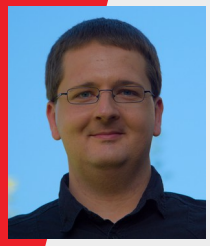
Exotic galaxies as tests for hydrodynamical simulations

Christoph Saulder

Collaborators



Christoph Saulder (KIAS)

Owain Snaith (KIAS)

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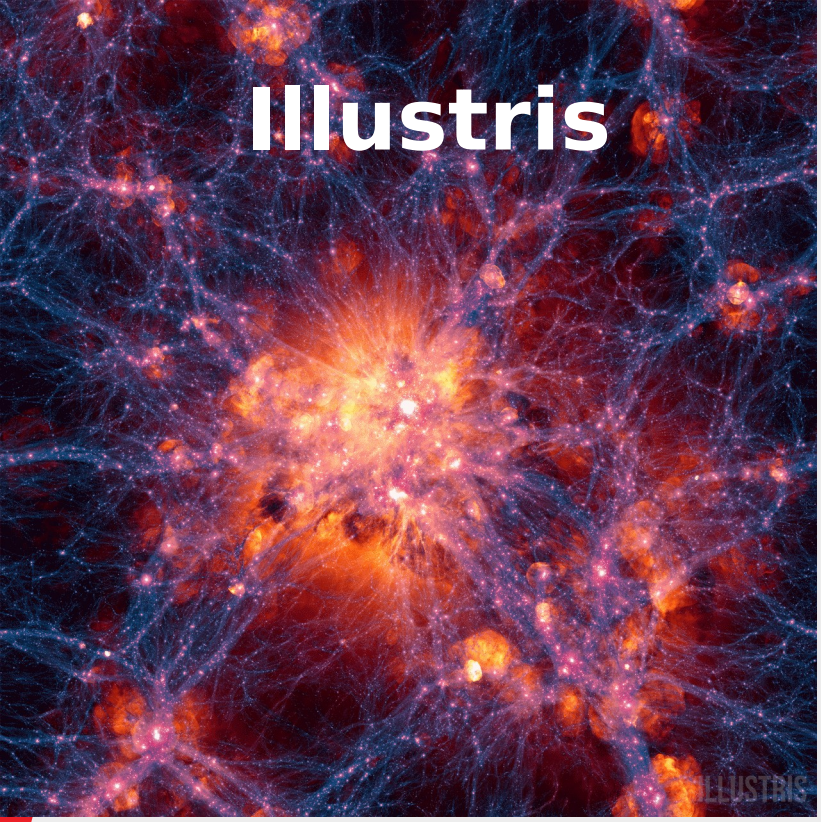
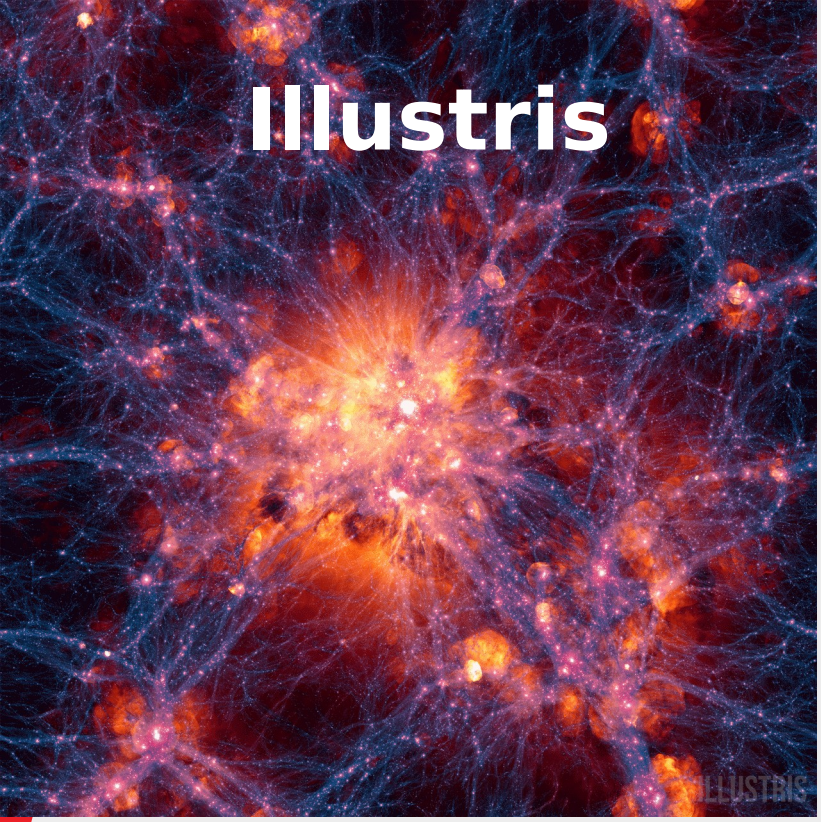
Clotilde Laigle (University of Oxford)

- IllustrisTNG team


Illustris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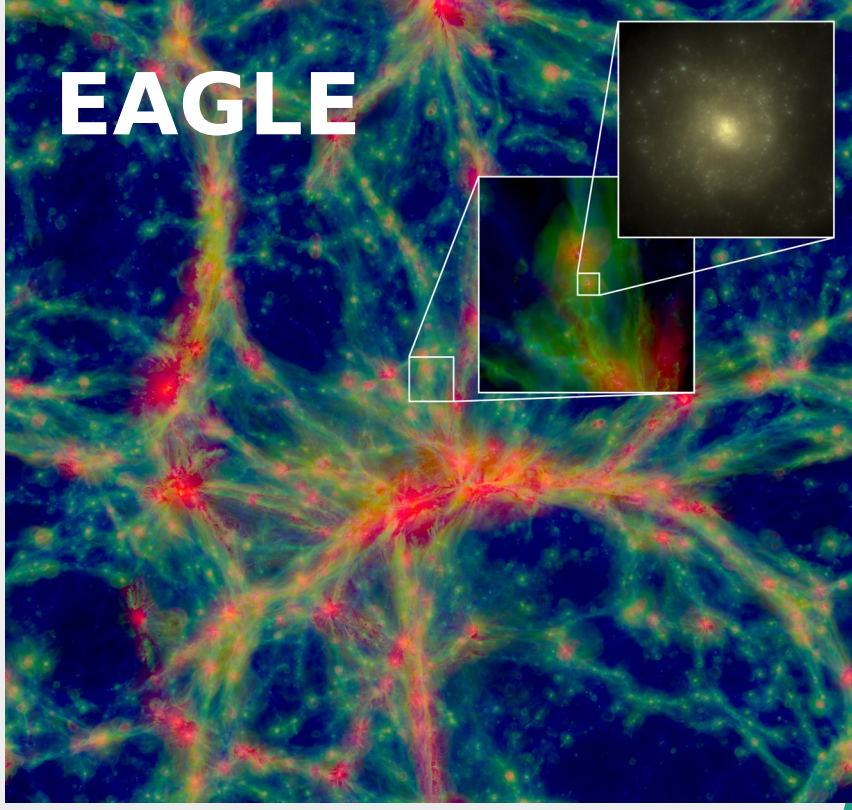
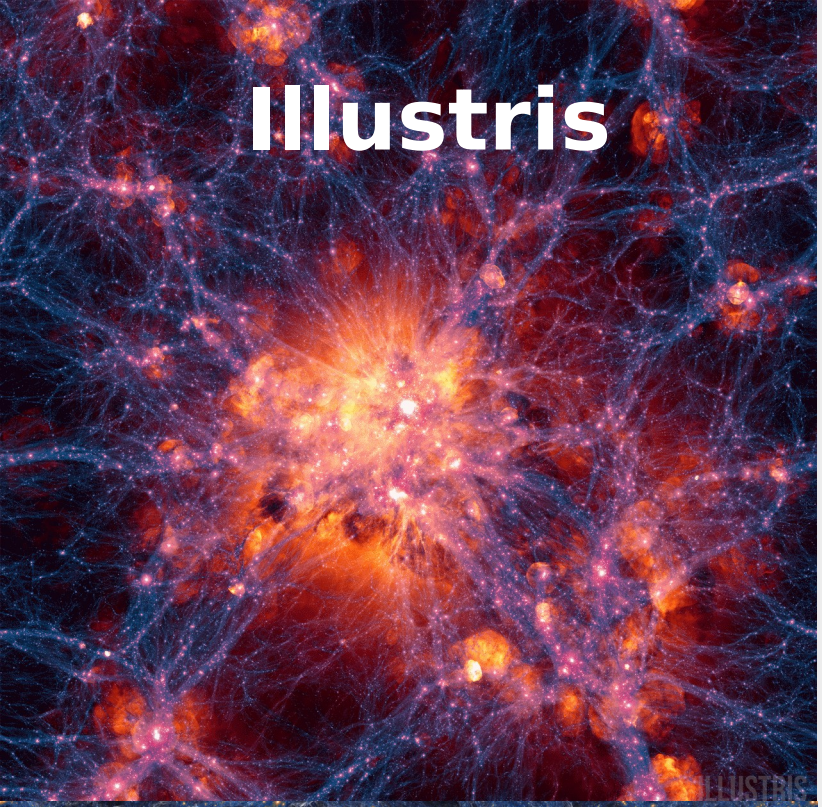

EAGLE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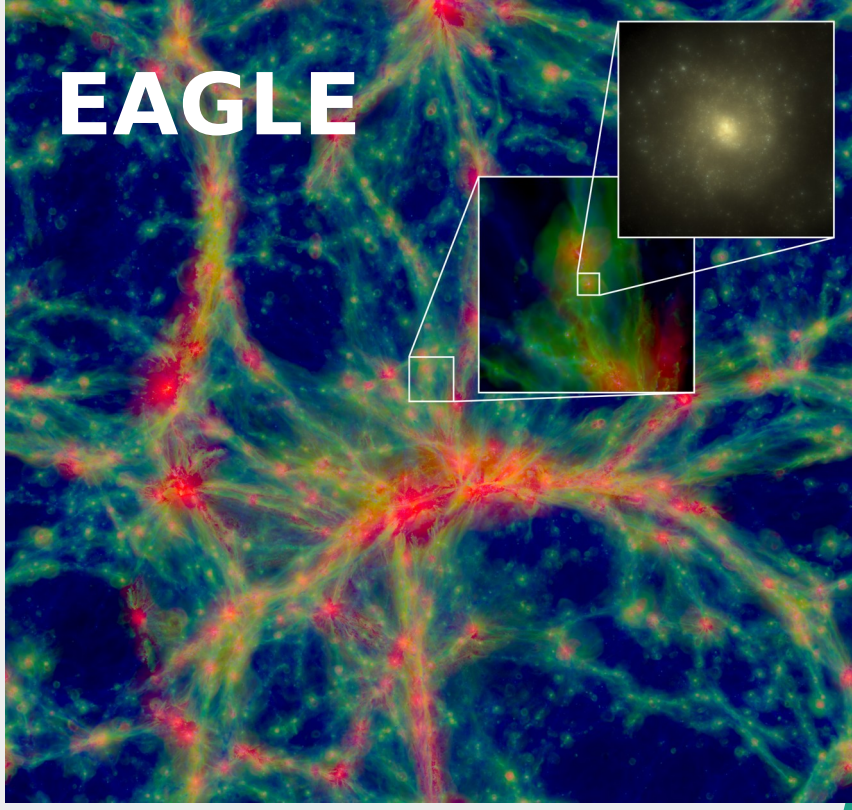
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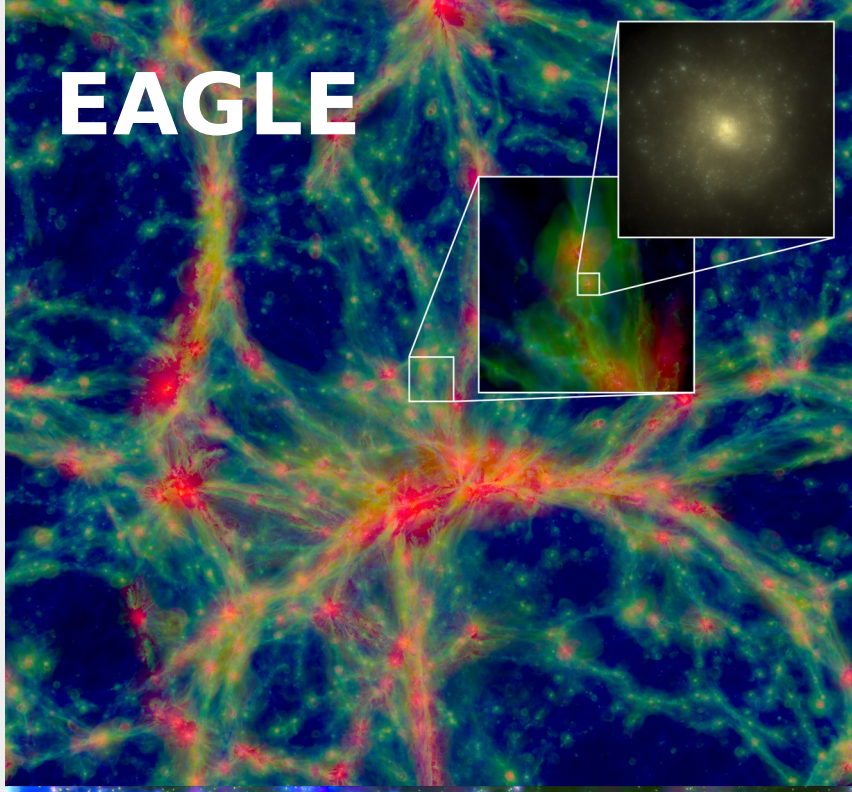
IllustrisTNG


