Strong link between the dark matter identity and the origin of the supermassive black holes

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K. Kohri, T. Nakama and T. Suyama in preparation

Motivation

Super massive black holes (SMBHs) observed at high redshift

(Mortlock et. al.2011)

$M \sim 10^9 M_\odot$ $z = 6 \sim 7$

Origin not known

Two possibilities

Astrophysical explanation (stars as seed BHs)

Seed BHs (hundreds of solar mass) and their growth due to accretion

Seems difficult due to short time which is available

Cosmological explanation (primordial BHs)

Primordial BHs formed directly from primordial perturbation in radiation dominated universe

No short time problem (primordial power spectrum modified)

Motivation

Coexistence of two different explanations is frustrating.

It is very nice if there is any method to exclude one of the two explanations.

Astrophysical explanation (stars as seed BHs)

Seed BHs (hundreds of solar mass) and their growth due to accretion

Seems difficult due to short time which is available

Cosmological explanation (primordial BHs)

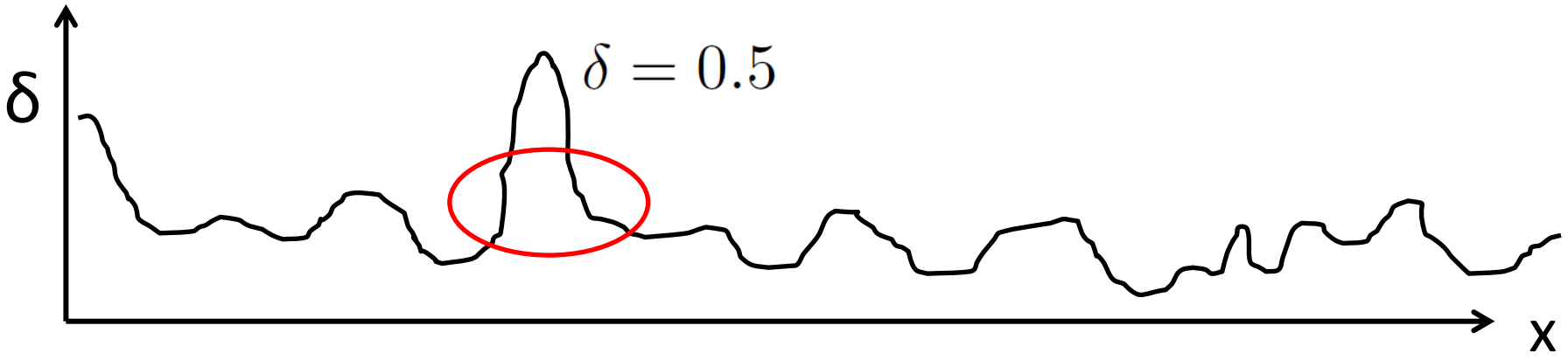
Primordial BHs formed directly from primordial perturbation in radiation dominated universe

No short time problem

In this talk, I propose a one method than can potentially testify the PBH scenario. (depending on the nature of DM)

Primordial Black Holes

In the radiation dominated universe, if the density contrast exceeds a threshold value (=0.5) at the time of horizon crossing, BH forms.



$$k \simeq 1 \text{ kpc} \left(\frac{M_{\rm BH}}{10^9 \ M_\odot} \right)^{1/2}$$

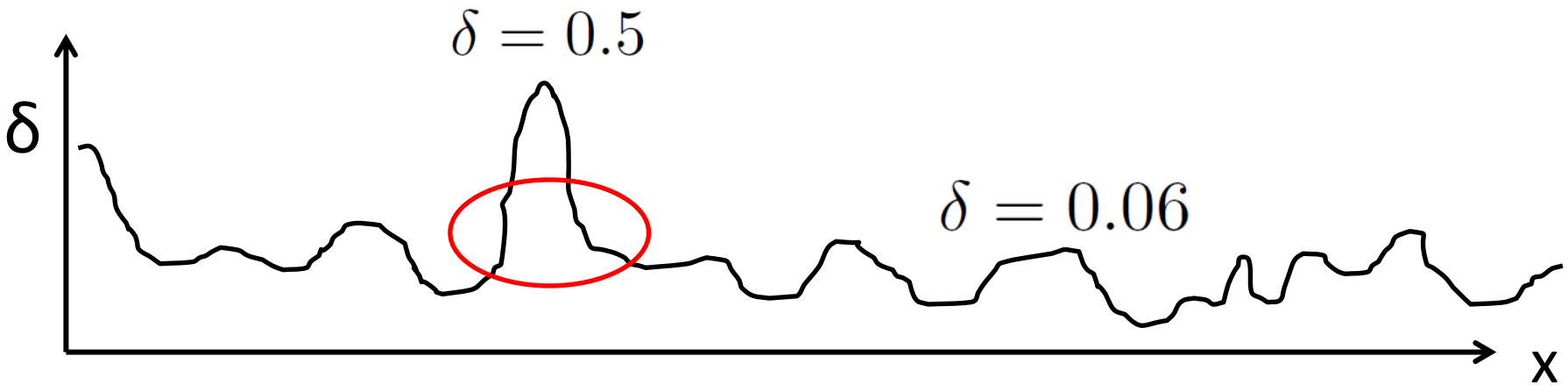
PBH mass is related to the (comoving) wavenumber of perturbations. (not directly probed by CMB observations)

