Leibniz-Institut für Astrophysik Potsdam

Ultra-Diffuse Galaxies: a formation scenario

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in collaboration with
Brook, Dutton, Maccio',Obreja, Dekel

Outline

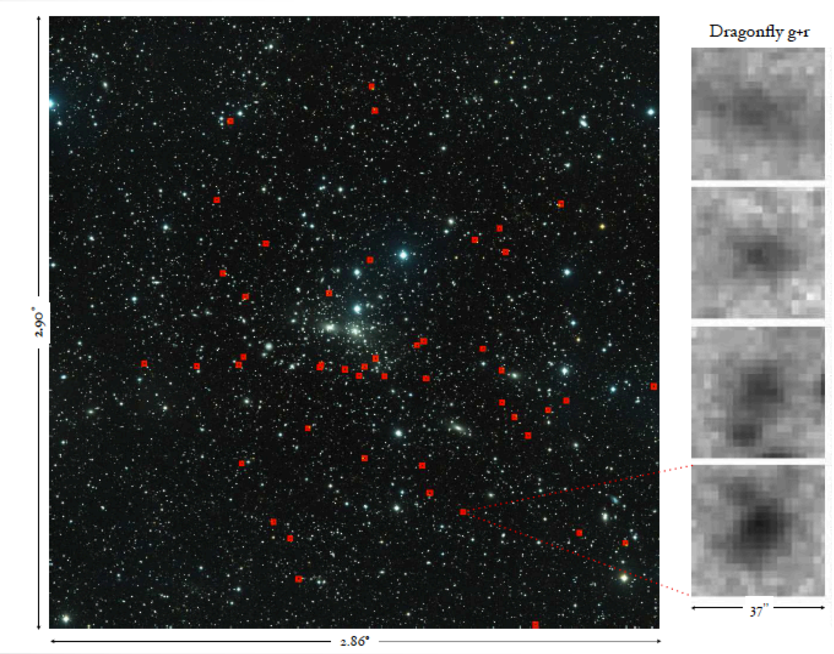
- What do we know about UDGs
- Can we reproduce them in simulations
- How do they form
- Theoretical predictions & current observations

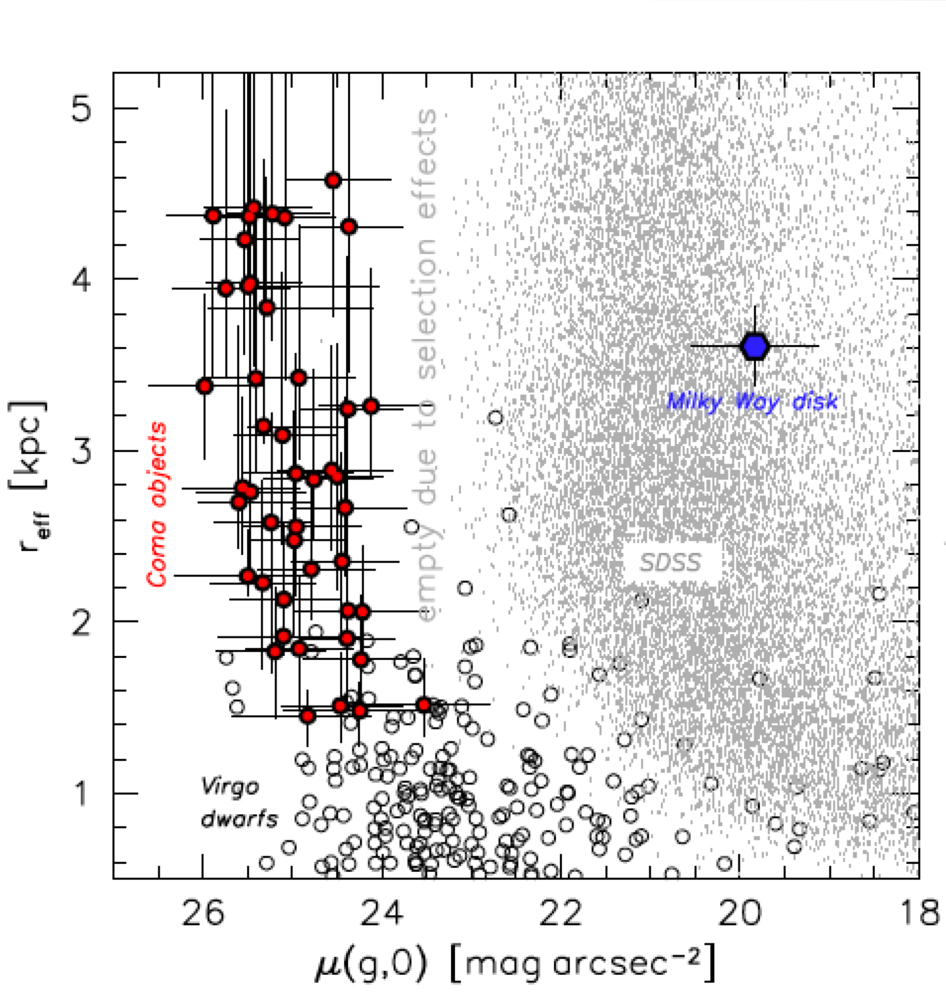
(rant about RAR and connection to cusp/cores and predictions from UDGs)

- Future prospects

47 UDGs in Coma cluster

Low surface brightness objects with
LUMINOSITY of dwarfs but
SIZES of Milky Way-type spirals
Are they failed L*?



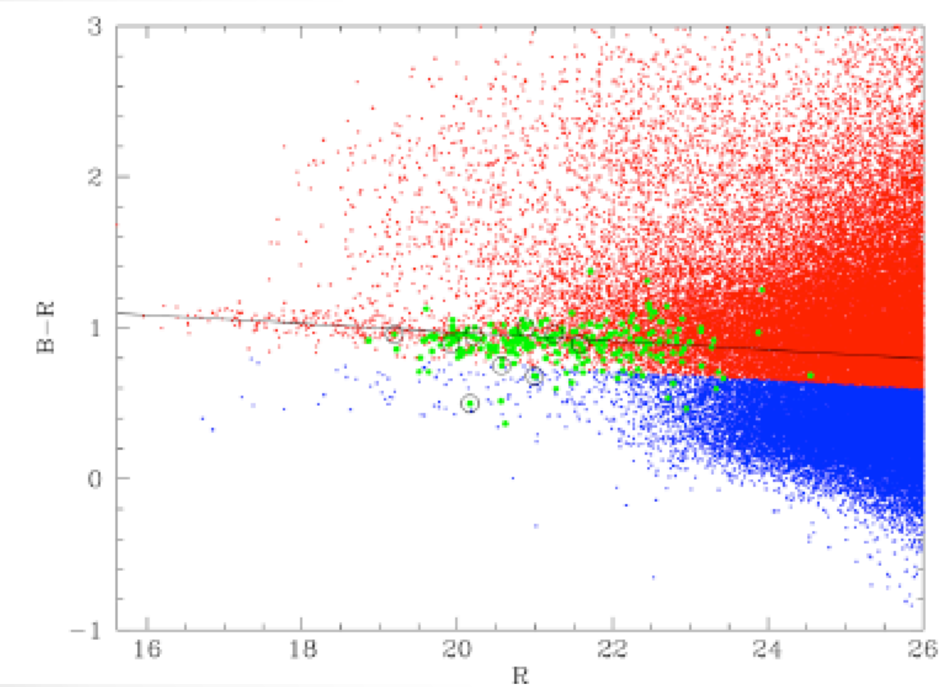


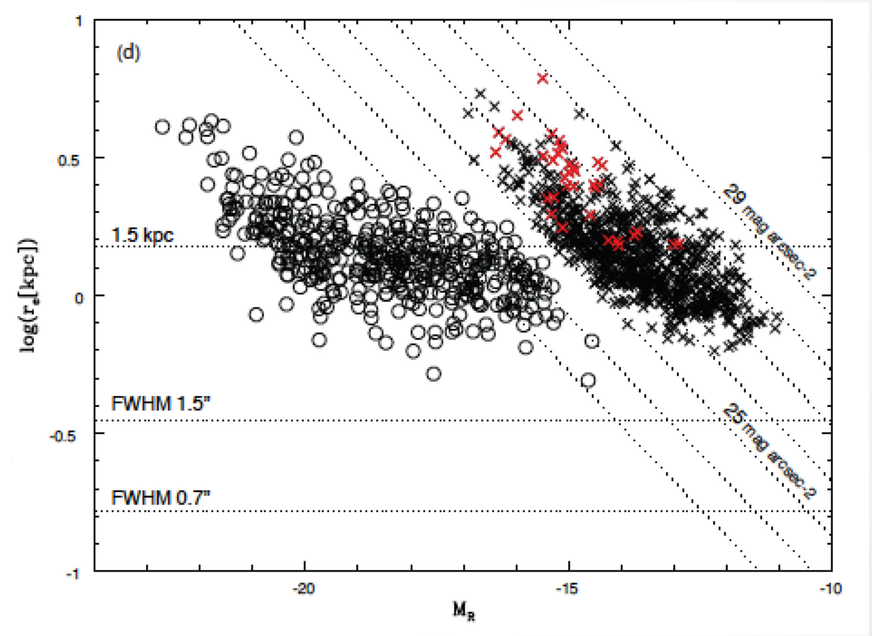
van Dokkum +15 using Dragonfly Telephoto Array

~ 1000 UDGs in Coma Cluster

Follow the red sequence of Coma

Passively evolving population?





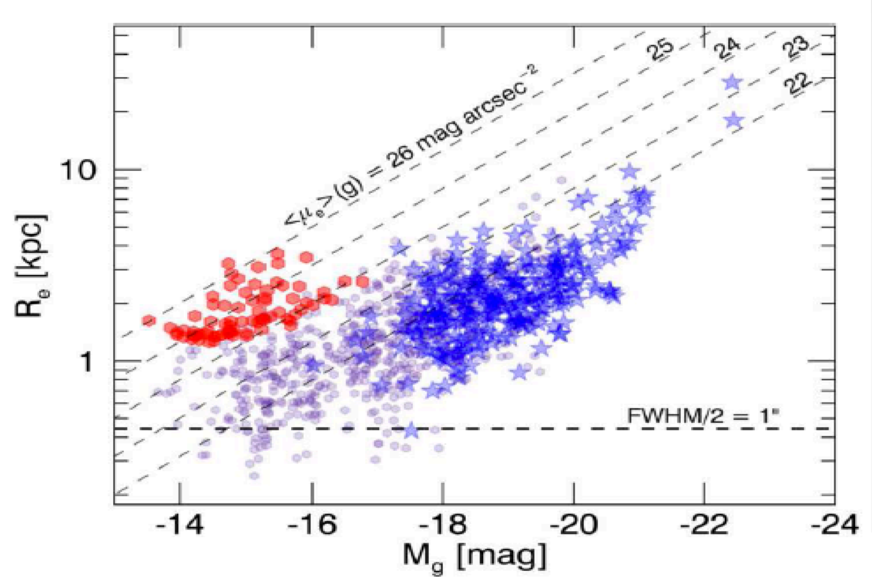
Koda +15 using SUBARU Suprime-Cam

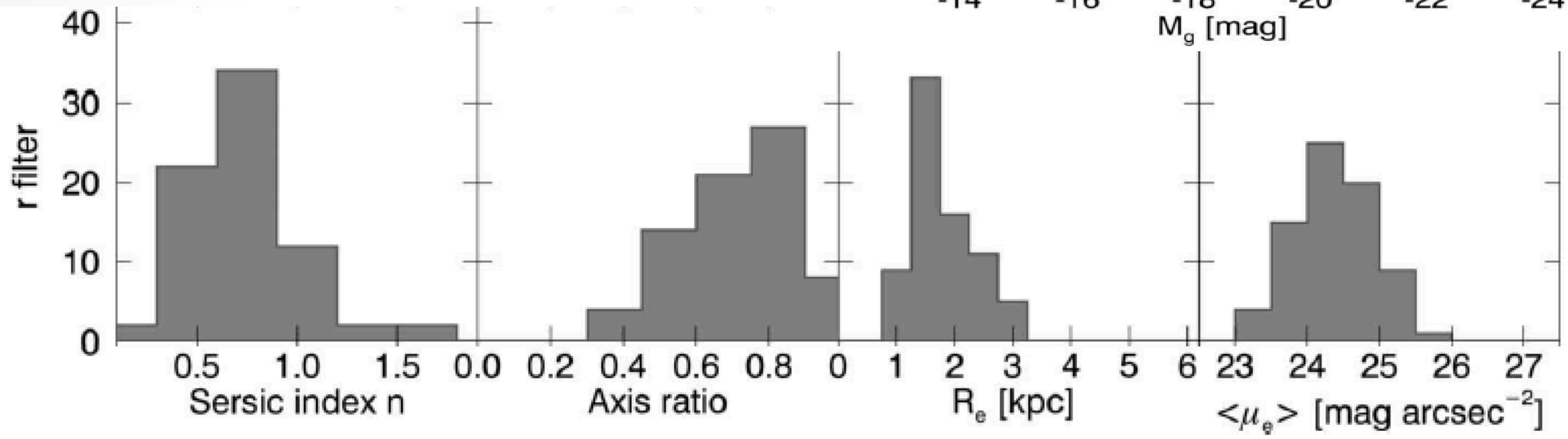
UDGs in/around Abell 168

42% of UDGs inhabit the cluster region

the rest are isolated

Are they formed outside of clusters?

