Theorem :

$$\mathrm{dSph} = \mathrm{TDG} \Longrightarrow \not{\mathrm{LCDM}}$$

Proof . . .

Pavel Kroupa

Two Zwicky Conjectures of fundamental importance :

1. Zwicky (1937) galaxies are about 500 times heavier in the Coma galaxy cluster than judged from their light emission. This is his famous conjecture that there must be **dark matter**.

2. Zwicky (1956) **:** when galaxies interact (e.g. when they collide), the expelled matter can re-condense in regions and form new smaller (dwarf) galaxies. This is his famous conjecture that **tidal-dwarf galaxies** can form out of the collisional debris of other galaxies.

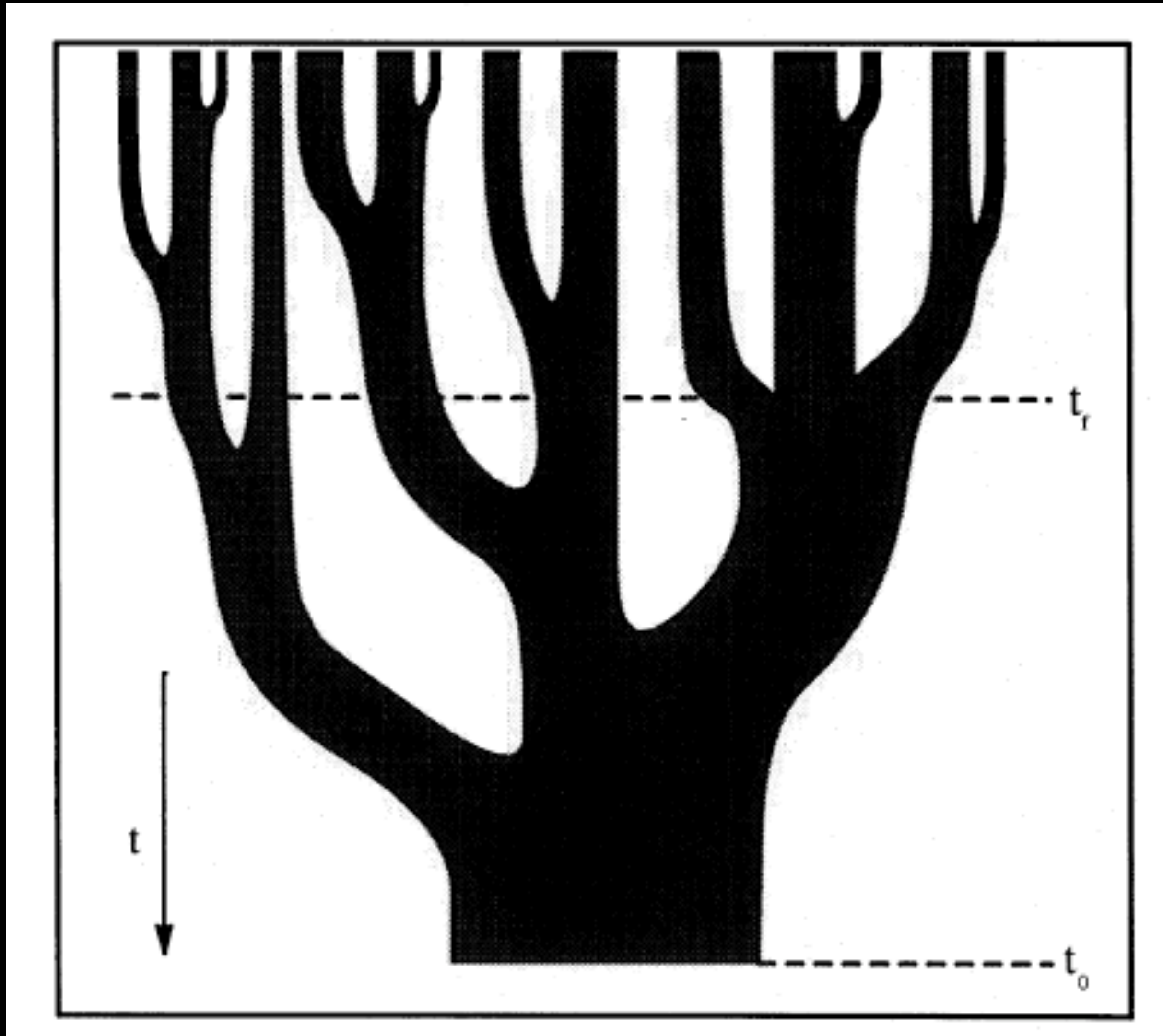
Both have to be true . . .

the LCDM model

Structures form according to the cosmological merger tree

the beginning

Lacey & Cole (1993)



today

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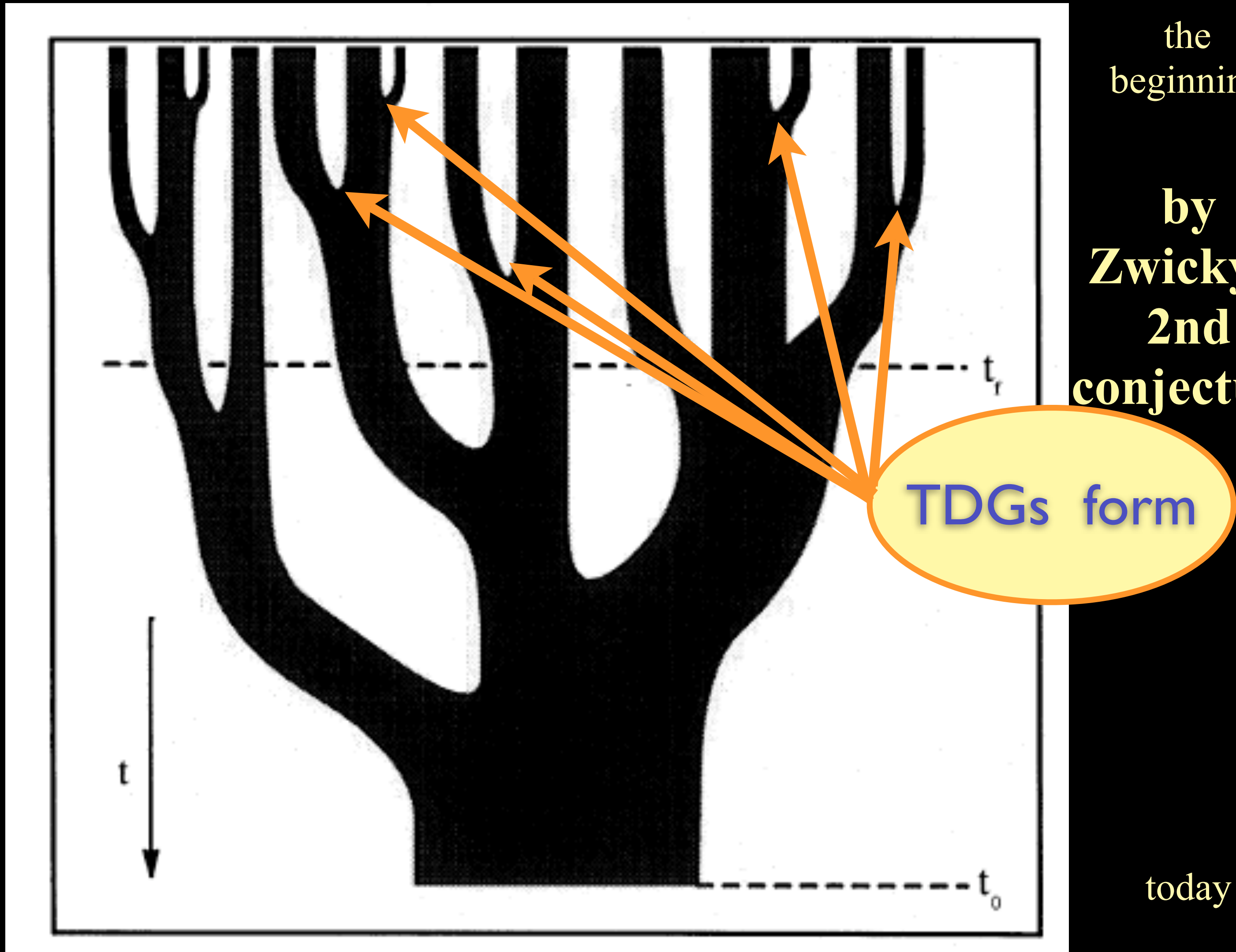
≈ 250 kpc
by Zwicky's 1st conjecture

Structures form according to the cosmological merger tree

Lacey & Cole (1993)



the beginning

by Zwicky's 2nd conjecture

today

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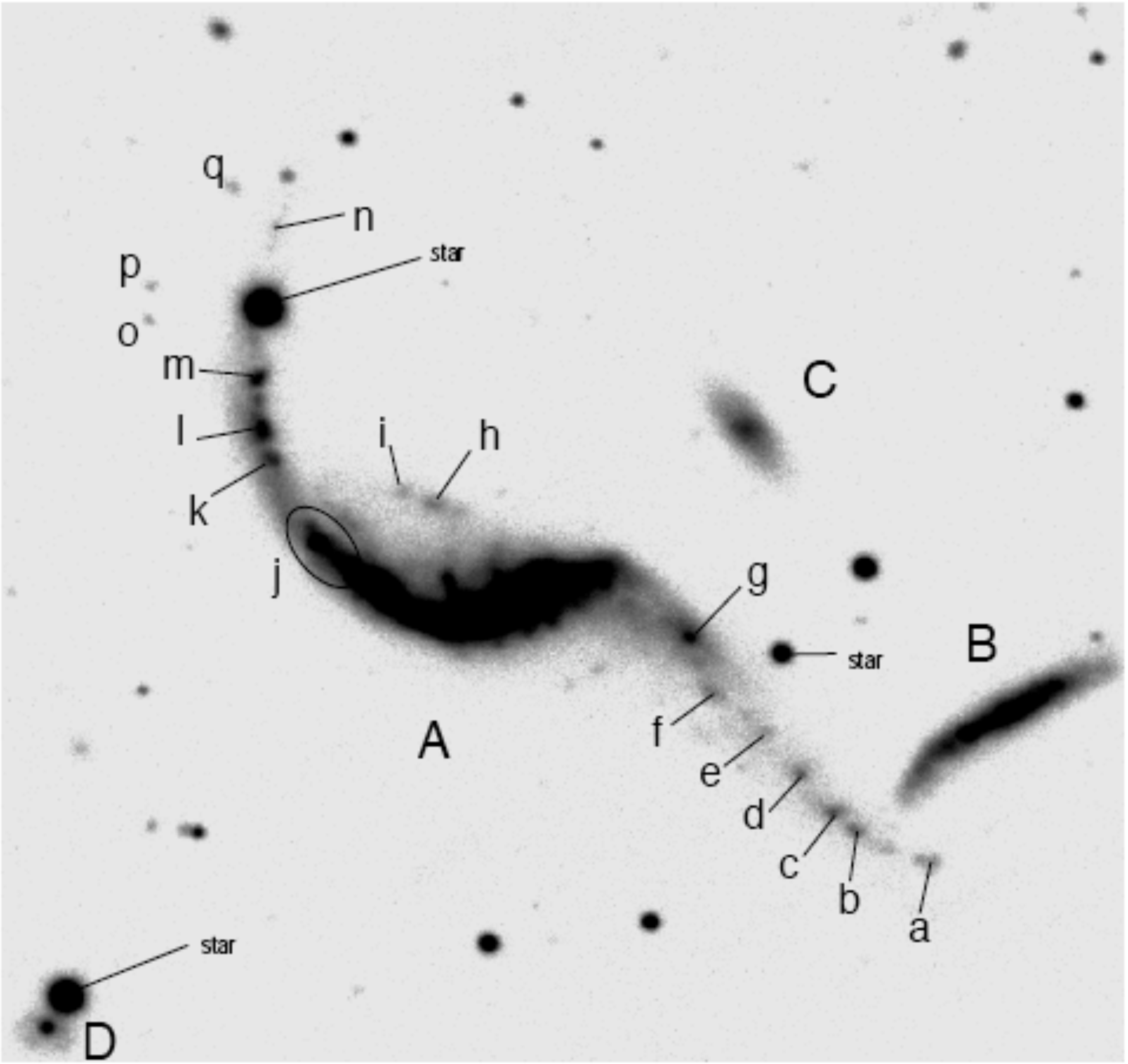


Fig. 21. Identification chart of field 10 around AM 1353-272.

(Weilbacher et al. 2000)

$N_{\rm TDG} \approx 14$

Fritz Zwicky's two conjectures have two immediate implications :

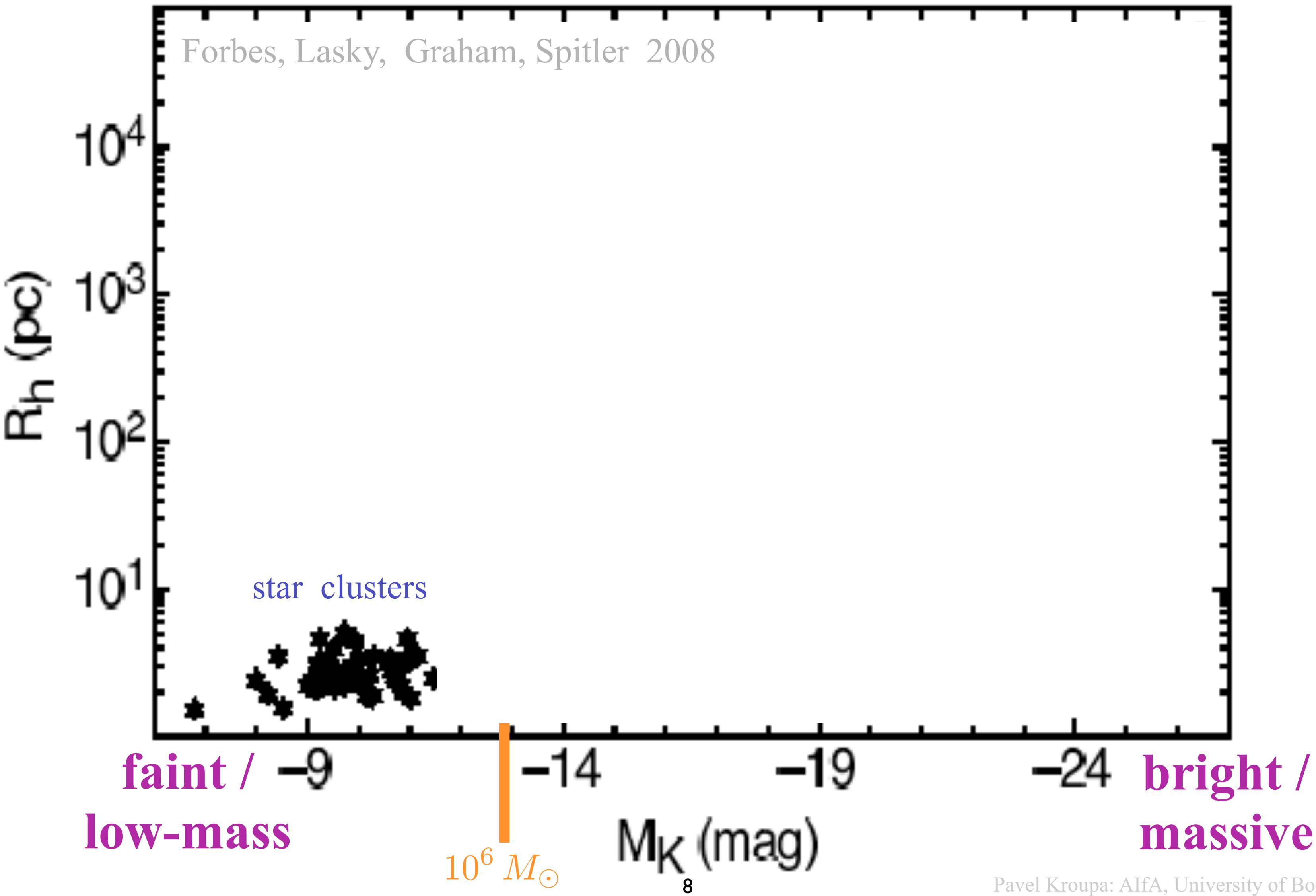
1. There exist large numbers of *dark-matter dominated satellite galaxies* (e.g. Moore et al., Klypin et al.).

2. There exist large numbers of *newly formed (tidal-dwarf) satellite galaxies* (they do not contain dark matter) (Okazaki & Taniguchi 2000).

This is OK, but are there
two different types of dwarf galaxy**?**

Radius vs luminosity :

Dabringhausen, Hilker, Kroupa 2008;
Misgeld & Hilker 2011



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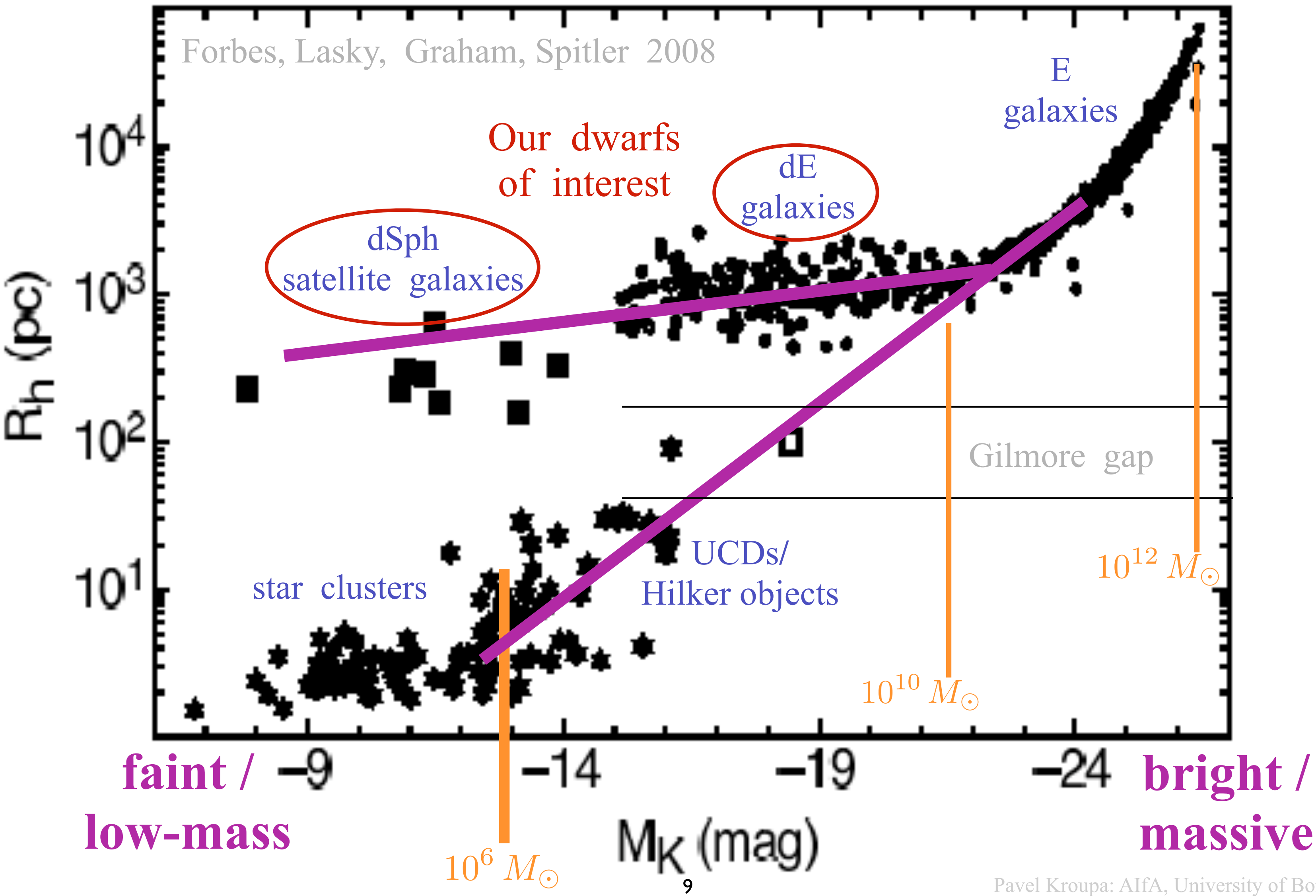
8

Radius vs luminosity :

Dabringhausen, Hilker, Kroupa 2008;
Misgeld & Hilker 2011



9

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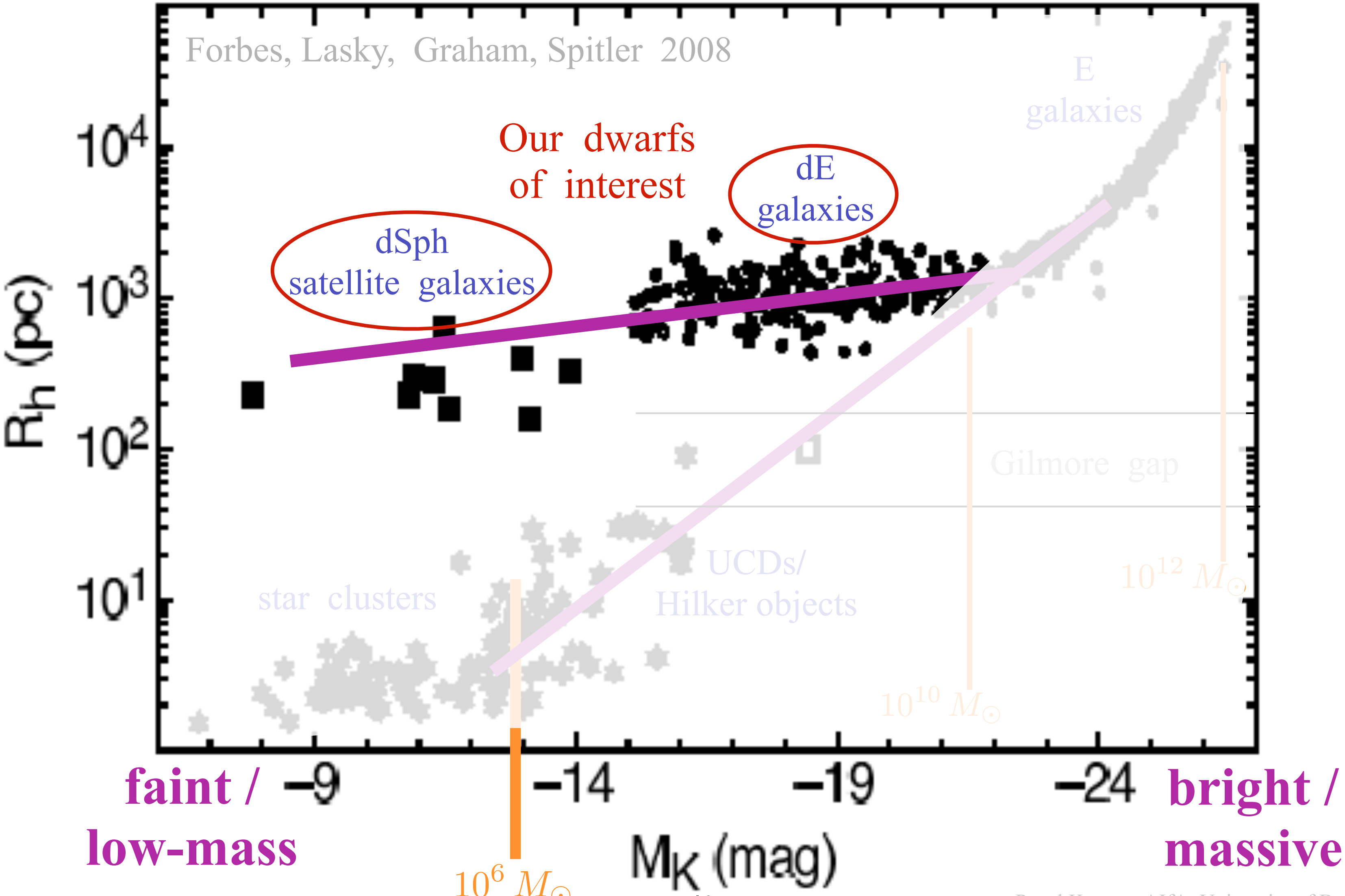
Radius vs luminosity :

