The spectral calibration of JWST/NIRSpec: results from ISIM/CV3

G. Giardino, N. Lützgendorf, P. Ferruit, B. Dorner, C. Alves de Oliveira, S. M. Birkmann, T. Boeker, T. Rawle, M. Sirianni

ATG Europe – ESA – MPIA Heidelberg

INTRODUCTION

The NIRSpec instrument of JWST can be operated in multi-object (MOS), long-slit, and integral field mode (IFU) with spectral resolutions from 100 to 2700. Its MOS mode uses about a quarter of a million individually addressable mini-slits for object selection, covering a field of view of ~ 9 square-arcminute.

The core element of the spectral and spatial calibration of NIRSpec is the instrument parametric model (Fig. 1) which captures the geometrical and optical properties of the instrument and provides the transformations to follow the path of the light entering NIRSpec [1].

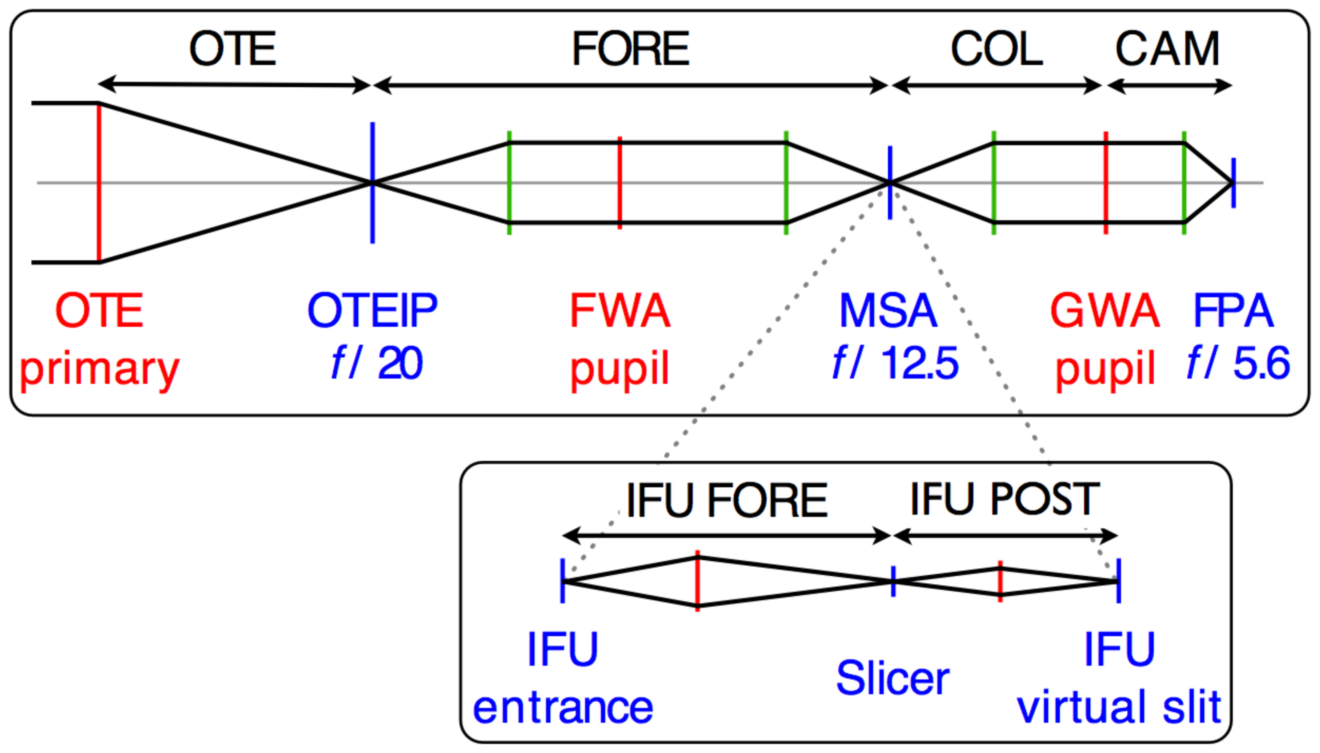

Fig. 1 Paraxial layout of the JWST telescope and NIRSpec optical train with elements at principal planes, and the insert for the IFU case. All these elements are encapsulated in the NIRSpec parametric model. See Dorner et al. [1] for more detail.

