Dark Matter
Substructure and Dwarf Galactic Satellites

By Andrey Kravtsov
Presented By Curtis McCully
Outline

• Introduction
• CDM Simulations vs Observations
• Quantifying the Substructure Problem
  • Dark Satellites
  • Luminous Satellites
• Possible Solutions
  • New Cosmological Model
  • Galaxy Formation Suppression
Fig. 1—Formation of a Milky Way-sized dark matter halo in a cosmological simulation of flat $\Lambda$CDM cosmology. $\Omega_m = \Omega_{\Lambda} = h^2 = \sigma_8 = (0.7, 0.99)$. The panels show an evolutionary sequence at nine redshifts (redshift of each epoch is shown in the left upper corner) focusing on the most massive progenitor of the main halo at each epoch. The rendering shows the dark matter particles with intensity indicating the local matter density on a logarithmic stretch. The build-up of the halo proceeds through a series of spectacular mergers, particularly frequent in the early stages of evolution. Many of the merging clumps survive until the present epoch in the form of "substructure." The size of the region shown is about \( \text{comoving } \text{Mpc} \) at \( z = 5.02 \), monotonically zooming in to a scale of \( \approx 0.001 \) comoving Mpc across at \( z = 0 \). This is a visual manifestation of approximate self-similarity of CDM halos of different mass. If we would compare similar images of distribution of luminous matter around galaxies and clusters, the difference would be striking. The manifestly different observed satellite populations around galaxies of different luminosities and expected approximately self-similar populations of satellite subhalos around halos of different mass is known as the substructure problem.

[9], [6]. In the case of the best studied satellite systems of the Milky [7]...
Via Lactea Movies can be found at the following url

- [http://www.ucolick.org/%7Ediemand/vl/movies.html](http://www.ucolick.org/%7Ediemand/vl/movies.html)
Luminous Satellite Galaxies
Circular Velocity and $m_{0.6}$ Slopes
Defining the “Substructure Problem”

“The substructure problem can be stated as the discrepancy in the slopes of the circular velocity and $m_{0.6}$ mass functions inferred for observed satellites of the Milky Way and the slopes of these functions predicted for dark matter subhalos in the MW-sized host halos formed in the concordance $\Lambda CDM$ cosmology”
Different Cosmology

- Suppressing density fluctuations
- Warm Dark Matter

\[ d = 2R = 2 \left( \frac{3M}{4\pi \Omega_m \rho_{\text{crit}0}} \right)^{1/3} \]
\[ = 360.4 \text{ kpc} \left( \frac{M}{10^9 M_\odot} \frac{0.3}{\Omega_m} \right)^{1/3} \left( \frac{H_0}{70} \right)^{-2/3}, \]

where \( \Omega_m \) is the present-day total matter density in units of the present-day critical density, \( \rho_{\text{crit}0} = 3H_0^2/8\pi G \) and \( H_0 \) is the current Hubble constant in units of km/s/Mpc.
Galaxy Formation

Subhalo Suppression

- Gas photoevaporated after reionization
- Supernovae Feedback
- Satellites could be in larger halos
Conclusions

• Models and Observation do not agree
• Satellites could be mostly dark
• If satellites are dark, need low star forming efficiency
• Mass-dependent suppression mechanism
Luminous Satellite Models

- Threshold Galaxy Formation
- Selective Galaxy Formation
Subhalo Populations

\[ V_{\text{max}} = \max \left( \frac{G m(<r)}{r} \right)^{1/2} \]

\[ m(<r) = 4\pi \int \rho(r)r^2 \, dr \]
Luminous Satellites
(Cont.)