VIRTUAL MOONS

the MOONS focal plane simulator

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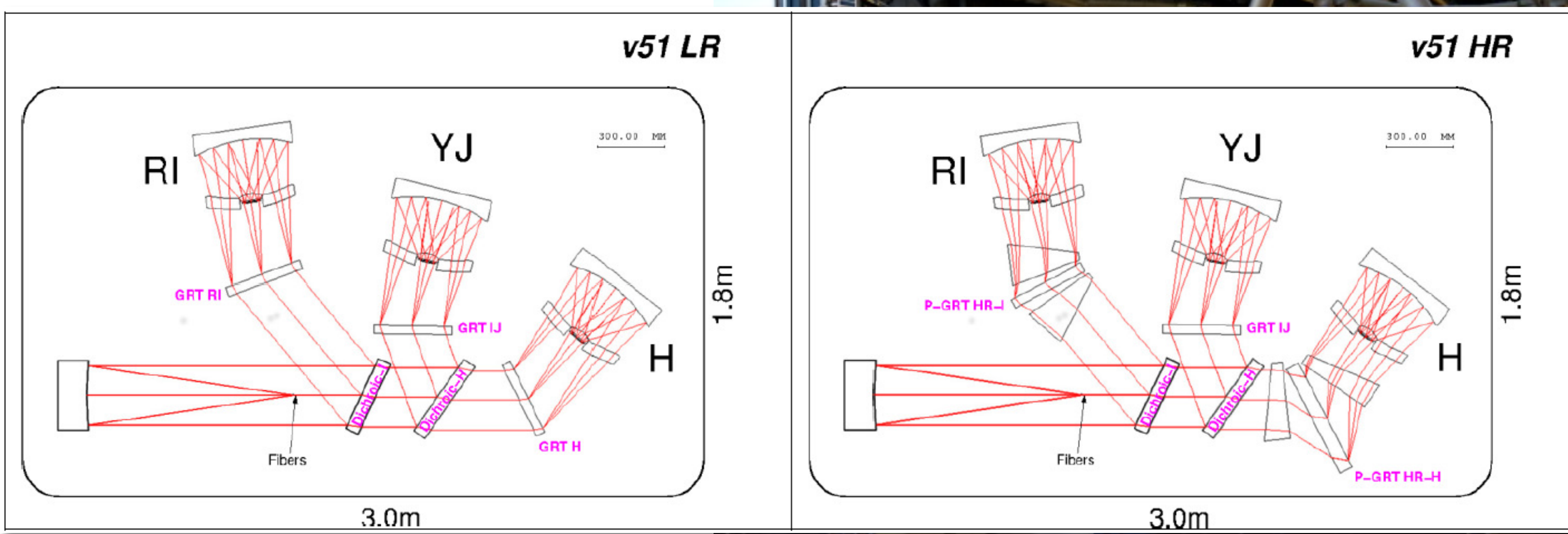
Moons

Multi Object Optical and Near-infrared Spectrograph for the VLT

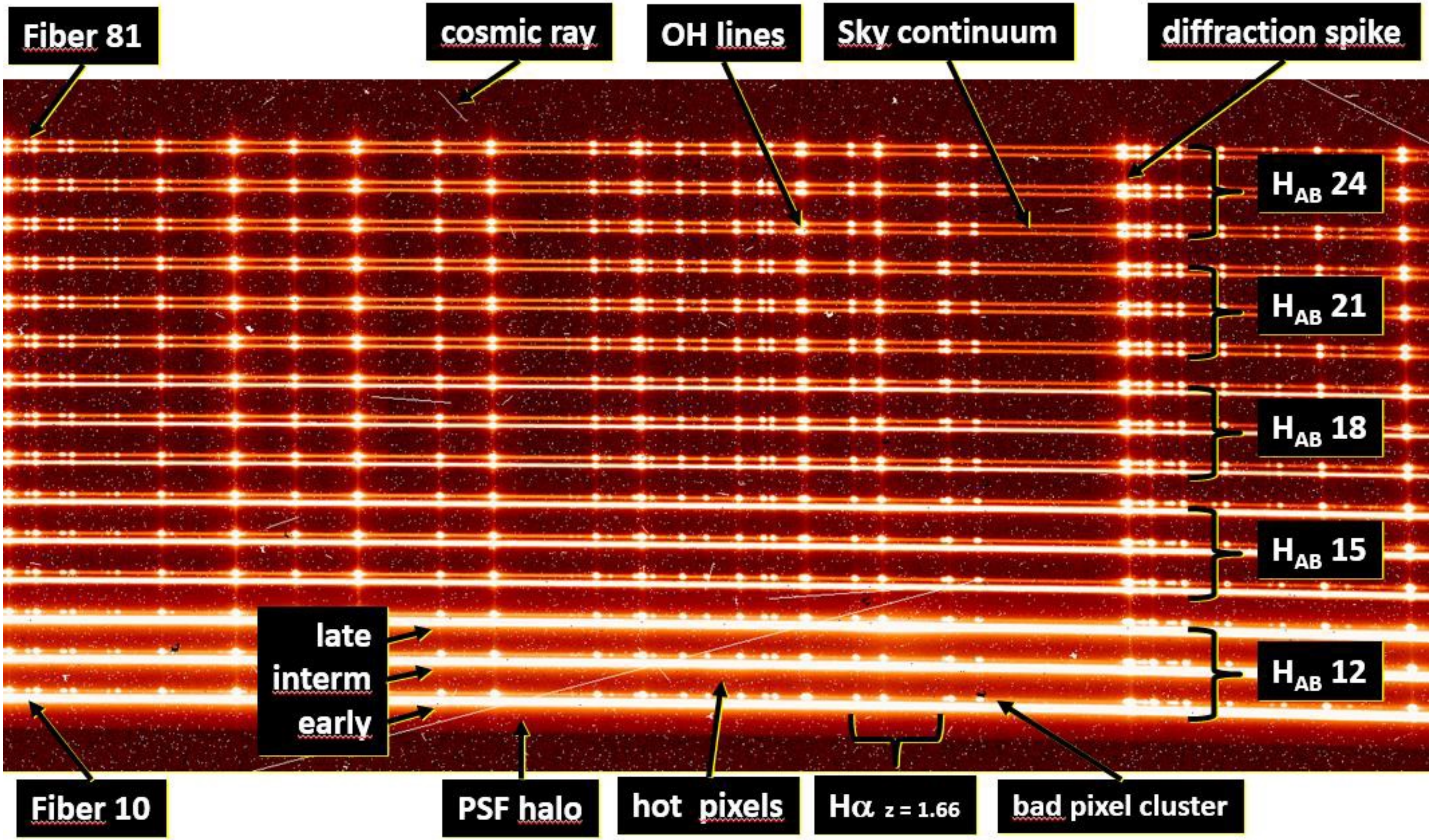
Specifications	
Field of View	**500 square arcmin**
Multiplex	**1024 fibres**
Simultaneous λ-coverage	**0.8μm-1.8μm**
Low resolution mode	***R*~ 4,000 – 8,000**
High resolution mode	***R*~8,000 + R~20,000**

Arm/configuration	Spectral coverage	R at λ_c	Comment
RI arm, low resolution	0.647 – 0.955 μm	4100	Simultaneous in LR mode
YJ arm, low resolution	0.934 – 1.350 μm	4300	
H arm, low resolution	1.452 – 1.800 μm	6600	
RI arm, high resolution	0.765 – 0.898 μm	9200	Simultaneous in HR mode
YJ arm, low resolution	0.934 – 1.350 μm	4300	
H arm, high resolution	1.521 – 1.641 μm	18300	



“Virtual moons” simulator

End-to-end in 3 stages from source templates to detector image



“Virtual moons” simulator

End-to-end in 3 stages from source templates to detector image

MOONS needs a simulator for testing the following:

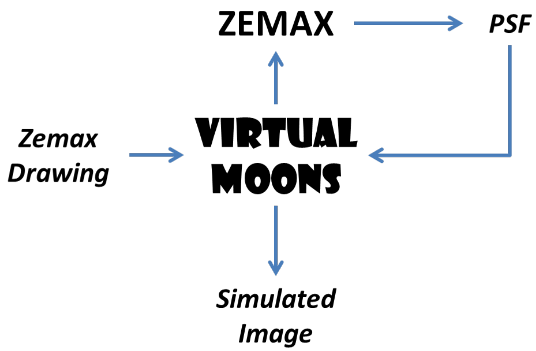
- **DRS pipeline**: extraction of 1D spectra from **highly packed spectral traces**
- **fiber cross talk** from PSF wings due to high fiber multiplex with a **very fast camera (F/0.95)**
- photon limited **OH subtraction**
- **pixel-to-pixel flat fielding** for very faint sources
- **PSF diffraction**

