Do we need to move beyond Cold Dark Matter?

Andrea V. Macciò

NYUAD, MPIA

October 6th, 2020

جامعة نيويورك أبوظبي

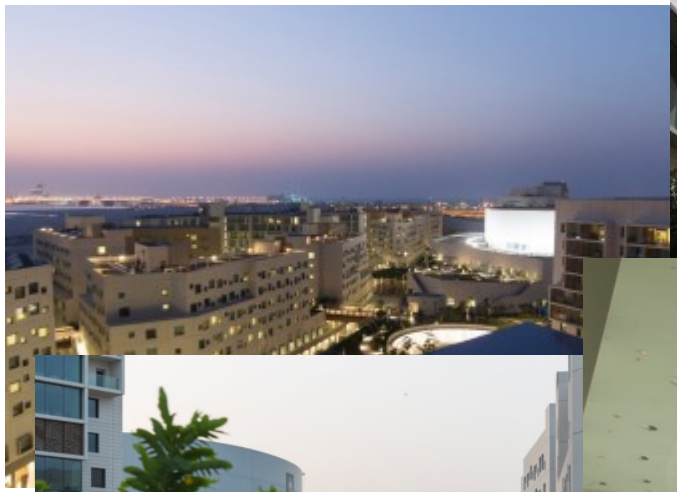
NYU | ABU DHABI

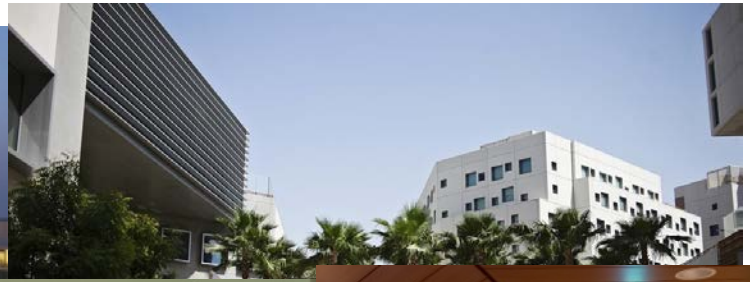
Where?


Denmark
United Kingdom
Ireland
Birmingham
London
Belarus
Poland
Germany
Ukraine
Austria
France
Romania
Italy
Kazakhstan
Caspian Sea
Uzbekistan
Kyrgyzstan
Portugal
Spain
Portugal
Spain
Greece
Turkey
Turkmenistan
Oran
وهران
Casablanca
الدار البيضاء
Tunisia
Syria
Afghanistan
Iraq
Iran
Morocco
Pakistan
Algeria
Libya
Egypt
Nepal
Western Sahara
Saudi Arabia
India
Oman
Mauritania
Mali
Niger

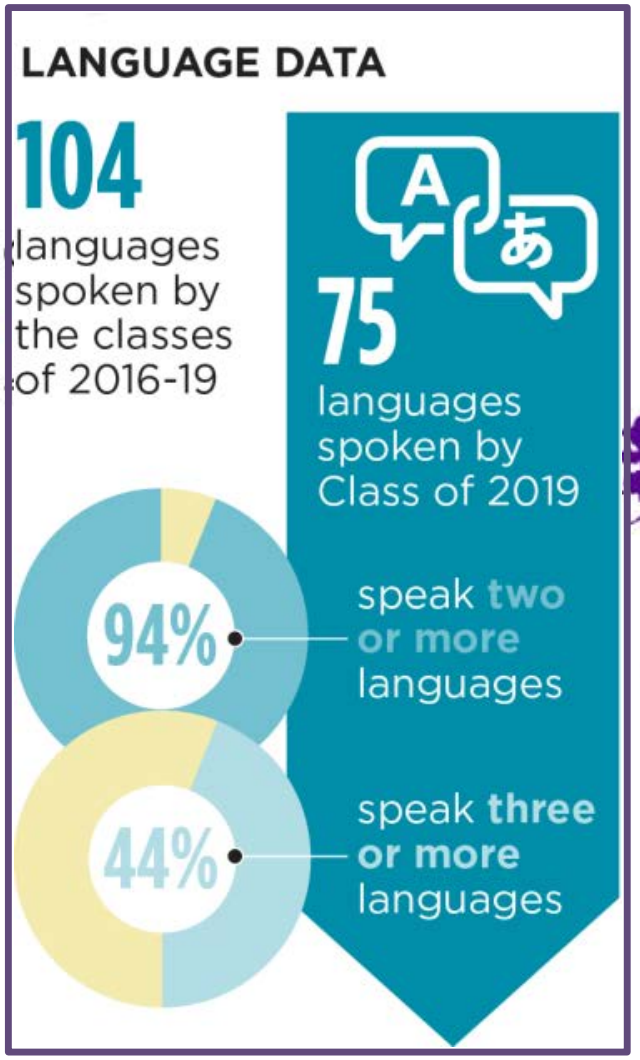
Where again?

NYUAD





NYUAD


LANGUAGE DATA
104
languages
spoken by
the classes
of 2016-19
75
languages
spoken by
Class of 2019
94%
speak two
or more
languages
44%
speak three
or more
languages


113
nationalities
(including dual nationalities)

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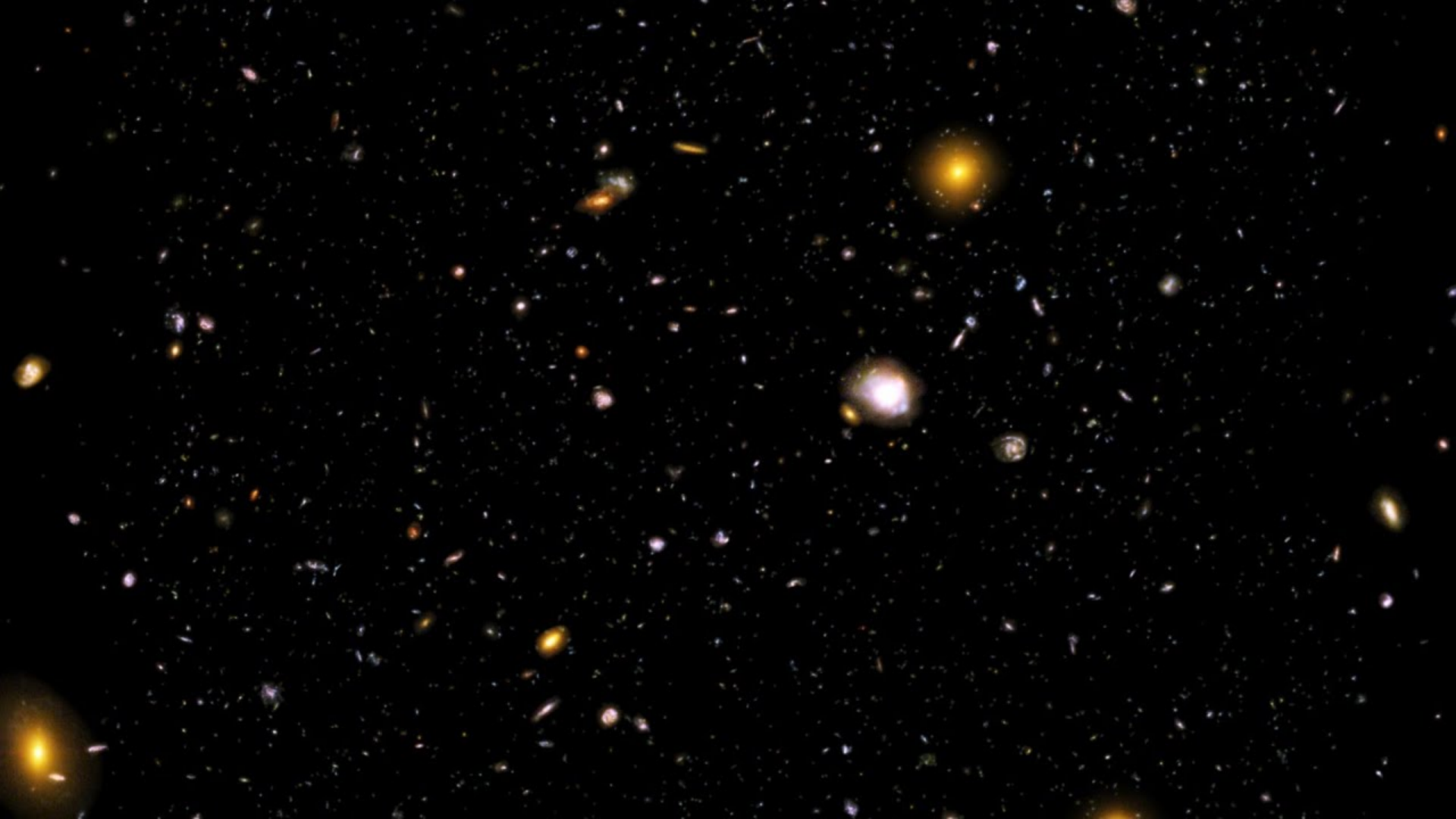
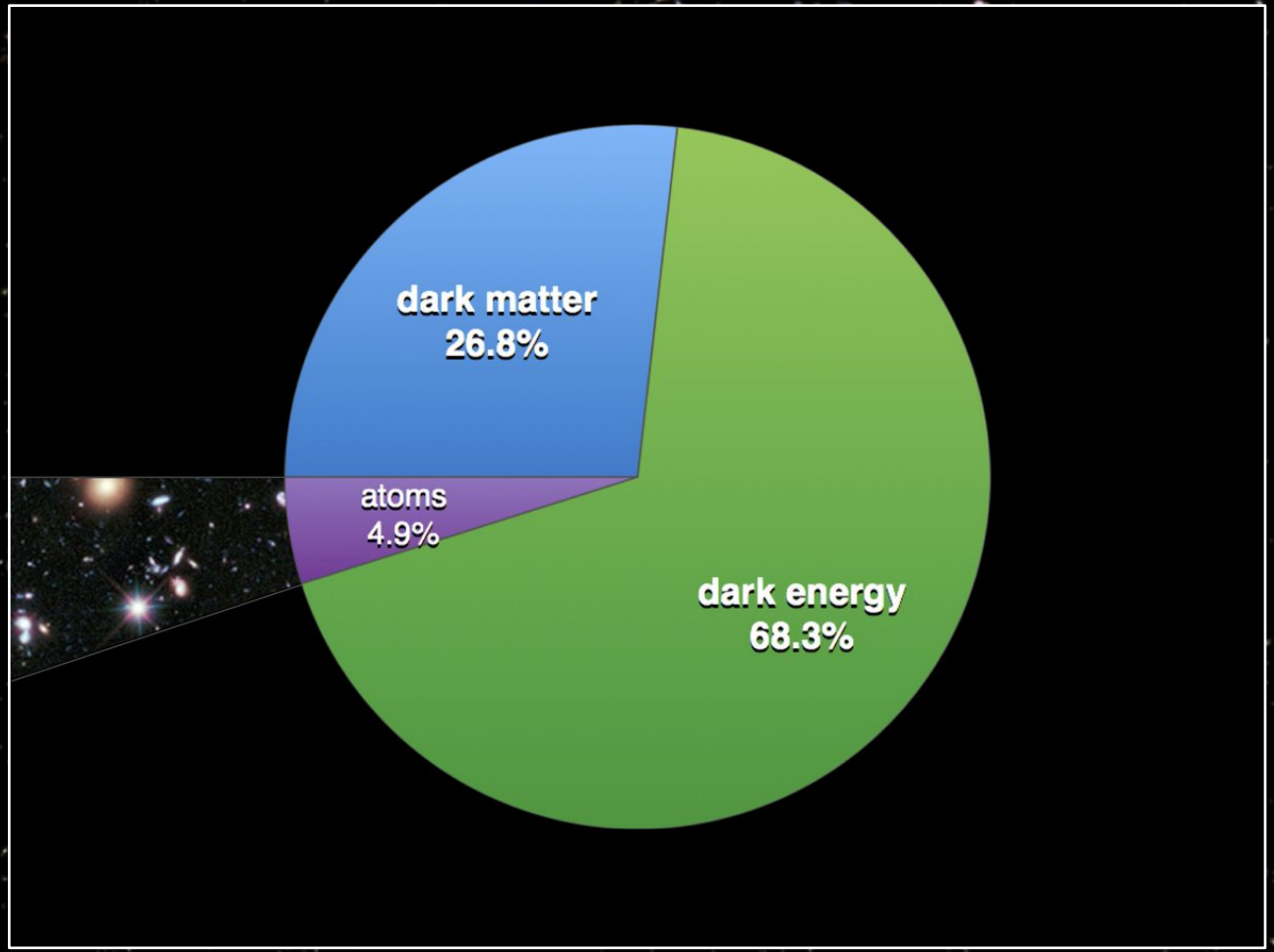
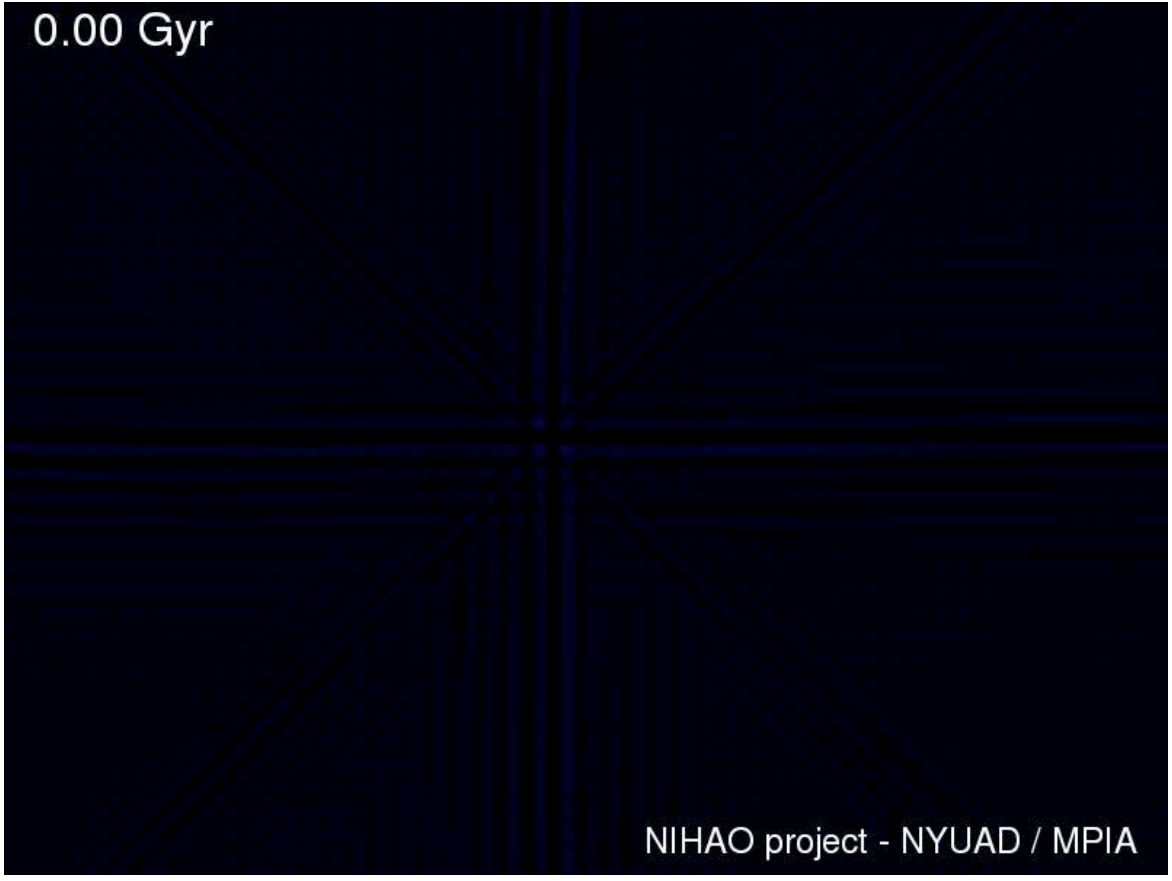



dark matter
26.8%
atoms
4.9%
dark energy
68.3%

Cold Dark Matter model

- Negligible thermal velocities at decoupling (Cold)
- Interacts only via gravitation with ordinary matter (Dark)
- Negligible cross section for scattering (Collisionless)

