Dark matter annihilation from cosmological IMBHs

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Intro: Dark Matter

Much evidence for its existence, but their true nature is unknown

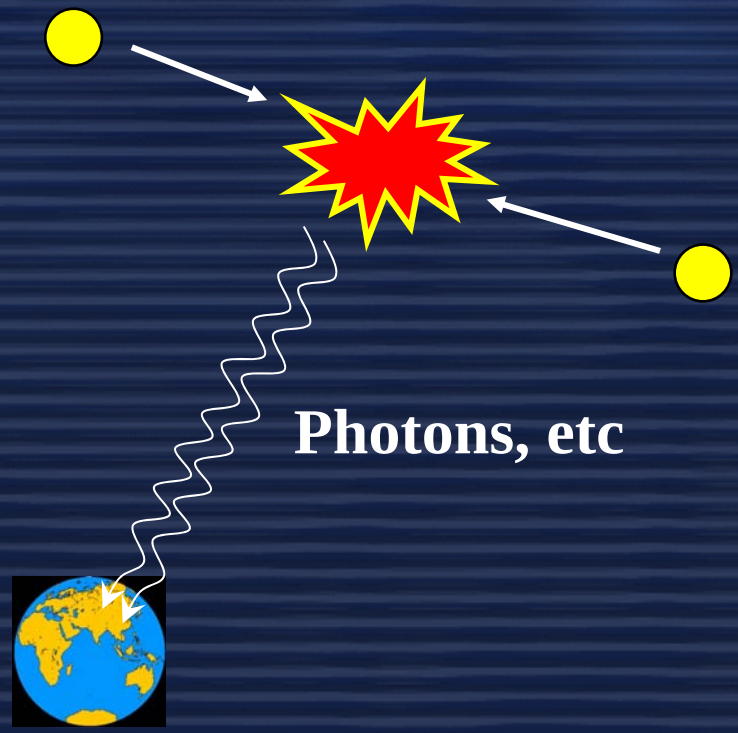
Fundamental Question : what is dark matter ?

Is it a particle?

Extensions of SM predict weakly interacting particles that has the right properties, e.g. the Neutralino

Search for Neutralino as a dark matter candidate

Indirect detection: detect signatures of pair-annihilation



DM Annihilation (galactic)

Well studied [*Bengtsson et al ('90), Bergstrom & Ullio ('97), etc*]

Flux of dark matter annihilation products:

$$\phi_i(\psi, E) = \frac{\langle \sigma v \rangle}{m_{DM}^2} \frac{dN_i}{dE} \frac{1}{4\pi} \int_{l.o.s.} ds\, \rho^2(r(s,\psi))$$

i **= annihilation product**

Dark matter particle properties

For the Neutralino:

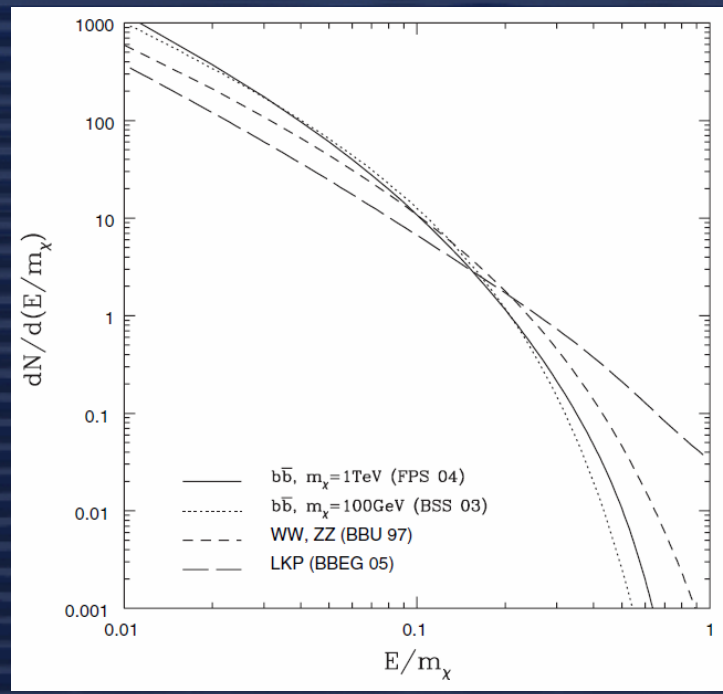
mass $O(100)$ **GeV ~** $O(100)$ **TeV**

