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Carbonaceous dust processing in the merger galaxy II Zw 096: High-resolution polycyclic aromatic hydrocarbon diagnostics with *JWST*

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ABSTRACT

Context. Galaxy mergers drive intense radiation environments that fundamentally alter interstellar dust properties through photo-destruction and thermal processing. The luminous infrared galaxy II Zw 096 presents several distinctive regions, including starburst clumps and a proposed buried Active galactic nucleus (AGN) in region D1, making it an ideal laboratory for studying dust evolution under extreme conditions.

Aims. This work aims to determine the carbonaceous dust properties across II Zw 096 by characterizing the spatial variations in carbonaceous feature ratios and to investigate how intense radiation fields process carbonaceous dust grains, using the relationship between dust processing signatures and traditional radiation field diagnostics.

Methods. Using *JWST* NIRSpec IFU and MIRI MRS, carbonaceous features were observed and analyzed using the Continuum and Feature Extraction tool (CAFE) with 61 carbonaceous features from the PDRs4all project and new absorption features for ice and crystalline silicates. We analyze spatial variations in carbonaceous feature ratios at multiple resolutions (0.281", 0.787", and 0.961") to trace dust composition and grain-size distribution. The 3.4/3.3 μm ratio probes aliphatic versus aromatic content, while the 11.3/3.3 μm ratio diagnoses grain-size distribution.

Results. The 3.4/3.3 μm ratio spans between 0.056–0.148, with the lowest values near the proposed AGN (D1) and starburst clumps (C0, D0), indicating preferential destruction of C–H bonds connected to aliphatic structures in highly irradiated environments. The 11.3/3.3 μm ratio varies from 0.334 to ~2.348 in D1. Both polycyclic aromatic hydrocarbon (PAH) ratios show no clear correlation with [Ne III]/[Ne II], suggesting ionization diagnostics break down either in extreme merger environments or as an effect of tracing different interstellar medium (ISM) phases and radiation-field regimes in this highly obscure merger environment. We detect water ice (3.1 μm), CO₂ ice (4.27 μm), and crystalline silicates (11.1 μm) with spatial distributions anti-correlating with carbonaceous processing signatures.

Conclusions. Spatial resolution critically affects dust diagnostics: the 3.4/3.3 μm dynamic range doubles when increasing the resolution from 0.961" to 0.281", demonstrating that apparent uniformity at low resolution masks significant variations in compact regions undergoing intense dust processing. Multiple coherent diagnostics point to intense dust processing, such as photo-destruction of the smallest nanograins and aromatisation, consistent with a buried AGN in D1, although definitive confirmation remains elusive.

Key words. methods: observational – techniques: spectroscopic – dust, extinction – galaxies: interactions – galaxies: ISM

1. Introduction

Understanding the evolution of dust in extreme environments is key to tracing star formation and active galactic nuclei

(AGNs) activity across cosmic time. Luminous infrared galaxies (LIRGs; $L_{\text{IR}} > 10^{11} L_{\odot}$) offer ideal laboratories for this, exhibiting intense starburst and AGN-driven processes within compact, dust-enriched regions. These objects represent some of the most extreme star-forming systems in the local Universe, often triggered by major mergers (Goldader et al. (1997);

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Iwasawa et al. (2011)). The merger-driven gas inflows fuel both starburst activity and potential AGN growth, while simultaneously concentrating vast quantities of dust that absorb ultraviolet and optical radiation and re-emit it in the infrared (IR), making LIRGs among the most IR-luminous objects in the nearby Universe. Understanding the physical processes in these systems provides critical insights into galaxy evolution, particularly during the peak epoch of cosmic star formation when LIRGs were far more common.

Interstellar dust grains, though comprising only $\sim 1\%$ of the interstellar medium (ISM) mass, play a fundamental role in galaxy evolution and the physics of the ISM (e.g. Draine 2011). Dust grains range from large micrometre-sized silicate and carbonaceous particles that shape the continuum to nanometre-sized polycyclic aromatic hydrocarbons (PAHs) responsible for prominent IR features at 3.3, 6.2, 7.7, 8.6, 11.3, and 12.7 μm . First detected as unidentified infrared features in the 1970s (Gillett et al. 1973; Merrill et al. 1975), these bands were later attributed to vibrational modes of PAH molecules – large aromatic structures containing tens to hundreds of carbon atoms arranged in benzene-like rings with hydrogen atoms at their periphery (Leger & Puget 1984; Allamandola et al. 1985). Beyond the aromatic features, the 3.4 μm complex arises from C–H bonds in aliphatic structures, open-chain hydrocarbons, providing a complementary probe of carbonaceous dust composition (Pendleton & Allamandola 2002; Boutéraon et al. 2019).

The physical and chemical properties of dust grains – their size, composition, and processing history – encode the conditions of their surrounding environment. In intense radiation fields, PAHs undergo photo-processing that preferentially destroys smaller grains and aliphatic bonds, shifting the grain population towards larger, more aromatic structures (Allain et al. 1996; Jones et al. 2013). This processing manifests observationally through variations in PAH feature ratios: the 3.4/3.3 μm ratio traces the aliphatic-to-aromatic content, while the 11.3/3.3 μm ratio probes the grain-size distribution (Li & Draine 2001; Maragkoudakis et al. 2018). With the advent of *James Webb* Space Telescope (*JWST*), we can now spatially resolve these dust signatures in nearby galaxies with unprecedented detail, revealing how extreme environments in merger systems process interstellar dust on sub-kiloparsec scales.

II Zw 096 ($z = 0.036$, $L_{\text{IR}} \sim 10^{11.9} L_{\odot}$) is a nearby LIRG undergoing a major merger that provides an ideal laboratory for studying dust processing in extreme environments. First mapped in detail by Goldader et al. (1997), the system consists of multiple interacting components with intense star formation concentrated in heavily obscured regions. The presence of multiple star-forming clumps with varying degrees of obscuration and possibly an obscured AGN (e.g. Inami et al. 2022; García-Bernete et al. 2024; Donnan et al. 2024; Riesco et al. 2025) makes II Zw 096 an exceptional target for investigating how merger-driven processes affect dust grain properties.

In this paper, we exploit the high spatial and spectral resolution of *JWST* NIRSpec IFU and MIRI MRS observations to map carbonaceous dust properties across the central regions of II Zw 096. This study pursues four primary goals: (1) characterize the spatial variations in PAH feature ratios to trace dust composition and grain-size distribution across different physical environments; (2) investigate how intense radiation fields in starburst and potentially AGN-dominated regions process carbonaceous grains; (3) examine the relationship between dust processing signatures and traditional radiation field diagnostics; and (4) assess the impact of spatial resolution on observed dust property variations in complex merger environments.

This paper is organized as follows. Section 2 provides an overview of II Zw 096 and its key components. Section 3 describes the *JWST* observations and data reduction procedures. Section 4 details our spectral analysis methodology, including new updates to the Continuum and Feature Extraction (CAFE) tool with new carbonaceous and absorption features. Section 5 presents our spatially resolved measurements of PAH ratios, absorption features, and their correlations. Section 6 interprets these results in the context of dust processing mechanisms and the nature of compact sources. Finally, Section 7 summarizes our findings and their implications for understanding dust evolution in extreme environments.

2. Merger galaxy: II Zw 096

II Zw 096 is a well-studied system characterized by Goldader et al. (1997), who identified four main regions A–D (see Figure 1), plus a fifth region, E, identified as an extended region of diffuse emission, attributed to tidal debris from the merger interaction. Region A is identified as a spiral galaxy with a distinct galactic nucleus, while region B is an extended spiral galaxy to the west. Riesco et al. (2025) used $H\alpha$ emission to estimate star formation rates of A and B at 12 and 18 $M_{\odot}/\text{yr}$ respectively. These galaxies are less affected by the merger compared to regions C and D, which exhibit high obscuration and intense star formation. Regions A, C, and D all have estimated starburst ages ~ 10 –100 times younger than most LIRGs (Goldader et al. 1997).

Riesco et al. (2025) propose that the E region could be an independent system in the merger and estimate the position angle and inclination angle to be $PA = 99^{\circ} \pm 24^{\circ}$ and $i = 40^{\circ} \pm 21^{\circ}$ for galaxy A, and $PA = 170^{\circ} \pm 5^{\circ}$ and $i = 65^{\circ} \pm 15^{\circ}$ for galaxy B. They also identified tidal tails in galaxy A stretching towards B, and a high density region of stars which does not follow the rotation of the galaxies. Inami et al. (2022) presented *JWST* NIR-Cam data that confirm the major merger nature of this system, as further analyzed by Riesco et al. (2025).

Regions C and D, close to the merger centre, have bright IR emission due to dust-enshrouded starburst and possibly AGN activity (Inami et al. 2022; García-Bernete et al. 2024). Inami et al. (2022) identified nine clumps in C and D using *JWST* MIRI photometry, with 15.0–5.6 μm colours ($F_{15\mu\text{m}}/F_{5.6\mu\text{m}}$) of ~ 15 –25, making the clumps twice as red as local LIRG nuclei. Three clumps (C0, D0, and D1) stand out as the reddest in $F_{7.7\mu\text{m}}/F_{5.6\mu\text{m}}$. These vary quite a lot in $F_{15\mu\text{m}}/F_{5.6\mu\text{m}}$ between all identified clumps, with D1 the reddest in the set and C0 the bluest, with D0 intermediate. D1 is responsible for the bulk of the system’s mid-IR emission, estimated between 40–70% or $(3\text{--}5) \times 10^{11} L_{\odot}$ (Inami et al. 2022). This region (ID 8 in Inami et al. 2022) is smaller than 175 pc and is still unresolved with *JWST*. Although the luminosity appears sub-Eddington for its compact size, the nature of D1 remains ambiguous; its colours are consistent with either a deeply obscured AGN or an extreme starburst (Inami et al. 2022). X-ray detections from *Chandra* and *XMM-Newton* of the full system were well fitted with a star formation model; however, it is not sufficient to decipher the nature of D1 only. Non-detections of X-ray emission by *NuSTAR* leave the possibility of D1 as a Compton-thick AGN if the column densities are $> 10^{25} \text{ cm}^{-2}$ (Ricci et al. 2021; Iwasawa et al. 2011). Since the column density of D1 is $\sim 10^{25} \text{ cm}^{-2}$, this Compton-thick AGN scenario is indeed possible (Inami et al. 2022). Riesco et al. (2025) also argued for an obscured AGN accompanied by a compact starburst in D1, based on optical line classification and