Structure formation

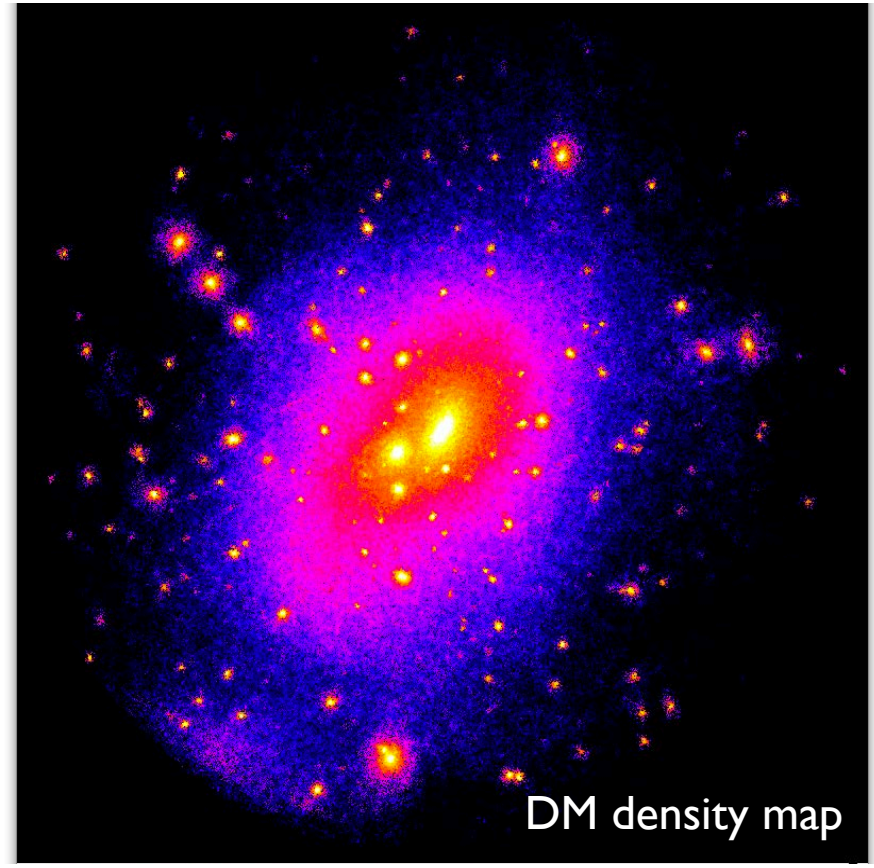


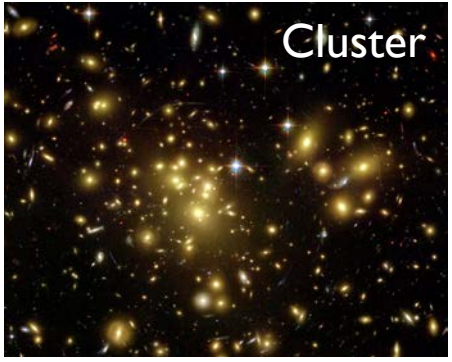
CDM issues (?)

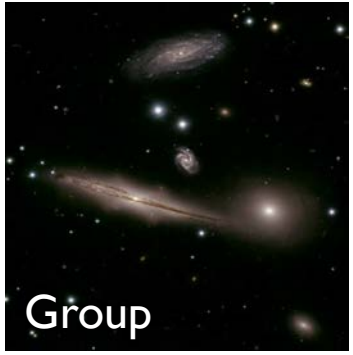
All issues come from a single “fact”

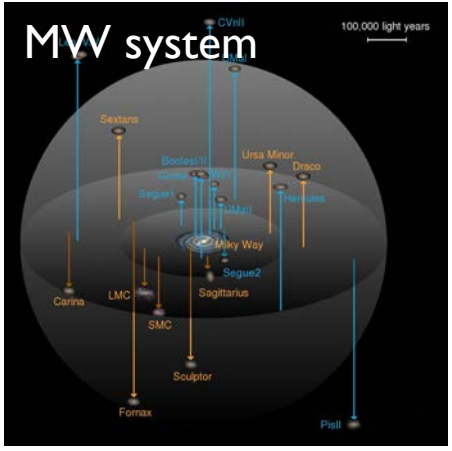
DM haloes are self similar
There is no specific scale in Gravity

