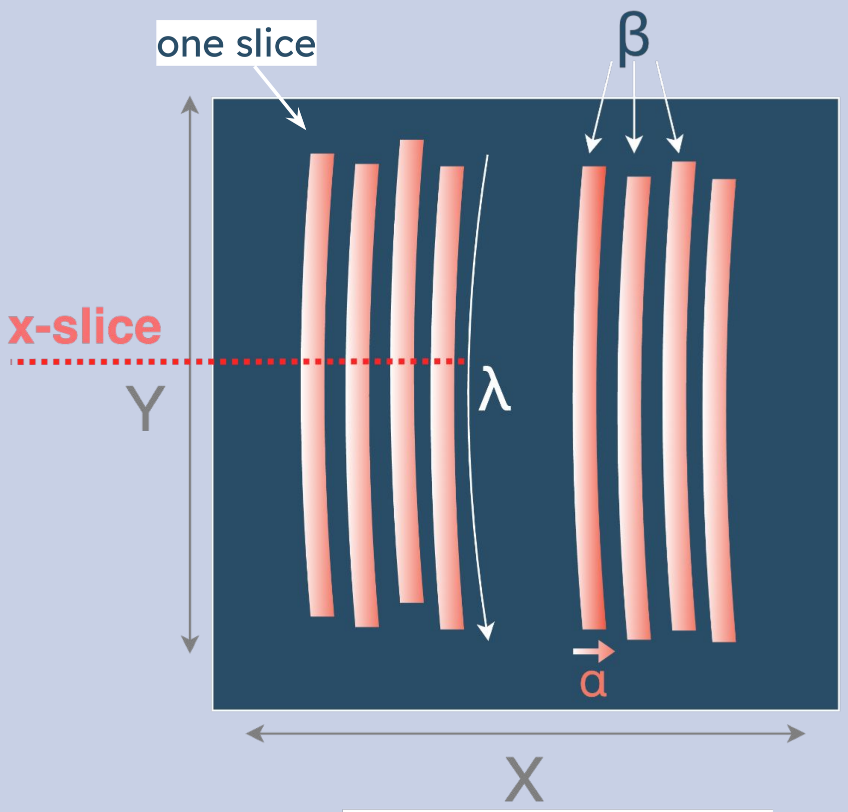
S.Juillard, D.Gasman, I.Argyriou, V.Christiaens and O.Absil

JWST/MIRI MEDIUM RESOLUTION SPECTROMETER (MRS)

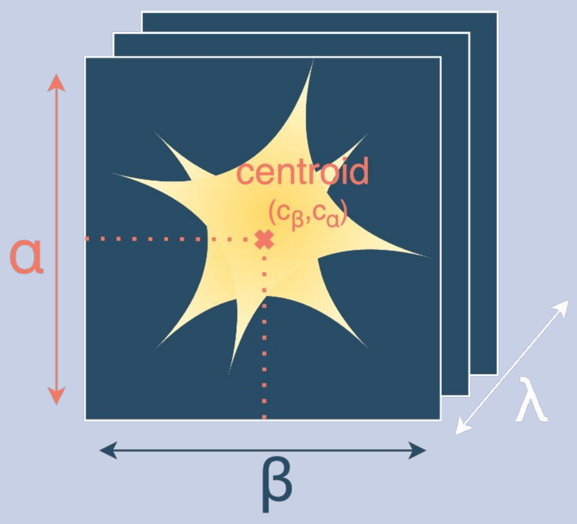
PSF SUBTRACTION IN THE DETECTOR PLANE

The Instrument

The MRS Integral Field Units (IFUs) divide the field of view into multiple spatial slices, each capturing a portion of the scene. To obtain the final spectral cube of the scene, data from all these slices must be aligned, combined, and interpolated.



Detector plan



Spectral cube (interpolated)

PSF subtraction - Reaching photon noise limit

Why PSF subtraction in the detector plane ?

The idea is to perform PSF subtraction before 3D interpolation of the undersampled science point cloud to avoid blurring of information. In addition for CH1/2, scattered light spreads across the slices and is spatially correlated in the detector plane. Hence, modeling the PSF at this stage ensures a better capture of the scattered light profile by avoiding non-representative model fits. Such detector based PSF subtraction allows to do detector based spectral extraction.

