4MOST – 4m Multi-Object Spectroscopic Telescope

TOAD: Instrument Performance Simulator

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www.4MOST.eu

Current Section

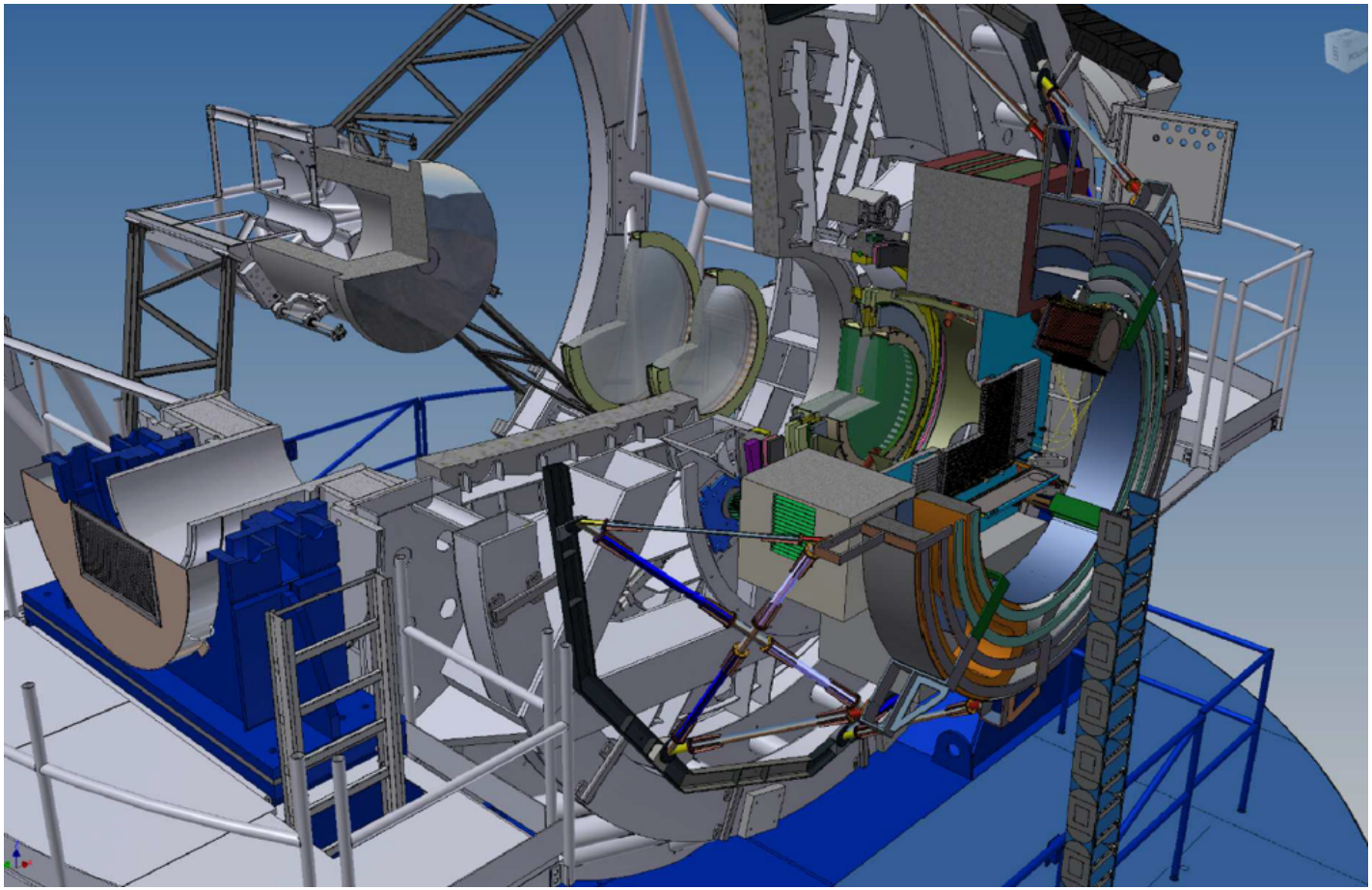
Introduction to 4MOST

Introduction to TOAD

Step by Step Instrument Performance

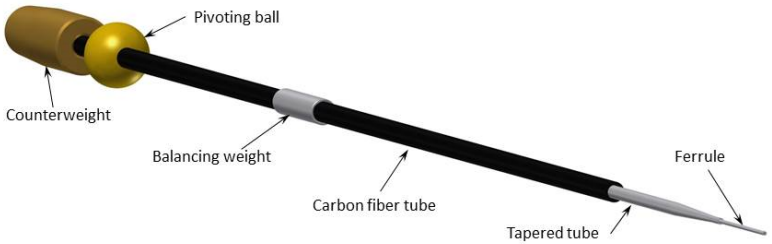
End-to-End Simulation Results

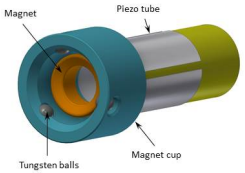
VISTA Telescope Optics



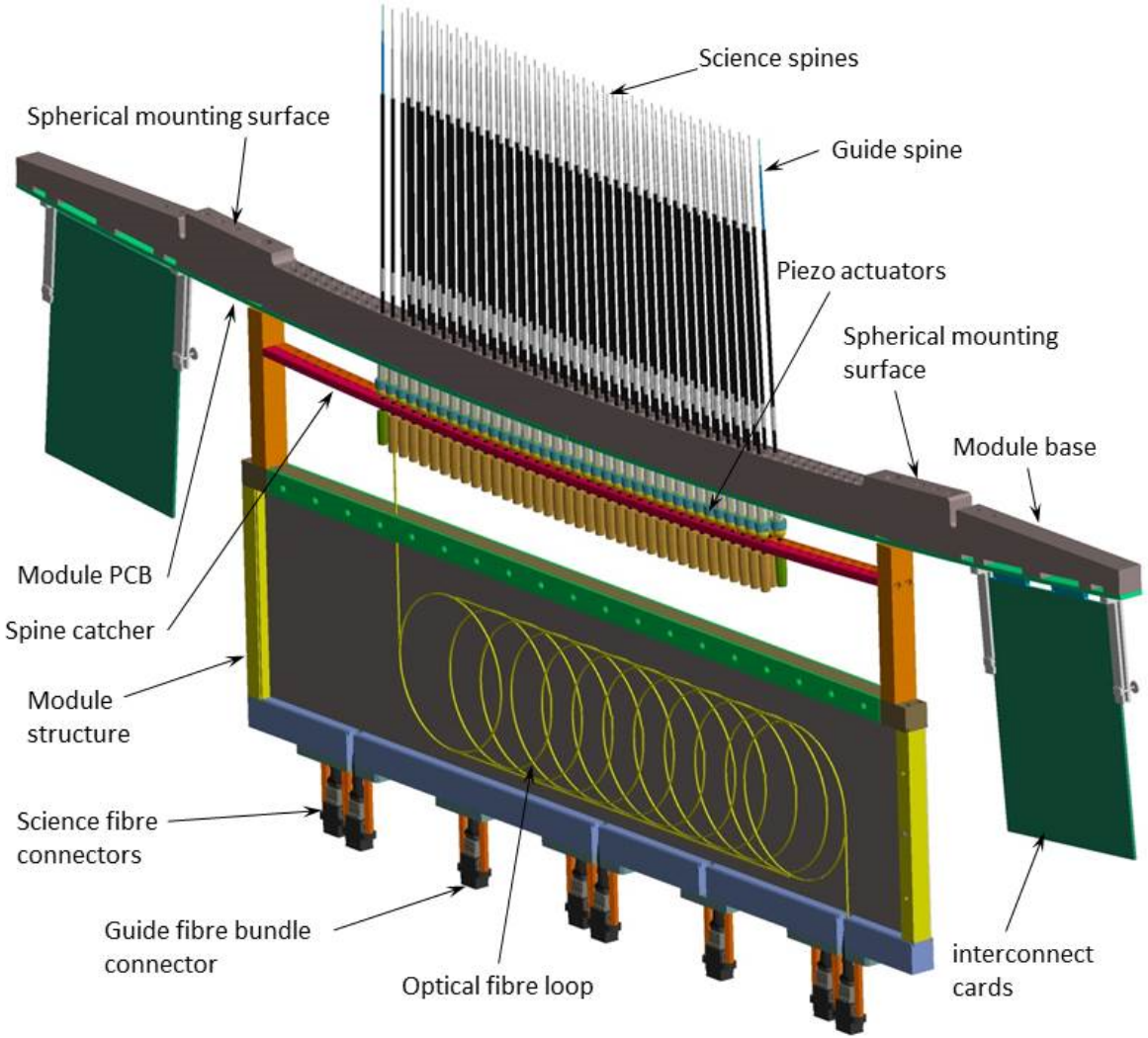
Spines

- Spines housing fibres mounted in caps, moved by piezos
- Patrol radius: 11.5*mm* or Patrol area: 32 sq. arc min on sky
- Fibre pitch: 9.5*mm*
- Positioning accuracy: 10μm or 0.17″ on sky



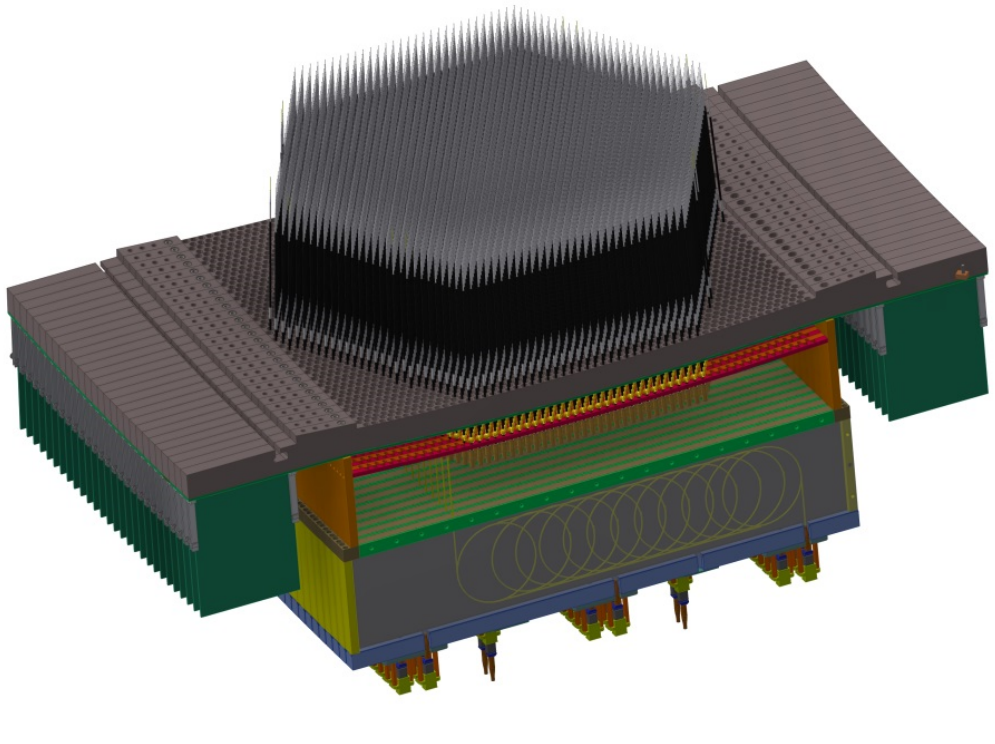


Module


Science spines
Spherical mounting surface
Guide spine
Piezo actuators
Spherical mounting surface
Module base
Module PCB
Spine catcher
Module structure
Science fibre connectors
Guide fibre bundle connector
Optical fibre loop
interconnect cards