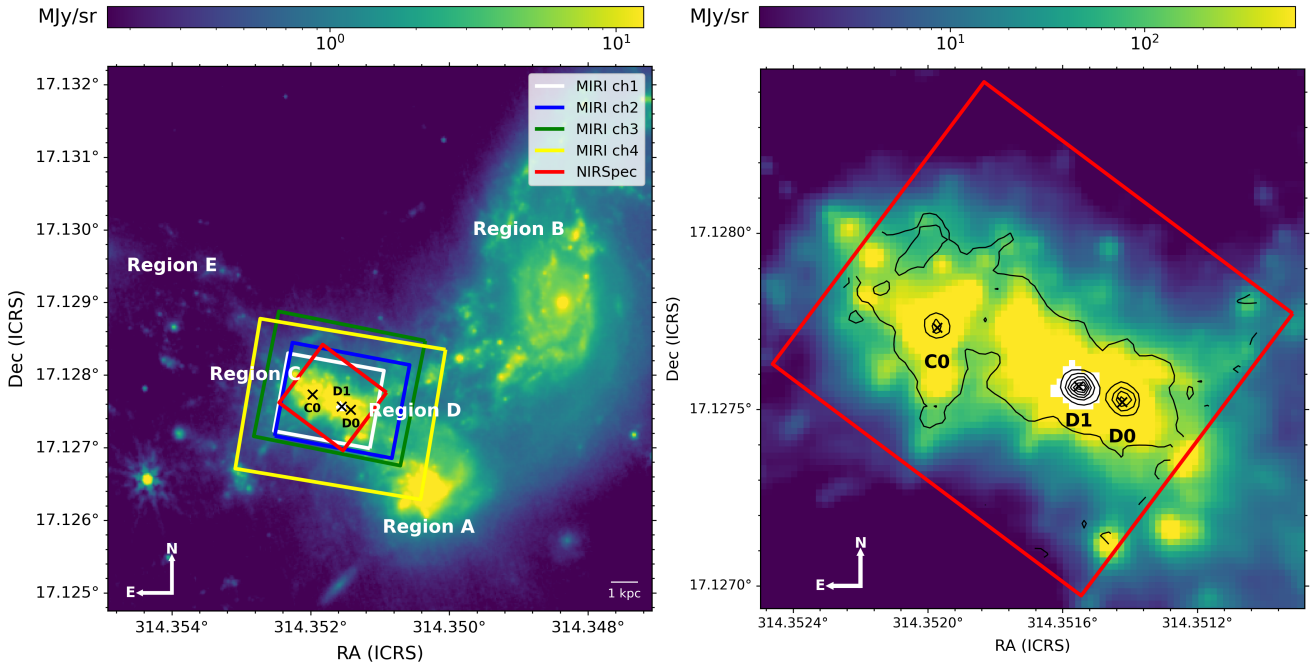


Fig. 1. *JWST* NIRCам F356W image of II Zw 096 merger with *JWST* field of view (FoV), major galaxy regions, and clumps from Goldader et al. (1997) indicated. *Left:* full merger system with galaxy A and B, bright IR region C and D, and tidal region E indicated together with the FoV of NIRSspec IFU (red), MIRI MRS ch1 (white), ch2 (blue), ch3 (green), and ch4 (yellow). *Right:* zoomed NIRCам image with NIRSspec IFU FoV (red box) indicated, contours are the NIRSspec IFU G395H/F290LP filter- and grating combination sub-channel at the aromatic 3.3 μm carbonaceous feature peak. Starburst regions (C0 and D0) and possible AGN region (D1) indicated.

high $L_{[\text{O III}]}$ of $\sim 10^{42}$ erg/s. The continuum emission detected in ALMA Band 3 observations is compact and unresolved, so far without a clear assessment on its physical origin (Riesco et al. 2025). Based on the model fitting of gas-phase H_2O and CO rovibrational lines obtained with *JWST*, García-Bernete et al. (2024) also attributed AGN activity to D1.

3. Observations and data reduction

3.1. *JWST* observations

The observations were carried out on October 6 and November 4 2022 with *JWST* as a part of the Great Observatories All-sky LIRG Survey (GOALS), Director’s Discretionary Time Early Release Science (ERS) program 1328 (Armus 2025) (co-PIs: L. Armus and A.S. Evans). The pointing was centred at RA = 314.50294°, Dec = 17.19979°, towards regions C and D (Figure 1) of II Zw 096. The observations consist of NIRSspec IFU and MIRI MRS data, along with NIRCам and MIRI imaging.

The NIRSspec IFU observations were done with a four-point cyclic dither pattern and an accompanied Micro-Shutter Assembly (MSA) imprint exposure which was subtracted during data reduction, resulting in data with filter and grating combinations G140H/F100LP (0.97–1.89 μm), G235H/F170LP (1.66–3.17 μm), G395H/F290LP (2.87–5.27 μm) with resolving power $R \sim 2700$.

The MIRI MRS observation (4.9–27.9 μm) was done with a four-point cyclic dither pattern enabling $R \sim 1500$ –3500. The MIRI MRS observations also have dedicated background observations. However, this was not used in the data reduction, as the background was later fitted by the spectral energy distribution (SED) decomposition program (see Section 4). The FoV

for NIRSspec IFU is $3'' \times 3''$ with spatial resolution of $0.1''$, corresponding to 75.2 pc at the distance of II Zw 096, and for MIRI MRS $3.2'' \times 3.7''$ to $6.6'' \times 3.7''$ (ch1 through ch4) see Figure 1. The total effective integration time was 365 and 222 seconds for NIRSspec and MIRI, respectively.

3.2. Data reduction pipeline

NIRSspec data were reduced using *JWST* data processing software version 1.18.0 (Build 11.3, Context jwst_1364.pmap) while MIRI MRS was reduced at a later time using calibration software version 1.18.1 (Build 11.3, Context jwst_1364.pmap) (Greenfield & Miller 2016; Bushouse et al. 2025). The NIRSspec data showed apparent flux offsets between the NRS1 and NRS2 detectors, separated in the spectra by the wavelength gap. The detector offset seemed to be most prominent in the east part of the FoV and the suspected cause was deemed to be substantial $1/f$ noise in the observations. To mitigate its effects, the CLEAN_FLICKER_NOISE step in CALWEBB_DETECTOR1 used a non-default setup with FIT_METHOD=fft, sigma-clipping level $n_\sigma = 1.5$ and MASK_SCIENCE_REGIONS as false, which was accompanied with the additional $1/f$ mitigation step NSCLEAN in CALWEBB_SPEC2, also with $n_\sigma = 1.5$. This proved to have some effect on the NRS detector’s flux offsets. However, some extracted spectra still required post-pipeline correction to achieve satisfactory SED fitting results. This was done by fitting a linear curve to the NRS detector data closest to the gap, using additive stitching with the NRS1 spectra as reference. To mitigate bad pixels missed by previous pipeline steps, a BADPIX_SELFAL was performed using FLAGFRAC_UPPER=0.005 in CALWEBB_SPEC2, BADPIX_REPLACE using N_ADJACENT_COLS=5 and the

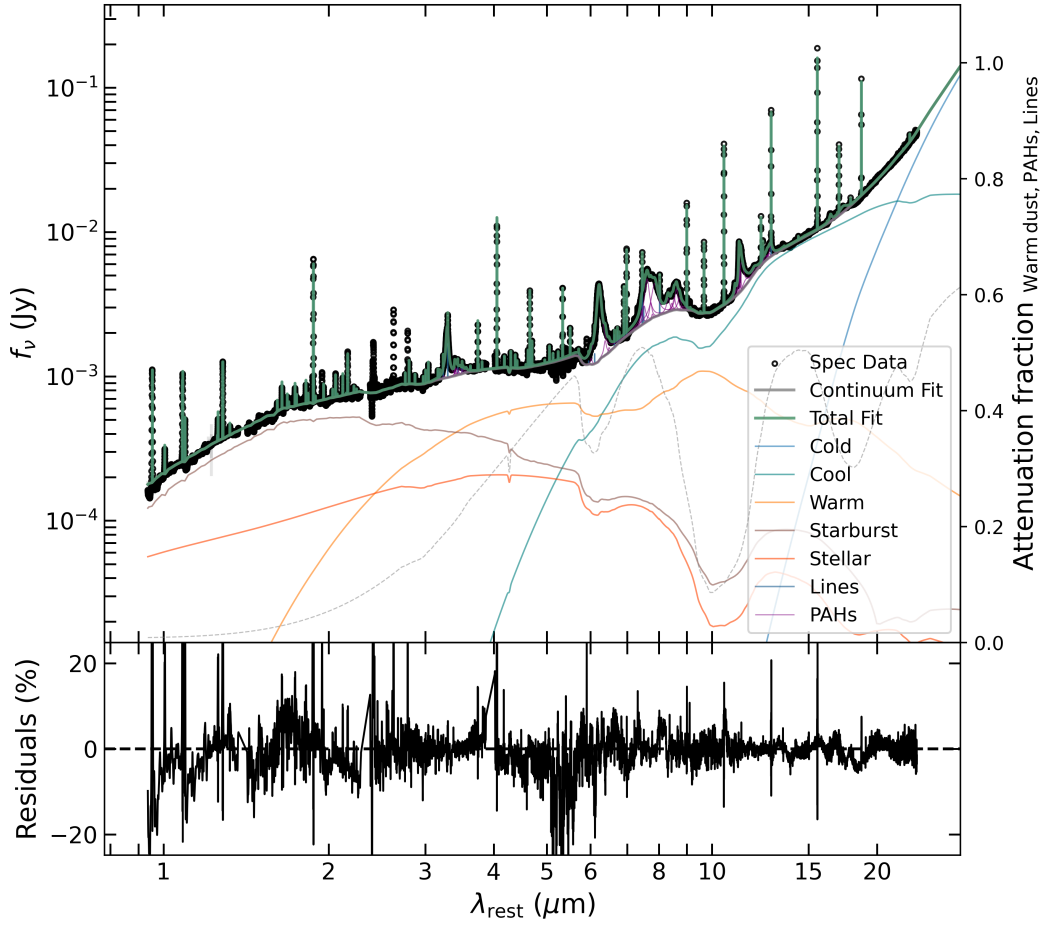


Fig. 2. Example fit of the SED using CAFE. Included are continuum components, PAH features, opacities, line emissions, and attenuation model. The SED is taken from aperture (A0–1), with wavelengths adjusted for redshift. Coloured lines correspond to flux components and the grey dashed line indicates the attenuation fraction.

FIT_PROFILE algorithm, as well as an outlier detection step with a 3-by-3 kernel size in CALWEBB_SPEC3.

The MIRI MRS data were reduced using the default pipeline with a few exceptions, for example using the RESIDUAL_FRINGE step and BADPIX_SELFCAL step with a flagging fraction of 0.5% in the CALWEBB_SPEC3 stage. Cosmic rays and data outliers missed by the pipeline were omitted in a later SED fitting.

The mean RMS noise levels in feature-free regions were measured to be 1.33 and 55.5 MJy/sr for NIRSpec IFU and MIRI MRS respectively after data convolution. The MIRI MRS data showed a larger spread in RMS with a lowest of 14.8 MJy/sr towards aperture (A0–2) and a highest of ~200 MJy/sr towards aperture (A2–1), due to residual fringes.

