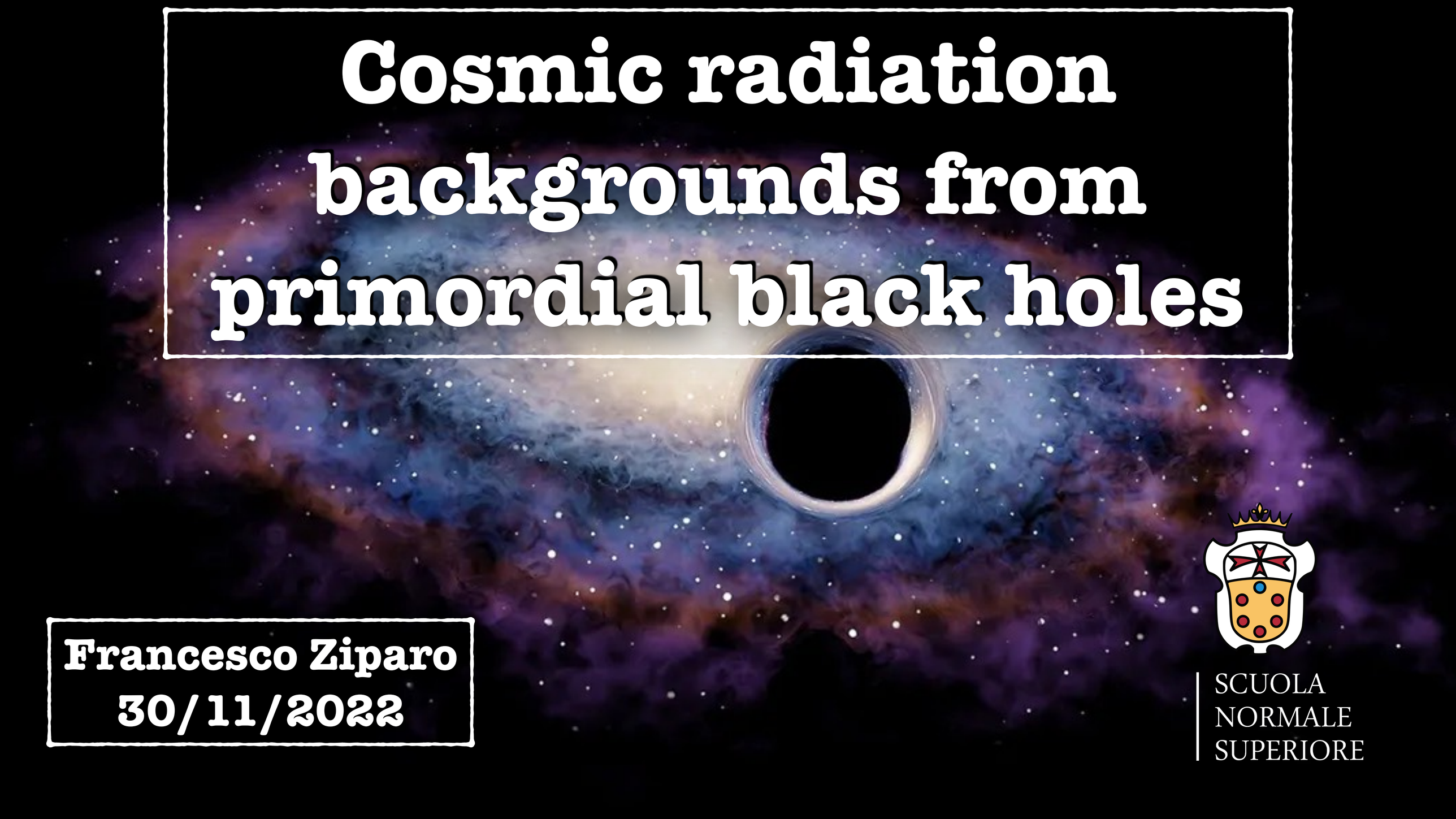
Cosmic radiation backgrounds from primordial black holes



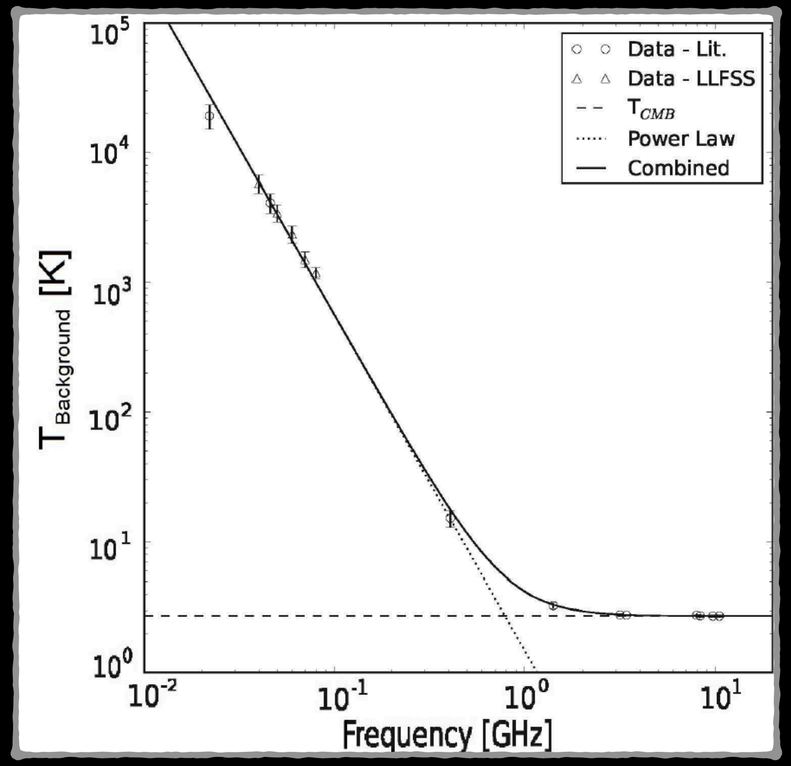
Francesco Ziparo

30/11/2022

SCUOLA
NORMALE
SUPERIORE

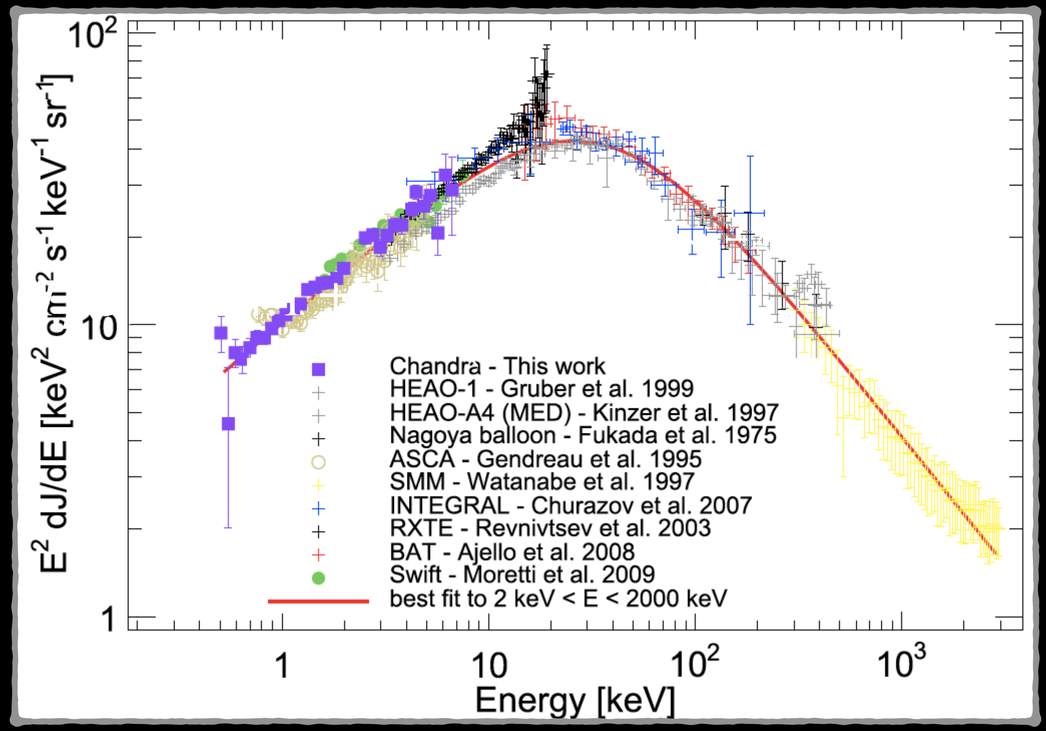
Motivations

Radio Background



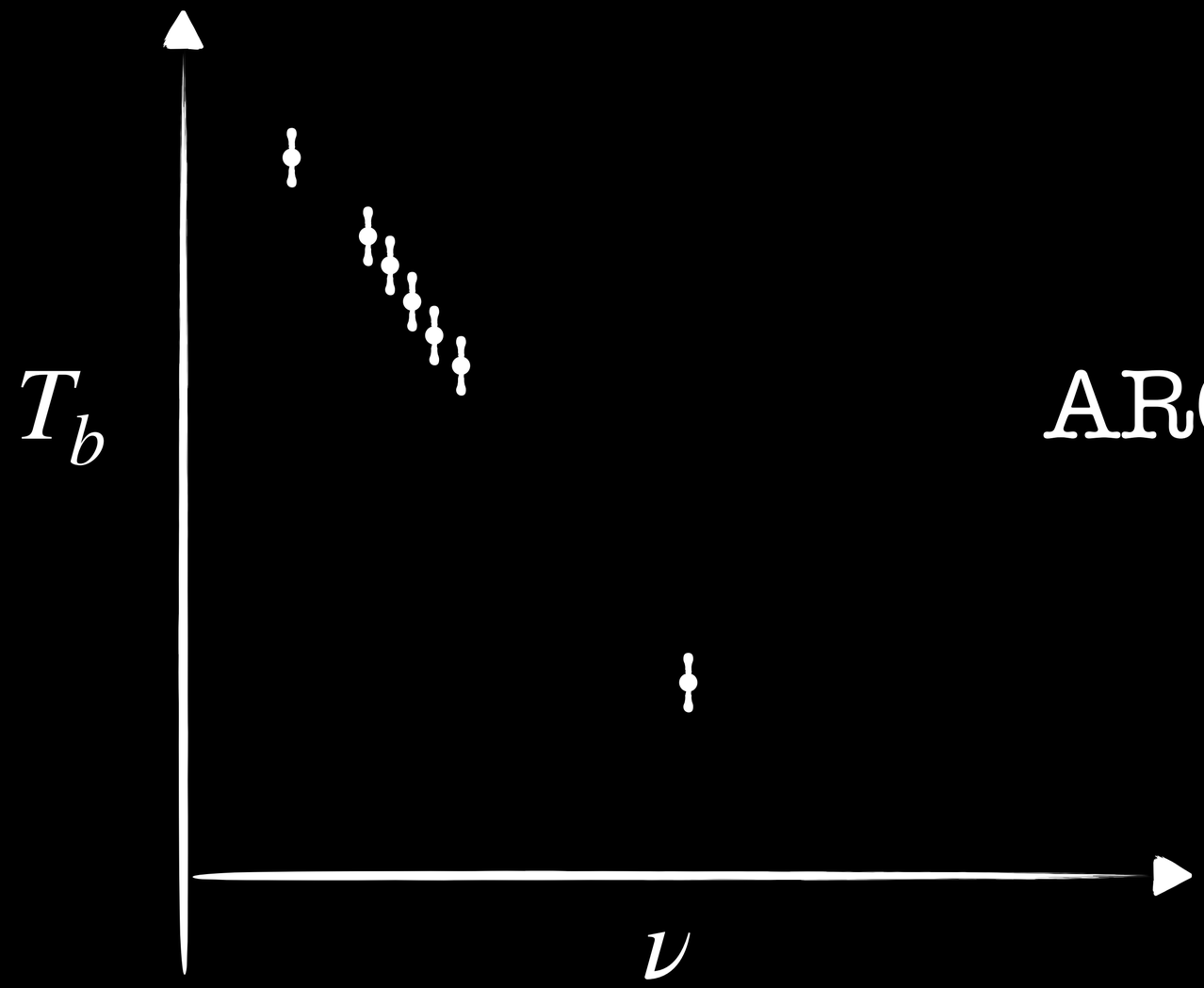
ARCADE2

X-ray Background



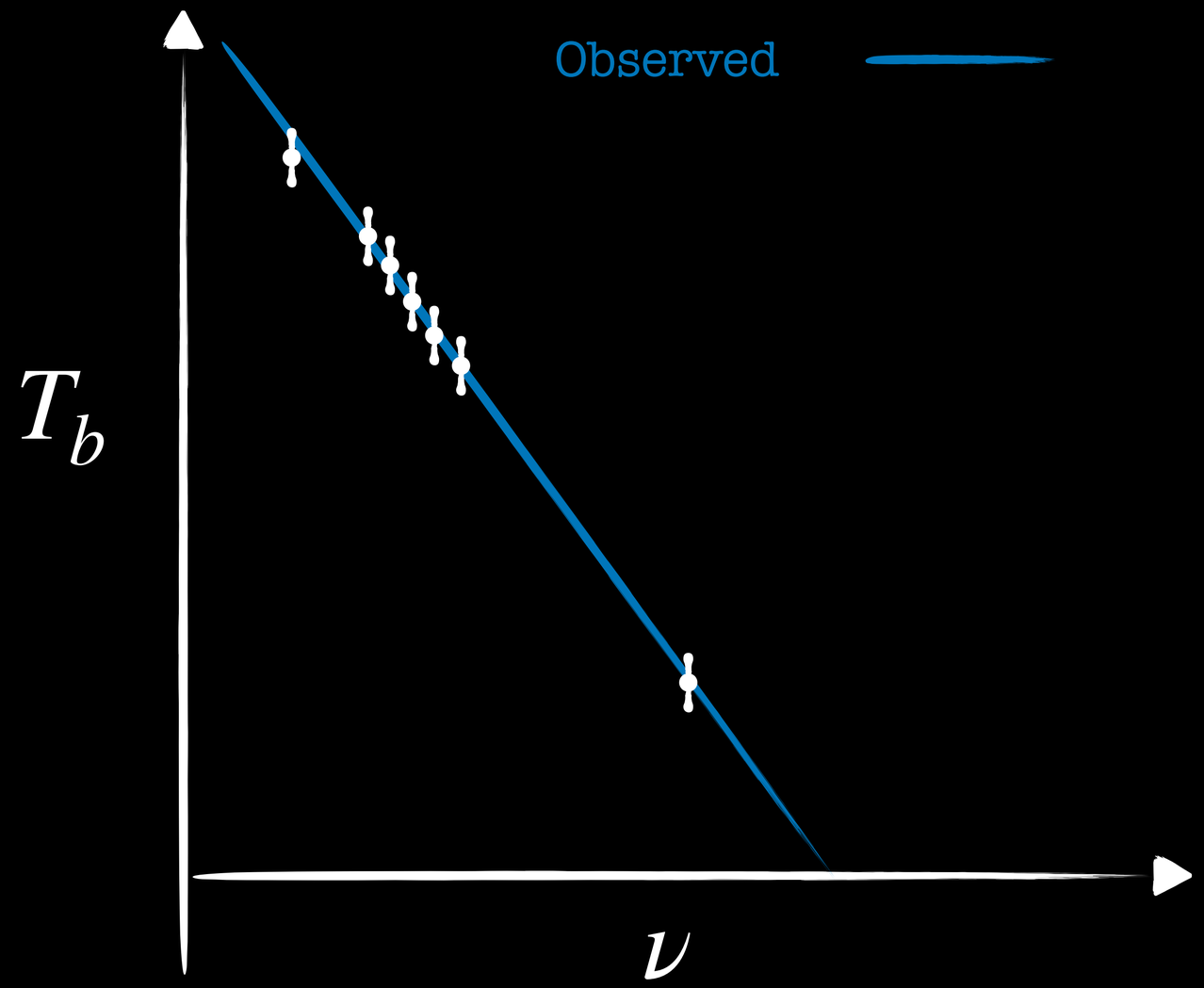
CHANDRA

Motivations



ARCADE2

Motivations

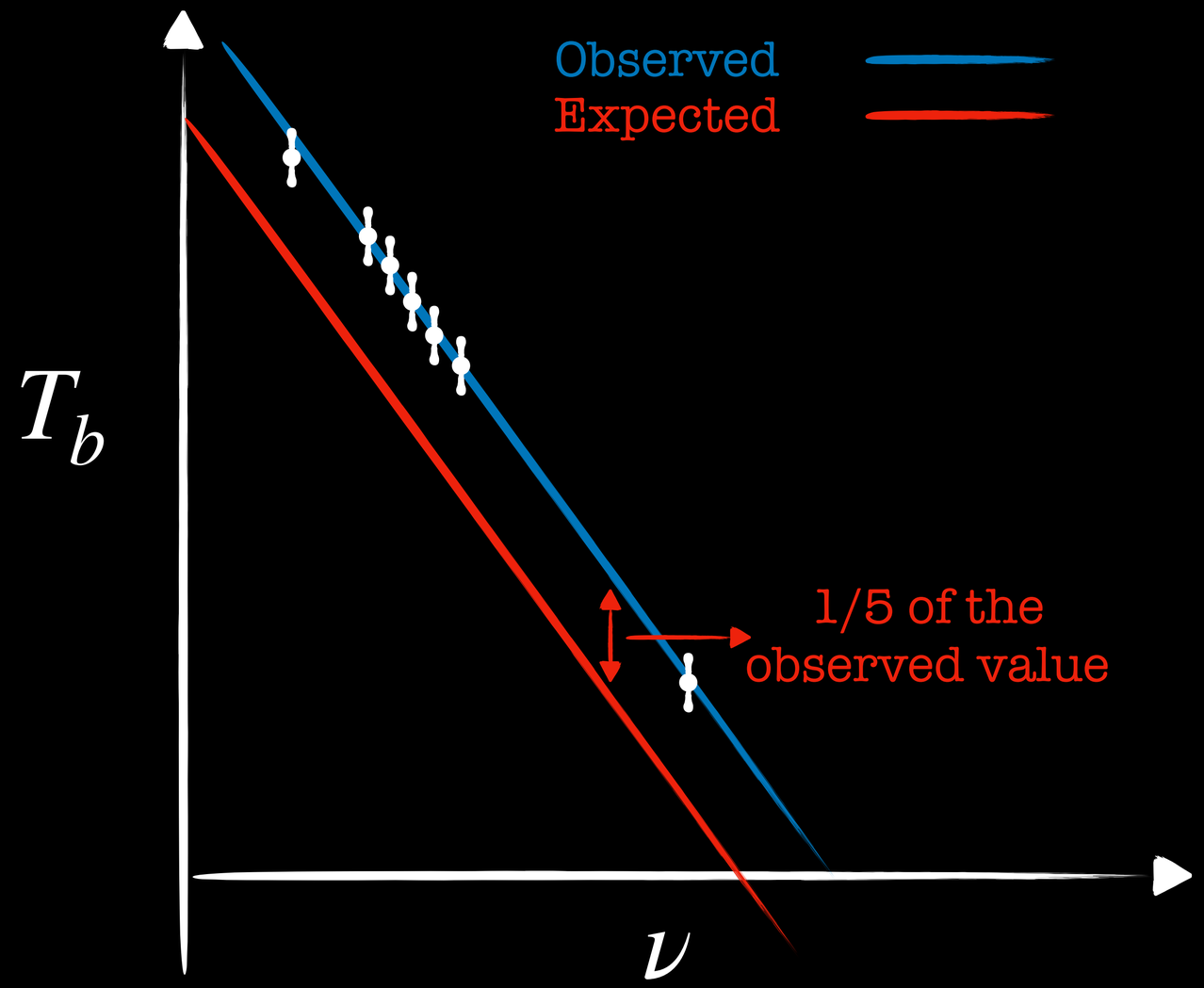


Excess fitted by:

$$T_b(\nu) = 24.1 \pm 2.1 \left(\frac{\nu}{310MHz} \right)^{-2.6}$$

[Fixsen +11]

