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Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INAF ISTITUTO NAZIONALE DI ASTROFISICA

ci²rce

INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO D'ABRUZZO

A new near-IR imager for the 1.1m infrared telescope of the Campo Imperatore Observatory

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Campo Imperatore
A site for NIR astronomy

Location

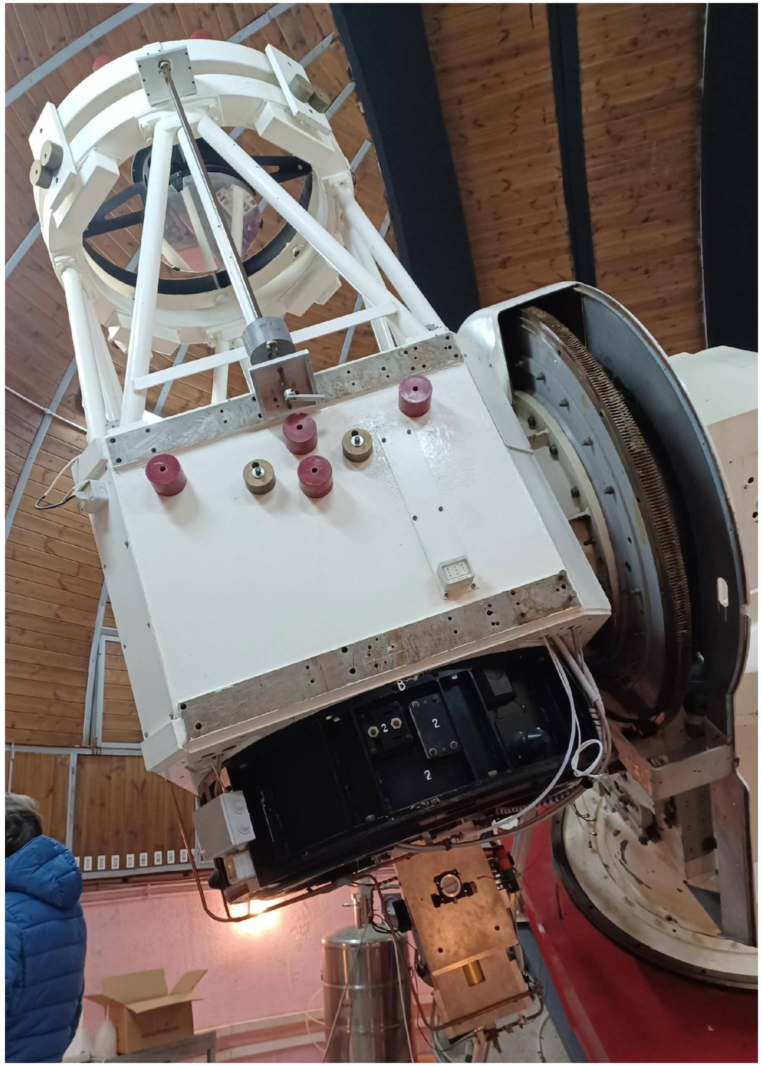
2154 m a.s.l. near Gran Sasso, Central Appennini, Italy reachable by car during the year and by cableway in winter. Driving time: 1h from Teramo OAAb, 45 min from L'Aquila.

Site characteristics

- Dark and high-transparency sky
- Dry atmosphere, faint telluric lines between 1 and 2 μm
- Low ambient temperatures at nights:
- down to -25 °C during winter
- < 15 °C during "hot" summer

- Efficient passive cooling for telescopes and instrumentation.

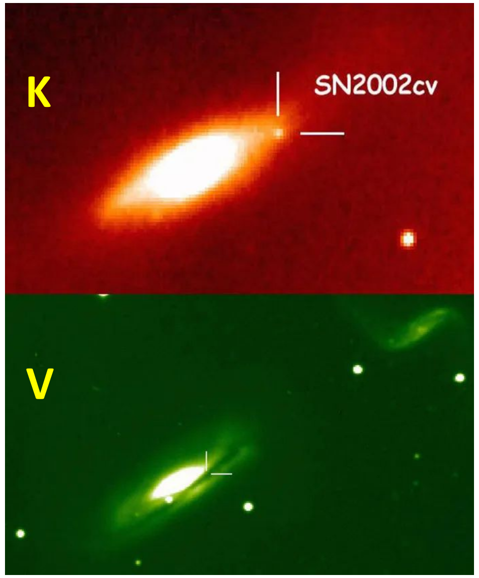
A brief history: ATZ24 + SWIRCAM



1997-1999: NIR camera SWIRCAM, equipped with a LN2-cooled HgCdTe 256x256 array for a scale of 1''/pixel, designed, built & installed at the focal plane of the AZT24 1.1-m telescope, into the East Dome (*Vitali et al., 2000*).

1998-2018: monitoring & follow-up projects like SWIRT (SNe), WEBT (AGNs) and for an extended set of «smaller» programs concerning stellar variability in the near-infrared (RR-Lyr, Cepheids, LPVs…).

13th May 2022: SN2002cv is discovered during the follow-up of SN2002bo in NGC3190 (*Di Paola et al., A&AL 2002).*
With V-K>6, SN2002cv is one of the most obscured supernovae ever observed.



A brief history: ATZ24 + SWIRCAM

Optical configuration	f/72. Ritchey-Chrétien
Primary mirror	1100 mm diameter 4533 mm focal length
Secondary mirror	590 mm diameter
Distance M1-M2	2605.5 mm
Cassegrain eq. focal length	7971 mm
Flat focal plane field size 20'	46 mm
Psf parameters @632.8 nm	
on axis	74% total light energy in 0”.52 circle 66% total light energy in 0“.31 circle
off axis	46% total light energy in 0”.52 circle 39% total light energy in 0''.31 circle *(Corresp. FWHM: ~0''.25 on axis, 0''.30 field edge)*
Telescope frame type	equatorial (German)
Total telescope weight	32 tons (moving part 24 tons)

Refurbishment ideas

The CI²RCE concept: Campo Imperatore InfraRed Camera with seeing Enhancer

Refurbishment program:

- Supported by NextGenerationEU funds (PNRR), VITALITY Program
- To be included in the larger program for remote/automated/robotic operations, unmanned operations.

SWIRCAM system criticalities:

- detector and camera obsolescence;
- LN2 cooling: closed-loop system installed in 2012 to recover N2, re-liquify and re-pumping it into the cryostat, BUT...
  … could not be installed onboard the telescope: daily cryostat refilling required anyway manual operations !

Refurbishment path:

- New detector and camera system, available as COTS on the market (sustainable costs)
- Local cooling (onboard the camera or the telescope), cryogenic or TEC
- Spectral coverage J H K (ideal) or J H (minimum goal)
- Larger format for the array detector wrt SWIRCAM, to cover a FoV wider than 4.4 arcmin
- Enhanced performances by increasing the Strehl Ratio: adaptive correction of the Tip/Tilt
- Reduced instrumental background: telescope secondary mirror resizing (mirrors remanufacturing)

NIR detector: adopting InGaAs (market) options

InGaAs technology proved new developments for ground-based NIR astronomy in the last few years.

Detectors available in several promising formats:
1280 x 1024 pixel
640 x 512 pixel

Typical **pixel sizes** (10 – 15 µm) much **smaller** than the SWIRCAM pixel size (40 µm), allow to cover **wider FoV**, with a **reduced background** per pixel and adequate PSF sampling.

QE much higher (peak 90%) than for SWIRCAM (peak 65%).

Spectral coverage limited to J and H bands: this limitation can be compensated by the advantages shown above.
With proper detector doping, coverage extended backward down to B V R I optical bands.

SPIE 2014

Near-Infrared InGaAs Detectors for Background-limited Imaging and Photometry

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[a]MIT-Kavli Institute for Astrophysics, 77 Massachusetts Ave., Cambridge, MA, USA;
[b]NASA Carl Sagan Fellow

ABSTRACT

Originally designed for night-vision equipment, InGaAs detectors are beginning to achieve background-limited performance in broadband imaging from the ground. The lower cost of these detectors can enable multi-band instruments, arrays of small telescopes, and large focal planes that would be uneconomical with high-performance HgCdTe detectors. We developed a camera to operate the FLIR AP1121 sensor using deep thermoelectric cooling and up-the-ramp sampling to minimize noise. We measured a dark current of 163 e- s^{-1} pix^{-1}, a read noise of 87 e- up-the-ramp, and a well depth of 80k e-. Laboratory photometric testing achieved a stability of 230

PASP 2022

Publications of the Astronomical Society of the Pacific, 134:065001 (14pp), 2022 June https://doi.org/10.1088/1538-3873/ac71cc

Laboratory and On-sky Testing of an InGaAs Detector for Infrared Imaging

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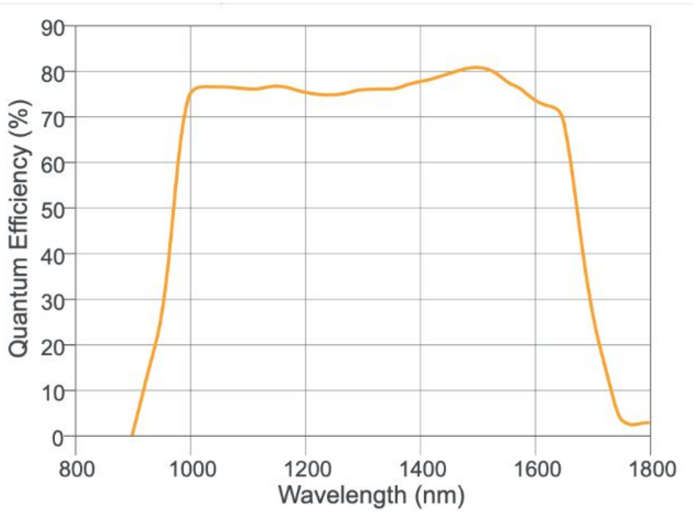
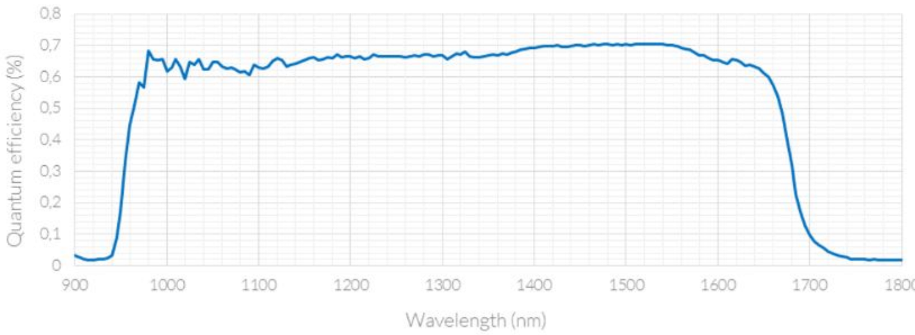
Abstract