Primordial Black Holes

Site of PBH formation must be rare, otherwise the universe becomes PBH dominated.

$$\sigma_{\bar{\delta}} = 0.06$$ (Gaussian PDF is assumed)

This value of the standard deviation must be realized in the corresponding scale if PBH scenario as seed of SMBHs is correct.



Ultra compact mini halos (UCMHs)

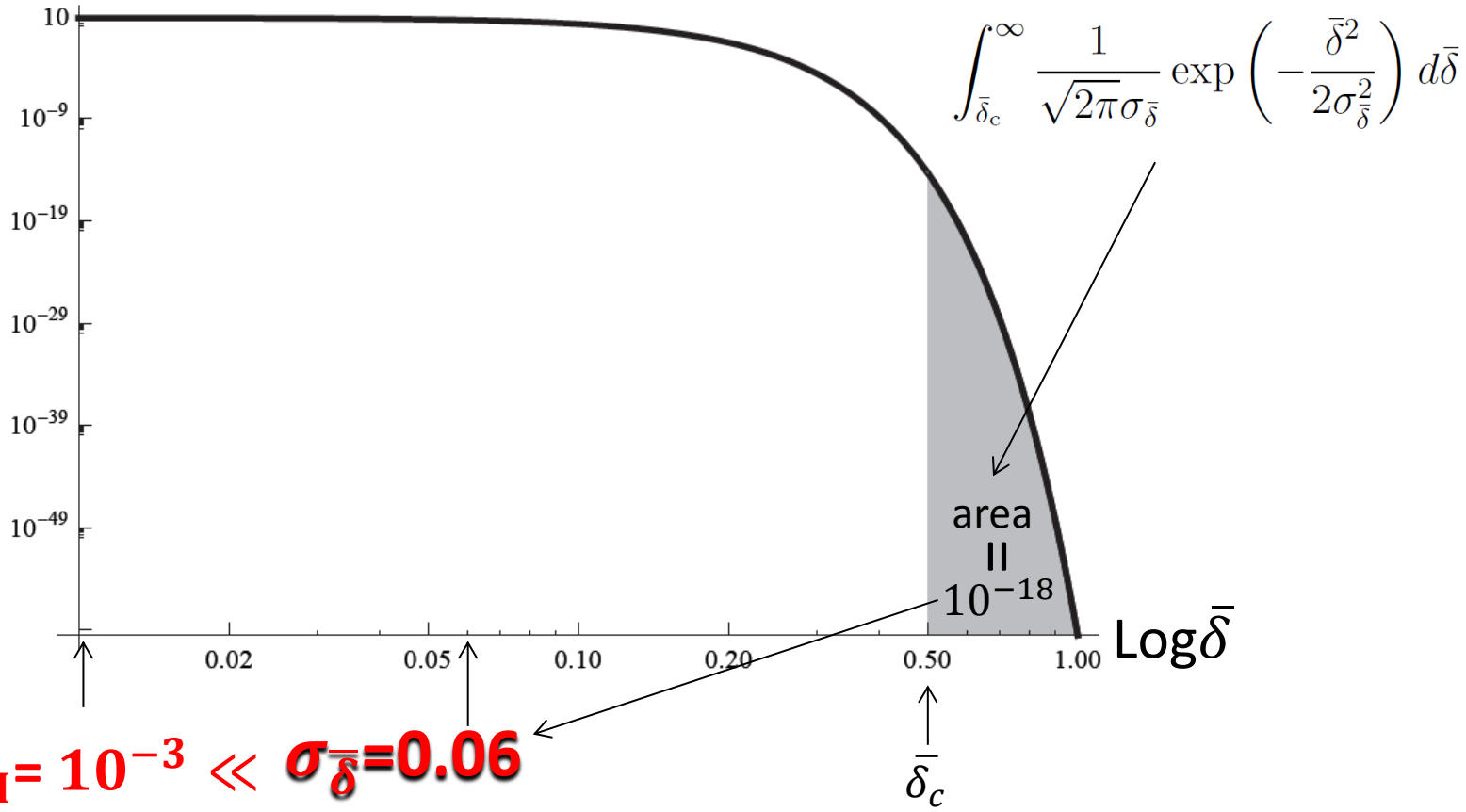
When the perturbations of the scale of interest cross the Hubble radius, dark matter perturbations grow and collapses at around the time of matter radiation equality.

