UNIVERSITÀ DEGLI STUDI FIRENZE

Scuola di Scienze Matematiche, Fisiche e Naturali

corso di laurea triennale

Ottica e optometria

cercachi

cerca nel sito

INAF - Arcetri

telescopi astronomici, ottica adattiva e....premi Nobel!!!

LIGHT ON OPTICS AND OPTOMETRY

Venerdì 19 marzo ore 14.30

Simone Esposito,

INAF, Osservatorio Astrofisico di Arcetri

Firenze

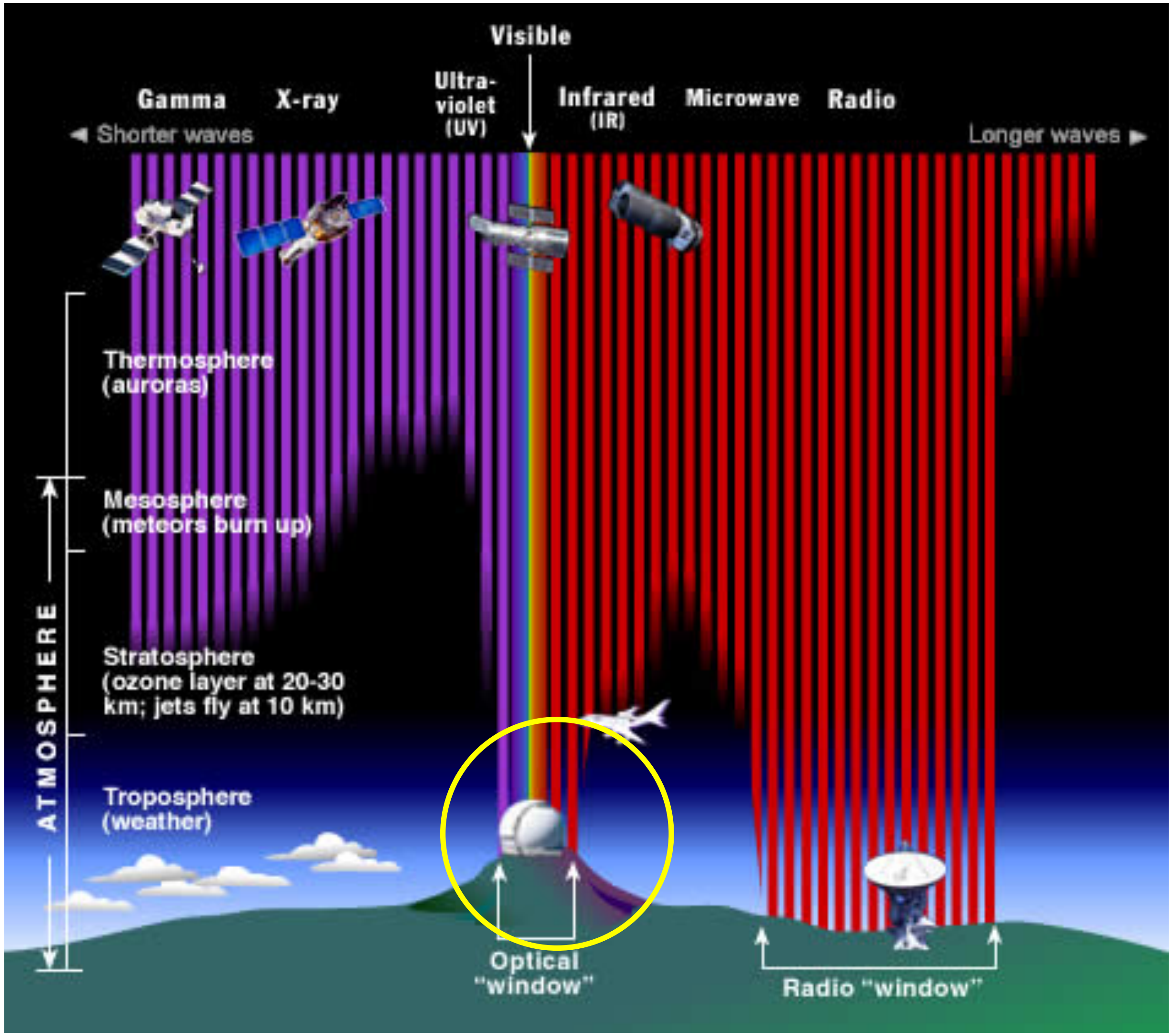
Sommario del colloquio

…..dare una idea di cosa sono (1) i telescopi moderni e (2) l'ottica adattiva.

- storia (brevissima!!) dei telescopi
- I telescopi attuali (8m class) e l'ottica adattiva
- I telescopi del prossimo futuro: gli Extremely Large Telescopes (ELT) e l'ottica adattiva

Quindi, di cosa si parla?

Grandi telescopi astronomici per osservazioni da terra nell'ottico e nel vicino IR: 0.5-20 microns.



Grandi telescopi per grande *sensibilità*

In astronomia la "grande sensibilità" si ottiene in vari modi:

- **Grande superficie di raccolta della luce**
  - per raccogliere abbastanza luce dagli oggetti più deboli

→ Grande diametro del telescopio

- **Grande risoluzione**
  - per vedere dettagli piccoli
  - Per eliminare la "confusione" di oggetti diversi

→ Grande precisione delle ottiche

Prima di cominciare pero'....i telescopi odierni.....

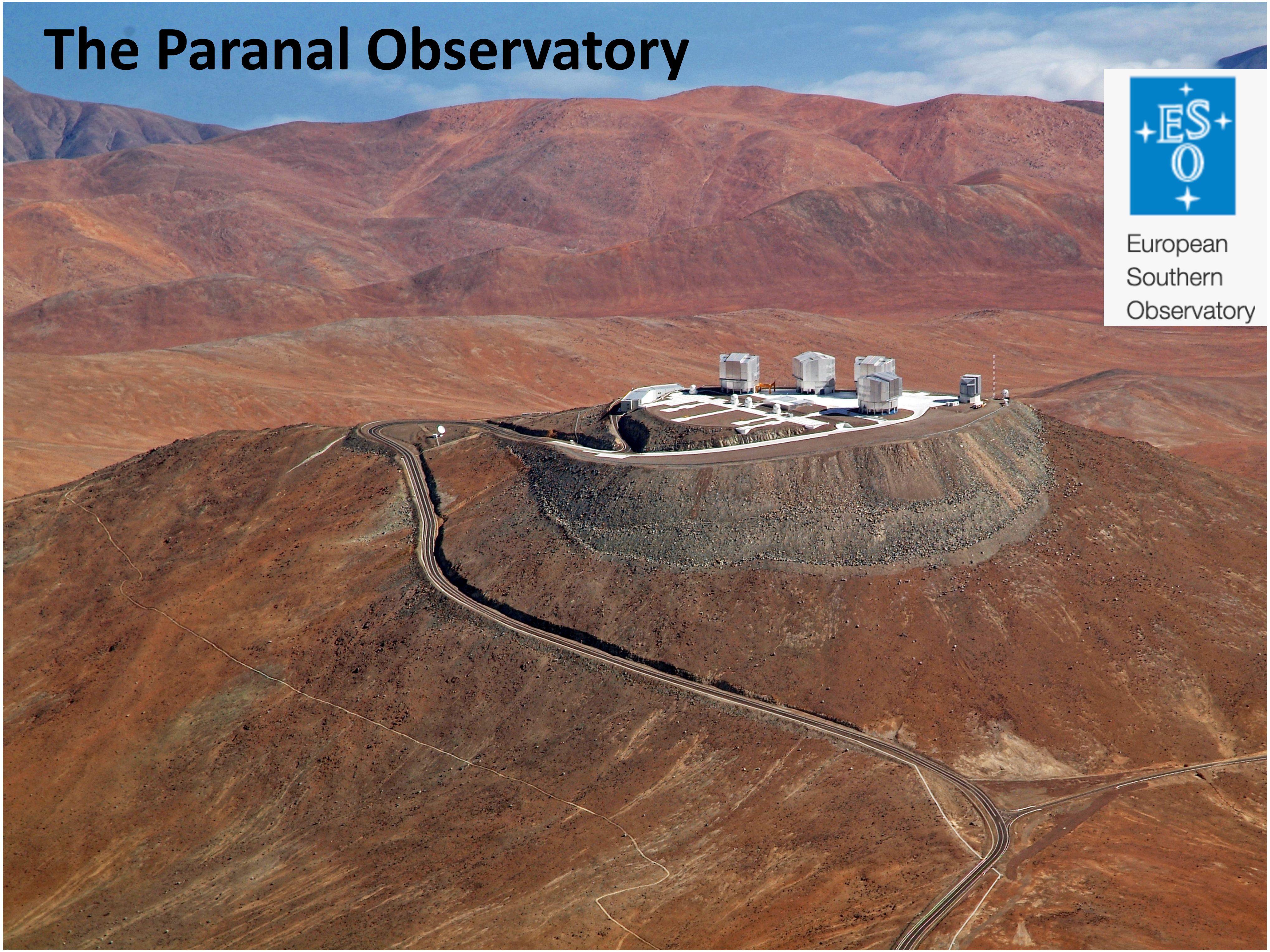
6 Ottobre 2020 !!!

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2020 with one half to Roger Penrose "for the discovery that black hole formation is a robust predi ... d the other half joi ... "for the discovery ... centre of our galaxy

AS: When you image the black hole at the centre of the galaxy, what do you see?

RG: Well, I mean, we are sensing … I mean, what we're doing, we're using electromagnetic waves and mostly infrared range with the telescopes of the European Southern Observatory in Chile, and initially we used one of the big 8m telescopes, then you have to combat the Earth's atmosphere, and make sure that the blurring of the images is removed. That's called adaptive optics. That was the first phase of innovation in the late '90s. But that's not sufficient to come very close to the galactic centre, so our most recent innovation has been to combine four of these telescopes, two of them cause an interferometer, so there's four 8m telescopes. And with that, we can then sense the motions of stars which are orbiting the black hole with exquisite precision. We also see actually gas in the … very close in the accretion zone

The Paranal Observatory



Big steps at 8m class telescopes

European
Southern
Observatory

eso0226 — Science Release

Surfing a Black Hole

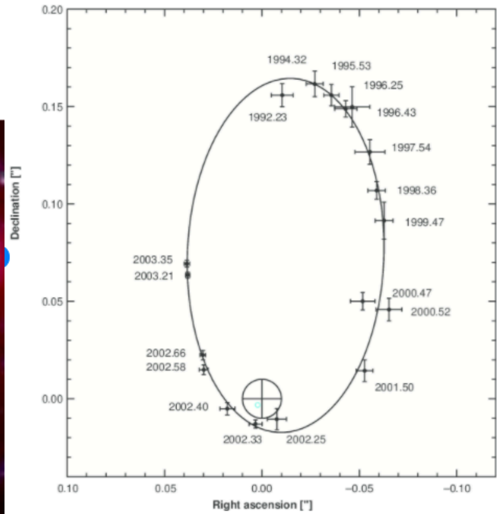
Star Orbiting Massive Milky Way Centre Approaches to within 17 Light-Hours

16 October 2002

An international team of astronomers [2], lead by researchers at the Max-Planck Institute for Extraterrestrial Physics (MPE) , has directly observed an otherwise normal star orbiting the supermassive black hole at the center of the Milky Way Galaxy. Ten years of painstaking measurements have been crowned by a series of unique images obtained by the Adaptive Optics (AO) NAOS-CONICA (NACO) instrument [3] on the 8.2-m VLT YEPUN telescope at the ESO Paranal Observatory. It turns out that earlier this year the star approached the central Black Hole to within 17 light-hours - only three times the distance between the Sun and planet Pluto - while travelling at no less than

© Nobel Media. Ill. Niklas Elmehed.

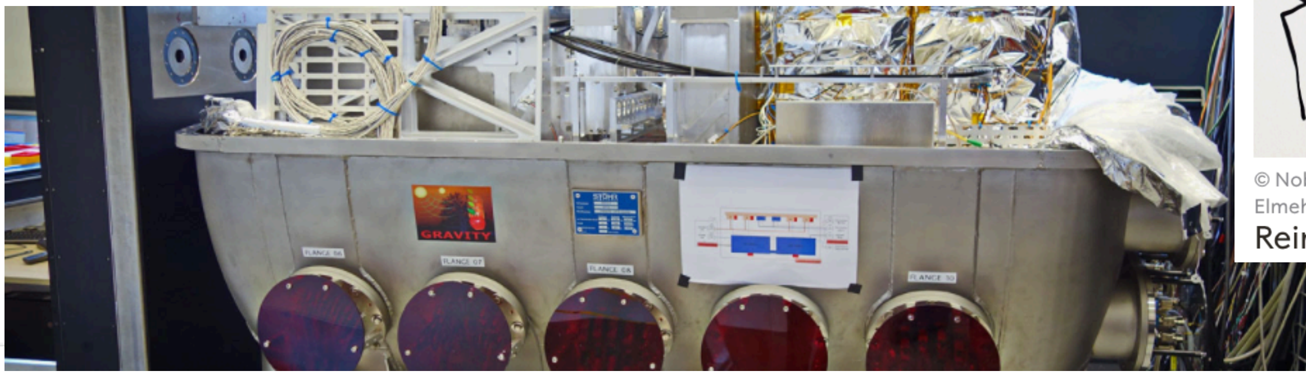
Reinhard Genzel



Orbit of the star S2 around Sgr A* [figure 1 of (17)]. The continuous curve shows the projected best fit Keplerian orbit, which has a period of 15.6 years and comes within 2000 Schwarzschild radii of the position of Sgr A* (shown as the large cross within a circle). The small blue open circle marks the focus of the elliptical orbit. Ghez et al. (16) report the orbits of several additional stars, including one that comes within 1000 R S of the putative black hole. Dates within years are shown as decimal fractions of years.

