Fermi and ACT Limits on WIMP Dark Matter from Galactic Satellites

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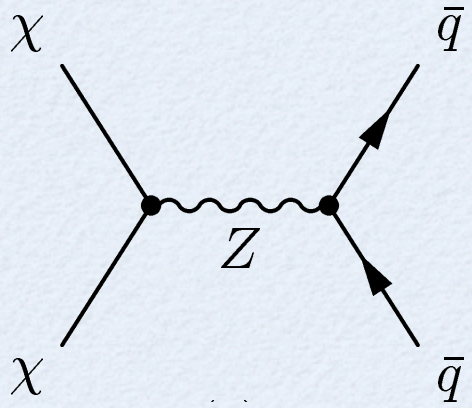
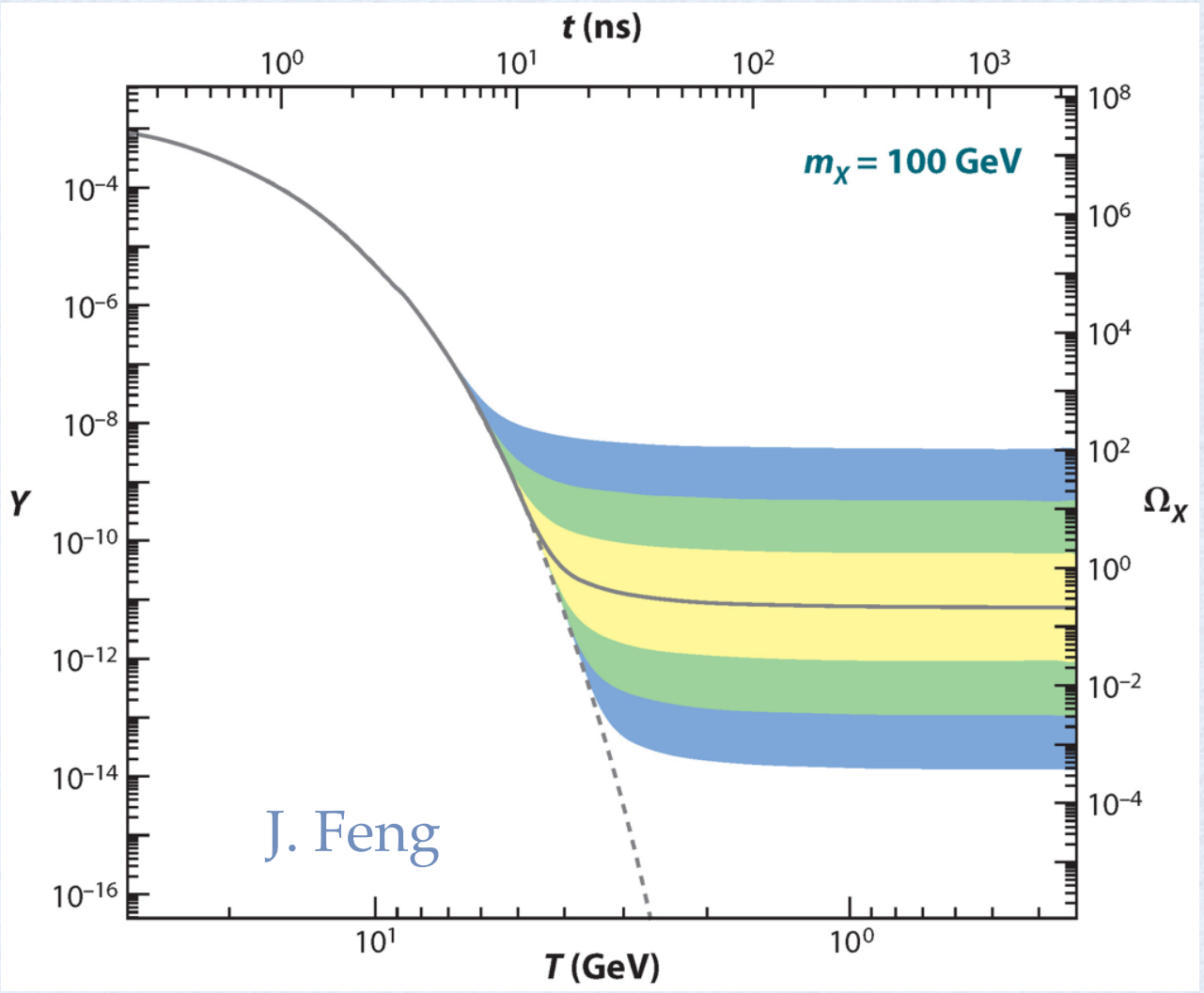
PITT Low Mass Dark Matter Workshop
11/15/2011