The collapsed object is called ultra compact mini halos (UCMHs).

(Ricotti and Gould, 2009)

Ultra compact mini halos (UCMHs)

Logarithm of Gaussian PDF



$\bar{\delta}_{c,UCMH} = 10^{-3} \ll \sigma_{\bar{\delta}} = 0.06$

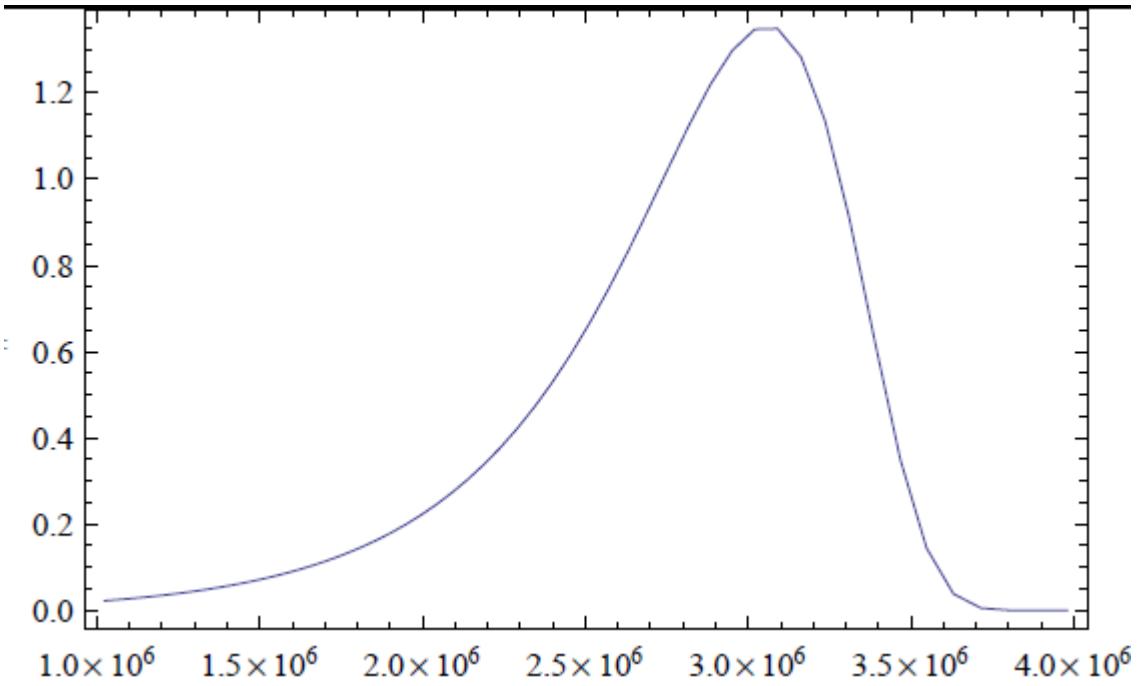
Perturbations leading to UCMH formation are common.

⇩

Decent fraction of DM particles are contained in UCMHs!

Ultra compact mini halos (UCMHs)

Only dark matter forms UCMHs. Thus, the typical mass of UCMH is less than that of PBHs.



Idea

If the PBH scenario is correct, substantial part of DM is in the form of UCMHs.