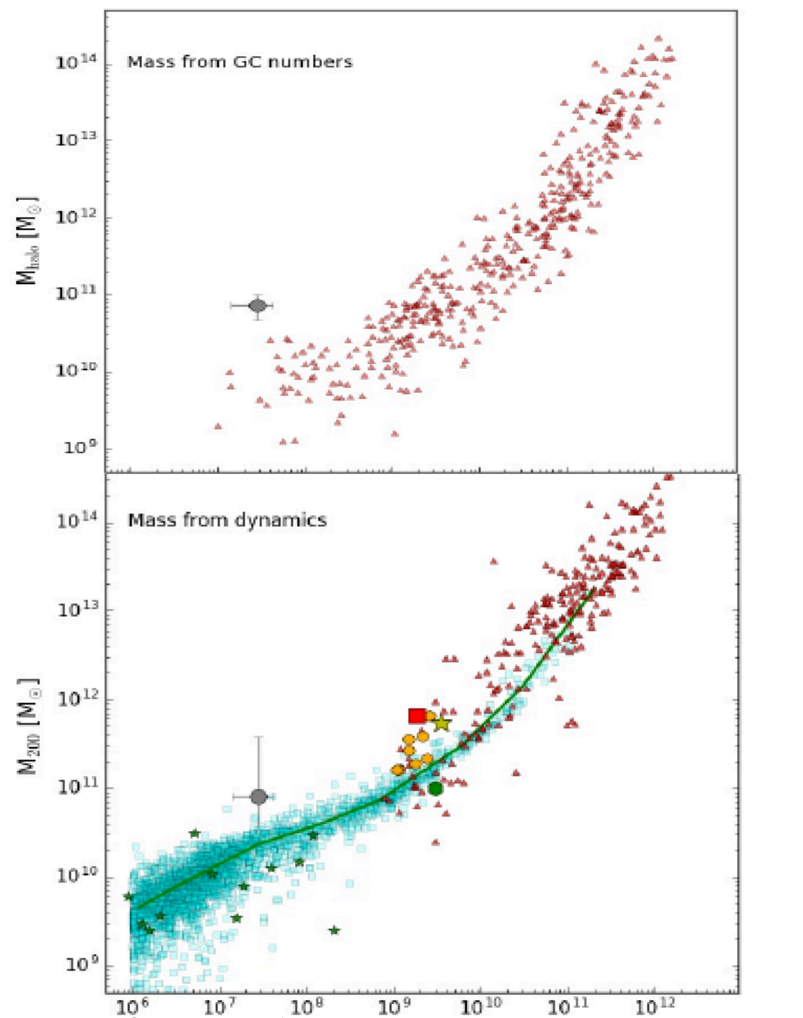




Roman & Truijllo 16 using SDSS Stripe82, See also Mihos+15, Van der Burg+16

Are UDGs dwarfs of failed L*?

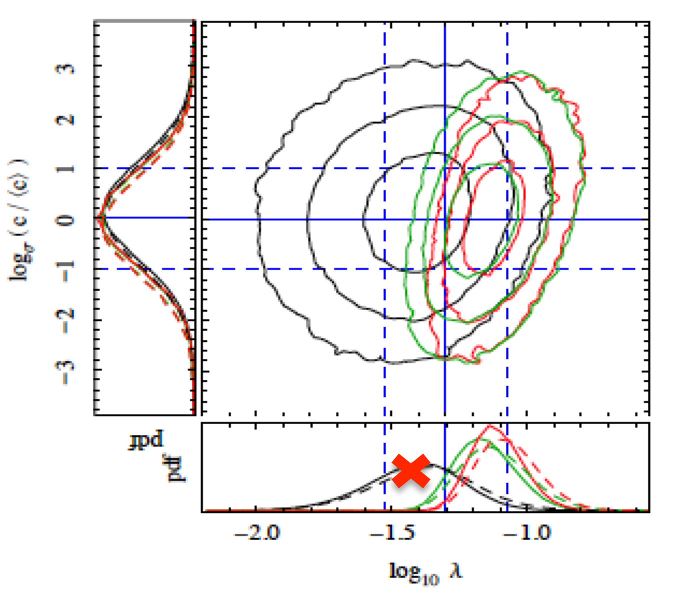
Measured **total mass** of VCC 1287 is (8.0±4.0) x **10^{10}** Msun



Beasley +16

They could be the the **high-spin tail** of an abundant dwarf galaxy population

Amorisco & Loeb16



Peak in spin parameter of haloes log(λ)=-1.45

Summary so far

Ultra Diffuse Galaxies properties:

Found NOT only in clusters

$7.0 < \log(M^*)/Msun < 9.0$

$-16.5 < M < -12.0$

$1.0 < Reff/kpc < 5.0$

$0.5 < n_{sersic} < 1.5$

$0.4 <$ Axis ratio < 1.0

$23.5 < \mu$ / mag arcsec$^2 < 28$

UDGs measured halo mass:

VCC 1287 = $(8.0\pm4.0) \times 10^{10}$ Msun

UDG DF17 = $(1.1\pm0.2) \times 10^{11}$ Msun (Beasley & Truijllo 16)

DF44 = 8×10^{11} Msun (Van Dokkum+16)

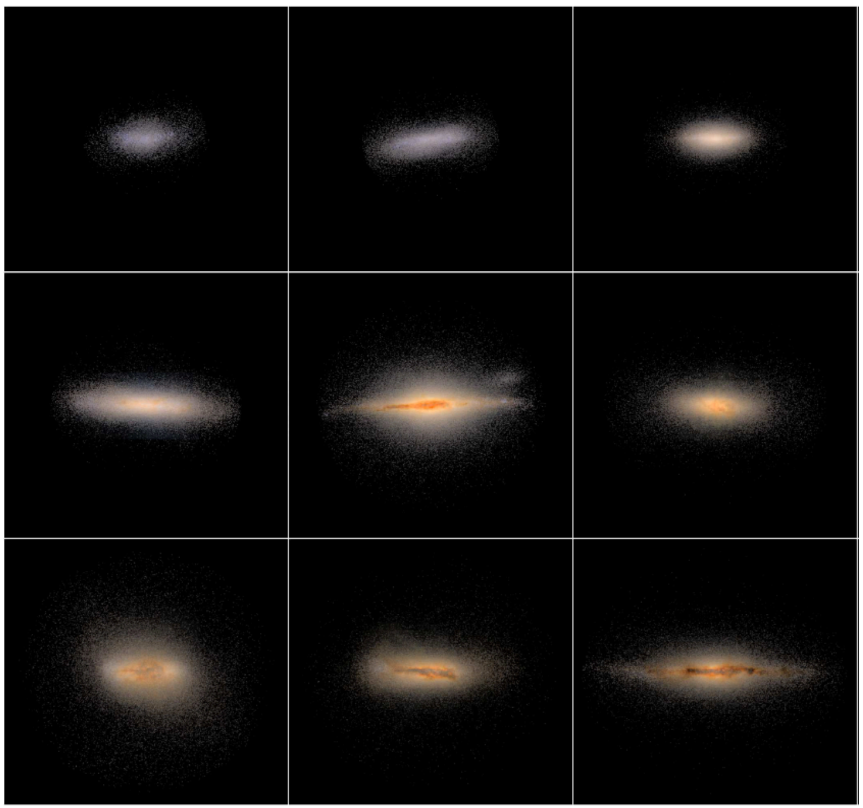
UDGs colors and environment:

Redder in clusters (Koda+15,vD+14),
Bluer in isolation (RT+16)?
Martinez-Delgado+16 => DGSAT I, in the outskirts of the Pisces-Perseus supercluster, With out-of-center, bluer over-density, compatible with a clump of recently formed stars

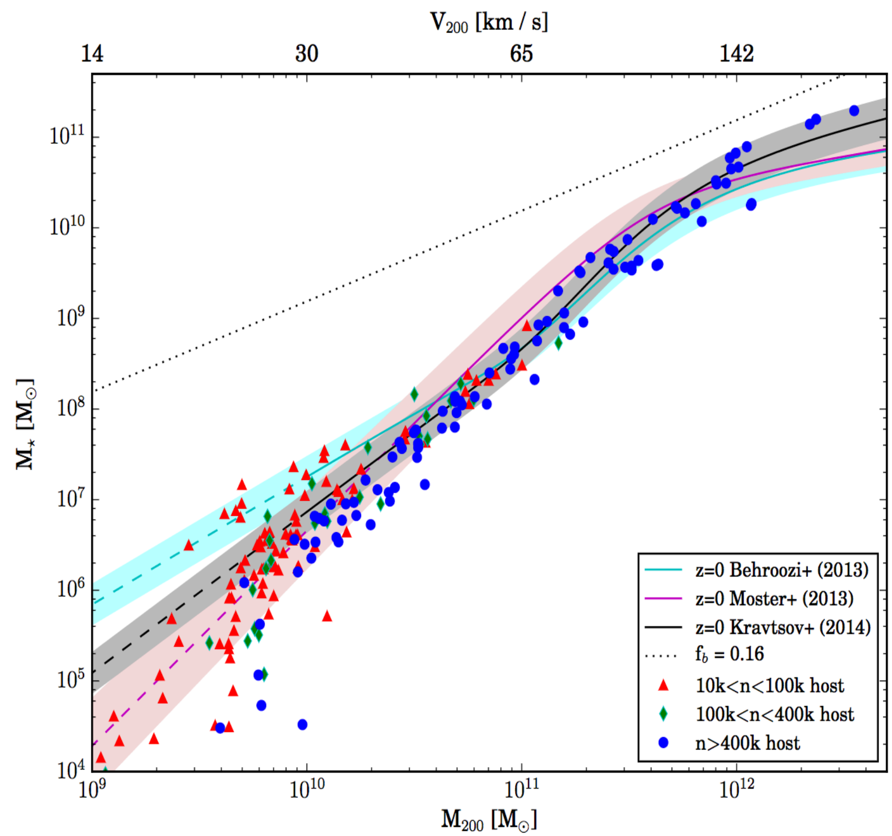
Can we create UDGs in simulations?

