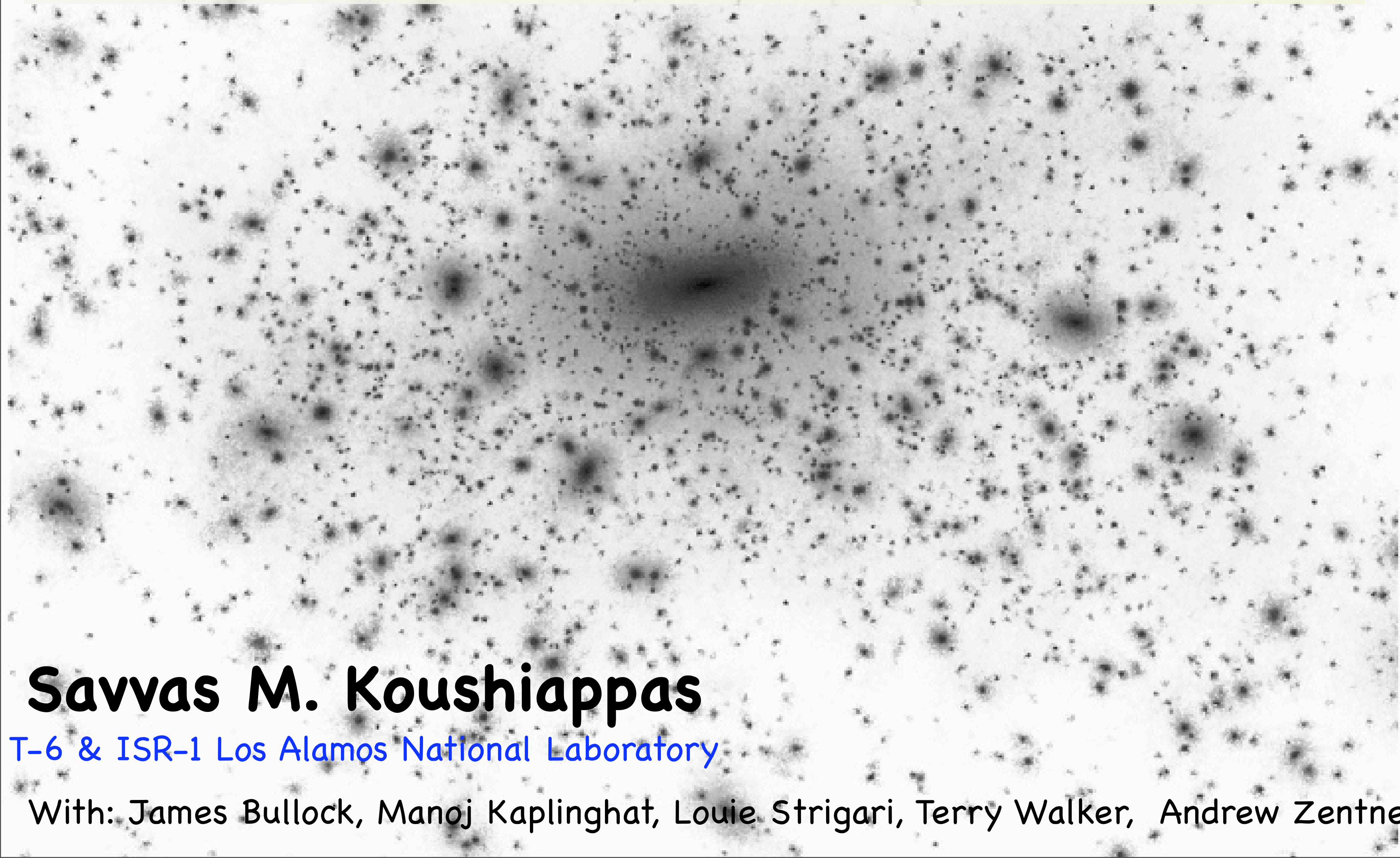
Dark matter substructure and detection with gamma-ray instruments



Savvas M. Koushiappas

T-6 & ISR-1 Los Alamos National Laboratory

With: James Bullock, Manoj Kaplinghat, Louie Strigari, Terry Walker, Andrew Zentner

Dark matter substructure and detection with gamma-ray instruments

If there are more things in heaven and Earth that are dreamt of in our natural philosophy, it is partly because the standard model of particle physics is inadequate.

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If there are more things in heaven and Earth that are dreamt of in our natural philosophy, it is partly because the standard model of particle physics is inadequate.

What to do:

1. Invent a model with new particles
2. Invent a symmetry that guarantees a stable particle
3. Fudge parameters so that the stable particle has the required relic density

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Dark matter substructure and detection with gamma-ray instruments

Particle Physics   Structure formation

$$\frac{dN_\gamma}{dAdt} = \frac{1}{4\pi}\,\mathcal{P}\left[\langle\sigma v\rangle, M_\chi, dN_\gamma/dE\right]\,\mathcal{L}(\rho_s, r_s, \mathcal{D})$$

$$\mathcal{P} = \int_{E_{\rm th}}^{M_\chi} \sum_i \frac{dN_{\gamma,i}}{dE}\frac{\langle\sigma v\rangle_i}{M_\chi^2}\,dE.$$

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

$$\mathcal{L}(\rho_s, r_s) = \frac{7\pi}{6}\,\rho_s^2 r_s^3$$

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Particle Physics

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Dark matter substructure and detection with gamma-ray instruments

I: Detecting dwarf spheroidals of the local group

II: Detecting the dark Milky Way substructure

III: Detecting hypothetical microhalos in the solar neighborhood

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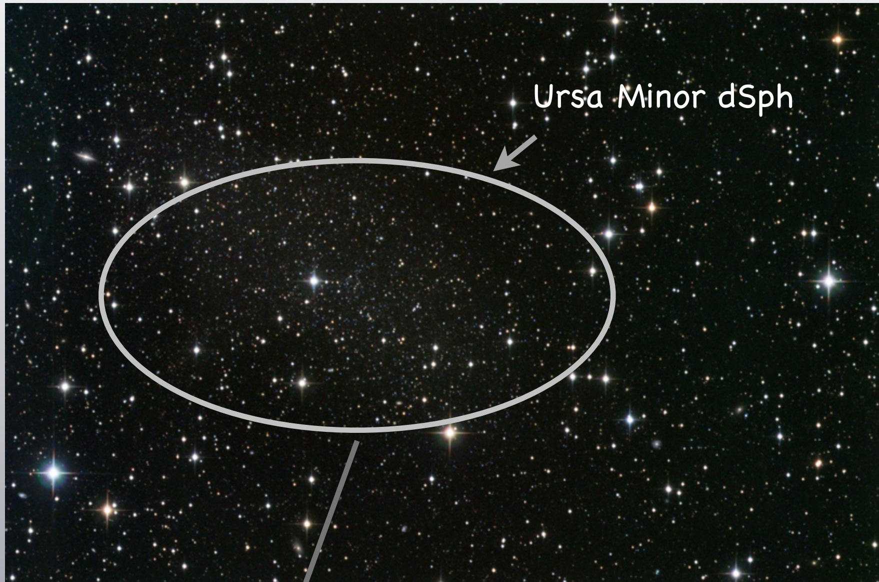
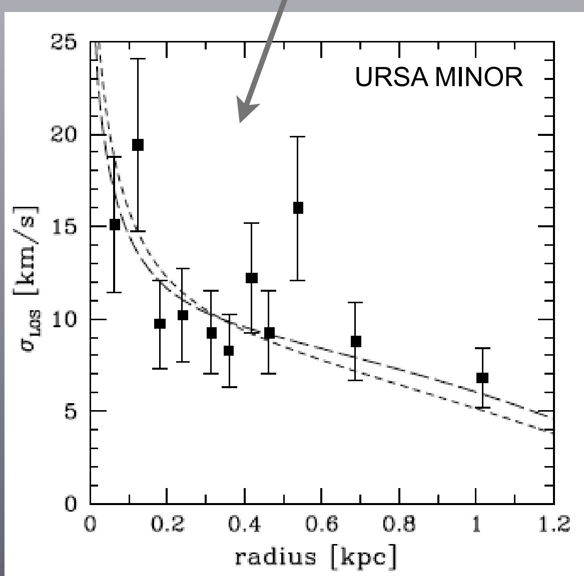
I: Dwarf satellites of the local group