4. Spectral analysis methods

4.1. CAFE framework overview

We used CAFE (Diaz-Santos et al. 2025) to perform continuum subtraction and decompose dust features. This updated version of CAFE is built on the original implementation, which was developed in IDL for *Spitzer* IRS spectra by Marshall et al. (2007) to include *JWST* data. The tool has two main components, the CAFE Region Extraction Tool Automaton (CRETA), which defines apertures or grids of apertures for extracting the SED of point or extended sources, and the CAFE fitter, which performs non-linear spectral decomposition of *JWST* SEDs. An

example fit from II Zw 096 using CAFE is shown in Figure 2. The software accepts calibrated *JWST* data products, which are fitted and decomposed using model continuum components and a library of PAH features, lines, and opacity features. The available continuum components include five reprocessed black body emission models; a cirrus cloud component and also cold (~0–40 K), cool (~40–150 K), warm (~150–500 K), and hot (≥ 500) dust components. Three additional model continuum sources can also be included: stellar and starburst continua as well as disk continuum from AGNs. Each component is fitted for flux, temperature (for dust components), optical depth, source geometry, and covering factor. Individual continuum components can be excluded or included to fit different science cases. The library includes PAH emission bands fitted using Drude profiles, absorption features (either from measured profiles or using Gaussians), including silicates (9.7 and 18 μm), water ice (3.0 and 6.1 μm), CO₂, aliphatic hydrocarbons (3.4 and 6.85 μm), and crystalline silicates (23 μm), and Gaussian profiles for atomic, molecular, and HI recombination lines. Additionally, a velocity gradient fitting is performed allowing for a global feature wavelength drift during the fit.

The fitting procedure in CAFE is powered by the LMFIT Levenberg–Marquardt algorithm with parameter ties and limits. All parameters to be optimized are user-controlled through option and initial guess files, including feature fixing and exclusion, bounds, masking, and tolerance thresholds. CAFE outputs the best-fit spectra, residuals, tables of continuum and feature

fluxes, full width at half maximum (FWHM), peak and central wavelength of Drude and Gaussian features, and goodness-of-fit statistics in FITS binary tables.

4.2. Modified IFU procedure

The current version of CAFE uses a user-specified input to start the fitting procedure. Since CAFE uses the least-squares minimization method, it requires careful selection of initial parameters to ensure convergence to the global minimum, particularly when fitting a large number of free parameters. To avoid the user having to define an initial guess for all regions in the grid, CAFE uses an approach where it arranges all regions from the highest S/N to the lowest, using the user-defined initial guess only to the highest S/N aperture. After fitting the highest S/N aperture first, the result of this decomposition will be used as the initial guess to the second one in the S/N order. This fitting routine proved to be inadequate for II Zw 096 due to the significant spatial variations in continuum and feature characteristics. Adjacent regions with similar S/N exhibit markedly different spectral energy distributions, resulting in poor convergence when using sequential fitting.

To address this issue, we used a new approach, implemented as a wrapper to CAFE, in which all apertures are processed individually using the same user-specified initial guess, but where a pre-defined increase in the number of fitted components generates a progressively tailored initial guess for each region. Since a large parameter space is more sensitive to local minimum of the fitting routine, the execution of CAFE in each aperture was done in three stages, all automated to ensure faster turnover times. In the first stage, only the continuum parameters were included in the parameter space, i.e. no PAHs features, opacities, or lines were included, enabling a fast and robust way of arriving in the vicinity of the correct continuum. The continuum parameters of stage 1 serve as initial values for stage 2, which includes PAH and opacity features as additional free parameters. In this second stage, the continuum was still allowed to vary, however, with narrower bounds to all its parameters, since an approximate continuum solution was reached in stage 1. The results of stage 2 were finally used as input to the last, third stage, where all parameters, continuum, PAH features, opacities, and lines were included as free parameters. Since the previous stages had achieved an approximate solution, the final result of stage 3 was significantly improved. Since Gaussian and Drude features generally include three free parameters each (central wavelength, width, and peak), and continuum components can have up to five (relative flux, screening effects, and clumpiness), a single aperture SED fit with ~500 free parameters can take up to several hours if the initial guess is poor; therefore, sequential execution of a full grid of apertures is quite time consuming. Our independent aperture approach makes use of parallel processing, which allows multiple regions to be fitted simultaneously, with computation time effectively constrained by the number of available computing cores.

4.3. CAFE features library upgrades

The current version of CAFE includes approximately 20 PAH features that can be fitted during decomposition. We have included the PAH features reported in the PDRs4all project (Chown et al. 2024) in an updated version of the CAFE feature library. These amount to 61 features grouped in 17 complexes allowed to be tested and possibly fitted to the aperture SEDs by CAFE. Although the original CAFE library covered the main

complexes, it was unable to fully capture the rich and ever-varying PAH features present in II Zw 096. The most important complexes for this study are the 3.3 and 3.4 μm complexes, where the former was previously described in CAFE by a feature centred at 3.289 μm , and the latter as two narrow sub-features at 3.403 and 3.52 μm and a wide plateau centred at 3.49 μm , these have here been replaced by the PDRs4all sub-features. The 3.3 μm complex has been complemented with a feature centred at 3.246 μm . The 3.4 μm complex with plateau now consists of six sub-features, most important being the 3.395 and 3.403 μm sub-features, later used in calculating feature ratios in II Zw 096. Additionally, the 11.3 μm complex constitutes an important role: it was previously described in CAFE by three sub-features, six now after implementation of the PDRs4all results; the 11.207, 11.250, 11.275, and 11.300 μm are included in feature ratio calculations. Following Wright et al. (2016), who observed similar features in multiple objects, including LIRGs, we added two Gaussian opacity features centred at 9.25 and 11.1 μm to improve the fit of the 8.6 and 11.3 μm complexes. These features change the profile of the wide 9.7 μm silicate absorption feature and are attributed to crystalline silicate.

4.4. SED extraction grids

We spatially convolved all *JWST* data below the longest wavelength of interest using a Gaussian kernel of size σ of the point spread function (PSF), calculated using WebbPSF (Perrin et al. 2012, 2014) and spectrally smoothed it to a common resolution up to the longest wavelength of interest. To achieve the highest possible spatial resolution for the SED decomposition, we created three versions of the input data convolved using a kernel the size of which was calculated using WebbPSF at three different wavelengths. We created the following extraction grids: a 3 $\times$ 3 grid of 0.961'' apertures for features up to the 15.56 μm [Ne III] line (Figure 3a), a 4 $\times$ 3 grid of 0.787'' apertures for features up to 11.3 μm (Figure 3b), and a 10 $\times$ 6 grid of 0.281'' apertures for features up to 3.4030 μm (Figure 3c), all wavelengths adjusted to the redshift of II Zw 096. Due to the extended source nature and complicated structure of II Zw 096, also on the scale of the extraction aperture sizes, the extracted spectra were not aperture corrected. This could introduce a common shift in feature ratio values when compared to aperture-corrected spectra depending on the extraction aperture size and feature wavelengths. It would have a small impact on the distribution of the ratio values within each respective grid and would mainly affect the overall ratio values, with a larger impact on the 11.3/3.3 μm ratio of ~15%. For the 3.4/3.3 μm and [Ne III]/[Ne II] ratios, the estimated shift is negligible.

5. Results

5.1. Spectral fitting overview

The environment changes significantly between starburst regions, possible AGN regions, and regions dominated by ISM emission (most regions outside the main clumps D1, D0, and C0), visible in the profile of the extracted SEDs. The quality of the spectral fits varies between regions, with particular attention given to the 3.3, 3.4, and 11.3 μm complexes. The representative mean residual values for the global fit are ~5%. In the immediate spectral environment surrounding the features of interest, the representative mean residual values are ~3.1%.

Figure 4 shows example SEDs and CAFE fittings for three different regions using the low-resolution 3 $\times$ 3 grid: the AGN

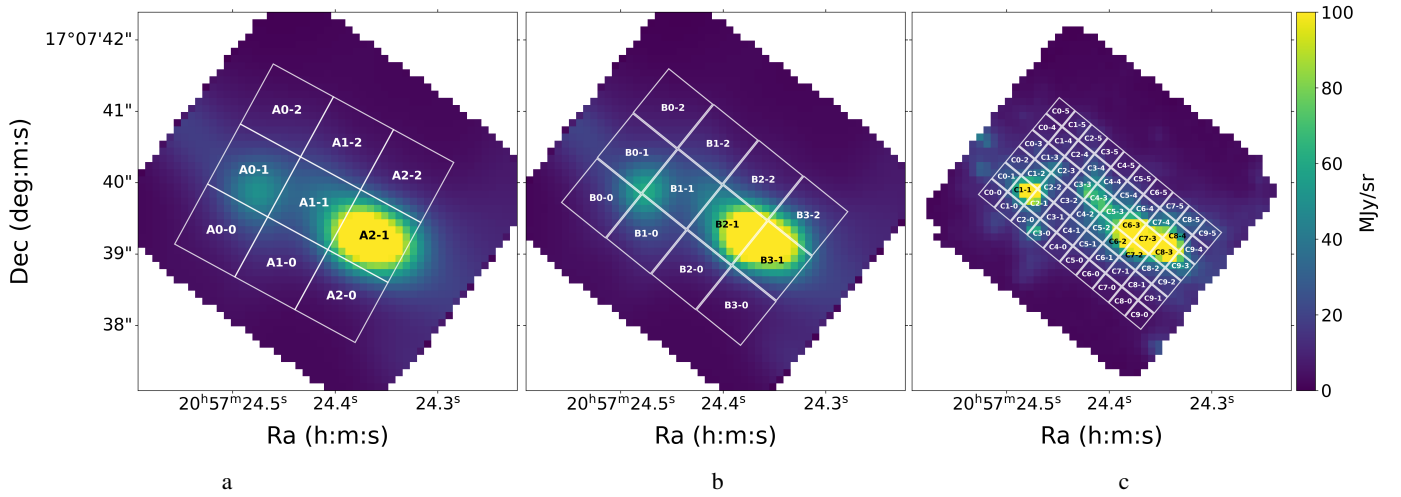


Fig. 3. CAFE SED extraction grid for different spatial convolutions of the *JWST* data enabling comparison between spectral features. (a) 3×3 grid of $0.961''$ for comparison of the features up to the [Ne III] ($15.56 \mu\text{m}$) line. (b) 4×3 grid of $0.787''$ aperture for comparison of the features up to the $11.3 \mu\text{m}$ complex. c: 10×6 grid with an aperture size of $0.2810''$ for comparison of features up to the $3.4 \mu\text{m}$ complex.

