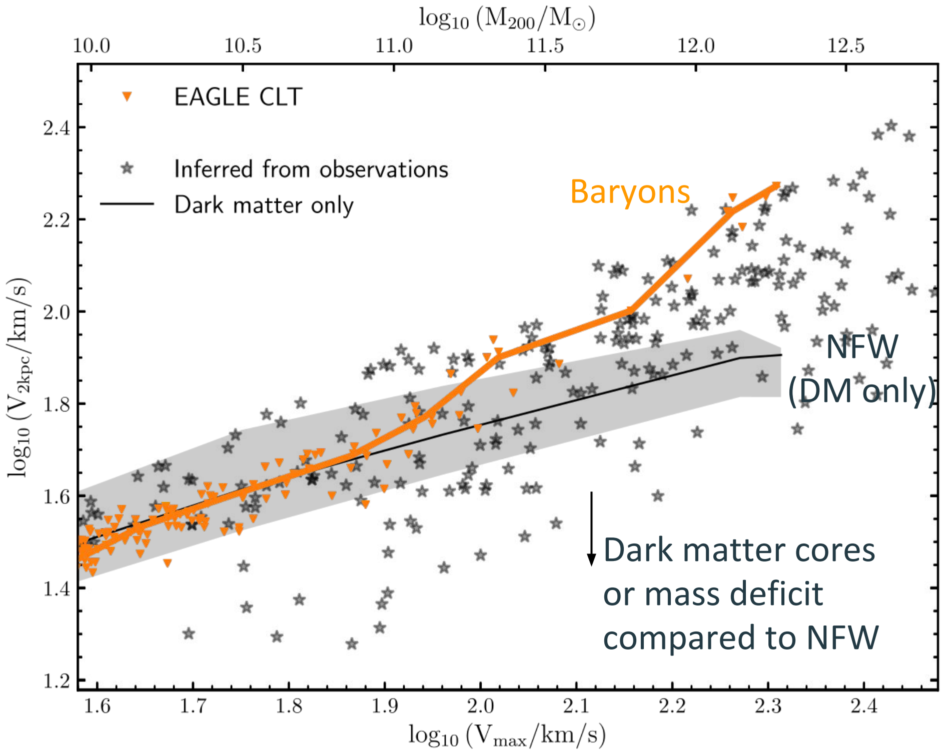
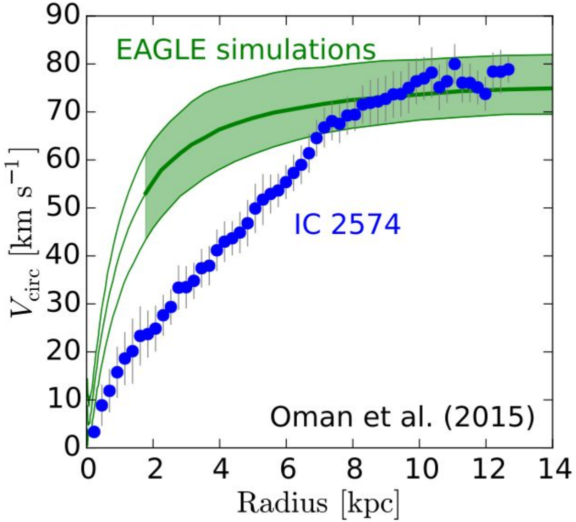
Baryon-induced dark matter cores in the EAGLE simulations

- Alejandro Benítez-Llambay -

Mass deficit in low-mass galaxies (cusp/core problem)

