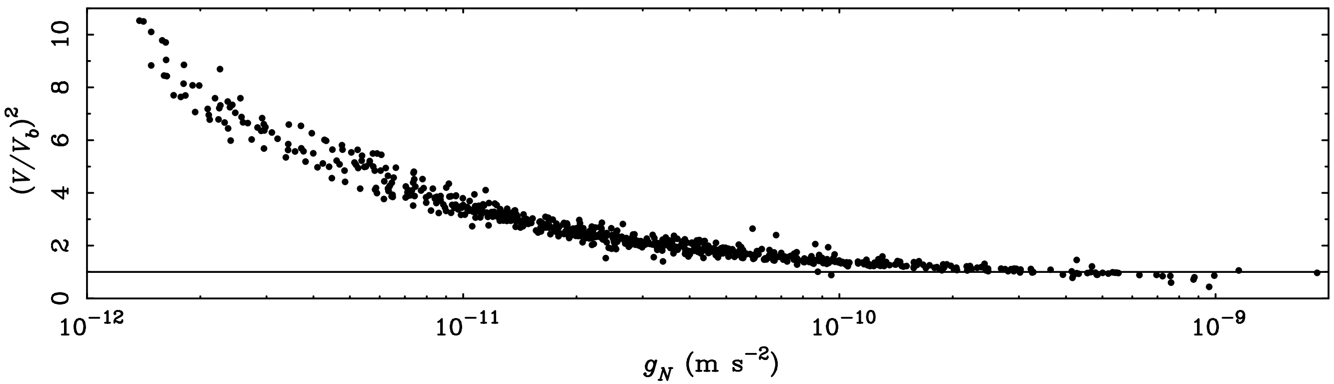

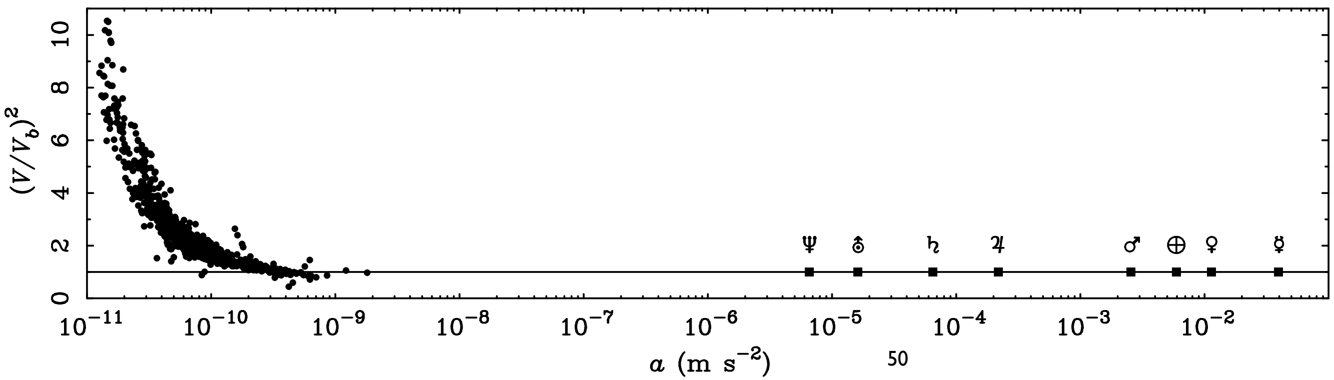

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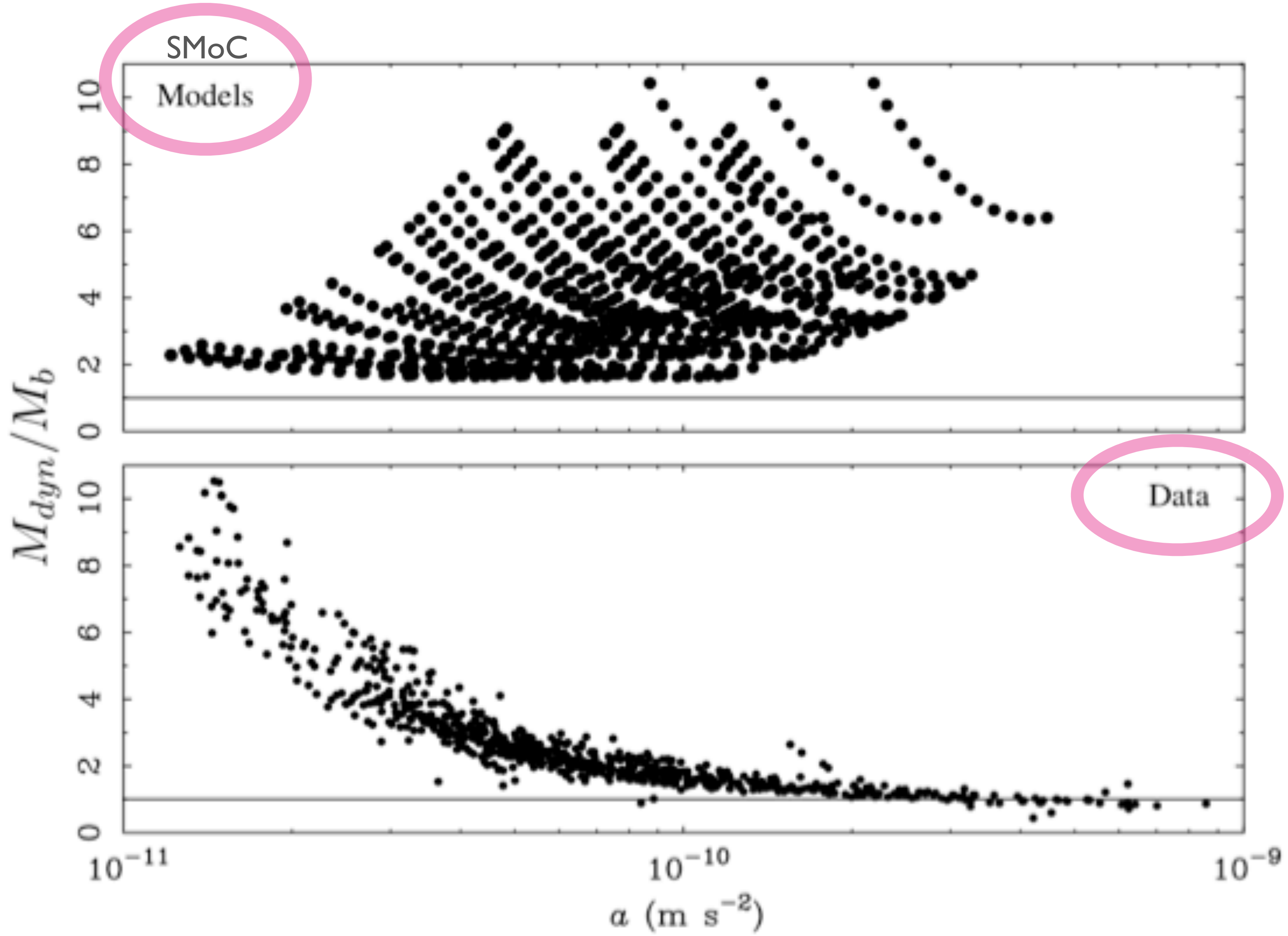
Correlation can't be explained by Dark Matter : DM particle physics is independent of the local acceleration in the SMoC.

