The "vast polar structures" (VPOSs) around the *Milky Way*, *Andromeda*, and other galaxies, and the implications thereof for fundamental physics

based on Kroupa, 2012;
http://adsabs.harvard.edu/abs/2012PASA...29..395K

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Heidelberg Joint Astronomical Colloquium
Heidelberg, 12. Nov. 2013

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 :

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

This talk
and our work in Bonn.

Standard model of cosmology :

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

Standard model of cosmology :

Assumptions are immediately falsified :

- Prediction of a highly curved highly inhomogeneous universe
- Prediction of falling *rotation curves* of galaxies and *structure formation* too slow

Solution:

- Postulate a mathematical trick (*inflation*) not understood
- Postulate existence of unknown exotic matter (*dark matter*) not found

But this also does not work:

- Universe expands today faster, than it should

Solution:

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

Problem :

- Model (=*Standard Model of Cosmology* = *LCDM*) does **not conserve energy**

Prelude

Conclusion

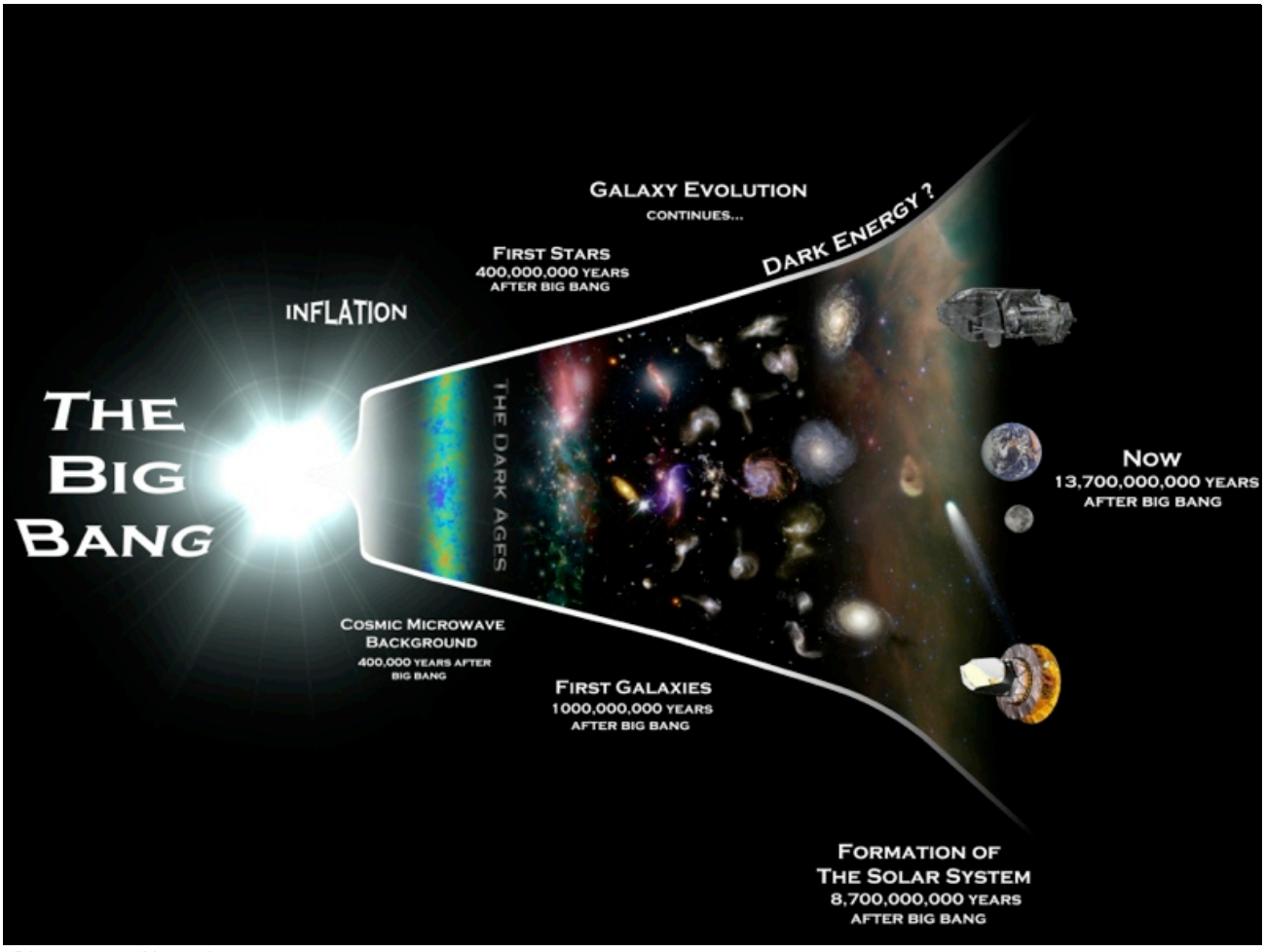
I was never against dark matter,

but when in 2010 I studied the SMoC
I had to conclude that it is the
positively worst theoretical construction
I have ever come across.

. . . but this statement does not
constitute a falsification of a model **!**

Assume **the standard model of cosmology (SMoC)**
is a valid description of the universe,

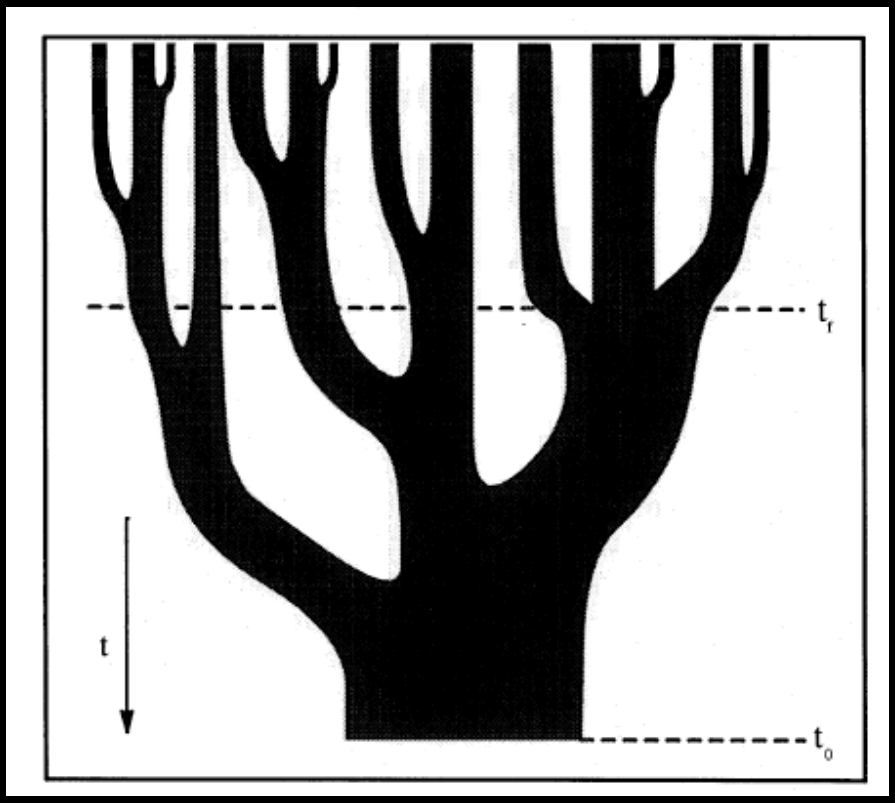
then test it where the data are of best quality . . .



Consequence I

Structures form according to the cosmological merger tree

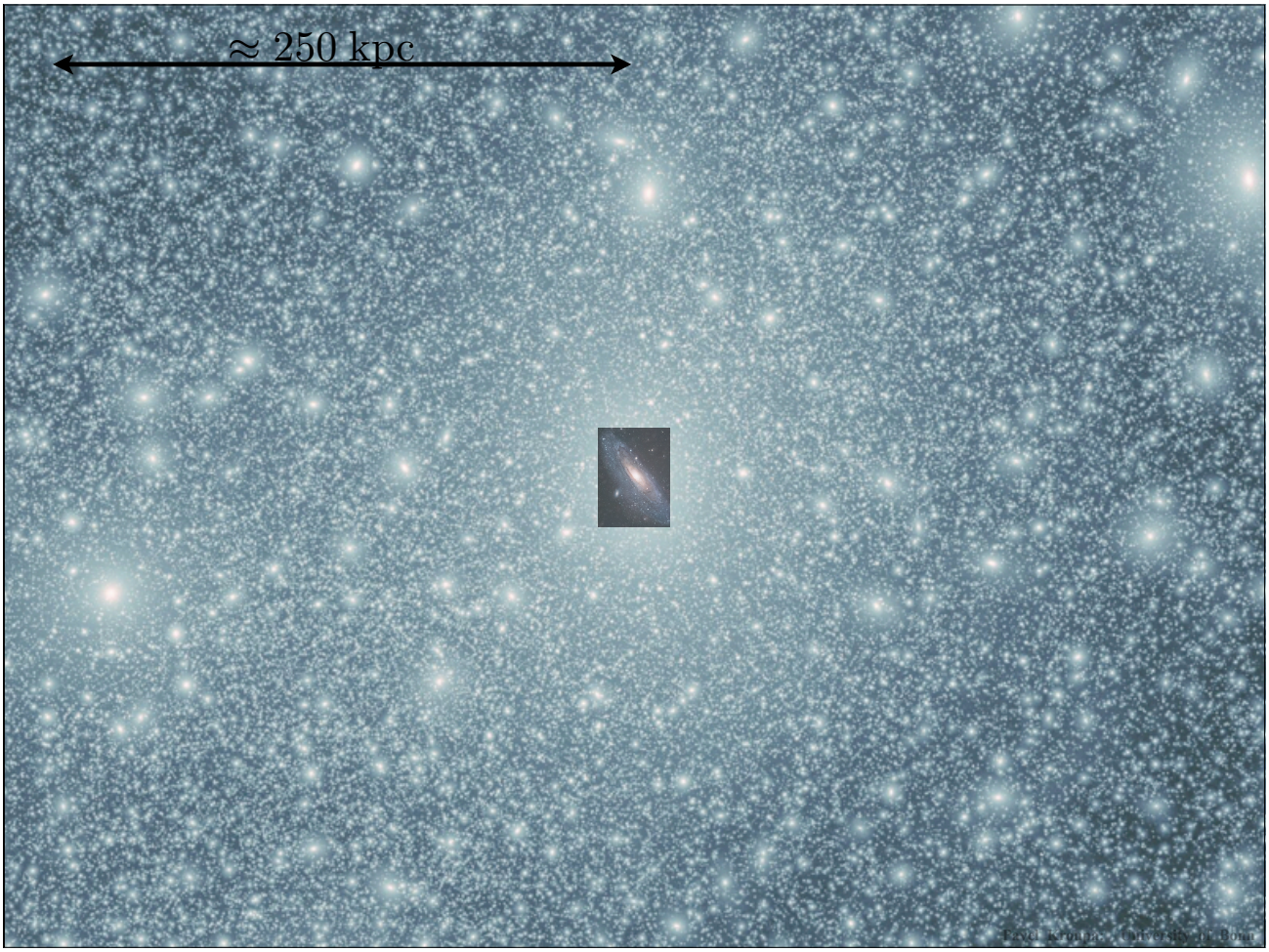
Lacey & Cole (1993)



the beginning Big Bang

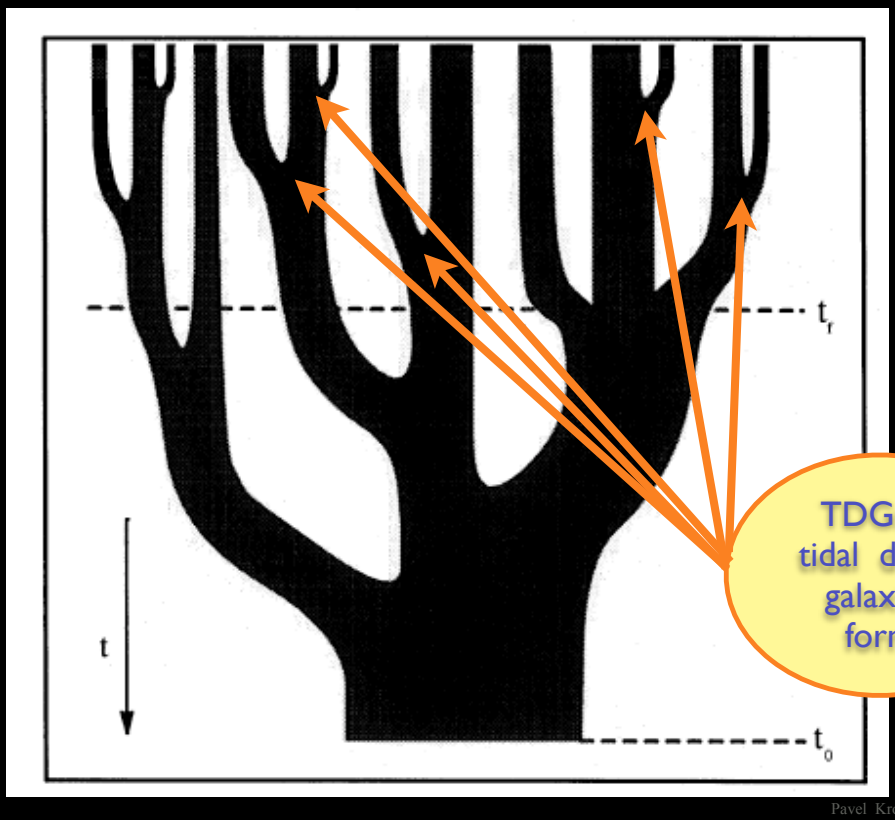
DM sub-structures form first and coalesce to larger structures

today



Consequence II

Structures form according to the cosmological merger tree



Lacey & Cole (1993)

