European Space Agency

Model based approach to the calibration of JWST/NIRSPEC
- spatial and spectral calibration

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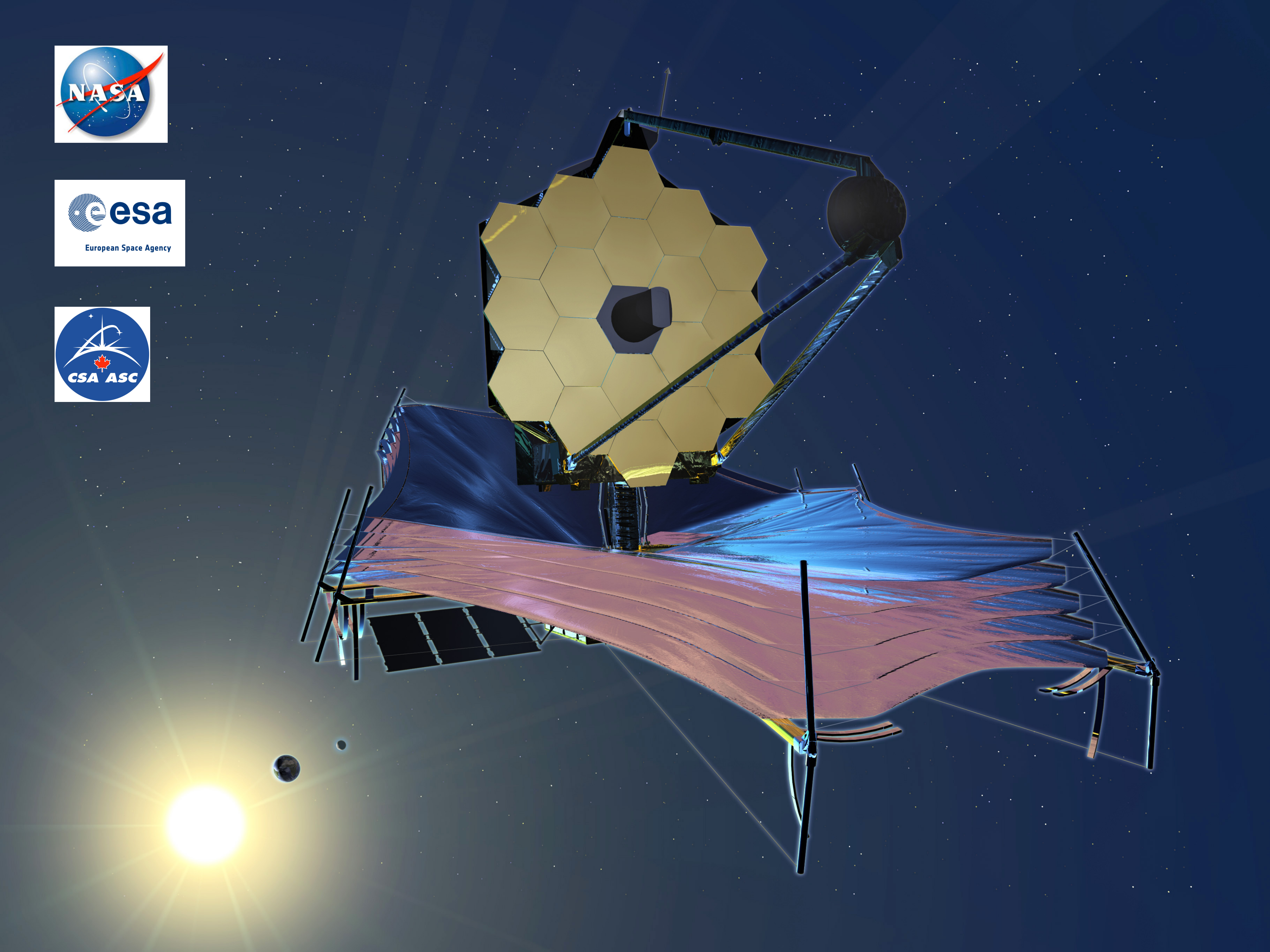
ESAC - 2016 EUCLID PHOTOMETRIC CALIBRATION WORKSHOP

Outline

- What is NIRSpec parametric model
- Why a model based approach to calibration?
- How do we adjust the model parameters to match the data from the instrument?
  - What calibration accuracy we have achieved?
- Why this could be relevant for the Euclid mission?


