Reconciling LCDM with the low mass satellites of the Milky Way and M31

Azadeh Fattahi
Institute for Computational Cosmology
Durham University

Durham University

with
Julio Navarro (Victoria)
Carlos Frenk (ICC)
Kyle Oman (Groningen)
Till Sawala (Helsinki)

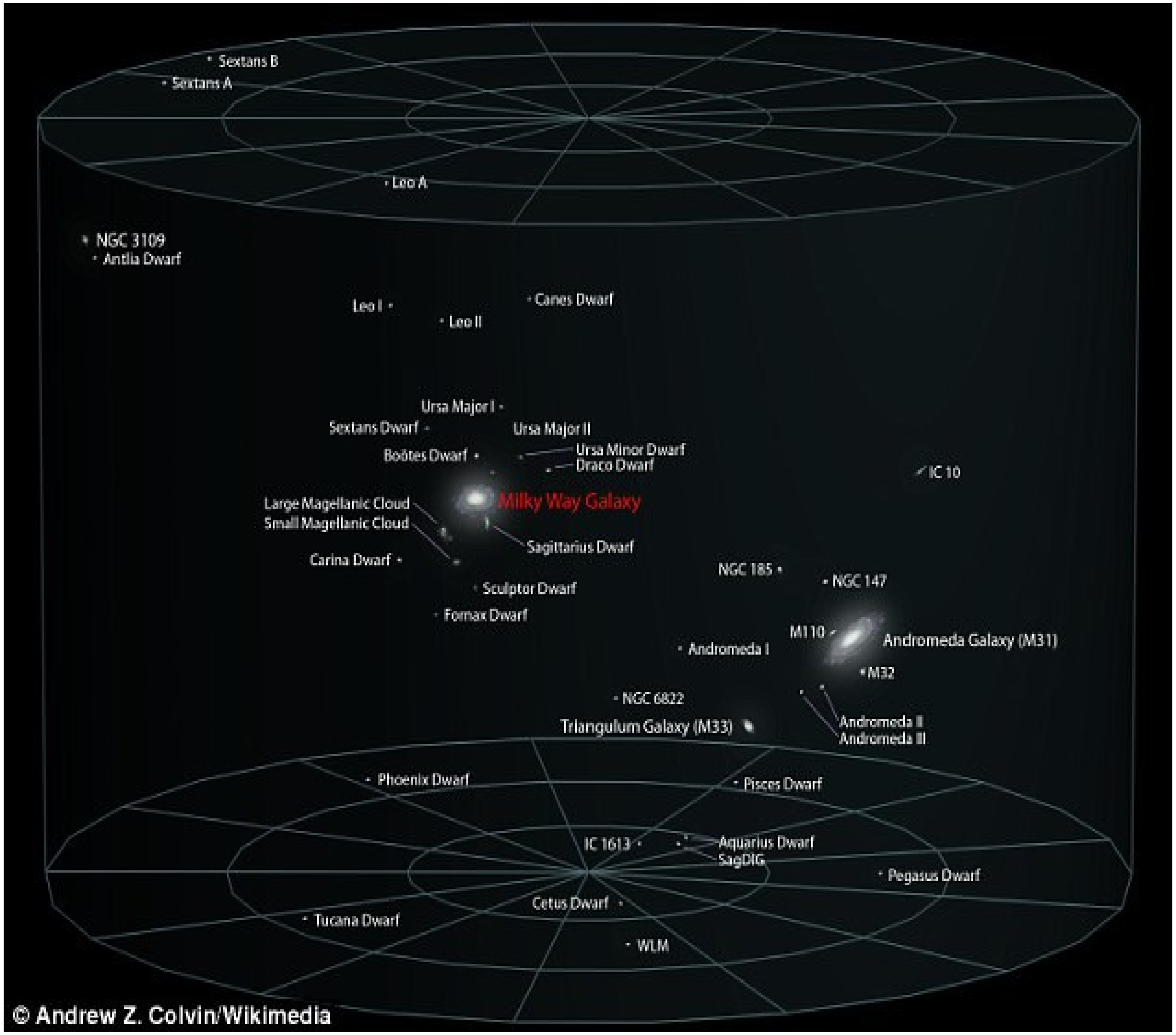
Image: APOSTLE simulation – T. Sawala

Outline
(Fattahi+2016, Fattahi+2018, Sawala+2016)

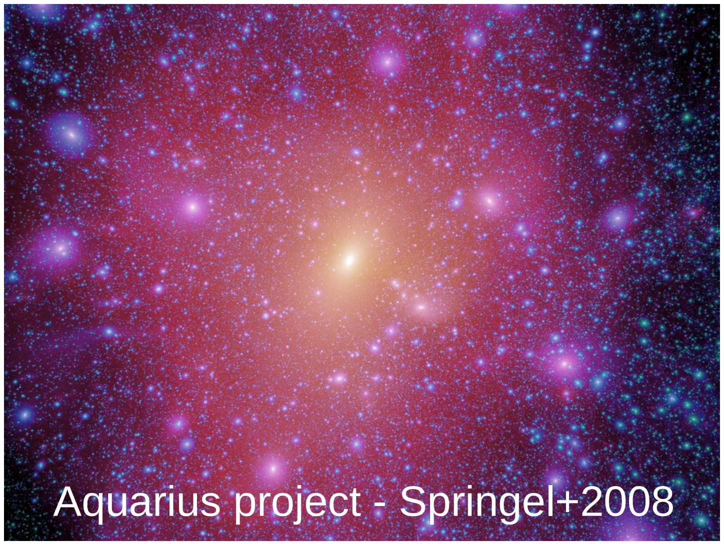
- Small Scale problems of LCDM in the Local Group
- The APOSTLE simulations
- Mass of the Local Group dwarfs and the ‘too-big-to-fail’ problem
- Extremely low mass satellites of the MW and M31
- LG dwarfs and MOND

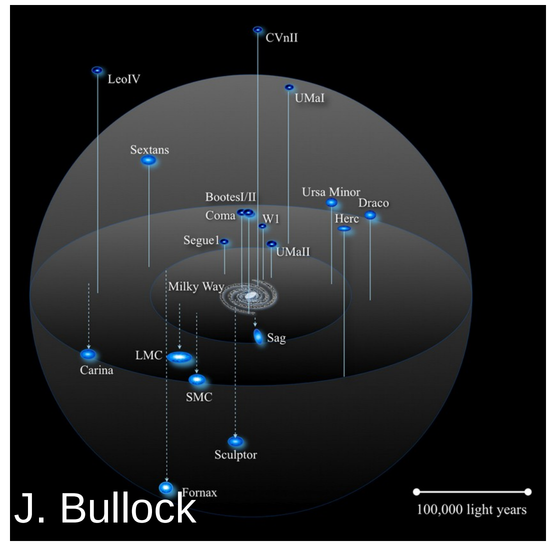
The Local Group of galaxies

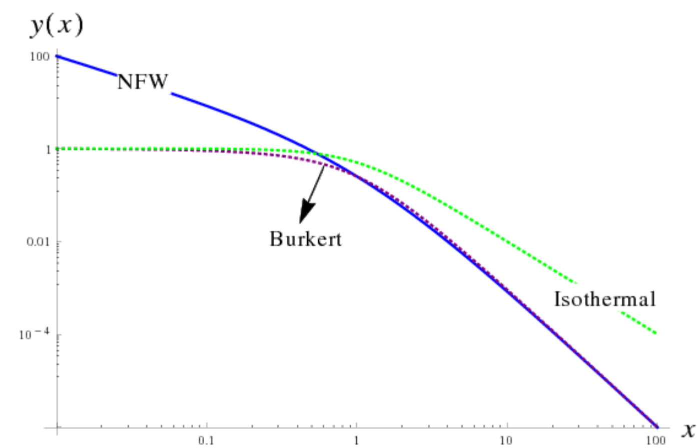
- Two large spiral galaxies, MW and M31, 1 Mpc apart
- ~100 dwarf galaxies
- Nearest large neighbour (~3.5 Mpc)

