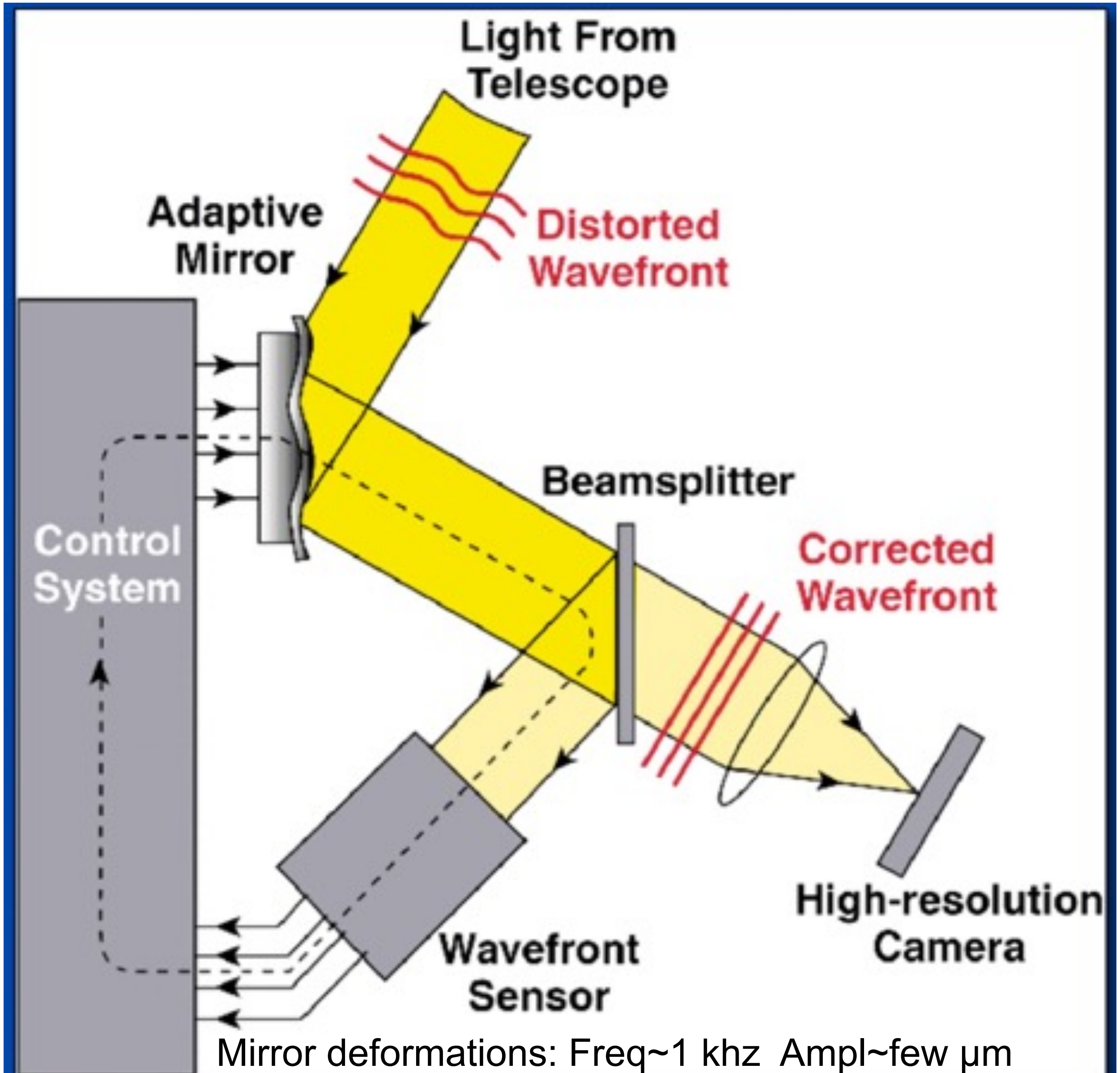
Taking part in the ELT adventure: Science Cases for MAORY

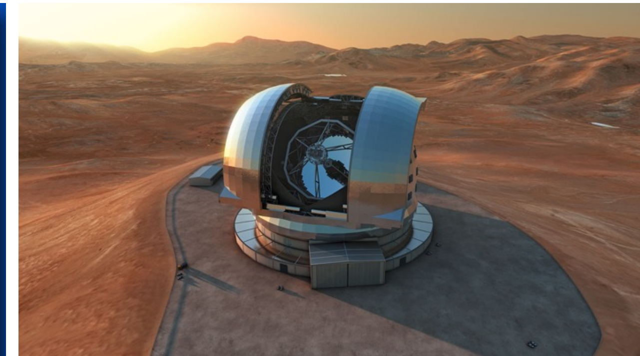
Michele Bellazzini (INAF-OABo)

