

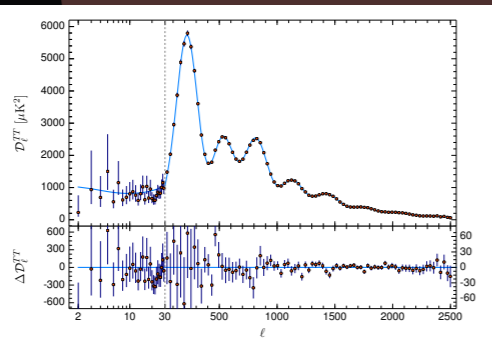
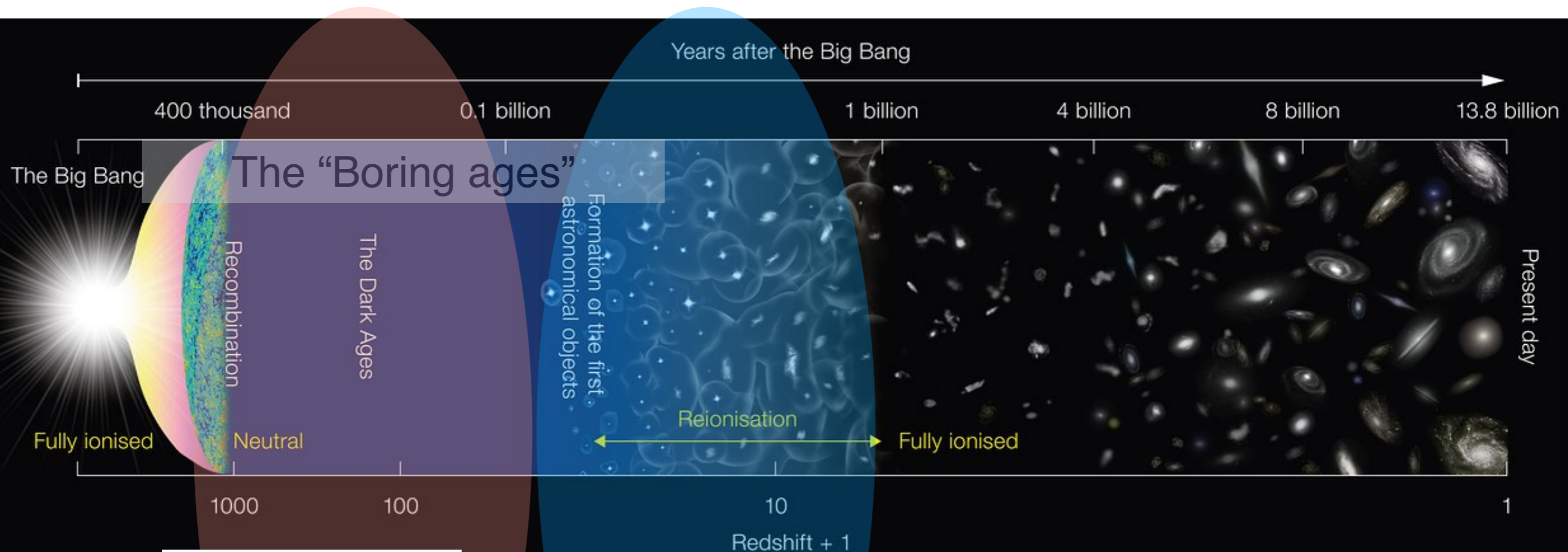
Looking for new (astro)physics in CMB and 21 cm data

TAsP meeting
Bologna
January 2026

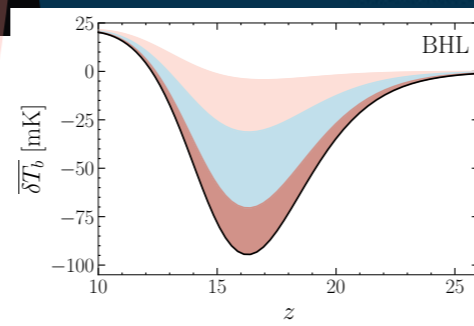
Daniele
Gaggero


Istituto Nazionale di Fisica Nucleare
Sezione di Pisa

Early VS Late-time Cosmology



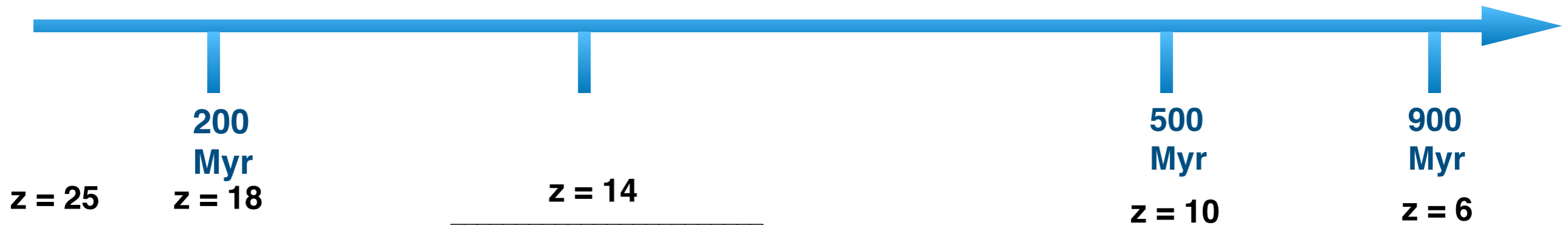
Dominic Agius,
 Rouven Essig, **DG**,
 Francesca Scarcella,
 Gregory Suzzewski,
 Mauro Valli,
[2403.18895](https://arxiv.org/abs/2403.18895)



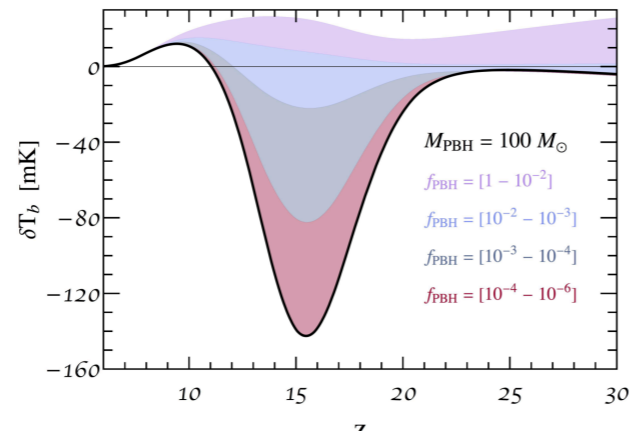
Dominic Agius,
 Rouven Essig, **DG**,
 Sergio Palomares-Ruiz, Gregory
 Suzzewski, Mauro
 Valli, [2510.14877](https://arxiv.org/abs/2510.14877)

The “Cosmic Dawn” timeline

Reionization of the Universe



“Blue Monsters”
(JWST)
2209.06840

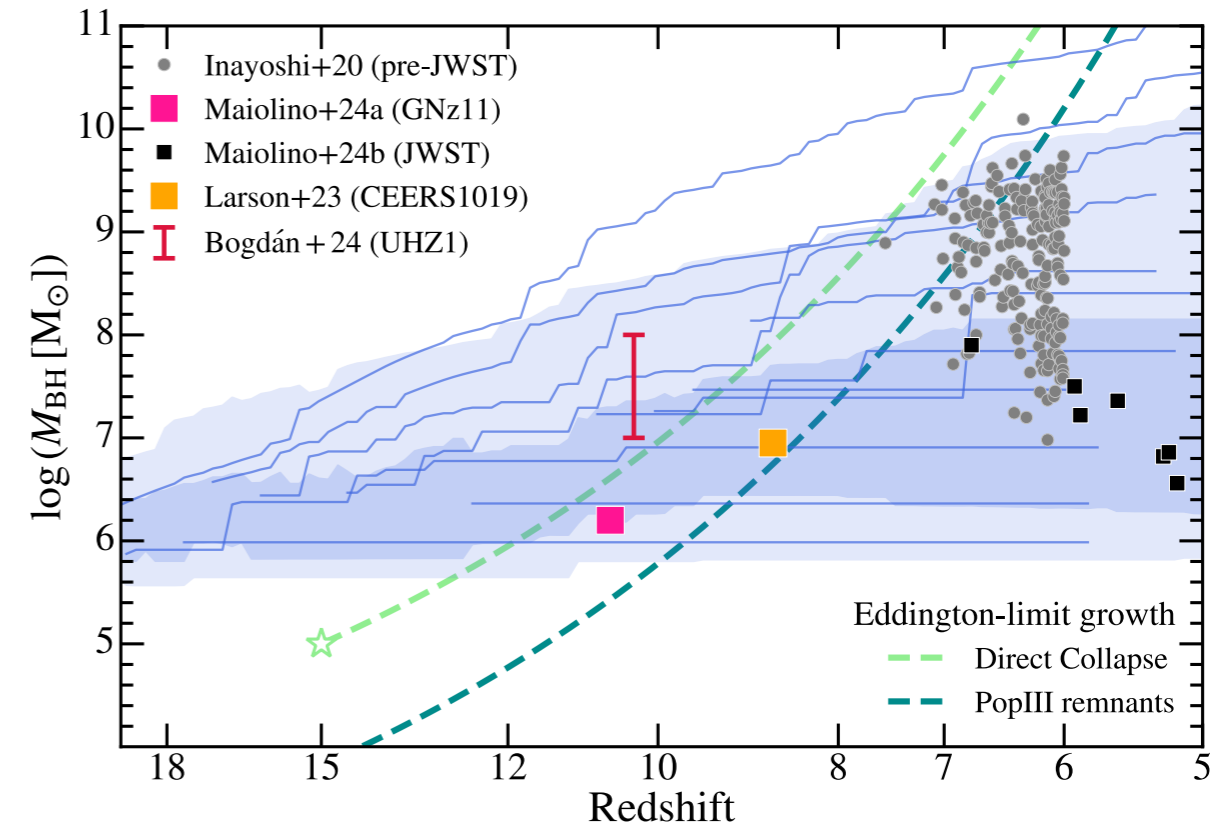


21 cm “Absorption Dip”
[expected]



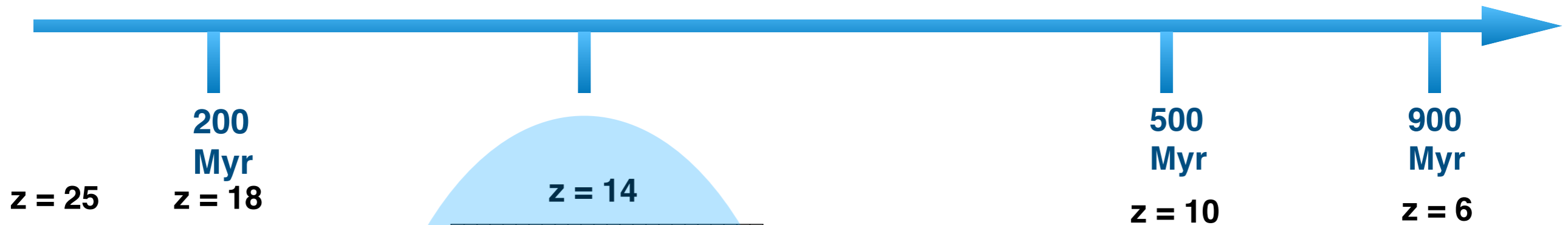
“SMBH era”

