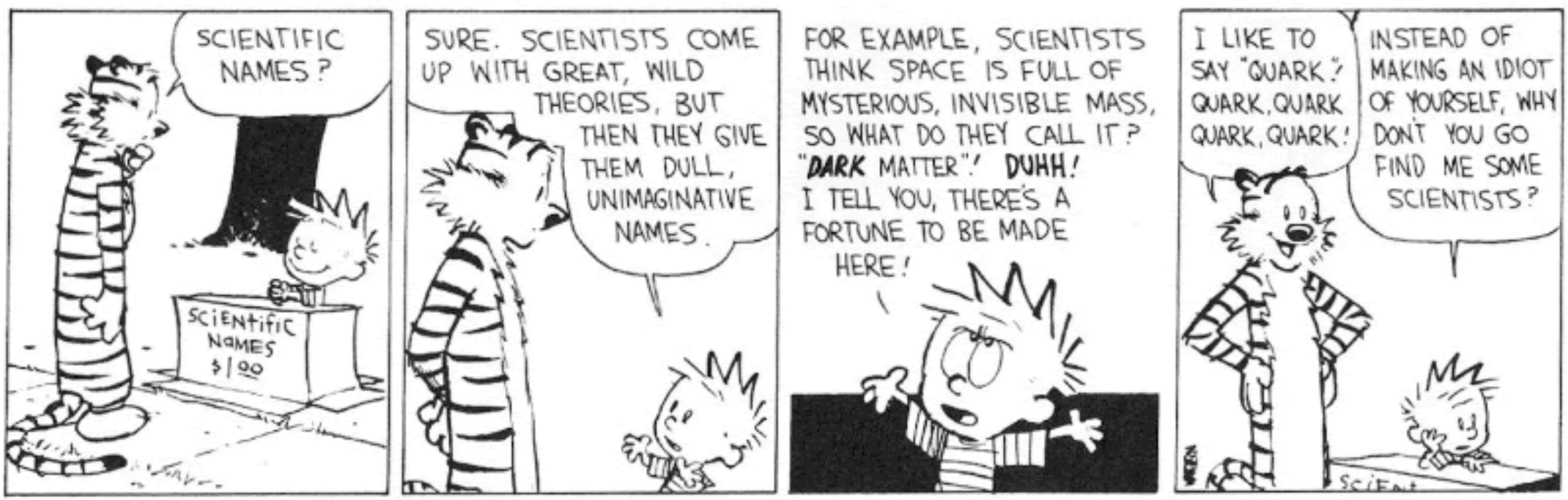
FERMI and Dark Matter

Savvas M. Koushiappas

BROWN



“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.”

$$\Omega_M = \frac{\rho}{\rho_c} \sim \left(\frac{10^{-27}\,\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle} \right) = 0.233 \pm 0.0013$$

Komatsu et al. (2009)

FERMI and Dark Matter

1. Why dark matter is relevant to FERMI

2. How can FERMI search for the dark matter signal (targets and limitations)

The connection between the Early Universe and FERMI

$$\chi\chi \leftrightarrow q\bar{q}$$

$$f_i(\mathbf{k},t)d^3\mathbf{k} = \frac{g_i}{(2\pi)^3}\frac{1}{e^{[E(\mathbf{k})-\mu_i]/T_i(t)} \pm 1}d^3\mathbf{k},$$

$$\rho = \int E f(\mathbf{k}) d^3\mathbf{k}$$

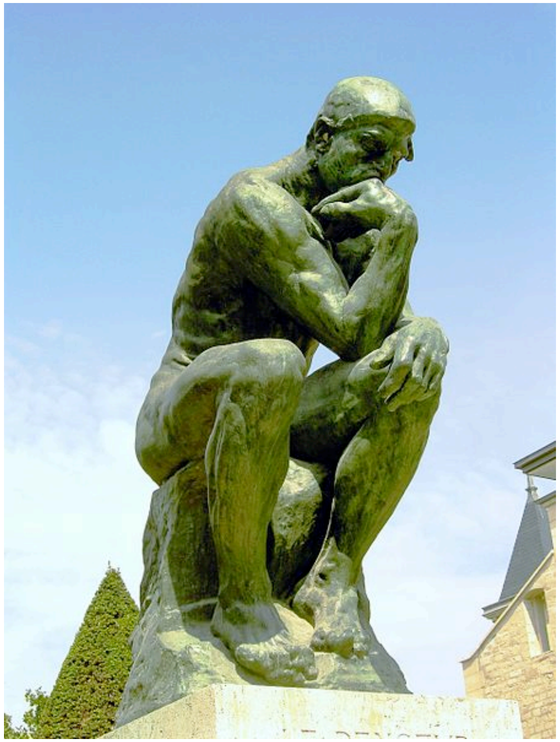
$$\hat{\mathbf{L}}[f] = \mathbf{C}[f]$$

$$\Omega_M =\sim \left(\frac{10^{-27}\,\mathrm{cm}^3\mathrm{s}^{-1}}{\langle\sigma v\rangle}\right) = \text{Observed value if } M_\chi \sim \mathcal{O}(\mathrm{GeV}-\mathrm{TeV})$$

Weakly Interacting Massive Particle (WIMP)

The connection between the Early Universe and FERMI

Theorist



WIMP's

Neutralinos
Axinos
Gravitinos
sneutrinos
Kaluza-Klein
Mirror matter
Heavy photons
...

Theories that solve problems with the Standard Model can naturally provide a WIMP dark matter candidate (e.g., supersymmetry)

The connection between the Early Universe and FERMI

$$\chi\chi \leftrightarrow q\bar{q}$$

The connection between the Early Universe and FERMI

$$\chi\chi \to q\bar{q}$$

The connection between the Early Universe and FERMI

$$\chi\chi \rightarrow q\bar{q}$$

This results in photon final states

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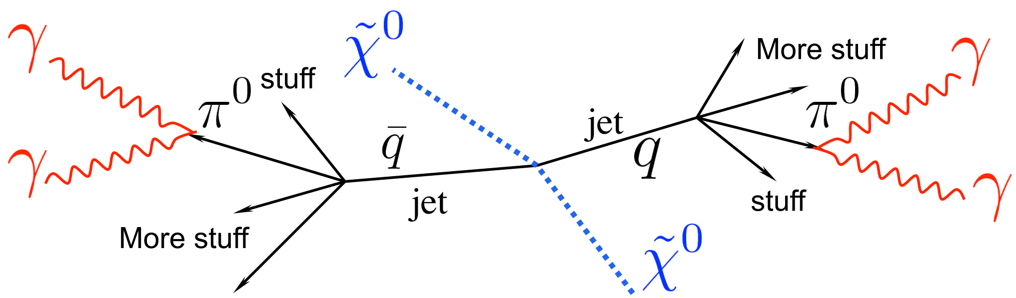
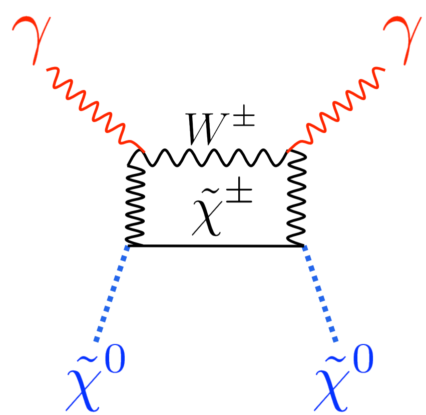


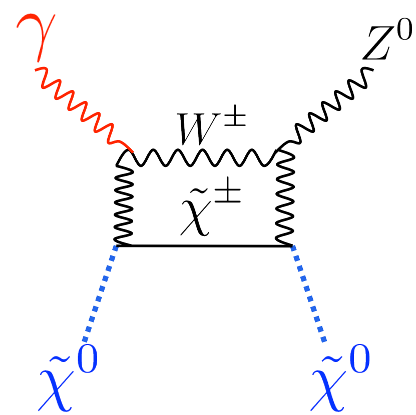
$E_\gamma < M_\chi$

Continuum

Line emission

$E_\gamma = M_\chi$





FERMI and Dark Matter

1. Why dark matter is relevant to FERMI

Because it can search for the photon emission from dark matter annihilation (a process we know must have taken place in the early universe).

Note: FERMI can also search for other annihilation by-products (e.g., antimatter)...no time to cover here but happy to discuss afterwards...

FERMI and Dark Matter

1. Why dark matter is relevant to FERMI

2. How can FERMI search for the dark matter signal (targets and limitations)

Photon searches

(An outcome of the requirement of proper relic abundance)

$$\chi\chi \to q\bar{q}$$

$$\Gamma \propto n_\chi^2$$

Photon searches

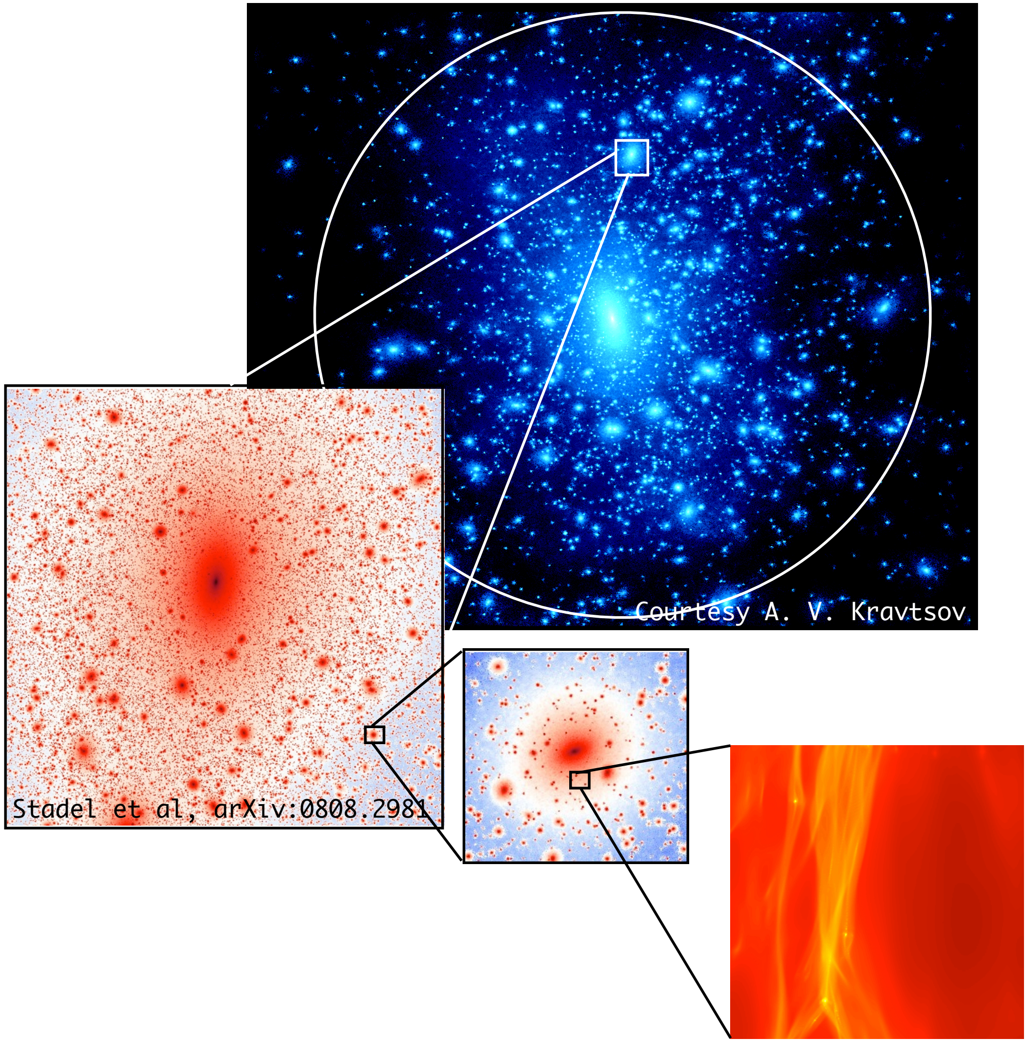
(An outcome of the requirement of proper relic abundance)

DANGER

It depends strongly on the distribution of dark matter

...and that’s where the difficulties are

Hierarchical structure formation in an evolving Universe



Photon searches

(An outcome of the requirement of proper relic abundance)

DANGER

It depends strongly on the distribution of dark matter

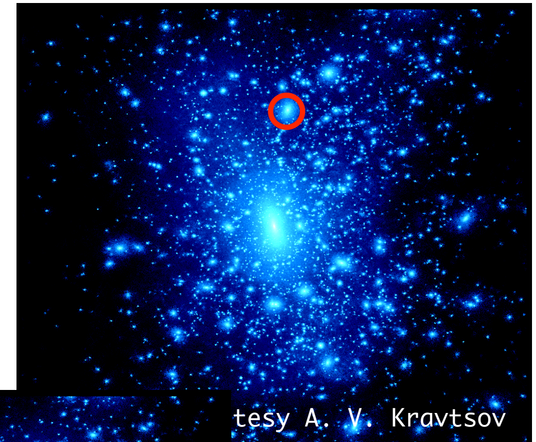
...and that's where the difficulties are

We can only discuss the distribution of dark matter in a statistical fashion (we do not know initial conditions)!