σv $< 10^{-26}$ **cm^{3}s^{-1}**

dN/dE continuous + monochromatic

mainly $b\bar{b}$**,**

$\pi^0 \rightarrow 2\gamma$



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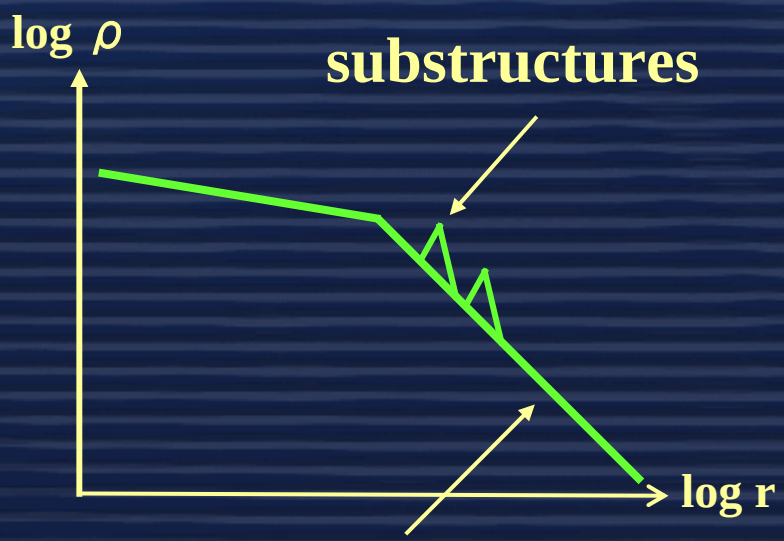
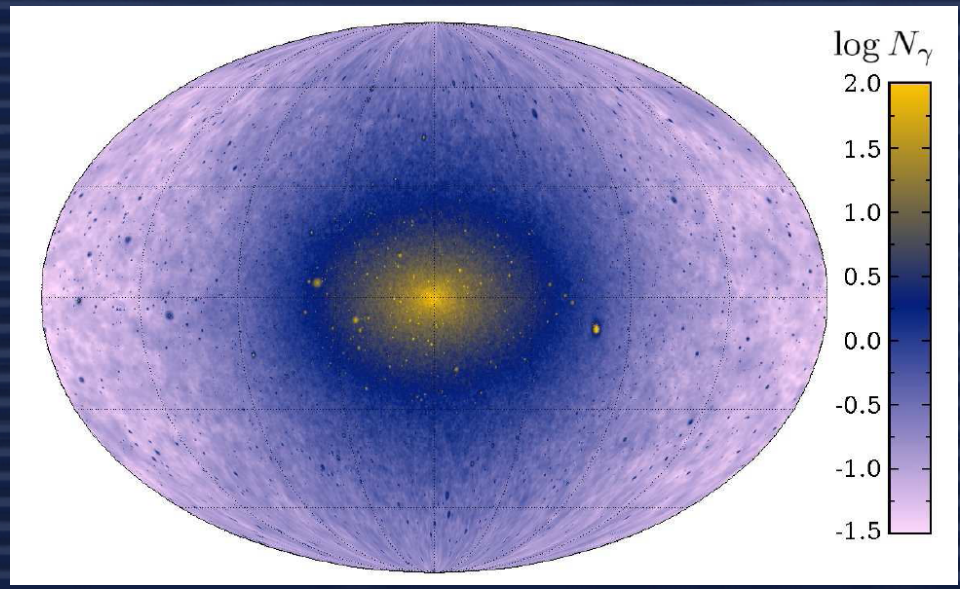
Dark matter density distribution



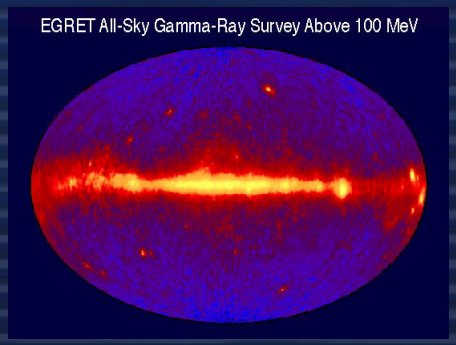
DM density profile:
NFW, Moore, Kravtsov, …

Kuhlen, Diemand & Madau. 2007



DM Annihilation (extragalactic)

The extragalactic γ ray background (EGB) is a diffuse γ ray signal observed by EGRET [*Strong et al ('04)*], its origin is the sum of unresolved γ-ray sources, but still not known well:

