KIAS KOREA INSTITUTE FOR ADVANCED STUDY

Galaxies with low dark matter fractions

- how they form and how to detect them using photometric and kinematic parameters

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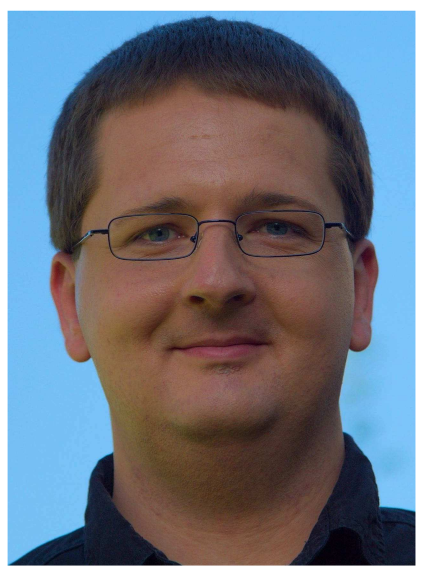

Abstract

Inspired by the kinematics of NGC 7507, which requires only a very low fraction of dark matter, we searched for galaxies with similar properties in numerical simulations that explicitly consider baryonic matter. Several galaxies, which we found in the Illustris and Eagle simulation, allowed us to study how they gain a surplus of baryonic matter or get deprived of dark matter. We also investigated the impact of the lower dark matter fraction on the angular momentum and kinematics of theses galaxies. Furthermore, we looked for correlations between their kinematic and photometric parameters, as well as their environment to help us to quickly identify candidates for galaxies with low dark matter fractions in large-scale surveys.

NGC 7507

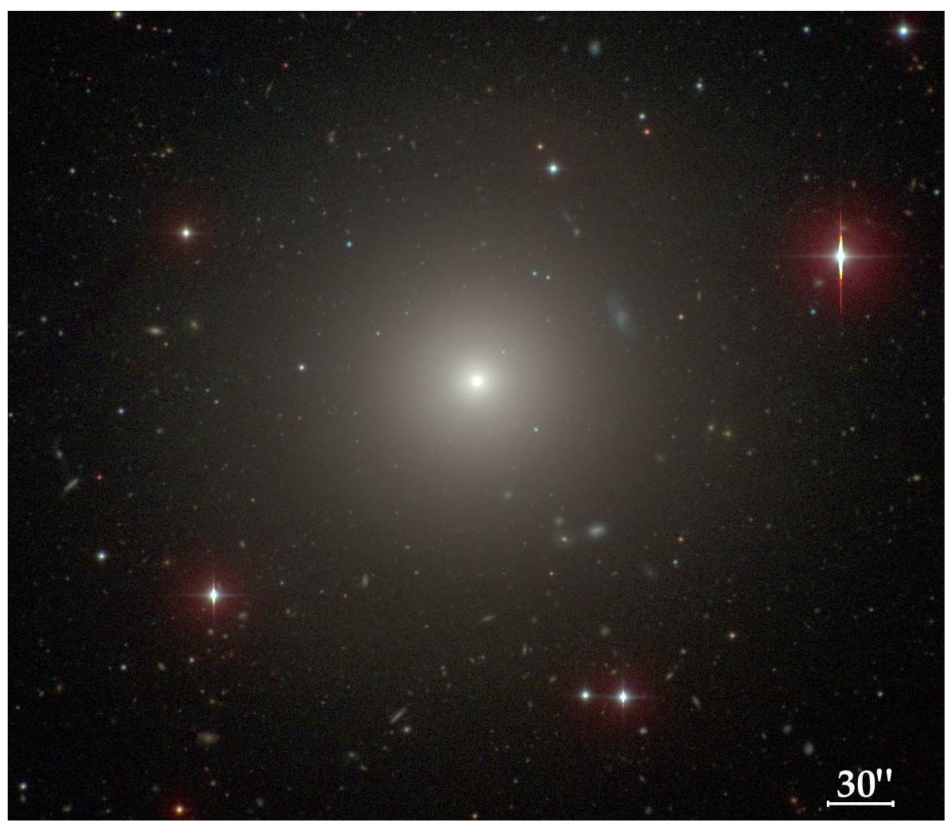

Figure 1: Composite image of NGC 7507 obtained from the Carnegie-Irvine Galaxy Survey.