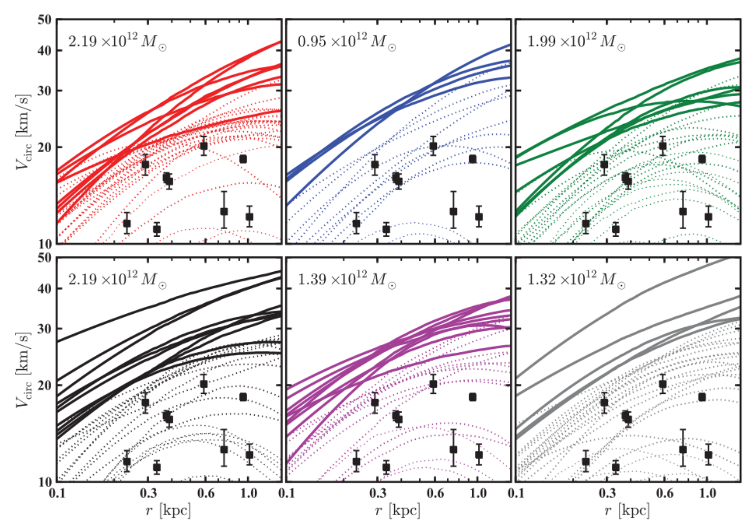


ΛCDM and the small scales problems









- **Missing Satellites**
- **Core-cusp**
- **Too big to fail**
- **...**

Estimating the mass of dwarf spheroidals

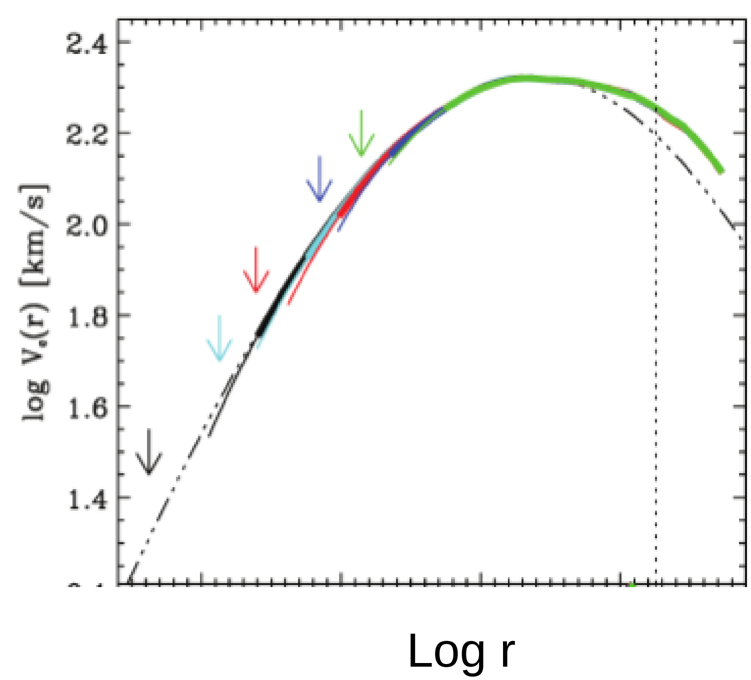
Velocity dispersion

Effective radius

$$M_{1/2} = const. \times \sigma_{los}^2 \times r_{1/2}$$

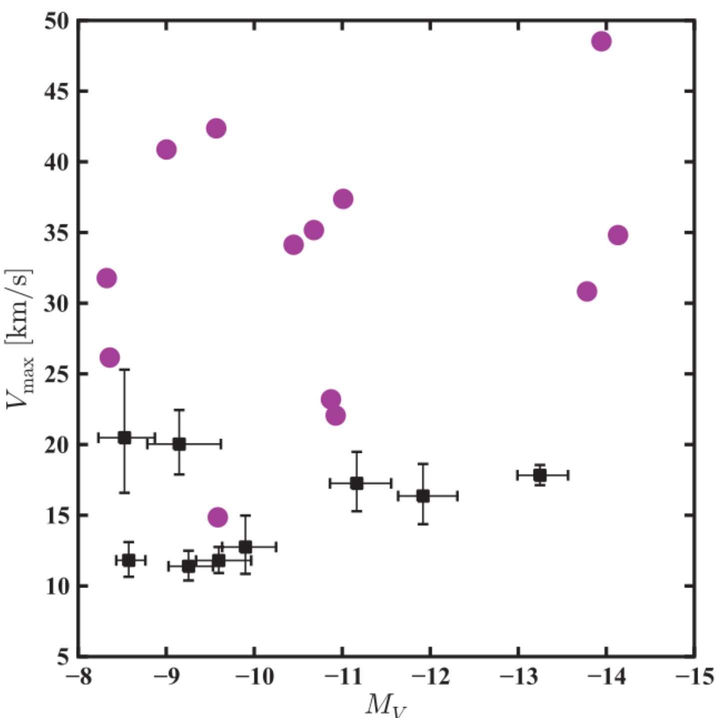
(e.g. Wolf+2010)

