

# Using cGANs for Anomaly Detection: Identifying Astronomical Anomalies in JWST Imaging

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## 1. ABSTRACT

We present a proof of concept for mining JWST imaging data for anomalous galaxy populations using a *conditional Generative Adversarial Network* (cGAN). We train our model to predict long wavelength NIRcam fluxes ( $LW : F277W, F356W, F444W$  between  $2.4\mu m - 5.0\mu m$ ) from short wavelength fluxes ( $SW : F115W, F150W, F200W$  between  $0.6\mu m - 2.3\mu m$ ) in  $\sim 2000$  galaxies. We test the cGAN on a population of 37 Extremely Red Objects (EROs) discovered by the CEERS JWST Team (Barro et al. 2023). Despite their red long wavelength colors, the EROs have blue short wavelength colors ( $F150W - F200W \sim 0$  mag) indicative of bimodal SEDs. Surprisingly, given their unusual SEDs, we find that the cGAN accurately predicts the  $LW$  NIRcam fluxes of the EROs. However, it fails to predict  $LW$  fluxes for other rare astronomical objects, such as a merger between two galaxies, suggesting that the cGAN can be used to detect some anomalies.<sup>1</sup>

## 2. METHOD

We use public domain JWST NIRcam data in the CEERS field, which covers  $100sq.arcmin$  of the EGS field, and our network is based on the *pix2pix* architecture described in Isola et al. (2017). The data for the model were obtained from the CEERS data release 0.5. Due to the different sensitivities of Module A and B of the JWST imaging, this study focussed on the subset of galaxies that were imaged using Module A. The images for each NIRcam filter were cropped into two regions of the NIRcam imaging field and a PSF-matching was done to match the PSF of each filter to that of F444W. Sources were detected using Python's *sep* package<sup>2</sup>(Barbary 2016; Bertin & Arnouts 1996) using  $F277W$  as the detection filter. A pixel threshold value  $\geq 2.0\sigma$  was used with  $\sigma$ , the global background RMS. This detection threshold is the minimum signal-to-noise ( $S/N$ ) ratio of a pixel to be regarded as a detection. All detected sources were extracted as  $90 \times 90$  pixel cutout images using Python's *Astropy* package<sup>3</sup>(Astropy Collaboration et al. 2013, 2018, 2022).

The cGAN was pre-trained on  $SW$  NIRcam filters for a subset of sources detected to predict  $LW$  filters using 90% of the  $\sim 2000$  galaxies for training and 10% for validation. After training the cGAN for 100 epochs, the validation dataset was used to assess the generalisation capability of the model. To assess the performance of the cGAN, photometry was measured on the predicted  $LW$  fluxes to compare the SED of the objects with those predicted by the model. Figure 1a shows the distribution of the absolute difference between the ground truth SED,  $y$ , and the SED predicted by the cGAN,  $\hat{y}$ , against a subset of the validation data set across the three  $LW$  NIRcam filters. The absolute difference is predominantly situated at  $\sim 0$  for the majority of sources for all of the  $LW$  filters. The distribution is roughly uniform for the  $F356W$  filter where there is a small difference between the ground truth SED and the predicted SED, respectively. Nevertheless, this shows that the model can accurately predict NIRcam  $LW$  filters such that we can reliably construct an SED.

