An End-to-End Instrument Model for the Proposed E-ELT Instrument METIS

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Abstract:

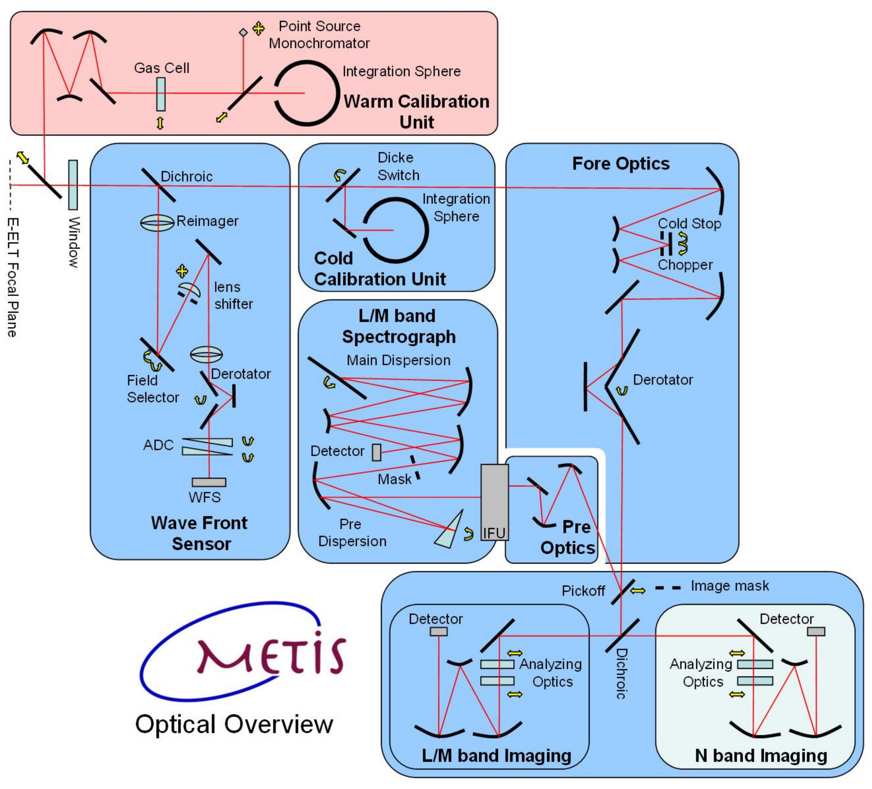
The optimal performance of an instrument relies critically on accurate performance estimates during its design phase. They need to be modelled to give the science and engineering teams a preview of the performance of the instrument, to guide the design process, to prove the capabilities of the instrument and to prepare science ready software tools before the instrument is operational. **METIS**, the **M**id-infrared **E**-ELT **I**mager and **S**pectrograph, is the only instrument concept for the E-ELT that covers the thermal infrared wavelengths from 2.9-14µm, covering the L, M and N bands. It contains a diffraction limited imager, a medium resolution long slit spectrograph and an integral field unit high resolution spectrograph and was identified in the instrument roadmap as the third instrument for the E-ELT, after two first light instruments. Because in the mid-infrared the Earth's atmosphere and the telescope mirrors radiate and produce a very high thermal background, it is crucial to develop techniques and mechanisms to measure and reduce this background and to achieve the desired performance of an E-ELT. To demonstrate tthe capabilities of METIS, years before the actual instrument is built and can be tested, we are developing an end-to-end instrument model, which will simulate the whole instrument. This can be used for example by the science team to investigate and show the unique capacities of METIS.

METIS is being designed and built by an consortium of NOVA (representing Leiden Observatory and ASTRON, The Netherlands), The Max Planck Institute for Astronomy (Germany), UK Astronomy Technology Center (UK), Katholieke Universiteit Leuven (Belgium), CEA Saclay (France), ETH Zürich (Zwitzerland) and Universität Wien (Austria).