“Little Red Dots”

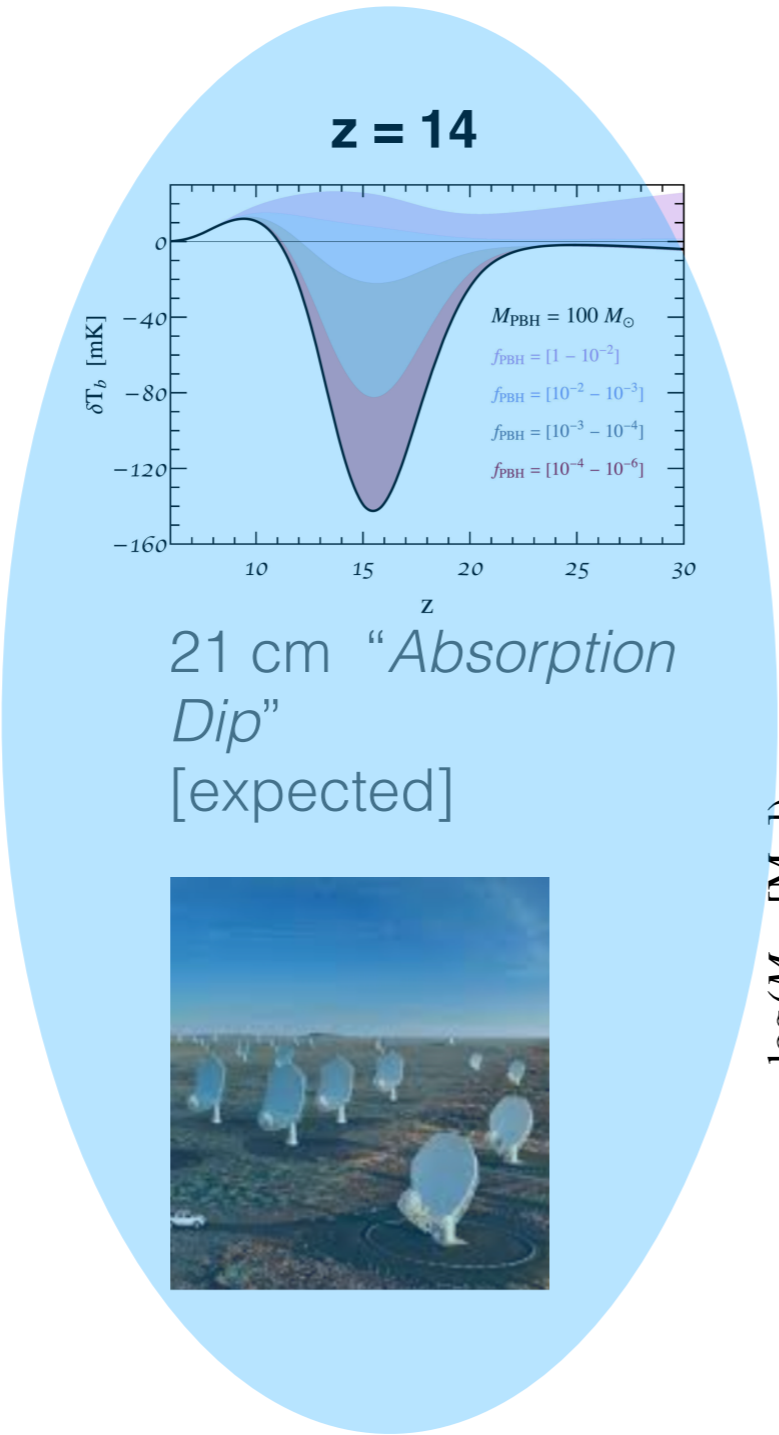


The “Cosmic Dawn” timeline

Reionization of the Universe

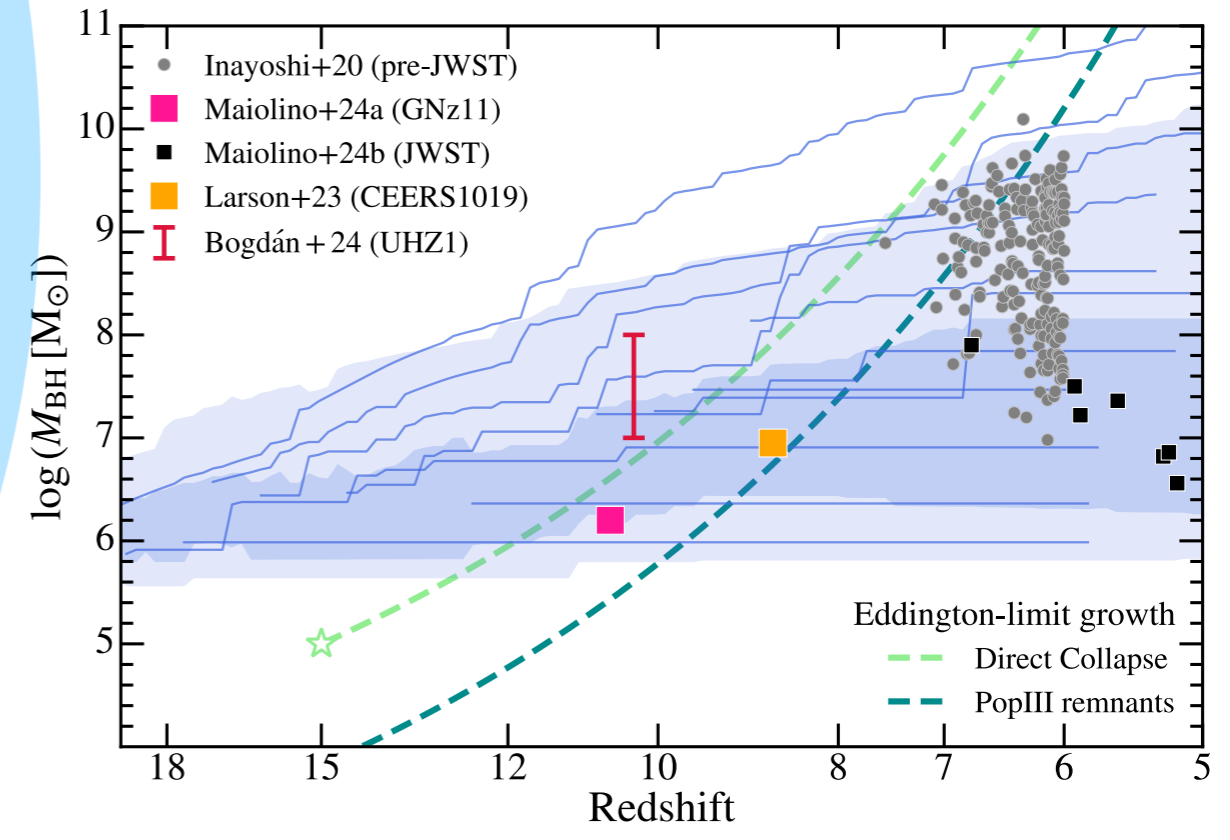


“Blue Monsters”
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2209.06840



“SMBH era”