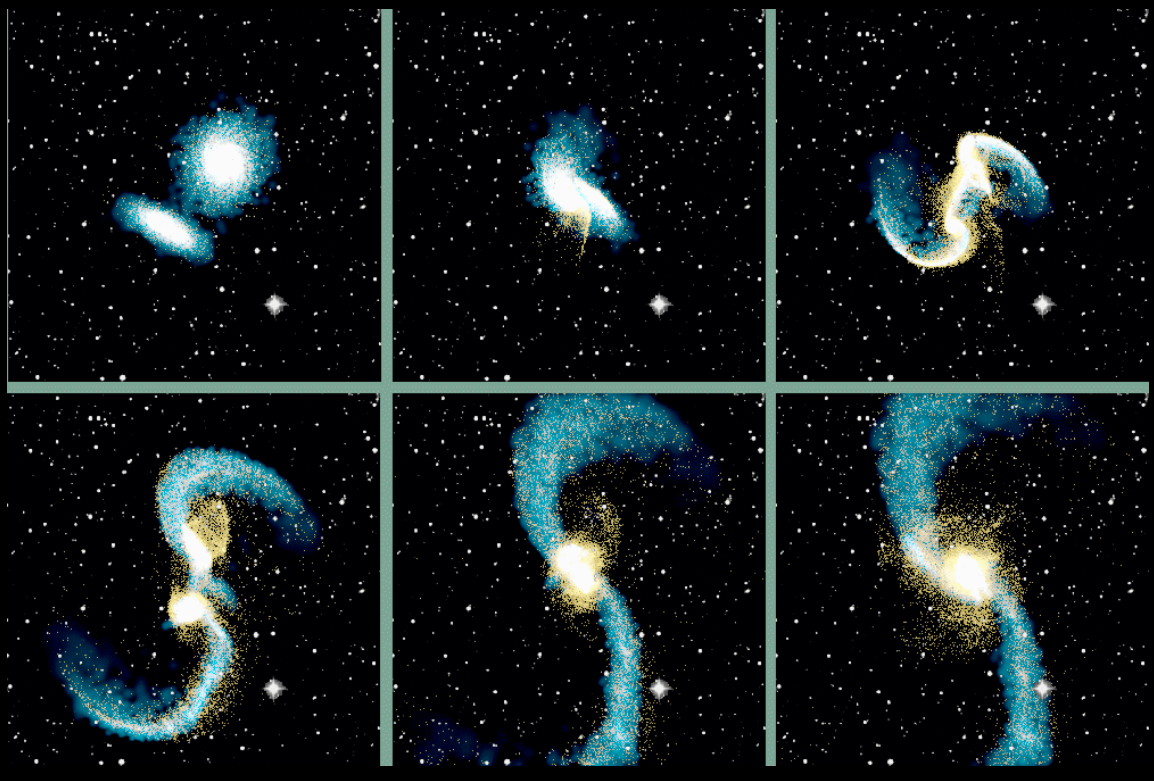
the beginning

galaxies interact and merge

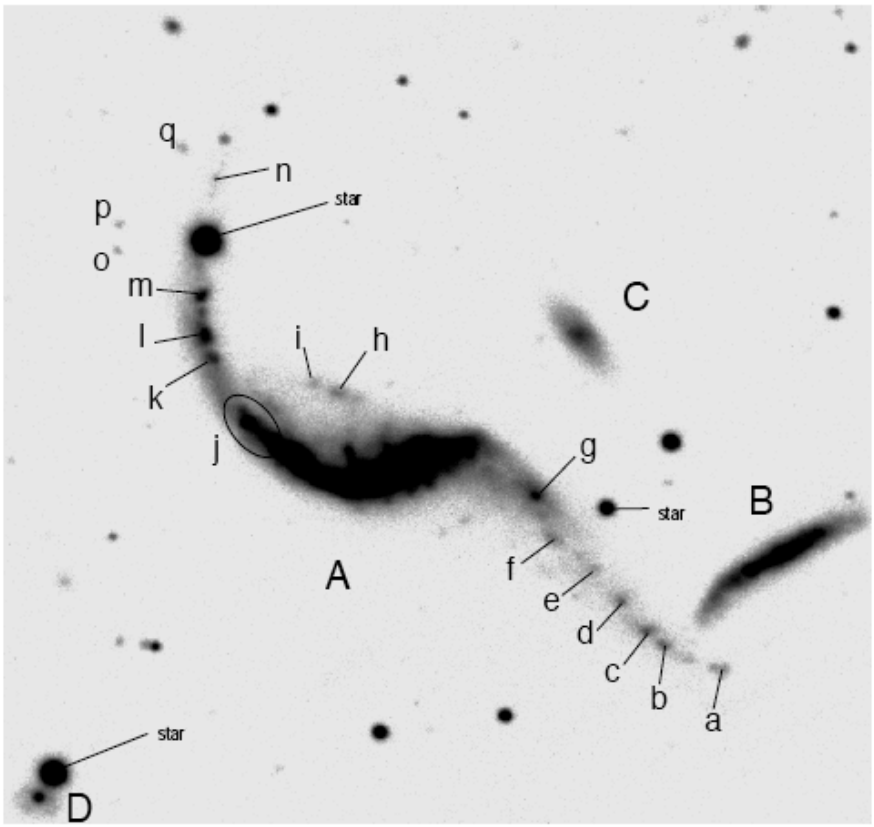
TDGs = tidal dwarf galaxies form

today

Tidal tails



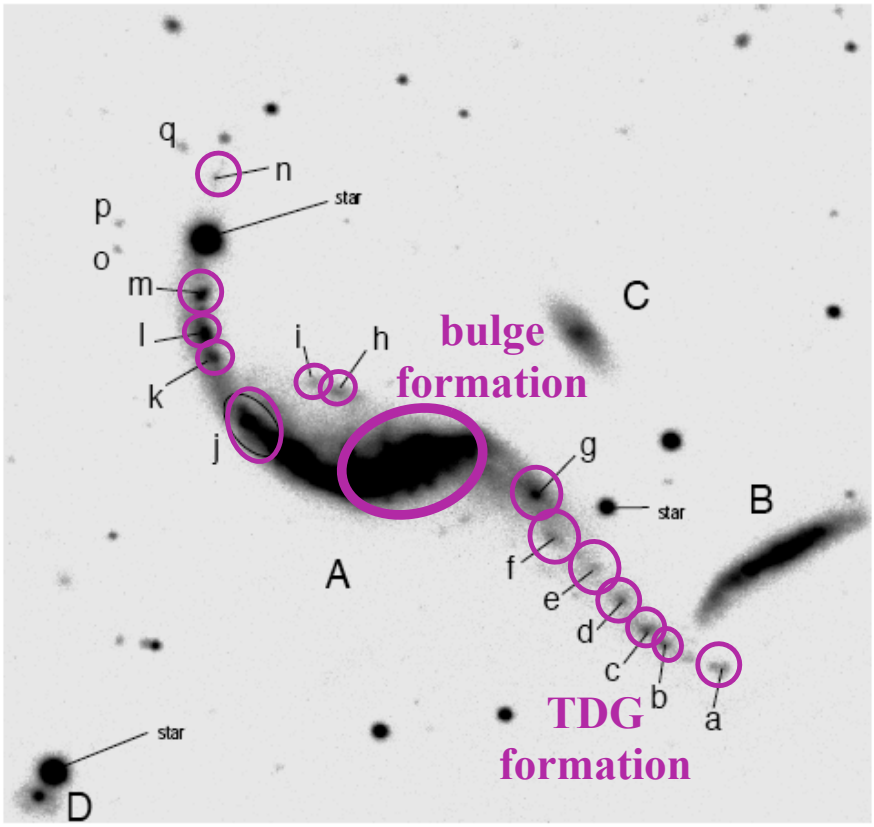
Miho & Maxwell, web



(Weilbacher et al. 2000)

$N_{\rm TDG} \approx 14$

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

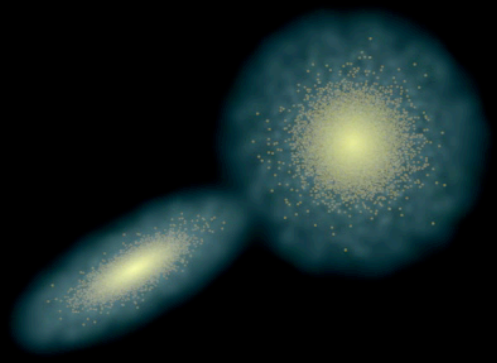


(Weilbacher et al. 2000)

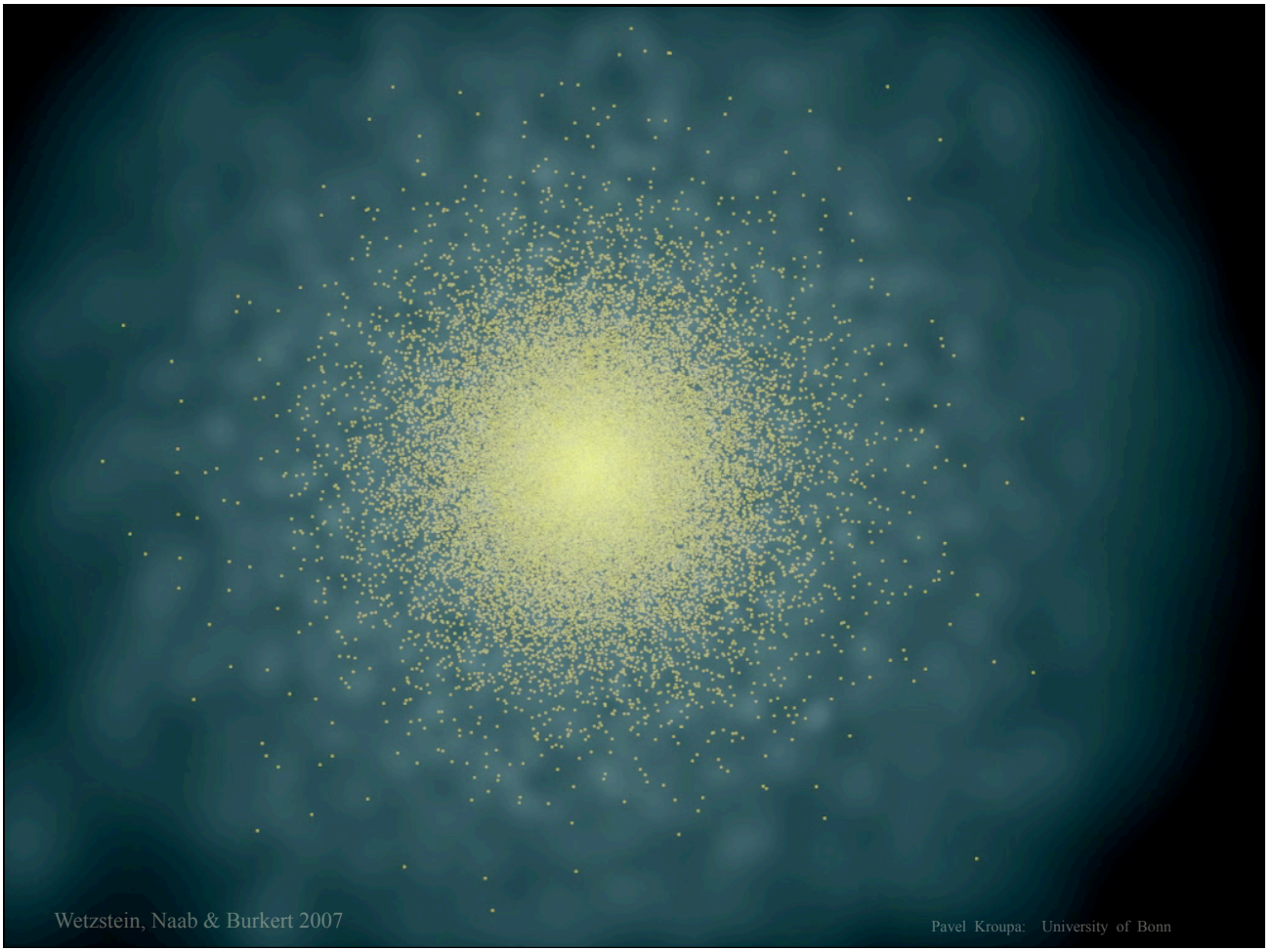
Phase-space correlated satellites form naturally in the same event as a *bulge* does.

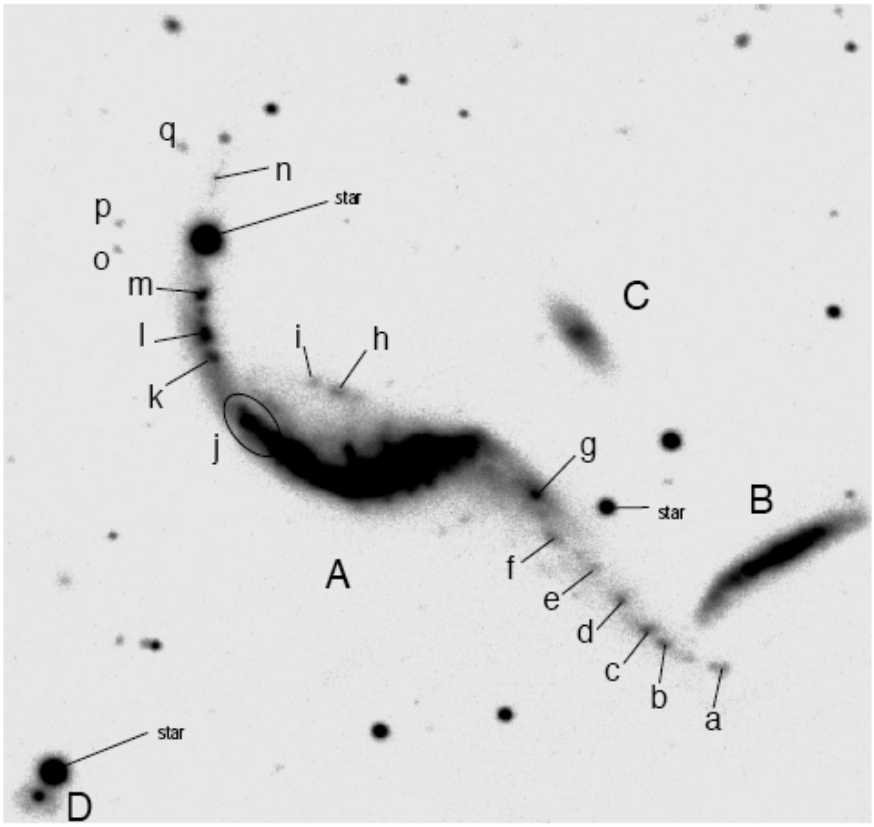
Fig. 21. Identification chart of field 10 around AM 1353-272.