Mass-Discrepancy correlation with acceleration



McGaugh 2014
also
Wu & Kroupa 2015

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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.

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

(**Milgrom 2009**; Kroupa, Pawlowski & Milgrom 2012; Kroupa 2015)

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centrifugal acceleration = centripetal acceleration

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

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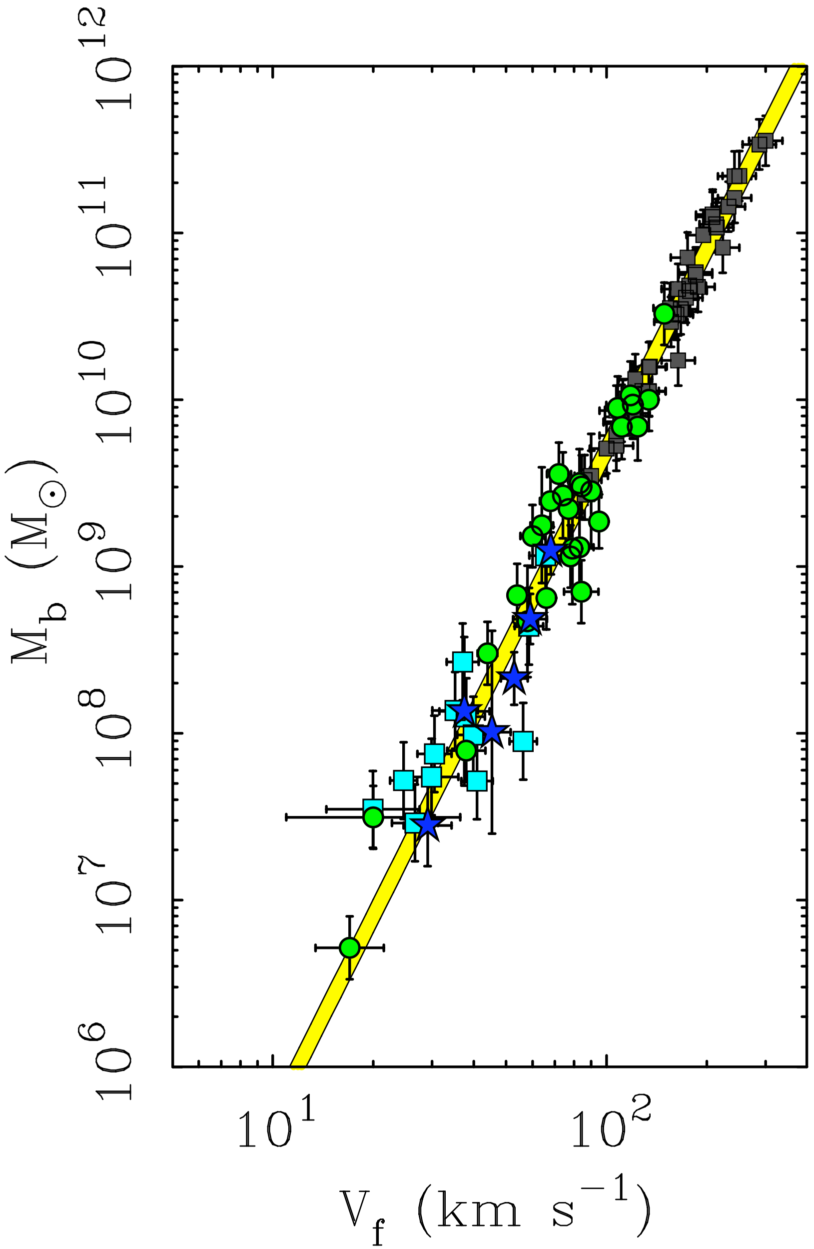
♣ $V = (GMa_0)^{\frac{1}{4}}$ the ***Tully-Fisher relation !***