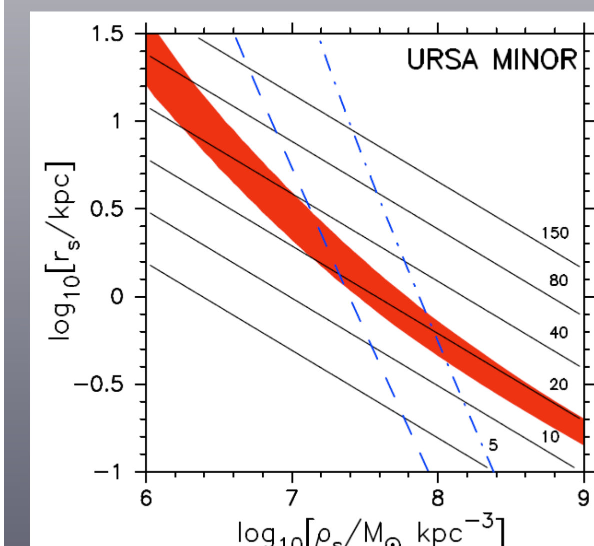


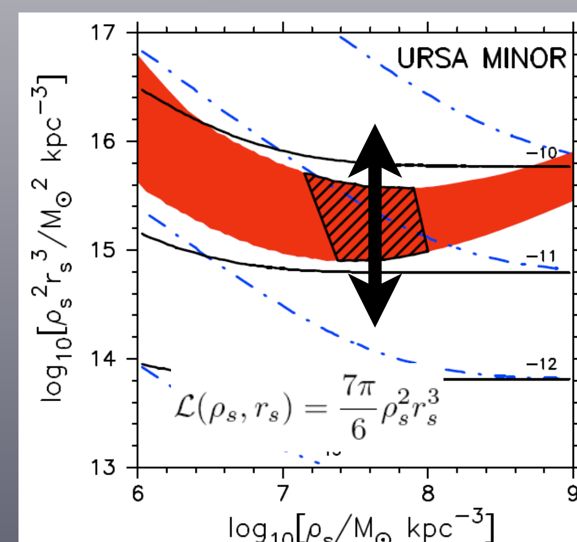
They are ideal laboratories for studying the distribution of dark matter:

- High mass-to-light ratios
- Astrophysical backgrounds relatively not present
- High galactic latitude - better prospects for detection

Baltz et al., Phys. Rev. D 61, 023514 (2000), Stoehr et al., MNRAS 345, 1313 (2003), Tyler, Phys. Rev. D 66, 023509 (2002), Evans, Ferrer & Sarkar, Phys. Rev. D 69, 123501 (2004), Bergstrom & Hooper, Phys. Rev. D 73, 063510, Strigari, Koushiappas, Bullock & Kaplinghat, Phys. Rev. D 75, 083506 (2007)



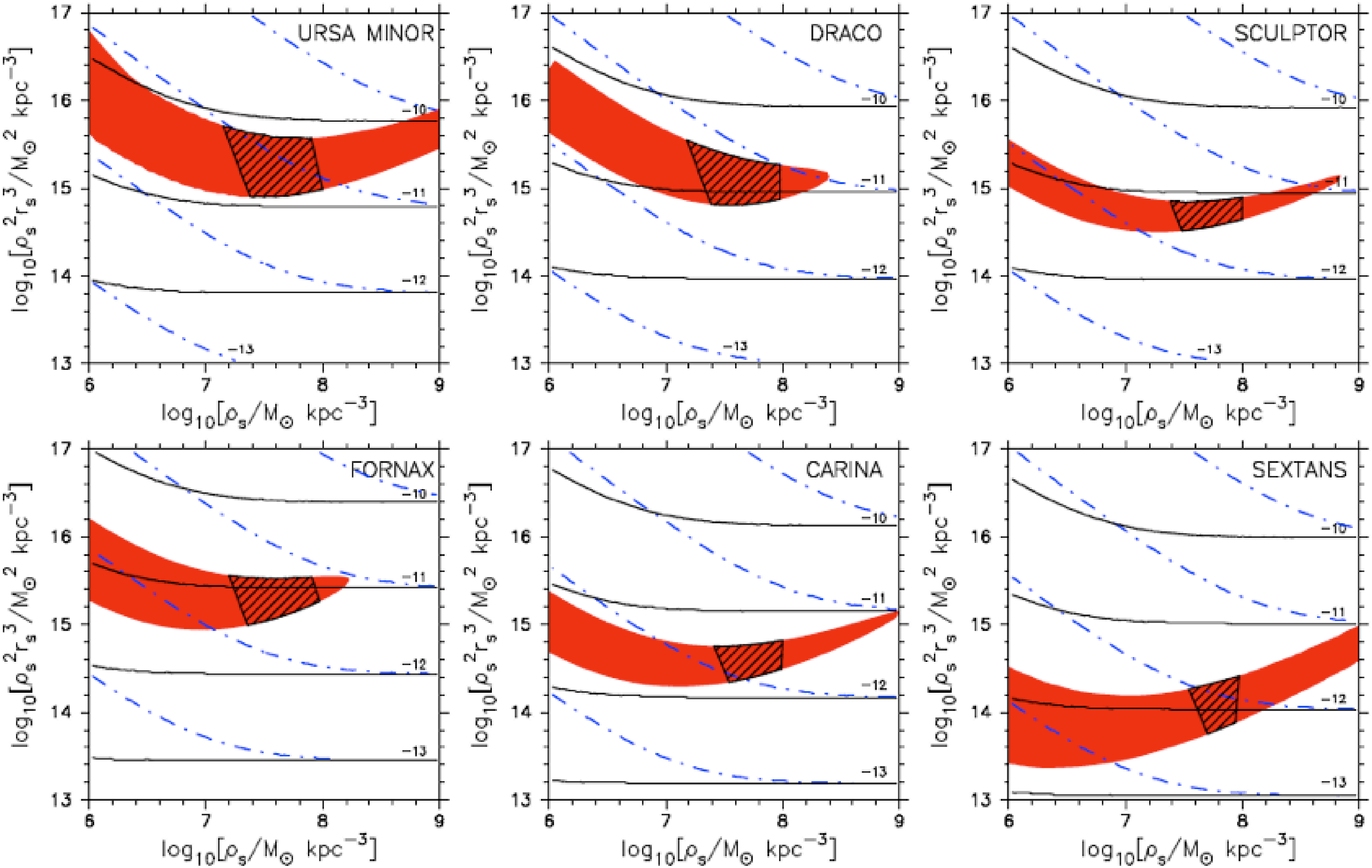




Strigari, Koushiappas, Bullock & Kaplinghat, Phys. Rev. D 75, 083506 (2007)

