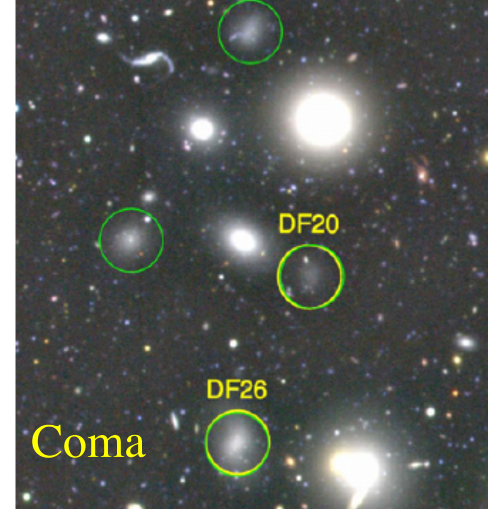
COLLÈGE DE FRANCE
1530

Chaire Galaxies et Cosmologie



Dwarf Galaxies and Dark Matter as a function of Redshift and Environment

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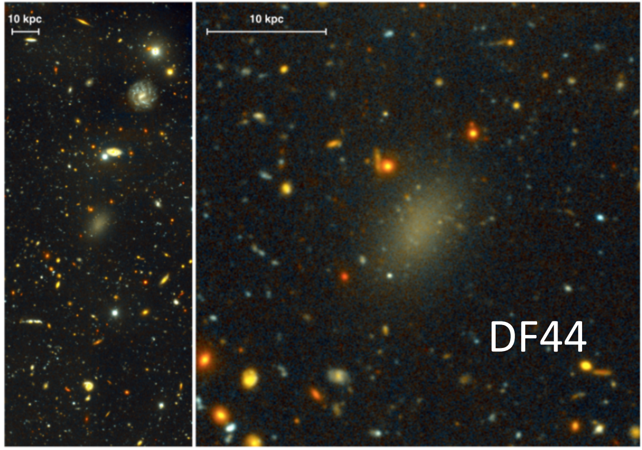
Outline



Van Dokkum et al 2016

➔Scaling laws : Giant and dwarfs, HSB, LSB

➔Constant surface density of dark matter

➔UDG: Ultra-Diffuse Dwarfs (Dragonfly, Subaru, etc)

➔Influence of clusters and environment?

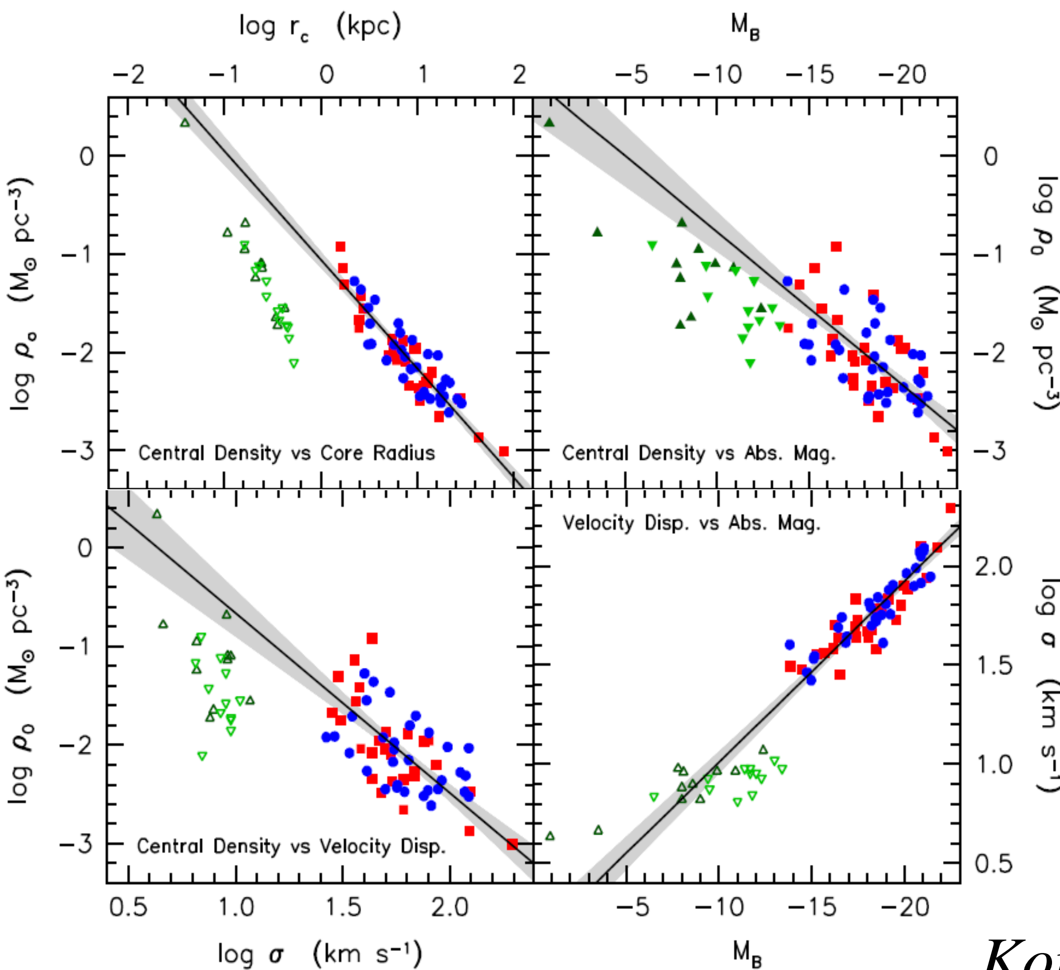
➔Evolution in redshift

Scaling laws including dwarfs

DM parameters from a rotation curve decomposition, or Jeans equations

ITS Isothermal sphere $\sigma^2 = \left(4\pi G \rho_o r_c^2\right)/9$ $V_c(r) \sim r \quad r < r_c$

$V_c = cst \quad r > r_c$



Green: dSph △ dIm ▽

Red & blue Sc-Im

Blue Isothermal sphere halos

Red pseudo-isothermal sphere

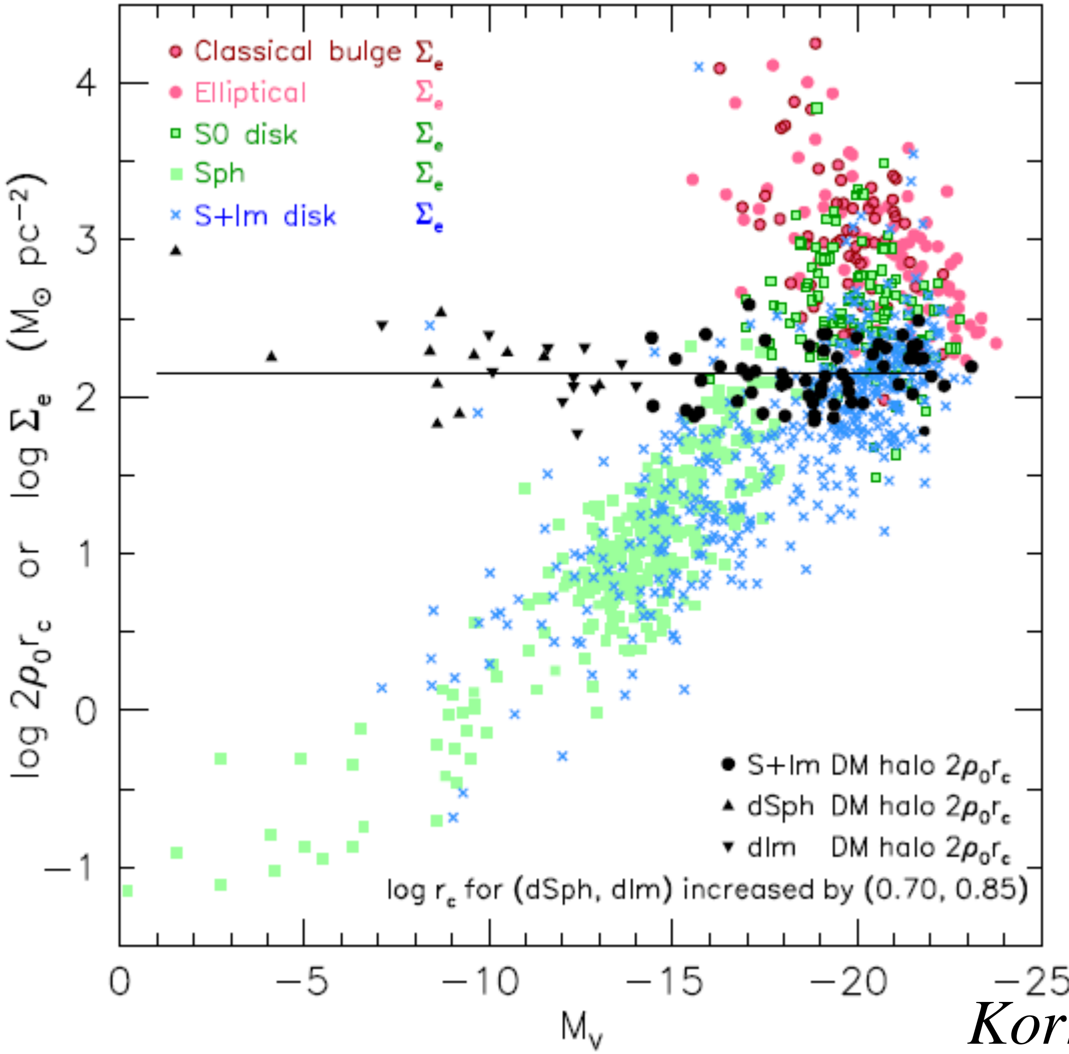
➔Possible to drive back dSph and dIM on the curve assuming baryon loss

$\rho_o \sim 1/r_c$

Kormendy & Freeman 2016

Constant surface density for DM?

If the dwarfs are driven back on the curve (M_B, r_c, σ)



However dwarfs are multiple

What about UDG?

Interesting to see that the stellar surface density Σ* changes behaviour from non-dominant to dominant