and ***flat rotation curves !***

The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



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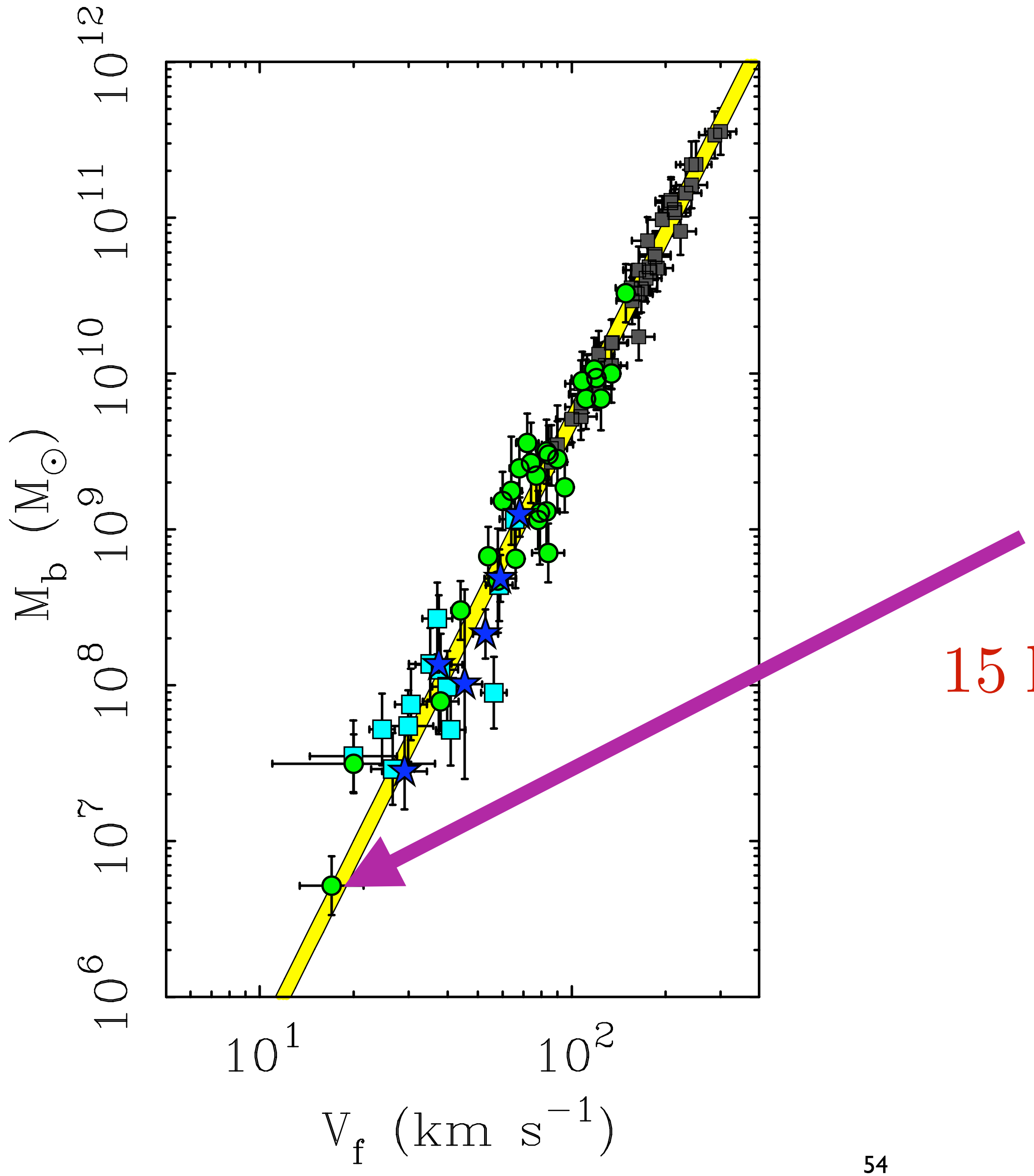
Pavel Kroupa: University of Bonn