on behalf of the MAORY consortium

Cerro Amazonas, Chile

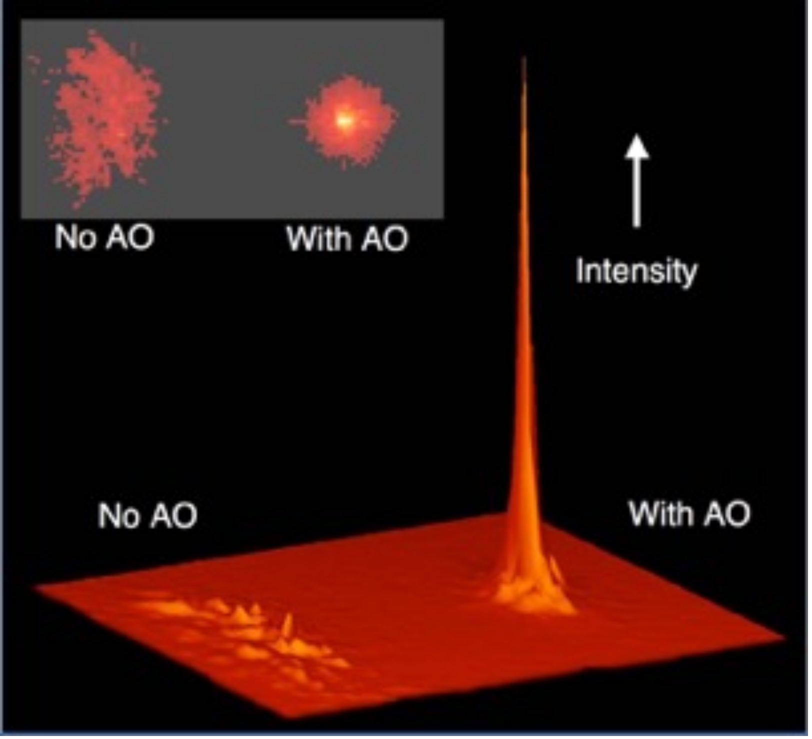


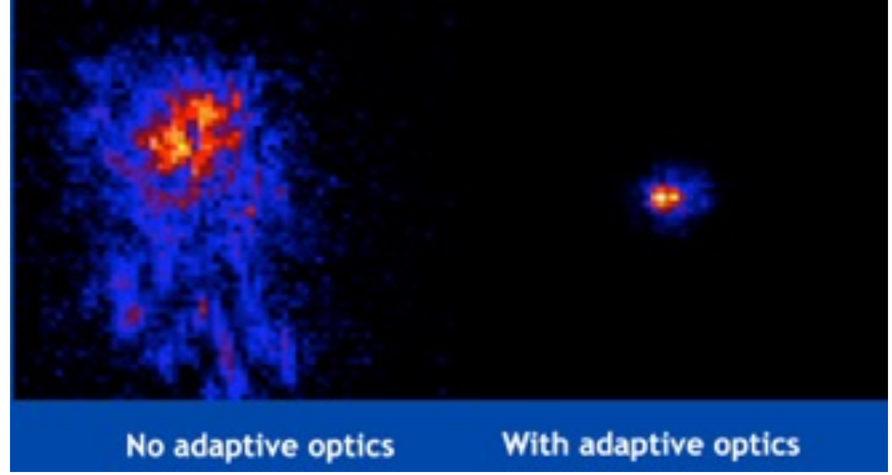
Mirror deformations: Freq~1 khz Ampl~few μm



Adaptive optics is essential to make Extremely Large Telescopes really worth doing: spatial resolution proportional to telescope aperture.

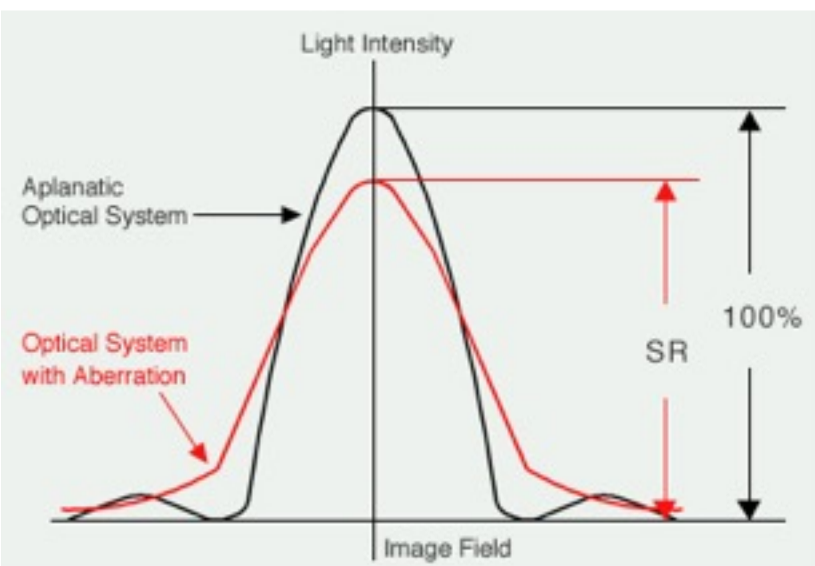
Diffraction-limited images from the ground.

