First simulation and data reduction of a JWST/NIRSpec observation

Bernhard Dorner[1], Pierre Ferruit[2], Laure Piqueras[1], Emeline Legros[1], Arlette Pecontal[1], Aurelien Jarno[1], Aurelien Pons[1], Xavier Gnata[3], Camilla Pacifici[4]

1-Centre de Recherche Astrophysique de Lyon, Observatoire de Lyon, France

2-European Space Agency - ESTEC, Noordwijk, The Netherlands

3-EADS Astrium GmbH, Munich, Germany

4-Institut d'Astrophysique de Paris, France

Abstract

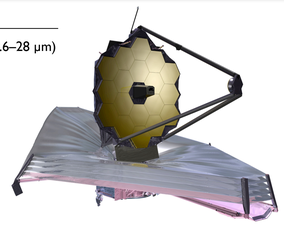
The James Webb Space Telescope (JWST), a joint project by NASA, ESA, and CSA, is the successor mission to the Hubble Space Telescope. One of the four science instruments of the observatory is the multi-object spectrograph NIRSpec. It will be able to measure the spectra of more than 100 objects simultaneously and will cover the near infrared wavelength range from 0.6 to 5.0 µm at various spectral resolutions. Due to the instrument complexity, it was seen as necessary to create an instrument simulator for studies of the instrument performance, optical and geometrical effects, as well as the creation of realistic calibration and science exposures to develop and test data analysis tools. The Centre de Recherche Astrophysique de Lyon (CRAL), as subcontractor to EADS Astrium GmbH, develops this Instrument Performance Simulator (IPS) software for NIRSpec.

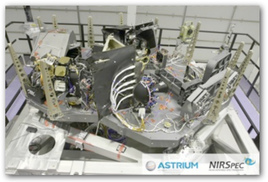
One of the key objectives of the IPS is to generate realistic simulated JWST/NIRSpec exposures of astrophysical sources, providing a check of NIRSpec in-orbit performances and inputs for the definition of the best observation strategies. We briefly summarize how the different input data is used for the instrument model, and present a first spectral extraction pipeline tailored to the IPS. Following this, we show the simulated exposure of an observation of a typical NIRSpec target, a modeled redshifted galaxy, and compare the finally extracted spectrum with the input.

The JWST and NIRSpec

James Webb Space Telescope

- Near- and mid-infrared space observatory (0.6–28 µm)
- 6.5 m diameter primary mirror
- Cooperative NASA–ESA–CSA mission
- Scientific topics:
  - First light and reionization
  - Assembly of galaxies
  - Formation of stars and planets
  - Origins of life





Near-Infrared Spectrograph

- Wavelength range 0.6–5 µm
- Multi-object spectroscopy of more than 100 objects simultaneously
- Configurable microshutter masks, fixed slits and Integral Field Unit (IFU)
- Spectral resolutions: R~100, 1000, 2700
- Two 2k x 2k HgCdTe detector arrays, MULTIACCUM readout
- ESA project with EADS Astrium GmbH as prime contractor

Instrument performance simulator (IPS)

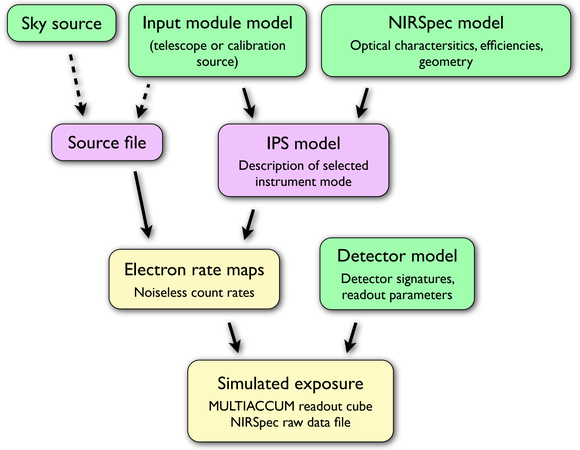
- End-to-end simulation for NIRSpec calibration and in-orbit science exposures
- Part of the Electrical Ground Support Equipment
- Early verification of instrument performance
- Inputs and verification for calibration and test campaigns and analysis software IQLAC
- Developed under contract to EADS Astrium GmbH
- Written in C/C++, Python data framework

IPS simulation modules

Question	Data needed	Main module
What is it like?	PSFs, image shape	Fourier optics
Where is it?	Position	Coordinate transforms
How much is it?	Final electron rate	Radiometry
Do we see it at all?	Noise and readout	Exposure creation

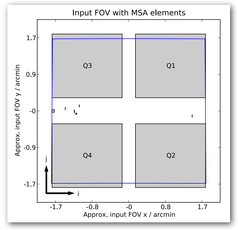
- Division into separate physical effects
- Coupling of Fourier optics with geometrical transforms and radiometry
- Standalone exposure creation from electron rate maps
- Separate tools for sensitivity and PSF calculation
- All data stored in database

IPS data workflow



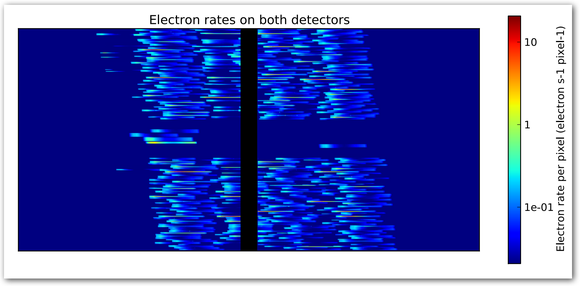
Sky source data interface

- IPS source file format is very general and only on sky
- Established a simpler interface to ease scene creation
- Usage of input FITS files with common data types
  - Single spectrum
  - Intensity image & spectrum
  - Data cube
- Direct placement in shutters, slits or IFU slices, or on sky
- IDL and Python scripts prepared