The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012

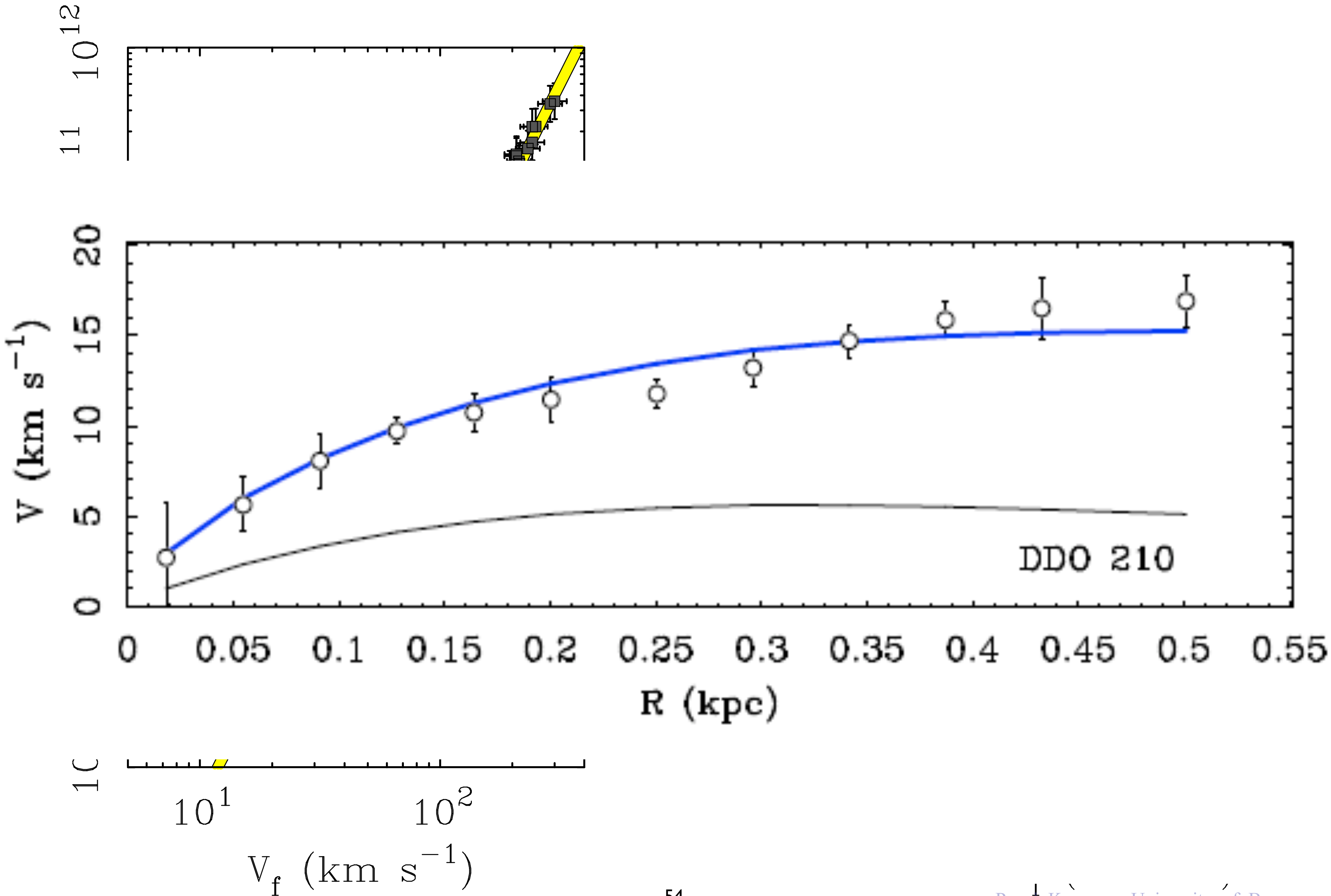


$15\ \mathrm{km/s};\quad M_b \approx 5 \times 10^6\ M_\odot$

54

The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



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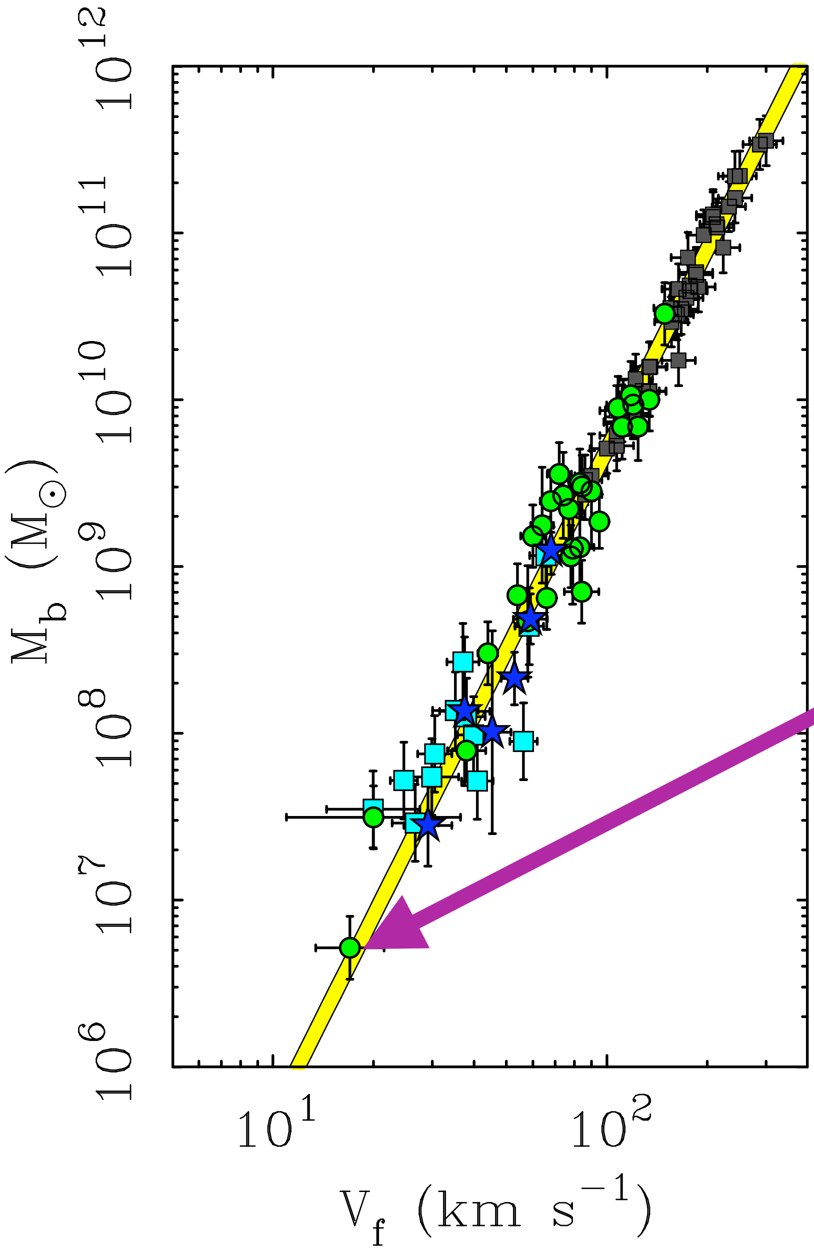

DDO 210

15 km/s; $M_b \approx 5 \times 10^6\, M_\odot$

The observational Baryonic Tully-Fisher Relation

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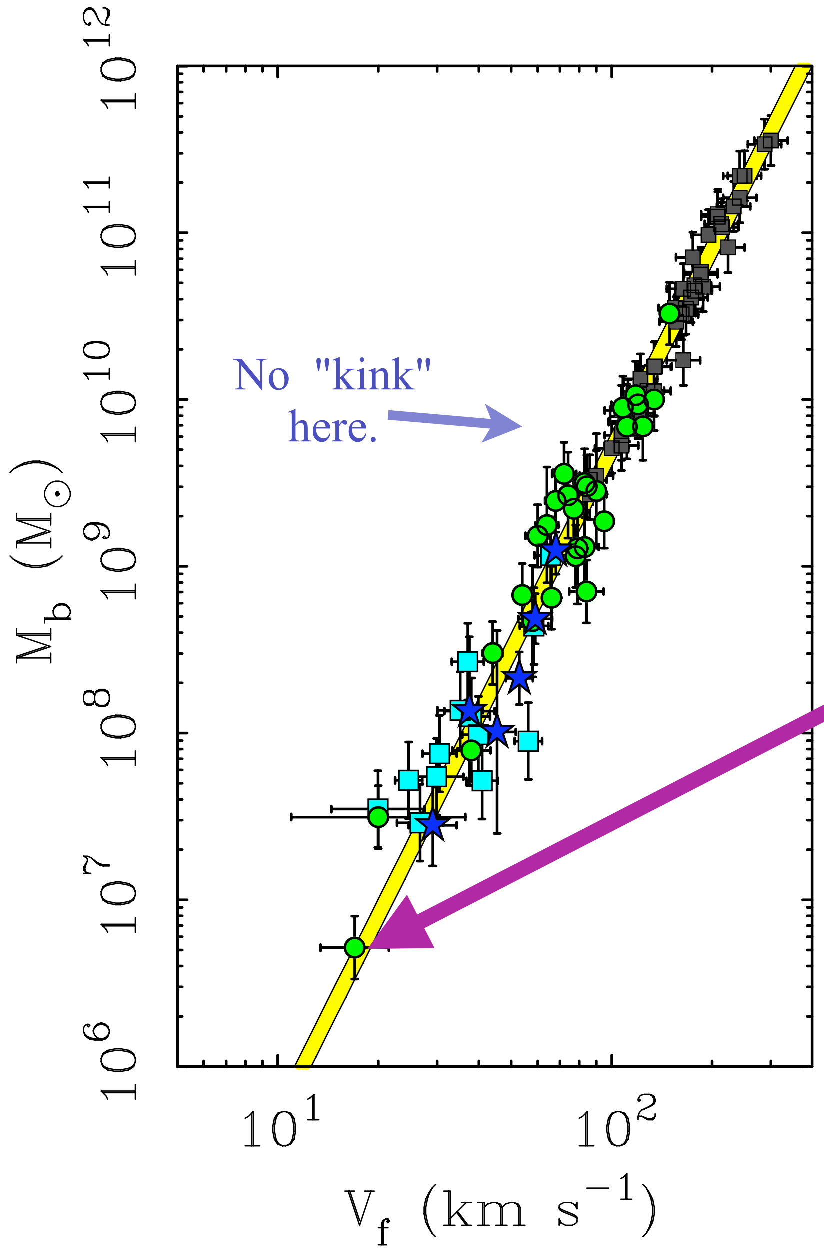