The instrument design:

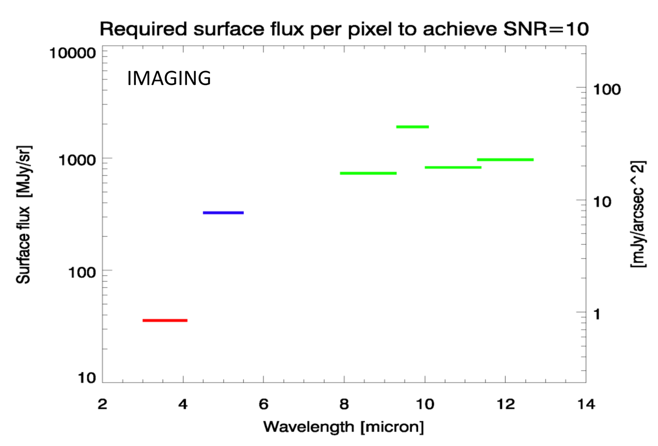
The instrument consists of two separate units, one for the imager and another for the spectrograph, and is entirely encased in a cryostat to maintain the stable low temperatures required for good performance at mid-infrared wavelengths. To achieve diffraction limited performance, METIS will use adaptive optics correction to compensate for atmospheric turbulence. The instrument will be able to observe with both natural and laser guide stars. METIS will have the following instrument design:

- Diffraction-limited imaging in L (2.9-4.2µm), M (4.5-5.5µm) and N (8.0-14.0µm) bands with a field of view of 18" x 18"
- Coronagraphic imaging in the L and N bands
- Low resolution long slit spectroscopy in L, M and N bands (R < 5000)
- Polarimetry in N band for imaging and low resolution spectroscopy
- IFU-fed high-resolution spectrograph in L and M bands with a field of view of 0.4" x 1.5" R ~100,000.



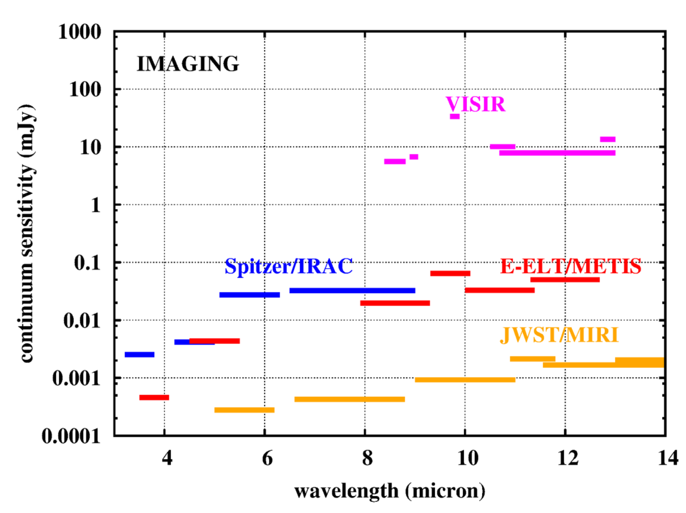
METIS Performance

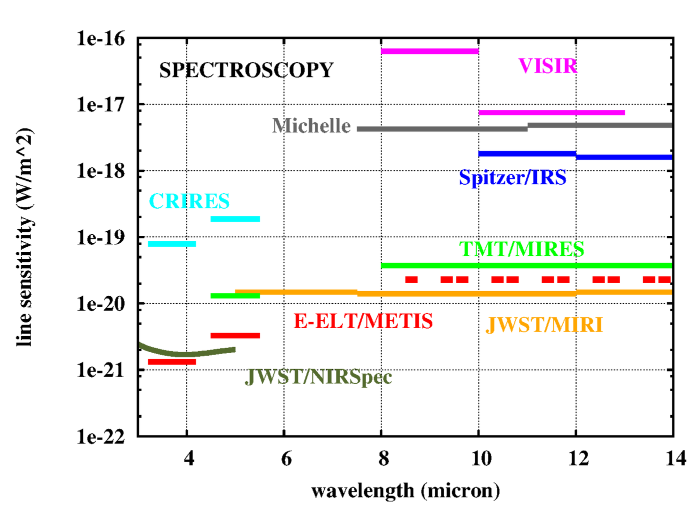
We calculated sensitivity estimates for METIS for extended and point sources.



The plot above shows the estimated sensitivities for extended sources in imaging mode on a minimum required flux-per-pixel basis to achieve a S/N=10 in 1 hour on-source integration time for the L, M and N band filters.

The combination of high angular resolution for imaging and the photon-collecting power for high-resolution spectroscopy makes METIS an extremely powerful instrument. METIS is highly complementary to JWST, with the former being superior in angular resolution and unique in high-resolution spectroscopy, while the latter provides unsurpassed imaging sensitivity, in particular low surface brightness objects. Having overlapping scientific goals with ALMA, but probing different physical conditions, there is also an excellent synergy between METIS and ALMA.





