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Differences in Halo Mass Accretion Rate Definitions between SPARTA and Consistent Trees

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1. INTRODUCTION

Mass Accretion Rate (MAR) is an important halo property that describes its dynamical state. It is measured in simulations by computing the mass accreted onto a halo over a given time. In this research note, we study differences in MARs computed with Consistent Trees (`CT`, Behroozi et al. 2013) and `SPARTA` (Subhalo and PARticle Trajectory Analysis, Diemer 2017). `CT` is an algorithm that builds merger trees while keeping the halo mass, position, and velocity consistent across snapshots. Dynamical properties measured with `CT` are given in `ROCKSTAR` halo catalogs (Behroozi et al. 2013). `SPARTA` is a general-purpose analysis framework for halo evolution and dynamics that follows the trajectories of dark matter particles. In this research note, we show that the two algorithms report different values for MARs. Understanding and correcting for these differences is important, for example, when considering the relationship between the splashback radius and MAR (Diemer 2017; Diemer et al. 2017).

2. METHODOLOGY AND RESULTS

`ROCKSTAR` catalogs contain five different computations of MAR:

- Acc_Rate_Inst: instantaneous MAR
- Acc_Rate_100Myr: MAR averaged over the past 100 Myr
- Acc_Rate_1Tdyn: MAR averaged over the past virial dynamical time
- Acc_Rate_2Tdyn: MAR averaged over the past 2 virial dynamical times
- Acc_Rate_Mpeak: Growth rate of $M_{\rm peak}$, averaged from z_1 to z_1+0.5 where z_1 is the snapshot under consideration.

Here we study differences in MAR computed over one dynamical time ($t_{\rm dyn}$), which is the only MAR definition in `SPARTA`. `CT` computes MAR as:

$$\text{Acc\_Rate\_1Tdyn} = \frac{\Delta M_{\rm CT}}{t_{\rm dyn}}, \tag{1}$$

where $\Delta M_{\rm CT}$ is the change in mass measured over 1 $t_{\rm dyn}$. Following Diemer et al. (2017), `SPARTA` measures MAR as:

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$$\Gamma_{\rm SP} = \frac{\Delta \log M}{\Delta \log a} = \frac{\log(M_1) - \log(M_0)}{\log(a_1) - \log(a_0)}, \tag{2}$$

where $\Delta\log(M)$ and $\Delta\log(a)$ are the change in the logarithmic mass and scale factor over $1t_{\rm dyn}$.

We use the L0063Bol simulation (Diemer & Kravtsov 2014) to compare the two MAR computations. L0063Bol is a dark matter only simulation with a box size of 62.5 Mpc/h and particle mass of $1.7 \cdot 10^7$ $M_{\odot}/h$, run with a Bolshoi cosmology. First, we run the `ROCKSTAR` halo finder on L0063Bol. Then, we compute MAR with `SPARTA` and `CT`. We adopt `SPARTA`'s definition of MAR (Eqn. 2) for both algorithms. While keeping `SPARTA`'s measurement unchanged, we recompute MARs with `CT` by matching one difference at a time. The upper left panel of Figure 1 displays the initial scatter between the two measurements.

Mass Definition. `SPARTA` and `CT` use different halo mass definitions in computing MAR. `SPARTA` measures $M_{\rm 200b}$ from both bound and unbound particles. `CT`'s default mass definition is $M_{\rm vir}$. Even if the user can select a different default mass definition, `CT` will compute Acc_Rate_1Tdyn using the virial bound mass. The top right panel of Figure 1 shows the scatter between the two measurements once we adopt the same mass definition (bound $M_{\rm 200b}$) for both `SPARTA` and `CT`. From Figure 1, it is clear that the mass definition is not the parameter that drives the scatter.

Snapshot 1 $t_{\rm dyn}$ ago. In order to measure the mass of the halo 1 $t_{\rm dyn}$ ago, both algorithms need to find the snapshot corresponding to the scale factor 1 $t_{\rm dyn}$ ago. `SPARTA` picks the snapshot that is the closest to the scale factor 1 $t_{\rm dyn}$ ago. `CT`, on the other hand, interpolates the halo properties across snapshots. The bottom left panel shows the scatter in the two measurements once we adopt `SPARTA`'s mass and snapshot 1 $t_{\rm dyn}$ definitions for both algorithms. The scatter between the two measurements in this case is larger than when only the mass definition is matched.

Dynamical Time. The two algorithms use different definitions of 1 $t_{\rm dyn}$. `CT` defines one dynamical time as the ratio between the halo radius and the infall velocity ($t_{\rm dyn,CT} = R_\Delta / v_\Delta$). `SPARTA` , on the other hand, defines $t_{\rm dyn,SP}$ as the time it takes a particle to reach the apocenter of its first orbit after infall ($t_{\rm dyn,SP} = 2R_\Delta/v_\Delta$). For the same overdensity definition, $t_{\rm dyn,SP} = 2t_{\rm dyn,CT}$. However, `CT` and `SPARTA` use different overdensity definitions in measuring their dynamical times. While `CT` uses $\Delta_{\rm vir}$, `SPARTA` uses $\Delta_{\rm 200m}$. The bottom right panel compares the MAR measurements from both algorithms once we match the definition of mass, dynamical time, and the method to determine the snapshot one dynamical time ago. From this panel, it is clear that the difference in dynamical time definition gives the most significant impact. However, all three effects must be taken into account in order to get the MAR values to match.

