Ariel simulators

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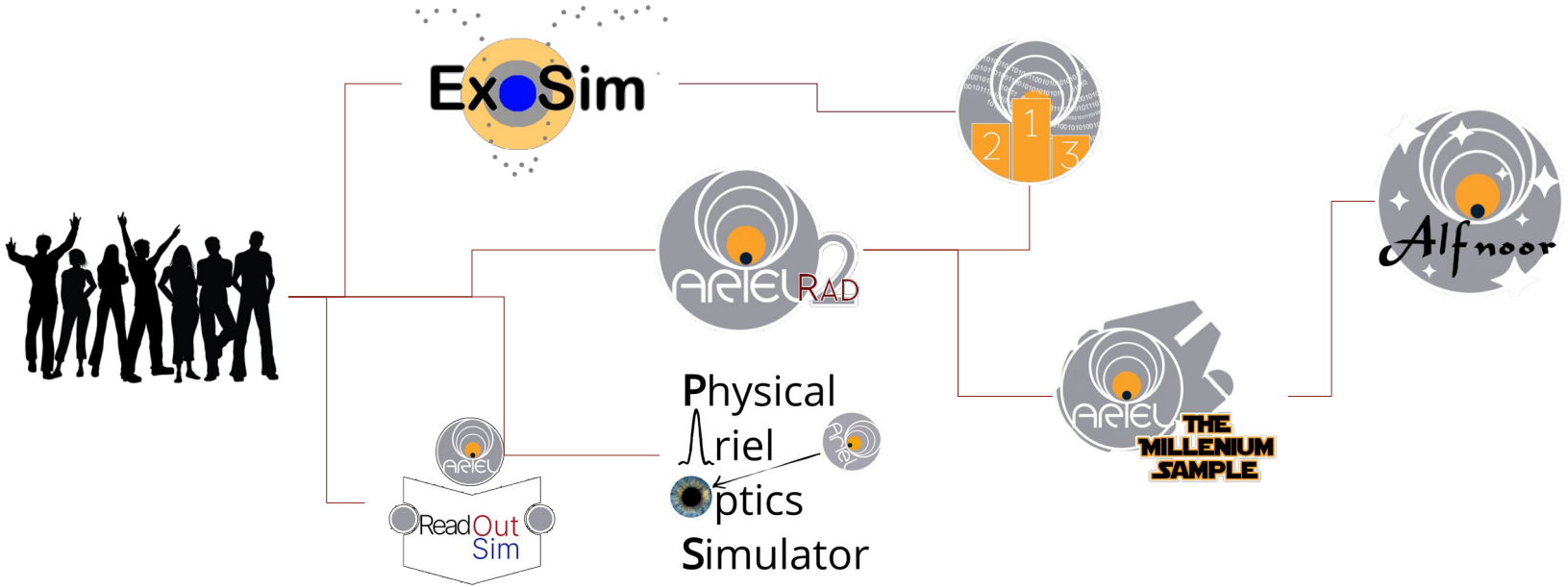
ARIEL performance and simulation WG

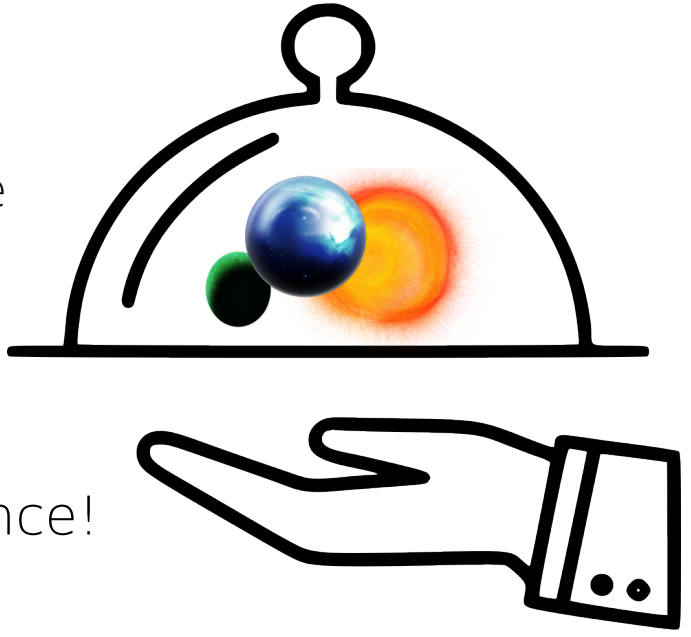
ARIEL performance and simulation WG has built tools to optimize the payload and mission design and to support the science teams.



What do we do?

ARIEL performance and simulation WG has built tools to optimize the payload and mission design and to support the science teams.

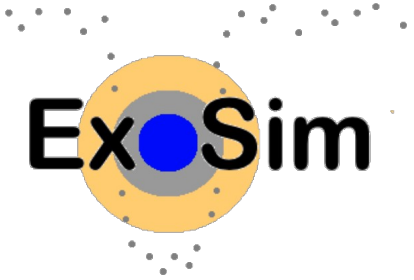
And we are able to accurately simulate ARIEL observations



We can help you to serve science!

Our family

Two of these tools are now publicly available and can be adapted to different instruments.



Soon to be released:

ExoRad 2

The generic point source radiometric simulator.

Given the payload design and a target, it returns observation performance estimates in terms of noise and SNR.

It analyses hundreds of targets in minutes.

Already validated and used for

- Ariel (*ArielRad*, Mugnai et al 2020)
- Excite

It **does not** require a data reduction pipeline to analyse the data.

How to install

https://github.com/ExObsSim/ExoRad2-public

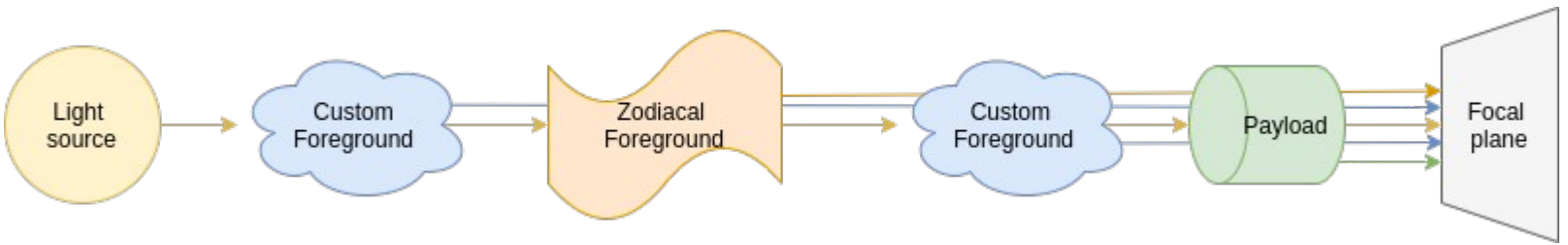
pip install exorad

Documentation

https://exorad2-public.readthedocs.io/en/latest/

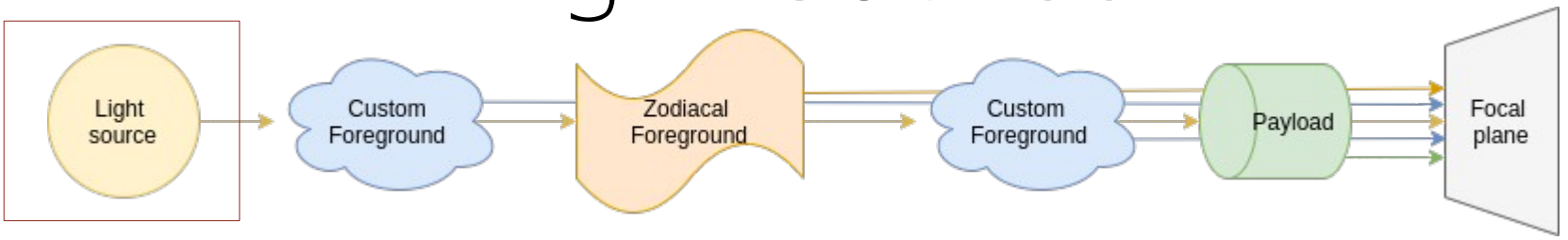
Propagate the light

- The target light is propagated through foregrounds selected by the user and then through the telescope.
- The foregrounds and telescope contribute to the total signal on the focal plane



