The dark matter crisis: problems with the current standard model of cosmology and steps towards an improved model

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"*Ripples in the Cosmos*"
Durham, 22. - 26. July 2013

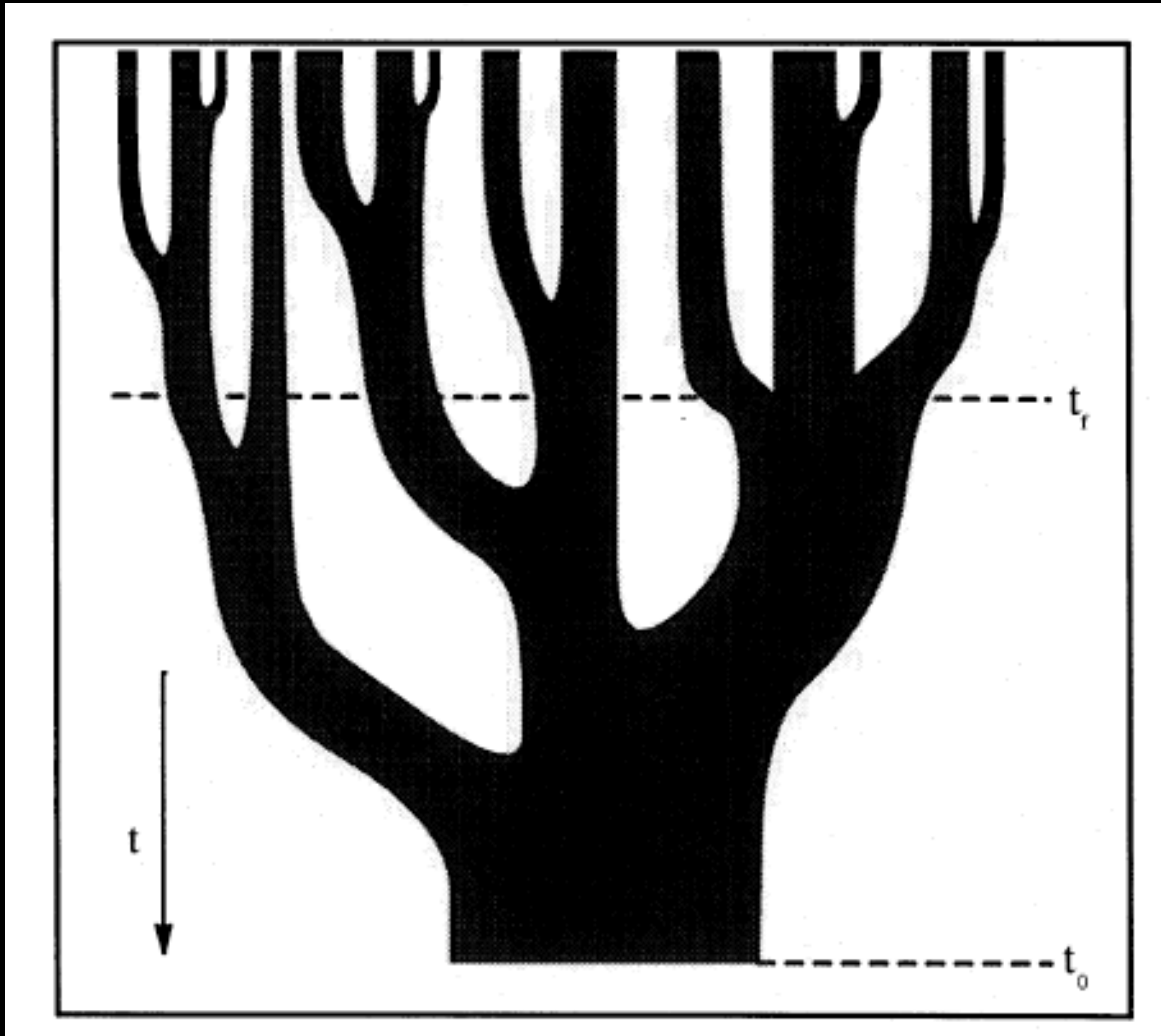
Assume **the standard model of cosmology (SMoC)**
is a valid description of the universe,

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

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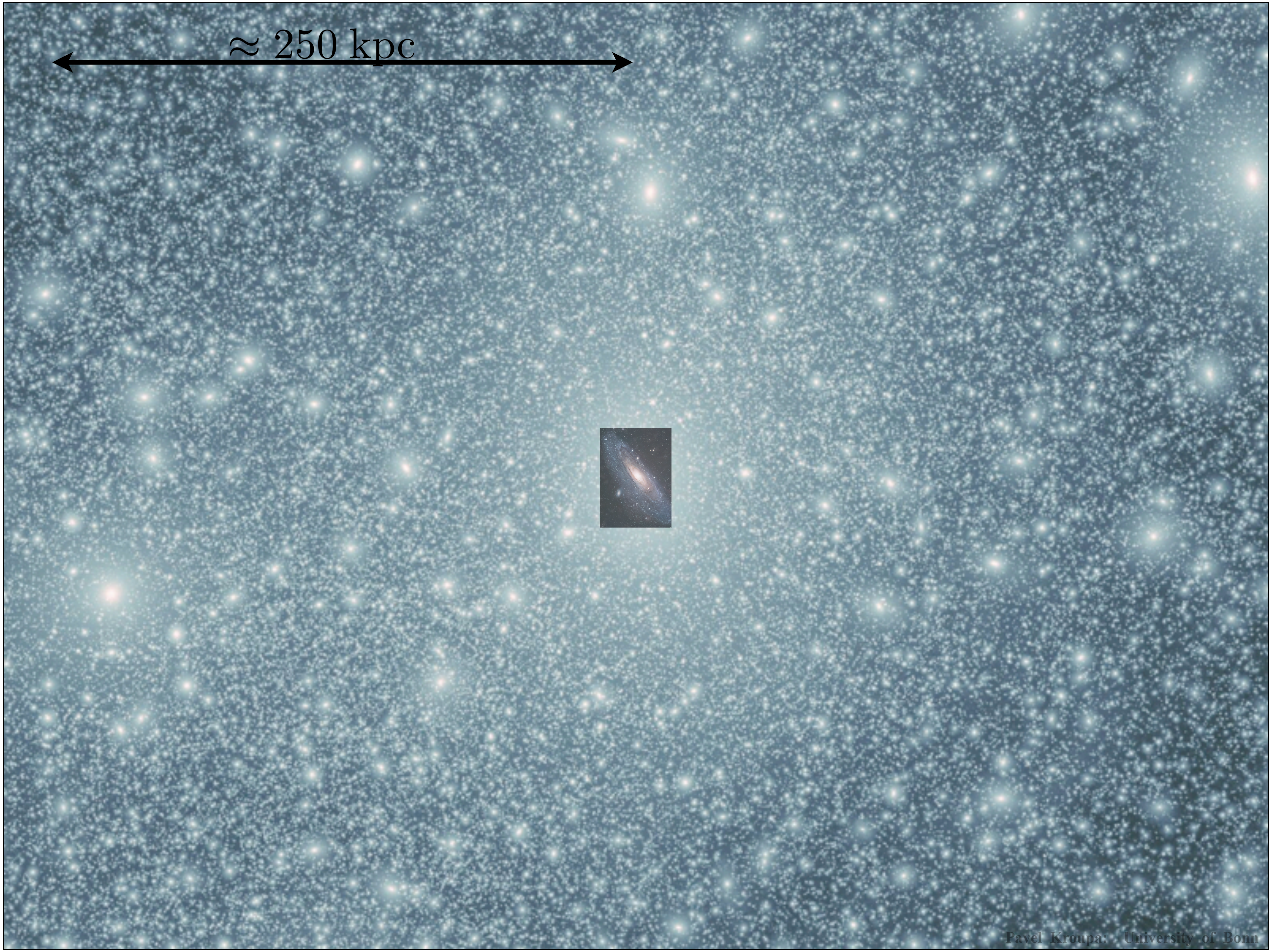
≈ 250 kpc
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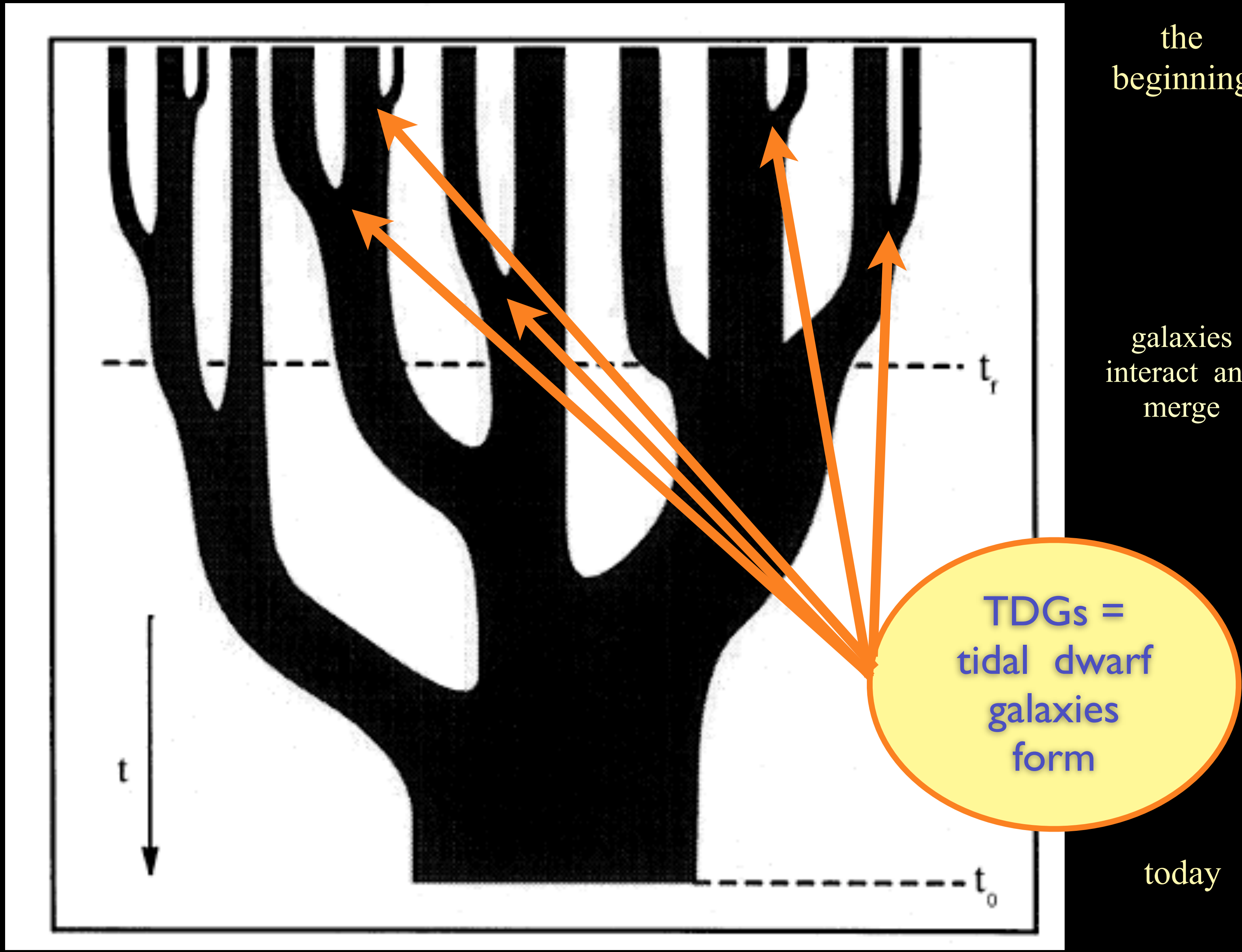
Consequence II

Structures form according to the cosmological merger tree

Lacey & Cole (1993)



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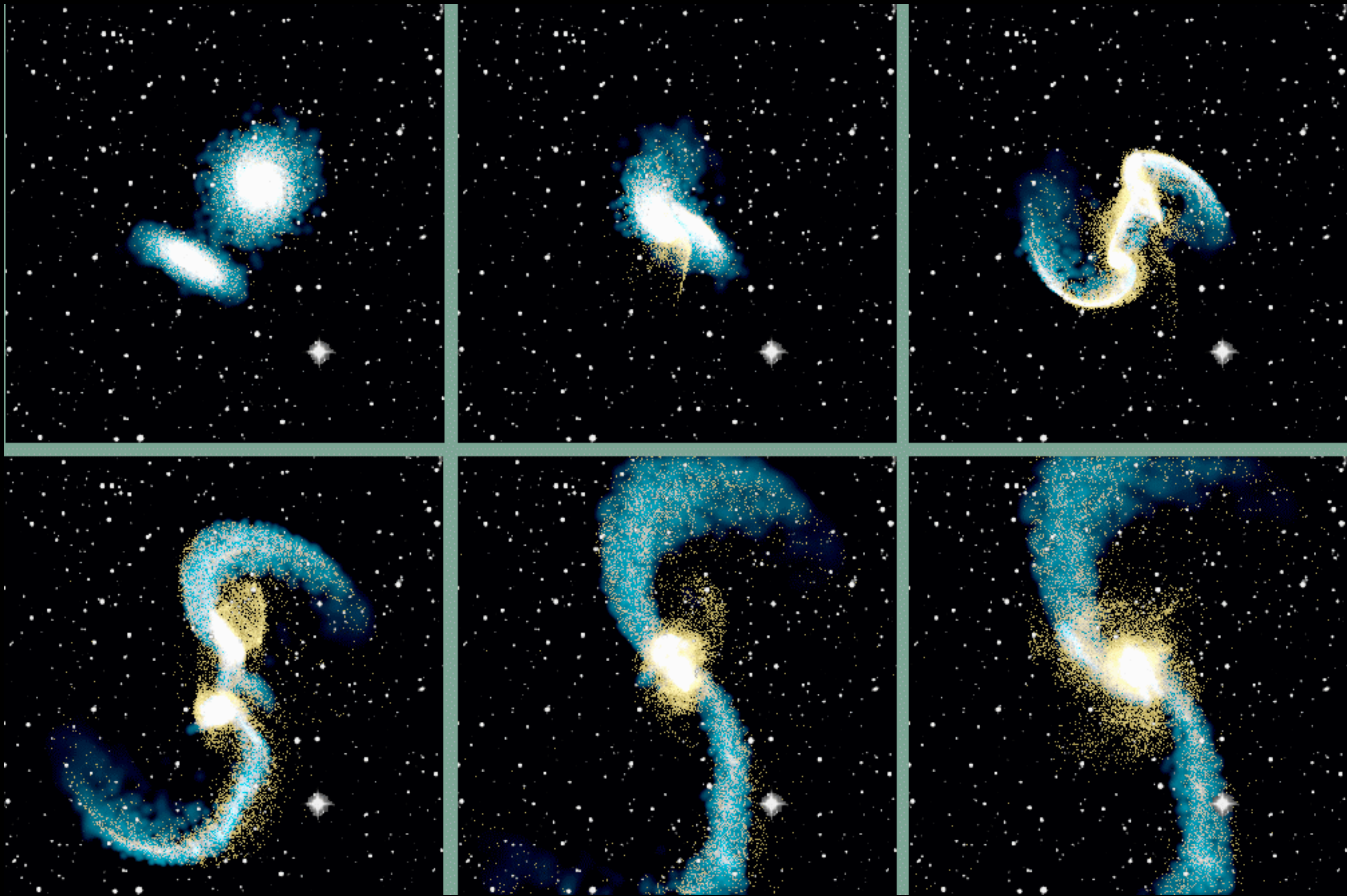
Tidal tails



Miho & Maxwell, web

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(Weilbacher et al. 2000)

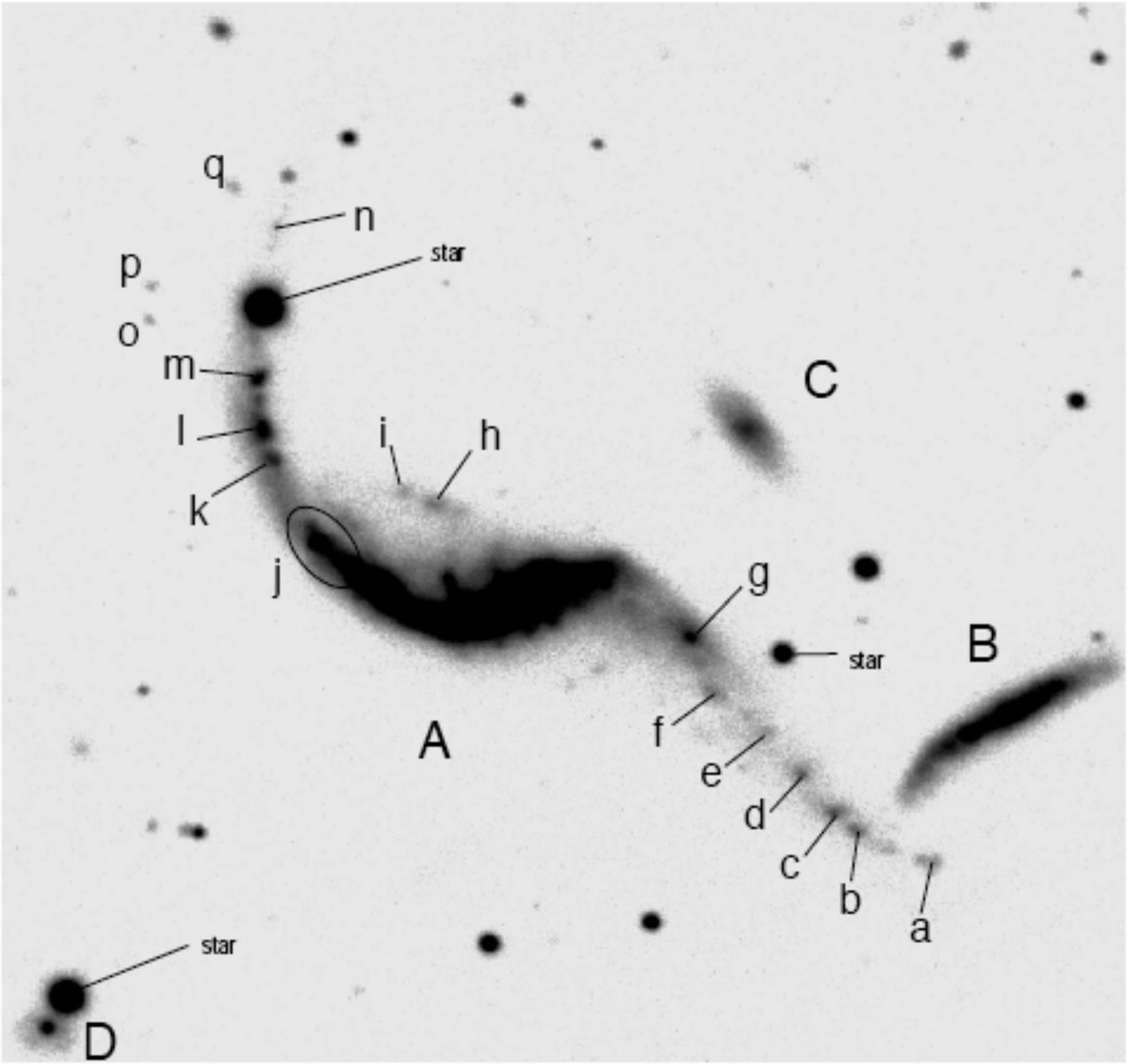

Fig. 21. Identification chart of field 10 around AM 1353-272.