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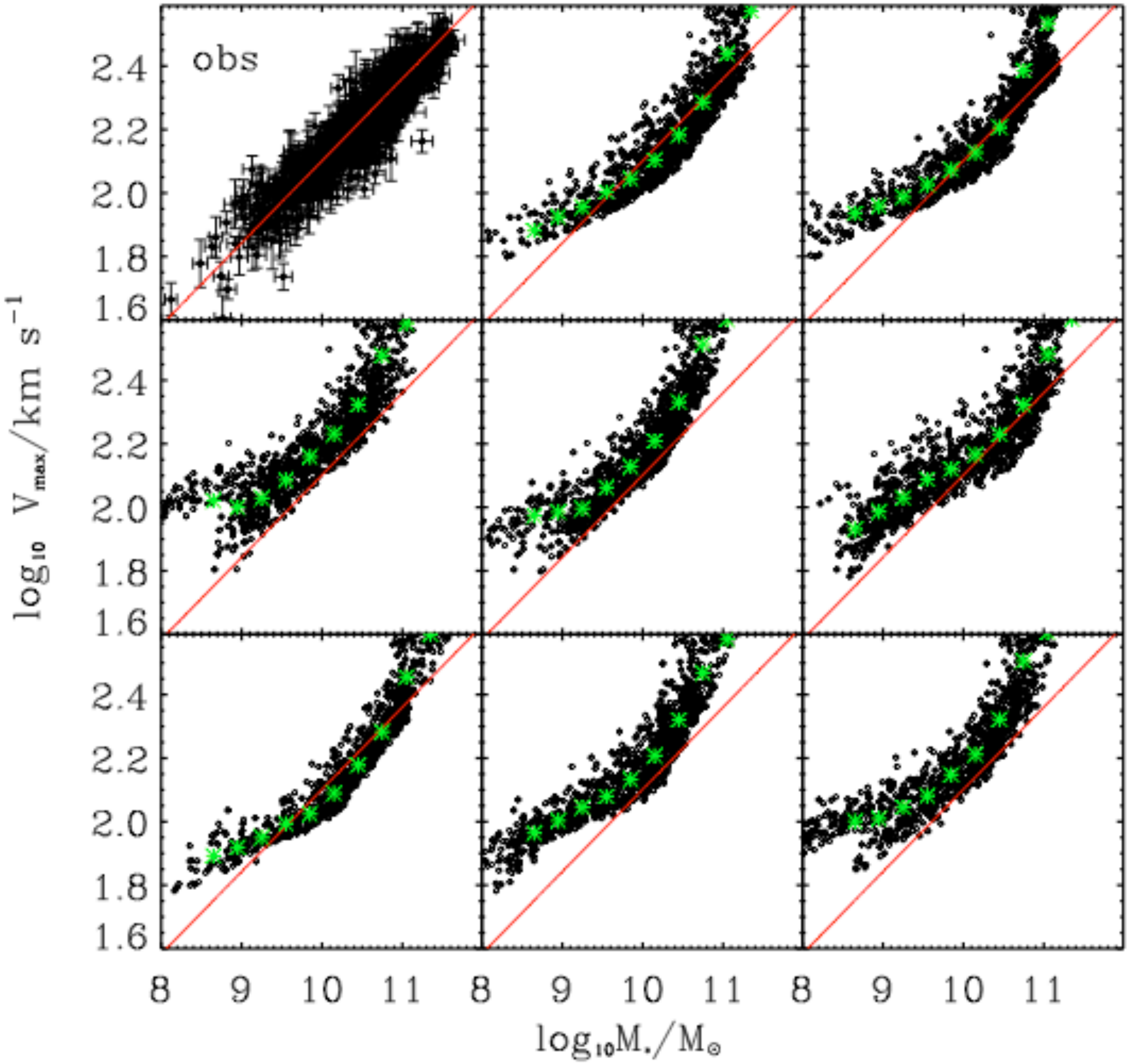
The SMoC Baryonic Tully -Fisher Relation

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).

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

(Milgrom 2009; Kroupa, Pawlowski & Milgrom 2012)

