METHODS

Definitions. Throughout this paper we adopt a Chabrier[31] initial mass function (IMF). For ease of comparison with previous studies, we take H_0 (the Hubble constant) to be 70 km s^{-1} Mpc^{-1}, $\Omega_{\rm m}$ (the matter density) to be 0.3, and Ω_Λ (the dark-energy density) to be 0.7, which gives a physical scale of 5.3 kpc per pixel at $z = 6.8$. Magnitudes are quoted in the AB system[32]. Units are given in terms of solar mass (where $M_\odot = 1.99 \times 10^{33}$ g) and solar luminosity (where $L_\odot = 3.84 \times 10^{33}$ erg s^{-1}) where possible.

Data. We obtained ALMA observations centred on the sources COS-3018555981 (right ascension (RA) = 10 h 30 min 185 s; declination (dec.) = +02° 15′ 59.81″) and COS-2987030247 (RA = 10 h 0 min 29.870 s; dec. = +02° 13′ 02.47″) as part of a filler programme (project code 2015.1.01111.S; principal investigator R.S.) on 14 April 2016, in cycle 3. We requested three tunings to cover the frequency range 1,870.74–1,971.43 GHz in band 6, in order to scan for [C II] at redshift $z = 6.45$–6.90, corresponding to the 99% photometric redshift probability range[7]. One tuning was executed, scanning the redshift range $z_{\rm [C\,II]} = 6.74$–6.90, with 24 min of source-integration time for each of the targets. The precipitable water vapour (PWV) of the observations was 1.34 mm. The array consisted of 36 antennas and three spectral windows having a bandwidth of 1.875 GHz, to cover a frequency range of 4.95 GHz in a single sideband.

We calibrated and reduced the data with Common Astronomy Software Application (CASA)[33] version 4.5.3, using the automated pipeline, and we imaged the data with the CLEAN task (requiring no iterations, as no continuum sources are detected in the data), using a natural weighting for optimal signal-to-noise. The resulting observations reached an image root-mean-square (r.m.s.) sensitivity of 0.32 mJy beam^{-1} at 243 GHz in a 50 km s^{-1} channel in both pointings. The primary beam has a resolution of 1.1″ × 0.7″ (position angle −48°) for both targets.

We also made use of Hubble Space Telescope (HST) WFC3/F160W (H_{160}) imaging, as well as the photometry of these objects that was used in the selection of our galaxies previously[7].

Line detections. *COS-3018555981.* We extracted a spectrum from the ALMA cube that was centred on the rest-frame UV continuum of the galaxy detected in the HST H_{160} band of COS-3018555981 as a first guess, and found a clear line detected at around 242 GHz, removed from any atmospheric absorption features and with a peak flux of more than 3.5σ above the local noise. Next, we extracted a spectrally averaged map between 241.85 GHz and 242.10 GHz; this map revealed that the emission line was centred on a faint wing of the UV-continuum detection, 0.27″ removed from the brightest UV clump (Fig. 1). This offset is similar to the typical uncertainty in the HST astrometry of 0.2″ (ref. 34); however, if instead the offset is real, this could quite reasonably suggest that the brightest star-forming region in the UV does not spatially coincide with the dynamic centre of the system.

We determined the significance of the detection by measuring the flux on the spectral-line-averaged map in a 1.1″ × 0.7″ aperture corresponding to the full-width at half-maximum (FWHM) of the beam, and we repeated this measurement 9,000 times at randomly selected positions of the image, resulting in an estimated signal-to-noise ratio of 8.2. To determine the redshift of COS-3018555981, we extracted a new one-dimensional spectrum from all pixels above the half-maximum of the line detection on the spectral-line-averaged map, and we fitted a Gaussian to the observed line to determine a line centre of 241.97 ± 0.01 GHz, corresponding to a [C II] redshift of 6.8540 ± 0.0003, and a linewidth of 232 ± 30 km^{-1} FWHM (Fig. 1). The only lines other than [C II] $\lambda = 158\,\mu$m that are expected to be bright enough to be able to explain our detection are [O I] $\lambda = 63\,\mu$m and [O III] $\lambda = 88\,\mu$m. However, the [O I] $\lambda = 63\,\mu$m and [O III] $\lambda = 88\,\mu$m redshifts of 18.6 and 13.02, respectively, are inconsistent with the HST photometry for this source[7]. Furthermore, the photometric redshift of 6.76 ± 0.07 (ref. 7) is also inconsistent with the [O I] $\lambda = 145\,\mu$m redshift of 7.5, which is the closest infrared line in frequency, if many times fainter, to [C II] $\lambda = 158\,\mu$m.

COS-2987030247. Similarly to the procedure for COS-3018555981, we first searched for an emission line in the spectrum extracted over the rest-frame UV continuum of COS-2987030247. We found a tentative narrow line at 243.4 GHz—40 MHz removed from an atmospheric absorption feature at 243.5 GHz, where the r.m.s. is 1.5 times greater than the median r.m.s. in the data cube. The spectral-line-averaged map extracted between 243.35 GHz and 243.45 GHz shows a >5σ detection close to the position of the HST counterpart; that is, the peak of the map is 0.17″ removed from the UV-continuum emission (Fig. 1).