Dark Matter Haloes are self-similar

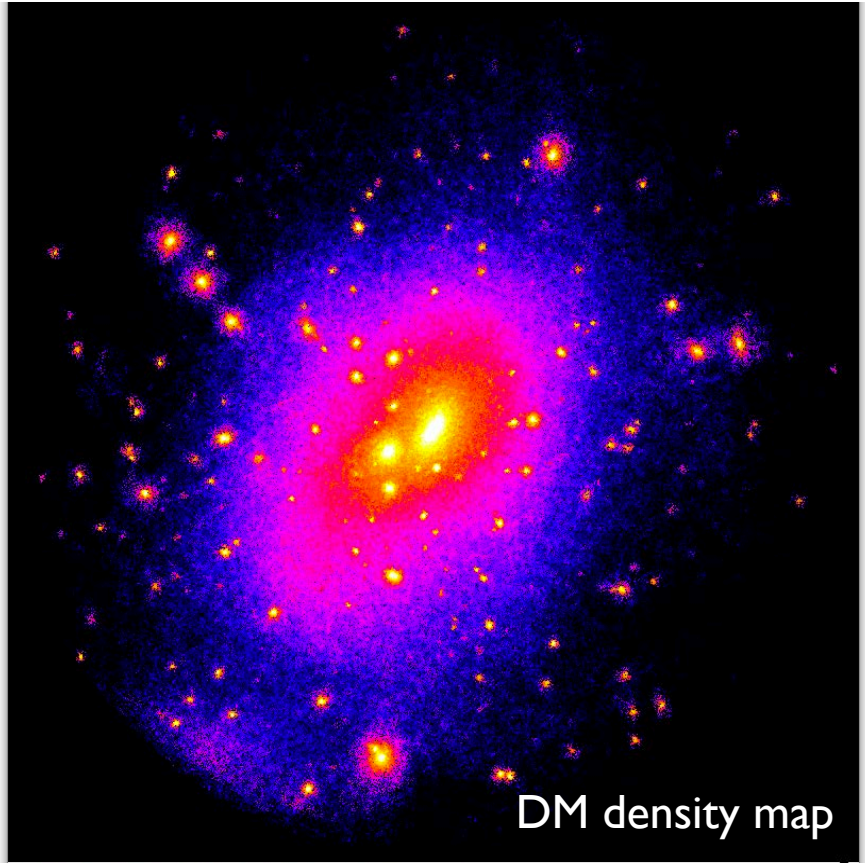


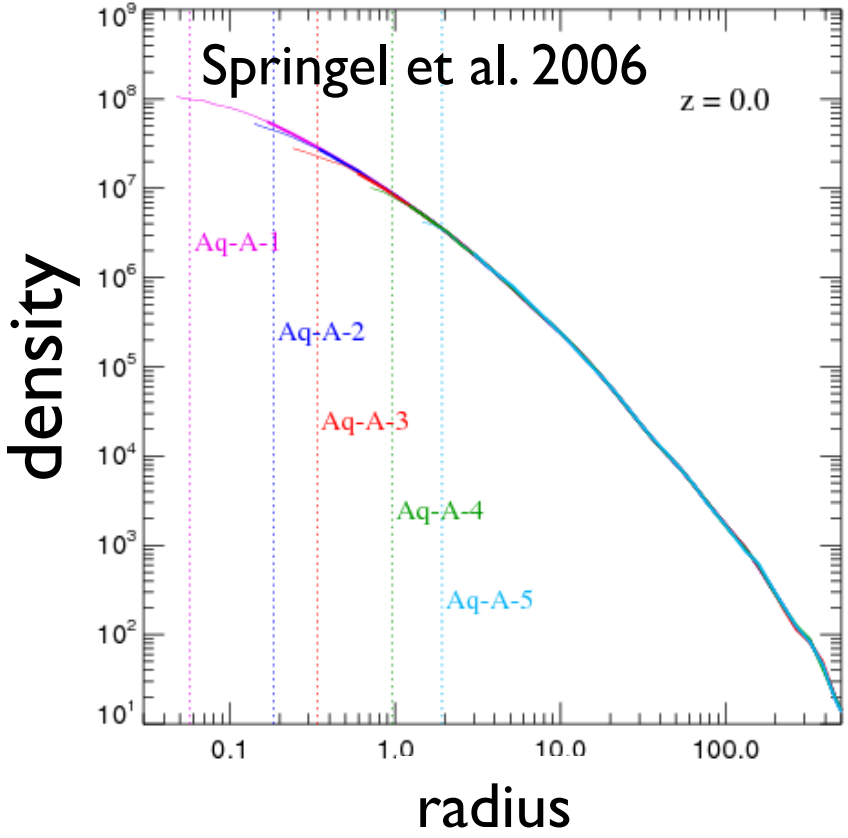




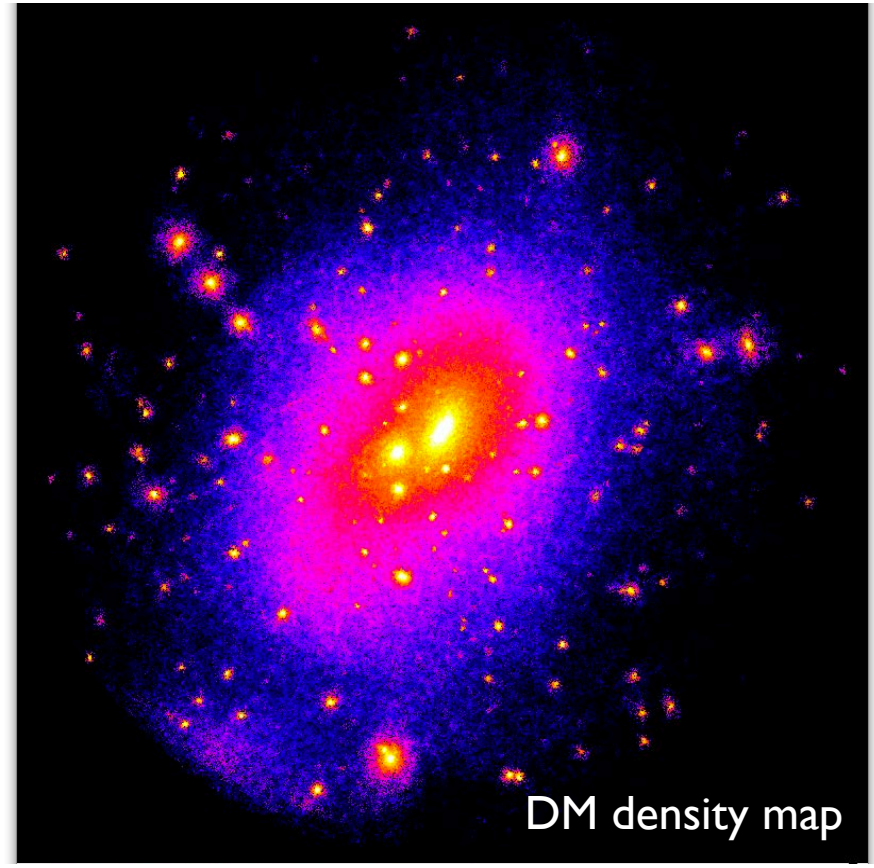


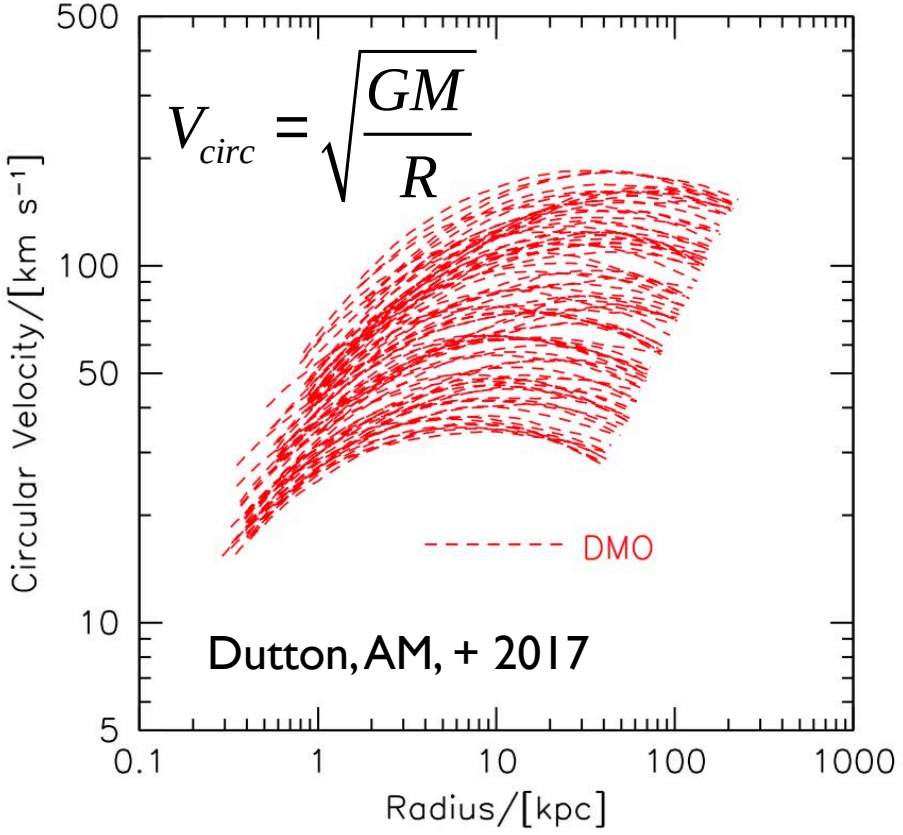
Dark Matter Haloes are self-similar



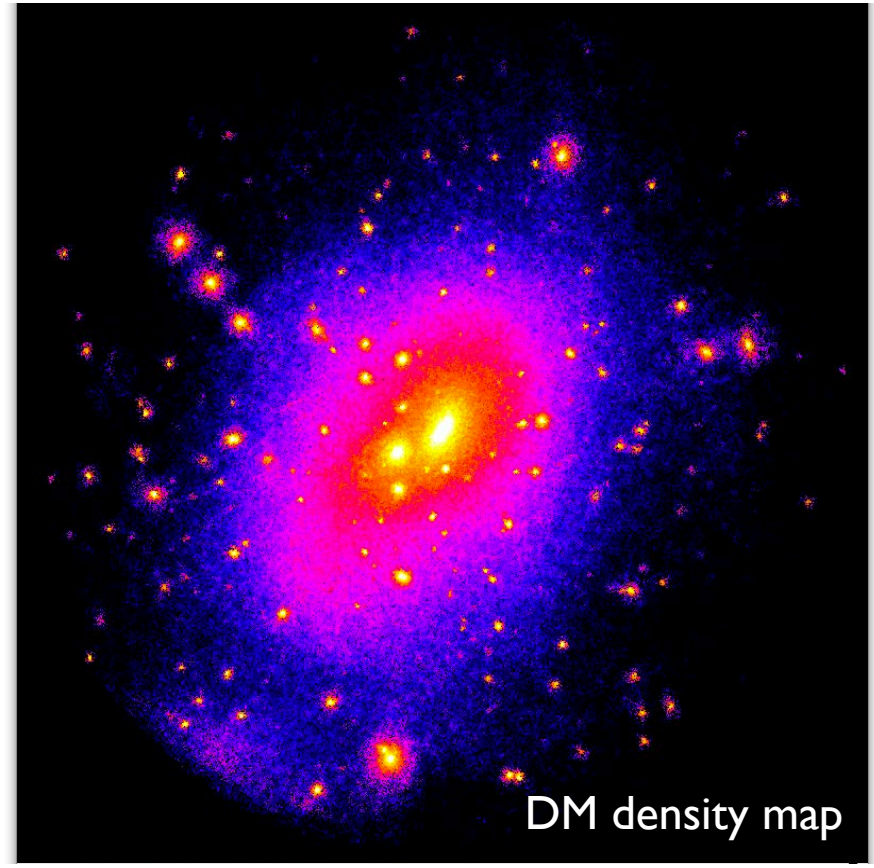


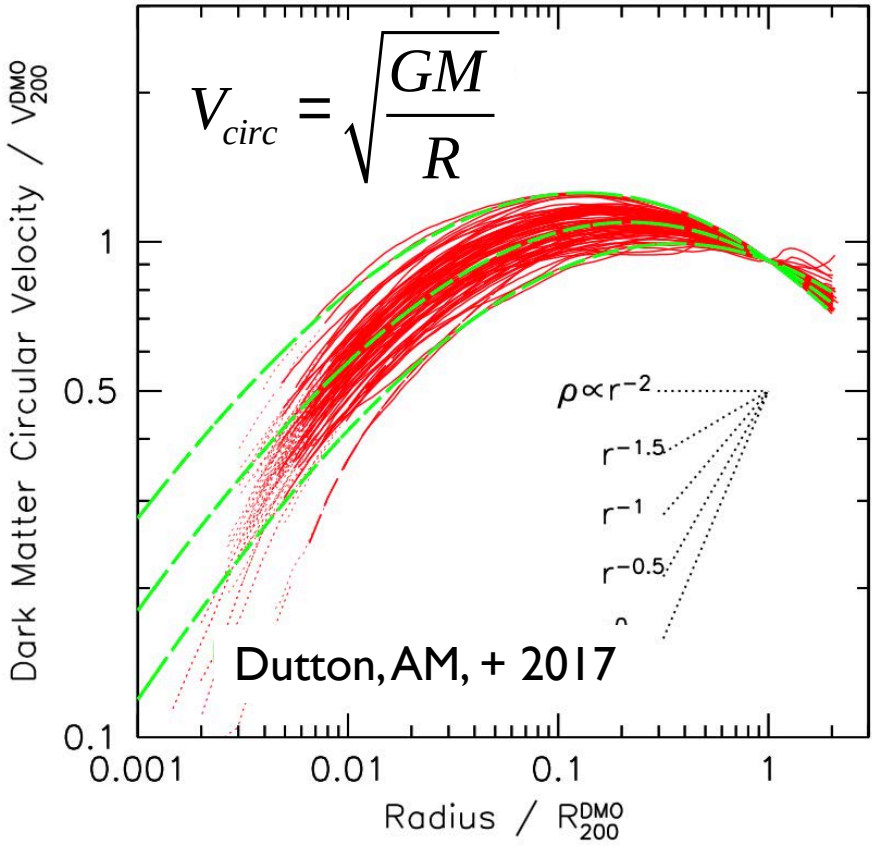
Dark Matter Haloes are self-similar



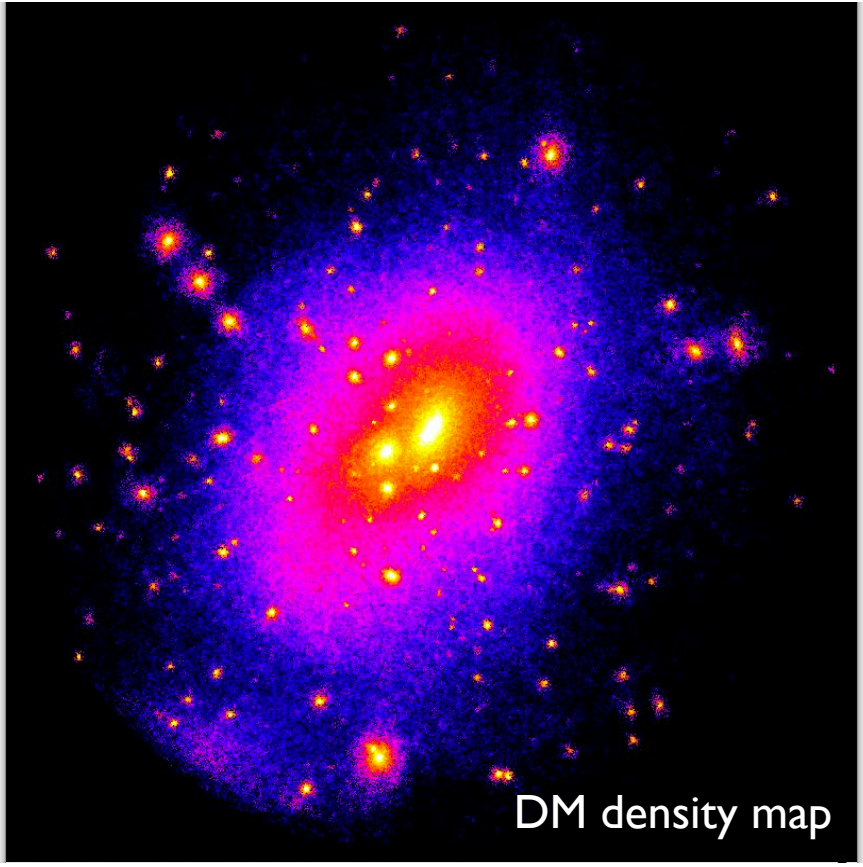


Dark Matter Haloes are self-similar





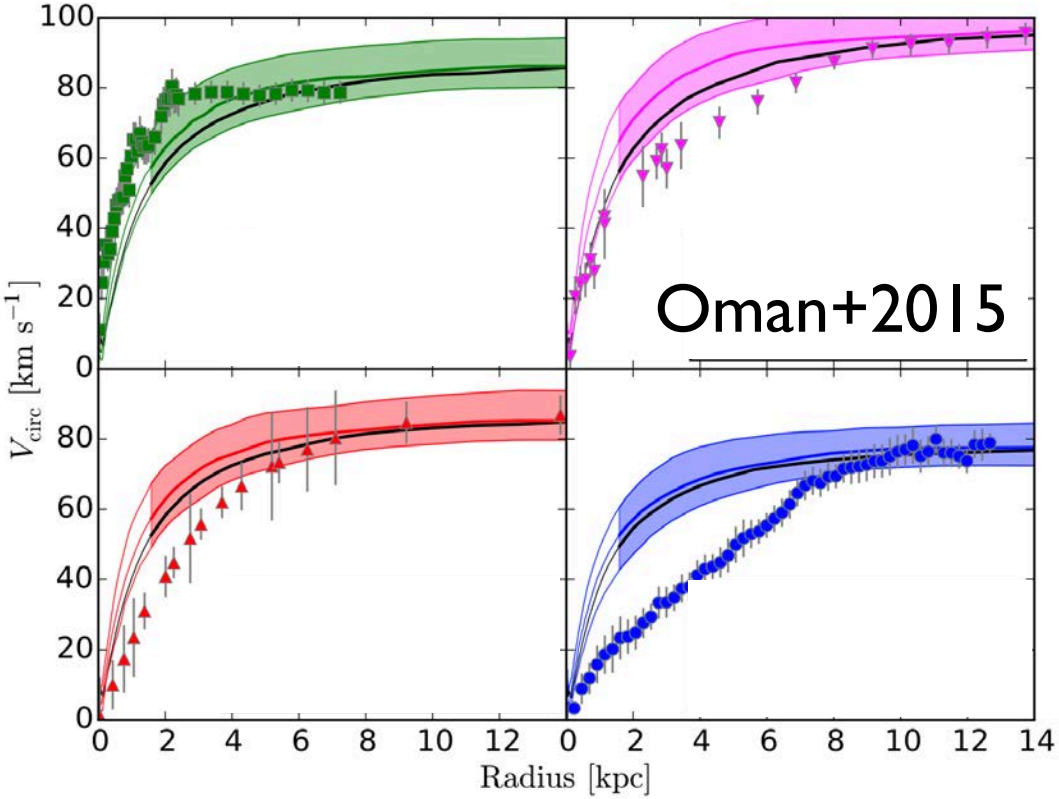
Dark Matter Haloes are self-similar

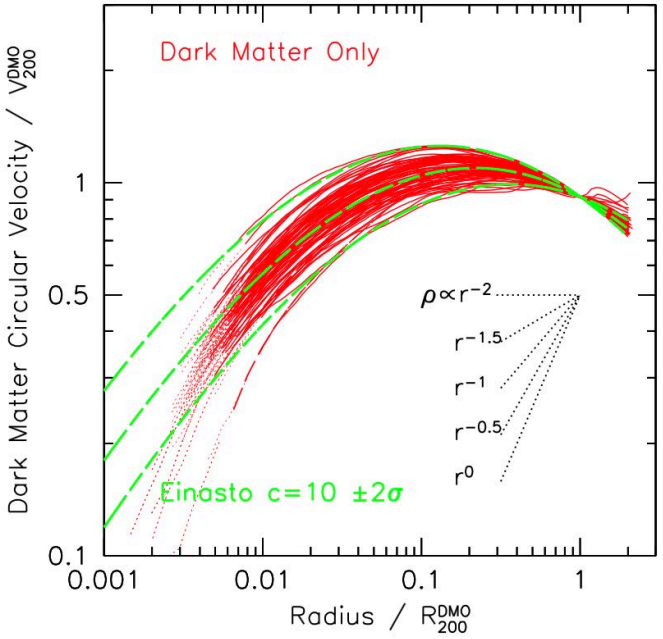


Same applies to substructers

Regardless of its mass each halo has about 300 subhaloes (satellites) with mass between 10^{-2} and 10^{-4} its own mass.