I: Dwarf satellites of the local group

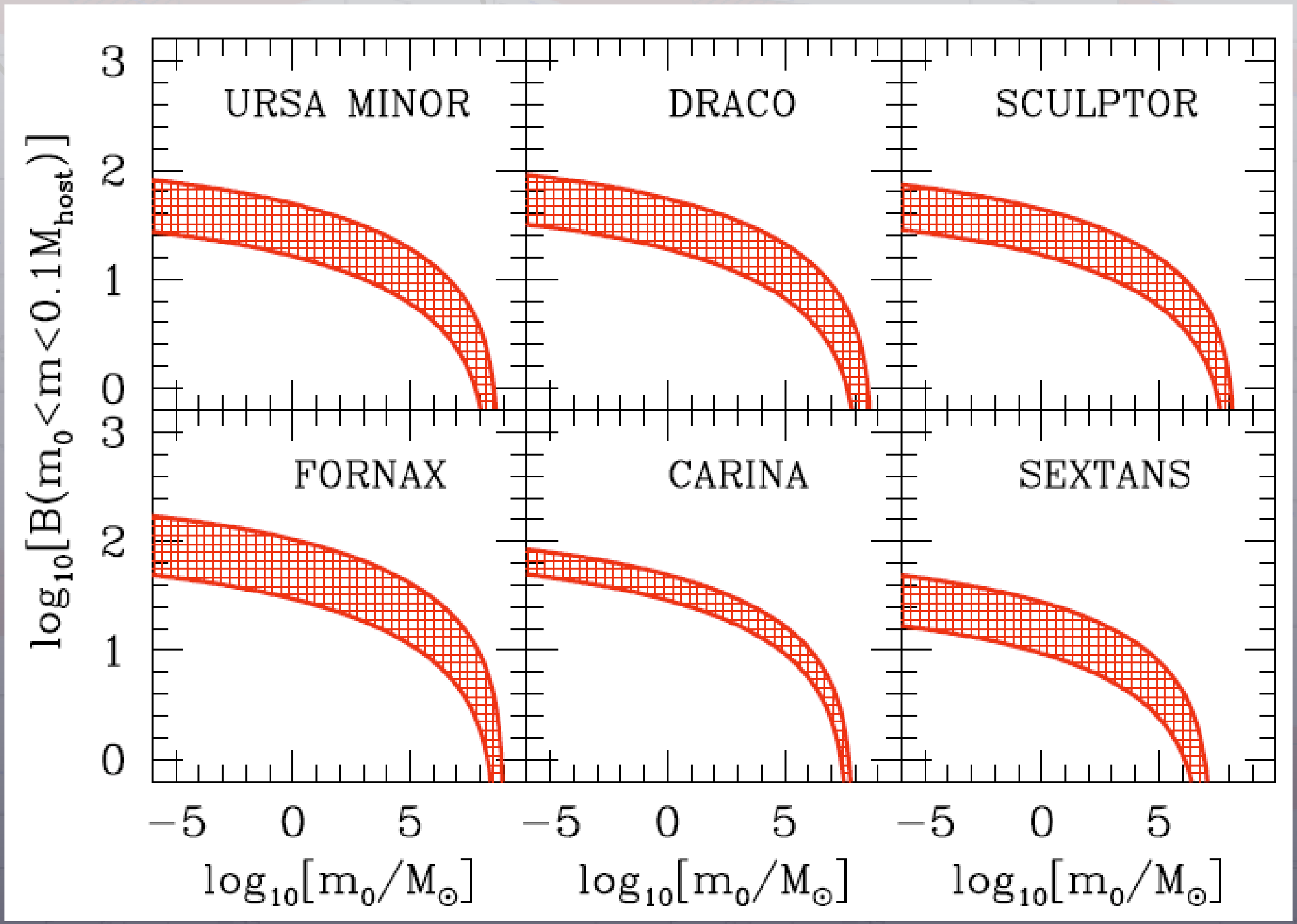
Strigari, Koushiappas, Bullock & Kaplinghat, Phys. Rev. D 75, 083506 (2007)



I: Dwarf satellites of the local group

Strigari, Koushiappas, Bullock & Kaplinghat, Phys. Rev. D 75, 083506 (2007)

Substructure can enhance the prospects for detection by increasing the flux by up-to a factor of ~ 100



I: Dwarf satellites of the local group

Strigari, Koushiappas, Bullock & Kaplinghat, Phys. Rev. D 75, 083506 (2007)

dSph	within 0.1 deg	within 2 deg
Draco	0.1–3.2	0.1–2.8
Sculptor	0.07–1.6	0.05–0.7
Fornax	0.07–2.2	0.05–1.1
Carina	0.04–1.0	0.02–0.4
Sextans	0.02–0.5	0.007–0.02

TABLE II: The predicted flux ratios for dSphs relative to the γ-ray flux from Ursa Minor in CDM theory.

Flux ratios between the 6 dwarf spheroidals are not arbitrary!

We are able to direct gamma-ray experiments to the proper detection scheme

dSph	Radius of the area of 90% flux emission in degrees
Ursa Minor	0.4–2.7
Draco	0.3–1.8
Sculptor	0.2–0.9
Fornax	0.2–1.0
Carina	0.1–0.6
Sextans	0.1–0.4

TABLE III: The CDM-predicted angular extent in degrees where at least 90% of the γ-ray flux should originate for each dSph.

