GLAST and Dark Matter substructure in the Milky Way Halo

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Q: Will GLAST detect γ-ray photons from dark matter annihilation?

(Bergström et al. 1999; Calcanéo-Roldán & Moore 2000; Stoehr et al. 2003; Taylor & Silk 2003; Tasitsiomi et al. 2004; Koushiappas et al. 2004; Baltz & Wai 2004; etc., etc.)

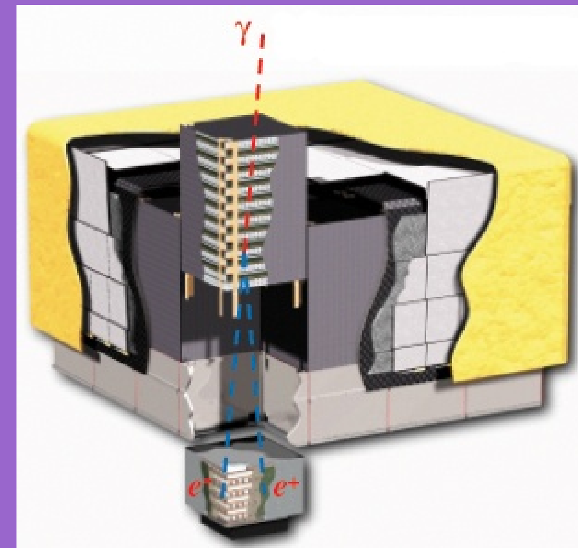
A: It depends. It depends on a lot of things:

1) DM particle properties: type, mass, cross section of particle
2) Backgrounds: extra-galactic and Galactic; how well can we subtract them?
3) DM distribution: how clumpy? subhalo spatial distribution? mass function? Internal density profile?

Numerical simulations of DM structure can help address 3).

- Run very high resolution simulation of a Milky Way scale DM halo.
- Run subhalo finder and determine subhalo abundance, distribution, and internal properties.
- Calculate annihilation fluxes and angular sizes, estimate boost factors.
- Pick a particular particle physics model, and create simulated GLAST allsky maps.

Astro physics



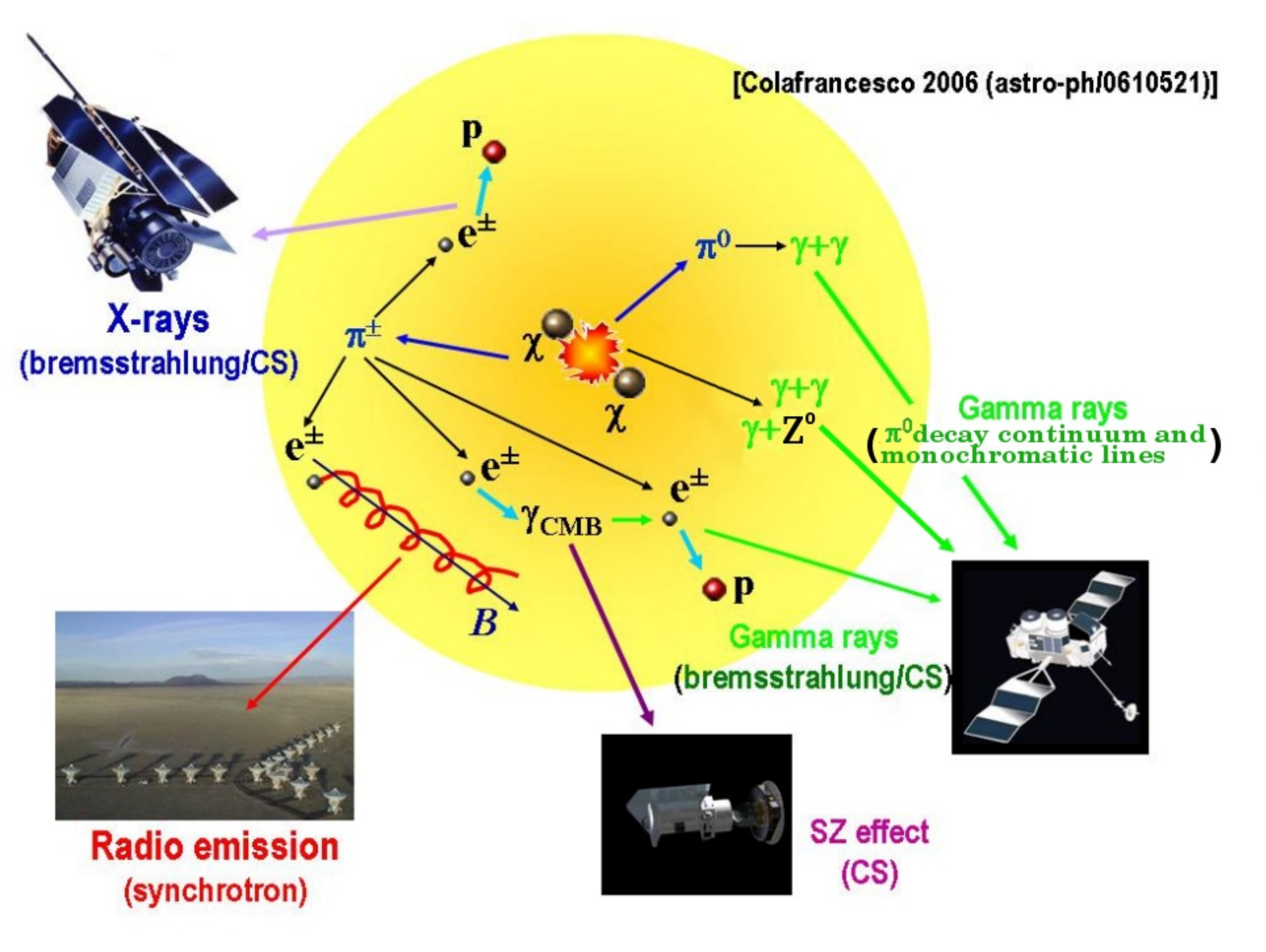
Detector properties

$$N_\gamma = \left[\int_{\text{line of sight}} \rho^2_{\text{DM}}\, dl(\psi)\right] \frac{\langle \sigma v \rangle}{M_\chi^2} \left[\int_{E_{th}}^{M_\chi} \left(\frac{dN_\gamma}{dE}\right)_{\text{SUSY}} A_{\text{eff}}(E)\, dE\right] \frac{\Delta\Omega}{4\pi}\, \tau_{\text{exp}}$$

Particle physics

Particle Physics

DM (WIMP) annihilation signal



Many different DM candidates: axions, WIMPs (neutralino, Kaluza-Klein, ...), etc.

In the following: DM = lightest SUSY particle (neutralino)

γ's from neutralino annihilation:

a) $\chi\chi \rightarrow \gamma\gamma$

b) $\chi\chi \rightarrow \gamma Z^0$

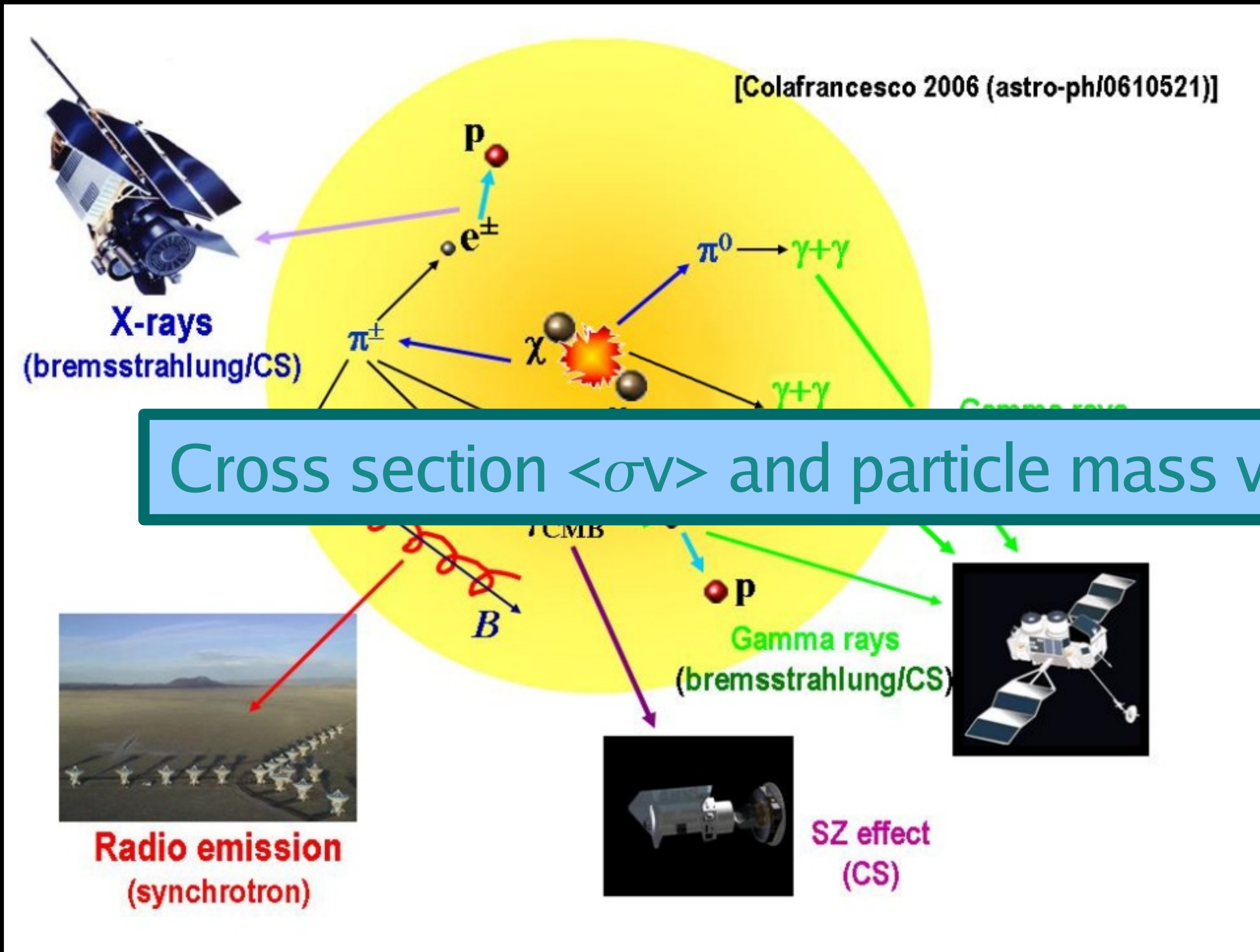
c) $\chi\chi \rightarrow \{WW, Z^0Z^0, b\bar{b}, t\bar{t}, u\bar{u}\}$

a)+b) spectral line, lower $<\sigma v>$

c) photon continuum from π^0 decay, higher $<\sigma v>$, more ambiguous signal

Particle Physics

DM (WIMP) annihilation signal



Cross section $<\sigma v>$ and particle mass very uncertain!