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

Pavel Kroupa: University of Bonn

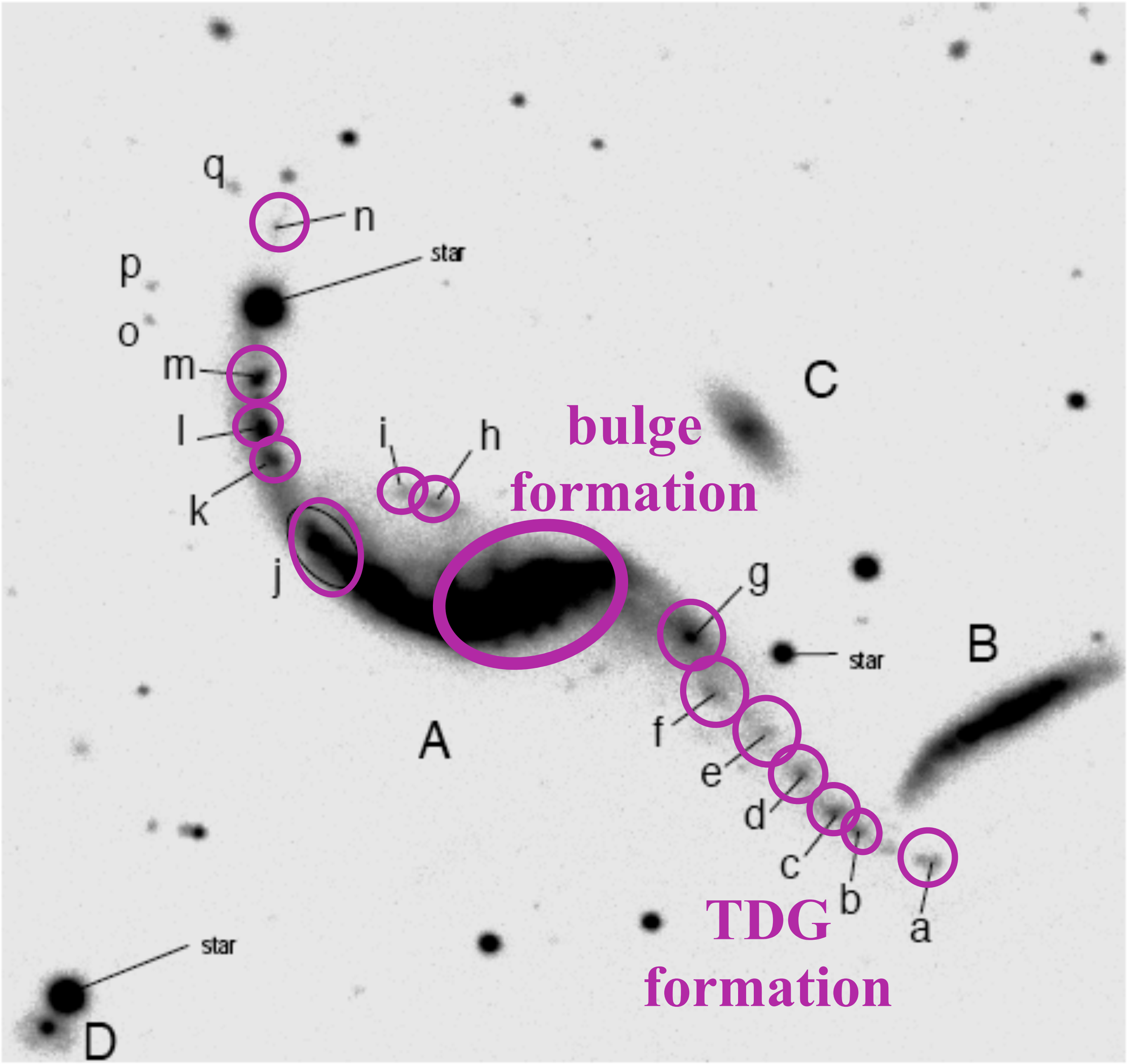

Fig. 21. Identification chart of field 10 around AM 1353-272.

(Weilbacher et al. 2000)

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


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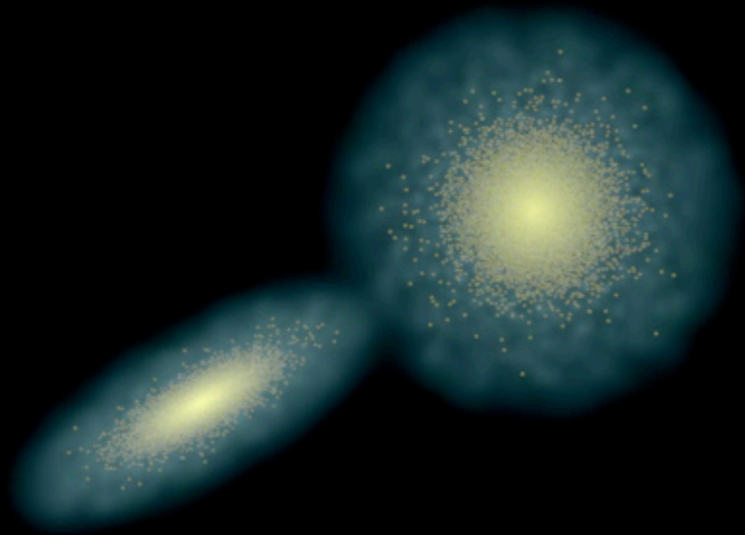
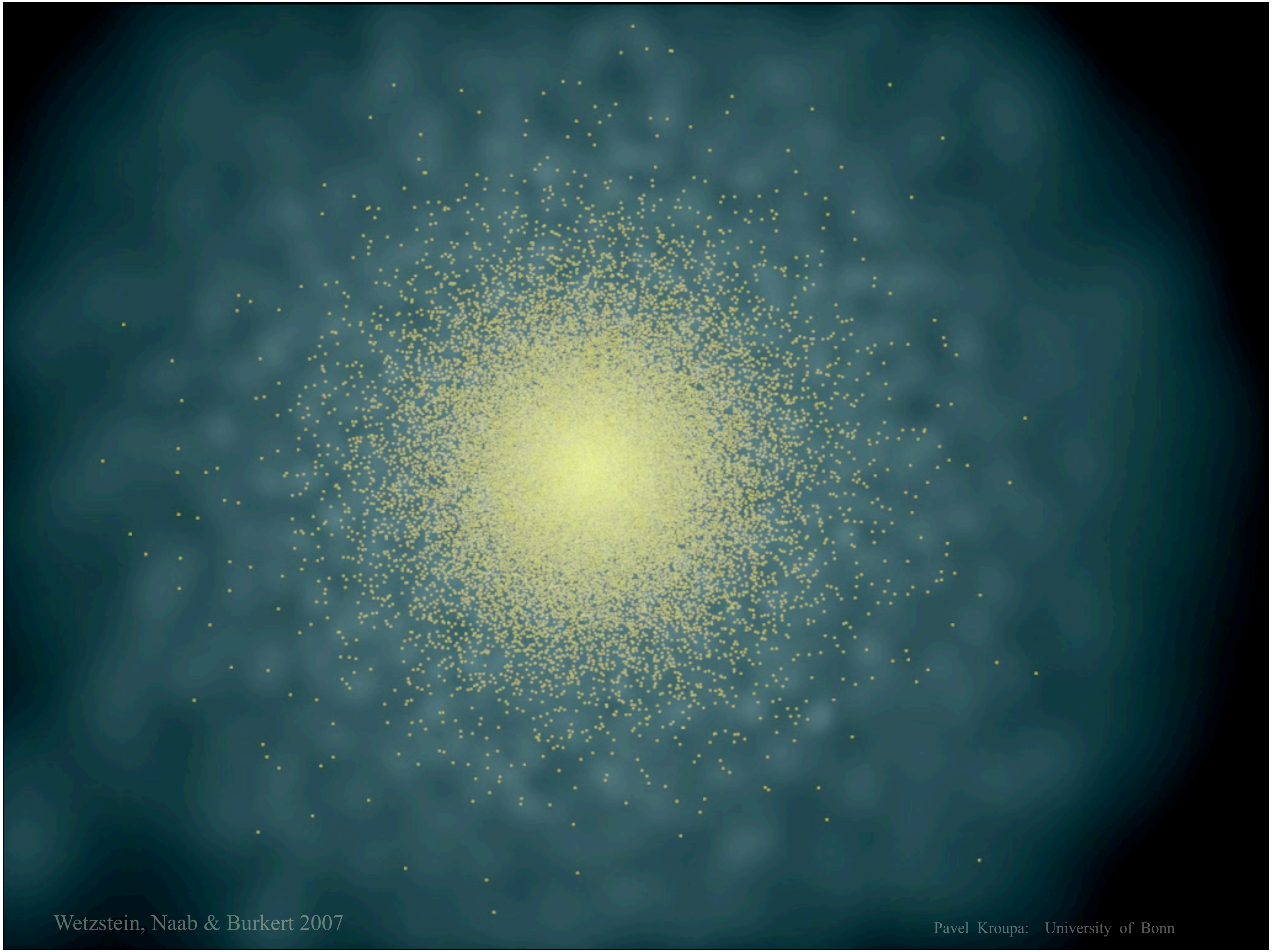
Relevance : The collision of two disks at high redshift



Wetzstein, Naab & Burkert 2007

Pavel Kroupa: University of Bonn



Wetzstein, Naab & Burkert 2007
Pavel Kroupa: University of Bonn

(Weilbacher et al. 2000)

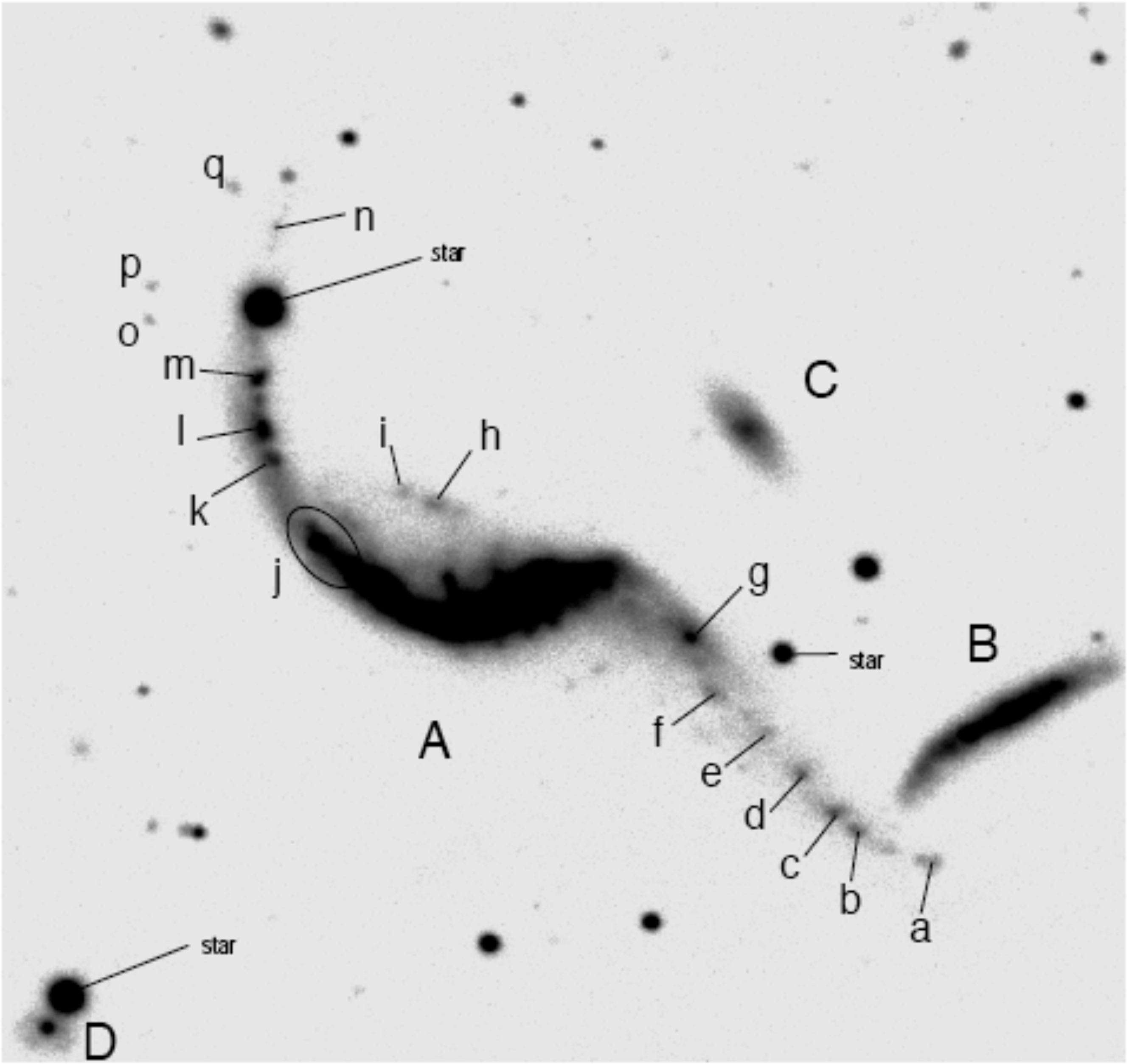


Fig. 21. Identification chart of field 10 around AM 1353-272.

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

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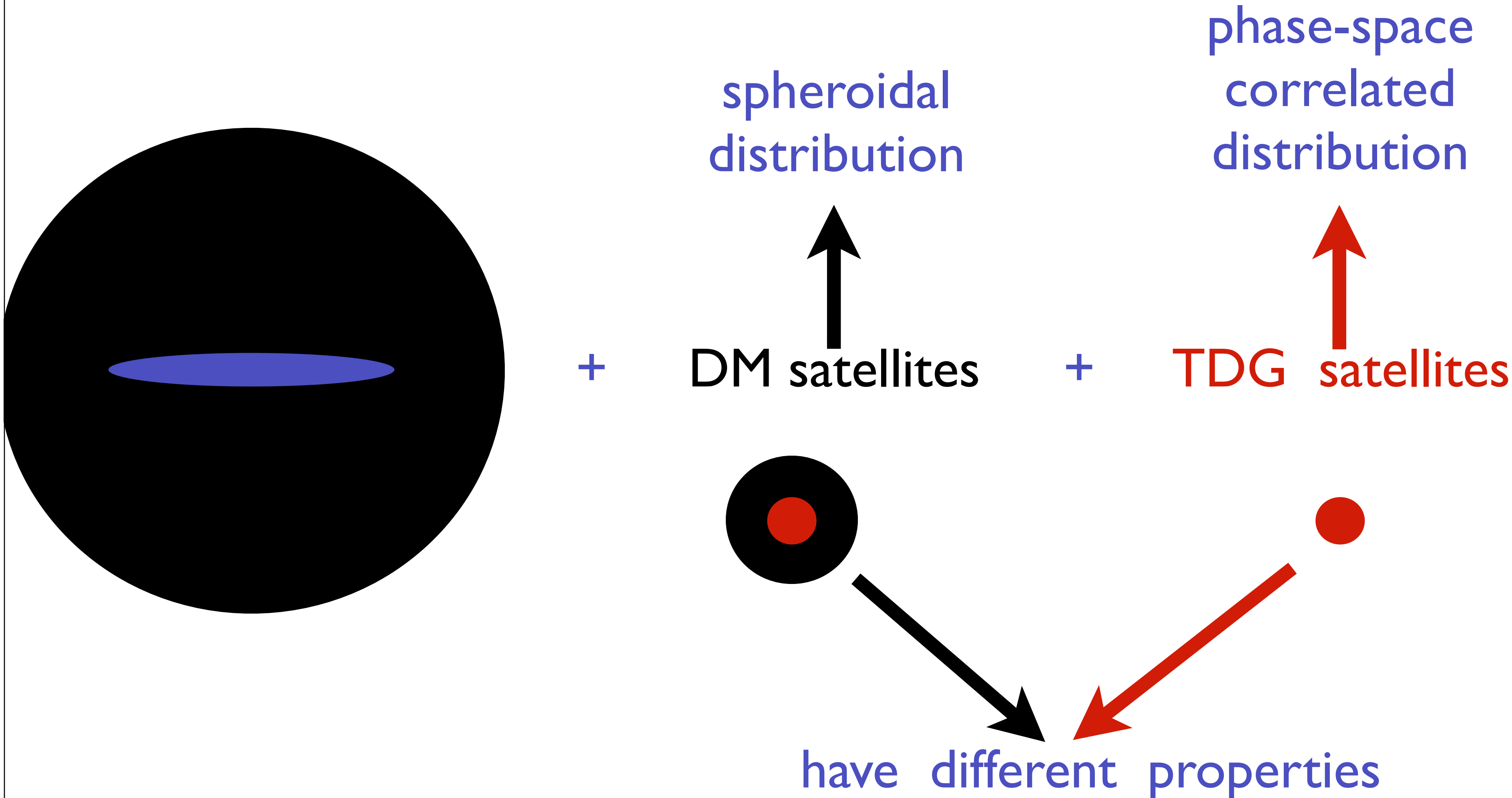
Thus in the *Standard Model of Cosmology* (SMoC) a galaxy must look as follows:



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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

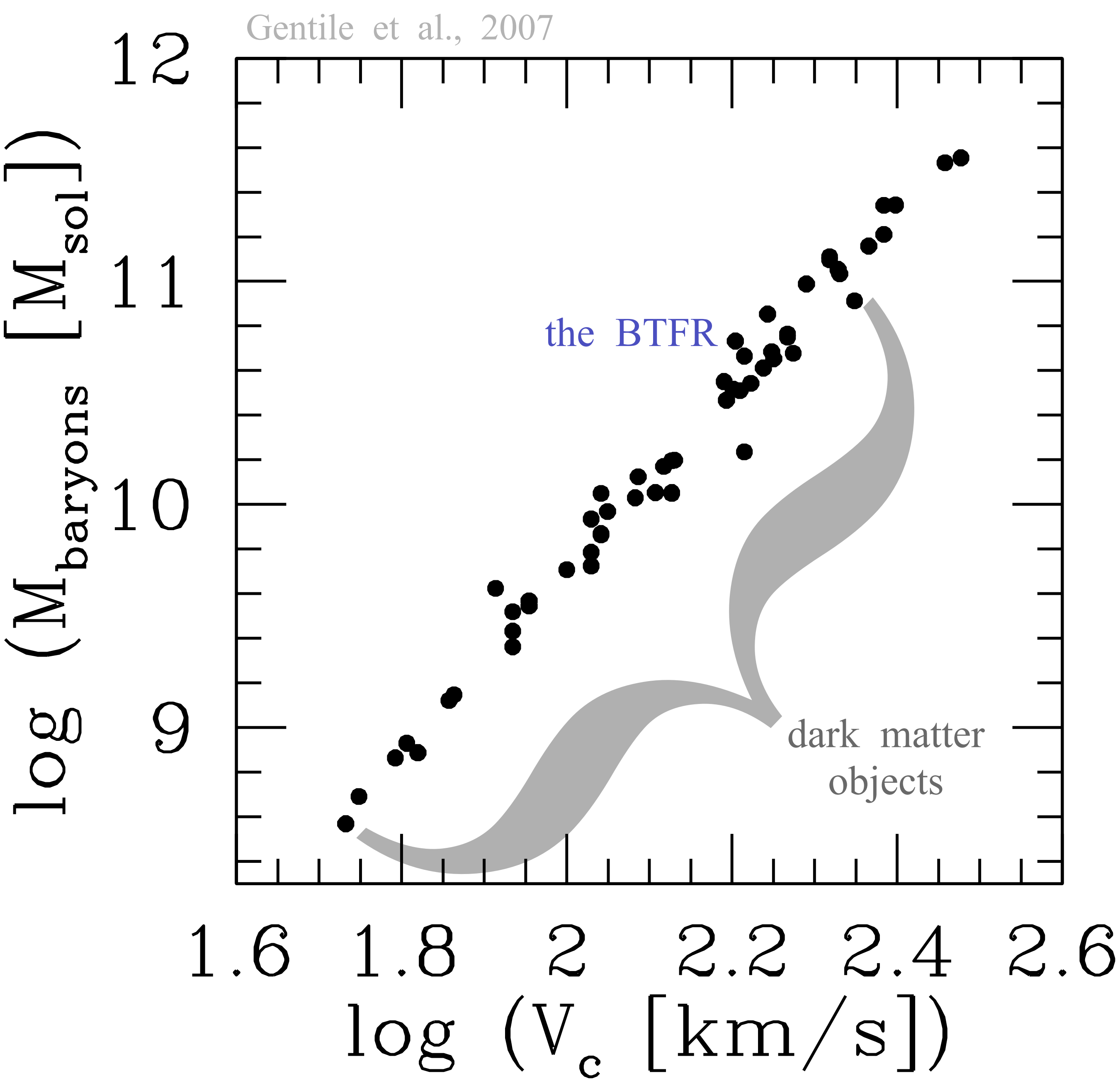
Kroupa 2012

with Dark Matter (DM) — TDGs w/o DM

spheroidal distribution — 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 **?**



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 !

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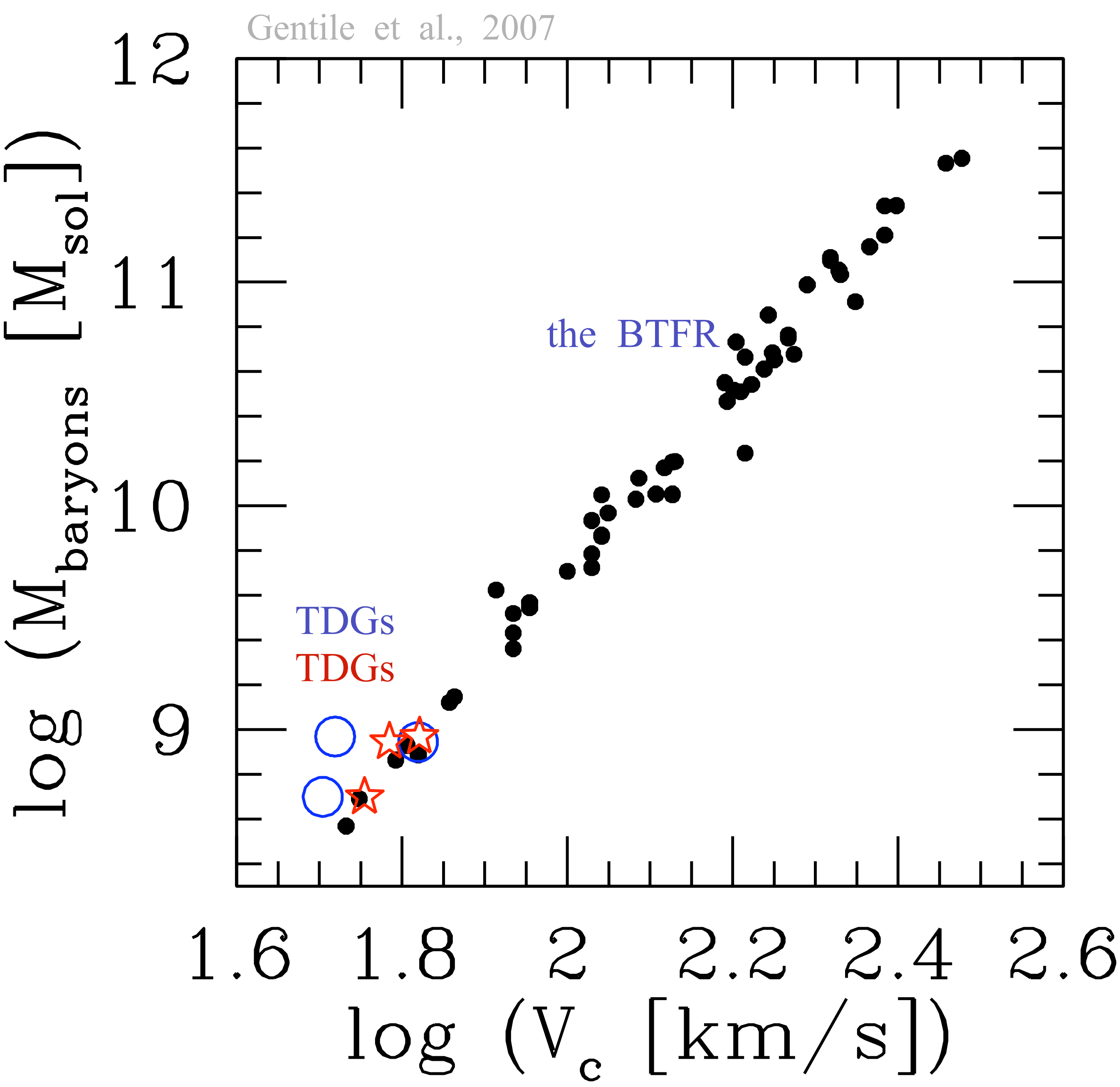
The Baryonic Tully -Fisher Relation :



But TDGs do lie on the same BTFR !?

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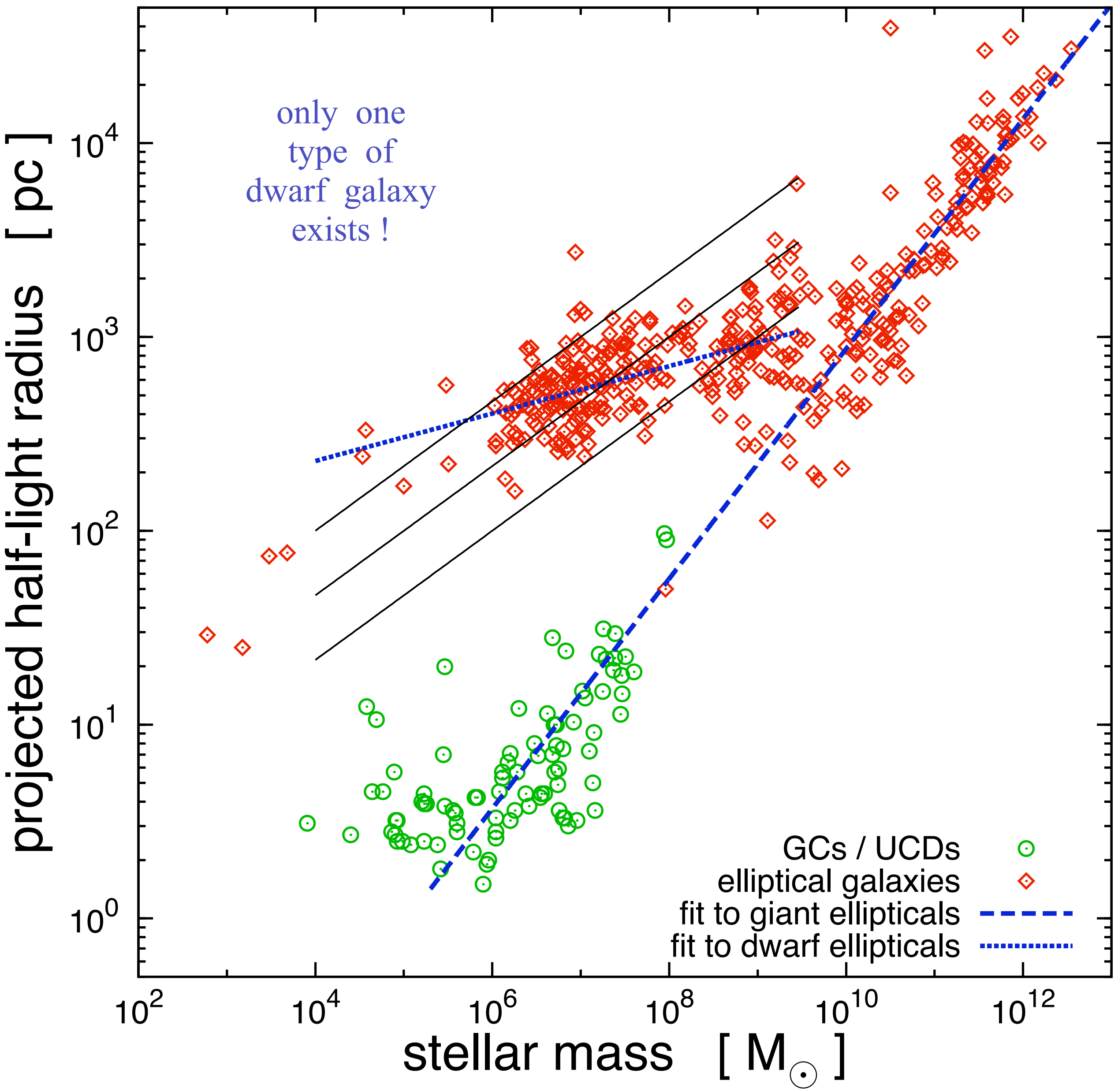
Types of stellar systems

Dabringhausen et al. 2012



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Types of stellar systems

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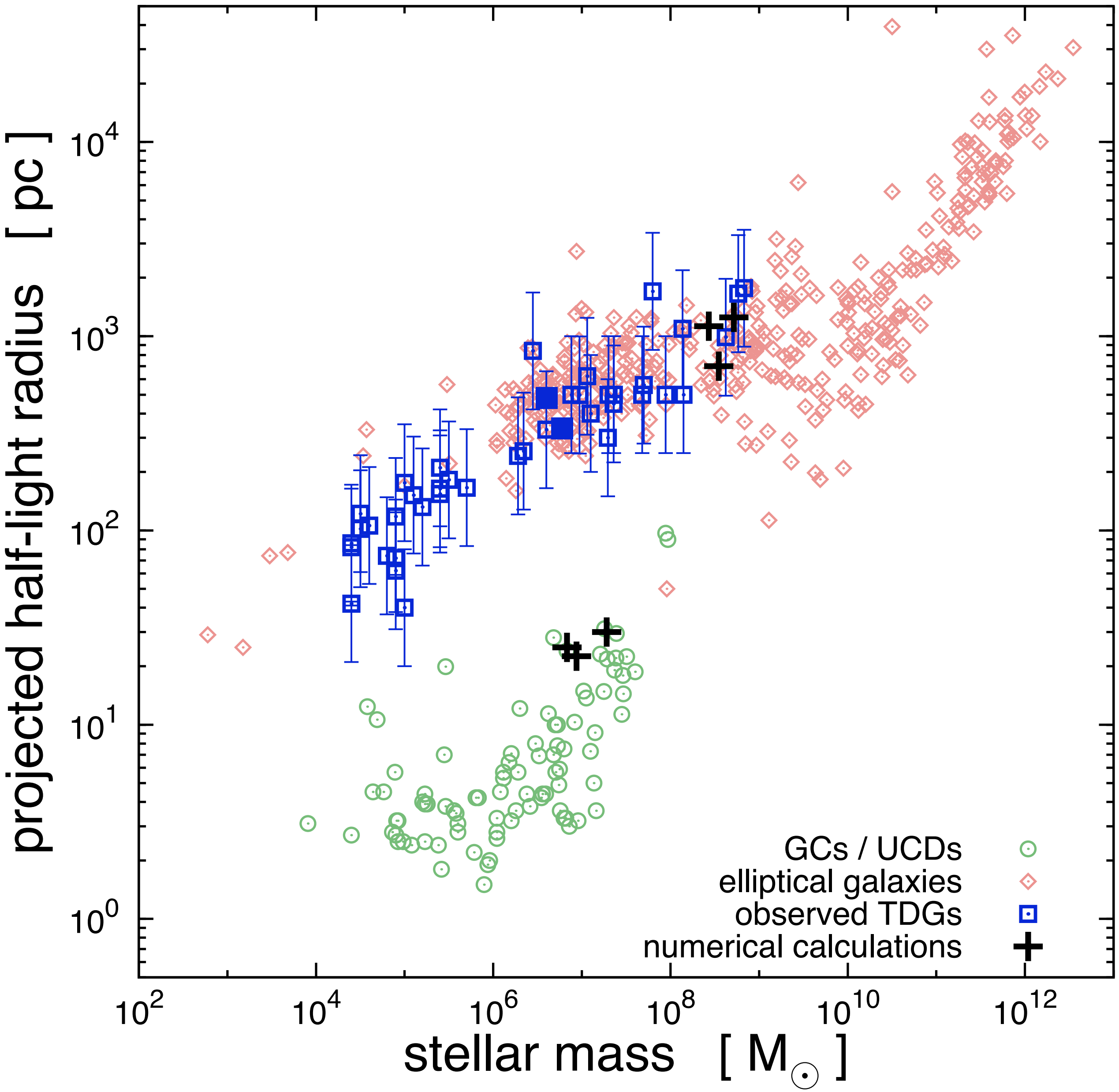

TDGs coincide with dE / dSph satellites

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Thus:

Kroupa 2012;
Dabringhausen & Kroupa 2013

The Dual Dwarf Galaxy Theorem **:**

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

→ only one type of dwarf galaxy is observed.

→ Dual Dwarf Galaxy Theorem is falsified.

$\Updownarrow$

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

has been shown

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 . . .