- Field elliptical galaxy in a group with NGC 7513
- Stellar mass: $2 \cdot 10^{11}$ $M_\odot$ (Salinas+ 2012)
- Dark matter mass: $1.5 - 2.7 \cdot 10^{11}$ $M_\odot$ (best fits), with an upper limit of $6 \cdot 10^{11}$ $M_\odot$ (Lane+ 2015)
- σ-bump: possible major merger in its history
- Kinematic data out to 15 kpc

Why are these galaxies interesting?

Galaxies with low dark matter fractions allow us to **test dark matter against various models of modified gravity**. A consistent theory of modifying gravity requires that given distribution of visible matter always yields the same kinematic signature (apparent dark matter distribution). On the other side dark matter allows for a certain variations of the luminous-to-dark matter ratio. Theoretically, two galaxies with the same distribution of visible matter can have different dark matter ratios yielding different kinematic signatures. Lane+ 2014 showed that the kinematic data of NGC 7507 is incompatible with Modified Newtonian Dynamics (MOND).
Furthermore, we may be able to study how baryons settled into dark matter halos and the importance of **stochastic effects** in this process. We will also be able to study the effects the environment has on dark matter halos and the **deprivation of dark matter** due to interaction.

Illustris and EAGLE

Most big cosmological simulations only considered dark matter and then populated the dark matter halos with semi-analytical galaxy models to predict observational parameters. Since we are specifically looking for galaxies with unusual baryonic-to-dark matter ratios, we have to use numerical simulations that **baryonic matter as its own component** for their entire run.
The Illustris simulation (Vogelsberger+ 2014, Nelson+ 2015) and EAGLE (Schaye+ 2015) are two hydrodynamical simulations that properly consider baryonic physics and allow us to search for and study galaxies with low dark matter fractions.

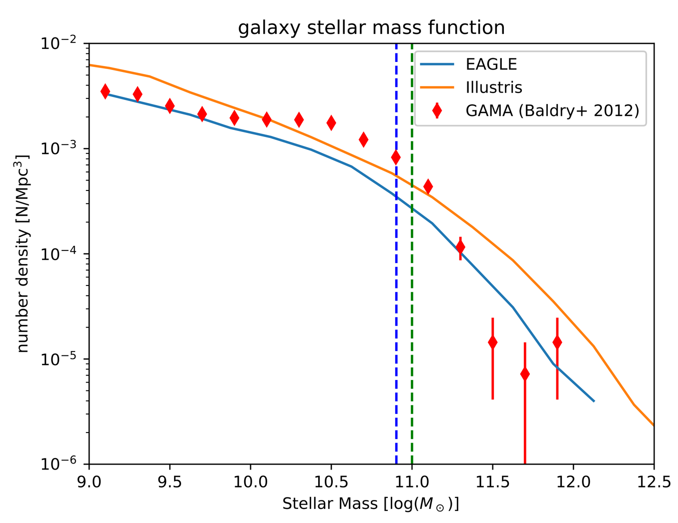

Figure 2: The stellar mass functions of both simulations compared to observational data. The vertical lines (Illustris: green, EAGLE: blue) indicate **knee of the stellar mass function** beyond which we consider galaxies as massive.

Candidate galaxies in simulations

We are primarily looking for **massive galaxies** (beyond the knee of the stellar mass function, see Figure 2) that are significant outliers from the usual stellar mass to dark matter mass relation.