Relevance : The collision of two disks at high redshift



Wetzstein, Naab & Burkert 2007



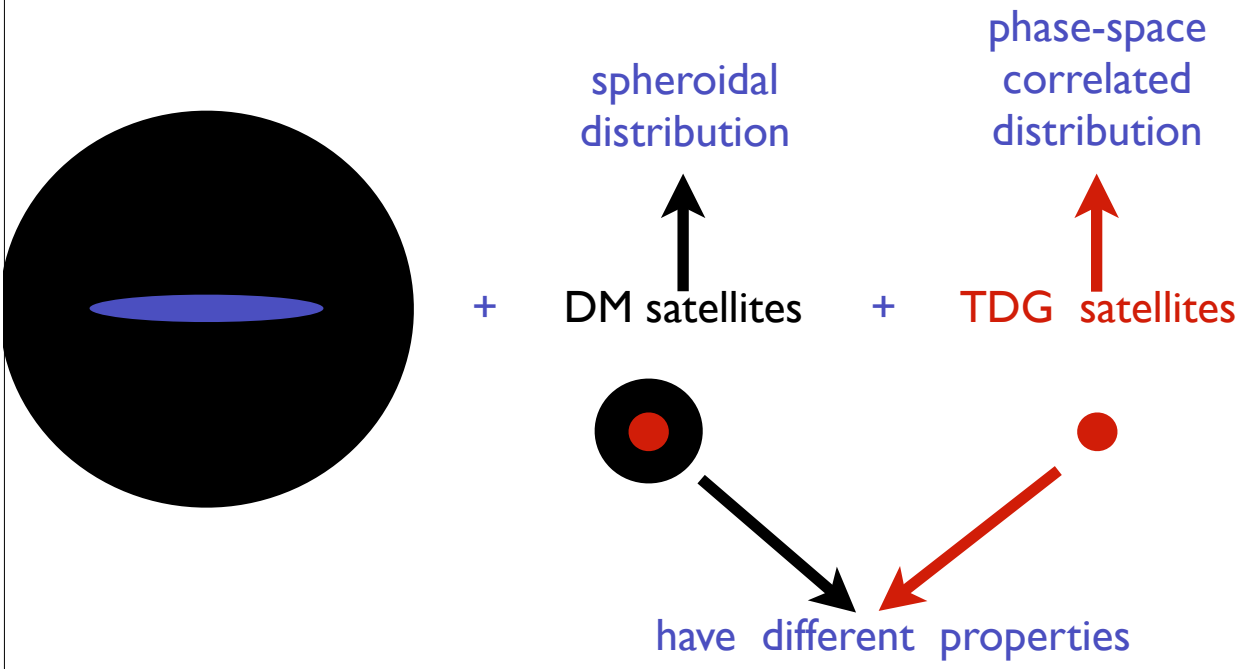


(Weilbacher et al. 2000)

$N_{\rm TDG} \approx 14$

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

Thus in the *Standard Model of Cosmology* (SMoC) a galaxy must look as follows:



The Dual Dwarf Galaxy Theorem must be true if the SMoC is true :

The Dual Dwarf Galaxy Theorem :

SMoC $\Rightarrow$ $\exists$ Type A dwarfs $\wedge$ Type B dwarfs

Kroupa 2012

with Dark Matter (DM) — spheroidal distribution

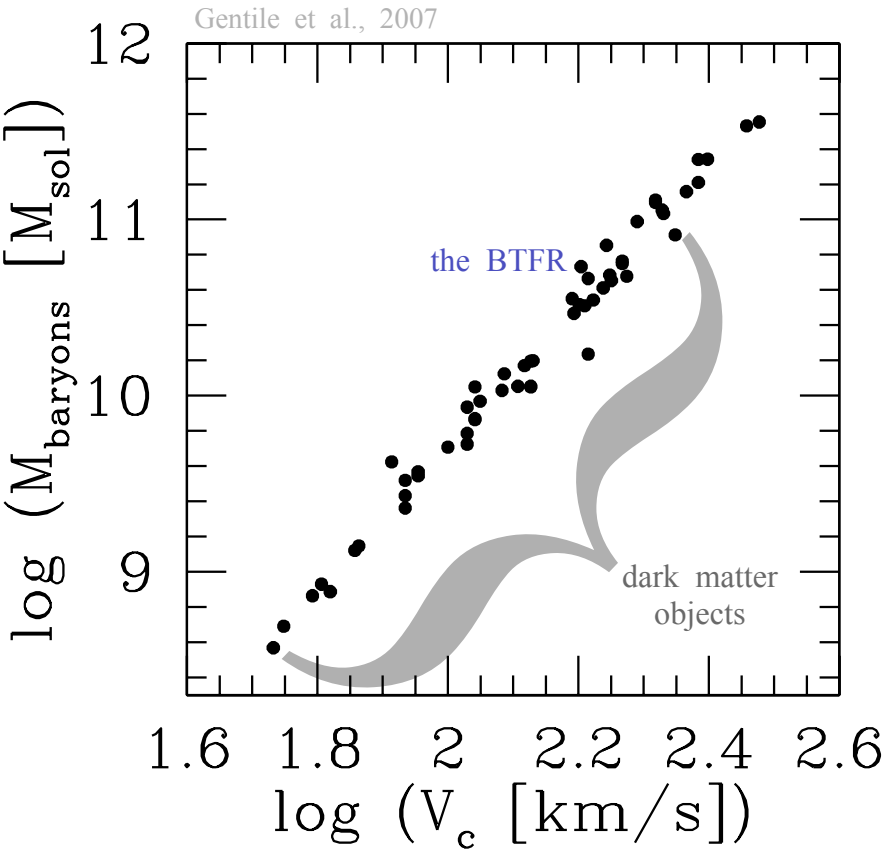
TDGs w/o DM — phase-space correlation

If only one type exists then the Dual Dwarf Galaxy Theorem is falsified.

Is there any evidence for the co-existence of two types of dwarf galaxy ?

Testing the dual dwarf galaxy theorem

Rotationally-supported stellar systems



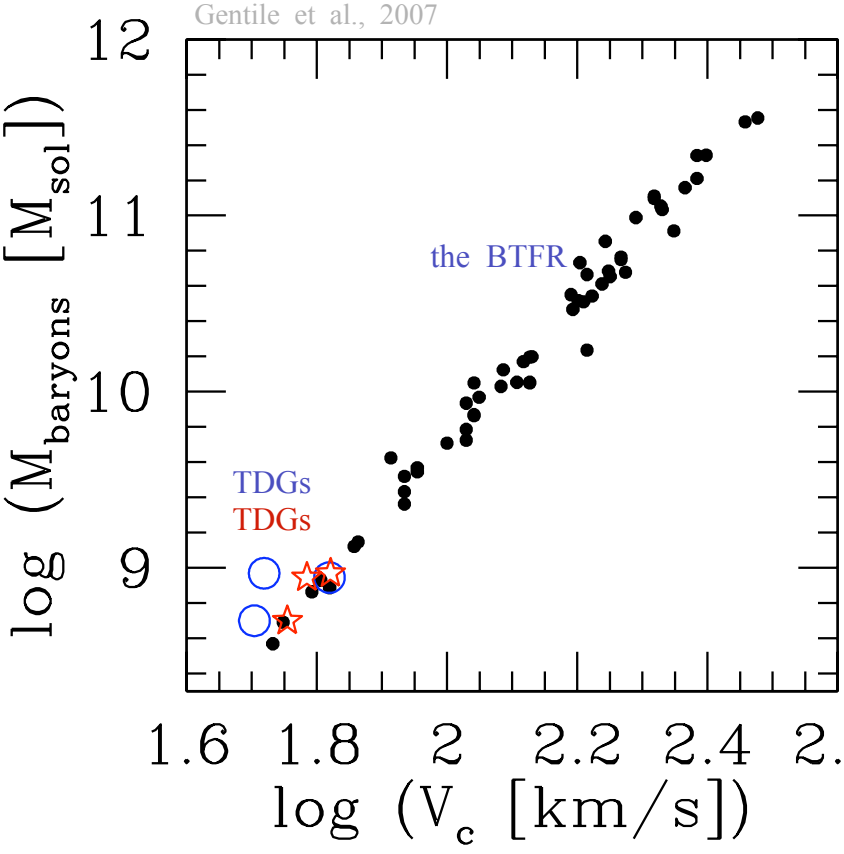
The Baryonic Tully -Fisher Relation :

If the SMoC is true
then the
BTFR
must
be given
by the dark matter halo

and
tidal dwarf galaxies
cannot
lie on the same BTFR !

Rotationally-supported stellar systems

Gentile et al., 2007



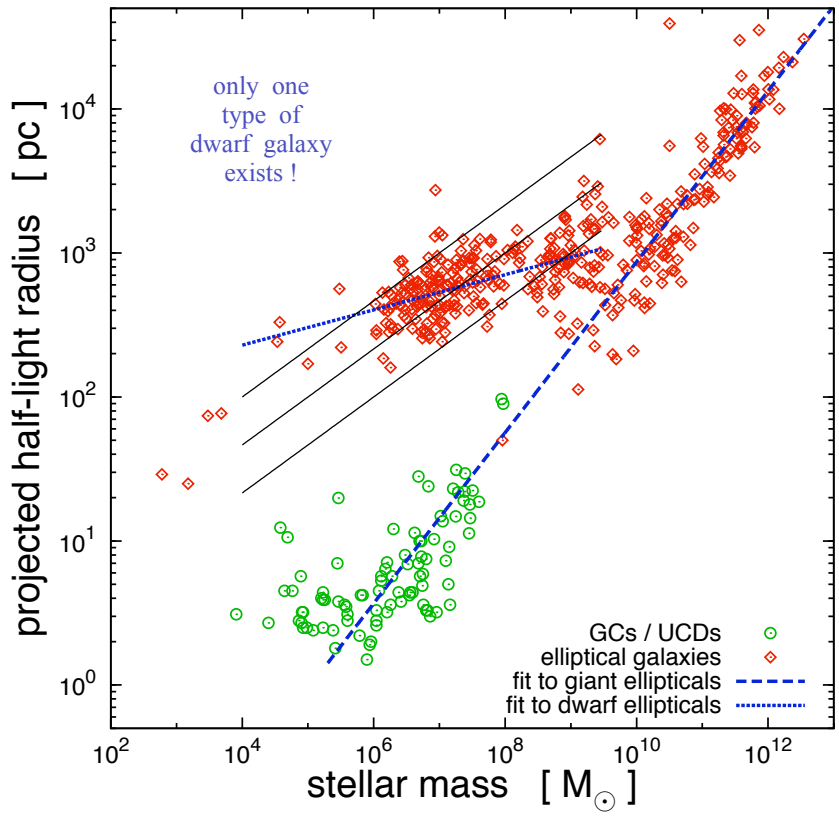
The Baryonic Tully -Fisher Relation :

But TDGs do lie on the same BTFR !?

galaxies with dark matter
=
galaxies w/o dark matter
!

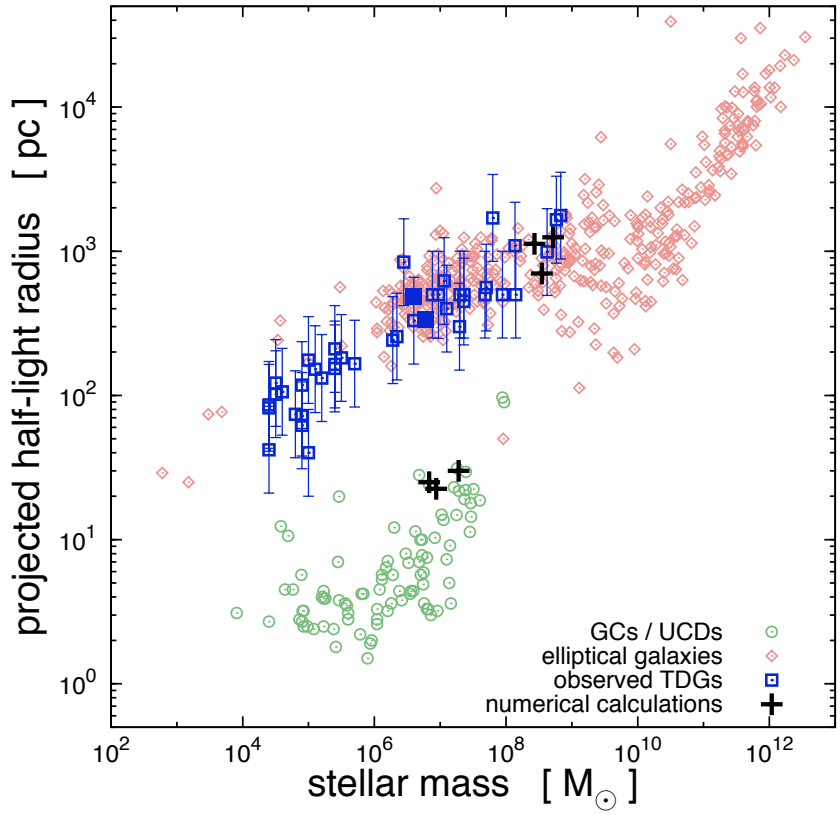
Pressure / random-motion supported stellar systems

Dabringhausen et al. 2012



Pressure / random-motion supported stellar systems

Dabringhausen et al. 2012



TDGs coincide with dE / dSph satellites

galaxies with dark matter = galaxies w/o dark matter !

Thus:

Kroupa 2012;
Dabringhausen & Kroupa 2013

The Dual Dwarf Galaxy Theorem :

SMoC $\Rightarrow$ $\exists$ Type A dwarfs $\wedge$ Type B dwarfs

$\Rightarrow$ only one type of dwarf galaxy is observed.

$\Rightarrow$ Dual Dwarf Galaxy Theorem is falsified.

$\Updownarrow$

Type A dwarf = Type B dwarf $\Rightarrow$ ~~SMoC~~

has been shown

THE END

Consistency Checks

Remember :

The Dual Dwarf Galaxy Theorem must be true if the SMoC is true : Kroupa 2012; Dabringhausen & Kroupa 2013

The Dual Dwarf Galaxy Theorem :

SMoC $\Rightarrow$ $\exists$ Type A dwarfs $\wedge$ Type B dwarfs

with DM TDGs w/o DM

spheroidal distribution

phase-space correlation

consistency check next . . .

Pavel Kroupa: University of Bonn

Concistency Check I

If
the Milky Way satellites are
TDGs without dark matter
then
they ought to be in a
phase-space correlated distribution.

