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LETTER TO THE EDITOR

First look with JWST spectroscopy: Resemblance among z ∼ 8 galaxies and local analogs

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ABSTRACT

Deep images and near-IR spectra of galaxies in the field of the lensing cluster SMACS J0723.3–7327 were recently taken as part of the Early Release Observations (EROs) program of the James Webb Space Telescope (JWST). Among these, two NIRSpec spectra of galaxies, at z = 7.7 and at z = 8.5, were obtained, revealing, for the first time, the rest-frame optical emission line spectra of galaxies in the epoch of reionization, including the detection of the important [O III]λ4363 auroral line (see JWST PR 2022-035). We present an analysis of the emission line properties of these galaxies, finding that these galaxies have a high excitation (as indicated by high ratios of [O III]/Hβ = 7.7, [Ne III]/O III] = 3727, [Ne III]/[O III] = 3727), strong [O III]/4363, high equivalent widths, and other properties typical of low-metallicity star-forming galaxies. Using the direct method, we determined oxygen abundances of 12 + log(O/H) = 7.9 in two z = 7.7 galaxies and a lower metallicity of 12 + log(O/H) = 7.4–7.5 (~5% solar) in the z = 8.5 galaxy using different strong line methods. More accurate metallicity determinations will require better data. With stellar masses estimated from spectral energy distribution (SED) fits, we find that the three galaxies lie close to or below the z ∼ 2 mass-metallicity relation. Overall, these first galaxy spectra at z ∼ 8 show a strong resemblance in their the emission line properties of galaxies in the epoch of reionization with those of relatively rare local analogs previously studied with the SDSS. Clearly, the first JWST observations demonstrate already the incredible power of spectroscopy to reveal the properties of galaxies in the early Universe.

Key words. galaxies: high-redshift – dark ages, reionization, first stars – galaxies: ISM

1. Introduction

Optical emission line spectroscopy has long provided important insights on the physical composition, properties of the interstellar medium (ISM), and the nature of the ionizing power of galaxies, yielding thus key information to understand many key aspects of galaxy evolution (see review of Kewley et al. 2019). The well-known emission lines of H, He, O, N, S, Ne, and other elements detected in optical galaxy spectra, emitted in the ionized ISM (H II regions primarily) have been detected in nearly one million of galaxy spectra, out to redshifts of z ∼ 0.5–1 with the Sloan Digital Sky Survey (SDSS, Ahumada et al. 2020). Ground-based near-IR spectroscopy has recently pushed these limits to z ∼ 1.5–3, where ~1500 measurements of the strongest rest-optical lines have been possible, for instance, with the MOSDEF survey (Kriek et al. 2015), thus revealing the ISM properties at cosmic noon (e.g., Förster Schreiber & Wuyts 2020).

The recent launch of the JWST and the spectroscopic capabilities of its multi-object near-infrared spectrograph (NIRSpec) has now opened up an entirely new window onto the early Universe, where, for the first time, all the “classical” optical diagnostics developed at low-z can be used to study the properties of galaxies over a wide redshift range, from z ~ 3 out to the epoch of reionization (z > 6.5).

The first public NIRSpec observations, part of the Early Release Observations (ERO) of JWST, have covered the SMACS J0723.3–7327 galaxy cluster, providing 1.8–5.2 µm spectra of 35 objects in the field. Among those, three galaxies in the epoch of reionization were observed, showing spectacular, rich rest-frame optical emission line spectra of objects at z = 7.7 and z = 8.5 (see JWST Press release 2022-035). Here, we report the first determination of the metallicity (O/H) of these galaxies, along with a detailed analysis of their emission line properties and a comparison with observed properties of low-z emission line galaxies. At the time of revision, the JWST targets have been the object of other studies analysing their emission line spectra and derived properties (see Arellano-Cordova et al. 2022; Brinchmann 2022; Carnall et al. 2022; Curti et al. 2022; Katz et al. 2022; Rhoads et al. 2022; Taylor et al. 2022; Trump et al. 2022).

