CASPEN Exit Report

Josh Borrow, ICC, visiting Daniel Angles-Alcazar, CCA

Overview

This visit was instigated as a follow-on to the Kavli Summer Program in Astrophysics, where I and Daniel first met and began working on a project to quantify large-scale baryonic flows between halos over cosmic time. The CASPEN program came to our attention a number of months after this through an e-mail from the ICC director, Carlos Frenk.

The initial aim of the visit was to spend some time working solely on the project, and to extend the analysis that we had already performed to the (now complete) 100 Mpc/*h* SIMBA (Dave et al. 2019) volume, as previously only the 50 Mpc/*h* volume had been available. However, plans quickly changed as we realised that there were a number of unclear points in our original draft, and there still many low-hanging fruit that we had not presented, so we turned our attention to these.

During the two weeks at the CCA, myself and Daniel met multiple times a day to discuss this, now long running, project and I was able to devote around 95% of my time towards the project while there. This was incredibly beneficial, as this side-project can often get left behind in favour of other work, and this program was an excellent way to produce some really focused work. We have also identified a number of avenues for future work.

Work completed during the visit

Our work, entitled 'Cosmological Mass Transfer in the SIMBA Simulations', co-authored by Romeel Dave, focuses around one main idea: construct metrics that tell us how baryons and dark matter move differently, with the aim of seeing whether this is able to pick out large-scale baryonic flows. Daniel wrote a paper in 2017 looking at some isolated galaxies in the FIRE zoom-in simulations (Hopkins et al. 2014) that showed that there was a significant level of transfer between sub-halos and their associated main halo pre-merger, even while these were far outside the virial radius of the halo (Angles-Alcazar et al. 2017). The main criticism of this work was that these objects merged by redshift *z=0* and so this transfer could be seen as spurious. We then attempted to extend a similar analysis to a cosmological volume, to see if there was any transfer between un-merged main halos at redshift *z=0*. It is possible to pick out this transfer by considering the Lagrangian regions that gas particles originate in, and the halos that they reside in at *z=0*, but this is somewhat messy and remains dependent on the choice of halo finder.

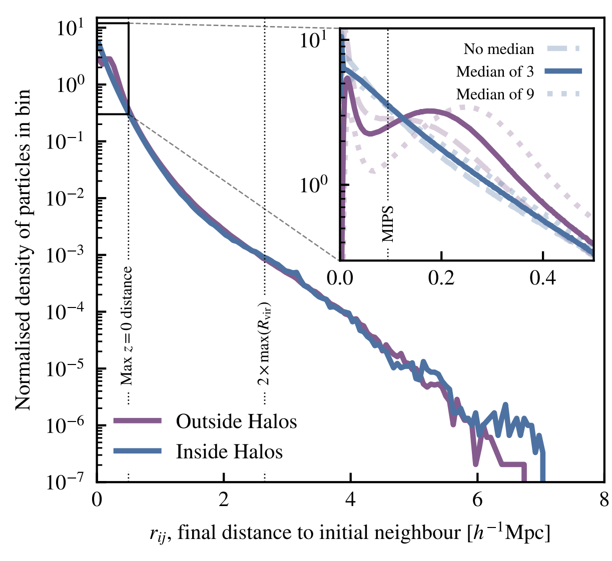

Figure 1: The histogram of spread distances is shown for all dark matter particles in the volume at *z=0* . The sensitivity of this metric to the numerical choice of the average over initial neighbours is shown in the central panel.

During the visit, we primarily worked on a complimentary metric, that we call the *spread metric*. This metric considers, for every particle in the initial conditions, the initial dark matter neighbour. Then, at redshift *z=0*, all particles find their initial neighbour, and calculate the distance between them. We can extend this analysis to find, for each particle, the median distance to the nearest *n* initial neighbours. This tells us how far the gas (or dark matter) has become spread from its initial neighbour. Figure 1 shows how the distribution of distances is affected by the choice of n; this is something previously un-explored before the CASPEN program. Figure 2 shows how cutting by the spread metric (or "distance that particles have travelled") allows for sub-structure to be identified in simulations. For the gas, the large-spread cut allows us to identify gas that has been involved in energetic feedback events and also gas that has been entrained by these events, which is notoriously difficult to identify in an analysis that only involves the initial conditions and one snapshot file.

