4MOST – 4m Multi-Object Spectroscopic Telescope

TOAD: The 4MOST instrument model

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The 4MOST instrument

4MOST: **4**-meter **M**ulti **O**bject **S**pectrograph **T**elescope

- Installed on the 4-meter-ish VISTA telescope near VLT
- 2.5 degrees diameter FoV
- Inscribed hexagon with 2436 fibres + some extra
- Tilting spine technology (Echidna)
- 2 spectrographs resolution > 5000, 370nm to 950nm continuously on 3 arms
- 1 spectrograph resolution > 18000, 3 selected intervals between 400nm and 700nm
- 15 years operational lifetime, all (south) sky survey, $\sim$ 75 Million targets

Instrument simulator TOAD

TOAD: **T**op **O**f the **A**tmosphere to **D**etector Simulator

- Use target spectra and target shape to simulate 2D detector images taking all relevant atmospheric, telescope and instrument effects into account
- Simulates image quality and throughput
- TOAD is used in all stages of the project for:
  - Performance preview
  - Trade-off studies
  - Statistics for the 4MOST Facility Simulator
  - Early images for pipelines
- TOAD matures as the instrument design gets more refined over time

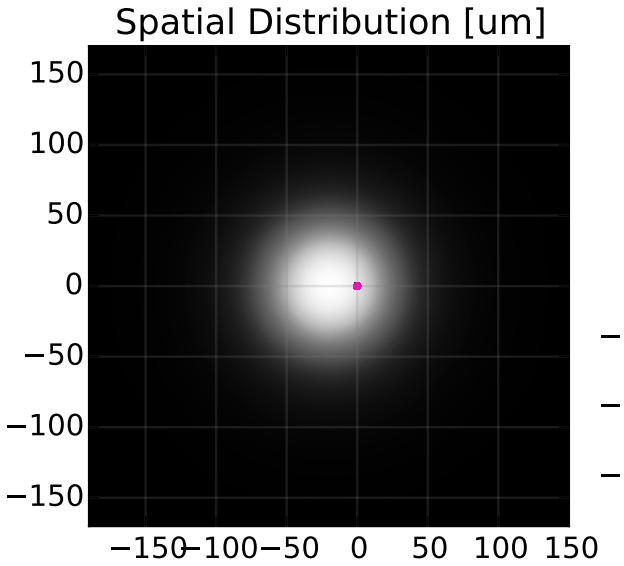
Design

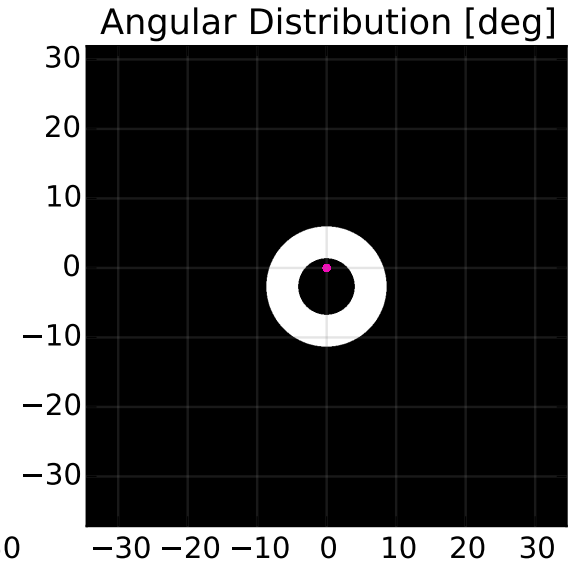
- Goals:
  - Modular and flexible design
  - Portable and easily usable
- Limitations:
  - Development: $<$ 0.5 FTE per Year
  - No special computer hardware
  - Only free licenses
- Solution:
  - Implementation in Python
  - No ray-tracing or wave-front simulation
  - Chain simulations from ZEMAX, etc. in a consistent model