2. Observations

2.1. JWST NIRSpec observations

Rest-frame UV and optical spectra were obtained on 30 June 2022 using NIRSpec with the micro-shutter assembly (MSA). Observations consist of two different pointings (s007 and s008), each of them using two grating-filter combinations: G235M/F170LP and G395M/F290LP. The total exposure time is 2 × 8754 s for each grating and filter pairing. This provides a spectral resolution $R \approx 1000$ and a continuous spectral coverage of $\lambda \approx 1.75$–5.20 $\mu$m. Fully calibrated spectra (calibration level 3) were retrieved from the Mikulski Archive for Space Telescopes, which had previously been processed with the JWST Science Calibration Pipeline (CAL_VER: 1.5.3 and CRDS_CTX: jwst-0916.pmap). For each source, two individual 1D spectra (s007 and s008) were combined using the average flux, following a masking of the spectral regions affected by cosmic rays and other artifacts based on an inspection of the 2D spectra. For 04590, we excluded data above $\lambda_{\text{obs}} \geq 4.5 \mu$m (i.e., after the detector gap) for observation s008, since the 2D spectrum in this region shows several artifacts that might compromise the flux calibration, including a considerable flux gradient along the spatial direction. An example of the combined spectrum of 06355 at $z = 7.7$ is shown in Fig. 1.

The spectra of the three sources show nebular emission lines, many of them detected with high significance (>3$\sigma$). These include Balmer lines (H$\beta$, H$\gamma$, H$\delta$), [O II] and [O III], [Ne III], and He I. In particular, the auroral [O III]$\lambda$4363 line, which is key for accurate determinations of the O/H abundance using the direct method, is detected in all galaxies with a significance of 3.9–5.7$\sigma$. Gaussian profiles are fitted to each line using the Python nonlinear least-squares function CURVE-FIT and assuming a constant level for the continuum (in $f_{\lambda}$). We derive the redshifts for these sources using the brightest lines, namely H$\gamma$, H$\beta$, and [O III]$\lambda$4959,5007 lines (Table 1). The continuum is clearly detected in the two $z \approx 7.7$ sources (10612 and 06355, see Fig. 1), allowing for the determination of the equivalent widths of the lines (Table 1). However, these do not include any correction for slit-losses and other possible effects attributed to the different morphologies of the continuum emission and nebular lines.

After careful inspection of the flux measurements we noticed that some line ratios have nonphysical values, suggesting systematics on the flux calibration and throughput in the current JWST pipeline. For example, the observed Balmer line ratios are found to be larger than the intrinsic H$\gamma$/H$\beta$ and H$\delta$/H$\beta$ ratios, assuming case B recombination. Before more accurate calibration reference files are available, we overcame this issue by applying an ad hoc correction to the flux calibration. More specifically, we fit a power law ($\propto \lambda^{p}$) to (i) the intrinsic H$\gamma$/H$\beta$ = 0.47, H$\delta$/H$\beta$ = 0.26 (case B), and (He I+H$\delta$)/H$\beta$ = 0.2 and to (ii) the observed line ratios. The correction factor as a function of wavelength is thus given by the division between (i) and (ii) for each source, and it is applied to the full spectral range covered by the G235M/F170LP grating/filter configuration. This empirical