Final step at 8m class telescopes

Gravity: an adpative optics assisted interferometer



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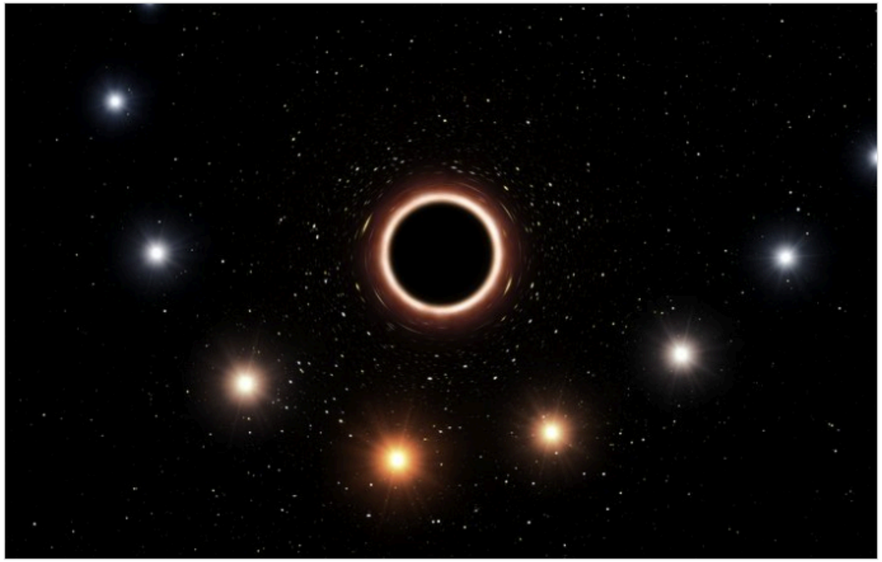
Reinhard Genzel

European Southern Observatory

Artist's impression of S2 passing supermassive black hole at centre of Milky Way



This artist's impression shows the path of the star S2 as it passes very close to the supermassive black hole at the centre of the Milky Way. As it gets close to the black hole the very strong gravitational field causes the colour of the star to shift slightly to the red, an effect of Einstein's general theory of relativity.

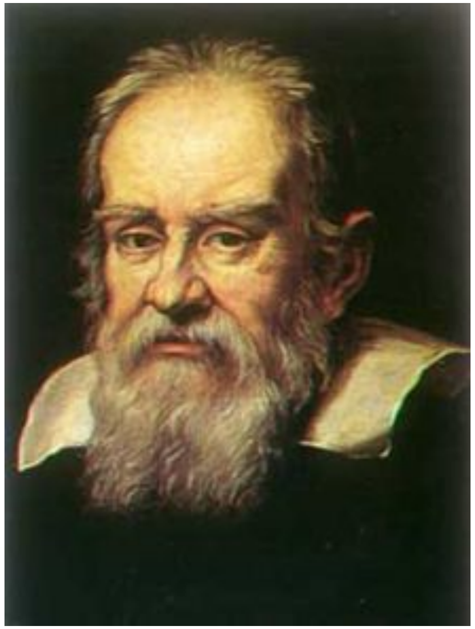
In this graphic the colour effect and size of the objects have been exaggerated for clarity.

Credit: ESO/M. Kornmesser

GRAVITY is an interferometer that combines the light of four VLT telescopes (either the four Unit Telescopes or the four Auxiliary Telescopes), each assisted by adaptive optics. The instrument provides imaging with four-milliarcsecond resolution, and can measure the positions and movements of stars and other celestial objects with a precision of a few ten microarcseconds

Come si è arrivati ai telescopi di oggi ?

I primi telescopi



G. Galilei costruì il suo strumento dopo aver sentito parlare a Venezia nel giugno 1609 dello strumento costruito in Olanda da Hans Lippershey and Sacharias Jansen.

Galileo punto' il canocchiale verso l'alto……e invento' il telescopio!!!!

30mm di diametro

Dall'osservazione del cielo ad occhio nudo si passo' alle osservazioni con il telescopio.

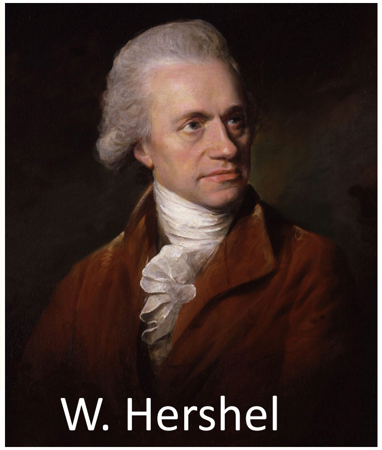
Con questo telescopio Galileo nel 1610 scoperse I satelliti di Giove, le macchie solari le valli e le montagne della Luna.

4-8mm di diametro

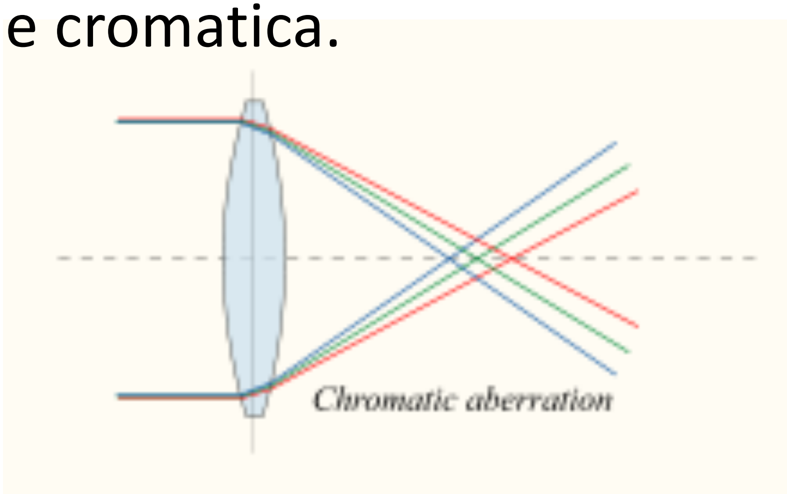
Introdurre uno strumento piu avanzato (il telescopio) gli consentì di ottenere nuove scoperte.

Telescopi riflettori

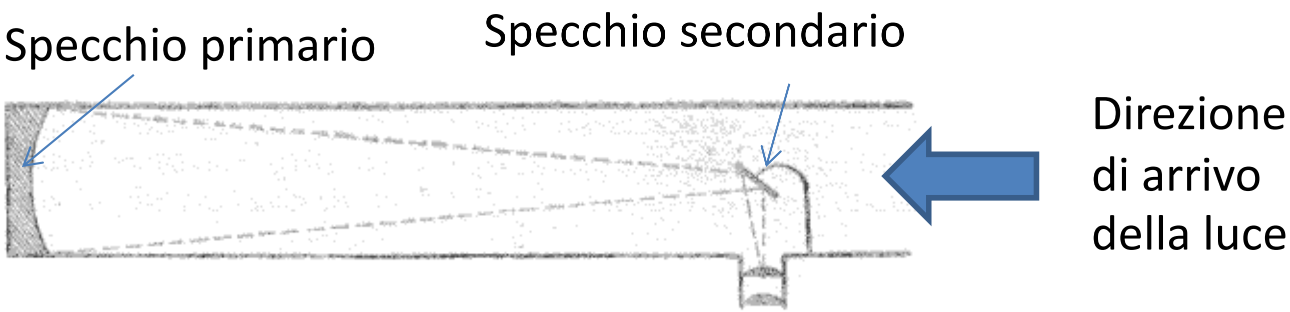
Il limite iniziale dei telescopi a lenti (rifrattori) era la cosiddetta aberrazione cromatica.



Luce di colore diverso va a fuoco in punti diversi rendendo confusa l'immagine



Newton nel 1666 propose l'uso di un telescopio fatto con due specchi metallici di cui uno concavo e uno piano. Il secondo specchio serve solo per accedere all'immagine



Telescopio Newtoniano

Riflettori con specchi di vetro !!!

Fu L. Foucault che nel 1856-1857 scoprì un processo per depositare uno strato sottile di argento su uno specchio in vetro. Lo specchio di vetro argentato aveva alcuni importanti vantaggi rispetto agli specchi in metallo.

1) Maggiore riflettività
2) Maggiore durata rispetto alla finitura degli specchi metallici
3) Possibilità di ridepositare un nuovo strato senza rilavorare lo specchio

Metodo utilizzato da fine 800 per produrre specchi sempre piu grandi. Nel 1917 costruzione dello Hooker telescope da 150cm Mount Wilson. Questo telescopio fu utilizzato da E. Hubble nella sua fondamentale scoperta dell'espansione dell'universo.

…l'uso di strumenti piu' avanzati consenti' di ottenere nuove scoperte !!!

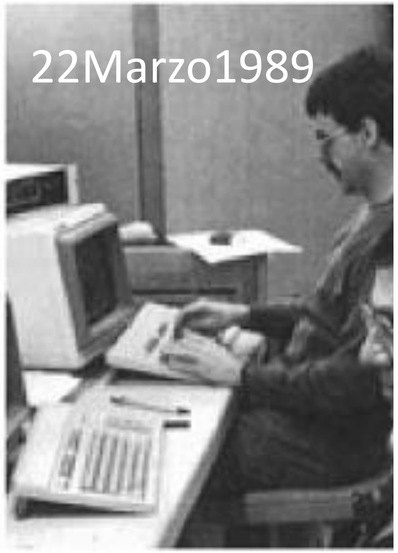
I telescopi post bellici

The 4-Meter Telescope

- Montature equatoriali
- Focali dei primari lunghe
- Specchi monolitici
- Grandi cupole

Ottica attiva e NTT

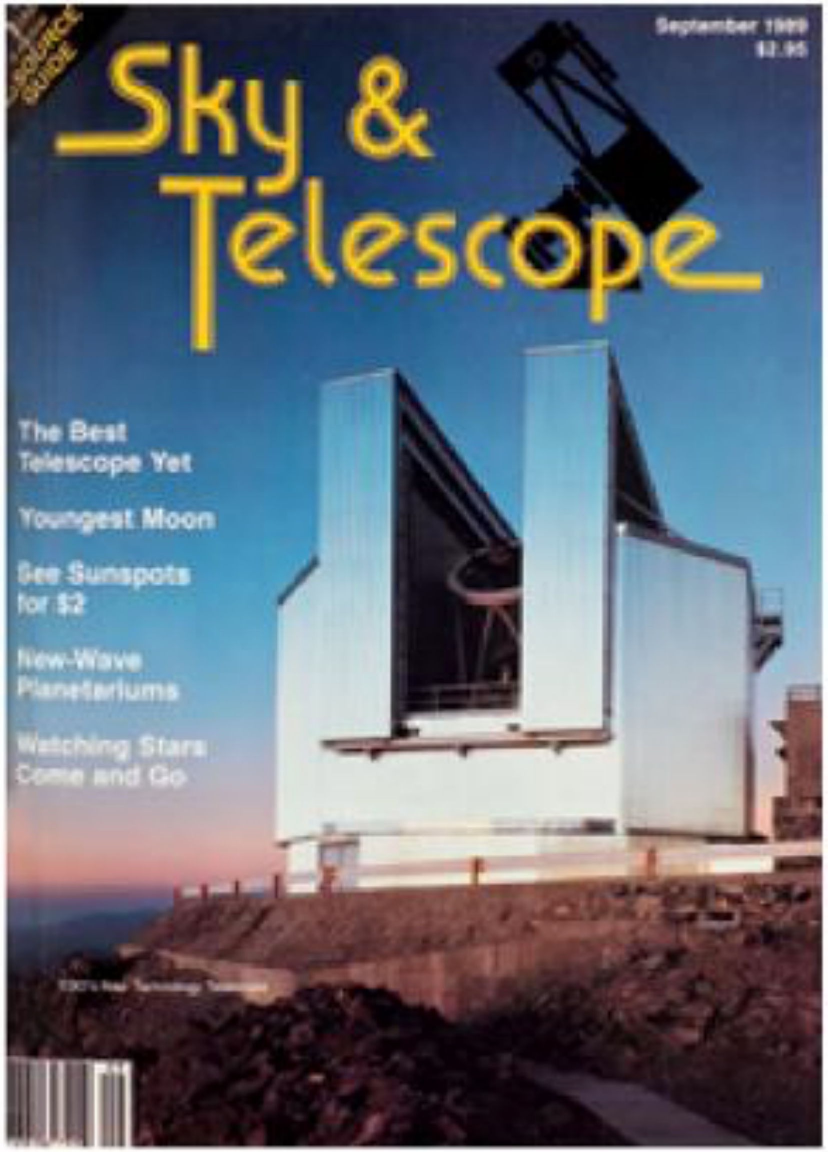
il prototipo degli at
Tecnology Telescop



