Dust modeling at the edge of the Horsehead PDR

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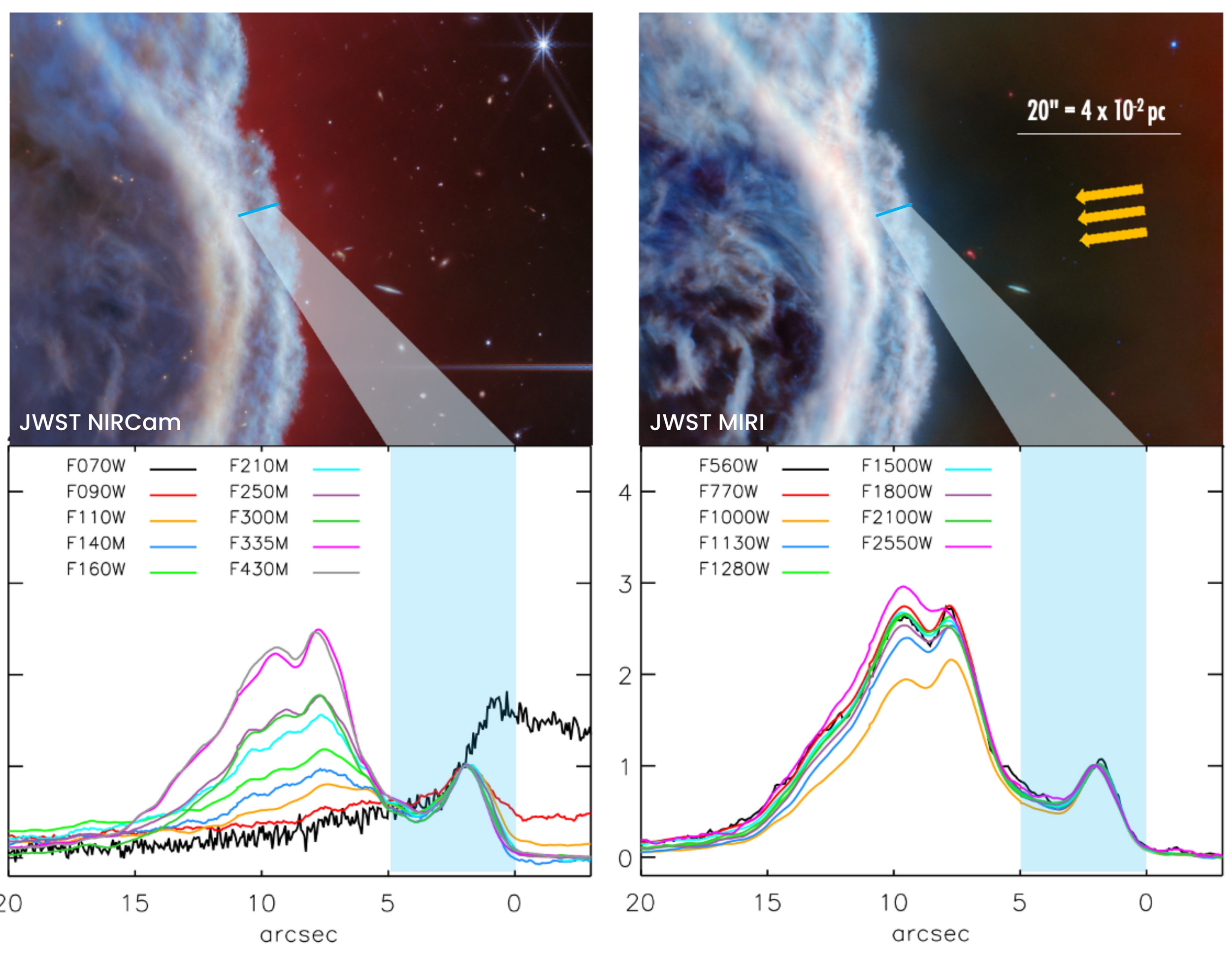
Elyajouri et al., 2025, accepted in A&A

