Astrophysical Interplay in Dark Matter Searches

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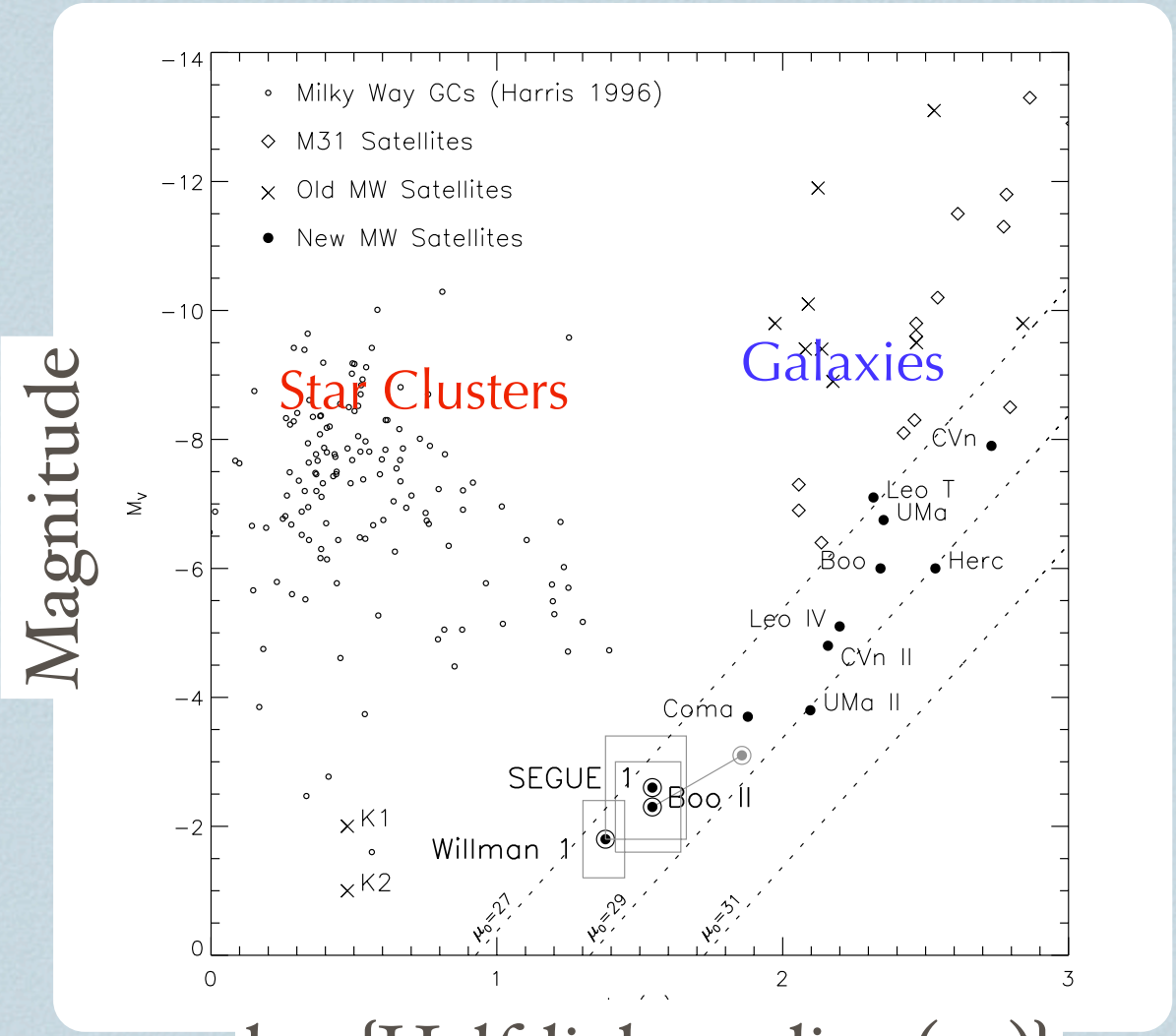
Dark Attack July 2012
Ascona, Switzerland

Overview

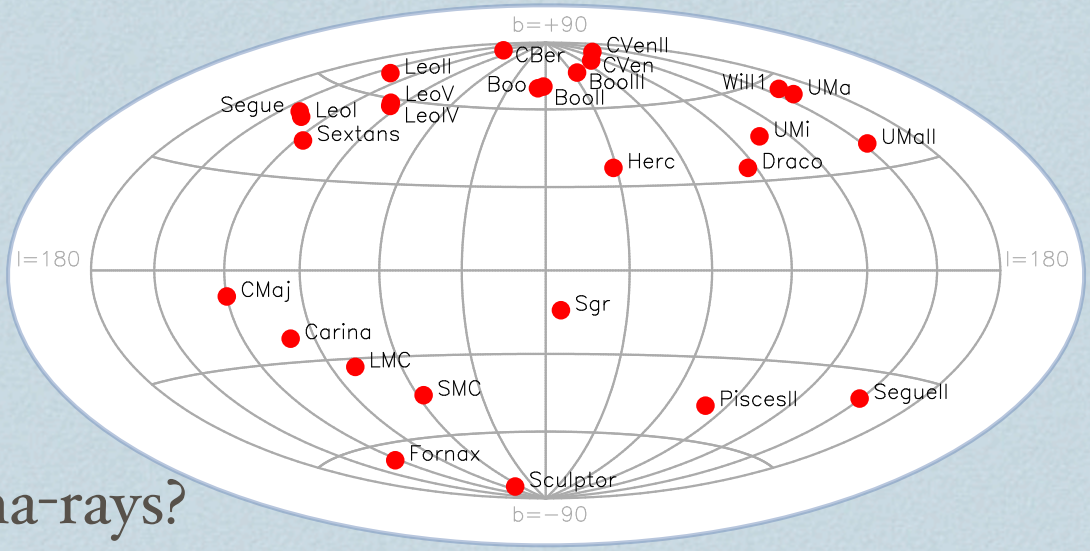
- Fermi/ACT Dark Matter dwarf spheroidal limits
- Missing satellites issue, redux
- Direct detection and the Galactic halo
  - Velocity distribution
  - Can the WIMP mass be determined?

What is a (dwarf spheroidal) galaxy?



Dwarf spheroidal questions

- Is it a galaxy?
- How much dark matter?
- Intrinsic sources of gamma-rays?



'Classical' satellites

Satellite	M_V	$L_V[L_\odot]$	$d_{\rm sun}$[kpc]
Large Magellanic Cloud	-18.5	2.15×10^9	49
Small Magellanic Cloud	-17.1	5.92×10^8	63
Sagittarius	-15.0	8.55×10^7	28
Fornax	-13.1	1.49×10^7	138
Leo I	-11.9	4.92×10^6	270
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'Ultra-faint' satellites

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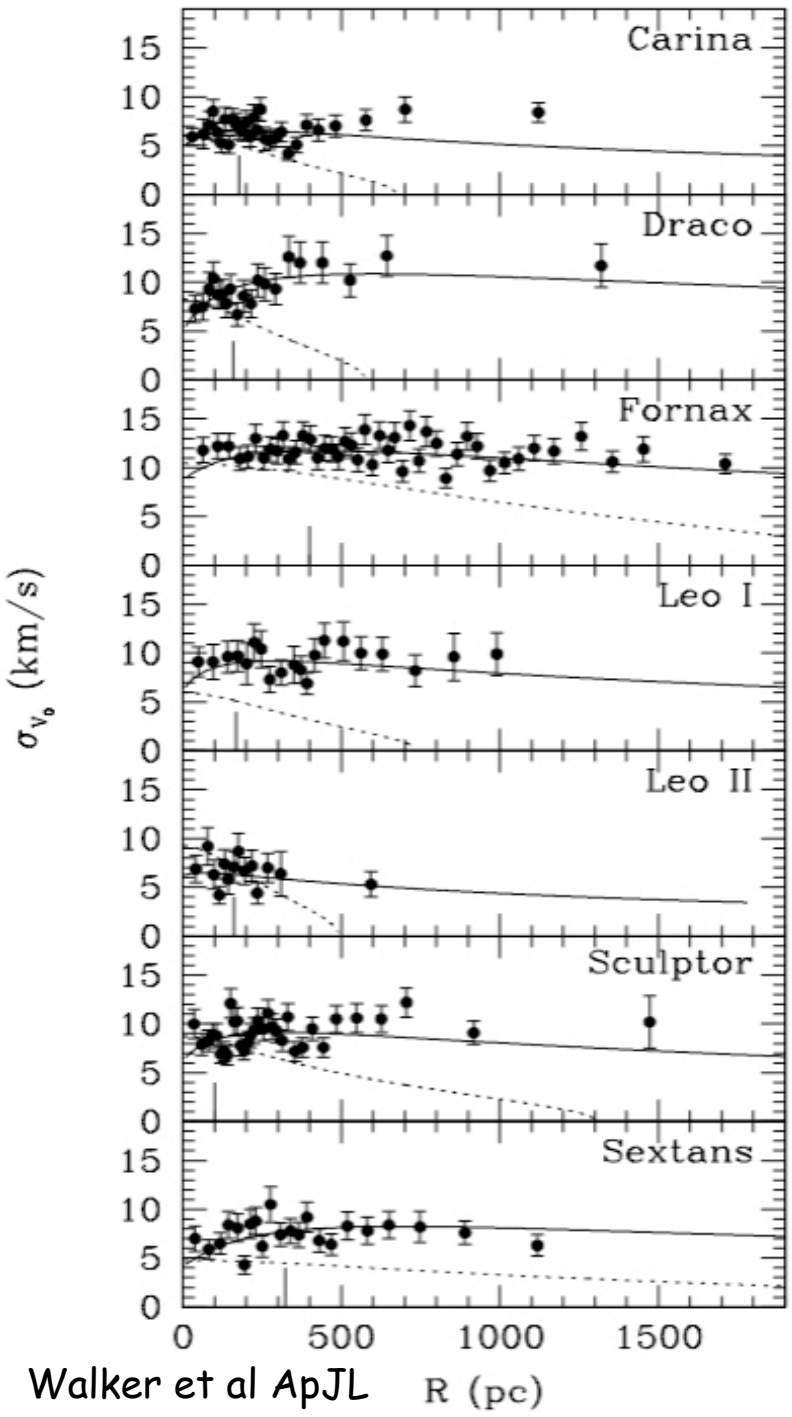
Segue 1	-1.5	3.40×10^2	23

Classical satellites How much dark matter?