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

⇒ $g^2 = a_o g_N$ or $a^2 = a_o g_N$

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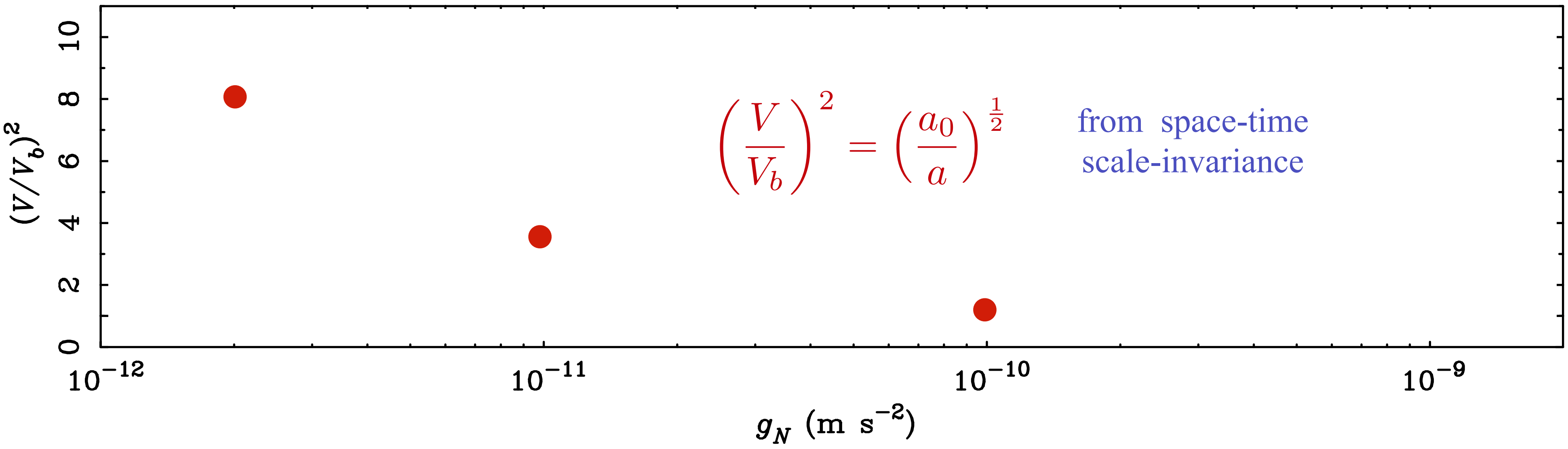
Mass-Discrepancy correlation with acceleration

The Sanders-McGaugh correlation explained



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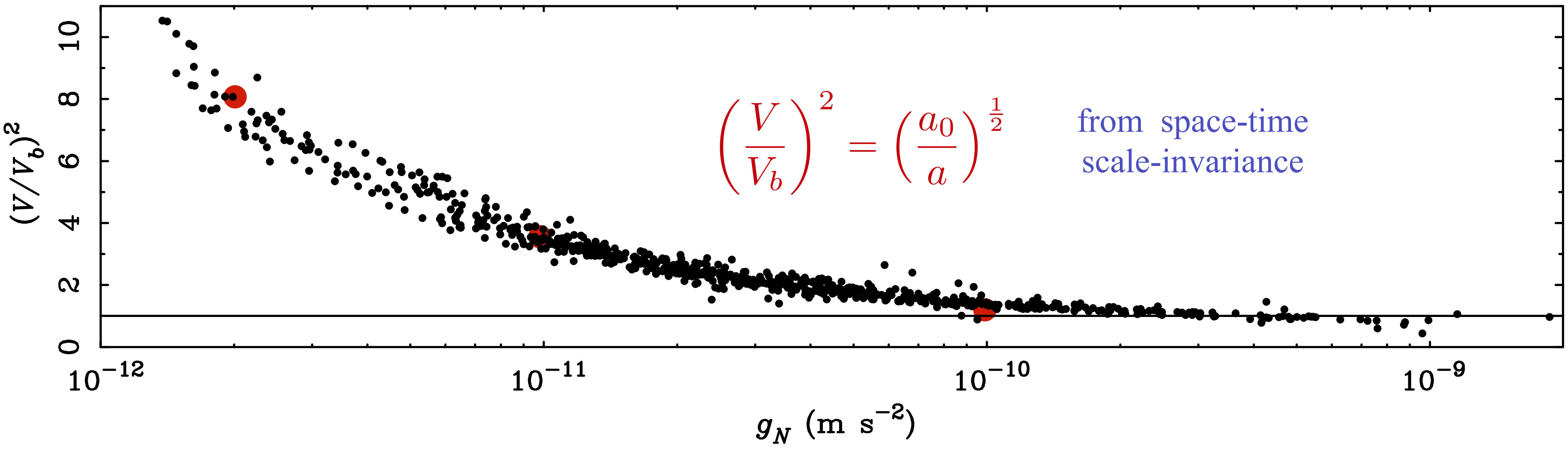

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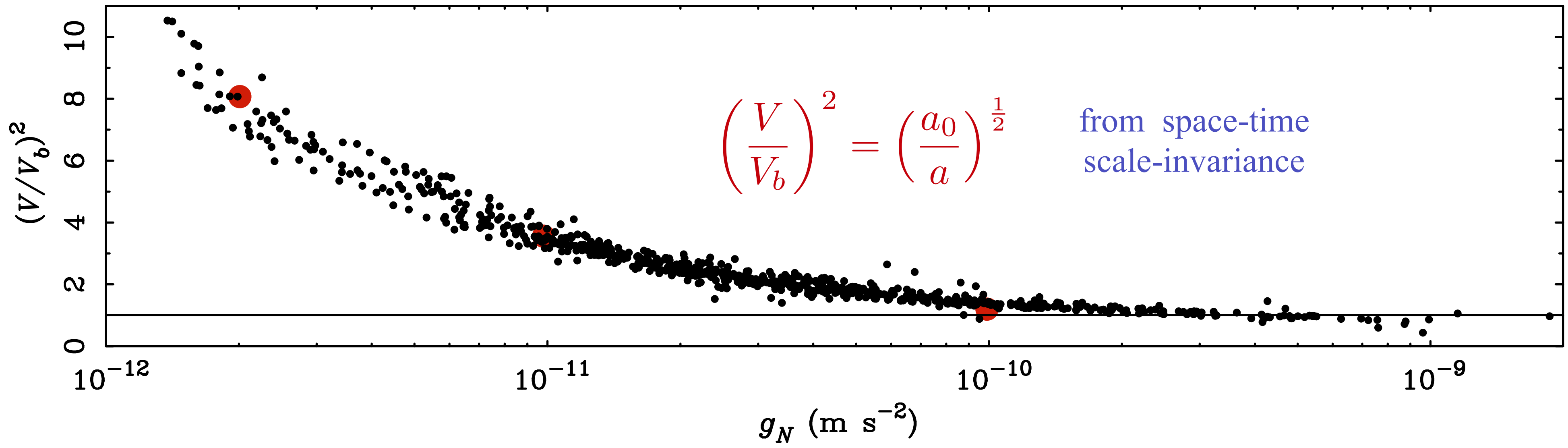
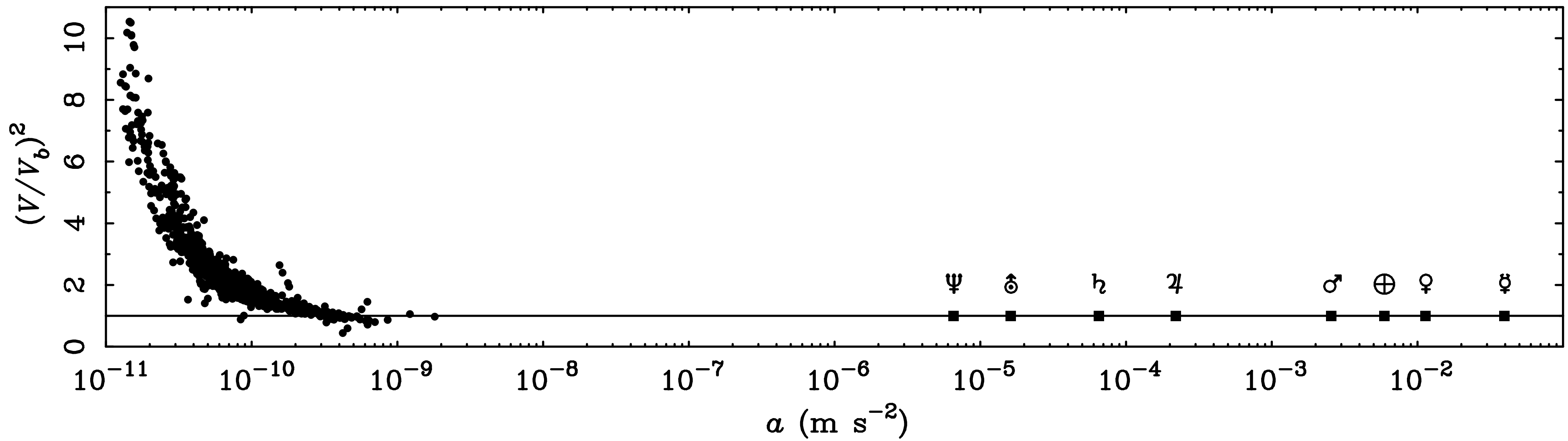