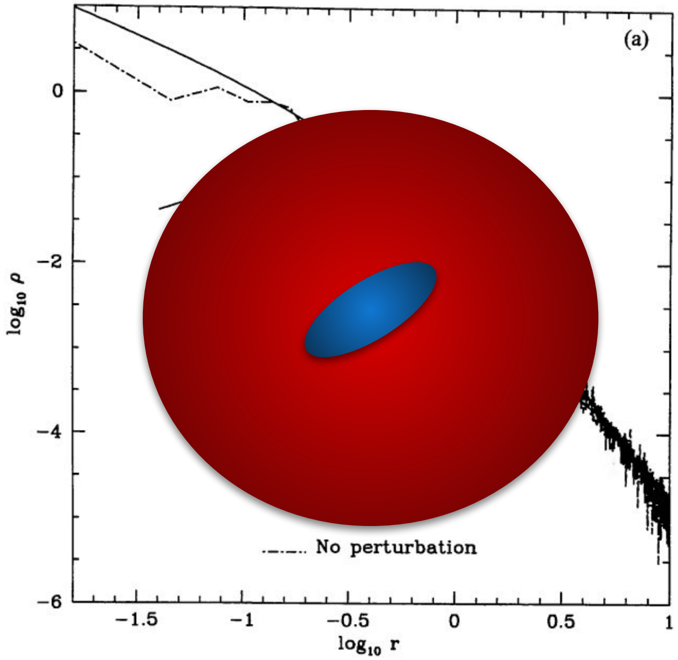




$$V_{circ} = \sqrt{GM(r)/r}$$

$$V_{max} = max\{V_{circ}\}$$

Physics of core formation

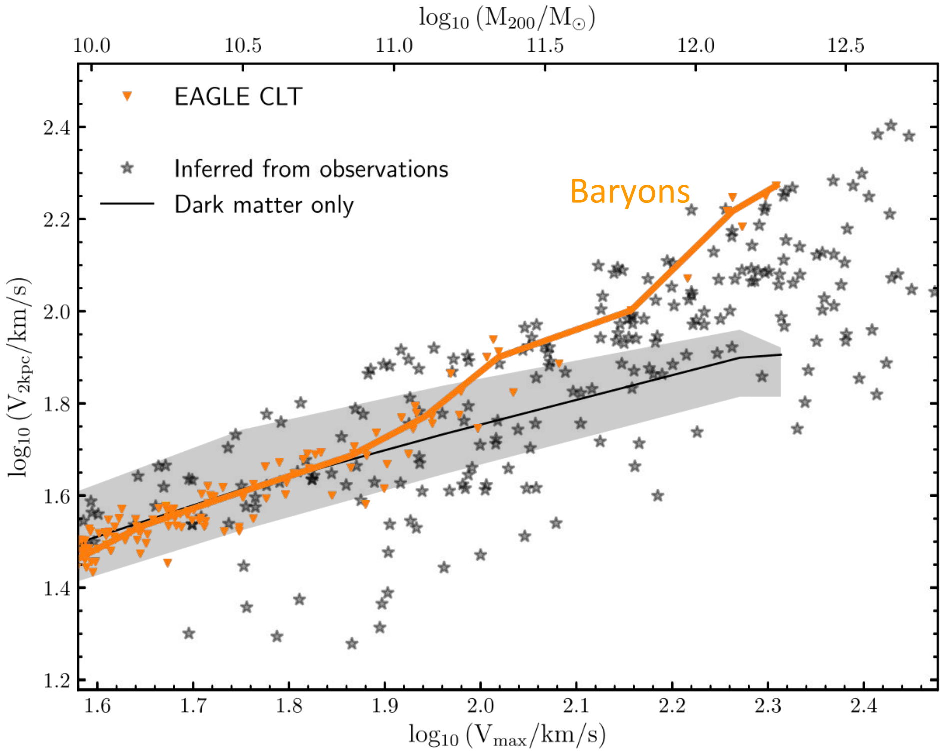


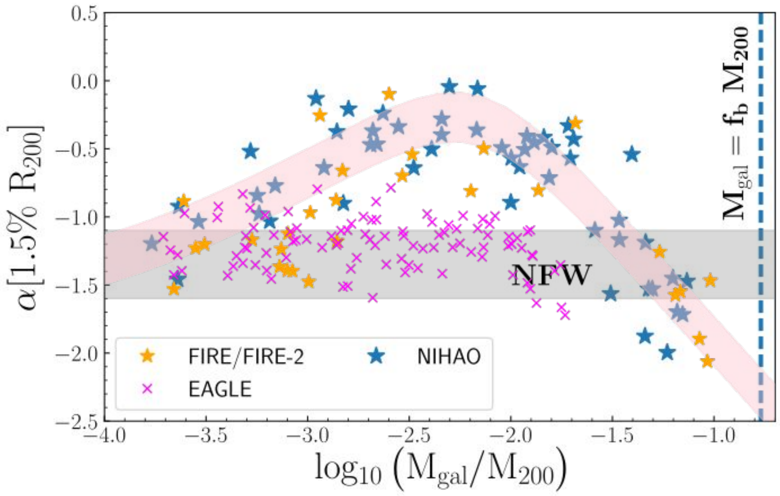
Navarro, Eke & Frenk (1996)

- Cusps can be converted into cores by perturbing the central regions of dark matter halos. Navarro et al. (1996) showed that if you manage to remove a significant amount of baryons from the centre of a dark matter halo, the halo will react by forming a core.