Motivations



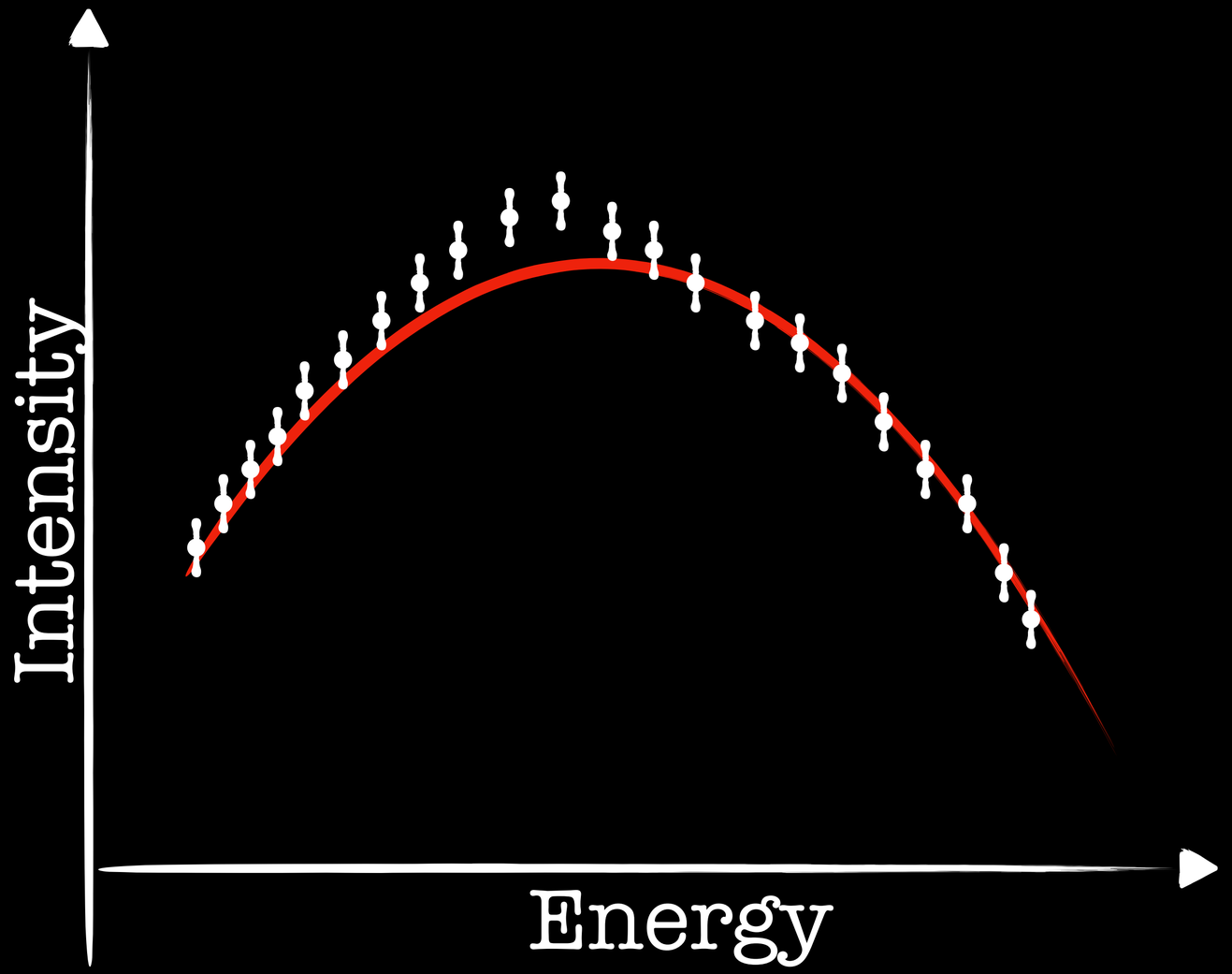
Excess fitted by:

$$T_b(\nu) = 24.1 \pm 2.1 \left(\frac{\nu}{310MHz} \right)^{-2.6}$$

[Fixsen +11]

The observed value is 5 times higher then the one expected from known radio sources

Motivations



CHANDRA

Unresolved excess

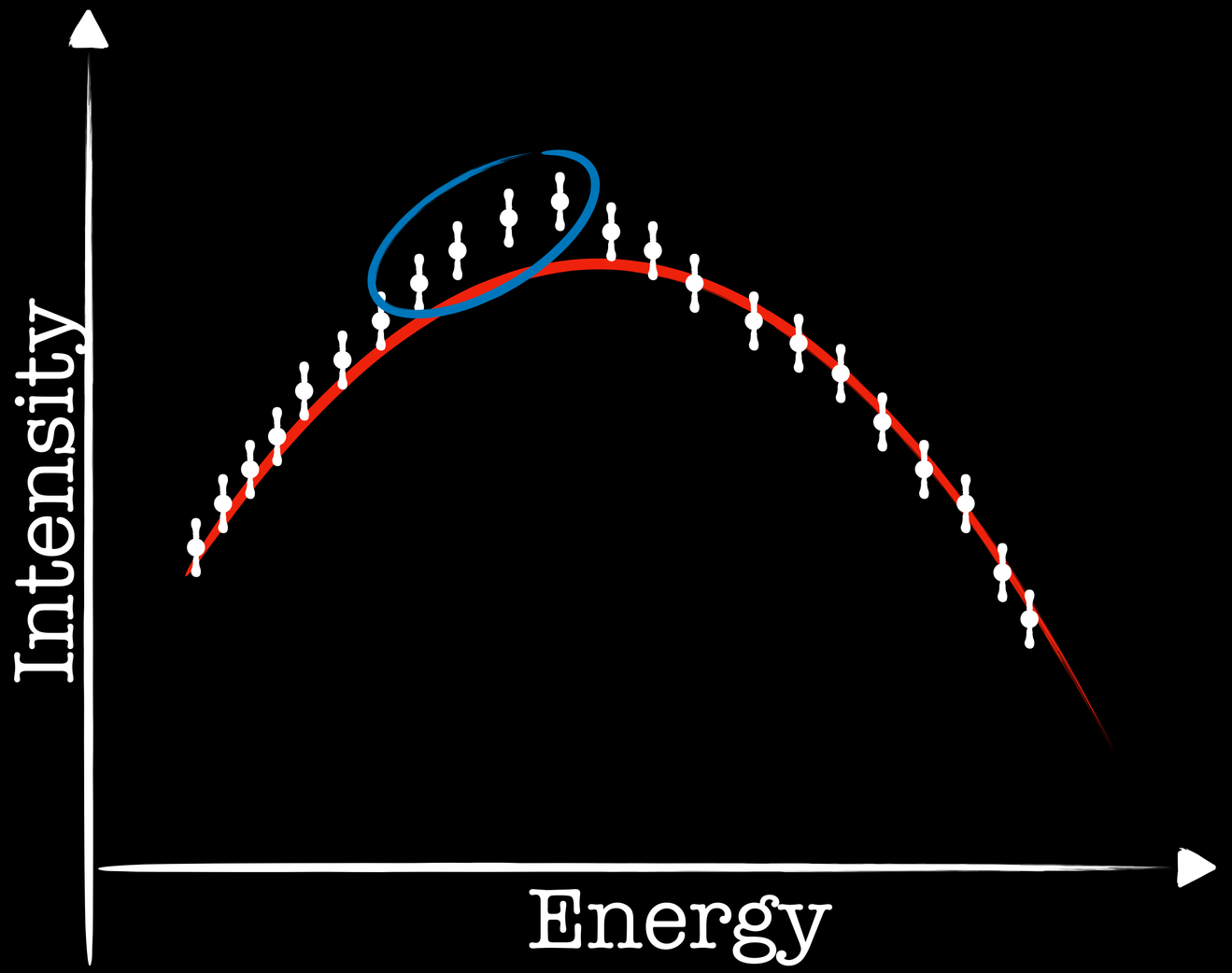
Table 3
Unresolved Extragalactic CXB Fluxes

BAND keV	Extragal. erg s^{-1} cm^{-2} deg^{-2}	$\%_{CXB}$
uCXB		
0.5-1.0	1.24 ± 0.17	23.0 ± 3.2
1.0-2.0	1.66 ± 0.06	36.5 ± 0.1
0.5-2.0	2.90 ± 0.16	30.1 ± 1.7
2.0-10.0	6.47 ± 0.82	31.8 ± 4.0
nsCXB		
0.5-1.0	$0.36^{+0.13}_{-0.11}$	$6.7^{+3.0}_{-2.8}$
1.0-2.0	$0.61^{+0.07}_{-0.07}$	$13.4^{+1.6}_{-1.6}$
0.5-2.0	$0.97^{+0.18}_{-0.16}$	$9.7^{+1.6}_{-1.8}$
2.0-10.0	$3.45^{+1.42}_{-1.19}$	$17.0^{+5.9}_{-7.0}$

Note. In units of 10^{-12} erg s^{-1} cm^{-2} deg^{-2}.

[Cappelluti et al. +17]

Motivations



CHANDRA

Unresolved excess

Table 3
Unresolved Extragalactic CXB Fluxes

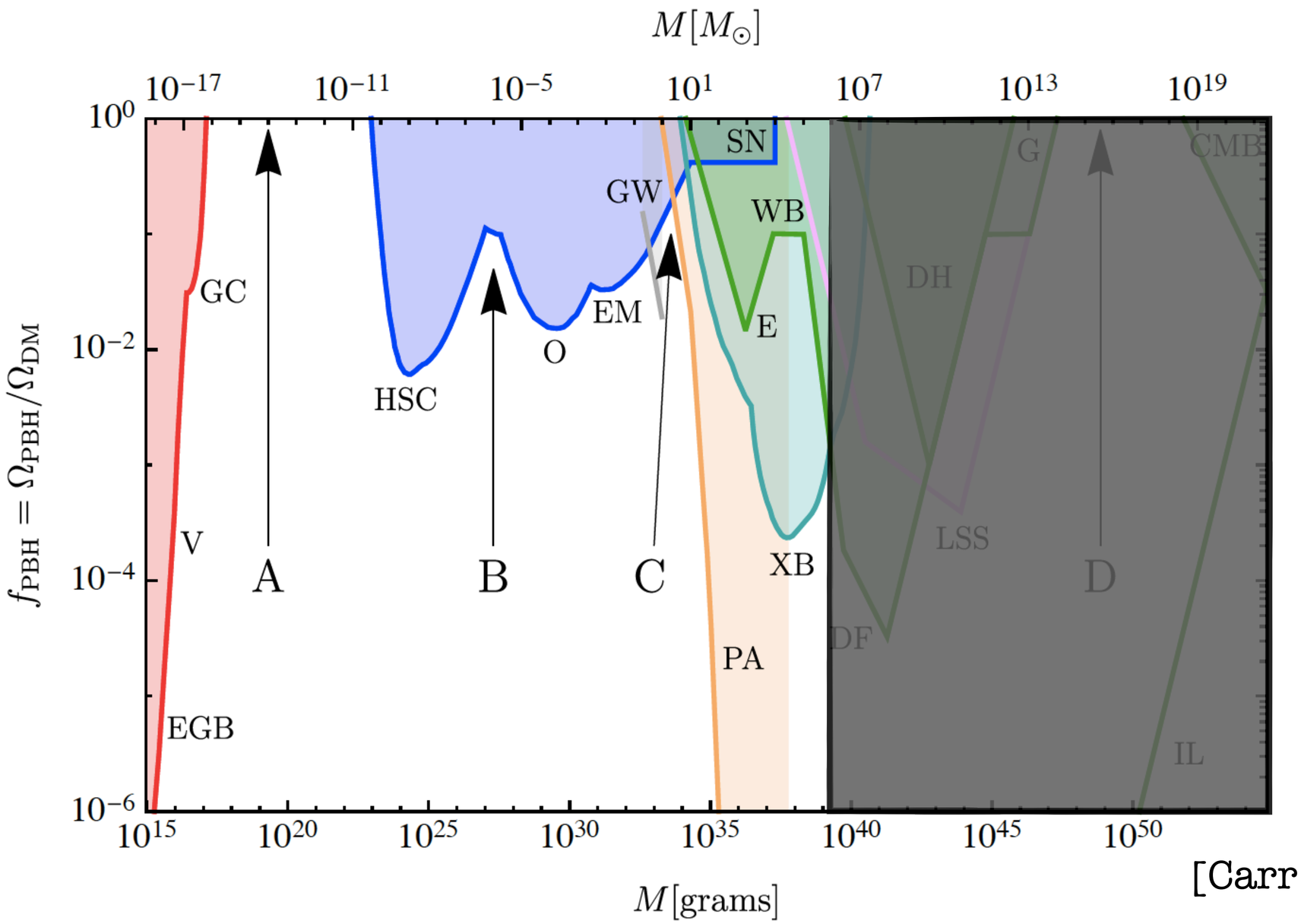
BAND keV	Extragal. erg s^{-1} cm^{-2} deg^{-2}	$\%_{CXB}$
uCXB		
0.5-1.0	1.24 ± 0.17	23.0 ± 3.2
1.0-2.0	1.66 ± 0.06	36.5 ± 0.1
0.5-2.0	2.90 ± 0.16	30.1 ± 1.7
2.0-10.0	6.47 ± 0.82	31.8 ± 4.0
nsCXB		
0.5-1.0	$0.36^{+0.13}_{-0.11}$	$6.7^{+3.0}_{-2.8}$
1.0-2.0	$0.61^{+0.07}_{-0.07}$	$13.4^{+1.6}_{-1.6}$
0.5-2.0	$0.97^{+0.18}_{-0.16}$	$9.7^{+1.6}_{-1.8}$
2.0-10.0	$3.45^{+1.42}_{-1.19}$	$17.0^{+5.9}_{-7.0}$

Note. In units of 10^{-12} erg s^{-1} cm^{-2} deg^{-2}.

[Cappelluti et al. +17]

PBHs Mass distribution

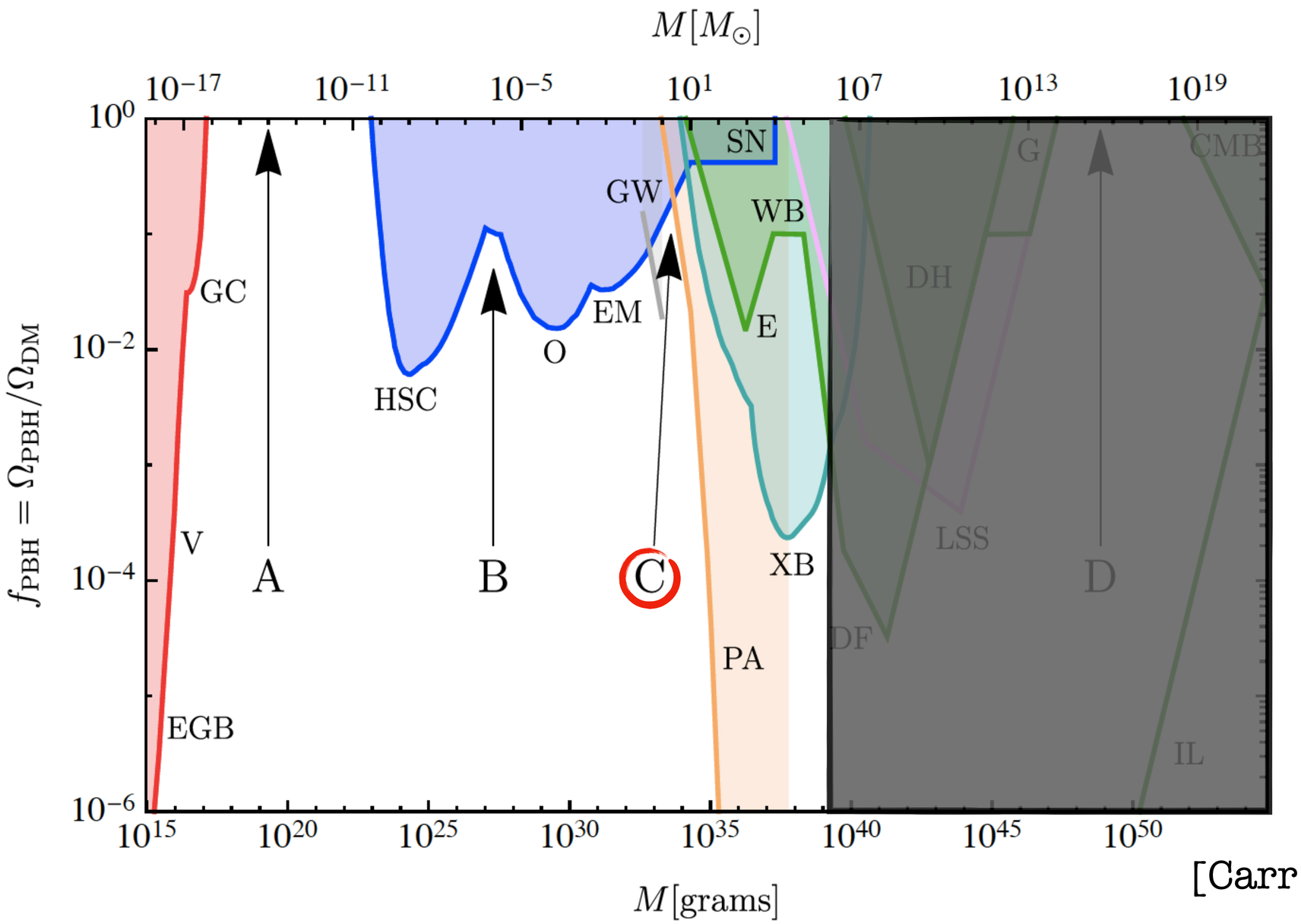
- Evaporation
- Lensing
- Gravitational Waves
- CMB distorsion
- Accretion
- Dynamical Effects



[Carr +20]