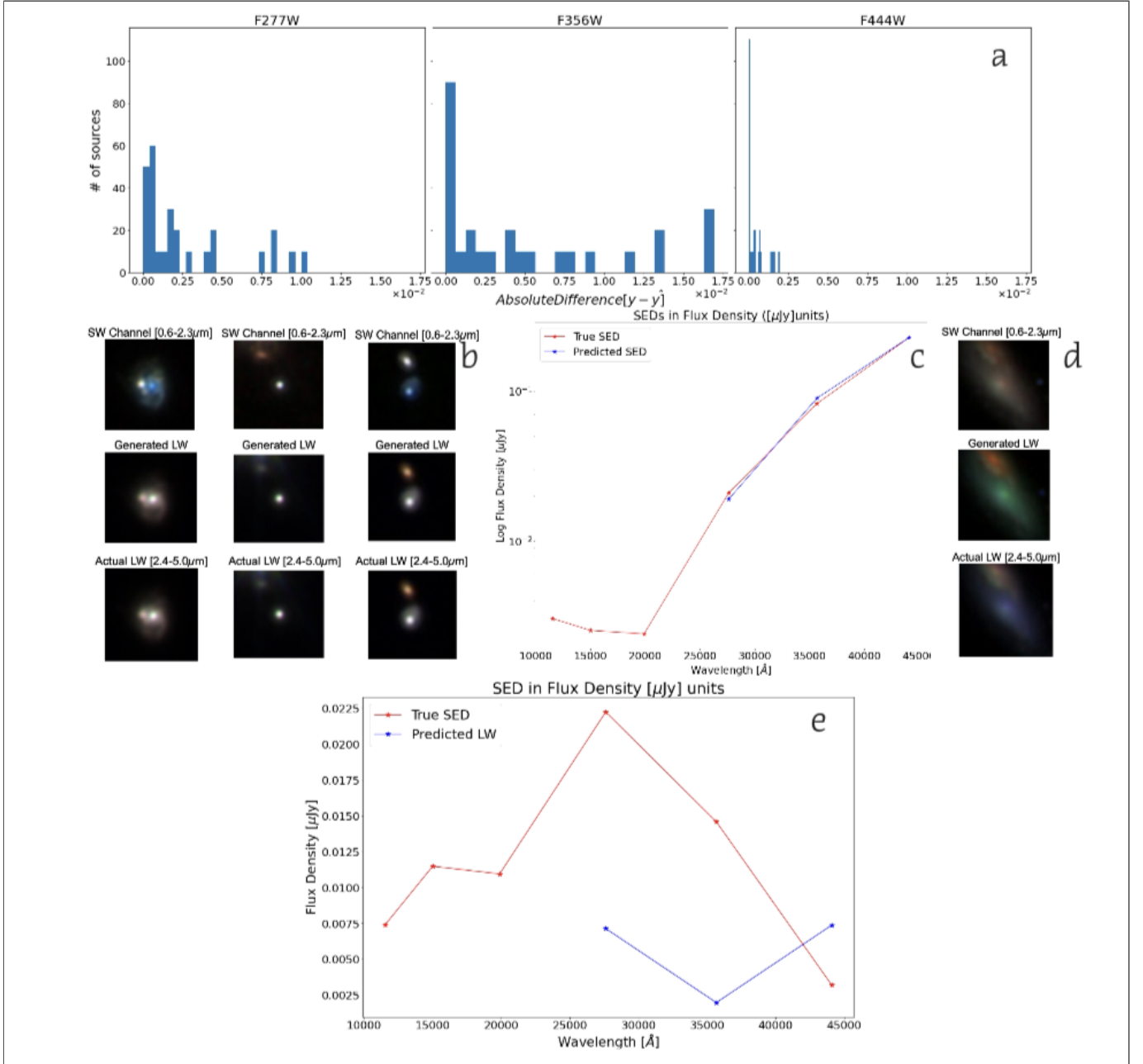
## 3. RESULTS

We tested the cGAN on the 37 EROs identified by Barro et al. (2023) with  $F444W < 28$  mag and photometric redshifts  $5 < z < 7$ . The 37 EROs were deliberately excluded from the model's training dataset. All of the EROs

<sup>1</sup> The source code and trained model (Pearce-Casey 2023) are available at [https://github.com/RubyPC/Anomaly\\_Detection\\_with\\_cGANs](https://github.com/RubyPC/Anomaly_Detection_with_cGANs).

<sup>2</sup> <https://sep.readthedocs.io/en/v1.1.x/>

<sup>3</sup> <https://readthedocs.org/projects/astropy/>



**Figure 1.** The results of the cGAN. *1a* shows the distribution of the absolute difference in SED between the ground truth and the cGAN's prediction, respectively, after testing on a subset of the validation data set of  $\sim 2000$  objects. *1b* shows the cGAN's prediction of the LW channel for a set of 3 EROs in the middle row comparing to the ground truth in the bottom row with the top row being the SW input to the model, and *1c* illustrates the cGAN's prediction for one ERO, showing its generalisation power of predicting the LW fluxes of objects with peculiar SEDs by excellently constructing the characteristic steep rise in the SED. Finally, *1d* shows the cGAN's poor prediction on a pair of merging galaxies with *1e* showing the poorly constructed SED, where the cGAN can be used as an anomaly detector.

40 are unresolved, point-like sources in all observed filters and are typically faint in all SW NIRcam filters. Barro et al.  
 41 (2023) found that the EROs exhibit a distinctive, bimodal SED with blue colors for  $\lambda > 2\mu\text{m}$  and they suggest that  
 42 the flux in some of the LW filters is partially boosted by strong emission lines, making the colors redder than the  
 43 stellar continuum. A defining feature of these EROs is that *all* of them have blue colors in the SW NIRcam filters  
 44 ( $F115W - F200W \sim 0$ ). Figure 1b shows the cGAN's prediction on 3 of the EROs with the top row being the SW

input to the model and the middle and bottom rows being the cGAN's prediction of the  $LW$  and the ground truth  $LW$ , respectively. Despite the peculiar, bimodal SEDs of the EROs, the cGAN performs just as well in predicting the  $LW$  filters for a sample of EROs, predicting red  $LW$  NIRcam fluxes. Additionally, Figure 1c shows the comparison between the ground truth SED of an identified ERO and the corresponding prediction from the cGAN. Although EROs are rare, and with a peculiar SED, the cGAN accurately predicts the steep rise in the SED at longer NIR wavelengths.

However, we find that the cGAN cannot accurately predict  $LW$  filters for *all* galaxy types. In particular, we find its predictions for galaxies with unusual or disturbed morphologies are less accurate, such as can be seen in Figure 1d where the prediction of the  $LW$  in the middle row is not accurate in comparison to the ground truth in the bottom row for a pair of merging galaxies. Figure 1e shows the construction of the SED for the galaxy merger and it is clear that the model fails to predict the  $LW$  NIRcam fluxes. Thus, we suggest that the cGAN can be used as an anomaly detector; it can accurately predict  $LW$  filters for the majority of galaxies in the CEERS field, including EROs, but its performance suffers when predicting on rare objects such as a merger between galaxies.

#### 4. CONCLUSION

In conclusion, our results demonstrate our cGAN's capability of detecting some rare astronomical objects. Therefore, for this specific case using JWST NIRcam filters, not only can cGANs be used for image generation and image segmentation tasks but also for anomaly detection. This technology can be deployed on the rapidly increasing archive of JWST imaging survey observations as well as forthcoming giant survey data sets from e.g. Roman and Euclid; anomalous systems such as strong gravitational lenses have already been seen in JWST surveys (e.g. Pearson et al. 2023; van Dokkum et al. 2023).

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*Software:* Astropy (Astropy Collaboration et al. 2013, 2018, 2022), Sep (Barbary 2016; Bertin & Arnouts 1996) .

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