➔Small systems brighter

Kormendy & Freeman 2016

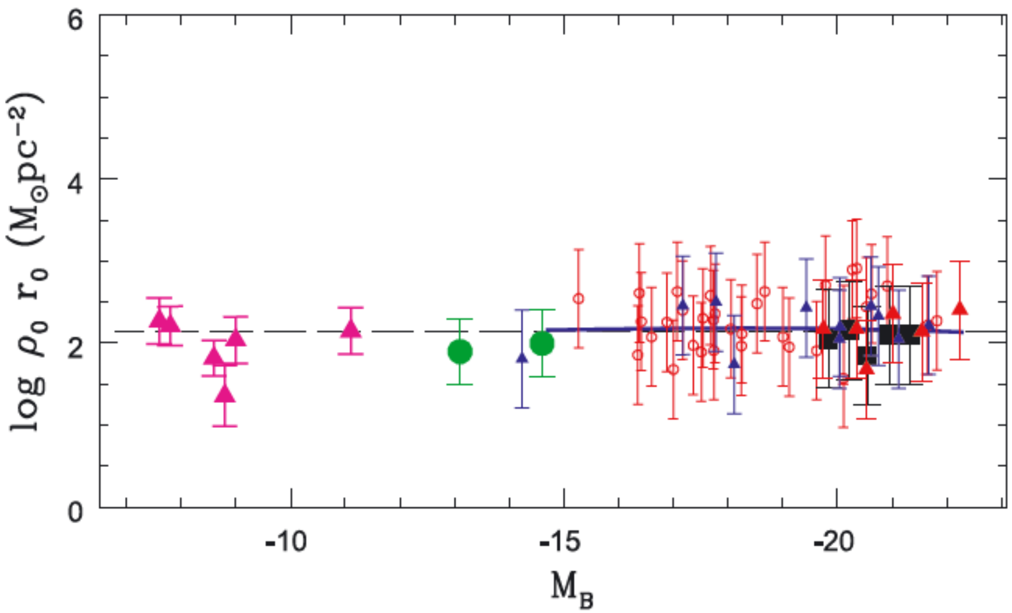
Constant DM surface density

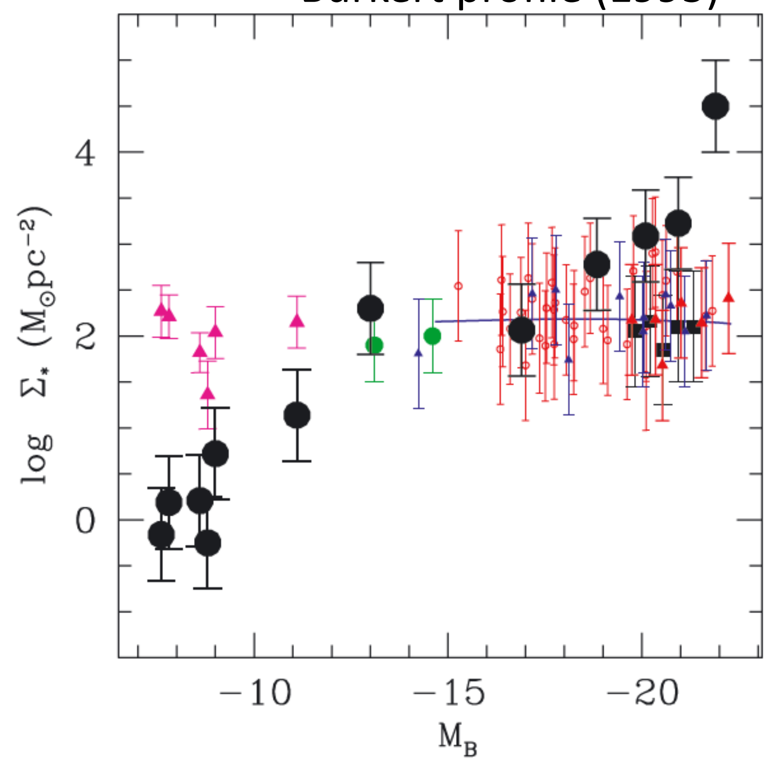
1000 spiral + dwarf galaxies *Donato et al 2009*

Sc, Sm, dIm, weak lensing..

$$\rho(r) = \frac{\rho_0 \, r_0^3}{(r + r_0)\left(r^2 + r_0^2\right)}$$

Burkert profile (1995)





Σ_{DM}~150 Mo/pc²

Contrary to the stellar surface density which increases with M

What are UDG (Ultra Diffuse Galaxies)

Very low luminosities, in average 6 10^7 Lo
But sizes r_{eff} =1.5-4.6 kpc, comparable to MW, L* sizes

Very low surface brightness $24 < \mu < 27$ mag/arcsec^2
Sersic n=1 (not n=4)

Found everywhere, but much more abundant in clusters
(Koda et al 2015 854 in Coma, van Dokkum et al 2015, Dragonfly)
Also in 8 other clusters at z=0.04-0.06 *(van der Burg et al 2016)*

No tidal features, appear quenched since a long time
In equilibrium in the cluster ➔ must be dominated by DM

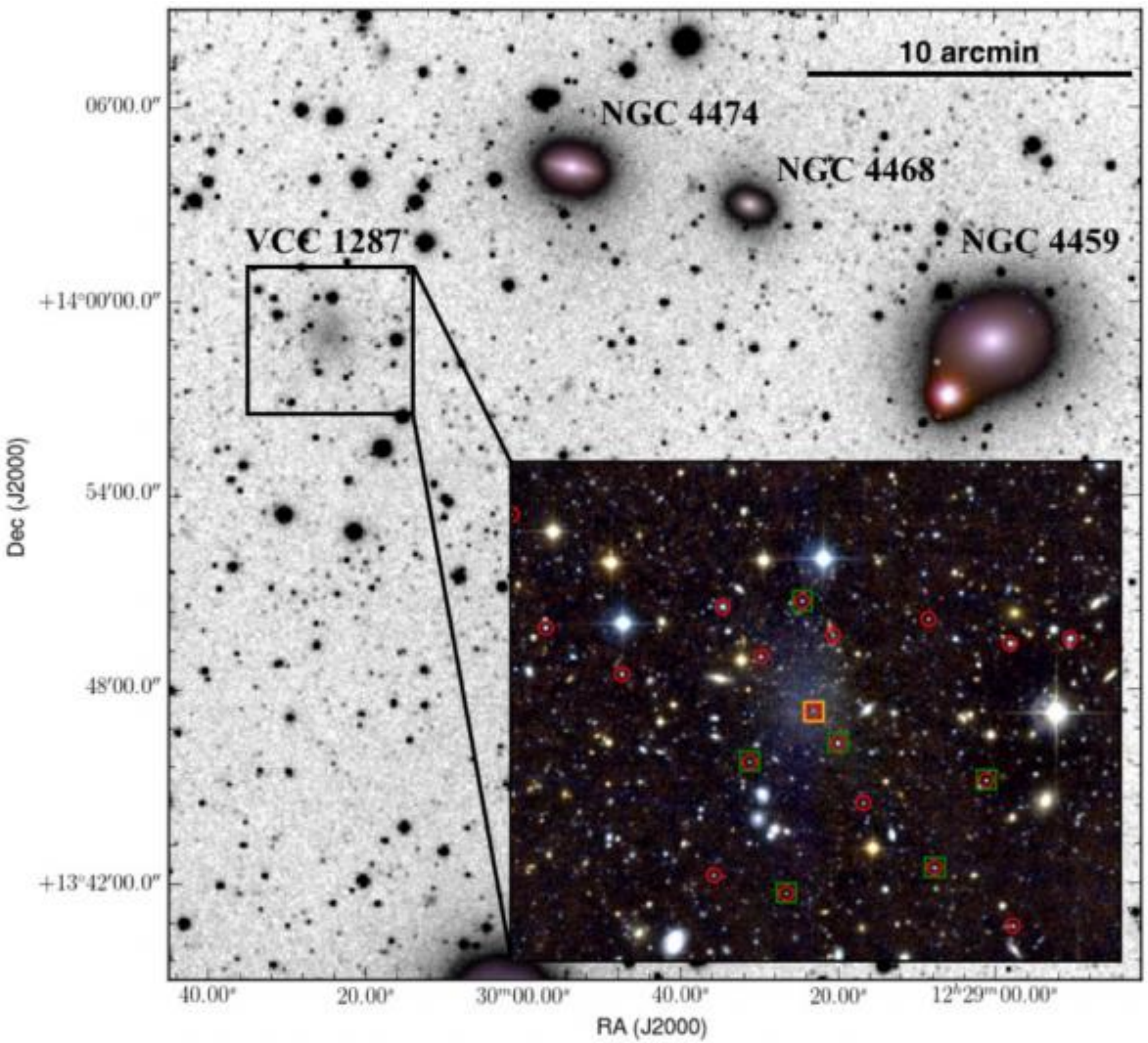
Globular cluster frequency, and their velocity give a clue