NB. this is just a scheme. It's not representative of all the involved Tasks

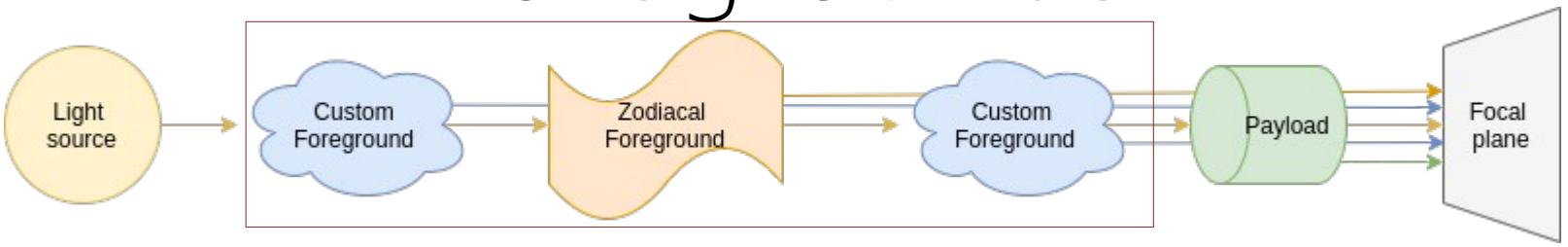
Light source



Can be:

- black body
- Phoenix spectra
- Custom *sed* from csv file

Foregrounds

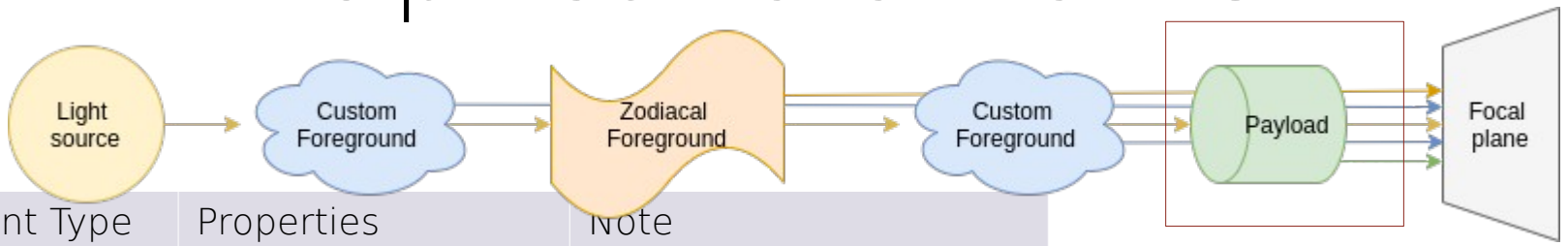


Foregrounds are optical elements in front of the light source

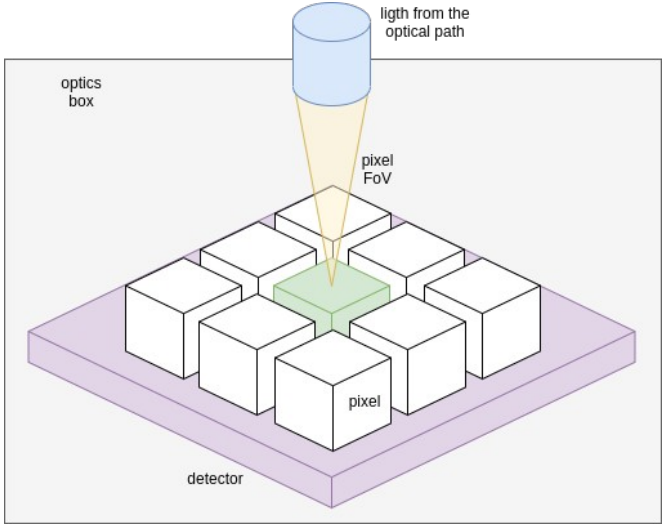
Can be:

- Custom (user defined with emission and transmission)
- Zodiacal (computed by ExoRad, if requested)

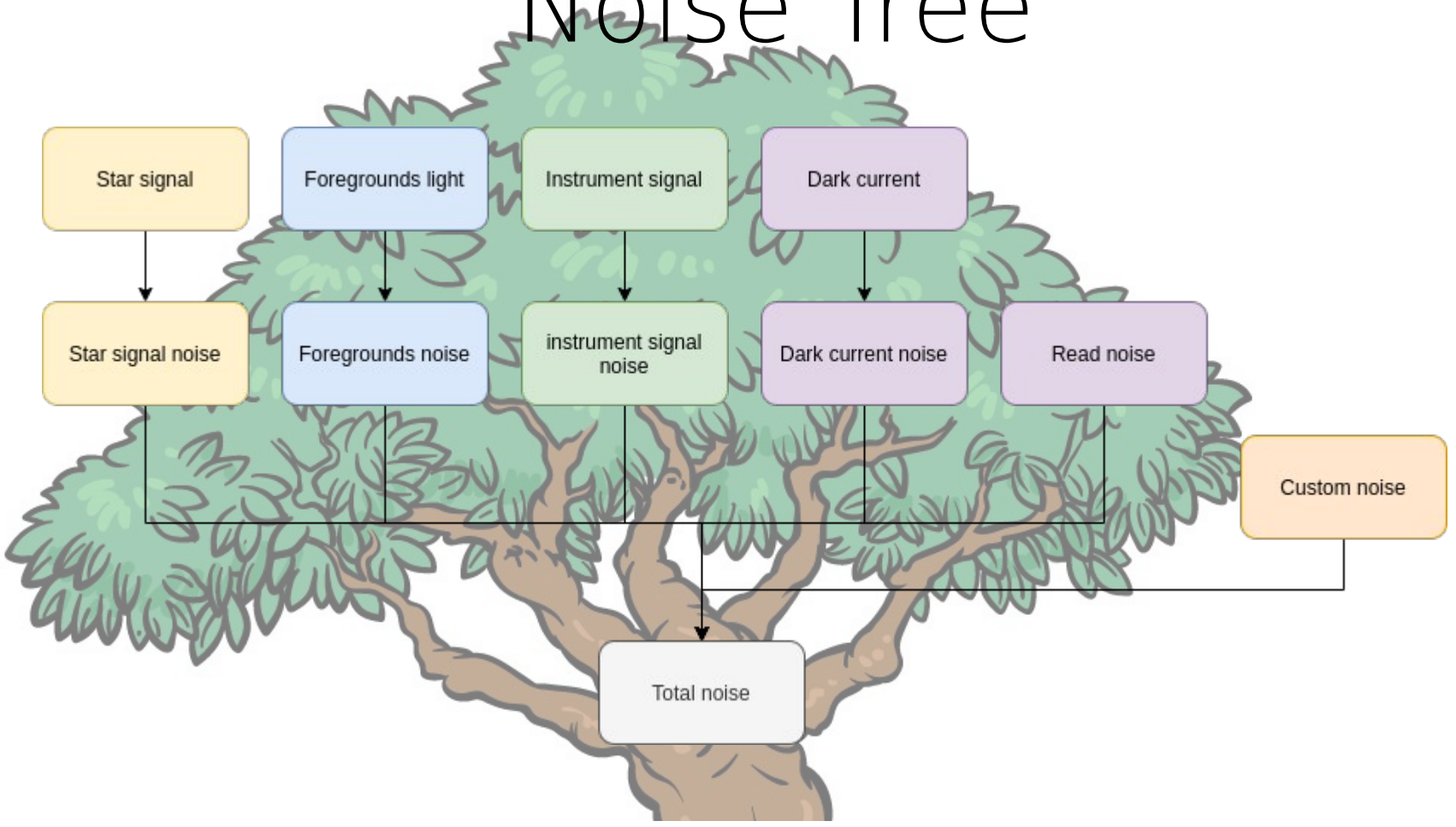
Optical elements



Element Type	Properties	Note
Surface	• Temperature • Transmission (or Reflectivity) • Emissivity	Mirrors, lenses Pixel solid angle Ω_{pix}
Filters	• Temperature • Transmission • Emissivity • Reflectivity	Pixel solid angle Ω_{pix} You can set wl_{min} & wl_{max}
Slit	• Width	
Optical box	• Temperature	Pixel solid angle $\pi - \Omega_{pix}$
Detector box	• Temperature	Pixel solid angle π



