MICADO

The E-ELT First Light Imager

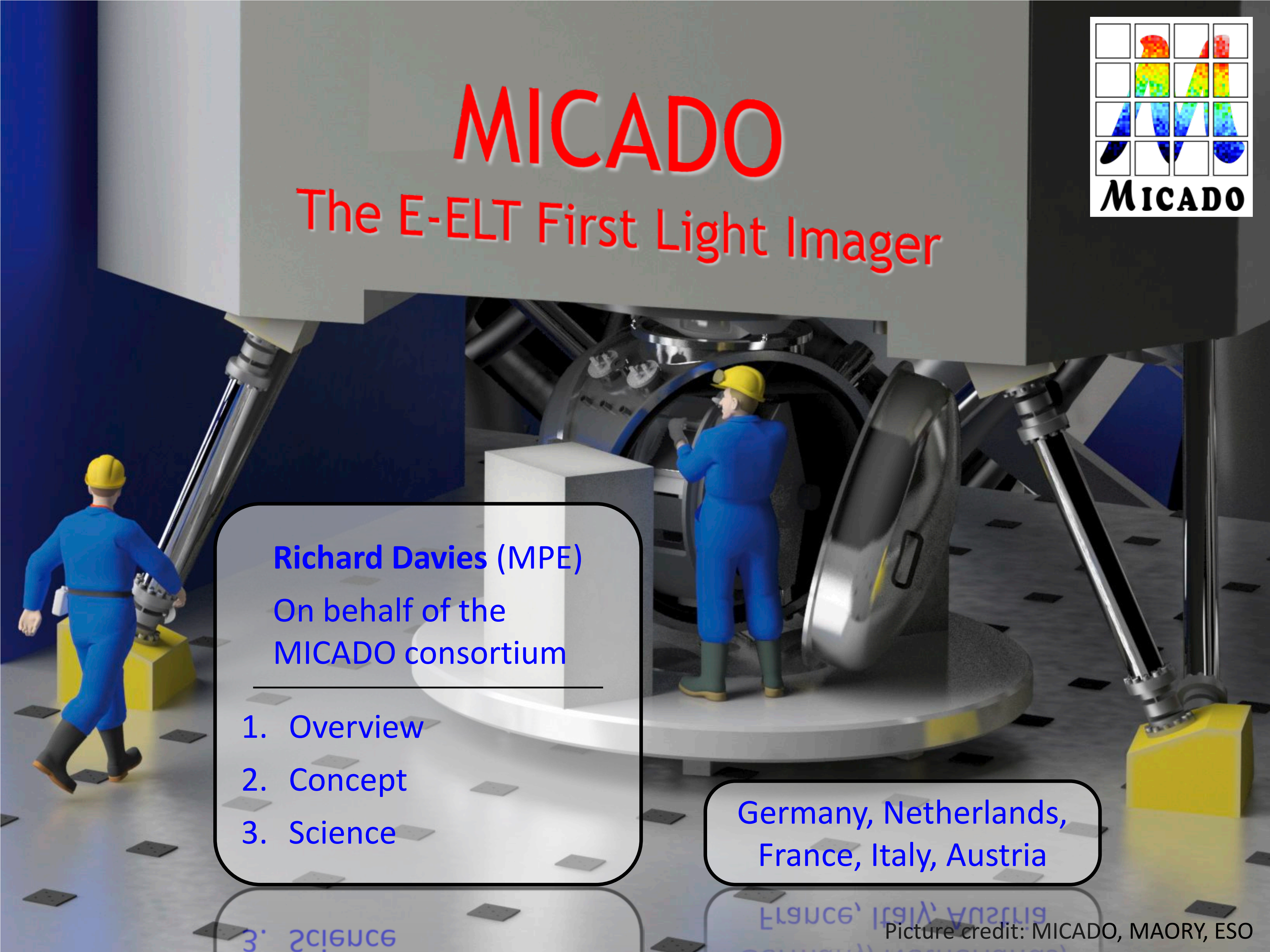
MICADO

Richard Davies (MPE)

On behalf of the MICADO consortium

1. Overview
2. Concept
3. Science

Germany, Netherlands, France, Italy, Austria



Picture credit: MICADO, MAORY, ESO

MICADO Key Capabilities

- **Sensitivity & Resolution**
  - resolution of 6-10mas over 1arcmin field
  - sensitivity up to 0.5mag deeper than JWST with advanced filters
  - up to 3mag deeper in crowded fields

- **Precision Astrometry**
  - <40μas over full 1arcmin field
  - 10μas/yr = 5km/s at 100kpc after 3-4 years
  - make precision astrometry available to everyone

- **Wide Coverage Spectroscopy**
  - high-throughput slit spectroscopy
  - ideal for compact sources with multiple lines
  - 0.8-2.5μm simultaneously at R~5000-10000

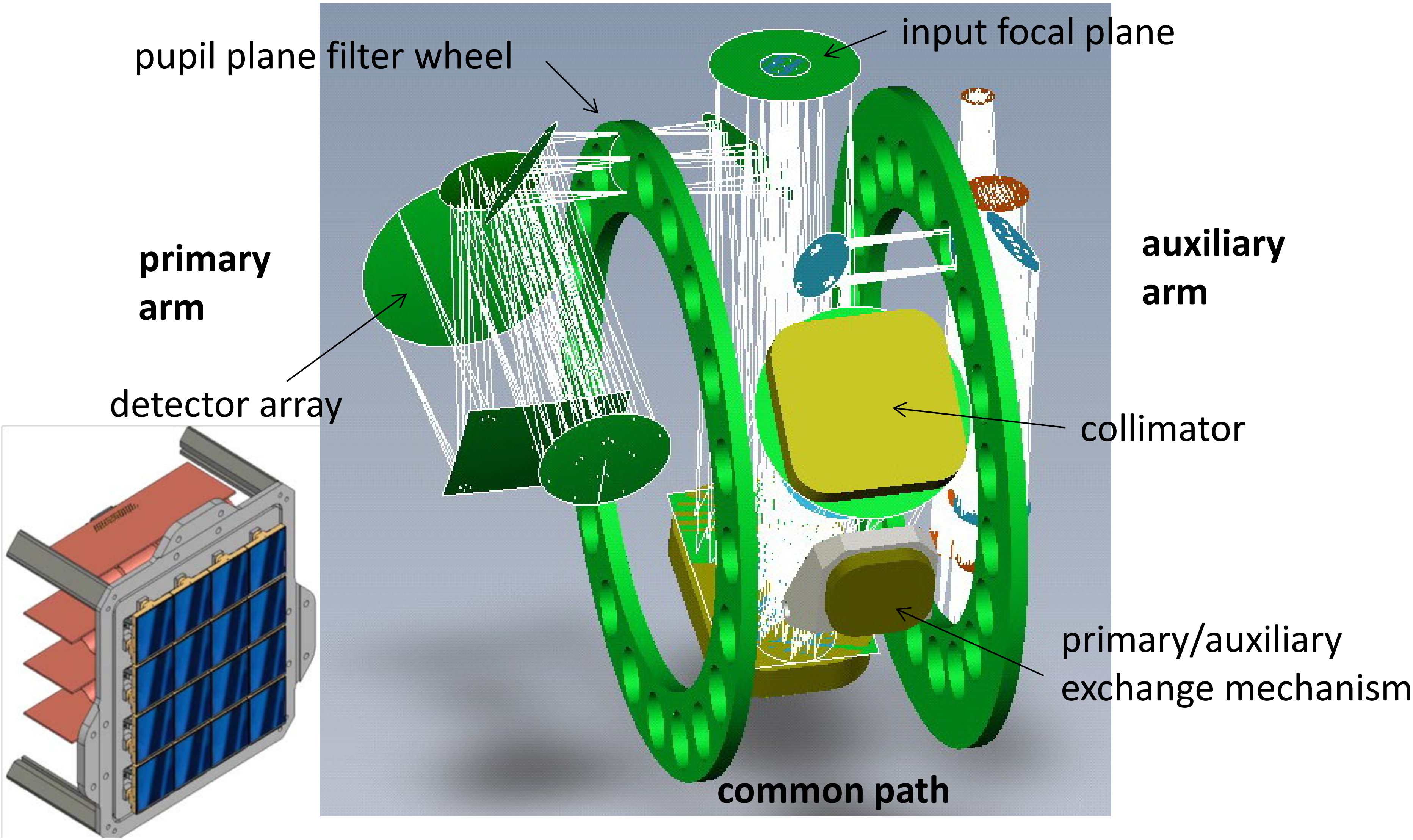
- **Simple, Robust, Available early**
  - optical & mechanical simplicity for stability
  - exemplifies most unique features of E-ELT
  - flexibility to work with SCAO & MCAO