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Astro Physics

"Via Lactea"

200 million particles in a Milky Way scale halo

particle mass = 20,000$M_\odot$

force resolution = 90 pc

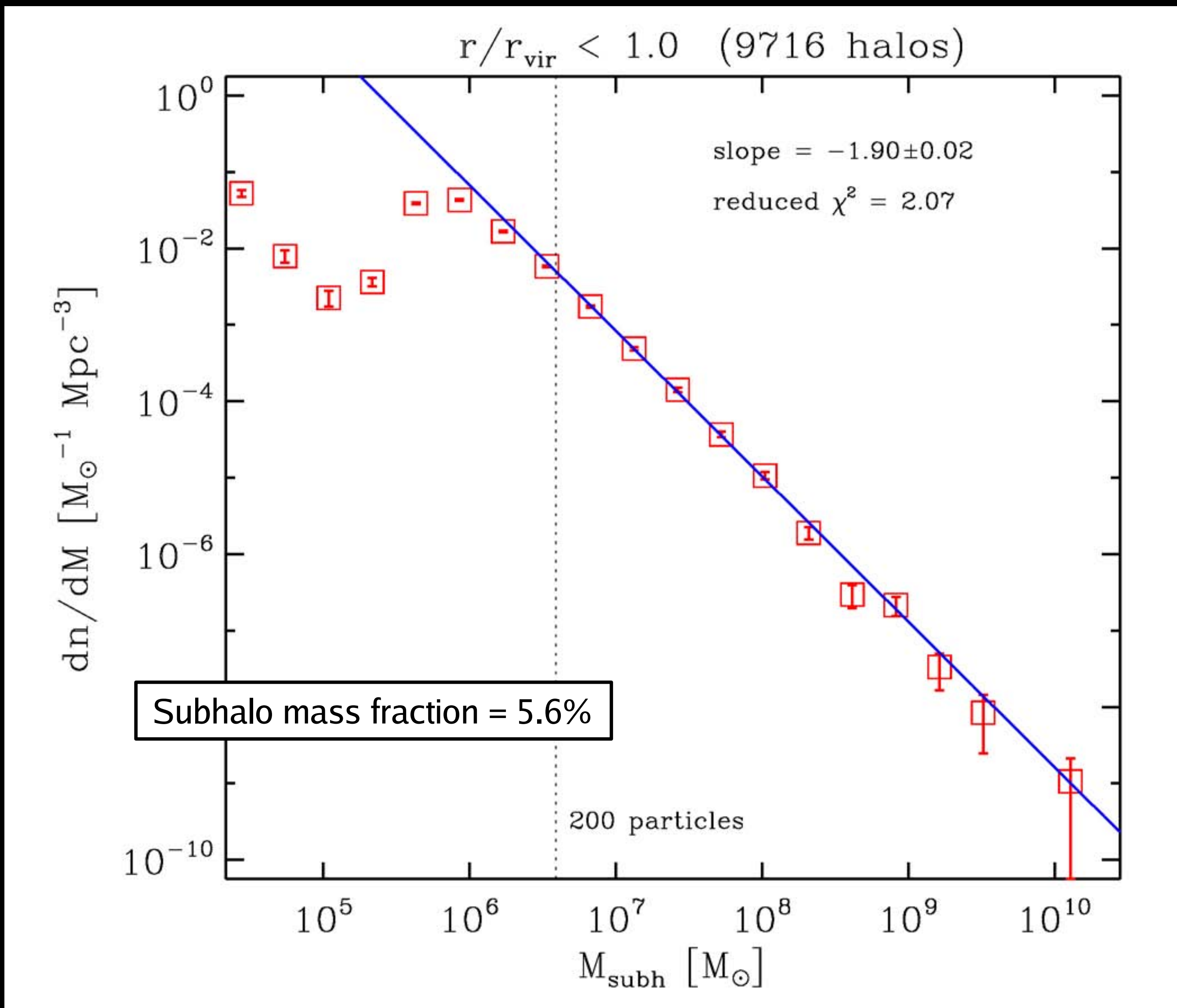
WMAP 3year parameters

We find 10,000 subhalos!

Simulation performed on NASA's Project Columbia

More movies and images can be found at: http://www.ucolick.org/~diemand/vl

Subhalo Mass Function

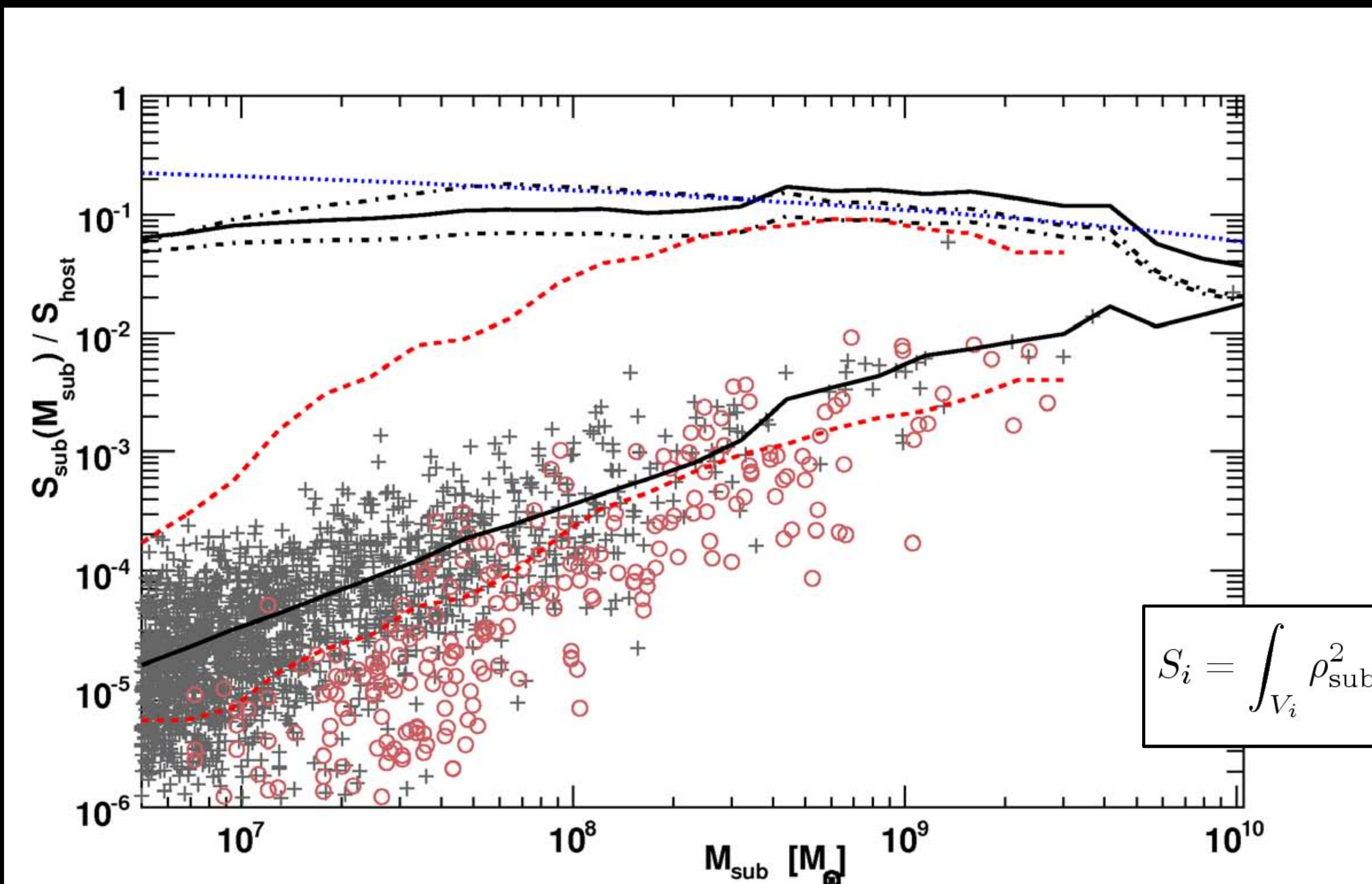


Consistent with single powerlaw down to ~200 particles

Very close to constant contribution to total mass per decade of subhalo mass.

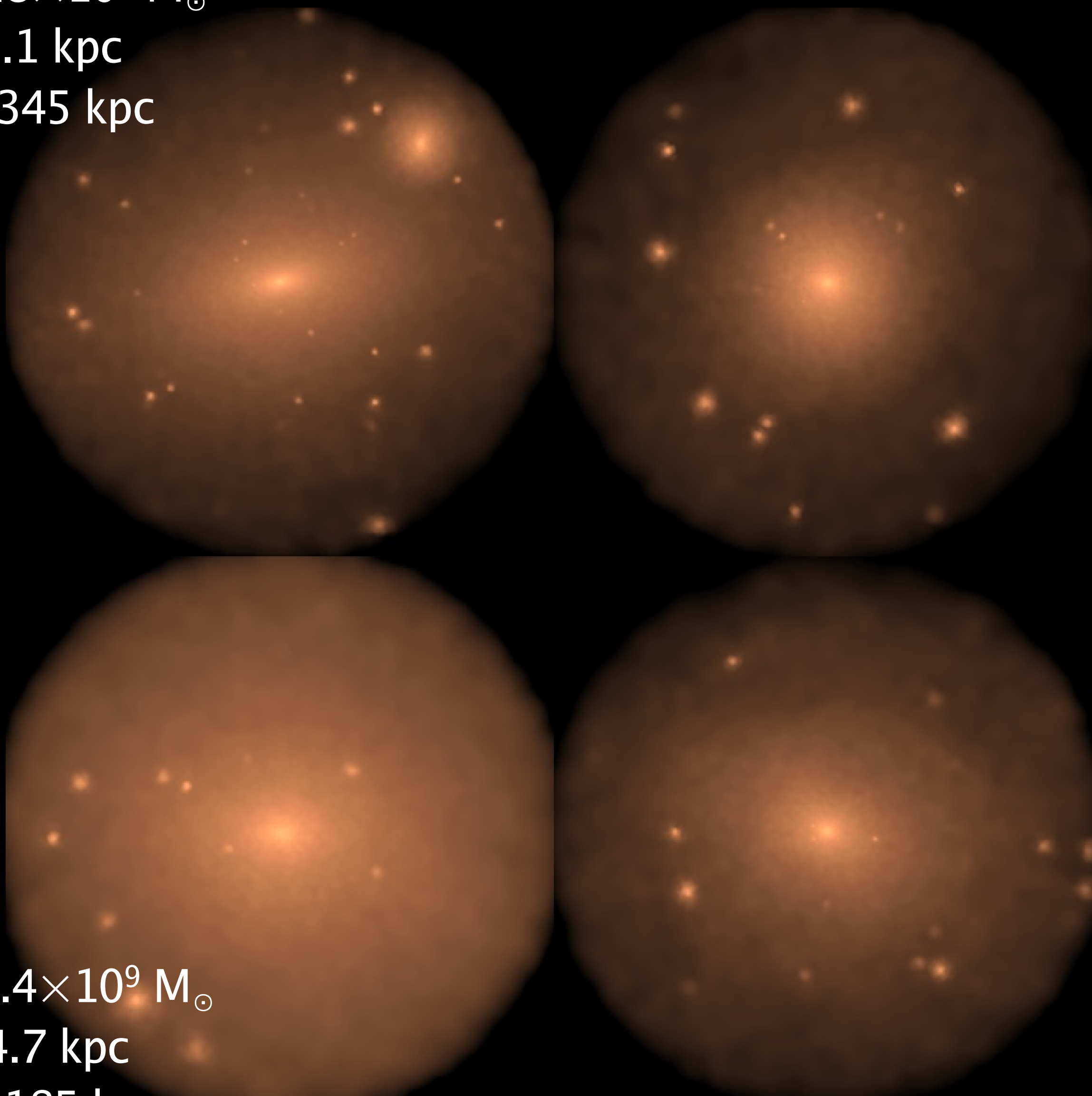
Subhalo mass fraction has not converged, depends on lower mass cutoff!

