Business opportunities in Optical Astronomy: The MAORY instrument

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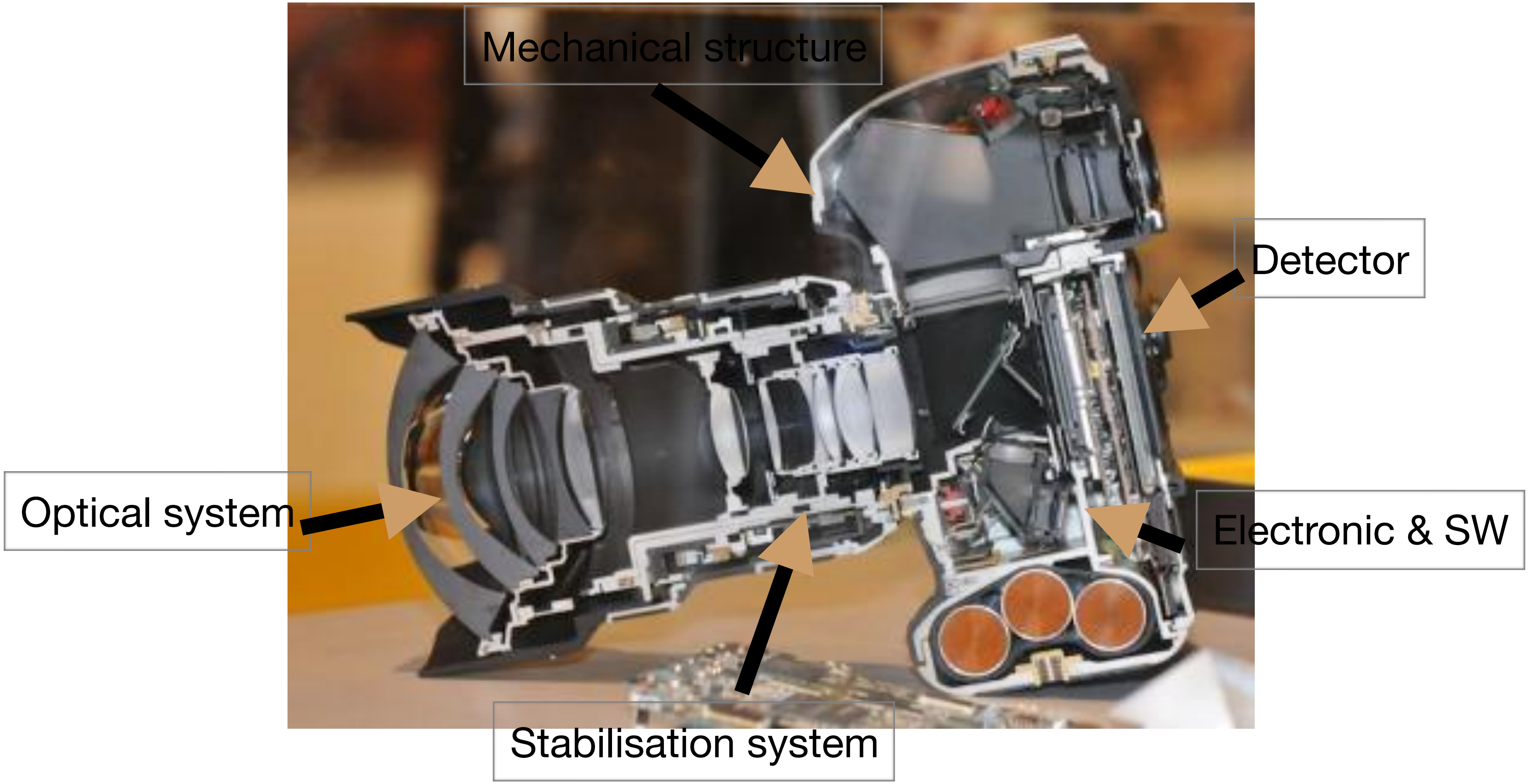
What is an astronomical instrument for a modern optical/IR telescope?
..a sort of camera…