Dabringhausen, Hilker, Kroupa 2008;
Misgeld & Hilker 2011



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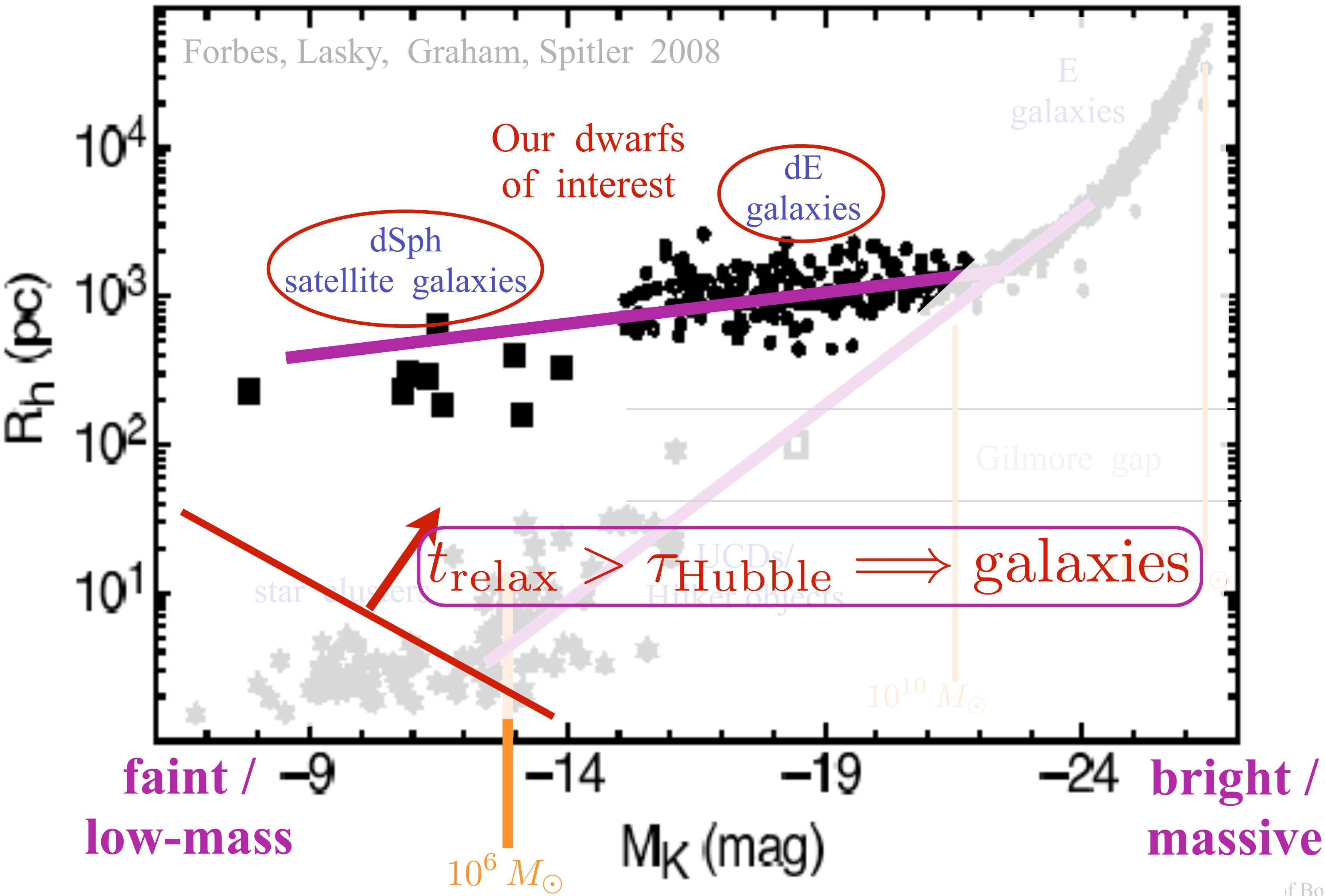
10

Radius vs luminosity :

Dabringhausen, Hilker, Kroupa 2008; Misgeld & Hilker 2011



Fritz Zwicky's two conjectures have two immediate implications :

1. There exist large numbers of *dark-matter dominated satellite galaxies.*

2. There exist large numbers of *newly formed (tidal-dwarf) satellite galaxies* (they do not contain dark matter).

This is OK, but are there
two different types of dwarf galaxy**?**

No, there is *only one type* of dwarf galaxy **!**

But, *which* one **?** And *why* only one **?**

Lets consider first the
dark-matter type satellite
dwarf galaxy.

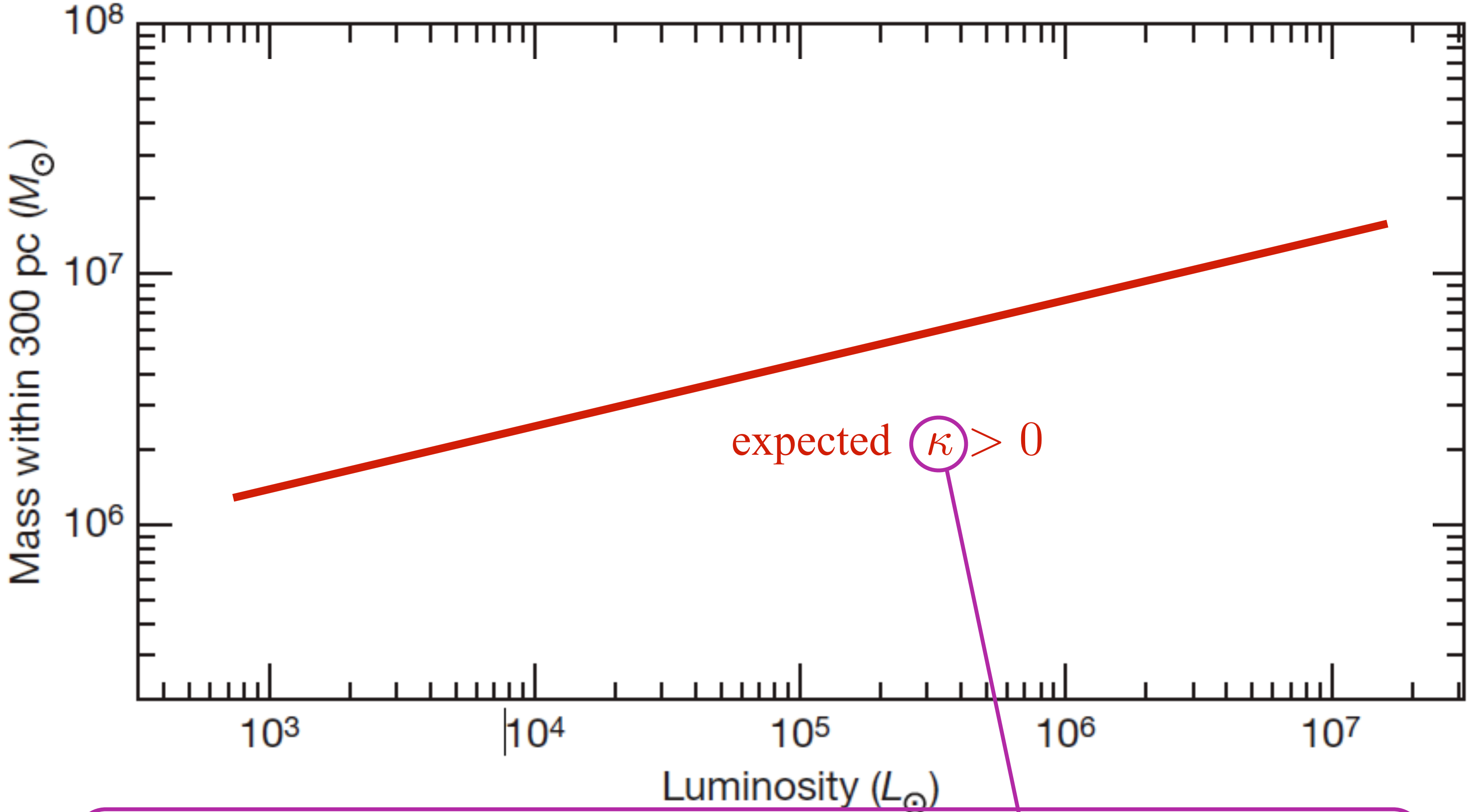
Test this idea with calculations
within the LCDM framework:

The mass-luminosity relation :

energy balance:

more gravitating mass,
more luminous mass ?

The mass - luminosity relation of satellite galaxies



$$\log_{20}(M_{0.3\,\mathrm{kpc}}/M_\odot) = \log_{10}(M_{03}/M_\odot) + \kappa \log_{10}(L_V/L_{V,\odot})$$

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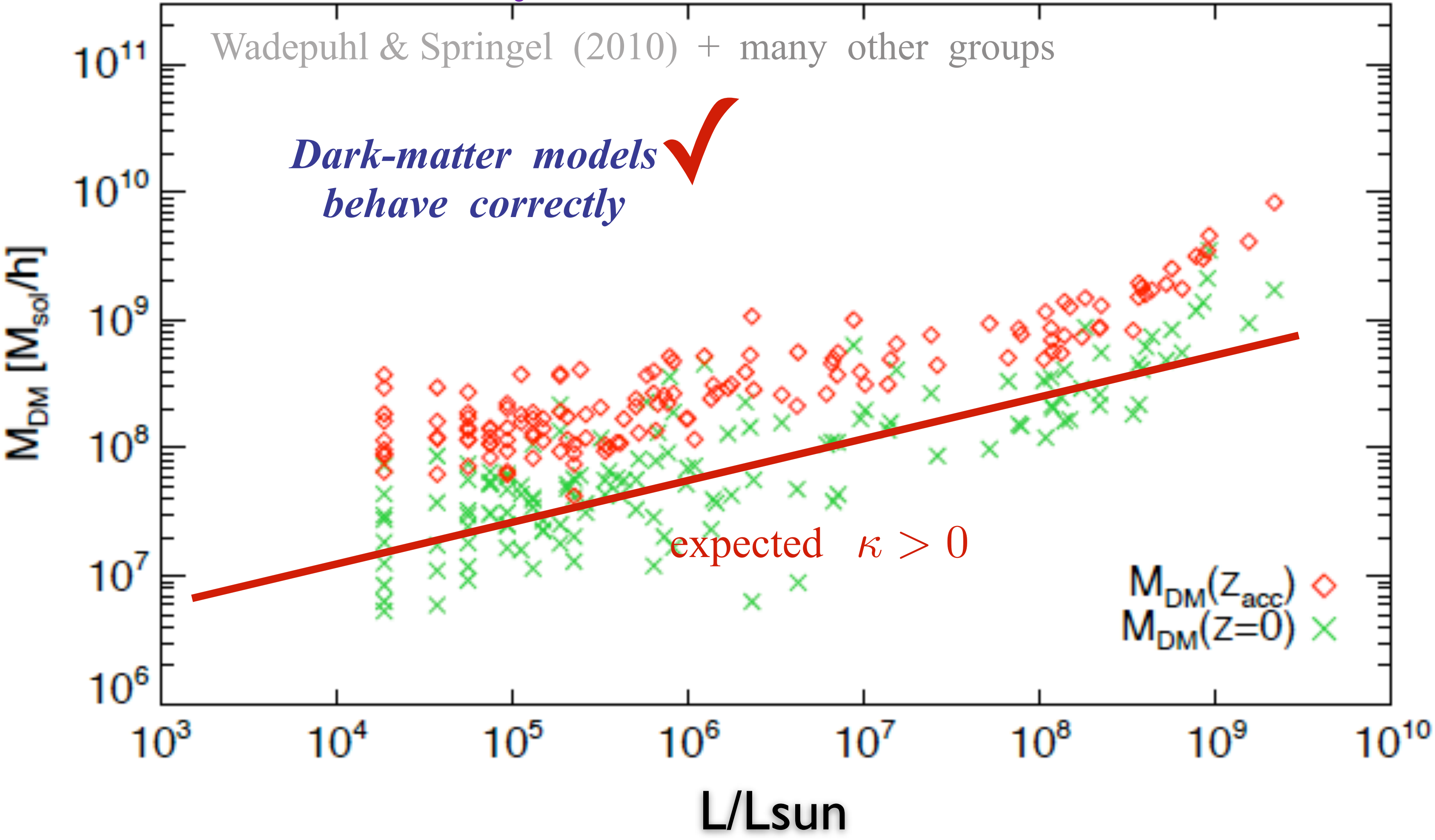
The DM-mass--luminosity relation of satellite galaxies

Theory - Models of Satellites



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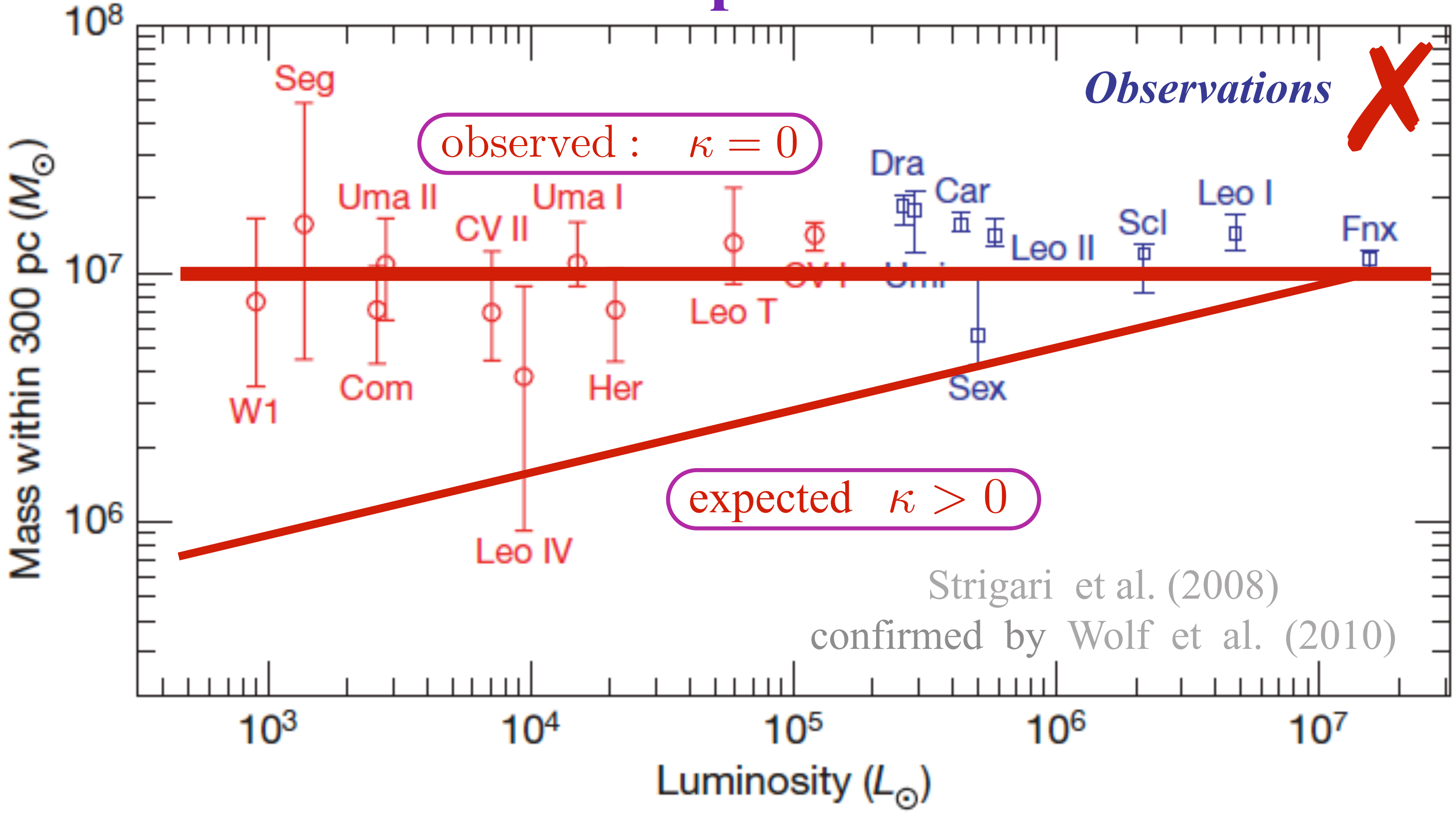
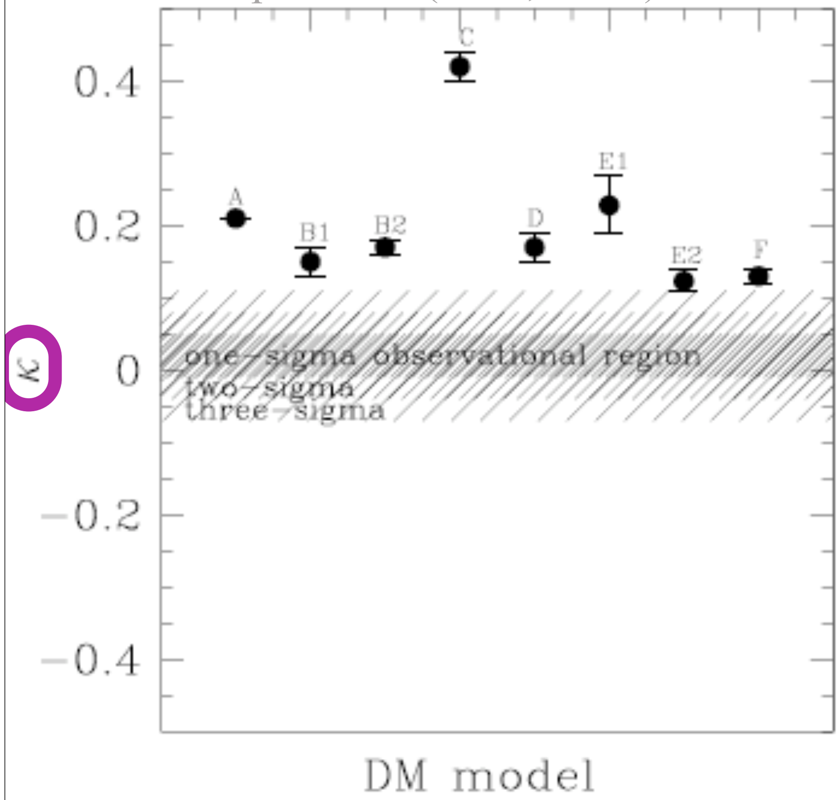
The DM-mass--luminosity relation of satellite galaxies

Observations - empirical data of Satellites



Kroupa et al. (2010, A&A)



$$\log_{20}(M_{0.3\,\mathrm{kpc}}/M_{\odot}) = \log_{10}(M_{03}/M_{\odot}) + \kappa \log_{10}(L_V/L_{V,\odot})$$

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All model satellite populations have

$\kappa > 0$

The *lack* of an *observed* mass-luminosity relation

($\kappa \approx 0$)

⬇

nature apparently does not care
about the existence of the
putative dark matter halo.

Thus, the *concept* of dark-matter halos appears to be *unphysical* for dSph satellites

~~dark-matter halos~~

Individual dSph morphology :

DM gravitating potential :

smooth luminous morphology ?

Significant isophote structure is present in many dSph satellites despite a large

$$\sigma \approx 700 \text{ pc}/100 \text{ Myr}$$

Substructure should smear-out if σ is really due to a DM halo, unless it has a harmonic core.

→ consistent with DM halo ?

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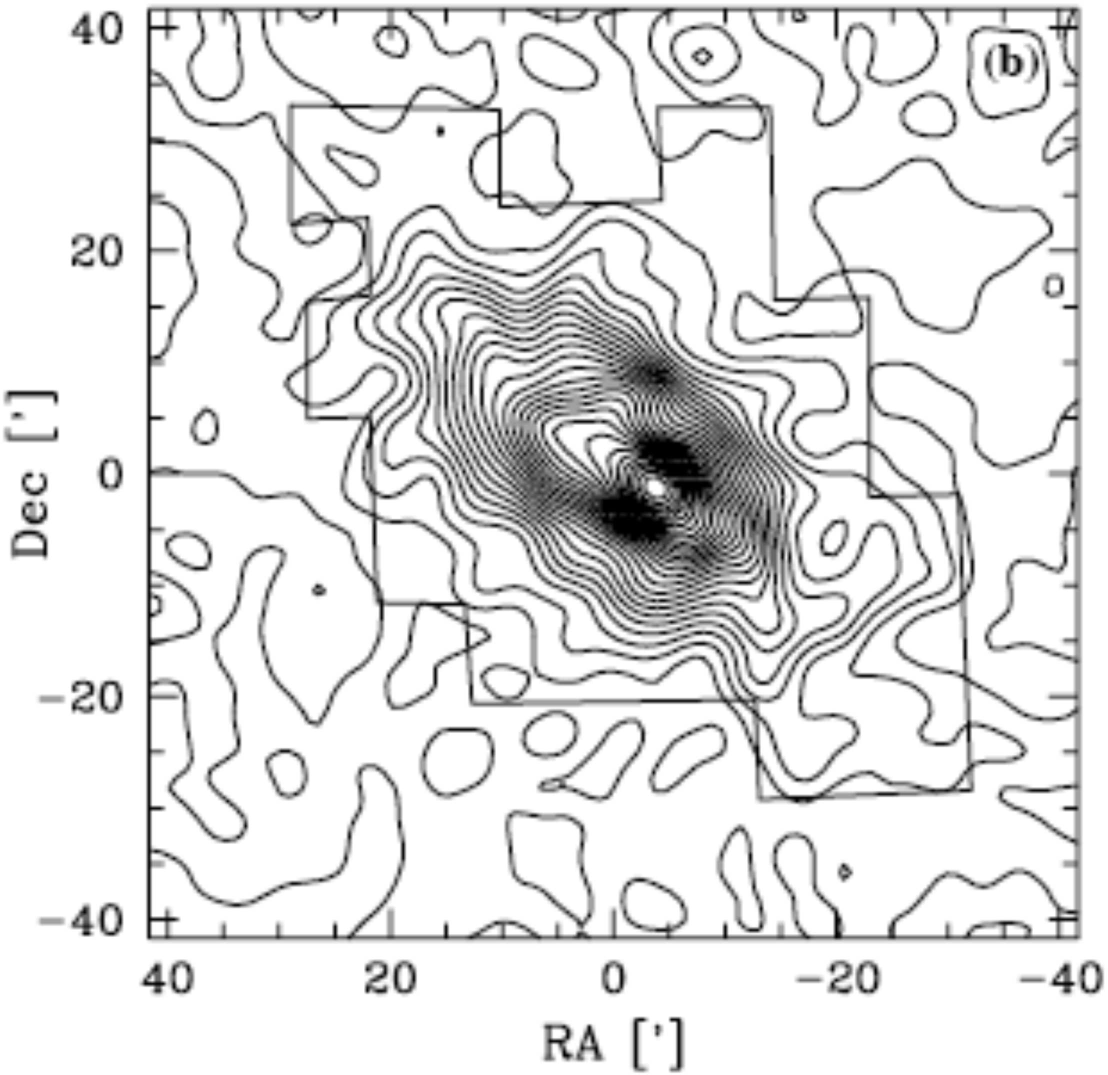