NASA
esa
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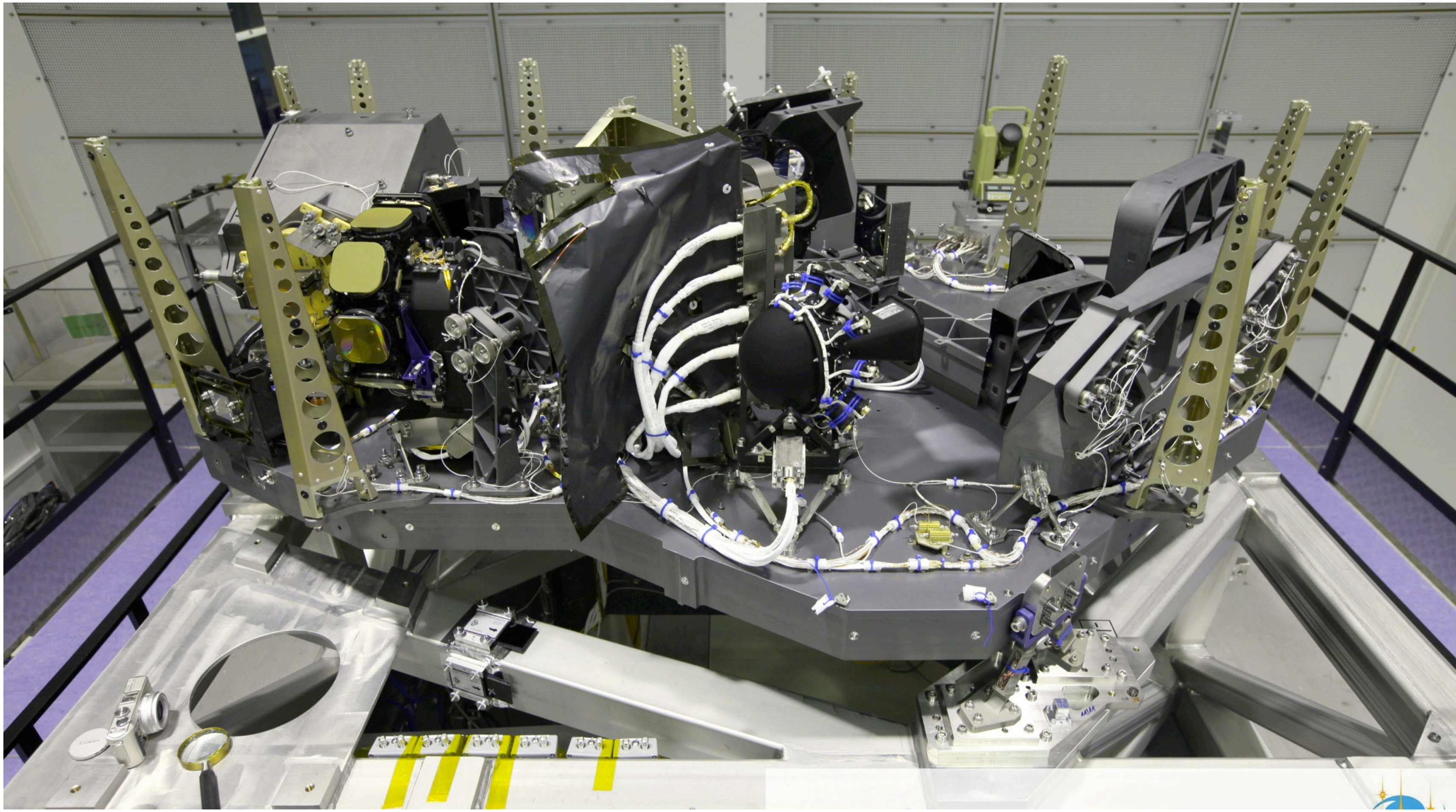
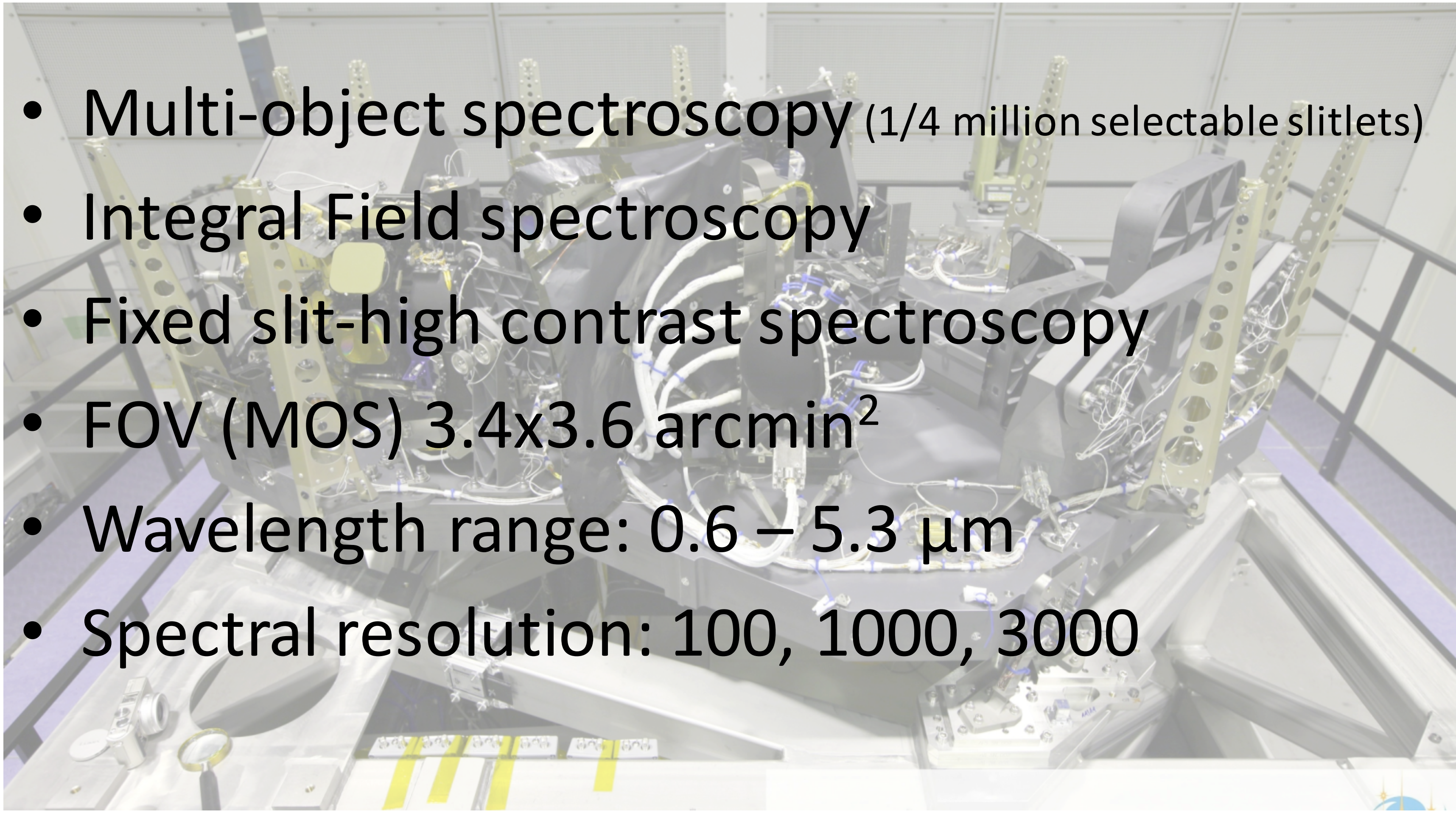
NIRSpec



NIRSpec flight model in November 2012 at the end of its integration at Airbus (Ottobrunn site), before undergoing an extensive test and calibration campaign in 2013

NIRSpec in a nutshell



- Multi-object spectroscopy (1/4 million selectable slitlets)
- Integral Field spectroscopy
- Fixed slit-high contrast spectroscopy
- FOV (MOS) 3.4x3.6 $arcmin^2$
- Wavelength range: 0.6 – 5.3 µm
- Spectral resolution: 100, 1000, 3000

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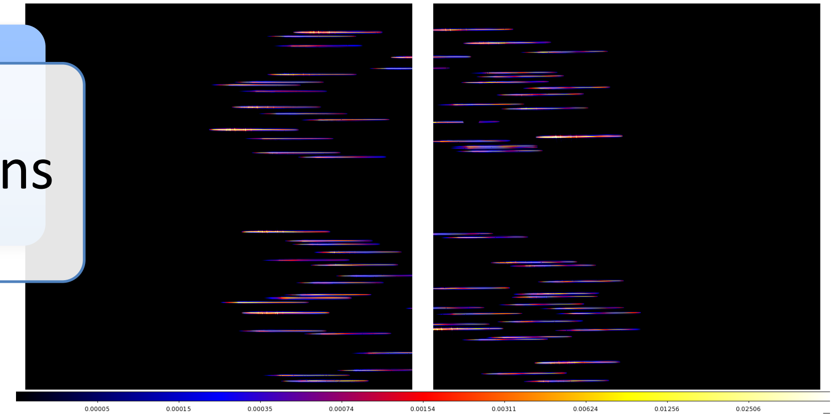
- Spectral resolution: 100, 1000, 30