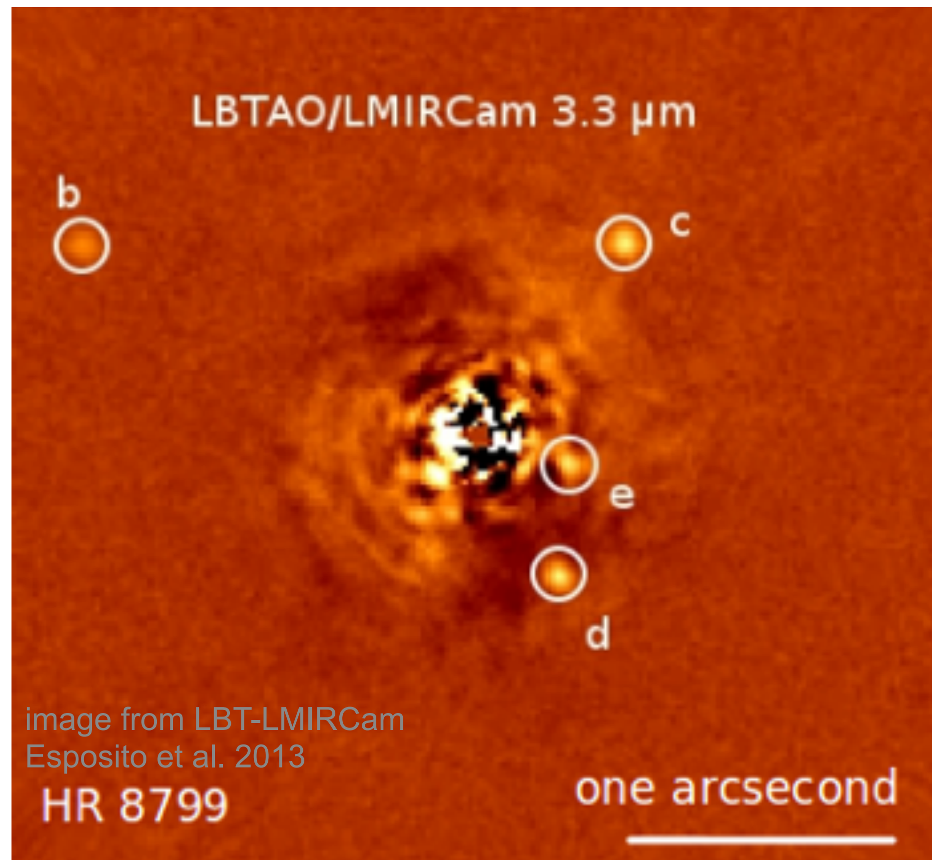




The power of Adaptive Optics

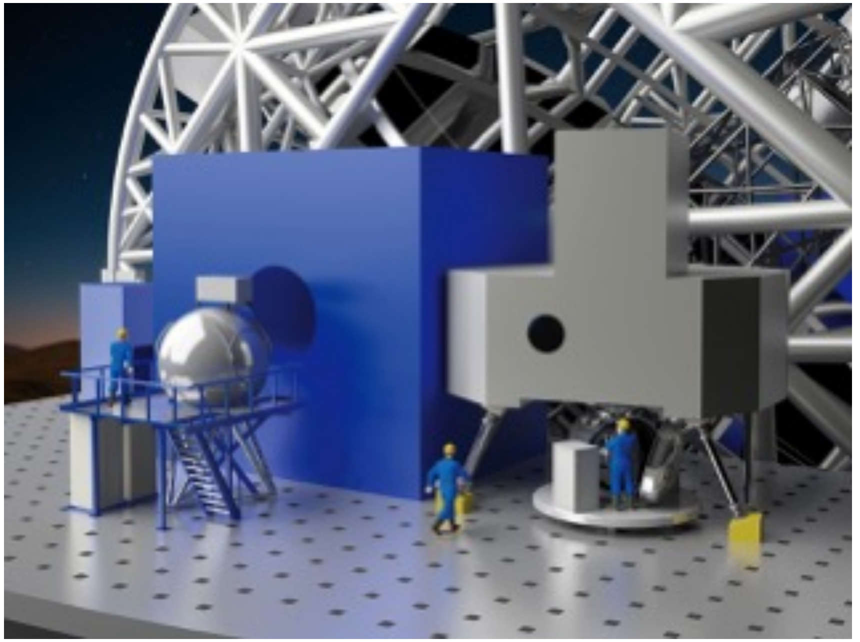
Strehl Ratio





MAORY is the first-light AO module of ESO-ELT: providing diffraction limited images from a D=39 m aperture

Designed and built by a consortium including INAF Institutes (OA-Bo, IASF-Bo, OA-Arcetri, OAPd, OA-Na, OA-Brera) + INSU-IPAG-Grenoble



SCAO mode: high Strehl correction Over a D~10” FoV with one bright NGS (7≤V≤16)

MCAO mode: moderate but homogeneous Strehl correction over a D~180” FoV with 3 NGS (H≤19) and 6 LGS

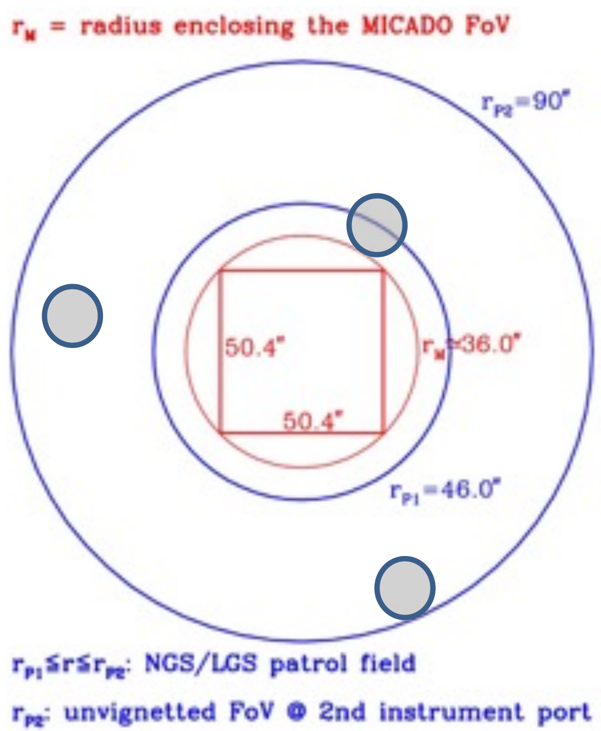
At first-light it will fed the imager/spectrograph MICADO

SCAO module is a joint project with MICADO

The consortium is lead by the AO group at OA-Bo
PI: E. Diolaiti
PM: P. Ciliegi

The instrument will be integrated in the IASF- Bo laboratories

MAORY-MCAO: the sky coverage machine.
SC≥50% everywhere, ~100% for b<30°
Spectral range I to K



5 mas = 0.005"
10 mas = 0.010"
50 mas = 0.050"

ELT Spatial Resolution:
~18 times better than, ~6 times better than JWST

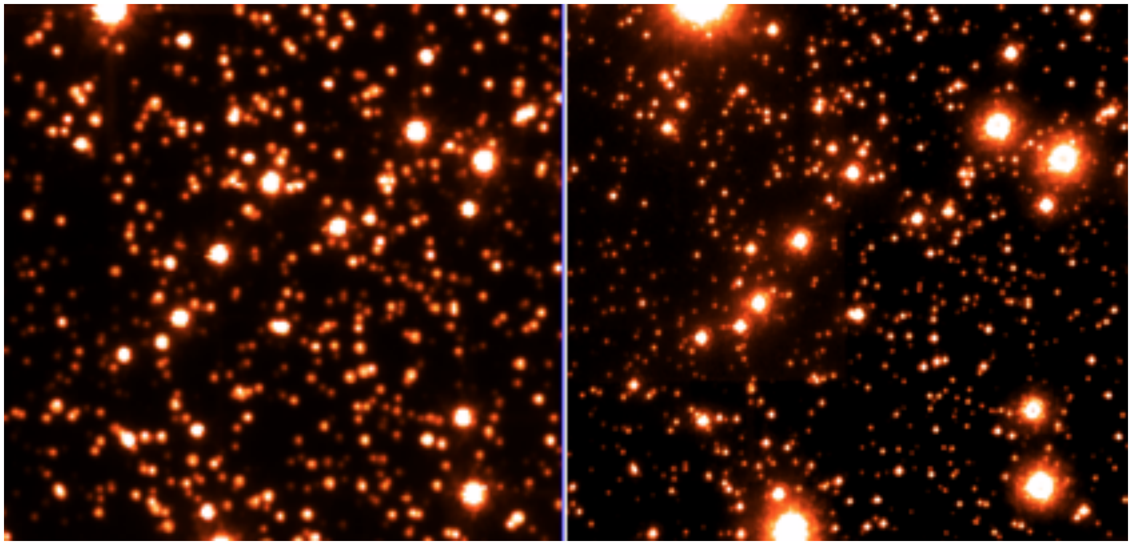
λ [μm]	Diffraction limit FWHM θ_{diff} [mas]	Seeing FWHM [arcsec] (best seeing)	Seeing FWHM [arcsec] (median seeing)	Seeing FWHM [arcsec] (sub-optimal)
0.88	4.7 JWST=27.9	0.39	0.57	0.65
1.22	6.5 JWST=38.7	0.36	0.54	0.60
1.63	8.6 JWST=51.7	0.34	0.51	0.57
2.20	11.6 JWST=69.8	0.32	0.48	0.54