II: Dark substructure in the Milky Way

Calcaneo-Roldan & Moore, Phys. Rev. D 62, 123005 (2002), Tasitsiomi & Olinto, Phys. Rev. D 66, 083006 (2002), Koushiappas, Zentner & Walker, Phys. Rev. D 69, 043501 (2004) Baltz, Taylor & Wai, astro-ph/0610731,

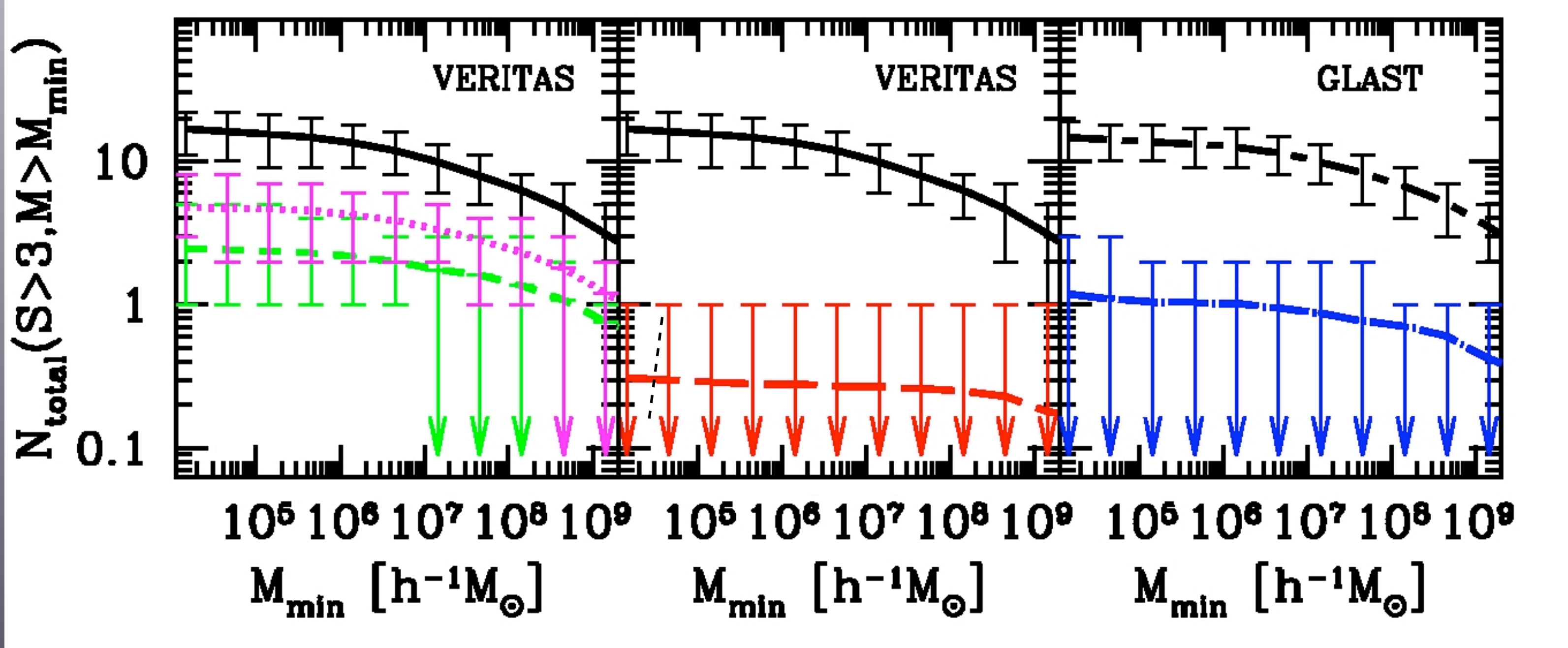
100 merger tree realizations of the Milky Way merger history

Monitor the interplay between:

- Accretion redshift
- Orbital evolution
- Tidal disruption

] ← **Set by cosmology**

Koushiappas, Zentner & Walker, Phys. Rev. D 69, 043501 (2004)



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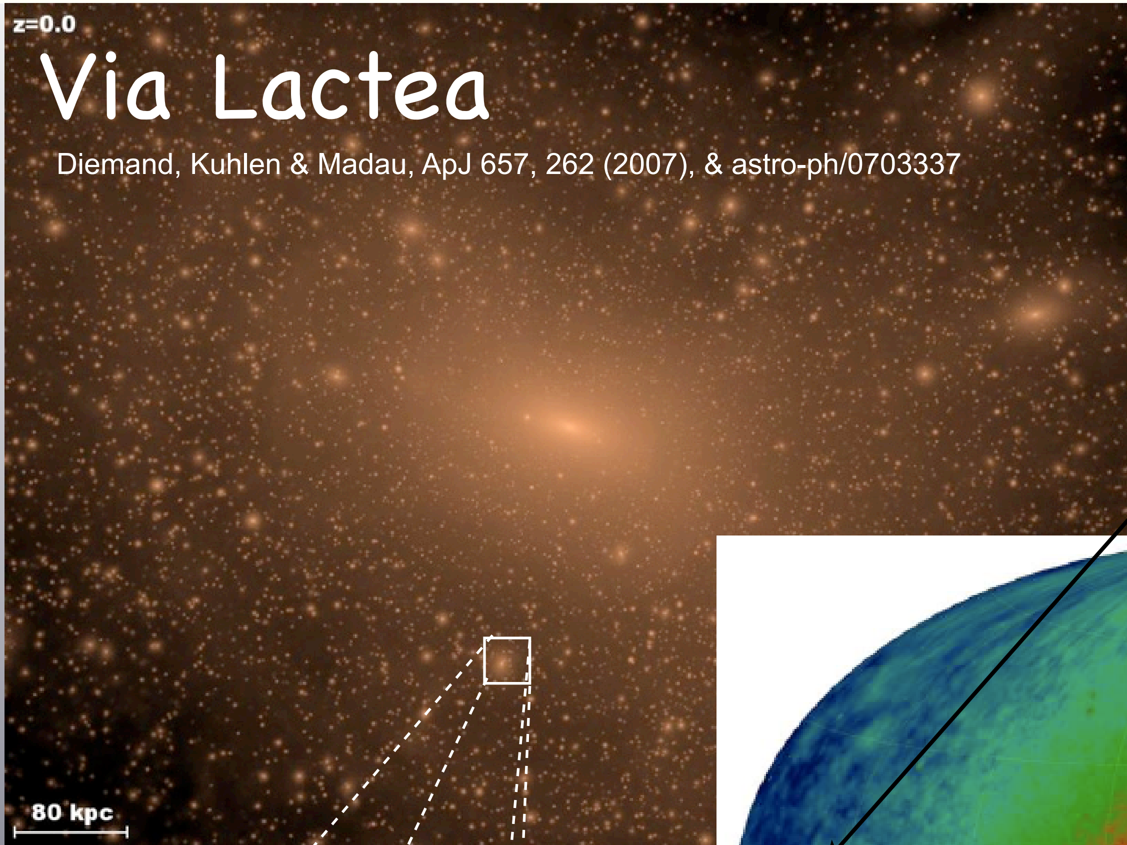
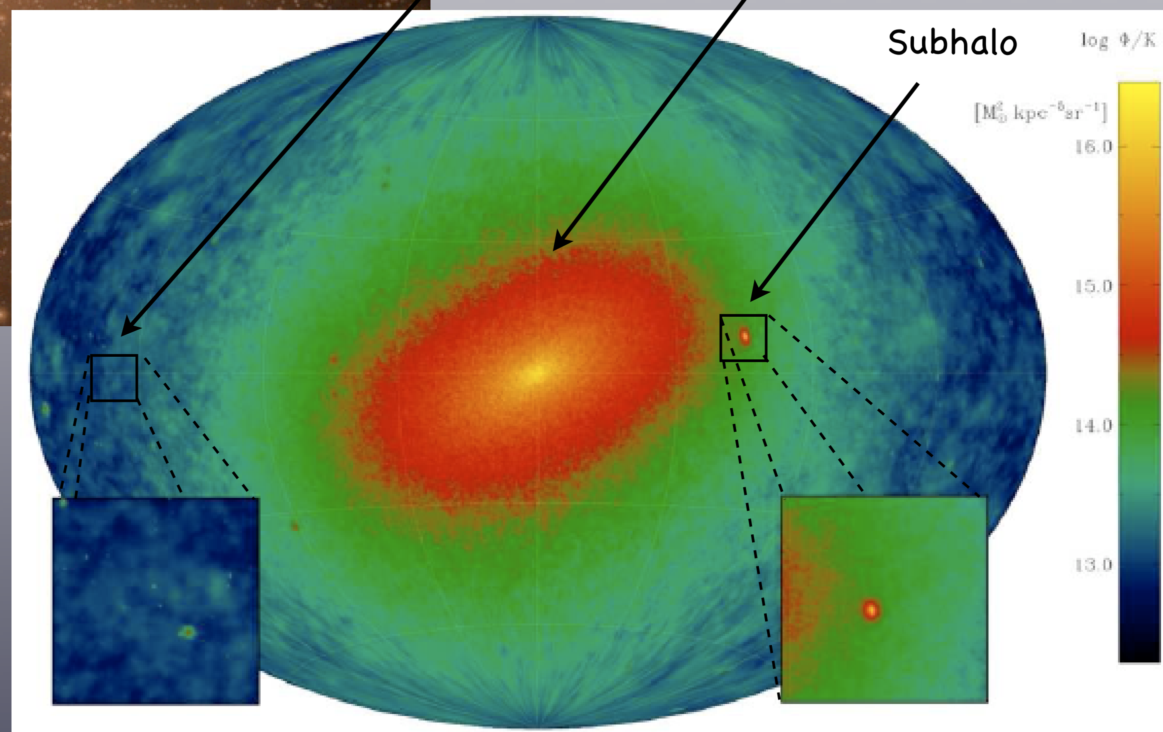