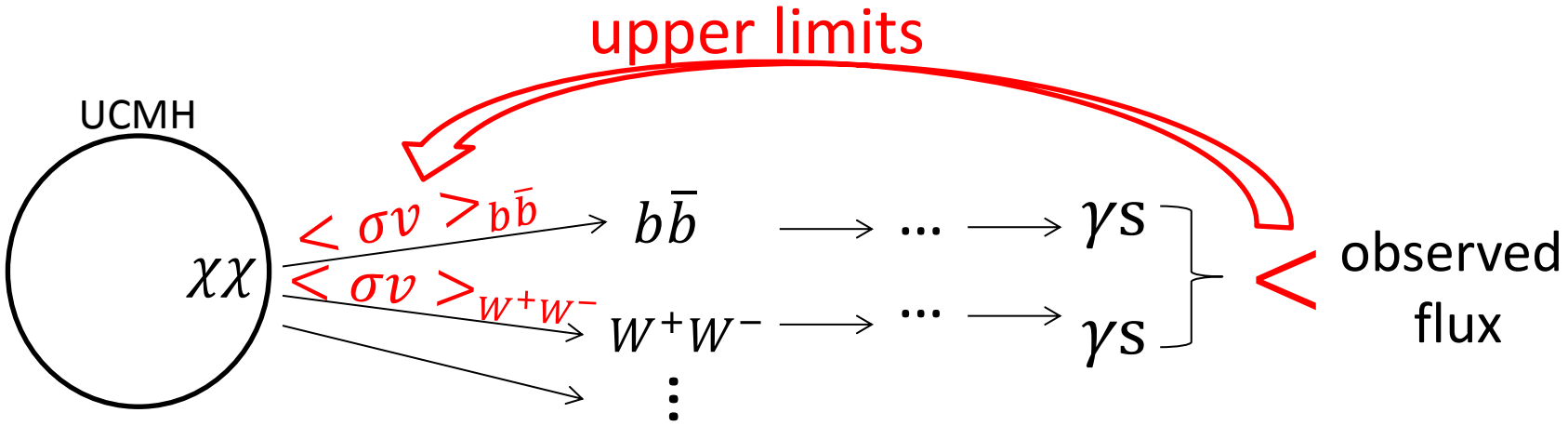
If dark matter particles annihilate and convert into standard model particles (such as photons), we expect some flux from UCMHs. We can then place upper bound on the annihilation cross section by using the observational data such as Fermi.

(Our hope)

Future experiments identify the nature of dark matter and determine annihilation cross sections. Those values turn out to exceed the upper bound set by the PBH scenario. -> PBH scenario is excluded.

Idea

- Assuming **PBHs (δ∼1)** explain SMBHs, **numerous UCMHs ($\delta\sim10^{-3}$)** should exist.

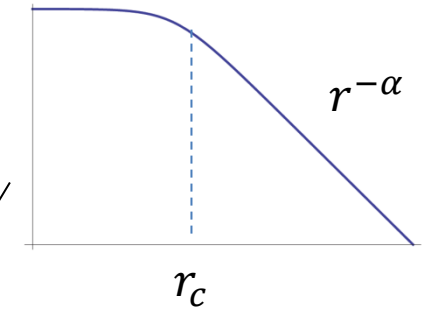


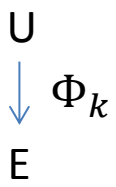
- The scenario of PBHs explaining SMBHs is INCOMPATIBLE with DM models in which the cross sections exceed these upper limits.

Method of calculation

Bringmann, Scott, Akrami, 2012

Kohri, Nakama, Suyama, in prep.





earth↔UCMH

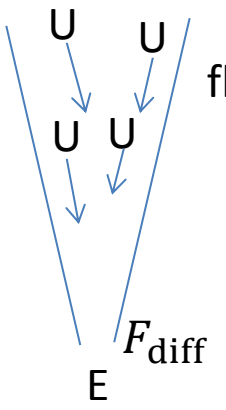
k-th mode

$$4\pi d^2 \Phi_k = \int_{\mathrm{UCMH}} d^3x N_k \frac{\rho_\chi^2 \langle \sigma v \rangle_k}{2m_\chi^2}$$

