MICADO: The Multi-adaptive Optics Imaging Camera for Deep Observations

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MICADO will image a ~ 1 arcminute field of view at the diffraction limit of the E-ELT. Its simple and robust design is optimised to yield unprecedented sensitivity and resolution across this field and to bring high precision astrometry into the mainstream. Its auxiliary arm provides the flexibility to include spectroscopy and other capabilities.

Science drivers

MICADO will address a large number of science topics that span key elements of modern astrophysics combining wide field, high resolution, and remarkable sensitivity. In what follows, we look at how MICADO's characteristics enable it to address these science cases.

MICADO will fully sample the 6–10-mas FWHM in the *J*–*K*-bands with the E-ELT. With a throughput exceeding 60%, its sensitivity at 1–2 μm will be comparable to, or surpass, JWST for isolated point sources. A project currently underway to develop OH-suppressing filters could significantly improve the sensitivity. MICADO will thus realise the full power and unique features of a 42-metre AO telescope. MICADO's resolution means that it will be clearly superior to JWST in crowded regions and its field of view of nearly 1 arcminute is much larger than for other cameras planned for ELTs. Together, these characteristics make MICADO a powerful tool for many science cases. Continuum and emission line mapping of high-redshift galaxies (see Figure 1) will enable us to address questions concerning their assembly, and subsequent evolution in terms of mergers, internal secular instabilities and bulge growth. The resolution of better than 100 pc at $z \sim 2$, equivalent to 1 arcsecond at the distance of the Virgo Cluster, will resolve the individual star-forming complexes and clusters, which is the key to understanding the processes that drive their evolution. Alternatively, one can probe a galaxy's evolution through colour–magnitude diagrams that trace the fossil record of its star formation. Spatially resolving the stellar populations in this way is a crucial ability, since integrated luminosities are dominated by only the youngest and brightest populations. MICADO will extend the sample volume from the Local Group out to the Virgo Cluster and push the analysis of stellar populations deeper into the centres of these galaxies.

With only fixed mirrors in its primary imaging field, gravity invariant rotation and HAWAII-4RG detectors (developed for space astrometry missions), MICADO is an ideal instrument for astrometry. A robust pipeline will bring precision astrometry into the mainstream. An analysis of the statistical and systematic effects by Trippe et al. (2010) shows that an accuracy of 40 μas in a single epoch of observations is achievable; and after only 3–4 years it will be possible to measure proper motions of 10 μas/yr, equivalent to 5 km/s at 100 kpc. At this level, many astronomical objects are no longer static, but become dynamic, leading to dramatic new insights into the three-dimensional structure and evolution of many phenomena. Proper motions of faint stars within light-hours of the Galactic Centre (Figure 2) will measure the gravitational potential in the relativistic regime very close to the central black hole, and may also reveal the theoretically predicted extended mass distribution from stellar black holes that should dominate the inner region. The internal kinematics and proper motions of globular clusters will yield insights on intermediate mass black holes as well as the formation and evolution of the Galaxy. Similar analyses of dwarf spheroidal galaxies will reveal the amount and distribution of dark matter in these objects, and hence test models of hierarchical structure formation.

Spectroscopy is an obvious and powerful complement to pure imaging, and is implemented as a simple slit spectrometer with a high throughput that is ideal for obtaining spectra of compact objects. The resolution of $R \sim 3000$ is sufficient to probe between the near-infrared OH lines. This simple addition will enhance many science cases, for example: deriving stellar types and 3D orbits in the Galactic Centre; using velocities of stars in nearby galaxies to probe central black hole masses and extended mass distributions; measuring absorption lines in galaxies at $z = 2$–3 and emission lines in galaxies at $z = 4$–6 to derive their ages, metallicities and star-forming histories; and obtaining spectra of supernovae at $z = 1$–6.