Subhalo Annihilation Luminosity vs. Mass



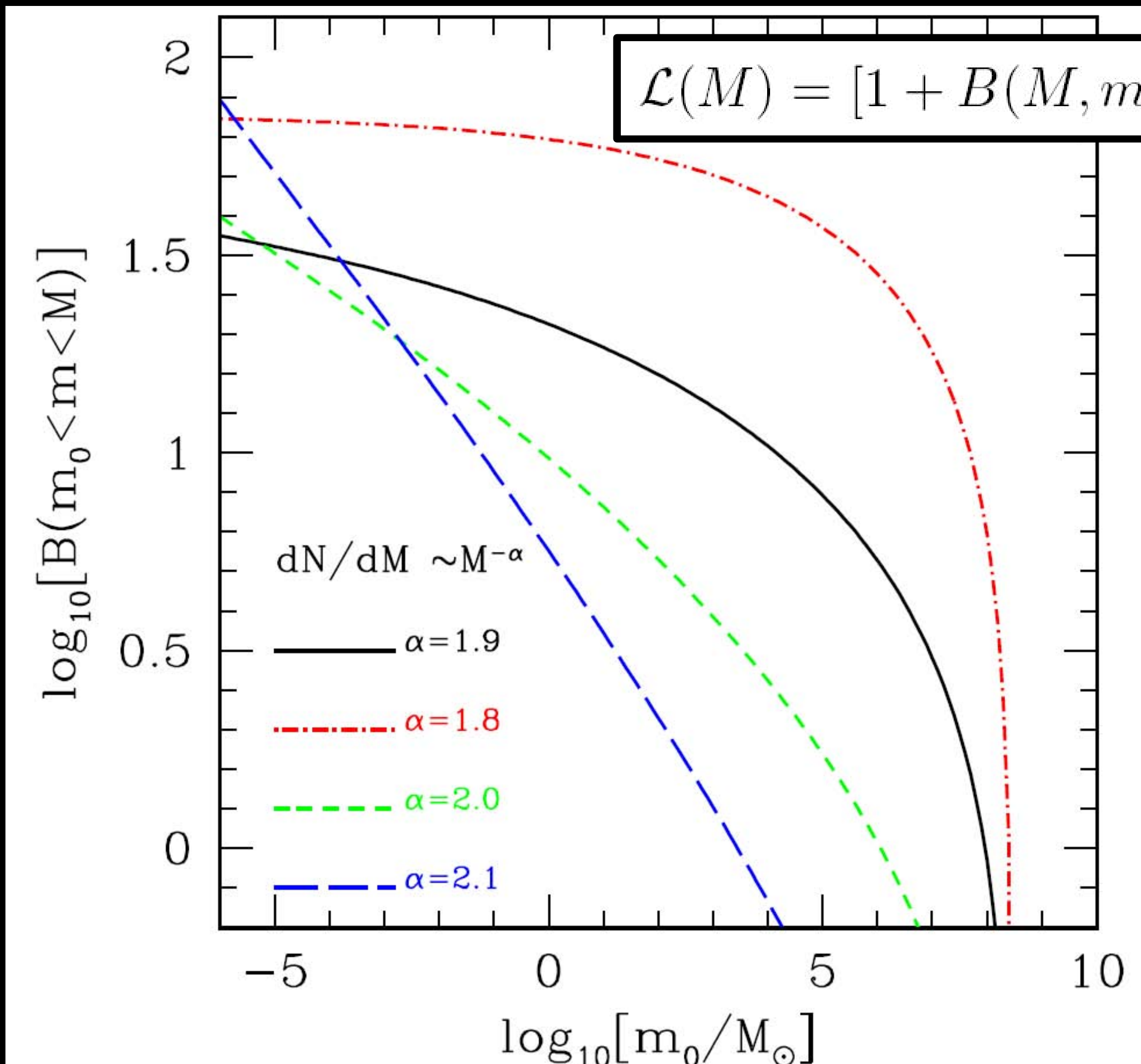
$$S_i = \int_{V_i} \rho_{\rm sub}^2 dV_i = \sum_{j \epsilon \{P_i\}} \rho_j m_p$$

Sub-Subhalos



Subhalo Luminosity Boost Factor

$$\mathcal{L}(M) = [1 + B(M, m_0)]\tilde{\mathcal{L}}(M)$$

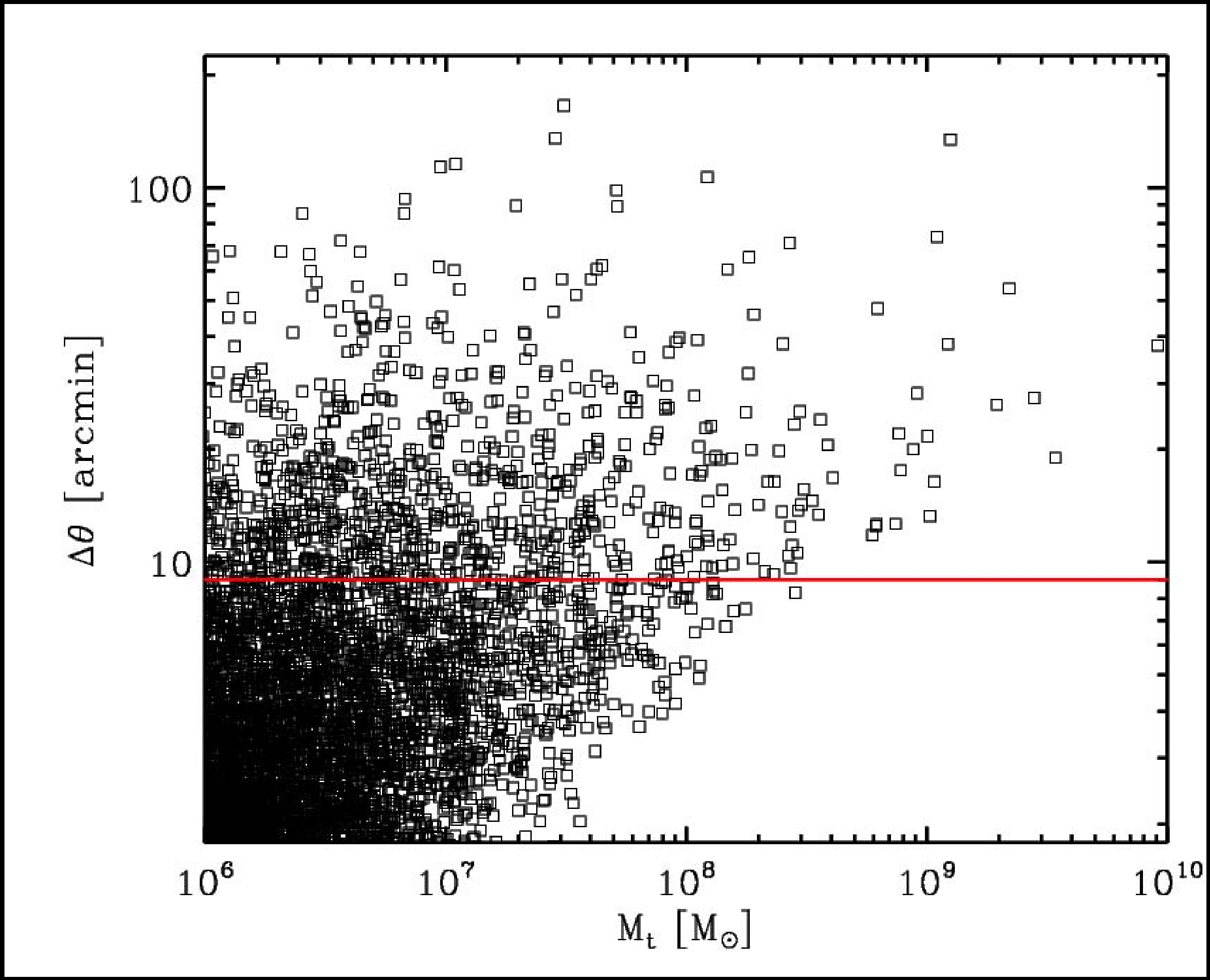


Strigari et al. 2006

Substructure can boost the total subhalo luminosity.

In numerical simulations: should correct for artificial heating in the central regions of subhalos.

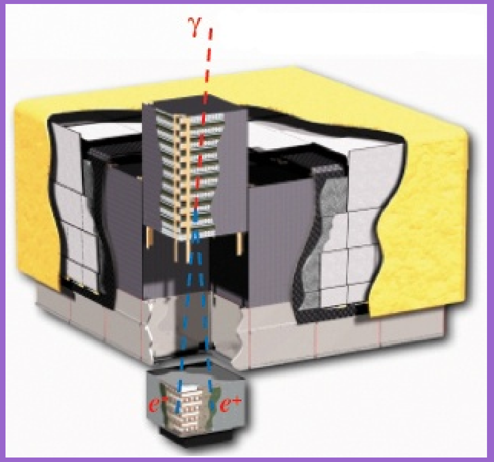
Angular Size vs. Mass



$\Delta\theta$ = angle subtended by twice the subhalo's scale radius r_s.

For an NFW profile 90% of the flux originates from within r_s.