Diemand, Kuhlen & Madau ApJ 657, 262 (2007), Diemand, Kuhlen & Madau, astro-ph/0703337, see also past work, e.g. Calcaneo-Roldan & Moore, Phys. Rev. D 62, 123005 (2002), Stoehr et al., MNRAS 345, 1313 (2003)

Fluctuations in the dark matter distribution (Ando & Komatsu PRD 73, 023521)

The dark matter halo is not spherical (Hooper & Serpico, astro-ph/0702328)

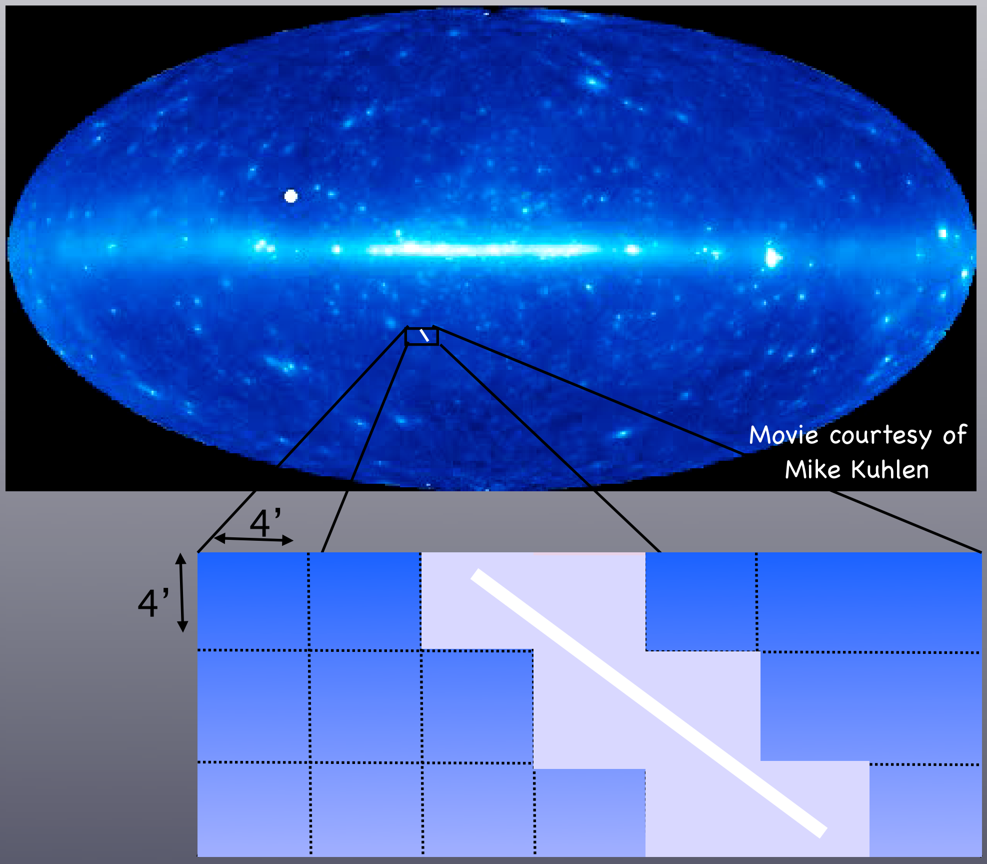


III: Microhalos present in the solar neighborhood

1. A possible detection can provide information about the particle physics properties of the dark matter particle.

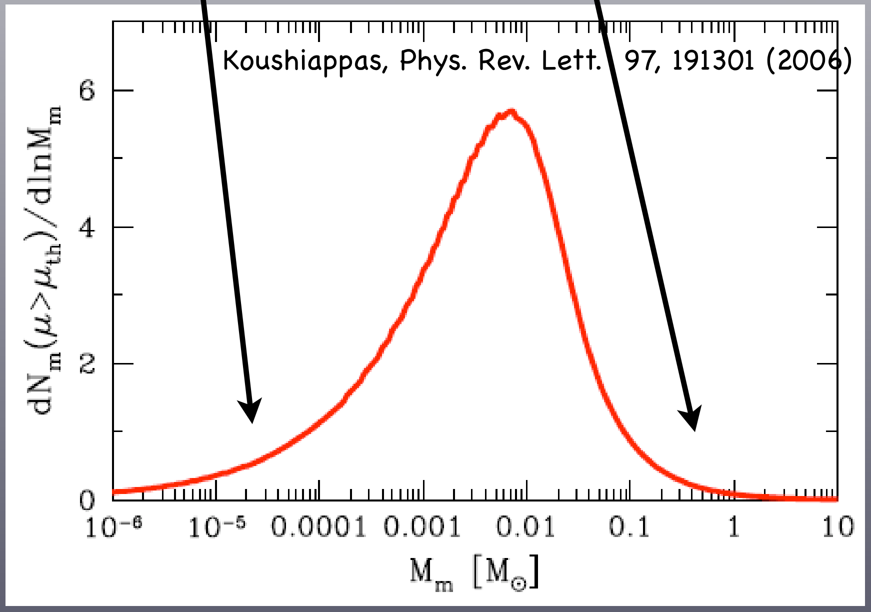
2. A measured abundance in the Milky Way halo contains information on the hierarchical assembly of dark matter halos at very early times (survival/disruption), a task unattainable by any other method.