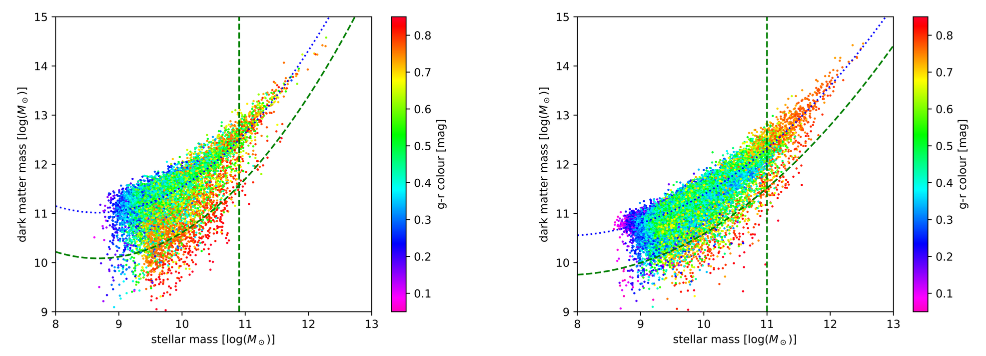

Figure 3: We define our candidates as massive galaxies that are outliers (beyond the green dashed line) from the stellar mass to dark matter mass relation (blue dotted line) produced by the simulation. There are clear systematic difference between the two simulations (left panel: EAGLE, right panel: Illustris), but both indicate that the majority of the dark matter deprived galaxies have **notably red colours**.

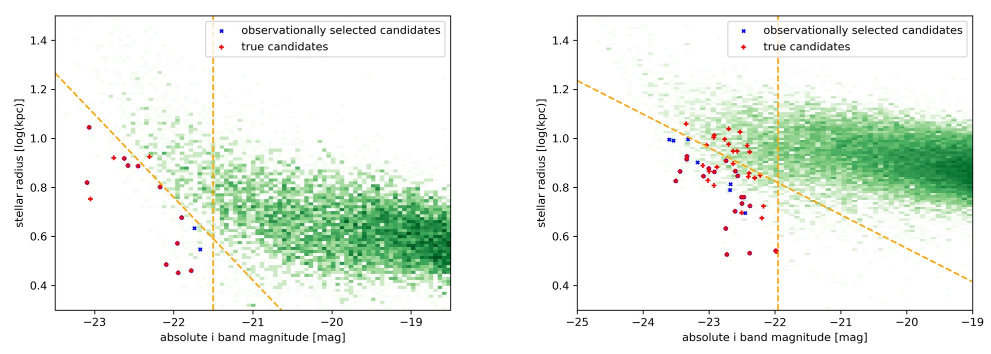

Figure 4: Galaxies with low dark matter fractions are notably **more compact** than other galaxies of the same luminosity. Seeing the systematic offset between the sizes and magnitude obtained from EAGLE (left panel) and from Illustris (right panel), we will eventually have to calibrate our photometric (orange dashed lines and others not shown in these figures) and spectroscopic selection criteria on survey data.

Kinematic parameters: Angular momentum and velocity dispersion

Since the **EAGLE** database directly provides the observationally interesting kinematic parameters of the stellar component, we carried out this part of our analysis primarily with EAGLE data. While galaxies with low dark matter fractions have **above average central velocity dispersion**, we find that the **stellar angular momenta** of galaxies with low dark matter fractions are **extremely low** for their stellar mass range. One would definitely classify these galaxies as slow rotators. Complimentary data from the Illustris simulation showed that the **total angular momentum** (including dark matter) is also notably **below average** for our candidates compared to other galaxies of their total mass range.