INTRODUCTION

Context. Photodissociation regions (PDRs) are ideal laboratories for studying dust evolution. This work is conducted as part of the **Physics and Chemistry of PDR Fronts** program dedicated to the study of dust and gas in the Horesehead and NGC 7023 with the James Webb Space Telescope (JWST). The Horsehead Nebula **(~400 pc, edge-on)** is an excellent PDR template for moderately excited PDRs **(with G_0 ~ 100).**

Aim. We study the evolution of the nano-grains across the illuminated edge of the Horsehead PDR and especially their abundance and size properties. Using unprecedented JWST observations, we seek to understand the mechanisms driving nano-grain formation and destruction in this region.



Top: (Left) NIRCam composite (1.4–4.7 µm). (Right) MIRI composite (5.6–25 µm). Blue lines show the cut analyzed in this study. *Credits: NASA, ESA, CSA, K. Misselt (U. Arizona), A. Abergel (IAS, U. Paris-Saclay).*

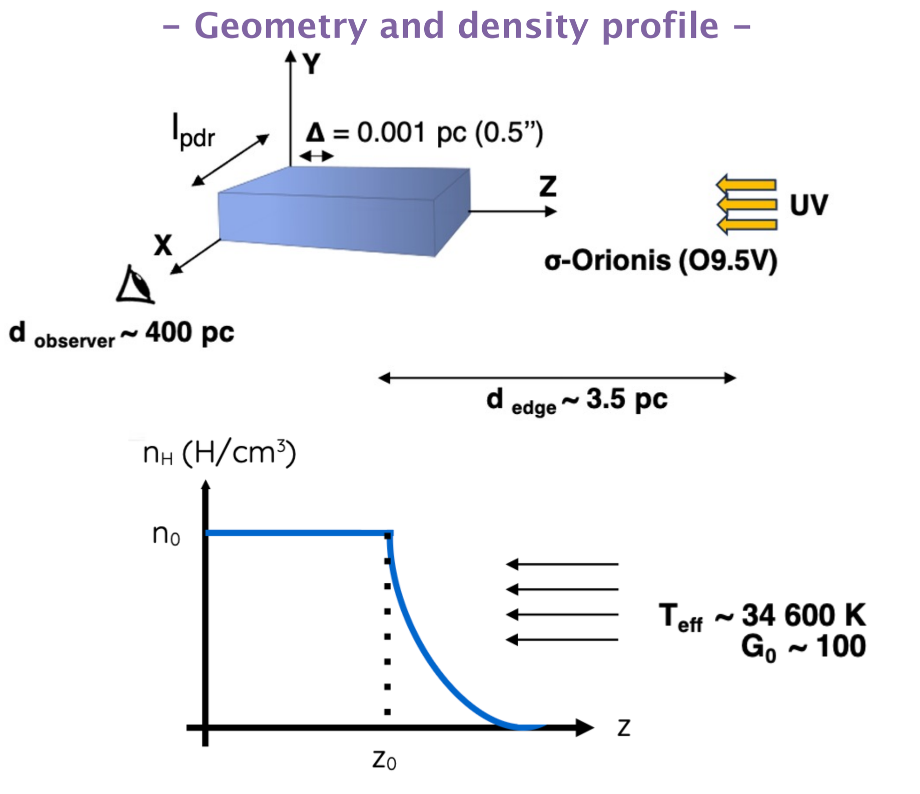
Bottom: Emission profiles (normalized at 2" from edge) for NIRCam and MIRI filters along the cut. *Adapted from Abergel, A., et al., 2024, 687, A4*

