Dark Matter Signals from Dwarf Galaxies

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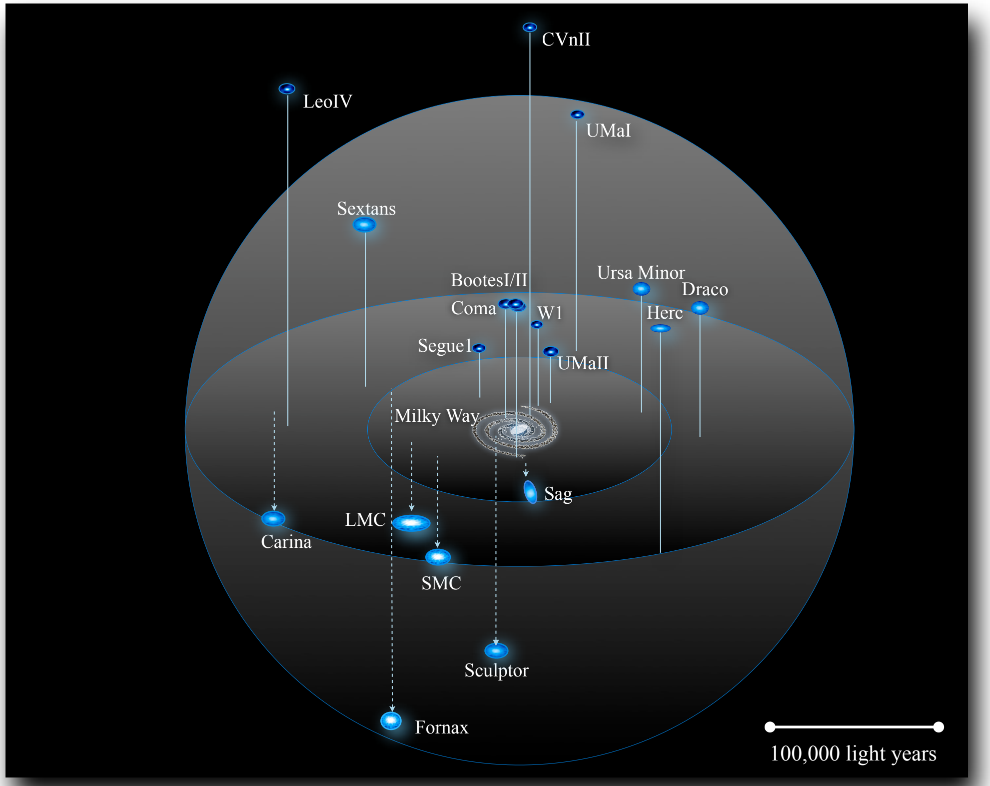
KIPAC

Shedding Light on Dark Matter
University of Maryland
April 2, 2009



Based on work with: James Bullock, Rouven Essig, Marla Geha, Manoj Kaplinghat, Greg Martinez, Neelima Sehgal, Josh Simon, Erik Tollerud, Beth Willman, Joe Wolf

Milky Way Circa 2009

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

Segue 2 2009

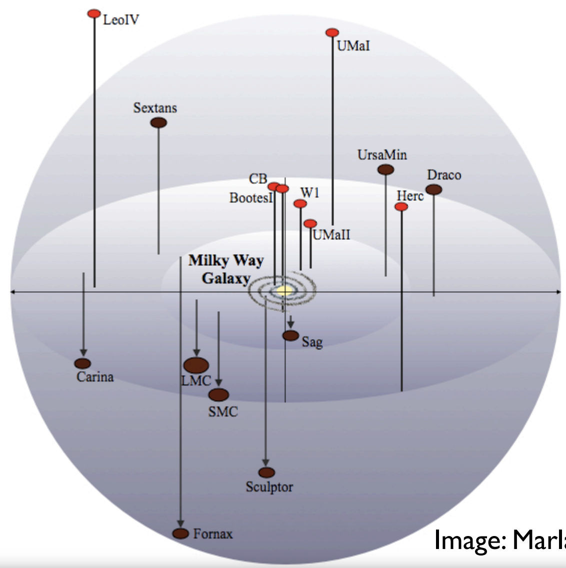
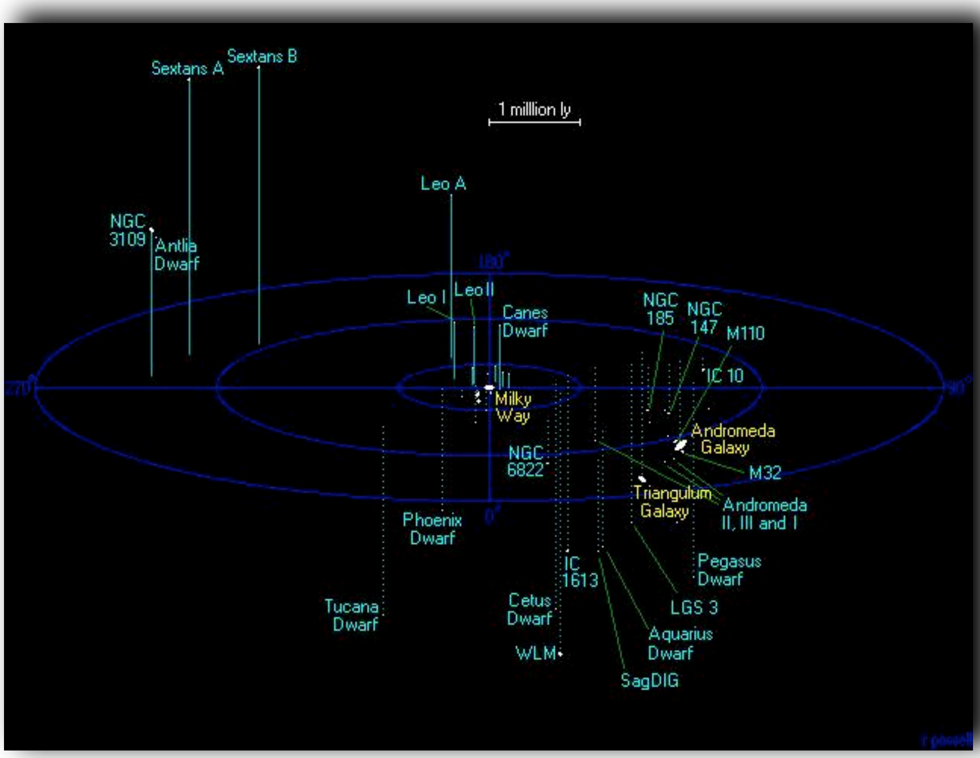
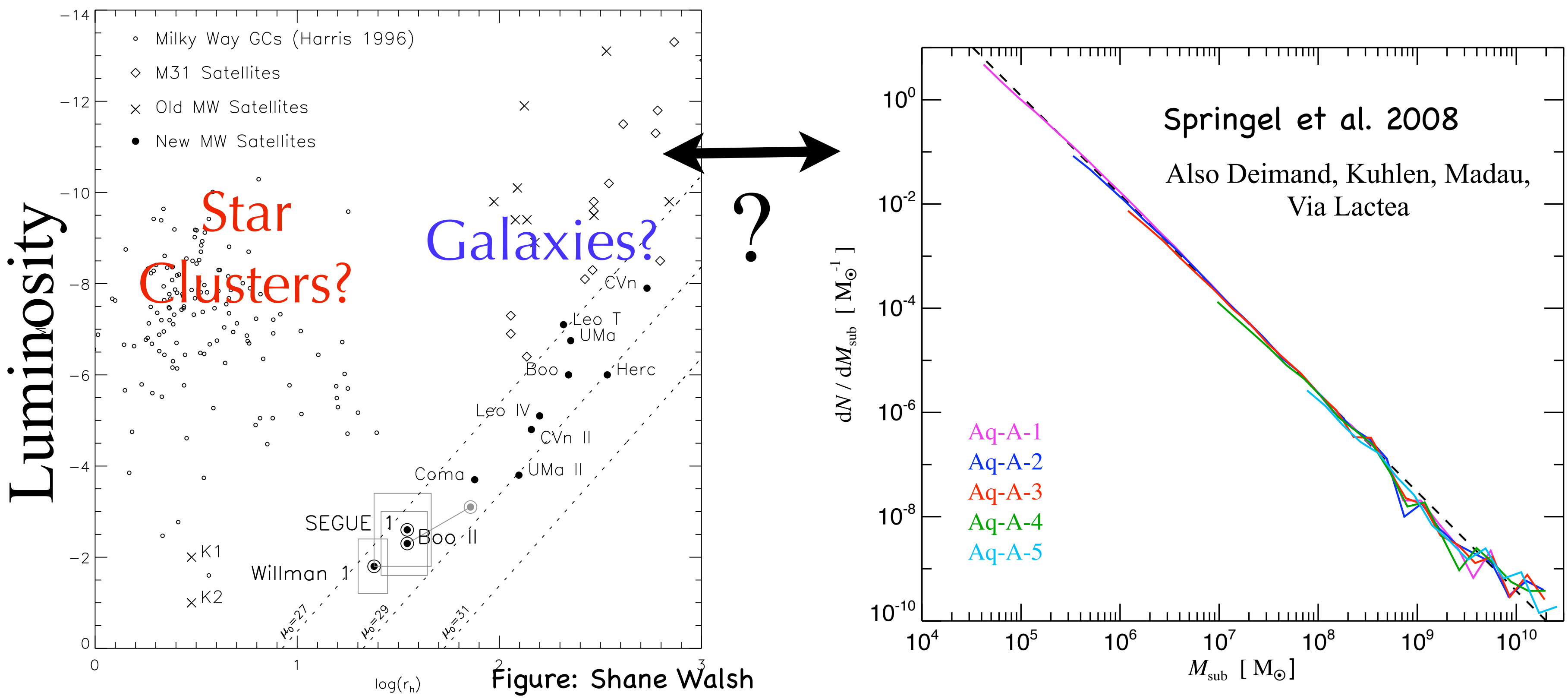


