MG/DM Debate: the meaning/ predictions of galaxy scaling relation

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MOND movies

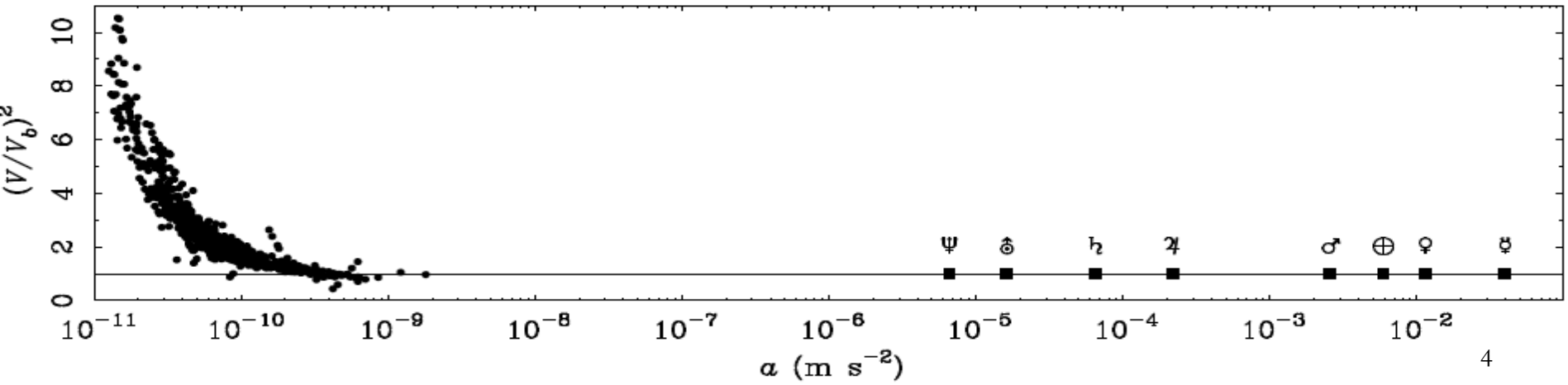
- https://astro.unistra.fr/fileadmin/upload/DUN/observatoire/Images/GFThomas_MONDSgrstream_movie.mp4
- https://inspirehep.net/record/1082173/plots
- https://inspirehep.net/record/1082173/files/olivier3.png

Meaning of Empirical Relation

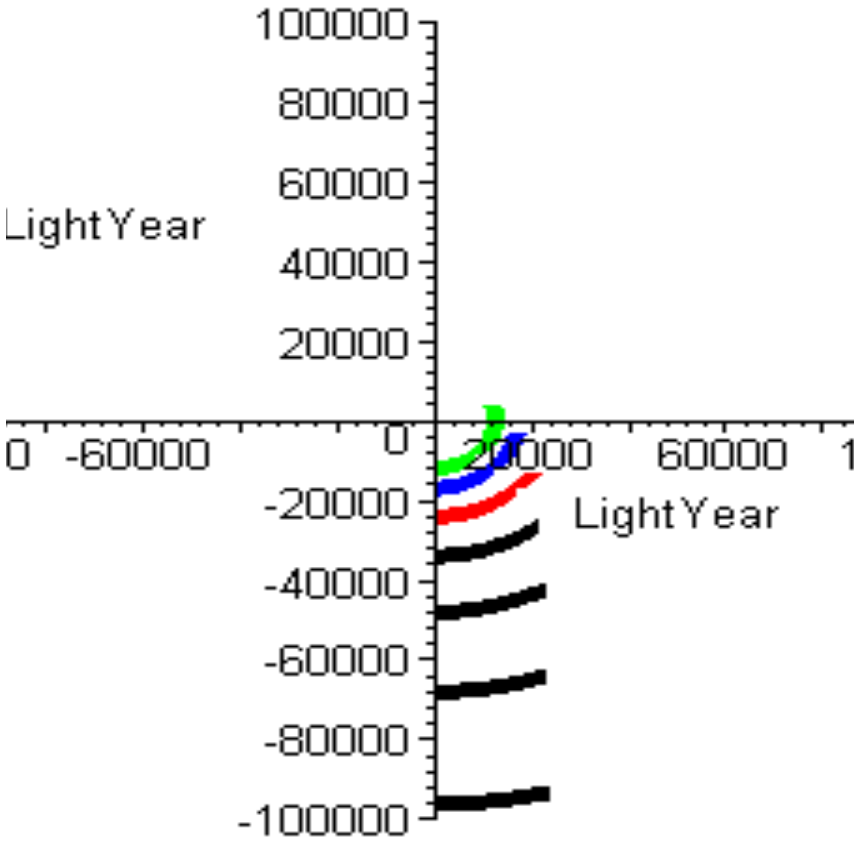
- Only a Generalized Kepler law.
- involves MG fields,
  - but not enough to uniquely (covariant) prescribe.
  - Zero? Scatter,
  - Works at ANY? point in a galaxy
  - Insensitive to
    - History/SF/gas fraction/shapes/Luminosity
    - Quiet Vrot and System with signs of interactions (rings).

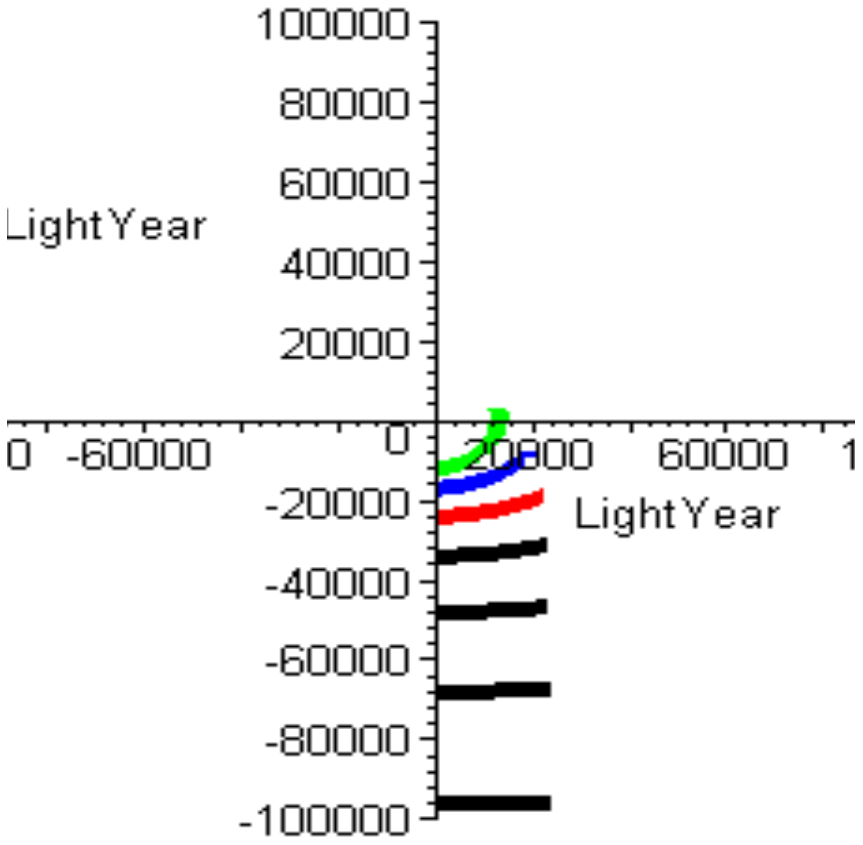
Galaxies tell us a modified "Kepler-law"

- $V^2 / r = a = \mathcal{G}\, M/r$
- $\mathcal{G} = 6.67 \times 10^{-11} (1 + 10^{-10}/a)$



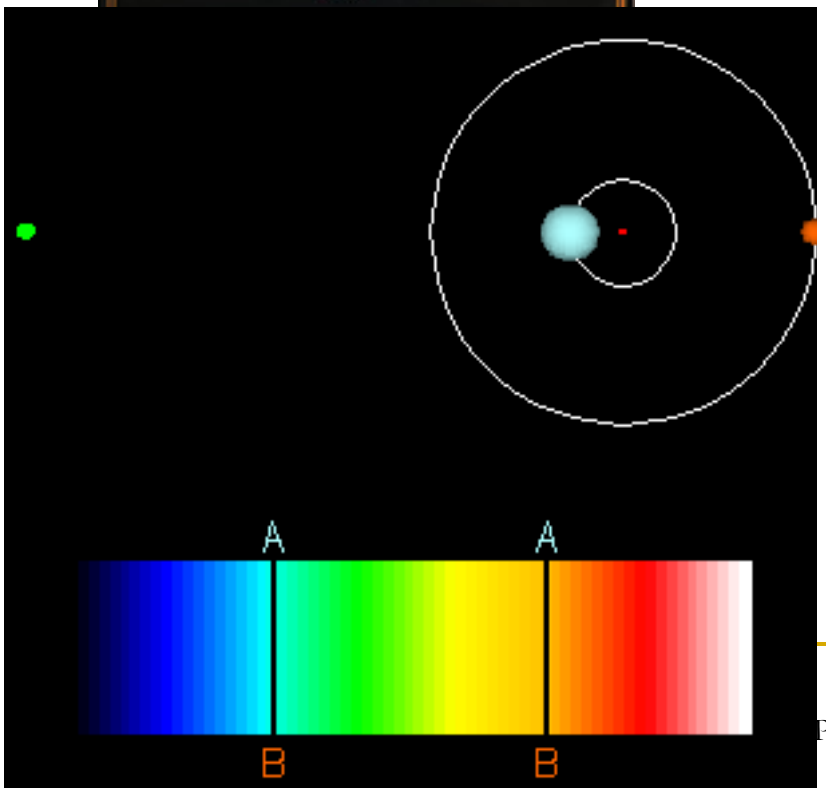
(Modified) Kepler-law seen in galaxy rotation: $a^4/P^4 \sim GM$