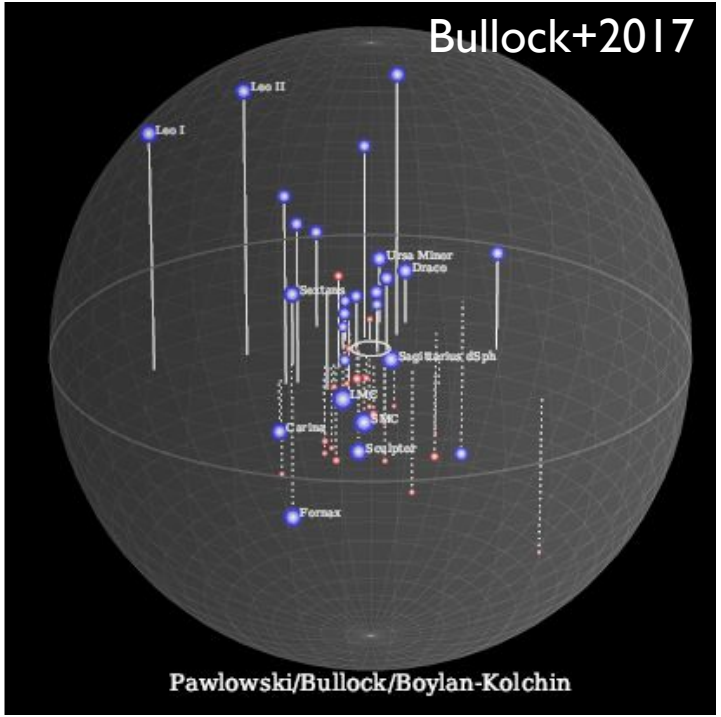
Galaxies are NOT self-similar



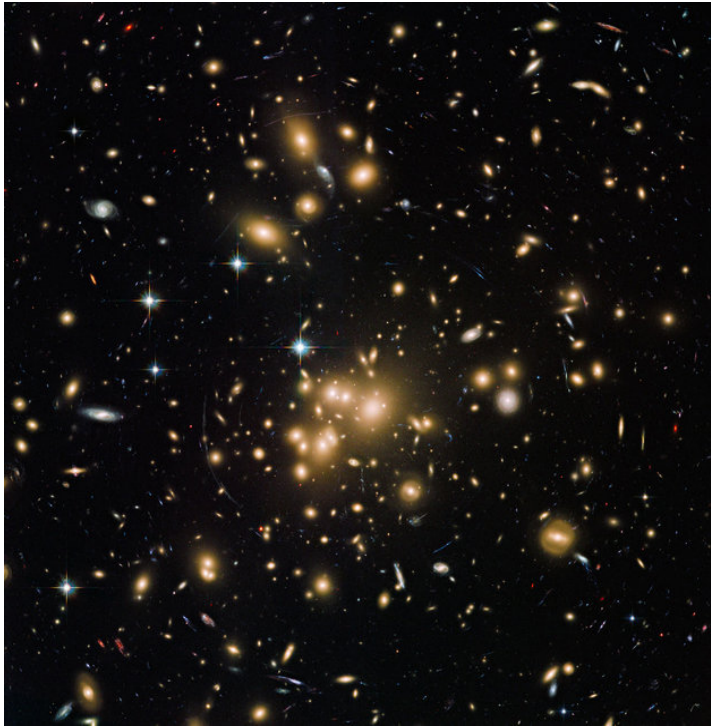


Dutton+2017

Galaxies and Clusters are NOT self-similar



50 satellites around MW



More than 700 galaxies around Abel 1689

How to break the self-similarity

Self-interactive dark matter

Fuzzy dark matter (de Broglie length)

Interactions in the dark sector

You-Name-It dark matter

How to break the self-similarity

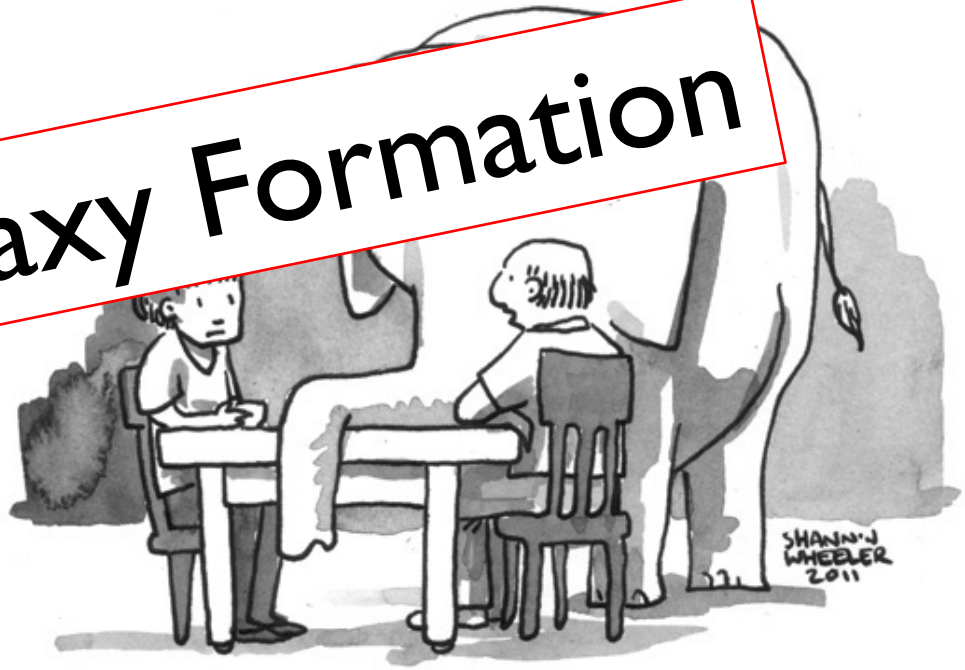
Galaxy Formation

er

ength)

In

tor



The NIHAO project

Numerical
Investigation (of)
Hundred
Astrophysical
Objects

你好

PI: A.V. Macciò (NYUAD)

Co-PI: A.A. Dutton, X. Kang

NIHAO members:
M. Blank (NYUAD), T. Buck (MPIA),
K.Dixon (NYUAD), A. Obreja(USM),
J.Chang (PMO), L.Wang (UWA),
J. Frings (MPIA), A. Di Cintio (AIP),
C. Brook (IAC)

The NIHAO project

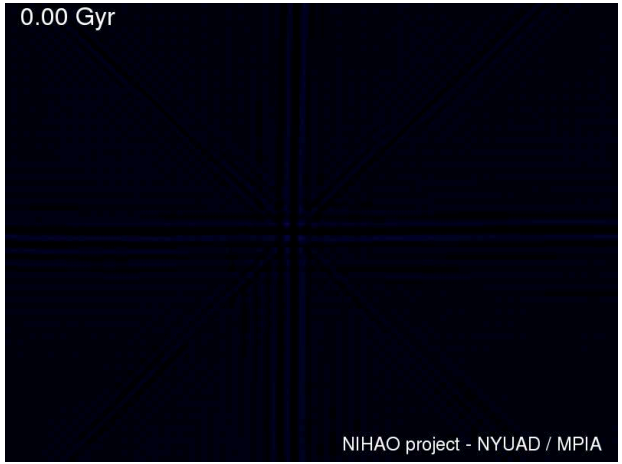
Largest database of high-res galaxies (172)
From tiny MW satellites to massive ellipticals

One million elements per galaxy
Able to resolve the galaxies internal regions

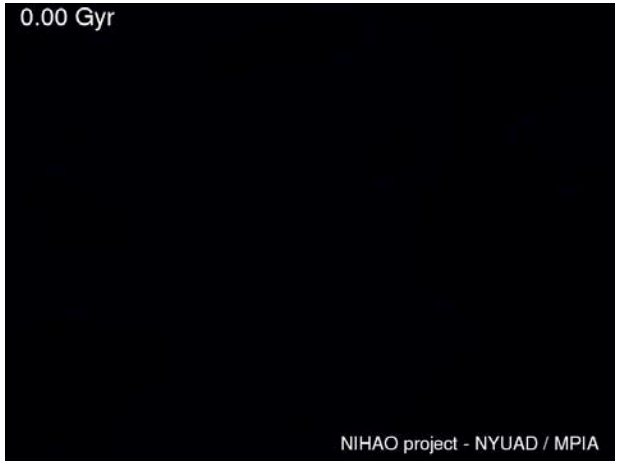
Code Gasoline2.0

- Cooling and star formation
- heavy elements production and enrichment
- SN feedback,
- Massive stars feedback
- BH creation and accretion
- AGN feedback,
- Local Photoionization feedback