We describe the results of testing a shortwave infrared CMOS camera using an indium gallium arsenide (InGaAs) detector. The new generation of InGaAs detectors offers a cost-effective alternative to mercury cadmium telluride (HgCdTe) for astronomy research, with current, off-the-shelf cameras requiring no modification before use. Testing was conducted in the laboratory and on-sky while mounted to the robotic, 2 m Liverpool Telescope using a *H*-band filter. The camera exhibits a dark current of 821 $e^- s^{-1} pix^{-1}$ and a bias level of 864 $e^- pix^{-1}$. The dark current associated shot noise is of similar size to the read noise of 32 $e^- pix^{-1}$ in one-second exposures. Linearity within the count region where readout noise and bit-depth saturation effects are not dominant is within a few tenths of a per cent. After field-compression by fore optics, the plate-scale yields 0.″3 pix^{-1}, near perfect for Nyquist sampling at the La Palma site. The sky background for the *H*-band filter dominates the other noise sources for the

CI2RCE current camera candidates



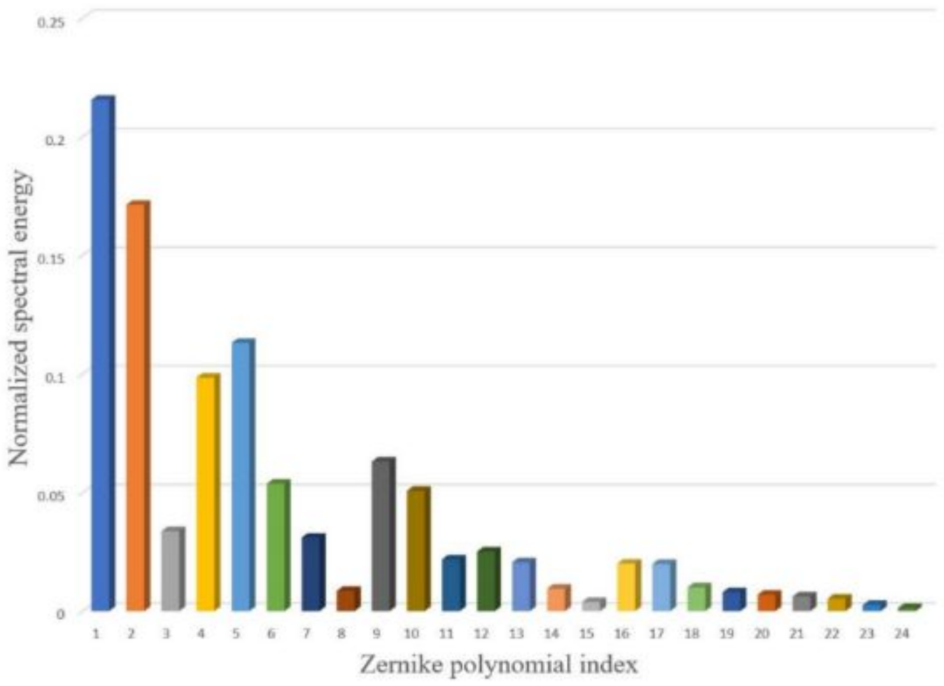
Credits: Raptor

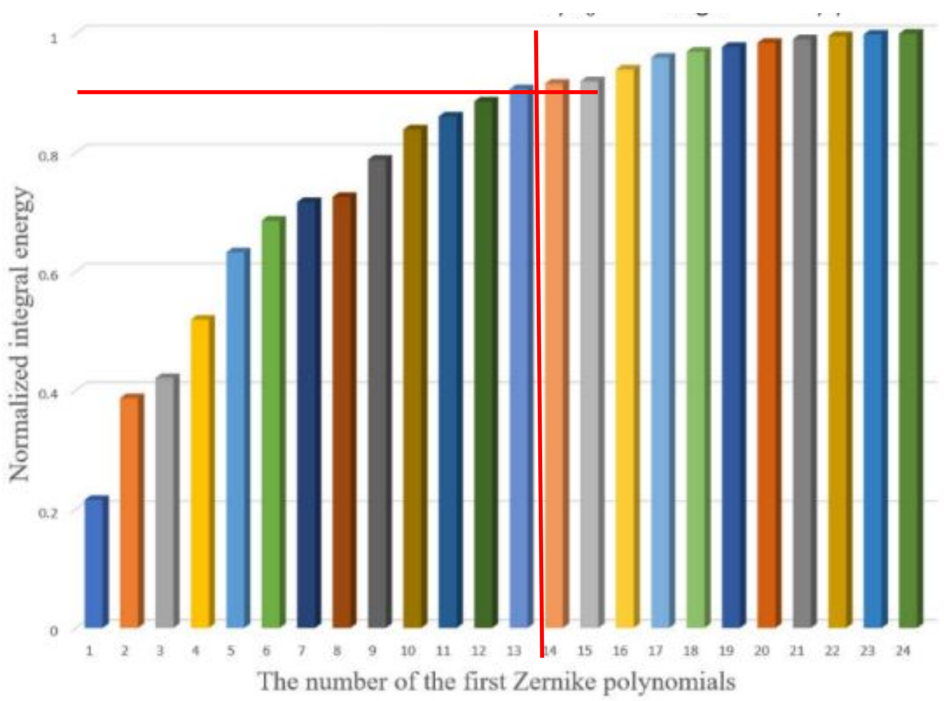


Credits: Lytid

Tip/Tilt corrections vs. FWHM

- Stabilization of the PSF motion caused by the atmospheric jitter
- The 90% of the atmospheric turbulence falls within the first 13 Zernike terms
- Expected shrink of PSF FWHM from 2.2 arcsec to 1.5 arcsec.



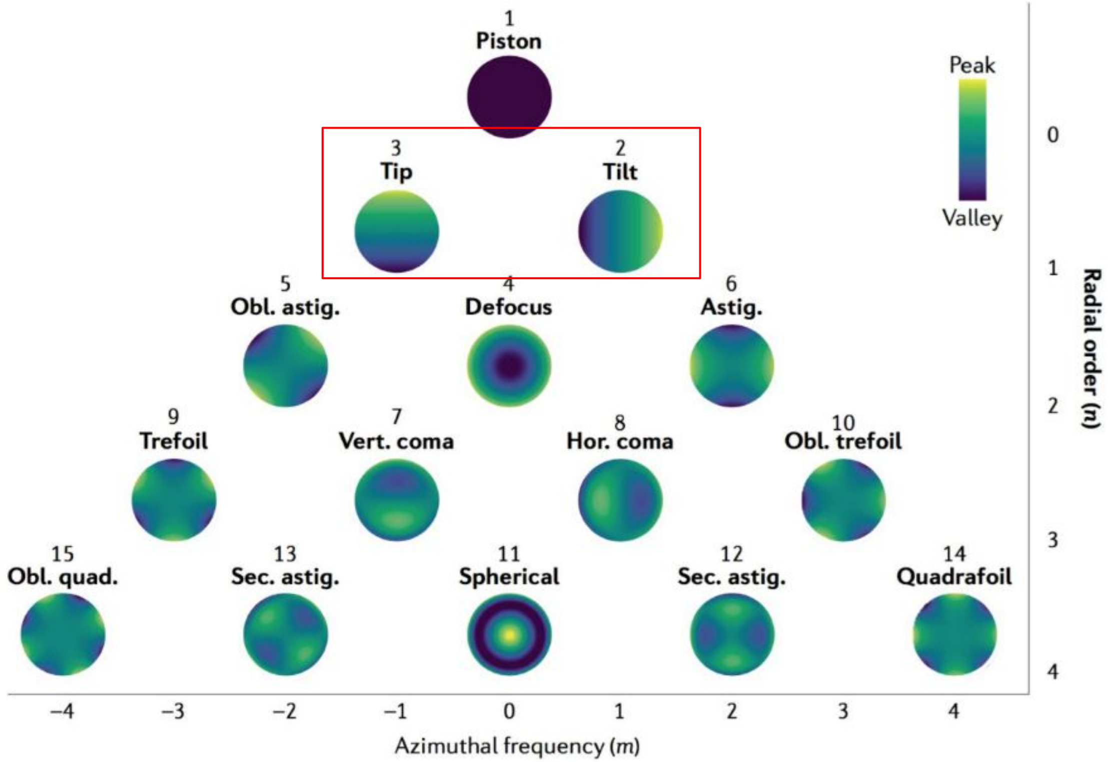


Credit: Rukosuev A., et al., 2021

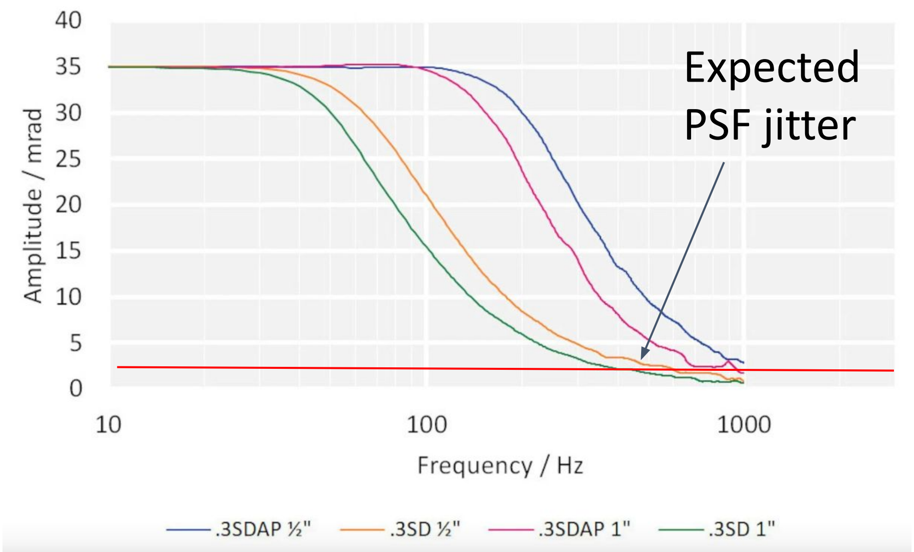
Tip/Tilt corrections vs. FWHM

- Stabilization of the PSF motion caused by the atmospheric jitter
- The 90% of the atmospheric turbulence falls within the first 13 Zernike terms
- Expected shrink of PSF FWHM from 2.2 arcsec to 1.5 arcsec.