UMi

D=65kpc

(Kleyna et al. 1998)

$$\left(\frac{M}{L}\right)_{0,\mathrm{V}} = 60$$

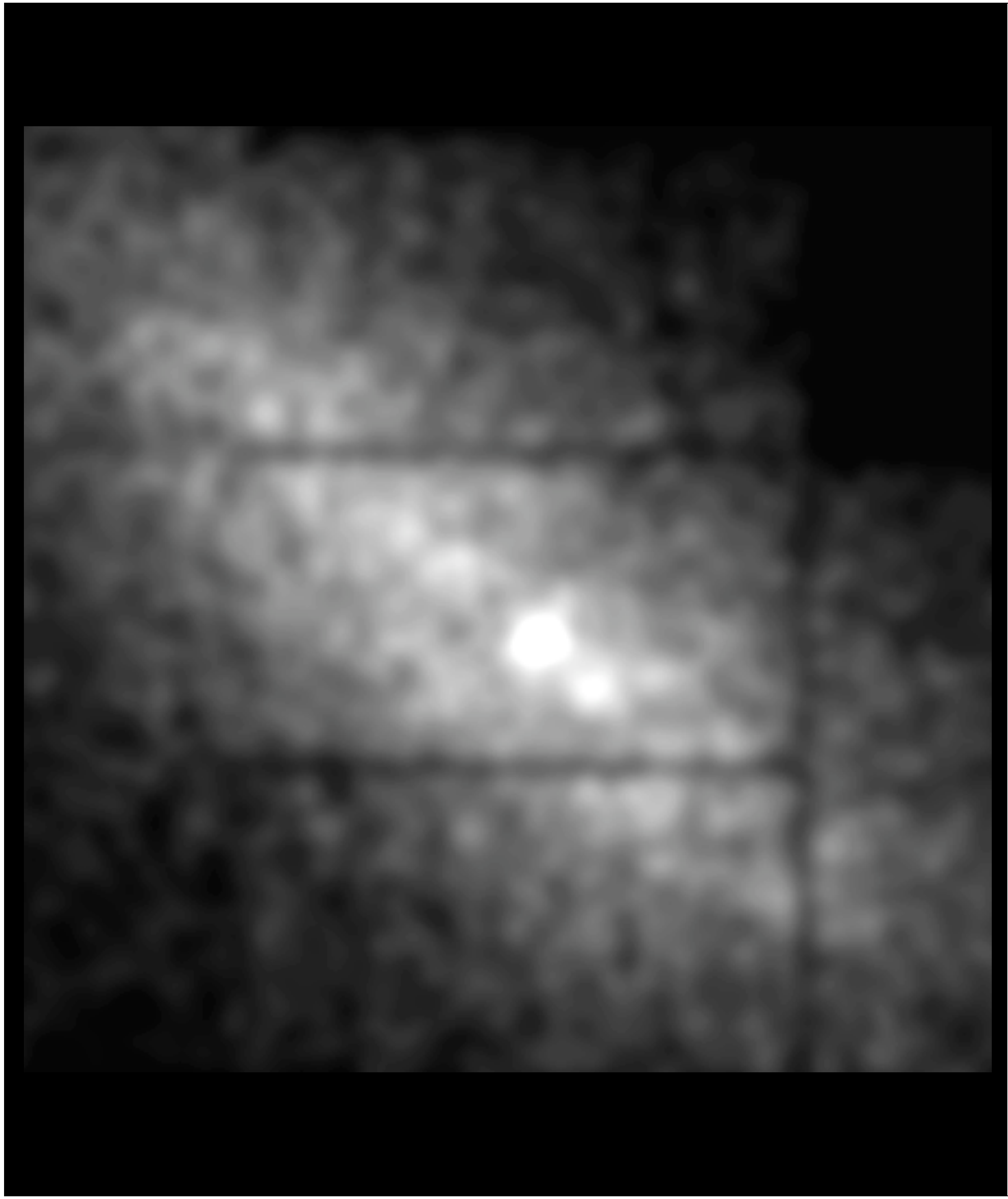
$$\left(\frac{M}{L}\right)_{\mathrm{tot,V}} = 79$$

(Mateo 1998)

But :

$$\left(\frac{M}{L}\right)_{\mathrm{particles}} = 12$$

(Gomez-Flechoso & Martinez-Delgado 2003)



UMi

D=65kpc

(Martinez-Delgado et al., in prep)

Substructure significant :

(Kleyna et al. 2003)

UMi

D=65kpc

(Martinez-Delgado et al., in prep)

S shape **:**
strong evidence for extra-tidal stars

Massive CDM halo ?

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Fornax

D=140kpc

(Demers et al. 1994)

$$\left(\frac{M}{L}\right)_{0,\mathrm{V}} = 4.8$$

$$\left(\frac{M}{L}\right)_{\mathrm{tot,V}} = 4.4$$

(Mateo 1998)

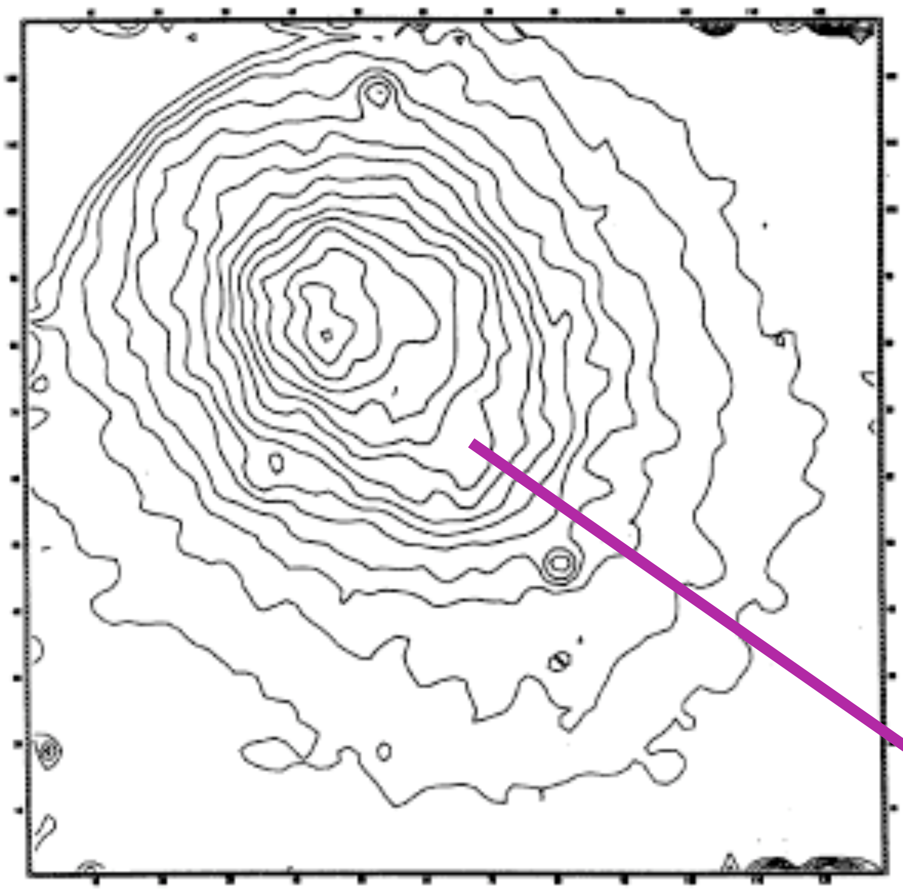

FIG. 4. Isophotes of equal stellar density of field 1 reveal that the structure of Fornax, near the center, is not symmetric.

Not consistent with being embedded / shielded by an extensive dark-matter sub-halo **!**

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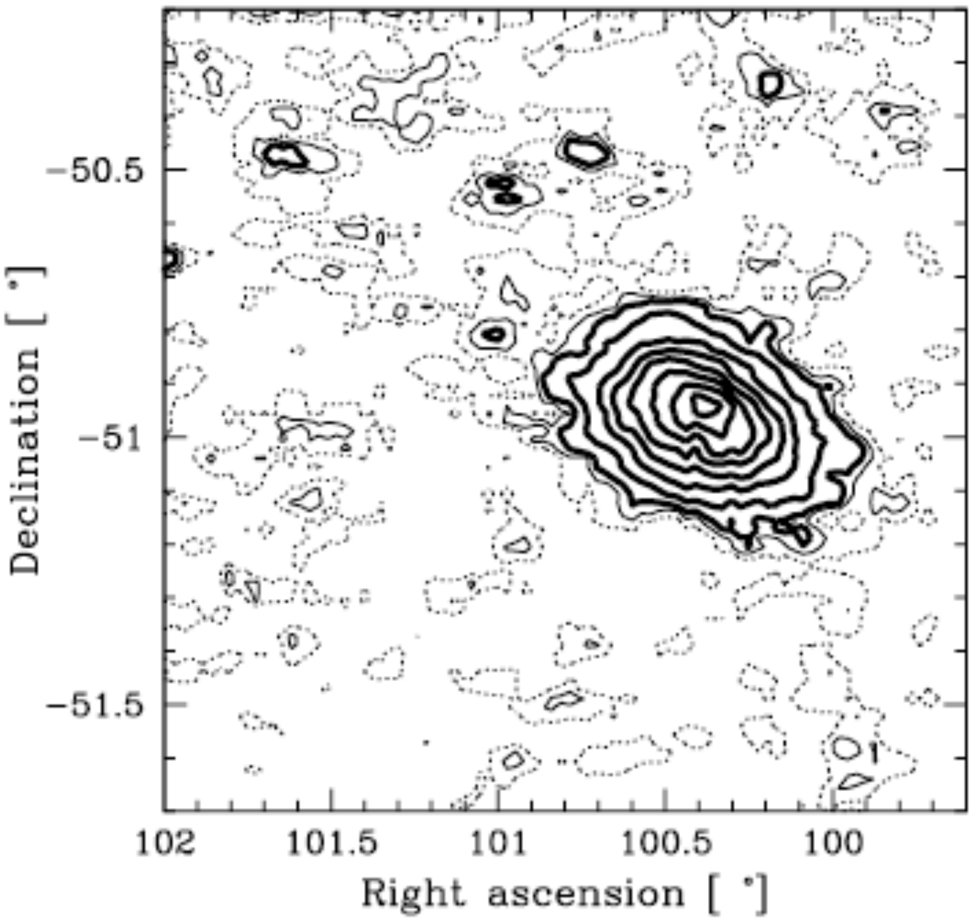


Fig. 1. Contour plot of the Carina dwarf spheroidal. The density levels correspond to background value (dotted line), 1σ above that (thin solid line), 2σ, 5σ, 10σ and so on (thick solid lines). No significant departure from the spheroidal shape can be seen. A galactic gradient can be seen from the northeastern to the southwestern corner.

Carina

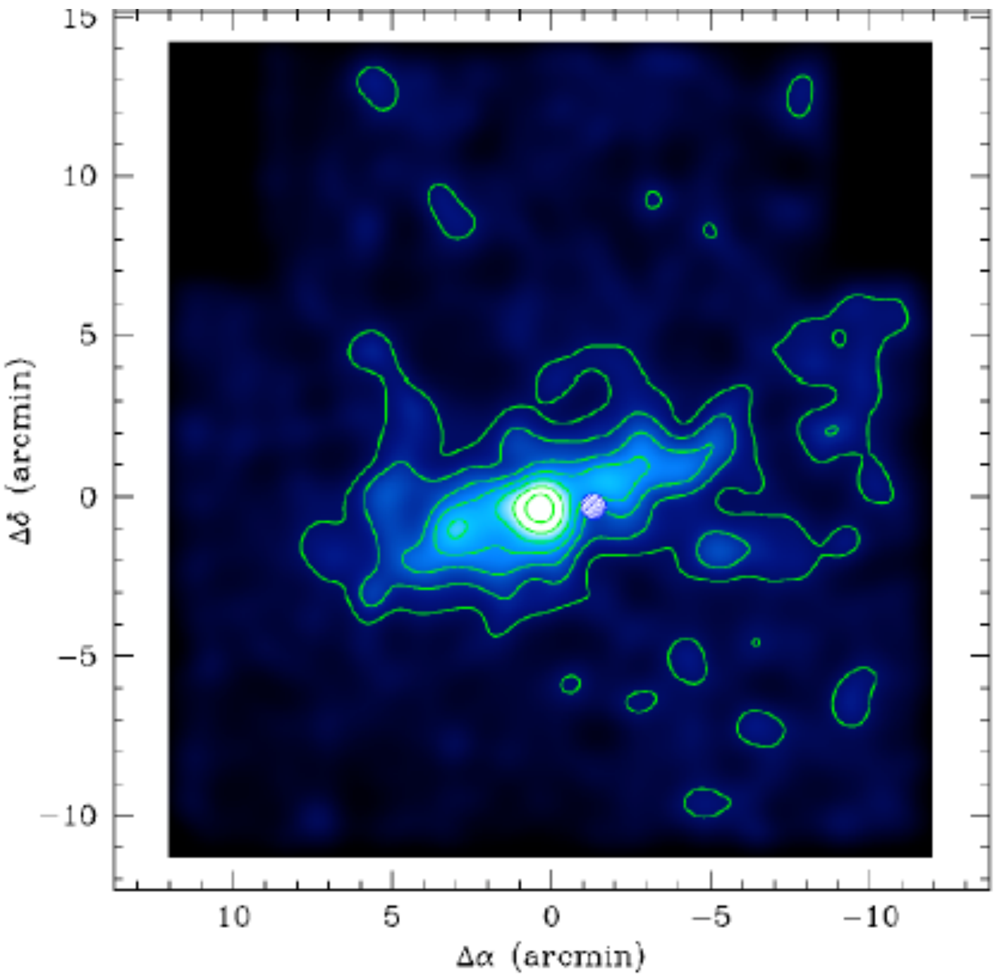
D=93kpc

(Walcher et al. 2003)

$$\left(\frac{M}{L}\right)_{0,\mathrm{V}} = 30$$

$$\left(\frac{M}{L}\right)_{0,\mathrm{V}} = 31$$

(Mateo 1998)



Hercules

D=130kpc

(Coleman et al. 2007)

TABLE 1
PROPERTIES OF THE HERCULES dSPH

Parameter	Value
R.A. (J2000)	16:31:02.0
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$c = \log(r_t/r_c)$	0.74 ± 0.25

The distortions apparent in many of the dSph satellites do not support the notion that they are shielded by $10^9\,M_\odot$ dark-matter halos.

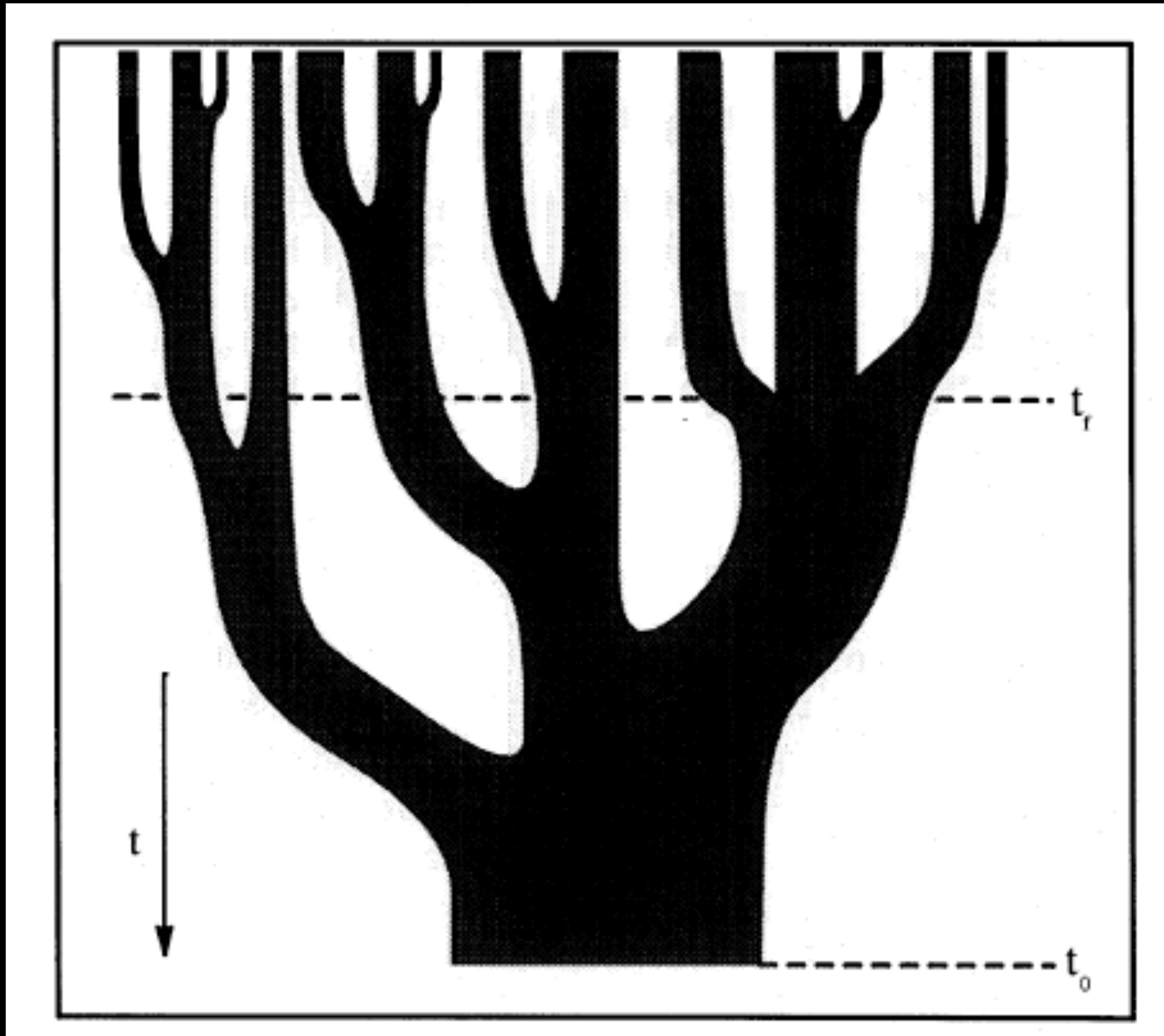
~~dark-matter halos~~

The
spatial distribution
of the
MW satellites

...further clues

Structures form according to the cosmological merger tree

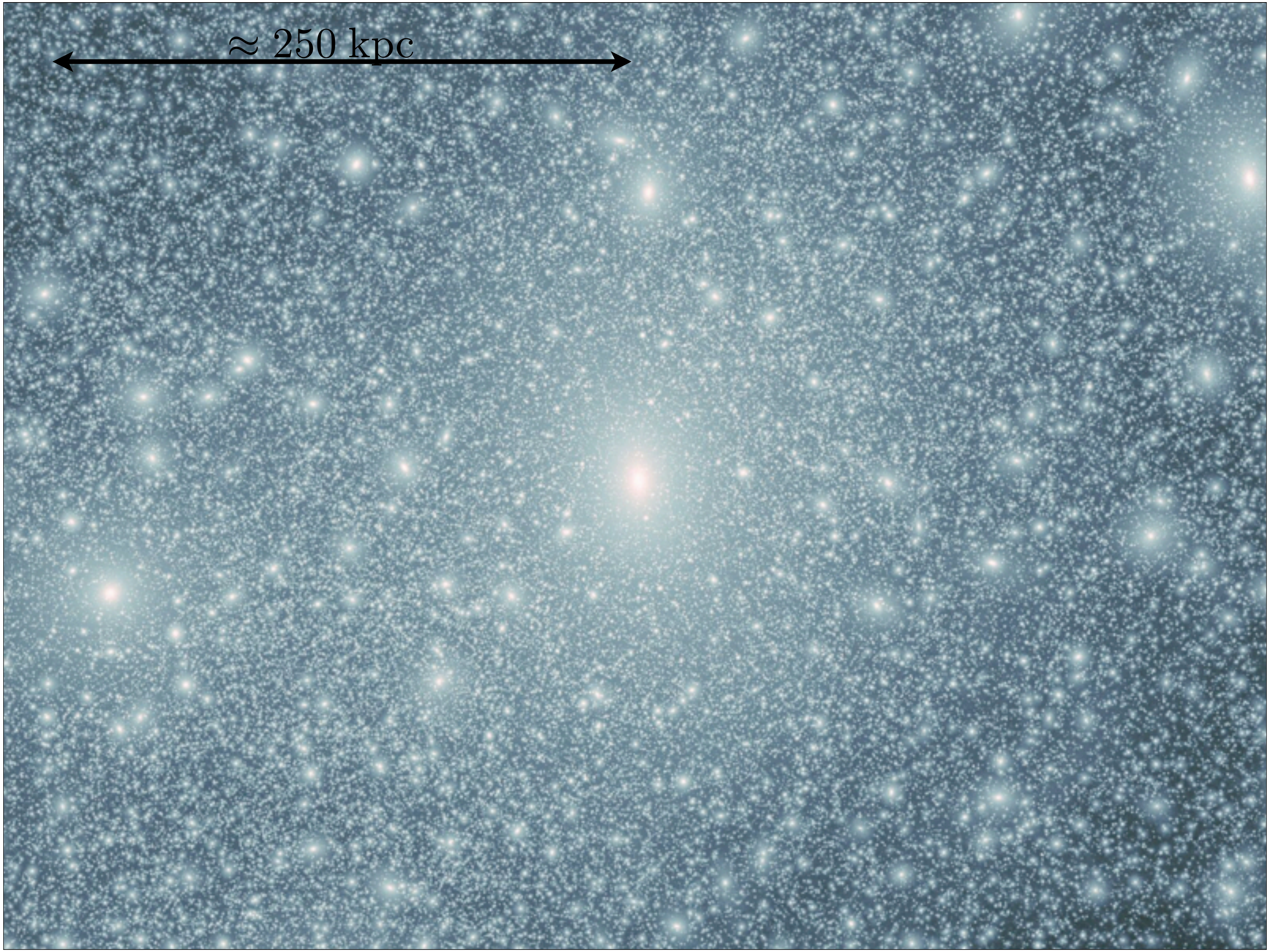
Lacey & Cole (1993)



the beginning

today

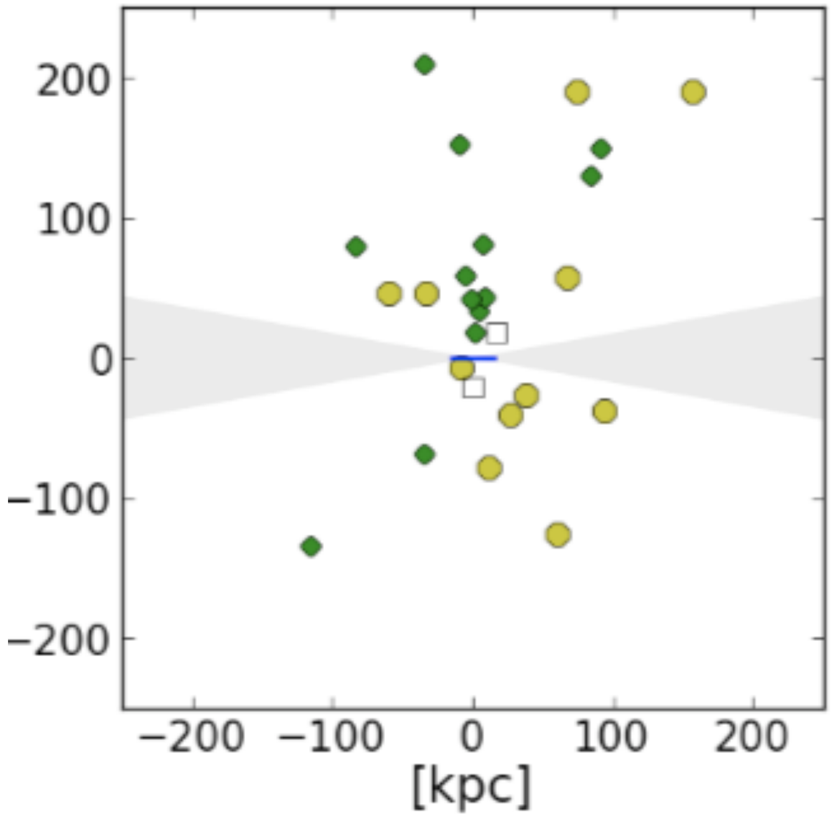
Pavel Kroupa: AIfA, University of Bonn


≈ 250 kpc

MW satellites are in a disk-like configuration:

- the 11 "classical" (brightest) satellites
- new satellites

Kroupa et al. (2010, A&A)



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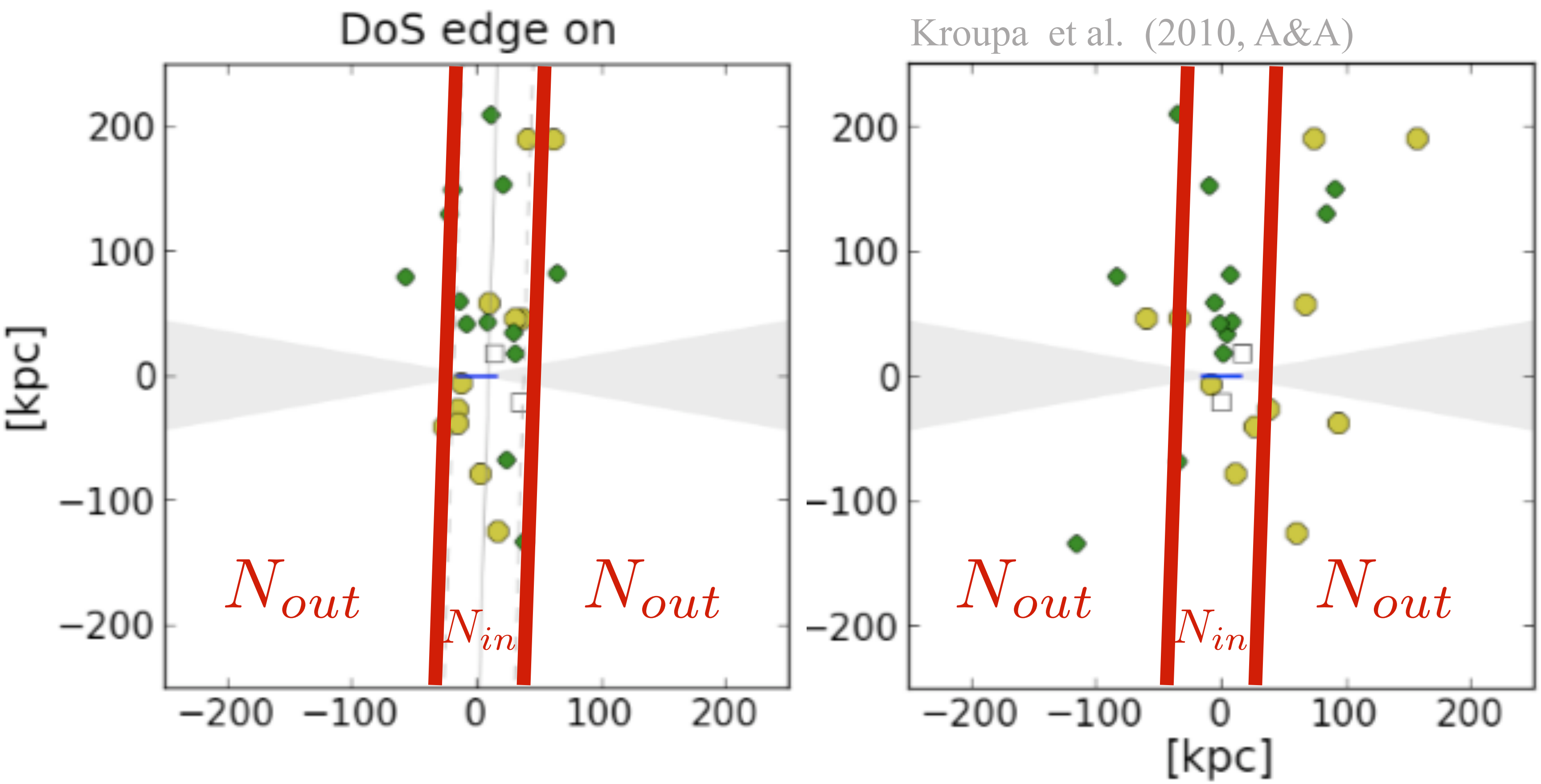

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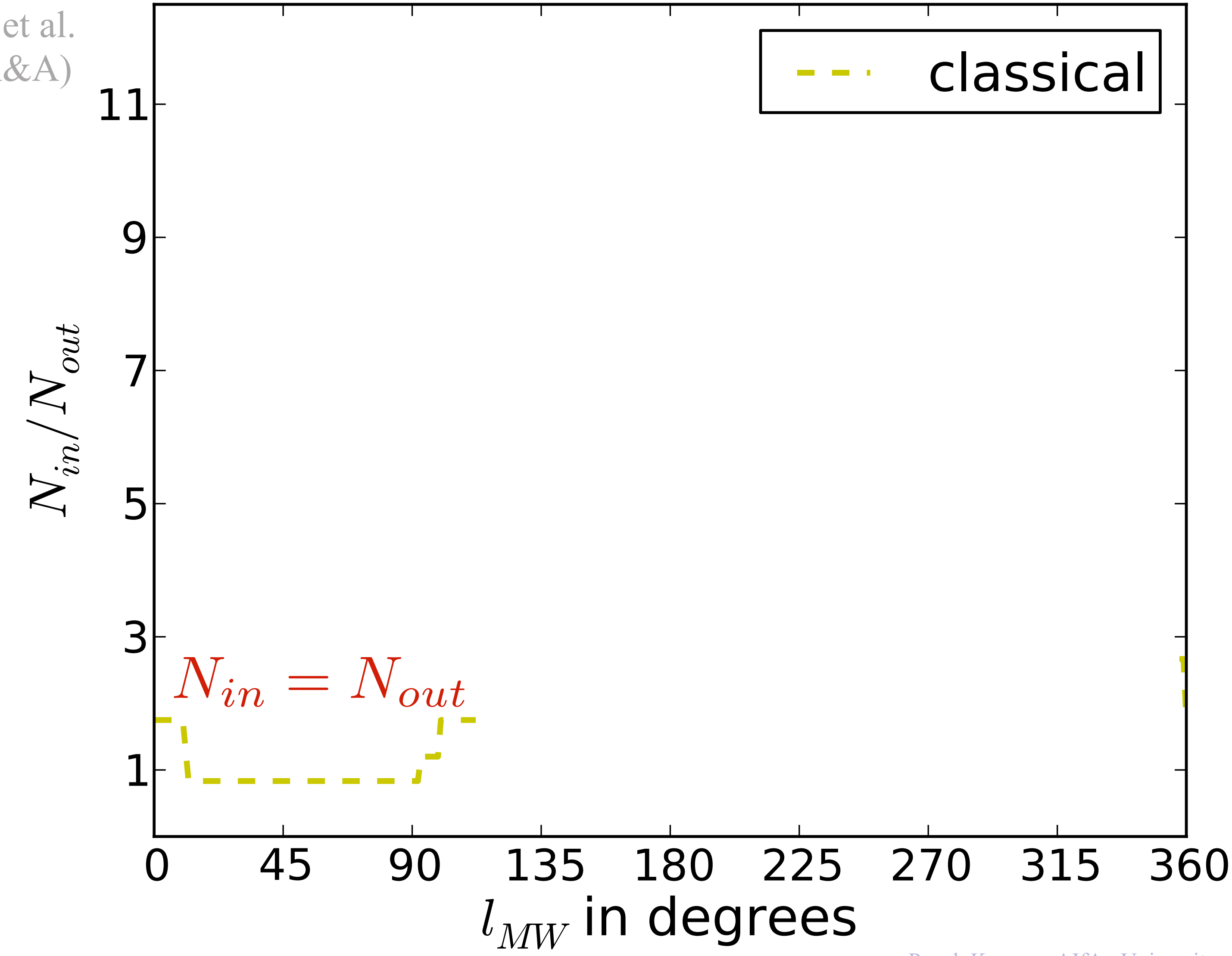

Pavel Kroupa: AIfA, University of Bonn

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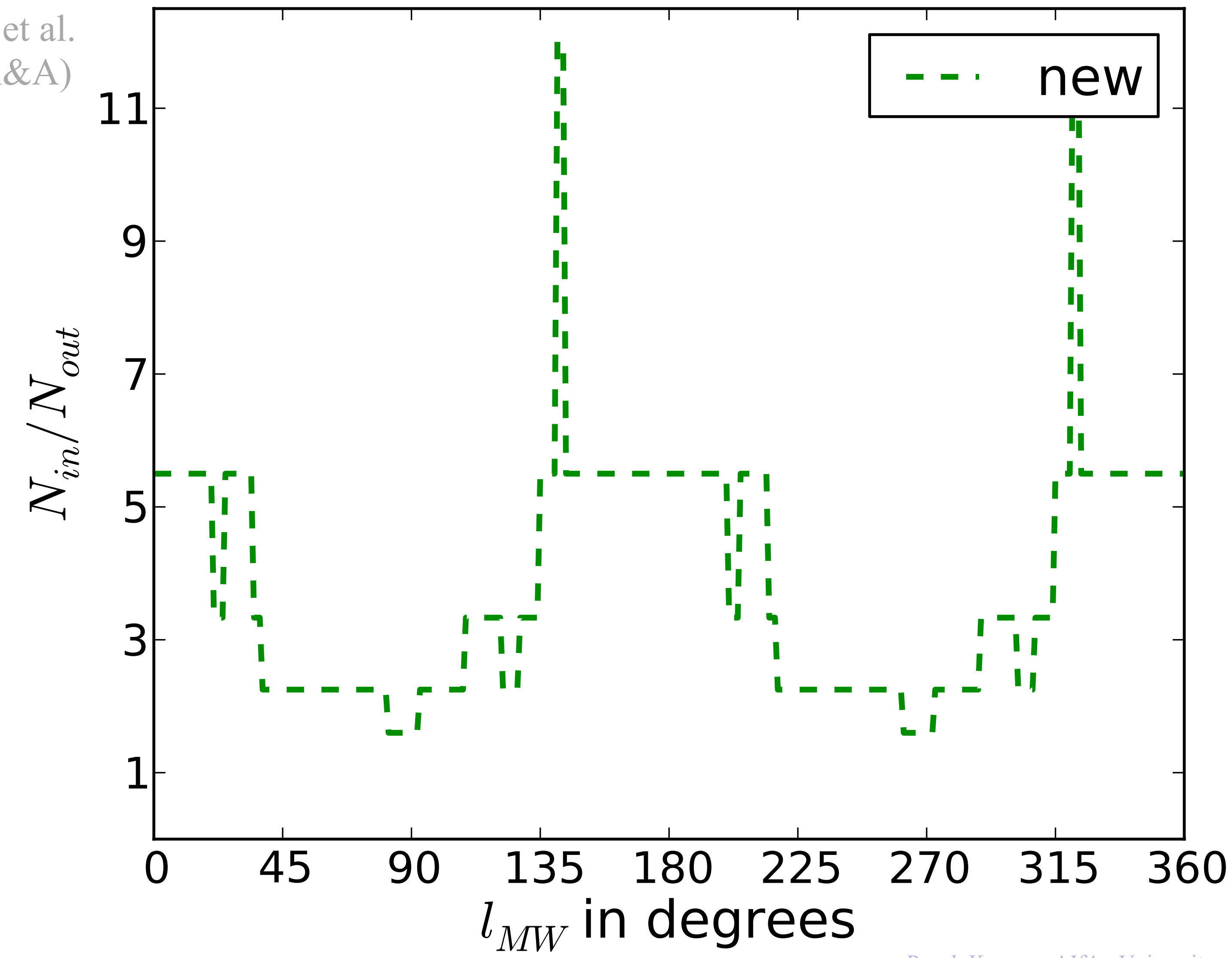

Pavel Kroupa: AIfA, University of Bonn

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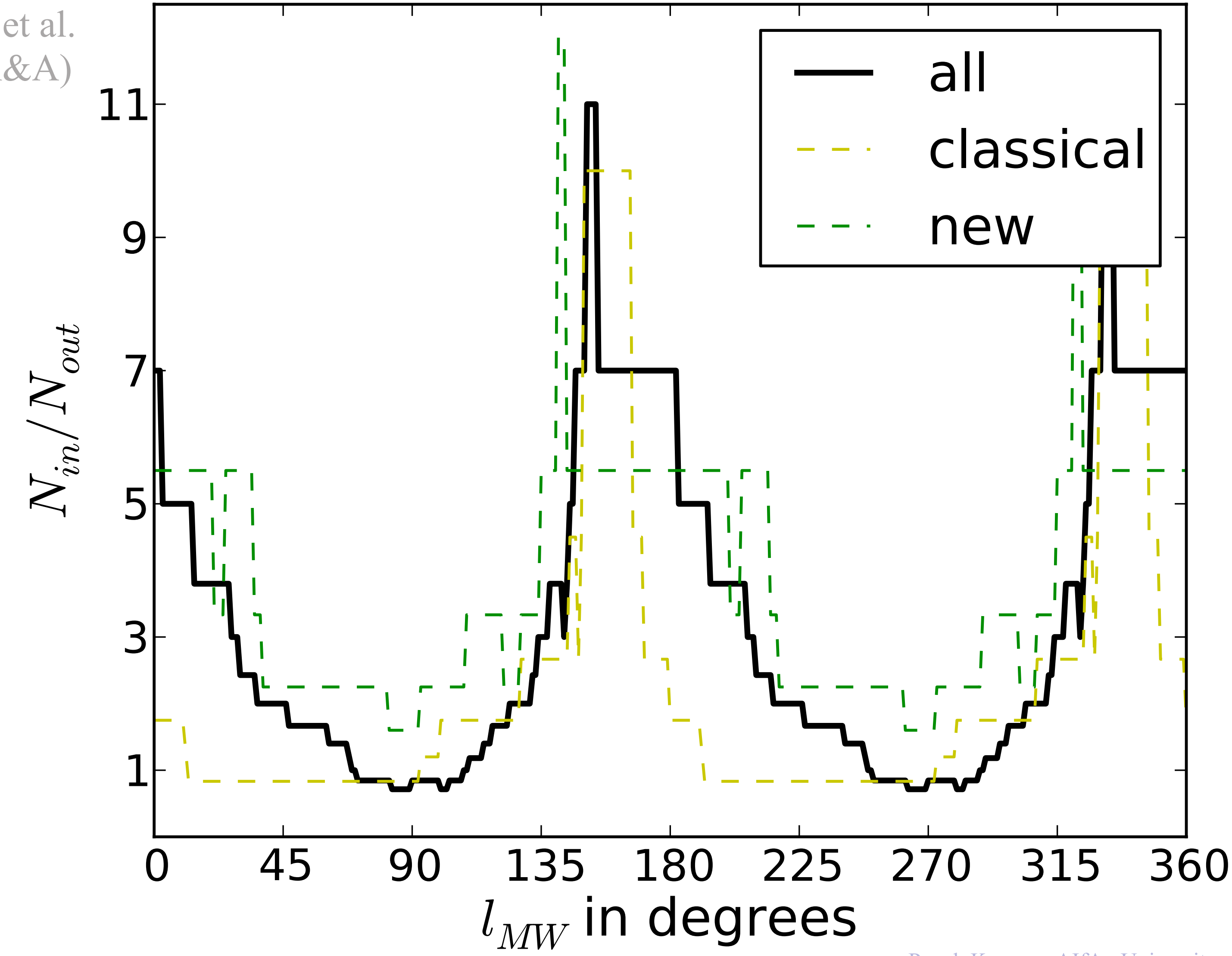

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Thus,

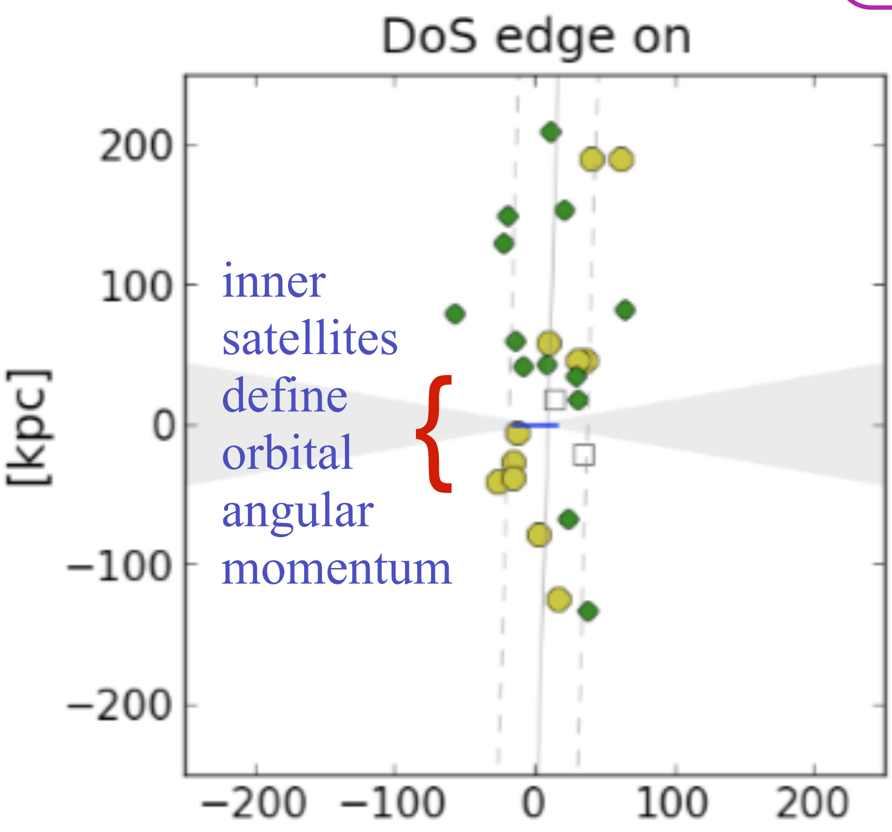
the
13 new ultra-faint
and the
11 classical satellites
independently
define the
same Disk of Satellites
(DoS).

Disk of Satellites

a rotational structure **?**

- the 11 "classical" (brightest) satellites
- new satellites

Kroupa et al. (2010, A&A)



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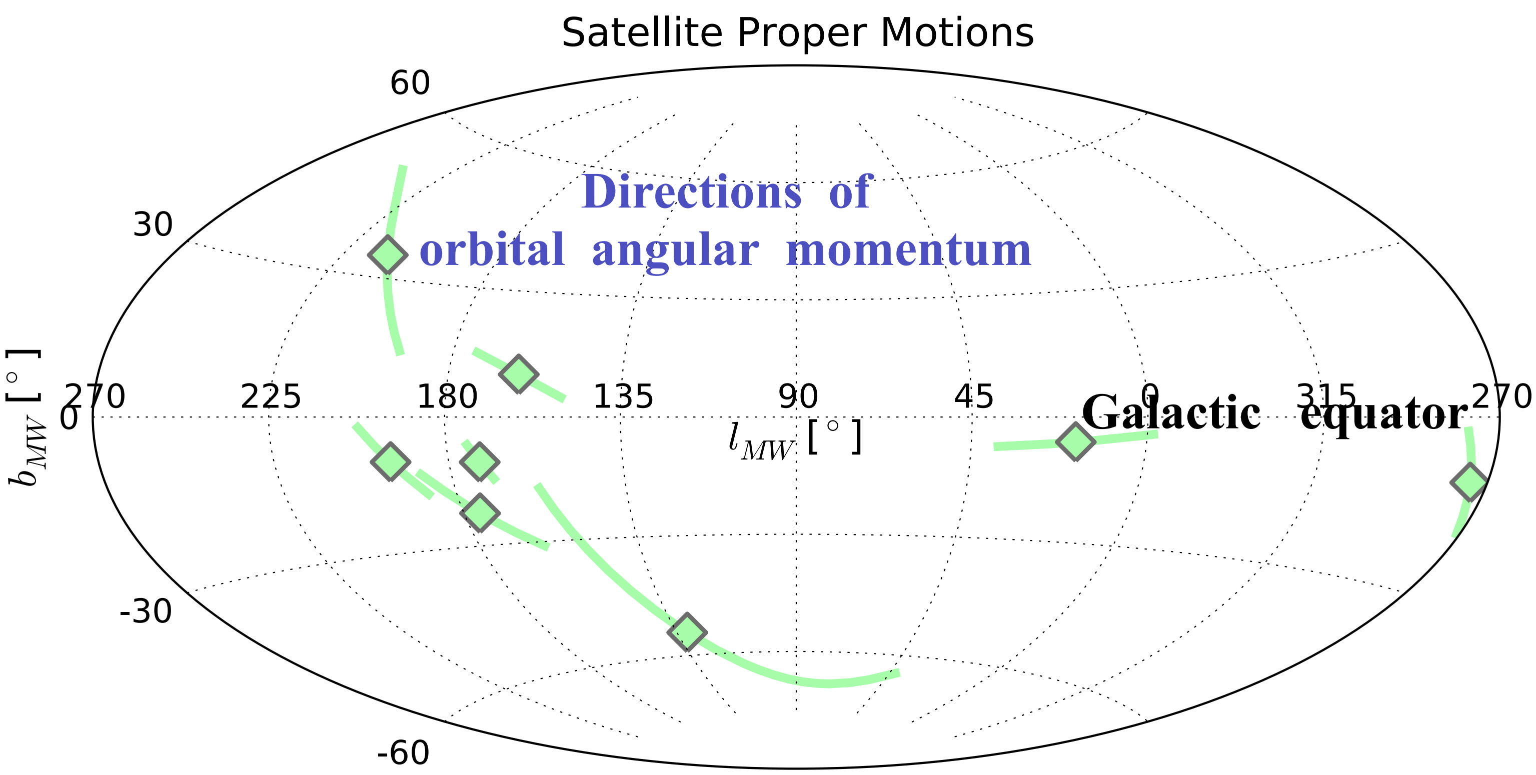
the Galactic sky