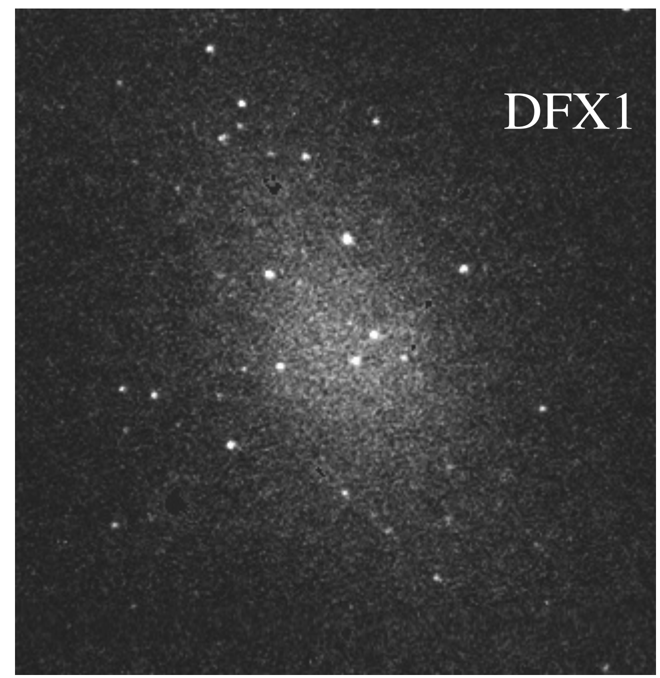
VCC1287 in Virgo, DFX1 in Coma

Spectroscopy of associated GC ➔ DM mass of 8 10^{10} Mo

True dwarfs, very LSB

Beasley et al 2016

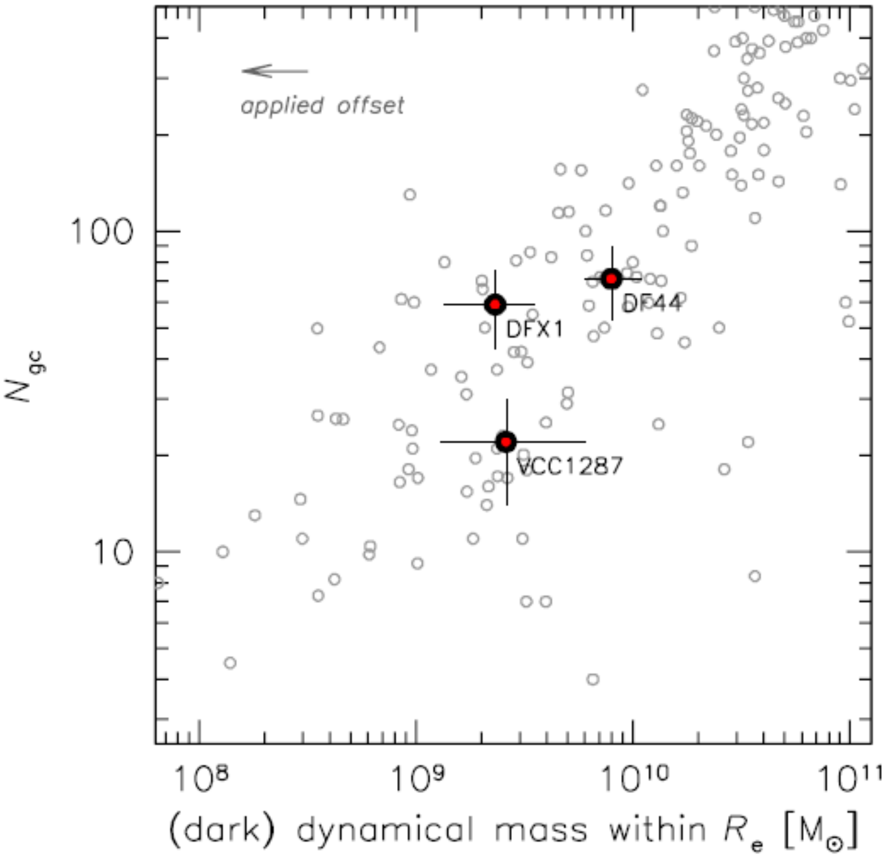


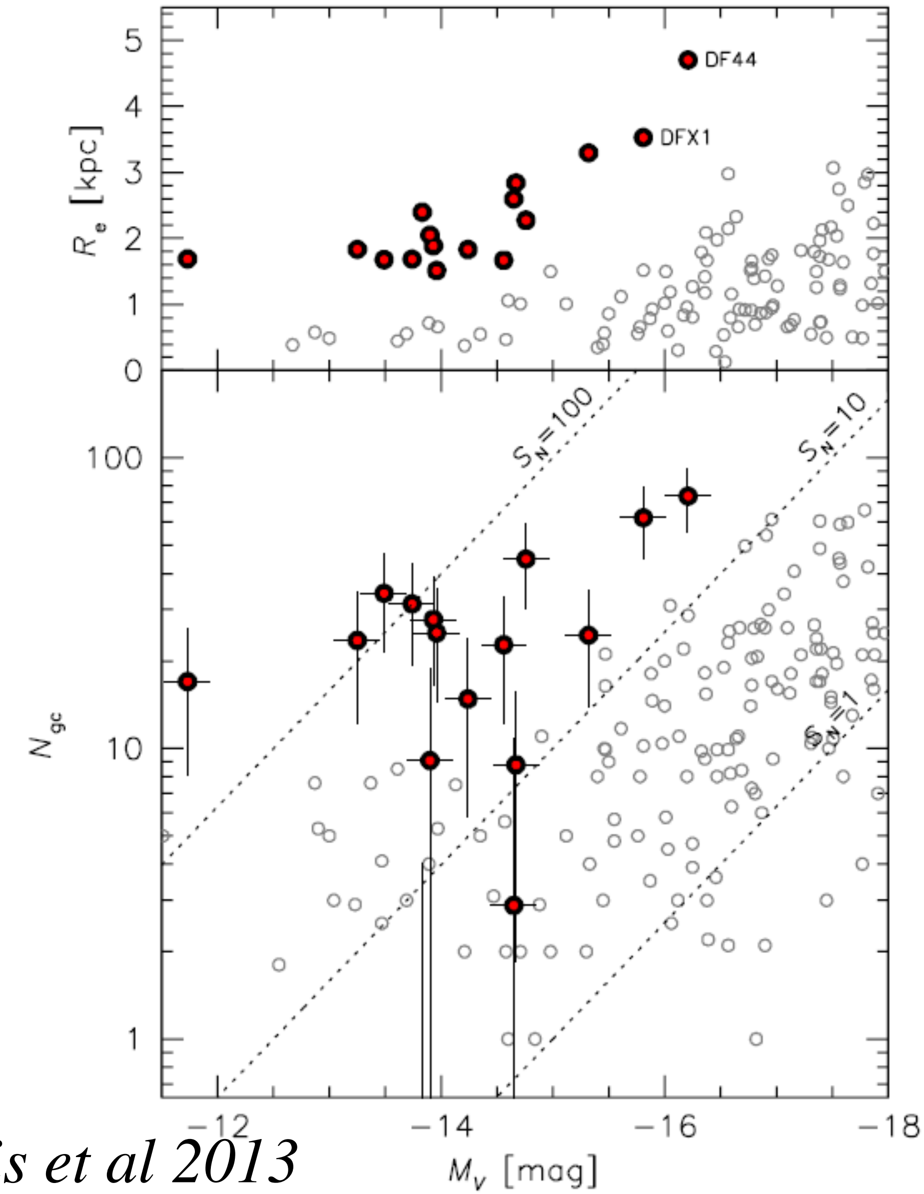


Van Dokkum et al 2017

GC and dynamical mass

Van Dokkum et al 2017





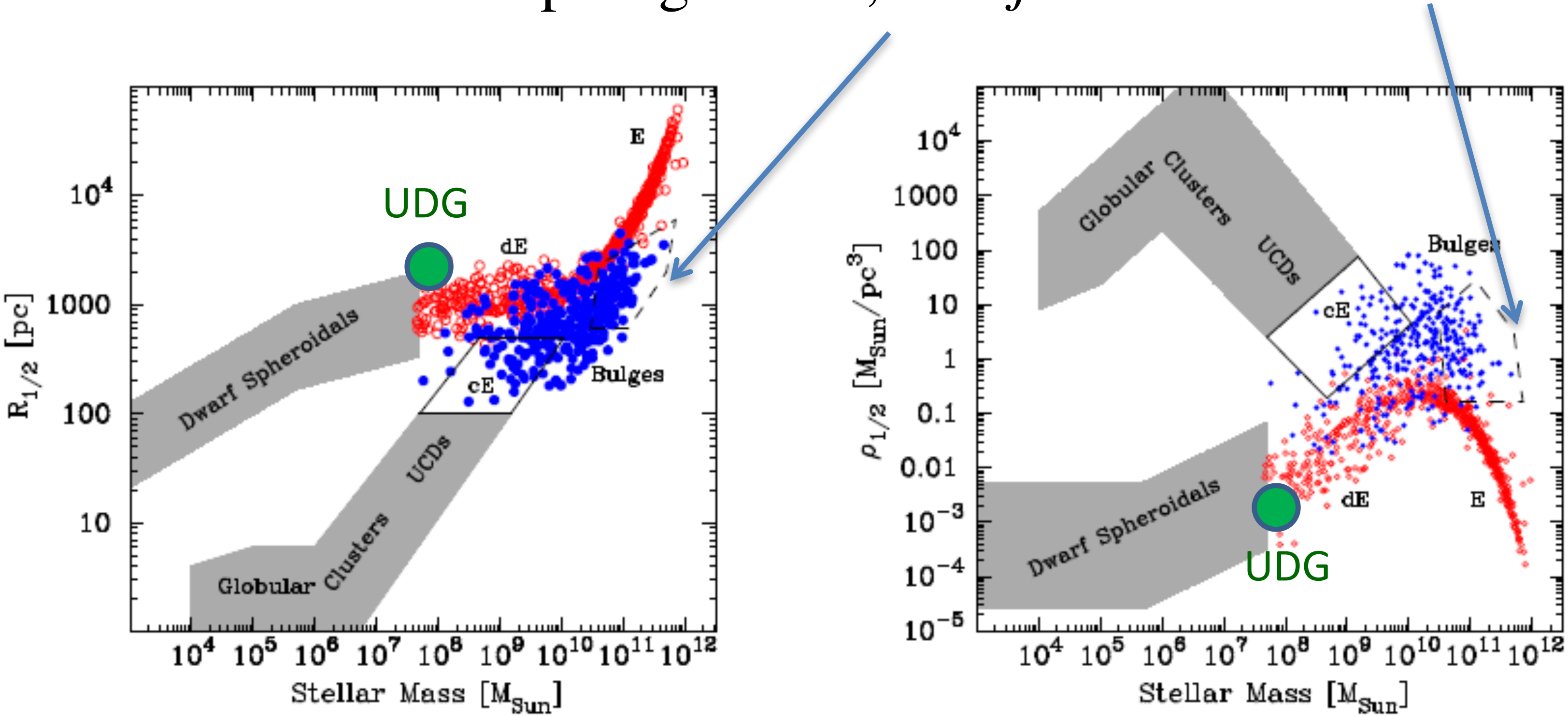
Massive UDG are the exception

Amorisco et al 2017

Normal galaxies from Harris et al 2013

Mass-size and density relations

z=1.5 compact galaxies, *Damjanov et al 2009*



UDG appear in the continuity of other dwarfs

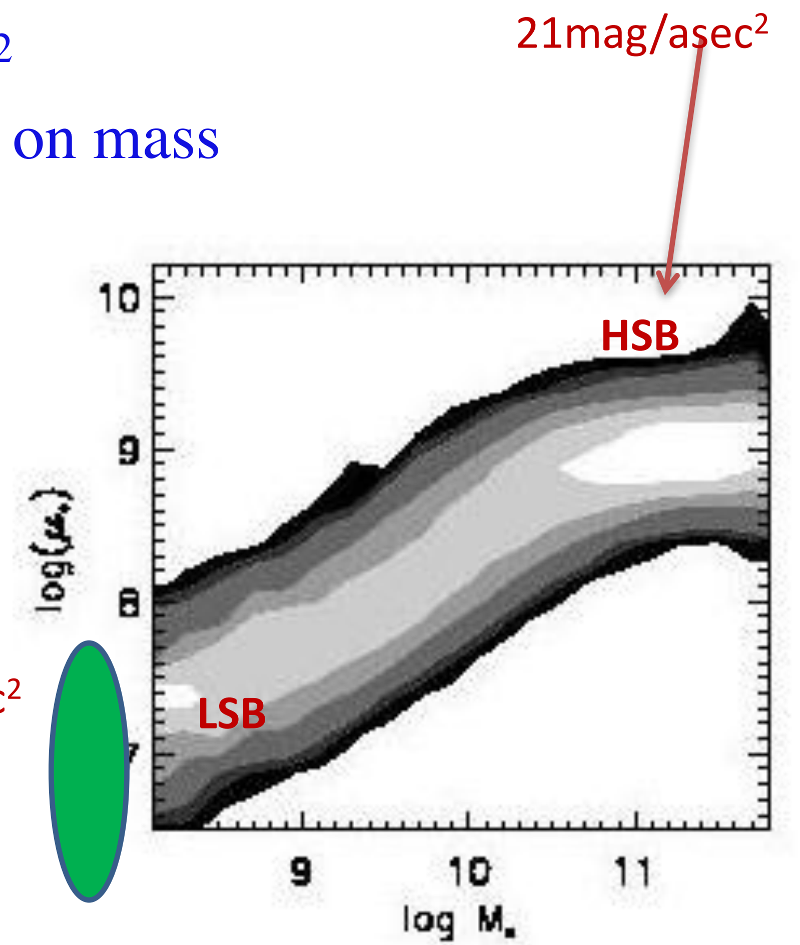
Graham 2011

Link between SF History and surface density

LSB/dwarfs, high gas content, high and young star formation
HSB high mass, concentrated, old population (μ x 40)

Transition at M_{*}=3 10^{10} Mo, 3 10^{8} Mo/kpc^2
SFH depends more on surface density than on mass

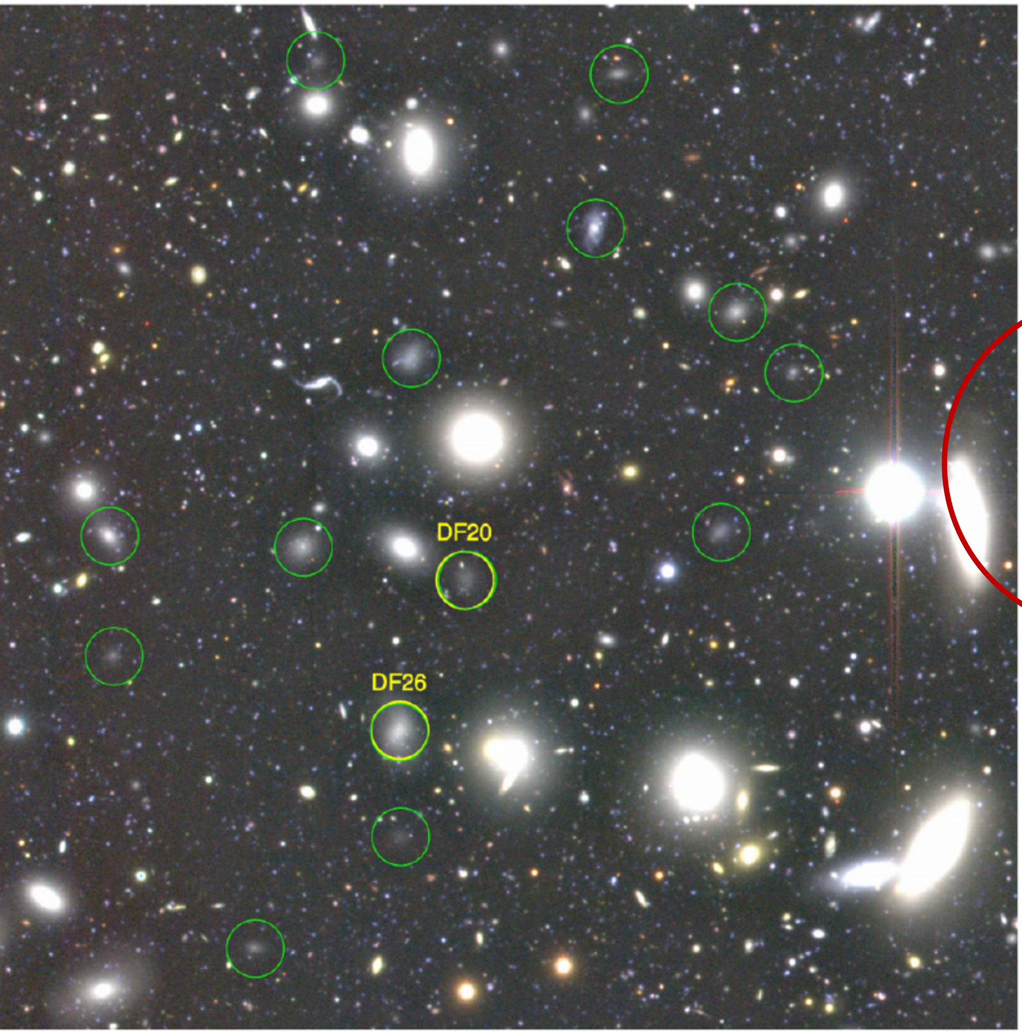
There is a transition where the gas begins to outflow, at the V_{SN} velocity ~100km/s (supernovae)