- Various theoretical approaches [Virial theorem, jeans, distribution functions, Schwarschild codes]
- Dark matter mass well-determined within ~ degree scale of Fermi-LAT
- No sensitivity to core/cusp for Fermi-LAT
- Modern/Future ACTs will be sensitive to DM and photometric core/cusp

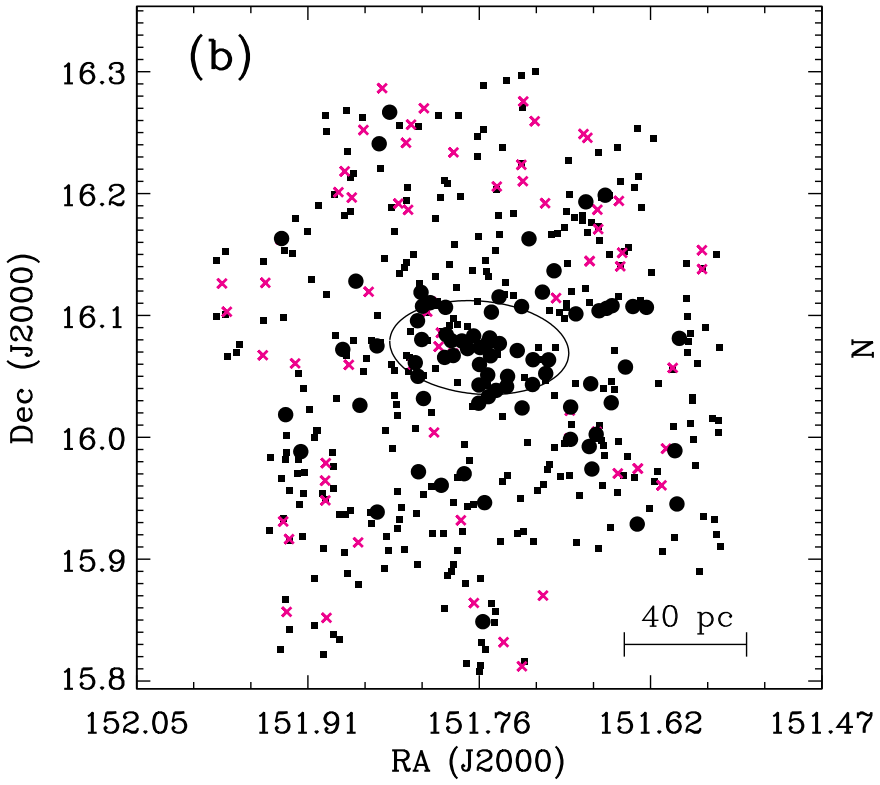


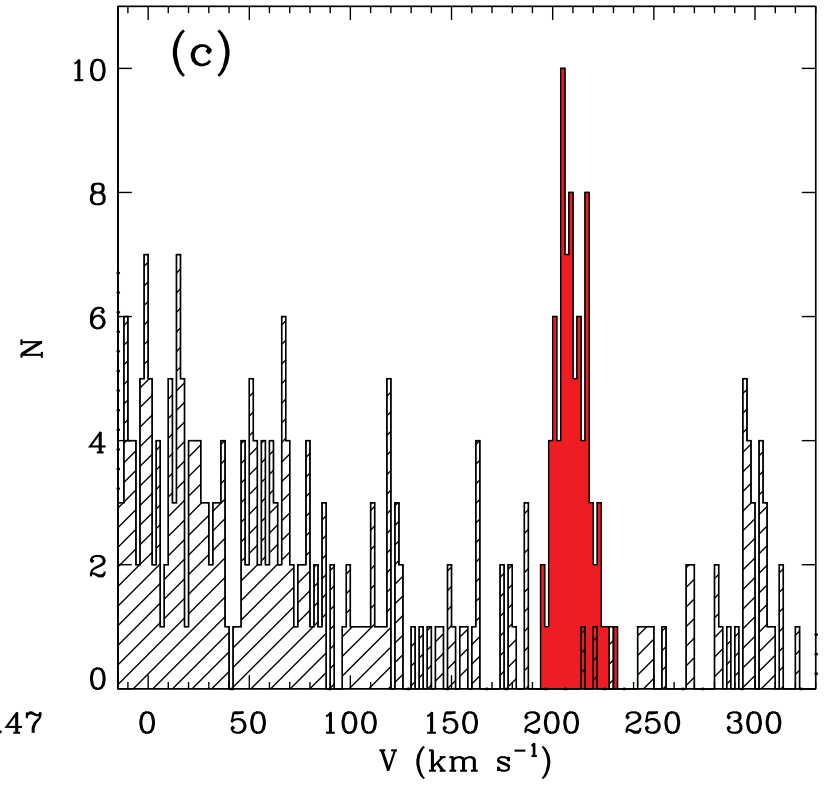
Walker et al ApJL

Ultra-faint satellites: How much dark matter?

A COMPLETE SPECTROSCOPIC SURVEY OF THE MILKY WAY SATELLITE SEGUE 1: THE DARKEST GALAXY*

Joshua D. Simon[1], Marla Geha[2], Quinn E. Minor[3], Gregory D. Martinez[3], Evan N. Kirby[4,5], James S. Bullock[3], Manoj Kaplinghat[3], Louis E. Strigari[6,5], Beth Willman[7], Philip I. Choi[8], Erik J. Tollerud[3], and Joe Wolf[3]

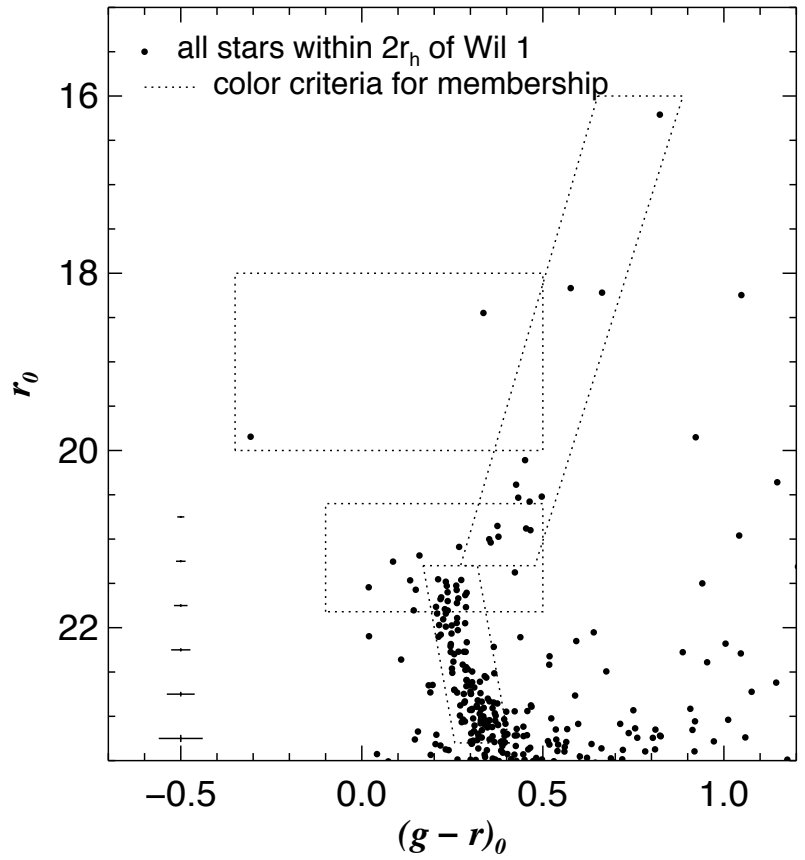


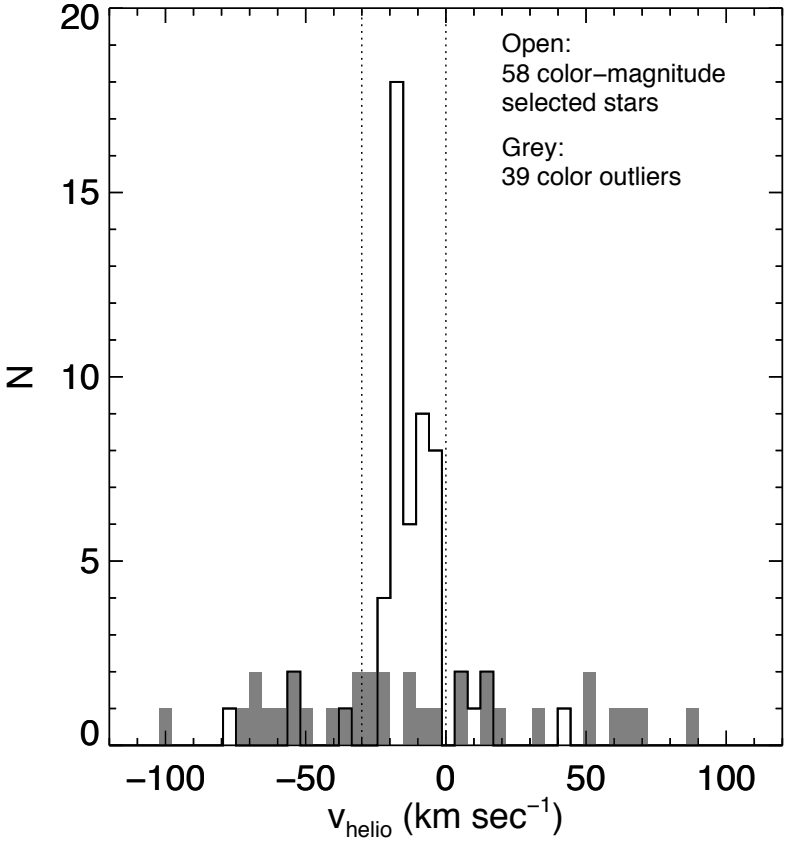


Ultra-faint satellites: How much dark matter?

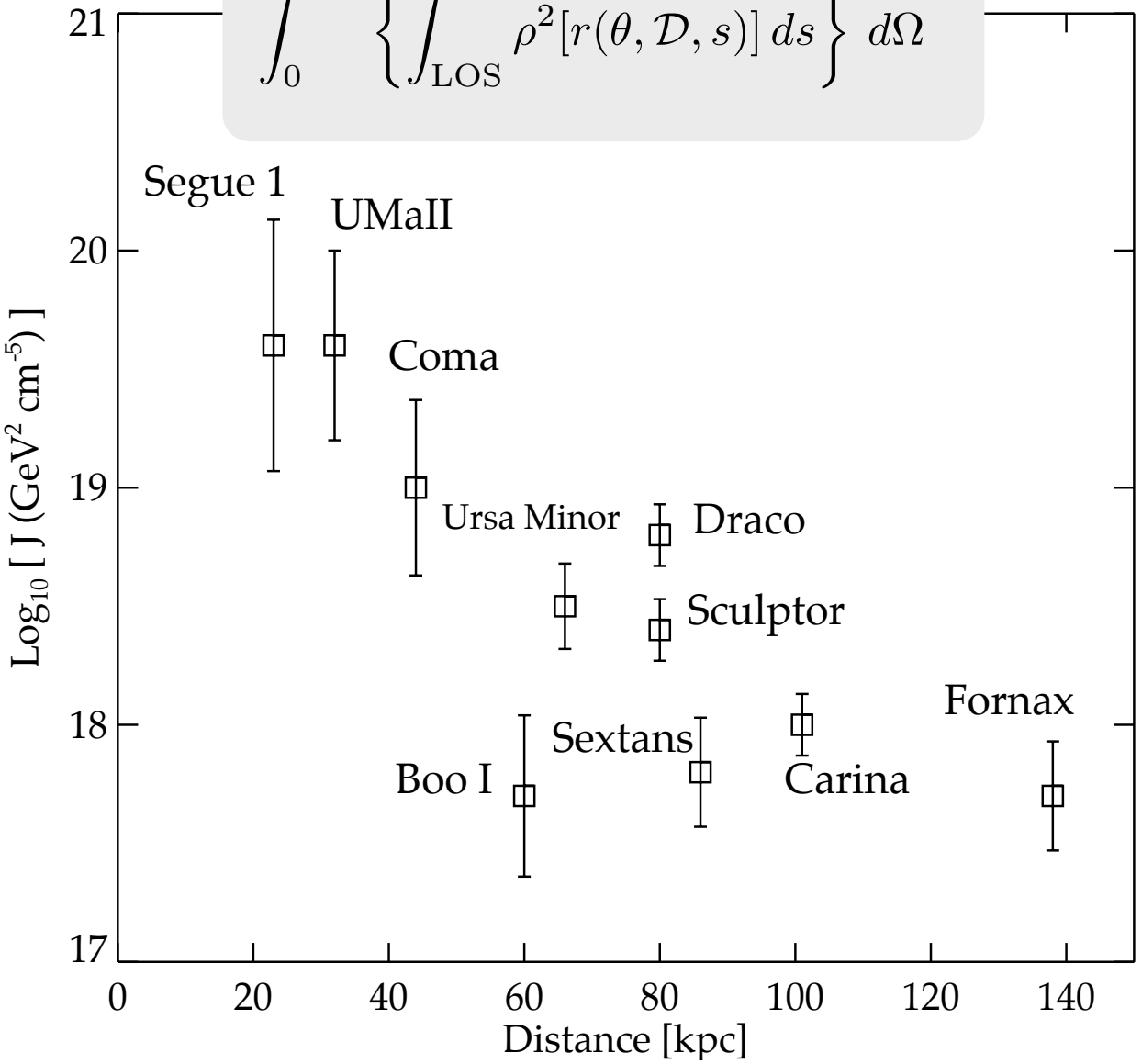
WILLMAN 1 - A PROBABLE DWARF GALAXY WITH AN IRREGULAR KINEMATIC DISTRIBUTION

Beth Willman[1], Marla Geha[2], Jay Strader[3,4], Louis E. Strigari[5], Joshua D. Simon[6], Evan Kirby[7,8], Nhung Ho[2], Alex Warres[1]



