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SUPPLEMENTARY INFORMATION

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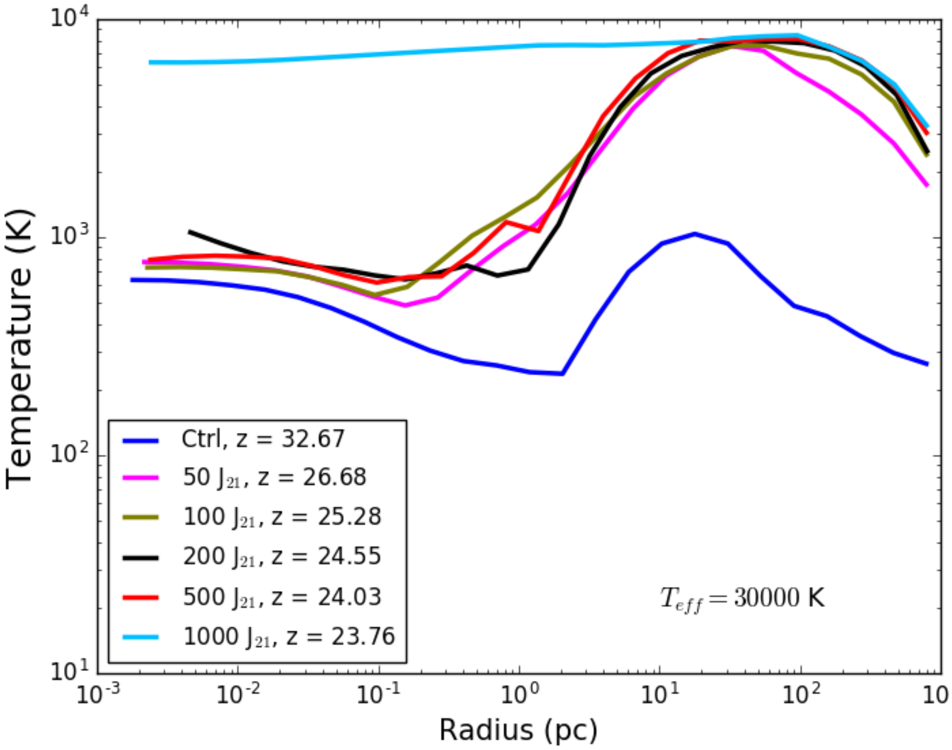
Rapid formation of massive black holes in close proximity to embryonic protogalaxies



Supplementary Figure 1: Background Radiation Fields. Radial profile of the temperature for different background field strengths. The background field is modelled as a blackbody with an effective temperature of 30000 K. The bright nearby source is not included in these simulations, and the radiation is purely that of the longer-lived background radiation field. The "Ctrl" field represents the no-background case, with the background field strength then increasing up to 1000 J_{21}. For this halo realisation, the critical field strength is reached when the background field is $\sim 1000\ J_{21}$. Achieving such a high background field in the high-z Universe is not viable, and in practice what will be required is a background augmented by an excess of local source(s), by unusually large streaming motions between baryons and dark matter, and/or by an unusually rapid merger history (see main text for discussion).

Supplementary Table 1: Simulation Details

Sim Name[a]	Background[b]	z_{on}[c]	$z^d_{collapse}$	T^e_{sync}	T^f_{on}	$\mathrm{R}^{\mathrm{g}}_{\mathrm{sep}}$	Result[h]
z2550_100_350	100	25.50	24.37	1.59	8.53	322	**Molecular**
z2550_100_250	100	25.50	24.19	1.59	9.97	251	Atomic
z2540_100_350	100	25.40	24.40	0.87	7.51	322	**Molecular**
z2540_100_250	100	25.40	24.20	0.87	9.13	276	Atomic
z2530_100_350	100	25.30	24.45	0.14	6.50	321	**Molecular**
z2530_100_250	100	25.30	24.25	0.14	8.05	242	**Molecular**
z25285_100_350	100	25.285	24.45	0.04	6.39	321	Atomic
z25285_100_250	100	25.285	24.26	0.04	7,91	242	**Molecular**
z2530_150_300	150	25.30	24.06	3.37	9.66	303	Atomic
z2515_150_200	150	25.15	23.98	2.27	9.30	218	Atomic
z2500_150_350	150	25.00	24.38	1.14	4.78	388	**Molecular**
z2500_150_250	150	25.00	24.10	1.14	7.10	237	Atomic
z2490_150_350	150	24.90	24.41	0.38	3.83	388	Atomic
z2490_150_250	150	24.90	24.18	0.38	5.68	236	Atomic
z2486_150_350	150	24.86	24.46	0.1	3.12	388	Atomic
z2486_150_250	150	24.86	24.23	0.07	4.88	235	Atomic
z2500_200_250	200	24.62	24.15	3.47	6.69	390	**Molecular**
z2500_200_350	200	24.62	23.93	3.47	8.51	238	Atomic
z2480_200_300	200	24.65	24.24	1.95	4.43	388	**Molecular**
z2480_200_400	200	24.65	23.99	1.95	6.48	262	Atomic
z2460_200_250	200	24.60	24.33	0.40	2.15	387	**Molecular**
z2460_200_400	200	24.60	24.16	0.40	3.53	235	Atomic
z2457_200_250	200	24.57	24.15	0.16	3.37	360	Atomic
z2457_200_400	200	24.57	23.93	0.16	5.20	262	Atomic
z24555_200_250	200	24.555	24.39	0.007	1.31	387	**Molecular**
z24555_200_400	200	24.555	24.26	0.007	2.36	309	Atomic

The above table contains the simulation name[a], the uniform background radiation field in units of J^b_{21}, the redshift at which the primary halo turns "on"[c], the collapse redshift of the secondary halo[d], the synchronisation time in Myrs[e], the time for which the primary halo was on in Myrs[f], the average separation, in parsecs, between the primary and the secondary[g] and finally the result of the collapse (i.e. an atomic collapse or a molecular collapse[h]). All units are physical, unless explicitly stated otherwise.

Supplementary Table 2: Radiation Spectrum

Source	L [ph/s]	Energy Bins [Ev]	Energy Fraction
Metal Enriched	1.2×10^{52}	$2.0, 12.8, 14.55, 25.05$	$0.7510, 0.1080, 1.33 \times 10^{-7}, 2.54 \times 10^{-3}$
PopIII	1.0×10^{52}	$2.0, 12.8, 18.37, 47.23$	$0.4585, 0.1509, 2.88 \times 10^{-4}, 4.77 \times 10^{-2}$

The radiation spectra for both the metal enriched galaxy model we used in this study as well as a comparable PopIII model. The spectra are convolved with a shielding function which is based on a simple model of interstellar-medium extinction and accounts for absorption of the ionising radiation within the primary halo itself. The density distribution and emission spectra are based on the high resolution simulations of Wise & Cen (2009)[1]. The model convolves the spectral energies (above 13.6 eV) with a simple modelling of the optical depth to ionising radiation[17].

References

[1] Wise, J. H. & Cen, R. Ionizing Photon Escape Fractions From High-Redshift Dwarf Galaxies. *Astrophys. J.* **693**, 984–999 (2009).