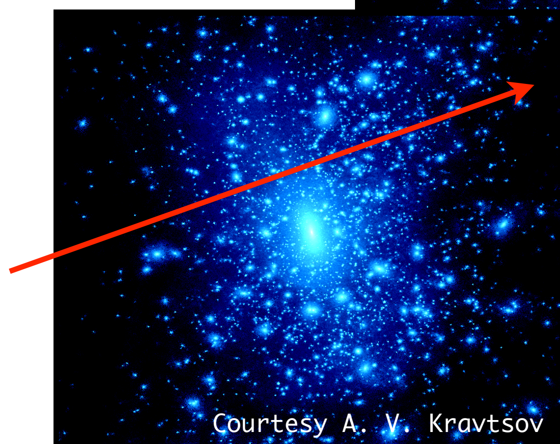
Photon searches

(An outcome of the requirement of proper relic abundance)

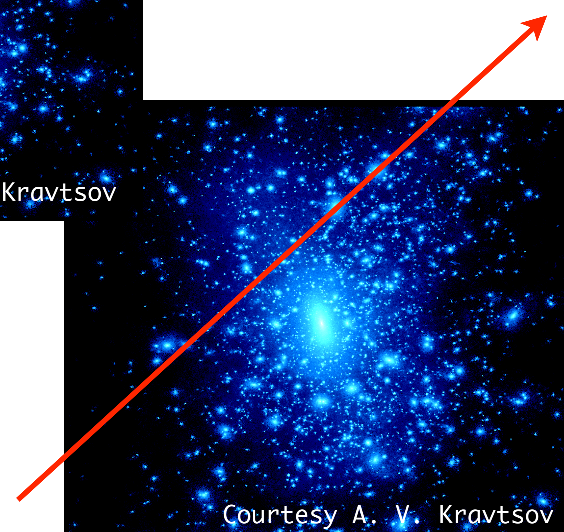
Individual objects



Along a line-of-sight



Objects along a line-of-sight



Photon searches

(An outcome of the requirement of proper relic abundance)

Individual objects

$$\Gamma_{\gamma,e^+,\bar{p}} \sim \frac{1}{d}\int_{\mathrm{V}} n^2(r)d^3r$$

Along a line-of-sight

$$\Gamma_{\gamma,e^+,\bar{p}} \sim \int_{\mathrm{LOS}} n^2(\ell)d\ell$$

Objects along a line-of-sight

$$\Gamma_{\gamma,e^+,\bar{p}} \sim \int_{\mathrm{LOS}} n(\ell)\mathcal{L}(\ell)d\ell$$

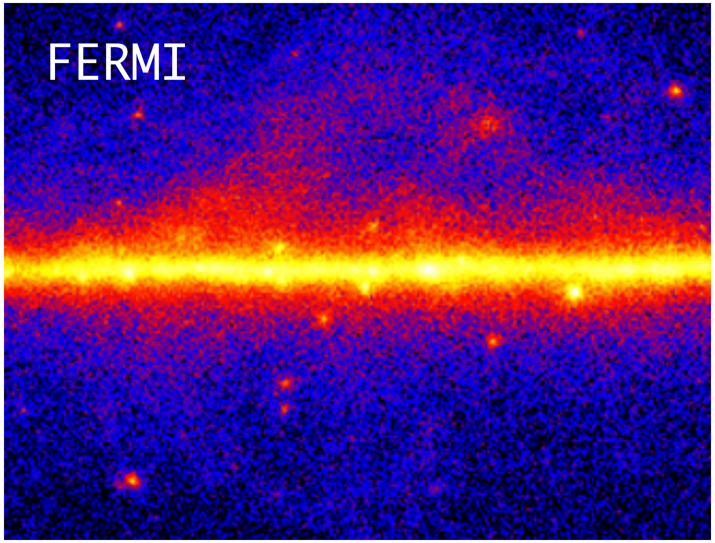
$$\mathcal{L} \sim \int_{\mathrm{V}} n^2(r)d^3r$$

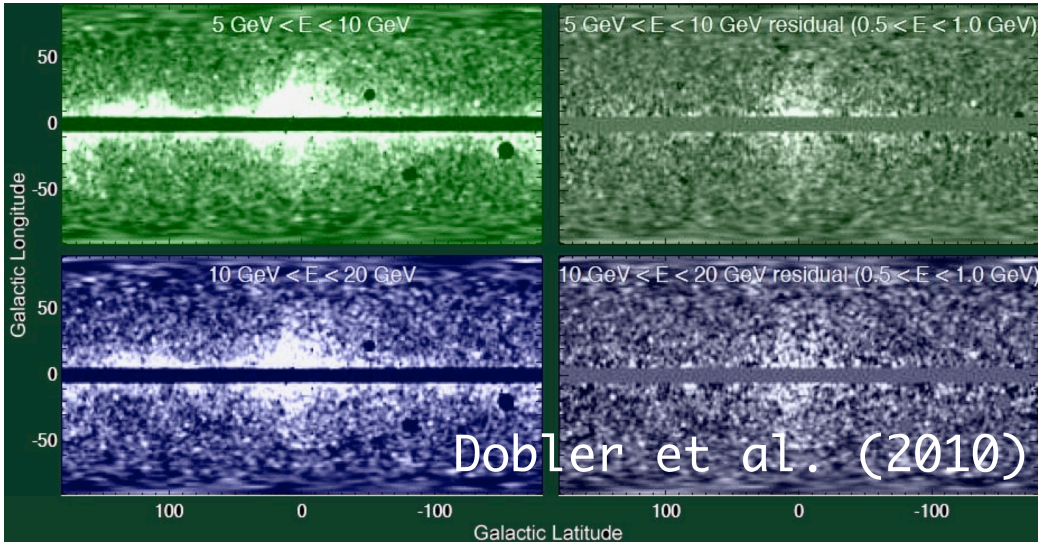
Photon searches

(An outcome of the requirement of proper relic abundance)

Individual objects	Dwarf spheroidals, Nearby galaxies/clusters
Along a line-of-sight	Galactic center, Diffuse Galactic halo, Extragalactic
Objects along a line-of-sight	Substructure contribution to the diffuse Galactic

Galactic center



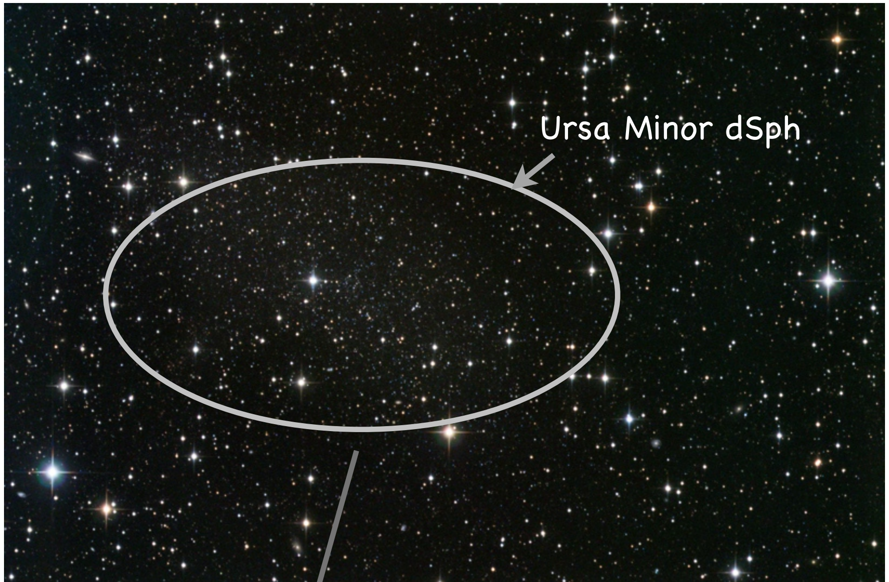


Distribution of dark matter unclear

A lot of astrophysical sources

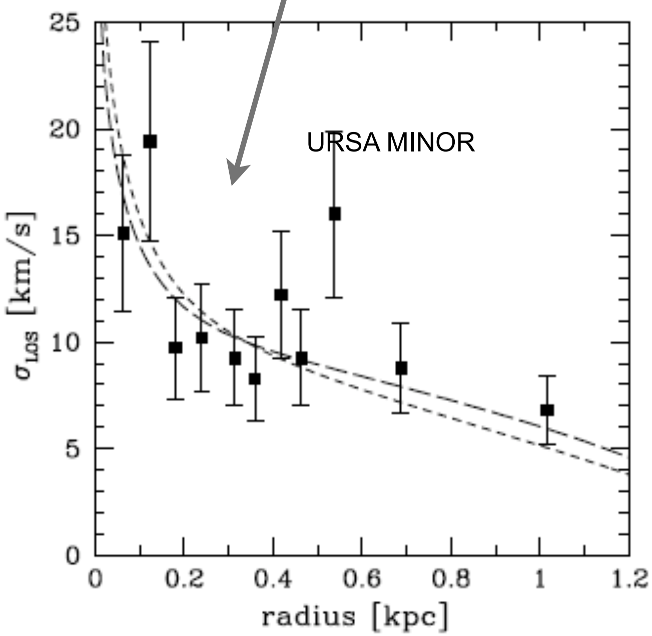
Bottom line: Very difficult

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

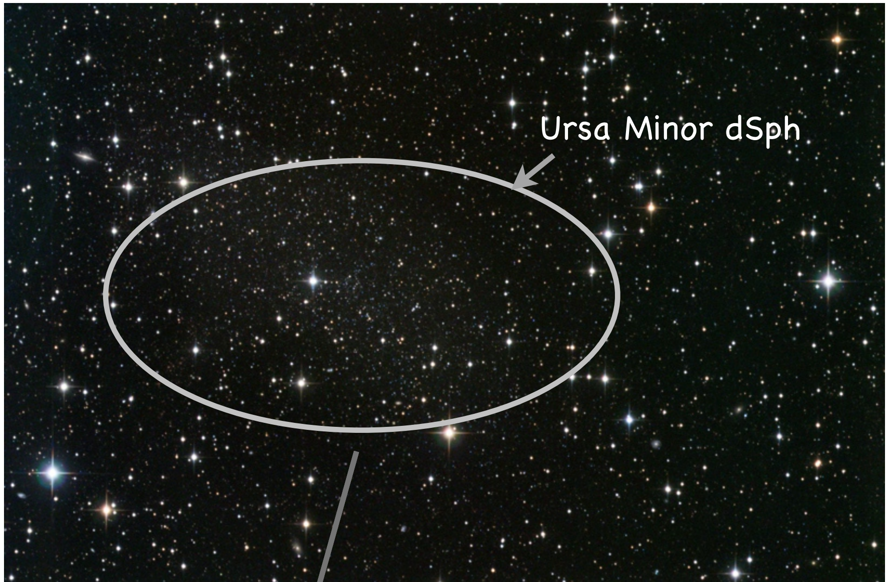


$$\sigma_t^2(R) = \frac{2}{I(R)} \int_R^\infty \left(1 - \beta \frac{R^2}{r^2}\right) \frac{\rho_\star \sigma_r^2 r}{\sqrt{r^2 - R^2}} dr$$

$$r \frac{d(\rho_\star \sigma_r^2)}{dr} = -\rho_\star(r) V_c^2(r) - 2\beta(r) \rho_\star \sigma_r^2$$

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

Dwarf satellites of the local group



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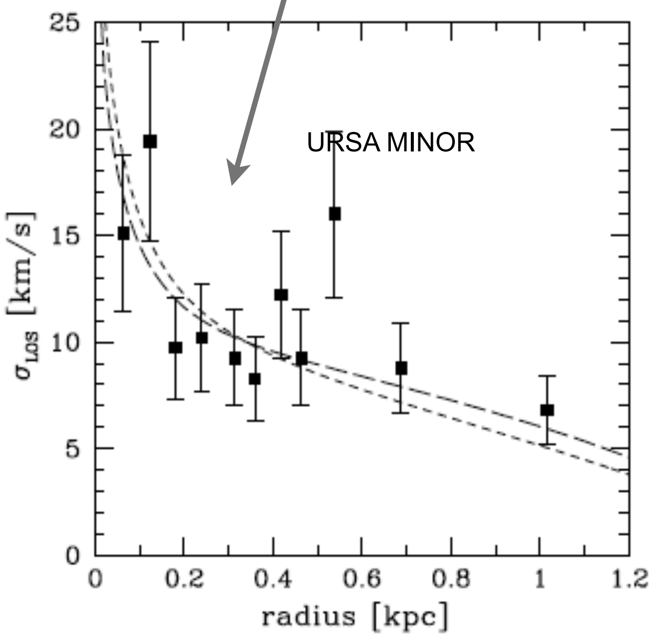

