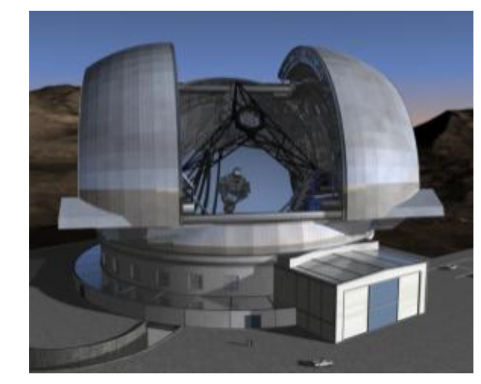
METIS - the thermal infrared instrument for the E-ELT



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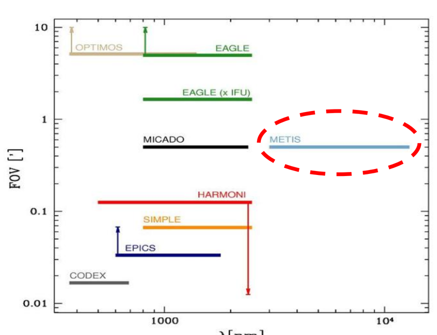
Abstract:

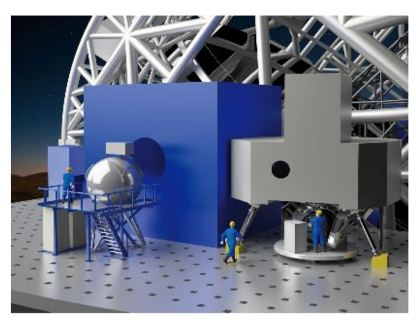
The **M**id-infrared **E**-**ELT** **I**mager and **S**pectrograph (**METIS**), will be the third instrument on the European Extremely Large Telescope (E-ELT). Taking full advantage of the supreme spatial resolution from a 39-m aperture, METIS will open up a huge discovery space at mid-infrared wavelengths as well as prove extremely complementary to the James Webb Space Telescope. METIS will provide diffraction limited imaging in the atmospheric L/M and N-band, as well as high contrast coronagraphy, medium-resolution (R ≤ 5000) long slit spectroscopy, and polarimetry. In addition, an integral field spectrograph will provide a spectral resolution of R ~ 100,000 at L/M band. Focusing on highest angular resolution and high spectral resolution, METIS will deliver unique science, in particular in the areas of exo-planets, proto-planetary-disks, high-redshift galaxies, and many other areas.

What is METIS?

METIS is the '**M**id-infrared **ELT** **I**mager and **S**pectrograph' for the E-ELT. It is the *only* E-ELT instrument to cover the thermal/mid-infrared wavelength range from 3 – 14 µm. The METIS instrument baseline includes two main subsystems with both of them working at or near the diffraction limit:

- An **imager** at L/M, and N band with an 18″×18″ wide FOV. The imager includes:
  - **coronagraphy** at L/M and N-band
  - low-resolution (R ≤ 5000) **long slit spectroscopy** at L/M & N
  - **polarimetry** at N-band (TBD)
- An IFU fed, **high resolution spectrograph** at L/M [2.9 – 5.3µm] band with an IFU FOV of ~0.4″×1.5″ and a spectral resolution of R ~ 100,000