Kauffmann et al 2003

Ultra Diffuse Galaxies in Coma

854 UDG, 332 as large as MW
Distributed around the cluster center
Koda et al 2015

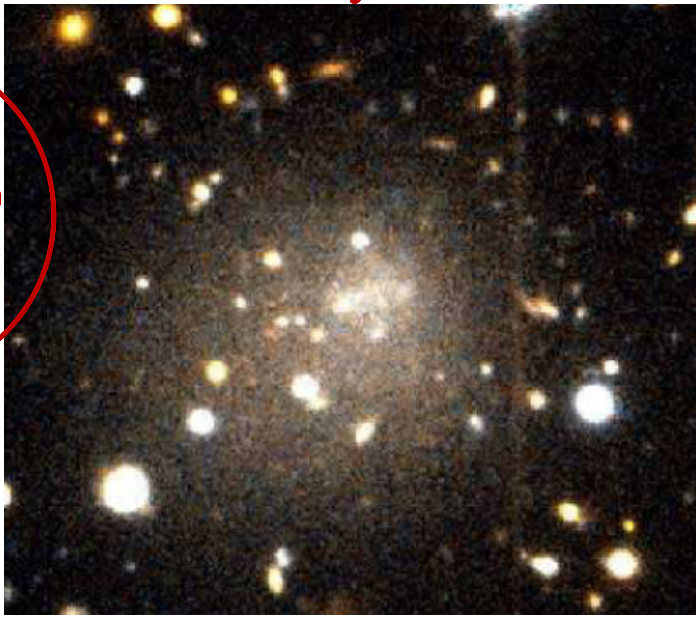


More in clusters than in the field ?
Some with gas (Papastergis +17)

May be the spheroidal shape
is due to tides and ram-pressure

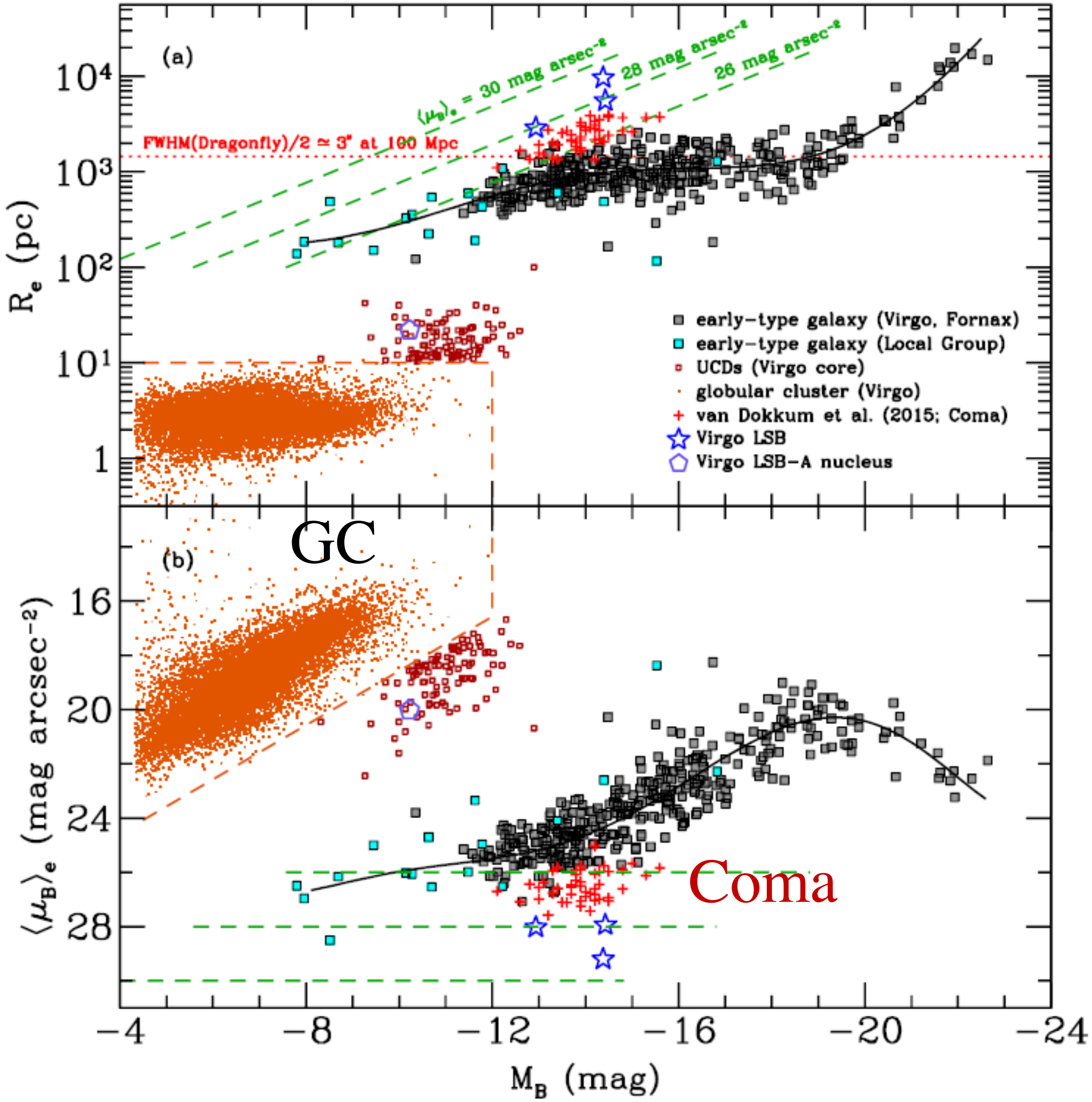
DGSAT-1, outside any cluster

No gas:
HI, CO
+DF44



Martinez-Delgado et al 2016
Roman & Trujillo 2017

UDG in Virgo: no tidal perturbation



Objects Re = 3–10 kpc

L_V = 2–9 × 10^7 Lo

No tidal perturbation

Lower brightness than in Coma

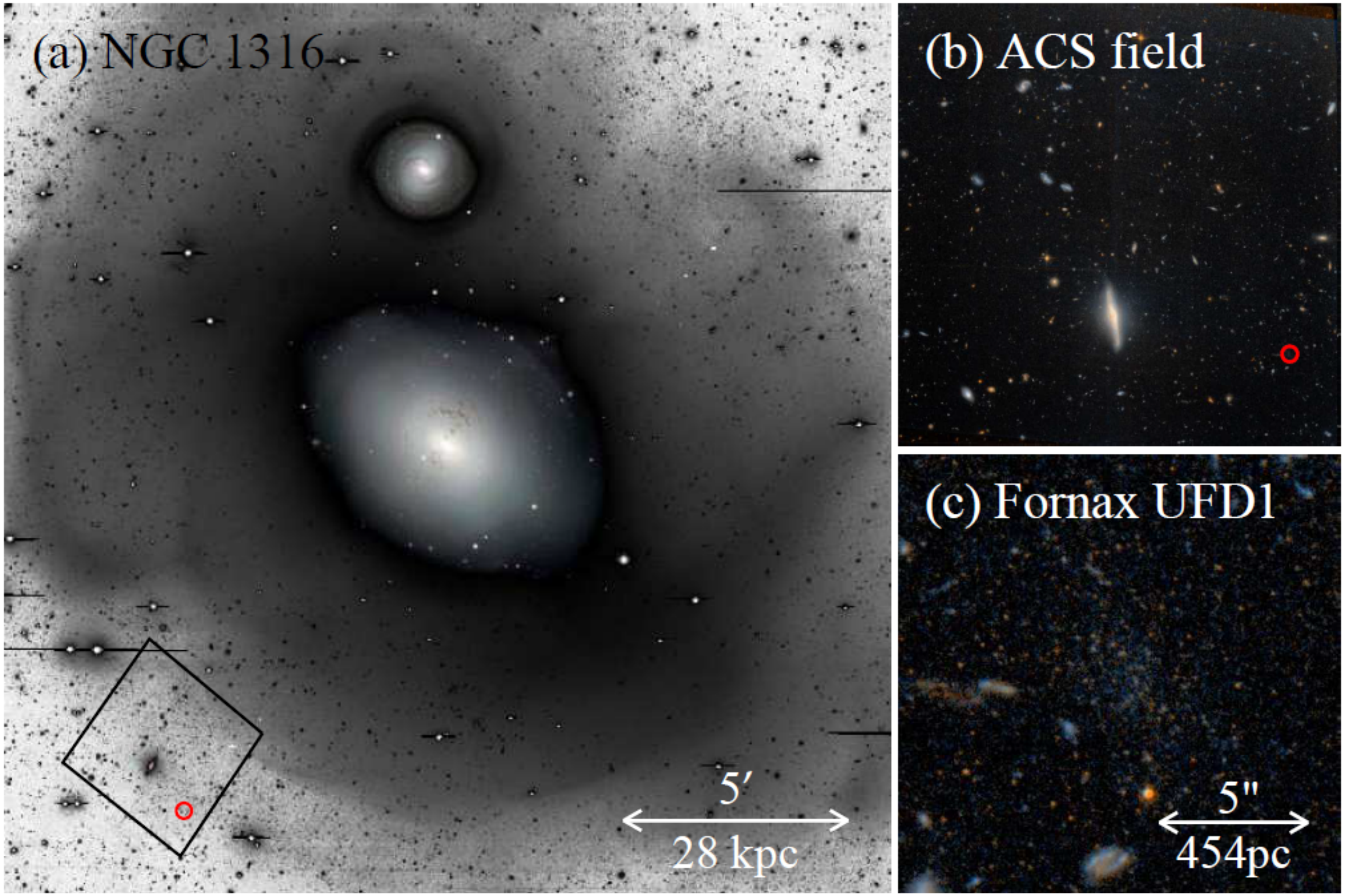
One nucleated,

➔ Becoming an UCD?