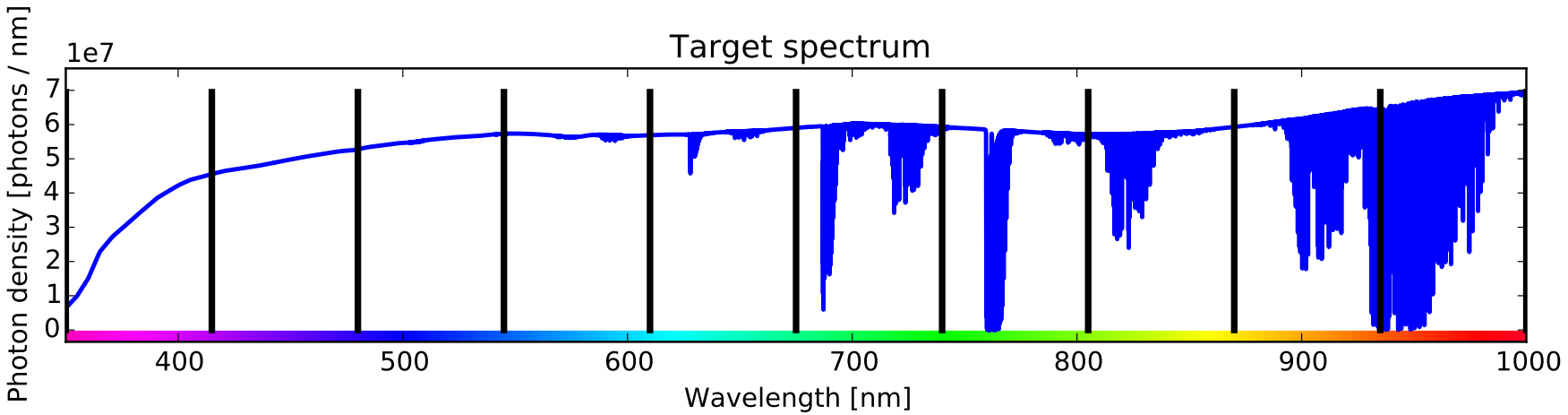
Comparing to other Simulators

Simulator	precursor	strategy	FTE/Y	lang.
HARMONI sim.	MUSE	wave-front propagation	1.5	python, C/C++
SiMCADO	-	intensity map	1.5	python, C/C++
METIS sim.	?	intensity map	< 1	IDL
VIRTUAL MOONS	-	ray tracing	0.5	IDL
TOAD	-	single target intensity map	0.5	python