$$V_{1/2} = \sqrt{(GM_{1/2}/r_{1/2})} = const. \times \sigma_{los}$$

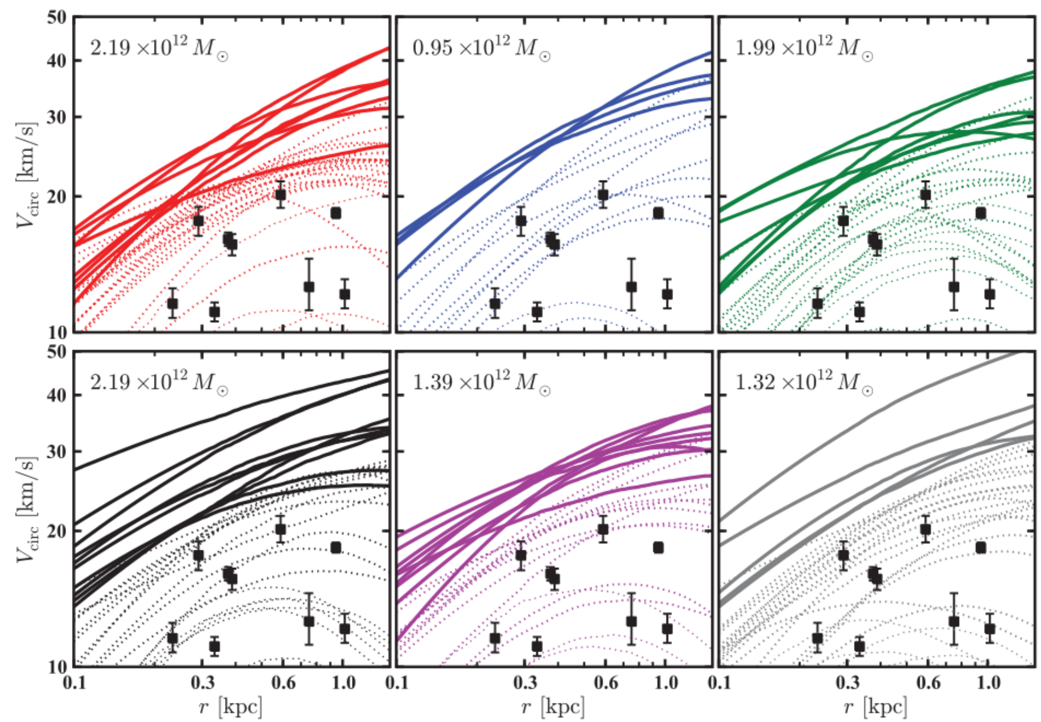


Dwarf galaxies,
and the too-big-to-fail (TBTF) problem

Halo mass



Luminosity

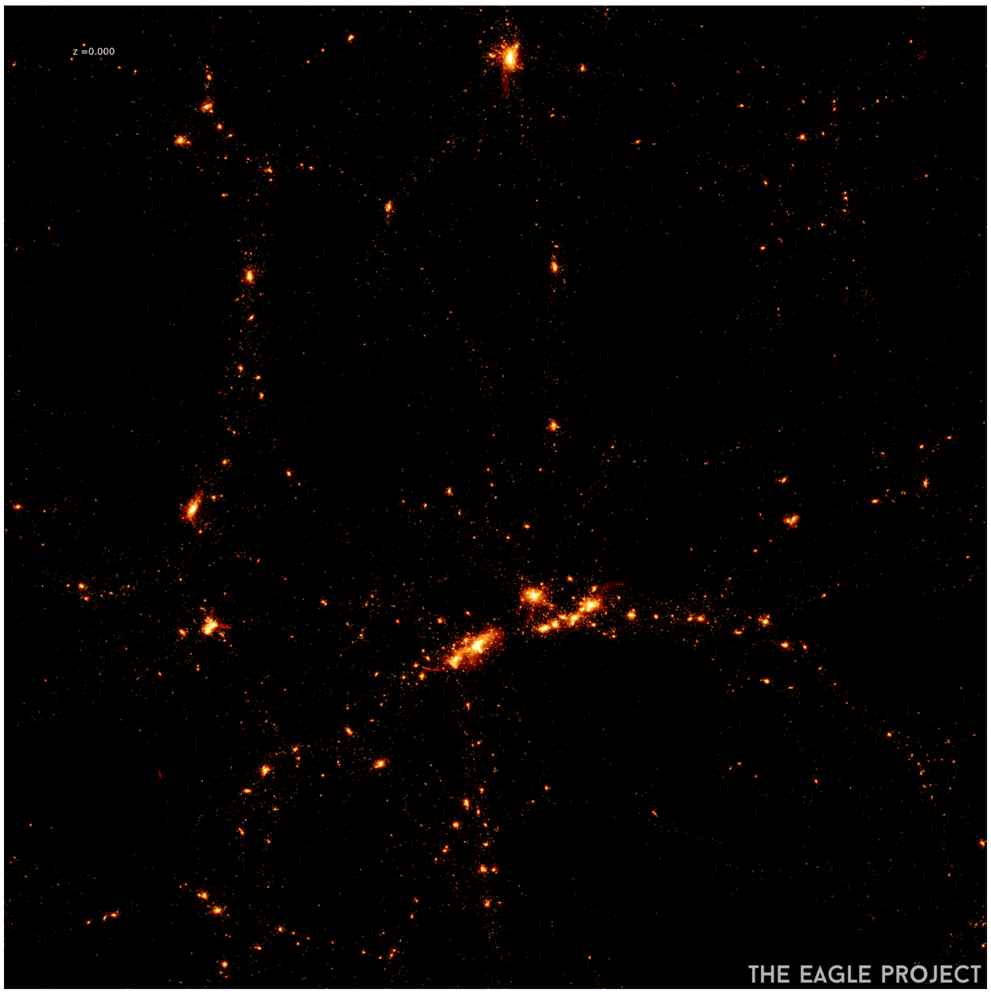


Boylan-Kolchin+2012

Subhalos (satellites) in simulations are more massive than MW satellites ?

EAGLE simulation
Evolution and Assembly of GaLaxies and their Environments

100 cMpc



Physics included:
- Star formation
- Metal dependant cooling
- Stellar evolution
- Feedback from evolving stars and supernova feedback,
- UV radiation background,
- Growth and evolution of SMBH and AGN feedback

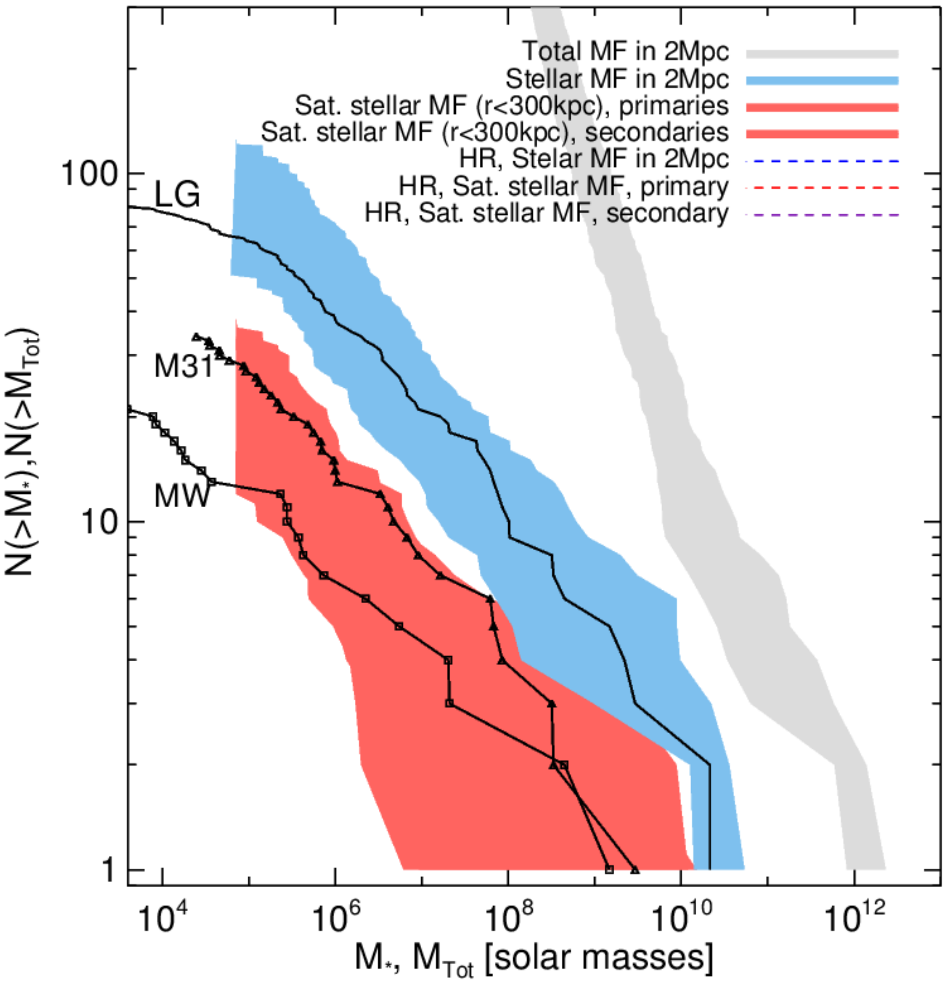
Box size	Particle resolution
100 cMpc	$1.8\times10^{6} M_{sun}$

APOSTLE project
A Project Of Simulating The Local Environment

Zoom-in hydrodynamical simulations of **12 Local Group like environments** using **EAGLE** galaxy formation model

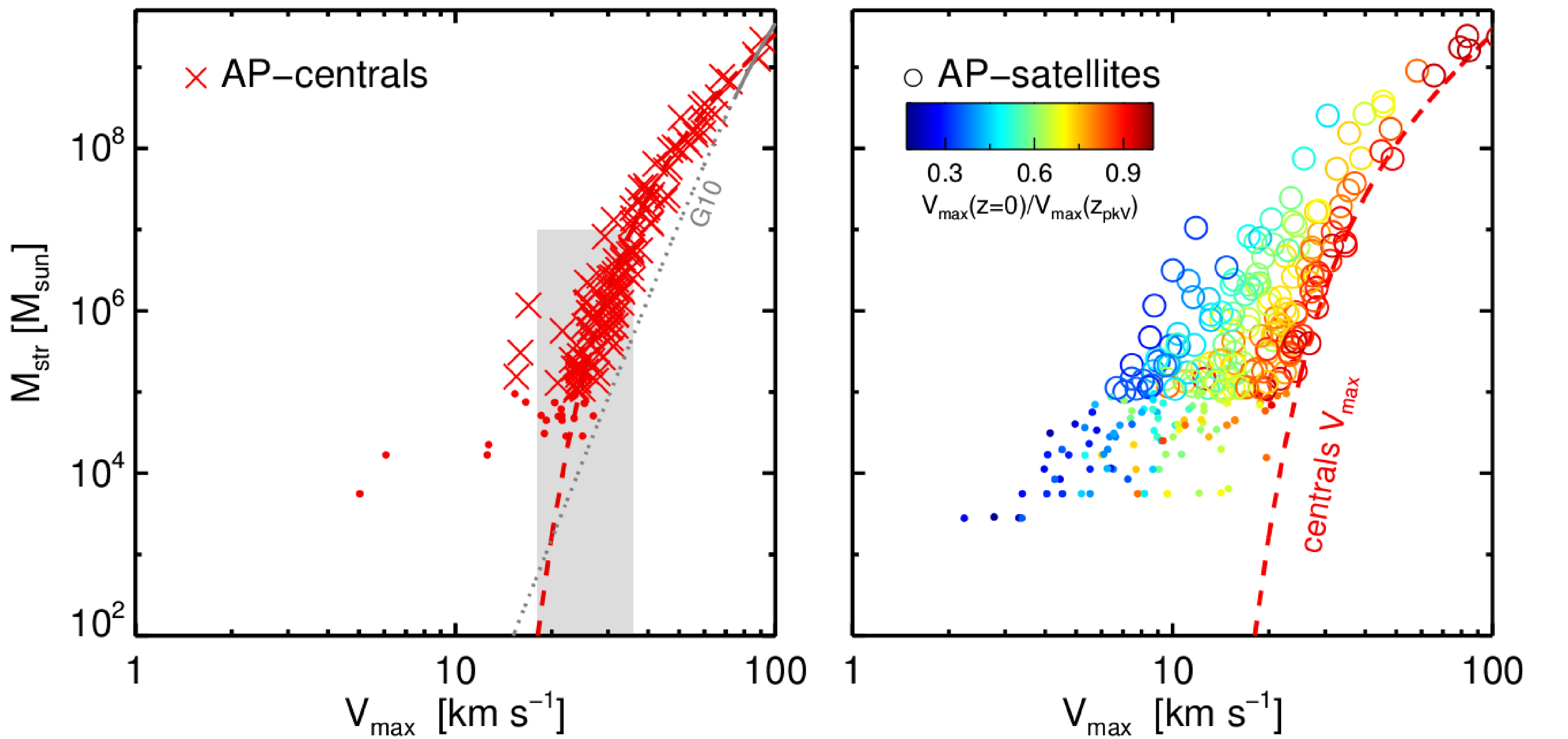
LG like:
- Separation of MW-M31
- Relative radial and tangential velocity of MW-M31
- Recession velocity of surrounding substructures (dwarfs)
- Mass of MW+M31