Mihos et al 2015

Fornax UFD1, Virgo UFD1

M_v ~-7.6 L_V ~10^5 Lo μ ~27 mag /asec^2

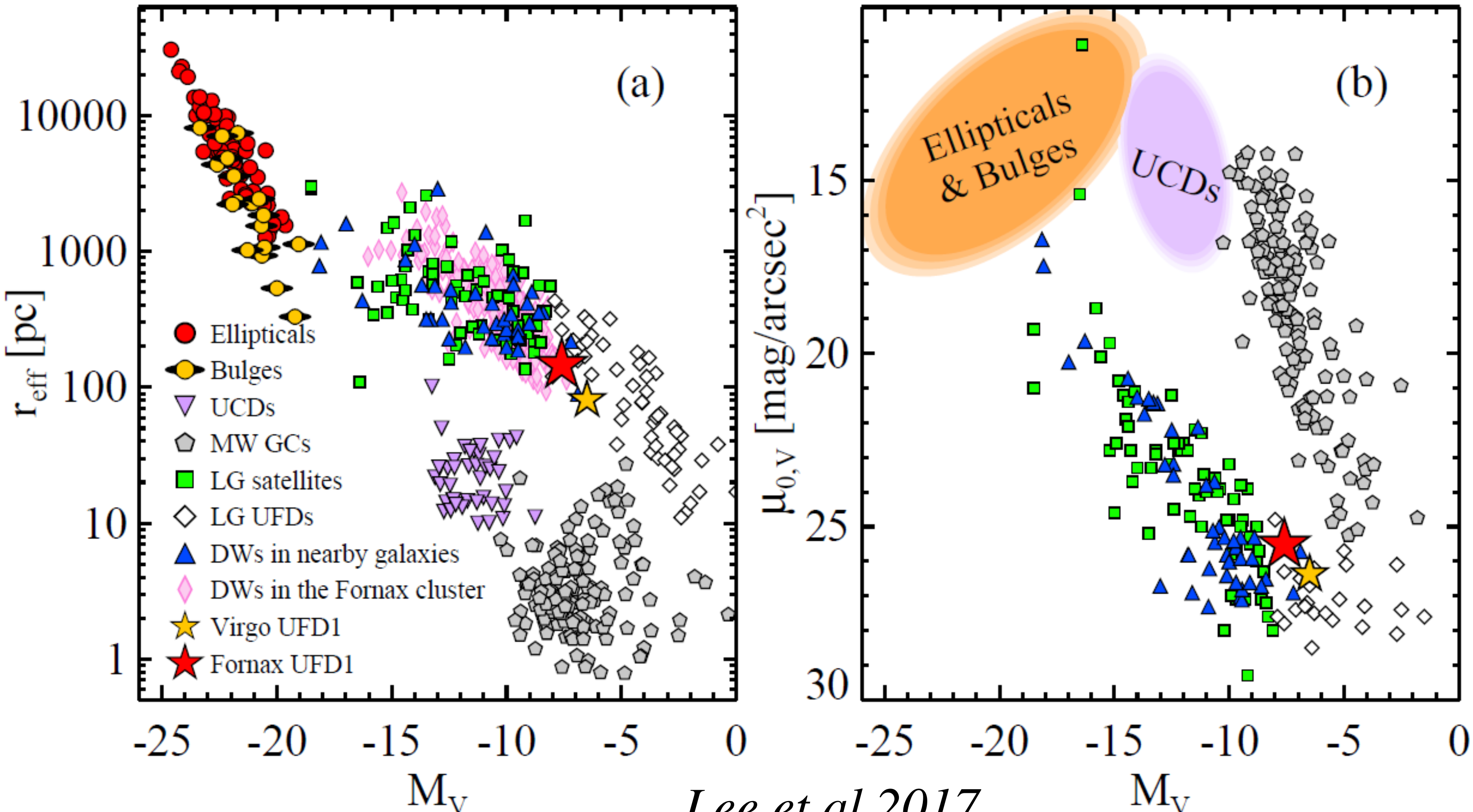


r_{eff}= 150 pc D=19 Mpc, *Lee et al 2017*

Magnitude-size, and surface brightness relations

Resolved stars are metal-poor,

Tip of RGB method ➔ Distance CMD ➔12Gyr isochrone



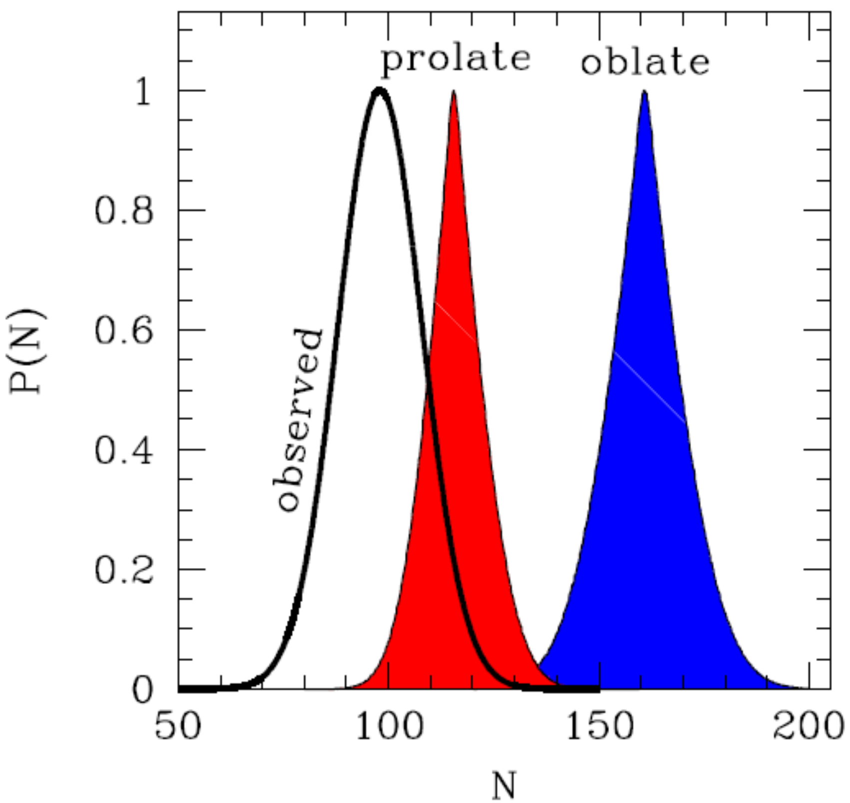
Lee et al 2017

Shape of the dwarfs

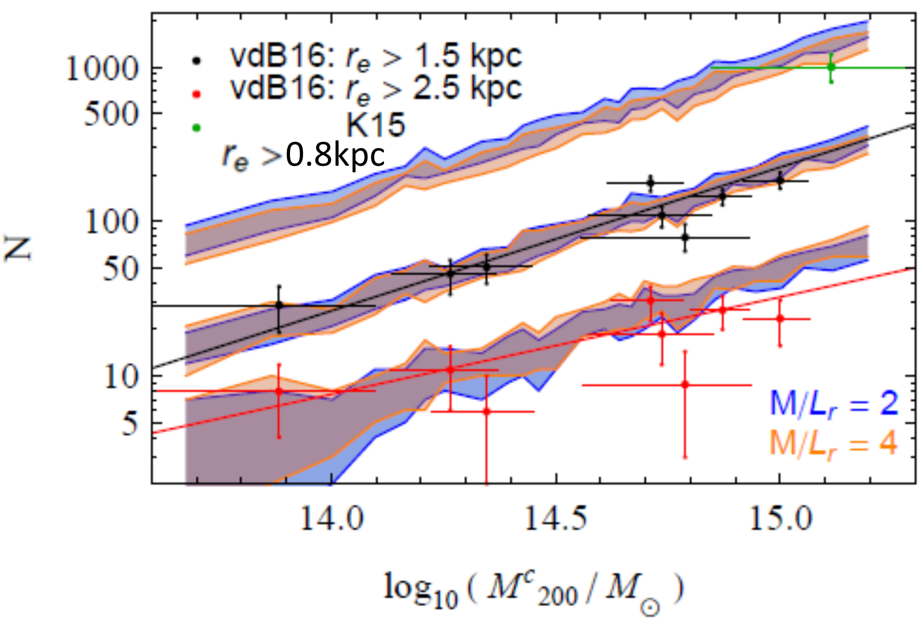
The high frequency of round projected galaxies is in favor of a dominant prolate population *(Burkert 2017)*

This is also true for faint dwarfs dSph in the Local Group (*Hayashi & Chiba 2015*)

Opposite interpretation:
UDG are the high-L tail of galaxies forming in dwarf-size haloes
Amorisco & Loeb 2016



Number of round galaxies expected

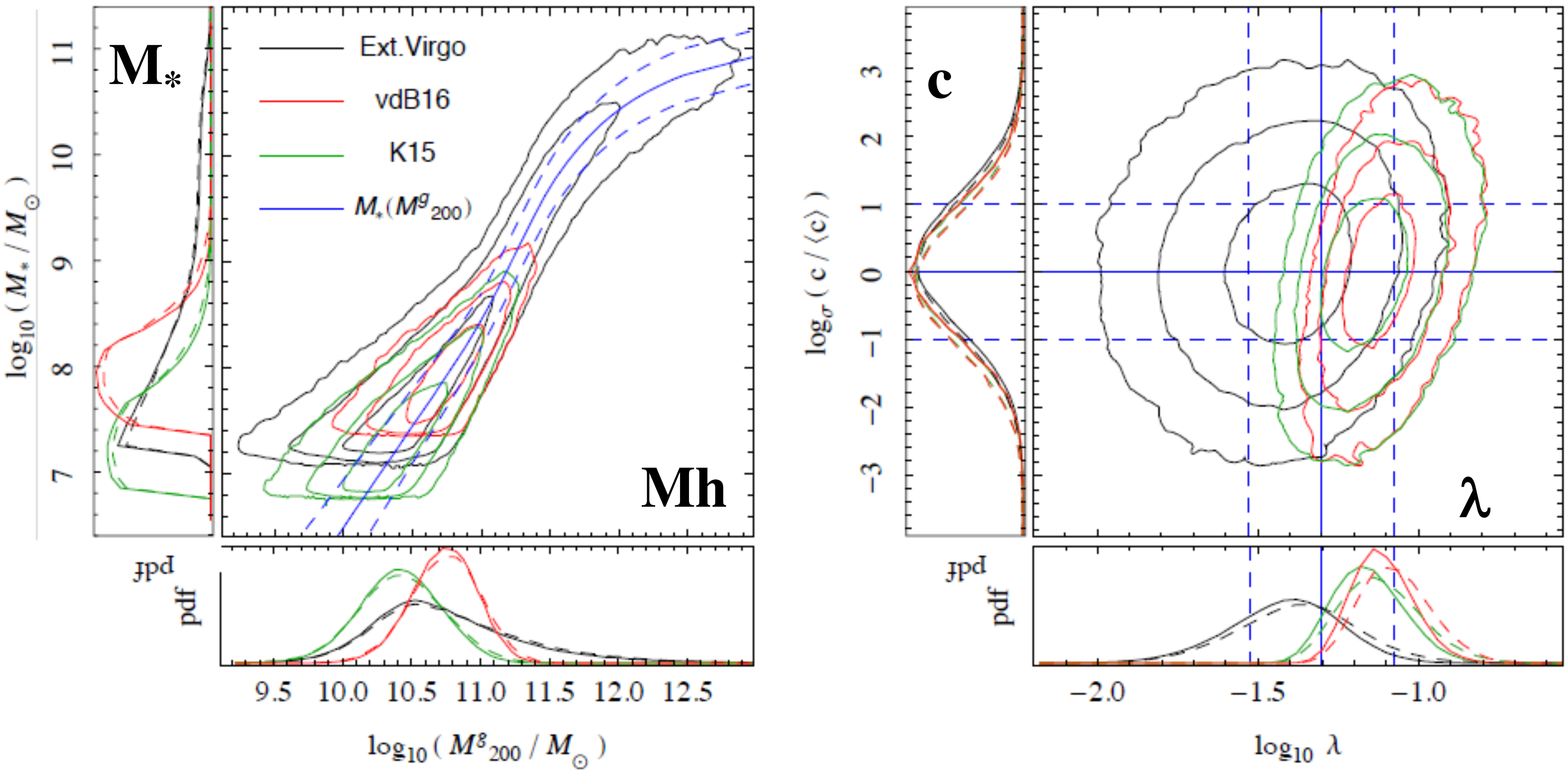


Angular momentum, M*, Mh, c

Full: cluster UDG

Dash: field ➔ not a big effect of tides

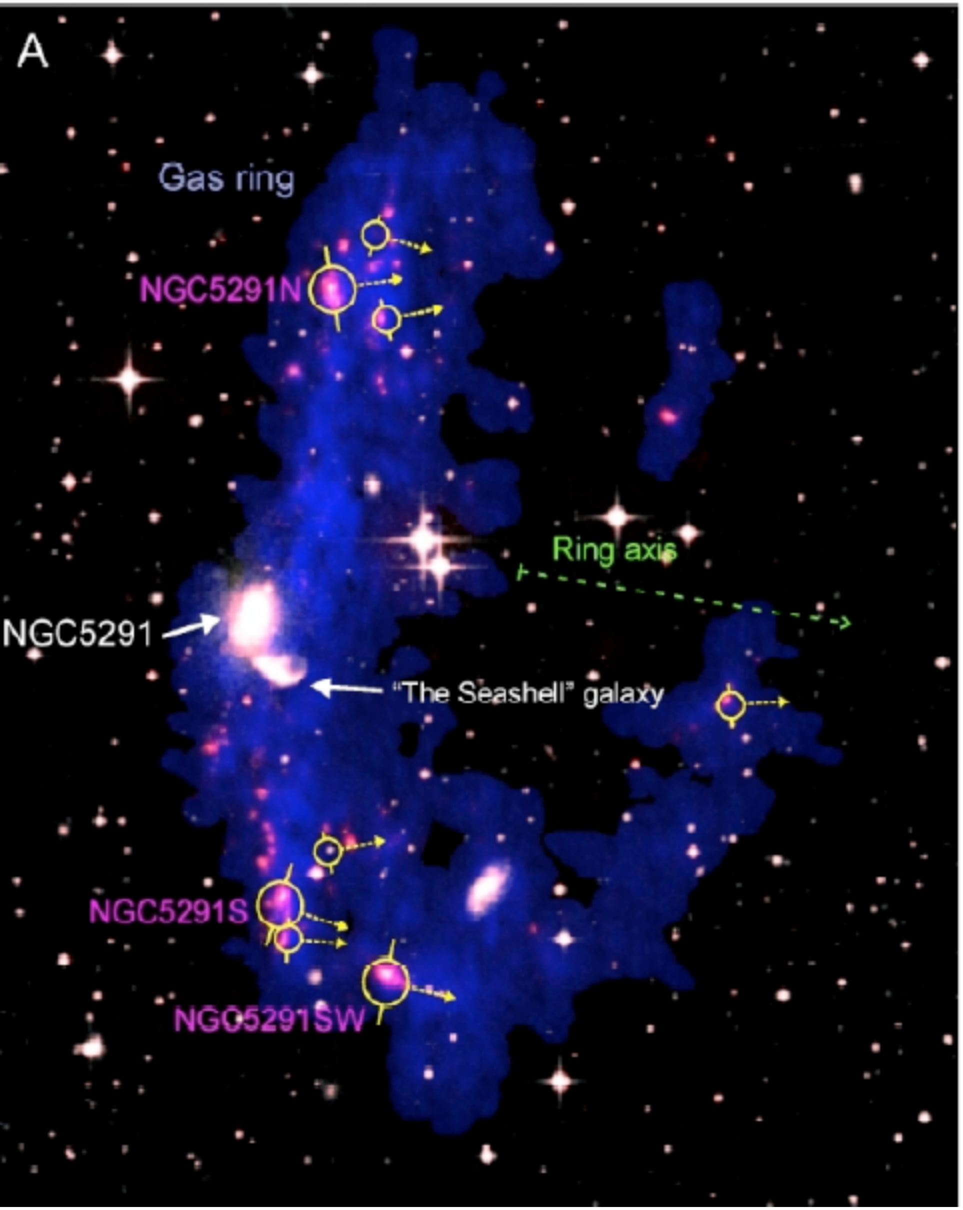
$$\lambda \equiv J|E|^{1/2}G^{-1}M^{-5/2}$$