The model transformations underpin our pipeline, NIPS (NIRSpec Instrument Pipeline Software), that we use to extract wavelength-calibrated spectra from NIRSpec detector count-rate images. We have developed a procedure that uses the calibration data acquired for a limited subset of the NIRSpec modes - and in particular only 1.5% of NIRSpec's a quarter of a million slits - to fine-tune the parameters of the instrument model

By enabling the extraction of wavelength calibrated spectra from any of the ≈ 250 000 slitlets, the model-based pipeline greatly improves the efficiency with which NIRSpec can be operated.

Matching calibration exposures for each individual slit and each disperser are no longer needed

METHODS

The principle underlying the model optimization consists in adjusting the many model parameters to minimize the distance between the model-computed and the measured location of a set of spectral lines and aperture images (the reference data), in the NIRSpec main optical planes.

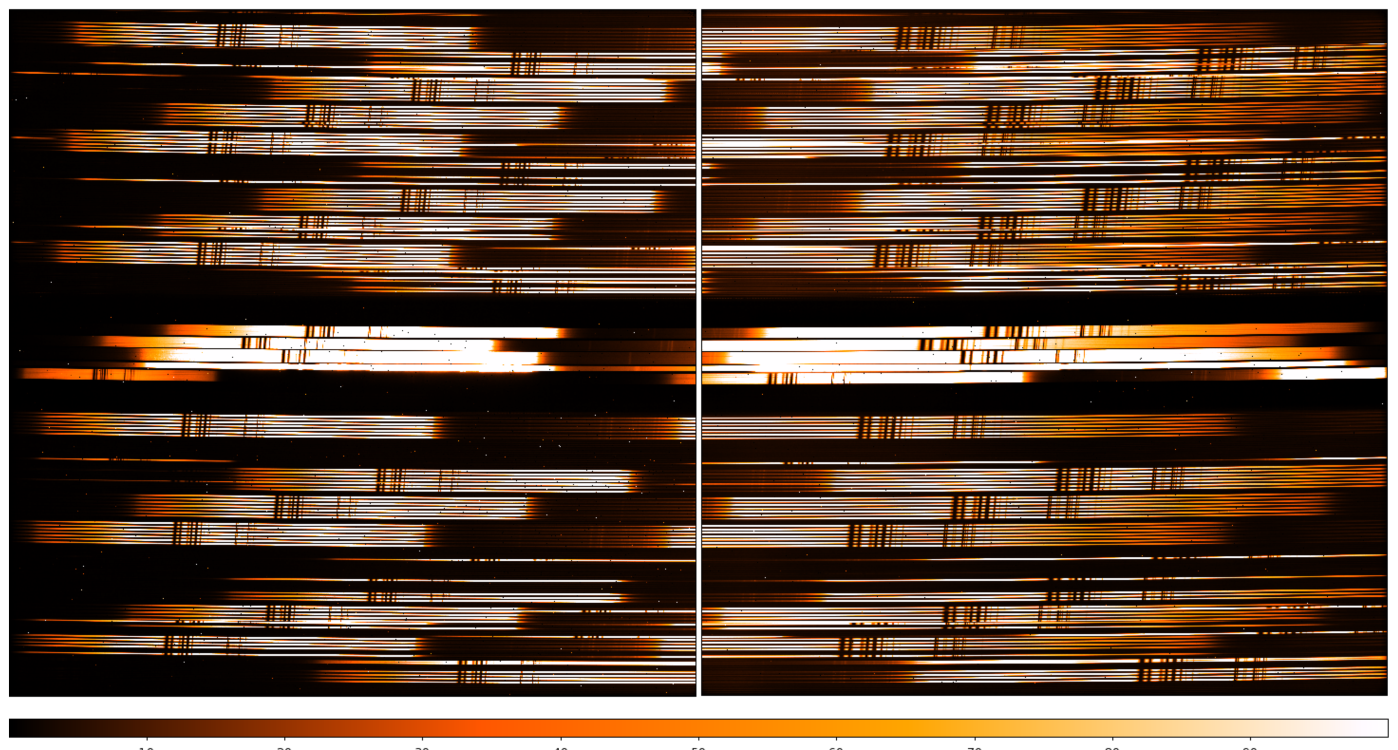

Fig. 2 Example of the exposures acquired by NIRSpec during ISIM/CV3 (see [2]) that we used to build the reference database to be used for the model optimization. In this case the internal REF lamp, dispersed using the high-resolution Band-III grating illuminated the fixed slits (at the center) and the MSA, where approximately 140 micro-shutters were open. The detector positions of this source's absorption features provide the reference points for the model optimization

- 6,000 reference points from imaging exposures
(focal-plane positions of micro shutter images)
- 20,000 reference points from spectral exposures
(focal-plane positions of spectral lines – absorption and emission features of NIRSpec internal calibration sources)

Optimization of model parameters (a_i) – 309 free parameters
Minimization of distance between model computed (f) and measured positions of reference points (y)

$$R^2 \equiv \sum [y_i - f(x_i, a_1, a_2, \ldots, a_n)]^2 \qquad \frac{\partial(R^2)}{\partial a_i} = 0$$

