Resolving polar dust in AGN with JWST: going beyond the PSF

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1. Abstract

The launch of the James Webb Space Telescope (JWST) promises to revolutionize infrared astronomy and our understanding of outflows in active galactic nuclei (AGN). Our approved Cycle 1 program, will use JWST's exquisite low surface brightness sensitivity in the mid-infrared (MIR; 8-25 μm) to observe the diffuse polar dust emission found in AGN with unprecedented sensitivity. Relying on JWST's stable PSF, we will use four deconvolution techniques (see §4) to establish the structure of this diffuse emission below the resolution of the telescope. To explore these techniques, we have used MIRISim to simulate JWST's complex PSF applied on a model of an AGN consisting of a resolved biconical structure and an unresolved AGN point source. Here we report on our assessment of the optimum deconvolution strategy, based on comparisons of the flux conservation, FWHM, and Strehl ratios of the deconvolved images with the input model. Our work aims to connect the observations of high-resolution MIR imagers on large ground-based telescopes (i.e., the Thirty Meter Telescope) with the much higher sensitivity JWST observations.

2. Background

Supermassive black holes (SMBH), and the outflows they drive, are an established part of our understanding of galaxy evolution. In the unified model of AGN (Antonucci 1993; Urry & Padovanni 1995), the central engine consists of a hot accretion disk orbiting a SMBH, surrounded by a geometrically and optically thick torus of gas and dust. The torus, on parsec (pc)-scales in the equatorial plane, can obscure the accretion disk and Broad emission Line Region (BLR) and absorbs a large fraction of the accretion disk radiation, which is then dominantly re-emitted from infrared (IR) to millimeter (mm) wavelengths. The torus is the main component of the obscuration of the central engine from edge-on lines of sight and was thought to be the main source of MIR emission in AGN. However, recent interferometric observations of several AGN have shown that the MIR emission shows a strong polar-extended component within the central pc-scales accounting for more than half of the total MIR emission (e.g., López-Gonzaga et al. 2016), complicating torus model studies. The emerging paradigm is the torus is the central structure in a gas flow cycle whereupon some material is accreted to the SMBH and some is driven out in a dusty wind (Hönig 2019).

We now have a multitude of different phenomenological torus models that might account for this emission but are lacking the observational data to test these models further. The Galactic Activity, Torus and Outflow Survey (GATOS; https://gatos.strw.leidenuniv.nl/index.html) collaboration has been awarded prime science time with JWST as part of an approved cycle 1 general observers (GO 2064) proposal to find evidence that this extended polar emission is fundamentally connected to the pc-scale dusty wind.