Vast Polar Structure around the Milky Way

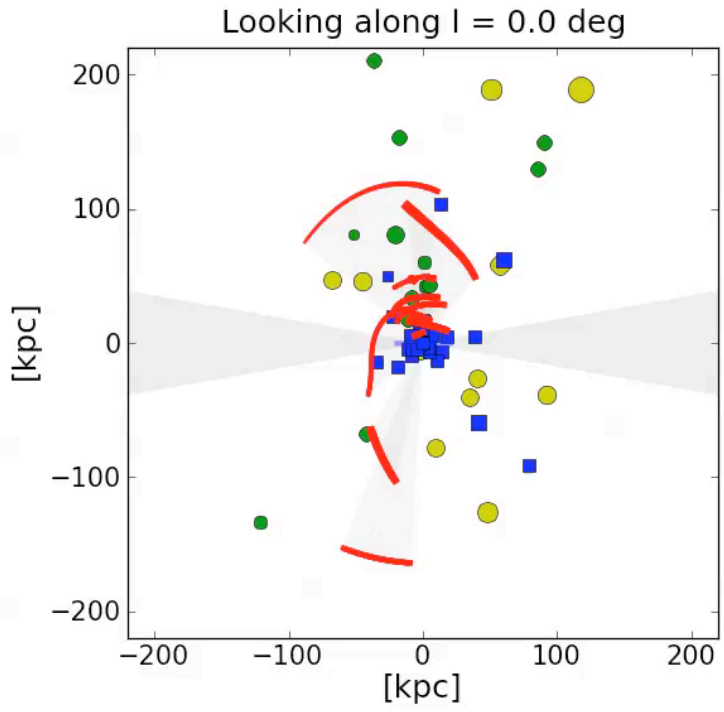
Pawlowski et al. 2012

YH globular clusters

dSph satellites

UFD satellites

streams



See also
YouTube video
"The Vast Polar Structure"

Vast Polar Structure around the Milky Way

Pawlowski et al. 2012

YH globular clusters

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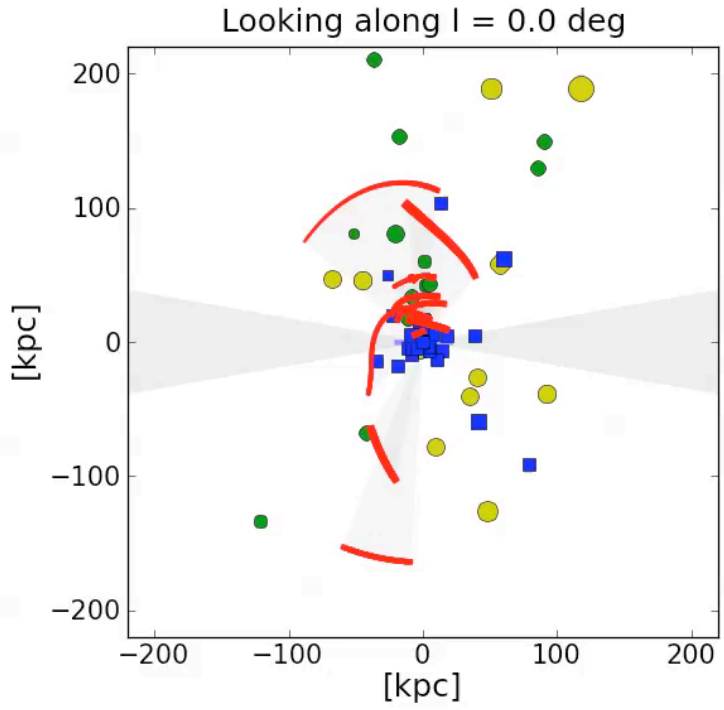
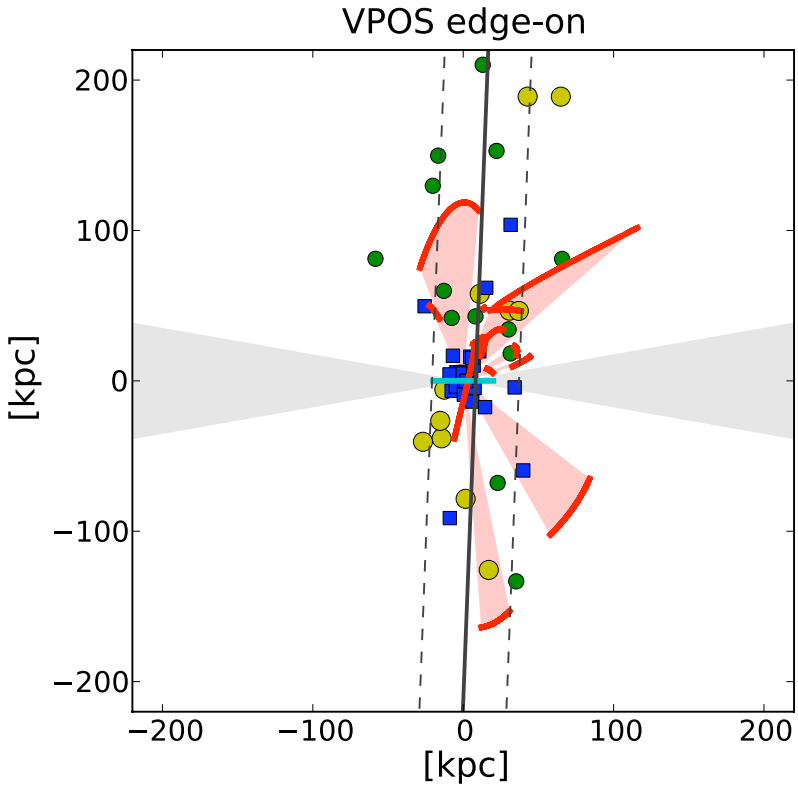


See also *YouTube video* "The Vast Polar Structure"

Vast Polar Structure around the MW

Pawlowski et al. 2012



Concistency Check I

If
the Milky Way satellites are
TDGs without dark matter
then
they ought to be in a
phase-space correlated distribution.

YES they are !

If the MW satelites are DM dominated sub-halos,
then

A) they have to have fallen-in recently (z<1) in order to be arranged in the DoS/VPOS
Deason et al. (2011)

AND

B) they have to have fallen in a long time ago (z=3-10) in order for them to have lost their gas
Nichols & Bland-Hawthorn (2011)

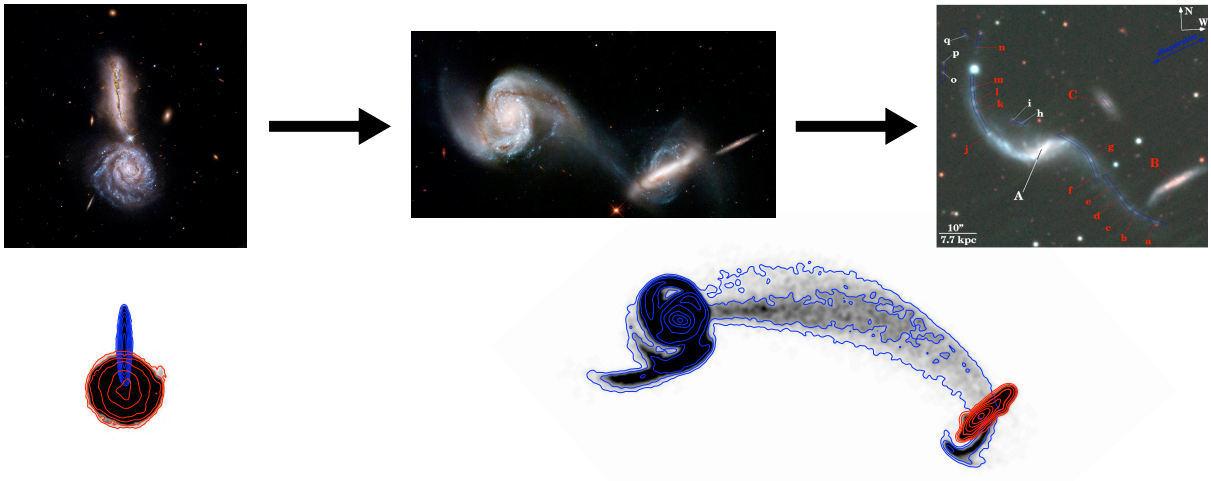
A and B are mutually exclusive.

==> further logical inconsistency of the standard cosmological model

Origin of the Vast Polar Structure ?

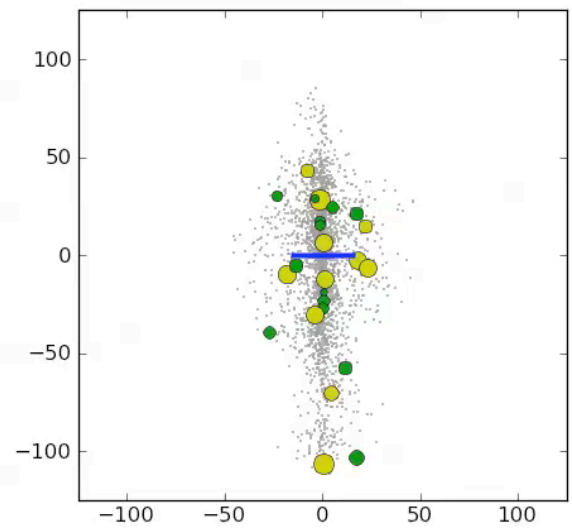
Phase-space-correlated tidal debris

Pawlowski et al. 2012



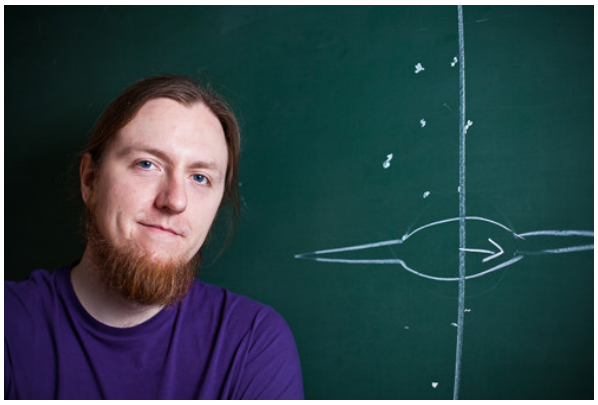
Fly-by encounter: e.g. Milky Way and Andromeda ? about 10-11 Gyr ago

Pawlowski et al. 2011



See also Fouquet, Hammer et al. (2012) for another elegant explanation.

The Milky Way satellite-galaxy system
is thus naturally explained
as having been born in a past encounter
between the young Milky Way and another young galaxy.



Marcel Pawlowski (Bonn)
/ structure of Local Group

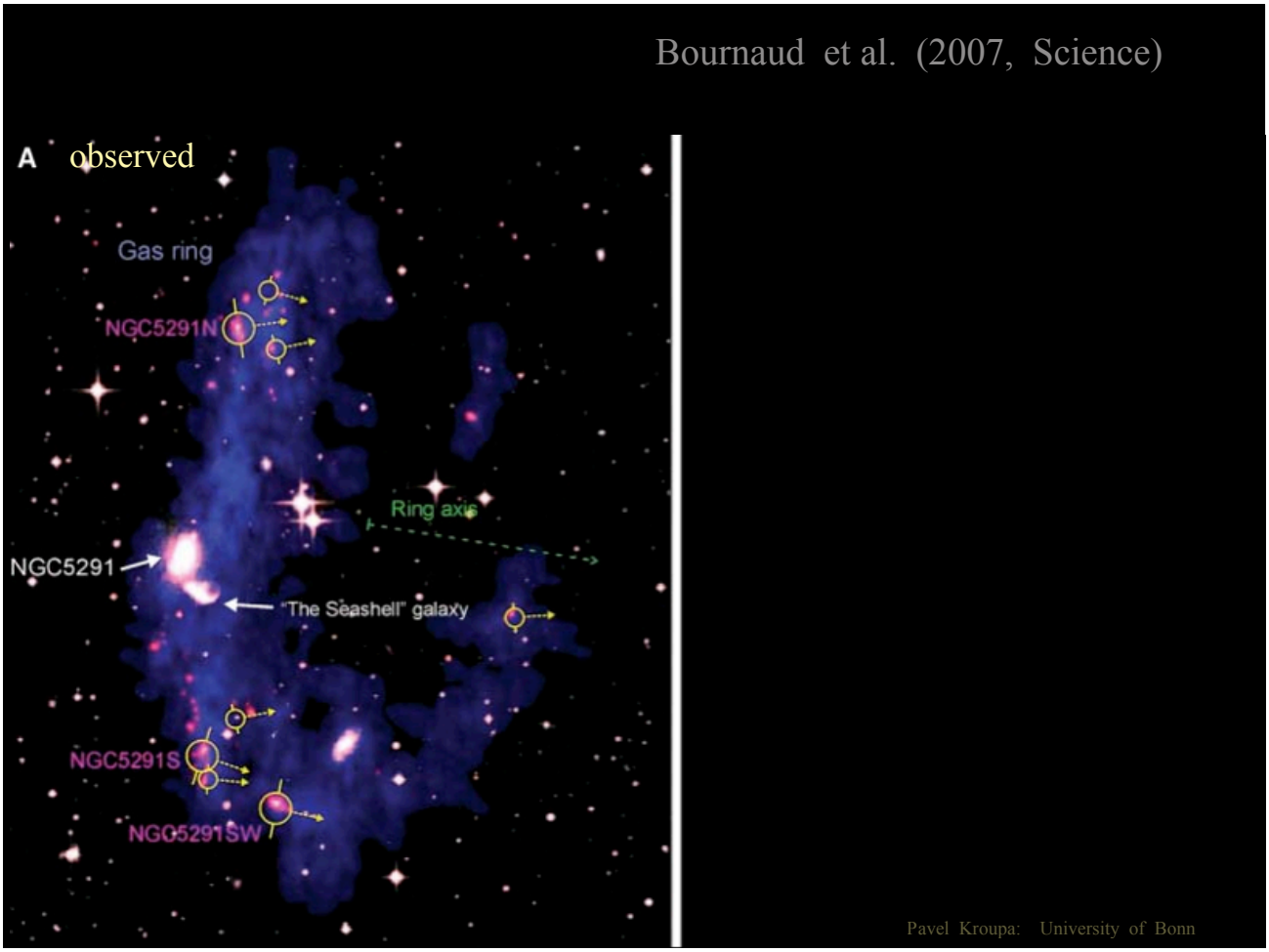
Joerg Dabringhausen (Bonn)
/ properties of TDGs