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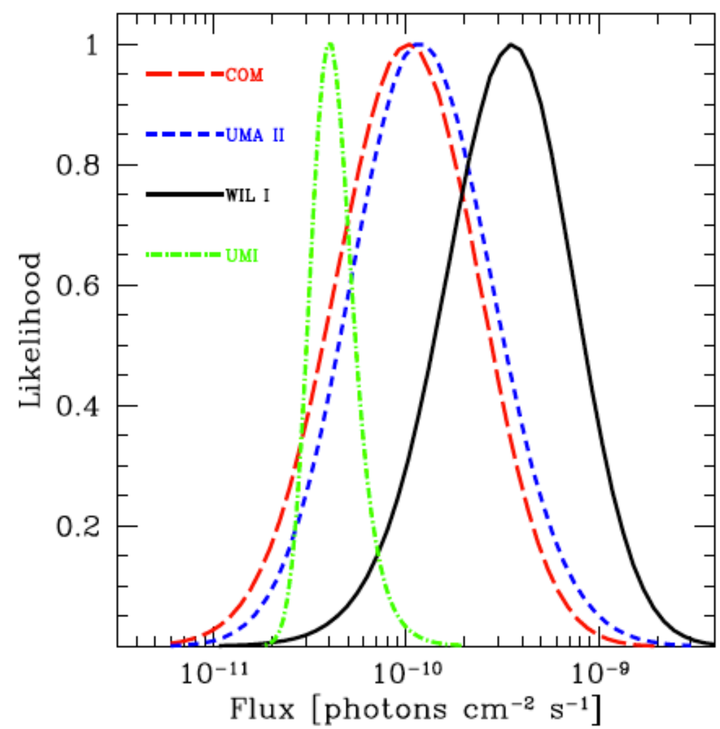

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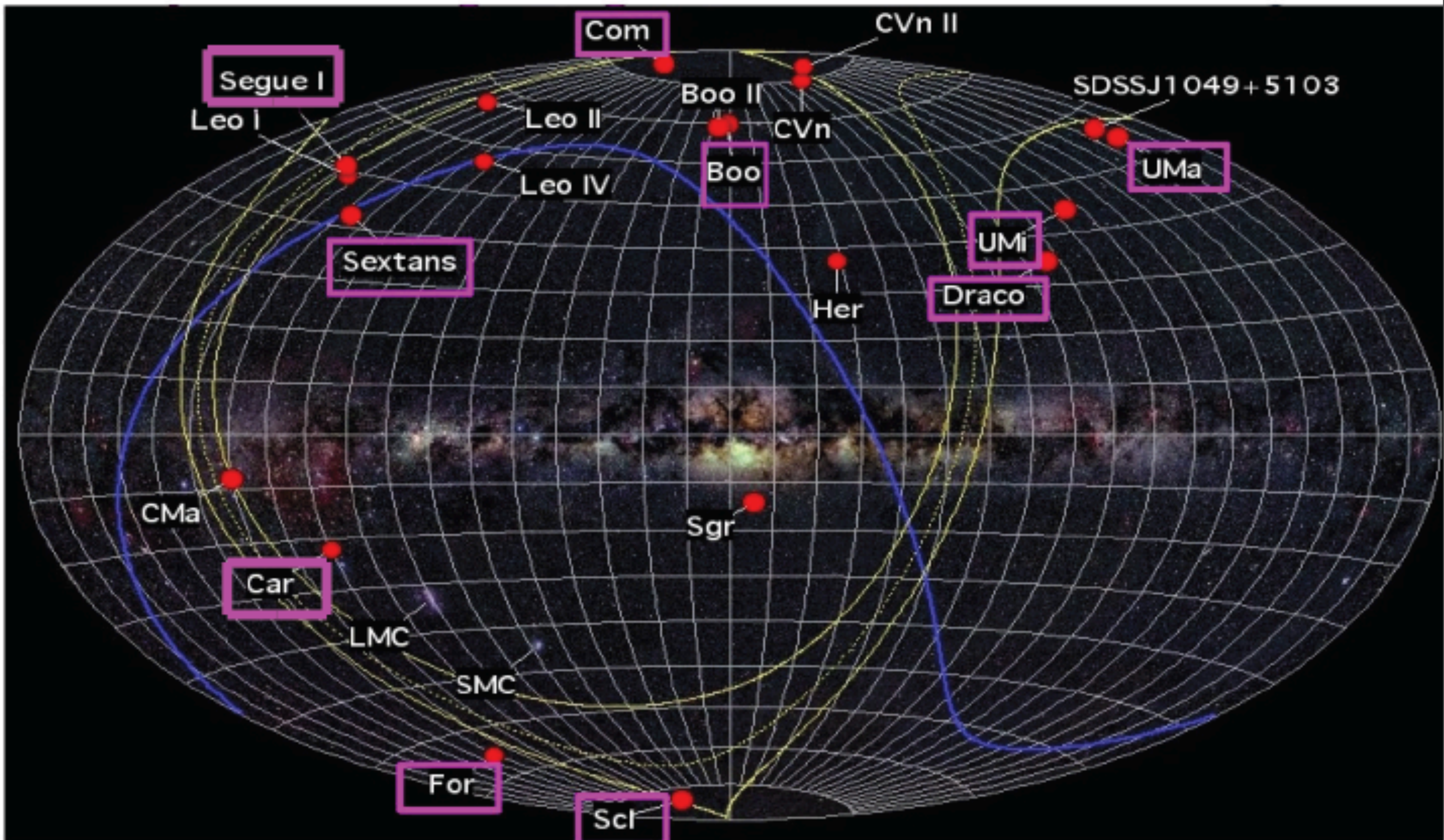

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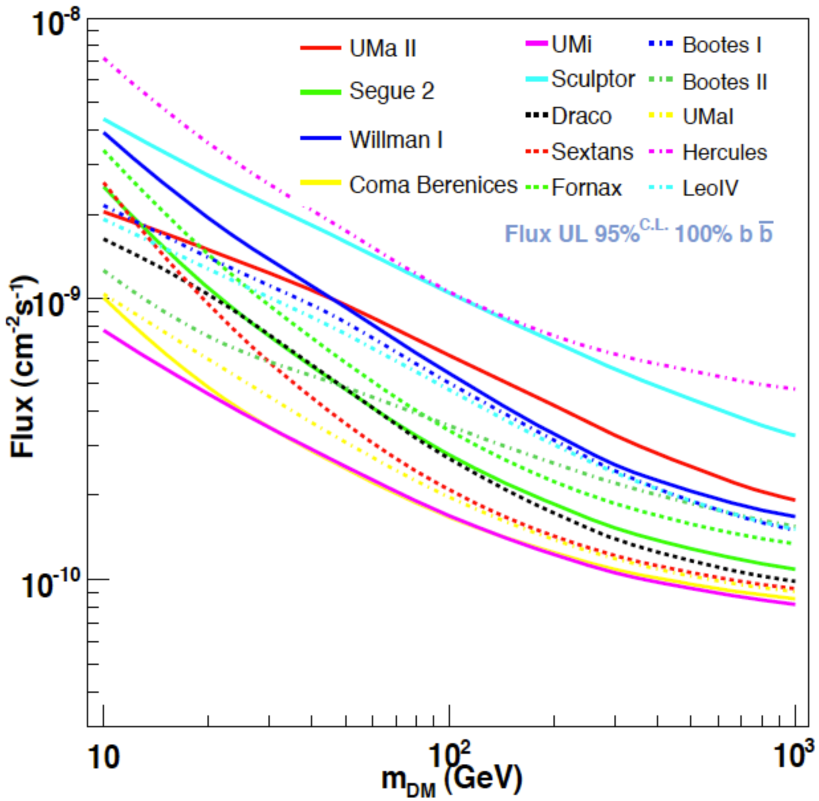
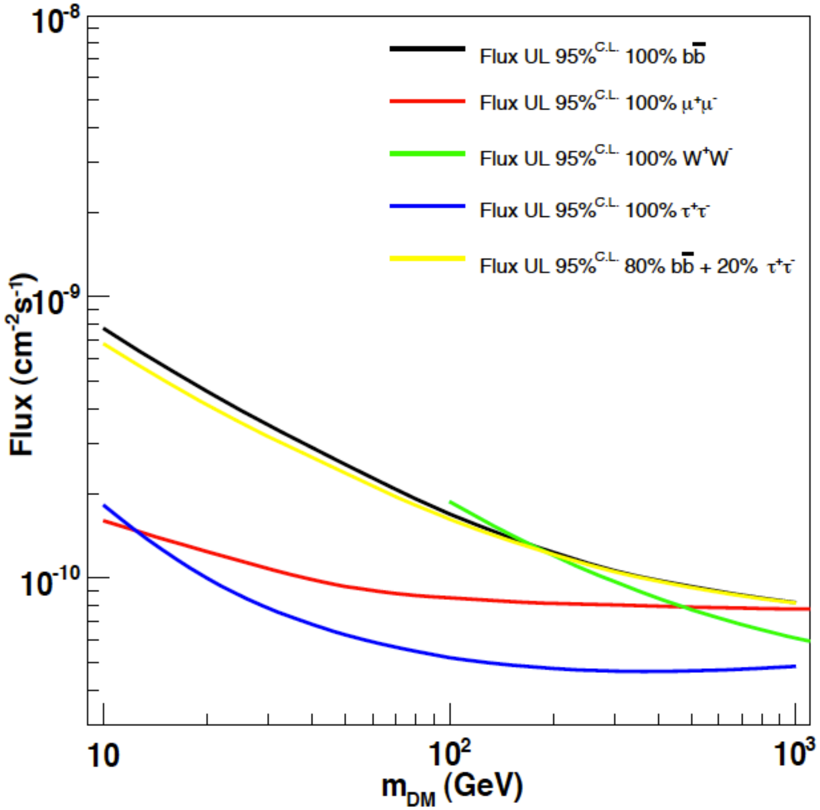
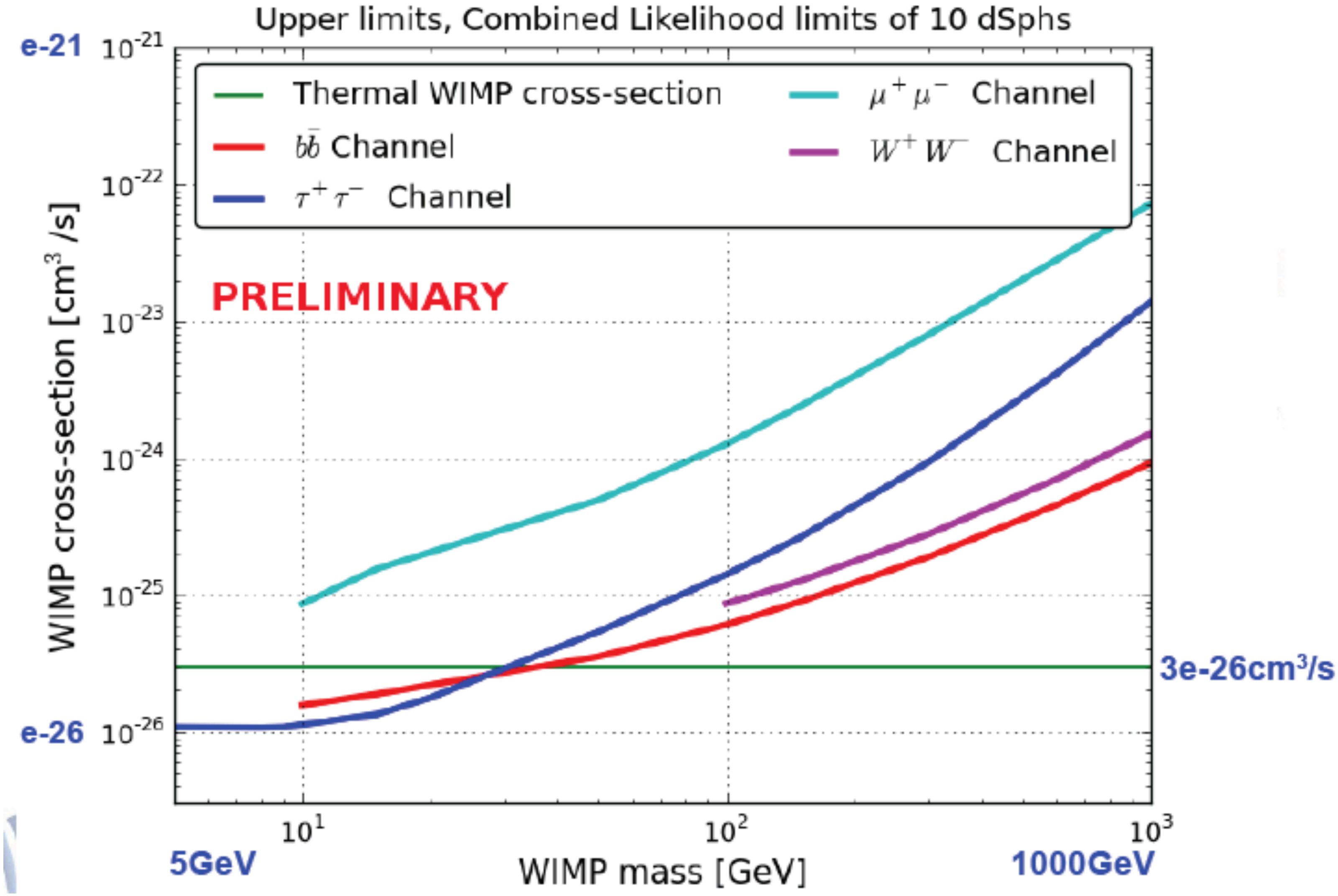