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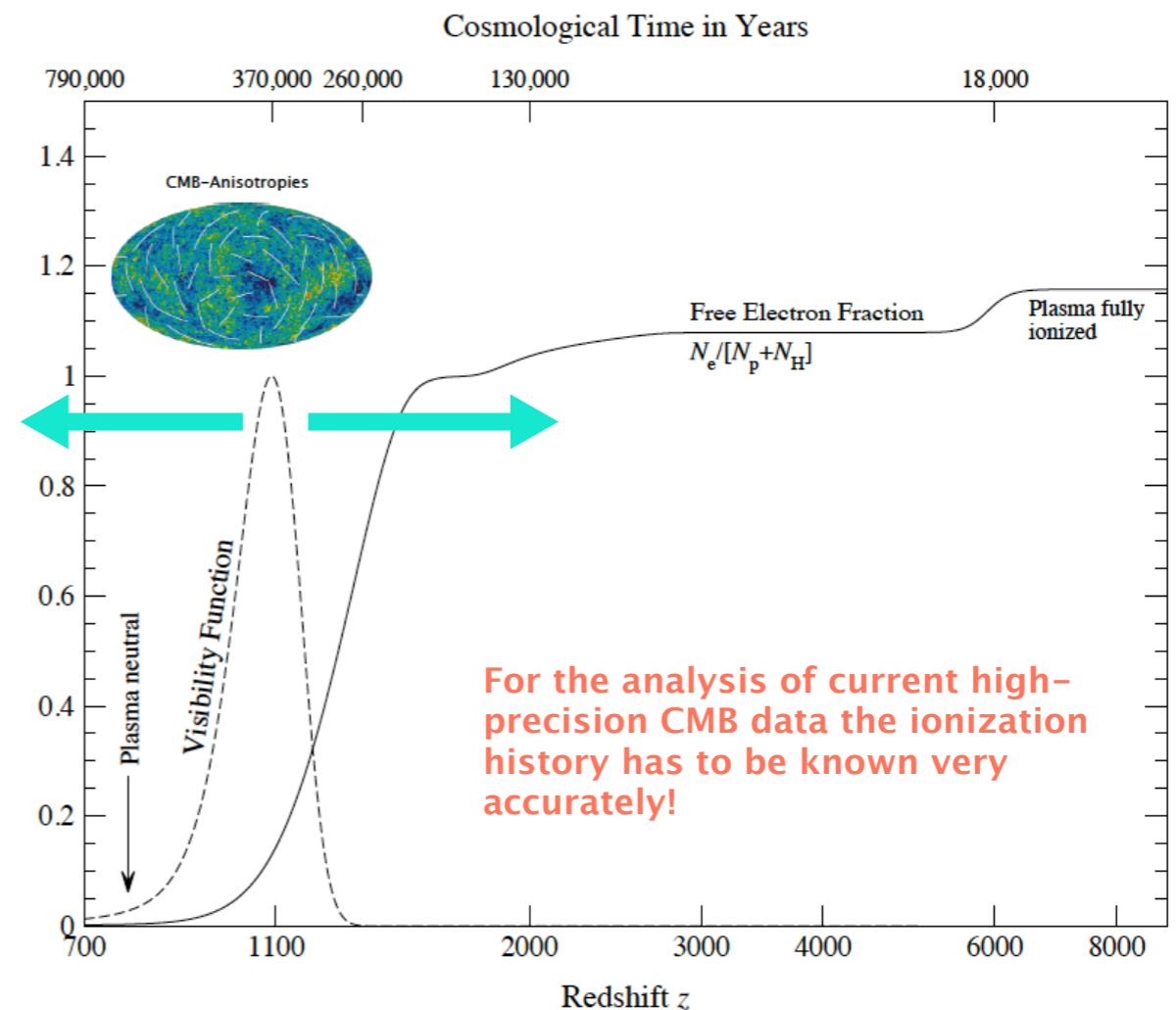
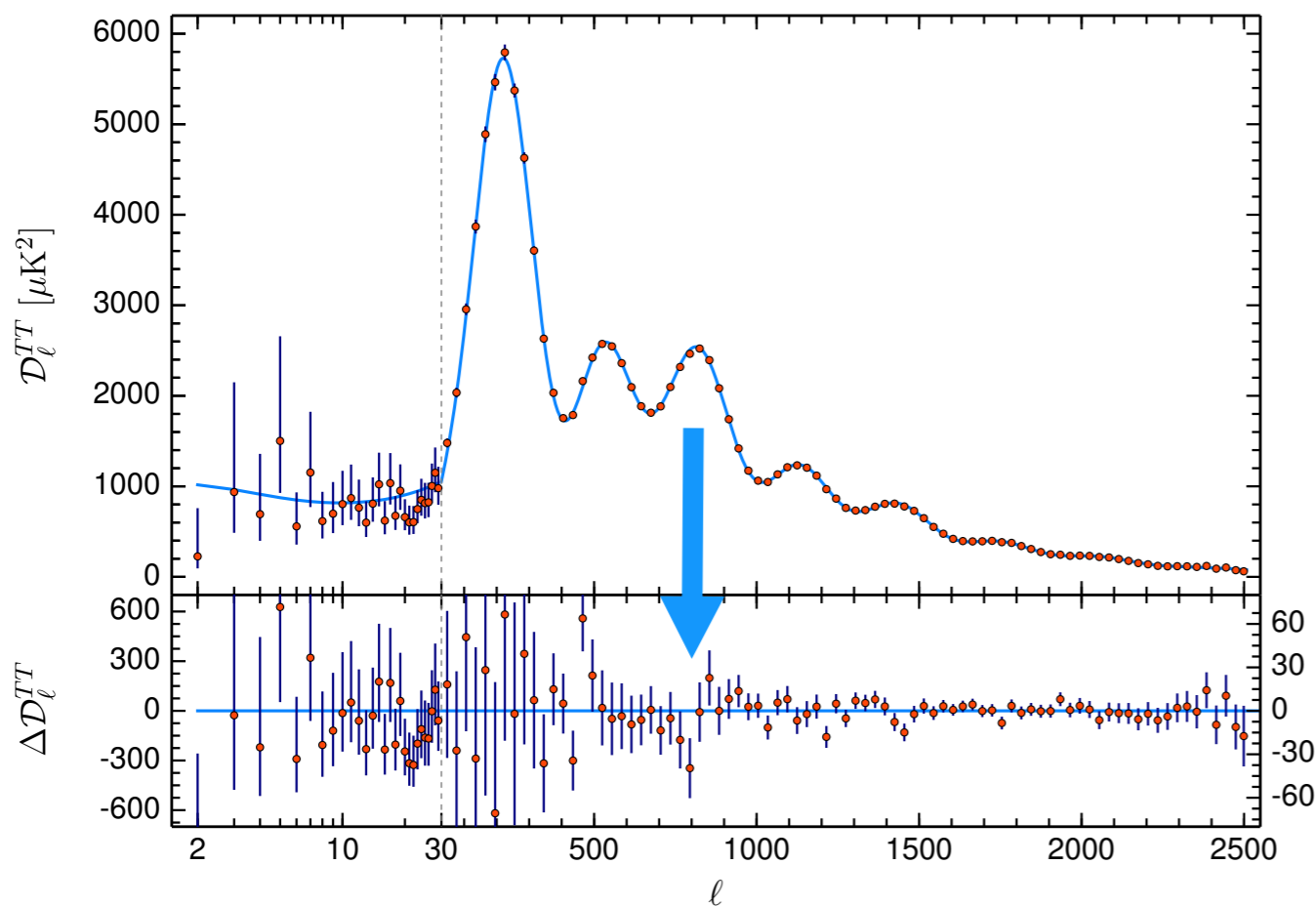
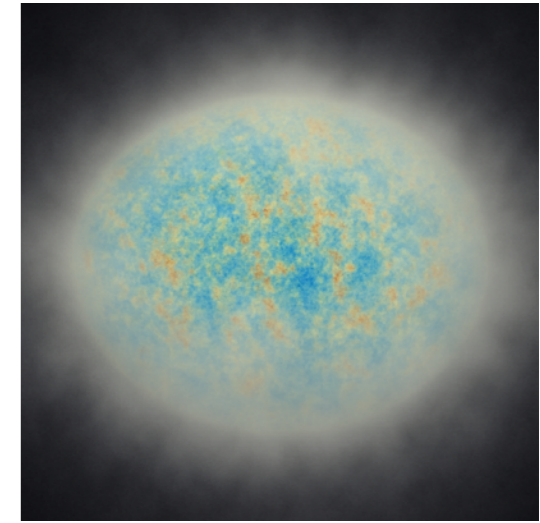


The CMB bound - the physics

DM annihilation injects particles that heat and ionize the IGM

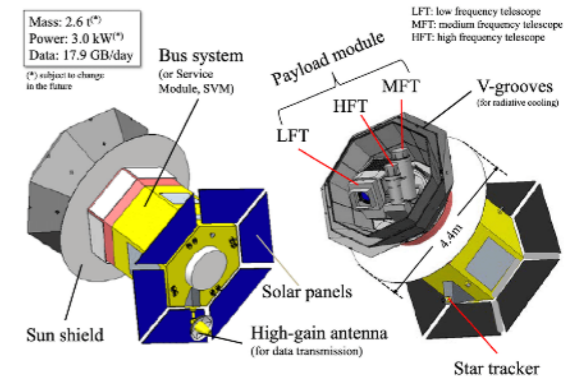
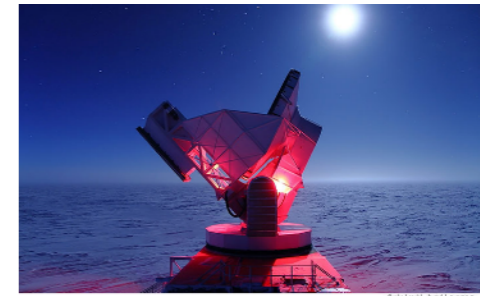
—> Increase of the free-electron fraction

- broadens the visibility function,
- adds **optical depth** between recombination and ionization
- suppresses the peaks

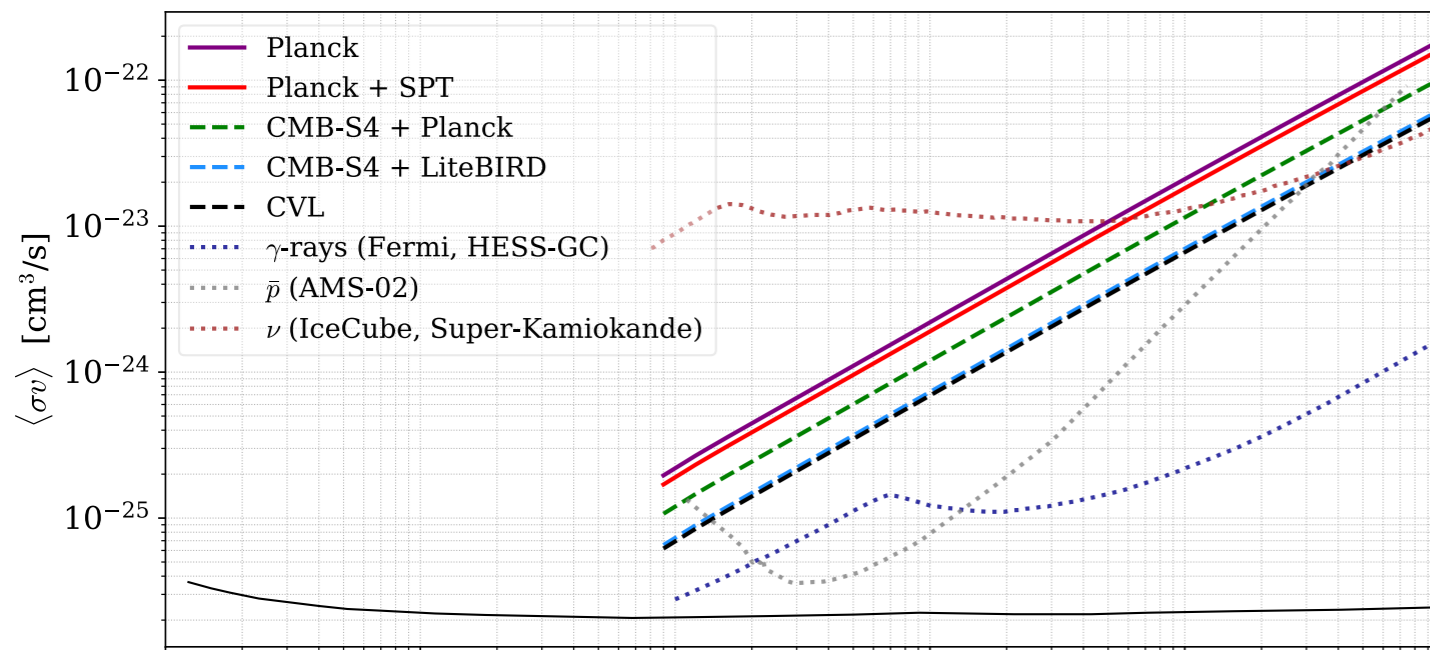


The CMB bound - the prospects: close to “saturation”