Noise Tree

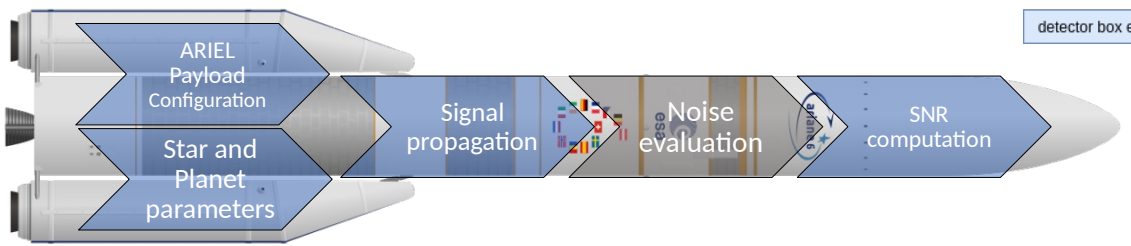

Star signal
Foregrounds light
Instrument signal
Dark current
Star signal noise
Foregrounds noise
instrument signal noise
Dark current noise
Read noise
Custom noise
Total noise

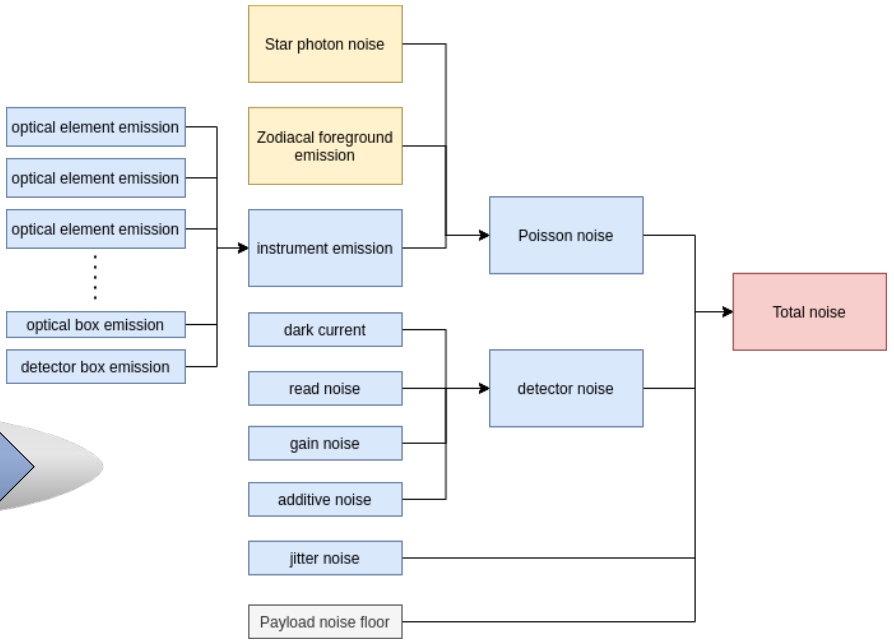
ArielRad

Mugnai et al. 2020

The new ARIEL radiometric model.

It is widely used to validate instrument design, mission strategy and to select candidate targets.





Ariel observed wl bands

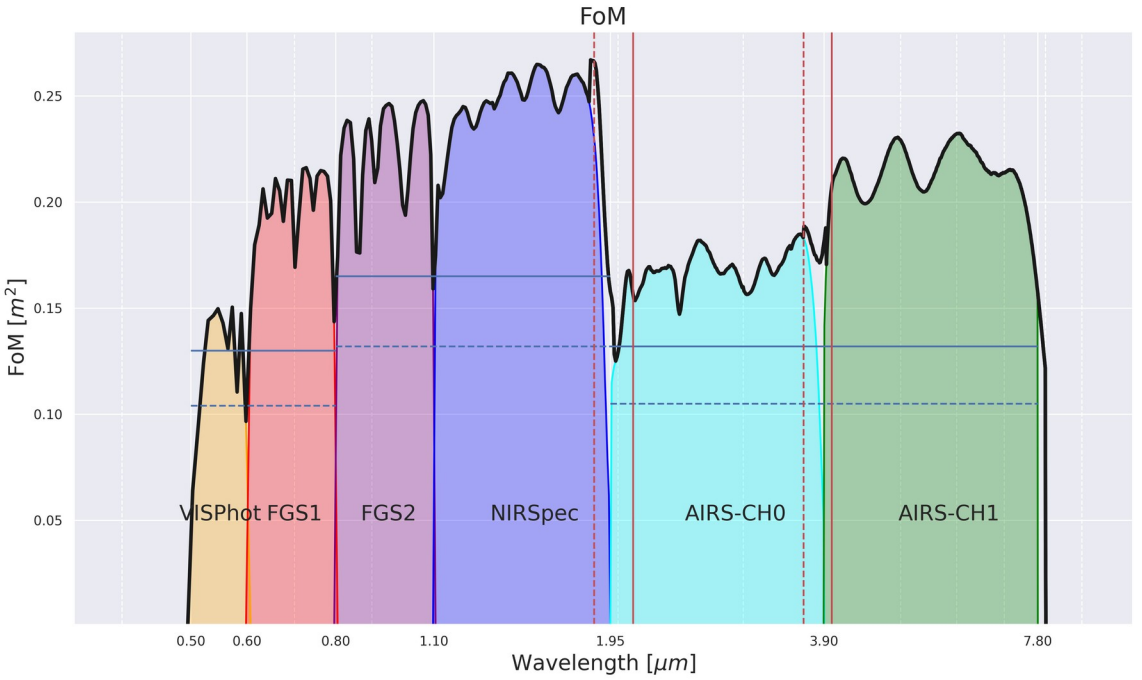
Here is reported the Figure of Merit of Ariel bands.

The FoM is defined as

$$FoM = A_{tel} \times QE \times TR$$

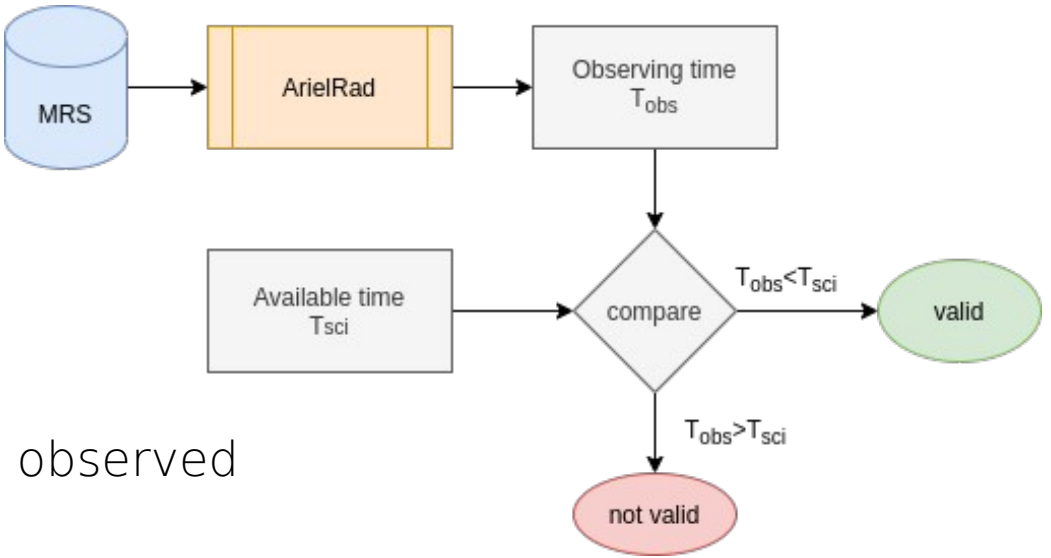
Horizontal lines show the payload requirements.

$$A_{tel} = 0.63\ m^2$$



ArielRad & Ariel

ArielRad produces the Noise Budget for each target.

