Spectroscopic confirmation of a gravitationally lensed Lyman break galaxy at $z_{[\text{CII}]} = 6.827$ using NOEMA

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1 INTRODUCTION

In the past decade hundreds of galaxies have been identified in the Epoch of Reionisation, A1703-zD1, through the detection of [C II]158$\mu$m at a redshift of $z = 6.8269 \pm 0.0004$. This source was selected behind the strong lensing cluster Abell 1703, with an intrinsic $L_{\text{UV}} \sim L_{\text{[CII]}}^z$ luminosity and a very blue Spitzer/IRAC [3.6]–[4.5] colour, implying high equivalent width line emission of [O III]+H$\beta$. [C II] is reliably detected at 6.1$\sigma$ co-spatial with the rest-frame UV counterpart, showing similar spatial extent. Correcting for the lensing magnification, the [C II] luminosity in A1703-zD1 is broadly consistent with the local $L_{\text{[CII]}} - \text{SFR}$ relation. We find a clear velocity gradient of $103 \pm 22$ km s$^{-1}$ across the source which possibly indicates rotation or an ongoing merger. We furthermore present spectral scans with no detected [C II] above 4.6$\sigma$ in two unlensed Lyman break galaxies in the EGS-CANDELS field at $z \sim 6.6 - 6.9$. This is the first time that NOEMA has been successfully used to observe [C II] in a ‘normal’ star-forming galaxy at $z > 6$, and our results demonstrate its capability to complement ALMA in confirming galaxies in the Epoch of Reionisation.

Key words: galaxies: evolution - galaxies: formation - galaxies: high-redshift
cover a larger frequency range in one setup, enabling faster line scans. These upgrades arguably make NOEMA the most powerful interferometer in the Northern Hemisphere, and therefore might play an important role in observing [C \text{II}] in galaxies at $z > 6$.

Here we report on a line search for [C \text{II}] 158\mu m with NOEMA, targeting 3 galaxies in the Northern Hemisphere at $z \sim 6.6 - 6.9$. The targets have been selected from a larger sample of Lyman Break Galaxies, with high-precision photometric redshifts (Smit et al. 2014, 2015). A1703-zD1 is the standout target of our sample, lying behind the strong lensing cluster Abell 1703, with a magnification of $\sim 9$ (Bradley et al. 2012). Due to its exceptional observed brightness, it has been targeted many times with previous observations attempting to observe $\text{Ly}_\alpha$, C IV and C III with the Keck Observatory (Schneider et al. 2012; Stark et al. 2015; Mainali et al. 2018) and a previous attempt with PdBI (Schaerer et al. 2015) to observe [C \text{II}], however, these observations did not result in a significant detection.

In this paper we present the successful spectroscopic confirmation of A1703-zD1 and constraints on the properties of the other two sources based on their non-detections. The plan of the paper is as follows. In Section 2 we describe the sample selection and observations. In Section 3 we discuss the method for line scanning and the findings from our scans. In Section 4 we provide the properties of the sources and comparisons to the literature and in Section 5 we give our summary and conclusions. In this paper we adopt a Kroupa IMF (Kroupa 2001). We adopt $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$ throughout. Magnitudes are quoted in the AB system (Oke & Gunn 1983).

2 SAMPLE SELECTION AND OBSERVATIONS

2.1 Target selection and properties

We obtained NOEMA observations of three sources, A1703-zD1 (Bradley et al. 2012; Smit et al. 2014), EGS-5711424617 and EGS-1952445714 (hereafter EGS-5711 and EGS-1952 respectively; Smit et al. 2015). These galaxies were initially selected with the Lyman break technique as HST/F814W drop-out galaxies and subsequently identified as sources with blue Spitzer/IRAC [3.6]–[4.5] colours, implying high equivalent width [O \text{II}]+H\beta emission (Smit et al. 2014, 2015). The spectral energy distribution (SED) for each galaxy is shown in Appendix A.

We selected these targets due to their observed brightness ($m_{\text{UV}} \sim 24 - 25$), but also as they are representative of ‘normal’ star-forming galaxies ($SFR < 100 \text{ M}_\odot \text{ yr}^{-1}$) at $z \sim 7$, with intrinsic (corrected for lensing magnification, A1703-zD1 is magnified $\sim 9\times$) UV SFRs of $5 - 38 \text{ M}_\odot \text{ yr}^{-1}$. A list of some of the basic properties for all three galaxies are shown in Table 1. These same selection criteria were recently used to successfully confirm galaxies with ALMA at $z_{[\text{C} \text{II}]} = 6.808 - 6.854$ (Smit et al. 2018).