flux from a UCMH

# of photons per one annihilation

1 TeV



flux from several UCMHs

radius of Milky Way

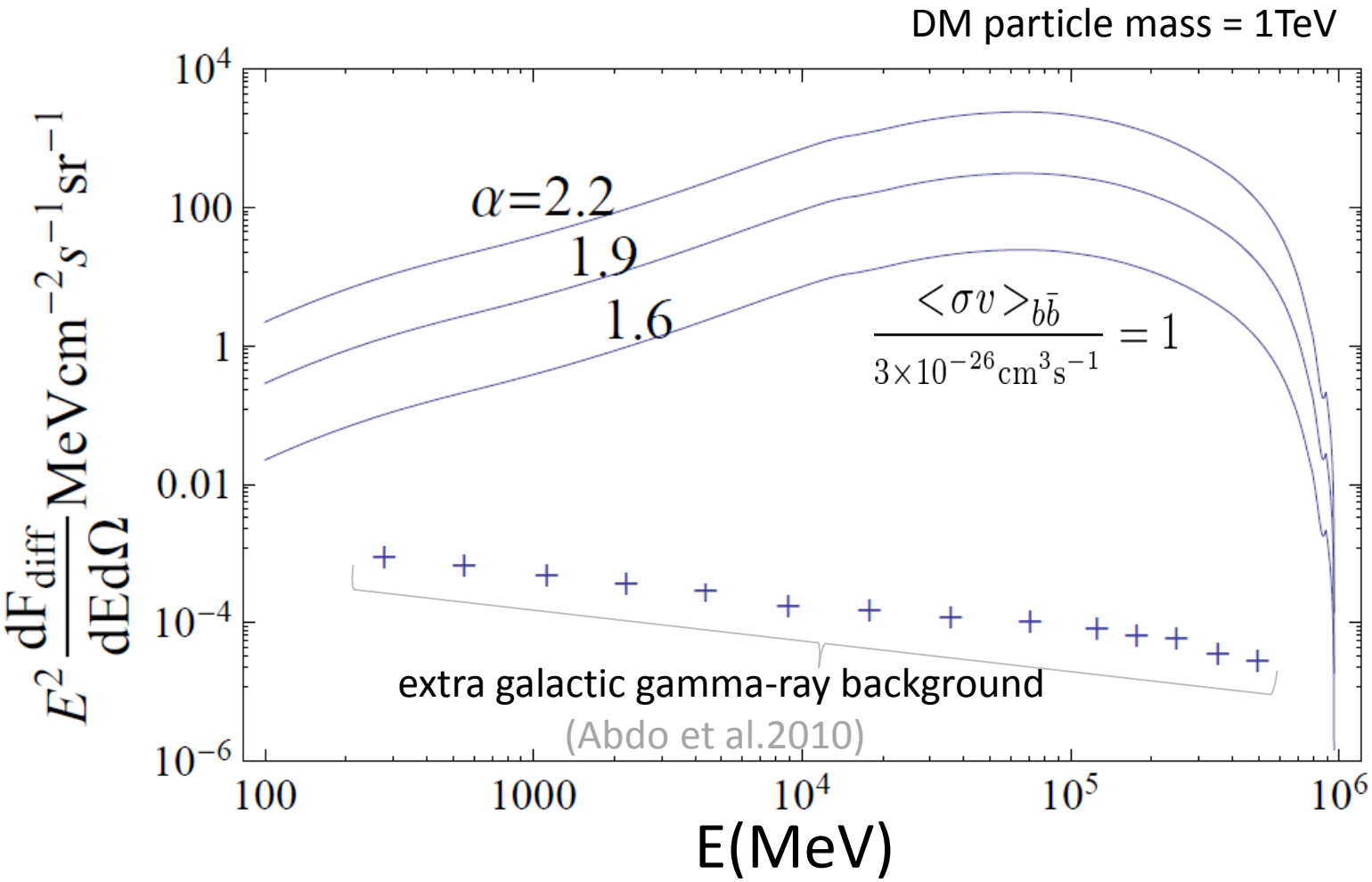
$$E^2 \frac{dF_{\mathrm{diff}}}{dEd\Omega} = \frac{1}{2M_{\mathrm{UCMH}}} \int_{d_{\mathrm{E}}}^{d_{\mathrm{MW}}} \rho_{\mathrm{MW}}(d') E^2 \frac{d\Phi(d')}{dE} d'^2 \mathrm{d}d'$$