Resolution	$m_{p,gas}(solar\,masses)$
L1 (5 LGs)	10^4
L2 (12 LGs)	10^5
L3 (12 LGs)	10^6



Sawala+2016, Fattahi+2016a

Stellar mass-halo mass relation



(~halo mass)

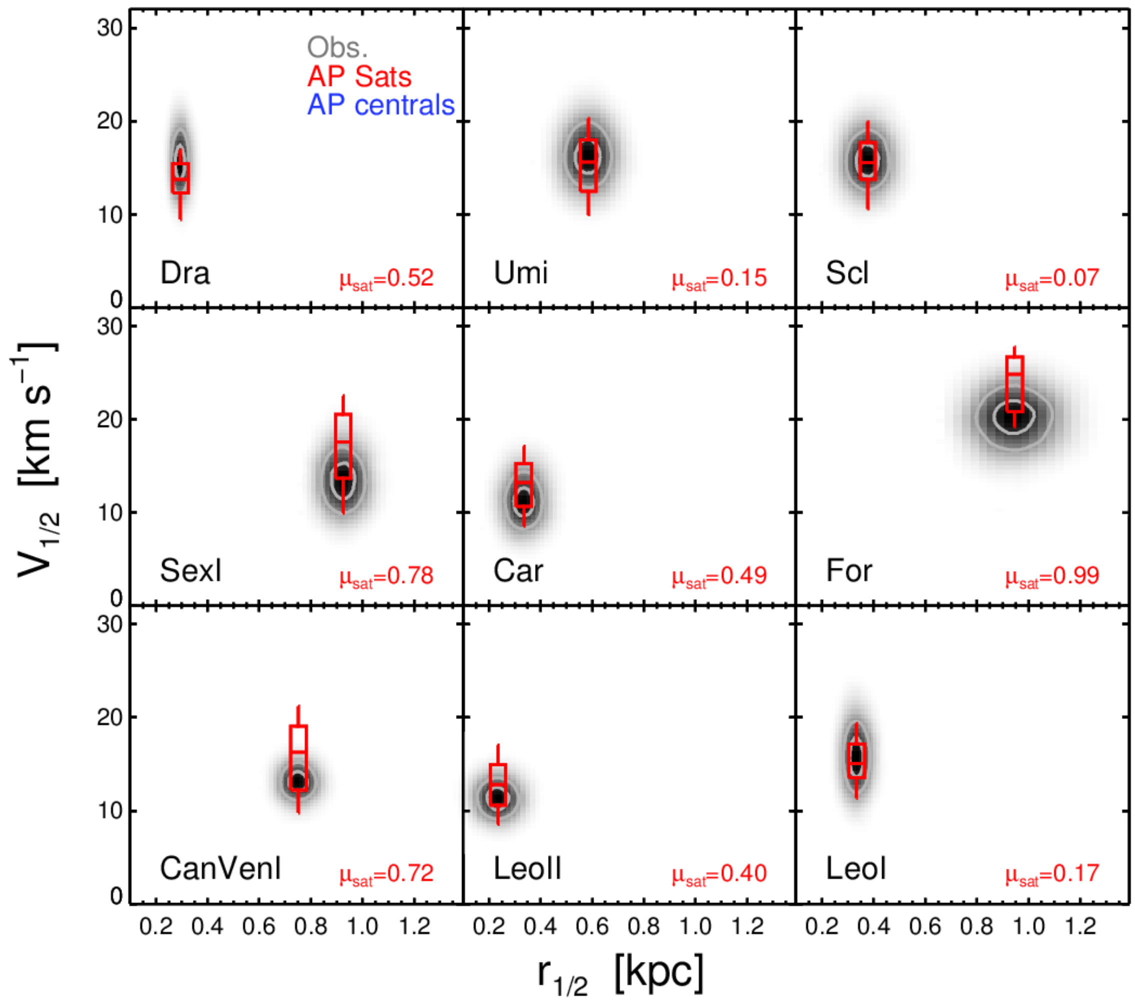
Fattahi+2018

Are observations and simulations consistent?

Mass (i.e. $V_{1/2}$) of the classical satellites of the MW compared to APOSTLE resultes

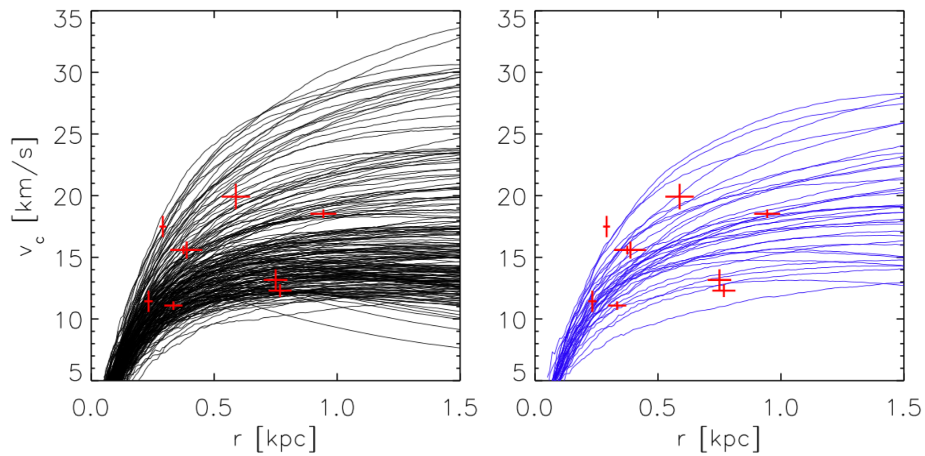
satellites are matched by stellar mass

Masses are measured within similar radii

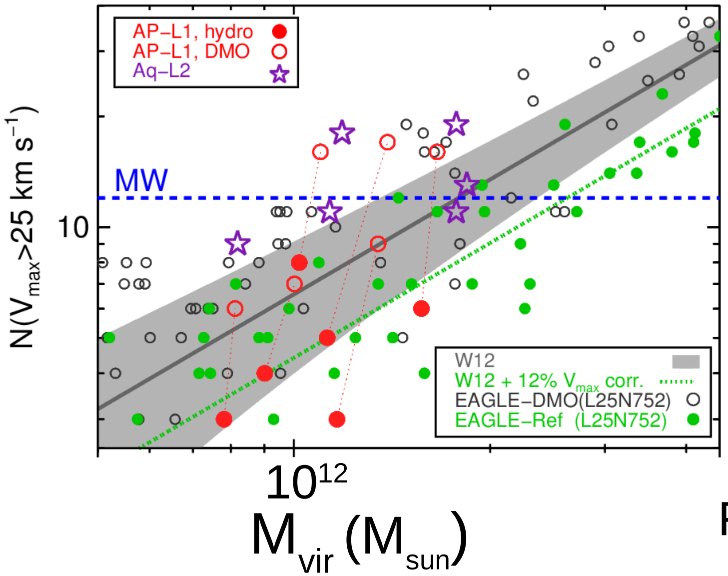


Too-big-to-fail and the number of massive subhalos

Sawala+2016



Number of massive subhalos is reduced in hydrodynamical simulations compared to DMO simulations



