A dusty starburst masquerading as a ultra-high-redshift galaxy in JWST CEERS observations

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ABSTRACT

Lyman Break Galaxy (LBG) candidates at $z \geq 12$ are rapidly being identified in JWST/NIRCam imaging. Due to the (redshifted) break produced by neutral hydrogen absorption of rest-frame UV photons, these sources are expected to drop out in the blue filters like F150W and F200W while being well-detected in redder filters (e.g., F277W, F356W, F444W). However, dust-enshrouded star-forming galaxies at lower redshifts ($z \lesssim 7$) may also mimic the near-infrared colors of $z > 12$ LBGs, representing potential contaminants in LBG candidate samples. Here, we report a galaxy, CEERS-DSFG-1, that drops out in the F115W, F150W, and F200W filters, for which a photometric redshift fit to the JWST data alone predicts a redshift of $z_{\text{phot}} \sim 18$. However, we show it is a dusty star-forming galaxy (DSFG) at $z \approx 5$ based on deep millimeter interferometric observations conducted with NOEMA. We also present a 2.6σ SCUBA-2 detection at 850 µm around the position of a recently reported $z \approx 16.7$ LBG candidate in the same field, CEERS-93316. While we cannot conclusively show this detection is astrophysical or associated with this object, we illustrate that if it is associated, the available photometry is consistent with $z \sim 5$ DSFG with strong nebular emission lines despite its blue NIR colors. Hence, we conclude that robust (sub)millimeter detections in NIRCam dropout galaxies likely imply $z \sim 4 - 6$ redshift solutions, where the observed near-infrared break would be the result of a strong rest-frame optical Balmer break combined with high dust attenuation and strong nebular line emission, rather than the rest-frame UV Lyman break. This provides evidence that DSFGs may contaminate searches for ultra-high-redshift LBG candidates from JWST observations.
1. INTRODUCTION

The superb sensitivity of the James Webb Space Telescope (JWST) coupled with its high angular resolution and its near infrared detectors (Rigby et al. 2022) provide a unique view of the Universe previously invisible to other telescopes, from nearby star-forming regions to the furthest, faintest galaxies ever found. In the field of extragalactic astronomy, JWST allows us to extend the Lyman Break Galaxy (LBG) selection technique beyond $z \gtrsim 11$, the redshift at which the Lyman break is redshifted beyond the reach of Hubble Space Telescope coverage (Hubble serving as the previous work-horse instrument for the identification of such galaxies before the arrival of JWST; see reviews by Finkelstein 2016; Stark 2016; Robertson 2021 and references therein).

The identification of very high-redshift LBGs has strong implications for our understanding of galaxy formation and evolution. For example, the confirmation of large numbers of $z > 11$ galaxies can provide strong constraints on the formation epoch of the first galaxies and their star formation efficiencies. Their existence can shed light on the dark matter halo mass function in the early Universe, particularly with the presence of very luminous sources found $\lesssim 400$ Myr after the Big Bang (e.g. Behroozi et al. 2019).

In the first few days after the release of JWST observations, an increasing number of samples of LBG candidates at $z \gtrsim 10$ have been identified (Adams et al. 2022; Atek et al. 2022; Castellano et al. 2022; Donnan et al. 2022; Finkelstein et al. 2022; Naidu et al. 2022; Yan et al. 2022). The presence of these sources start to be in tension with the predictions from most galaxy formation models (Finkelstein et al. 2022). Nevertheless, the observed colors for some of these very high-redshift candidates may be degenerate with other populations of galaxies at lower redshifts. This results from confusion between the Lyman-$\alpha$ forest break at $z > 12$ with the Balmer and the 4000 Å breaks combined with dust attenuation and/or strong nebular emission. This means that Dusty Star Forming Galaxies (DSFGs) in particular at significantly lower redshifts ($z \lesssim 6 – 7$) can mimic the JWST/NIRCam colors of LBGs (particularly in the shortest-wavelength filters). While models tend to assume these galaxies are universally red in color, thus distinguishable from the typically very blue LBGs, the complex environments of the ISM within DSFGs plus contamination from nebular emission lines could lead to a mix of observed near-infrared colors (Howell et al. 2010; Casey et al. 2014b), further obfuscating the secure identification of ultra high-redshift LBGs. The phenomenon of DSFGs contaminating high redshift LBG searches is, in fact, not new to JWST, as often $z \sim 2 – 3$ DSFGs were found to contaminate $z \sim 6 – 8$ LBG samples selected by HST (e.g. Dunlop et al. 2007); here, both the contaminants (DSFGs at $z \sim 4 – 6$) and LBG targets ($z \sim 11 – 20$) for JWST have shifted to higher redshifts.

The secure identification of LBGs is thus important not only to quantify the contamination fraction in $z > 12$ LBG samples (which could relax the observed tension between observations and model predictions) but also to constrain the volume density and physical properties of early massive quiescent galaxies and high-redshift DSFGs, an important step towards our ultimate goal of understanding galaxy formation and evolution. However, distinguishing these galaxies from other populations has proven challenging and requires spectroscopic or multi-wavelength observations probing the older stellar populations (for the quiescent systems) or the dust thermal emission (for DSFGs).