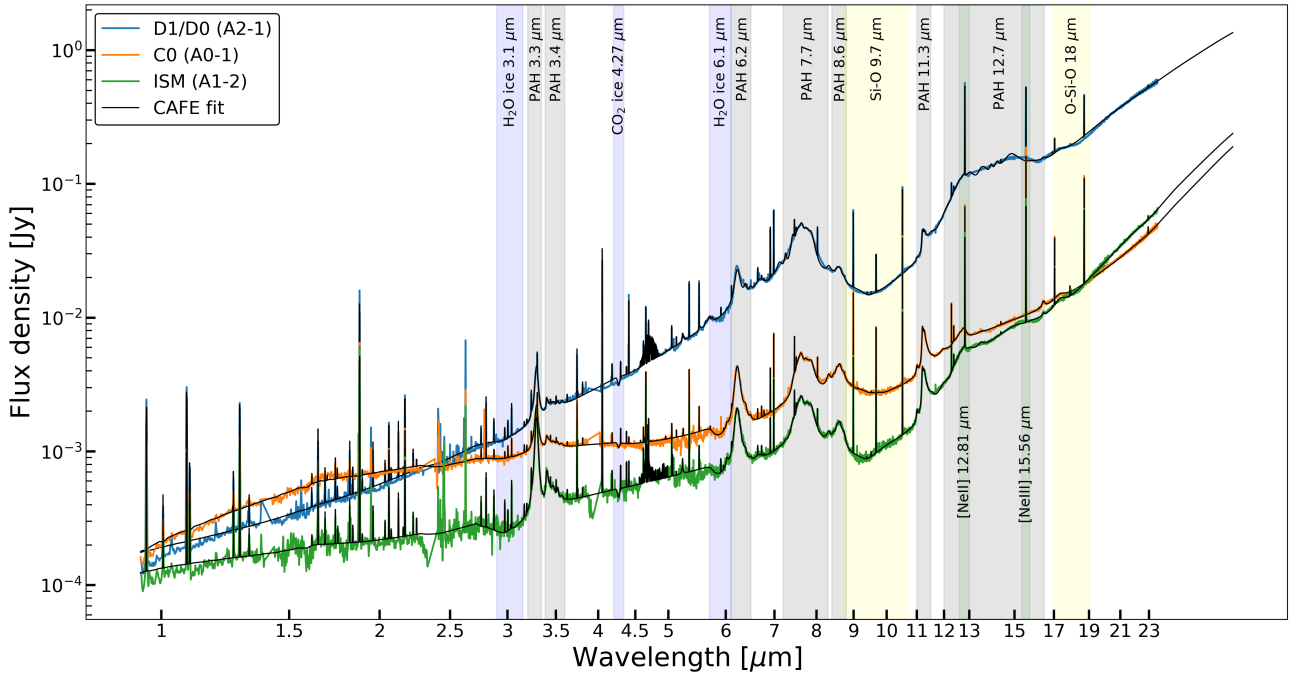


Fig. 4. Rest frame SED extractions and decomposition using CAFE for three apertures of size $0.961''$. The blue line corresponds to the proposed AGN region D1 and starburst region D0 (A2–1), orange is the starburst region C0 (A0–1), and green is the ISM-dominated region (A1–2). Black lines correspond to the CAFE fitting results. Shaded regions indicate emission and absorption features observed.

region D1 and starburst region D0 (aperture A2–1), the starburst region C0 (aperture A0–1), and an ISM-dominated region (aperture A1–2). All SEDs have been fitted using a cold, cool, and warm dust continuum component as well as starburst and stellar emission models. Other configurations of continuum components, such as an AGN accretion disk and/or an even warmer dust component, have been experimented with. No AGN component and warmer dust was needed to fit the data, even for region D1, which contains the proposed AGN.

Notable features include prominent PAH complexes, varying depths and profiles of the $9.7 \mu\text{m}$ silicate absorption feature across different regions, $14.0 \mu\text{m}$ HCN absorption in D1/D0, and the gas-phase H_2O and CO rovibrational features centred

around $5 \mu\text{m}$ in D1/D0 aperture (A2–1). The latter molecular features have been thoroughly investigated by [García-Bernete et al. \(2024\)](#). Figure 5 shows the continuum-subtracted SED towards aperture (A1–0), focusing on the main carbonaceous feature complexes at 3.3 , 3.4 , 6.2 , 7.7 , 8.6 , 11.3 , and $12.7 \mu\text{m}$.

5.2. Absorption features

Most apertures for all spatial convolutions show broad absorption features at $3.1 \mu\text{m}$ and $6.1 \mu\text{m}$ due to H_2O ice (e.g. [Dartois & d'Hendecourt 2001](#)), with the former being attributed to the vibrational modes involving the stretching of the O–H bond (e.g. [Leger et al. 1979](#)), and the latter to O–H bending modes (e.g.

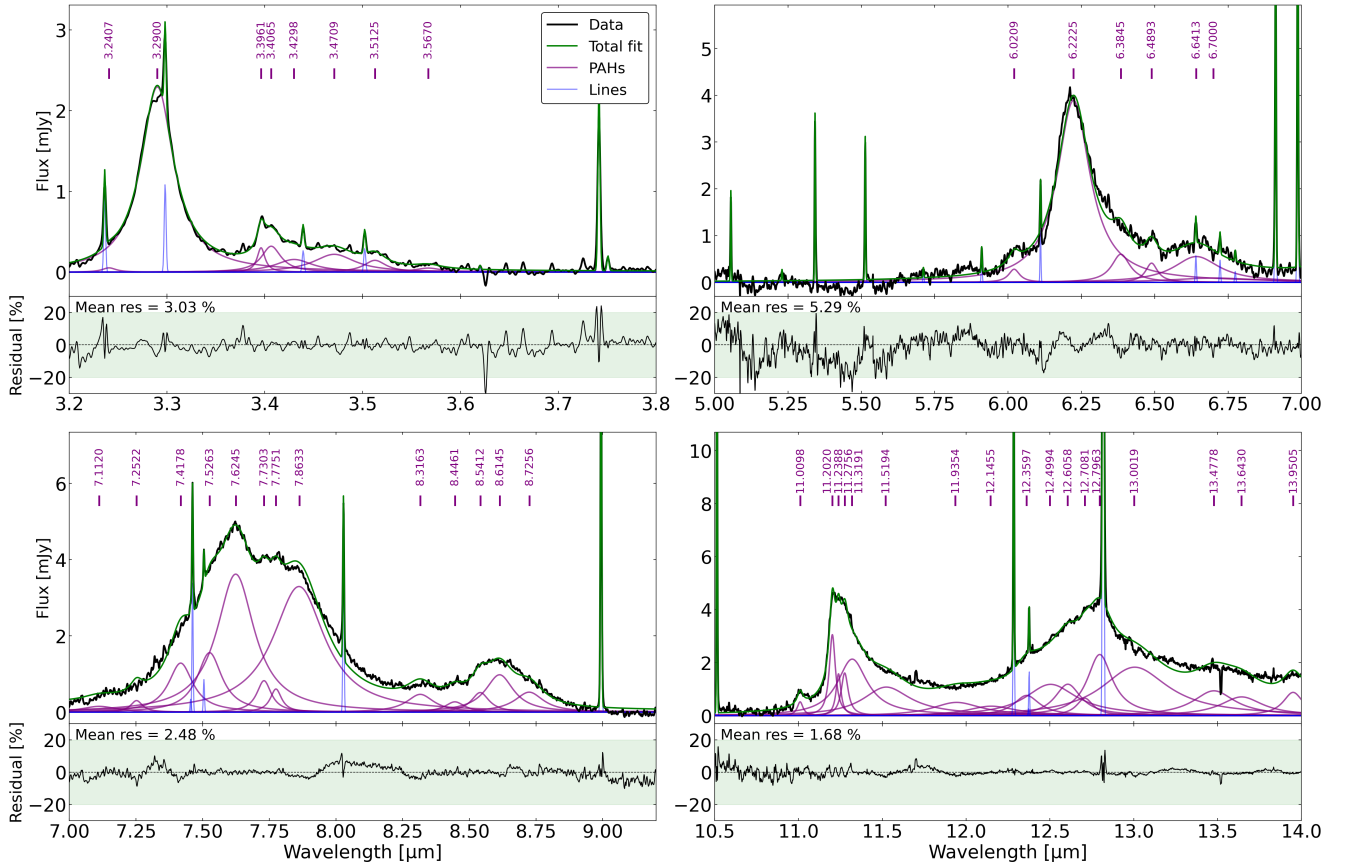


Fig. 5. Focused plots in different spectral regions of the low-resolution grid aperture (A1–0) to illustrate the model fit. The black line is the continuum-subtracted *JWST* SED with total fit in green. In magenta are the carbonaceous sub-features plotted with fitted central wavelength indicated above. Blue lines are fitted atomic, molecular, and hydrogen recombination lines. Panel a: aromatic 3.3 μm and aliphatic 3.4 μm carbonaceous features. Panel b: aromatic 6.2 μm complex. Panel c: aromatic 7.7 and 8.6 μm complexes. Panel d: aromatic 11.3 μm complex. The residual panels show the full model fit residual, including continuum.

Tielens et al. 1984), both having been observed towards multiple objects, including ultra-luminous infrared galaxies (ULIRGs, $L_{\text{IR}} > 10^{12} L_{\odot}$) (Imanishi et al. 2007). These are generally well fitted with the included CAFE template spectra from ULIRGs IRAS 00188-0856 and IRAS 00183-7111 observed by GTO *Spitzer IRS* guaranteed time observations. Using a linear fit to the local continuum, the optical depths at 3.1 and 6.1 μm due to H_2O ice in the extracted apertures are all below unity, with the former having a mean value of $\tau_{3.1, \text{mean}} = 0.25$, minimum of $\tau_{3.1, \text{min}} = 0.09$ towards aperture (A0–1), and maximum $\tau_{3.1, \text{max}} = 0.39$ at (A1–0). We also detect CO_2 ice absorption at 4.27 μm between these water features, attributed to the anti-symmetric stretching mode of the molecule, with feature width slightly varying with ice mixture environment (Ehrenfreund et al. 1996; Dartois et al. 2022). It has been appreciated as an indicator of ice growth on dust grains, having been observed towards objects such as massive protostellar objects (Dartois et al. 2022) and external galaxies (e.g. Lai et al. 2023; Buiten et al. 2024).

Also detected everywhere in II Zw 096 is the wide 9.7 μm silicate absorption feature originating from vibrational modes involving the stretching of the Si-O bonds in silicate dust (Draine & Lee 1984). The feature stretches well over a micrometre with a mean optical depth across the FoV of $\tau_{9.7, \text{mean}} = 0.95$, max $\tau_{9.7, \text{max}} = 1.20$ towards aperture (A1–0), and minimum $\tau_{9.7, \text{min}} = 0.51$ at (A0–1) using the lower-resolution extraction grid and calculated using a polynomial fit to the continuum to isolate the optical depth of the feature..

Wright et al. (2016) reported crystalline silicate absorption features at $\sim 11.1 \mu\text{m}$ in evolved stars, embedded young stellar objects (YSOs), background sources, and the Galactic centre. The feature was also observed in a sample of ULIRGs by Spoon et al. (2006). Following their work, we included a Gaussian absorption feature at 11.1 μm (width $\sim 0.1 \mu\text{m}$), which substantially improved the fit of the 11.3 μm complex and is considered necessary to obtain reliable results. Similarly, some apertures exhibit a slightly deeper and more narrow profile to the 9.7 μm feature on the lower wavelength side of $\sim 9.7 \mu\text{m}$, seen as feature profile differences between aperture SEDs in Figure 4. This is also to be expected from crystalline silicate, and therefore where the 11.1 μm feature is observed (Wright et al. 2016). To accommodate this, a Gaussian absorption feature centred at $\sim 9.2 \mu\text{m}$ was included, with a width of $\sim 0.05 \mu\text{m}$ depending on the aperture. Inclusion of this feature improved the quality of fit for the 8.6 μm carbonaceous dust feature.