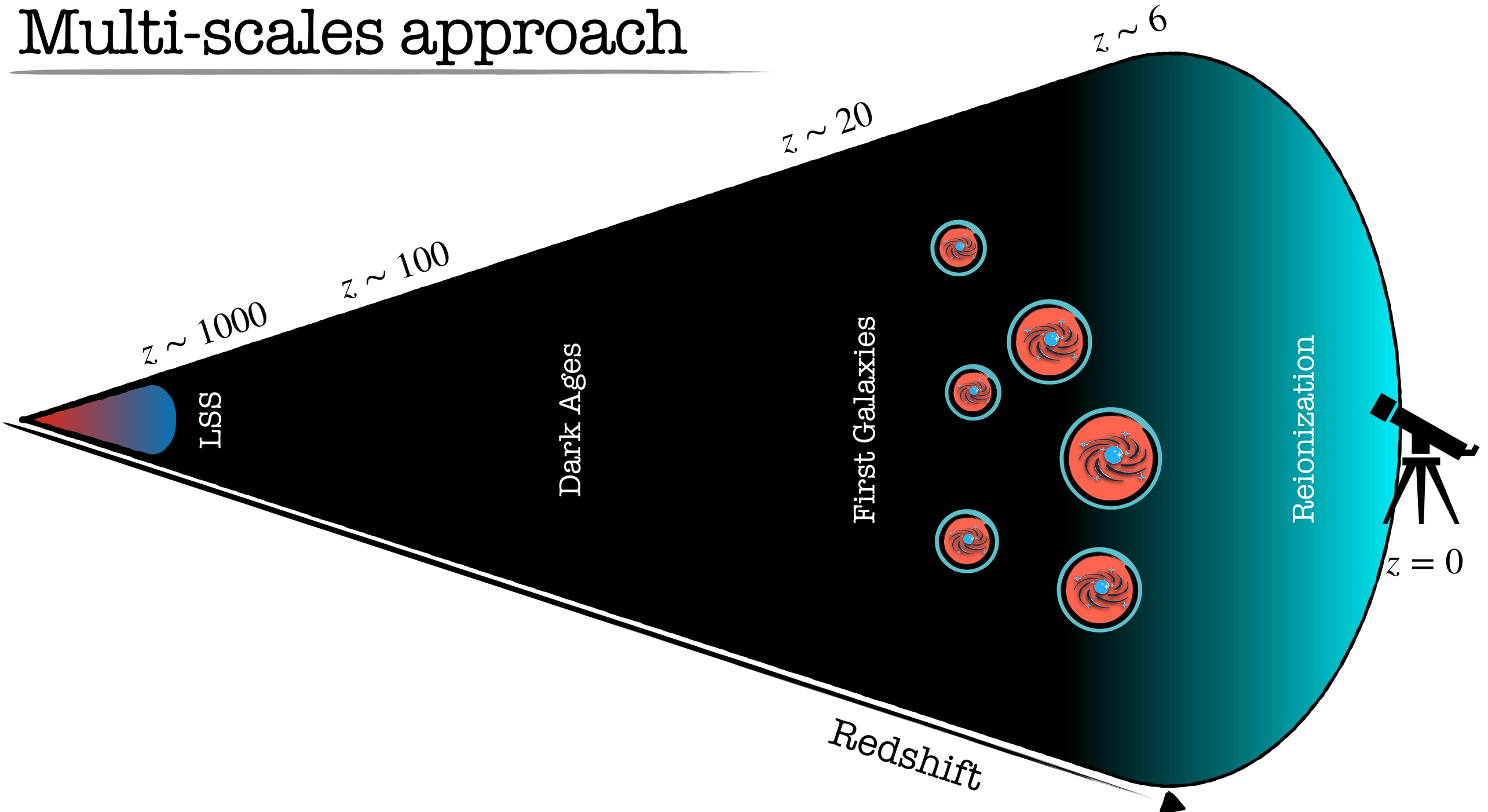
PBHs Mass distribution

- Evaporation
- Lensing
- Gravitational Waves
- CMB distorsion
- Accretion
- Dynamical Effects

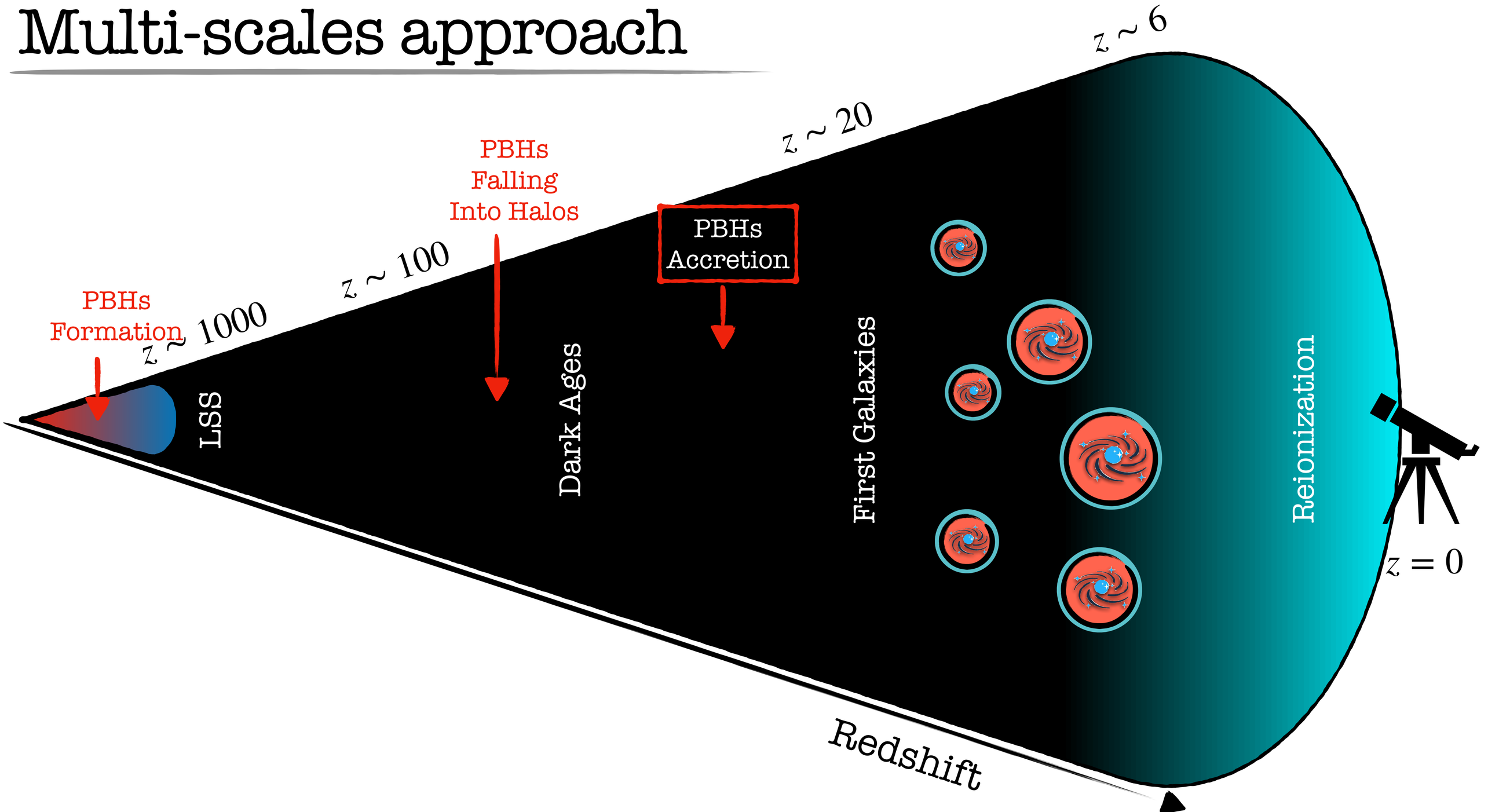


[Carr +20]