OBSERVATIONS & METHODS

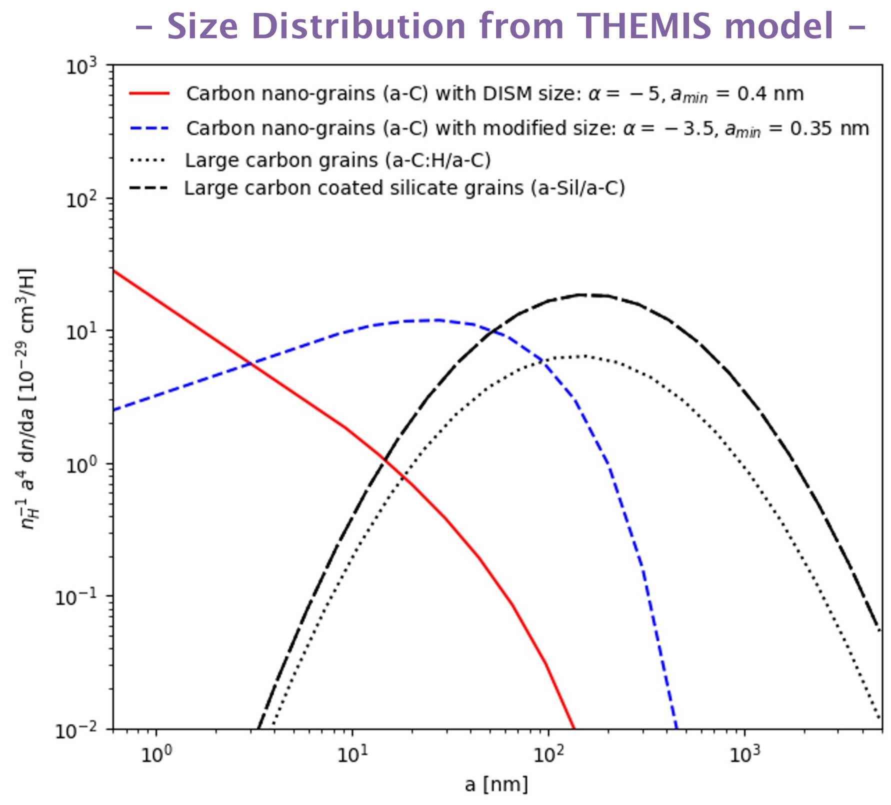
Data: NIRCam (3.0–4.3µm) + MIRI (5.6–25.5µm) imaging and NIRSpec+MRS spectroscopy of the illuminated edge (Abergel et al. 2024; Misselt et al. 2025).

Modeling: Same methodology as in Elyajouri et al. (2024)
THEMIS dust model (Jones et al. 2013, 2017) + DustEM (Compiegne et al. 2010) + SOC 3D radiative transfer (Juvela 2019).