MICADO Science

- **Sensitivity & Resolution**
  - star formation history via resolved stellar populations to Virgo cluster
  - high-z galaxies at 100pc scales : galaxy formation & evolution
  - environment and host galaxies of QSOs at high-z
  - nuclei of nearby galaxies (stellar cusps, star formation, black holes)
- **Precision Astrometry**
  - stellar motions within light hours of the Galaxy's black hole
  - intermediate mass black holes in stellar clusters
  - globular cluster proper motions: formation & evolution of the Galaxy
  - dwarf spheroidal motions test dark matter & structure formation
- **Wide Coverage Spectroscopy**
  - Galactic Centre: stellar types & 3D orbits
  - absorption lines: ages, metallicities, dispersions of ellipticals at z=2-3
  - metallicity gradients (e.g. via auroral lines) of galaxies in nearby clusters
  - extragalactic transients: γ-ray bursts, first supernovae at z=1-6
- **New Requirements**
  - solar system science with narrow-band imaging
  - exo-planet characterisation (5×10^{-5} at 100mas)

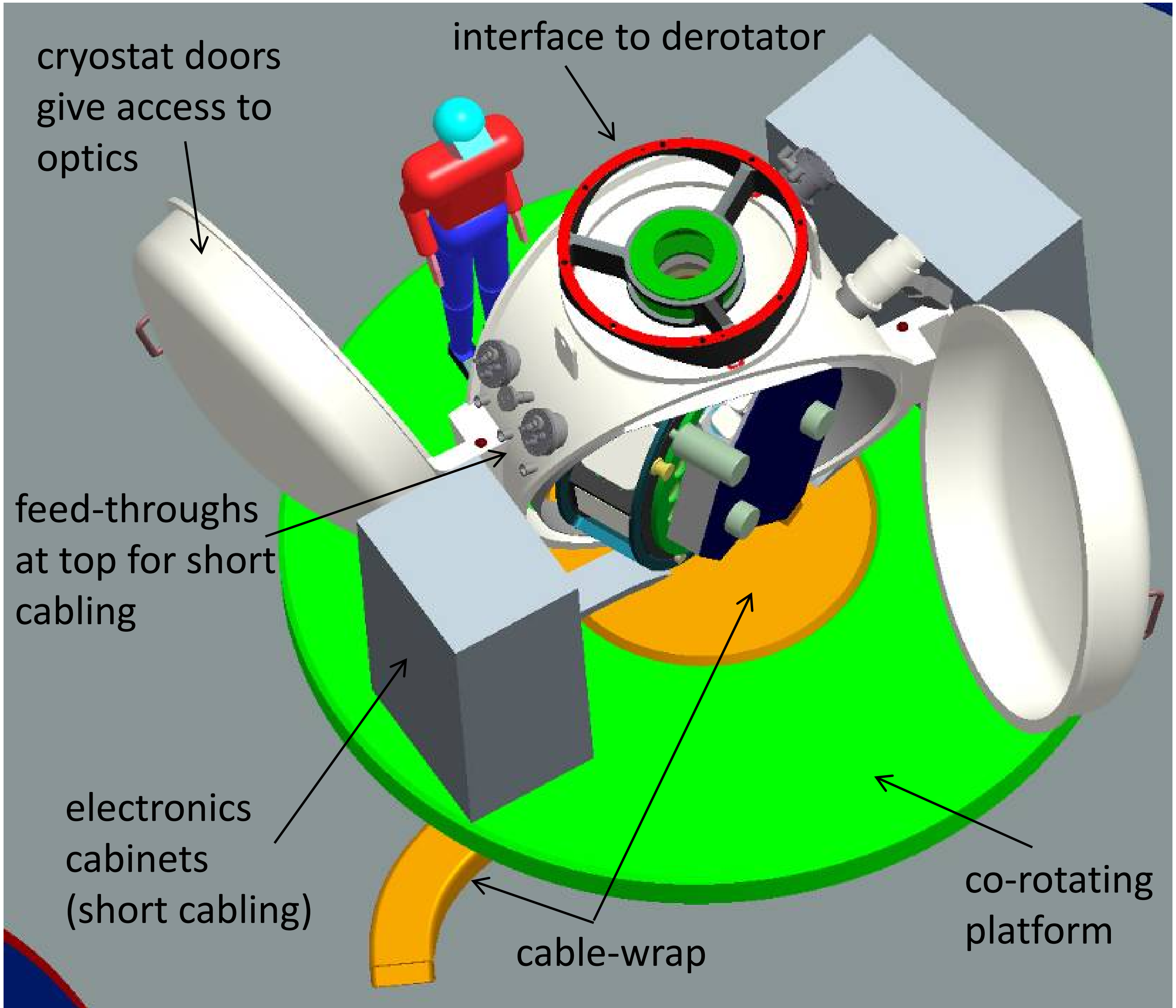
MICADO opto-mechanics overview (Phase A)

- gravity invariant high-throughput reflective design using only fixed mirrors; optimised for photometric & astrometric precision



Mechanics: instrument & cryostat

- cryostat ~2m across; mounts underneath SCAO & MAORY



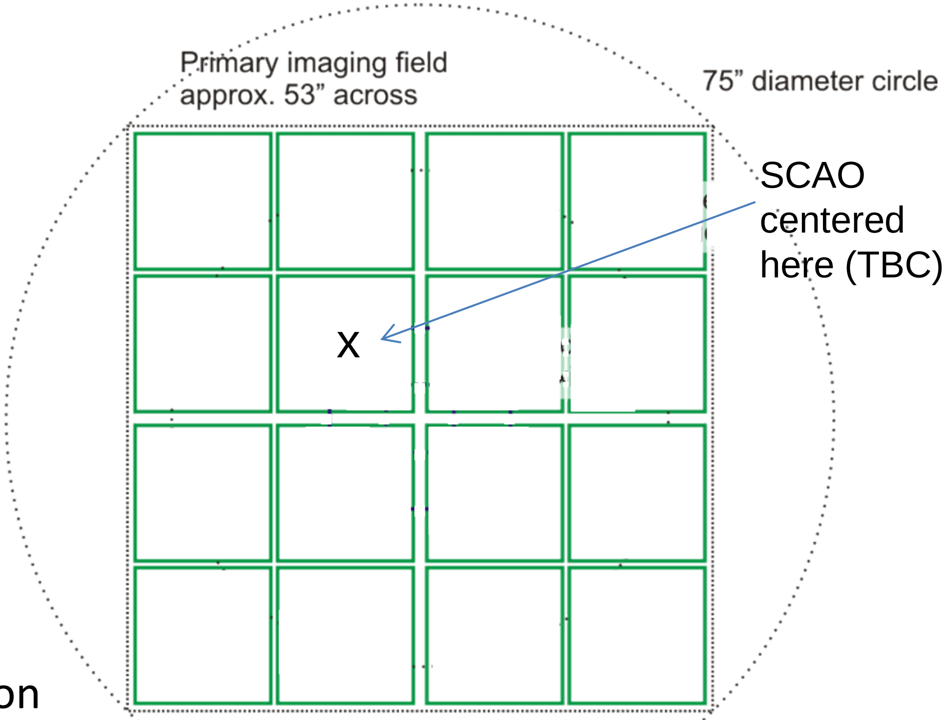
Mass:	
under derotator	3000 kg
on Nasmyth	2800 kg
calibration unit	500 kg

MICADO: *M*ulti-AO *I*maging *C*amer*a* for *D*eep *O*bservations

- 0.8-2.5µm

Primary Imaging Field

- 53” across*, 3mas pixels*
- geometry fixed for robust astrometry*
- high throughput (>60%)
- many filter slots (20 in Phase A)



- 4×4 HAWAII 4RG detectors

Auxiliary Arm (Phase A only)

- mainly for spectroscopy
- potential for additional options, e.g. tunable filter (dual imager) high time resolution

Changes since Phase A

- increase filter slots to ~40
- dispense with auxiliary arm
- put spectroscopy in primary arm: simultaneous 0.8-2.5µm coverage in ‘XShooter-like’ mode
- include finer pixel scale (1-2mas) over a small field (10”-20”) in primary arm
- include coronagraph for high contrast imaging

(* Strongly endorsed by Phase A Review Board)