Here, we use JCMT/SCUBA-2 850$\mu$m and NOEMA 1.1 mm interferometric observations, in combination with the JWST data from the Cosmic Evolution Early Release Science (CEERS) Survey (Finkelstein et al. 2017; Finkelstein et al., in prep), to search for dust emission around $z > 12$ galaxy candidates and NIRCam dropout sources. We report a detection of a galaxy, CEERS-DSFG-1, that is undetected in the NIRCam F115W, F150W, and F200W filters and whose photometric redshift is constrained to be around $z \sim 18$ when using only the JWST photometry, but favored to be around $z \sim 5$ after including the (sub)millimeter data. We also find a tentative 2.6$\sigma$ detection at 850 $\mu$m around the $z \sim 16.7$ candidate, CEERS-93316, reported in Donnan et al. (2022). If real and localized to CEERS-93316, this detection would imply a lower redshift solution around $z \sim 5$. Conversely, we examine all the available long-wavelength (mid-IR to millimeter) observations around the $z \approx 14.3$ candidate known as Maisie’s Galaxy (Finkelstein et al. 2022), finding no evidence of continuum emission.

This manuscript is organized as follows: §2 describes the new observations and the ancillary datasets. In §3 we describe the SED fitting methodology and the best-fit SED fitting for CEERS-DSFG-1 along with the inferred physical properties. Then, §4 introduces our search for potential contamination from other DSFGs in the current samples of $z > 12$ LBGs candidates in the CEERS...
field including CEERS-93316 and Maisie’s Galaxy. Finally, our conclusions are summarized in §5.

In this manuscript, we assume $H_0 = 67.3 \text{km s}^{-1} \text{Mpc}^{-1}$ and a flat cosmology (Planck Collaboration et al. 2016).

2. OBSERVATIONS

2.1. SCUBA-2 and NOEMA observations

We obtained NOEMA continuum observations on a sample of 19 DSFG candidates in the Extended Groth Strip (EGS) field in preparation for CEERS JWST data, as part of the NOEMA Program W20ck (PIs: Buat & Zavala). The targets were selected from the original sample reported in Zavala et al. (2017, 2018) based on deep observations at both 450 and 850 $\mu$m obtained with the SCUBA-2 camera on the James Clerk Maxwell Telescope (JCMT). These observations have a central depth of $\sigma_{450\mu m} = 1.2 \text{mJy beam}^{-1}$ and $\sigma_{850\mu m} = 0.2 \text{mJy beam}^{-1}$, respectively, and a beam-size of $\theta_{450\mu m} \approx 8''$ and $\theta_{850\mu m} \approx 14.5''$ (Zavala et al. 2017).

The 19 sources targeted with NOEMA were selected due to the lack of counterparts in optical and/or radio catalogs or because their far-infrared (FIR)-to-submillimeter colors suggest photometric redshifts above $z \sim 3$. NOEMA observations were performed using the wideband correlator Polyfix covering the frequency ranges 252.5 – 260 GHz (with the lower side band) and 268 – 275.5 GHz (with the upper side band). The on-source integration time varies from $\sim 10$ to $\sim 50$ min and was determined based on the 850 $\mu$m flux densities of each target. For the main target of this paper, CEERS-DSFG-1 (known as 850.0027 in Zavala et al. 2017), the on-source integration time was around 25 min. Calibration and imaging of the uv visibilities were then performed with GILDAS\(^1\), producing continuum maps with $0''.15 \times 0''.15$ pixels centered at 270 GHz. For CEERS-DSFG-1, the achieved RMS is measured to be $\sigma_{1.1mm} = 0.10 \text{mJy beam}^{-1}$ and the beam-size 1''35 $\times$ 0''85.

Our NOEMA observations did not explicitly target the other two sources we include in this paper, CEERS-93316 or Maisie’s Galaxy, although the former is covered in a low sensitivity, outlying part of the primary beam of the observations of CEERS-DSFG-1. We discuss this further in § 4 below.

2.2. CEERS data

JWST/NIRCam observations were conducted as part of the CEERS (Finkelstein et al., in prep) Survey program, one of the early release science surveys (Finkelstein et al. 2017). Here, we only use data from CEERS pointing #2, which covers all three objects we study in seven filters: F115W, F150W, F200W, F277W, F356W, F410M, and F444W. After a three-dither pattern, the total exposure time was typically 47 min per filter, with the exception of F115W, whose integration time is longer (see details in Finkelstein et al. 2022 and Finkelstein in prep.).