The inferred emission lines in the Spitzer observations reduce the probability range for the redshift such that observations can be carried out using one NOEMA setup. For both A1703-zD1 and EGS-1952 the photometric redshifts of $6.74^{+0.11}_{-0.10}$ and $6.75^{+0.11}_{-0.10}$, respectively, are within this range. However, we note that EGS-5711 has $z_{\text{phot}} = 6.47^{+0.11}_{-0.10}$ outside of the colour selection range due to a tentative detection in the HST/F814W band. For the extreme emission line sources from (Smit et al. 2015), systematic changes in the estimated photometric redshift ($\Delta z \sim 1$) are found when making changes to the input template set (in particular the strength of the emission line equivalent widths of the templates) used to fit the SEDs. As a result of these systematic uncertainties, we rely on the Spitzer/IRAC colour selection from Smit et al. (2015) to identify sources most likely in the redshift range $z \sim 6.6 - 6.9$, which includes some cases (like EGS-5711) where the $z_{\text{phot}}$ is not within this range.

For A1703-zD1 we use a magnification value of $9.0^{+0.9}_{-0.4}$ taken from Bradley et al. (2012) calculated using the model described in Zitrin et al. 2010. The magnification error represents the extreme value obtained from the minimum and maximum magnifications obtained within 0.5 arcsec of the target and assuming $\Delta z \pm 1.0$ for the source redshift. To obtain a better handle on the systematic uncertainties in the lensing magnification we ran two more trial models, one using a revised version of the Light Traces Mass (LTM) technique and one fully parametric model. These models suggest a magnification in agreement with that of Bradley et al. (2012) within the uncertainties, though towards the lower end ($\mu \sim 4 - 5$). Critically, the weight of the nearby cluster galaxy (seen in the bottom of Figure 1) is fixed according to the scaling relations, but in reality has a significant uncertainty that affects the magnification value. We therefore adopt the published magnification by Bradley et al. (2012) ($\mu=9.0^{+0.9}_{-0.4}$), as the uncertainties are broad enough to include the new magnifications from the trial models.

Throughout the paper, we report measured quantities (i.e. [C \text{II}] flux) as observed in the image plane, without a magnification correction, whereas derived physical quantities (i.e. $L_{\text{[CII]}}, SFR_{\text{[CII]}}$ and physical size) are corrected for the adopted lensing magnification.

2.2 NOEMA observations and data reduction

We obtained 1.2 mm observations using NOEMA in its most compact 10D configuration, with a single setup for each of the three sources, A1703-zD1, EGS-5711 and EGS-1952, approved in program W18FC.

Observations of A1703-zD1 were taken on 21 March 2019, with 4.1 hours on source, and covering the frequency range 241.45 – 249.08 GHz (upper side band, USB) and 225.97 – 233.60 GHz (lower side band, LSB), corresponding to a redshift range 6.63 – 6.87 and 7.14 – 7.41 respectively. The USB frequency range partly overlaps with PdBI observations taken in 2013 by Schaerer et al. (2015) and we combine the NOEMA and PdBI data in the UV-plane to obtain maximum depth over the redshift range of 6.80 – 6.88.

We observed EGS-5711 on 16 April, 30 April 2019 and 02 May with 7.1 hours on source in total. EGS-1952 was observed on 08 and 09 April 2019 as well as on 02 and 03 May 2019 with 8.7 hours on source in total. Observations for both of these targets covered the same frequency and redshift range. LSB coverage was 240.4 – 248.3 GHz, corresponding to redshift of 6.66 – 6.91 and USB coverage was 255.8 – 263.7 GHz, corresponding to redshift of 6.21 – 6.43. The coverage described here is shown alongside the SED in Appendix A.

All of the data were reduced using the GILDAS software. From the NOEMA data of A1703-zD1 alone, we obtain a datacube with a median rms of 0.87mJy in a 40 km s$^{-1}$ channel, with a beam size of 1.52 $\times$ 1.28 arcsec. After merging with PdBI data (Schaerer et al. 2015) we obtain a datacube with a median rms of 0.83mJy in a 40 km s$^{-1}$ channel, with a beam size of 1.57 $\times$ 1.31 arcsec ($\sim 2$ times lower sensitivity than ALMA observations in Smit et al. 2018). We then tapered the datacube for A1703-zD1 such that the beam size matched the spatial extent of the source in the HST imaging using a 50 metre taper at a 170 degree angle, in order to obtain a more accurate measurement of the total flux. We also cleaned the data with 100 iterations before imaging the datacube, including a threshold of 0.85mJy (2 $\times$ rms) to reduce the effects of contamination from a strong CO(3-2) emission line signal observed from a serendipitous...
source. This leads to a median rms in the datacube of 0.73 mJy in a 40 km s\(^{-1}\) channel, with a beam size of 2.88 × 1.48 arcsec.