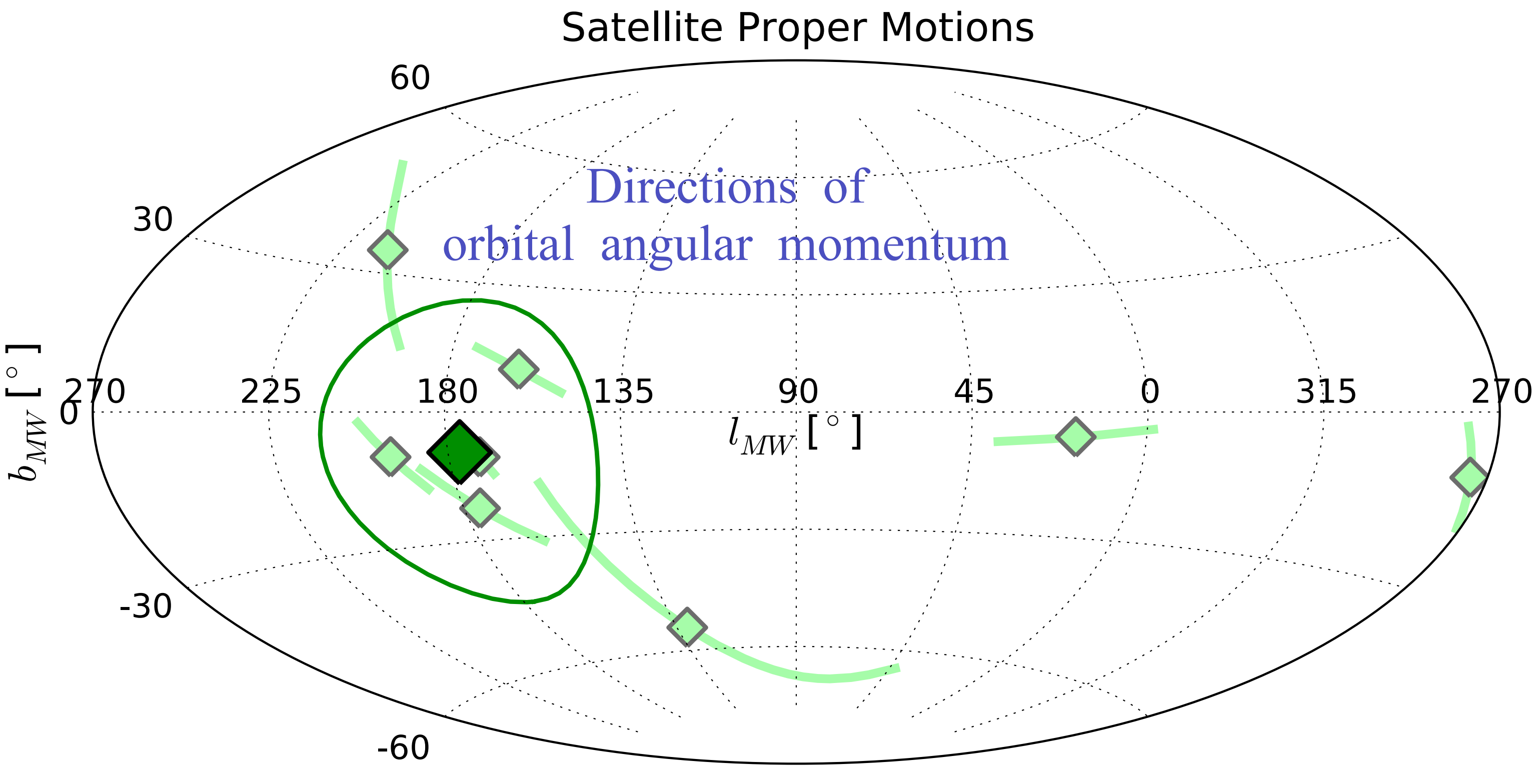
(Galactic spherical coordinates)



Pawlowski et al. 2011

the Galactic sky

(Galactic spherical coordinates)



South GP

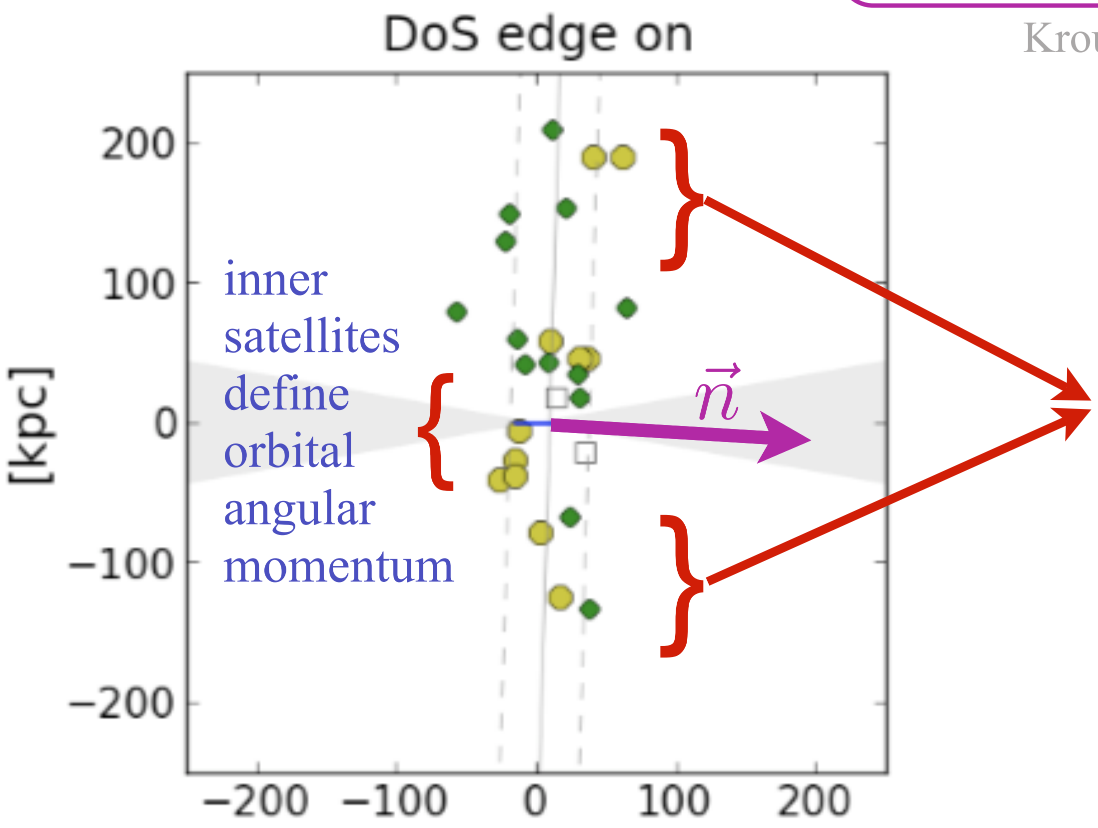
Pawlowski et al. 2011

Disk of Satellites

→ ***a rotational structure*** **?**

- the 11 “classical” (brightest) satellites
- new satellites

Kroupa et al. (2010, A&A)



outer satellites define $\vec{n}$ normal to DoS

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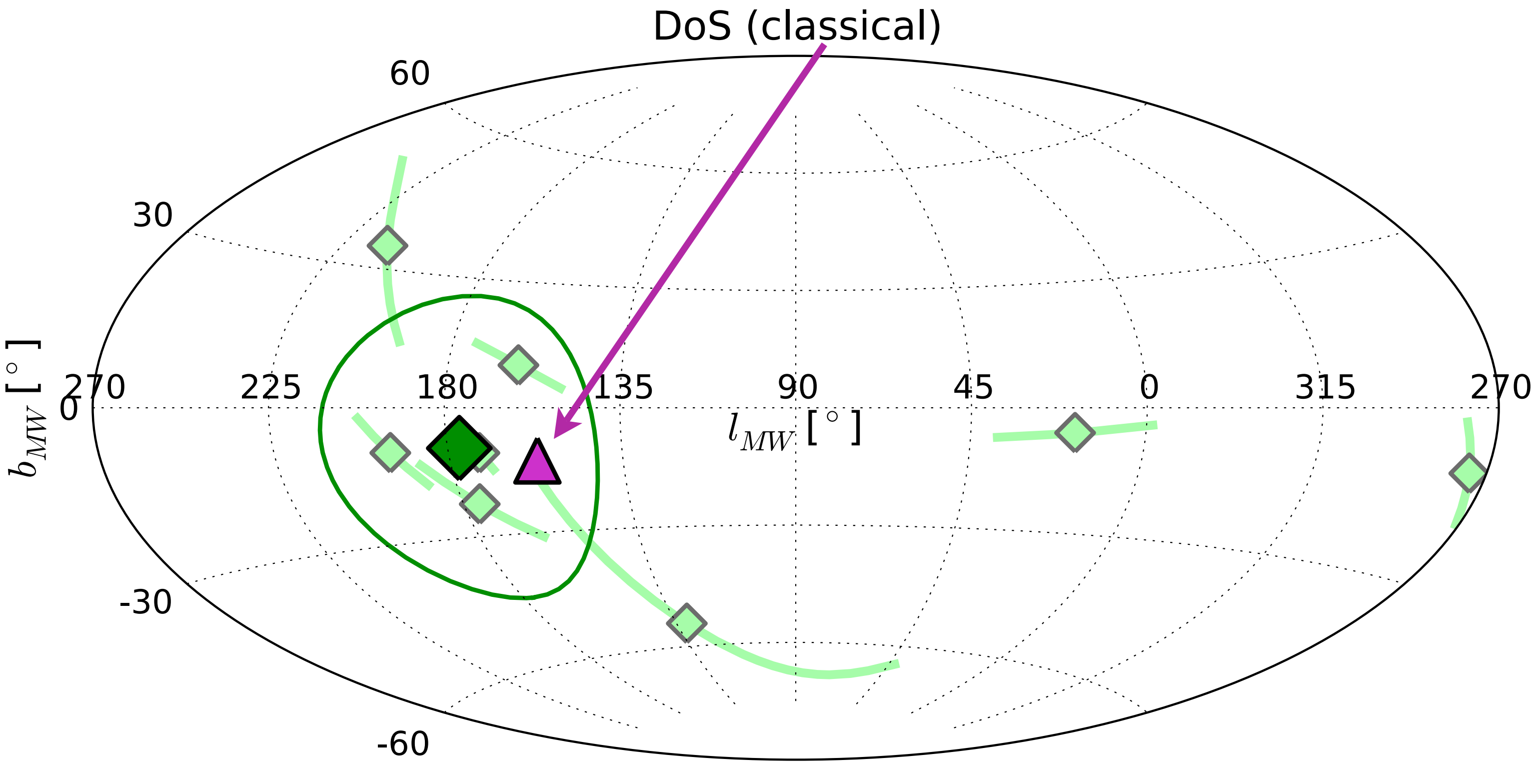
the Galactic sky

(Galactic spherical coordinates)

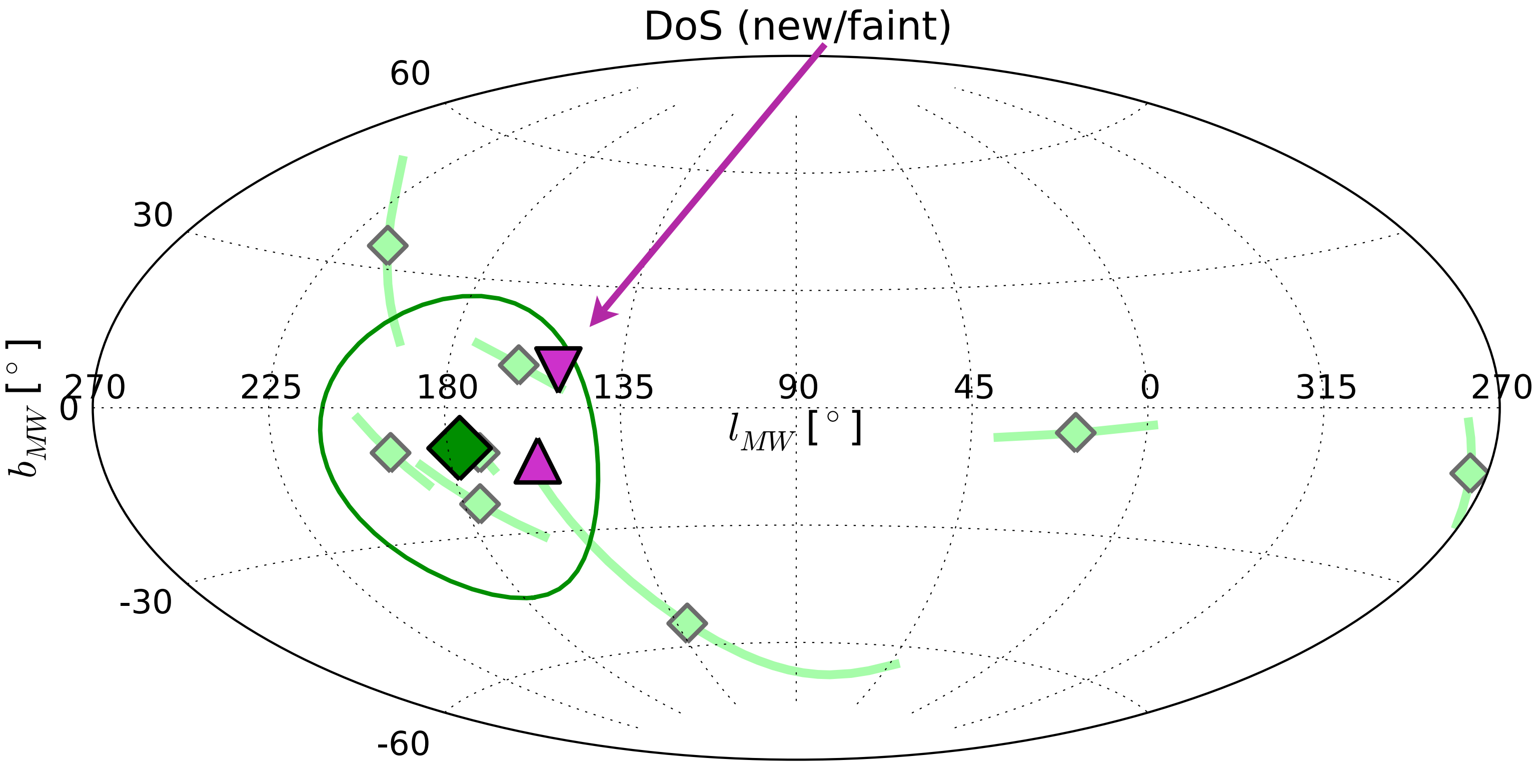


South GP

Pawlowski et al. 2011

the Galactic sky

(Galactic spherical coordinates)



South GP

Pawlowski et al. 2011

This
correlated phase-space
population
is *inconsistent* with
the satellites being
dark-matter sub-haloes
that fell into the MW halo
in a group or *individually*.

~~dark-matter halos~~

Logical inconsistencies within LCDM framework

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Deason et al. (2011, MNRAS) (abstract):

To get the DoS:

"The satellite galaxies have been accreted relatively recently"

Nichols & Bland-Hawthorn (2011, ApJ) ignore the DoS (abstract):

Get gas-poor dSph around the Galaxy and M31:

"if the dwarfs fell in at high redshifts (z~3-10)."

All these independent arguments

The dark-matter ansatz fails.

(no consistent natural solution has come forth)

Remember the two implications of Fritz Zwicky's two conjectures :

~~**1.** There exist large numbers of dark-matter dominated satellite galaxies~~

2. There exist large numbers of newly formed (tidal-dwarf) satellite galaxies.

No, there is *only one type* of dwarf galaxy **!**

But, *which* one **?** And *why* only one **?**

Lets consider now the
tidal-dwarf type satellite
dwarf galaxy :

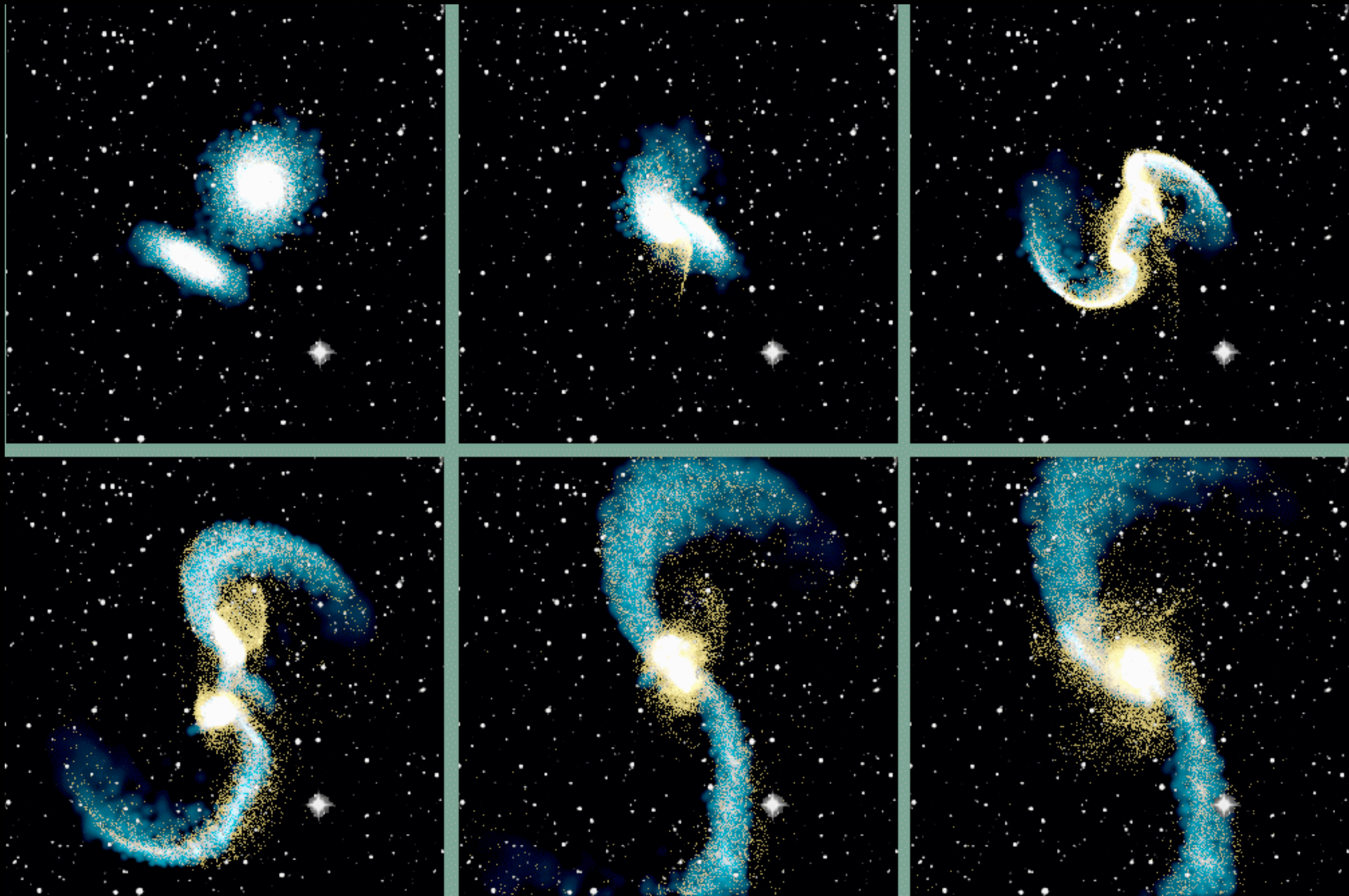
Tidal dwarf galaxies.

Pioneering work by

Felix Mirabel,
Pierre-Alain Duc,
Frederic Bournaud,
Francoise Combes,
Olivier Tiret
=
"*The French*"

And see also
Barnes & Hernquist;
Elmegreen;
Wetzstein

Tidal tails



Miho & Maxwell, web

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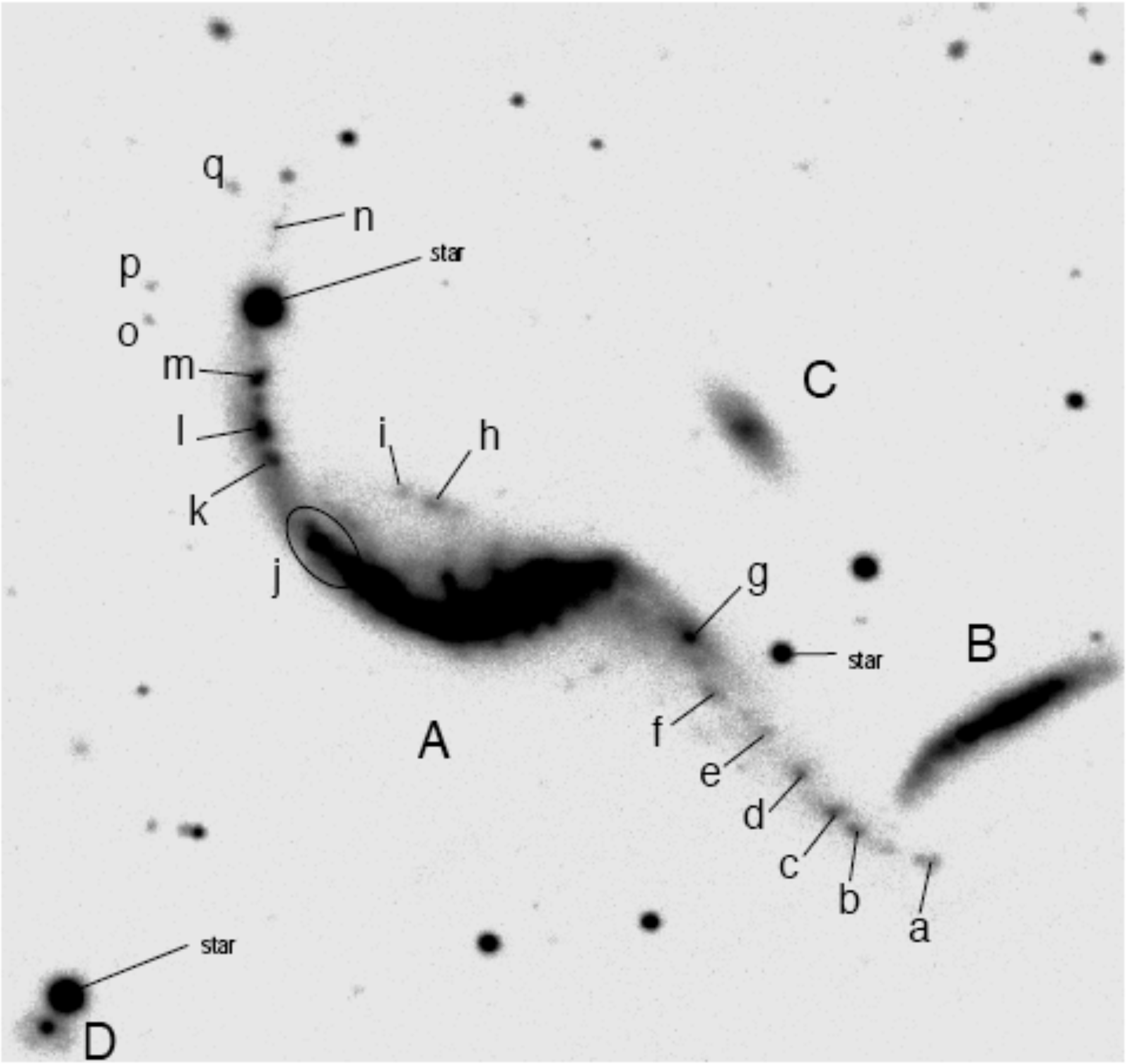
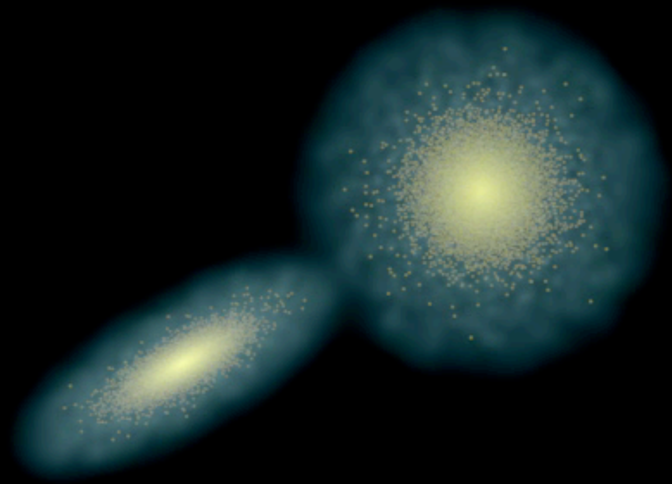


Fig. 21. Identification chart of field 10 around AM 1353-272.