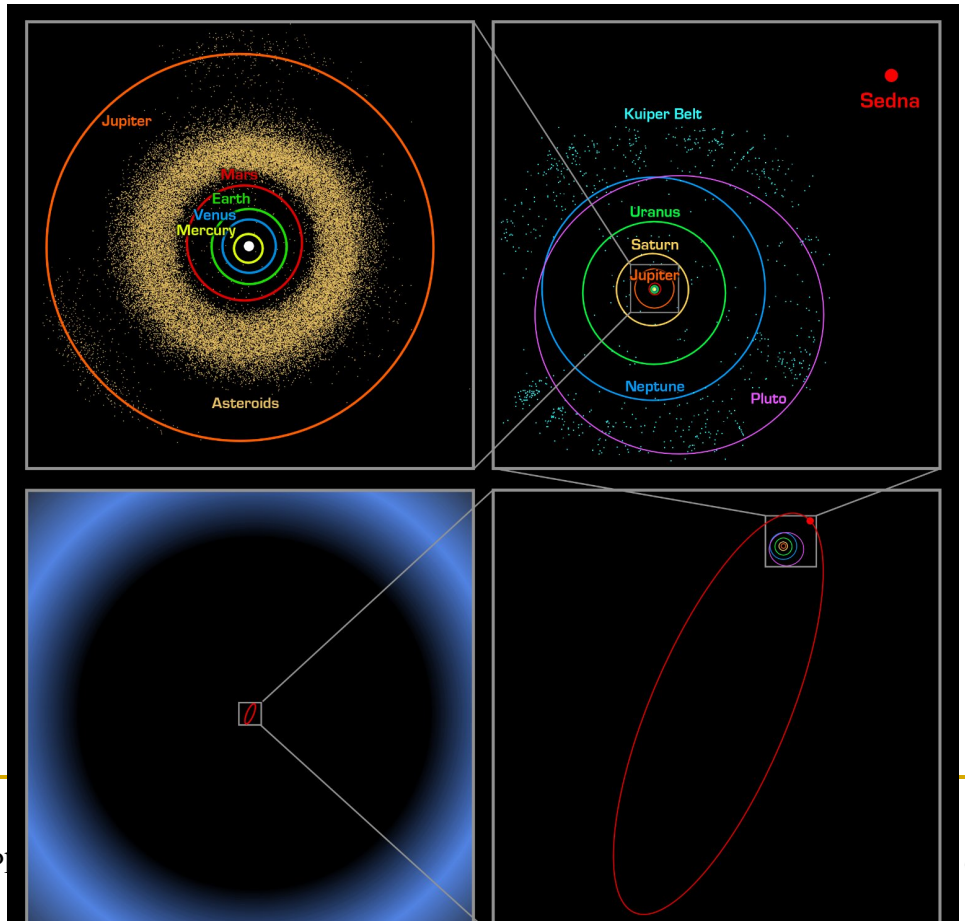




Empiric Kepler law to Newton Grav

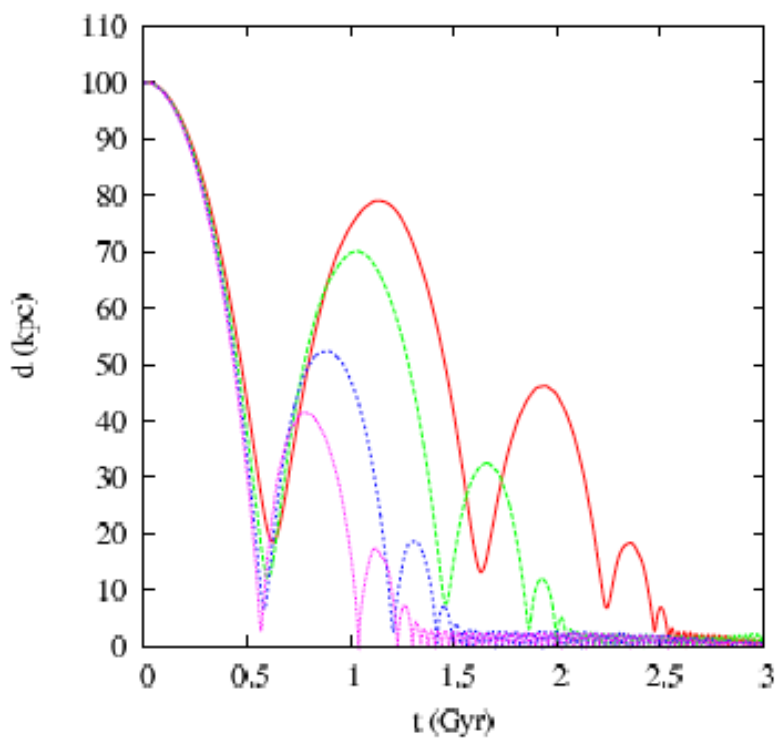
$a^3 / P^2 \sim$ constant for all planets

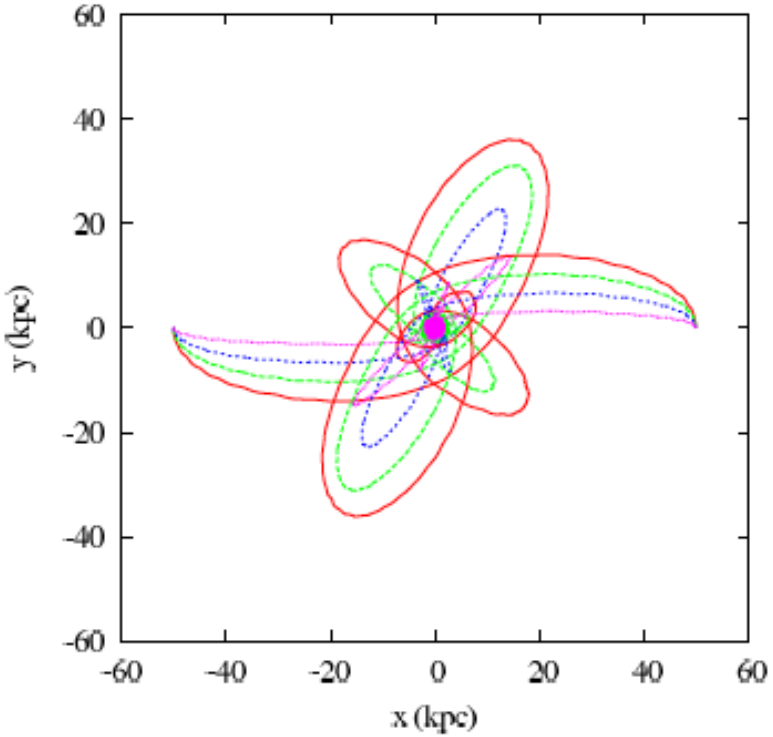




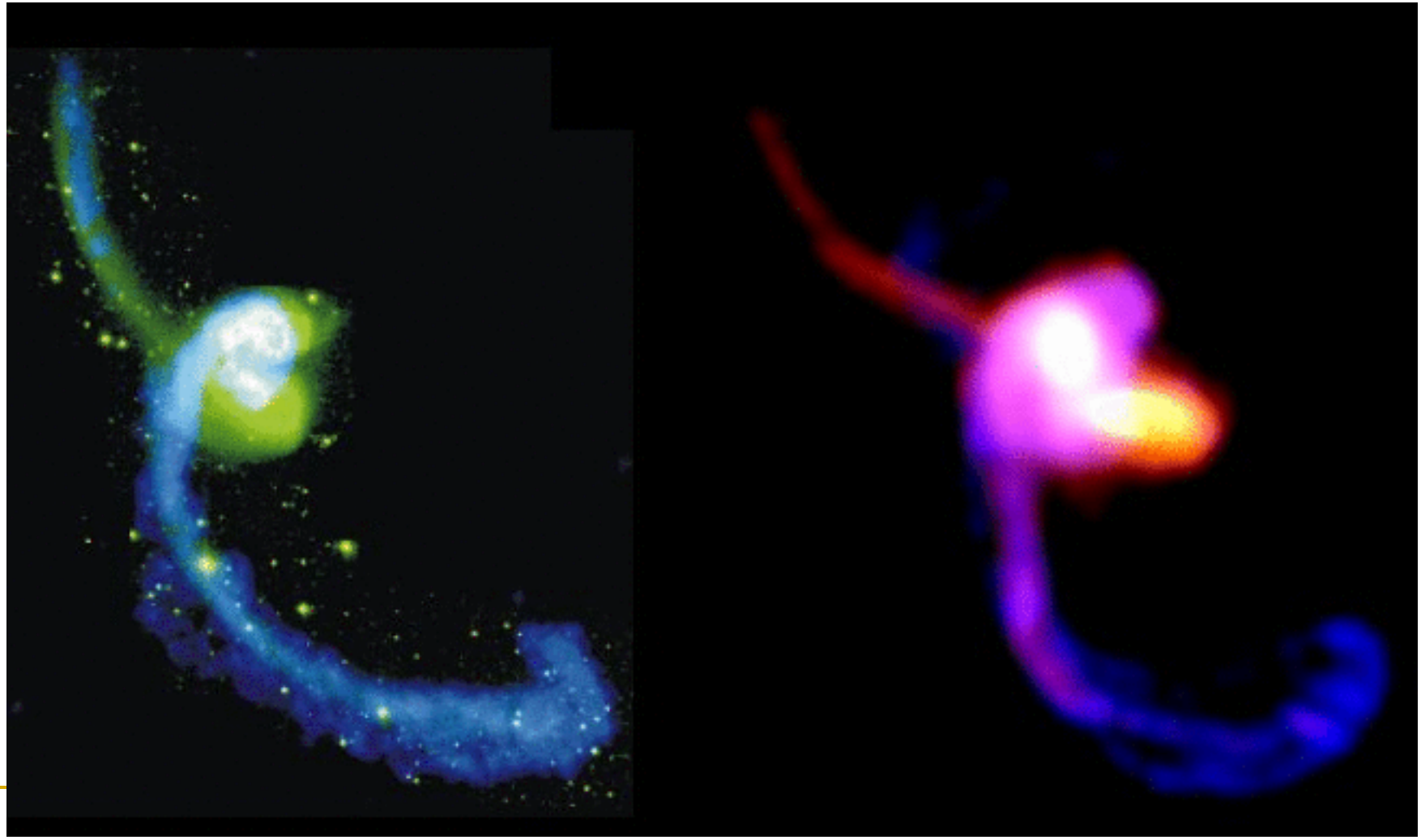
- Footprints of Galactic “Kepler-law”?

