obscuration and is not unusual[16]. Although SPT0311−58 E is the less massive of the two components, even it is rare among ultraviolet-detected galaxies at $z \approx 7$. Such galaxies are found in blank-field surveys to have a sky density of just one per 30 square arcminutes[17].

The far-infrared continuum and line emission of SPT0311−58 E and SPT0311−58 W (Fig. 1d–f) imply substantial differences in the physical conditions in these objects. Compared to SPT0311−58 W, SPT0311−58 E has a higher ratio of [C II] line emission to 160-μm continuum emission and a much larger luminosity ratio between [O III] and [C II]. The [O III] emission is much more luminous in SPT0311−58 E, with most of SPT0311−58 W (excluding the southern end) showing no emission at all. Because the formation of O^{++} ions requires photons with energies of more than 35.1 eV, this line arises only in ionized regions around the hottest stars and near active galactic nuclei[18]. It is unlikely that active galactic nuclei are the origin of the [O III] line in SPT0311−58 E, because the continuum and line emission both extend across most of the galaxy rather than being concentrated in a putative nuclear region. Observations of [O III] 88-μm emission in actively star-forming galaxies at low[7,19] and high[20] redshift have found that the line luminosity ratio between [O III] and [C II] increases as gas metallicity decreases. The ultraviolet photons capable of forming O^{++} have a longer mean free path in a lower-metallicity interstellar medium than in a higher-metallicity one, and the electron temperature remains higher for the same ionizing flux, both of which favour increased [O III] emission[21]. The difference in the [C II] line-to-continuum ratio may result from multiple effects: the known suppression[22–24] of the [C II]-to-L_{IR} ratio in regions of increased star-formation surface density (higher in SPT0311−58 W), and the increased [C II]-to-L_{IR} ratio in star-forming galaxies of lower metallicity[7]. Whether SPT0311−58 E (or the southern edge of SPT0311−58 W, which is similar to SPT0311−58 E in these properties) has a more primordial interstellar medium than does the bulk of SPT0311−58 W can be tested with future observations.

The masses of the components of SPT0311−58 are remarkable for a time only 780 Myr after the Big Bang. In Fig. 2 we compare SPT0311−58 to objects at $z > 5$ for which we have estimates of dust mass (M_{dust}) or total gas mass (M_{gas}). For SPT0311−58, the best constraints on both of these quantities come from the joint analysis[6] of its far-infrared continuum and line emission, specifically the rotational transitions of carbon monoxide and neutral carbon. Here we have divided these masses between the two galaxies according to the lensing-corrected ratio of dust continuum emission (6.7) that we determined from our three high-resolution ALMA continuum observations because the dust continuum luminosity is roughly proportional to the dust mass. The corresponding dust and gas masses for SPT0311−58 W are $M_{gas} = (2.7 \pm 1.7) \times 10^{11} M_\odot$ and $M_{dust} = (2.5 \pm 1.6) \times 10^9 M_\odot$, and for SPT0311−58 E are $M_{gas} = (0.4 \pm 0.2) \times 10^{11} M_\odot$ and $M_{dust} = (0.4 \pm 0.2) \times 10^9 M_\odot$. The gas mass can also be estimated using the carbon monoxide luminosity, although the conversion between luminosity and gas mass in this optically thick line is known to vary substantially depending on many factors, including star-formation intensity and metallicity[25]. Taking the observed[6] luminosity in the $J = 3$–2 line of carbon monoxide, converting it to $J = 1$–0 under the conservative assumption of thermalized emission, and connecting luminosity to mass using a standard value of $\alpha_{CO} = 1.0 M_\odot$ (K km s^{-1}pc^2)$^{-1}$, we derive $M_{gas} = (6.6 \pm 1.7) \times 10^{10} M_\odot$ for SPT0311−58 W and $M_{gas} = (1.0 \pm 0.3) \times 10^{10} M_\odot$ for SPT0311−58 E. The gas mass of SPT0311−58 W is well above those of all of the known galaxies at $z > 6$, that is, during the first approximately 900 Myr of cosmic history.