Three simulation stages:

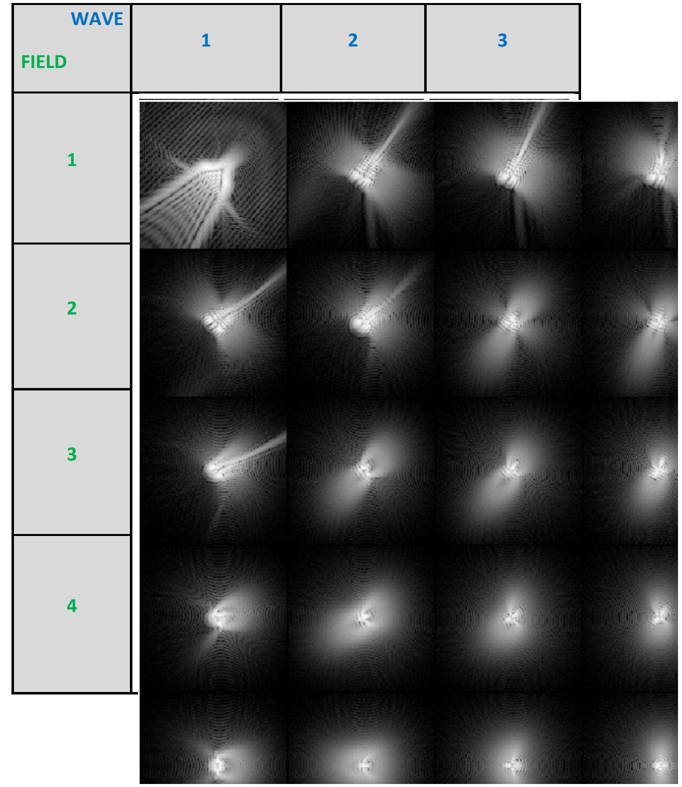
1. **Ideal spectral image on focal plane:**
   synthetic source spectra; sky and atmosphere; PSF variations and diffraction; dispersion and distortion as from ZEMAX optical design; etc.
2. **Physical simulation of the optics:**
   telescope and spectrograph optical budget; fiber optics transmission; VPH efficiencies; stray light; focal plane illumination; detector-induced defocus; etc.
3. **Photon noise and detector:**
   photon noise; gain, bias, dark, RON; pixel cross talk; pixel to pixel response; blooming, saturation, persistence; non linearity; bad pixels/clusters; cosmic rays; different reading schemes; etc.

Stage 1 – spot shape and location

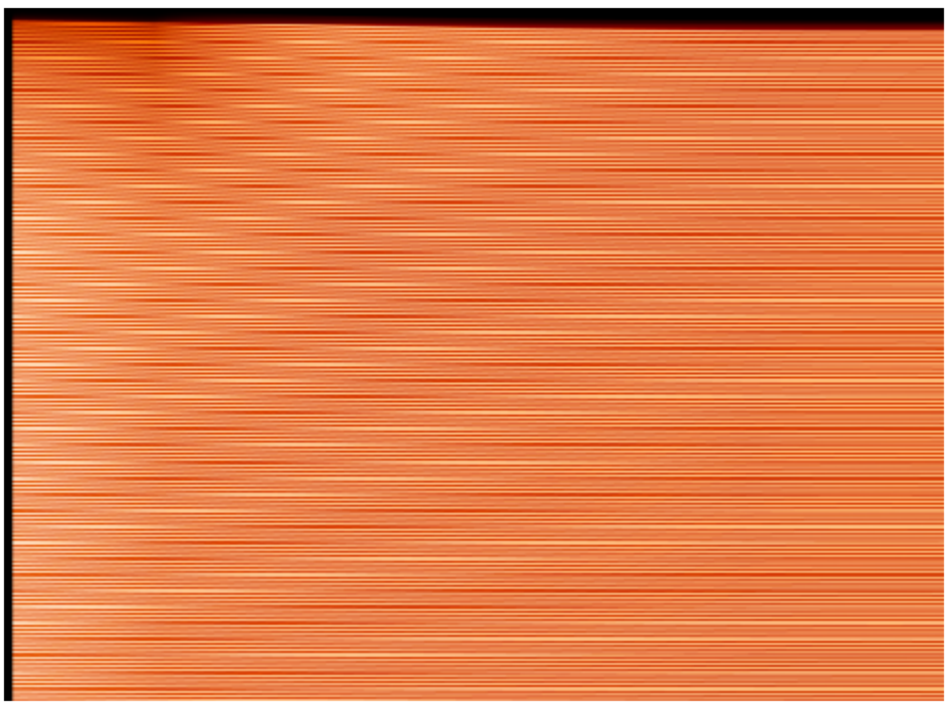
Optical aberrations and spot locations



Zemaxlib IDL library
by Lorenzo Busoni
https://github.com/lbusoni/zmxIDL
based on the ZEMAX DDE Toolbox for Matlab



Huyghens PSF aberrations



Spot location by
minimum curvature interpolation

Stage 1 – spot shape and location

Obstruction and diffraction spikes

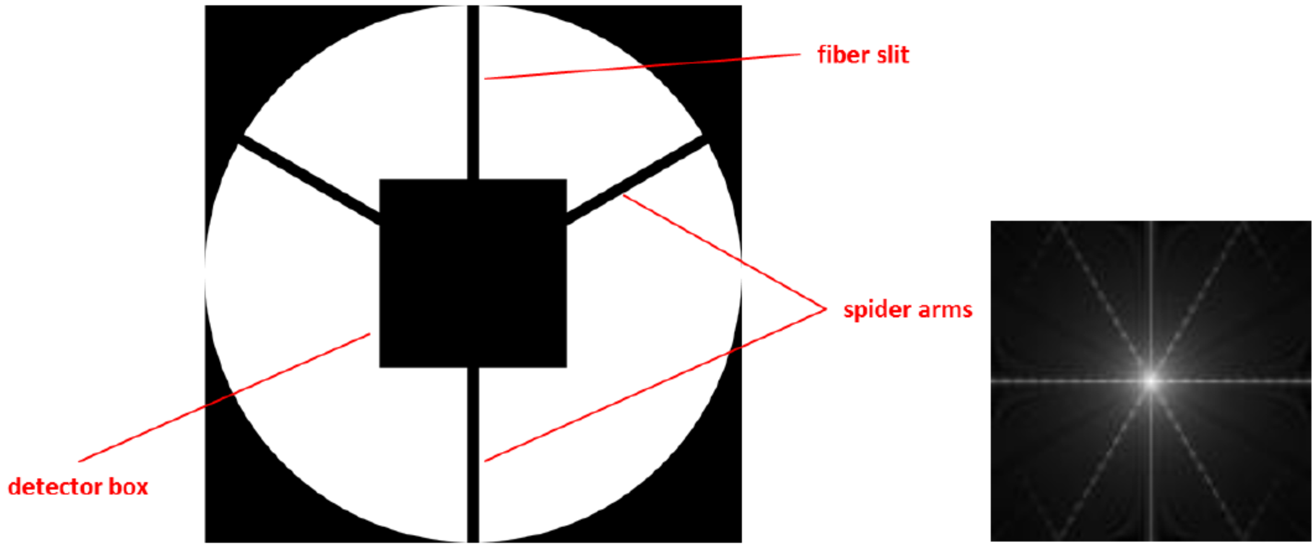


Figure 1: Obstruction and diffraction image (log grayscale) for an spot at detector center.