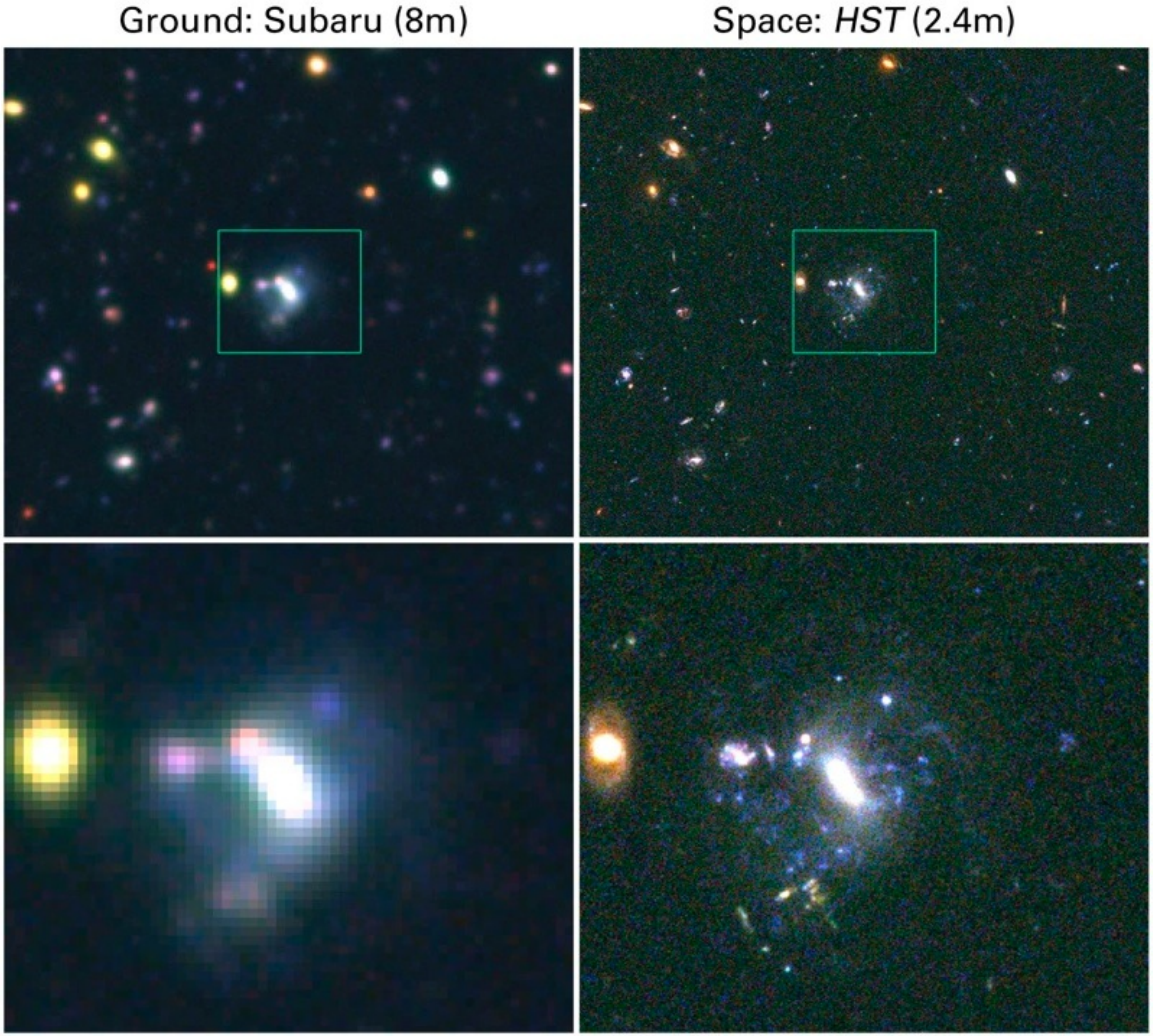


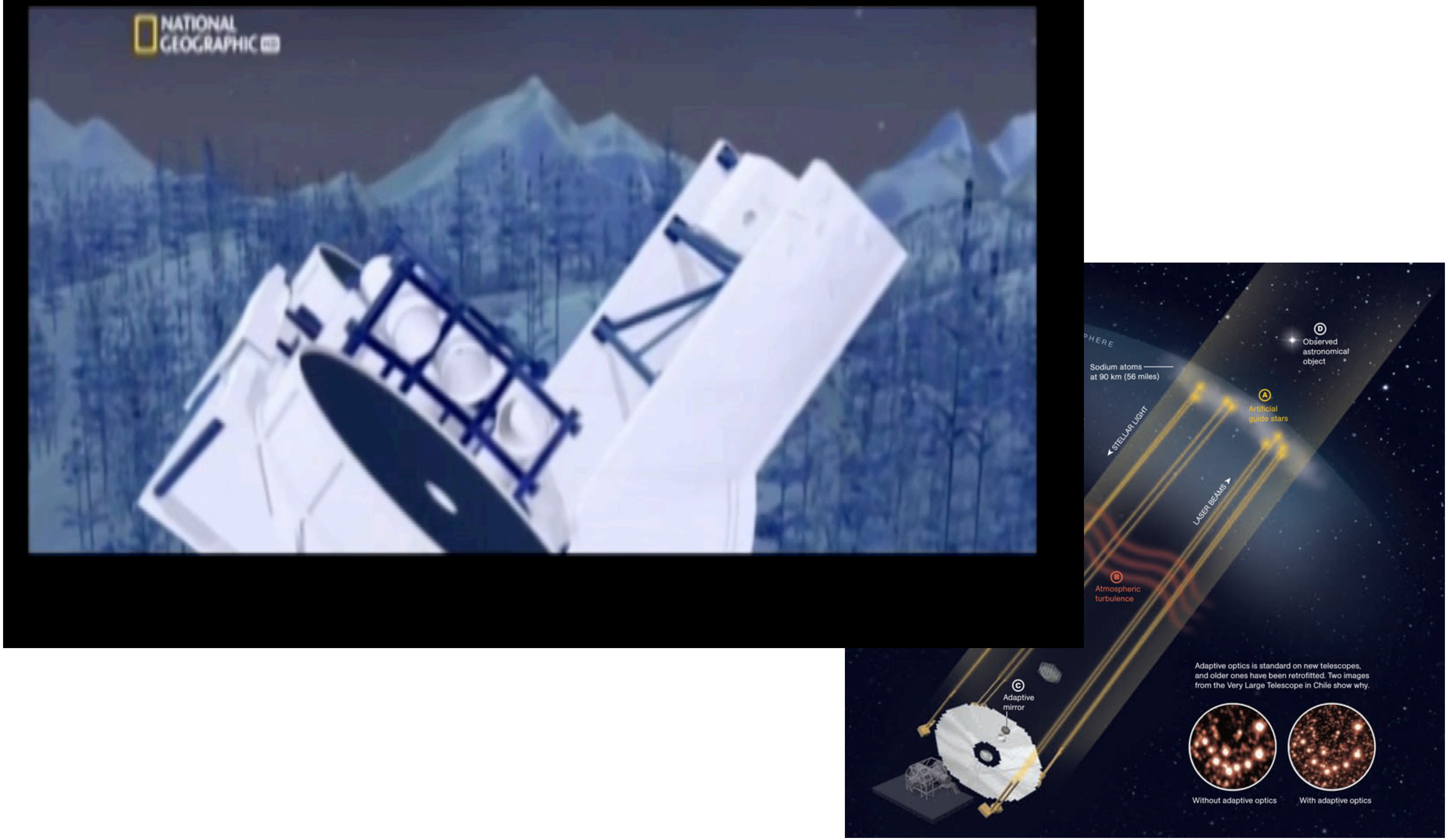
What is an astronomical instrument for a modern optical/IR telescope?
… but a very BIG camera!

Extremely Large Telescope (ELT)
The largest optical/IR telescope ever built.
Primary mirror is 40m wide
Overall structure is the size of the colosseum.

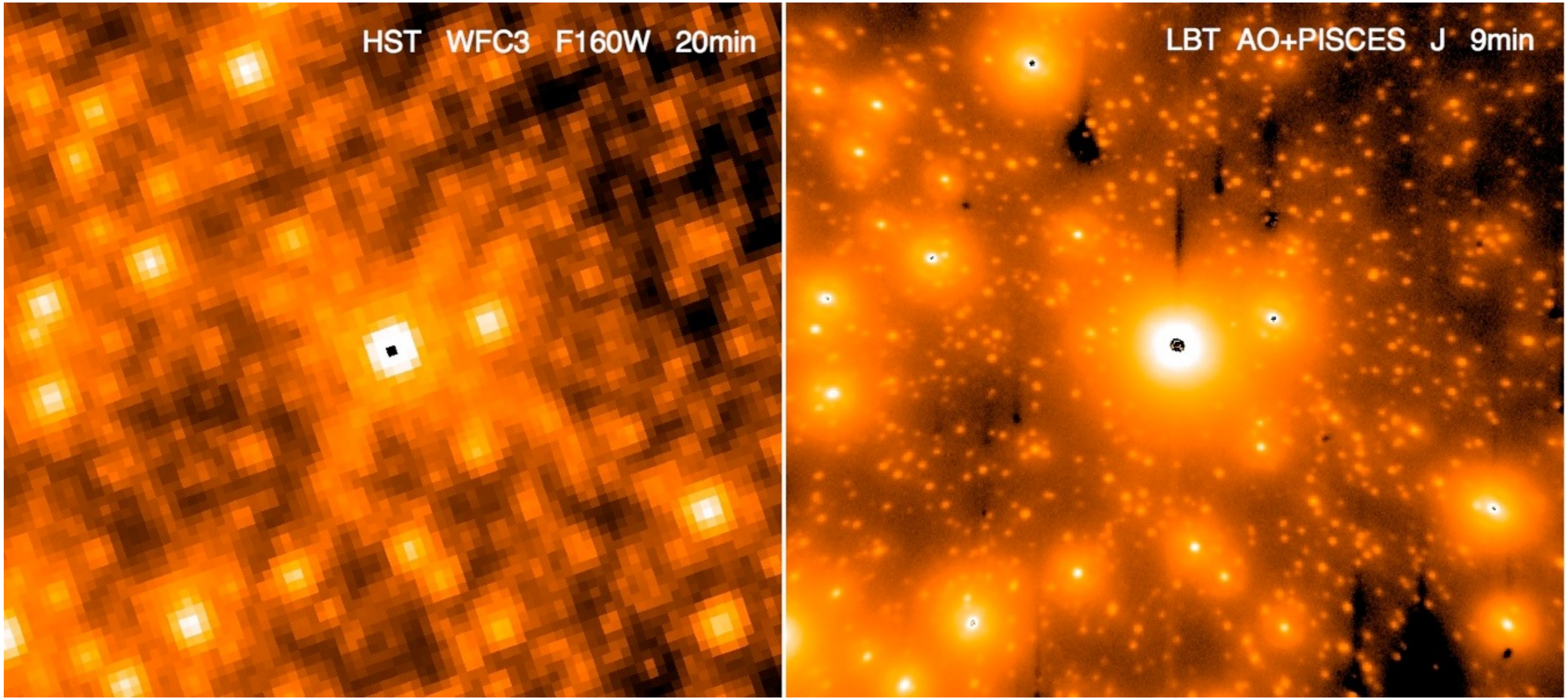
ELT is being built by ESO
Instruments built by scientific partners (INAF in Italy)