- In a more realistic scenario, cores can form from repeated fluctuations of the potential in the central parts of the halo (e.g., SN explosions) (see e.g., Pontzen & Governato 2012; 2014 or Bullock & Boylan-Kolchin 2017 for recent reviews on this).

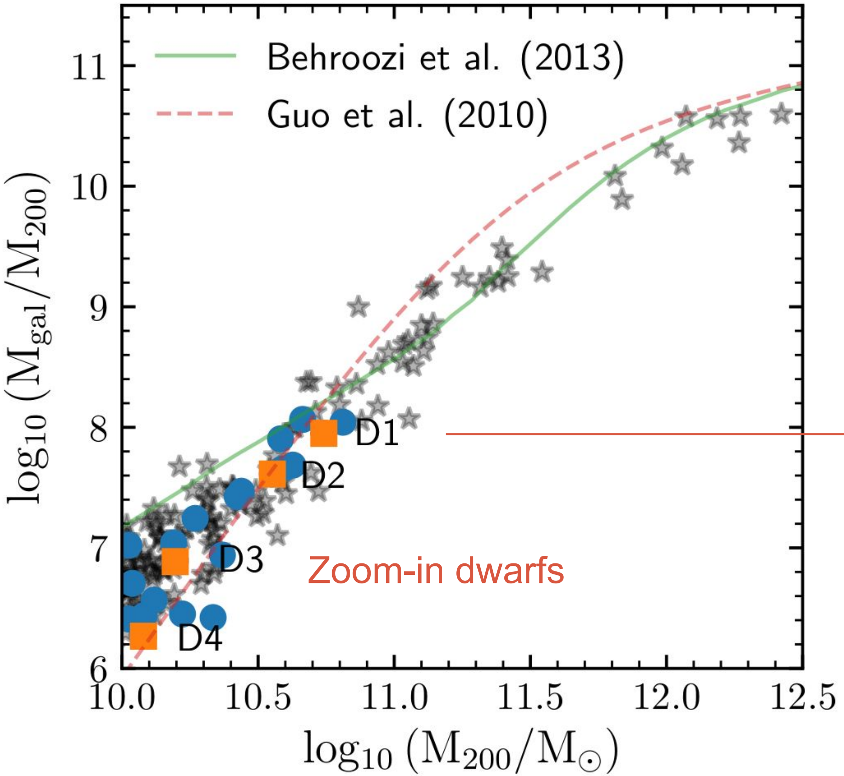
Mass deficit in low-mass galaxies (cusp/core problem)





See e.g. Tollet et al. (2016), Hopkins et al. (2017), Di Cintio et al. (2014), Oñorbe et al. (2015)

Zoom-in simulations of low-mass galaxies with EAGLE

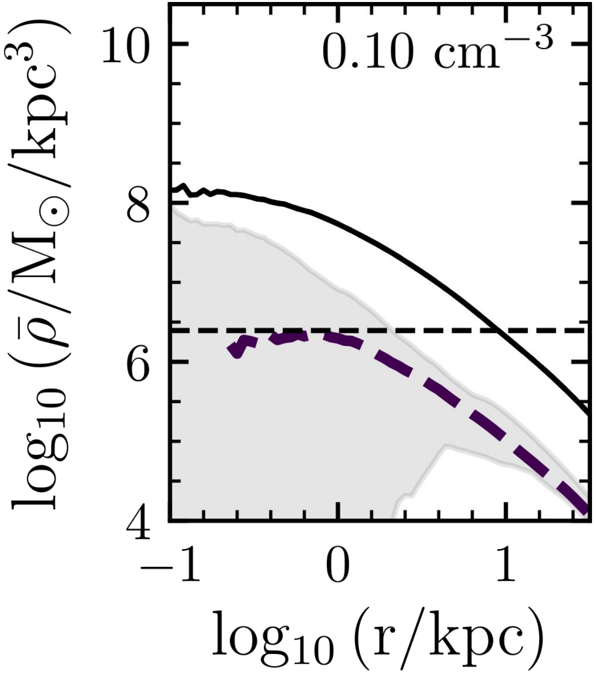


I performed zoom-in simulations of 4 low-mass galaxies at high-resolution ($M_{gas} \sim 5\text{x}10^4\ M_O$).

Following slides show results for this dwarf

How to make cores in EAGLE

Zoom-in simulations of a 5×10^{10} $M_{\odot}$ halo using P-Gadget3 + EAGLE. Gas particle mass ~ 5×10^{4} $M_{\odot}$.



Either scenario require the gravitational coupling between the gas content and the dark matter halo.