Concistency Check I

If

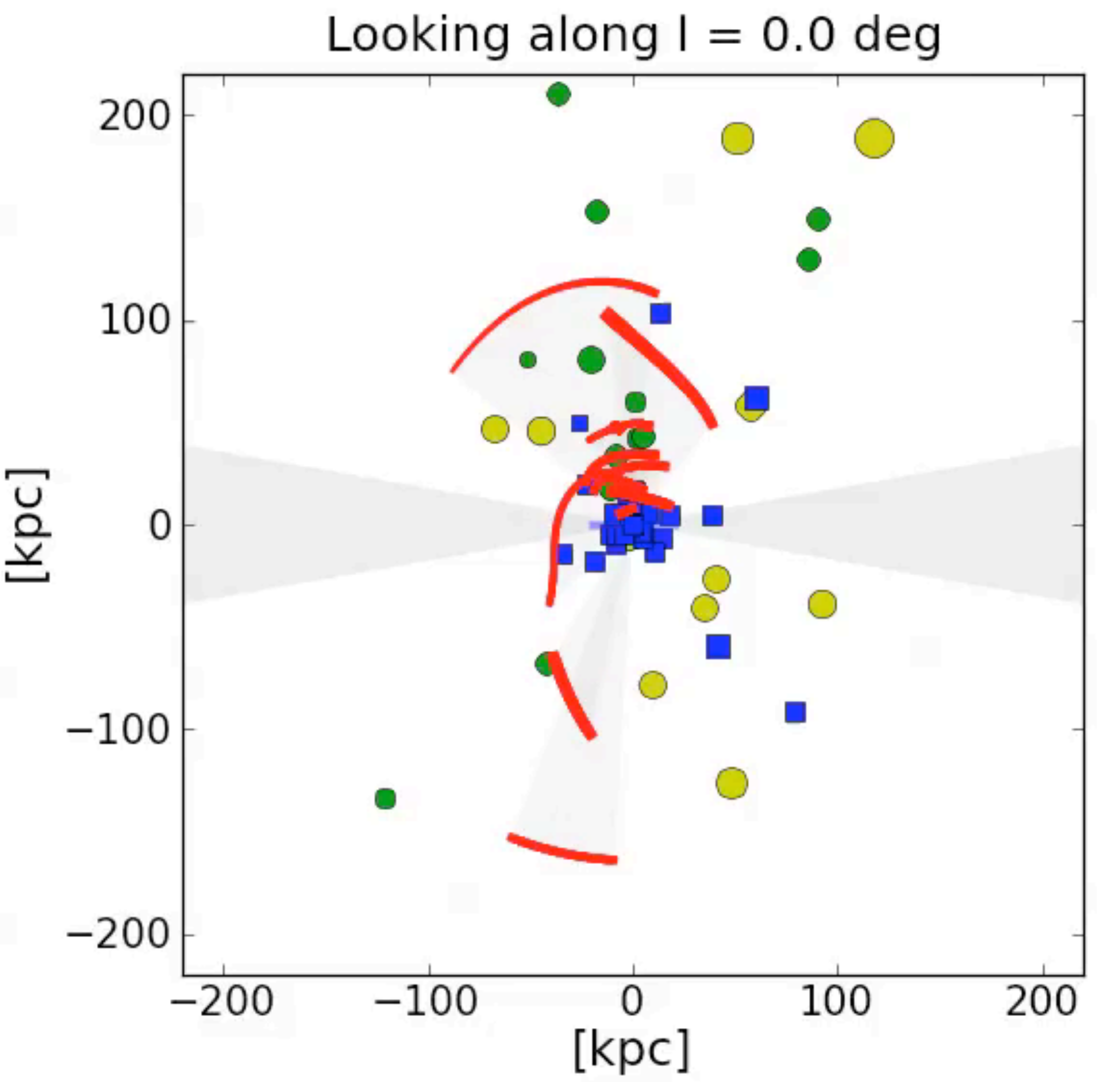
the Milky Way satellites are TDGs
without dark matter

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"

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Vast Polar Structure around the Milky Way

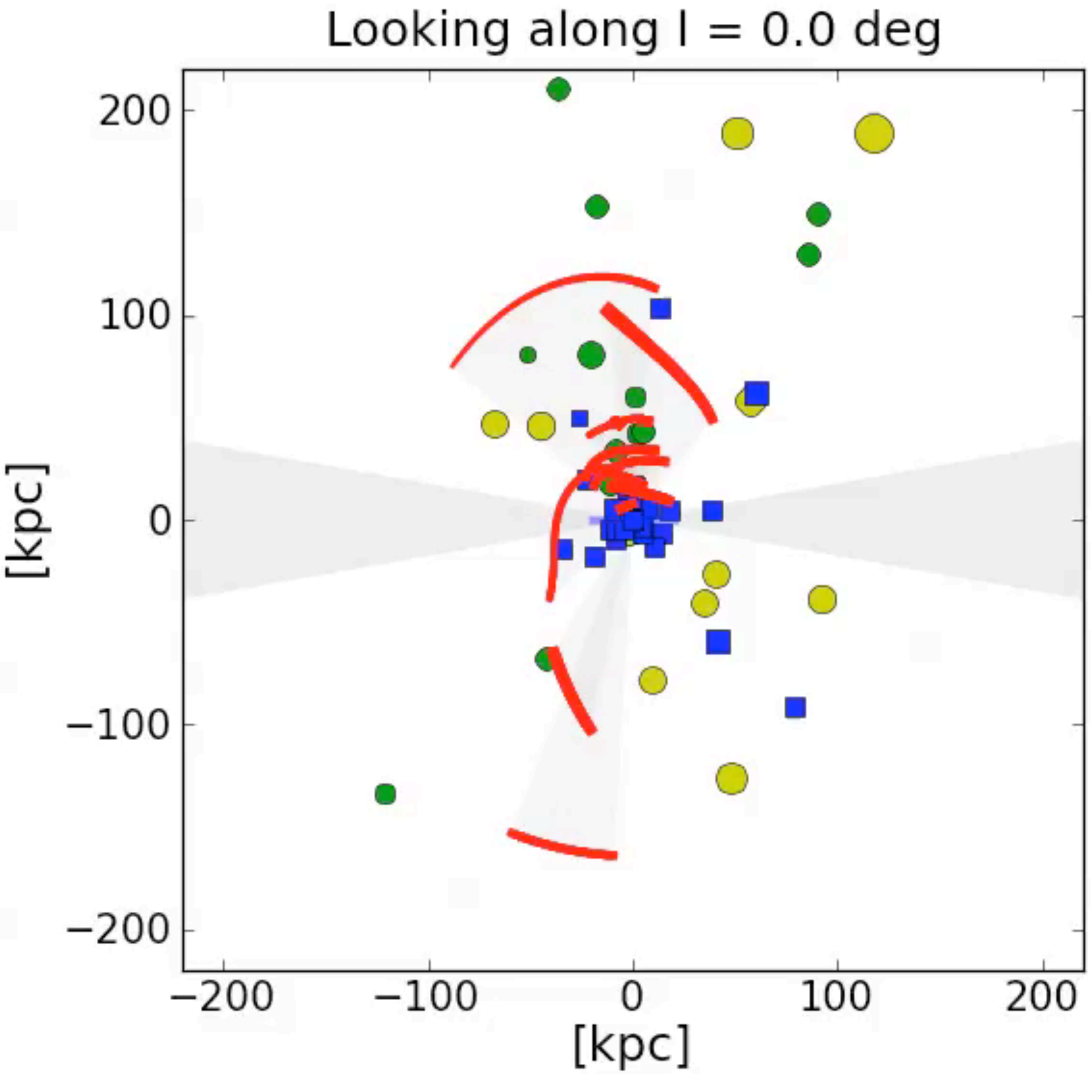
Pawlowski et al. 2012

■ YH globular clusters

● dSph satellites

● UFD satellites

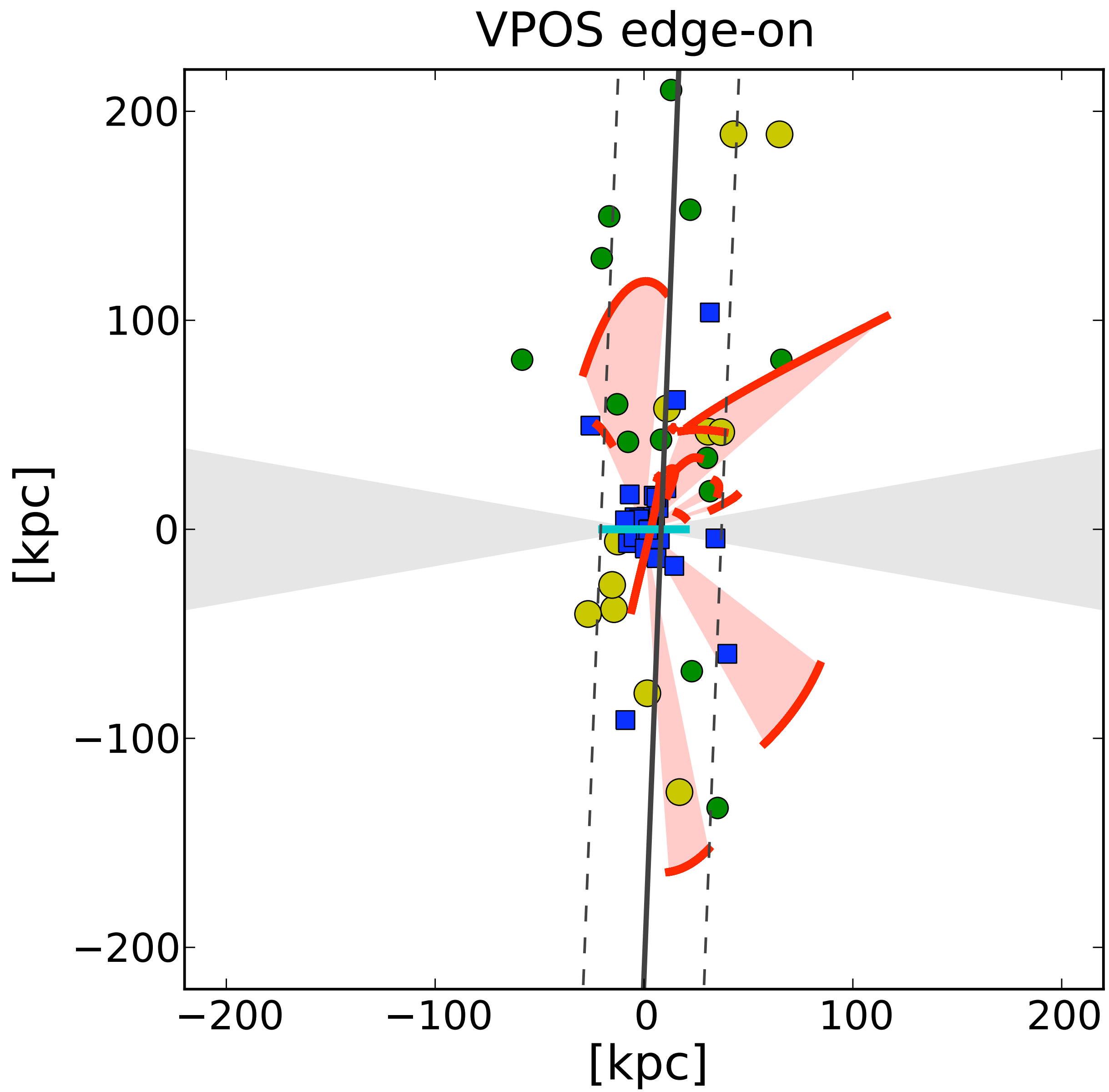
streams



See also
YouTube video
"The Vast Polar Structure"

Vast Polar Structure around the MW

Pawlowski et al. 2012



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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

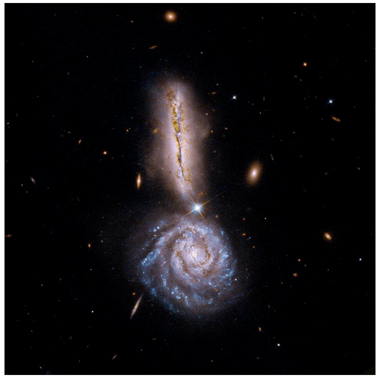
Nichols & Bland-Hawthorn (2011)

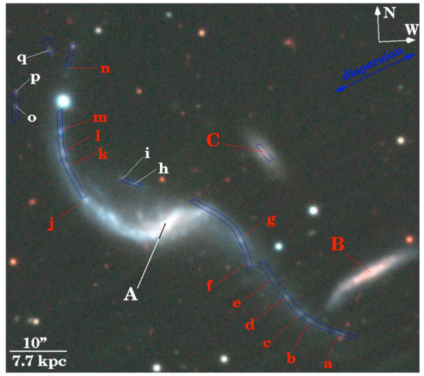
A and B are mutually exclusive.

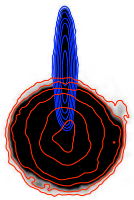
==> logical inconsistency of the model

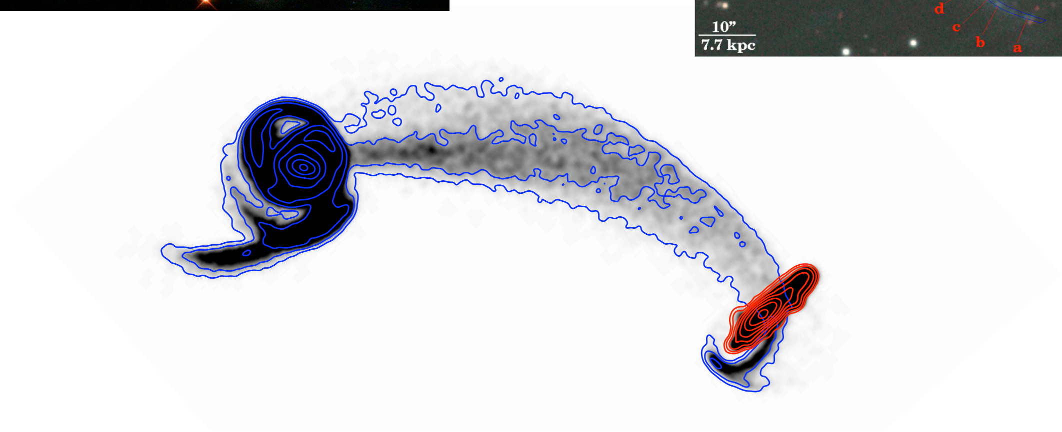
Phase-space-correlated tidal debris

Pawlowski et al. 2012









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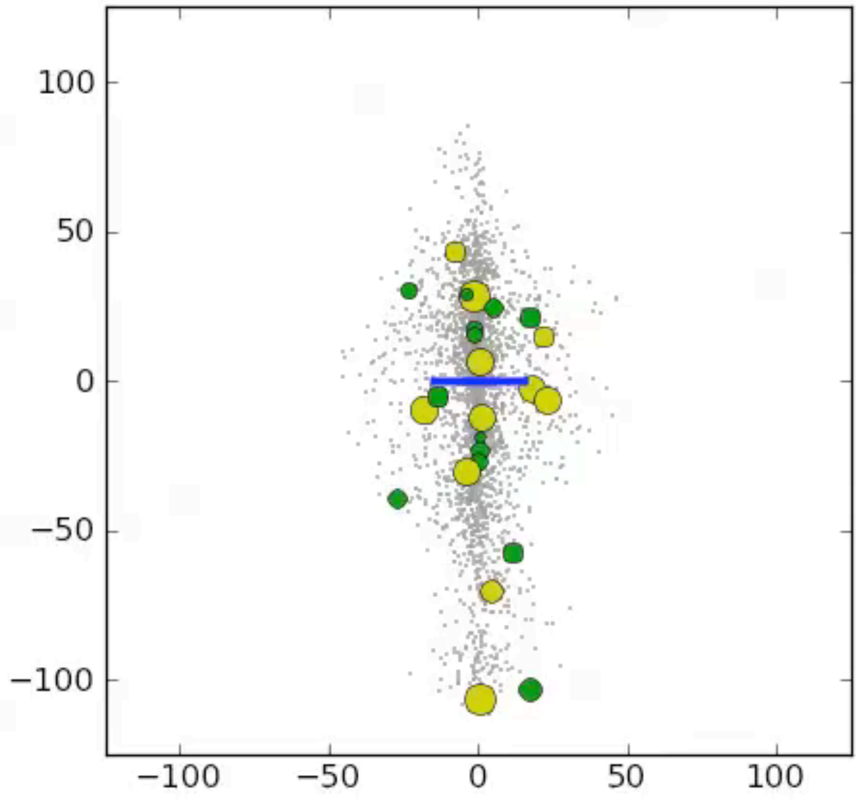
Fly-by encounter: e.g. Milky Way and Andromeda ?
about 10-11 Gyr ago

Pawlowski et al. 2011



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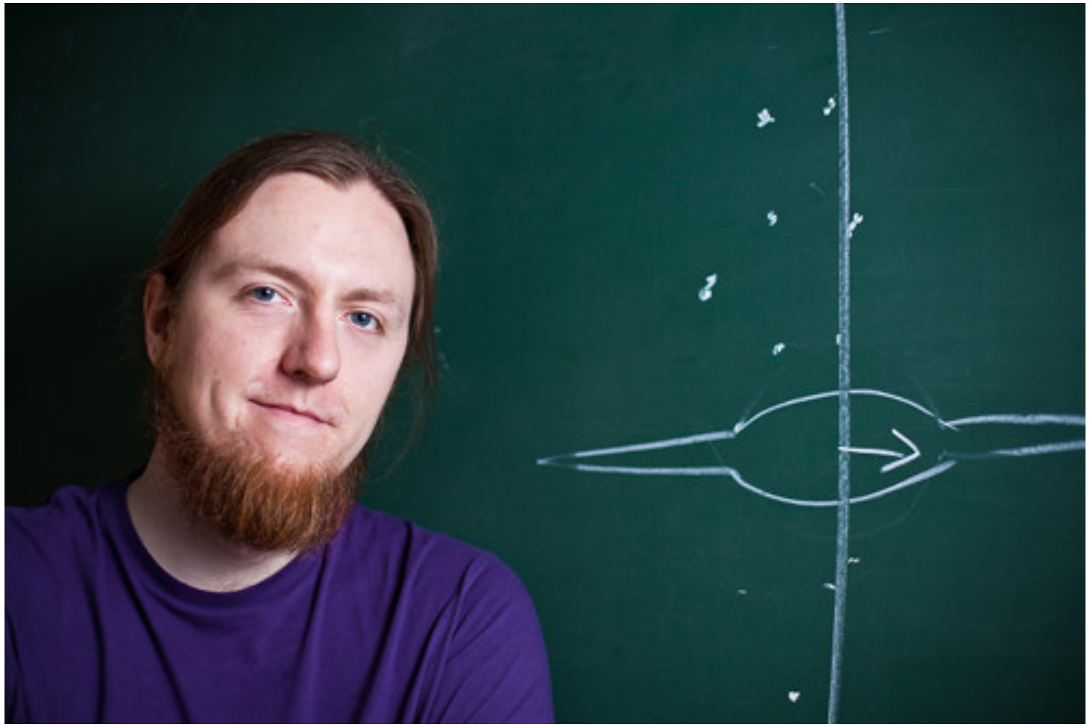

Marcel Pawlowski

Joerg Dabringhausen

Concistency Check II

Other, extra-galactic,

phase-space correlated distributions

of satellite systems.

