The PSF Reconstruction of MICADO@EELT A. Grazian (INAF-OAPd) on behalf of the MICADO PSF-R Team 18/02/2020

CINIC

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MICADO/MAORY

- MICADO will be a first light instrument for the ELT
- It will work with the MAORY adaptive optics system.
- It'll do imaging at 6-12mas resolution over a 50" field to J/H/K ~ 29 mag AB,

R~20000 spectroscopy covering H & K simultaneously,

(also astrometric & high contrast imaging).

- It'll use SCAO in stand alone mode
 MCAO, providing uniform correction over the field.
- It'll provide the user with a reconstructed PSF reference.

(slide from Ric Davies)

Key Capabilities

Spectroscopy

MICADO will be used with the MAORY system to provide:



- fixed configuration for 0.84-1.48µm & 1.48-2.46µm
- R ~ 20000 for point sources (R ~ 10000 across slit)

(see talk by Paolo Ciliegi)

(slide from Ric Davies)

SCAO for initial operations - an example

The structure of lensed Lyman- α absorbers/emitters at 4 < z < 5



Cluster CL0102 (El Gordo):

- 4 spectroscopically confirmed Lyα emitters/absorbers at z=4.3, within ~8" of a star with H_{AB} = 15.6 mag & Gaia G =15.9 mag.
- Even with lensing magnification, HST resolution of 90mas is insufficient to resolve morphology.



ID3-b

Highest magnification of 10 Observed magnitude $H_{AB} = 23.6$

PSF-R is fundamental to derive galaxy sizes

MICADO Science Cases

Potential to address a large number of science topics.

Themes where MICADO can make major progress:

-Dynamics of dense stellar systems (3D kinematics) -Black Hole at the center of the Milky Way (SgrA*)

- -Super Massive Black Holes in local galaxies
- -Star Forming Clumps in high-z galaxies



- -Formation and evolution of high-z galaxies in the early Universe -Resolved stellar populations of local galaxies (up to Virgo and Fornax)
- -Exoplanets discovery and characterization -Solar System

All these science cases require a detailed knowledge of the PSF

IMPORTANCE OF PSF-R

The Reconstructed PSF is fundamental for:

Quality control of scientific frames (esp. blank extragalactic fields)
 Flux calibration of spectroscopic data (PSF depends on lambda)
 Unbiased photometry in crowded fields (talk by D. Massari)
 Image Restoration (e.g. Richardson-Lucy deconvolution)







PSF-RECONSTRUCTION SERVICE

The PSF-Reconstruction Service is a deliverable of MICADO Consortium.

Goal: reconstruct the PSF of MICADO, both for SCAO and MCAO, using AO and non-AO telemetry data (independently from the science data).

PSF-R service will support state-of-the-art scientific analysis of MICADO/MAORY imaging and spectroscopic data. It will not be available for coronographic observations.

PSF-Reconstruction Methods

- Pure PSF reconstruction, which is done without recourse to the science data (although testing can only be via comparison to PSFs in the science data). (Veran et al. 1997)
- Hybrid PSF reconstruction, which makes use of point sources in the (co-added) science data to derive parameters in the model and hence optimise the reconstruction.(Massari et al. 2020)
- Calibrated PSF reconstruction, which uses optimisations from the hybrid approach to calibrate the model parameters, in order to improve the reconstruction on other science fields.
- Empirical PSF derivation, which exploits the brighter more isolated point sources in the science data to enable interpolation of the PSF anywhere in the field. (talk by A. Marasco)
- Adaptive PSF reconstruction, which exploits (myopic) deconvolution techniques on a series
 of science exposures to improve the reconstructed PSF beyond the initial estimate. Such
 techniques can, in principle, be employed to improve the derived PSF even if the deconvolution itself is not required. (Fusco et al. 1999)

→ MASTER initiative at INAF !!! Pedichini Baseline: "pure" PSF reconstruction, using telemetry data only. Hybrid approach (pure+science data) will be explored as well, but it will not be possible for all observations (e.g. blank fields or saturated star).

Empirical vs Reconstructed PSF

How many stars in the field?