Resolution is limited by atmospheric turbulence



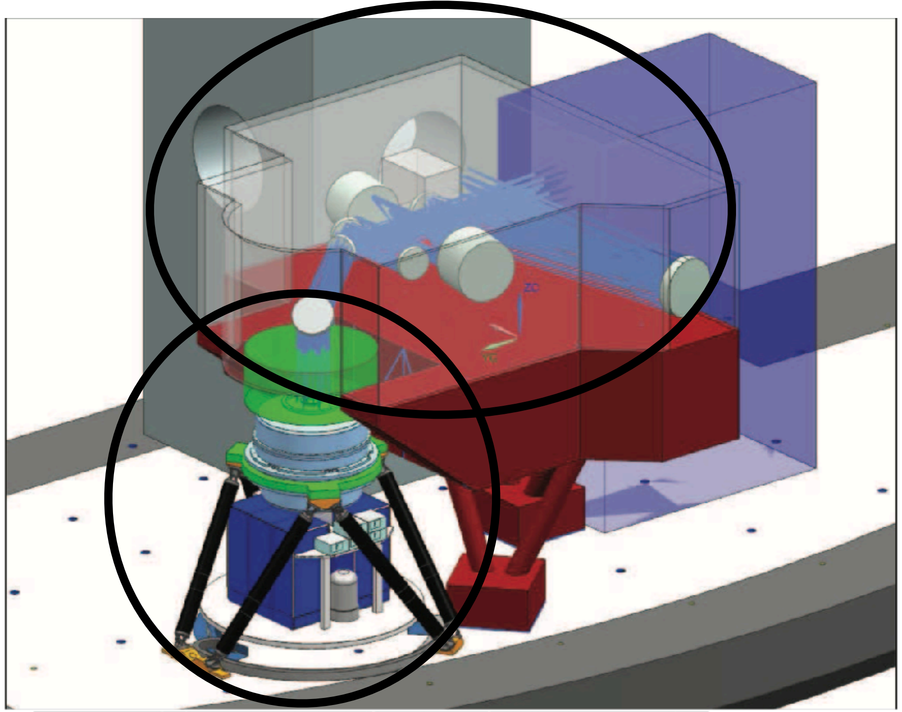


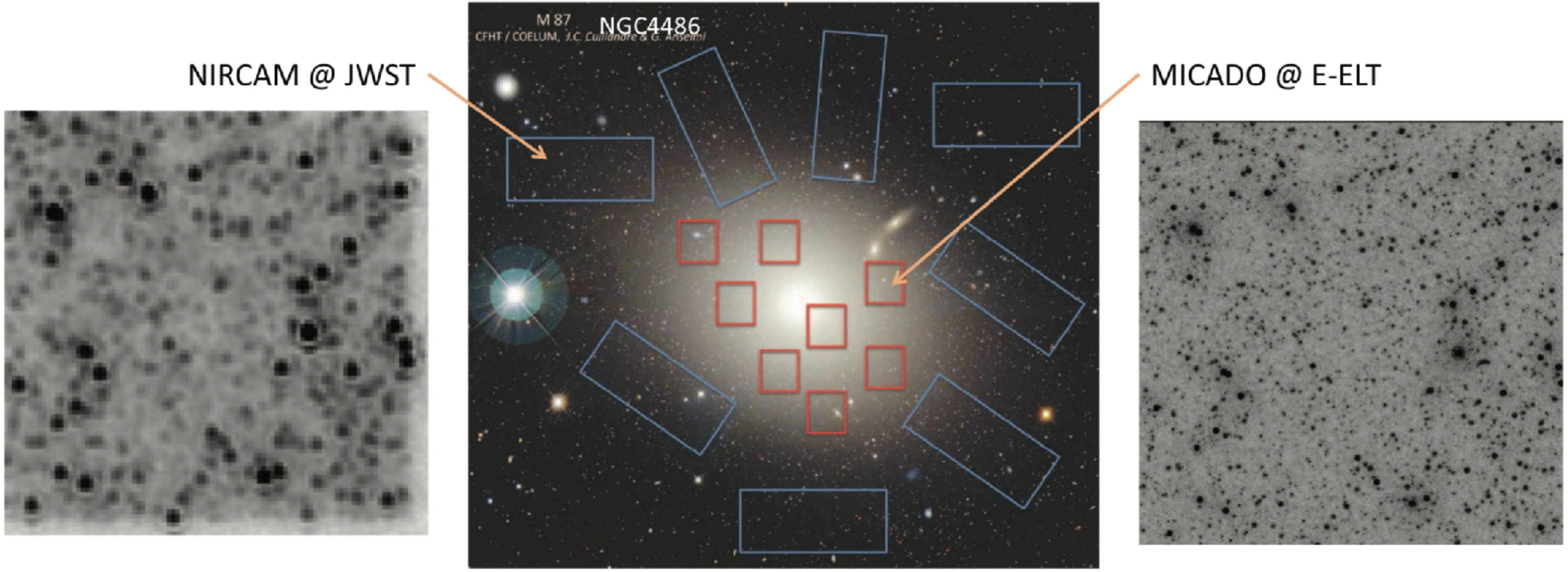
Adaptive optics is standard on new telescopes, and older ones have been retrofitted. Two images from the Very Large Telescope in Chile show why.

