

Spatial correlations of PAH, UV, H α emission and IMF–PAH variations in the star-forming complexes of NGC 628

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ABSTRACT

We examine the spatial correlation of emission from polycyclic aromatic hydrocarbons (PAH) (3.3, 7.7, and 11.3 μm) with the far-ultraviolet (FUV), near-ultraviolet (NUV), and H α emission from star-forming complexes (SFCs) in different regions of NGC 628. We use the *James Webb Space Telescope* to detect PAH emission, along with the Ultraviolet Imaging Telescope and Multi-Unit Spectroscopic Explorer observations to sample the UV and H α emission, respectively. We investigate the correlation of PAH luminosities with FUV, NUV, and H α luminosities for the extracted SFCs. We find that the arm and spur SFCs show bright PAH emission, except for those with only NUV emission, located primarily in bubbles and superbubbles. We also examine these correlations in the phantom void, the largest superbubble in NGC 628. We investigate the trend for FUV-NUV and the Initial mass function (IMF) index α_2 derived from the ratio of B stars with PAH band ratios (F335M/F1130W, F770W/F1130W, and F335M/F770W). We find that PAH band ratios increase as the IMF becomes more top-heavy and the SFCs become bluer, consistent with enhanced PAH excitation and ionization in stronger UV radiation fields. However, α_2 of spur SFCs shows a flat trend with PAH band ratios compared to arms. Upon closer examination, two SFCs in the shell region of the phantom void showed a flatter IMF compared to the SFC located near the elongated bubble. This is likely due to gas accumulation, possibly through feedback mechanisms in the shell region, while the SFC near the elongated bubble may have formed in a region affected by shear.

Key words: galaxies: individual: NGC 628 – infrared: galaxies – infrared: ISM.

1 INTRODUCTION

Star formation is crucial for understanding the evolution of galaxies (R. C. Kennicutt 1998). The most commonly used star formation tracers are UV and H α , however there are others found throughout the electromagnetic spectrum (D. Calzetti 2013). Although both UV and H α trace recent star formation, UV emission arises directly from massive stars and traces star formation for around 200 Myr (D. A. Thilker et al. 2007), whereas H α is the recombination line emission from the ionized regions around massive stars, hence tracing star formation for around 10 Myr. However, both can experience extinction, and these tracers alone will not provide complete information on the star formation rate (SFR). On the other hand, mid-infrared (MIR) and near-infrared (NIR) emissions are less affected by extinction (F. Belfiore et al. 2023). Polycyclic aromatic hydrocarbons (PAHs) have also been proposed as effective SFR tracers (D. Rigopoulou et al. 1999; E. Peeters et al. 2004).

PAHs are organic molecules with multiple aromatic rings containing 20–1000 carbon atoms (L. J. Allamandola et al. 1989; D. Rigopoulou et al. 2021). These molecules are an essential part of the interstellar medium (ISM), and up to 20 per cent of the total IR emission in star-forming galaxies can come from these molecules (J. D. T. Smith et al. 2007; A. Li 2020). They emit in distinctive IR bands at 3.3, 6.2, 7.7, 11.3, 12.7, and 17 μm (A. Leger & J. L. Puget 1984; L. J. Allamandola et al. 1989). These molecules can be vibrationally excited with a single UV photon, and they de-excite emitting the distinctive PAH features (A. G. M. Tielens 2008). Both stretching and bending vibrational modes contribute to these features. The 3.3 μm feature is seen when C-H bonds stretch, whereas C-C bending and C-H out-of-plane bending contribute to the features at 6–9 μm and features beyond 11 μm , respectively (A. Leger & J. L. Puget 1984; L. J. Allamandola et al. 1989).

PAH molecules can be excited by the wide range of radiation fields (A. Li & B. T. Draine 2001). PAH emission is observed to remain relatively constant in regions of a galaxy with uniform metallicity and weak radiation fields, tracing the diffuse ISM (K.

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M. Sandstrom et al. 2023b). However, it is particularly bright in regions illuminated by UV and visible photons from massive stars in star-forming regions tracing the front of the photodissociation regions (PDRs) around stars, which separates the ionized gas from the surrounding molecular gas (A. G. G. M. Tielens et al. 1993). Hence, their bright emission is closely associated with star formation. Their band ratios can be used to investigate the properties of the molecules, such as size and charge, which in turn helps us understand the source of UV photons (B. T. Draine et al. 2021; A. Maragkoudakis et al. 2022; J. Chasten et al. 2023b; D. Rigopoulou et al. 2024). Small PAH molecules emit strongly at 3.3 μm . Larger molecules emit at longer wavelengths, specifically around 11.3 and 17 μm . Ionized PAHs are associated with C-C vibrational modes, leading to 6.2 and 7.7 μm emissions. Meanwhile, neutral PAHs emit at 3.3, 11.3, and 17 μm , which are primarily linked to C-H vibrational modes. Hence, emission from the various PAH bands traces the size and charge (or degree of ionization) of PAH molecules (L. J. Allamandola et al. 1999).

PAHs have been extensively studied in various astrophysical regions, from planetary, protoplanetary, and reflection nebulae to the H II regions and ISM of galaxies (A. G. G. M. Tielens 2008). The 3.3, 6.2, 7.7, and 11.3 μm features have been mostly used to study the PAH properties in galaxies (D. Rigopoulou et al. 2021, 2024; K. M. Sandstrom et al. 2023a; J. Lyu et al. 2025). Early-type and active galaxies show an abundance of neutral larger molecules, whereas star-forming galaxies have more ionized molecules (H. Kaneda et al. 2008; O. Vega et al. 2010; I. García-Bernete et al. 2022, 2024). Smaller molecules may undergo preferential destruction from a harsh environment (J. D. T. Smith et al. 2007) or their abundance could also increase due to the shattering of large grains (M. Yamagishi et al. 2012). There can also be the destruction of PAHs in regions with strong emission from active galactic nuclei (AGNs). However, some studies have shown that there is no clear evidence for the preferential destruction of smaller PAH molecules (D. Rigopoulou et al. 2024). Rather, ionization appears to be the dominant factor governing PAH emission. Furthermore, PAHs have been detected in the immediate vicinity of AGNs (I. García-Bernete et al. 2022; T. S.-Y. Lai et al. 2022; L. Armus et al. 2023). In addition to this, properties such as metallicity affect the production and emission of PAH molecules (S. C. Madden et al. 2006; K. M. Sandstrom et al. 2012; J. Chasten et al. 2019). With the *James Webb Space Telescope* (JWST), several studies are dedicated to understanding PAH molecules and their emissions in detail. These include spectroscopic (F. R. Donnan et al. 2022; I. García-Bernete et al. 2022, 2024; T. S.-Y. Lai et al. 2023) and photometric studies of nearby galaxies (O. V. Egorov et al. 2023; K. M. Sandstrom et al. 2023b; A. Pedrini et al. 2024; M. J. Rodríguez et al. 2025; J. Yadav et al. 2026) and also those focusing on high redshift (z) galaxies (L. Shen et al. 2023; J. Young et al. 2023; I. Shivaie et al. 2024; J. McKinney et al. 2026).

Our study uses the JWST filters covering the PAH bands (F335M, F770W, and F1130W) of NGC 628 to compare the spatial distribution of PAH with UV, using observations from the Ultraviolet Imaging Telescope (UVIT) as well as the H α distribution obtained from the Multi-Unit Spectroscopic Explorer (MUSE) instrument. Our aim is to understand how the physical properties of the PAHs in star-forming complexes (SFCs) vary with different stellar initial mass functions (IMFs). The latter have been obtained from the catalogue of star-formation properties of NGC 628 by S. Amrutha & M. Das (2025) (hereafter A&D25). We investigated how the PAH properties vary over the different regions

(arms and spurs). We also closely examined the PAH distribution around the phantom void, which is prominent in the PAH bands of NGC 628 (also known as the Phantom galaxy).

NGC 628 is a well-known grand design spiral galaxy, at a distance of 9.84 Mpc (G. S. Anand et al. 2020). This massive galaxy ($\log(M_*/M_\odot) = 10.34$; A. K. Leroy et al. 2019) is nearly face-on ($i = 8^\circ 9'$; P. Lang et al. 2020) and shows young and massive star formation (J. Yadav et al. 2021). Owing to its favourable orientation and active star formation, NGC 628 has been a common target for spatially resolved studies of star formation, including investigations of PAH emission using the broad-band and medium-band filters (e.g. K. M. Sandstrom et al. 2023a) of JWST. Most studies have focused on understanding variation of the PAH fraction as a function of the properties of the ISM, along with their variation with properties such as star formation rate, stellar age, metallicity, and gas ionization (J. Chasten et al. 2023a; D. A. Dale et al. 2023; D. Baron et al. 2024; J. Sutter et al. 2024; U. Krishnan et al. 2024). D. A. Thilker et al. (2023) examined the diffuse and filamentary emissions seen in PAH emission and their relationship to star formation. One of the striking features observed in the JWST is the bubbles and superbubbles formed due to feedback from massive stars and supernovae (SNe) explosions. This has also been a key research topic for NGC 628 (A. T. Barnes et al. 2023; Y. D. Mayya et al. 2023; E. J. Watkins et al. 2023).

In the following sections, we first present the data in Section 2, and then in Section 3 we describe the analysis of our data, along with the results. In Section 4, we discuss our results and compare them with previous studies. Finally, we summarize all our findings in Section 5.

2 DATA

We used archival fully calibrated level 3 JWST Mid-Infrared Instrument (MIRI; G. H. Rieke et al. 2015) F770W ($\Delta\lambda = 1.95 \mu\text{m}$), F1130W ($\Delta\lambda = 0.73 \mu\text{m}$) images, and the Near Infrared Camera (NIRCam; M. J. Rieke et al. 2005) F335M image ($\Delta\lambda = 0.38 \mu\text{m}$) to study the PAH emission in NGC 628. To estimate and remove the underlying stellar and dust continuum, we additionally used the NIRCam F300M and F360M images for the F335M band, and the MIRI F560W and F2100W images for the F770W and F1130W bands. We also used MIRI F2100W for extinction correction. These images (except F560W) are part of the Physics at High Angular resolution in Nearby Galaxies (PHANGS-JWST; J. C. Lee et al. 2023; T. G. Williams et al. 2024) treasury survey. The image F560W is part of the Feedback in Emerging extragalactic Star clusters (FEAST; D. Calzetti et al. 2024; A. Pedrini et al. 2024; A. S. M. Buckner et al. 2026) survey. These high-level science products were retrieved from the Mikulski Archive for Space Telescopes portal. The F770W and F1130W images have an angular resolution of $0''.269$ and $0''.375$, respectively. The NIRCAM filters F300M, F335M, and F360M have an approximate angular resolution of $0''.11$.