Dynamical Friction *small* in Modified Kepler-law





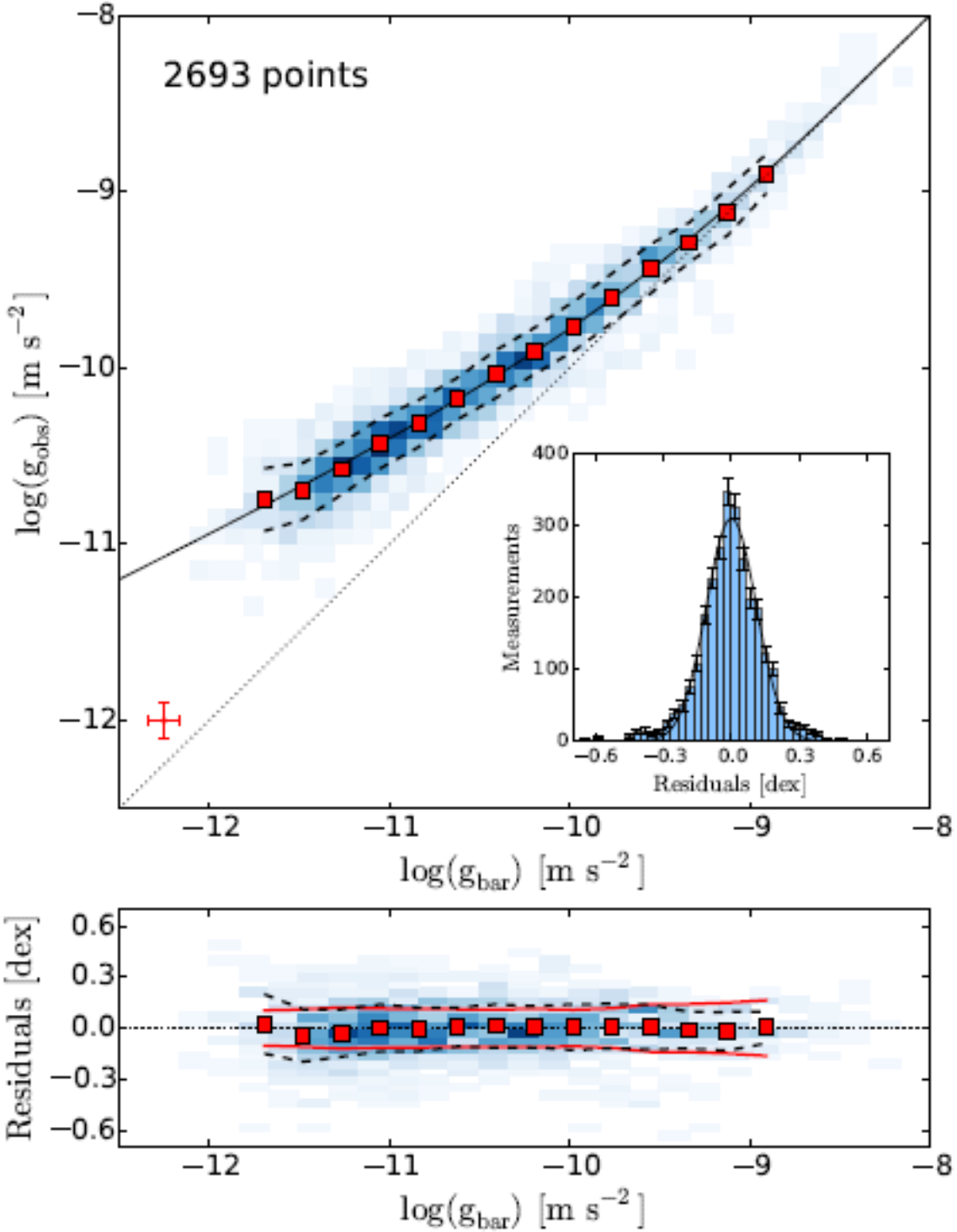
Tiret & Combes 2007, A&A 464, 517



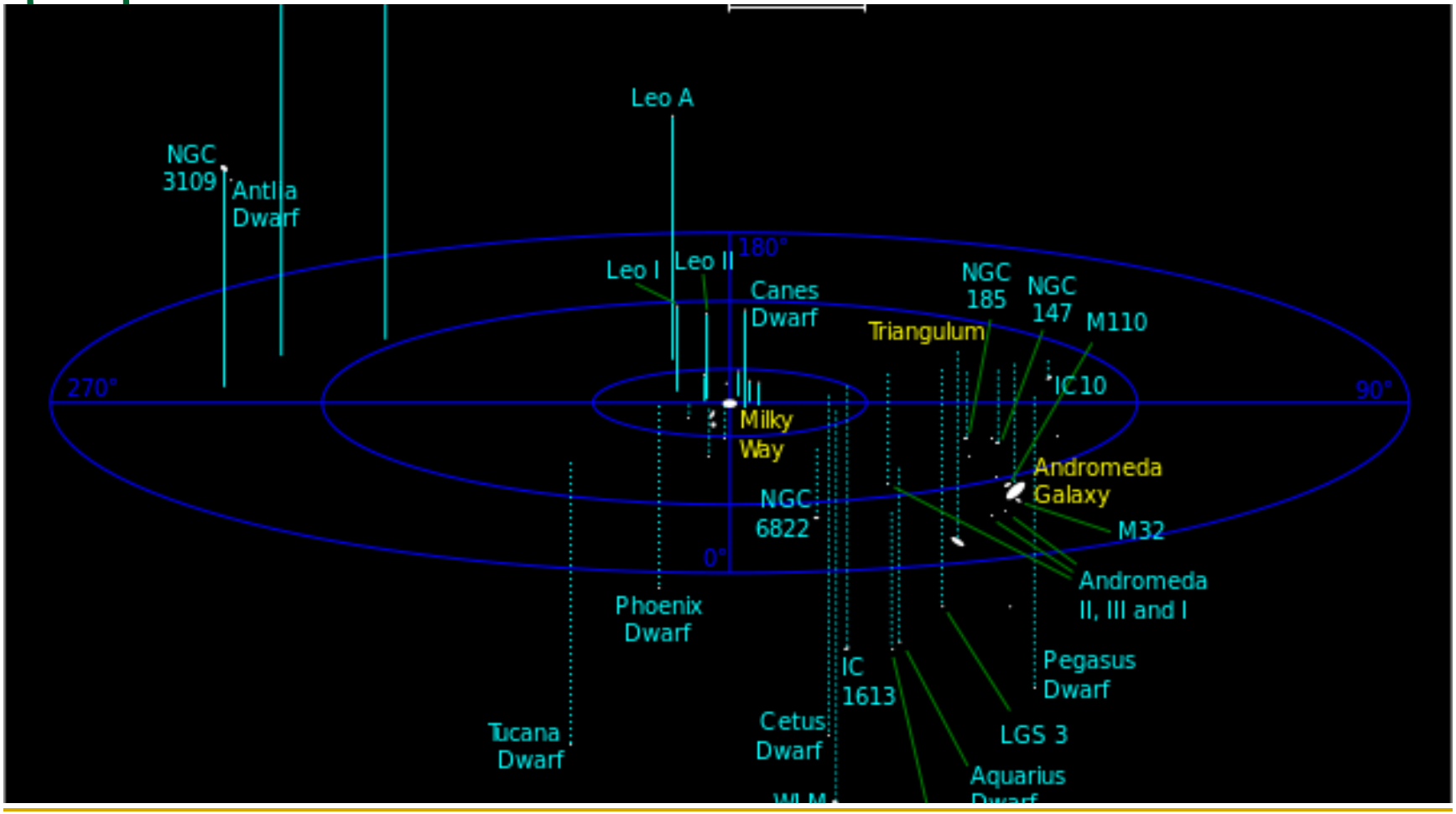
Polar rings

MG: history independent

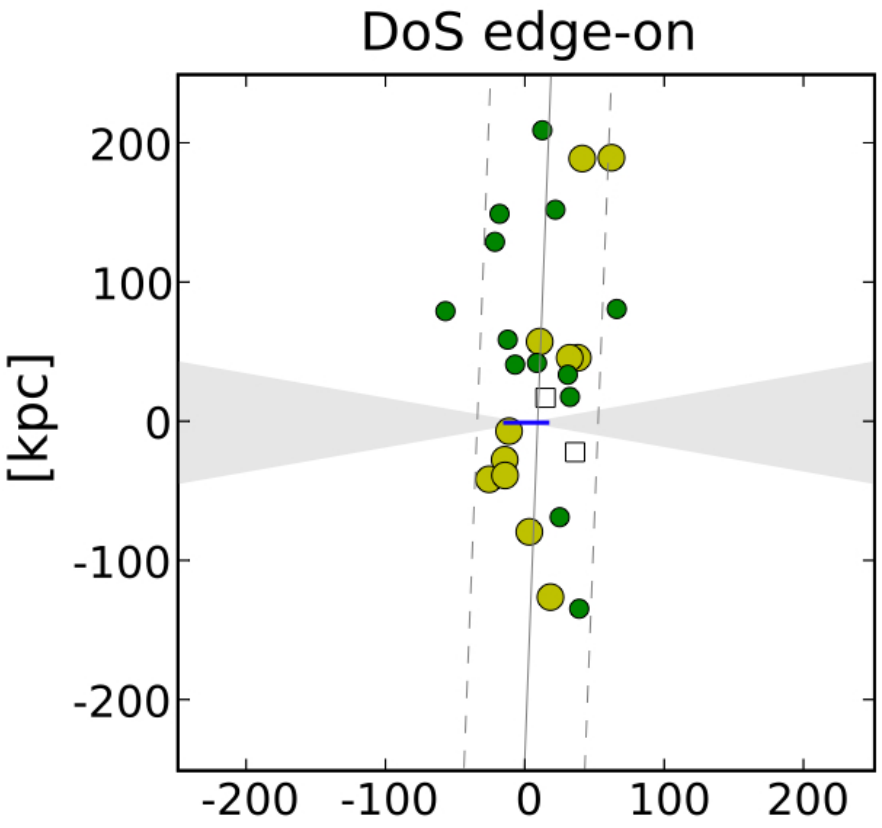
- Mgaugh et al. prediction
- Crater 2: flattening might not be real
  Walker et al., 2017 private comm.



Most satellites has 10 Gyrs old populations.

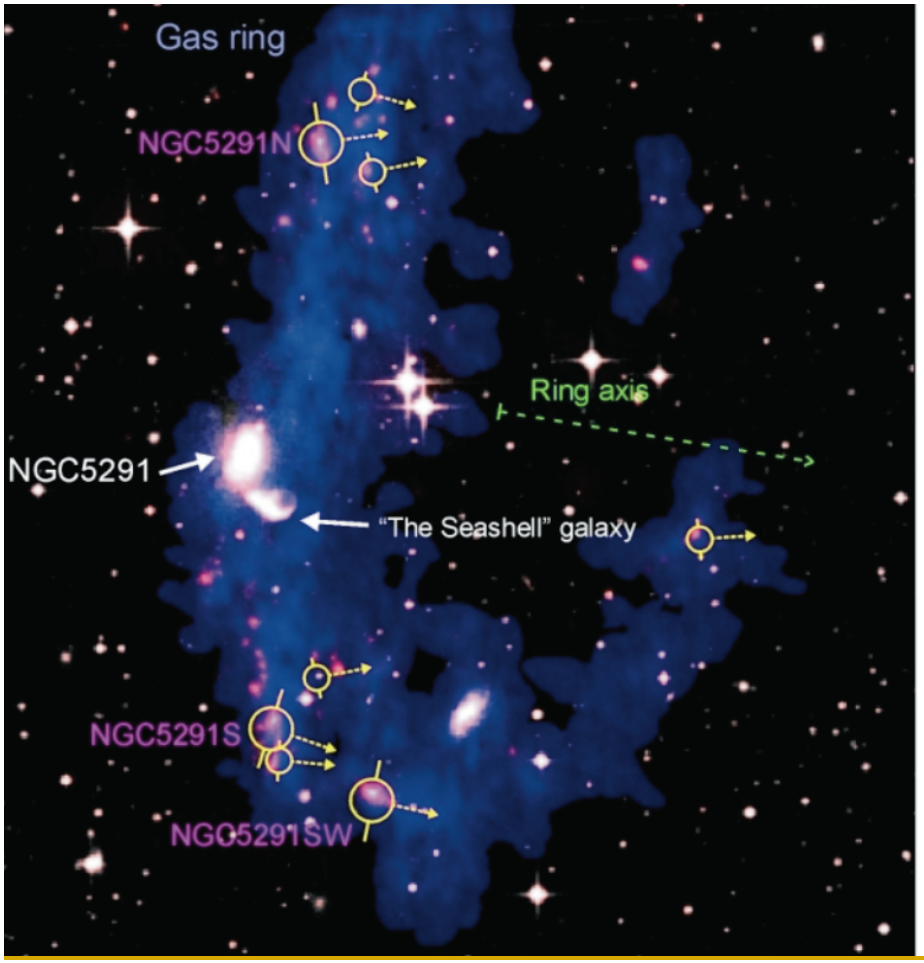


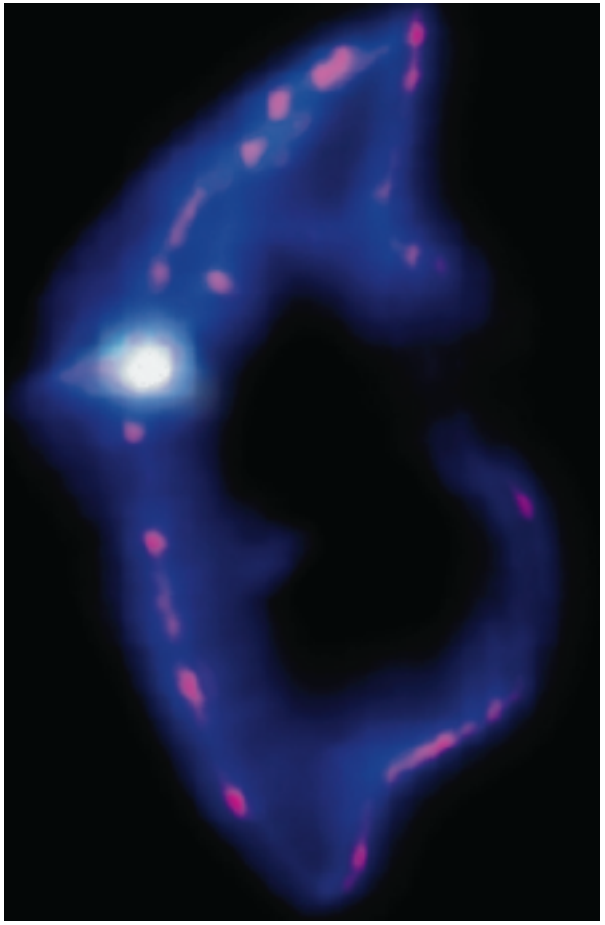
Milky Way



Kroupa, Famaey, et al. (2010)