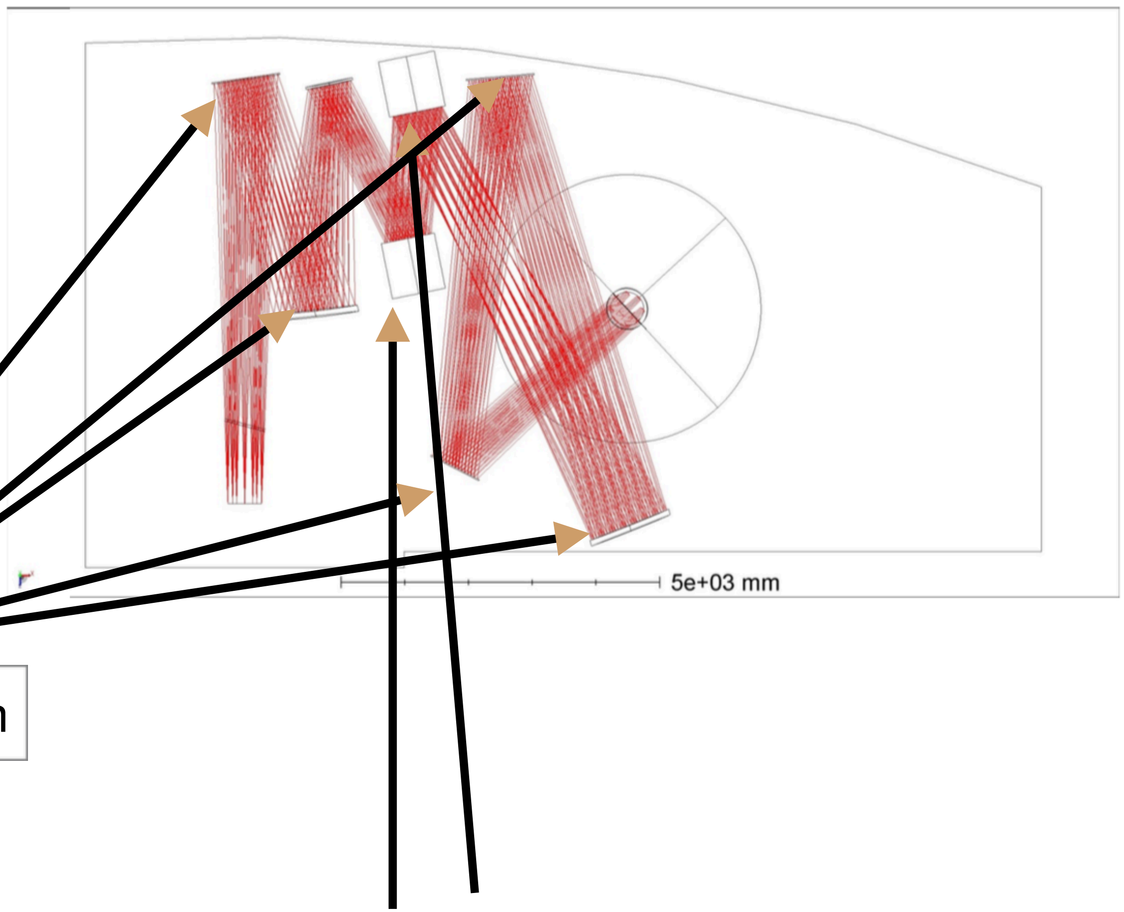

HST WFC3 F160W 20min
LBT AO+PISCES J 9min

MAORY: THE ADAPTIVE OPTICS MODULE FOR ELT

MAORY+MICADO



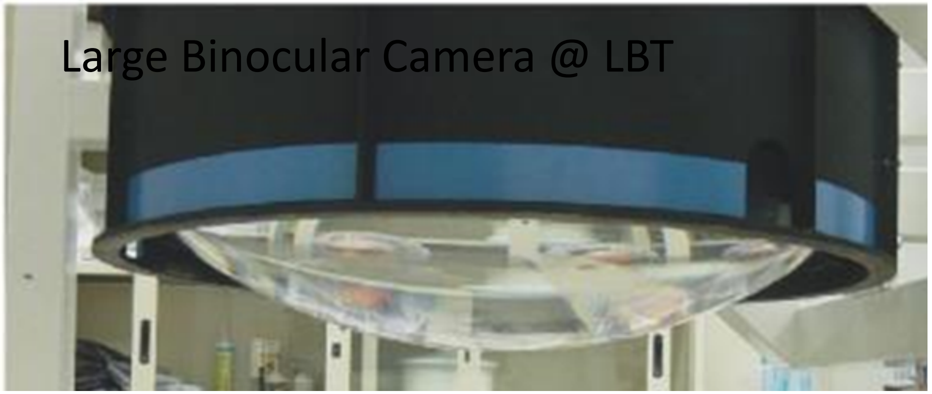


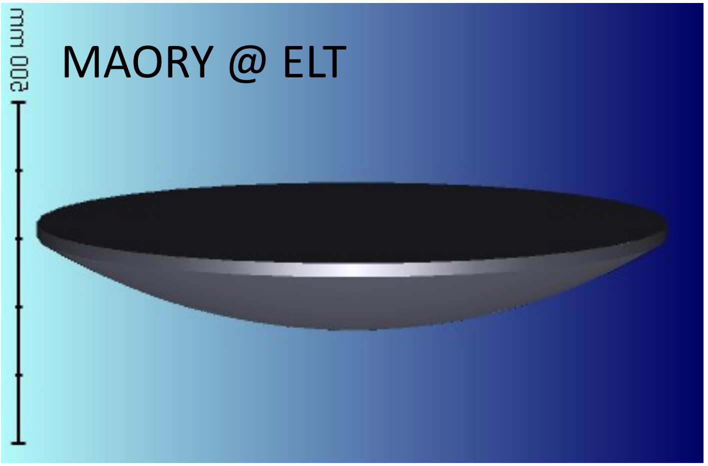


Optical system

Stabilisation system

LARGE SIZE SPHERIC/ASPHERIC LENSES





Large spheric meniscus lens
D = 810 mm (120Kg)

High glass (SILICA) quality and homogeneity
Refractive index $\Delta n < 2\times10^{-6}$
Bubbles < 0.25 mm^2/cm^3

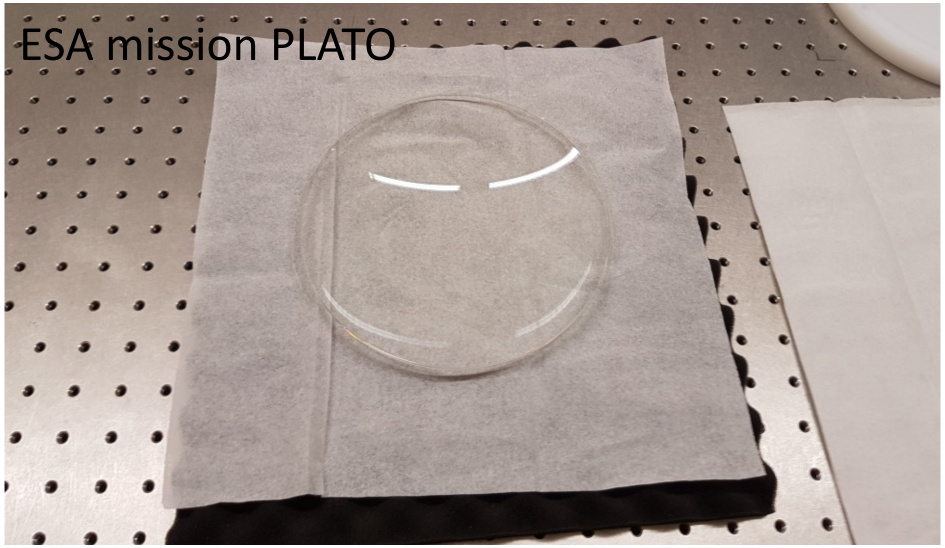
High surface quality
Errors on radii < ±0.3% (knowledge < 0.02%)
Surface quality < 60 nm RMS
Mid frequencies < 5 nm RMS
Micro-roughness < 2 nm RMS

Large meniscus lens with one conic surface
D = 930 mm, one conic surface (K=2.0037)

High glass quality and homogeneity (SILICA, BK7, F2)
Refractive index $\Delta n < 2\times10^{-6}$
Bubbles < 0.25 mm^2/cm^3

High surface quality
Errors on radii < ±0.1% (knowledge < 0.01%)
Surface quality < 50 nm RMS
Mid frequencies < 5 nm RMS
Micro-roughness < 2 nm RMS

MEDIUM SIZE HIGH ASPHERIC LENSES


ESA mission PLATO


Protype lens

High order aspheric lens
D = 180 mm
Deviation from best fitting sphere > 1 mm
Slope variation close to 12 milliradians

High glass quality and homogeneity (S-FPL51)
Refractive index $\Delta n < 2\times10^{-6}$

High surface quality
Errors on radii < ±0.1% (knowledge < 0.01%)
Surface quality < 50 nm (25nm goal) RMS
Mid frequencies < 5 nm RMS
Micro-roughness < 1-2 nm RMS

AR coating > 99% in the visible

High precision metrology required!
Dedicated measurement set-up.