→ 0.6 pc @ D=10 Mpc

λ [μm]	Best seeing conditions 30° from zenith D = 20" FoV		Median conditions close to zenith D = 1' FoV		Sub-optimal conditions 30° from zenith D = 2' FoV	
	Reqs.	Goal	Reqs.	Goal	Reqs.	Goal
0.88	0.01	0.04	-	0.01	-	-
1.22	0.10	0.19	0.02	0.10	-	0.02
1.63	0.28	0.39	0.11	0.28	0.03	0.11
2.20	0.50	0.60	0.30	0.50	0.15	0.30

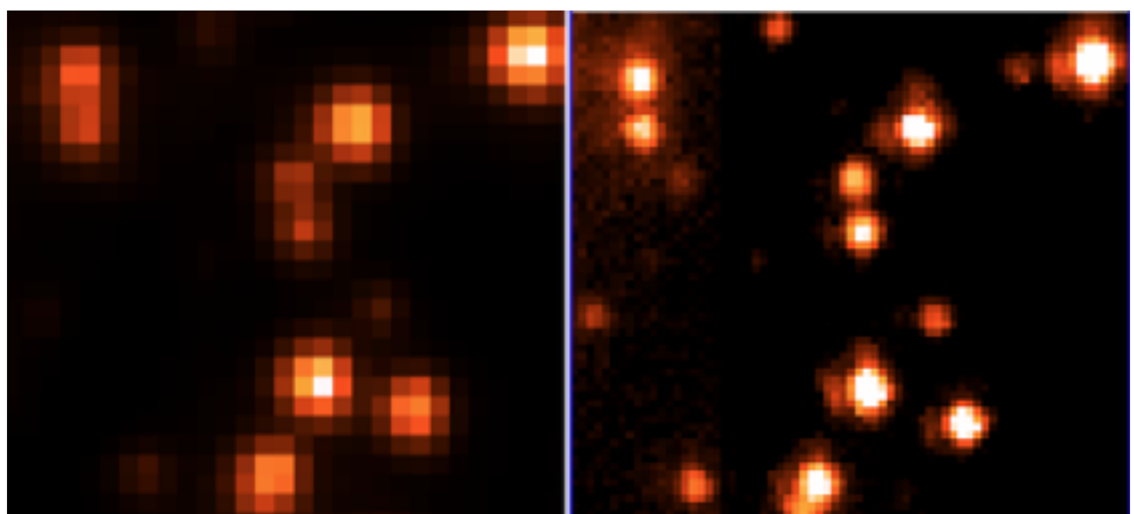
Table 2. Expected Strehl Ratio for some representative wavelengths in MCAO mode. All values are TBC.

How good is Strehl Ratio=0.4?



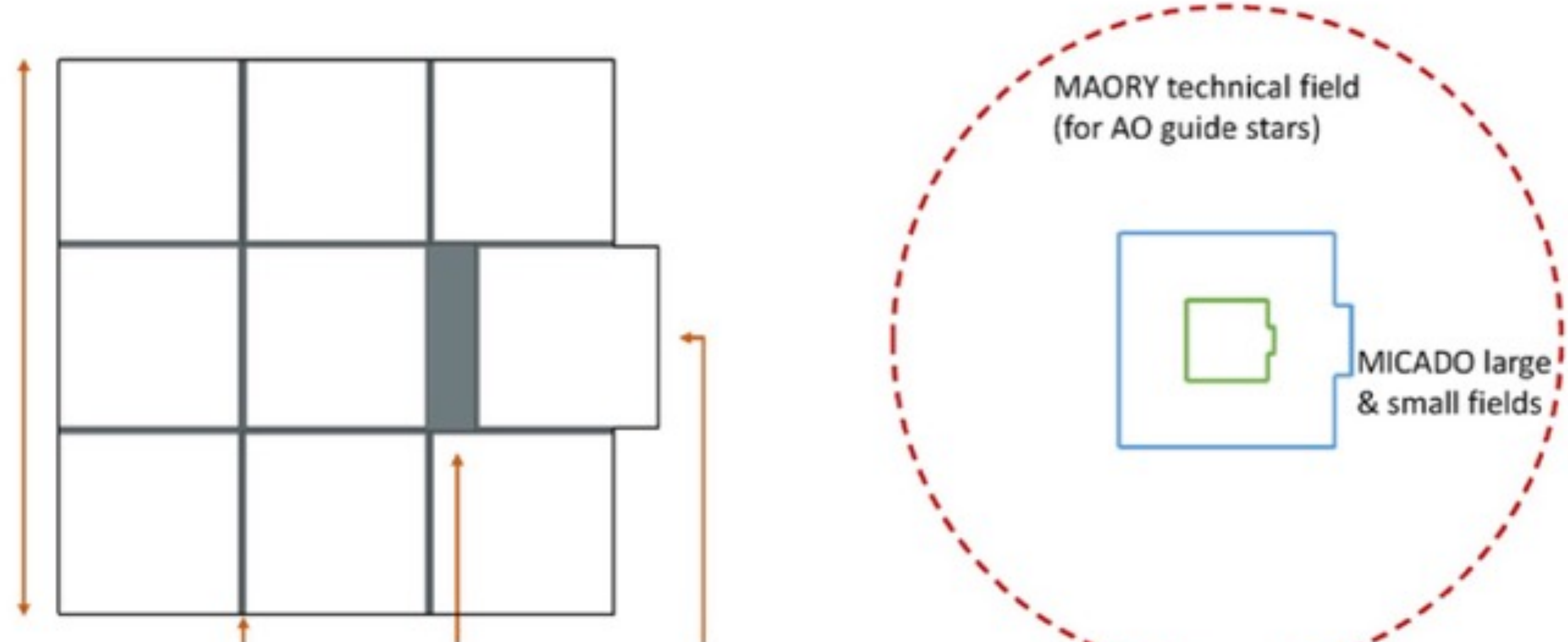
GeMS@Gemini D=8.2m
Ks
SR=0.4

ACS F606W



Credit: Giuliana Fiorentino

Feeding MICADO: imager



189.1mm	2.4mm	18.1mm	61.4mm	Actual size	
50.4″	0.6″	4.8″	16.4″	Large field	Scale=4 mas/px Nyquist sampling H,K
18.9″	0.2″	1.8″	6.1″	Small field	Scale=1.5 mas/px Nyquist sampling down to I