We imaged the two EGS datacubes with natural weighting for optimal point source sensitivity, resulting in a beam size of 1.69 × 1.41 arcsec and 1.63 × 1.37 arcsec for EGS-5711 and EGS-1952 respectively. Our data reached a typical rms of 0.34 and 0.41 mJy in our beam sizes are expected to cover any observable \([\mathrm{C}]\) at \(z\) = 1 we removed the frequency range in which \([\mathrm{C}]\) and \(\mathrm{LSB}\) before making the continuum images. In the case of A1703-zD1 we taper the datacube to match the spatial extent of these compact targets (Carniani et al. 2020).

We also produced continuum images using GILDAS for all three targets to provide constraints on the dust obscured star formation and on the dust content itself. For all three targets we merged the USB and LSB before making the continuum images. In the case of A1703-zD1 we removed the frequency range in which \([\mathrm{C}]\) was detected in the corresponding side band. We find no continuum detections above 3\(\sigma\) within 1 arcsec of each source and therefore provide upper limits for the \(L_{\mathrm{IR}}\) and \(\mathrm{SFR}_{\mathrm{IR}}\), presented in Table 2. These upper limits are derived by taking 3 \(\times\) rms from the continuum image. Discussion about the significance of these continuum measurements can be found in Section 4.2.

We correct for any offset in the HST astrometry by identifying the closest star to the target galaxy in the Gaia Data Release 3 (DR3). For EGS-5711 and EGS-1952 the observations were taken ~4 years apart and we correct for the proper motion of the star during that timeframe, before shifting our HST image to the Gaia reference star. Unfortunately for A1703-zD1, none of the stars present in the HST image had proper motion data from Gaia DR3 as a result of being too faint (G magnitudes > 21). Given that the HST imaging for Abell 1703 was taken in 2004 (~10 years apart from Gaia), and assuming a similar proper motion to the stars in the EGS field, we expect a ~0.3 arcsec offset from the reported Gaia DR3 position due to proper motion. This angular distance is similar to the typical spatial offset found for the stars in the Abell 1703 field between the HST imaging and Gaia DR3 catalogue. As a result, no improvement in the astrometry of A1703-zD1 could be obtained and we relied on the original HST imaging (see Bradley et al. 2012), but note that a maximum 0.3 arcsec astrometrical offset between the HST and NOEMA data is possible. However, we point out that the morphology and size of the \([\mathrm{C}]\) emission for A1703-zD1 matches well to the HST image, as shown in Figure 1, so any real offset is perhaps likely to be small. Further, the detection of a serendipitous source with much higher S/N is also present and is seen to be co-spatial with the host galaxy as shown in Figure D2.

### Table 1. Table of source properties based on previous observations.

| Target ID | A1703-zD1 | EGS-5711424617 | EGS-1952445714 |
|-----------|-----------|----------------|----------------|
| RA        | 13:14:59.418 | 14:19:57.114 | 14:19:19.524 |
| DEC       | +51:50:00.84 | +52:52:46.17 | +52:44:57.14 |
| \(\zeta_{\text{phot}}\) | 6.7±0.2 \(^{a}\) | 6.47±0.11 \(^{b}\) | 6.75±0.11 \(^{b}\) |
| \(m_{\mathrm{H}160}\) | 24.0 ± 0.1 \(^{a}\) | 25.1 ± 0.1 \(^{b}\) | 25.3 ± 0.1 \(^{b}\) |
| \(M_{\mathrm{UV}}\) | -20.6 ± 0.5 \(^{c}\) | -21.77 ± 0.10 | -21.64 ± 0.10 |
| \(\beta_{\mathrm{UV}}\) | -1.56±0.32 | -2.18±0.36 | -2.36±0.43 |
| \(\mu\) | 9.0±0.9 \(^{a}\) | – | – |

*\(^{a}\) Values from Bradley et al. (2012), \(^{b}\) Values from Smit et al. (2015), \(^{c}\) Values from Smit et al. (2014).*

### Figure 1. The detection of \([\mathrm{C}]\) at \(z = 6.827\) in A1703-zD1. The left panels show the NOEMA+PdBI data collapsed over the frequency range 242.76-242.86 GHz for the untapered (top panels) and tapered (bottom panels) imaging. The right panels show HST \(H_{160}\) imaging (grey-scale image) overlaid with the 2, 3, 4, 5 and 6 \(\sigma\) contours of the \([\mathrm{C}]\) narrowband (red contours). The filled ellipses in the bottom right corner indicate the beam sizes (1.57 × 1.31 arcsec and 2.88 × 1.48 arcsec).