The NIHAO project



DM density



Gas Temperature

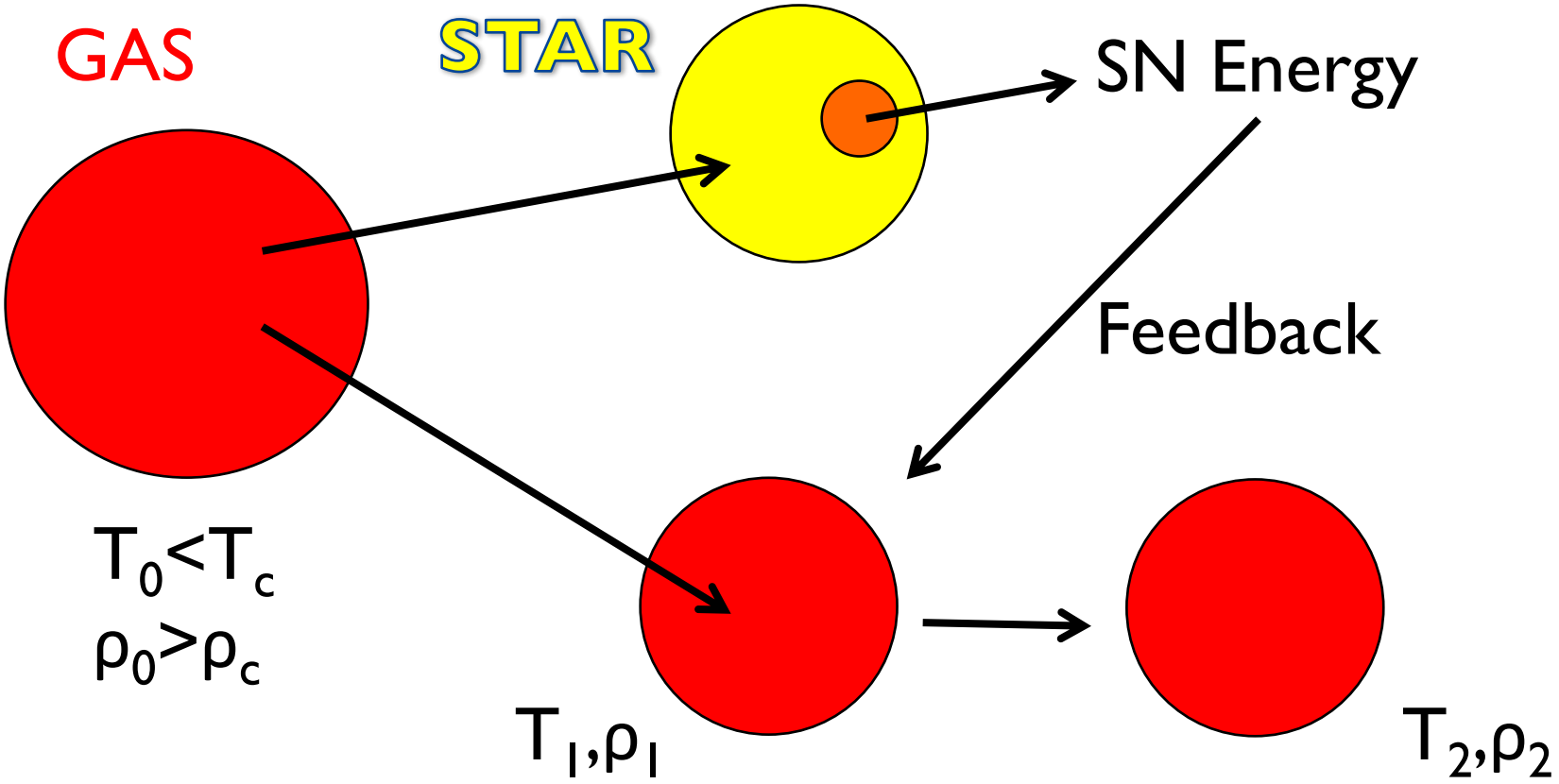
Stellar density


© Tobias Buck & NIHAO simulations

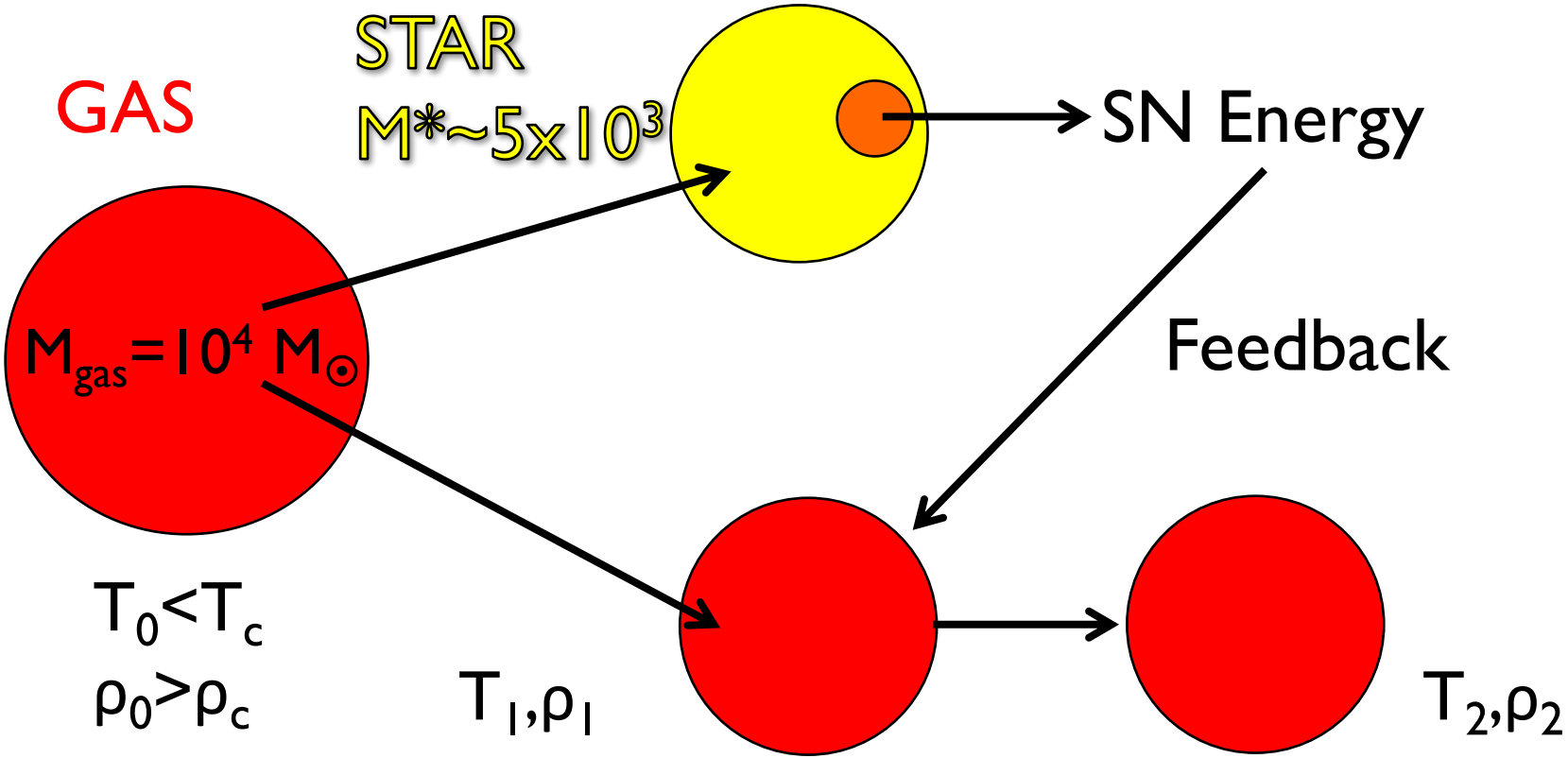
Caveat

We cannot simulate galaxy formation from first principles

Star Formation and Feedback



Star Formation and Feedback

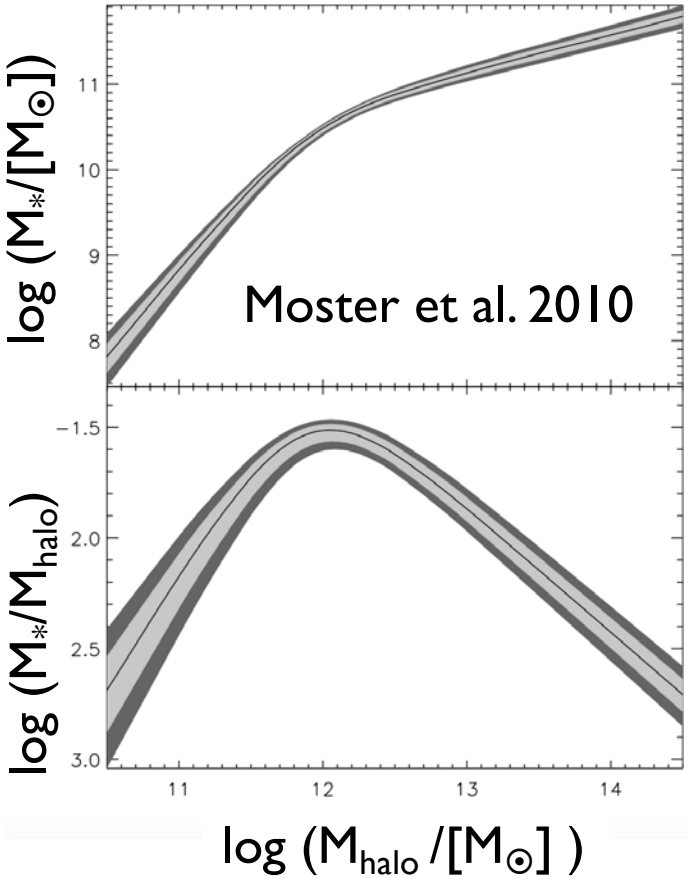


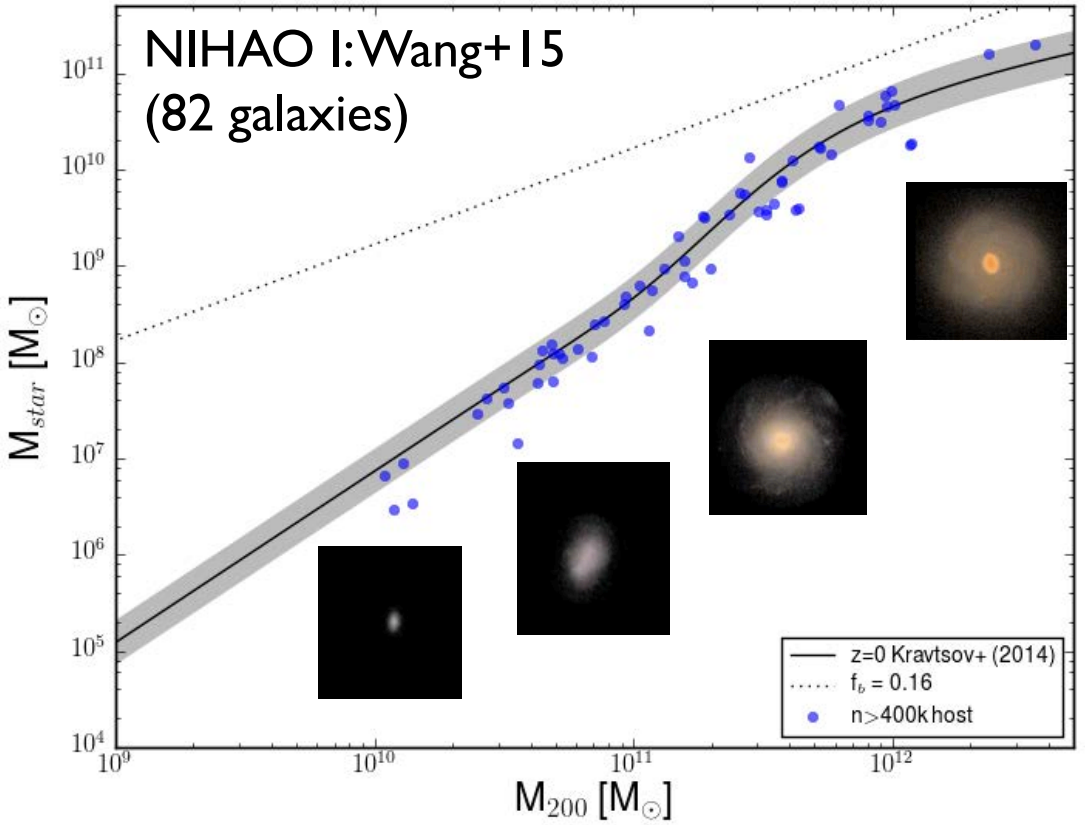
~100 pc

Molecular cloud

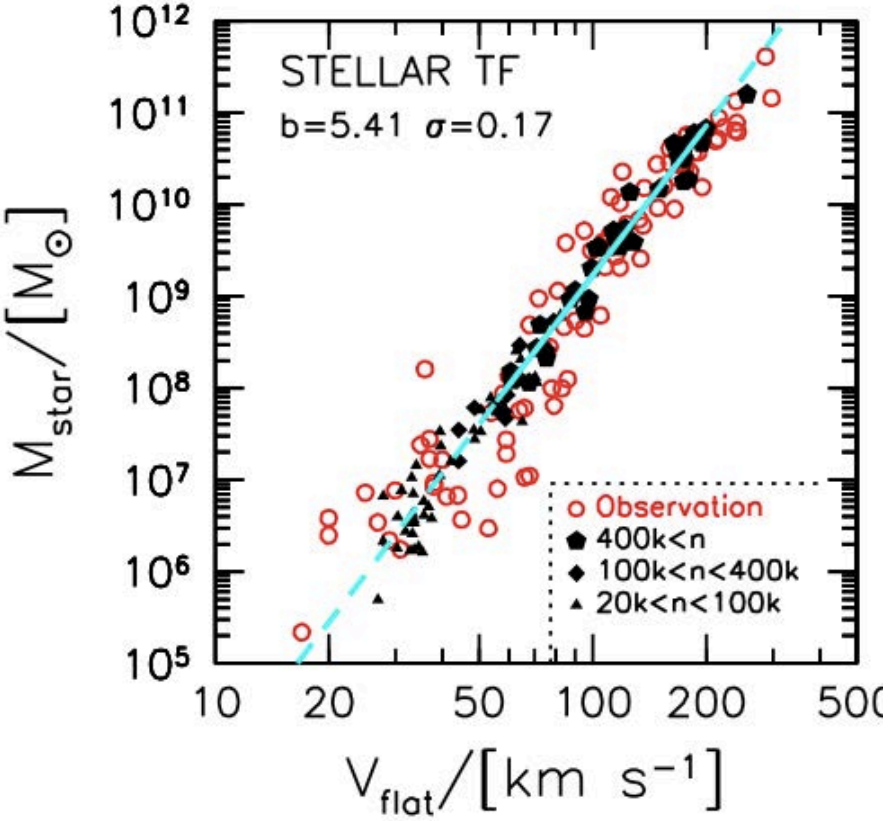
Validate simulations against observations

Simulating realistic galaxies



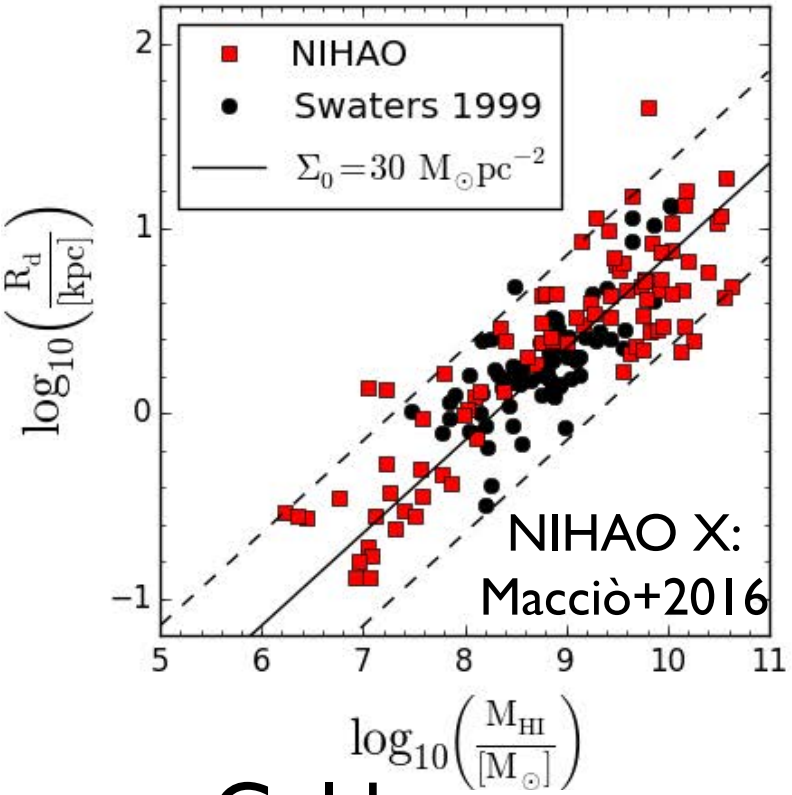


Simulating realistic galaxies



NIHAO XII: Dutton+2017

Gas Disk size



Cold gas mass

XIV: **Santos-Santos+2018** Galaxy rotation curves

XV: **Buck+2018** Satellites properties

XVI: **Obreja+2018** Kinematically selected discs

XVII: **Dutton+2018** Dwarf galaxy kinematics

XVIII: **Tollet+2018** Gas cycle in galaxies

XIX: **Blank+2018** Black Holes and galaxy formation

XX: **Dutton+2018** Dark Matter response and SF

XXI: **Di Cintio+2019** Low Surface Brightness galaxies

Edge of galaxy formation series

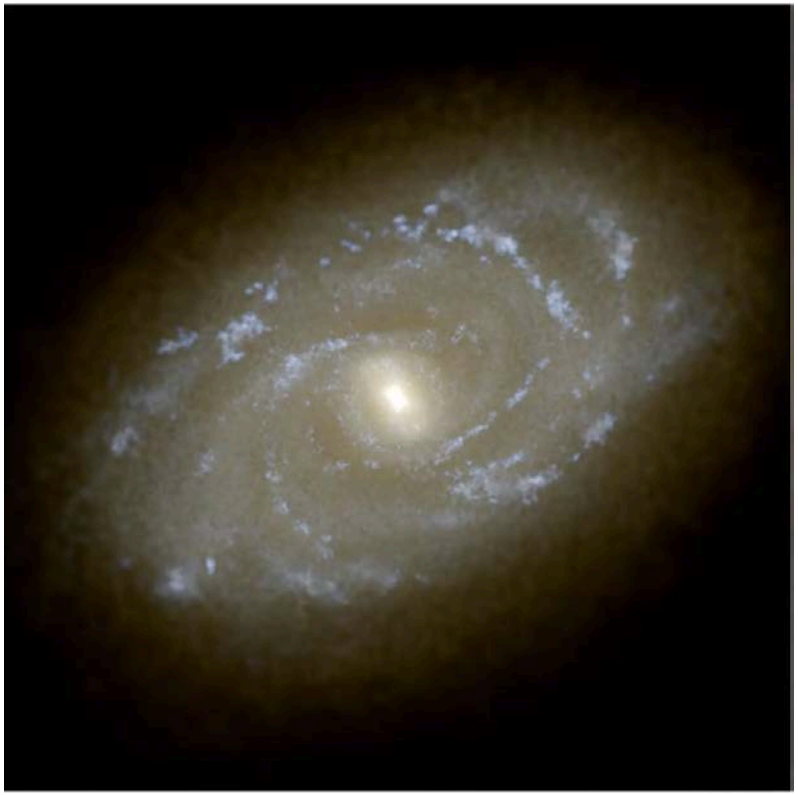
I: **Macciò+2017** Satellites evolution before accretion