See Schmid et al., Phys Rev. D 59, 043517 (1999), Hofmann et al., Phys. Rev. D 64, 083507 (2001), Chen et al., Phys Rev. D 64, 021302 (2001), Berezinsky et al, Phys. Rev. D 68, 103003 (2003), Green, Hoffmann,and Schwarz, MNRAS 353, L23 (2004),Green et al., JCAP 08, 003 (2005), Loeb & Zaldarriaga , Phys. Rev. D, 71, 103520 (2005) Profumo et al., Phys. Rev. Lett., 97, 031301 (2006), Koushiappas, Phys. Rev. Lett. 97, 191301 (2006)



Limited by the **abundance** of detectable microhalos

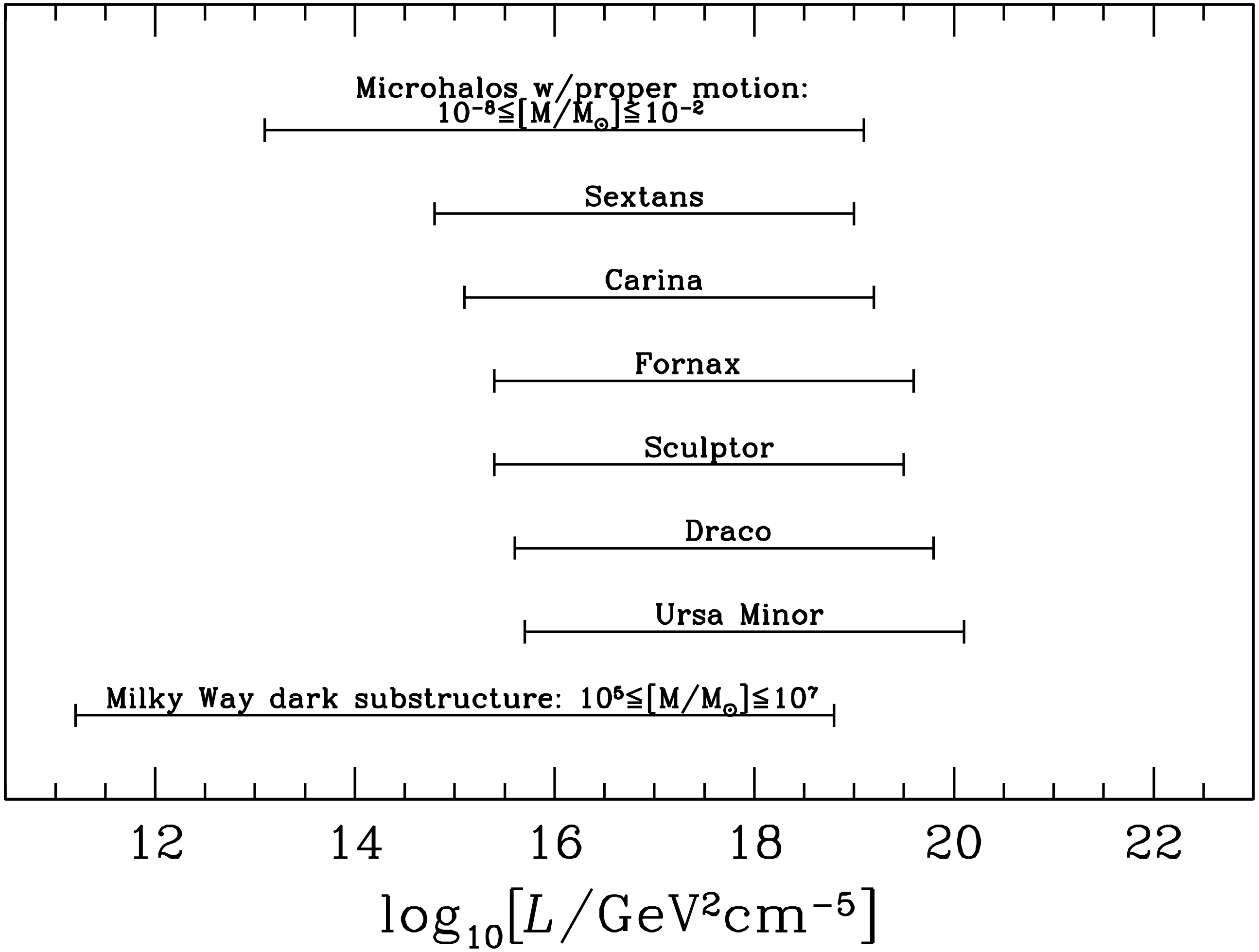
Limited by the amount of **proper motion** exhibited



Where are we now?

$$\frac{dN_\gamma}{dAdt} = \frac{1}{4\pi}\,\mathcal{P}\left[\langle\sigma v\rangle, M_\chi, dN_\gamma/dE\right]\,\mathcal{L}(\rho_s, r_s, \mathcal{D})$$

$$\mathcal{L} \approx 10^{18}\mathrm{GeV}^2\,\mathrm{cm}^{-5}\,\mathrm{s}^{-1}\left(\frac{\mathrm{Sensitivity}}{10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}}\right)\left(\frac{\langle\sigma v\rangle}{10^{-26}\mathrm{cm}^3\,\mathrm{s}^{-1}}\right)\left(\frac{M_\chi}{50\mathrm{GeV}}\right)^2\left(\frac{N_\gamma}{30}\right)$$