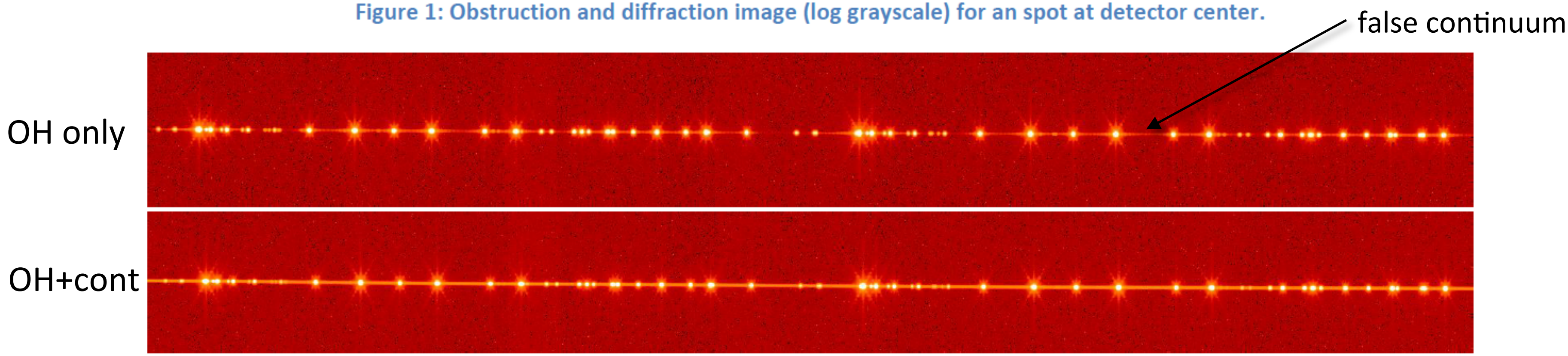
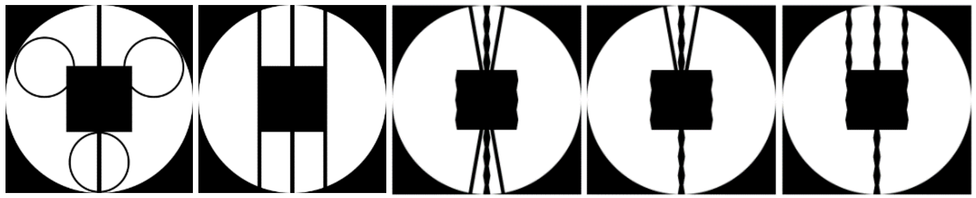


Figure 2: Focal plane simulation considering diffraction spikes (and no other effects): top spectrum is made by OH lines only, bottom spectrum is OH plus sky continuum.

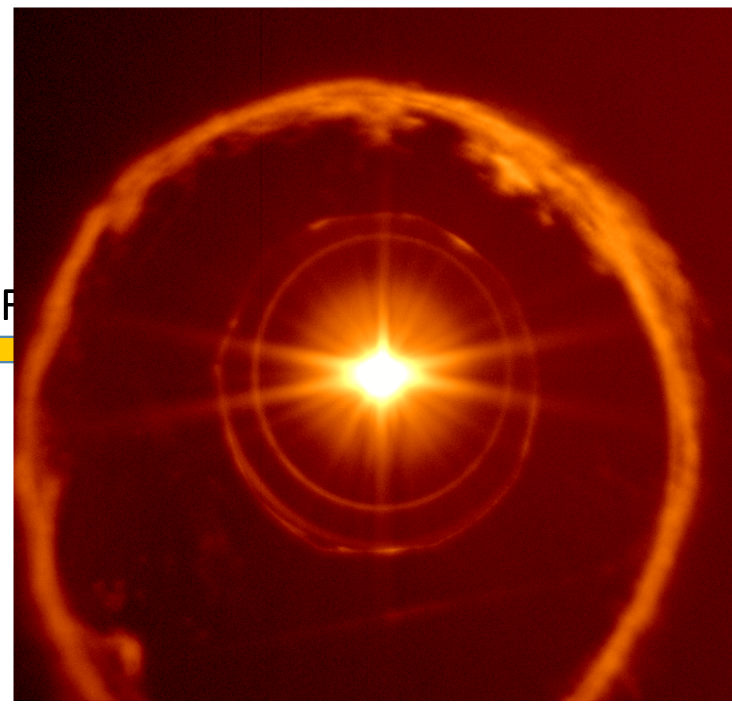
Stage 1 – spot shape and location

Obstruction and diffraction spikes

Lots tries on obstruction shapes to minimize false continuum still avoiding fiber cross talk