NIHAO project – PIs Maccio', Dutton

Like MAGICC galaxies but with improved GASOLINE code, blastwave feedback a la Stinson+06



- Obreja +14

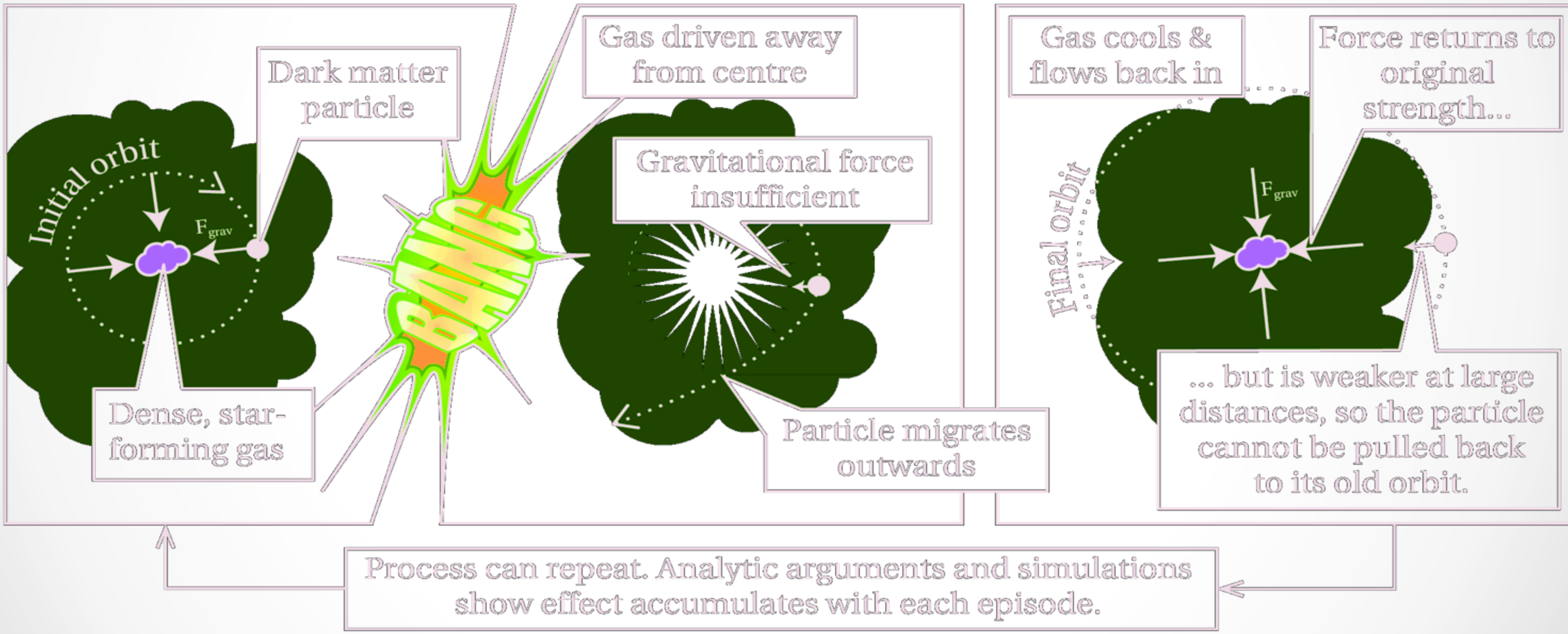


Wang +15


Credit:A. Dutton, NIHAO simulations

DM core formation

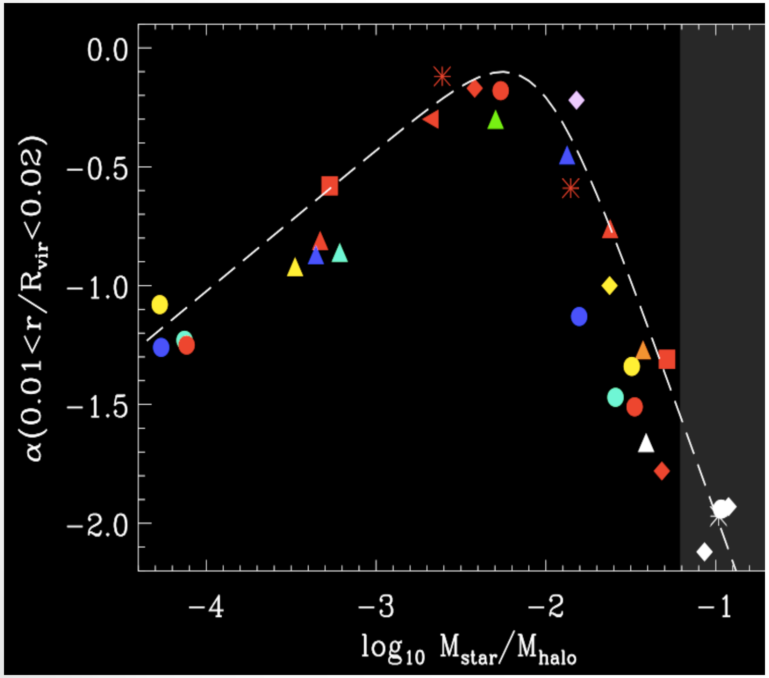
Core formation mechanism -> outflows driven by SNae feedback

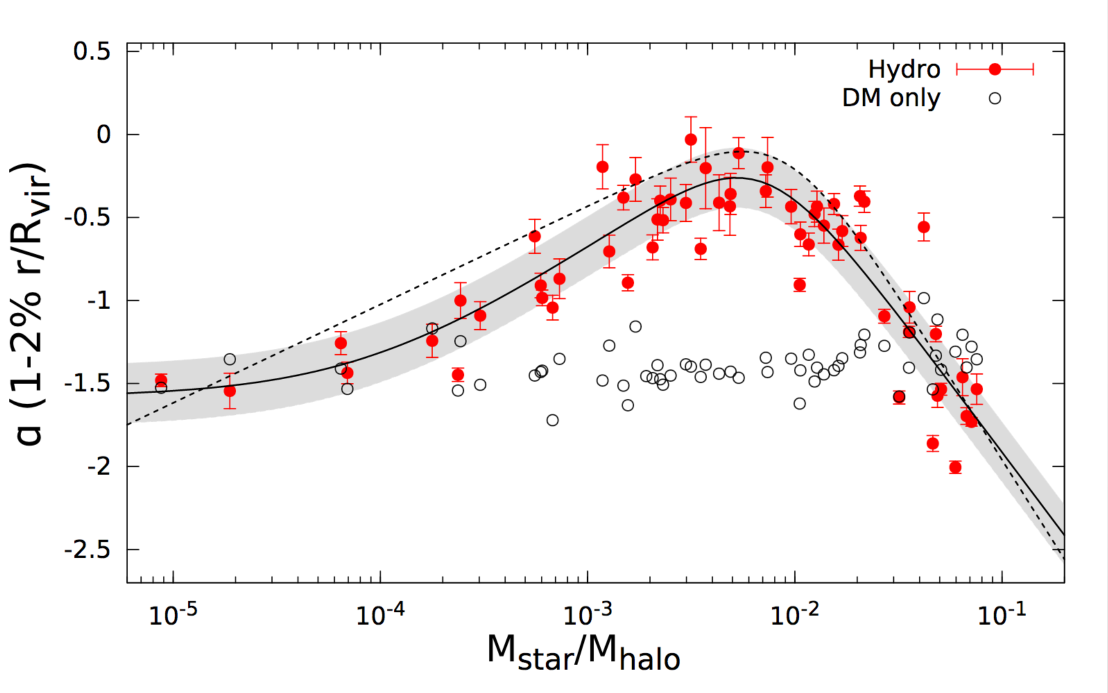


- Pontzen & Governato 14

NIHAO galaxies form DM cores

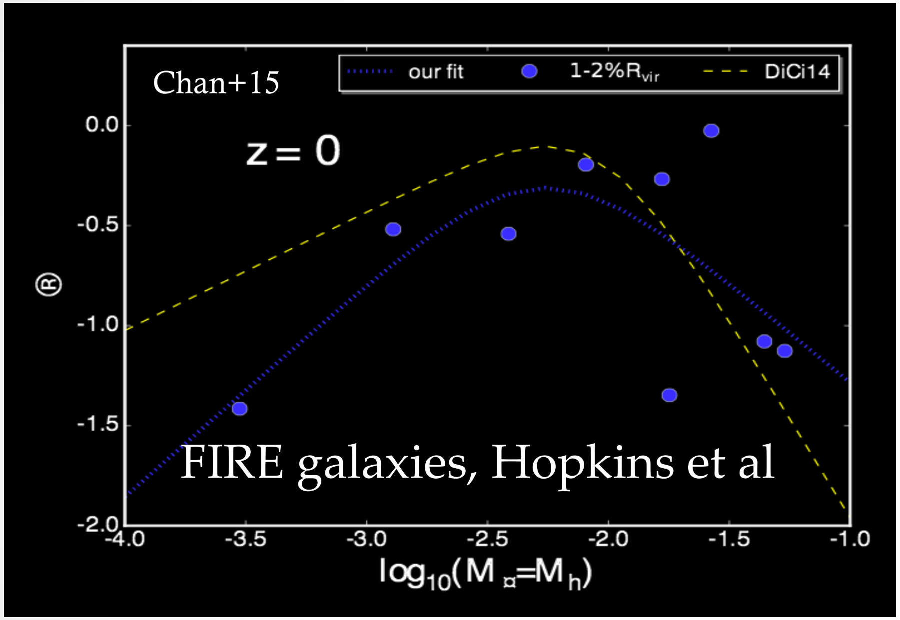
Peak of core formation at log(M*/Mhalo)~-2.4 → M*~$10^{8.5}$ Msun (Di Cintio+14)
Core created during starburst events that launch powerful gas outflows

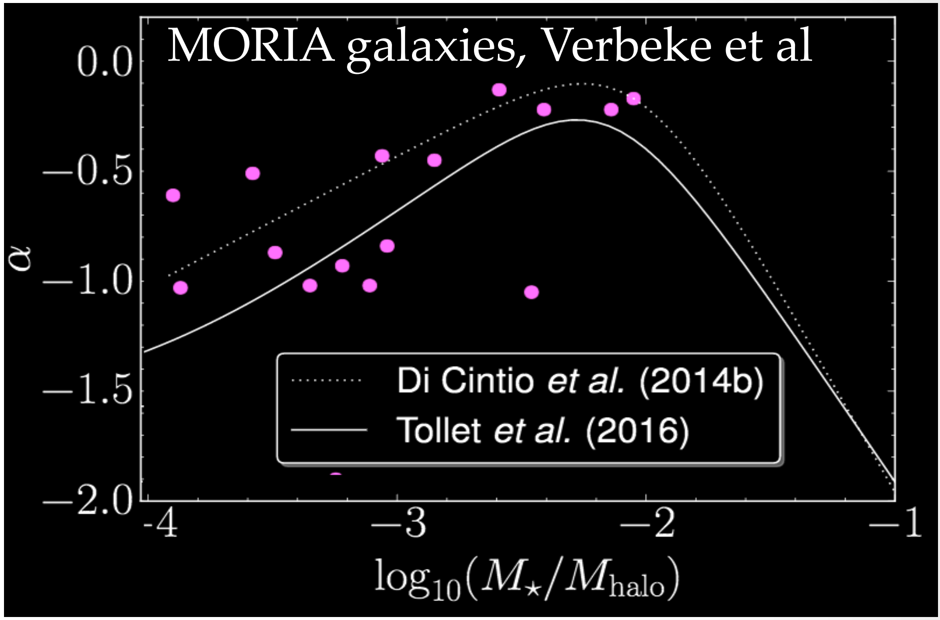




Di Cintio +14 a,b
Tollet+15

Result confirmed with other sims/feedback



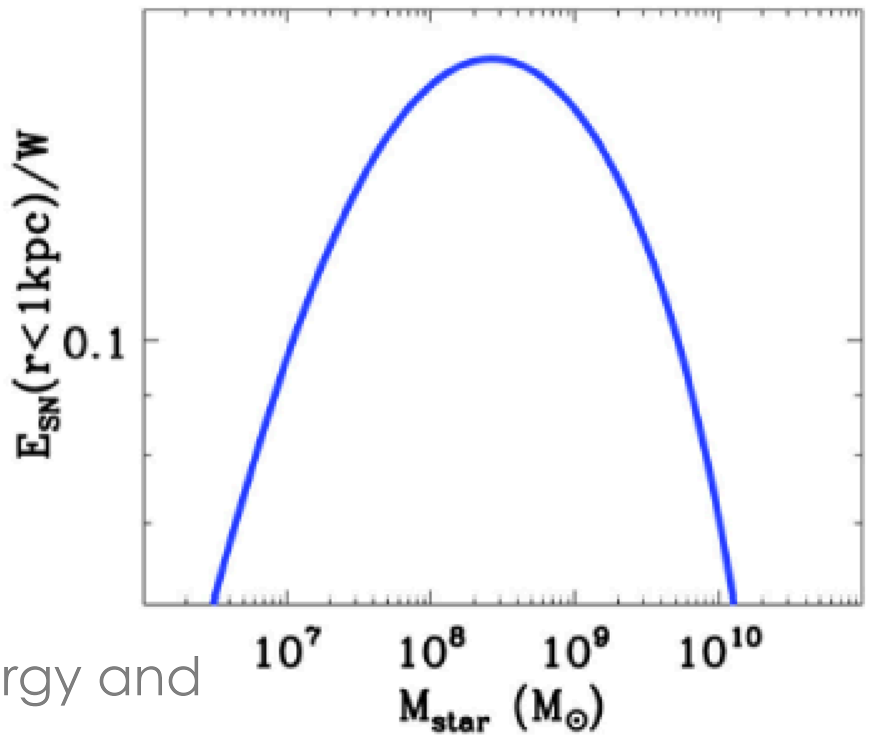


Dark matter profiles determined by two opposite effects: energy from Sne vs underlying gravitational potential of the DM halo