– Geometry and density profile –

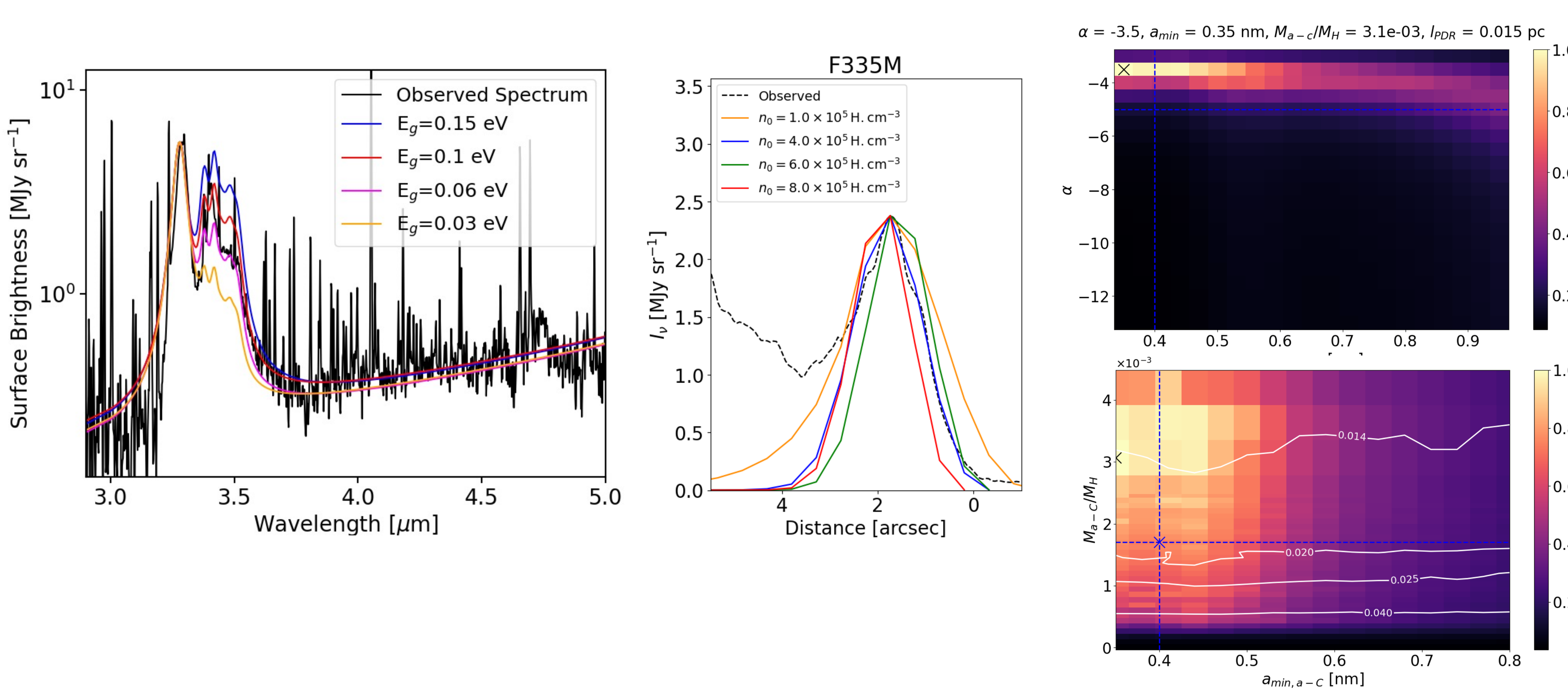


– Size Distribution from THEMIS model –



→ **Free parameters:** PDR length (lpdr), density parameters (n_0, z_0), nano-grain abundance ($M_{a\text{-}C}/M_H$), minimum size (amin), size distribution slope (α)

Approach:
Step 1 -> Hydrogenation (Eg) from 3.3/3.4 µm ratio (NIRSpec)
Step 2 -> Density profile (n_0, z_0) from emission FWHM (photometry)
Step 3 -> Nano-grain properties (amin, α, $M_{a\text{-}C}/M_H$) via grid modeling



