MICADO, the first light ELT camera

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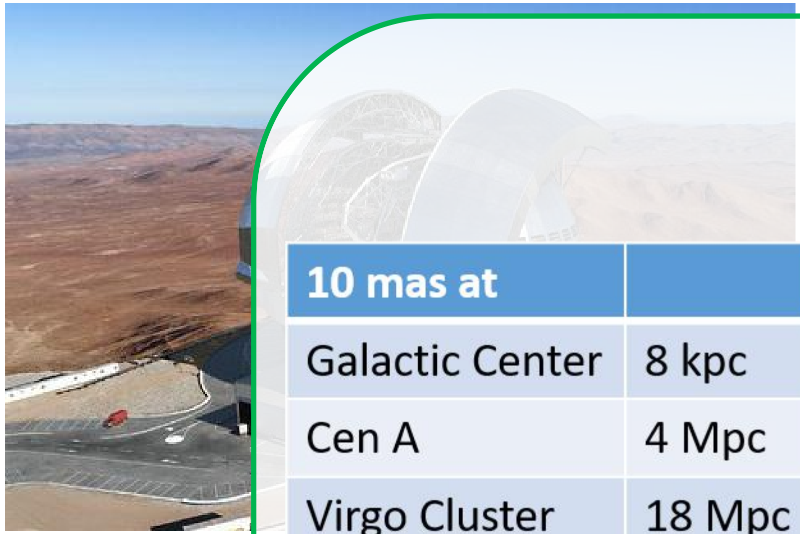
on behalf of >150 MICADO consortium members in

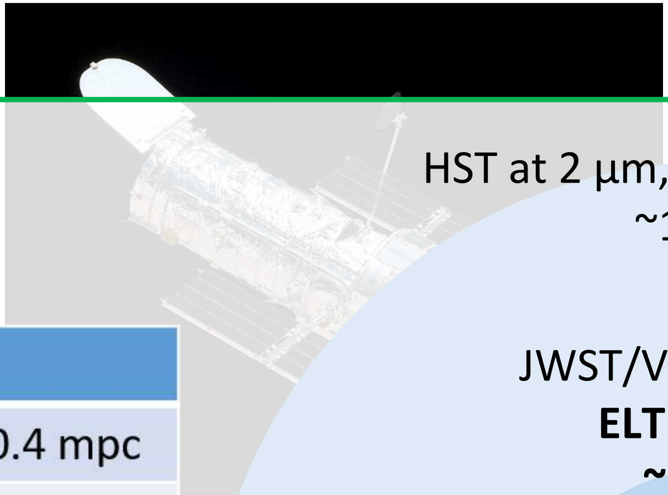
Key Capabilities

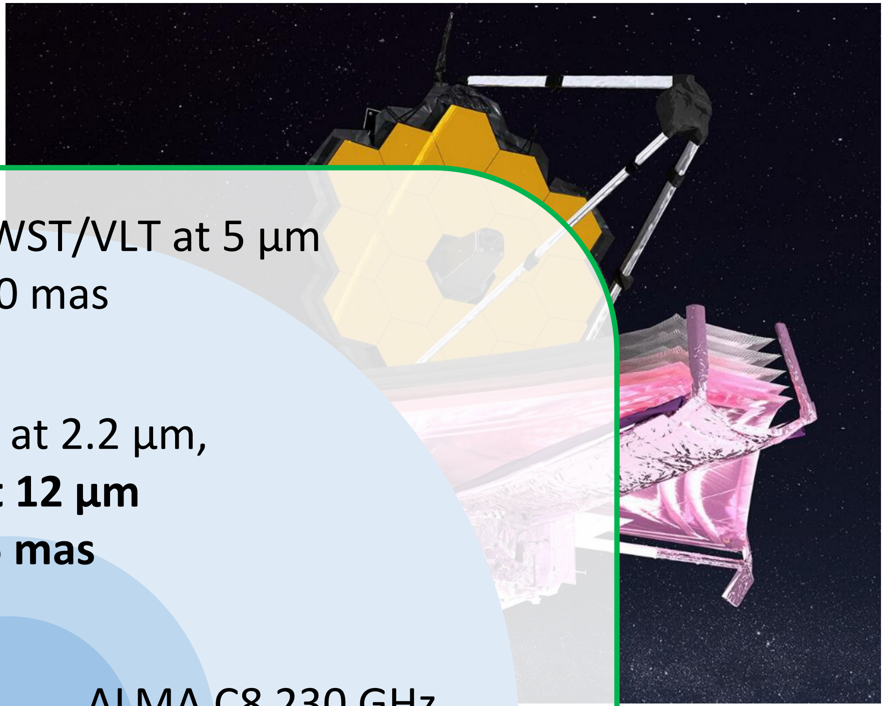
MICADO will be used with MORFEO to provide:

- ❑ Imaging
  - 0.8-2.4μm with 30 broad/narrow filters
  - 1.5 & 4mas pixels for 19” & 51” FoV at 6-12mas
  - Similar sensitivity to JWST, and 6× better resolution
- ❑ Astrometric imaging
  - 10-50μas precision anywhere in the field
  - 10μas/yr = 5km/s at 100 kpc after only a few years
- ❑ High Contrast imaging
  - focal & pupil plane coronagraphs
  - angular differential imaging
  - small inner working angle
- ❑ Spectroscopy
  - for compact sources
  - fixed configuration for 0.83-1.57μm & 1.50-2.46μm
  - R ~ 20000 for point sources (R ~ 10000 across slit)