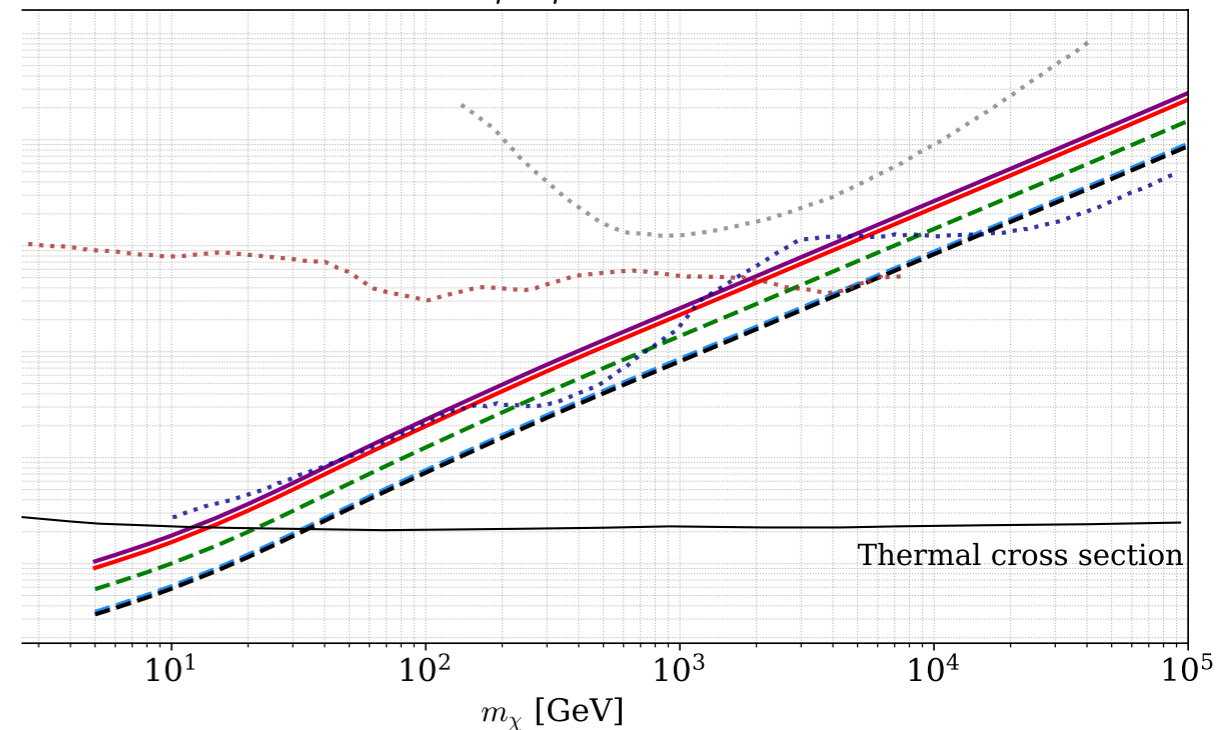
- **ACT, SPT, Simons Observatory:** Large collection area. Sharp view for high- l modes
- **LiteBIRD:** No atmosphere (which is bright, polarized, $1/f$ noise), perfect for low- l polarized modes



W^+W^-



$\mu^+\mu^-$



Charlotte Myers, Dominic Agius, DG, Angelo Ricciardone [2512.10896](https://arxiv.org/abs/2512.10896)

The CMB bound - the “astro uncertainty” in the PBH case

- **Bondi-Hoyle-Littleton accretion:** based on Euler + Continuity equation

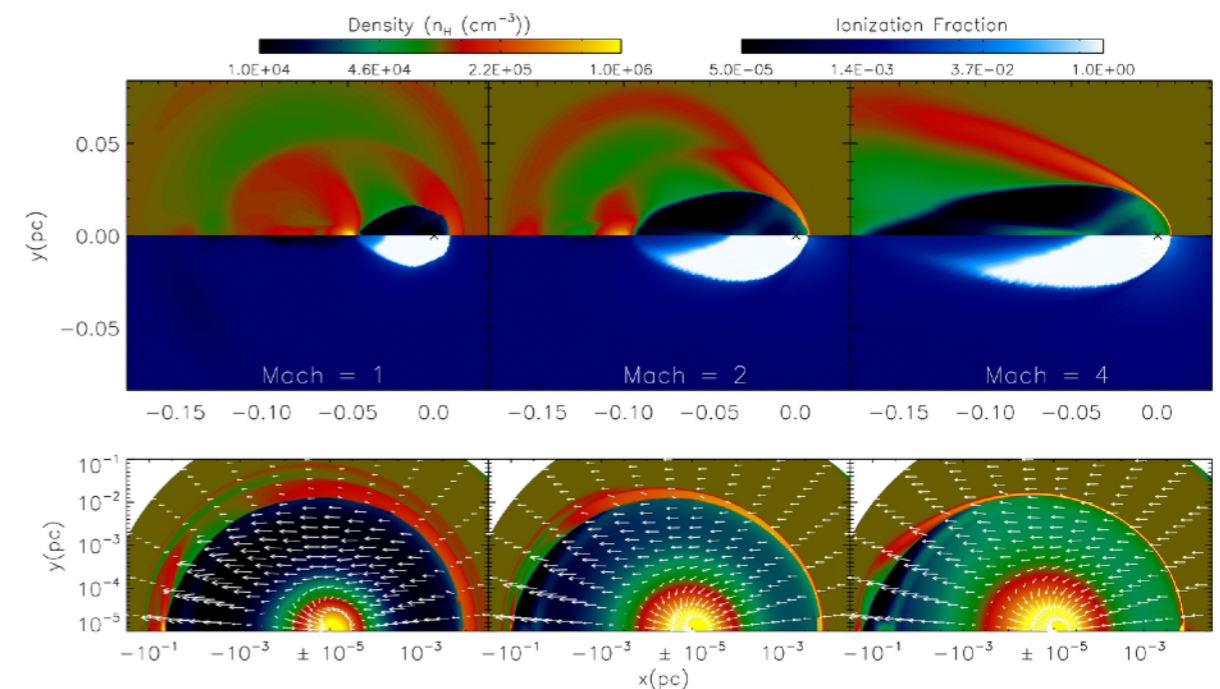
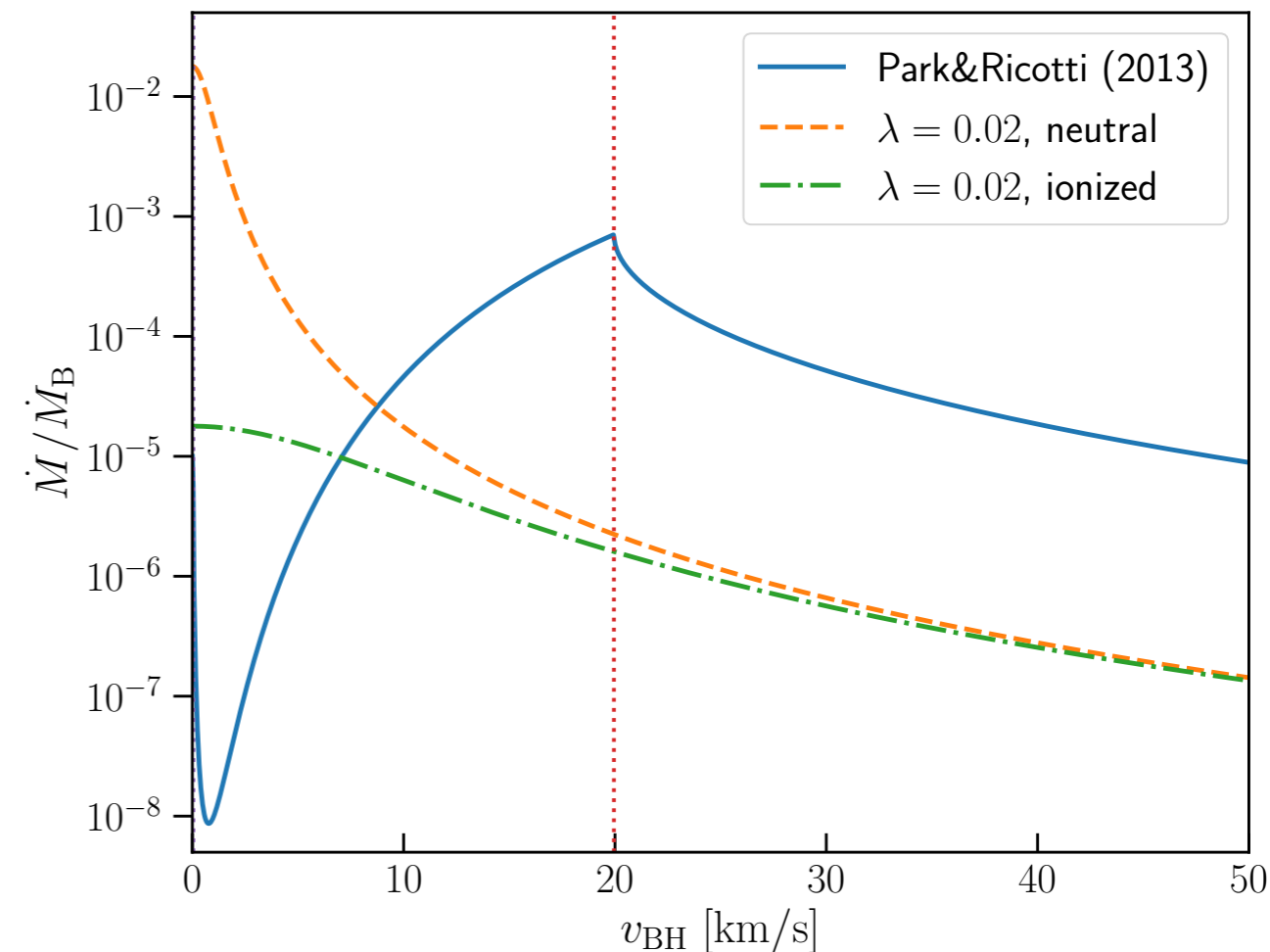
$$\dot{M}_{\text{BHL}} = 4\pi \frac{(GM)^2 \rho_\infty}{(v^2 + c_\infty^2)^{3/2}}$$

H. Bondi, MNRAS 112(2):195–204, 1952

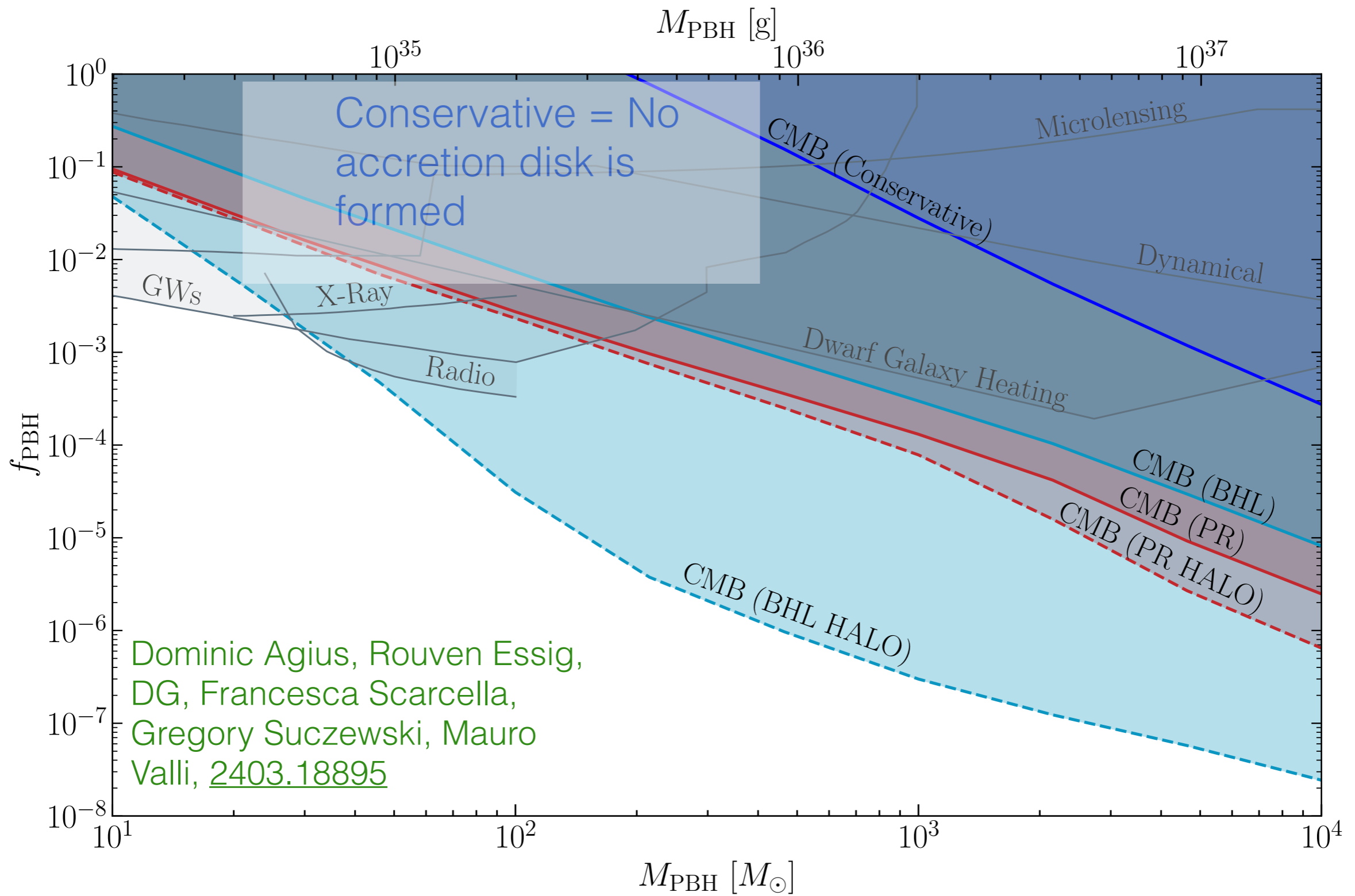
H. Bondi and F. Hoyle, MNRAS 104(5):273–282, 1944