5.3. PAH feature spatial distribution

5.3.1. Aliphatic to aromatic band ratios

II Zw 096 shows a rich variation in PAH features and its properties, such as peak flux and width. In Figure 6a, the integrated flux ratio morphology of carbonaceous features 3.4 (3.395 and 3.403 μm sub-features) and 3.3 μm is presented. Laboratory,

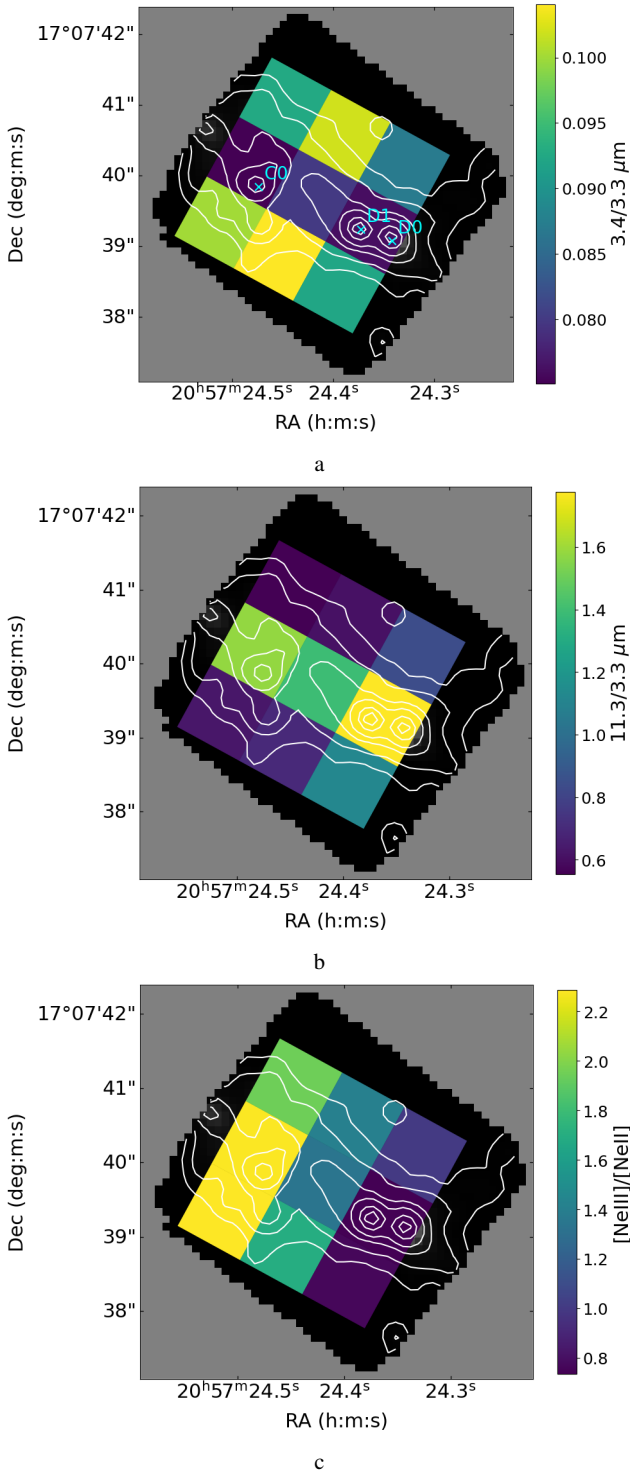


Fig. 6. Low-resolution morphology of integrated intrinsic flux ratio of carbonaceous features and neon lines with data convolved with a kernel size corresponding to [Ne III]. (a) 3.4 (3.395 and 3.403 μm sub-features) to 3.3 μm . (b) 11.3 μm complex to 3.3 μm . (c) 15.56 μm [Ne III] to 12.81 μm [Ne II] lines. Overlaid is the NIRSIFU G395H/F290LP contours at the 3.3 μm peak.

theoretical, and observational evidence all indicate that the intensity ratio of 3.4–3.3 μm is a sensitive tracer of the relative abundance of C–H bonds connected to aliphatic versus aromatic in interstellar carbonaceous grains. Early IR absorption studies of diffuse Galactic sightlines showed that the strength of the 3.4 μm aliphatic C–H stretch, relative to the aromatic

3.3 μm feature, is linked to the fraction of aliphatic side-groups attached to aromatic backbones (Pendleton & Allamandola 2002). Quantum-chemical calculations later demonstrated that the addition of methyl or methylene substituent to PAHs boosts the 3.4 μm emission almost linearly with the number of aliphatic C atoms, yielding a monotonic increase of the 3.4–3.3 μm ratio with aliphatic content (Yang et al. 2016). Analytic modelling of the unidentified infrared bands further constrained the overall aliphatic-carbon budget of the carriers to $\leq 15\%$ using this ratio (Li & Draine 2012). Empirically, Infrared Space Observatory (ISO) and ground-based spectra have revealed systematic variations in the 3.4–3.3 μm ratio along different interstellar sightlines (Günay et al. 2018), while high-resolution Very Large Telescope (VLT) data for the protoplanetary disk HD 100546 mapped a radial rise in the ratio away from the star, consistent with UV-driven aromatisation of nano-grains (Habart et al. 2021). *JWST* now confirms these trends, and PDRs4All spectroscopy across the Orion Bar finds elevated 3.4–3.3 μm ratios in shielded regions with less intense radiation fields (Schroetter et al. 2024). Together, these studies establish the 3.4 μm to 3.3 μm ratio as the most widely used single-band probe of the aliphatic content of interstellar and circumstellar hydrocarbon dust. Physically, when C–H bonds in aliphatic side chains are destroyed through UV radiation processing or thermal desorption, the carbon atoms form additional C=C aromatic bonds, making the material more hydrogen-poor and structurally more aromatic. This aromatization process specifically decreases the 3.4 μm aliphatic C–H stretch while enhancing the 3.3 μm aromatic C–H stretch, resulting in a lower 3.4/3.3 μm ratio in exposed regions.

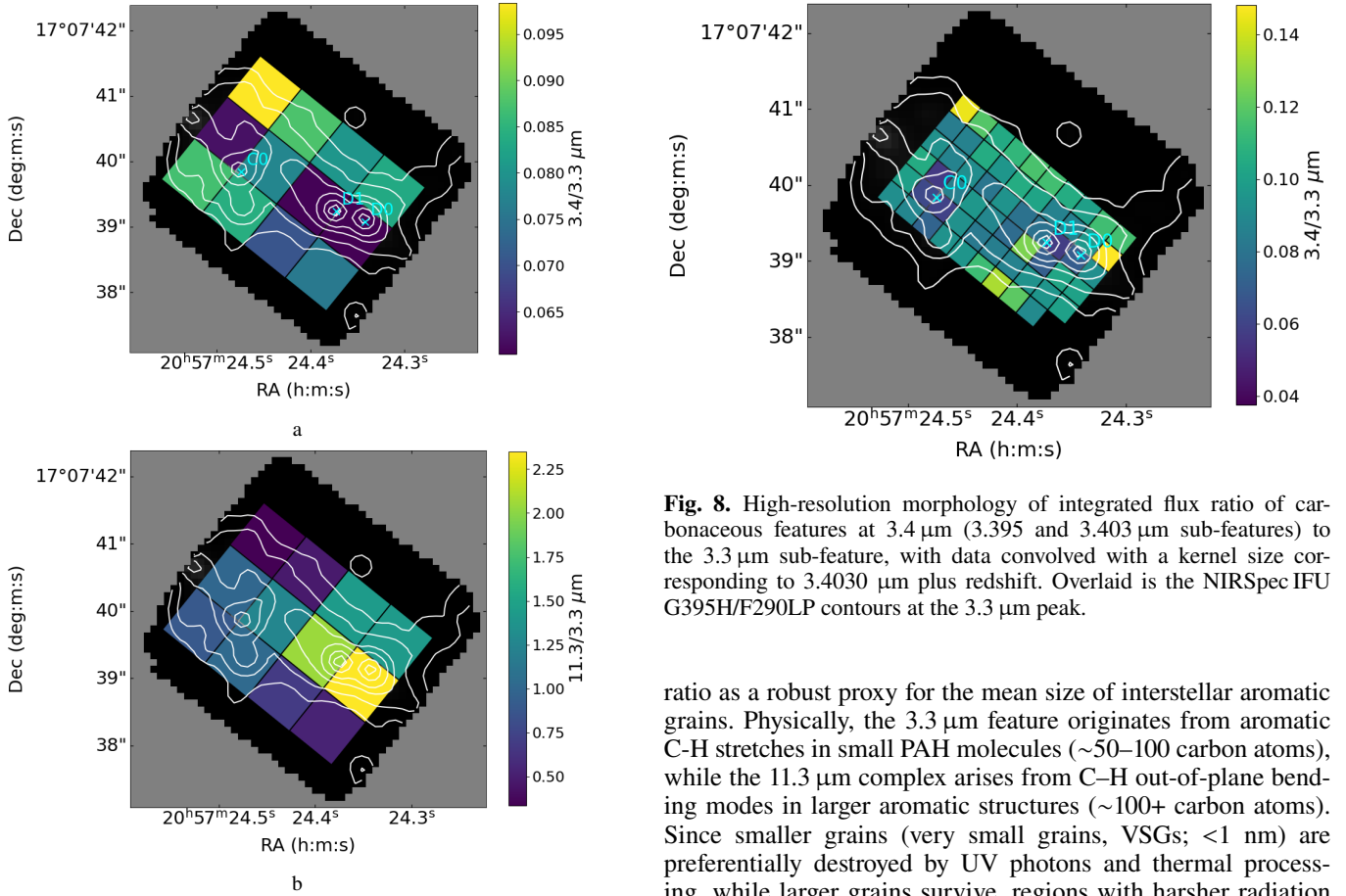
In Table 1, we show the different feature ratios for the low-resolution 3×3 grid. While the variation of the 3.4 to 3.3 μm ratio is small, C0 (Figure 6a, aperture A0–1) stands out with the lowest ratio at 0.075, followed by the proposed AGN and starburst region D1/D0 (aperture A2–1) at 0.076. At the intermediate resolution grid of 4×3 apertures (Figure 7a), the 3.4/3.3 μm ratio shows the same trend across FoV with values ranging from 0.06 to 0.10 with the lowest ratio at location of the proposed AGN at D1 (aperture B2–1), starburst regions D0 (B3–1), and neighbouring aperture to C0 (B0–1). The morphology of the 3.4/3.3 μm ratio persists also in the finer resolution 10×6 grid (Figure 8), now again showing a low ratio at the exact position of C0 (C2–1). At this resolution values range from 0.056 to 0.148, with the lowest ratio apertures still found at the location of the AGN (C7–3 and adjacent regions) and starburst region (C2–1 and adjacent regions), aligning with observations in other studies (e.g. Pilleri et al. 2015; Lai et al. 2020).