Detector properties



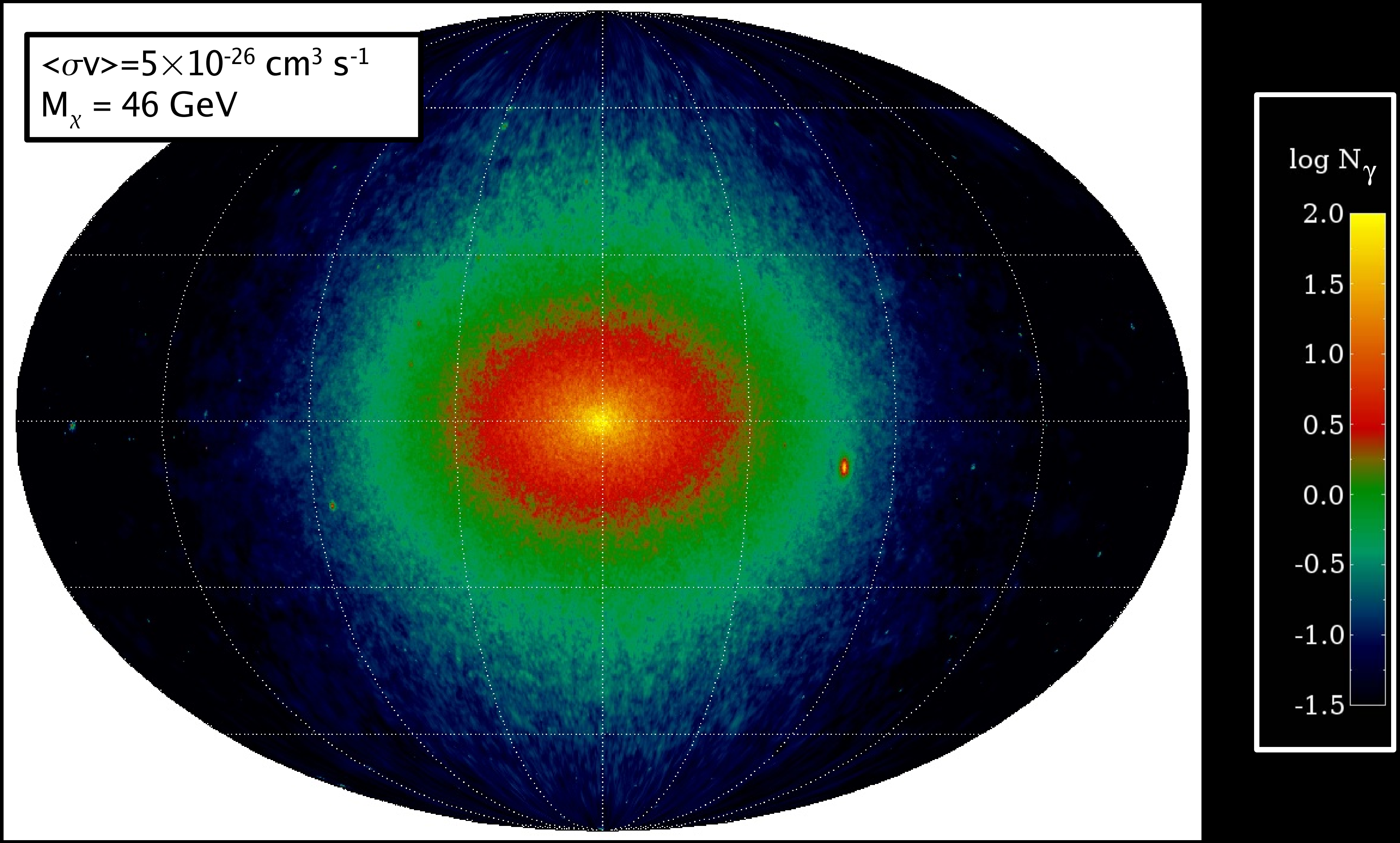
Science Performance Requirements Summary

From the SRD:

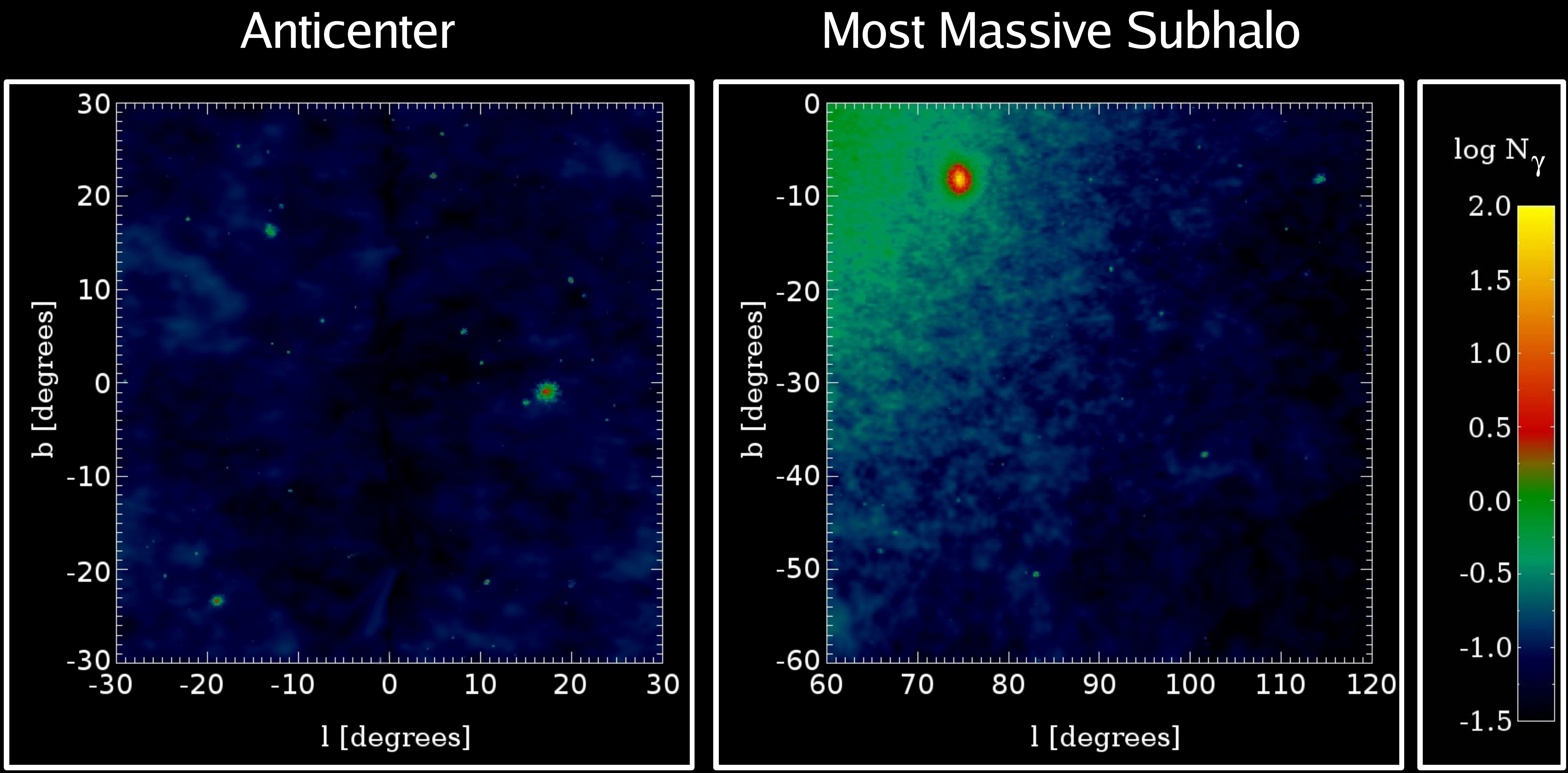
Parameter	SRD Value	Present Design Value
Peak Effective Area (in range 1-10 GeV)	>8000 cm^2	10,000 cm^2 at 10 GeV
Energy Resolution 100 MeV on-axis	<10%	9%
Energy Resolution 10 GeV on-axis	<10%	8%
Energy Resolution 10-300 GeV on-axis	<20%	<15%
Energy Resolution 10-300 GeV off-axis (>60º)	<6%	<4.5%
PSF 68% 100 MeV on-axis	<3.5°	3.37° (front), 4.64° (total)
PSF 68% 10 GeV on-axis	<0.15°	0.086° (front), 0.115° (total)
PSF 95/68 ratio	<3	2.1 front, 2.6 back (100 MeV)
PSF 55º/normal ratio	<1.7	1.6
Field of View	>2sr	2.4 sr
Background rejection (E>100 MeV)	<10% diffuse	6% diffuse (adjustable)
Point Source Sensitivity(>100MeV)	<$6x10^{-9}$ $cm^{-2}s^{-1}$	$3x10^{-9}$ $cm^{-2}s^{-1}$
Source Location Determination	<0.5 arcmin	<0.4 arcmin (ignoring BACK info)
GRB localization	<10 arcmin	5 arcmin (ignoring BACK info)