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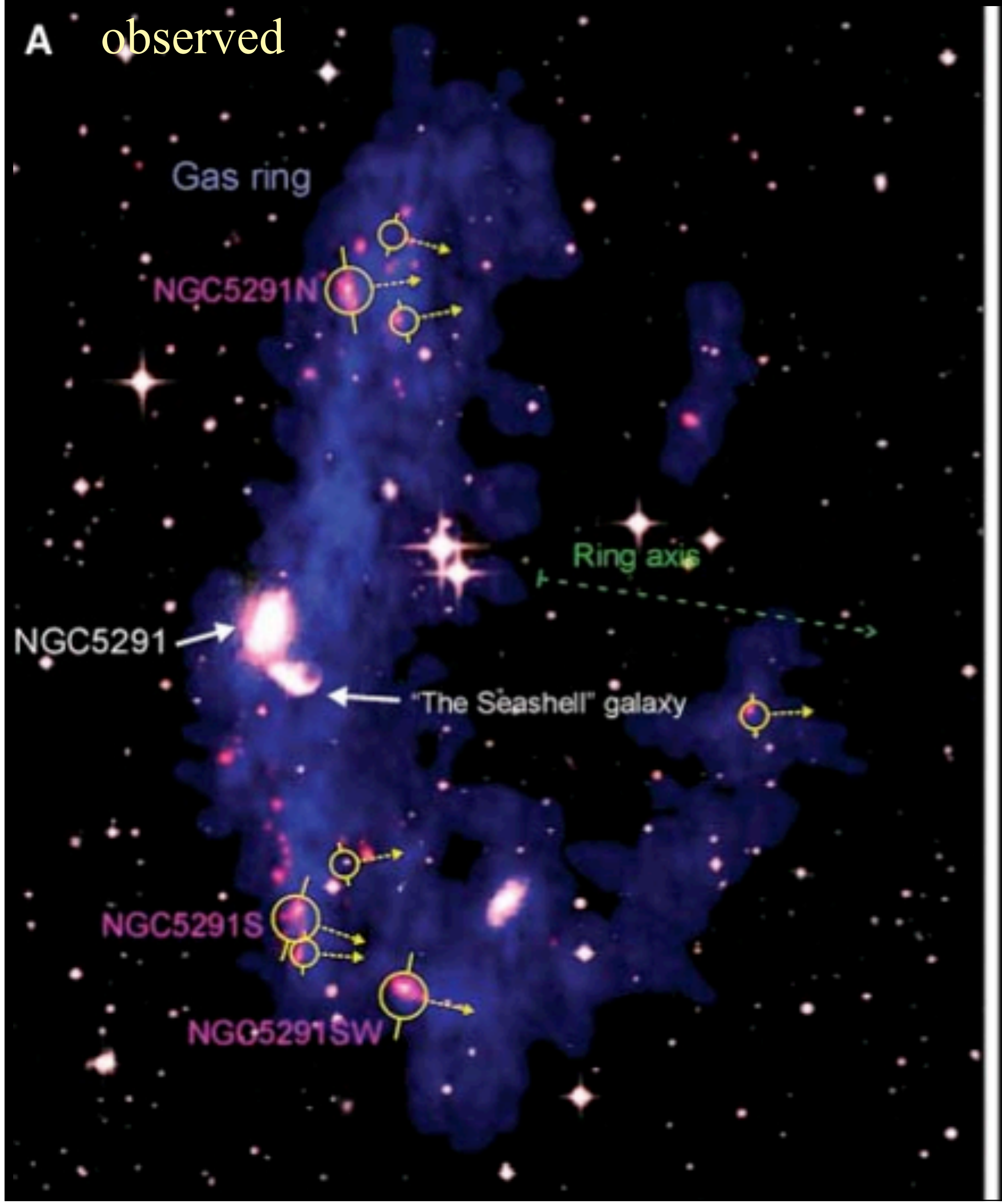
Bournaud et al. (2007, Science)



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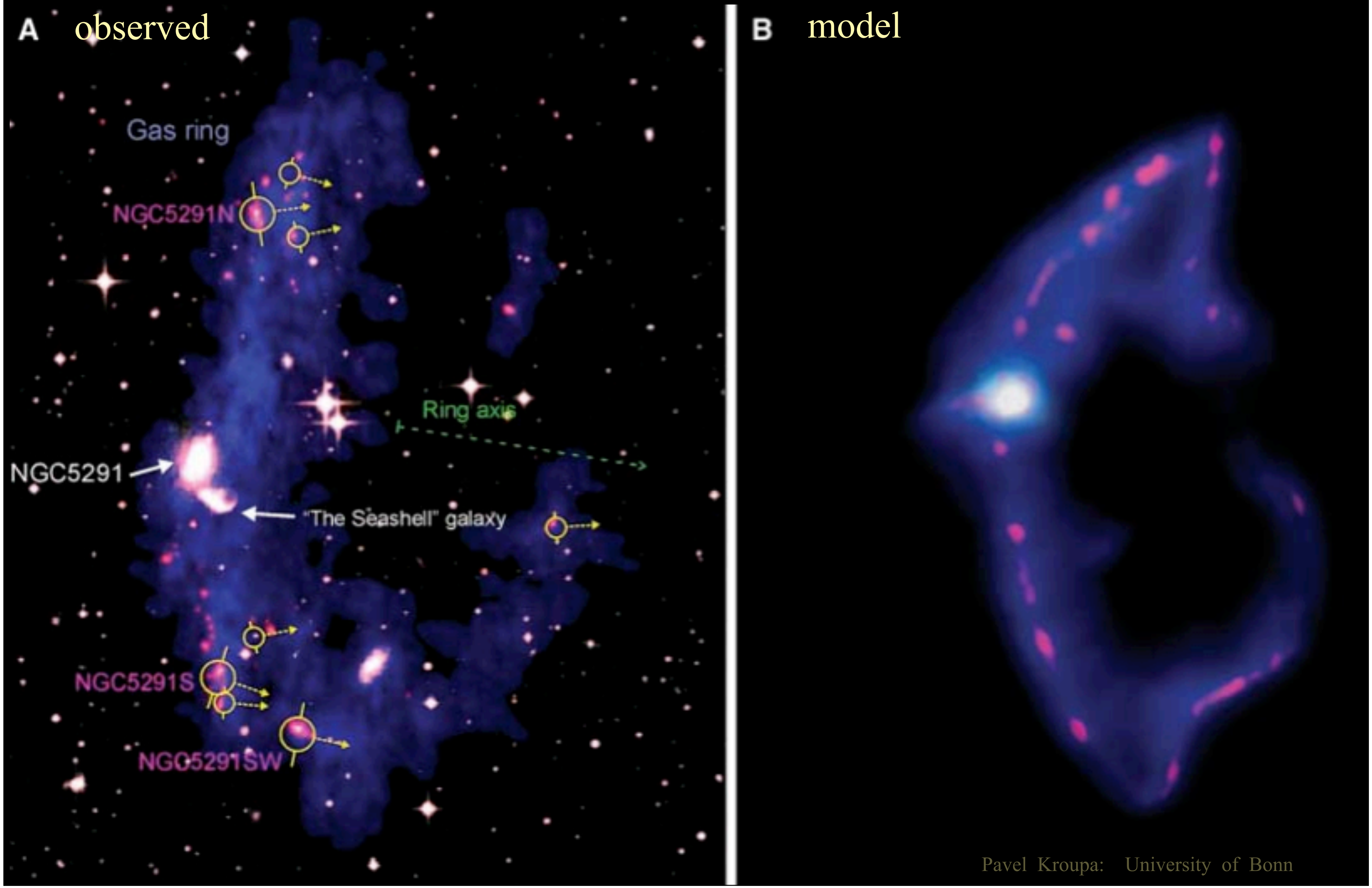

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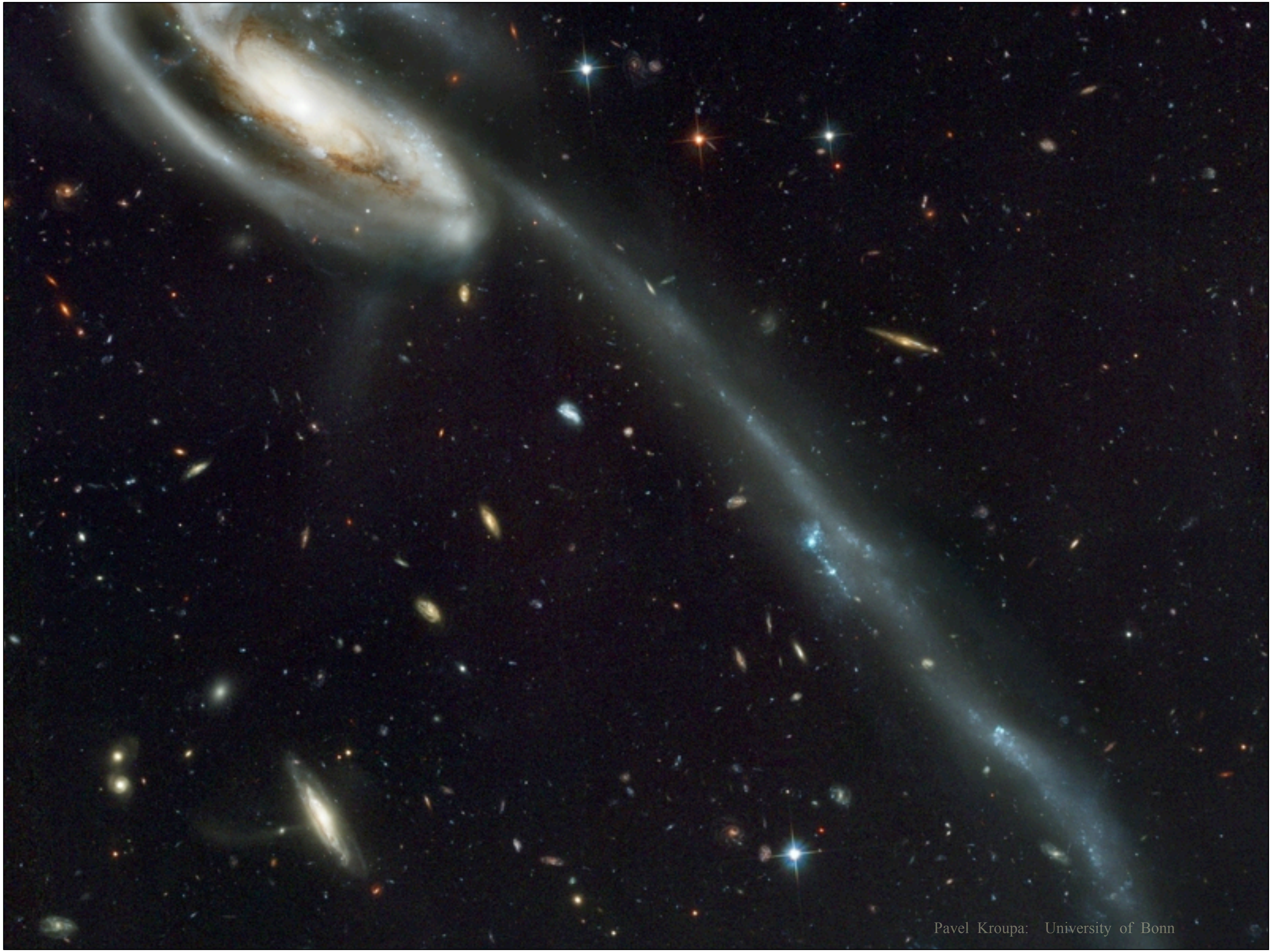
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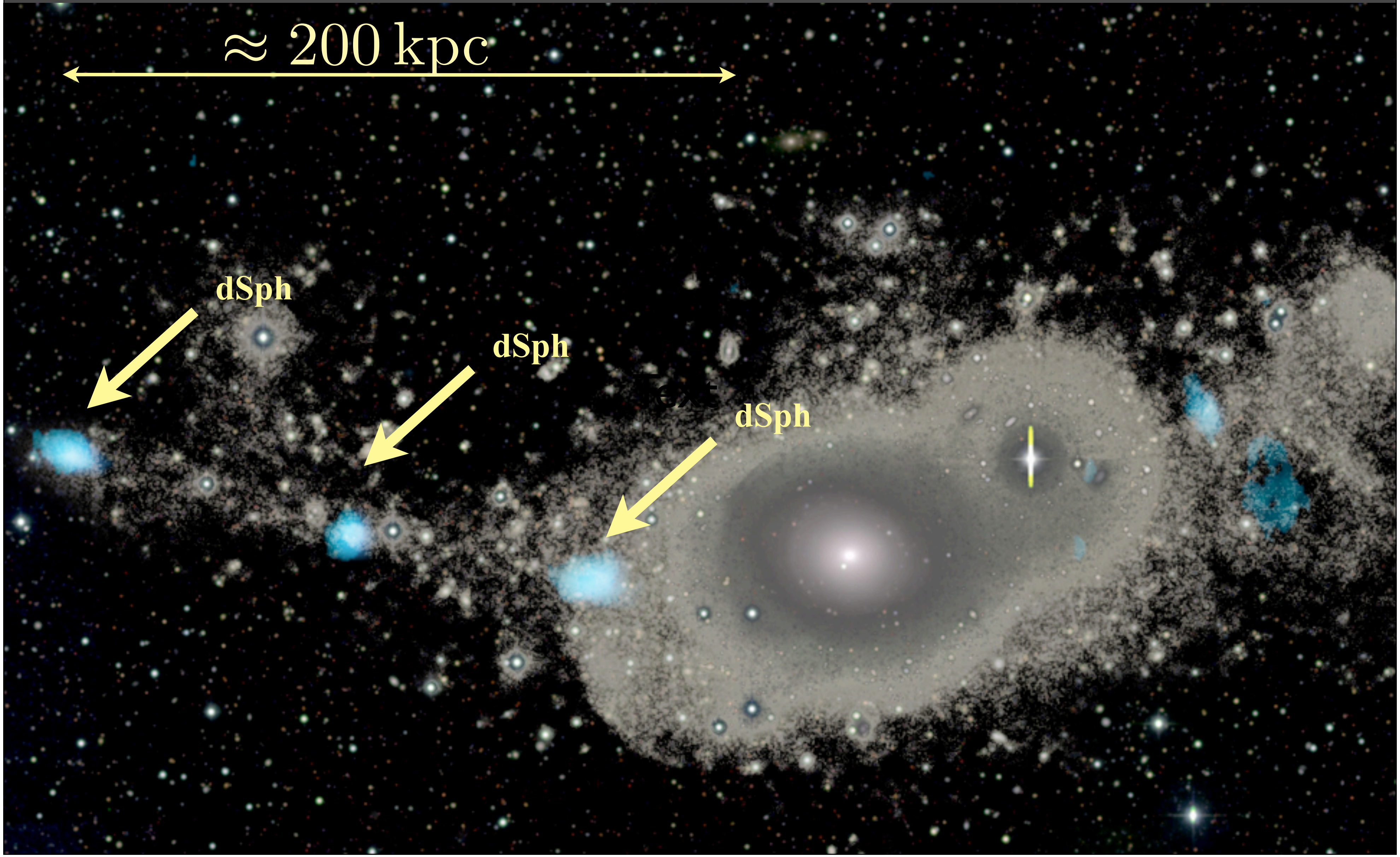
NGC 5557

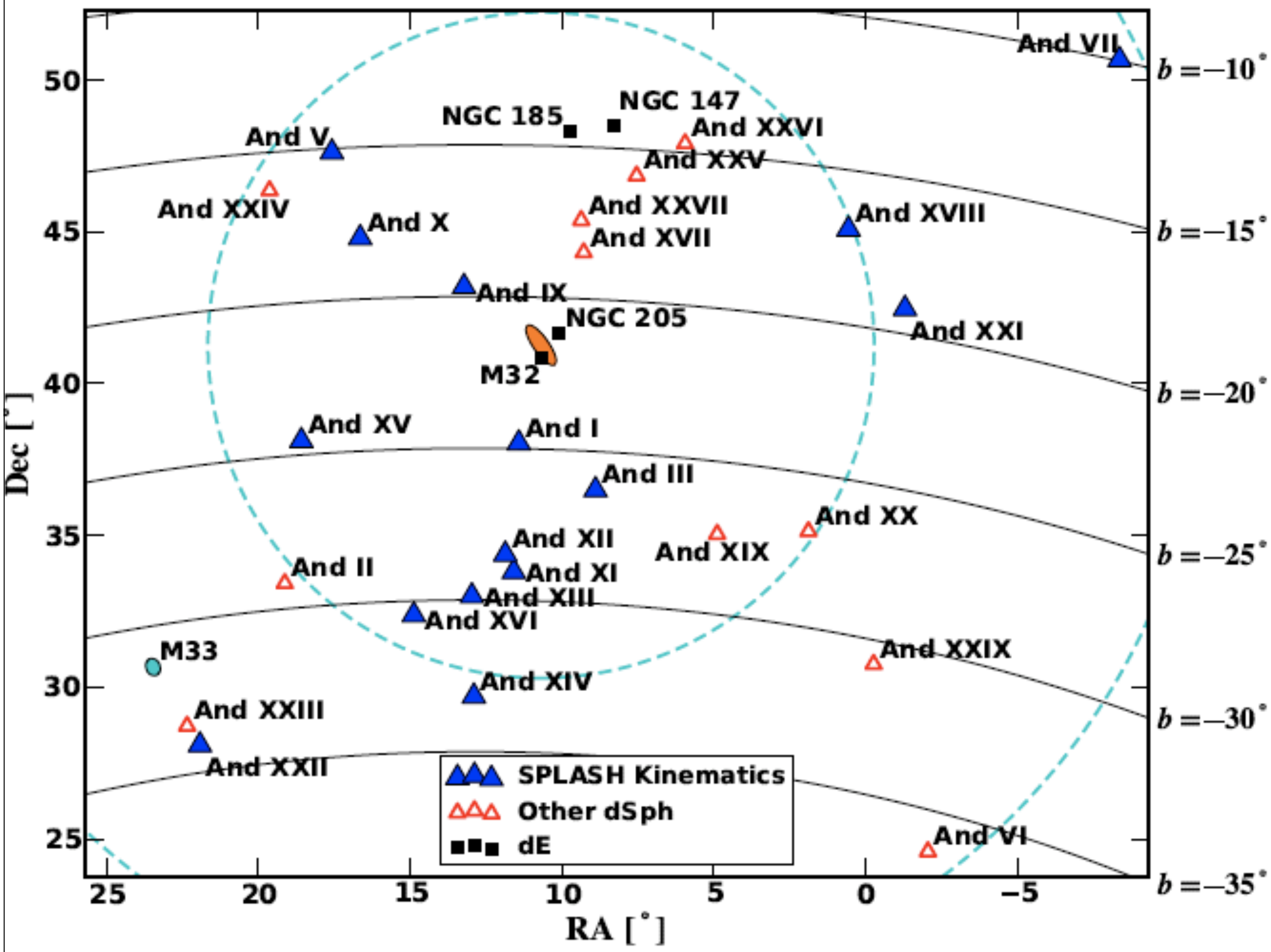
(post-merger 2-3 Gyr)

