Can dwarf galaxies discriminate between CDM and alternatives?

The Physics of Galaxy Scaling Relations and the Nature of Dark Matter
July 20, 2018
Kingston, Ontario

1) Fermi gamma-ray limits
2) DM core/cusps
3) dSph orbital motions/Gaia
Alternatives to cold dark matter?

- The WIMP paradigm is starting to be tested experimentally
- E.g. spin-independent operators strongly constrained, but many other are possible (Fan et al. 2010; Fitzpatrick et al. 2012)
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Observational systematics make it difficult to distinguish between CDM and alternatives
Milky Way satellites

Dark Energy Survey:
Drlica-Wagner et al. 2016
Milky Way satellites

Dark matter bounds from dSphs with gamma rays

- Integrated DM masses of dSphs well-determined within characteristic Fermi-LAT angular resolution
- Combine measured gamma-ray flux upper bound with the total dark matter mass in each satellite to get upper bound on the annihilation cross section

Fermi-LAT collaboration
PRL, 1108.3546
PRD, 1310.0828
PRL, 1503.02641

- Bounds at higher DM mass from ground-based observatories
- Lower mass bounds from CMB (Planck)
Gamma-ray excesses?

Possible gamma-ray excesses in a few ultra-faint satellites: e.g. Reticulum II

Geringer-Sameth et al. PRL 2015  
Hooper & Linden JCAP 2015  
Li et al. PRD 1805.06612
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Gamma-ray excesses do not correlate with measured J-factors

Can DM signal be found with Fermi?

Spectroscopic follow up likely to be more difficult for MW satellites discovered in future

Mild correlation between J-factor and structure parameters.
Are dSphs simple single population stellar systems?

- Many DM density profiles explored
- Corrections from non-spherical potentials (Hayashi & Chiba 2012; Kowalczyk et al. 2013)
- Stellar distribution function-based models (Strigari, Frenk, White 2010, 2015, 2018)
- Orbit-based models (Breddels et al. 2012; Jardel & Gebhardt 2012, 2013)
Multiple stellar populations

- Some dSphs (Sculptor, ANDII) show evidence for multiple stellar populations

- Some kinematic studies disfavor NFW for Sculptor (Walker & Penarrubia 2011; Amorisco & Evans: Agnelle & Evans 2012)

- Some studies show NFW cannot be ruled out for Sculptor (Breddels & Helmi 2014; Strigari, Frenk, White 2014)

- No apparent addition information from ANDII multiple populations (Ho et al. 2013)
Internal stellar proper motions

3D motions in the Sculptor dwarf galaxy as a glimpse of a new era

D. Massari\textsuperscript{1,2,*}, M. A. Breddels\textsuperscript{1}, A. Helmi\textsuperscript{1}, L. Posti\textsuperscript{1}, A. G. A. Brown\textsuperscript{2}, E. Tolstoy\textsuperscript{1}

- Internal stellar proper motions provide missing phase space measurements (Wilkinson et al. 2001; LS, Bullock, Kaplinghat 2007)
- Potential to distinguish between DM cores/cusps
- HST Requirements:
  - Sculptor requires PMs $\sim 22$ micro-arcsec/year
  - Positional accuracy of 0.003 ACS/WFC per epoch
  - For N exposures, the positional accuracy per exposure is 0.003 sqrt(N)
  - For N $\sim$5-19, positional accuracy per exposure is $\sim$ 0.01 pixel
- Not easy!

\[
\sigma_R = 11.5 \pm 4.3 \text{ km s}^{-1} \quad \sigma_T = 8.5 \pm 3.2 \text{ km s}^{-1}
\]
Sculptor stellar populations & proper motions

- Self-consistent stellar DF model + LOS velocities predict the PM velocity dispersion profiles
- Multiple populations + PMs provide most significant test of NFW vs cored Burkert model in dSphs
- Gaia + data unable to discriminate cores vs. cusps
- Require PM velocity dispersions to \( \sim 1 \) km/s (LS, Frenk, White 2018)
Orbits of dSphs

- 3D orbital dynamics of dSphs from Gaia
- Members from stellar spectra (Gaia collaboration/Helmi et al., Fritz et al., Simon 2018)
- Members from Gaia photometry (Masser & Helmi 2018)

- Members identified from DES photometry & Gaia (Pace & Li 2018)
Orbits of dSphs

- Fornax analogues in APSOTLE show a range tidal disruption possibilities (Mei-Yu Wang, Azi Fattahi et al. 2017)

- Difficult to match the kinematics & the orbital dynamics simultaneously

- Best model: Stream with surface brightness ~ 32 mag/arcsec^2 (DES, LSST?)
dSphs with deep photometry

- **Fornax**
  - Enhanced SF ~3-4 Gyr ago (Coleman & de Jong 2008)
  - CDM infall times ~9 Gyr ago (Rocha et al. 2012, Wang et al. 2015)
  - Heavily stripped halo
  - No apparent tidal signature

- **Carina**
  - Tidal disruption
  - Multiple episodes of star formation
  - Kinematic models include tidal effects (Ural et al. 2015)
  - DECam observations indication minimal tidal disruption (McMonigal et al. 2015)
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Table 1. Fornax VST ATLAS catalogue

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As a sample of the final Fornax catalogue. The full catalogue is available online as supplementary material. Cambridge Astronomical Survey Unit pipeline classifications are described in Section 2.
dSphs with deep photometry

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Summary

How far can sensitivity go?

Forthcoming Gaia data releases?