Cusps and cores at the EDGE of galaxy formation

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1. The cusp-core problem

Simulations of a ΛCDM universe containing only dark matter predicted the formation of “cusped” halos, with centrally divergent density profiles. However, observational evidence suggests that many galaxies have instead a central constant density “core”.

A solution to this problem is the introduction of “baryonic physics”. Repeated gas inflow due to cooling, and outflow due to stellar winds and supernovae, causes the central gravitational potential to fluctuate with time. This dynamically “heats” the inner dark matter halo, gradually transforming a cusp into a core [1,2,3,4].

A cusp can also be regenerated through dry mergers with cuspy dark matter halos [5].

- Do cusp-core transformations happen in all dwarf galaxies?
- How is the process affected by assembly history and/or environment?
- What do we expect to see in the very faintest “ultra-faint” dwarfs?

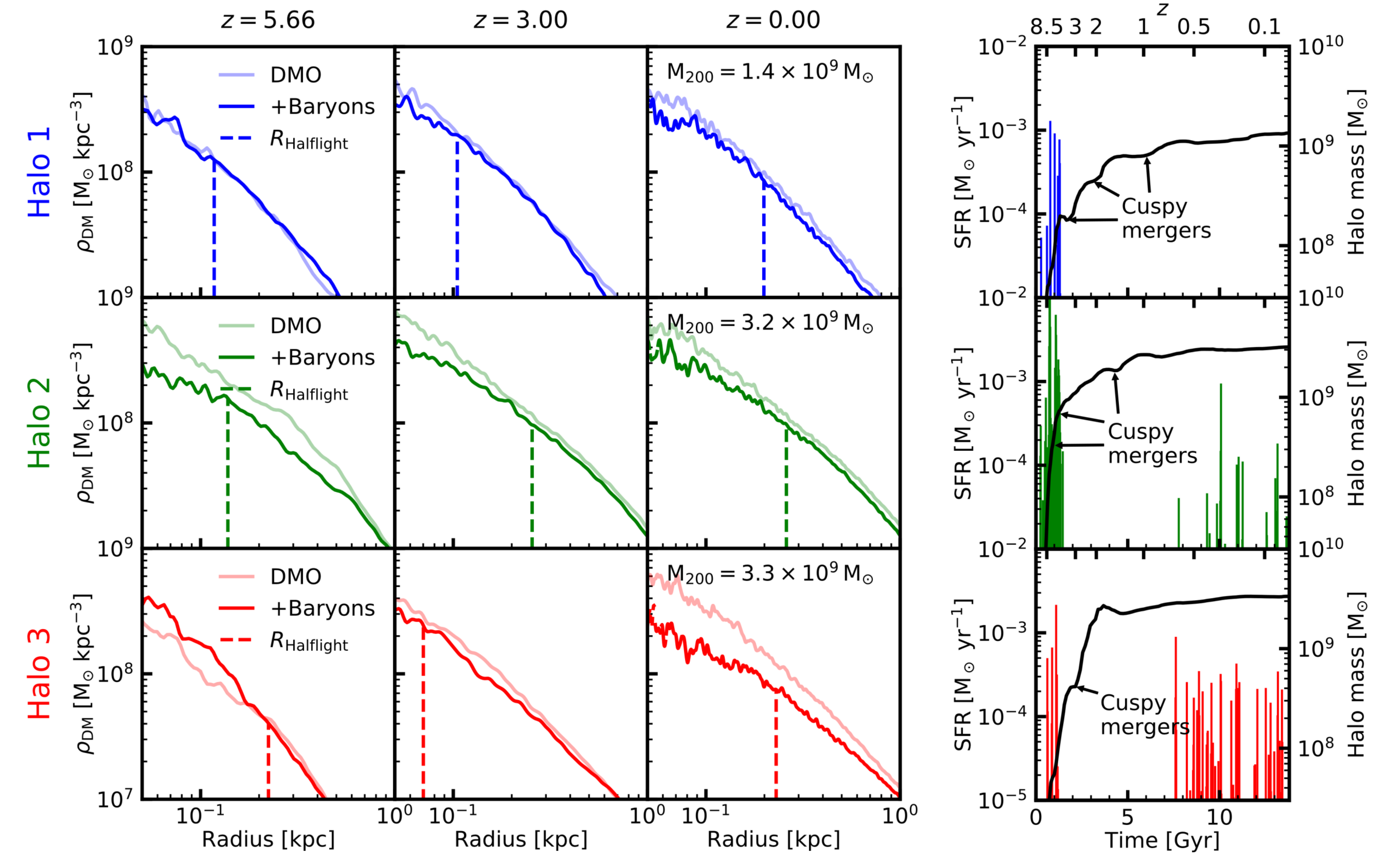
2. EDGE simulations

❖ Cosmological zoom simulations of six dwarf galaxies, selected from a large “void” region to span a range of masses $10^9 < M/M_\odot < 10^{10}$ and environments/assembly histories.

❖ Run with the adaptive hydrodynamic mesh code RAMSES [6], with sub-grid physics as in [7].

❖ All simulations shown here have a maximum dark matter mass resolution of ~$1000 M_\odot$, baryonic mass resolution of ~$20 M_\odot$, and spatial resolution of ~3pc.

❖ The “edge” of galaxy formation remains poorly understood both observationally and theoretically. EDGE will shed light on the processes that inhibit and shape the formation of the smallest galaxies.



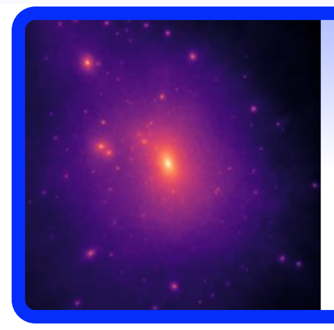
Left panels: The dark matter density of three halos, simulated with pure dark matter: “DMO”, faint line and with baryons: “+Baryons”, solid line.

The vertical dashed line is the 2D halflight radius of the stars.

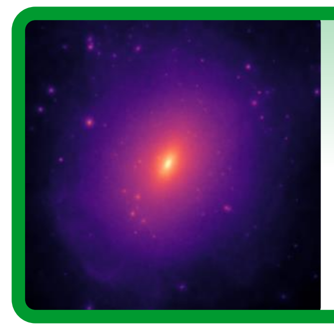
Right panels: The star formation (left axis) and mass assembly (right axis) of the main progenitor as a function of time.

Annotations indicate notable mergers with cuspy halos that experienced too little star formation to excite a cusp-core transformation.

