Indirect Detection from dSphs with Fermi-LAT and ACTs

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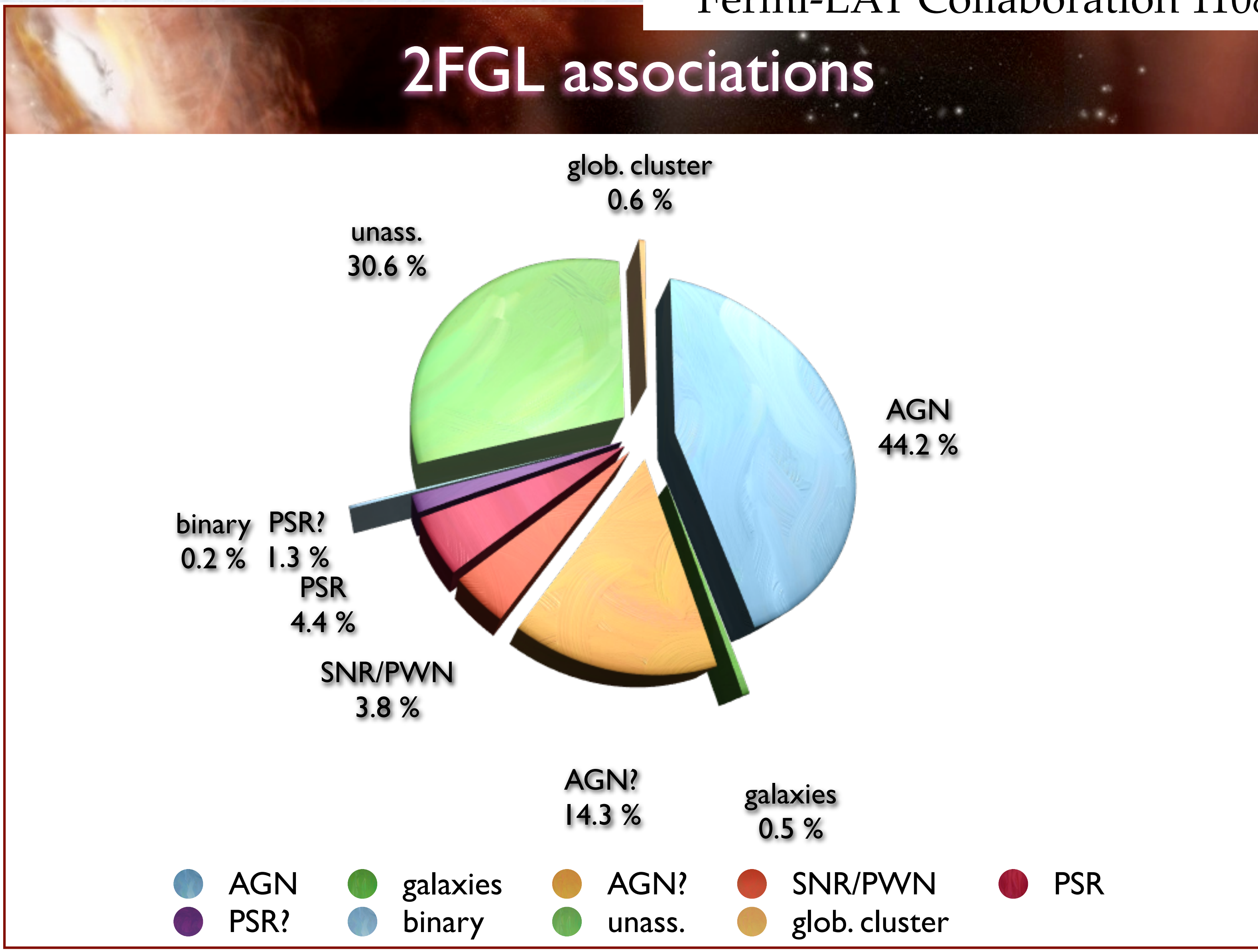
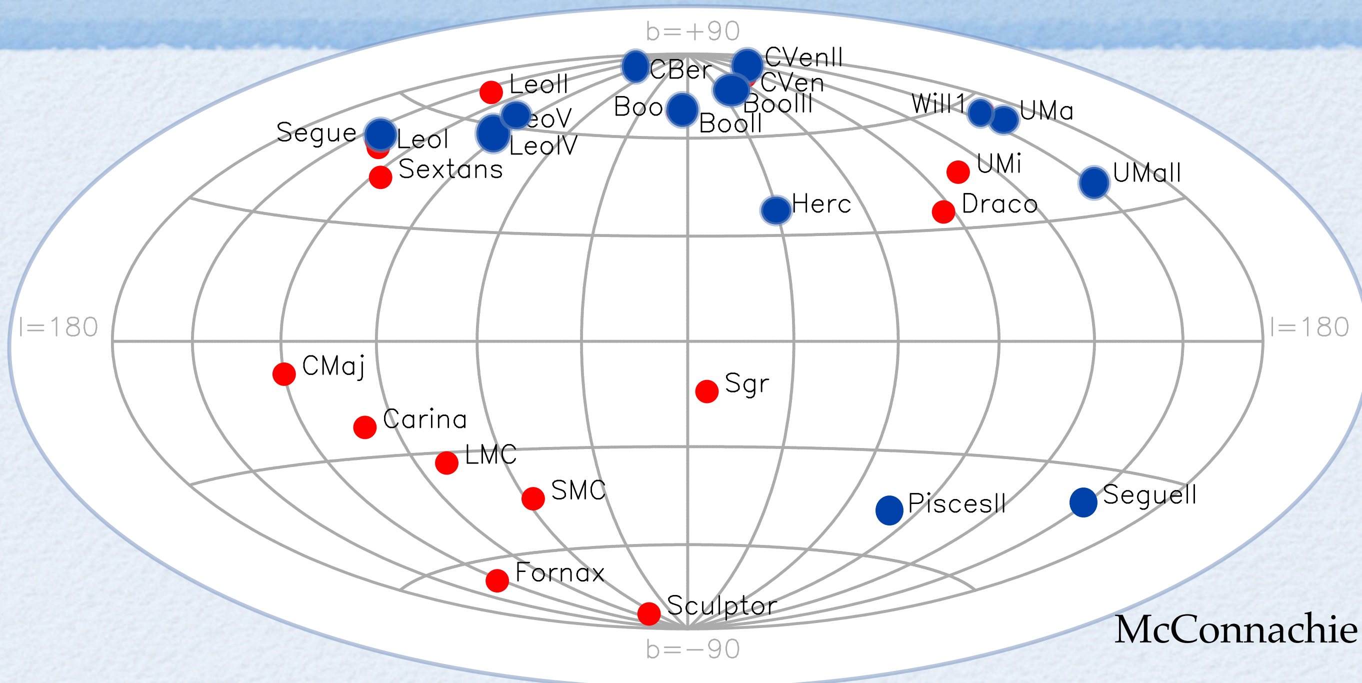
Dark Matter in the gamma-ray sky workshop
University of Texas 5/6/2012
[Also talks today by M. Kaplinghat and S. Koushiappas]

Point Sources in Fermi

Fermi-LAT Collaboration 1108.1435



Census of Milky Way Satellites

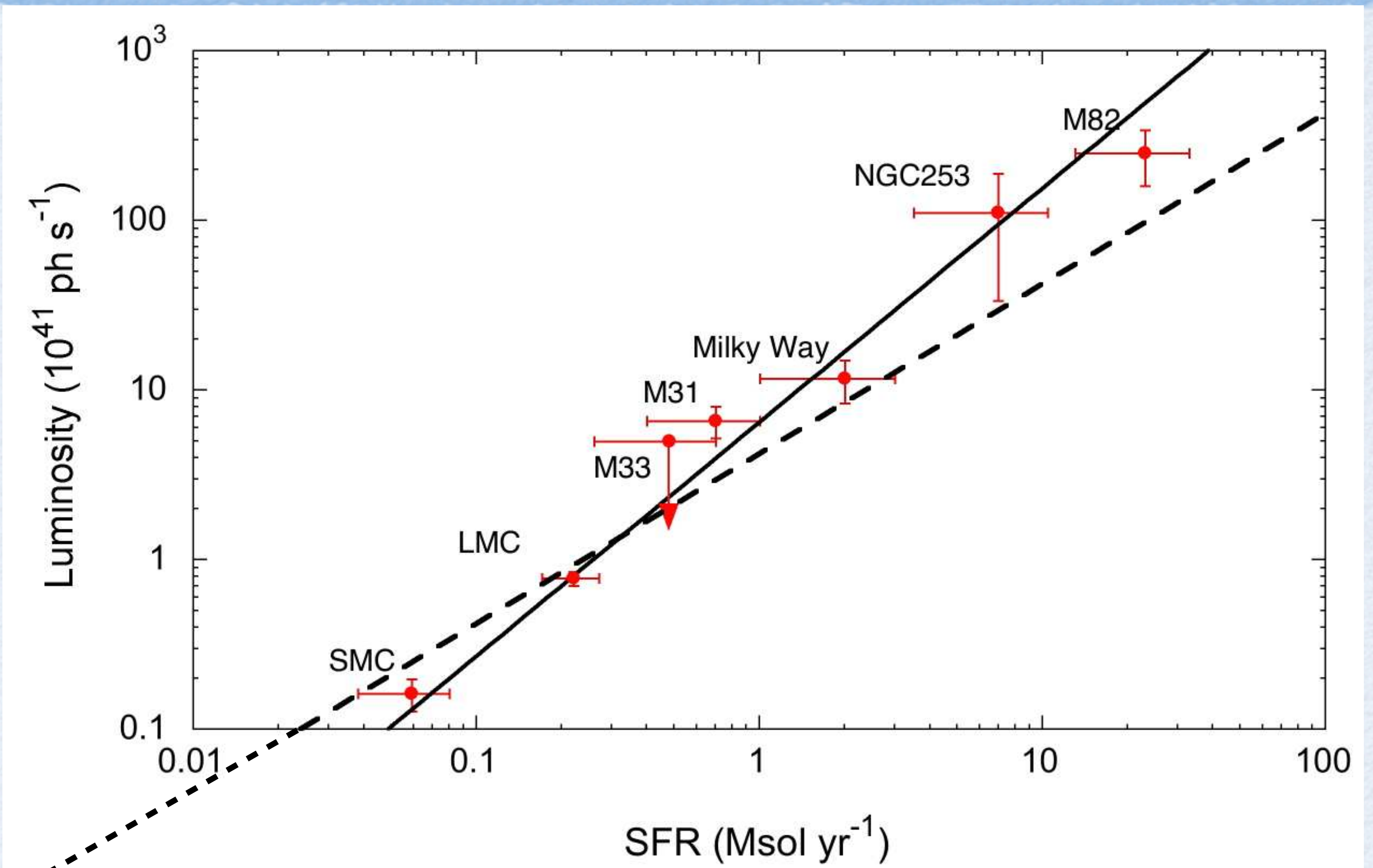


McConnachie 2012

Satellite	M_V	$L_V [L_\odot]$	d_{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
Leo II	-10.1	9.38×10^5	205
Sculptor	-9.8	7.11×10^5	88
Sextans	-9.5	5.40×10^5	86
Carina	-9.4	4.92×10^5	94
Draco	-9.4	4.92×10^5	79
Ursa Minor	-8.9	1.49×10^5	69