MAIN RESULTS

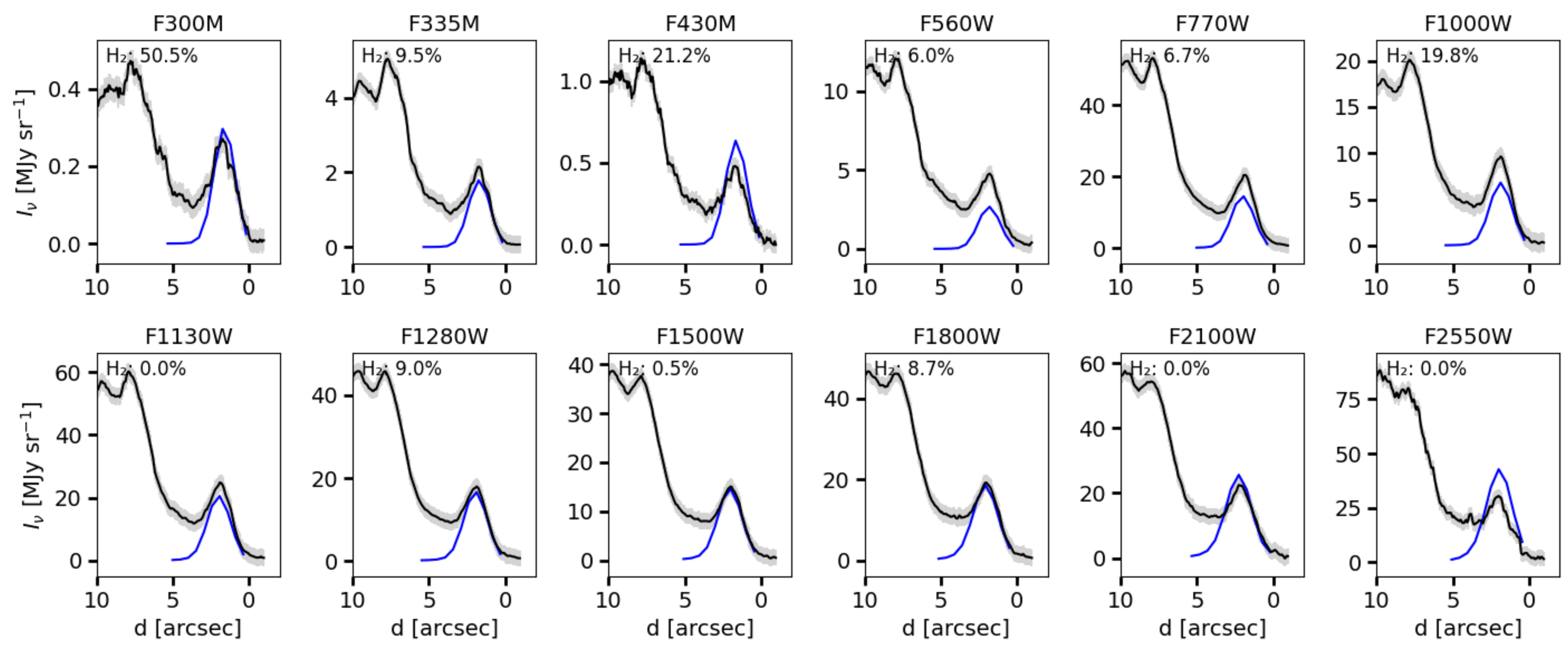
✓ High density: $n_0 = (4\pm1)\times10^5$ H cm^{-3}; $z_0 = (7\pm1)\times10^{-3}$ pc
→ Sharp transition (<650 AU) between molecular/ionized gas