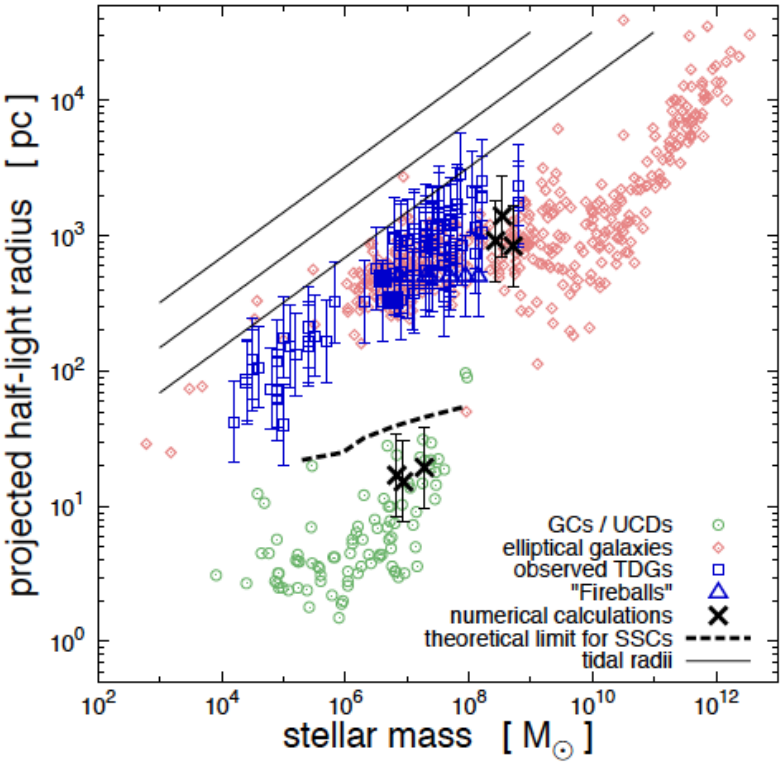
Dwarf galaxies on tidal rings





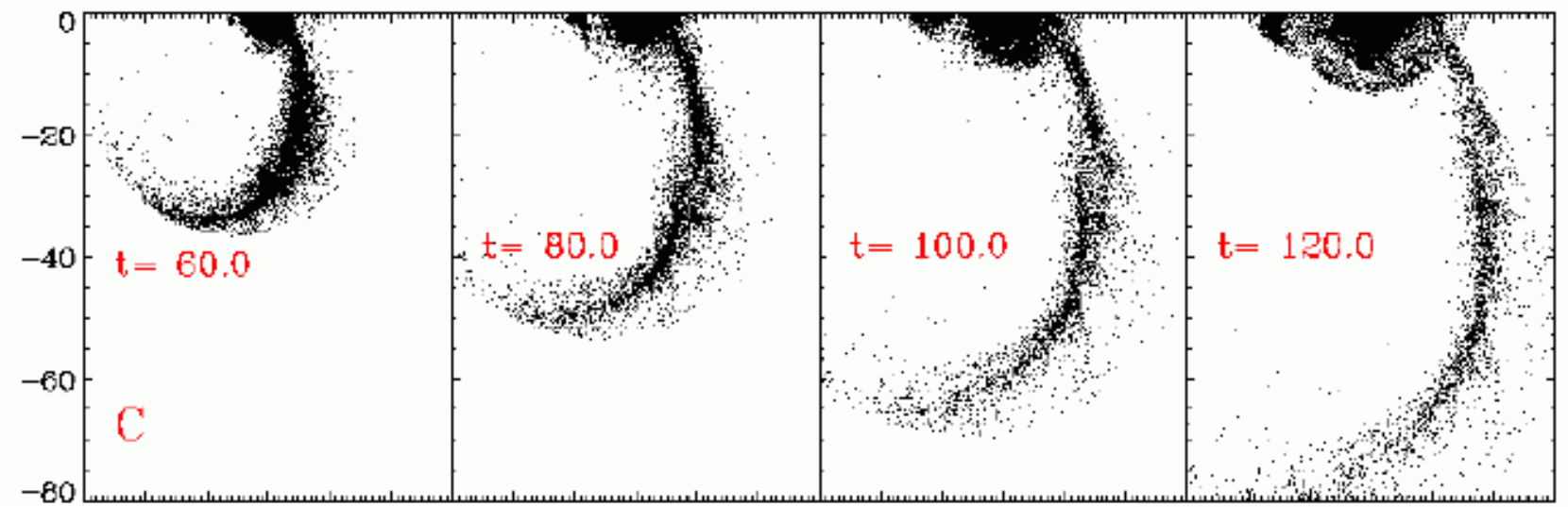
Bournaud, Duc et al. 2007, Science

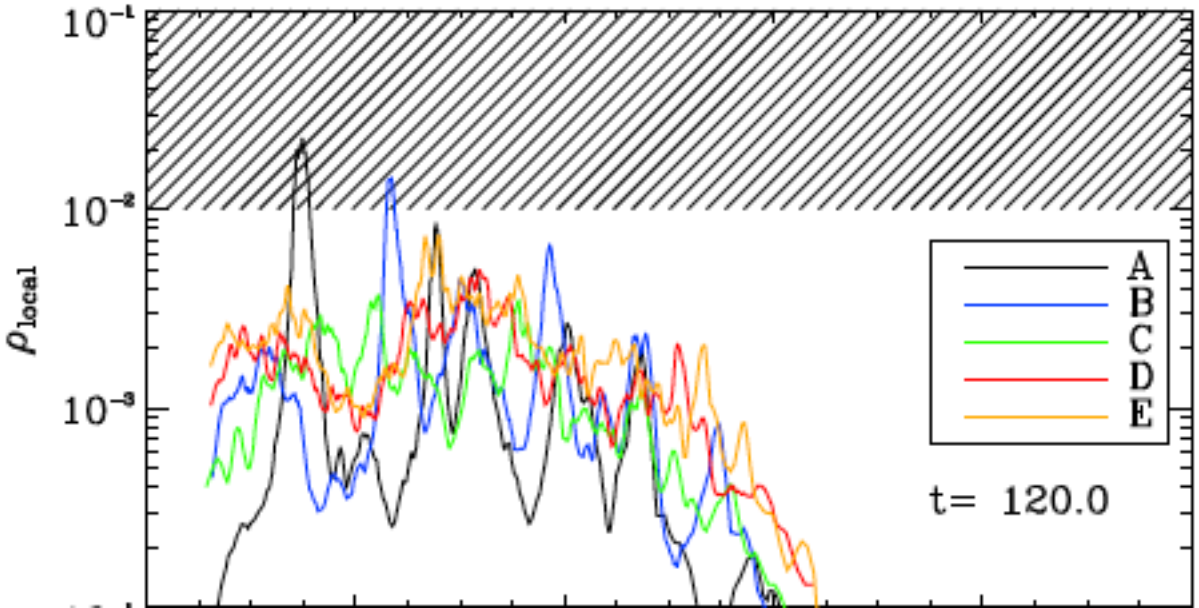
All Dwarfs have high M/L



Kroupa et al.

No dwarfs form by DM recollapse





Do dwarf galaxies form in tidal tails?

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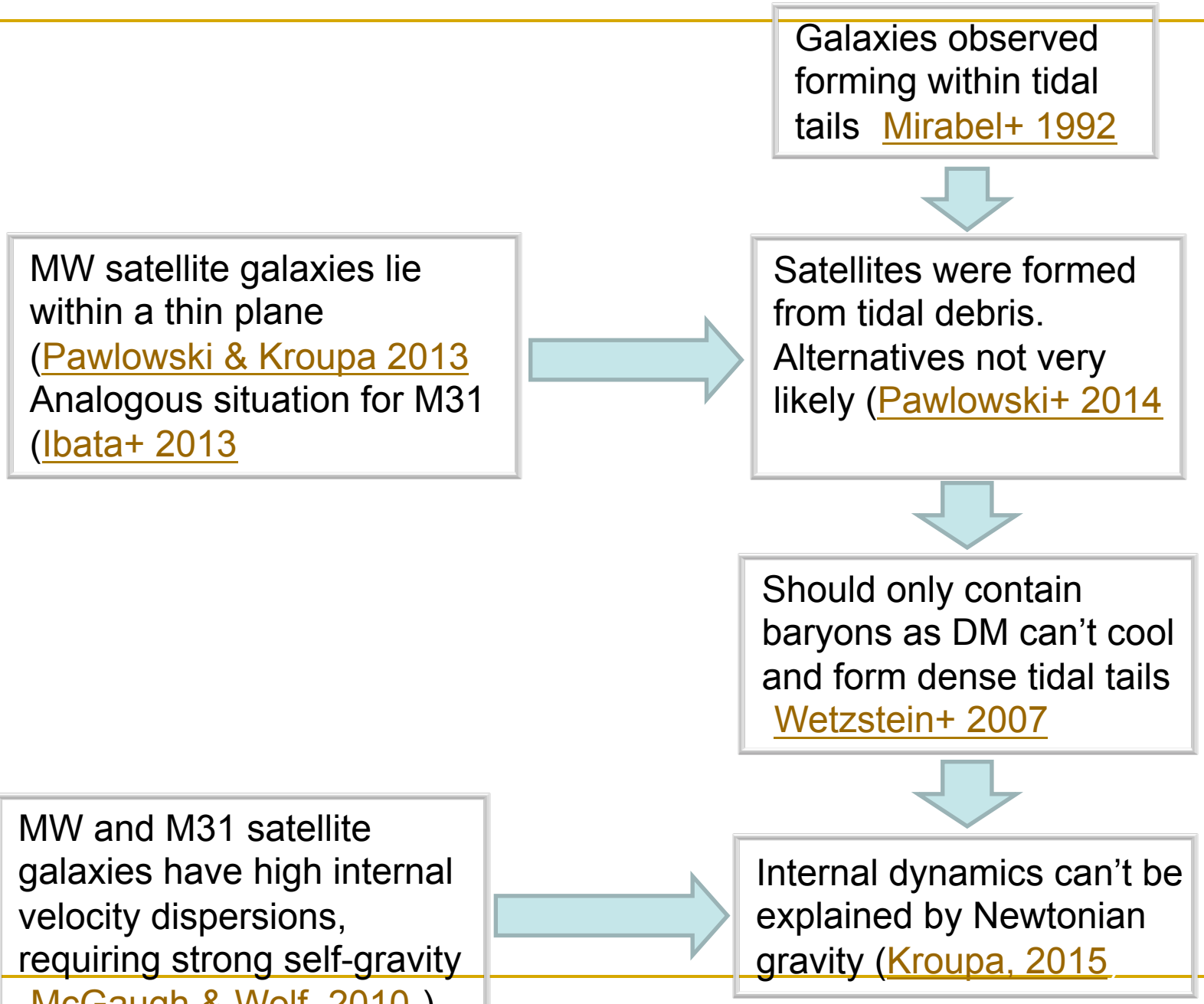
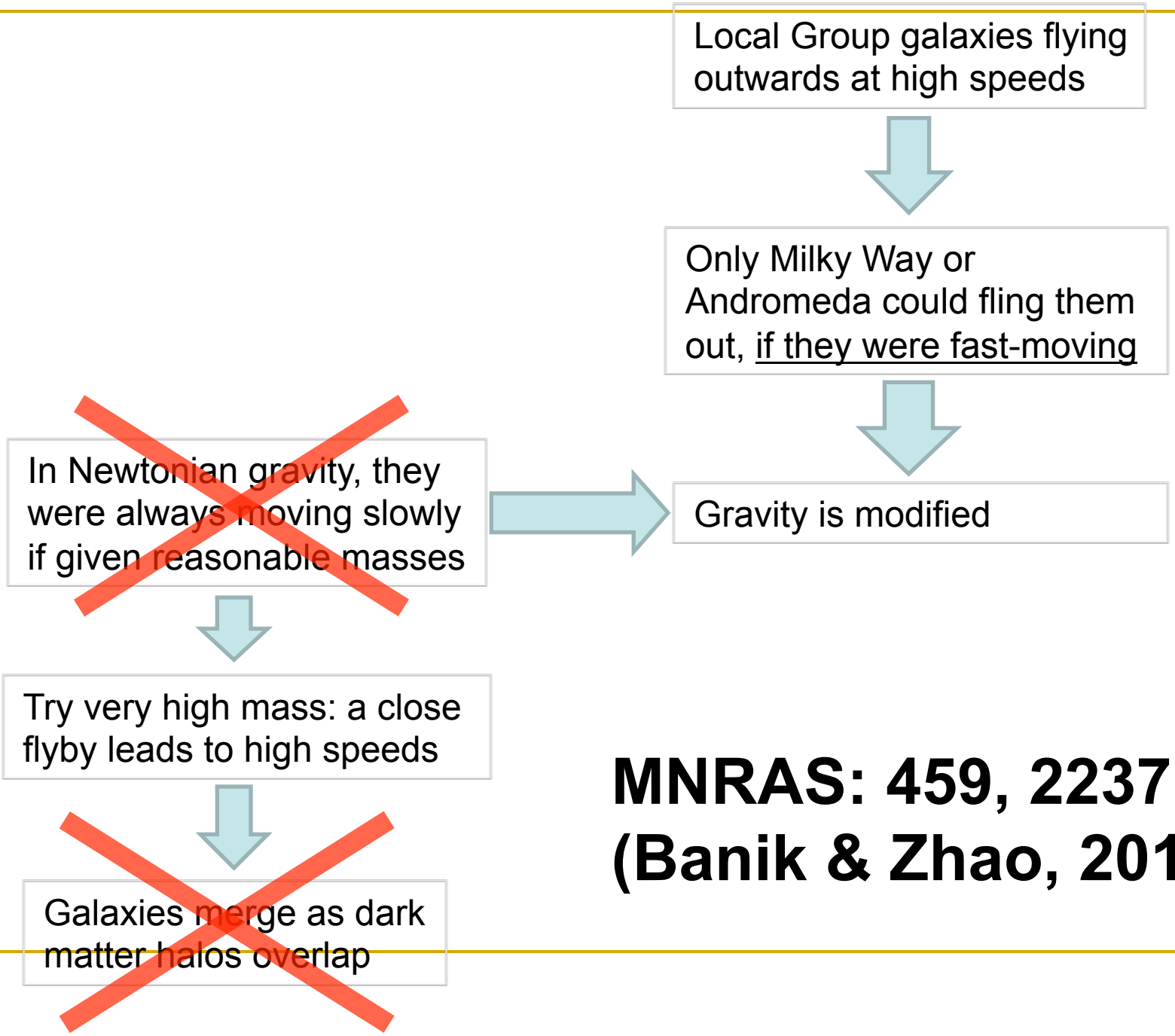
23 January 2014