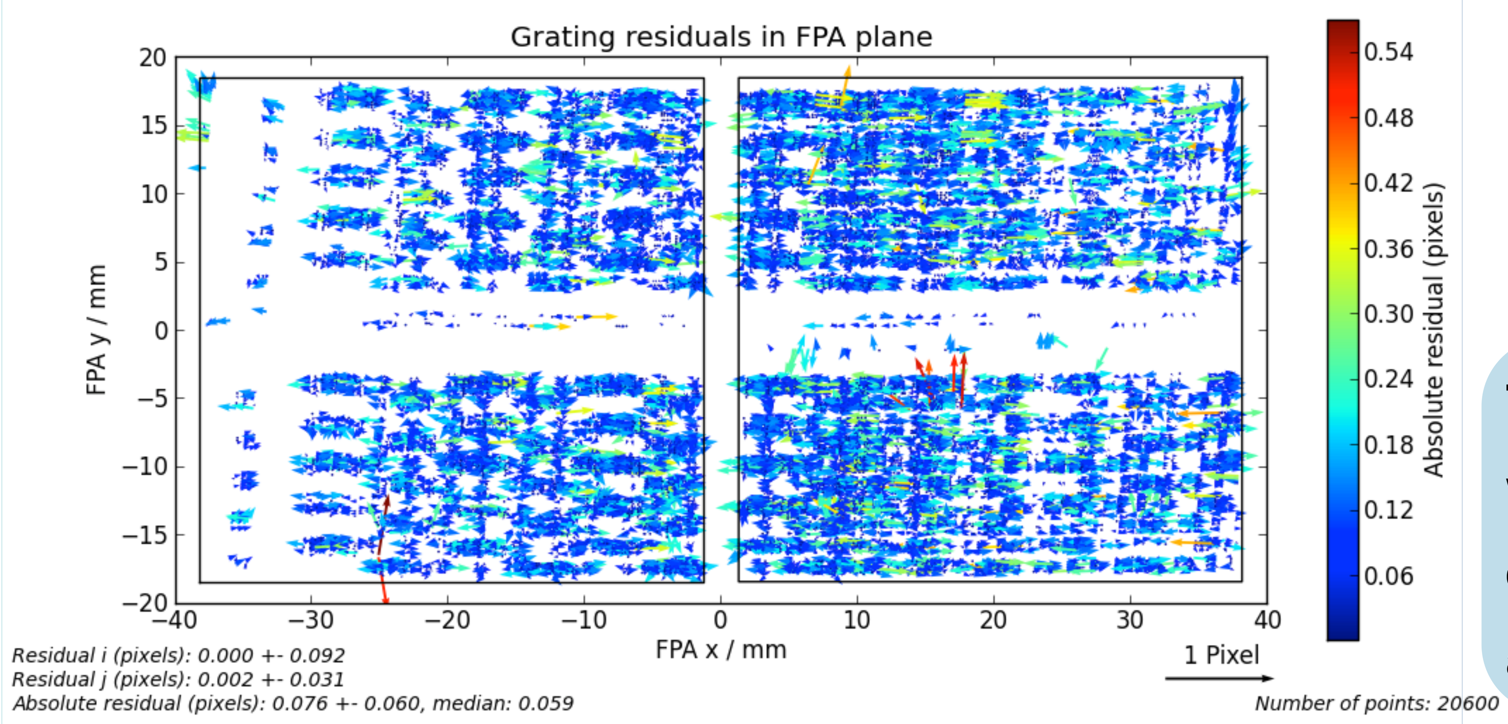

Fig. 3 Residuals between measured and model-computed location of the reference points at the focal plane for all 6 gratings, after optimization of the model parameters

RESULTS

With the model fully optimized one can now evaluate the accuracy of the model wavelength calibration by looking at the residuals between the "true" wavelength of the reference lines and their values as measured in NIRSpec spectra, extracted using our model based pipeline (Table 1).

	Residual [pixel]		
Disperser	SLIT	MOS	IFU
G140H	0.042 ± 0.047	-0.005 ± 0.083	-0.019 ± 0.046
G235H	0.033 ± 0.051	-0.011 ± 0.097	-0.073 ± 0.049
G395H	0.043 ± 0.080	0.007 ± 0.095	-0.010 ± 0.068
G140M	0.018 ± 0.052	0.004 ± 0.102	-0.041 ± 0.061
G235M	0.035 ± 0.046	-0.003 ± 0.075	-0.072 ± 0.042
G395M	-0.009 ± 0.070	-0.014 ± 0.073	-0.058 ± 0.064
PRISM	-0.003 ± 0.061	-0.006 ± 0.135	-0.075 ± 0.134

Table 1. Residuals between the 'true' wavelengths of the lines of NIRSpec internal sources and the same lines as measured in NIRSpec spectra (1D) extracted using the optimized parametric model. The values are average and RMS of the difference between the two quantities, over many lines.

In terms of wavelength calibration, the residuals (1-σ) RMS of the model are at the level of 1/10 of a pixel or better, for all the grating modes, corresponding to a wavelength calibration accuracy of at least 1/20 of a resolution element. This is two times better than the formal error allocation of 1/10 of a resolution element (RMS) specified for this step in the overall wavelength calibration budget of NIRSpec. For the prism, the model accuracy is at the level of a 1/14 of a resolution element, also well within the requirements.

CONCLUSIONS

Using data acquired at ISIM-CV3[2], we have successfully carried out the first and most crucial aspect of the NIRSpec wavelength calibration strategy:

the optimization of the instrument parametric model

The model transforms allow us to compute the spatial and wavelength positioning of the spectra with an accuracy far exceeding the formal requirements, for all of the instrument apertures and spectral modes.

REFERENCES

1. Dorner, Giardino, Ferruit et al., A&A Accepted (arXiv:1606.05640).
2. Kimble, Vila, Van Campen et al. This SPIE Conference, 2016

Want to know more about NIRSpec?
Visit our website: http://www.cosmos.esa.int/jwst or scan the QR code ➔