![Fig. 1. 2D (top) and 1D (bottom) NIRSpec/JWST spectrum of 06355 at $z = 7.664$ (black) and 1$\sigma$ uncertainty (grey). Vertical dashed lines mark the position of well-detected nebular emission lines. The continuum emission is also detected as seen in the 2D spectrum. X-axis in the bottom and top panels refer to the observed ($\mu$m) and rest-frame wavelengths (Å), respectively.](https://mast.stsci.edu/)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>04590</th>
<th>06355</th>
<th>10612</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redshift $z$</td>
<td>8.495</td>
<td>7.664</td>
<td>7.660</td>
</tr>
<tr>
<td>$T_{\text{e}}$/O(H) $^{(a)}$</td>
<td>15584</td>
<td>18146</td>
<td></td>
</tr>
<tr>
<td>12 + log(O/H) $^{(b)}$</td>
<td>7.86</td>
<td>7.88</td>
<td></td>
</tr>
<tr>
<td>12 + log(O/H) $^{(c)}$</td>
<td>7.50</td>
<td>7.85</td>
<td>8.0</td>
</tr>
<tr>
<td>O32</td>
<td>7.39</td>
<td>7.76</td>
<td>7.91</td>
</tr>
<tr>
<td>EW([O III],4363$\lambda$)</td>
<td>172 ± 150</td>
<td>723 ± 78</td>
<td>638 ± 176</td>
</tr>
<tr>
<td>$m_F$/F277W</td>
<td>27.8</td>
<td>26.6</td>
<td>25.6</td>
</tr>
<tr>
<td>$M_{\text{1500}}$ $^{(d)}$</td>
<td>−20.29</td>
<td>−21.09</td>
<td>−20.38</td>
</tr>
<tr>
<td>$M_{\text{1500}}$ $^{(e)}$</td>
<td>−18.06</td>
<td>−20.51</td>
<td>−19.81</td>
</tr>
<tr>
<td>$\beta_{\text{1000}}$</td>
<td>−2.20 ± 0.15</td>
<td>−1.96 ± 0.22</td>
<td>−2.31 ± 0.11</td>
</tr>
<tr>
<td>log($M_\ast \times \mu$)</td>
<td>9.0 ± 0.3</td>
<td>9.2 ± 0.3</td>
<td>8.9 ± 0.3</td>
</tr>
<tr>
<td>Magnification $\mu$</td>
<td>7.9</td>
<td>1.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Notes. $^{(a)}$Direct method. $^{(b)}$Assuming $T_{\text{e}} = 16 000$ K. $^{(c)}$Using strong line methods (Izotov et al. 2019, 2021b). $^{(d)}$Observed, including lensing. $^{(e)}$Corrected for lensing.
correction results in a maximum increase of ~20–50% (depending on galaxy) for the O32 = [O III] \( \lambda 5007/\lambda 3727 \) ratio, and smaller corrections for other line ratios. By doing this, we are also applying a first-order correction to the Balmer decrement, thus losing the information on the dust attenuation. Given the uncertainties on the flux calibration and on our empirical correction, we conservatively add 20% of uncertainties on our flux measurements, which should also account for other sources of uncertainty, such as those arising from the estimation of the continuum level. This depends on the different assumptions (e.g., size of the spectral windows used in the fit, constant level or straight line, noise fluctuations, etc.) and may affect the flux measurements of different lines. The measured line ratios, prior to and after correction, are shown in Fig. 2. Where possible, our analysis will focus mostly on lines ratios between nearby lines (see Sect. 3), thus minimizing possible issues on the flux calibration and dust attenuation.

It must be noted that presently the data reduction process is still in a preliminary stage, which involves, in particular, pre-launch calibration files (Rigby et al. 2022). To tackle with these limitations, different groups have used different approaches, including observations of a standard star, different extractions of the 2D spectra, different combinations of the two visits and other corrections (cf., Curti et al. 2022; Rhoads et al. 2022; Trump et al. 2022). A comparison shows differences in several line ratios, by amounts that are sometimes larger than the quoted uncertainties. To illustrate this, we subsequently compared our measurements with those from Curti et al. (2022), who improved the calibration using a standard star. For other comparisons see also Taylor et al. (2022) and Brinchmann (2022).

2.2. JWST NIRCam observations

We make use of a single NIRCam pointing in the six wide filters F090W, F150W, F200W, F277W, F356W, and F444W, with a uniform exposure time of 2.1 h in each and shallower NIRISS imaging in F115W. We obtained the calibrated and distortion-corrected NIRCam and NIRISS images from the publicly available reduction by Brammer (2022). The images were processed with the standard JWST pipeline up to stage 2b, before they were WCS aligned and combined with the grizli\(^3\) pipeline (see Brammer et al., in prep.). The images were pixel aligned at 40 mas pixel scales, before producing a multi-wavelength catalog with SExtractor (Bertin & Arnouts 1996). Fluxes are measured in small circular apertures of 0.32 diameter and corrected to total fluxes using the AUTO fluxes from the F200W detection image.

To determine stellar masses, SED fits to the seven bands were carried out using the latest versions of the CIGALE and Prospector codes (Boquien et al. 2019; Johnson et al. 2021), exploring a relatively wide range of priors. Without correcting for magnification, we found masses of log(M∗/M⊙) ~ 8.9–9.2 as well as significant differences between the codes. We also note that the masses derived by Carnall et al. (2022) are systematically lower than ours, which should mainly be due to consistently younger ages found by these authors. Before more detailed analyses of the SEDs and spectra of these galaxies become available, we adopt the stellar masses from our preferred CIGALE fits and a conservative uncertainty of ±0.3 (see Table 1). To correct the masses for gravitational magnification from the cluster, we used the magnification factors \( \mu \) from the lens models of Caminha et al. (2022). Other lens models, such as those used by Carnall et al. (2022), yield similar magnifications (differences of 10–50% at most) for the sources studied here.

