Dark Matter Halo Assembly

By
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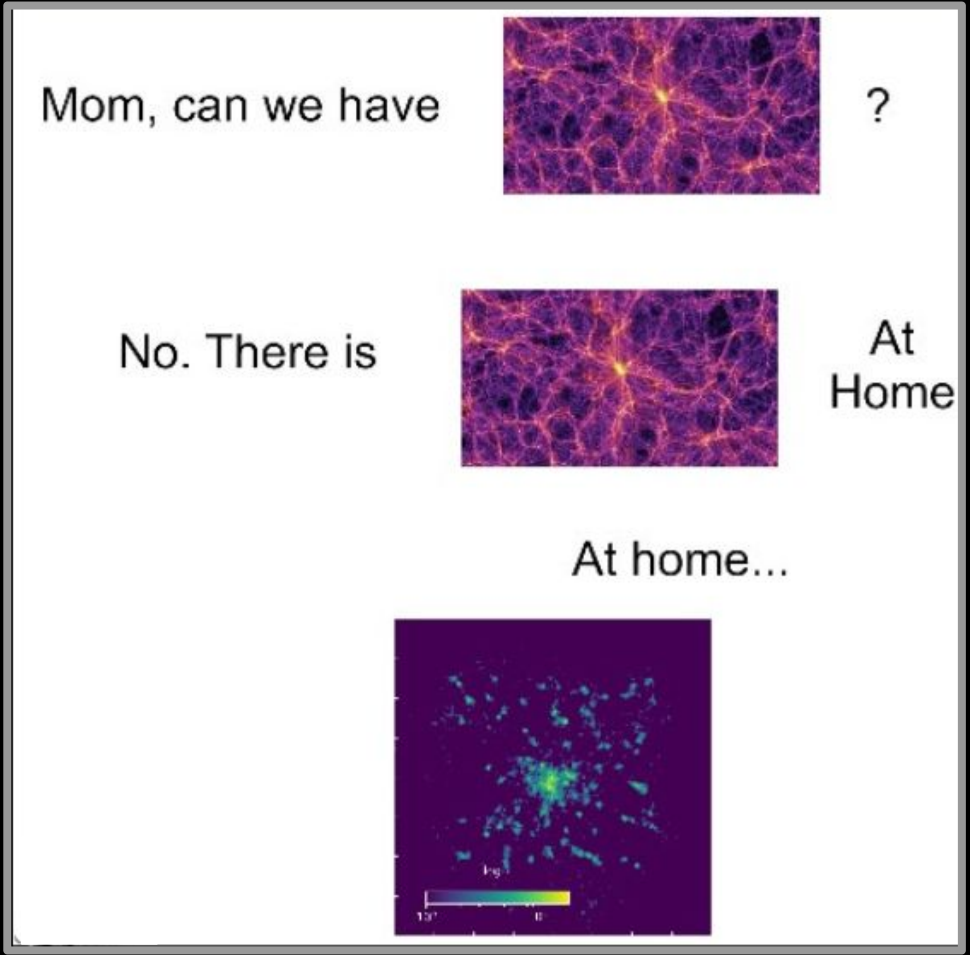
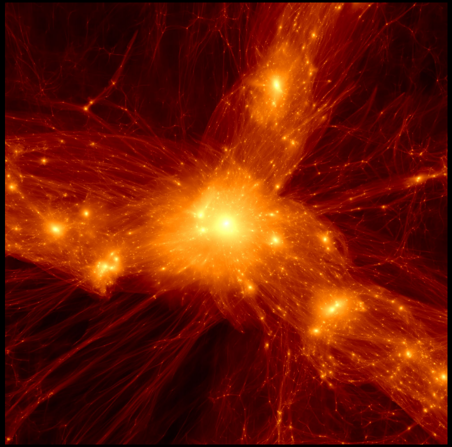
Fred (just Fred is fine), *Her Majesty Duchess of Norwich Elaine Taylor*