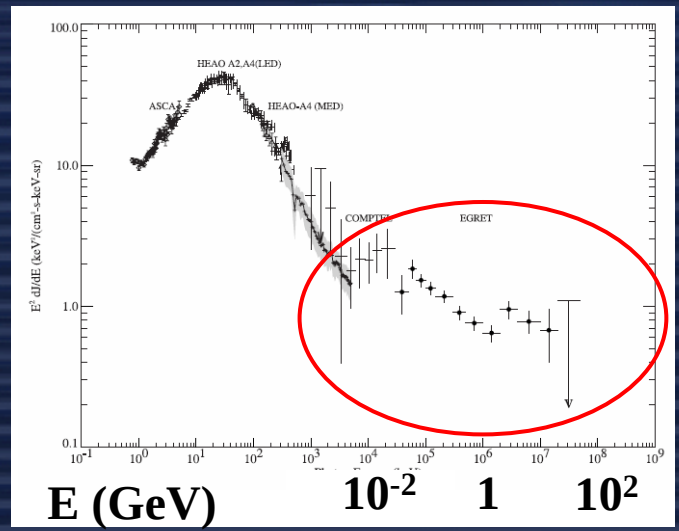


γ-ray map

—

1. point sources
2. CR int. model

=

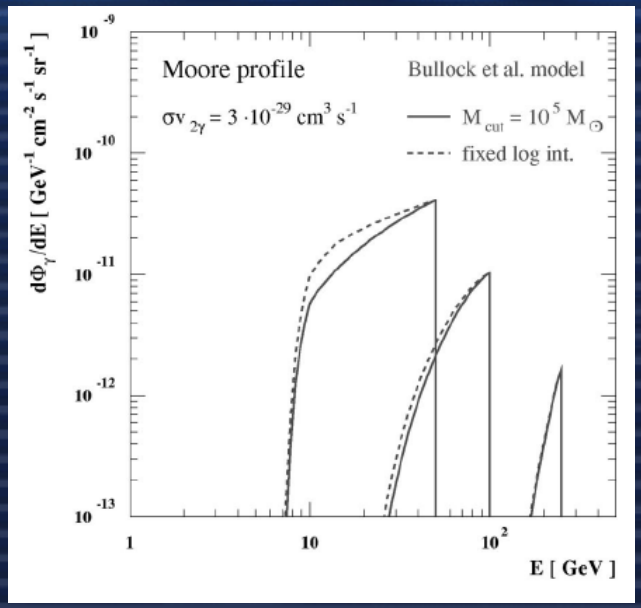


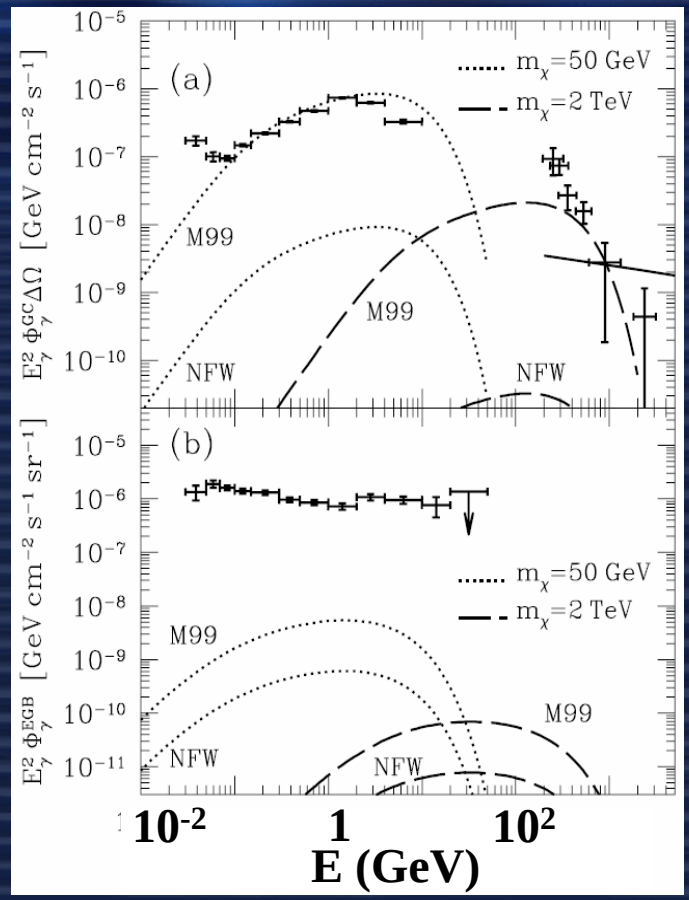
Strong et al ('04)

- **Blazars?** *Stecker&Salamon 1996*
- **Galaxy clusters?** *Loeb&Waxman, 2000*
- **GRBs?** *Casanova et al 2007*
- **DM annihilation?** *Bergstrom et al 2001*

DM Annihilation (extragalactic)

Monochromatic γ-rays are distorted by redshift [*Ullio et al 2002*]

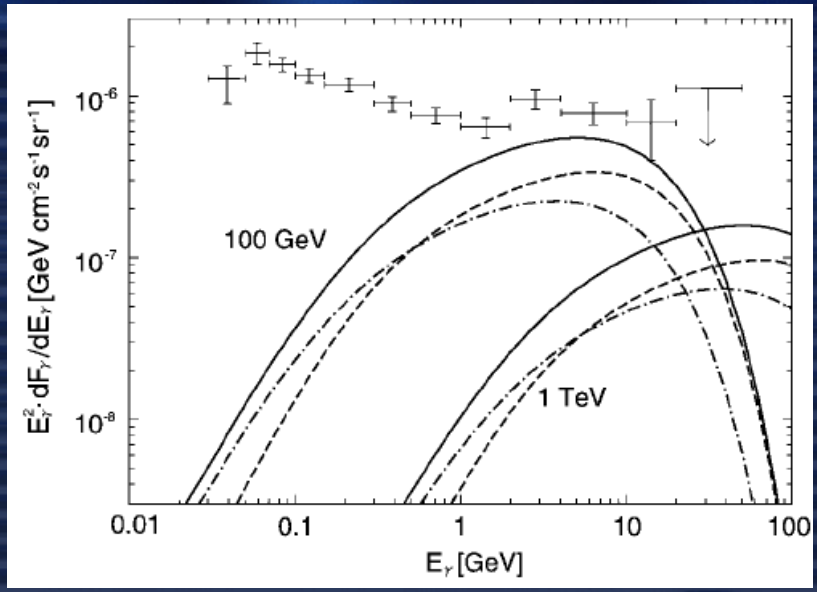




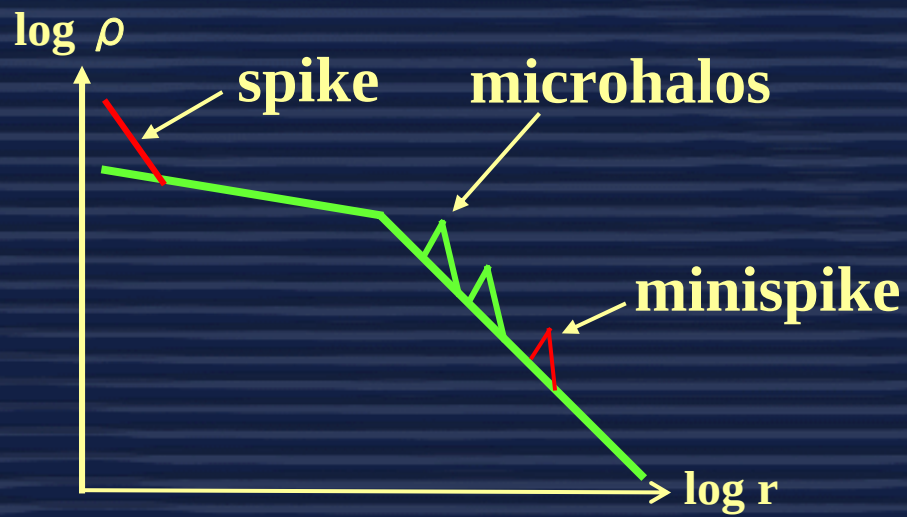
However, assuming universality of halo profiles (e.g. NFW), DM annihilation is a minimal component of the extragalactic γ-ray background [*Ando 2005*].