Swiss-army knife of Near-IR spectroscopy

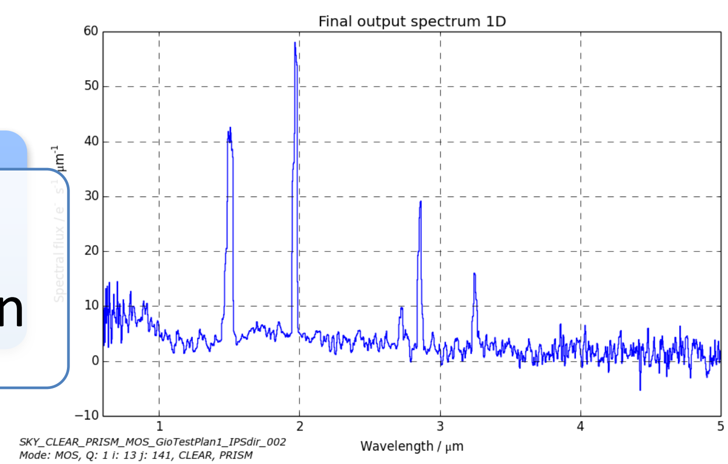
NIRSpec parametric model

Parametric model

Simulations

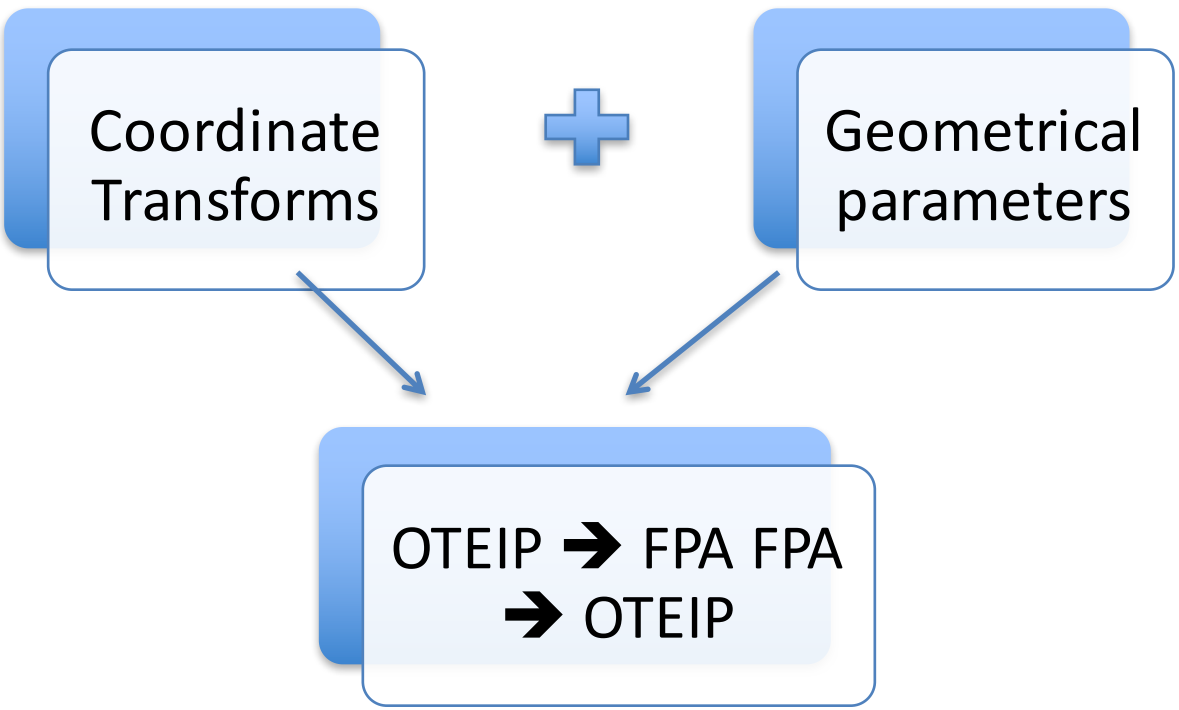


Spectral calibration



What is NIRSpec parametric model?

(optical geometry part)



What is NIRSpec parametric model?

(optical geometry part)

