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Erratum: Signatures of primordial black holes as seeds of supermassive black holes

José Luis Bernal,[a,b] Alvise Raccanelli,[a] Licia Verde[a,c] and Joseph Silk[d,e,f]

[a]Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (IEEC-UB), Martí Franquès 1, E08028 Barcelona, Spain
[b]Dept. de Física Quàntica i Astrofísica, Universitat de Barcelona, Martí i Franquès 1, E08028 Barcelona, Spain
[c]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain
[d]Department of Physics and Astronomy, Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21218, Maryland, U.S.A.
[e]Institut d'Astrophysique de Paris, UMR 7095, CNRS, UPMC Univ. Paris VI, 98 bis Boulevard Arago, 75014 Paris, France
[f]BIPAC, Department of Physics, University of Oxford, Keble Road, Oxford OX1 3RH, U.K.

E-mail: joseluis.bernal@icc.ub.edu, alvise@icc.ub.edu, liciaverde@icc.ub.edu, joseph.silk@physics.ox.ac.uk

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This is an erratum of the paper "Signatures of primordial black holes as seeds of supermassive black holes" published in the Journal of Cosmology and Astroparticle Physics, ref. [1]. In the original version of the paper there was a misinterpretation of fitting formulae for the hydrogen de-excitation rates due to collisions with electrons. This fitting formula (corresponding to eq. (2.6) in the original version) was obtained from ref. [2]. In turn, ref. [2] took the γ term from the functional fit of ref. [3]. While the logarithms appearing in the fit for γ are base 10, they were interpreted as natural logarithms in this work. This confusion arose from the lack of specification of the logarithm's bases.

In order to amend this confusion, we explicitly discuss the changes needed in the equations presented in section 2.1 of the original version, as well as correct typos and transcription

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errors in some of the equations (which did not modify the results, since they only appeared in the paper and not in our computations). The correct fitting formulae for the de-excitation rates due to neutral hydrogen, electrons and protons, are given by:

$$C_H = n_H x_H \kappa, \tag{1}$$

$$C_e = n_H(1 - x_H)\gamma_e, \tag{2}$$

$$C_p = 3.2 n_H(1 - x_H)\kappa, \tag{3}$$

where n_H is the hydrogen comoving number density, x_H is the hydrogen neutral fraction, $\kappa = 3.1 \times 10^{-11} T_k^{0.357} \exp(-32/T_k)$, $\log_{10} \gamma_e = -9.607 + 0.5 \log_{10}(T_k) \exp[-(\log_{10} T_k)^{4.5}/1800]$ for $T_k \leq 10^4$ K, otherwise, $\gamma_e(T_k > 10^4\,\mathrm{K}) = \gamma_e(T_k = 10^4\,\mathrm{K})$, and T_k is the kinetic temperature of the gas. Note that the changes in equations (1), (2), and (3) with respect to the original version are only due to typos, and did not affect the calculations. On the other hand, the confusion on the base of the logarithms in the fitting formula for γ did affect our calculations, and propagated through the radial profiles around the primordial black holes (PBHs) of the different quantities shown in section 3.

By using natural logarithms instead of the correct base 10 logarithms, the de-excitation rate due to collisions with electrons was overestimated. Since this contribution dominated the spin temperature at large distances from the PBH, it artificially extended the radial profiles of the spin temperature T_s to larger distances. The corrected T_s radial profile results in a much smaller bubble around the PBH where the 21 cm brightness temperature, T_{21}, and the derivative of T_{21} with respect to the baryon overdensities, α, signals are different from the background, as well as the almost total disappearance of the dip features.

The absence of the strong absorption feature and the reduced extension of the radial profiles have a critical impact in the observables considered in this work. With the corrected $T_{21}(r)$ profiles, the contribution of the local modifications to the global sky-averaged signal of T_{21} around PBHs is too small to be distinguished from the standard, no PBHs, scenario. The contribution from PBHs to the T_{21} angular power spectrum is smaller and it is limited to smaller scales. We show the total T_{21} angular power spectrum, including the PBH contribution, as a function of the PBH abundance Ω_{PBH}, M, λ, and redshift, in figure 1. When compared with the previously reported results, the corrected contribution of the PBHs to the T_{21} angular power spectrum does not depend much in redshift, and it is indeed limited to smaller scales and its amplitude is lower.