Satellite	M_V	$L_V [L_\odot]$	d_{sun}[kpc]
Canes Venatici I	-8.6	2.36×10^5	224
Leo T	-8.0	5.92×10^4	417
Hercules	-6.6	3.73×10^4	138
Boötes I	-6.3	2.83×10^4	60
Ursa Major I	-5.5	1.36×10^4	106
Leo IV	-5.0	8.55×10^3	158
Canes Venatici II	-4.9	7.80×10^3	151
Ursa Major II	-4.2	4.09×10^3	32
Coma	-4.1	3.7×10^3	44
Boötes II	-2.7	1.03×10^3	43
Willman 1	-2.7	1.03×10^3	38
Segue 1	-1.5	3.40×10^2	23

Intrinsic gamma-rays from dSphs?

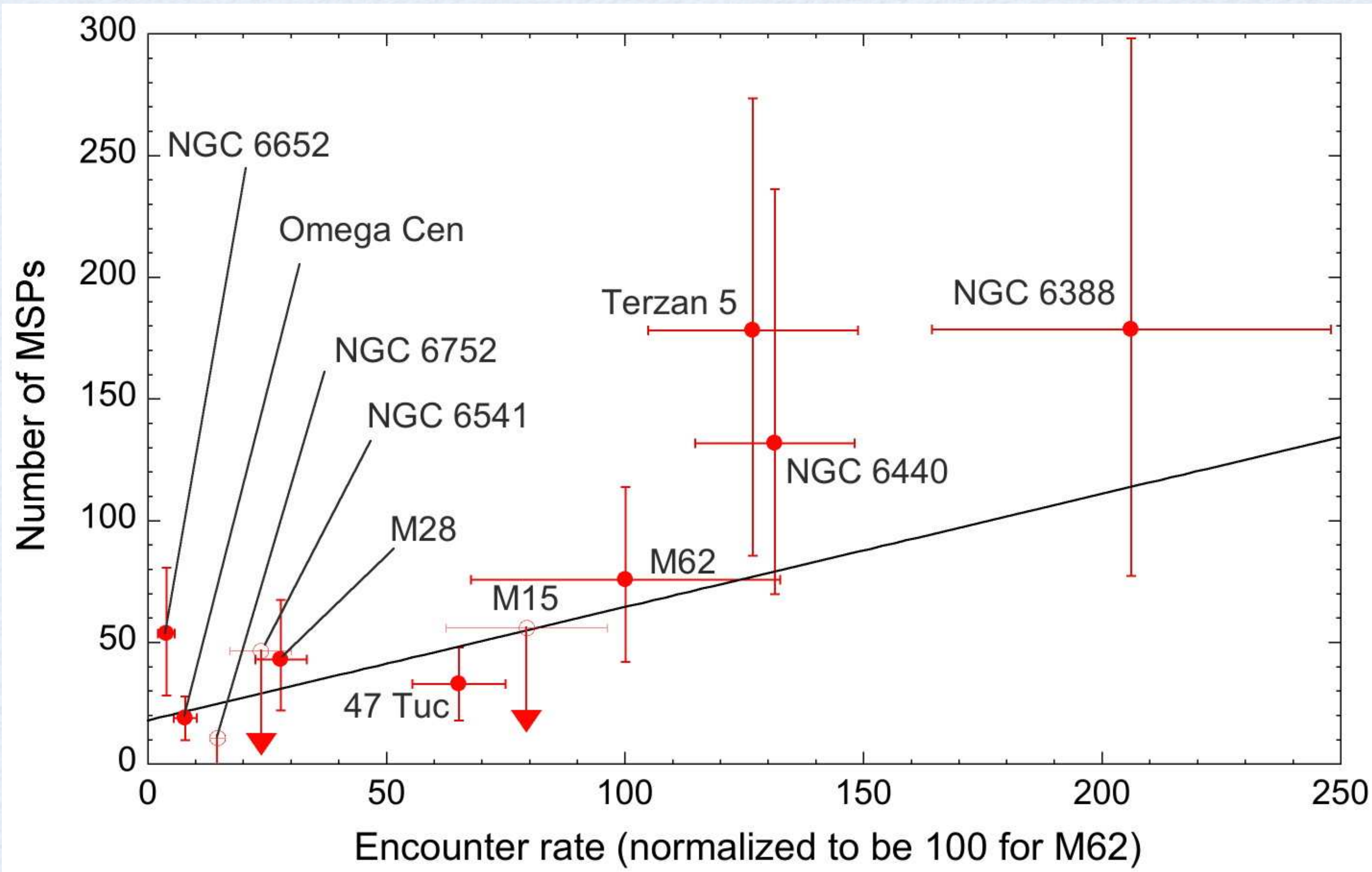


Fermi/LAT Collaboration A&A 523 L2 2010

Leo T: Luminosity = 7×10^{-7}

[Likely only about an order of magnitude better if use unconfirmed HI associated w/ Sculptor]