Simulated Maps

Observer along host halo's **intermediate** ellipsoidal axis

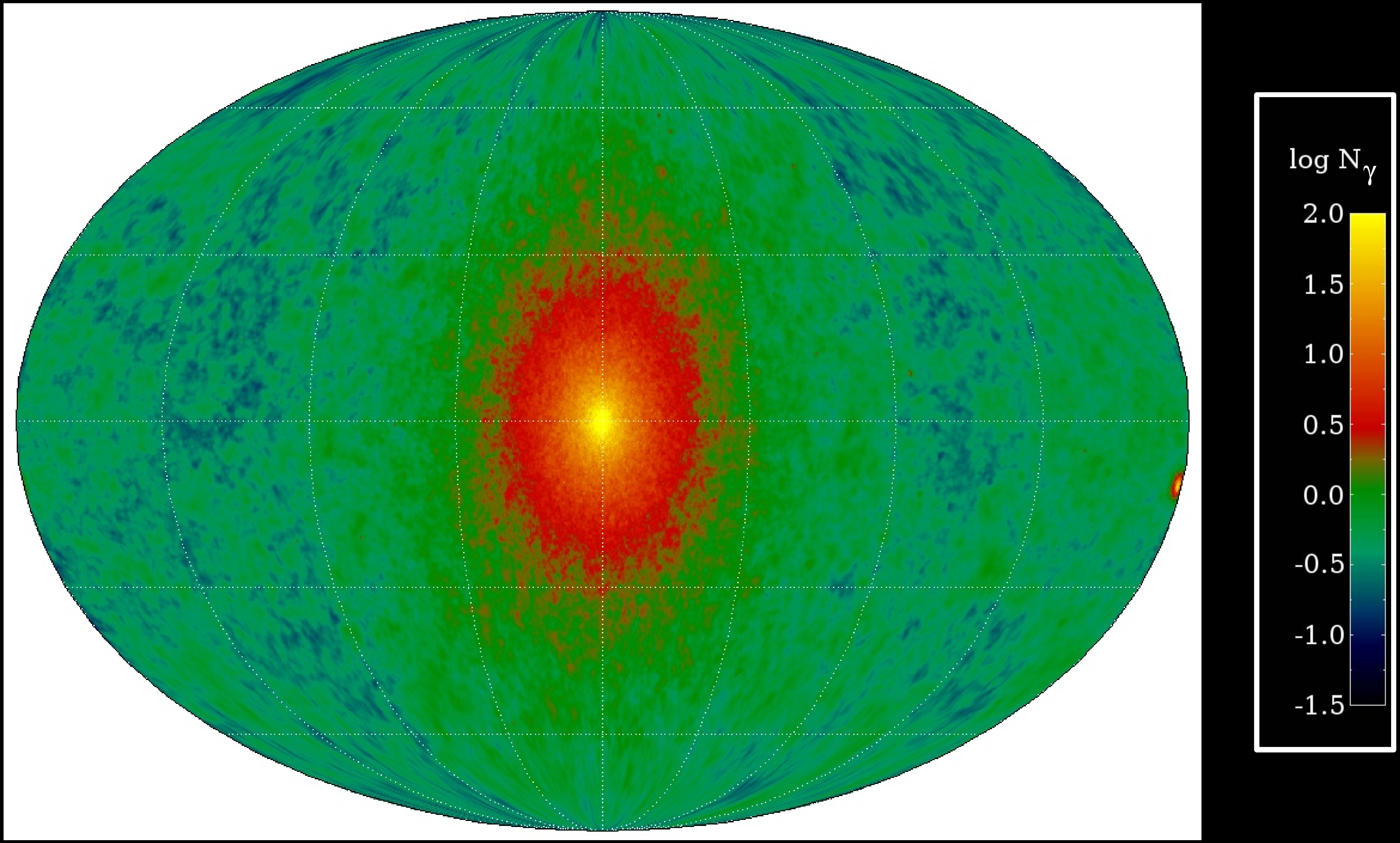


Simulated Maps



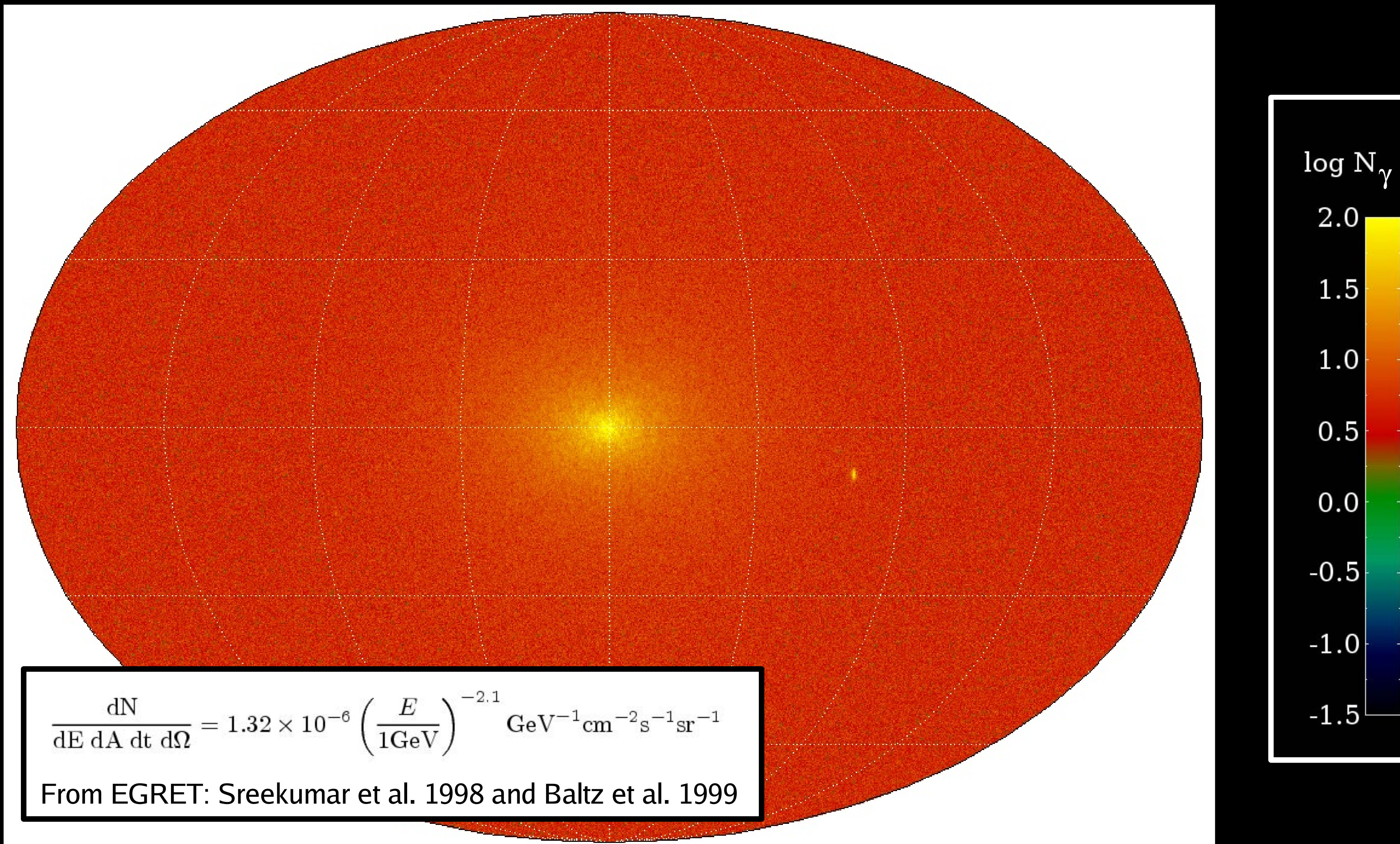
Simulated Maps

Observer along host halo's **major** ellipsoidal axis



Simulated Maps

Including a Poisson realization of the extra-galactic background.

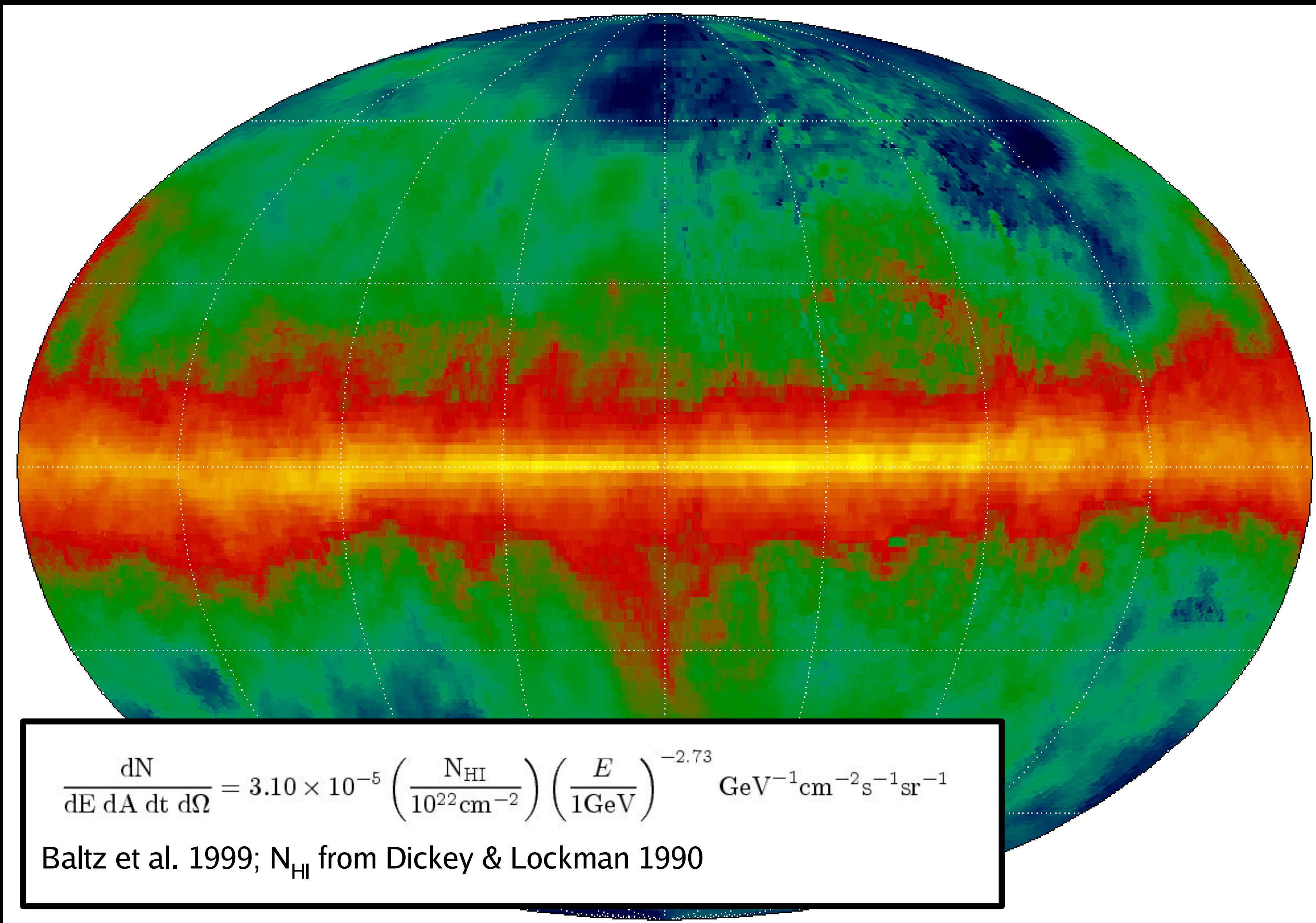


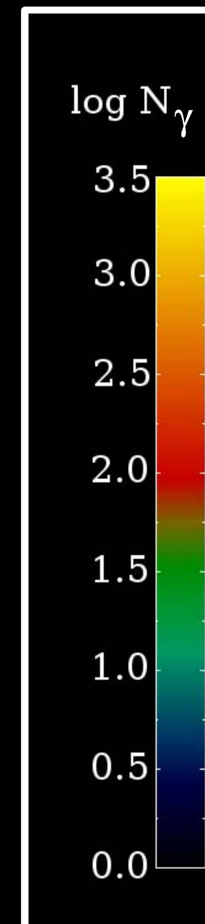
$$\frac{dN}{dE\ dA\ dt\ d\Omega} = 1.32 \times 10^{-6} \left(\frac{E}{1\mathrm{GeV}}\right)^{-2.1} \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

From EGRET: Sreekumar et al. 1998 and Baltz et al. 1999

Simulated Maps

The Galactic background ($\propto N_{HI}$) dominates the annihilation signal.