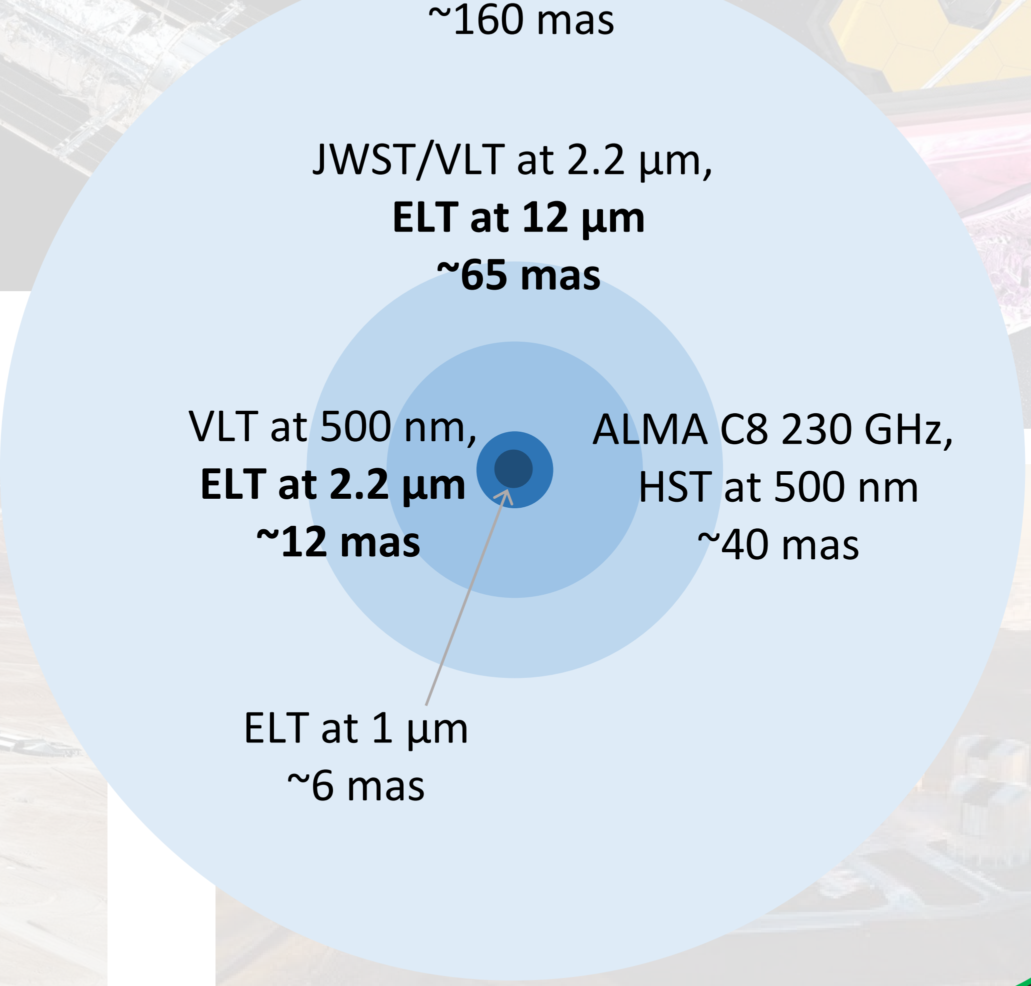
Resolution in context

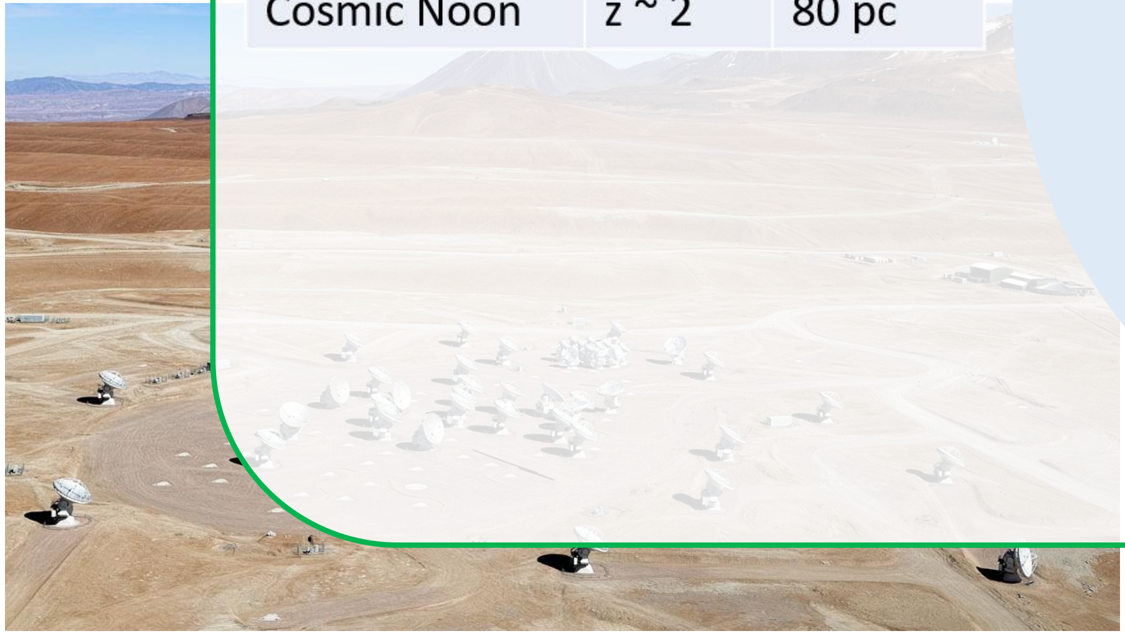






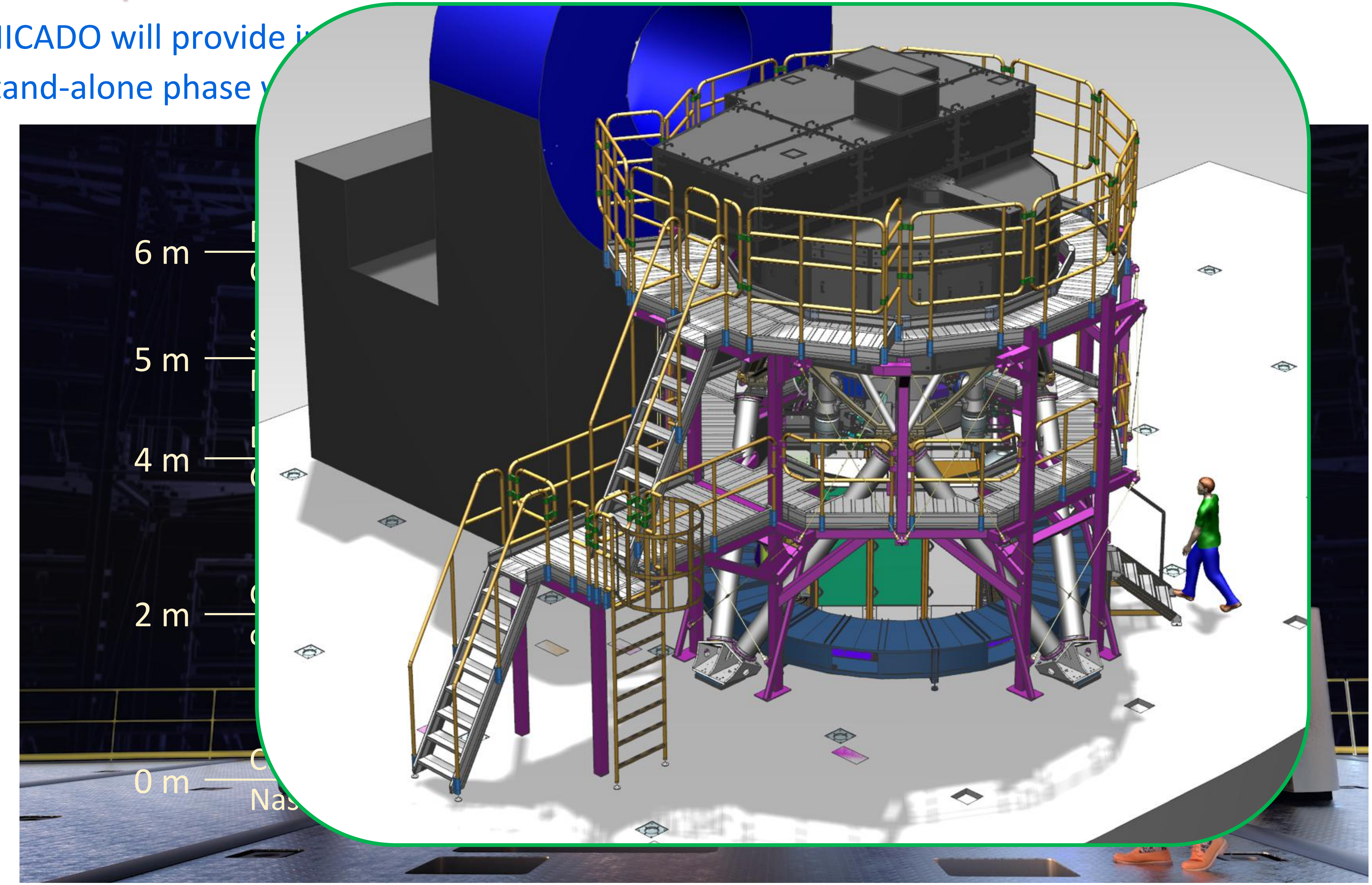
10 mas at		
Galactic Center	8 kpc	0.4 mpc
Cen A	4 Mpc	0.2 pc
Virgo Cluster	18 Mpc	1 pc
Cosmic Noon	z ~ 2	80 pc





MICADO quicklook

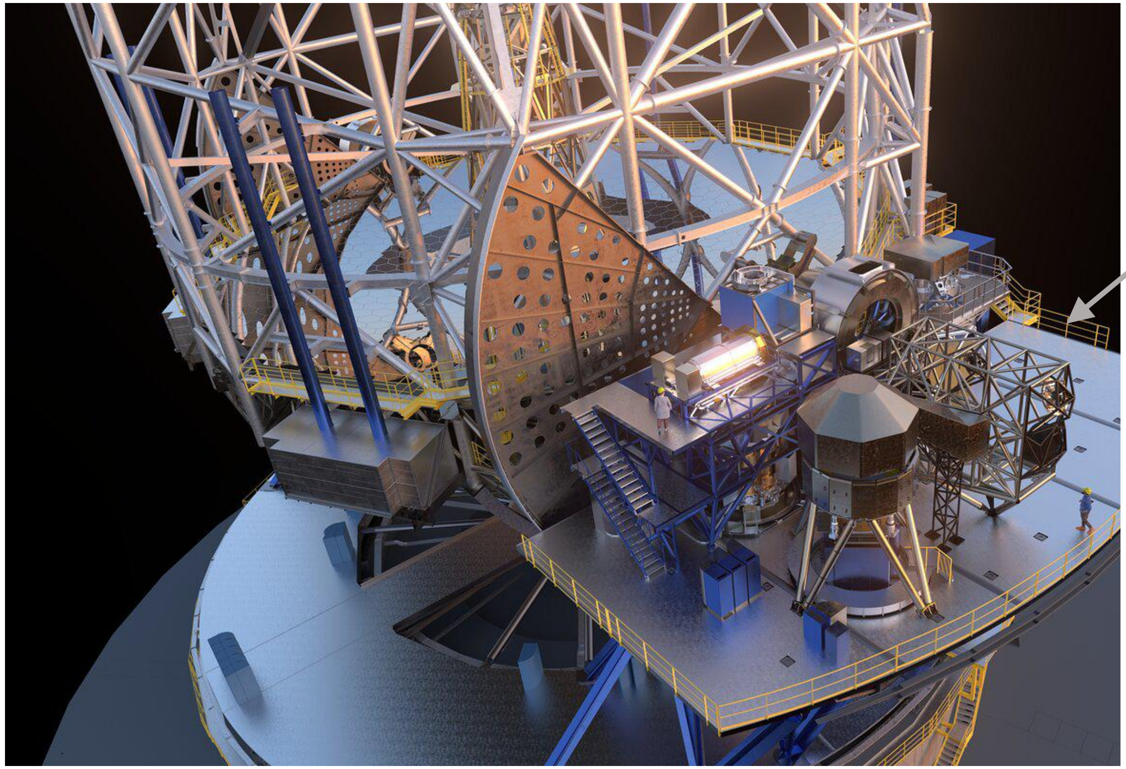
- MICADO will provide i
- Stand-alone phase v

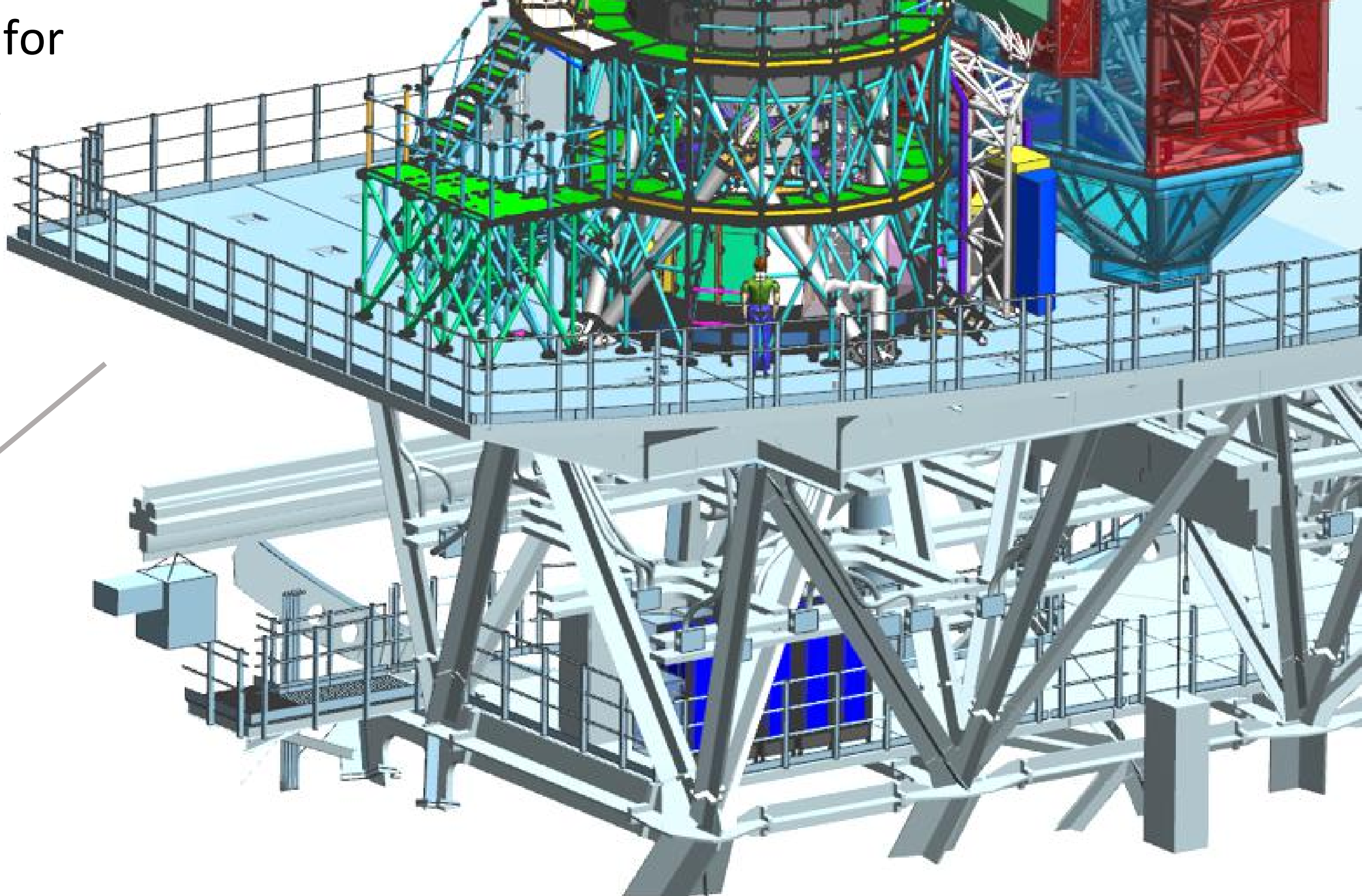


MICADO & MORFEO

- MICADO will provide imaging, astrometry, slit spectroscopy, coronagraphy.
- Stand-alone phase with just SCAO during initial operations – on Nasmyth A.
- Long term operation with MORFEO (LGS-MCAO,
  & keeping SCAO) – on Nasymth B.

Project led by INAF, uses 6 LGS & up to 3 NGS for uniform AO correction over full MICADO field.