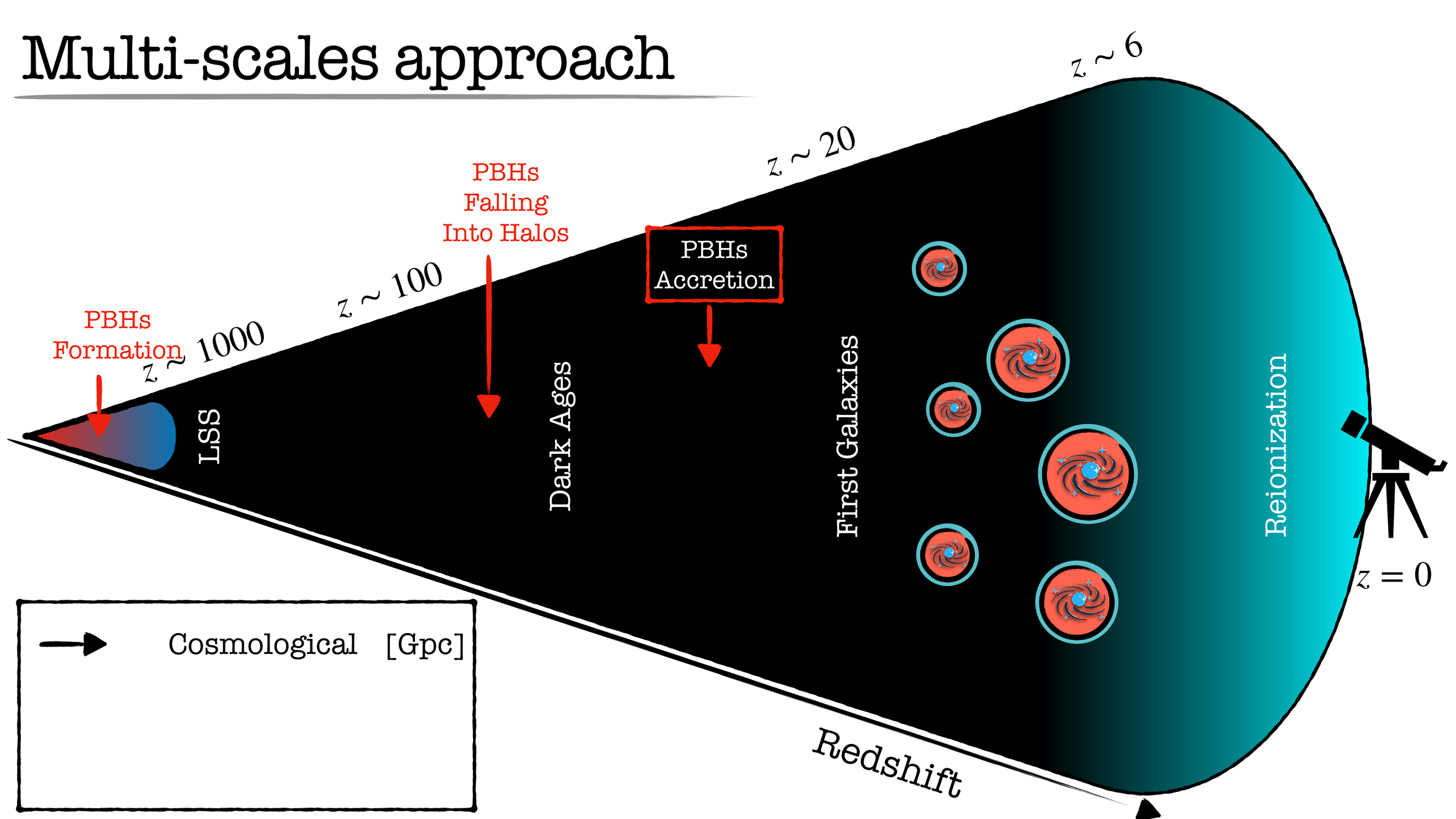
Multi-scales approach



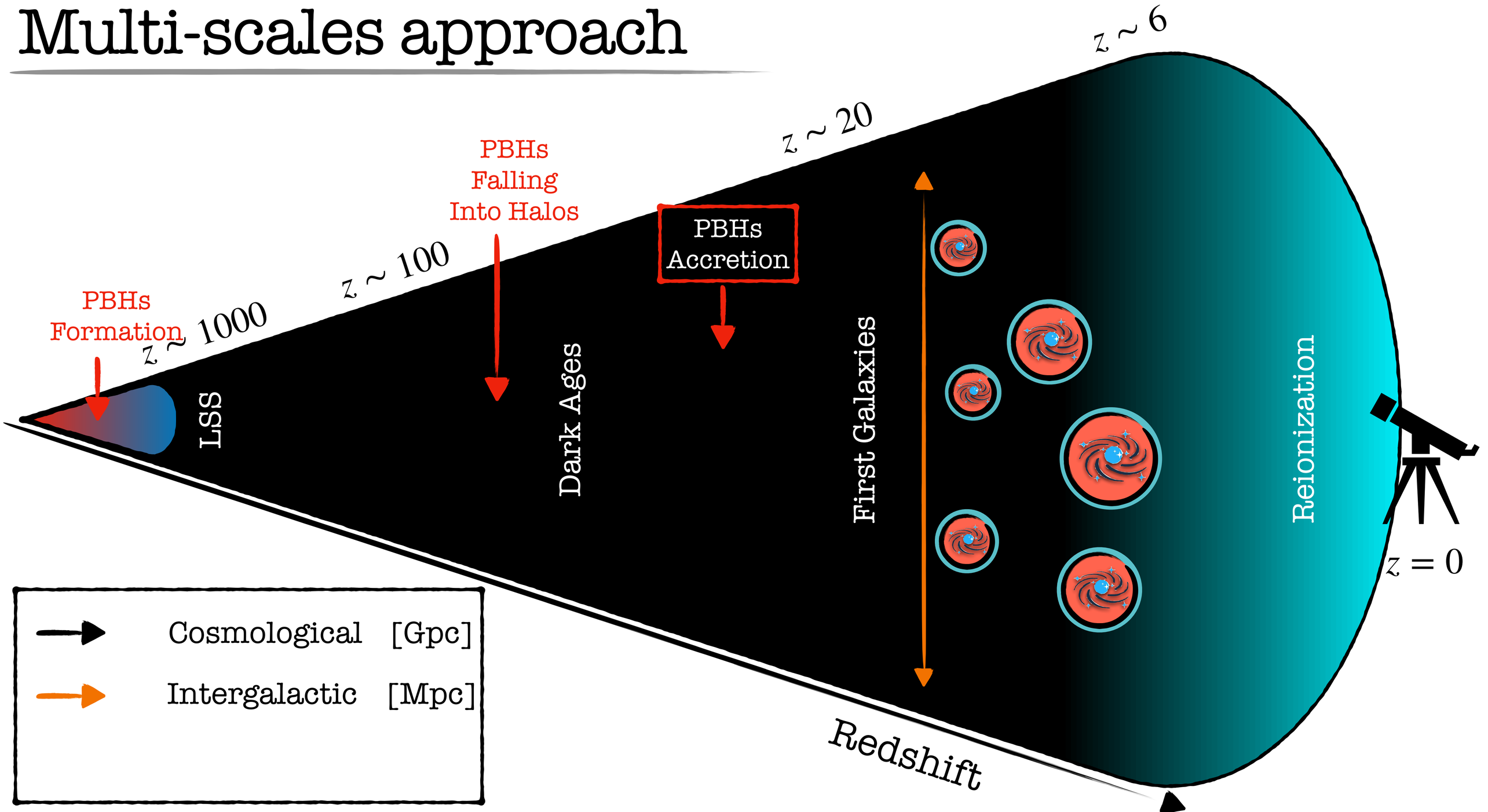
Multi-scales approach



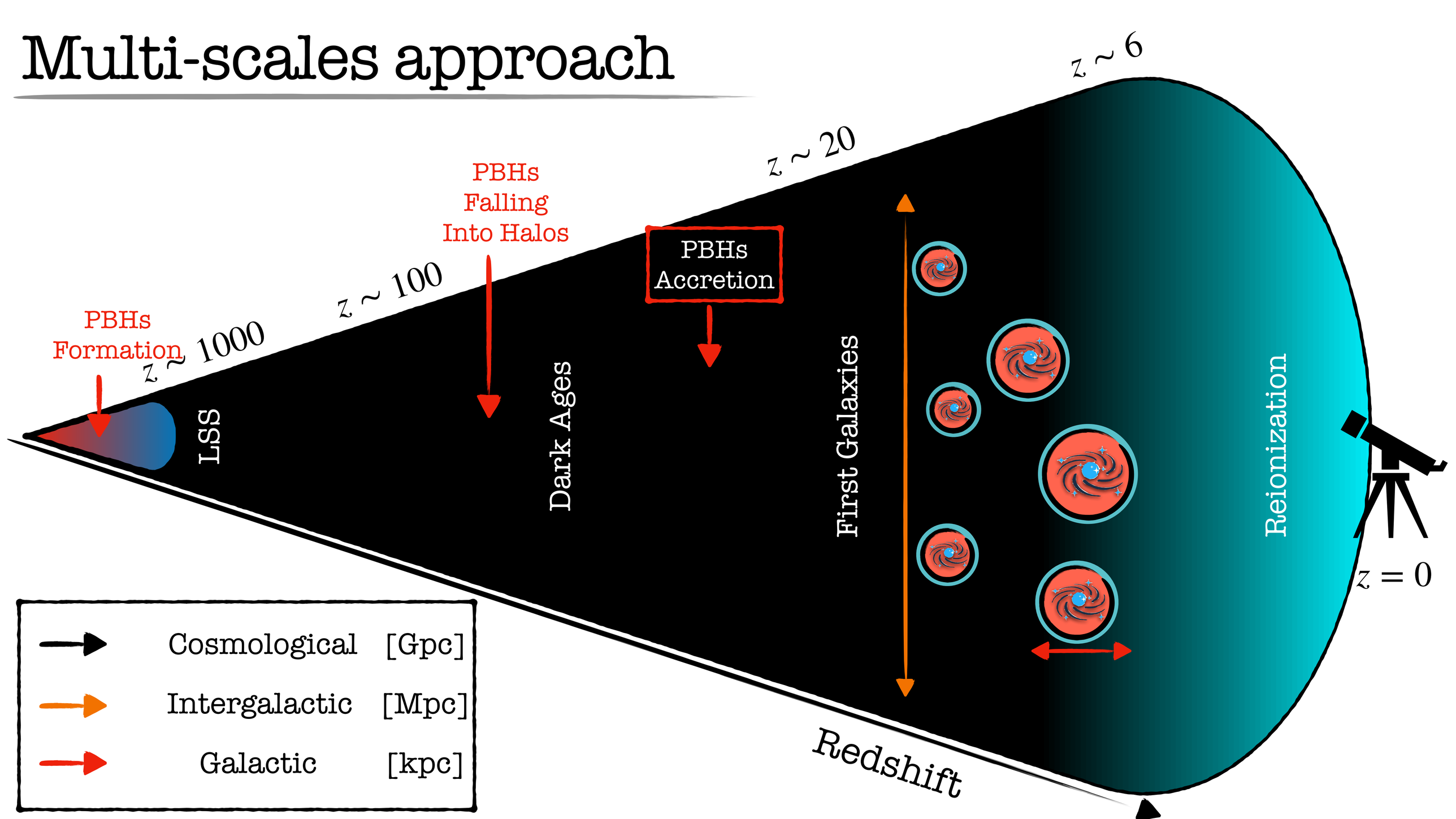
Multi-scales approach



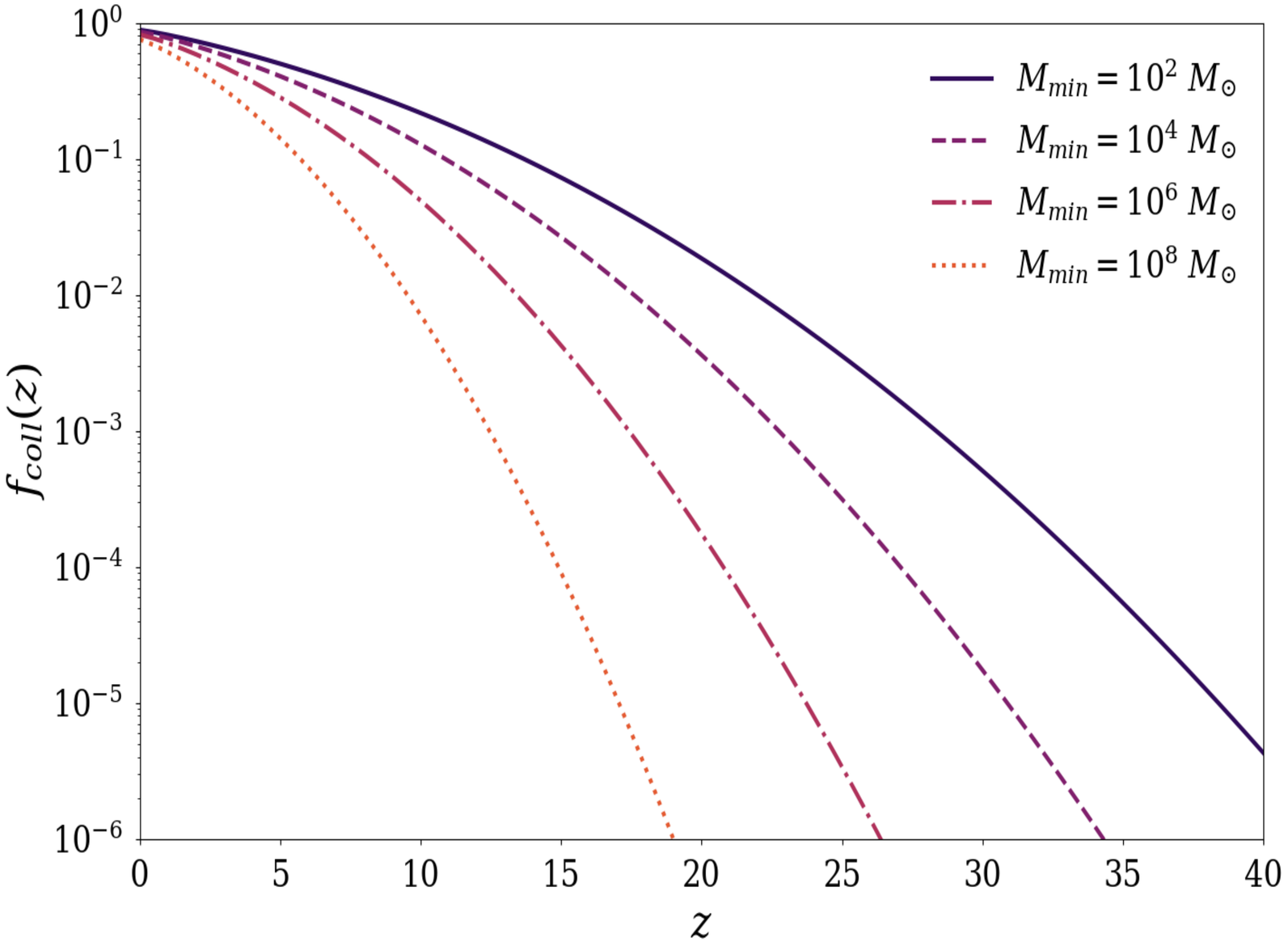
Multi-scales approach

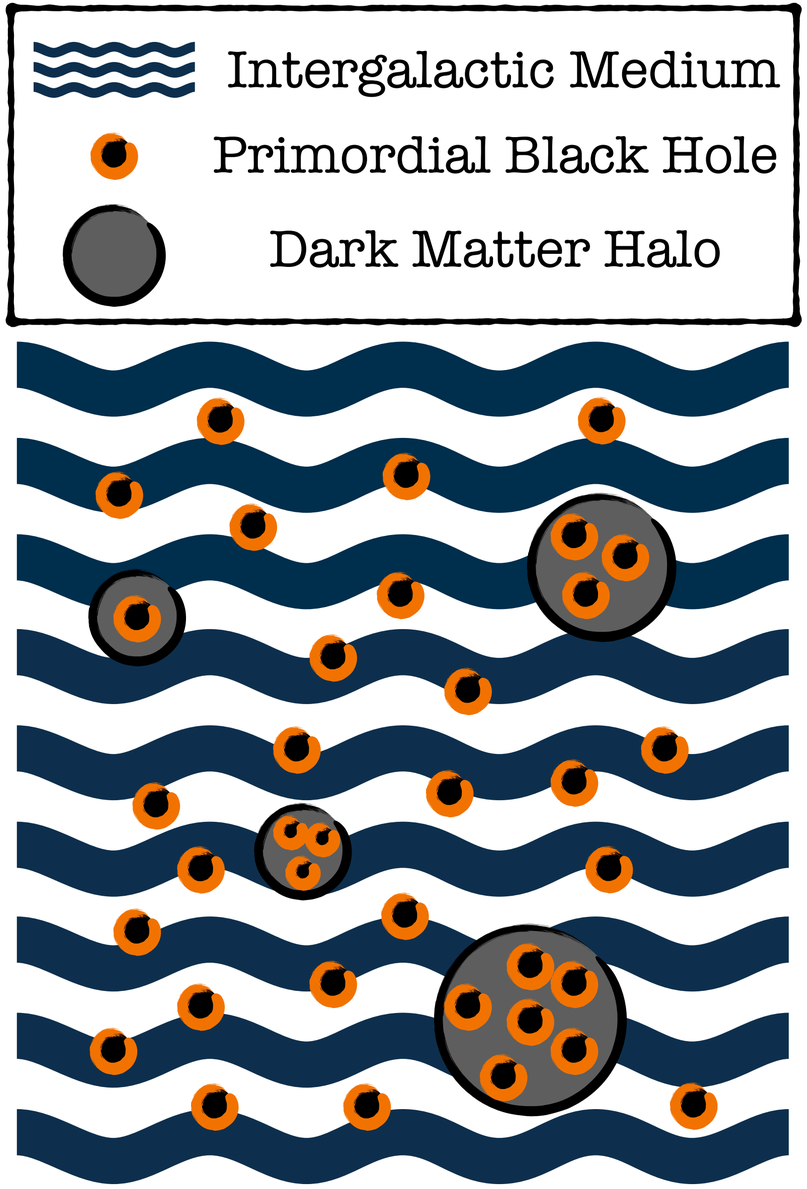


Multi-scales approach

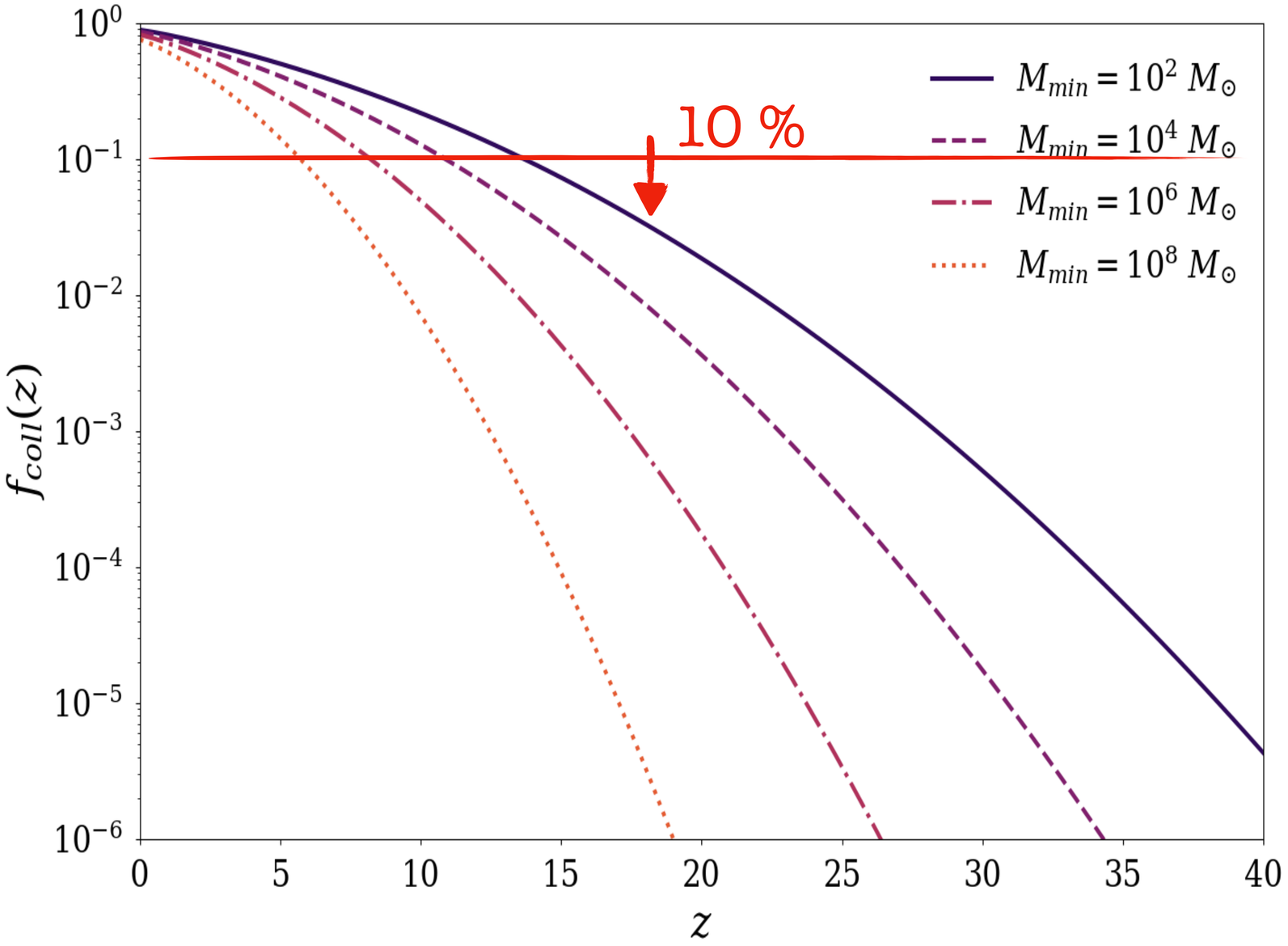


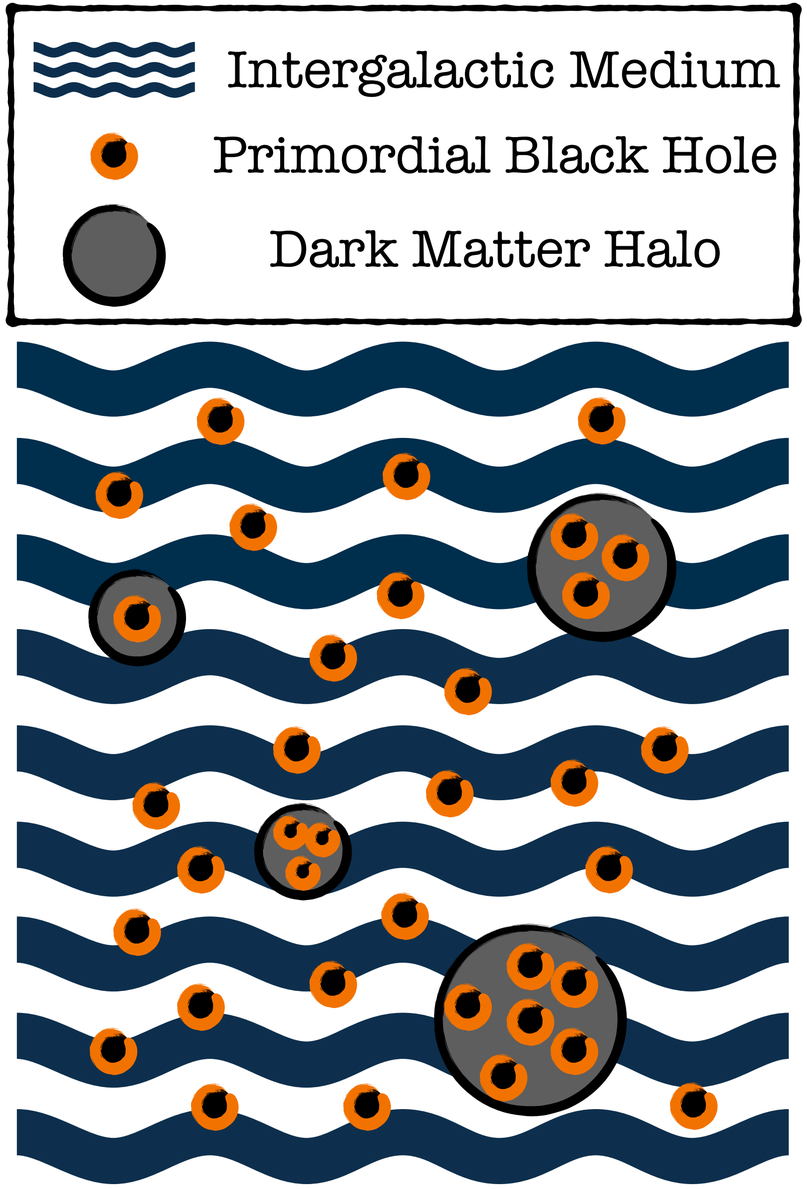
Novel approach



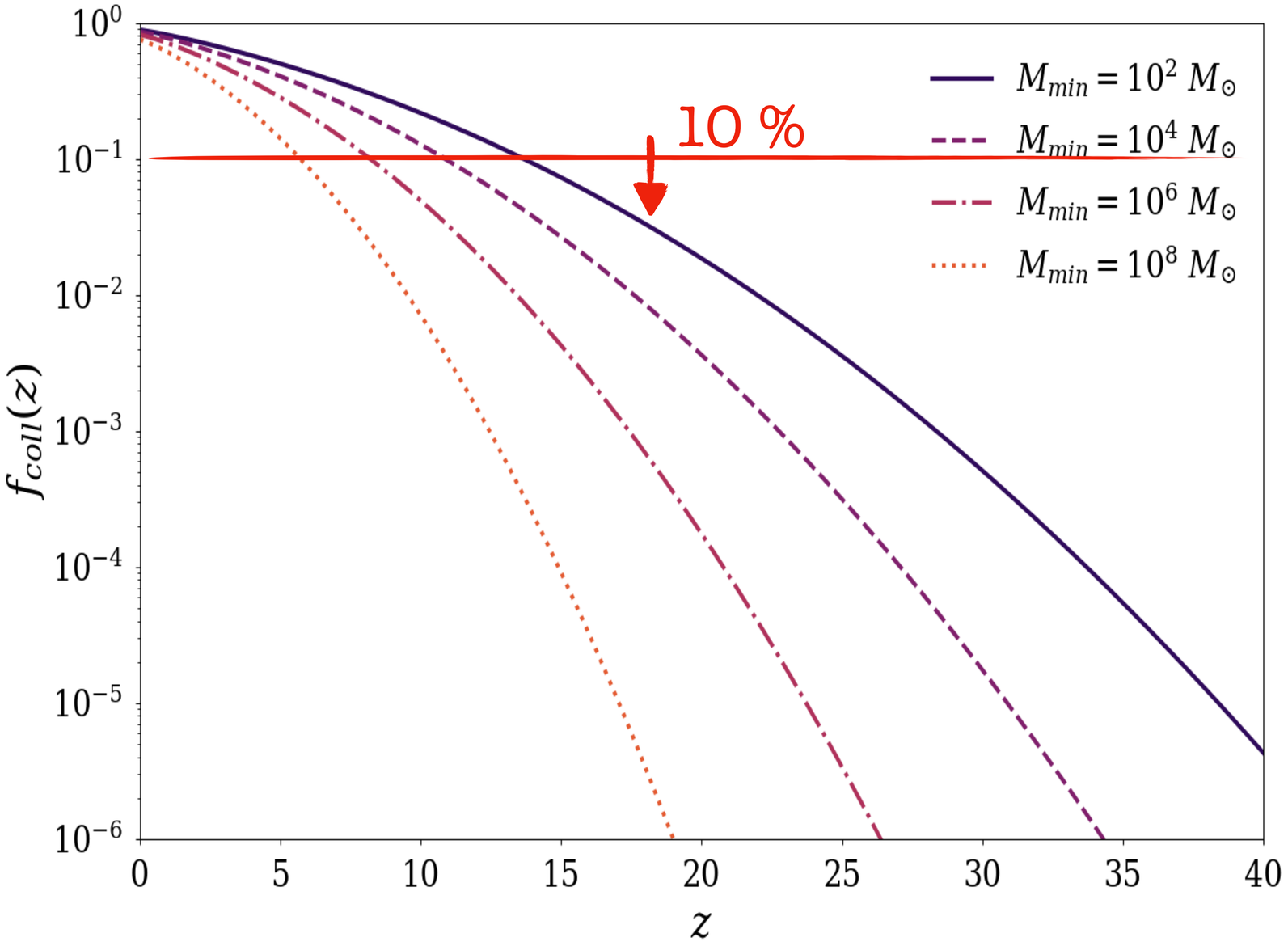


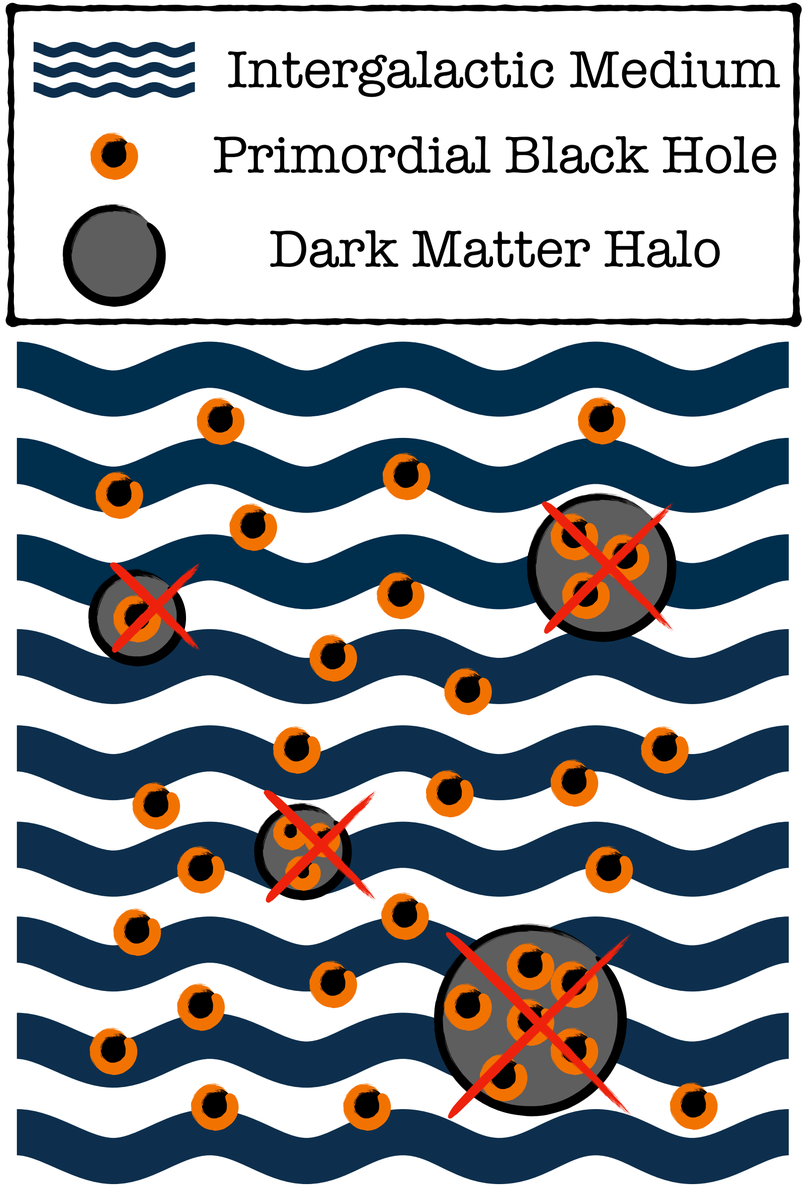
Novel approach





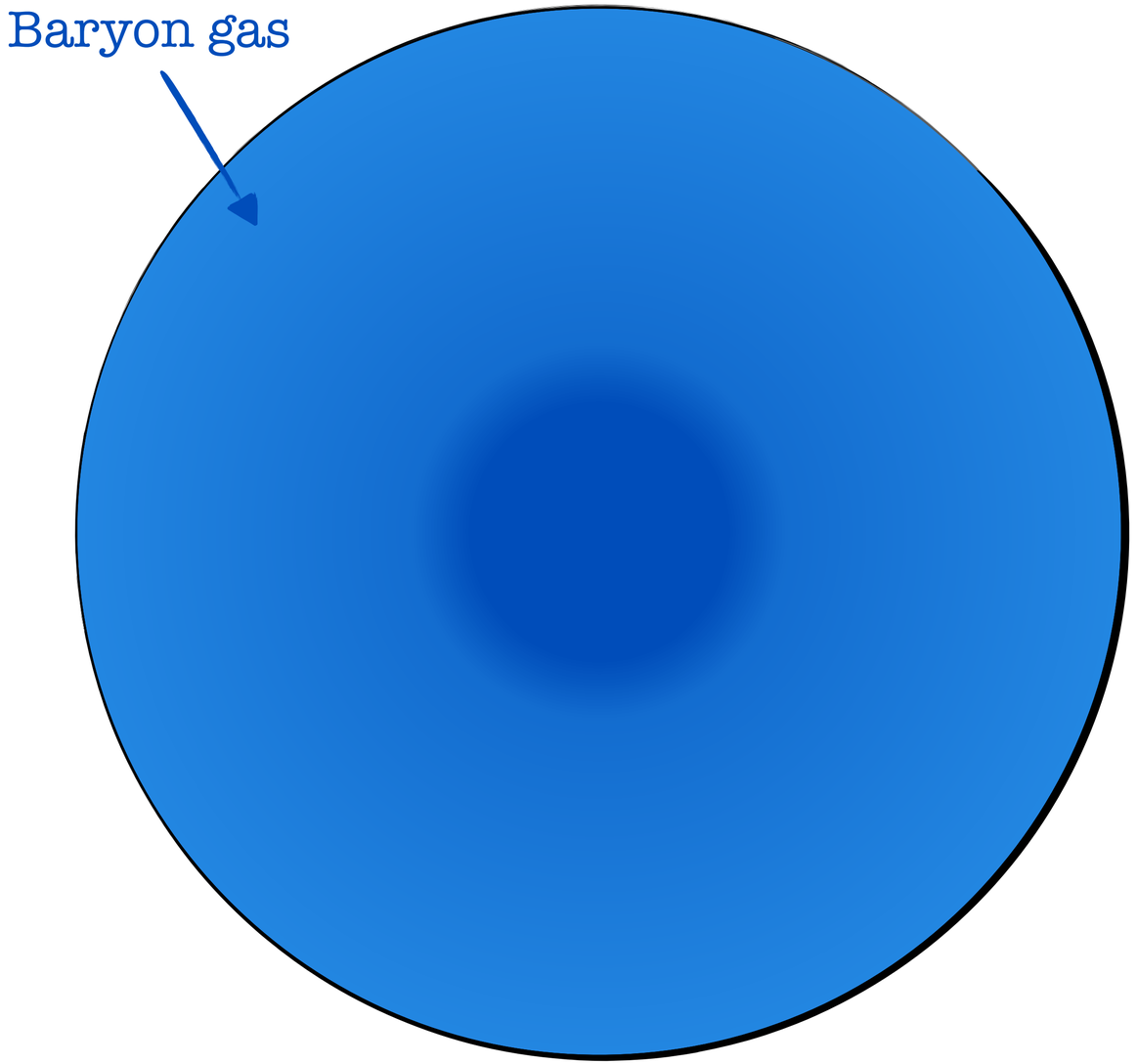
Novel approach





GALACTIC

Inside Dark Matter Halos



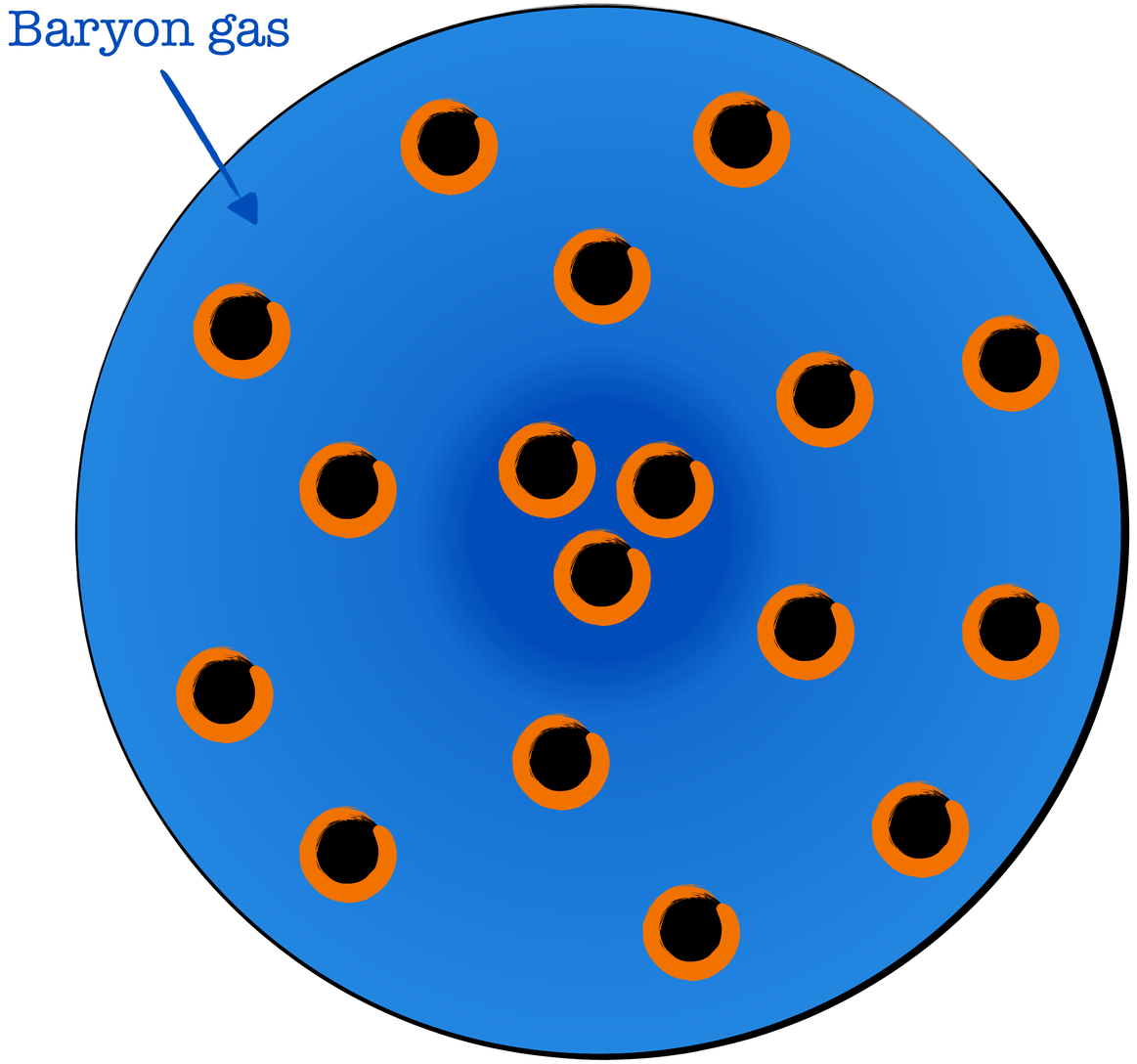
Baryon density distribution

$$\rho_b(r) = \rho_0 \exp\left(-\frac{\mu m_p}{2k_B T_{vir}}[v_e^2(0) - v_e^2(r)]\right)$$

[Makino +98]

Normalization set by fixing $\frac{M_b}{M_h} = \frac{\Omega_b}{\Omega_{DM}}$

Inside Dark Matter Halos



Baryon density distribution