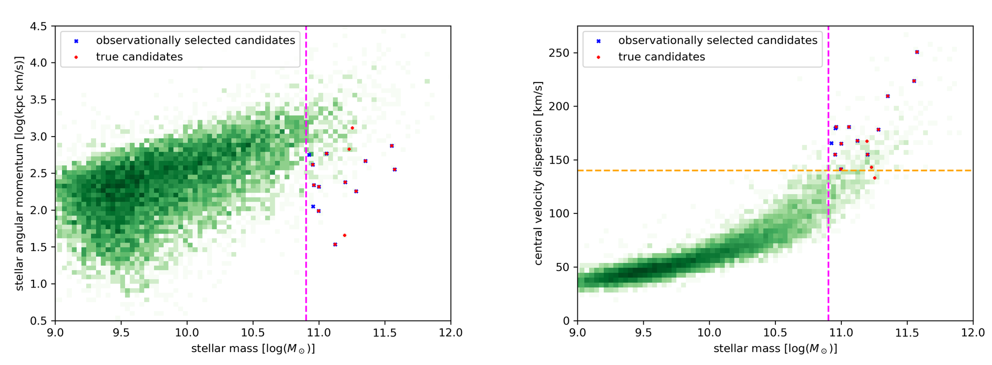

Figure 5: Stellar angular momentum (left panel) and stellar central (1kpc aperture) velocity dispersion (right panel) obtained from the EAGLE simulation.

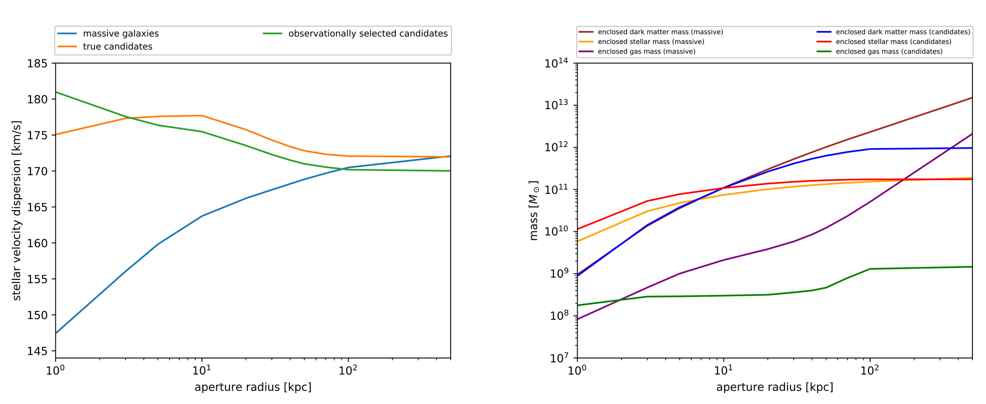

Figure 6: The stellar velocity dispersion and various mass components within different apertures of galaxies with low dark matter fractions compared to other galaxies of the same mass range using data from the EAGLE simulation. The **stellar mass** for our candidates is **more concentrated**, while the **dark matter distribution** is the same until the halo gets **truncated** due tidal stripping.

Evolution and Formation

The merger trees are more easily accessed and analysed using the **Illustris** simulation, hence we primarily used it for this part of our research. We studied the history of galaxies with present-day low dark matter fractions and compared their evolution to other galaxies within the same mass range.

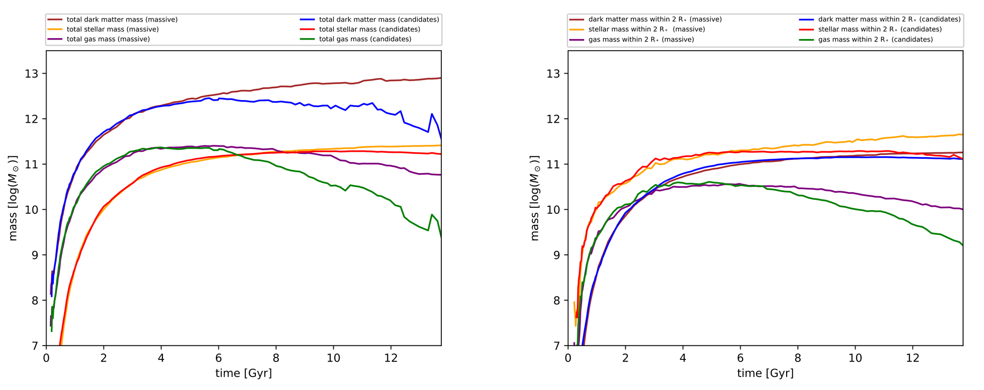

Figure 7: A stacked analysis of our candidate galaxies compared to other massive galaxies shows that over time the **outer dark matter halo** of galaxies with low dark matter fractions **is stripped** and gas is these galaxies is removed effectively.