We performed a detailed reduction as described in Finkelstein et al. (2022) and Bagley et al. (in prep). What follows is a brief summary of the main steps, and we refer the reader to these two papers for more details. We used version 1.5.3 of the JWST Calibration Pipeline\(^2\). Raw images were processed through Stages 1 and 2 of the pipeline, which apply detector-level corrections, flat fielding, and photometric flux calibration. We also applied a custom step to measure and remove 1/f noise. We align the F200W images to an HST/WFC3 F160W reference catalog created from 0''03/pixel mosaics in the EGS field with astrometry tied to Gaia-EDR3 (see Koekemoer et al. 2011, for more details about the methodology). We then aligned each NIRCam filter to F200W, achieving a median astrometric offset $\lesssim 0''.005$. Our steps represent an initial reduction that will be iteratively improved with updates to the Calibration Pipeline and reference files. Please see Finkelstein et al. (2022) for a summary of important caveats related to this version of our image reduction.

2.3. Other ancillary data

Besides the datasets described above, we also make use of Spitzer IRAC 8 $\mu$m (Barro et al. 2011) and MIPS 24 $\mu$m observations (Magnelli et al. 2009), as well as, Herschel photometry from PACS (at 100 and 160 $\mu$m; Lutz et al. 2011) and SPIRE (at 250, 350, and 500 $\mu$m; Oliver et al. 2012). Note, however, that the sources studied here are not detected in the Spitzer or Herschel maps and so we adopt only upper limits.

In addition, we use a 3 GHz mosaic of the EGS field (Dickinson, private communication) obtained using observations from the Karl G. Jansky Very Large Array (VLA) as part of the program 21B-292 (PI: M. Dickinson). It reaches a sensitivity of 1.5 $\mu$Jy beam$^{-1}$ and angular resolution of 2.3 $\times$ 2.3 arcsec.

3. A JWST/NIRCAM DROPOUT: A DSFG AT REDSHIFT FIVE

The sub-arcsecond positional accuracy of the NOEMA observations allows us to directly identify the

\(^1\) www.iram.fr/IRAMFR/GILDAS

\(^2\) jwst-pipeline.readthedocs.io
The CEERS collaboration

Figure 1. A 3′ × 3′ composite image centered at the position of CEERS-DSFG-1; the JWST/NIRCam F115W observations are in blue, F277W in green, and F444W in red (the data has been smoothed to roughly match the F444W resolution for better visualization). The 1.1 mm NOEMA signal-to-noise ratio levels starting at 2.5σ to 10σ (in steps of 2.5σ) are represented by the white contours, clearly indicating that the dust thermal emission detected at submillimeter/millimeter wavelengths corresponds to the position of CEERS-DSFG-1.

submillimeter-selected galaxy, CEERS-DSFG-1, in the JWST/NIRCam observations (see Figure 1). As can be seen in Figure 2, CEERS-DSFG-1 is well-detected in the longer wavelength filters (F277W and redder bands) but abruptly drops out in F200W and shorter wavelength filters. The drop-out nature of this galaxy may satisfy simple selection criteria to identify very high-redshift galaxies at z > 15 based on these colors. In contrast, the identification of this source as a DSFG is counterintuitive to such a very high-redshift solution, given that the highest redshift dust continuum detections ever reported are at z ∼ 7−8 (Laporte et al. 2017; Strandet et al. 2017; Marrone et al. 2018; Tamura et al. 2019; Inami et al. 2022). Moreover, the (sub)millimeter selection would imply an extreme IR luminosity in excess of ∼ 10^{13} L_☉.

Here we conduct a more thorough investigation as to the possible redshift of CEERS-DSFG-1 using JWST photometry alone and the predicted SEDs when using fits from the near-infrared through the millimeter. The respective best-fit redshift probability density distributions are shown in Figure 4. Below, we discuss in detail the performed SED fittings, the inferred photometric redshifts, and the physical characteristics implied by the adopted best-fit solution.

### Table 1. Measured Photometry of CEERS-DSFG-1

| Instrument/Filter | Wavelength (µm) | Flux Density (nJy) |
|-------------------|-----------------|--------------------|
| NIRCam/F115W      | 1.15            | 4.6±4.2            |
| NIRCam/F150W      | 1.50            | 2.3±6.4            |
| NIRCam/F200W      | 2.00            | 4.1±4.0            |
| NIRCam/F277W      | 2.77            | 113.5±4.2          |
| NIRCam/F356W      | 3.56            | 209.7±5.1          |
| NIRCam/F410M      | 4.10            | 329.8±10.1         |
| NIRCam/F444W      | 4.44            | 379.1±6.7          |
| PACS/100 µm       | 100 µm          | 0.11±0.51          |
| PACS/160 µm       | 160 µm          | 0.1±3.5            |
| SPIRE/250 µm      | 250 µm          | -1.1±5.8           |
| SPIRE/350 µm      | 350 µm          | -4.5±6.3           |
| SCUBA-2/450 µm    | 450 µm          | -2.5±1.7           |
| SCUBA-2/850 µm    | 850 µm          | 2.25±0.36          |
| NOEMA/1.1 mm      | 1.1 mm          | 1.36±0.11          |

Note—CEERS-DSFG-1 is formally not detected in F115W, F150W, F200W, all of the Herschel bands from 100–500 µm, as well as SCUBA-2 450 µm.