Small scale structures

Small scale structures (e.g. microhalos) increase the DM annihilation rate.
The galactic centre contains less substructures.



Oda&Totani 2006

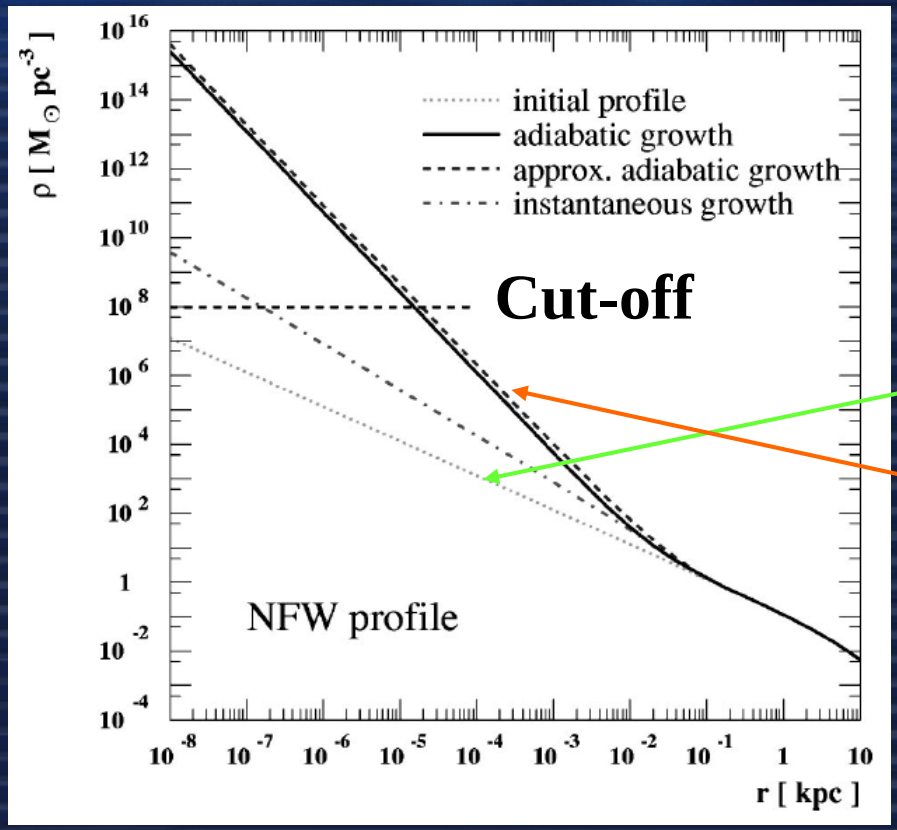


But also,
- spikes
- minispikes

Cosmological Minispikes

(Mini) Spikes

Spikes = dense DM structures around BHs [*Gondolo&Silk 1999*]



Ullio Zhao Kamionkowski 2002

(c.f. if a BH grows inside a given population of stars, the stellar density in the vicinity of the BH is enhanced)

$$\rho_i \propto r^{-\gamma}$$

$$\rho_f \propto r^{-A}\ ;\ A = \frac{9-2\gamma}{4-\gamma}$$

Minispikes = dense DM structures around IMBHs [*Bertone Zentner Silk 2005*]

IMBH

We consider minispikes around intermediate mass black holes (IMBH, mass $10^{2\text{-}6}\ M_{sun}$). Do IMBHs exist? It is motivated:

***observationally*:**

1. **connection with ULXs ?**
2. **high-z quasars**

***theoretically*:**

1. **seed-BHs for SMBHs**
2. **naturally predicted in hierarchical structure formation**
3. **fills the BH mass range**

A. Population-III model

$M_{BH} = 100\ M_{sun}$

Madau & Rees 2001

B. Protogalactic disk model

$M_{BH} \sim 10^5\ M_{sun}$

Koushiappas et al 2005

(Mini) Spikes [cont.]

For a strong spike to form, one requires the following:

- adiabatic BH growth (i.e. growth time >> DM orbital time)

- the BH grows within the central *O*(10) pc of the halo centre

the spike then forms from DM within the gravitational influence of the central BH [*Ullio Zhao Kamionkowski 2002***].**

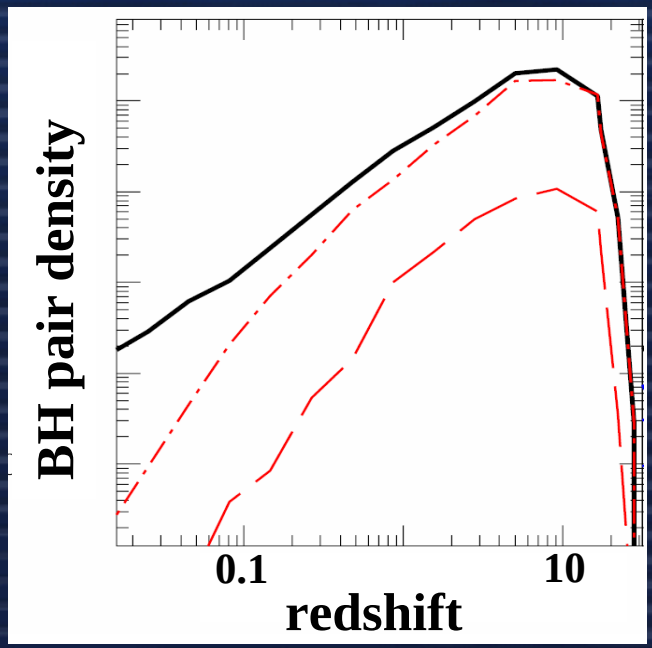
- **In Pop-III model, stars form anywhere within the halo => a weak minispike can form,** $\rho_f \propto r^{-3/2}$
- **For Protogalactic Disk model, the above conditions are satisfied => a strong minispike can form, with**

$$\rho_f \propto r^{-7/3}$$

Number Density

Take into account depletion due to BH-BH mergers [*Merritt et al, 2002*].