Illustris


EAGLE


IllustrisTNG


HorizonAGN

4 big hydrodynamical simulations

- About 100 Mpc/h cubes each (300Mpc/h for TNG)
- Considering baryonic physics, but sub-grid physics are implemented slightly differently
- Different time resolution (number of snapshots)
- Different cosmological parameters
- Different ways to detect subhalos (HorizonAGN does not use SubFind)
- Different parameters provided by the simulations and value added catalogues

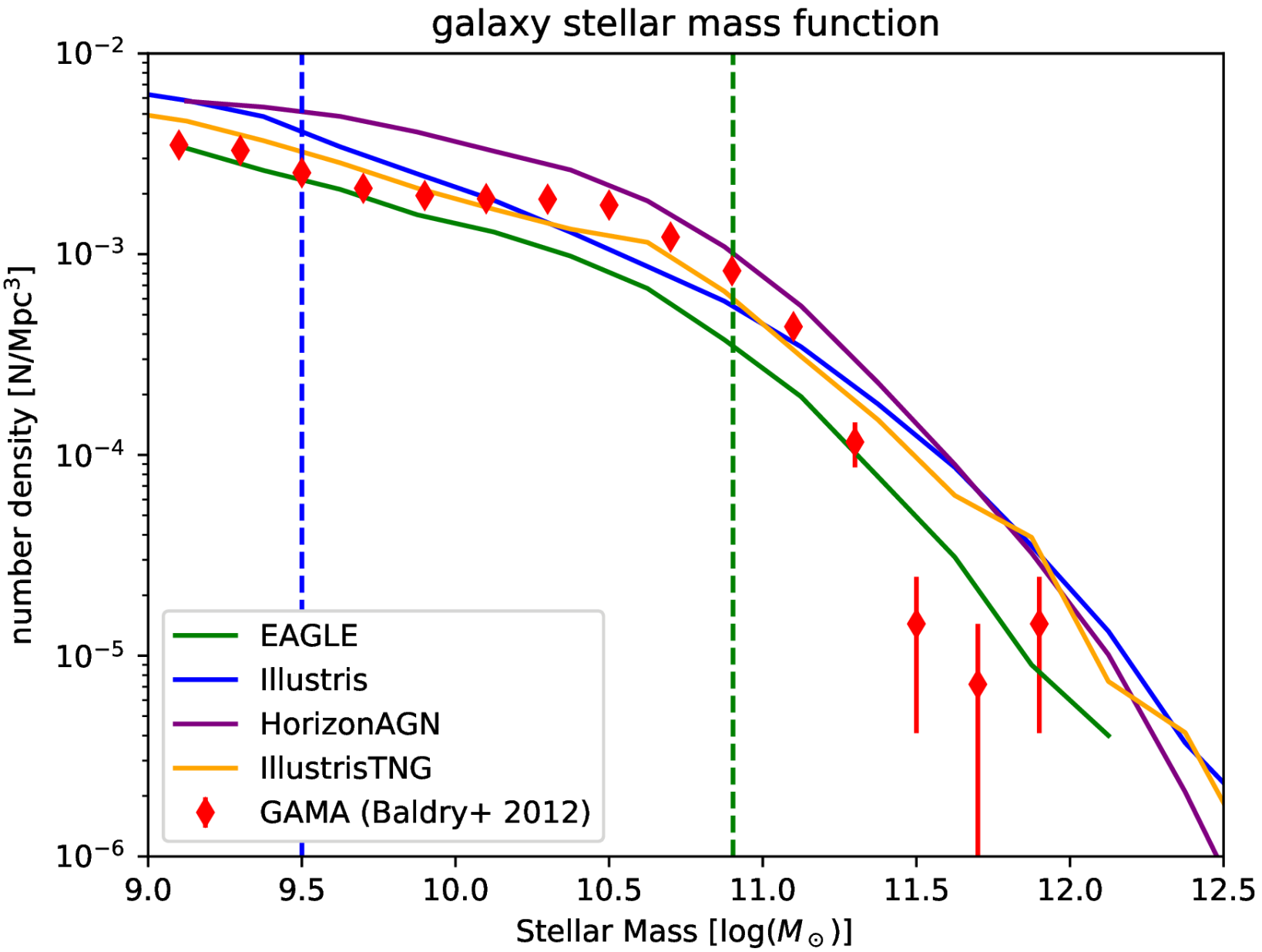
Dark matter deprived galaxies

- How could one get those?
  - Stripping of the outer dark matter halo (Limousin+ 2007, 2009)
  - Stochastic effects
  - Violent interactions disrupting the dark matter halo

- Looking for massive galaxies (beyond the knee of the stellar mass function)

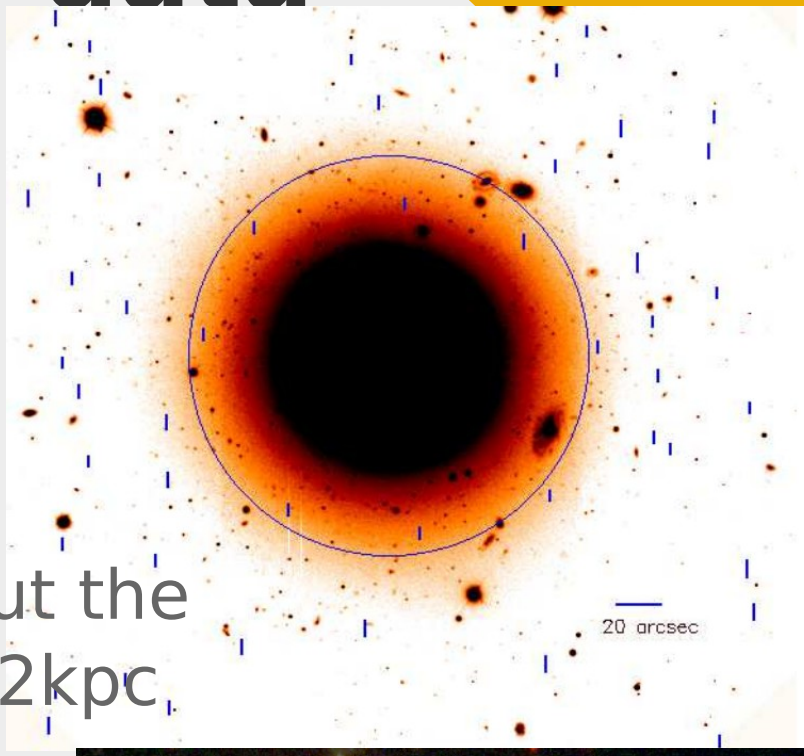
  (**NOT** similar too NGC1052-DF2 (vanDokkum+2018))

- Stellar masses > $8 \times 10^{10}\ M_{\odot}$

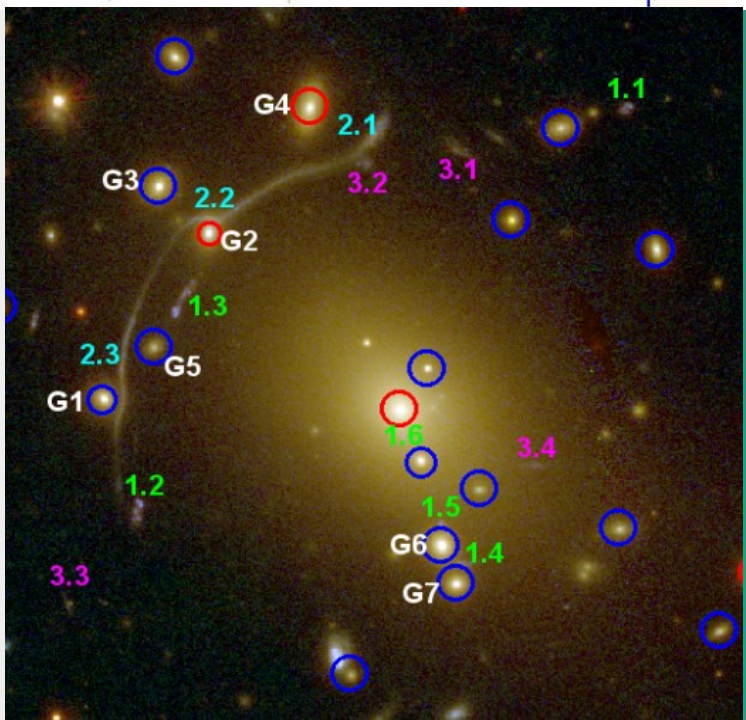


Observational data

- NGC7507 (Lane+ 2016)
  - Analysis of the kinematics of its globular clusters and planetary nebulae
  - “isolated elliptical”
  - 2×10^{11} $M_{\odot}$ stellar mass and about the same for dark matter within ~22kpc

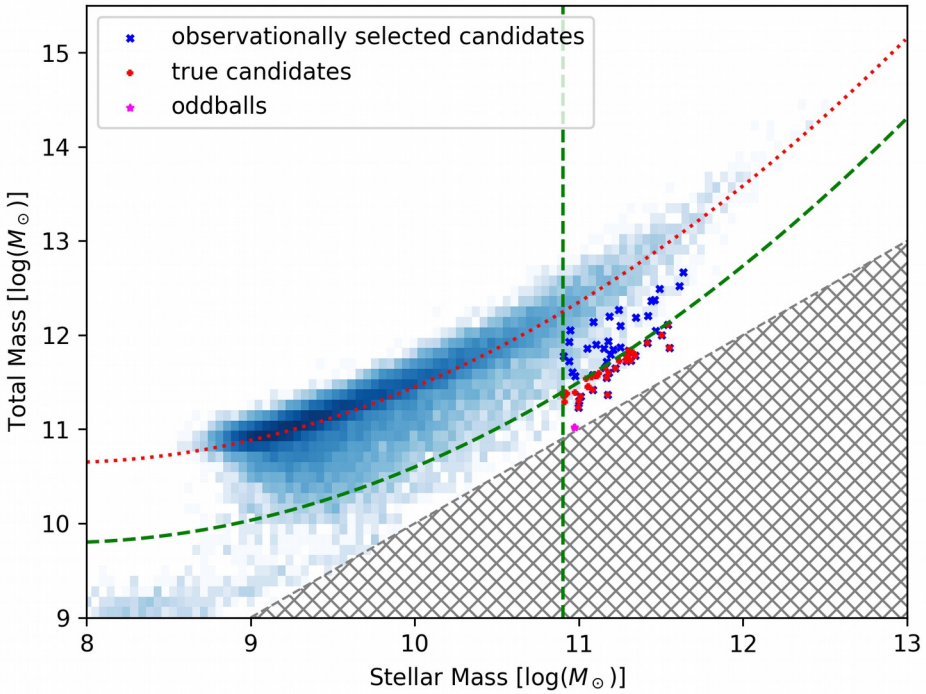


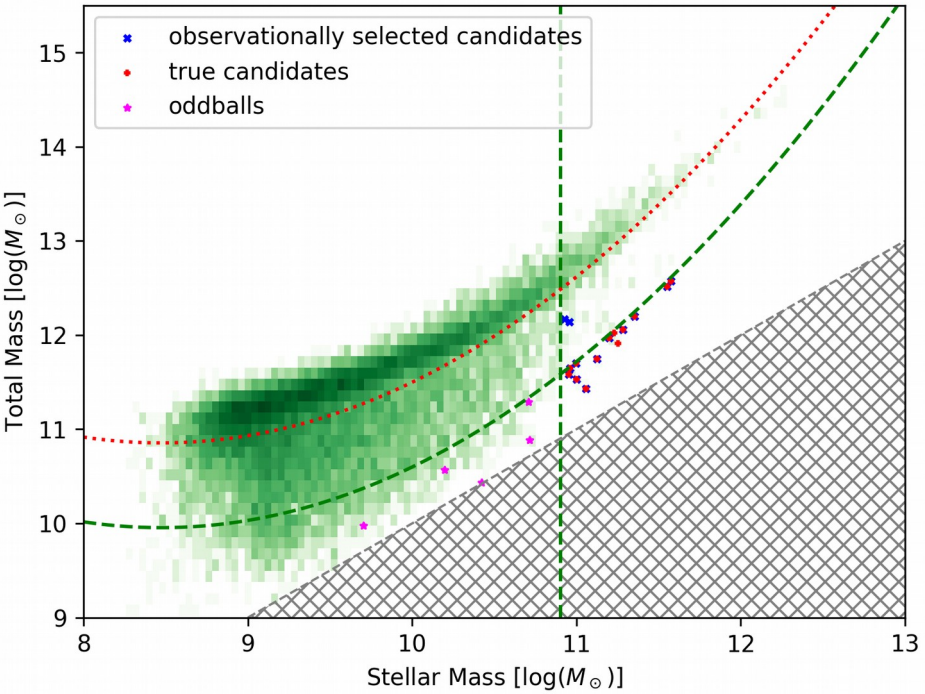
- Two galaxies in A611 (Monna+ 2016)
  - Strong lensing cluster
  - G1 and G2 have dark matter halo radii < 15kpc