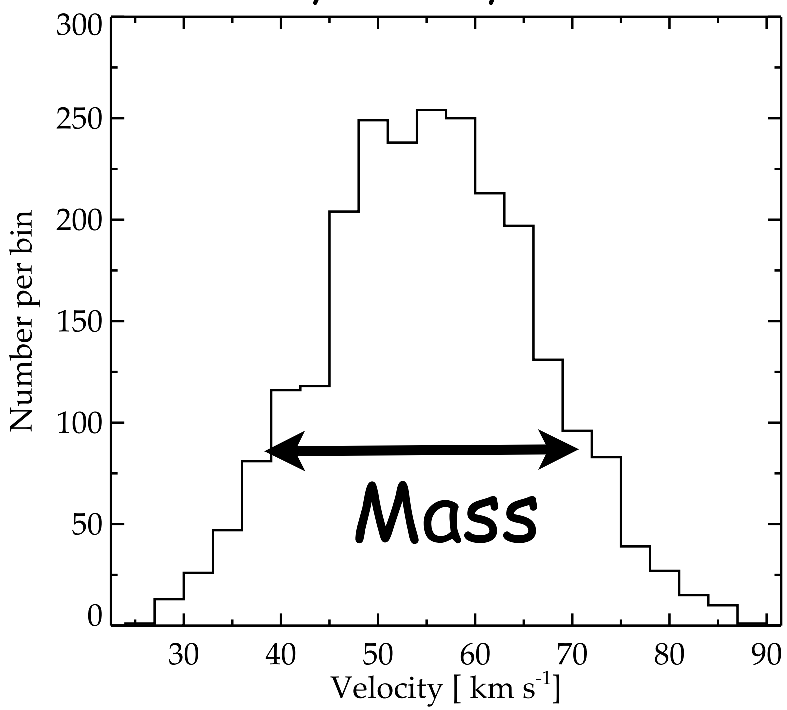
Gamma-rays from Globular Clusters

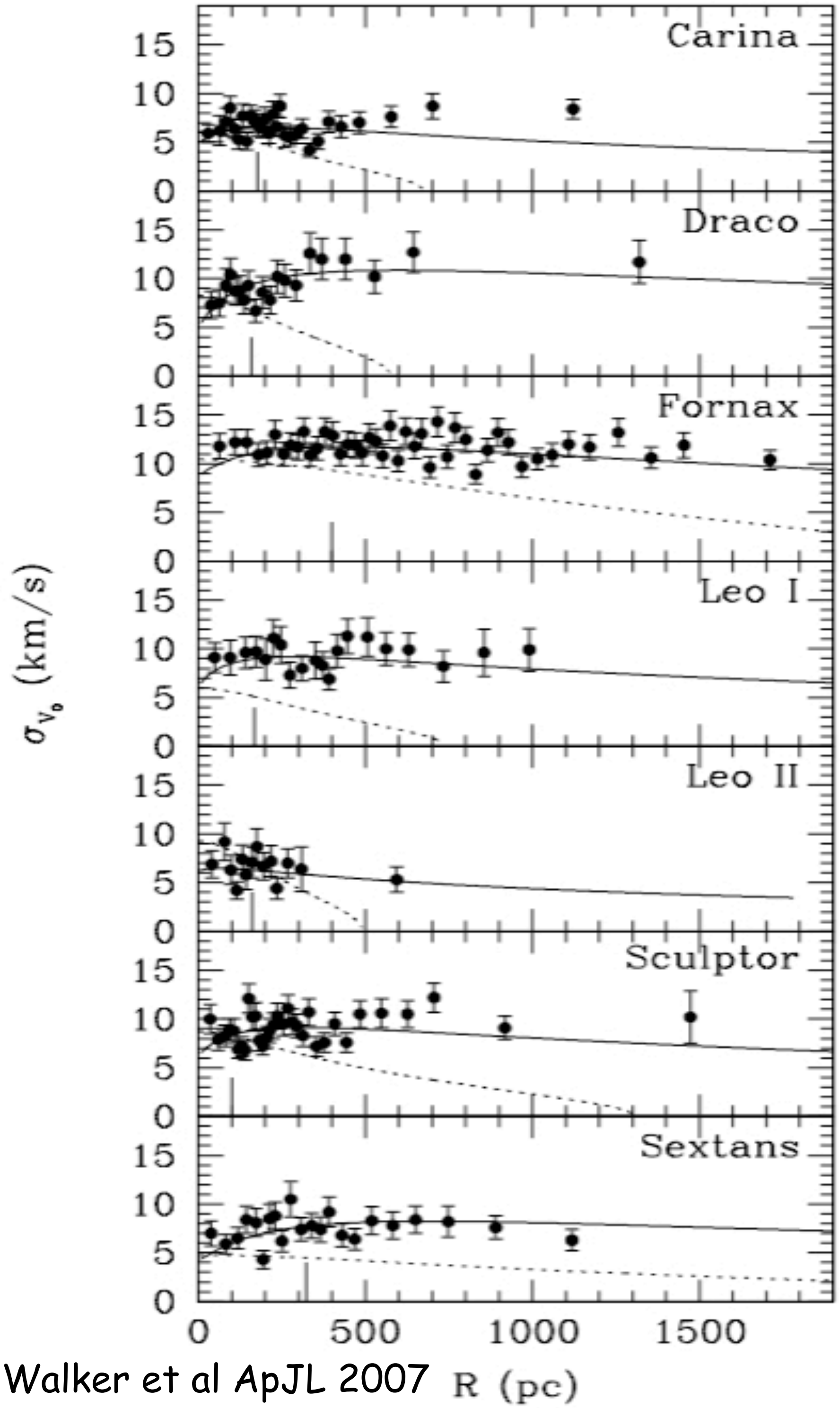


Fermi/LAT Collaboration A&A 524 75 2010

Large Dark-to-Luminous mass ratios

Walker, Mateo, et al. 2009





Walker et al ApJL 2007

Outstanding questions

- How precise can the masses and J values be determined?
  (Strigari et al. ApJ 2007; Lokas et al. MNRAS 2009; Walker et al ApJ 2009; Wolf et al. MNRAS 2009)
- Do CDM-based NFW profiles provide best model? Core/cusp issue? (e.g. Gilmore et al. ApJ 2007; Walker & Penarrubia ApJ 2011)
- Are models self-consistent?
- Better data per dwarf or more dwarfs?

Approaches to modeling

- Hydrostatic equilibrium [jeans modeling]
- Models with simplified stellar distribution functions [Wilkinson et al. 2002; Kleyna et al. 2002, Strigari, Frenk White MNRAS 2010].
- Non-parametric distribution function w/ parametric potential [Wu & Tremaine ApJ 2007; Wu 2007; Bagraham, Afshordi, LS to appear]
- Schwarschild modeling [Jardel & Gehhardt ApJ 2012; Breddels et al. 2011]

Standard dSph Kinematics Cookbook

- Model both the stellar and the dark matter distribution
- Statistics of stellar orbits (velocity anisotropy)
- Assume hydrostatic equilibrium, determine mass

$$\sigma_{los}^2(R) = \frac{2}{I_\star(R)} \int_R^\infty \left(1 - \beta \frac{R^2}{r^2}\right) \frac{\nu_\star \sigma_r^2 r dr}{\sqrt{r^2 - R^2}}$$

$$\mathcal{L}(\mathscr{A}) \equiv P(\{v_i\}|\mathscr{A}) = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi(\sigma_{los,i}^2 + \sigma_{m,i}^2)}} \exp\left[-\frac{1}{2}\frac{(v_i - u)^2}{\sigma_{los,i}^2 + \sigma_{m,i}^2}\right]$$

Important Implications. I

- Uncertainty on the dark matter mass is minimized at about the half light radius [Strigari, Bullock, Kaplinghat ApJL 2007; Walker et al. ApJ 2009; Wolf et al. MNRAS 2009]

- For dark matter density profiles less steep than about $r^{-1.5}$, J value within about 0.5 deg is insensitive to the slope of the DM density profile [Strigari et al. ApJ 2008; Martinez et al. to appear].

Important Implications. II

- For gamma-ray telescopes with better angular resolution (ACTs), slope of the DM density profile more important [Charbonnier et al. MNRAS 2011].
- Need better measurements of the stellar velocity dispersion and the photometric profile of stars

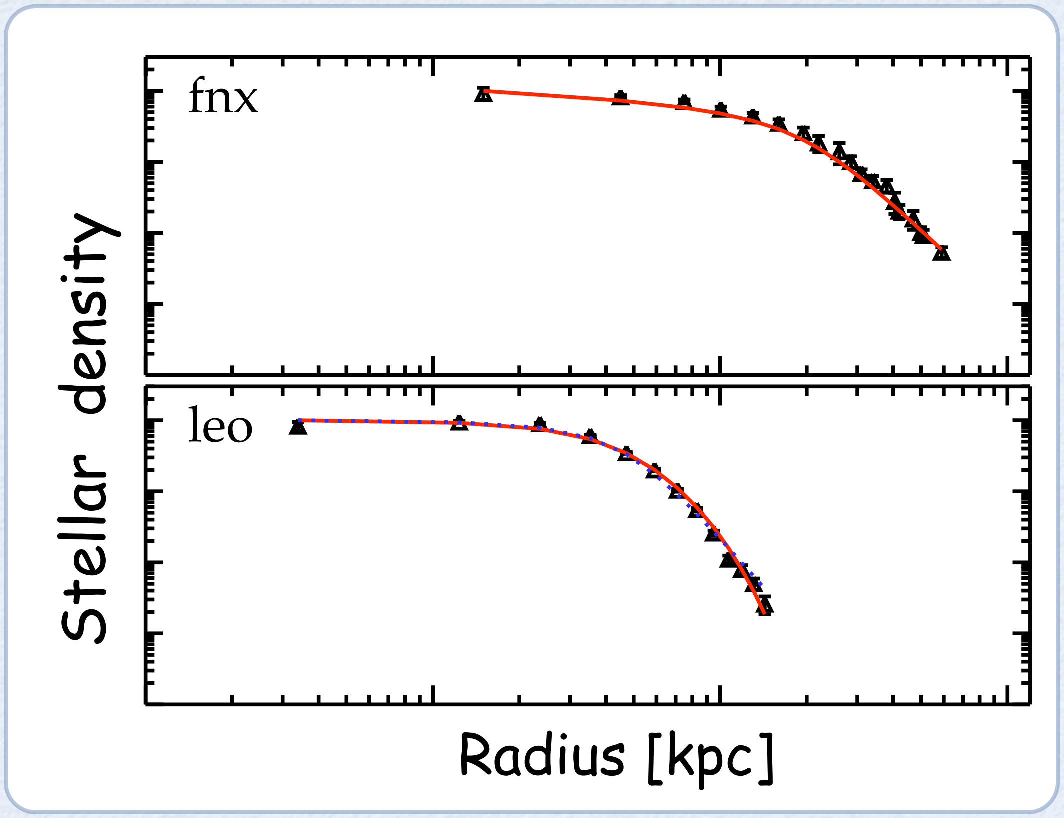
dSph Photometry

Core in 3D

$$\rho_{\rm pl}(r) = \frac{\rho_0}{[1 + (r/r_{\rm pl})^2]^{5/2}}$$

Cusp in 3D

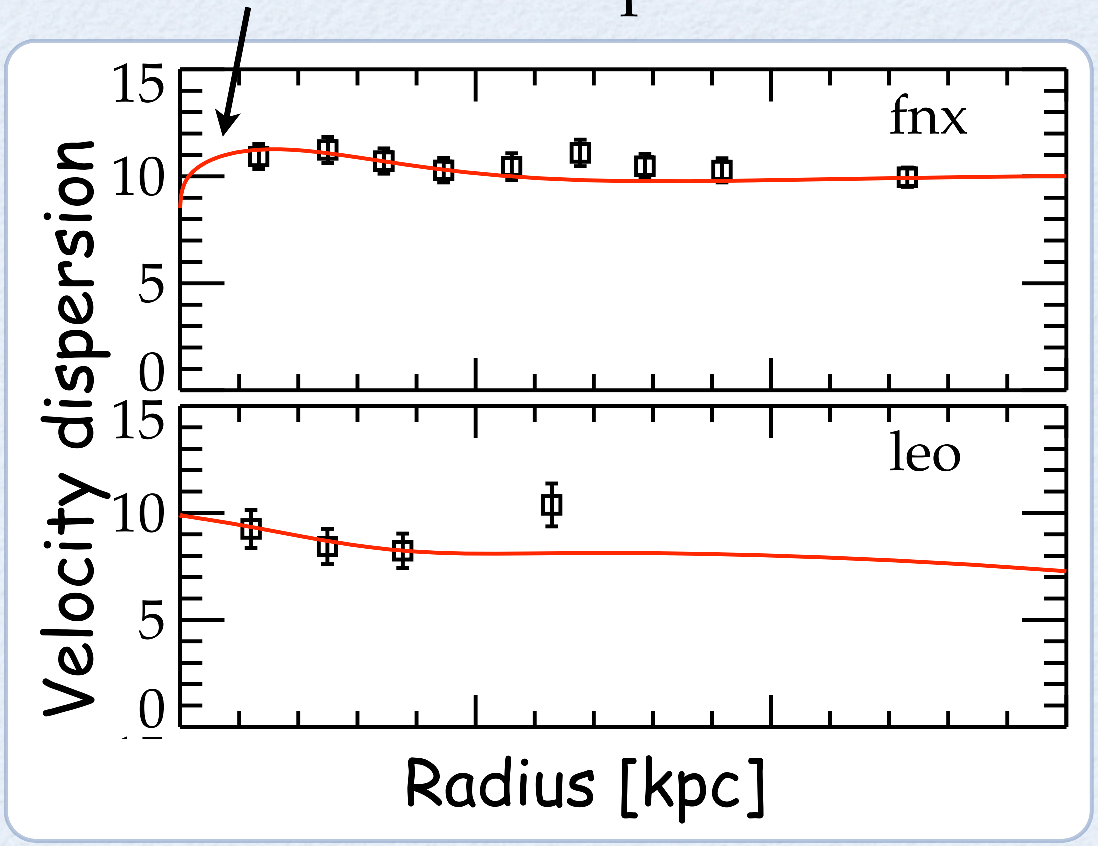
$$\rho_\star(r) \propto \frac{1}{x^a(1 + x^b)^{(c-a)/b}}$$