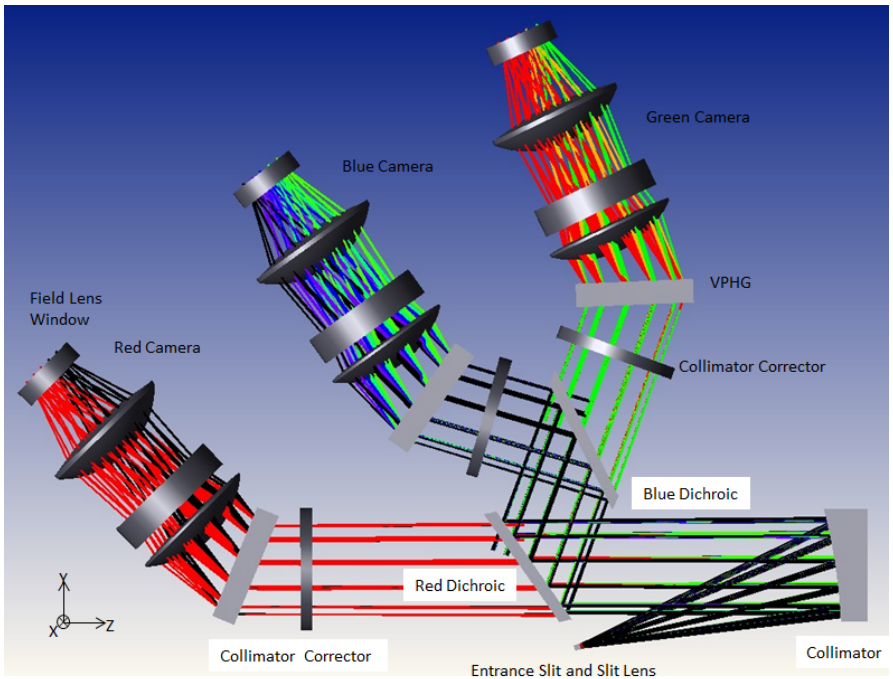
Positioner

- 2436 Science fibres



Spectrographs

- Resolution 5000 spectrograph (see figure blow)
- Resolution 18000 sectrograph
- 812 science fibres per spectrograph + some calibration fibres



Current Section

Applications for TOAD

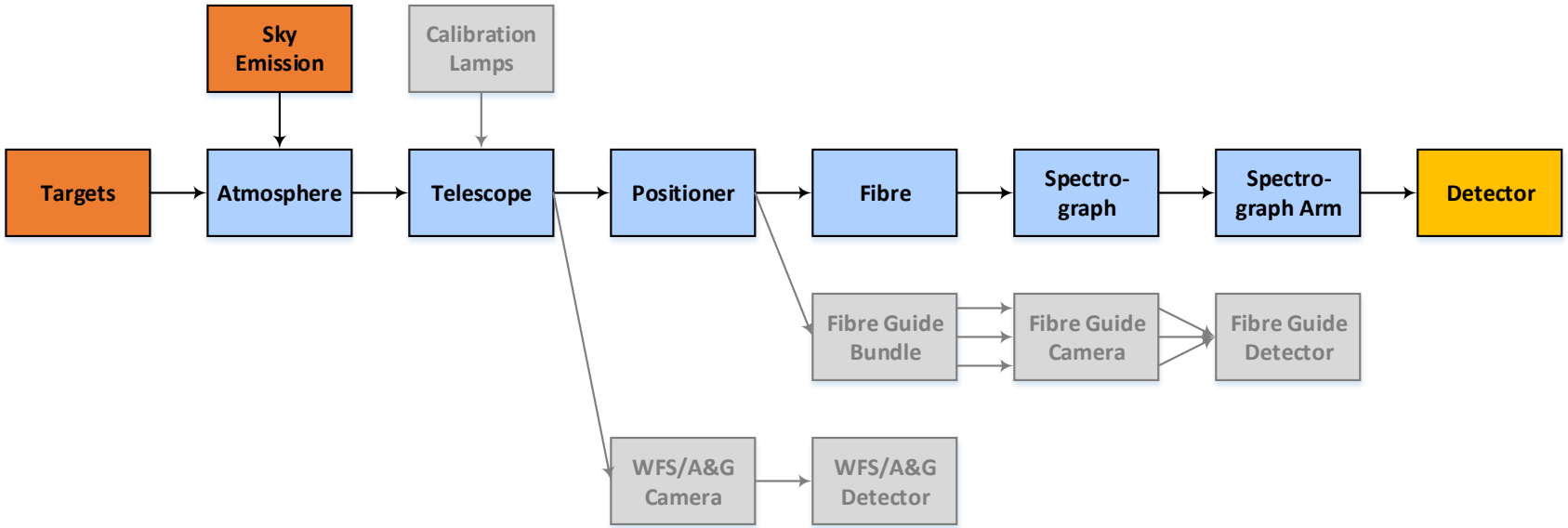
TOAD: **T**op **O**f the **A**tmosphere to **D**etector Simulator

- Use spectra and target shape to generate 2D detector images
- Simulates image quality and throughput
- Use TOAD in all stages of the project
- Applications:
  - Performance preview
  - Trade-off studies (WFC/ADC designs, spine focus, etc.) and design decisions
  - Simulations as input for 4FS
  - Early images for the data reduction pipelines

Design

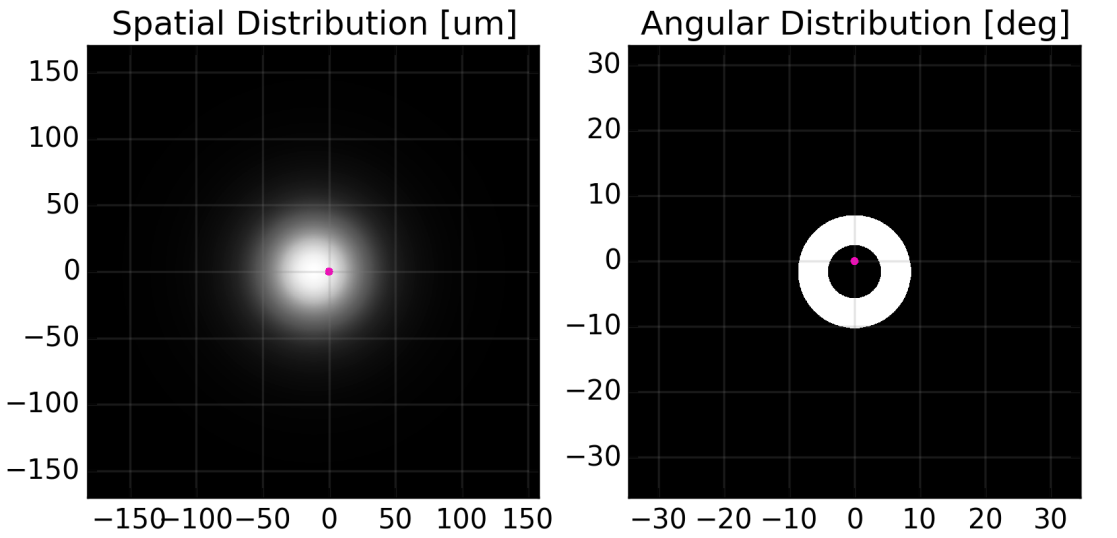
- Goals:
  - Illumination accuracy: 5% per pixel
  - Modular and flexible design
  - Portable and easily usable
- Limitations:
  - Development: $<$ 0.5 FTE per Year
  - No special computer hardware
- Solution:
  - Implementation in Python
  - Simulation of one light source at a time
  - No ray-tracing or wave-front simulation
  - Chain simulations from ZEMAX, etc. in a consistent model

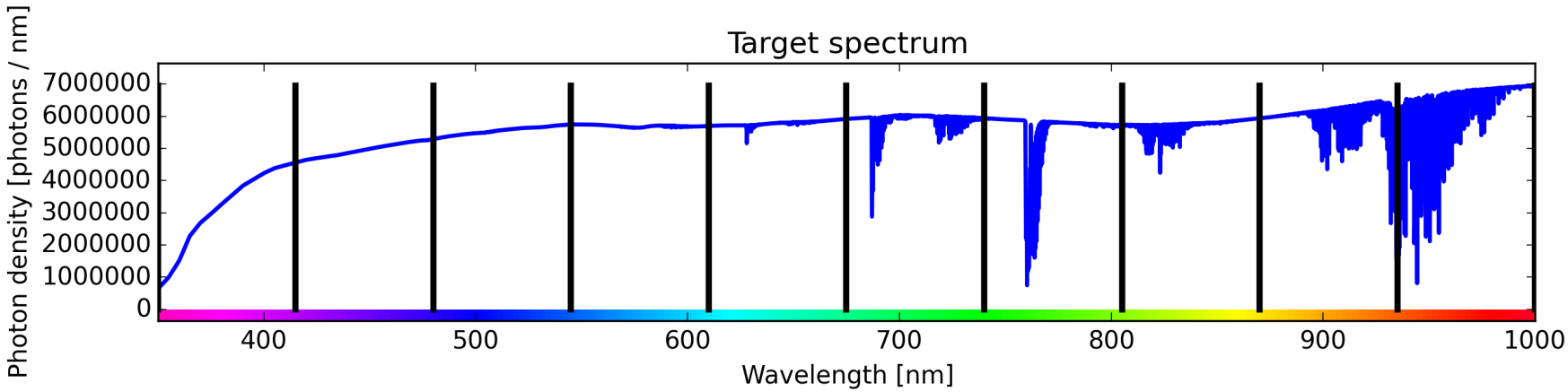
TOAD Modules



- Data transmitted between modules (the arrows) in a uniform data interface

Data model illustration





Current Section

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Step by Step Instrument Performance

End-to-End Simulation Results

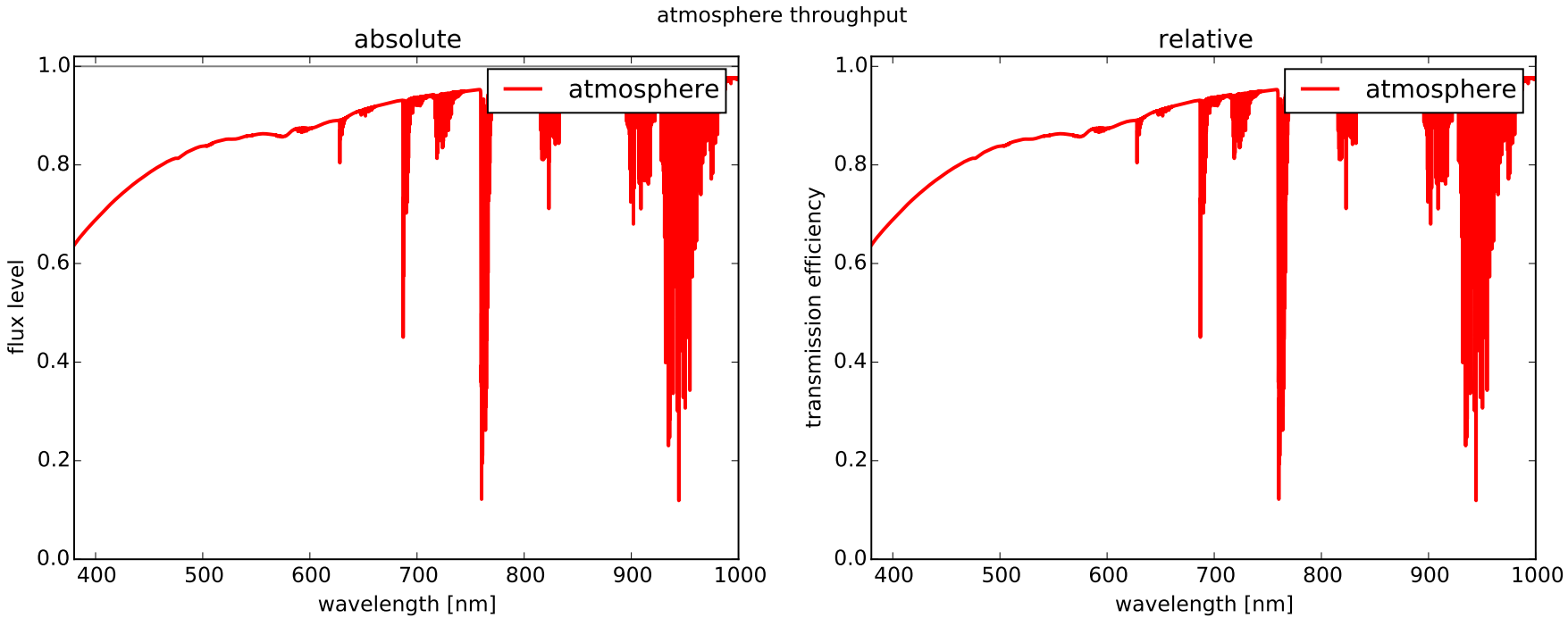
Atmosphere

- Seeing
  - Wavelength dependent: $s_\lambda = s_{500} \cdot \left(\frac{500}{\lambda}\right)^{\frac{4}{5}}$
  - Moffat profile with $\beta = 2.5$
- Absorption
  - Extinction calculation via ESO SkyCalc
  - No clouds (can be implemented)
- Emission
  - Replaces light plane data with emission spectrum
  - Using ESO SkyCalc