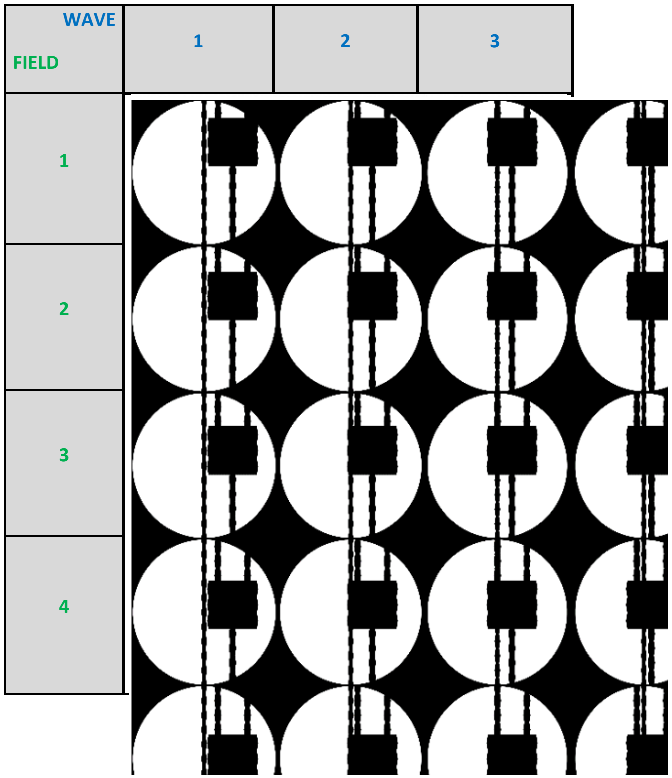
Final obstruction



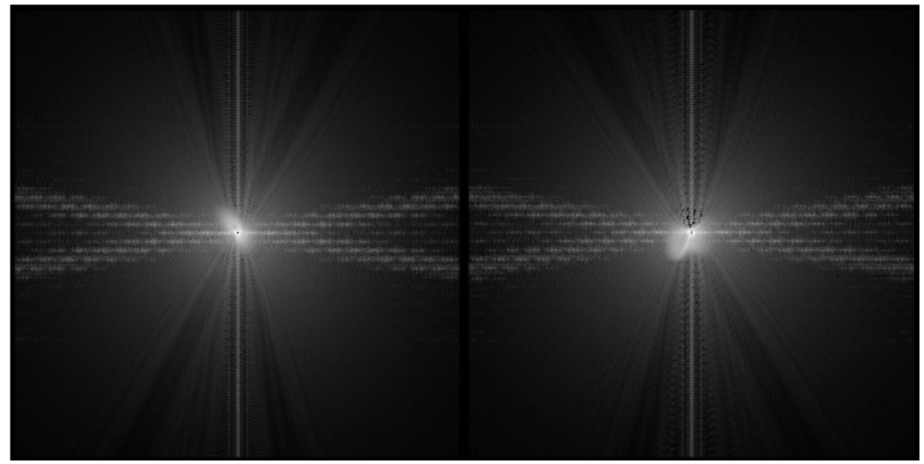
No overlap to spectrum

Stage 1 – spot shape and location

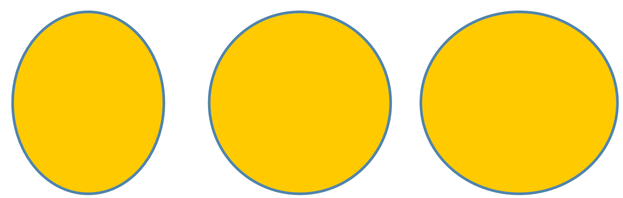
Obstruction and diffraction spikes



Obstruction and vignetting
vs spot location



Adding aberrations

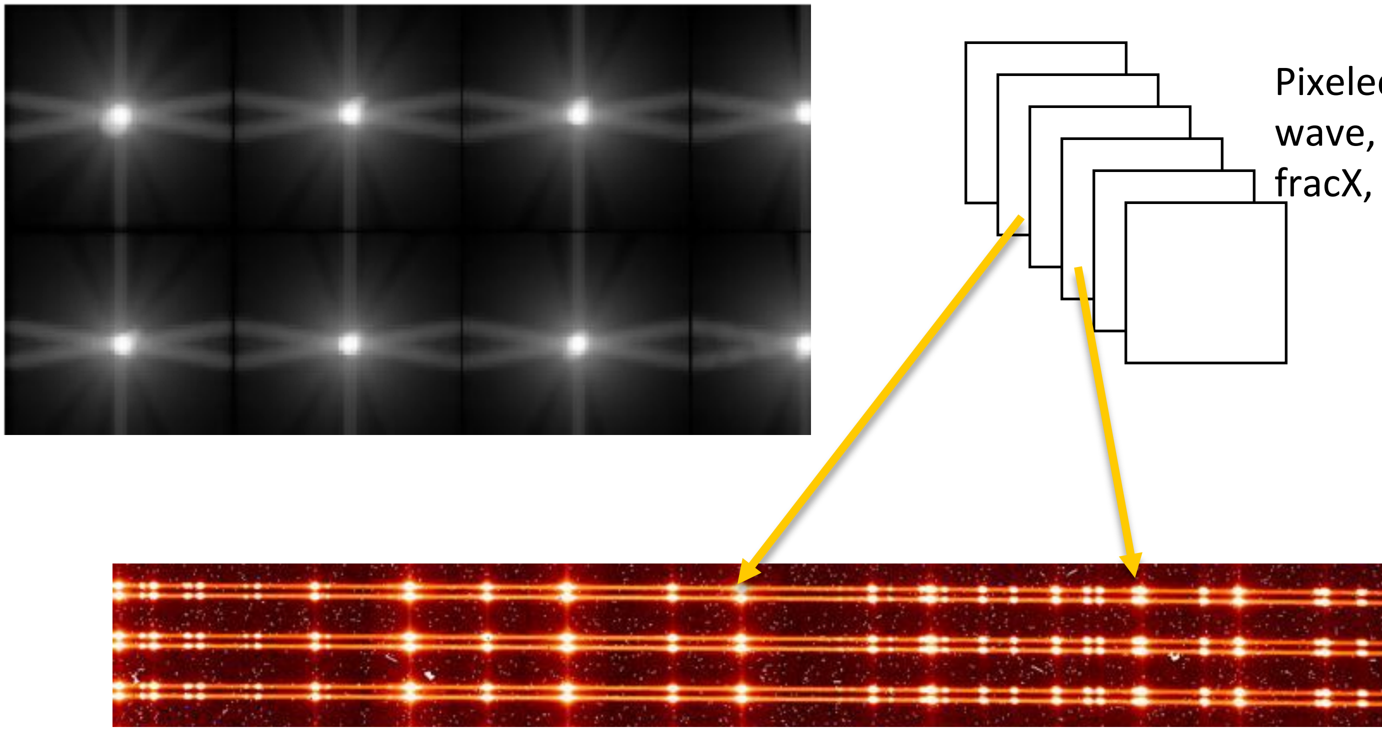


Projected fiber shape to be convolved

Stage 1 – spot shape and location

Obstruction and diffraction spikes

Pixelization depending on fractional pixel shift of the PSF



Pixeled spots 6D cube:
wave, field,
fracX, fracY

Final pixeled spot shape got by linear interpolation of pixeled spots cube at minimum curvature interpolation of chief ray location.

Stage 2 – Physical optics

Flux entering fiber: differential refraction and centering error

MOONS - Atmospheric Refractive Index & Differential Atmospheric Refraction (A.Cabral 25-10-2014)

The model is based on the Filippenko model. Differential Atmospheric Refraction is calculated considering the temperature, humidity and altitude to determine the pressure. If pressure is available (to consider its variation for a fixed altitude), instead of P(h) use directly the value of the pressure in Pa.

$$ns(\lambda) := 1 + 10^{-6}\left[64.328 + \frac{29498.1}{146 - \left(\frac{\mu m}{\lambda}\right)^2} + \frac{255.4}{41 - \left(\frac{\mu m}{\lambda}\right)^2}\right]$$

$Ps := 1013.25\cdot 10^2 Pa$ $\quad Ts := 288.15K$ $\quad Ts = 15\cdot°C$ $\quad ho := 7km$

$$P(h) := Ps\cdot e^{\frac{-h}{ho}}$$

$$nd(\lambda,T,P) := 1 + (ns(\lambda) - 1)\cdot\frac{P}{T}\cdot\frac{Ts}{Ps}$$

$$Pw(H,T) := 6.11\cdot 10^{\frac{7.5\cdot\left(\frac{T}{K} - 273.15\right)}{\frac{T}{K} - 35.45}}\cdot\frac{H}{\%}\cdot Pa$$

Difference between this and Filippenko is < 1:1000

$$ndd(\lambda,T,P,Pw) := 1 + \left[(nd(\lambda,T,P) - 1) - 43.49\cdot 10^{-6}\left[1 - 7.956\cdot 10^{-3}\cdot\left(\frac{\mu m}{\lambda}\right)^2\right]\frac{Pw}{Ps}\right]$$

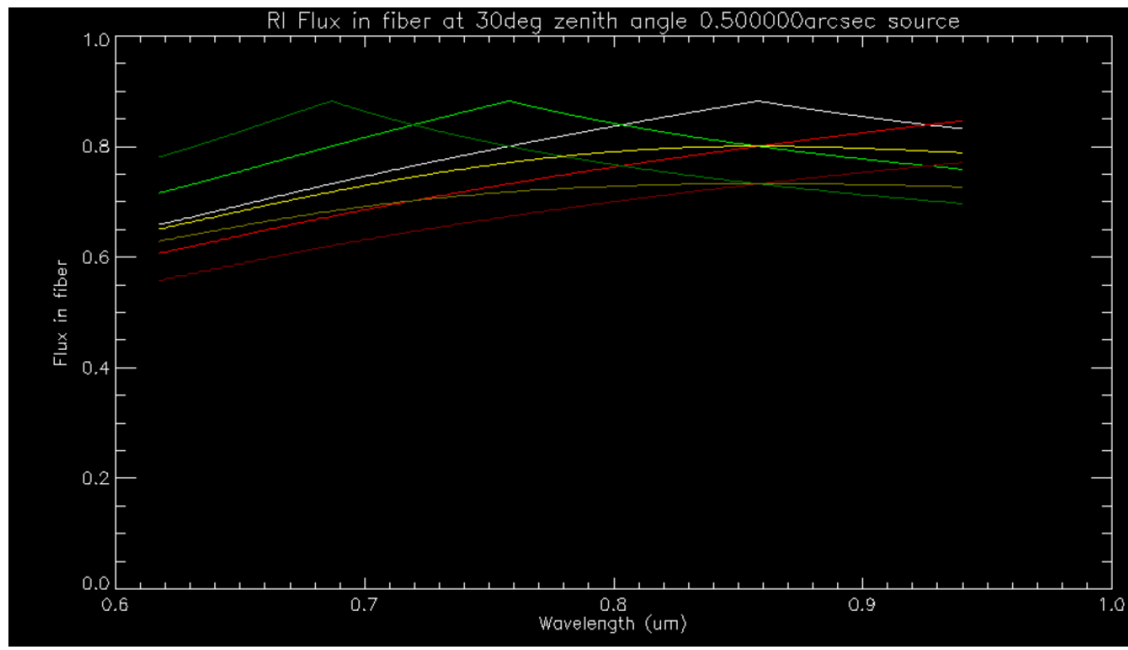
Atmospheric Refractive Index

$$n\_atm(\lambda,T,h,H) := ndd(\lambda,T,P(h),Pw(H,T))$$

Differential Atmospheric Refraction

$$d\delta atm(\lambda,\lambda ref,Z,T,h,H) := (n\_atm(\lambda,T,h,H) - n\_atm(\lambda ref,T,h,H))\cdot\tan(Z)$$

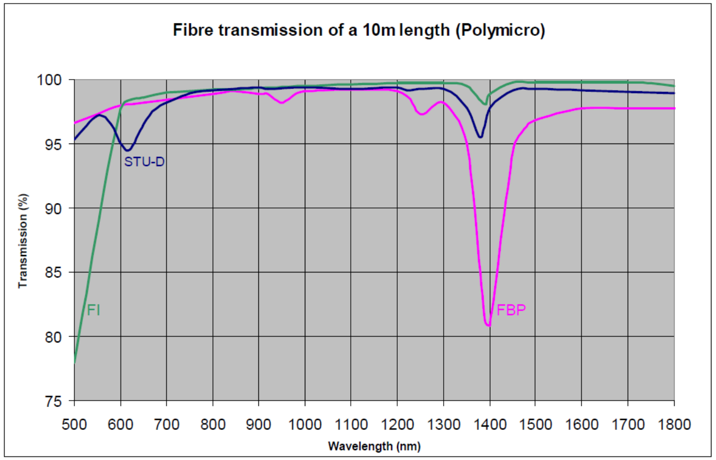
seeing_FWHM = 0.7 ;arcsec
pointing_zenith_angle = 30. ;deg
Altitude = 2.665 ;km ;Paranal
Air_temp = 12. ;Celsius
Air_humidity = 0.15 ;fraction
Air_pressure = 69.243 ;kPa