We used the archival MUSE H α emission-line map (PHANGS-MUSE; Emsellem et al. 2022). The angular resolution of the MUSE H α map is around $0''.6$. We used reduced UVIT's far-ultraviolet (FUV) and near-ultraviolet (NUV) observations from A&D25. The UVIT is a twin telescope with FUV (1300–1800 Å) as one instrument, and the other instrument has the NUV (2000–3000 Å) and visible (VIS) bands. We used the CaF2 F148W ($\Delta\lambda = 500 \text{ Å}$), and the NUVB4 N263M ($\Delta\lambda = 275 \text{ Å}$) filter images for our analysis. The angular resolution of the FUV and NUV bands is around $1''.2$ – $1''.5$. By looking at the field stars in the FUV and

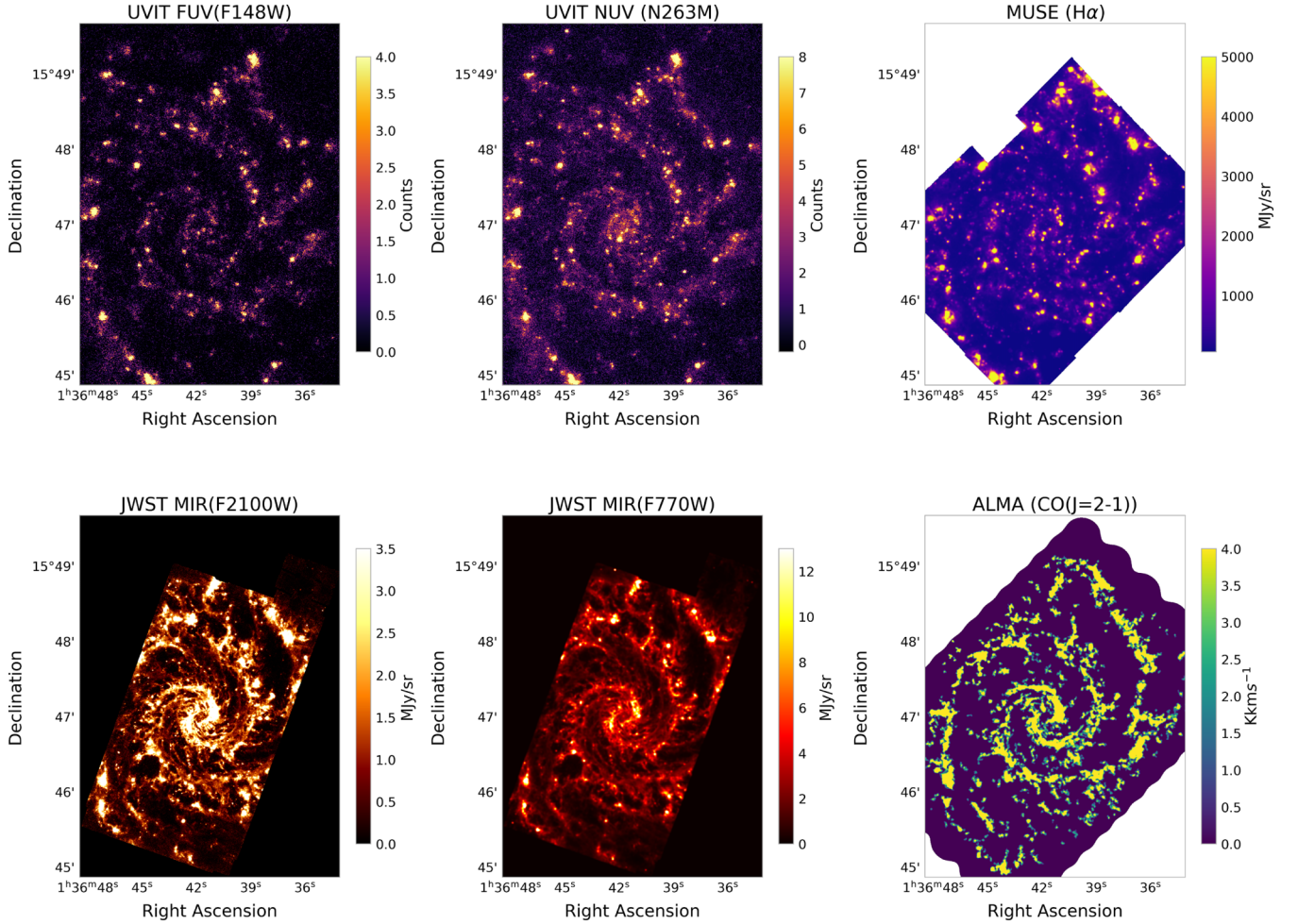


Figure 1. Multiwavelength images of NGC 628.

NUV images, we obtained a mean PSF of those stars to be around $1''.2$. The information on the reduction and other analyses to get a science-ready UVIT image of NGC 628 is explained in A&D25.

We convolved all *JWST* and MUSE images with appropriate Gaussian kernels using *ASTROPY*'s `convolve_fft` to match the UVIT resolution, with a full width at half-maximum of approximately $1''.2$. For *JWST* images, we approximated the native PSF of each image as a Gaussian and computed the required Gaussian convolution kernel from the difference between the native and target resolutions. The kernel width was determined separately for each filter to match all images to a common final resolution. We utilize these convolved images for further analysis. With this resolution, we are able to resolve OB associations that are approximately 57 parsecs in size.

To characterize star-forming regions, we make use of an existing catalogue from A&D25, which lists the star formation properties of SFCs in NGC 628, including UV and $H\alpha$ emission. These SFCs were extracted using *SEXTRACTOR* (E. Bertin & S. Arnouts 1996) with a threshold of 5σ in all three bands for a confident detection. The NUV image reaches a 5σ limiting magnitude of $m_{\text{NUV}} = 23.36$, yielding 690 SFCs, while the FUV image is shallower, with a 5σ limiting magnitude of $m_{\text{FUV}} = 22.78$, resulting in 195 SFCs. The SFCs were then classified based on their location (arm, spurs, and interarm regions), and the associated emission in the $H\alpha$, FUV, and NUV bands. Arms and interarm SFCs were

classified based on their location in the NUV image. However, spurs are features that extend outward from the spiral arms and are evenly spaced in azimuth. They can extend up to kiloparsec scale lengths as per simulations (T. G. Williams et al. 2022b). Spurs are observed better in molecular gas maps as seen in the ALMA image in Fig. 1. Hence, the SFCs were plotted on the ALMA CO map (PHANGS-ALMA; A. K. Leroy et al. 2021a, a) to identify those SFCs associated with spur regions (See fig. 2 in paper A&D25).

2.1 Continuum subtraction from *JWST* PAH bands

The *JWST* F335M, F770W, and F1130W filters are dominated by PAH emission features. However, these medium- and broad-band filters also contain significant contributions from the underlying stellar and dust continuum. Therefore, it is necessary to separate the PAH emission from the continuum components to obtain accurate measurements of the PAH fluxes.

The starlight continuum from F335M is removed by linearly interpolating between F300M and F360M with a varying slope as mentioned in T. S.-Y. Lai et al. (2020). However, with this method, the F335M continuum is oversubtracted in regions where PAH emission is dominant. This is due to the presence of PAH contribution in the F360M band in such regions (K. M. Sandstrom et al. 2023a). Hence, we use the following relation from K. M.

Table 1. Prescription parameters for MIRI PAH extraction.

	7.7 μm		11.3 μm	
Filters (B, R)	g_{con}	α	g_{con}	α
F560W, F1000W	0.53	0.91	1.22	1.18
F560W, F2100W	0.23	0.62	0.53	0.49
F1000W, F2100W	-0.36	1.51	0.17	1

Note. g_{con} and α are parameters for equations (3) and (4). These equations are from G. P. Donnelly et al. (2025).

Sandstrom et al. (2023a) for optimized continuum subtraction, which is given below.

$$F_{335\text{M}_{\text{Cont}}} = \left(\frac{B_{\text{Lai}}}{B_{\text{PAH}} - B_{\text{Lai}}} \right) (B_{\text{PAH}} F_{360\text{M}} - F_{335\text{M}} + A_{\text{Lai}} F_{300\text{M}}) + A_{\text{Lai}} F_{300\text{M}} \quad (1)$$

$$F_{335\text{M}_{\text{PAH}}} = F_{335\text{M}} - F_{335\text{M}_{\text{Cont}}}. \quad (2)$$

The coefficients A_{Lai} and B_{Lai} in equation (1) are 0.35 and 0.65, respectively, as mentioned in T. S.-Y. Lai et al. (2020). $B_{\text{PAH}} = 1.6$ is the observed slope of the colours for PAH-dominated regions as obtained for NGC 628 in K. M. Sandstrom et al. (2023a).

We used the spectroscopically calibrated method developed by G. P. Donnelly et al. (2025) to derive 7.7 and 11.3 μm PAH fluxes from the broad-band MIRI F770W and F1130W filters. This method calibrates photometrically derived PAH fluxes against spectroscopic measurements using synthetic MIRI photometry. The thermal dust continuum is approximated by a single power law with index α , allowing the continuum contribution to be estimated from pairs of MIRI filters consisting of a blue (B) and red (R) continuum band selected from F560W, F1000W, F1500W, and F2100W. For NGC 628, observations are available in F560W, F1000W, and F2100W, enabling the application of several filter combinations. The resulting expressions for the 7.7 and 11.3 μm PAH fluxes are given by equations (3) and 4, respectively.

$$F_{\text{PAH}7.7} (\text{Wm}^{-1}) = (9.00 \pm 0.21) \times 10^{-14} \times (f_{F770} - g_{\text{con}} f_B^{1-\alpha} f_R^\alpha) \quad (3)$$

$$F_{\text{PAH}11.3} (\text{Wm}^{-1}) = (1.77 \pm 0.04) \times 10^{-14} \times (f_{F1130} - g_{\text{con}} f_B^{1-\alpha} f_R^\alpha), \quad (4)$$

where the flux densities f are given in Jy, while f_B and f_R are flux densities from blue and red filters, respectively, and filter combinations are shown in Table 1. The adopted filter combinations and the corresponding values of g_{con} and α for particular combinations are listed in Table 1.