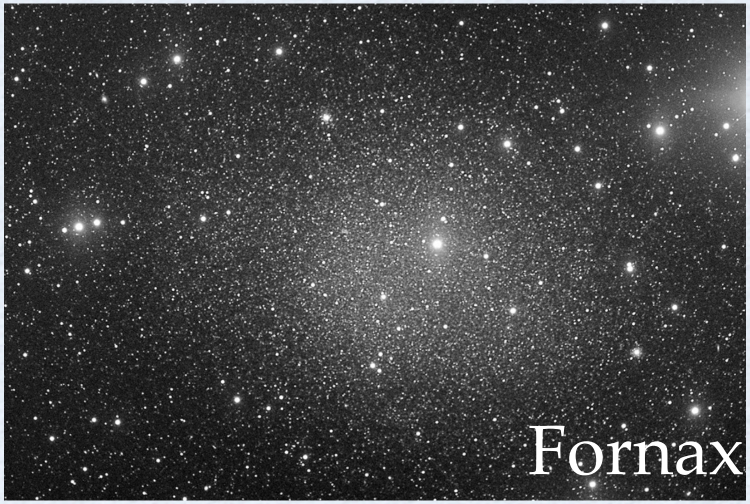
Strigari, Frenk, White MNRAS 2010

Velocity profiles

3D Core increases central dispersion



Strigari, Frenk, White MNRAS 2010

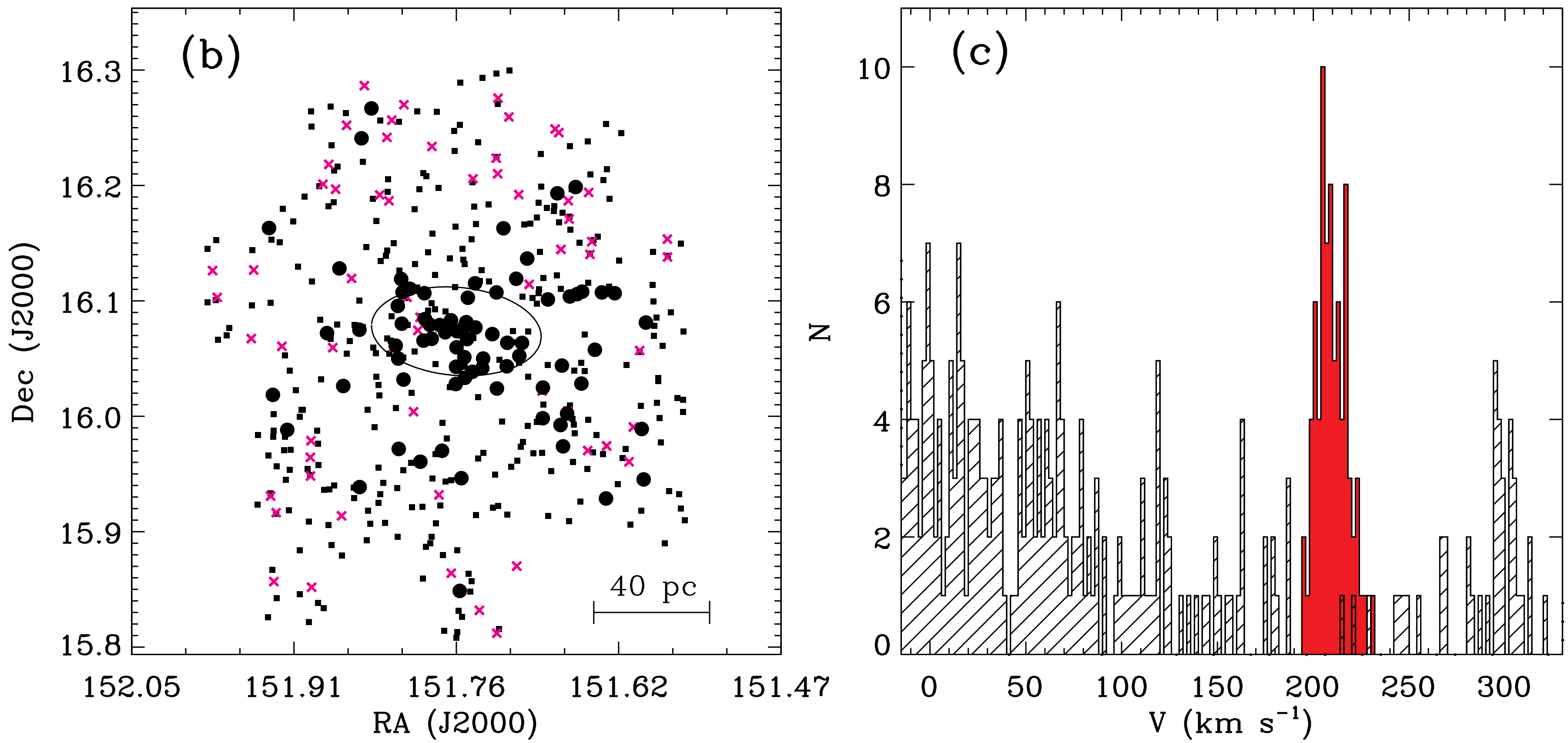


Results for classical satellites

- For jeans-based modeling, systematics in calculations of J values for classical satellites generally well-understood
- Better observations will be required for current ACTs, and in the future for CTA
- Pros and cons for ultra-faint satellites
    - Nearby and DM dominated
    - Must understand each object in detail on individual basis

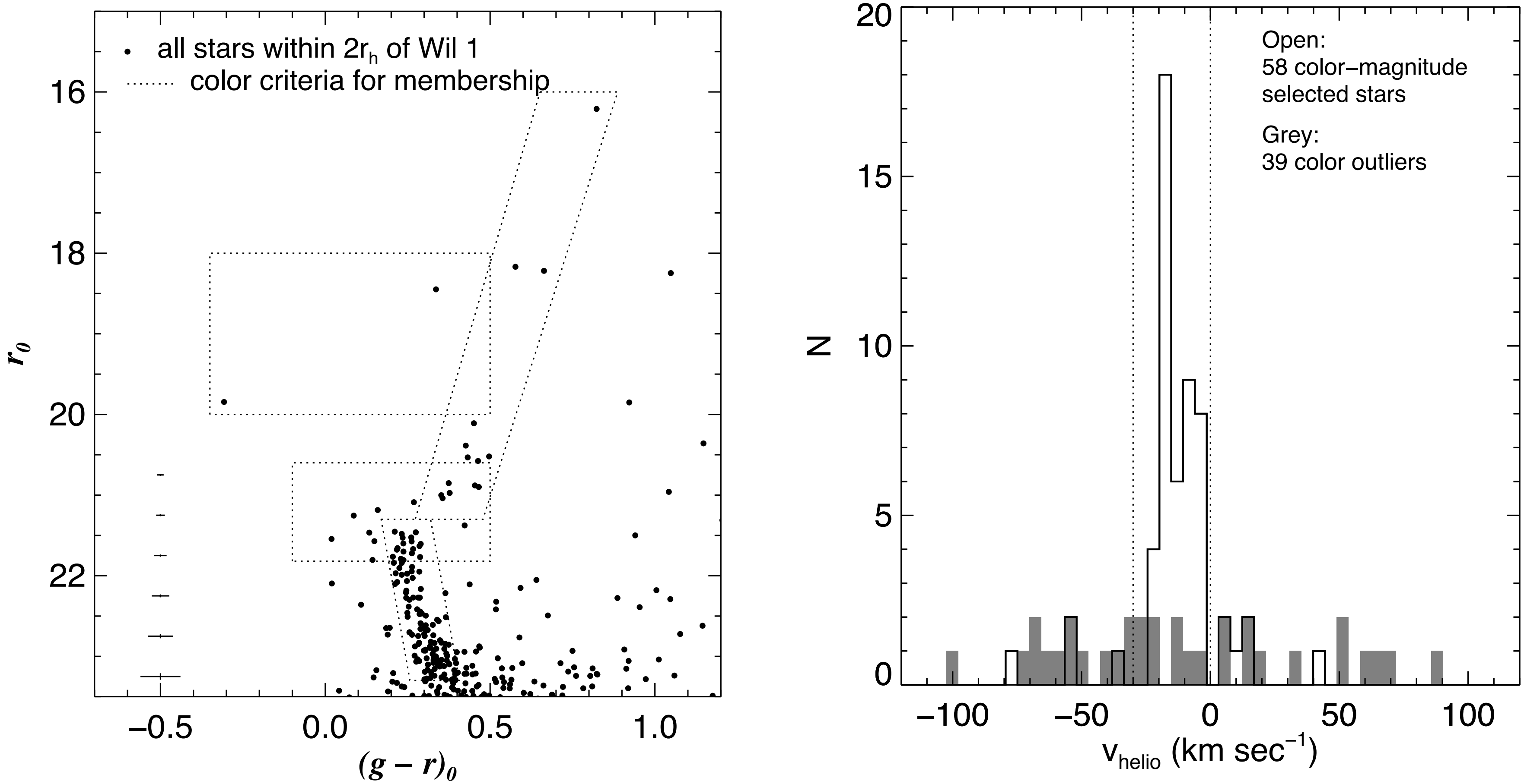
A COMPLETE SPECTROSCOPIC SURVEY OF THE MILKY WAY SATELLITE SEGUE 1: THE DARKEST GALAXY*

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]