- Piezo fast tip/tilt mirror
- 1kHz res. frequency
- micro-rad resolution



Credit: Karen M. Hampson et al., Nat. Rev., 2021

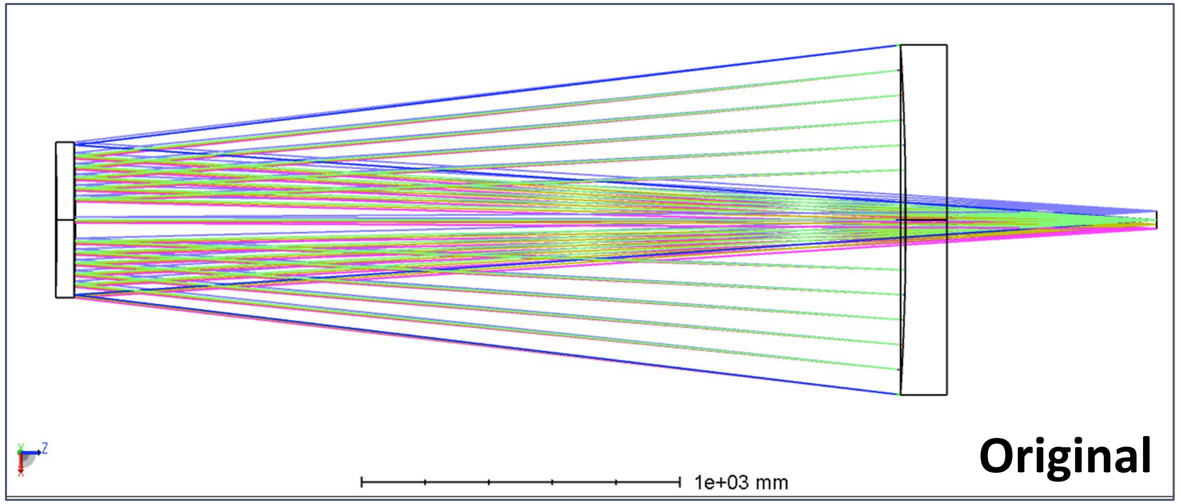


Credits: PI

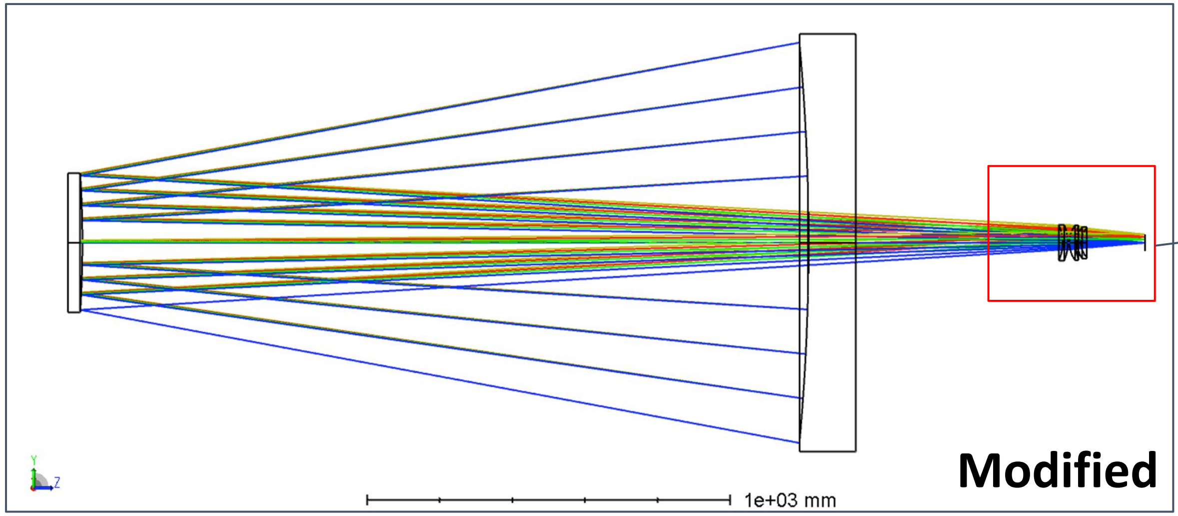
CI²RCE Optical Layout

First step - Telescope focal reduction

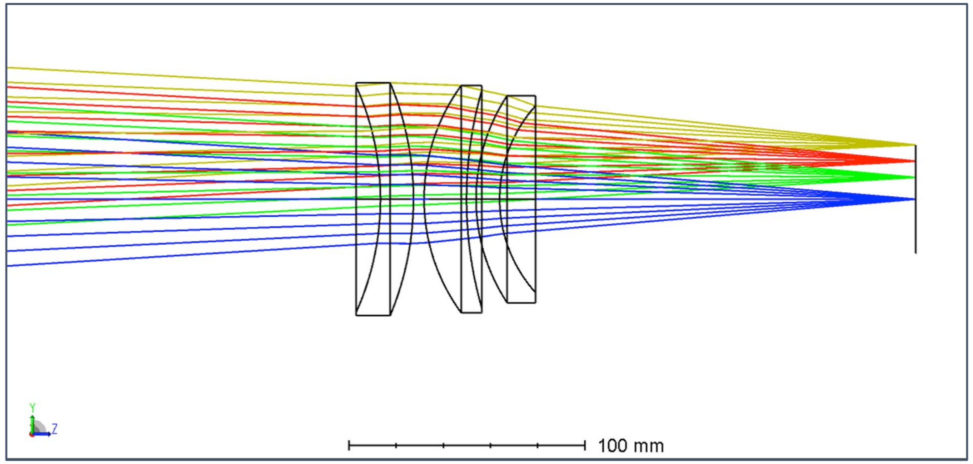
- Focal reducer & field corrector f/7.2 to f/6 to match CI2RCE detector size
- 3 spherical lenses
- Corrected FoV 0.4°x 0.4°



Original



Modified



Design by Paolo Spanò

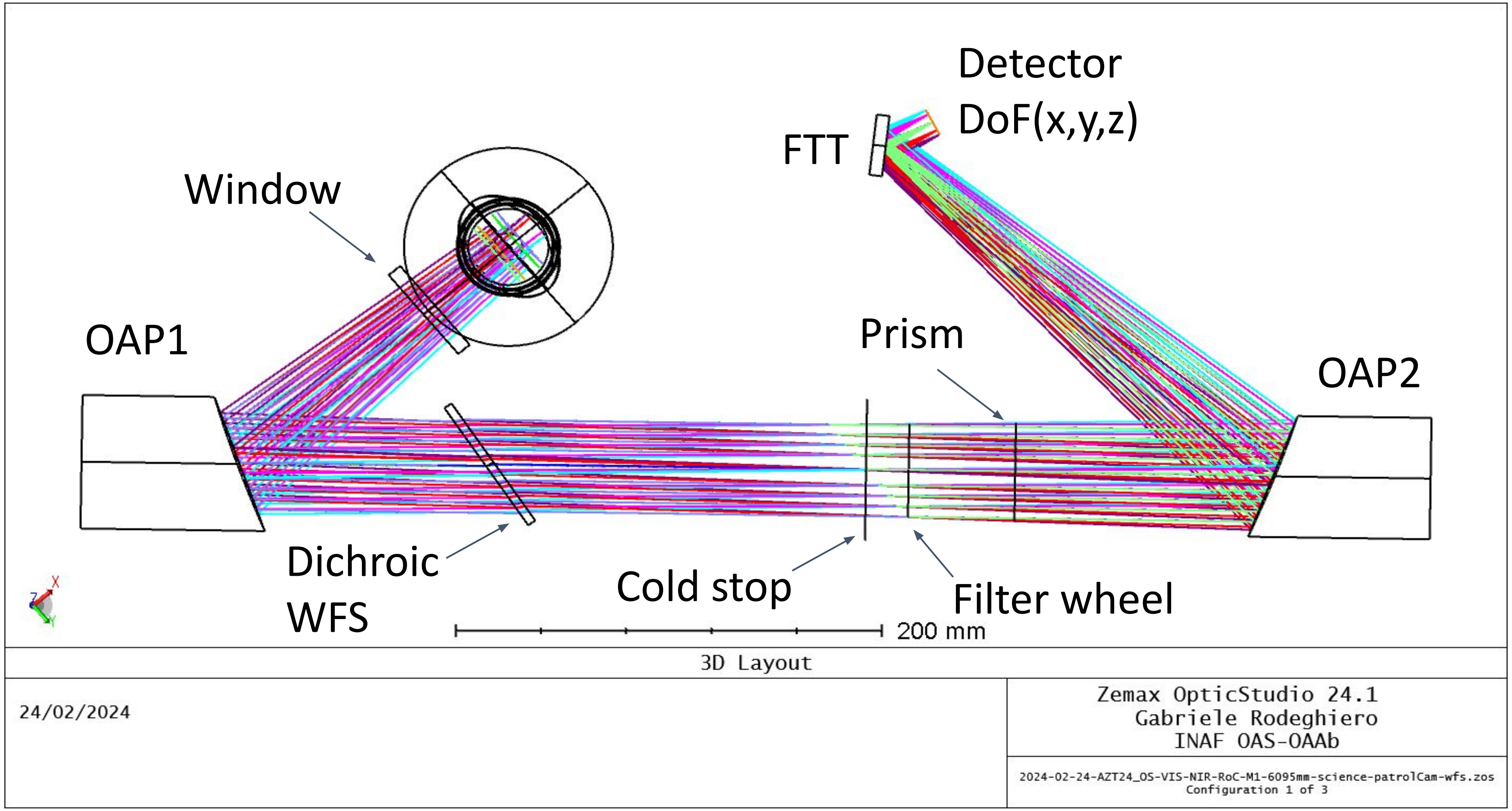
CI^2RCE Optical Layout

Science Path

FoV 7 arcmin
PS 33"/mm, 0.5"/15 μm pix
1:1 image relay
Fast Tip/Tilt mirror
Cold stop
Filter wheel
Objective prism wheel

