Contribution to the Extragalactic Gamma-ray Background from Dark Matter Annihilation around Intermediate-Mass-Black Holes

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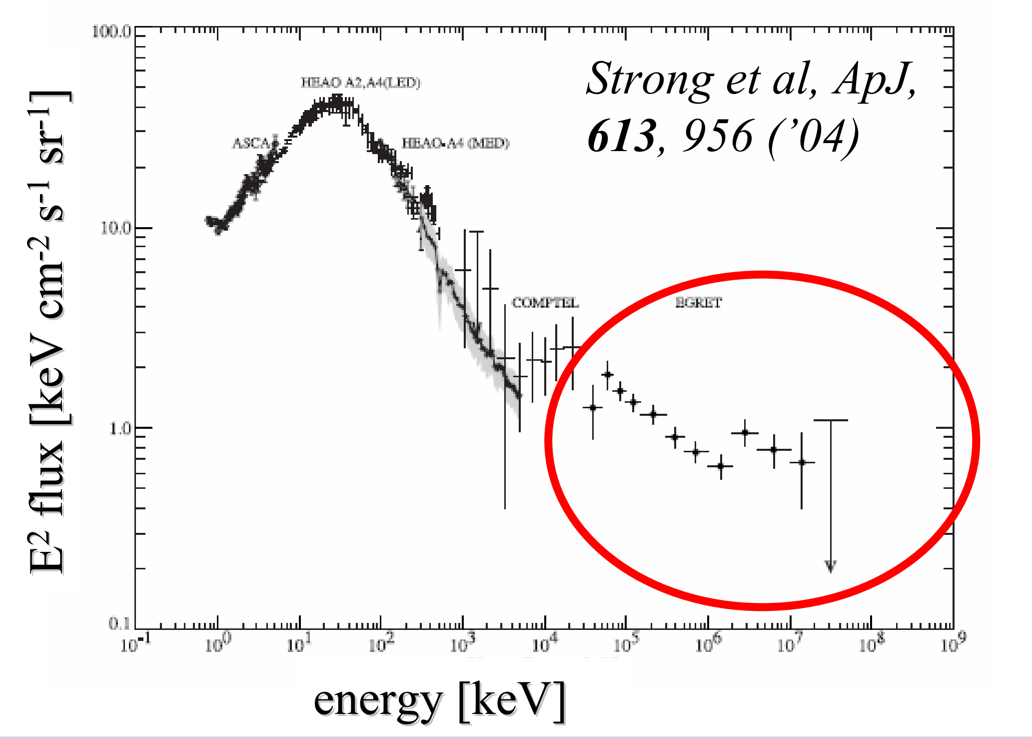
Abstract

- The exact origin of the extragalactic gamma-ray background (EGB) is currently unknown.
- The EGB can provide invaluable information regarding the true nature of particle dark matter (DM), because DM particles are expected to pair-annihilate into gamma-ray photons. A cosmological distribution of DM is thus expected to contribute to the EGB.
- The energy range of interest has been partially detected by EGRET, and awaits for GLAST.



Review of DM (I)

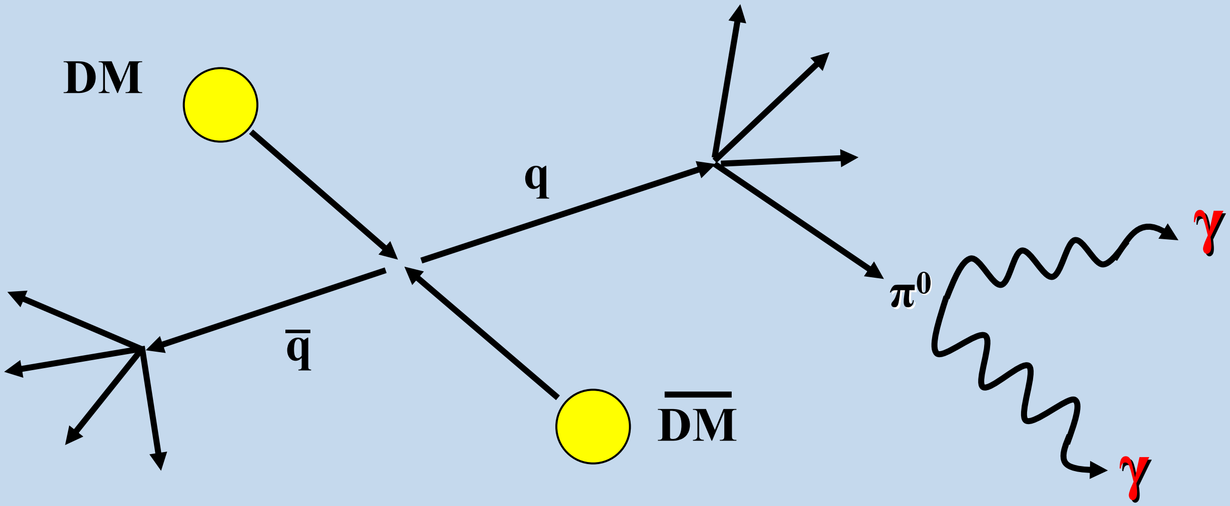
- There is now strong evidence for the existence of dark matter (DM) from astrophysics. Combining CMB, type-1a supernovae, and other observations, we also know that DM dominates the universe's mass content.
- DM is independently supported by extended models of particle physics, which gives particle candidates for DM. The most promising is the neutralino.
- However, the true identity of DM remains ***unknown***.

Fundamental question: What is dark matter??

Current limits: mass (50 GeV - 10 TeV), annihilation cross-section ($< 3 \times 10^{-26}$ cm^3s^{-1})

Review of DM (II): Indirect Search

- Particle DM is expected to pair-annihilate into, amongst others, **γ-rays**, and their detection will yield clues on DM properties.

