Dark Matter Halos of M31 Galaxies

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Santa Cruz Galaxy Formation Workshop August 25th, 2008
Missing Satellites Problem

Milky Way dSphs have been studied extensively.

Mass function of M31 - same or different?

M31 dSphs: Larger than MW dSphs

Are the DM halos the same or different?

1. If same or larger, M31 dSphs should have a larger stellar velocity dispersion ($\sigma$).


2. If DM halos less dense, $\sigma_{M31} \leq \sigma_{MW}$ at fixed luminosity.

McConnachie & Irwin, MNRAS 2006
Keck/DEIMOS Spectroscopy

<table>
<thead>
<tr>
<th>Name</th>
<th># of Stars</th>
<th>Vel. Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>And I</td>
<td>76</td>
<td>9.1 ± 1.0</td>
</tr>
<tr>
<td>And II</td>
<td>95</td>
<td>7.3 ± 0.8</td>
</tr>
<tr>
<td>And III</td>
<td>43</td>
<td>4.7 ± 1.0</td>
</tr>
<tr>
<td>And X</td>
<td>22</td>
<td>3.9 ± 1.2</td>
</tr>
<tr>
<td>And XIV</td>
<td>38</td>
<td>5.4 ± 1.1</td>
</tr>
</tbody>
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Dispersion profile falls as projected R approaches the stellar extent.

Dispersion vs Luminosity

\[ \sigma_{M31} < \sigma_{MW} \] at fixed L suggests dark matter halos less dense!

Dispersion vs Size

Mass Modeling

What information do we have?

- Stellar kinematics
- Photometry

Spherical Jeans Eq.

\[ r \frac{d(\rho_\star \sigma_r^2)}{dr} = \frac{-GM(r)}{r} \rho_\star(r) - 2\beta(r) \rho_\star \sigma_r^2 \]

Velocity Anisotropy

(3 parameters)

\[ \beta(r) = (\beta_\infty - \beta_0) \frac{r^2}{r_\beta^2 + r^2} + \beta_0 \]

Mass Density

(6 parameters)

\[ \rho(r) = \frac{\rho_s e^{-r/r_{cut}}}{(r/r_s)^c [1 + (r/r_s)^a]^{(b-c)/a}} \]
Mass Modeling

How do we get a mass likelihood?

Integrate a probability distribution function

\[
P(x|\theta) = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi(\sigma_{t,i}^2 + \sigma_{m,i}^2)}} \exp\left[-\frac{1}{2} \frac{(v_i - u)^2}{\sigma_{t,i}^2 + \sigma_{m,i}^2}\right]
\]

\[
\mathcal{L}(m) \propto \int P[v|u, \sigma_t(\bar{\theta})] \delta(m - M) d\bar{\theta}.
\]

- **Markov Chain Monte Carlo (MCMC):** Randomly pick flat deviates from 13 dimensional parameter space to solve Jeans equation. Algorithm accepts or rejects based on likelihood value. Equivalent to integrating over the distribution function.
Mass Likelihoods

What is best radius to constrain mass?

Cyan Plot I

Illingworth approximation
(mass follows light)

Stellar Mass

Money Plot

Interpretation/Future Work

• M31 dSphs are less dense → Galaxy formation may be different for MW and M31.
• Could imply that M31’s dark matter halo collapsed later.
• Feedback processes may be different for each galaxy.

Question:
Is there a consistent mass scale or just a threshold? More kinematics are needed to examine the rest of the M31 dSph population.
\( V_{\text{max}} \) Likelihoods

<table>
<thead>
<tr>
<th>Name</th>
<th>( V_{\text{max}} )</th>
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<tbody>
<tr>
<td>And I</td>
<td>( 18^{+31}_{-1} )</td>
</tr>
<tr>
<td>And II</td>
<td>( 15^{+15}_{-2} )</td>
</tr>
<tr>
<td>And III</td>
<td>( 11^{+8}_{-4} )</td>
</tr>
<tr>
<td>And X</td>
<td>( 8^{+8}_{-6} )</td>
</tr>
<tr>
<td>And XIV</td>
<td>( 12^{+14}_{-4} )</td>
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Name | CDM prior |
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<tr>
<td>And I</td>
<td>( 20^{+15}_{-2} )</td>
</tr>
<tr>
<td>And II</td>
<td>( 15^{+5}_{-2} )</td>
</tr>
<tr>
<td>And III</td>
<td>( 11^{+8}_{-4} )</td>
</tr>
<tr>
<td>And X</td>
<td>( 8^{+10}_{-3} )</td>
</tr>
<tr>
<td>And XIV</td>
<td>( 12^{+11}_{-4} )</td>
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Take-Home Message

Extra Plots
$M_{600}$ vs $L_V$

$M_{\text{Stellar extent}} / L_V \text{ vs } L_V$