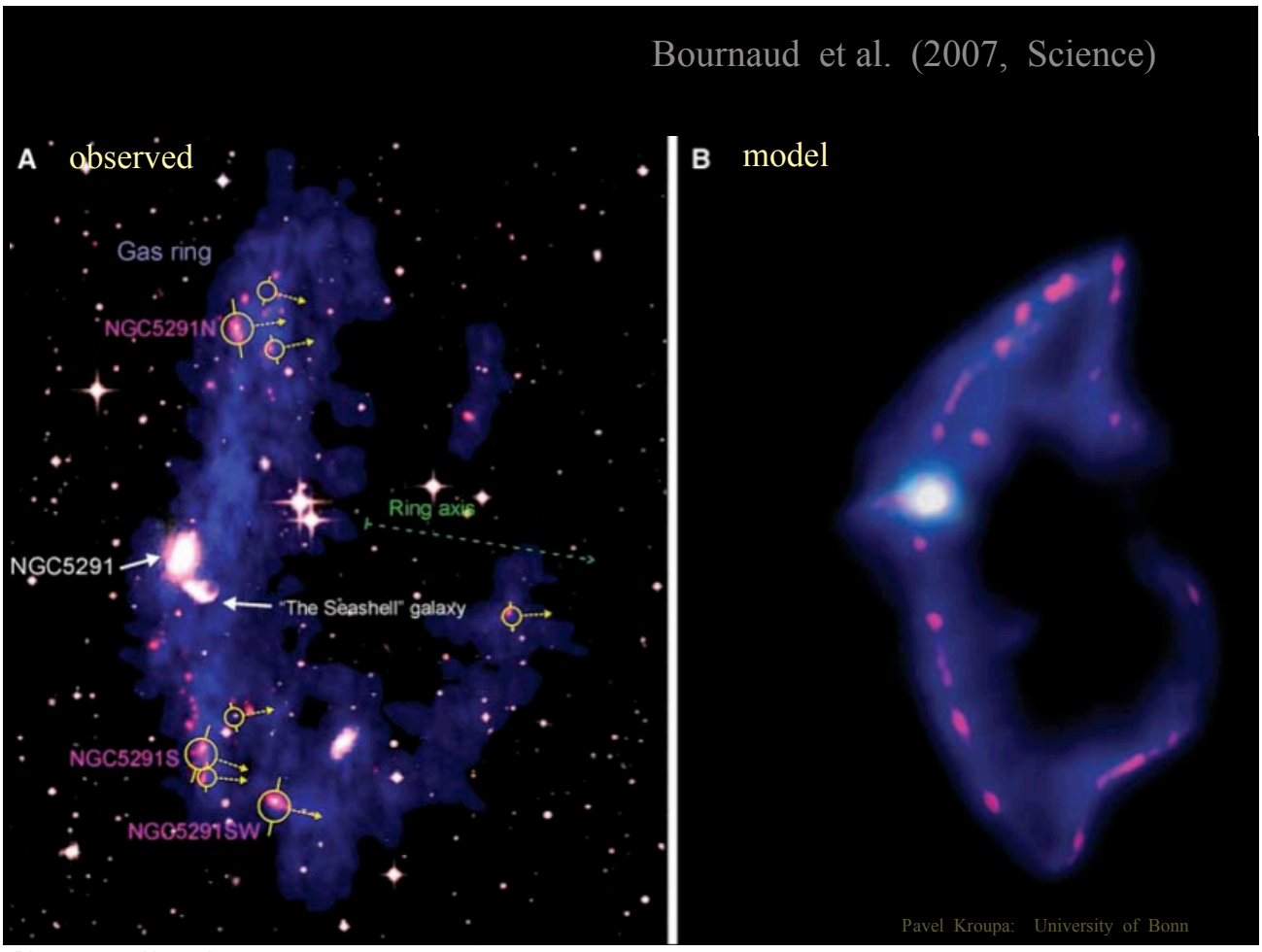
Sylvia Ploeckinger (Vienna) / evolution of TDGs

Concistency Check II

Other, extra-galactic,
phase-space correlated distributions
of satellite systems.

Is the Milky Way galaxy unique or
an extreme outlier **?**


Bournaud et al. (2007, Science)
A observed
Gas ring
NGC5291N
Ring axis
NGC5291
"The Seashell" galaxy
NGC5291S
NGC5291SW
Pavel Kroupa: University of Bonn


Bournaud et al. (2007, Science)
A observed
B model
Gas ring
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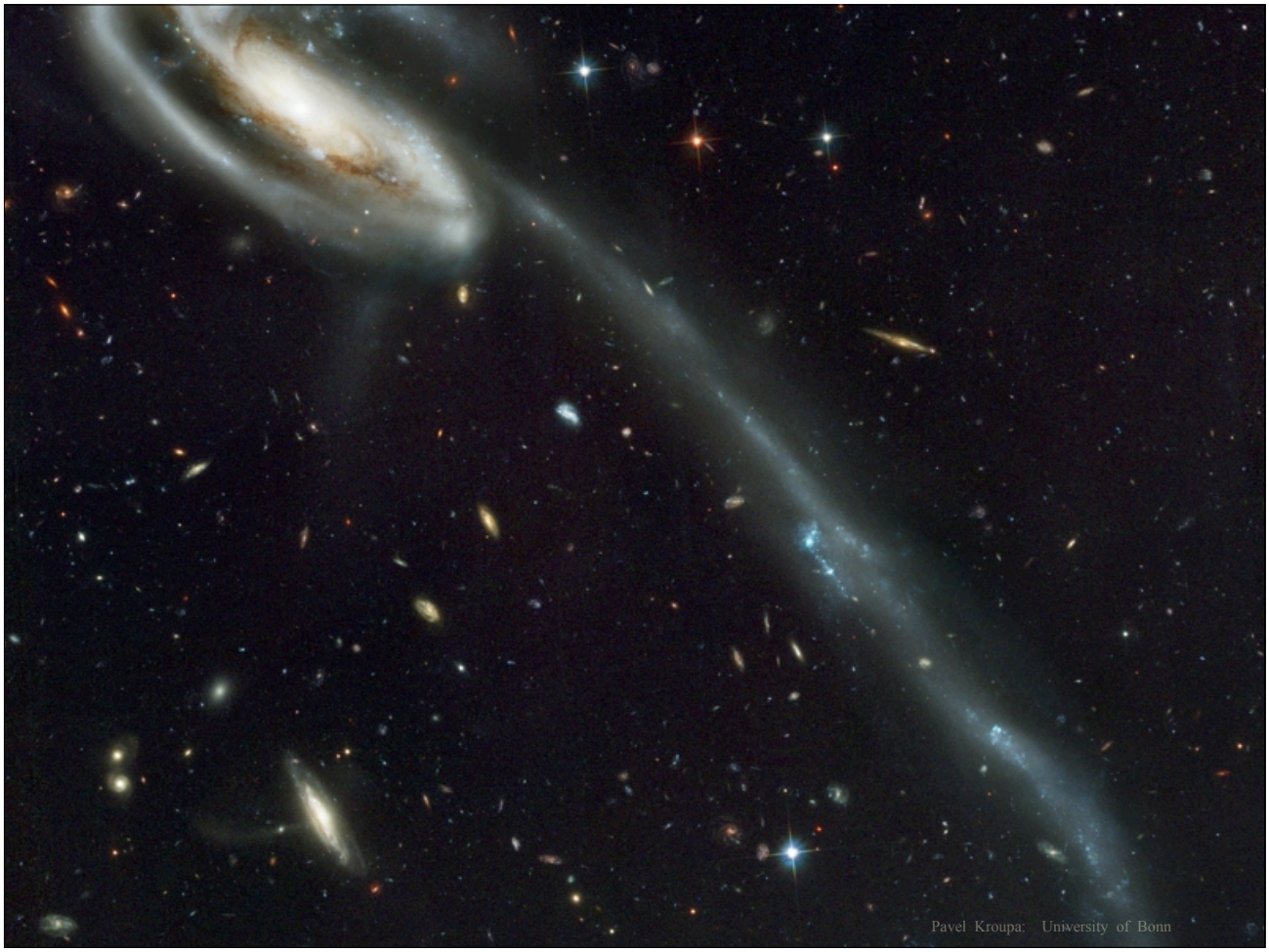
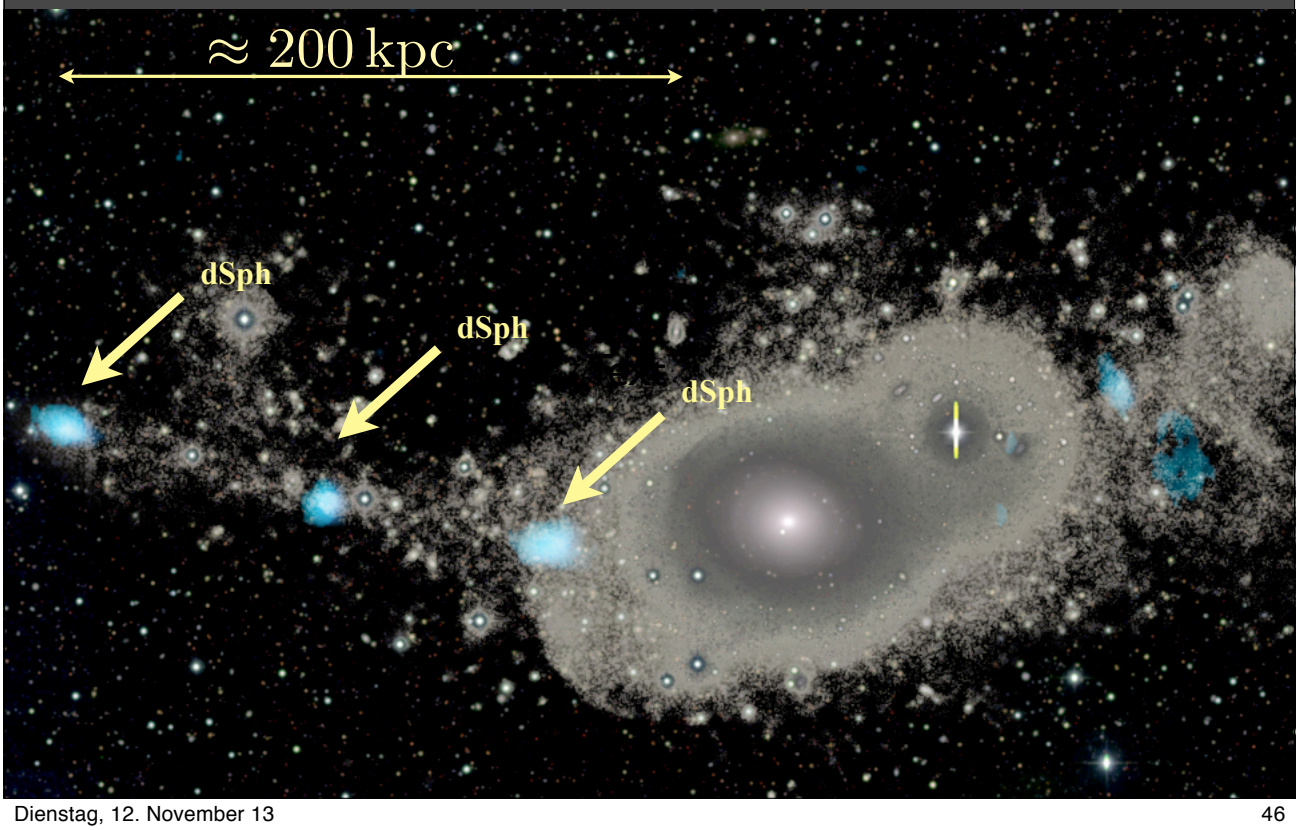


NGC 5557

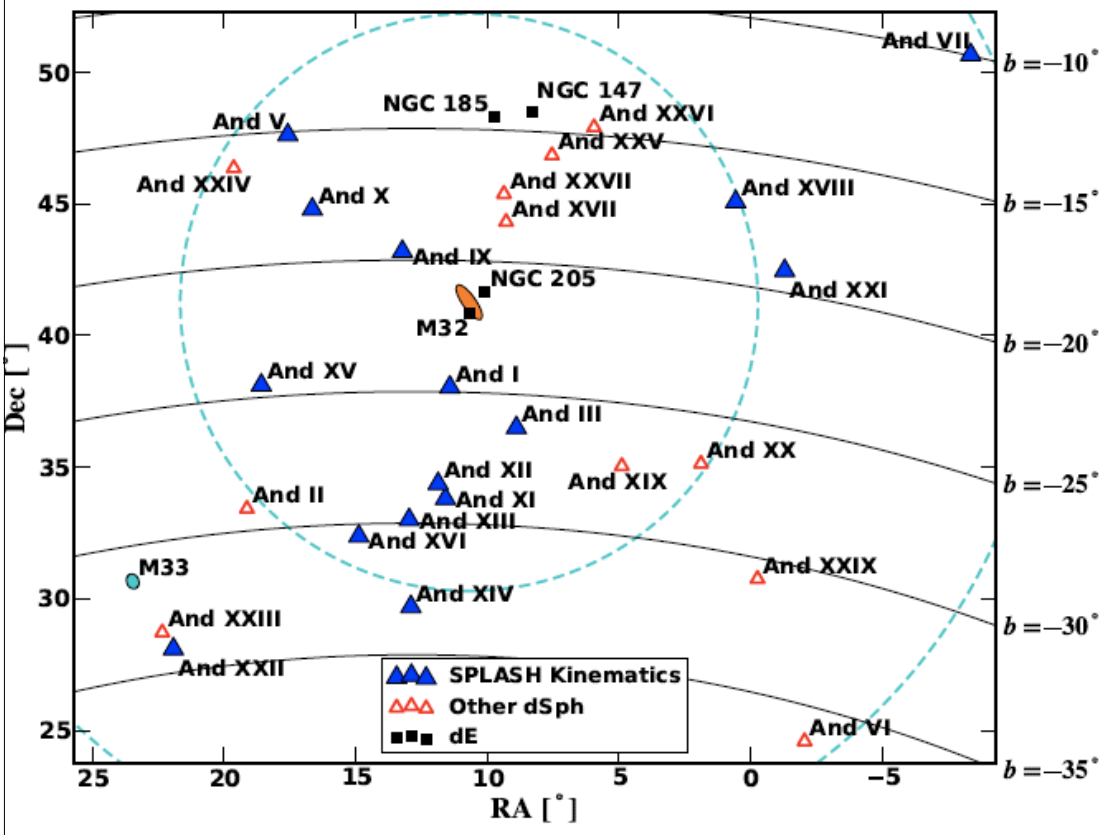
(post-merger 2-3 Gyr)

Duc et al. (2011 MNRAS)