$$\rho_b(r) = \rho_0 \exp\left(-\frac{\mu m_p}{2k_B T_{vir}}[v_e^2(0) - v_e^2(r)]\right)$$

[Makino +98]

Normalization set by fixing $\frac{M_b}{M_h} = \frac{\Omega_b}{\Omega_{DM}}$

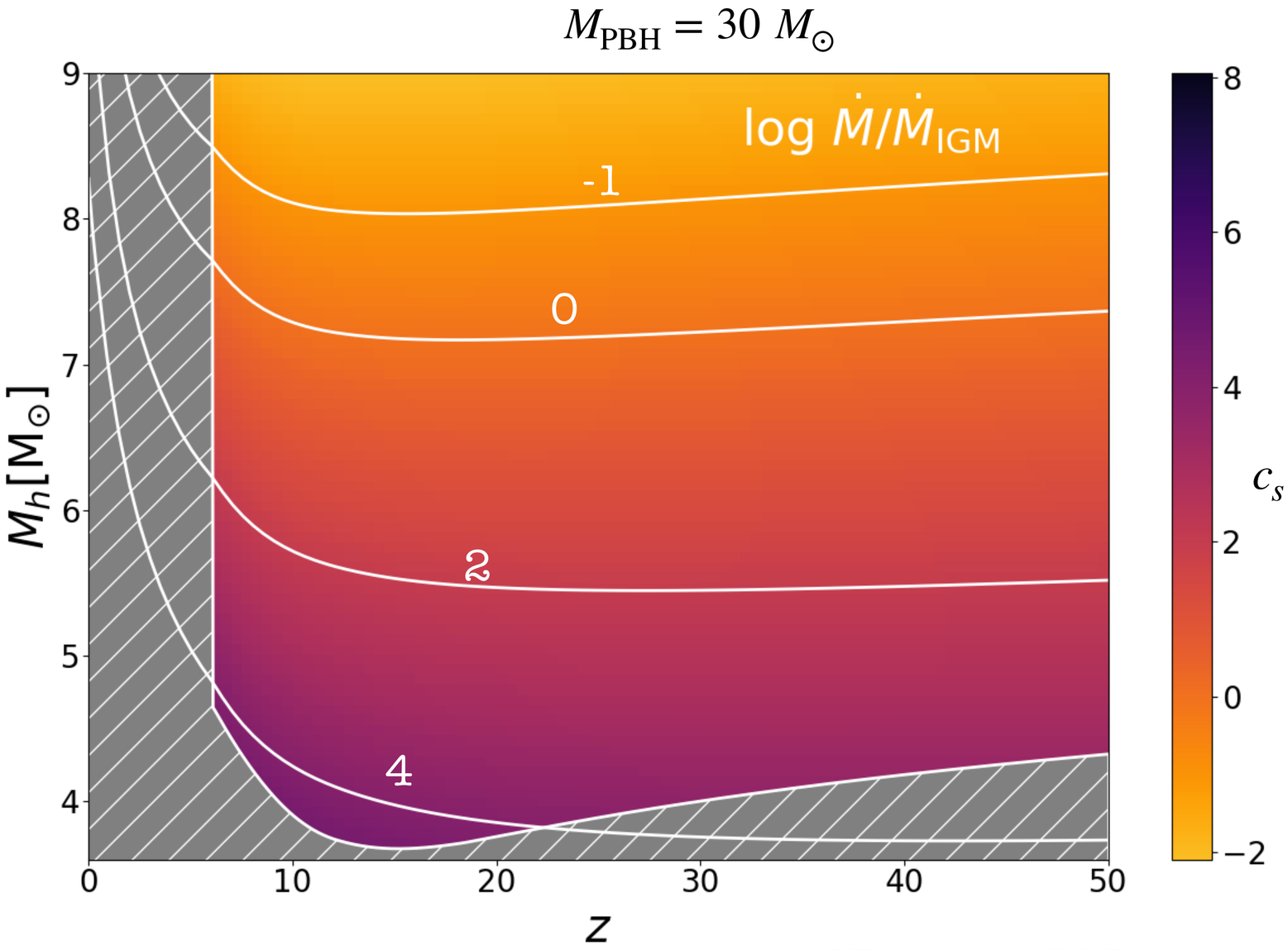
Navarro-Frank-White profile

$$\rho_{DM}(r) = \frac{\delta_c \rho_c}{r/r_s(1 + r/r_s)^2}$$

Number of PBHs in the halo

$$N_{\rm PBH}(M_h) = f_{\rm PBH}\frac{M_h}{M_{\rm PBH}} \qquad f_{\rm PBH} = \frac{\Omega_{\rm PBH}}{\Omega_{\rm DM}}$$

Primordial black holes accretion



[Ziparo +22]

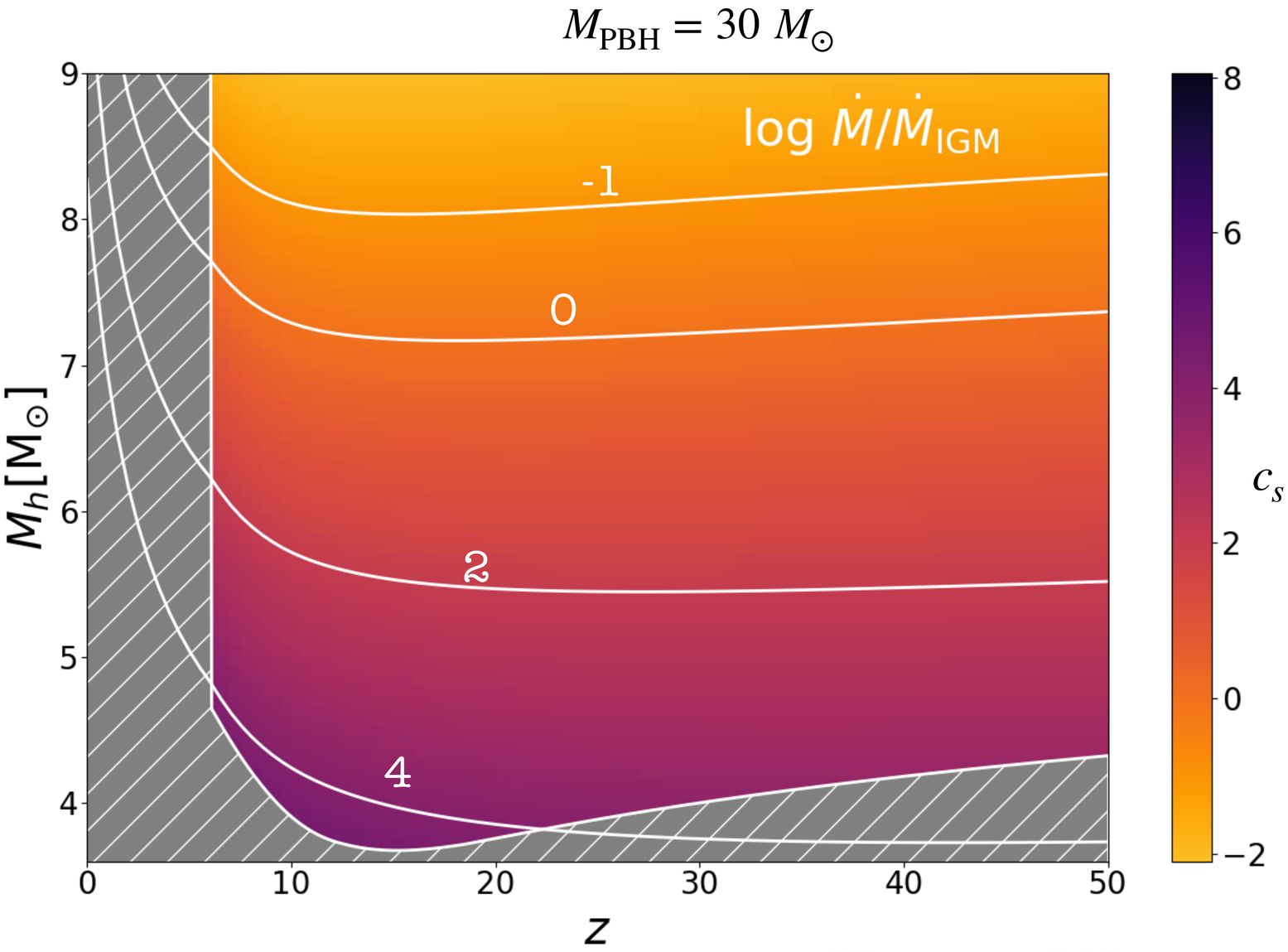
Accretion Model

$$\dot{M}_{PBH} = 4\pi\lambda \frac{G^2 M_{\rm PBH}^2}{(c_s^{3/2} + v_{b,\rm PBH}^{3/2})^2} \rho_b$$

$$c_s = (k_B T_{\rm vir}/\mu m_p)^{1/2} \text{km s}^{-1} = 8.3\ T_{\rm vir,4}^{1/2}\ \text{km s}^{-1}$$

Accretion in the center of the halo can be up to 10^4 times higher than in the IGM

Primordial black holes accretion



[Ziparo +22]

Accretion Model

$$\dot{M}_{PBH} = 4\pi\lambda \frac{G^2 M_{\rm PBH}^2}{(c_s^{3/2} + v_{b,\rm PBH}^{3/2})^2}\rho_b$$