Coordinate Transforms + Geometrical parameters

+ telescope coordinate transform

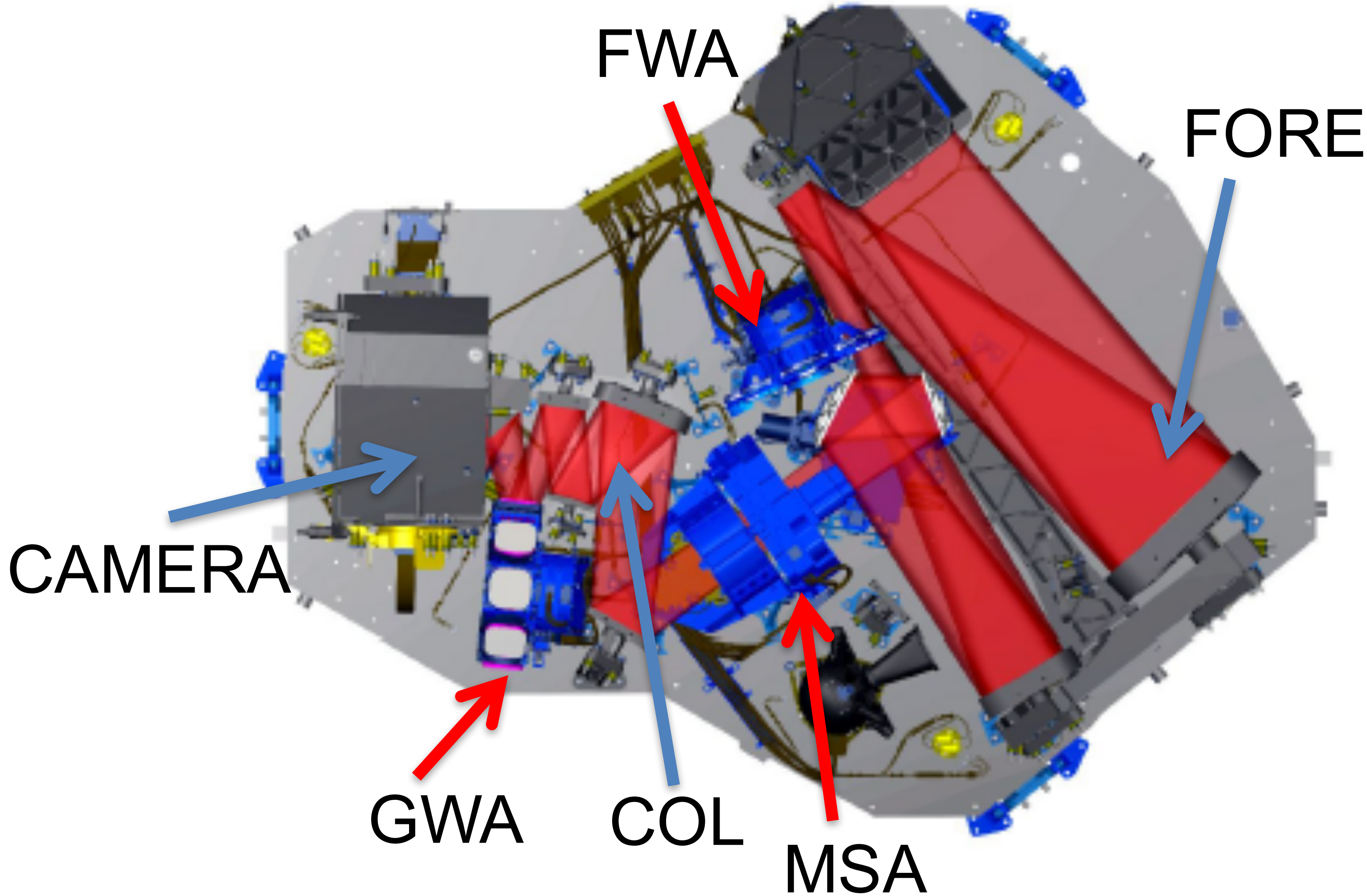
SKY → FPA

FPA → SKY

→ Simulations

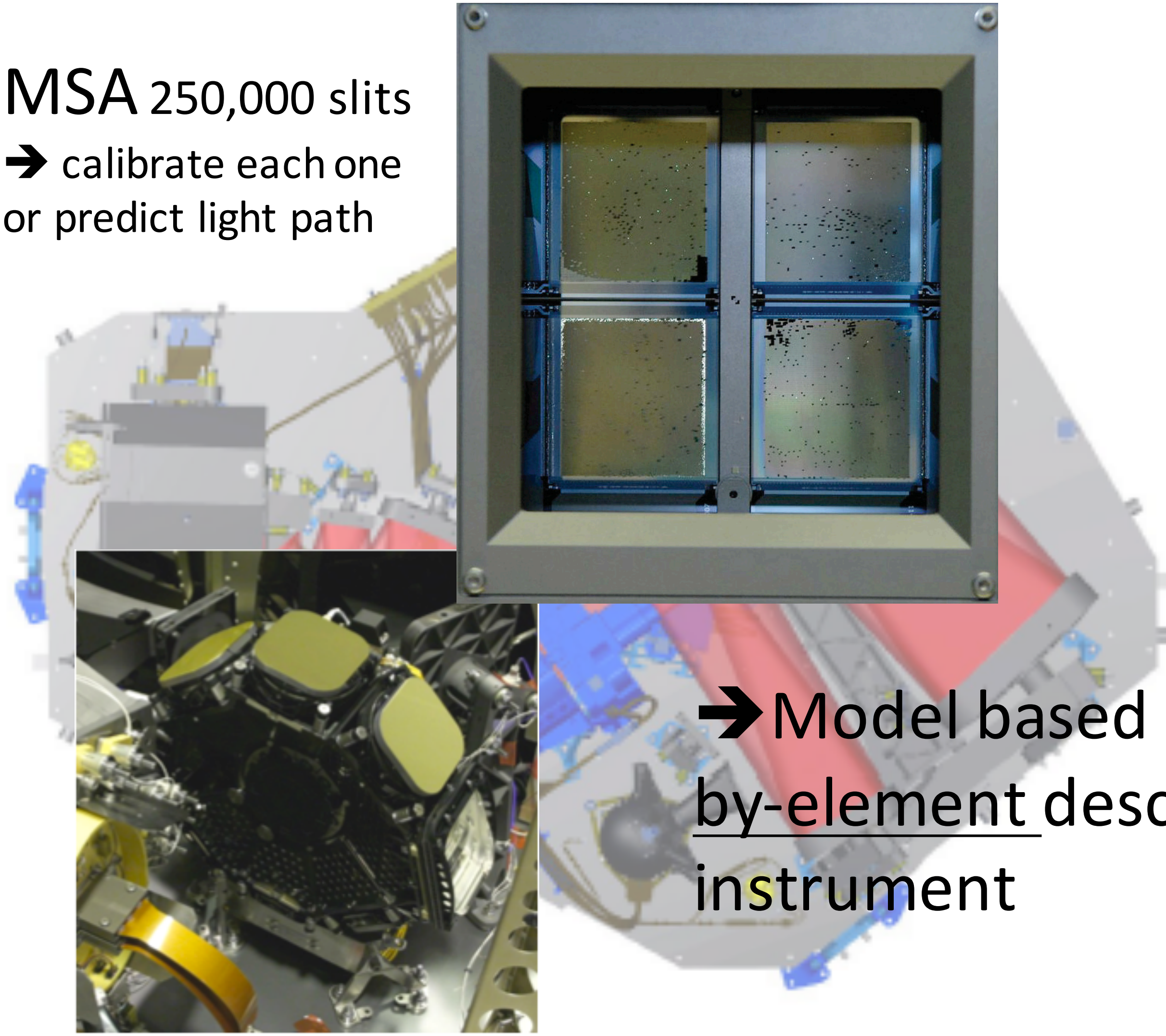
→ Extraction

NIRSpec design



NIRSpec design – Why model approach?

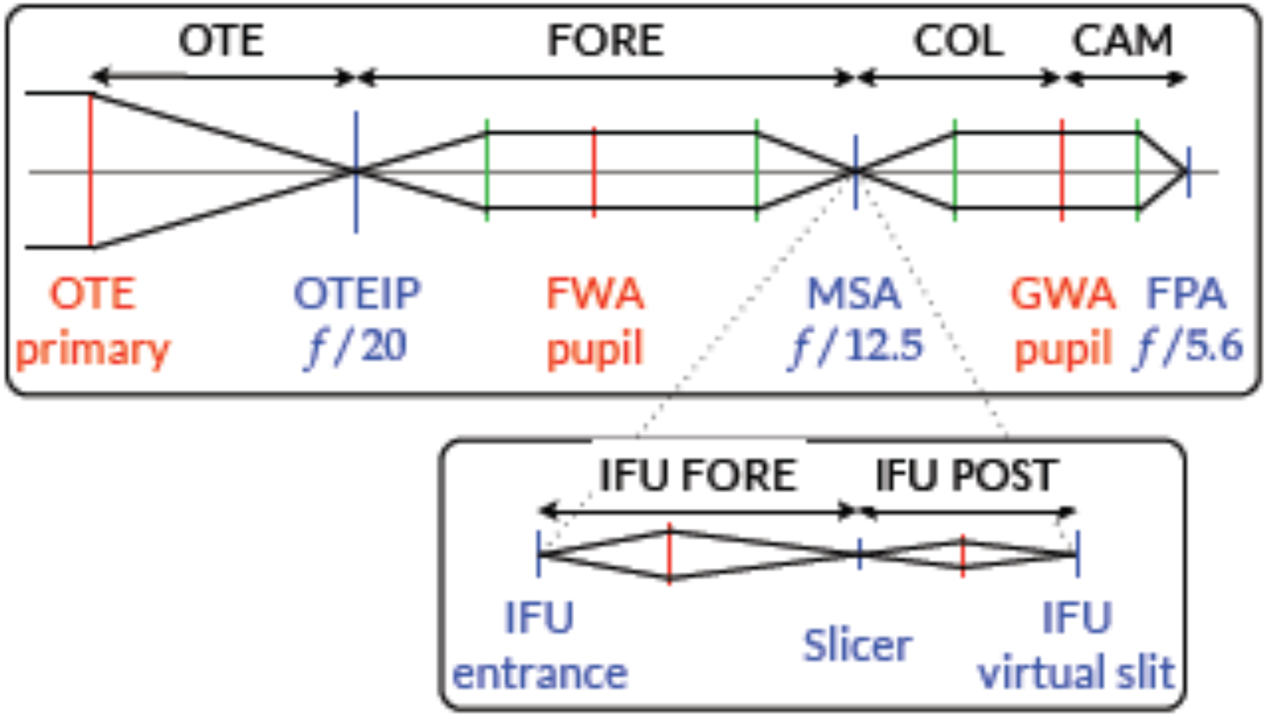
MSA 250,000 slits
➔ calibrate each one or predict light path