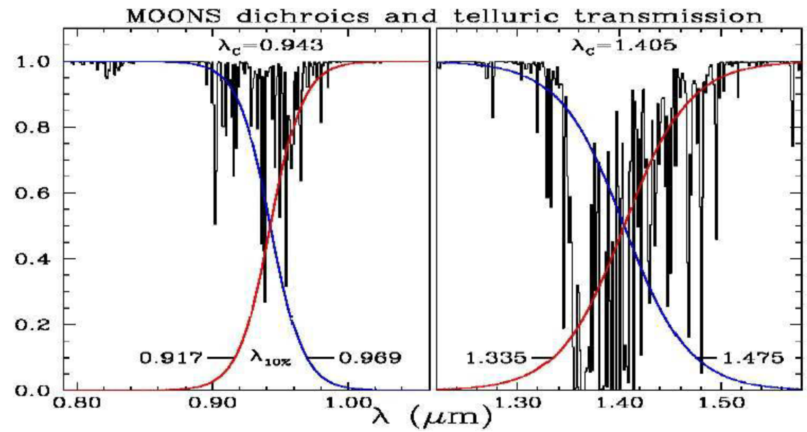
Flux in fiber depending on atmo refraction and fiber position error

Stage 2 – Physical optics

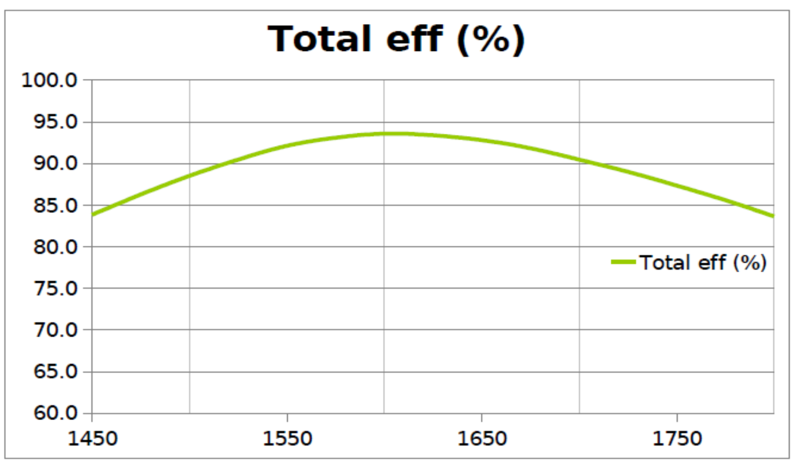
Optical budget



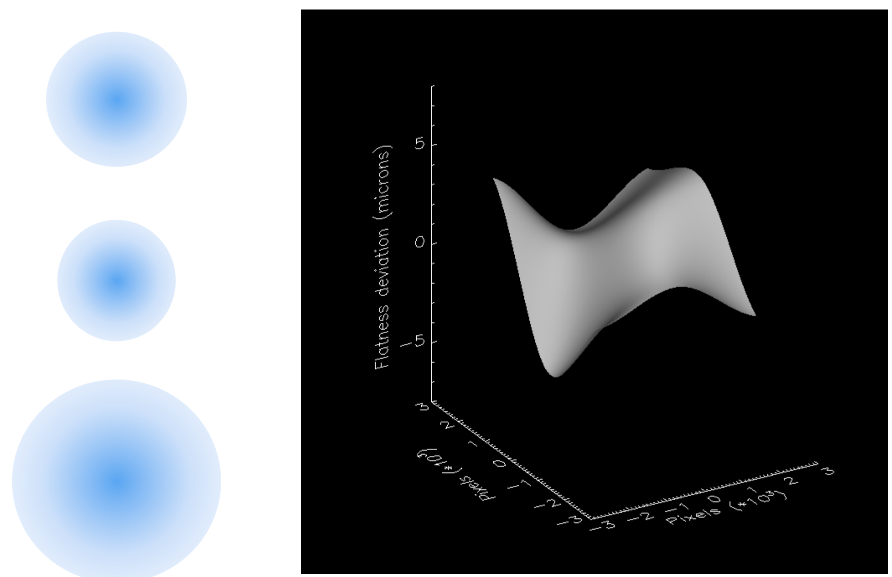
Fiber spectral trasmittance



Dichroics efficiency



VPH blaze function

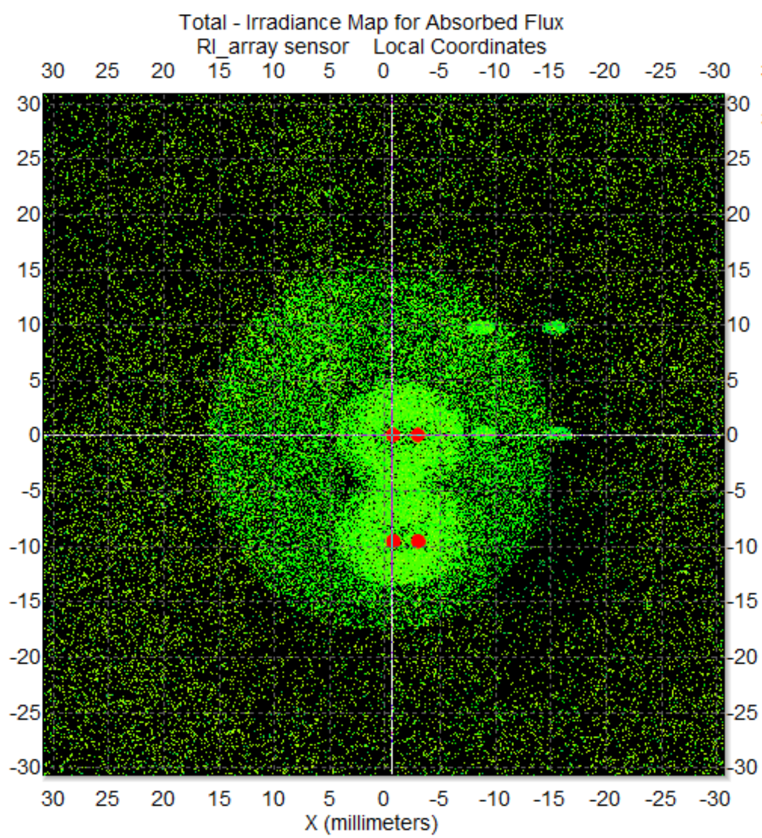


F/1 camera -> local defocus for detector unflatness

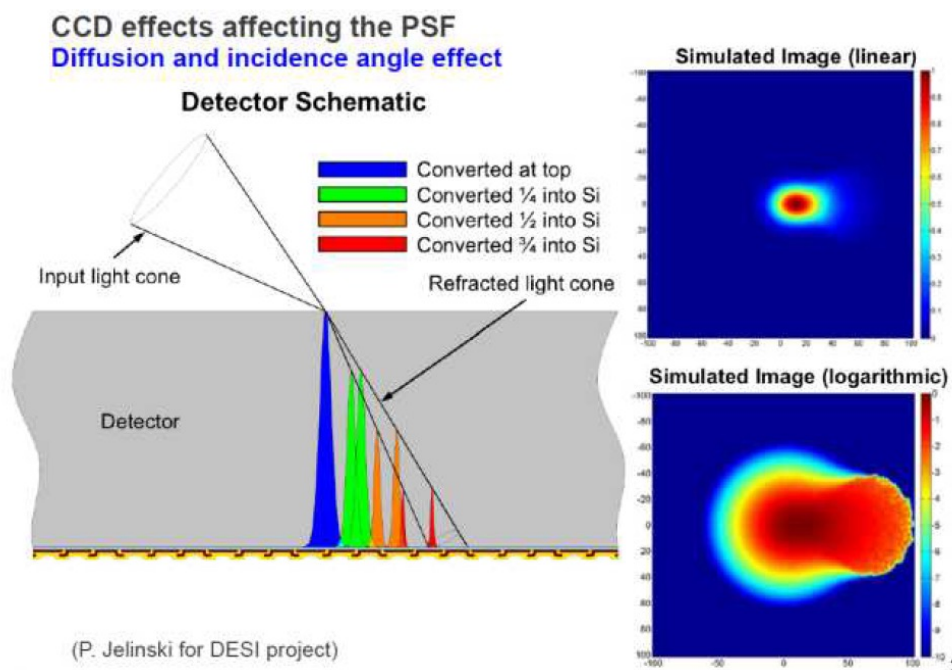
Stage 2 – Physical optics

Ghosts, stray light, and CCD thickness defocusing

- Used in Virtual MOONS but computed outside
- Interpolation / morphing difficulties…