`https://www.eso.org/observing/etc/skycalc/`

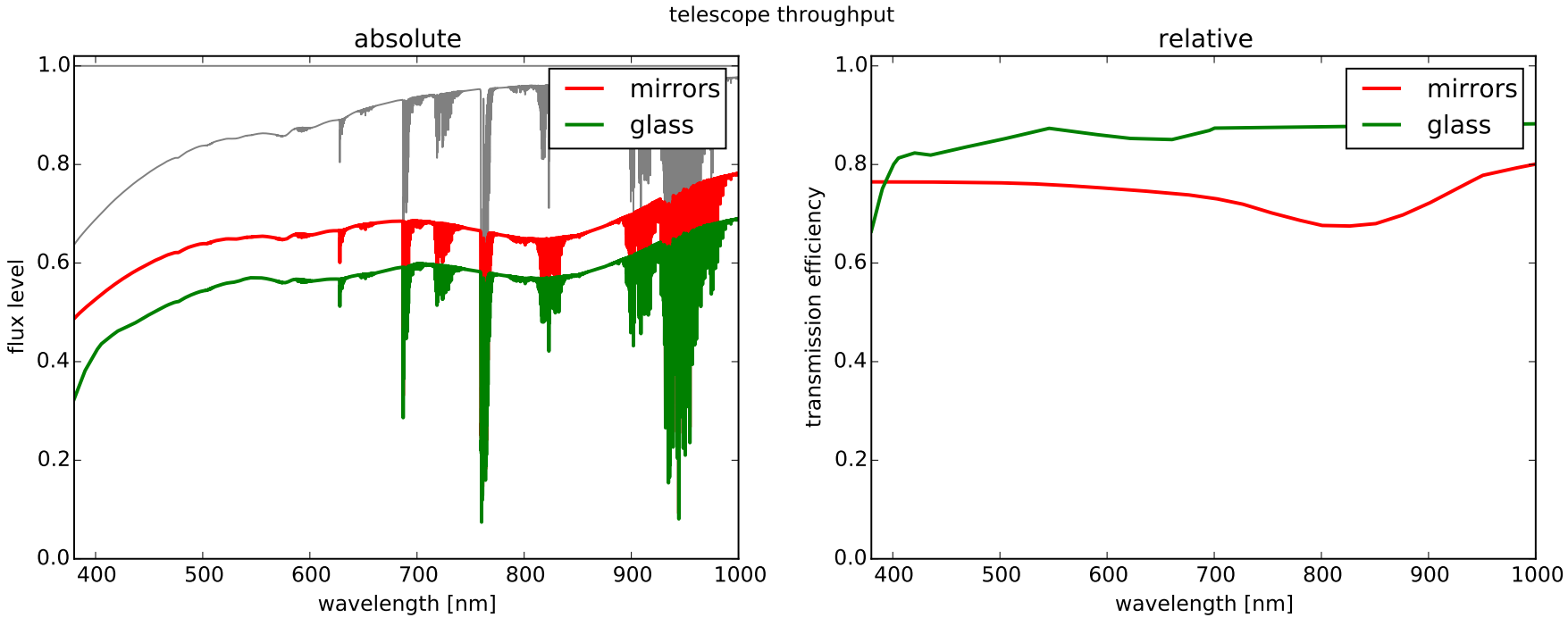
Atmosphere Throughput

- Median seeing: 0.9″ (0.8″ at zenith) at 500nm and median airmass: 1.2



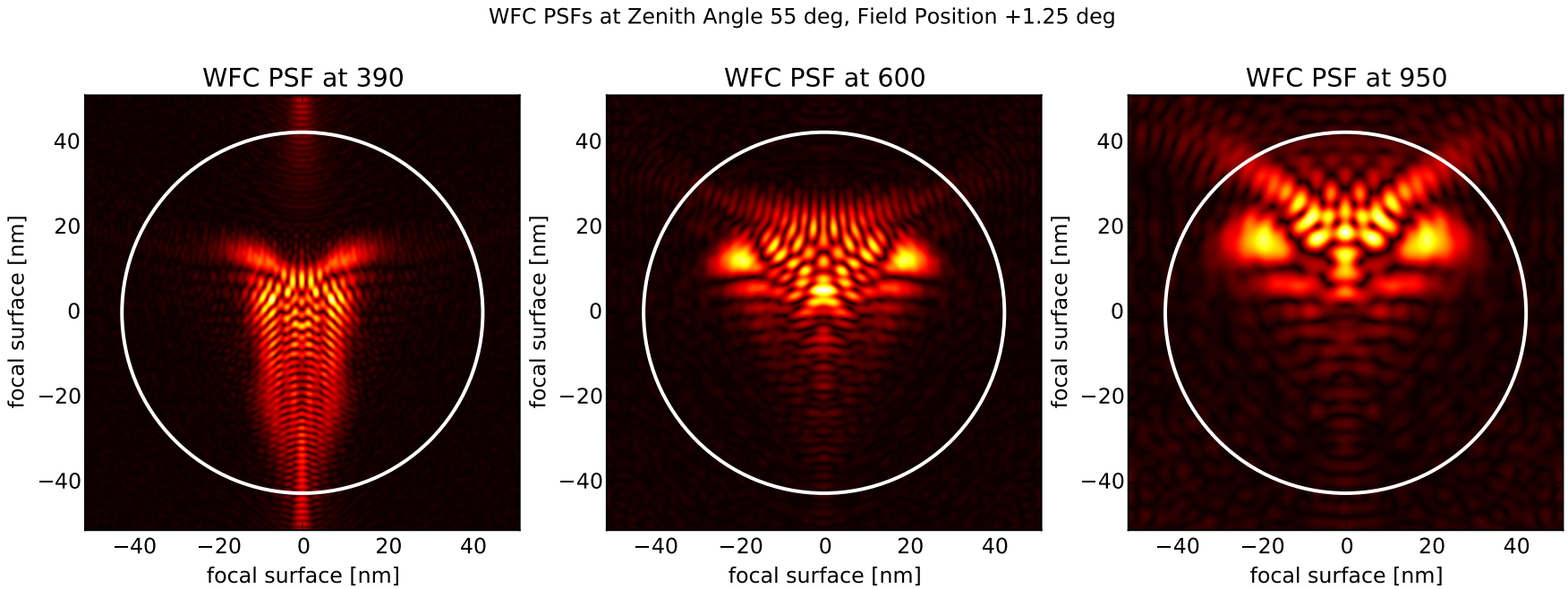
Telescope and WFC/ADC

- Mirror reflectivity based on material values after CO_2 cleaning
- Glass throughput based on material, thickness and coatings



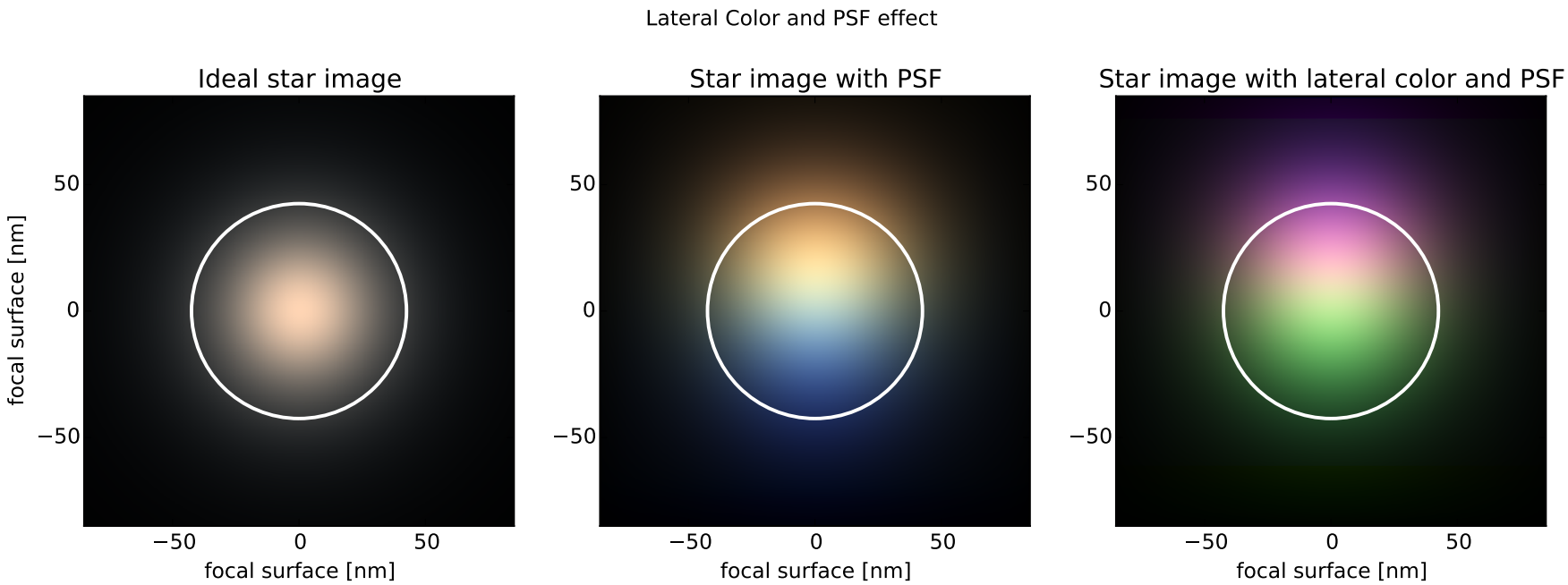
ADC/WFC Point Spread Functions

- ZEMAX simulations
- Field position: +1.25 deg, ZA: 55 deg (airmass: 1.75)
- Intensity scaled colors for better visibility
- For reference: fibre indicated by white circle