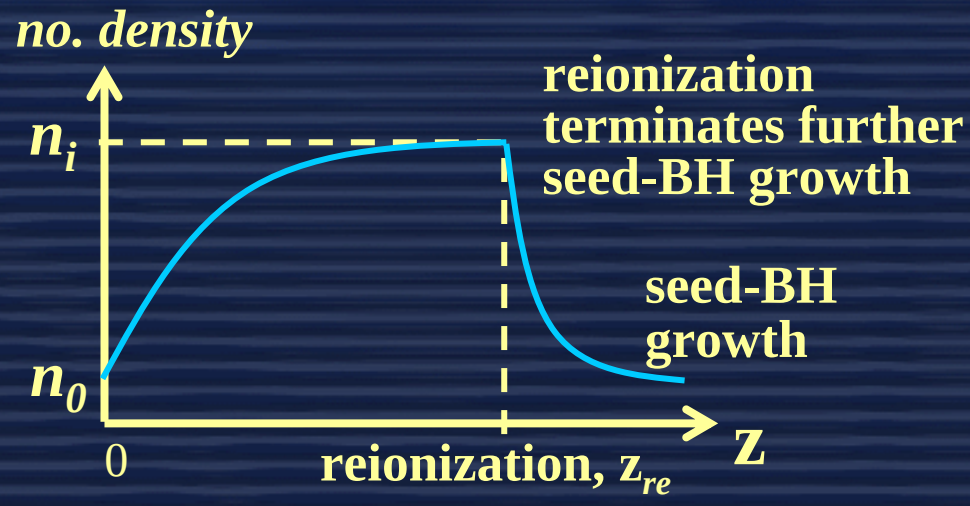
Number of seed-BH pairs follows a power-law of z:



Koushiappas & Zentner, 2005

We fit the number density as

$$n_{IMBH}(z) = n_i \left(\frac{1+z}{1+z_{re}} \right)^{\beta}$$



n_i : determine from IMBH model

n_0: *Bertone Zentner Silk 2005*

Results

Continuous Photons

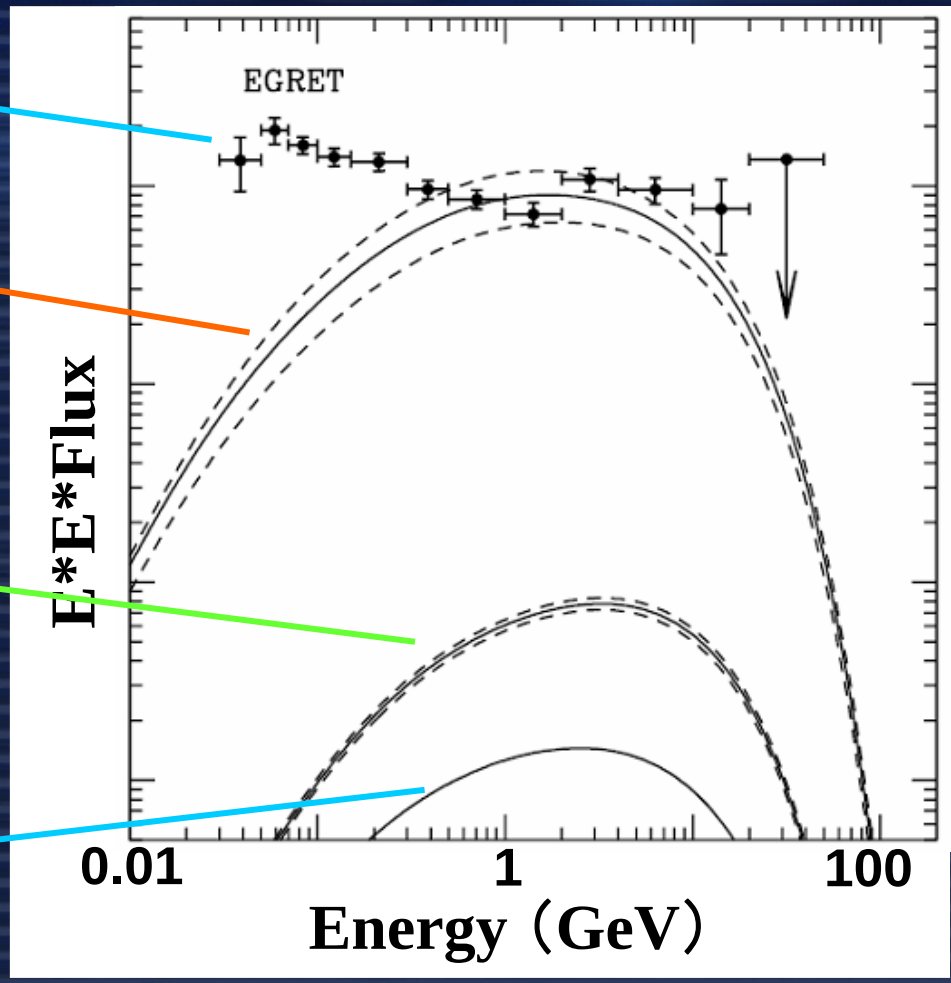
Predicted γ ray increases by 1-3 orders

data (EGRET)

Protogalactic Disk model (~10^5 M_{sun})

Pop-III model (100 M_{sun})

no IMBH



Monochromatic Photons

Will GLAST be able to detect smoking-gun γ rays?