t_{exp}=1 h in H band MCAO K2V star ➔ V=30 with S/N>5, V=28 with S/N~35

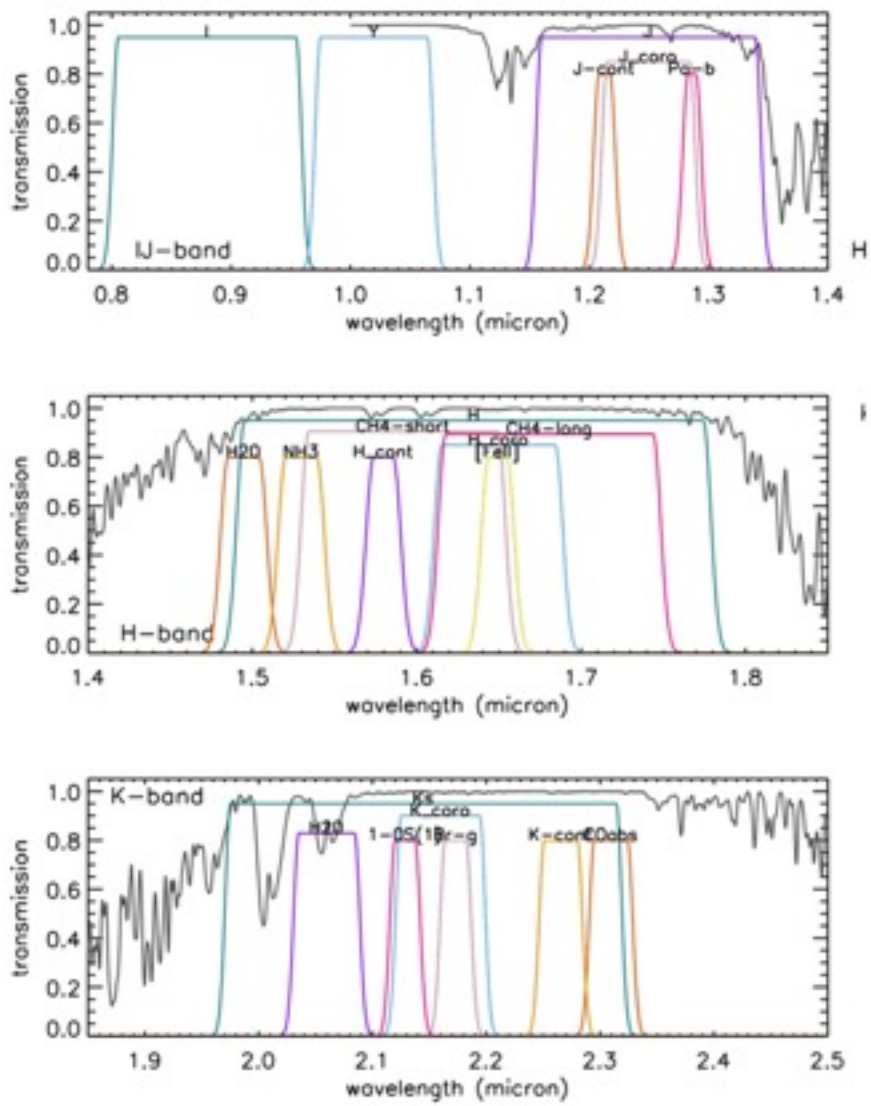
Astrometric accuracy 50 μas (goal 10 μas) ➔ 50 μas/yr are measured at 5 σ in 5 years baseline ➔ 12 km/s @50 kpc
There is also a coronographic mode and a sparse aperture masking mode

MICADO possible dithering

Table 8: the four types of dithers/offsets available for MICADO

Small dithers	Shifts of +/-0.3arcsec to move targets onto different pixels (for reducing systematics), performed in closed loop and associated with the shortest overheads of around 1-2sec. Small dithers will also be used in spectroscopic mode and, at the discretion of the user, are one option for nodding back and forth along the slit.
Large dithers	Shifts of up to 60arcsec from the initial pointing (in practice, it is expected that these dithers will normally be within 15arcsec of the initial pointing to ensure a large overlap between frames). Enables the background to be derived from the object frames via, for example, a running median; and allows regions of sky that fall in the gaps between detectors to be covered. Short large dithers of 1-2arcsec will also be used in spectroscopic mode for nodding back and forth along the slit. It may be possible to execute these with the AO loops closed. Longer large dithers will involve opening the AO loops and offsetting the telescope, and so are associated with a larger overhead of 10-15sec.
Sky offsets	Shifts in the range 1-15arcmin from the initial pointing to take separate sky frames. The AO loop is open at the offset position (because the guide stars may no longer be accessible), and re-closes on the return. The overhead for these will be large, and is likely to exceed 30sec.
Rotational dithers	These are envisaged primarily for SCAO where options for translational dithering may be limited. With MCAO, the NGS probes may constrain the allowed rotation angles. The time taken for a rotational dither depends on the angle, and is limited by the rotational speed of the cryostat.

MICADO as an imager: filters



Feeding MICADO: spectrograph

Long central slit with fixed orientation (parallactic angle)

Slit1: 16mas x 4arcsec; R~8000 if the source fills the slit. R~11000/18000 for point sources

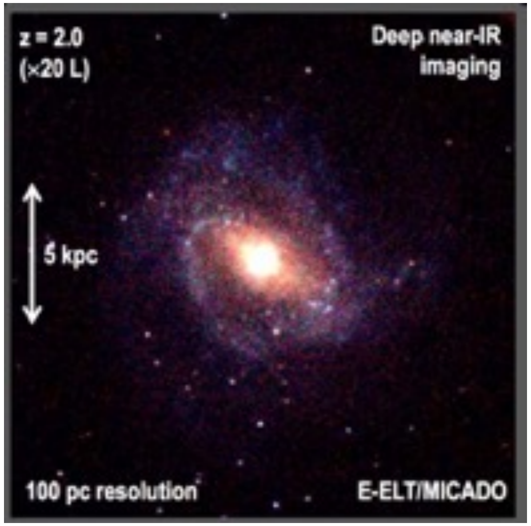
Slit2: 50mas x 4arcsec; R~2500 if the source fills the slit.

