MICADO: science & AO requirements

Richard Davies

on behalf of

MPE Garching, Germany
MPIA Heidelberg, Germany
USM Munich, Germany
OAPD Padova (INAF), Italy
NOVA Leiden, Groningen, Dwingeloo (ASTRON), Netherlands
LESIA Paris Observatory, France
distortions in a series of frames caused by MAD as it corrected for improper field derotation.
MICADO: Multi-AO Imaging Camera for Deep Observations

Primary Imaging Field
- 53” across, 3mas pixels
- high throughput
- 4x4 HAWAII 4RG detectors
- ~20 filter slots

Xmas Tree Arm
- 1.5mas & 4mas pixels
- imaging & spectroscopy
- ~20 filter slots
- [polarimetry]
- [tunable filter (dual imager)]
- [high time resolution]

movable pick-off switches between Primary field & Xmas Tree
MICADO Key Capabilities

- **Sensitivity & Resolution**
  - JHK sensitivity comparable to JWST
  - resolution of 6-10mas over 1arcmin field
  - <50μas over full 1arcmin field
  - 10μas/yr = 5km/s at 100kpc after 3-4 years
  - bring precision astrometry into mainstream

- **Precision Astrometry**
  - simple high-throughput slit spectroscopy
  - ideal for compact sources
  - 12mas (& 48mas) slits, R~3000

- **High throughput Spectroscopy**
  - optical & mechanical simplicity for stability
  - exemplifies most unique features of E-ELT
  - flexibility to work with SCAO & MCAO

- **Simple, Robust, Available early**
**Opto-Mechanics Overview**

- imager: high-throughput reflective gravity invariant design using only fixed mirrors; optimised for photometric & astrometric precision
- cryostat ~2m × ~2m; mounts underneath SCAO & MAORY
a few examples to illustrate what is possible

➢ **Astrometry**

  • Galactic Centre (see Thibaut Paumard’s talk) & other supermassive black holes

  • Globular Clusters:
    • intermediate mass black holes
    • proper motions

➢ **PSF & Photometry**

  • QSO hosts

  • resolved stellar populations
**Astrometry - systematic & statistical effects**

**Fundamental Limit**
- 34μas for S/N=100 (measurement noise)
- Equivalent to 0.5% of H-band FWHM

**Goal**
- 50μas over 50" field: 1/1000000 precision

**Sources of error**

**Requirement**

**Instrument**
- **Sampling**
  - Pixel scale 3mas (less in crowded fields)
- **Instrument Distortions**
  - Calibration with mask to 0.01pix (30μas)
- **Plate scale & derotation**
  - Low order warping → coordinate transform

**Atmosphere**
- Achromatic differential refraction
  - Low order warping → coordinate transform
- Chromatic differential refraction
  - Tunable ADC (10-20μas) or multi-colours

**AO**
- **Differential Tilt Jitter**
  - 270μas/ T½ [Ellerbroek 07] → ‘integrate it out’ statistically [cf Cameron+ 08]
- **NGS instrumental effects**
  - Low order warping? → coordinate transform
- **NGS atmospheric effects**
  - Low order warping? → coordinate transform
- **PSF variations & asymmetries**
  - Minimal PSF variation & good PSF model

**Trippe+ in prep.**
Intermediate Mass Black Holes

Arches
$M_{\text{BH}} \sim 1000M_{\odot}$? (Portegies Zwart et al. 06)
proper motion: 5.6mas/yr (Stolte et al. 08)

IRS 13
$M_{\text{BH}} \sim 1300M_{\odot}$? (Maillard et al. 04)

Omega Cen: $M_{\text{BH}} \sim 10000M_{\odot}$?
**Omega Cen: does it have a black hole?**

Noyola+ 08

- used luminosity profile & l.o.s. dispersion
- isotropic spherical model yielded $M_{\text{BH}}=4 \times 10^4 M_{\text{sun}}$
- considered radial anisotropy, but argued against it since model without BH required $\sigma_t/\sigma_r<0.67$
Omega Cen: does it have a black hole?

Anderson+ 09, van der Marel+ 09
- used >50000 (faint) stars, 4-yr baseline, individual errors ~100μas/yr
- proper motion dispersions along tangential & radial directions
- models account for small but significant anisotropy (pm_t/pm_r=0.983±.006)
  since isotropic models overpredict $M_{\text{BH}}$

➢ models with shallow cusp require $M_{\text{BH}}\sim 9\times 10^3 M_\odot$
➢ models with core profile (formally the best fit) require no central dark mass!
Globular Cluster Proper Motions

Kalirai+ 07

NGC6397
red: galaxies
black: field stars & cluster members

10 years of HST data:
\( \mu_\alpha \cos \delta = 3.56 \pm 0.04 \text{ mas yr}^{-1} \)
\( \mu_\delta = -17.34 \pm 0.04 \text{ mas yr}^{-1} \)

➢ provides orbit around Milky Way
➢ frequent passages through the disk
➢ impact on structure & evolution
**QSO hosts**

- Black hole – bulge mass relation @ $z=3, 4$
- Luminosities, colours, structure of active galaxies @ $3 < z < 7$
  - Luminosity function of host galaxies over cosmic time
  - masses/SF, trace co-eval BH and galaxy evolution
  - drivers of AGN activity, trace galaxy formation in DM density peaks

Yuexing Li: sim QSO+host @ $z=6.5$ (priv. com.)
Detecting QSO hosts with MICADO

MAORY PSF & elliptical galaxy profile

Strong requirement on accurate knowledge of PSF (Strehl & shape)

Strehl error 20%, $\rightarrow$ scaling error $\sim$100%,
2% $\sim$ 10%

![Graph showing relative intensity vs radius (mas)]

- blue: elliptical galaxy profile ($R_{\text{eff}}=3\text{kpc}=400\text{mas}$) convolved with PSF
- red: QSO (5x brighter PSF)
- green: QSO & galaxy together
Detecting QSO hosts with MICADO

MAORY PSF & elliptical galaxy profile

Strong requirement on accurate knowledge of PSF (Strehl & shape)

Strehl error 20%, $\rightarrow$ scaling error $\sim$100%,

$2\%$ $\sim 10\%$

![Graph showing intensity ratio for Galaxy/QSO against radius (mas)]
Resolved Stellar Populations to Virgo

- simulation of 3” stellar field with MAORY PSFs
- photometry with StarFinder using PSF from data
- CMD for elliptical galaxy
- aim: probe star formation history with cosmic time (i.e. oldest stars)

~0.3”

1 hr integration

~18Mpc (Virgo)
- giants & main sequence to ~4M_{\odot}

~3Mpc (Cen A)
- giants & main sequence to ~1.5M_{\odot}

see Atul Deep’s talk
Crowded Field Photometry: MICADO vs JWST

Resolution gives an effective sensitivity gain – cf. 3mag for MAD vs ISAAC

Omega-Cen

5-hr K-band simulated exposure

MAD

MICADO

ISAAC

JWST
Resolution & Crowding

(note: location of arrows approximate)
MICADO:

Science & AO Requirements

- MICADO is the adaptive optics imaging camera for the EELT & makes use of SCAO & the MCAO system MAORY
- sensitivity is comparable to JWST and resolution is 6 times better
- astrometric accuracy will be better than 50μas across the 1’ field
- Requirements for AO:
  - astrometry: impact of instrumental & atmospheric effects on NGS
  - PSF: detailed knowledge of PSF & its spatial variations