Abdo et al. 1001.4531 (2010)

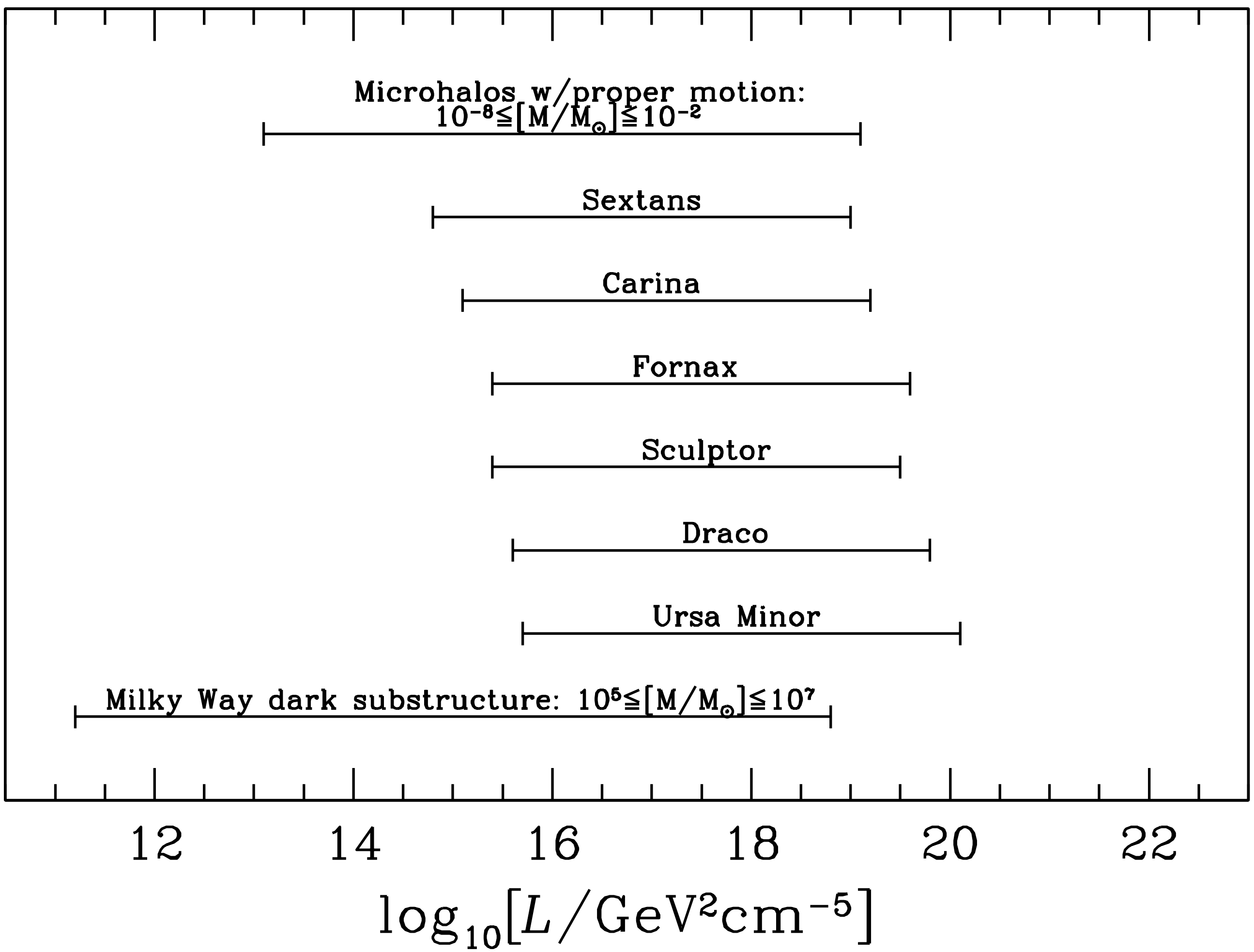
Dwarf satellites of the local group



From Maja Llena Garde's talk at the 2011 Fermi Symposium

Dwarf satellites of the local group

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



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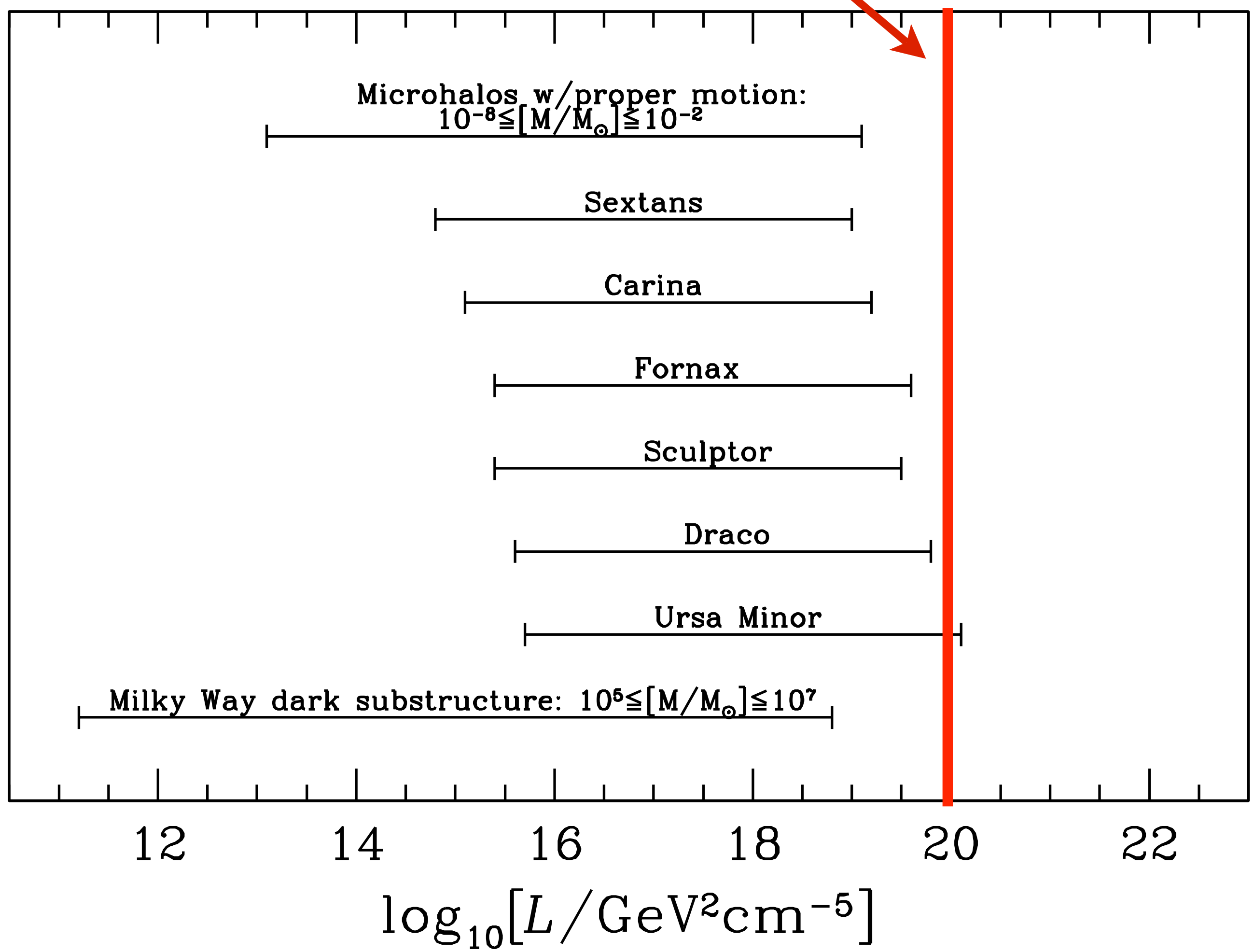

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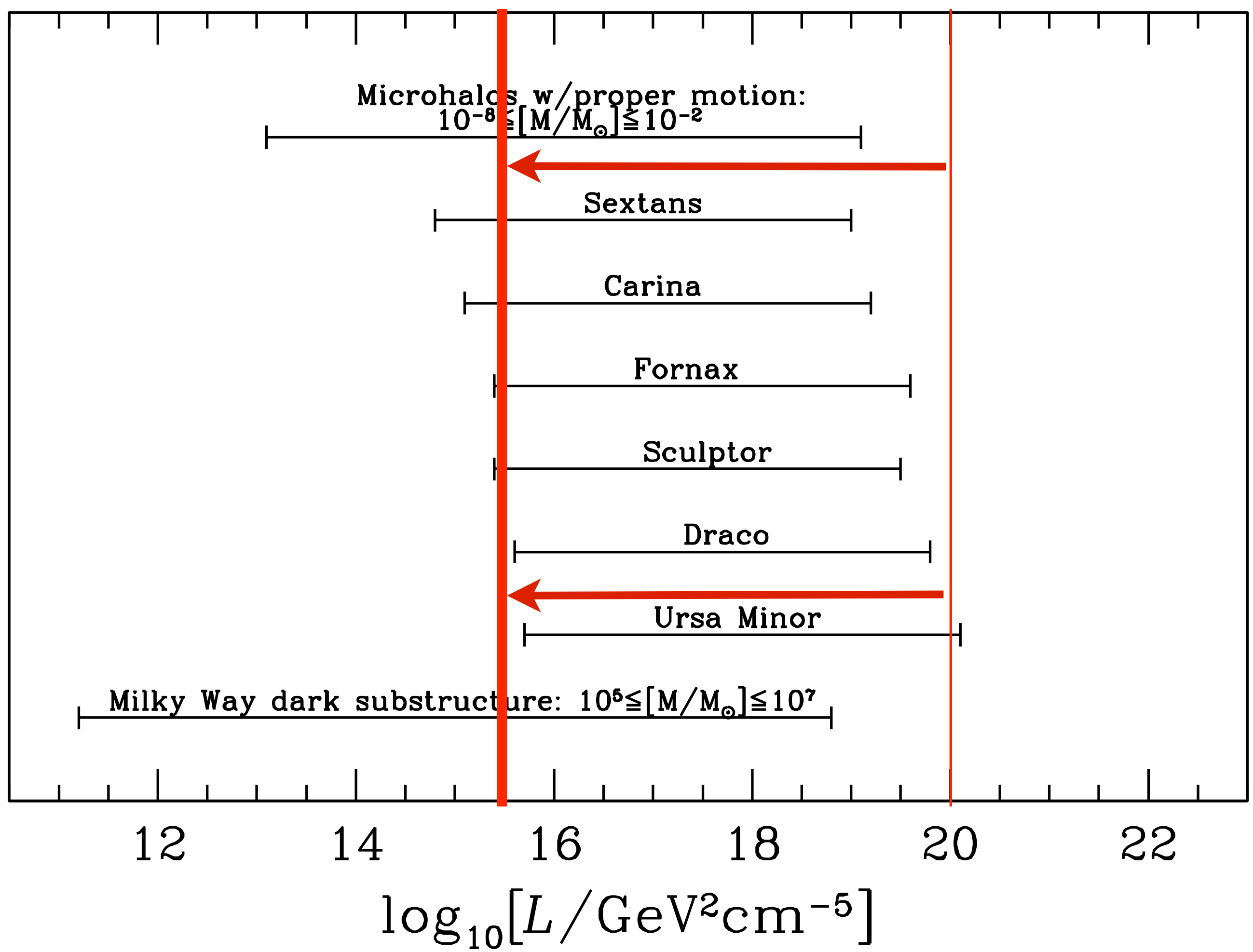
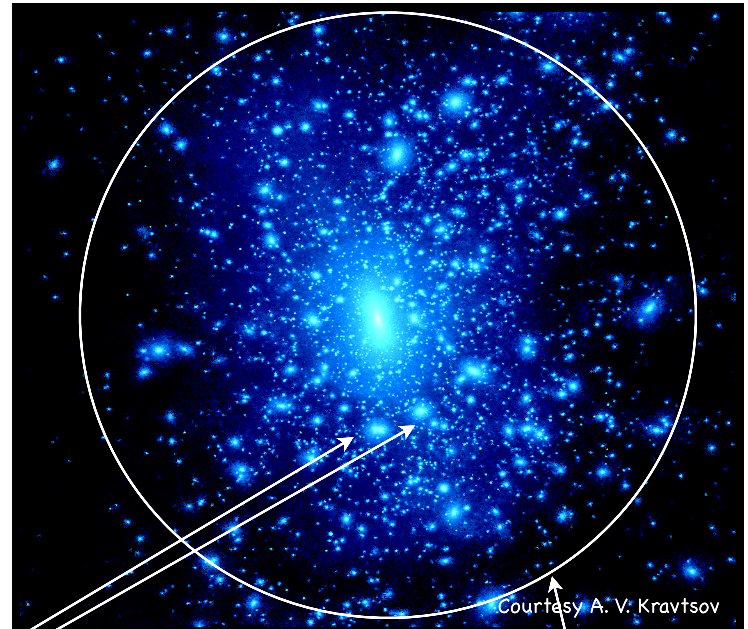
We need something like the Cerenkov Telescope Array