Wavelength coverage	*Notes*
0.8-1.45µm	IzJ bands simultaneously
1.45-2.4µm	HK bands simultaneously

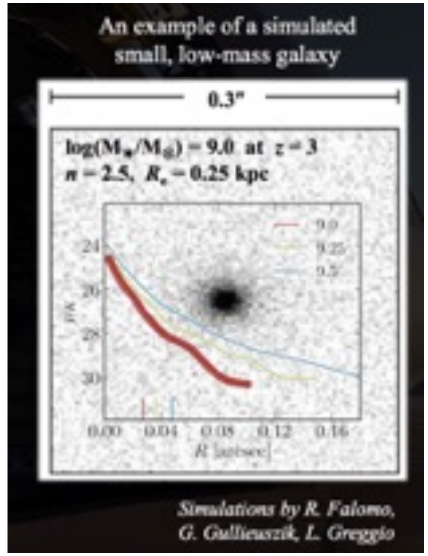
Key science cases for MICADO

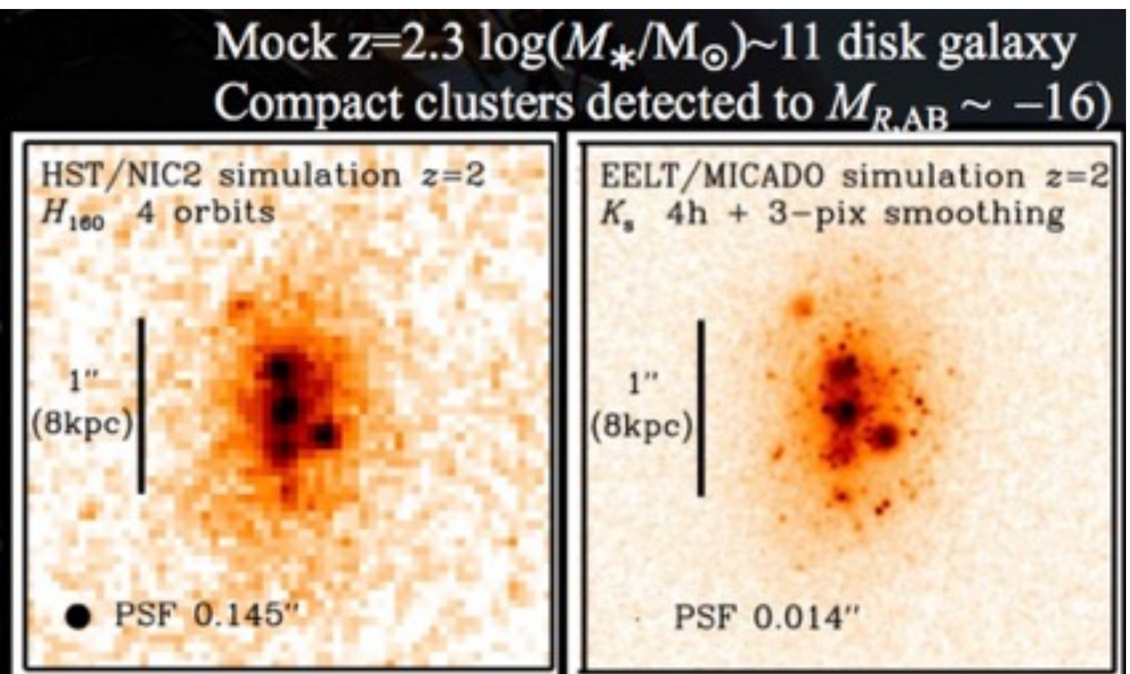
- Galactic Center: deeper photometry high precision astrometry
- Solar System Science: minor bodies (e.g., TNO), time evolution of features on planets
- Direct imaging of exoplanets (SCAO, coronography)
- Discovery of exoplanets using astrometry
- Astrometry of Globular Clusters and dwarf galaxies
- Resolving stellar populations up to Virgo
- Extragalaxtic transients (spectra of high-z objects)
- Resolved Structure and physical properties of high-redshift galaxies

Key science cases for MICADO. An example: structure and properties of high-z galaxies