### 3 LINE SCANS

Using the datacubes we obtain after processing, we scan for prominent lines by collapsing channels in the range of 80-400 km s\(^{-1}\) (the range of expected \([\mathrm{C}]\) line-widths). This optimises the width of the collapsed narrowband for which the strongest point-source signal within a 1 arcsec radius of the target source (identified in the HST-imaging) is found, if any. Scanning through the datacube also enables us to identify any lines present from serendipitous sources.

We replicate this scanning in the sign-inverse of the datacube, to check if any noise is comparable to the signal detected from the target source and assess the robustness of any tentative \((>3\sigma)\) line detections. We extract spectra from identified line candidates by summing all pixels detected at S/N > 2 in the collapsed narrowband.

#### 3.1 A1703-zD1

Taking our NOEMA observations of A1703-zD1 in isolation we find a signal at 242.90±0.01 GHz with S/N=4.6, co-spatial with the lower bright clump and extended along the lensed arc, visible in HST-imaging (See Figure 1). From previous observations by Schaerer et al. (2015), we independently identified a tentative detection of \([\mathrm{C}]\) at S/N=3.4 at 242.853±0.009 GHz. The top panel of Figure 1 presents the line detection after combining both data-sets (see Section 2.2), collapsed in a 120 km s\(^{-1}\) channel centered on 242.8 GHz, with a peak S/N of 5.5. To obtain an unresolved measurement of A1703-zD1 we taper the datacube to match the spatial extent of A1703-zD1 (described in Section 2.2). From this we find a detection at 242.82±0.01 GHz with an increase in the peak S/N to 6.1, yielding a best-fit \(\xi_{\text{CII}}\) = 6.8269±0.0004 from the extracted spectrum (See...
Figure 2. The spectrum of A1703-zD1 extracted by summing the flux over the source from all pixels with S/N>2, using the tapered imaging. The red line shows the best fit Gaussian line profile. The grey shaded region gives the measured rms throughout the spectrum.

When scanning for [C II] in EGS-5711 we find a tentative signal with S/N = 4.6 at 246.16 ± 0.02 GHz, 0.5 arcsec away from the centre of the target. This line, if real, would put the source at z = 6.7263 ± 0.0006. A second signal at 242.10 ± 0.07 GHz, 0.5 arcsec away from the A1703-zD1 source, has S/N = 5.1. We also measure a 68 μJy continuum flux from this source with S/N of 5.1.

### 3.2 EGS-5711 & EGS-1952

For EGS-1952 we find no evidence for [C II] with S/N>3, co-spatial with the source. The spectra at the location of the source can be found in the appendix (Figures C1 and C2). Further, we find no continuum signal for both EGS-5711 and EGS-1952 and as a result, we only provide upper limits for the continuum flux and an upper limit estimate for the [C II] line flux, based on the spectral line obtained for A1703-zD1, scaled to the median rms of the EGS-5711 and EGS-1952 datacubes.

Table 2. Galaxy Properties

Due to the low dust content of these sources or alternatively it is possible that the limited frequency range that was scanned for each object missed the line emission entirely. Deeper and wider scans would be needed to distinguish between these two interpretations (see Appendix A).

### 4 SOURCE PROPERTIES

Here we present the physical properties of our three targets derived from our observations and comparisons to the literature. A full table of galaxy properties is shown in Table 2.

#### 4.1 L_{[CII]} vs SFR relation

In Figure 3 we present the measured [C II] luminosity as a function of SFR and include sources from the literature for comparison (Matthee et al. 2019; Knudsen et al. 2016; Bradač et al. 2017; Fujimoto et al. 2021). The UV SFRs are calculated using the Kennicutt & Evans (2012) conversion, using a Kroupa IMF. EGS-5711 and EGS-1952 are given as 3σ upper limits.