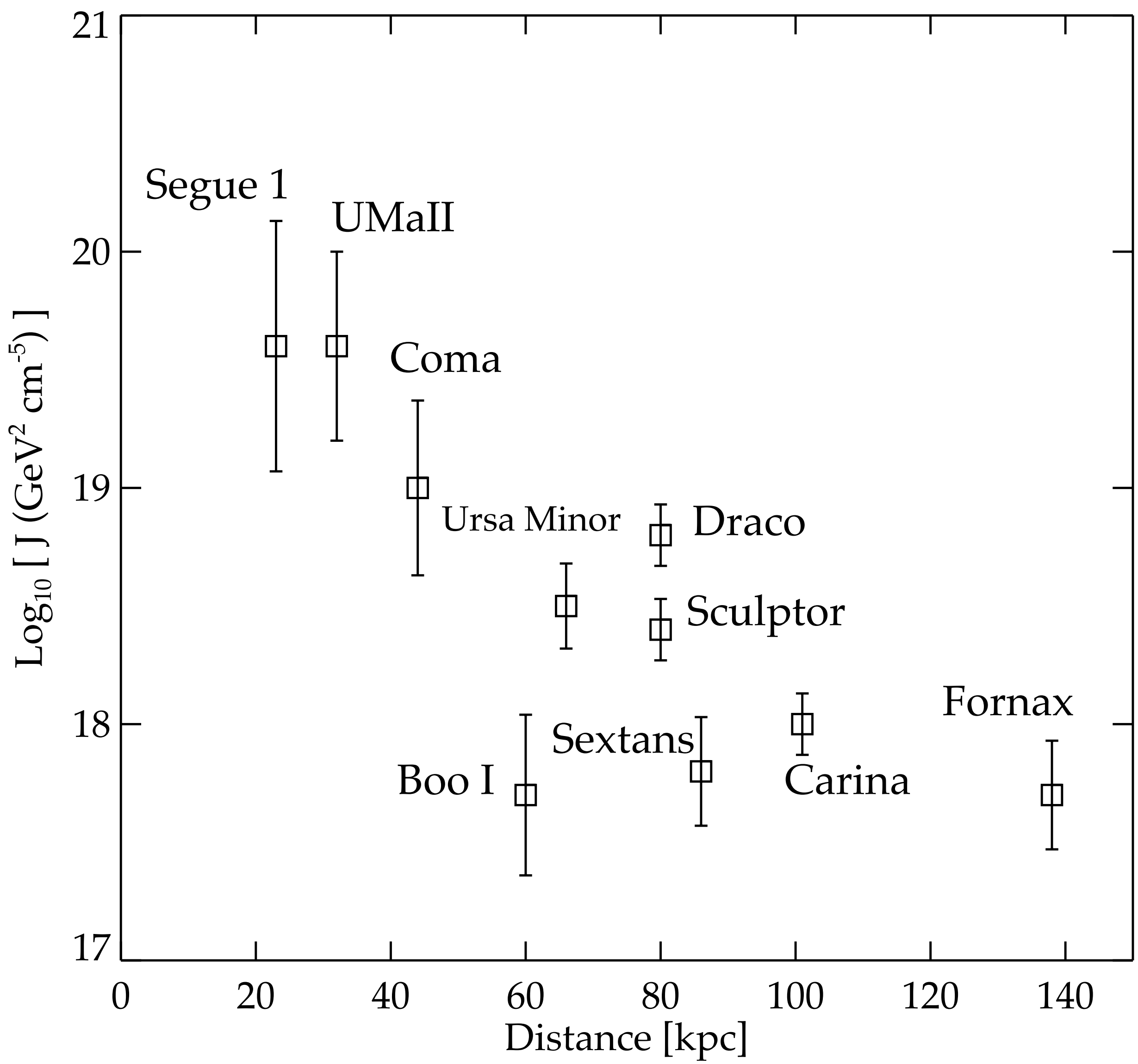


WILLMAN 1 - A PROBABLE DWARF GALAXY WITH AN IRREGULAR KINEMATIC DISTRIBUTION

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]

