Dark Matter Halos

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J. Wadsley (McMaster, Canada)
## Major codes:

<table>
<thead>
<tr>
<th>Code</th>
<th>Authors</th>
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<tbody>
<tr>
<td>GADET</td>
<td>Springel, SDM White</td>
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<tr>
<td>PKDGRAV - GASOLINE</td>
<td>Quinn, Steidel, Wadsley, Governato, Moore</td>
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<tr>
<td>ART</td>
<td>Kravtsov, Klypin, N.Gnedin, Gottlober</td>
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<td>ENZO</td>
<td>Bryan, Norman</td>
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Mass function of distinct halos
Mass function of distinct halos

• It started long ago: 32 years to be precise
• Now we live through 5th generation of this.
Mass function of distinct halos

Warren et al. 2005: 13 sims each with 1G particles
Mass function of distinct halos

Warren et al. 2005: 13 sims each with 1G particles

Fig. 2.— Shown are the residuals from the binned simulation data to the fit presented in this work as square data points of different colors per simulation. The Jenkins fit is the solid (purple) line, ST original fit the dashed (dark gray) line, the ST fit with parameters $A$, $a$, $p$ free with dot-dashed line (red), and the ST fit with $a$, $p$ free and amplitude $A$ set to require all dark matter in halos as a triple-dot-dashed line (light gray). The binned mass function from the Virgo Hubble Volume simulation are the asterisk points with errors (pink).
Halos are not self-similar: Large halos have more substructure. Yet the effect is very weak.
Clustering: DM halos and L

Conroy, Wechsler, Kravtsov (2005): \textit{N-body only}

- Get all halos from high-res simulation
- Use maximum circular velocity (NOT mass)
- For subhalos use $V_{\text{max}}$ before they became subhalos
- Every halo (or subhalo) is a galaxy
- Every halo has luminosity: LF is as in SDSS
- No cooling or major mergers and such. Only DM halos

Reproduces most of the observed clustering of galaxies
SDSS: z=0

DM galaxies

DM

SDSS

$M_z - 5 \log(h)$

$10^3$

$10^2$

$10^1$

$r_p (h^{-1} \text{Mpc})$

$r_p \cdot \omega_p(r_p)$
DEEP: $z=1$
Dark Matter and Galaxies
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- **Central** DM closely correlates with $L$: Tully-Fisher, Faber-Jackson
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- Environment (how many neighbors) is just an indicator of halo mass
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Young et al. (2003-5), Berrier et al. (2005): Halo occupation distribution → the same conclusions
Dark Matter and Galaxies

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Voids
R>10Mpc

Patiri et al 2006: SDSS
Number-density Profiles of Voids:

$n(R)/\langle n \rangle$

Patiri et al 2006

SDSS

LCDM

$1 + \delta_{gal}$

$r/R_{void}$

$R_{void} [\text{Mpc}/h] > 13.0$

$10.0 < R_{void} [\text{Mpc}/h] < 13.0$
Infall velocity for halos of different mass:

Average radial velocity at a given distance from the center of a halo
SDSS and LCDM: surface number density of satellites around isolated galaxies
SDSS and LCDM: surface number density of satellites around isolated galaxies
Very small scales

Cusps and rotation curves
DDO 47:

Vmax = 80km/s

Distance = 4Mpc

HI is very lumpy

Stellar light does not align with HI
Observations:

- A large fraction of dwarf Galaxies in the central 1kpc has a maximal disk: stellar populations with observed colors.
- Signs of a weak bar are frequent.
- ISM is very clumpy.
DM in central regions of galaxies: Can cusps be destroyed?

- bars (Weinberg & Katz 2002).
  - Answer no: Colin etal 2005: DM density increases as bars form

- baryons:
  - Very artificial and unrealistic setup
  - Real N-body+Hydro sims (30pc resolution) show increase in DM density

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<td>El-Zant, Shlosman, Hoffman (2001)</td>
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<td>Gnedin &amp; Zhao (2002)</td>
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<td>Mashchenko, Couchman, Wadsley (2006)</td>
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Valenzuela et al 05

Isolated Galaxy:
NFW halo   1-2M particles
Exponential disk 200K particles
Gas 100K
Resolution 60 pc
Star formation, feedback ....

Cold gas in central 2kpc region

simulations:
dwarf: 70km/s

Code: GASOLINE
**Simulation:** dwarf 5

Resolution: 60pc

Valenzuela, Rhee, Klypin, Governato et al. 2005

Models of NGC3109 and NGC6822

Graph showing gas rms velocity as a function of radial distance (R(kpc)). Different lines represent gas rms velocity, baryons, and dark matter (dm).
**Simulation:** dwarf 5

Resolution: 60pc

Valenzuela, Rhee, Klypin, Governato et al. 2005

Models of NGC3109 and NGC6822
Simulation: dwarf 5

Resolution: 60pc

Valenzuela, Rhee, Klypin, Governato et al. 2005

Models of NGC3109 and NGC6822
True and recovered density profiles

\( V_{\text{rot}}(r) \Rightarrow \rho(r) \)

True slope: -1.8
Recovered: -0.5
True and recovered density profiles

\[ V_{\text{rot}}(r) \Rightarrow \rho(r) \]

True slope: -1.8
Recovered: -0.5
Effects at $r = r_d$

Naive correction for asymmetric drift:

$V_{\text{circular}} = 39$ km/s
$V_{RMS} = 10$ km/s
error in density = 2.2 times

Accurate corrections for asymmetric drift:

for rms velocities only: $V_{\text{circular}} = 47$ km/s
for pressure gradient only: $V_{\text{circular}} = 49$ km/s
Total: $V_{\text{circular}} = 57$ km/s

$V_{\text{rotation}} = 37$ km/s
$V_{\text{circular}} = 58$ km/s
$V_{RMS} = 22$ km/s
Temp = $25e3$ K
log-log slope density = -1.8
NGC 6822

Magellanic-type
dwarf irregular

0.5Mpc from Milky Way
NGC 6822

Magellanic-type
dwarf irregular

0.5Mpc from Milky Way

Observations

$V_{\text{circ}}$(total)
CONCLUSIONS

★★ Cusps are not destroyed by baryons
★★ Adiabatic compression makes cusps steeper
★★ Cores are ‘observed’ where there is a real cusp.
★★ Observations are compatible with cuspy DM profiles