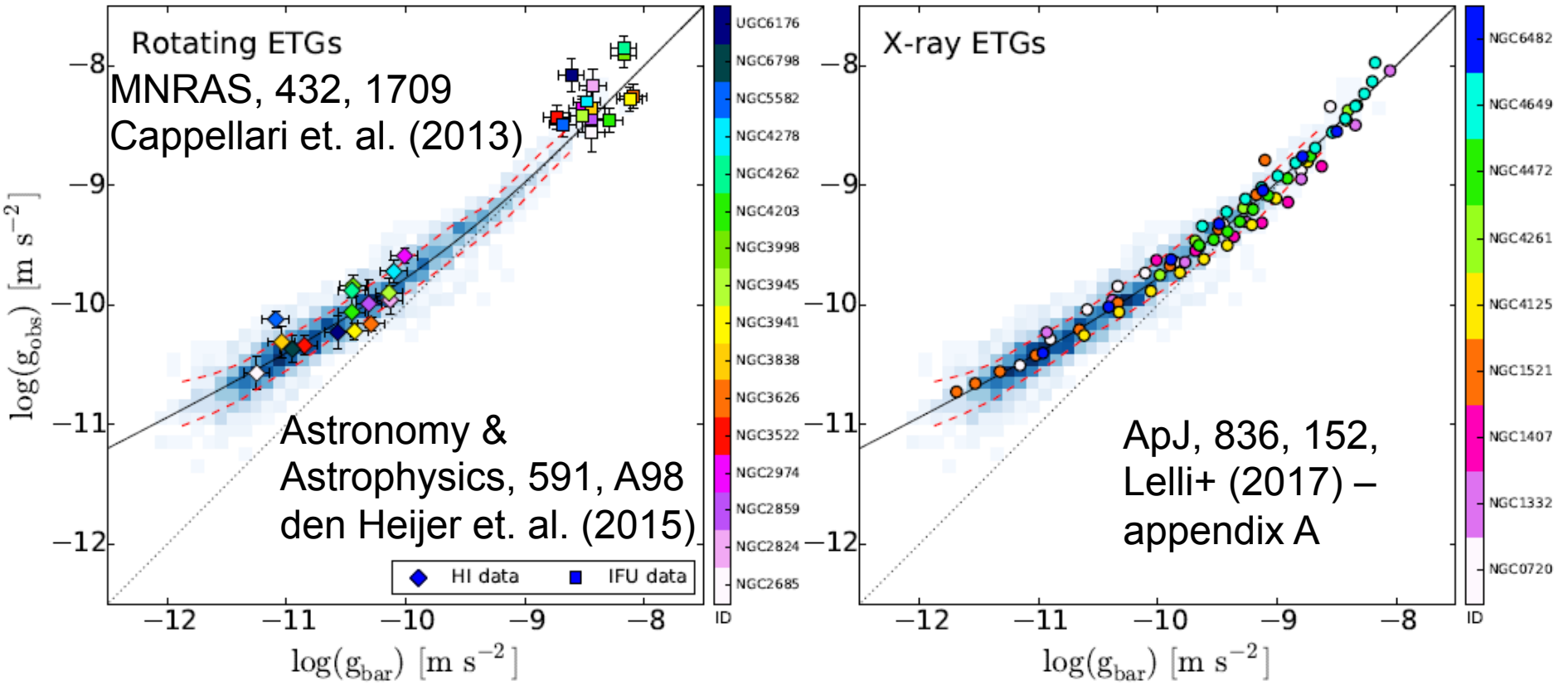
ABSTRACT

The formation of tidal dwarf galaxies (galaxies has been studied with N-body and olutions. In pure N-body simulations no bo At low resolution bound objects can form work. We conclude that tidal dwarf galaxies collapse in tidal tails. However, the presen gas component in the progenitor disk supp in the tidal arms. Our results clearly favor the formation of TDGs is induced by the lo collapse of the stellar component.


Galaxies observed forming within tidal tails Mirabel+ 1992
MW satellite galaxies lie within a thin plane (Pawlowski & Kroupa 2013
Analogous situation for M31 (Ibata+ 2013
Satellites were formed from tidal debris. Alternatives not very likely (Pawlowski+ 2014
Should only contain baryons as DM can't cool and form dense tidal tails Wetzstein+ 2007
MW and M31 satellite galaxies have high internal velocity dispersions, requiring strong self-gravity McGaugh & Wolf, 2010)
Internal dynamics can't be explained by Newtonian gravity (Kroupa, 2015



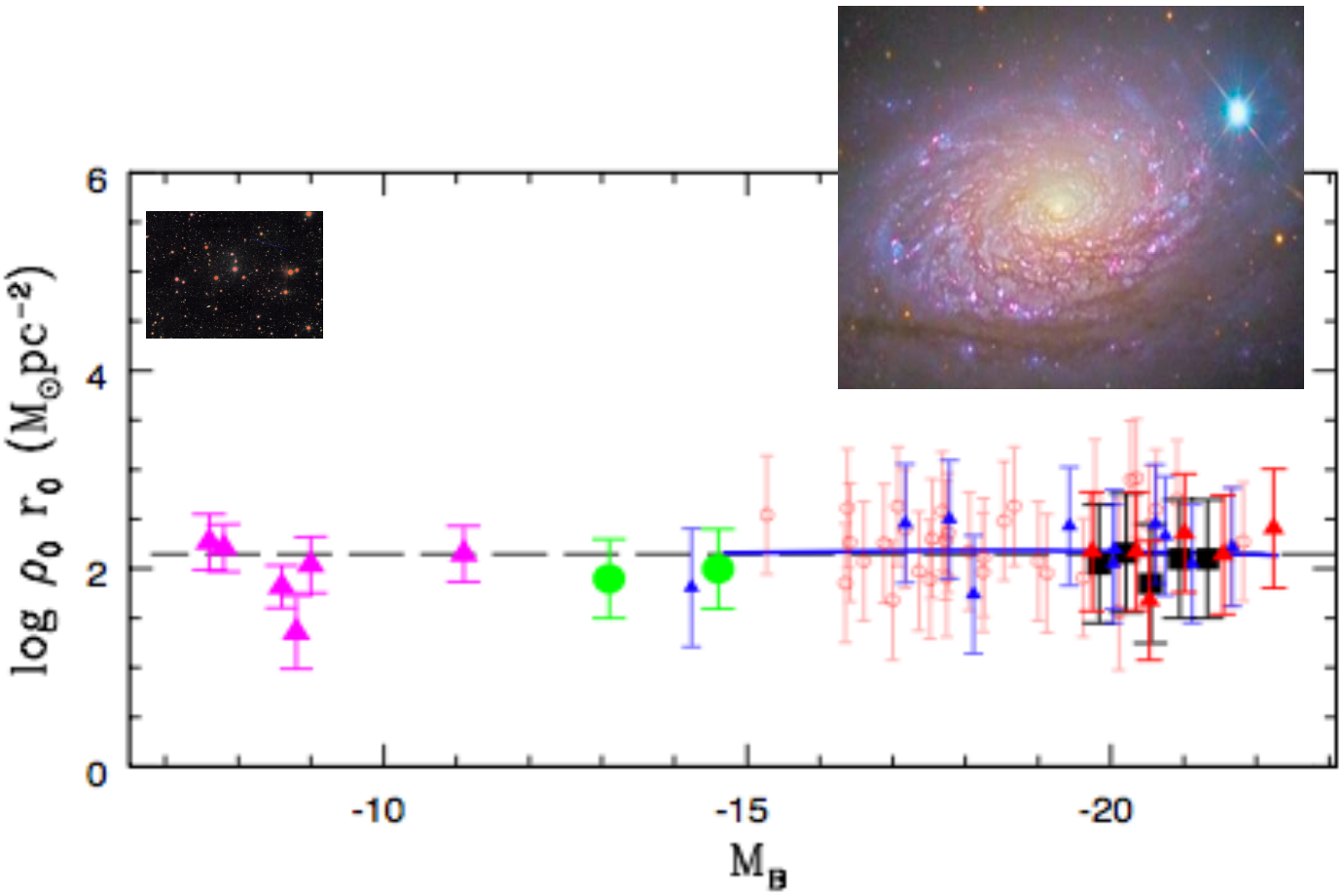
MNRAS: 459, 2237 (Banik & Zhao, 2016)


Rotating ETGs
MNRAS, 432, 1709
Cappellari et. al. (2013)
Astronomy &
Astrophysics, 591, A98
den Heijer et. al. (2015)
HI data
IFU data
UGC6176
NGC6798
NGC5582
NGC4278
NGC4262
NGC4203
NGC3998
NGC3945
NGC3941
NGC3838
NGC3626
NGC3522
NGC2974
NGC2859
NGC2824
NGC2685
ID
X-ray ETGs
ApJ, 836, 152,
Lelli+ (2017) –
appendix A
NGC6482
NGC4649
NGC4472
NGC4261
NGC4125
NGC1521
NGC1407
NGC1332
NGC0720
ID
log(g_obs) [m s^-2]
log(g_bar) [m s^-2]
−8
−9
−10
−11
−12

In the DM framework $\mathrm{rho}_{dm} = \mathrm{rho}_0 r_0^3/[(r + r_0)(r^2 + r_0^2)]$

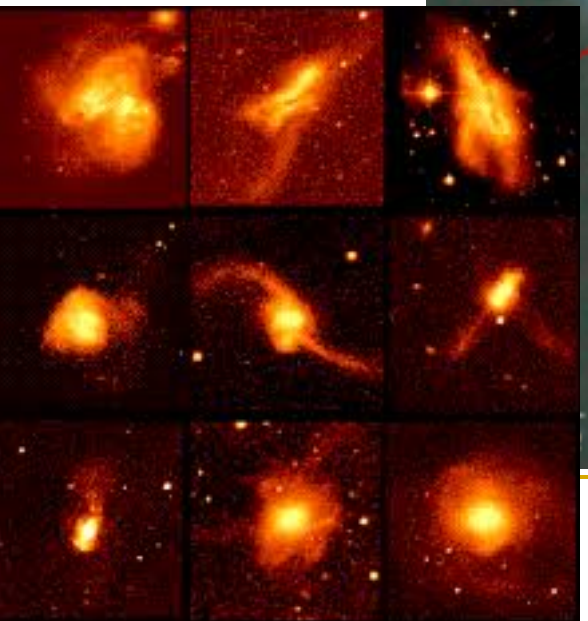
a typical **DM halo surface density** $\mathrm{rho}_0 r_0 \approx a_0/(2\pi G)$

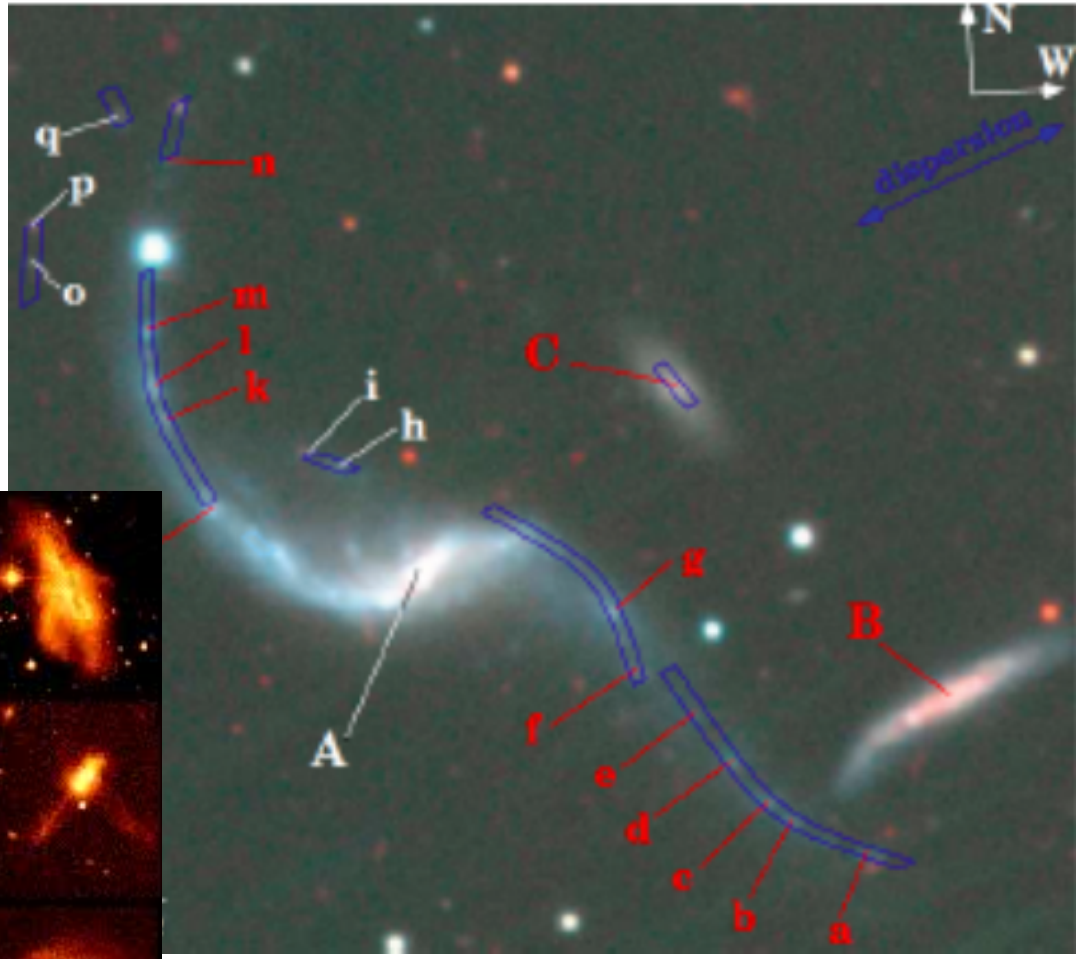
defines an acceleration constant *a0*



Donato et al. (2009); Gentile, Famaey, Zhao, Salucci (Nature 2009)