3.1. SED fitting procedure and redshift constraints

3.1.1. EAZY

We first fit the SED of CEERS-DSFG-1 to JWST/NIRCam photometry alone using the EAZY (Brammer et al. 2008) spectral energy distribution (SED) fitting code. The fitting was performed in an identical fashion as in Finkelstein et al. (2022). To summarize, EAZY makes use of a user-supplied template set to generate linear combinations of stellar populations that fit the data and generate redshift probability distributions. The template set used in our case includes the “tweak_fsp_QSF_12_v3” set of 12 templates as well as six additional templates that span bluer colors (R. Larson, in prep). No luminosity prior is used and colors are measured in a Kron-aperture and corrected to total fluxes. The best fit photometric redshift using EAZY
Figure 2. $1''8\times1''8$ cutouts around CEERS-DSFG-1 from the CEERS JWST/NIRCam bands. The source is undetected in F115W, F150W, and F200W (the source’s position is indicated with the red circle in the stacked F115W+F150W and F200W images, the dropout bands). The galaxy is well-detected in bluer filters with a red spectral shape. All images follow the same color-code with a maximum value equal to $15\times$ the sky RMS and a minimum value of $-1.5\sigma$.

Figure 3. The full near-infrared through millimeter spectral energy distribution of CEERS-DSFG-1 overplotted with several of the best-fit SEDs described in § 3 along with the current photometric constraints (the detections used in the fits are represented by the solid circles while $2\sigma$ upper limits are illustrated by the downward arrows). We show the CIGALE fit to NIR data only in red, EAZY to NIR data only in orange, CIGALE joint fits in light green, an alternate configuration of CIGALE parameters in teal, and PROSPECTOR fit in light blue. Fits that include both the near-infrared JWST photometry as well as (sub-)mm constraints are shown on the full SED – all of which favor a redshift solution $z \sim 4–6$ whereas the inset plot zooms in to the near-infrared portion of the spectrum only, highlighting the fits performed on JWST photometry alone (which favor $z \sim 18$). For clarity on the full shape of a $z \sim 18$ template, we also add the EAZY fit to the NIRCam data alone to the full SED panel. There is a significant discrepancy between the best predicted redshifts produced by JWST photometry alone vs all photometric constraints out to the millimeter regime, as clearly illustrated in Figure 4.

is $z_{\text{EAZY}} = 18.2^{+1.2}_{-0.7}$ with more than 99% probability of being at $z > 15$ (see full redshift distribution in Figure 4 and the best-fit SED in the inset plot of Figure 3).

3.1.2. CIGALE

We also fit the photometry using CIGALE (Burgarella et al. 2005; Noll et al. 2009; Boquien et al. 2019) assuming a delayed star formation history (SFH): $\text{SFR}(t) \propto t^{\exp(-t/\tau)}$ with stellar models from Bruzual & Charlot (2003) (BC03). Dust attenuation is also added following the dust attenuation law from Calzetti et al. (2000) for the stellar continuum. The nebular emission (continuum and lines) is attenuated with a screen model and an SMC extinction curve (Pei 1992). During the SED fitting, the same E(B-V) is used, both for the stellar and nebular emissions. Finally, the dust
emission reemitted in infrared (IR) is modeled with Draine et al. (2014) models.

Including only JWST/NIRCAM photometry in the fit gives a redshift $z_{CIGALE} = 17.3^{+0.6}_{-0.6}$. A secondary peak in the redshift distribution appears at $z_{CIGALE} \sim 5$ with an integrated probability of 10% of the probability density distribution (see Figure 4). To test the impact of our assumptions on the derived results, we conduct an independent fitting using a different approach. In this second configuration, we use non-parametric SFHs (Ciesla et al., in prep), a Charlot & Fall (2000) attenuation law, and the dust emission templates of Dale et al. (2014). With this setup, and using only the NIRCAM photometry, the best redshift solution is $z_{CIGALE} = 17.8 \pm 0.9$, which agrees well with aforementioned value.

In addition, we fit the JWST data along with SCUBA-2 and NOEMA detections (Herschel upper limits were not included in the fit) using the first CIGALE configuration described above. The addition of the long-wavelength data, significantly impacts the best-fit SED. With the joint fit, the redshift distribution clearly shows a single maximum at $z_{CIGALE} = 4.6 \pm 0.4$. The resulting SEDs are shown in Fig. 3 (where both CIGALE configurations are shown at a redshift of 4.6) while the redshift probability distribution is shown in Figure 4 (we plot only the distribution derived from the first CIGALE configuration).