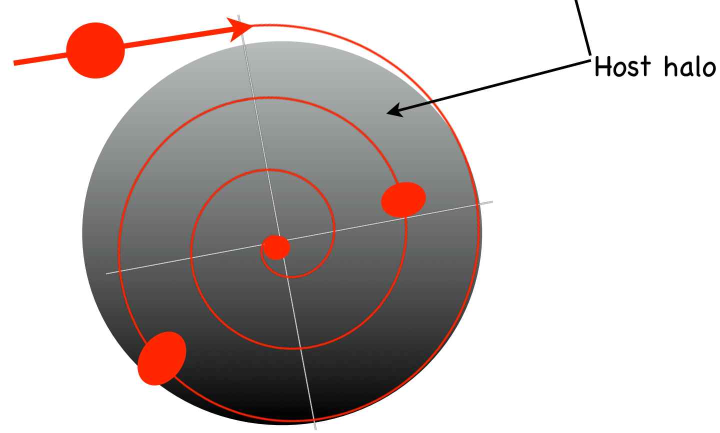
Individual Objects

$$\Gamma_{\gamma,\mathrm{e}^+,\bar{\mathrm{p}}} \sim \int_V n^2 dV$$

The spectrum of dark matter subhalo properties originates from the host assembly history



These two may have the same mass, but different history



Koushiappas, Zentner & Walker, PRD 69, 043501 (2004), but see also Baltz, Tayor & Wai, ApJ 659, L125 (2006), Kuhlen, Diemand & Madau , arXiv:0805.4416

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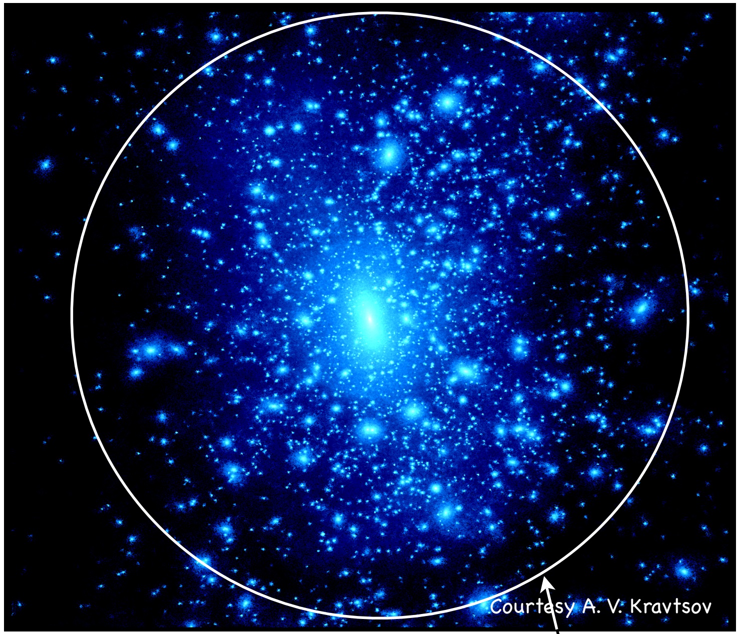

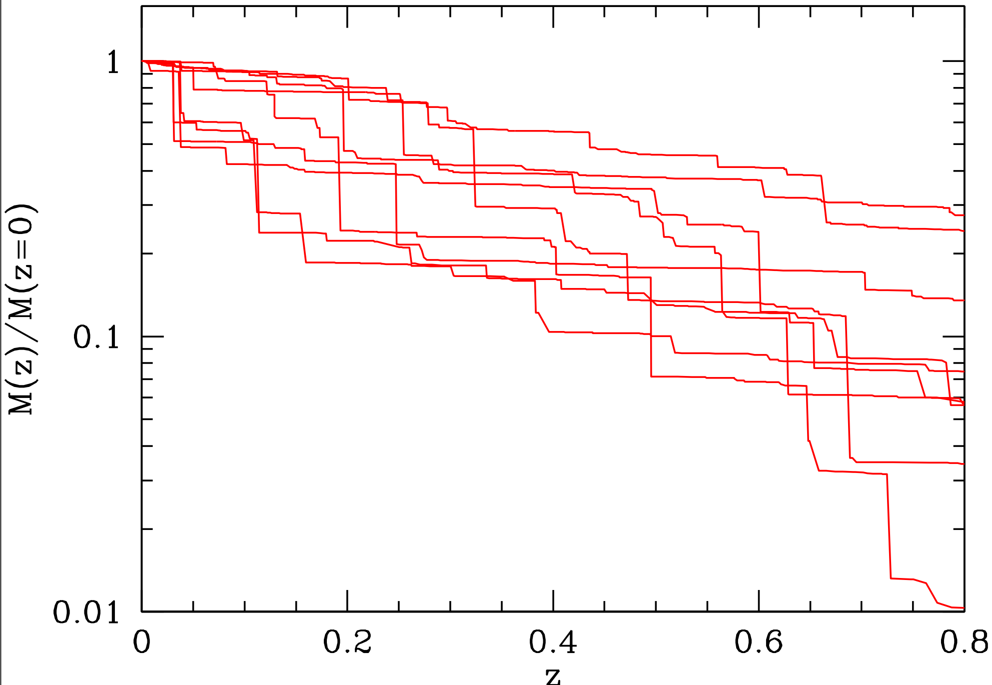

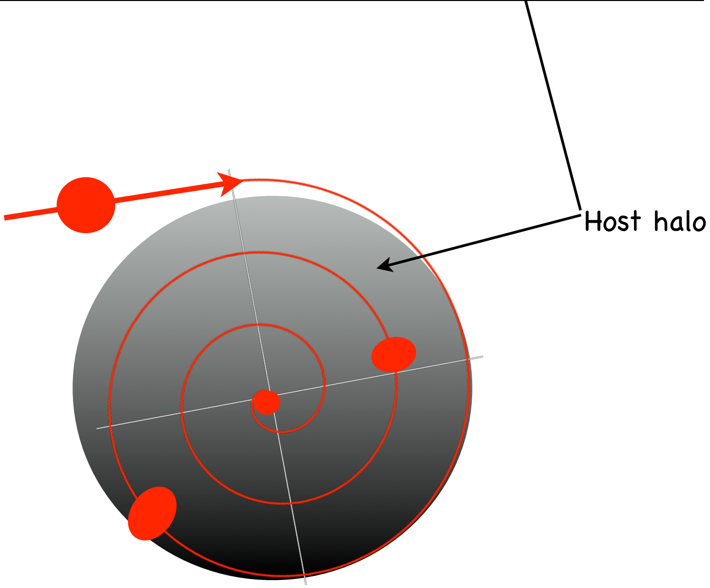

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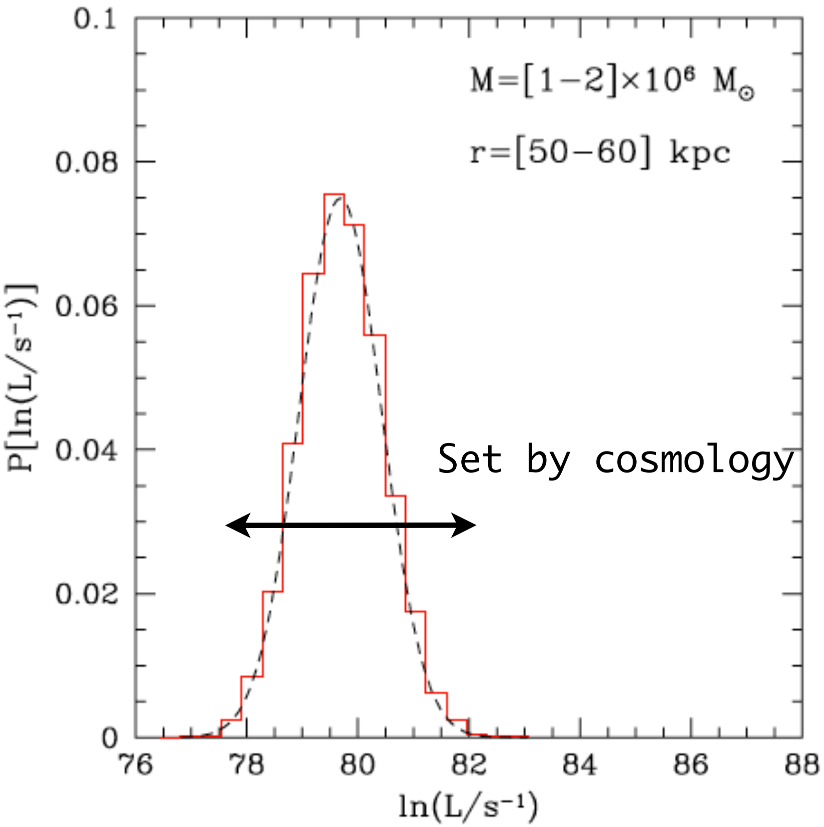
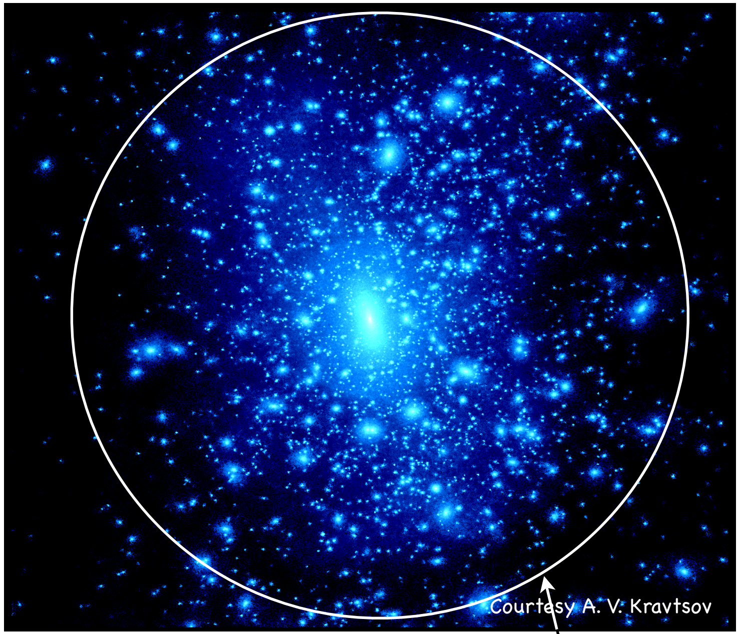
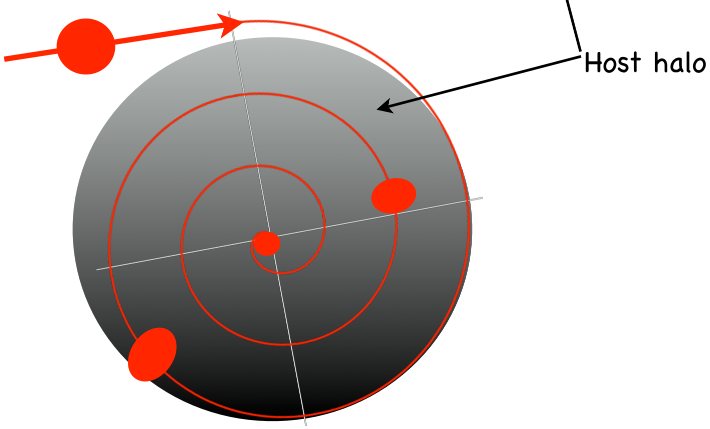


Koushiappas, Zentner, Kravtsov, PRD 82:083504(2010)





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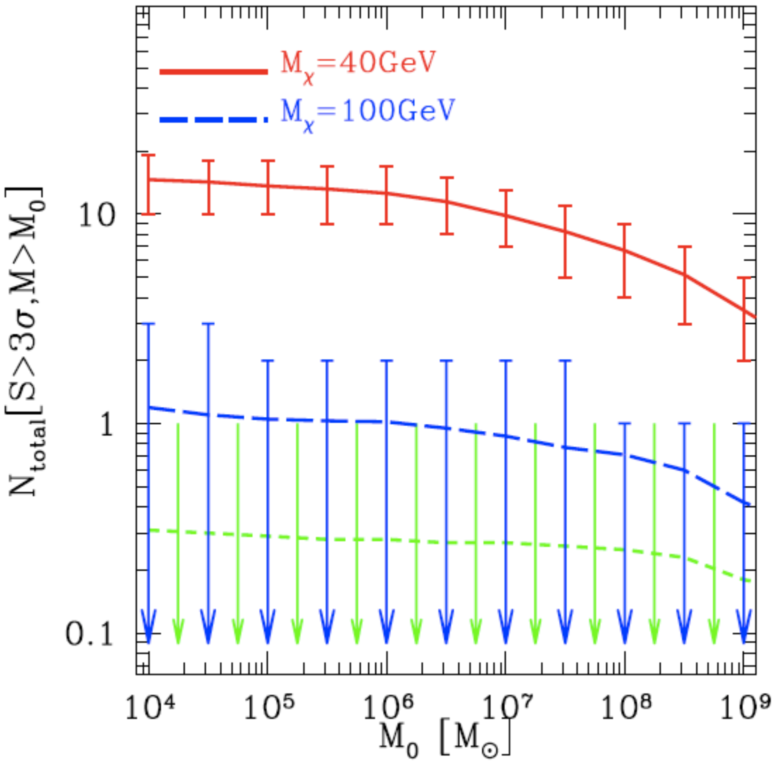