(Weilbacher et al. 2000)

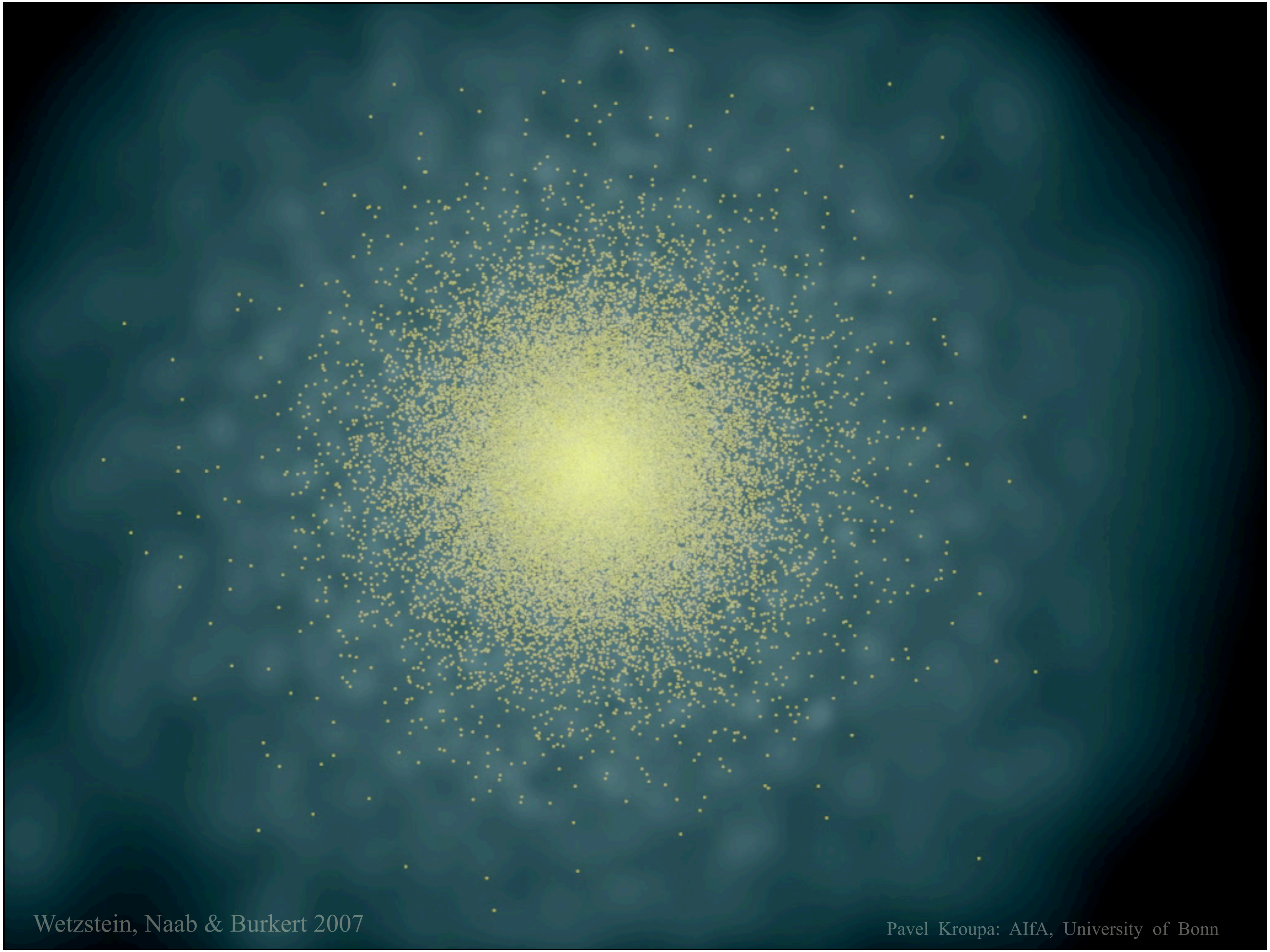
$$N_{\mathrm{TDG}} \approx 14$$

Relevance : The collision of two disks at high redshift



Wetzstein, Naab & Burkert 2007

Pavel Kroupa: AIfA, University of Bonn


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

Thus, by direct observation *new dwarf galaxies* with masses comparable to dE/dSph galaxies form like ***shrapnel***.

They are baryon dominated

(Barnes & Hernquist 1992).

Evolution of TDGs


Evolve dwarf galaxies
w/o dark matter
in a computer
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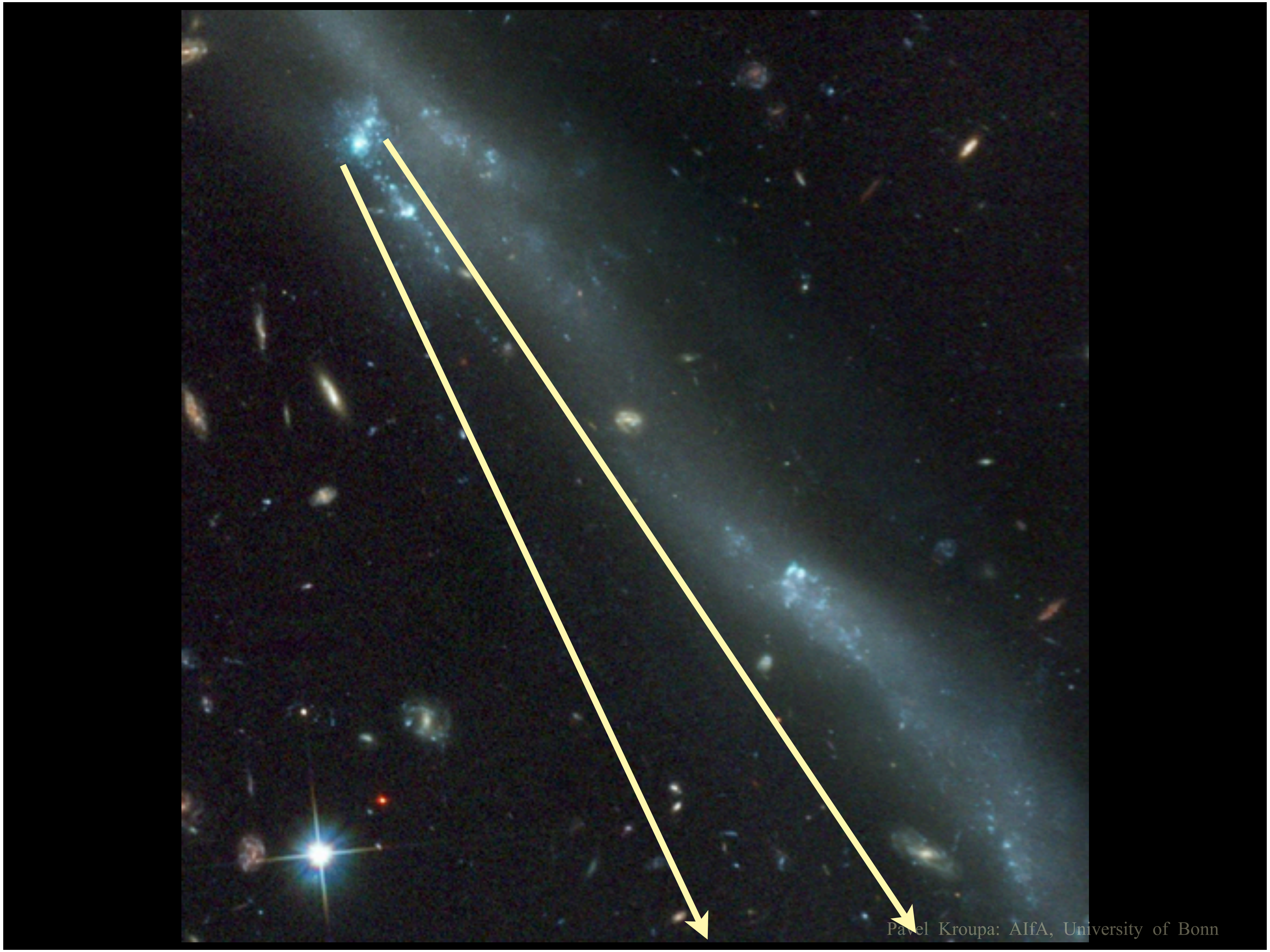
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Star-cluster complex
(cf *Tadpole*)

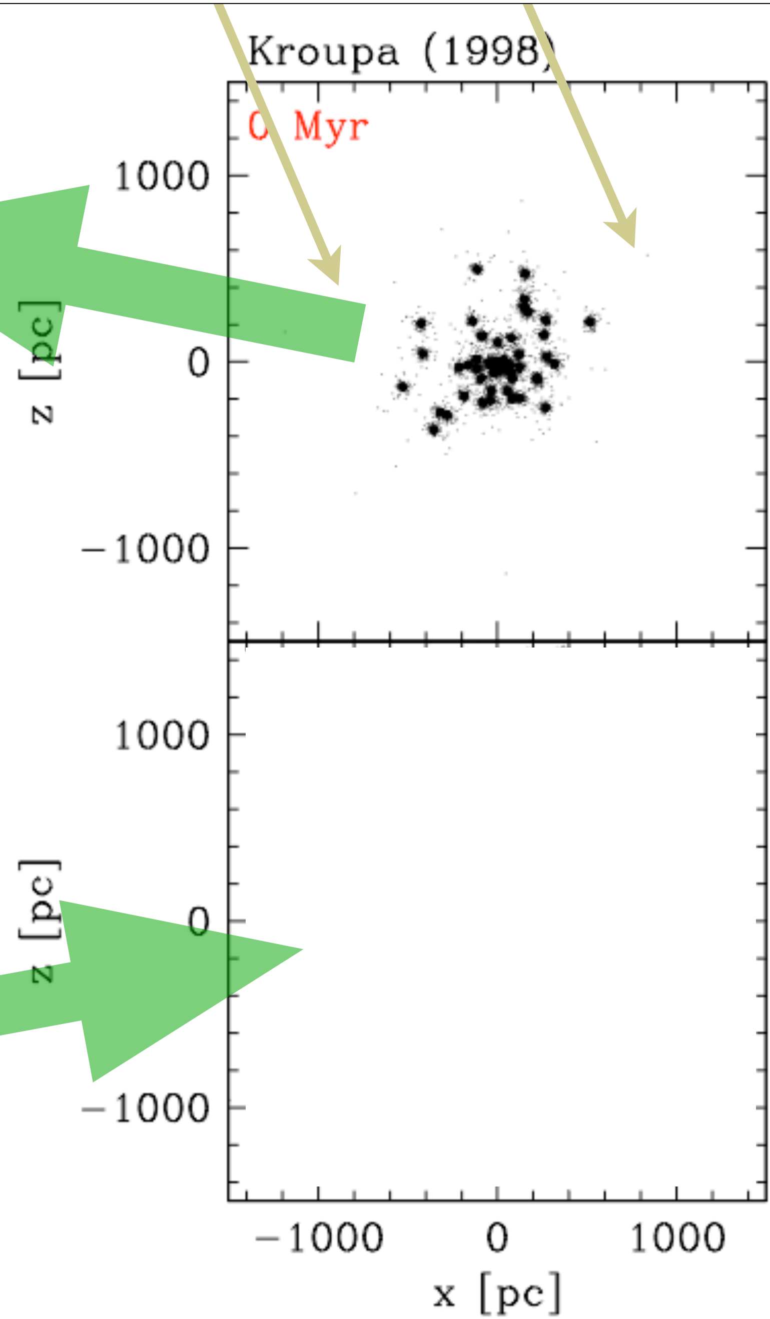
50 clusters
each $10^6\ M_\odot$

clusters as
fundamental galactic building blocks

⇓

Spheroidal dwarf galaxy !

(Fellhauer et al. 2001, 2002a,b,c, 2005; Bekki et al. 2004)



Pavel Kroupa: AIfA, University of Bonn

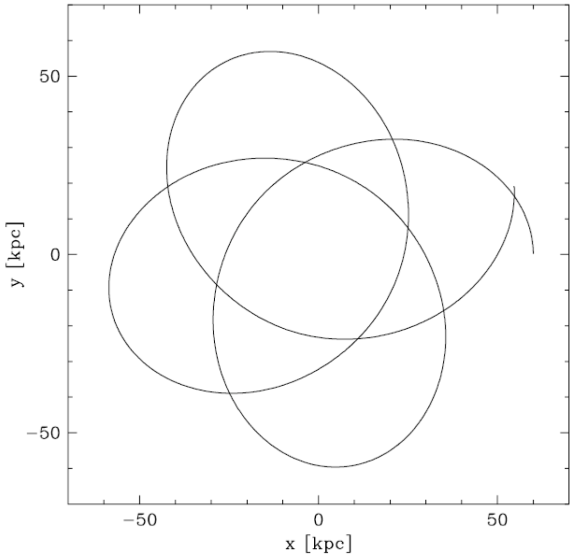
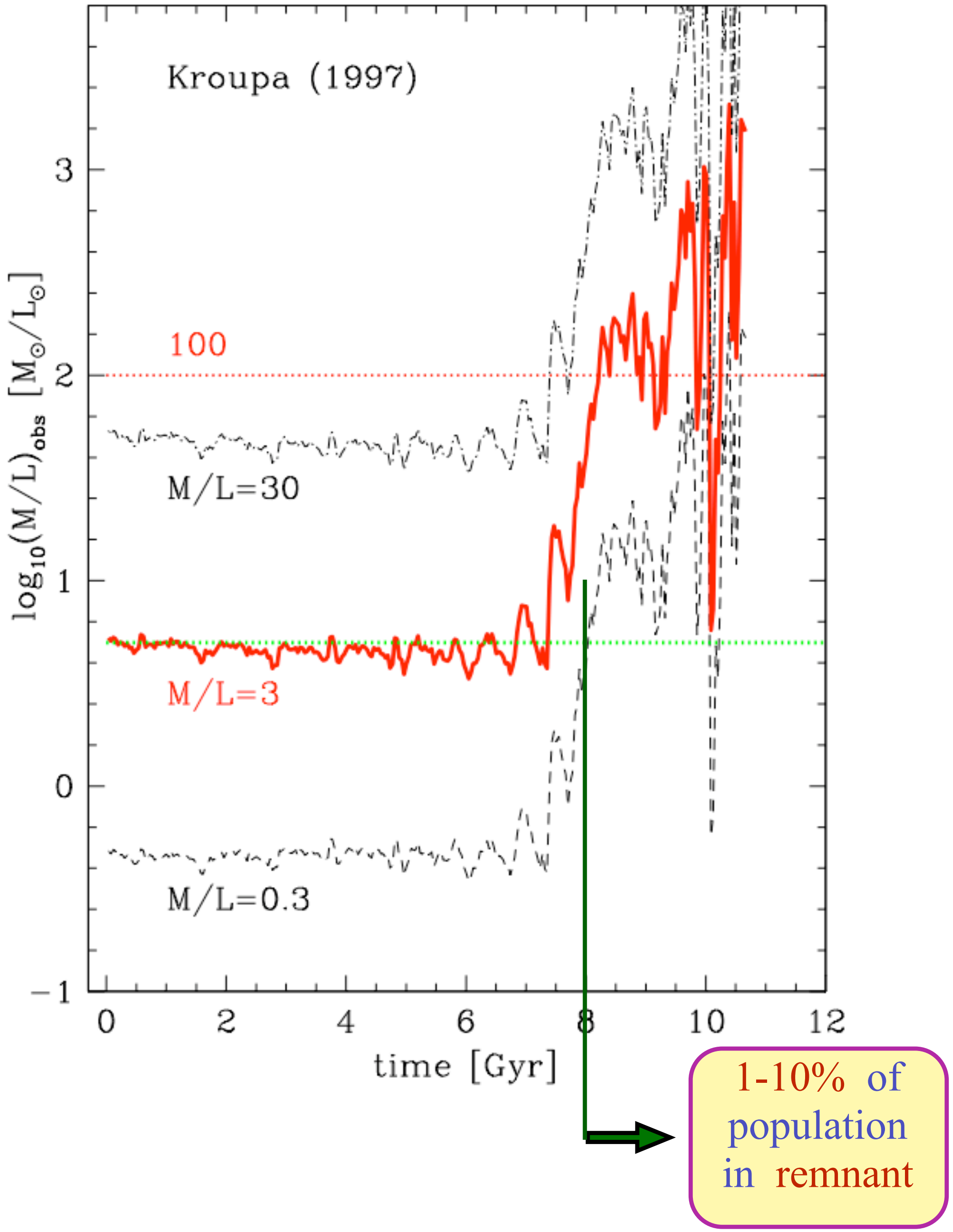
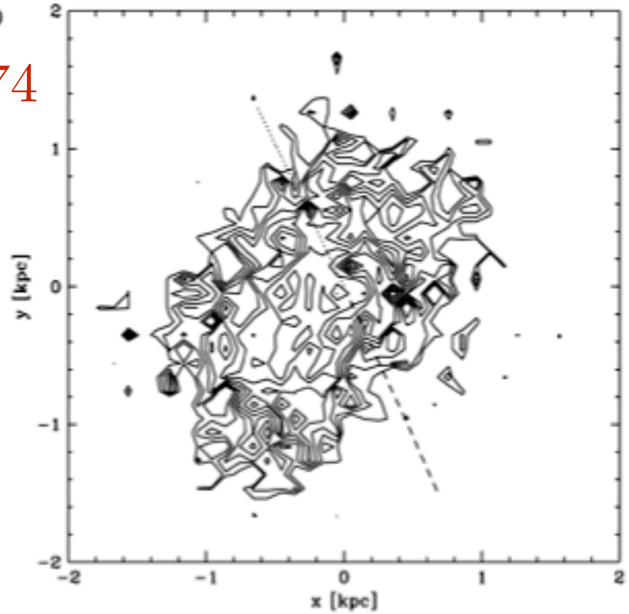


FIG. 3.—Orbital path of the satellite in simulations RS1-113 and Sat-M2.



(Kroupa 1997)

$e = 0.74$

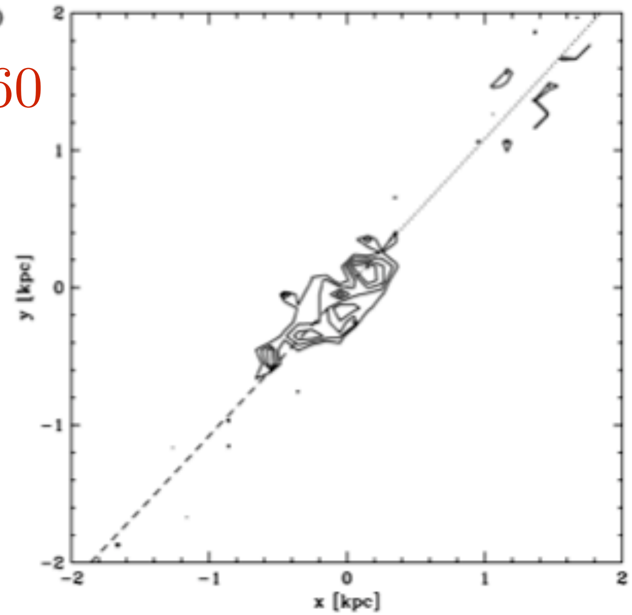


Remnants have a highly anisotropic $f(\mathbf{R}, V)$ and mass $\approx 10^5\ M_\odot$

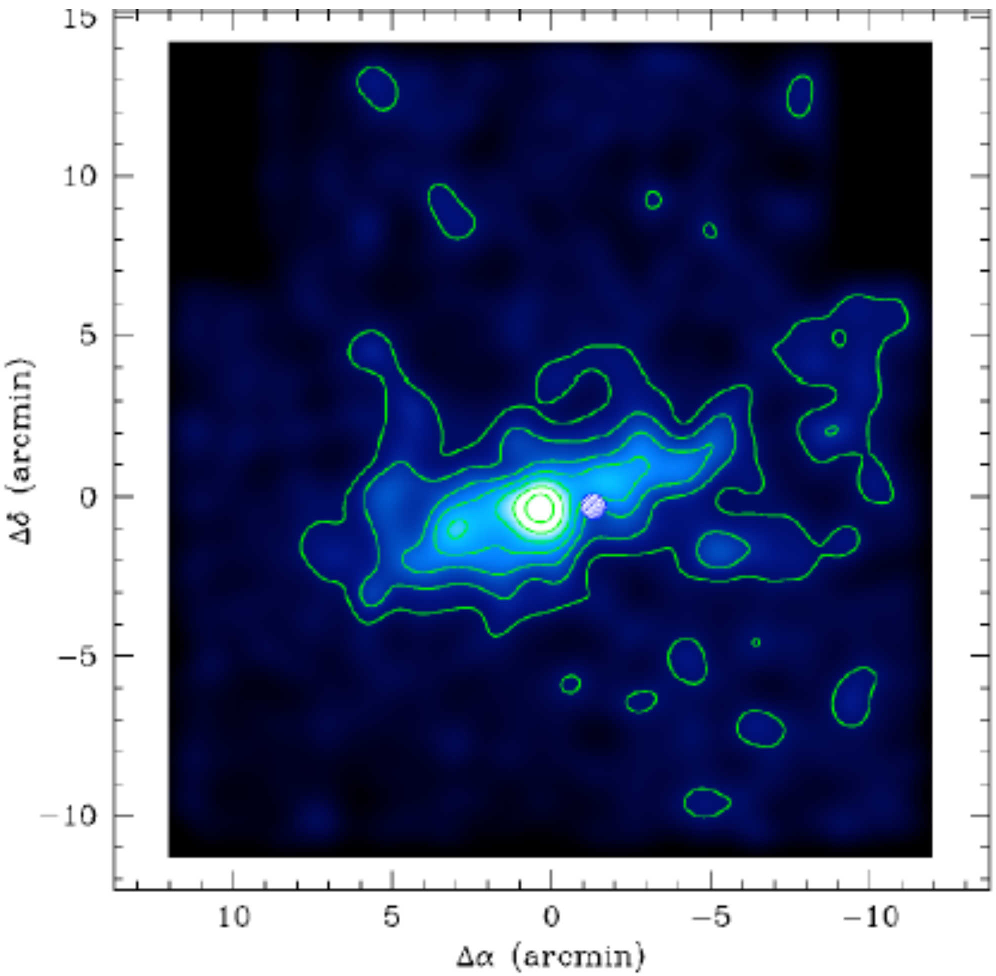
$R \approx$ few 100 pc

and $\dfrac{M}{L} \approx 10^{2-3}$ **!**

$e = 0.60$



Pavel Kroupa: AIfA, University of Bonn



Hercules

D=130kpc

(Coleman et al. 2007)