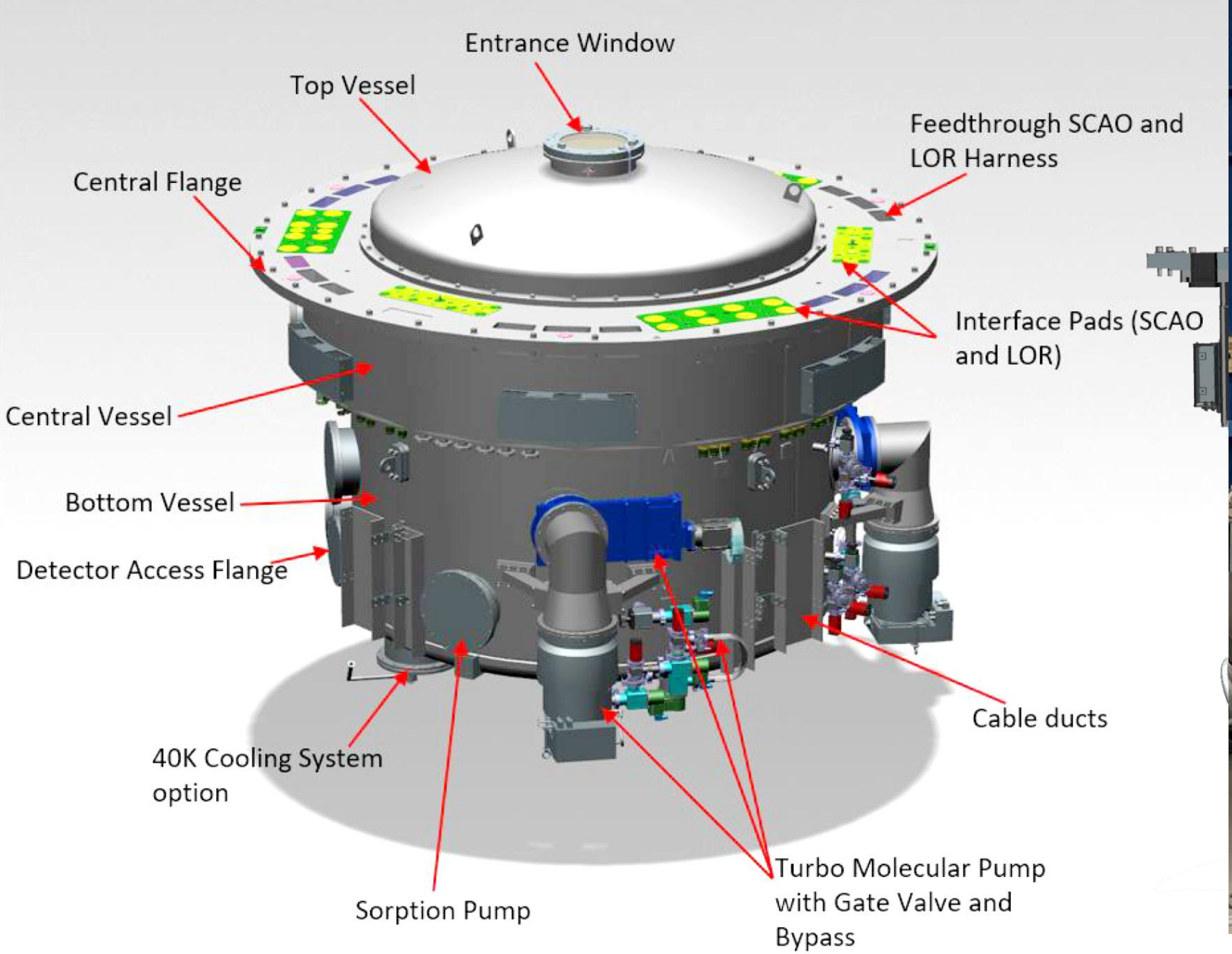




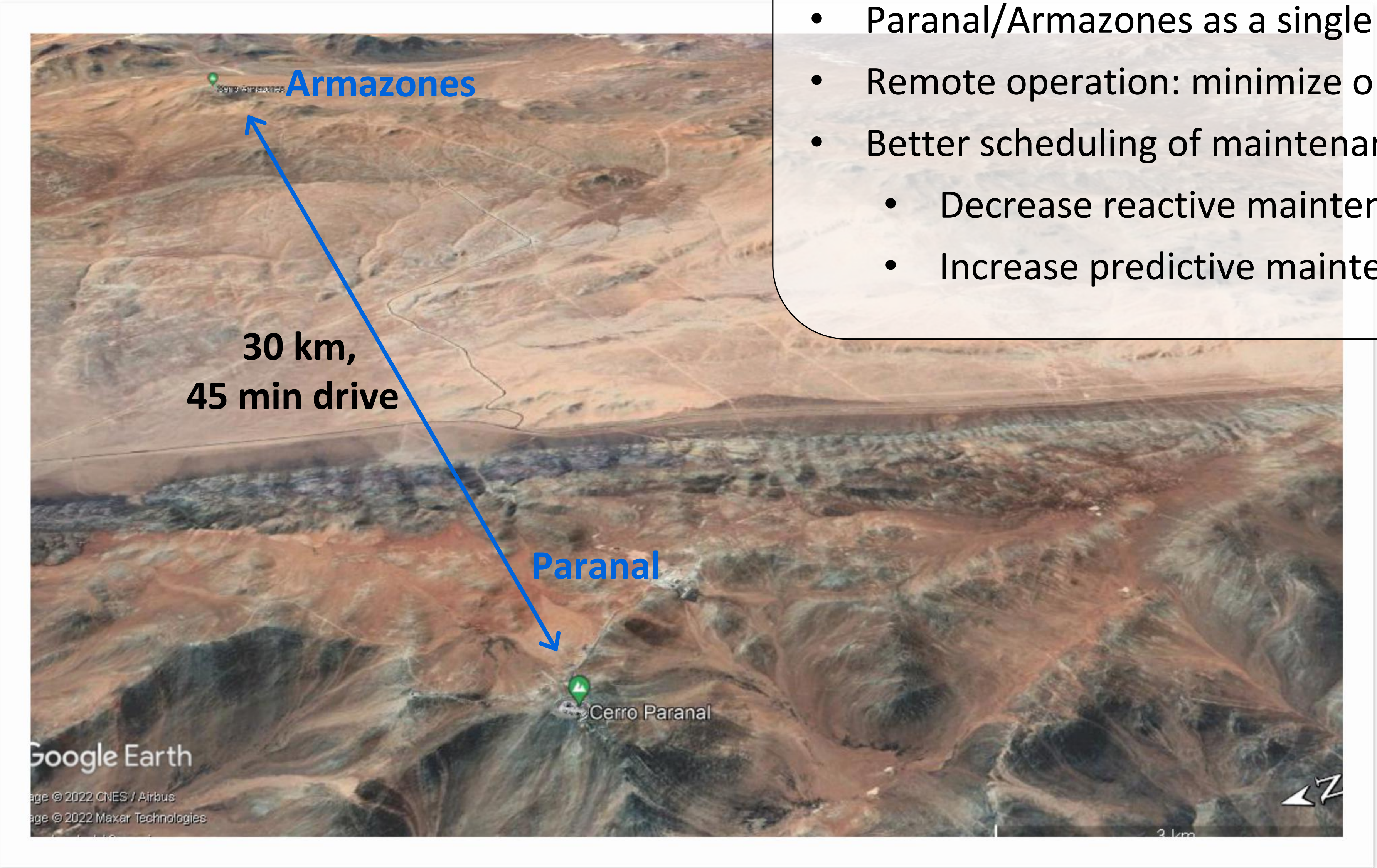
MICADO with MORFEO on Nasmyth Platform

MICADO from concept to hardware

Views of the cryostat



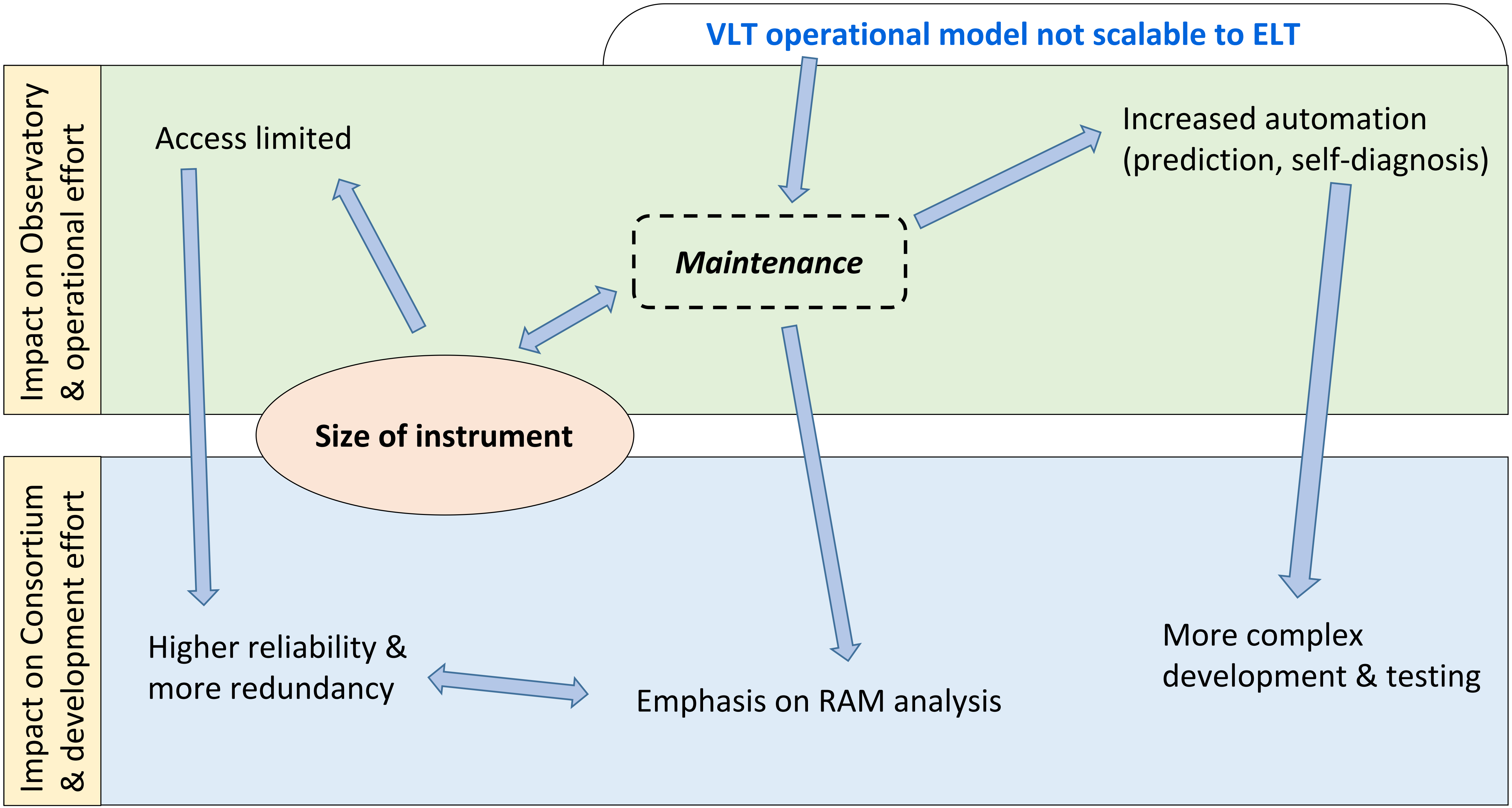
Challenges of ELT vs VLT instrument development



VLT operational model not scalable to ELT

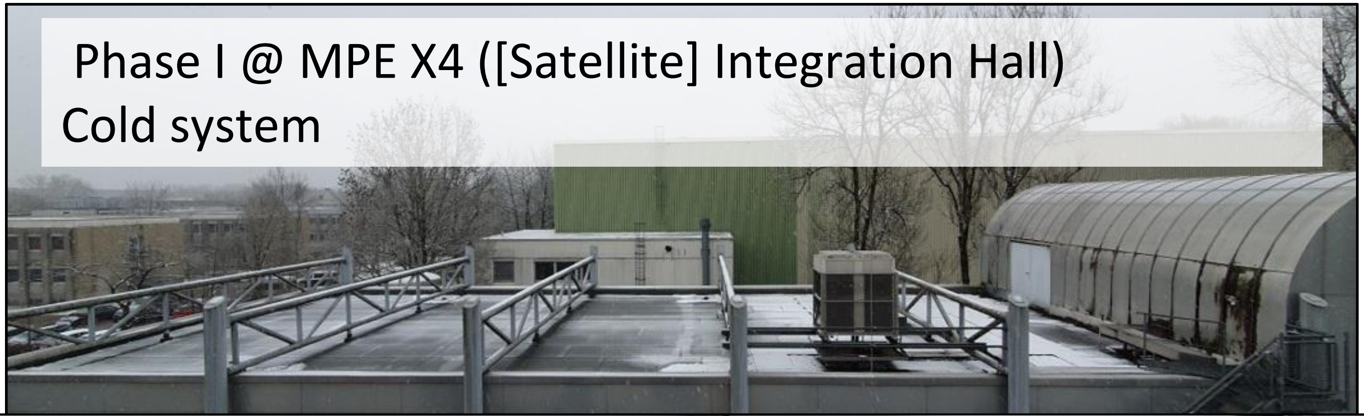
- Paranal/Armazones as a single multi-site observatory.
- Remote operation: minimize on-site activity & commuting.
- Better scheduling of maintenance activities:
  - Decrease reactive maintenance.
  - Increase predictive maintenance.

Challenges of ELT vs VLT instrument development



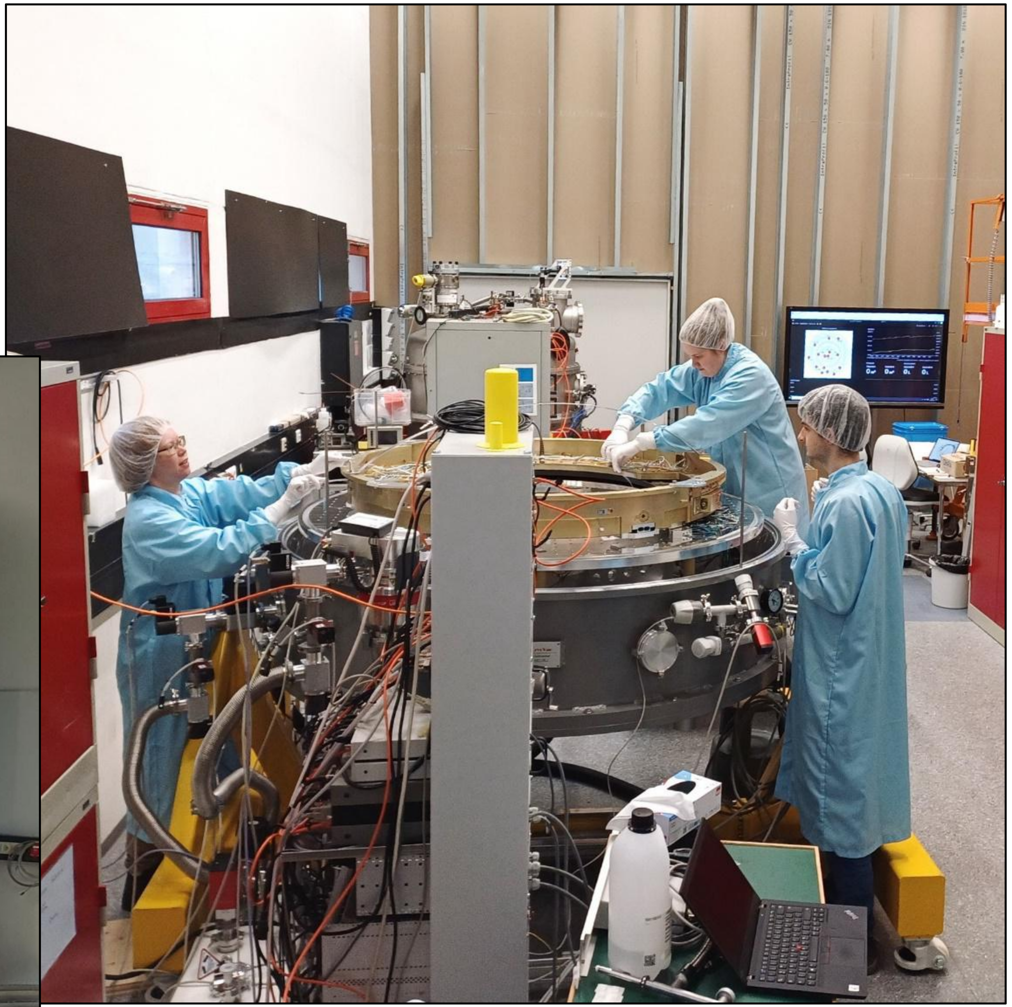
Challenges of ELT vs VLT instrument development