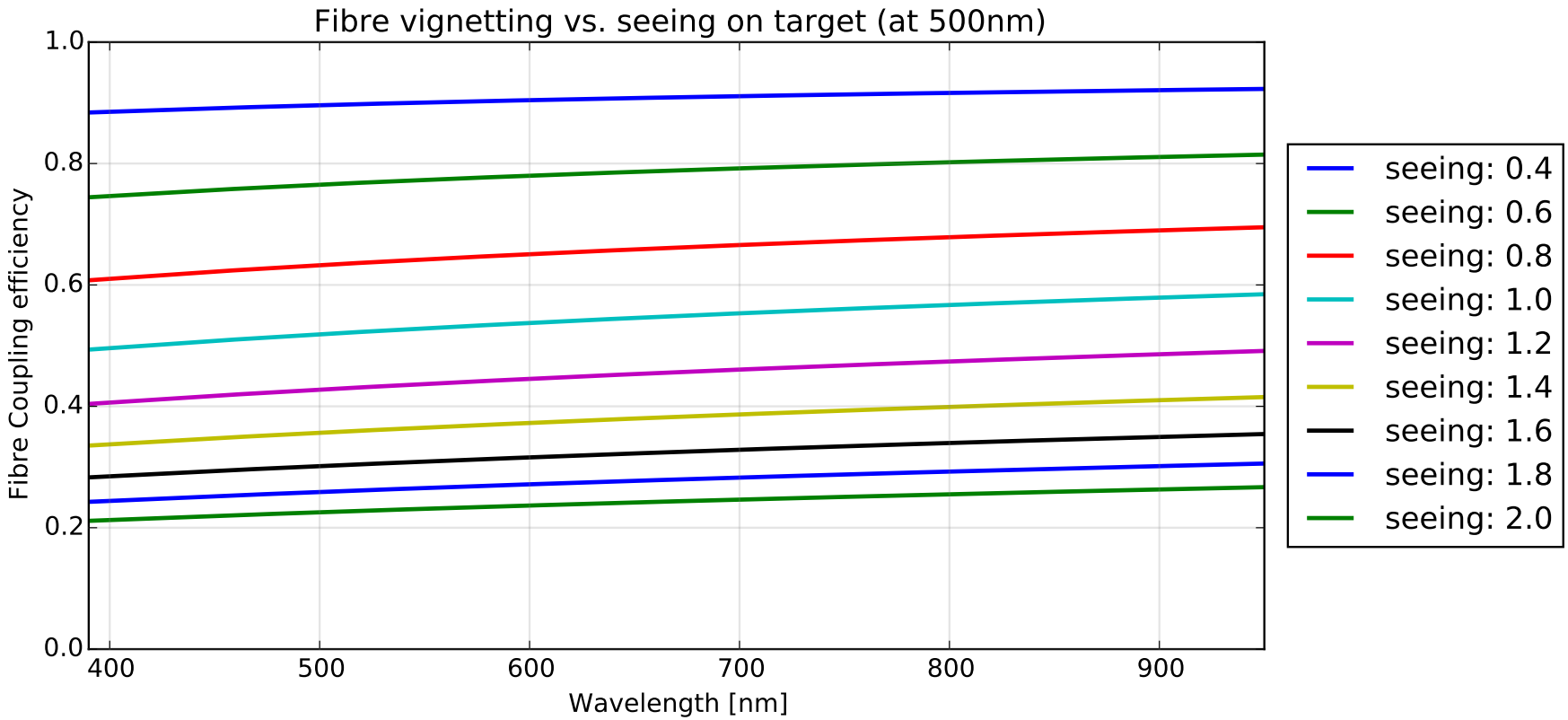
ADC/WFC PSF and Lateral Color

- Field position: $+1.25$ deg, ZA: 55 deg (airmass: 1.75)
- Seeing: $1.0''$ at 500*nm* and airmass 1.75
- Focus position probably small influence on color



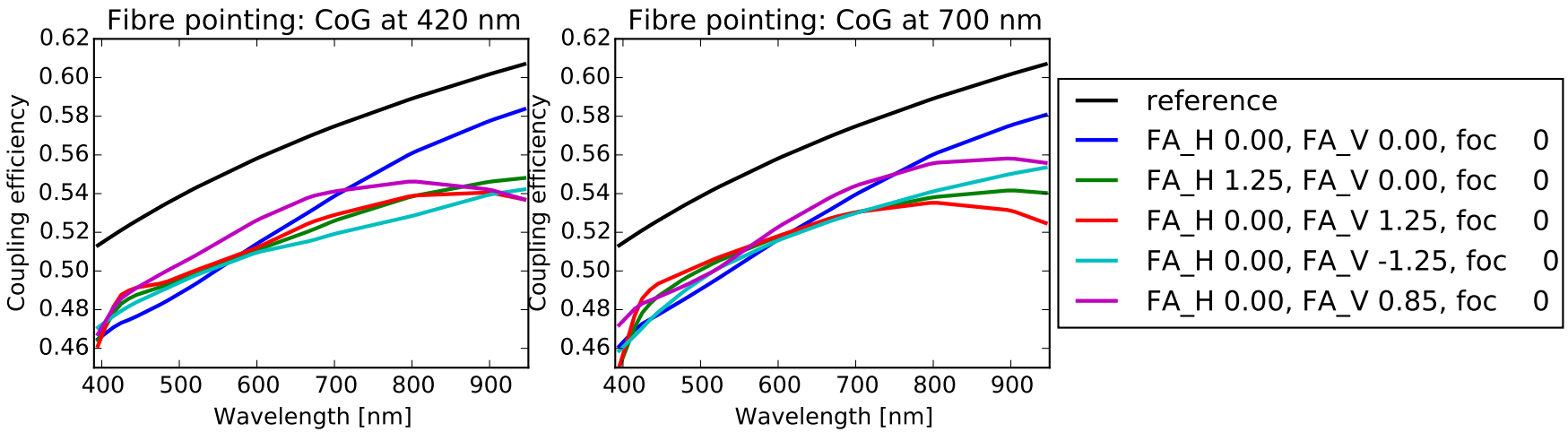
Fibre Vignetting and Seeing

- Ideal telescope considered for this plot (no PSF effect mentioned last slide)



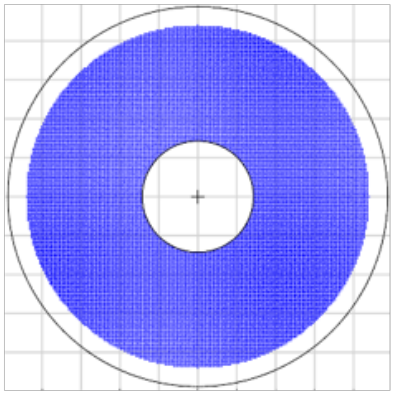
ADC/WFC PSF and Lateral Color

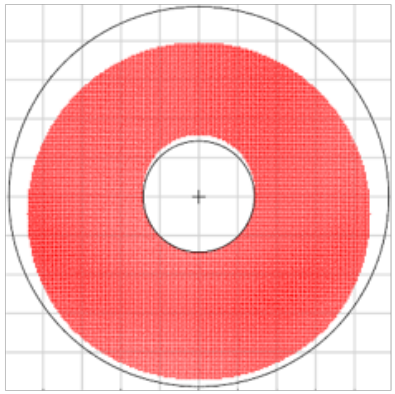
- Fibre centred at the CoG of the target image at 420nm (left) and 700nm (right)
- Only relevant for (near-) point sources
- Effect not visible with the fibre flat



Coming soon to TOAD

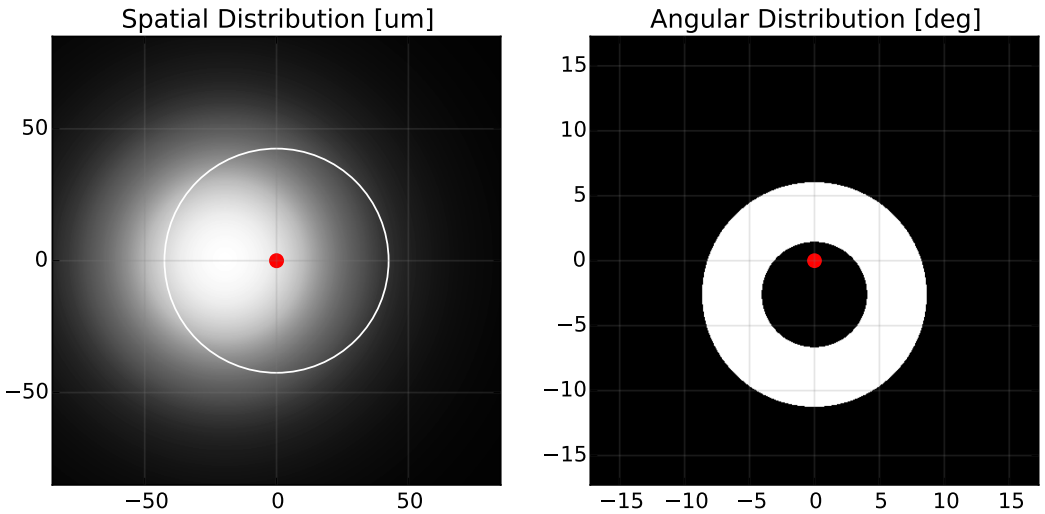
- Field dependent effects
  - Illuminated section of M1
  - Position of central obstruction
- Field and Cassegrain rotation dependent
  - M2-spider vignetting
- TOAD will be able to quantize the effects





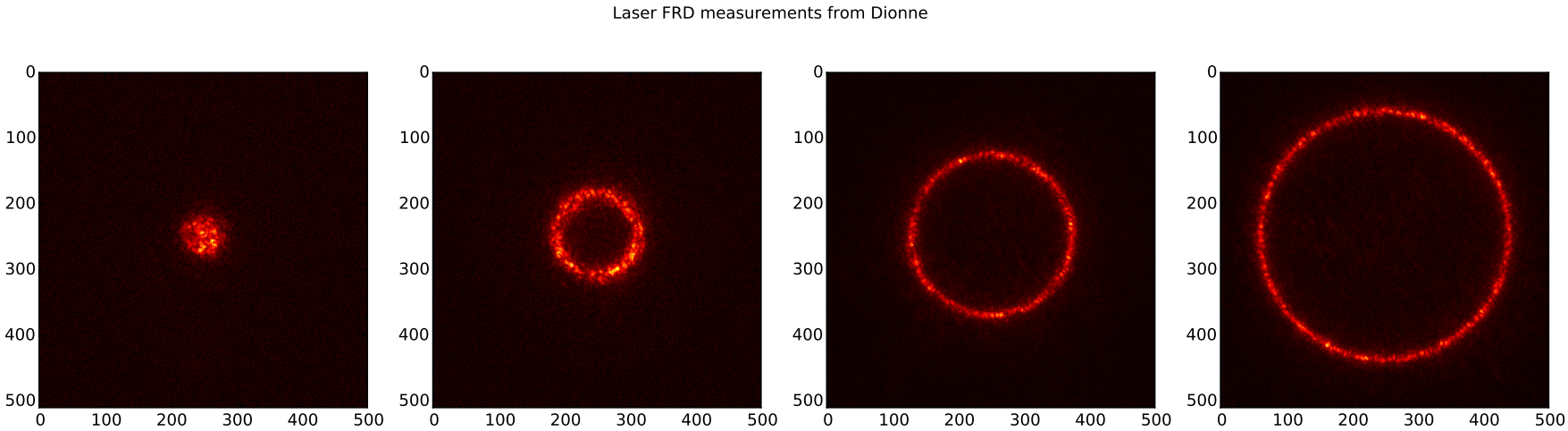
Positioner Simulation

- 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)