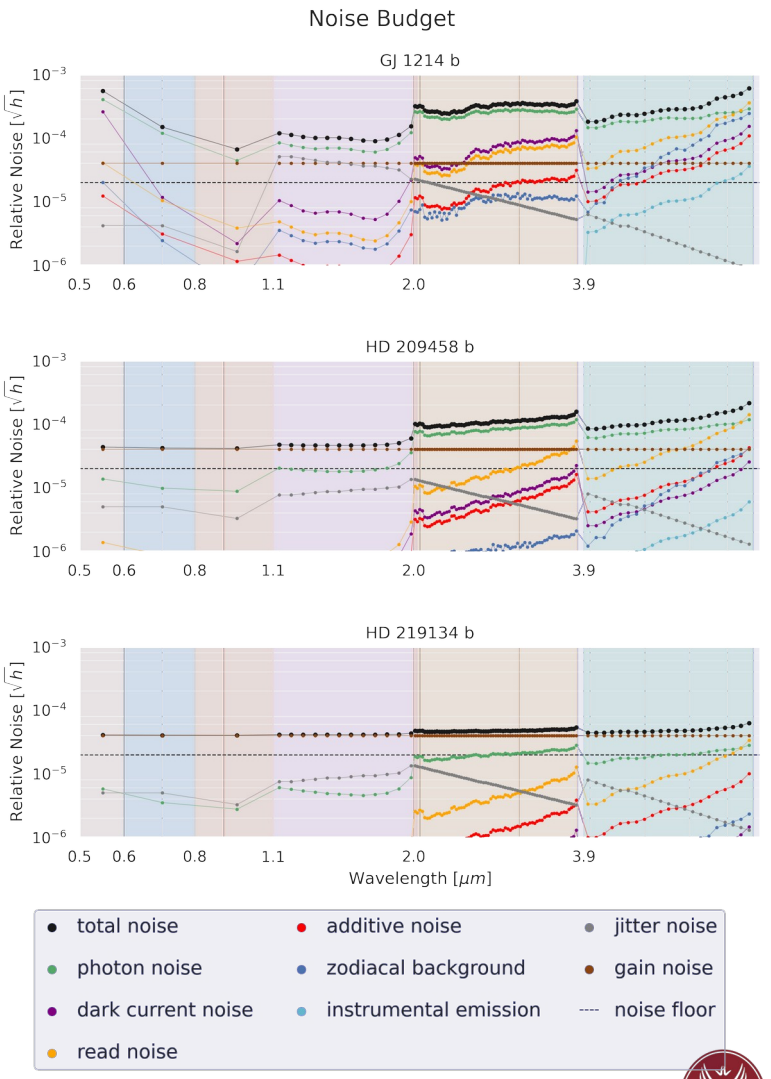


It has be used to

- derive requirements,
- select candidate target
- build entire target list
- produce expected error-bars on observed spectra.

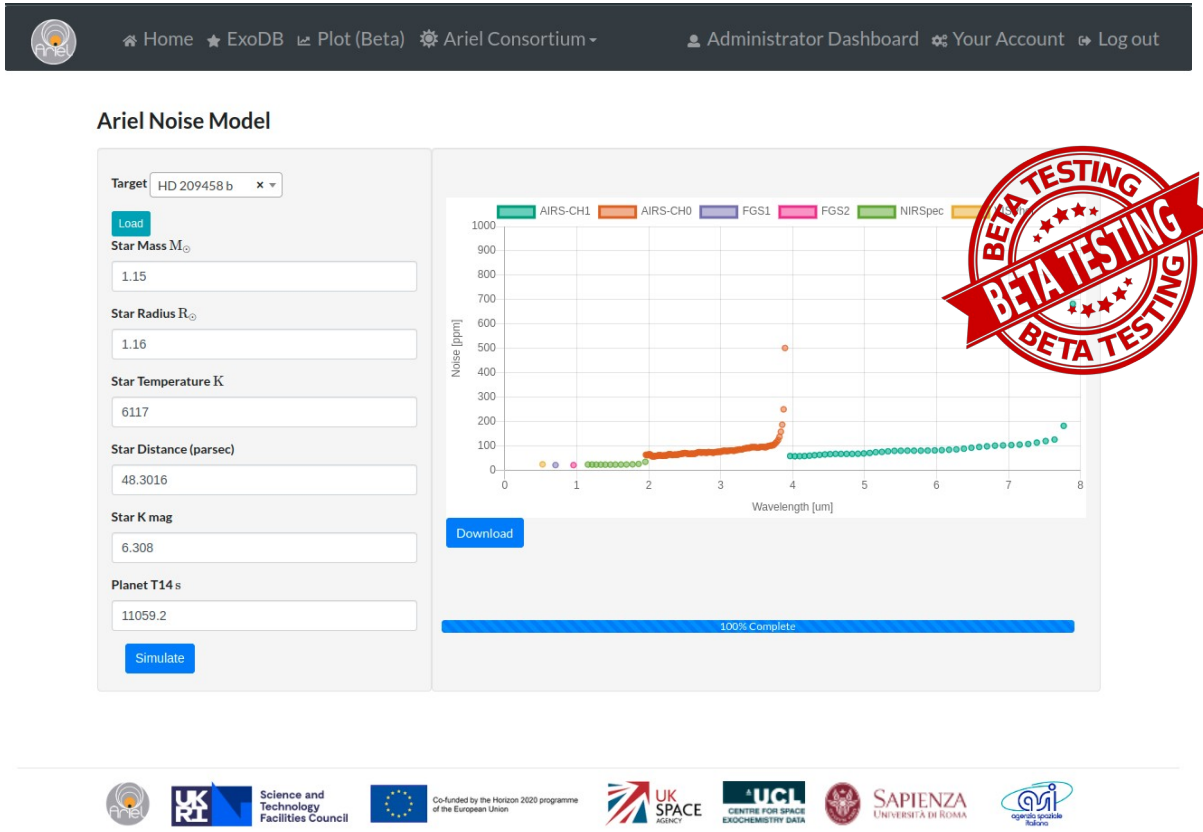
The photon noise limit

From the noise budget we observe that for most of the targets, the payload is target photon noise limited.



ArielRad Online

An online version of ArielRad will soon be available for the consortium members, along with the candidate targets database, to support the science development.

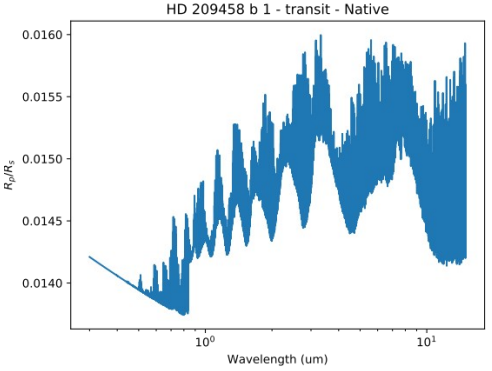


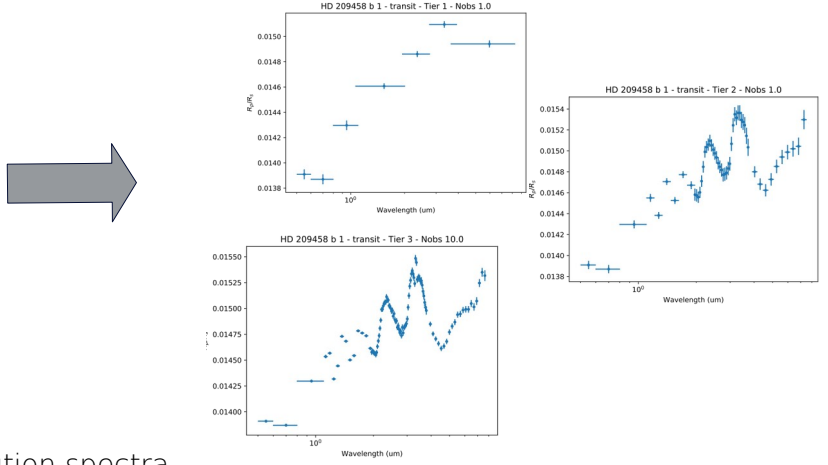
Alfnoor

Combining ArielRad with an atmospheric retrieval code we can simulate Ariel observed planetary spectra.

Here we use TauREx3.