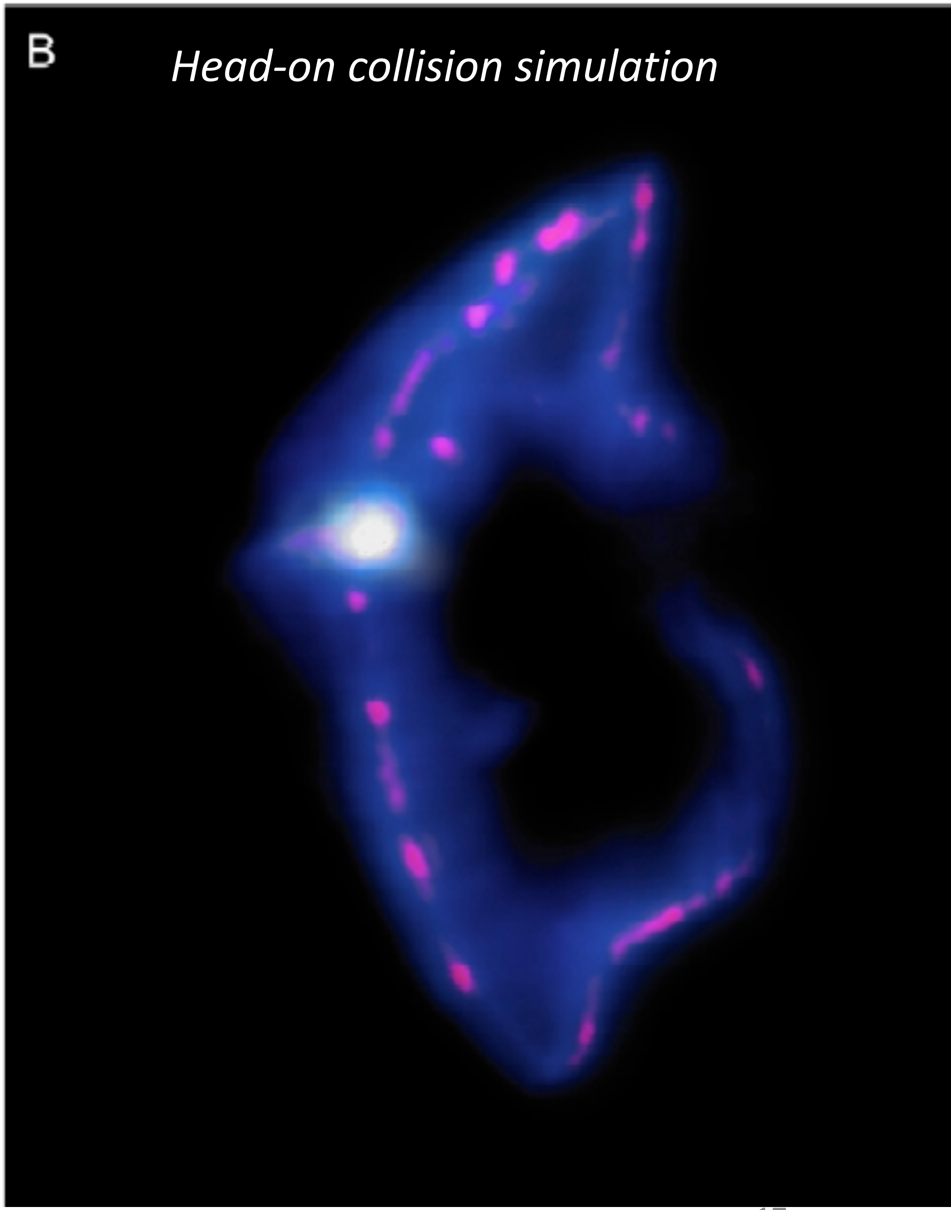


Blue: abundance matching relation

Amorisco & Loeb 2016

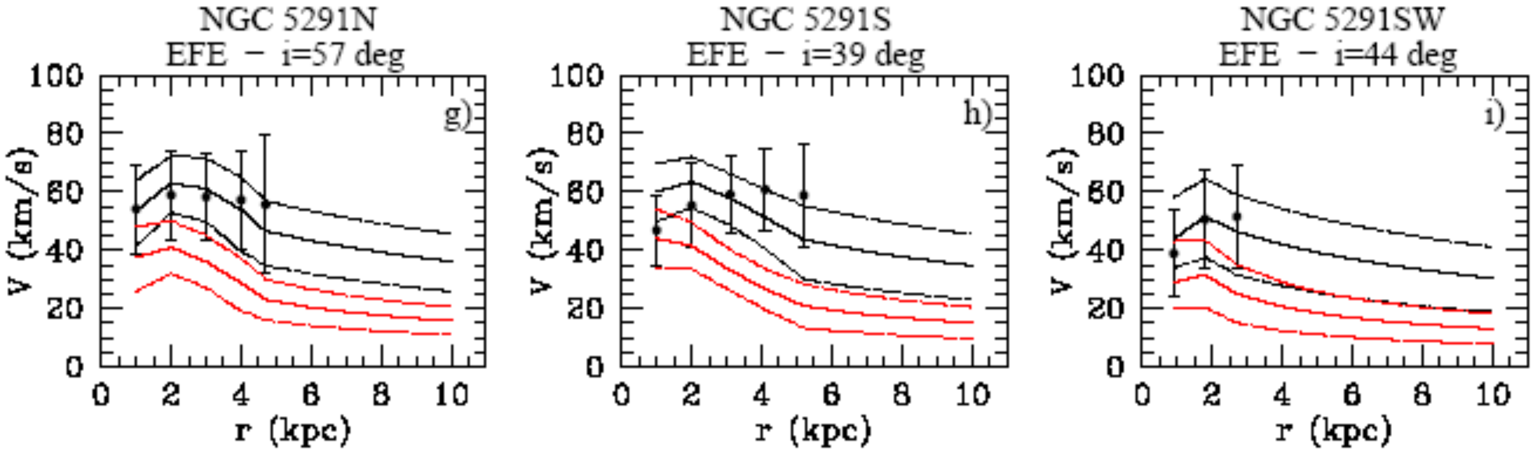
TDG in N5291 HI ring





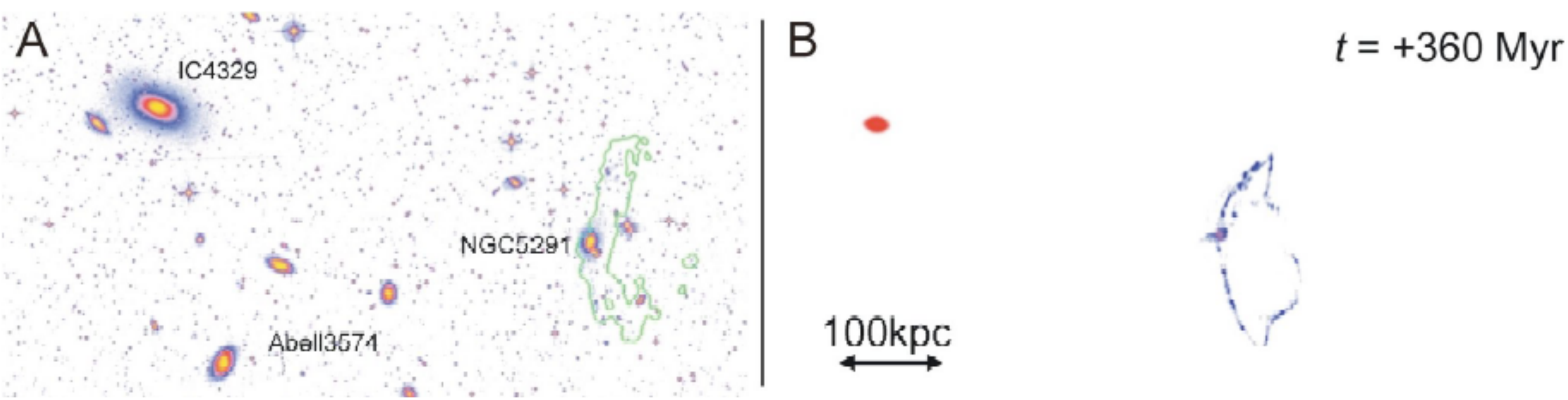
Bournaud et al 2007

Dynamics of the TDGs



With MOND, *Gentile et al 2007*

All inclinations= 45°, from simulations (Bournaud et al 07) ➔ dark H_2

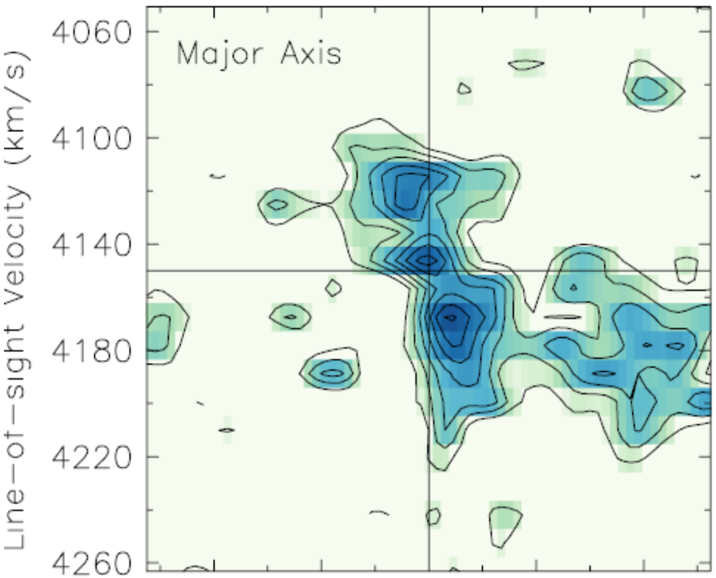


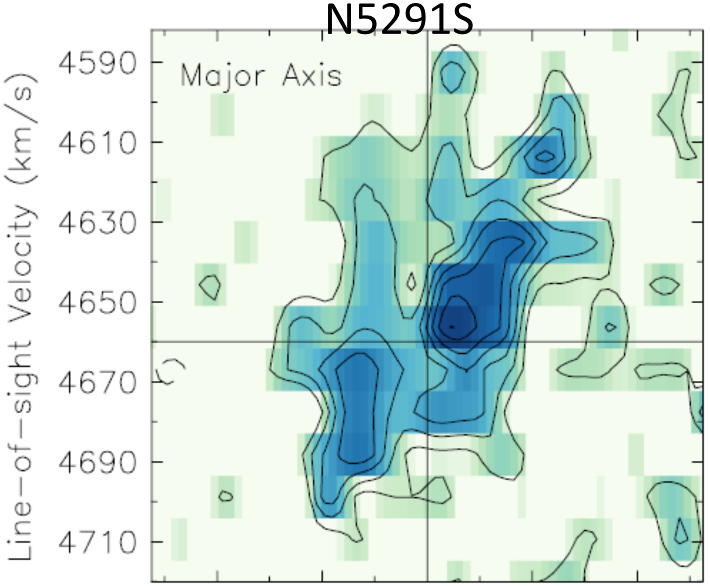
But debatable

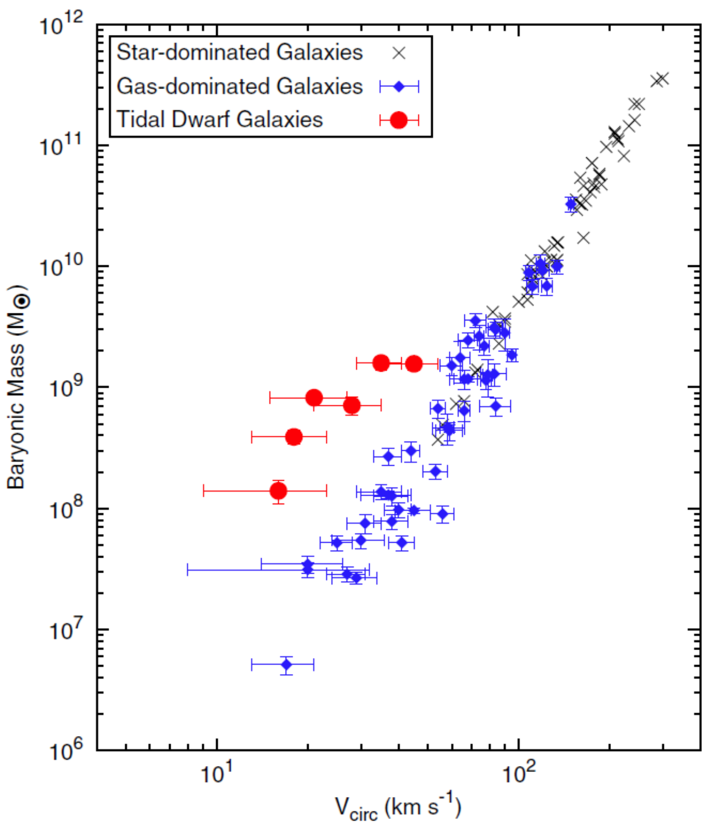
The systems are not yet in equilibrium
Less than a full HI rotation has passed since the merger