Capabilities

Imaging 1-1.7 micron
Image stabilization
Slitless low-res spectroscopy
Detector dithering & nodding



CI²RCE Optical Layout

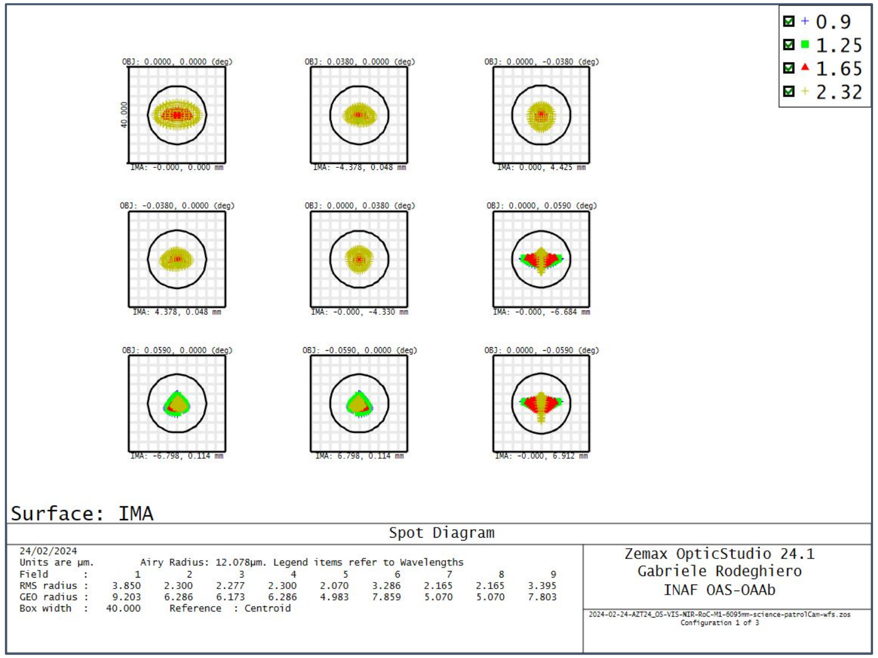
Science Path

FoV 7 arcmin
PS 33”/mm, 0.5”/15 μm pix
1:1 image relay
Fast Tip/Tilt mirror
Cold stop
Filter wheel
Objective prism wheel

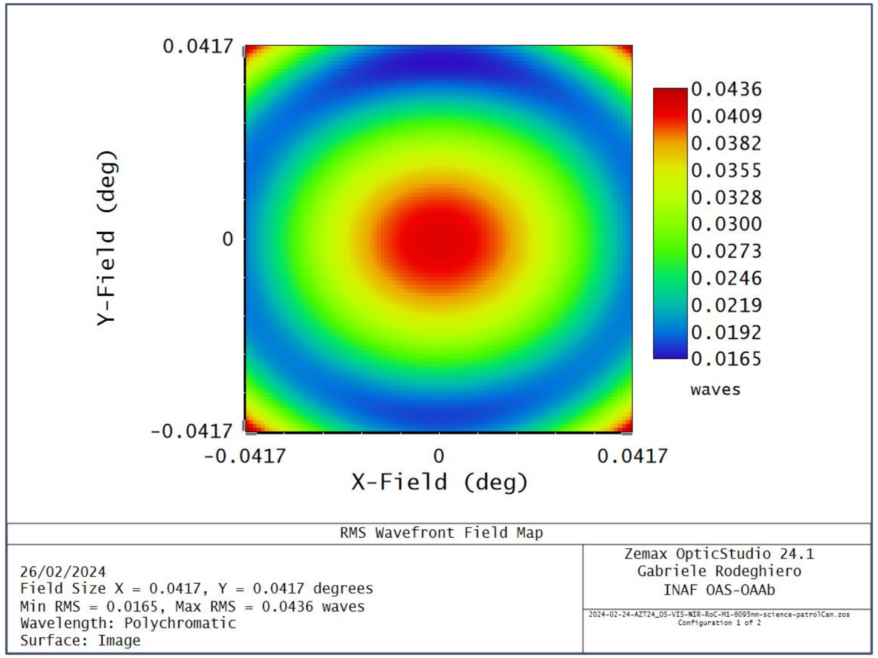
Capabilities

Imaging 1-1.7 micron
Image stabilization
Slitless low-res spectroscopy
Detector dithering & nodding