Number of massive subhalos is dependent on the mass of the MW

Fattahi+2016b

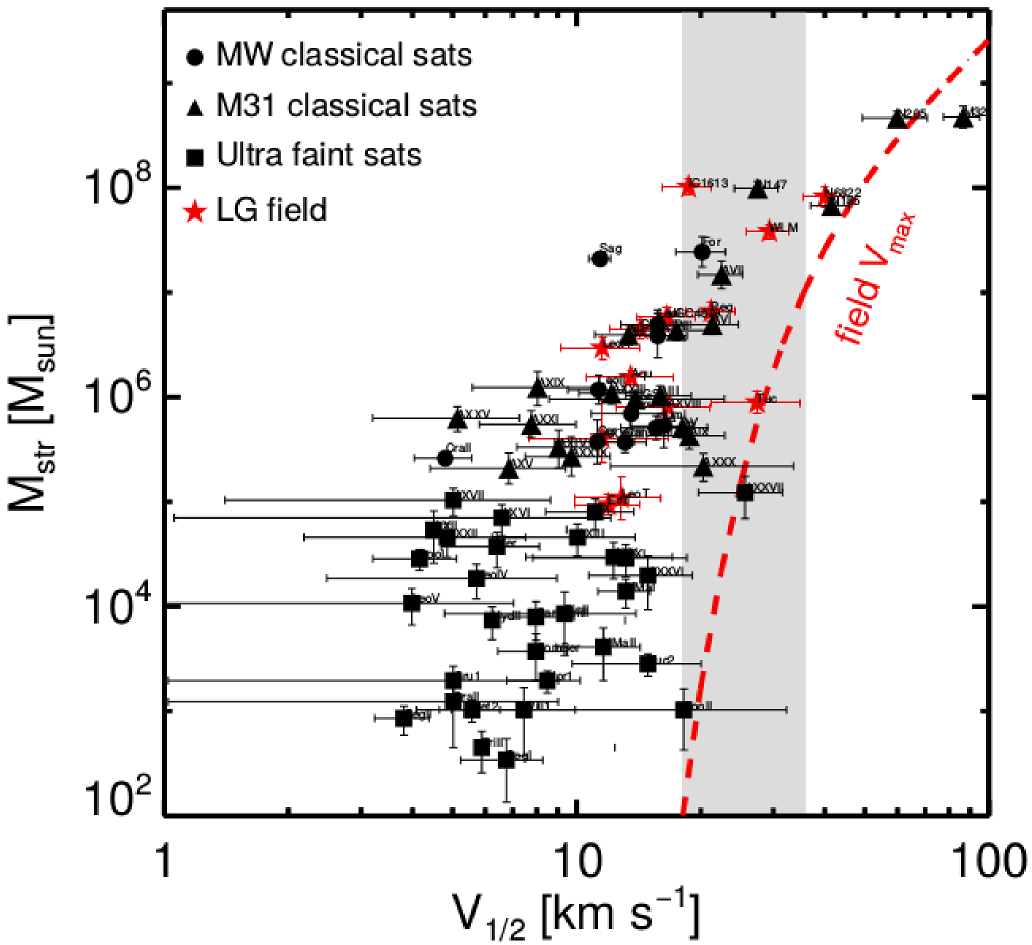
Take away points (1)

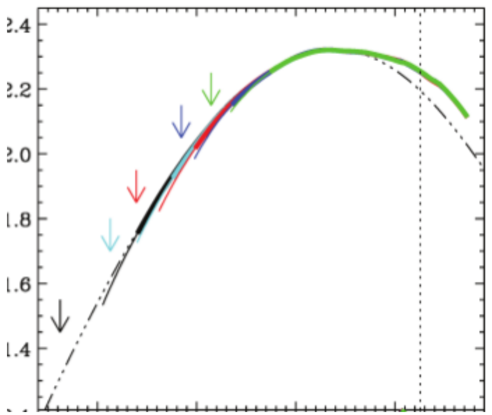
Is the too-big-to-fail problem resolved for classical satellites of the MW?

- Simulations are consistent with observation when we compare the mass at the half-light radii
- Number of massive subhalos are lower in hydrodynamical simulations
- Mass of the MW should be less than 2.5e12 M_{sun}

Stellar mass – $V_{1/2}$ of LG dwarfs

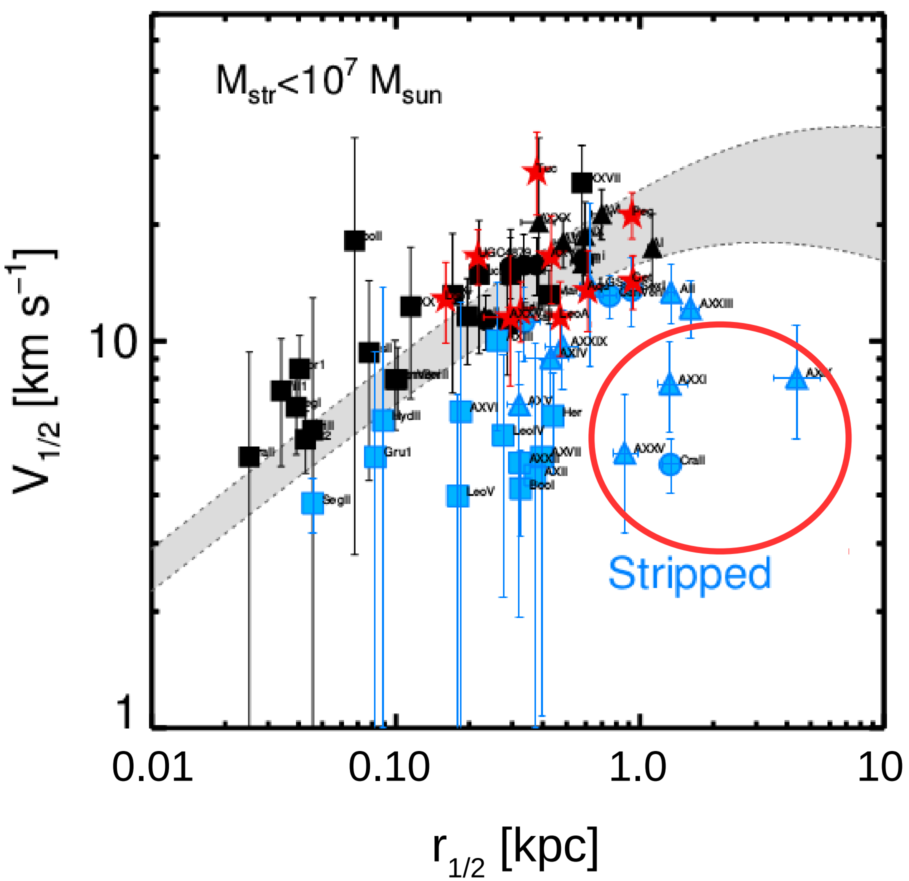
All LG dwarfs with velocity dispersion measurements