Tidal dwarf galaxies





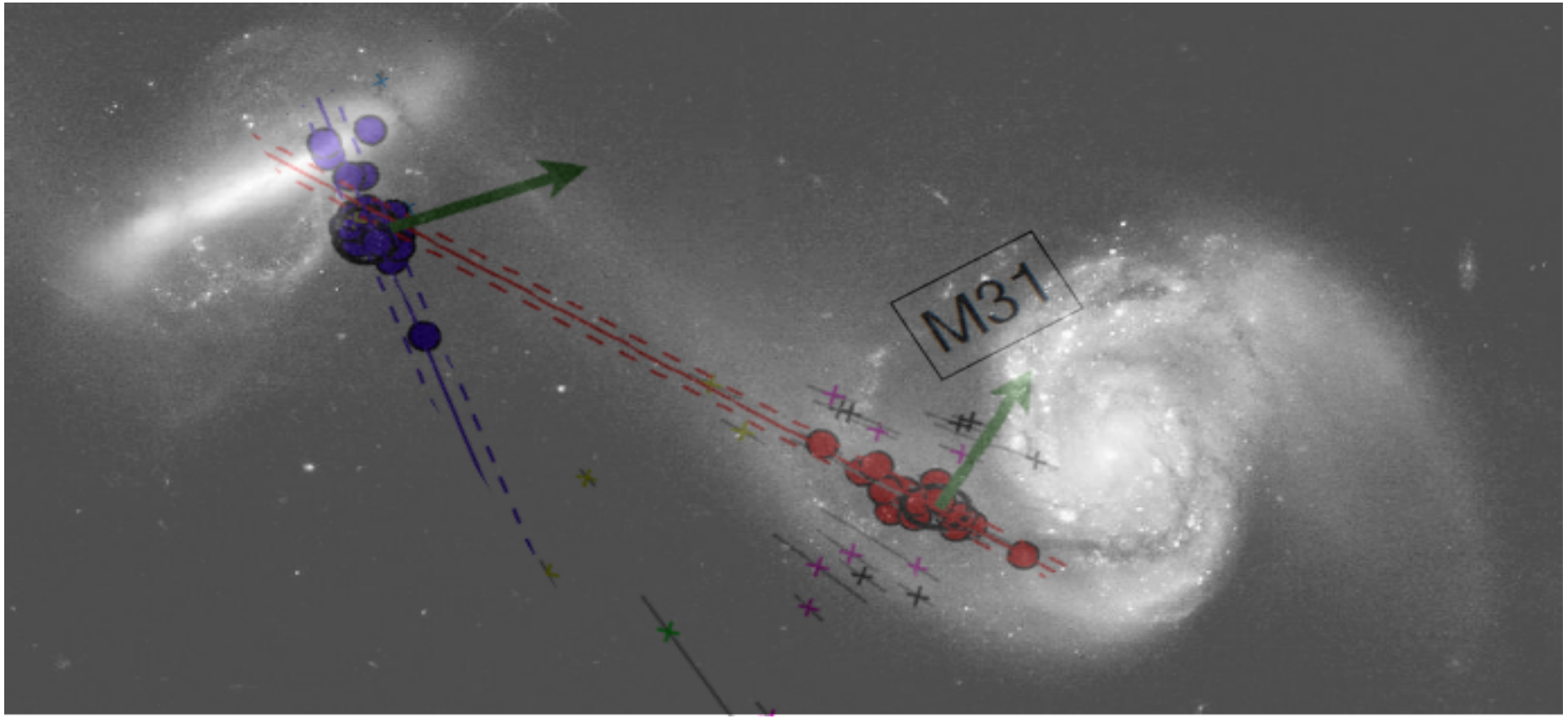
Weibache et al.

DM must exchange Energy & J

- Fat CDM haloes must merge, give only a few slow back splashers in 2Rvir

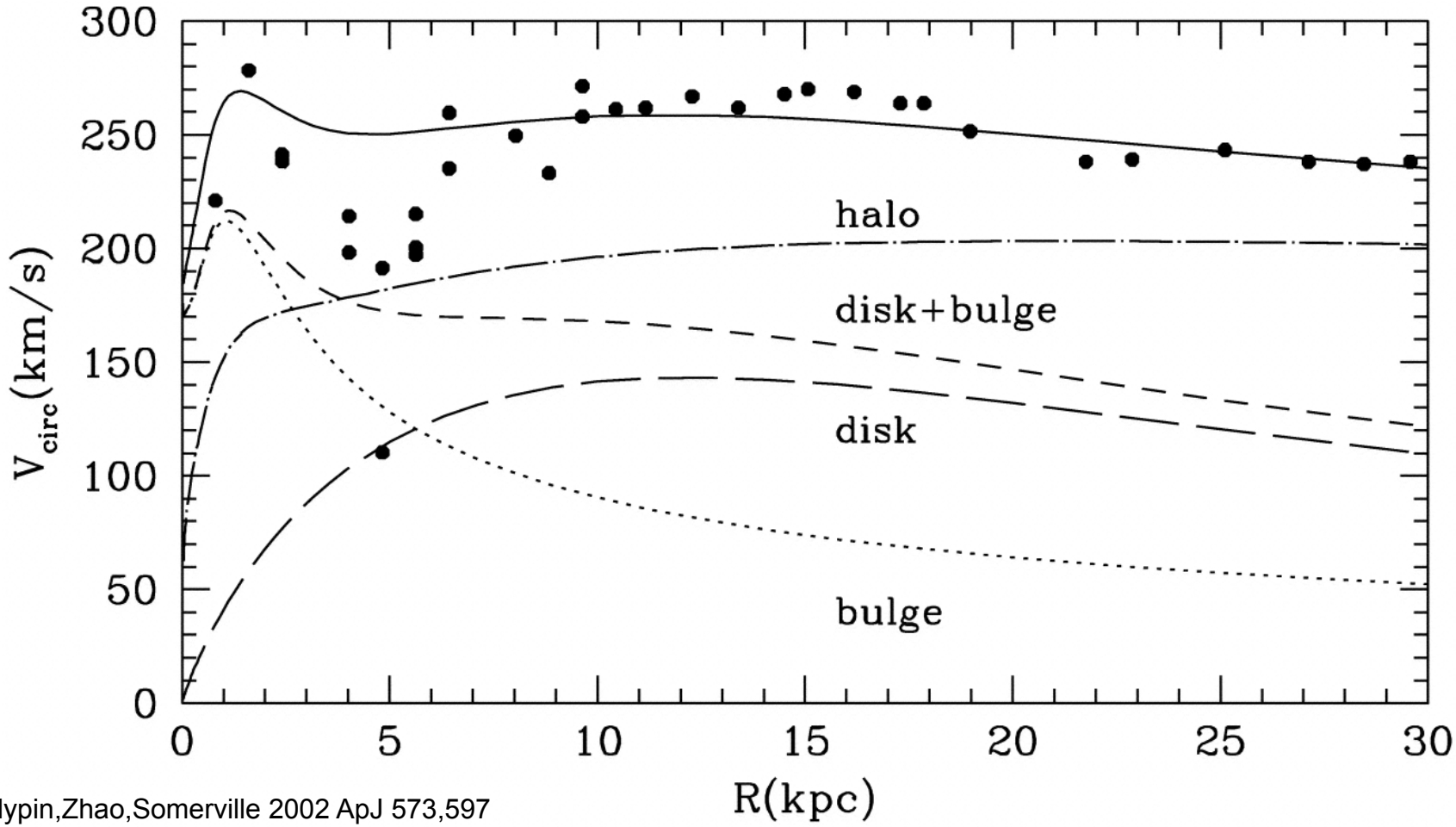
- MG fields do not absorb E & J
- Galaxies can FAST fly-by within 30 kpc,
  - Satellites or dwarf can be sling-shot to large 10Rvir / super-hubble velocity / planes /timing
  - Free MG gravity/EFE in every satellite 0.2-2Mpc.
  - ALL SIX must be true if MG