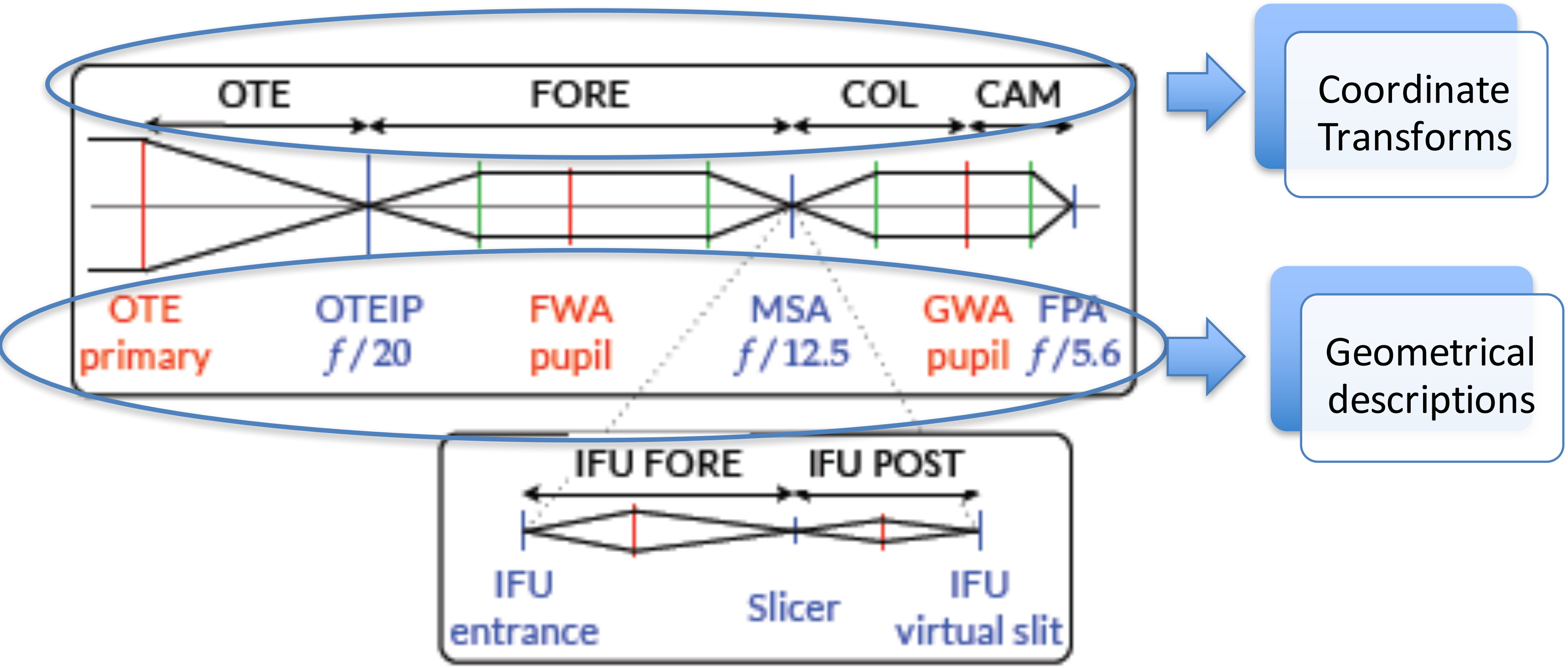
➔Model based on <u>element-by-element</u> description of the instrument

GWA
Repositioning ➔ differences in dispersers tilt angle

NIRSpec parametric model



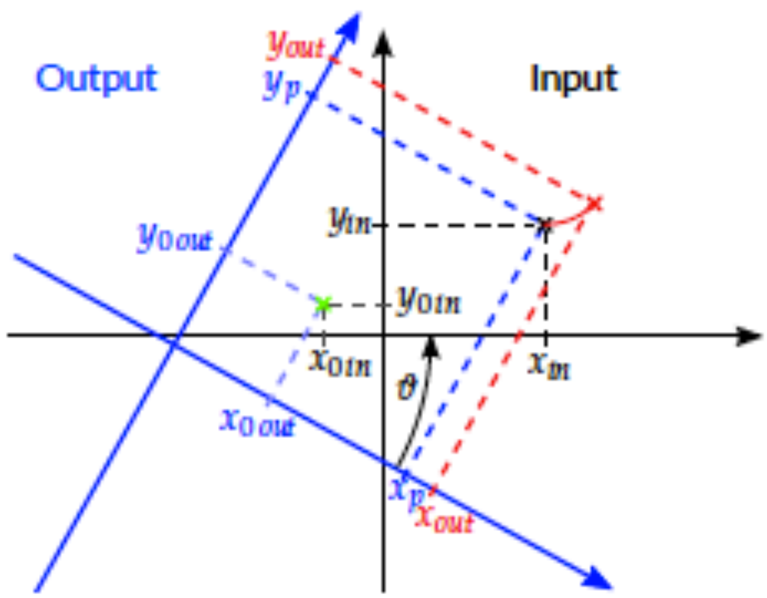
NIRSpec parametric model



Coordinate transform

$$
\begin{aligned}
x_p &= \gamma_x \cdot [(x_{in} - x_{0\,in})\cos(\vartheta) + (y_{in} - y_{0\,in})\sin(\vartheta)] + x_{0\,out} \,, \\
y_p &= \gamma_y \cdot [-(x_{in} - x_{0\,in})\sin(\vartheta) + (y_{in} - y_{0\,in})\cos(\vartheta)] + y_{0\,out} \,.
\end{aligned}
$$