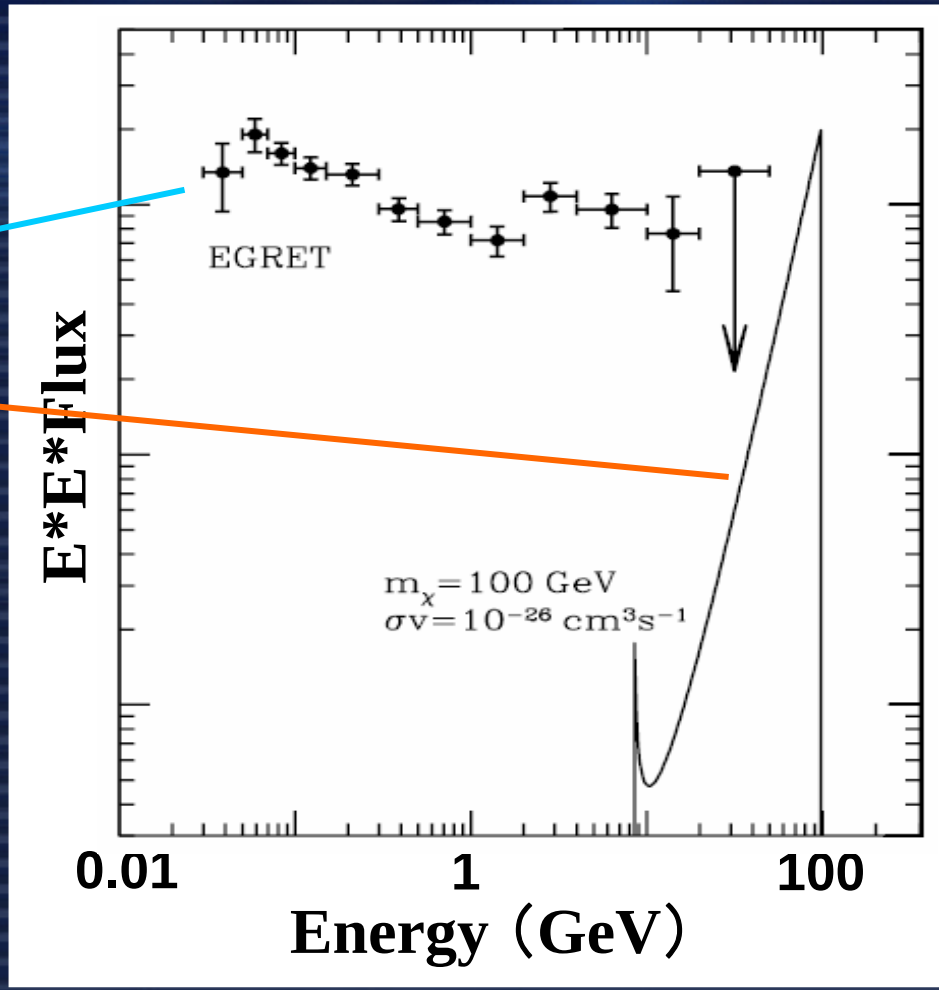
Under optimistic (but allowed) **Protogalactic disk model**

data (EGRET)

Monochromatic line spectrum

GLAST will observe to ~300GeV with up to x10 sensitivity of EGRET

=> within reach!