Particle Dark Matter: WIMPs

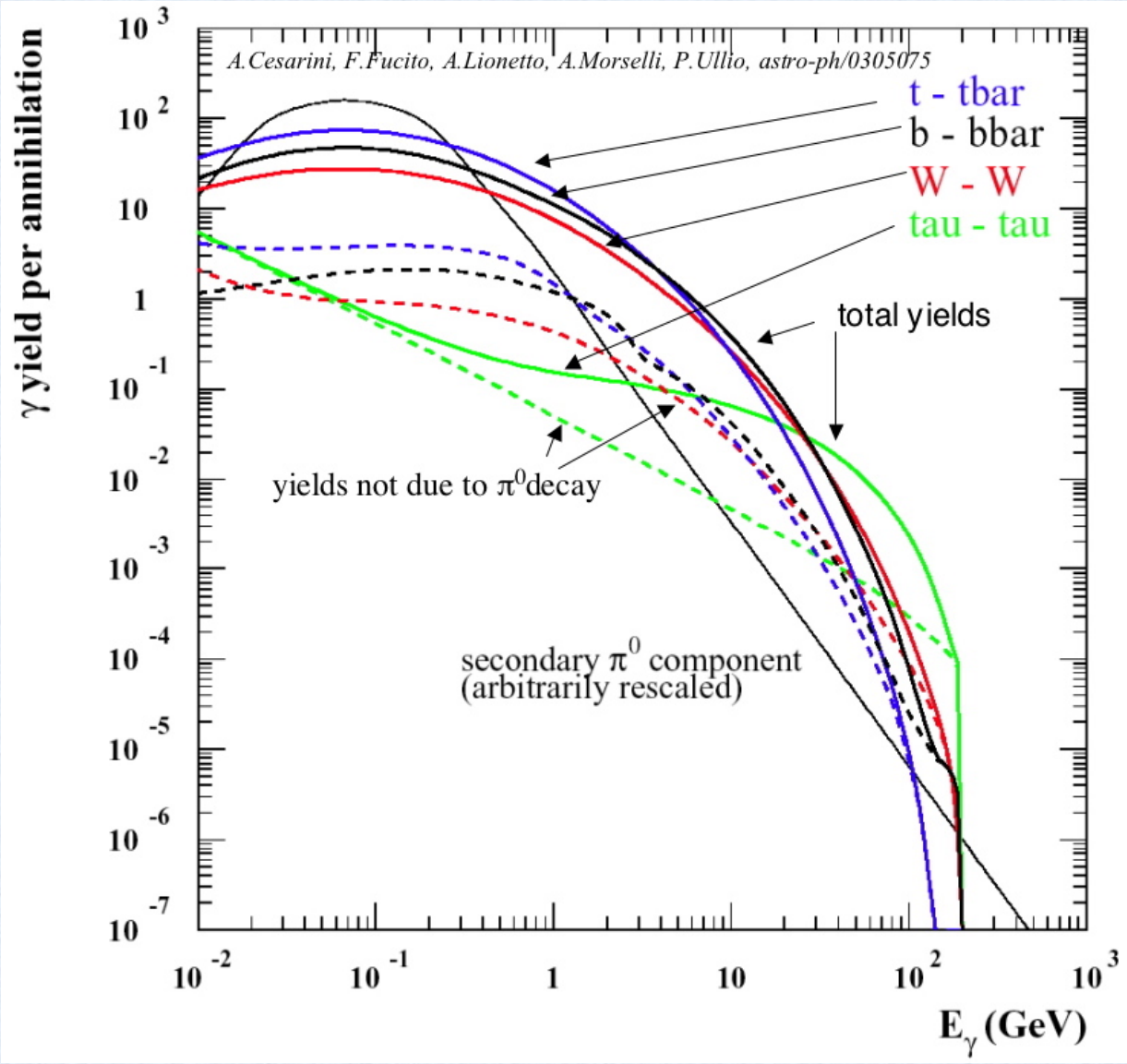


$\langle\sigma v\rangle \sim 3 \times 10^{-26}\ \mathrm{cm^3\ s^{-1}}$



e. g. Zeldovich 1965, Chiu 1966

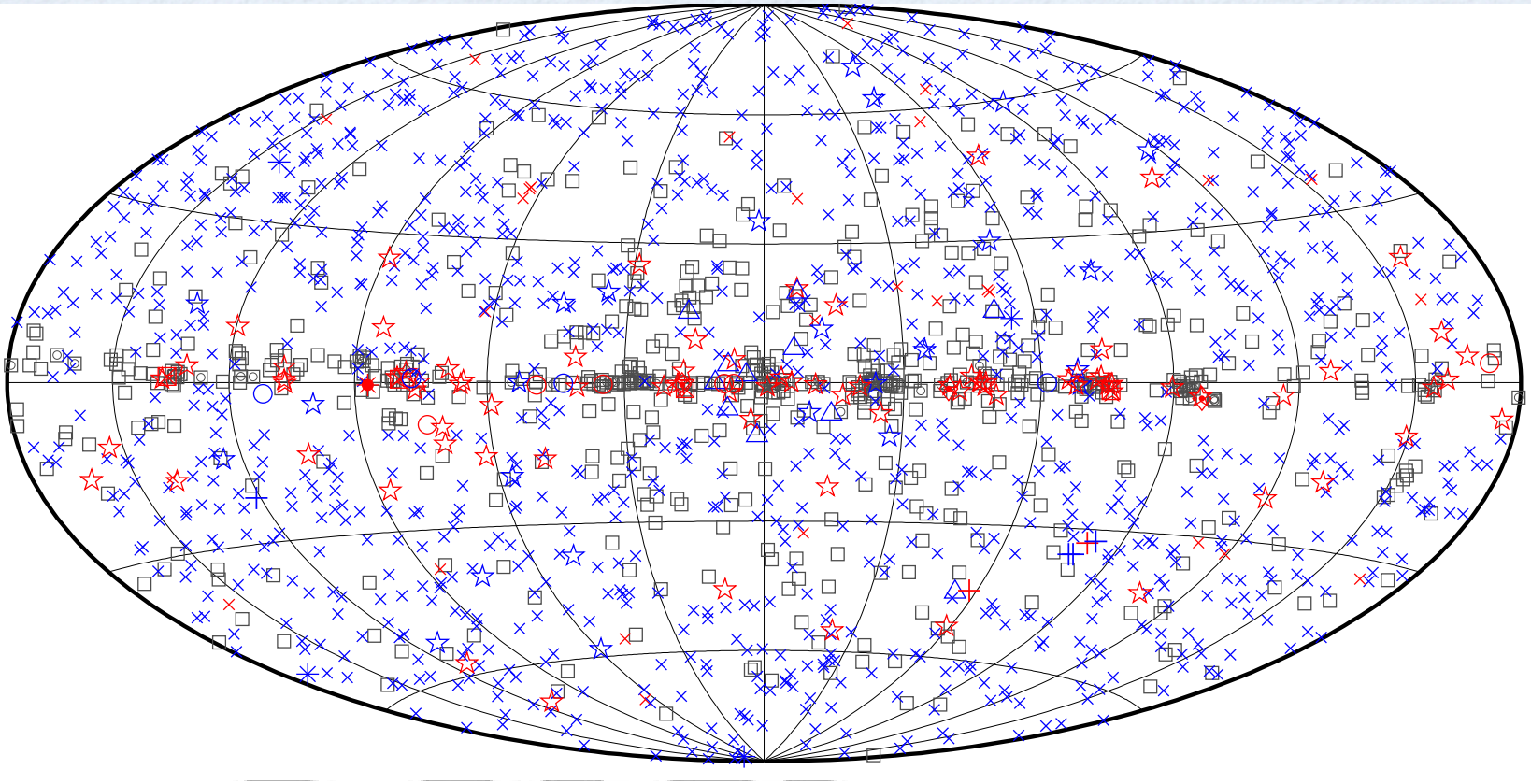
How to find the dark matter



Fermi two-year all-sky map

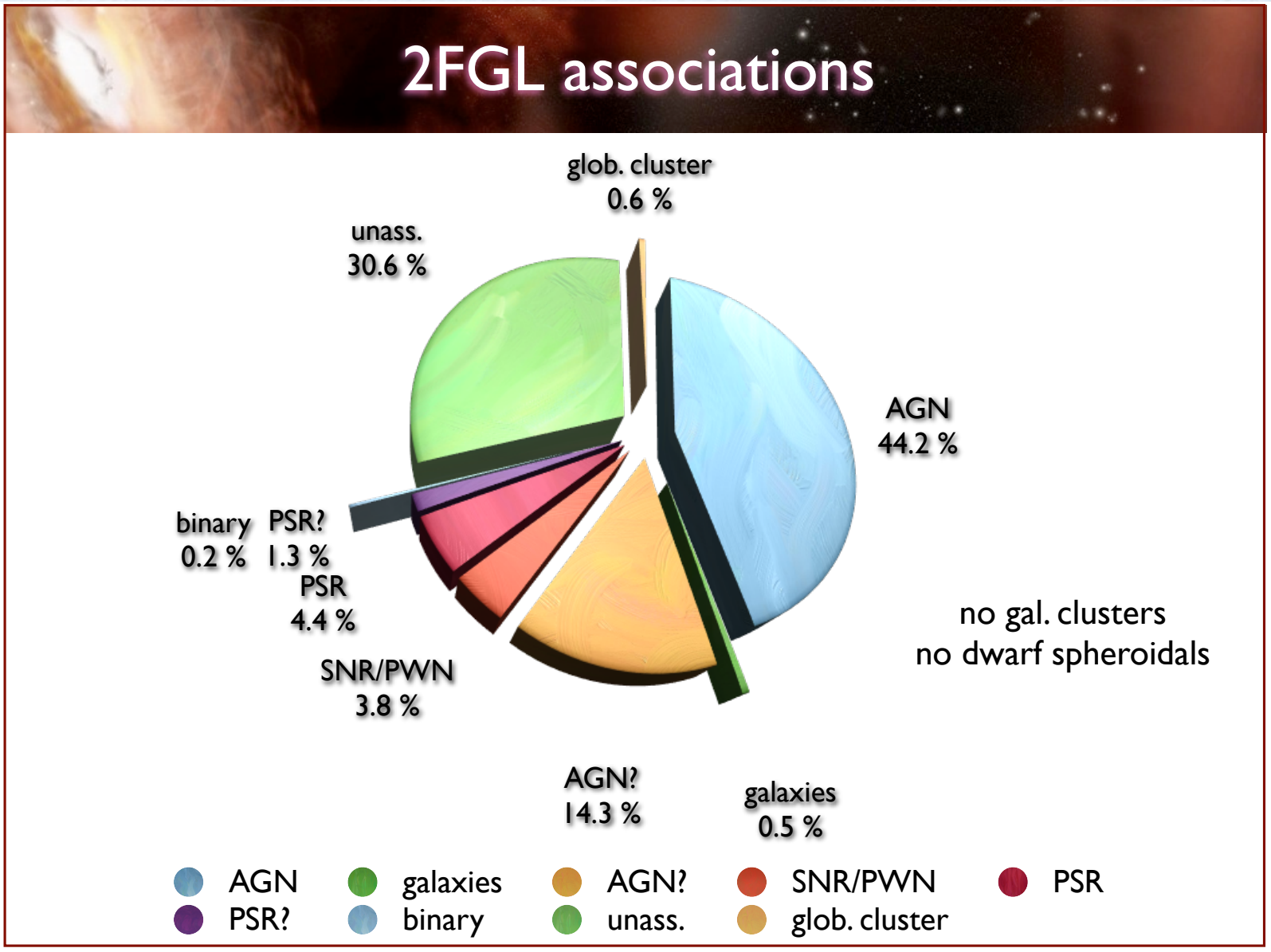
Credit: NASA/DOE/Fermi/LAT Collaboration

2 year source catalog



□ No association	⧈ Possible association with SNR or PWN	
× AGN	☆ Pulsar	△ Globular cluster
✳ Starburst Gal	⧫ PWN	⊠ HMB
+ Galaxy	○ SNR	✷ Nova

2 year source catalog

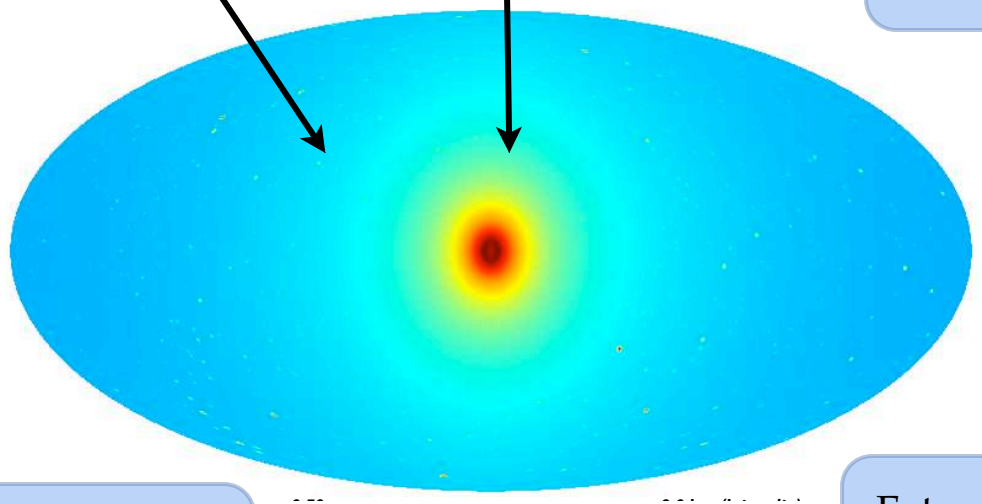


WIMP annihilation:Search Strategies

Satellites: Low bkgd, good source id, low statistics

Galactic center: Good statistics, source confusion/ diffuse backgrounds

Halo: Good statistics but diffuse backgrounds

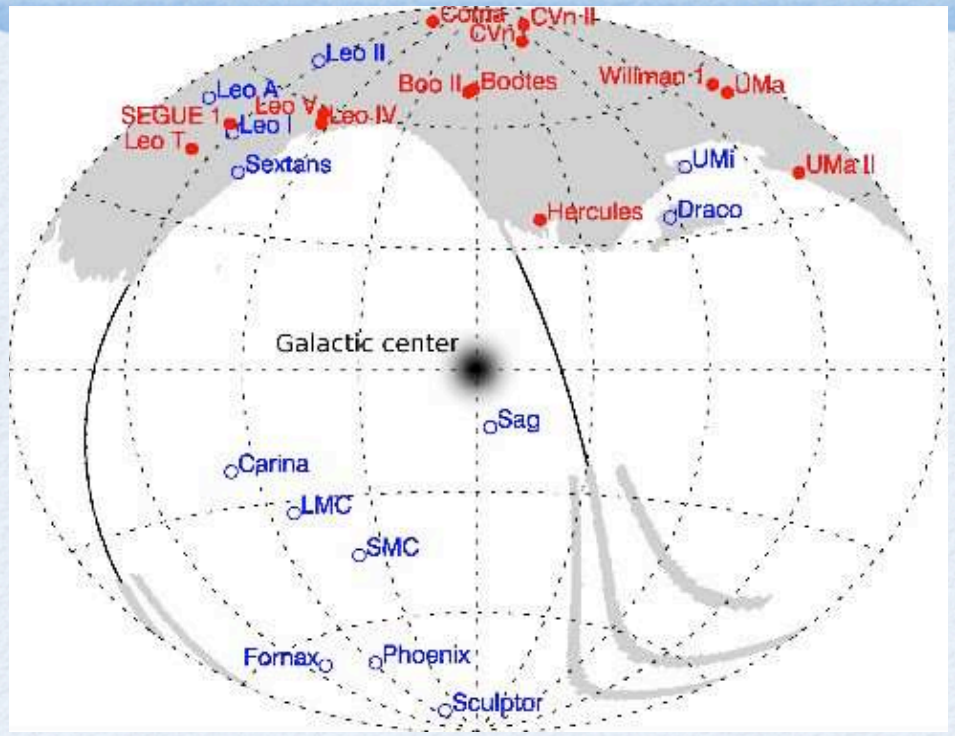


Spectral lines: Good source id, low statistics

Extragalactic: Good statistics, diffuse bkgds and astrophysics

Galaxy clusters: Low backgrounds but low statistics

Milky Way Satellite Galaxies

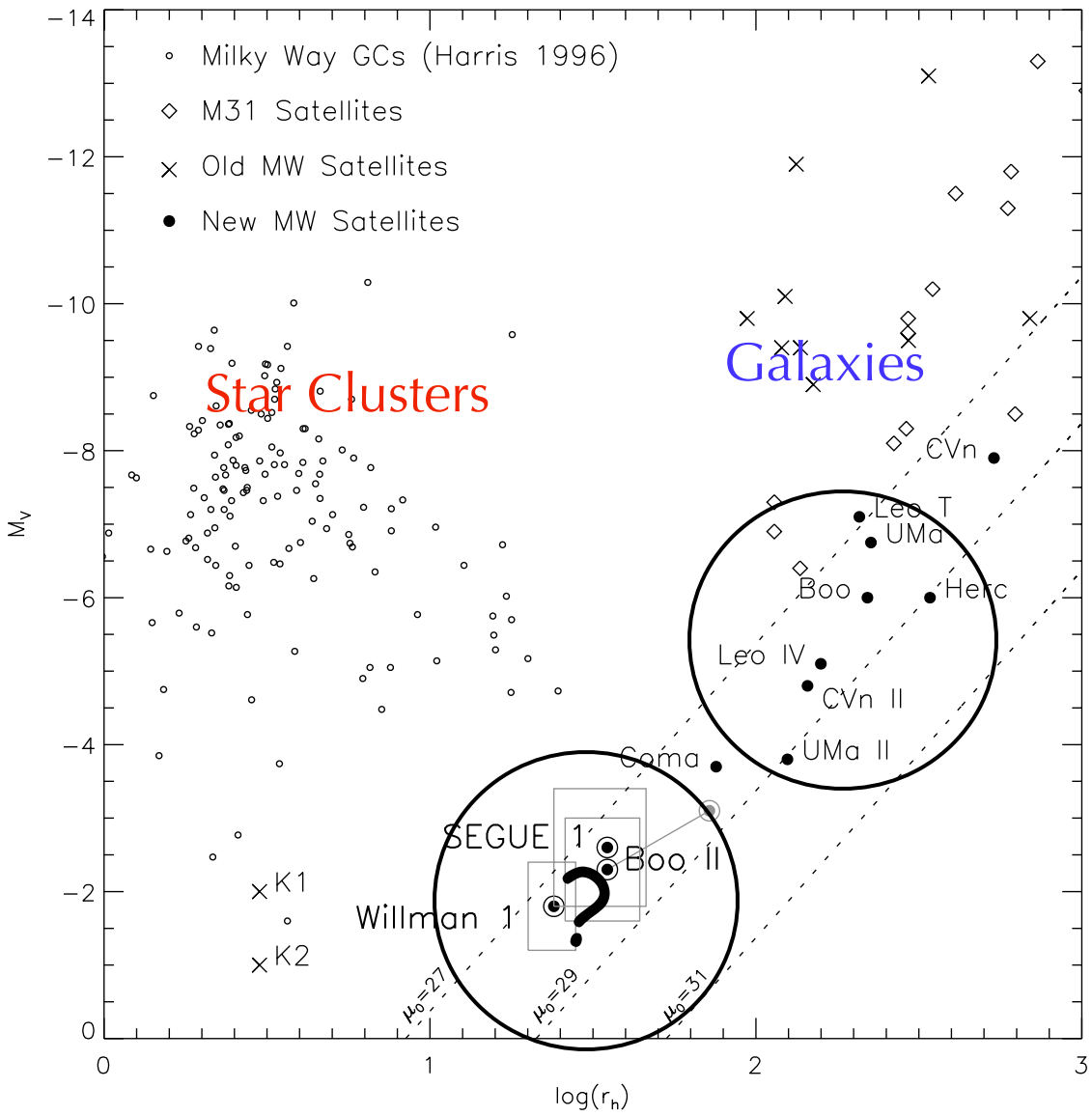


- Old stars
- Dark-matter dominated
- Same central dark matter densities [Strigari et al. Nature 2008)

[Mateo ApJ 1993; Gilmore et al. ApJ 2007]

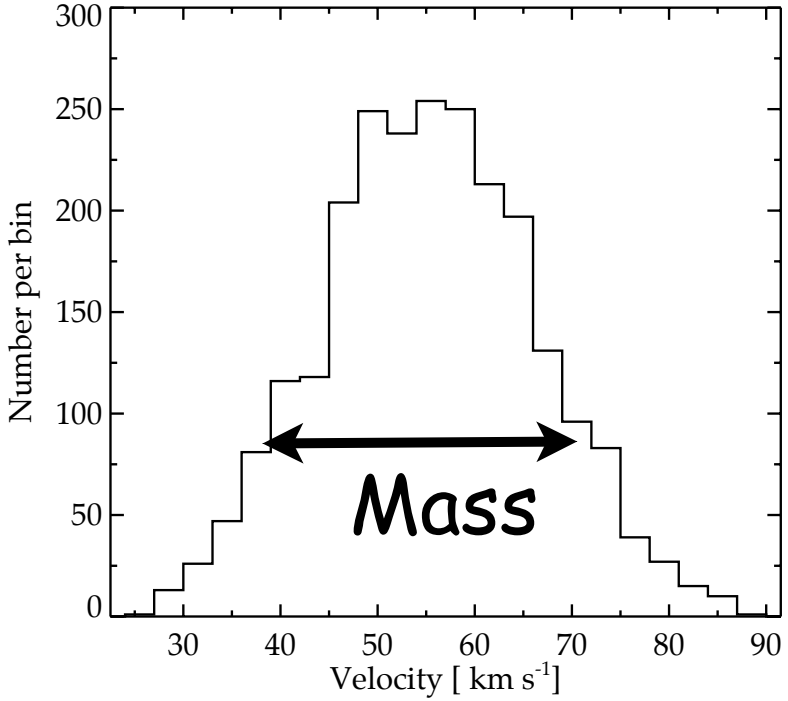
Satellite	Year Discovered
LMC	1519
SMC	1519
Sculptor	1937
Fornax	1938
Leo II	1950
Leo I	1950
Ursa Minor	1954
Draco	1954
Carina	1977
Sextans	1990
Sagittarius	1994
Ursa Major I	2005
Willman 1	2005
Ursa Major II	2006
Bootes I	2006
Canes Venatici I	2006
Canes Venatici II	2006
Coma Berenices	2006
Segue 1	2006
Leo IV	2006
Hercules	2006
Bootes II	2007
Leo V	2008
Pisces I	2009
Segue 2	2009
Segue 3	2010
Pisces II	2010