MICADO new optical concept

optical concept is not yet available for distribution

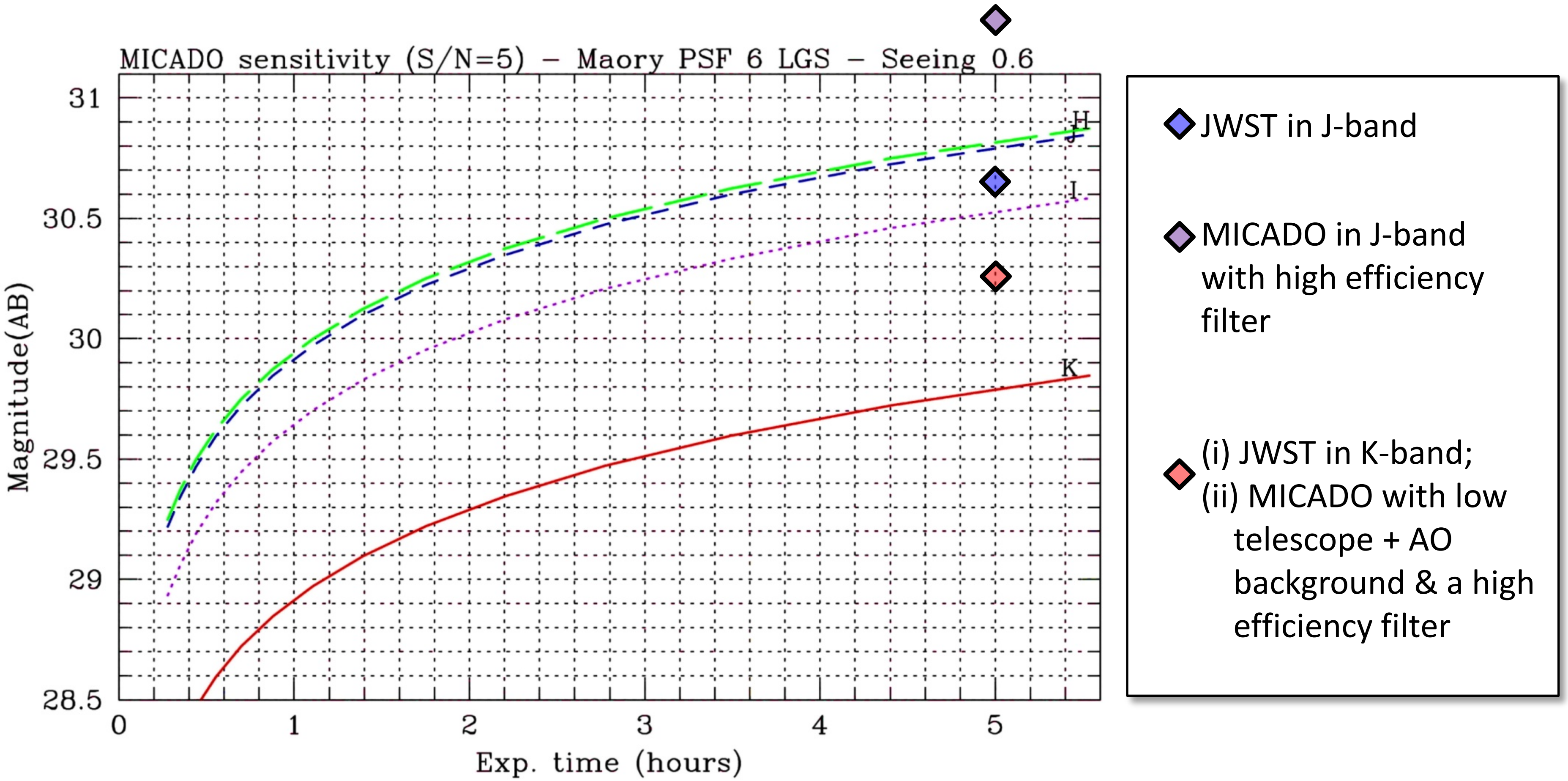
- Primary imaging mode: 3mas pixel scale over ~50” field, high stability for astrometry
- Purely reflective, fixed configuration, no moving parts (except filters)

- Zoom mode: 1-2mas pixel scale over 10”-20” field
- Re-uses optics & detectors from primary mode
- Only requires addition of 2 lenses

- Spectroscopy: 6mas pixel scale, slit width 12mas (24mas), slit length 15”-20”
- Re-uses optics & detectors from primary mode
- Requires ~20cm lenses, fold mirrors & reflective grating(s)

Sensitivity: imaging

Isolated Point Sources to 5σ



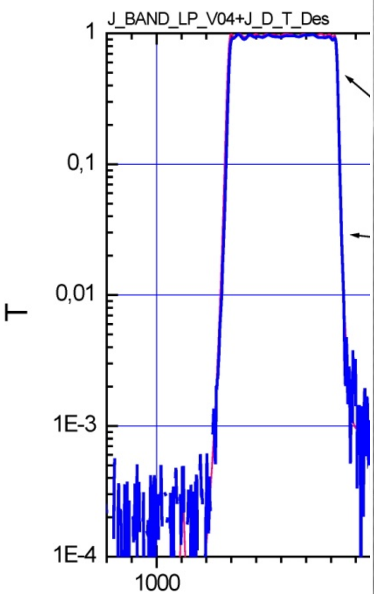
5hrs, 5σ	J_{AB}	H_{AB}	K_{AB}
Imaging	30.8	30.8	29.8
Imaging with advanced filters	31.3	31.3	30.2

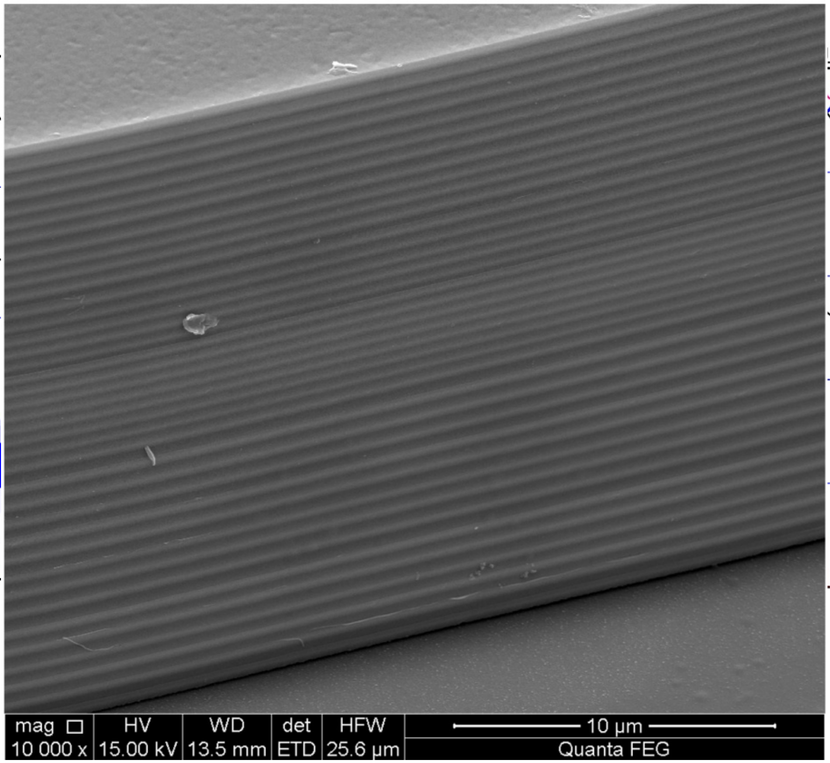
Advanced Filters

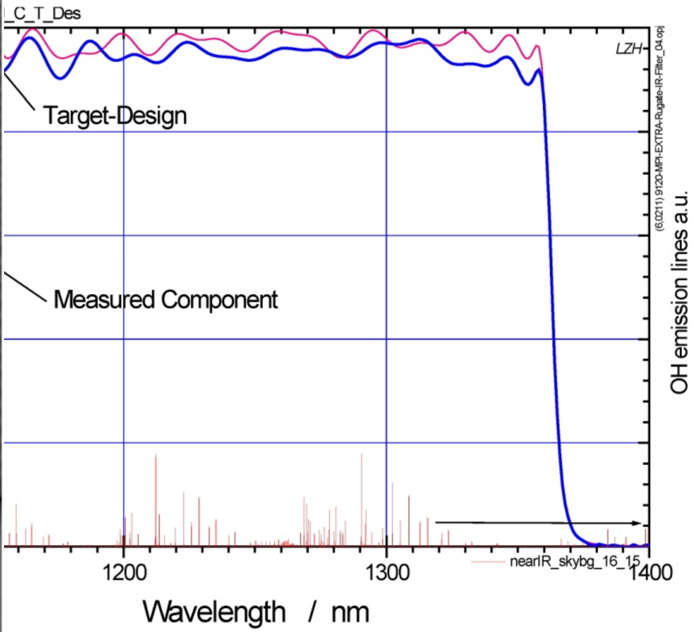
- prototyping in collaboration with Laser Center Hannover
- manufactured J-band filter, 95% throughput (80 layers, 20μm thick); also OH blocker

  ×1.34 increase in S/N wrt HAWK-I filters;

  ×1.8 more efficient in terms of observing time to reach same S/N
- many issues clarified: tension warping, cold cycling
- ongoing developments with USM & LZH to reach MICADO requirements
  - 5nm resolution filter, design is 100μm thick, (manufacturability?)
  - homogeneity over large (10cm diameter) filter size