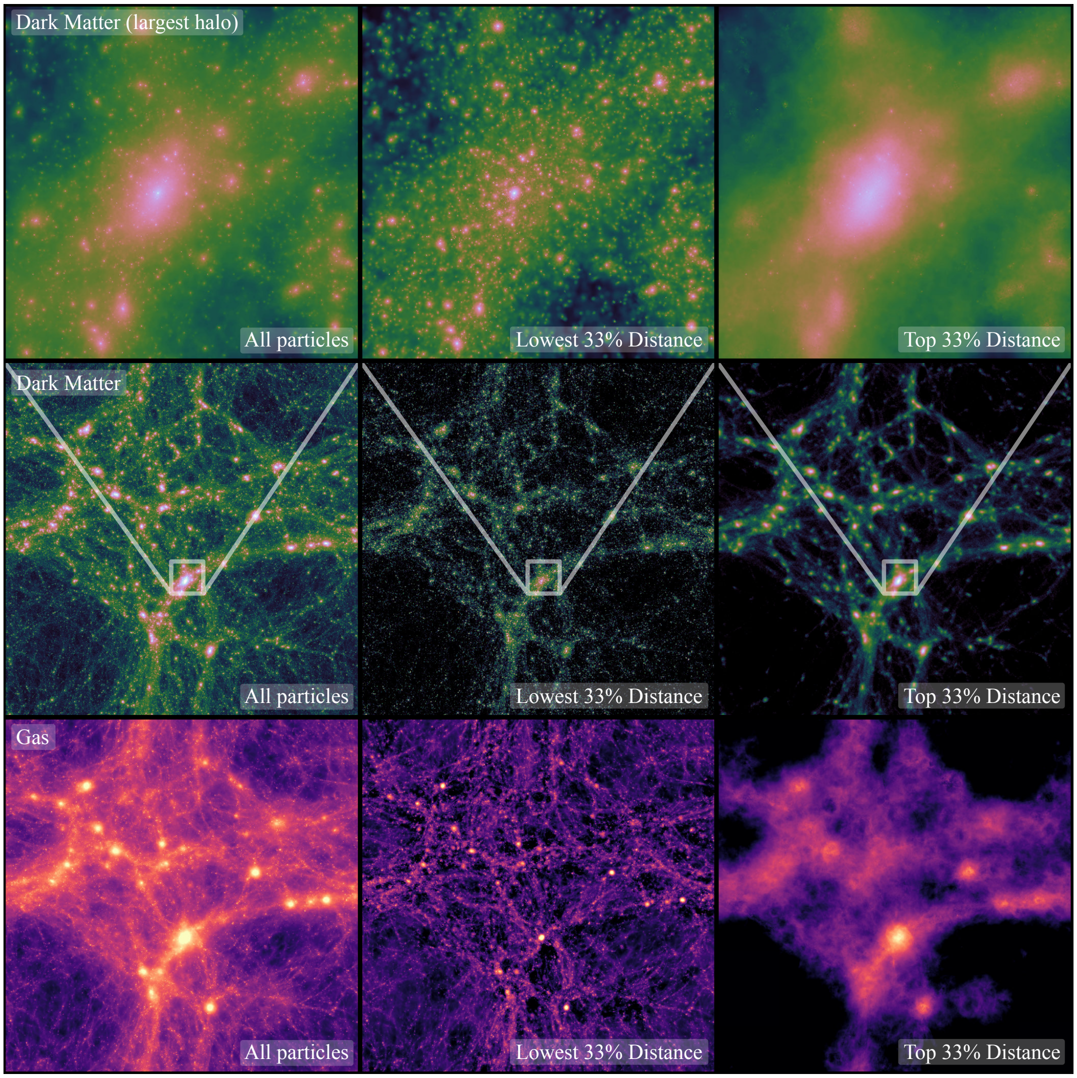

Figure 2: The three rows show the following selections of particles (from top to bottom): the dark matter present in the largest halo, and surrounding it (this is a 4.5 Mpc/h cube centered around the halo centre, which has a virial radius of approximately 1.3 Mpc/h); all dark matter particles in the box; and all gas particles present in the box. All images are shown in the final state of the simulation at redshift $z=0$. Each column then shows (from left to right): all particles that are in the volume; the particles that have spread the least, selecting the first 33% from the histogram figures; and the particles that have spread the 33% most. For the dark matter, these cuts correspond to particles that have travelled less than 0.1 Mpc/h, and greater than 0.25 Mpc/h respectively. For the gas, these numbers increase to 0.45 Mpc/h and 1.25 Mpc/h respectively due to the larger spread that these praticles expereice. Each image has smoothing lengths generated to encompass 32 nearest neighbours, as is used in the SIMBA simulations, and smoothing lengths are kept consistent across columns; i.e. they are not re-smoothed. All images in a given row also use the exact same (logarithmic) normalisation and colour map to enable comparisons. Note how even with this extremely conservative cut there is a significant difference between the images, with sub-structure picked out by the low-distance cut and large-scale structure for the large-distance cut.

Post-Visit

I was able to extend my visit to the U.S. by a week, with help from the Simons Foundation and *Intel,* to give talks at both MIT (brown bag) and Harvard (at Lars Hernquist's group meeting) on our SWIFT code (Schaller et al. 2016, Borrow et al. 2018; see **swift.dur.ac.uk**) and on the work that was completed during the Kavli and CASPEN programs.

We have plans, of course, to finish the paper by the end of May 2019. The work will be presented on my behalf by Daniel at an upcoming conference, 'Feedback and its Role in Galaxy Formation'.

References

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