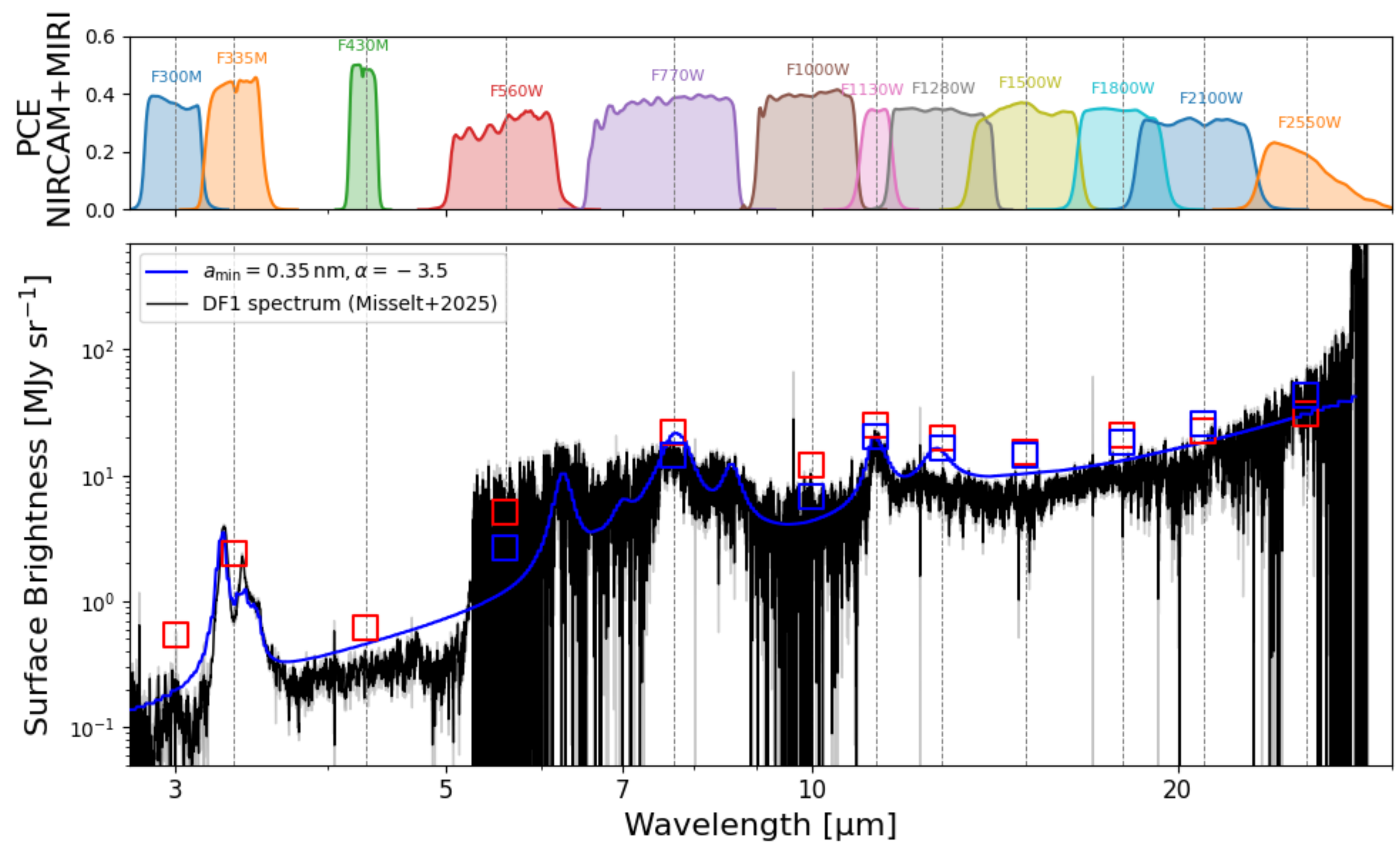
✓ No dehydrogenation: E_g = 0.1 eV (same as diffuse ISM)
→ Requires G_0 > 100 for noticeable dehydrogenation

✓ Modified size distribution:

- a_{min} = 0.35–0.45 nm (DISM: 0.4 nm)
- α = −3.5 (less steep than DISM: α = −5)

✓ No depletion: $M_{a\text{-}C}/M_H$ > 0.003 (DISM: 1.7×10^{-3})
→ Unlike Orion Bar (15× depletion; Elyajouri et al. 2024)





Comparison of JWST data with SOC + THEMIS models:
Top: Observed (black) vs. modeled (blue) dust emission across 12 photometric bands (NIRCam: 3.0, 3.3, 4.8 µm; MIRI: 7.7–25.5 µm). Gray: errors. Blue line (Fig.1): cut location. Middle: Wavelength coverage and PCE of NIRCam and MIRI filters. Bottom: Model SED at AIB peak (blue squares) vs. NIRSpec+MRS spectrum (black) for DF1 region. Red squares: photometric band maxima. *Full spectrum from Misselt et al. (2025).*

CONCLUSION

- We have investigated the dust emission by comparing model predictions with JWST/NIRCaM-MIRI imaging, and NIRspec-MRS spectroscopic observations.
- We focussed on the illuminated edge of the Horsehead nebula, a highly irradiated dense PDR. We used radiative transfer modelling to investigate the spatial distribution of the dust emission along a cut through the Horsehead PDR and compute the emerging spectrum. We firstly examined the spectrum and then the spatial variations in all used filters at the PDR edge.
- Our findings indicate a high-density environment and a less steep size distribution for nano-grains at the illuminated edge, in contrast with the diffuse ISM. This implies that nano-grain destruction mechanisms, such as UV-induced destruction, might be less efficient in the Horsehead low-UV field than in PDRs with more intense radiation, like the Orion Bar.
- These results support a model where nano-grain population recovery, potentially through fragmentation of larger grains, is slower in moderate-UV environments, revealing a unique dust evolution signature at the Horsehead edge.