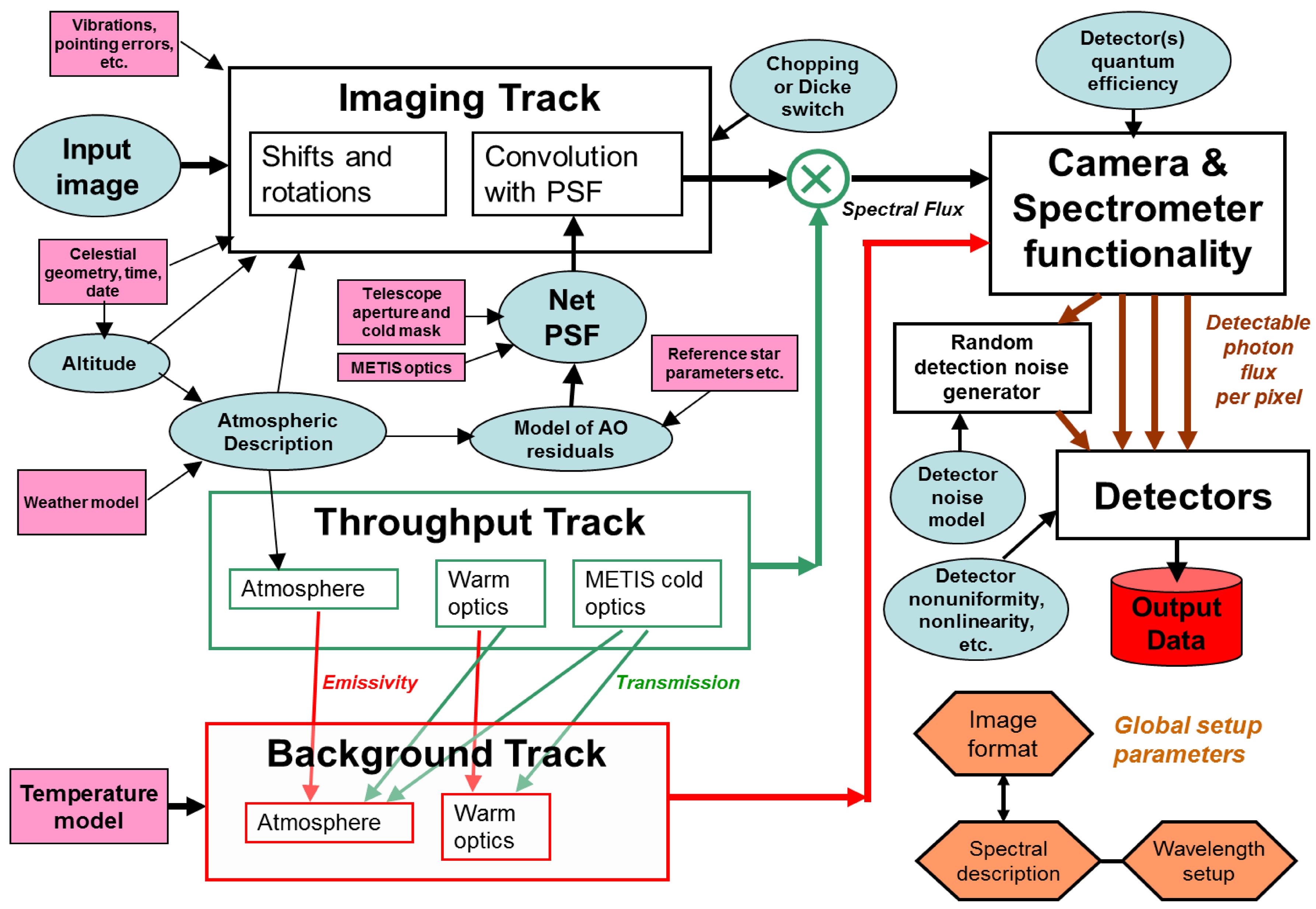
Sensitivity of the IFU-spectrograph and imager of METIS compared to other current and future instruments. Sensitivities are given for a one hour exposure of a point source /unresolved line, with 20% overhead and a signal-to-noise of 10. The calculations of the spectrometer sensitivities are based on an earlier version of the simulator developed by Kendrew et al.

Description of the simulator:

The simulator is composed of a number of modules, independent from each other as far as possible, which together perform the function of following radiation from the simulated target, along with thermal radiation especially from the atmosphere and warm optical elements, all the way to the production of photoelectrons in the detector which are presented to the readout electronics and digitized to produce the expected data product supplied by the METIS hardware. Input and output data employ FITS files to describe the images and detector outputs, along with FITS image extensions to encode the spectral aspects of the simulated input images. The simulator is written in IDL and a portable version will be available in the future. In addition to support and control aspects of the software, the simulator contains modules which implement the following functions required to process simulated optical signal from an astronomical target as seen from above the atmosphere, to the point of producing the output of the detectors.