Image: Marla Geha



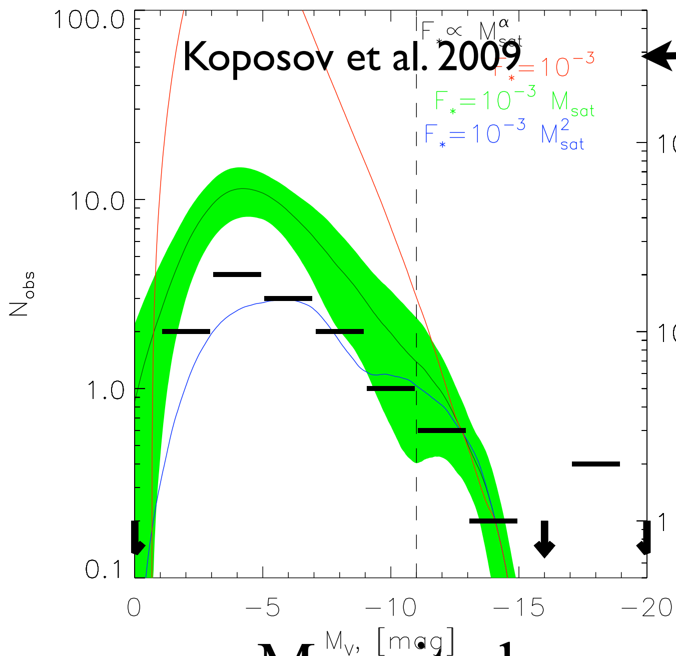
What is the minimum mass dark matter halo?
What is the minimum mass ``galaxy?”



Half-light radius

Belokurov et al. 2006,
Gilmore et al. 2007

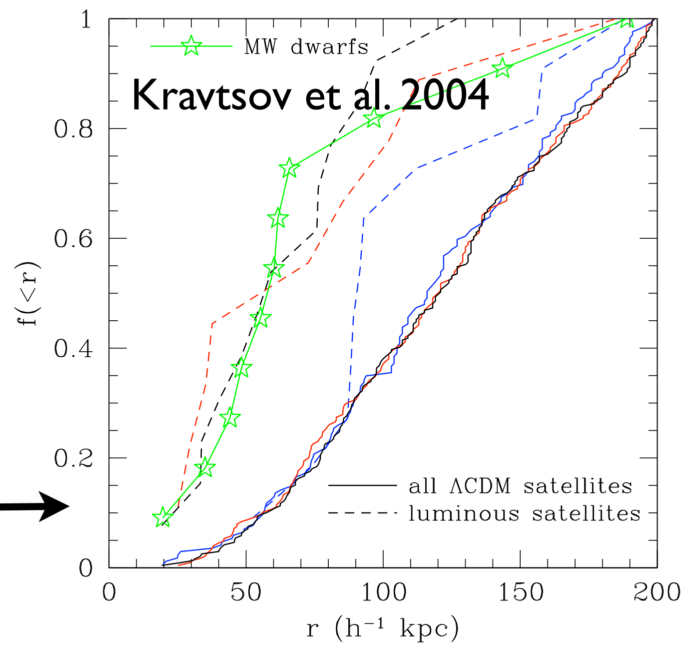
Mapping satellites onto CDM subhalos



Magnitude

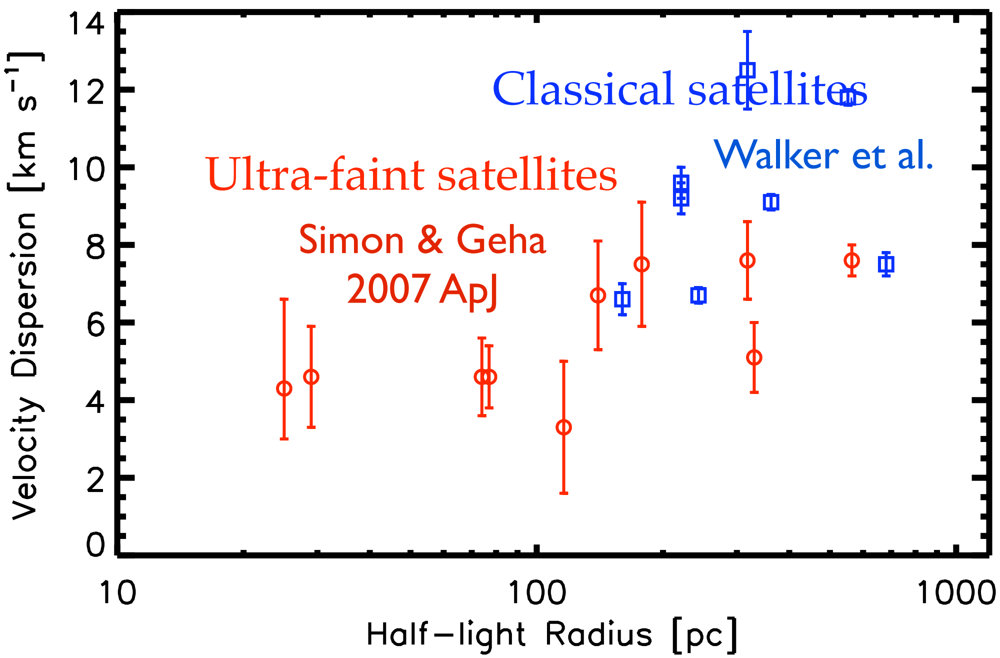
Luminosity function [e.g. Bullock et al. 2001, Benson et al. 2002, Somerville et al. 2002, Kravtsov et al. 2004, Koposov et al. 2008, Tollerud et al. 2008, Busha et al. 2009, Bovill & Ricotti 2009, Koposov et al. 2009]

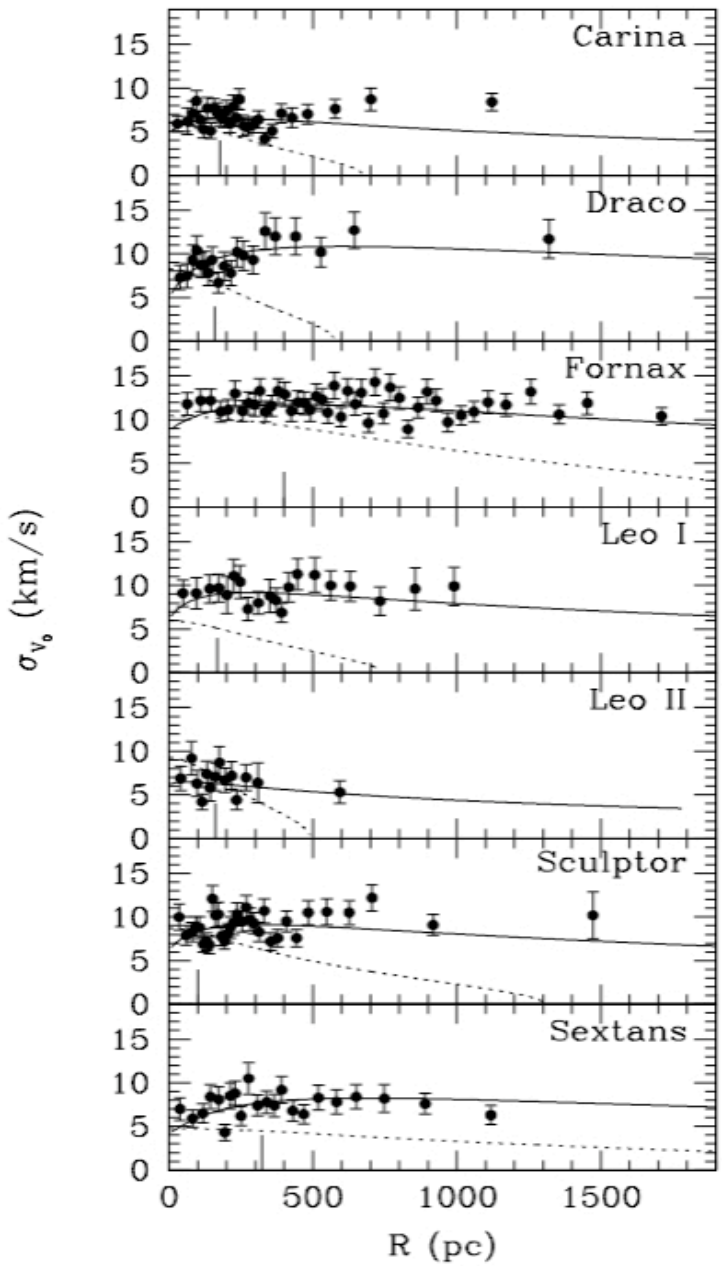
Radial/Velocity distribution
[e.g. Willman et al. 2004, Kravtsov et al. 2004]