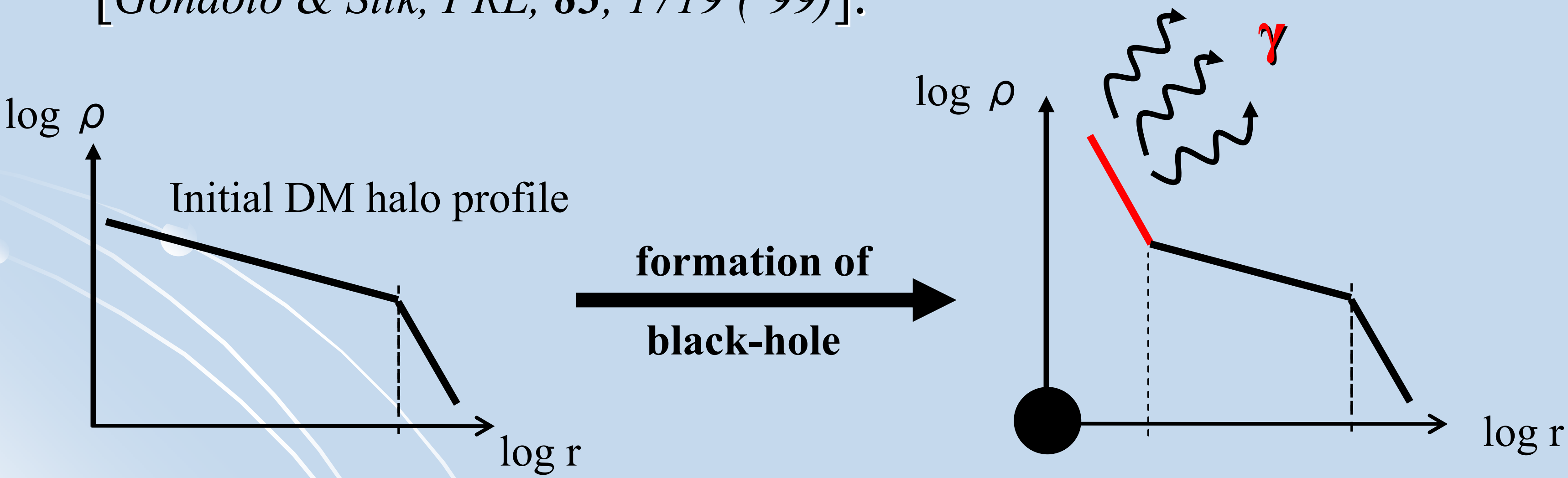


- The flux of annihilation products is proportional to the initial DM density squared, so there is great advantage in looking at areas where the DM density is expected to be high, e.g.
    1. Galactic Centre → but too many other gamma-ray sources
    2. Isolated large masses → e.g. earth, sun, … , **IMBHs**

Intermediate-mass Black Holes (I)

- We define intermediate-mass black holes (IMBHs) as BHs with mass (20 – 10^6) M_{solar}.
- Why consider IMBHs for indirect DM search?

  Answer: because their formation is predicted to enhance their surrounding DM distribution, and form a "**minispike**" [*Gondolo & Silk, PRL, **83**, 1719 ('99)*].



We can expect **enhancement** of DM annihilation γ -rays!

Intermediate-mass Black Holes (II)

- Do IMBHs really exist? They have not been directly detected, but are theoretically and observationally motivated.
  - Theoretically, a population of IMBHs supports the hierarchical formation scenario of supermassive-BHs.
  - Observationally, the most powerful ultra-luminous X-ray sources (ULX) support the existence of IMBHs.
- The direct consequence of such IMBHs is a population of wandering IMBHs residing in all galactic halos.
- Bertone et al [*PRD,* ***72****, 103517 ('05)*] showed that γ-rays from IMBH minispikes in the Wilky-Way can easily be detected by GLAST as point gamma-ray sources.
- Our work: How much will a cosmological distribution of IMBHs contribute to the EGB?

Method (I): IMBH Formation

- We consider two IMBH formation scenarios, in order to cover the wide range of IMBH mass ($10^2\ M_{sun} \sim 10^5\ M_{sun}$)

1. Protogalactic Disk Model [*Koushiappas et al, MNRAS, **354**, 292 ('05)*]
   IMBH forms by gas collapse at the centre of protogalactic disks. This process occurs at high redshifts of ~15, and can occur until reionization. The formed black holes have mass
   $M_{BH} \sim 10^5\ M_{sun}$
2. Population-III Remnant Model [*Madau & Rees, ApJ, **551**, L27 '01*]
   IMBHs are remnants of Pop-III stars. Formation occurs at high redshifts of ~18, and yields black holes with masses
   $M_{BH} > 100\ M_{sun}$.

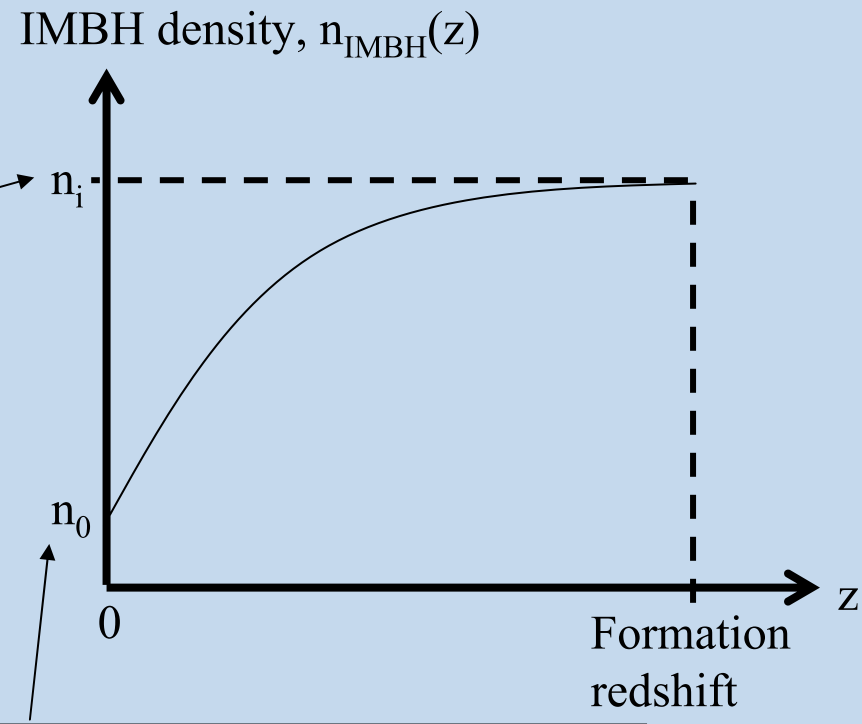
Method (II): IMBH Number Density

- We make a fitting of how the IMBH number density evolves with redshift. We fit:

n_i determined using the formation scenario. The exact value heavily depends on the formation redshift.