Duc et al. (2011 MNRAS)



Andromeda

Tollerud et al. (2011, MNRAS)



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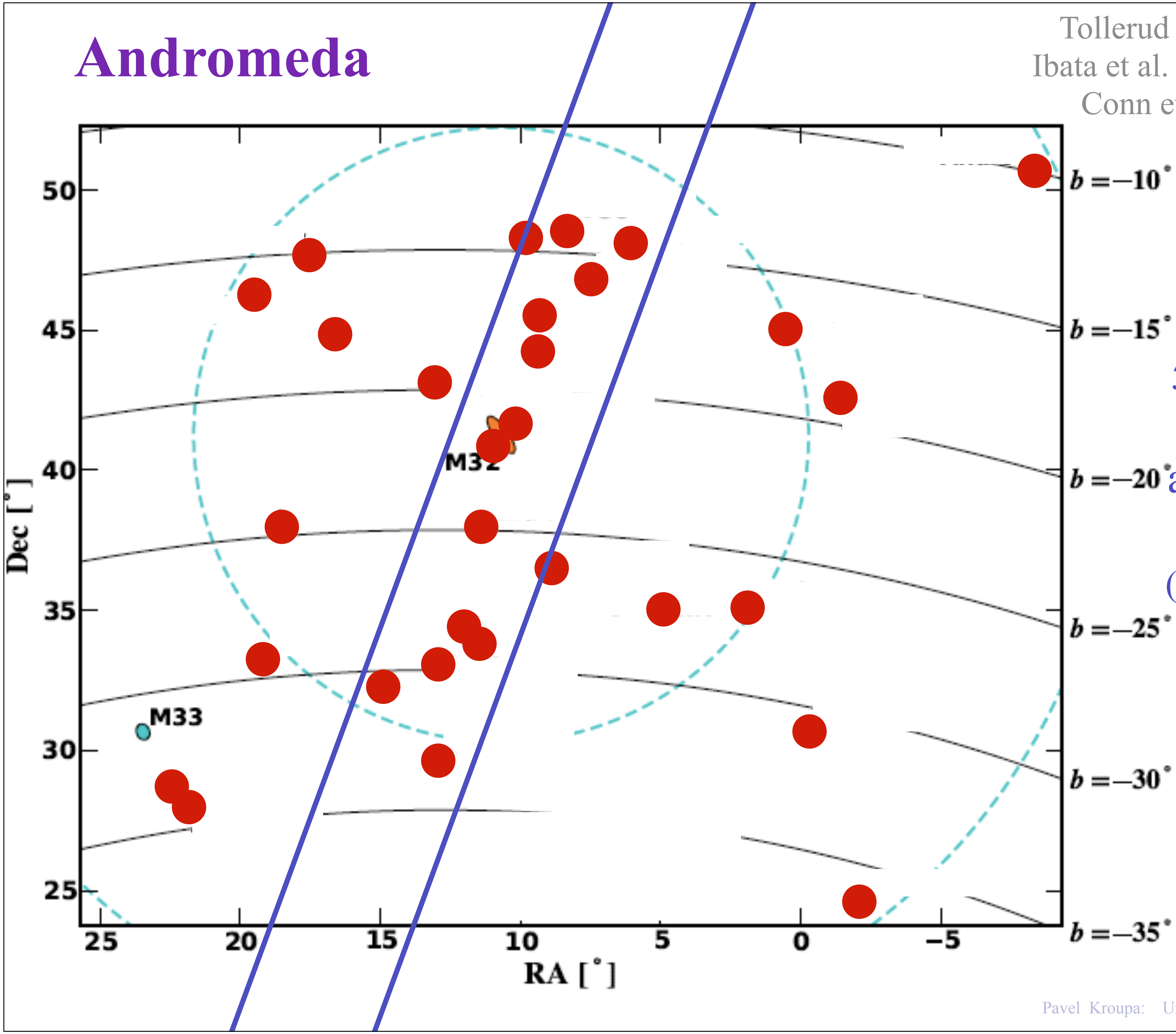
Andromeda

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



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

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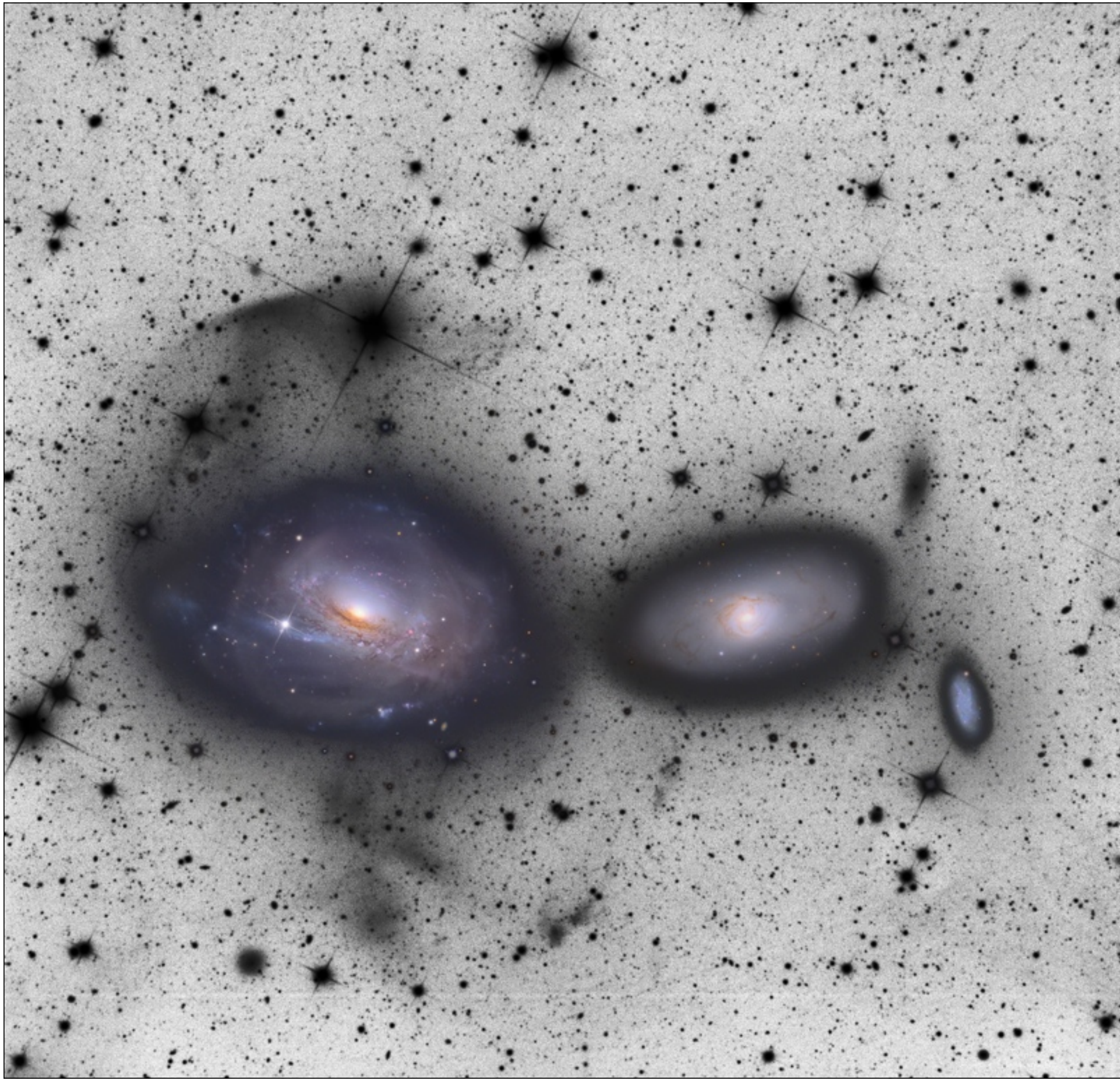
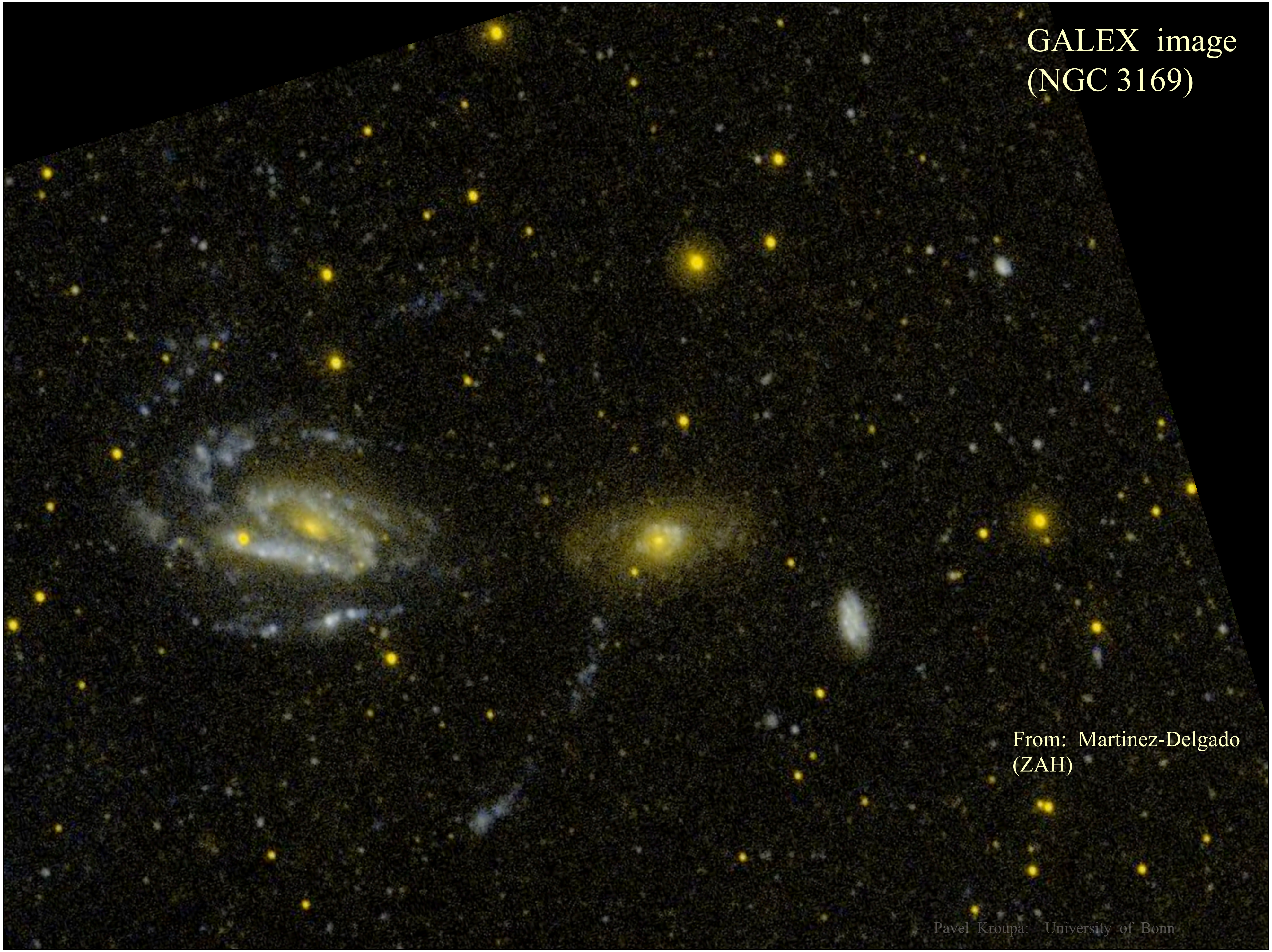


The formation of faint dwarf galaxies in the interaction between two spirals (NGC 3169)

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


GALEX image
(NGC 3169)
From: Martinez-Delgado
(ZAH)
Pavel Kroupa: University of Bonn

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

→ only one type of dwarf galaxy is observed.

→ Dual Dwarf Galaxy Theorem is falsified.

$\Updownarrow$

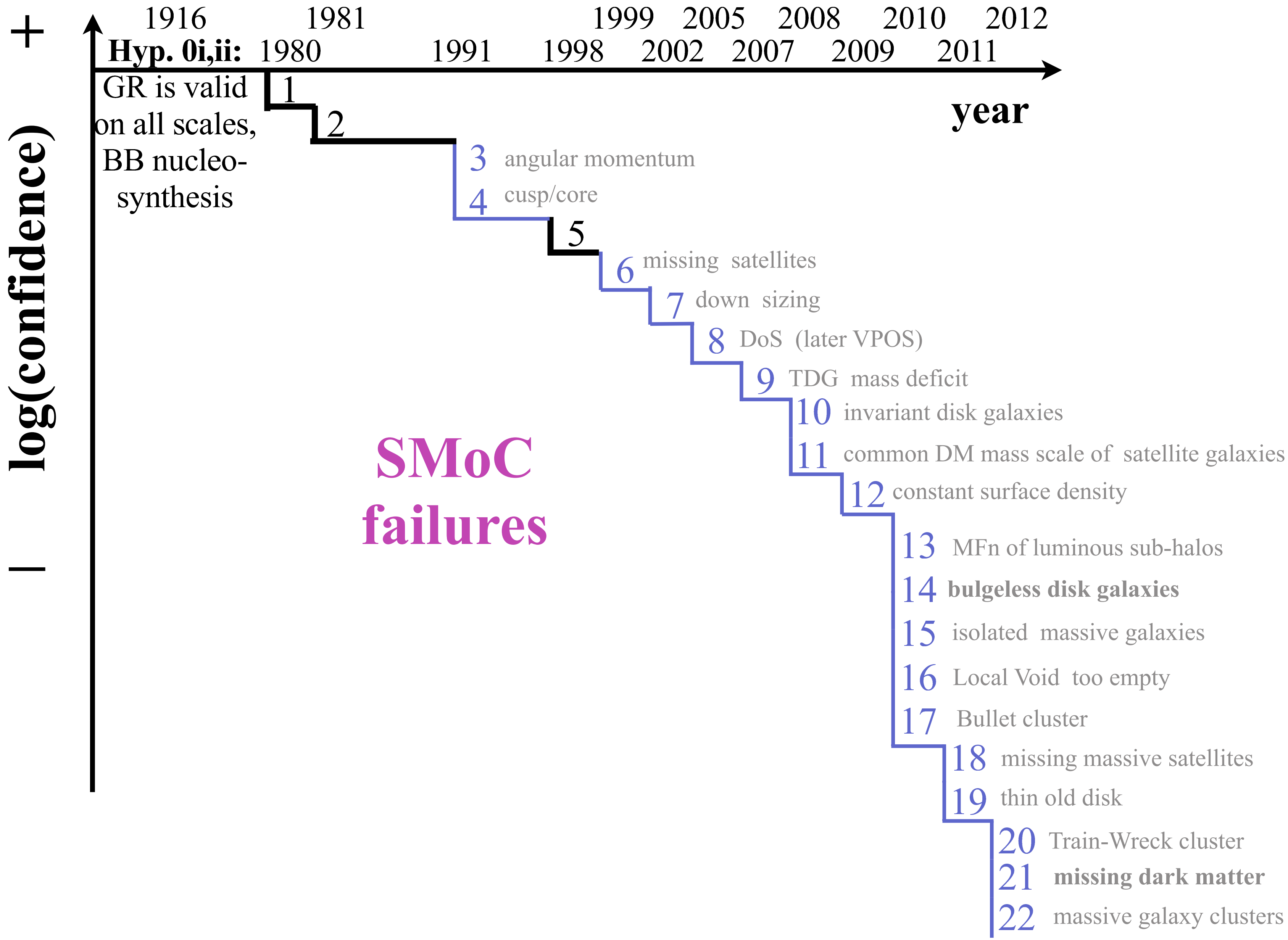
Type A dwarf $=$ Type B dwarf $\Rightarrow$ ~~SMoC~~

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



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Failure 14 :

58–74 per cent of all observed disk galaxies are claimed to **not** have a classical bulge (Kormendy et al. 2010).

This is in conflict with the heavy merging history expected for bright galaxies if the SMoC were true (Hammer et al. 2007).

Failure 21 :

Over spatial scales of 100 Mpc the density of matter fluctuates by 10% if the SMoC were valid.

By counting up all matter within the local sphere with a radius of 50 Mpc, Karachentsev (2012) demonstrates the actual density to be too low by a factor of 3–4.
Most of the missing mass is DM.

Kroupa 2012

The SMoC cannot be the correct description of this universe.

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)

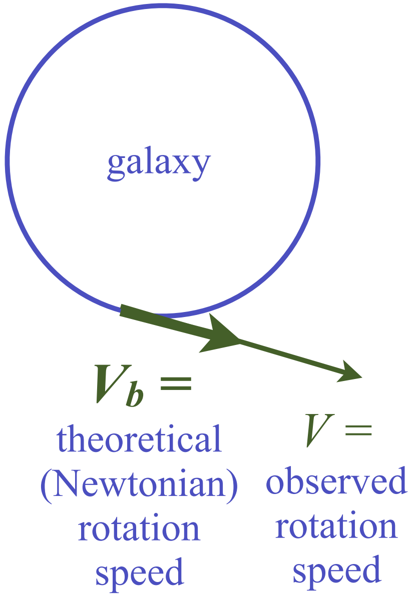
Which impact does this have for understanding dynamics in galaxies and on a cosmological scale ?