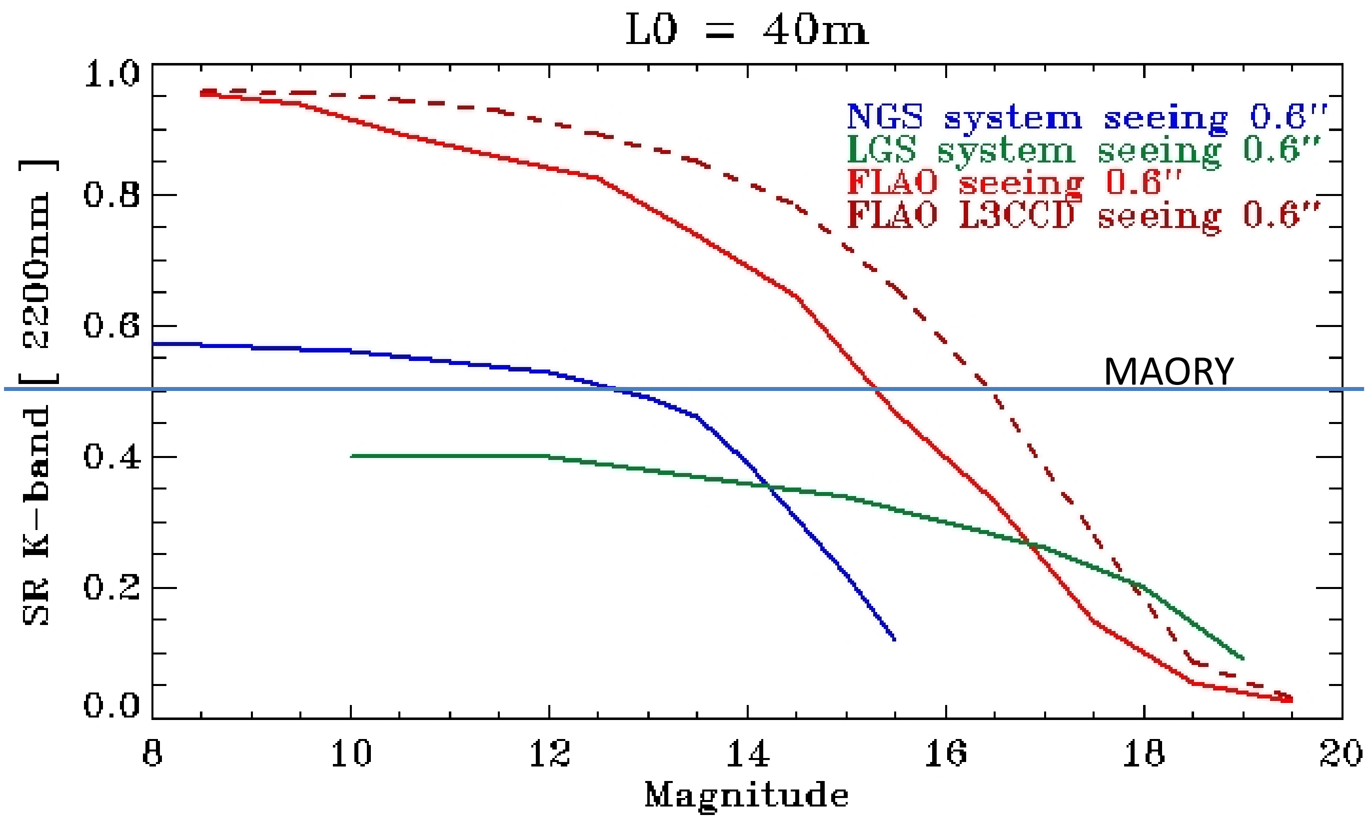
Günster, Ristau & Davies, 2011

Simple & Robust Adaptive Optics for MICADO

MCAO: - (MAORY) good, uniform performance over full field with high sky coverage.

SCAO: - complementary AO capability for highest performance on compact targets (also risk mitigation & diffraction limited science during MAORY commissioning)

- pyramid WFS for a single natural guide star, correct with the E-ELT's DM
- simple, robust, well developed, well understood
- option for novel WFS approaches: e.g. hybrid AO could gain another 1 mag



AO performance on 8-m telescope, courtesy of Simone Esposito

Operations, Data Rate, & Processing

Imaging & longslit spectroscopy are standard techniques

- use standard procedures for processing data
- astrometry is an exception; detailed astrometric calibration scheme developed

Operations: dithering scheme

- balances requirements of:
  - science (frequent dithering)
  - telescope (infrequent dithering)
  - AO (precision vs distance)

small dither	+/-0.3” from centre, accuracy <2mas, cadence 10-30sec
large dither	up to 10” from centre, cadence a few minutes
sky offset	up to 15arcmin, cadence 20-30mins

Data Rates & Volumes:

typical observation for a 1hr OB might be:

preset + [((3s exp. + 1s readout)×5 + 2s small dither)×10 + 20s large dither]×14

1 preset
14 telescope offsets
700 detector readouts (58% efficiency)
700GB raw data (i.e. 6-7TB per night)

Resolved Stellar Populations

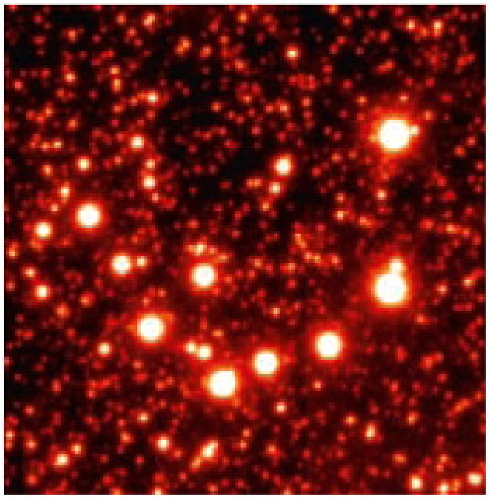
Resolution gives an effective sensitivity gain wrt JWST – cf. 3mag for MAD vs ISAAC.

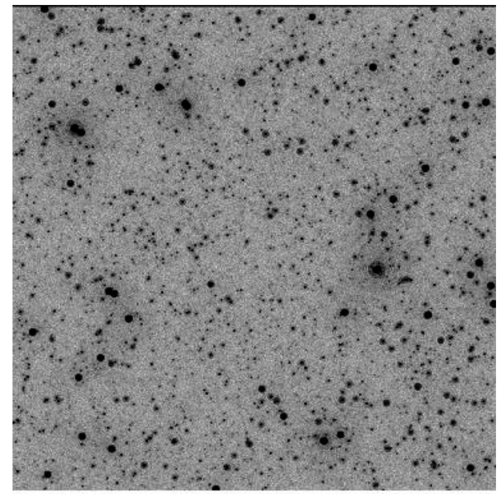
Can probe tip of RGB out to Virgo (δ_{Virgo} = +12.5°, zd at transit is 37° -> seeing ~0.1" worse)

Data for Omega-Cen
(Marchetti+ 07)