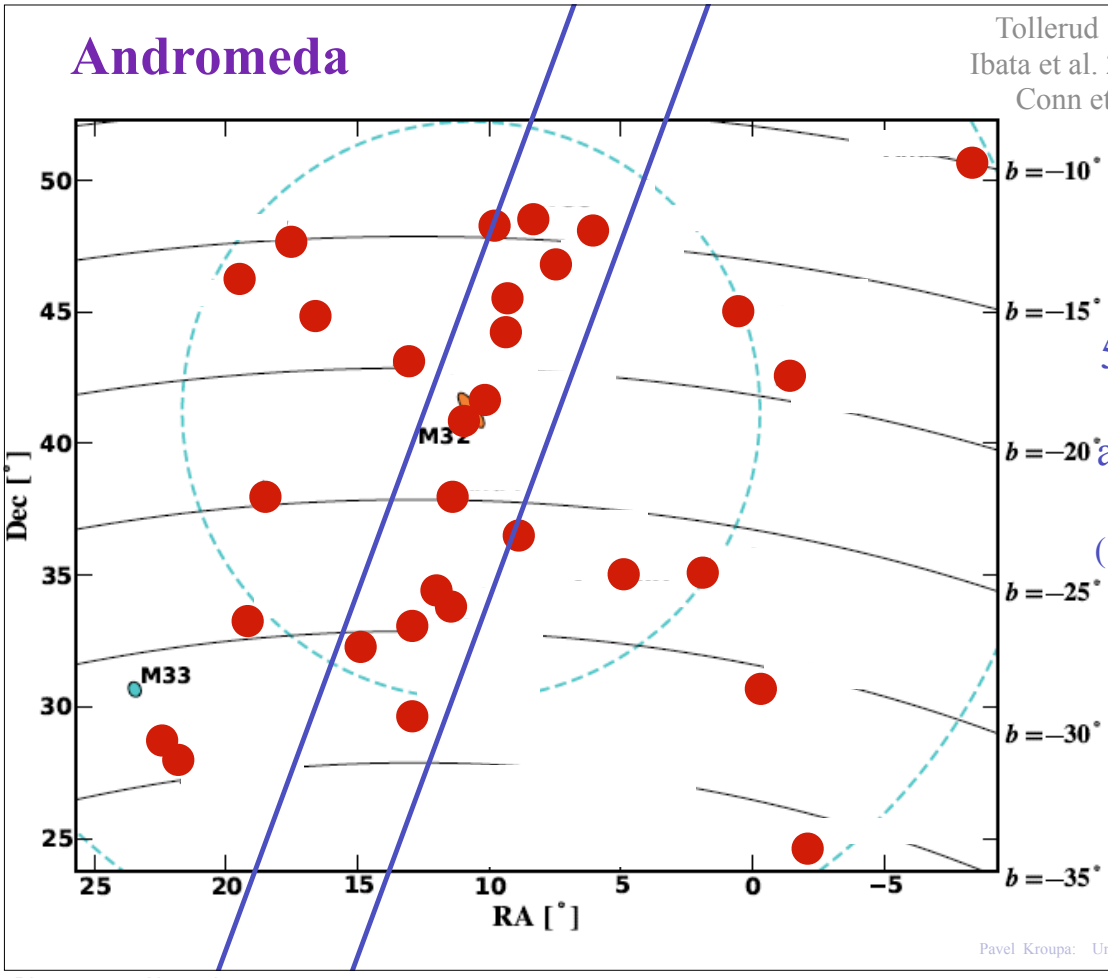
Andromeda

Tollerud et al. (2011, MNRAS)

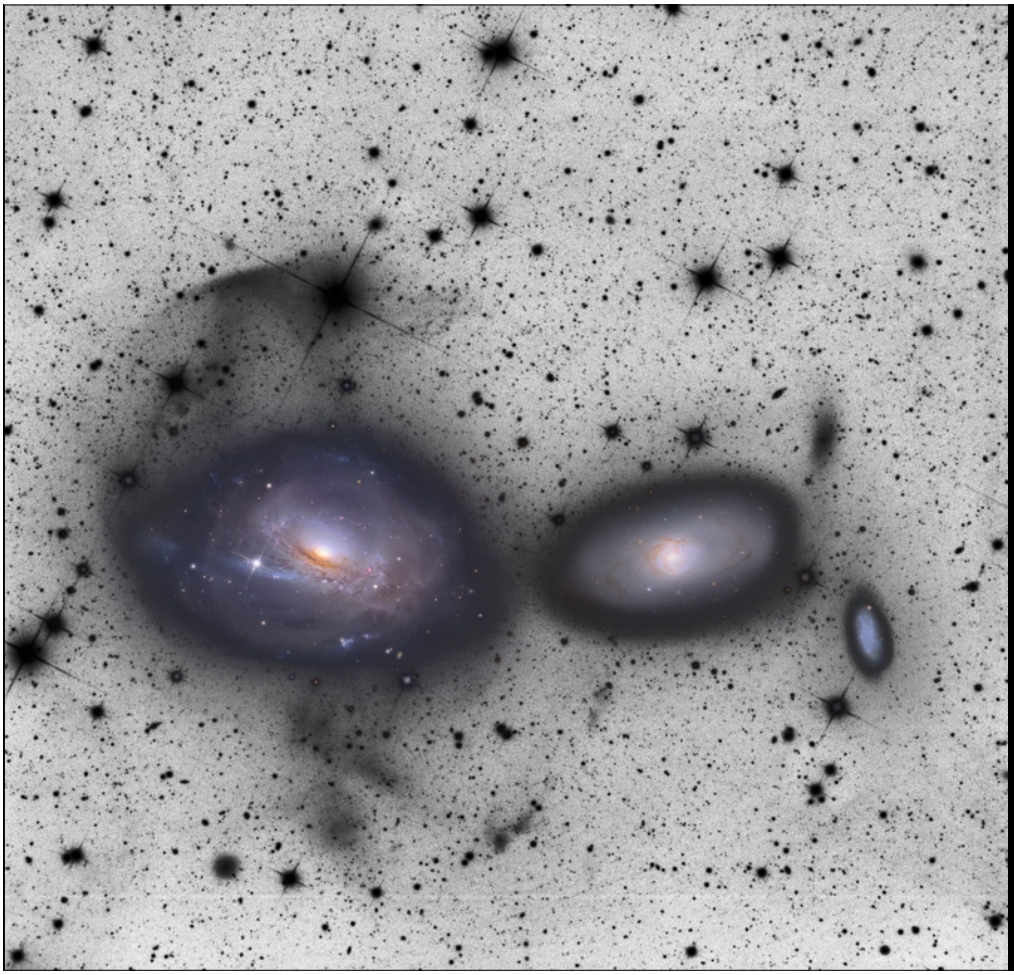


Andromeda

Tollerud et al. 2011, Ibata et al. 2013, Nature; Conn et al. 2013)

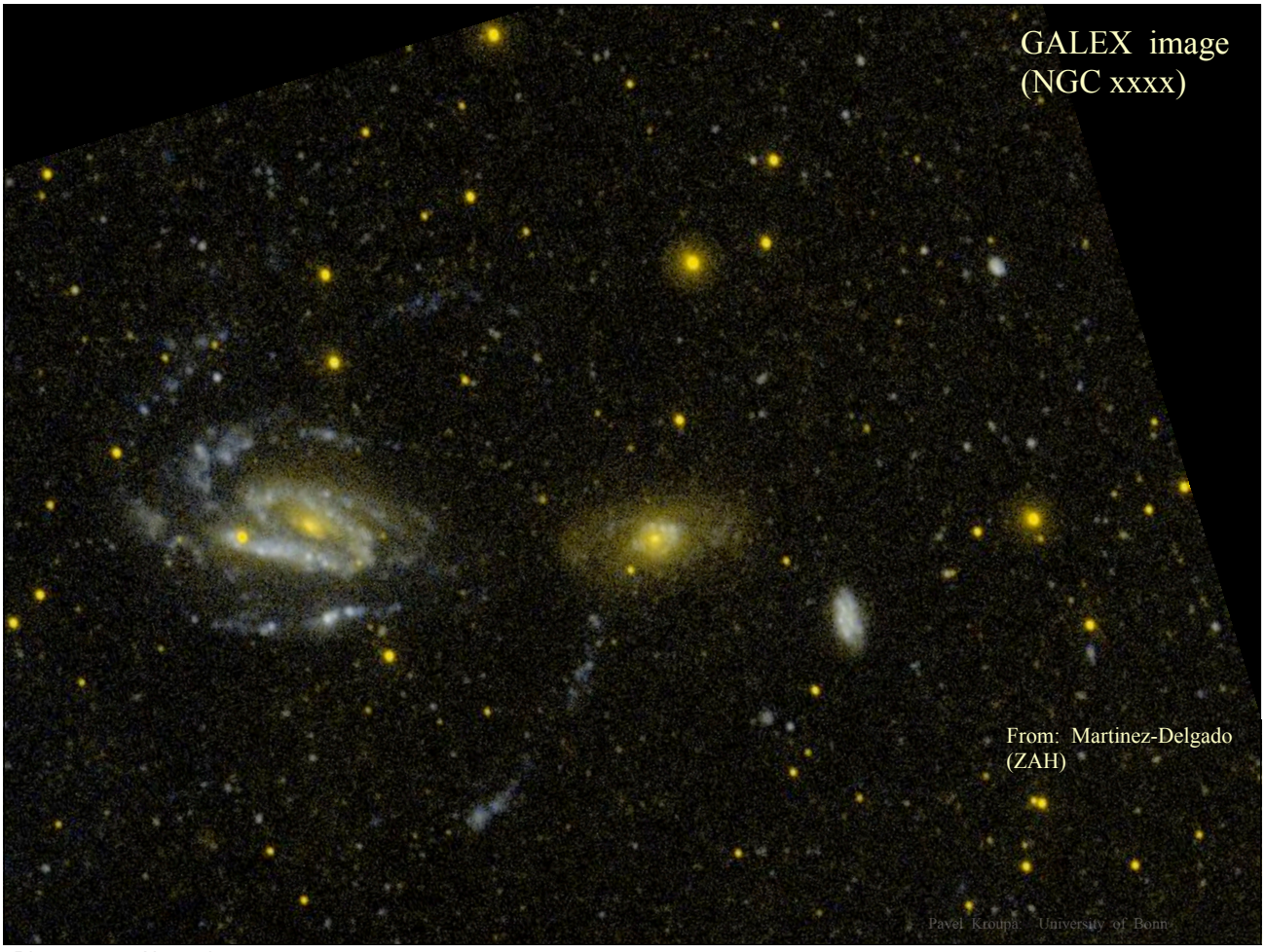


50 % of all satellites are in thin disk (14 : 400kpc).



The formation of faint dwarf galaxies in the interaction between two spirals (NGC xxxx)

Credit: Martinez-Delgado (ZAH) and Adam Block (MtLemmon Obs)



GALEX image (NGC xxxx)

From: Martinez-Delgado (ZAH)

Concistency Check II

Other, extra-galactic,
phase-space correlated distributions
of satellite systems.

Is the Milky Way galaxy unique or an extreme outlier ?

NO, it is not !

Remember :

Kroupa 2012

The Dual Dwarf Galaxy Theorem must be true if the SMoC is true :

The Dual Dwarf Galaxy Theorem :

SMoC $\Rightarrow$ $\exists$ Type A dwarfs $\wedge$ Type B dwarfs

with DM | TDGs w/o DM

spheroidal distribution | phase-space correlation

consistency check next . . .

Thus:

Kroupa 2012

The Dual Dwarf Galaxy Theorem **:**

SMoC $\Rightarrow$ $\exists$ Type A dwarfs $\wedge$ Type B dwarfs

$\Rightarrow$ only one type of dwarf galaxy is observed.

$\Rightarrow$ Dual Dwarf Galaxy Theorem is falsified.

$\Updownarrow$

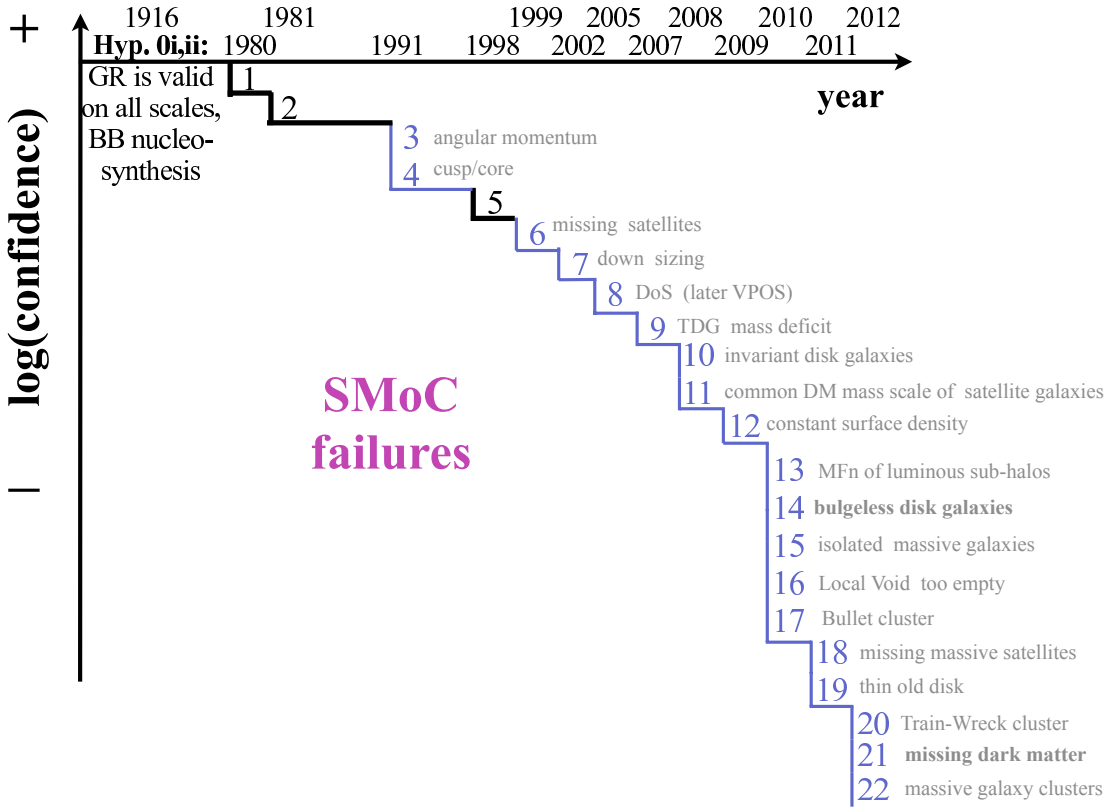
Type A dwarf = Type B dwarf $\Rightarrow$ ~~SMoC~~

has been shown

If this falsification is true,
then the
standard model of cosmology
must show other and general
discrepancies
with data . . .

The Theory Confidence Graph

Kroupa 2012



Kroupa 2012

Neither the observed (real) galaxies nor the nearby 50Mpc universe show properties typical of dark matter.