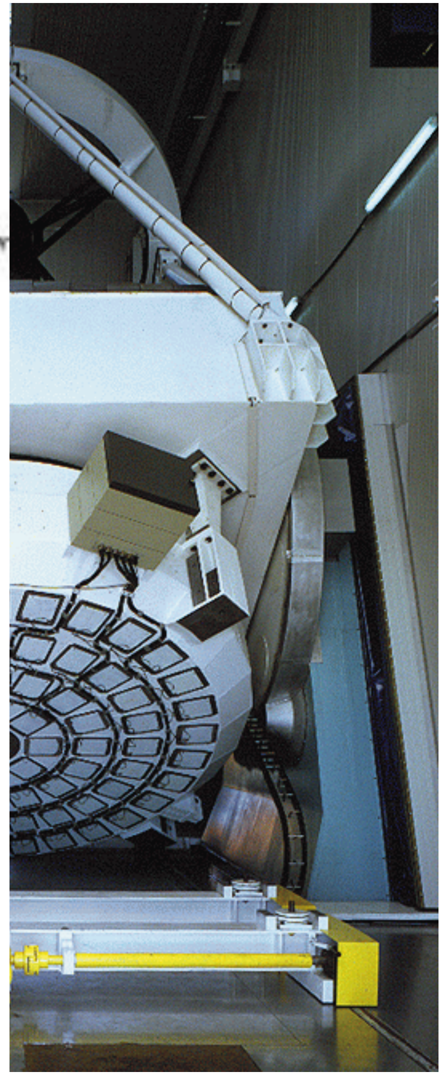
Lothar Noethe, Gaetano Andre
NTT control room during first li

1-m

NTT



"The Best Telescope Yet" was the headline about the NTT in Sky and Telescope, *the American popular astronomy magazine in September 1989.*



caratteristich

- ***ottica att***
- ***controllo***

ESO) , 3.5 m
...ca attiva.

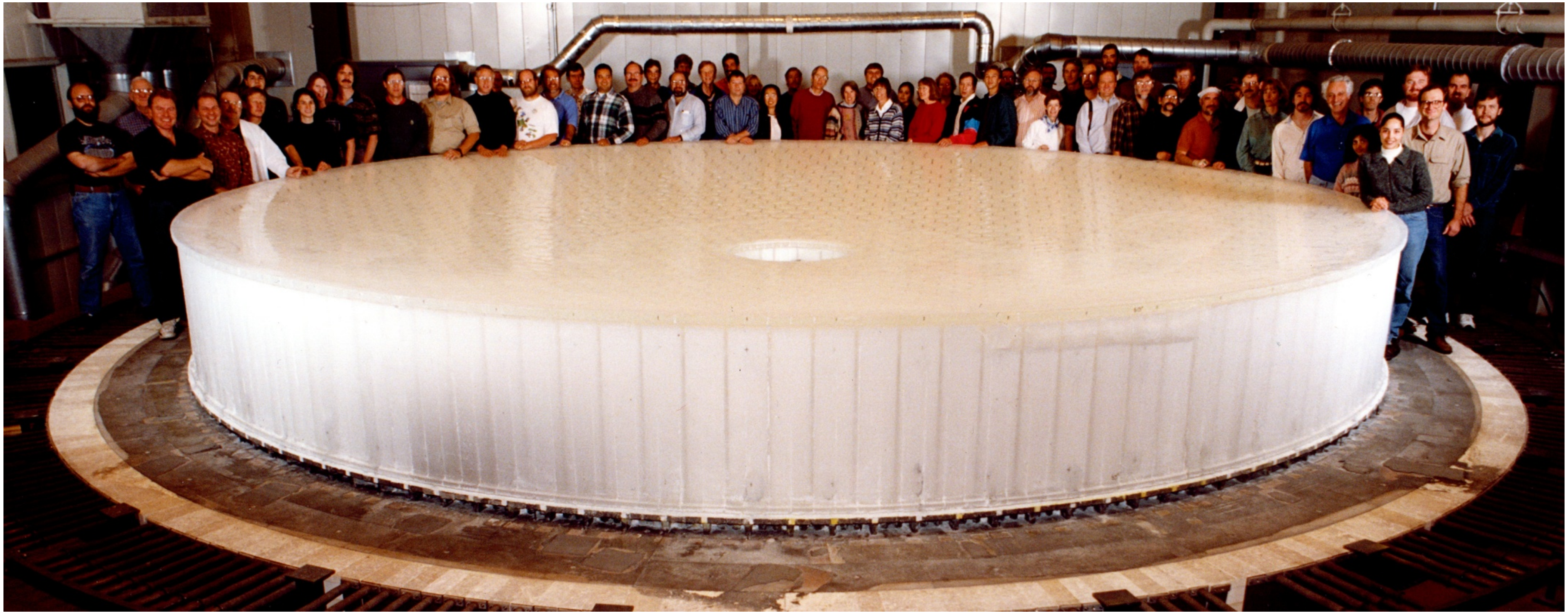
I telescopi da 8/10m di diametro

....poi a fine anni ottanta, si sono concepiti i telescopi di fine millennio,

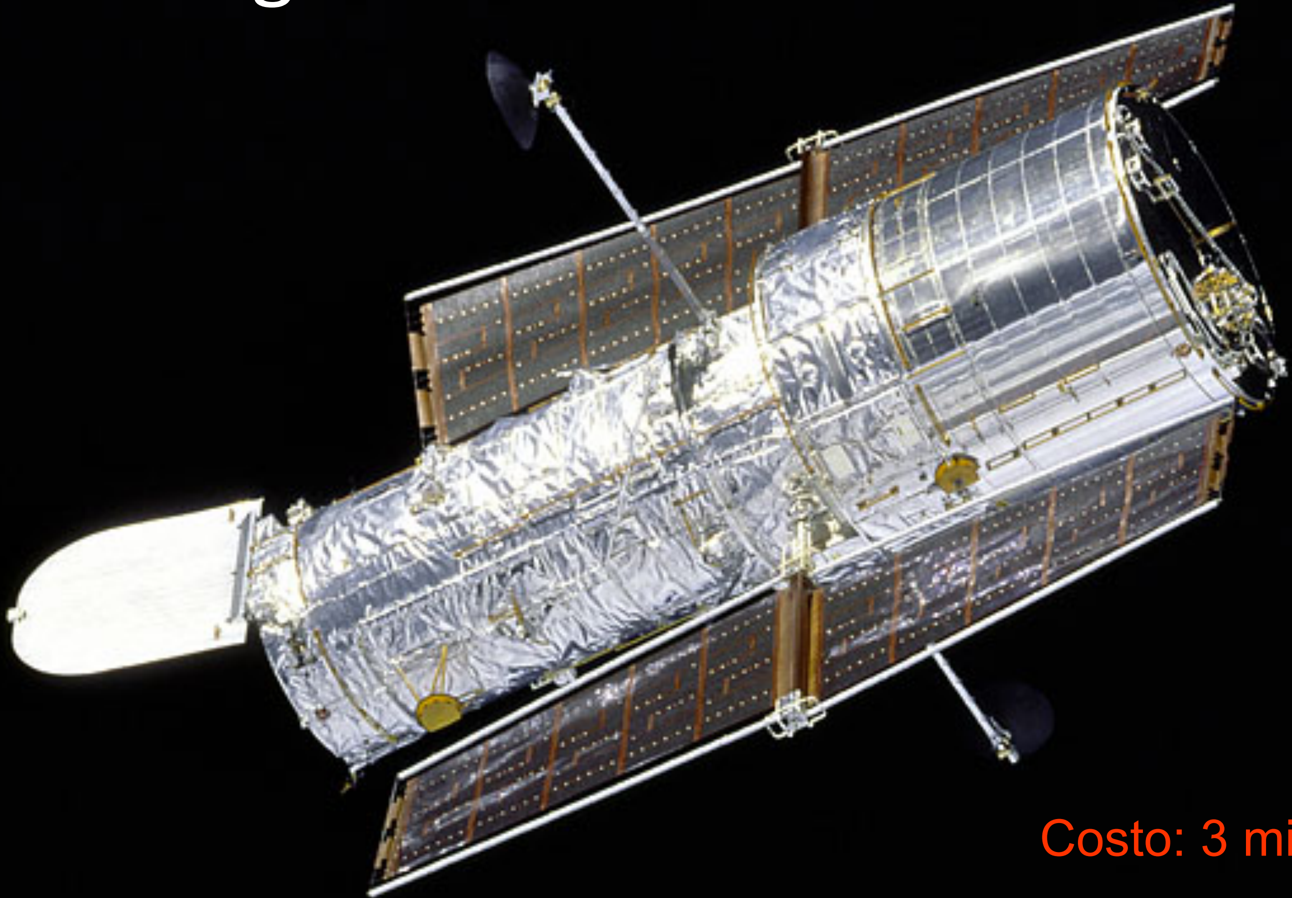
- *più grandi, 8-10 m,*
- *più numerosi, una dozzina,*
- *basati su tecnologie diverse*
- *spesso interferometrici*

....dalla metà degli anni '90, *dotati di Ottica Adattiva (che consente di migliorare (x10 e piu!) qualità d'immagine e sensibilità)*

Specchi di 8m di diametro!!!



La generazione di fine millennio



Costo: 3 miliardi di dollari!

Lo Hubble Space Telescope
Lancio 1990 (a piena capacità nel 1993)
Diametro specchio 2,4 m
Risoluzione angolare 0.1 arcosecondi (perché fuori dall’amosfera)

La generazione di fine millennio: I VLT

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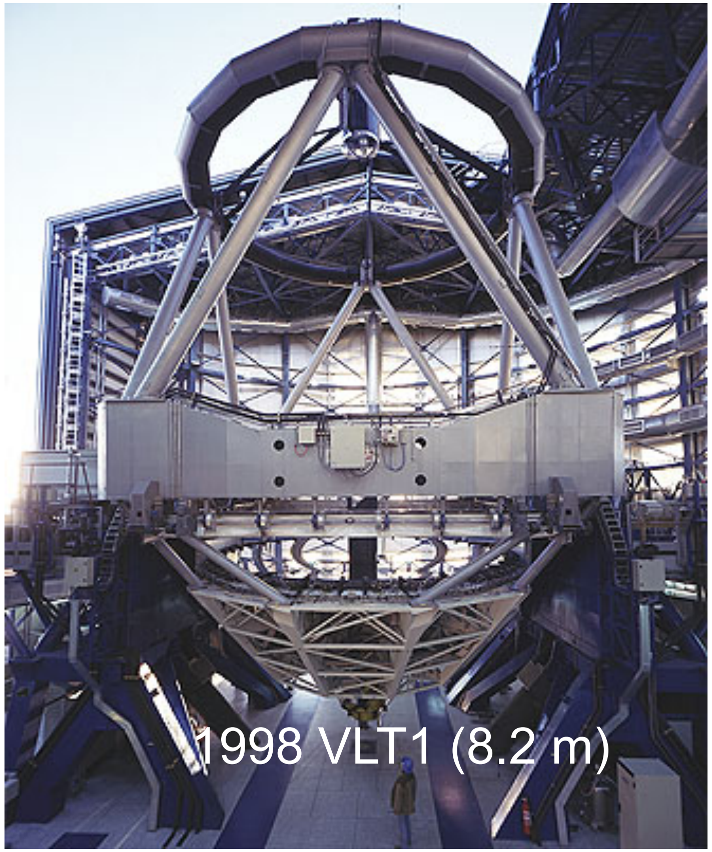
Reinhard Genzel

La generazione di fine millennio: VLT

Il più grande e versatile sistema di telescopi esistente, può essere utilizzato come interferometro



Uno dei VLT: la meccanica e le cupole sono di costruzione Italiana

Costo: ~ 400 M$

L’interferometro VLTI

La generazione di fine millennio: I due Keck

Costo: ~ 250 milioni di dollari
(12 volte meno di HST)