II: **Frings+2017** Satellite-Host interaction

III: **Macciò+2019** Satellites and Warm Dark Matter

XIII: Buck+2017 Clumpy Galaxies

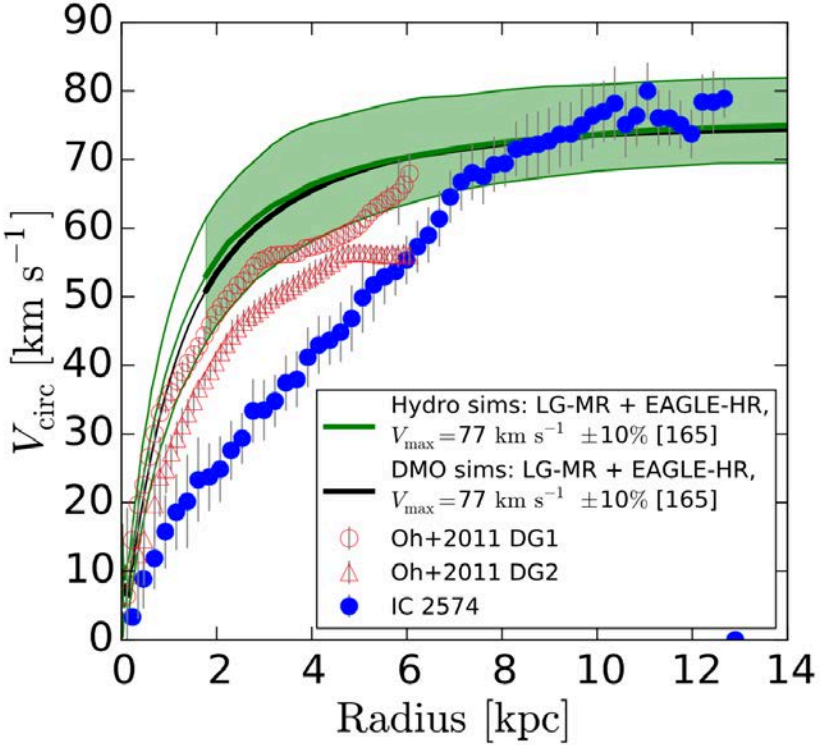
Simulated and real galaxies



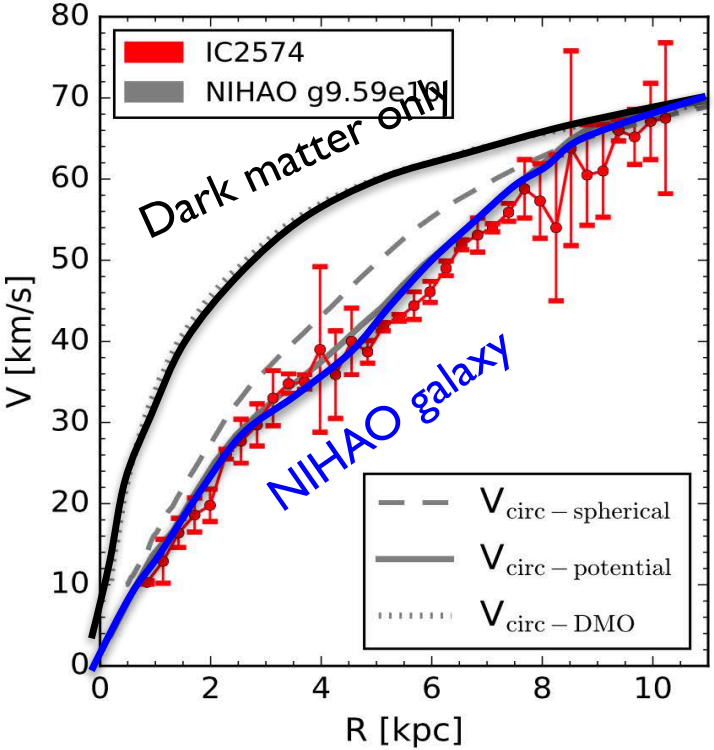
NIHAO XV – Buck+17

NGC4051 @SDSS

Breaking the self-similarity

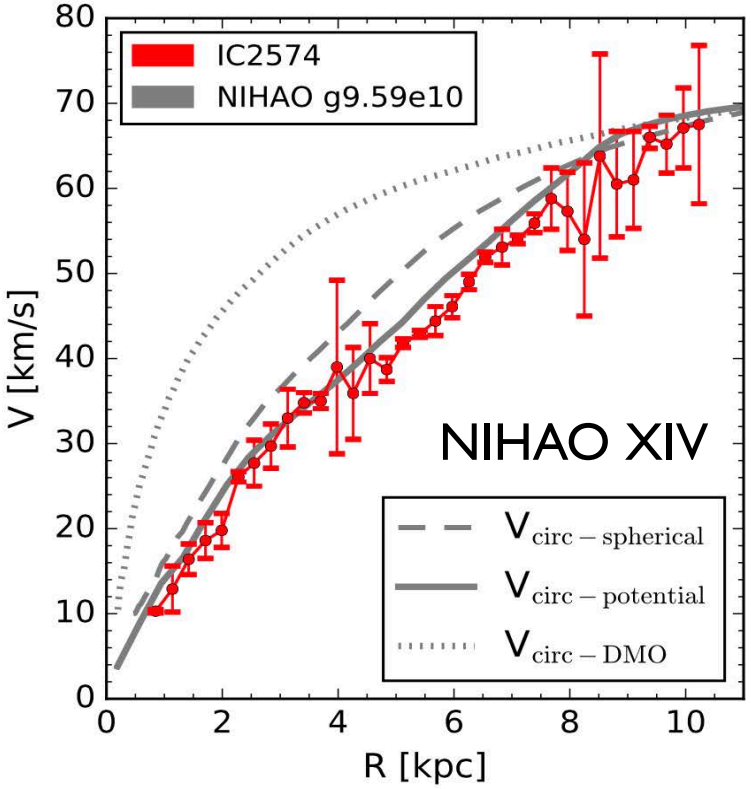


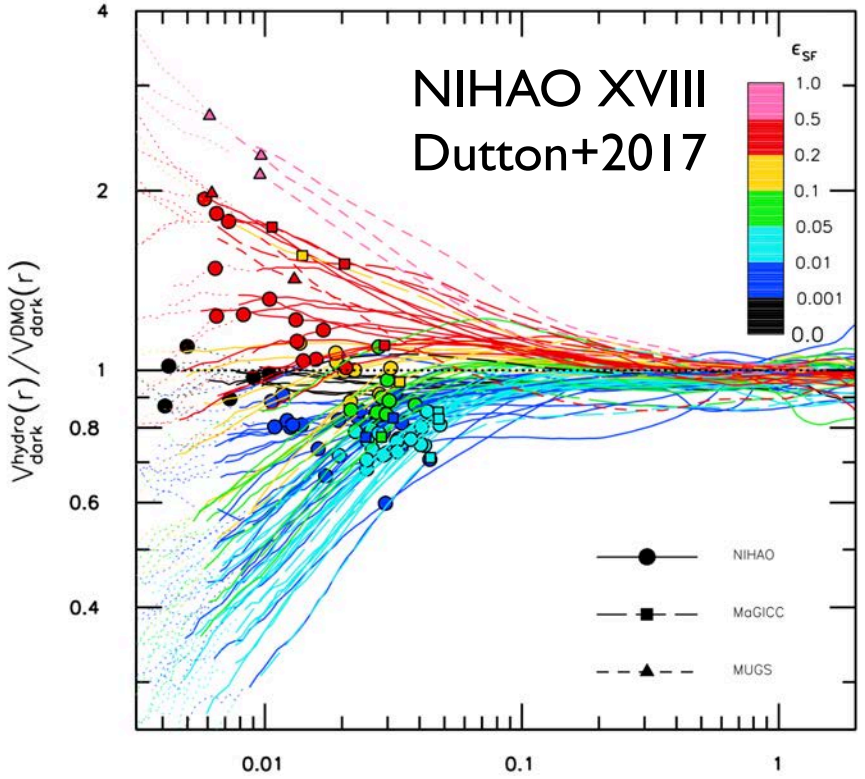
Oman2015 EAGLE simulations



Santos-Santos+2017 NIHAO XIV

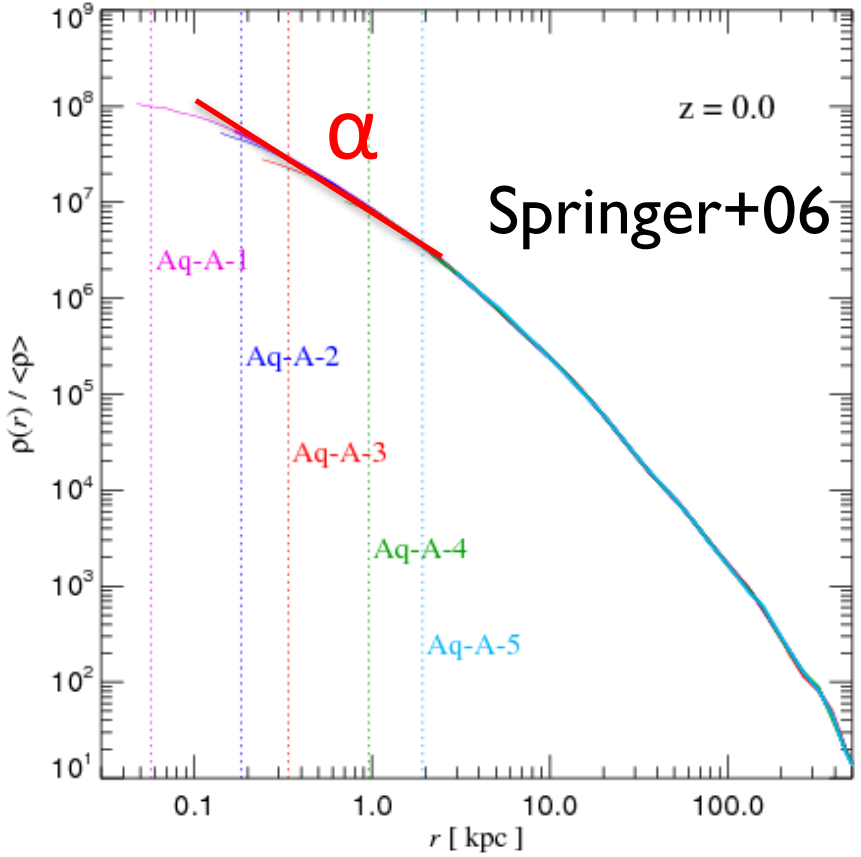
Breaking the self-similarity






0.00 Gyr
NIHAO project - NYUAD / MPIA

No Universal Density Profile

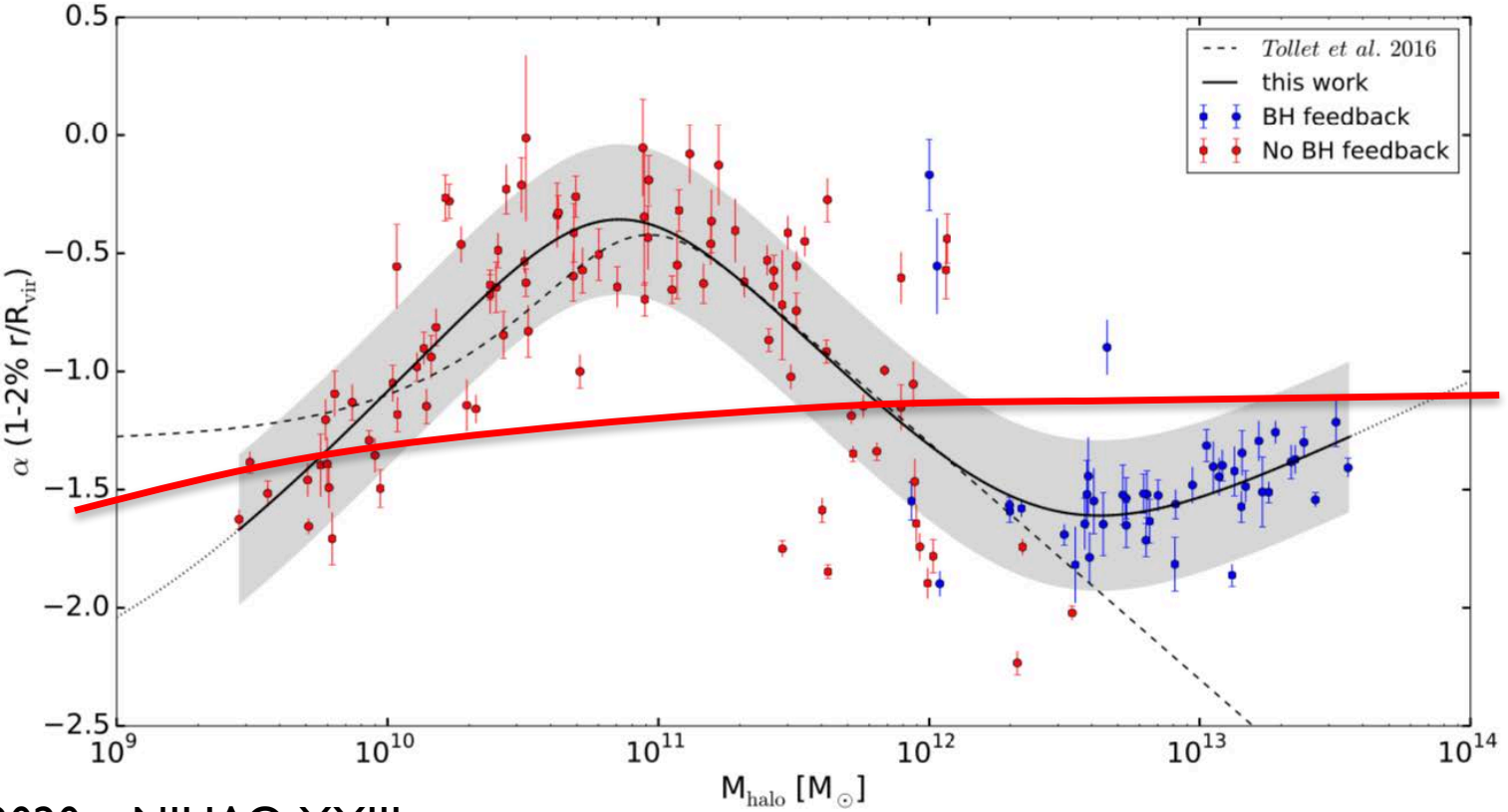


$$\lim_{r \to 0} \rho(r) = r^{\alpha}$$

$$\alpha \sim -1$$

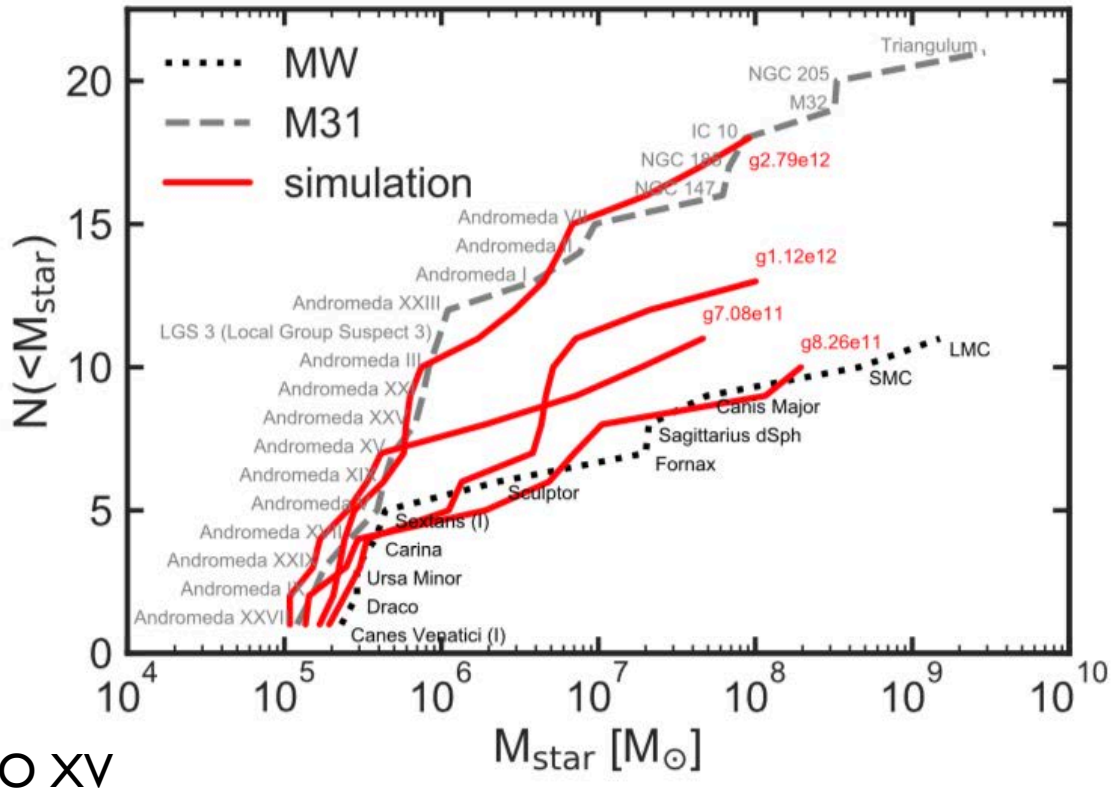
For CDM haloes in pure gravity simulations