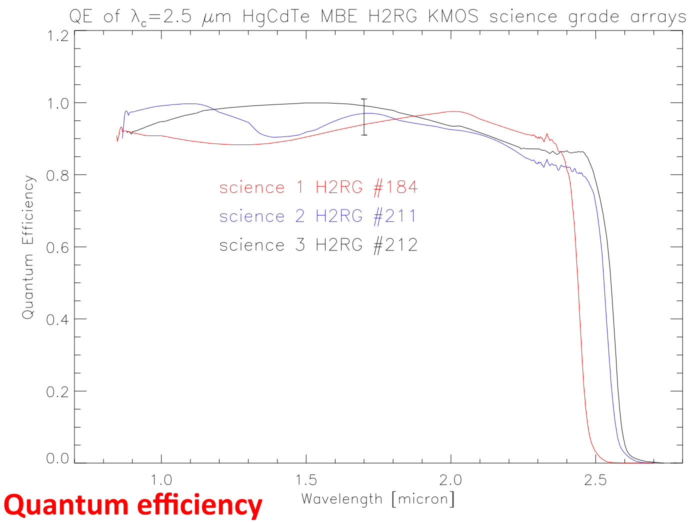
Ghosts and stray light (from D. Lee)



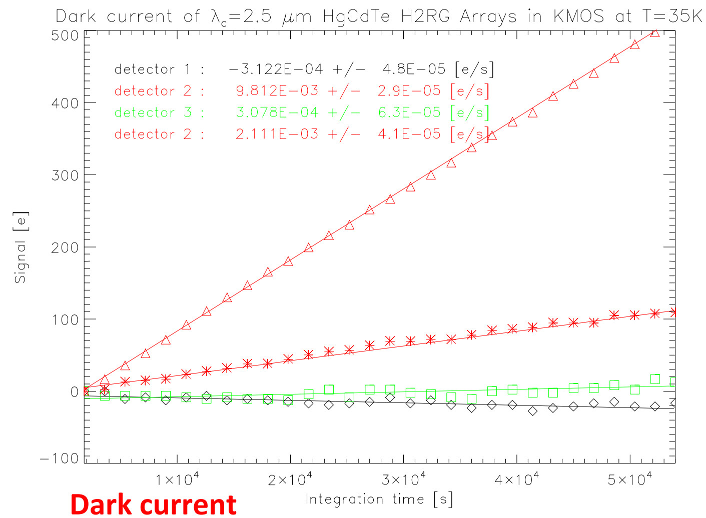
PSF broadening in thick CCD (from D. Lee)

Stage 3 – noises and Detector

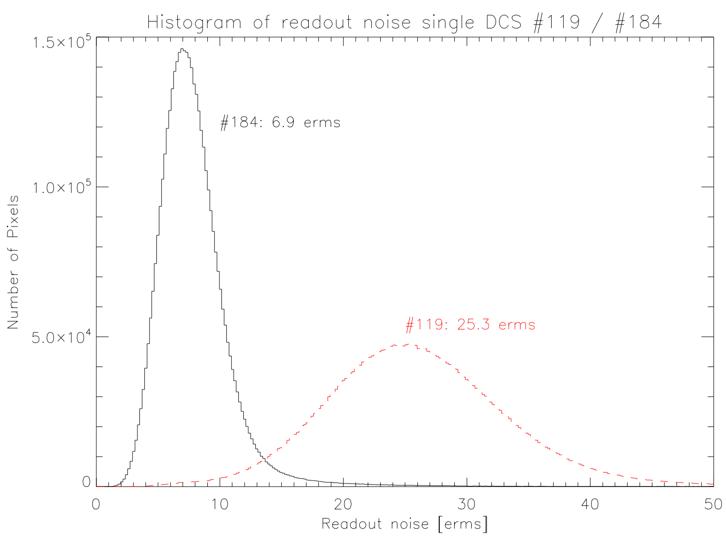
Detector signature



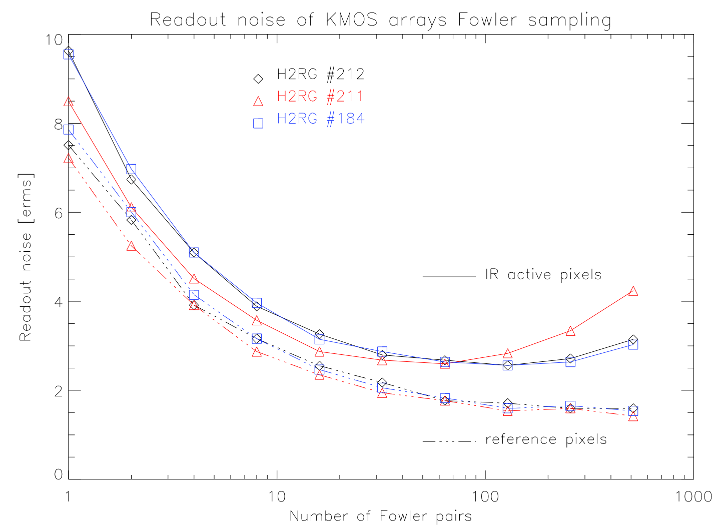
Quantum efficiency



Dark current



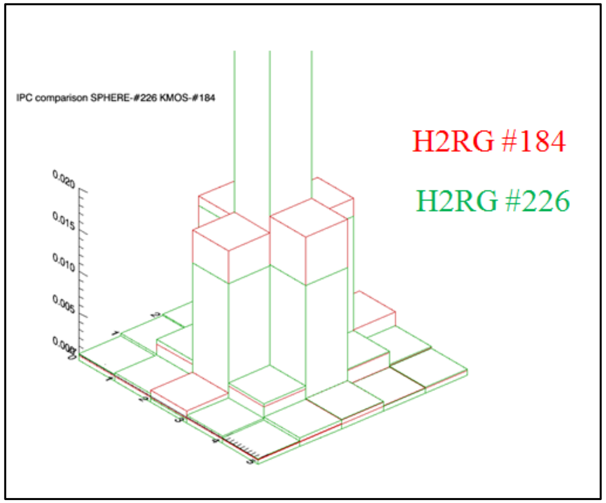
Read out noise statistics



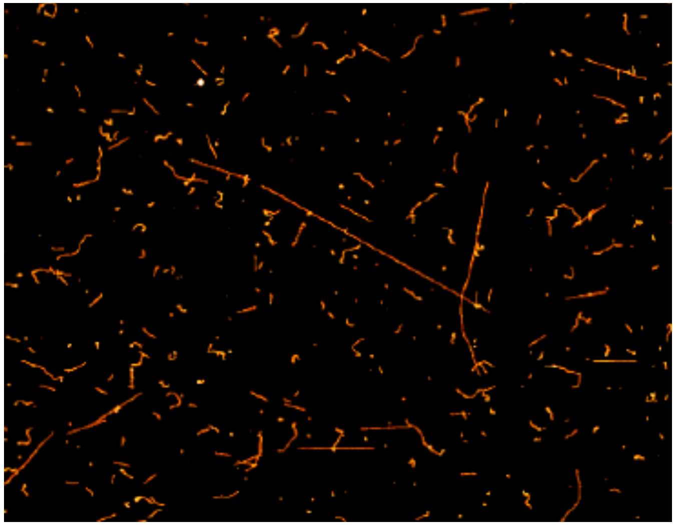
Multiple non destructive readout

Stage 3 – noises and Detector

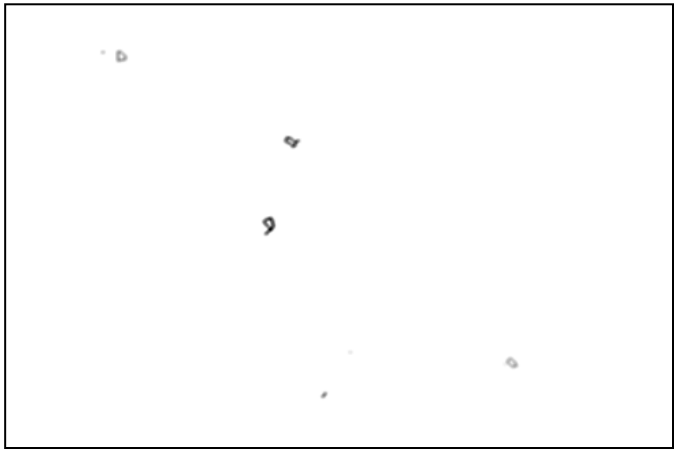
Detector signature



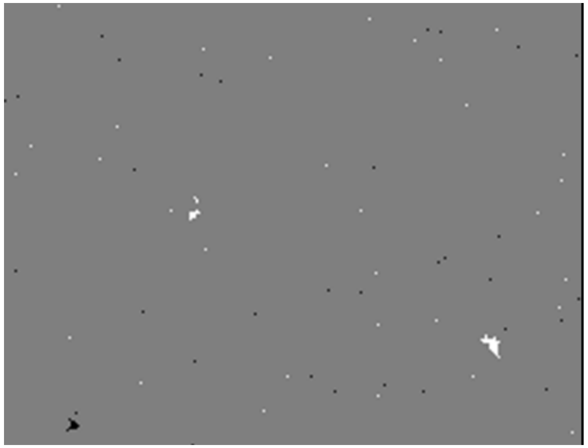
Pixel cross talk (charge diffusion)