Keck I exterior

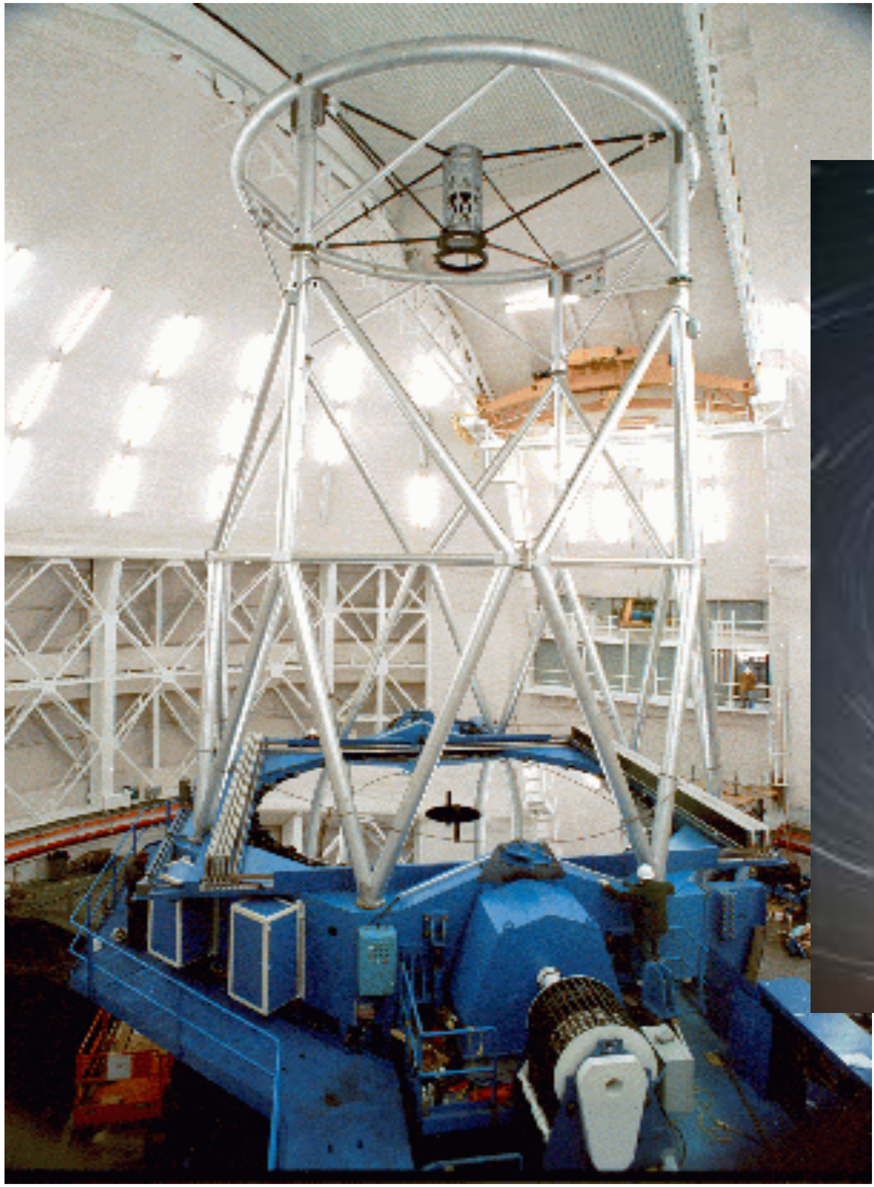
Close-up of primary mirror

© Nobel Media. Ill. Niklas Elmehed.
Andrea Ghez

Il primo grande telescopio con specchio primario segmentato. Può essere usato come interferometro

La generazione di fine millennio: Gemini

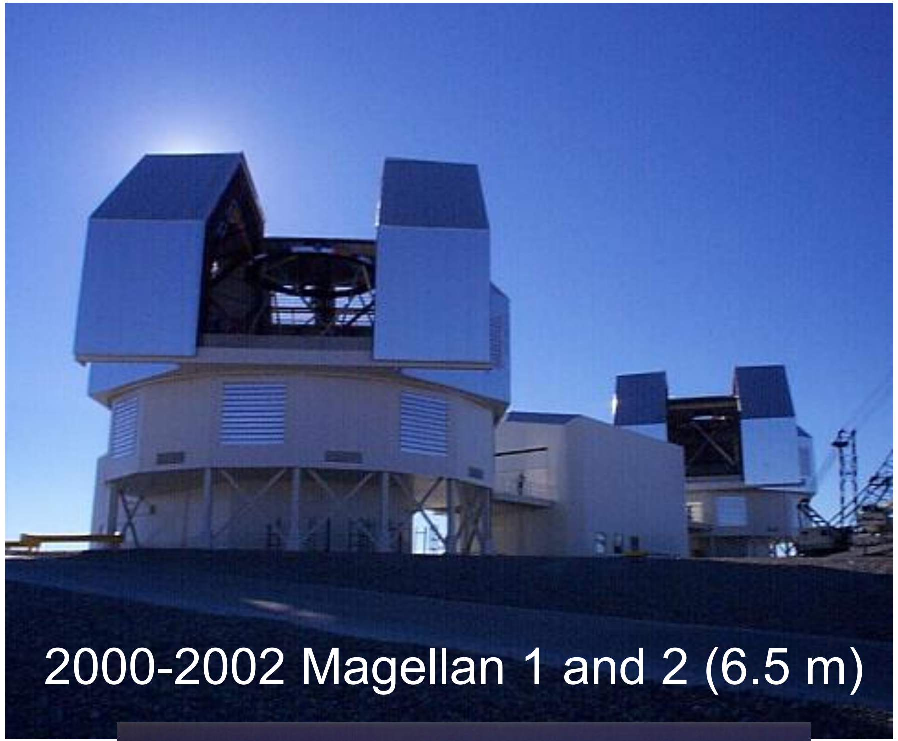
Due gemelli, uno per emisfero



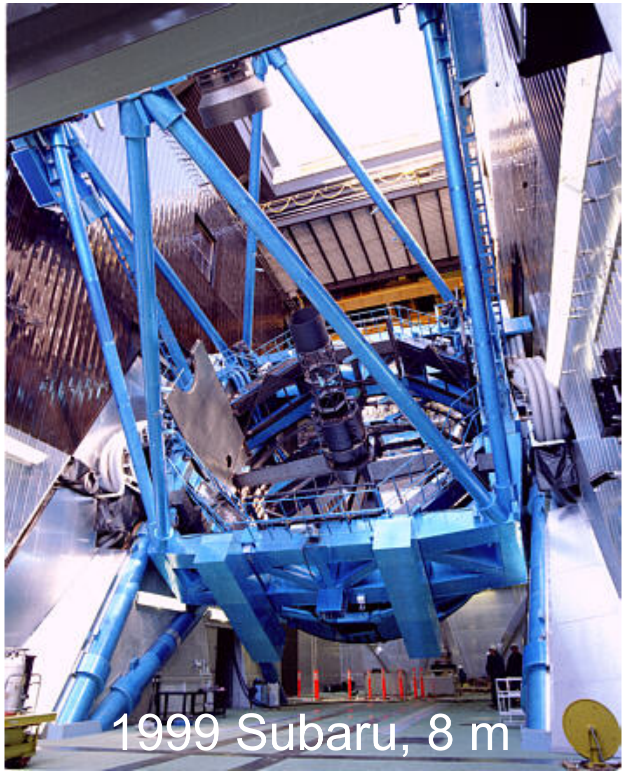
1998 Gemini North (8 m)

2002 Gemini South

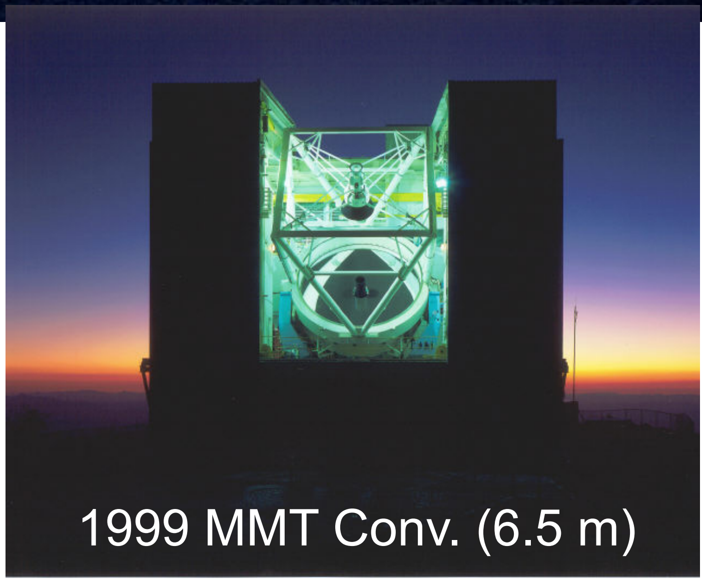
La generazione di fine millennio: Subaru, Magellan, MMT, GTC



2000-2002 Magellan 1 and 2 (6.5 m)



1999 Subaru, 8 m



1999 MMT Conv. (6.5 m)

2008, GTC , 10 m Segmented.

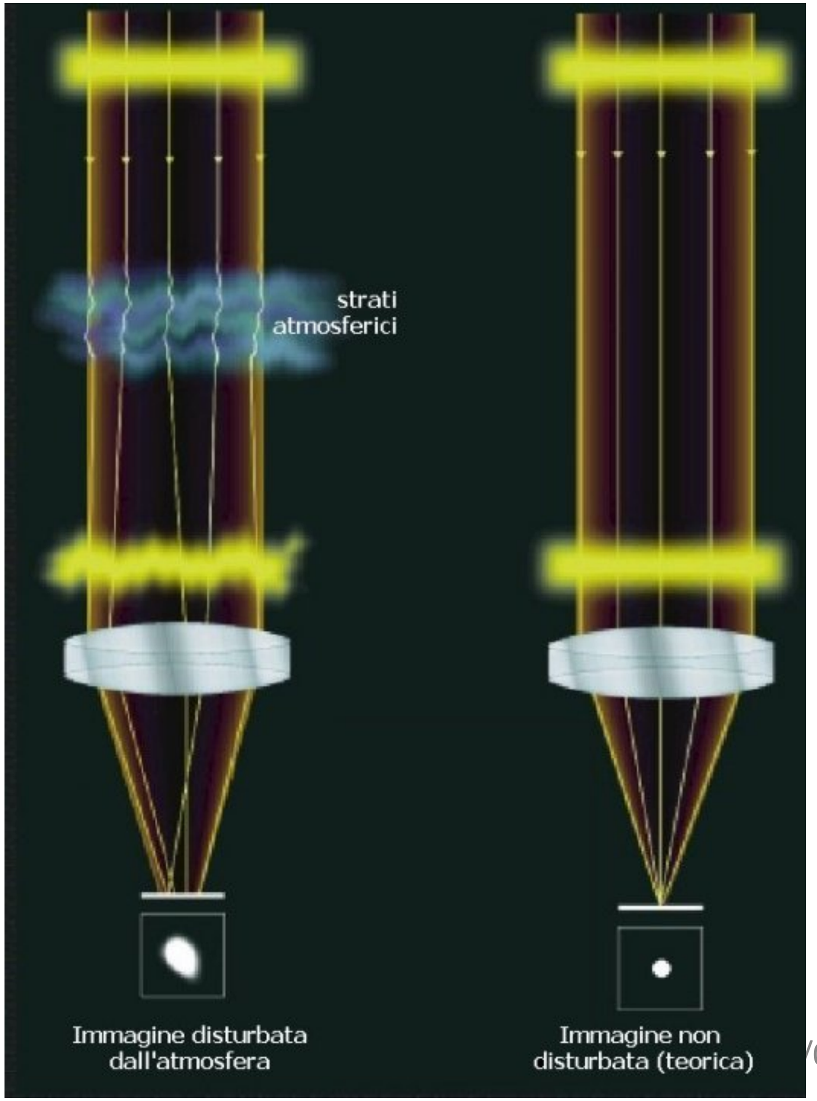
Cos'e l'ottica adattiva

L'ottica adattiva è una tecnica che si propone di eliminare le aberrazioni subite dalla luce che attraversa l'atmosfera terrestre per raggiungere i telescopi astronomici.

A) L'atmosfera terrestre ha una temperatura che varia con la altezza da terra.
B) I venti nella atmosfera mischiano volumi di aria a temperatura diversa.
C) La diversa temperatura genera diversa densità e quindi diverso indice di rifrazione
D) l'immagine ottenuta a terra ha la risoluzione di un telescopio da 10-20 cm.