Phase I @ MPE X4 ([Satellite] Integration Hall)
Cold system

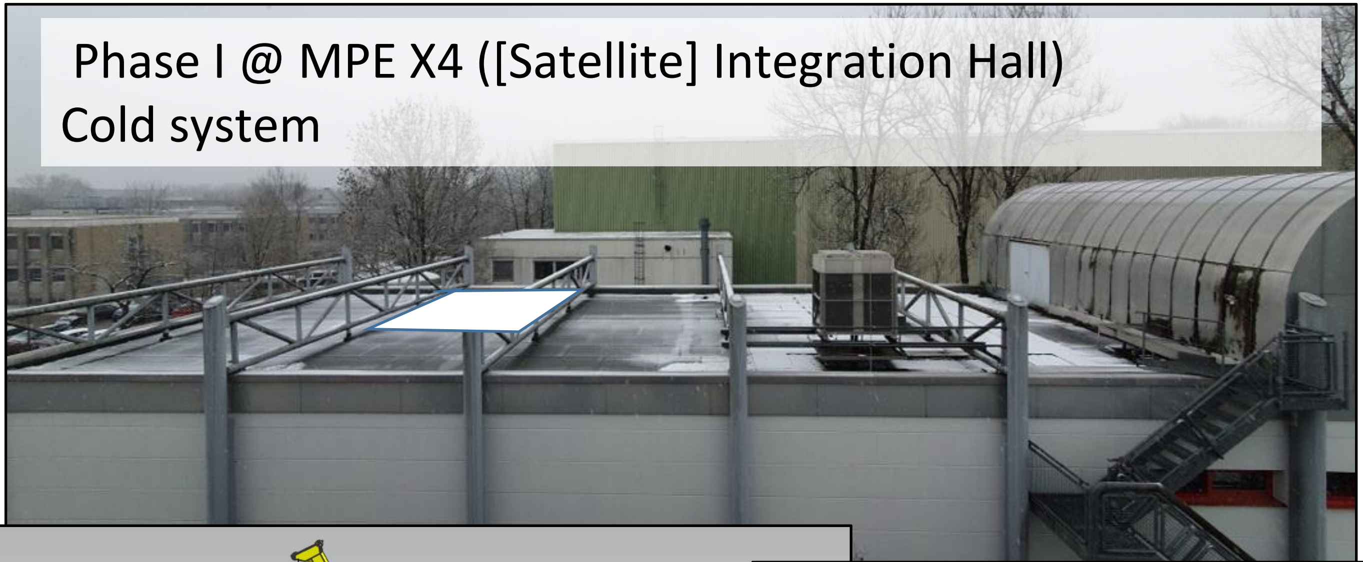


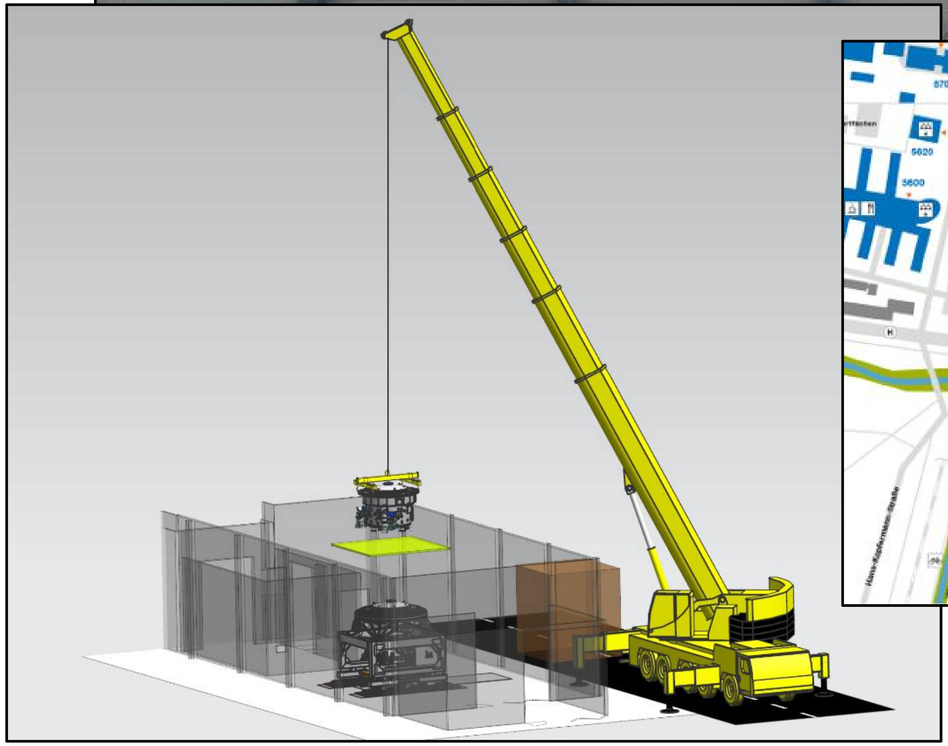
Bringing the de-rotator into the X4 Integration Hall at MPE

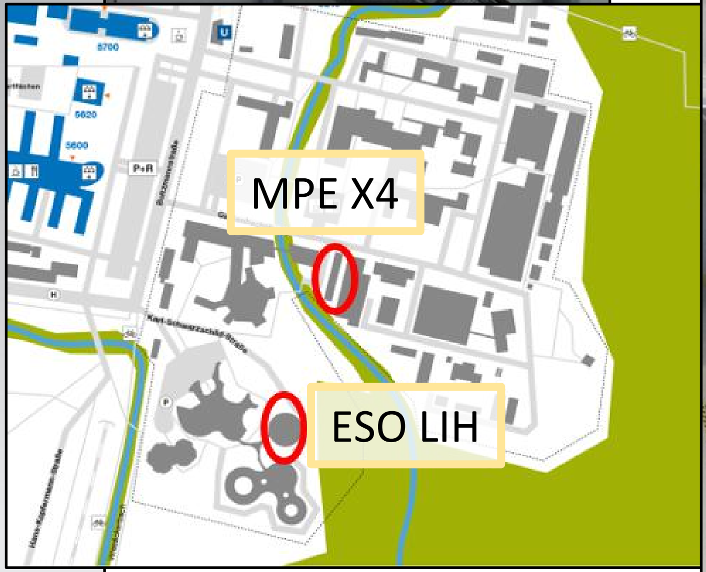
Cold test of NOVA's Pupil Wheel Mechanism at MPE