Required pre-processing

To reach the photon noise limit and accurately match references with science, it is necessary to properly take into account effects such as the **Brighter-Fatter Effect and fringe correction.** These steps have been addressed by the work of Danny Gasman (Gasman+ 2024, Gasman+ 2025, submitted).

This project requires a particular dither mosaic for the references which is used in the programme PID 3779 (PI : Danny).

Presentation of the method step-by-step

INTERPOLATE THE POINT CLOUD

For the CH3/4 : There is not much scattered light between slices. We use all the dithers and perform interpolation and rescaling in alpha/beta point cloud. We obtain $f_{\text{psf-model}}(\alpha, \beta)$

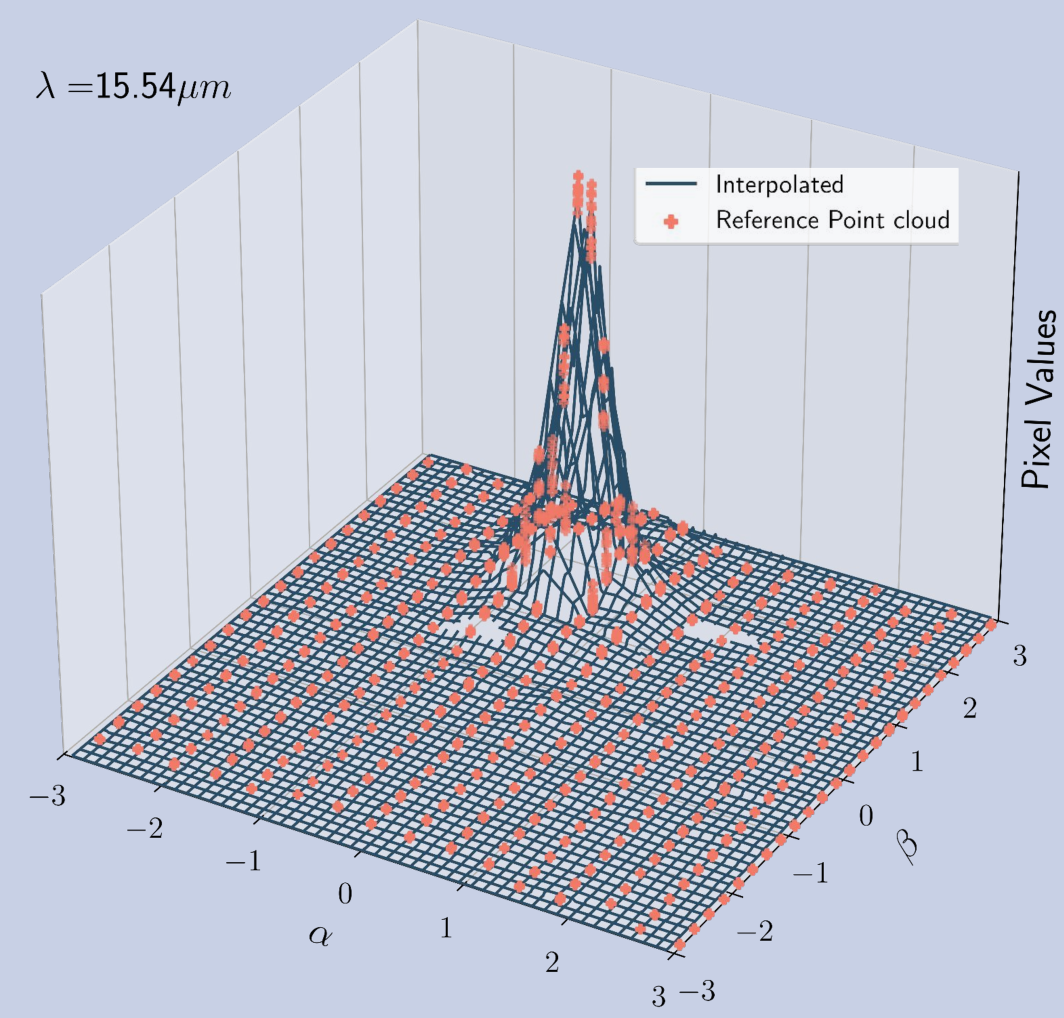


Fig. 1: Example of the 3D point cloud of reference dithers (image pla)for a given λ and the interpolated function, shown as a wireframe.