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

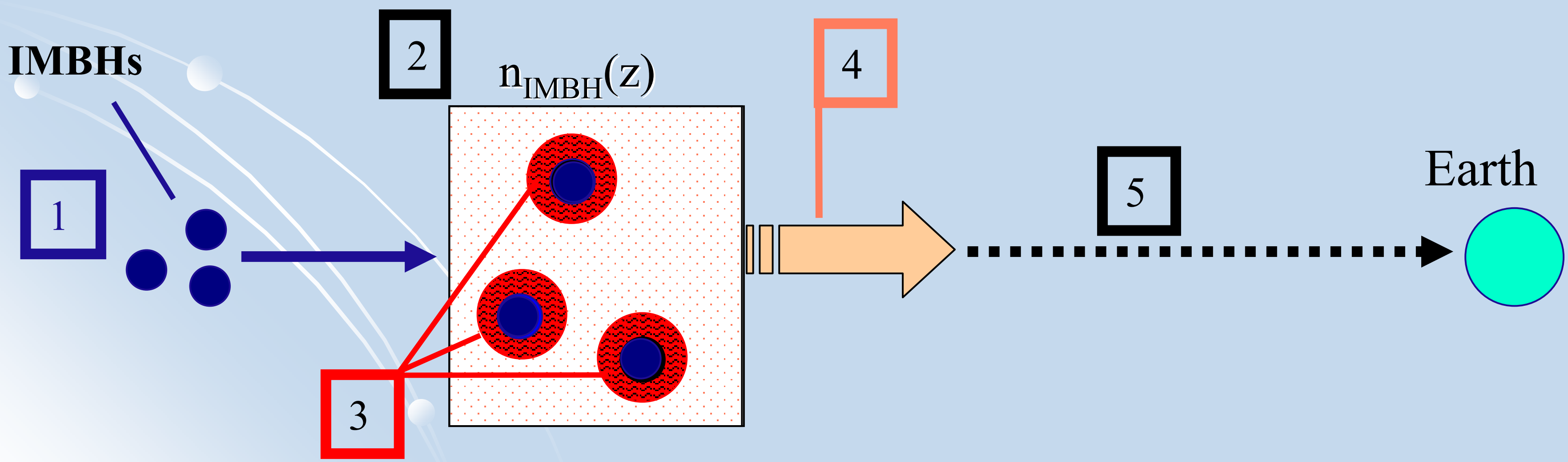
Between n_i and n_0, it has been suggested by numerical simulations that n_{IMBH} decreases as a power-law of z with index ~1 [*Koushiappas & Zentner '05*]



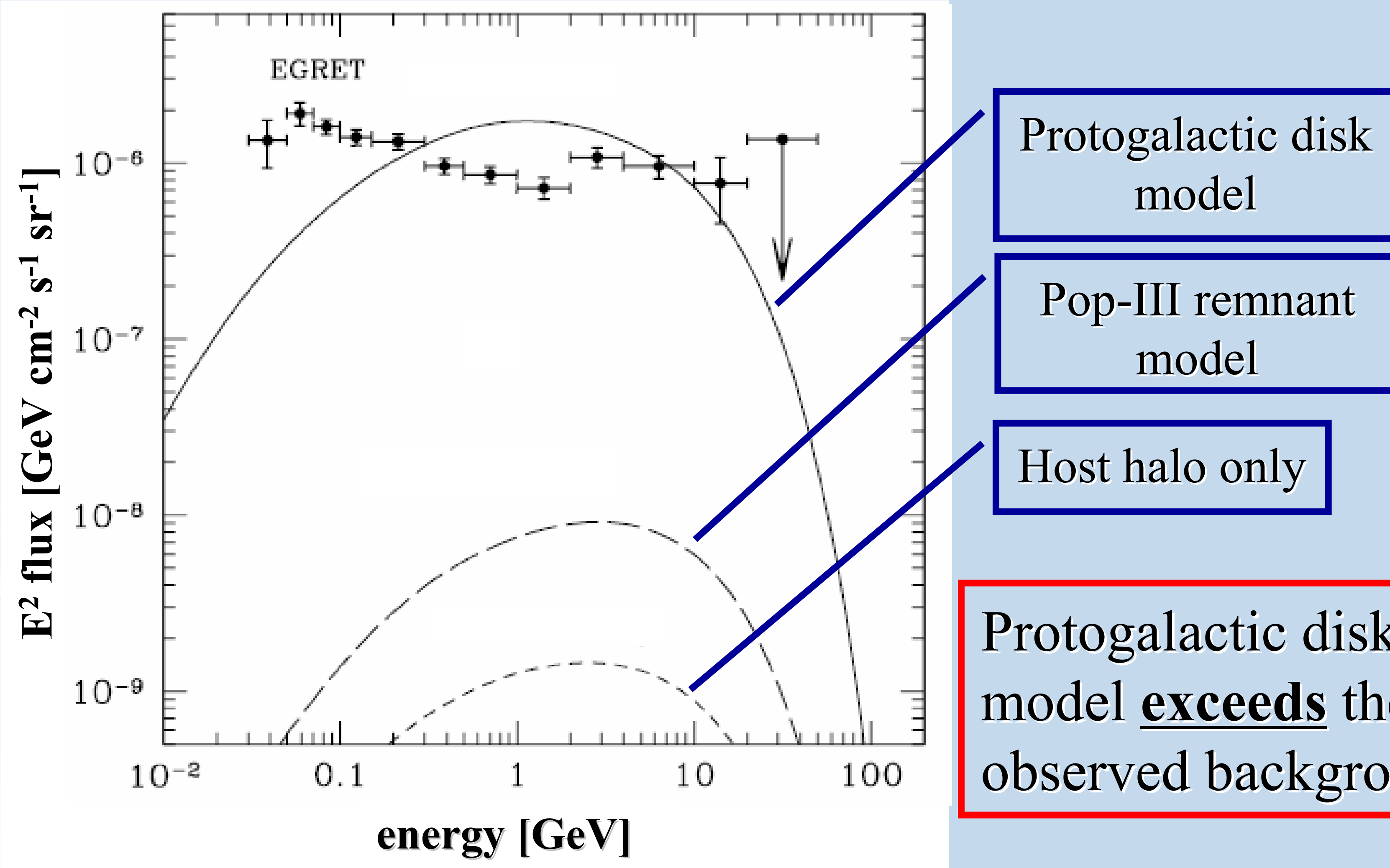
n_0 calculated from results of numerical studies by Bertone et al. **Fitting this yields $\beta = 0.8$**

Method (III): Our Calculation

	Parameters involved
1. Plant IMBHs at formation redshift	z_f
2. Evolve the IMBH number density	index β
3. Minispike enhancement to IMBH	
4. Determine DM annihilation γ-ray flux	σv
5. Attenuation during propagation	



Result (I): EGB Contribution



Protogalactic disk model **exceeds** the observed background!

