METIS: A Mid-infrared E-ELT Imager and Spectrograph

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METIS is the only instrument concept for the E-ELT that covers the thermal infrared wavelengths from 2.9–14 μm. METIS contains a diffraction-limited imager and an integral field unit high resolution spectrograph. The science case for METIS includes exoplanets, circumstellar discs, Solar System objects, supermassive black holes and high-redshift galaxies.

Science drivers

Generally, mid-infrared astronomy focuses mainly on objects that are very dusty or dust-obscured, intrinsically cool or significantly redshifted by the cosmic expansion. Furthermore, the mid-infrared (MIR) wavelength range is extremely rich in spectral diagnostics, such as emission and absorption lines of virtually all molecules, numerous atoms and ions, and solid-state features — most of which are unique or complementary to diagnostics found at other wavelengths.

The five main science drivers, for which METIS is expected to produce breakthrough science, are:

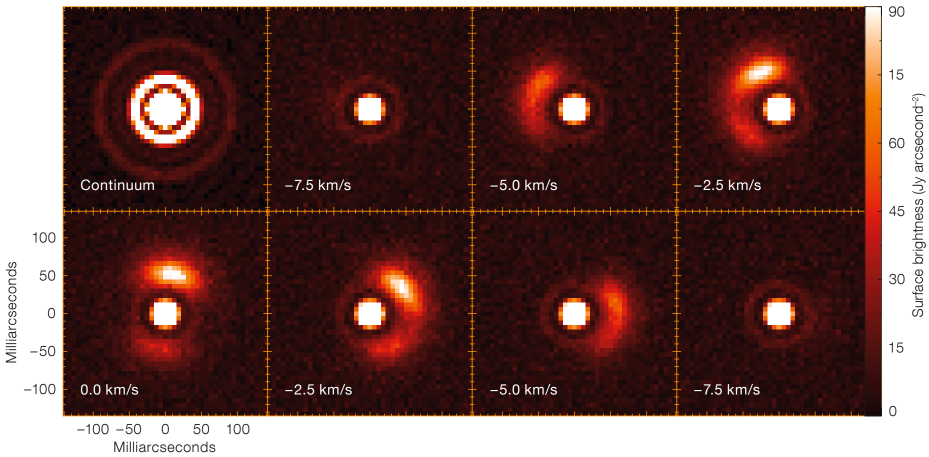
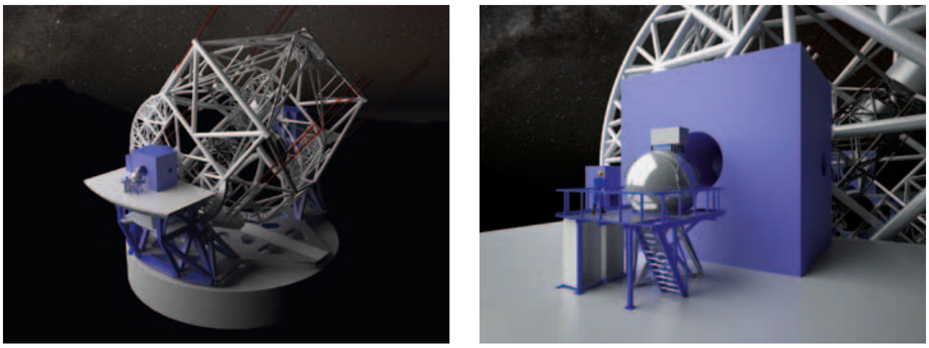


Figure 1. Simulation of a METIS IFU image cube of the CO P(8) line from SR 21 for an assumed distance of 125 pc (Pontoppidan et al., 2009). The disc has an inner gap in the gas at 6.5 AU (similar to the orbit of Jupiter) and is oriented at 20 degrees inclination, with the far side of the disc toward the top of the image.