Polychromatic spot diagram over FoV



WFE map over FoV



CI^{2}RCE Optical Layout

Wavefront sensing path

Patrol camera

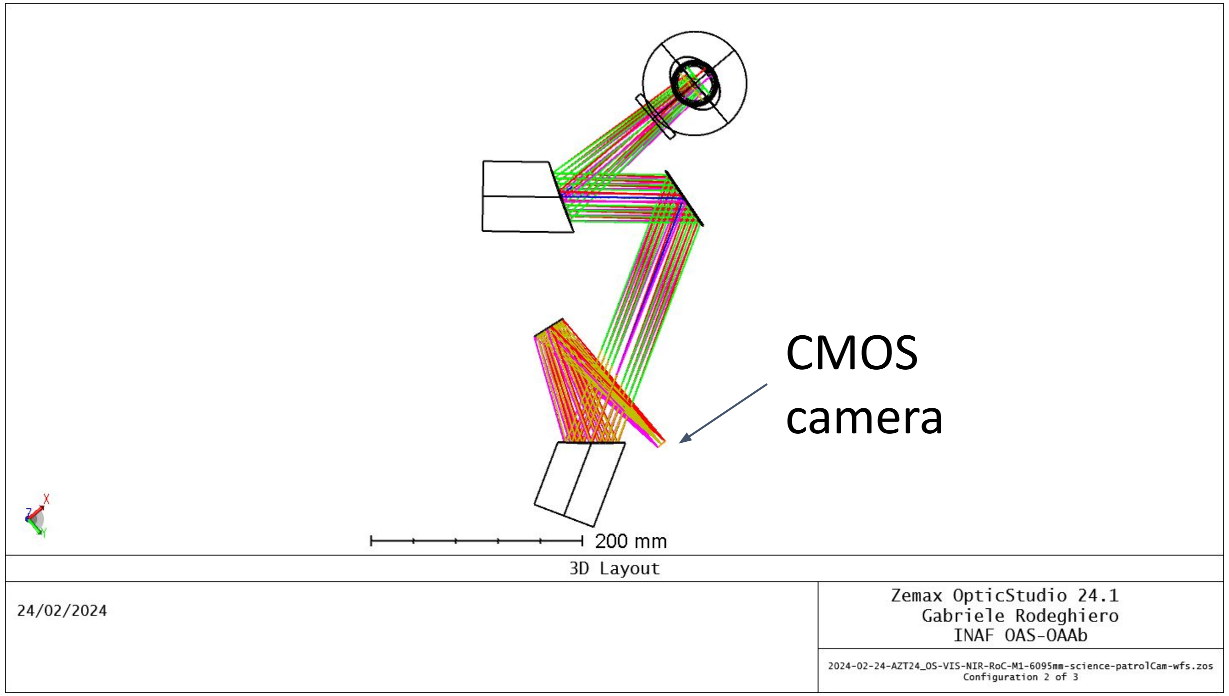
CMOS detector

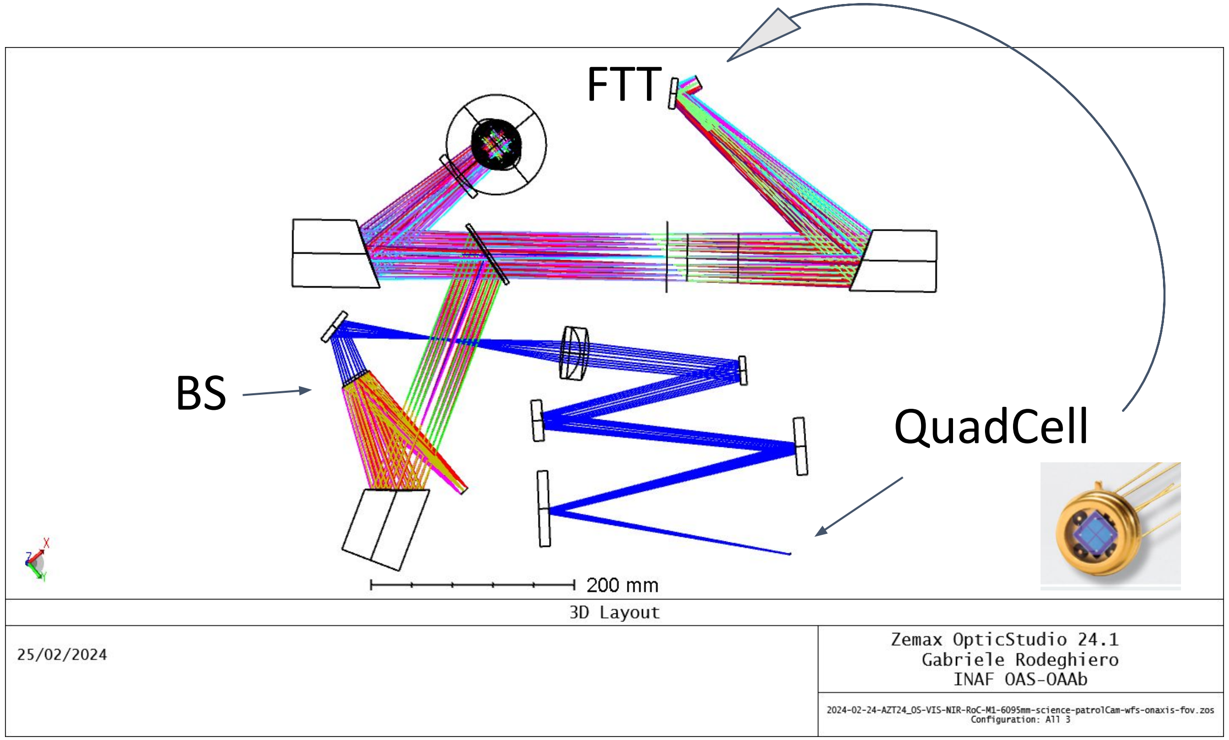
FoV 4.5 arcmin

WFS Quad Cell

Quad cell photodiode ∽1 mm^2 on 2D motor stage

Patrol FoV 4.5 arcmin



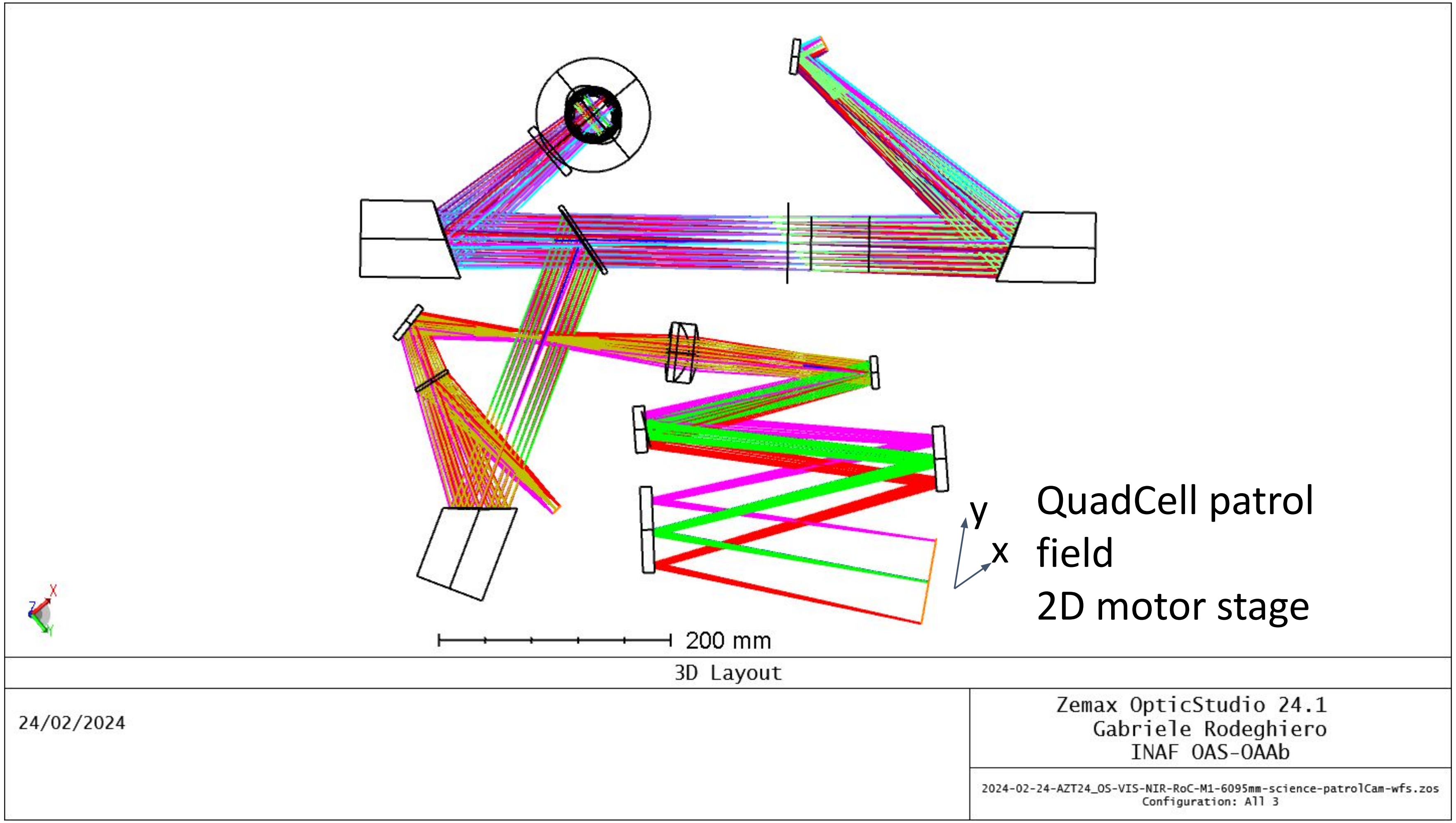


CI²RCE Optical Layout

Wavefront sensing & science path

Advantage
Quad Cell high sensitivity and speed

Disadvantage
- Opto-mechanical stability
- Semi-'blind' pointing (LUTs)



CI²RCE Optical Layout

WFSensing with Patrol Cam

Advantage

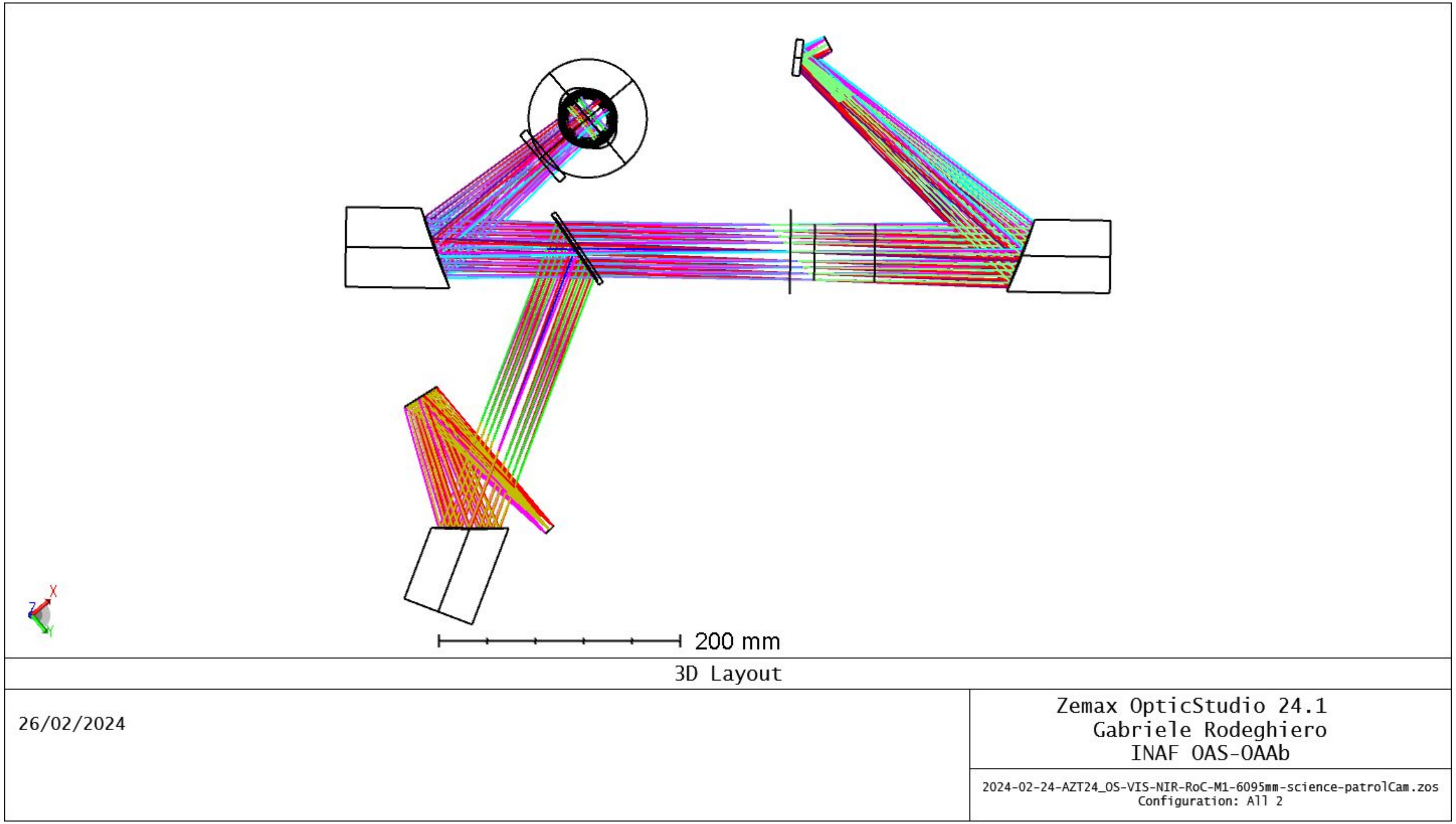
Quad Cell high sensitivity and speed

Disadvantage

- Opto-mechanical stability
- Semi-‘blind’ pointing (LUTs)