We applied these relations to all SFCs using each available filter combination listed in Table 1. To assess the sensitivity of the derived PAH fluxes to the continuum estimate, we compared the fractional continuum contribution removed from the F770W and F1130W fluxes for each filter combination. The resulting distributions are shown in Fig. 2.

We favour the correction involving F560W and F2100W filters for further analysis, as the continuum covered by these two filters is relatively flat without prominent emission lines compared to the F1000W, which contains the silicate absorption feature and the pure rotational H_2 0-0 S(5) line. In addition, the F560W-F2100W combination produces the smallest scatter in the continuum-corrected PAH fluxes for both F770W and F1130W bands (Fig. 2), indicating a more stable continuum subtraction.

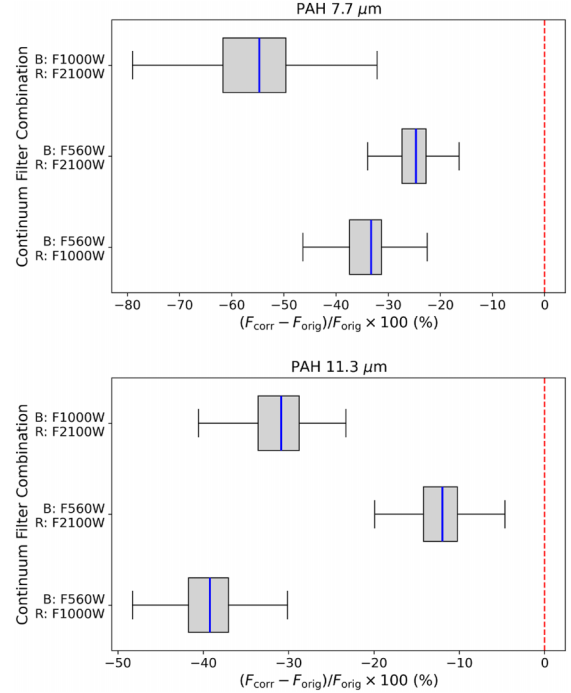


Figure 2. Comparisons between corrected photometric PAH flux and uncorrected PAH flux from F770W (top panel) and F1130W (bottom panel) filters for various combinations of JWST/MIRI filters using equations (3) and (4). The blue lines are median values, the ends of the boxes are 25th and 75th percentiles, respectively, and the whiskers indicate the largest percent difference within 1.5 times the 25th–75th percentile range on either side.

3 ANALYSIS AND RESULTS

3.1 PAH correlation with the UV and $\text{H}\alpha$ emission

The correlation of PAH with SFR has been established in previous studies (D. Calzetti et al. 2007; H. V. Shipley et al. 2016). Earlier studies have used the Infrared Space Observatory (ISO) and *Spitzer* low-resolution data and broad-band MIR emission to establish the relation (D. Calzetti et al. 2007; A. J. Battisti et al. 2015). These have used integrated luminosities of galaxies to obtain this correlation. Therefore, it is important to verify whether this correlation also applies to individual SFCs. Recent studies using *JWST* have further explored PAH-based SFR calibrations using longer wavelength recombination lines (such as $\text{P}\alpha$ and $\text{Br}\alpha$) at ~ 40 pc scales in nearby galaxies (B. Gregg et al. 2024, 2026). In this work, we instead examine whether the established UV and $\text{H}\alpha$ correlations with PAH emission hold in spatially resolved regions such as SFCs.

Here we investigate how the PAH emission from *JWST* filters correlates with $\text{H}\alpha$, FUV, and NUV emission using SFCs from the A&D25 catalogue. The $\text{H}\alpha$ and UV luminosities of SFCs are corrected for extinction using the Balmer decrement and MIR emission (here using *JWST* F2100W band), as detailed in A&D25. For the Balmer decrement, we used the ratio of two nebular Balmer emission lines, $\text{H}\alpha$ and $\text{H}\beta$. To correct for extinction using MIR emission, we employed well-established extinction correction relations from J. Kennicutt et al. (2009) and C.-N. Hao et al. (2011). These corrections are based on the *Spitzer* MIPS 24 μm luminosity. Hence, we identified a set of bright regions in the matched-resolution images and measured their fluxes in both

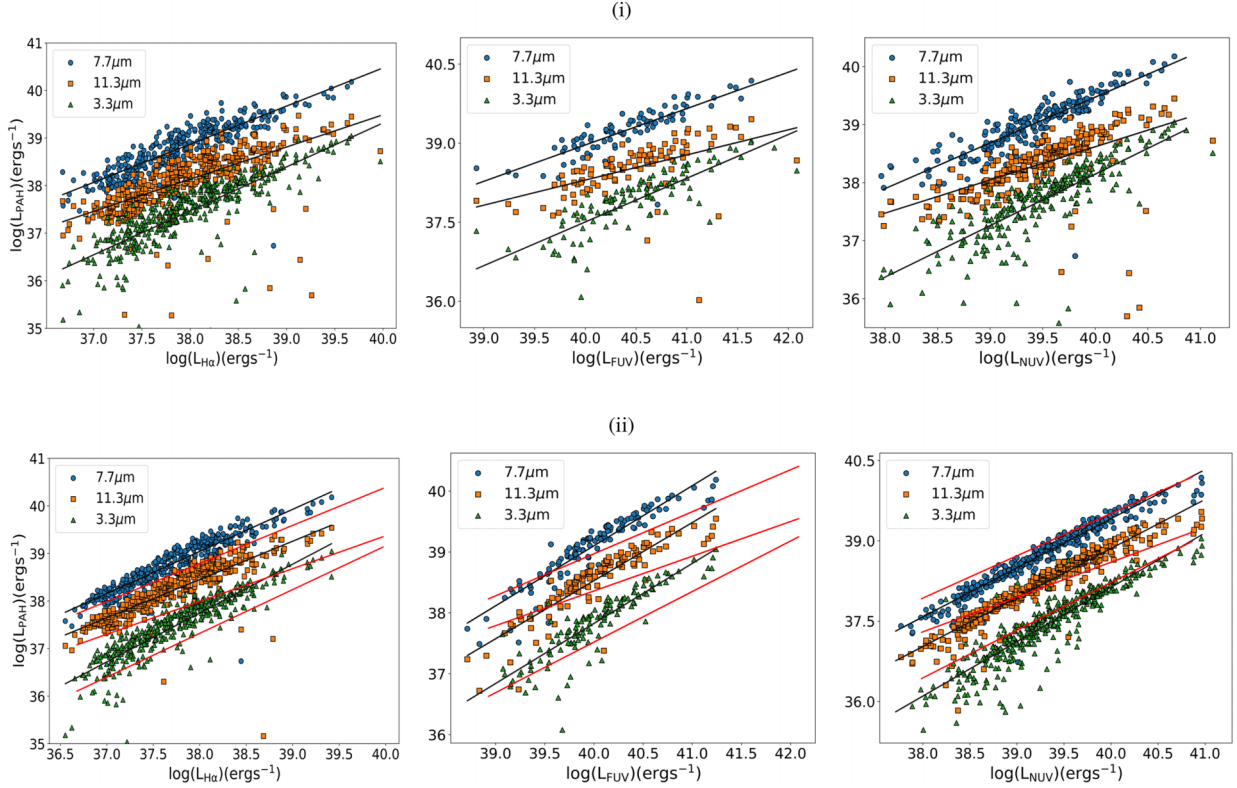


Figure 3. Correlation of $H\alpha$, FUV, and NUV luminosities with different PAH luminosities (7.7 μm , 11.3 μm , and 3.3 μm). This correlation is for extracted SFCs, whose UV and $H\alpha$ luminosities are corrected for extinction with (i) the Balmer decrement method and (ii) MIRI 21 μm . The black trend lines represent the best fit for each plot, while the red lines in panel (ii) show the trend lines from panel (i) overplotted for comparison.

bands. We calculated the ratio of the *JWST* 21 μm luminosity to the MIPS 24 μm luminosity for several bright regions and found a ratio of 4.54. We then multiplied this ratio by the 21 μm luminosity to apply it in the extinction correction relation. In our further analysis, we primarily used the luminosities corrected with the Balmer decrement; however, we also considered the *JWST* 21 μm method for comparison.

We overlaid the SFCs on convolved PAH images (F770W, F1130W, and continuum-subtracted F335M) and measured luminosities in each band. However, we implemented signal-to-noise (S/N) limits on the *JWST* data, as continuum-subtracted PAH maps, particularly the F335M map, can contain negative pixel values owing to oversubtraction and background fluctuations. To ensure robust measurements, we restricted our analysis to SFCs with $S/N > 3$ in all PAH maps. For the 7.7 and 11.3 μm PAH measurements, this criterion was imposed on the original F770W and F1130W fluxes before continuum subtraction. We plotted the correlation of different PAH bands with $H\alpha$, FUV, and NUV emission as shown in Fig. 3. We fitted linear regression as given below,

$$\log(L(\text{PAH})) = A \log(L(K)) + B, \quad (5)$$

where $L(\text{PAH})$ is continuum-subtracted PAH luminosity (7.7 μm , 11.3 μm , 3.3 μm) and the term $L(K)$ corresponds to the extinction-corrected luminosity for $H\alpha$, FUV, or NUV, with K denoting any of these star formation tracers. Both $L(\text{PAH})$ and $L(K)$ are in erg s^{-1} . A and B are fitting parameters as mentioned in Table 2.

H. V. Shipley et al. (2016) derived the calibration relation between the extinction-corrected $H\alpha$ luminosity and the individual PAH luminosities. The slopes of the linear relation for 7.7

and 11.3 μm PAH luminosities are 1 and 0.94 with intercepts of 1.12 and 2.87, respectively. Certainly, there is a clear difference between the parameters of H. V. Shipley et al. (2016) calibration relation and those mentioned in Table 2. However, the relations reported in H. V. Shipley et al. (2016) are based on integrated emission from the whole galaxy with very diverse samples, and therefore, there is a lot more scatter in their correlations.