For the CH1/2 : There is significant amount of scattered light spilling in between slices. Interpolation and rescaling are in X, Y point cloud. We obtain $f_{\text{psf-model}}(X, Y)$

From the pattern of dither, we select two rows of 3 dithers with similar beta-displacement.

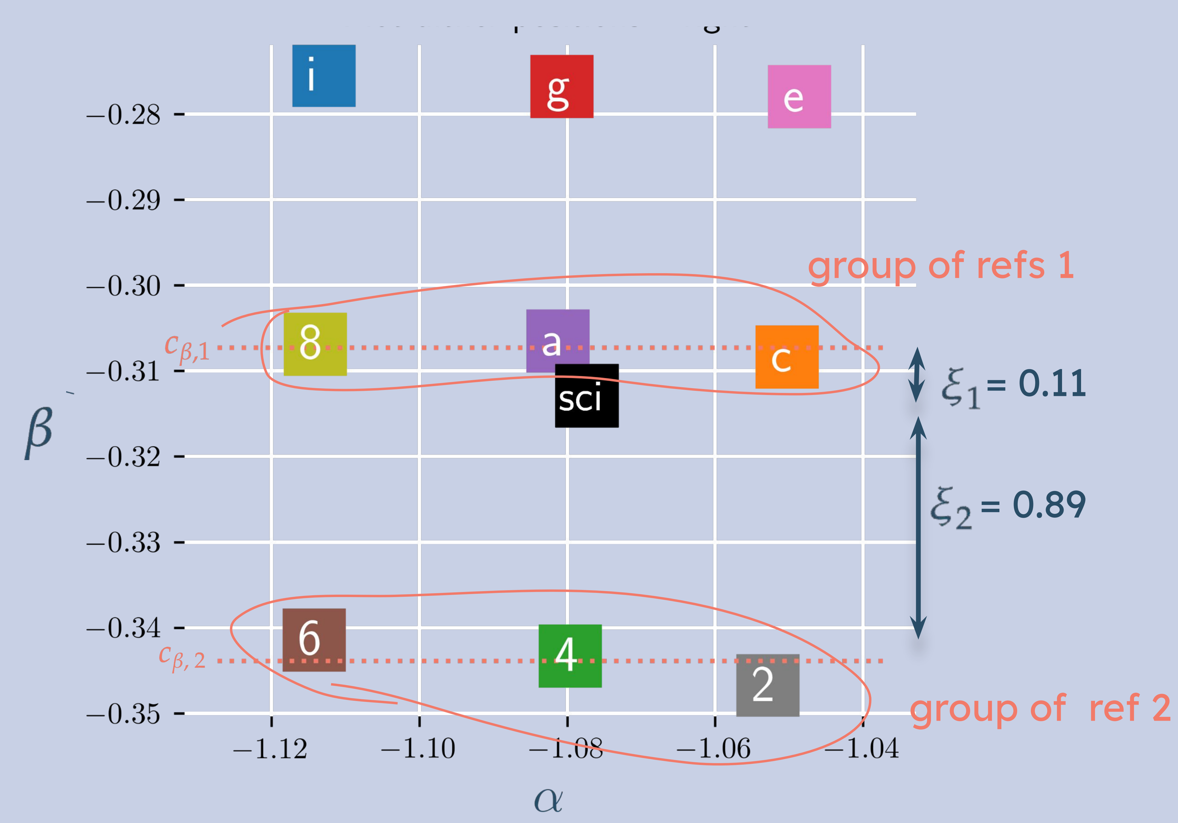


Fig. 2: Centroid positions of the references (colored) compared to the science frame (black).

We interpolate each of these row separately to obtain two model PSF.