5.3.2. Dust grain size

Figure 6b shows the integrated flux ratio of the carbonaceous feature complex at 11.3 μm and 3.3 μm at the low-resolution grid. Laboratory, theoretical, and observational work consistently shows that the intensity ratio of the ‘solo’ C–H out-of-plane bend at 11.3 μm to the aromatic C–H stretch at 3.3 μm rises monotonically with the number of carbon atoms in carbonaceous grains. Early cascade-emission models linked larger PAHs (≥ 40 C atoms) to higher 11.3/3.3 μm values (Allamandola et al. 1989; Draine & Li 2001; Li & Draine 2001). Density functional theory calculations for the coronene and ovalene families later demonstrated an almost linear scaling of the 11.3–3.3 μm ratio with PAH size, independent of charge state (Ricca et al. 2012). Using *Spitzer* IRS spectra of HII regions in M33 and M83, Maragkoudakis et al. (2018) empirically confirmed that this ratio

Table 1. Integrated carbonaceous feature ratios and [Ne III]/[Ne II] ratio for apertures in the low-resolution 3×3 grid.

Aperture	3.4/3.3	11.3/3.3	11.3/7.7	6.2/7.7	[Ne III]/[Ne II]
<i>Starburst region</i>					
A0–1 (C0)	0.075	1.578	1.071	0.902	2.279
<i>Proposed AGN region</i>					
A2–1 (D1/D0)	0.076	1.776	0.129	0.198	0.736
<i>General ISM apertures</i>					
A0–0	0.100	0.629	1.156	0.864	2.287
A0–2	0.093	0.555	1.824	0.944	1.947
A1–0	0.104	0.696	0.337	0.503	1.697
A1–1	0.080	1.393	0.285	0.244	1.339
A1–2	0.102	0.608	0.569	0.642	1.406
A2–0	0.092	1.118	0.315	0.288	0.763
A2–2	0.087	0.836	0.897	0.450	0.997
Min	0.075	0.555	0.129	0.198	0.736
Max	0.104	1.776	1.824	0.944	2.287
Mean	0.090	1.021	0.732	0.559	1.495

**Fig. 7.** Intermediate resolution morphology of integrated flux ratio of carbonaceous features with data convolved with a kernel size corresponding to 11.3 μm plus redshift. (a) 3.4 μm (3.395 and 3.403 μm sub-features) to 3.3 μm sub-feature. (b) 11.3 μm complex to 3.3 μm features. Overlaid is the NIRSIFU G395H/F290LP contours at the 3.3 μm peak.**Fig. 8.** High-resolution morphology of integrated flux ratio of carbonaceous features at 3.4 μm (3.395 and 3.403 μm sub-features) to the 3.3 μm sub-feature, with data convolved with a kernel size corresponding to 3.4030 μm plus redshift. Overlaid is the NIRSIFU G395H/F290LP contours at the 3.3 μm peak.

ratio as a robust proxy for the mean size of interstellar aromatic grains. Physically, the 3.3 μm feature originates from aromatic C–H stretches in small PAH molecules (~ 50 – 100 carbon atoms), while the 11.3 μm complex arises from C–H out-of-plane bending modes in larger aromatic structures (~ 100 + carbon atoms). Since smaller grains (very small grains, VSGs; < 1 nm) are preferentially destroyed by UV photons and thermal processing, while larger grains survive, regions with harsher radiation environments can lead to larger grain sizes on average, thus enhancing 11.3 μm emission relative to 3.3 μm .

The 11.3 to 3.3 μm ratio in our FoV shows a variation in values from 0.555 to 1.776 (see Table 1), with the largest value at D1/D0 (aperture A2–1) followed by 1.578 towards C0 (aperture A0–1) in the low-resolution grid. Figure 7b shows the ratio morphology at the intermediate resolution grid, where the regions D1 and D0 are separated into different apertures. The ratio values range from 0.334 to 2.348. The highest values here are also found in regions D1 and D0 (B2–1 and B3–1, respectively).

cleanly separates PAH populations by size while remaining far less sensitive to ionization than other common diagnostics such as 7.7/6.2 μm or 11.3/7.7 μm , establishing the 11.3 to 3.3 μm

Importantly, the 11.3/3.3 μm ratio shows a similar spatial trend to the 3.4/3.3 μm ratio in the low-resolution grid, with both C0 and D1/D0 regions displaying enhanced values (1.5–1.8) that are approximately three times higher than the minimum observed across the field, confirming the correlation between grain processing and size distribution changes.

5.3.3. Radiation field hardness

Figure 6c shows the integrated flux ratio of the 15.56 μm [Ne III] to 12.81 μm [Ne II] emission lines. The mid-IR [Ne III] to [Ne II] line ratio increases with radiation field hardness since Ne^{2+} requires photons ≥ 41 eV whereas Ne^+ forms above 22 eV (Rubin 1985). The ISO and *Spitzer* observations show that very young, high-excitation starbursts reach [Ne III]/[Ne II] ratios $\lesssim 0.5$, while evolved or metal-rich regions drop below 0.1 (Thornley et al. 2000; Pereira-Santaella et al. 2010). Photo-ionization grids translate the ratio into stellar-temperature and ionization-parameter scales for galaxies. The *JWST*/MIRI mapping now resolves sub-arcsecond peaks of [Ne III] to [Ne II] ratios at ionization fronts, confirming its reliability as a hardness tracer in HII regions (Putte et al. 2024).

Empirically, radiation field hardness has also been shown to affect PAH ratios (e.g. Sales et al. 2010; García-Bernete et al. 2022). Lai et al. (2022) found a decreasing PAH 6.2/7.7 μm ratio (also tracing dust grain size) with increasing radiation field hardness. Smith et al. (2007) found the PAH 7.7/11.3 μm ratio (tracing PAH ionization fraction) in Seyfert-like galaxies to rapidly decrease with radiation field hardness while being constant for galaxies with HII region or starburst-like optical spectra. Schroetter et al. (2024) found a decrease in the shielded PAH spectral component to that of irradiated with respect to the Habing field, probed by O I emission, when fitting to *JWST* data from the Orion bar. However, they could not distinguish whether the observed trend had a radiation field hardness parameter or not. In the Seyfert galaxy NGC 7469, Lai et al. (2023) observed an average decrease in the 3.4/3.3 μm ratio in the gap region between the star formation ring and AGNs, where the [Ne III]/[Ne II] ratio was elevated. Toward the AGN, where the highest [Ne III]/[Ne II] ratio was found, they were unable to detect 3.4 μm emission.

The [Ne III]/[Ne II] ratio across our FoV varies from 0.74 to 2.29 in the low-resolution 3×3 grid (see Table 1), estimated with a single Voigt profile post-CAFE execution. The highest value is found south of the starburst region C0 (aperture A0–0), with C0 (A0–1) having almost the same elevated value, while the lowest value is observed in the D1/D0 region containing the proposed buried AGNs (A2–1). We do not observe clear correlations of the [Ne III]/[Ne II] ratio with the 3.4/3.3 μm or 11.3/3.3 μm PAH ratios, with the latter being different from the results found by Lai et al. (2025); we discuss these results further in Section 6.

5.4. PAH ratio maps and spatial variations

The smallest SED extraction aperture is 1.5 times the FWHM of the PSF at the longest wavelength of interest to reduce undersampling artefacts below 1% (Law et al. 2023). Therefore, in order to correlate the 3.4/3.3 μm and 11.3/3.3 μm ratios, we use the intermediate resolution grid of 4×3 apertures. Figure 7b shows large variations in the 11.3/3.3 μm ratio, with the maximum value being an increase of $\sim 220\%$ compared to the minimum, while the values on the 3.4/3.3 μm map (Figure 7a) do not compare ($\sim 40\%$ increase). At this resolution, we see a correlation of high ratio values of 11.3/3.3 μm with low values of the

3.4/3.3 μm towards D1 and D0 (aperture B2–1 and B3–1). However, at the finer resolution grid in Figure 8, a few points of a significantly low 3.4/3.3 μm ratio can be identified, with values of 0.057 towards D1 (C7–3), 0.070 towards D0 (aperture C8–3), and 0.056–0.062 towards C0 (aperture C2–1 and adjacent apertures). This convolution reveals that the major contribution of low aliphatic to aromatic ratio originates from even smaller regions within the FoV. This demonstrates a critical point: while the 3.4/3.3 μm ratio shows some variation at the intermediate resolution (4×3 grid), the true extent and magnitude of the spatial variations only become apparent at high resolution, where the 10×6 grid is a step in that direction. The minimum ratio decreases from ~ 0.075 in the 3×3 grid to ~ 0.060 in the 10×6 grid, revealing that the most extreme grain processing occurs in very compact regions. This underscores the importance of spatial resolution in carbonaceous dust studies: the full range of physical variations can be significantly underestimated if the observations do not adequately resolve the source structure.

6. Discussion

6.1. Morphology and structure of II Zw 096

Although our study cannot definitively establish the presence of an AGN, the high IR luminosity observed in D1 does not refute a buried AGN scenario, where high-energy emission is absorbed by surrounding dust and re-emitted in the IR. As UV radiation from the AGN propagates through the surrounding dust, it becomes progressively absorbed, with the dust closest to the AGN experiencing the most intense processing. In irradiated environments, UV photons preferentially destroy weaker C-H bonds connected to aliphatic structures (responsible for the 3.4 μm feature) compared to those connected to aromatic structures (responsible for the 3.3 μm feature). This progressively converts aliphatic material into aromatic compounds, thereby decreasing the 3.4/3.3 μm ratio. We therefore attribute the low 3.4/3.3 μm ratio observed in this region to the highly processed dust in the immediate vicinity of the proposed AGN.

Further evidence comes from our spectral fitting, which required a crystalline silicate absorption feature at 11.1 μm to fit the 11.3 μm complex in D1. This feature, observed in environments such as YSOs, the Galactic centre (Wright et al. 2016), and ULIRGs, indicates highly processed dust, since the formation of crystalline structures requires substantial heating to overcome the energy barriers of amorphous silicates (Spoon et al. 2006). Additionally, H_2O ice is needed to fit the 3.3 and 6.2 μm complexes properly and the gas-phase rovibrational H_2O and CO are highly visible in this region (García-Bernete et al. 2024).

A similar behaviour is observed towards the starburst regions, which is to be expected as these share key similarities with the possible AGN site, namely an energetic radiation source surrounded by dense molecular material. We would expect the same processes to be visible here: UV photo-destruction of aliphatic bonds driving a shift towards a more aromatic dust composition. Regions away from D1, D0, and C0 exhibit higher 3.4/3.3 μm ratios, consistent with their greater distance from intense radiation sources, which allows C-H bonds in aliphatic compounds to survive (see Section 6.2).