Cosmic rays (on R channel 250um thick CCD)



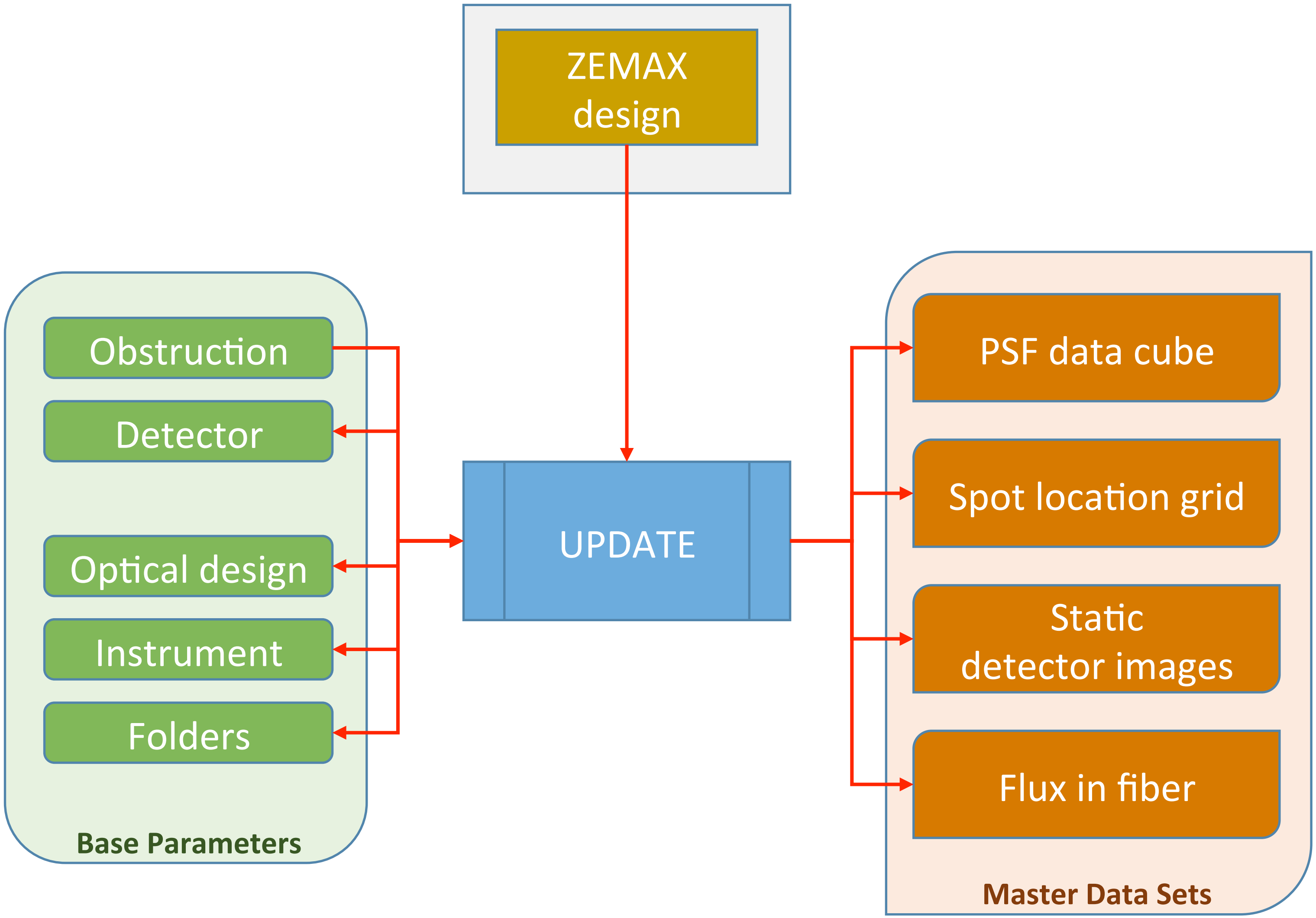
Dust on detector



Detector cosmetics

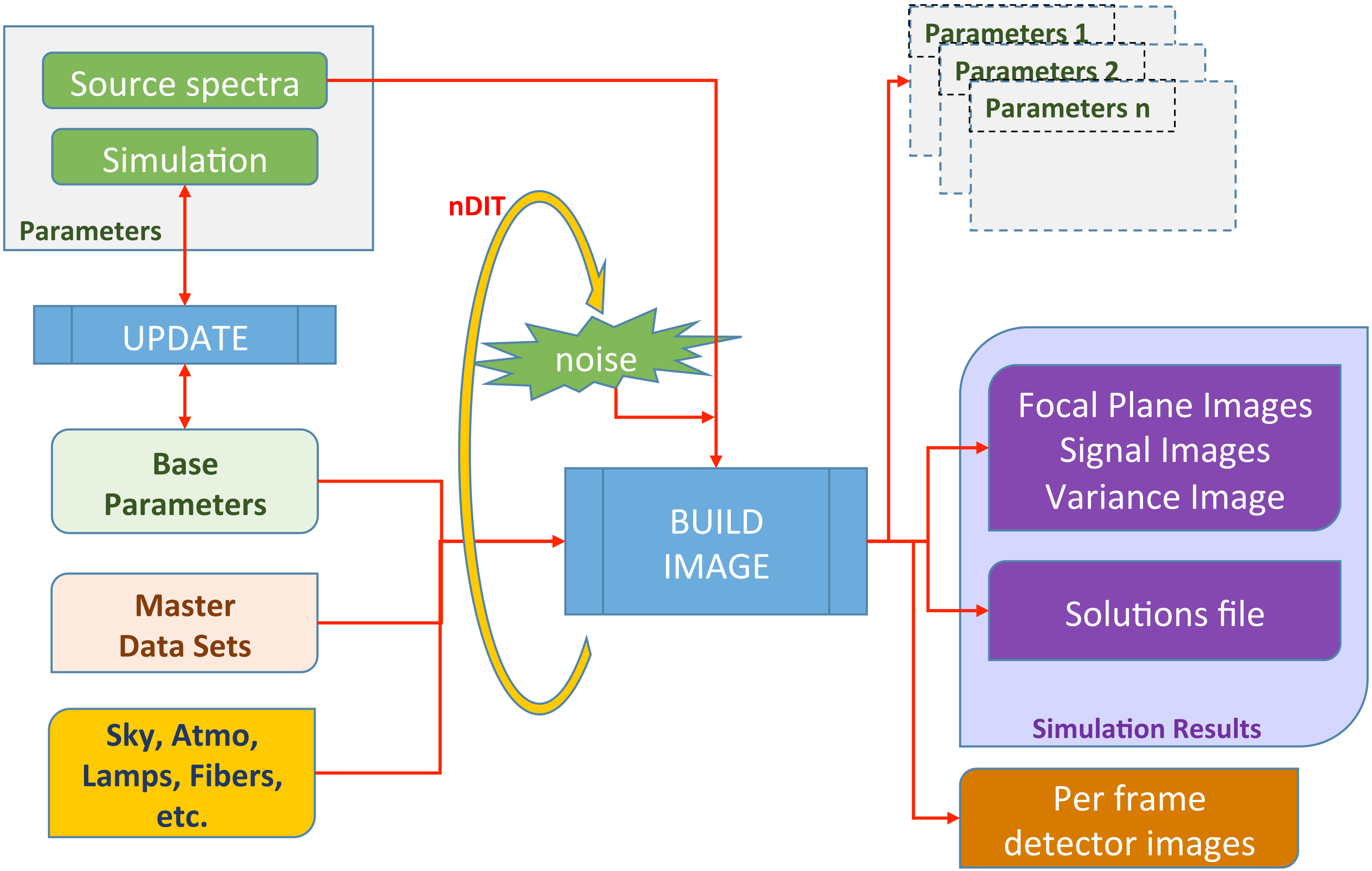
IMPLEMENTATION

Building Parameters and System Data



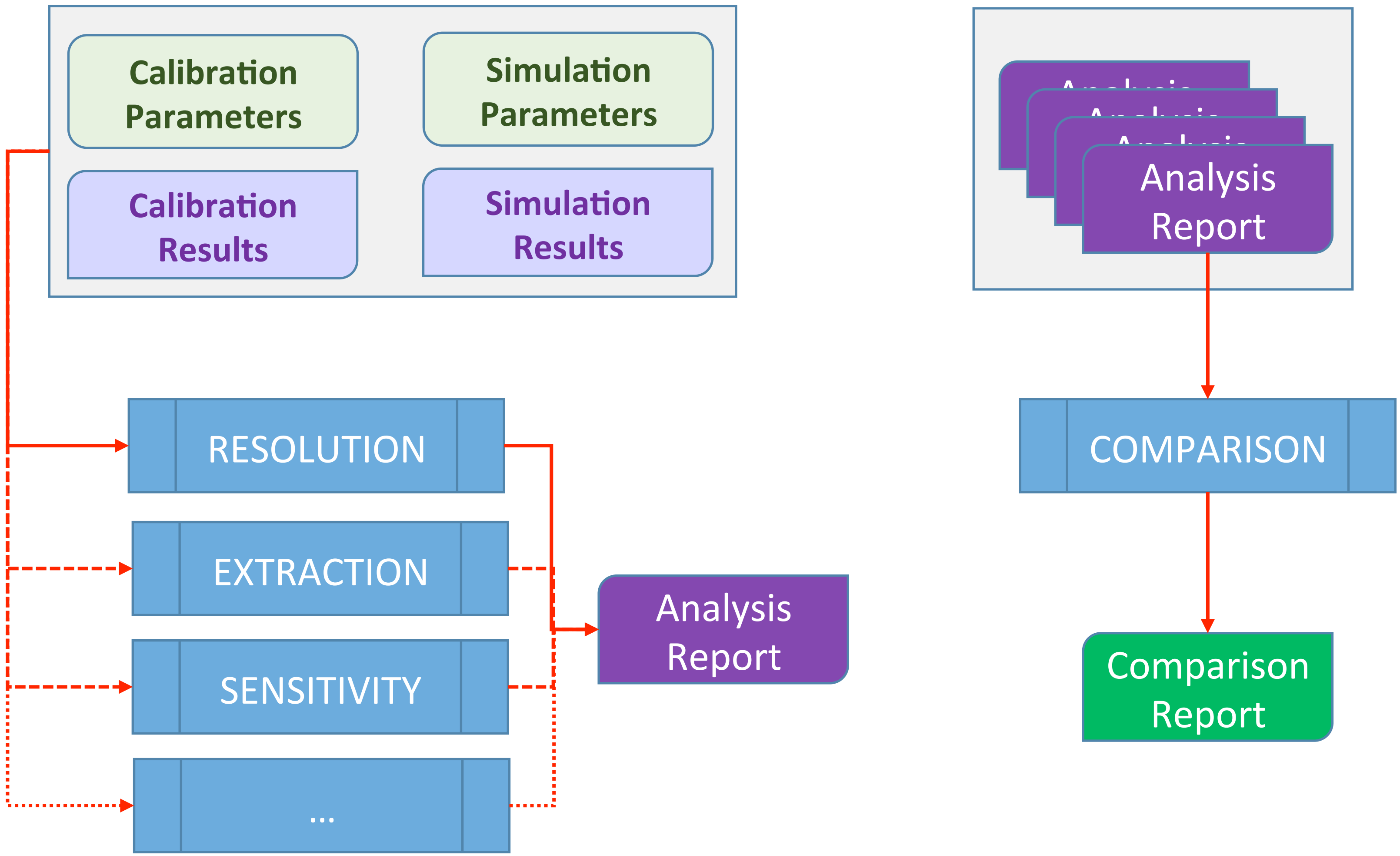
IMPLEMENTATION

Building Simulated Images