Cold or warm dark matter particles therefore cannot exist.

(**Remember:** Cold or warm dark matter is postulated as a result of adopting the Einstein's field equation on galactic and cosmological scales)

The SMoC cannot be the correct description of this universe.

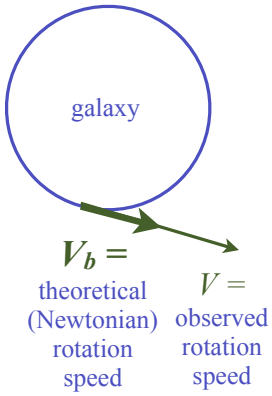
Which impact does this have for fundamental physics ?

Do the data on galaxy-scales contain clues ?

Mass-Discrepancy correlation with acceleration

The McGaugh correlation

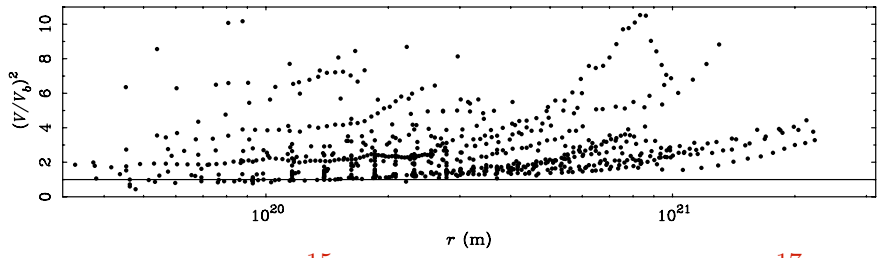
McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012



V_b = theoretical (Newtonian) rotation speed

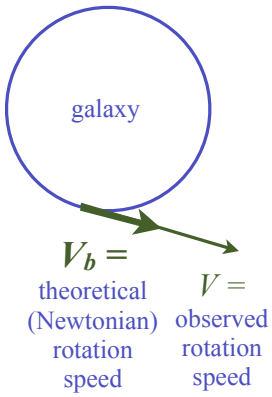
V = observed rotation speed

Mass-Discrepancy correlation with acceleration



McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012

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



V_b = theoretical (Newtonian) rotation speed

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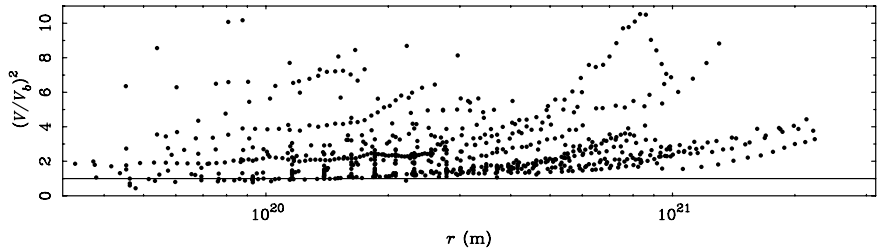
Mass-Discrepancy correlation with acceleration



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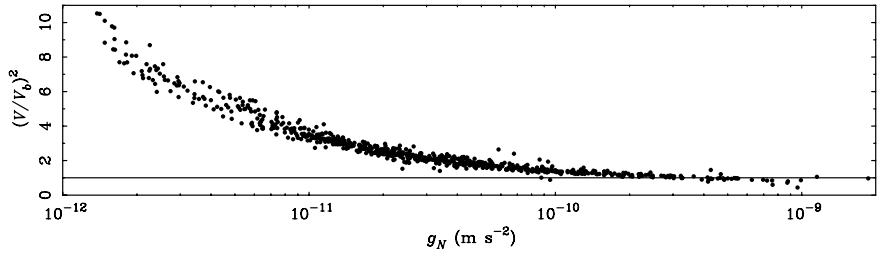

McGaugh 2004
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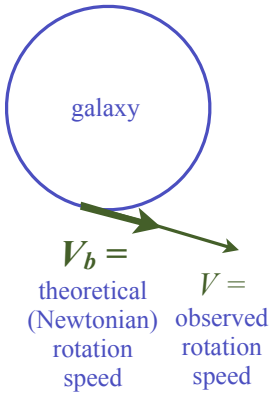
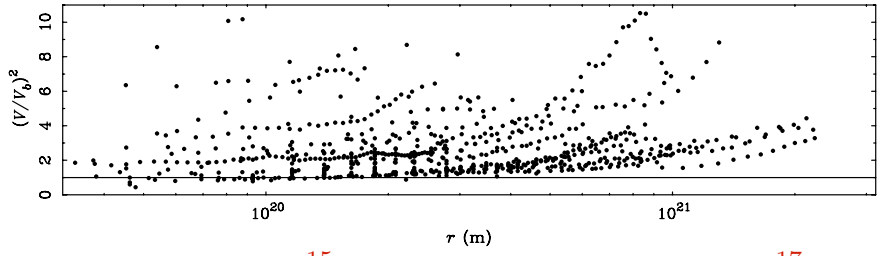
Kroupa 2012



Mass-Discrepancy correlation with acceleration



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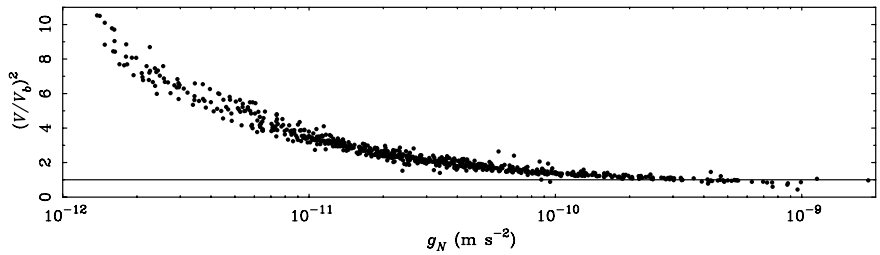
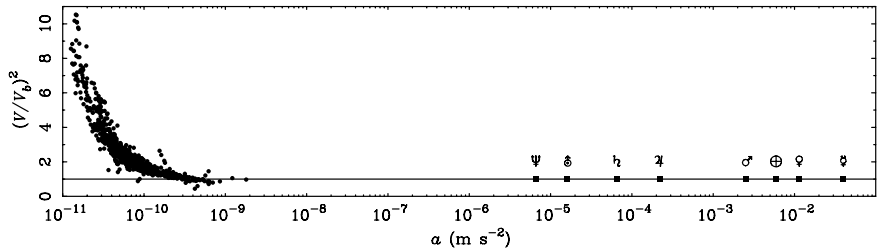




McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012

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

Consider *space-time scale invariance* :

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

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. $g \propto \left(a_o g_N\right)^{1/2}$ $\qquad g^2 = a_o g_N$ 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 $a = \frac{\sqrt{GM}}{r}\sqrt{a_0}$

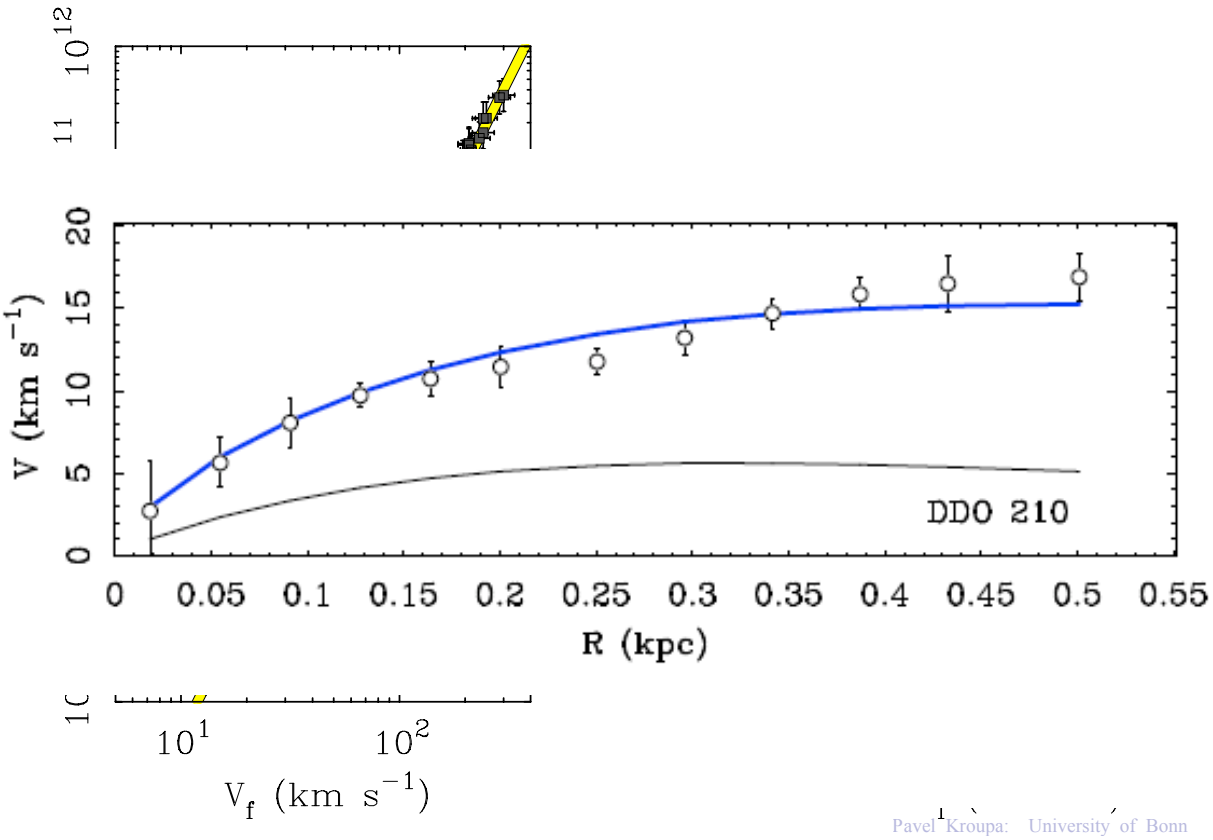
centrifugal acceleration = centripetal acceleration

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

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

The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



The observational Baryonic Tully -Fisher Relation

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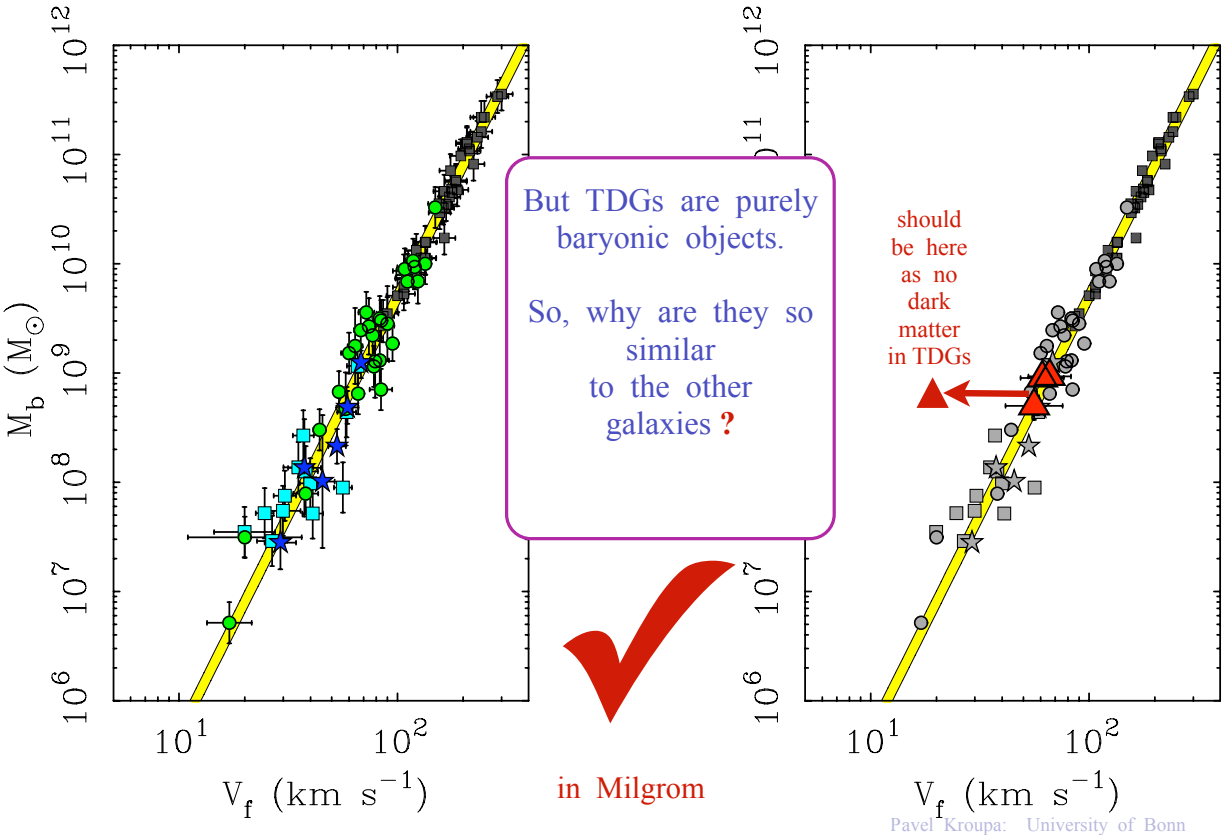


Consider *space-time scale invariance* :

(Milgrom 2009; Kroupa, Pawlowski & Milgrom 2012)