The EAGLE simulations form stars at low densities, and the gas never becomes self-gravitating:

Therefore

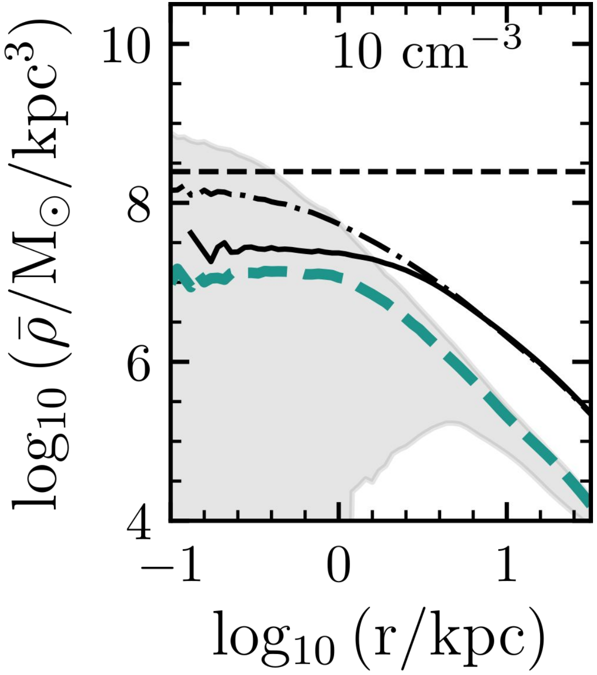
Low-mass dark matter haloes in the EAGLE simulations are indistinguishable from their counterparts in dark matter only simulations (all haloes are well described by self-similar NFW profiles)

If we want the gas to become self-gravitating before being ejected by SN feedback, the simulation must form the stars at much higher densities.

Benitez-Llambay et al. (2018)

How to make cores in EAGLE

Zoom-in simulations of a 5×10^{10} $M_{\odot}$ halo using P-Gadget3 + EAGLE. Gas particle mass ~ 5×10^{4} $M_{\odot}$.



Increasing the gas density threshold for star formation enables the gas to become self-gravitating before being ejected by SN explosions.

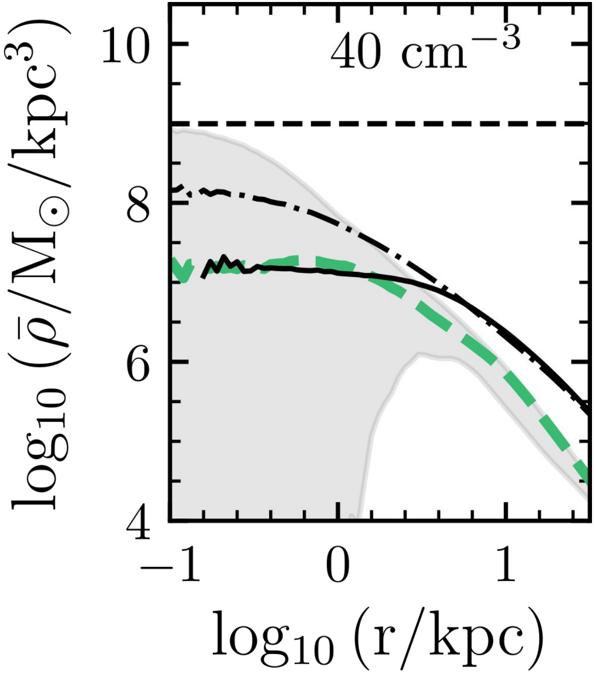
↓

Low-mass dark matter haloes develop a core. The region of the halo affected by baryonic blowouts roughly corresponds to the region in which baryons become self-gravitating.

Benitez-Llambay et al. (2018)

How to make cores in EAGLE

Zoom-in simulations of a $5x10^{10}$ M_O halo using P-Gadget3 + EAGLE. Gas particle mass ~ $5x10^4$ M_O.



Increasing the gas density threshold for star formation enables the gas to become self-gravitating before being ejected by SN explosions.