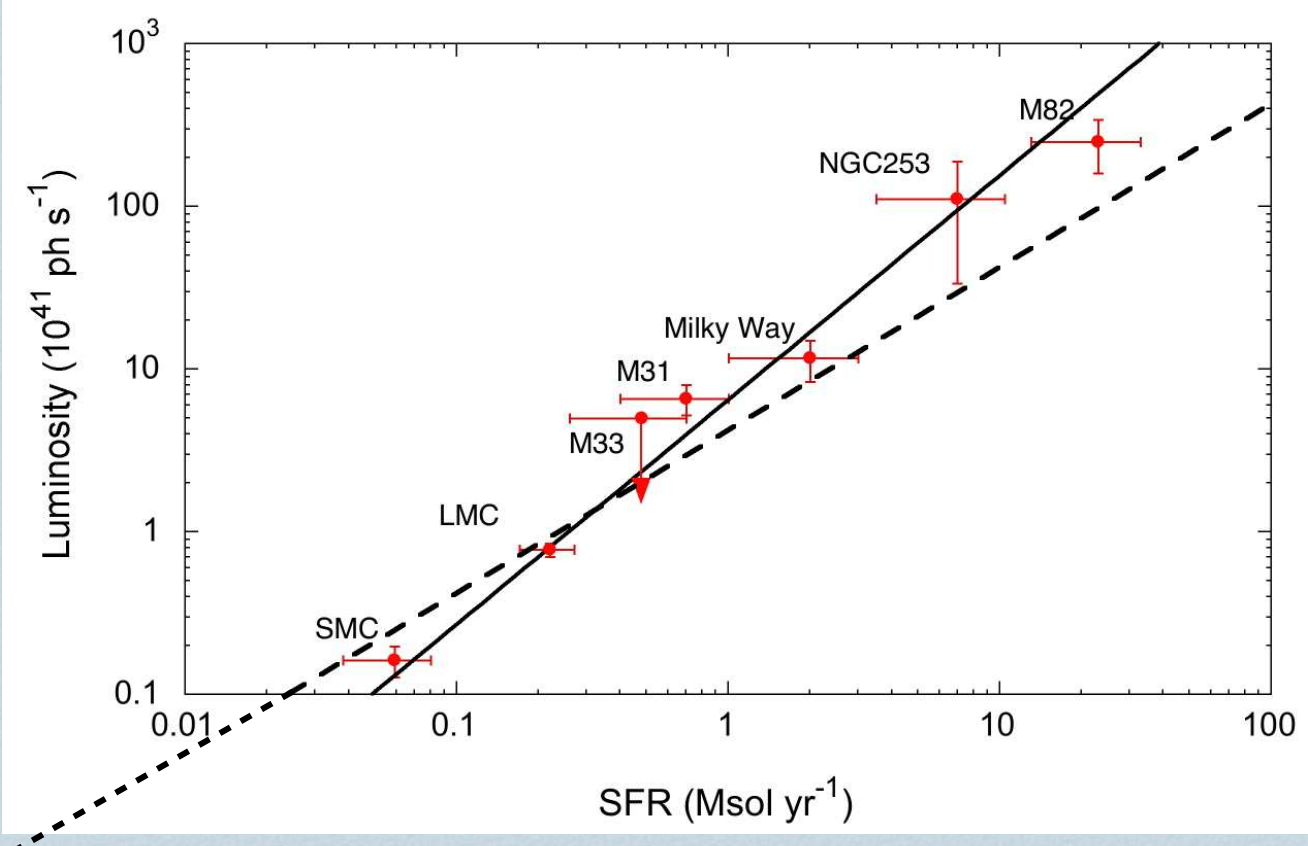


$$\int_0^{\Delta\Omega} \left\{ \int_{\mathrm{LOS}} \rho^2[r(\theta, \mathcal{D}, s)]\, ds \right\} d\Omega$$