Parameter Dependency

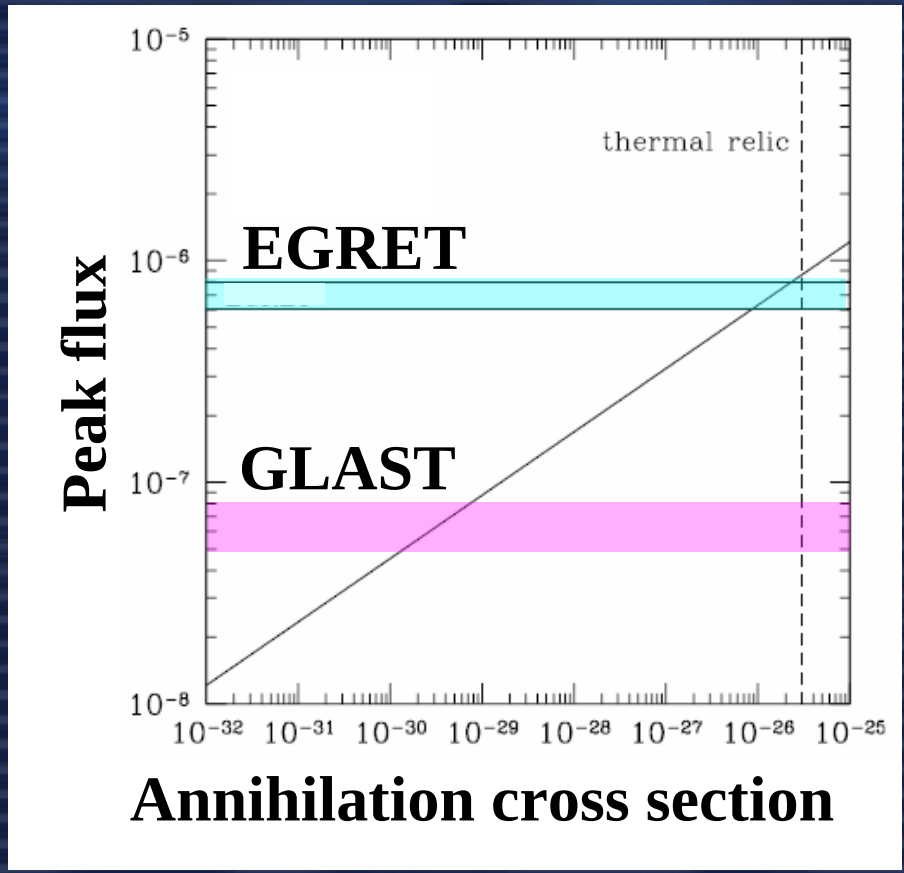
Advantage using minispikes

Normally, the annihilation rate scales with the annihilation cross section.

However, a small σv works to maintain a sharp minispike, and:

$$\text{flux} \propto \langle \sigma v \rangle^{2/7} m_\chi^{-9/7}$$

i.e. a weak dependency on Neutralino parameter



Summary

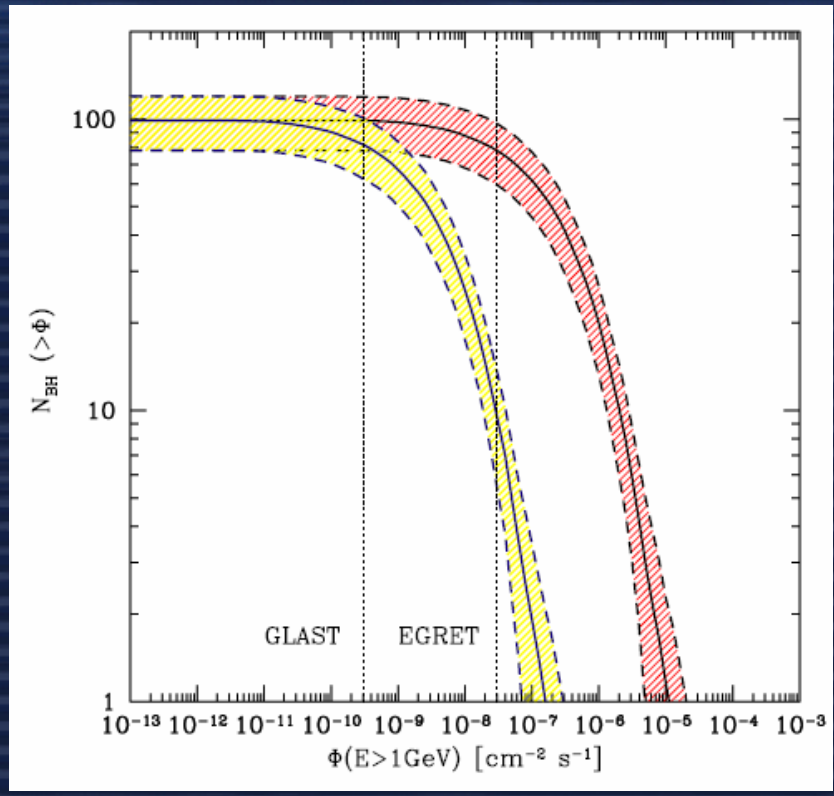
- **Neutralino DM annihilates and contributes to the extragalactic γ ray background (EGB). Small scale structures are important for predicting the total flux.**
- **IMBH minispikes are a possible substructure, and more natural than spikes.**
- **How much do they increase contributions to the EGB?**

Model	BH mass	Minispike strength	Multiplication factor
Max*	10^5	strong, $\propto r^{-7/3}$	10^3
Conserv.	10^2	weak, $\propto r^{-3/2}$	10