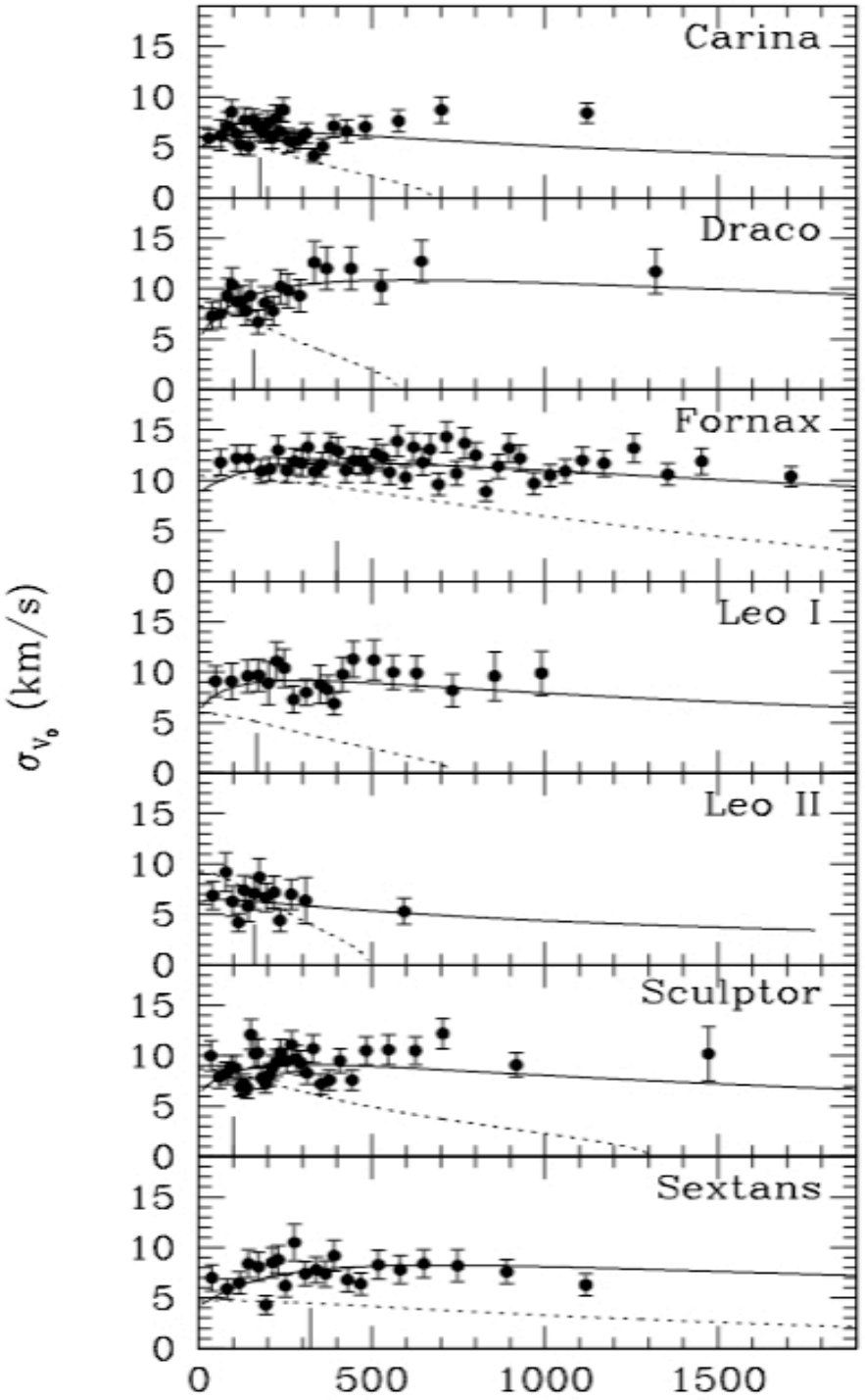
Low mass stellar systems



Galaxies!

Walker, Mateo, et al. 2009

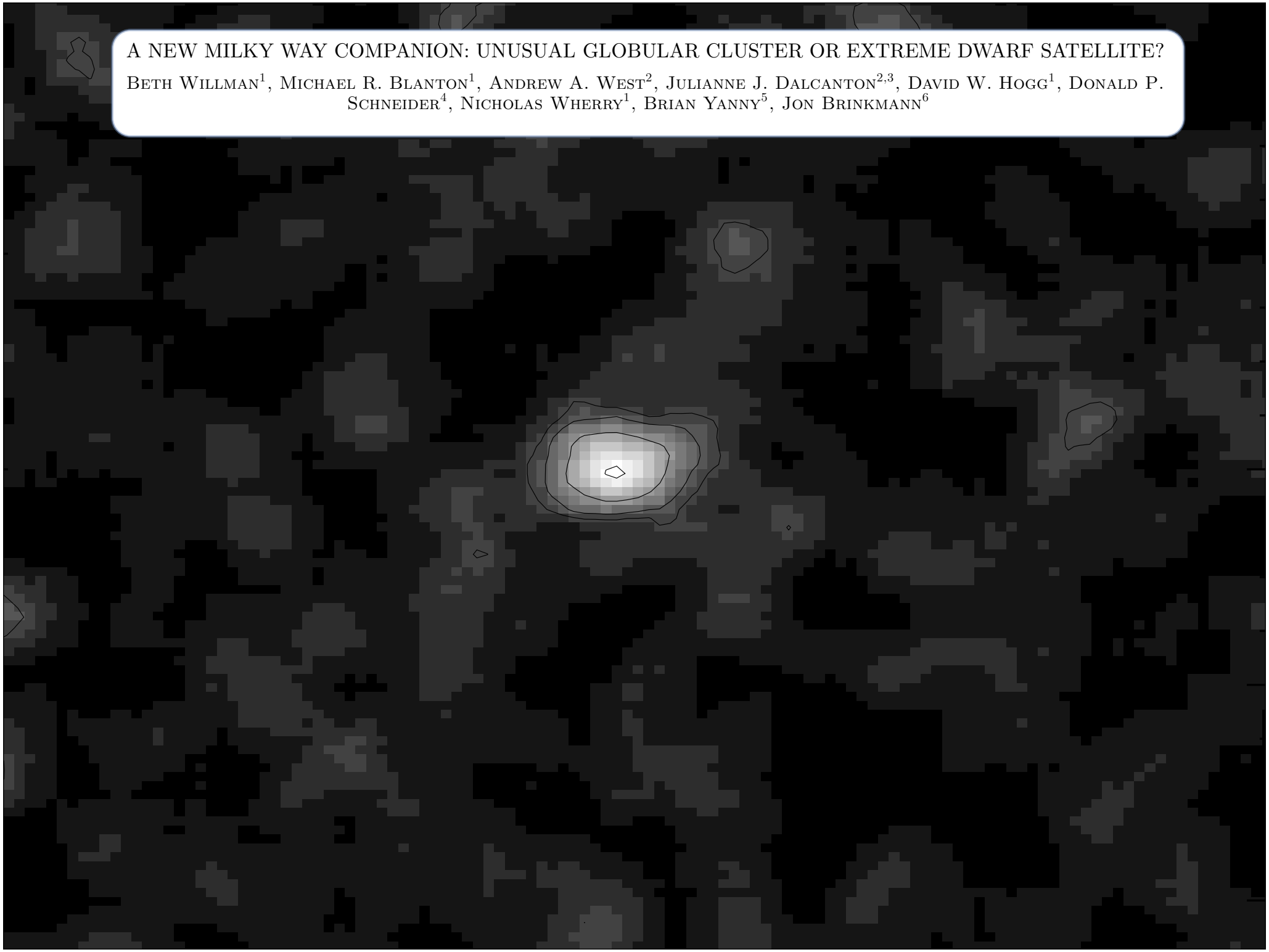




Walker et al ApJL 2007

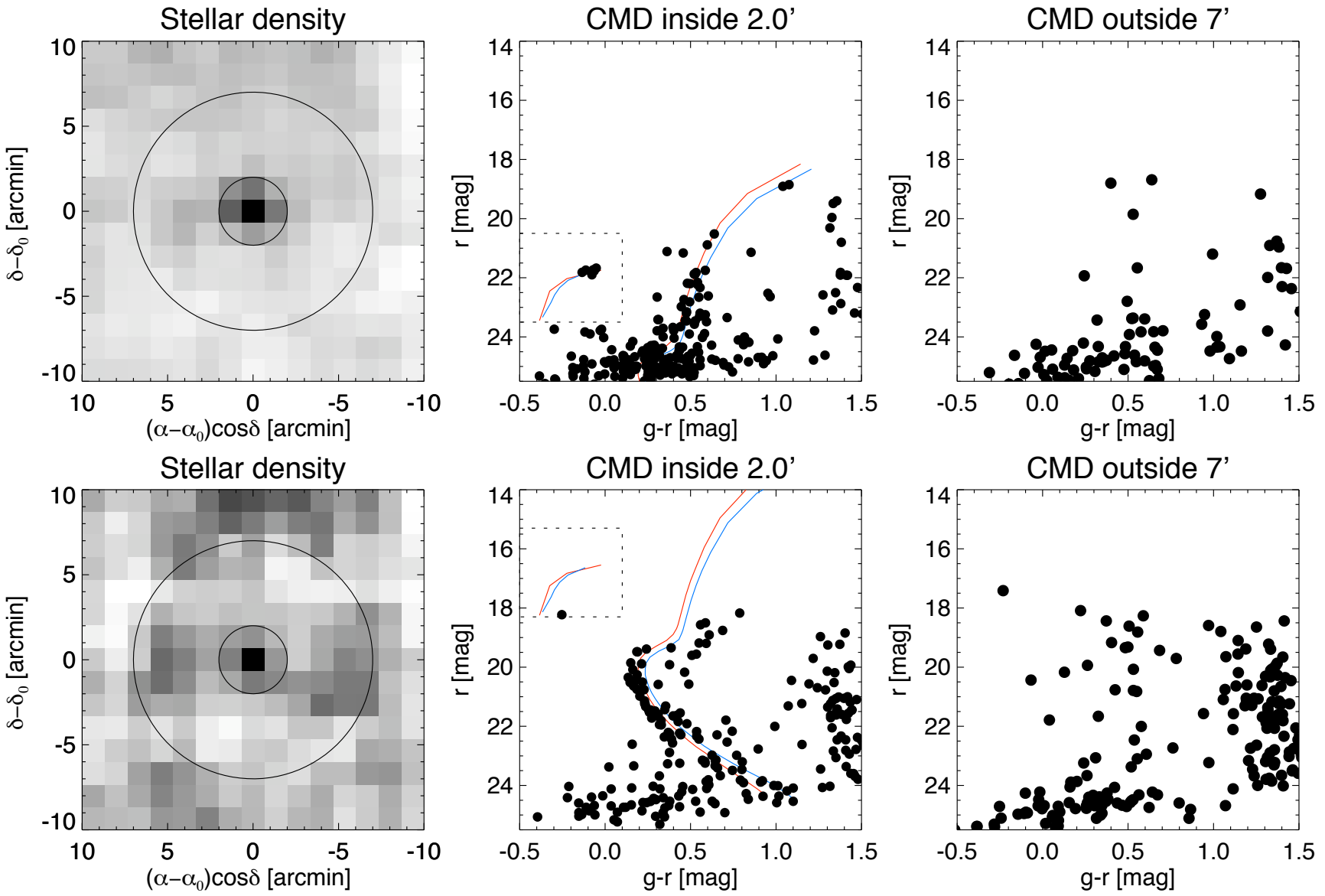
A NEW MILKY WAY COMPANION: UNUSUAL GLOBULAR CLUSTER OR EXTREME DWARF SATELLITE?