K. Park and M. Ricotti, 1211.0542

- **Park-Ricotti model:** simulations + semi-analytical parametrization in presence of radiative feedback.
- Suppression of the accretion rate at low velocity, due to the formation of an ionized bubble



The CMB bound - the “astro uncertainty” in the PBH case

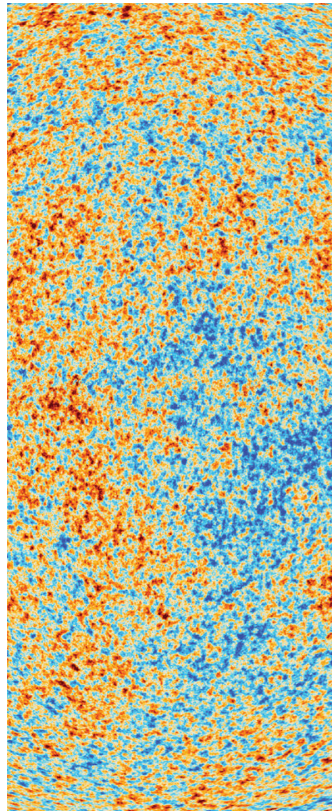


Made with Cobaya+CLASS (modified to account for energy injection)

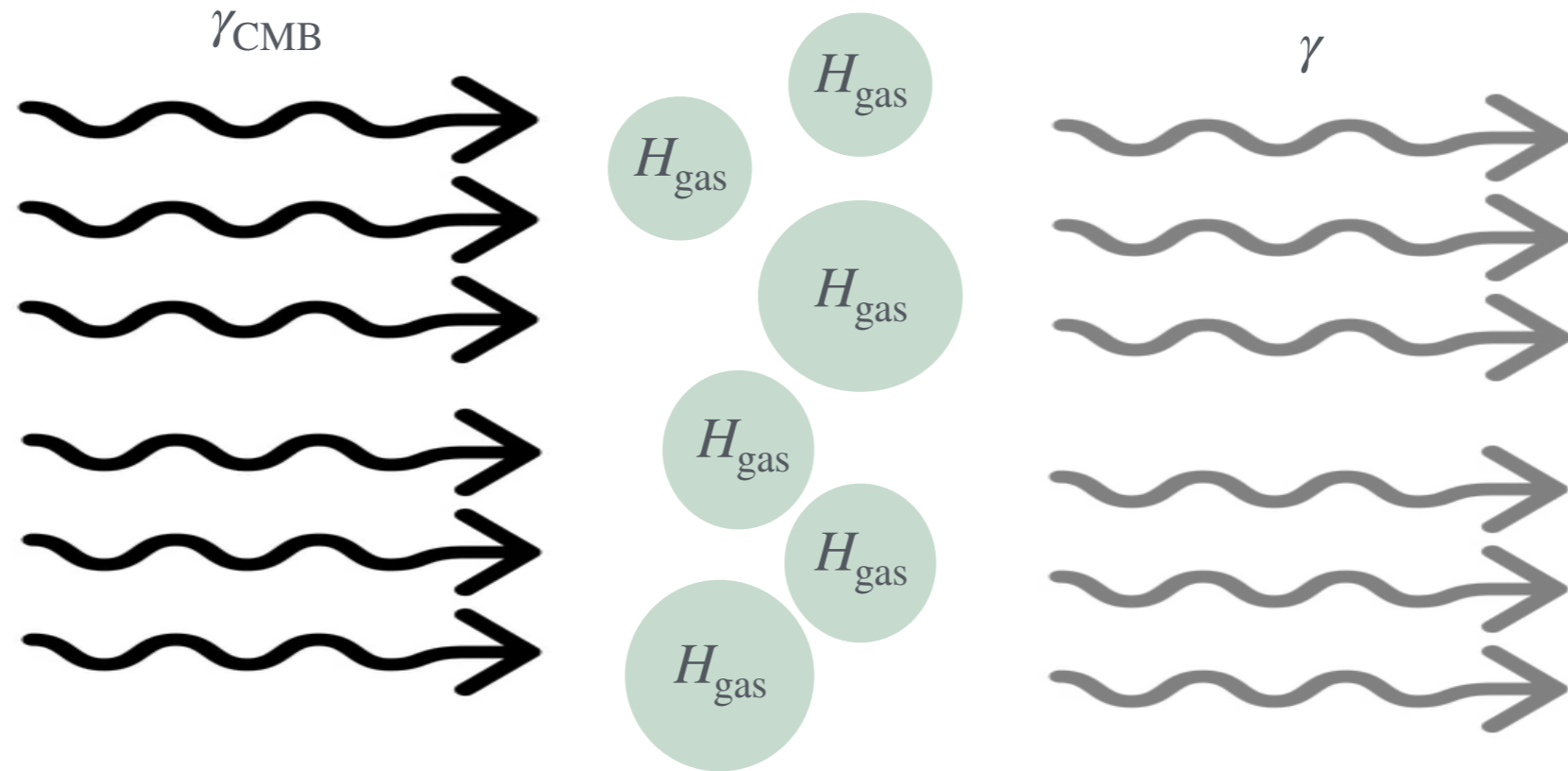
2018 low- l Planck TT.EE, high- l Planck TT.TE.EE, lensing, ACT, BAO

21 cm and PBHs - other astro uncertainties

CMB



[ESA]



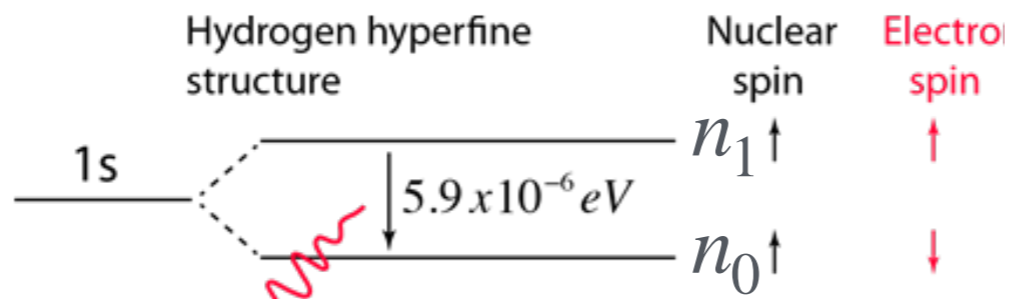
SKA



[SKAO]

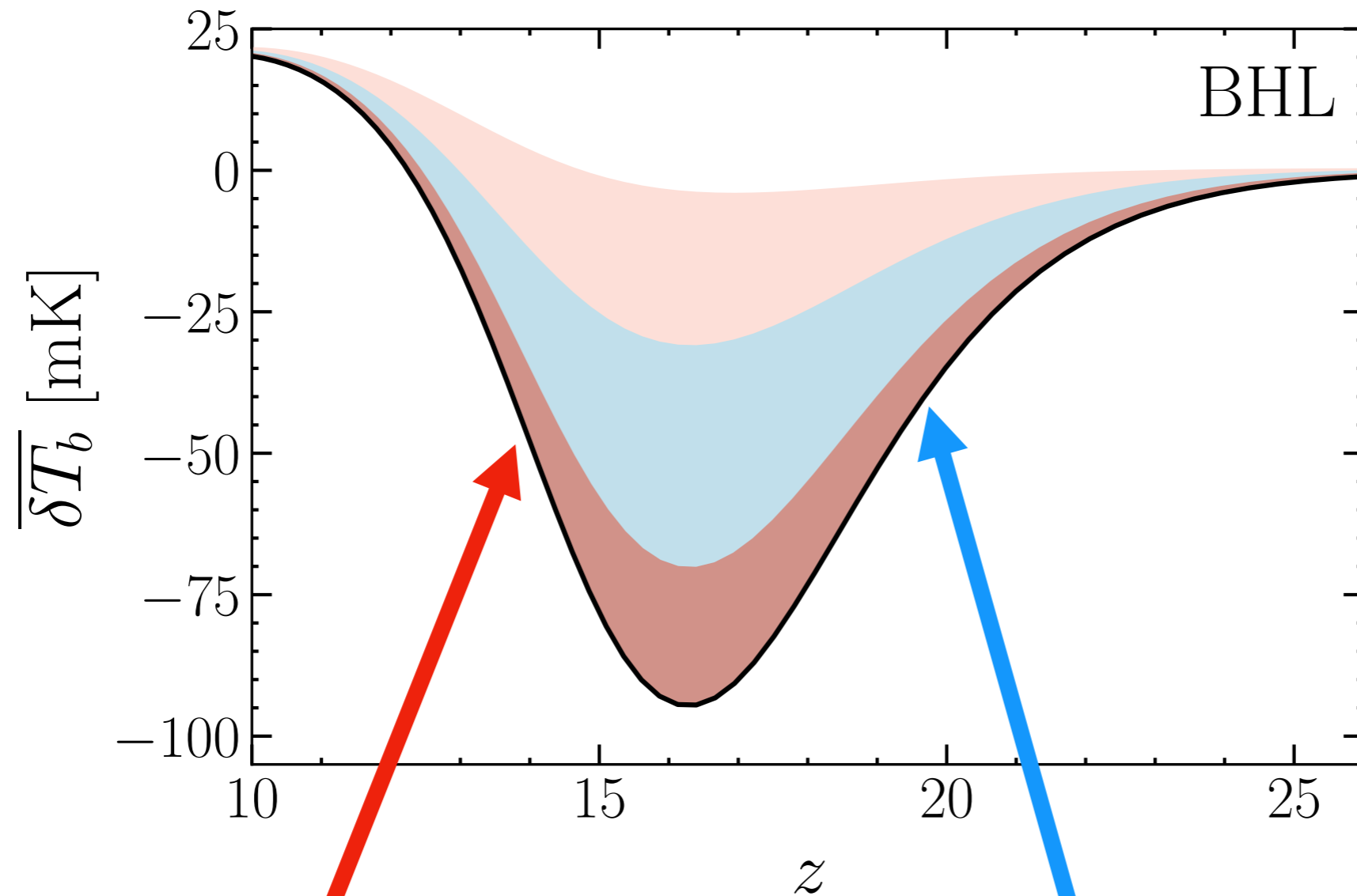
$$\frac{n_0}{n_1} = 3e^{-T_{21}/T_S}$$

$$T_{21} = \frac{h\nu_0}{k_B} \sim 0.068 \text{ K}$$



Sensitive to the spin temperature of the gas at the end of the dark ages
A cosmic redshift-dependent “thermometer”