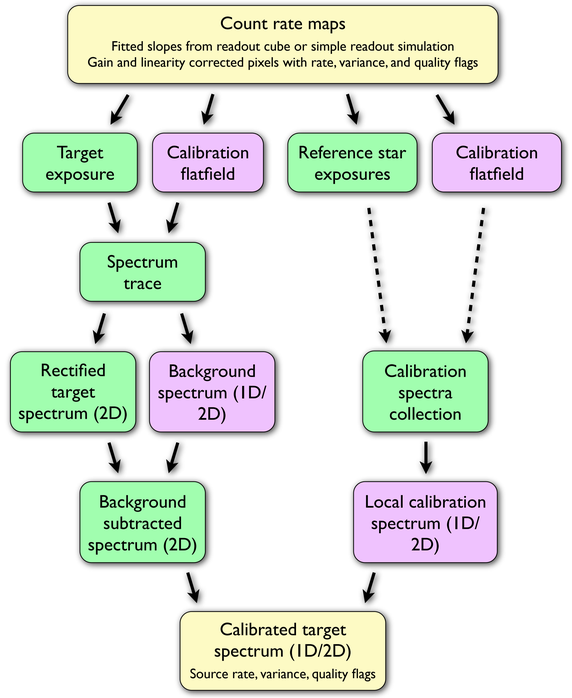


Simulated multi-object scene

- Simulated galaxy spectra at reshifts z=2–6
- Set as point sources in shutters
- Zodiacal background in field of view
- Scene construction respecting failed shutters
- PRISM configuration (R~100)
- More than 300 objects in single exposure

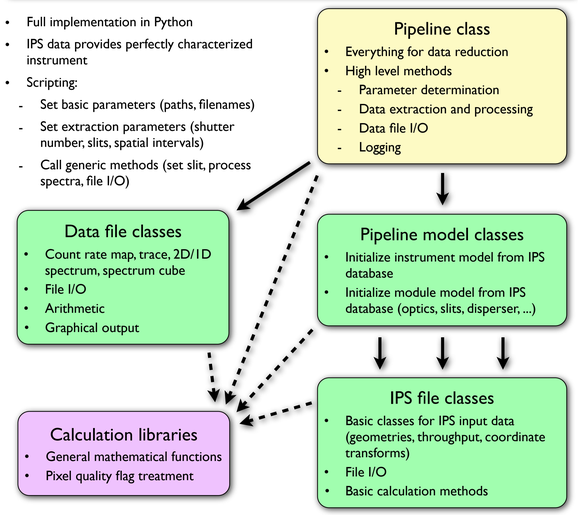


Extraction pipeline workflow



Extraction pipeline framework

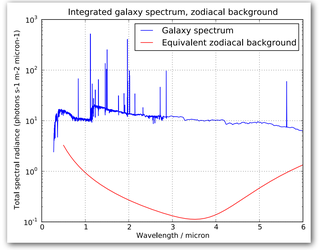
- Full implementation in Python
- IPS data provides perfectly characterized instrument
- Scripting:
  - Set basic parameters (paths, filenames)
  - Set extraction parameters (shutter number, slits, spatial intervals)
  - Call generic methods (set slit, process spectra, file I/O)



Extraction example: galaxy spectrum

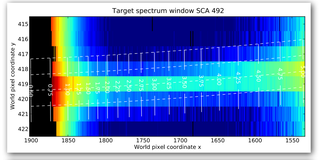
Simulated galaxy at redshift z=2

- Modeled as point source on top of zodiacal background
- Instrument: minisit (1x3 shutters) and prism (R~100)
- Standard exposure (902 sec) and synthetic noise
- Flatfield with calibration lamp exposure



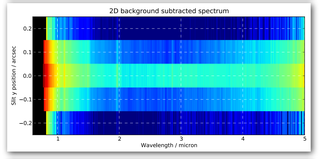
Spectrum trace on detector

- Contour: slit y and iso-wavelength lines (micron)
- Masked pixels with quality flags, e.g. bad flatfield correction



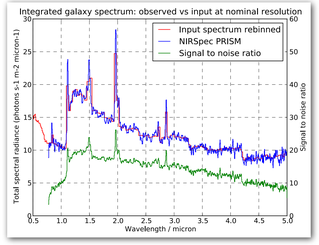
Rectified and background subtracted spectrum

- Spatial dimension in arcsec on sky
- Pixel size approximately as on detector



Calibrated spectrum

- Calibration with fake reference star exposure
- 1D extraction: collapsed in y
- Propagated variances and quality flags
- Very good match with input spectrum rebinned to nominal resolution



Conclusion and outlook

- IPS3 delivery to Astrium in Dec 2010
- IPS provides realistic and high-accurate simulation of NIRSpec
- Tools allow easy interface to astronomical users
- First sky simulations with as-built instrument model going on
- Data reduction pipeline for the IPS output in development
- Point sources successfully extracted
- Automated calibration and extension to background objects and IFU in the near future
- Possible use during instrument cryo tests and as testbed for extraction techniques

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Questions? I'm around!