There are very few calibration relations connecting $L(\text{PAH})$ with UV luminosities. L. Zhang et al. (2020) derived calibration relations for integrated PAH luminosity with $H\alpha$, FUV, and NUV luminosities, and found slopes of 0.849 ± 0.026 , 0.842 ± 0.027 , and 0.865 ± 0.029 . However, when we examined our fitted parameters for individual PAH bands against $H\alpha$ and UV luminosities corrected for extinction using the Balmer decrement, we observed band-to-band variations, depending on the specific PAH band used. We find that the fitted slopes decrease with increasing PAH wavelength. 7.7 and 11.3 μm PAH luminosities exhibit flatter linear fits compared to the 3.3 μm luminosity, suggesting that the 3.3 μm feature is more sensitive to variations in recent star formation. We also find that the correlations involving the 3.3 μm PAH luminosity exhibit larger scatter than those involving the 7.7 and 11.3 μm PAH luminosities, likely reflecting the intrinsically weaker nature of the 3.3 μm PAH feature. In addition, uncertainties associated with continuum subtraction in the F335M band may contribute to the observed scatter.

The fitted relations involving $H\alpha$ and NUV luminosities are broadly similar across the PAH bands. In contrast, the FUV correlations show significant variation, as indicated in Table 2, with shallower slopes and larger uncertainties than those of the

Table 2. Fitting parameters for equation (5).

Star formation Tracer	PAH bands μm	Balmer decrement method				21 μm method			
		A	B	σ	ρ	A	B	σ	ρ
$\text{H}\alpha$	3.3	0.92 ± 0.04	2.36 ± 1.39	0.46	0.86	1.03 ± 0.02	-1.32 ± 0.94	0.27	0.93
	7.7	0.80 ± 0.02	8.39 ± 0.96	0.27	0.89	0.88 ± 0.02	5.42 ± 0.81	0.22	0.94
	11.3	0.69 ± 0.03	11.77 ± 1.29	0.37	0.84	0.80 ± 0.03	7.86 ± 1.16	0.32	0.90
FUV	3.3	0.83 ± 0.07	4.32 ± 2.76	0.29	0.85	0.99 ± 0.05	-1.59 ± 2.04	0.28	0.90
	7.7	0.69 ± 0.05	11.37 ± 2.08	0.24	0.88	0.99 ± 0.04	-0.33 ± 1.47	0.20	0.96
	11.3	0.57 ± 0.06	15.56 ± 2.51	0.29	0.80	0.95 ± 0.04	0.37 ± 1.77	0.25	0.94
NUV	3.3	0.89 ± 0.04	2.62 ± 1.78	0.40	0.86	1.02 ± 0.02	-2.49 ± 0.96	0.28	0.92
	7.7	0.79 ± 0.03	7.91 ± 1.30	0.25	0.91	0.92 ± 0.01	2.73 ± 0.50	0.16	0.98
	11.3	0.65 ± 0.05	12.60 ± 2.03	0.40	0.83	0.92 ± 0.02	2.22 ± 0.61	0.19	0.97

Note. A and B are the fitting parameters for the equation (5), which represents the correlation between PAH bands and star formation tracers as shown in Fig. 3. σ and ρ represent the standard deviation and Spearman's correlation coefficient of these fits, respectively.

other tracers. For example, the fitted slope for $\text{H}\alpha$ and NUV with 7.7 μm PAH is 0.80 ± 0.02 and 0.79 ± 0.03 , respectively. Whereas, the slope for the correlations with FUV has a value of 0.69 ± 0.05 . Similarly, the fitted parameters are shallow for the FUV and other PAH bands. One plausible explanation for this is that the FUV data is intrinsically shallower than the other data sets, resulting in lower completeness at faint luminosities. Consequently, under a fixed detection threshold, a larger fraction of low-luminosity FUV-emitting SFCs may remain undetected, which can contribute to both the reduced number of identified FUV SFCs and the increased uncertainty in the fitted relations.

We also examined correlations between the PAH-band luminosities and extinction-corrected luminosities derived using MIR-based extinction corrections. In this case, the correlations are stronger (Spearman's correlation coefficient, $\rho \geq 0.9$), and the fitted slopes are steeper than those obtained using Balmer-decrement extinction corrections [Fig. 3(ii) and Table 2]. This indicates that the derived calibration relations are sensitive to the adopted extinction-correction method.

3.2 PAH emission across the different regions of NGC 628

In this section, we investigate how the intensity of PAH emission varies across the arm, spur, and interarm region. For that reason, we overplotted the SFCs onto the PAH images. We note the spatial overlap of 3.3 μm PAH emissions with SFC's position across the regions in Fig. 4. We have also overplotted NUV-only (No FUV and $\text{H}\alpha$ counterparts), $\text{H}\alpha$ -only (No FUV and NUV counterparts), and FUV-emitting (3 σ threshold) SFCs on the F335M image (bottom panel of Fig. 4).

Visually, we find that arm and spur SFCs overlap with PAH emission, except for those that fall within bubbles and superbubbles, as seen in Fig. 4(d). However, around half of the interarm SFCs (a total of 62 SFCs) do not show a bright PAH counterpart. We plotted the Kernel density estimate (KDE) to examine the 11.3 μm luminosity distribution for the SFCs in arm, spurs, and interarm regions, as shown in Fig. 5(i). We clearly see that the median luminosity of the interarm SFCs [$\log(L_{\text{F1130W}}/\text{ergs}^{-1}) = 37.8$] is lower than that of the arms [$\log(L_{\text{F1130W}}/\text{ergs}^{-1}) = 38.3$] and spurs [$\log(L_{\text{F1130W}}/\text{ergs}^{-1}) = 38$]. However, the lower luminosity limit of arm SFCs is distributed below $\log(L_{\text{F1130W}}/\text{ergs}^{-1}) = 36.5$.

We also checked the KDE of 11.3 μm luminosity for SFCs with emission in all bands, only-NUV and only- $\text{H}\alpha$. The SFCs with emission in all bands clearly have very strong PAH counterparts.

All of these SFCs with emission in all bands (82 SFCs) are at the higher end of the luminosity distribution.

The median values of these distributions depend on how we have classified SFCs by location (arms and spurs). The figure in Appendix A shows 11.3 μm PAH luminosity distribution of arm SFCs (top figure) and spur SFCs over the F1130W *JWST* band. In both figures, we can see that the luminosity distribution is nearly uniform. Hence, a slight shift in the boundary does not affect the trend, $\text{arm} \geq \text{spurs} > \text{interarm}$.

Over 60 per cent of SFCs within bubbles and superbubbles show only NUV emission, particularly in the southern arm, which hosts the phantom void. Therefore, we plotted the KDE of the 11.3 μm luminosity for SFCs with NUV emission (with and without counterparts), only NUV emission, and SFCs with only NUV emission within the phantom void region as shown in Fig. 5(iii). Here, we observed that SFCs with only NUV show a distribution shifted towards a lower PAH luminosity. We also plotted PAH and NUV luminosity correlations for SFCs with NUV emission, as shown in Fig. 6. The correlation between PAH and NUV luminosity reveals that NUV-only SFCs are at the lower end of both luminosity distributions, including those within the void region.

We also find that the galaxy centre has very faint PAH emission in all bands, with the 3.3 μm being even further suppressed compared to the 7.7 and 11.3 μm emission. This indicates a dearth of small PAHs in the centre of this galaxy. We found that the SFCs around the centre are either NUV-only or show NUV and $\text{H}\alpha$ emission. The presence of $\text{H}\alpha$ emission indicates some recent star formation, or it could be emission from diffuse ionized gas.

As described in Section 2, SFCs were extracted by applying a constant threshold (5σ) in all three bands. Although the detection threshold was identical, the intrinsic depths of the images differ. Hence, to see if there are any faint FUV and $\text{H}\alpha$ emitting SFCs in the bubble and superbubble regions, we applied a 3σ threshold. This does not alter the intrinsic depth of the FUV image, however corresponds to a formal 3σ limiting magnitude of $m_{\text{FUV}} = 23.4$. Using this less conservative selection, we identify 463 SFC candidates, which is significantly more than the 195 obtained using the 5σ cutoff. The formal 3σ FUV limit is comparable to the 5σ depth of the NUV image. Since lowering the detection threshold can introduce spurious sources, we performed an empirical contamination test by running the identical source detection procedure on the inverted FUV image. We detect no sources in the negative image, corresponding to an estimated contamination fraction of zero. We there-