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Parameter	Value
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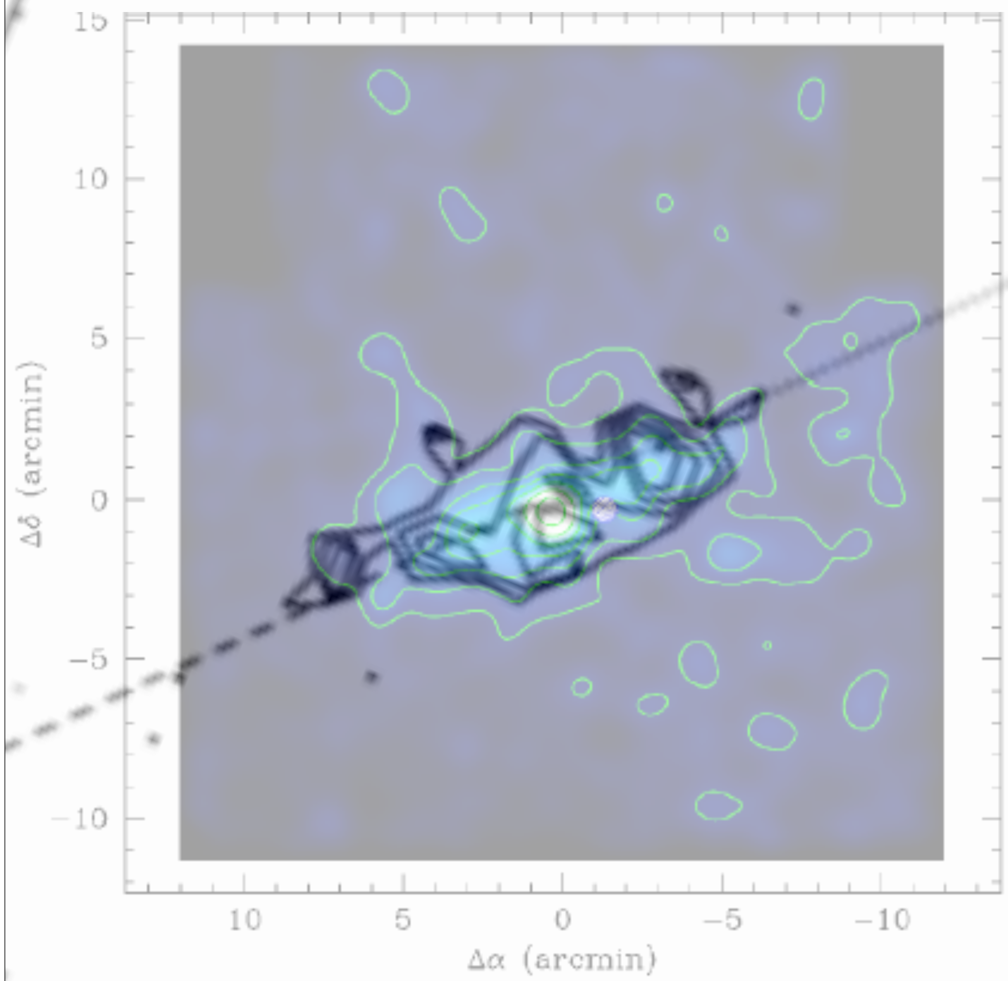

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Decl. (J2000)	12:47:29.6
$E(B-V)$ (mag)	0.055 ± 0.005^{a}
$(m-M)_0$ (mag)	20.6 ± 0.2
Distance (kpc)	132 ± 12
[Fe/H]	-2.1 ± 0.2
Age (Gyr)	13 ± 3
King r_h	$4.37' \pm 0.29'$ $(168 \pm 11$ pc)
King r_c	$4.74' \pm 0.57'$ $(182 \pm 22$ pc)
King r_t	$25.9' \pm 11.1'$ $(994 \pm 426$ pc)
$c = \log(r_t/r_c)$	0.74 ± 0.25

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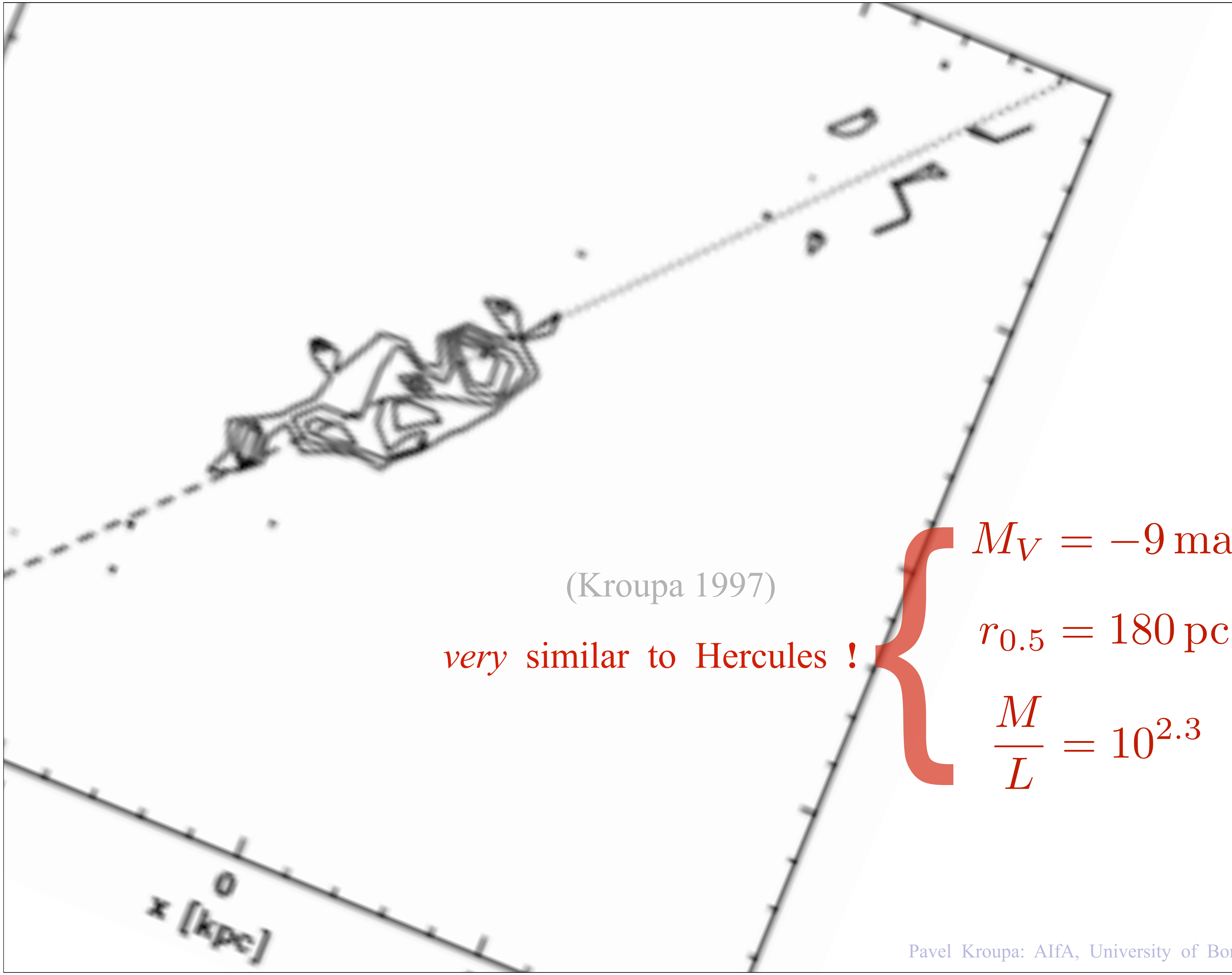


(Kroupa 1997)

very similar to Hercules !

$$
\left\{
\begin{aligned}
M_V &= -9\,\mathrm{mag} \\
r_{0.5} &= 180\,\mathrm{pc} \\
\frac{M}{L} &= 10^{2.3}
\end{aligned}
\right.
$$

This is a

real prediction

10 years before

the discovery

of this

type of celestial object !

For TDGs we know today that

The early (<100Myr) star-formation and chemical enrichment evolution is similar to the observed dSph satellites.

(Recchi et al. 2007)

Later dynamical evolution does not destroy the satellites.

(Kroupa 1997)

The number of old TDGs amounts to the dE population observed.

(Okazaki & Taniguchi 2000)

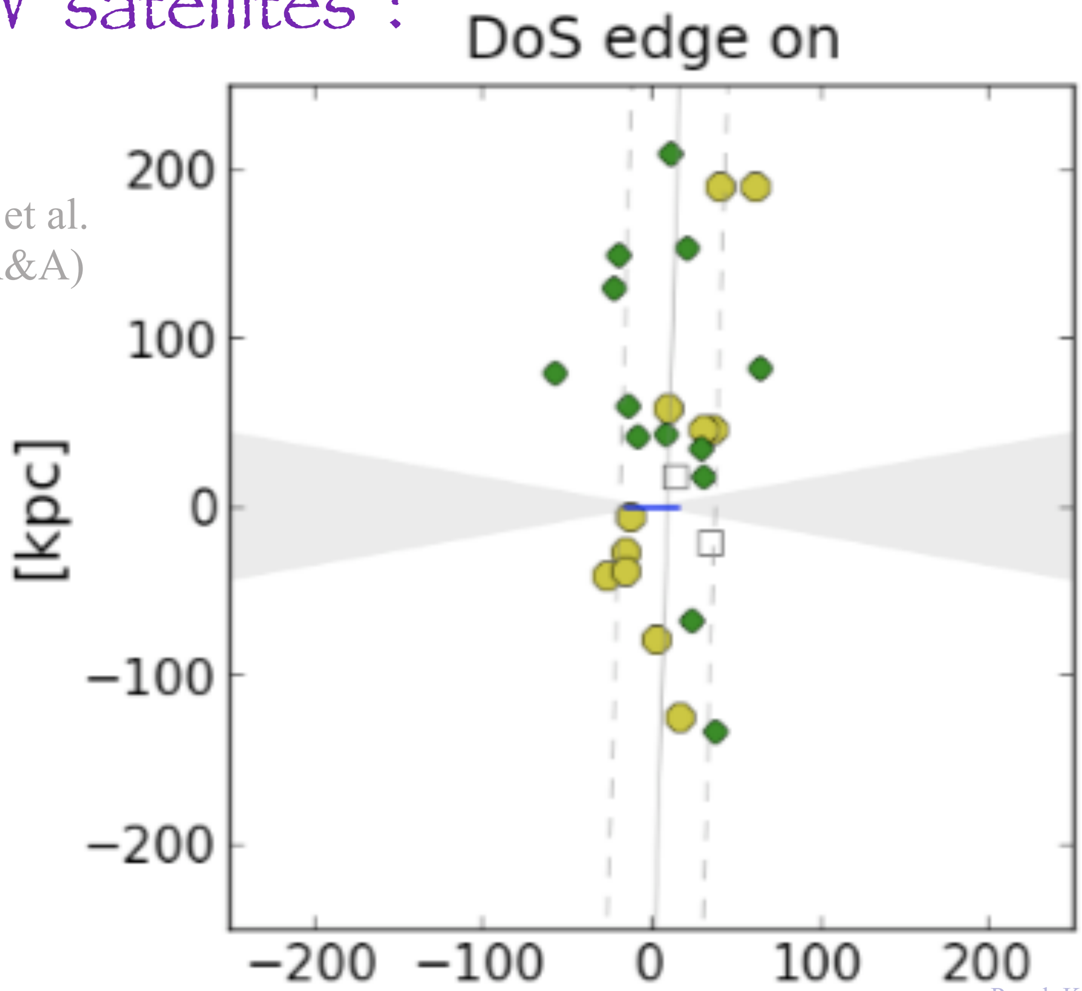
dE galaxies are observed to contain *no Dark Matter*, consistent with them being *TDGs*.

(Toloba et al. 2010, arXiv:1011.2198v1)

What about the disk-like configuration of MW satellites ?

- the 11 "classical" (brightest) satellites
- new satellites

Kroupa et al. (2010, A&A)



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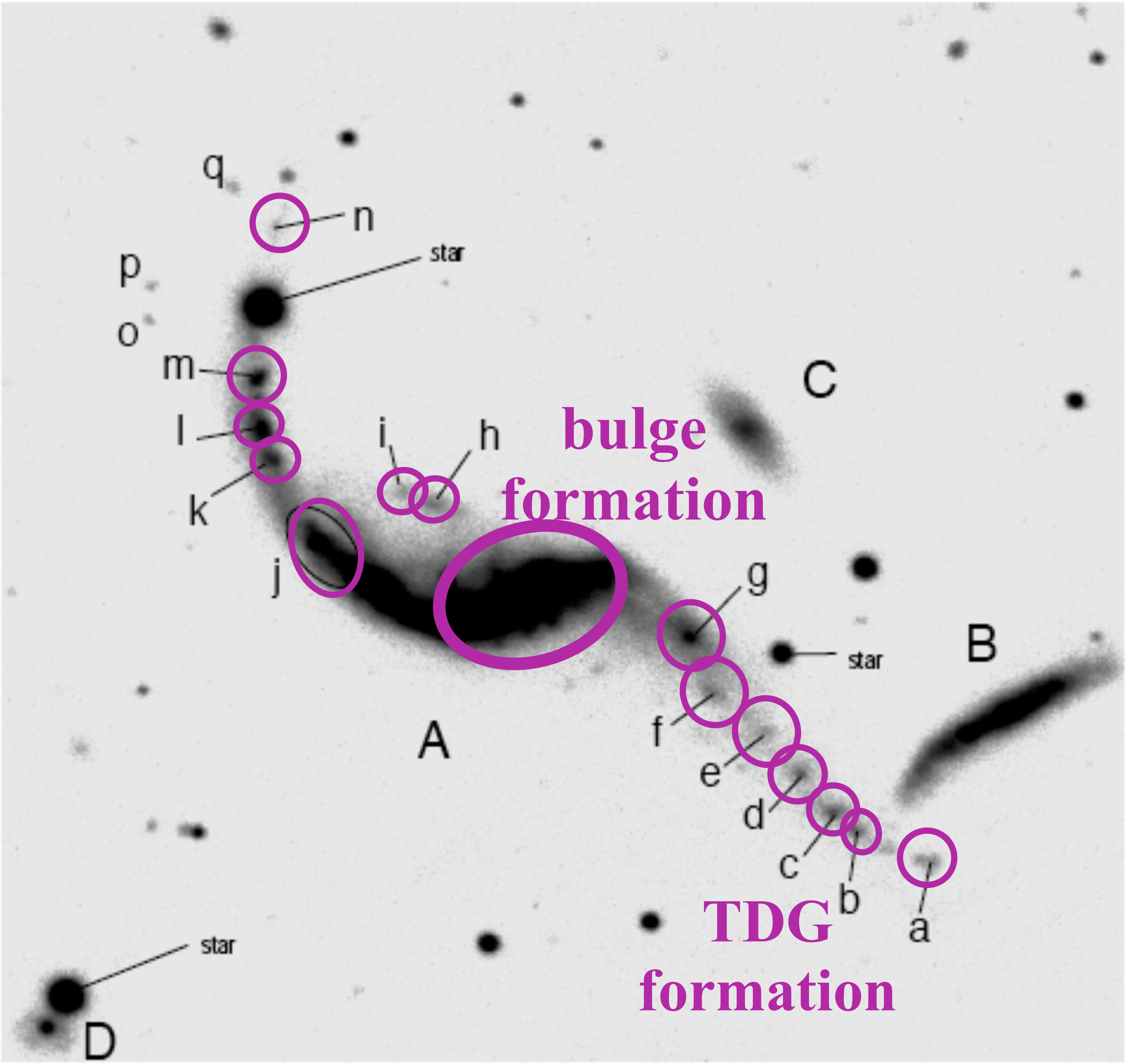
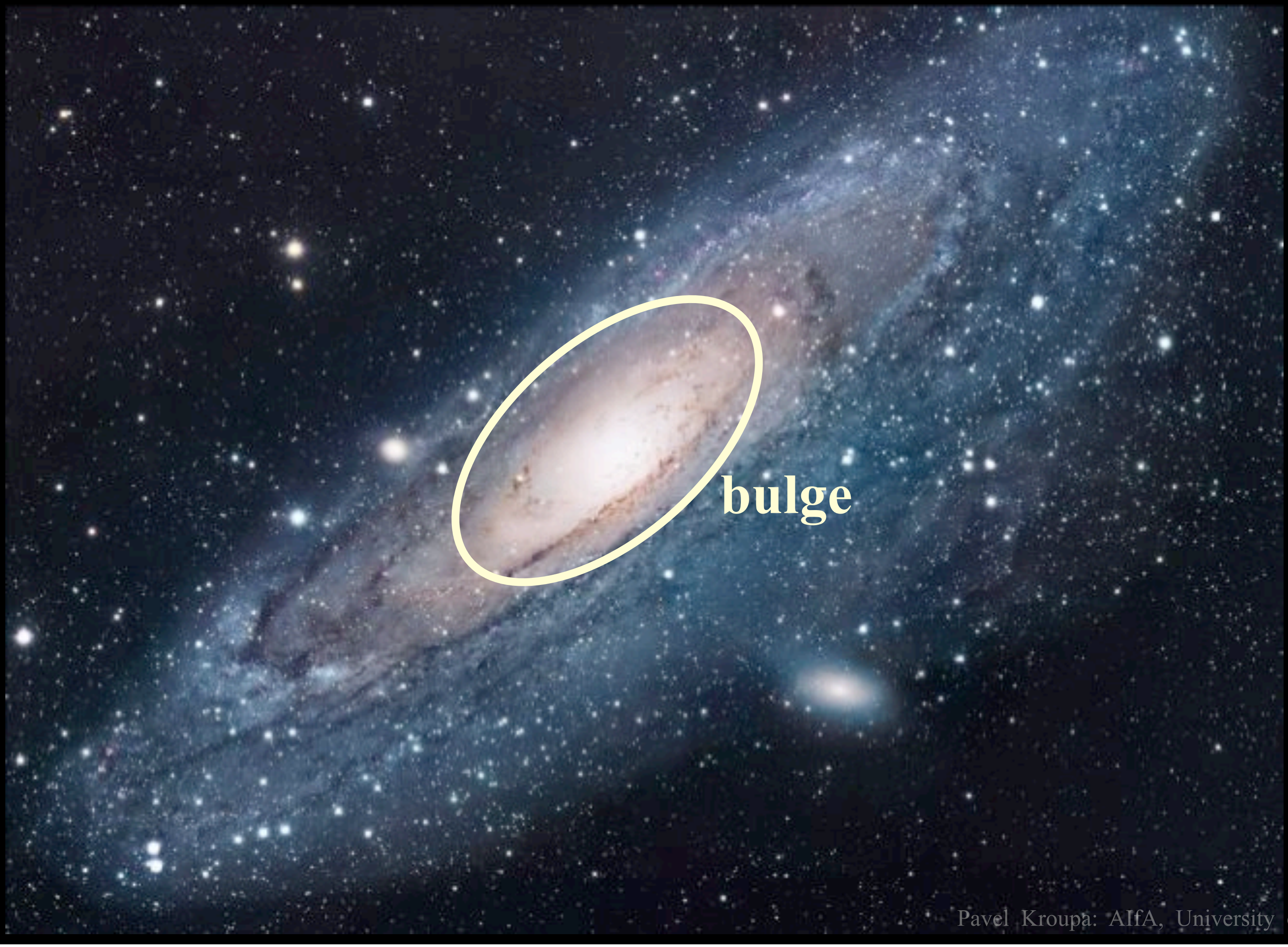


Fig. 21. Identification chart of field 10 around AM 1353-272.

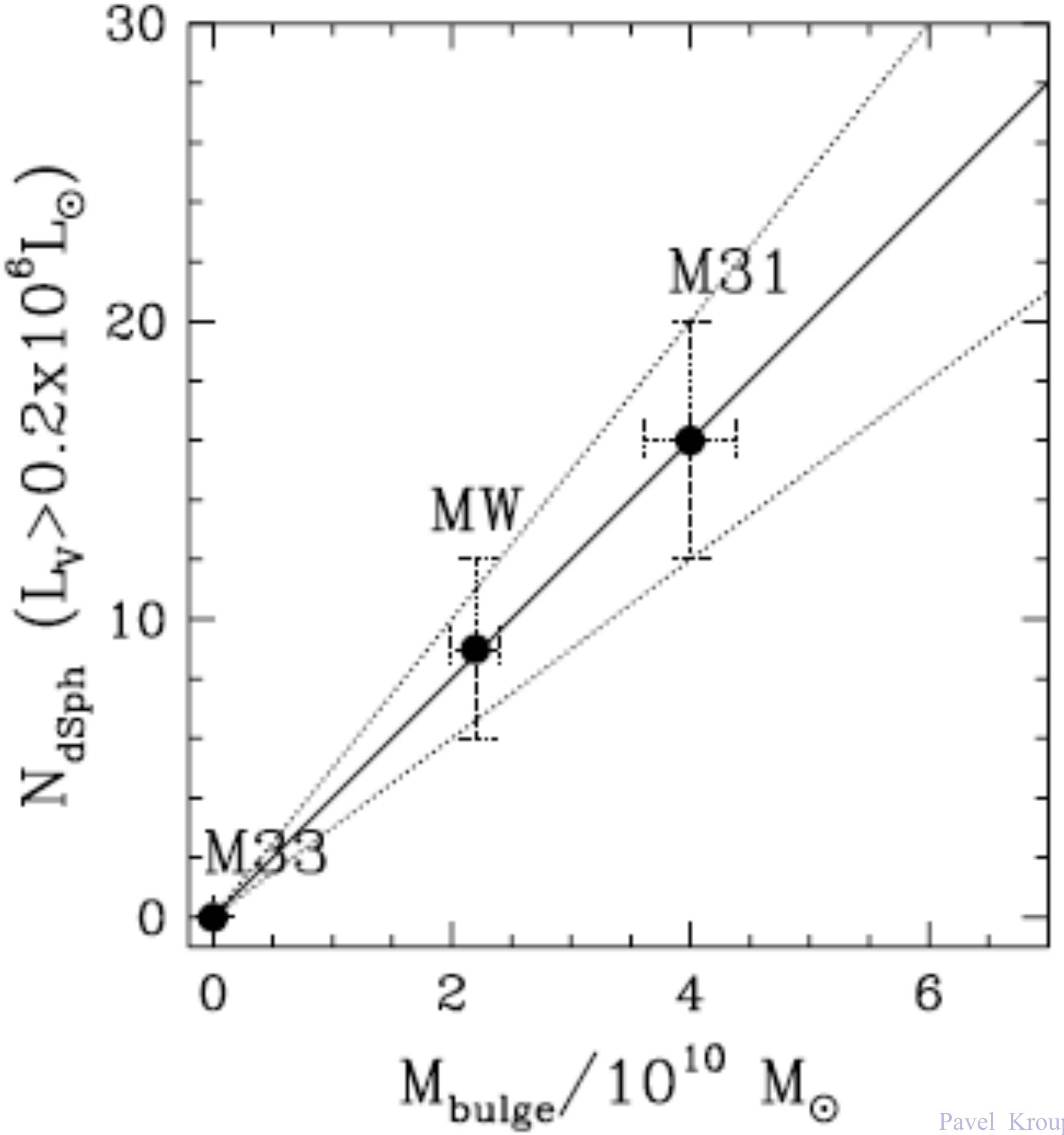
(Weilbacher et al. 2000)

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

...and, a bulge mass vs number of satellites correlation ?



A bulge - satellite correlation



Kroupa et al. (2010, A&A)

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Both,

the *Disk of Satellites*

and

the *bulge--satellite correlation*

are naturally understandable

if the MW satellites are *ancient TDGs*.