Pavel Kroupa: University of Bonn

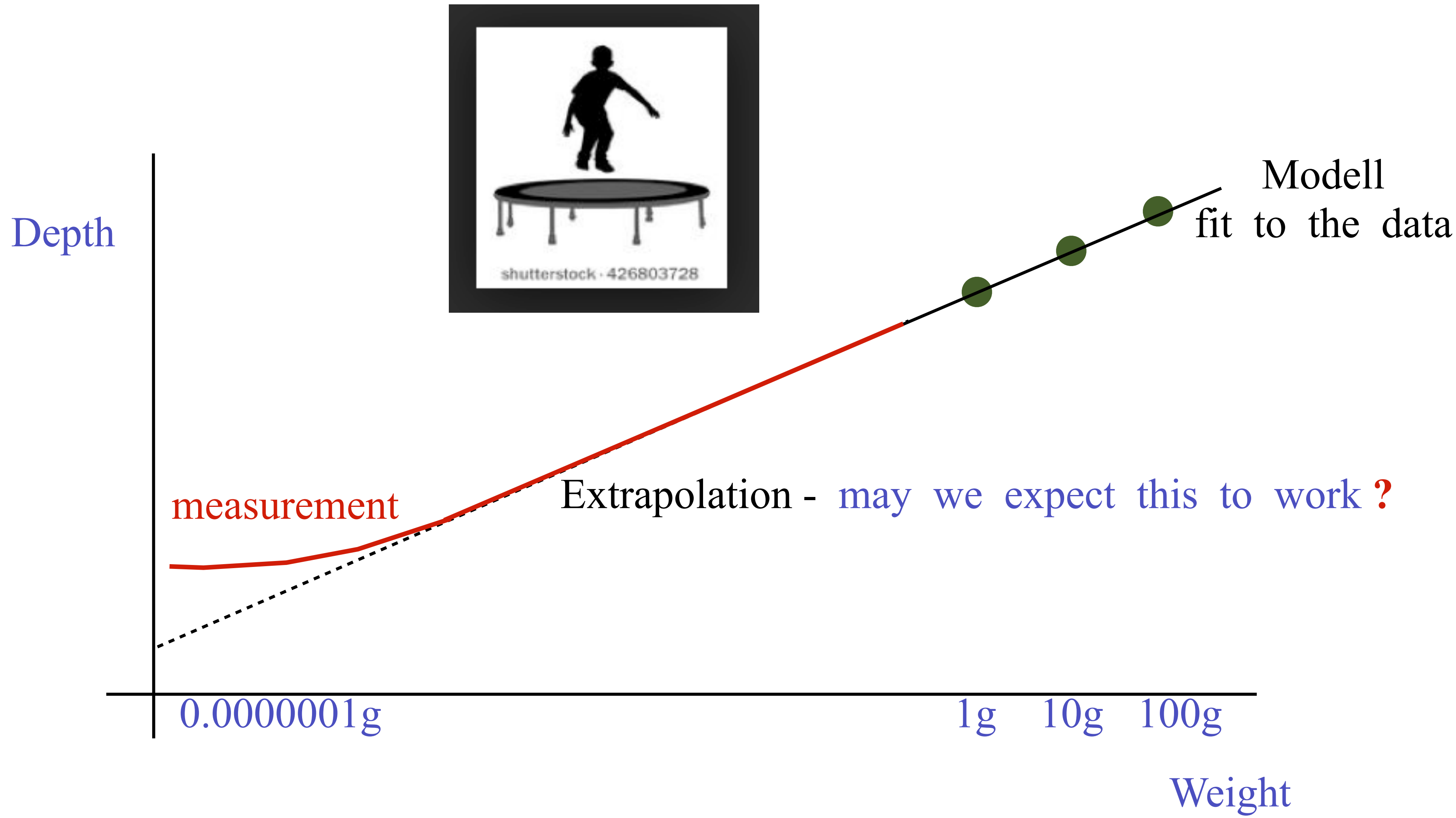
Remember :

60

Remember : ***Gedankenexperiment***

by Indranil Banik
(St. Andrews)

Depth of a trampolin with increasing weight :



Polar rings

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Polar ring galaxies allow tests of gravitational theory