(see also Governato+12,Read+16,Onorbe+15,Brooks&Zolotov12)

Peak in CORE formation efficiency

$$\frac{E_{SN}}{W} = \frac{M^{*}(<1Kpc) \times f_{SN}/\bar{m} \times 10^{51} erg \times \epsilon}{-4\pi G \int_0^{rvir} \rho(r) M(r) r dr}$$

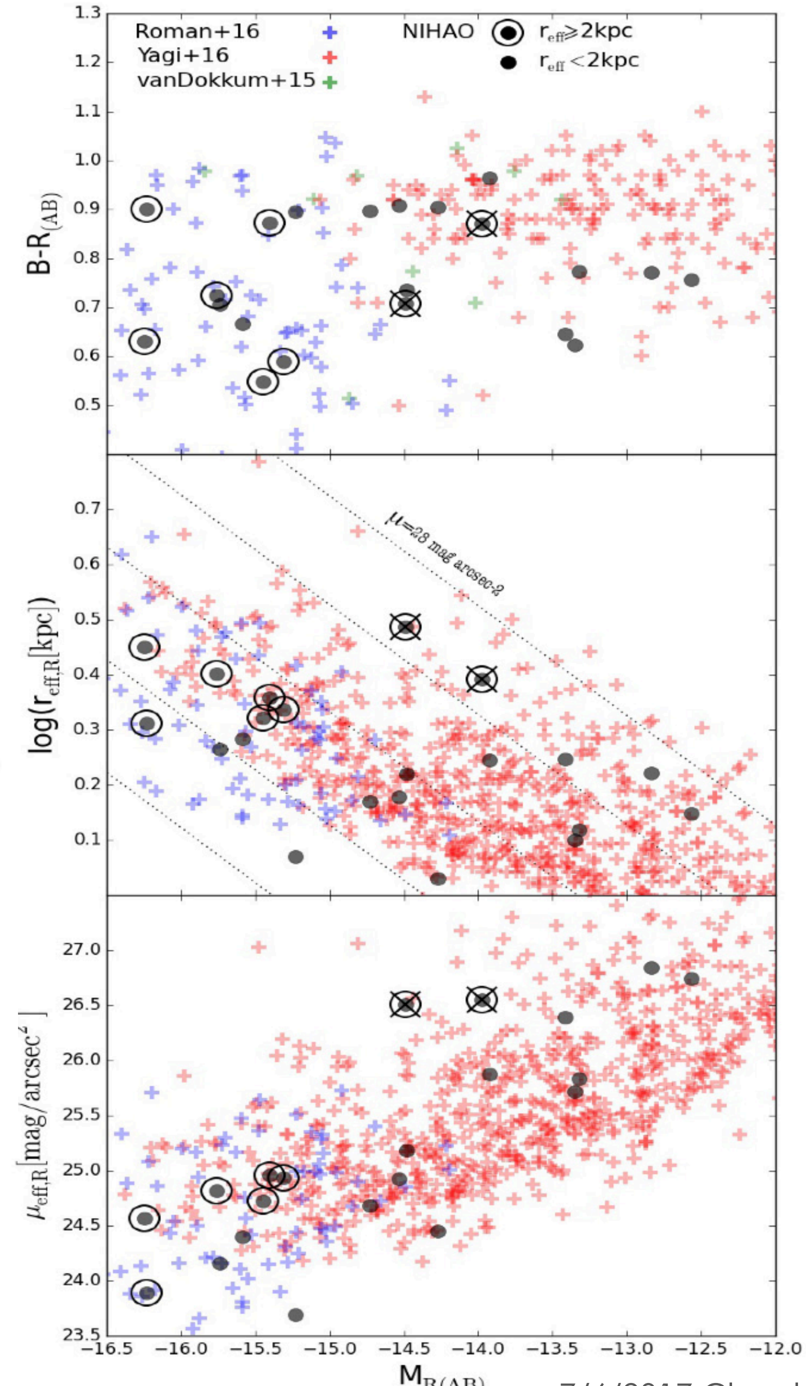


Energy balance between SNe energy and potential energy of NFW halo.
Flattest profiles expected at $M_* \sim 10^{8.5} M_\odot$

Searching for UDGs in NIHAO

X	$\overline{X} \pm \sigma$	$X_{min,max}$
$\log(M^\star[M_\odot])$	7.66±0.42	6.83 , 8.40
$\log(M_{halo}[M_\odot])$	10.53±0.18	10.22 , 10.85
r_e[kpc]	1.87±0.53	1.07 , 3.06
μ_e[mag/arcsec^2]	25.23±0.94	23.69 , 26.84
M_R	-14.61±1.07	-16.25 , -12.57
B-R	0.77±0.12	0.54 , 0.97
n_{Sersic}	0.83±0.27	0.31 , 1.46
γ(1-2%R_{vir})	0.37±0.18	0.01 , 0.78
$\log(\lambda)$	-1.48±0.25	-2.04 , -1.17

They are dwarfs!
And isolated…



- Di Cintio +17

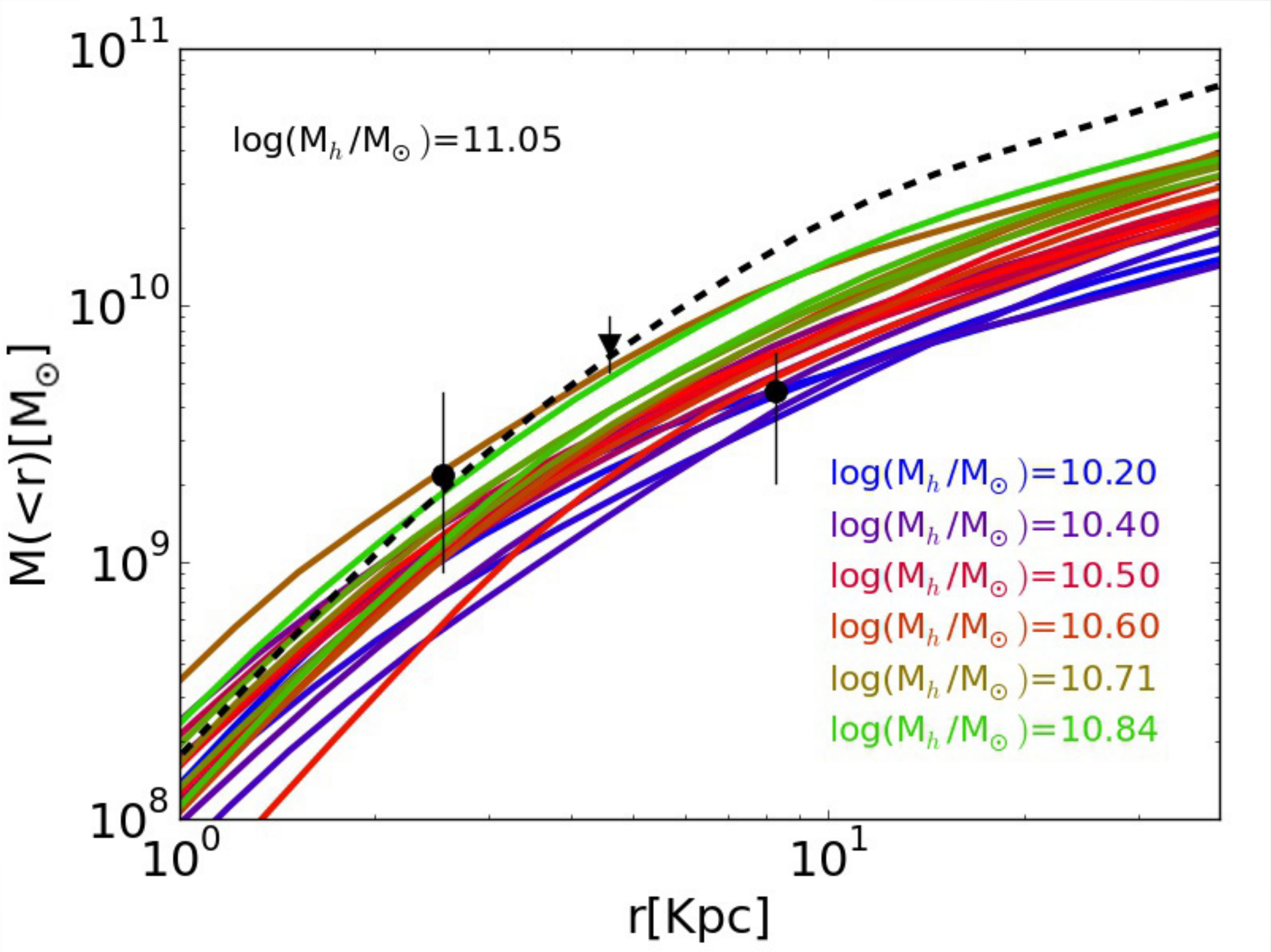
Predictions!

- Halo mass of dwarfs
- Found in isolation
- Gas rich => the largest ones have higher gas fraction
- Bluer in field than in cluster
- Large gas extent
- ALFALFA dark galaxies can harbor UDGs
- Correlation between SFH and size
- Sersic index n~1
- Dark matter core!

Masses of isolated UDGs

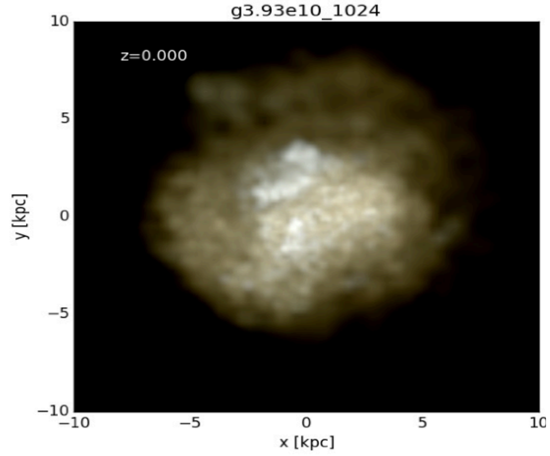
They are isolated dwarfs! Obs data compatible with M_{halo}~$10^{10\text{-}11}$ M_{sun}

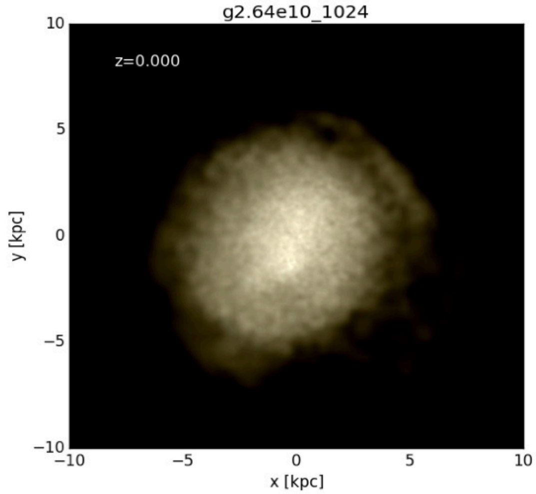
DF44 does NOT live in a $8*10^{11}$ M_{sun} halo