(Kroupa et al. 2010)

Other extragalactic correlated dSph satellite systems

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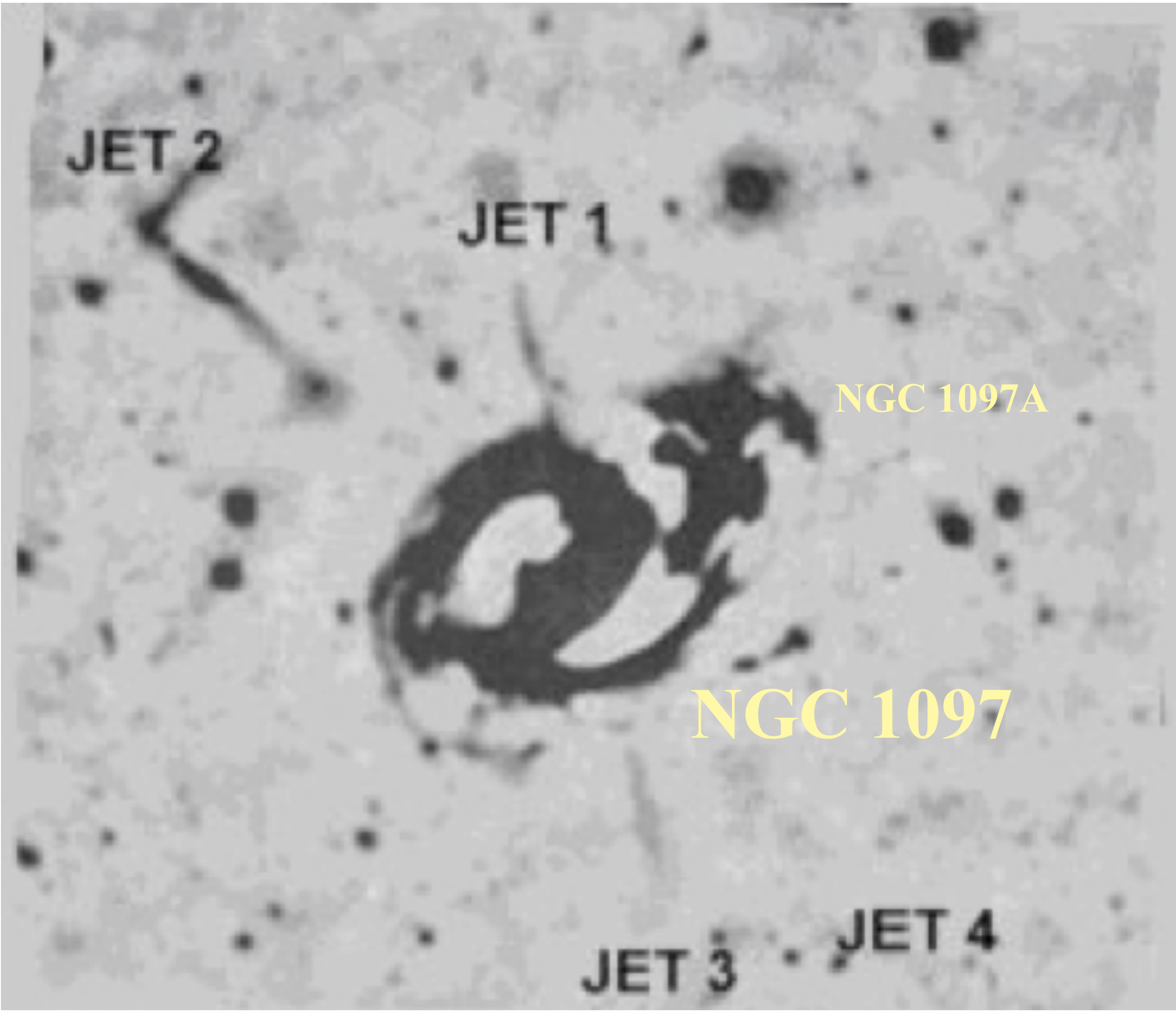
NGC 1097's "dog-leg" tidal stream

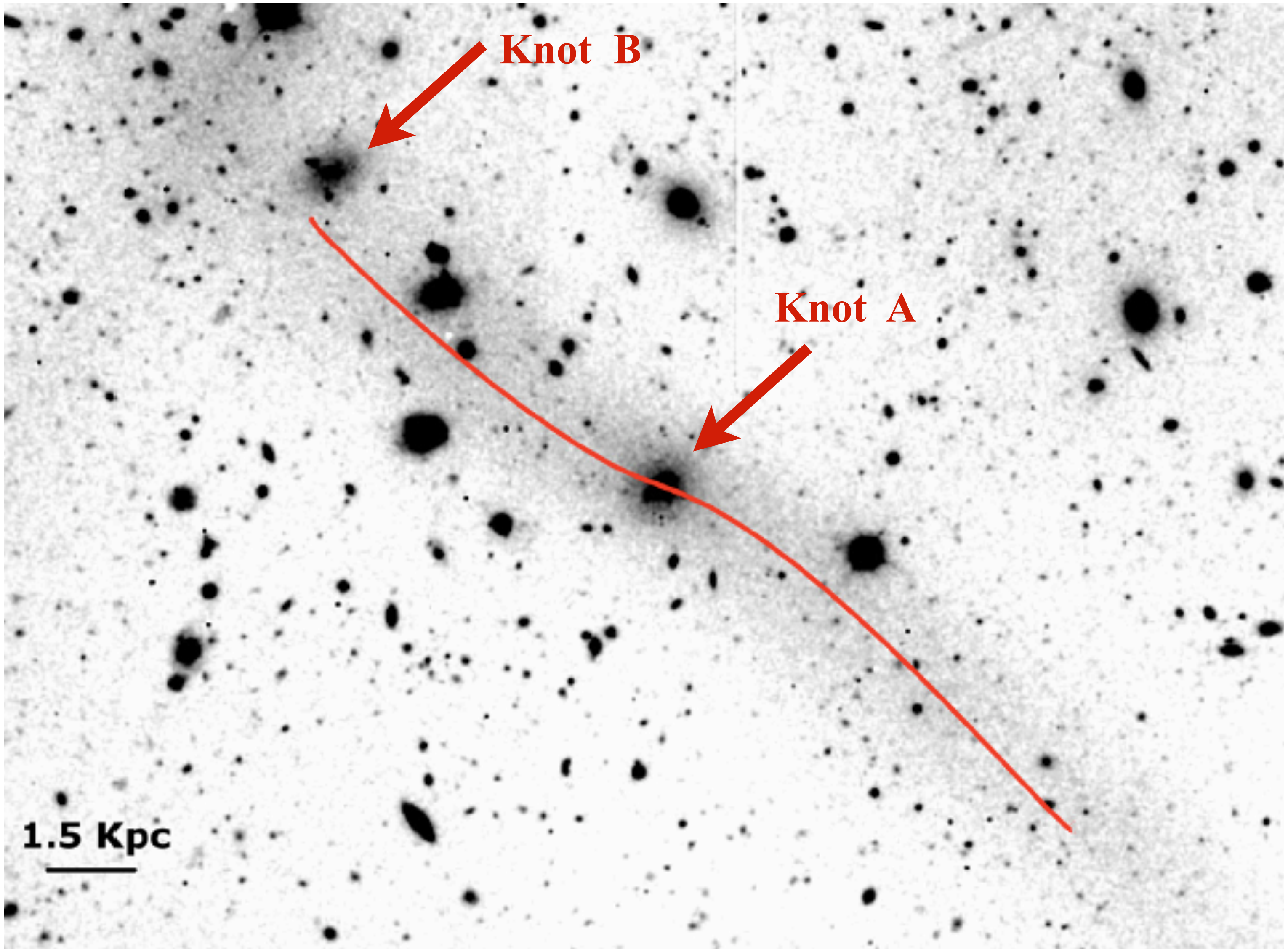
Galianni, Patat et al. (2010 A&A)



"Jet2" = dog leg is a stellar stream

NGC 1097's "dog-leg" tidal stream

Galianni, Patat et al. (2010 A&A)



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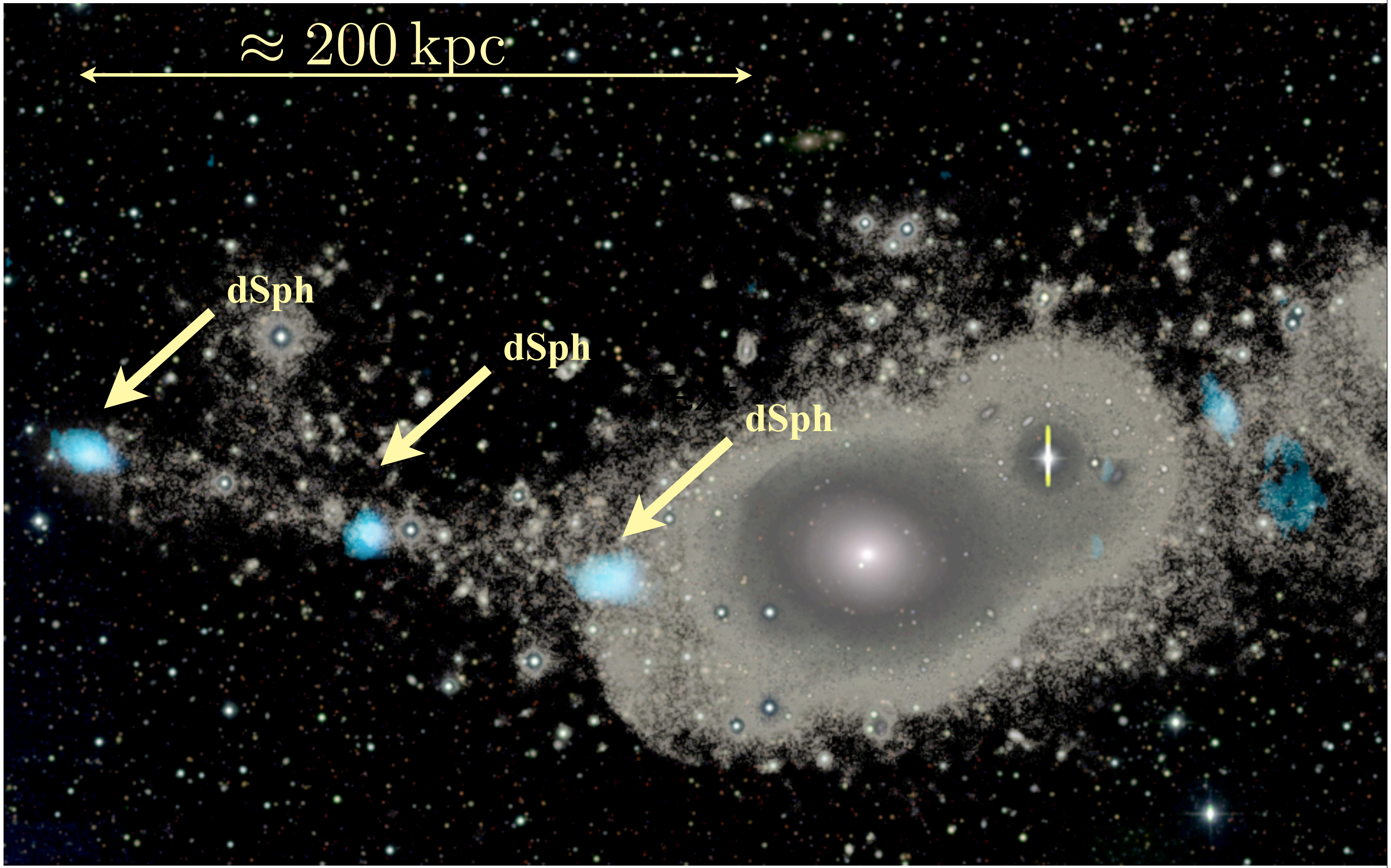
NGC 5557 (post-merger 2-3 Gyr)

Duc et al. (2011 MNRAS)



The
observed and theoretical
TDGs
coincide
with dE galaxies !

Thus,

(1) a *fully self-consistent TDG scenario* thus emerges which very naturally accounts for the properties of dE and satellite galaxies;

(2) *no consistent*, and in fact a *contradictory picture* emerges in the *dark-matter framework*;

(3) there is simply *no evidence for* the existence of *DM satellites*.

Dark matter galaxies

vs

baryonic ones :

why so similar ?

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The Tully -Fisher Relation :

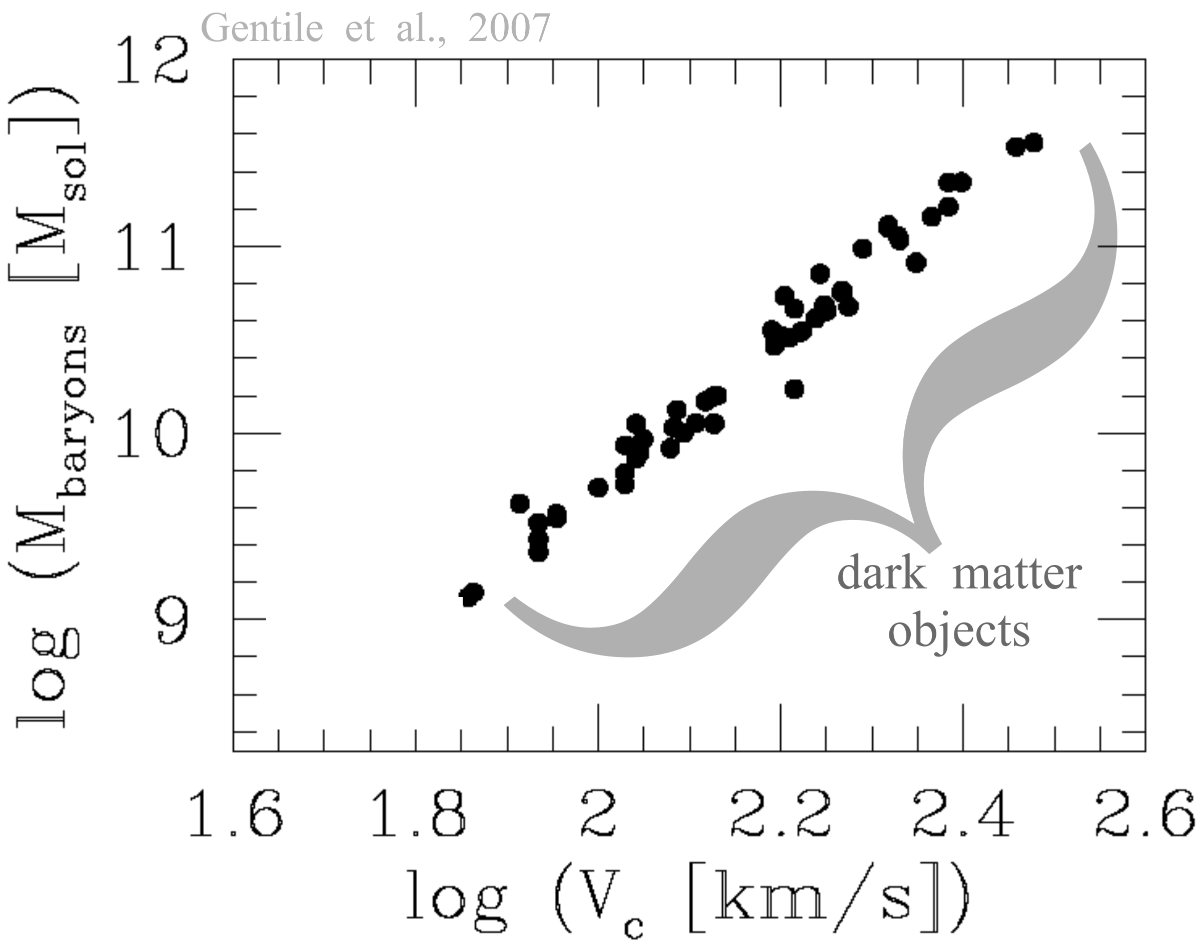

Fig. 2. Baryonic Tully-Fisher relation (baryonic mass vs. circular velocity). The small full circles are the disk galaxy data from McGaugh (2005). The 3 TDGs studied here are shown as blue empty circles (i = 45°) and red stars (i as a free parameter).

The Tully -Fisher Relation and internal dynamics of young TDGs :

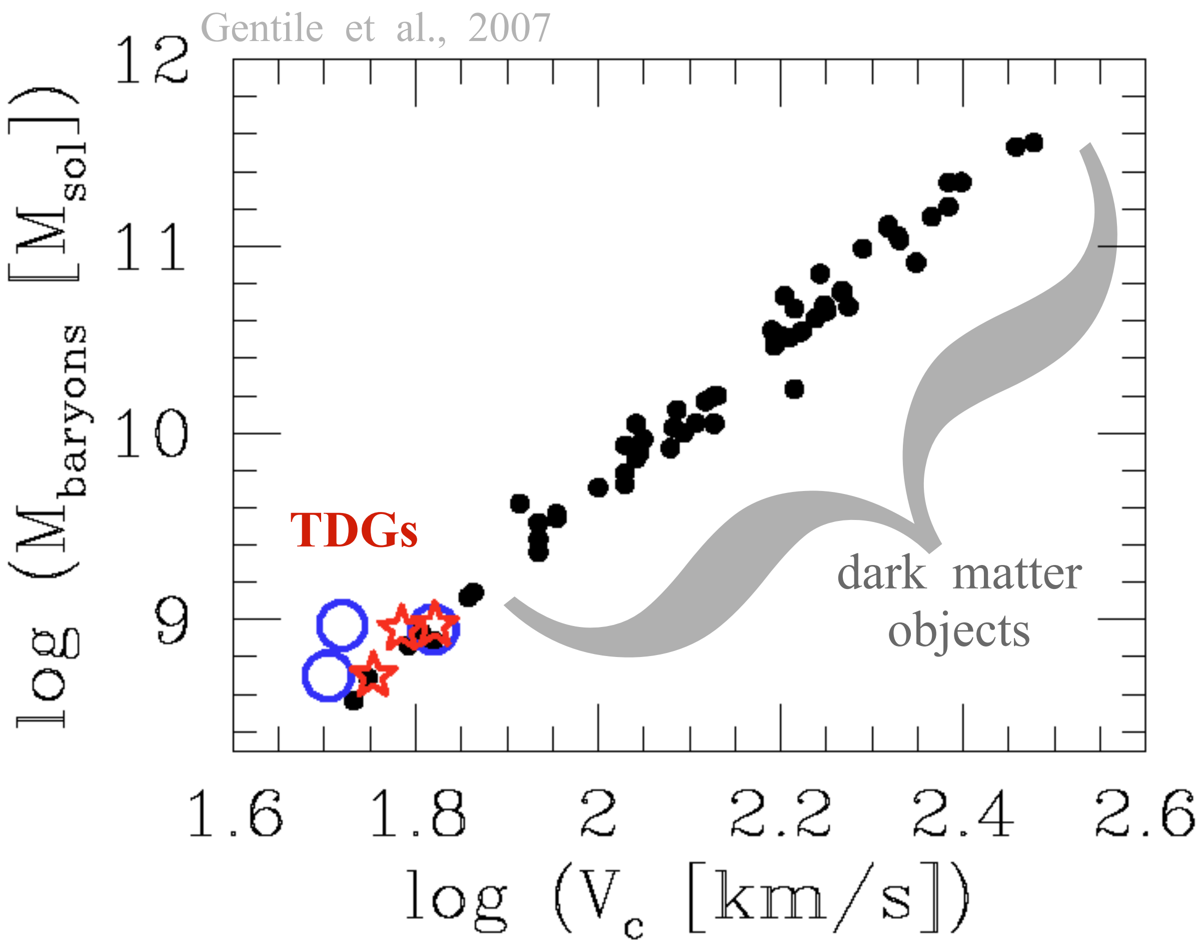

Fig. 2. Baryonic Tully-Fisher relation (baryonic mass vs. circular velocity). The small full circles are the disk galaxy data from McGaugh (2005). The 3 TDGs studied here are shown as blue empty circles ($i = 45°$) and red stars (i as a free parameter).

But TDGs are purely baryonic objects.

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

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. . .

Summary

&

Conclusions

. . .

The two Fritz Zwicky Conjectures :

A. DM dominates large galaxies (postulate from kinematics).

B. New dwarf galaxies form in tidal debris (direct observational fact).

CONTRADICTION
because

1. There ***must be*** many satellite galaxies with massive dark matter halos (*type A dwarfs*).

2. there ***must be*** many (tidal - dwarf) satellite galaxies without dark matter (*type* ***B*** *dwarfs*).

But
only one type of dE / dSph galaxy
is observed to exist.

This can only be *type* ***B*** because this type is a consequence of well-known physical laws.

The DoS and bulge-satellite correlation are additional, independent, supporting evidence.

DISCARD
Conjecture A.

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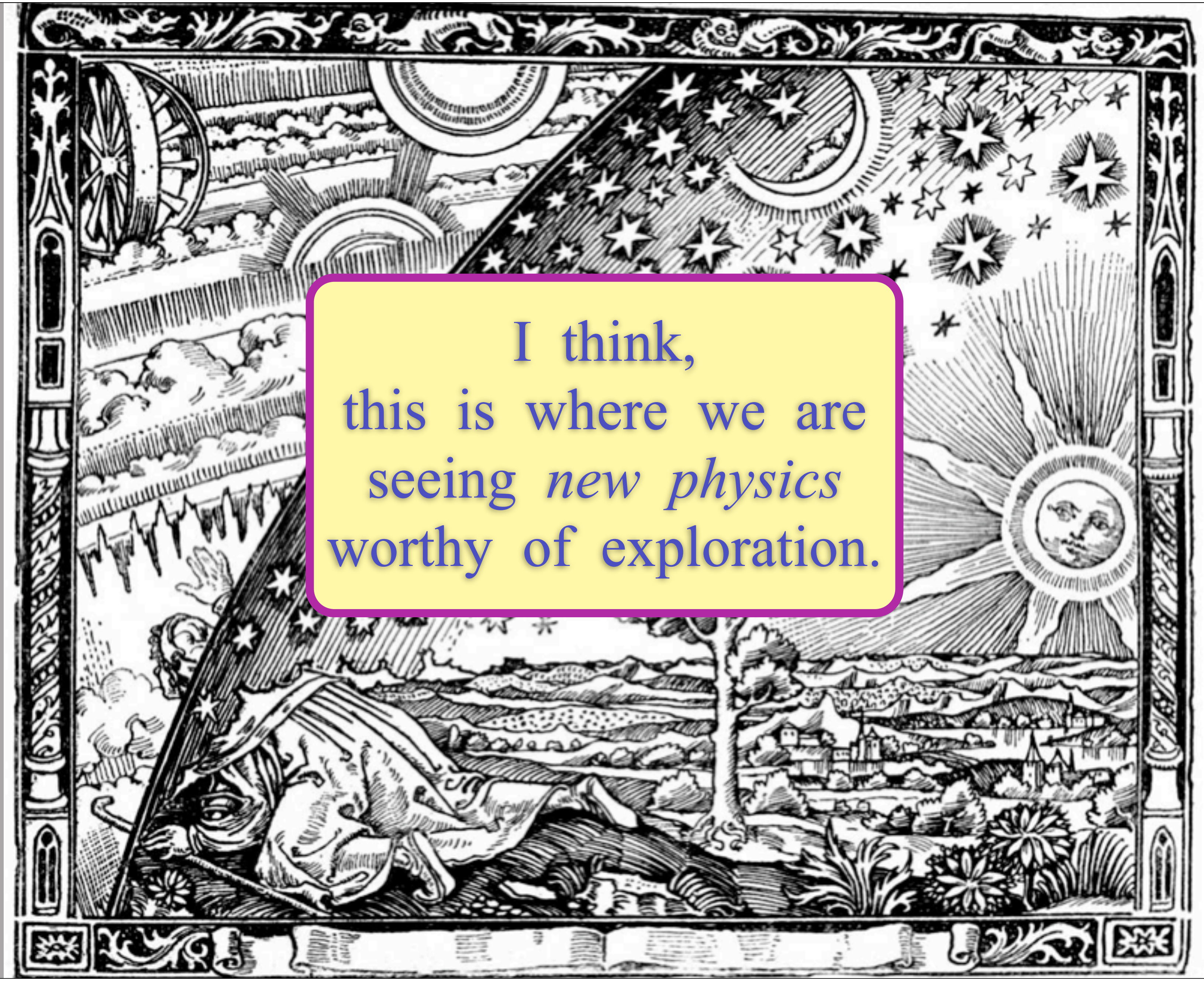

I think,
this is where we are
seeing *new physics*
worthy of exploration.

$$\mathrm{dSph} = \mathrm{TDG} \Longrightarrow \not{\mathrm{LCDM}}$$

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The END