Kinematics [e.g. Strigari et al. 2007, 2008, Li et al. 2008, Maccio et al. 2008]

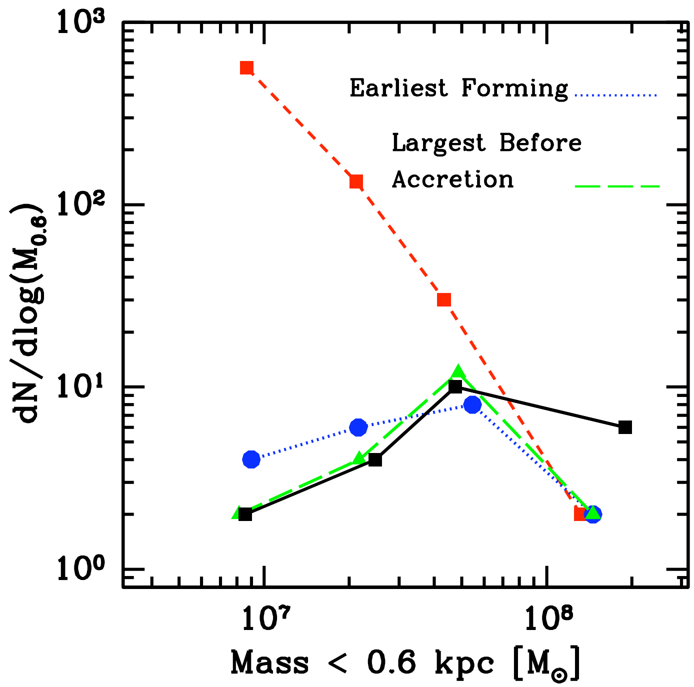
Dwarf halo kinematics





Walker et al ApJL 2008

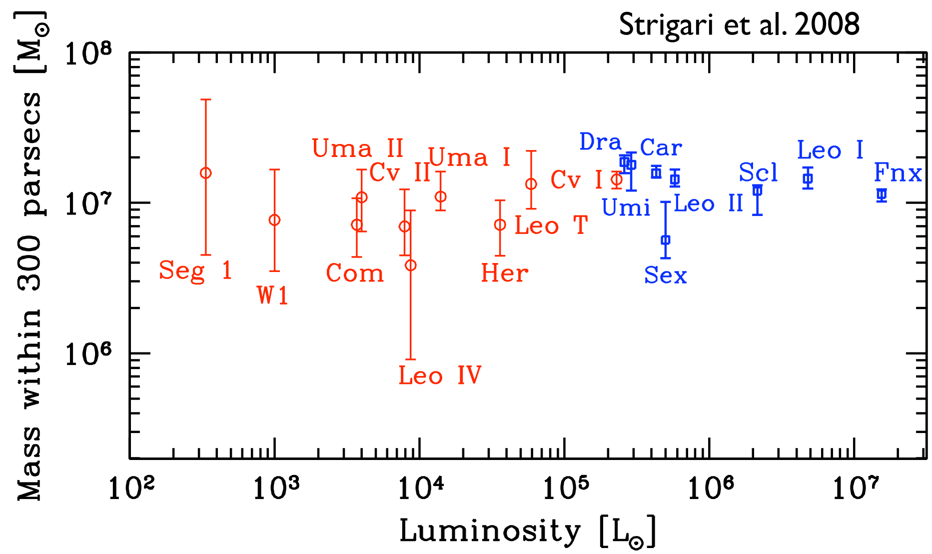
Satellite Masses



Does not appear that the satellite distribution correlates with z=0 mass
[Kazantzidis et al. 2003, Kravtsov et al 2004, Moore et al. 2005]

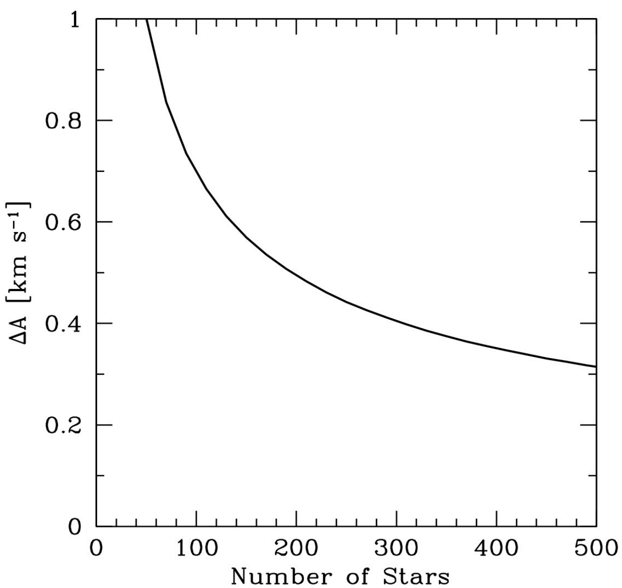
- Derived from spherical-symmetric analysis with variable velocity anisotropy
- Up to 8 parameters are free, though all not necessary for the faintest systems

Agrees with results from Lokas 2009, given assumptions



- Estimated total mass-to-light ratios: 10-1000+
- Segue 1: Least luminous known galaxy (Geha et al. 2009)
- Tidal effects important, but not within stellar radius (Penarrubbia et al. 2008)

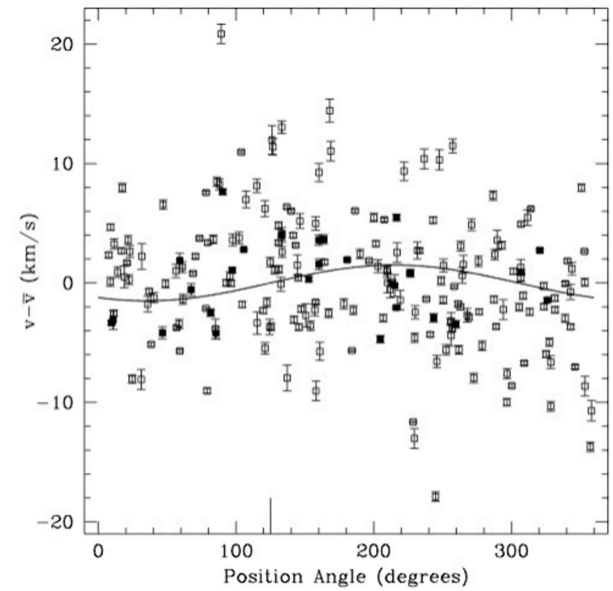
Tidal Disruption and Rotation



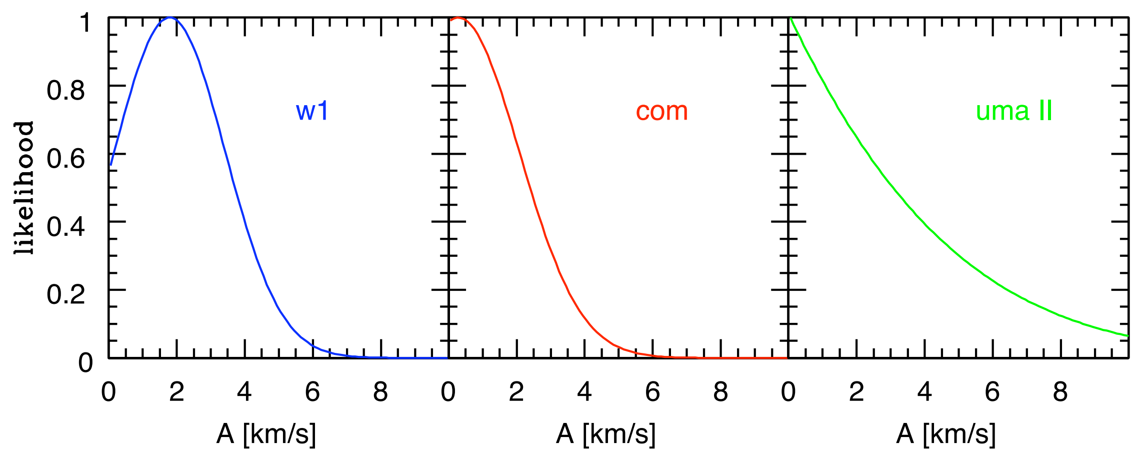
Error projections assuming 1 km/s rotation/gradient

- *Theoretical error modeling indicates that hundreds of stars needed for detection of a gradient*

Rotation in this sense detected in M15 GC [Drukier et al. 1998]