5-hr K-band simulated exposure

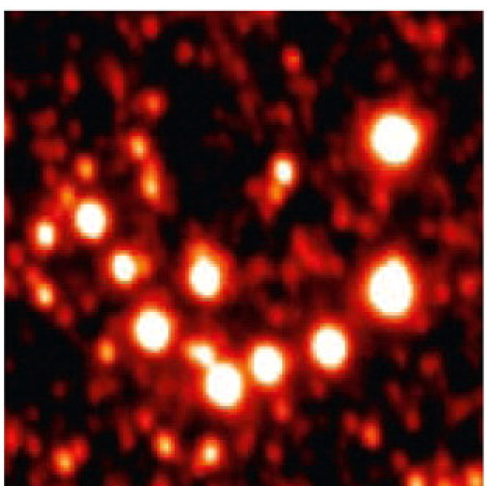
MAD

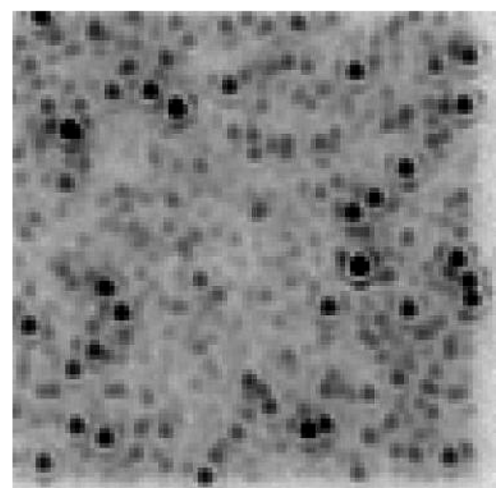




MICADO

ISAAC





JWST

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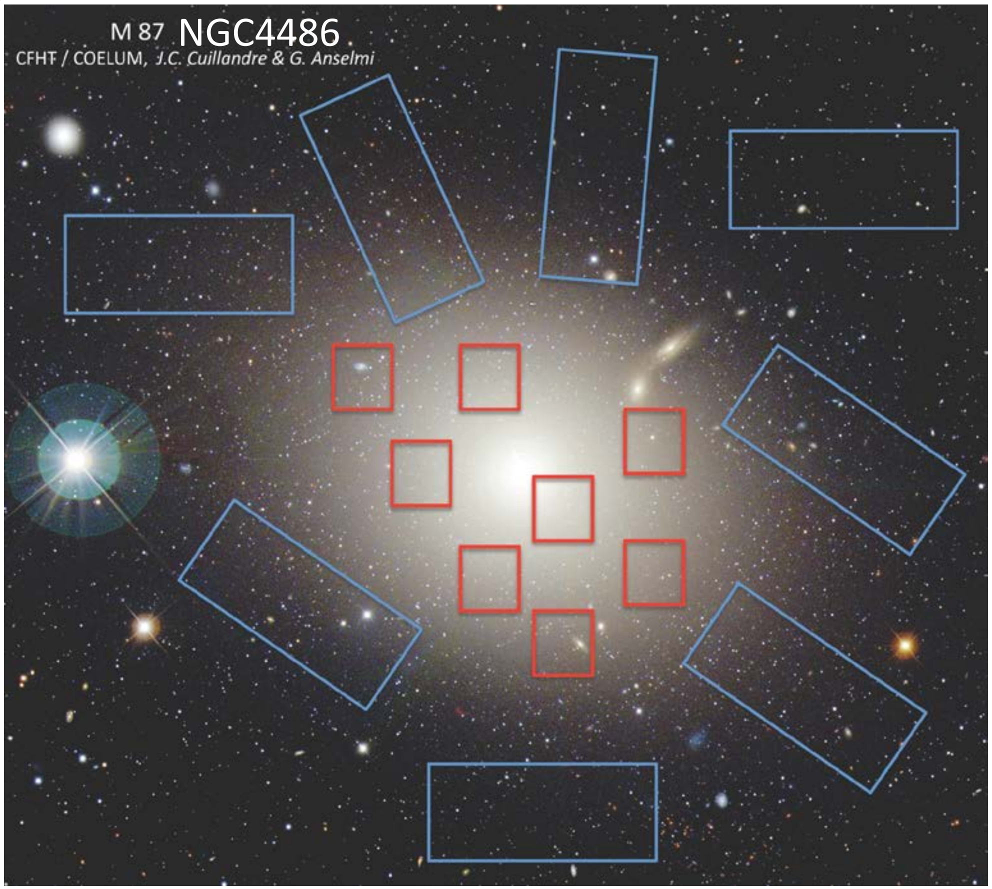
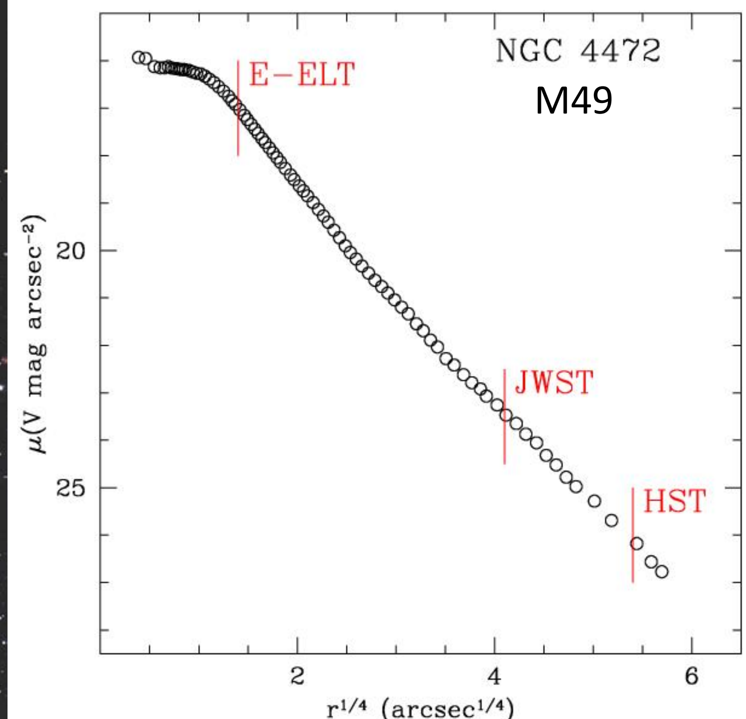
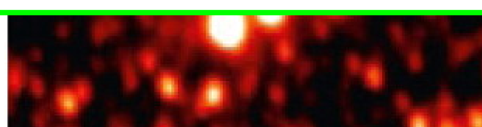
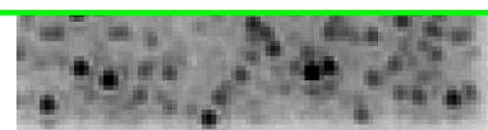


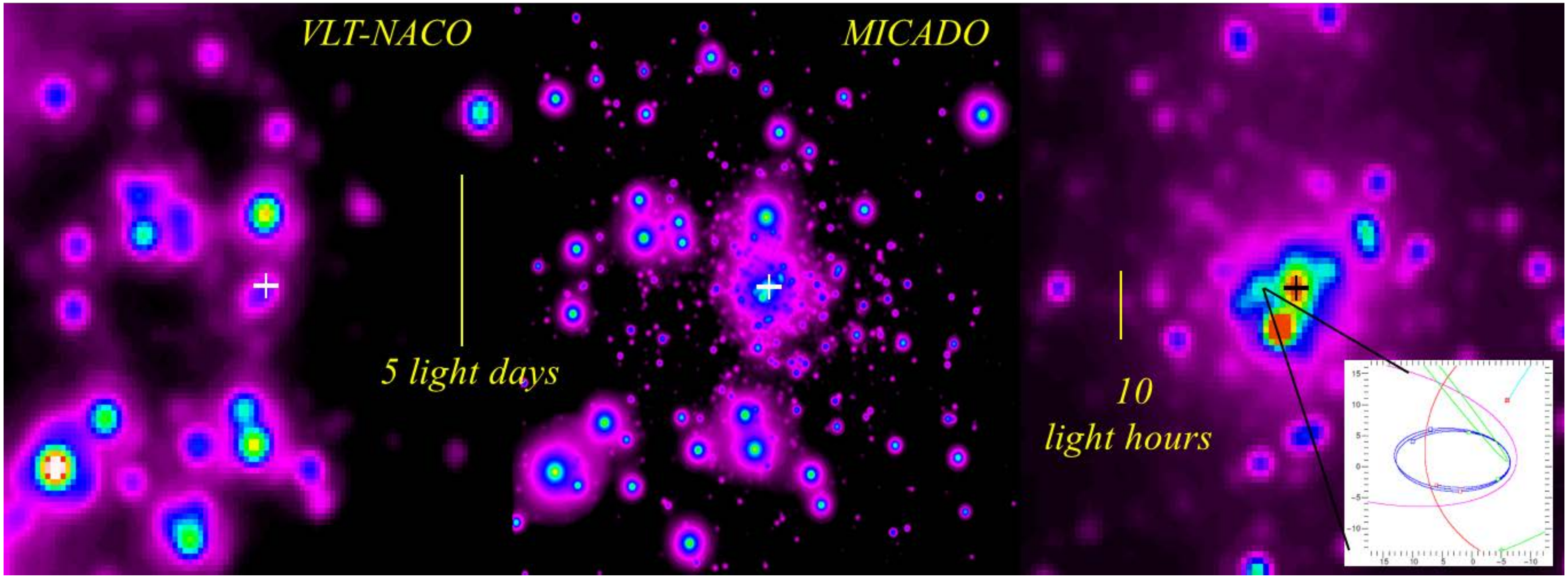






Galactic Centers near & far

- Unique laboratory for exploring strong gravity around the closest massive black hole
- Crucial guide for accretion onto black holes & co-evolution of star clusters and AGN



- sensitivity >5mag fainter, resolution & astrometry 5x better than NACO on VLT
- density profile, luminosity function to <1M_{sun}, shape of IMF
- orbits of stars closest to BH; prograde & retrograde precession
- proper motions of ~1000 stars: accurate distance, phase-space clumping (disks), binary fraction, intermediate mass BHs

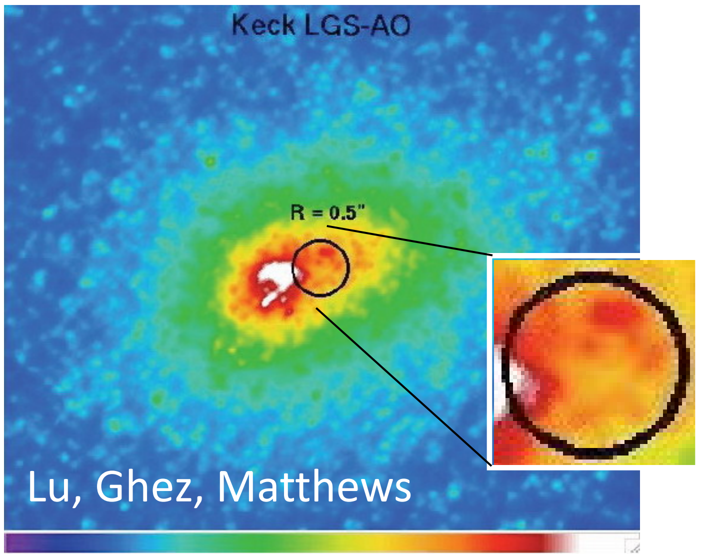
- spectroscopy

  3D orbits (enhances many of the above analyses), stellar types, spectral properties of accretion events