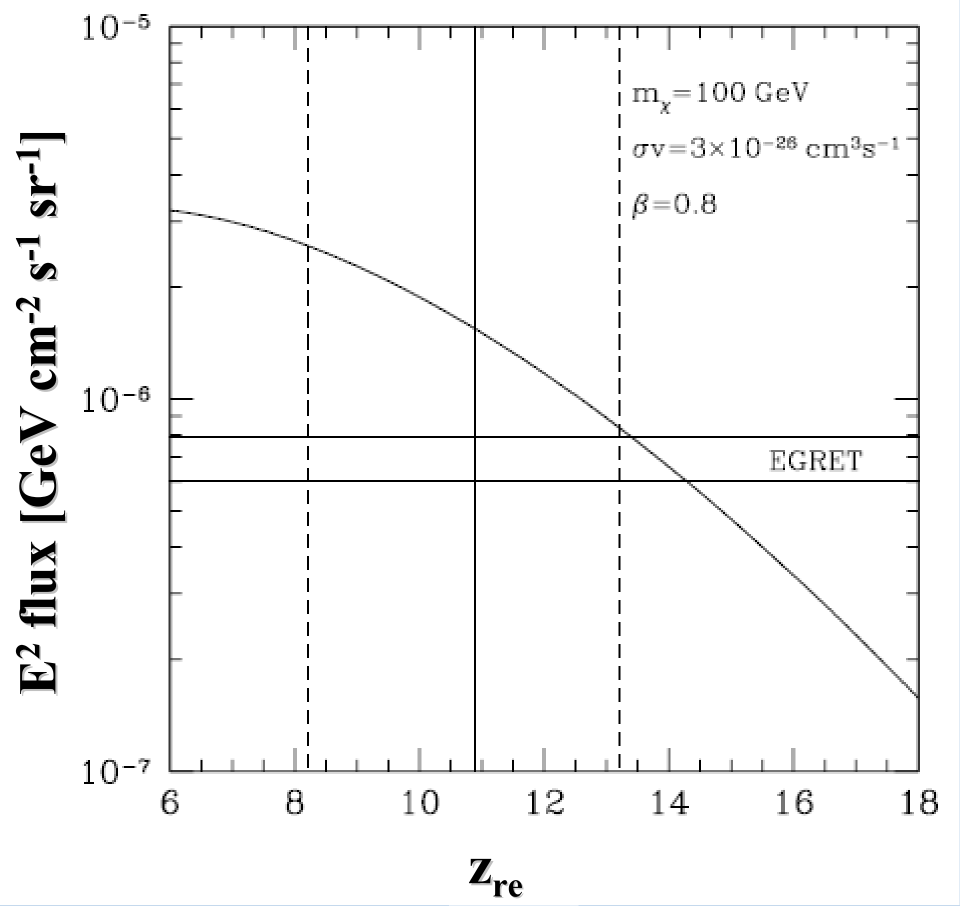
→Let us consider uncertainties in our calculation.

Uncertainty 1: IMBH Formation

- It turns out that the number of IMBHs formed depend on the lower limit of z_f, which is the reionization redshift z_{re} for the protogalactic disk model.
- Increasing z_{re} results in a reduced number of IMBHs.
- We change z_{re} within the latest WMAP results†:

$$z_{re} = 10.9^{+2.3}_{-2.7}$$

However, cannot decrease flux enough

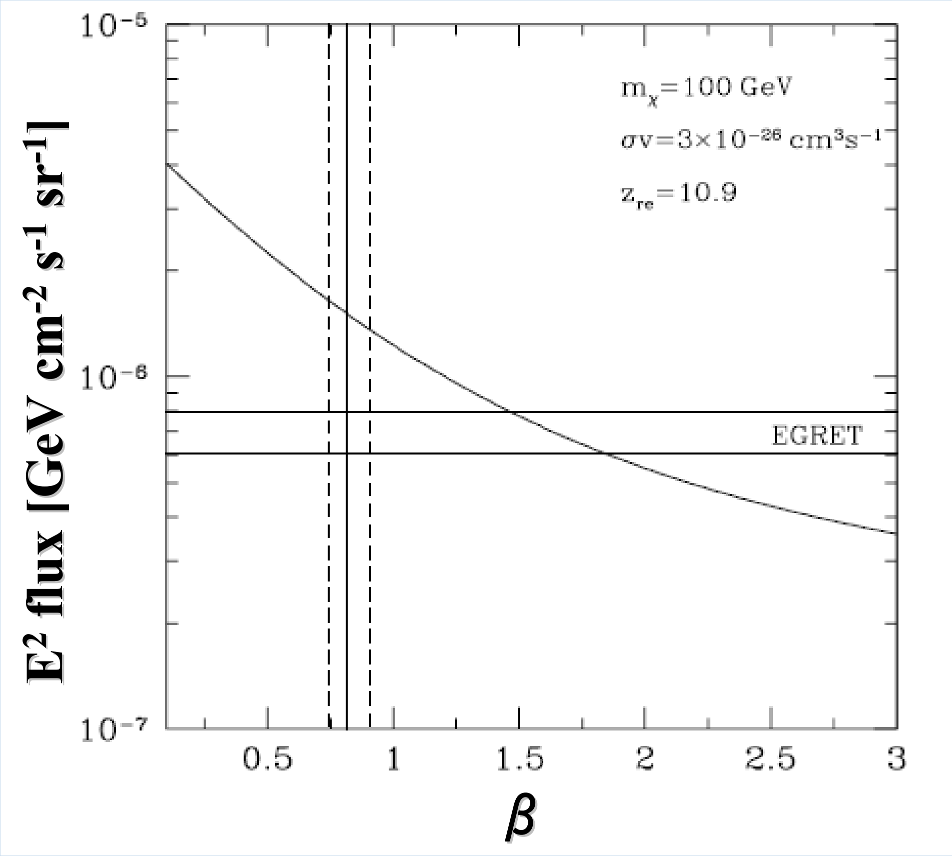


†*Page et al, astro-p/0603450*

Uncertainty 2: IMBH Number

- We have made a fitting of the IMBH number density; will a reasonable change in the index β yield significantly smaller contributions?
- We take into account the error-bars in calculating n_0, which we have indicated by the vertical dotted lines.