IMPLEMENTATION

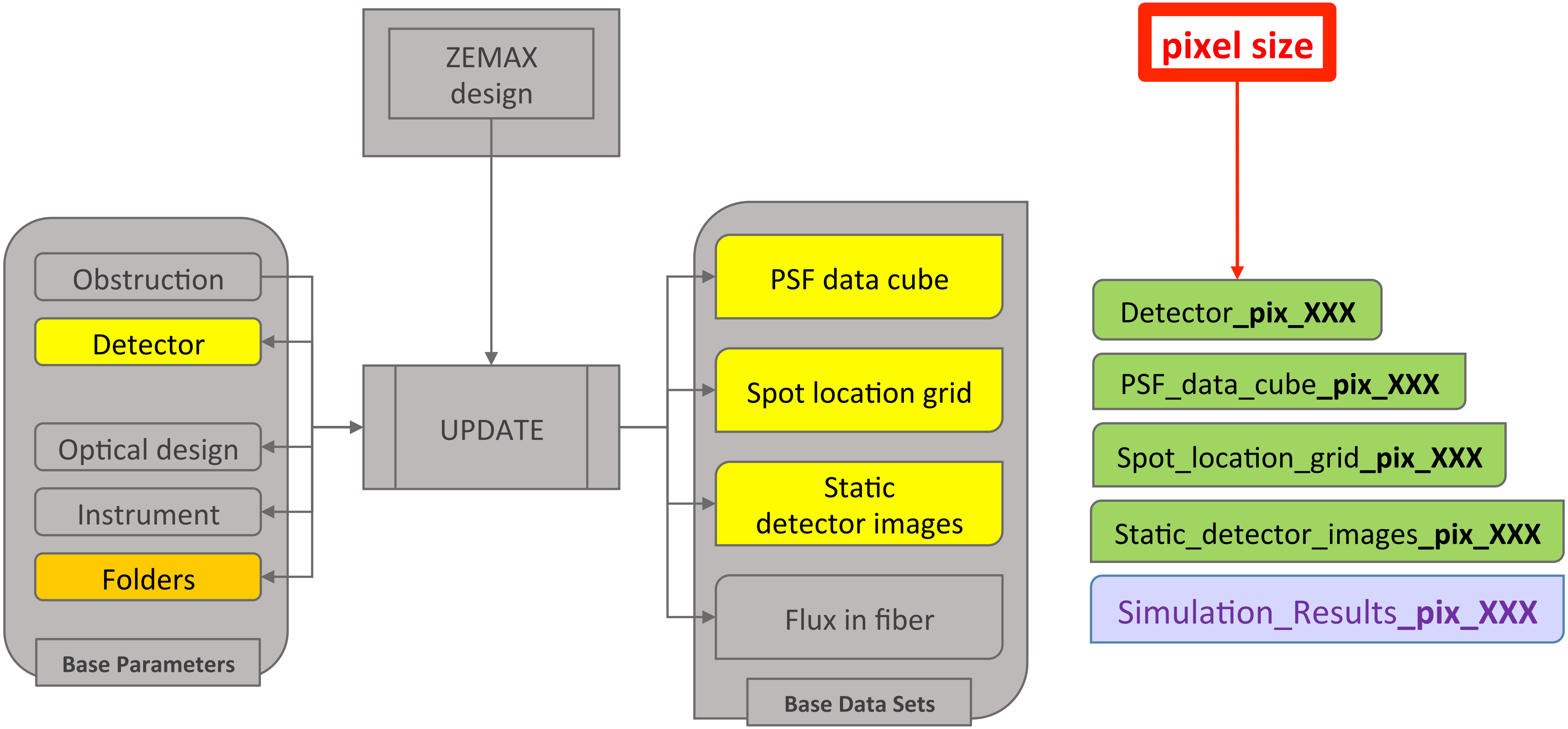
Analysis Scripts



Implementation

Difficulties in flexibility: propagating parameter changes

- Different entry points in process tree
- Intricate folders and naming management…



Implementation

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