Instrument design concept

The instrument design has been optimised for the MCAO module MAORY. But the MICADO study included its own simple and robust single-conjugate natural guide star AO system, with which it can operate before the full multi-conjugate system MAORY is available. In this way the camera can exploit and promote the E-ELT scientifically, at the earliest opportunity. The optical relay and support structure for

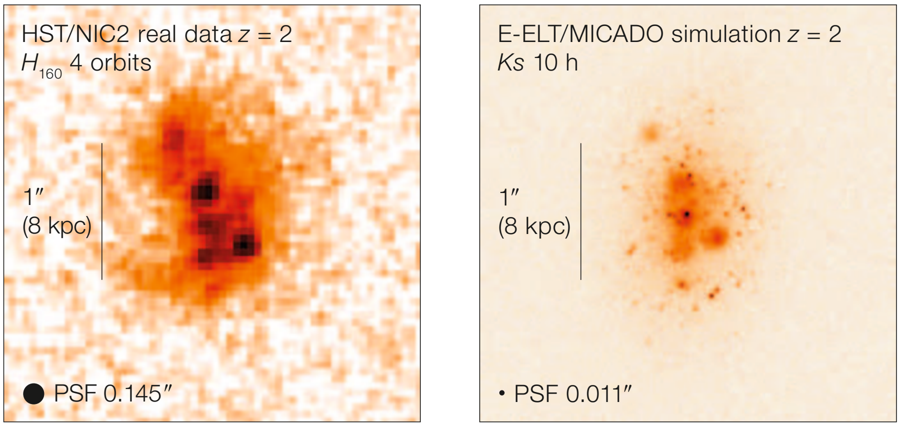

Figure 1. Two views of a high-redshift galaxy. Left: HST/NICMOS image of a $z \sim 2$ galaxy, showing several bright clumps. Right: Simulation of how such a galaxy might appear when imaged with MICADO. Numerous faint clumps were included in the simulation, to show what structures might be observable. Observations with MICADO will be able to confirm the number, size, luminosity, and distribution of the star-forming complexes in such galaxies.

single conjugate AO provide the same interface as MAORY, and in principle enable MICADO to be used with other AO systems such as ATLAS. This phased approach means that MICADO will be able to make use of increasingly sophisticated AO systems as they become available.

The instrument is compact and is supported underneath the AO systems, rotating in a gravity invariant orientation to minimise flexure (Figure 3). A tunable atmospheric dispersion corrector ensures that the images are always sharp. The collimator is at the centre of the instrument, with a mechanism to switch between the two arms, each of which has space for 20 broad- and narrowband filters mounted in a large wheel. These, and also the focal plane mask, are driven at their rim to lessen torque on the motors. The primary arm is a high-throughput camera that images a 53-arcsecond field with a fixed 3-mas pixel scale on a 4 × 4 array of detectors. This arm is designed with fixed monolithic mirrors for superior stability, optimising astrometric precision. In addition, MICADO will have an auxiliary arm with one detector to provide an increased degree of flexibility. In the current design, a mechanism in this arm switches between (i) imaging a smaller field at a finer 1.5-mas pixel scale, and (ii) a 4-mas pixel scale for spectroscopy. However, in principle the auxiliary arm also opens the door to many other options, including a "dual imager" based on a Fabry–Perot etalon to image separate emission line and continuum wavelengths simultaneously, or a high time resolution detector.

The mechanical design minimises torques and maintains optical alignment during cooldown. The electronics racks are mounted on a co-rotating platform on the Nasmyth floor, which minimises cable lengths, limits the mass mounted on the derotator, and houses the cable-wrap for external supplies. Servicing the key elements of the instrument, while mounted, is possible through two large doors in the cryostat, which is rotated by 25° with respect to the core structure to maximise access. MICADO will be cooled by liquid nitrogen to avoid vibrations that could otherwise have an adverse effect on the AO performance.

Performance

The broadband imaging performance for the MICADO primary field has been calculated for isolated point sources using PSFs provided by the MAORY consortium and for standard broadband filters similar to those in HAWK-I. It shows that the 5σ sensitivity will be better than a few nano-Jy (30 mag AB) in one hour for the *J*- and *H*-bands, and in two hours for the