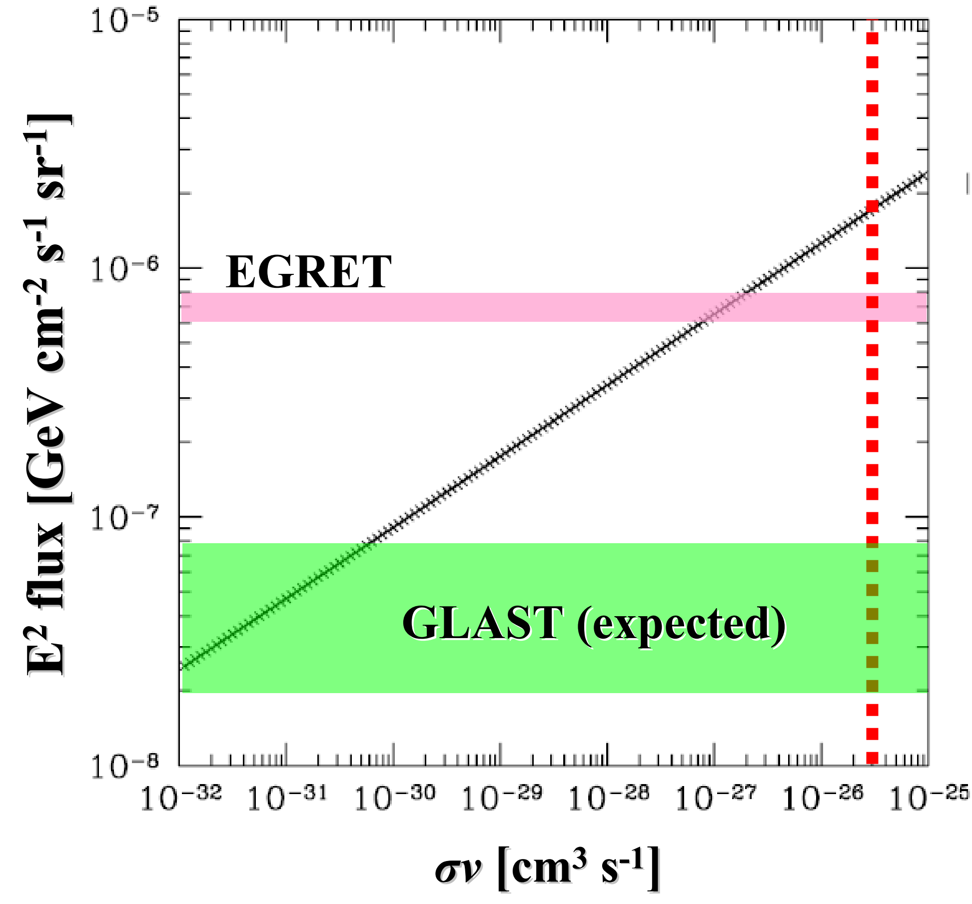
Again, cannot decrease the flux enough



Result (II): Constraining DM Paramaters

Constrains:
$\sigma v < 3 \times 10^{-27}$ cm^3 s^{-1}

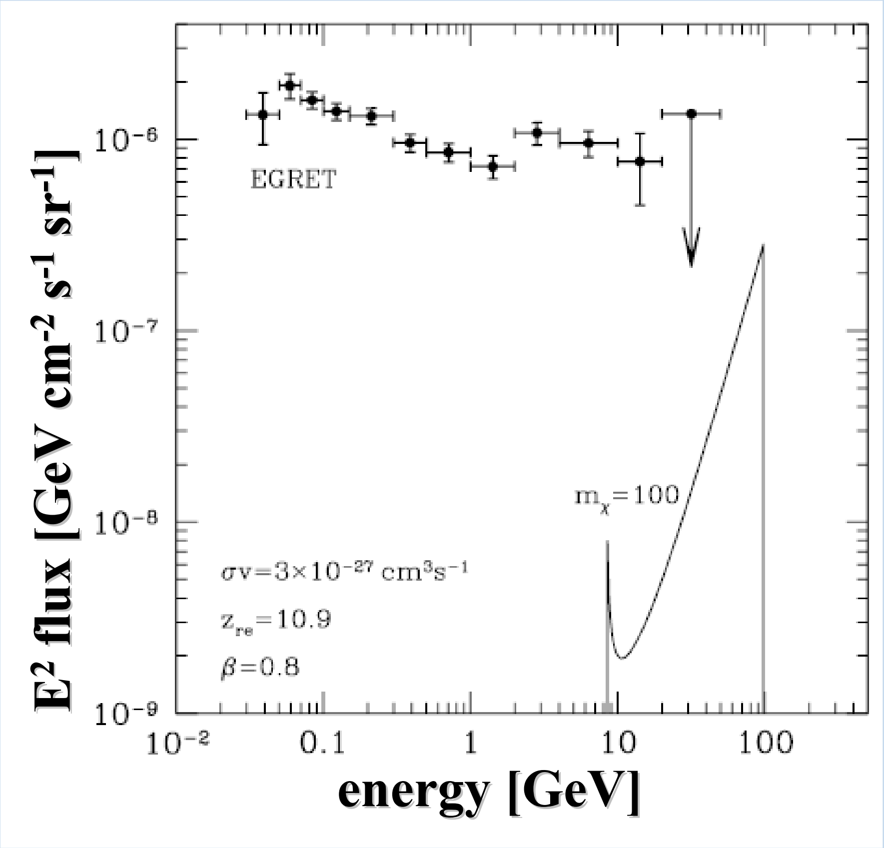
- The flux scales linearly with σv, and thus a smaller σv means less γ-rays. But in our scenario, this is compensated by a denser minispike and the fact that it is maintained longer. Thus we find that the flux scales as $\langle \sigma v \rangle^{2/7}$
- With the launch of GLAST (with increased sensitivity × 10~100), we may be able to probe down to $\sigma v \sim 10^{-30}$ cm^3 s^{-1}



This is such a small value, one that cannot be probed by any other experiment for the next few decades.