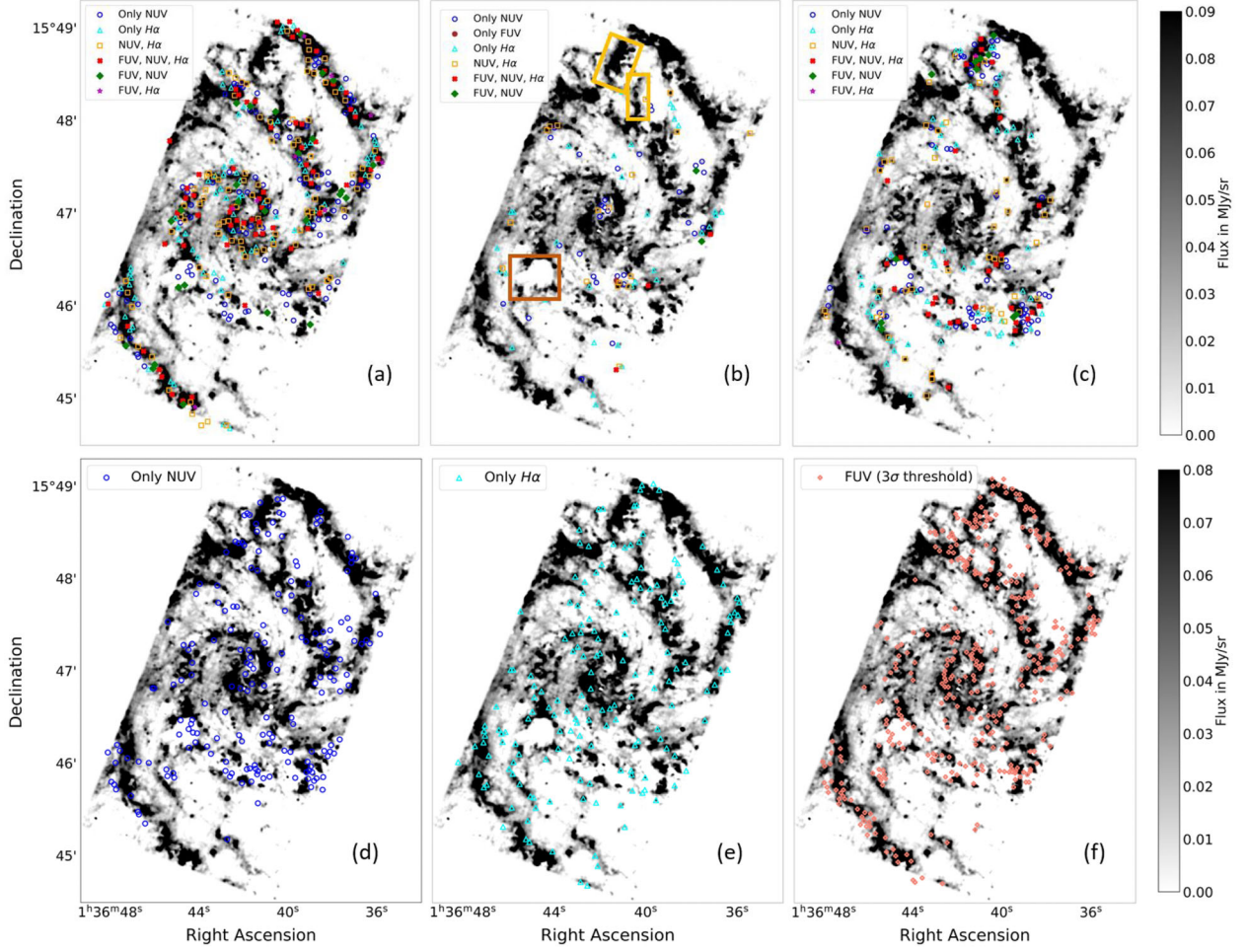


Figure 4. (i) Association of $3.3 \mu\text{m}$ PAH emission with arm (a), interarm (b), and spur (c) SFCs. We also plotted the association of $3.3 \mu\text{m}$ PAH with NUV-only SFCs(d), $\text{H}\alpha$ -only SFCs(e), and FUV-emitting SFCs detected with a 3σ threshold (f). The SFCs are overlaid on the continuum-subtracted *JWST* F335M image. Yellow rectangles in panel (b) show an example of the spurs, and the brown rectangle indicates the position of the phantom void in NGC 628.

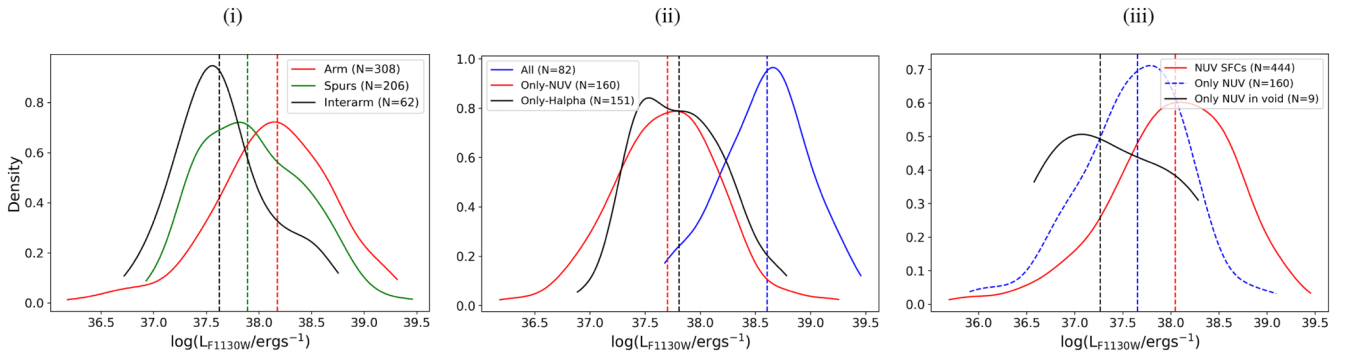


Figure 5. The KDE plots representing the $11.3 \mu\text{m}$ PAH luminosity distribution (i) for SFCs in different regions, (ii) for SFCs emitting in all bands (UV and $\text{H}\alpha$), only-NUV and only- $\text{H}\alpha$ emissions, (iii) for SFCs emitting in NUV, only-NUV and only-NUV SFCs in the void region. The vertical lines represent the median values.

fore conclude that the additional detections introduced by the 3σ threshold are unlikely to be dominated by noise. However, even after decreasing the threshold, we find that four out of eight FUV-emitting SFCs are associated with NUV-emitting SFCs in the phantom void (at 5σ , only 1). Since other NUV-only SFCs lie at the faint end of the NUV luminosity distribution, their

non-detection in FUV is consistent with the relative shallowness of the FUV image and the expected FUV–NUV colours of low-luminosity stellar populations. This likely indicates a relative deficiency of the most massive stars. A few FUV SFCs are located between the phantom void and two connecting bubbles, as shown in Fig. 4(f).

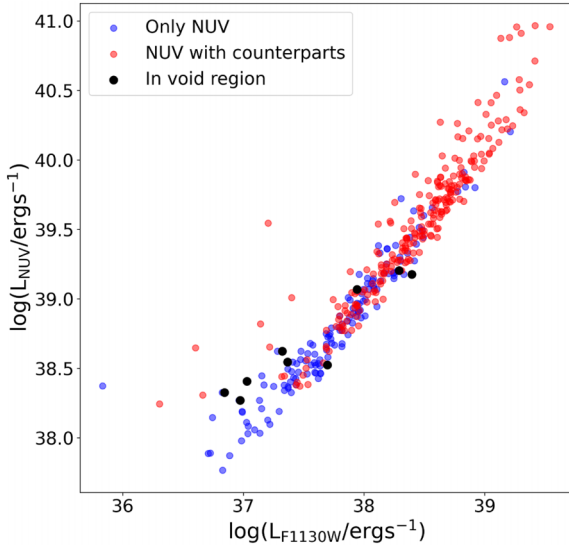


Figure 6. Correlation of extinction corrected NUV luminosity of SFCs with NUV-only emission and NUV with counterparts ($H\alpha$, FUV) with the $11.3\ \mu\text{m}$ PAH luminosity.

3.3 The variation of PAH band ratios with the IMF for the SFCs

The determination of the IMF indices follows A&D25, where it was assumed that $H\alpha$ emission originates solely from O-type stars. Using this assumption, an approximate number of O stars was estimated. The number of B stars was then estimated from UV emission. From the O star to massive B stars ($M_* > 10\ M_\odot$; BOV type stars) ratio, we derived the IMF index α_1 , and from the ratio of massive B stars to less massive B stars ($10\ M_\odot \geq M_* \geq 3\ M_\odot$), the IMF index α_2 was estimated. The α_1 IMF index represents the present-day IMF (relatively high-mass IMF), and α_2 , derived from the ratio of B stars, can provide a better estimate of the stellar IMF. In A&D25, α_2 showed strong trends with properties such as stellar mass and gas mass density. There was also a prominent correlation of α_2 with UV colour and star formation rate density. Hence, in this section, we use these IMF values to examine how the properties of PAH molecules change under different IMF conditions (e.g. when SFCs are top-light or top-heavy).

Both statistical and systematic uncertainties are associated with the estimation of these IMF indices. Statistical uncertainties are observed due to the stochastic sampling of O stars in the multiple realizations and photometric uncertainties in the measured fluxes. Systematic uncertainties arise from assumptions about the stellar types contributing to the $H\alpha$ emission (e.g. O8 only, O7–O9, and O3–O9 populations), and considering different O star combinations results in variations in the derived IMF α_1 slope of up to ~ 1 . This reflects the strong sensitivity of the inferred α to the assumed massive-star population. The values, especially α_1 , depend on the mass limits we take. Although α_2 depends on α_1 , both statistical and systematic uncertainties are very small compared to α_1 . Hence, α_2 is a more robust indicator of the approximate IMF value.

As explained in Section 1, the relative strength of the PAH band ratios gives us information about the size and charge of the PAH molecules in that environment. An increase in the F335M/F1130W ratio likely indicates that the fraction of small PAH molecules is increasing. Similarly, the fraction of ionised

molecules increases with an increase in F770W/F1130W. Recent studies, such as D. Rigopoulou et al. (2021) and D. Rigopoulou et al. (2024), use diagnostic grids of PAH band ratios derived using theoretically computed PAH spectra by varying the numbers of carbon atoms, charge, and intensity of exposed radiation fields. These studies reveal the number of carbon atoms in the PAH molecule, the charge of the ISM, and information on what kind of radiation field the molecules are exposed to. Our study uses some of these results to explore the IMF variation with PAH band ratios.

We plotted α_1 and α_2 as a function of PAH band ratios (F335M/F1130W, F770W/F1130W, F335M/F770W) (Fig. 8). We find no significant trend with α_1 , which remains relatively flat across the range of PAH band ratios. In contrast, α_2 exhibits a noticeable trend with PAH band ratios. For arm SFCs, both F335M/F1130W and F770W/F1130W increase as the IMF becomes more top-heavy. However, α_2 remains relatively flat for spur SFCs, clumps around values of 2.5–3.5 over a broad range of PAH ratios. The increasing PAH band ratios in arm SFCs are consistent with a relatively enhanced contribution from smaller and ionised PAH molecules, likely driven by stronger radiation fields associated with more top-heavy IMFs. None the less, spur SFCs that exhibit a top-heavy IMF in the α_1 PAH relation also tend to show an enhanced contribution from smaller and ionized PAH molecules.

We retained only SFCs with higher PAH ratios for the case where we populated SFCs with O3 to O9 type stars, as these correlate with high $H\alpha$ luminosity and can host massive stars (O stars up to $100\ M_\odot$). Hence, this shows that SFCs with higher $H\alpha$ luminosity exhibit a relatively enhanced contribution from smaller and ionized PAH molecules. However, Fig. 8 shows that higher $H\alpha$ luminosity does not necessarily imply a flatter IMF.

Besides the correlation of IMF with PAH ratios, we investigated the IMF of SFCs in the shell region around the phantom void. Unfortunately, we have only three SFCs with $H\alpha$, FUV, and NUV emission. We named these SFCs SFC 1, 2, and 3, as shown in Fig. 7. The SFCs 1 and 2 have α_1 (present-day mass function) value flatter than SFC 3, which is near the connecting elongated bubble. For the case where O7–O9V stars are populated, SFCs 1 and 2 have α_1 values of $3.17^{+0.5}_{-0.4}$ and $2.48^{+0.6}_{-0.5}$, respectively, while SFC 3 has an α_1 value of $4.57^{+0.4}_{-0.3}$. Although the values differ across all three cases, we see the same trend. Hence, at the present day, SFC 1 and 2 host more massive stars than SFC 3. The mean α_2 for three SFCs is 2.79 ± 0.09 for all the cases. We discuss the IMF variation with PAH band ratios, and the IMF of SFCs in the shell region around the phantom void, in more detail in Section 4.