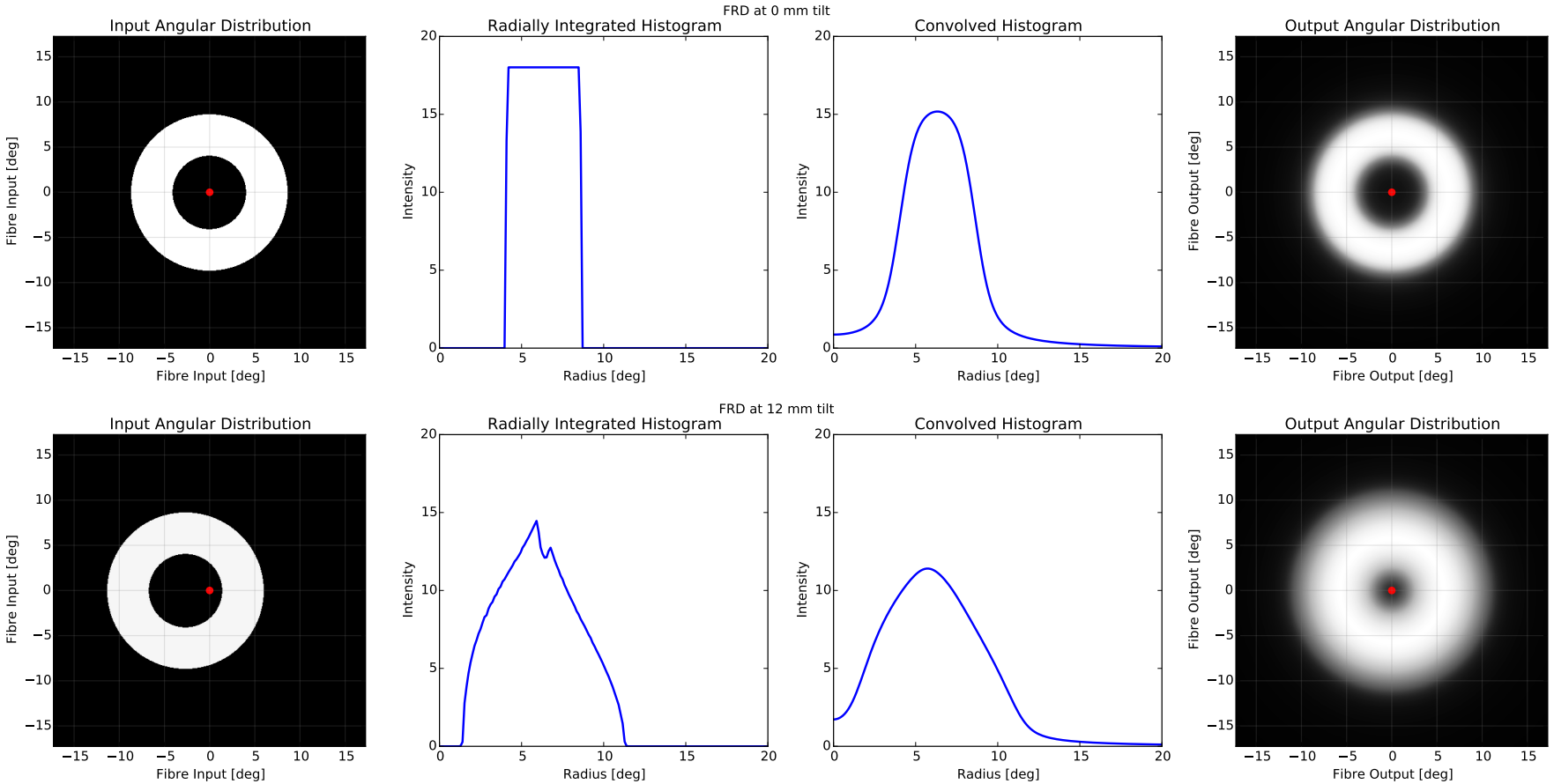


Fibre FRD: Laser measurements

- Azimuthal scrambling
- Focal ratio degredation (FRD)
- Old laser FRD measurements by Dionne, new model based on fibre prototype

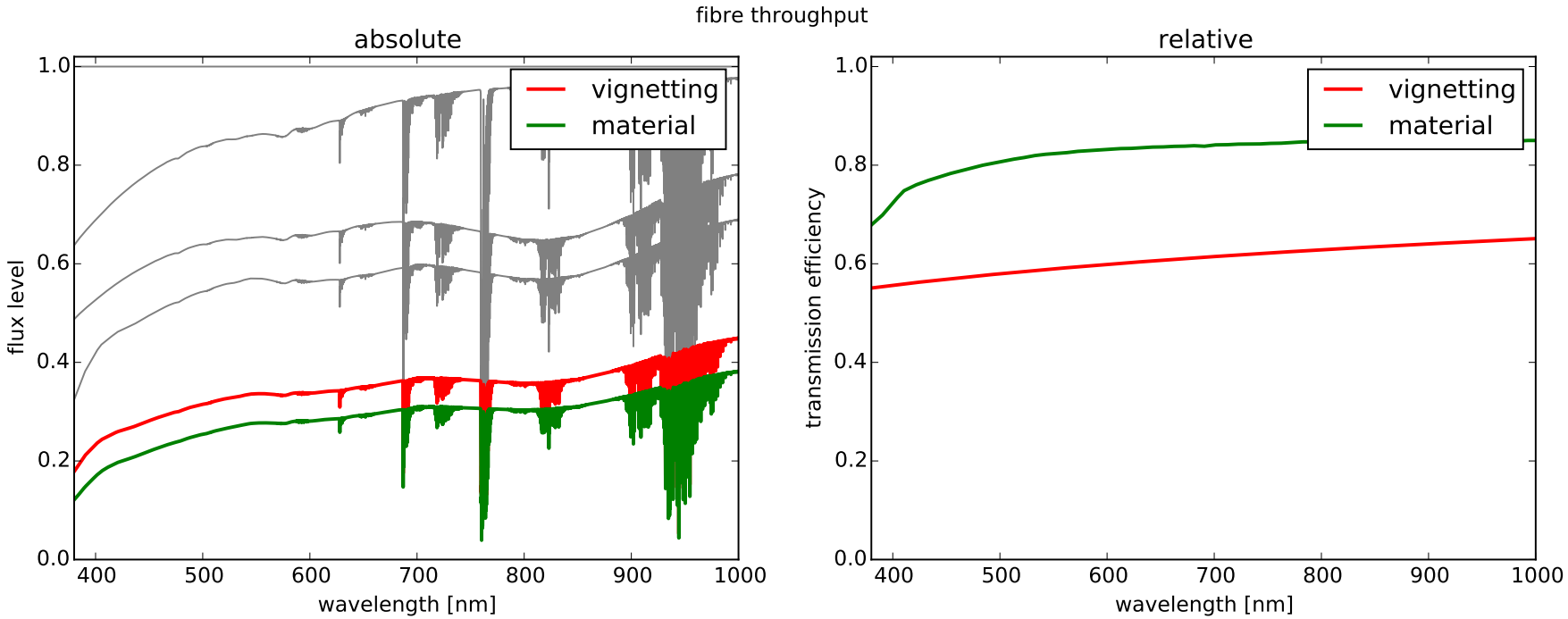


Fibre FRD: Simulations



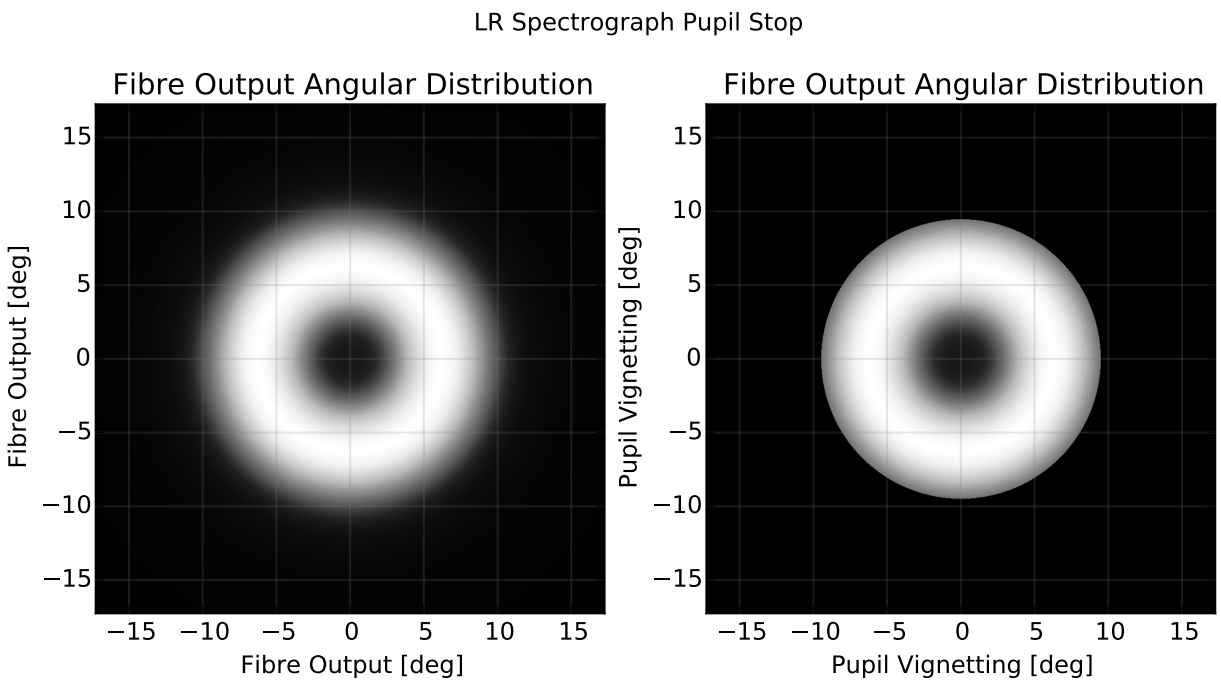
Fibre Throughput

- Seeing 0.9″ at 500*nm* and airmass 1.2
- Fibre Tilt: 7*mm*, fibre misalignment: 10μm ($\approx$ 0.15″)
- Fibre length: 20*m*