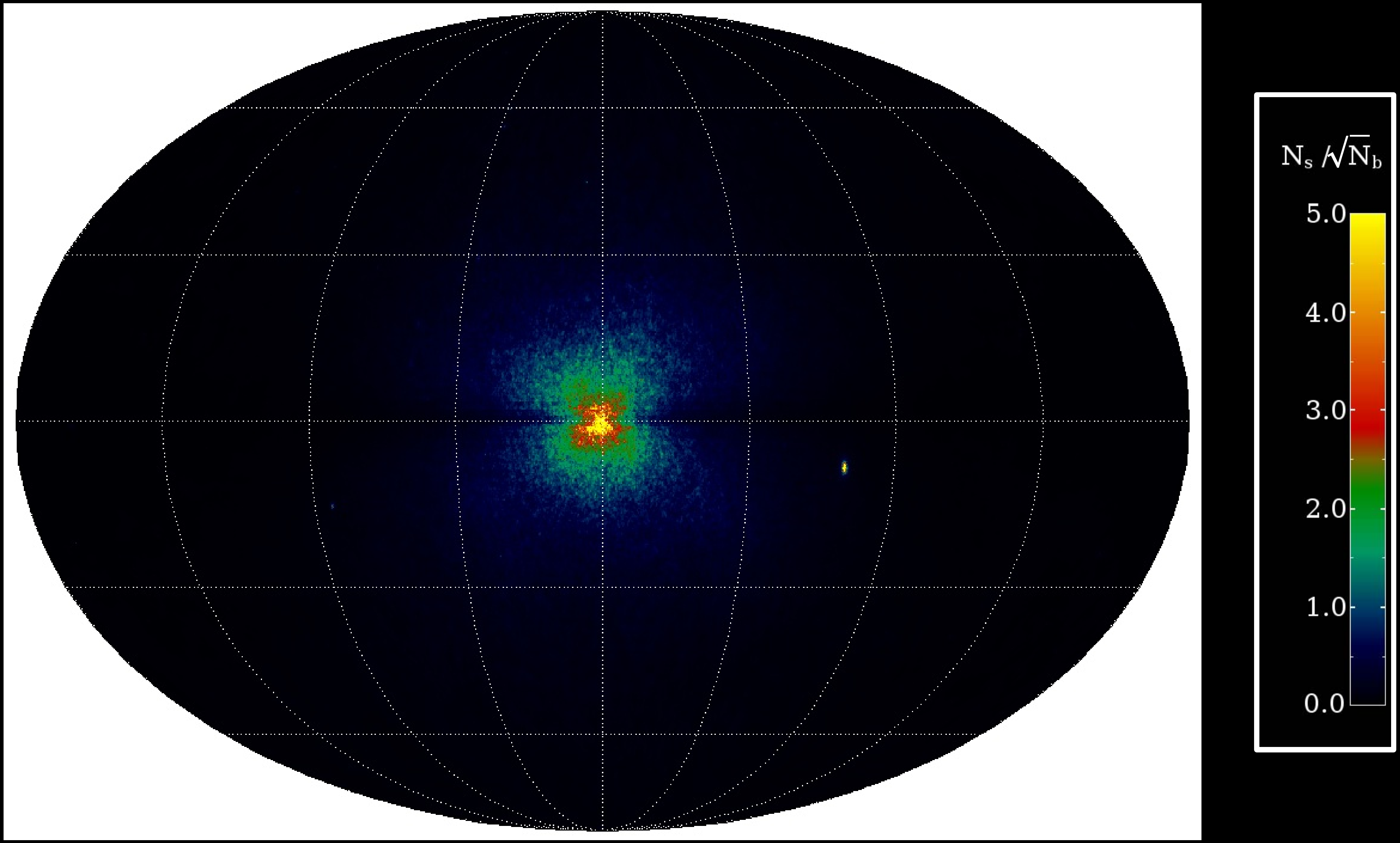


$$\frac{dN}{dE\,dA\,dt\,d\Omega} = 3.10 \times 10^{-5} \left(\frac{N_{HI}}{10^{22}\mathrm{cm}^{-2}}\right)\left(\frac{E}{1\mathrm{GeV}}\right)^{-2.73} \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

Baltz et al. 1999; N_{HI} from Dickey & Lockman 1990

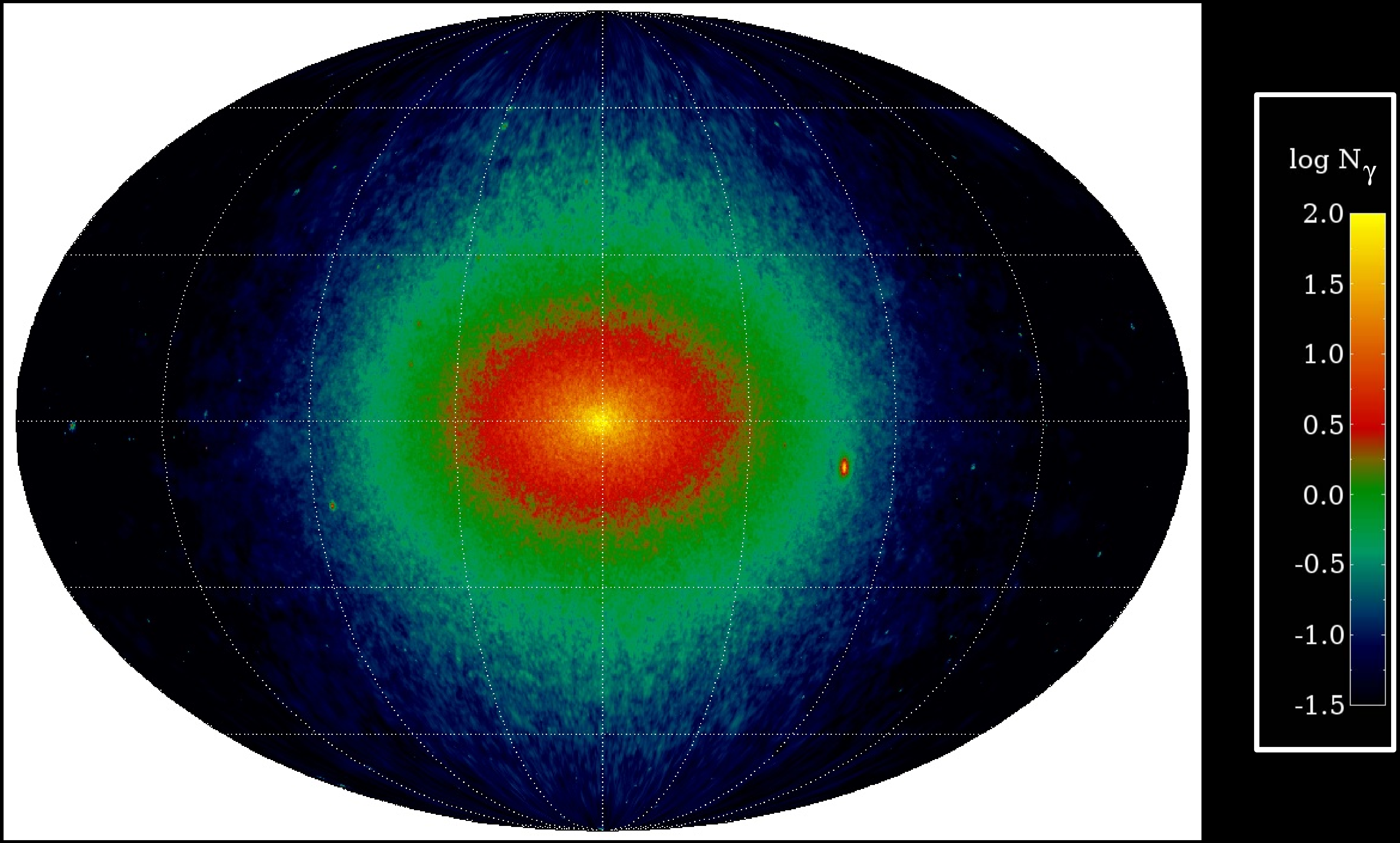
Simulated Maps

The detection significance exceeds 5 in the Galactic center and in one subhalo.



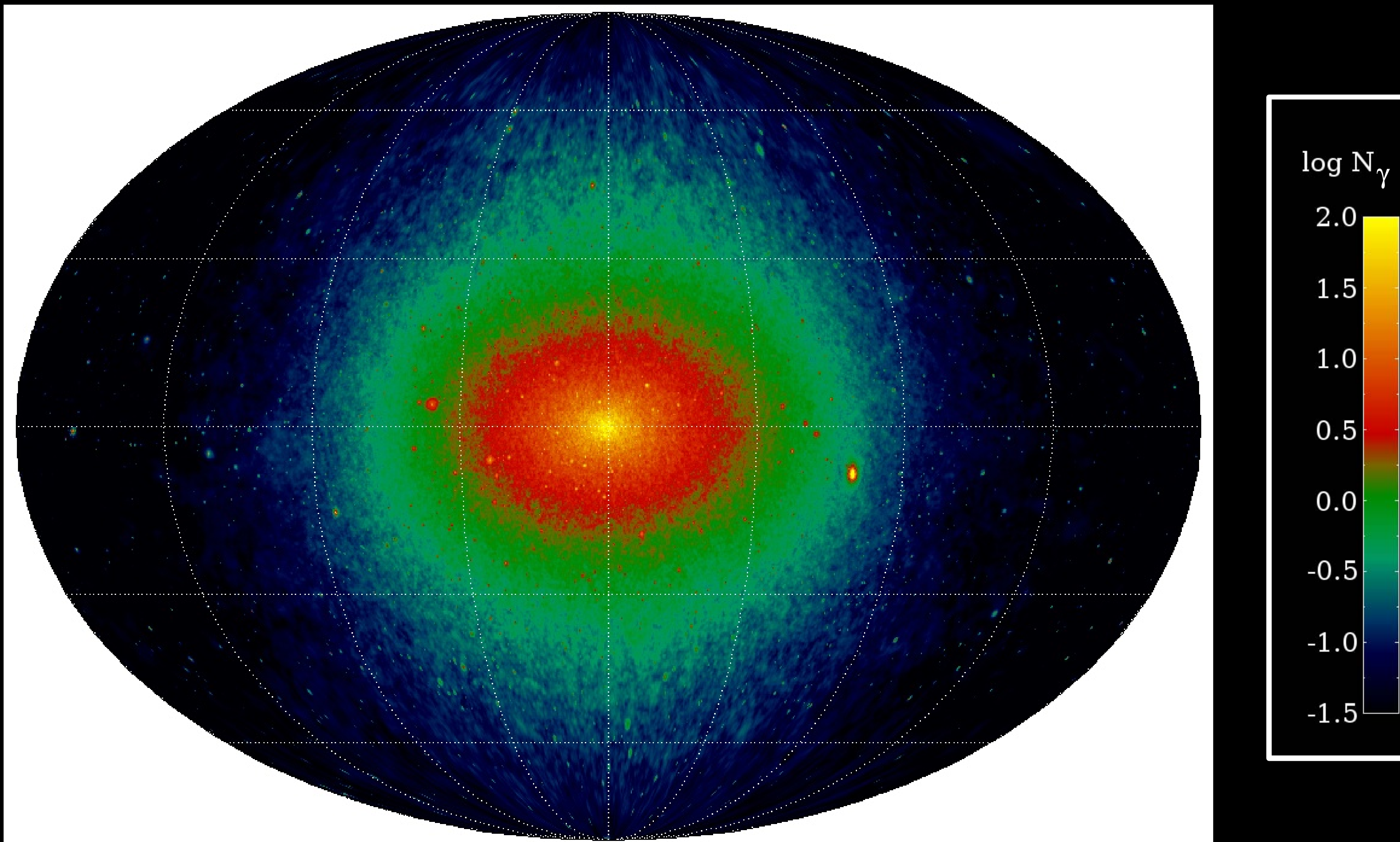
Simulated Maps

Signal with subhalo boost factor = 1 (no boost)