3.1.3. Prospector

We also fit the JWST data alone and jointly with the long wavelength data together using Prospector (Johnson et al. 2021), a Bayesian SED fitting code following the same procedure as Tacchella et al. (2022). In summary, we model the SED with a 13-parameter fit including redshift, stellar mass, metallicities, dust attenuation, and nebular emission. The fit to the JWST data alone suggest a very high redshift similar to the CIGALE and EAZY results, with a clear peak at $z \sim 17$ (see Figure 4). On the other hand, when fitting the JWST data in combination with the (sub)millimeter photometry, a bimodal distribution peaking at $z \sim 5.5$ and $z \sim 16.5$ is obtained. From this latest run we constrain the redshift of CEERS-DSFG-1 to be $z = 5.5^{+0.7}_{-0.6}$ (when focusing only on the main peak of the distribution). These results are broadly consistent with those found using CIGALE, both on JWST data alone and when using the combined photometry.

3.1.4. MMPz

Finally, though the long wavelength data on CEERS-DSFG-1 are somewhat limited, we are able to calculate an independent photometric redshift for the source based on long wavelength data alone using the MMPz package (Casey 2020). MMPz presumes that sources with significant (sub)mm emission follow an empirically measured relationship between the rest-frame peak wavelength of emission, $\lambda_{peak}$, which is inversely proportional to the characteristic luminosity-weighted dust temperature of the ISM, and the total emergent IR luminosity, $L_{IR}$. This $L_{IR} - \lambda_{peak}$ relation is fairly well constrained out to $z \sim 5$ (Casey et al. 2018; Drew & Casey 2022) where more intrinsically luminous sources have warmer temperatures; MMPz generates a redshift probability distribution by computing the $L_{IR}$ and $\lambda_{peak}$ at all possible redshifts, and contrasts that against the empirical distribution of measured SEDs. By design, redshift solutions found using MMPz are very broad (due to the degeneracy between ISM dust temperature, constrained via $\lambda_{peak}$, and redshift). The best fit redshift generated from the long wavelength data alone (including both detections and non-detections) is most consistent with the low redshift solution, with $z_{MMPz} = 4.9^{+2.3}_{-1.5}$ (see Figure 4).
Table 2. Properties of CEERS-DSFG-1

| Property                          | Value                      |
|----------------------------------|----------------------------|
| Source ID                        | CEERSJ141938.19+525613.9   |
| RA (J2000 [deg])                 | 214.9091152                |
| Dec (J2000 [deg])                | 52.9371977                 |
| zEAZY                            | 18.2±1.2                  |
| zCIGALE                          | 4.6±0.4                   |
| zProspector†                     | 5.5±0.7                   |
| zMMPs                            | 4.9±2.3                   |
| \(M_\star [M_\odot]\)            | \((4.9±1.0)\times10^{10}\) |
| SFR (M_\odot yr\(^{-1}\))       | 137±28                    |
| sSFR (Gyr\(^{-1}\))             | 2.80±0.81                 |
| E(B-V) (mag)                     | 1.18±0.04                 |
| Age (Myr)                        | 700±200                   |
| Mass weighted Age                | 270±70                    |

Note—zEAZY was derived using only the JWST/NIRCam data while zCIGALE and zProspector† were derived using all the available photometric constraints including the (sub)millimeter data. The physical properties listed below the horizontal line were derived from the joint fit of CIGALE with the first set of parameters described in the text.† The reported redshift was estimated considering only the lower redshift peak of the distribution. A secondary peak at \(z \sim 16.5\) is also seen.

3.2. Physical properties from best-fit SED

We adopt the results from the joint fit of CIGALE using the JWST/NIRCam and the (sub)-millimeter data, and with the first set of parameters described above, as our fiducial values. The inferred physical properties are summarized in Table 2 and discussed below.

Assuming a redshift of \(z = 4.6\), the stellar mass of CEERS-DSFG-1 is constrained to be \((4.9±1.0)\times10^{10}M_\odot\). This is a factor of \(\sim 2\) smaller than the average mass of typical DSFGs detected in single-dish telescopes (e.g. da Cunha et al. 2015), although within the observed dispersion. This is aligned with expectation since our source was selected from one of the deepest SCUBA-2 850\(\mu\)m surveys and has a fainter 850\(\mu\)m flux density than the typical submillimeter-selected galaxies (SMGs) identified in shallower single-dish telescope surveys. Indeed, the stellar mass of our target is in very good agreement with the population of galaxies identified in recent deeper ALMA surveys (e.g. Gómez-Guijarro et al. 2022; see also Khusanova et al. 2021). Similarly, the SFR of CEERS-DSFG-1 of \(137±28\, M_\odot\, \text{yr}^{-1}\) (averaged over the last 10 Myr) lie between those from SMGs and fainter DSFGs identified in deeper ALMA observations (da Cunha et al. 2015; Aravena et al. 2020; Casey et al. 2021; Khusanova et al. 2021; Gómez-Guijarro et al. 2022). These properties imply a specific star formation rate of sSFR = \(2.80±0.81\, \text{Gyr}^{-1}\), meaning that CEERS-DSFG-1 lies on the main-sequence of star forming galaxies, similar to the so-called population of “HST-dark” galaxies3 (e.g. Wang et al. 2019).