***monochromatic γ-ray signal can be strong enough for GLAST**

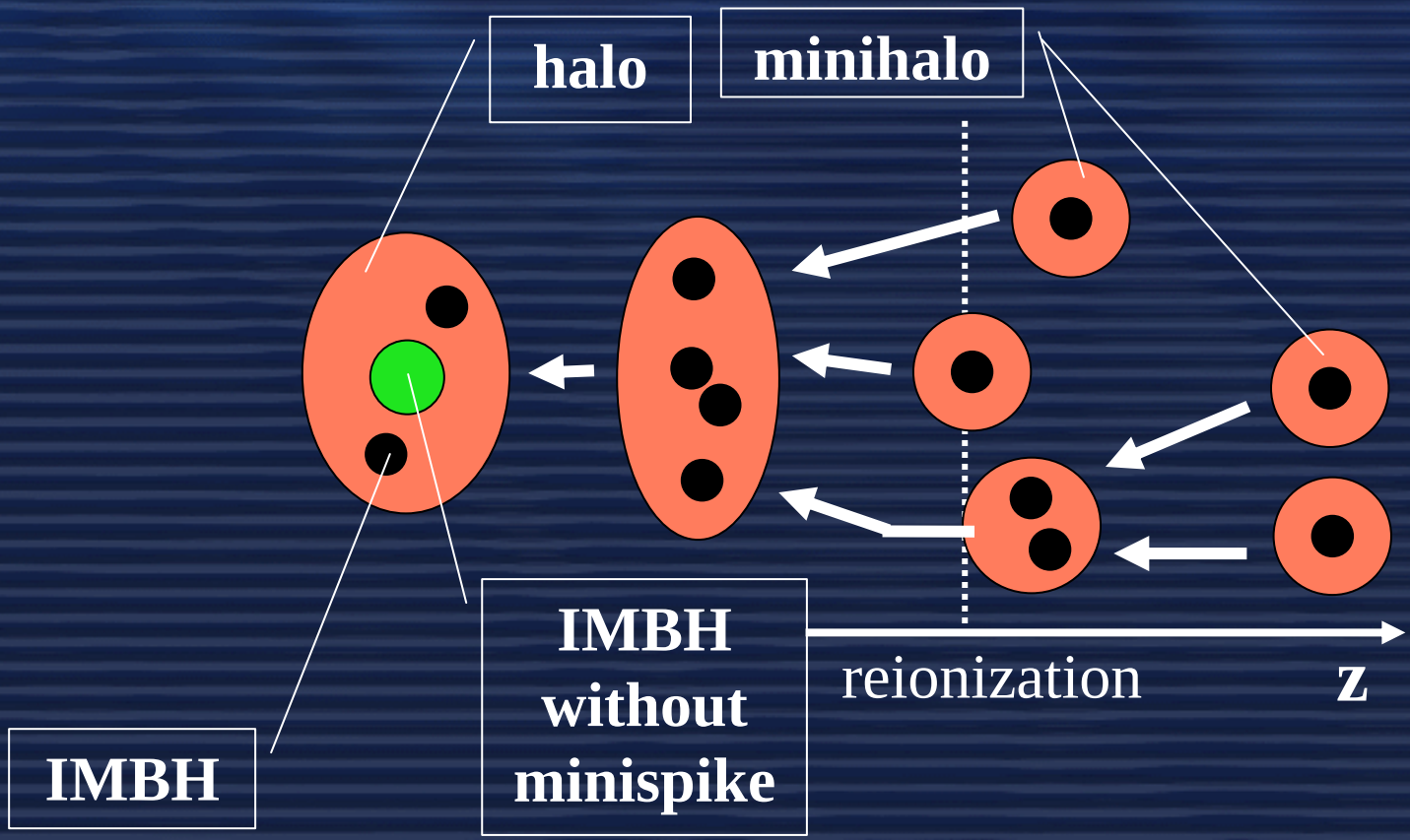
IMBHs in our galaxy

Bertone et al. considered g-rays from IMBHs residing in the Milky Way halo [*Bertone et al, PRD ('05)***]**



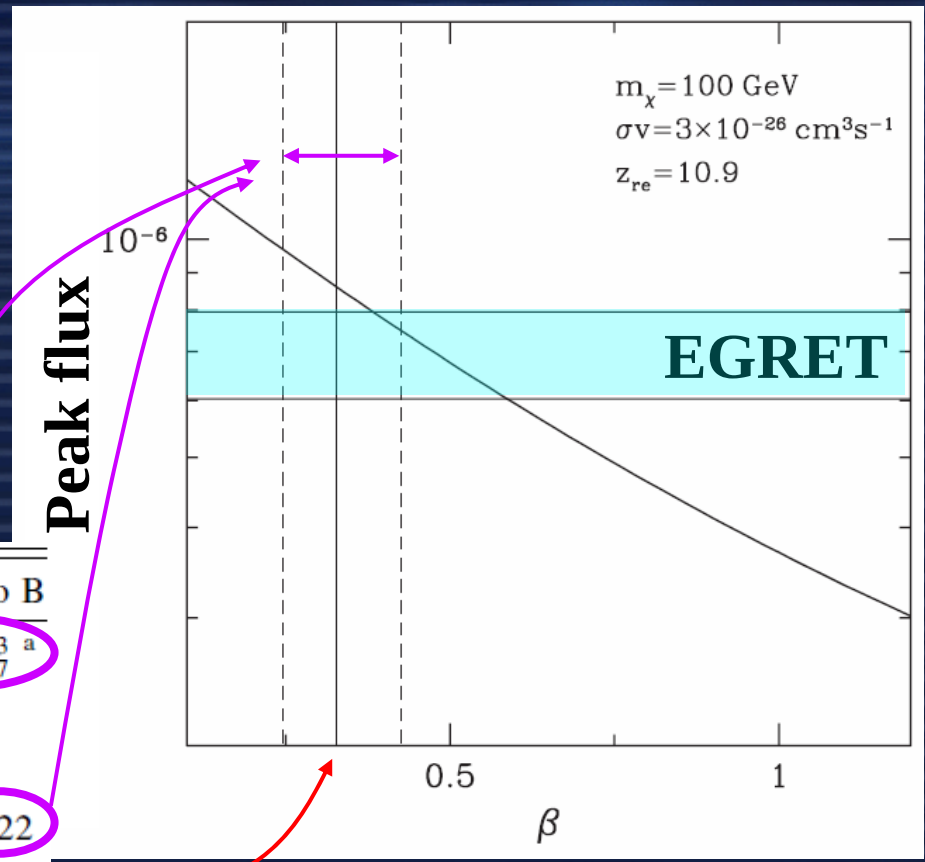
IMBH number density decreases

BH-BH mergers destroy minispikes



Parameter β

Shows the peak flux (at $E_\gamma \sim 1$GeV) as a function of β for the Protogalactic Disk model.



1σ error bars

	Scenario A	Scenario B
z_f	18	$10.9^{+2.3}_{-2.7}$ [a]
$M_{\rm bh}$ $[M_\odot]$	10^2	10^2
$M_{v,\rm crit}(z_f)$ $[M_\odot]$	4×10^6	10^8
$n_{\rm bh}(z_f)$ [Mpc^{-3}]	23	2.5
$N_{\rm bh}$	1027 ± 84	101 ± 22
$n_{\rm bh}(0)$ [Mpc^{-3}]	12	1.1
β	0.2	0.3

DM Parameters