No Universal Density Profile



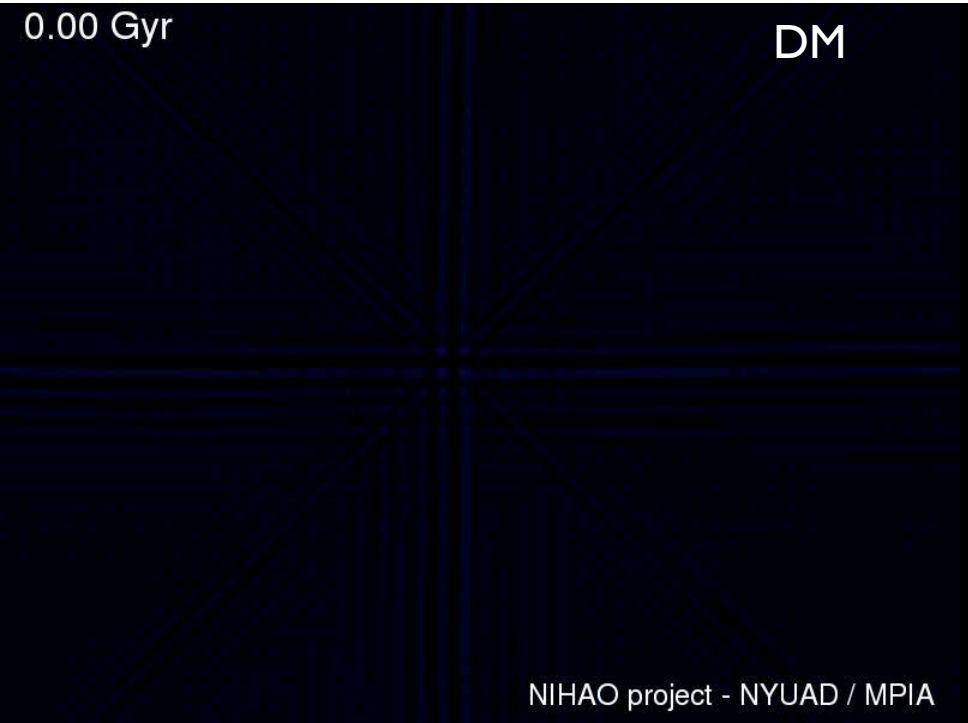
Macciò+2020 – NIHAO XXIII

Satellites are also not self-similar

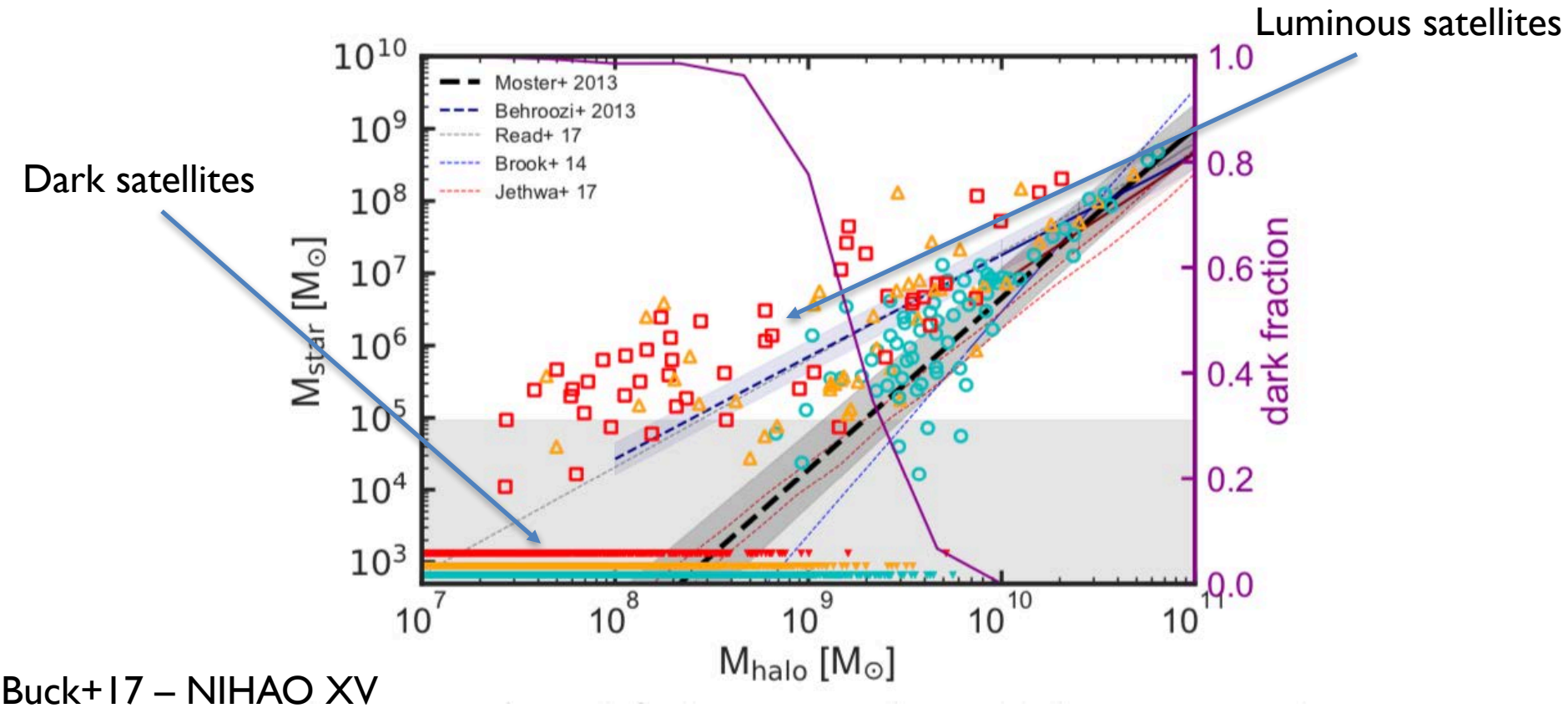


Buck+17 – NIHAO XV

Not all DM satellites harbor a galaxy

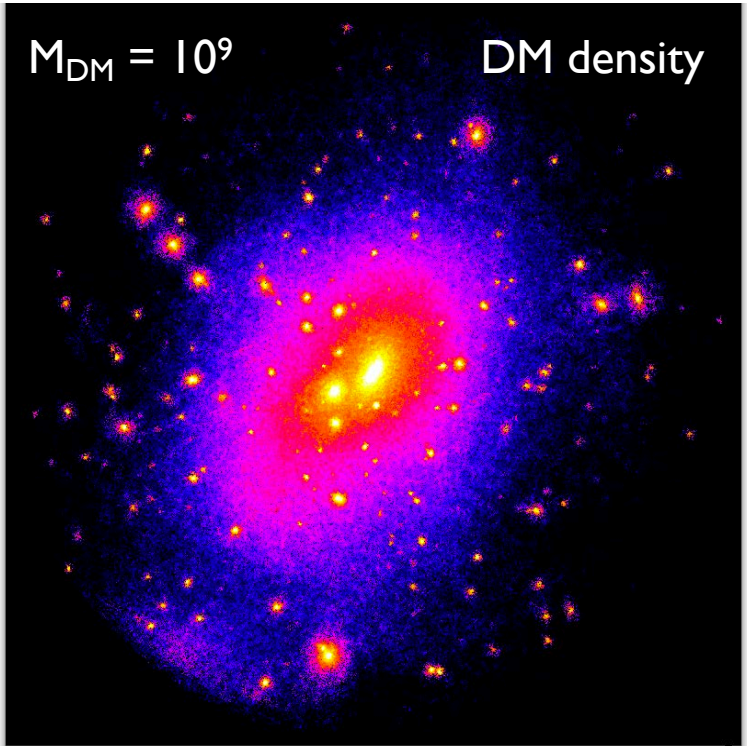


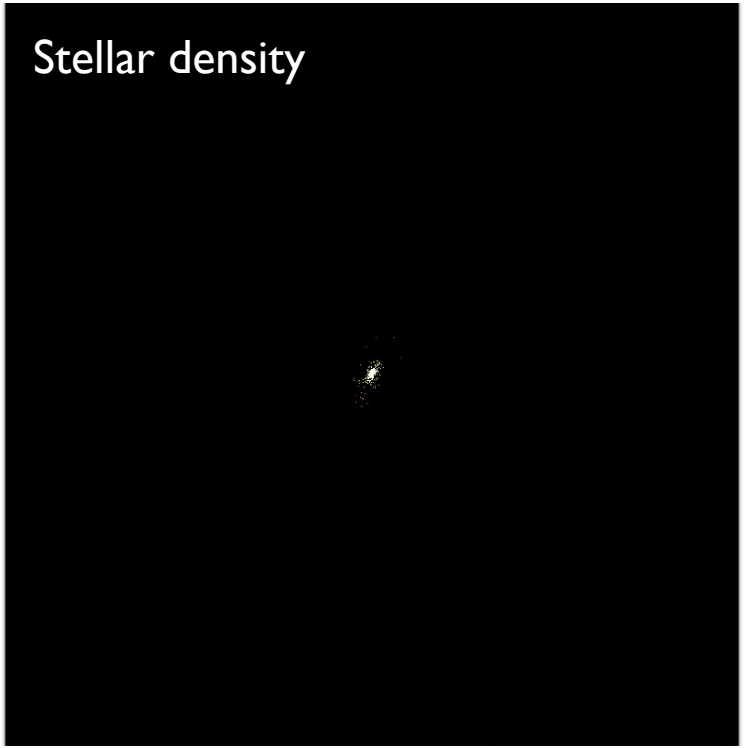
Satellites are also not self-similar



Buck+17 – NIHAO XV

Self similarity is broken





$M_*/M_{DM} = 10^{-5}$ $R_*/R_{DM} < 0.01$

Frings+2017, Macciò+2017, 2019

(partial) Conclusion

There is no observational evidence forcing us to move away from a simple CDM model

CDM + galaxy formation is able to reproduce all current observations

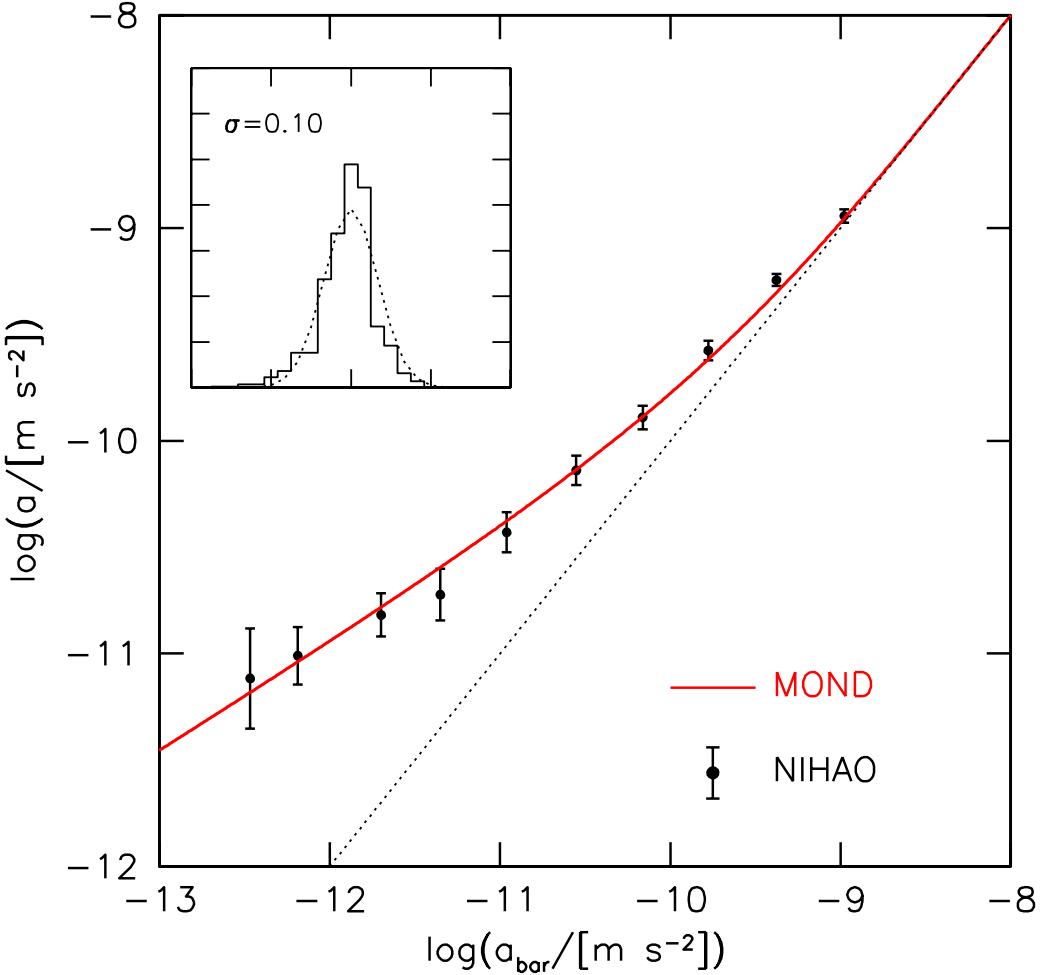
Is CDM then the answer?