By sampling the noise in the spectral-line-averaged map in ellipsoidal apertures of the beam size, we measured a signal-to-noise ratio of 5.1 for the detected line at 243.5 GHz, suggesting that the line is indeed a real detection. To further test the significance of the line we performed a blind line search of the data cube. For each pixel in the cube we extracted a one-dimensional spectrum from averaging all pixels within the ellipsoidal aperture of the beam size, and we fitted any tentative lines in the spectrum with a Gaussian. If the difference between the χ^2 of the line fit and that of a straight line was greater than 25 (that is, 5σ), we extracted a velocity-averaged image over the FWHM of the line and inspected the significance of the detection on this image. To remove spurious line detections, we again assessed the significance of any potential line from the random sampling of the flux in ellipsoidal apertures on the line map. While we robustly detected the line over COS-2987030247, we found no other sources with a >5σ detection in both the one-dimensional spectrum and the spectral-line-averaged map. This test, in combination with the small spatial offset from our HST target, confirms that our line detection over COS-2987030247 is real, and not due to a spurious detection showing up close to the r.m.s. peak of the atmospheric absorption feature.

We extracted a new spectrum from all pixels with a flux above the half-maximum flux in the spectral-line-averaged map, and used this to measure a spectroscopic redshift of $z_{\rm [C\,II]} = 6.8076 \pm 0.0002$ for COS-2987030247, in good agreement with the photometric redshift of $z_{\rm phot} = 6.66 \pm 0.14$.

Dust. We obtained dust continuum measurements after identifying the [C II] line in our data, by averaging the remaining part of the data cubes in frequency. We did not find any evidence for flux above the 1σ noise level in the mean continuum image at the source positions. Therefore, we put an upper limit on the continuum flux, and assumed a grey-body approximation for the dust continuum by considering a range of infrared slopes where we varied both the slope (in the range $\beta_{\rm IR} = 1$–2) and the dust temperature (in the range $T_{\rm dust} = 20$–60 K). We derived a 3σ upper limit on the infrared luminosity of $1.3 \times 10^{11} L_\odot$ and $1.1 \times 10^{11} L_\odot$ for COS-3018555981 and COS-2987030247, respectively.

Given that the UV continuum of galaxies is substantially attenuated by even small amounts of dust, comparing the UV colour and the infrared excess—IRX = $L_{\rm UV}/L_{\rm IR}$—can provide insights into the dust-attenuation curve in these galaxies. We derived the UV-continuum slope $\beta_{\rm UV}$, where the flux density is $f_\lambda \propto \lambda^{\beta_{\rm UV}}$, from a power-law fit to the HST J_{125} and H_{160} photometry; we found values of −1.22 ± 0.51 and −1.18 ± 0.53 for COS-3018555981 and COS-2987030247, respectively. Often, interpreting the infrared excess as a means to constrain the dust-attenuation curve can be affected by the geometry of the dust[35]. In particular, a spatial offset between dust-obscured star-forming regions and unobscured UV-emitting regions can produce bluer UV colours for a given IRX[36]. The small spatial offsets measured between the UV continuum and [C II] emission in our sources might indicate such an effect of dust geometry here. However, given that our sources already appear much redder than would be predicted by the Meurer[13] relation for a given IRX, our conclusions are not affected by any spatial offsets of the dust continuum with respect to the UV light.

Star-formation rate and stellar mass. We obtained constraints on the UV-based SFRs rates from the J_{125} band photometry (corresponding to the rest-frame at around 1,600 Å), and on the infrared-based SFRs from the upper limits on the infrared luminosity, and we converted from luminosity to SFRs using the Kennicutt[37] scaling relations. For COS-3018555981, a foreground object of $z = 0.74$ is visible at a projected distance of 2.6″, which could introduce a small boost to the measured fluxes owing to gravitational lensing. However, the stellar mass of this object is only $4 \times 10^9 M_\odot$ (ref. 38), which suggests a modest halo mass, and therefore we estimate the magnification of this source to be no more than 0.1 magnitude (that is, no larger than the measured random errors), as discussed recently[22].

Using the deconvolved size of the [C II] emission as the size of the galaxy, we found a SFR density, $\Sigma_{\rm SFR}$, of $0.91 M_\odot$ yr^{-1} kpc^{-2} and $0.75 M_\odot$ yr^{-1} kpc^{-2} for COS-3018555981 and COS-2987030247, respectively. This is in good agreement with the SFRs obtained using [C II] as a spatially resolved SFR indicator, using the relation calibrated for galaxies from the local KINGFISH sample[20], which predicts a $\Sigma_{\rm SFR}$ of $0.68 M_\odot$ yr^{-1} kpc^{-2} and $0.34 M_\odot$ yr^{-1} kpc^{-2} on the basis of the [C II] surface brightness, $\Sigma_{\rm [CII]}$, of 8.5×10^{40} erg s^{-1} kpc^{-2} and 4.6×10^{40} erg s^{-1} kpc^{-2}.

Although the rest-frame optical photometry of $z > 4$ galaxies can be heavily affected by strong nebular emission lines[39,40], the redshift range $z \approx 6.6-7.0$ offers a unique window where the 4.5 Spitzer/IRAC band is free from contamination by nebular emission lines[7,8], providing a good constraint with which to model the stellar population of galaxies at these redshifts. We used the Bayesian code MAGPHYS[41] with the HIGHZ extension[42] to fit the stellar population. We included the continuum constraints at 243 GHz, but we removed the 3.6-μm Spitzer/IRAC photometry, as this band is affected by high equivalent-width nebular emission ($\mathrm{EW}_{\rm [O\,III]\,+\,H\beta}$ is about 1,000–1,500 Å; ref. 7). We find that both galaxies have best-fitting stellar masses of about $(1–2) \times 10^9 M_\odot$.

Velocity structure and dynamic mass. The line maps extracted in Fig. 1 suggest that the [C II] emission is spatially resolved in both galaxies, which allows us to investigate the presence of any velocity structure in these galaxies. For the central 4″ of the data cube, we extracted a one-dimensional spectrum at every pixel, by averaging all the flux within an elliptical aperture the size of the beam centred on the pixel. We fitted a Gaussian to these spectra, using the parameters from the fit