LARGE FLAT/SPHERIC/ASPHERIC MIRRORS

MAORY mirrors like class

FLAT MIRRORS
Diameters ~ 800-1100 mm
Surface quality < 15 nm (goal 10 nm) RMS
Residual flatness < 0.5-1 wave

SPHERIC MIRRORS
Diameters ~ 1300-1350 mm
Radius of curvature ~ 10-20 m
Surface quality < 10 nm RMS
Micro-roughness < 1-2 nm

ASPHERIC OFF-AXIS MIRRORS
Diameters ~ 600-1000 mm
Shapes (concave and convex): elliptic, bi-conic, parabolic, hyperbolic, free-form
Surface quality < 20-40 nm RMS
Mid frequencies < 4 nm RMS
Micro-roughness < 1-2 nm RMS

Coating: silver protected VIS-NIR reflectivity 98-99%

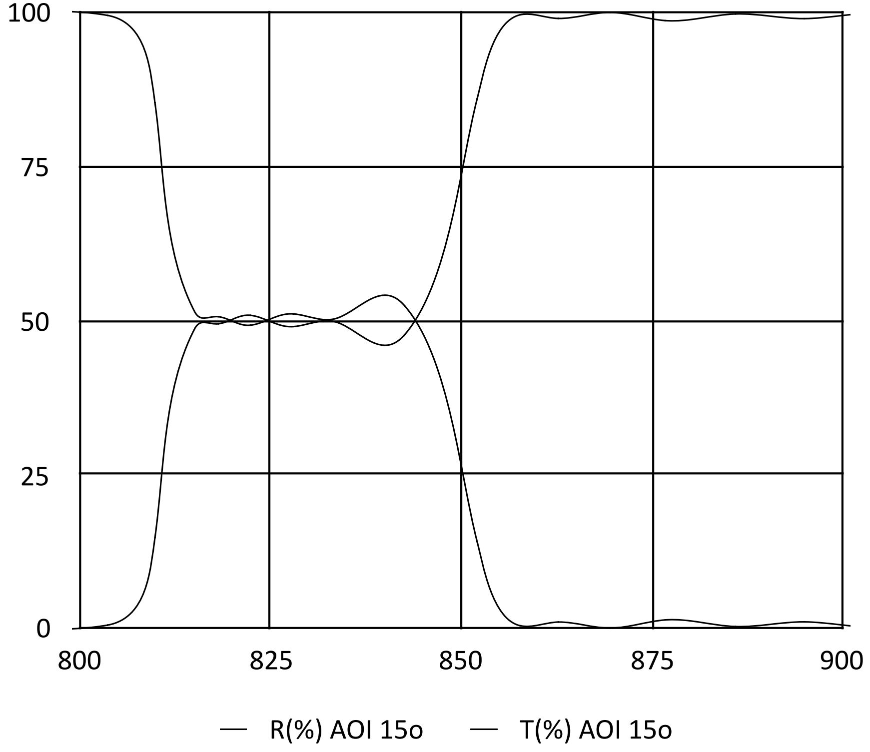
These mirrors will stand in vertical position!

It is required metrology with mirrors installed on the mounting to compensate for residual errors due to gravity.

Metrology of surfaces has to be know with respect to external references!

Nowadays, alignment methods and instrument stability monitoring require the knowledge of the optical surfaces positioning in the space with respect to fiducial markers down to 0.1mm and 10-20 arcsec.

CUSTOM COATINGS

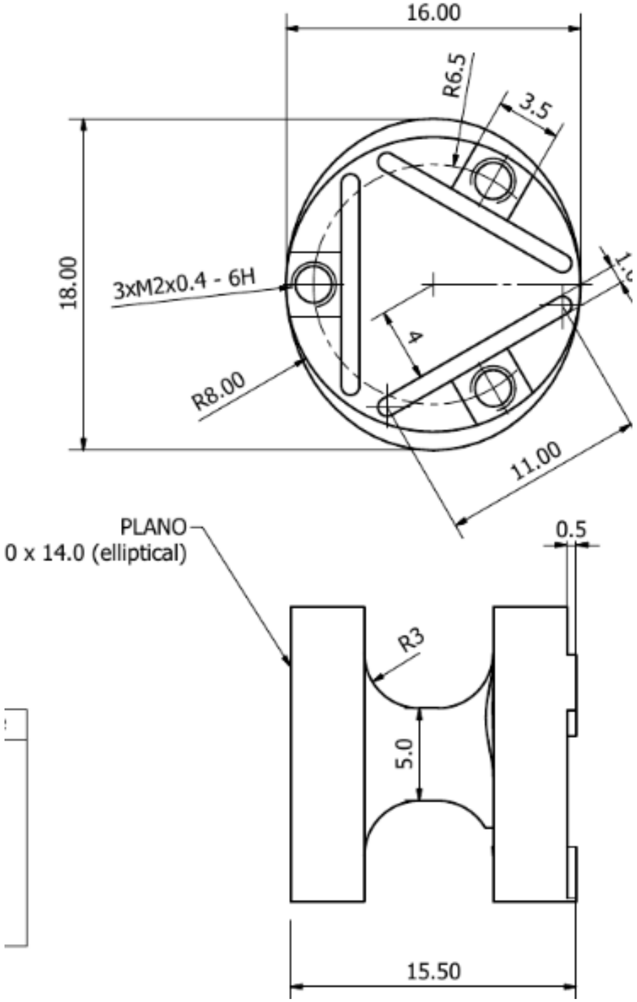


SOXS Main Dichroic

- Flat step required to allow arms cross calibration→ custom multilayer coating to be designed
- Required T>95%
- Step ‘flatness’ 50%, 7%Ptv

- Simulation from Thin Films Physics

ALUMINIUM MIRRORS

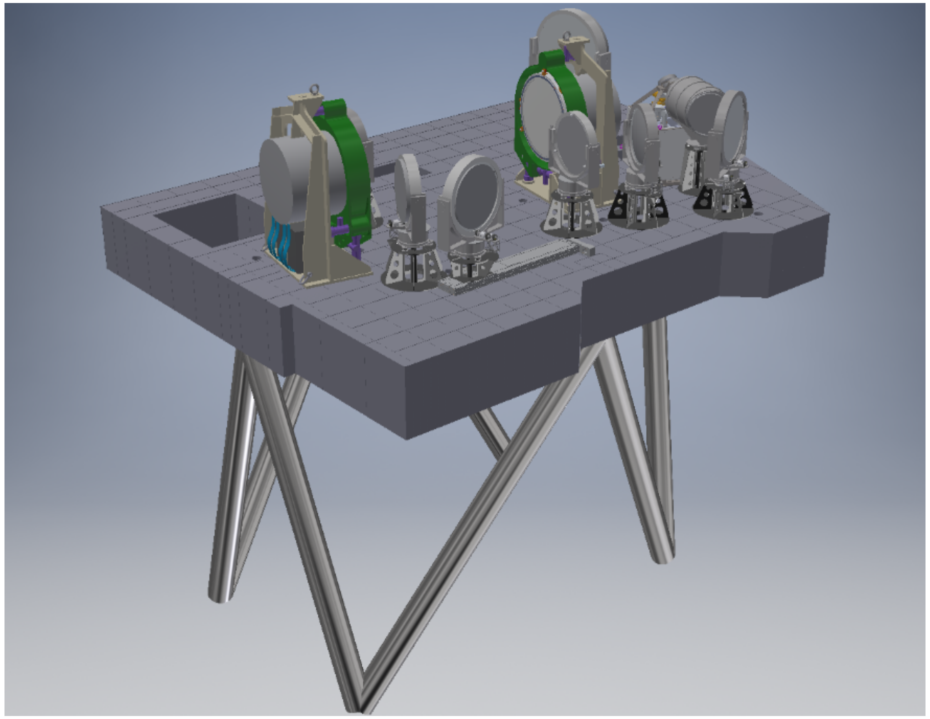


SOXS NIR spectrograph

- Bench same material to reduce thermal issues
- Part of mounting from the same block
- Roughness problems: hard to go under 3.5-5.0 nm

MAORY INSTRUMENT: PRESENT BASELINE MECHANICAL DESIGN

In order to fulfil all the requirements, including the best shape for a good accessibility to all opto-mechanical component, we have chosen to design a full-custom optical bench (welded and/or bolted box structure) made in structural steel.