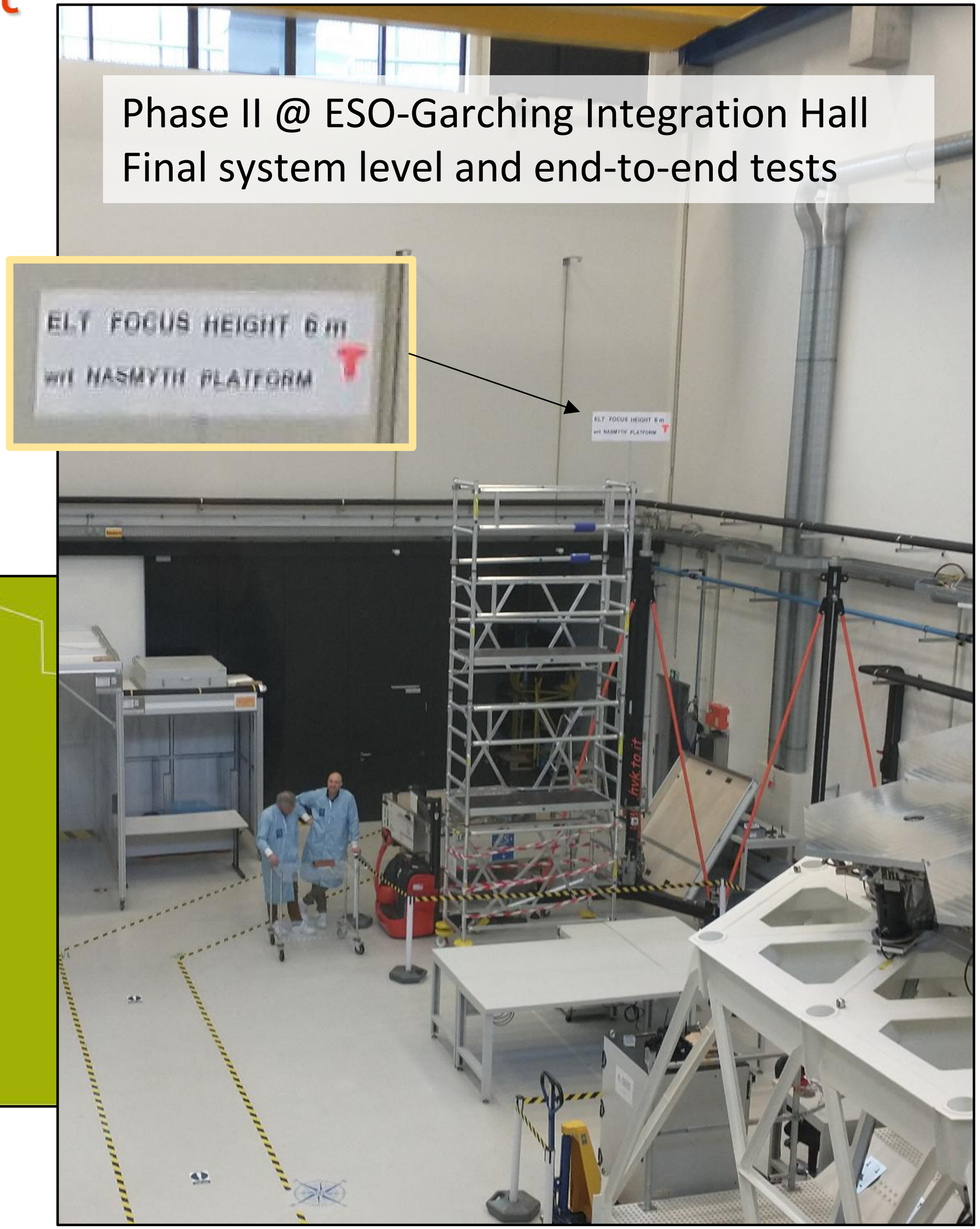


Challenges of ELT vs VLT instrument development



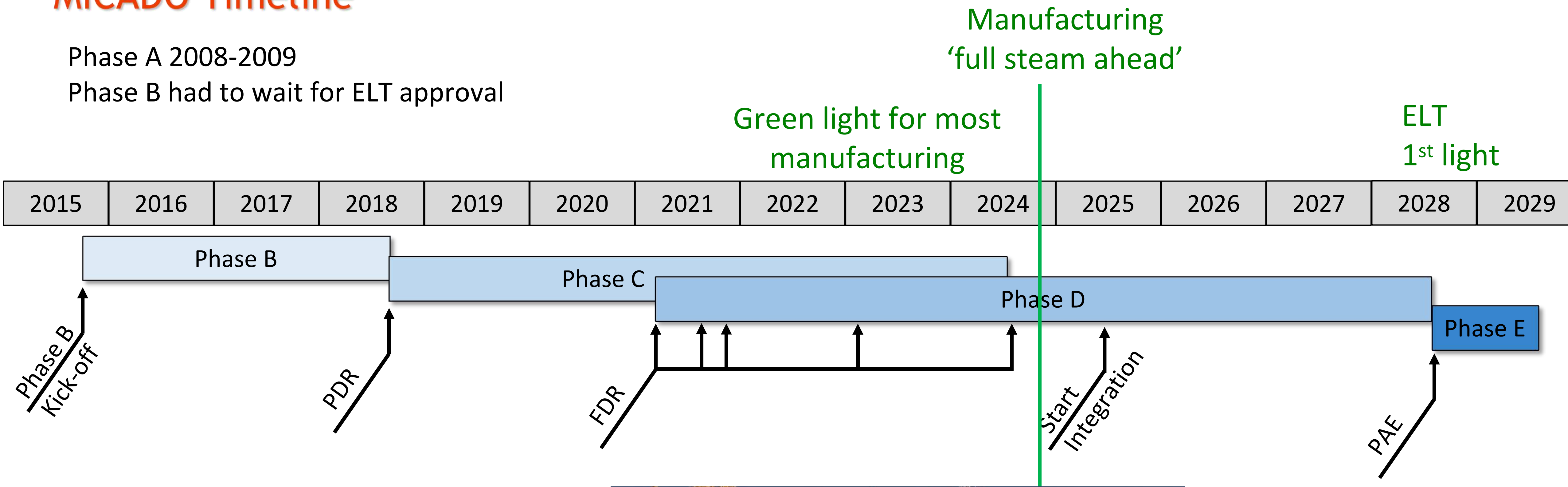






MICADO Timeline

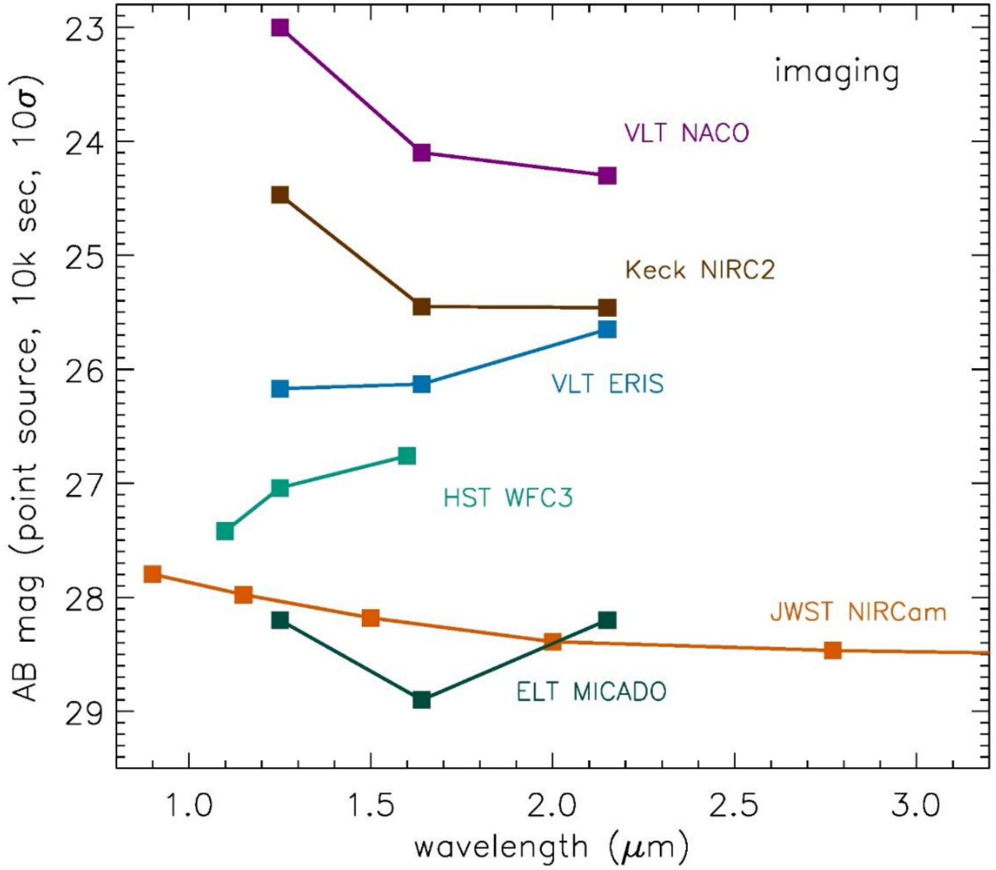
Phase A 2008-2009
Phase B had to wait for ELT approval

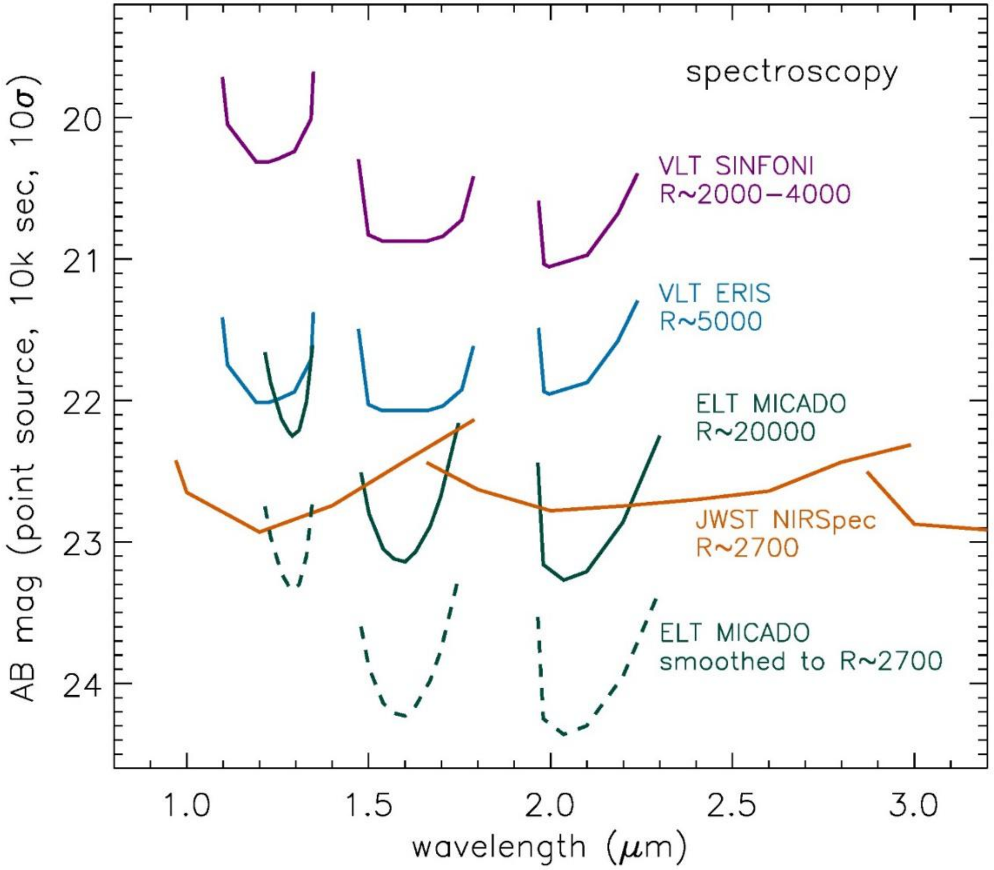


ELT on 27 Sep 2024
(ESO webcam)

A rough guide to sensitivity

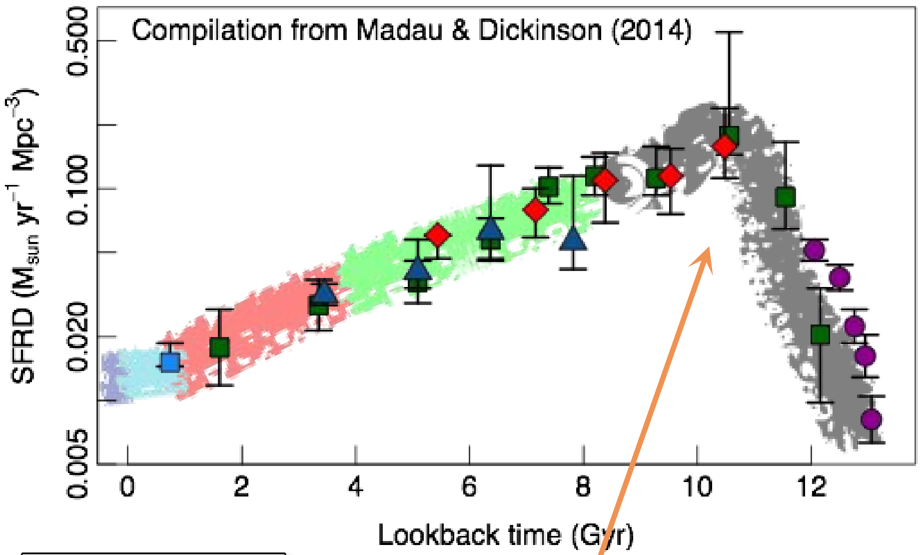
- Resolution is equally important
- Depends on a lot of assumptions
  (atmospheric conditions & AO performance, exposure configuration & detector read noise, etc)
- Better if you use ScopeSim

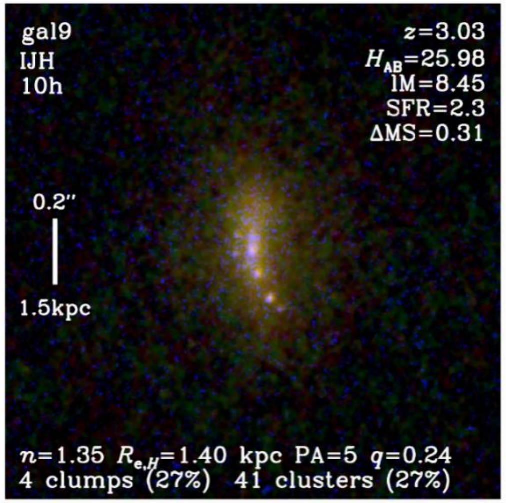


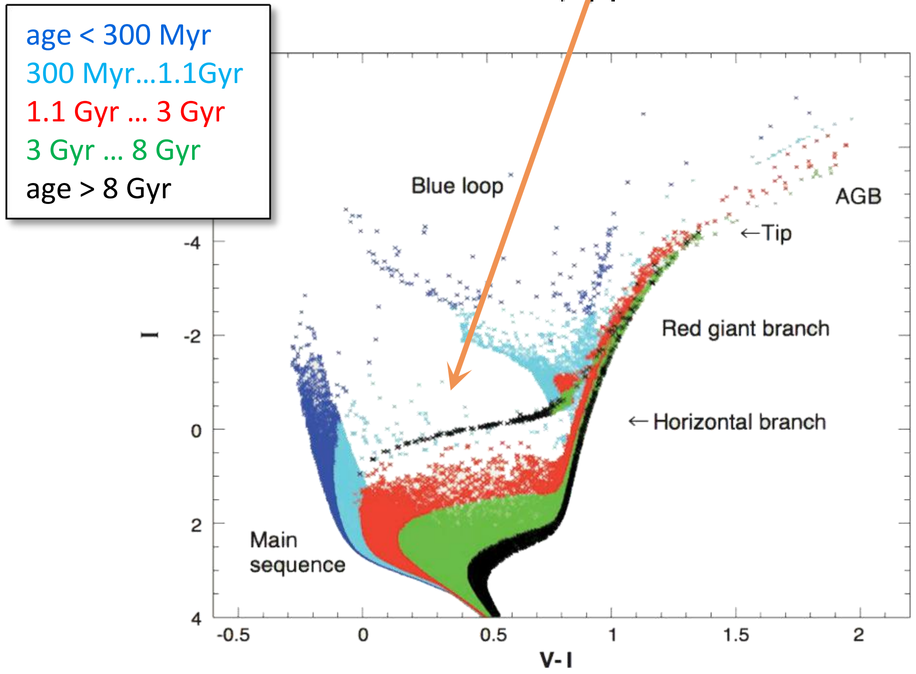


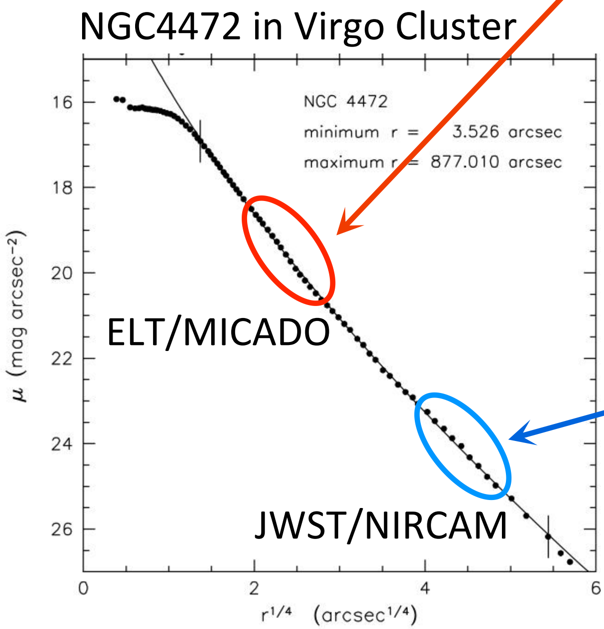
Galaxy Evolution: In-situ vs Archaeology