Strigari et al. PRD 2008; Martinez et al. JCAP 2009

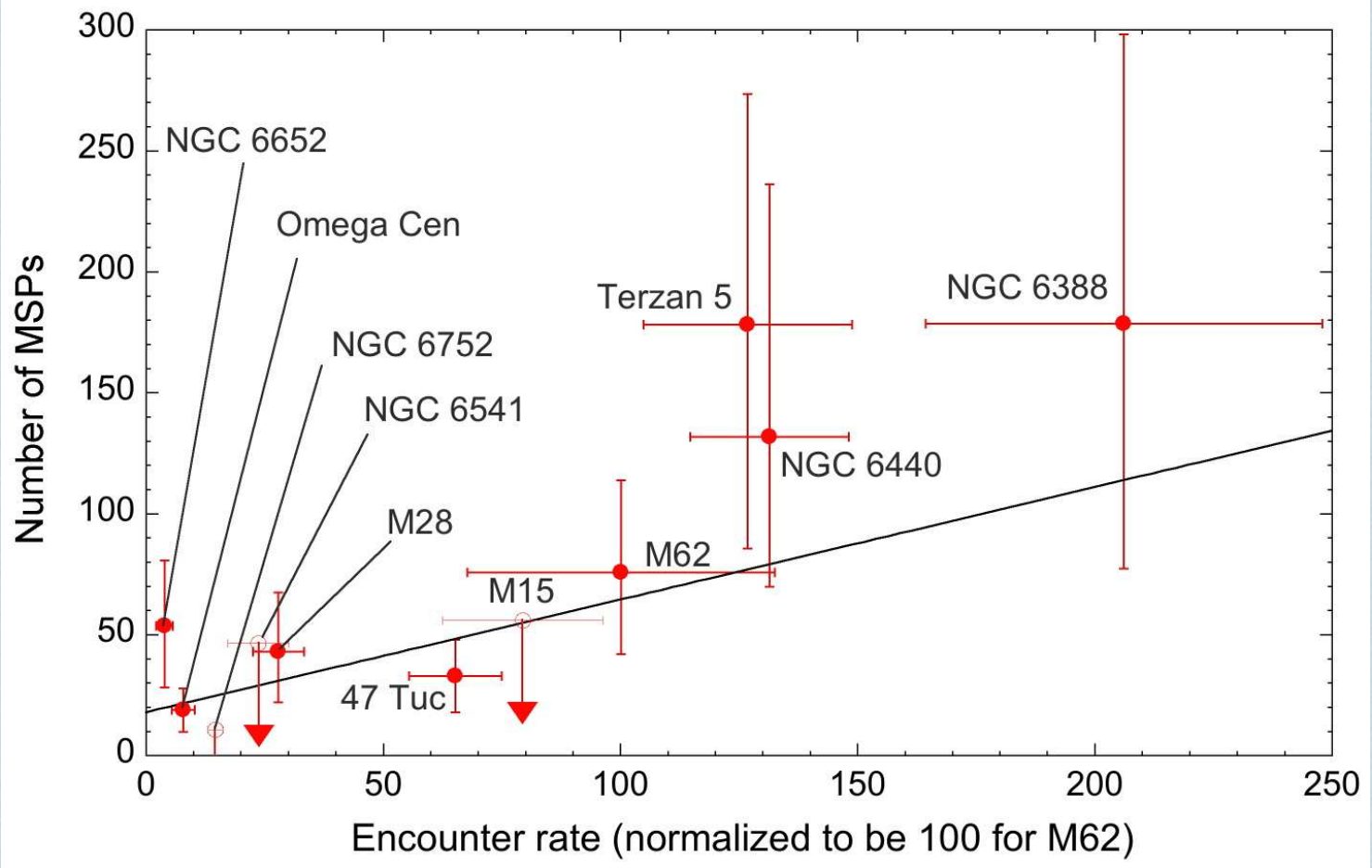
(No) Intrinsic gamma-rays



Fermi/LAT Collaboration A&A 523 L2 2010

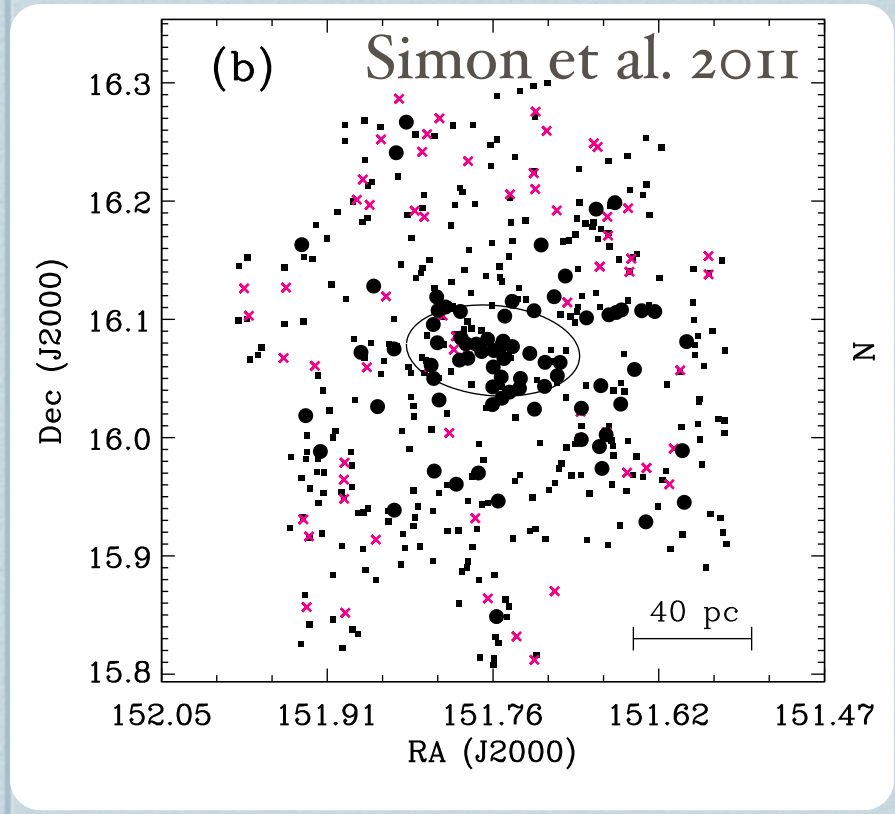
- Leo T: Luminosity = 7×10^{-7}

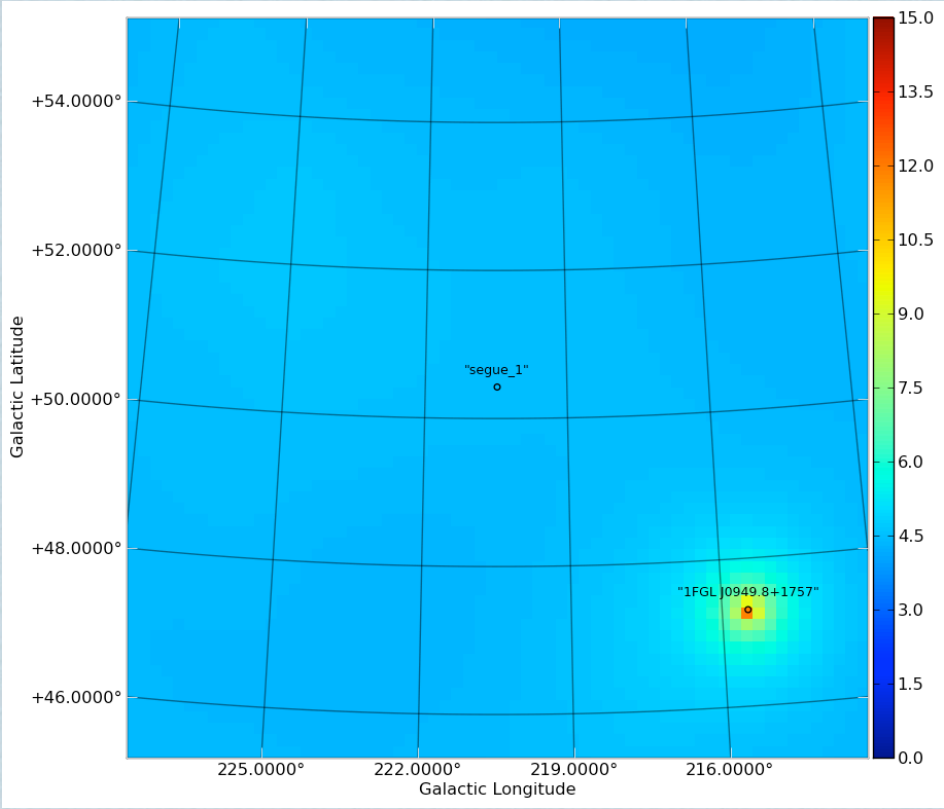
Gamma-rays from Globular clusters



Fermi/LAT Collaboration A&A 524 75 2010

Search for gamma-rays from dSphs

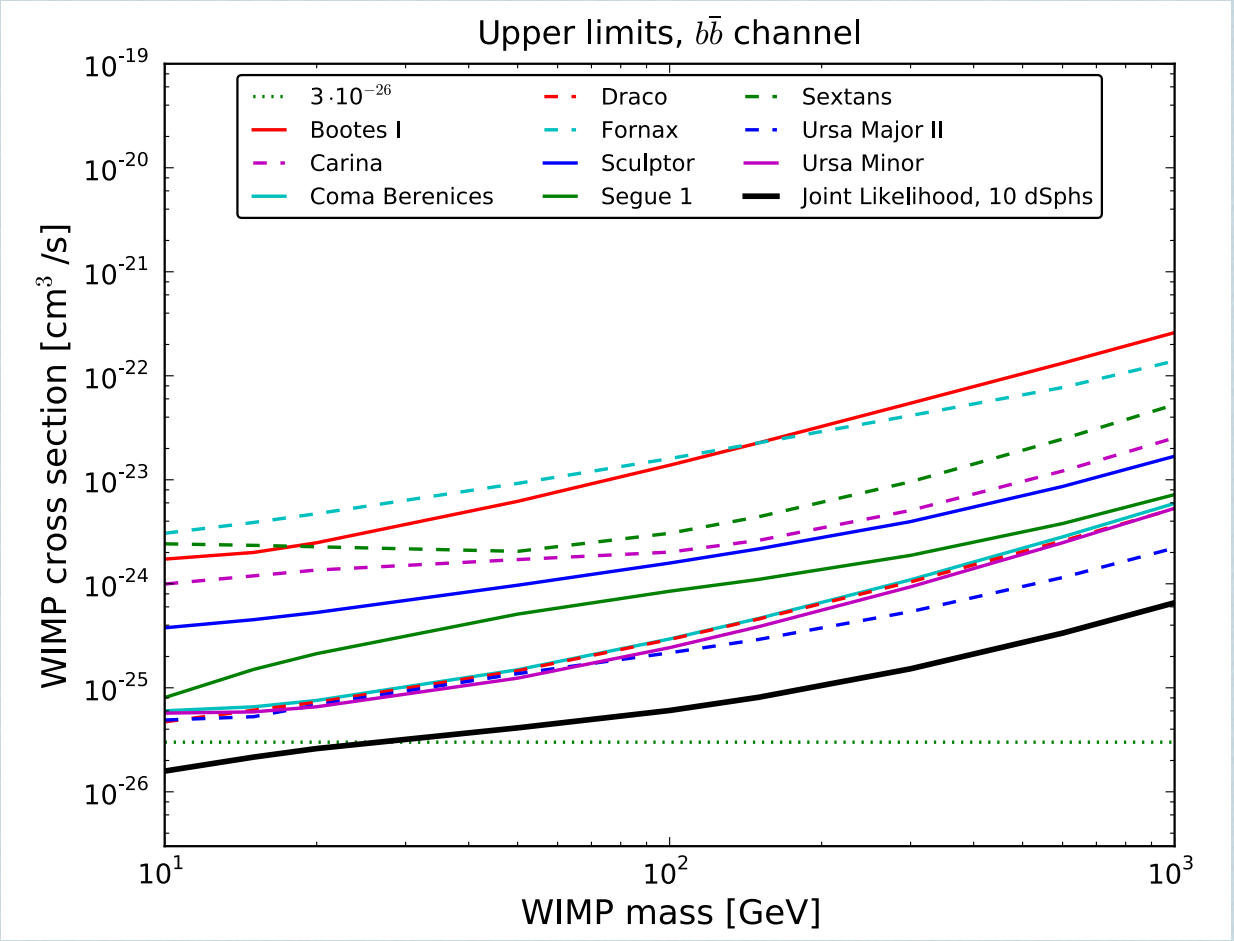




Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope

Fermi-LAT Collaboration, PRL

$$L(D|\mathbf{pw},\{\mathbf{p}\}_i) = \prod_i L_i^{\mathrm{LAT}}(D|\mathbf{pw},\mathbf{p}_i) \times \frac{1}{\ln(10)\, J_i \sqrt{2\pi}\sigma_i} e^{-\left[\log_{10}(J_i)-\overline{\log_{10}(J_i)}\right]^2/2\sigma_i^2}$$



[Also Geringer-Sameth & Koushiappas 2012]

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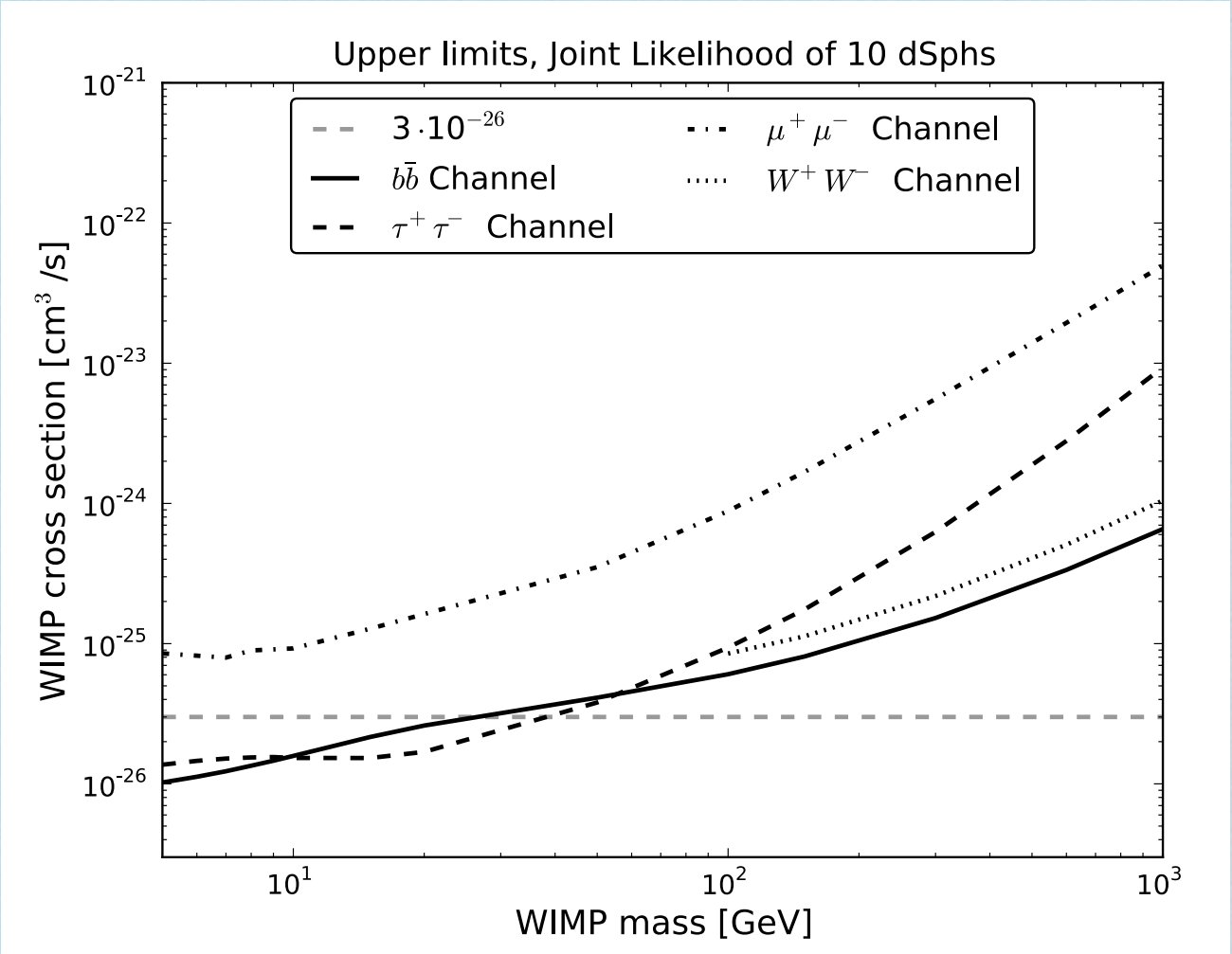
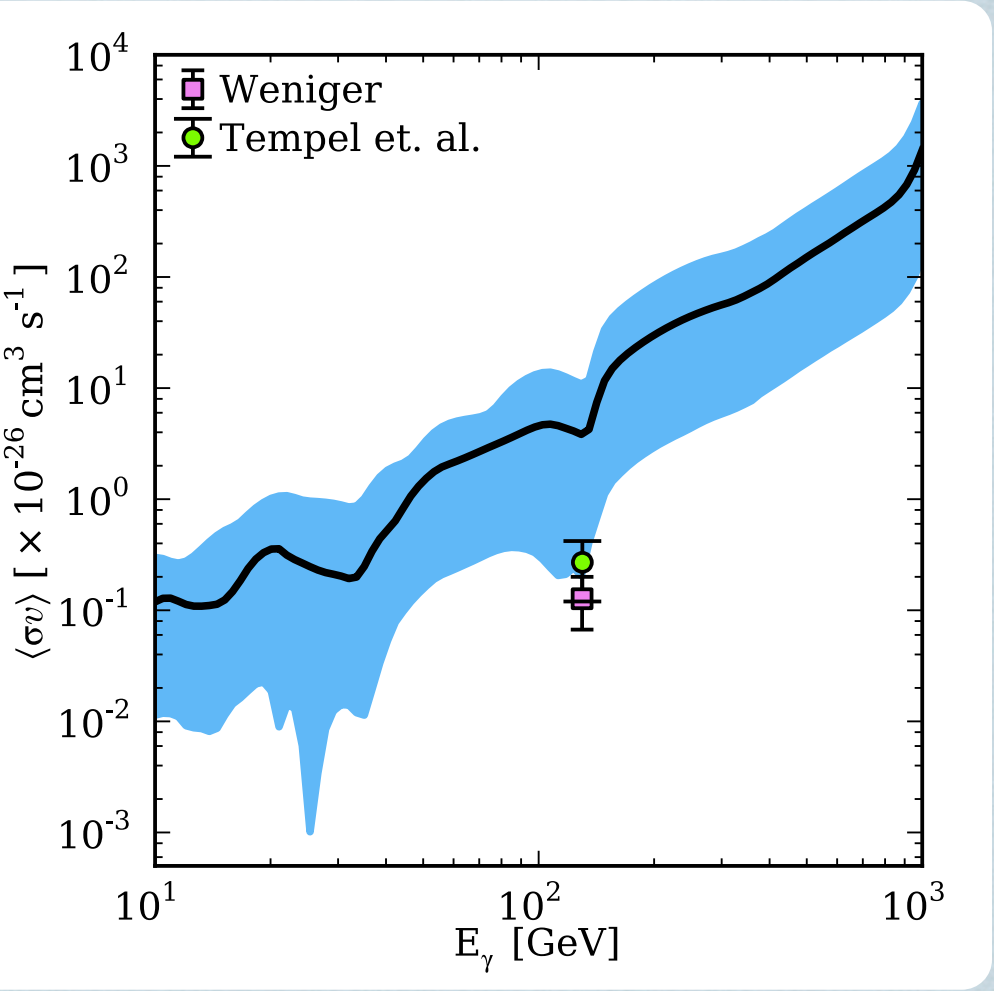


Dark Matter line?