3. How do dark matter cusps evolve in EDGE?



Halo 1: This light halo ($M_{200} = 1.4 \times 10^9 M_\odot$) experiences a small burst of star formation at early times, but after reionization at z=8.5 the halo begins to run out of cold gas and is quickly quenched. Any reduction in the central dark matter density at this time is obliterated by several cuspy mergers.



Halo 2: This heavier halo ($M_{200} = 3.2 \times 10^9 M_\odot$) experiences a much greater burst of star formation at early times, and this is reflected by a reduction in the central dark matter density at z=5.66. The halo merges with a large cuspy subhalo after z=2, and this reintroduces a cusp into the density profile. There is some star formation after this merger event, but it is not sufficient to significantly lower the central dark matter density profile before z=0.

Halo 3: Despite being the most massive halo by z=0 ($M_{200} = 3.3 \times 10^9 M_\odot$), Halo 3 has an abnormally low mass at early times ($M_{200}(z=5.66) = 5.1 \times 10^7 M_\odot$) and experiences only a small burst of star formation. After this initial burst, the halo is rapidly assembled and restarts its star formation. This star formation at late times is enough to significantly lower the central dark matter density of the dwarf by z=0, though it is not sufficient to form a constant density core.

4. Conclusions

❖ In agreement with previous studies, erosion of the cusp in dwarfs is driven by repeated cycles of gas inflow and outflow during star formation.

❖ The evolution of the final central dark matter density in EDGE depends on the assembly history of each halo.

❖ Although the cusp softening in dwarf galaxies is stochastic, the scatter is predictable, depending on the mass assembly and star formation history.

5. What’s next?

❖ The shape of dark matter halos also responds to repeated gas inflow/outflow. We will investigate the halo shape evolution with time and radius.

❖ We will compare our simulations with observed galaxies, such as the faint dwarf galaxy Leo T.

❖ We are running a simulation suite with ×10 higher mass resolution to ensure convergence.

❖ We are running a simulation suite with on-the-fly radiative transfer, as in [7].

6. References

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