Science with MICADO at E-ELT

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New Challenges to European Astronomy
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**MICADO**

**MCAO Imaging Camera for Deep Observations**

Phase A study

design a simple & robust near-IR imaging camera, ready for the first light of E-ELT. Used primarily for MCAO but also compatible with GLAO, LTAO, etc.

**consortium**

MPE Garching, Germany
MPIA Heidelberg, Germany
USM Munich, Germany
OADP Padova Astronomical Observatory (INAF), Italy
NOVA Leiden, Groningen, Dwingeloo (ASTRON), Netherlands
MICADO - The project

Board of Directors
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K. Jahnke, L. Greggio, E. V. Held, L. Bedin, G. Piotto, R. Saglia
# MICADO - The instrument

## Main characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength range</td>
<td>(0.6)-0.8 to 2.5 mic</td>
</tr>
<tr>
<td>Field of View</td>
<td>30 x 30 arcsec</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>3 mas</td>
</tr>
<tr>
<td>PSF</td>
<td>FWHM 6(J), 10(Ks) mas</td>
</tr>
<tr>
<td></td>
<td>Strehl 0.13(J), 0.47(Ks)</td>
</tr>
<tr>
<td></td>
<td>EE(10mas) 0.10(J), 0.22(Ks)</td>
</tr>
</tbody>
</table>

## Throughput

Telescope + instrument + detector = 0.3
MICADO - Expected performance

AB mag limits for isolated point sources

\[ J(AB) = 30 \text{ in } 5h \ (S/N=5) \]
\[ K(AB) = 29 \text{ in } 5h \ (S/N=5) \]
MICADO - The science

The main science cases

• Dinamics of the Galactic Center [ Genzel, Davies,...]
• Globular Cluster Astrometry and Photometry [ Piotto,]
• Galaxy cores : structure and SMBH [ Bender, Saglia ]
• Resolved stellar populations in distant galaxies [ Greggio, Falomo, Held ]
• QSO host galaxies and environments at high z [ Jahnke, Rix, Falomo]
• High Redshift resolved colour and emission line imaging
• High mass SF [ Herbst, Feldt ]
• Dwarf spheroidal kinematics [ Kuijken ]
• Structure of high z galaxies [ Franx ]
MICADO - Science Cases

The Galactic Center

• MICADO is uniquely suited for the exploration of a number of important issues in the GC
• The GC is confusion limited for current AO observations on 8m class telescopes.
• At ~10 mas resolution MICADO will push the effective detection by ~ 5 mag.

• It will be possible to carry out 50-100 μ arcsec precision astrometry and thus investigate a number of key issues of the physics of massive black holes and their surroundings

Proper motions at GC
Genzel et al
MICADO - The science

Globular Cluster Astrometry and Photometry

The expected astrometric precision for MICADO is \( \sim 36\mu\text{as} \) (@1.2\( \mu \text{m} \)), but including systematics it could be of 50 \( \mu\text{as} \) in a single image and better than 30 \( \mu\text{as} \) in multiple images.

This implies a proper motion precision better than 10 \( \mu\text{as/yr} \) in 5 yrs

- Decontamination of cluster samples
- Internal motion and rotation of cluster stars
- Absolute Motions of GCs
- Binaries in GC cores

G. Piotto et al

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Galaxy cores; structure and SMBH

HST observations of local early-type galaxies have shown that two types of cores are present in these objects, correlated with absolute luminosity, kinematic anisotropy and isophote shapes of the galaxy.

**Luminous E** cuspy cores, fainter **E** and bulges have power-law cores

Galaxy cores at Virgo appear unresolved with the optical resolution of HST

MICADO at the ELT in the K band with optimal AO will be able to achieve 0.01 arcsec resolution and detect core radii down to approximately one pc at the distance of Virgo cluster.

This will allow one to study the relationship between core structure (including rings, bar, etc) and SMBH.

Bender, Saglia

Search for binary SMBH and galaxy merging systems.


MICADO - The science

Resolved stellar population in distant galaxies

Greggio et al

• **Aims**: Probe the Star Formation History (SFH) of galaxies of different morphology and environment

• **The tool**: stellar photometry in the NIR and star count in selected regions of the CMD

• **Output**: Derive age (metallicity) and mass of different stellar components of a galaxy

• **Test**: Assess the basic requirements for MICADO observations
Resolved Stellar Populations in Distant Galaxies

SFH from analysis of stellar distribution on the CMD using stellar evolution theory

Best diagnostic from MS TOs where different luminosities sample different stellar ages, but old TOs are faint

Old SPs can be sampled on the bright RGB, at ~ 7 mags brighter, a gain in volume of a factor of ~ $15 \times 10^6$

SCIENCE CASE FOCUSSES ON DERIVING SFH FROM THE INTRINS. BRIGHTEST PORTION OF THE CMD

Probe as much as possible distant SP
THE METHOD

Simulation of a Stellar Population with ages between 0 and 12 Gyr and metallicity between 0.02 and 1 times solar (IMF by Kroupa)

Code ZVAR (Bertelli et al. 92 + updates)

Selected Areas in the CMD in order to:
• Sample specific AGE ranges
• Minimize effects of photometric errors
• Include enough objects for statistics