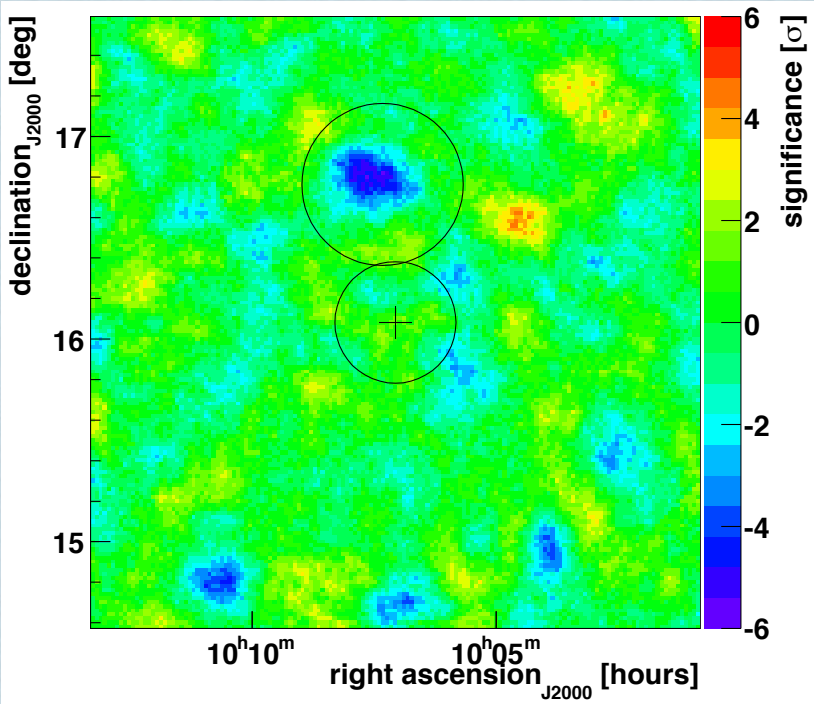


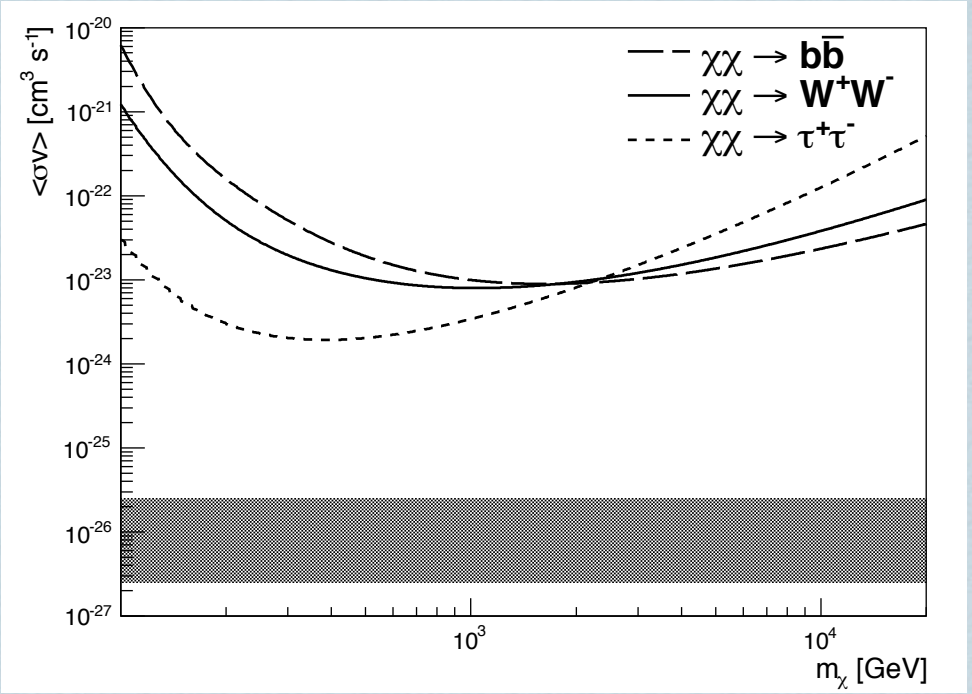
Don't yet verify/deny claim of a line from the Galactic center
[Geringer-Sameth & Koushiappas 2012]

How can we do better?

- More kinematic data per dSph
  - Improved stellar dynamical models
  - Proper motions in addition to radial velocities
- More Fermi-LAT data
- Complementarity with ground based detectors
- More MW Satellites will be discovered

ACT Limits from Segue 1

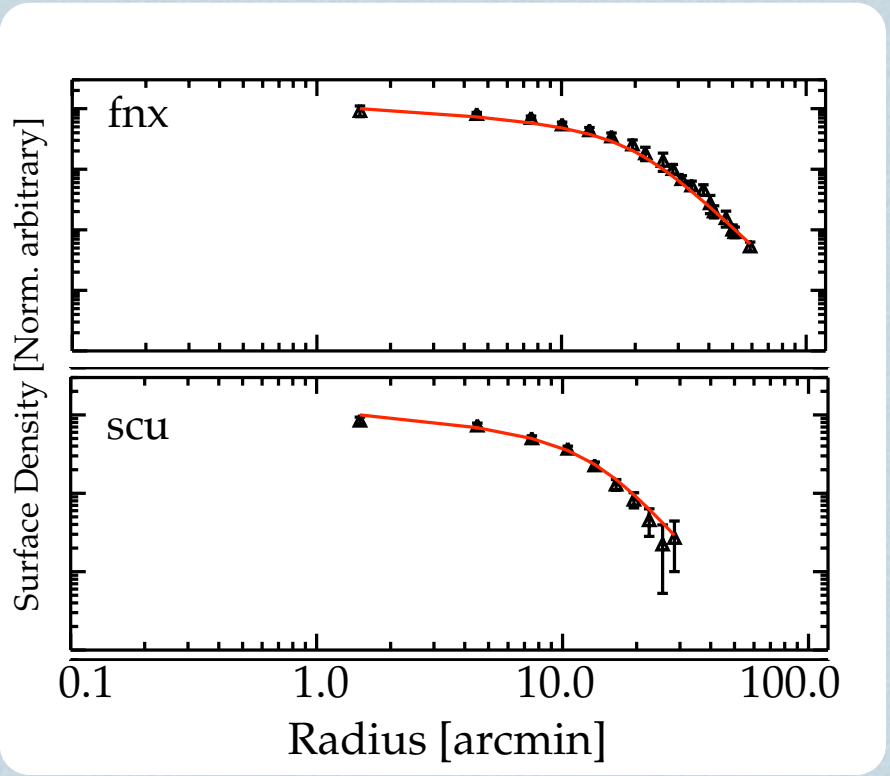


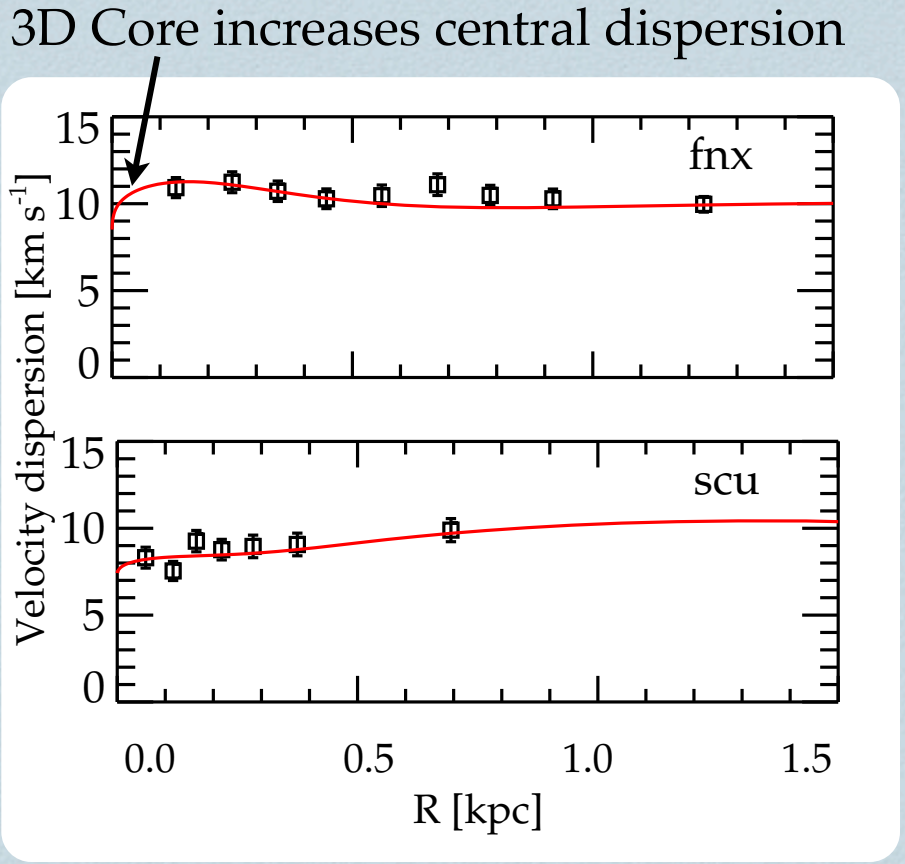


Veritas, arXiv:1202.2144

CTA could reach thermal relic scale (2017?; Funk & Hinton arxiv 2012)

Core/Cusp issue revisited





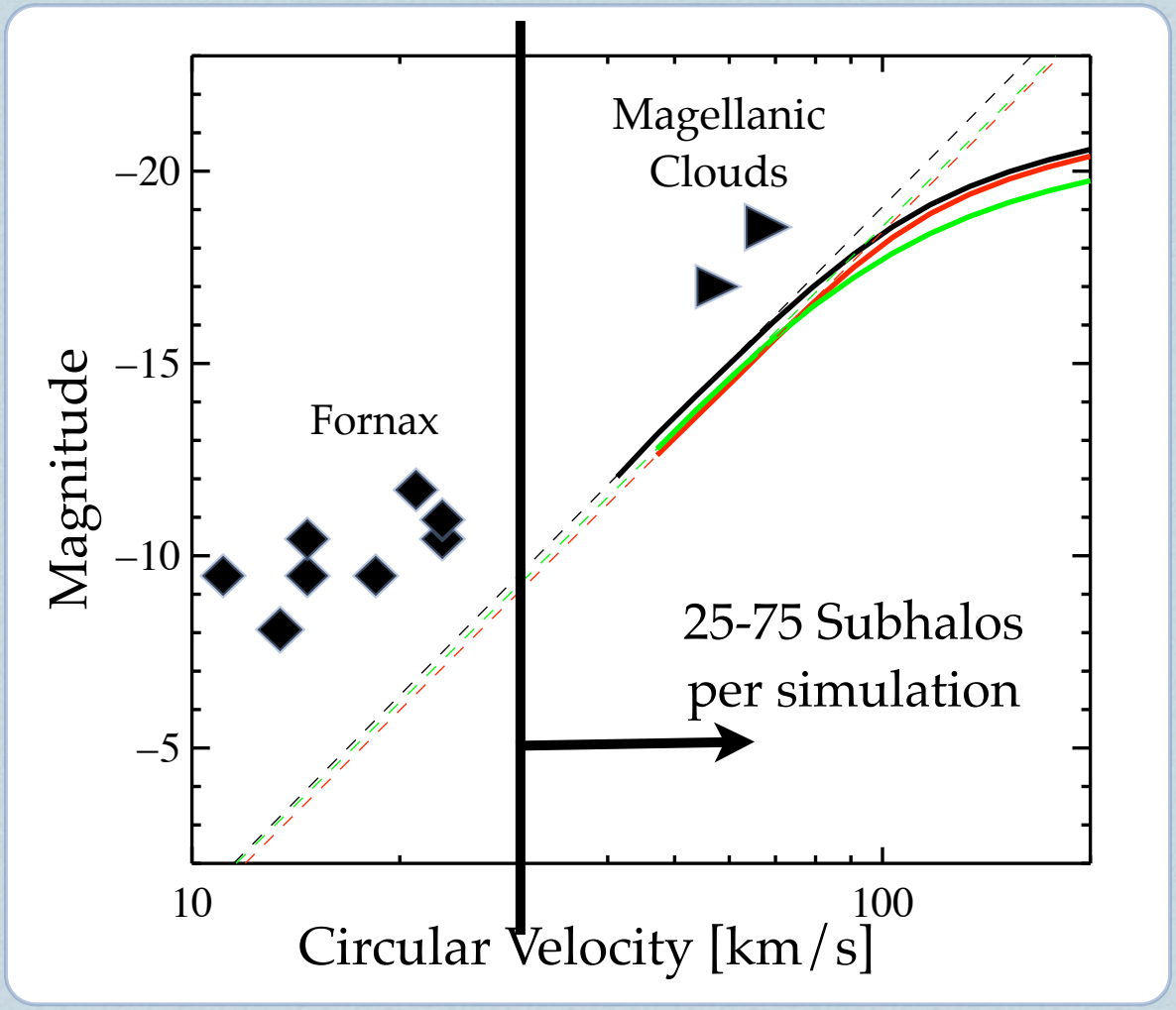
Implications for future ACTs:

[Essig, Sehgal Strigari PRD 2010; Charbonnier et al. 2011]

Part II
How many MW satellites?