The optical distortion is applied in the form of a 2D polynomial of order n, so the final output coordinates of the transform (x_{out}, y_{out}) are



$$
\begin{aligned}
x_{out} &= \sum_{i=0}^{n}\sum_{j=0}^{n-i} a_{i,j}(\lambda)\, x_p^i\, y_p^j \,, \\
y_{out} &= \sum_{i=0}^{n}\sum_{j=0}^{n-i} b_{i,j}(\lambda)\, x_p^i\, y_p^j \,.
\end{aligned}
$$

FORE transform: filters cause chromatism

$$
\begin{aligned}
a_{i,j}(\lambda) &= \alpha_{x\,i,j}\lambda + \beta_{x\,i,j} \,, \\
b_{i,j}(\lambda) &= \alpha_{y\,i,j}\lambda + \beta_{y\,i,j} \,.
\end{aligned}
$$

Model parameters

Element	Type	Description	N. parameters
COL	Paraxial transform	Input and output plane centers, rotation angle and scaling factors	7
	Geometrical distortion	Forward and Backward 2D polynomials	42+42
CAM	Paraxial transform	Input plane center, rotation angle and scaling factors	5
	Geometrical distortion	Forward and Backward 2D polynomials	42+42
MSA	Quadrant position	Position of shutter (1,1) and rot. angle	12
	Aperture sizes	Micro shutter pitch (X & Y) (per quad.)	8
	Fixed slits	Positions and rot. angle	15
GWA	Grating orientation	Alignment angles	6×3
	Mirror orientation	Alignment angles	2
FPA	Detector position	y-position pixel(1,1), detector gap in X and r rot. angle of SCA492	4

➔ Tot = 225 free parameters

➔Dorner, Giardino, Ferruit et al., 2016 A&A, 592, A113

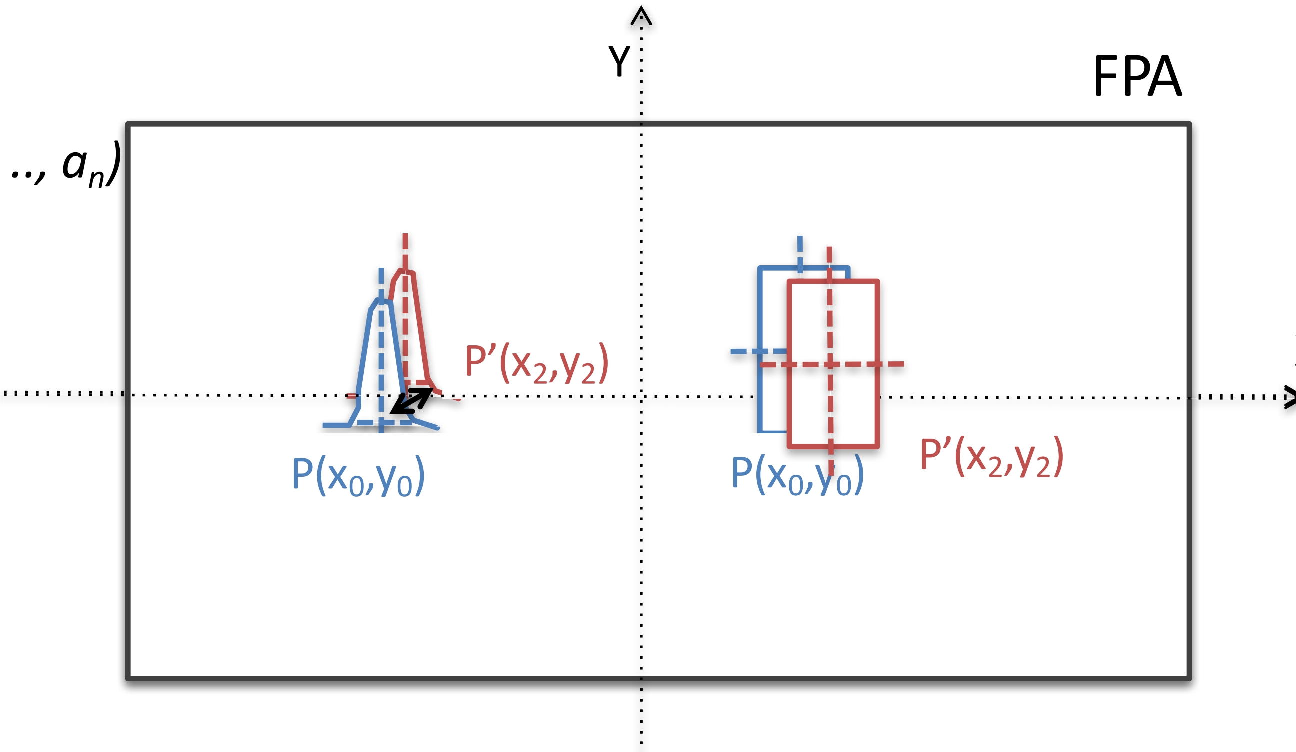
➔Giardino, Luetzgendorf , Ferruit et al., 2016, SPIE Proc, Vol. 9904

How do we calibrate the model?

$$R^2 \equiv \sum_{j=1}^{m} d_j(a_1, a_2, .., a_n)$$

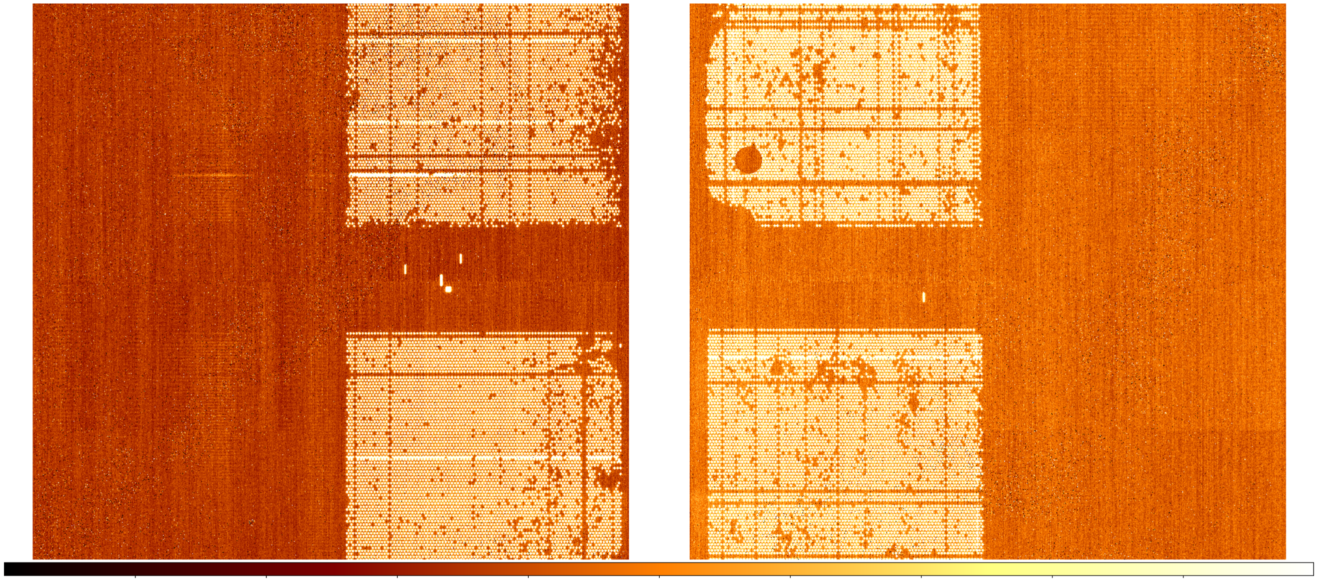
$$\frac{\partial(R^2)}{\partial a_i} = 0$$