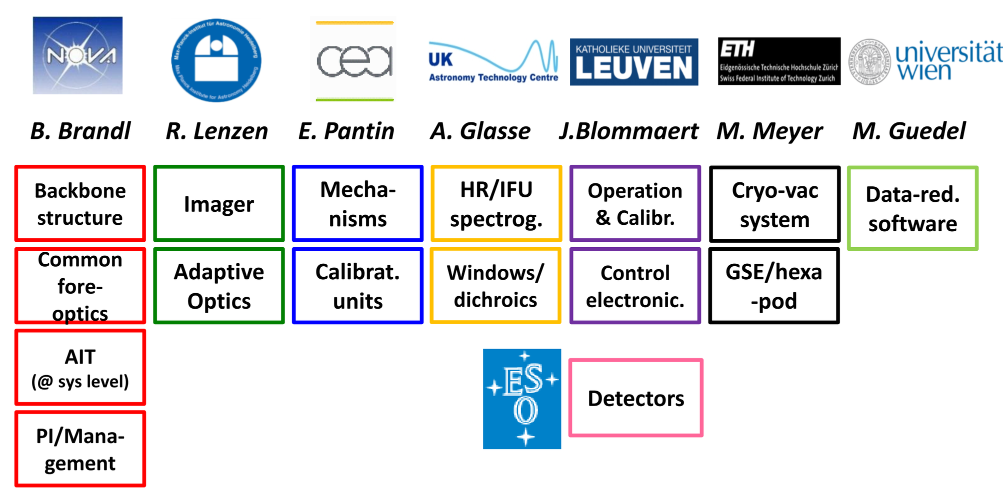




Left: METIS is the only E-ELT instrument which covers the thermal/mid-infrared wavelength range. *Right*: METIS at the Nasmyth platform of the E-ELT. Also shown are the cryostat support structure, the rig and the location of the electronics racks.

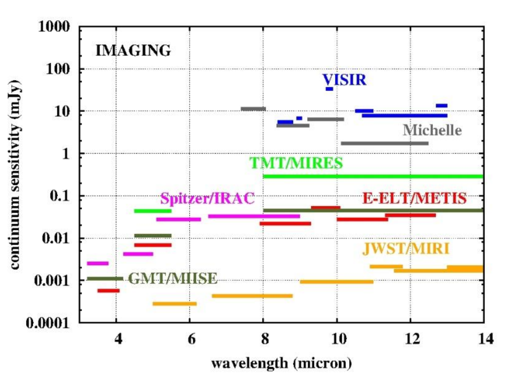
Who is building METIS?

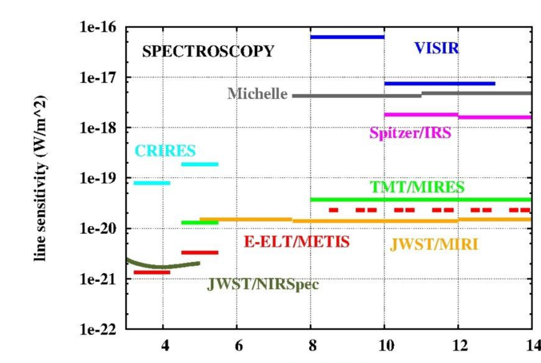
METIS is being designed and built by a consortium of NOVA (representing Leiden Observatory and ASTRON, Netherlands), the Max Planck Institute for Astronomy (MPIA, Germany), UK Astronomy Technology Center (UKATC, UK), Katholieke Universiteit Leuven (Belgium), CEA Saclay (France), ETH Zürich (Switzerland) and the Universität Wien (Austria).
Below, the contributions from the individual partners are shown.



Expected performance of METIS:

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 imager and IFU-spectrograph of METIS compared to other current and future instruments. Sensitivities are given for a one hour exposure of a pointsource /unresolved line, with 20% overhead and a signal-to-noise of 10. The calculations of these sensitivities are based on an instrument simulator developed by Kendrew et al. (2010)[1].

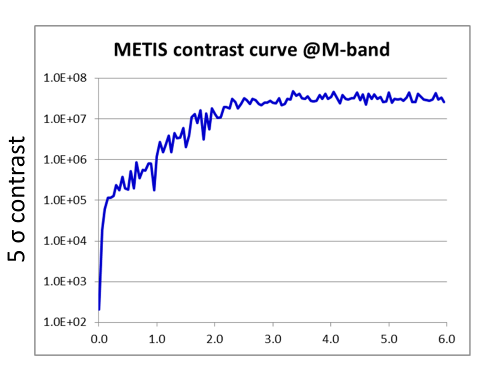
Science case highlights:

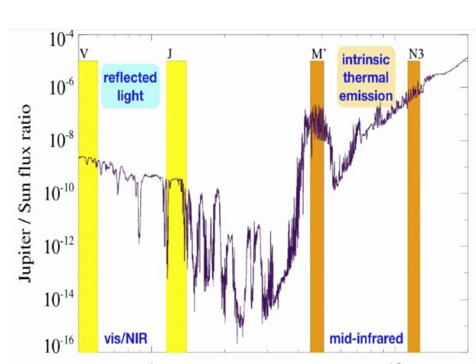
We have identified five science drivers for METIS from where the top level requirements for METIS were derived: exoplanets, proto-planetary disks, Solar System bodies, active galactic nuclei, and high redshift infrared galaxies. In addition, we have identified numerous additional science areas for METIS, including the Martian atmosphere, the properties of low-mass brown dwarfs, the Galactic Center, evolved stars and their environments, high-mass star formation and UCHIIRs, the IMF and disk survival in massive stellar clusters, and gamma-ray bursts as cosmological probes. All these cases have been previously described in some detail by Brandl et al. (2010) [2]. Here we focus on only three exciting areas for which we have recently run new simulations, based on the modified E-ELT baseline: exoplanets, proto-planetary disks and high-z infrared galaxies.

Exoplanets:

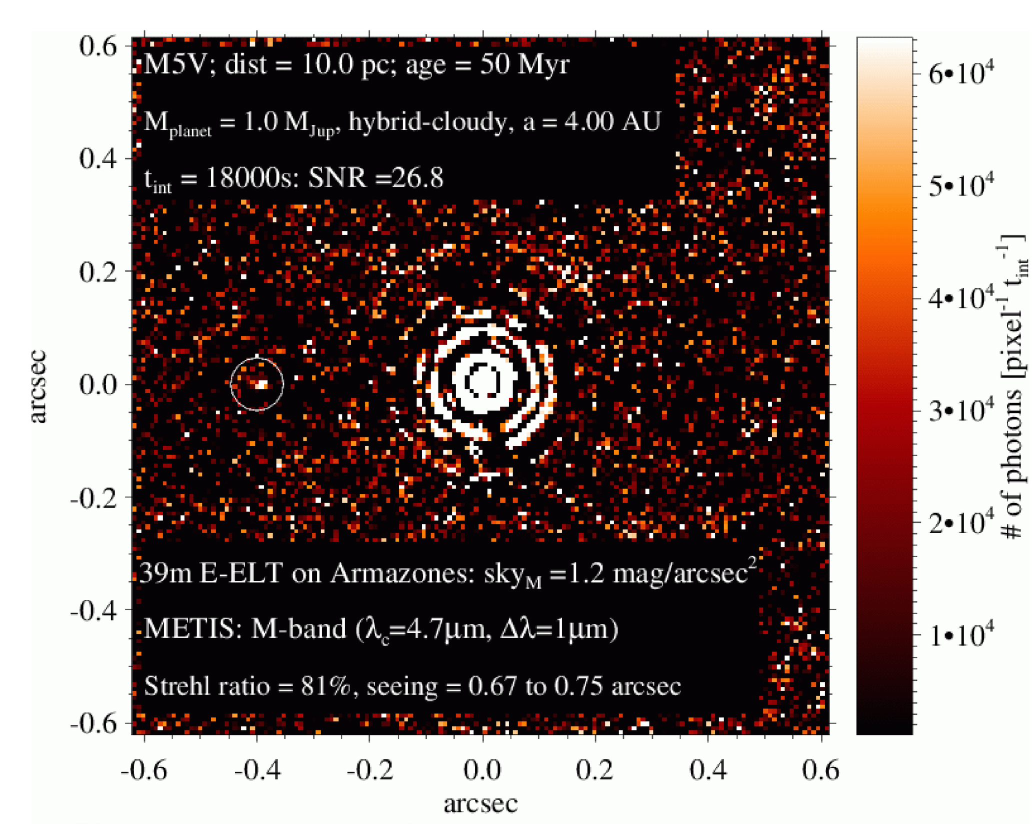
METIS will allow us to investigate the basic physical and chemical properties of exoplanets like their orbital parameters and internal structures, temperature profiles, composition of their atmospheres, weather, seasons and biomarkers. In this regard, METIS will be rather unique in its ability of photometric and spectroscopic characterization of a large number of young exoplanets.
The main reason to detect and characterize exoplanets in the thermal infrared is three-fold:

- The contrast between star and planet is much reduced at longer wavelengths, making the planet relatively brighter by typically 3 – 4 magnitudes at 5 µm with respect to the near-infrared. In addition, more sensitive instruments will probe lower mass and older planets, which are colder and redder.
- The performance of "extreme" adaptive optics is better (or significantly easier to achieve) at longer wavelength. For a given AO system, the Strehl ratio is typically about 3 – 5 times better at 5µm with respect to 1.6µm.
- The thermal infrared spectral range is full of strong atmospheric features, the brightest ones being CO, H_2O, CH_4, NH_3, allowing us to characterize the planetary atmosphere.



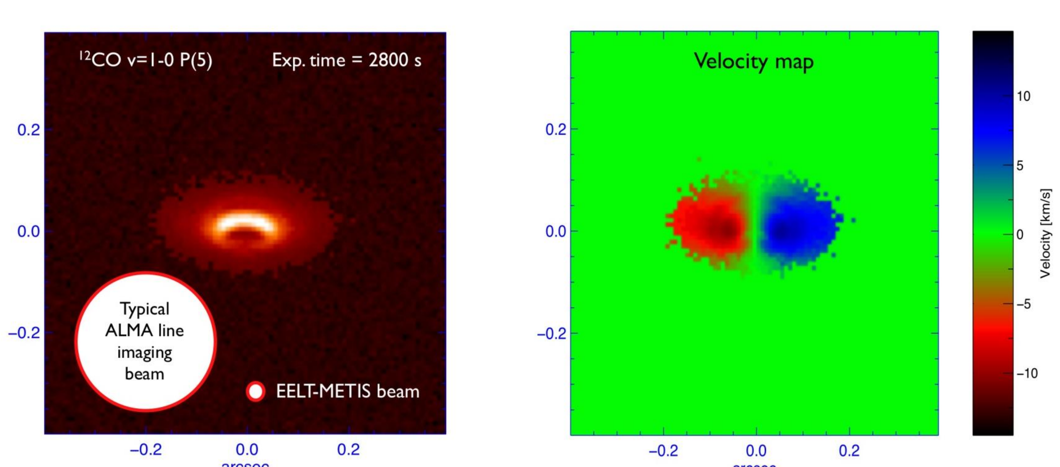


Left: Achievable 5-σ radial contrast curves for an A0V star at 10 parsecs observed with METIS at M-band over one hour. *Right:* Much reduced star-planet contrast in the thermal infrared.



Simulation of a 1 $M_{Jupiter}$ 50 Myr old exoplanet (Spiegel & Burrows 2012 [3]) at 4 AU around at M5V star at 10 pc distance from the Earth. The on-source integration time is approximately five hours and ADI methods have been used. The location of the planet is indicated by a white circle.

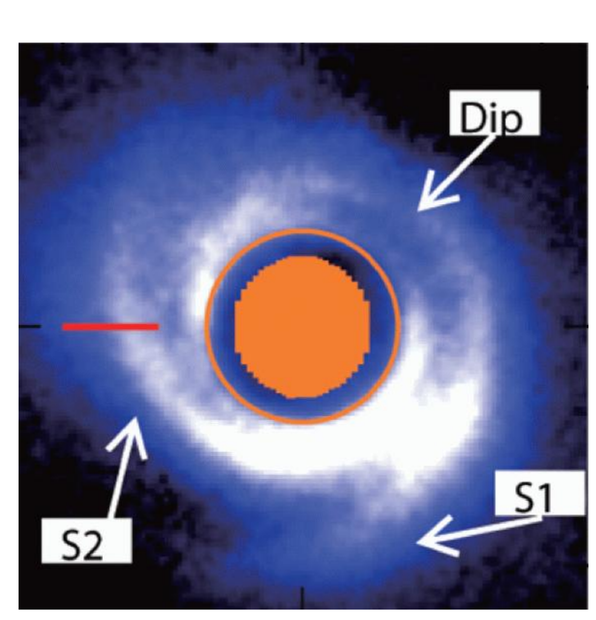
Proto-planetary disks:



Left: Simulated ^{12}CO line emission at 4.7µm of a proto-planetary disk, reconstructed from the IFS data cube. The map is continuum-subtracted and the velocity channels are optimally co-added. Also indicated is the "typical" ALMA beam for line imaging of disks, estimated from Semenov et al. 2008 [4]. Simulated parameters: 39m aperture. *Right:* velocity map calculated as the first moment of the data cube. It shows that a resolving power of 100,000 (3 km s⁻¹) is well matched to the spatial resolution of the ELT for a typical proto-planetary disk.

METIS will allow us to spatially resolve proto-planetary disks by means of spectral line imaging (above Figure, right) and spectro-astrometry. Here the high resolution integral field spectrograph (IFS) mode of METIS becomes a key tool. By imaging the emission line (e.g., the ^{12}CO(1-0) line at 4.7µm) and subtracting the spectral continuum the stellar light subtracts out and the remaining signal shows the emission of the disk.
METIS will address scientific key questions, such as:

- What are the main mechanisms for gas dissipation transforming a young accretion disk into a debris disk?
- What is the chemical composition of the planet-forming region(s)? What is the role of water and organic molecules which are of astrobiological interest?
- Is there evidence for accreting protoplanets or accretion flows?
- Is there indirect evidence for planets from holes or gaps in the disk?

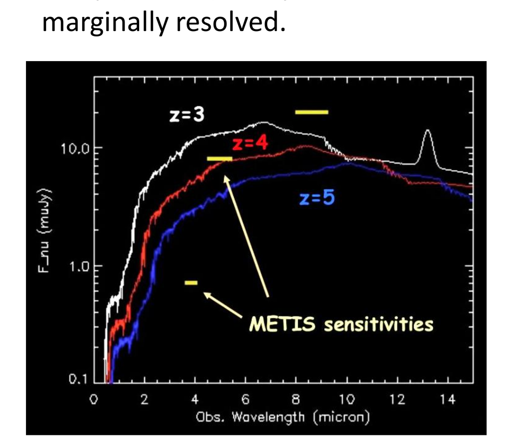


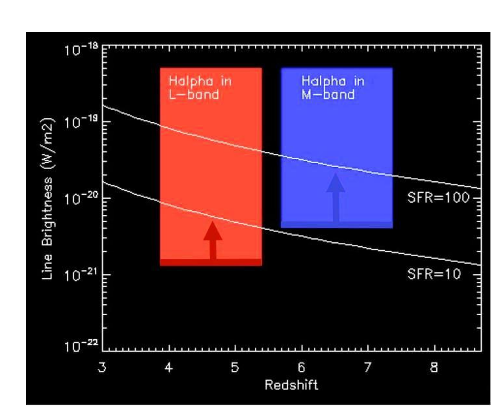
H-band image of the protoplanetary disk around the star SAO 206462. Recent observations with SUBARU/SEEDS revealed a two-arm spiral around the debris disk (Muto et al. 2012 [5]). One possible explanation for the spiral pattern is the presence or formation of two giant planets. METIS, with its high resolution, would be able to directly image the planets, which was not possible in the SUBARU H-band image tracing scattered light.

High redshift galaxies:

One of the key topics in extragalactic astronomy is the connection between star-forming and nuclear activity in galaxies throughout cosmic time. In principle, the thermal infrared regime is the ideal wavelength range to study luminous galaxies in the early Universe, for several important reasons:

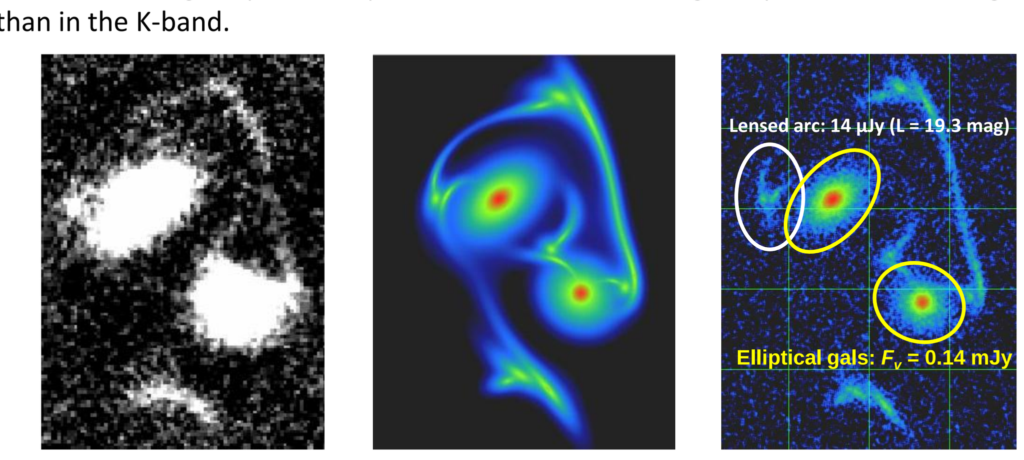
- Due to the cosmic expansion, the *stellar* continuum emission of galaxies is shifted beyond 3µm at z>3
- H-α, arguably the strongest and most frequently used emission line, is shifted into the L-band at z> 3.3
- the angular resolution of METIS at a redshift of z=2 correspond to approximately 200 pc, hence, many of the luminous emission regions will be not or just marginally resolved.





Left: Stellar continuum emission shifted beyond 3µm at z~3. Sub-mm galaxies at z~3 have1-10 µJy at 3.6 µm. *Right:* Due to the extinction, the optical/NIR sees the red-shifted UV continuum. H-α is much less affected by the extinction and is shifted to the L-band z > 3.3 and detectable up to z~5.

To demonstrate the feasibility of METIS observations we have modeled L-band image of the lensed sub-millimeter galaxy HATLAS J114637.9-001132. The analysis of this object was recently published by Fu et al. [6]. The global system is made of two elliptical galaxies at z~1 and a lensed component at z=3.26. From their K-band observation at the Keck telescope, Fu et al. derived a K-band model for both components, which we extrapolated to L-band using their respective SEDs. This "image" was used as input to the METIS newly developed METIS instrument simulator (Schmalzl et al. 2012 [7]). The simulation shows that, within one hour integration time, METIS will be able to detect faint features of high redshift galaxies at L-band. For reference, the flux density of the two ellipticals together is ~150µJy, while the spatially integrated flux density of the lensed arc to the left of the Northern elliptical is only 14 µJy (L~19.3 mag). The comparison with the K-band image from Keck also shows that METIS will probe a wavelength range where the signature of the lensed sub-millimeter galaxy with respect to the two "disturbing" ellipticals is much brighter than in the K-band.



Left: Original K-band observation by Fu et al. with the Keck adaptive optics system, yielding 0.16 arcsec resolution [5]; *Center:* derived model image at L-band, used as input to the METIS simulator. *Right:* output of the METIS simulator, corresponding to one hour integration time (composed from 4862 exposures of 0.74 s exposure time each). The image has been resampled by a factor of five to enhance the visibility of the gravitationally lensed arcs.

References:
[1] S. Kendrew et al., *Mid-infrared astronomy with the E-ELT: performance of METIS*, SPIE vol. 7735-201 (2010)
[2] Brandl et al., *Instrument concept and science case for the mid-IR E-ELT imager and spectrograph METIS* , SPIE vol. 7735-83 (2010)
[3] Spiegel & Burrows, *Spectral and Photometric Diagnostics of Giant Planet Formation Scenarios*, ApJ, 745, 174 (2012)
[4] Semenov et al., *Chemical and Thermal structure of Protoplanetary Diska as Observed with ALMA*, ApJ, 673, 195 (2008)
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[6] Fu et al., *A comprehensive view of a strongly lensed Planck-associated submillimeter galaxy*, ApJ, 753, 134 (2012)
[7] Schmalzl et al., *An end-to-end instrument model for the proposed E-ELT instrument METIS*, SPIE vol. 8449-61 (2012)