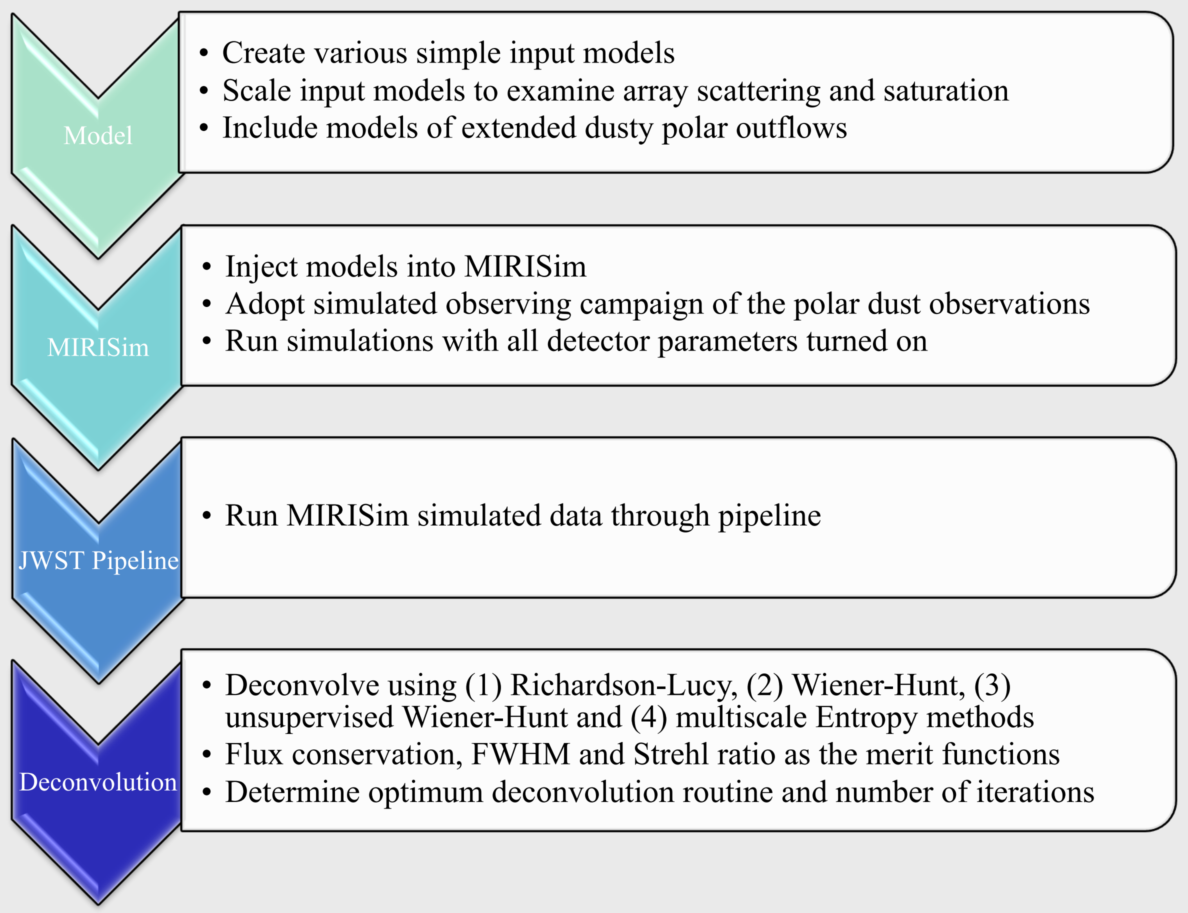
3. Motivation

The JWST Mid-Infrared Instrument (MIRI) has been chosen to make our observations based on our desire for the highest surface brightness sensitivity possible over an area corresponding to the central kpcs (10s of arscec) of our targets (Rosario et al. 2021). Five filterbands were chosen to avoid the strong and complex contamination in the Polycyclic Aromatic Hydrocarbon (PAH) bands, while sampling silicate-sensitive absorption and emission features.

The high sensitivity of JWST MIRI should reveal the characteristics of this polar dust structure. Simulations have shown that deconvolution techniques (e.g., Stalevski et al. 2017) could reveal this polar dust structure below the resolution of the telescope (~0".07 at 2 μm; Milam et al. 2015). Our work aims to find the optimum deconvolution method to find low surface brightness emission within the complex JWST point spread function (PSF). ***Fig. 1*** displays the JWST PSF from the telescope only, observed at the wavelengths of MIRI.

4. Study Design

The stable JWST image quality compared to ground observations requires careful attention when searching for low surface brightness features. We've created several simple models, emphasizing different components of the AGN, building towards our model of a resolved biconical structure and an unresolved AGN point source. To test how the complex JWST PSF will affect our models and deconvolution results, we used MIRISim (Klaassen et al. 2020) to simulate test observations. We outline the study design we have adopted for this work below:



5. Results

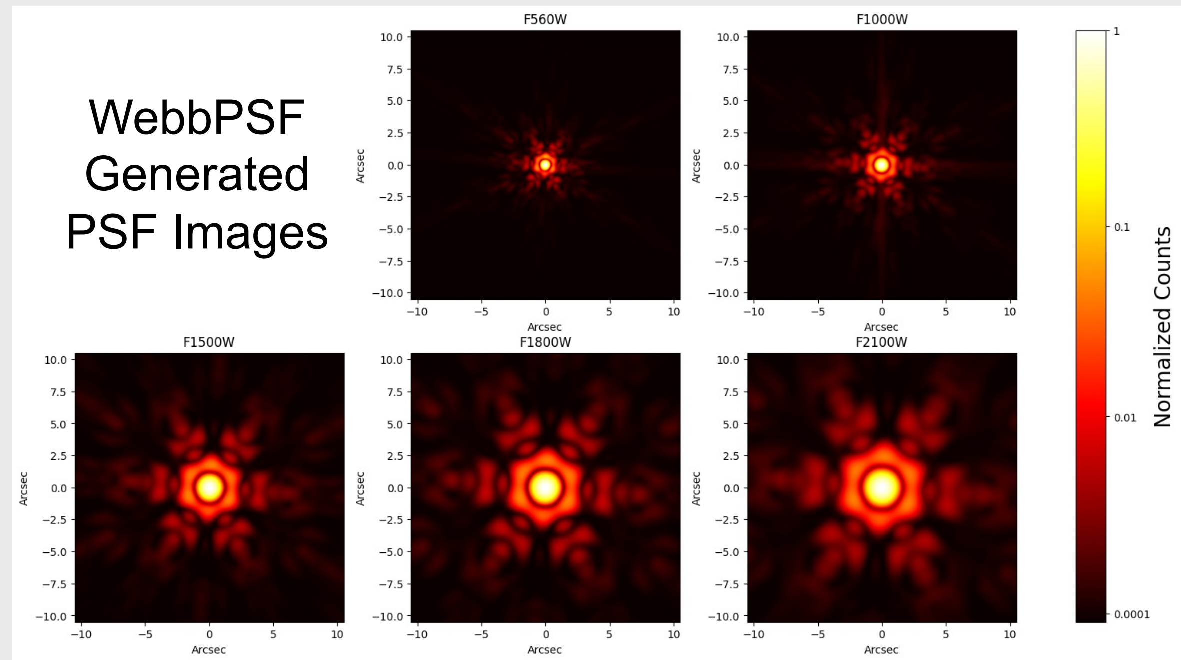


Fig. 1: The JWST PSF from the telescope only, simulated at the wavelengths of MIRI, generated by WebbPSF (Perrin et al. 2012). Each PSF image is 512 x 512 pixels (~20" on a side) and normalized to the peak pixel value. The titles correspond to the wavelength of each filter (e.g., F560W is the filter centered at 5.6 μm).

To understand what additional instrumental effects will be introduced to our simple models, we began by injecting a single pixel, with known flux value, into MIRISim and conducted simulated observations at all five wavebands of our planned observations (Rosario et al. 2021). The results are displayed in ***Fig. 2***.