The rotation curves may be explained through baryons only

Not in the TF

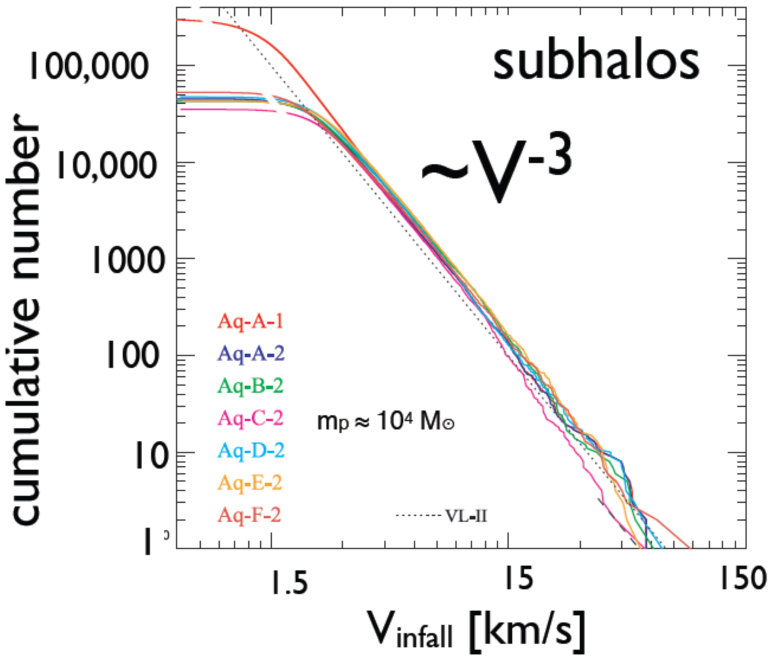






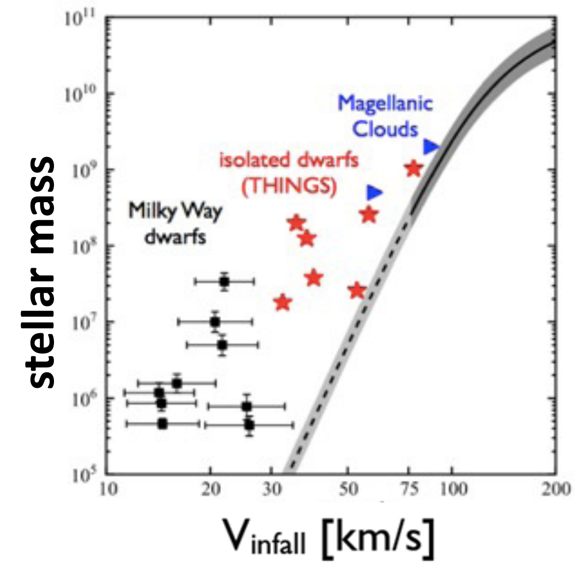
Lelli et al 2015

Missing satellites and SF efficiency

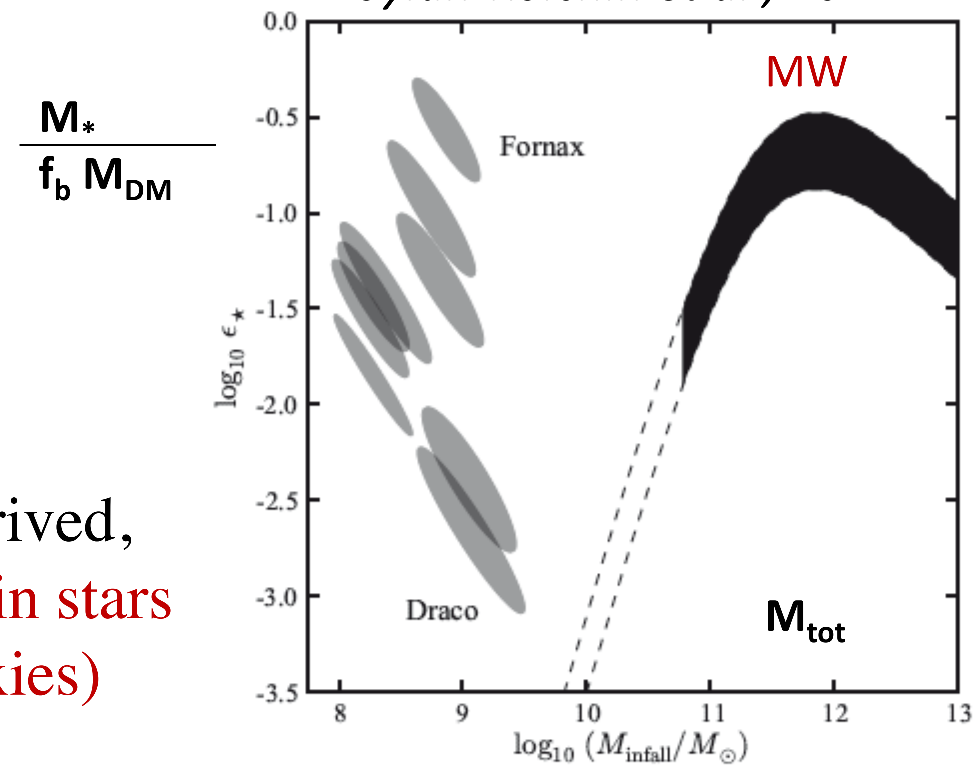


Springel et al. 2008

9-10 satellites with $L_V > 10^5$Lo



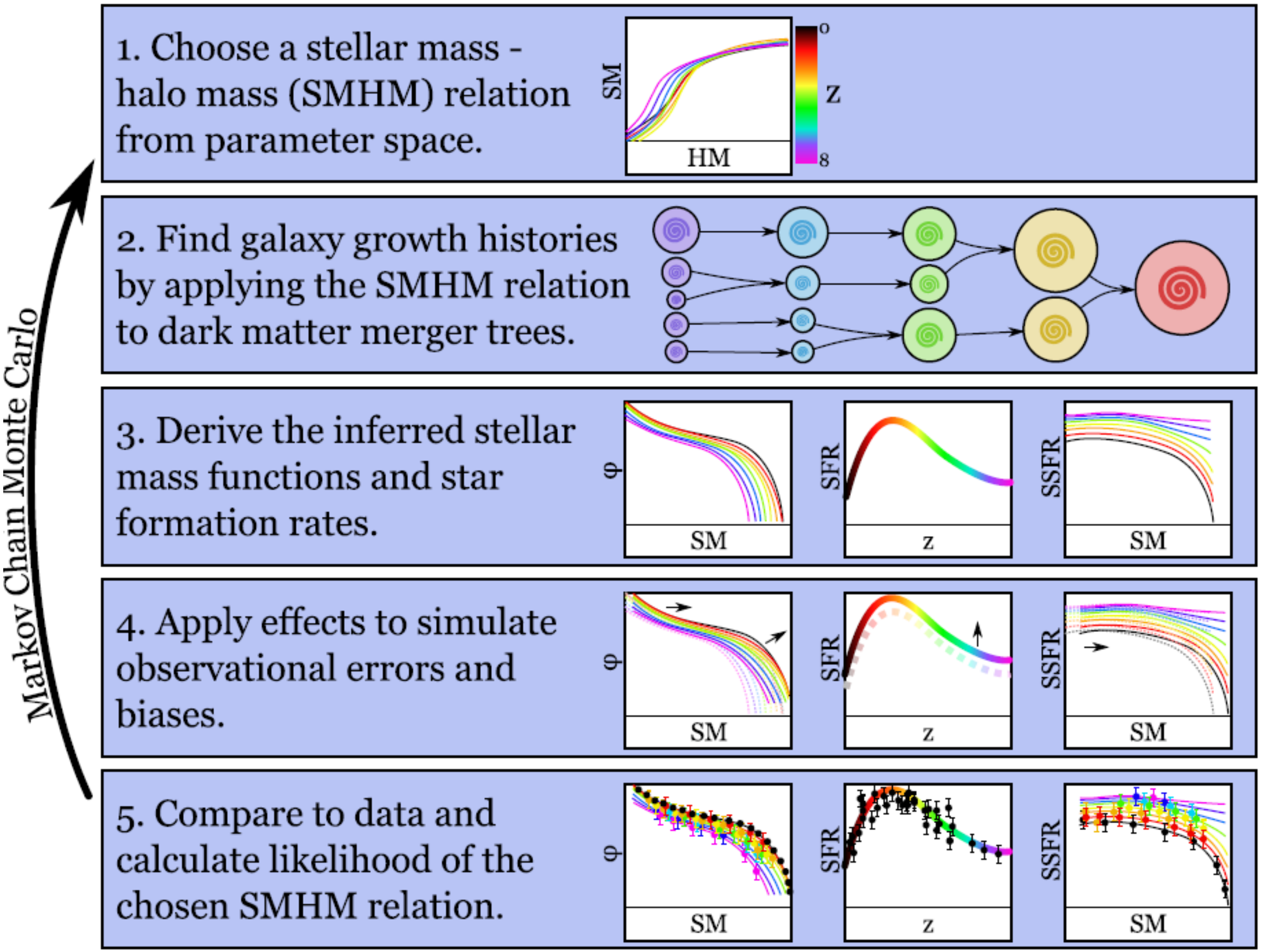
Boylan-Kolchin et al , 2011-12



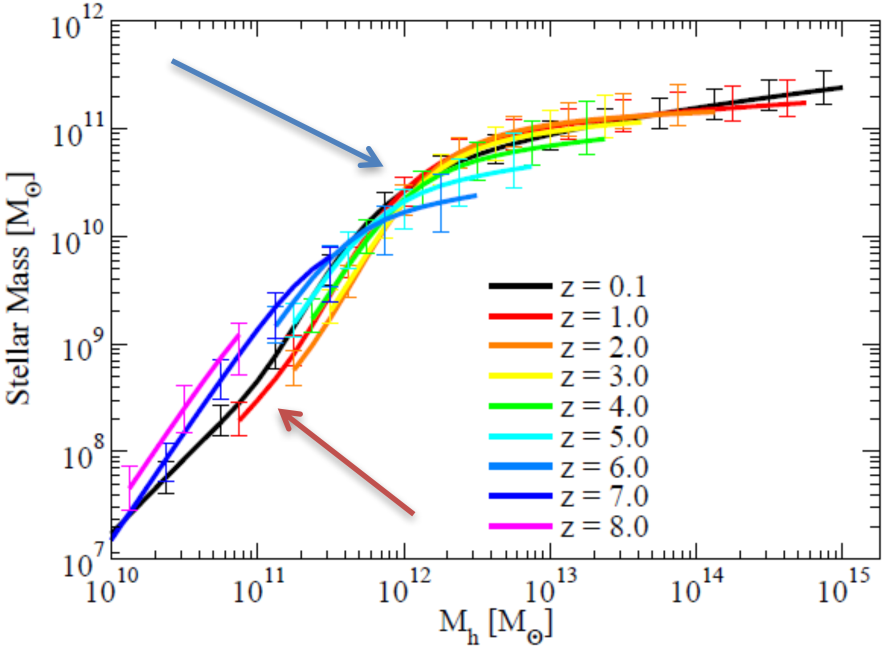
From halo abundance matching,
the efficiency to form stars is derived,
➔must peak at 20% of baryons in stars
at M_{tot} ~10^{12}Mo (MW-type galaxies)