SPT0311−58 highlights an early and extreme peak in the cosmic density field and presents an opportunity to test the predictions for the growth of structure in the current cosmological model. The mass of the dark-matter halo that hosts SPT0311−58 is uncertain, but can be estimated in several ways. For most massive star-forming galaxies[26,27] the gas mass represents the dominant component of

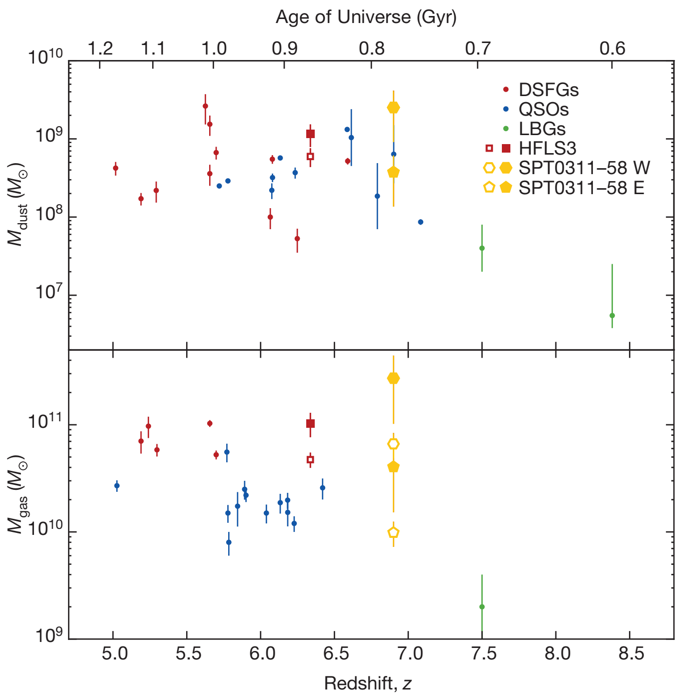

Figure 2 | Mass measurements for high-redshift galaxies. Dust masses (M_{dust}) are taken from the literature, as described in Methods. Gas masses (M_{gas}) are primarily derived from observations of various rotational transitions of carbon monoxide, with previously reported line luminosities converted to molecular gas masses under standardized assumptions (see Methods). The comparison sample (small filled circles) includes three classes of object: dusty star-forming galaxies (DSFGs; red), quasars (QSOs; blue) and Lyman-break galaxies (LBGs; green). These objects are typically selected by far-infrared emission (DSFGs) or by optical or infrared emission (QSOs and LBGs). Three additional DSFGs—SPT0311−58 E (yellow pentagons), SPT0311−58 W (yellow hexagons) and HFLS3 (red squares)—have extensive photometry and line measurements, which enable more sophisticated estimates of their dust and gas masses[6,29] from a combined analysis of the dust and carbon monoxide line emission. For these objects we also show masses derived under a simpler assumption as open symbols (for SPT0311−58 the methods give very similar answers for M_{dust}). Error bars represent 1σ uncertainties.

baryons that have cooled and assembled at the centre of the dark-matter halo. In this case, for the lower (α_{CO}-based) estimate of gas mass, the cosmic baryon fraction[10] $f_b = 0.19$ places a hard lower bound on the total halo mass of $4 \times 10^{11} M_\odot$. A less conservative assumption incorporates the knowledge, based on observations across a wide range of redshifts, that only a fraction of the baryons in a dark-matter halo (less than one-quarter, $M_b/M_{halo} = 0.05$; see figure 15 of ref. 3) are destined to accrue to the stellar mass of the central galaxy[3]. In this case, a total halo mass of $(1.4$–$7.0) \times 10^{12} M_\odot$ is implied, depending on which estimate of gas mass is adopted. To understand the rareness of the dark-matter halo that hosts SPT0311−58, we calculate curves that describe the rarest haloes that should exist in the Universe at any redshift[28]. In Fig. 3, we show the halo masses that are inferred for many high-redshift galaxies, using the same methods for converting gas mass to halo mass as described above. We find that SPT0311−58 is indeed closest to the exclusion curves and therefore marks an exceptional peak in the cosmic density field at this time in cosmic history.

We have found a system of massive, rapidly star-forming, dusty galaxies at $z = 6.900$, the most distant galaxies of this type discovered so far. Two compact and infrared-luminous galaxies are seen, separated by less than 8 kpc in projection and 700 km s^{-1} in velocity, probably in the process of forming one of the most massive galaxies of the era. Even before coalescence, the larger galaxy in the pair is more massive than any other known galaxy at $z > 6$. Although the discovery of such