At \(z = 4.6\), the NIRCam photometry samples rest frame wavelengths from 0.2 to 0.8\(\mu\)m, allowing us to constrain the stellar dust attenuation. The red spectral shape in the NIRCam bands implies a strong dust attenuation (as typically found for this kind of galaxies; e.g. Simpson et al. 2017) with \(E(B-V) = 1.18±0.04\), which results in a dust luminosity of \((1.7±0.2)\times10^{12}\, L_\odot\). Interestingly, our fiducial SED suggests some non-negligible contribution from the [OIII] emission lines to the F277W band given the inferred line luminosities of \((1.3±0.7)\times10^{-17}\, \text{ergs}^{-1}\, \text{cm}^{-2}\). Availability of multiple broad- and medium-band filters in large samples may make it possible to constrain line luminosities and thus galaxies’ ISM properties for similar sources.

These properties do not depend strongly on the adopted parameters or SED code, although we note that the best-fit SED obtained with the second CIGALE configuration and with PROSPECTOR suggest a slightly lower stellar mass (~\(2\times10^{10}\, M_\odot\)) and SFR (~ 50 – 100\, M_\odot\, yr\(^{-1}\)).

4. SEARCHING FOR DSFG CONTAMINANTS IN HIGH-REDSHIFT LBG CANDIDATES IDENTIFIED WITH JWST

The SCUBA-2 observations from Zavala et al. (2017) partially overlap with the CEERS NIRCam survey and thus can be used to look for dust continuum emission around \(z > 12\) candidates in the field. Here we focus on two recently reported high-redshift candidates: CEERS-93316 reported to be at \(z \approx 16.7\) (Donnan et al. 2022) and Maisie’s Galaxy at \(z \approx 14.3\) (Finkelstein et al. 2022).

4.1. A deeper look into CEERS-93316

A 2.6\(\sigma\) detection around the position of CEERS-93316 (Donnan et al. 2022) was found in the 850\(\mu\)m SCUBA-2 map with a flux density of \(0.65±0.26\, \text{mJy}\) (see Figure 5). While this source is only 26\(^\circ\) away from CEERS-DSFG-1 and from the center of our NOEMA map, unfortunately CEERS-93316 lies in the outer part of the NOEMA primary beam where the sensitivity is very low (with a primary beam response of \(\lesssim 0.1\), implying an RMS of \(\sigma_{1.1\, \text{mm}} \gtrsim 1\, \text{mJy beam}^{-1}\)), which prevents us from confirming the detection.

3 CEERS-DSFG-1 is, by definition, also an “HST-dark” galaxy.
We emphasize that there are two primary reasons why this marginal detection may not conclusively imply that CEERS-93316 is a significant thermal dust emitter. The first concern is the significance of the detection itself: at $2.6\sigma$, simulations of blind detection, single-dish submillimeter sources indicate false-positive rates as high as $30-40\%$ (Casey et al. 2013, 2014a). These rates of false-positives are estimated by both searching SCUBA-2 maps for negative significance peaks at $-2.6\sigma$ as well as conducting source injection tests on SCUBA-2 jackknife maps (following the same methodology as Casey et al. 2013, see their Figure 7). To further test the reliability of these low signal-to-noise ratio detections, we create a catalog of $2.5\sigma$ to $3.0\sigma$ SCUBA-2 sources and search the deep VLA 3GHz map (Dickinson, private communication) for counterparts, finding clear detections for at least 50% of the sources$^4$, implying a $>50\%$ fidelity rate. A similar result is obtained using the 24$\mu$m map. Since it is well-known that a significant fraction (as high as 30-40%) of submm sources lack radio or mid-infrared counterparts (particularly those at $z>3$; Chapman et al. 2003; Barger et al. 2007; Pope et al. 2006; Dye et al. 2008), the reliability fraction of 50% should be considered a lower limit. We conclude that our $2.6\sigma$ SCUBA-2 detection has a considerable probability of being real, at more than 50% (and as high as $\sim 70\%$).

The second significant concern is that even if the detection is real, the SCUBA-2 beamsize is large enough that the 850$\mu$m emission could arise from another galaxy at a close angular separation with CEERS-93316 on the sky. Figure 5 shows the neighboring sources within the beamsize of the SCUBA-2 marginal detection, with contours overlaid for Spitzer 8$\mu$m emission, 24$\mu$m emission, and VLA 3GHz continuum (Dickinson, private communication). Unfortunately, there is no clear emitter at these wavelengths to which we can definitively associate the 850$\mu$m emission to unequivocally rule out association with CEERS-93316. Note that the lack of such a counterpart does not imply the tentative SCUBA-2 emission is not astrophysical, since $z>3$ galaxies are usually undetected in these bands (this is indeed the case for CEERS-DSFG-1). This lack of detection rather means that it is not implausible to associate the 850$\mu$m emission to unequivocally rule out association with CEERS-93316. Another possible counterpart could be the 8$\mu$m emitter (with a $\sim 2.5\sigma$ significance) to the northwest that has a photometric redshift of $z\sim5$, though it is farther from the signal-to-noise peak in the SCUBA-2 map than CEERS-93316.

