Merger Histories of Galaxy Halos and Implications for Disk Survival

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Abstract

We study the merger histories of galaxy dark matter halos using a high resolution ΛCDM N-body simulation. Our merger trees follow ~ 17,000 halos with masses $M > 10^{11} - 10^{13} h^{-1} M_{\odot}$ at $z = 0$ and track accretion events involving objects as small as $m \approx 10^{9} h^{-1} M_{\odot}$. We find that mass assembly is remarkably self-similar in $m/M_{\odot}$, and dominated by mergers that are ~ 10% of the final halo mass. While very large mergers, $m \gtrsim 0.4 M_{\odot}$, are quite rare, sizeable accretion events, $m \sim 0.1 M_{\odot}$, are common. Over the last ~ 10 Gyr, an overwhelming majority (~ 95%) of Milky Way-sized halos with $M_{\odot} = 10^{12} h^{-1} M_{\odot}$ have accreted at least one object with greater total mass than the Milky Way disk ($m \gtrsim 5 \times 10^{10} h^{-1} M_{\odot}$) and approximately 70% have accreted an object with more than twice that mass ($m \gtrsim 10^{11} h^{-1} M_{\odot}$). Our results raise serious concerns about the survival of thin-disk dominated galaxies within the current paradigm for galaxy formation in a ΛCDM universe. In order to achieve a ~ 70% disk-dominated fraction in Milky Way-sized ΛCDM halos, mergers involving $m \approx 2 \times 10^{11} h^{-1} M_{\odot}$ objects must not destroy disks. Considering that most thick disks and bulges contain old stellar populations, the situation is even more restrictive: these mergers must not heat disks or drive gas into their centers to create young bulges.

1 The Simulation

Our simulation consists of $512^{3}$ particles, each with mass $m = 3.16 \times 10^{6} h^{-1} M_{\odot}$, evolved within a comoving cubic volume of 80$h^{-1}$ Mpc on a side using the Adaptive Refinement Tree (ART) N-body code (Kravtsov et al., 1997). The cosmology is a flat ΛCDM model, with parameters $\Omega_{m} = 1 - \Omega_{\Lambda} = 0.3$, $\Omega_{\Lambda} = 0.7$, and $\Omega_{\Lambda} = 0.9$. The simulation root computational grid consists of $512^{3}$ cells, which are adaptively refined to a maximum of eight levels, resulting in a peak spatial resolution of $1.2 h^{-1}$ kpc in comoving units. See full text for more details. This simulation and the methods we use to construct merger trees have been discussed elsewhere for even further detail (Allgood et al., 2006; Wechsler et al., 2006).

We present results in terms of absolute mass thresholds on the inflating mass $m$. Our principle statistics are quantified using the inflating mass thresholds in terms of the final $z = 0$ mass of the main progenitor halo (e.g. $m \approx 0.1 M_{\odot}$). A parallel discussion that uses $m/M_{\odot}$ is presented in the full text.

2 Results

Figure 1: A "typical" merger history of a halo with $M_{\odot} = 10^{12} h^{-1} M_{\odot}$ with a merger of mass $m \approx 0.1 M_{\odot}$ at $z = 0.5$. Time progresses downward, with the redshift $z$ printed on the left hand side. The hold, vertical line at the center corresponds to the main progenitor, with filled circles proportional to the radius of each halos. The minimum mass halo shown in this diagram has $m = 10^{9} h^{-1} M_{\odot}$. Solid (black) and dashed (red) lines and circles correspond to isolated field halos, or subhalos, respectively. The dashed (red) lines that do not merge with main progenitor represent surviving subhalos at $z = 0$.

Figure 2: The fraction of Milky Way-sized halos, $M_{\odot} = 10^{12} h^{-1} M_{\odot}$, that have experienced at least one merger larger than a given mass threshold, $m$, since look-back time $t$.

Figure 3: The cumulative number of mergers that a halo experiences with objects larger than $m/M_{\odot}$, integrated over the main progenitor's formation history. Lines through the data points show the fits. The upper/lower dashed lines indicate the ~ 25%/20% of halos in the $10^{12} - 10^{13} M_{\odot}$ sample that have experienced exactly twice/more than $L_{\odot}$ merger events.

Figure 4: (a) The fraction of Milky Way-sized halos with $M_{\odot} = 10^{12} h^{-1} M_{\odot}$ that have accreted an object with more than twice that mass ($m \gtrsim 10^{11} h^{-1} M_{\odot}$) vs. redshift. (b) Typical, a small fraction, ~ 20~30%, of a halo's final mass $M_{\odot}$ is accreted since the last large merger. If a disk is destroyed as a result of a large-m$M_{\odot}$ accretion event, it is unlikely that a new "disk-dominated" system can be regrown from new material that is accreted into the host halo after the merger.

3 Conclusions

- An overwhelming majority (~ 95%) of Milky Way-sized halos with $M_{\odot} = 10^{12} h^{-1} M_{\odot}$ have accreted an object larger than the Milky Way disk ($m \gtrsim 5 \times 10^{10} h^{-1} M_{\odot}$) in the last 10 Gyr. Approximately 70% have had accretions with $m \gtrsim 10^{11} h^{-1} M_{\odot}$ objects, over the same period, and 40% have had $m > 2 \times 10^{10} h^{-1} M_{\odot}$ events (Figure 2).
- Mass accretion into halos of mass $M_{\odot}$ at $z = 0$ is dominated by mergers with objects of mass $m \approx (0.03 - 0.003) M_{\odot}$ (Figure 3).
- Halo merger histories are approximately self-similar in $m/M_{\odot}$ for halos with masses in the range $M_{\odot}/10^{13} - 10^{13} h^{-1} M_{\odot}$ (Figure 4).
- Typically, a small fraction, ~ 20~30%, of a halo’s final mass $M_{\odot}$ is accreted after the most recent large merger with $m > (0.1 - 0.2) M_{\odot}$ objects (Figure 4).


References


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