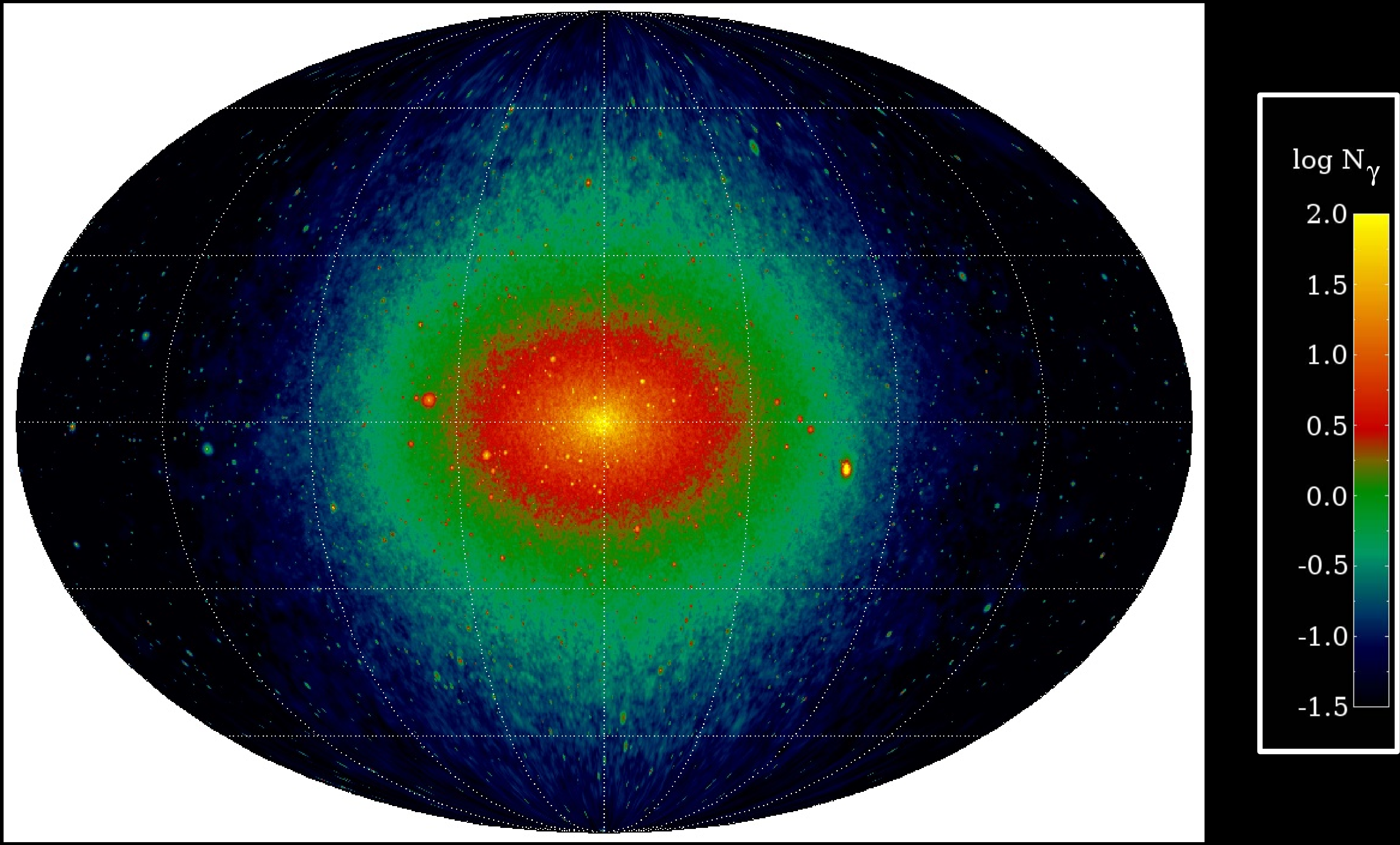
Simulated Maps

Signal with subhalo boost factor = 5 (medium boost)



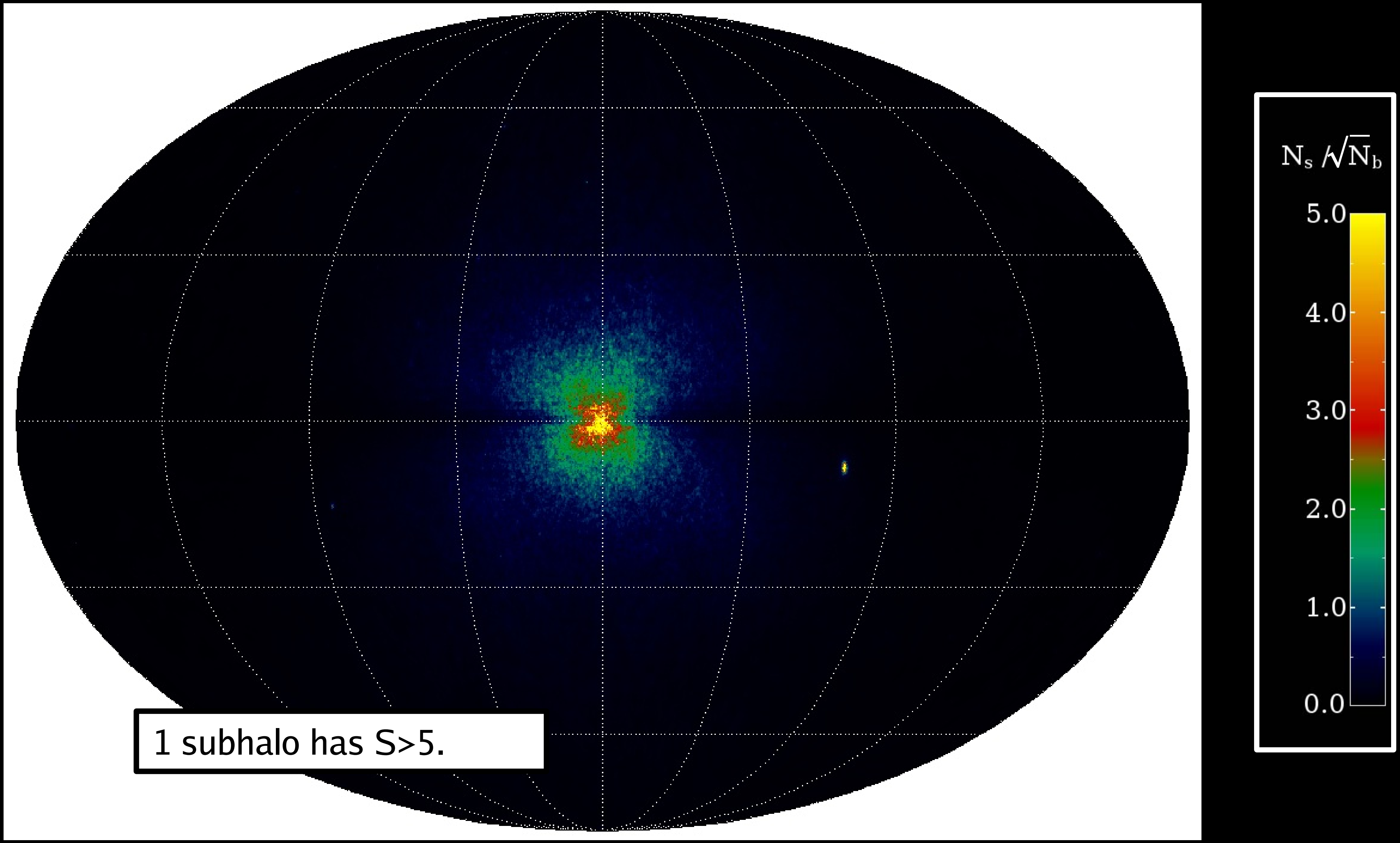
Simulated Maps

Signal with subhalo boost factor = 10 (strong boost)