In both the starburst and proposed AGN regions, it is also expected to see larger ratios of 11.3/3.3 μm , compared to the more shielded regions. Both features are attributed to aromatic structures, with the 11.3 μm feature being associated with the out-of-plane bending of the C-H bonds, as opposed to the stretching mode giving rise to the 3.3 μm feature. Variations

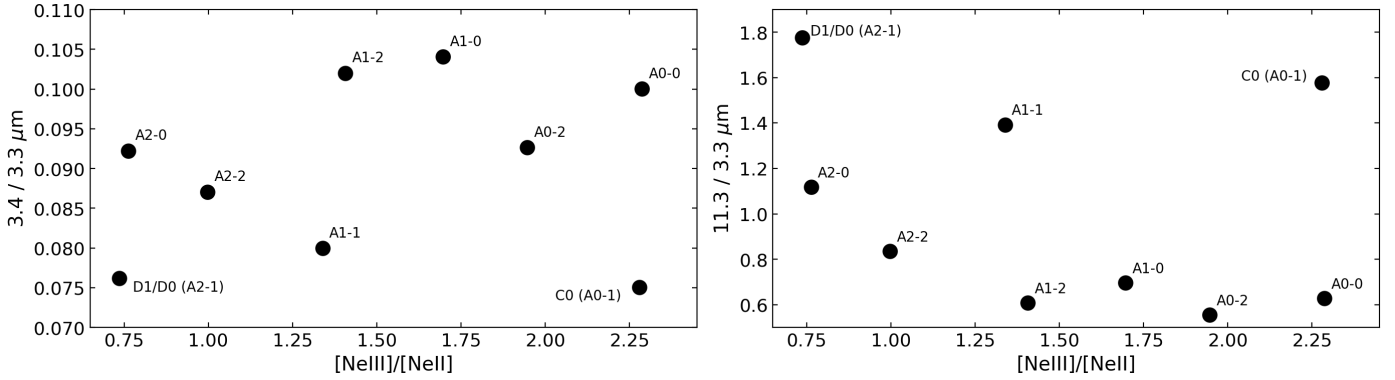


Fig. 9. Integrated feature ratios in the low-resolution grid plotted against the proxy for the radiation field hardness as probed by the [Ne III] to [Ne II] flux ratio. *Left:* 3.4 μm (3.395 and 3.403 μm sub-features) to 3.3 μm ratio show no correlation with the radiation field hardness, supported by a high P-value of 0.59 and an R^2 of 0.04. *Right:* integrated flux ratio of the 11.3 μm complex to 3.3 μm ratio as compared to the [Ne III] to [Ne II] flux ratio, also without correlation with P-value of 0.39 and R^2 of 0.11.

in this ratio likely reflect changes in the average dust size (see Section 5.3.2). The smallest dust grains in the composition are more easily destroyed by the high energy photons in these regions, while the larger grains can dissipate the energy, leading to an increase in the average size of the dust population. Larger grains excite the 11.3 μm feature more efficiently than the 3.3 μm feature, causing the 11.3/3.3 μm ratio to reflect the dust size distribution, as observed in II Zw 096.

6.2. Aliphatic to aromatic ratio (3.4/3.3 μm) in irradiated environments

We observe lower 3.4/3.3 μm ratios in regions D1, D0, and C0, consistent with the expected preferential destruction of C–H bonds in aliphatic structures in highly irradiated environments. The 3.4 μm feature is attributed to vibrations of the $-\text{CH}_3$ (methyl) and $-\text{CH}_2$ (methylene) groups in aliphatic hydrocarbons, while the 3.3 μm feature traces the C–H stretching modes associated with aromatic structures (Joblin et al. 1996; Yang et al. 2016). The variation in this ratio is indicative of dust processing in the ISM, as the C–H bonds in aliphatic structures are more fragile compared to those in aromatic structures (Lai et al. 2023). This behaviour aligns with observations: Pilleri et al. (2015) fitted photodissociation region (PDR) NGC 7023 spectra from the IRC instrument onboard *AKARI* using single component Gaussian profiles for the 3.3 and 3.4 μm complexes and plateau centred at 3.45 μm respectively. They found a linear decrease of the 3.4/3.3 μm ratio with radiation field intensity in the far-UV (G_0), and Lai et al. (2023), who used CAFE and single component Drude profiles of the same features to fit *JWST* spectroscopic data of NGC 7469, observed a 20% decrease in the 3.4/3.3 μm ratio between the star-forming ring and gap region, with ratios ranging from 5–8% in the ring, where the [Ne III]/[Ne II] ratio is elevated. This is what we would expect to see in the intense radiation environments of D1 (proposed AGN) and C0 (starburst region).

However, when examining the relationship between the 3.4/3.3 μm ratio and the radiation field hardness as traced by [Ne III]/[Ne II], we find no clear correlation (see Figure 9). Lai et al. (2023) also found the 3.4/3.3 μm ratio to show large scatter when [Ne III]/[Ne II] > 0.5, suggesting that it may not be a straightforward tracer of the radiation field relevant for PAH processing in spatially unresolved or highly obscured external galaxies, or that such diagnostic relationships may break down in

very hard radiation fields. If such a relationship exists, following Boutéraon et al. (2019), there may be continuous replenishment of aliphatic grains through fragmentation of larger, predominantly aliphatic grains at disk surfaces via photo-destruction or collisional processes, disrupting a possible correlation. The lack of correlation may be due to insufficient spatial resolution, where our apertures probe mixed PDRs and shielded regions. This is supported by the minimum 3.4/3.3 μm ratio, which increases from ~0.060 at a resolution of 0.281'' to ~0.075 at 0.961'', indicating that a finer spatial resolution than what *JWST* can provide would be needed to fully capture the relationship. Also, in very energetic environments like AGNs, the [Ne III]/[Ne II] ratio may not reliably trace the radiation field hardness. As discussed by Zhang et al. (2025), theoretical photo-ionization models predict that [Ne VI] (ionization potential 126.2 eV) becomes populated in hard radiation fields, causing the [Ne III]/[Ne II] ratio to plateau as Ne^{2+} is stripped to form Ne^{3+} . Finally, [Ne III] and [Ne II] are emitted primarily in H II regions, whereas the 3.3 and 3.4 μm bands are strongest in the transition regions of atomic hydrogen and H I to H2 in PDRs. The [Ne III]/[Ne II] ratio therefore probes a different ISM phase from the PAH bands, and the radiation field reaching the PAH-emitting material may have been substantially attenuated or spectrally modified. In this case, no direct correlation would be expected.

The comparably low [Ne III]/[Ne II] ratio in D1 could indicate partial extinction or a buried AGN. García-Bernete et al. (2024) successfully modelled the IR emission in D1 using a very compact dusty torus (~3 pc diameter at 5 μm) plus a star formation component, suggesting a highly obscured AGN that prevents direct detection. This would explain both the low [Ne III]/[Ne II] ratio and our limited success in including AGN disk components in our SED decomposition.

6.3. Dust grain size diagnostics (11.3/3.3 μm ratio)

The 11.3/3.3 μm ratio varies across II Zw 096, from 0.555 in quiescent regions to 1.776 and 1.578 in the intense radiation environments of D1 and C0, respectively (see Table 1). This indicates differences in the dust grain size distribution across the galaxy. The 11.3/3.3 μm ratio provides superior size discrimination compared to the traditional 6.2/7.7 μm ratio due to its much larger wavelength separation, with both features tracing neutral carbonaceous grains (Draine & Li 2007; Croiset et al. 2016; Lai et al. 2023). For comparison, Lai et al. (2023) used CAFE to fit

the 11.3 μm complex with three sub-features in the range 11.2–11.4 μm and found 11.3/3.3 μm ratios of 2.5 ± 0.3 in star-forming regions and 5.2 ± 1.1 near the AGN in NGC 7469. Although differences in the adopted sub-features and decomposition details mean that the comparison should be treated as indicative rather than exact, our values in II Zw 096 are lower.

The physical basis for this diagnostic lies in the different vibrational modes. Smaller grains emit preferentially at shorter wavelengths because each bond gets excited to higher vibrational levels upon UV photon absorption. The enhanced 11.3/3.3 μm ratio in D1 and C0 therefore indicates a shift towards larger average grain sizes, driven by the selective photo-destruction of the smallest grains in these intense radiation fields.

Photo-destruction of carbonaceous nano-grains occurs through dissociation of the aliphatic and olefinic bridges connecting aromatic domains. Three main processes contribute: direct dissociation, thermal (vibrational) dissociation, and Coulomb explosion (Montillaud et al. 2013; Alata et al. 2014, 2015). Studies of PDRs reveal that the critical size for grain survival increases systematically with radiation field intensity: from 0.4 nm in the diffuse ISM to ~ 0.7 nm in reflection nebula IC63, and up to ~ 0.8 nm in the Horsehead and Orion Bar (Jones et al. 2013; Schirmer et al. 2020, 2022). This sharp threshold exists because photo-destruction timescales increase dramatically with grain size. Allain et al. (1996) showed that the timescales range from 10^2 – 10^3 years for small molecules such as benzene (C_6H_6) to ovalene ($\text{C}_{32}\text{H}_{14}$), but reach $\sim 10^{10}$ years for 50-carbon molecules. Since the number of dissociable bonds scales with grain volume ($N_C \propto a^3$), this creates an effective cutoff below which grains are rapidly destroyed. The observed correlation between high 11.3/3.3 μm and low 3.4/3.3 μm ratios in these same regions indicates coherent grain processing throughout the size distribution: the intense radiation field simultaneously removes the smallest grains and depletes aliphatic content in the surviving grains.

6.4. Ice features and dust-shielding environments

The detection of the 3.1 μm H_2O ice absorption feature across regions C and D indicates substantial quantities of ice-covered dust grains, providing insight into the local radiation environment and molecular gas shielding (Whittet et al. 1988; Imanishi 2006). H_2O ice forms on dust grain surfaces in dense cold molecular clouds where temperatures drop below the sublimation point (~ 100 – 150 K) and the grains are shielded from destructive UV radiation.

The spatial distribution of ice optical depths follows an anti-correlation with the carbonaceous feature ratios, showing lower $\tau_{3.1 \mu\text{m}}$ values towards the intense radiation sources D1/D0 and C0, and higher values in more distant shielded regions. This distribution is consistent with the expected survival of ice mantles in molecular gas well shielded from UV radiation (Whittet et al. 1988). The H_2O ice sublimation temperature of ~ 150 K provides a natural boundary: regions closer to intense radiation sources experience higher dust temperatures and stronger UV fields that can photodesorb ice mantles.

Interestingly, we detect ice features even in some apertures of the more UV-exposed regions (see Figure 4), which might initially seem contradictory. However, Imanishi (2006) demonstrated that such ice survival in exposed environments can occur under two scenarios: (1) in normal starburst galaxies where stellar energy and dust are well mixed, creating a complex geometry of shielded and exposed regions, or (2) in the immediate vicinity

of highly dust-obscured AGNs where extreme column densities can provide sufficient shielding even close to the energy source.

For the buried AGN scenario in D1, the latter explanation appears more plausible. However, the presence of ice would typically be associated with strong dust absorption features and correspondingly weak carbonaceous emission, which is not observed in D1. The detection of both ice absorption and relatively strong carbonaceous emission suggests that D1 contains a complex mixture of environments: highly obscured regions where ice can survive alongside less obscured regions where carbonaceous grains are efficiently excited. This spatial complexity, which our observations cannot fully resolve, may reflect the clumpy structure of the dusty torus or the coexistence of AGN-heated and star formation regions within our aperture.