Identifying dark matter deprived galaxies in simulations

- Looking for outliers of the stellar mass-halo mass relation
- How common are those galaxies?
- Comparing their properties between the different simulations.
- What are the processes forming such exotic galaxies?


observationally selected candidates
true candidates
oddballs
Total Mass [log($M_\odot$)]
Stellar Mass [log($M_\odot$)]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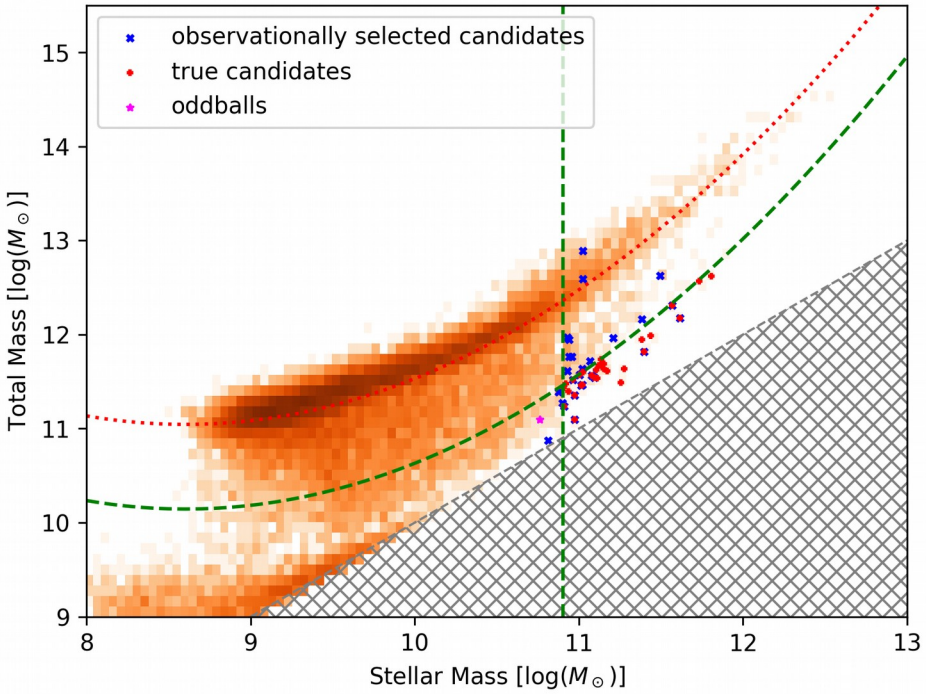
Total Mass [log($M_\odot$)]
Stellar Mass [log($M_\odot$)]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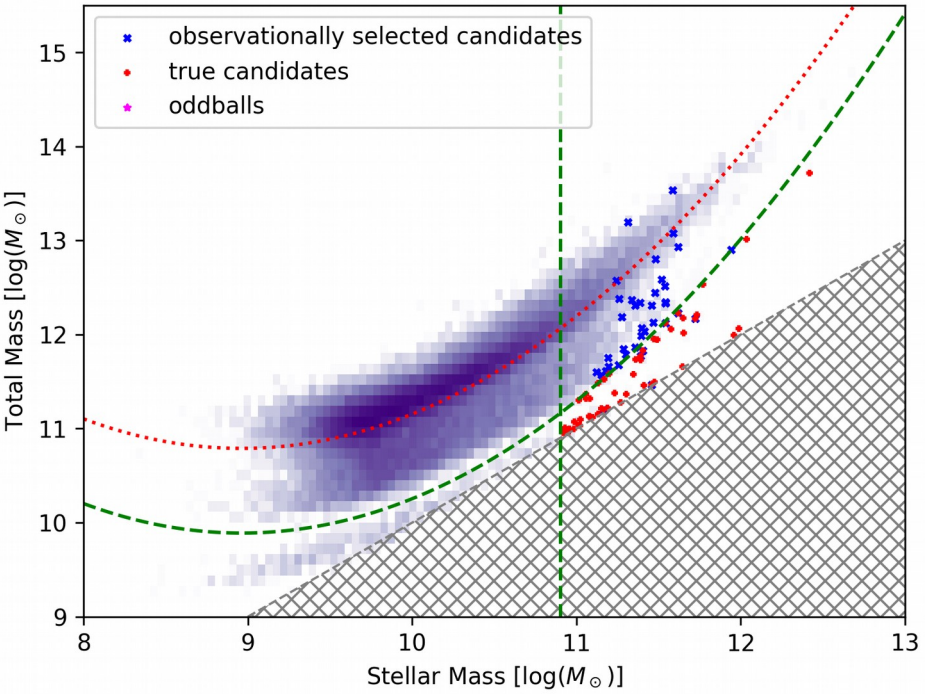
Stellar Mass [log($M_\odot$)]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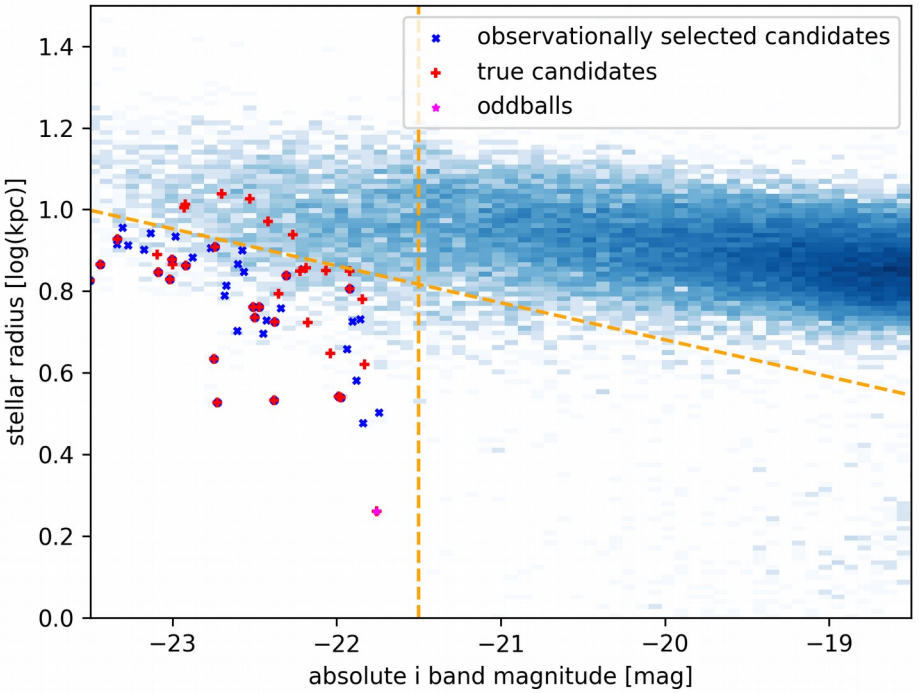
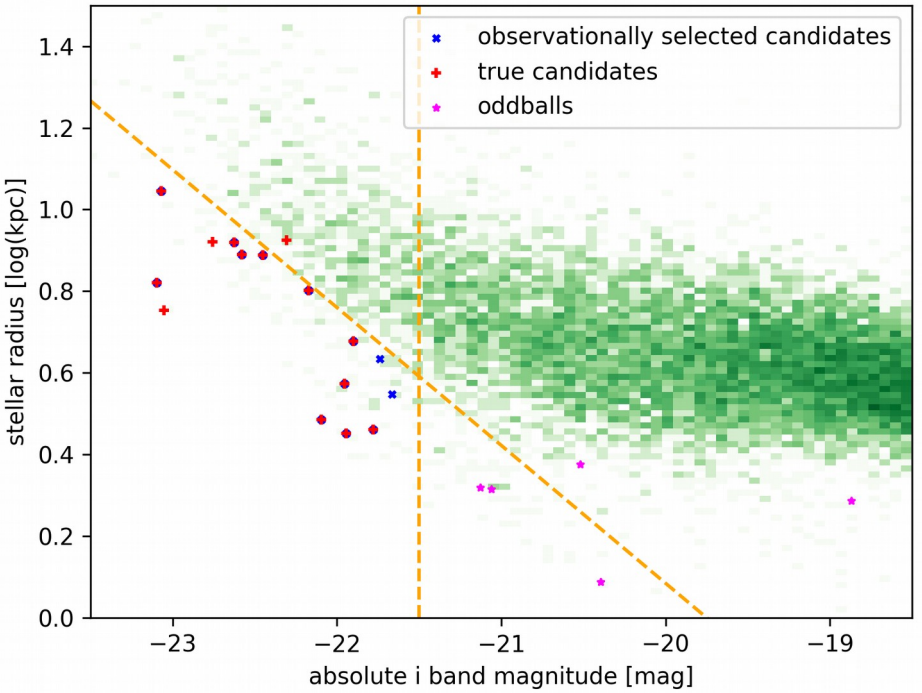