center of Milky Way

↔earth

NFW profile

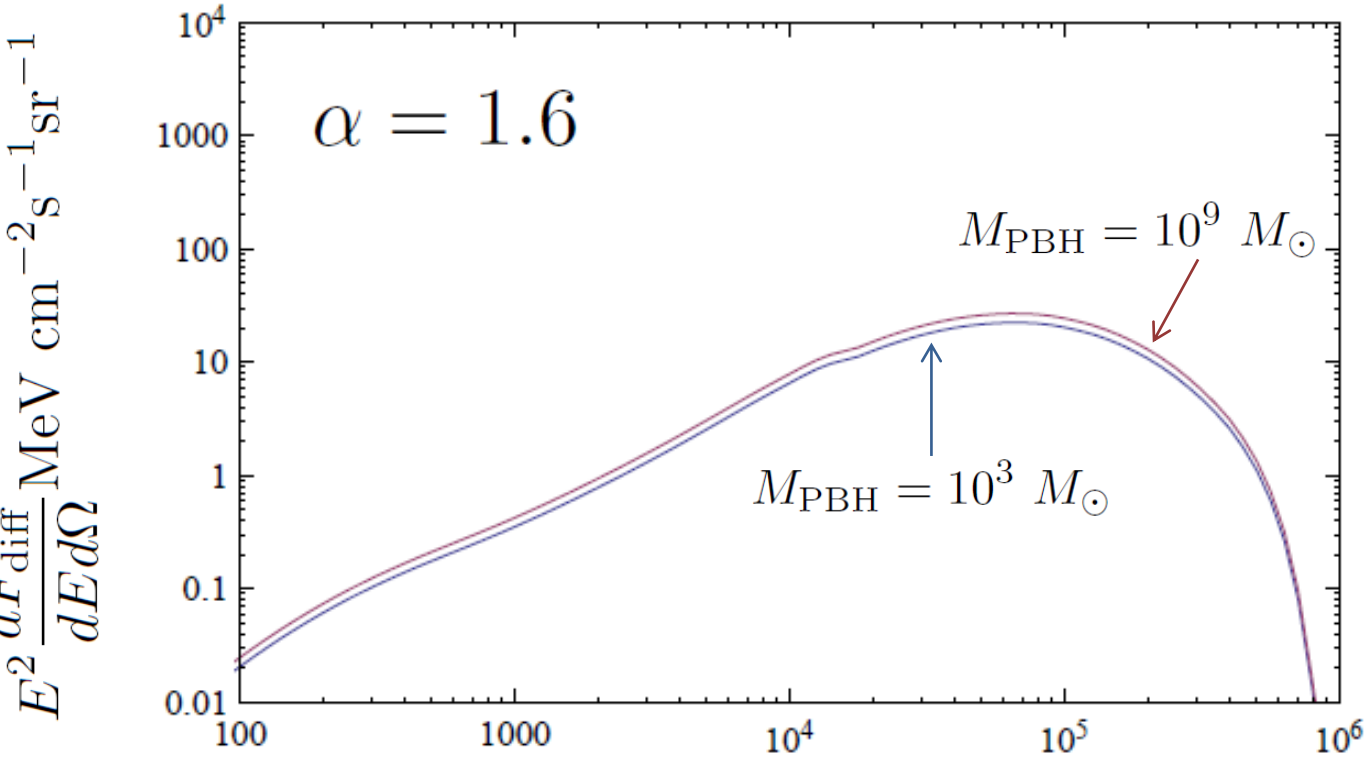
Comparison of γ-rays from UCMHs and observation



$$\frac{<\sigma v>_{b\bar{b}}}{3\times10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}} \lesssim 10^{-5}$$ to be consistent with observation.