Background

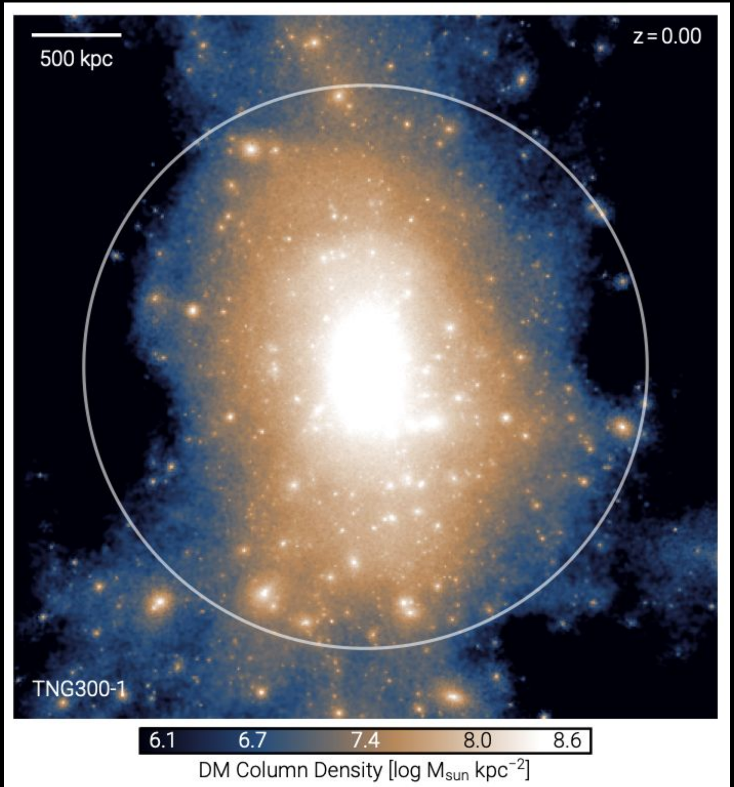
- In the early universe, dark matter is thought to be distributed more uniformly
- Smaller-scale clumps of 1 Mpc across formed from perturbations
- These grew into large-scale filaments over Gyr timescales
- We simulated a cube of side length 50 Mpc containing numerous dark matter clumps



Source: B. Diemer

Our Model and Goals

- Simulating Halo assembly
  - Hierarchical formation
  - Requires non-uniform initial condition
  - Need to provide a setup with sub-halos around a central halo
- Hubble Flow
  - Scale is sufficient that the expansion of the universe becomes significant
  - Requires expansion of software capability to incorporate



Source: IllustrisTNG

Methods

- Code built off of leapfrog from HW6
  - Adapted for arbitrary particle number
- Hubble flow incorporated
  - Apply kick of 67 km/s/Mpc to particles, depending on positions
  - Decoupling of dr/dt and velocity - prevent over-counting
- 50 Mpc box (physical, non-comoving)
  - 0.1 Mpc length unit
  - 10 kpc Softening length
- 10,000 particles
  - Masses selected for consistency with ~2x ρ_{crit}
  - $3.5 \times 10^9\ M_\odot$ per particle

$\rho_{c,0} = 9.47 \times 10^{-27}$ kg/m^3

Initial Conditions

Normalized PDF distribution:

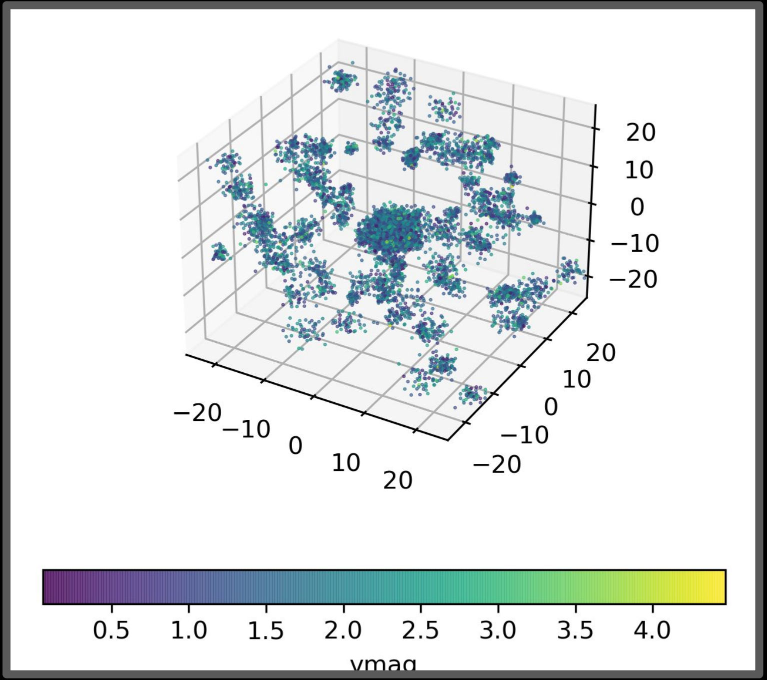
$$n(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

Uniform PDF distribution:

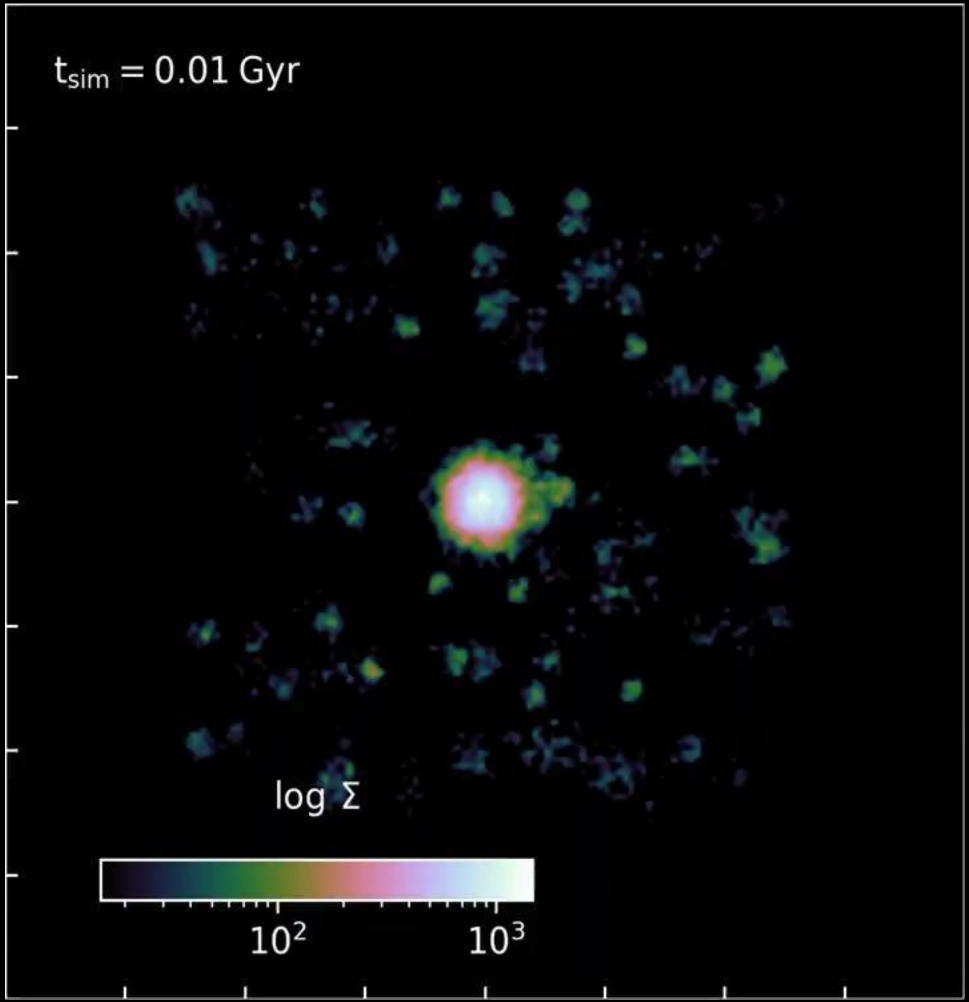
$$u(x) = \begin{cases} \frac{1}{b-a} & (a \geq x \leq b) \\ 0 & (x < a \text{ or } x > b) \end{cases}$$