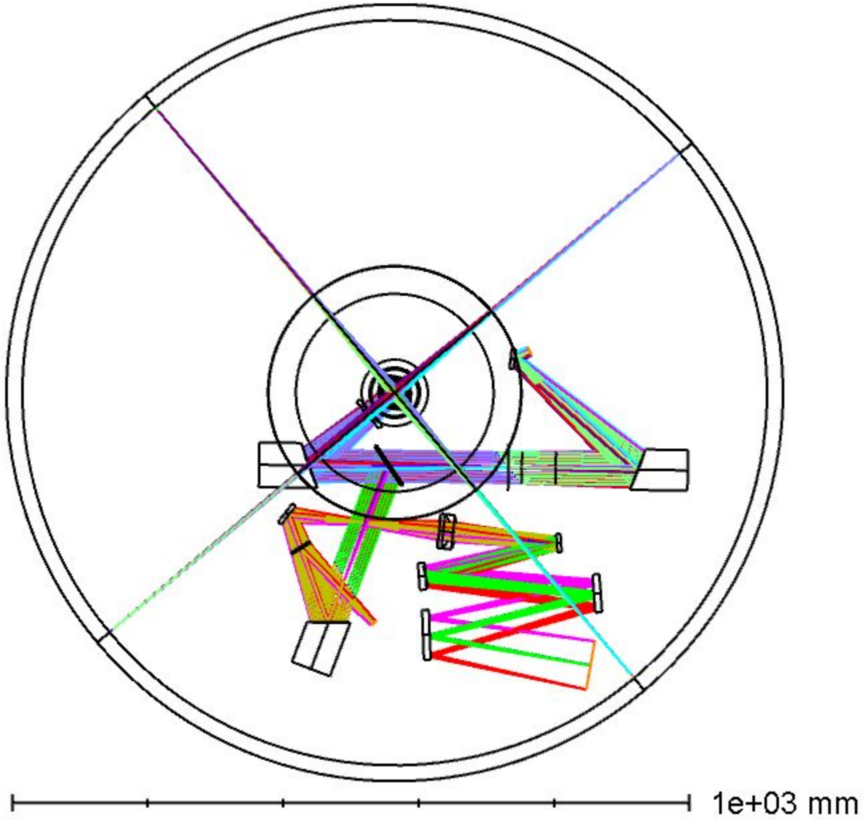
Depending on sky coverage

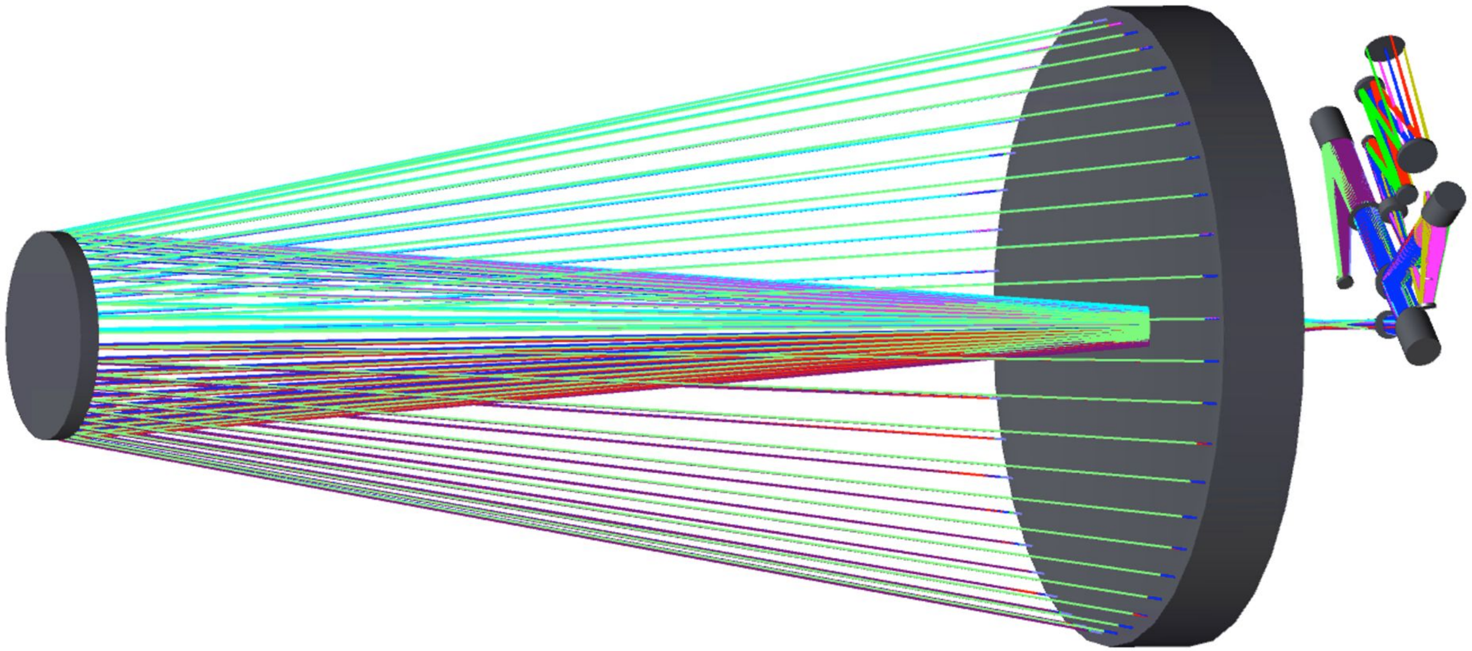
- Quad Cell might be removed
- Centroiding on Patrol Camera



CI^2RCE Optical Layout

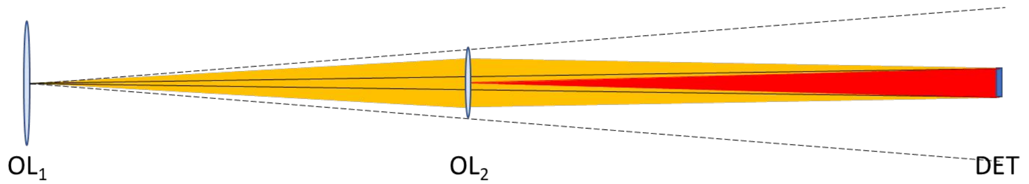
- Design is coplanar
- Leave volume behind the M1 for other instruments
- Folding mirror -> instrument selector





Preliminary performance estimation

Preliminary “toy-model” to estimate the thermal background from telescope and camera fore-optics.
Encouraging results even with overestimated throughputs.
Cooling would be only needed for K-band.

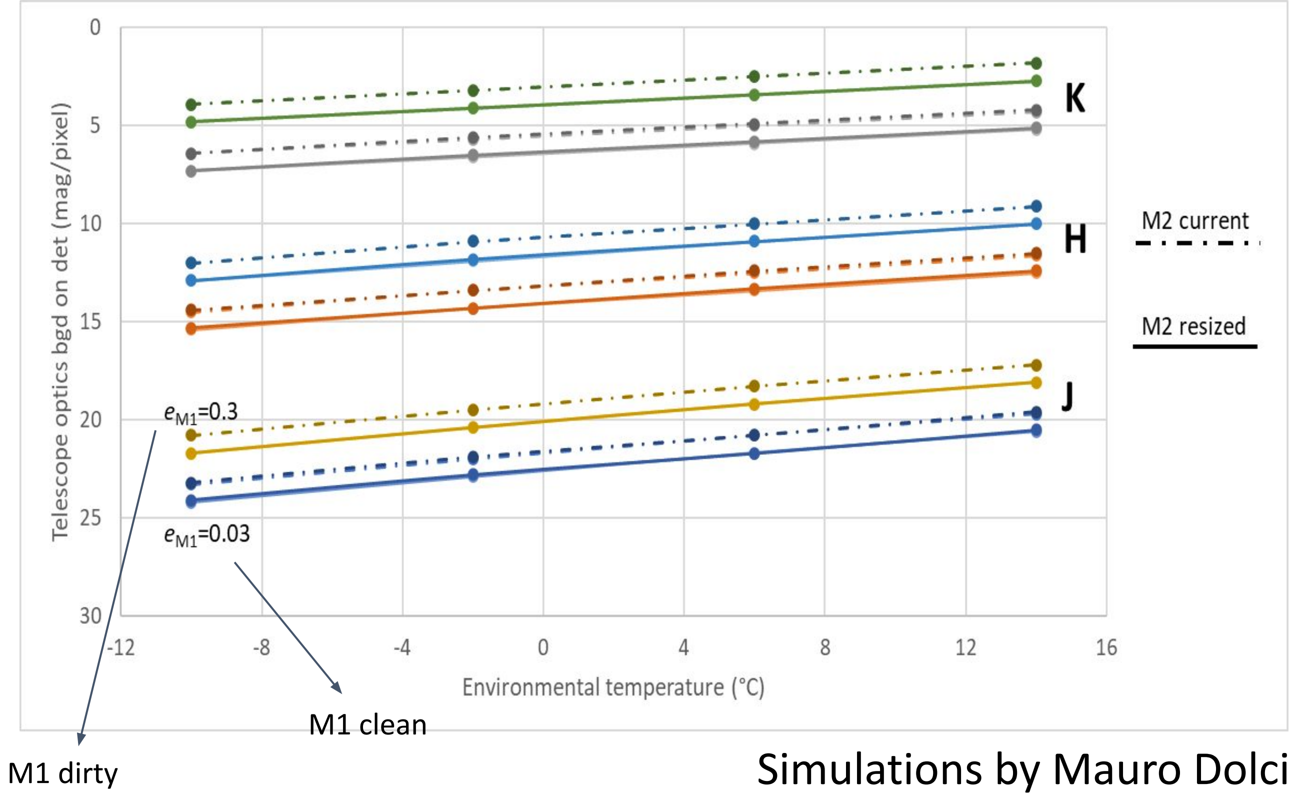


Filled area (yellow and red): <u>real</u> throughput from optical elements OL1 and OL2 centers to detector (DET).