3.4 The variation of PAH band ratios with the colour for the SFCs

A prominent correlation was observed for α_2 with UV colour FUV–NUV in A&D25. It followed a quadratic fit, and FUV–NUV was red for the SFCs with top-light IMF and blue for SFCs with top-heavy IMF, indicating more recent star formation in the latter. Therefore, we plotted FUV–NUV as a function of PAH band ratios (F335M/F1130W, F770W/F1130W, F335M/F770W) (see Fig. 9) for the case with a larger number of SFCs. We fitted linear regression for each ratio as given below.

$$(FUV - NUV) = Ck + D, \quad (6)$$

where C and D are fitting parameters given in the Table 3. k is the PAH band flux ratio. As expected, we observe the general

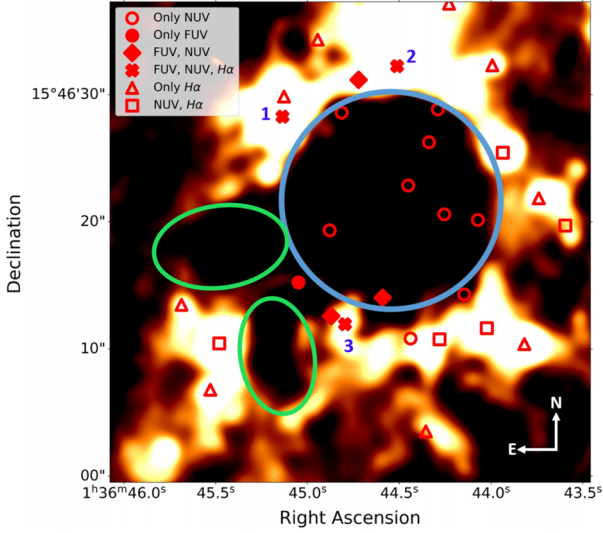


Figure 7. The phantom void region of NGC 628. The markers are overlaid on the continuum-subtracted *JWST* F335M image. The blue superbubble is the phantom void, and the two green ellipses represent the connecting bubbles. Different markers represent the positions of SFCs emitting at different wavelengths. The SFCs with both UV and $H\alpha$ emission are numbered.

trend of F335M/F1130W, F770W/F1130W, and F335M/F770W increasing as SFCs get bluer. However, in Fig. 9, especially for ratios F335M/F1130W and F335M/F770W, we found that more spur SFCs are below the fit than arm in the range $0.1 > \text{FUV-NUV} > -1$. This indicates that for the same colour, the relative contribution from smaller molecules is higher for arms SFCs than for spurs.

4 DISCUSSION

Although PAH emission traces star formation, its strength depends on the nature of the source exciting the molecules and the local environment. For example, the median PAH luminosity is lower in interarm regions than in spiral arms and spurs, where the star formation efficiency remains lower than in the arms, even though molecular hydrogen gas is present (K. Foyle et al. 2010; K. Kreckel et al. 2016). Besides, studies have reported a central deficit of PAH emission in unbarred galaxies, attributed to the lack of continuous gas inflow typically driven by a bar (M. W. Regan et al. 2006). Consistent with this, we find a compact peak of PAH emission at the nucleus of NGC 628, surrounded by a region of relatively faint PAH emission extending over ~ 0.1 kpc. Such limited gas inflow may suppress star formation, as indicated by the presence of NUV emission from an evolved stellar population and the absence of FUV emission associated with ongoing star formation (Fig. 1).

In addition to the interarm and nuclear regions, bubbles and superbubbles in NGC 628 also exhibit a deficit of PAH emission (A. T. Barnes et al. 2023; Y. D. Mayya et al. 2023). Within these regions, we detected several NUV-only emitting SFCs. Lowering the FUV emission threshold increases the total number of FUV-emitting SFCs by a factor of 2.4, with a fourfold increase in the Phantom void (eight SFCs). The FUV-emitting SFCs within bubbles have minimal overlap with NUV-only emitting SFCs and are primarily located along the shell regions. The presence of NUV-

only emitting SFCs suggests the presence of relatively evolved stellar populations and other intermediate-age stars. A few massive stars, such as O-type and massive B stars (as inferred from the FUV), are also found in these regions and may contribute to the formation and powering of these bubbles and superbubbles, while the most massive stars may have already evolved. This is consistent with A. T. Barnes et al. (2023), who reported several NUV emission peaks within the Phantom void, along with compact stellar emission sources from *Hubble Space Telescope* (*HST*) and *AstroSat* NUV observations. They also found diffuse $H\alpha$ within the void and associated it with ionization by an older generation of stars. This explains the absence of distinct $H\alpha$ SFCs in these regions. However, the detection of FUV and the absence of $H\alpha$ SFCs suggest that the ionized gas has been expelled, likely due to feedback from massive stars or SNe.

Interestingly, bubbles in the northern arm have few NUV-only-emitting SFCs and lack other star formation tracers, suggesting they are older than those in the southern arm and show no recent star formation. This may be due to stellar feedback from evolved massive stars that has cleared the cold gas needed for star formation. Studies such as A. S. Gusev & Y. N. Efremov (2013) and A. S. Gusev et al. (2013) have also confirmed the drastic difference in the inner structures between the spiral arms of NGC 628, proposing that a shock wave along the northern arm creates high pressure and suppresses star formation, while a regular magnetic field stabilizes star formation along the southern arm. Alternatively, these holes may arise from galactic dynamical processes, such as spur or feathering instabilities and shear driven by the galaxy's rotation (E. J. Watkins et al. 2023).

The prominent superbubble in the southern arm, the phantom void, has a radius of around 600 pc (E. J. Watkins et al. 2023). Two additional bubbles appear to have merged with it (green ellipses in Fig. 7). Such superbubbles likely form from the merging of smaller bubbles and are powered by stellar feedback from massive stars and successive SNe. Given their short lifetimes, low-mass massive stars are expected to remain within them (S. Jiménez et al. 2023; Y. D. Mayya et al. 2023). Therefore, we examined SFCs within the phantom void and found low luminosity NUV-only emitting SFCs in it (See Fig. 6). The faint FUV-only-emitting SFCs (detected only after reducing the threshold) are detected between the phantom void and the adjacent bubbles, while the connecting bubbles themselves show no detectable emission in these tracers. It is likely that they are older structures currently powered by massive stars located between them and the phantom void.

There is also a clear age-dependent spatial segregation in the stellar population. Y. D. Mayya et al. (2023) observed the youngest population at larger radii up to a radius of 450 pc and is moving away from the centre as the bubble expands. As in theirs, we also see that FUV-emitting SFCs are far from the bubble centre and the older population, suggesting star formation triggered in the swept-up material. However, a small number of O and B stars formed within the bubble could explain the detection of faint SFCs.

There is clear evidence of star formation in the shell of the phantom void (as seen in Fig. 7) due to positive feedback consistent with Y. D. Mayya et al. (2023). Fig. 7 shows that most of the SFCs in the shell have NUV and $H\alpha$ emission, and there are very few FUV-emitting SFCs. However, we detected a few additional FUV SFCs when we lowered the threshold. Since $H\alpha$ emission confirms the presence of young massive stars, the relative deficit

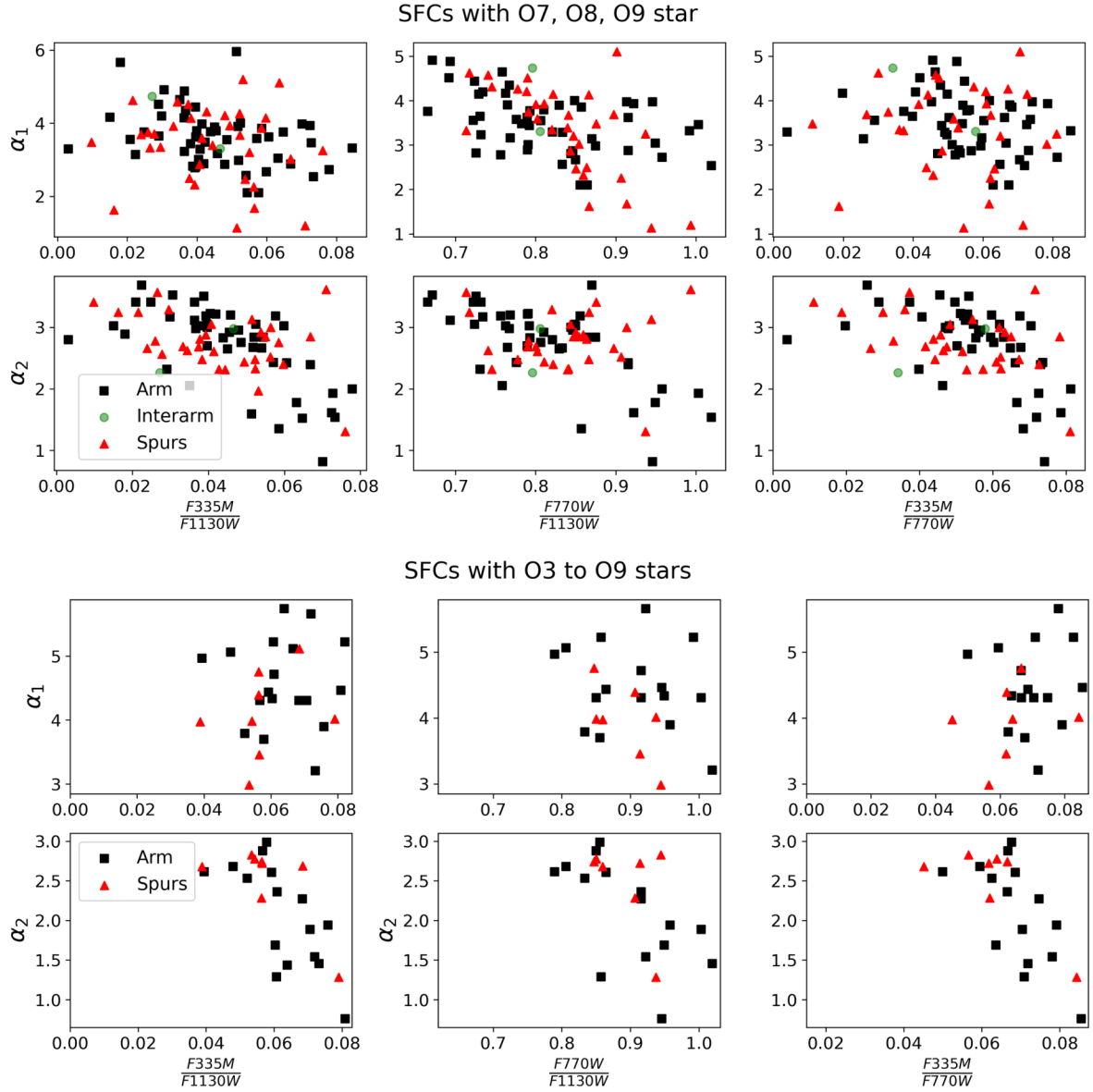


Figure 8. Variation of IMF index (α_1 and α_2) with the PAH band ratios – F335M/F1130W, F770W/F1130W, and F335M/F770W (from left). Square, triangle, and circles represents arm, spur, and interarm SFCs, respectively.