- Protoplanetary discs and formation of planets: METIS will allow us to spatially resolve protoplanetary discs in the MIR to search for the footprints of protoplanets as well as to perform spectral line imaging (see Figure 1) and spectro-astrometry. METIS may be able to directly detect the signatures of hot, accreting protoplanets and the dynamical structure of the accretion flow onto the planet. METIS will reveal the dominant mechanisms for gas dissipation and the chemical content of the planet-forming regions, and clarify the role of water and organic molecules of astrobiological interest. Probing the warmer molecular gas, these studies will complement the work of ALMA.
- Physical and chemical properties of exoplanets: METIS will allow us to investigate the basic physical and chemical properties of exoplanets such as their orbital parameters and internal structures, temperature profiles, composition of their atmospheres, weather and seasons. METIS has the greatest detection potential in younger planetary systems, and will be able to study exo-Neptunes with a few tens of Earth masses. METIS will be rather unique in its ability for photometric and spectroscopic characterisation of a large number of young exoplanets.
- The formation history of the Solar System: METIS will enable the determination of the composition and temperature gradients in the planetary formation disc, as well as the D/H isotope ratios in cometary volatiles and how they relate to that of terrestrial H_2O. Furthermore, METIS will substantially extend the study of surface ices and organics in Kuiper Belt objects (currently, only Pluto is detectable), and measure the thermal inertia of asteroidal bodies and cometary nuclei to constrain their internal constitution.
- The growth of supermassive black holes (SMBHs): METIS provides a unique opportunity to investigate the nuclei in local AGN and ultra-luminous IR galaxies by mapping gas flows and measuring dynamic black hole masses. The unique combination of high angular resolution, high sensitivity and dust-penetrating wavelengths, will allow METIS to determine the masses of SMBHs, especially in heavily obscured nuclei. Detailed imaging

Figure 2. Left: The E-ELT with METIS on its Nasmyth platform A. Right: Zoom-in to show details of the cryostat, the detached service platform, and the location of the electronics racks.



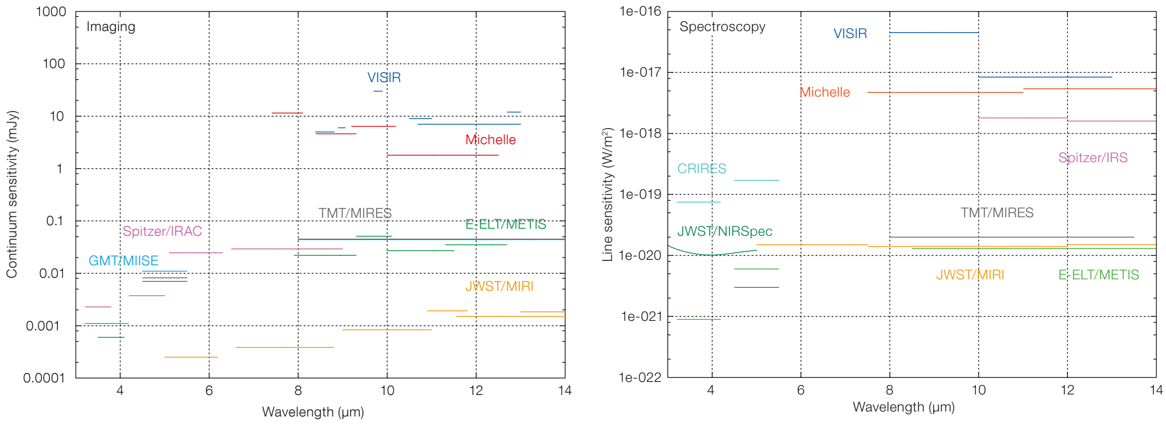


Figure 3. Point source/unresolved line sensitivities, 10σ, 1-hour exposure for METIS and its competitors. Note that the instruments shown under "Spectroscopy" have different spectral resolutions: R = 100 000 (CRIRES), R = 25 000 (VISIR), R = 30 000 (Michelle), R = 600 (IRS), R = 3000 (MIRI), R = 2700 (NIRSpec).

and spectroscopy will help to analyse the size, geometry and dynamics of the circumnuclear tori and to investigate the interplay between star formation and nuclear feedback.