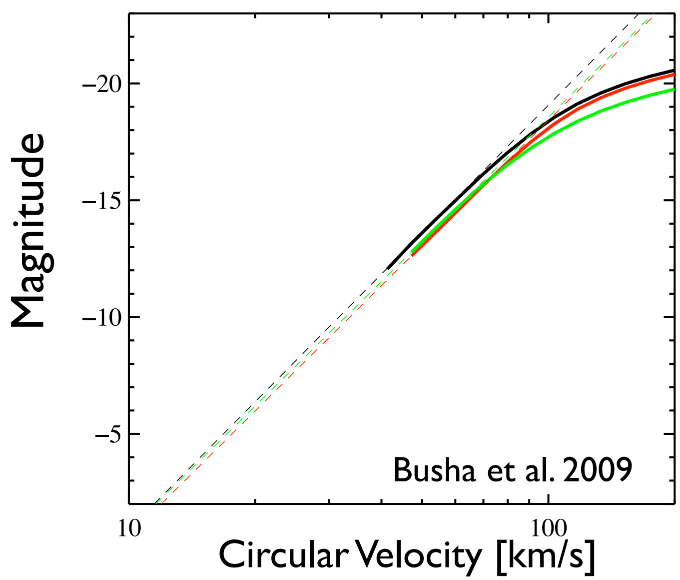


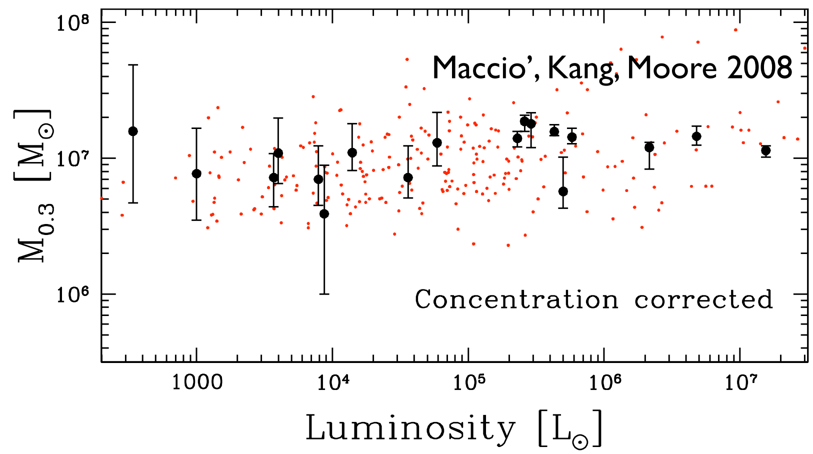
New results for ultra-faints in M. Geha talk, Friday

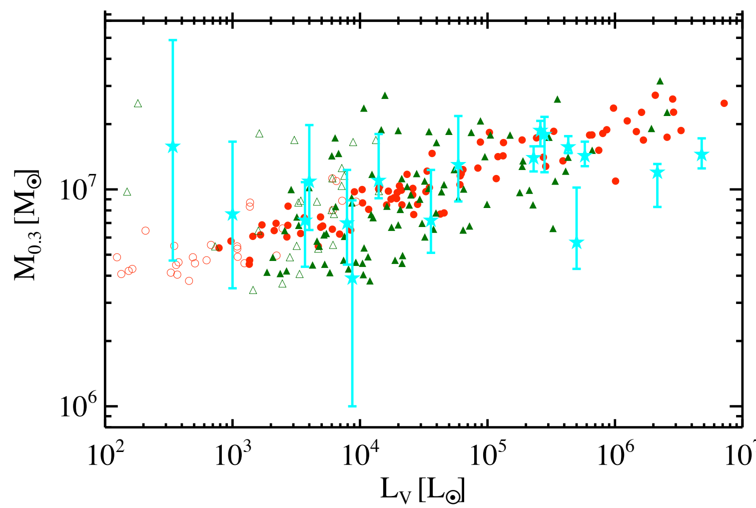


Rotation Amplitude

LCDM and the M_{300}/M_{600} relation



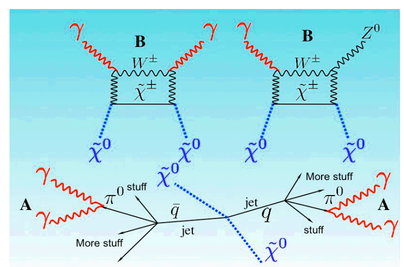




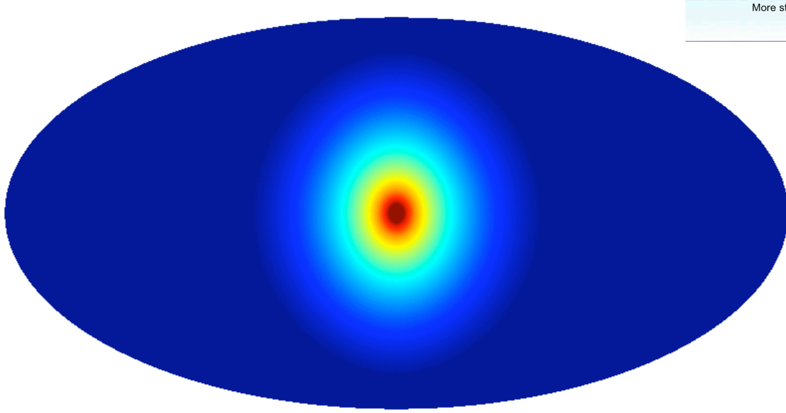
- Extrapolation of abundance matching technique [e.g. Kravtsov et al. 2004] implies the least luminous galaxies live in halos of about 10^8 Msun

See also Li, Helmi, De Lucia, Stoehr 2008; Koposov et al. 2009

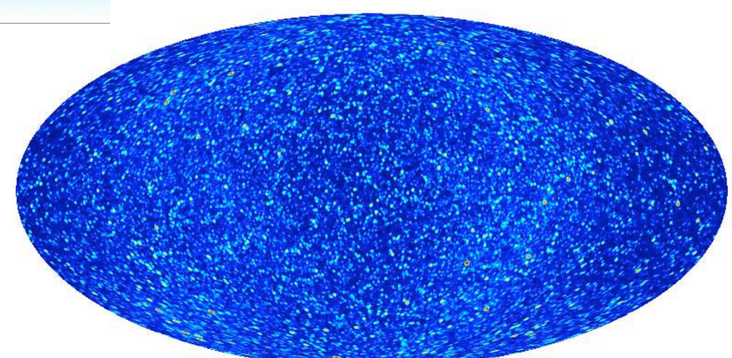
Dark Matter annihilation radiation in the Milky Way



smooth main halo emission (MainSm)



emission from resolved subhalos (SubSm+SubSub)



Springel et al. Nature 2008

Indirect Detection

If the halo is smooth:

Smooth halo flux = Particle Physics x Astrophysics

$$\mathcal{P}[\langle \sigma v \rangle, M_\chi, dN_\gamma/dE]$$

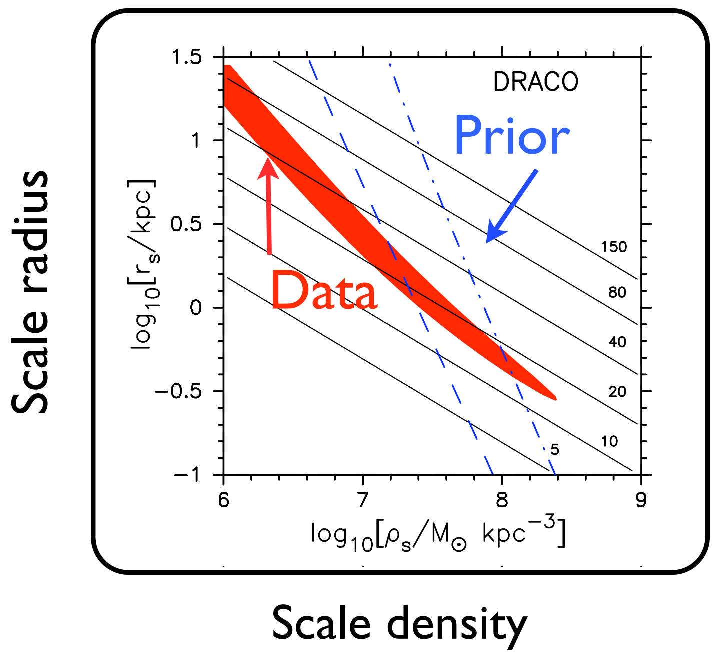
$$\mathcal{L} = \int_0^{\Delta\Omega} \left\{ \int_{\mathrm{LOS}} \rho^2[r(\theta, \mathcal{D}, s)] ds \right\} d\Omega,$$

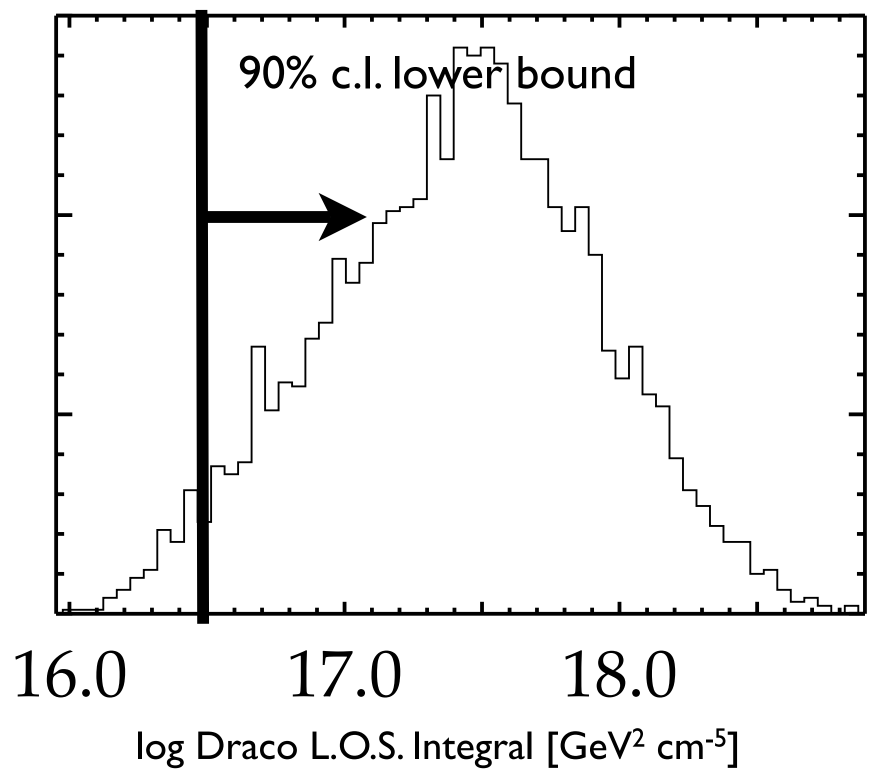
If there is sub-structure:

Total flux = [Smooth halo Flux] x [Substructure Boost]

Annihilation Signals + Halo Kinematics

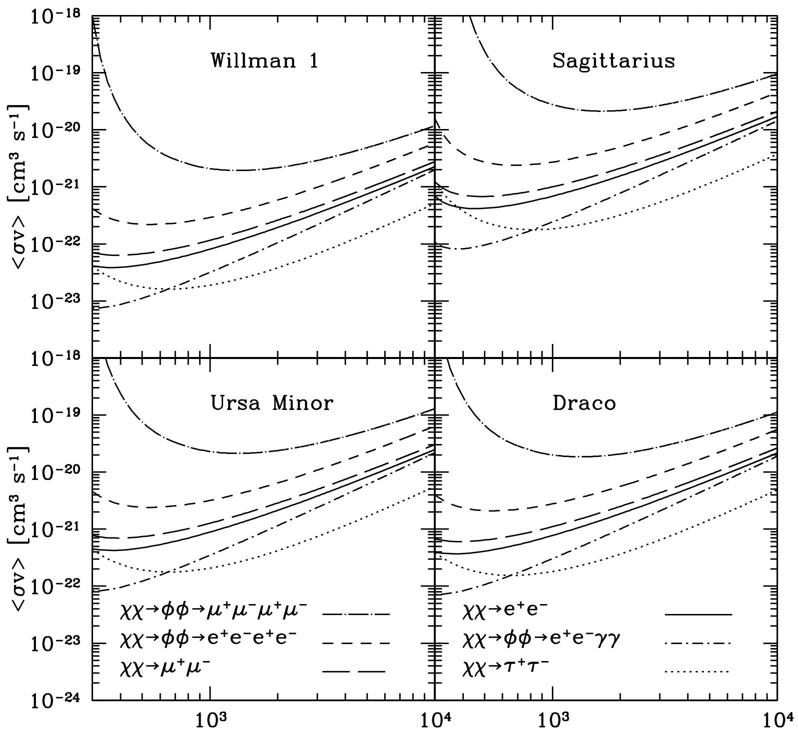
- Combine MCMC code that determines best fitting halo parameters with a DM particle model
  - Provides robust bounds on the DM properties, accounting for astrophysics
  - Can either use ``CDM” or ``non-CDM” based models by marginalizing over varying ranges of the inner and outer slopes





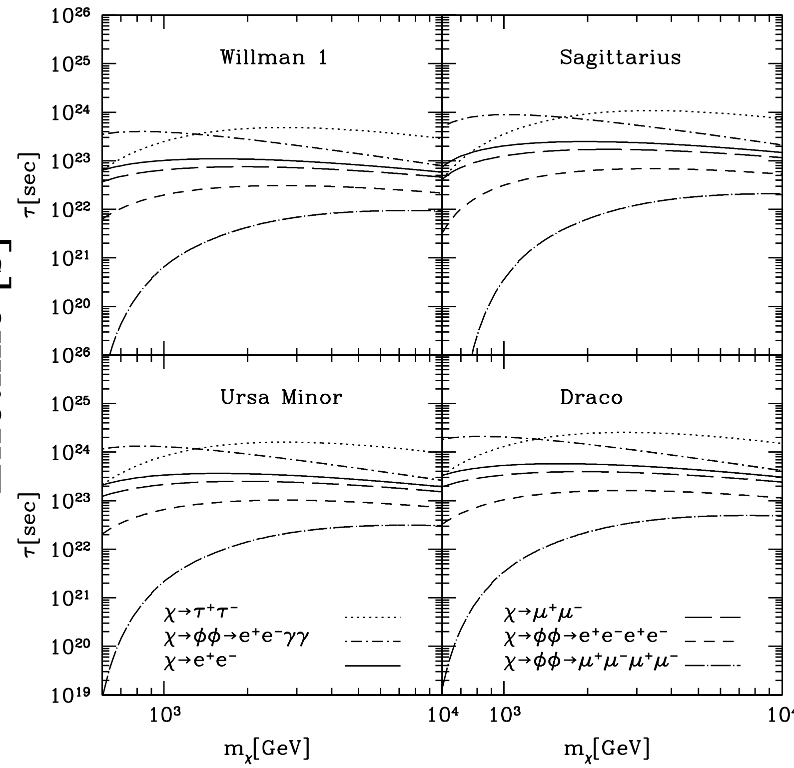
Cross Section/Lifetime Bounds

Annihilation Cross Section [cm^3 s^{-1}]



Dark matter mass [GeV]

Lifetime [s]

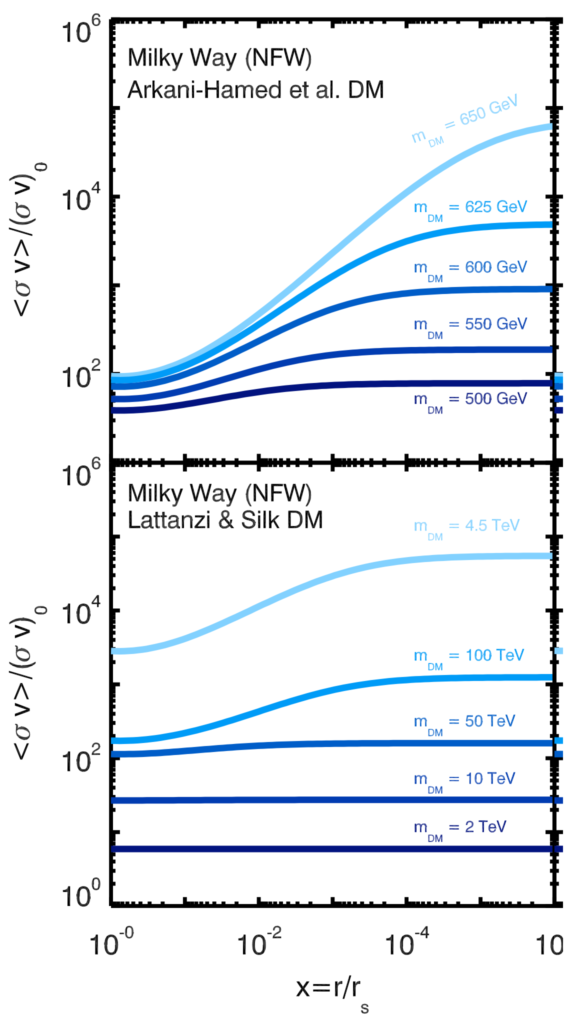


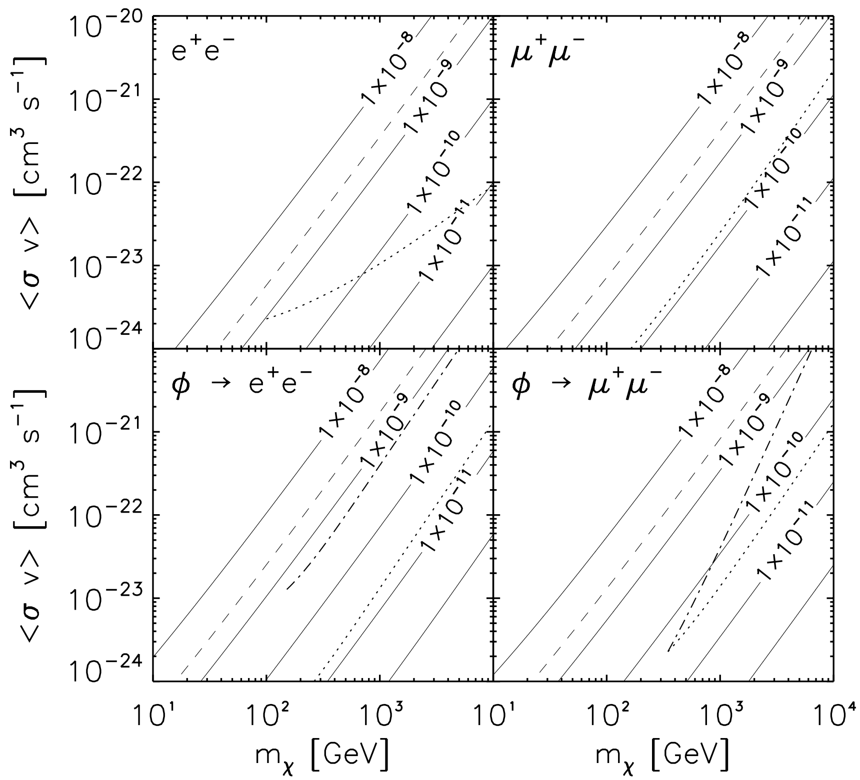
Dark matter mass [GeV]