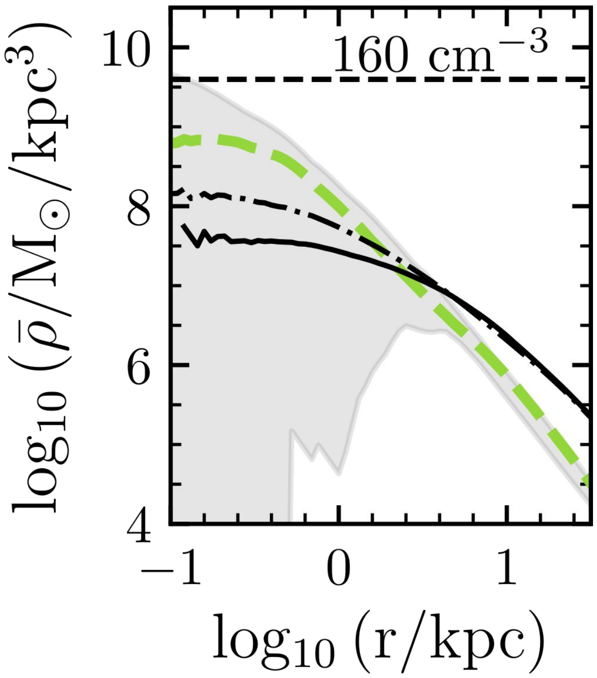
↓

Low-mass dark matter haloes develop a core. The region of the halo affected by baryonic blowouts roughly corresponds to the region in which baryons become self-gravitating.

Benitez-Llambay et al. (2018)

How to make cores in EAGLE

Zoom-in simulations of a 5×10^{10} M_O halo using P-Gadget3 + EAGLE. Gas particle mass ~ 5×10^4 M_O.



Increasing the gas density threshold for star formation enables the gas to become self-gravitating before being ejected by SN explosions.

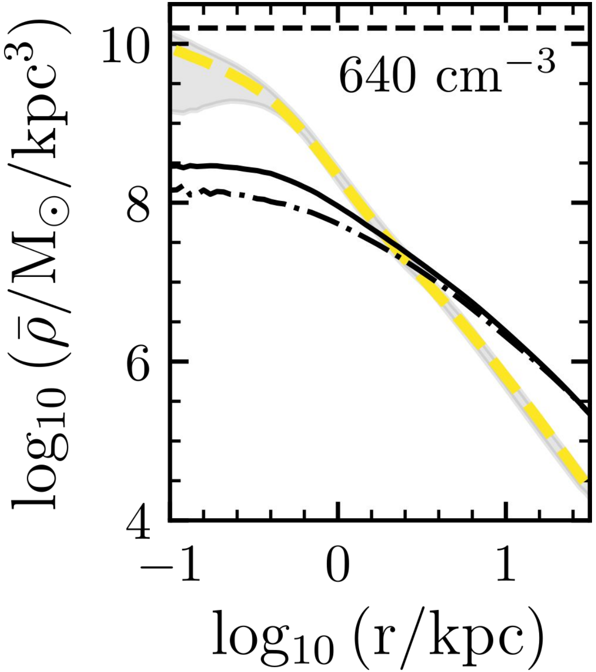
↓

Low-mass dark matter haloes develop a core. The region of the halo affected by baryonic blowouts roughly corresponds to the region in which baryons become self-gravitating.

Benitez-Llambay et al. (2018)

How to make cores in EAGLE

Zoom-in simulations of a 5×10^{10} $M_{\odot}$ halo using P-Gadget3 + EAGLE. Gas particle mass ~ 5×10^{4} $M_{\odot}$.



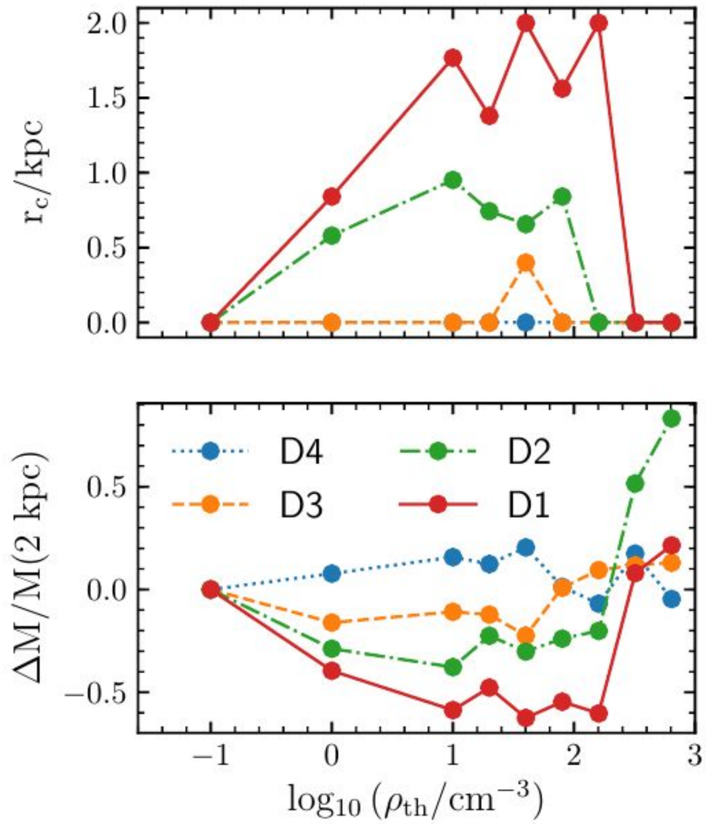
Increasing the gas density threshold too much make it hard for the gas to escape the system (radiative losses).