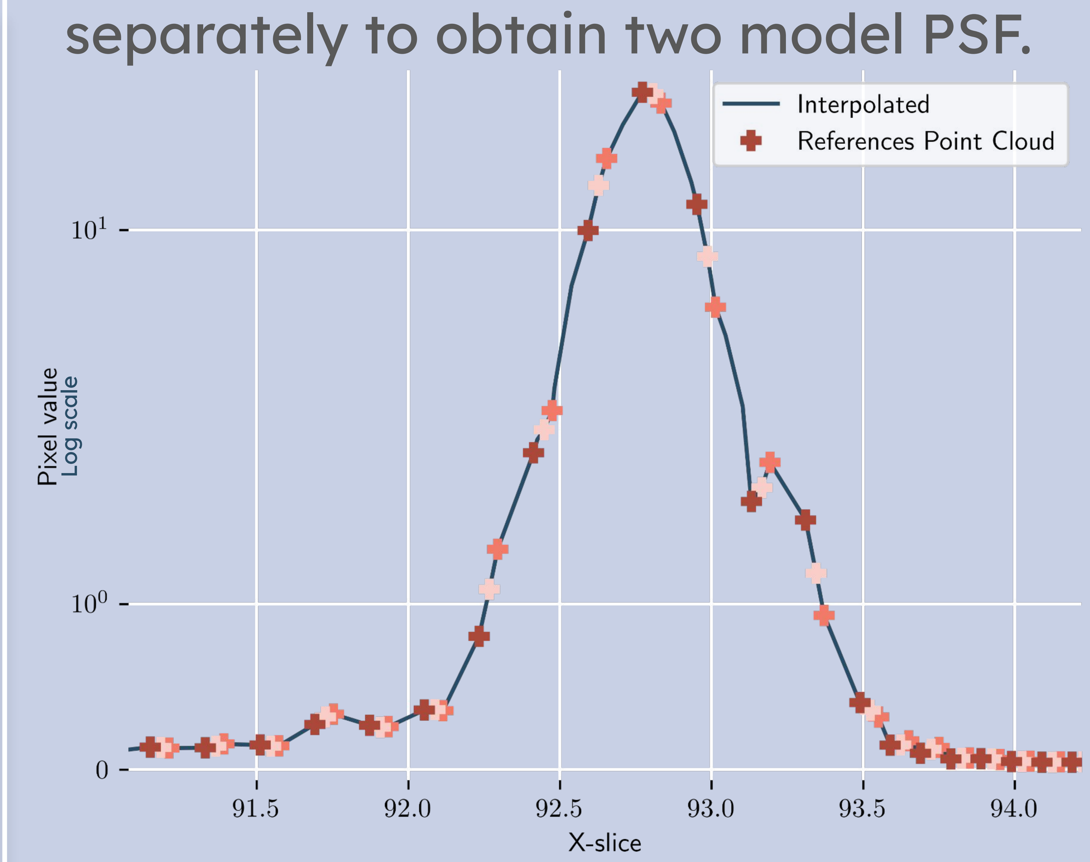


Fig. 3: X-slice (detector plane) of the references group point cloud and the interpolated function computed over 3k points. Different shades are used to differentiate the dithers.

Then we combine the two model such as :

$$f_{\text{psf-model}} = \xi_1 \times f_{\text{refs 1}} + \xi_2 \times f_{\text{refs2}}$$

$$\text{with } \xi_1 = \frac{\| c_{\beta,\,\text{sci}} - c_{\beta,1} \|}{\| c_{\beta,2} - c_{\beta,1} \|}$$

$c_{\beta,\alpha}$ being the beta centroid of the reference group/science target.