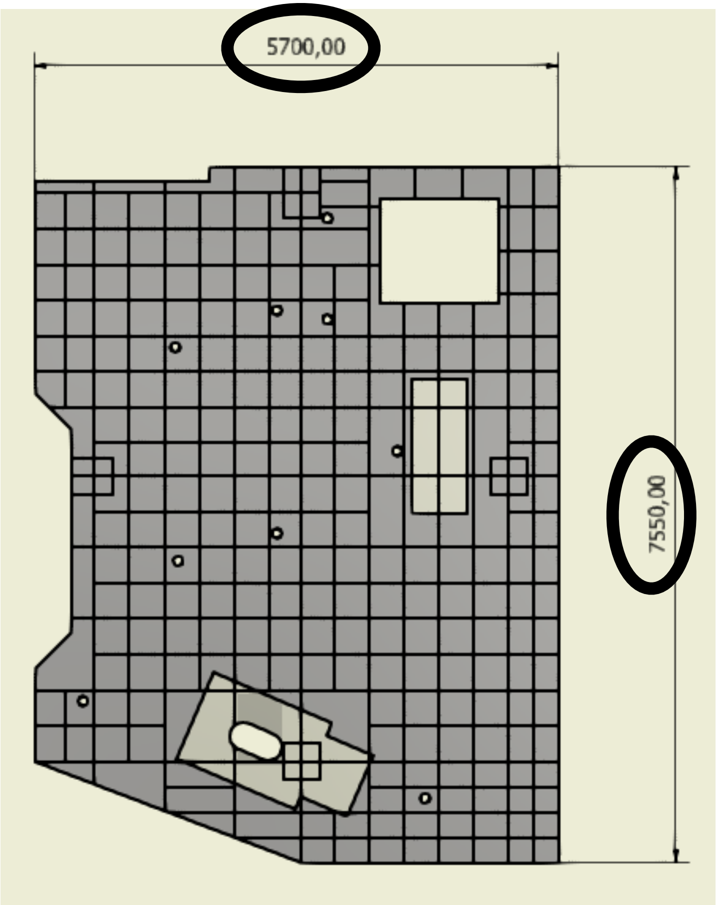


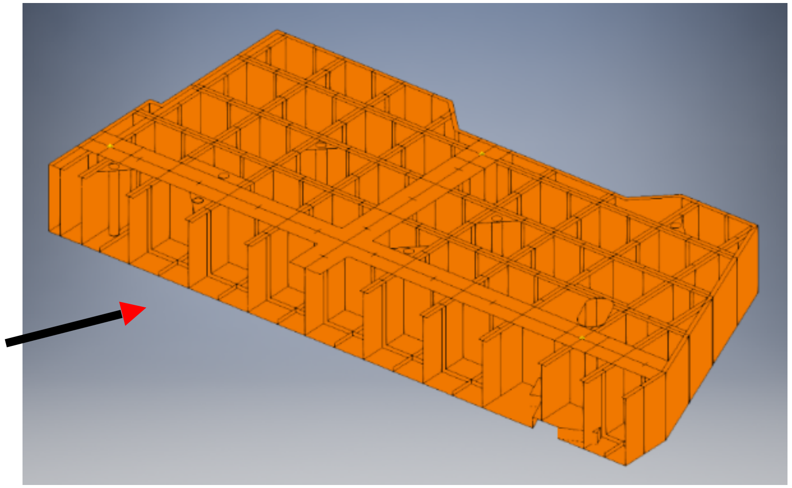
- ➢ For the optical Bench and legs we have a weight requirement of 12tons (+ contingency),

  and

- ➢ stability tolerances and positioning of ±0.1mm for the optical elements.