Beth Willman[1], Michael R. Blanton[1], Andrew A. West[2], Julianne J. Dalcanton[2,3], David W. Hogg[1], Donald P. Schneider[4], Nicholas Wherry[1], Brian Yanny[5], Jon Brinkmann[6]

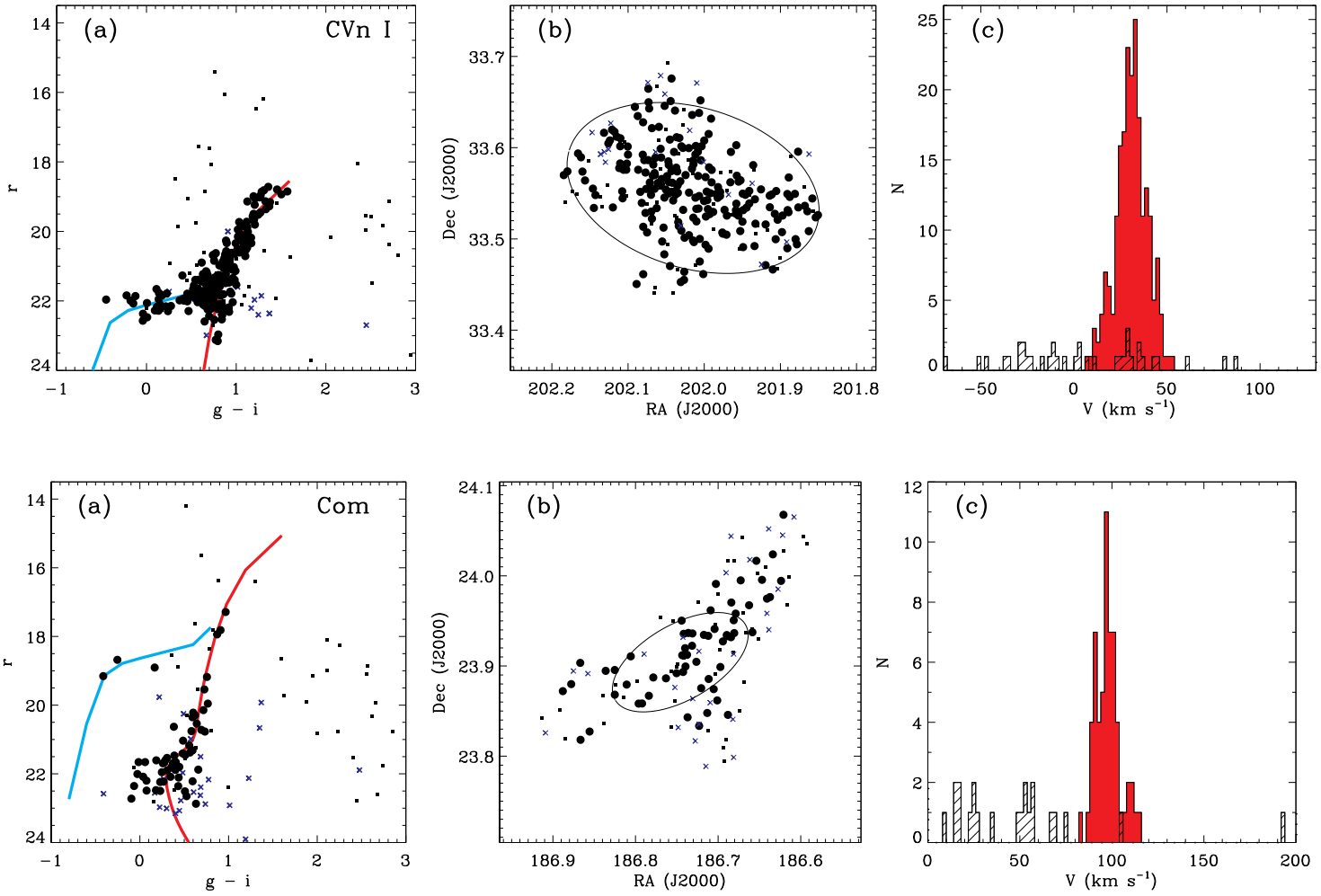


BIG FISH, LITTLE FISH: TWO NEW ULTRA-FAINT SATELLITES OF THE MILKY WAY

V. Belokurov[1], M. G. Walker[1], N. W. Evans[1], G. Gilmore[1], M. J. Irwin[1], D. Just[2], S. Koposov[1], M. Mateo[3], E. Olszewski[2], L. Watkins[1], and L. Wyrzykowski[1]

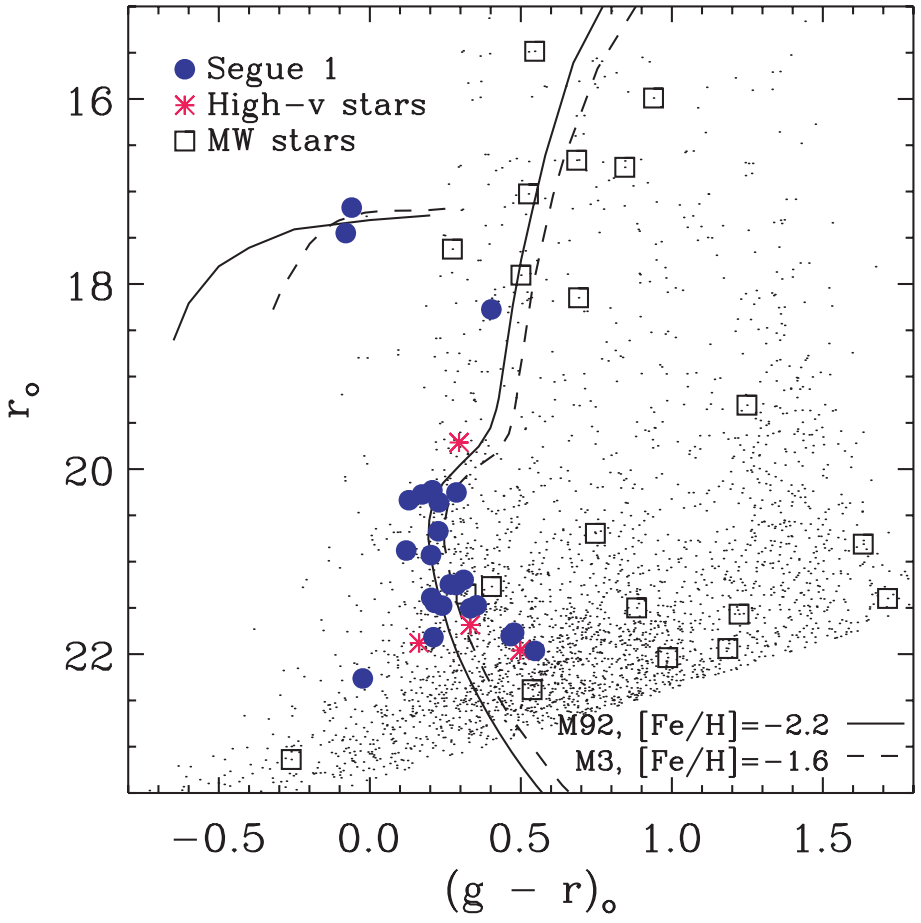


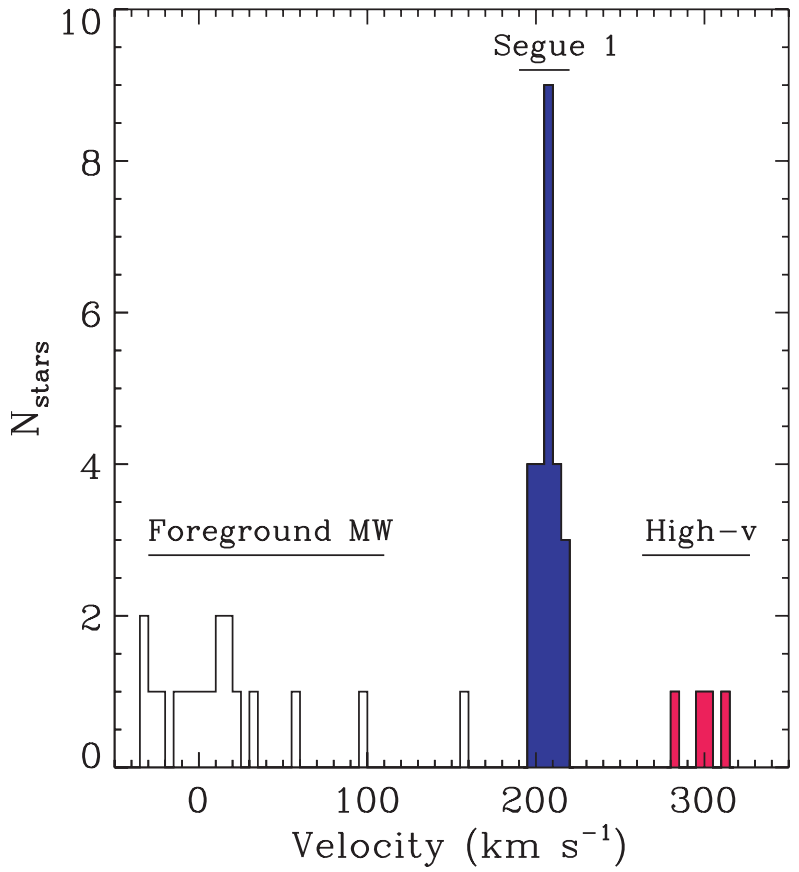
Ultra-faint satellites: kinematics



Simon & Geha ApJ 2007

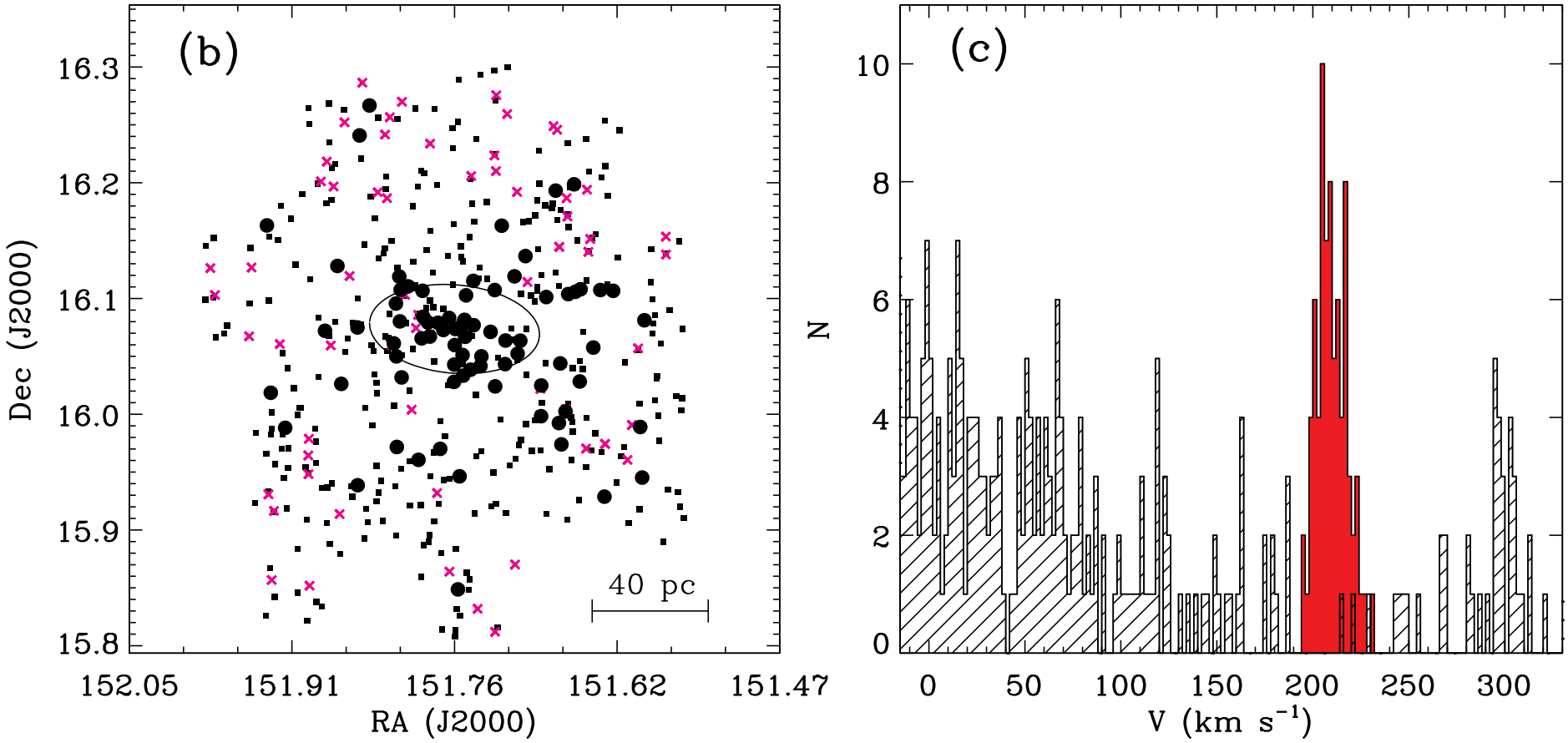
The Darkest Galaxy: Segue 1





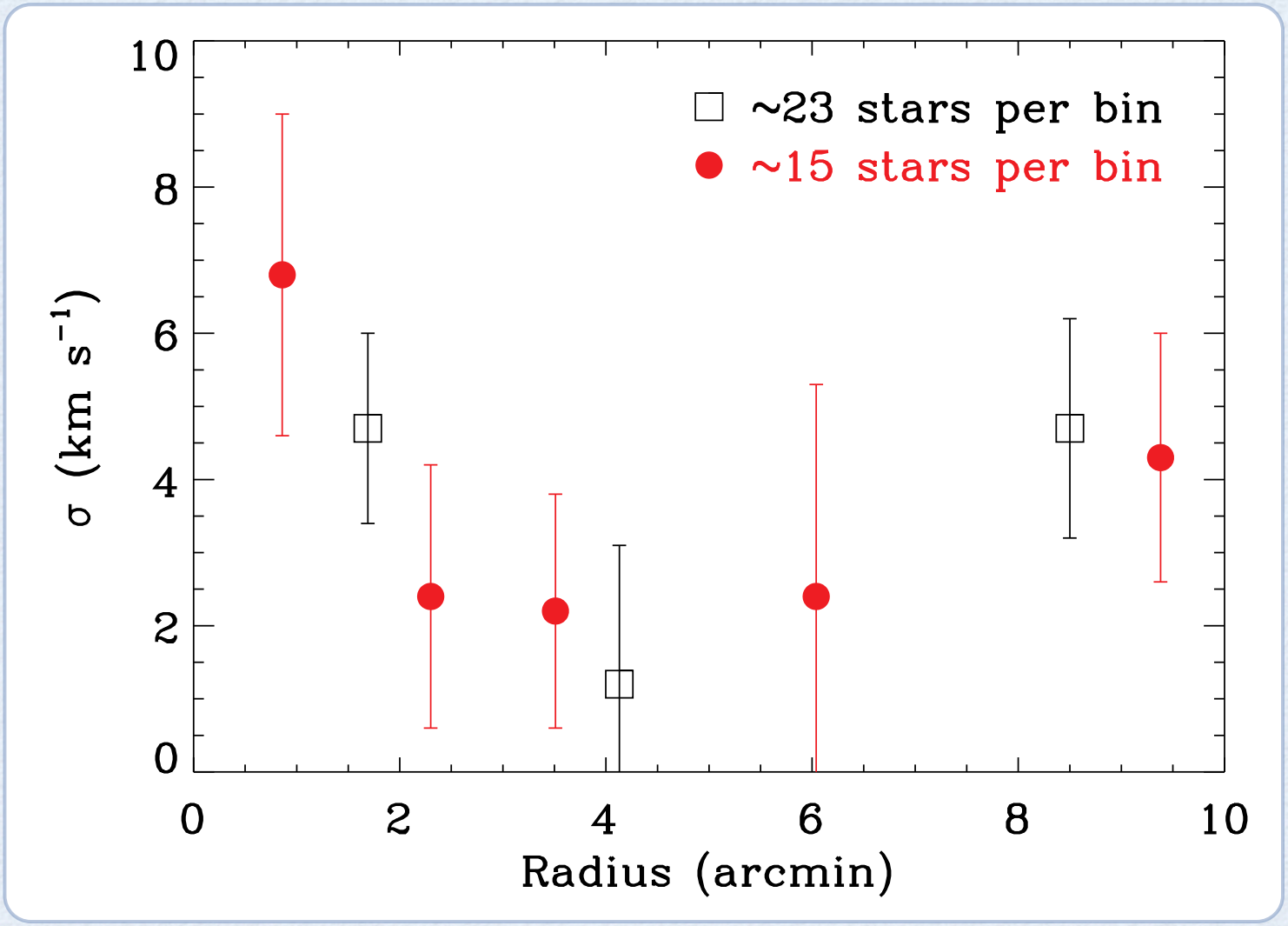
Geha, Willman, Simon, Strigari, Kirby, Law, Strader, ApJ 2009