The original work had a mistake in the signal-to-noise (S/N) estimation and the Fisher forecast: it did not account for all the multipoles that would be observed by the considered experiments, and it only used band powers without correctly accounting for their width. We correct that mistake by explicitly considering each observable multipole and summing the individual contributions. This implies that, while the PBH contribution is smaller and affects the T_{21} angular power spectrum at smaller scales than previously predicted, the total S/N that we report here is not significantly smaller than in the original work. The main limitation of the experiments will be their angular resolution, and subsequent observable maximum multipole. We show the evolution of the total S/N with redshift for different PBHs populations and each realization of the Lunar Radio Array (LRA) in figure 2, showing explicitly its dependence on the PBH parameters. The PBH contribution would be detectable with high significance by LRA2 and LRA3, as well as by the advanced realization of SKA (although with much lower significance and only for some PBHs population parameters).

Finally, table 1 reports forecasted relative errors on Ω_{PBH} and λ for several choices for the parameters of the PBH population. Given that the PBH contribution dominates at very

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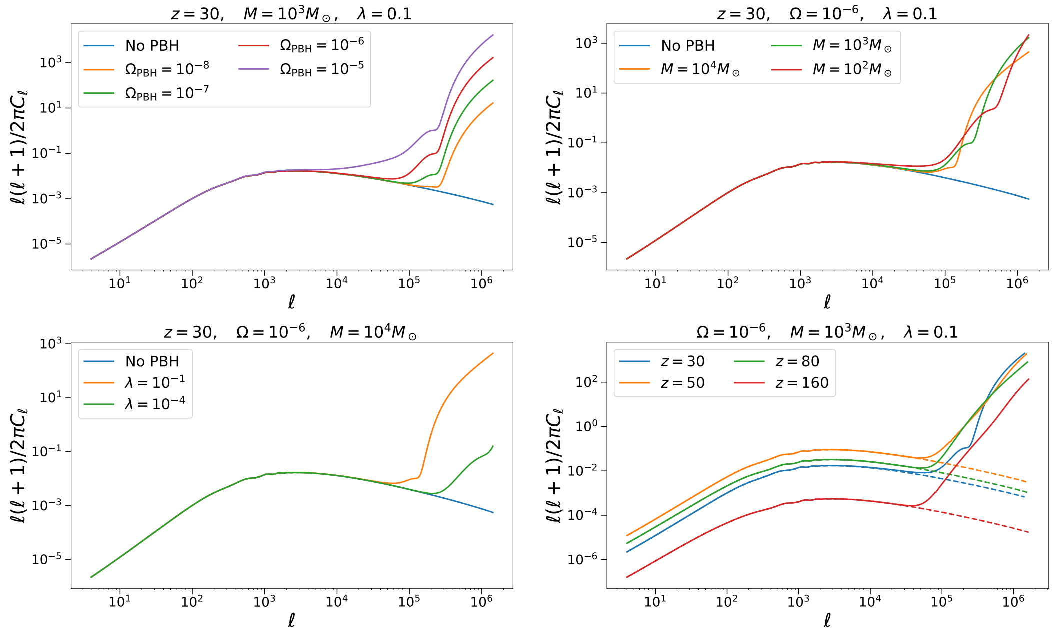


Figure 1. Total T_{21} angular power spectrum compared with the standard scenario without PBHs (in blue in all panels except in the lower right panel, where it is shown as dashed lines) varying the PBHs abundance, their mass, the Eddington ratio, and the redshift.