A bold test of friction: split MG/DM linking kpc/Mpc



Zhao et al 2013, Pawlowski et al. 2013

Empirically Modified Kepler-law force ~ $(250\text{km/s})^2$ /r



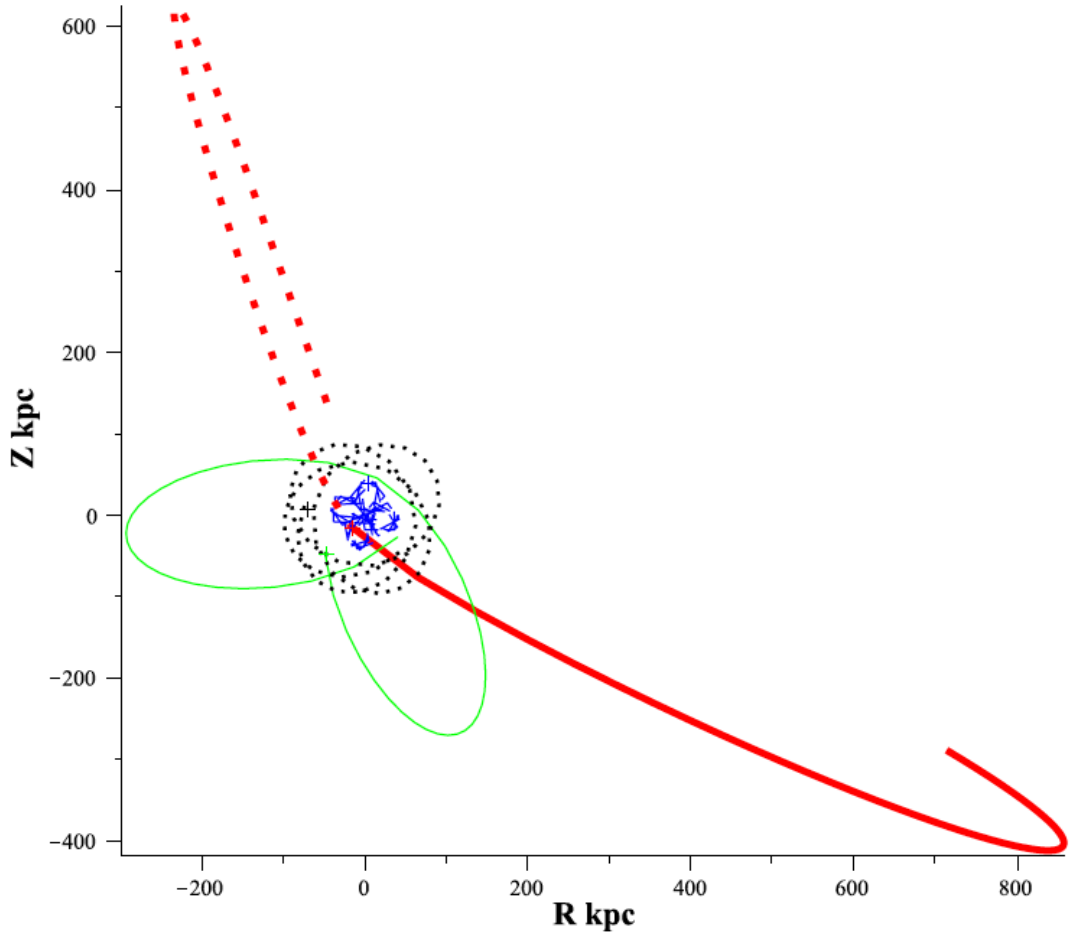
Klypin,Zhao,Somerville 2002 ApJ 573,597

Equation of motion
Under Force $F_{12} \sim (200\mathrm{km/s})^2/r_{12}$

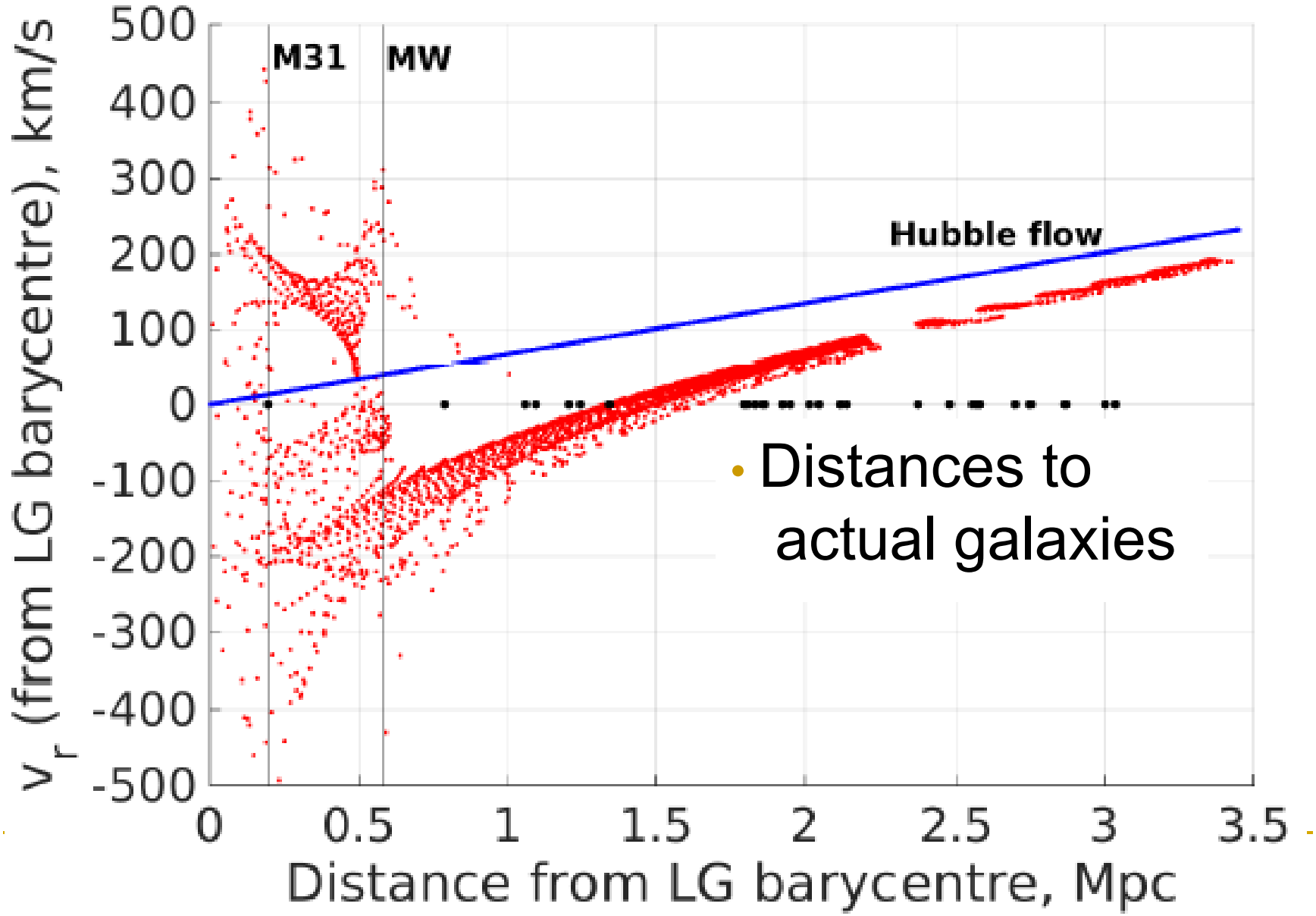
$$\frac{d^2}{dt^2}\mathbf{r}_{12} = K\mathbf{r}_{12} - \frac{m_1 + m_2}{m_1}\left[\frac{\mathbf{F}_{12}}{m_2}\right], \; K \equiv \frac{\mathrm{d}^2 a}{a\mathrm{d}t^2}$$

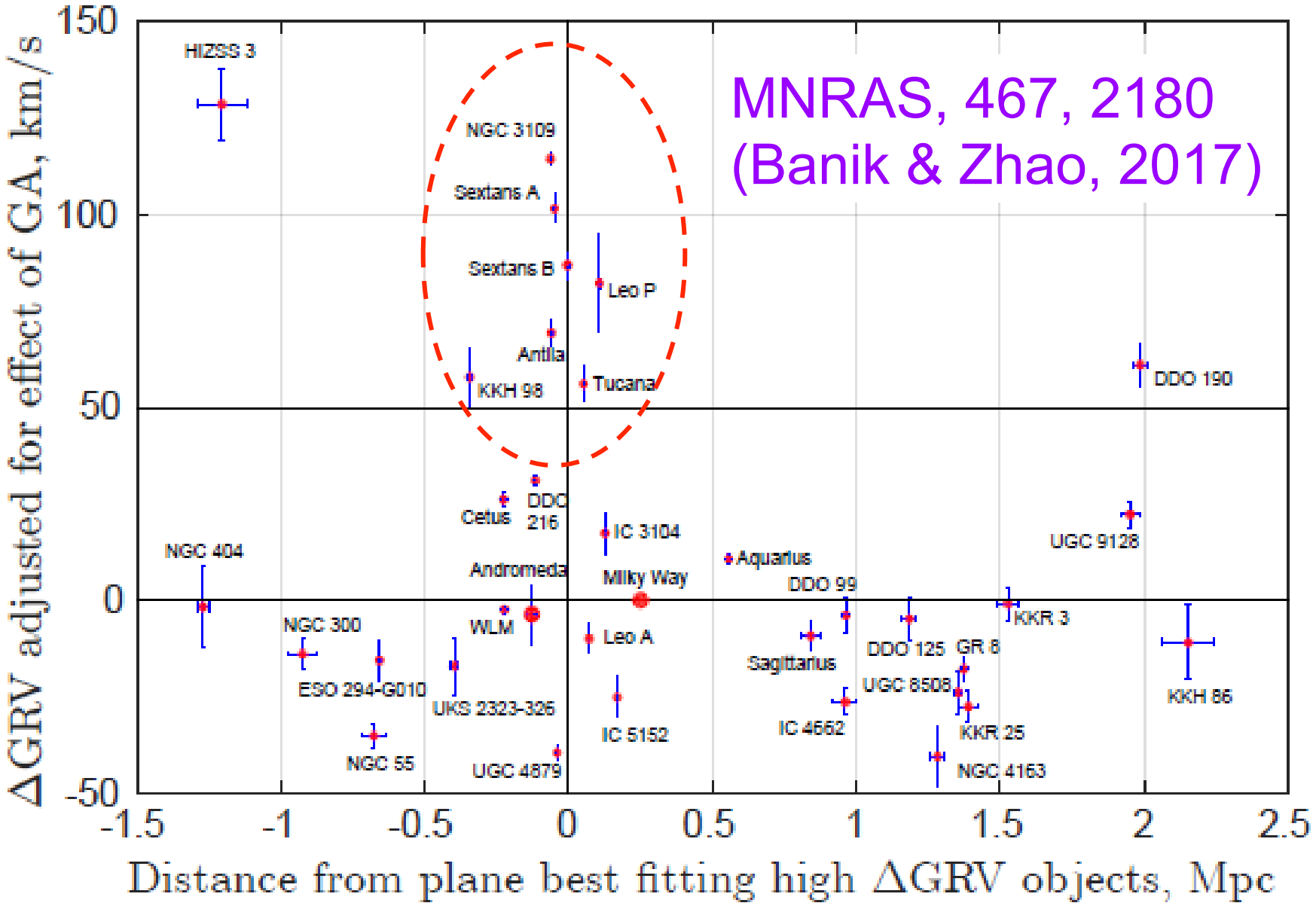
$$F_{12} = \frac{Gm_1m_2}{r_{12}^2}[1 + y^{-1/2}], \; y \equiv \left[\frac{\sqrt{G(m_1 + m_2)a_0}}{r_{12}Qa_0}\right]^2$$