Al-Refaie et al. 2020



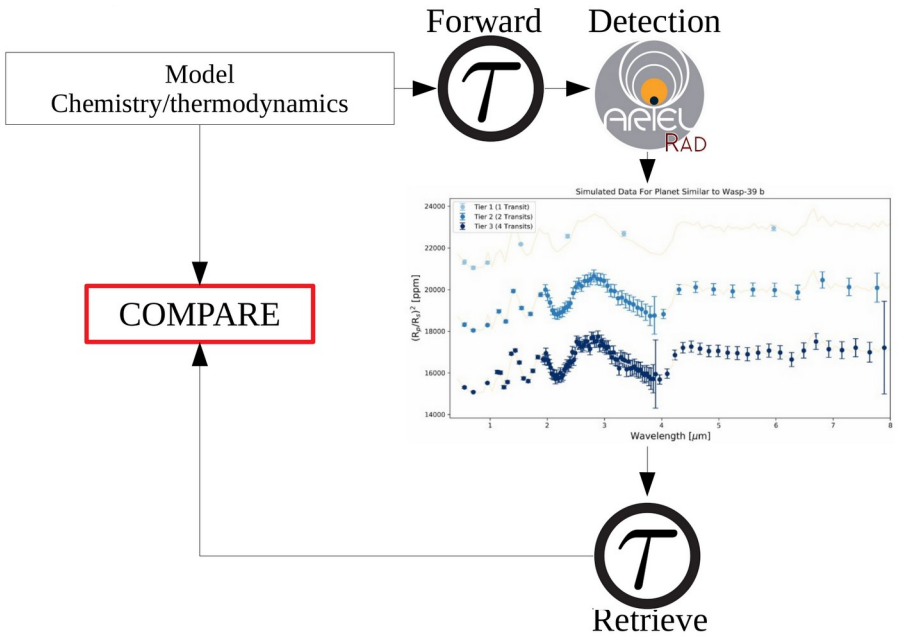


HD 209458b-like planet high resolution spectra binned according to ARIEL three tiers strategy.

Alfnoor for Ariel

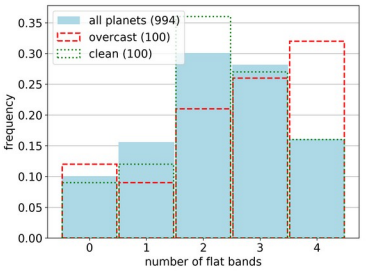
Tier 2

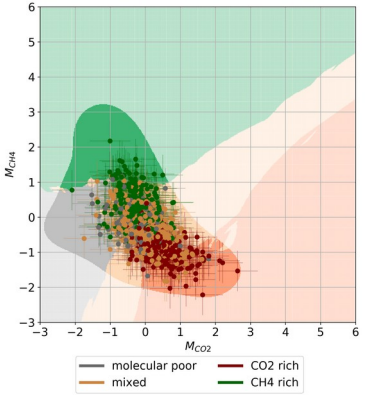
Changeat et al. 2020.



Tier 1 - I

Mugnai et al. 2021.





Tier 1 - II

Bocchieri et al. In Prep..

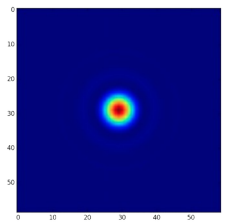
Deep Learning

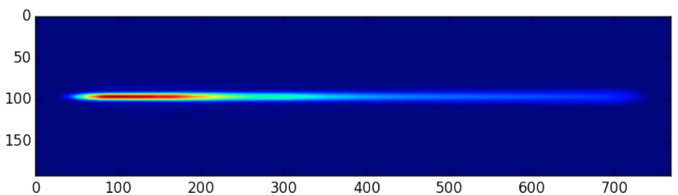
Yip et al. 2021

ExoSim

https://github.com/ExoSim/ExoSimPublic

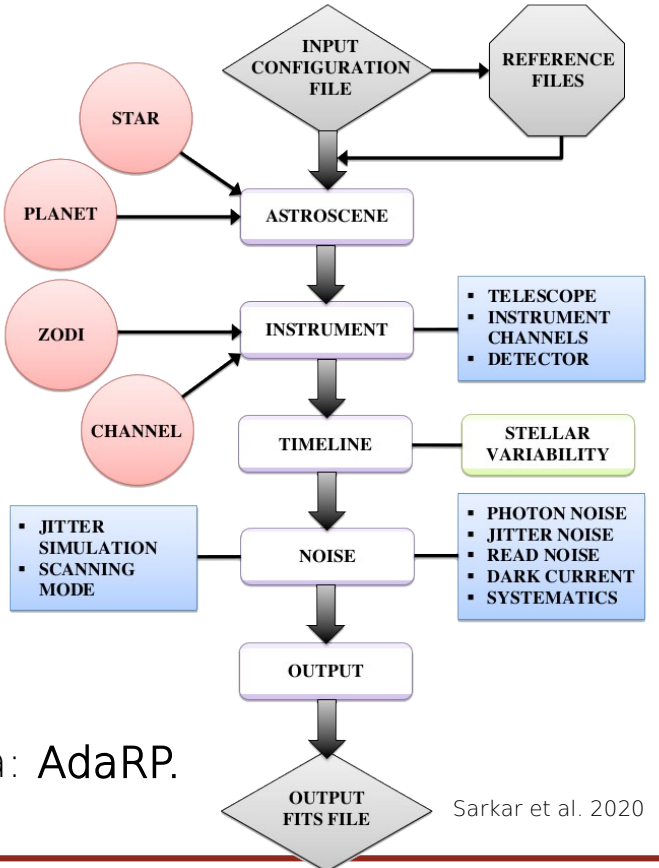
End-to-end time domain simulator for transiting exoplanet observations.





Already validated and used for

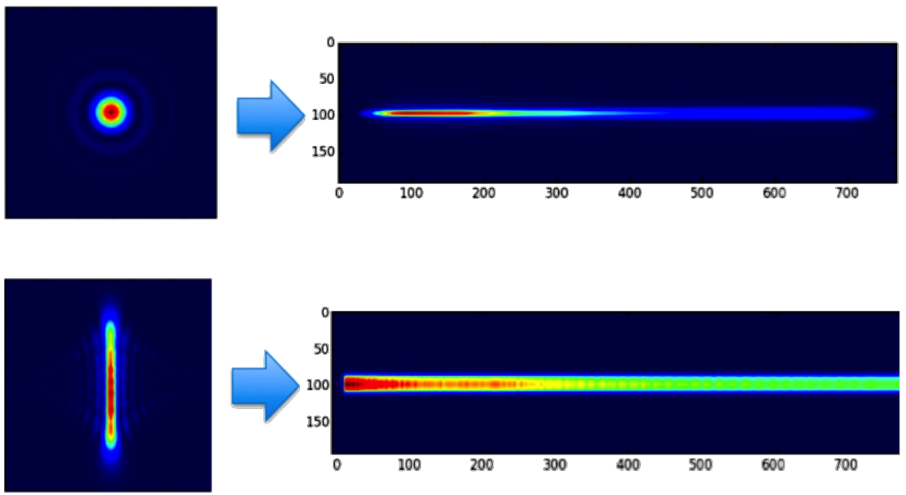
- HST
- Ariel
- JWST (*Exosim*, Sarkar et al 2019, 2020)



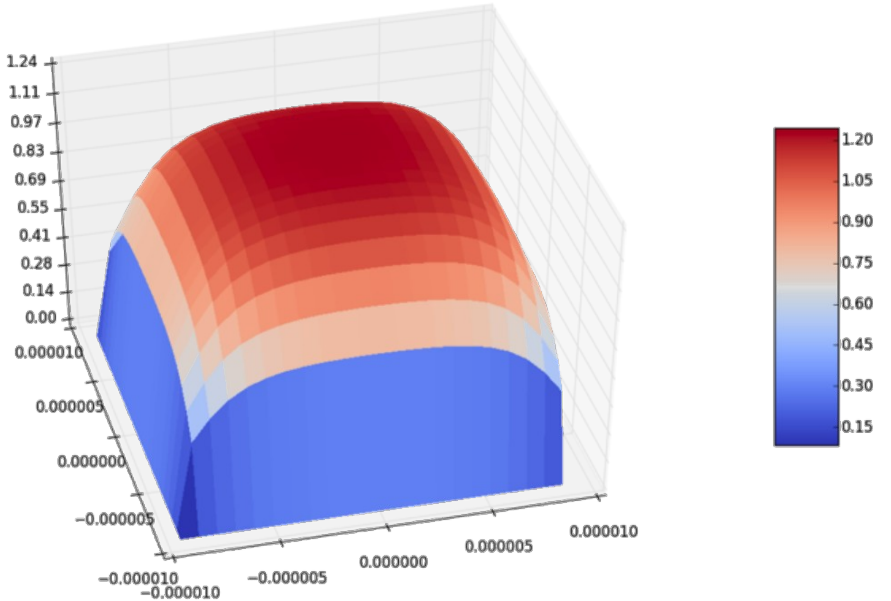
Sarkar et al. 2020

It requires a data reduction pipeline to analyse the data: AdaRP.