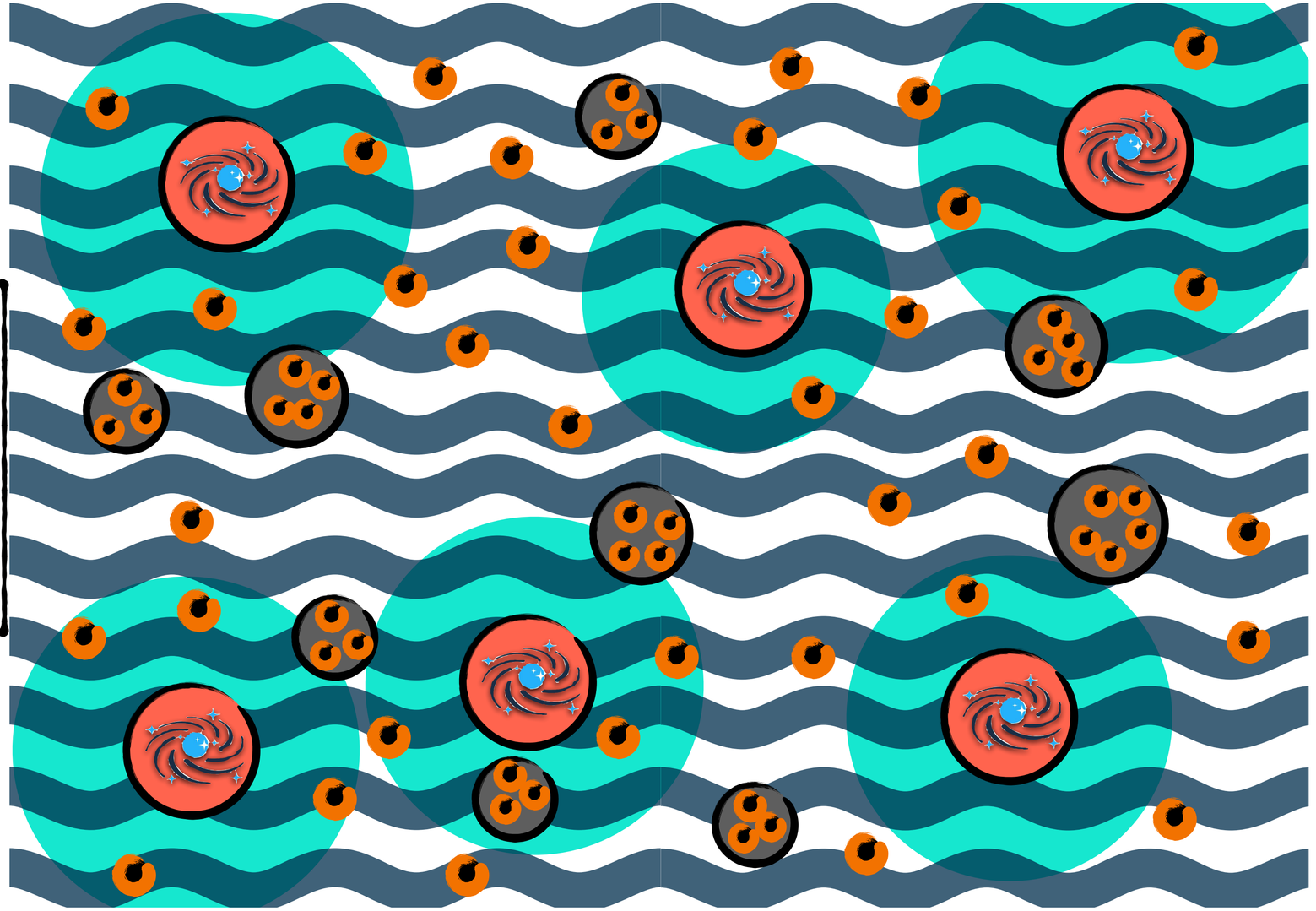
$$c_s = (k_B T_{\rm vir}/\mu m_p)^{1/2} \text{km s}^{-1} = 8.3\ T_{\rm vir,4}^{1/2}\ \text{km s}^{-1}$$

Accretion in the center of the halo can be up to 10^4 times higher than in the IGM

INTERGALACTIC

Large scale evolution

Coherent evolution of the temperature and ionization state of the IGM



IGM

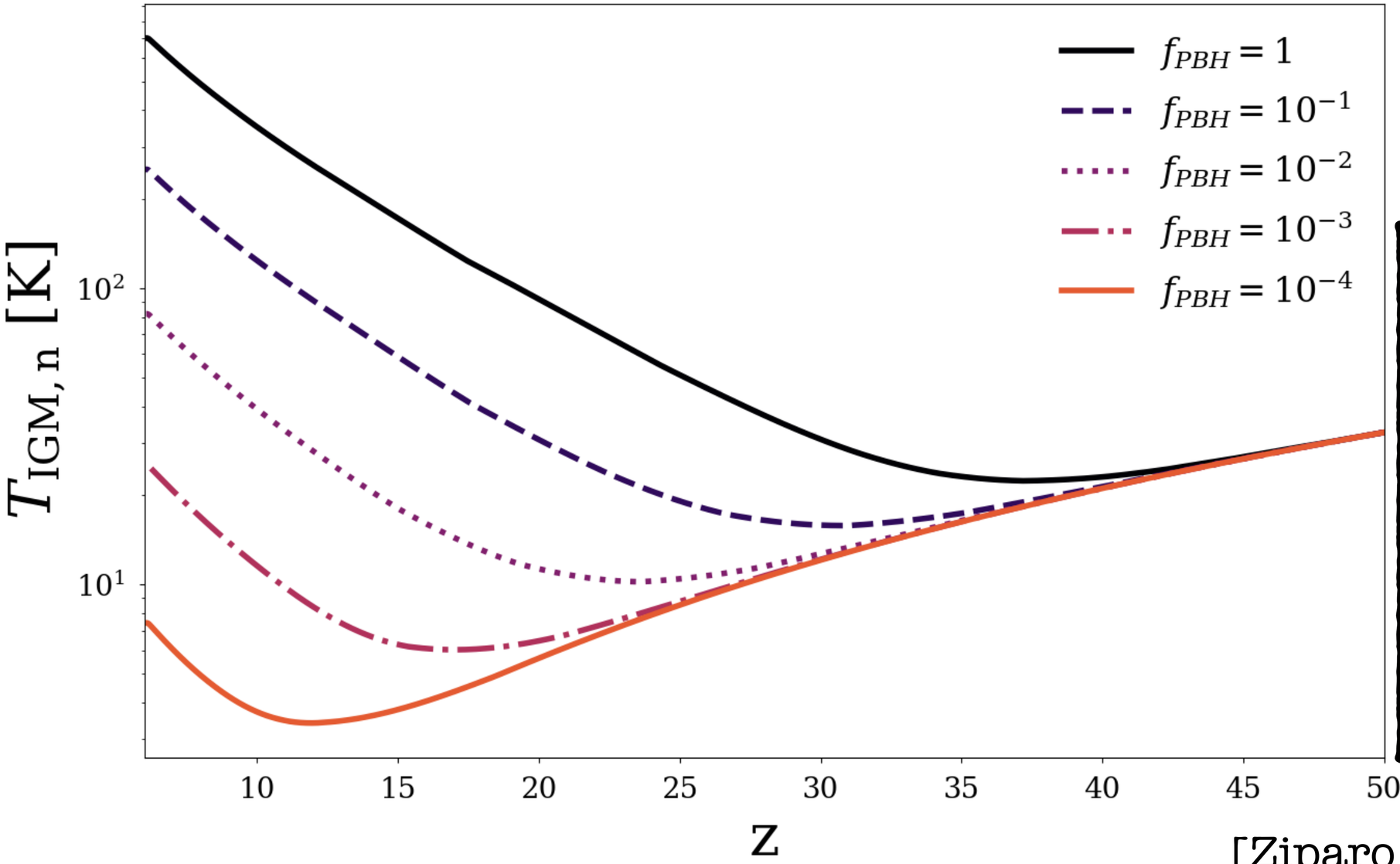
PBH

DM Halo

SF Galaxy

HII region

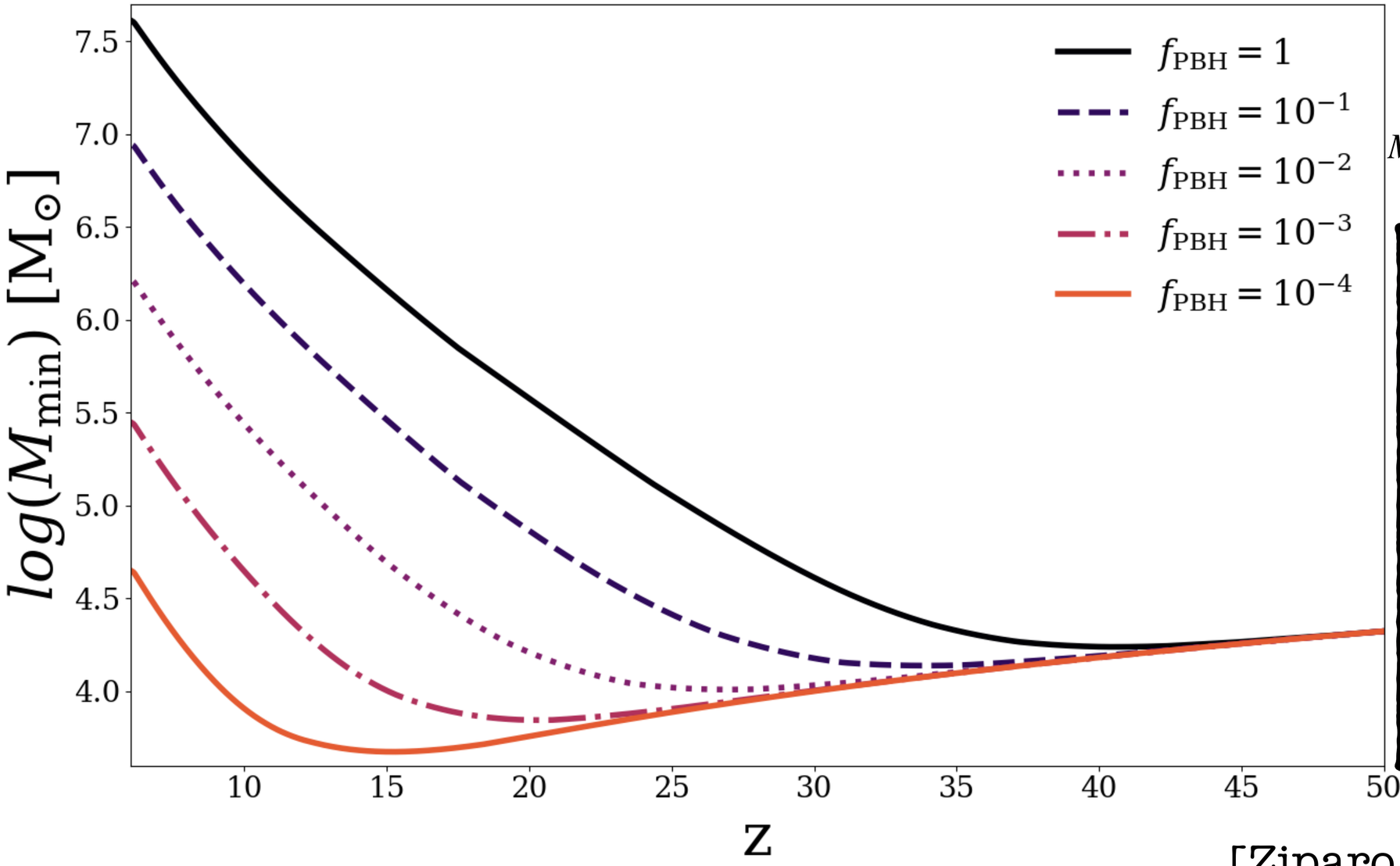
PBHs impact on neutral regions



The heating feedback is stronger for high f_{PBH}

[Ziparo +22]

PBHs impact on neutral regions



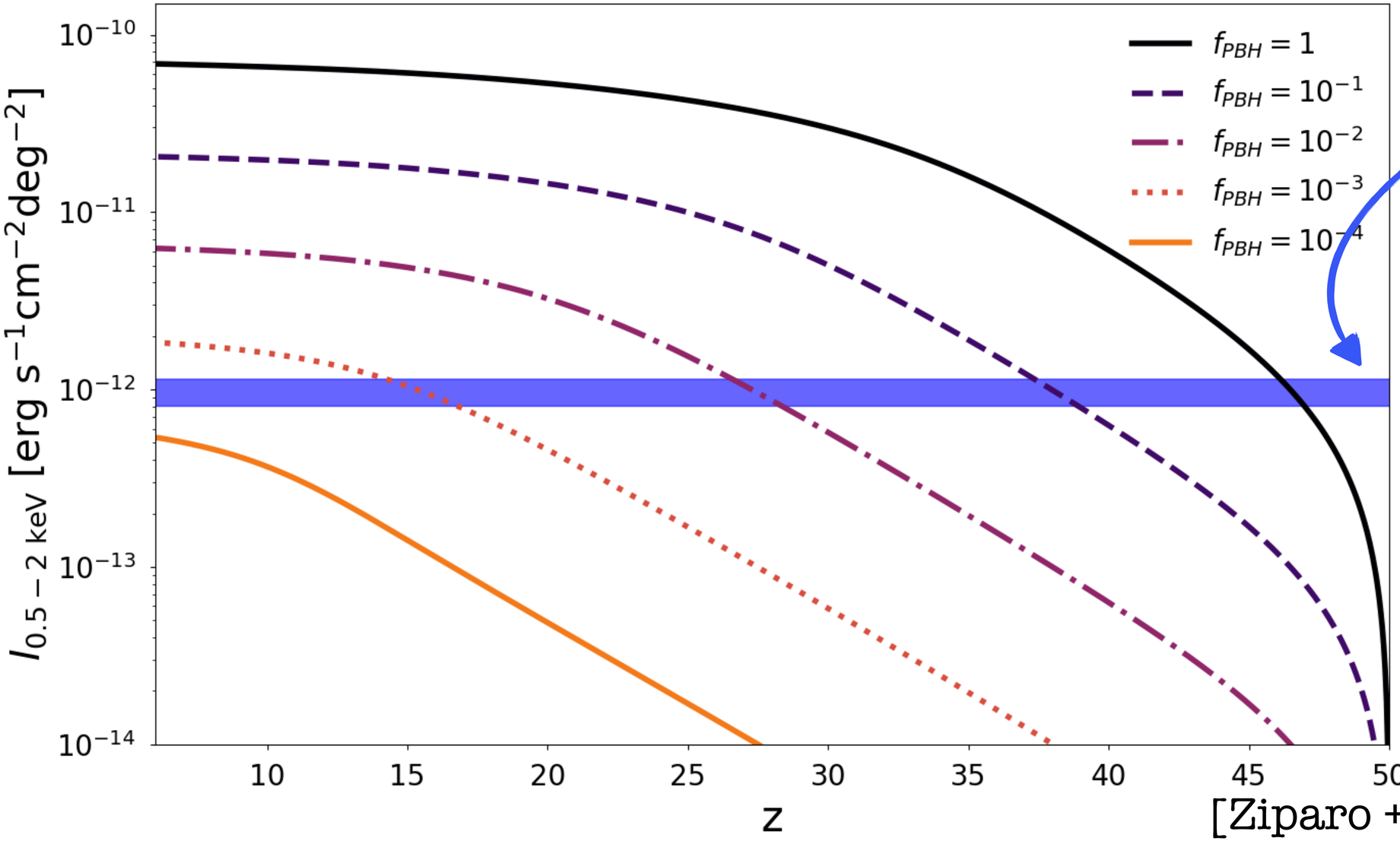
$$M_{min} = 1.3 \times 10^3 \left(\frac{1+z}{10}\right)^{-3/2} \left(\frac{T_{\rm IGM}}{1\rm K}\right)^{3/2}$$

Increasing M_{min} suppresses the signal

[Ziparo +22]

COSMOLOGICAL

X-ray background

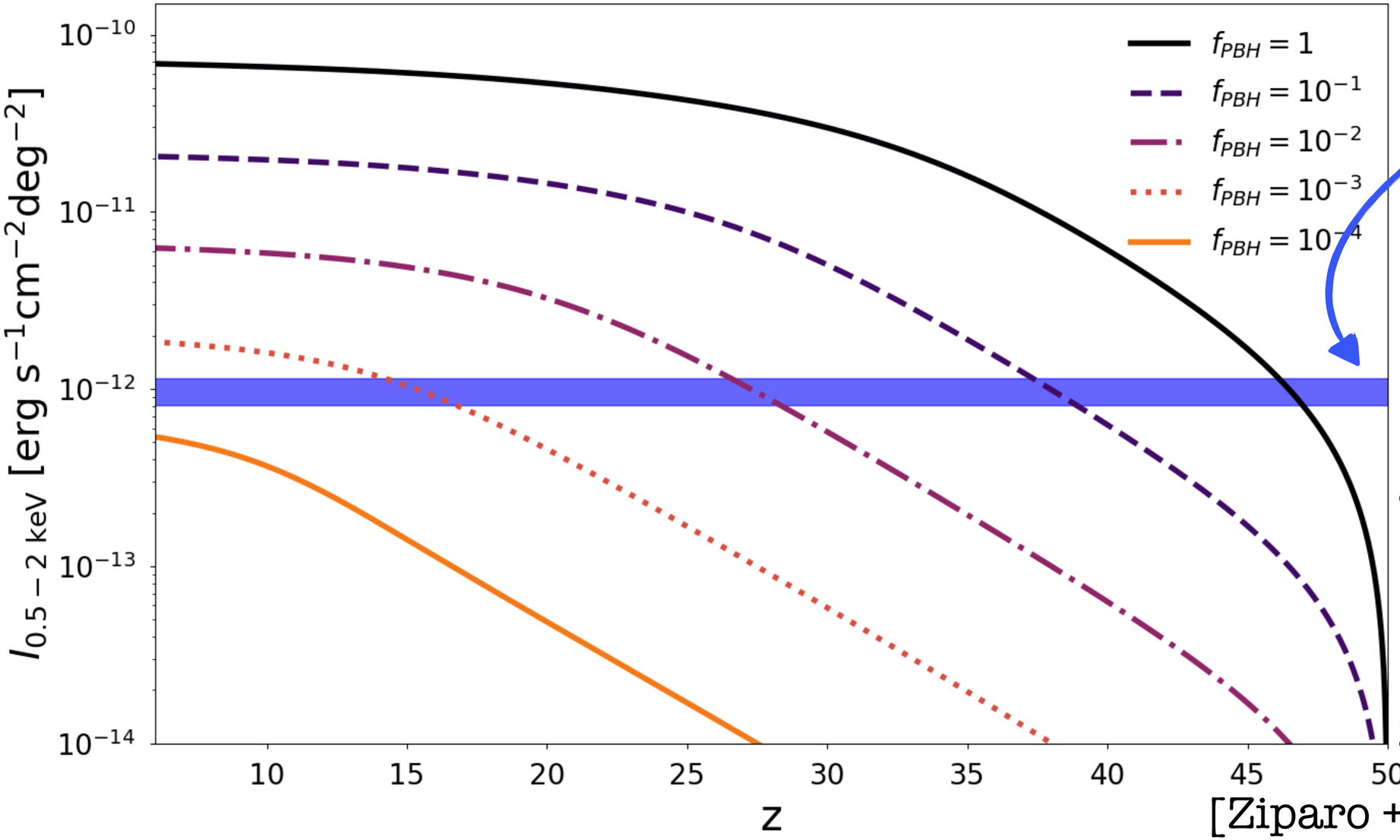


Excess value

$I_{0.5-2\ \mathrm{keV,obs}} = 9 \times 10^{-13}$
[erg s^{-1}cm^{-2}deg^{-2}]

[Ziparo +22]