for $i=1,..,n$

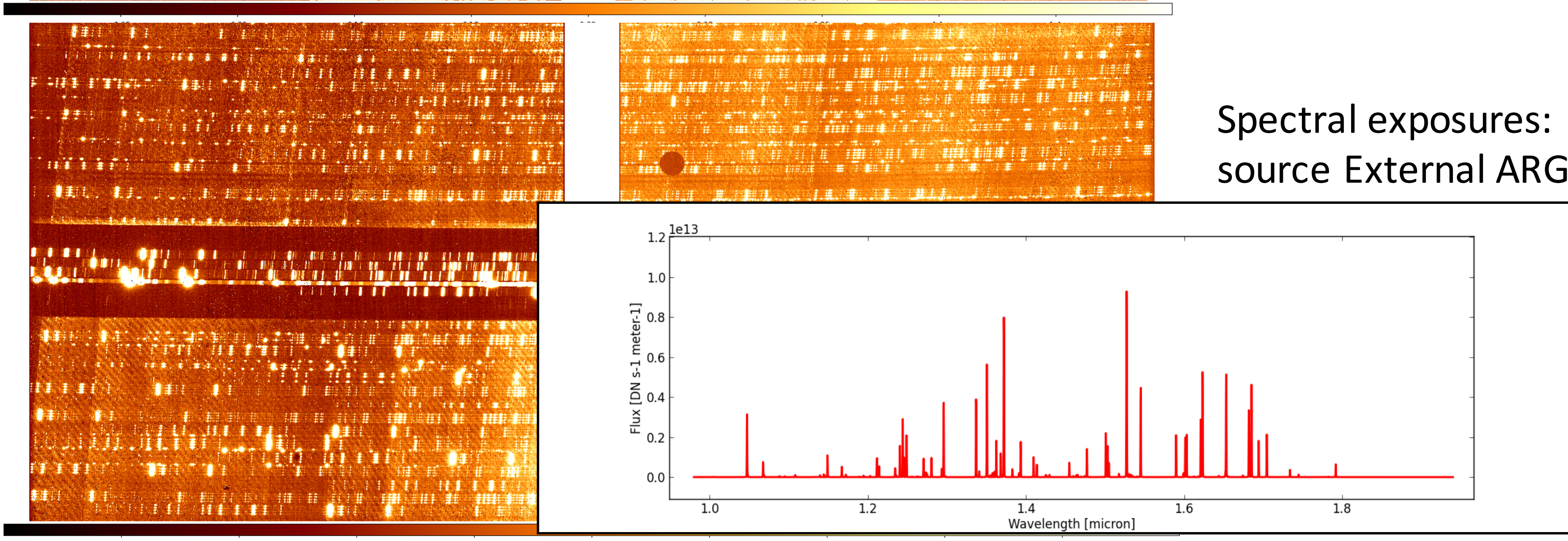


➔ Approach successfully used for calibration of Instrument Level testing (IABG 2013) & Goddard 2015

Calibration exposures at IABG (2013)