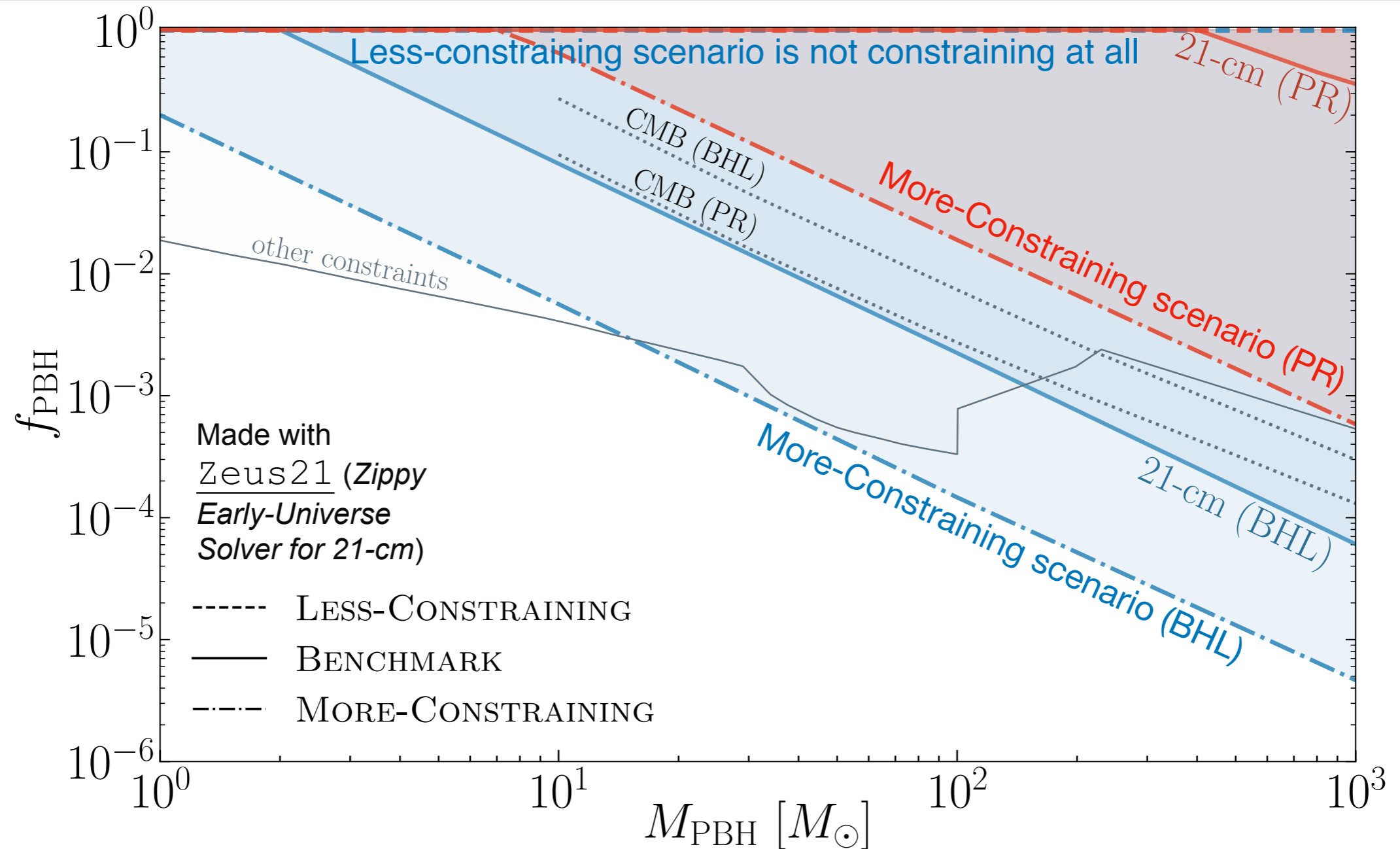
21 cm and PBHs - other astro uncertainties



- Gas is **heated** by **X-ray** emitted by first X-ray binaries. End of “*absorption era*”

- **LyAlpha** coupling - Spin temperature starts to be coupled to Kinetic temperature. Gas is **cooler** than CMB. “*Absorption Dip*”

21 cm and PBHs - other astro uncertainties

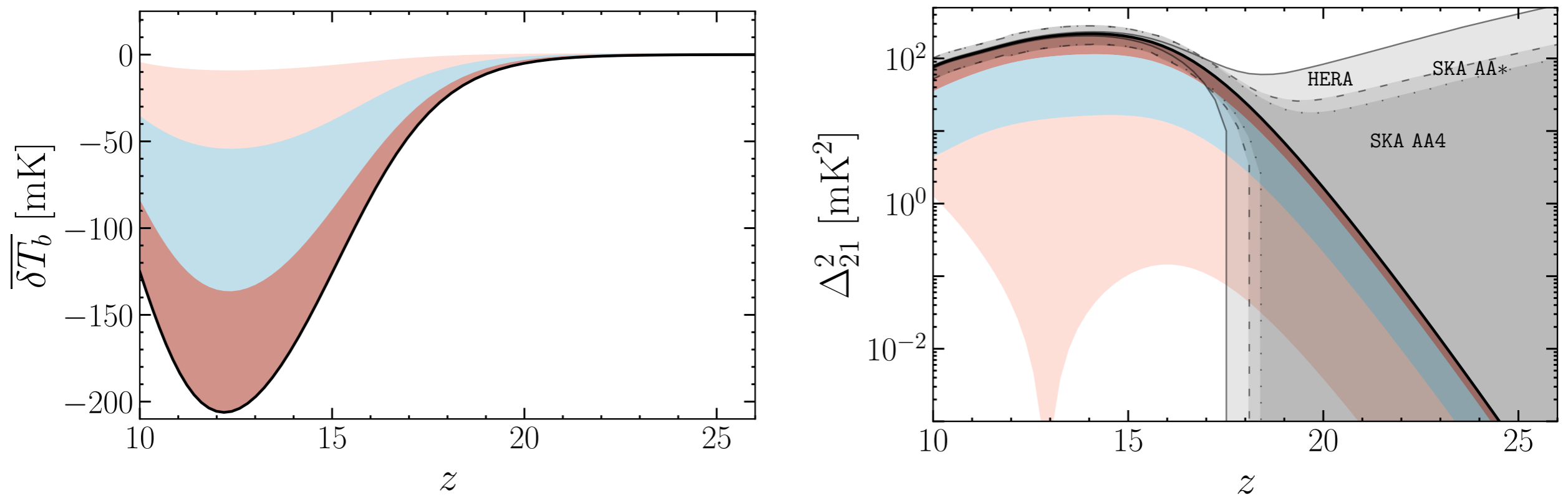


Astrophysical parameter	BENCHMARK	LESS-CONSTRAINING	MORE-CONSTRAINING
N_α	9690	3×10^3	4×10^4
$\log_{10} L_X / \dot{M}_* \left[\frac{\text{erg}}{\text{s}} \frac{\text{yr}}{M_\odot} \right]$	40.5	41	39.5
$T_{\text{vir}} [K]$	10^4	10^4	10^5

More- and Less-Constraining scenarios

The optimal scenario for new physics searches:

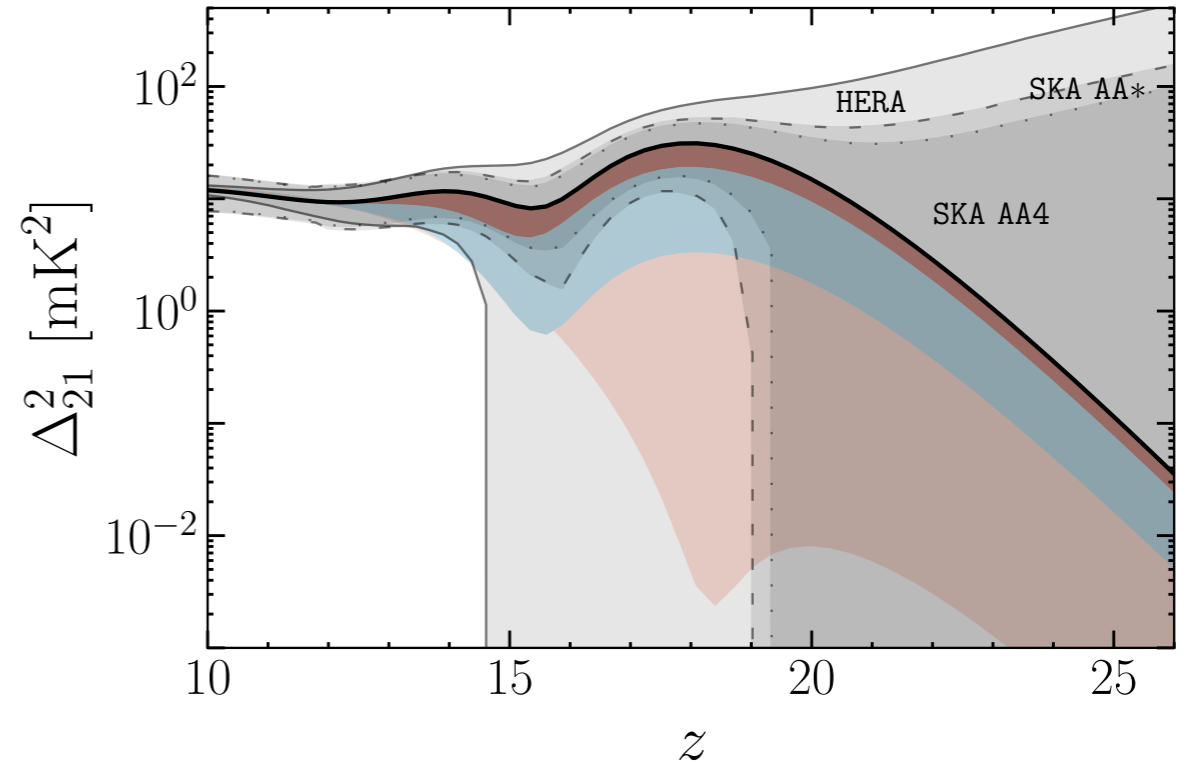
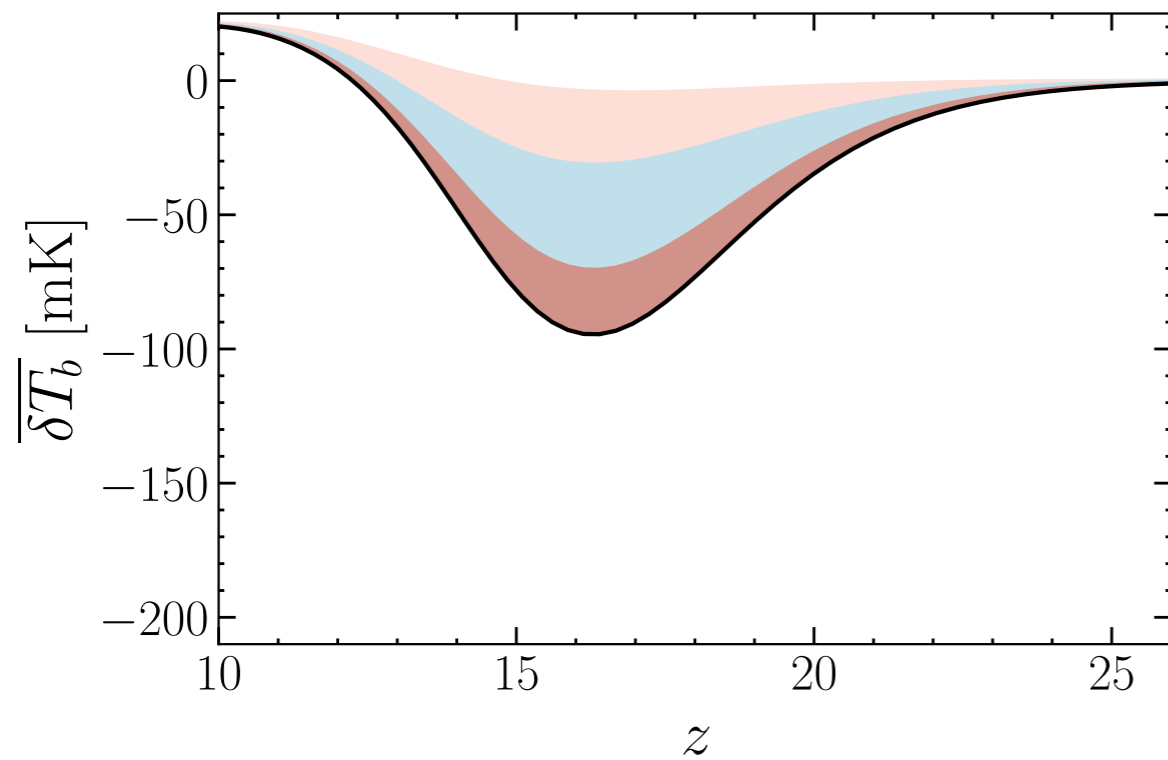
MORE-CONSTRAINING SCENARIO: $N_\alpha = 4 \times 10^4$, $L_X = 10^{39.5} \text{ erg s}^{-1} M_\odot^{-1} \text{ yr}$, $T_{\text{vir}} = 10^5 \text{ K}$.



- **More Lyman-alpha coupling + Small X-ray heating:** Deeper absorption dip
- **Larger mass threshold to form stars:** Radiation fields are generated by rarer late-forming massive halos. All is delayed, more sensitivity

More- and Less-Constraining scenarios

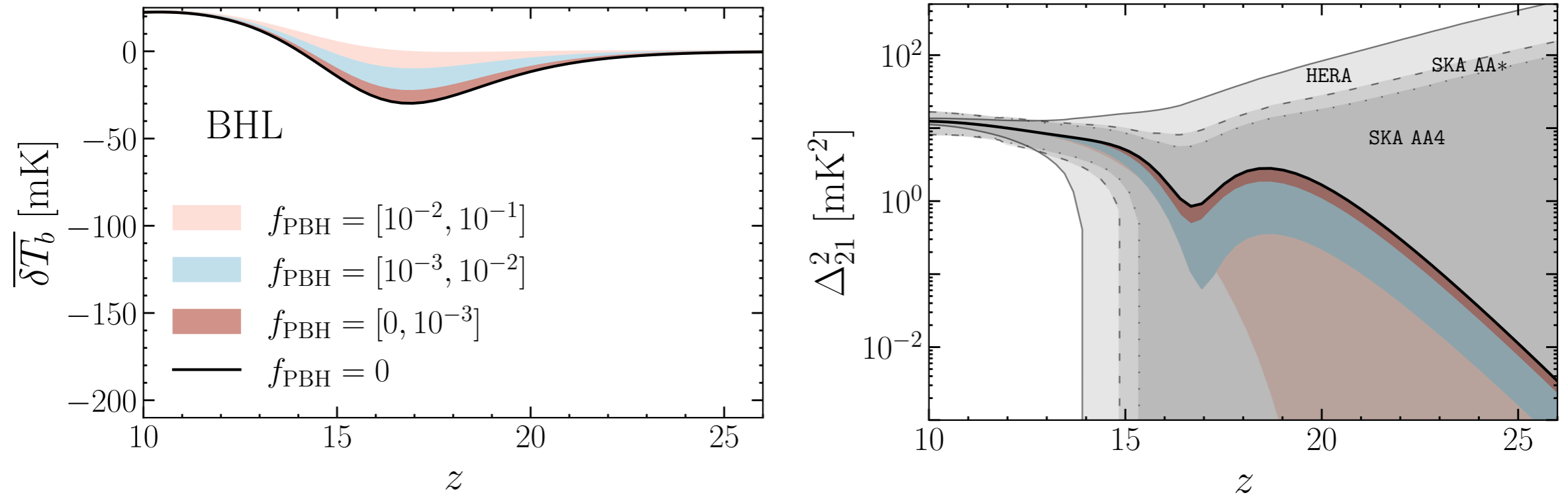
BENCHMARK SCENARIO: $N_\alpha = 9690$, $L_X = 10^{40.5} \text{ erg s}^{-1} M_\odot^{-1} \text{ yr}$, $T_{\text{vir}} = 10^4 \text{ K}$.



More- and Less-Constraining scenarios

The nightmare scenario

LESS-CONSTRAINING SCENARIO: $N_\alpha = 3 \times 10^3$, $L_X = 10^{41} \text{ erg s}^{-1} M_\odot^{-1} \text{ yr}$, $T_{\text{vir}} = 10^4 \text{ K}$.

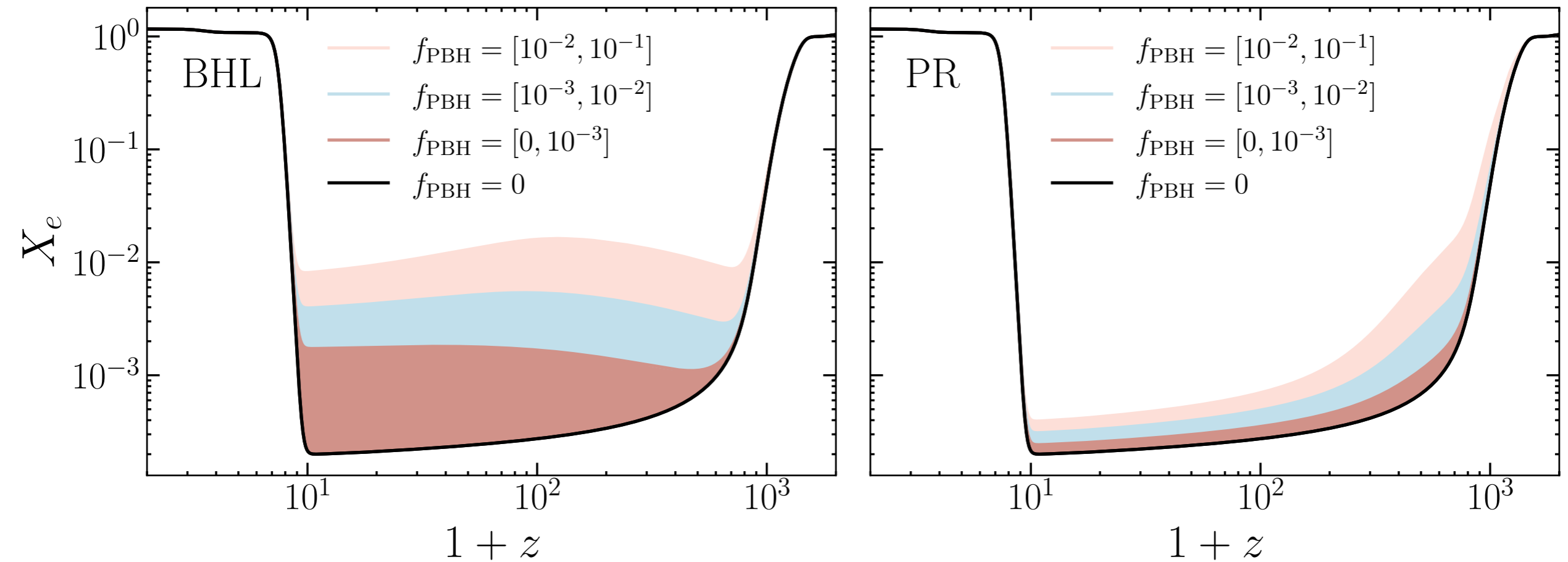


Conclusions

- **CMB** is a clean and accurate observable for a bound on new physics. However, close to saturation
- **PBH** science case: astro uncertainties due to accretion physics
- **21 cm** future is extremely useful, still it is a very “messy” channel. More data needed on X-ray and LyAlpha radiation fields. If you want to find new physics, you have to delve into that and love those stars!