Do the data on galaxy-scales contain clues ?

Mass-Discrepancy correlation with acceleration

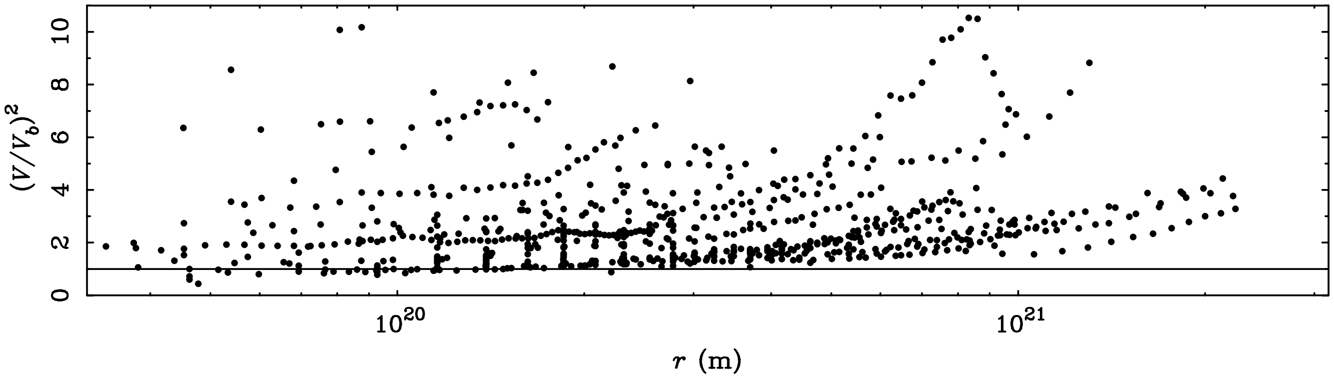
The McGaugh correlation

McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012

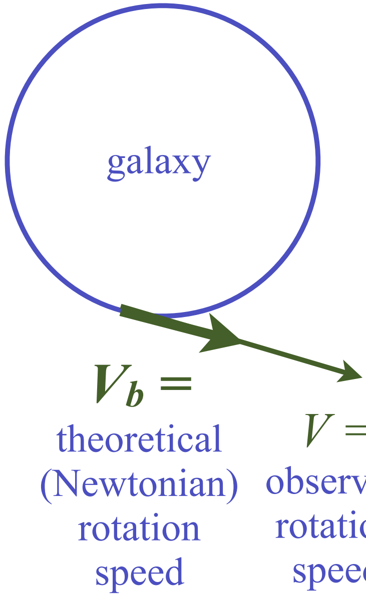


Mass-Discrepancy correlation with acceleration

McGaugh 2004
Famaey & McGaugh 2012
Kroupa 2012



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



Mass-Discrepancy correlation with acceleration

McGaugh 2004
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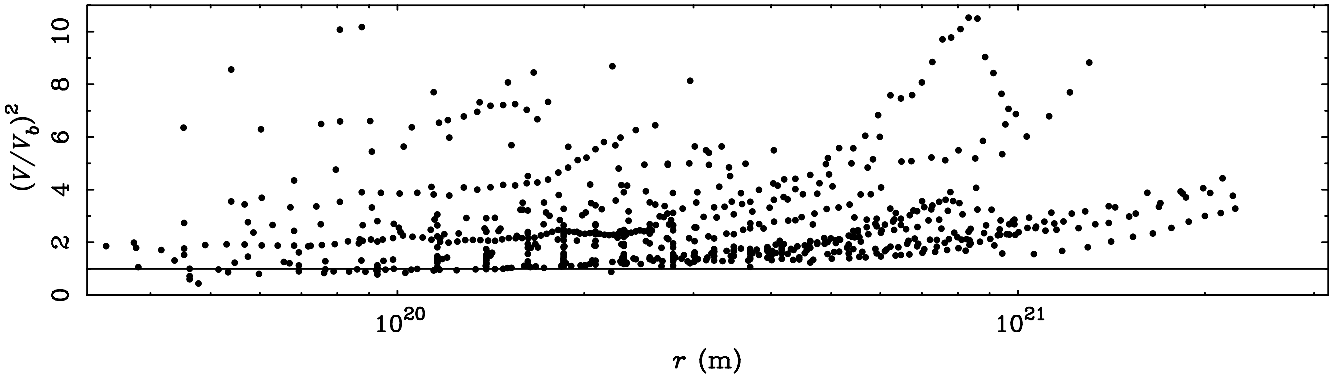
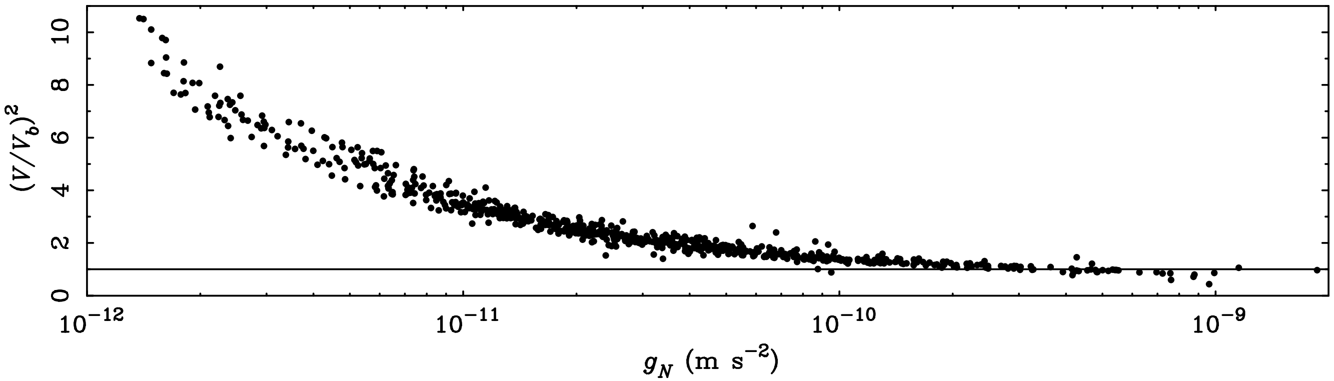
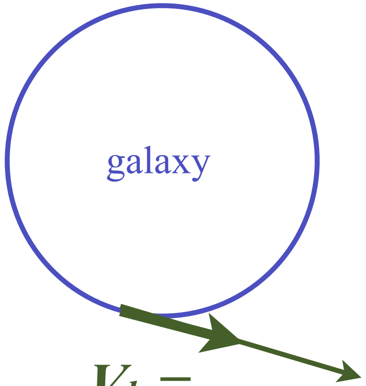


$1 \text{ pc} = 31 \times 10^{15} \text{ m}$ $\quad$ $1 \text{ m} = 3.2 \times 10^{-17} \text{ pc}$



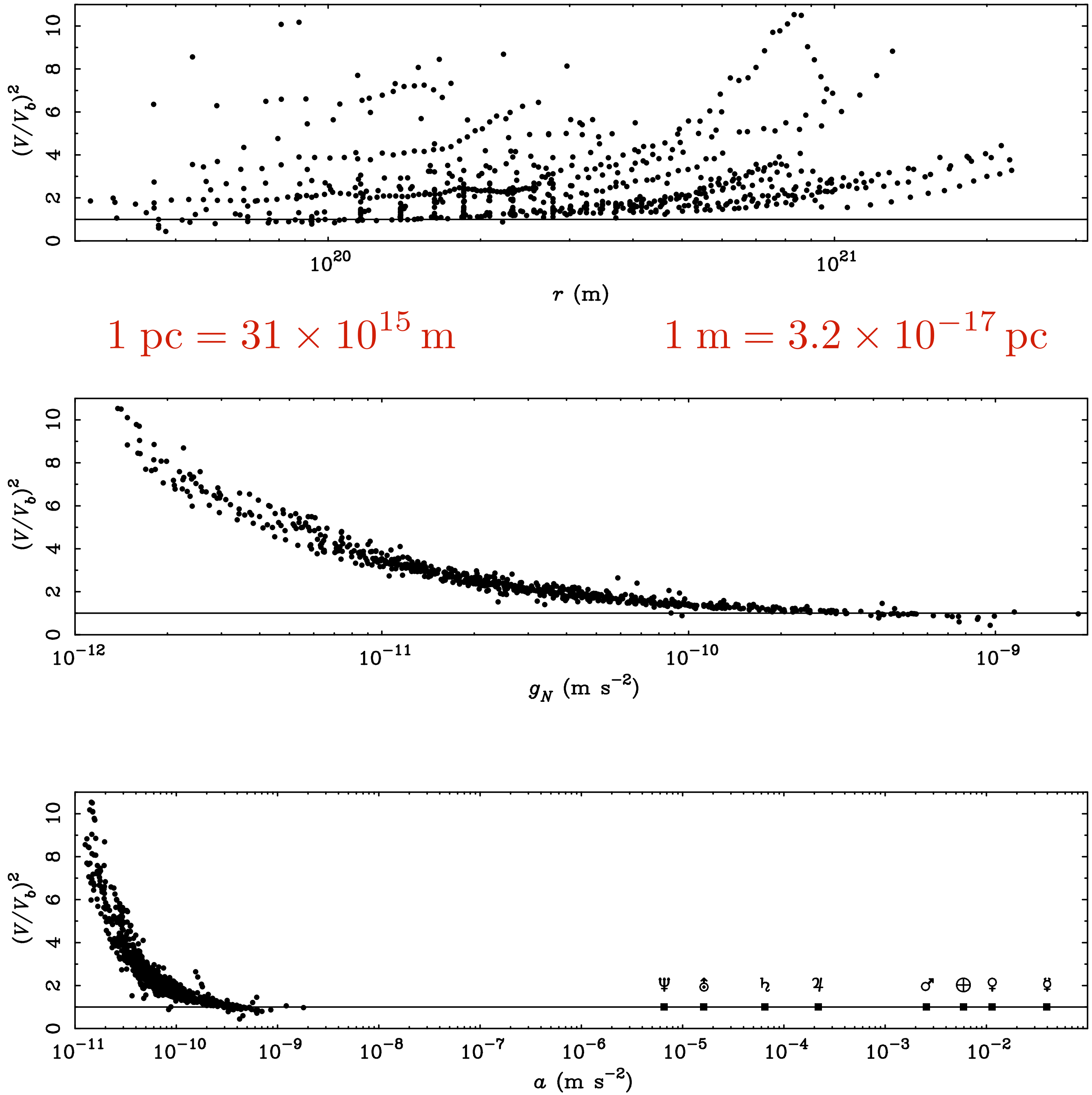


$V_b =$ theoretical (Newtonian) rotation speed

$V =$ observed rotation speed

Mass-Discrepancy correlation with acceleration

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.

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

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

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

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

Pavel Kroupa: University of Bonn

space-time scale invariance (from above) :

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

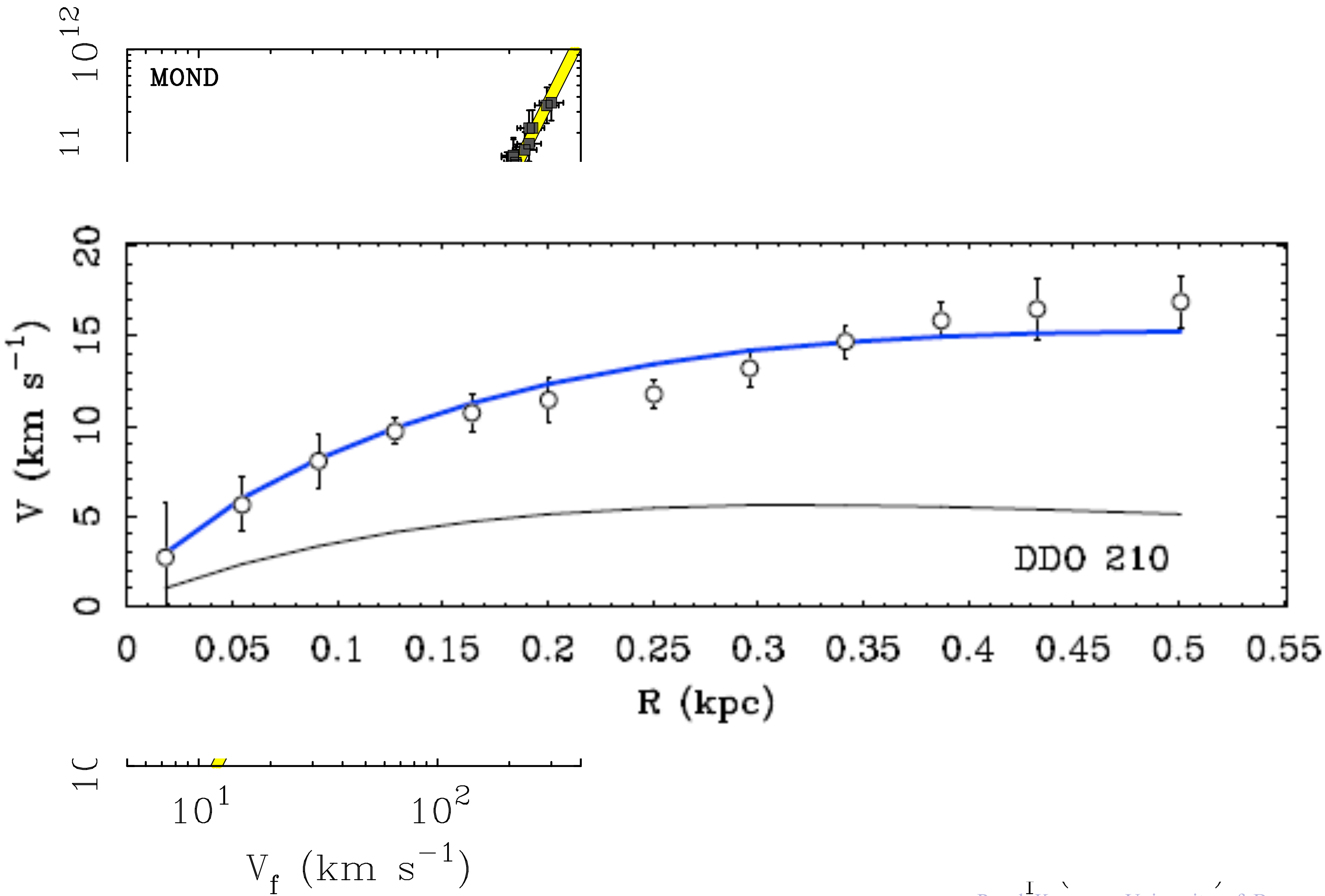
centrifugal acceleration = centripetal acceleration

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

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

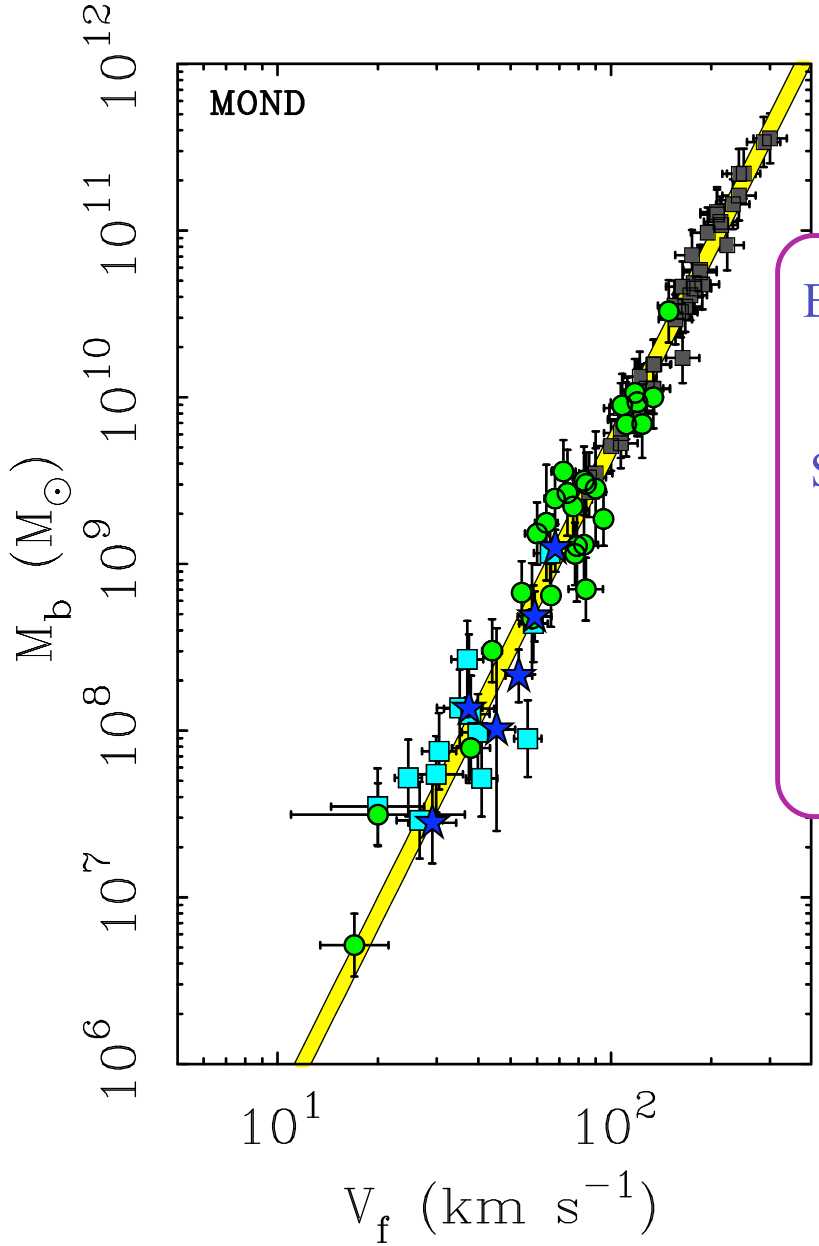
The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