In the local universe we see a tight L_{[CII]} – SFR relationship as shown by the De Looze et al. 2014 relation (log SFR = −6.99 + 1.01 × log [CII]) in Figure 3. Recent studies of ‘normal’ (i.e. main sequence) star-forming galaxies with redshifts at 4.4 < z < 5.9 and galaxies at z ~6.5 with high Lyα luminosities have also shown consistency with the local relation when including the dust-obscured SFR (e.g., Matthee et al. 2019; Schaerer et al. 2020). In contrast, a few studies have found that lensed galaxies with a lower SFR are more likely to be below the locally observed relation (e.g., Knudsen et al. 2016; Bradač et al. 2017). In particular the strongest lensed object, MS0451-H (Knudsen et al. 2016), with the lowest intrinsic SFR shows the strongest deficit in L_{[CII]}. If confirmed, this could suggest differing ISM properties in faint, and possibly more metal-poor, high-redshift galaxies. A1703-zD1 is a strongly lensed galaxy with a modest intrinsic SFR_{UV} of 6.7 ± 0.6 M_☉ yr^{-1}, but we find no evidence of a significant offset to the local relation, as A1703-zD1 lies slightly below, but still within 1σ of, the local L_{[CII]} – SFR relation.
4.2 $L_{IR}$ and SFR$_{IR}$ constraints

As discussed in Section 2.2, the continuum flux remains undetected for all our sources. We calculate upper limits for $L_{IR}$ and SFR$_{IR}$ by assuming an optically-thin grey-body infrared SED (Casey 2012) using $T = 50K$ and $\beta = 1.5$, and present the results in Table 2. We estimate that these sources are likely below the classification of Luminous Infrared Galaxies (LIRG; $L_{IR} > 10^{11} L_\odot$). We furthermore find obscured SFR below $5-58 M_\odot yr^{-1}$ ($3\sigma$ limits), which suggests less than 44 – 74% of star-formation comes out in the IR, consistent with recent studies (e.g., Bowler et al. 2018; Schouws et al. 2021).

We derive UV slopes ($\beta$) and upper limits on the Infrared Excess ($IRX = L_{IR}/L_{UV}$) for all our targets (see Tables 1 and 2) and find that the upper-limits for EGS-5711 and EGS-1952 are consistent with either the Meurer et al. (1999) relation or a SMC-like dust attenuation.

However, given a moderately red UV slope for A1703-zD1 of $\beta ~ -1.56$, we find this galaxy to be more consistent with an SMC-like dust attenuation law, in agreement with stacking results of faint LBGs at $z \approx 2 - 10$ (Bouwens et al. 2016; Fudamoto et al. 2017, though see Schouws et al. 2021 for a discussion on the impact of the assumed dust temperature).

4.3 Velocity Structure

We use the spatial extent of the [C ii] detection to investigate the velocity structure of A1703-zD1. We see a velocity gradient across A1703-zD1 shown in Figure 4. We find a maximum projected velocity difference over the galaxy ($\Delta v_{\text{obs}}$) of 103 ± 22 km s$^{-1}$ from the first moment map. Such a velocity gradient could be the signature of a rotating disk, whilst another possibility is a merger of [C ii] emitting galaxies. Similar velocity gradients are present in previous observations of high redshift galaxies (e.g., Smit et al. 2018; Hashimoto et al. 2019; Matthee et al. 2019; Fujimoto et al. 2021) as well as in simulations (Dekel & Burkert 2014).

To determine the likelihood of a disk-like rotation we compare the projected velocity range of a galaxy with the velocity dispersion of the system using $\Delta v_{\text{obs}}/2\sigma_{\text{tot}}$, where a ratio of >0.4 indicates a likely rotation dominated system (Förster Schreiber et al. 2009). We find $\Delta v_{\text{obs}}/2\sigma_{\text{tot}} = 0.79 \pm 0.23$ for A1703-zD1, which supports the interpretation of a possibly rotation dominated system. Bradley et al. (2012) find three distinct star-forming clumps with an extended linear morphology in the source-plane reconstruction of A1703-zD1. In Figure 4 we show the deflection due to the lensing magnification, using the LTM strong-lensing model published by Zitrin et al. (2010). This stretching of the source plane leads to an effective increase in the interpretation of a possibly rotation dominated system.