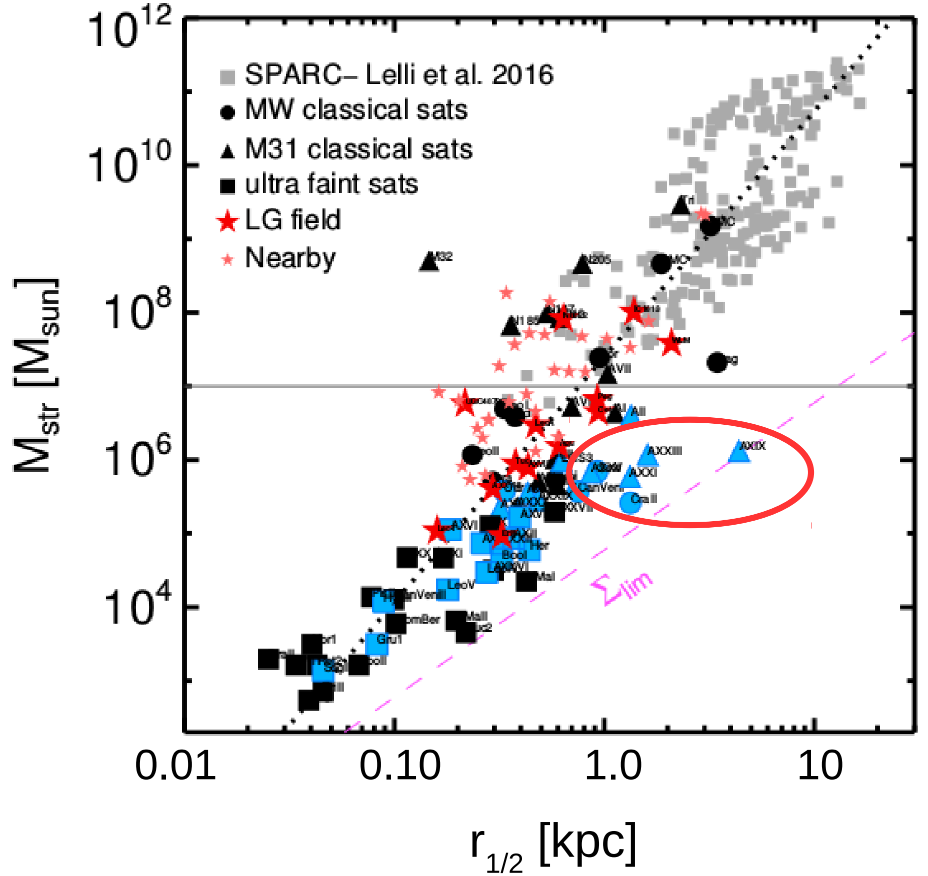




Log r

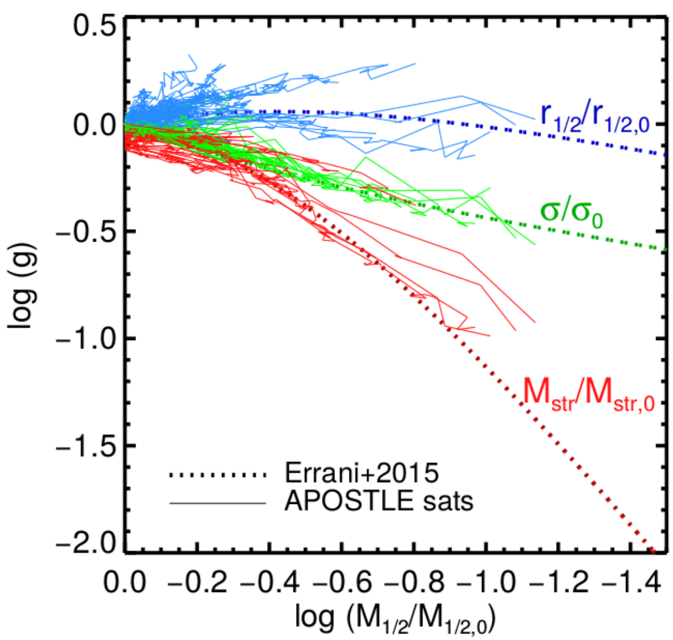
Tidal stripping of satellites



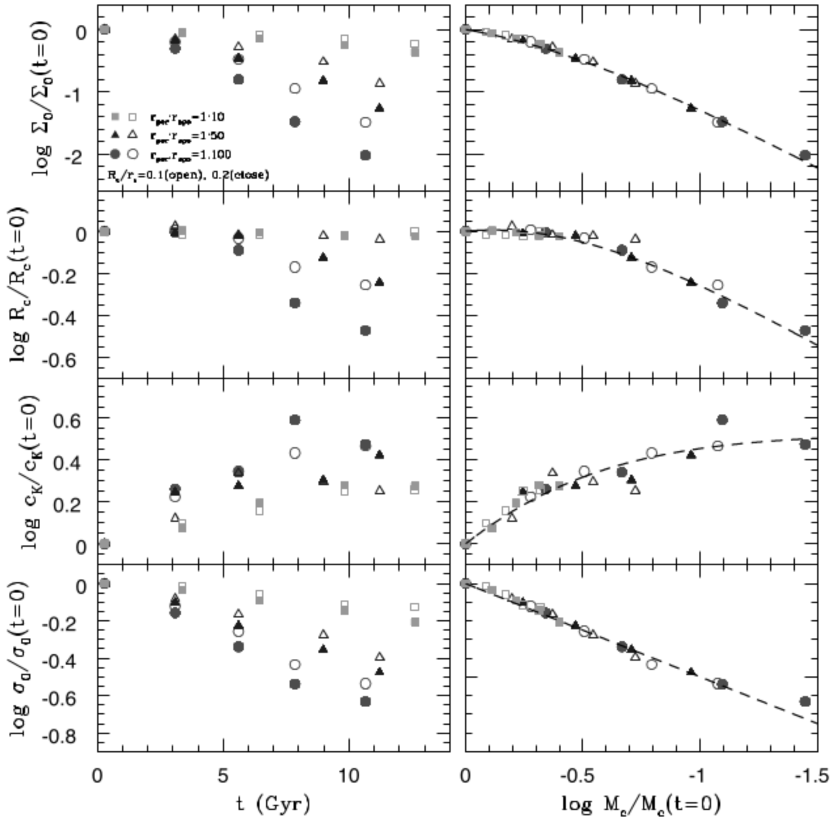


Tidal stripping of dSph galaxies

For spheroidal systems embeded in cuspy DM halos:
Change in structural parameters can be uniqly expressed in terms of total mass loss within the half-stellar mass radius