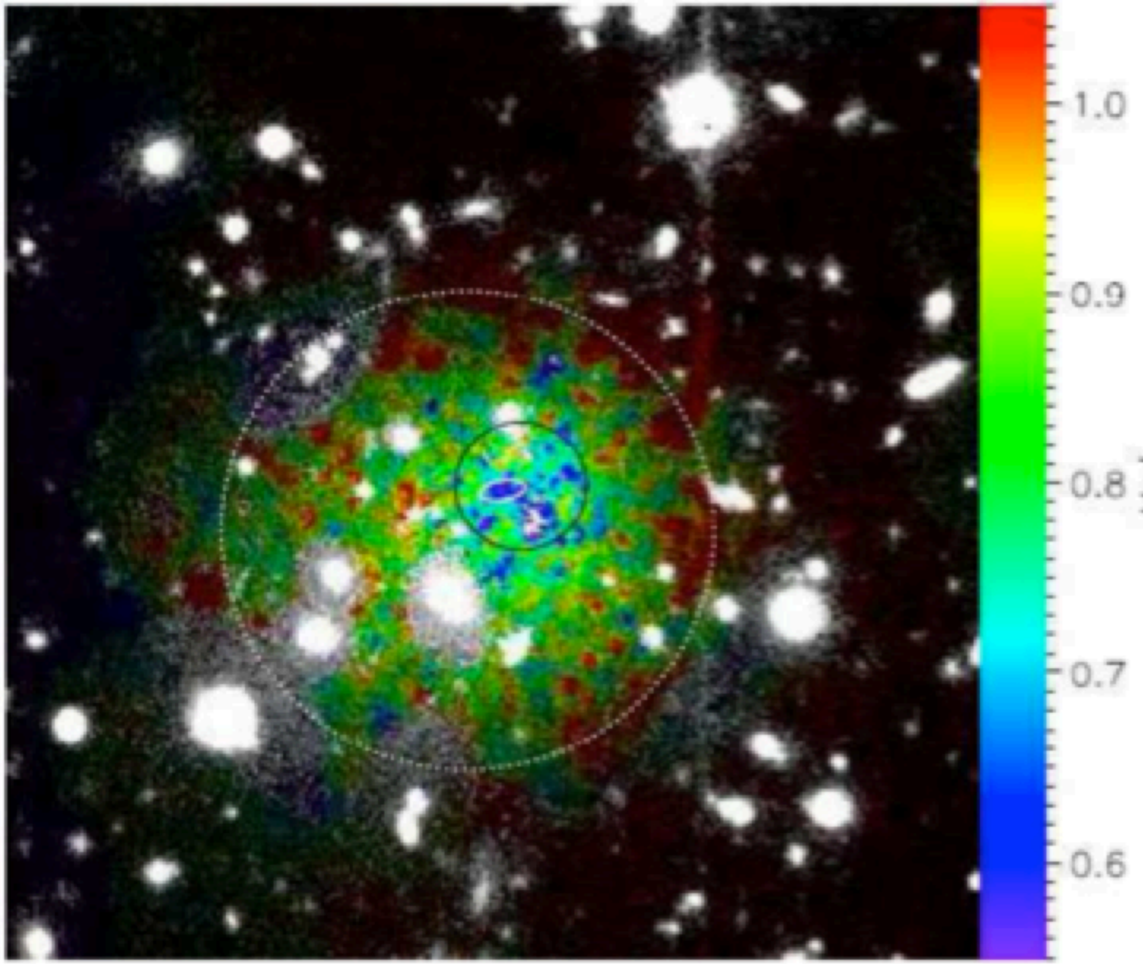


Observed UDG masses from
Beasley+16a,b
Van Dokkum+16

SFH and SB profile of UDGs



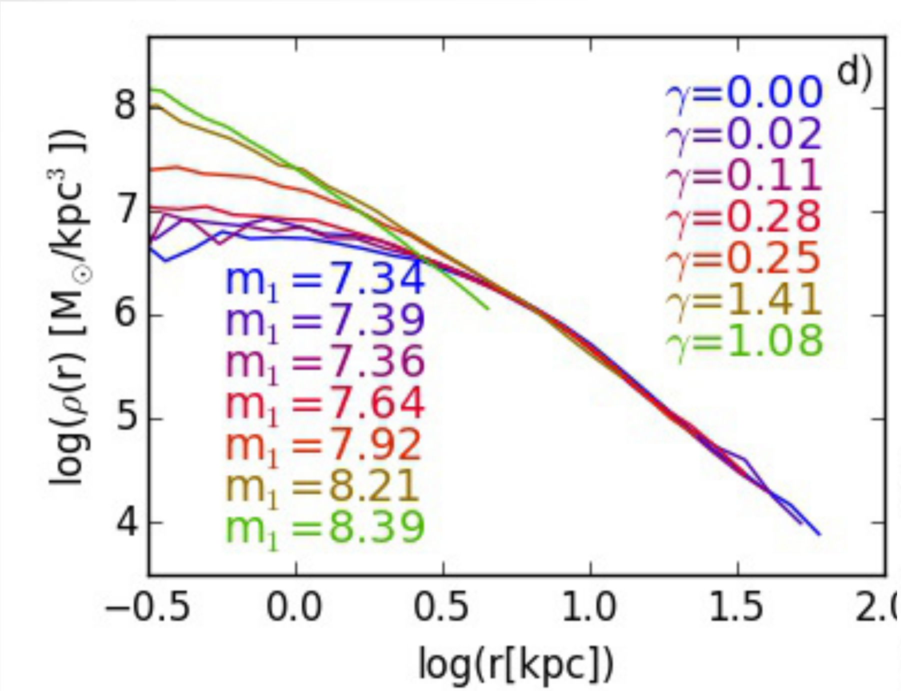




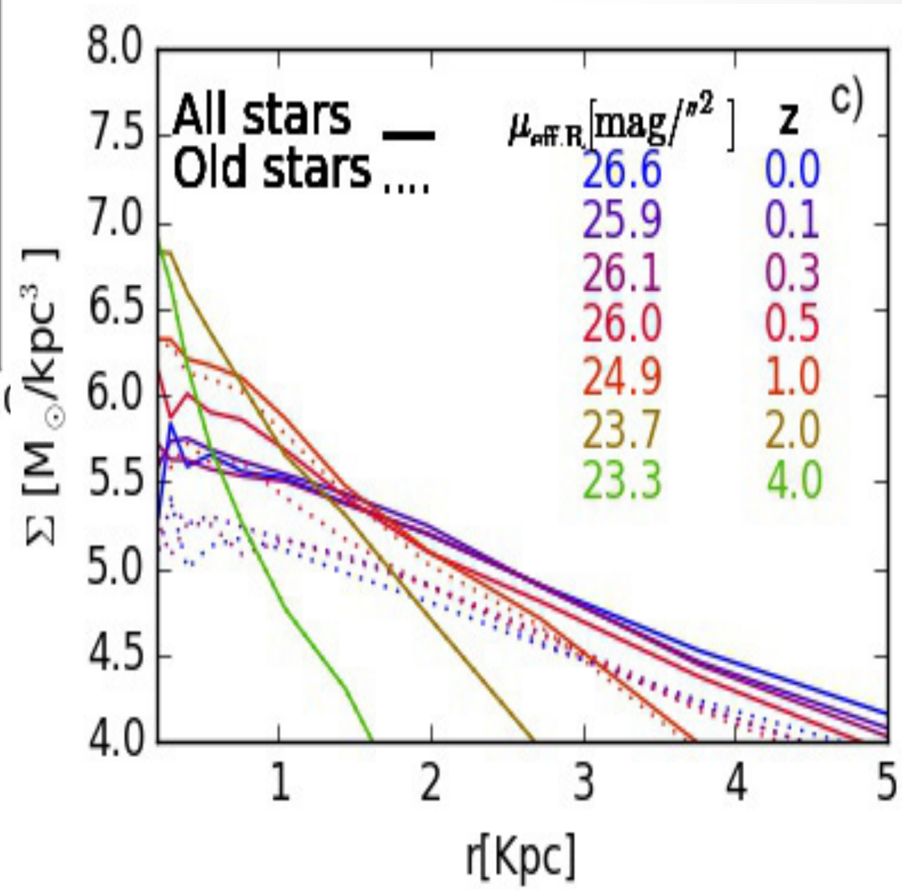
Martinez-Delgado +16

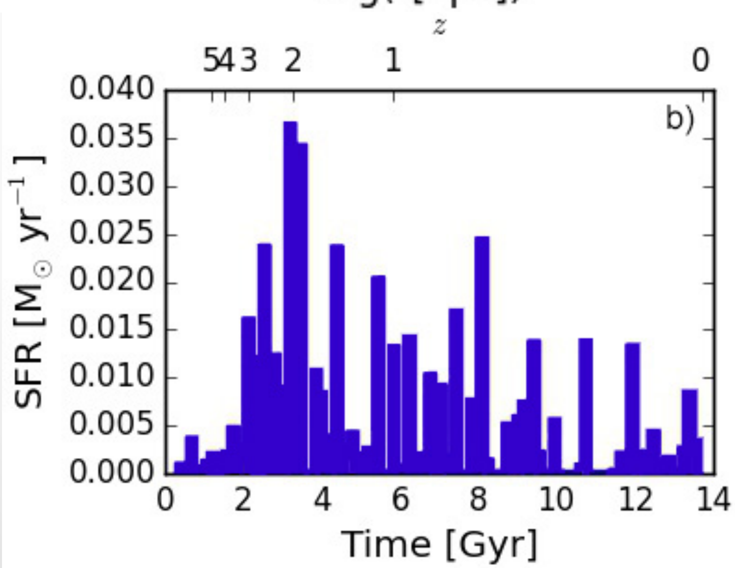
- Di Cintio +17

Formation scenario of UDGs



By z=1 this galaxy is a UDG reff=1.66

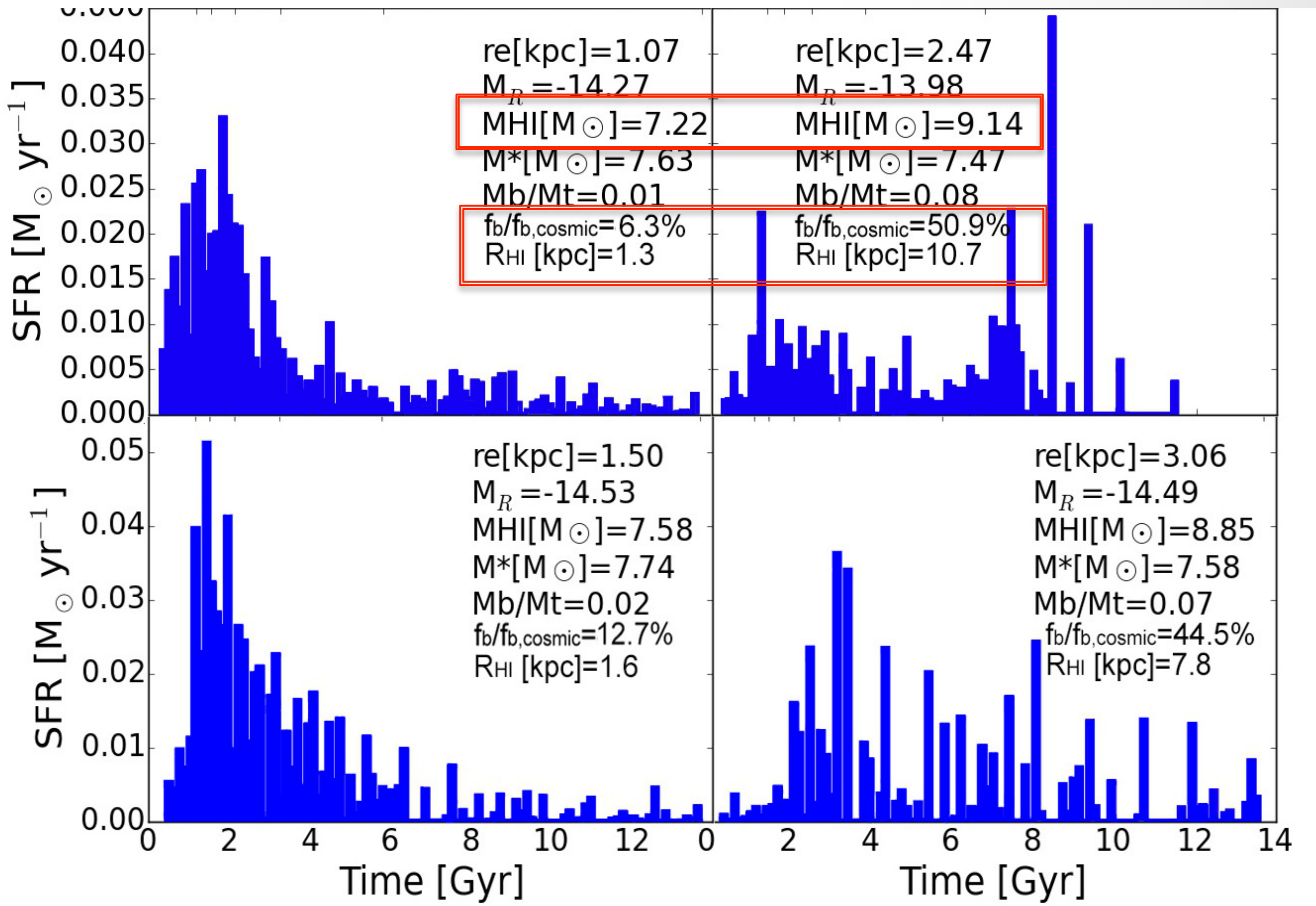




Di Cintio +17

Observational Predictions

The largest isolated UDGs should contain more HI gas, have a larger baryon fraction and a more extended and *bursty* SFH than less extended dwarfs of similar M⋆