Essig, Sehgal, Strigari 2009

Sommerfeld Effect in dSphs

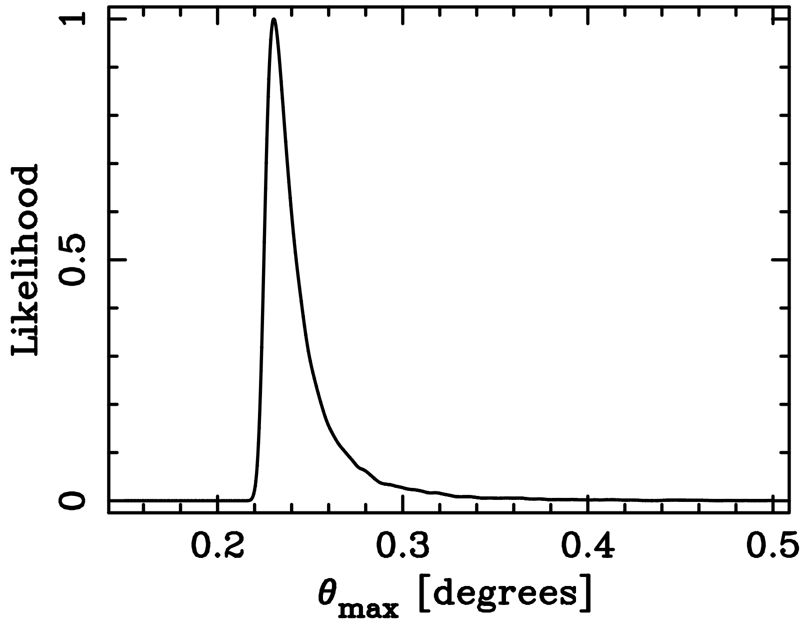
Robertson & Zentner



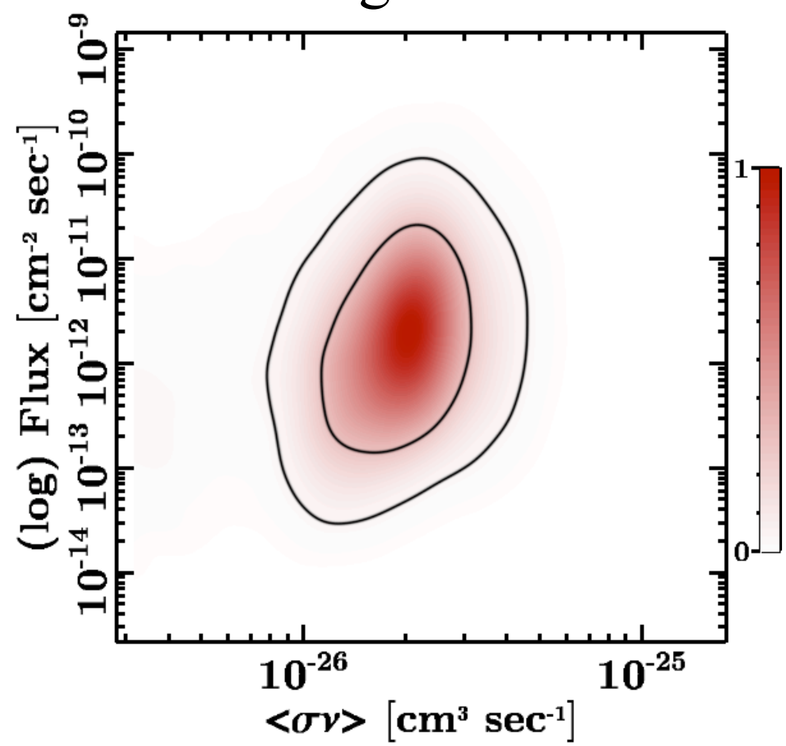


If sommerfeld effect explains PAMELA, flux detectable within about 1 year with Fermi
[Essig, Sehgal, Strigari 2009]

Supersymmetry predictions



Segue 1



G. Martinez et al. 2009

- Marginalizes over all CMSSM parameters (SuperBayes, Ruiz de Austri et al. 2006)
- Marginalizes over all astrophysical parameters, including Boost

Milky Way/Local Group Mass

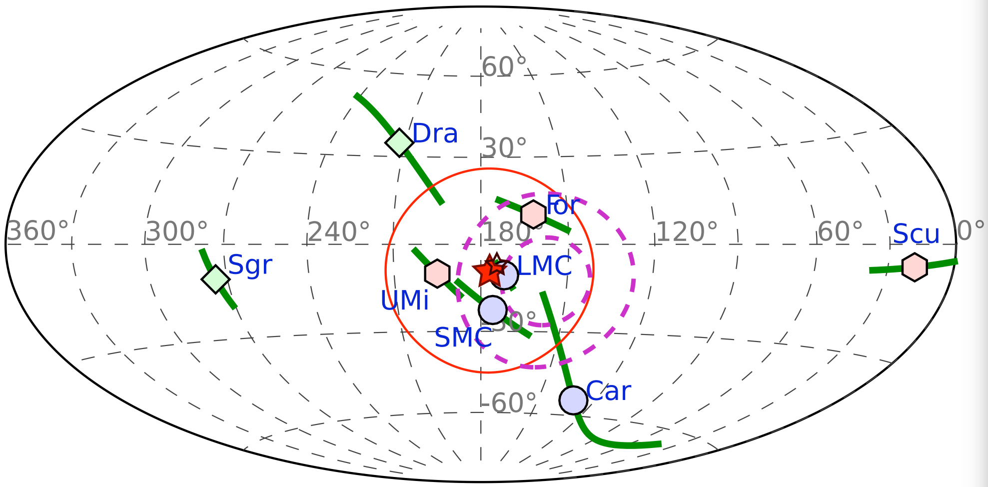
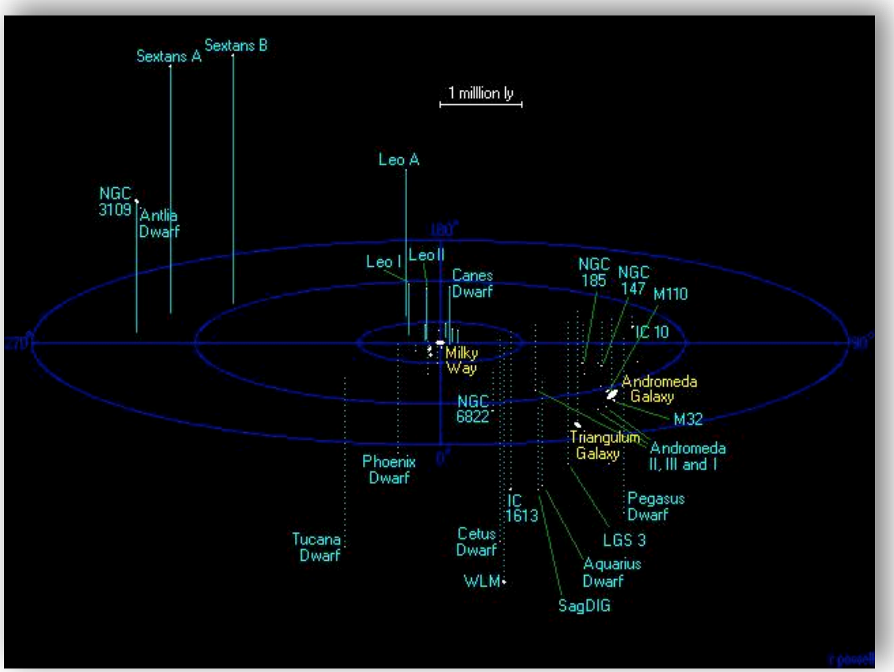


Figure from Metz & Kroupa 2008



Updated applications of Timing argument imply Local Group mass of 5×10^{12} Msun and MW mass of 2×10^{12} Msun [van der Marel & Guthalakurta 2008, Li & White 2008]

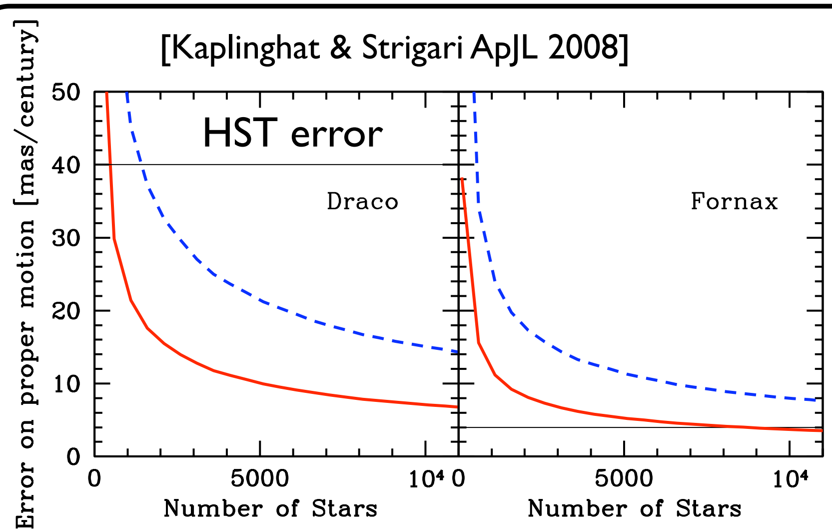
- Ground-based proper motions: Scholz & Irwin 1994, Schweitzer et al. 1997, Ibata et al. 1997, Dinescu et al. 2005
- Space-based proper motions: Piatek et al. 2002-2007