Initial Conditions

- Critical density model
  - Mass is a function of critical density
- 50 Mpc x 50 Mpc x 50 Mpc box
- 10,000 Particles
  - Location: normal PDF distribution around central position
- 100 Subhalos
  - Uniform distribution
- Velocity
  - normalized PDF distribution




Jif
CREAMY
PEANUT BUTTER
7g
PROTEIN
PER SERVING
NET WT 16 OZ (1 LB) 454g
NON GMO* – GLUTEN



$t_{sim} = 0.01$ Gyr
log Σ
10^2
10^3

https://arxiv.org/abs/astro-ph/9508025

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THE STRUCTURE OF COLD DARK MATTER HALOS

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ABSTRACT

We use *N*-body simulations to investigate the structure of dark halos in the standard cold dark matter cosmogony. Halos are excised from simulations of cosmologically representative regions and are resimulated individually at high resolution. We study objects with masses ranging from those of dwarf galaxy halos to those of rich galaxy clusters. The spherically averaged density profiles of all our halos can be fitted over two decades in radius by scaling a simple "universal" profile. The characteristic overdensity of a halo, or equivalently its concentration, correlates strongly with halo mass in a way that reflects the mass dependence of the epoch of halo formation. Halo profiles are approximately isothermal over a large range in radii but are significantly shallower than r^{-2} near the center and steeper than r^{-2} near the virial radius. Matching the observed rotation curves of disk galaxies requires disk mass-to-light ratios to increase systematically with luminosity. Further, it suggests that the halos of bright galaxies depend only weakly on galaxy luminosity and have circular velocities significantly lower than the disk rotation speed. This may explain why luminosity and dynamics are uncorrelated in observed samples of binary galaxies and of satellite/spiral systems. For galaxy clusters, our halo models are consistent both with the presence of giant arcs and with the observed structure of the intracluster medium, and they suggest a simple explanation for the disparate estimates of cluster core radii found by previous authors. Our results also highlight two shortcomings of the CDM model. CDM halos are too concentrated to be consistent with the halo parameters inferred for dwarf irregulars, and the predicted abundance of galaxy halos is larger than the observed abundance of galaxies. The first problem may imply that the core structure of dwarf galaxies was altered by the galaxy formation process, and the second problem may imply that galaxies failed to form (or remain undetected) in many dark halos.

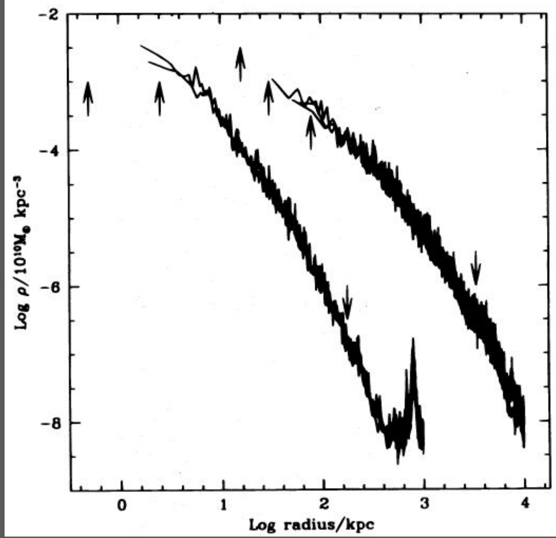
Subject headings: cosmology: theory — dark matter — galaxies: halos — methods: numerical