The Darkest Galaxy: Segue 1



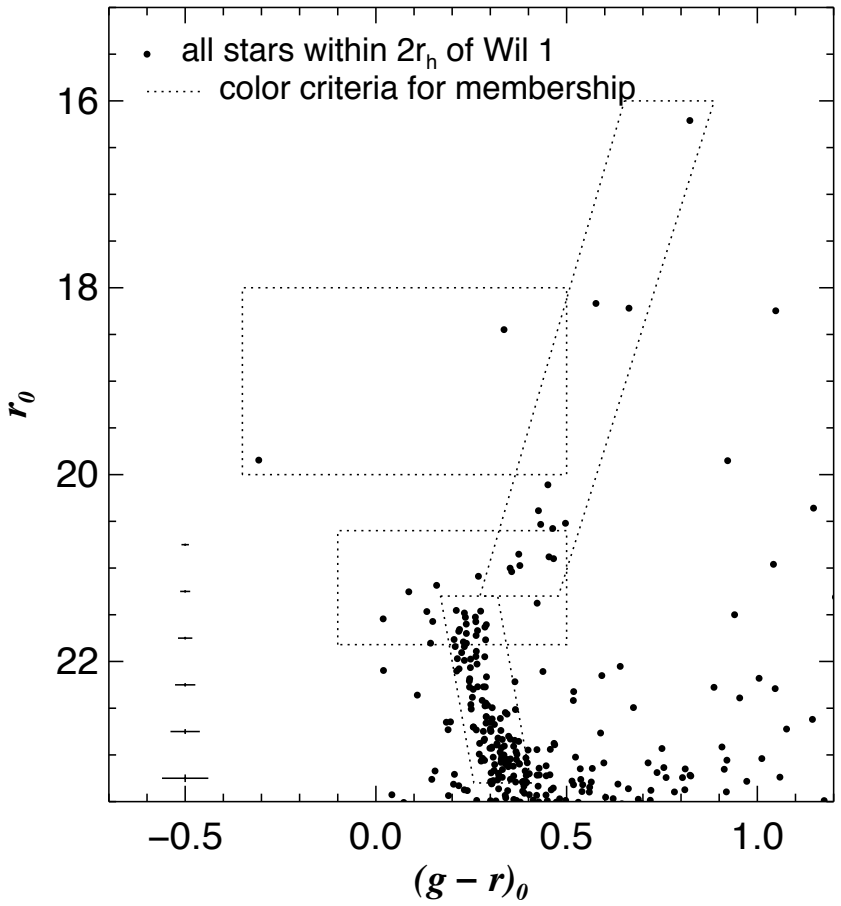
Simon, Geha, Martinez, Minor, Kirby, Bullock, Kaplinghat, Strigari, Law, Willman, Choi, et al., ApJ 2011

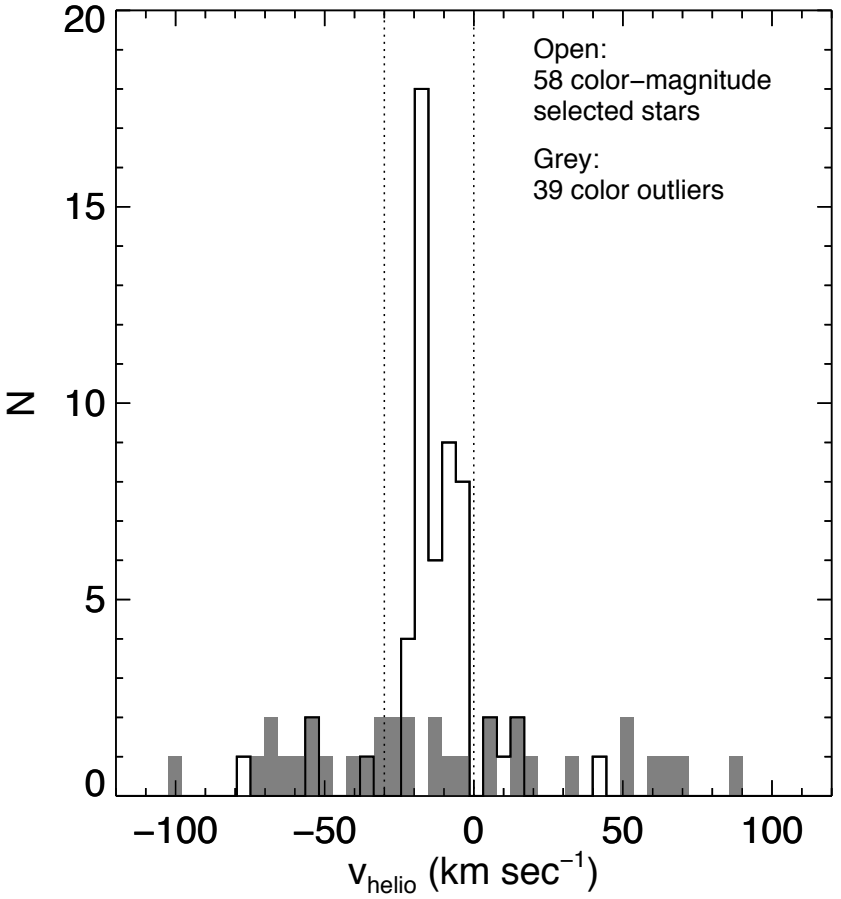
The Darkest Galaxy: Segue 1



Inclusion of binaries: Martinez et al. 2011, McConachie & Cote 2011

Willman 1: A probable galaxy





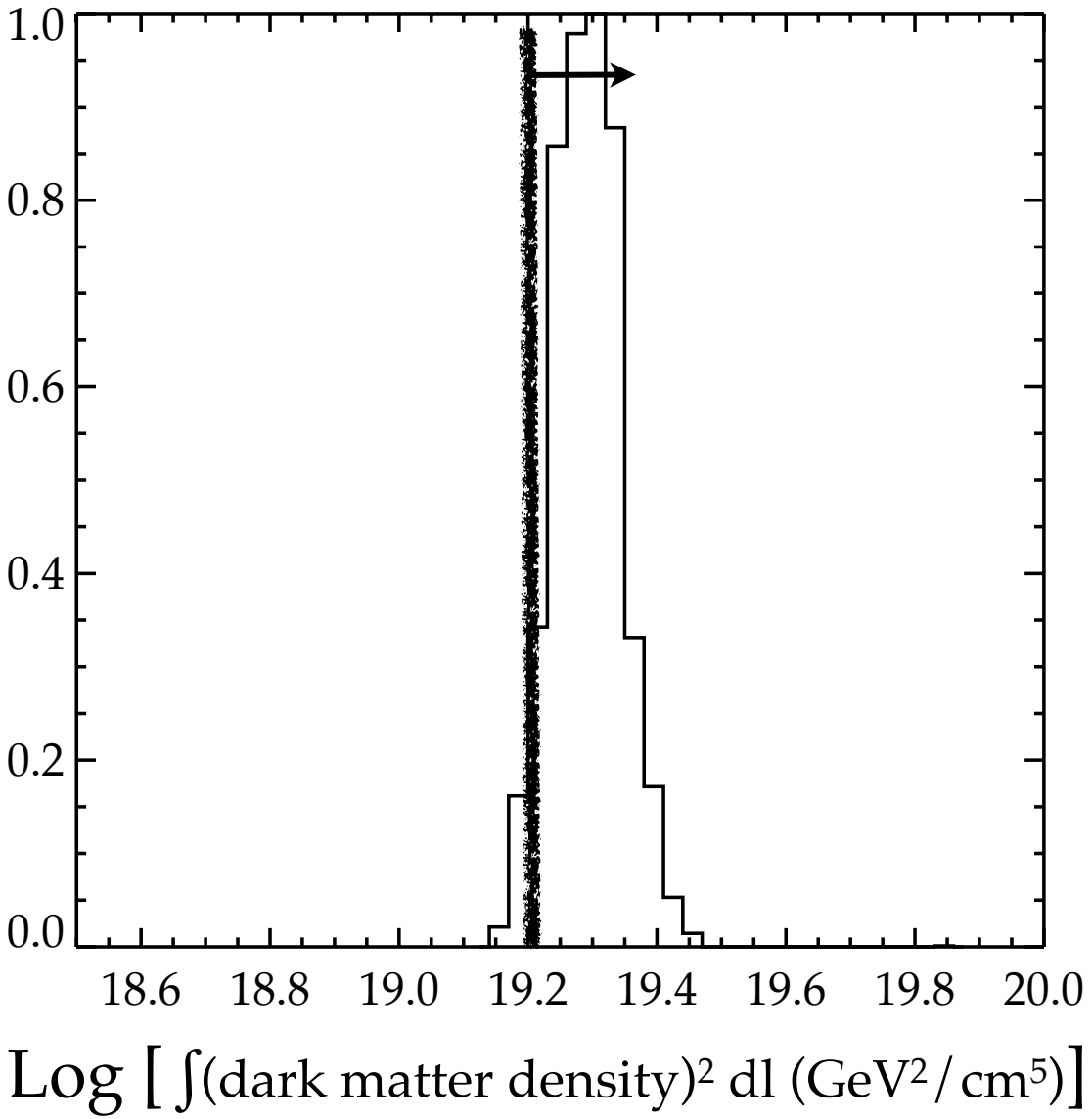
Willman, Geha,Simon, Strigari, Kirby, Strader, Warres, AJ 2010

Kinematics: More detailed look

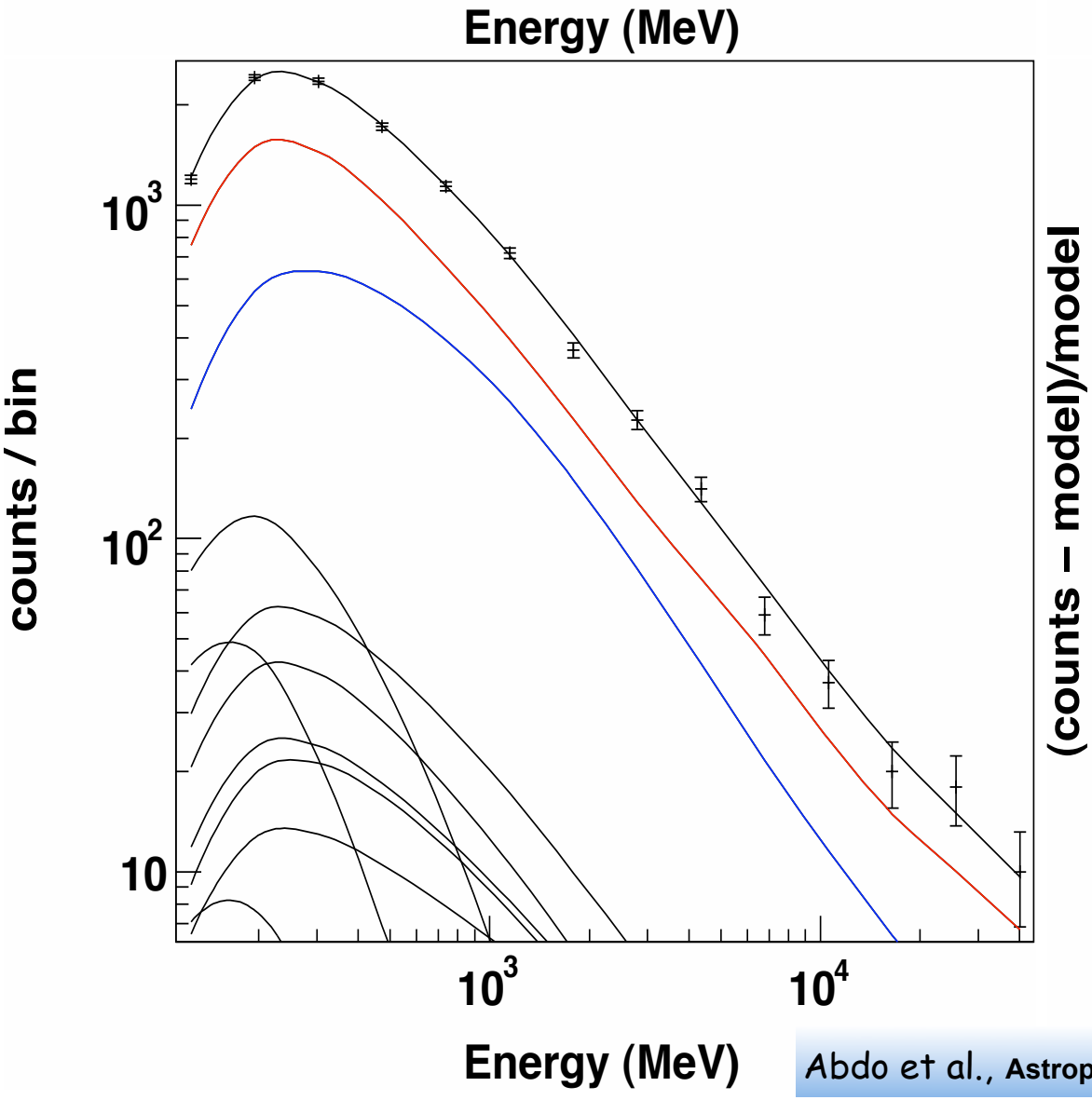
- Model both the stellar and the dark matter distribution
- Statistics of stellar orbits (velocity anisotropy)
- Assume hydrostatic equilibrium, determine mass
- Warning!: acceptable solutions don't guarantee consistent distribution function