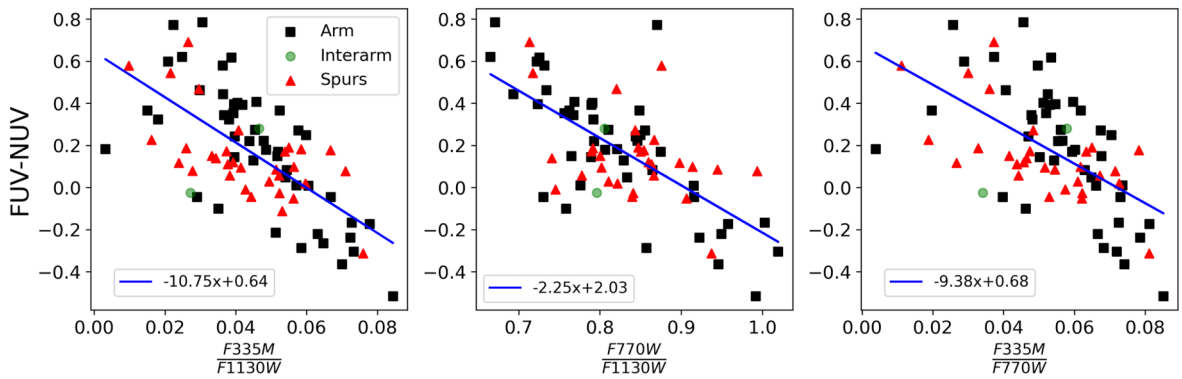


Figure 9. Variation of FUV-NUV with the PAH band ratios – F335M/F1130W, F770W/F1130W, and F335M/F770W (from left).

Table 3. Fitting parameters for equation (6).

k	C	D	σ	ρ
F330M/F1130W	-14.02 ± 1.71	0.67 ± 0.06	0.19	-0.64
F770W/F1130W	-2.95 ± 0.34	2.07 ± 0.21	0.19	-0.63
F330M/F770W	-9.38 ± 1.51	0.68 ± 0.08	0.22	-0.58

Note. C and D are the fitting parameters for the equation (6), which represents the correlation between FUV-NUV and PAH band ratios as shown in Fig. 9. σ and ρ represent the standard deviation and Spearman's correlation coefficient, respectively.

of FUV detections may therefore reflect both the shallowness of the FUV imaging and possible attenuation of FUV emission by dust. However, PAH emission is very bright throughout this region, indicating enough PAH molecules and radiation sources to excite the PAHs.

Out of three SFCs with emission detected in both UV and H α , SFCs 1 and 2 exhibit flatter IMF slopes compared to SFC 3. This difference may be related to the formation and dynamical evolution of the structure. As shown in Fig. 7, the phantom void may have formed through the merging of bubbles and/or been influenced by galactic shear. The elongated morphology of the connecting bubbles indicates the influence of shear forces, while the phantom void near SFCs 1 and 2 (northeast of the superbubble) remains nearly circular, implying weaker shear in that region. Furthermore, A. T. Barnes et al. (2023) identified supernova remnants mainly in the northwestern shell of the superbubble, which may contribute to its continued expansion. The flatter IMF slopes observed in SFCs 1 and 2 could therefore result from higher gas densities in the swept-up shell of the expanding superbubble. In contrast, the molecular gas near SFC 3 may have experienced stronger shear, reducing the gas density and the potential for forming massive stars. Consistent with this interpretation, the ALMA map in Fig. 1 shows little molecular gas in that region.

To obtain information on the molecule size and the ionization state of the PAH molecules in different environments, we compared PAH band ratios (F335M/F1130W, F770W/F1130W, and F335M/F770W) between NUV-only emitting SFCs and those emitting in NUV that also have counterparts in at least H α or FUV. This is to examine if there is any difference in PAH molecule properties, as shown in Fig. 10. We found no significant difference in the median F770W/F1130W ratio; therefore, there is no difference in the charge of PAH molecules between NUV-emitting SFCs with or without counterparts. However, the median F335W/F1130W and F335M/F770W ratio for the NUV emitting SFCs with counterparts is slightly higher than for the NUV-only emitting SFCs, implying a higher fraction of small molecules in the NUV emitting SFCs with counterparts. If we say that NUV-emitting SFCs with counterparts in other bands host massive stars, whereas others do not, then here we see that the presence of massive stars slightly influences the size of molecules in the ISM, not their charge.

We also checked the IMF and UV colour trends against PAH band ratios for arms and spurs. As seen in A&D25, only the IMF index α_2 , obtained from the B-star ratio, correlates with PAH band ratios. The trend for cases where we populated H α SFCs with O7, O8, and O9, and also with only O8 stars, is similar. Hence, we only present the former in Fig. 8. Unlike previous observations in A&D25, here we observe differences in the trends for the arm and spurs. We find that spurs have only a few SFCs with top-heavy IMF ($\alpha_2 < 2.3$) compared to arm SFCs. Consequently, the

spurs display a flat trend, mostly clumped between 2 and 4, while arms show a decreasing trend in IMF with increasing PAH ratios. The lack of SFCs with a top-heavy IMF in the spurs could be due to low molecular gas relative to the arm. Interestingly, we also found that, for SFCs with the same UV colour, the fraction of small PAHs is higher in the arms than in the spurs. According to E. Schinnerer et al. (2017), the star formation is biased towards spurs rather than arms in galaxy M51, and suggested that the young clusters in spurs are larger and more massive than what we see in the arms. IMF index α_2 in A&D25 is derived from the ratios of massive to less massive B stars, whereas α_1 is from the ratios of the number of O stars to massive B stars. In Fig. 8, we see that many spur SFCs are top-heavy if we consider α_1 , in contrast to α_2 . Hence, there might be more massive young stars in spurs than in arms, as mentioned in E. Schinnerer et al. (2017). The study has also shown that star formation in spurs is independent of the spiral arm. However, it is preferred towards the arm within the spurs.

Previous *JWST* studies of NGC 628 have shown that the star-forming regions or H II regions with a high star formation rate density exhibit elevated values of F335M/F1130W, F770W/F1130W, and F335M/F770W, which are commonly associated with enhanced contributions from small and ionized PAHs (J. Chasten et al. 2023b; O. V. Egorov et al. 2023; U. Krishnan et al. 2024). As in previous studies, we also observed that as the IMF for arm SFCs becomes top-heavy and blue (indicating recent star formation), the PAH band ratios F335M/F1130W, F770W/F1130W, and F335M/F770W increase, consistent with enhanced excitation and ionization of PAHs in stronger UV radiation fields. The SFCs with top-heavy IMF host more massive stars and hence higher UV luminosity. The intense UV radiation density from the compact PDRs in these regions can dominate the particle density, affecting recombination and ionization rates. This leads to an increase in the number of charged particles in these regions (J. McKinney et al. 2021; D. Rigopoulou et al. 2024). There will also be an increase in the fraction of shocked gas to total gas in such a high UV radiation region, which can increase the relative contribution of ionized PAHs to the observed emission (J. Chasten et al. 2023b; O. V. Egorov et al. 2023). In contrast, theoretically, small molecules will not survive longer in such an extreme environment (E. R. Micelotta et al. 2010). However, numerical models show that shocks in dense clouds can cause gas-grain collisions, grain-grain collisions, and large-grain fragmentation, which in turn increases the fraction of small molecules (A. P. Jones et al. 1996; V. Guillet et al. 2011). It is also known that stronger UV radiation fields increase PAH temperatures, leading to enhanced emission at shorter wavelengths (B. T. Draine et al. 2021). Recent studies suggest that variations in these ratios reflect changes in the local radiation field more strongly than changes in the intrinsic PAH size distribution (D. Baron et al. 2024; K. F. Henny et al. 2025).

Studies have shown that the properties and emission characteristics of PAH molecules vary with the age of stellar clusters and associations. B. C. Whitmore et al. (2025) reported a rapid decline in PAH emission and infrared dust emission with increasing age, which they attributed to dust grain destruction and stellar feedback processes. This provides a natural explanation for the lower PAH luminosities observed in the NUV-only emitting SFCs (Fig. 5ii). Furthermore, D. A. Dale et al. (2025) found that the F335M/F1130W and F335M/F770W flux ratios decrease with increasing age. This behaviour is expected because older regions

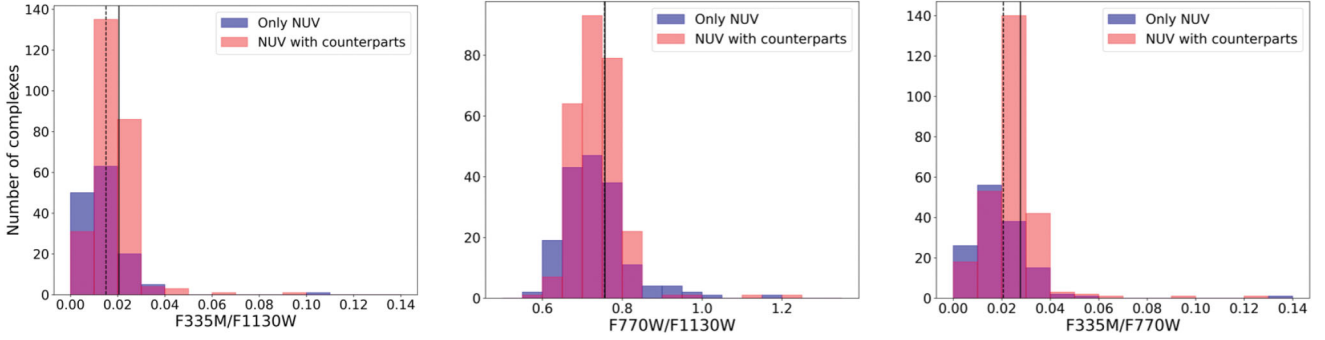


Figure 10. The distribution of PAH band ratios (F335M/F1130W, F770W/F1130W, and F335M/F770W) for only NUV-emitting SFCs and NUV-emitting SFCs with counterparts in UV and/or $H\alpha$.

are characterized by softer radiation fields, which reduce PAH excitation and maintain lower dust temperatures (B. T. Draine et al. 2021). Our results, shown in Figs 9 and 10, are consistent with this picture, as NUV-emitting SFCs exhibit redder UV colours and lack associated FUV and $H\alpha$ emission, both of which are indicative of more evolved stellar populations.