Fly-by 7 Gyrs ago

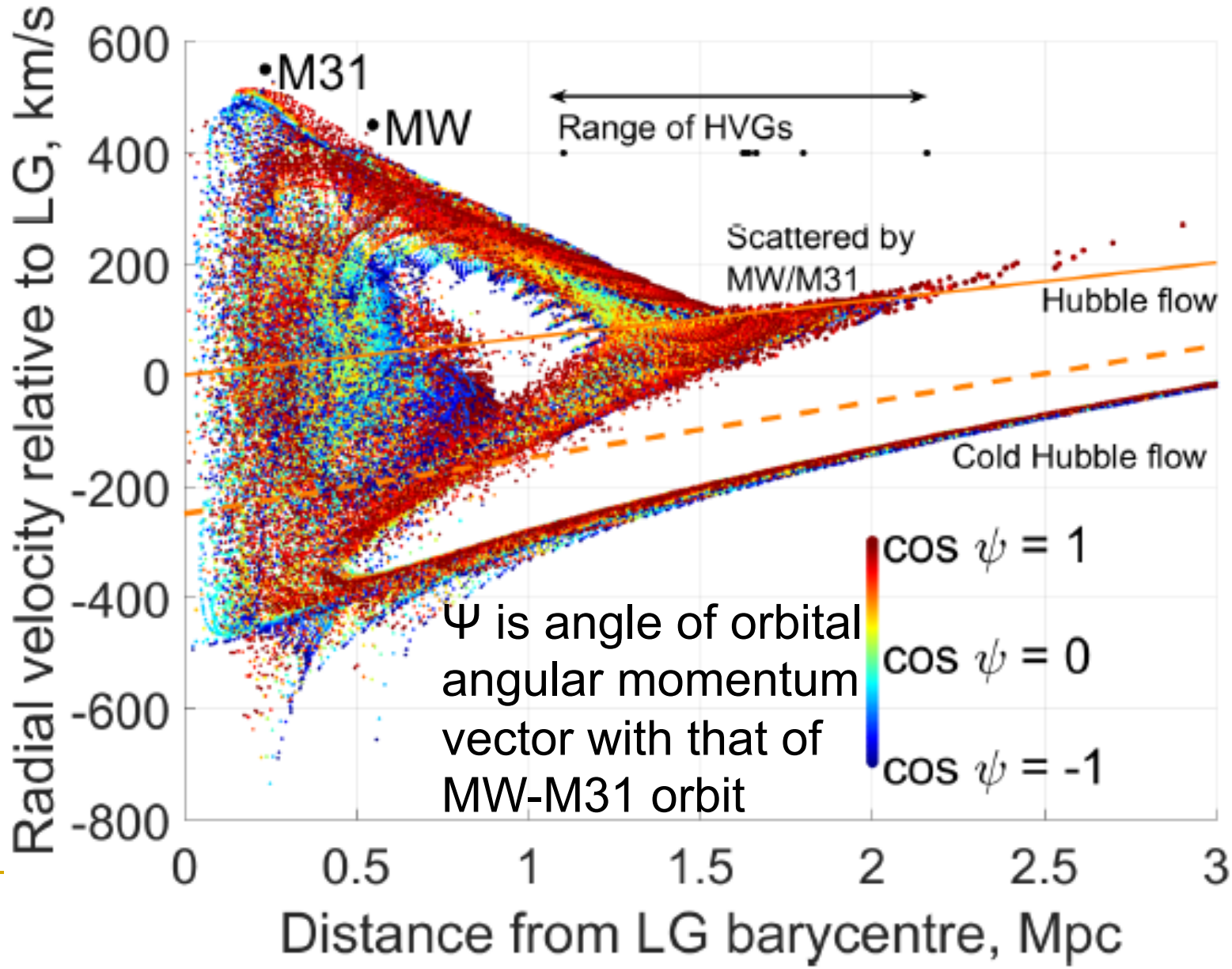


Hubble diagram in ΛCDM

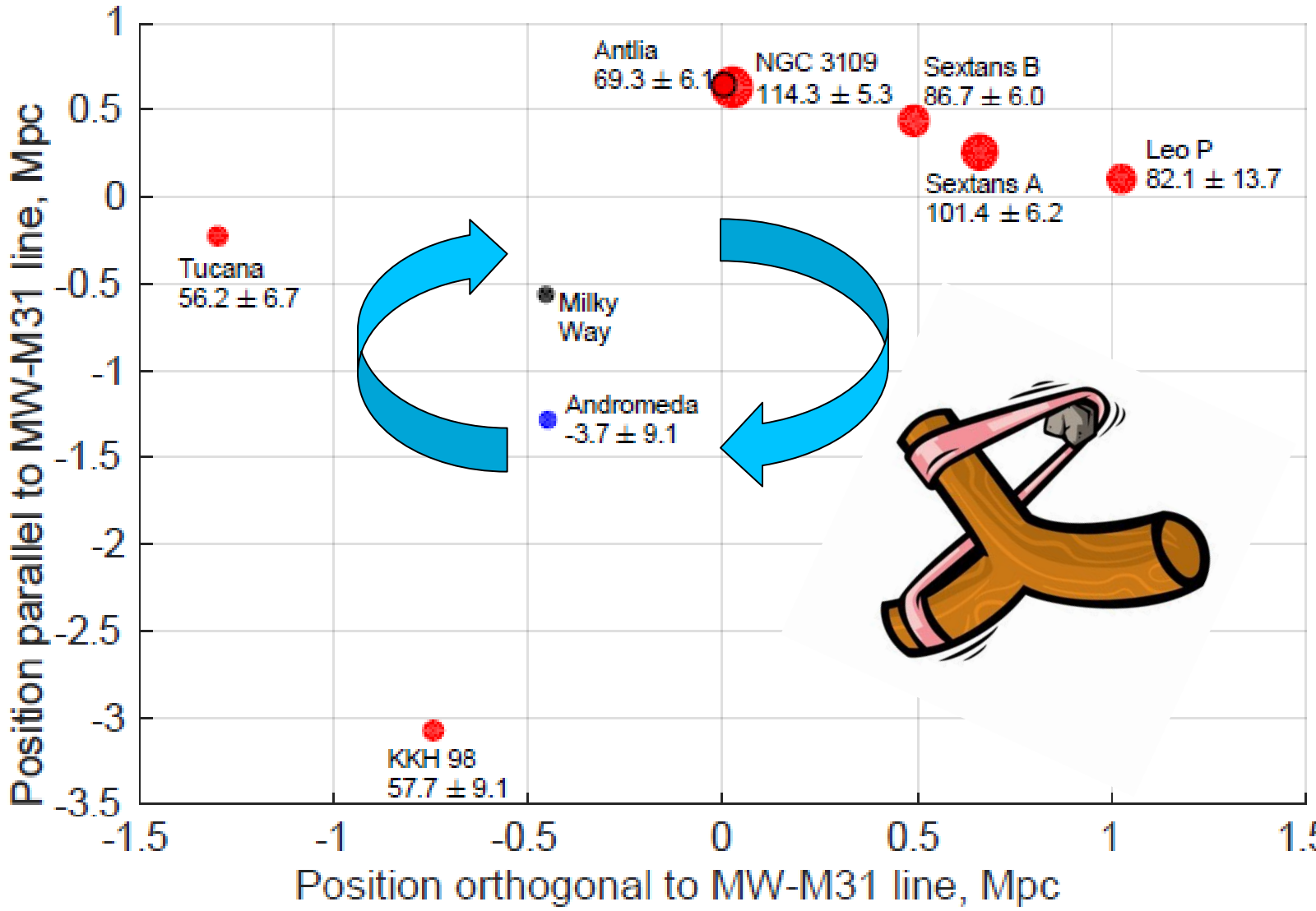



MNRAS, 467, 2180
(Banik & Zhao, 2017)
ΔGRV adjusted for effect of GA, km/s
Distance from plane best fitting high ΔGRV objects, Mpc
150
100
50
0
-50
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
HIZSS 3
NGC 3109
Sextans A
Sextans B
Leo P
Antlia
KKH 98
Tucana
DDO 190
Cetus
DDO 216
IC 3104
NGC 404
Andromeda
Milky Way
Aquarius
DDO 99
UGC 9128
NGC 300
WLM
Leo A
KKR 3
Sagittarius
DDO 125
GR 8
ESO 294-G010
UKS 2323-326
UGC 8508
KKH 86
IC 4662
KKR 25
IC 5152
NGC 55
UGC 4879
NGC 4163

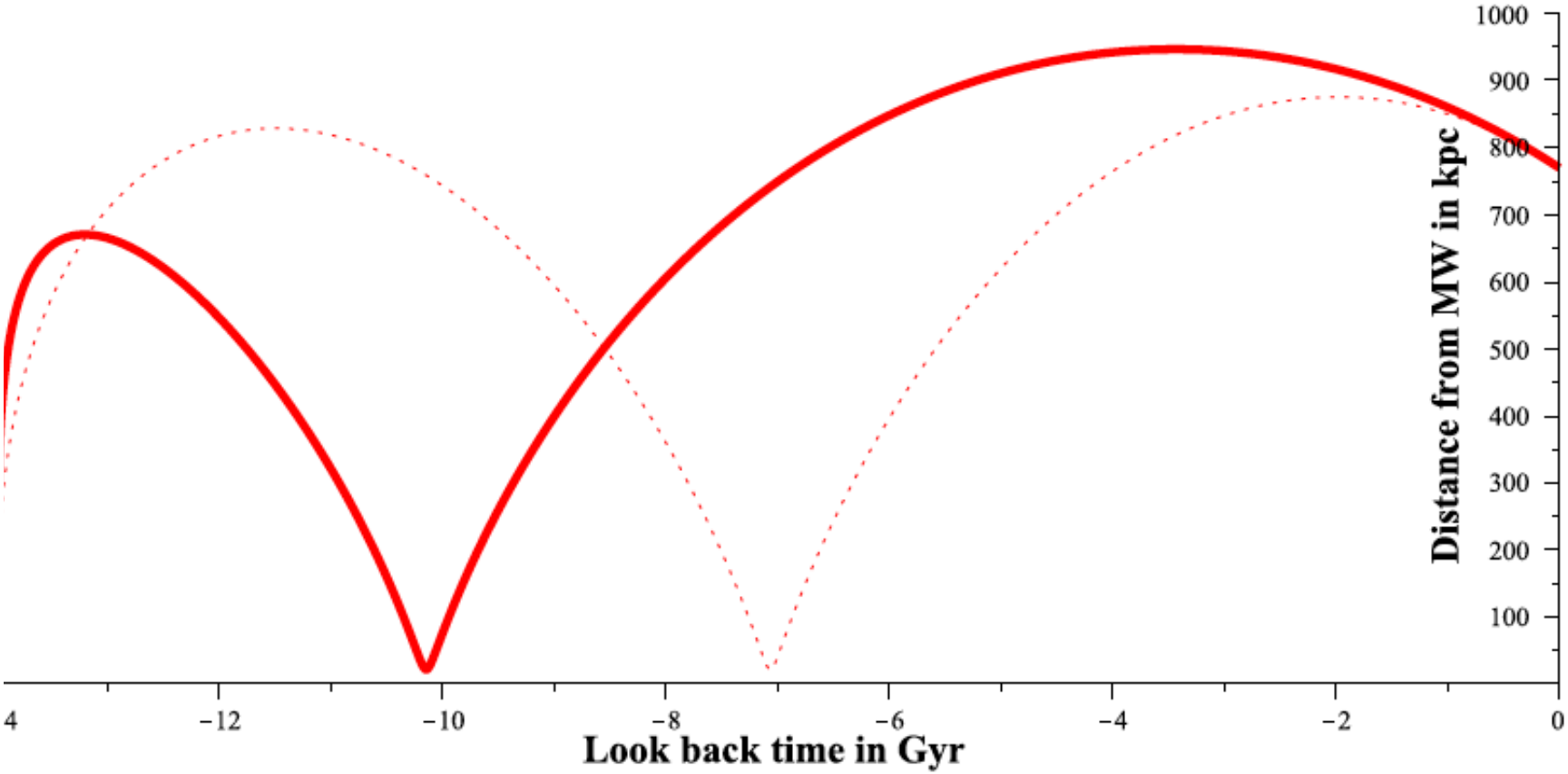
Hubble diagram in MOND



Banik & Zhao 2017



Encounter 7-10 Gyrs ago

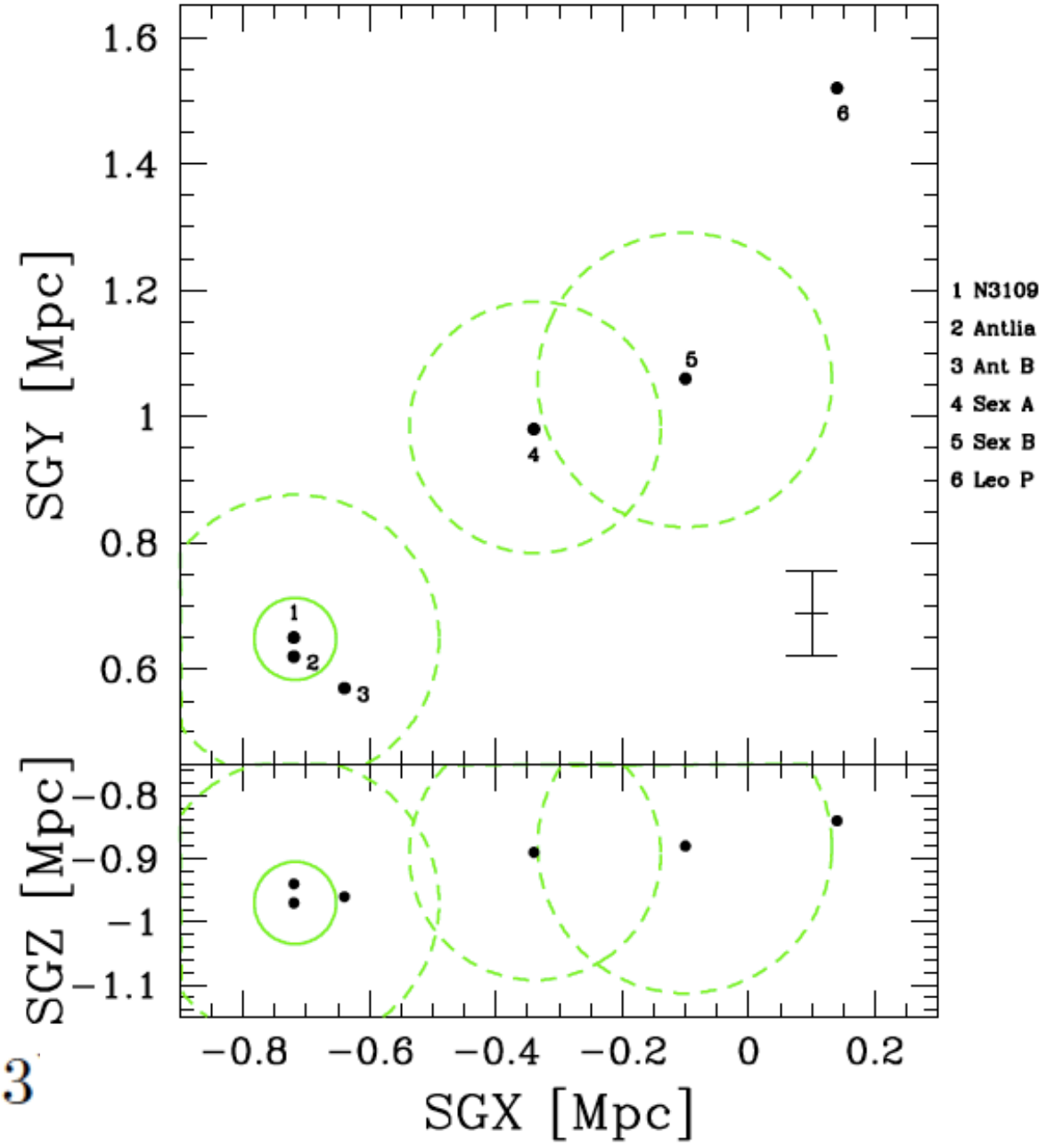


Zhao et al. 2013, A&A Lett

Dwarf line:

Kourkchi
Tully

Bellazzini et al. 2013



Future

- GAIA cleaner data on dwarfs
- External field effect of MOND (Banik et al.)

DM / MG: two sides of a coin?

- DM is relying on baryon effects and new scales
- MG is trying to imitate particles (by weird particles or scalar fields) on Mpc scale.
- Nature is Chemistry,
  - property = emmergent
  - ice = water = vapor.
  - MG falsifiable by SIX effects in Mpc besides Lelli -relation

Conclusion

- Modified Kepler-law predicts M31-MW frictionless fly-by.
  - which must produce thick disk and tidal arms
- Satellites/star clusters born in tidal arm
  - will show large M/L (e.g. LMC, Draco, YHG pal5).

- Need new theories for modified Kepler law:
- CDM dynamical friction produces low M/L baryon-only satellites on polar tidal arms of a merged elliptical.