- On average, ~3 stars / sq. arcmin for K_{AB} < 27 mag in classical deep fields.
- Would be well detected in integrations > 1 hr, so could be used as PSF reference (for MCAO).
- But MICADO field is 0.7 $arcmin^2$, so 35-45% chance there is ≤ 1 star in a pointing.
- PSF reconstruction is mandatory and is part of MICADO project.



Simulation of 3 hr integration

(slide from Ric Davies)

PSF-Reconstruction process

Method proposed by J.-P. Veran et al. 1997

Estimation of the adaptive optics long-exposure point-spread function

irradiance a 0.8 0.6 plane 0.2 0.0 image .0 0.8 normalized **Bright Star** 0.4 0.2 the õ 0.8 root 0.6 0 Square 0.2 0.0 -0.50.5 -1.01.0 Angular distance (arcsec)

using control loop data

Jean-Pierre Véran



Calculate OTF: (Veran 1997) PSF = FFT(OTF)

$OTF_{tot}(\tilde{n}) = OTF_{stat}(\tilde{n}) \cdot OTF_{\varepsilon \parallel}(\tilde{n}) \cdot OTF_{\bot}(\tilde{n})$

Static aberrations: fiber image Controlled modes: modal covariance matrix Un-controlled modes: Kolmogorov covariance matrix

CURRENT SCAO RESULTS

(R. Wagner)



COMPASS simulated data provided by LESIA: Bright Star, Pyramid WFS+M4 geometry.

Metric	Input Value	Reconstruc ted Value	Difference (%)
Strehl	0.4121	0.4089	0.8%
FWHM	11.46 mas	11.58 mas	1%
EE(5px)	50.32%	49.28%	2%

PSF-RECONSTRUCTION I/O

Off-line tool: reconstruction of the PSF from AO and non-AO telemetry data.

Input: position of object, filter, observing mode, exposure time, telemetry data, calibration data.

Output: a FITS image with the reconstructed PSF, or a cube of PSFs for each wavelength. This output will be used by the MICADO User pipeline to aid the scientific analysis of both imaging and spectroscopic data.



SCAO PSF

(image by Matteo Simioni)

MICADO PSF-R Team

PSF-R Team of MICADO has 21 members spread in 6 institutes within Europe:

Carmelo Arcidiacono, Lorenzo Busoni, Yann Clenet, Ric Davies, Simone Esposito, Eric Gendron, Andrea Grazian, Marco Guilleuszik, Miska Le Louarn, Seppo Mattila, Fernando Pedichini, Elisa Portaluri, Ronny Ramlau, Arnaud Sevin, Matteo Simioni, Gijs Verdoes Kleijn, Fabrice Vidal, Benedetta Vulcani, Roland Wagner, Anita Zanella, Werner Zeilinger.

MICADO GTO

MICADO Consortium will have 81 ELT nights of GTO, shared between partners. GREAT OPPORTUNITY FOR INAF YOUNG RESEARCHERS!!!

M3ARS initiative (talk by C. Arcidiacono)

ON-GOING PSF-R ACTIVITIES

Development Plan Definition Data Flow Definition Simulations to obtain Figure of Merit (Science→PSF-R→Telemetry RTC) Prototype Algorithms Development for SCAO Regular telecons and meetings

Contact us if you want to join PSF-R activities: job opportunity (AdR) open at OARoma to work with Fernando Pedichini.

SUMMARY

MICADO-EELT will be the workhorse facility for AO-assisted NIR imaging and spectroscopy. First light instrument for ESO-ELT!

MICADO will use both SCAO and MCAO: corrected FoV ~1 arcmin2.

A detailed knowledge of the PSF is required by a great number of MICADO science cases.

Baseline: "pure" PSF reconstruction, using only telemetry data. Method proposed by Veran et al. (1997).

Strhel and FWHM: ~1-2% accuracy reached in simulations of bright star (mag~15).

INAF will share within the MICADO Consortium 81 ELT nights of GTO: GREAT OPPORTUNITY FOR INAF YOUNG RESEARCHERS!!!

Thank You!