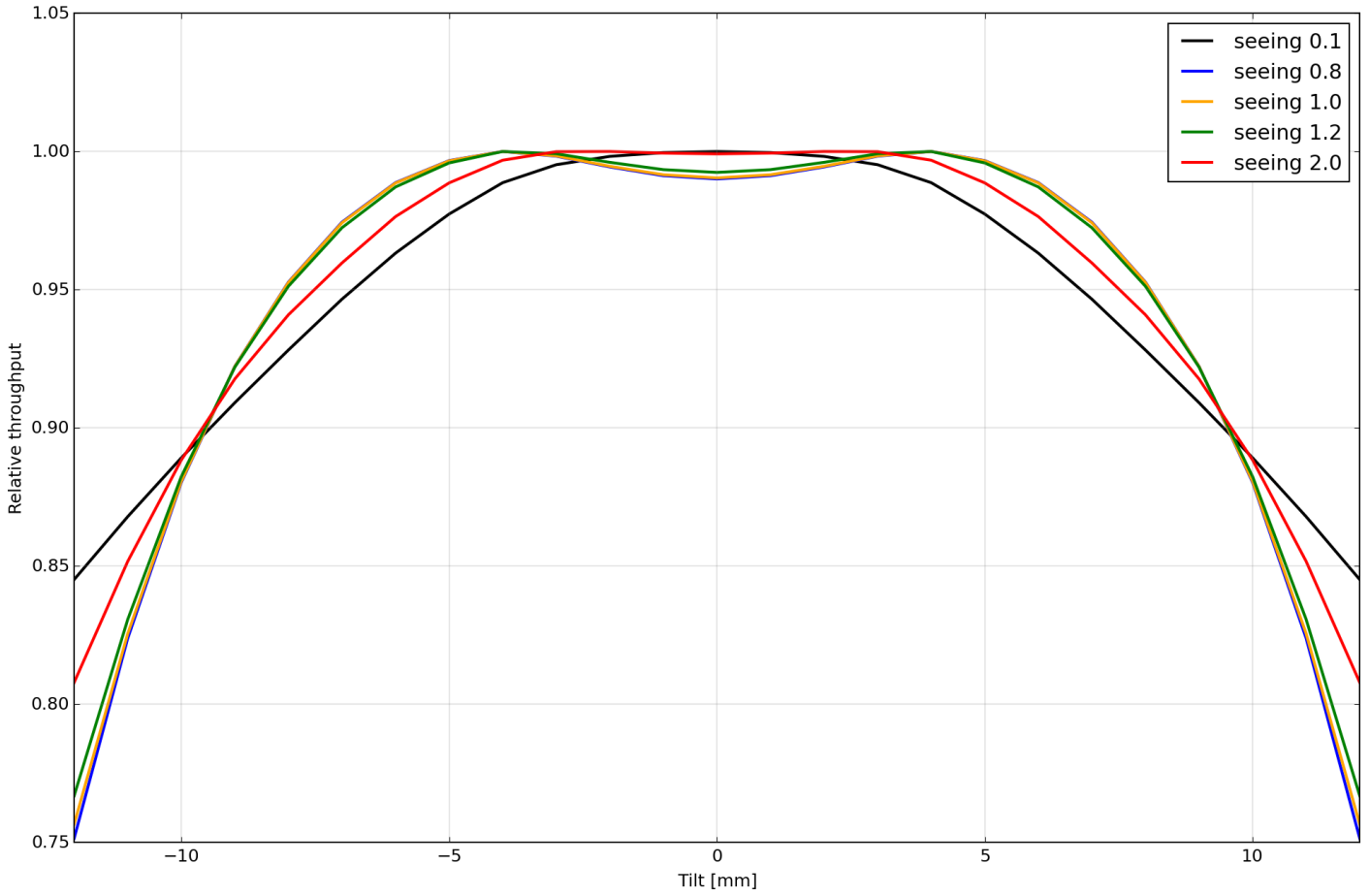
Spectrograph Pupil Stop

- Pupil stop at f/3
- Only good quality photons go through



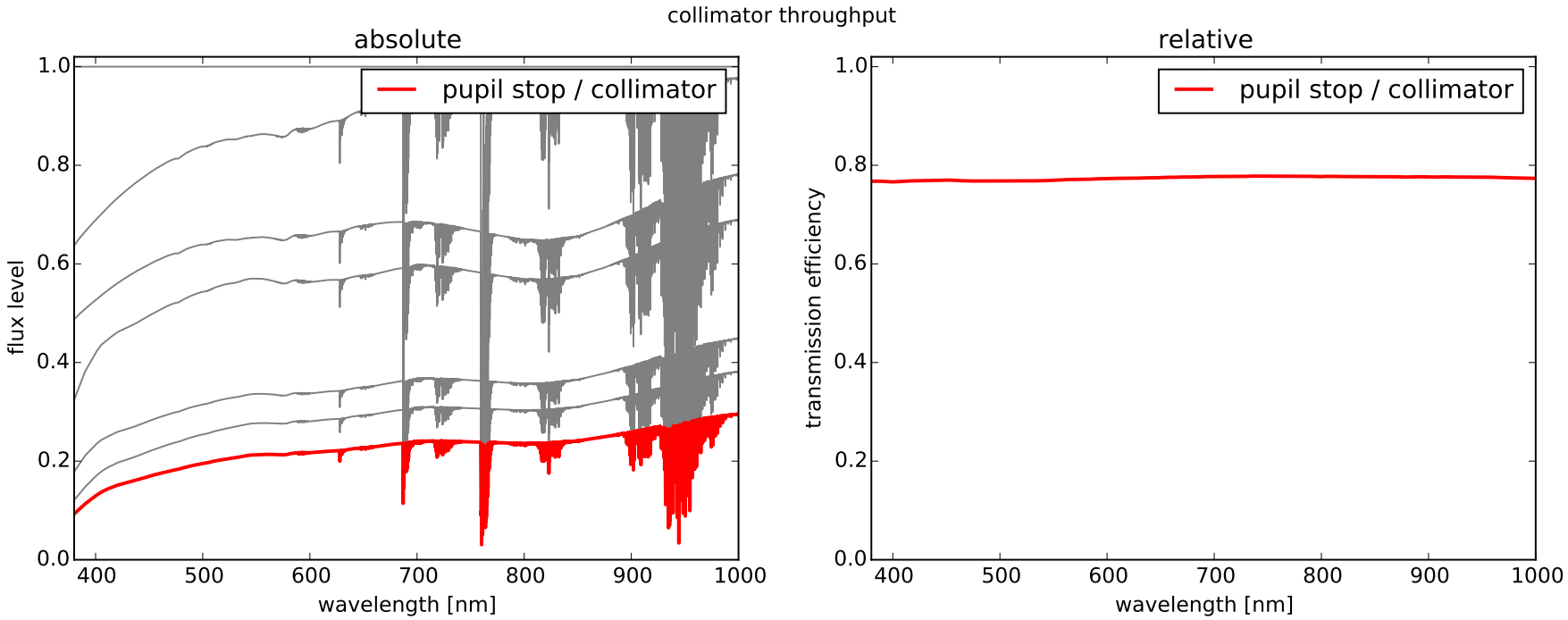
Throughput vs. Fibre Tilt

- Combined effect of fibre tilt induced focus losses and fibre tilt induced spectrograph-pupil losses



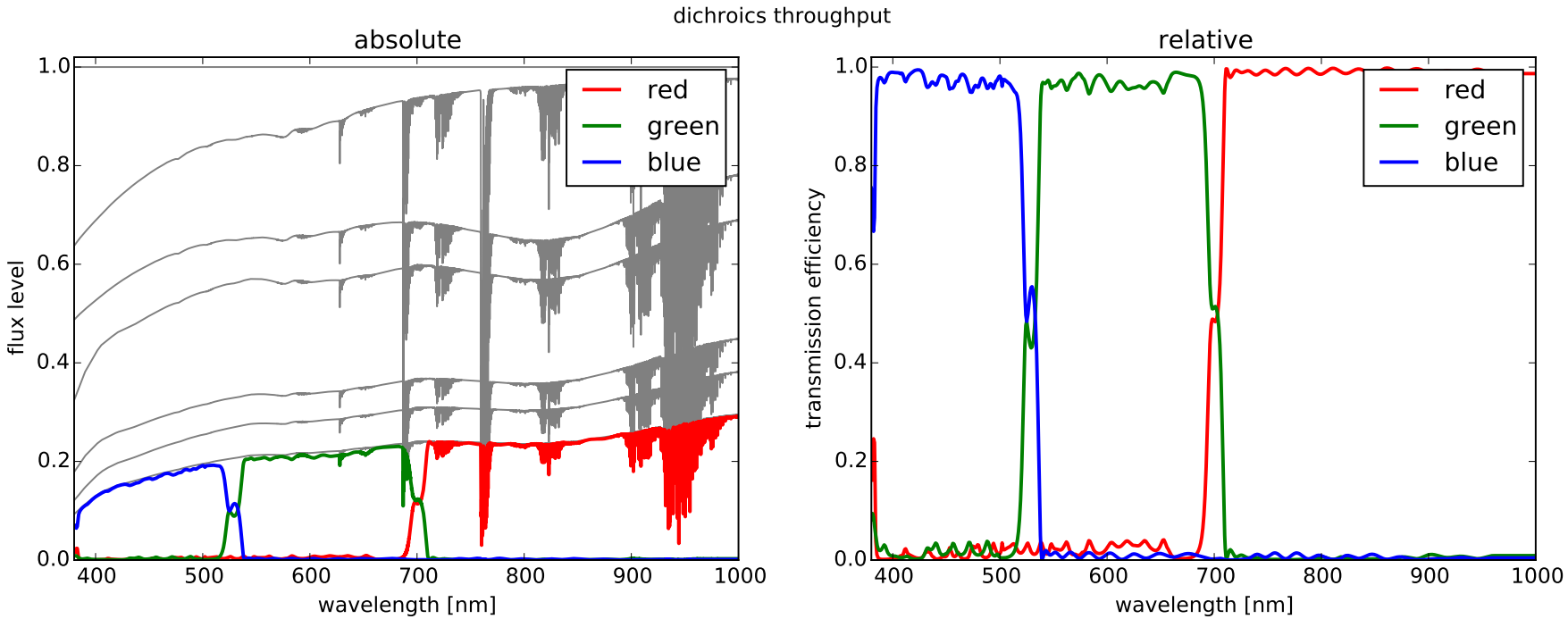
Collimator and Pupil Stop Throughput

- Median seeing: $0.9''$ at $500nm$, (median ?) fibre Tilt: $7mm$, approx. median fibre misalignment: $10\mu m$ ($\approx 0.15''$)
- Pupil Stop at $f/3.0$