6.5. Nature of D1 as a buried AGN: Insights from other multi-wavelength tracers

The possible presence of a buried AGN in source D1 can be constrained through several indirect tracers. Notably, empirical correlations between millimetre (mm) continuum emission and hard X-ray luminosity offer a valuable diagnostic. Studies such as Ricci et al. (2023) and Kawamuro et al. (2022) have established relationships at 3 mm and 1 mm, respectively. From the available ALMA Band 3 data for II Zw 096 at $\sim 0.3''$ resolution, we measured a flux density at 100 GHz from D1 of ~ 1.2 mJy. We can then use the relations from Ricci et al. (2023) to convert the mm flux to an expected AGN luminosity of $L_{\text{AGN}} \sim 2 \times 10^{45} \text{ erg s}^{-1}$ ($\sim 5 \times 10^{11} L_{\odot}$). However, a spectral analysis using the method from Palacio et al. (2025) indicates that at these angular scales the 100 GHz flux is dominated by diffuse (free-free or synchrotron) emission, without any significant coronal (nor dust) contribution. Thus, the AGN luminosity we inferred is only an upper limit to the luminosity of the proposed AGN. In fact, such a high AGN luminosity would imply that the entire IR luminosity of II Zw 096 originates from D1, which appears implausible. Gao et al. (2025), using the broad-band SED fitting, estimate an AGN luminosity of $L_{\text{AGN}} = 2.3 \times 10^9 L_{\odot}$. However, they caution that their method is limited in its ability to recover L_{AGN} for deeply buried sources, suggesting that this estimate represents a lower limit.

Although at this stage our study cannot definitively confirm the presence of a buried AGN, the findings in this paper are consistent with this scenario. To definitively determine whether an AGN is buried within D1, more constraining observations are required in the future. Deeper X-ray imaging could yield positive results, although it is hard to predict. Alternatively, deep ALMA observations at high angular resolution ($< 0.1''$) and a densely sampled SED coverage would be required to apply the model of Palacio et al. (2025) to unambiguously disentangle the dust, free-free, and coronal synchrotron components, isolating the AGN contribution to the galaxy's luminosity at 100 GHz.

6.6. Molecular line diagnostics of obscuration

The D1 region is embedded in dense columns of gas and dust. Archival ALMA Band 7 observations reveal a tentative detection of the vibrationally excited $\text{HCN } J = 4-3, v = 1f$ transition (García-Bernete et al. 2024). Excitation of this line requires both a high mid-IR surface brightness and substantial column densities, and its luminosity relative to the total IR luminosity, $L(\text{HCN-vib } J = 4-3, 1f)/L_{\text{IR}}$, serves as a tracer of compact obscured nuclei (CONs) (e.g. Aalto et al. 2015a,b; Falstad et al. 2021). The CONs are characterized by extreme obscuration, with

hydrogen column densities $N(\text{H}_2) > 10^{25} \text{ cm}^{-2}$. In D1, we find an $L(\text{HCN-vib})/L_{\text{IR}}$ ratio that is a factor of 2–3 below the threshold typically associated with CONs. Nevertheless, the observed level implies very high column densities.

Further support for strong obscuration comes from *JWST*/MIRI observations, which reveal absorption features of HCN at $14 \mu\text{m}$ (see Appendix A, Figure A.1). A simple local thermodynamic equilibrium (LTE) fit to the primary Q -branch features yields a column density $N(\text{HCN}) = (3 \pm 1) \times 10^{15} \text{ cm}^{-2}$ and a temperature of $T = 200 \pm 100 \text{ K}$. These values likely represent lower limits, as the spectrum may include continuum emission from surrounding regions, thus diluting the absorption depth (Buiten et al. 2025). Assuming HCN abundances in the range 10^{-9} to 10^{-7} at these temperatures, the implied $N(\text{H}_2)$ falls between 3×10^{22} and $3 \times 10^{24} \text{ cm}^{-2}$. The upper end of this range is consistent with a Compton-thick source. This is also consistent with the 0.8 mm band $7 \text{ HCN } J = 4-3, v = 1f$ transition being detected in emission. Even in high temperature scenarios, this requires large $N(\text{H}_2)$ column densities approaching 10^{24} cm^{-2} (Aalto et al. 2015a,b).

Such extreme column densities suggest that any central energy source, whether a starburst or an AGN, could be dust-bounded (Abel et al. 2009). In this regime, UV photons are absorbed by dust before they can ionize the surrounding gas. This effect is especially critical for a buried AGN, where the UV radiation may never escape the nuclear region. In this scenario, the AGN becomes nearly invisible in traditional diagnostics, contributing only to the IR luminosity and to millimetre-wavelength synchrotron emission. This underscores the diagnostic importance of millimetre synchrotron measurements for identifying deeply buried AGNs.

7. Conclusions

In this study, we applied the Continuum and Feature Extraction tool (CAFE) to *JWST* NIRSpec IFU and MIRI MRS observations of the merger galaxy II Zw 096, focusing on regions C and D near the merger centre. We significantly extended the CAFE feature library by implementing 61 carbonaceous emission features from the PDRs4all project (grouped in 17 complexes), including six sub-features for the $3.4 \mu\text{m}$ aliphatic complex and six for the $11.3 \mu\text{m}$ aromatic complex. Additionally, we incorporated crystalline silicate absorption features at 9.2 and $11.1 \mu\text{m}$, alongside current absorption features for H_2O ice (3.1 and $6.1 \mu\text{m}$), CO_2 ice ($4.27 \mu\text{m}$), and the broad $9.7 \mu\text{m}$ silicate feature. We developed a modified SED fitting procedure with parallel processing and three-stage fitting to handle the significant spectral variations across the FoV. Our spectral decomposition successfully fitted the complex SEDs.

We mapped the spatial distribution of carbonaceous feature ratios at three different resolutions: $0.961''$, $0.787''$, and $0.281''$ (3×3 , 4×3 , and 10×6 grids) to trace dust composition and grain-size variations. The $3.4/3.3 \mu\text{m}$ ratio, which probes aliphatic versus aromatic content, shows a significant variation from 0.056 to 0.148 , with the lowest values found at the proposed buried AGN location D1 (aperture C7–4) and starburst regions C0 and D0. This indicates preferential destruction of weaker C–H bonds connected to aliphatic structures in these highly irradiated environments. The $11.3/3.3 \mu\text{m}$ ratio, which is a diagnostic of grain-size distribution, varies from 0.334 to 2.348 , with the highest values at D1 (aperture B3–1).

We find no correlation between the radiation field hardness traced by $[\text{Ne III}]/[\text{Ne II}]$ and either of the two carbonaceous

ratios ($3.4/3.3 \mu\text{m}$ and $11.3/3.3 \mu\text{m}$). The $[\text{Ne III}]/[\text{Ne II}]$ ratio varies from 0.74 to 2.29 , with counterintuitively low values at the proposed AGN and starburst regions. This may indicate that $[\text{Ne III}]/[\text{Ne II}]$ is not a reliable diagnostic in these extreme environments, possibly due to the population of higher ionization states ($[\text{Ne IV}]$), differential extinction effects, spatial structures not resolved, or $[\text{Ne II}]$ and $[\text{Ne III}]$ not probing the same regions in the ISM as the origin of the bulk PAH emission.

Critically, the dynamic range of the $3.4/3.3 \mu\text{m}$ ratio increases with spatial resolution: the minimum value decreases from ~ 0.075 at $0.961''$ resolution (3×3 grid) to ~ 0.060 at $0.281''$ resolution (10×6 grid). This demonstrates that apparent uniformity in carbonaceous ratios at low resolution does not indicate absence of variation but rather insufficient spatial resolution to resolve the compact regions where dust processing occurs. Even our highest resolution ($0.281''$ apertures) may not fully capture the true extent of the variation.

We detect H_2O ice absorption at 3.1 and $6.1 \mu\text{m}$ across the FoV, with optical depths $\tau_{3.1}$ ranging from 0.09 to 0.39 , with the $3.1 \mu\text{m}$ feature showing an anti-correlation with carbonaceous ratios. The $3.1 \mu\text{m}$ H_2O ice feature is below mean towards D1/D0 and C0, consistent with sublimation in these intense radiation environments; the $6.1 \mu\text{m}$ feature shows less correlation with other features. The presence of crystalline silicate features at 9.25 and $11.1 \mu\text{m}$, particularly prominent in D1, provides additional evidence for highly processed dust. CO_2 ice at $4.27 \mu\text{m}$ and broad silicate absorption at $9.7 \mu\text{m}$ ($\tau_{9.7} = 0.51-1.20$) are detected throughout, indicating significant dust column densities.

These *JWST* observations reveal spatial variations in dust properties across II Zw 096, with regions D1, D0, and C0 showing clear signatures of intense dust processing. The coherent behaviour of multiple diagnostics (low $3.4/3.3$, high $11.3/3.3 \mu\text{m}$, weak ice features, crystalline silicates) strongly supports the presence of extreme radiation sources in these locations. The proposed buried AGN in D1 remains consistent with our observations, though not definitively proven.

This work demonstrates the critical importance of high spatial resolution for dust diagnostics in complex environments. The factor of two increase in the dynamic range between our lowest- and highest-resolution observations implies that even finer spatial sampling would reveal more extreme variations. Future observations with higher angular resolution ALMA data, deeper X-ray imaging, and radio continuum measurements will be essential to definitively characterize the nature of D1 and fully map the dust processing in this merger system.

Data availability

Extracted spectra and model fits to apertures in Figure 3 are available at the CDS via <https://cdsarc.cds.unistra.fr/viz-bin/cat/J/A+A/714/A43>. Model fits are also available on Zenodo via <https://doi.org/10.5281/zenodo.20591408>.

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Appendix A: Mid-infrared HCN spectrum

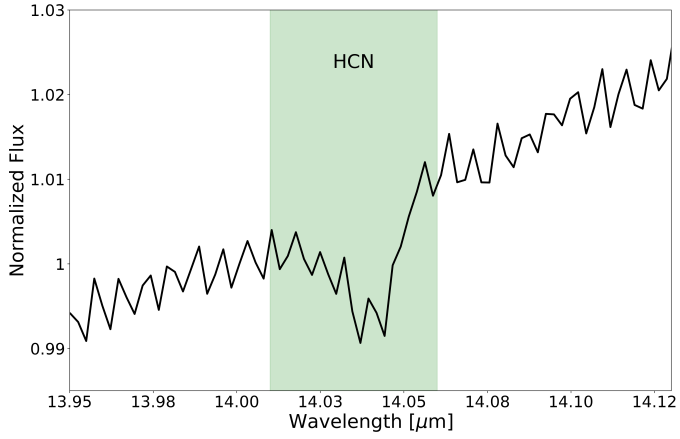


Fig. A.1: Mid-infrared spectrum (black line) normalized at 14 μm of detected HCN absorption feature (shaded). Extracted from data convolved with a kernel size corresponding to [Ne III] using a circular aperture with diameter of 0.89'', centered at D1.