In the NFW profile, the density of dark matter as a function of radius is given by:

$$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}\left(1 + \frac{r}{R_s}\right)^2}$$

where ρ_0 and the "scale radius", R_s, are parameters which vary from halo to halo.

$$M_{\rm vir} = \frac{4\pi}{3} r_{\rm vir}^3 \, 200 \rho_{\rm crit}$$



Results

Analytical NFW fit for the density profiles for a given time.
Density decreases due to unconstrained Hubble flow.
Assumed:

```
concentration_param = 4
rho_not = 1e-2
r_s = vir_rad / concentration_param
rho_not = 0.20 * np.sum(mass) / r_s ** 3
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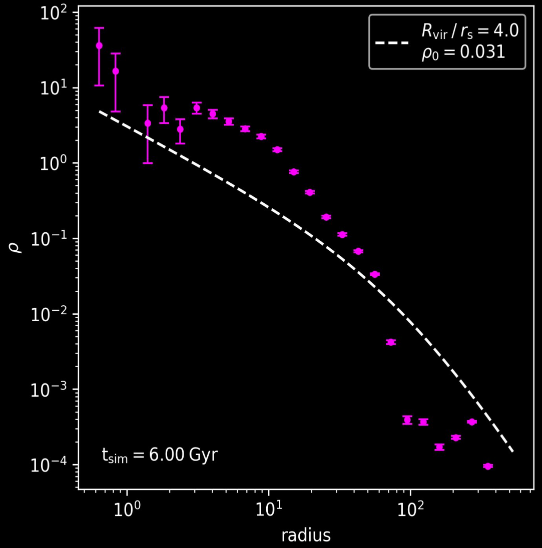
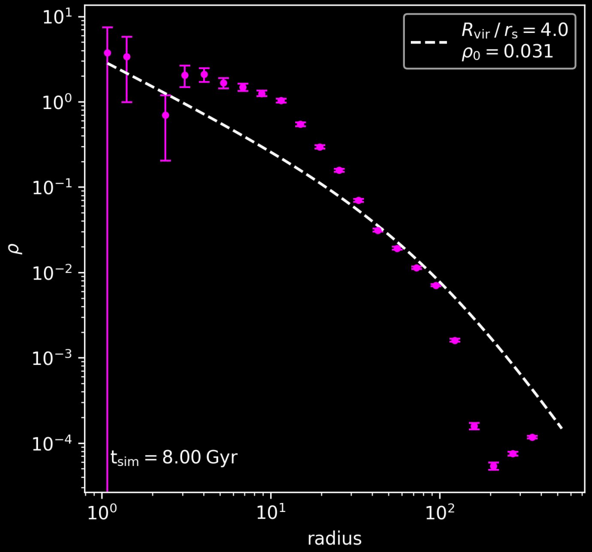