No…from the point of view of galaxy formation

- As of today there is no indication that we need a WHIMP-like particle
- Any DM particle not "too warm" will do as well
- Current limits $m_{DM} > 10$ keV (for a thermal candidate

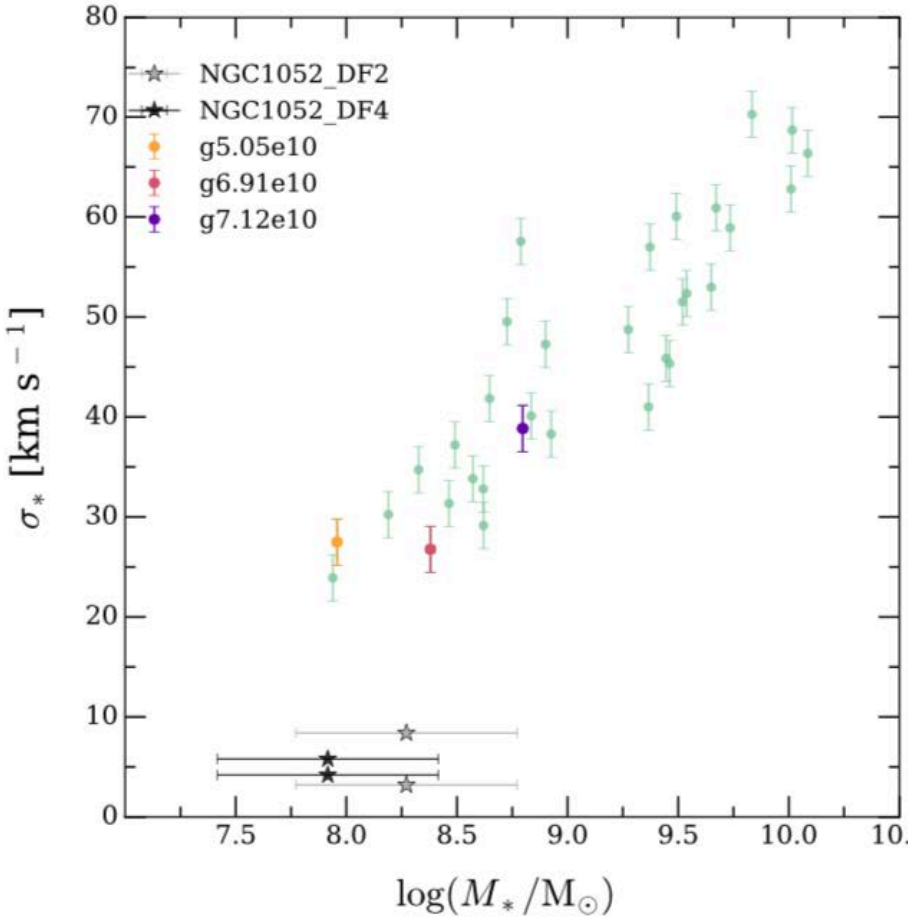
CDM is not wrong
but this does not mean that
it is right

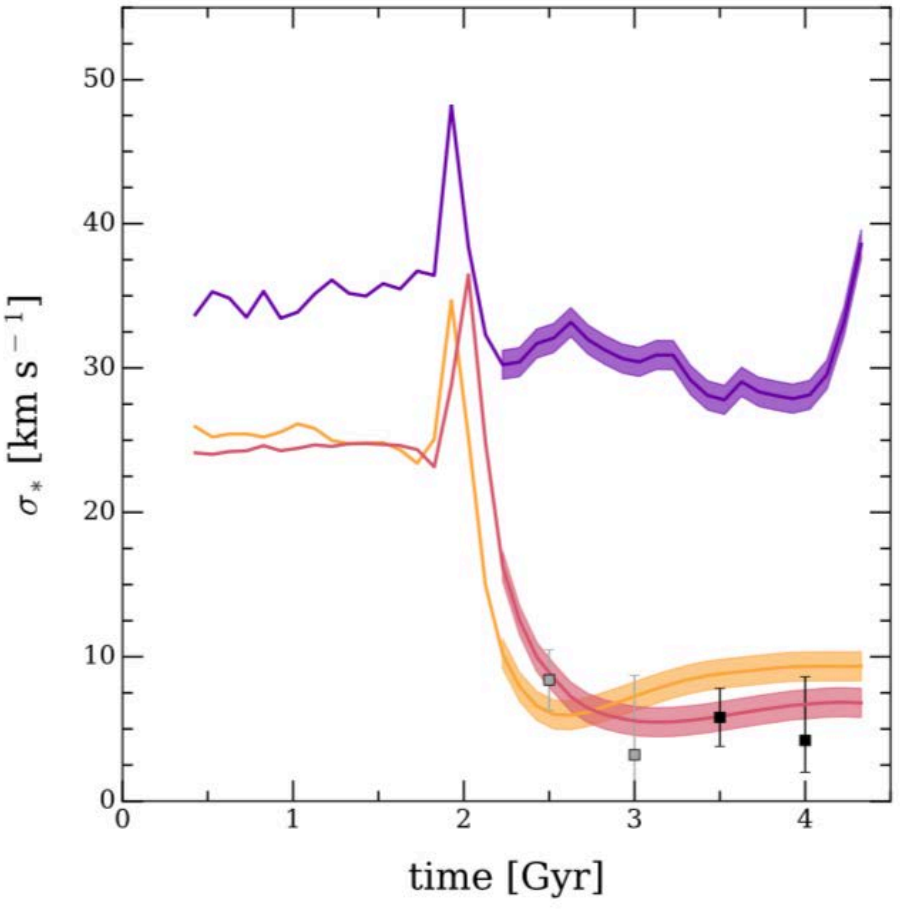
Thank you for your attention

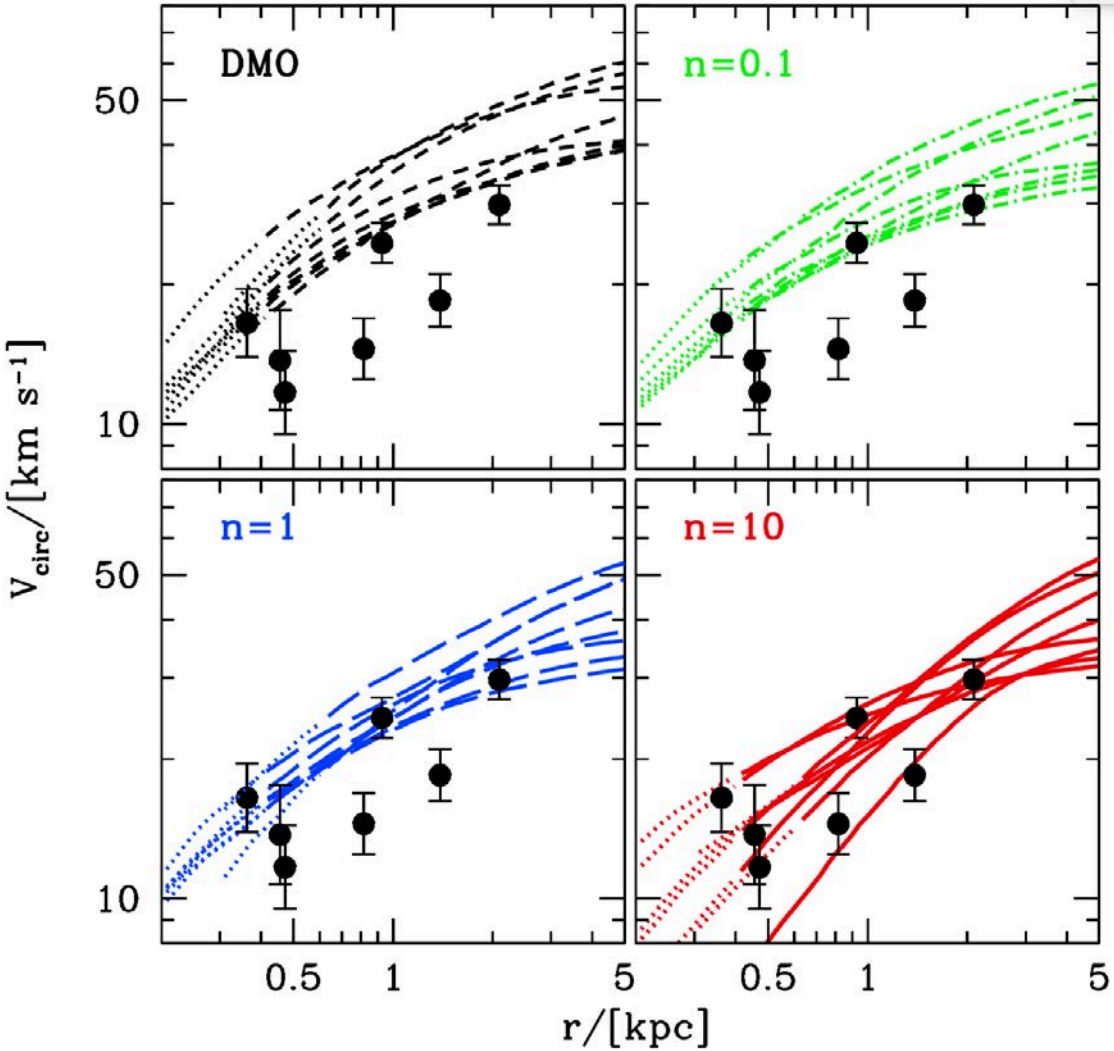


MOND is fully reproduced
by galaxy formation simulations

Wadsley+2018
Dutton+2019 – NIHAO XVIII


NGC1052_DF2
NGC1052_DF4
g5.05e10
g6.91e10
g7.12e10
σ_* [km s^{-1}]
$\log(M_*/\mathrm{M}_\odot)$

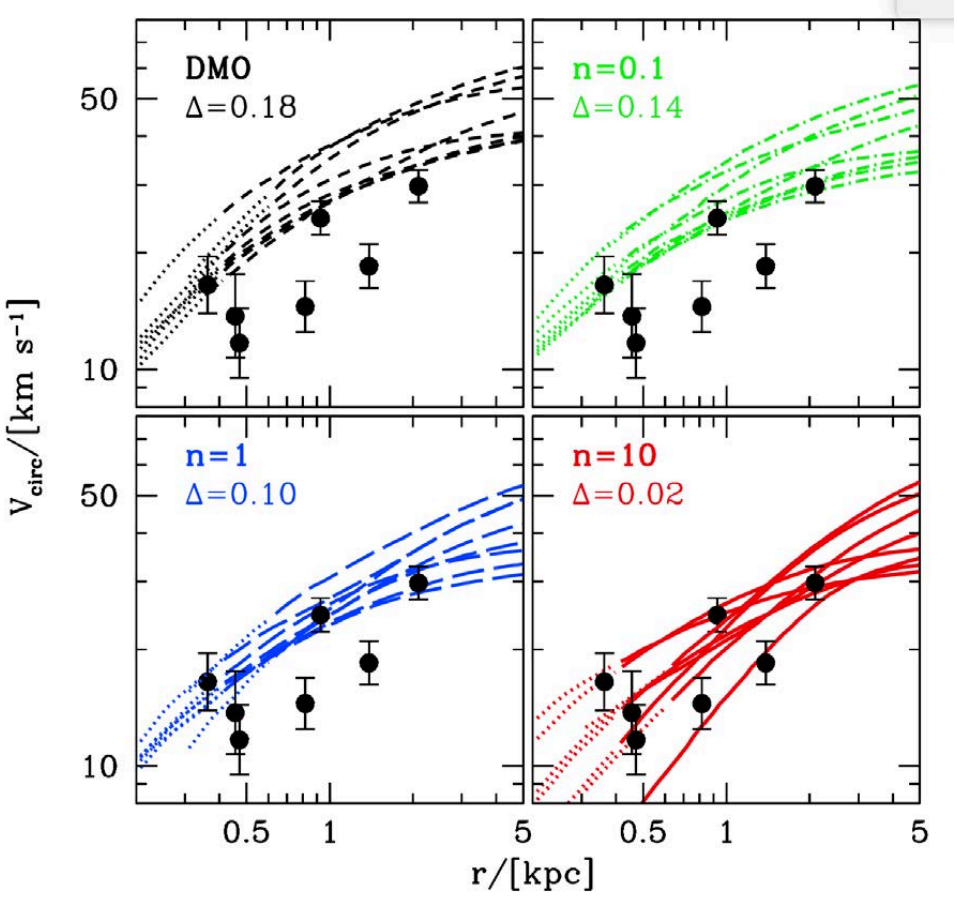

σ_* [km s^{-1}]
time [Gyr]



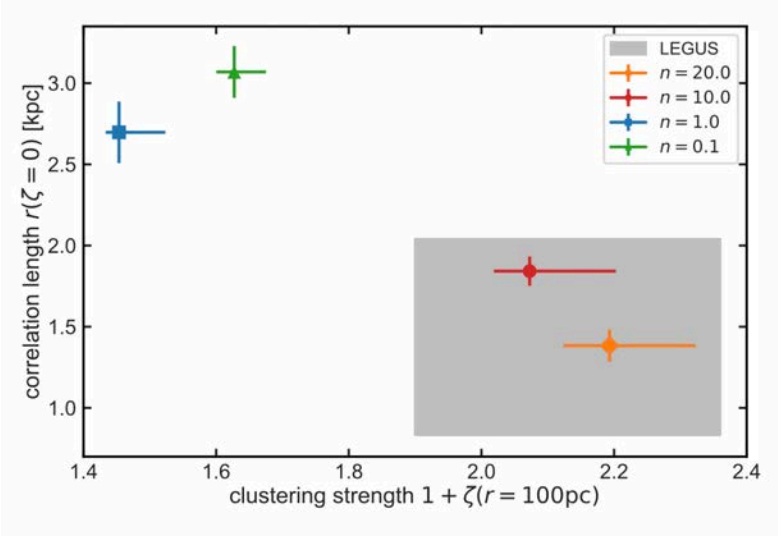
LCDM is in trouble

LCDM is safe

Dutton et al 2019: NIHAO XX:



n=0.1
LCDM is in trouble



n=10
LCDM is safe

Survival of Cold Dark Matter → Clustering of young stars