In conclusion, accretion rates from `CT` and `SPARTA` are different because of mass definitions, dynamical time definitions, and how the snapshot one dynamical time ago is determined. Out of the three, the dynamical time definition has the most significant impact.

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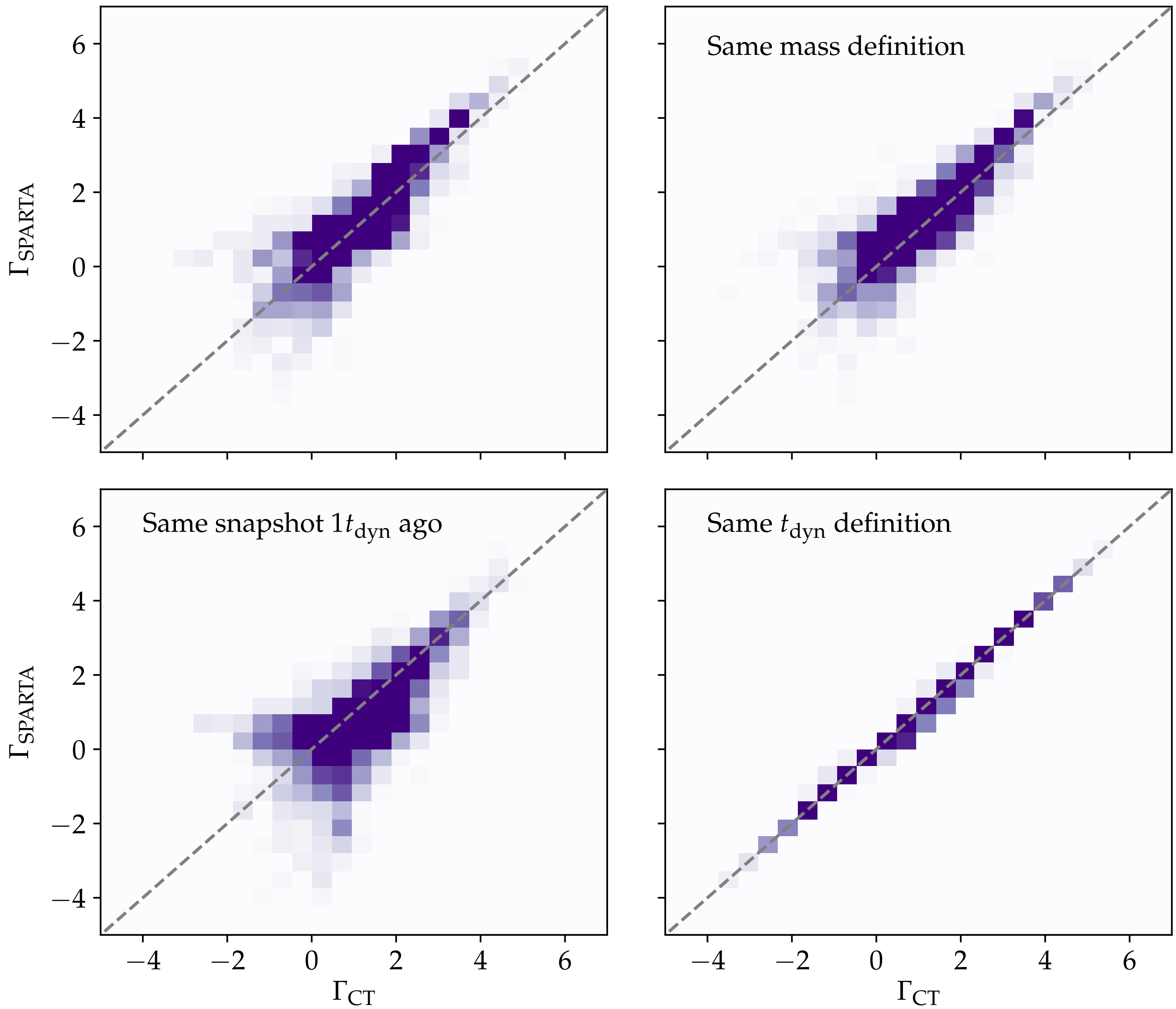

Figure 1. Comparison between MAR values measured with `CT` and `SPARTA`. Here, we use `SPARTA`'s definition of MAR for both of the algorithms. Each panel shows how the scatter changes once we match each of the three differences. Top left: original scatter between the two measurements. Top right: matching mass definitions. Bottom left: matching the snapshot 1 $t_{\rm dyn}$ ago. Bottom right: matching $t_{\rm dyn}$ definitions.