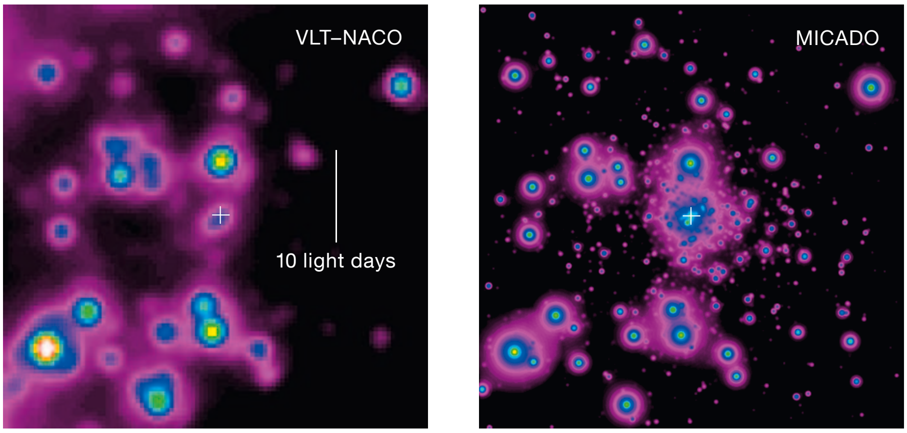

Figure 2. The innermost arcsecond of the Galactic Centre. Left: NACO image at the VLT diffraction limit, showing S-stars and the location of the black hole Sgr A* (cross). Right: A simulated image with MICADO, extrapolating from the measured luminosity function and density profile. Proper motions of hundreds of stars will be measurable, providing detailed constraints on the black hole mass and extended mass distribution.

I-band. The *K*-band performance depends strongly on the thermal background and hence the ambient temperature, but is likely to be about 1 mag less. Advanced filters — high throughput broadband filters and OH suppressing filters — will have a very significant impact on MICADO sensitivity. The prototype *J*-band filters increase the sensitivity by 0.3 mag. More advanced design optimisation techniques could lead to a 0.5-mag sensitivity gain in this band, and comparable gains may be expected for the *I*-band and *H*-band.

The spectroscopic performance has been calculated for isolated point sources that are nodded back and forth along a slit that is 8 arcseconds long and 12 milliarcseconds wide. Because of the unusually extreme core + halo shape of the adaptive optics PSF, this width maximises the signal-to-noise reached for point sources in the *J*- and *H*-bands. In the *K*-band, additional diffraction losses at the slit reduce the throughput slightly. The sensitivity calculation takes account of all effects (including the Strehl ratios predicted by MAORY, the limited coupling efficiency due to the PSF shape, diffraction losses at the slit, and the thermal background). The resulting 5σ sensitivities are $J_{AB} = H_{AB} = 27.2$ mag between the OH lines in a five-hour integration; and similarly $K_{AB} = 25.7$ mag (brighter limit again primarily due to the thermal background).

References

Trippe, S. et al. 2010, MNRAS, 402, 1126

Links

http://www.mpe.mpg.de/ir/instruments/micado/micado.php

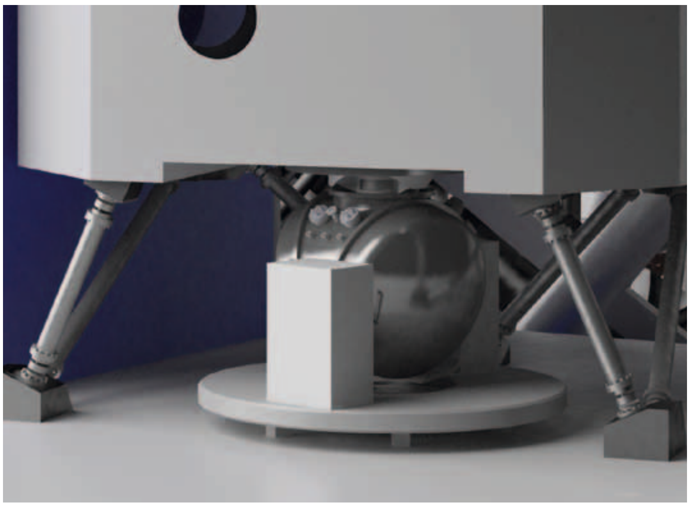

Figure 3. CAD view of MICADO mounted in the 2.5 m space underneath the multi-conjugate adaptive optics system MAORY. The feedthroughs in the cryostat, and the large access doors for on-site maintenance, are visible. The electronics are mounted on a co-rotating platform that also houses the cable-wrap.