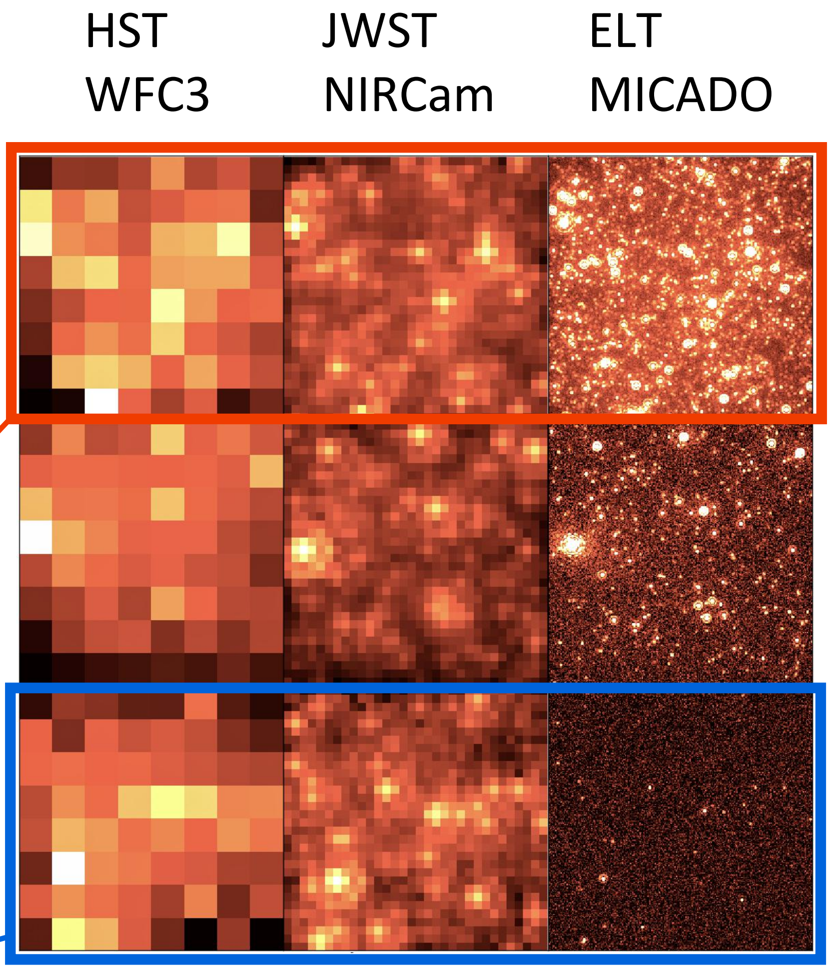
"JWST will tell us the *When* and the *Where*, but with MICADO, we will be able to tell the *How*" (NMFS)







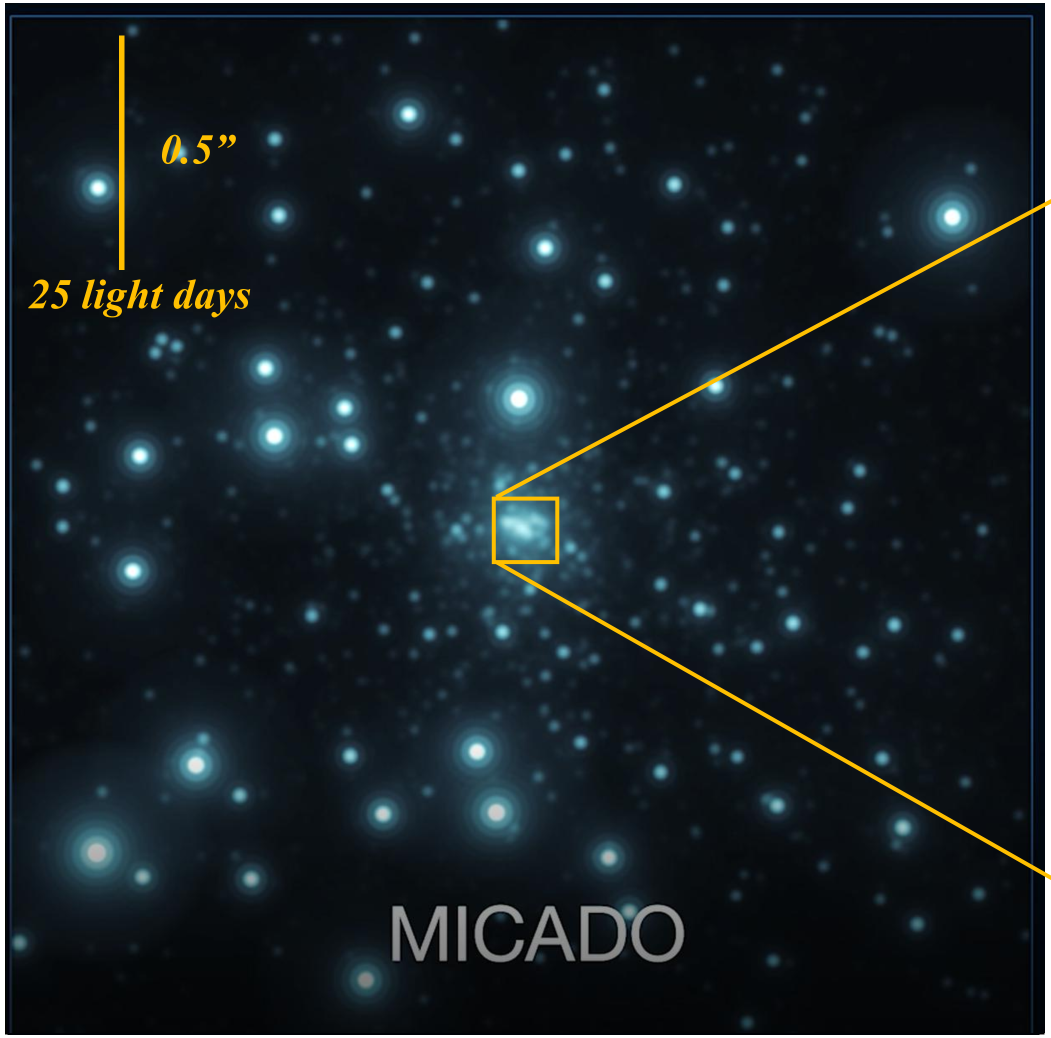


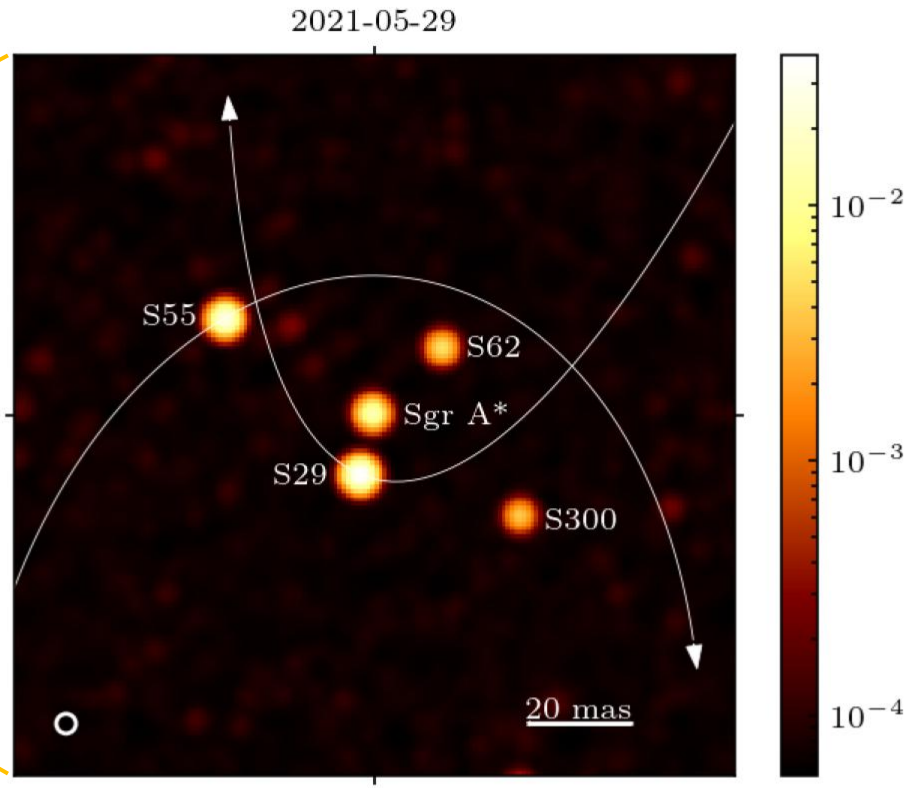


1" fields with 10^4 to 10^6 stars/arcsec^2

Ever closer in the Galactic Center

- Unique laboratory to explore strong gravity around the closest massive black hole
- Combine with the ultra-precise GRAVITY results to reach fainter magnitudes & larger scales





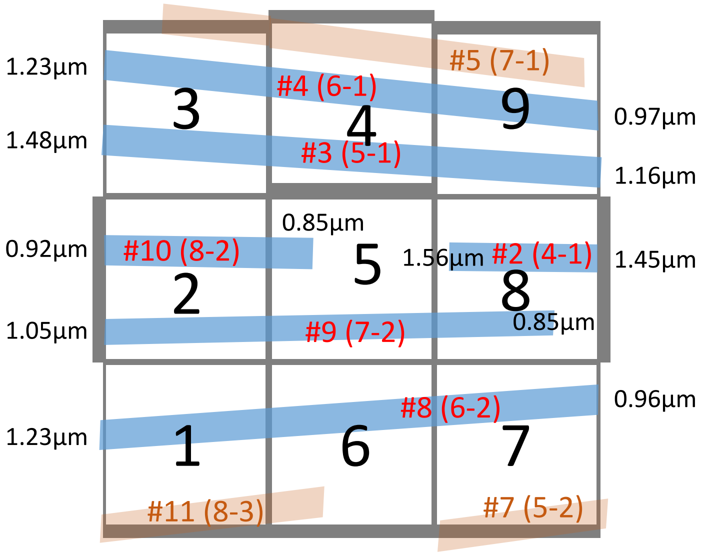
GRAVITY Collab+ 2022

S29: closer than S2
S55: shorter period than S2
S300: K = 19.5 mag

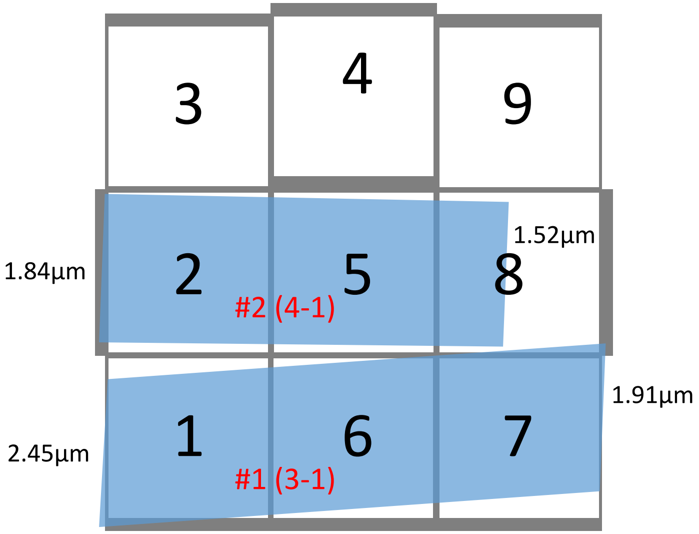
MICADO spectroscopy

- Cross-dispersed gratings in fixed configuration; waveband selection via order sorting filters.
- Short 3” slit for IzJ band; long 15” slit for HK & J bands to allow better sky characterization.
- Default operation with slit along parallactic angle; can use at fixed sky position angle, but full spectral range may not be coupled.