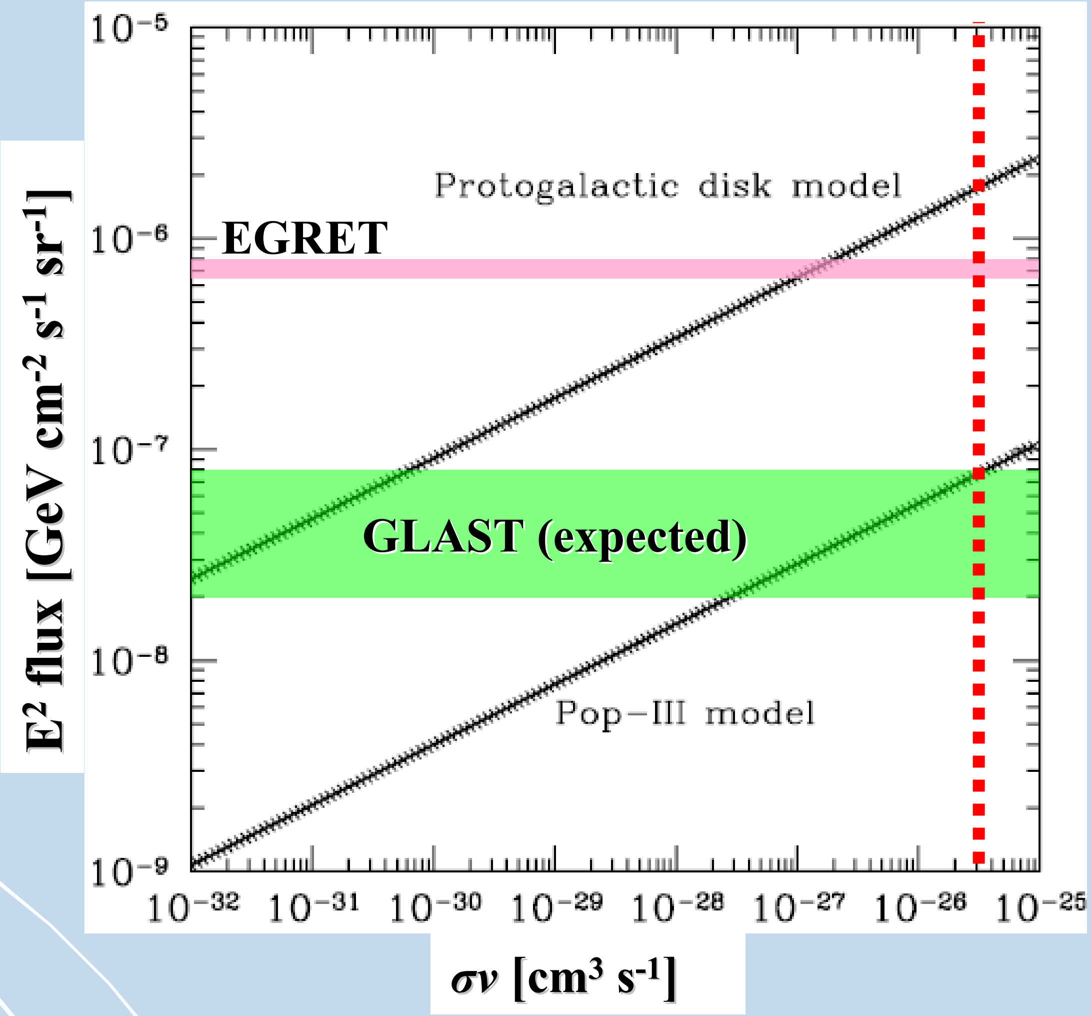
Result (III): Line-Gamma Spectra

- Although subdominant compared to the previously considered continuous gamma-rays, DM can annihilate directly into photons via loop-diagrams. The resulting line-gamma photons have energy that is a function of the DM mass, and thus, if detected, provide strong evidence for DM.
- Detection with GLAST is promising because
  - GLAST's energy window extends to ~300GeV
  - GLAST's better resolution will resolve more gamma-ray sources, a fact that will improve EGB observations.
- GLAST is expected to improve EGB observations by at least several factors. Detection of the high energy peak is promising.



D. Summary & Discussion

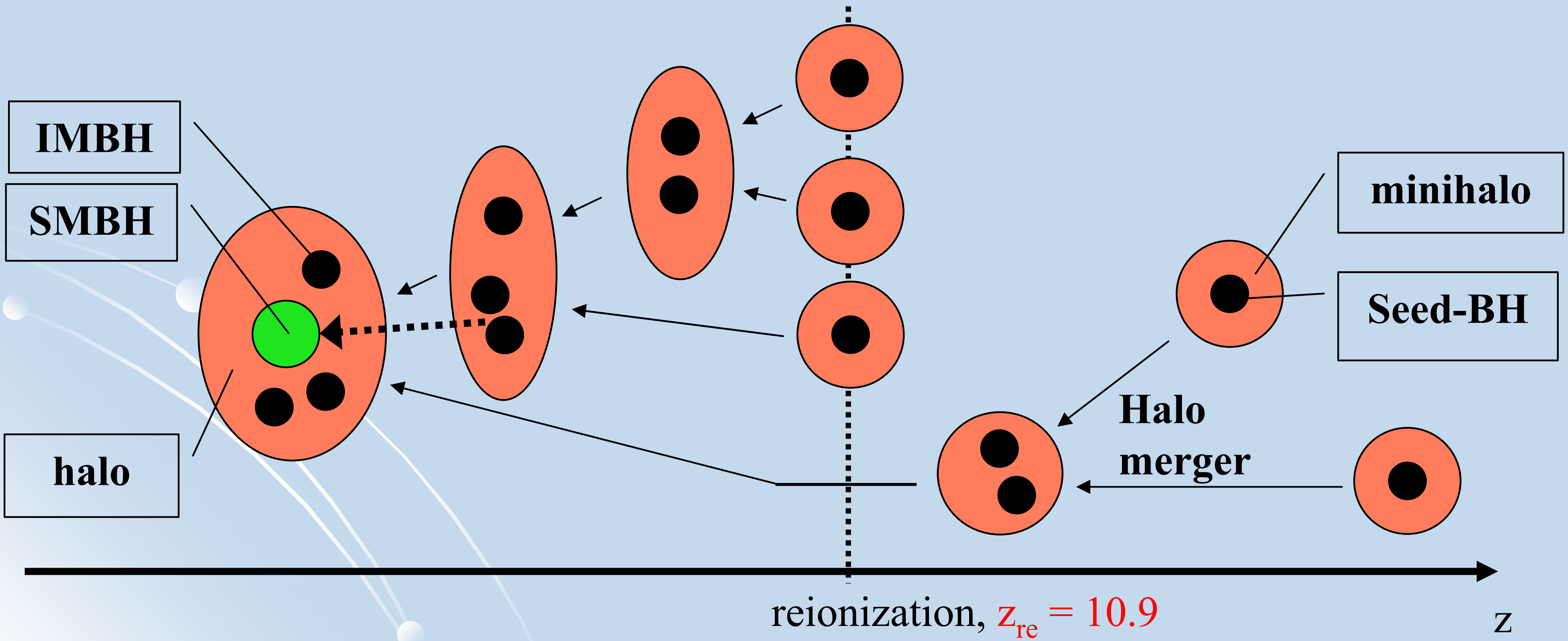
- We have **calculated contributions to the extragalactic γ-ray background** due to DM annihilation in minispikes around a cosmological distribution of IMBHs.
- We found that for reasonable parameters, the **protogalactic disk model exceeds current observations**. This is greatly unchanged by a consideration of IMBH scenario uncertainties, and we thus constrain the DM σv to: $\boldsymbol{\sigma v < 3 \times 10^{-27}\ \mathrm{cm}^3\ \mathrm{s}^{-1}}$
- The Pop-III model yields smaller contributions (2-orders), and requires GLAST. EGB contributions therefore sheds light on IMBH and SMBH scenarios as well.
- The properties of the minispike yields a weak dependence on DM parameters, such that GLAST can probe to $\boldsymbol{\sigma v < 10^{-30}\ \mathrm{cm}^3\ \mathrm{s}^{-1}}$
- The line-gamma spectrum, very characteristic of DM annihilation, is within reach by GLAST.