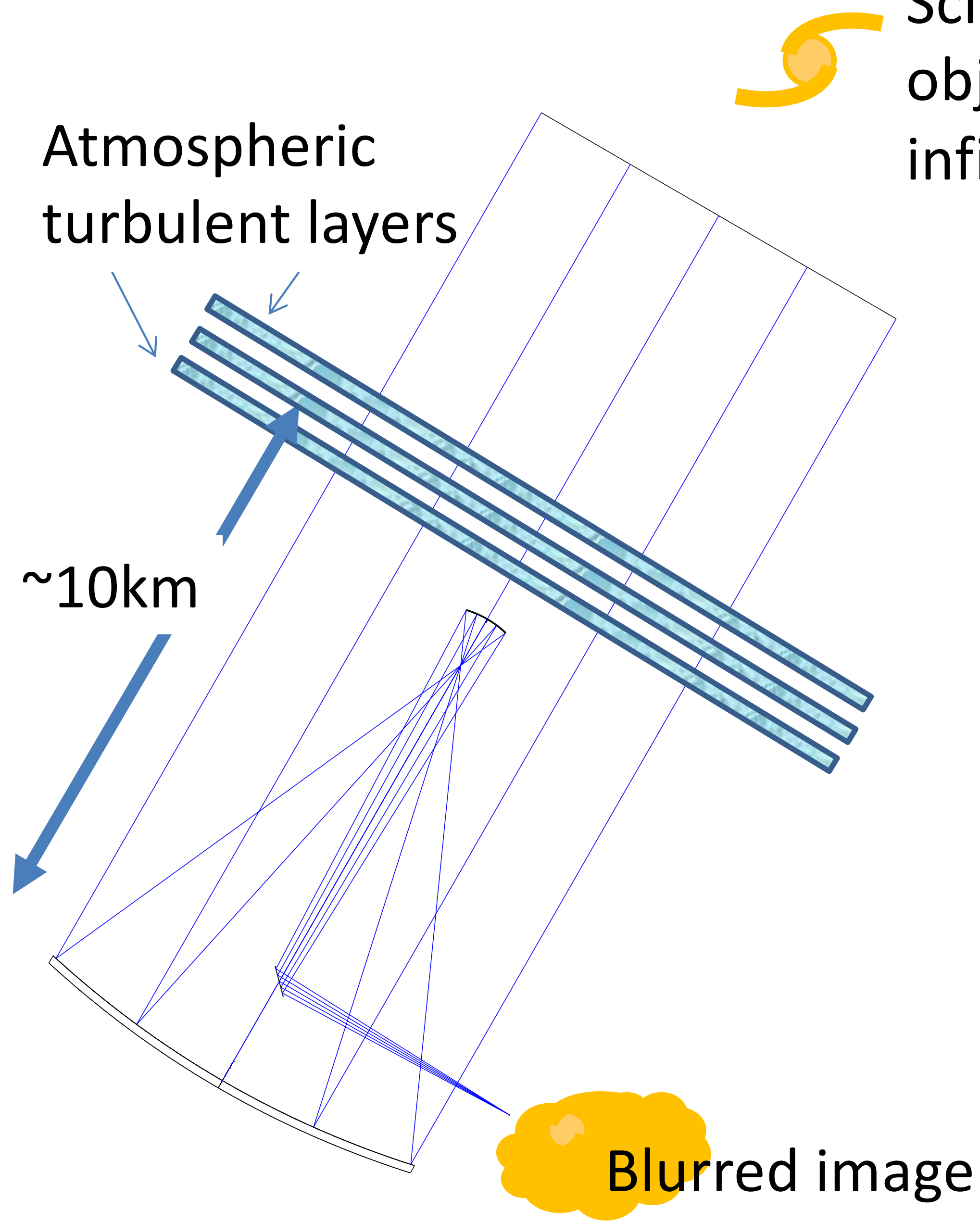
I sistemi adattivi si pongono l'obiettivo di misurare in tempo reale le aberrazioni introdotte dalla atmosfera e correggerle.

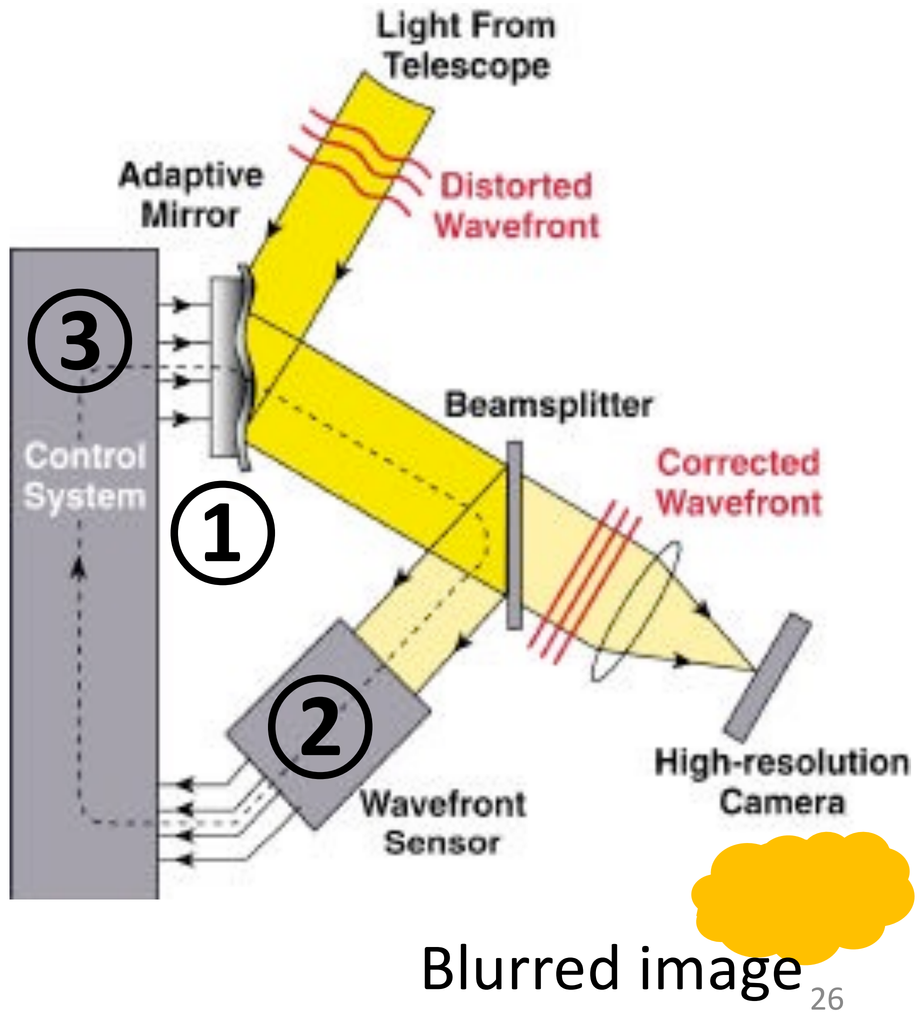
Fatto ciò, un telescopio a terra si comporterà come un telescopio posto nello spazio !!!



An Astronomical AO system

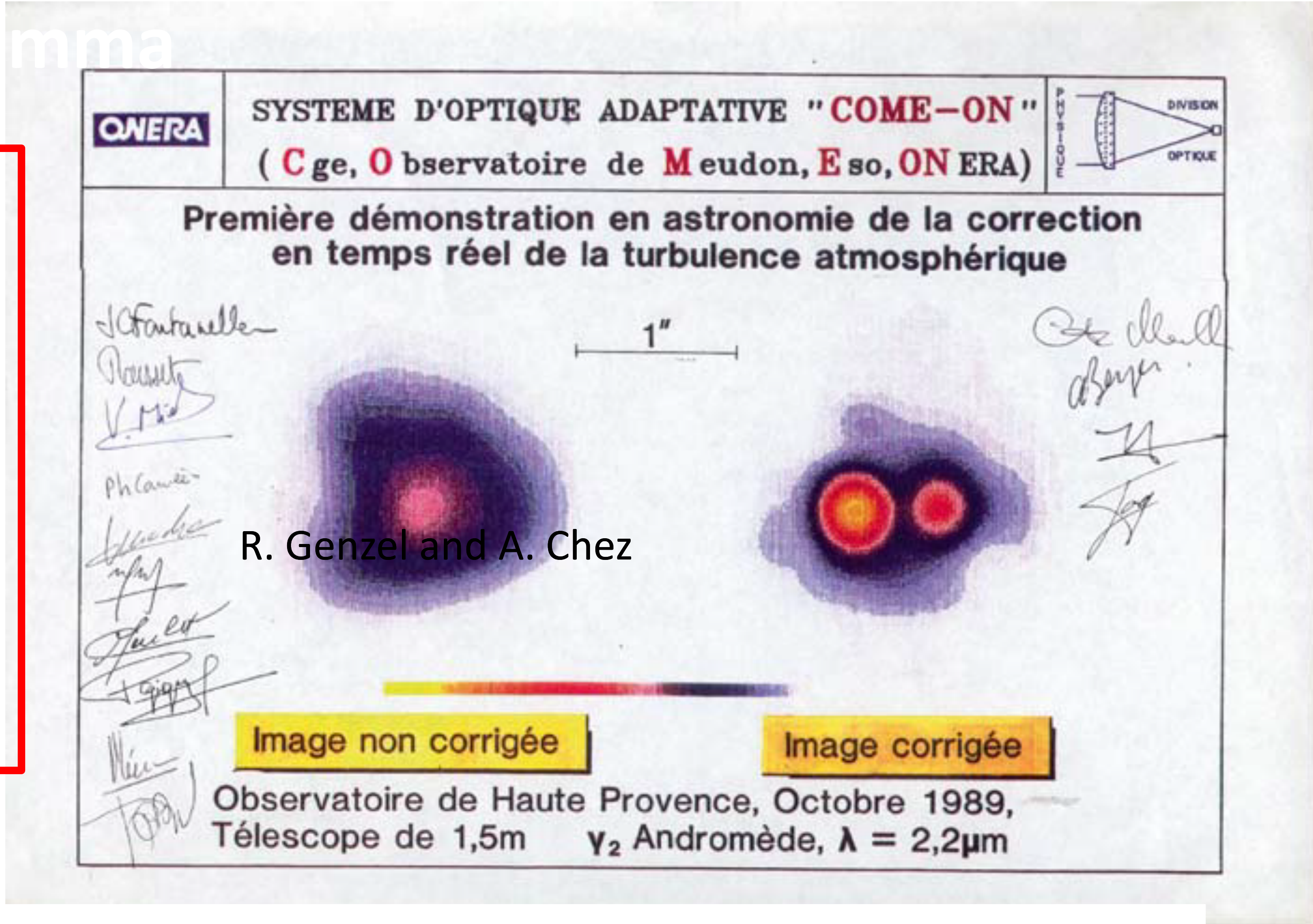
Main components:
1) Adaptive mirror
2) Wavefront sensor
3) Control system





The first example:

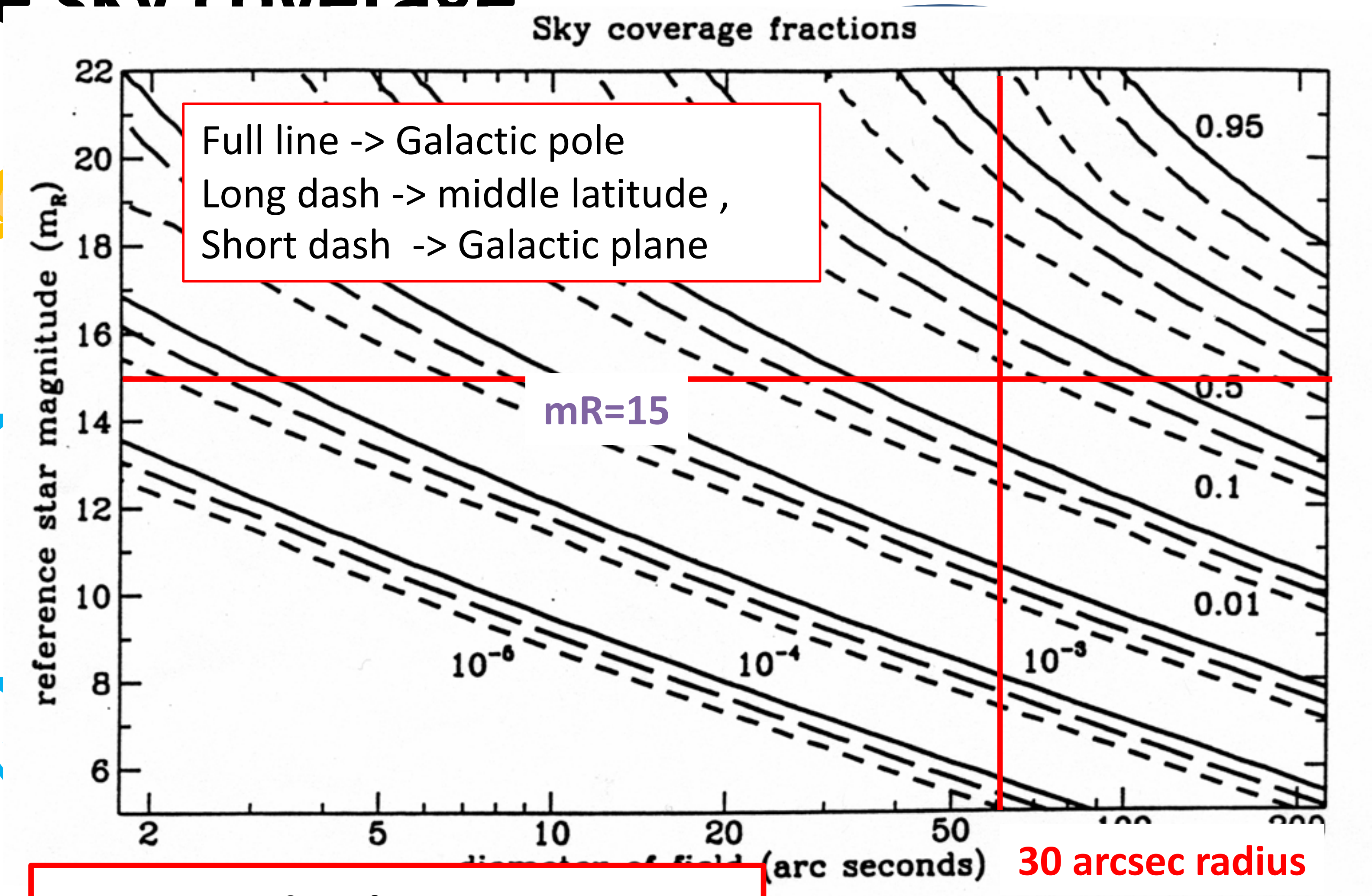
A double star with separation smaller than the seeing value (0.8 arcsec). An example from Come-OnAO system installed on the 1.5m telescope of Haute Provence, France.