UDGs could be the ***dark galaxies*** of the ALFALFA survey

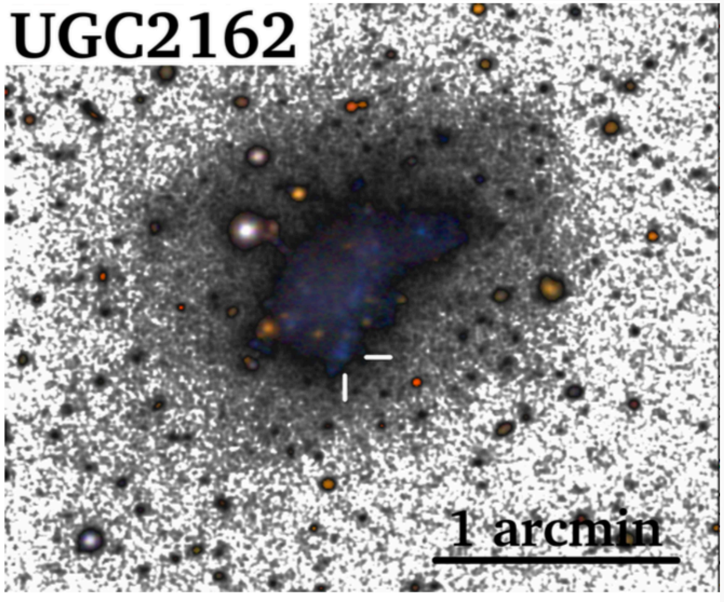
Di Cintio +17

- (see also Onorbe+15, Read+16 for core size dependence on SFH in smaller haloes)

Observations of Isolated UGDs

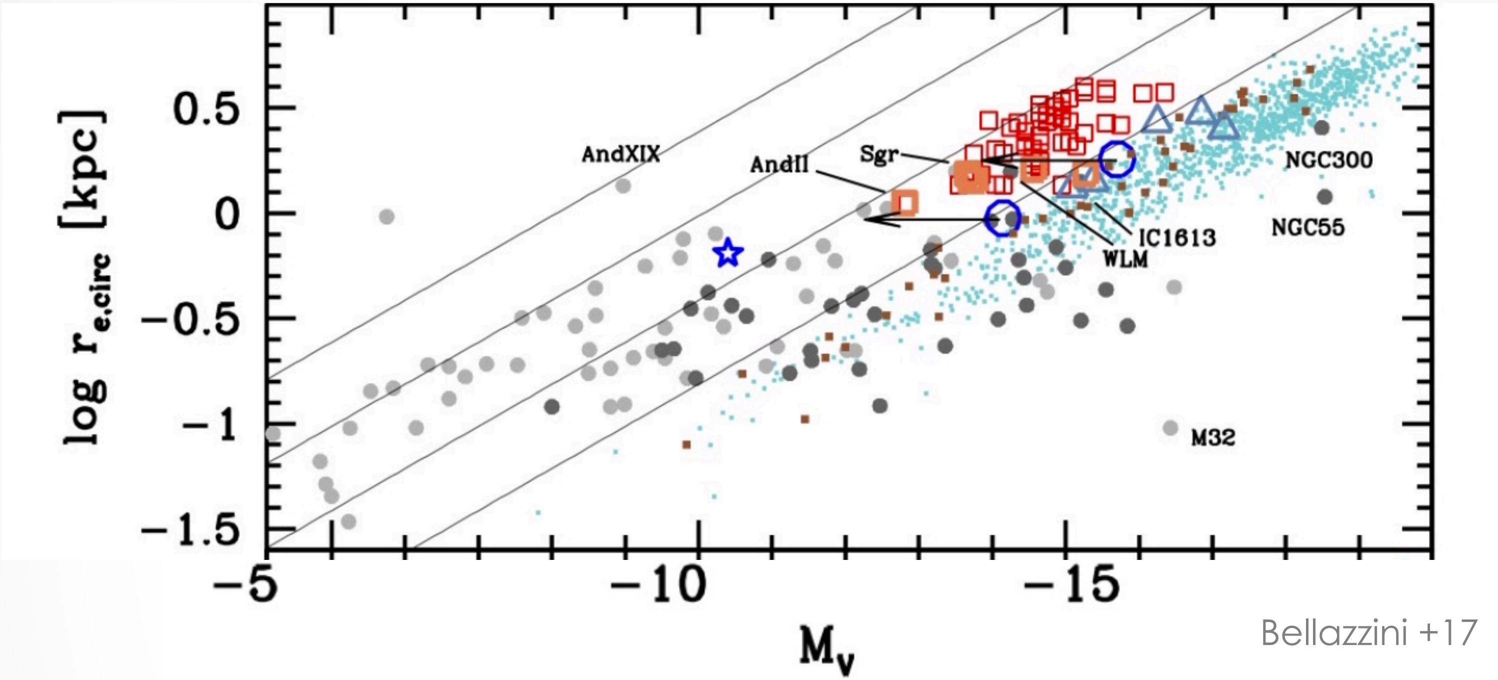
- Nearest UDG:

UGC2162 irregular (Trujillo+17)
Observed within IAC Stripe 82
Legacy Survey
Isolated at 12 Mpc (M77 group)
$M^* \sim 2\times10^7\ M_\odot$ $M_{HI} \sim 10\times M^*$
derived $M_{halo} \sim 8\times10^{10}\ M_\odot$
SFR ~0.01 $M_\odot$/yr.



NIHAO simulations predict the dwarf-like halo mass of UGC2162, its stellar mass, gas mass, Sersic index, effective radius, absolute magnitude, SFR, irregular appearance and its off-center-star formation episodes

Observations of Isolated UGDs



Bellazzini +17

SdI-1 - SdI-2 the most isolated UDGs identified ➔isolated field dwarfs can evolve into UDGs

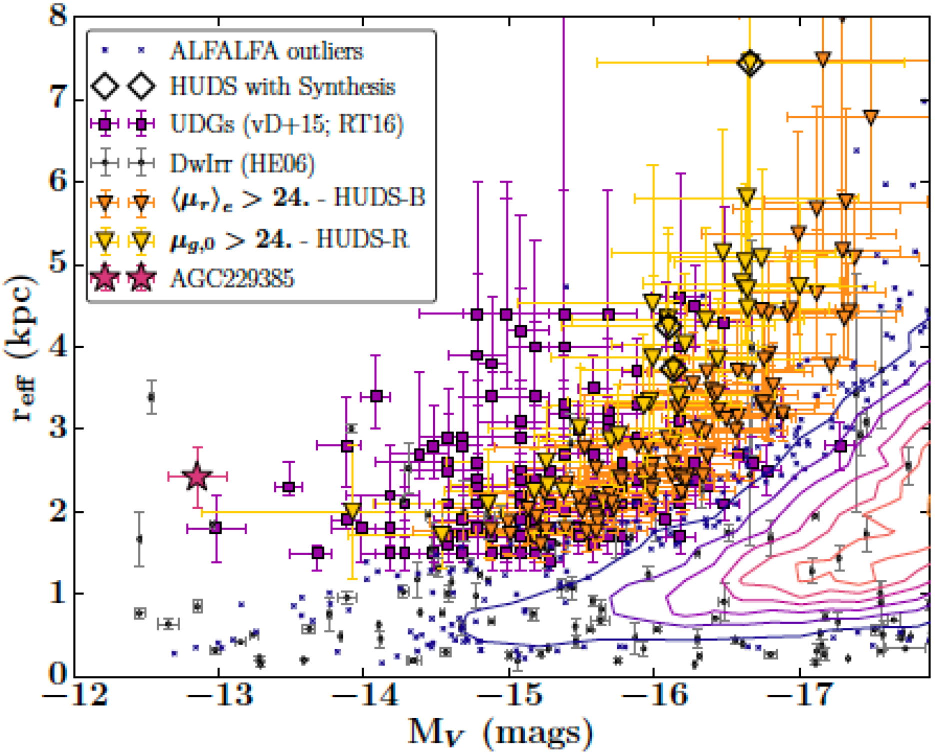
MHI/M⋆ ~ 90, typical of almost-dark dwarfs

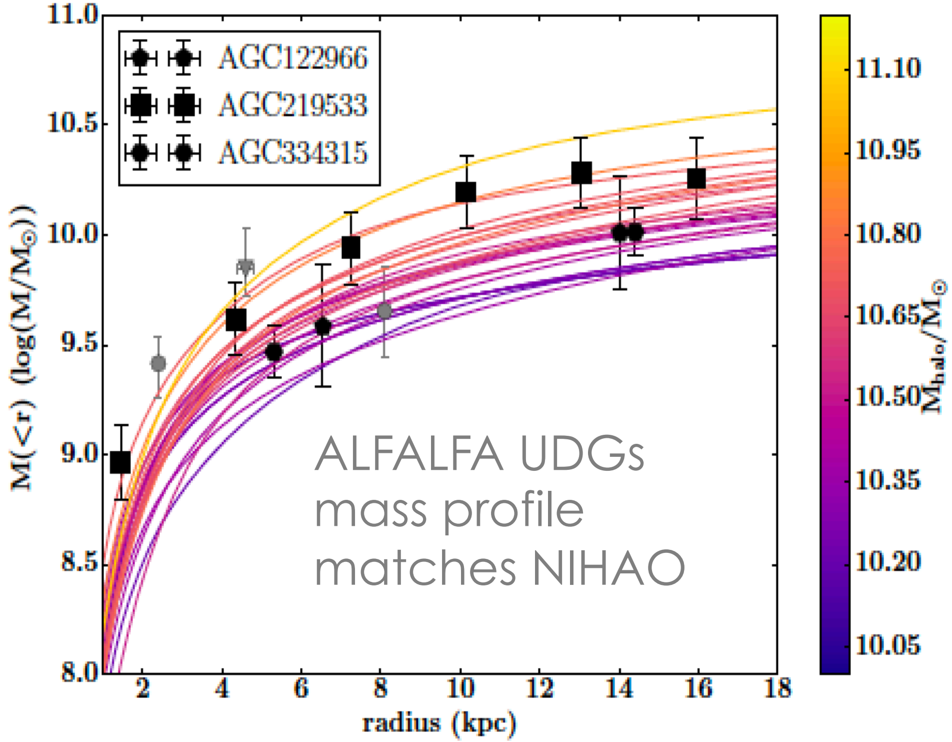
Evolutionary link between dwarf irregulars and UDGs

it is expected to take place also in the field. A specific prediction of the simulations by Di Cintio et al. (2017) is that UDGs evolved in isolation should have larger gas content than regular dwarfs of similar stellar mass. It is intriguing to note that this prediction is vindicated by the the very high H I/M_* ratio observed in SdI-1, the most extended among our two isolated, star-forming UDGs.