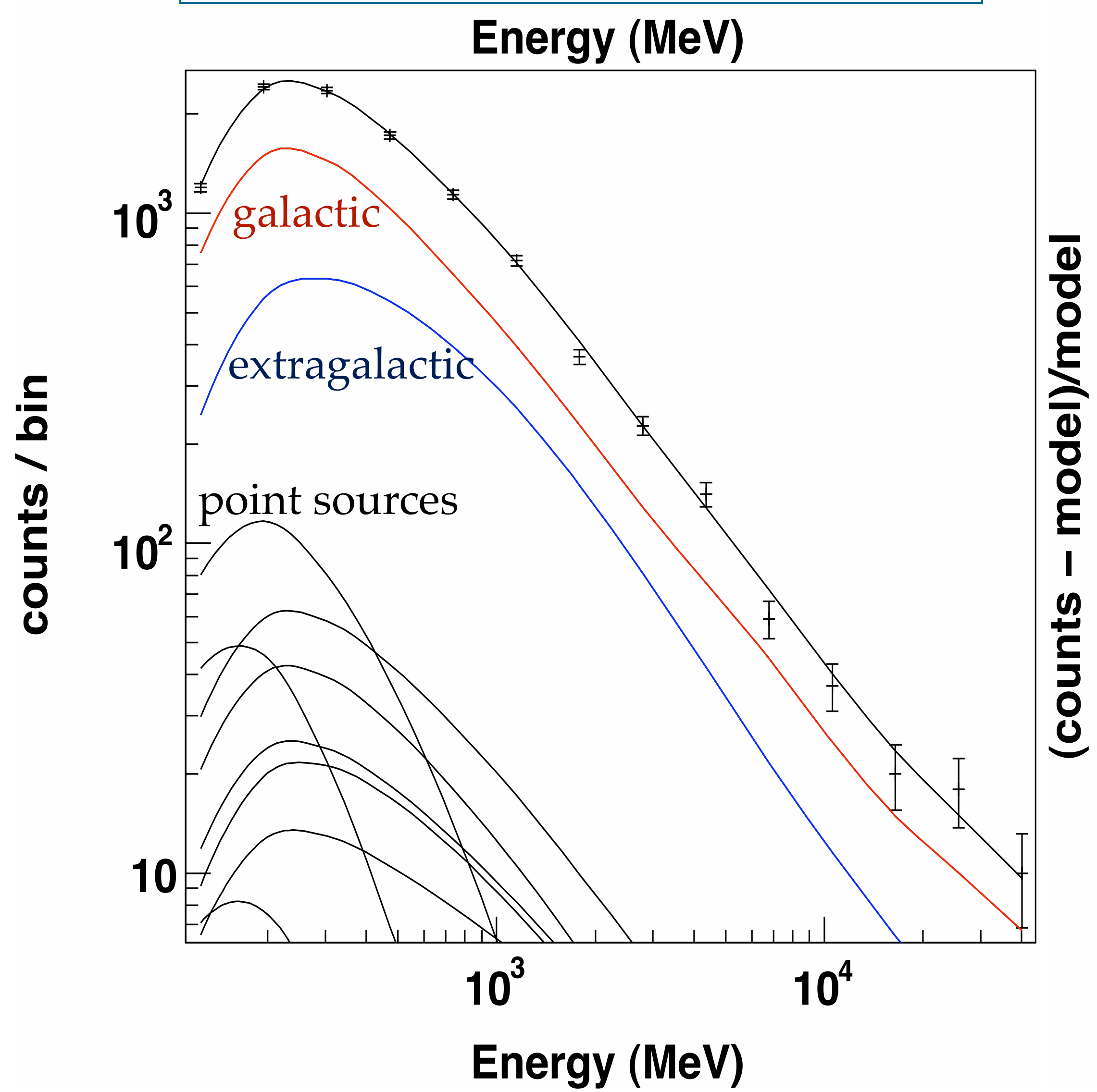


Dark matter distributions



Search for emission from satellites

Fermi-LAT Collaboration, ApJ 2010



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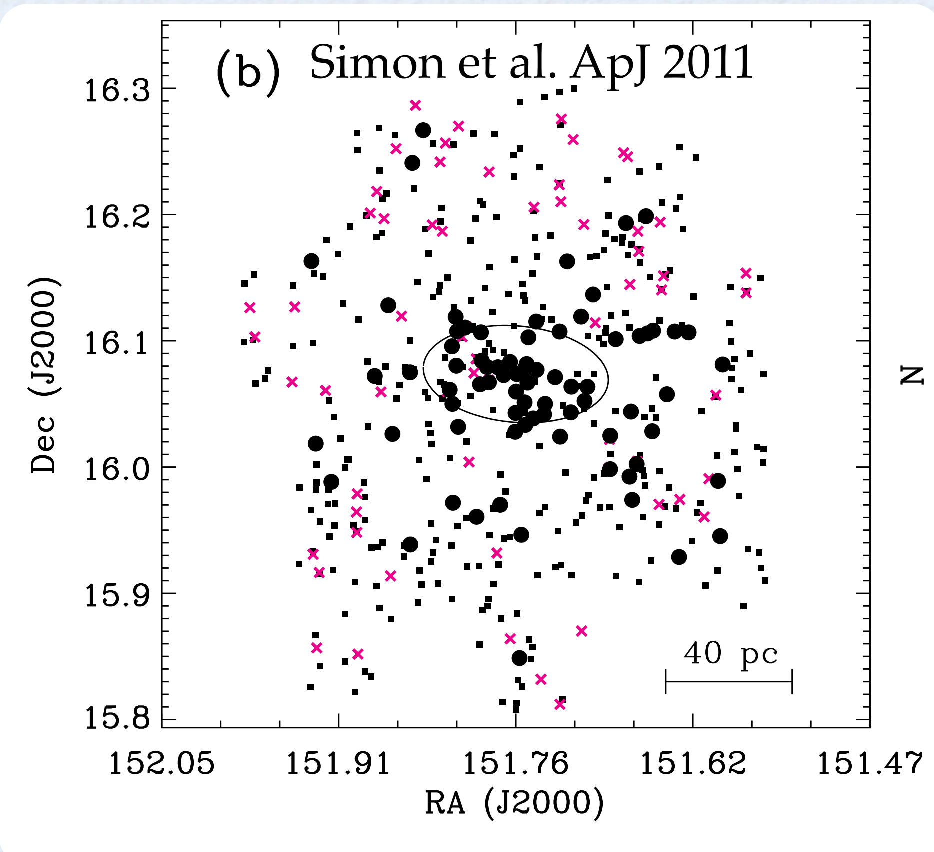
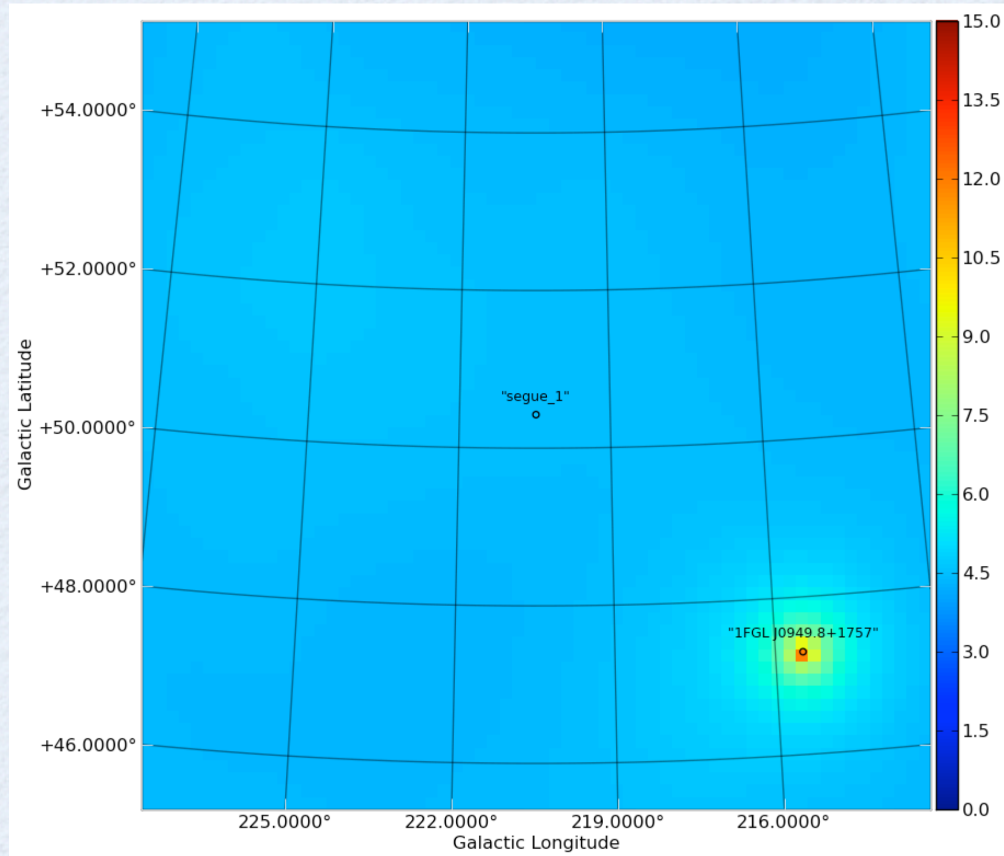
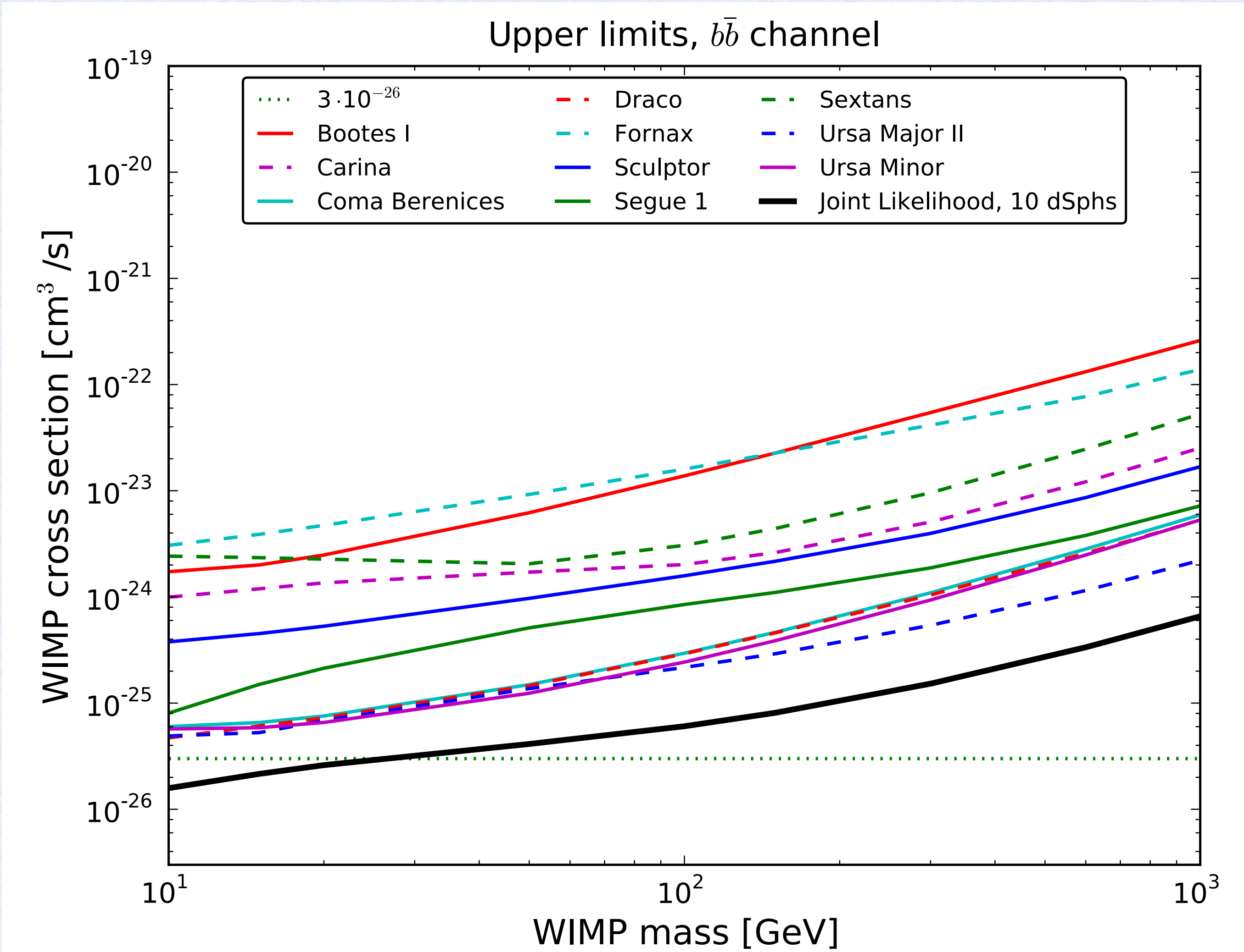




Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope

Fermi-LAT Collaboration, PRL 2011

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



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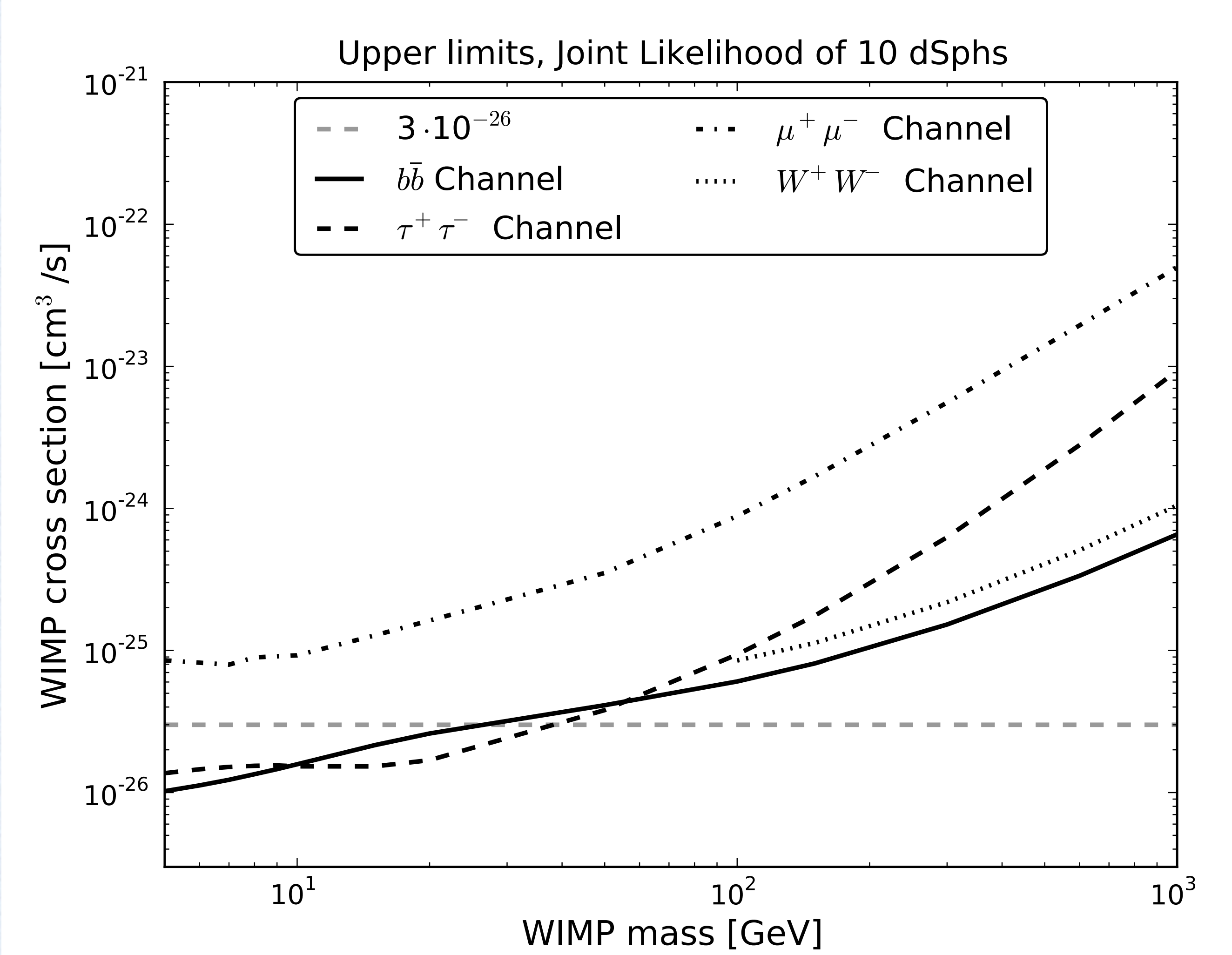
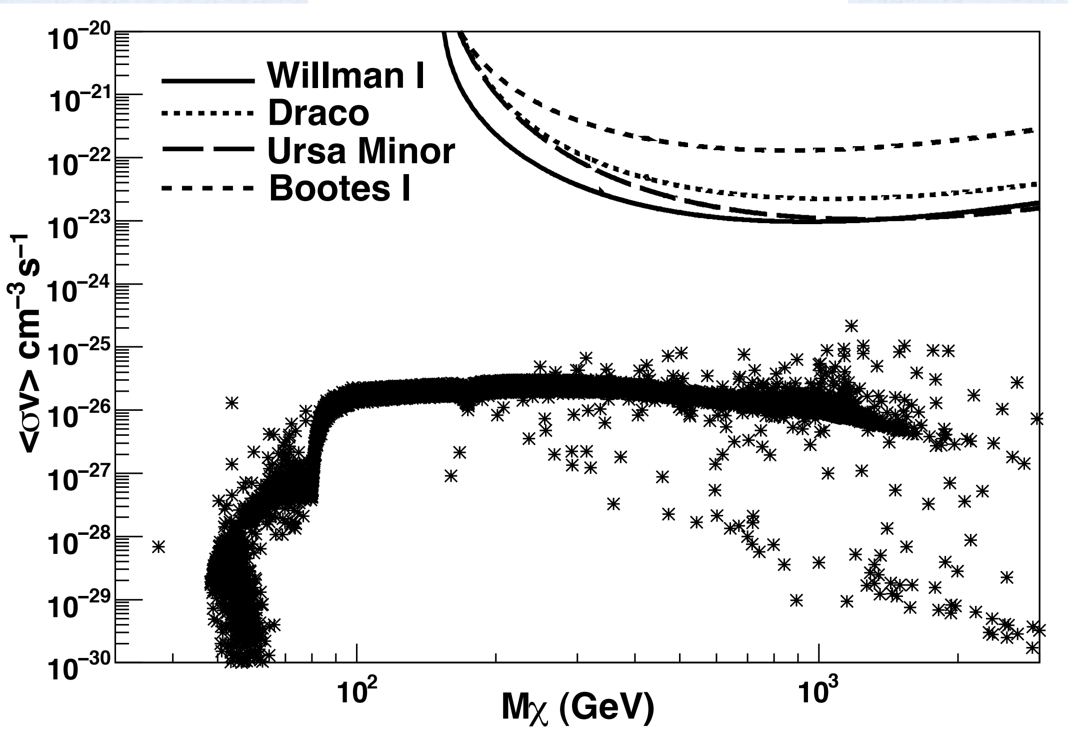