– Morphologies and dynamics of high-z galaxies: METIS can ideally be used to study the structures and dynamics of high-redshift galaxies and the validity of scaling laws and the concept of a fundamental plane. Observationally, the ideal probe of stellar dynamics is provided by the calcium triplet, which is redshifted to the METIS wavelength range. It will take the resolution provided by a 42-metre telescope to provide an accurate measurement of stellar dynamical masses of high-redshift galaxies. ALMA in its widest configuration can only measure the gas kinematics from the CO line, but the stellar velocities.

Other typical objects to be studied with METIS are the Martian atmosphere, low-mass brown dwarfs, the Galactic Centre, evolved stars and their environments, the birthplaces of massive stars and ultra-compact H II regions and the initial mass function (IMF) in massive stellar clusters.

Instrument design concept

The science case for METIS, as sketched above, requires two main instrument modes:

1. A diffraction-limited imager at *LM*-bands, and *N*-band with an approximately 18 × 18 arcsecond wide FoV. The imager includes the following observing modes: coronagraphy at *L*- and *N*-band, low resolution (900 ≤ R ≤ 5000) long-slit spectroscopy at *LM*- and *N*-bands, and polarimetry at *N*-band.
2. An integral field unit (IFU) feeding a high resolution (R ~ 100 000) spectrograph at *LM*-bands (2.9–5.3 µm) with a FoV of about 0.4 × 1.5 arcseconds.

All of these observing modes require AO correction, unless the atmospheric conditions are very favourable (METIS will be able to achieve quasi-diffraction-limited images at 10 µm without AO when the outer scale of turbulence becomes significantly smaller than the telescope aperture). METIS will achieve diffraction-limited performance with the E-ELT's M4/M5 and does not require additional adaptive mirrors. METIS AO will follow a two-step approach: first, an internal wavefront sensor, which is optimised for the highest Strehl ratios for on-axis, self-referencing targets, will be used; then a couple of years after commissioning, an LGS with an LTAO system will be needed to provide full sky coverage.

The optical system of METIS uses all-reflective optics (with the exception of the spectral filters and dichroic beam splitters) to simplify testing and integration and to minimise chromatic aberrations. The optical system provides superb diffraction-limited performance. The main optical modules of METIS are:

– The wavefront sensor module, which hosts the internal wavefront sensor, an atmospheric dispersion corrector, field selector and derotator.
– The warm and cold calibration units, which provide a set of important calibration sources, including an integrating sphere as flux reference.
– The common fore-optics, which is the central part of the optical system. It directs the science beam to the AO/calibration modules, and it includes two essential optical components: (i) the cold pupil stop, which can also provide fast, two-dimensional chopping (± 5 arcseconds) and residual tip/tilt beam stabilisation; (ii) the image derotator to provide a stable focal plane in both science modules.
– The *LMN*-band imager consists of two very similar, parallel channels for *LM*-band and *N*-band. They include a reimaging system with slit, filter and grism wheels, as well as pupil imaging optics. Coronagraphy can be performed by inserting a four quadrant phase mask (4QPM) into the entrance focal plane with a matched pupil mask.
– The *LM*-band high-resolution IFU spectrograph cuts the image in 24 slices, rearranges the slices and sends the light to an echelle grating spectrometer. Tilt of the grating allows selecting the spectral range within the preselected diffraction order.

The modules are mounted to a common "backbone" structure, which acts as a mechanical and thermal interface. The cold system is surrounded by a spherical cryostat, with a diameter of approximately 2.5 m, made of stainless steel. Figure 2 shows METIS at the A1–Nasmyth port of the E-ELT.

Performance

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 to 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.

The sensitivity of METIS on the 42-metre E-ELT for a Paranal-like site, in comparison with other major facilities, is shown in Figure 3. All sensitivities have been normalised to one hour, 10σ point source/unresolved line sensitivities.

References

Pontoppidan, K. M. et al. 2009, ApJ, 704, 1482