HI-bearing isolated UDGs

115 isolated UDGs found in ALFALFA survey. Bluer than in clusters, supporting scenario in which UDGs form in isolation and are then accreted into clusters

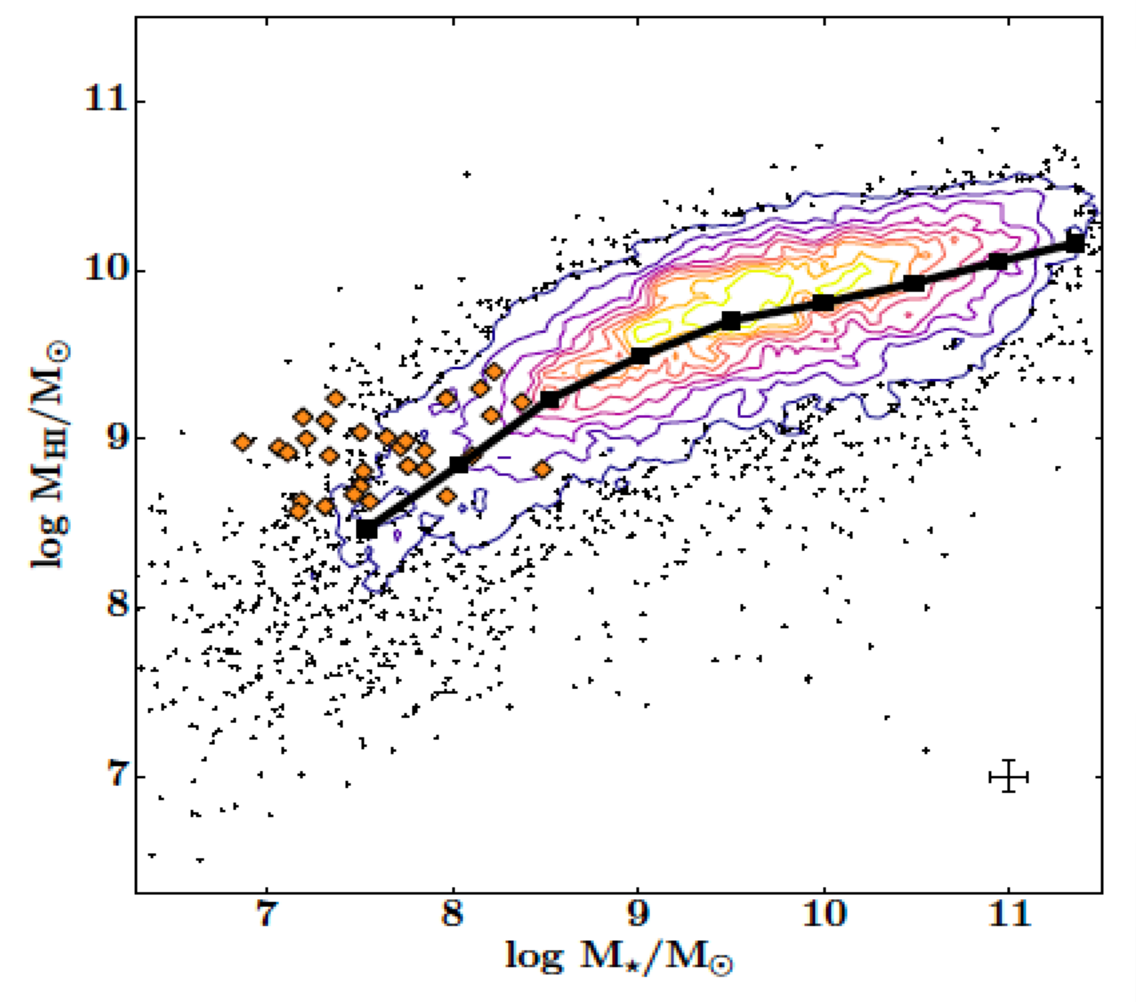




Leisman +17 using ALFALFA data

Gas content of ALFALFA-UDGs

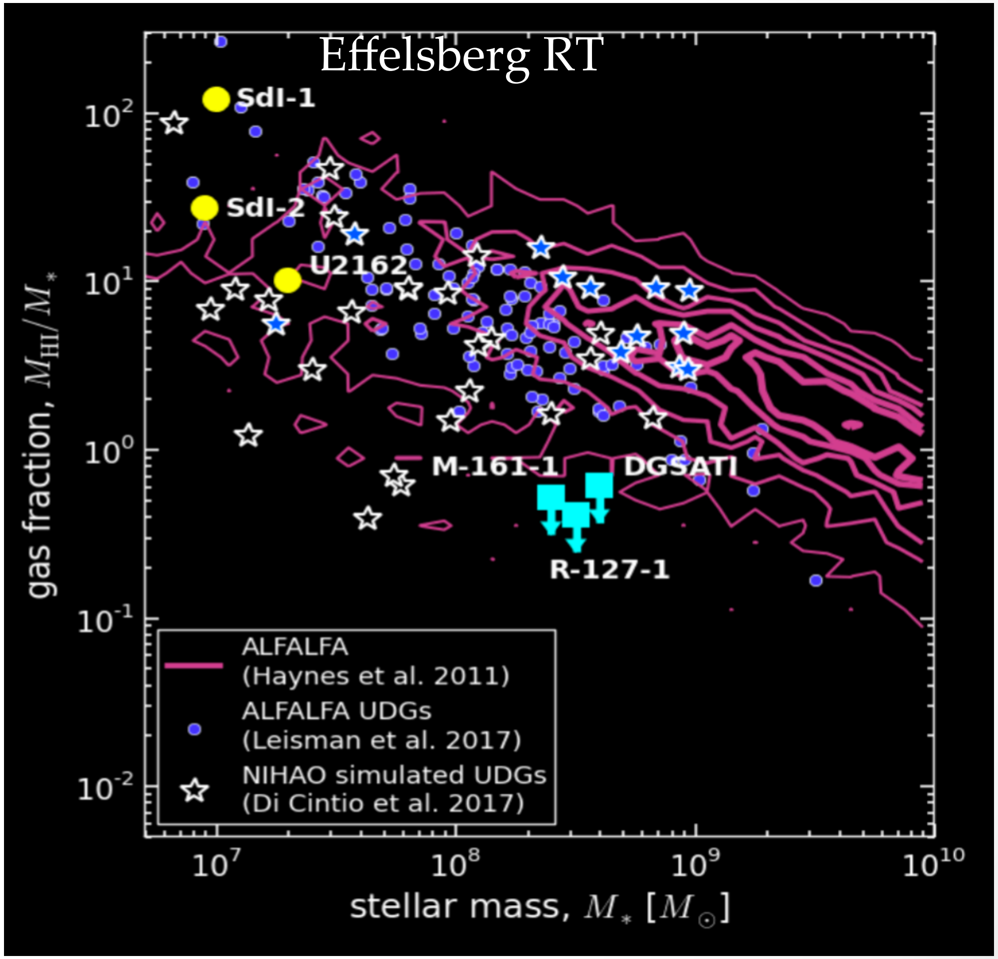
Isolated UDGs tend to be HI-rich relative to their stellar mass



- Leisman +17

Several formation mechanisms for UDGs?

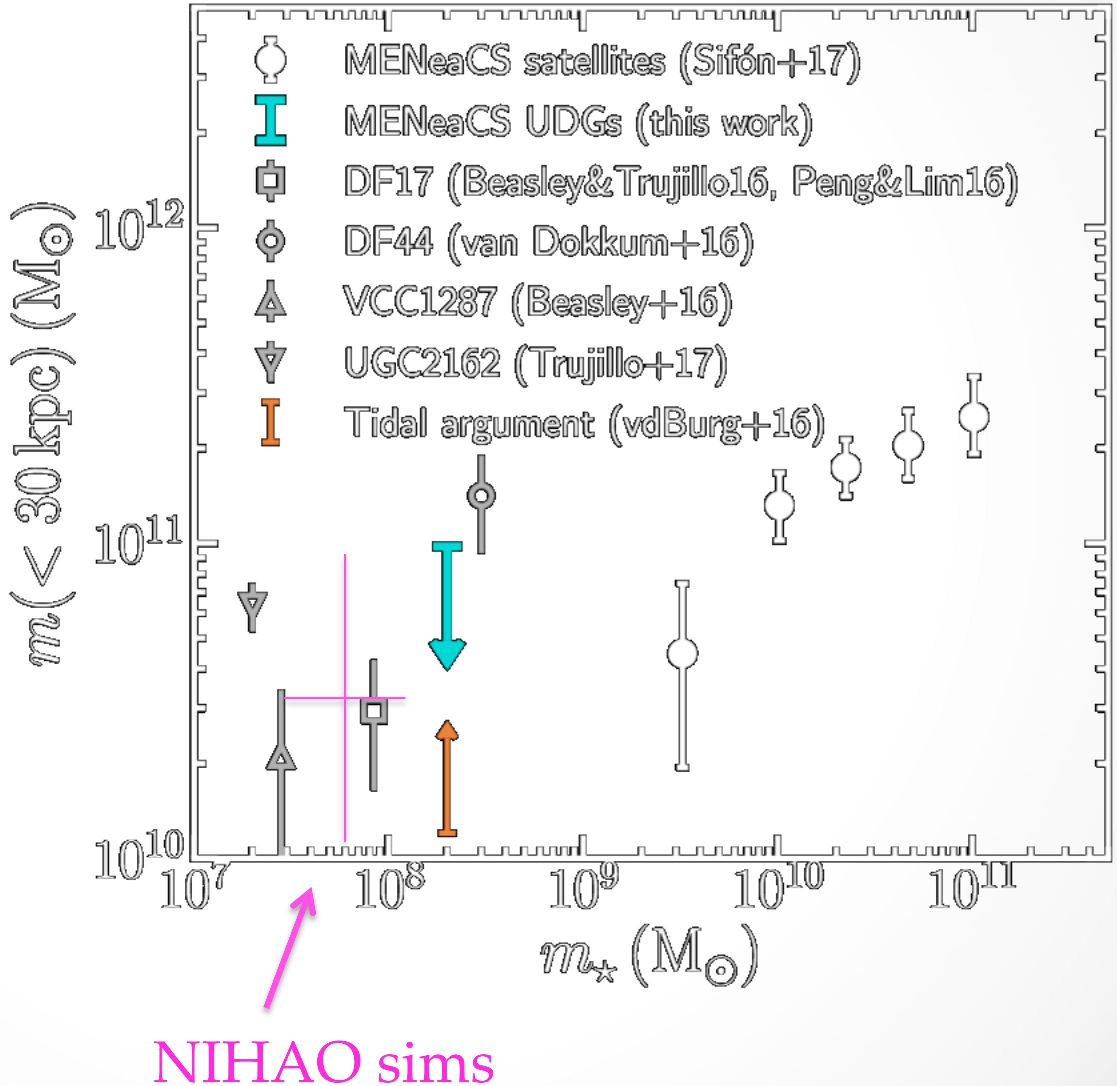
Some Isolated UDGs have high gas fractions, others seems to be gas-poor