At present, we lack sufficient data to clearly associate the emission with CEERS-93316 or other neighboring sources. Follow-up interferometric observations would be necessary to provide both a confirmation of the emission and astrometric localization to CEERS-93316 or to a neighboring source. Nevertheless, given the remarkable properties of CEERS-93316 (being one of the highest-redshift candidates ever reported with a bright UV magnitude of $M_{UV} = -21.8$), below we explore the impact that the submm detection might have on its redshift solution if the dust emission is real and associated with it.

4.1.1. Caveats of a Marginal SCUBA-2 Detection

4.1.2. Implications if Dust Emission is associated with CEERS-93316

$^4$ Given the surface density of radio sources and the SCUBA-2 detections, the probability of chance alignment is $<5\%$.
First, we consider what the implications would be if CEERS-93316 had significant dust emission at its proposed redshift of \( z = 16.7 \). The observed 850\( \mu \)m emission would probe the rest-frame \(~50\mu \)m regime; in this scenario, the IR luminosity would, at minimum, be \(~4 \times 10^{12} \)L\(_{\odot} \) with a dust mass of \(~10^8 \)M\(_{\odot} \). A system with such high dust mass found \(~230 \)Myr after the Big Bang would surely be extraordinary, likely implausibly so (e.g., Dwek et al. 2014).

We therefore explore if a lower redshift solution would be plausible given the JWST/NIRCam photometric constraints and the observed blue colors in these bands (which contrasts with those from CEERS-DSFG-1). To do that, we fit the JWST/NIRCam data\(^5\) along with the tentative 850\( \mu \)m flux density with CIGALE (using the fiducial configuration used for CEERS-DSFG-1) but fixing the redshift to \( z = 4.6 \), which is the secondary peak in the best-fit photometric redshift in the CIGALE fitting of the NIRCam data alone.

The resulting SED is shown in Figure 6 along with our best-fit EAZY fit to the NIRCam data alone for the sake of comparison (we only focus on the NIR region for clarity, but we stress that the best-fit SED of CIGALE satisfactory reproduces the SCUBA-2 850\( \mu \)m flux density with \((S_{\text{model}} - S_{\text{obs}})/\sigma_{\text{obs}} \approx 0.5 \). In the low-redshift scenario, the strong break seen between F200W and F277W in CEERS-93316 is attributable to strong [OII] and H\( \beta \) emission in the F277W band (see Figure 6). Similarly, the excess flux in F356W above the continuum, which produces a blue F356W-F410M color, would be attributable to H\( \alpha \) emission. The measured NIRCam photometry would thus require a young starburst with strong nebular line emission to satisfy a \( z \sim 4.6 \) solution, but this would be within the realm of expectation for an early-stage DSFG in formation at these redshifts.

The \( z = 4.6 \) best-fit SED would imply a SFR averaged over 10 Myr of \( 30 \pm 8 \)M\(_{\odot} \) yr\(^{-1} \) and a stellar mass equal to \((1.2 \pm 0.3) \times 10^9 \)M\(_{\odot} \), with a dust attenuation of \( E(B-V) = 0.7 \pm 0.1 \) and a dust luminosity of \((2.7 \pm 0.6) \times 10^{11} \)L\(_{\odot} \). These properties are in broad agreement with those derived for the relatively faint population of \( z \sim 7 \) dusty galaxies in the REBELS survey (Bouwens et al. 2020; Inami et al. 2022). In addition, the line fluxes required to reproduce the given NIRCam photometry range from \(~1 \times 10^{-18} - 1 \times 10^{-17} \)ergs\(^{-1} \)cm\(^{-2} \), which are within the range of those predicted for CEERS-DSFG-1.

While deep interferometric observations at millimeter wavelengths are required to confirm or refute dust continuum emission in CEERS-93316, here we show that a \( z \sim 4.6 \) scenario associated with a DSFG with strong nebular emission is plausible (and highly likely if the submillimeter detection is confirmed and associated), despite its blue NIR colors which are usually associated with the emission of dust-free sources (e.g. Finkelstein 2016, and references therein).

### 4.2. A deeper look into Maisie’s Galaxy

Given that the recently reported \( z = 14.3 \) galaxy candidate from Finkelstein et al. (2022) lies close to the two galaxies described above (\( \sim 78’’ \) and \( \sim 65’’ \) away from CEERS-DSFG-1 and from the source reported Donnan et al. (2022), respectively), we carefully examine the available long-wavelength observations to investigate any possible detection of dust emission.