Backup: PBHs and CMB

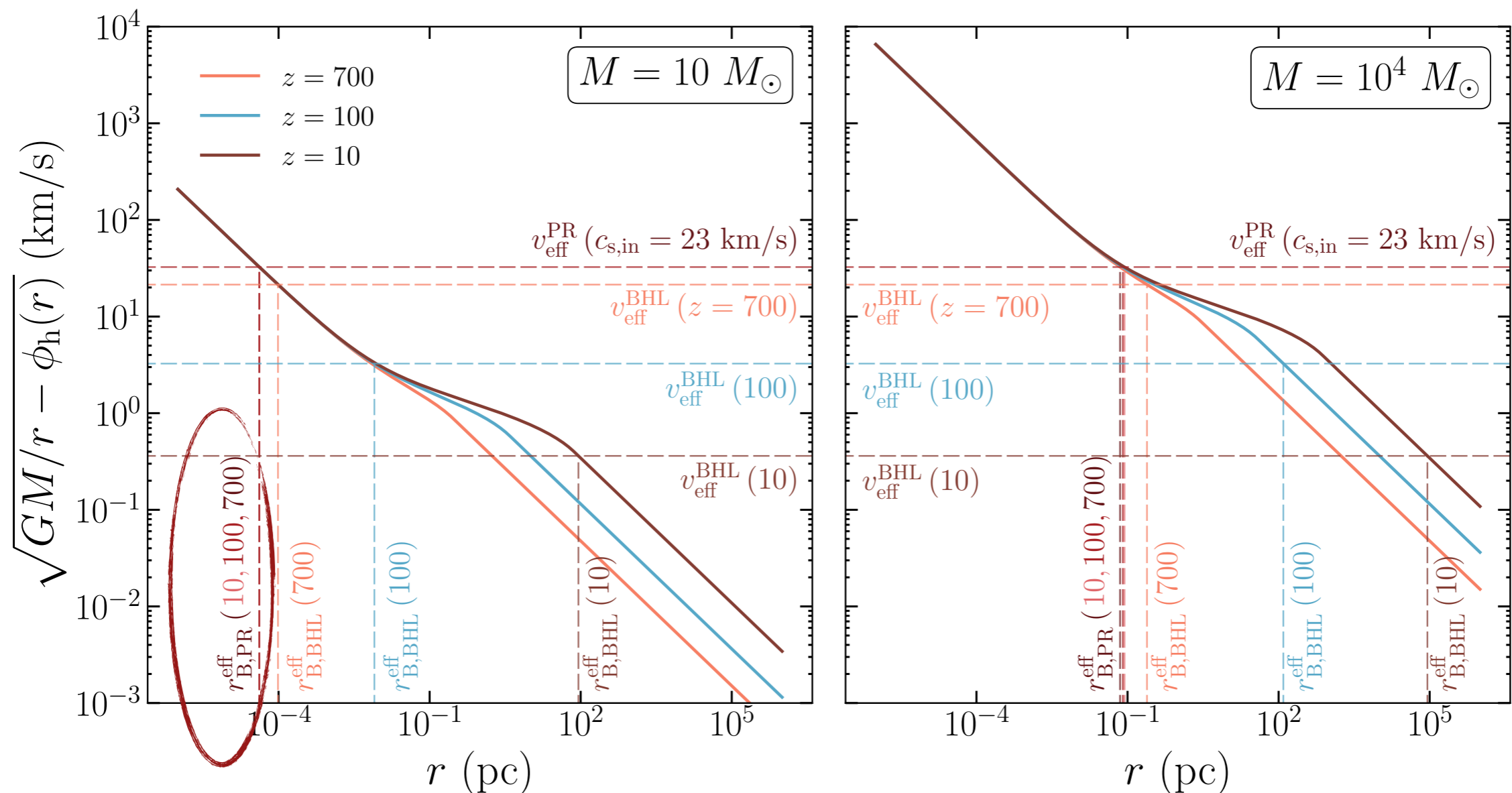
Dominic Agius, Rouven Essig,
DG, Francesca Scarcella,
Gregory Suczewski, Mauro
Valli, *2403.18895*



Backup: Feedback VS DM Mini-halos

The Park-Ricotti model can be recast into a **Bondi problem inside the ionized radius**

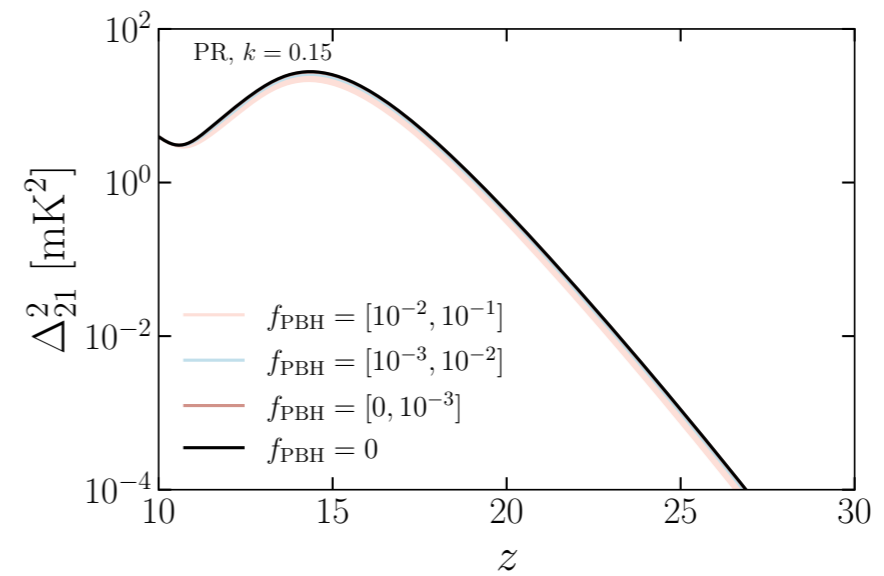
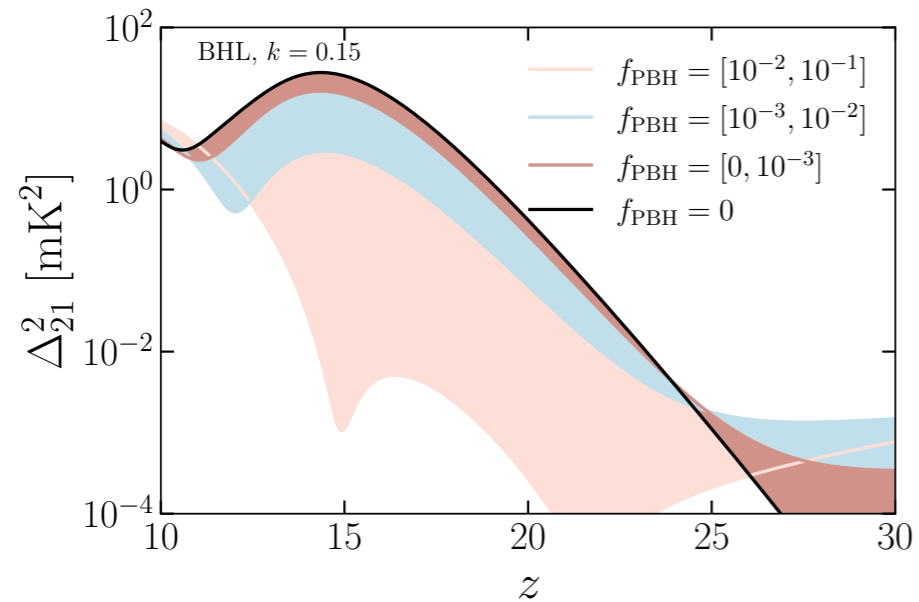
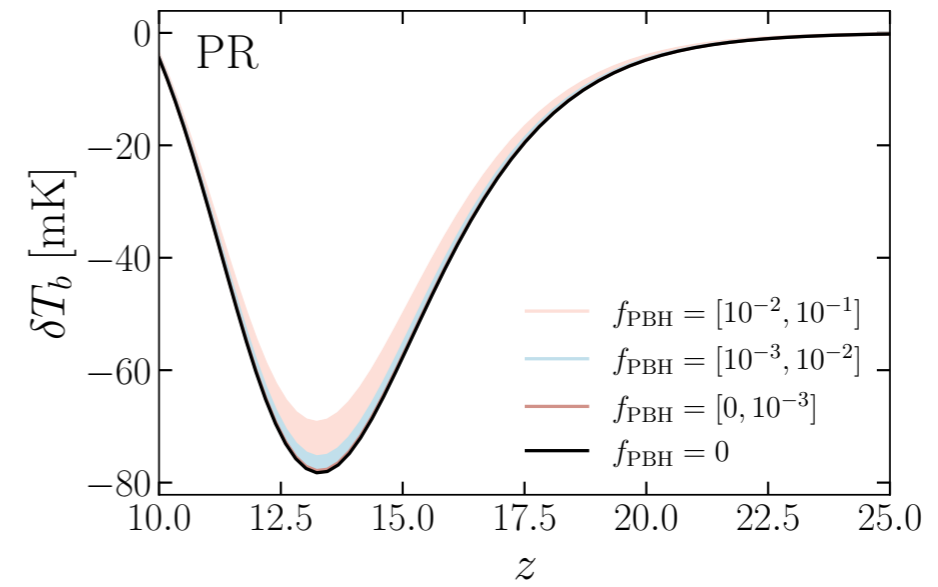
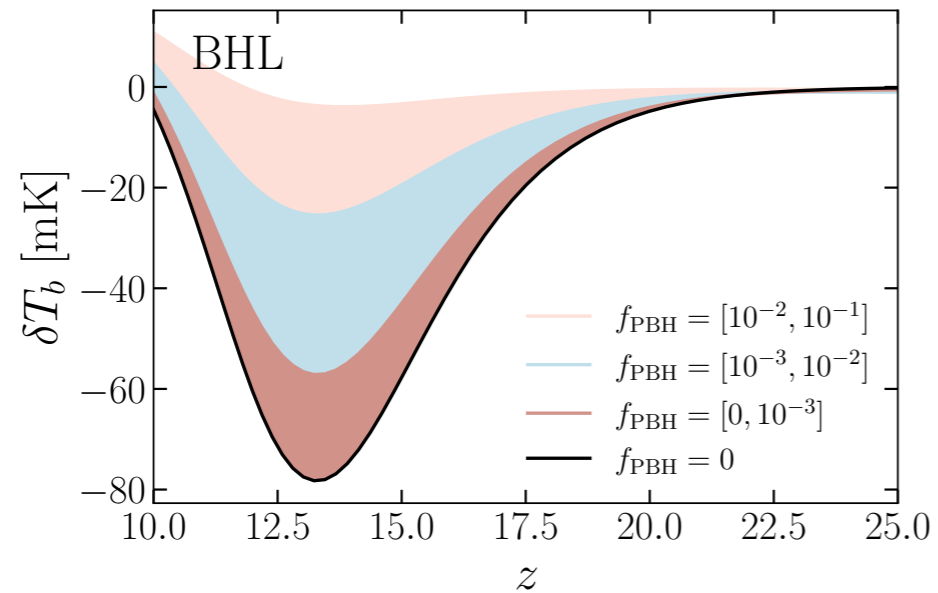
$$\dot{M} = 4\pi\rho_b v_{\text{eff}} (r_B^{\text{eff}})^2 \quad v_{\text{eff}}^{\text{PR}} = (c_{s,\text{in}}^2 + v_{\text{in}}^2)^{1/2} \quad v_{\text{eff}}^2 = \frac{GM}{r} - \phi_h(r)$$



Backup: 21cm impact of PBHs

BHL vs. PR - effect on observables

Made using
ZEUS21 + CLASS



Courtesy of Dominic Agius