Satellite proper motions

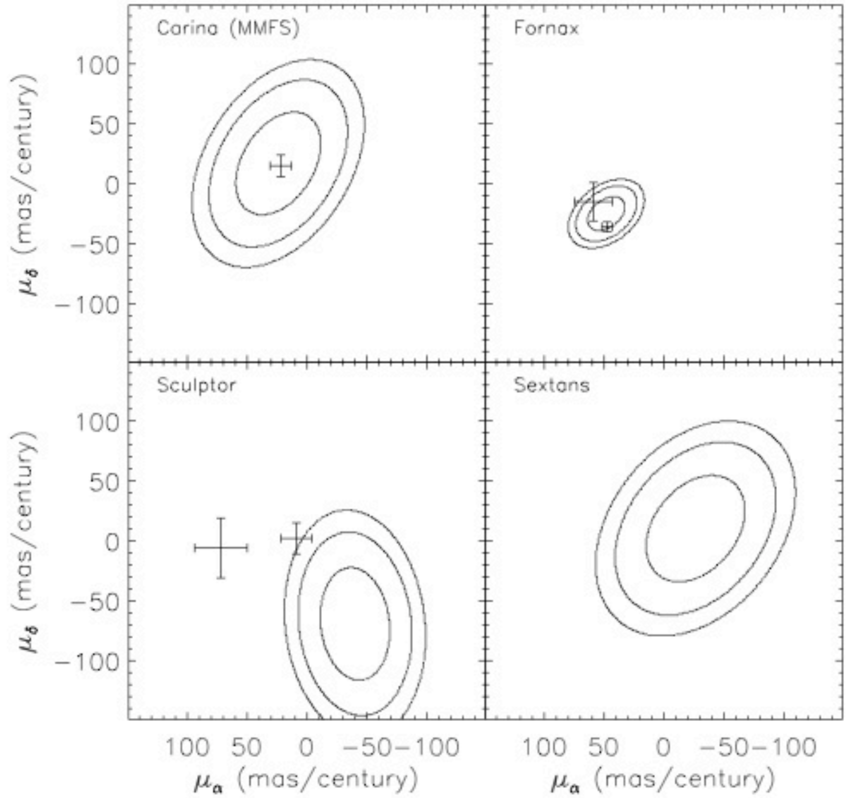
``Perspective rotation”; see Feast, Thackeray, & Wesselink MNRAS 1961

- Line-of-sight velocities in some cases better than HST proper motions
- Sagittarius: Constraints on the shape of the MW halo
- Is Leo I bound to the MW? LMC, SMC?

[Kaplinghat & Strigari ApJL 2008]



Walker, Mateo, & Olszewski ApJL 2008



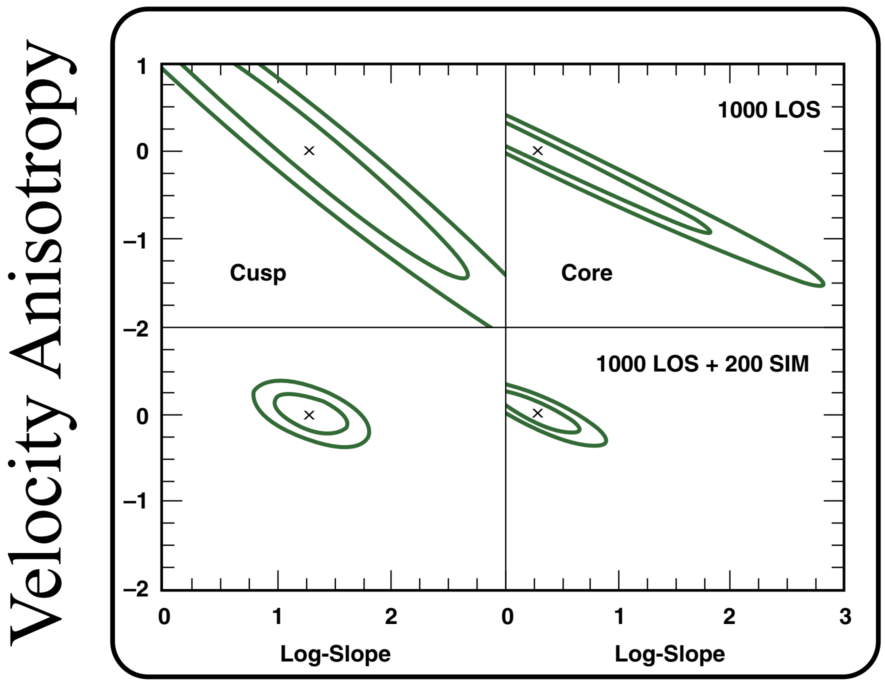
The core/cusp ``problem”

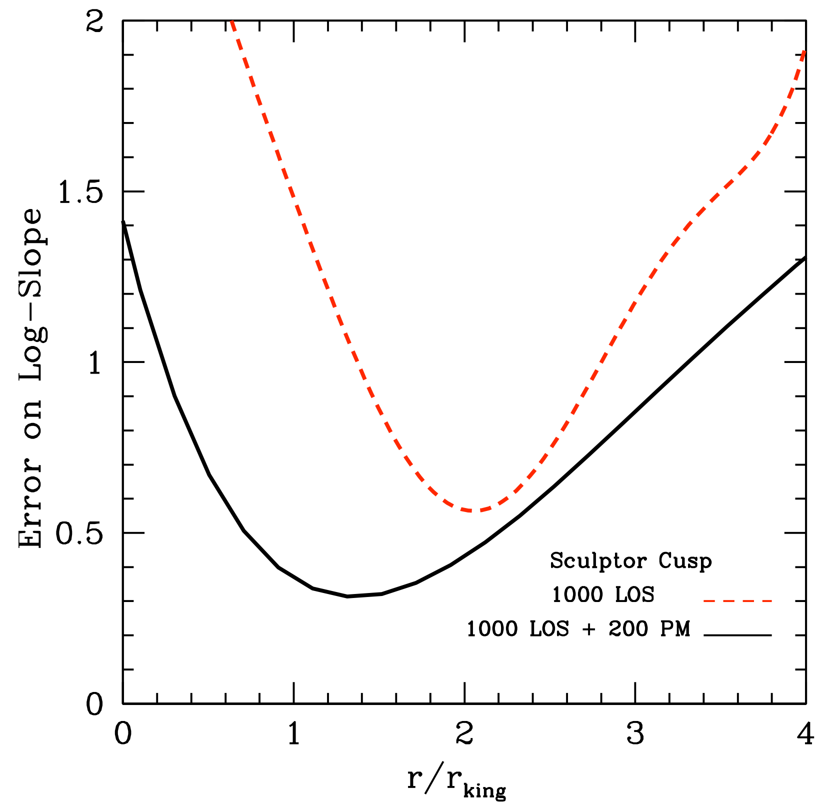
- CDM predicts NFW/Einasto cuspy profiles
- WDM or some alternatives predict shallower central densities
- Current data from MW dwarf spheroidals are unable to conclusively establish whether these galaxies have cores or cusps

Projections

Beta/log-slope degeneracy precludes measurement of central density profile

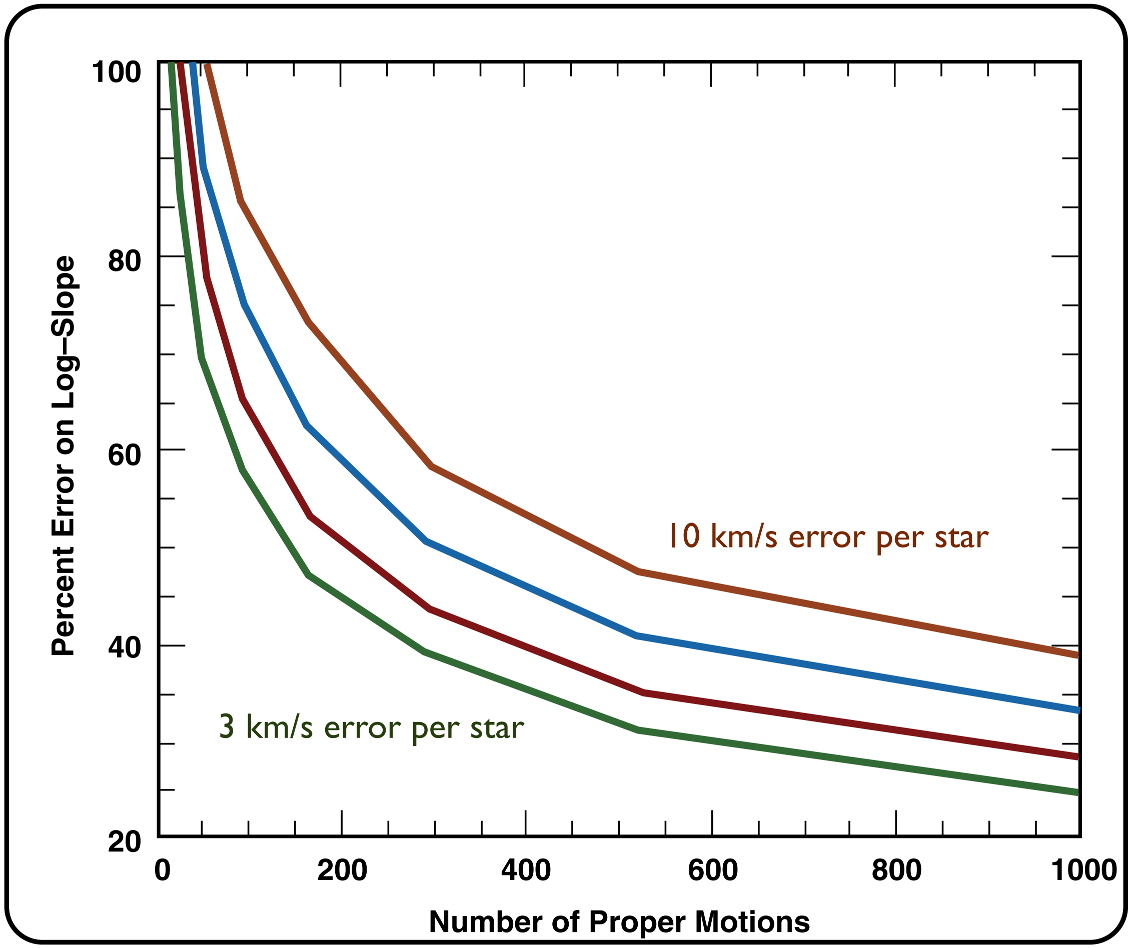
See Wilkinson et al. MNRAS 2002 for earlier modeling