Black line, solid: *underestimated* throughput from OL1 center to detector DET (correct for the last OL only (OL2))

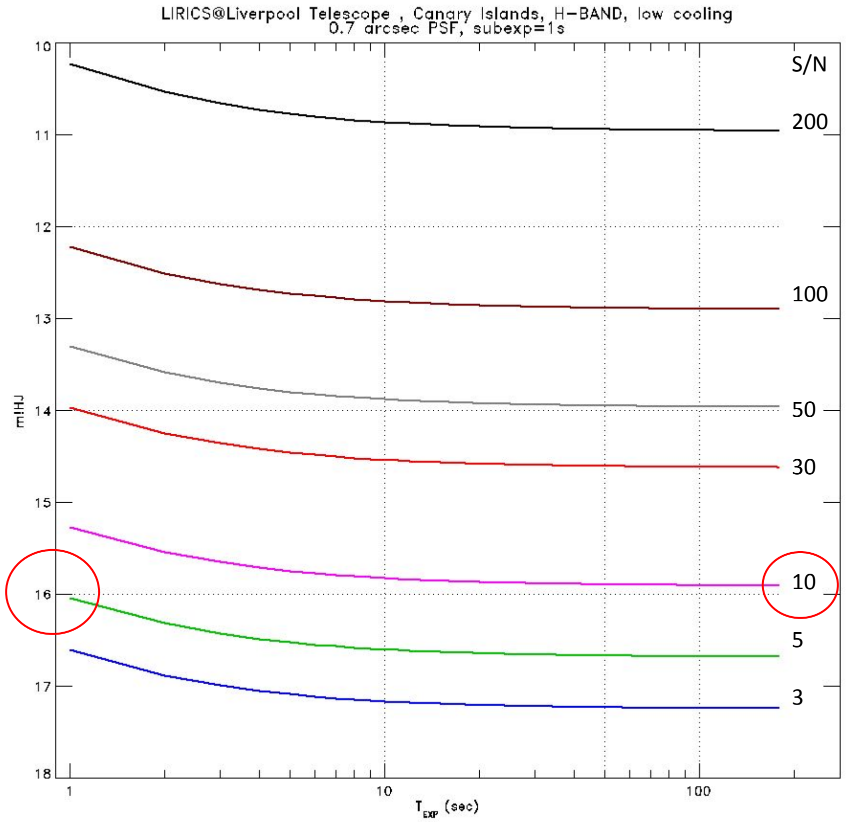
Back line, dashed: **overestimated** throughput from OL1 center to detector DET (correct for the last OL only (OL2))

Magnitudine difference 0.9 mag/pixel, about 2 mag/arcsec

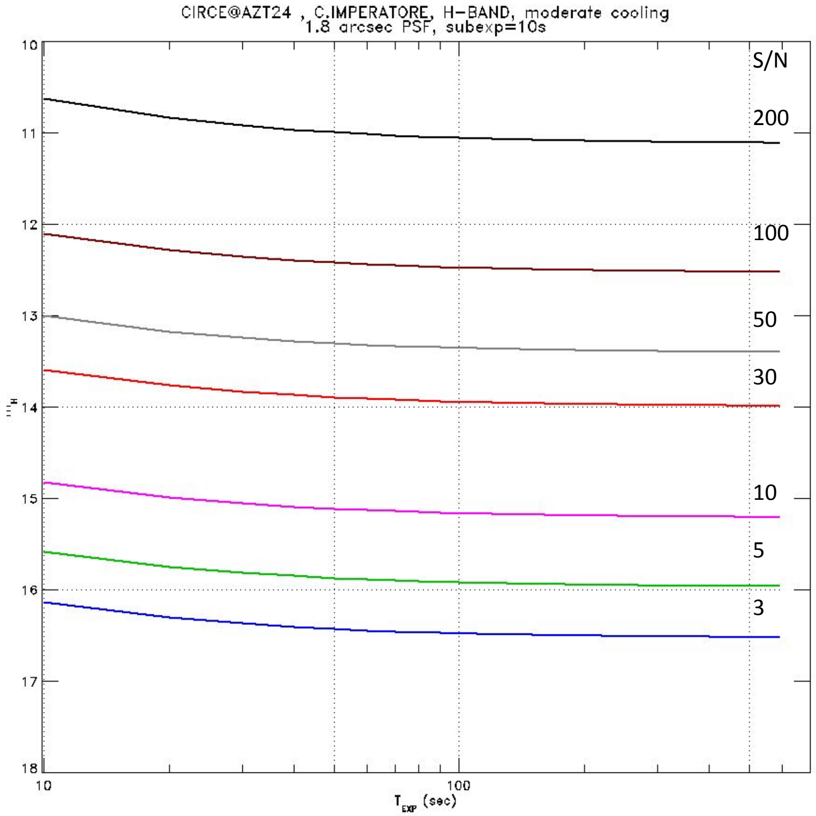


Simulations by Mauro Dolci

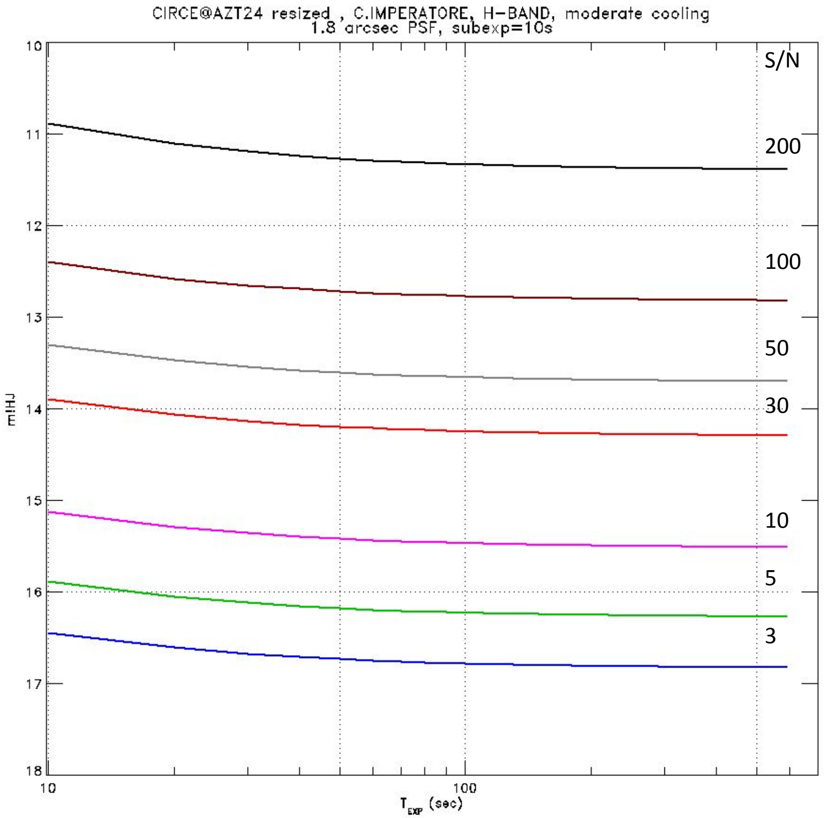
Preliminary sensitivity computation H-band



Reference *(Roque de Los Muchachos)*
K. Batty, I. Steele and Ch. Copperwheat, *Laboratory and On-sky Testing of an InGaAs Detector for Infrared Imaging*, PASP 134, 2022

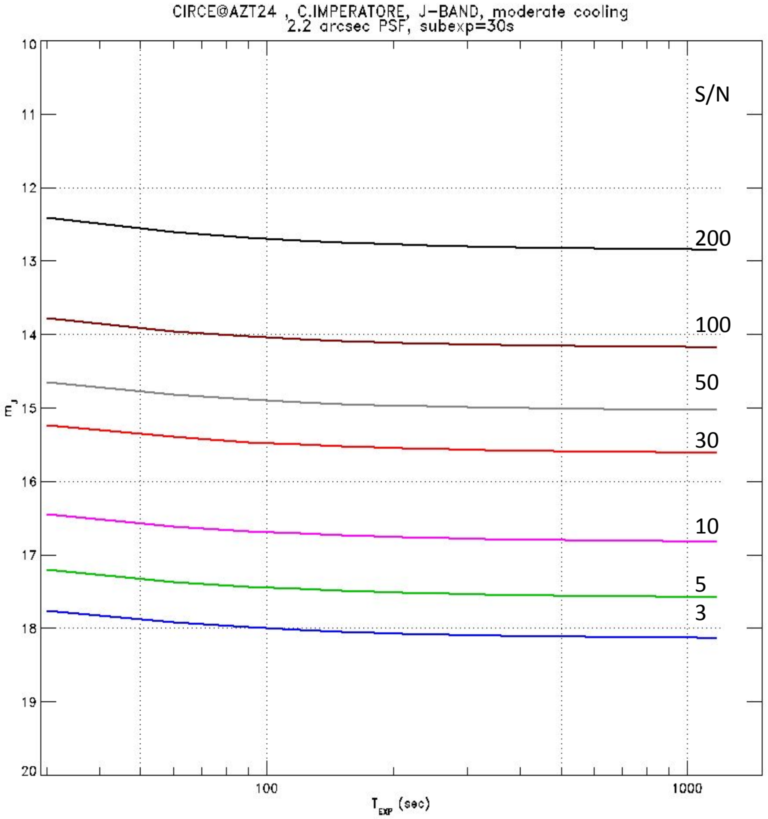


(Campo Imperatore)
Seeing-enhanced

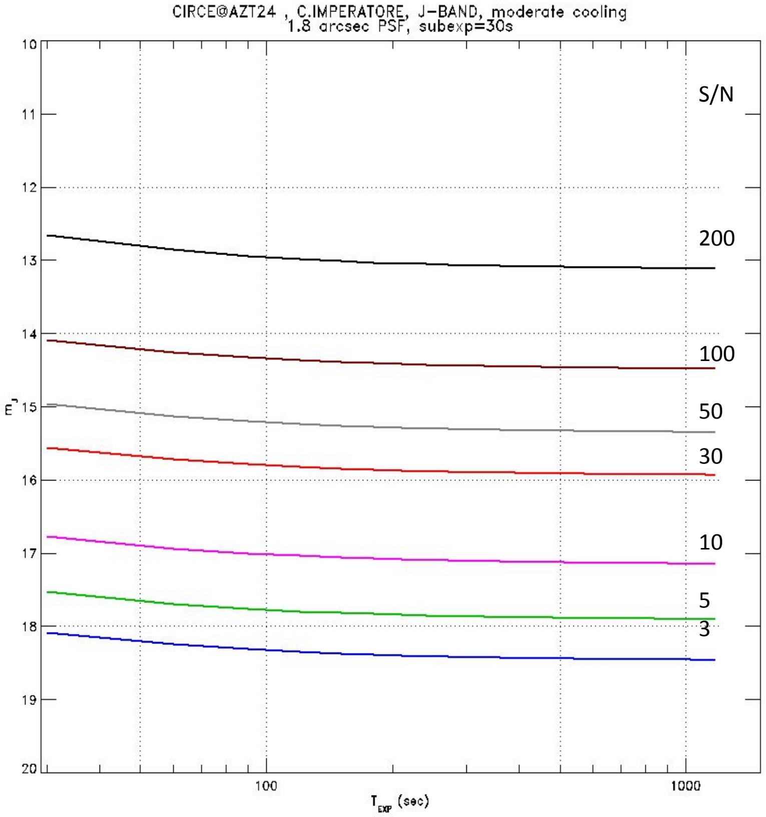


(Campo Imperatore)
Seeing-enhanced
M2 downsized (+M1 reworked)