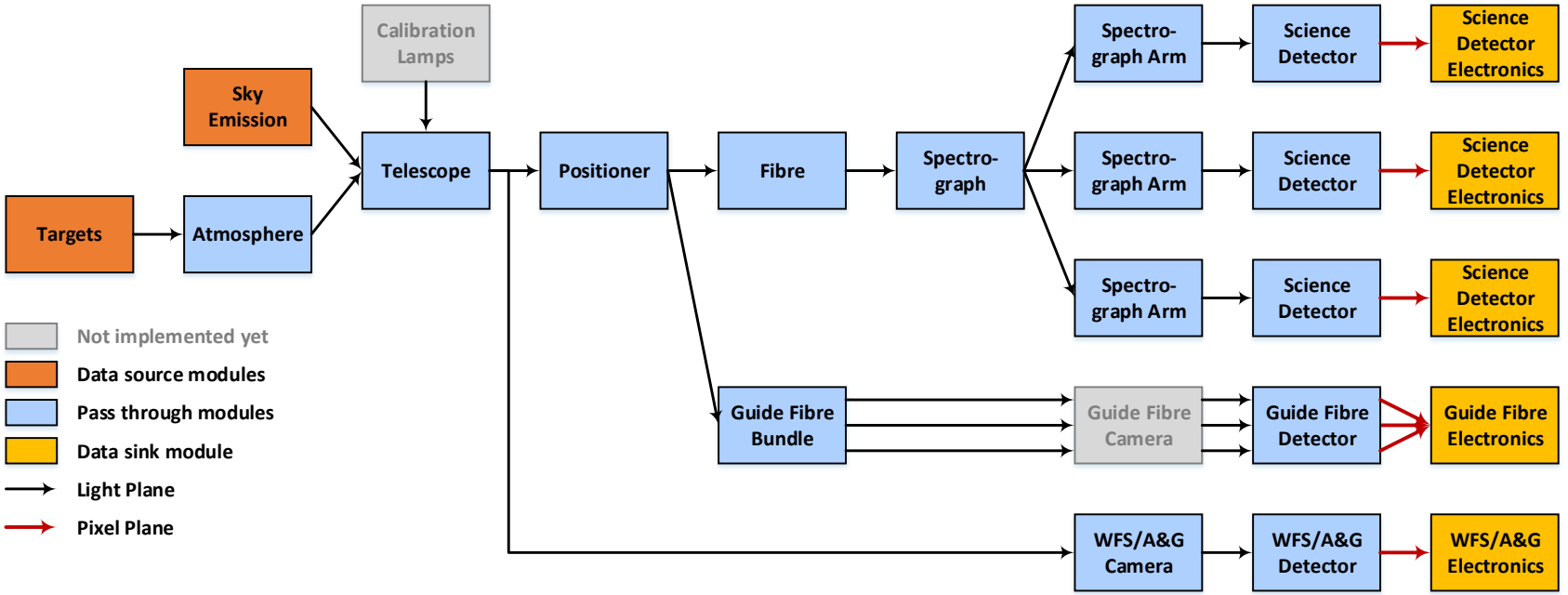
Light Plane data model illustration





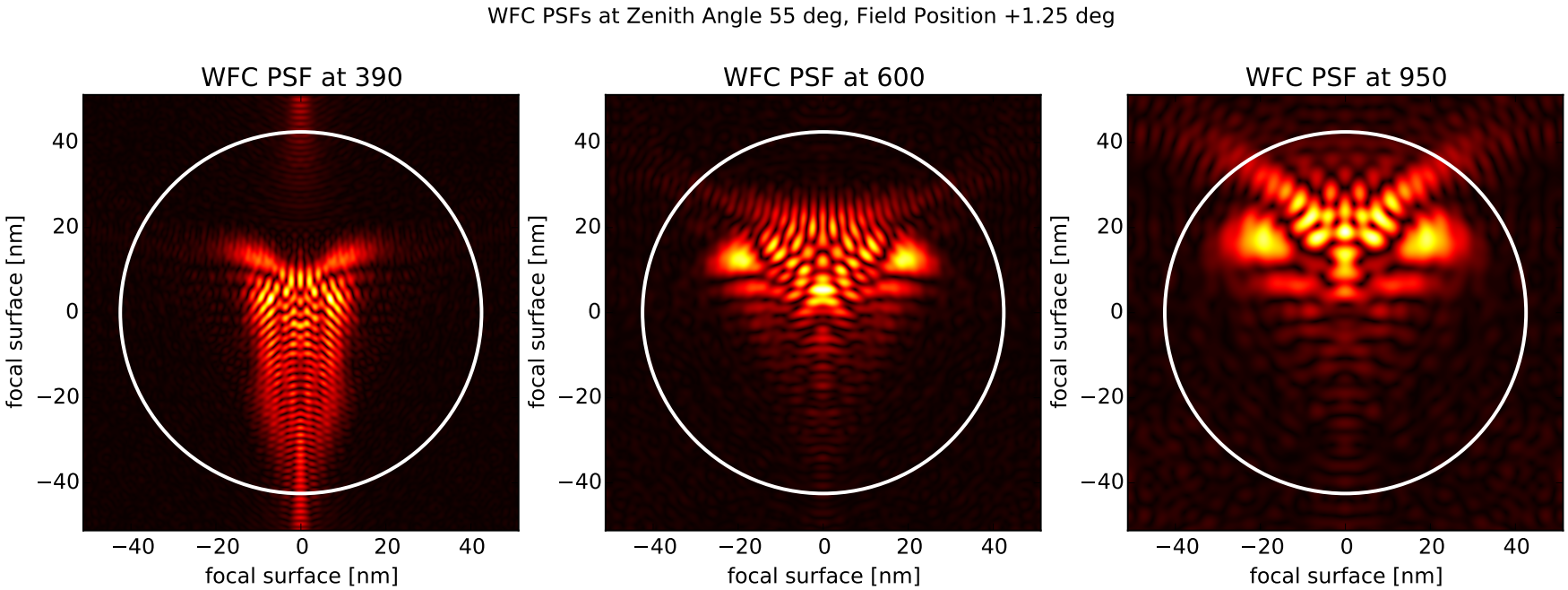


TOAD Modules



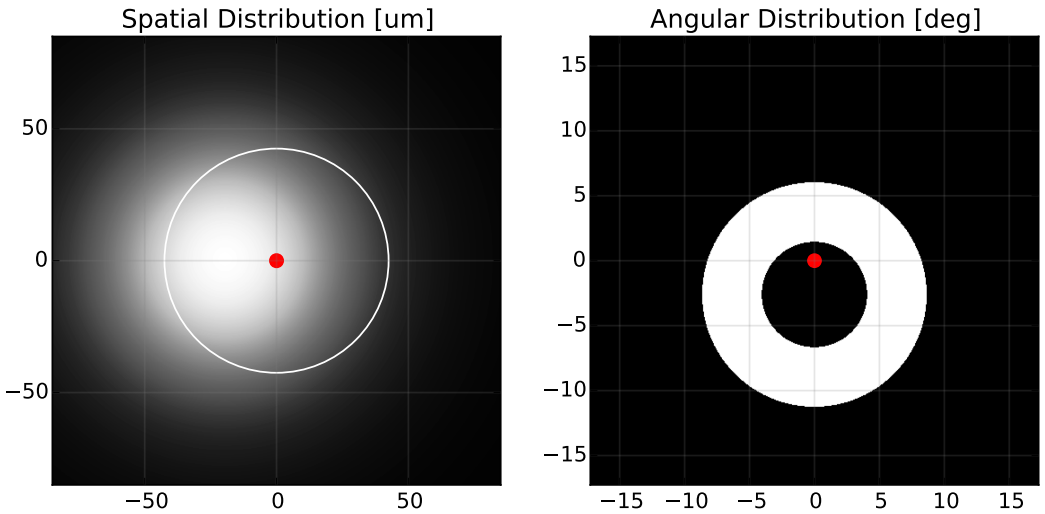
ZEMAX Input for TOAD

- Use various ZEMAX models of the 4MOST optics
- Access ZEMAX by a python script to generate PSF maps depending on instrument setup, field position and wavelength
- Example WFC/ADC: fibre indicated by white circle for scale