Details are important for Realistic simulations



Spectral images in ExoSim, produced from the co-addition of 2-D PSFs..



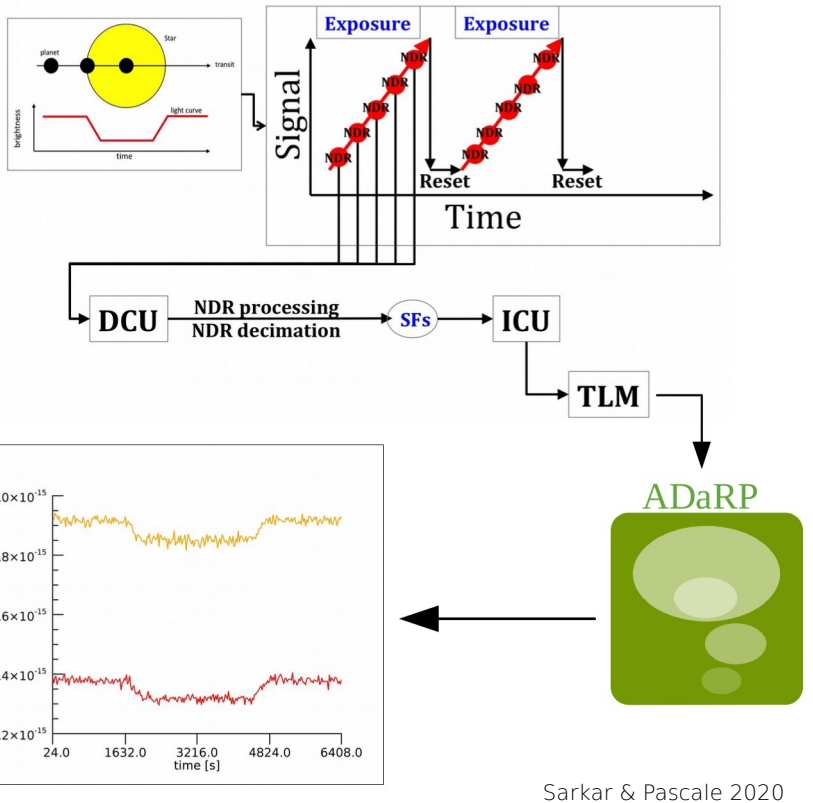
2-D pixel response function used to simulate intra-pixel variation in responsivity.

ADaRP

Ariel Data Reduction Pipeline:

Thanks to ExoSim, we can develop a realistic data reduction pipeline.

AdaRP pipeline is a deliverable for ESA



Sarkar & Pascale 2020

What next?

Mugnai et al. In Prep.

We are preparing the next version:

- Object oriented
- Faster
- Easier to customize
- Multi-order spectrometers

Compatible with PAOS

See presentation by A. Bocchieri.:

Physical Ariel Optics Simulator

How to install

Source code available

pip install exosim

Documentation

Soon available on ReadTheDocs

Stats

32.252 python lines

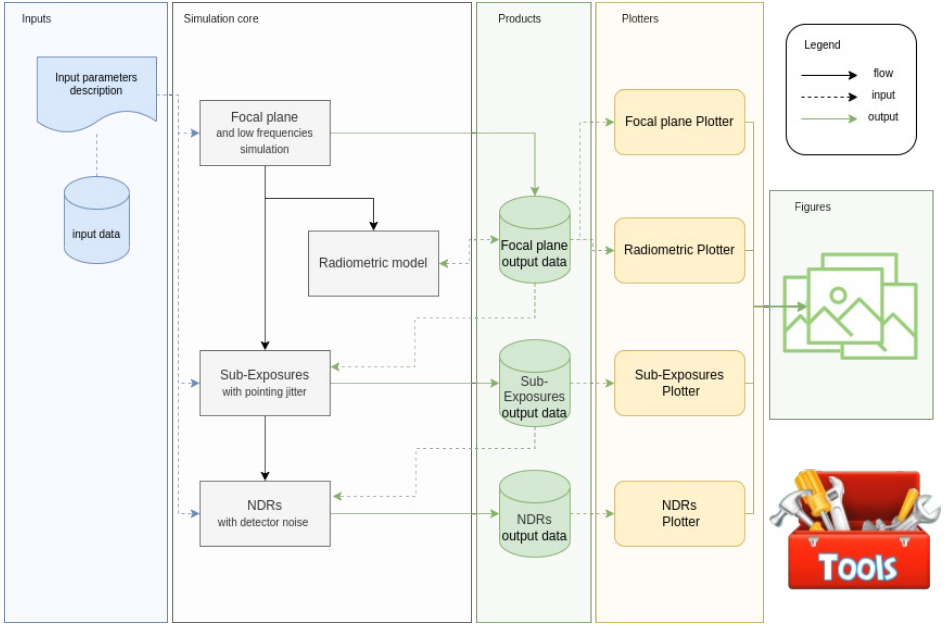
7208 docs lines → (~250 pdf pages)

94% code tested

The code and the docs

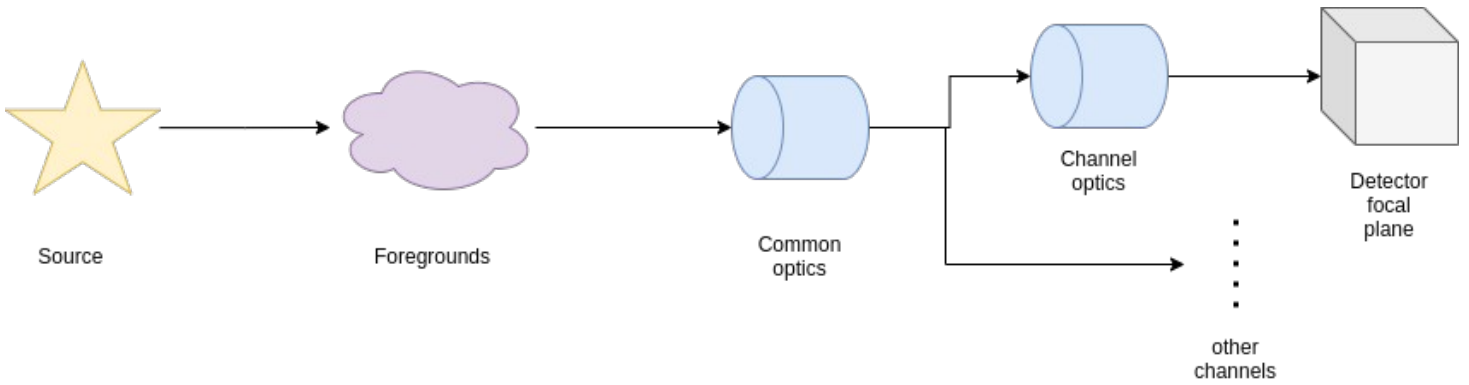
This refactored version is
- easier to use than its predecessor
- largely customizable
- completely written in Python
- tested against Python 3.7+,
- follows the object-oriented philosophy.