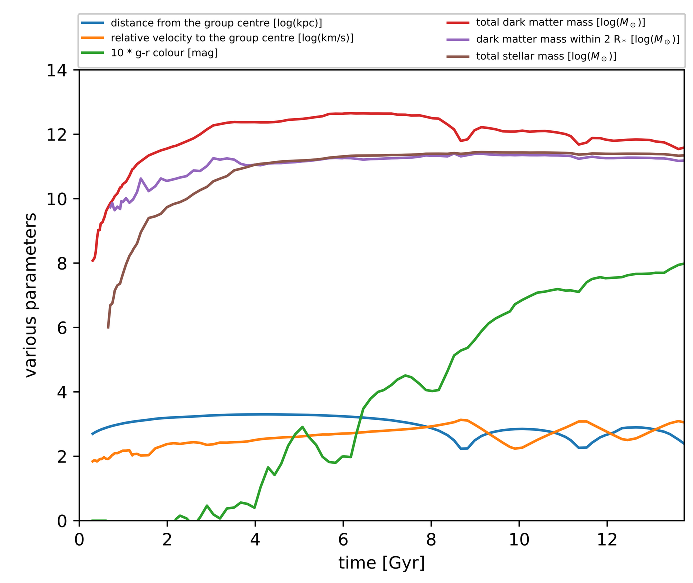

Figure 8: The evolution of a typical galaxy with a low dark matter fraction from the Illustris simulation. Most candidates can be found in a **high density environment** and experience the highest loss rates of dark matter at the pericentral passage of their orbits. Ram pressure stripping reduces the gas content at the same time and causes the galaxies to redden significantly.

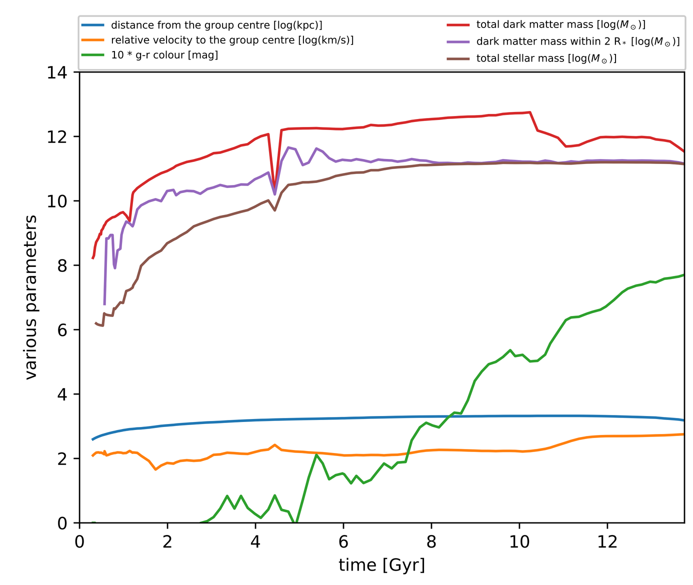

Figure 9: Some candidates can also be found in lower density environment, where their evolution is slightly different.

Conclusions and Outlook

We found several massive galaxies with low dark matter fractions in both simulations. Our candidates are:

- **different from** what we know about **NGC 7507**
- **slow rotators** (very low stellar angular momentum)
- **dark matter deprivation** dominant over stochastic effects
- **ram-pressure stripped** and **tidally disrupted**

Observationally, these features manifest in:

- a **compact stellar component**
- notably **red colours**
- **above average central velocity dispersion**
- **not** being the **brightest cluster galaxy**

With this set of criteria and some fine tuning to the observational data, we will be able to achieve a **true positive** identification rate of our candidate galaxies in surveys of **more than 50%**.
In the future, we plan on using data from **IllustrisTNG** (Pillepich+ 2018) to supplement our analysis. Furthermore, we want to complete the part of our analysis, which have only been carried out in using data from one simulation, in the other simulation and provide a better comparison.