Clumps like this have been identified previously in high redshift galaxies (e.g., Smit et al. 2018; Hashimoto et al. 2019; Matthee et al. 2019; Fujimoto et al. 2021) as well as in simulations (Dekel & Burkert 2014).
sources, suggesting less than 44 – 74% of star-formation comes out consistent with, but slightly below, the local L–SFR relation. We have presented new NOEMA observations, scanning for the [C II] emission in three Lyman break galaxies with photometric redshifts at z = 6.6 – 6.9. Our main findings are as follows:

- We detect [C II] in one of our three sources, confirming the redshift at z = 6.8269 ± 0.0004 for the strongly lensed galaxy A1703-zD1 (6.1σ). Our non-detections are consistent with these being dust-poor galaxies with low [C II] luminosity.
- We carefully account for any extended emission of [C II] due to lens smearing in A1703-zD1 and find the [C II] luminosity to be consistent with, but slightly below, the local L–SFR relation.
- No continuum emission is detected in any of the three targeted sources, suggesting less than 44 – 74% of star-formation comes out in the IR. For A1703-zD1, our results are most consistent with an SMC attenuation curve.
- We see a velocity gradient across A1703-zD1, with a kinematic ratio that suggests a possible rotation dominated system, though higher resolution [C II] observations will be needed to confirm this.

Over the last few years ALMA has demonstrated its role as a “redshift machine” in the Epoch of Reionisation by confirming galaxies out to redshift z = 9. In this paper we have demonstrated the ability of NOEMA to search for [C II] in ‘normal’ star-forming galaxies at z > 6, complementing ALMA by observing EoR galaxies in the Northern Hemisphere, with [C II] as a reliable spectroscopic tracer of these distant systems. With the launch of JWST this capability will be particularly useful for rare, lensed sources and intrinsically luminous objects that will be discovered far outside the limited JWST survey area using the next generation of large area surveys, such as the Euclid mission and the Rubin observatory.

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DATA AVAILABILITY
The reduced data underlying this article will be shared on reasonable request to the corresponding author.

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APPENDIX A: PHOTOMETRIC REDSHIFT COVERAGE
Here we present the SEDs for all three targets in this paper, alongside the photometric redshift probability distributions, redshift coverage of the observations and in the case of A1703-zD1, the measured $z_{\text{CII}}$. The SED fitting was done using the software Easy and Accurate Zphot from Yale (EAZY; Brammer et al. (2008)), see Smit et al. (2015) for a full description.

We note that for EGS-5711, NOEMA did not cover the central $5_{\text{phot}}$ of 6.47$^{+0.11}_{-0.10}$. The systematic uncertainties in estimating photometric redshifts in extreme emission line galaxies are discussed in section 2.1, which motivated a line search at $z = 6.6 - 6.9$ based on the Smit et al. (2015) colour selection.

APPENDIX B: EGS-5711 TENTATIVE DETECTION
Here we present a 4.6$\sigma$ signal for EGS-5711, with the contours overlayed on the HST imaging in Figure B1 and the corresponding spectra in Figure B2. The spectral extraction is the same as described in Section 3. The weak signal is very narrow and clearly offset from the HST target, which likely makes this a spurious detection.
Figure B1. The S/N = 4.6 signal found for EGS-5711. Background shows the HST H-band image with red contours corresponding to 3 and 4 $\sigma$ [C II] emission. The extracted spectrum is also shown in Figure B2. This source would require further observations to confirm a robust detection.

Figure B2. EGS-5711 spectrum of the S/N = 4.6 signal, extracted from the region of the contours shown in Figure B1, with the best-fit Gaussian line profile in red.

APPENDIX C: EMPTY SCANS

In Figures C1, C2, C3 and C4 we present the empty line scans in the LSB and USB for both EGS targets. The extractions were taken simply from the central pixel of the observations.

APPENDIX D: SERENDIPITOUS SOURCE IN A1703-ZD1 CUBE

Here we present a serendipitous 14$\sigma$ detection in the datacube of A1703-zD1, with the spectra shown in D1 and the line contours overlayed on the HST imaging in D2. The spectral extraction is the same as described in Section 3. The detection is co-spatial with a fore-
Figure C4. USB spectra taken at the location of EGS-1952.

Figure D1. Spectrum of the serendipitous line identified in the datacube of A1703-zD1, with the best-fit Gaussian line profile in red. The redshifts plotted along the upper horizontal axis are based on the assumption the line detection is CO(3-2) for the source J131459.75+515008.6. The S/N of the line is 14.

ground source (J131459.75+515008.6) which has $z_{\text{phot}} = 0.44 \pm 0.11$ (found in Sloan Digital Sky Survey DR12, Alam et al. 2015). We therefore attribute the line detection to CO(3-2) (rest frame wavelength 867\,$\mu$m) putting the source at $z_{\text{spec}} = 0.43127 \pm 0.00003$, consistent with the $z_{\text{phot}}$.

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