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

Flux = $\left\{ \int_0^{\Delta\Omega} \left\{ \int_{\rm LOS} \rho^2[r(\theta, \mathcal{D}, s)]\, ds \right\} d\Omega \right\} \left\{ \int_{E_{\rm th}}^{M_\chi} \sum_i \frac{dN_{\gamma,i}}{dE} \frac{\langle \sigma v \rangle_i}{M_\chi^2}\, dE \right\}$

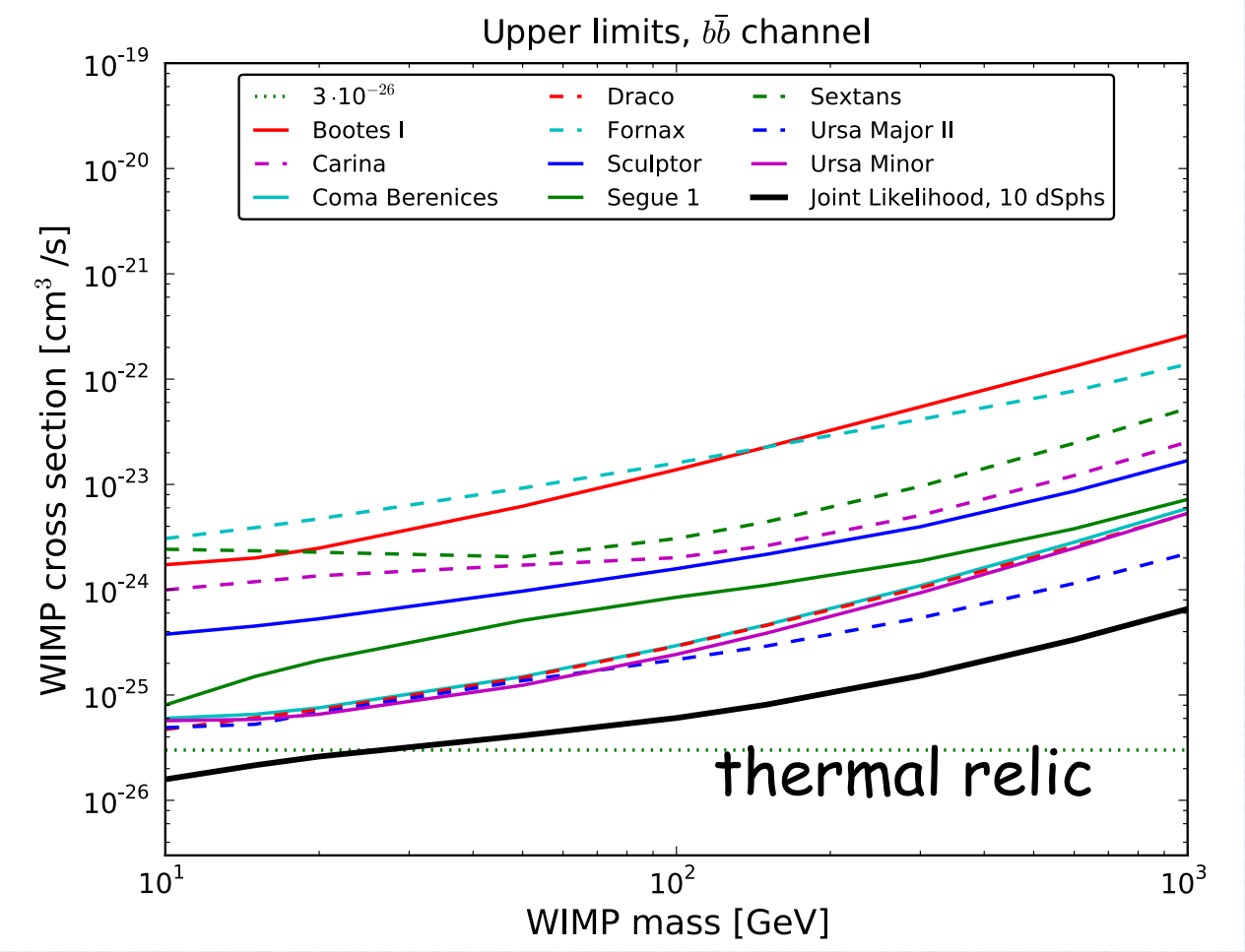


Are satellites gamma-ray sources?



Abdo et al., **Astrophys.J. 712 (2010) 147-158**

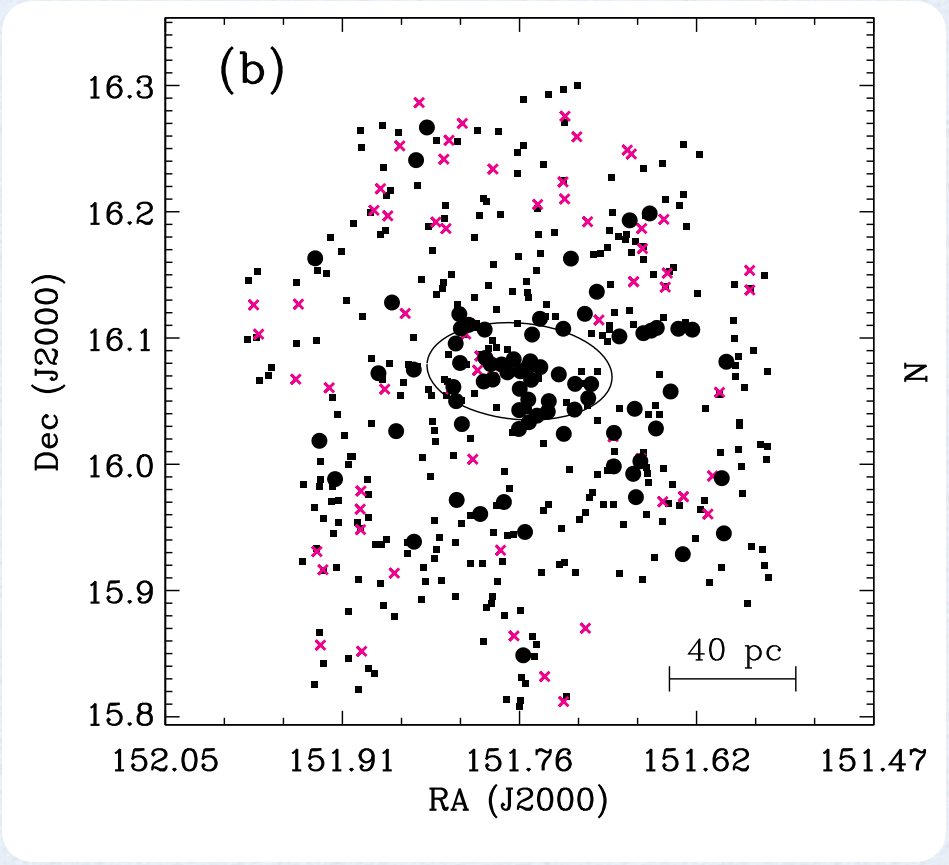
Stacked Satellite Search

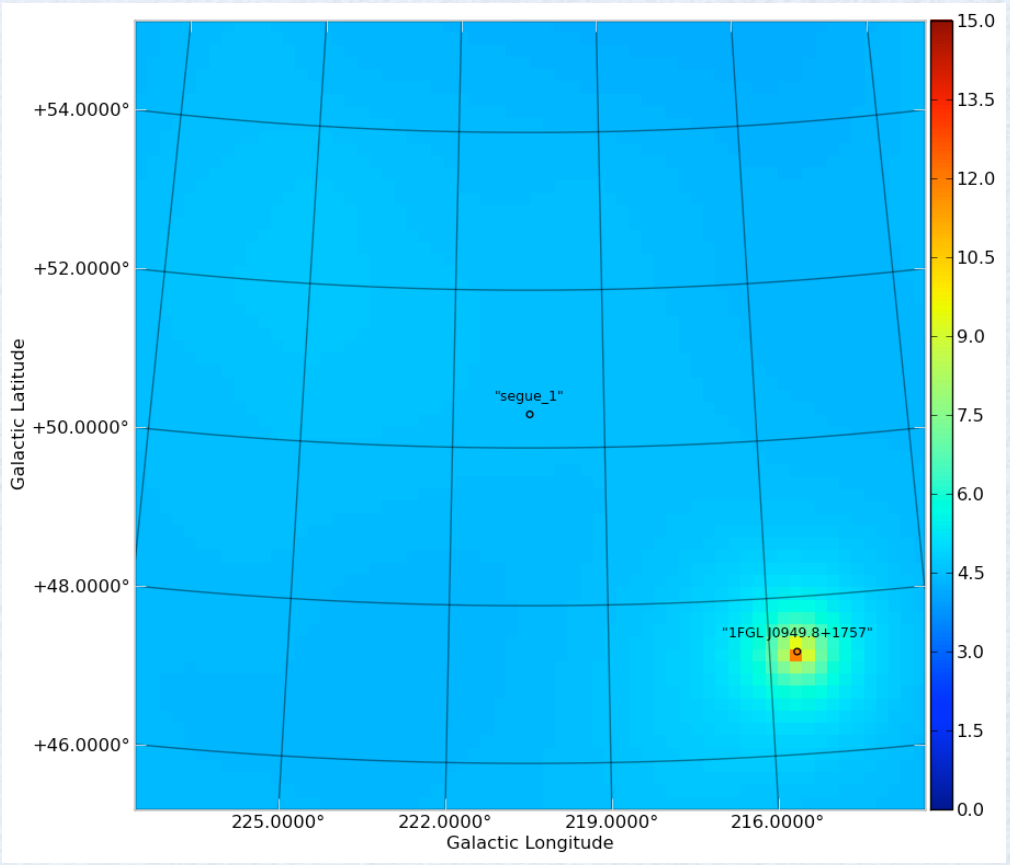


Fermi-LAT Collaboration, 1108.3546

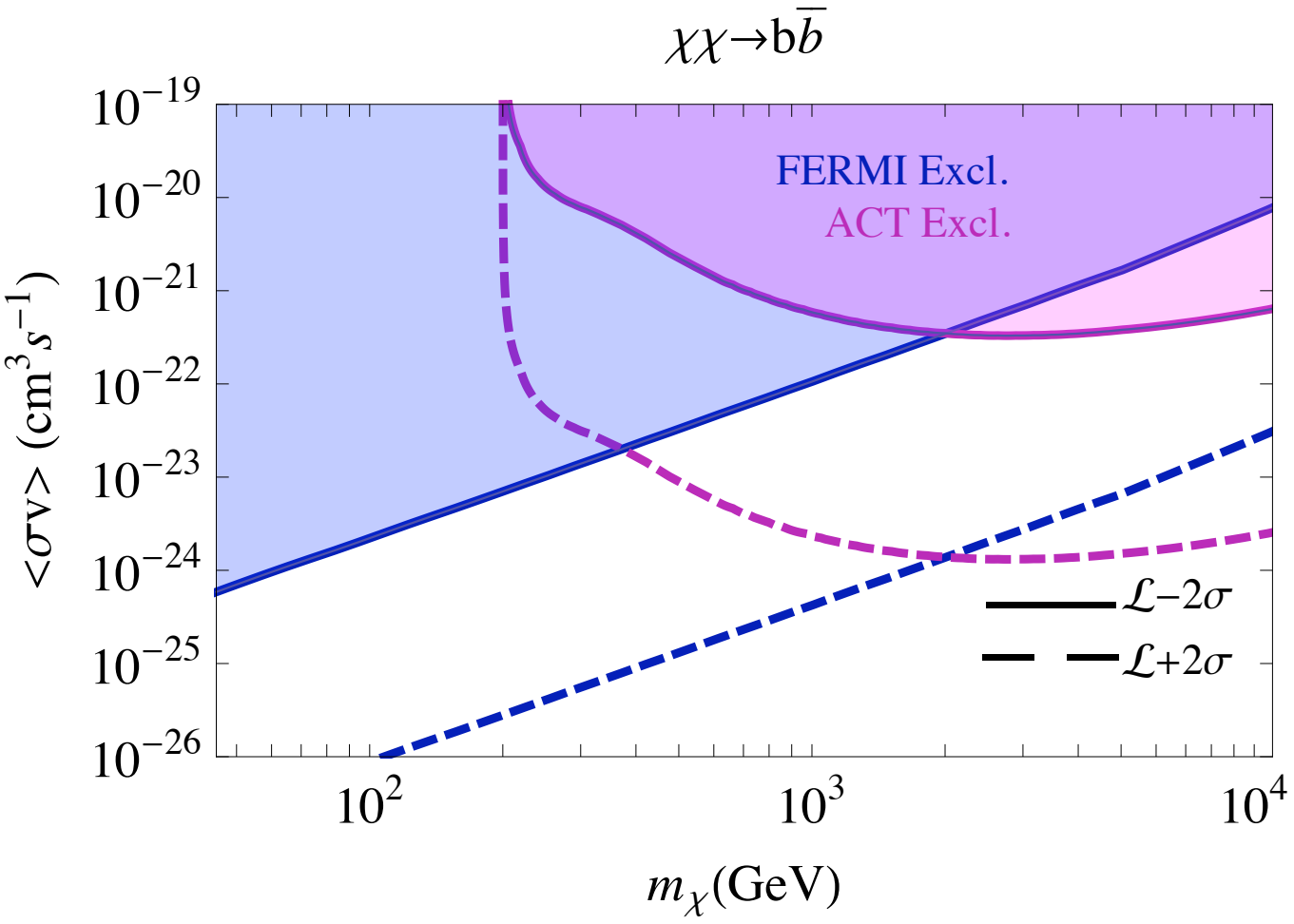
See also Geringer-Sameth & Koushiappas 2011 1108.2914