R. Genzel and A. Chez

"The first astronomical adaptive-optics observation (1989). A nearly-diffraction limited image of the double star *γ*2 And is resolved at the 1.52-m telescope of the Observatoire de Haute- Provence in October 1989, with the come-on instrument. Signatures from team members J.-C. Fontanella, P. Gigan, P. Léna, F. Merkle, G. Rousset and a few others celebrate the event." (Picture & text from P. Lena, 2009)

The AO reference star and the sky coverage



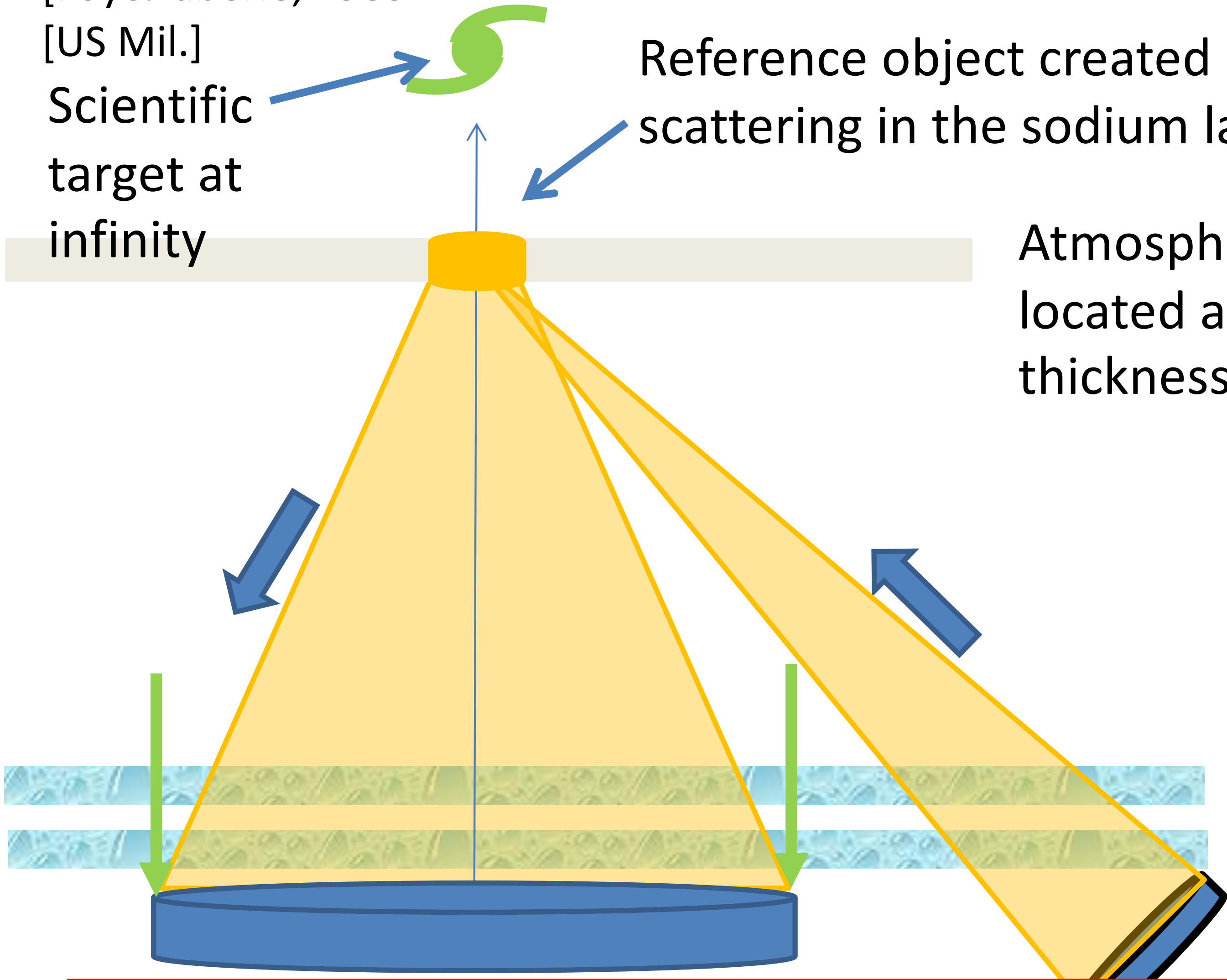
< 10% di sky coverage

Telescope aperture

A typical ϑiso value for astronomical observations is 30 arcsec for H-K band

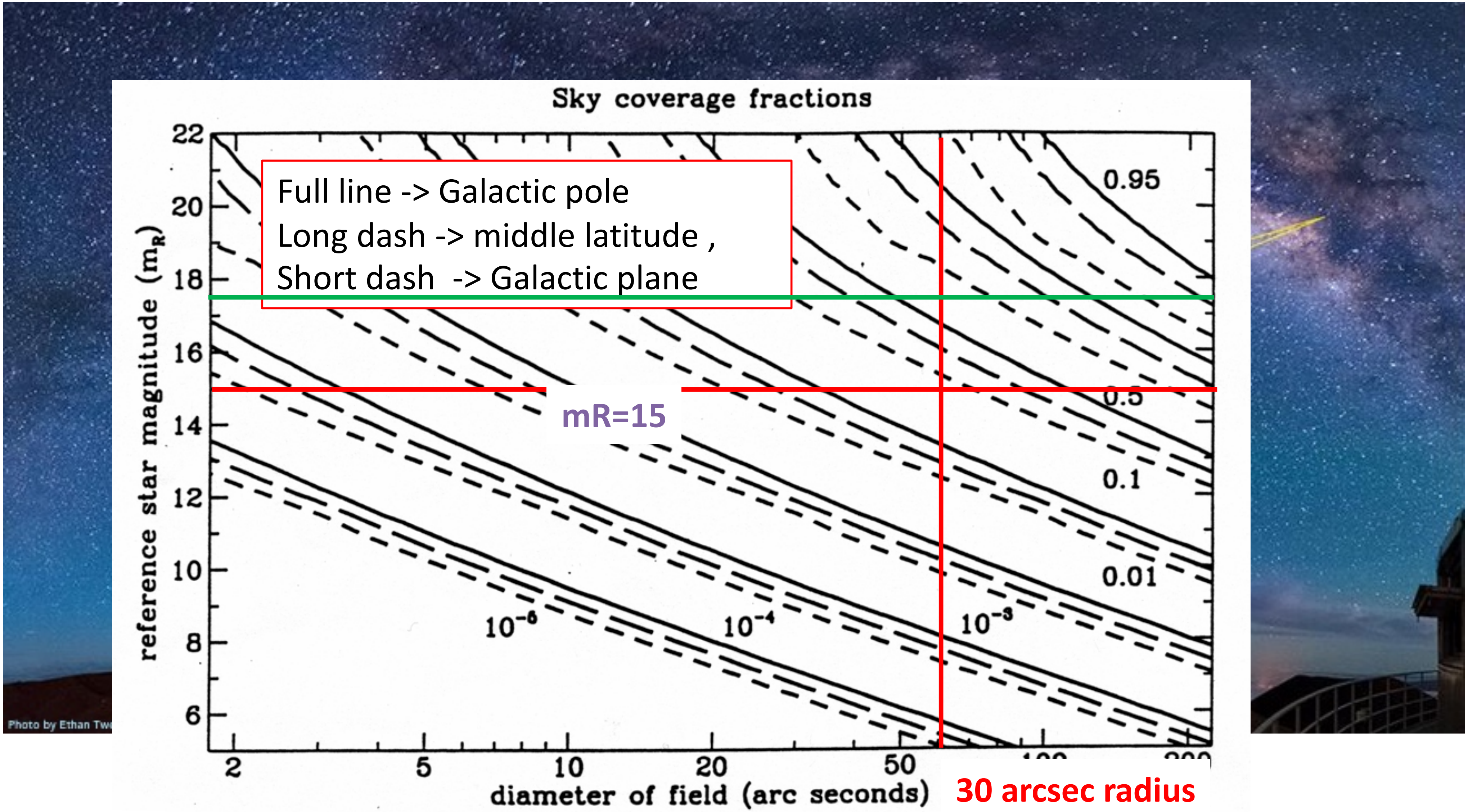
Laser Guide stars (the sodium case)

[Foy&Laberie, 1985
[US Mil.]



Laser passes twice in the atmosphere so, tip tilt is undetermined. A NGS is needed for tilt measurements.