Improvements in analysis

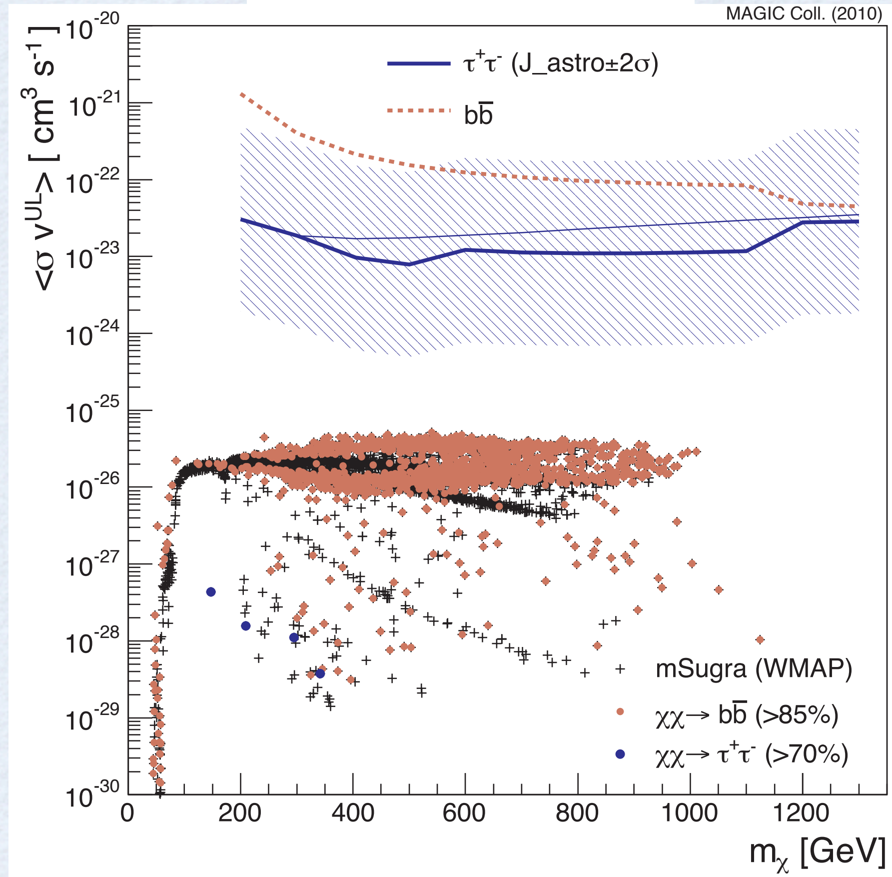
- Better data on stellar kinematics
  - Improved models
  - Proper motions
- More MW satellites will be discovered
- Only used 2 years of possible 10 years of Fermi data
- Complementarily with ground-based detectors