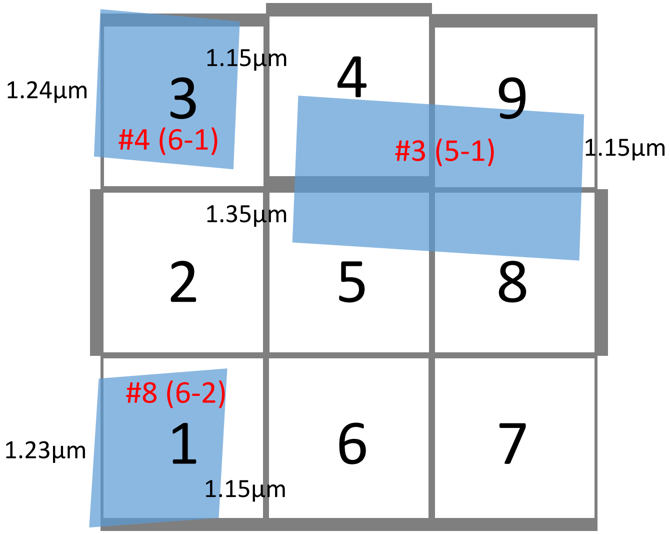
IzJ spectral layout with 3” slit



HK spectral layout with 15” slit



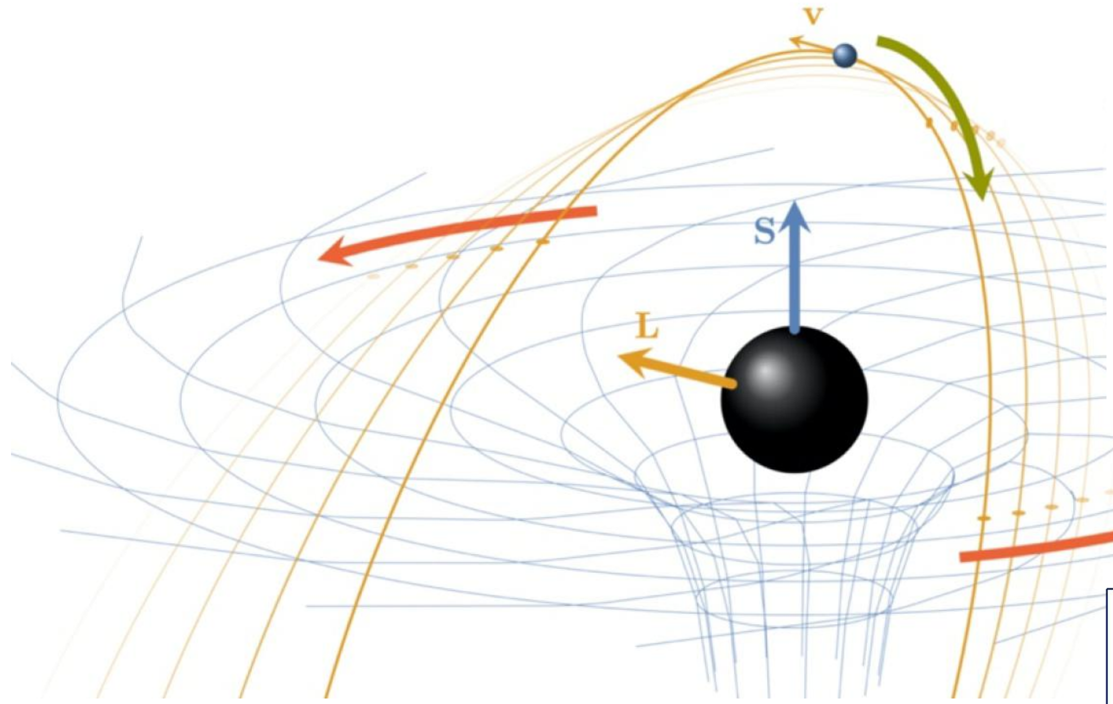
J spectral layout with 15” slit



Galactic Center: measuring black hole spin with MICADO spectroscopy

"A hypothetical S2-like star, but with 3-5x smaller semi-major axis, would enable us to detect the spin" (SG)

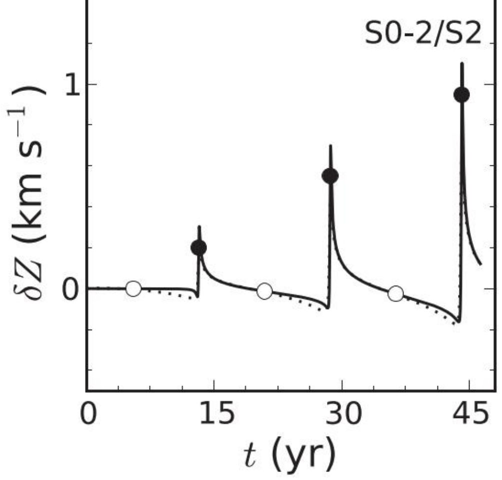
- Schwarzschild precession of orbit in its plane: measured by GRAVITY already.
- First spin term: frame dragging (Lense-Thirring precession), but spin effects ∝ r^{-3}.

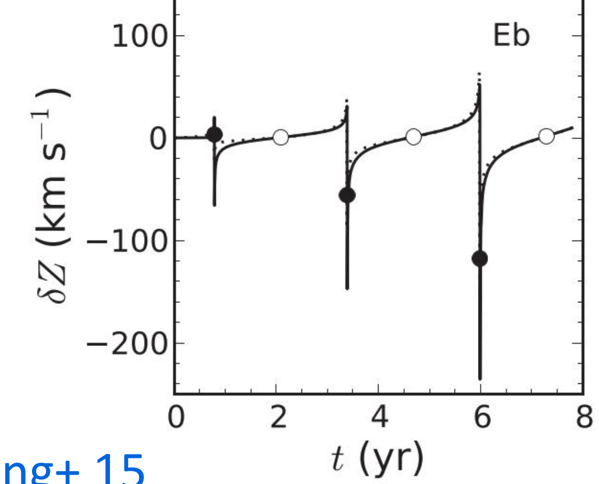


Velocity difference due to spin

S2, < 1 km/s

Simulated star at $0.3a_{S2}$ 10-100 km/s





Zhang+ 15

precision needed depends on spin, orbit inclination, size, eccentricity

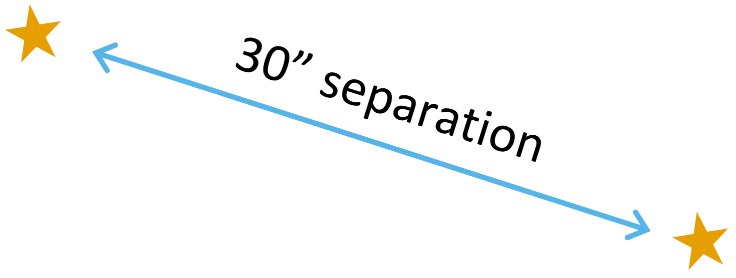
Astrometry

- Standard imaging achieves ~2 mas precision.
- Astrometry requirement is 50 µas precision (within any local region over the field); relative not absolute.
- Configuration options might be more limited for highest precision (filters, wavebands, airmass, etc)
- Astrometric mode essentially the same as standard imaging, but achieving 10-100× higher precision will likely take time & experience.

We *cannot* measure precisely the separation of 2 stars anywhere in the field.

On largest scales, 50µas is nearly $\sim 10^{-6}$.

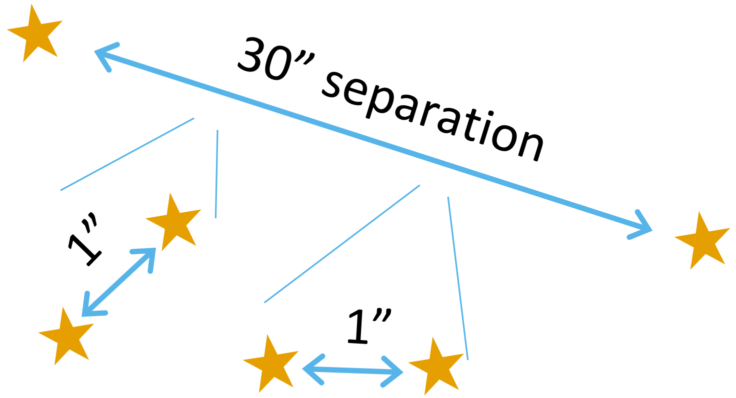
Plate scale uncertainty of 10^{-4} limits precision over 30” to a few mas.



We *can* measure precisely the separation of 2 stars locally, anywhere in the field.

On 10” scales, precision limited to order ~100µas by uncalibratable distortions (e.g. from ELT).

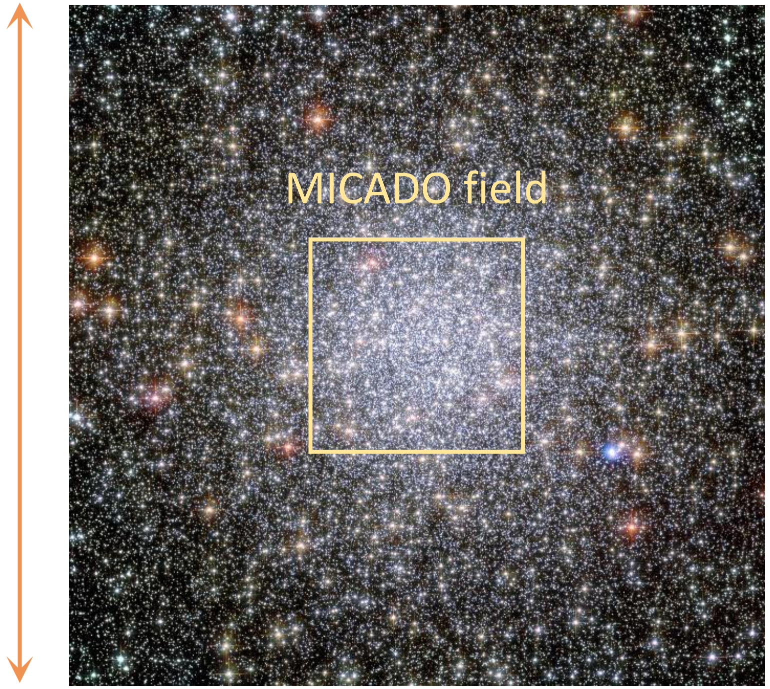
Below ~1” separation, plate scale error no longer dominates, so <50µas achievable.



Measuring Black Holes in Globular Clusters

- No robust IMBHs in globular clusters.
- Mass of IMBH uncertain to orders of magnitude.
- Location of IMBH uncertain to arcsec scales.
- Even existence uncertain (& stellar mass BH cluster is an alternative).

165”

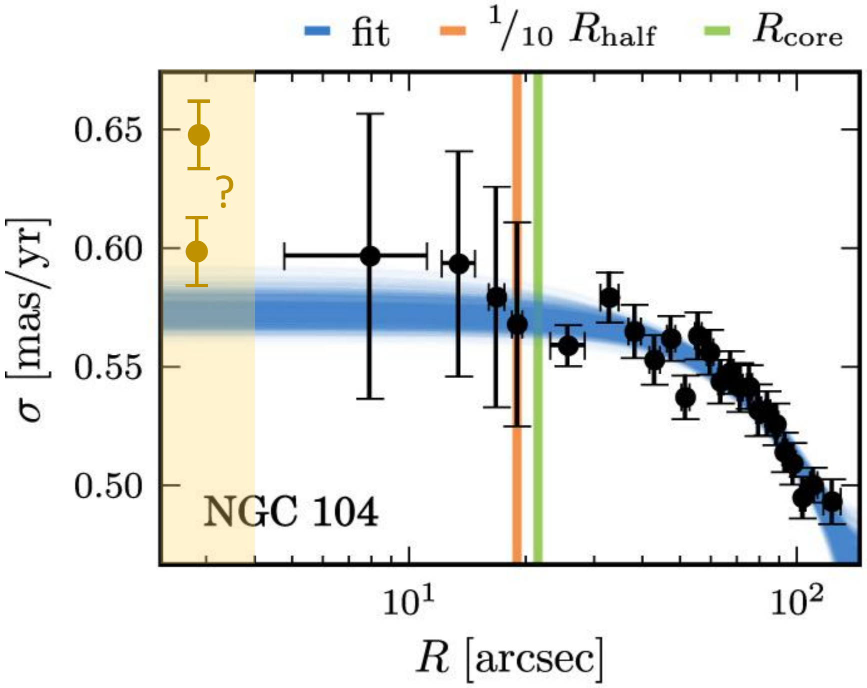


NGC 104 (47 Tuc) at 4.5 kpc

Dispersion profile from HST proper motions in NGC 104 (Watson+ 15): yellow region cannot be sampled due to crowding.

MICADO’s role:

- Image wide field at high resolution.
- Overcome extreme crowding in central region: probe dispersion to subarcsec scales.
- Uncertainties from simulations show MICADO can distinguish whether there is a BH.