How many satellites?

- dSphs don't reside in the most massive subhalos in CDM simulations
- More focused statement of the missing satellites issue [Strigari, Frenk, White MNRAS 2010; Boylan-Kolchin et al. 2011]



A few ways out

- Baryons in simulations [Wadepuhl & Springel 2011; Parry et al 2012]
- More fundamental modifications
  - Warm dark matter
  - Primordial power spectrum
- Low mass of the Milky Way [Vira-Ciro et al., 2012; Wang et al. 2012]
- The Milky Way is an oddball

The oddball hypothesis

- Search MW-analogs in SDSS for satellite galaxies
- Probabilistic model using background subtraction
- Combine spectroscopic and photometric redshifts

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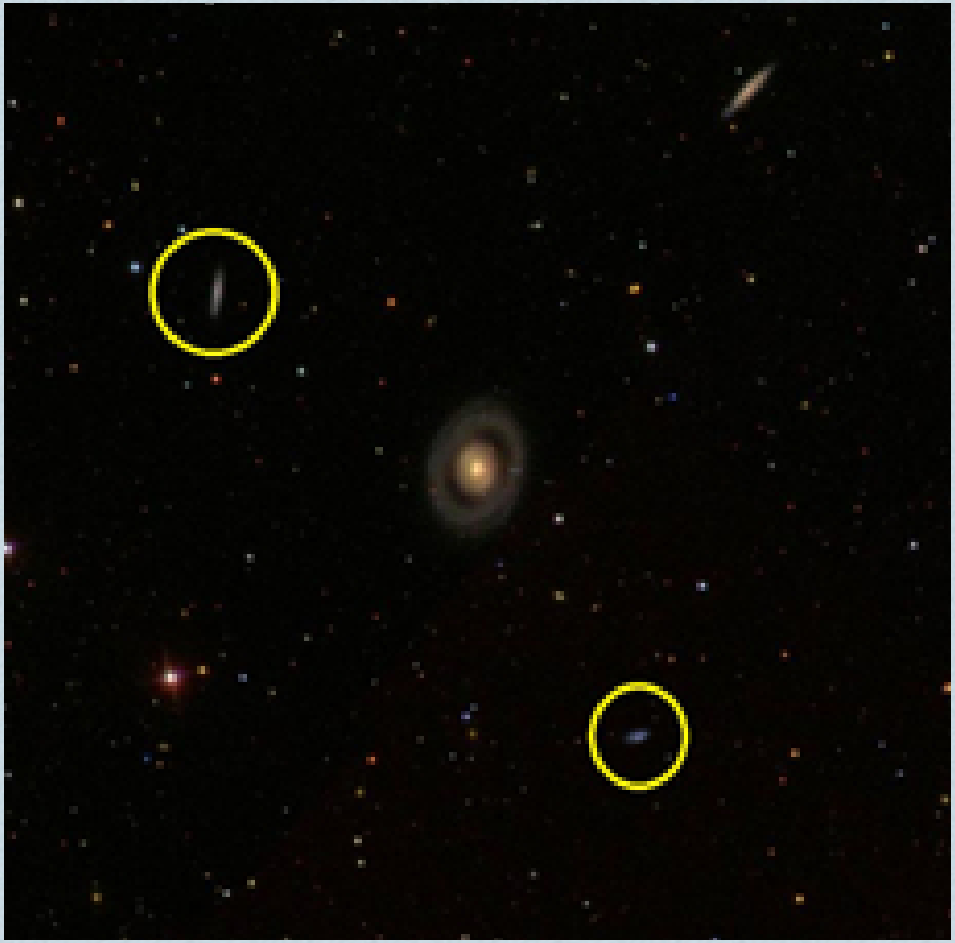
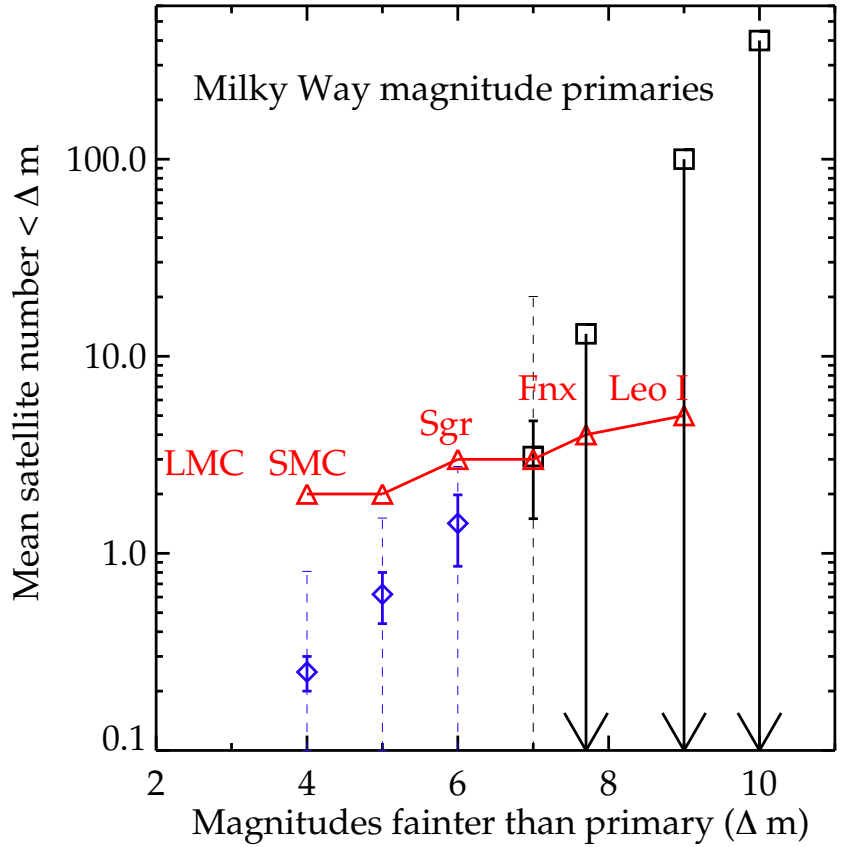
The oddball hypothesis

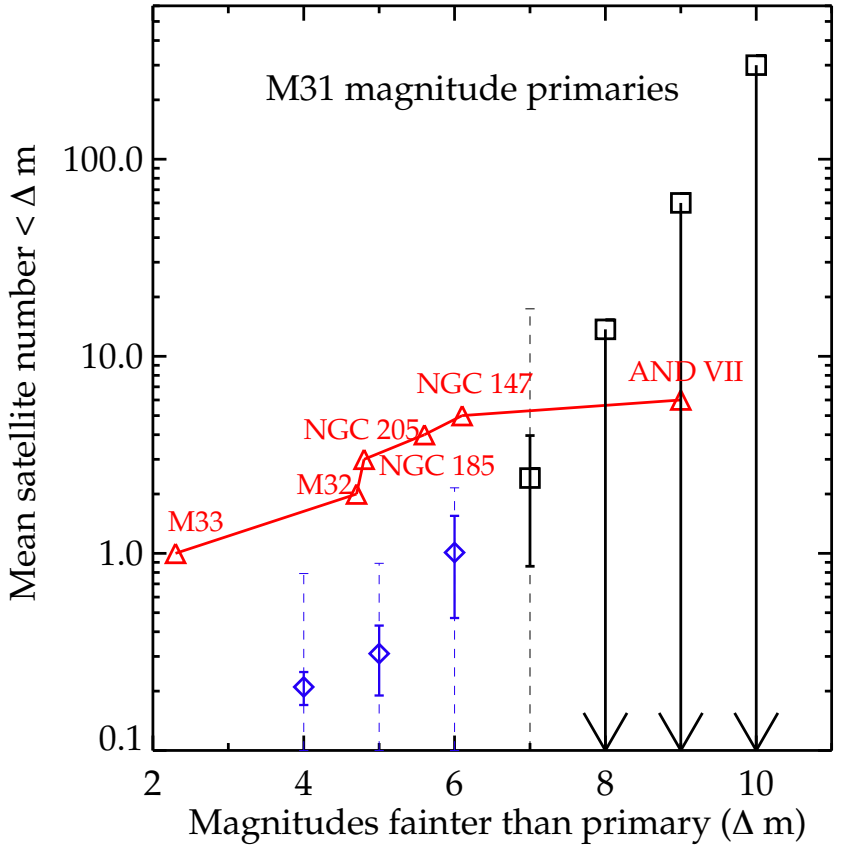
- About 600 systems with spectra on MC-like satellites
- About 10,000 systems with photometric redshifts on MC-like satellites
- About 1,00 systems with photometric redshifts for Fornax-like satellites



Liu et al. 2011

Cosmic abundance of MW satellites





Strigari & Wechsler ApJ 2012

Improving results

- Dark energy survey will give about 4x more MW like galaxies than SDSS
- External satellites about two orders of magnitude fainter than SDSS
- For nearby systems satellites are identified and velocity dispersions can be determined
- Perhaps ~tens more satellites of the MW

Part III: Direct detection and Galactic halo models

Part III: Direct detection and Galactic halo models

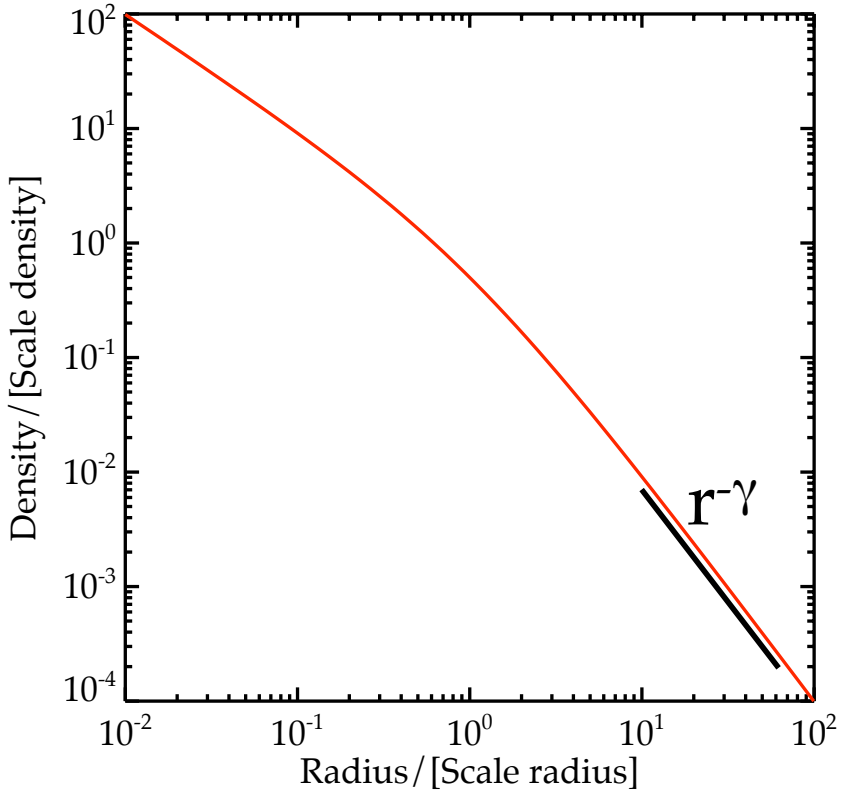
- How much dark matter is in your coffee cup?
- How fast is it moving?
- How does it interact with ordinary matter?