observationally selected candidates
true candidates
oddballs
stellar radius [log(kpc)]
absolute i band magnitude [mag]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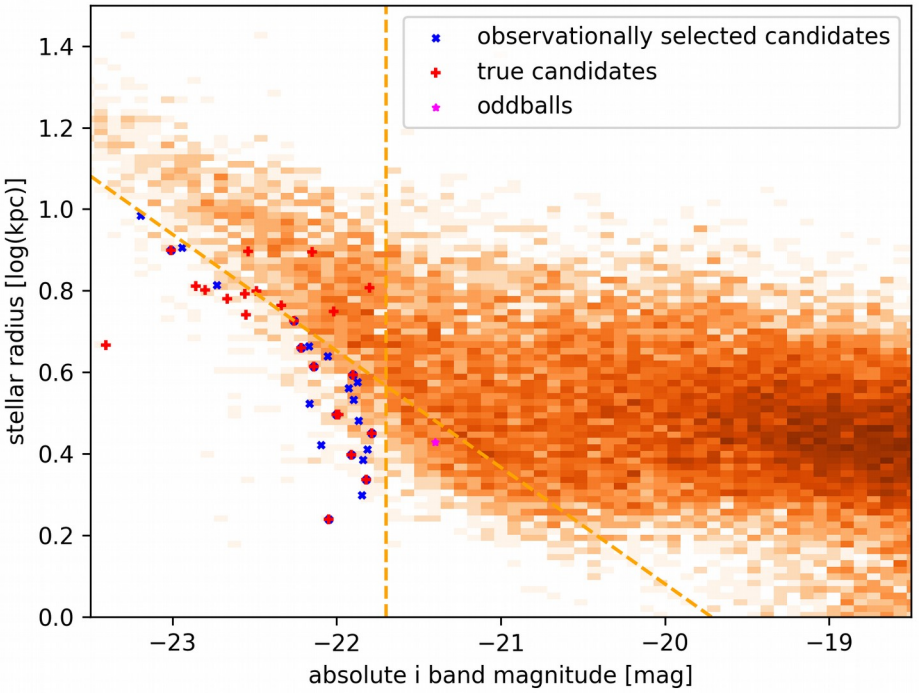
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stellar radius [log(kpc)]
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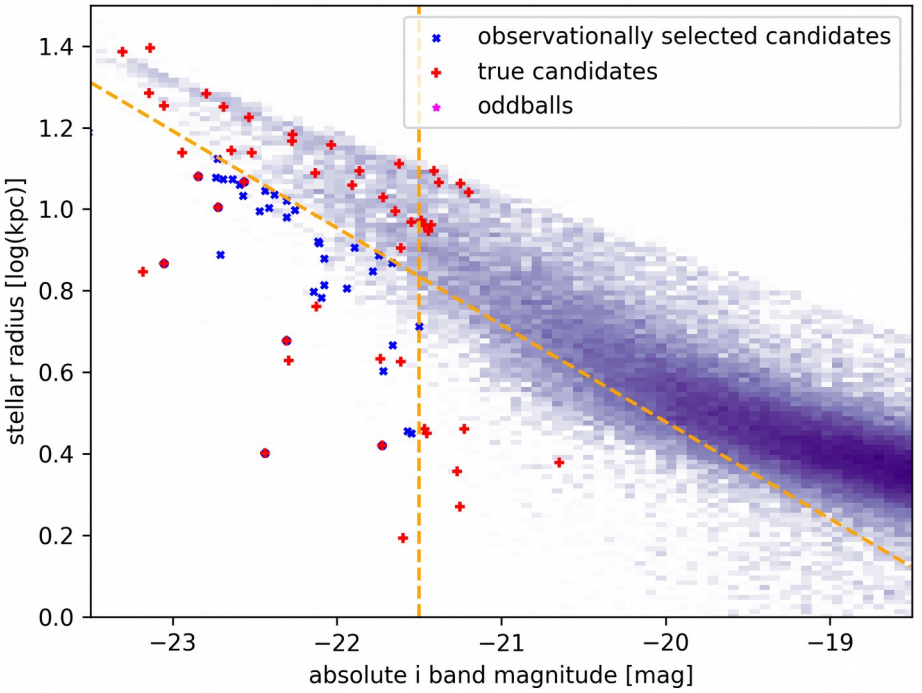
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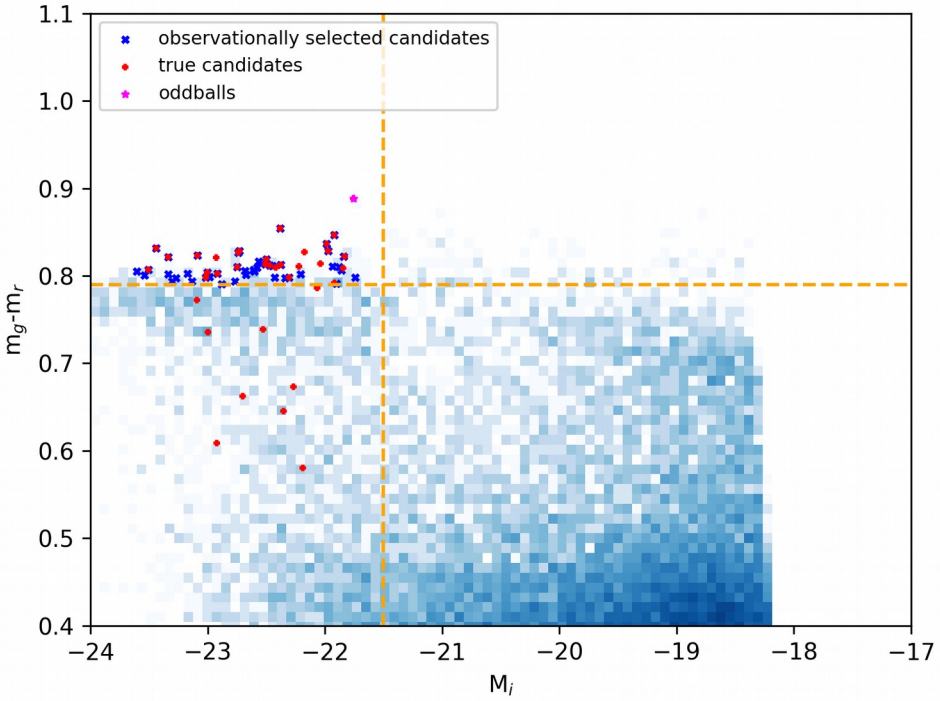
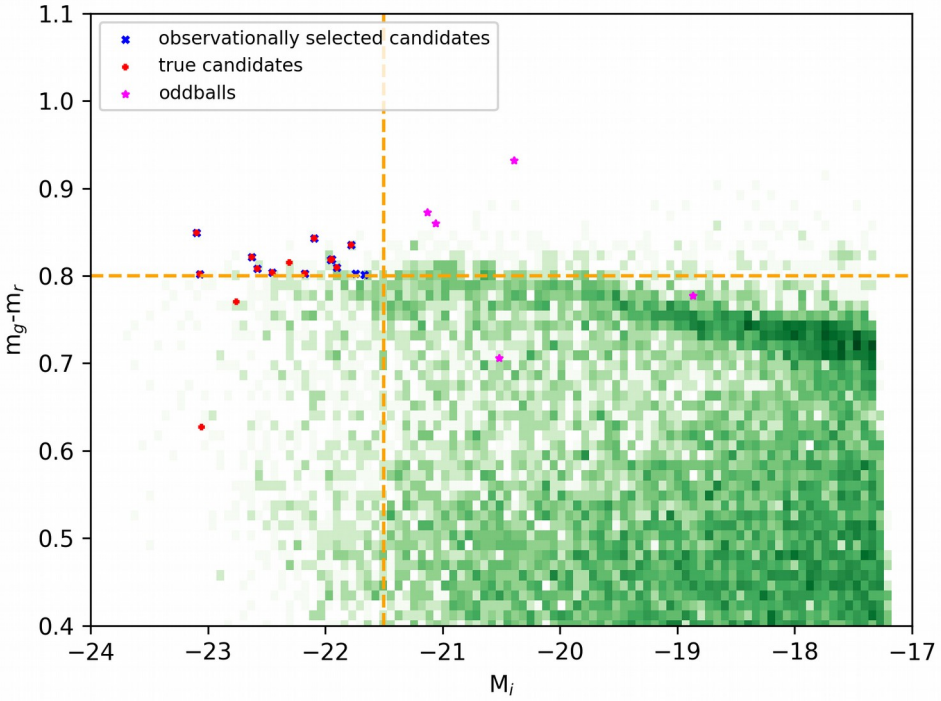
absolute i band magnitude [mag]


observationally selected candidates
true candidates
oddballs
m_g-m_r
M_i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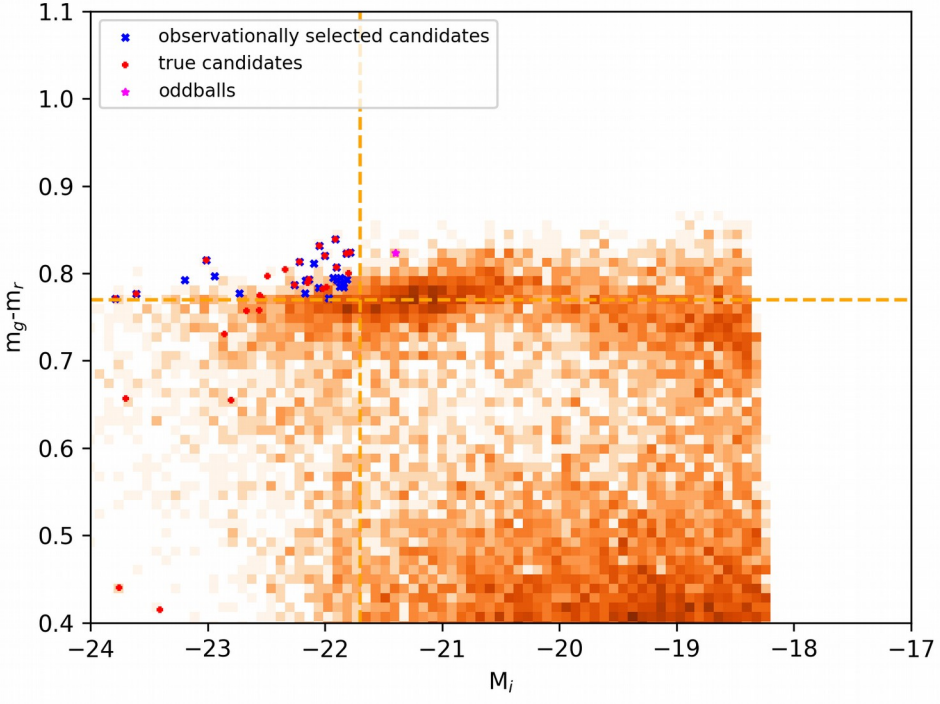
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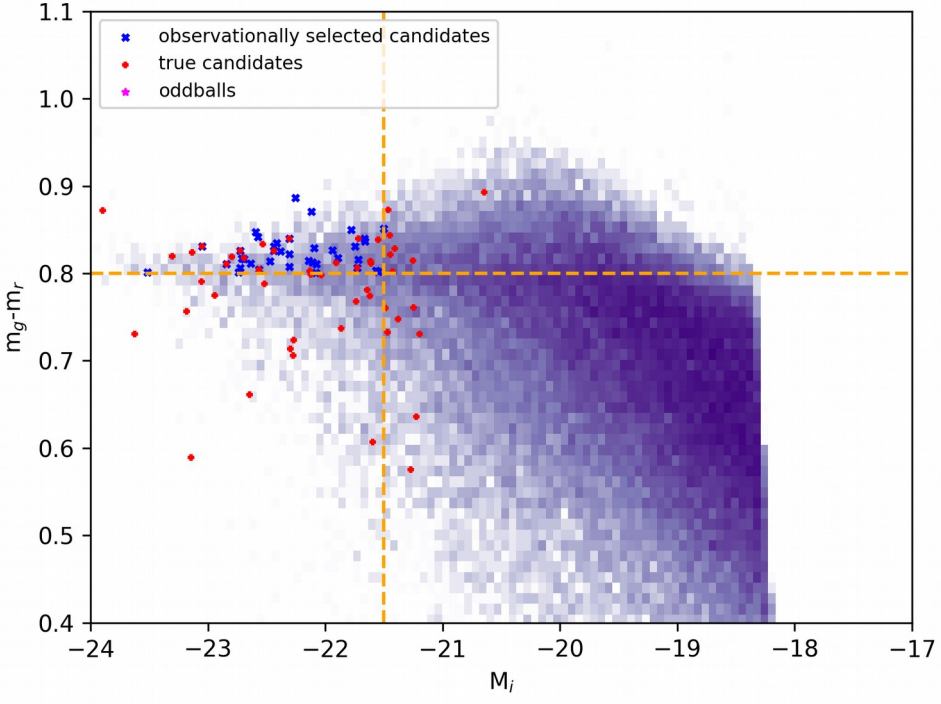
observationally selected candidates
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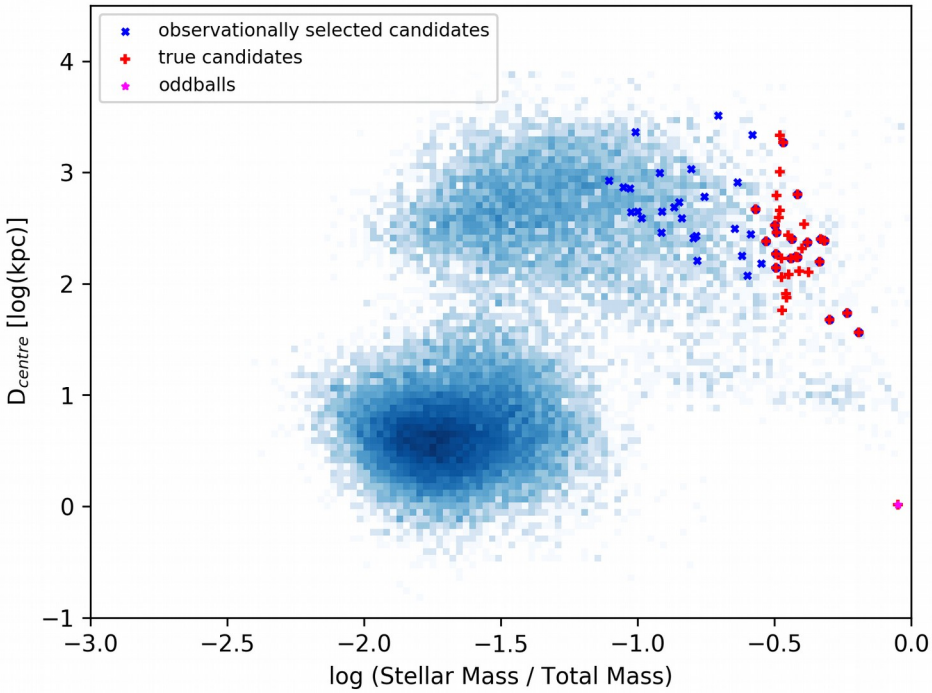
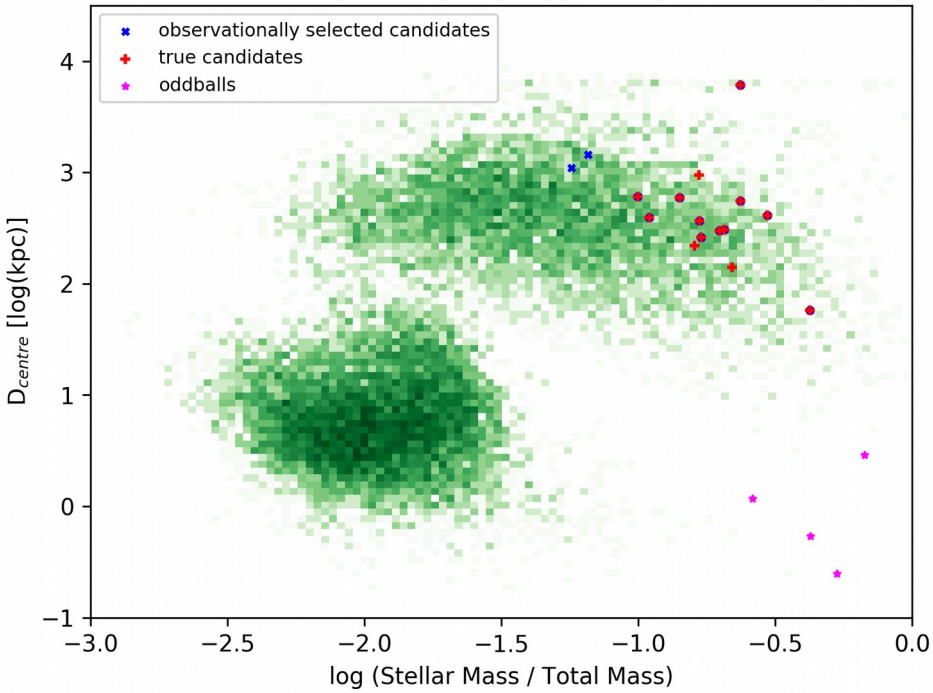
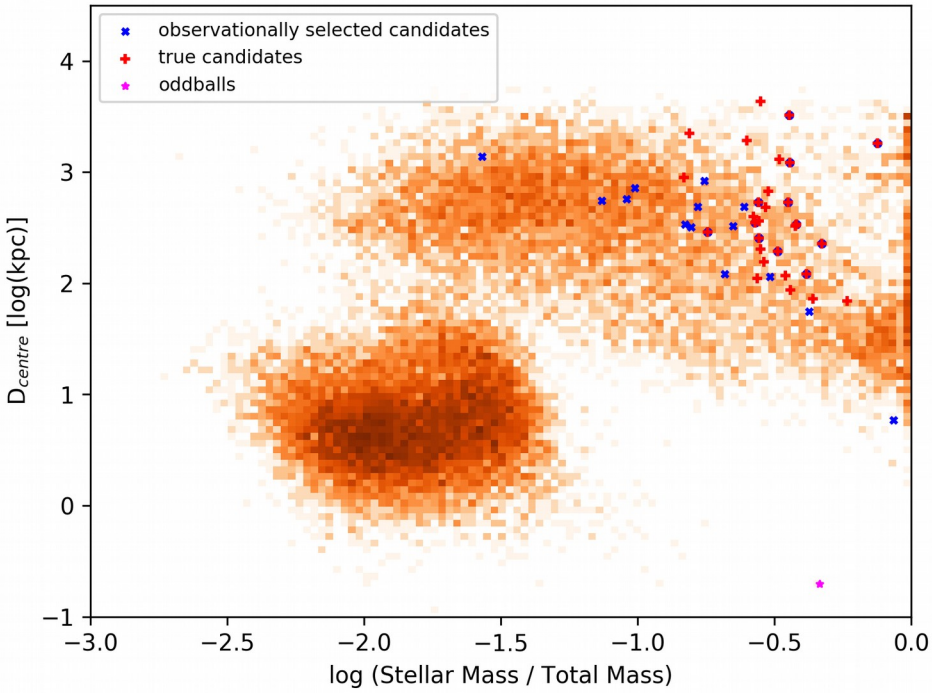
M_i