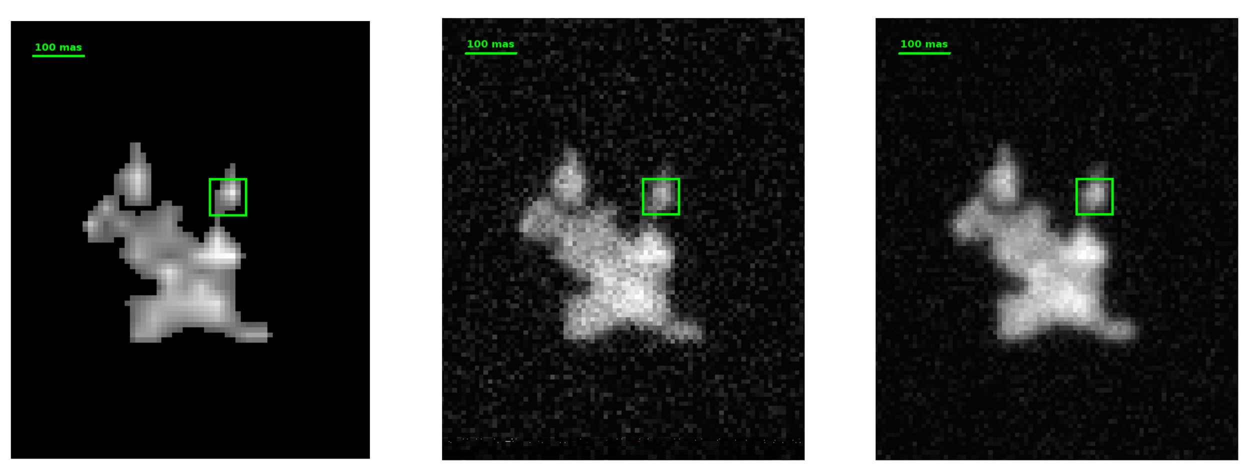
- The *image track* follows the underlying spatial image through the atmosphere, telescope, and METIS optics up to the camera or spectrometer
- The *throughput track* calculates the effect that those optical components have in reducing the (spectral) brightness of that image independent of image position.
- The *background track* processes the same series of optical components addressed by the throughput track, but models the emission from these elements due to their temperature (the elements that are not in the cryostat) to determine the net background emission that is incident at the entrance of the modelled camera or spectrometer
- The *camera or spectrometer function* is implemented for each of the instrument modes in order to map photons outputted according to the imaging, throughput, and background tracks onto one or more of the three detector arrays.
- The *detector function* receives that photon flux and produces not only the intended photocurrent, but detection noise and any detector artifacts (such as non-linearity, saturation, non-uniform pixel gain or dark level, etc.) that we choose to model.

A detailed description of the simulator's structure and input/output format is given in this SPIE proceeding: Schmalzl et al., *An end-to-end instrument model for the proposed E-ELT instrument METIS*, SPIE vol. 8449-61 (2012)



First results:

A performence simulation for the imaging arm is shown below. The underlying model of the input file was generated by Emeric Le Floc'h from CEA Saclay and taken from the HST/ ACS z-band observations of the Chandra Deep Field South, which probes the redshifted UV emission (hence the starforming activity) of the source. The images show the H_α-emission of the distant galaxy S13025 (z=4.3, Shim & Chary 2011). S13025 is classified as a strong H_α-emitter candidate from its apparent excess of 3.6 µm emission with respect to its stellar U-to-8 µm spectral energy distribution. The left image shows the input image. The feature marked in the green box has a total flux of 1.8 µJy within the L-band. The middle image shows a simulated observation with one hour integration time (8921 frames of 0.40 sec each) in a wideband L-band filter (3.0-4.1 µm). The marked feature can be detected with a signal-to-noise of ~35. The right image shows a one hour simulation (51 frames of 71 sec integration each) with a narrow-band filter only covering the H_α-emission (3.4959-3.5064 µm). METIS will allow to constrain the H_α-emission of the marked feature with a signal-to-noise of ~67. More results on exo-planet detections based on simulations with this simulator are presented by Sascha P. Quanz, ETH Zürich (poster).



References:

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Questions?

Feel free to ask!

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