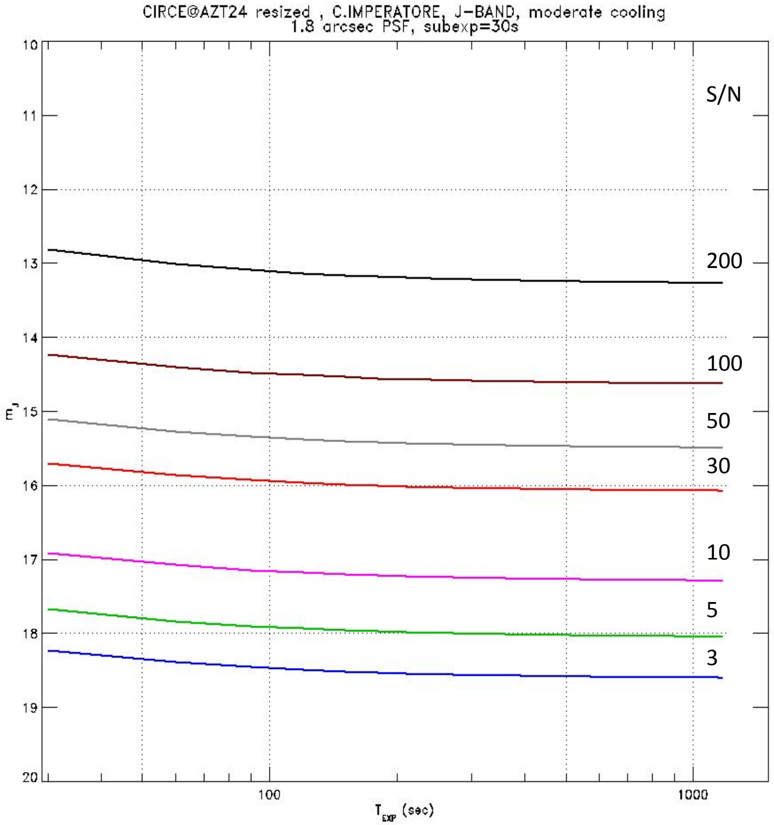
Preliminary sensitivity computation
J-band



(Campo Imperatore)
Seeing limited
-
-



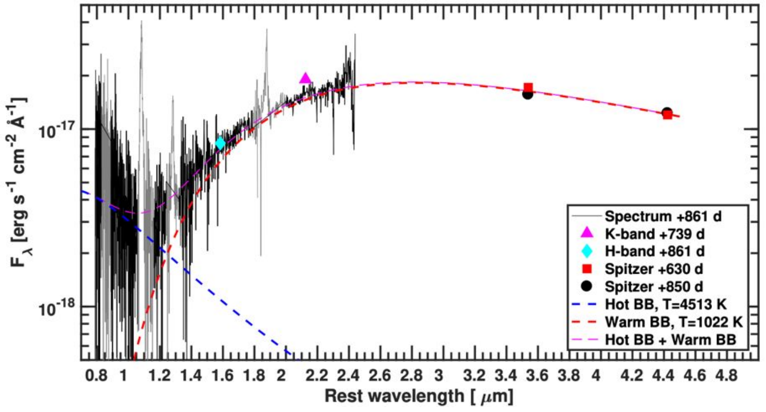
(Campo Imperatore)
-
Seeing-enhanced
-



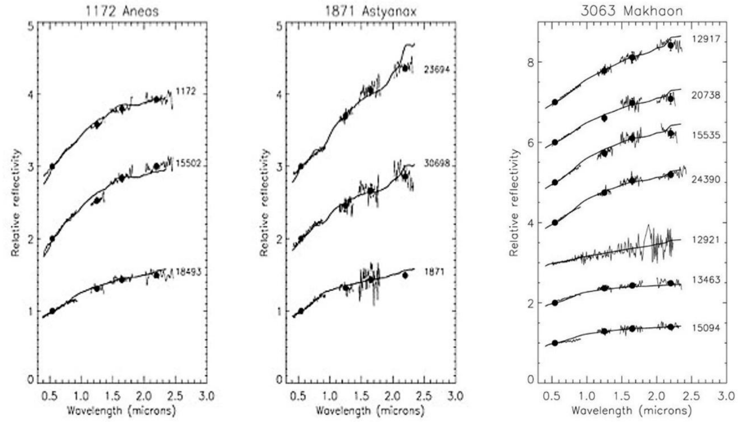
(Campo Imperatore)
-
Seeing-enhanced
M2 downsized (+M1 reworked)

CI²RCE science cases & applications

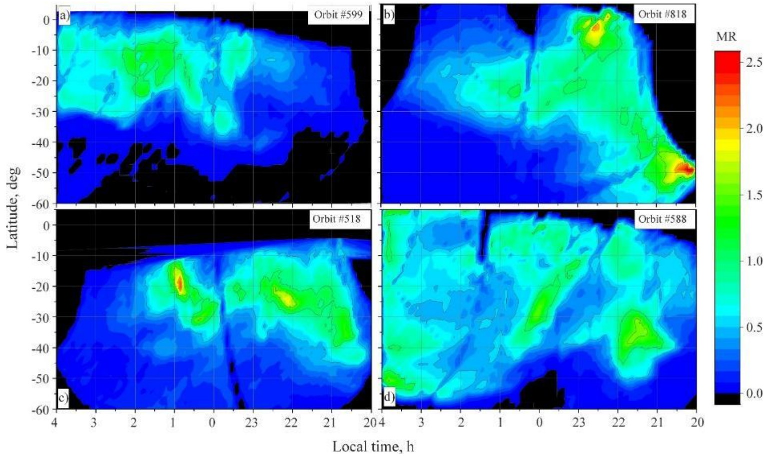
- Extragalactic transients, GW near infrared counterparts
- Stellar variability (general & GAIA Cepheids for distance calibration)
- NEOs and Jupiter Trojans photometry
- Io's volcanism
- Ground support to space missions, study of the Venus airglow
- Lucky imaging on bright targets
- Machine Learning for sub-noise sources detection.



Emission of the transient SN 2013L (Taddia et al. 2020)



JTs combined VNIR spectra and photometry data.



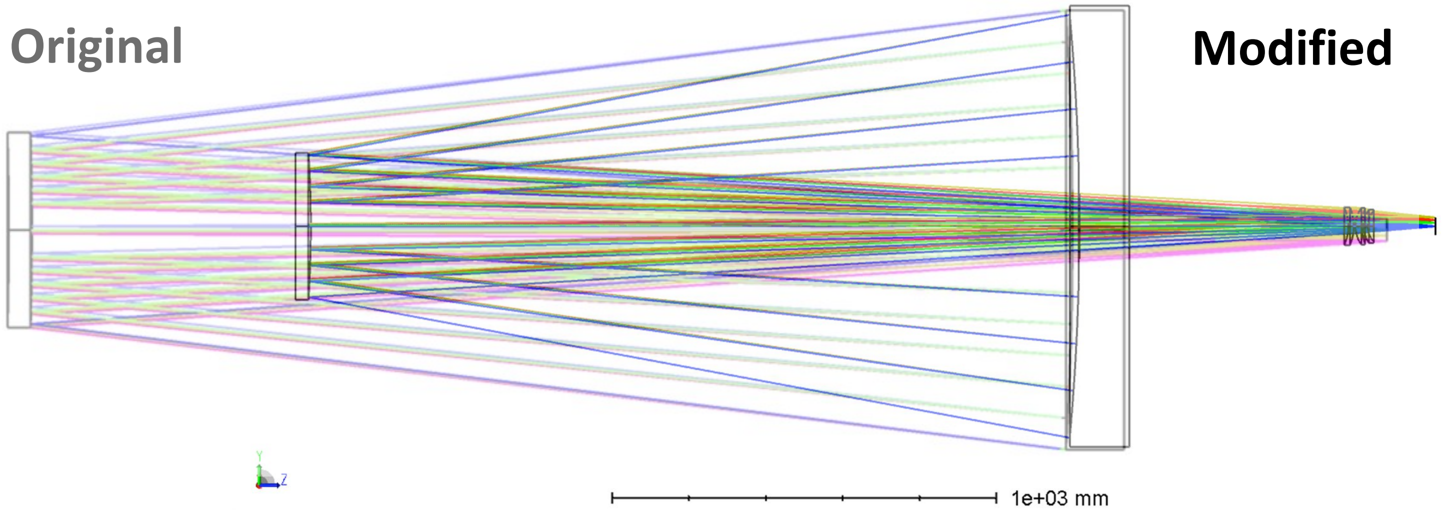
Venus O2 airglow (Shakun, A. et al. 2023)

A further step: telescope remanufacturing

Envisioned changes

- M2 downsized, 590 mm -> 400 mm
- M1 RoC & k (re-)manufacturing
- More compact structure

- Higher throughput
- Lower IR background
- Lighter optomechanics



Development path

First phase - PNRR horizon (end 2025)

- Development of the CI^{2}RCE instrument
- Manufacturing and installation of the telescope focal reducer/field corrector
- Integration and alignment of the CI^{2}RCE opto-mechanical assembly
- Development and testing of the WFS arm
- First light of CI^{2}RCE @ AZT24 and science operations
- **PhD opportunity:** we are looking for a PhD student candidate to support the instrument development (design & WFS).

Second phase - beyond PNRR horizon - not funded yet

- Manufacturing of the downsized M2
- (Re-)manufacturing of the M1
- Manufacturing and installation of re-adapted telescope focal reducer/field corrector
- CI^{2}RCE instrument will be unchanged.

THANK YOU!