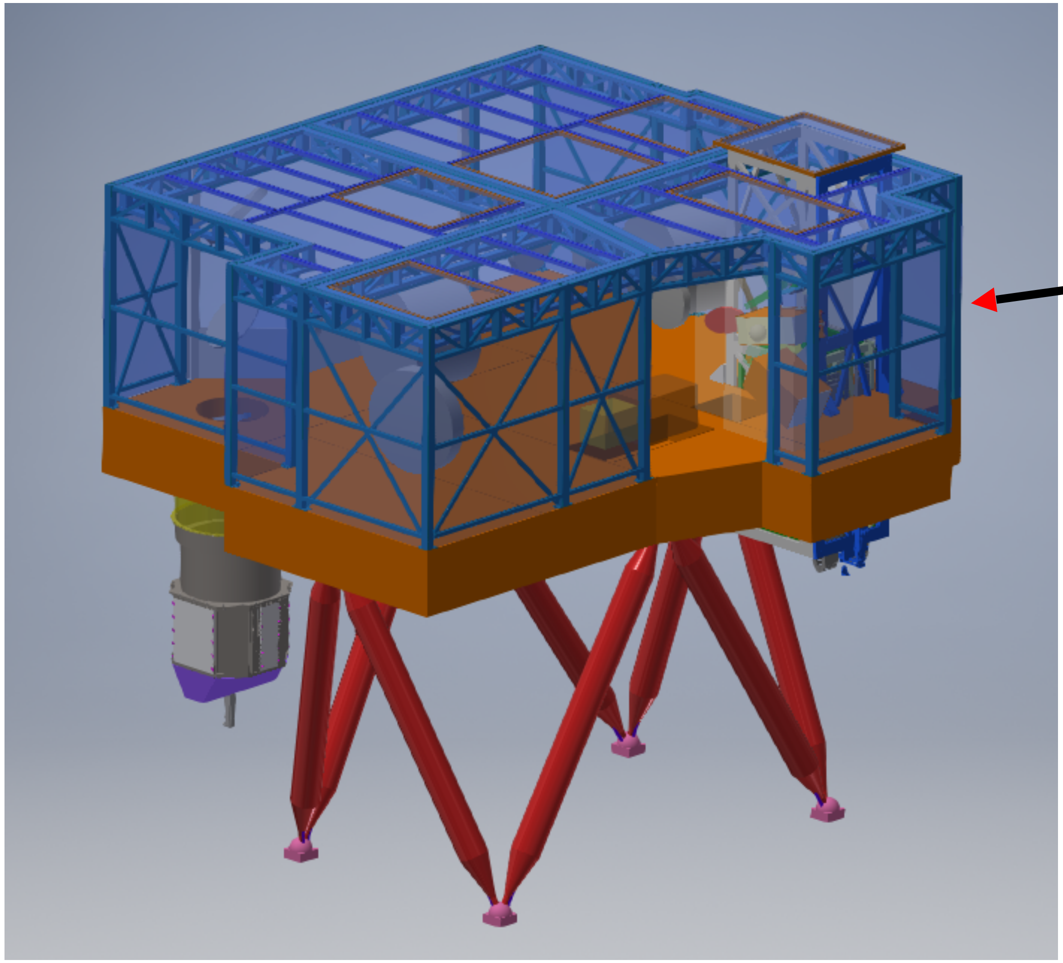
Top view – overall dimensions



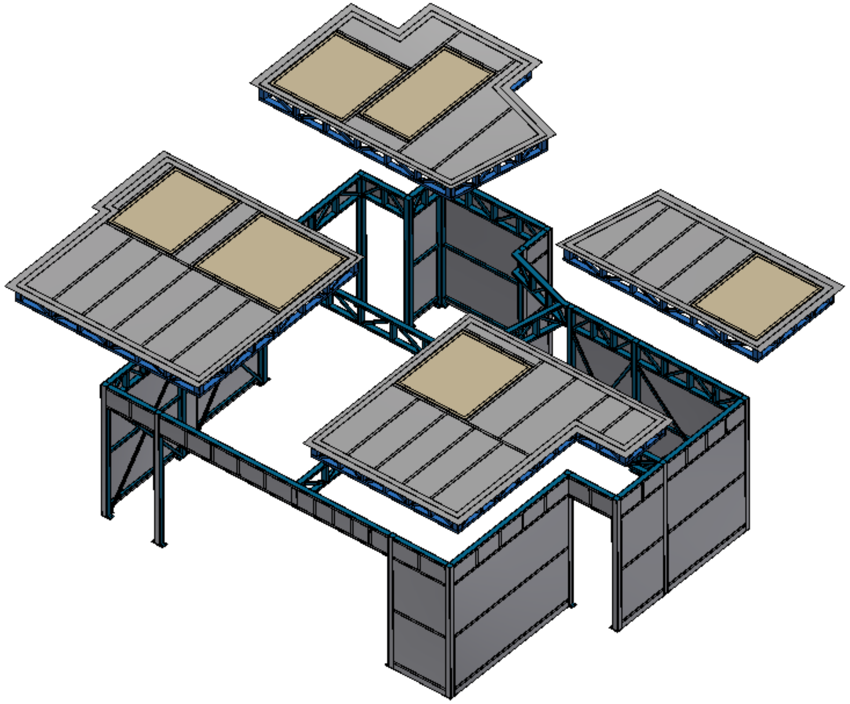


Cutted bottom view

MAORY INSTRUMENT: PRESENT BASELINE MECHANICAL DESIGN



An Enclosure, mounted on the bench, will be make in order to protect the internal optical elements from the light and achieving, as much as possible, a uniform temperature distribution inside it.



The enclosure is made of a number of modular aluminum panels and standard rectangular hollow sections (bolted or welded each other)

Electronic & SW

The Instrument Control Hardware includes all the electronics infrastructure required to control the Instrument

The MAORY electronic architecture design follows this guidelines:

- The control HW is based on a distributed system composed by industrial standard Commercial-Off-The-Shelf (COTS) components.
- The communication between the components is based on industrial, standard, real-time buses.

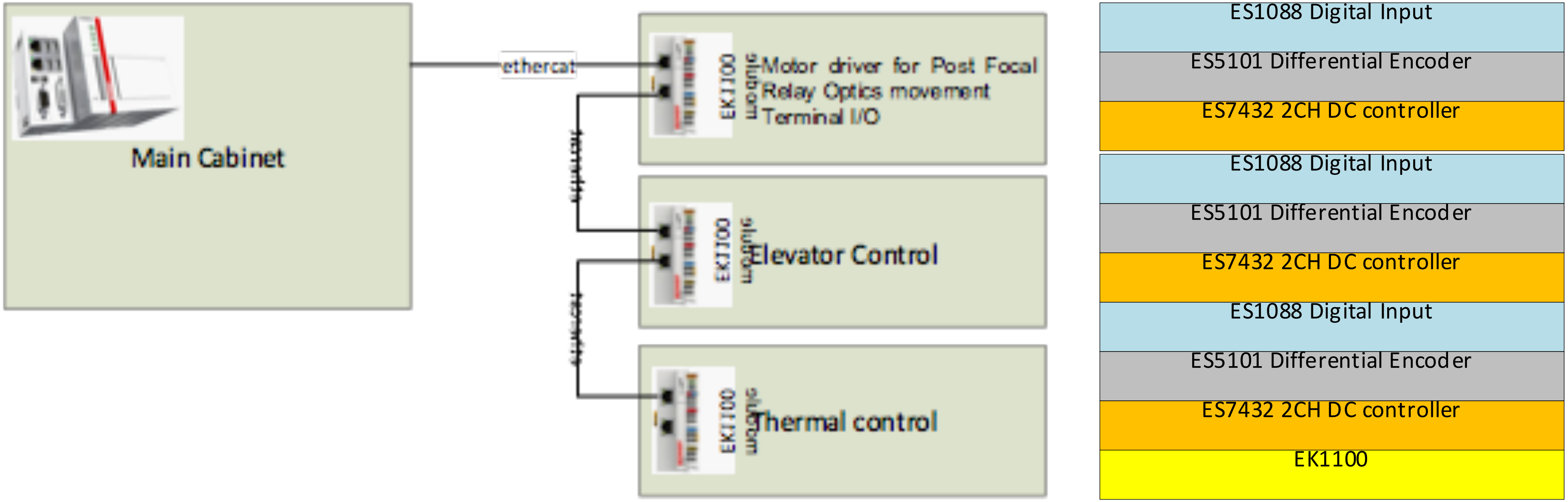
Few differences in astronomical application respect industrial ones e.g. light pollution, thermal control, etc.

Electronic components of ICH

ICH is based on Beckhoff PLC and EtherCat fieldbus.
Main modules are:

- Digital I/O, for devices with discrete control signal and status output
- Analog I/O, for devices with continuous control signal and status output
- Communication modules, for devices with high level interface (for example serial interface)
- Motion control modules, for the motorized functions
- Safety

Example of distributed system



Main Cabinet

ethercat

EK1100 module

Motor driver for Post Focal Relay Optics movement Terminal I/O

Elevator Control

Thermal control

ES1088 Digital Input

ES5101 Differential Encoder

ES7432 2CH DC controller

ES1088 Digital Input

ES5101 Differential Encoder

ES7432 2CH DC controller

ES1088 Digital Input

ES5101 Differential Encoder

ES7432 2CH DC controller

EK1100

Shopping List

Items	Description
Electronic Cabinet	Schroff Varistar LHX 3 with heat exchanger included
Electronic Components and Cabinet Management	Beckhoff PLC with I/O terminal
Power Supplies	Kniel Low Emission Power Supplies

OPTICAL DETECTORS

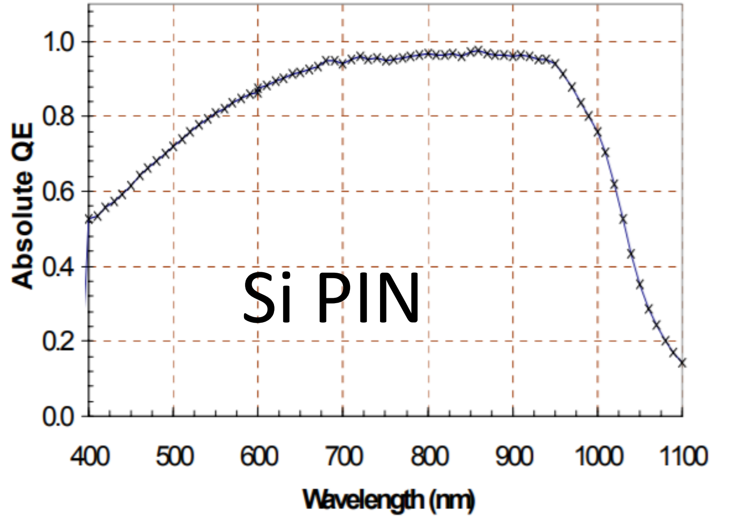
- VISIBLE (0.3-0.9 μm)
  - CCD
  - EM-CCD
  - CMOS
- NIR-MWIR (0.9-5.0 μm)
  - CMOS
  - Hybrid CMOS
  - APD array
- LWIR (8-14 μm)
  - Hybrid CMOS
  - Micro Bolometer