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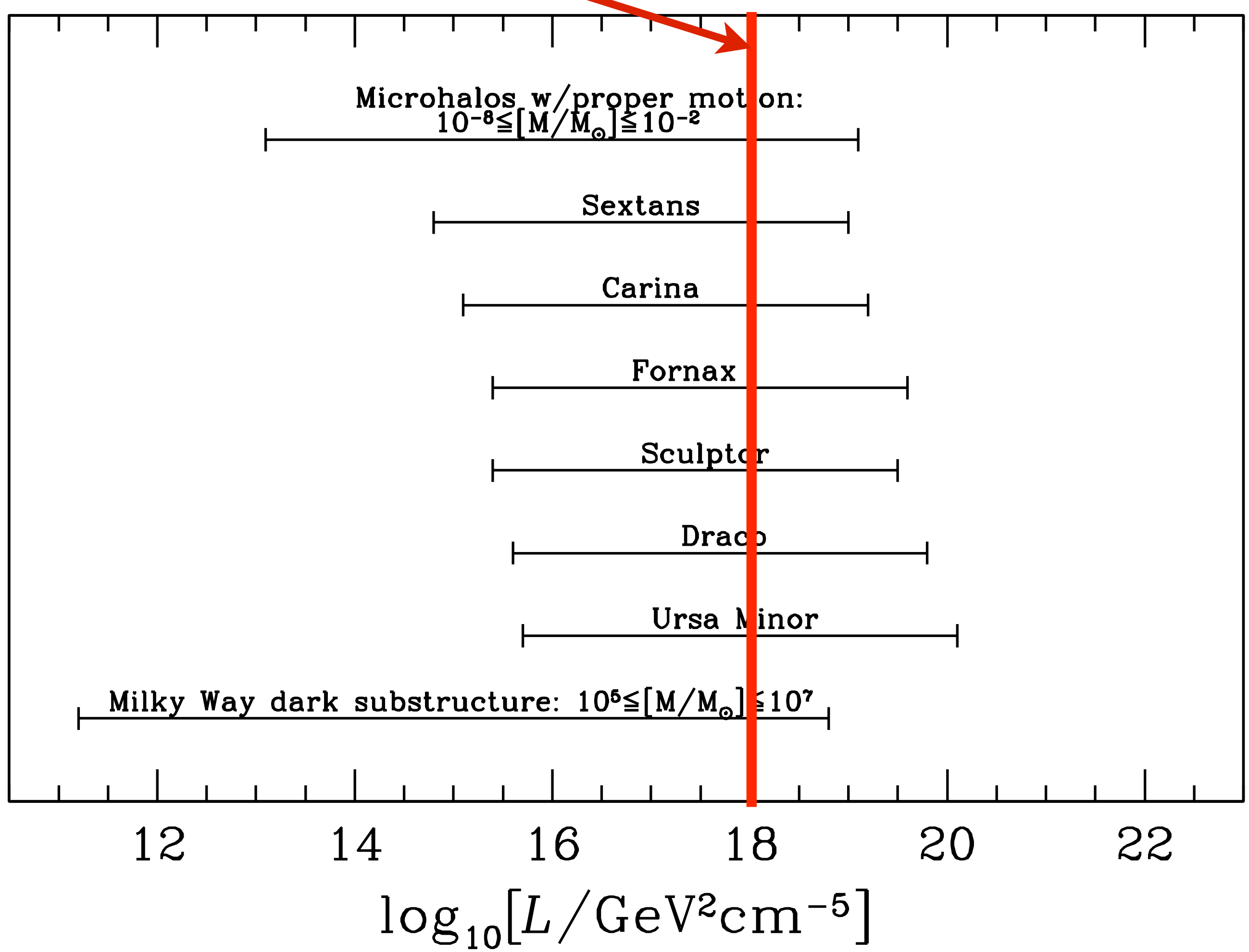
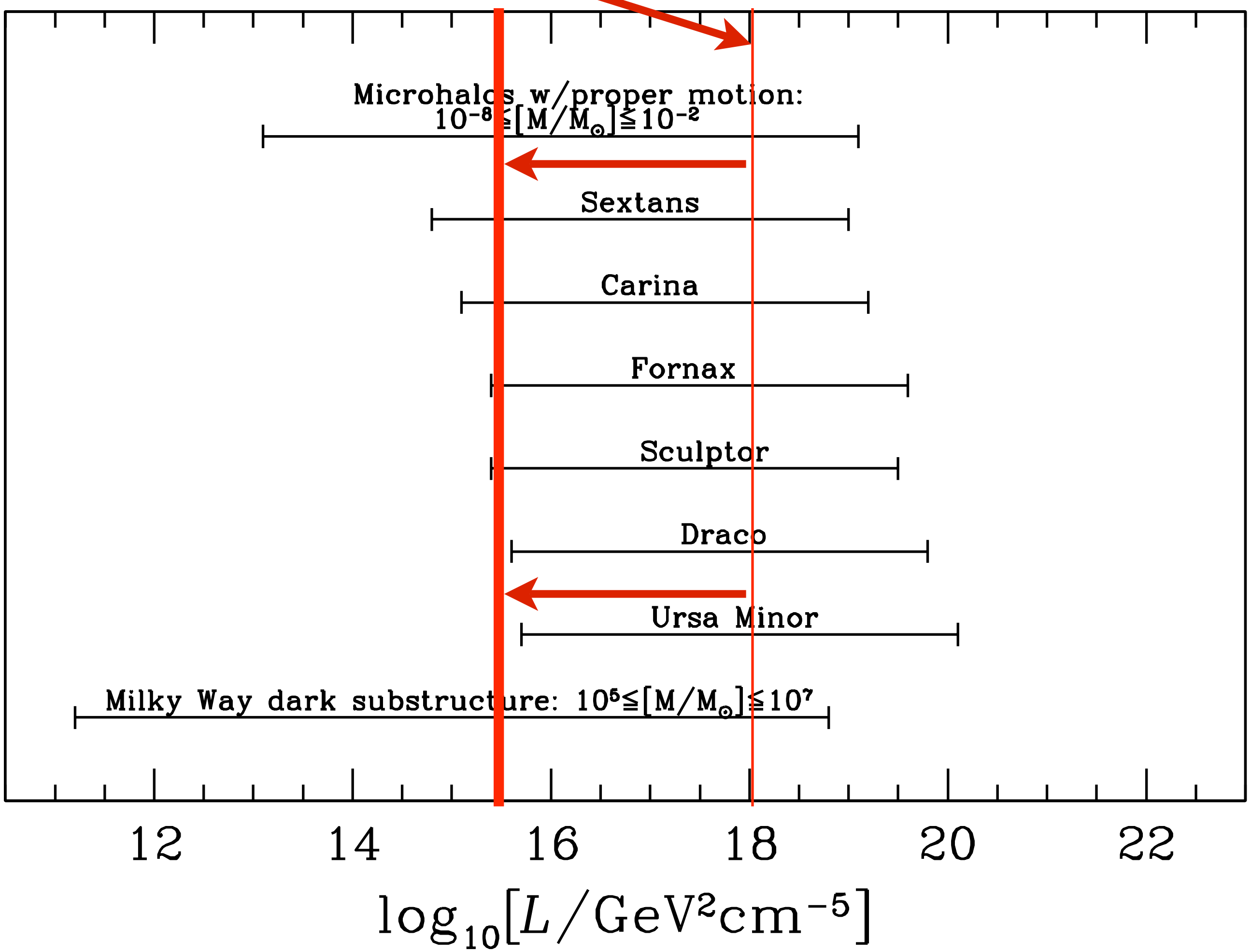


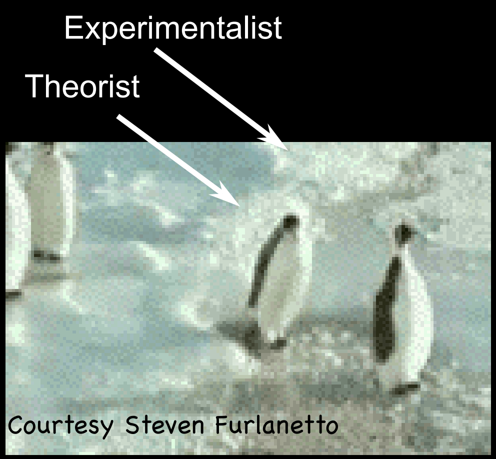
What we need?