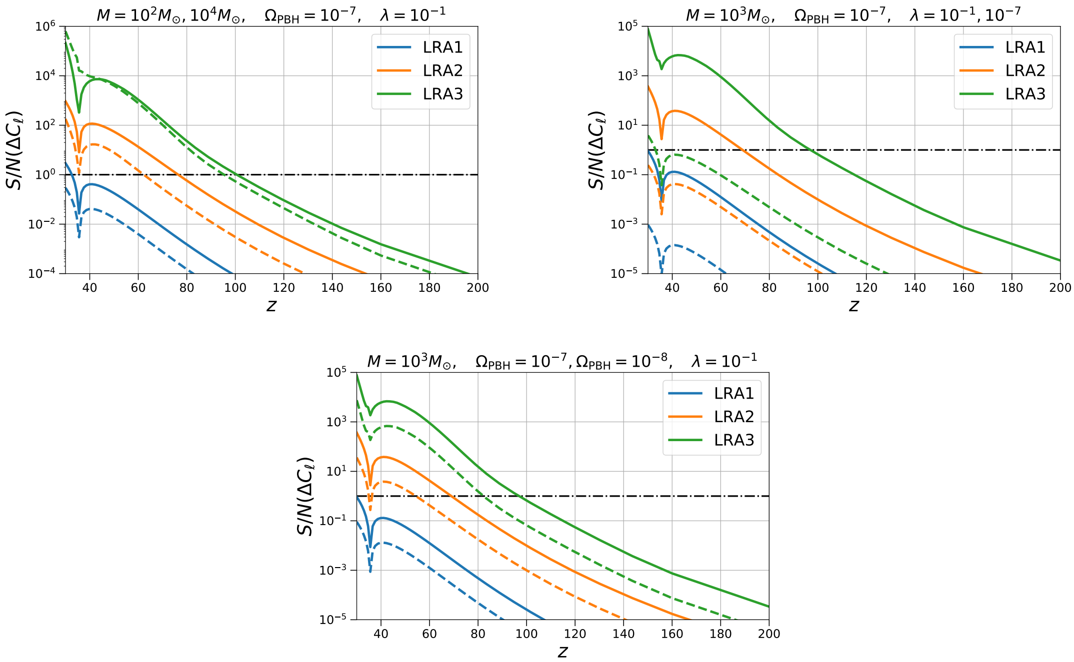
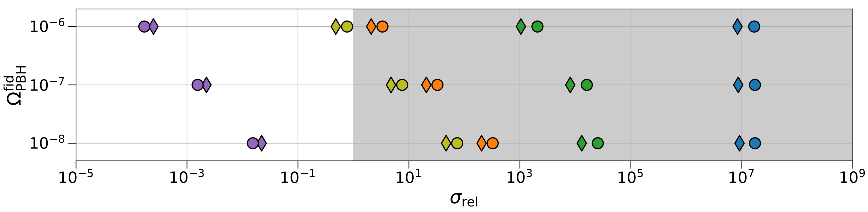
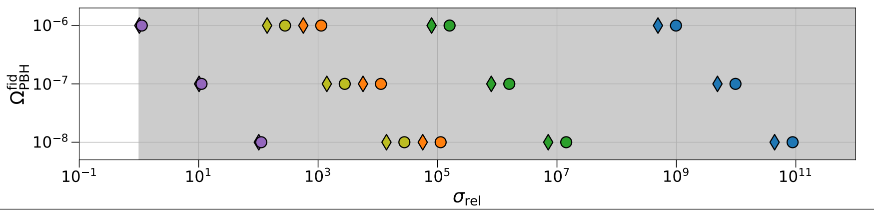
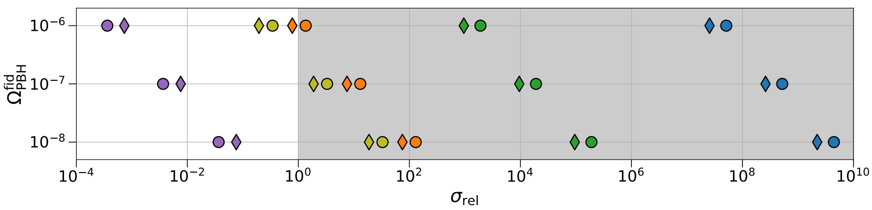
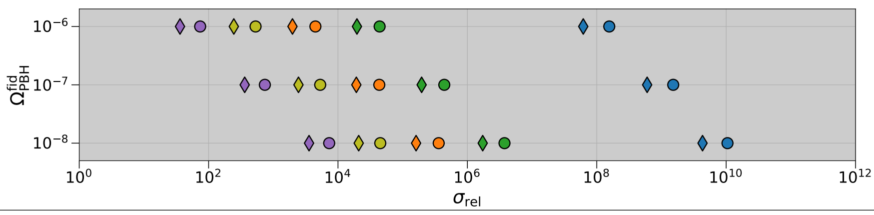
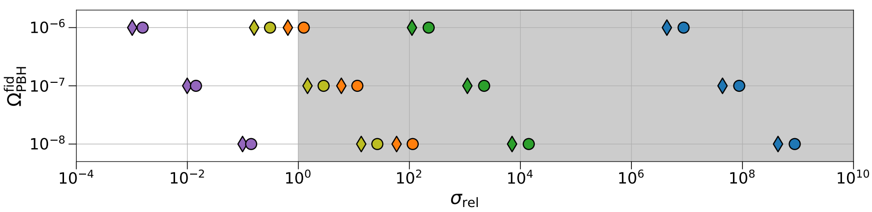
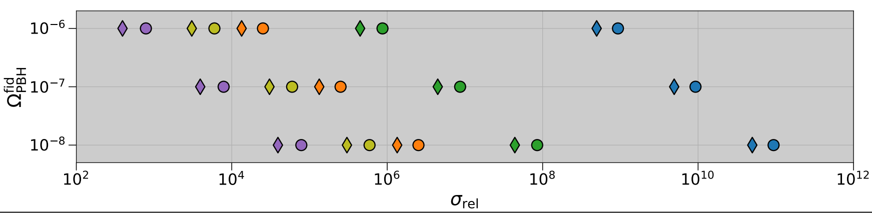