Source: Natascha Förster Schreiber

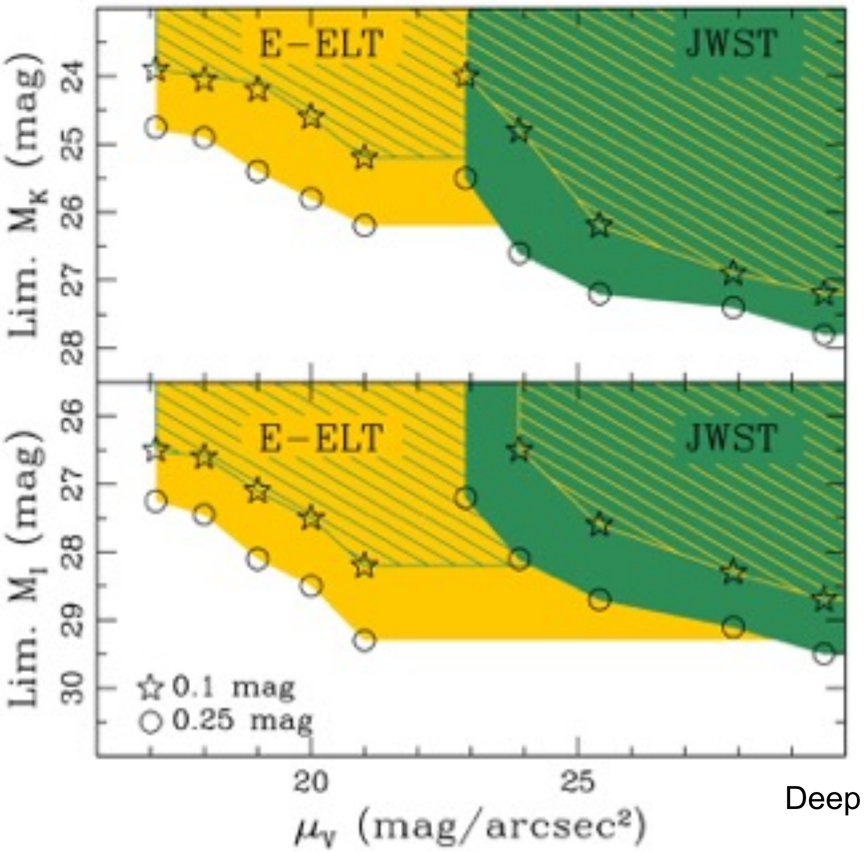




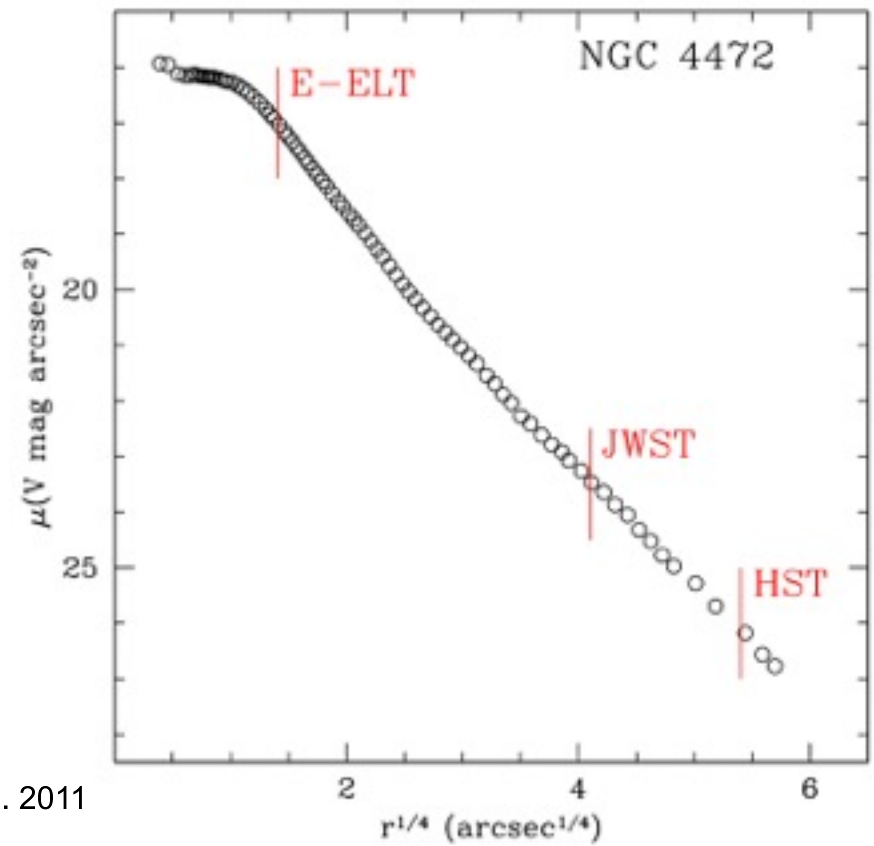
“**Observations at the diffraction limit of the E-ELT will correspond to approximately 60 pc in physical length (for z > 1), and will be of comparable quality to 1 arcsec imaging of Virgo galaxies.**
This will allow us to isolate and even resolve regions with sizes comparable to individual star-forming complexes such as 30 Dor in the LMC, N66 in the SMC, or super-star clusters seen in nearby starburst galaxies. Furthermore, this resolution will typically provide >100 resolution elements across the galaxies, and deliver detailed information about the morphology, dynamical state, and variations in stellar/physical parameters across the galaxy. “

“At very high redshifts (z ~ 7 and beyond) galaxies may be discovered and studied via their Lyman- α emission by imaging in narrow wavelength windows in the NIR. Such observations constrain the galaxy luminosity function at very high redshift, which in turn constrains the possible sources of reionisation in the early Universe. “

Key science cases for MICADO. An example: resolving stellar populations up to Virgo



Deep et al. 2011



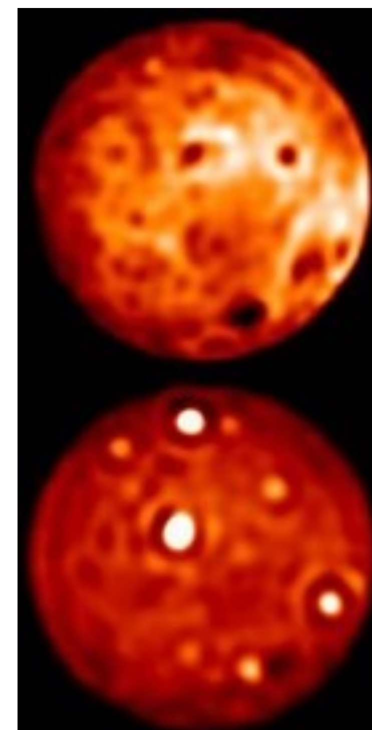
"The ultimate goal is to study the resolved stellar populations in giant elliptical galaxies, of which there is no example in the LG, and we have to look at Cen A to find the closest example of a peculiar elliptical. **However, the best place to look at the properties of a range of elliptical galaxy types is the Virgo cluster which contains thousands of large galaxies and tens of giant ellipticals of a range of size and position in the cluster.** Of particular interest are the crowded central regions of galaxies where most of the stellar mass lies. "

MICADO pixels image 5-15 km on Jupiter

Jupiter apparent D = 29.8 – 50.6 arcsec

Io

apparent D=1200 mas
=300 / 800 MICADO px



Marchis et al. VLT/NACO

MAORY Science Team

- **To contribute ELT Science Cases**
- **To find scientific drivers constraining MAORY (and MICADO) design**
- **To support the technical team in defining and fulfilling specifications**
- **To prepare the exploitation of the ELT GTO awarded to INAF for building MAORY: 54 ELT nights**

Chair: M. Bellazzini (INAF-OA Bo)
Deputy: G. Fiorentino (INAF-OA Bo)

P. Ciliegi (INAF-OA Bo)
E. Maiorano (INAF-IASF Bo)
F. Mannucci (INAF-OA Arcetri)
M. Mapelli (INAF-OA Pd)
P. Saracco (INAF-OA Brera)
M. Spavone (INAF –OA Na)
S. Douté (IPAG)
G. Chauvin (IPAG)

Started activity in phase B, kick off February 2, 2016

MAORY Science Cases: assembling the MAORY SC book

You can contribute with your own Science Case

It is an opportunity to begin thinking at this key facility and to take part in the ELT adventure

The authorship of the will be recognised

It is easy: you have to fill a 2 page form with the basic idea and a basic observational strategy