Segue 1: The Darkest Galaxy



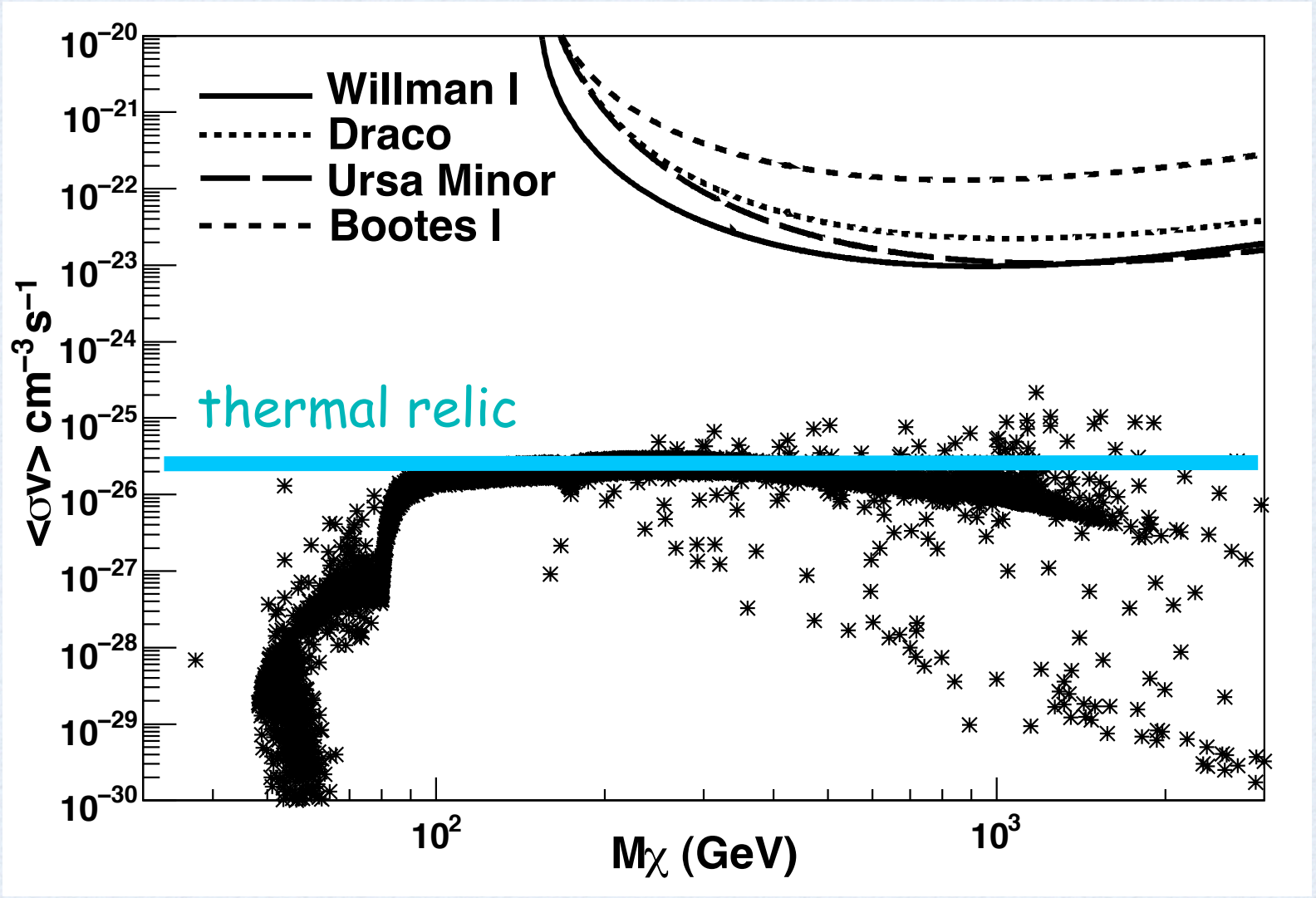


Gamma-ray limits: Segue 1

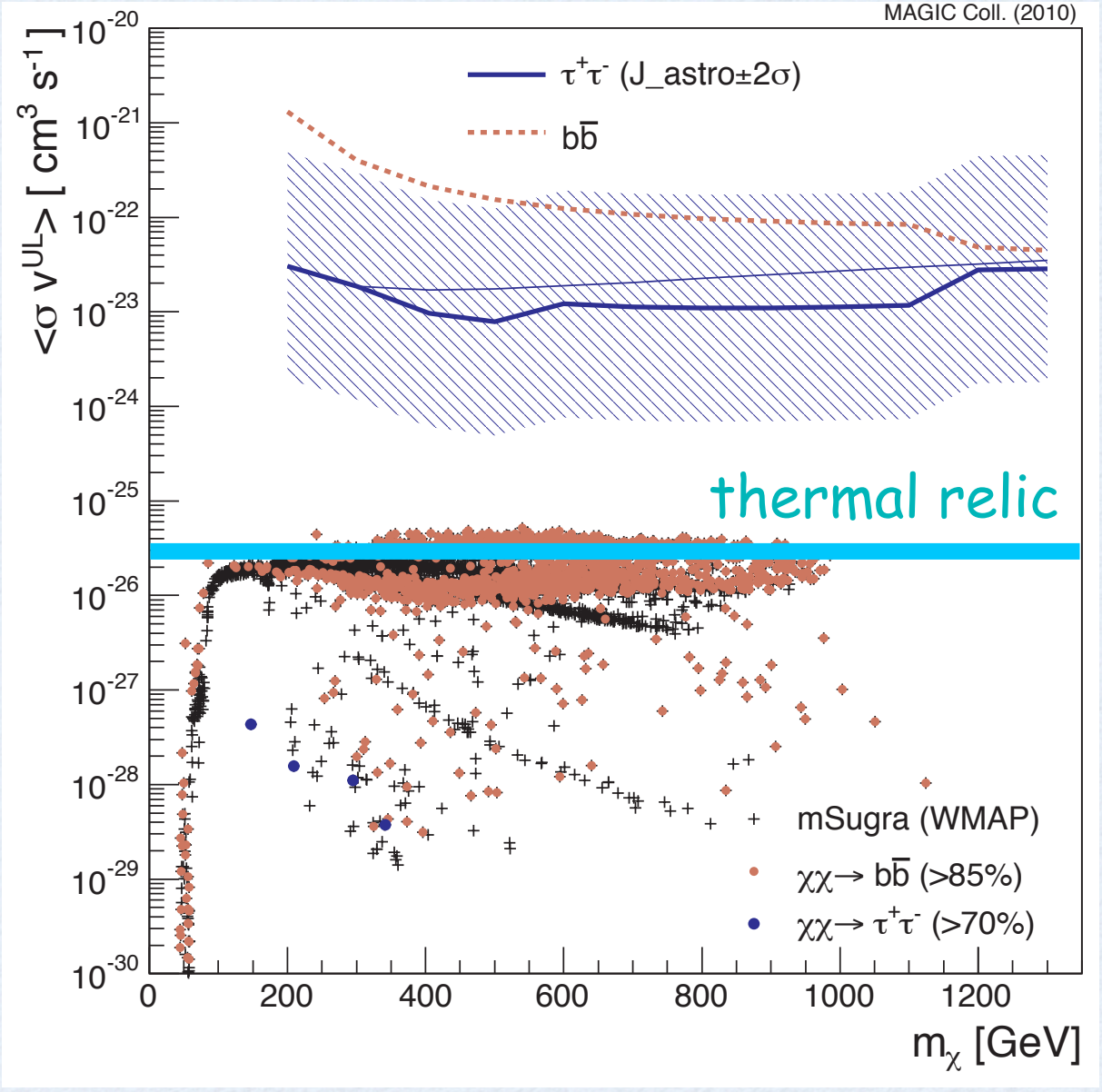


Essig, Sehgal, Strigari, Simon, Geha, PRD 2010

VERITAS


Willman I
Draco
Ursa Minor
Bootes I
thermal relic
<σV> cm⁻³ s⁻¹
Mχ (GeV)
10⁻²⁰
10⁻²¹
10⁻²²
10⁻²³
10⁻²⁴
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10⁻³⁰
10²
10³

MAGIC


MAGIC Coll. (2010)
$\tau^+\tau^-$ (J_astro±2σ)
$b\bar{b}$
thermal relic
mSugra (WMAP)
$\chi\chi \rightarrow b\bar{b}$ (>85%)
$\chi\chi \rightarrow \tau^+\tau^-$ (>70%)
$<\sigma v^{UL}>$ [$cm^3 s^{-1}$]
m_χ [GeV]

