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JWST PHOTOMETRY OF CEPHEIDS IN NGC 1365, NGC 5584 AND NGC 4258

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Abstract. We developed a python based pipeline which would perform PSF photometry on a known list of Cepheids in a JWST image. We used synthetic PSF to perform photometry on three JWST images of NGC 1365, NGC 5584, and NGC 4258. We plotted the Cepheid magnitudes against their known periods and compared the intercept of the Period-Luminosity fit with reference works. In the pipeline, we also included a routine to determine the crowding bias present around each Cepheid and corrected the flux values accordingly. We found that these crowding bias values have a correlation with the local surface brightness of the galaxy. We used the known distance of NGC 4258 as an anchor to determine the distances to the other galaxies.

Keywords: James Webb Space Telescope, Cepheids, Photometry, Crowding, Cosmology, Hubble tension, Hubble constant

1 Introduction

One of the most fundamental parameters of cosmology is the Hubble Constant, H_0 which describes the present expansion rate of the universe. In recent years, precise measurements have given rise to a tension between the values of H_0 from two different classes of measurements. Early-universe cosmology-dependent approaches, e.g. Planck Collaboration et al. (2020), find $H_0 \approx 67$ kms^{-1}Mpc^{-1}, the late-universe direct measurements, mostly find $H_0 \approx 73$ kms^{-1}Mpc^{-1}. One of the key contributors to the latter value is the SH0ES (Supernovae H_0 for the Equation of State) project, which measures $H_0 = 73.04 \pm 1.04$ kms^{-1}Mpc^{-1} (Riess et al. 2022), bringing one of the most precise measurements of H_0 which is in 5σ tension with the early universe results. This so-called 'Hubble Tension' demands further scrutiny and refinements of both of the observation methods.

We aim to use Cepheid variable stars to determine distances of SNIa host galaxies using the Leavitt law (Leavitt & Pickering 1912). This project aims to develop a pipeline to perform photometry on known Cepheids in the JWST images (Gardner et al. 2023; Rigby et al. 2023) of several galaxies. Instead of using DOLPHOT (Dolphin 2000, 2016) like the SH0ES team, we have built our pipeline using AstroPy (Astropy Collaboration et al. 2022), PhotUtils (Bradley et al. 2023). We used NIRCam images of NGC 1365, NGC 5584 - two type Ia Supernovae host galaxies and NGC 4258 - a nearby galaxy which has 1.5% maser-based geometric distance measured. Although the resolutions of the JWST images are very high, the fields around Cepheids are still very crowded, which poses significant difficulty to the process of precise photometry measurements. We have introduced a routine to correct the effect of crowding on the flux measurements. The aim of this work is to accurately measure the magnitude of the Cepheids in each galaxy and using the known distance of NGC 4258 as an anchor, measure the distance of the other galaxies.

2 Methodology

We obtained the JWST NIRCam images from the Mikulski Archive for Space Telescopes (MAST). And we obtained the coordinates and periods of Cepheids in the galaxies NGC 1365, NGC 5584 and NGC 4258 from Yuan et al. (2022b, Table 1), Riess et al. (2023, Table 2) and Yuan et al. (2022a, Table 2) respectively. Then we confirmed that the Cepheids are correctly positioned by correcting the shift in the coordinates and filtering

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out coordinates that were outside the image. We opted to use the *WebbPSF* package to simulate PSFs over measuring PSFs from the images to obtain higher accuracy and reduced workload.

The PSF photometry of the Cepheids was done in the following way: A small window is taken around each Cepheid where the photometry will be done independently. The PSF is iteratively fitted at the known position of the Cepheid and detected positions of other sources and then removed until no sources are detected in the residual. This residual is used to check the quality of the fitting and to determine the background level (Fig. 1).

The PSF tails of nearby sources increase the flux measurement of a source in a crowded field. To measure this bias, we inject an artificial source with known flux into each Cepheid's neighborhood and do the photometry routine on this window and recover the flux. We repeat this ∼100 times with different fluxes and positions. We fit the injected flux and measured flux of the artificial star to determine the crowding bias. And with this value, we correct the flux measurement of the Cepheid in interest.

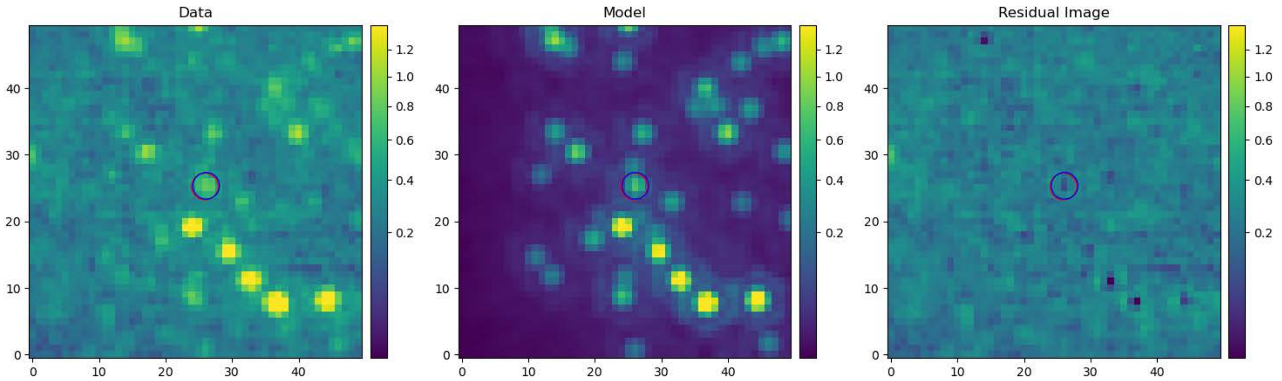

Fig. 1. From left: 50x50 sq pixel window around a Cepheid to perform photometry on, modelled stars in the window, and the residual after removing the modelled stars.