T. G. Williams et al. (2022a) demonstrated that the inner disc of NGC 628 shows minimal metallicity variation ($8.45 < 12 + \log(O/H) < 8.6$). Therefore, properties of PAHs in different regions of the inner disc should not be affected by metallicity. However, trends can vary if there is a contamination by continuum. Though the F335M is continuum subtracted, as discussed in Section 2, K. M. Sandstrom et al. (2023a) has addressed that the aliphatic PAH at $3.4 \mu\text{m}$ and plateau at $3.47 \mu\text{m}$ might also contribute slightly to the detected $3.3 \mu\text{m}$ after continuum subtraction. However, their strength are too low (8 per cent, T. S.-Y. Lai et al. 2020) compared to the $3.3 \mu\text{m}$ PAH emission to have a significant effect on the observed trends. Even with the F770W band, approximately 80 per cent of the emissions are from $7.7 \mu\text{m}$ PAHs, and 70 per cent of the emission seen in the filter F1130W is due to $11.3 \mu\text{m}$ PAH molecules (C. M. Whitcomb et al. 2023). The continuum-subtraction prescription of G. P. Donnelly et al. (2025) applied to the F770W and F1130W filters yields PAH flux estimates with typical accuracies of ~ 7 –8 per cent. Therefore, continuum contamination is unlikely to be the primary driver of the observed regional variations in PAH emission.

Several star cluster catalogues exist for NGC 628 that resolve clusters on scales of a few tens of parsecs, such as Legacy Extra-Galactic Ultraviolet Survey (LEGUS; D. Calzetti et al. 2015 and PHANGS-HST; J. C. Lee et al. 2022; D. A. Thilker et al. 2022; D. A. Thilker et al. 2025). These catalogues identify compact star clusters and associations using high-resolution *HST* imaging. In contrast, due to UVIT’s lower spatial resolution, our analysis detects larger stellar associations (OB associations and larger complexes). While using *HST*-based cluster catalogues would probe smaller spatial scales and may introduce some variation in the relations, the overall SFC–PAH trends are expected to remain broadly consistent with those found in this work.

By comparing PAH emissions with other star formation indicators at a resolved scale of 57 pc, we aimed to gain insights into the properties of these SFCs and their surrounding environments. We also observed variations in star formation properties across different regions (arms and spurs) in NGC 628 at such small scales. This highlights the significance of examining star formation on a local level.

5 SUMMARY

In this work, we used PAH maps (F335M, F770W, and F1130W) from *JWST* observations of NGC 628. We also utilized the catalogue of star formation properties of SFCs of NGC 628 from A&D25, which includes $H\alpha$ and UV (FUV and NUV) luminosities from MUSE and UVIT, respectively. We used these luminosities to get a correlation with PAH at a scale of 57 pc. We also analysed the PAH emission at the different regions (arm, spurs, interarms, and bubbles) of NGC 628, and the effect of the environment on PAH emission. From the A&D25 catalogue, we used the IMF of the SFCs and derived some important trends with the PAH band ratios (F335M/F1130W, F770W/F1130W, and F335M/F770W) to understand the PAH size and ionized state in arms and spurs. We summarize the main results of our study below,

1. The PAH luminosities show a strong correlation (Spearman’s correlation coefficient, $\rho > 0.73$) with FUV, NUV, and $H\alpha$ luminosities for the extracted SFCs, even at the scale of SFCs (size > 57 pc).
2. The 7.7 and $11.3 \mu\text{m}$ PAH luminosities exhibit a flat linear fit compared to the linear fit with the $3.3 \mu\text{m}$ luminosity, suggesting that the $3.3 \mu\text{m}$ feature is more sensitive to variations in recent star formation.
3. The PAH emission is generally well associated with SFCs located in the spiral arms and spurs. In contrast, SFCs located within bubbles and superbubbles, including both the predominantly NUV-only SFCs and the few FUV-emitting SFCs, generally lack associated PAH emission. The predominance of NUV-only SFCs in these regions suggests that they are mainly populated by low-mass B stars, A stars, and a few evolved stars. The presence of a small number of FUV-emitting SFCs indicates that some O and massive B stars are still present, potentially contributing to the ongoing expansion of bubbles and superbubbles.
4. PAH molecules in only NUV-emitting SFCs and in NUV-emitting SFCs with counterparts in at least $H\alpha$ or FUV exhibit similar charge states, as indicated by their comparable median F770W/F1130W ratios. However, the median F335M/F1130W and F335M/F770W ratios are higher in NUV-emitting SFCs with counterparts than in only NUV-emitting SFCs. This suggests either enhanced emission from small PAH molecules or more efficient excitation of the $3.3 \mu\text{m}$ PAH feature in the former population. Conversely, the lower ratios in only NUV-emitting SFCs may be consistent with softer radiation fields that reduce PAH excitation.
5. There is a clear age-dependent spatial segregation in the stellar population in the phantom void, consistent with the pre-

vious study. The youngest population emitting FUV is at larger radii, far from the bubble's centre, and the older population. This segregation suggests that the recent star formation must have been triggered in the material swept by the expanding bubble.

6. Two SFCs located in the shell region of the phantom void show flatter IMF slopes compared to an SFC near the elongated bubble. This difference may arise from gas accumulation driven by stellar feedback in the shell region, whereas shear in the elongated bubble may hinder the formation of more massive stars.

7. IMF index α_2 derived from the ratio of B stars and UV colour (FUV – NUV), shows a decreasing trend with PAH band ratios (F335M/F1130W, F770W/F1130W, and F335M/F770W). These elevated ratios are commonly associated with enhanced contributions from small and ionized PAHs, although recent studies suggest they may primarily reflect variations in the local radiation field. For a given FUV – NUV colour, arm SFCs exhibit systematically higher PAH band ratios than spur SFCs, indicating stronger PAH excitation and/or different ISM environments in the arm regions.

8. Spur SFCs have a flat trend with PAH band ratios compared to the arm SFCs. This is because of fewer spur SFCs with a top-heavy IMF.

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DATA AVAILABILITY

All the UVIT data used in this paper are publicly available at http://astrobrowse.issdc.gov.in/astro_archive/archive/Home.jsp.

The specific *JWST* observation analysed can be accessed via <https://doi.org/10.17909/76c4-r832>.

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APPENDIX A: SOME EXTRA MATERIAL

The Fig. A1 shows 11.3 μm PAH luminosity distribution of arm SFCs (top figure) and spur SFCs over the F1130W JWST band.

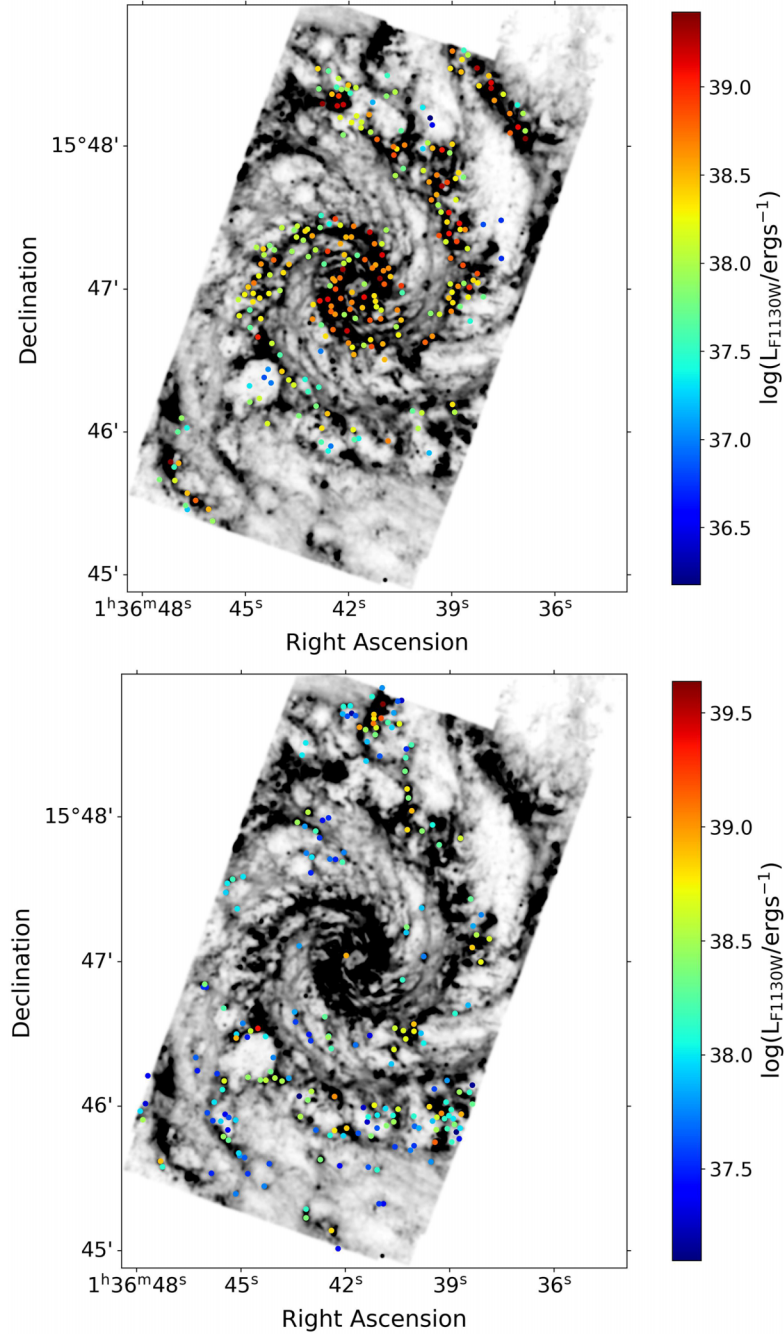


Figure A1. 11.3 μm PAH luminosity distribution of arm SFCs (top figure) and spur SFCs over F1130W *JWST* band.

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