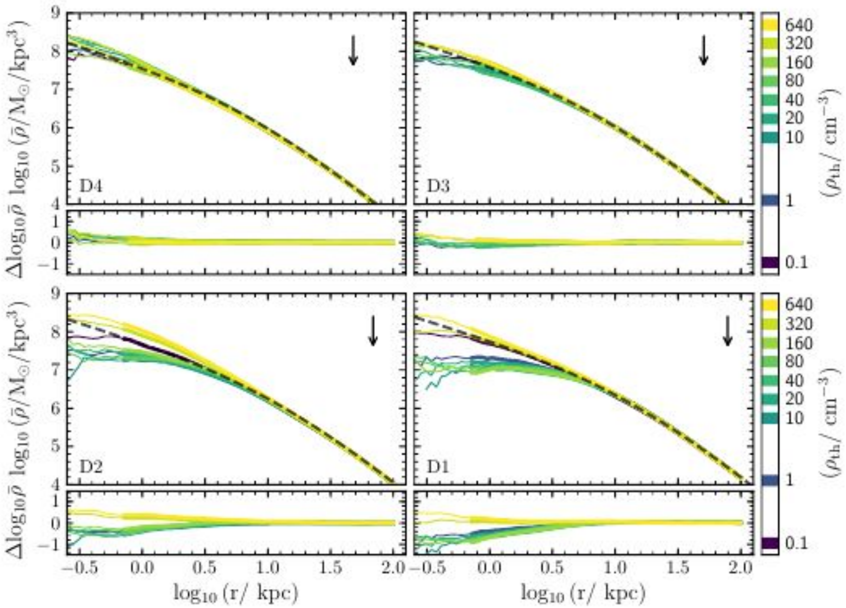
Dark matter haloes become too compact.

EAGLE model does not allow very high density thresholds because thermal feedback becomes inefficient at driving gas out from the inner regions of dark matter haloes (cooling time is shorter for higher density gas so that SN heated bubbles cool before expanding). See e.g., Schaye & Dalla Vechia (2012).

Benitez-Llambay et al. (2018)