2.3. Comparison samples

To make a comparison with low-z galaxies, we used a sample of 5607 star-forming galaxies from the SDSS Data Release 14 compiled by Y. Izotov and collaborators, analyzed in earlier publications (e.g., Guseva et al. 2019; Ramabhadran et al. 2020). The selection criteria used for the extraction of star-forming galaxies are presented in Izotov et al. (2014). Then we require a detection of the [O III] \( \lambda 4363 \) line with an accuracy better than 4\( \sigma \), thus allowing for direct abundance determinations to be obtained using the T\( _\text{e} \)-method (this sample is subsequently referred to as Izotov-DR14).

We also used the spectra of 89 galaxies at z ~ 0.3 from the Low-Z Lyman Continuum Survey (LzLCS), the first large sample of galaxies with UV spectroscopy covering both the Lyman continuum and non-ionizing UV (see Flury et al. 2022a,b). Approximately half of the sample has [O III] \( \lambda 4363 \) detections.

3. Observed and derived properties of the z ~ 8 galaxies

3.1. Emission line properties

First, we examined the observed emission line ratios in the three high-z galaxies and compared them to those of the low-z samples (cf., above). Figure 3 shows the line ratios including the lines of [Ne III] \( \lambda 3869, \lambda 3967, \lambda 3953, \lambda 4363, \lambda 4630, \lambda 4959, \lambda 5007, \lambda 6563 \) and H\( \gamma \), which were detected in the JWST spectra. The [Ne III]/[O II] \( \lambda 3727 \) ratio is well known to closely trace O32, since both high ionization lines of [Ne III] and [O III] originate in the same zone of the H II region. Our measurements in the high-z galaxies (and those from Curti et al. 2022, shown for comparison) are compatible with the observed correlation, providing confidence for our empirical flux calibration. Based on these line ratios, the three high-z galaxies are found at relatively high excitation, corresponding to the tail of the distribution in low-z compact star-forming galaxies (cf. Izotov et al. 2021a). Compared to the low-z samples, the intensity of [O III] \( \lambda 4363 \) is also found to be relatively high, with [O III] \( \lambda 4363/H\gamma \sim 0.3–0.5 \).
as illustrated in Fig. 3. The highest-$z$ source (04590) is a bit offset towards low [O III]$\lambda$5007/[O III]$\lambda$4363 and thus allows abundance determinations using the so-called “direct method” (see e.g., Kewley & Dopita 2002). To do this, we follow the prescriptions of Izotov et al. (2006), assuming low densities. The results are listed in Table 1. We find electron temperatures $T_e$ that are in excess of the highest accurate electron temperatures ($T_e = 16,000–18,000$ K) for two $z = 7.7$ galaxies and nebular O/H abundances of $12 + \log(O/H) \approx 7.86–7.88$ for the two objects. This includes both oxygen and $O^{++}$, determined from the optical lines; in both cases $O^{++}$ dominates. For 04590, the unusually low [O III]$\lambda$5007/[O III]$\lambda$4363 ratio leads to unphysically high electron temperatures ($T_e \sim 35$ kK) that are in excess of the highest accurate electron temperatures measured for star-forming galaxies at low-$z$ ($T_e = 24,800 \pm 900$ K, Izotov et al. 2021b). This result is consistently found by all other papers who have analyzed the JWST; some authors have derived electron temperatures as high as $27,200 \pm 9900$ K (Rhoads et al. 2022). Although the detection of the [O III]$\lambda$4363 line has been confirmed beyond a doubt, we find that better data will be needed before the electron temperatures can be accurately determined. Therefore, the direct metallicity determinations for these high-$z$ galaxies should presently be taken with caution.

Different metallicity estimates can be obtained for the $z = 8.495$ galaxy 04590 (see Table 1): From their finding of $T_e \gtrsim 20$ kK, Trump et al. (2022) concluded that $12 + \log(O/H) < 7.69 < 1/10$ solar, from the empirical relation between $T_e$ and $12 + \log(O/H)$ (cf. Pérez-Montero et al. 2021). Since standard strong line methods are not applicable at such low metallicities and for objects with “extreme” line ratios, we can, for instance, use the empirical calibration of Izotov et al. (2021b) based on measurements of R23$^+$ and O32, established at $12 + \log(O/H) < 7.5$. For 04590, we find $12 + \log(O/H) = 7.39$ with our measurements and $12 + \log(O/H) = 7.24$ using the line ratios reported by Curti et al. (2022), who derived $12 + \log(O/H) = 6.99 \pm 0.11$ by the direct method. With the measurements from Rhoads et al. (2022) we obtain an intermediate metallicity, $12 + \log(O/H) = 7.30$, using the same calibration. All studies are thus far in agreement that 04590 shows the lowest metallicity among the three $z = 8$ galaxies.