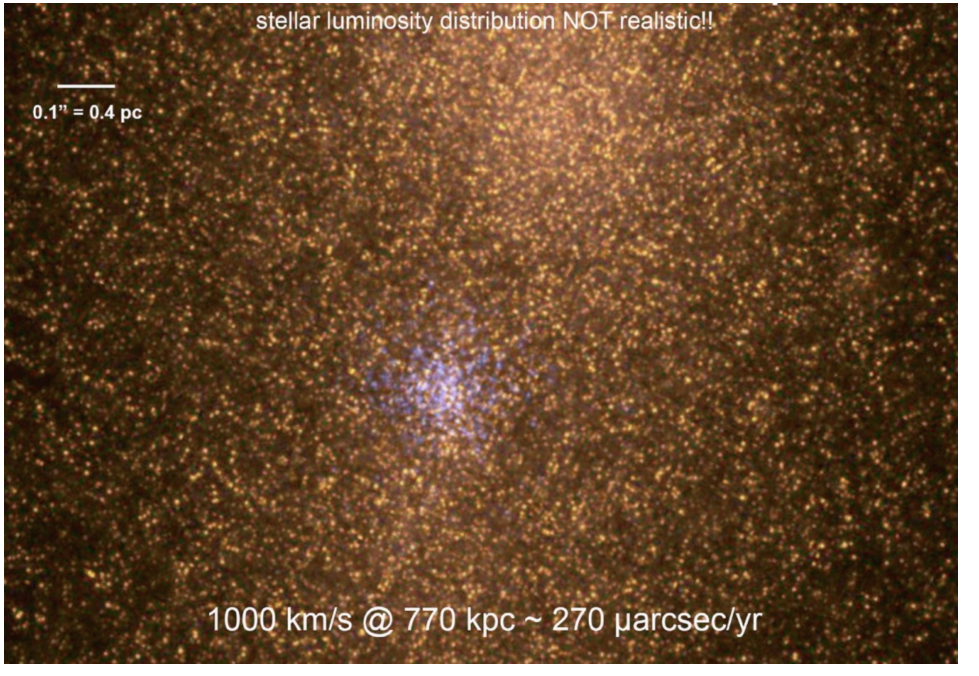
Galactic Centers near & far

- Cen A: $M_{BH}=5\times10^7 M_{sun}$ velocities 1000km/s = 50μas/yr are measurable
- determine mass & location of black hole, nuclear stellar populations & kinematics

Keck's view of M31



MICADO's view of M31… or equally Cen A



spectroscopy:
- numerous emission/absorption diagnostics simultaneously
- molecular/ionised inflow/outflow, extinction, stellar pops., etc.
- reliable black hole masses in statistically useful galaxy samples
- dispersion in local dwarf ellipticals, or massive ellipticals to z~0.35
- link between nuclear stellar clusters & central black holes

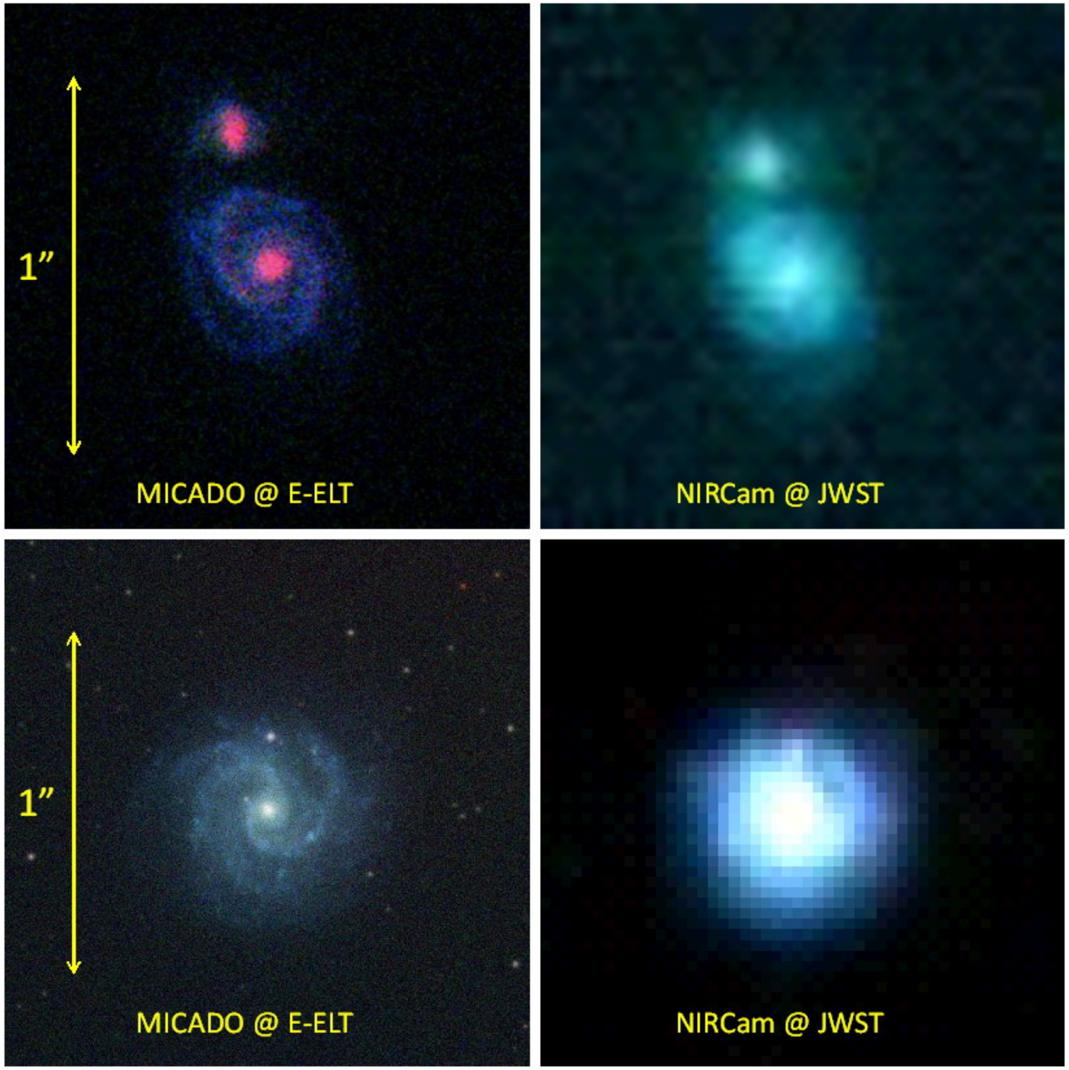
Galaxies at High Redshift

JWST will select samples & measure basic galaxy properties

MICADO will provide the details of their structure to answer: What are the physical processes driving their evolution?

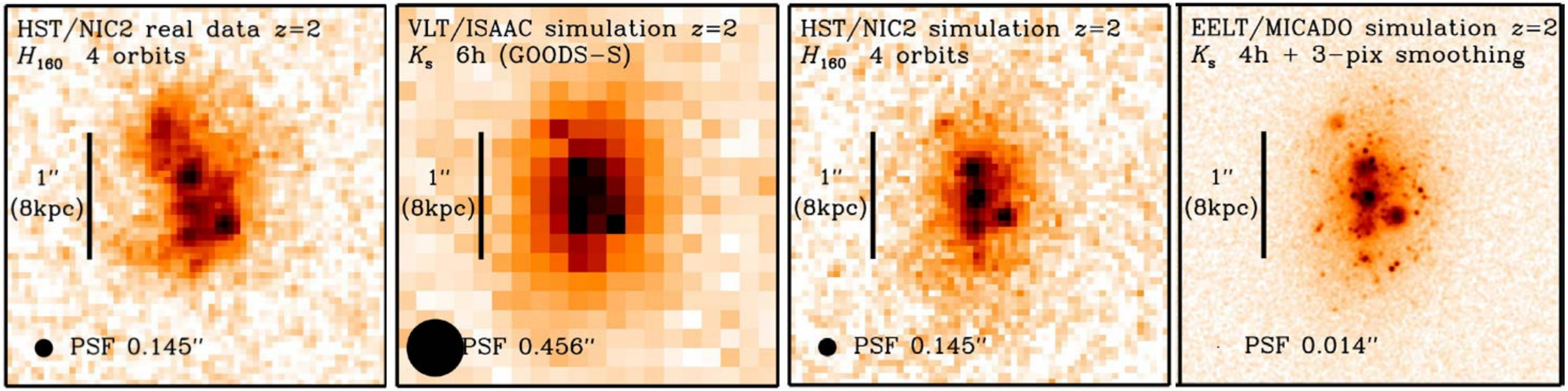
1arcmin field provides significant multiplex

obvious synergies with ALMA, HARMONI, etc for kinematics, gas content, etc.



combined JHK images of local templates (BVR bands) shifted to z=2 (top) and z=1 (bottom), with R_{eff}=0.5” and Mv=-21. 5hrs integration.