Core properties depend on subgrid modelling

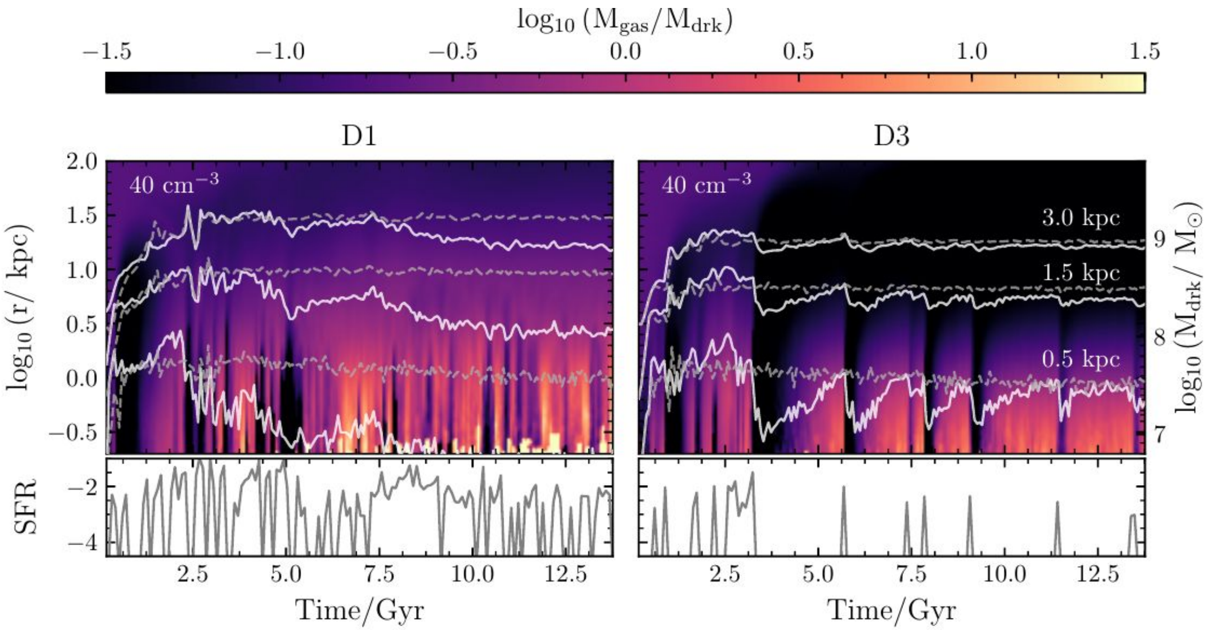




The structure of low-mass dark matter haloes inevitably depends on the modelling of star formation, and in particular, on the density of star-forming gas.

Benitez-Llambay et al. (2018)

Why do some dwarfs form cores and others do not?



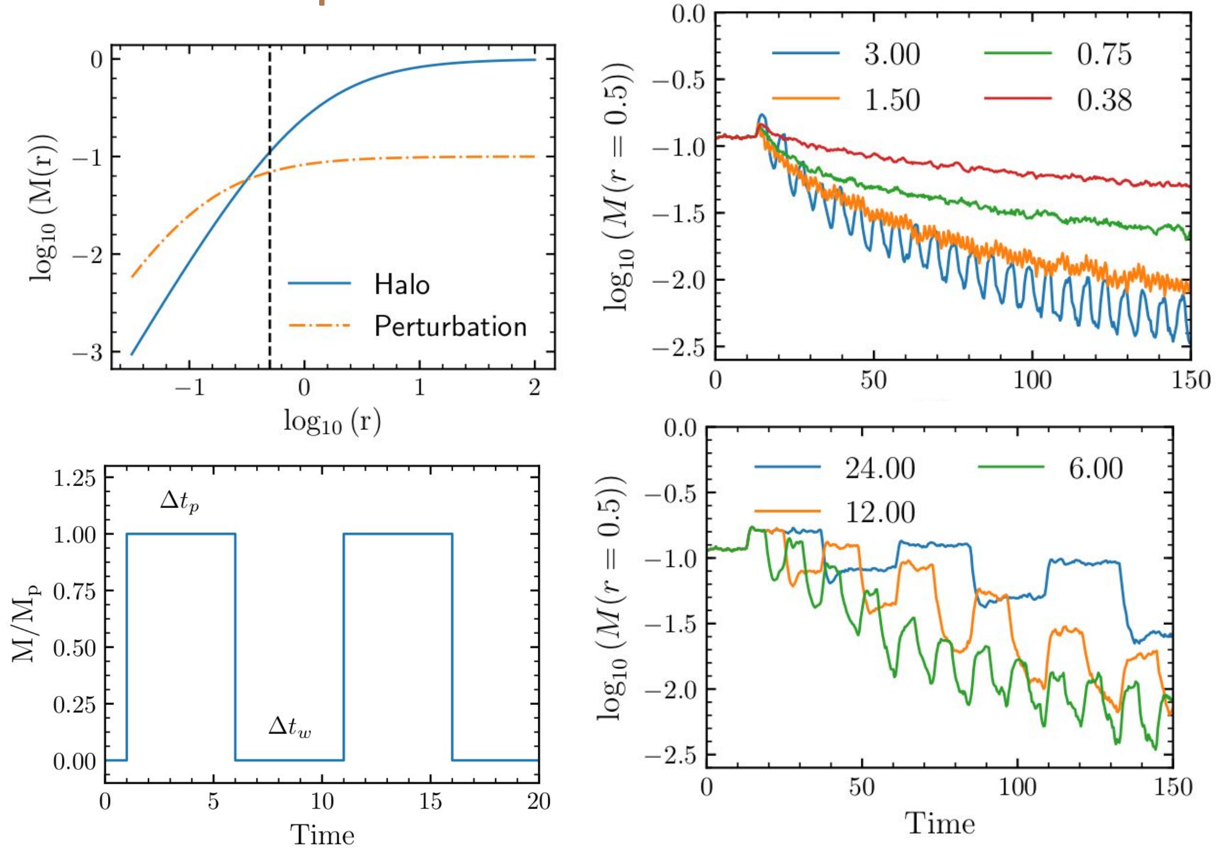
Benitez-Llambay et al. (2018)

Burstiness in the SF histories (Pontzen & Governato 2012) is less effective at making a core than single instantaneous gaseous blowouts (Navarro et al. 1996).