In Fig. 4 we show the Ne3O2 and [O III]$\lambda$4363/Hβ ratios as a function of metallicity for the low-$z$ samples and the three $z = 8$ galaxies. We use these line ratios, which are close in wavelength, to minimize possible uncertainties of the flux calibration, differential slit losses, and other properties. Empirically, these line ratios can also provide a simple estimate of the metallicity O/H, as discussed by earlier studies (see e.g., Nagao et al. 2006; Sanders et al. 2020). In any case, we see that our metallicity estimates of the high-$z$ galaxies lead to fairly compatible locations in these diagrams. We conclude that the three $z = 8$ star-forming galaxies have low metallicities, in the range of $12 + \log(O/H) \sim 7.4–8.0$. More accurate determinations and a proper evaluation of the uncertainties require better data overall, including higher signal-to-noise ratio (S/N) spectra, proper

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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3}
\caption{Observed Ne3O2 ratio vs. O32 (left panel) and [O III]$\lambda$4363/Hγ vs. [O III]$\lambda$5007/[O III]$\lambda$4363 (right panel) for the $z = 8$ galaxies (black stars: our measurements; green stars: data from Curti et al. 2022), the Izotov-DR14 sample of star-forming galaxies (grey and red points, according to EW(Hβ) $< 100$ Å and $>100$ Å, respectively), and the LzLCS sample (blue points).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4}
\caption{[Ne III]$\lambda$3869/[O II] $\lambda$3727 ratio (left panel) and intensity of the auroral [O III]$\lambda$4363 line relative to [O III]$\lambda$5007 (right panel), as a function of O/H. Same symbols as in Fig. 3.}
\end{figure}
calibrations, and a more sophisticated data reduction process, as well as continuum and line flux extractions.

Since the continuum is also detected in the NIRSpec spectra of the two $z = 7.7$ galaxies (and very weakly in the third object as well), we also measured the [O III] equivalent width (see Table 1). We compared our measurements with those from the low-$z$ galaxies in Fig. 5, where strong correlations between EW([O III])<5007> and properties such as O32, Ne3O2, and others have been found (Tang et al. 2019; Izotov et al. 2021a). It is possible that the high-$z$ sources are somewhat offset. In any case, the EWs are high in the galaxies with significant continuum detections, with EW([O III])<5007> ~ 700 Å in the brightest source.

Empirically, the ionizing photon production efficiency, $\xi_{ion}$, is found to increase with the [O III]<5007> equivalent width, as also shown in Fig. 5. Using the relations found at low-$z$ and $z \sim 1$–2 (see Tang et al. 2019; Izotov et al. 2021a), we estimate $\log(\xi_{ion}) \approx 25.1$–25.5 erg$^{-1}$ Hz, up to a factor of $\sim 2$ higher than the “canoncal” value often assumed in ionizing photon budget calculations (Robertson et al. 2013). This is comparable to other estimates of $\xi_{ion}$ at high redshift (e.g., Stefanon et al. 2022).

### 3.2. Physical properties of the $z \sim 8$ galaxies and the mass-metallicity relation

As discussed in this work, the three $z \sim 8$ galaxies show emission line properties comparable to compact star-forming galaxies at low-$z$ with strong emission lines. Izotov et al. (2021a) have shown that the low-$z$ galaxies with strong lines (EW(Hβ) > 100 Å) are good analogs of many of the $z \sim 1$–3 star-forming galaxies (Lyman-alpha emitters and Lyman-break galaxies) studied so far. By inference, the emission line properties of the three $z \sim 8$ galaxies studied here also resemble those at intermediate redshifts.

By construction, the galaxies selected here cannot be claimed to be “typical,” and larger, systematic studies will be needed. From our measurements, one object (10612) shows a very high ratio [O III]<5007> /Hβ $\approx 10$ and a strong [O III]<4363 line, which could indicate an active galaxy (Seyfert, see also Brinchmann 2022; Curti et al. 2022). On the other hand, we clearly find evidence for one star-forming galaxy with a fairly low metallicity (04590, with $12 + \log(O/H) \approx 7.2$–7.4).