X-ray background



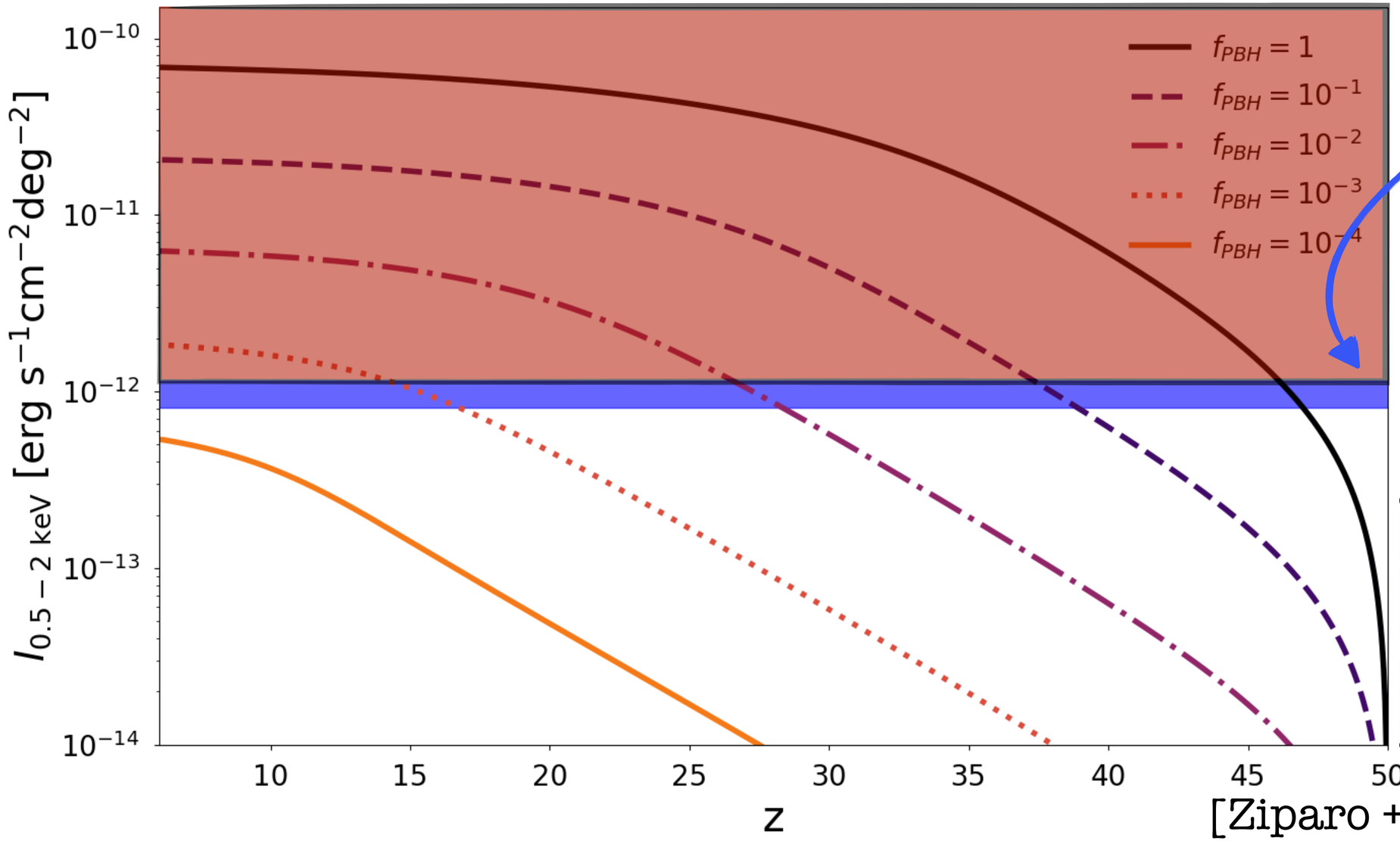
Excess value

$I_{0.5-2\ \mathrm{keV,obs}} = 9 \times 10^{-13}$
[erg s^{-1}cm^{-2}deg^{-2}]

100% X-ray background excess
$f_{\mathrm{PBH}} = 3 \times 10^{-4}$

[Ziparo +22]

X-ray background



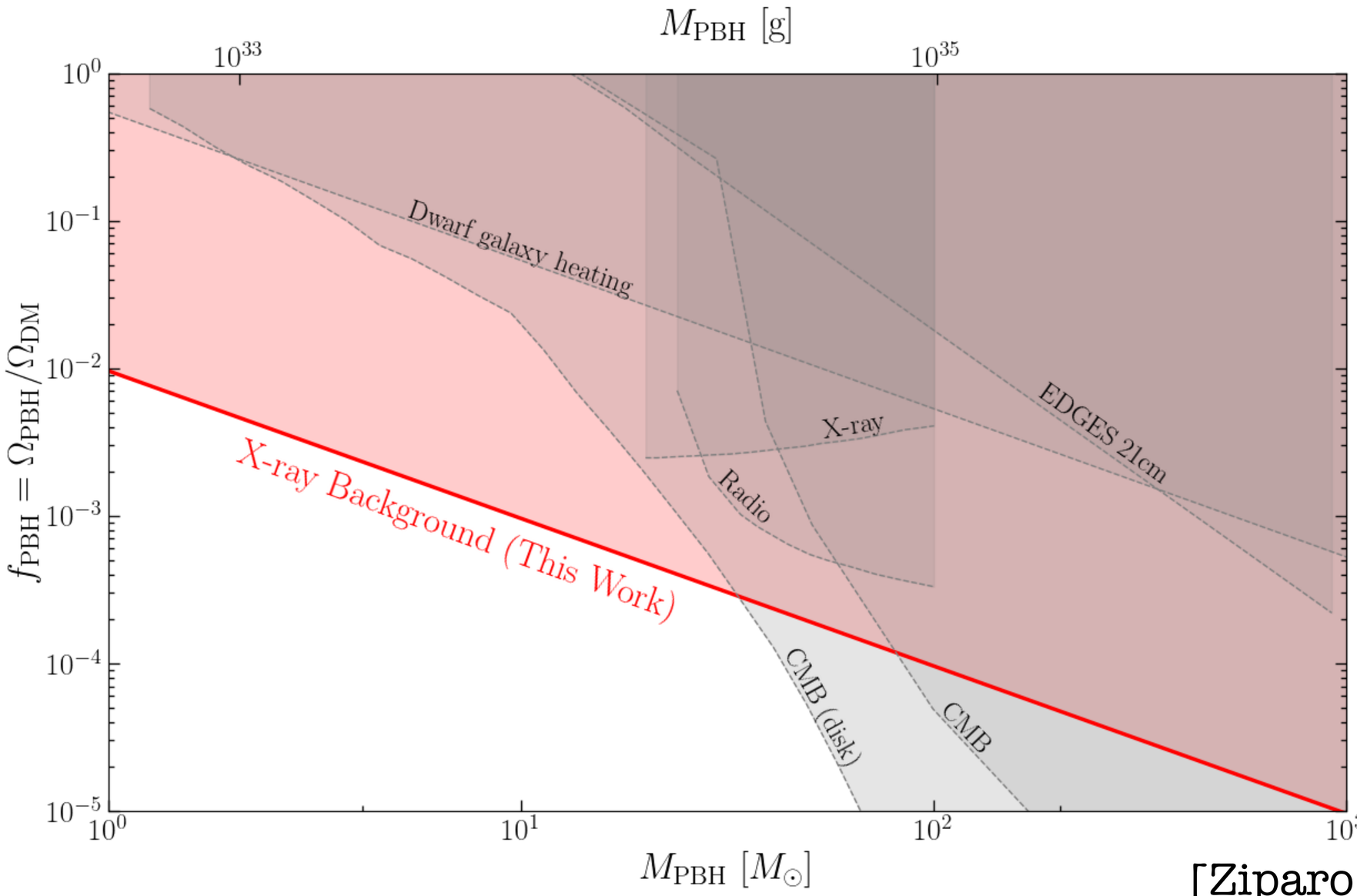
Excess value

$I_{0.5-2\ \mathrm{keV,obs}} = 9 \times 10^{-13}$
[erg s^{-1}cm^{-2}deg^{-2}]

100% X-ray background excess
$f_{\mathrm{PBH}} = 3 \times 10^{-4}$

[Ziparo +22]

New Constraint

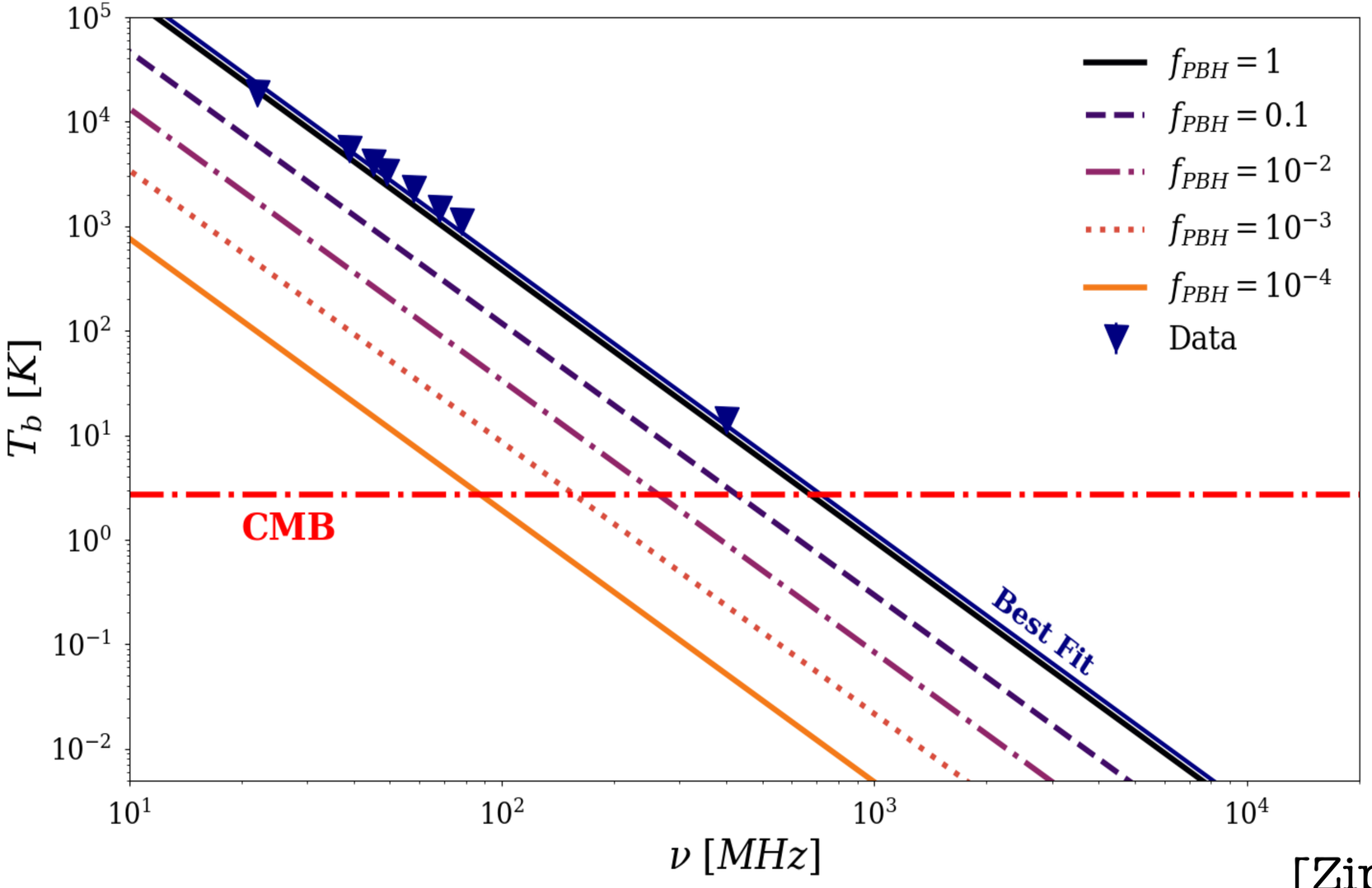


$$f_{\rm PBH} \leq 3 \times 10^{-4} \left(\frac{30\ M_\odot}{M_{\rm PBH}} \right)$$

We provide a strong constraint on f_{PBH} for $M_{PBH} = 30\ M_\odot$

[Ziparo +22]

Radio background



$z = 0$

$f_{\rm PBH}$	$T_b(z=0)/{\rm K}$	$T_b(z=17)/{\rm K}$	A_r
1	0.402	579.67	11.80
0.1	0.123	174.42	3.55
0.01	0.035	42.81	0.87
10^{-3}	0.009	7.59	0.15
10^{-4}	0.002	1.10	0.02

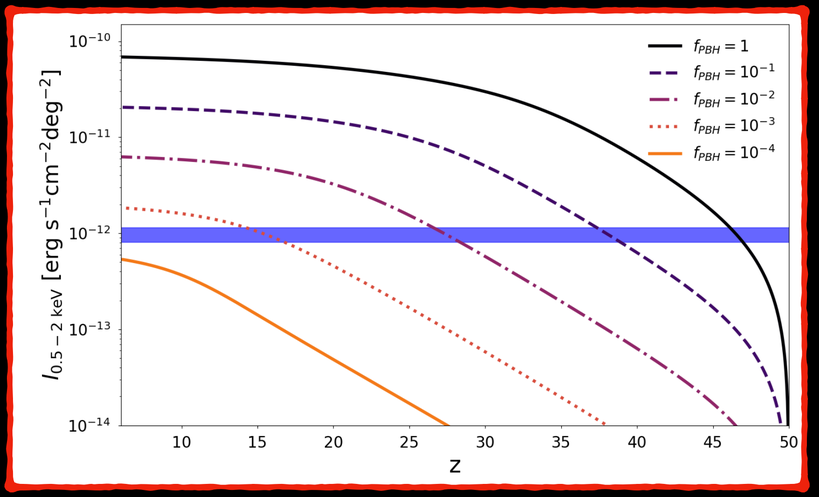
$$T_{b,obs}(z=0) = 0.48{\rm K}$$

For the allowed values of $f_{\rm PBH}$, we're only able to recover 1% of the CRB

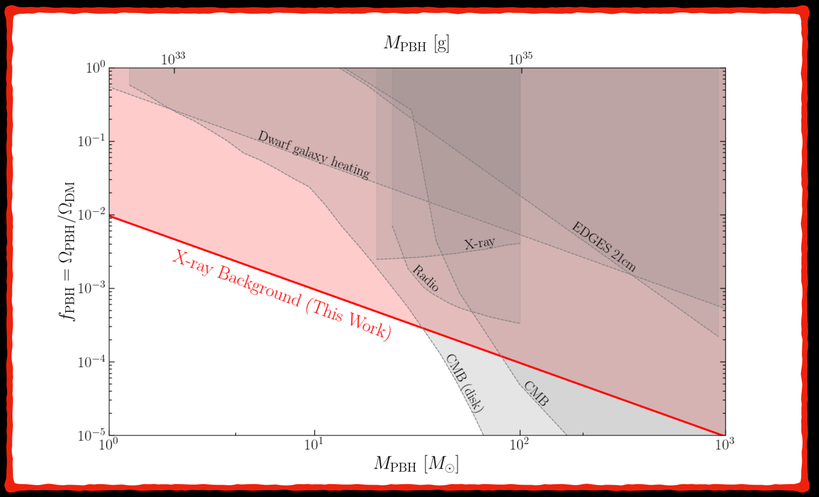
[Ziparo +22]

Summary

- Formulation of a new PBHs accretion model inside Dark Matter Halos
- Set a new constraint on the fraction of Dark Matter into PBHs
- Match the intensity of the X-ray background excess
- Recover 1% of the observed radio background excess

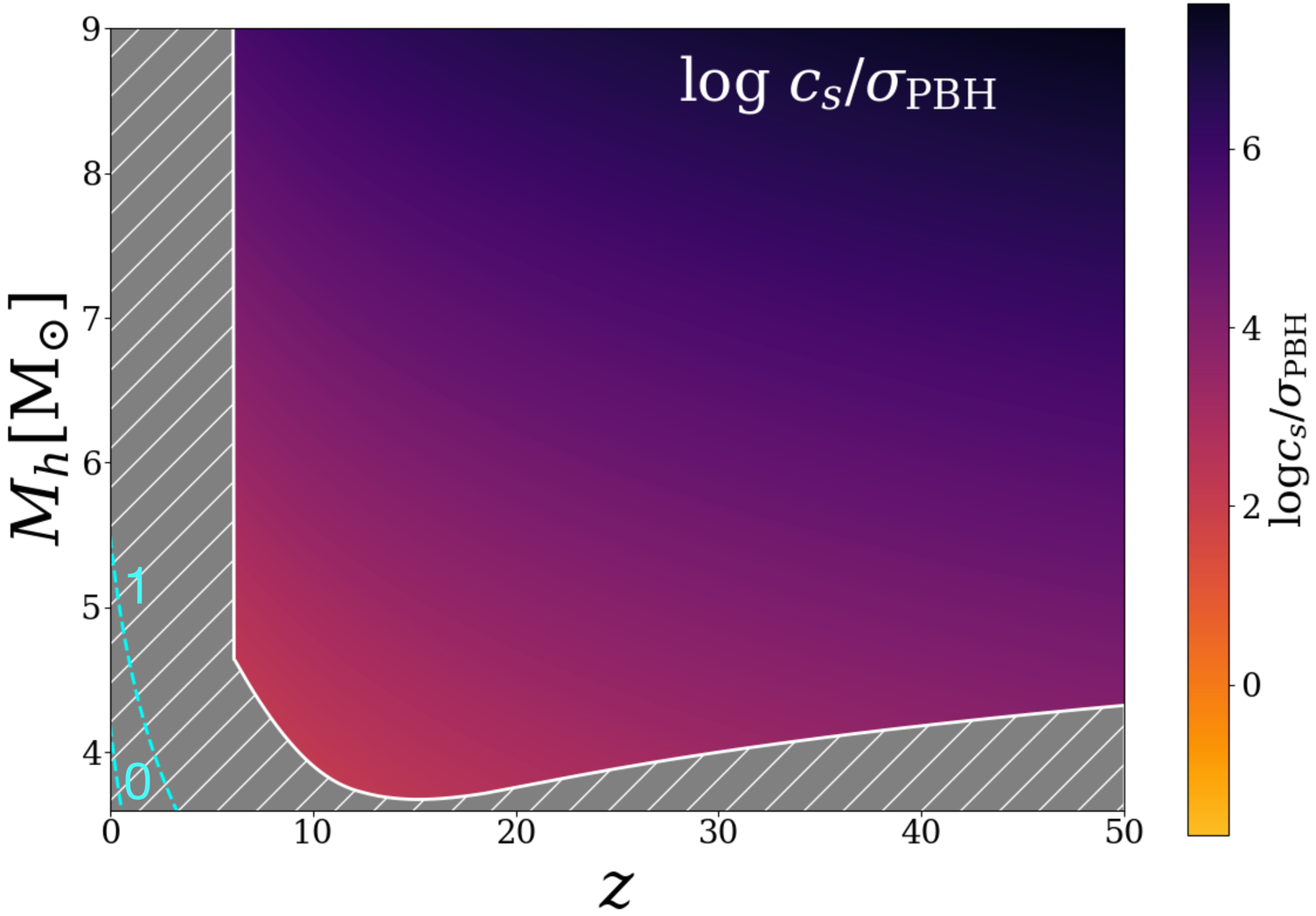


[francesco.ziparo@sns.it]