Figure 2. Evolution of the signal-to-noise ratio for the contribution of PBH to the power spectrum (i.e., the difference between the power spectrum accounting for the PBH contribution and the standard one, without PBHs) as a function of redshift. We show different PBH parameters (in each panel dashed lines denote the second value for the corresponding parameter specified above the panels). Results for the three realizations of the LRA are shown in different colors.

small scales, SKA will not have enough angular resolution to detect the PBH contribution. Moreover, given the low significance of the measurement of the PBH contribution by LRA1 and the advanced SKA, these experiments would enable a detection of the signal but not to constrain the PBH parameters. Thanks to a better angular resolution, LRA2 could be able to constrain the PBH parameters for the cases with high Eddington ratio and PBH abundance. Finally, LRA3 will have the power to precisely constrain the PBH parameters in the cases of high Eddington ratio, since it will be able to observe the shape of the PBH contribution at very small scales. However, for the cases with small Eddington ratio, these scales would be too small even for LRA3.

With the corrections addressed in this erratum, some of the caveats discussed in the original work disappear. Given the reduction of the sizes of the bubbles around the PBHs, bubbles will not overlap, so our treatment of isolated PBHs in the halo model context remains correct. We emphasize that we have focused solely on the local effects of the PBHs (i.e., on the modifications to the 21 cm signal in the PBH vicinity) and the Poisson contributions. If the radiation from the PBH accretion can escape its vicinity, it may heat and ionize the intergalactic medium. In this case, there would be an uniform modification to the sky-averaged 21 cm signal (see e.g., [4] for a study at redshifts below 30). Nonetheless, this contribution during the dark ages would only affect the amplitude of the power spectrum, and therefore it will be degenerate with the standard T_{21} and the eventual bias of the line-intensity maps, hence being less informative than the shape of the angular power spectrum.

$M_{\rm fid}(M_\odot)$	$\lambda_{\rm fid}$	Forecasted precision
10^4	10^{-1}	
	10^{-4}	
10^3	10^{-1}	
	10^{-7}	
10^2	10^{-1}	
	10^{-10}	

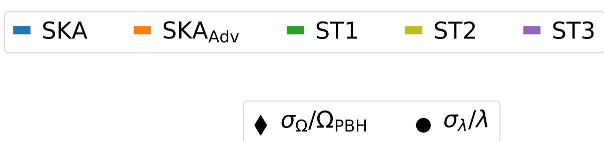


Table 1. 1σ forecasted relative uncertainties on the abundance of PBHs, $\Omega_{\rm PBH}$, $(\sigma_\Omega/\Omega_{\rm PBH})$ and the Eddington ration, λ (σ_λ/λ) for different fiducial cases and experiments using Fisher matrices. Note the change of scale in $\sigma_{\rm rel}$ for each case. We denote the region $\sigma_{\rm rel} > 1$ with a shaded background.

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