RESCALE AND SUBTRACT THE MODEL

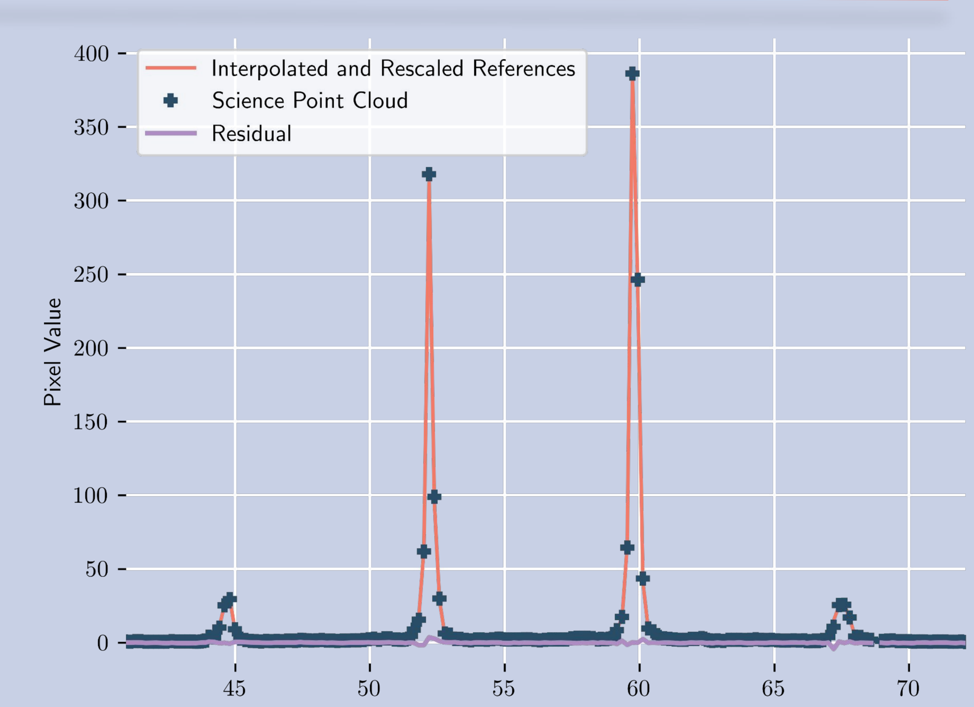
For CH1/2, we assess one rescaling factor per X-slice to account for the intensity difference across λ-slices. For CH3/4, one factor is found in the image plane (α, β). The scaling factors As determined via:

$$\underset{A_Y \in \mathbb{R}^{n,+} \setminus \{0\}}{\operatorname{argmin}} \left[I_{sci} - A_Y \times f_{\text{psf-model}}(X, Y) \right]$$

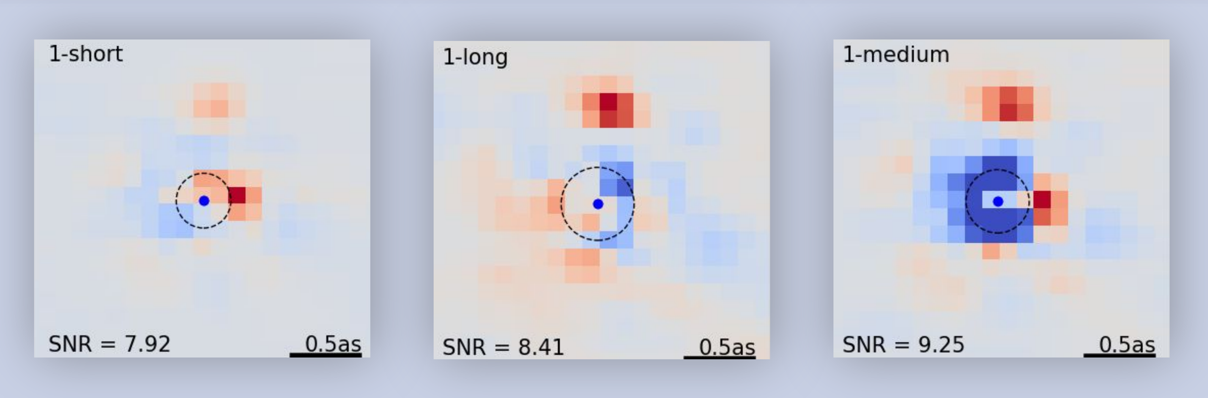
where I_{sci} is the image in the detector plane and A_Y a vector of size n corresponding to I_{sci} height in pixels.

Our results shows that we can subtract >95% of the stellar PSF.

Fig. 4: X-slice of the detector plane showing the science point cloud (individual dither), the interpolated and rescaled PSF model, and the residual after subtraction from the science data.



Results



We applied our PSF-subtraction method to a dataset of GQ Lup, recently published by Gabriele Cugno (2024). (Gabriele is giving a talk on Friday.)