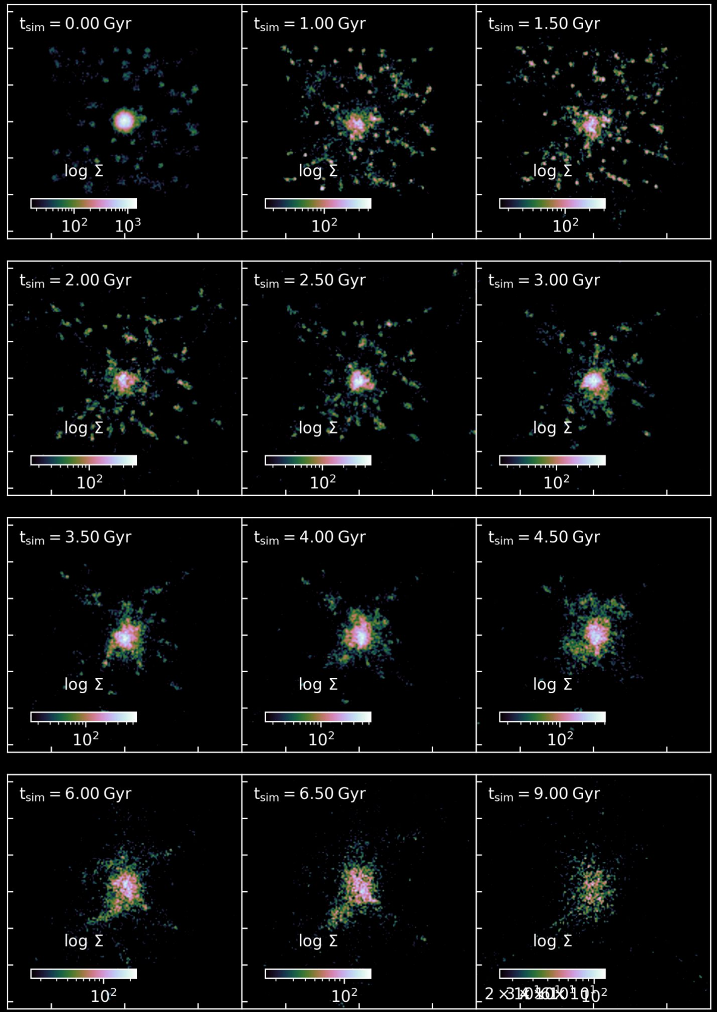
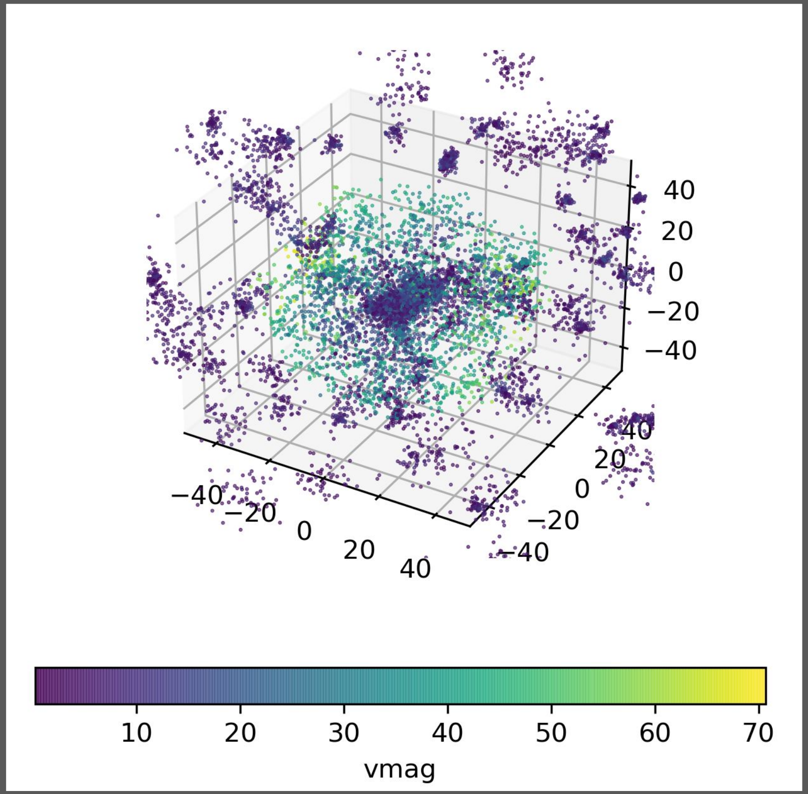






Results - Low Density Run

- Interparticle spacing doubled
  - Other parameters held constant
  - Decreases density to around 0.25 of critical density
- Hubble flow found to be dominant
  - Satellites fail to accrete
  - Central halo loses large number of the most weakly bound particles



Conclusions

- As expected, the dark matter eventually coalesced inwards to form a more densely packed structure
- This is reasonably consistent with the theoretical density profile
- With more computational power, we could simulate a larger volume in space and thus start to see more of the extremely large-scale filament structures