Protogalactic disk model
EGRET
GLAST (expected)
Pop−III model
E² flux [GeV cm⁻² s⁻¹ sr⁻¹]
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻³²
10⁻³¹
10⁻³⁰
10⁻²⁹
10⁻²⁸
10⁻²⁷
10⁻²⁶
10⁻²⁵
σv [cm³ s⁻¹]

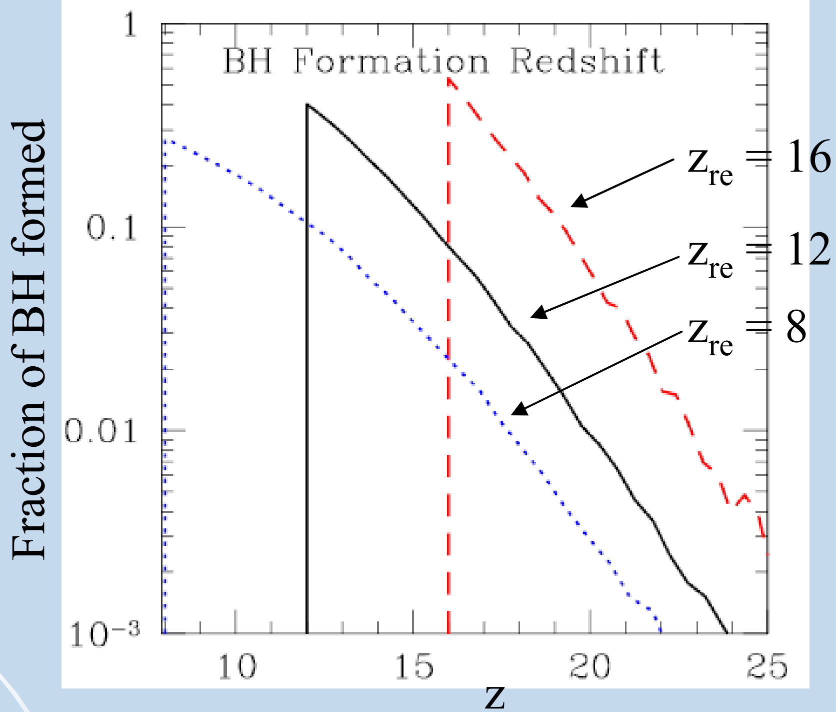
B2. IMBH Formation

- In both models, formation continues from high z until reionization
- Before reionization, formation falls exponentially



B2. IMBH Formation (2)

- Before reionization, formation falls exponentially

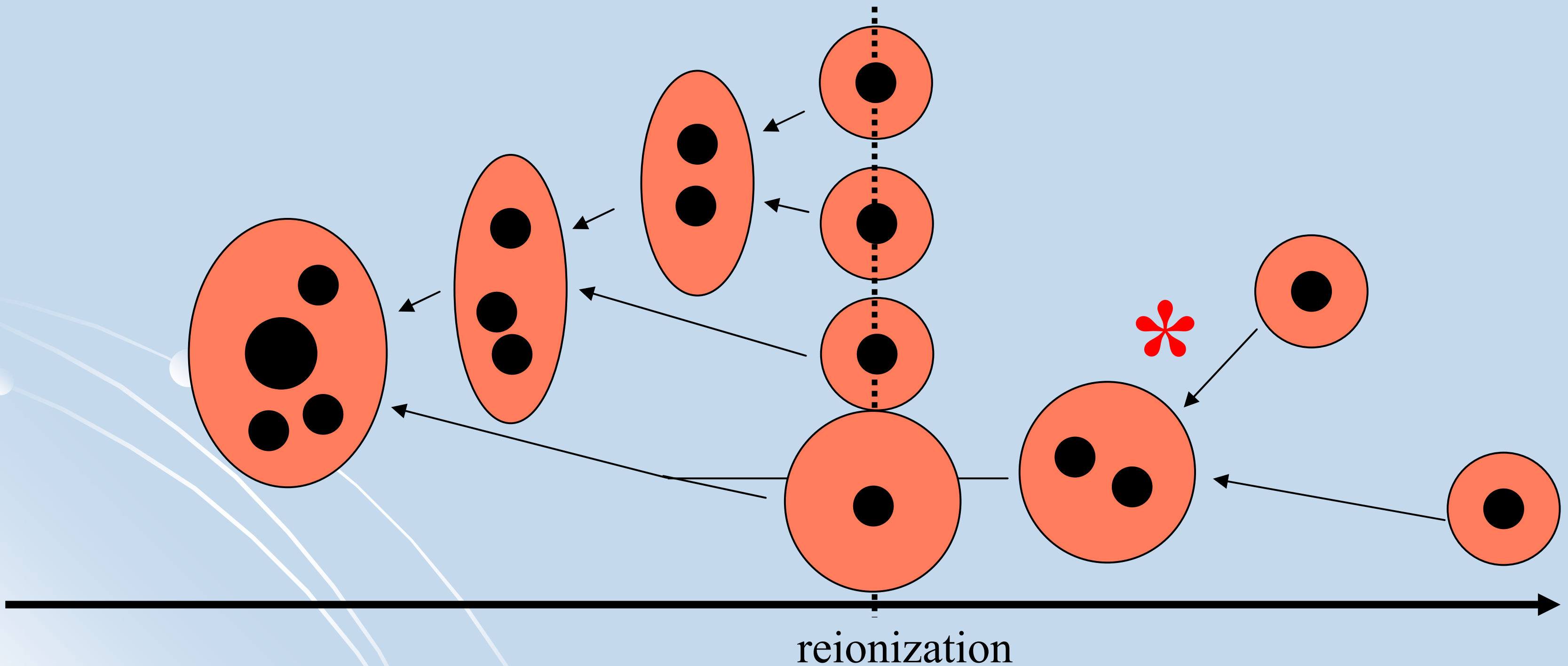


- Use z_{re} as the formation parameter.

B1. Approximation

- Assuming a delta-function formation red-shift at z_{re} means haloes like [*] are now replaced by a single seed-BH.