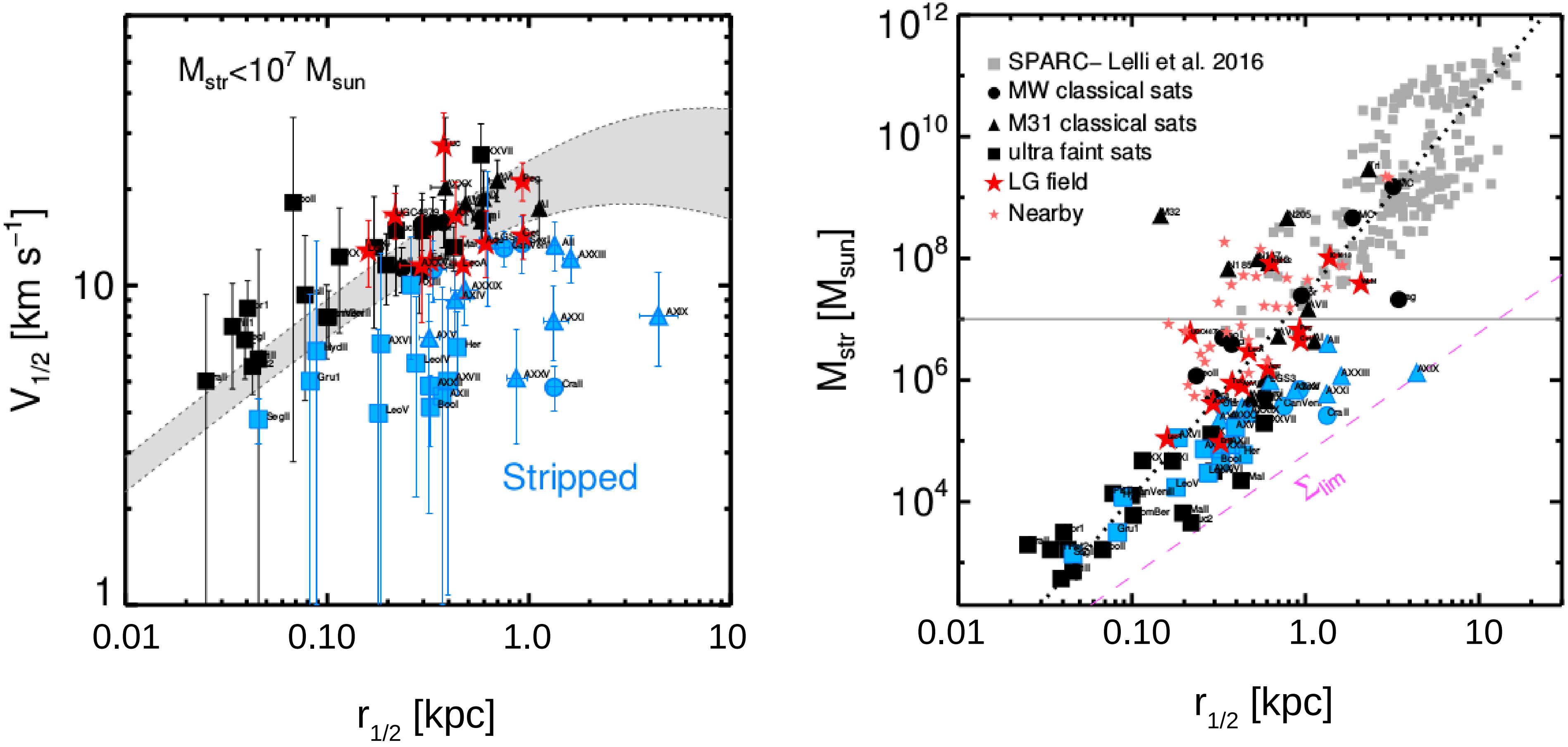


Fattahi+2018



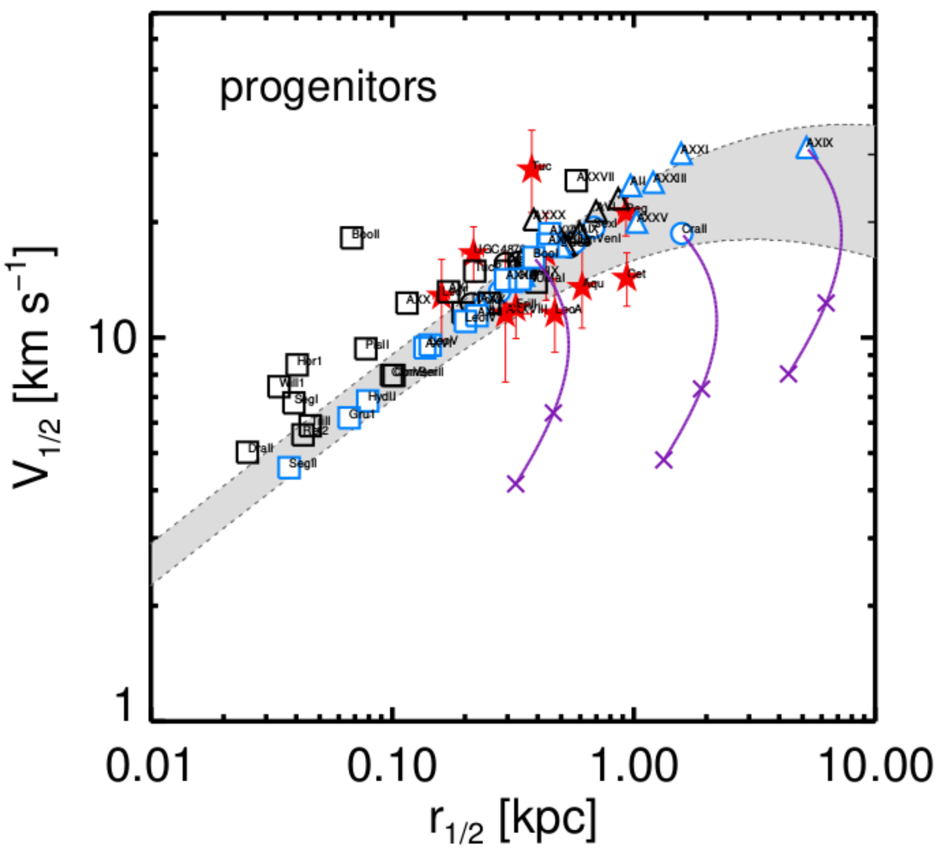
Penarrubia+2008; Errani+2015

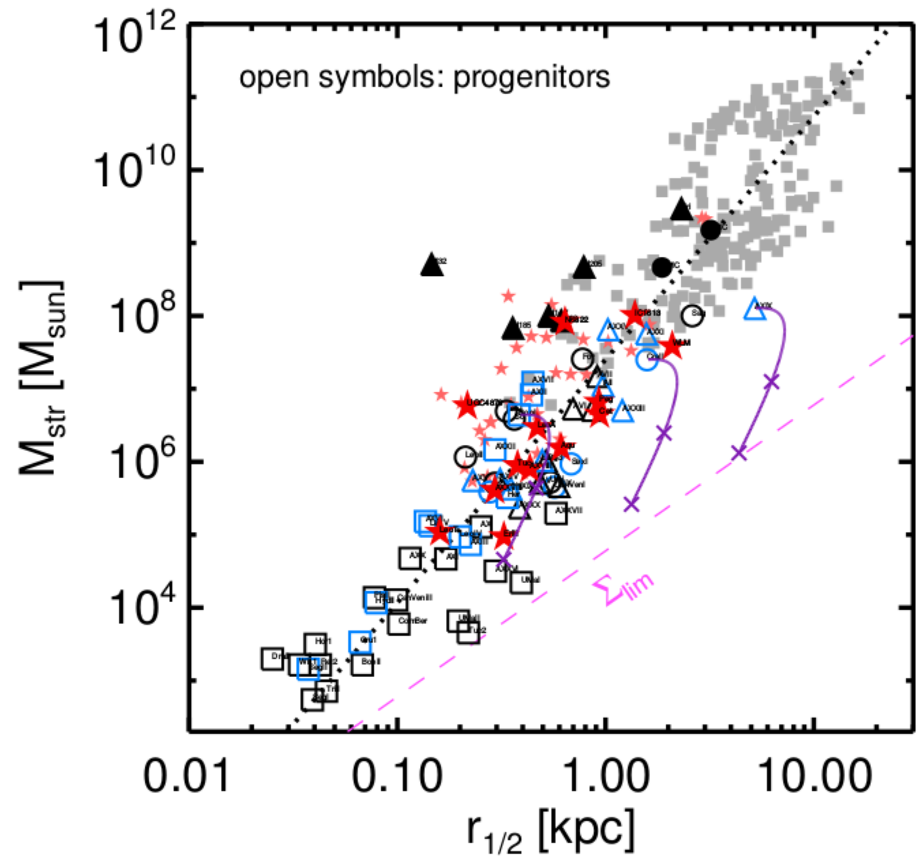
Tidal stripping of satellites



Tidal stripping of satellites

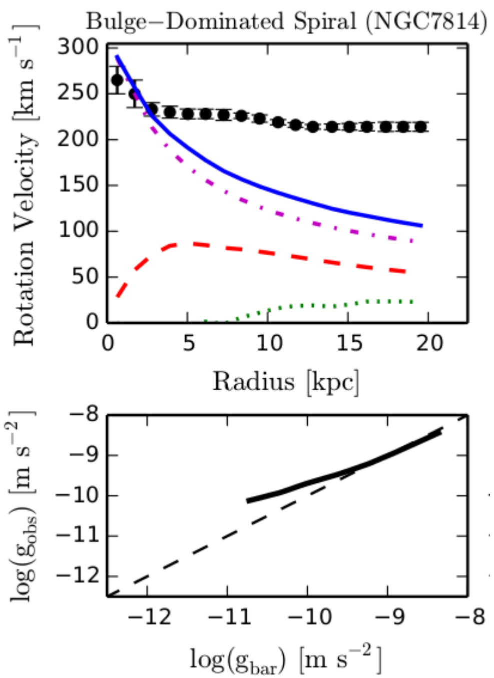
the progenitors

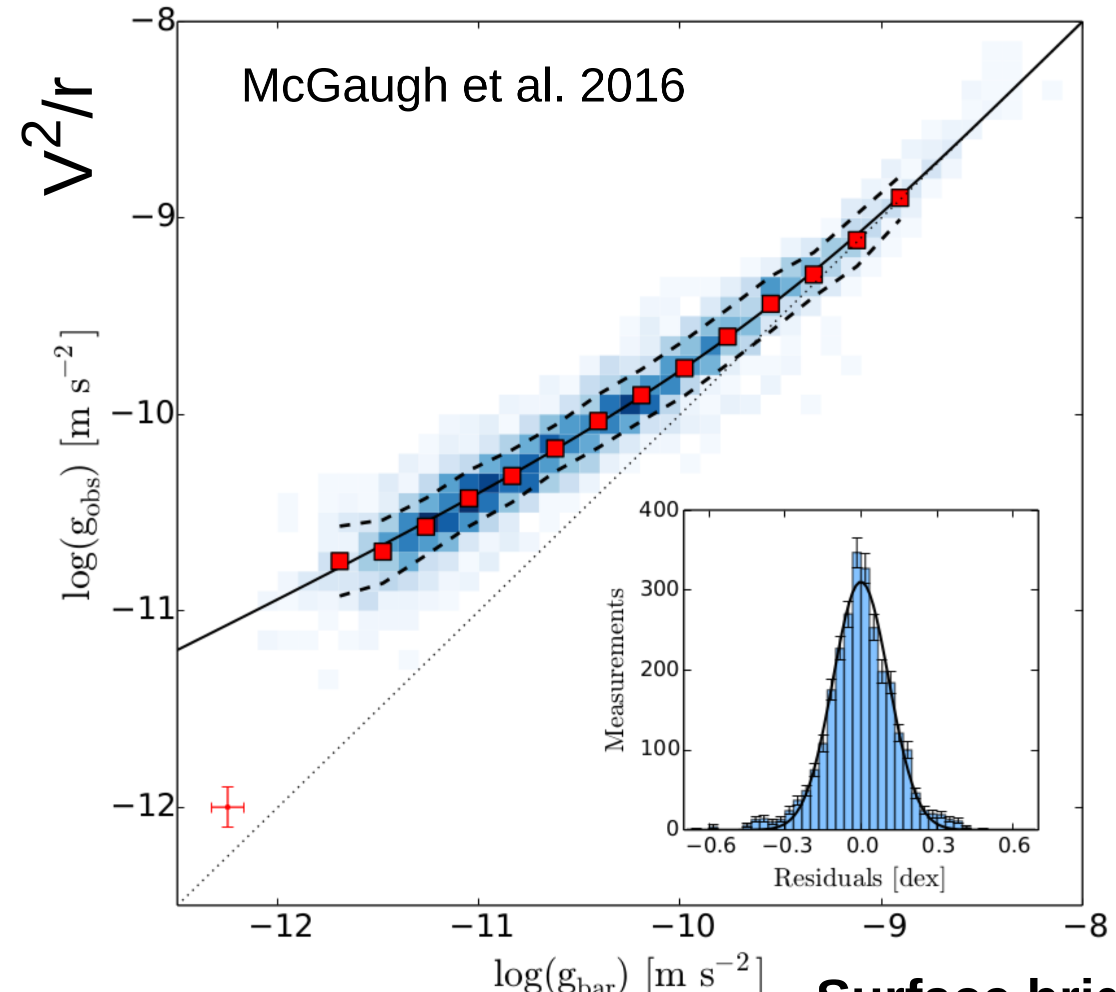




Breaking news: according to Gaia DR2, pericentre of Crater 2 orbit is relatively small ~ 20kpc +/- 10

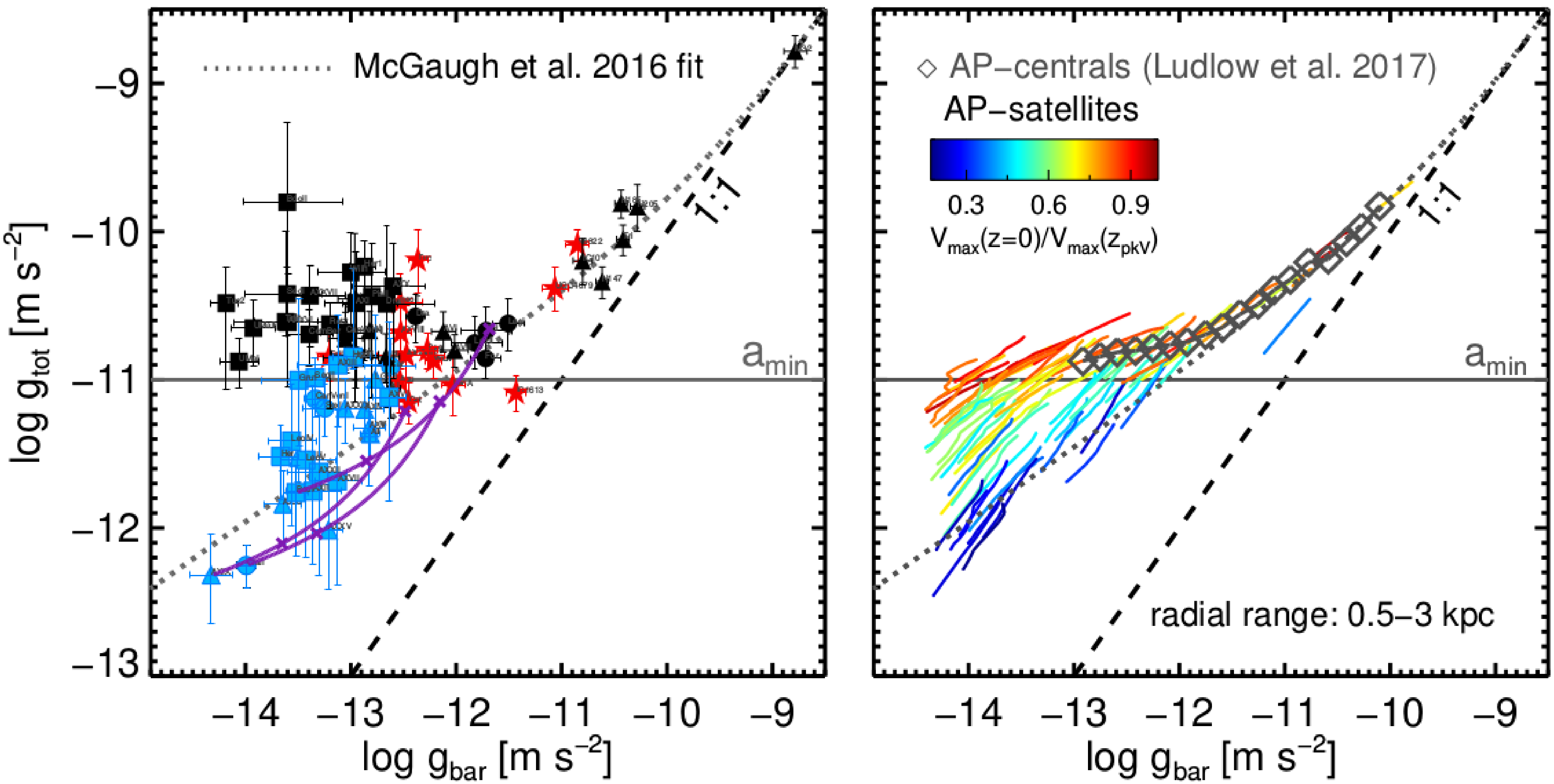
Mass discrepancy-acceleration relation (MDAR)





Surface brightness

MDAR and tidal stripping



Take away points (2)

- The steep shape of the stellar mass-halo mass in APOSTLE predicts that tidal stripping must play an important role in the evolution of dwarf satellites galaxies. The extreme cases include Cra 2, And XIX, and And XXV who must have lost 99% of their stellar mass in the past.

- The same level of stripping that explains the low mass of dwarf satellites, can explain their deviations from the stellar mass-size, and metallicity-velocity dispersion relations.

- Tidal stripping naturally explains the scatter in the MDAR relation of dwarf satellites.