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

$$\Rightarrow \quad g^2 = a_o g_N \quad \text{or} \quad a^2 = a_o g_N$$

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

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

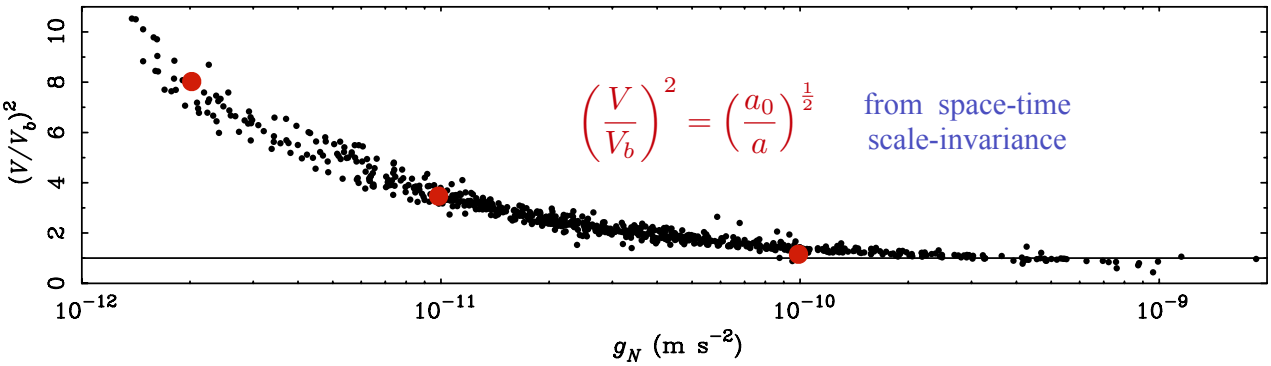
$$V_b^2 = \frac{GM}{r}$$

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

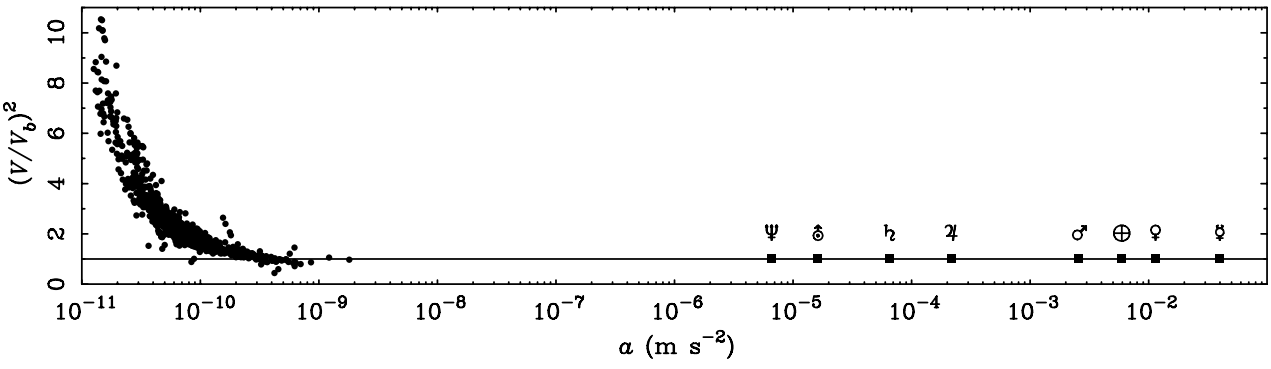
$$\text{i.e.} \quad \left(\frac{V}{V_b}\right)^2 = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$$

Mass-Discrepancy correlation with acceleration

The McGaugh correlation explained



$$\left(\frac{V}{V_b}\right)^2 = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$$ from space-time scale-invariance



Milgromian Dynamics
from quantum mechanical processes in the vacuum

Kroupa et al. (2010), Appendix A:

". . . an accelerated observer in a de Sitter universe (curved with a positive cosmological constant Λ) sees a non-linear combination of the Unruh (1975) vacuum radiation and of the Gibbons & Hawking (1977) radiation due to the cosmological horizon in the presence of a positive Λ. Milgrom (1999) then defines inertia as a force driving such an observer back to equilibrium as regards the vacuum radiation (i.e. experiencing only the Gibbons-Hawking radiation seen by a non-accelerated observer).

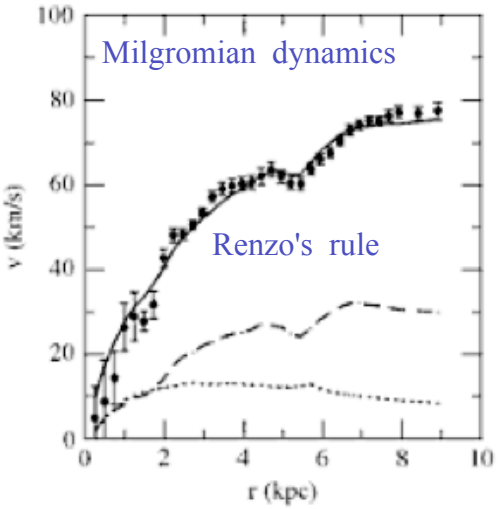
Observers experiencing *a very small acceleration* would thus see an Unruh radiation with a low temperature close to the Gibbons-Hawking one, meaning that *the inertial resistance defined by the difference between the two radiation temperatures would be smaller than in Newtonian dynamics, and thus the corresponding acceleration would be larger*. This is given precisely by the formula of Milgrom (1983) with a well-defined transition-function $\mu(x)$, and $a_0 = c\,(\Lambda/3)^{1/2}$. Unfortunately, no covariant version (if at all possible) of this approach has been developed yet."

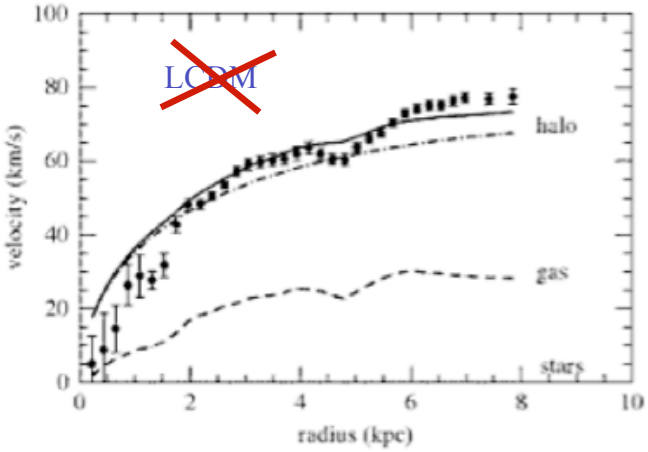
. . .

Scale-invariant / Milgromian Dynamics (current best bet)

. . .

From Robert Sanders' Book
on
"*The Dark Matter Problem*",
Cambridge University Press, 2010





In fact, given an *observed baryonic matter distribution*, the rotation curve

can be precisely predicted using Milgromian dynamics

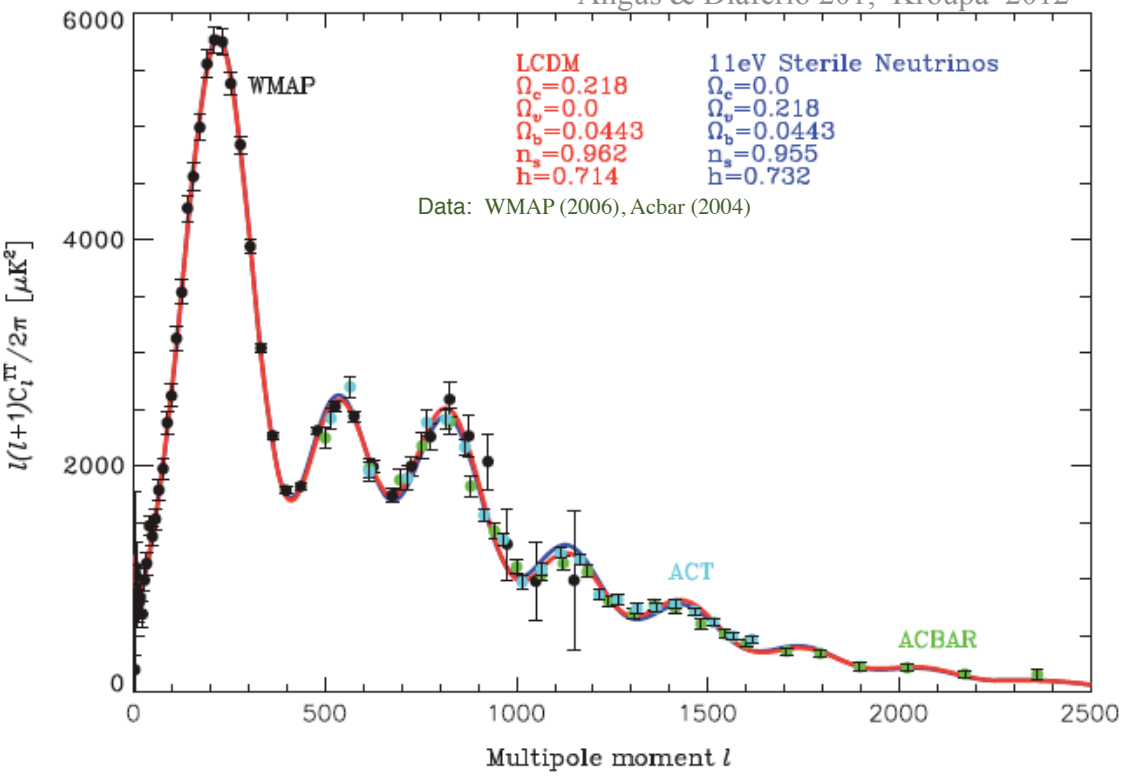
cannot be predicted using LCDM.

plus in Milgromian dynamics dark matter significantly reduced in galaxy clusters

(e.g. Sanders 2009 (review) **:**
"*Modified Newtonian Dynamics* **:**
A Falsification of Cold Dark Matter")

CMB power spectrum in Milgromian dynamics

Angus & Diaferio 201; Kroupa 2012



Thus,

The Concordance Cosmological Modell
does ***not uniquely***
account for the CMB nor for
Large Scale Structure.

In fact, with the falsification of the SMoC,
it has become irrelevant to ask whether any set of data
(e.g. large-scale structure or CMB)
fit the SMoC.

Conclusions

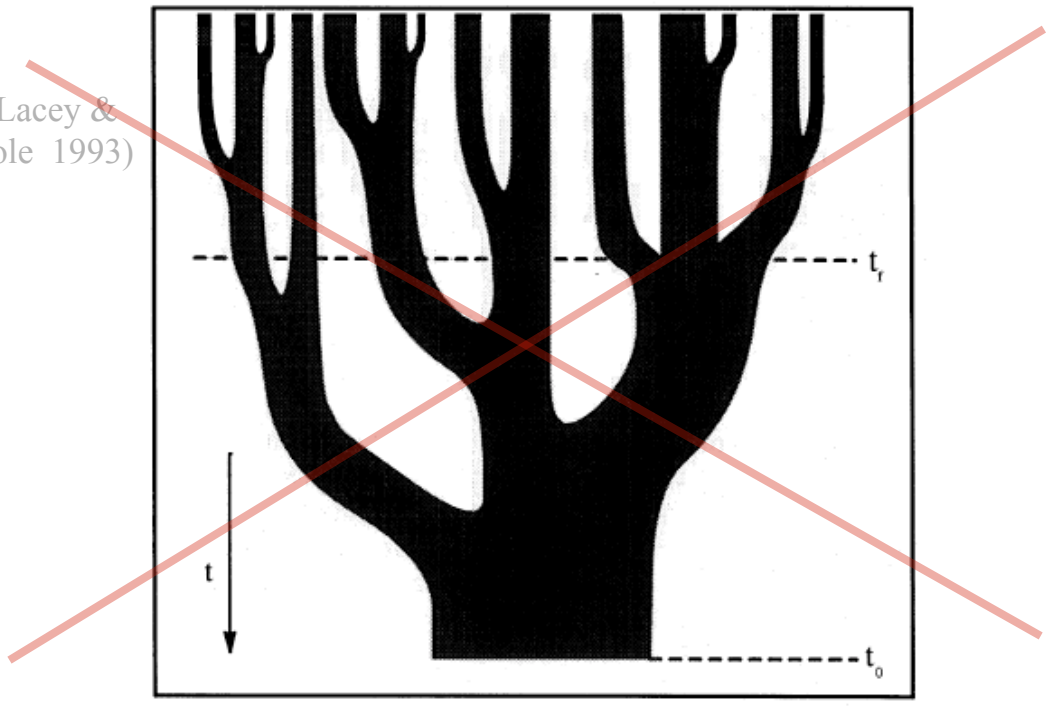
The *dual dwarf galaxy theorem* is violated
by the real universe and
thus the standard model of cosmology is falsified :

Dynamically relevant dark matter cannot exist in galaxies.
(The search for it will be fruitless).

Effective dynamics ***is*** scale-invariant / Milgromian.
(i.e. "dark matter" ***must be mathematically equivalent*** to
Milgromian dynamics).

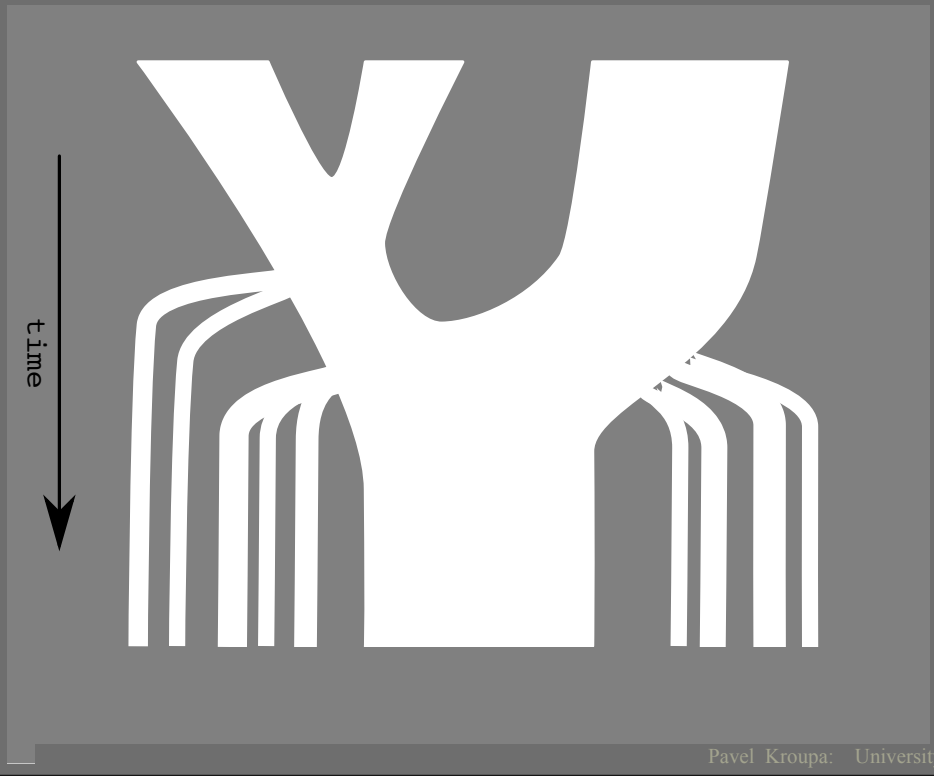
The Standard LCDM Model of Cosmology structure formation tree

(Lacey & Cole 1993)



The new baryonic-galaxy structure formation tree within the VBLC

(Metz: PhD 2008; Kroupa et al. 2010)



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