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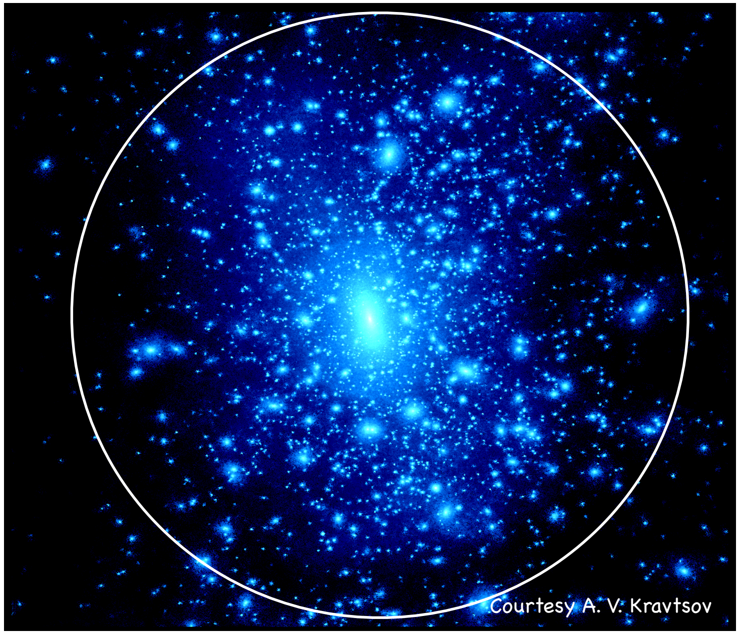
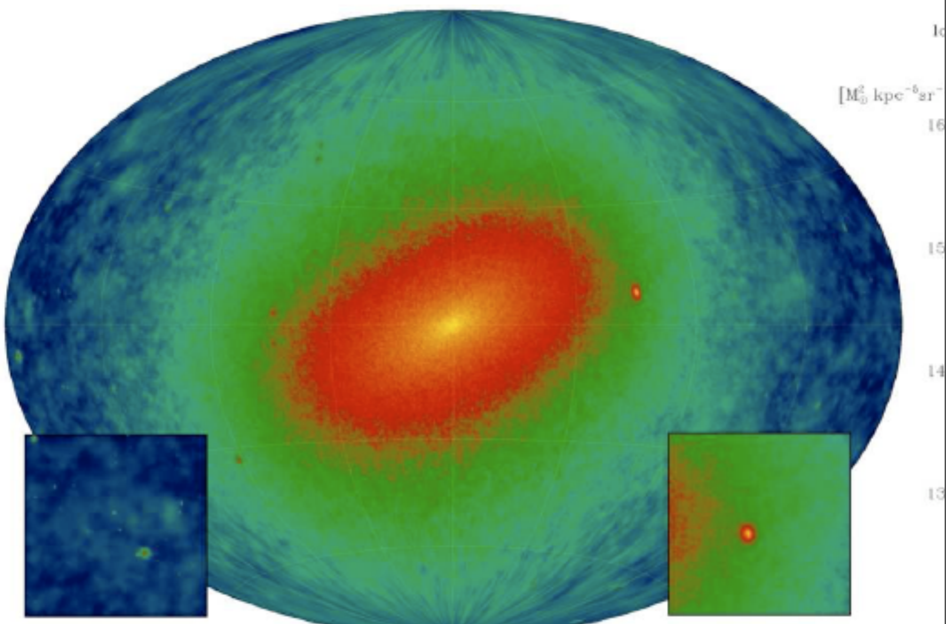
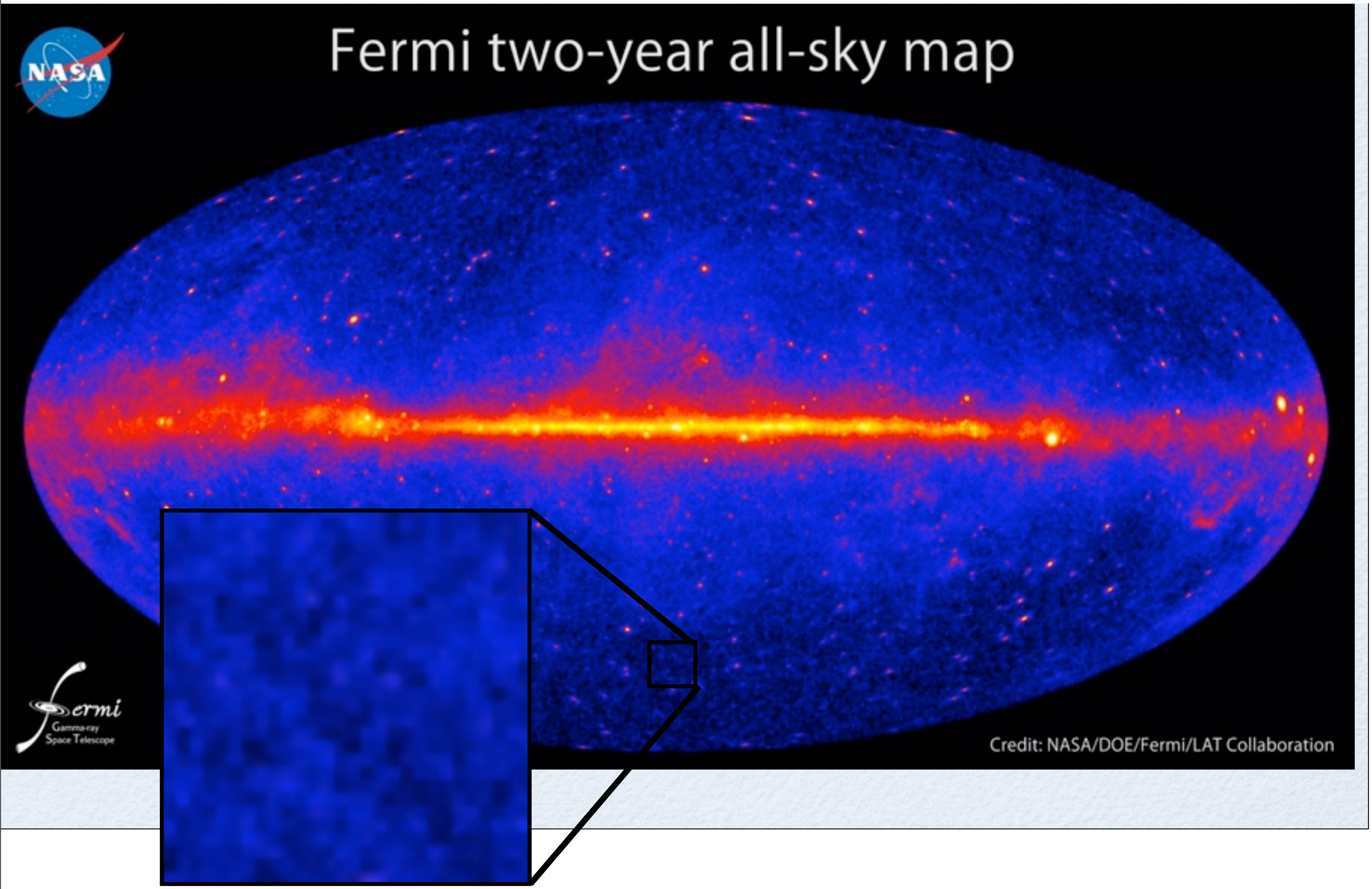




Diemand, Kuhlen & Madau, ApJ 657, 262 (2007)

The Galactic gamma-ray background



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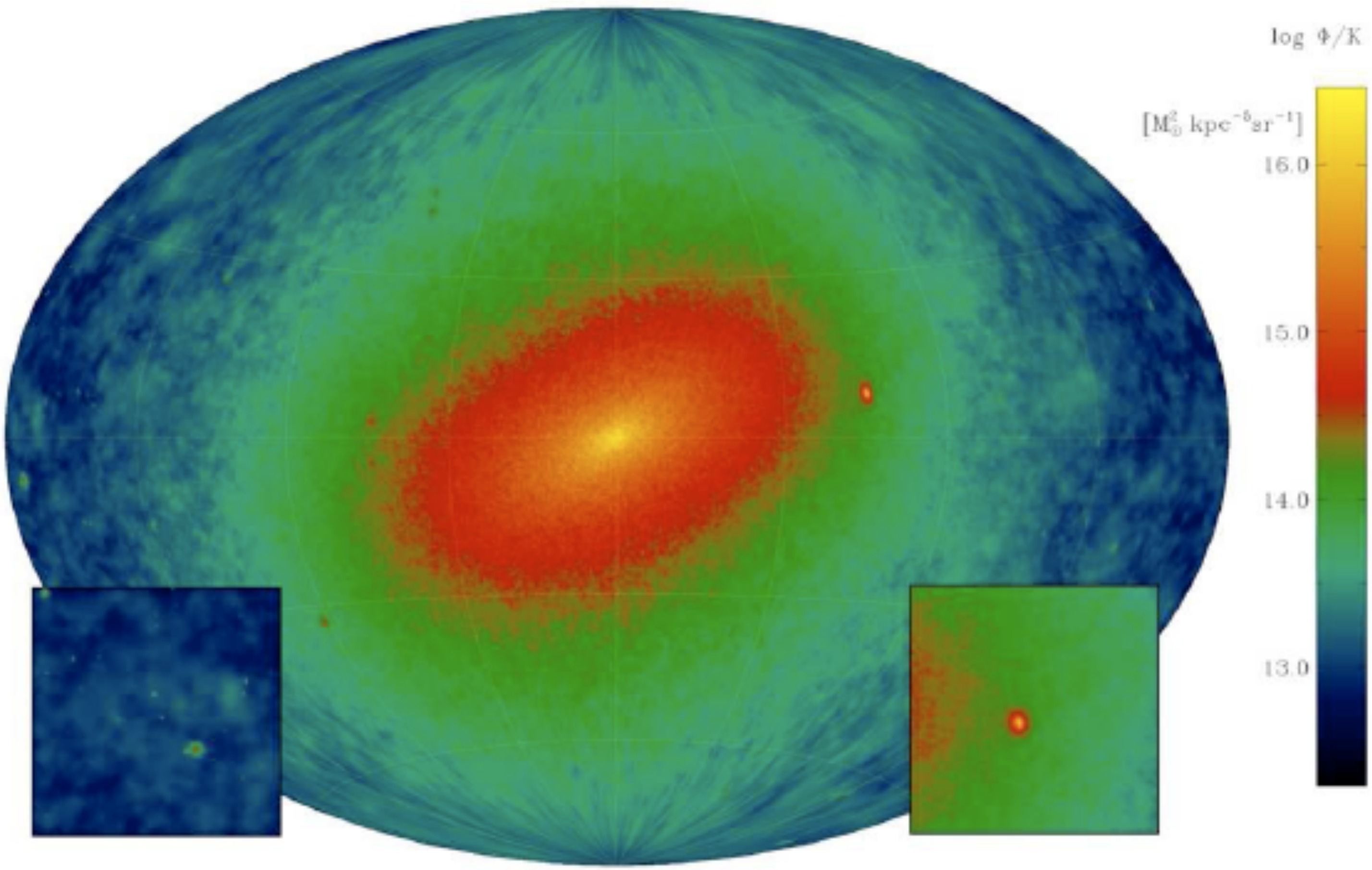