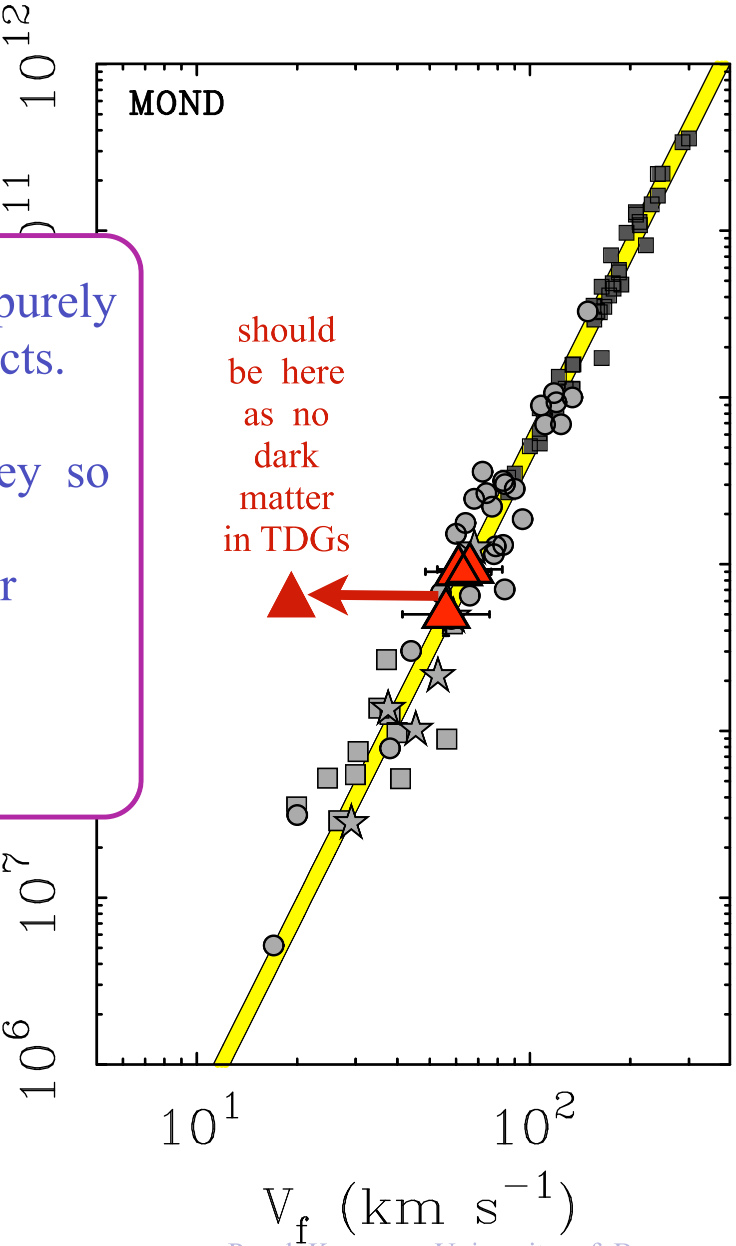
The observational Baryonic Tully -Fisher Relation

Famaey & McGaugh 2012



But TDGs are purely baryonic objects.

So, why are they so similar to the other galaxies ?



in Milgrom

Pavel Kroupa: University of Bonn

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 $a^2 = a_o g_N$

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

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

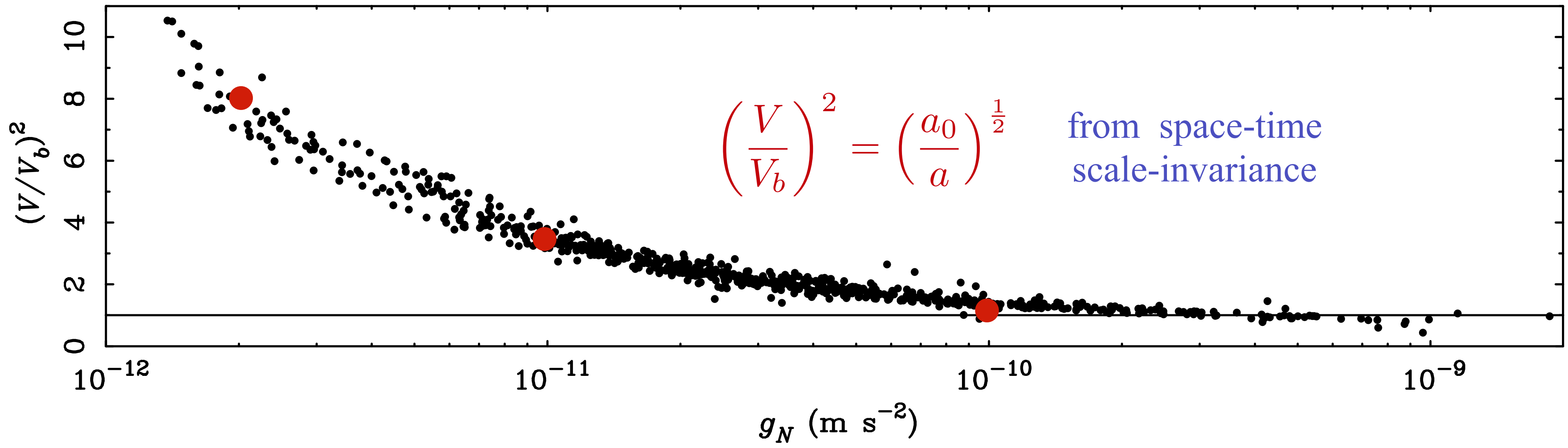
$$V_b^2 = \frac{GM}{r}$$

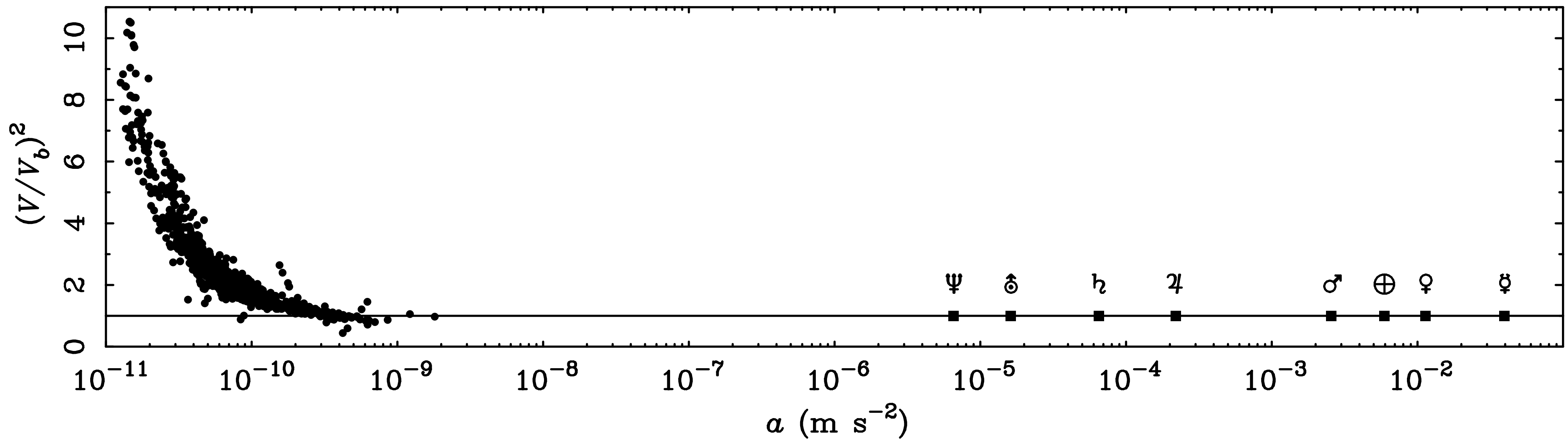
$$\Rightarrow \left(\frac{V}{V_b}\right)^2 = \frac{(G a_0 M)^{\frac{1}{2}}}{r \frac{GM}{r^2}} = \frac{(G a_0 M)^{\frac{1}{2}}}{r a} = \left(\frac{a_0}{a}\right)^{\frac{1}{2}}$$

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

Mass-Discrepancy correlation with acceleration

The McGaugh correlation explained





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."

. . .

Milgromian Dynamics (current best bet)

. . .

Milgromian Dynamics

Ansatz : (Milgrom 1983, ApJ, 270, 371)

$$\mu\left(\frac{a}{a_0}\right)\,\vec{a} = \vec{g}_{\rm N} \quad \left\{ \begin{array}{l} \mu(x) = 1 \text{ if } |x| \gg 1 \\ \mu(x) = x \text{ if } |x| \ll 1 \end{array} \right.$$

i.e. $\vec{a} = \vec{g}_{\rm N}\,\mu^{-1} \geq \vec{g}_{\rm N}$

What is the interpretation ?

Milgromian dynamics can be understood to be

a different effective Law of Gravity

through a different "Poisson" equation

$$\vec{\nabla}\cdot\left[\mu\left(\frac{\left|\vec{\nabla}\phi\right|}{a_0}\right)\vec{\nabla}\phi\right] = 4\,\pi\,G\,\rho$$

giving the Milgromian potential

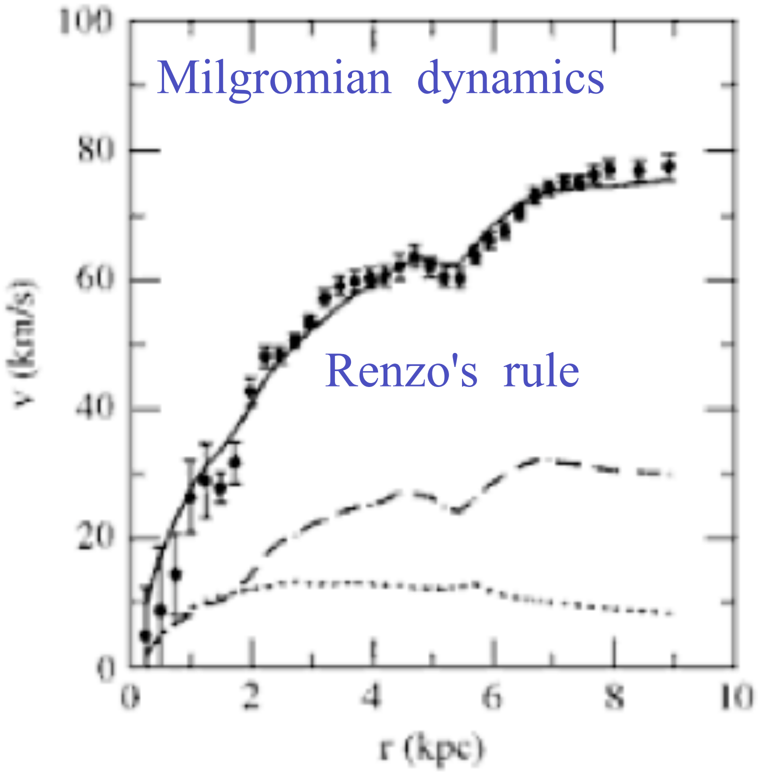
a modification of the Law of Inertia

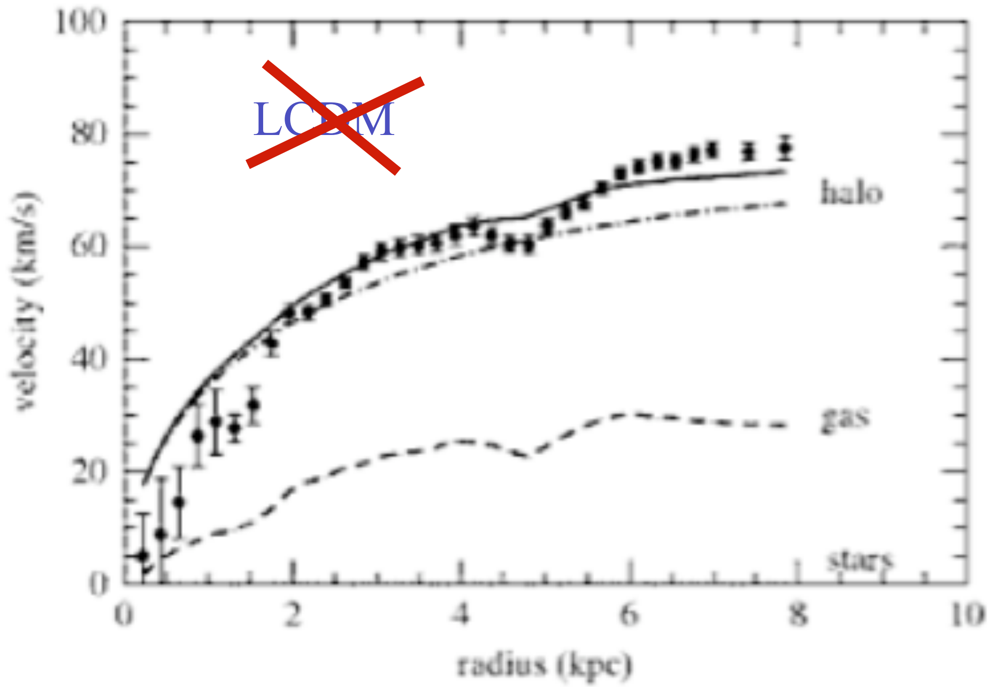
through the breaking of the equivalence of inertial and gravitating mass

$$\vec{a} = \vec{F}\left[m\,\mu\left(\frac{\left|\vec{\nabla}\phi\right|}{a_0}\right)\right]^{-1}$$

where $\vec{F} = m\,\vec{g}_{\rm N}$ for gravity

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





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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"*)

Milgromian dynamics and structure formation

Combes & Tiret 2009, arXiv:0908.3289 :

"... simulations yield comparable results between [Milgromian dynamics] and the standard model for the large-scale structure, ... "

Milgromian dynamics and structure formation

Skordis et al. 2006, PhRvL

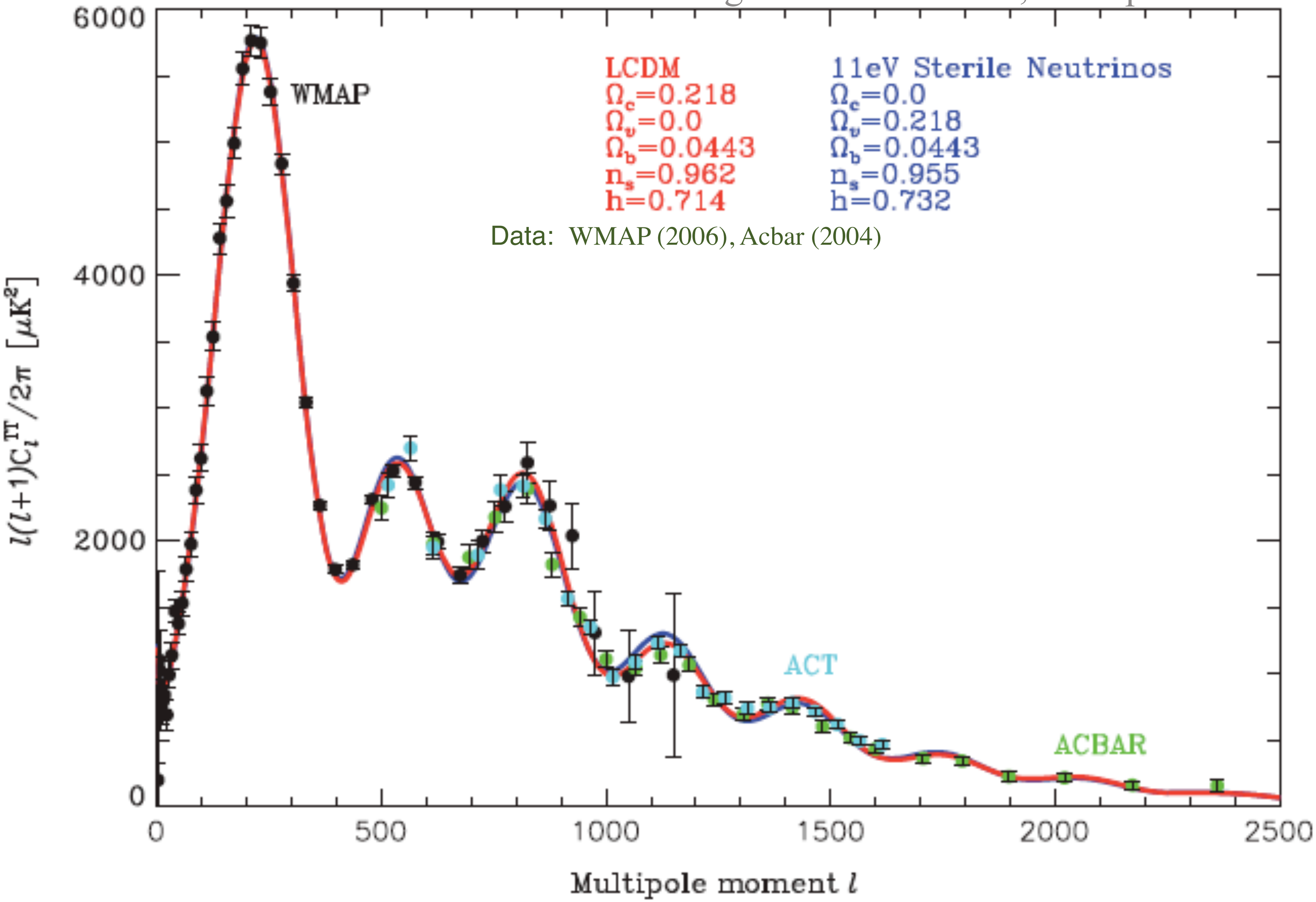
"We show that it may be possible to reproduce observations of the cosmic microwave background and galaxy distributions with Bekenstein's theory of" Milgromian dynamics.

Angus 2010 on SciLogs: "State-of-the-art cosmology: the current status"

Perfect fit to all CMB peaks with 11ev sterile neutrino.

CMB power spectrum in Milgromian dynamics

Angus & Diaferio 201; Kroupa 2012



Pavel Kroupa: University of Bonn

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 standard model of cosmology is falsified **:**

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

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