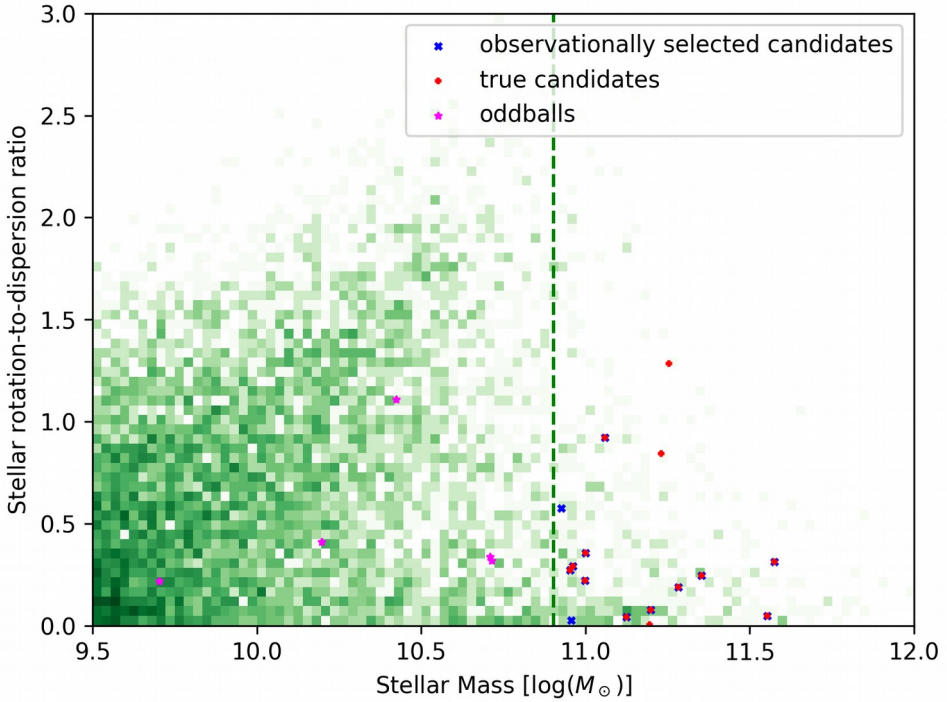


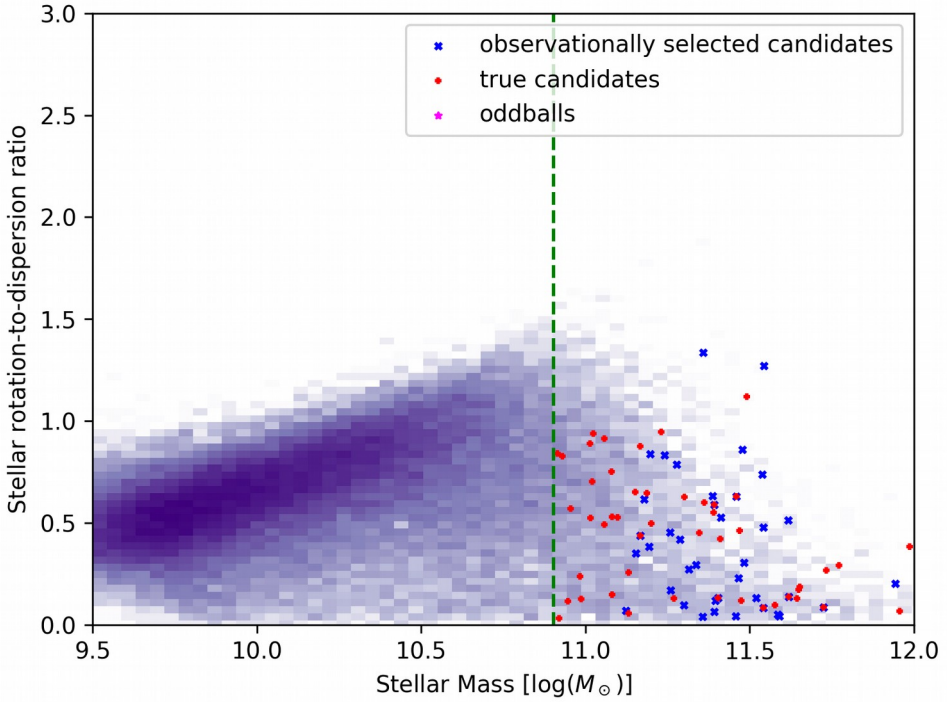


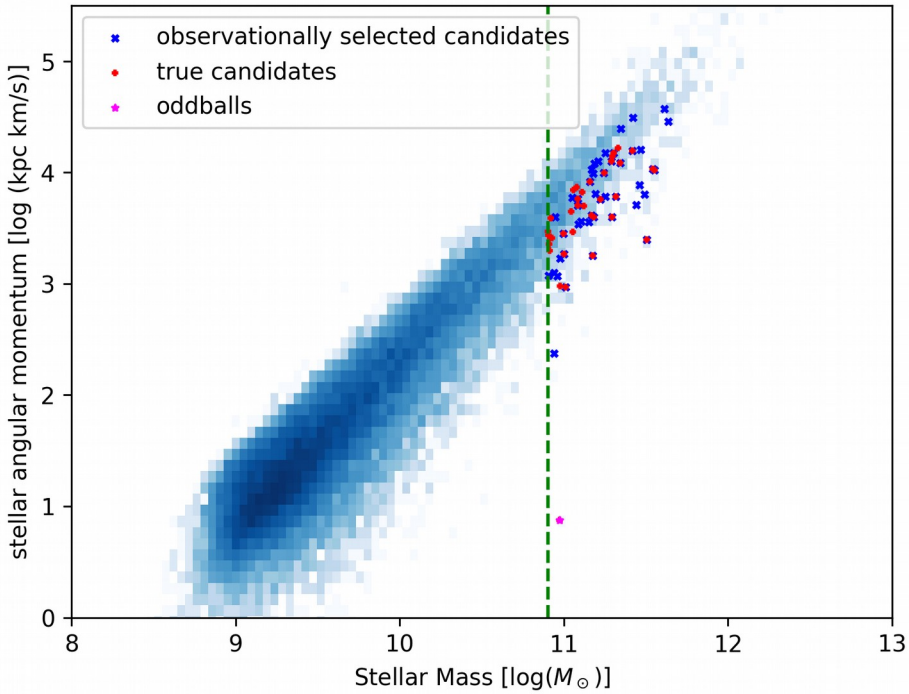


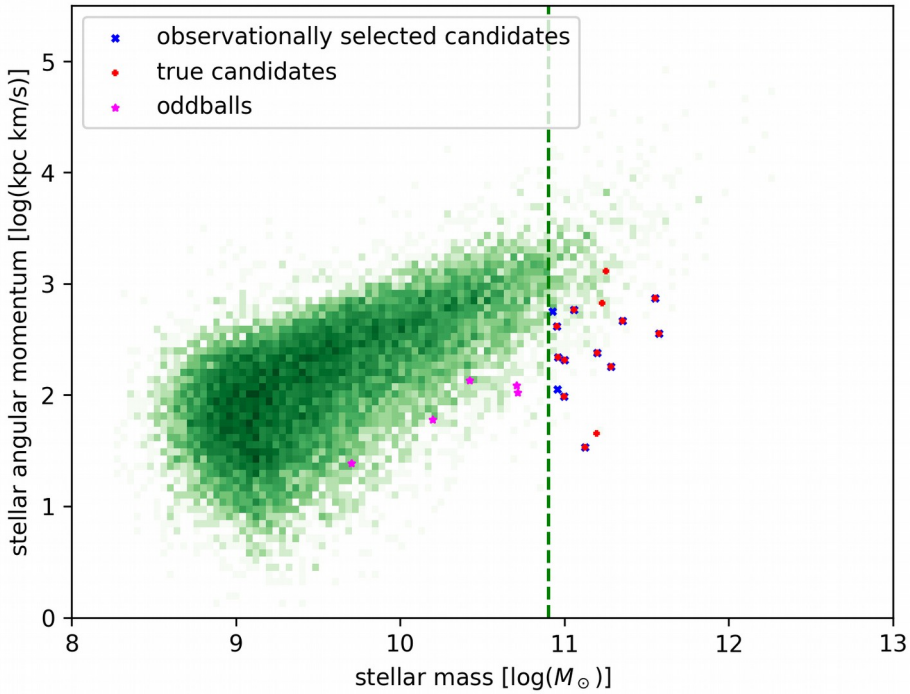
Dark matter deprived galaxies orbit the centre of clusters at a few 100kpc