Pointed observations at higher energy

VERITAS

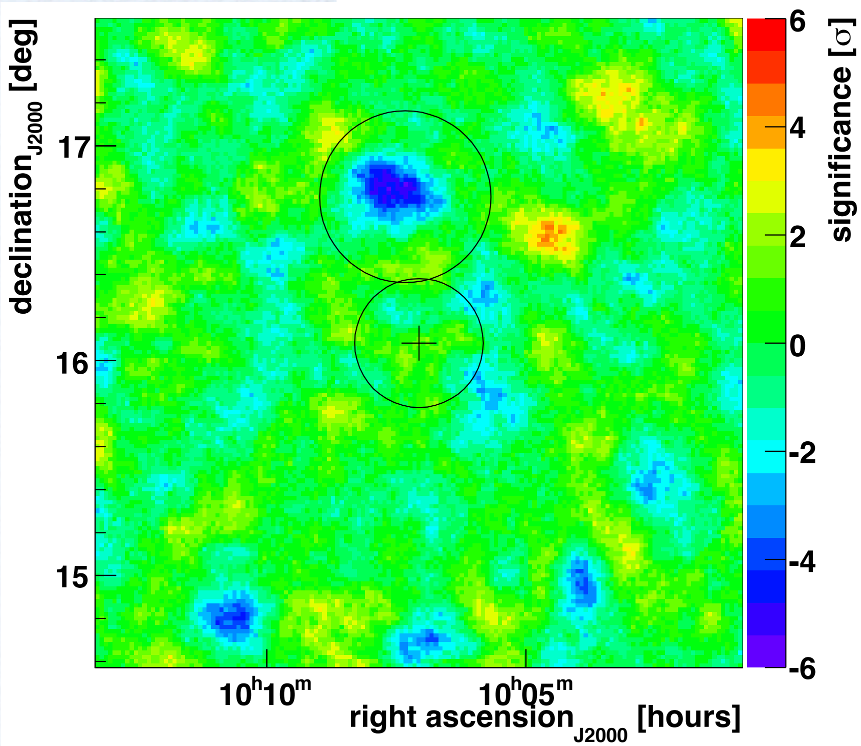


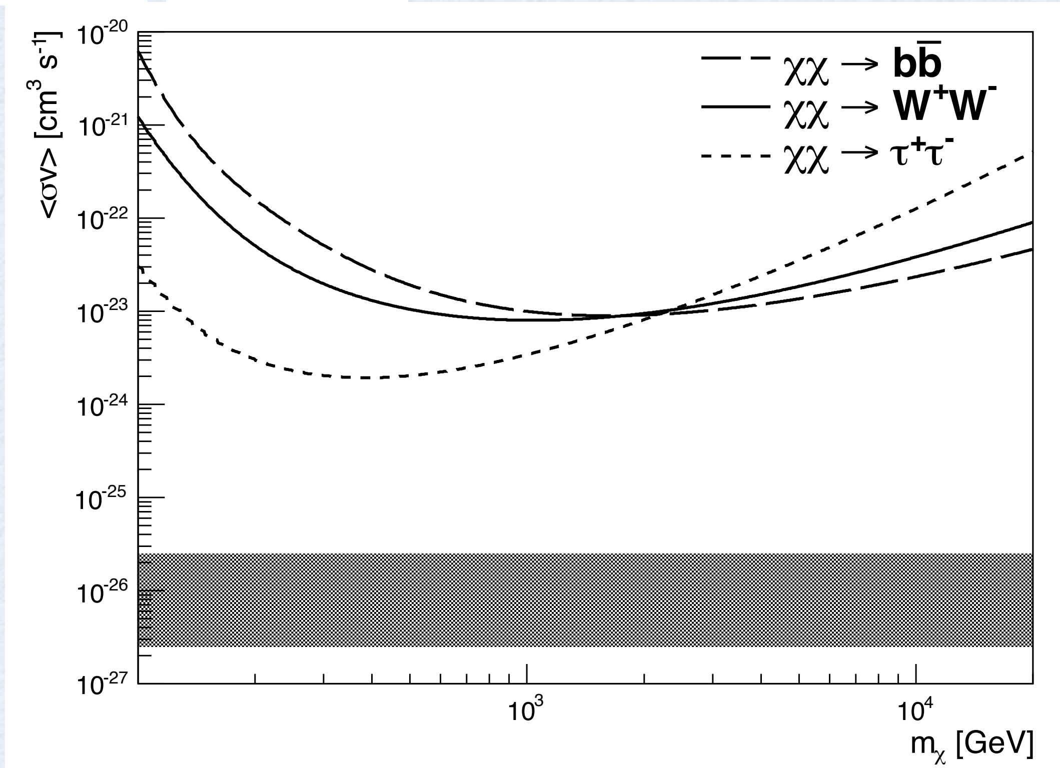
MAGIC



Pointed observations at higher energy

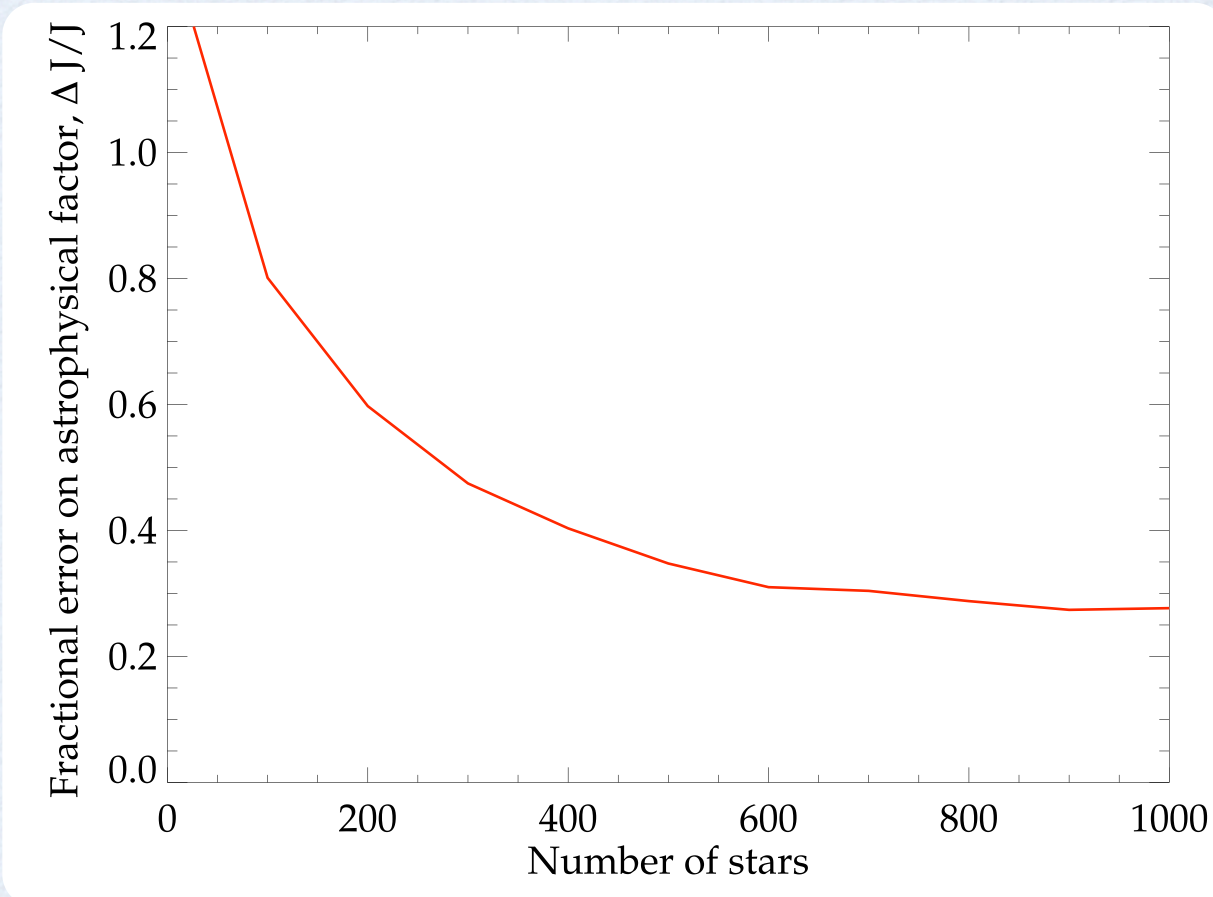
Veritas, arXiv:1202.2144 Segue 1



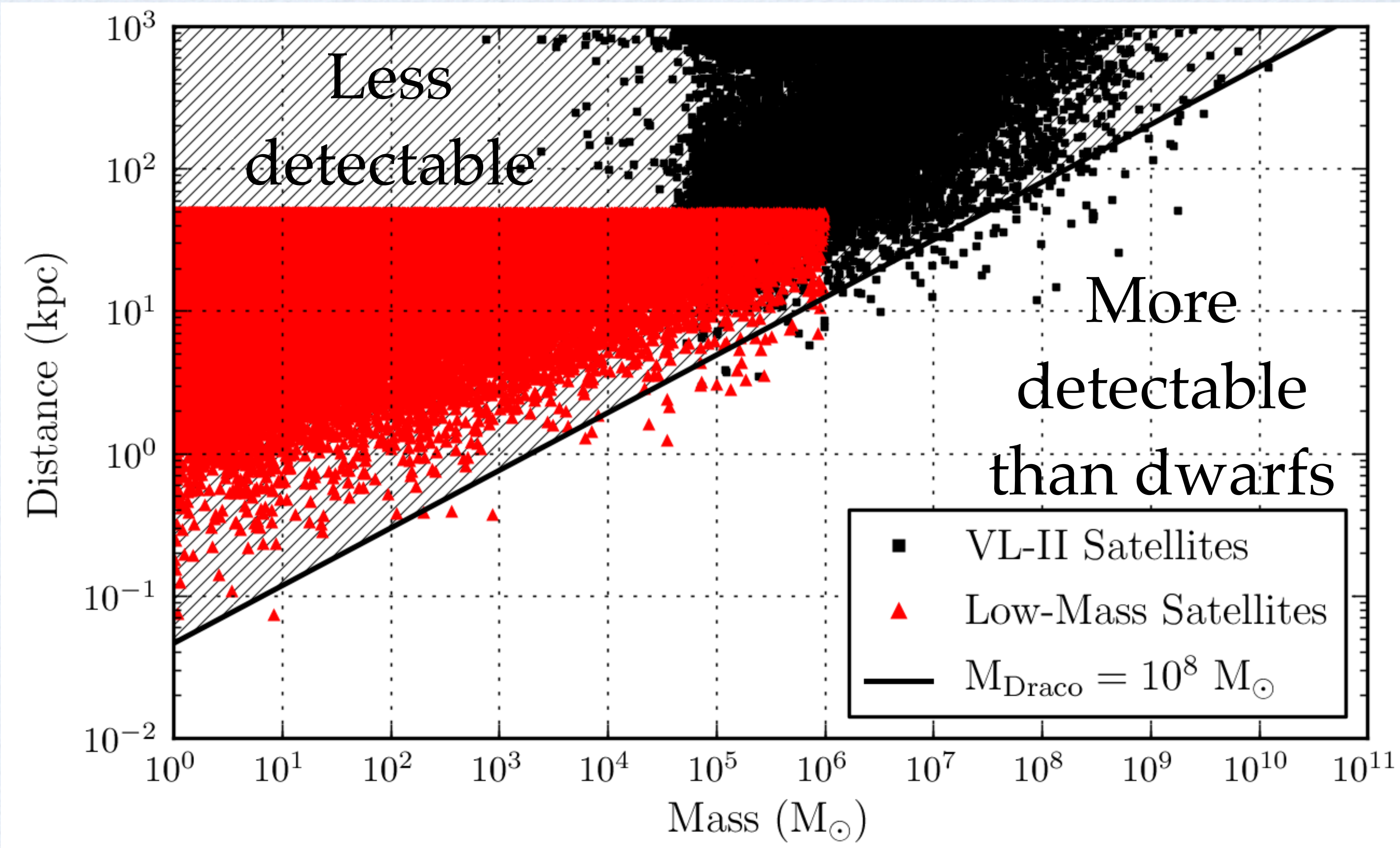


More stars or more dwarfs?

- Probably the bigger reward comes from more dwarfs. Discovery space for Pan-STARRS, Dark Energy Survey, LSST, etc.

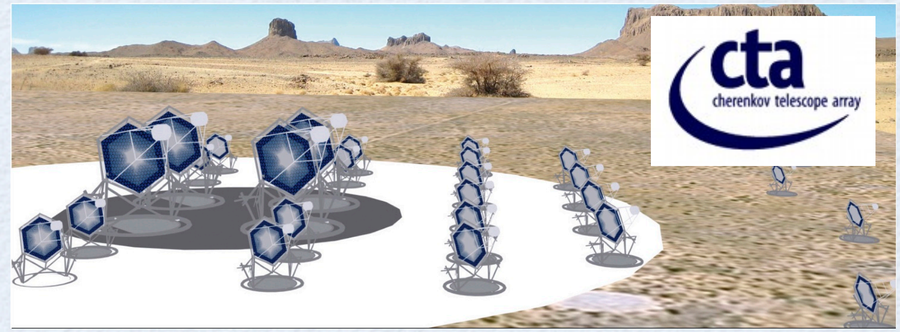


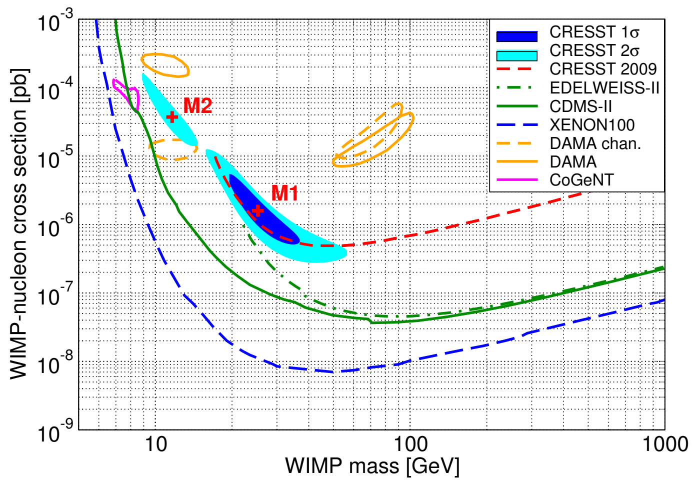
Search for Dark Subhalos



Fermi-LAT Collaboration, ApJ 2012

Going forward





- Fermi-LAT results now rule out thermal relic particle DM in the mass range 10-25 GeV
- More Galactic satellites are out there, and more data is on the way
- Complementarity with direction detection results
- Stay tuned...