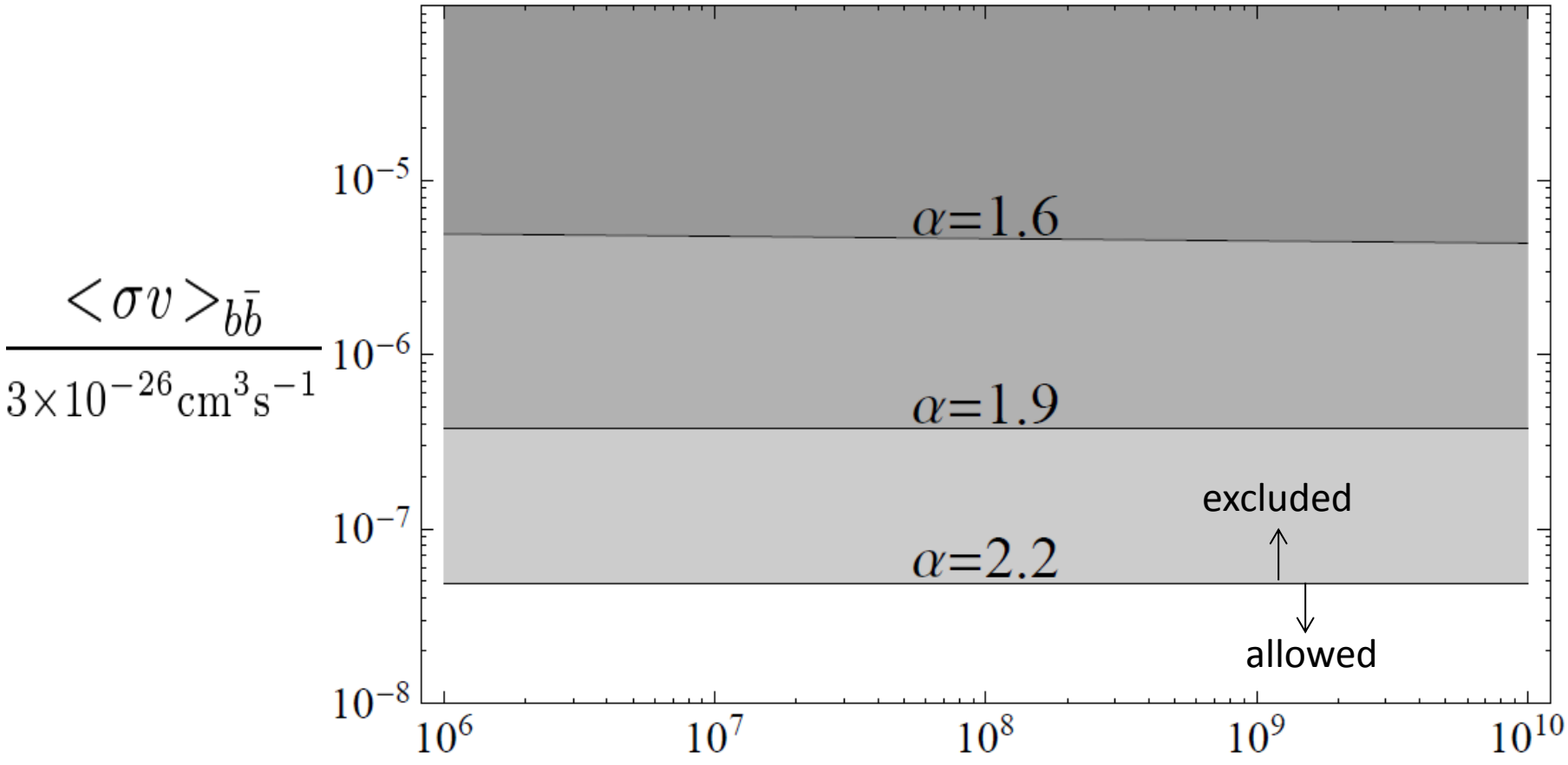
Dependence of the flux on PBH mass

DM particle mass = 1TeV



The flux is very insensitive to the PBH(UCMH) mass.