Back up

Velocities in halos

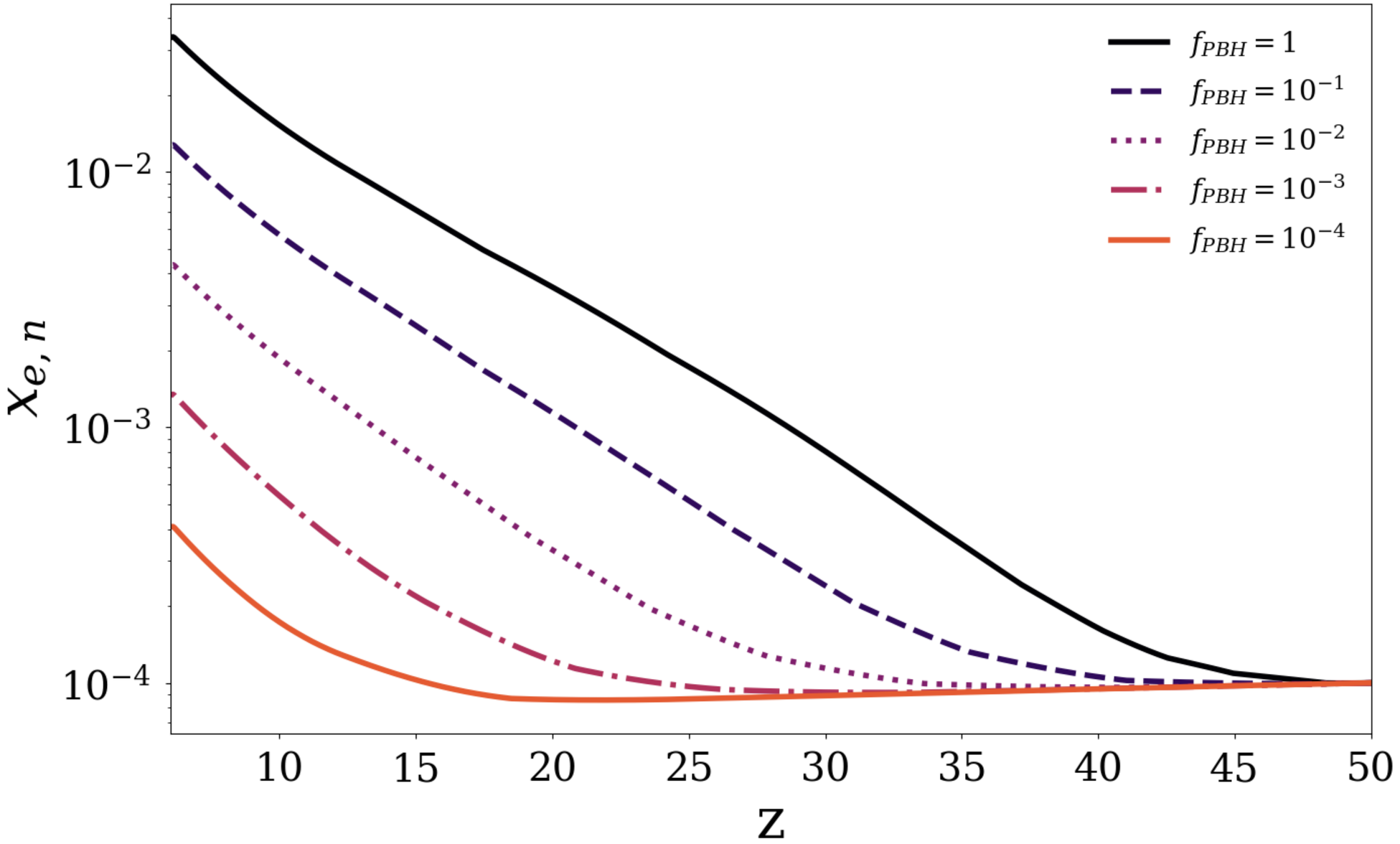


$$f_{\rm PBH} = 10^{-3}$$

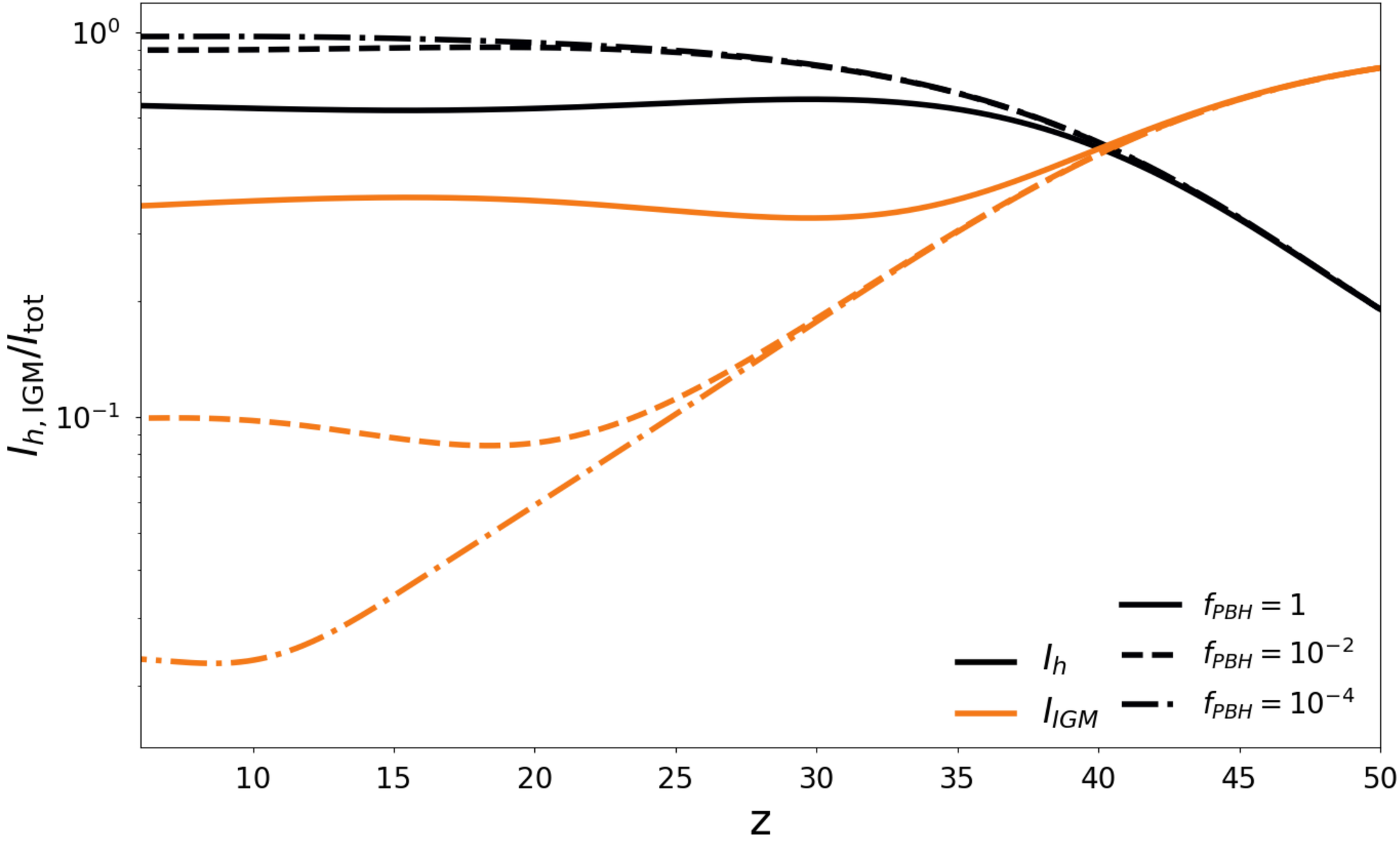
$$\sigma_{\rm PBH}(z) = 6.0\ {\rm km/s}\frac{f_{\rm PBH}^{2/3}(M_{\rm PBH}/M_\odot)}{\sqrt{1+z}}$$

[Hütsi +19]

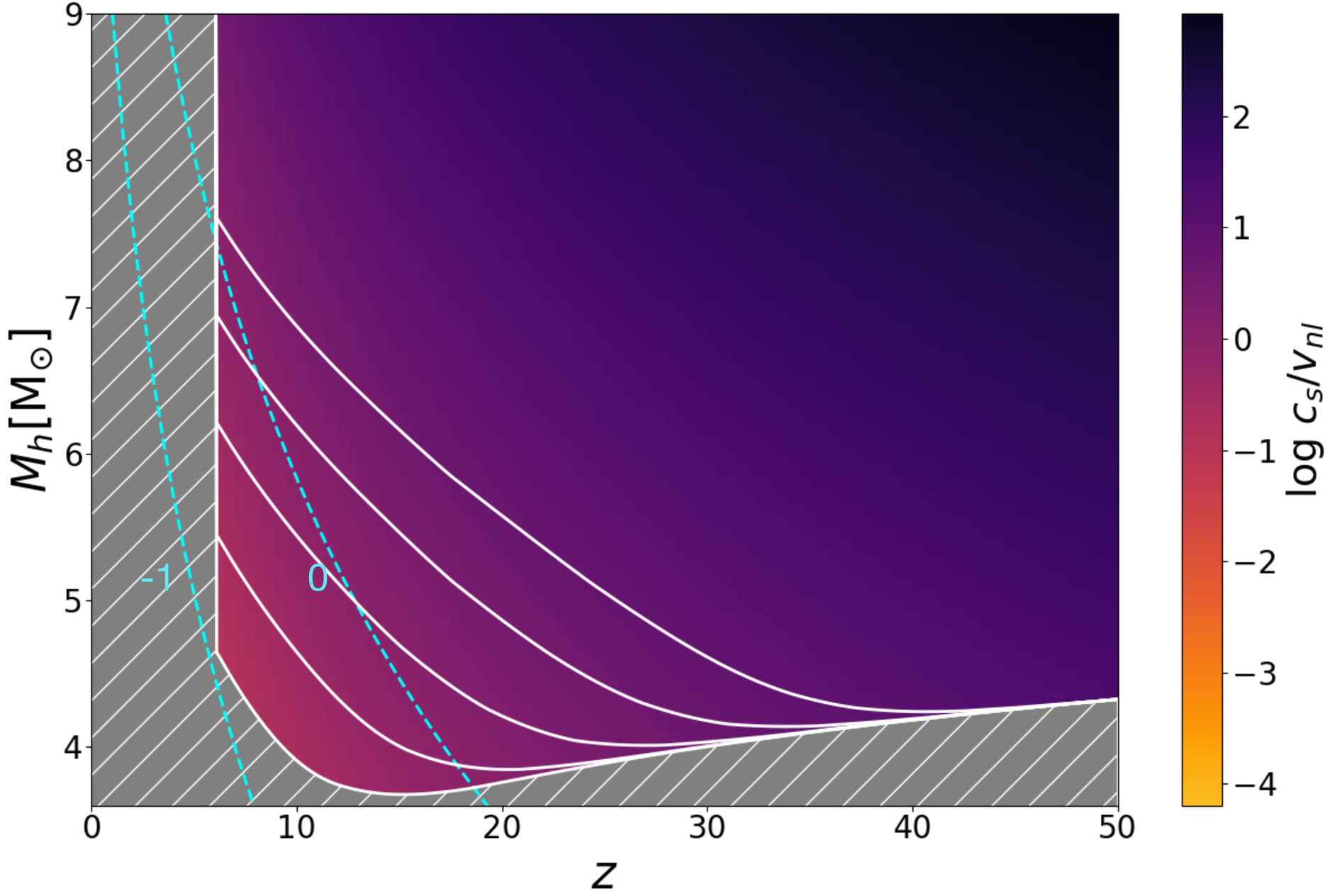
Secondary ionization



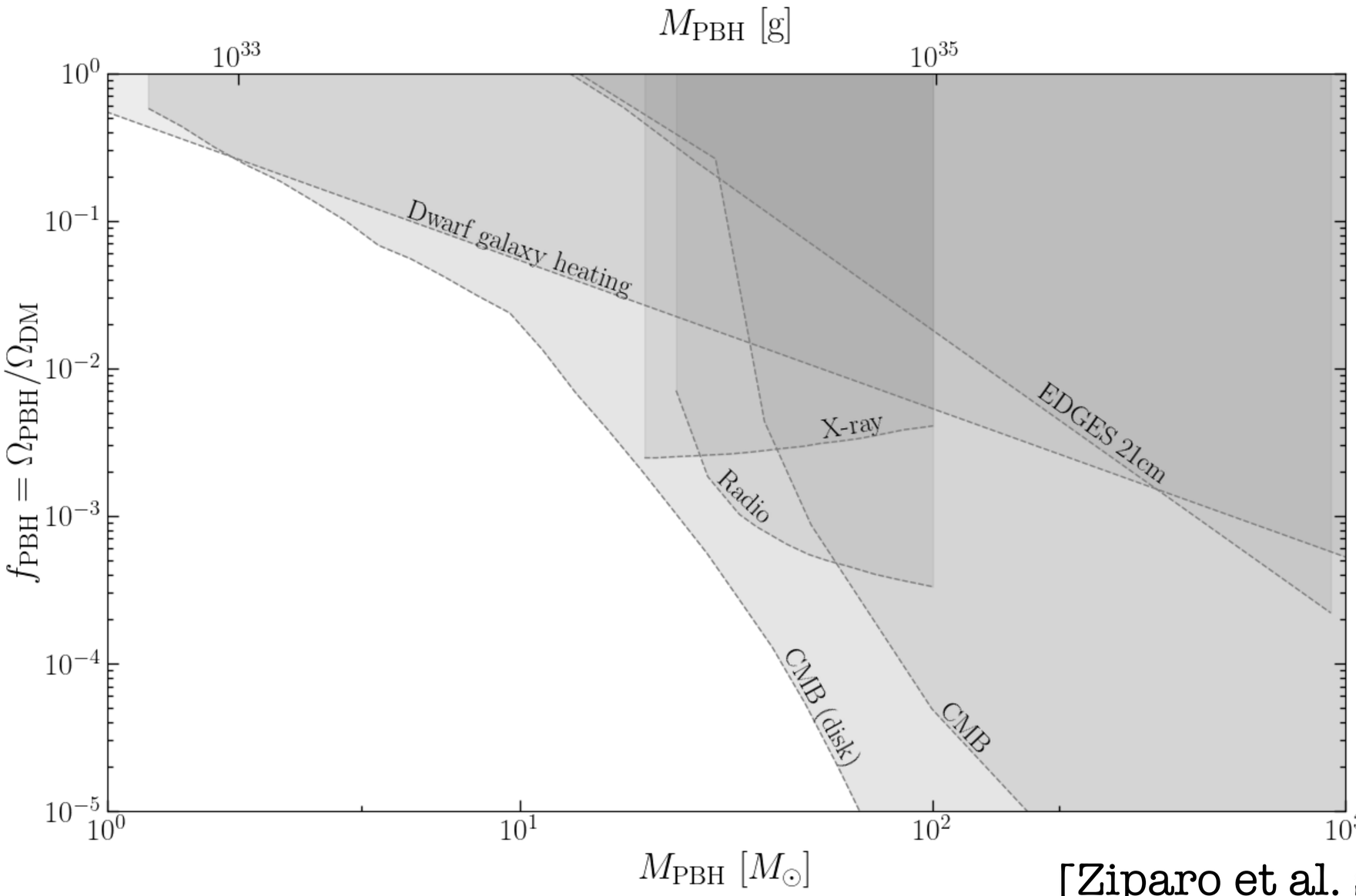
Relative Fluxes



Velocities in halos



Accretion constraints



- EDGES 21cm
- Dwarf galaxy heating
- X-ray and Radio
- CMB distorsion:
  - Spherical
  - Disk

[Ziparo et al. submitted]

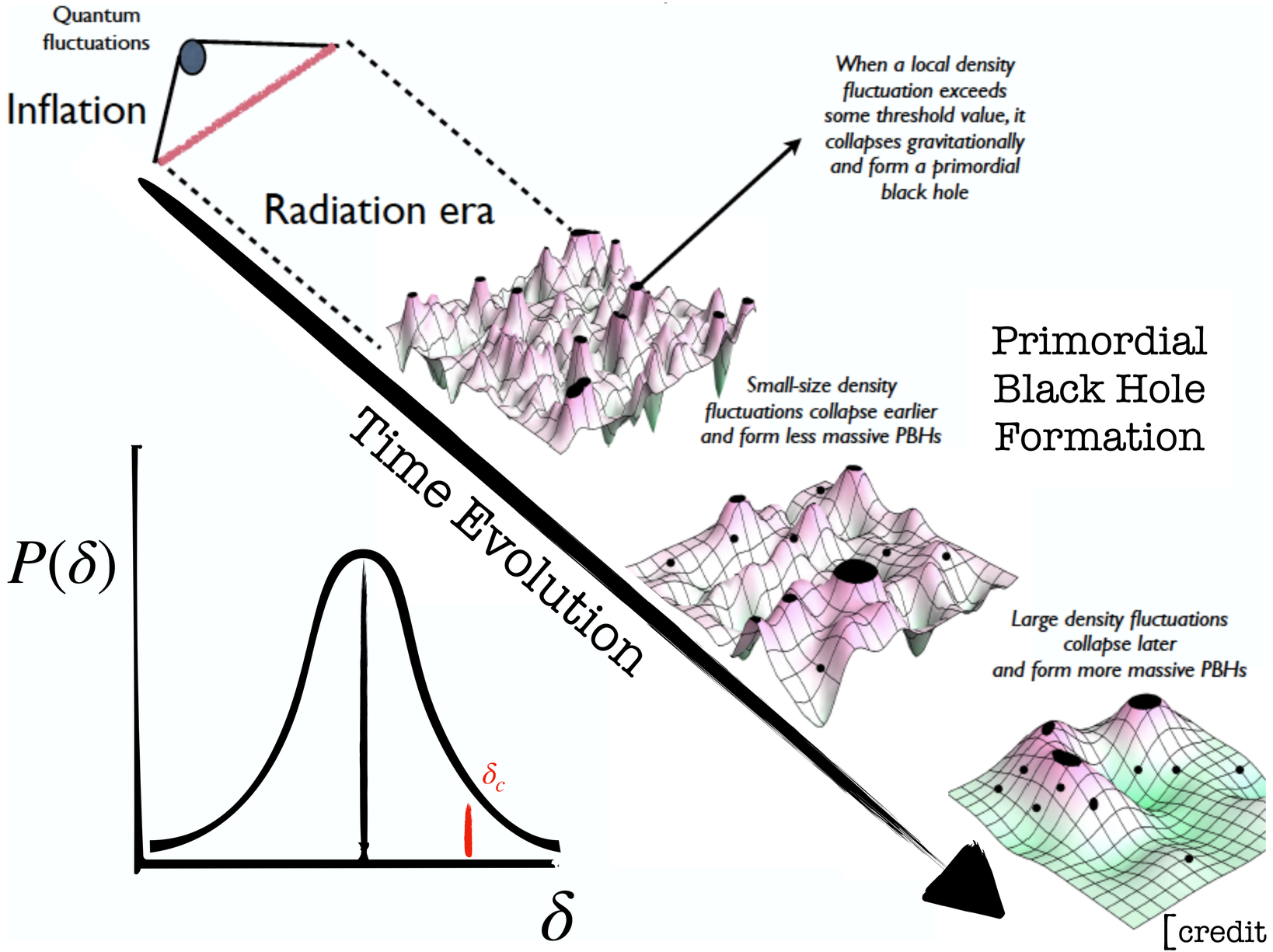
PBHs formation

Gaussian Field

$$P(\delta) = \frac{1}{\sqrt{2\pi\sigma^2}} exp(-\frac{\delta^2}{2\sigma^2})$$

PBHs Abundance

$$\Omega_{PBH} = \int_{\delta_c} M(\delta)P(\delta)d\delta$$



Primordial Black Hole Formation

[credit S. Clesse]