It comes with
- an installer,
- documented examples,
- a comprehensive guide,



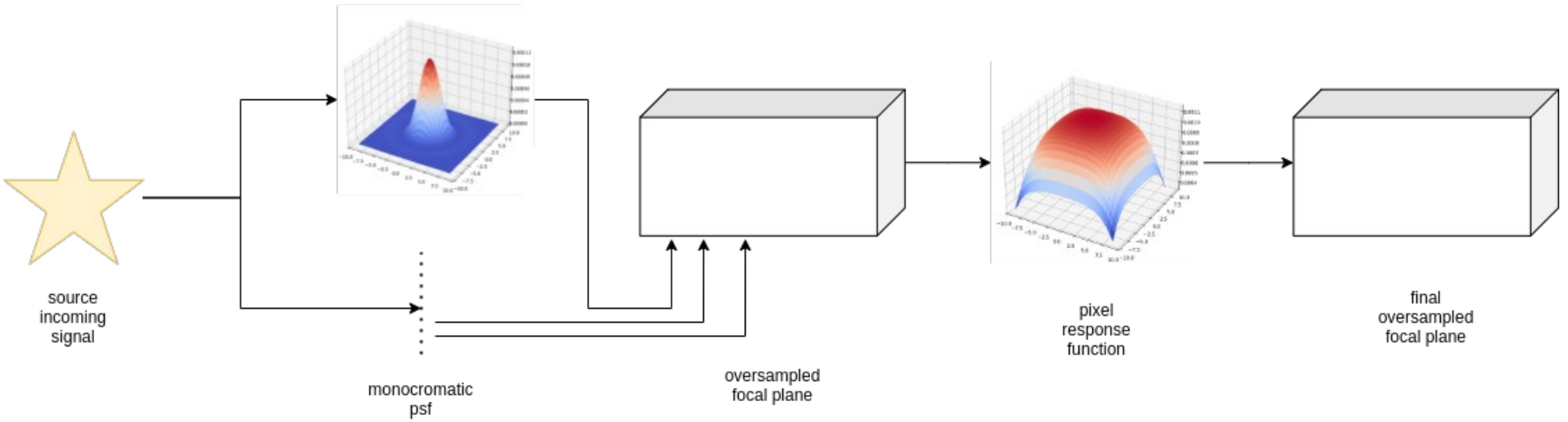
and almost every part of the code can be replaced by a user-defined function,
which allows the user to include new functionalities to the simulator

Road to focal plane



As in ExoRad, the light from the source is propagated through the foreground and optical path for each channel before reaching the focal plane.

Populate focal plane



The focal plane is built considering

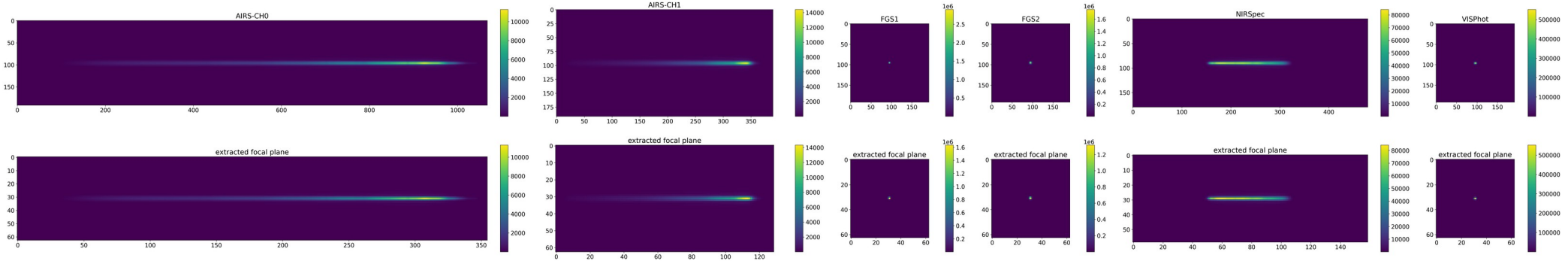
- The wavelength and time dependent efficiency
- The wavelength and time dependent signals from the sources
- The wavelength and time dependent PSFs
- The intra-pixel response function

Resulting focal planes

Finally, ExoSim produces the focal plane images for each channel.

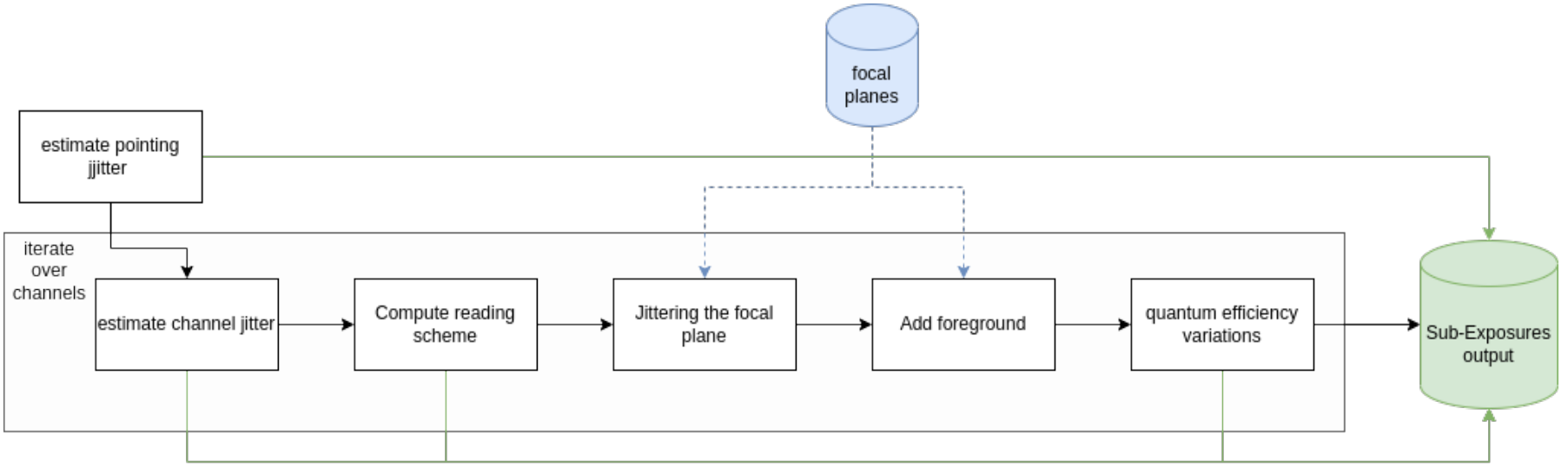
The focal planes are oversampled to facilitate the next simulation steps.

Focal planes has been validated against ArielRad.