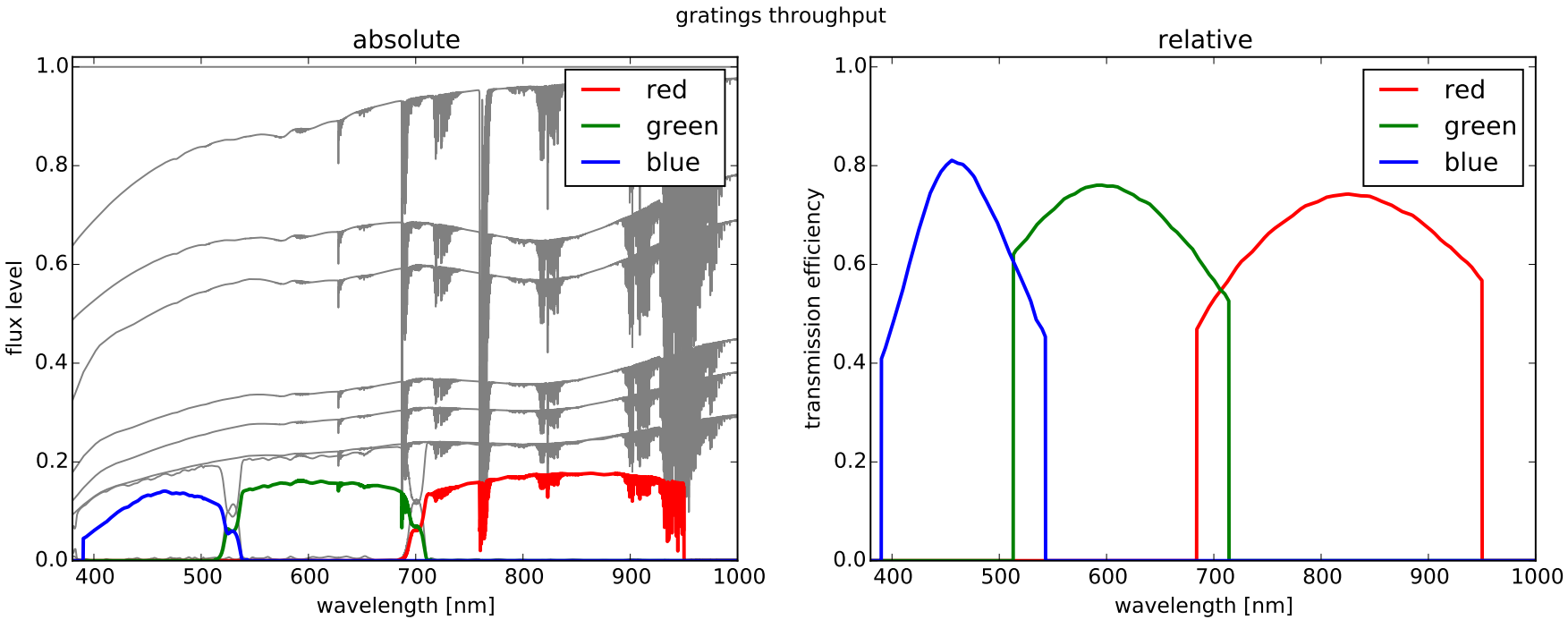
LR Spectrograph Dichroics Throughput

- Dichroic model guestimated by rescaling one example curve



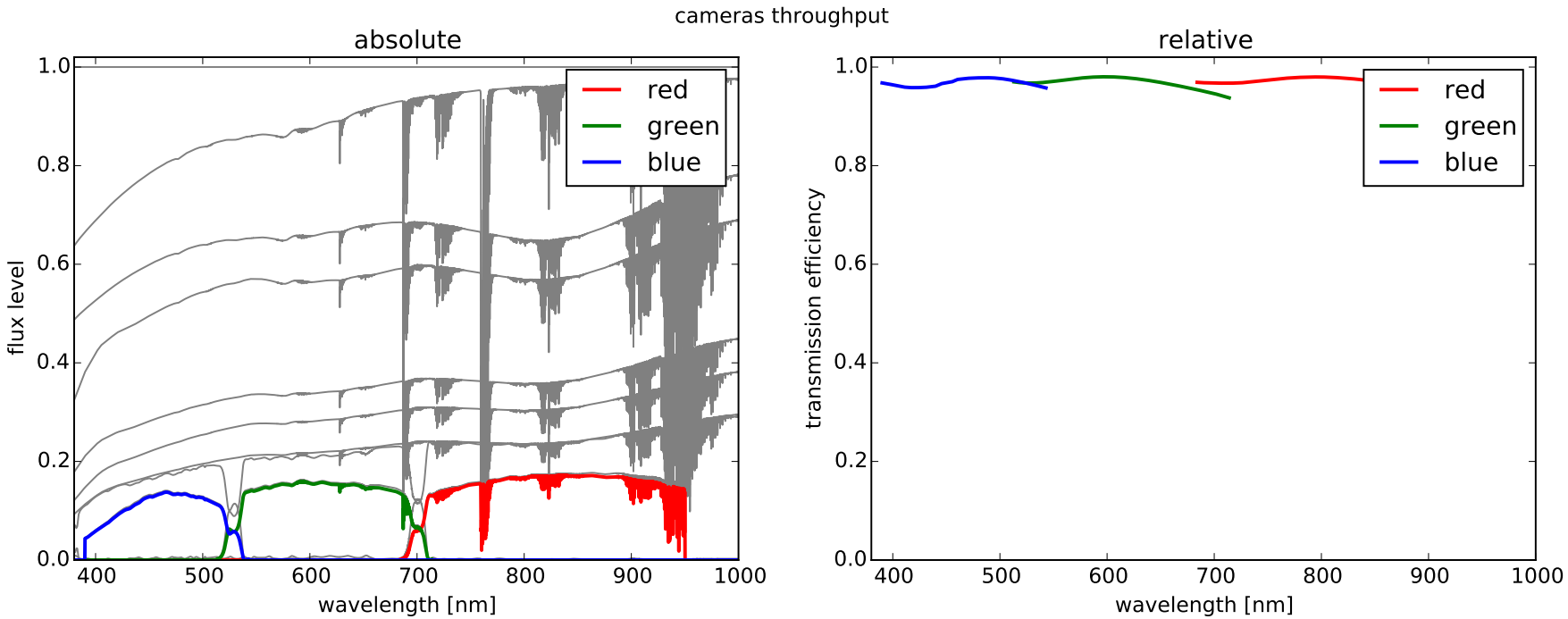
LR Spectrograph VPH Throughput

- VPH blaze simulation from Sam



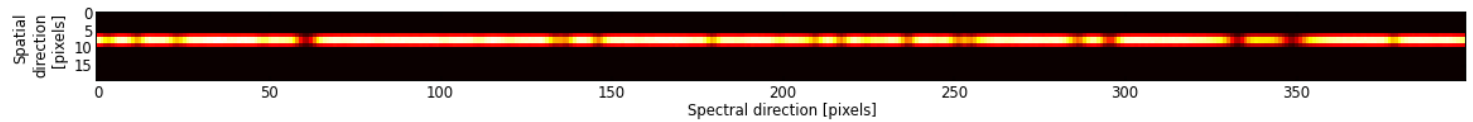
LR Spectrograph Camera Throughput

- Glass throughput based on material, thickness and coatings



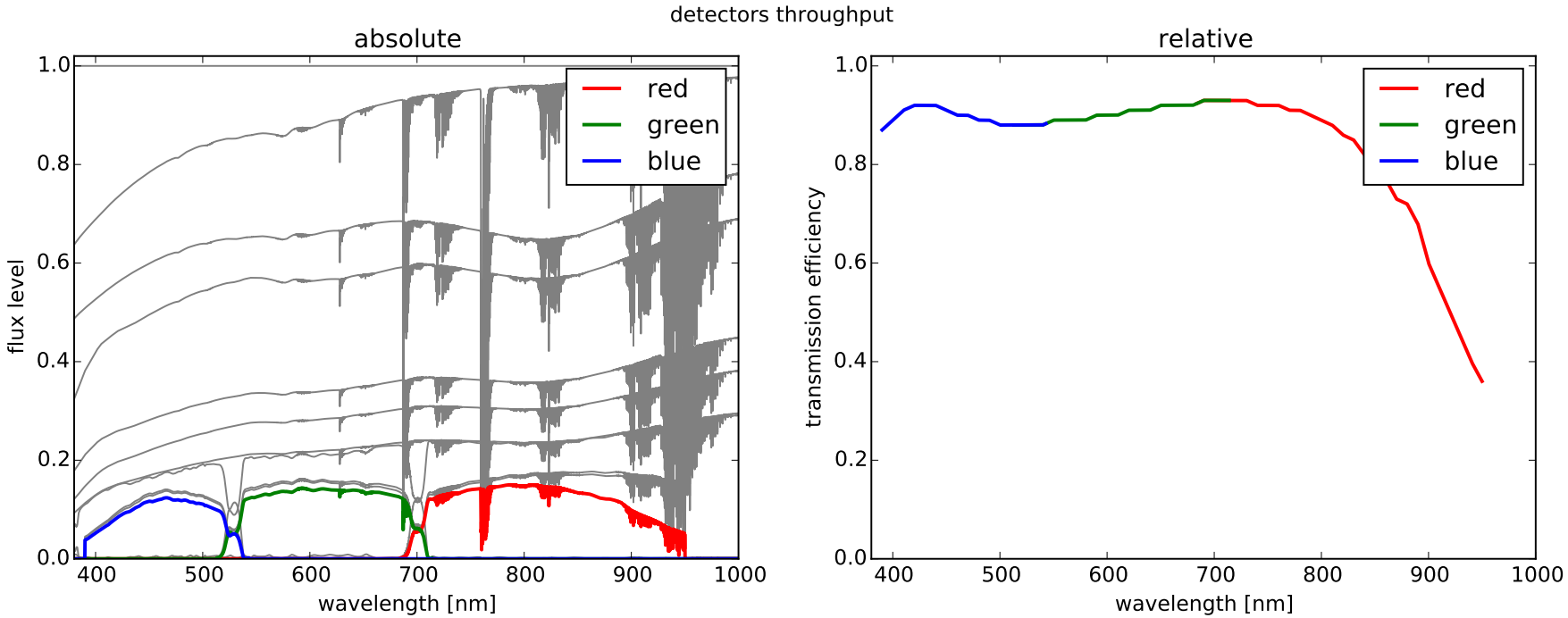
2D detector simulation

- Projection of light on detector by ’stamping’ fibre image
- Effects taken into account (planned, near-future procedure):
  - All effects wavelength and slit position dependent
  - Dispersion map, distortion map, spectrograph PSFs, scattered light
- Noise on detector separately stored from target flux
- Randomized pixel flux possible
- Full detector population with individual targets possible
- First 2D data for data reduction after PDR



Detector 'Throughput'

- QE curve provided Olaf
- S/N calculations based on detector image



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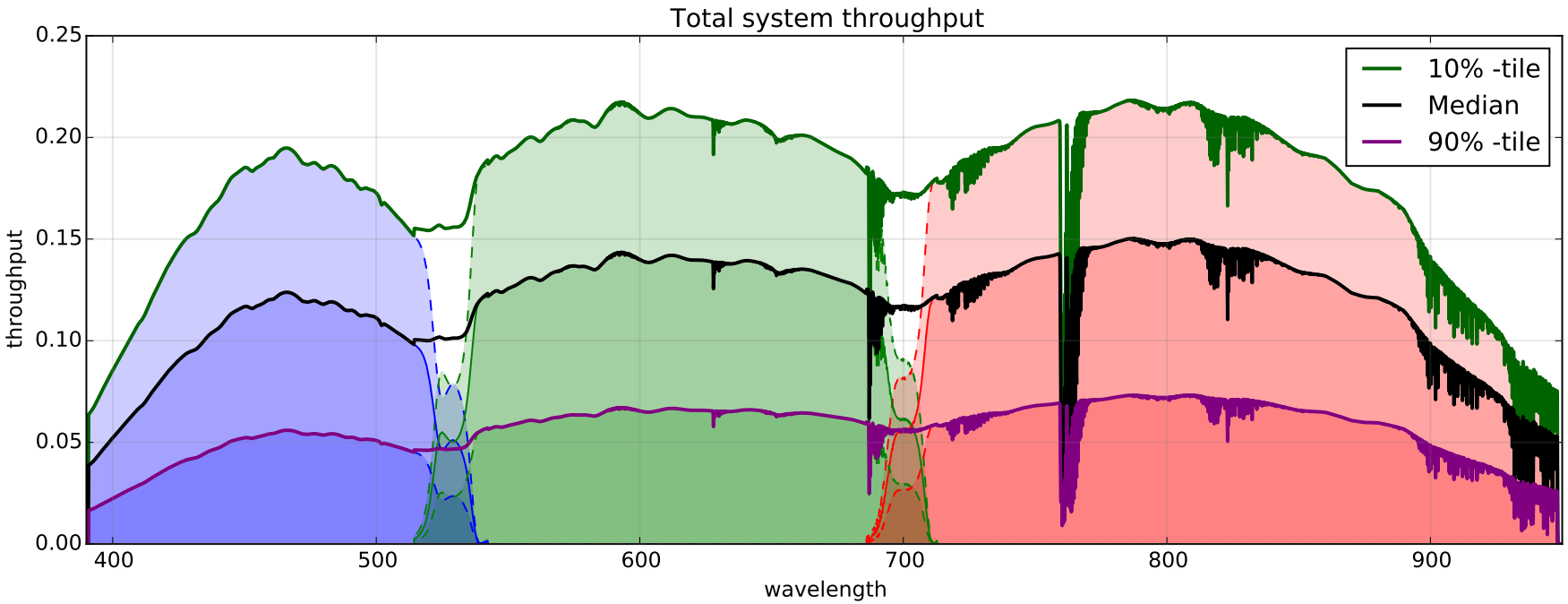
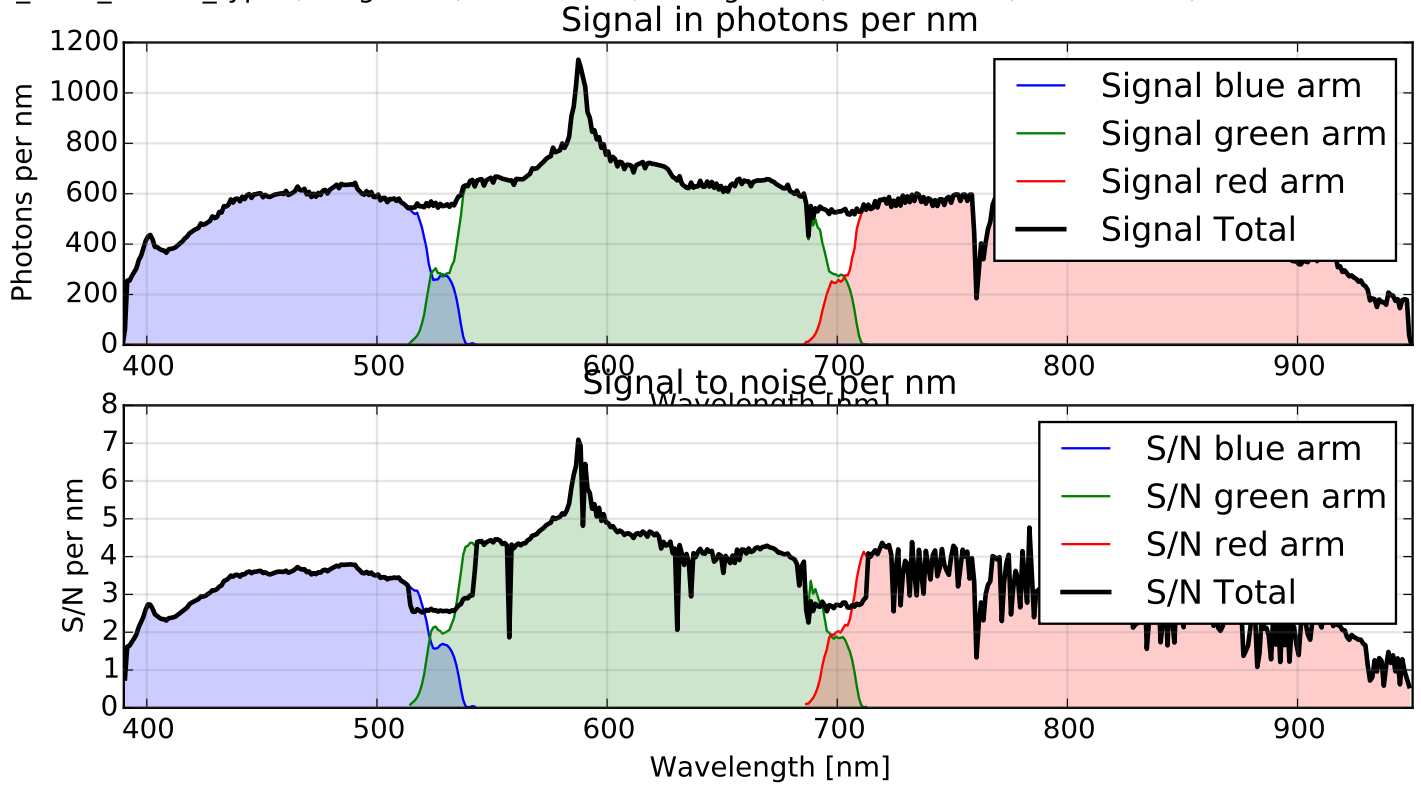
Final throughput

