Dark Matter Halos of M31 Galaxies

“Joe Wolf”

TASC

October 24th, 2008
Team Irvine: Louie Strigari, James Bullock, Manoj Kaplinghat
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October 24th, 2008
What is a dwarf spheroidal (dSph) galaxy?

- Typical galaxies have M/L ~1 - ~10, with baryon dominated centers.
- Dwarf spheroidal galaxies are the most dark matter dominated systems known: M/L ~10 - ~1000
- Excellent laboratories to compare DM simulations to observations.
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Small scale problems with CDM:

- Missing Satellites Problem → Erik Tollerud’s talk

- Cusp - Core Problem

- Galaxy formation theories disagree with observations

And VI: George Jacoby/WIYN/NOAO/NSF
Overview

What is a dwarf spheroidal (dSph) galaxy?
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Predictions from mass models:
- Gamma ray annihilation signals → Greg Martinez’s talk

And VI: George Jacoby/WIYN/NOAO/NSF
Another Dataset: Andromeda!
M31 dSphs: Larger than MW dSphs

McConnachie & Irwin, MNRAS 2006
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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
Dispersion vs Luminosity

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

Dispersion vs Size

Milky Way

Andromeda

Mass Modeling

What information do we have?

• Stellar kinematics
• Photometry

Spherical Jeans Eq.

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

What information do we have? • Stellar kinematics • Photometry

Spherical Jeans Eq.

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

Velocity Anisotropy
(3 parameters)

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

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

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

• 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?


What is best radius to constrain mass?
Cyan Plot I

Illingworth approximation
(mass follows light)

Approximating Mass

\[ M_{r_{\text{half}}} = 3 \sigma_0^2 r_{\text{half}} / G \]

Money Plot I

Money Plot II

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.
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Question:
Is there a consistent mass scale or just a threshold? More kinematics are needed to examine the rest of the M31 dSph population.
Take-Home Message

Extra Plots
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>
</table>


Dispersion profile falls as projected R approaches the stellar extent.

M$_{\text{Stellar extent}}$ vs $L_V$

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