- Notably low v_{rot}/σ_0 in EAGLE
- Indication for slow rotators
- Not as prominent in HorizonAGN





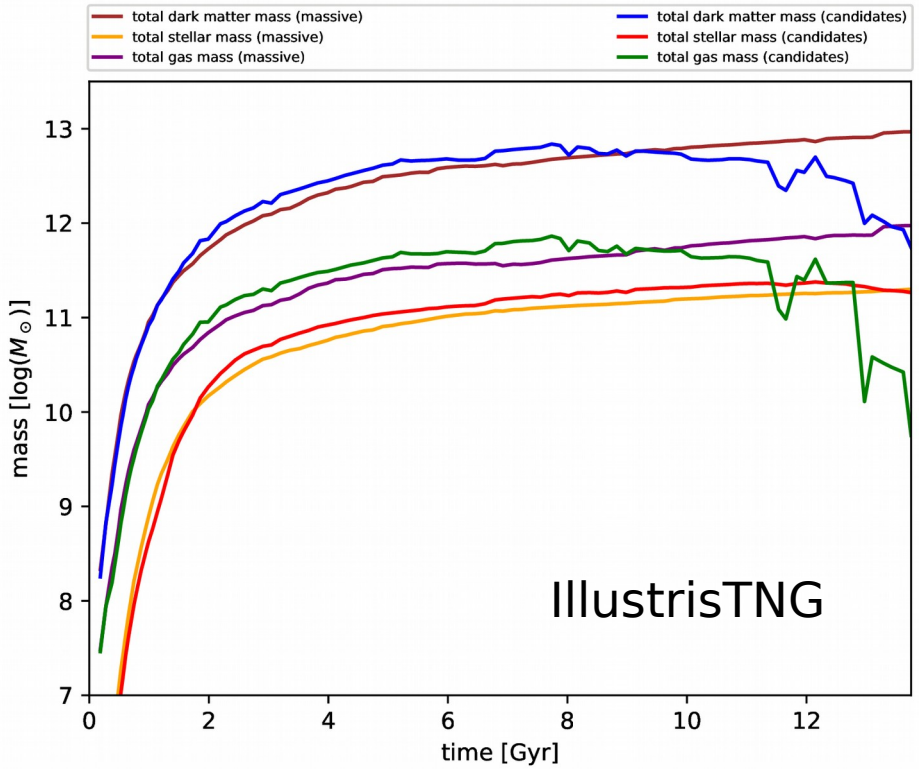


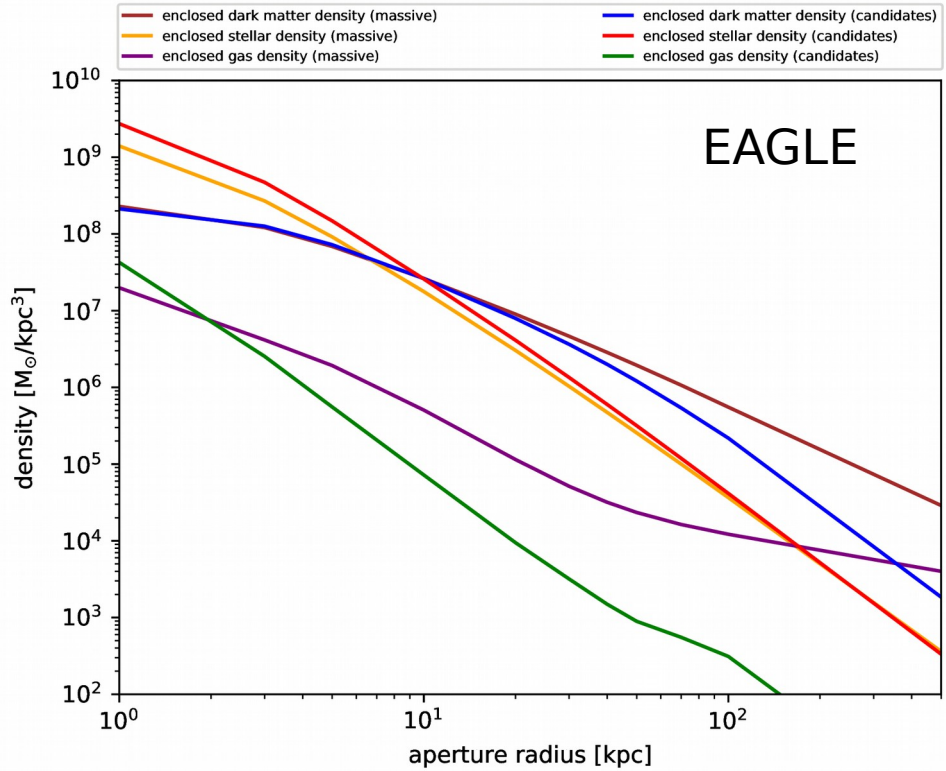


- Below average stellar angular momentum in Illustris
- In EAGLE dark matter deprived galaxies have notably low stellar angular momentum –> clear outliers for their mass range

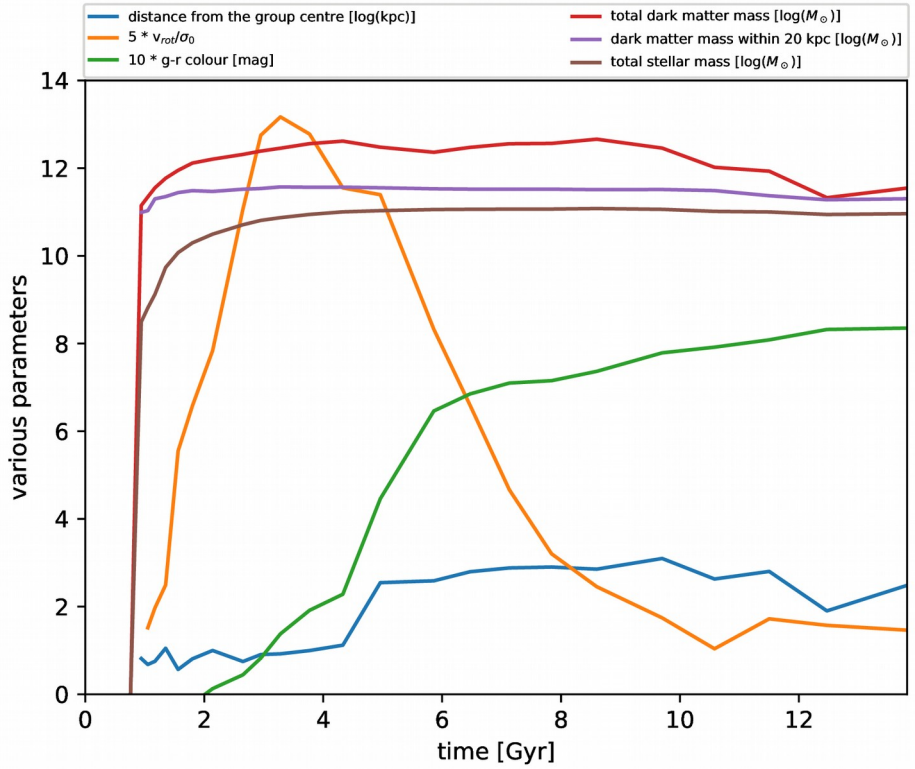
The loss of dark matter

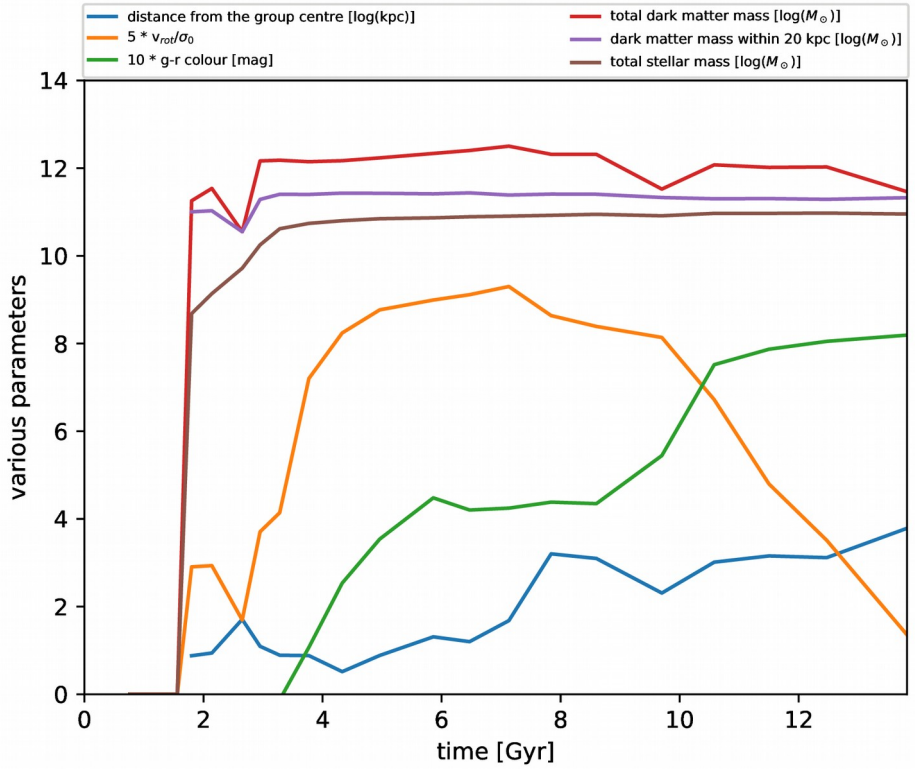
- Candidates are near the centre (a few 100kpc from the BCG) of rich cluster
- Gradual loss of the outer dark matter halo via tidal stripping (peaks at pericentre)