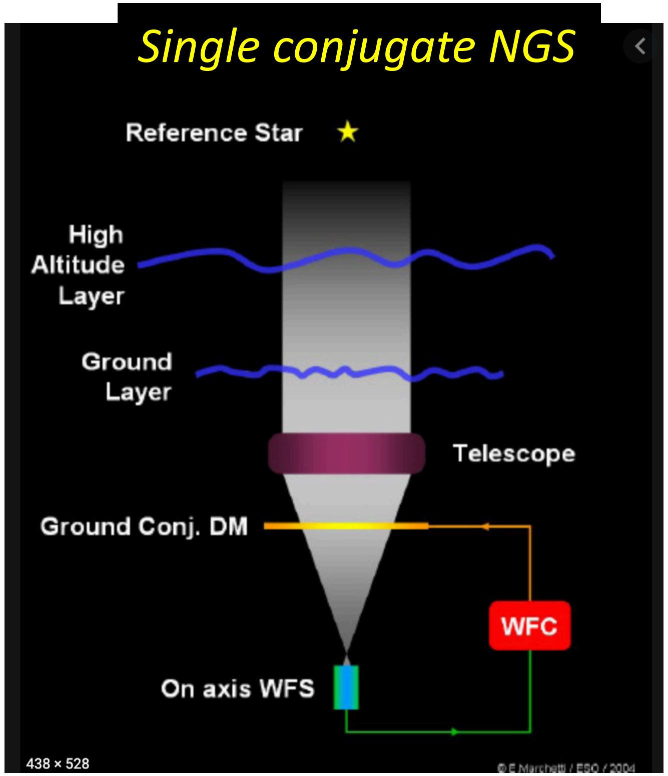
Keck telescopes Laser Guide Star

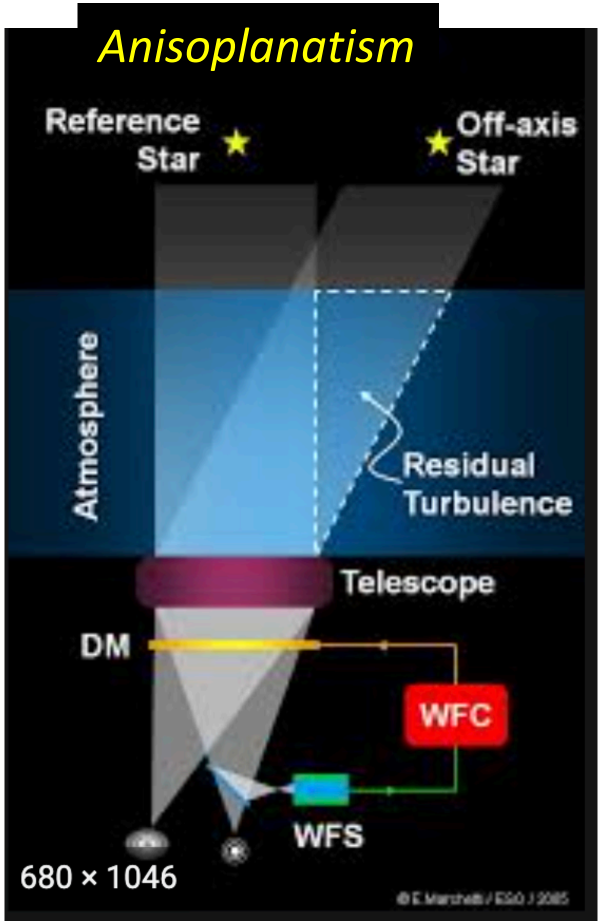


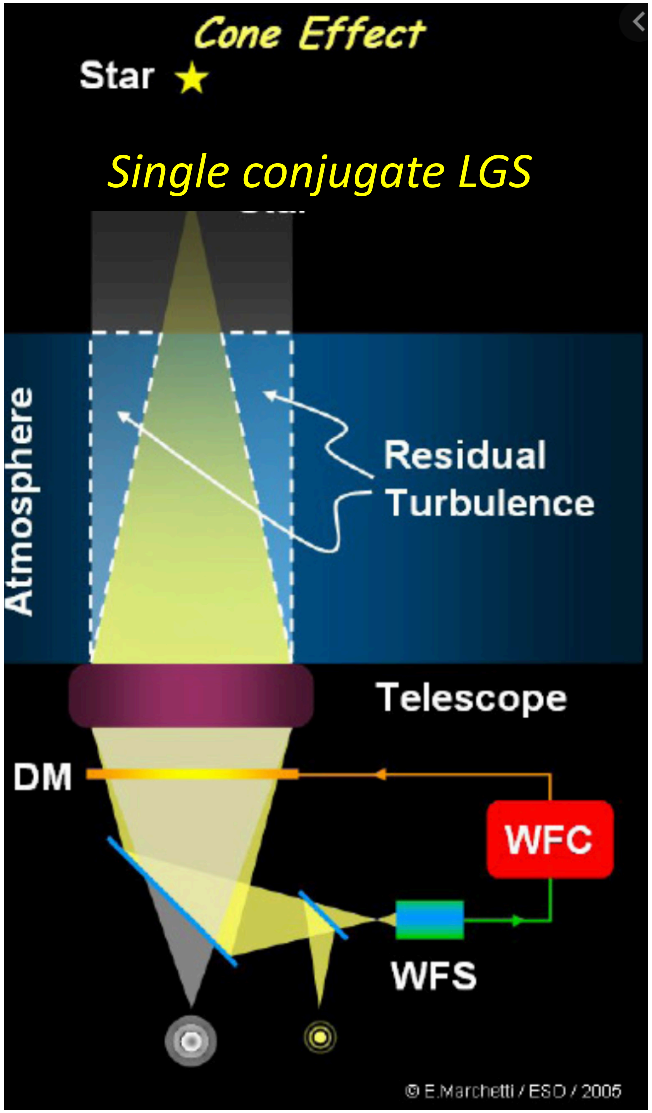
> 30% di sky coverage

Pictures from E. Marchetti, ESO

AO systems



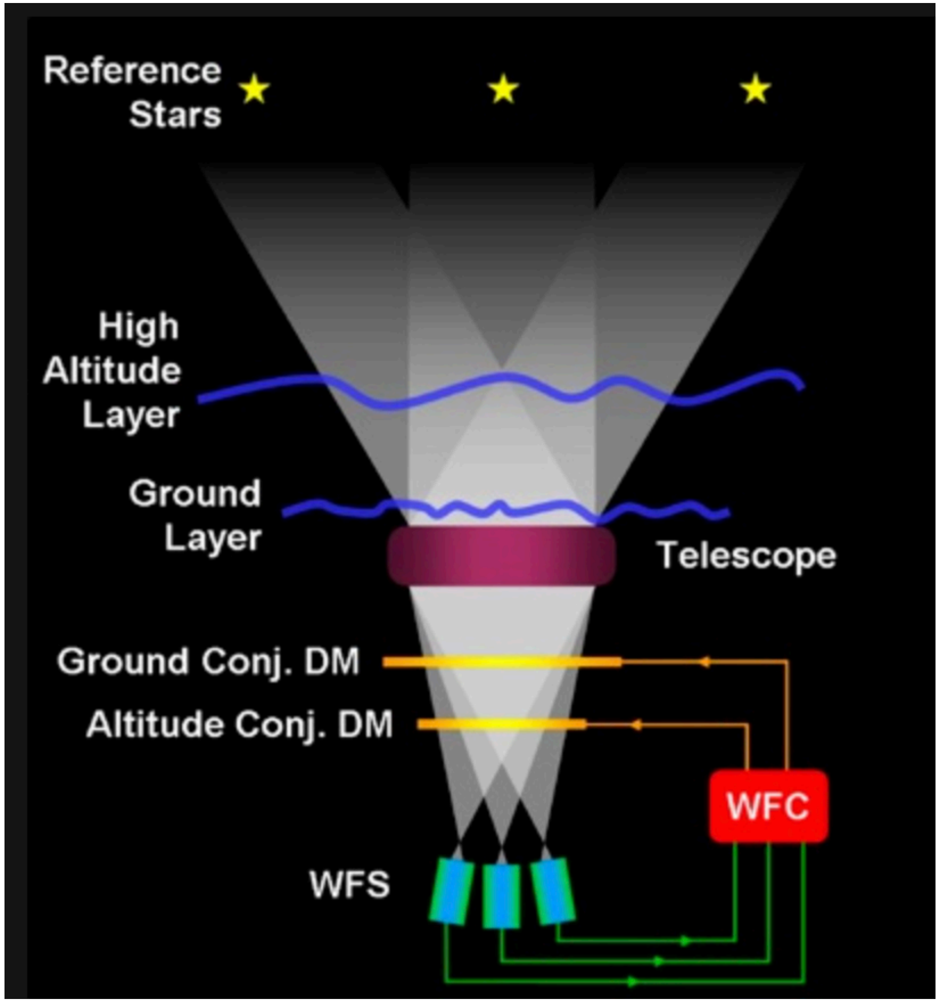


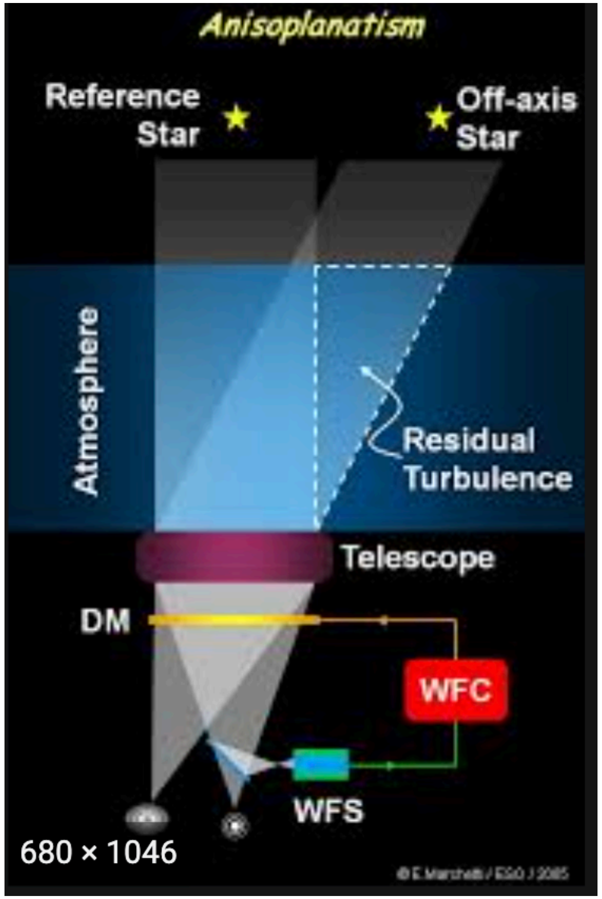


Cosa succede quando vogliamo correggere un campo più esteso dell'angolo isoplanatico ovvero 20-30arcsec in NIR o 5-10arcsec in VIS?

MCAO systems

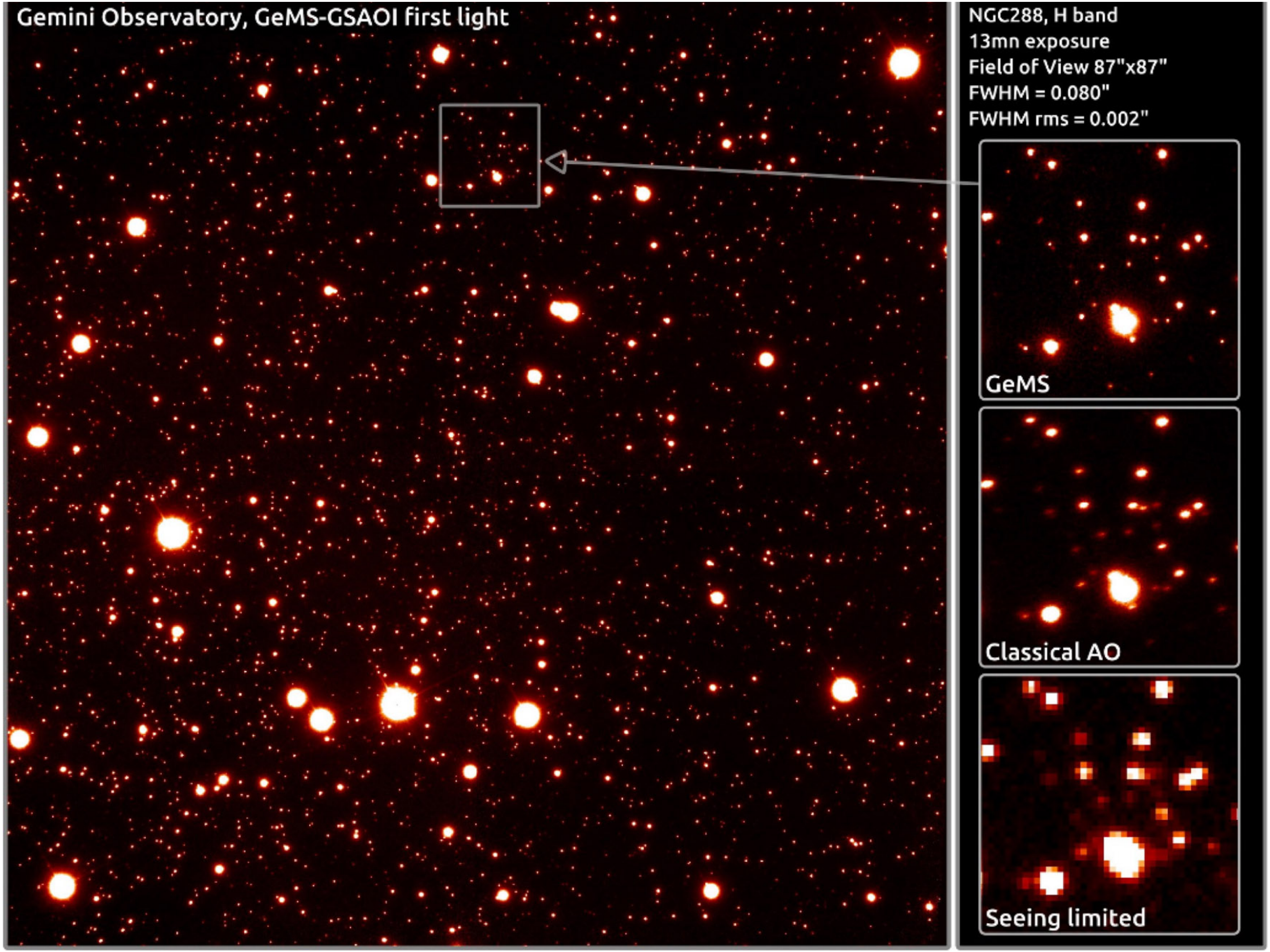
Si vuole correggere una *porzione* di atmosfera più grande!! Si utilizzano i sistemi multiconiugati che utilizzano piu stelle e piu sensori di fronte d'onda, uno per stella.