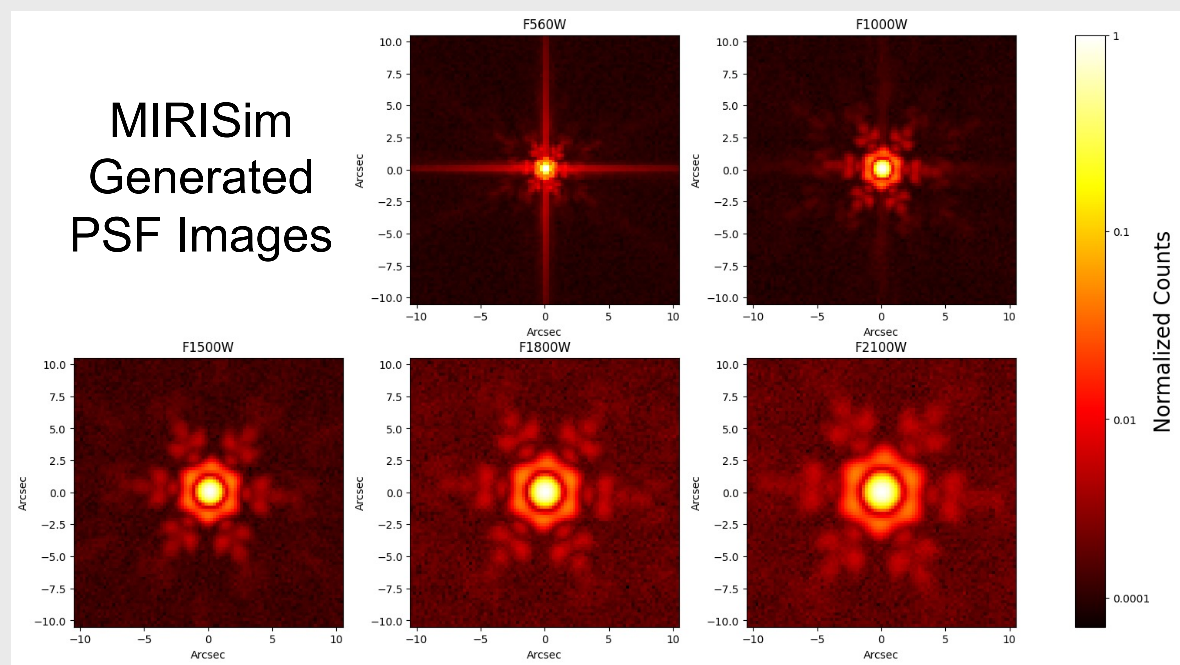


Fig. 2: The JWST PSF generated by MIRISim. Each PSF image is 128 x 128 pixels (~20" on a side), normalized to the peak pixel and utilizes the same title naming convention as ***Fig. 1***. Simulations were conducted utilizing the SUB256 array configuration.

6. Early Results

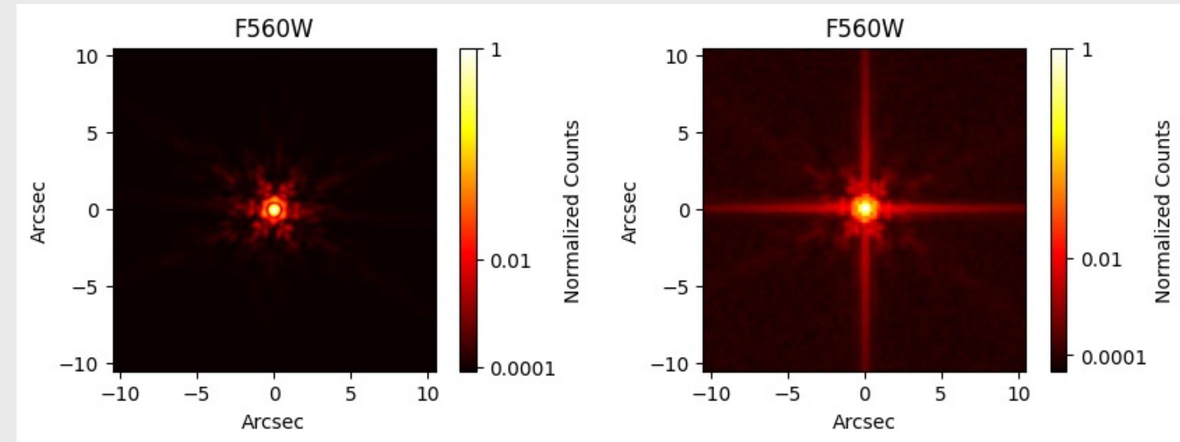


Fig. 3: (Left) the JWST PSF from the telescope only, simulated at 5.6 μm using WebbPSF. (Right) the JWST PSF from MIRI, simulated at 5.6 μm using MIRISim.

A clear "cross-hair" image effect is observed when introducing instrumental effects caused by MIRI, highlighted in ***Fig. 3***. This cross-hair artifact is attributed as internal reflective diffraction within the detector only, observed at < 10 μm, which disappear at longer (> 10 μm) wavelengths (Gáspár et al. 2020) .

7. Conclusions

This poster reports our current progress, our search for the optimum deconvolution method (see §4) that could reveal low surface brightness structures in AGN below the resolution of JWST is ongoing. As we move into the 30-m era, diffraction limited observations afforded by extreme adaptive optics (ExAO) systems (and PSF reconstruction from those ExAO systems) will become typical. Thus, with the complex PSFs expected by those telescopes (e.g., Nikutta et al. 2021) deconvolution algorithms are likely to become more commonly used and important to investigate low-surface brightness features.

8. References

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