VISIBLE
(0.3-0.9 μm)

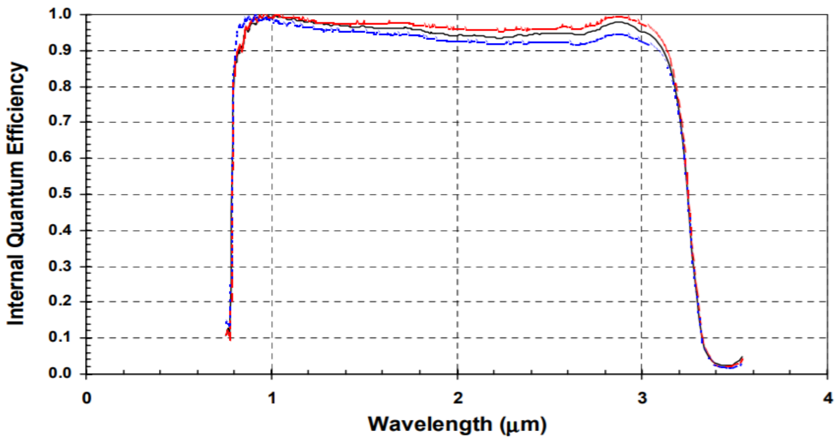
Doped Silicon active media substrate
Cooled at -50 -100 Celsius dark signal <1e-/h

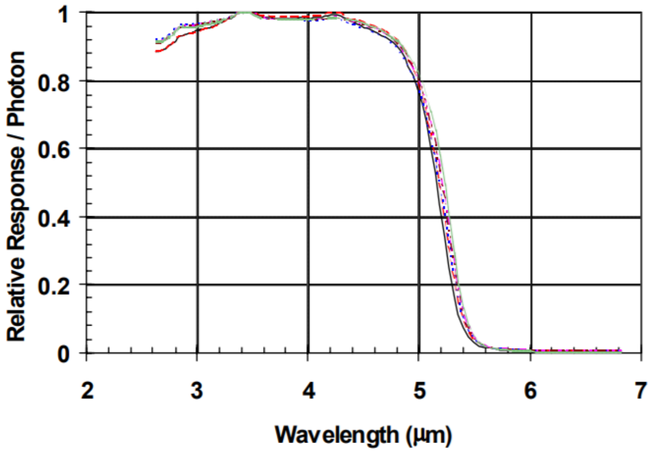
CCD	Work-horse of astronomy, few electron noise, format up to 6k x 6k pixel (Science imagers)
EM-CCD	Very fast and ultra low noise < 0.1e- at 40 Mpix/s format up to 1k x 1k pixel (Wave Front Sensing)
CMOS	Small pixel, fast, large format, low noise ~1e- at 200 Mpix/s, low cost, radiation tolerant (space mission)

FUTURE TRENDS ⇒ EM-CMOS
Ultra low noise



NIR-MWIR (0.9-5.0 μm)	**Ge, HgCdTe or InSb** active media substrate Hybridized on a CMOS Cooled below 77 Kelvin Typical dark signal < 10e-/h
CMOS	Small format up to 1k x 1k based on Ge (on development)
Hybrid CMOS	HAWAII 2 serie up to 4k x 4k pixel at 16 Mpix/s 3-4 e- noise (Science focal plane for IR astronomy)
APD array	Small pixel, fast, medium format (300x200), ultra low noise < 0.1e-, SELEX technology (EU) (NIR WFS)





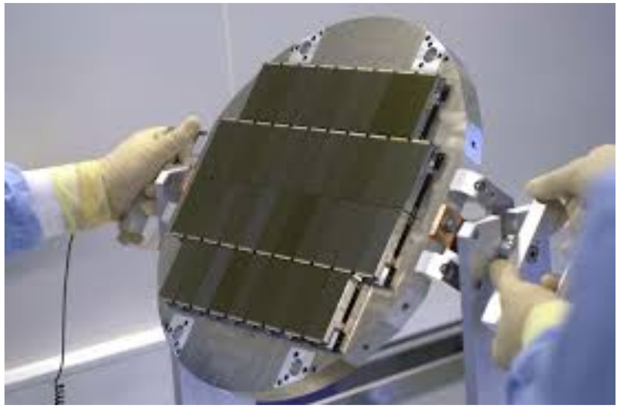
INAF DETECTOR PROVIDERS:

- **TELEDYNE** : NIR and SWIR CMOS *infrared imaging and spectroscopy, space application*
- **e2V**: CCD, EM-CCD, sCMOS *imaging and Wavefront sensing*
- **SONY**: sCMOS, CCD
- **ANDOR**: sCMOS
- **HAMAMTSU**: CCD, sCMOS
- **RAYTHEON**: LWIR CMOS *space application*
- **SELEX**: APD arrays *Wavefront sensing*

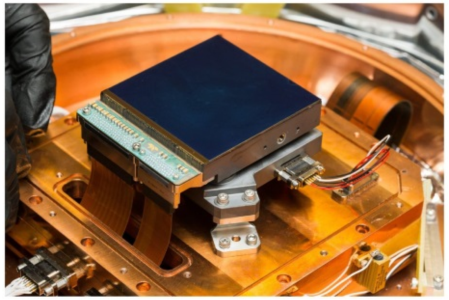
It is now possible to develop custom CMOS detectors @ home thanks to the EuroPractice consortium at a reasonable cost.

THE MOST USED DETECTORs

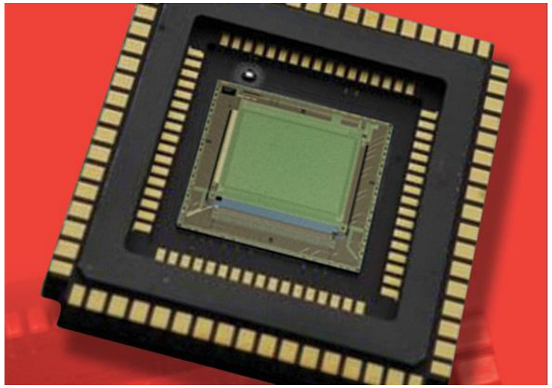
e2V CCD-220 (Wavefront sensor 200x200 pix at 2kfps)



e2V CCD-4290 (4k x 2k pix buttable)



Teledyne HAWAII2 RG (2k x 2k pix NIR buttable)



SELEX Saphira 320 x 200 NIR Wavefront sensor

Summary

Optical-nearIR instruments require a combination of:

- highly customised optical elements (lenses & mirrors in the range 200-1000mm, potentially aspheric);
- stiff/light mechanical structures
- COTS electronic for hardware control
- fast/extremely low noise detectors (optical/nearIR)

Hardware cost is in the range 2-20M€/instrument

In addition to MAORY, several other instruments are under construction today - tenders will emerge in the next year(s)