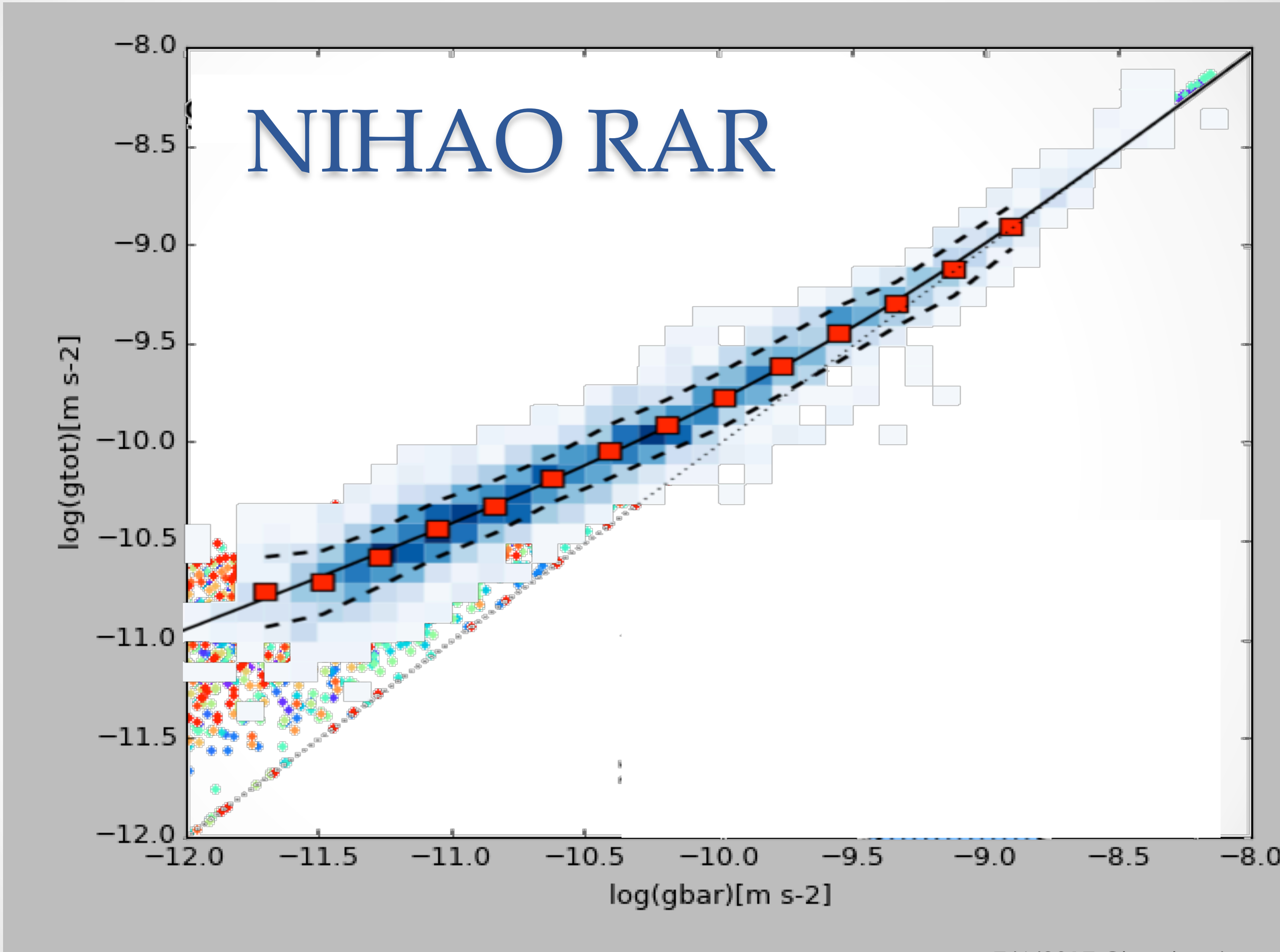


Mass of cluster UDGs with lensing

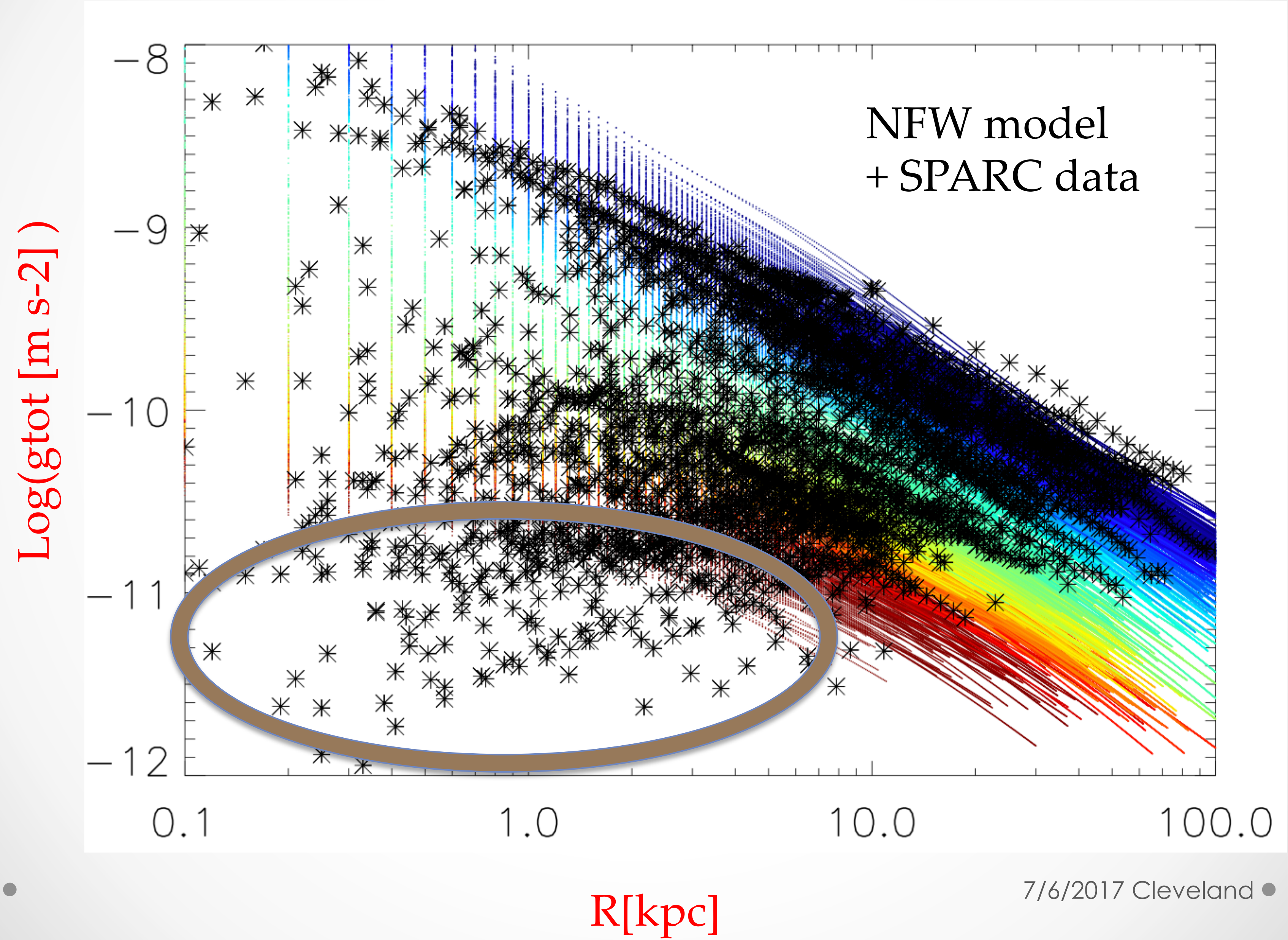
Weak lensing–inferred upper limit on the average halo mass of 784 UDGs selected in 18 clusters at z<0.09

log*m*UDG(*r*<30kpc) ≤10.99 M☉ at 95% credibility, implying an effective virial mass log*m*200≤11.80 M☉

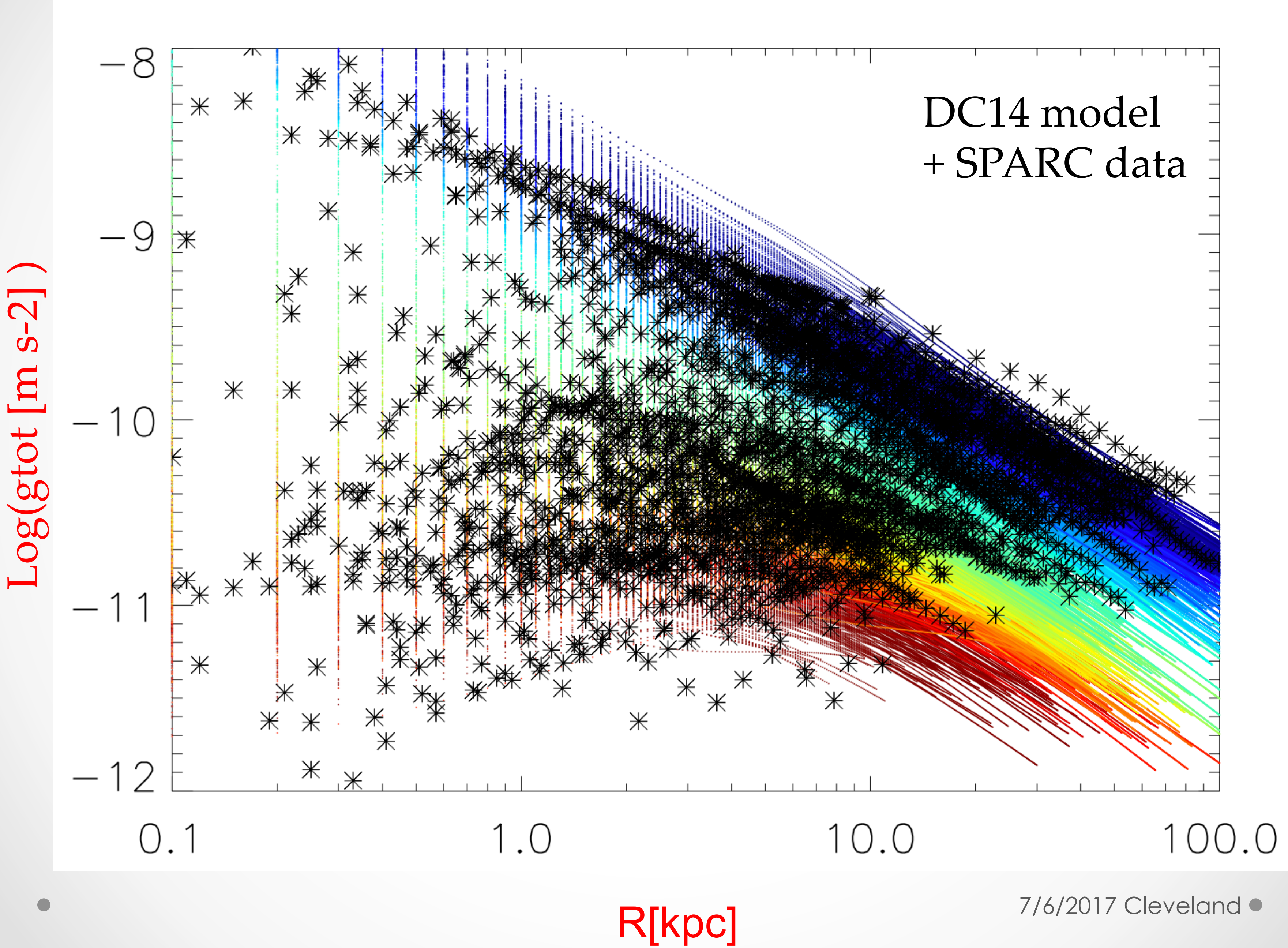



NIHAO RAR
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
log(gtot)[m s-2]
−12.0
−11.5
−11.0
−10.5
−10.0
−9.5
−9.0
−8.5
−8.0
log(gbar)[m s-2]

Can we explain the MDAR without DM cores?...not really.. gtot CAN be < 10^{-11}



Can we explain the the acceleration profiles of Galaxies with DM cores?
Much better!



Conclusions & Future

- UDGs are a natural outcome of LCDM that includes the role of baryons at modifying the DM haloes of galaxies: DM (and stellar) core formation is most efficient exactly in the range of UDGs
- UDGs are the dwarf tail of Low Surface Brightness galaxies: halo masses compatible with being dwarfs
- UDGs are found in clusters and isolation: in the SPARC sample of local HI-rich galaxies, 20% of objects with $10^7 < M^*/Msun < 10^{8.5}$ have re>2 kpc
- Explore the role of environment, how does it affect colors and gas content?
- Abundance of UDGs in the field: KiDS and DES survey

Conclusions & Future

- Derive UDGs SFH to study the link between the SFH shape and the final distribution of dark matter, stars and gas. Is there on-going SF in the most expanded UDGs ? How does the SFH impact the UDG sizes and evolution?

- Proposal submitted with scientists @ IAC-Tenerife to derive the first SFH of UDG
  Using MUSE instrument to obtain SFH from integrated spectra
  2 morphologically similar UDGs, with similar stellar masses but different colors

DIGESTIVO

DIffuse **G**alaxy **E**xpansion **S**igna**T**ures **I**n **V**arious **O**bservables project: understanding the emergence of diffuse, low surface brightness galaxies and the link to their dark matter haloes

MARIE CURIE ACTIONS