Near-field Cosmology with Isolated Dwarf Galaxies

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Background

[LCDDM, successes, small scale puzzles]
Background | The ‘cusp-core’ problem

Flores & Primack 1994; Moore 1994; Read et al. 2017
Pure Dark Matter $\rightarrow$ Observed Universe
Predictive Simulations with baryons

[Getting feedback right for one isolated dwarf]
Simulations | Resolving feedback

Warm H2 in the M82 Galactic wind | Veilleux et al. 2009

Image composite credit: Leisa Townsley
Simulations | Resolving feedback

\[ E_c = 10^{51} \text{ ergs} \]

\[ L = 100 \text{ pc} \]

\[ n = 10 \text{ atoms/cc} \]

\[ \Rightarrow T_c = 1.7 \times 10^4 \text{ K} \]

\[ T_c = \frac{2}{3k_b} \frac{E_c}{nL^3} \]

Agertz et al. 2013; Dalla Vecchia & Schaye 2008
Simulations | Resolving feedback

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\[ L = 10 \text{ pc} \]
\[ n = 100 \text{ atoms/cc} \]

\[ \Rightarrow T_c = 1.7 \times 10^6 \text{ K} \]

\[ T_c = \frac{2}{3k_b} \frac{E_c}{nL^3} \]

Agertz et al. 2013; Dalla Vecchia & Schaye 2008
Simulations | Resolving feedback

Read et al. 2016a,b

$10^9 M_\odot$ | Quiescent

$10^9 M_\odot$ | Starburst

$\Delta x = 4\, \text{pc} \, | \, M_* \sim 300 \, M_\odot \, | \, M_{dm} = 250 \, M_\odot \, | \, n_{th} = 300 \, \text{atoms cm}^{-3}$
Simulations | Resolving feedback

IC 1613

10^9 M☉ | Starburst

Density

Δx = 4 pc | M_☉ ∼ 300 M☉ | M_{dm} = 250 M☉ | n_{th} = 300 atoms cm^{-3}
Simulations | Cusp-core transformations

$\rho_{DM} [M_\odot \text{kpc}^{-3}]$

$r [\text{kpc}]$

Fiducial (M8c28_4e5)

M8c28_4e5_pST

M8c28_4e5_e001

M8c28_4e6_r1e3

ICs

Read et al. 2016
Simulations | Cusp-core transformations

\[
\rho_{DM} [M_\odot \text{kpc}^{-3}]
\]

- 1 Gyr
- 4 Gyr
- 8 Gyr
- 14 Gyr
- ICs

Read et al. 2016; and see Navarro 1996; Read & Gilmore 2005; Pontzen & Governato 2012
Simulations | Cusp-core transformations

Read et al. 2016; and see di Cintio et al. 2014; Onorbe et al. 2015; Munshi et al. 2017
Isolated dwarfs
[rotation curves + abundance matching]
Measurement | Rotation curves

![Graph showing rotation curves for different components: stars, gas, fit NFW, and WLM. The graph includes error bars and a vertical line at R = 1 kpc. The text "LCDM; no baryons" is mentioned.]

Read et al. 2016a,b; Read et al. 2017
Measurement | Rotation curves

![Graph showing rotation curves for different components: Stars, Gas, Fit coreNFW, and WLM. The graph includes error bars and models like LCDM+baryons.]

Read et al. 2016a,b; Read et al. 2017
The stellar mass-halo mass relation
Measurement | The stellar mass-halo mass relation

Read et al. 2016a,b; Read et al. 2017
The stellar mass-halo mass relation

Measurement | The stellar mass-halo mass relation

Bolshoi; Klypin et al. 2011
SDSS
LCDM

Read et al. 2016a,b; Read et al. 2017
Measurement | The stellar mass-halo mass relation

Read et al. 2016a,b; Read et al. 2017
Measurement | The stellar mass-halo mass relation