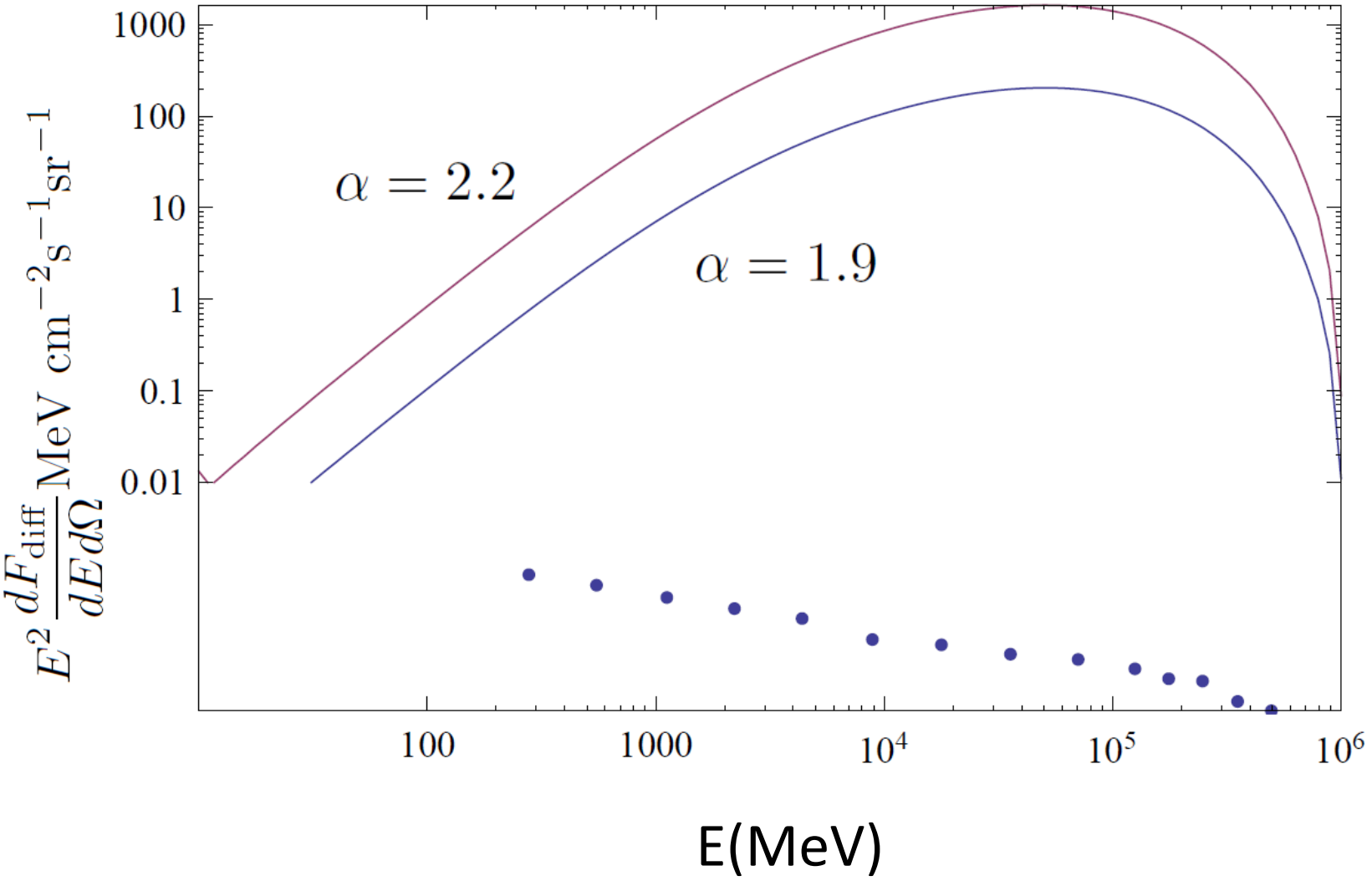
Upper limits on the cross section



$$\frac{<\sigma v>_{b\bar{b}}}{3\times10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}} \lesssim 10^{-5}$$ to be consistent with observation.

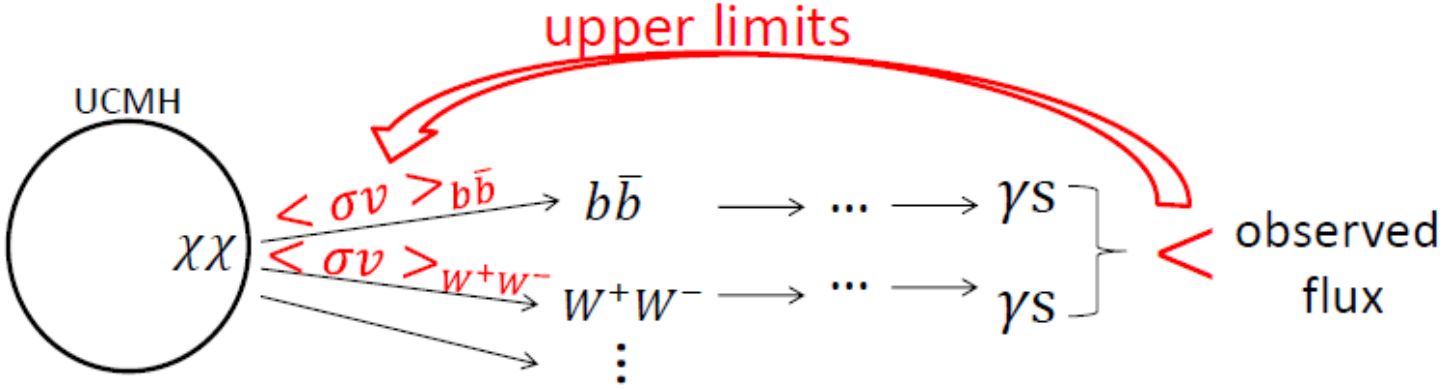
$$\frac{\langle \sigma v \rangle_{W^+W^-}}{3 \times 10^{-26}\ \mathrm{cm^3 s^{-1}}} = 1$$

DM particle mass = 1TeV



Summary

- Assuming **PBHs (δ∼1)** explains SMBHs, **numerous UCMHs (δ∼10^{-3})** should exist.



$$\frac{<\sigma v>_{b\bar{b},W^+W^-,\tau^+\tau^-}}{3\times10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}} \lesssim 10^{-5}$$

- The scenario of PBHs explaining SMBHs is INCOMPATIBLE with DM models in which the cross sections exceed these upper limits.

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