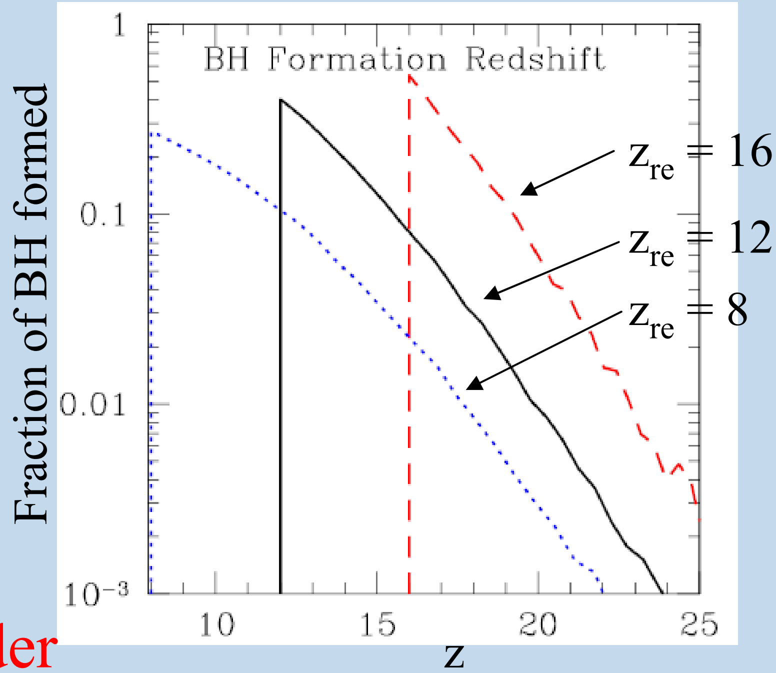
  → Hence we underestimate the density of seed-BHs.



- However this effect is small as formation falls off exponentially above z_{re}

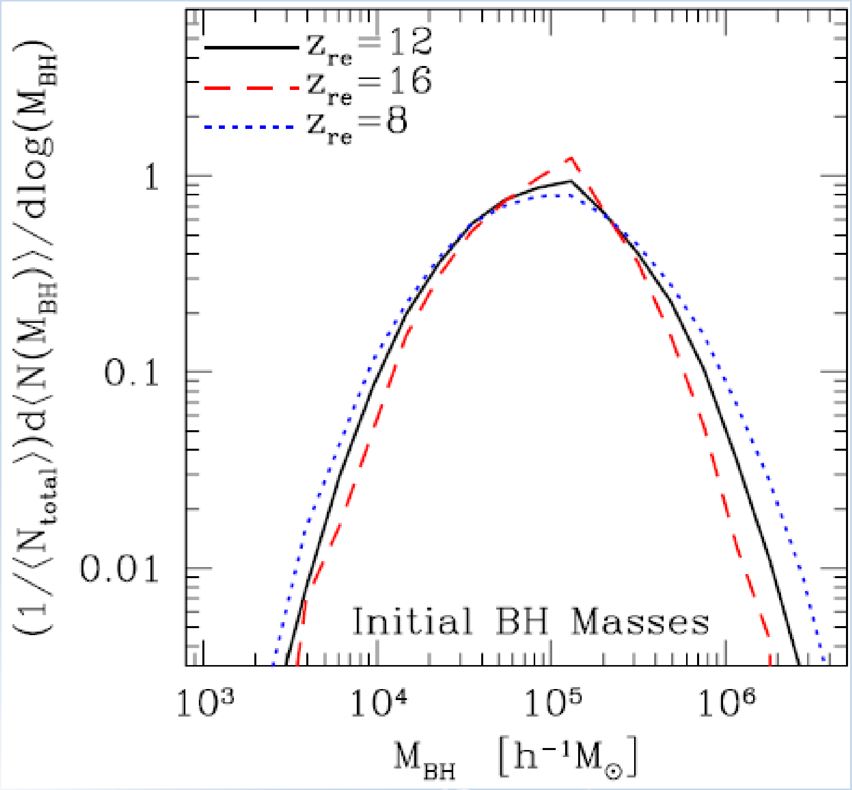
B1. Approximation (2)

- Formation stops at reionization, and falls off exponentially before
  [*Koushiappas & Zentner '05*]
- Approximating this distribution by a delta function at z_{re} reduces the resulting flux by ~ a factor.
- However, this is over-shadowed by uncertainties in z_{re} which cause ~ order

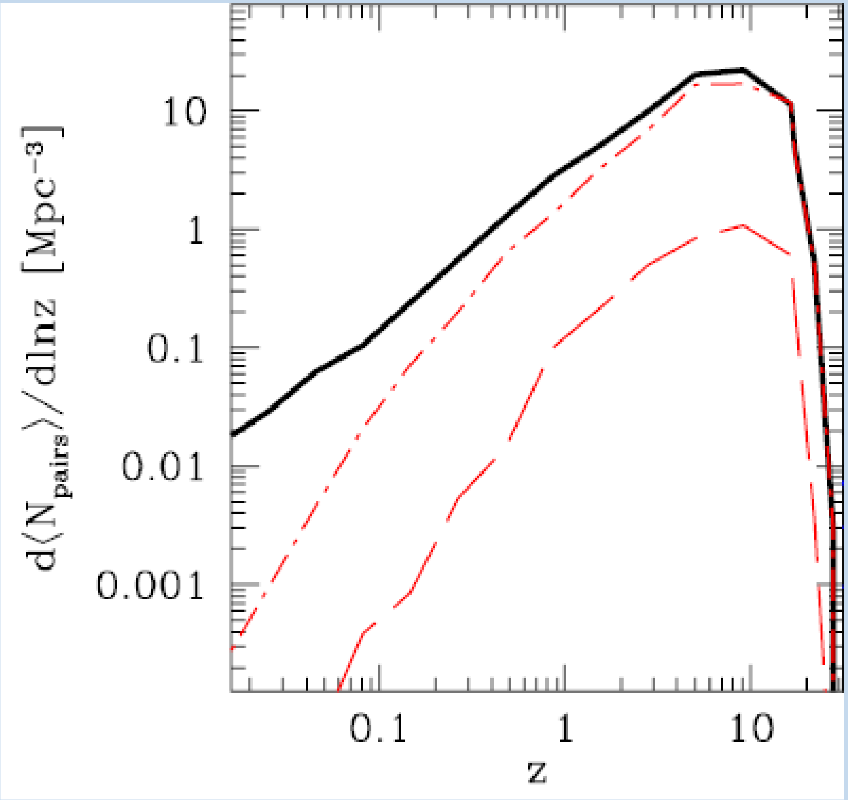


➡ We assume all BHs form at z_{re} in haloes with mass > a critical mass,

- Note as this acts to decrease the flux, thus still allowing us to set constraints



$Z_{re}=12$
$Z_{re}=16$
$Z_{re}=8$
Initial BH Masses
$(1/\langle N_{total}\rangle)d\langle N(M_{BH})\rangle/d\log(M_{BH})$
M_{BH} $[h^{-1}M_\odot]$



$d\langle N_{pairs}\rangle/d\ln z$ $[Mpc^{-3}]$
z