Because this source is not covered by our NOEMA observations, we started by looking at the deep SCUBA-2 850\( \mu \)m map (Zavala et al. 2017). As shown in Figure 7 no significant detection is found (with a measured flux density of \( S_{850} = -0.40 \pm 0.25 \)mJy at the position of the source). We also search for significant emission in the Spitzer 8\( \mu \)m and 24\( \mu \)m map, Herschel 100, 160, 250, 350, and 500\( \mu \)m imaging, and SCUBA-2 450\( \mu \)m observations, finding only non-detections. We thus conclude that a

\(^{5}\) Note that since we performed our own data reduction and followed our own source extraction procedure designed to measure accurate colors, the NIRCam fluxes for CEERS-93316 used in this paper could differ from those in Donnan et al. (2022). We list the adopted fluxes for the SED fitting Appendix A.
lower redshift, dusty scenario for Maisie’s Galaxy is very unlikely.

5. CONCLUSIONS

Using the available datasets from the JWST CEERS survey in combination with NOEMA and SCUBA-2 observations, we have demonstrated that DSFGs at \( z \approx 4 - 6 \) can dropout in the bluest JWST/NIRCam filters (F115W, F150W, and even F200W) while being well-determined in the redder filters. A simple photometric redshift used to identify \( z > 12 \) LBGs based merely on this drop-out technique could thus introduce significant contaminants from lower redshift systems. These kind of galaxies could even been misidentified as very high-redshift candidates when performing SED fitting to near-infrared photometry alone.

This is illustrated by studying the source CEERS-DSFG-1, a 850\( \mu m \)-selected galaxy with robust interferometric observations at 1.1 mm by NOEMA. The results from an SED fitting using the JWST photometry alone suggest \( z \approx 18 \), whereas a joint SED fitting analysis including the NIRCam constraints and the long-wavelength (sub-)millimeter data implies a photometric redshift of 4.6 \( \pm 0.4 \) (with physical properties that resemble other DSFGs: \( M_*= (5.3 \pm 1.3) \times 10^{10} \), \( \text{SFR} = 152 \pm 66; \ L_{\text{dust}} = (1.9 \pm 0.6) \times 10^{12} \ L_\odot \)).

We extended the search for dust continuum emission to two \( z > 12 \) LBG candidates recently reported in the same field, CEERS-93316 at \( z \approx 16.7 \) (Donnan et al. 2022) and Maisie’s Galaxy at \( z \approx 14.3 \) (Finkelstein et al. 2022), and report a 2.6\( \sigma \) detection at 850\( \mu m \) around the position of CEERS-93316. A confirmation of this flux density measurement and a firm spatial association requires higher resolution sub-mm imaging.

While additional observations are required to corroborate this identification, we use this possible association to illustrate that \( z \approx 5 \) DSFGs can also exhibit blue colors in the JWST/NIRCam bands when strong nebular emission lines are present (with line fluxes in the order of \( \sim 10^{-18} - 10^{-17} \text{erg s}^{-1} \text{cm}^{-2} \)). We thus conclude that (sub)millimeter emission in samples of \( z > 12 \) LBGs likely imply misidentifications of DSFGs at \( z \approx 4 - 6 \). If the dust continuum detection in CEERS-93316 is real and associated then it would imply a lower redshift solution of \( z \approx 5 \), similar to what what found for CEERS-DSFG-1.

This work has illustrated both the importance and potential of combining JWST observations with interferometric submillimeter/millimeter data, a synergy that allows us to identify and characterize populations of galaxies that were previously unreachable, including both \( z \gtrsim 5 \) DSFGs as well as ultra high-redshift \( z > 12 \) LBGs. In particular, it will become crucial for searches of ultra high-redshift LBGs to closely consider contamination from lower redshift (\( z \approx 4 - 7 \)) dusty sources with significant nebular line emission that can mimic the colors of a higher redshift Lyman break.

Despite sitting at lower redshift, new discoveries and characterizations of \( z \approx 5 \) DSFGs will also shed new light on an otherwise mysterious population, where fewer than a few dozen systems are currently known. Such discoveries will enable a major step forward in our understanding of massive galaxy formation in the first \( \sim 1 \text{Gyr} \) of the Universe’s history.

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**Facilities:** JWST, NOEMA
APPENDIX

A. EXTRACTED PHOTOMETRY FOR CEERS-93316

The extracted photometry that was used during the SED fitting procedure on CEERS-93316 is listed in Table 3.

Table 3. Measured Photometry of CEERS-93316

| Instrument/Filter | Wavelength (µm) | Flux Density (nJy) |
|-------------------|----------------|-------------------|
| NIRCam/F115W      | 1.15           | 1.8±2.3           |
| NIRCam/F150W      | 1.50           | 4.0±2.9           |
| NIRCam/F200W      | 2.00           | 19.0±1.7          |
| NIRCam/F277W      | 2.77           | 107.5±2.5         |
| NIRCam/F356W      | 3.56           | 100.4±2.4         |
| NIRCam/F410M      | 4.10           | 101.4±4.7         |
| NIRCam/F444W      | 4.44           | 87.46±4.2         |
| SCUBA-2/850µm     | 850            | 0.65±0.26         |

Note—CEERS-93316 is formally not detected in F115W and F150W.

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