High Contrast Imaging

- Focal plane masks: CLC-15, 25, 50
- Pupil plane masks: vAPP, SAM-9, SAM-12 – used with 6” FoV
- Central detector only, small 1.5 mas pixel scale, special (faster) read mode

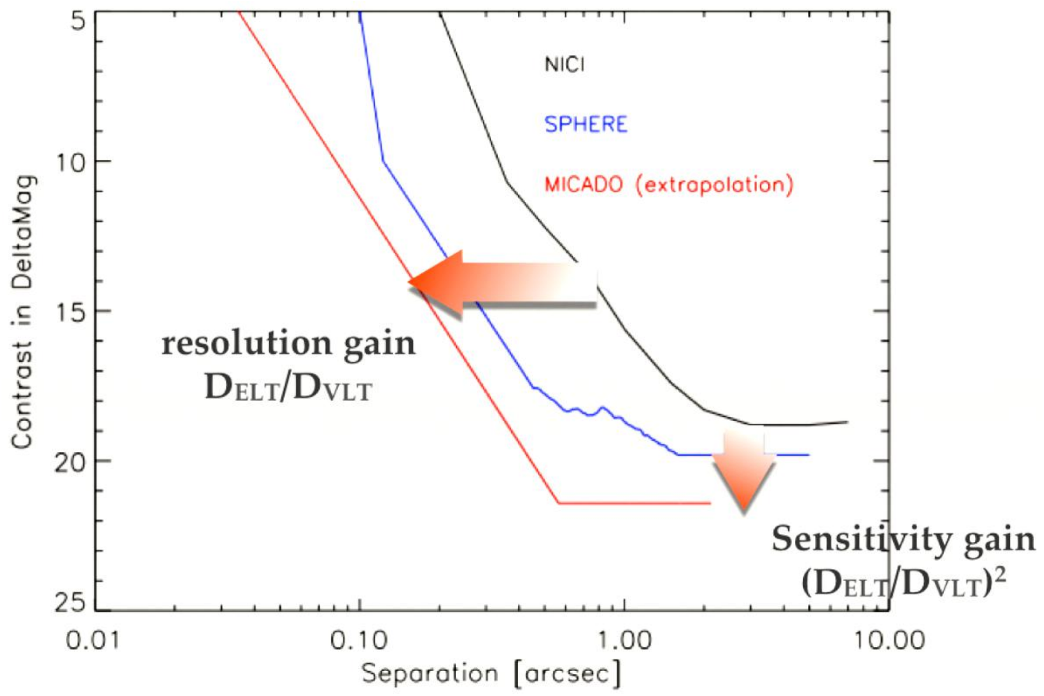
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	focal plane wheel	Lyot + ND3	Lyot + ND1	Lyot	vAPP	stop-IJH + H-cont	stop-IJH + [FeII]	stop-K	stop-IJH	stop-K + K-long	stop-K + K-cont	stop-K + Br-gamma	stop-K + H2_1-0S(1)	SAM-9	SAM-12	stop-K + He-I	stop-IJH + Pa-beta
2	High Contrast Field (6")	x	x		x									x	x		
3	Small Field (19")	x	x			x	x	x	x	x	x	x	x			x	x
4	Large Field (50.5")	x	x			x	x	x	x	x	x	x	x			x	x
5	CLC-15	x	x	x	x									x	x		
6	CLC-25	x	x	x	x									x	x		
7	CLC-50	x	x	x	x									x	x		

- Orange: not official configurations, but to be kept as possible options when/if testing allows

MICADO as an exoplanet camera & pathfinder

Primary aim to exploit smaller inner working angle

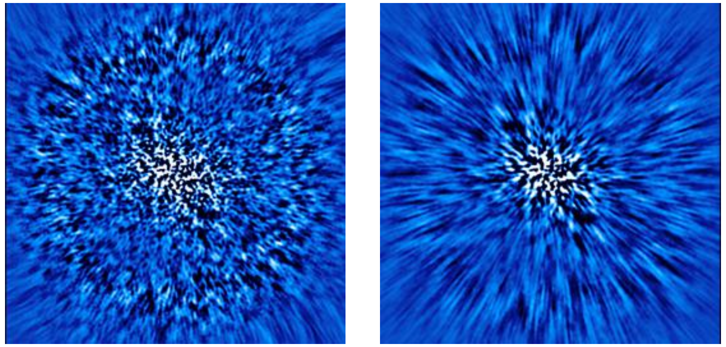
- Exoplanets at small orbital separations (a few AU) around nearby (<20pc) stars.
- Exoplanets at larger separations (>10 AU) around nearby stars (complementary to SPHERE) as well as more distant stars (>100pc).
- Circumstellar disks.



K-band MICADO $3\lambda/D$ ~ 30mas
SPHERE $3\lambda/D$ ~ 150mas

Speckle gain

K-mid	Ks
$\Delta\lambda$=0.1µm	$\Delta\lambda$=0.35µm



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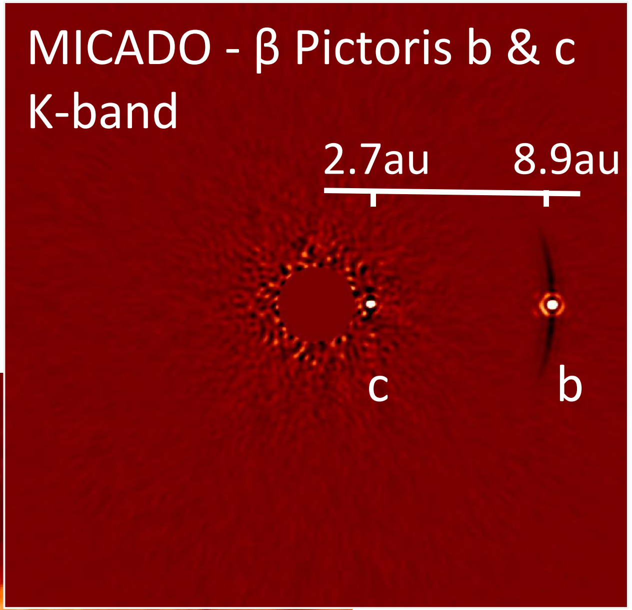
COMPASS/MISTHIC (Baudoz/Huby)
- β Pic c, 9 M_{Jup} planet at 2.7 au (e = 0.24)
- MICADO 1 hr observation sequence at meridian



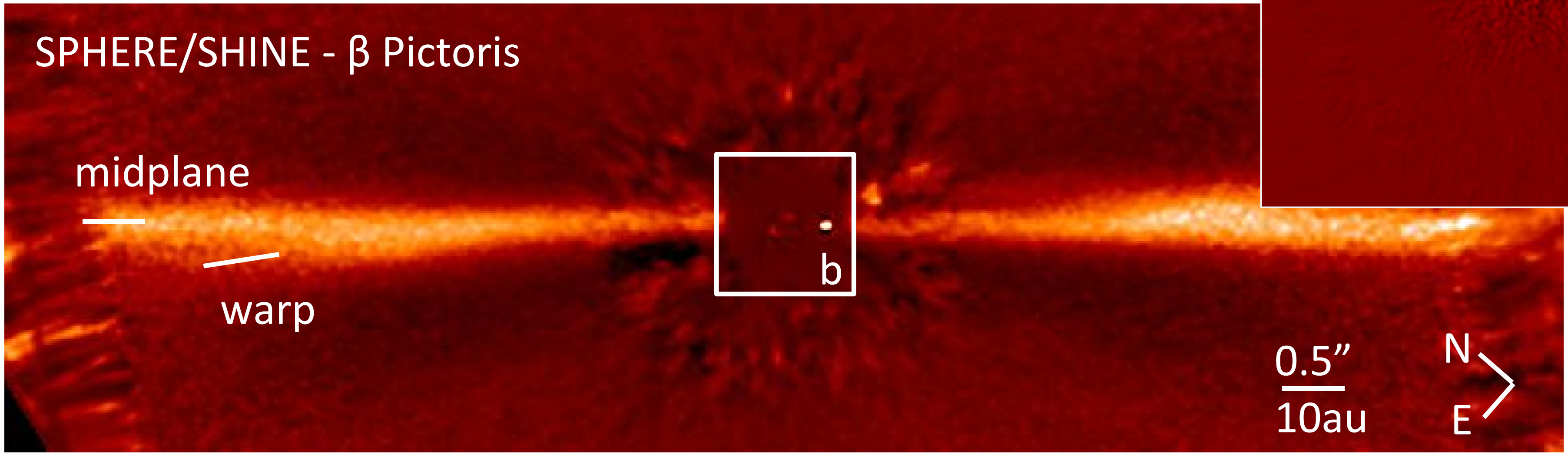
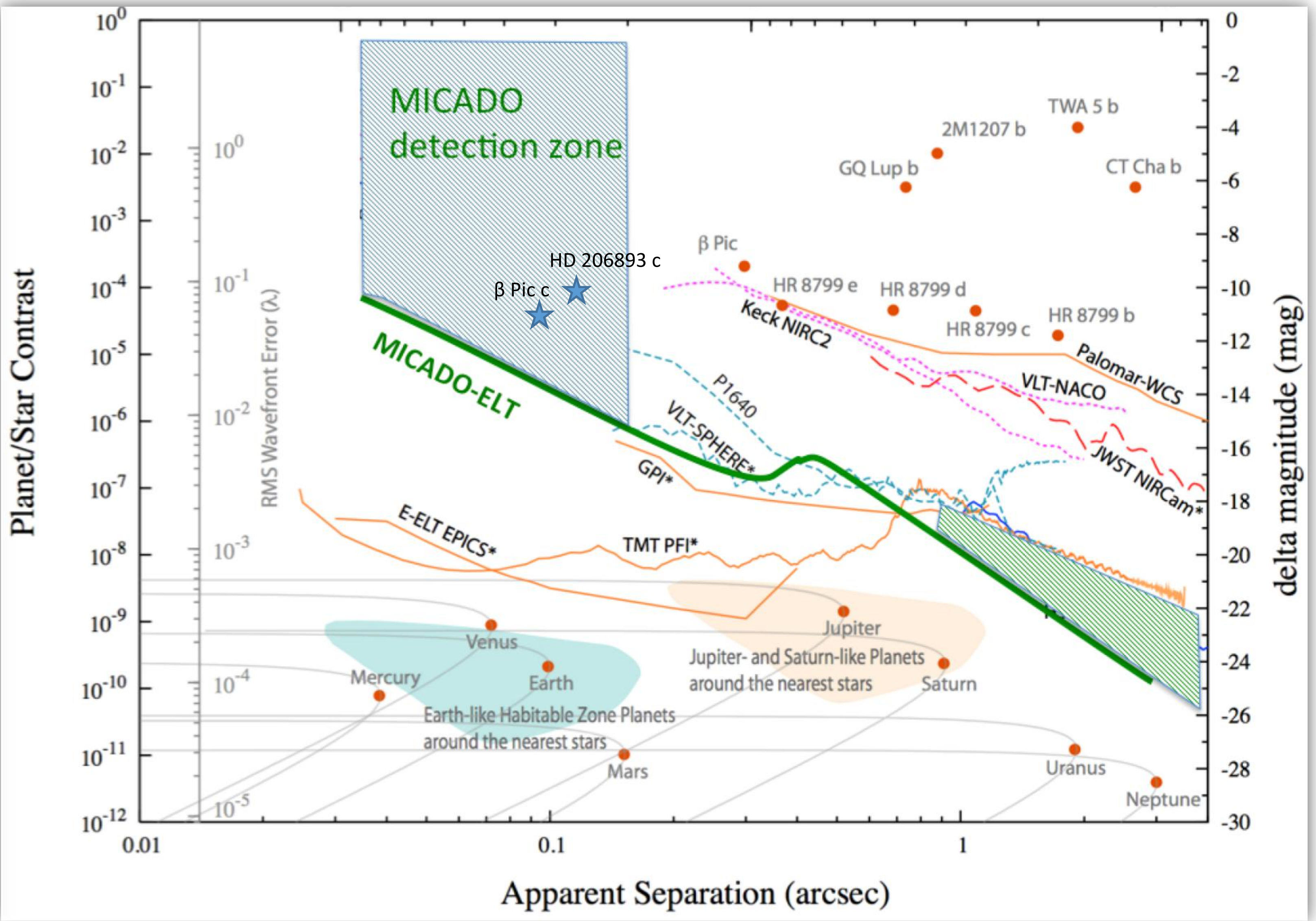


Figure courtesy of G. Chauvin

MICADO as an exoplanet camera & pathfinder

- Post processing with ADI -> Contrast to ~10^{-6}.
- In good seeing, MICADO can detect an 800 K planet at 5 AU in H & K-band in 30 mins.
- Small inner working angle -> characterise exoplanets in synergy with Gaia or RV surveys.
- GRAVITY can detect (but not image) planets in the MICADO regime, that are not observable with HCI on 8-m telescopes (from Pourré+ 24).



Baudoz et al. 2019, Huby et al. 2022

MICADO…

- will do imaging, astrometry, slit spectroscopy, and coronagraphy.
- is identified by ESO as a camera for ELT first light.
- will initially work with its own SCAO system, and then with the MORFEO MCAO system.
- is a camera you’ll want to use: try out ScopeSim https://scopesim.readthedocs.io/

See also:

The ESO Messenger vol. 182, p.17

https://www.mpe.mpg.de/ir/micado

https://elt.eso.org/instrument/MICADO/