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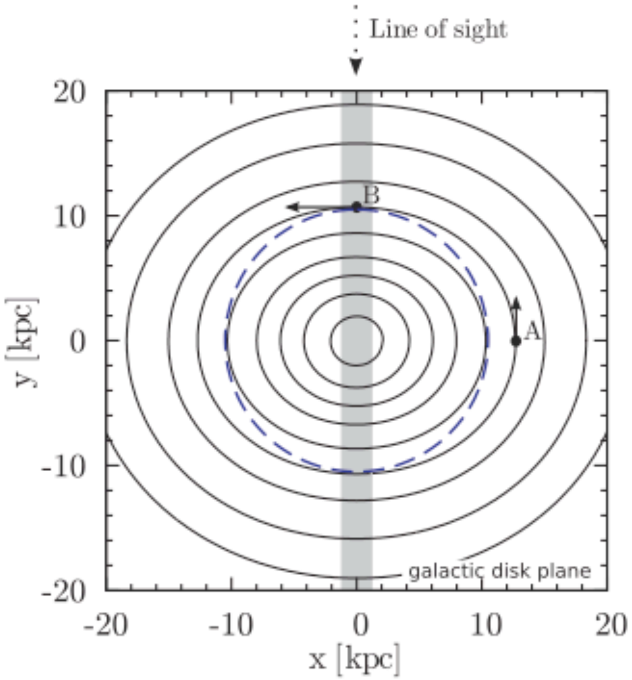

Figure 2. Closed orbits (black solid lines) within the potential of the benchmark model (Sequence 1, $M_{PR} = 1.45\, M_{disc}$) in the plane of the host galaxy. The PR, which is located in the y–z plane, is illustrated by the thick grey line. The blue dashed line is a circle which, by comparison, demonstrates the non-circularity of the closed-loop orbits. The major axis of the eccentric orbits points in the x-direction, because the test particles orbiting in the galactic disc (x–y) plane 'fall' through the PR (y–z) plane, i.e. they feel a stronger acceleration in x than in the y-direction. However, to fulfil closed orbits, the oscillation period in both directions must be the same, which means that the oscillation amplitude in the x-direction must be larger (major axis) than that in the y-direction (minor axis). The rotation velocity thus is minimal at point A (along the line of sight) and maximal at point B.

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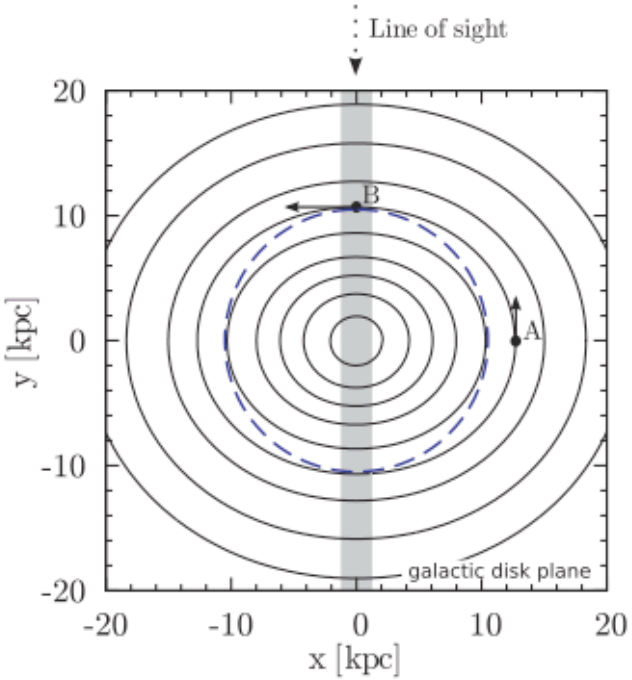

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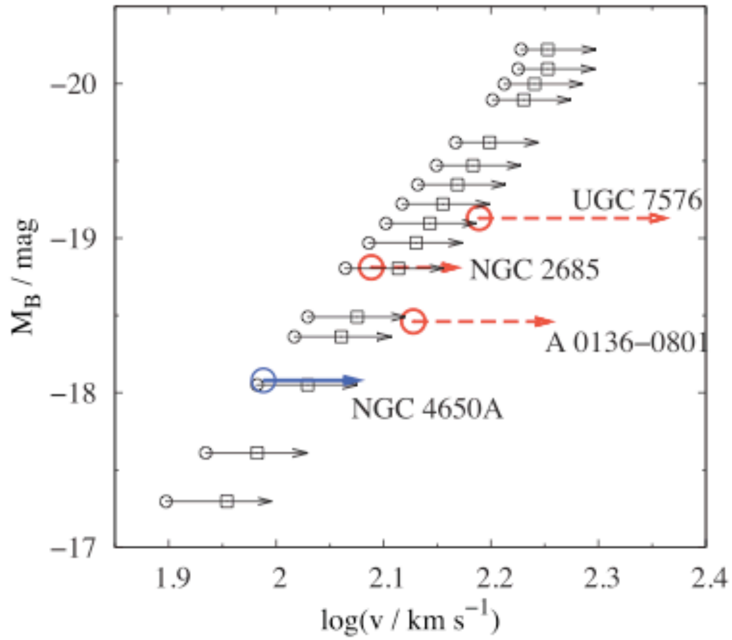

Figure 8. Comparison of observational data of PRGs with our numerical results using the luminous Tully–Fisher relation. The plot shows the absolute *B*-band luminosity in magnitudes versus the rotation velocity. Each arrow refers to one galaxy or galaxy model. The blue and red data points are adopted from Iodice et al. (2003) and represent measurements of various PRGs. The circles show the rotation velocity measured in the hosts and the arrow heads the ones measured in the PRs. The blue data correspond to NGC 4650A. For the theoretical data points (black), the squares show the rotation velocity in the host galaxy at $r = 40$ kpc, the circles show the rotation velocity in the host at $r = 15$ kpc (where it is actually measured) and the arrow heads point to the PR rotation velocity at $r = 40$ kpc. The theoretical data are obtained from models of Sequence 5. The absolute *B*-band magnitude is calculated from the total mass using a mass-to-light ratio of $M/L_B = 4$, as was assumed by Combes & Arnaboldi (1996).

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Mordecai Milgrom
(+PK)
Strasbourg, 29.06.2010.

Ansatz :

(Milgrom 1983, ApJ, 270, 371)

Pavel Kroupa: AIfA, University of Bonn

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