- 10%-tile: am=1.02, s=0.5” (0.5” at z), t=4mm, missal=2μm
- Median: am=1.2, s=0.9” (0.8” at z), t=7mm, missal=10μm
- 90%-tile: am=1.5, s=1.53” (1.2” at z), t=10mm, missal=20μm



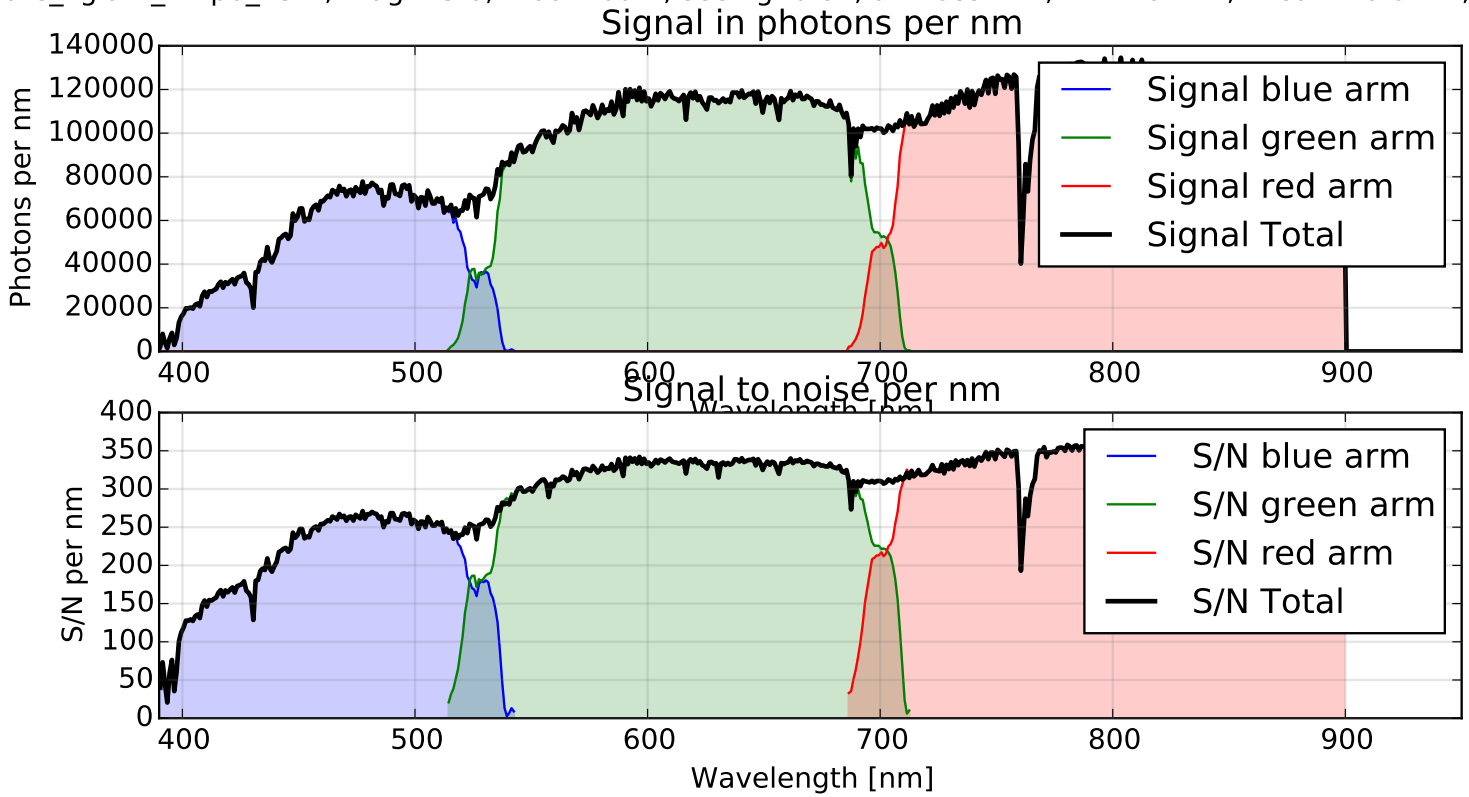
AGN, $z = 1.1$, $mag = 22.5$

AGN_v1.0_z110_mr225_type1, mag: 22.5, moon: dark, seeing: 0.81, airmass: 1.2, tilt: 7.0 mm, misall: 10.0 nm, exposures: 6



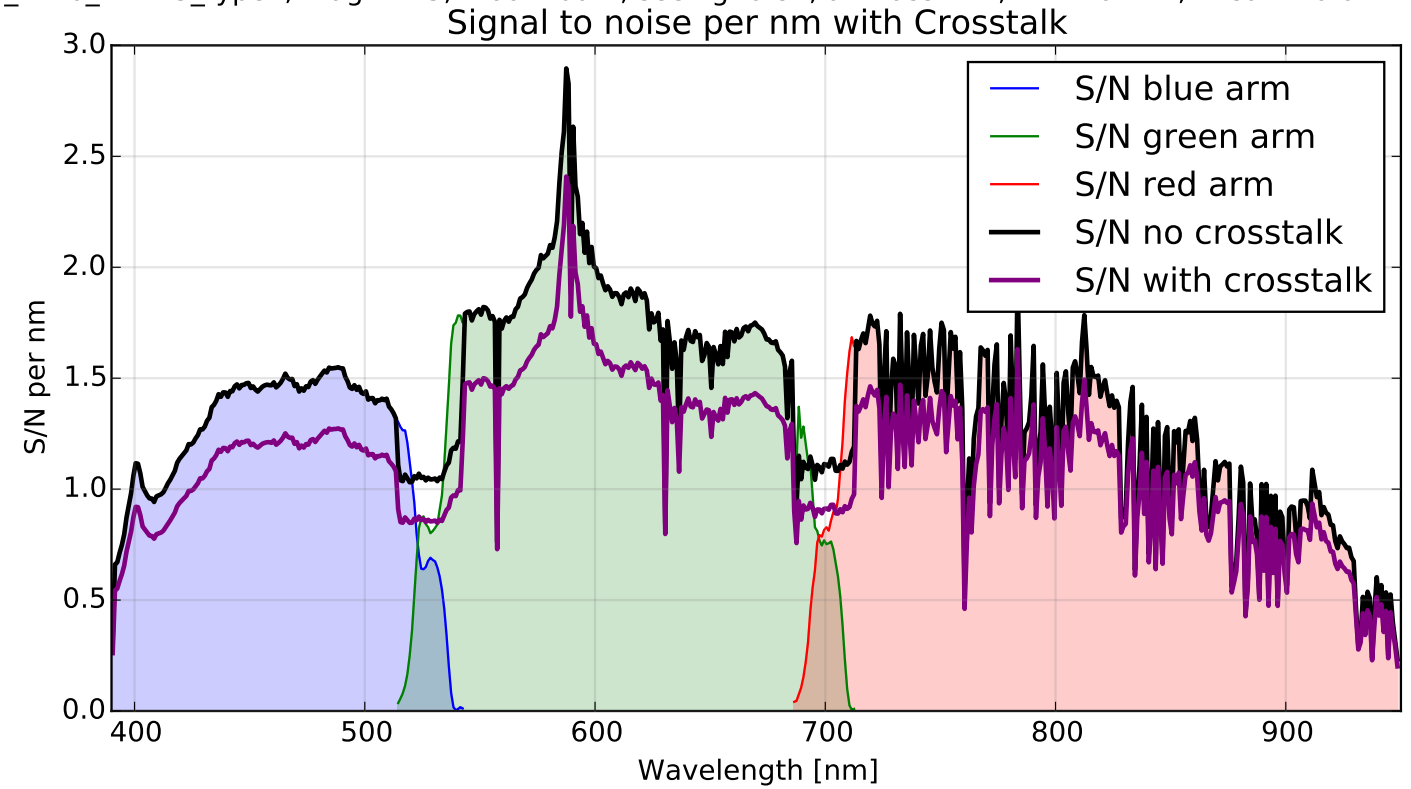
Halo Red Giant *mag* = 15

template_kgiant_m1p0_15th, mag: 15.0, moon: dark, seeing: 0.81, airmass: 1.2, tilt: 7.0 mm, misall: 10.0 nm, exposures: 1



Crosstalk: AGN and Halo Red Giant

AGN_v1.0_z110_mr225_type1, mag: 22.5, moon: dark, seeing: 0.81, airmass: 1.2, tilt: 7.0 mm, misall: 10.0 nm, exposures: 1



Summary

- TOAD requires input from almost all subsystems
- TOAD will evolve over time
- Verification by using ZEMAX for optics parts and prototypes for fibres
- For simulation requests:
  - Assign a JIRA ticket to rwinkler, for scientists oschnurr as watcher
  - Make sure you know what you want
  - Results and discussion will happen within the JIRA ticket for documentation
- TOAD will be become open source shortly after commissioning