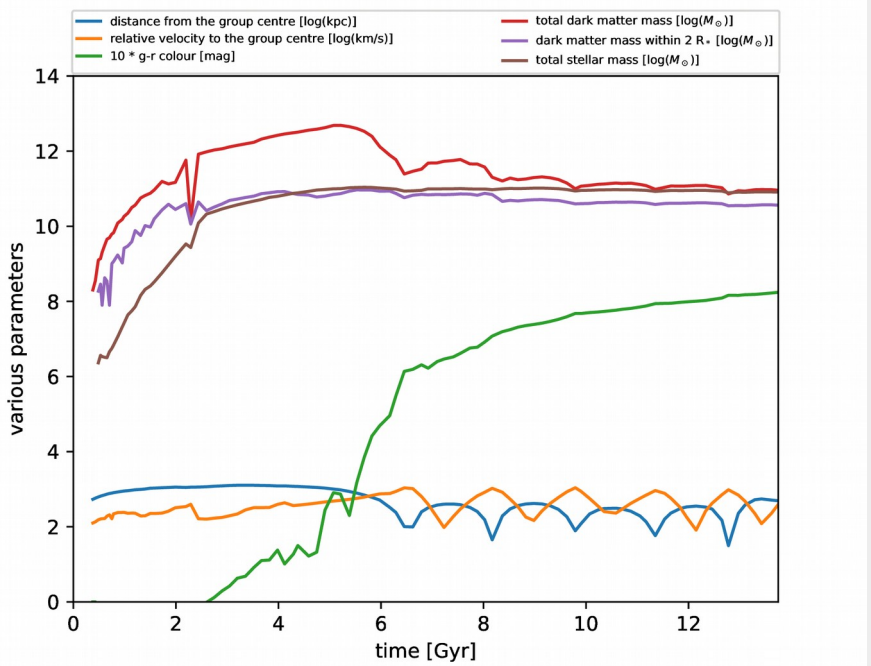
Examples in EAGLE

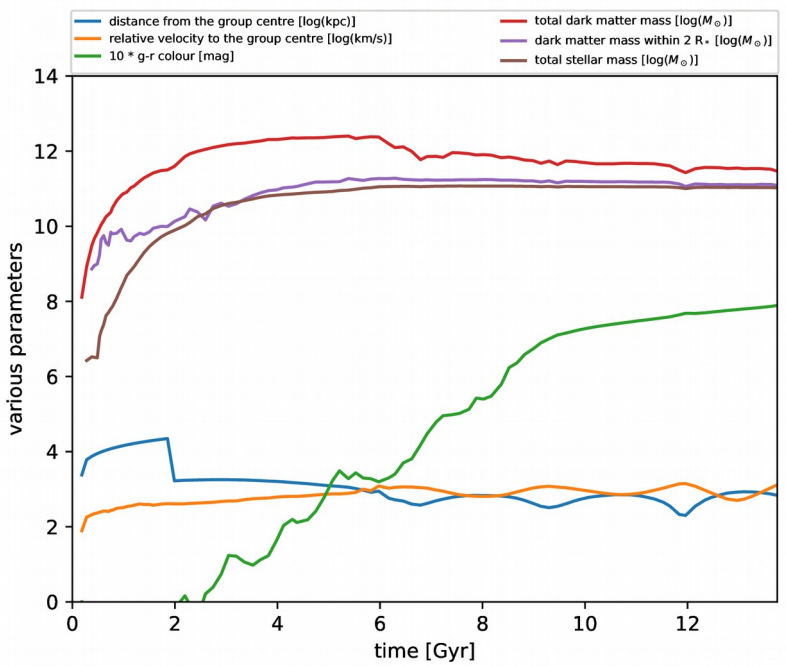


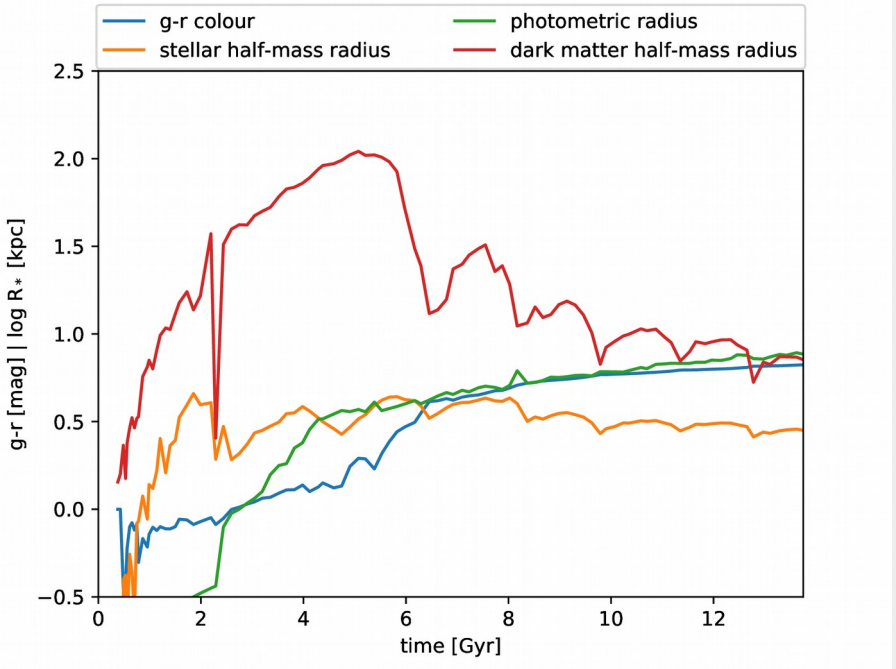


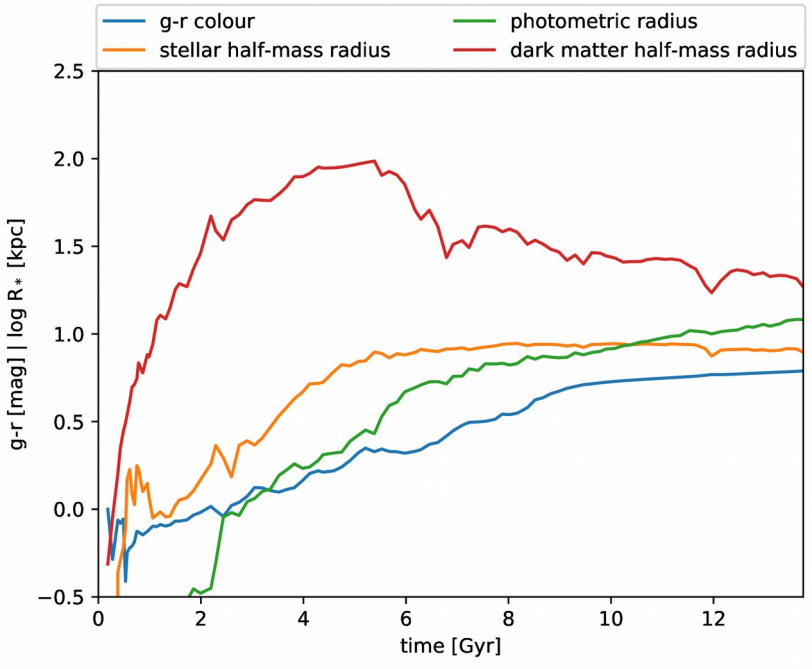
- Loss of rotation
  - No correlation with loss of the dark matter halo
  - Correlation with the end of starformation

Examples in IllustrisTNG



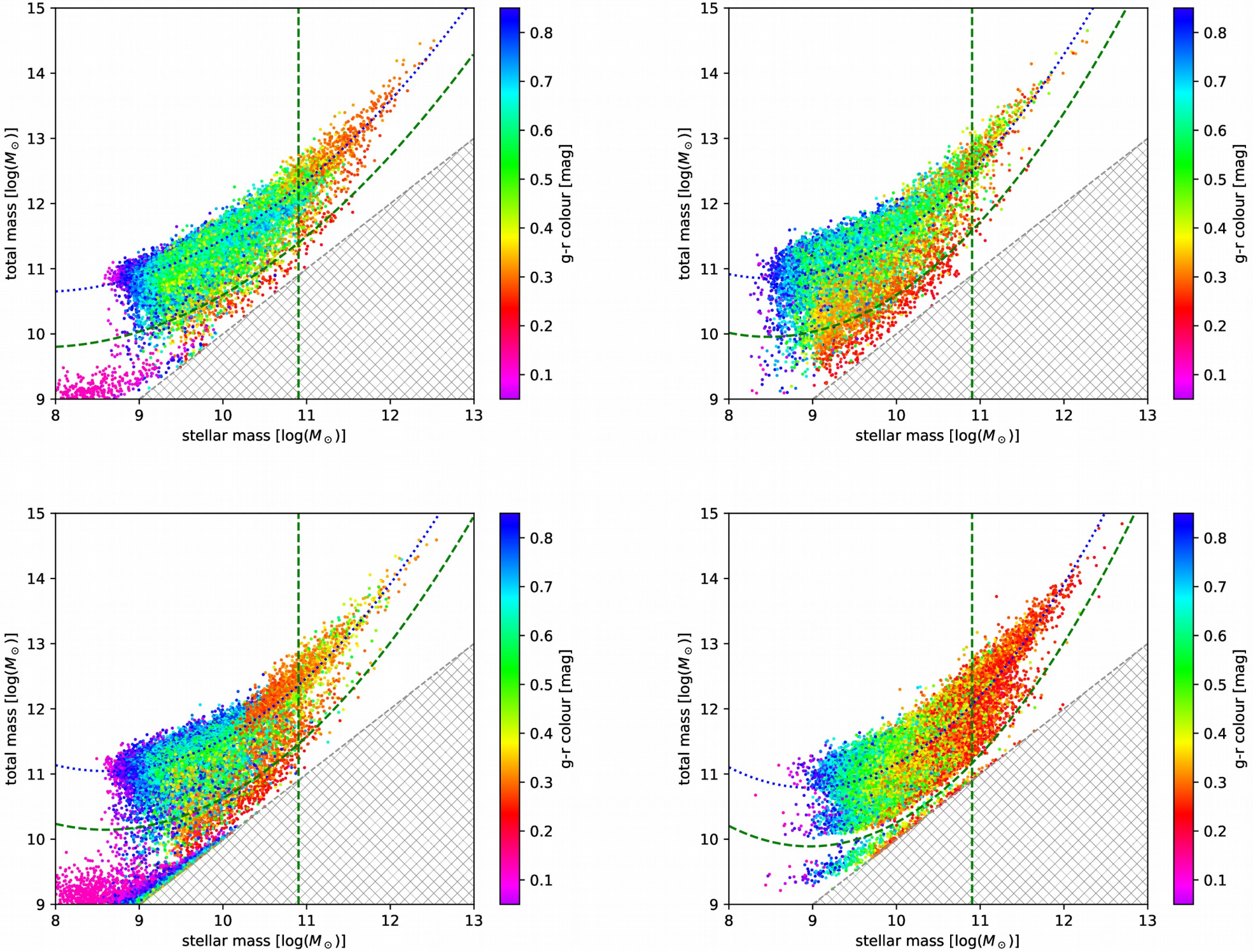


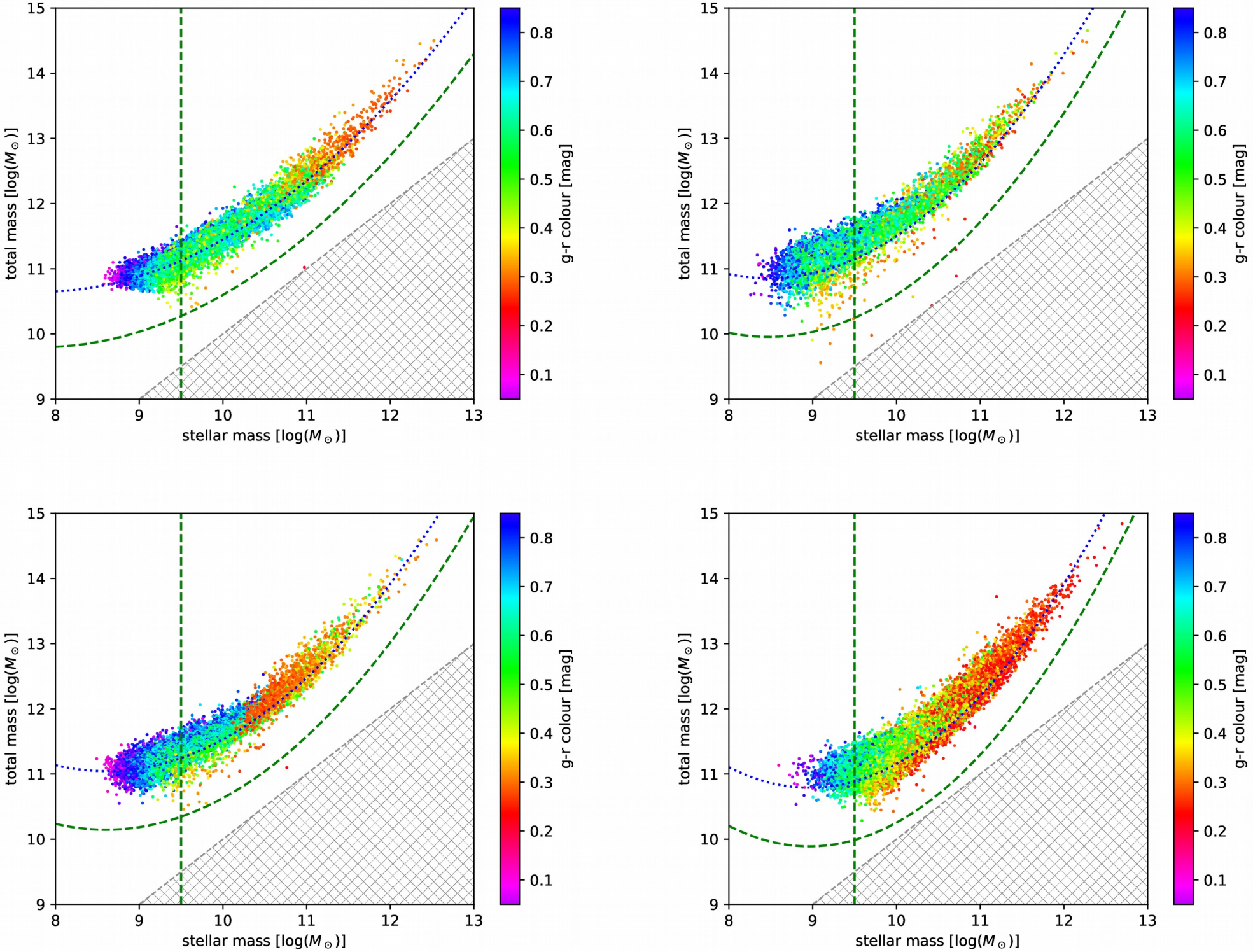




Statistics

- **Illustris**
  - 37 candidates
  - 3% of massive galaxies
  - 1.1% of bright galaxies
  - 42% precision for observational recovery
- **IllustrisTNG**
  - 29 candidates
  - 3% of massive galaxies
  - 1.5% of bright galaxies
  - 44% precision for observational recovery
- **Eagle**
  - 14 candidates
  - 3% of massive galaxies
  - 1.6% of bright galaxies
  - 85% precision for observational recovery
- **HorizonAGN**
  - 50 candidates
  - 1.4% of massive galaxies
  - 2.3% of bright galaxies
  - 18% precision for observational recovery