Galaxies at High Redshift

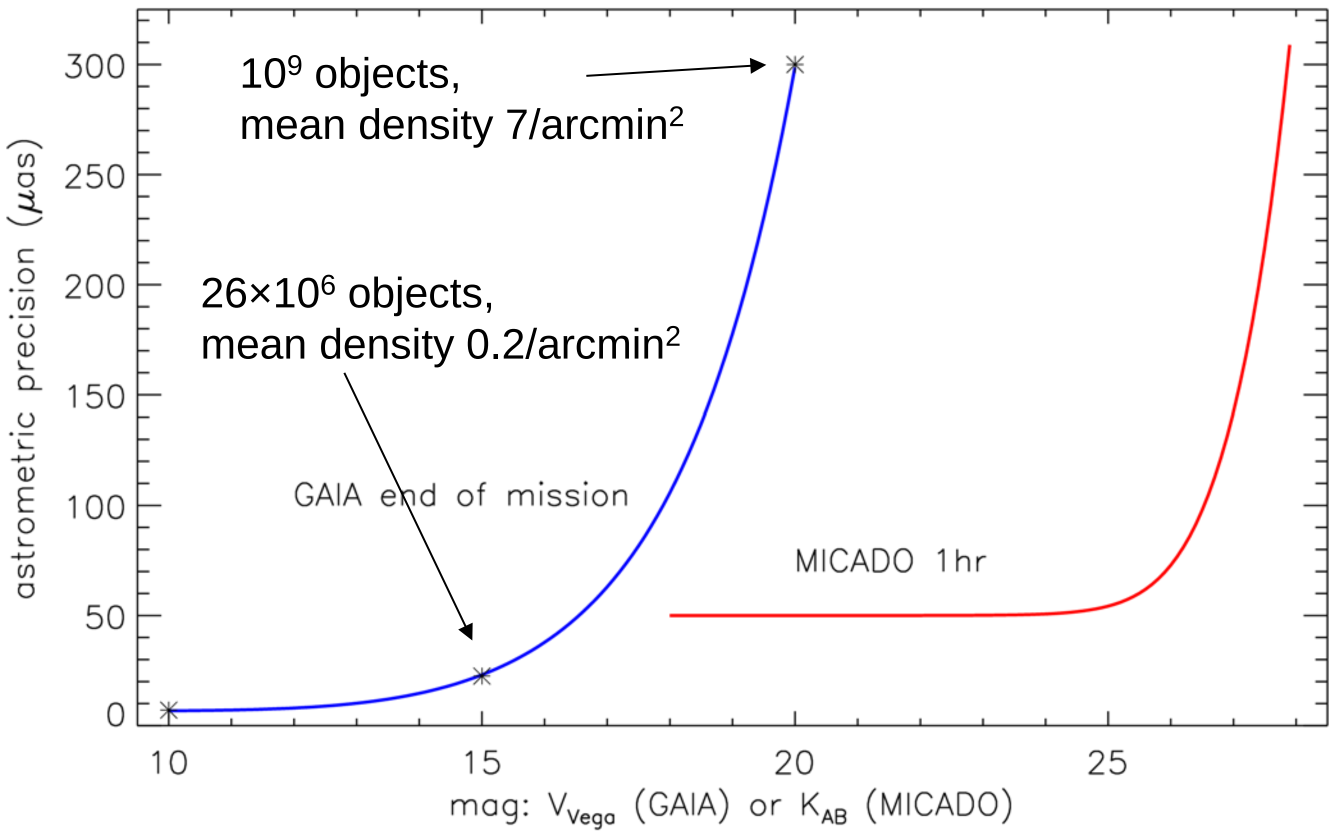


simulation of a large bright disk galaxy at z = 2.3 ($R_{1/2}$ = 5 kpc, K_{AB} = 21.3), showing that MICADO will be able to measure sizes, distribution and luminosity functions of compact clusters to K_{AB} ~ 28.5

spectroscopy:
- essential emission/absorption diagnostics simultaneously
- metallicity, extinction, stellar populations, (weak) AGN contribution
- relations between mass, SFR, metallicity, needed to understand galaxy evolution

Astrometry: GAIA & MICADO

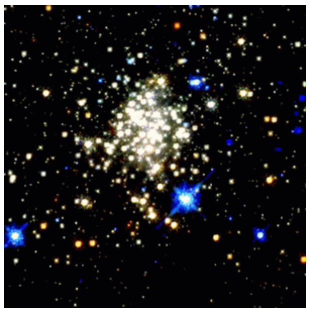
- GAIA: launch August 2013, with 5 year mission
- Very different science as a result of sensitivity & crowding limits:
  - GAIA: Milky Way structure & evolution, exoplanets, solar system minor bodies
  - MICADO: dense &/or dusty regions, IMBHs, star clusters, dwarf galaxies



V_{Vega} and K_{AB} magnitudes are roughly equivalent

Intermediate Mass Black Holes

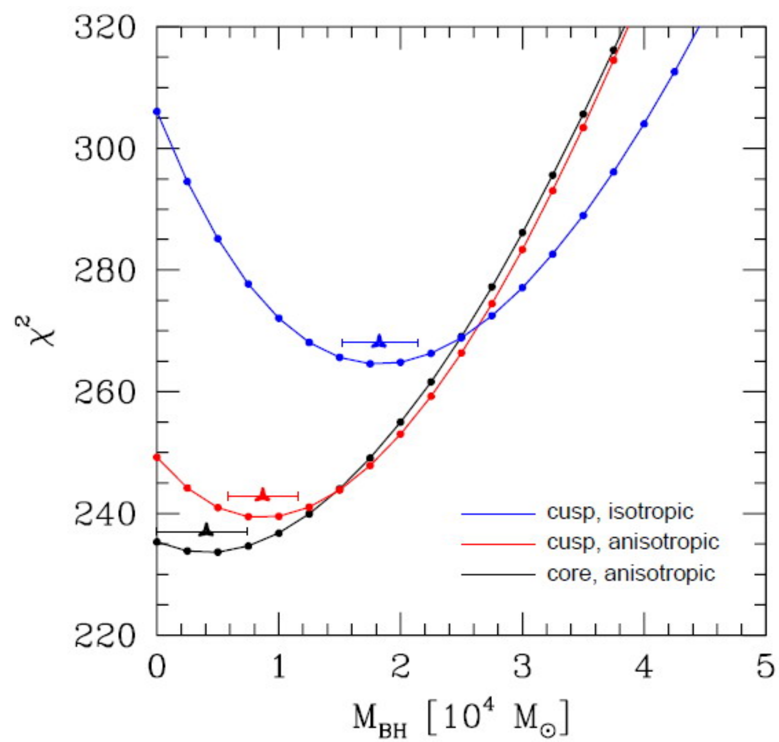
Arches
M_{BH}~1000M_{sun}?
(Portegies Zwart et al. 06)



IRS 13
M_{BH}~1300M_{sun}?
(Maillard et al. 04)

Omega Cen:
M_{BH}~10000M_{sun}?
(Noyola+ 08)

Andersen+ 09, van der Marel+ 09
Omega Cen
- more than 50000 (faint) stars, 4-yr baseline, errors ~100µas/yr
- proper motions show small but significant anisotropy
- models with shallow cusp require M_{BH}~$2\times10^4 M_{sun}$
- models with core profile require no central dark mass !



Intermediate Mass Black Holes with MICADO

Arches, Quintuplet, open clusters, globular clusters, etc.