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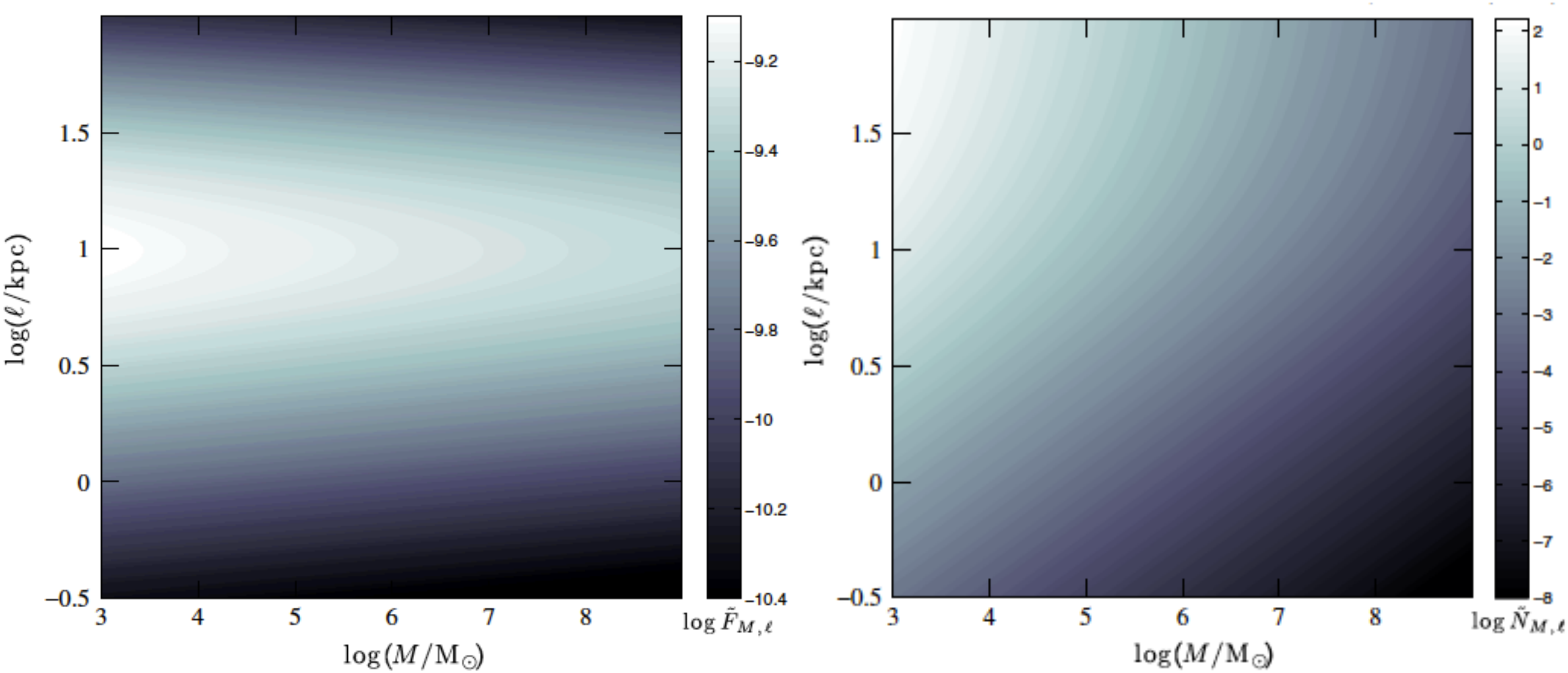

Koushiappas, Zentner & Kravtsov, PRD 82 3504 (2010)

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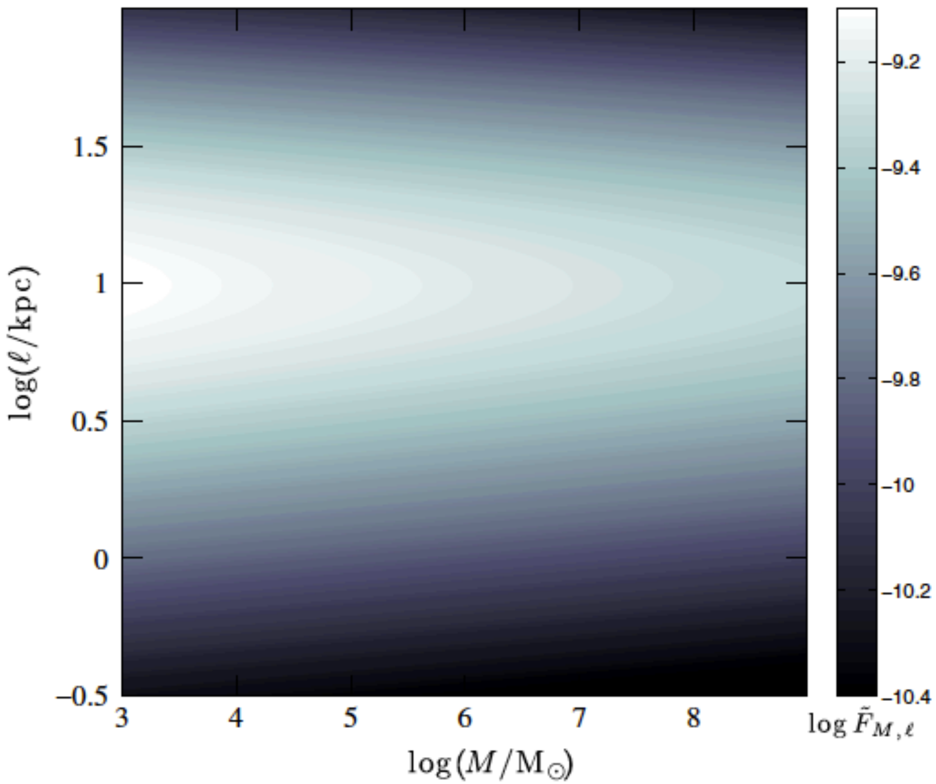

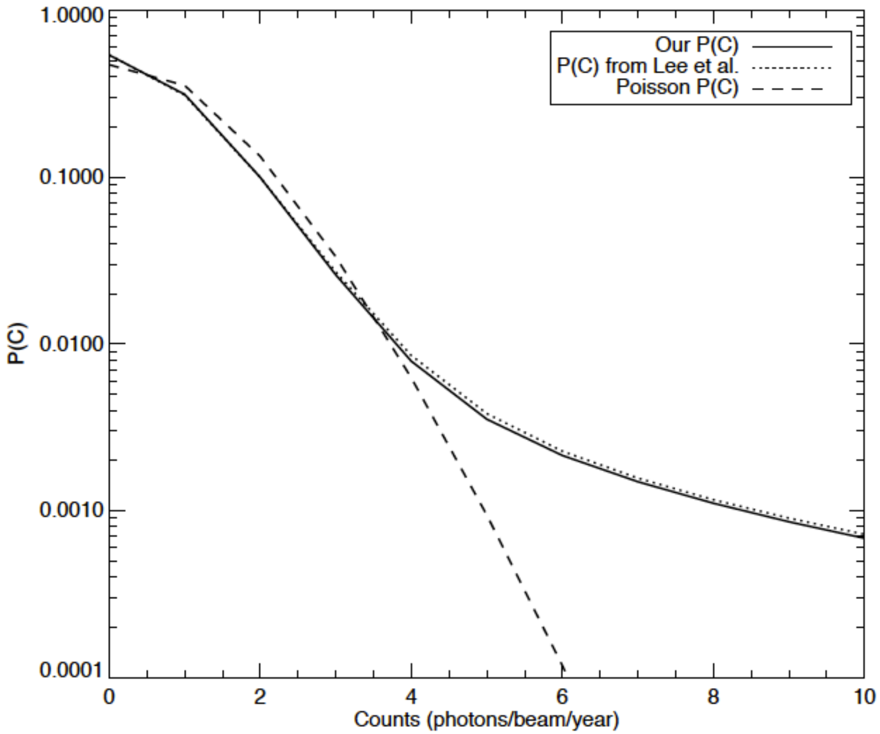

Koushiappas, Zentner & Kravtsov, PRD 82 3504 (2010)

Baxter, Dodelson, Koushiappas & Strigari, arXiv:1006:2399 (2010)
See also Lee, Ando & Kamionkowski, JCAP 07, 007 (2009)

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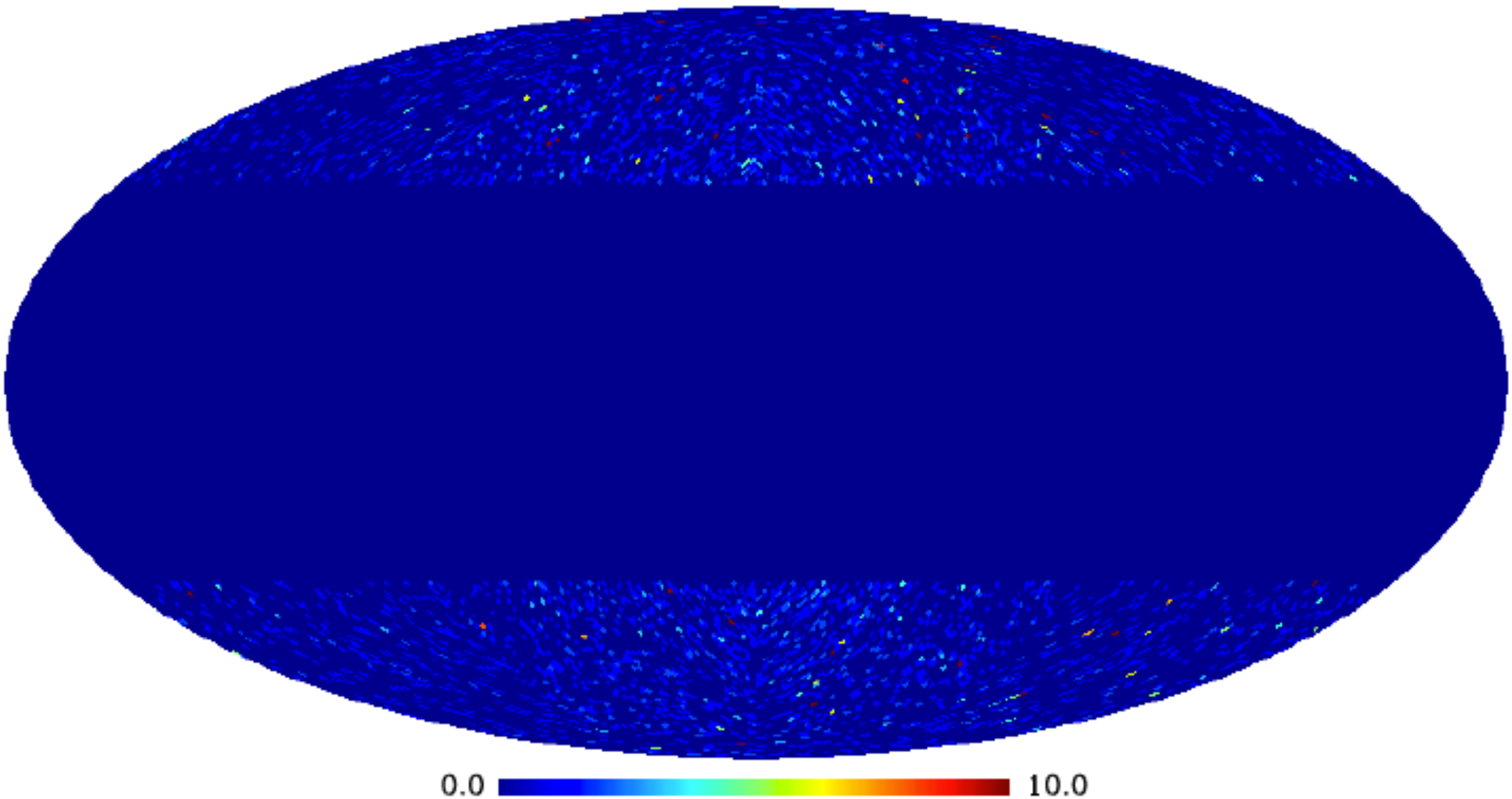