total mass [log($M_\odot$)]
stellar mass [log($M_\odot$)]
g-r colour [mag]
15
14
13
12
11
10
9
8
9
10
11
12
13
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1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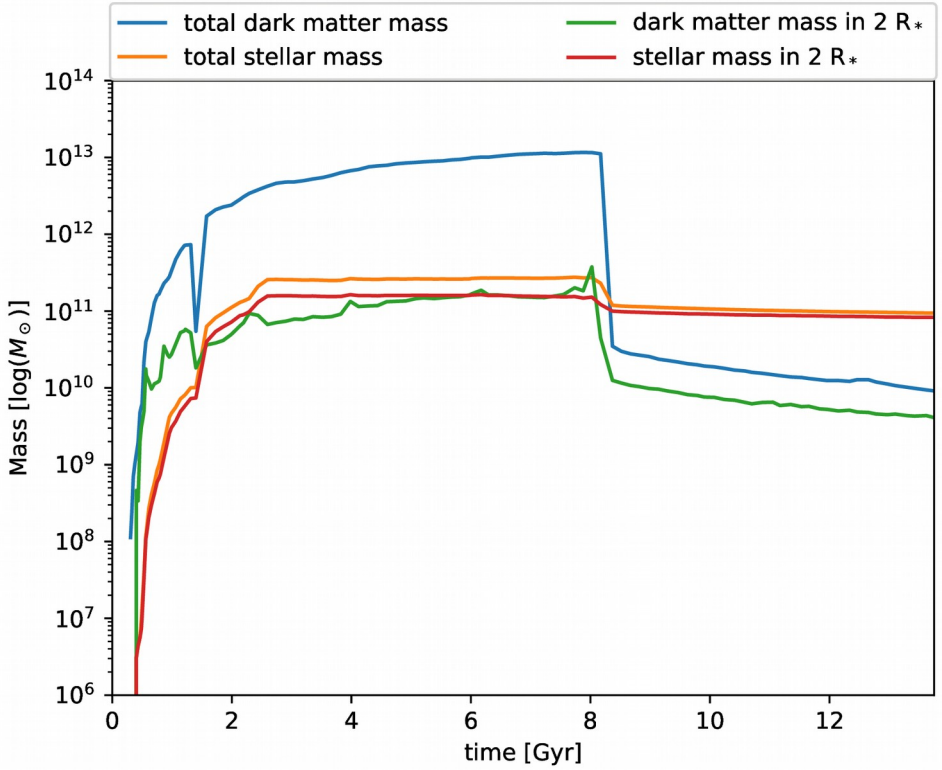
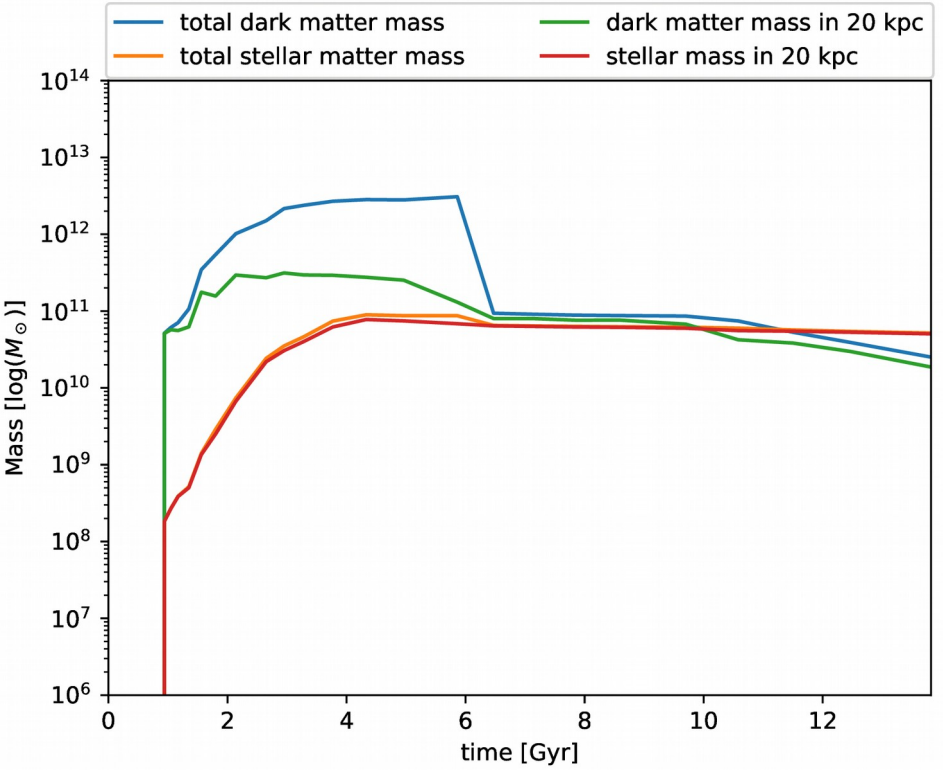
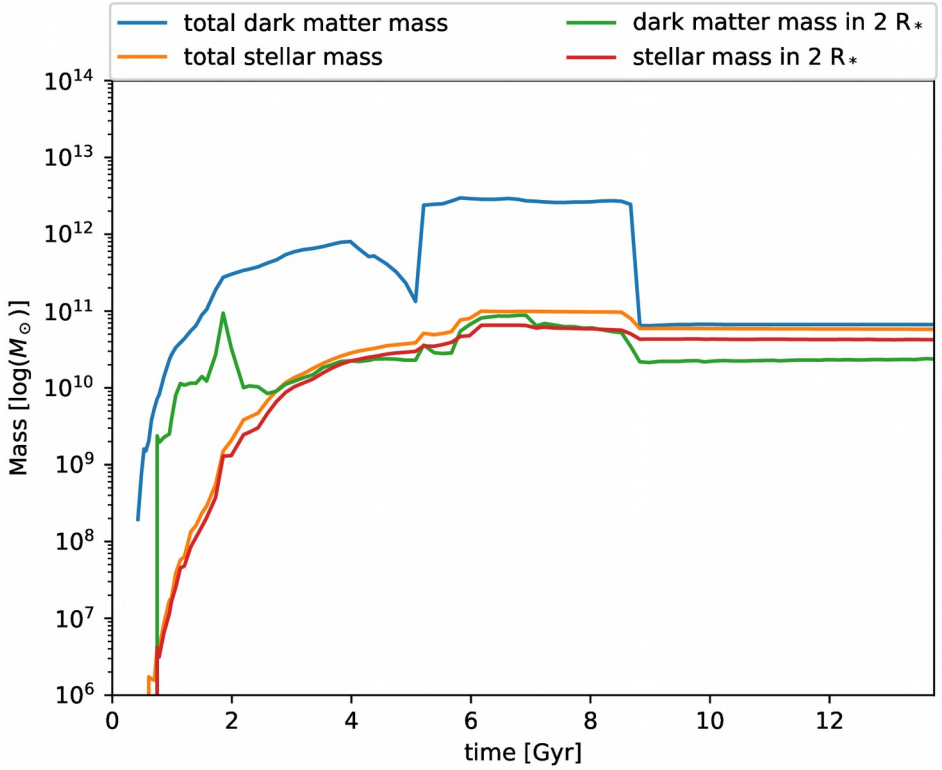
11
12
13
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

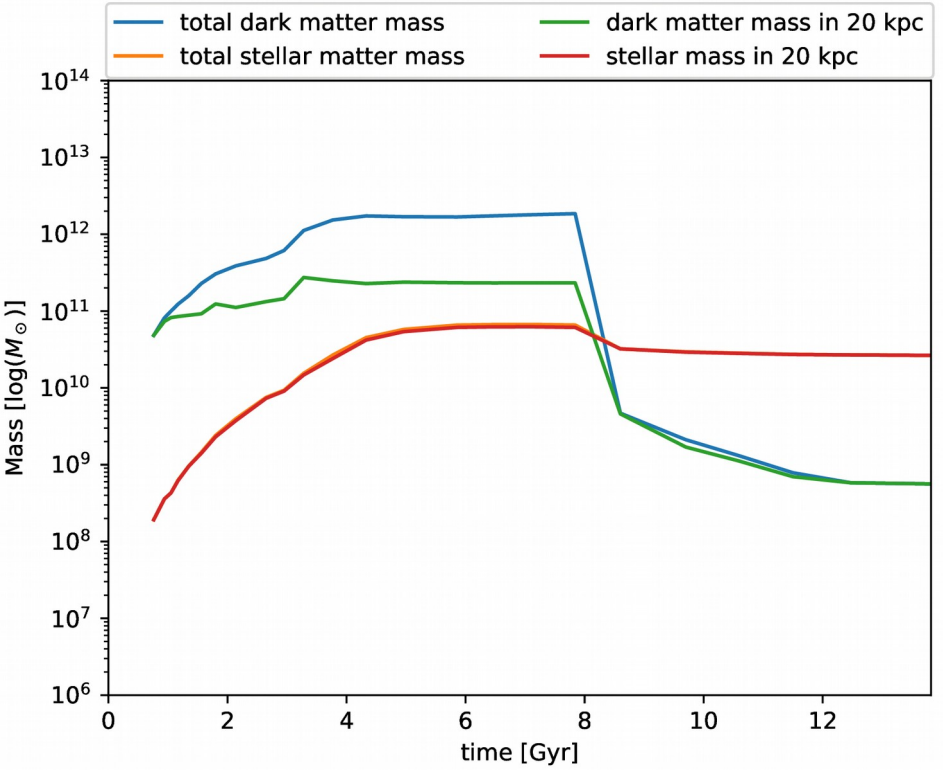
Oddballs

- Extremely rare (5 in EAGLE, 1 in Illustris, 1 in IllustrisTNG) isolated dark matter deprived galaxies
- Oddball in Illustris already discussed in Yu+ 2018 ... passage and deflection through a cluster destroyed its dark matter halo
- These galaxies remain stable for several Gigayears.
- No clear properties ... one even retains a disc and some star formation, while others are red, dead, but chaotic.


total dark matter mass
total stellar mass
dark matter mass in 2 R*
stellar mass in 2 R*
Mass [log(M⊙)]
time [Gyr]


total dark matter mass
total stellar matter mass
dark matter mass in 20 kpc
stellar mass in 20 kpc
Mass [log(M⊙)]
time [Gyr]


total dark matter mass
total stellar mass
dark matter mass in 2 R*
stellar mass in 2 R*
Mass [log(M⊙)]
time [Gyr]


total dark matter mass
total stellar matter mass
dark matter mass in 20 kpc
stellar mass in 20 kpc
Mass [log(M⊙)]
time [Gyr]

Outlook

- Identify candidates for dark matter stripped galaxies in surveys (using our criteria)
- Look for suitable archive data or carry out follow up observation to confirm their properties (especially kinematics)
- Looking for known suitable strong lenses
- Comparison with the predictions of the simulations (Illustris(TNG) vs EAGLE)
- Possible confusion with certain local red nugget survivors (no over-massive central black holes like in NGC 1277 (van den Bosch+ 2012))

Summary and Conclusions

- Slow stripping of the outer dark matter halos in rich clusters
- Compact, red galaxies near the centre that might be slow rotators
- Different simulations predict similar number densities but different properties for them
- Rare oddball galaxies
- Isolated dark matter deprived galaxies with a violent event in their history
- Potential laboratories to test modified gravity
- Upcoming paper: **Saulder et. al in preparation**

ANY QUESTIONS?