Dwarfs may exhibit either a core or a cusp depending on when they are observed

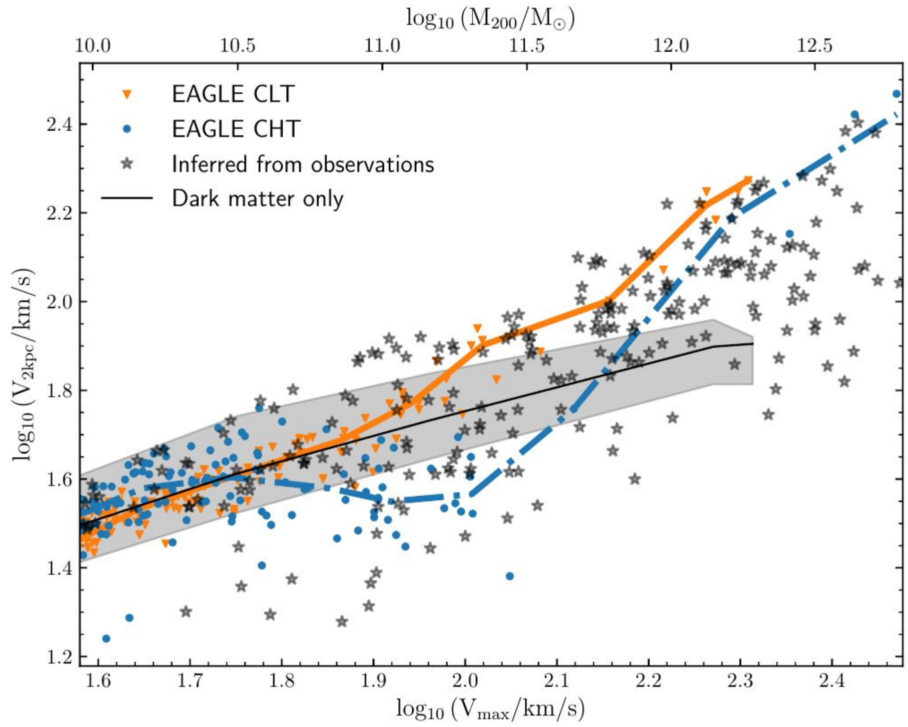
Burstiness is needed in galaxies that are forming stars to prevent the halo from recovering its cusp, but it is not needed to make a core.

Idealised experiments

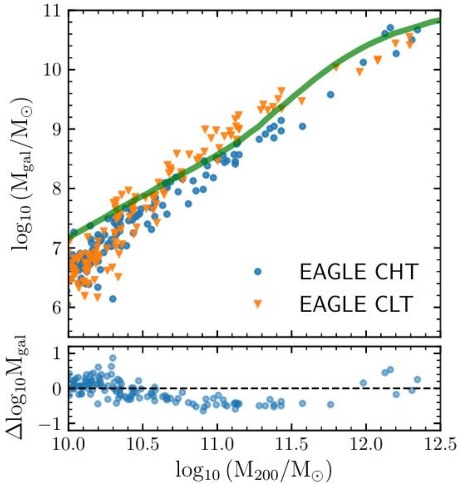


Perturbations comparable or shorter than the local orbital time are more inefficient at perturbing the halo than perturbations that are much longer.

EAGLE (12 Mpc)^3 with a higher SF density threshold



Although an EAGLE simulation with a higher density threshold for star formation produces sizeable cores, the model does not manage to account for the huge diversity of ration curves of nearby galaxies.



Benitez-Llambay et al. (2018)

Conclusions

- Cores can form in low-mass galaxies provided the gas becomes self-gravitating before being ejected from the system. In practice this can be achieved by increasing the density threshold above which gas is eligible to form stars. (Values ~ $10^8\ M_o$ / kpc^3 usually satisfy this condition).

- The region of the dark matter halo that is affected by baryonic blowouts is very sensitive to the assumed value of the gas density threshold for SF. This hinders robust predictions and the interpretation of observations. If baryons don't manage to escape, dark matter haloes become more compact than NFW.

- **Burstiness, understood as the rapid assembly and removal of baryons by SF, is less effective than a single large blowout at forming a core, but is necessary to maintain the core in galaxies that continue forming stars.**

- An EAGLE simulation with a higher density threshold, although producing sizeable cores, cannot reproduce the diversity of ration curves observed in nearby galaxies (if taken at face value).