If you have smart ideas about filters, please let us know asap

MAORY Science Cases: assembling the MAORY SC book

Programme: E-ELT

Project: ELT MCAO Construction – MAORY

MAORY Science Case Template

1.1 Title of the case

Authors: *names*

Brief description of science case: *[one page maximum]*

MICADO Pixel Scale / Fov: *1.5mas/px and 20arcsec FoV or 4mas/px and 53arcsec FoV*

MICADO Spectral set-up:

Filters required: *and brief justification*

Estimate Survey Area/Sample Size/ Number of Images/Epochs:

Average Integration time per image (magnitude of targets; S/N required):

Observation requirements: *dithering patterns, how important is precise positioning, rotation, scale stability?Non-sidereal tracking*

Strehl or EE required: *what drives this requirement*

Image Stability Required: *what drives this requirement*

Astrometric Accuracy:

SCAO vs. MCAO:

Comparison with JWST or other facilities: *specify the advantage of using MAORY+ MICADO/HARMONI*

Synergies with other facilities (4MOST/MOONS, LSST/ALMA/HARMONI/METIS, HIRES/MOSAIC), but also VLT or other smaller telescope instruments: are additional data required or desirable, if so from which facility. Are preparatory observations needed?

Simulations made/needed to verify science case or feasibility:

Origin of the targets: *catalogs / observations still to be performed, etc*

NGS: *availability, average surface density, etc.*

Acquisition: *how precise pointing is required? Can the pointing be verified with a finding chart?*

Calibrations: *'Standard' or something more; day-time vs. night-time; flat-fields; standard stars or star fields; astrometric; at what level do image ditortions matter; are there calibrators in the field? Or might you need calibrators in other fields (this might motivate the need for fainter standard fields than are currently available. How accurate is photometry and astrometry required (be clear if this is absolute or relative).*

Data Processing Requirements: *detailed PSF knowledge? Special issues/requirements? What are the desired final data products as starting point for the scientific analysis? Including the crucial metadata.*

MAORY Science Cases: assembling the MAORY SC book
Take what you need:

ESO ELT Science (include ETC): https://www.eso.org/sci/facilities/eelt/science/

ELT Science cases: https://www.eso.org/sci/facilities/eelt/science/

"MAORY for Dummies", SC Template and this presentation:
http://wwwmaory.oabo.inaf.it/index.php/science-pub/

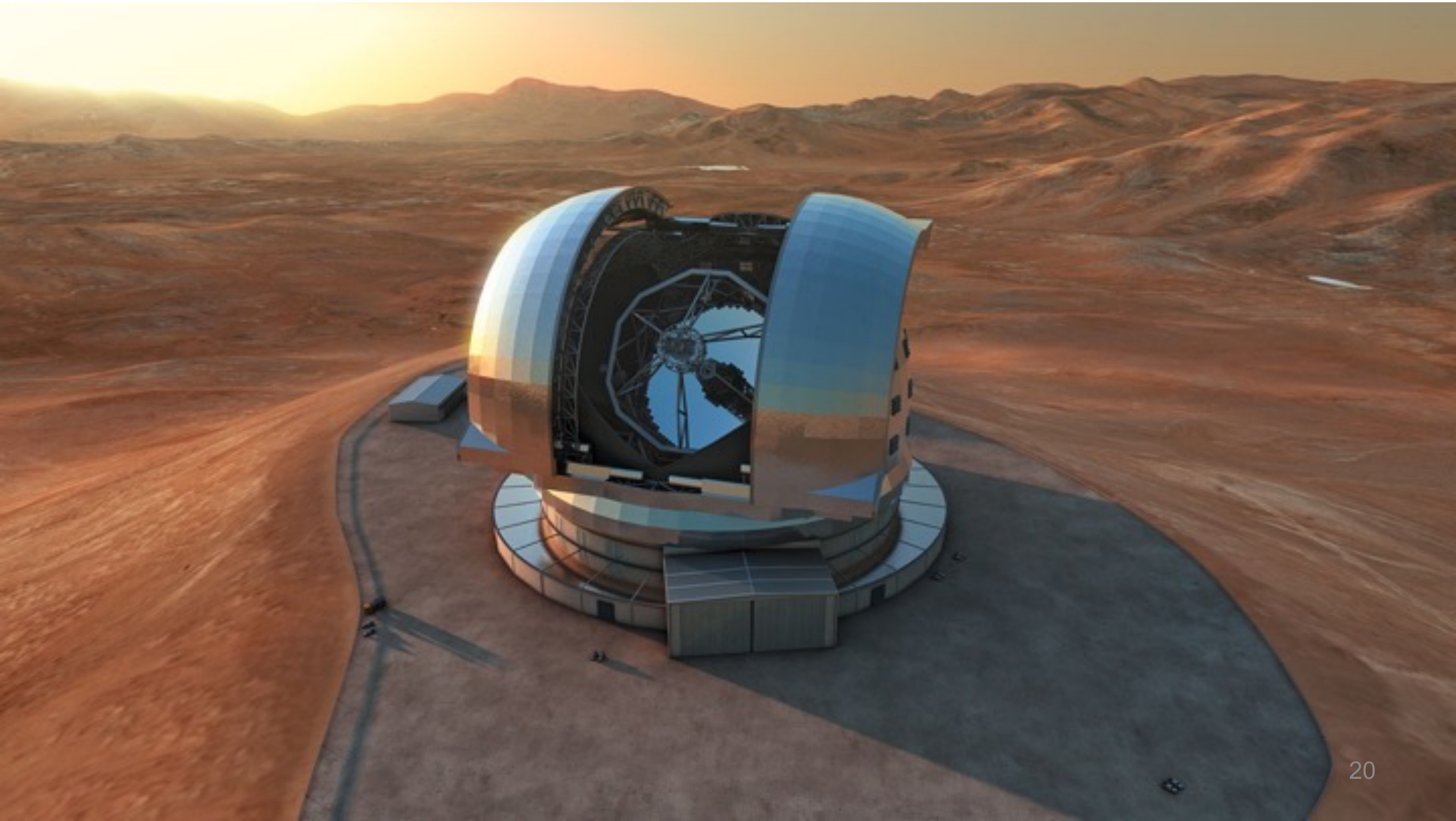
MAORY page: http://wwwmaory.oabo.inaf.it

MICADO page: http://www.mpe.mpg.de/ir/micado

HARMONI page: http://www-astro.physics.ox.ac.uk/instr/HARMONI/

Deadline March 1, 2017

Thanks!



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