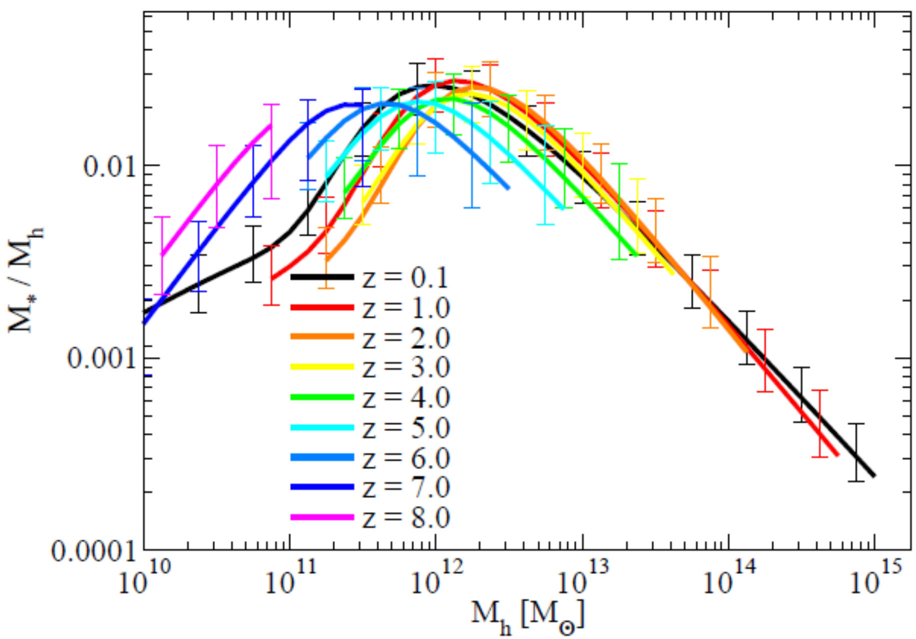
SAM for SF History from z=8 to 0

Behroozi et al 2013



Dwarfs and DM as a function of redshift



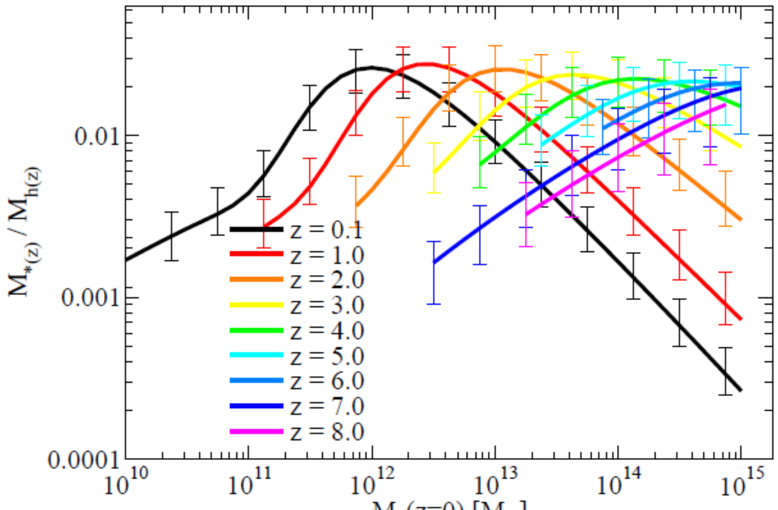


Massive halos form stars actively in the past, then drop after a peak

Dwarfs today are less active

Always the same peak

The most efficient Mh=10^{12}Mo



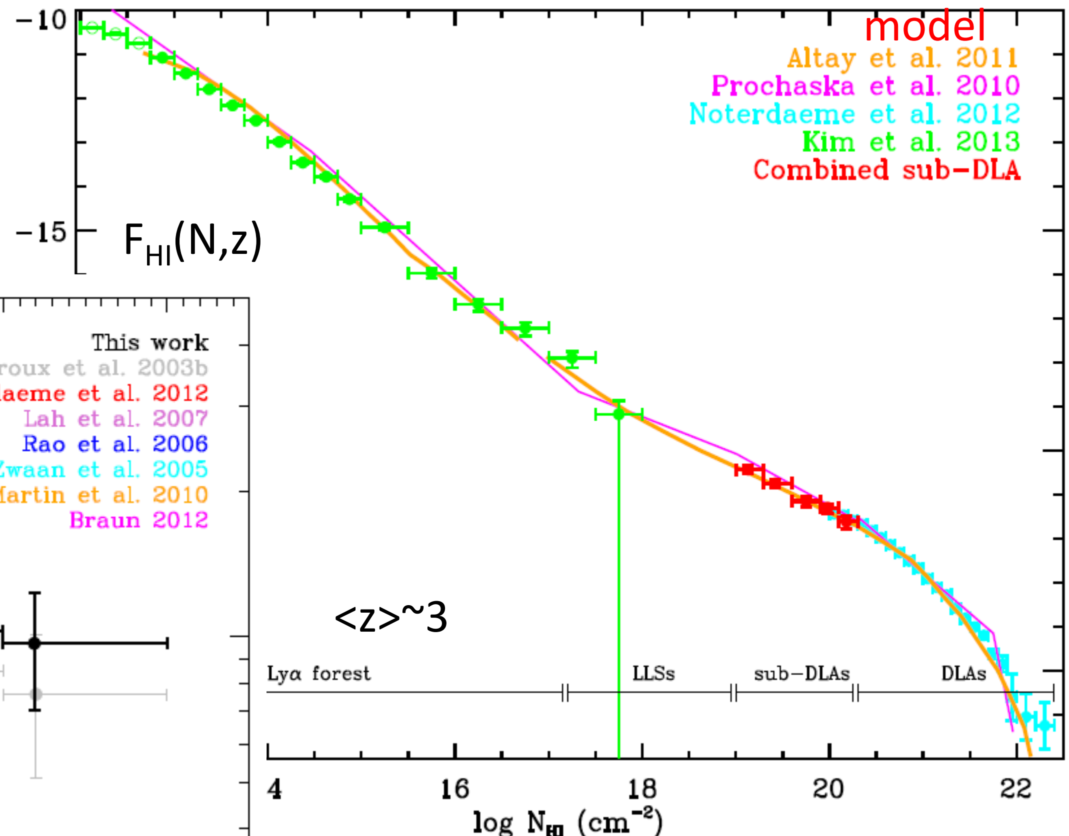
Behroozi et al 2013

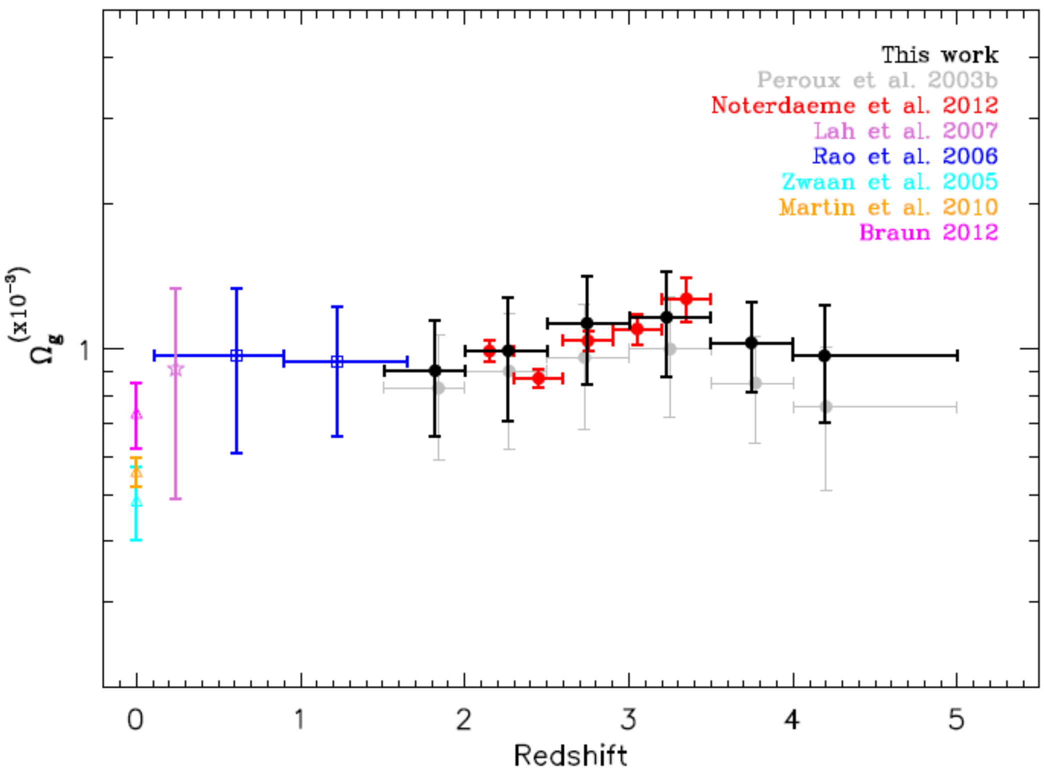
Evolution of HI-rich dwarfs with z

DLA NHI > 2 10^{20} cm^{-2}

Sub-DLA: 10^9 – 2 10^{20} cm^{-2}

➔ More sub-DLA at high z

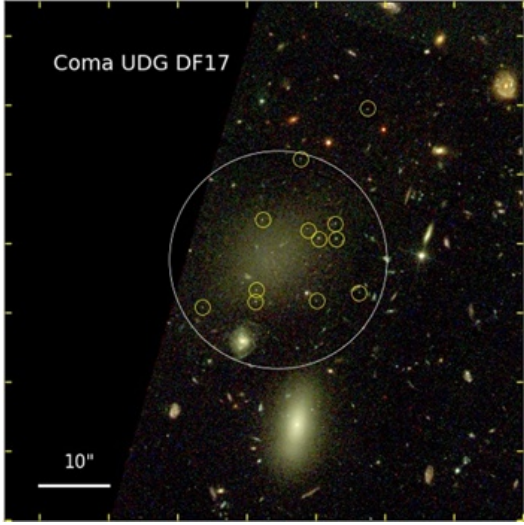




Gas consumption in stars compensated

Replenishment from ionized (or dense) gas

122 QSO, Zafar et al 2013



Beasley & Trujillo 2016

Conclusion

➔Scaling laws : two much scatter, or baryon loss?

➔Constant surface density of DM, Σ_{DM}~150 Mo/pc^2 (MOND)

➔UDG: may be true dwarfs, and not L* galaxies, after all

➔Influence of clusters? UDG in Coma, but in the field, too

➔Evolution in redshift