Projected limits

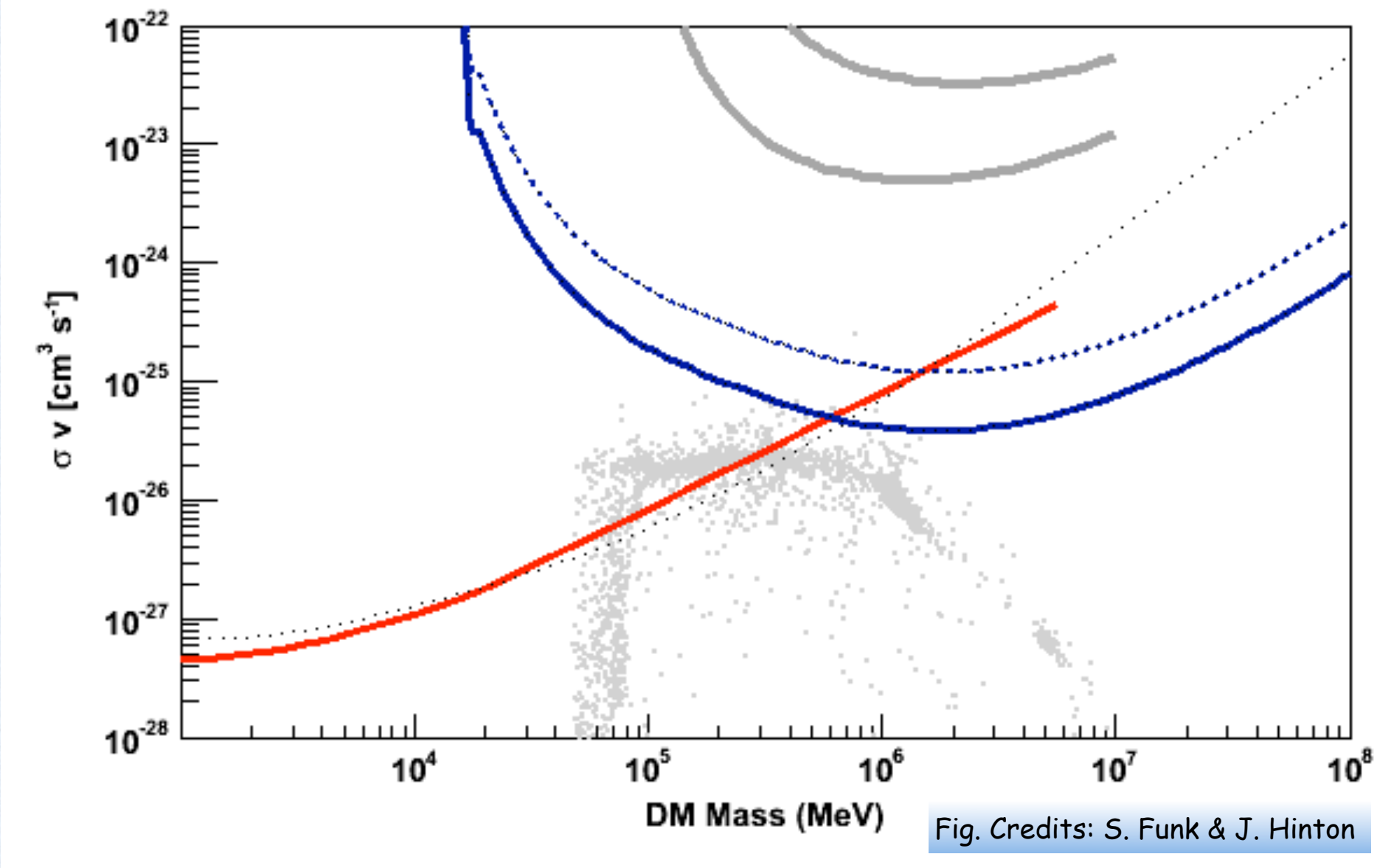
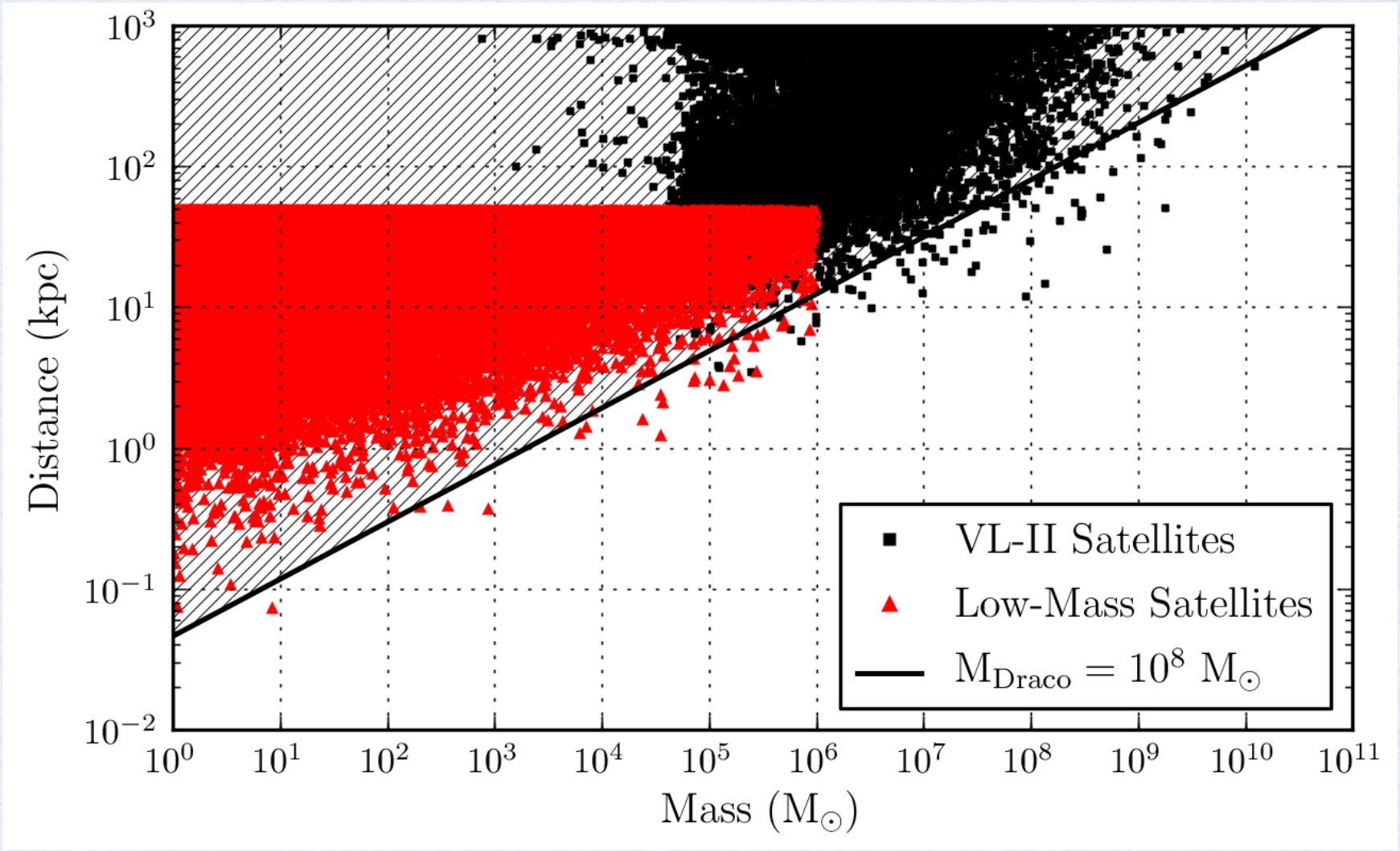


Fig. Credits: S. Funk & J. Hinton

Search for Dark Subhalos

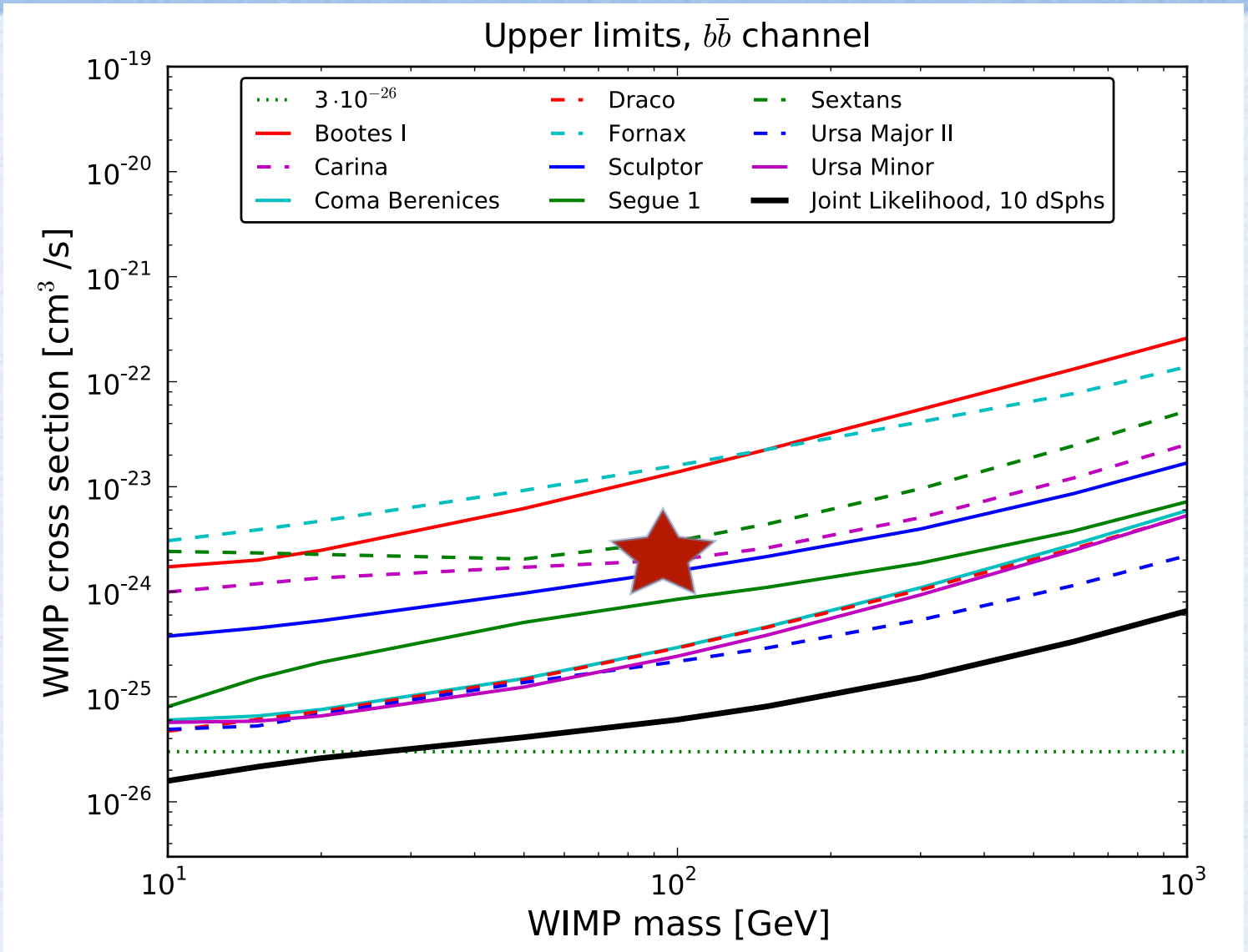
- Search for objects that only shine because of dark matter annihilation
- Some satellites could be within a few kpc of the Sun, and their extension may be resolved by the LAT
- Search criteria:
  - More than 20 degrees from Galactic plane
  - No counterpart at other wavelengths
  - Emission constant in time
  - Spatially extended: 1 degree radial extension
  - See also Belikov, Hooper, Buckley, 1111.2613

Search for Dark Subhalos



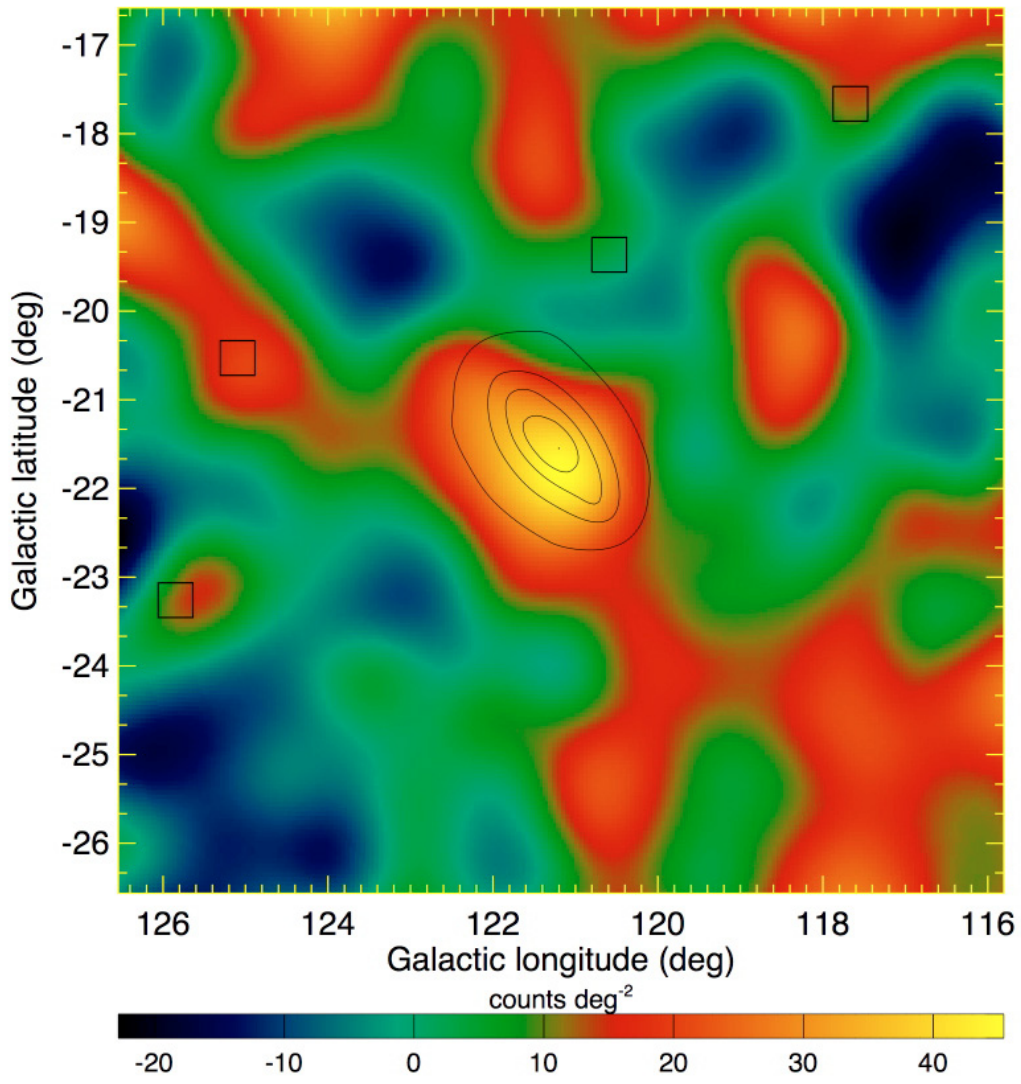
Preliminary, Fermi-LAT Collaboration, submitted to ApJ

Search for Dark Subhalos



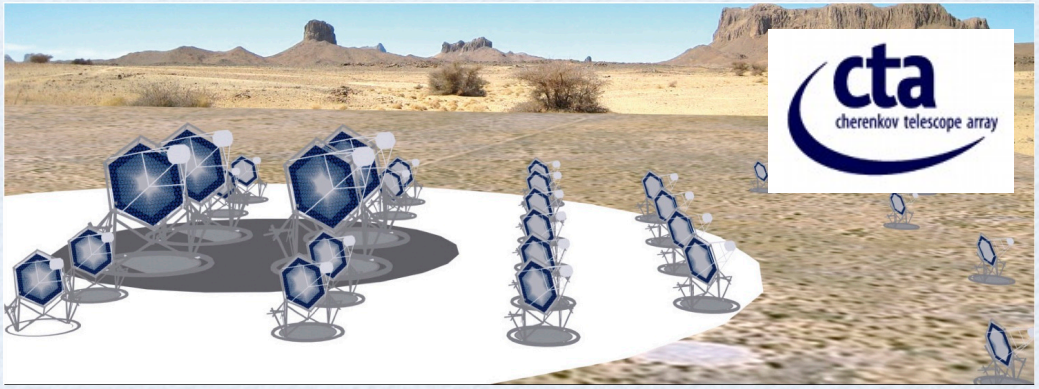
Preliminary, Fermi-LAT Collaboration, submitted to ApJ

Fermi-LAT detection of M31



Fermi-LAT collaboration, Astronomy and Astrophysics, 523, L2

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
- Stay tuned...