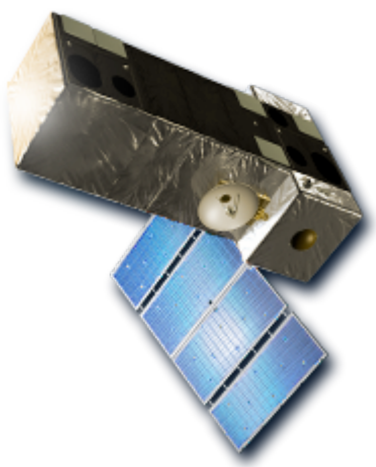
Proper motions probe DM halo profile in central regions

Error projections

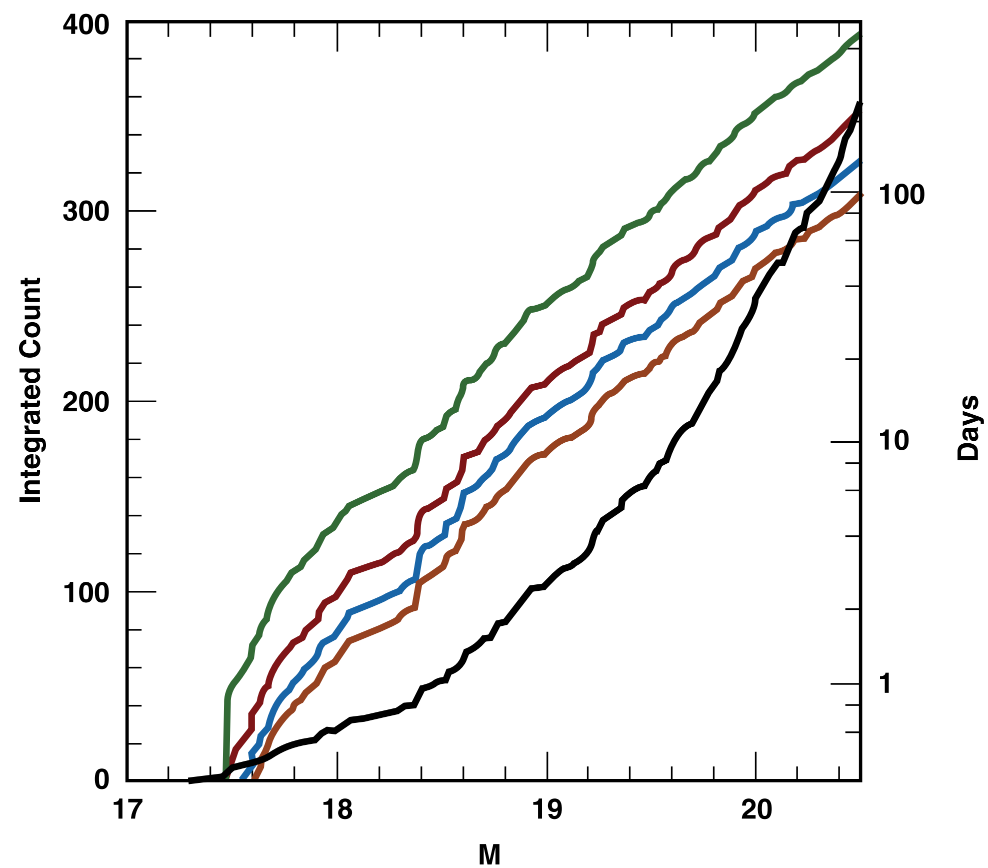


Observational Estimates

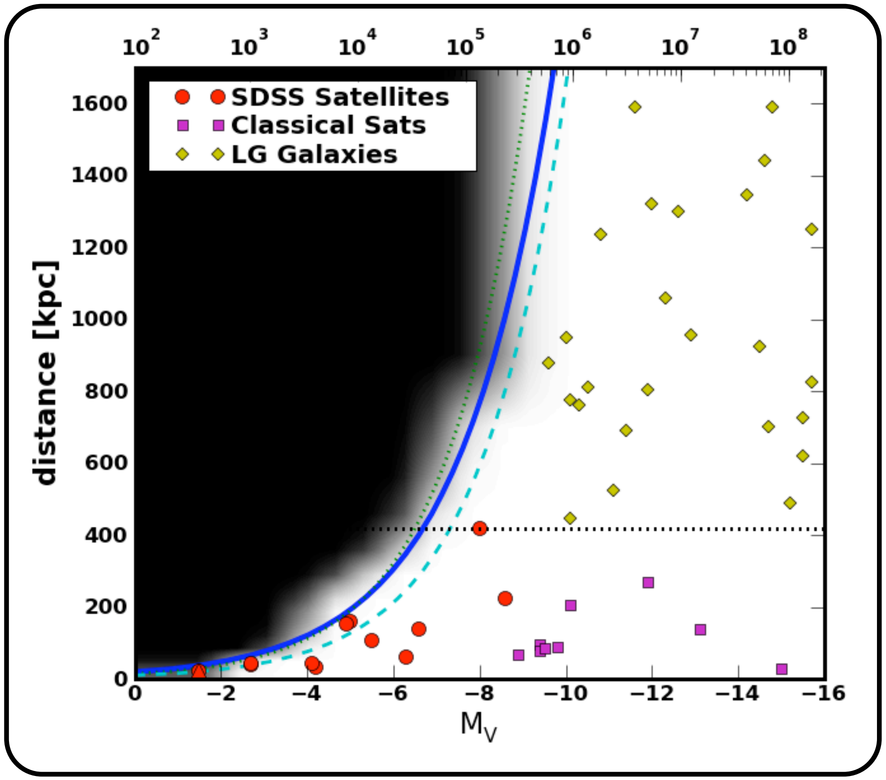
Goal: 200+ proper motions from 1+ dSphs

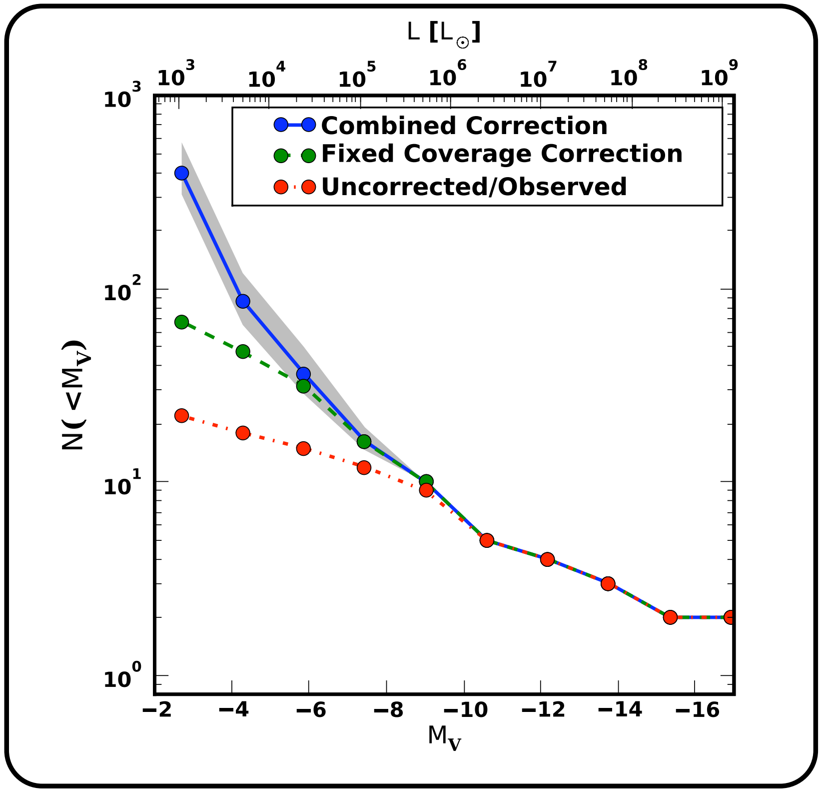


SIM ASTROMETRIC OBSERVATORY



Hundreds+ Milky Way Satellites?





- An empirical correction to the luminosity function, assuming the Via Lactea 1 radial distribution, gives 100-1000 satellites [Tollerud et al. ApJ 2008]
- Corrections assumed population of satellites resembles the known population