- Milky Way has ~150 GCs
- Typical GC has central dispersion ~10km/s
- 10km/s is 50μas/yr at a distance of 40kpc
- This is ~10x distance to Omega Cen & covers large part of GC system
- Can measure proper motions on relatively short timescale

in a few years we can constrain masses of BHs at centres of GCs

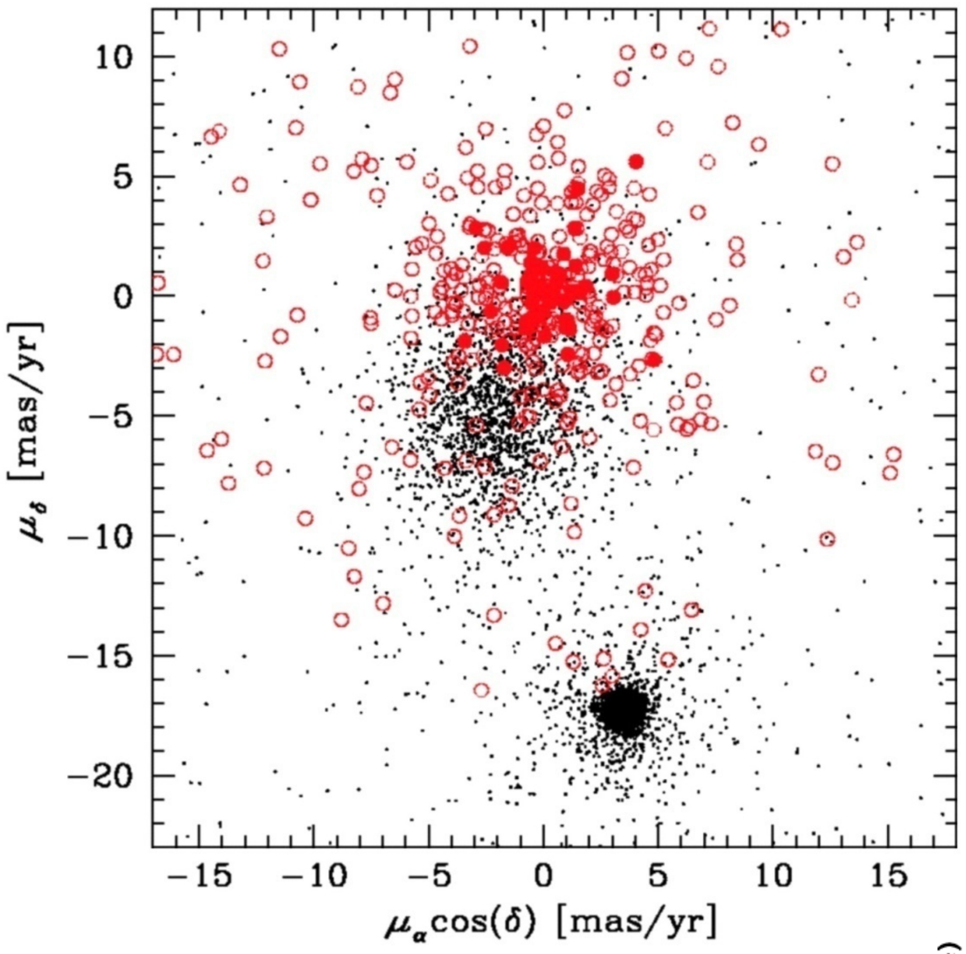
- ➢ impact on M_{BH}-σ_* relation
- ➢ dynamical evolution of GCs

internal proper motions:

- ➢ rotation, flattening and internal structure of GCs
- ➢ binary fraction: 50μas is sufficient to measure wobble for stars with a dark companion >0.5M_{sun} and separation >0.5AU out to 10kpc

Cluster Proper Motions: orbits around Milky Way, passages through disk
decontamination of cluster CMDs

Globular Cluster Proper Motions



Kalirai+ 07

red: galaxies

black: field stars & cluster members

NGC6397

10 years of HST data:

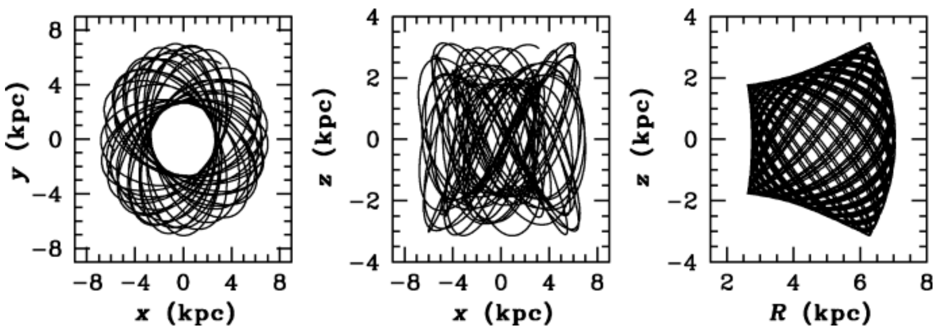
$\mu_\alpha \cos\delta = 3.56 \pm 0.04$ mas yr^{-1}

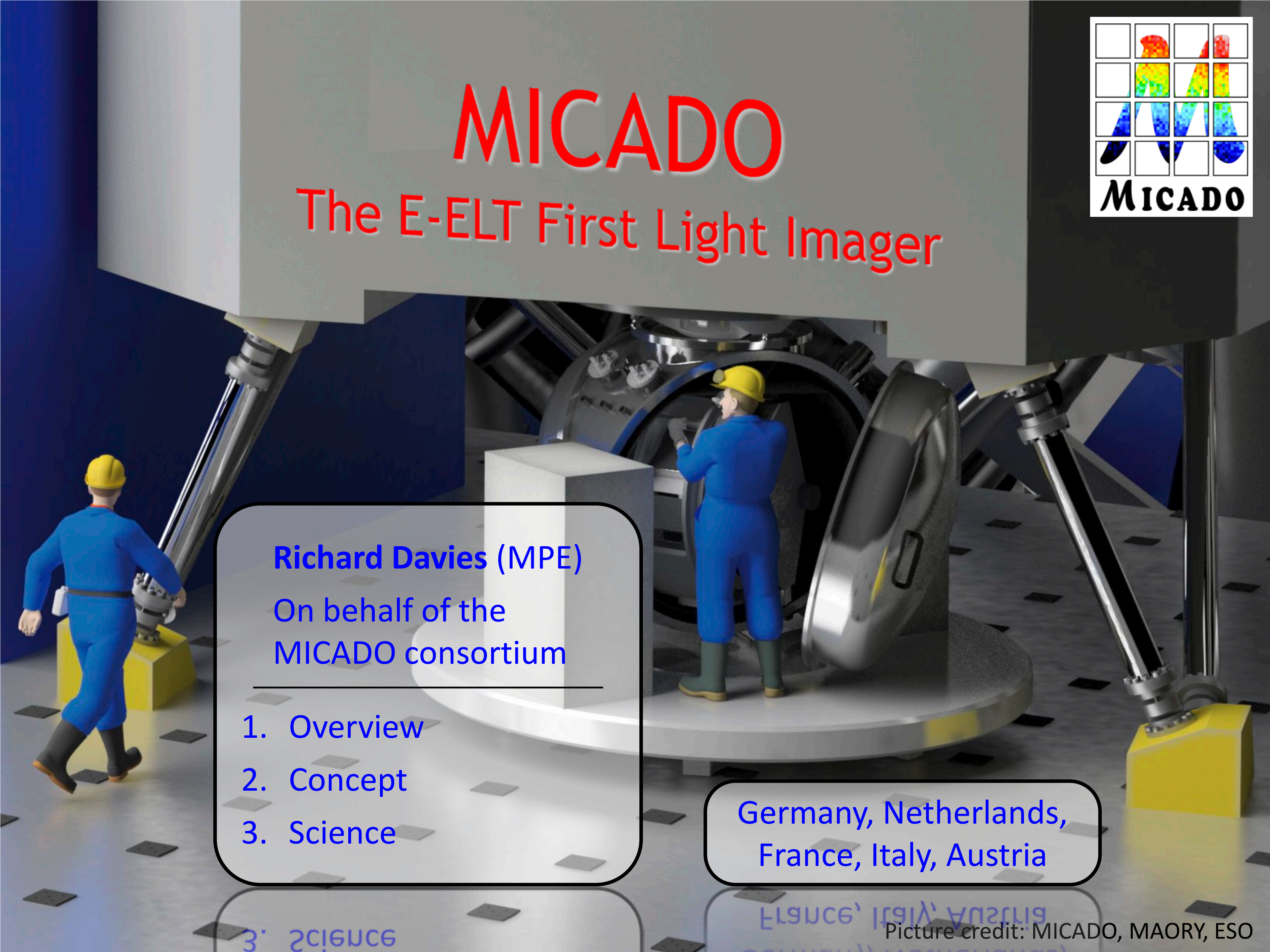
$\mu_\delta = -17.34 \pm 0.04$ mas yr^{-1}

MICADO can reach this precision in just 1 year

proper motions:

- orbit around Milky Way
- kinematic families ?
- impact on cluster evolution of frequent passages through MW disk





Picture credit: MICADO, MAORY, ESO

Project Consortium

Partners

MPE	Max-Planck-Institut für extraterrestrische Physik
USM	Universitäts-Sternwarte München
IAG	Institut für Astrophysik Göttingen
MPIA	Max-Planck-Institut für Astronomie
NOVA	Nederlande Onderzoekschool voor Astronomie [specifically including: University of Leiden, University of Groningen, NOVA optical/IR instrumentation group]
LESIA	Laboratoire d'Etudes Spatiales et Instrumentations pour l'Astrophysique, Paris Observatory
Austria	University of Vienna, University of Innsbruck, University of Linz
INAF	Osservatorio Astronomico di Padova