If we combine our nebular metallicity estimates with the stellar masses described earlier, we obtain the mass–metallicity relation shown in Fig. 6. Our objects are found close to or below the mass–metallicity relation observed at $z \sim 2$ and possibly offset by $0.2$–$0.3$ below this relation, in good agreement with the relation derived by Ma et al. (2016) from simulations. Similar results were also obtained by Jones et al. (2020) using an indirect method based on ALMA emission line detections. However, at the present stage, we consider the stellar masses uncertain, since these strongly depend on assumptions of the star formation history and on the age of stellar populations (see also Tang et al. 2022), as well as the uncertainties with the zero-points of NIRC2 (see Rigby et al. 2022). For example, comparing the masses derived from SEDs by Carnall et al. (2022), Curti et al. (2022), and our work, we can see differences that are generally larger than the uncertainties cited. Then, adopting the lower masses from Carnall et al. (2022), for instance, would imply that our $z \sim 8$ galaxies lie close to the $z \sim 2$ mass–metallicity relation. The lower masses are mostly due to the very young ages ($\sim 1$–2 Myr) inferred by these authors, whereas our SED fits appears to favor less extreme populations. Although Carnall et al. (2022) have claimed that the SEDs show evidence for Balmer jumps (i.e., Balmer breaks in emission due to strong nebular continuum), we do not see such a behavior in the NIRSpec spectrum of the brightest source, 06355, shown in Fig. 1.

Having shown that the $z \sim 8$ galaxies closely resemble strong emission line galaxies from our low-$z$ sample, it is tempting to indirectly infer other properties using correlations established at low-$z$. Certainly, the high O32 ratios, low metallicity, and blue UV slopes ($\beta$) suggest that these galaxies could contribute to cosmic reionization, that is to say, have escaping Lyman continuum photons. For example, for the observed values of O32, $12 + \log(O/H)$, and $\beta$, the LzLCS results suggest a $30$–$60$% detection fraction of the Lyman continuum. Adopting the mean relation between the LyC escape fraction, $f_{esc}$, and the UV slope, we estimate $f_{esc} = 0.03$–0.08 for the three $z \sim 8$ galaxies, although the LyC escape could also be significantly higher (see Chisholm et al. 2022).

Future improvements in the calibration and data reduction and additional observations will allow us to more accurately
4. Conclusion

We analyzed the rest-frame optical spectra of two galaxies at $z = 7.7$ and one at $z = 8.5$ from the JWST EROs. The spectra exhibit numerous emission lines of H, He I, [O II], [O III], and [Ne III], as commonly seen in metal-poor star-forming galaxies at low redshift. These provide, for the first time in the epoch of reionization, detailed information on the chemical composition and interstellar medium of these galaxies. Our main results are summarized as follows:

- The auroral [O III] λ4363 line is significantly detected in all galaxies with 3.9 – 5.7σ, allowing us to determine the O/H abundance (metallicity) using the direct method. With this method and different strong-line methods, we estimate metallicities between $12 + \log(O/H) = 7.4\pm 0.8$, namely, $\sim 5\pm 20$% of solar.
- All three galaxies show a high excitation, as measured by their line ratios of $O32 = 6-11$ and $Ne32O = 0.4-0.7$, or even higher, according to Curti et al. (2022) and Rhoads et al. (2022). The observed emission line ratios are similar to those of rare low-$z$ star-forming galaxies, which are considered analogs of high-redshift ($z \sim 1-3$) galaxies. One of the $z = 7.6$ galaxies shows unusually high $[O III] \lambda5007/H\beta \approx 10$, possibly indicative of nuclear activity (Seyfert 2).
- The $z \sim 8$ galaxies show quite high equivalent widths, that is, EW([O III] λ5007) up to $\sim 700$ Å, as expected from low-$z$ galaxies with high excitation. Such galaxies are known to be efficient producers of ionizing photons. We conservatively estimate $log(\xi_{\text{ion}}) \sim 25.2-25.5$ erg$^{-1}$ Hz for our galaxies.
- Using stellar mass estimates from SED fits, we find the $z \sim 8$ galaxies to lie close to or below the mass–metallicity relation (MZR) at $z \sim 2$. To assess whether the MZR continues to evolve from $z = 2$ to $8$, future studies of larger galaxy samples and accurate metallicity determinations will be required. Overall, the first analysis of the rest-frame optical spectra of galaxies at $z \sim 8$ indicates that the emission lines properties of galaxies in the epoch of reionization resemble those of relatively rare “local analogs” that have previously been the subject of study by the SDSS and for which numerous physical properties have already been determined. These low-$z$ samples will soon be rivaled by numerous measurements with NIRSpec onboard JWST. Clearly, the first data release reveals already an extremely promising “preview” of upcoming science with JWST in the early Universe. More robust inferences will require better data, including higher S/N spectra and improvements in the calibration, data reduction, and continuum and line flux extractions.

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