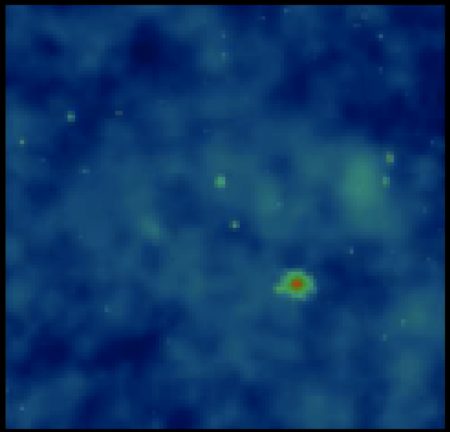
Something like the Advanced Gamma-ray Imaging System

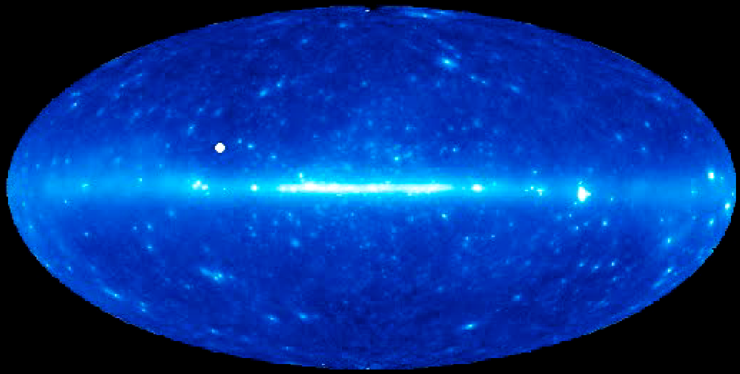
$$\mathcal{L} \approx 10^{18}\mathrm{GeV}^2\,\mathrm{cm}^{-5}\,\mathrm{s}^{-1} \left(\frac{\mathrm{Sensitivity}}{10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}}\right)\left(\frac{\langle\sigma v\rangle}{10^{-26}\mathrm{cm}^3\,\mathrm{s}^{-1}}\right)\left(\frac{M_\chi}{50\mathrm{GeV}}\right)^2\left(\frac{N_\gamma}{30}\right)$$



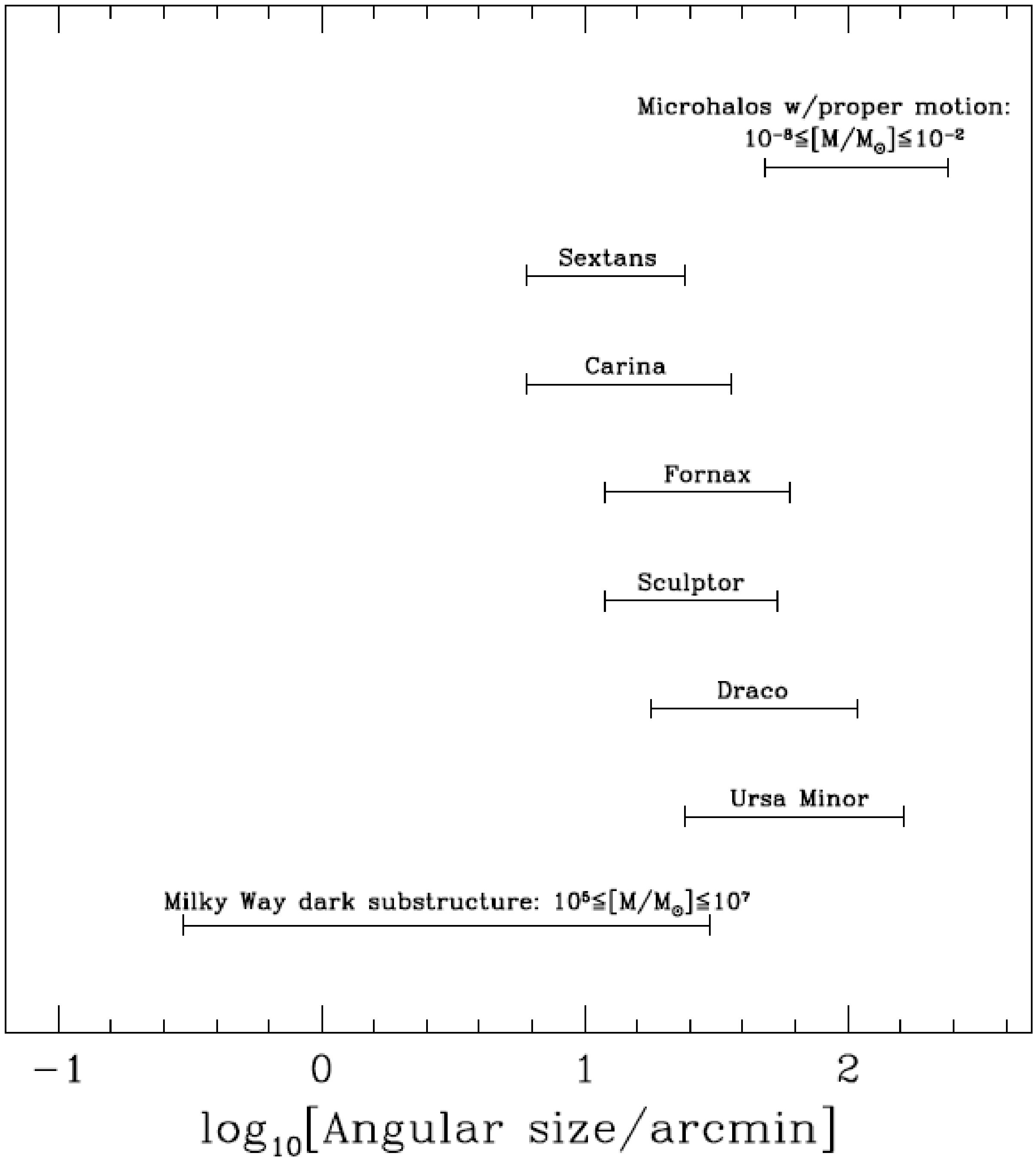
Summary







- Microhalos that survive in the Milky Way halo could be observed via their proper motion signal measured in γ-rays - an extremely clean signature of dark matter - No other known object can mimic this potentially detectable phenomenon!
- Dwarf spheroidals of the local group are ideal laboratories for the detection of gamma-rays from dark matter annihilation
- It may be possible to detect the dark Milky Way substructure with future gamma-ray instruments


Microhalos w/proper motion:
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Sextans
Carina
Fornax
Sculptor
Draco
Ursa Minor
Milky Way dark substructure: $10^5 \leq [M/M_\odot] \leq 10^7$
−1
0
1
2
$\log_{10}$[Angular size/arcmin]