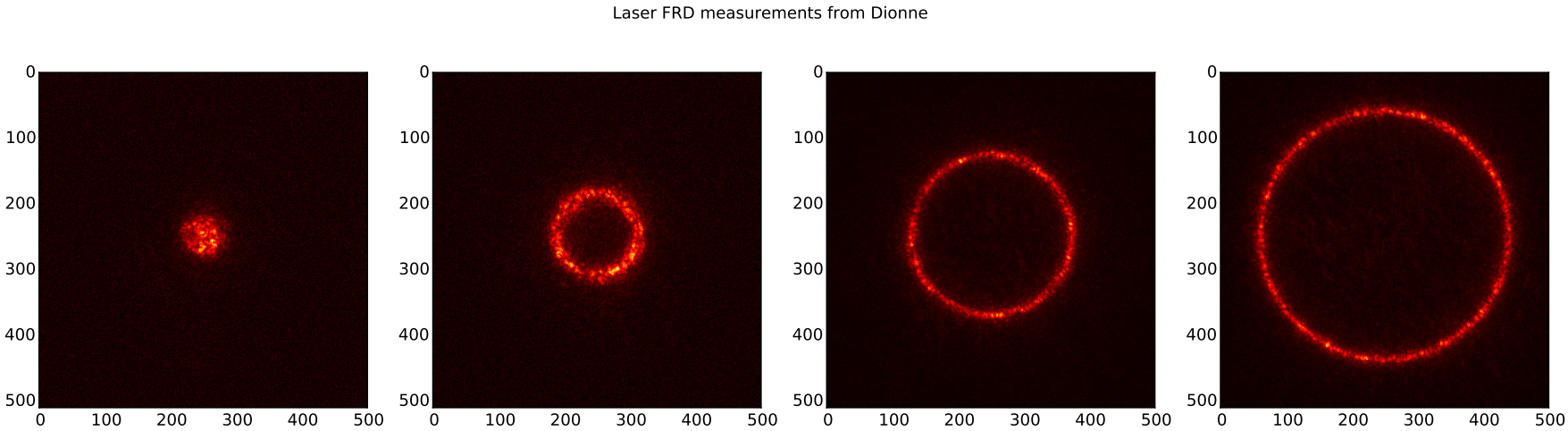
Positioner Simulation

- Spine tilt induced effects:
  - Shift of the angular distribution $< 2.7°$ (at $11.5mm$)
  - Defocus between approx. $+100\mu m$ at $0mm$ tilt and $-150\mu m$ at $11.5mm$ tilt
  - Defocus implemented by convolving the spatial distribution (near field) with suitably scaled angular distribution (far field)
- Fibre position inaccuracies ($< 10\mu m$ RMS)