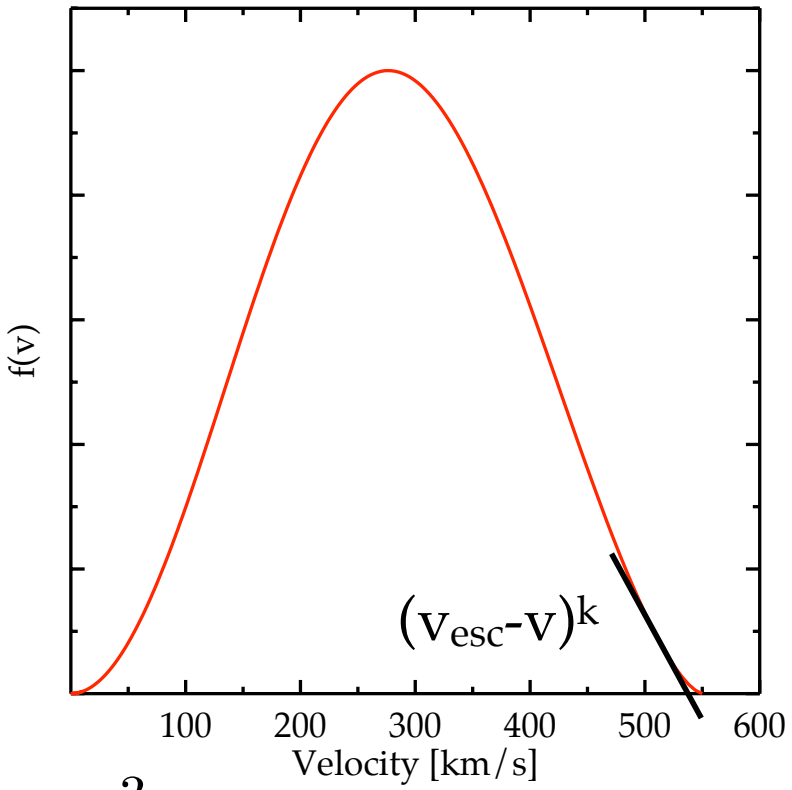
Theoretical approach

- Typically assume 'Standard Halo Model' maxwellian velocity distribution
- Not necessarily 'self-consistent': velocity distribution does not follow from dark matter density profile
- Assuming isotropy and spherical symmetry, mapping is simple:

$$f(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2}\left[\int_0^{\mathcal{E}} \frac{\mathrm{d}^2\rho}{\mathrm{d}\Psi^2}\frac{\mathrm{d}\Psi}{\sqrt{\mathcal{E}-\Psi}} + \frac{1}{\mathcal{E}^{1/2}}\left(\frac{\mathrm{d}\rho}{\mathrm{d}\Psi}\right)_{\Psi=0}\right]$$

Spherical and Isotropic Halos

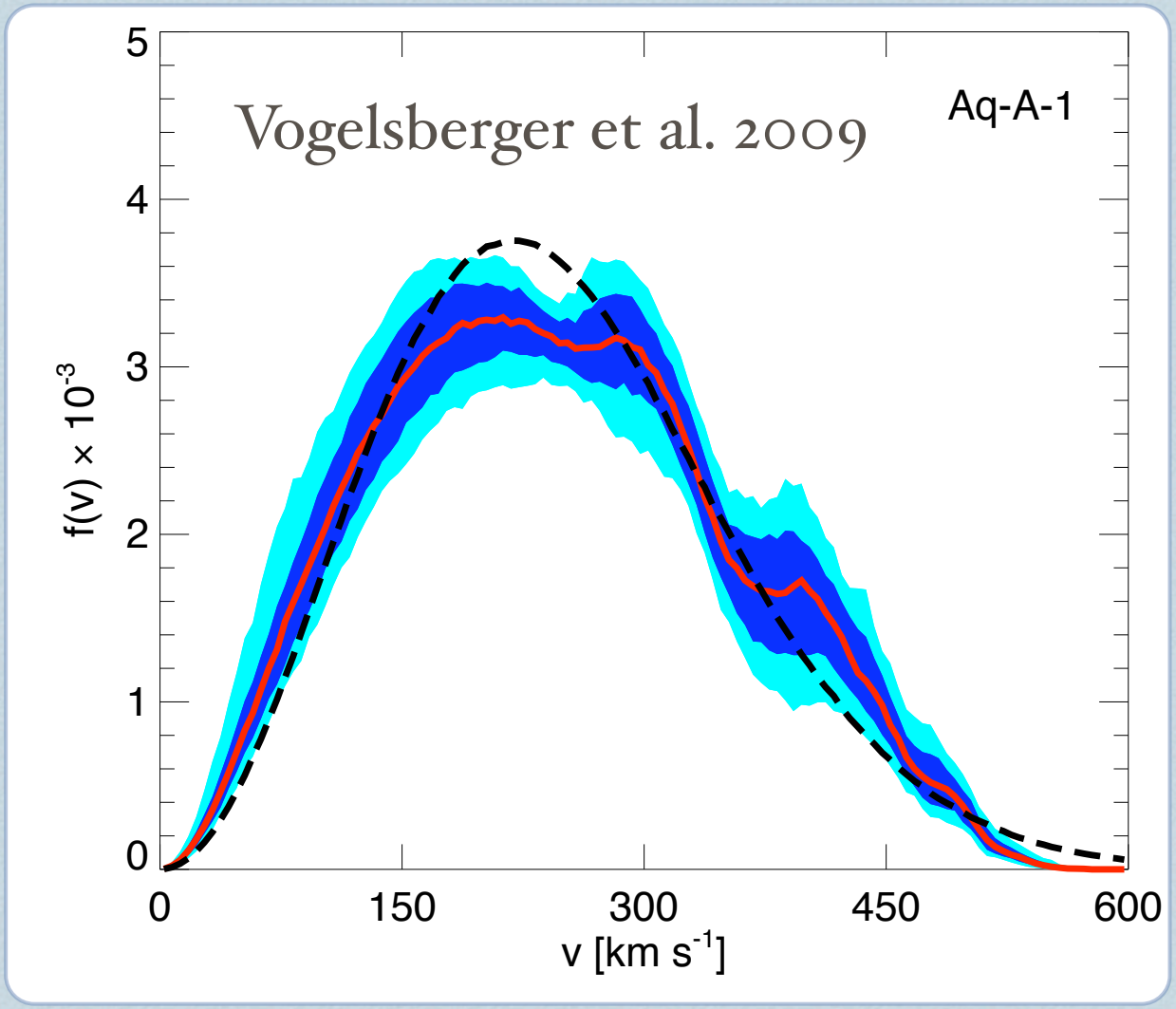




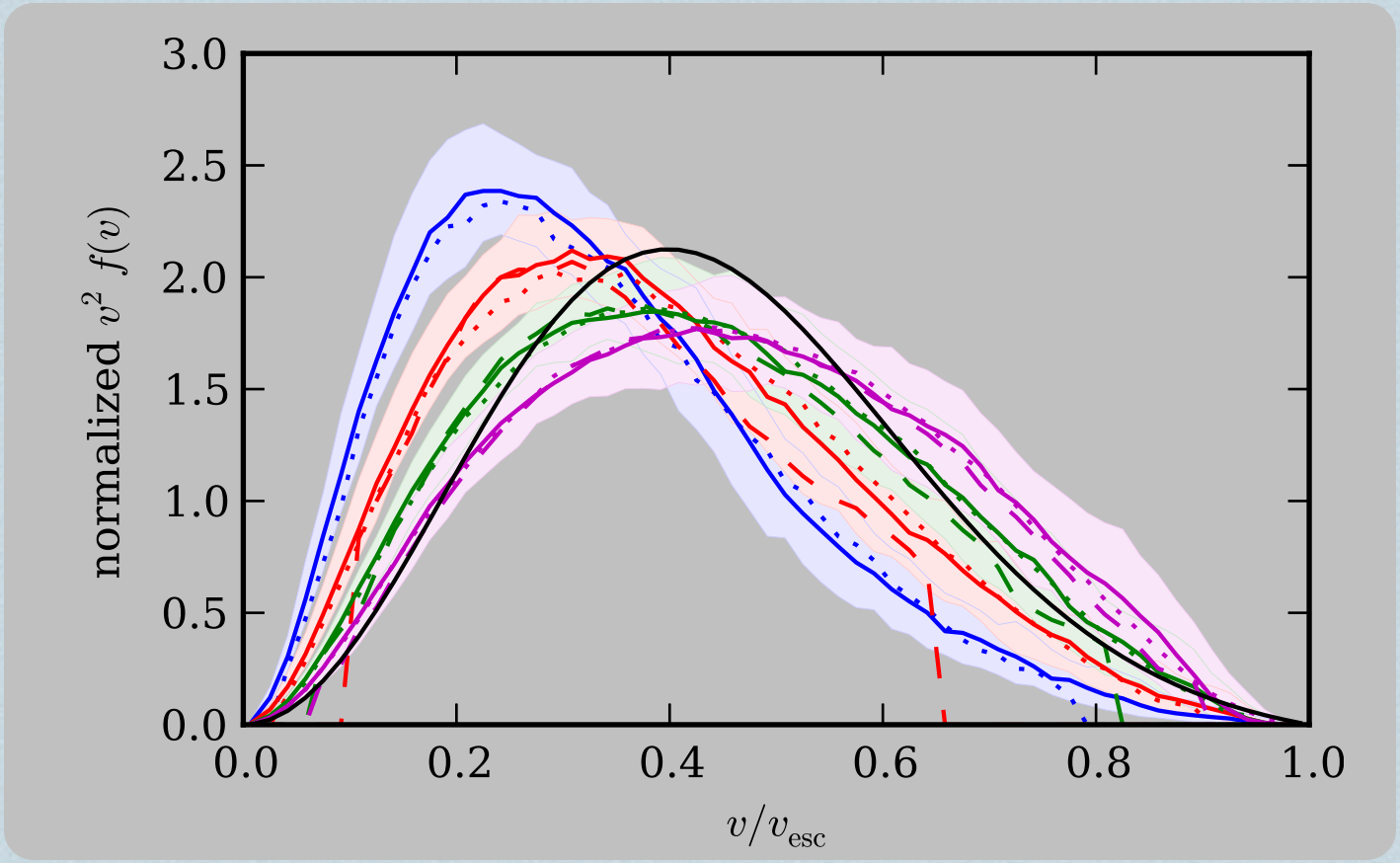
$$k = \gamma - \frac{3}{2}$$

Important low mass WIMP implications [Lisanti, LS, Wacker, Wechsler PRD 2011]