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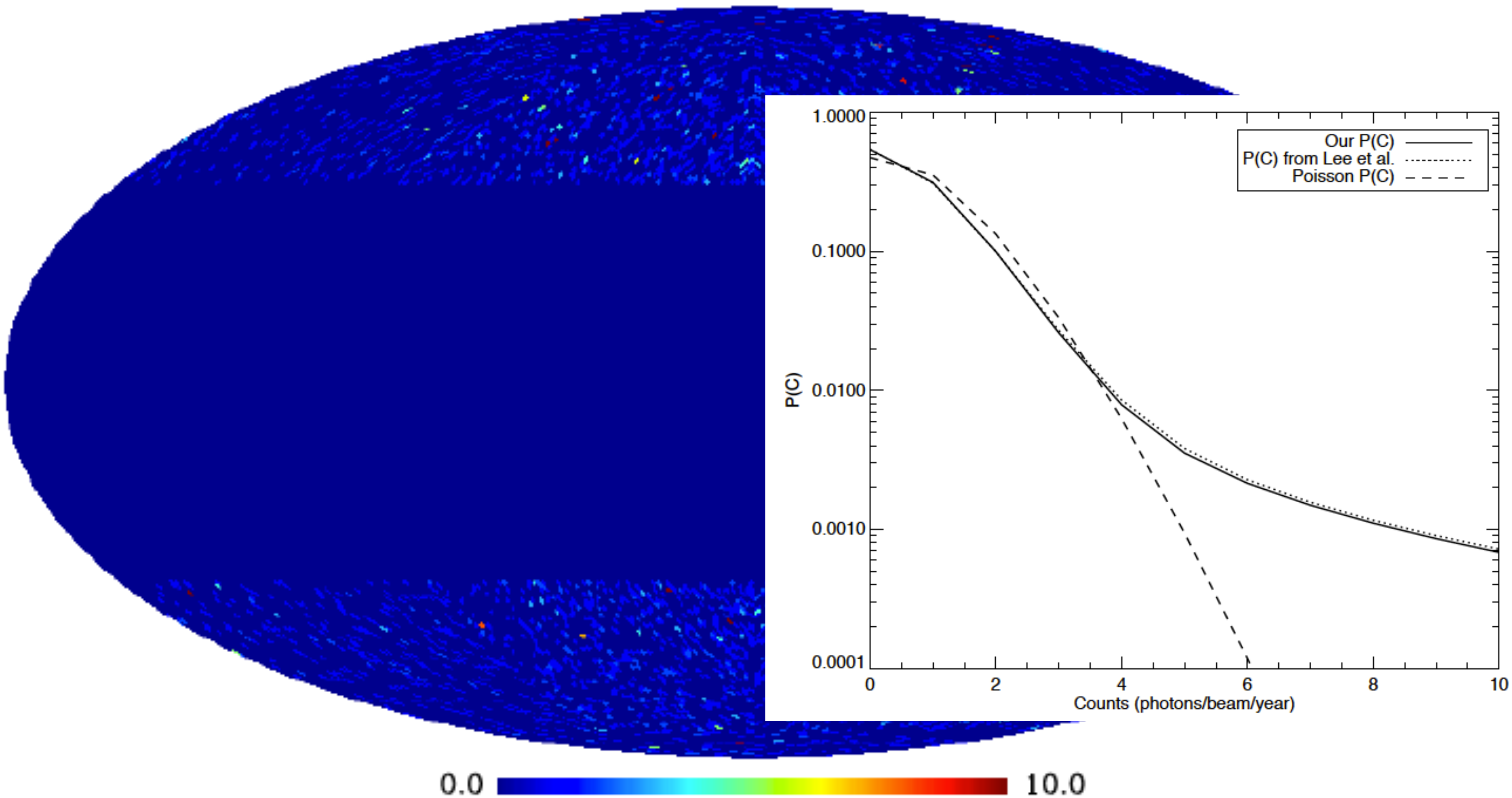
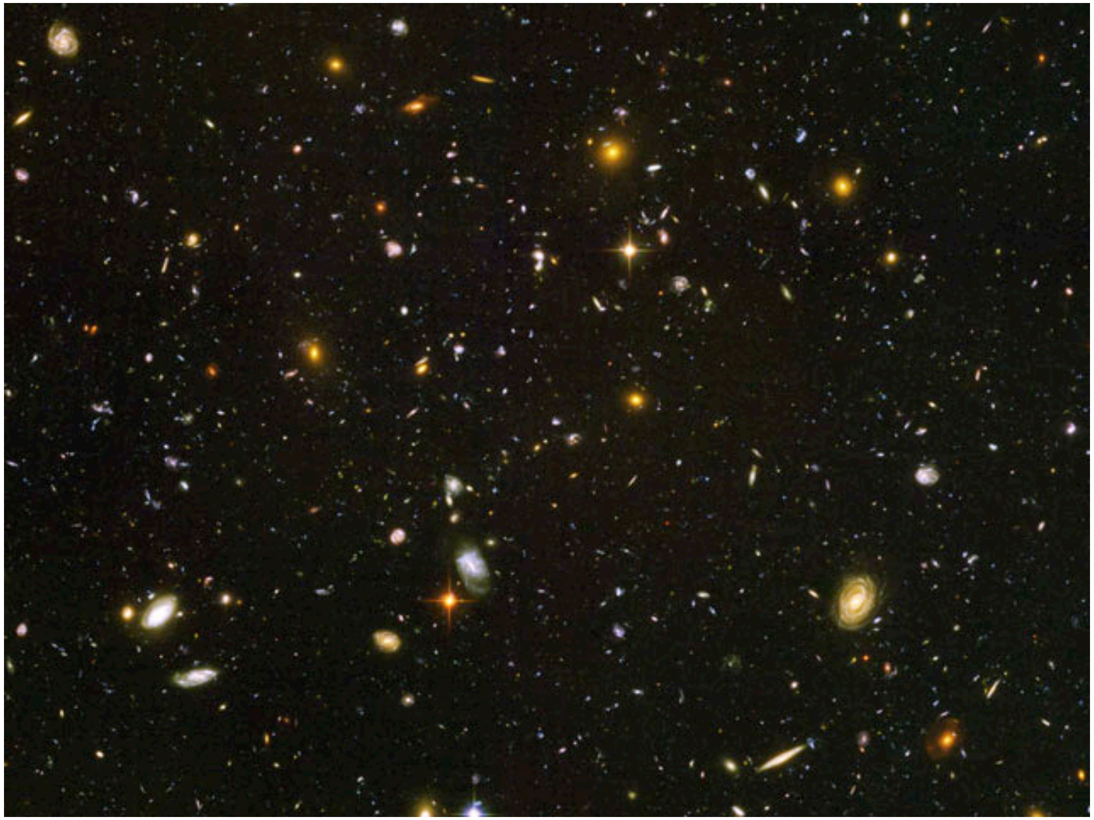


Baxter, Dodelson, Koushiappas & Strigari, arXiv:1006:2399 (2010)

The extragalactic gamma-ray background



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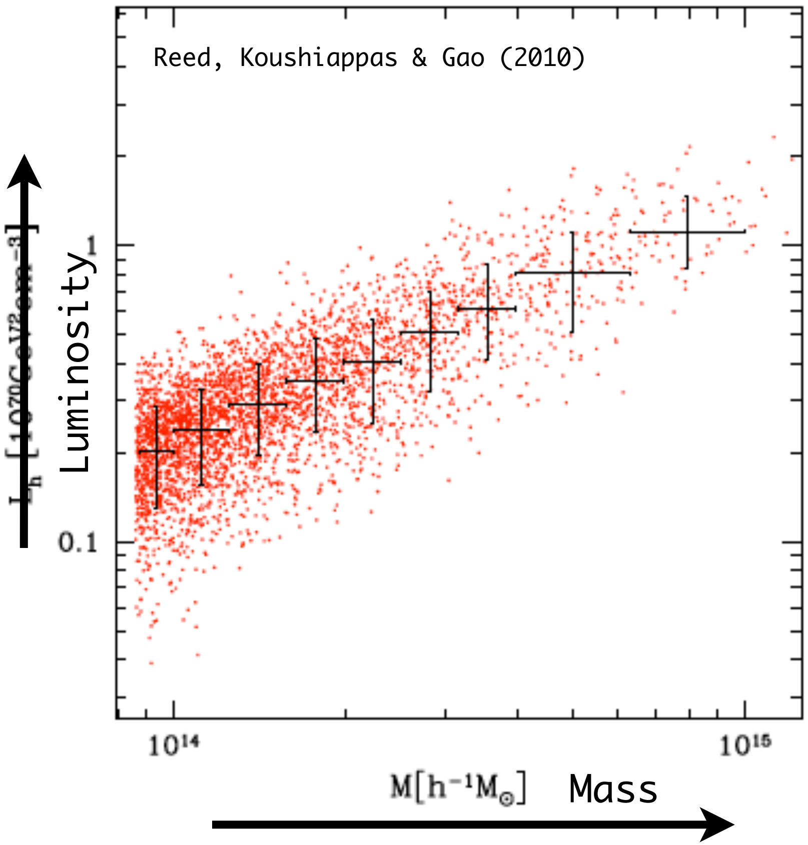

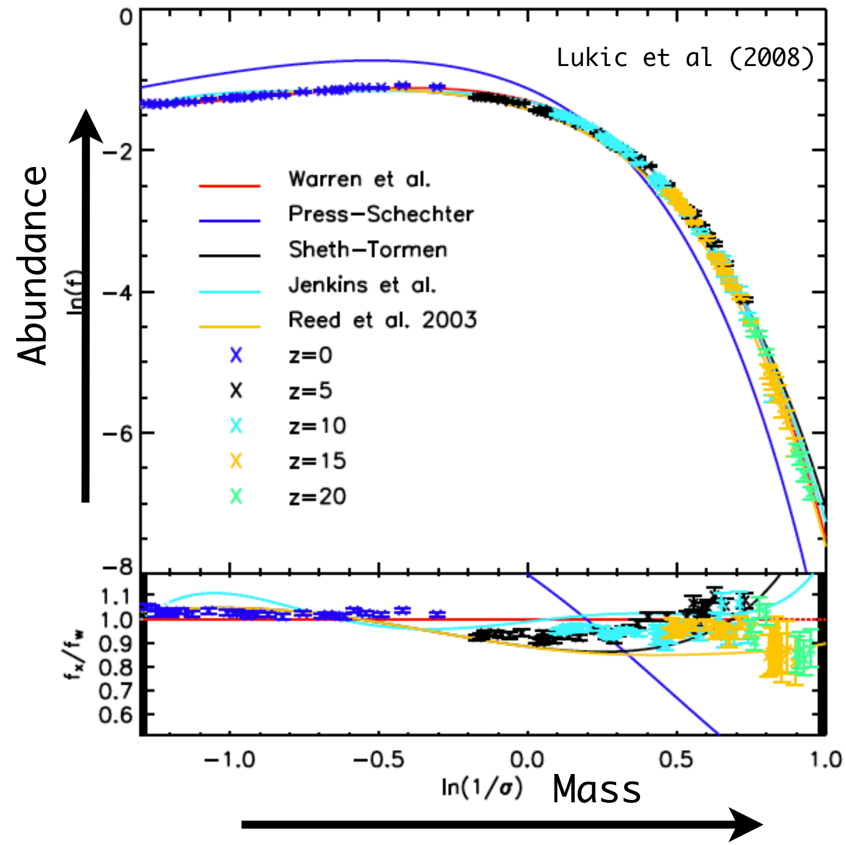

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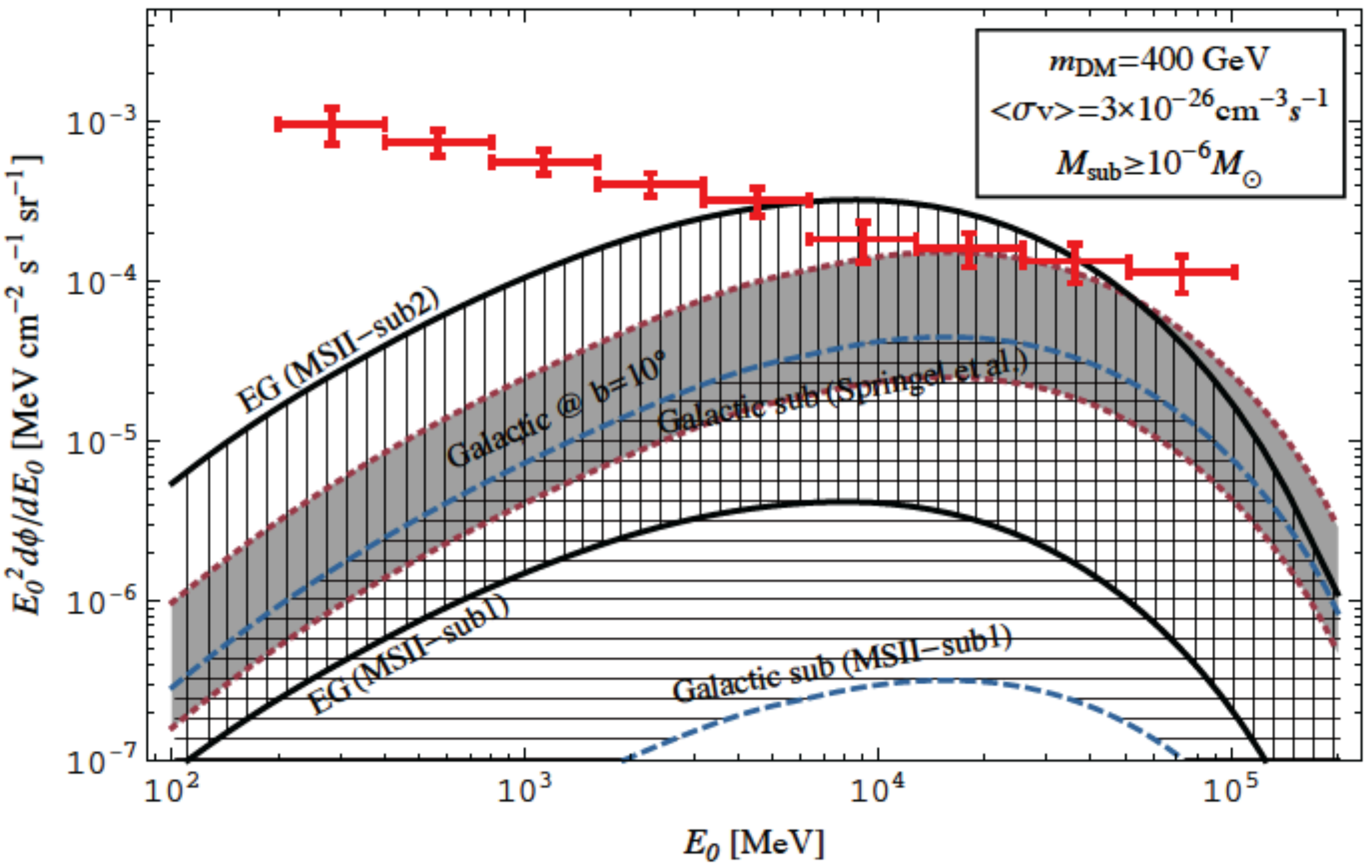

Abdo et al., arXiv:1002:4415 (2010)

Conclusions

A WIMP dark matter candidate results in photon final states

Annihilation takes place in high density regions

FERMI's energy range is well within viable dark matter candidates

Targets include dwarf spheroidals, the Galactic center, the diffuse Galactic halo emission as well as the extragalactic background

All studies are affected severely by the level of our understanding of the distribution of dark matter