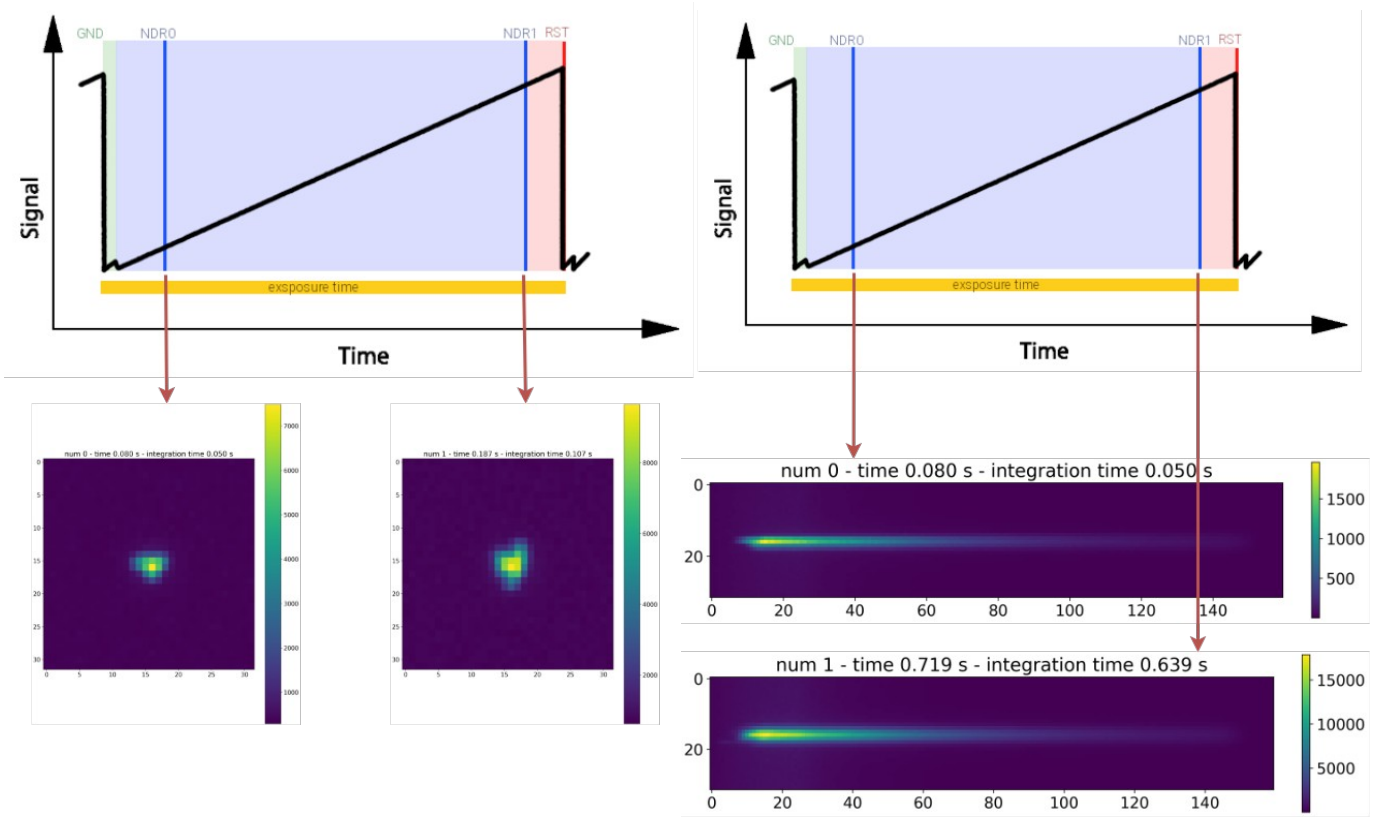
Sub Exposures and jitter

Given the static focal planes, we can introduce the time effects, as the jitter. This is done in the second step: the Sub-Exposures step.

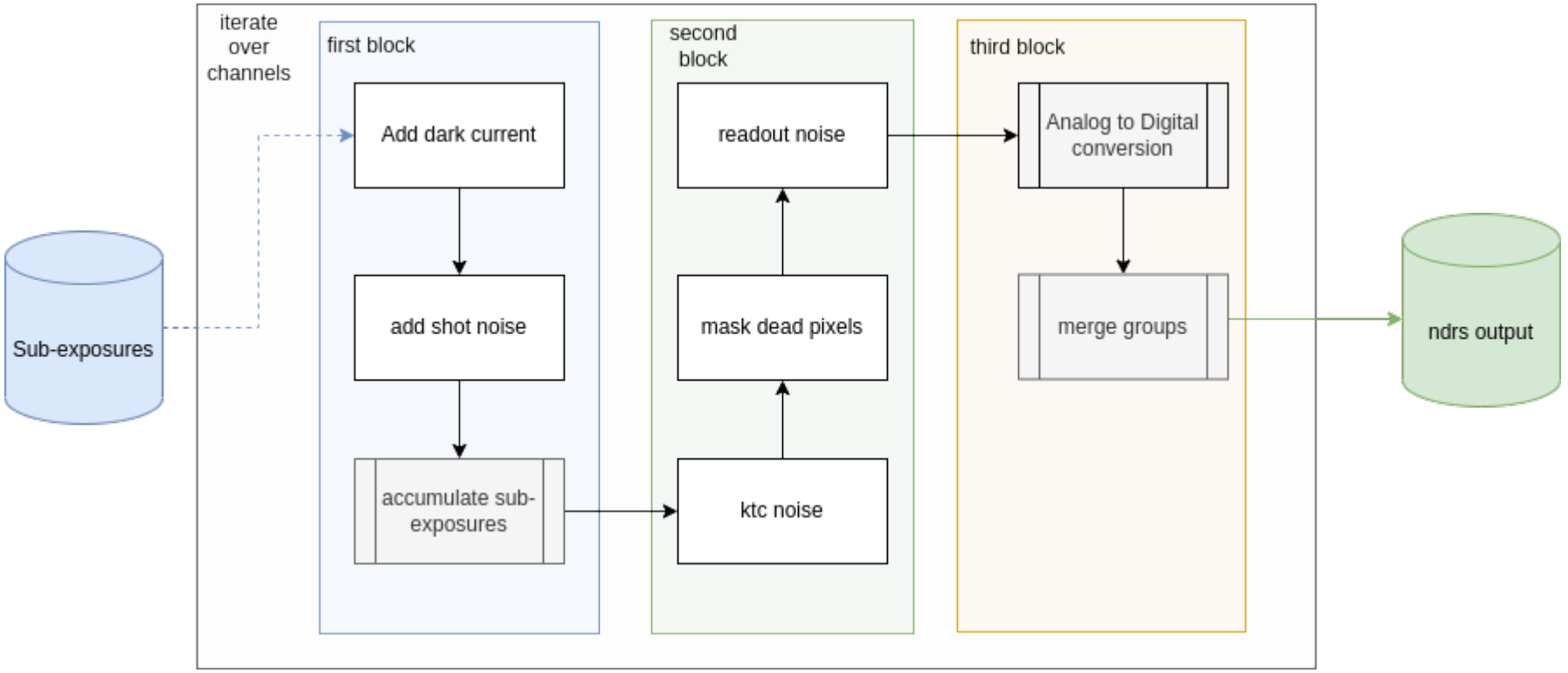


Sampling the ramp

ExoSim2 includes a MULTIACCUM module for the ramp sampling.

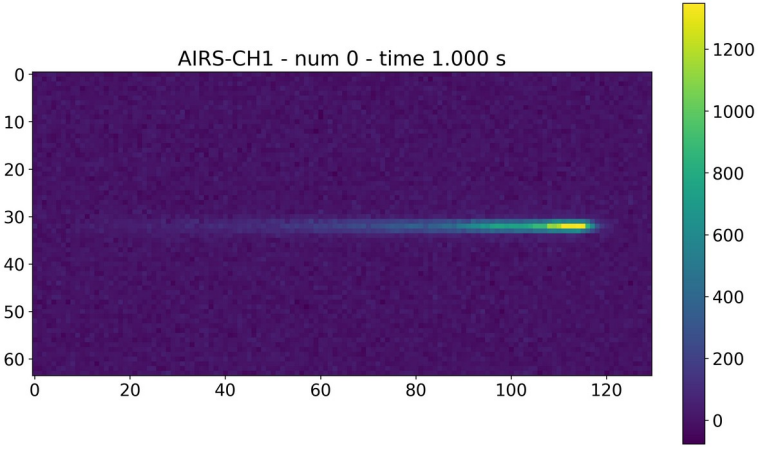


Producing the NDRs

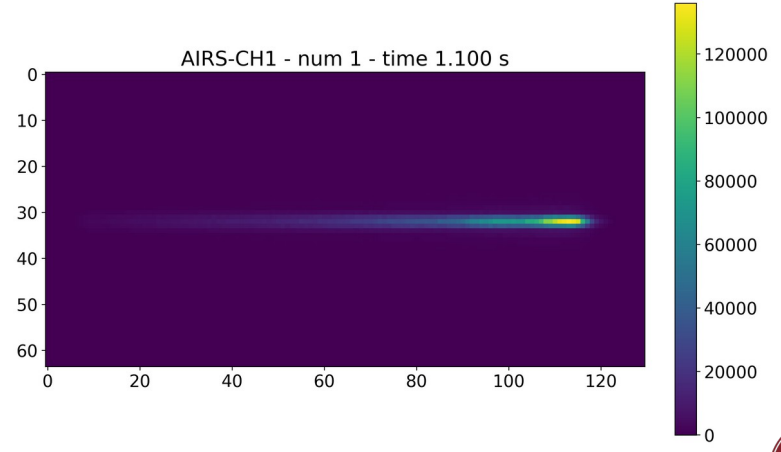


NDRs

ExoSim produces spectral images like those produced by the observation



It can be used to assess the impact of astronomical and instrumental systematics on astrophysical measurements, and to prepare the data reduction pipeline against realistic data sets



Take home messages

To predict the instrument performance is important to optimise the design and the observation strategy.

ExoRad2 (ArielRad) is used to select the candidate target and to investigate the noise budget after the data reduction procedure.

ExoSim allows to estimate the time correlated noise and to develop a data reduction pipeline.

Both ExoSim and ExoRad2 can be adapted to different telescopes.