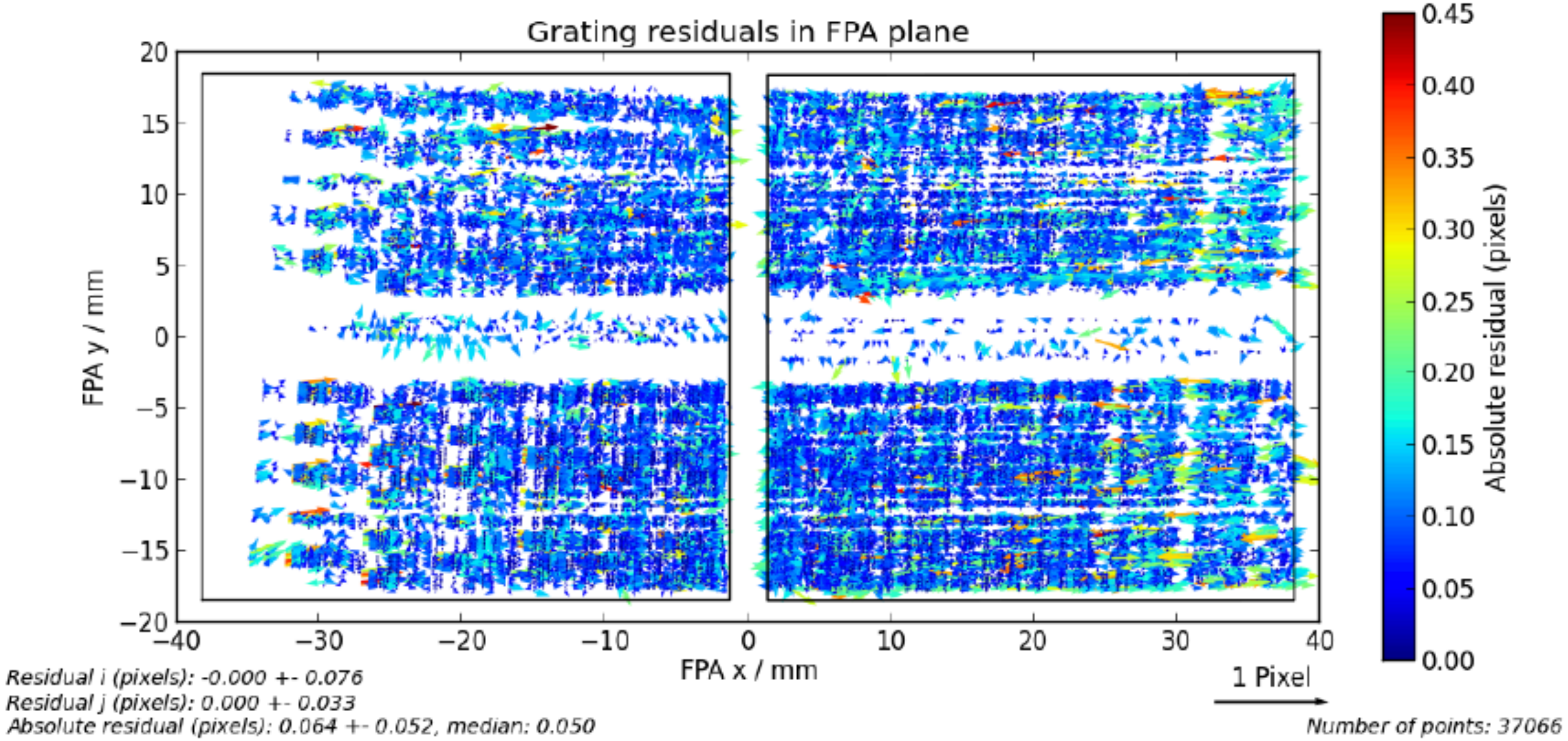
Imaging exposures:
source CAA/TEST



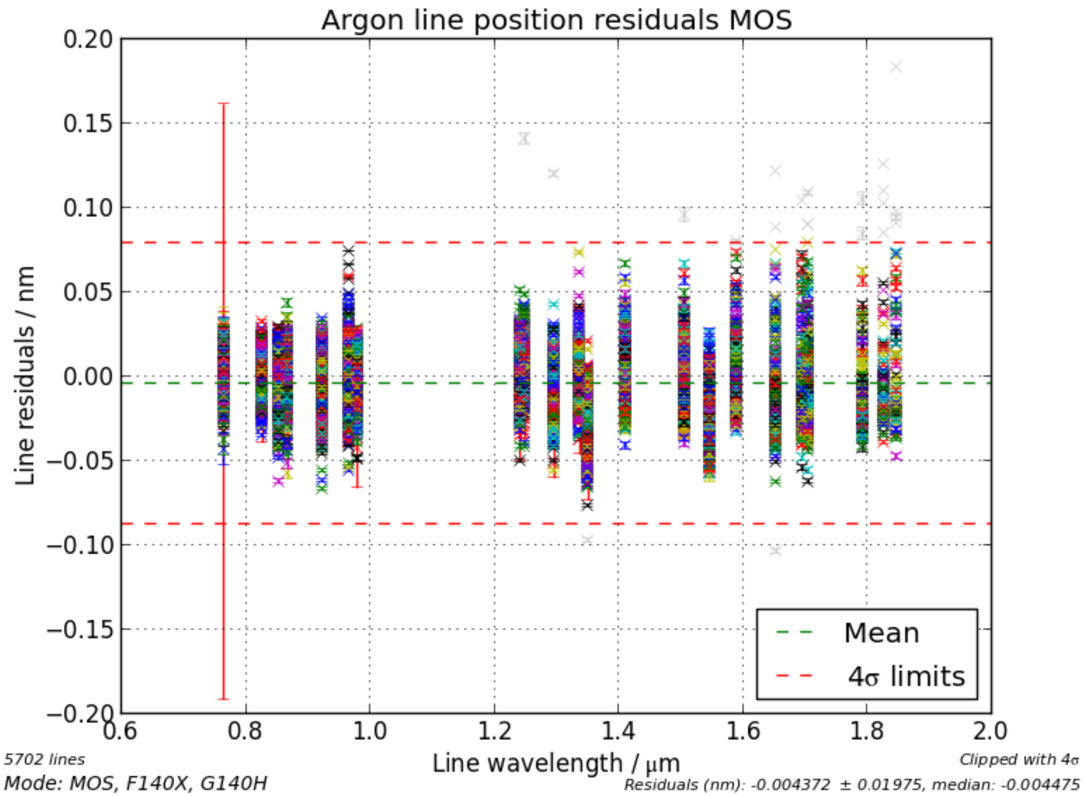
Spectral exposures:
source External ARGON

Results: residuals at the FPA

- Number of reference points in imaging: 5945
- Number of spectral reference points (argon line positions): 30766



Results: wavelength calibration accuracy



G140H wavelength calibration

➔ Line residuals < 1/20 of a resolution element

Results: wavelength calibration accuracy

Disperser	SLIT / nm	MOS / nm	IFU / nm
G140H	-0.007±0.015	-0.004±0.020	0.017±0.024
G235H	-0.024±0.028	-0.019±0.036	0.022±0.036
G395H	-0.039±0.040	-0.030±0.060	0.000±0.033
G140M	-0.006±0.025	-0.013±0.033	0.051±0.019
G235M	-0.005±0.047	-0.012±0.054	0.076±0.049
G395M	-0.006±0.080	-0.034±0.085	0.095±0.064

→ Better than 1/20 of a resolution element for all gratings
→ Better than 5-7 km/s for all gratings
→ Better than 1/10 of a resolution element for Priism

→Dorner, Giardino, Ferruit et al., 2016 A&A, 592, A113
→Giardino, Luetzgendorf , Ferruit et al., 2016, SPIE Proc, Vol. 9904

Summary

- The model approach allows us to extract wavelength calibrated spectra from any the of NIRSper 1/4 million slits, having acquired calibration exposures for only 1.5% of all the apertures
  ➔ enormous advantages for NIRSpec operational efficiency

EFFICIENCY

- Model optimization procedure ensure a solid calibration of the parametric model
  ➔ a accurate wavelength calibration: better of a 1/10 of pixel (or 1/20 of a resolution element), for each grating.

ACCURACY

- Good handle on calibration procedure and accuracy well before launch

PROCEDURE

There is more …

Instrument Performance Simulator

- Fourier optics software
  - ➔ compute synthetic PSF in all of NIRSpec optical planes
- Radiometric response computation tool
  - ➔ throughput from all surfaces
  - ➔ slit and diffraction losses
- An exposure simulator
  - ➔ to generate synthetic detector readouts

⬇

Mock exposures

Conclusions

- Parametric model of the instrument:
  - assess in detail NIRSpec design
  - asses instrument performance as the hardware components are being manufactured and characterized at sub-system level

CONSTRCTION

- Forced to think through Performance Verification and Calibration campaign of NIRSpec
  - device the right test/calibration exposures
  - simulate these exposures to validate concepts
  - develop the necessary processing tools to extract all the necessary calibration and performance numbers

TEST

- The model has become integral part end-to-end simulations of NIRSpec: sky scene to level 2 products… (JWST 'sky' is much simpler than Euclid's)

LAUNCH

Imaging residuals

IFU residuals

Model implementation

Each element of the model is described in a file.
There are two basic types of files:

Description files

- MSA
- IFU slicer
- Disperser (two files for each disperser)
- FPA

Coordinate transform files

- FORE transforms (one file for each filter)
- COL transform
- CAM transform
- IFU FORE
- IFU POST (one file per IFU slice)