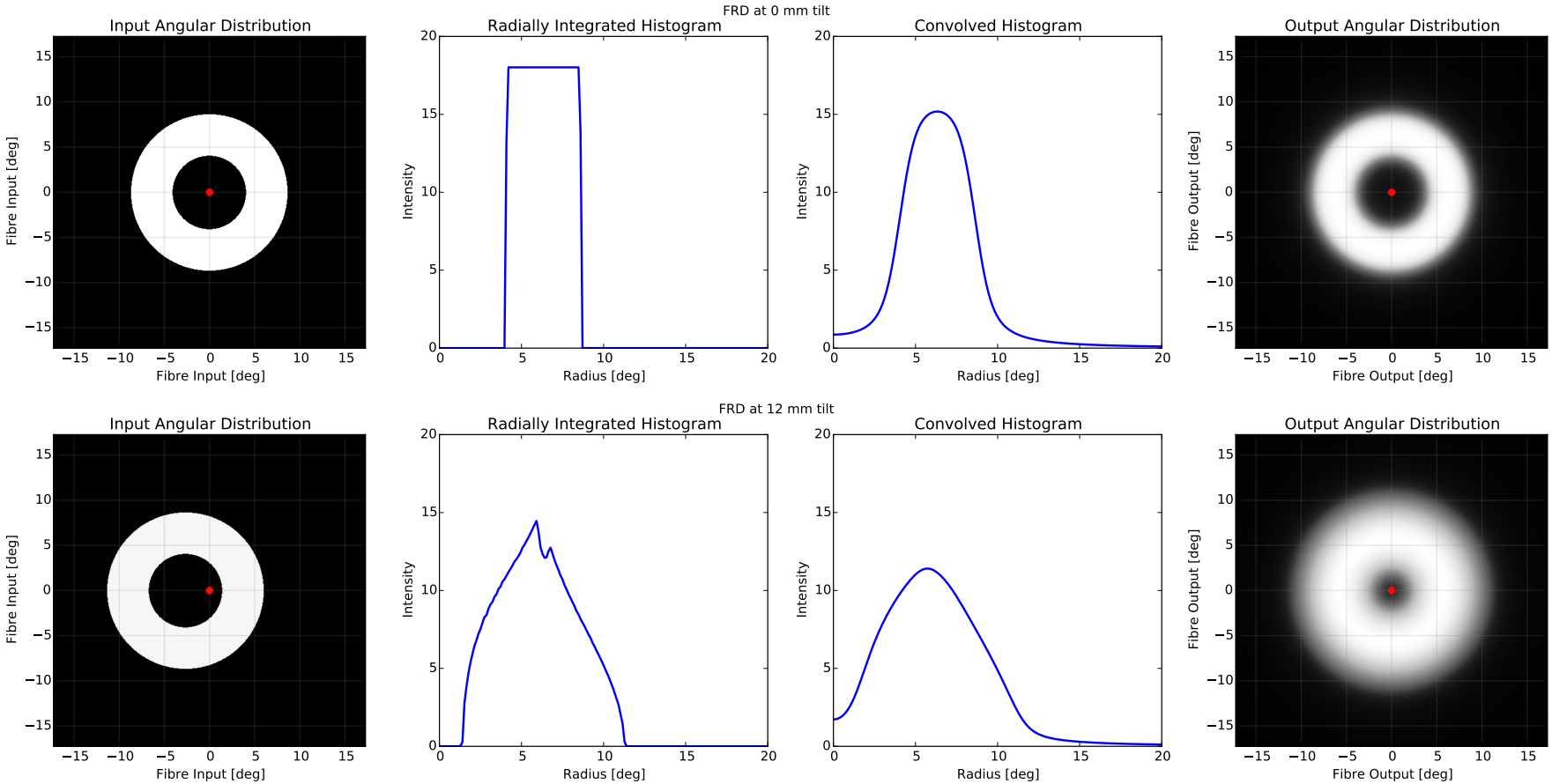


Fibre FRD: Laser measurements

- Azimuthal scrambling
- Focal ratio degredation (FRD)
- Old laser FRD measurements, new model based on a 4MOST fibre prototype in development

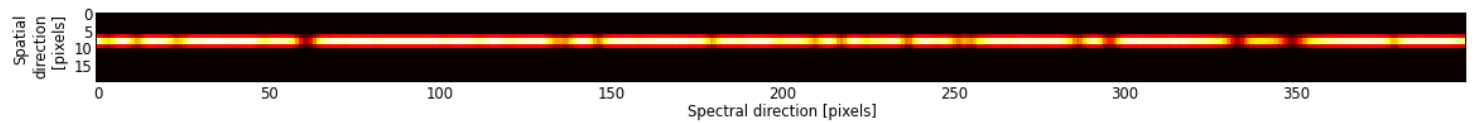


Fibre FRD: Simulations



2D detector simulation

- Projection of light on detector by ’stamping’ fibre image
- Effects taken into account (planned, near-future procedure)
- Noise on detector separately stored from target flux
- Randomized detector effects possible for image simulation
- Full detector population with individual targets possible



GIT, JIRA and python venv

- For each simulation request: create a JIRA ticket that contains the request and all discussions, the code and simulation results
  - \+ : Requests often lack context, blanks are filled within the ticket
  - \+ : Automatic documentation to understand simulations later
  - \- : People hate JIRA tickets
- Specify version of TOAD; represented as tags in TOADs GIT repository
- Attach code related to the request and analysis for the JIRA ticket
- Easy to go back to each simulation using a dedicated venv that pulls from the GIT repository

Verification

- Biggest concern of TOAD: model verification
- Under development
  - unit tests of basic subroutines
- Planned
  - subsystem verification by comparing with ZEMAX
  - verification by comparing with prototypes
- Unlikely
  - verification by modeling a different instrument with TOAD
- Even unlikelier
  - verification by modeling 4MOST with a different simulator

The Lone Wolf Problem

- All other simulations above are basically done by one developer
- Most ESO instruments build a new simulation tool from scratch or personal history of developers
- It would make sense for current projects to build a common instrument simulation suite
- Could solve the verification problem for future simulations
- Would require investment by projects for the benefit of other projects

Summary

- Used in all project stages, following in its accuracy the development needs of the project
- Provides data for trade-offs, data reduction and performance forecast
- Based on a probabilistic model of the light distribution in space, angle and wavelength similar to SiMCADO and the METIS simulator
- Uses a combination of JIRA, GIT and python venv for simulation runs
- Model verification still biggest concern
- TOAD will be become open source shortly after commissioning of 4MOST