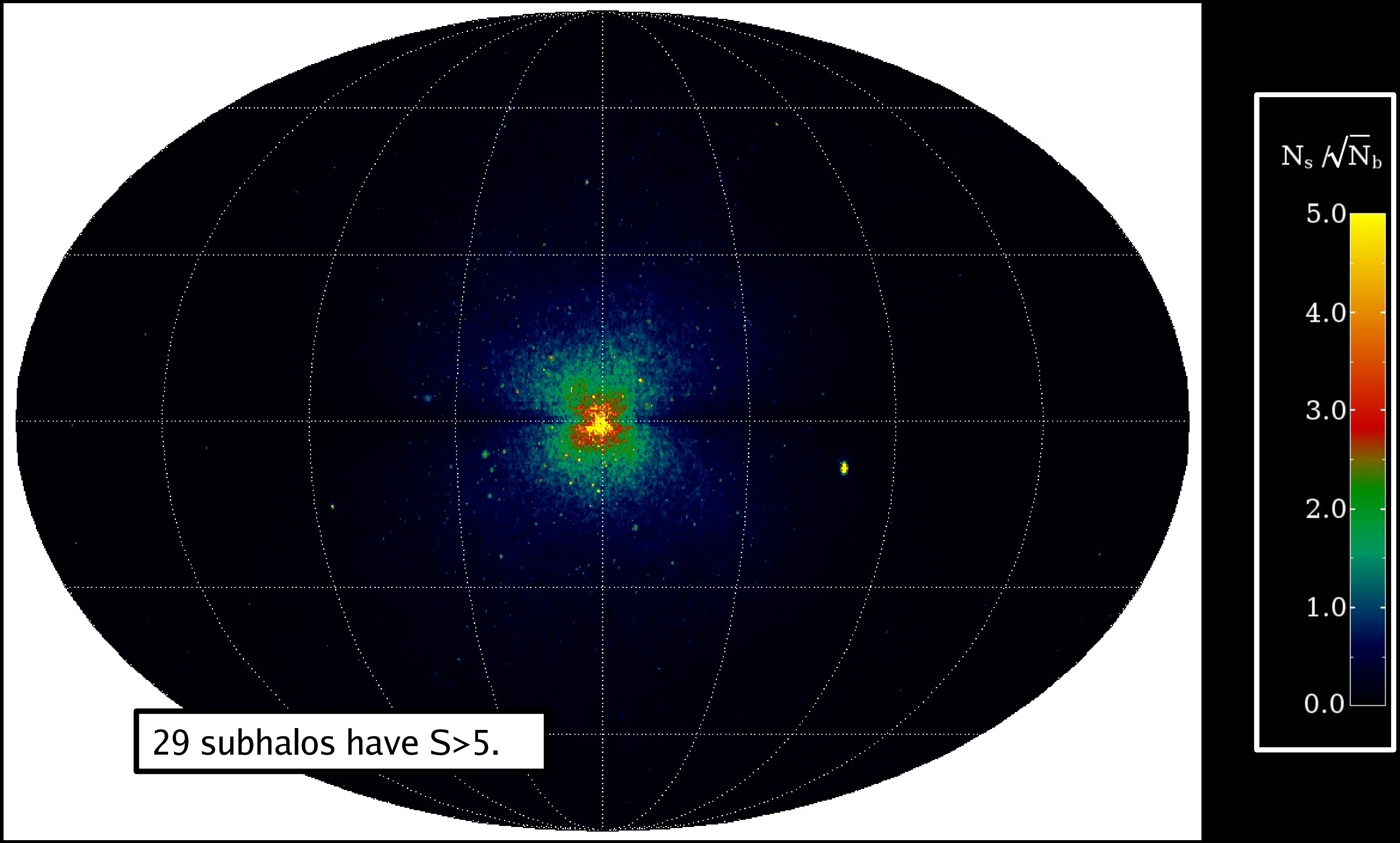
Simulated Maps

Detection significance with subhalo boost factor = 1 (no boost)



Simulated Maps

Detection significance with subhalo boost factor = 5 (medium boost)



Simulated Maps

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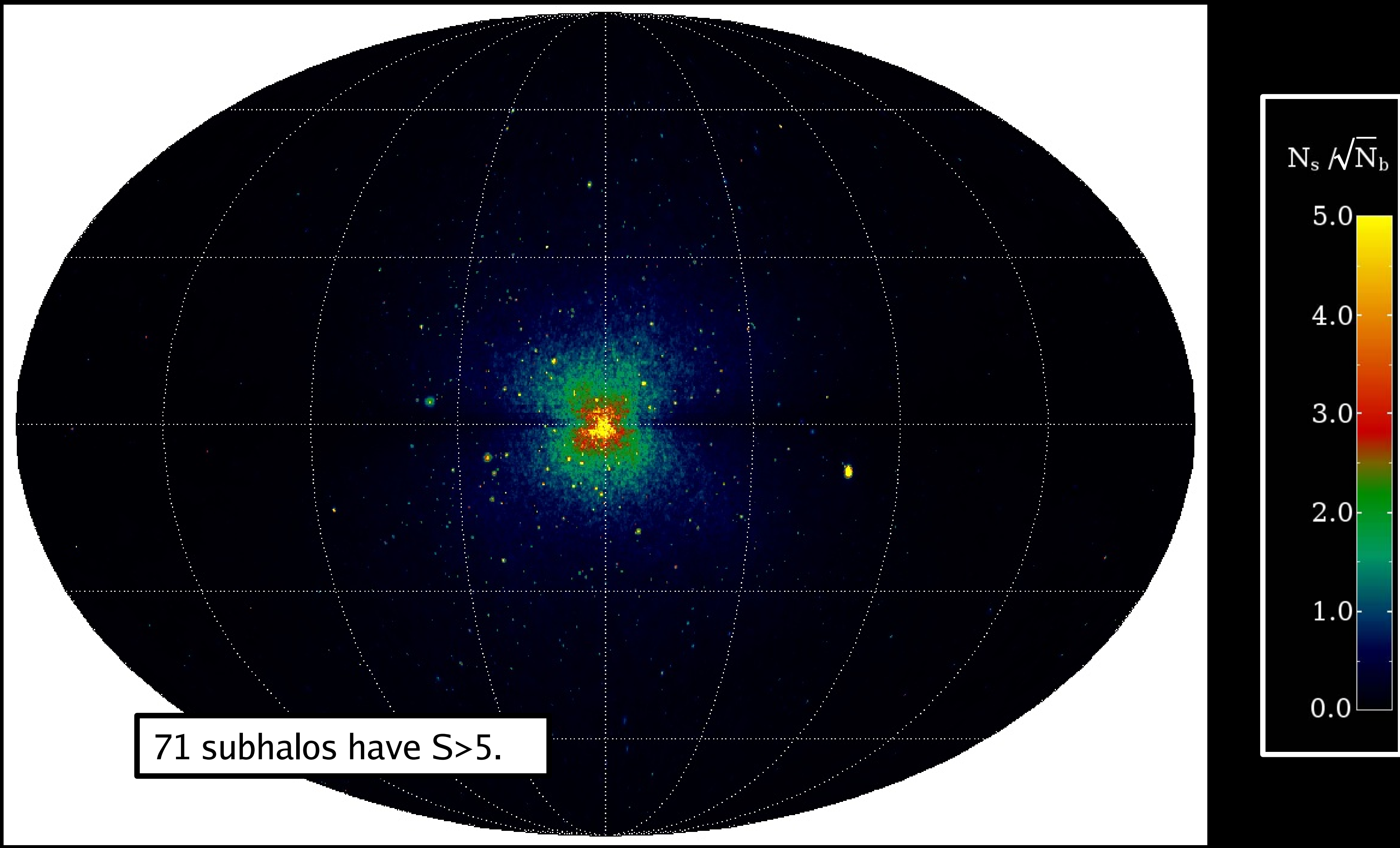
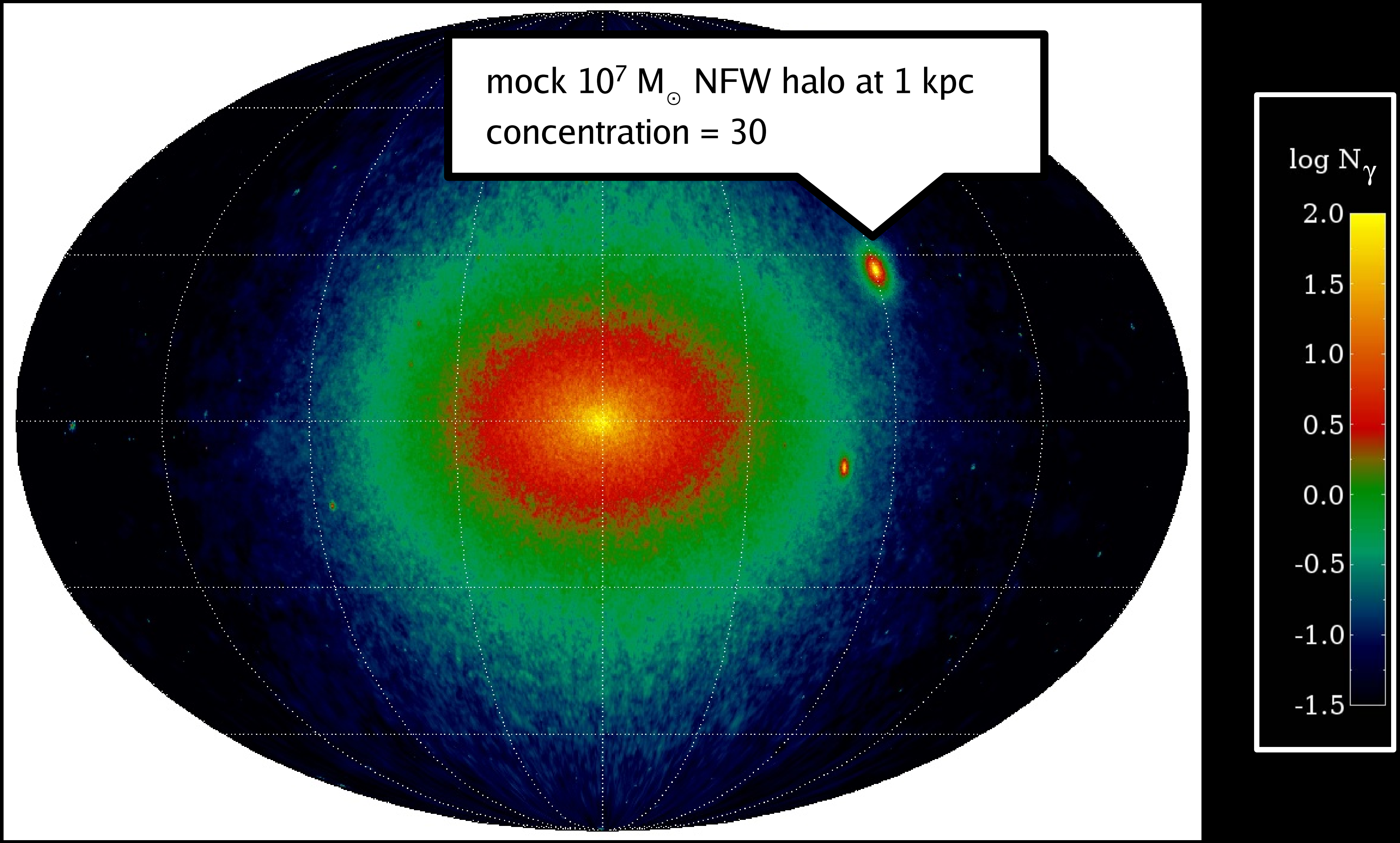


Simulated Maps

What if we happen to be sitting close to a dark halo?



Conclusions

- Exciting possibility that GLAST may detect dark matter annihilation!
- We have simulated the DM structure of a Milky Way halo at unprecedented resolution, and detect an order magnitude more subhalos (~10,000) than past simulations, some even within the inner 10% of R_{vir}.
- We find equal mass in subhalos per decade in subhalo mass all the way down to the smallest resolved halos. 5.6% of M_{vir} is contained in substructure, likely a lower limit.
- Substructure boosts the total halo luminosity by **at least** a factor of 2 over a smooth halo.
- With an optimistic cross section and particle mass we find that DM annihilation from the Galactic center and the most massive subhalo would be detectable by GLAST.
- With a luminosity boost factor of 5 (10), we find that 29 (71) subhalos are detected with S>5.

Caveat: the annihilation cross section may very well be orders of magnitude lower!