![Graph showing the stellar mass-halo mass relation with various energy levels and galaxy labels such as LWDM, NGC6822, WLM, DDO168, CVnIdwA, Aquarius, DDO126, DDO87, DDO52, DDO154, NGC2366, LeoT, WDM, CDM, and Extrapolated. The graph includes measurements for isolated dwarfs and isolated galaxies such as Carina and LeoT.](image-url)
Measurement | The stellar mass-halo mass relation

- Field (SDSS)
- Extrapolated
- Read+16a [No reion.]
- Isolated dwarfs
- Carina
- LeoT

$M_\star$ [$M_\odot$] vs. $M_{200}$ [$M_\odot$]

Read 16a

Contenta et al. 2017

Contenta et al. 2017
Measurement | The stellar mass-halo mass relation

Contenta et al. 2017
The stellar mass-halo mass relation

Measurement

Contenta et al. 2017

FIRE
Measurement | The stellar mass-halo mass relation

Munshi et al. 2017
Cosmological simulations
E.D.G.E.

Engineering Dwarfs at Galaxy formation’s Edge

Oscar Agertz
Andrew Pontzen
Justin Read
$M_{DM} = 960 \, M_\odot$ (fiducial), $120 \, M_\odot$ (high) | $M_{bar} = 160 \, M_\odot$
Halo 197, DM + adiabatic hydro

\[
M_{200,DM} [M_\odot] \sim (r) [kpc] \\
\]

\(z = 8\) \(\Delta\) \(SFR > 0\) \(\Delta\) \(Core\ formation\)

\(z = 6\) \(\Delta\)

\(z = 5\) \(\Delta\)

\(z = 4\) \(\Delta\) \(3\) \(\Delta\) \(SFR = 0\) \(\Delta\) \(Cusp\ grinding\ stops\)

\(z = 4\) \(\Delta\)

\(z = 3\) \(\Delta\)

\(z = 2\) \(\Delta\)

\(z = 1\) \(\Delta\)

\(z = 0\)

Agertz, Pontzen & Read in prep. 2017
Cosmological simulations | **Cores & cusps in an ultra-faint**

Halo 197, DM profiles

<table>
<thead>
<tr>
<th>$z$</th>
<th>DM halo growth</th>
<th>DM core formation</th>
<th>Merger with cuspy halo</th>
</tr>
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<tbody>
<tr>
<td>8</td>
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$\rho(r) \left[ M_\odot \, kpc^{-3} \right]$ vs $r \left[ kpc \right]$

$z = 8 \rightarrow 4$ | DM core formation

$z = 2 \rightarrow 0$ | Merger with cuspy halo

$z = 4 \rightarrow 2$ | no SF, core formation stops

$z = 1 \rightarrow 0$ | Merger with cuspy halo

Agertz, Pontzen & Read in prep. 2017; and see Laporte & Penarrubia 2014; Onorbe et al. 2015
A DM core in the ultra-faint dwarf Eridanus II
A DM core in an ultra faint Eridanus II and its lone cluster

Contenta et al. 2017; Koposov et al. 2015; Crnojevic et al. 2016; Amorisco 2017
A DM core in an ultra faint | Cusped models

Age: 0.0 Gyrs

$M_{200} = 5 \times 10^8 M_{\odot}$

Contenta et al. 2017
A DM core in an ultra faint | Cored models

Age: 0.0 Gyrs

\[ M_{200} = 5 \times 10^8 \, M_\odot \]

Contenta et al. 2017
Results

Best model in cusped galaxy

Best model in cored galaxy
Conclusions

• Isolated dwarf simulations at ~4pc resolution predict dark matter cores of size ~$R_{1/2}$, if SF not truncated.

• Abundance matching isolated dwarfs $\rightarrow m_{\text{dm}} > 2$ keV.

• Even ‘ultra-faints’ can form DM cores; evidence for one in Eridanus II.

• Evidence for a dark matter cusp in Draco $\rightarrow$ evidence for “dark matter heating”; SIDM $\rightarrow \sigma/m < 1 \text{ cm}^2/\text{g}$.

• Dark matter likely a cold(ish) & collisionsless particle.