In each area:

\[ N_{*, box} = \delta n_{box} \times M_*(\Delta \tau_{box}) \]

from Stellar Evolution
Greggio 2002, ASPC 274 444

Counting stars in selected boxes
GIVES STELLAR MASS IN THE SPECIFIC AGE RANGE
Simulation and testing:

M99 spiral galaxy in Virgo cluster
MICADO - The science
Resolved stellar population in distant galaxies

Simulation and testing

Stellar population: constant SFR (Age 0 to 12 Gyr)

FoV = 3x3 arcsec \((0.01 \times \text{FoV})\)

Distance module = 31 (Virgo cluster)

All stars with \(M(K) < -0.8\) (Vega mag)

Case A

70000 stars

Average SB: \(\mu(K) \sim 18\)

Case B

12000 stars

Average SB: \(\mu(K) \sim 20\)
Advanced Exposure Time Calculator

R. Falomo¹, M.Uslenghi², D. Fantinel¹, L.Greggio¹

¹) INAF-Osservatorio Astronomico di Padova, Italy
²) INAF-IASF Milano, Italy

produce simulated images of the sky from any telescope
Advanced Exposure Time Calculator

- Input Stellar Population
- Input Source Specs
- Object Distribution
- Image Simulator
- Telescope & Instrument Specs
- Input Background Specs
- ObservationParms
- Options
- ETC
- Output Products
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AETC

Simulation and testing: PSF

Smart featureless PSF (constant FoV)

- FWHM (core)
- Enc. Energy
- Strehl
- Seeing wing (0.6 arcsec)

- ELT-LTAO – PSF (ESO)
- MAORY – PSF (TBD soon)

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Resolved stellar population in distant galaxies

Simulation and testing: Images

MICADO: J filter – 5 h
MICADO: K filter – 5 h

FoV = 3x3 arcsec

MICADO: K filter – 5 h
Filter: J
EXP: 5h
FoV : 3x3 arcsec

4860 good stars over
5010 detected
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Simulation and testing: run DOPHOT

Completeness is good up to $J(AB) \sim 29$

Magnitude limit for $S/N = 10$
**MICADO - The science**

Resolved stellar population in distant galaxies

**Simulation and testing: preliminary results**

CMD studies of resolved SP in distant galaxies are feasible for the most luminous ($M < -3$) stars at Virgo distance

**Work is in progress in order to:**

1. Optimize the SW parameters (DOPHOT, STARFINDER, …)
2. Check for phot accuracy vs crowding level
3. Experiments with positional dependent PSF
4. Use more complex (structured) PSF.
Virtually all massive galaxies contain a supermassive central black hole, and a quite tight relation exists between the mass of the BH and the stellar mass of the galaxy's bulge.

The evolution of galaxies and their central black holes is intimately linked.

- A precise empirical determination of the actual bulge mass to black hole mass relation and its evolution since the early Universe needs to be obtained, to constrain the possible physical mechanisms connecting bulge and black hole.

- The only galaxies for which both masses can be estimated are galaxies in the luminous AGN phase, since for broad-line AGN the black hole mass can be estimated using spectral information.

Jahnke, Rix
High sensitivity combined with a very narrow PSF together with an optimal characterization of the shape of the PSF are the crucial issues to decompose the light of the host galaxy from that of the bright central nucleus.

**Expected (requested) MICADO capabilities are able to disentangle the light from the two components (nucleus & host galaxy) for high z luminous QSO.**

Falomo et al 2007

Jahnke, Rix
Environment of QSO at the peak of their cosmic evolution

QSO galaxy environment

- 0.3 Mpc
- 100 kpc
- Close environments
- Low z QSO in cluster
  - ESO-NTT + SUSI + R
Close Environment of QSO at the peak of their cosmic evolution

MICADO  Field of View : 30 arcsec

FoV is adequate for close environments study in a single frame BUT requires multiple fields to study larger scale.
Environment of QSO at the peak of their cosmic evolution

Properties of high z galaxies

- disk galaxies at $M^*(M_R=-22) + 2 (3)$
- goal is $K(AB) = 24$ (with $S/N = 30-50 !!!$)
- 1 arcsec at $z = 2.5 \rightarrow 8 \text{kpc}$ (concordant cosmology)
- BUT size evolution get smaller galaxies $\rightarrow 1-2 \text{kpc}$ !!
- thus the observed Half Light Radius is $\sim 0.2$ arcsec
- this leads to a significantly higher SB and thus improve their detection (but requires adequate spatial resolution to study the morphology)
Environment of QSO at the peak of their cosmic evolution

Measuring distant galaxies at z=2.5
Environment of QSO at the peak of their cosmic evolution

@z=3 : K observed is rest frame band V

Direct comparison of QSO environments in the local Universe
Environment of QSO at the peak of their cosmic evolution

MICADO@E-ELT

1. Detection of $M^*$ (+2-3) galaxies *seems* feasible up to redshift $z = 2-3$

2. Morphology should be attainable from relatively high S/N images of brightest members

3. Direct comparison with QSO environments at present epochs should be possible for the first time

4. Color information (restframe U,B,V,R) derived directly from I,J,H,K images (*hint for SF and stellar population*)
Science with MICADO at E-ELT

E-ELT PROGRAMME

MICADO Phase A
Scientific Analysis Report

Document: E-PLA-MiC-561-0005
Issue: 0.1
Date: 27.08.08

Coming soon

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