3 Results

In the magnitude vs (logP -1) plot (Fig. 2), we fitted a straight line with a fixed slope given by (Riess et al. 2023, section 3.3) of -3.2 mag. We obtain the intercept of the linear relation at logP = 1 (P = 10 days).

The results of the work are presented in table 1 in the form of intercept at logP = 1. The plots in figure 2 show the scatters of the P-L relation before and after crowding correction.

Table 1. P-L intercepts and distance modulus for the Cepheids in the three galaxies. The distance of NGC 4258 is taken from Reid et al. (2019). The reference intercepts are taken from Riess et al. (2023) and Yuan et al. (2022b).

Host	Intercept [mag]	Median Crowding [MJy/sr]	Corrected Intercept [mag]	Distance Modulus [mag]	Reference Intercept [mag]	Filter
NGC 4258	23.326 ± 0.007	1.868	23.398 ± 0.008	*29.397 ± 0.032*	23.42 ± 0.175	F150W
NGC 5584	26.025 ± 0.004	0.661	26.121 ± 0.005	32.120 ± 0.033	25.851 ± 0.161	F150W
NGC 1365	25.289 ± 0.018	2.835	25.44 ± 0.023	31.439 ± 0.040	25.752 ± 0.059	F200W

In addition to these results, by plotting the values of crowding bias onto the map of the galaxy (Fig. 3), it was seen that there is a relation between the local surface brightness of the galaxy and the crowding bias. So, we tried to demonstrate this relation using a linear fit in figure . This relation can potentially be used to estimate the crowding bias instead of calculating it by the computationally heavy routine used in this work.

4 Conclusions

This work highlights the efficiency of a PhotUtils-based photometry pipeline and WebbPSF-based synthetic PSF to measure the Cepheid fluxes in JWST images. Moreover, the effectiveness of a routine to determine

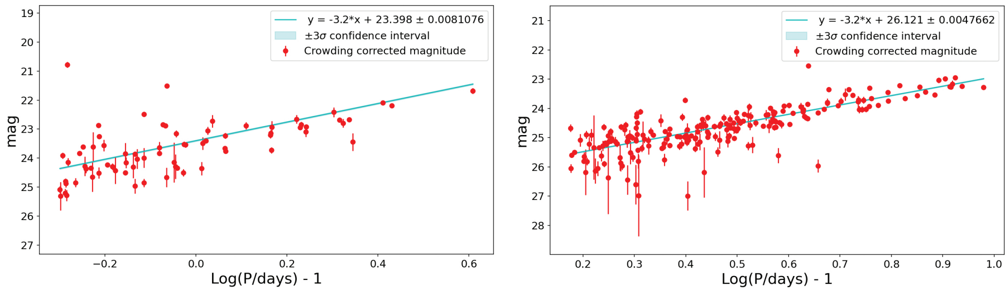

Fig. 2. Luminosity-Period relations of Cepheids in (from left) NGC4258 and NGC5584. The linear fittings were done only on the intercept using a constant slope -3.2

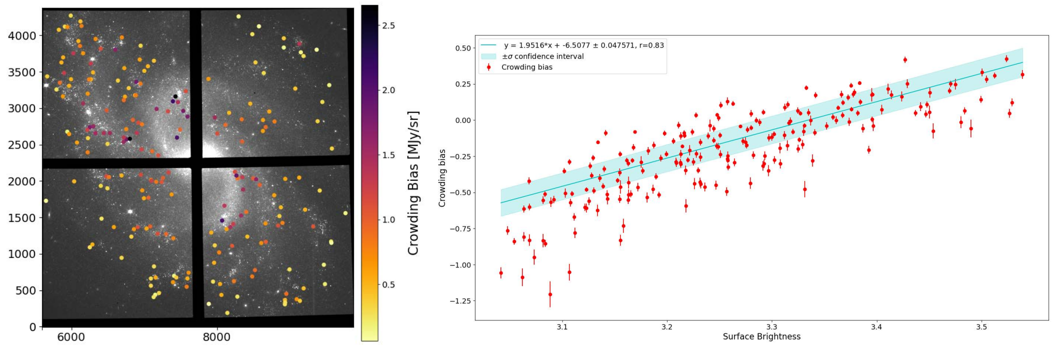

Fig. 3. Left: Map of the crowding bias at the positions of Cepheids in NGC 5584. **Right:** Fitting the relation of crowding bias vs local surface brightness.

the crowding bias was tested. Although we couldn't calculate the measurements in every band and epochs and correct for possible errors due to time limitations and availability, our results were in close proximity with the values from reference works. Moreover the values of the crowding bias have shown a close correlation with the local surface brightness of the galaxy, which demands further attention.

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