Simulations: In halo variance



Simulations: Halo-to-Halo variance



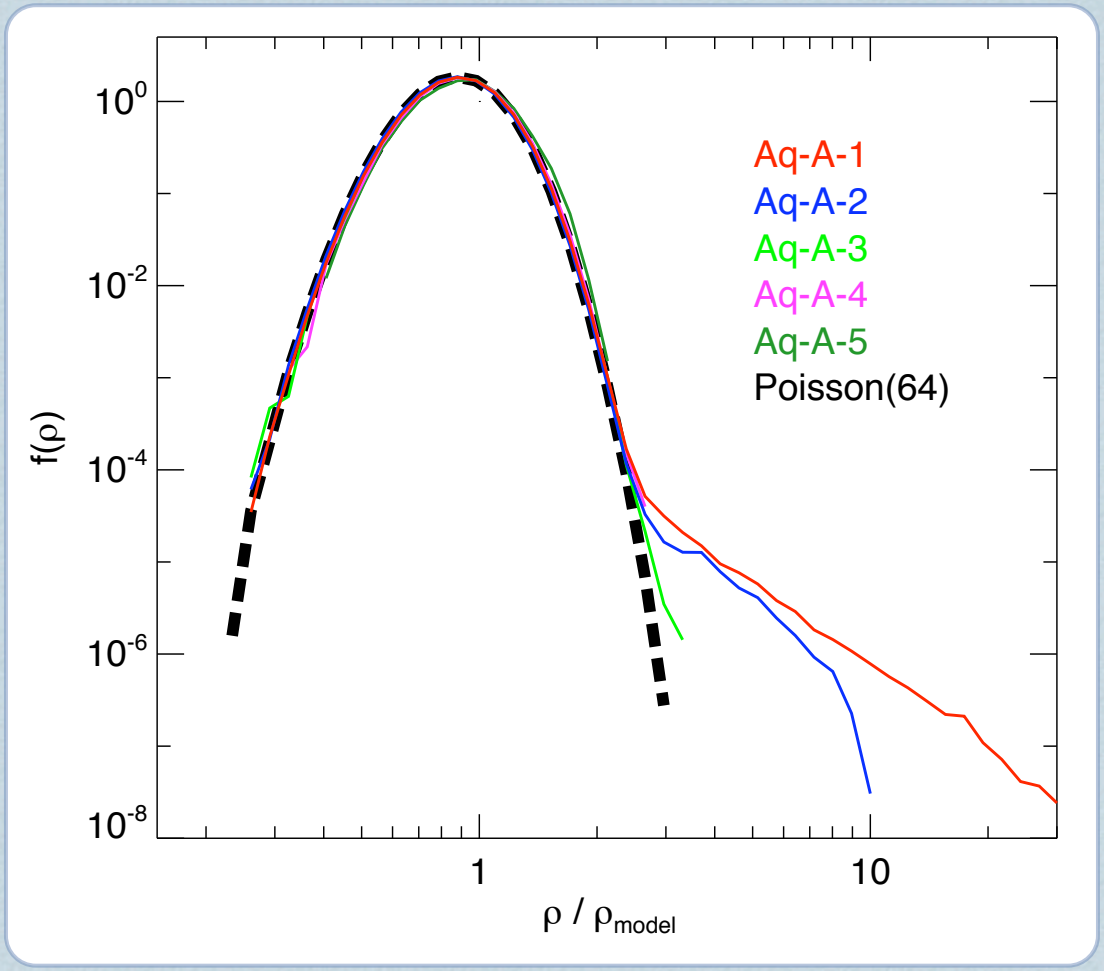
Appears to be a uniform non-maxwellian DM distribution in cosmological simulations

Mao, LS, Wechsler 2012 et al.

Interesting trends

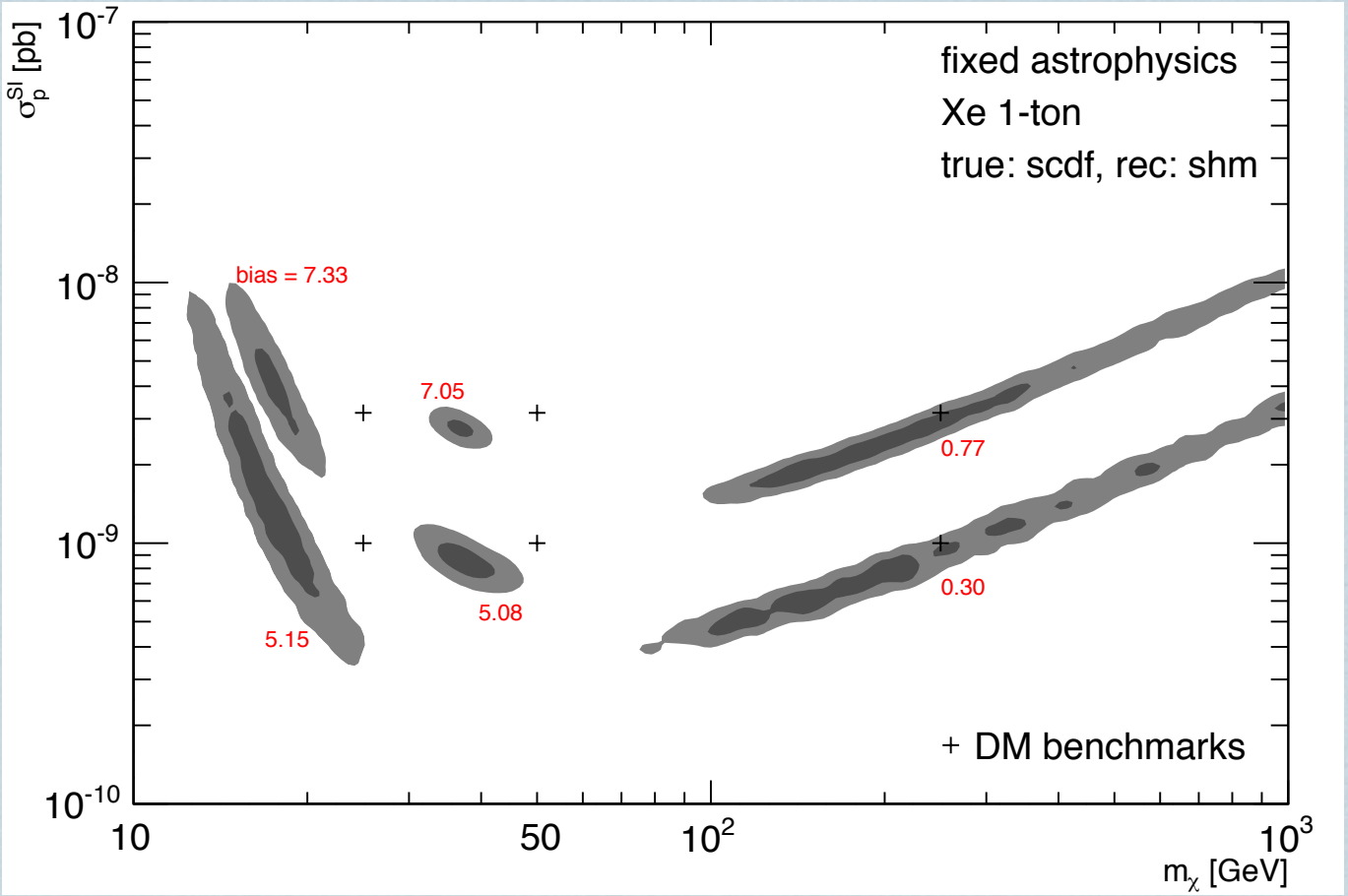
- Asymptotic tail of distribution suppressed relative to Maxwell-Boltzmann distribution
- At z=0, full velocity distribution not straightforwardly related to the density profile
  - Dominated by 'debris flows'? [Kuhlen, Lisanti, Spergel 2012]
- However, correspondence appears better at z=1. Opposite of what's expected?

Does dark matter substructure matter?



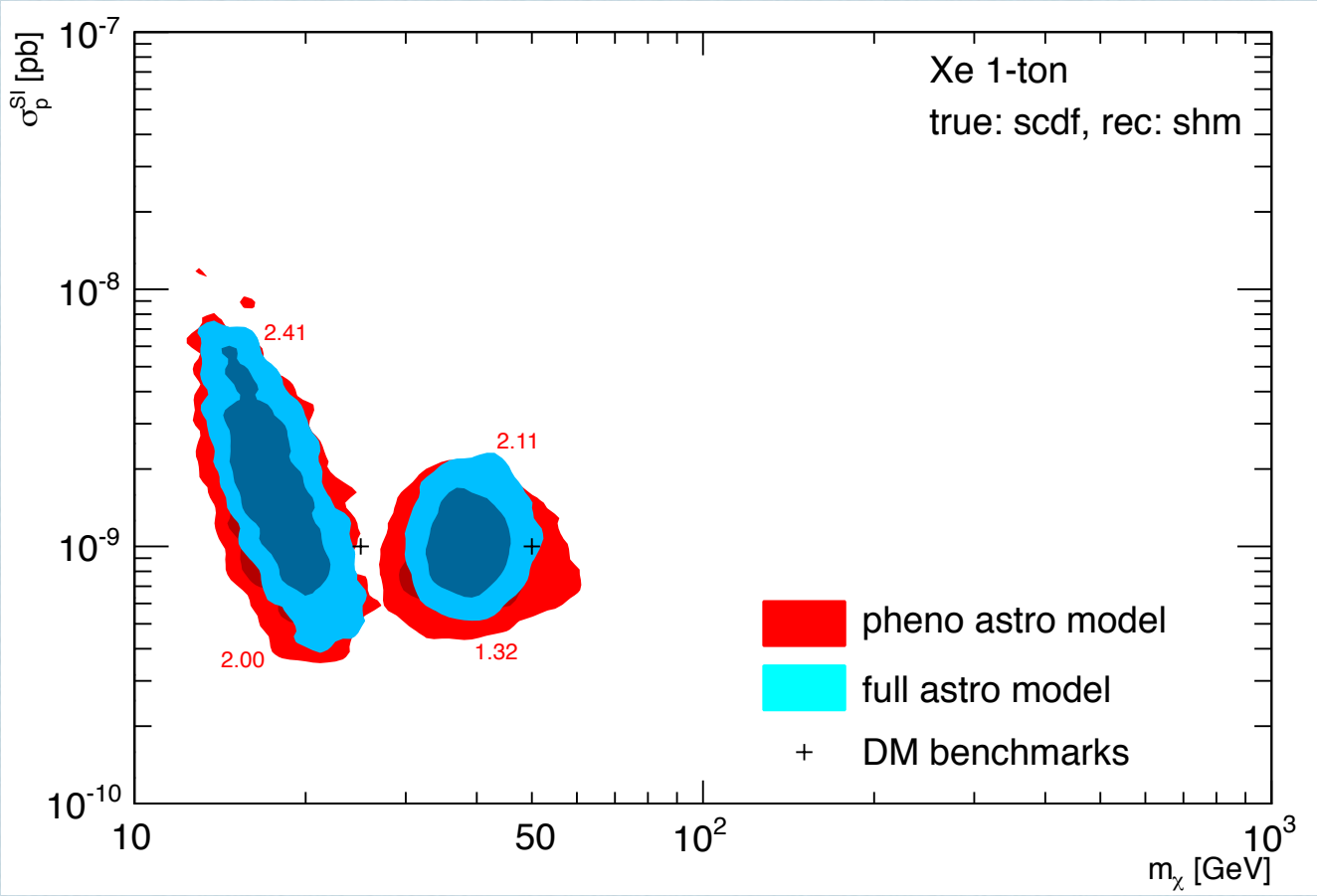
Koushiappas & Kamionkowski PRD 2008;
Vogelsberger et al. MNRAS 2008

Reconstructing WIMP mass



Strigari & Trotta JCAP 2009; Pato, Baudis, Bertone, Ruiz de Austri, LS, Trotta PRD 2011

Reconstructing WIMP mass



Strigari & Trotta JCAP 2009; Pato, Baudis, Bertone, Ruiz de Austri, LS, Trotta PRD 2011

Take away messages

- Fermi-LAT dSph results now test s-wave thermal relic cross sections with mass 10-25 GeV
- More Galactic satellites sure to exist
  - Is one nearby? (detectable via annihilation)
  - Hinting to something different about DM?
- Galactic astrophysics to extract from direct detection
  - Perhaps complicates, but makes detection more interesting