The Gemini MCAO system GeMS

Photo credit: Gemini Observatory/Association of Universities for Research in Astronomy Inc., AURA)


Gemini Observatory, GeMS-GSAOI first light
NGC288, H band
13mn exposure
Field of View 87"x87"
FWHM = 0.080"
FWHM rms = 0.002"
GeMS
Classical AO
Seeing limited

Visible MCAO @ VLT

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Australian National University

AAO

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

MACQUARIE University
SYDNEY·AUSTRALIA

ESO

MAVIS overview

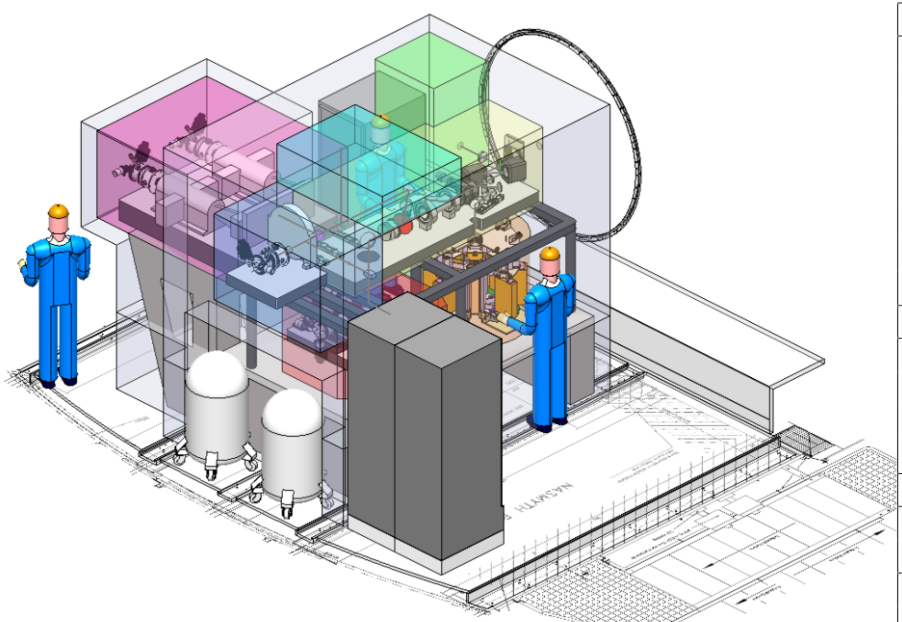


Figure 9. Mechanical overview of MAVIS on the Nasmyth platform

Table 1. Main characteristics of the AO module, Imager and Spectrograph

General Properties - AO Module				
Focus	Nasmyth A VLT-AOF (UT4)			
NGS Field of View	120″ diameter disk			
Number of NGS	≤ 3			
Limiting magnitude	Hmag ≥ 18.5			
LGS beacons	8 on a circle of 17.5″ ⌀			
Sky coverage	≥ 50% at the South Galactic Pole			
Ensquared Energy	> 15% within 50mas at 550nm			
Strehl	> 10% (15% goal) in V-band			
Imager				
Field of View	30″ x 30″			
Pixel Scale	7.36 mas/pix			
Sensitivity	V > 29mag (5σ) in 1hr			
Filters	BVRI, ugriz, various narrow bands			
Spectrograph				
IFU Spaxel Size and FoV	Fine Sampling: 20-25mas spaxels, 2.5″ x 3.6″ FoV Coarse Sampling: 40-50mas spaxels, 5″ x 7.2″ FoV			
Spectral Configurations	LR-BLUE	LR-RED	HR-BLUE	HR-RED
Median Resolution ($\lambda/\Delta\lambda$)	5,900	5,900	14,700	11,500
Wavelength	370-720nm	510-1000nm	425-550nm	630-880nm
Sensitivity (10σ in 1hr, ABmag, Fine Sampling)	21@550nm	21.5@750nm	19.6@475nm	20.7@725nm

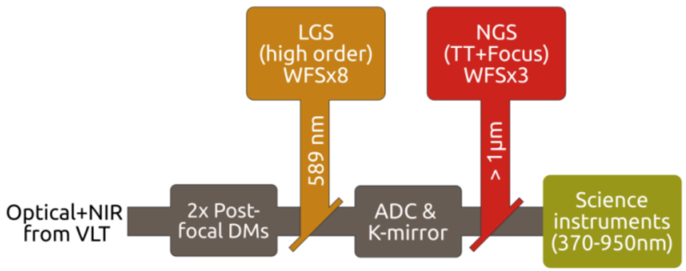
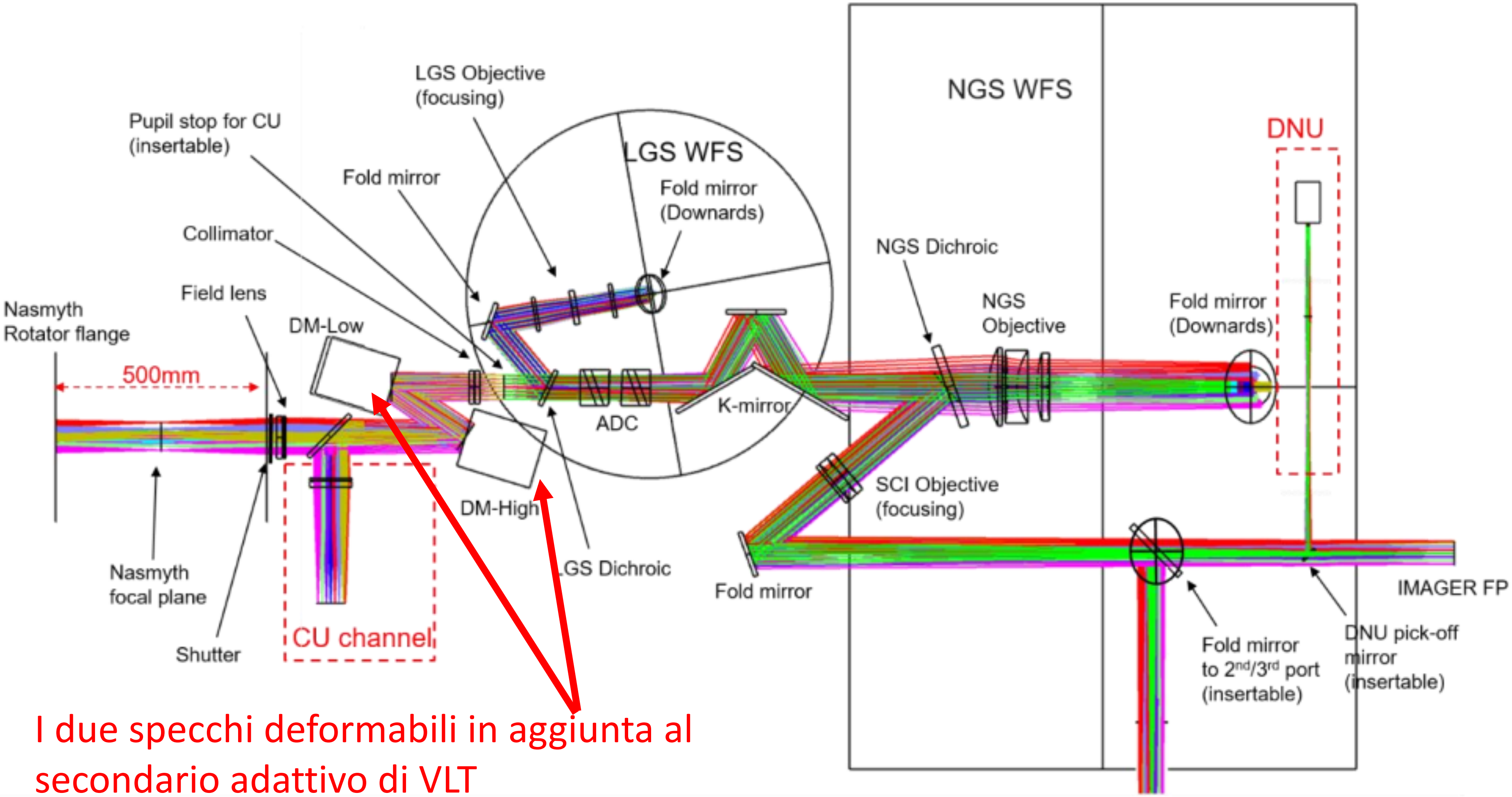


Figure 6. Guide star pick up cascade and wavelength split

MAVIS AO Module



I due specchi deformabili in aggiunta al secondario adattivo di VLT

E dopo?

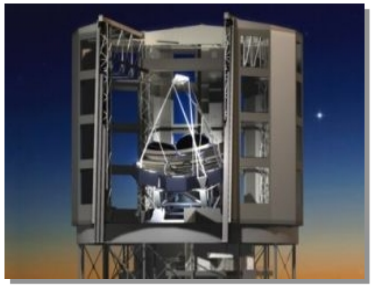
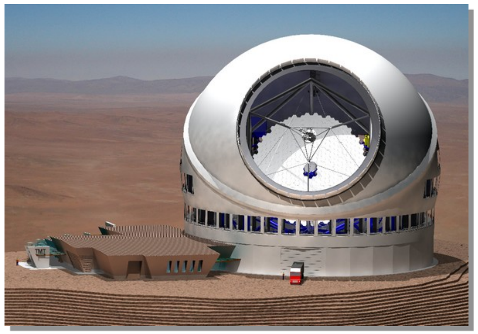
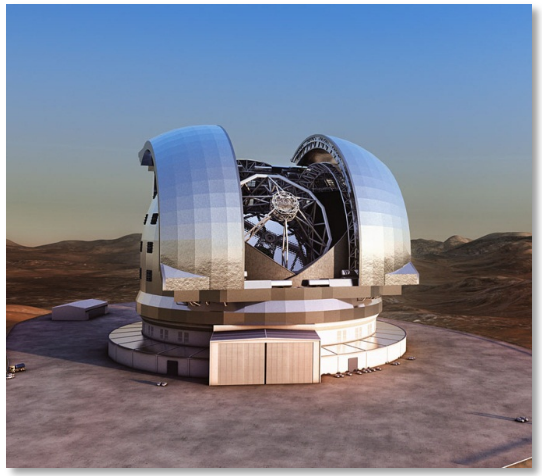
Vediamo cosa bolle in pentola….

Gli Extremely Large Telescopes

Ancora una volta nuovi strumenti!!!!

Discoveries by opening a new parameter space

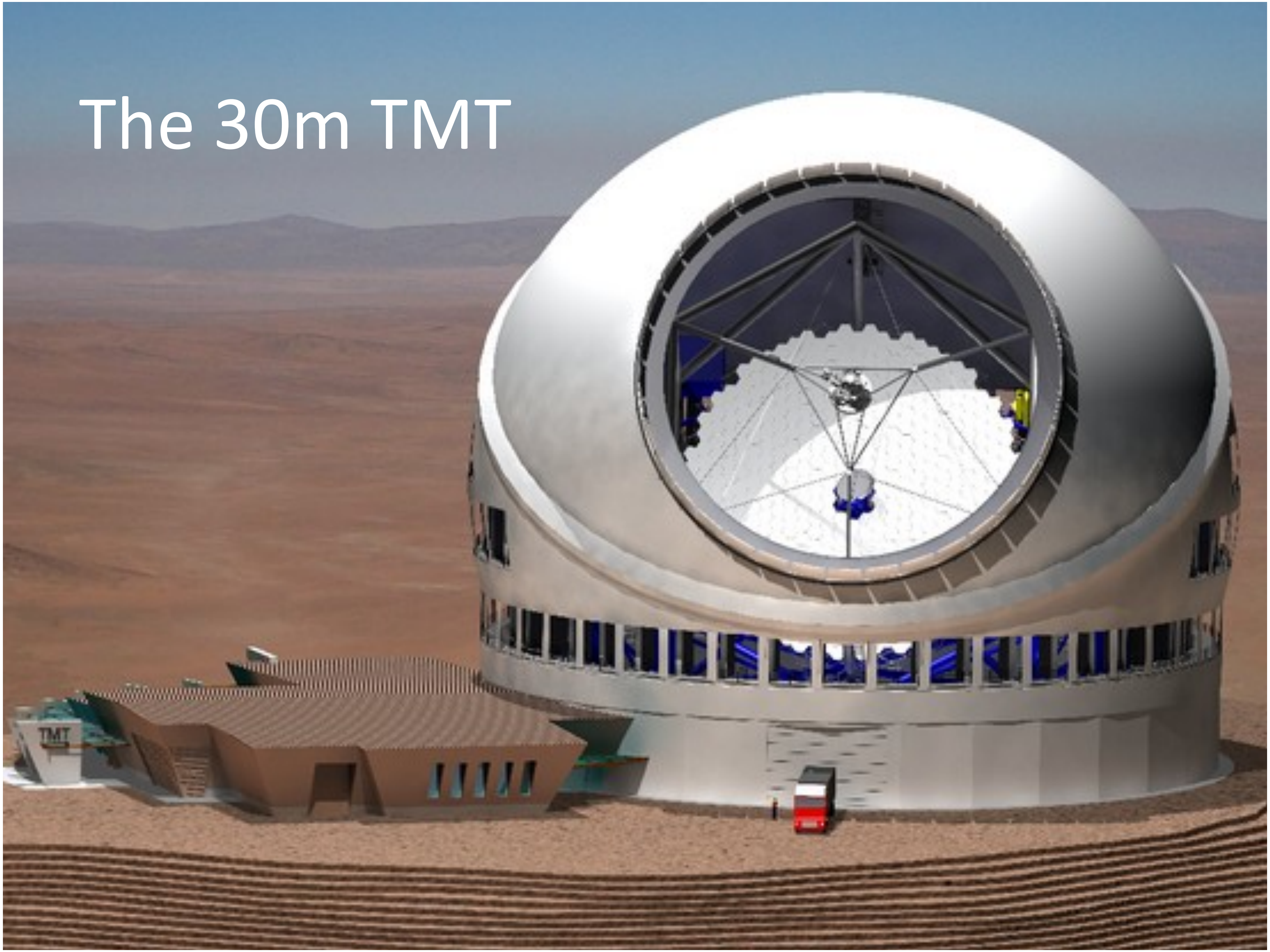
- **Increased Sensitivity**
- **Spatial resolution (10 mas scale)**

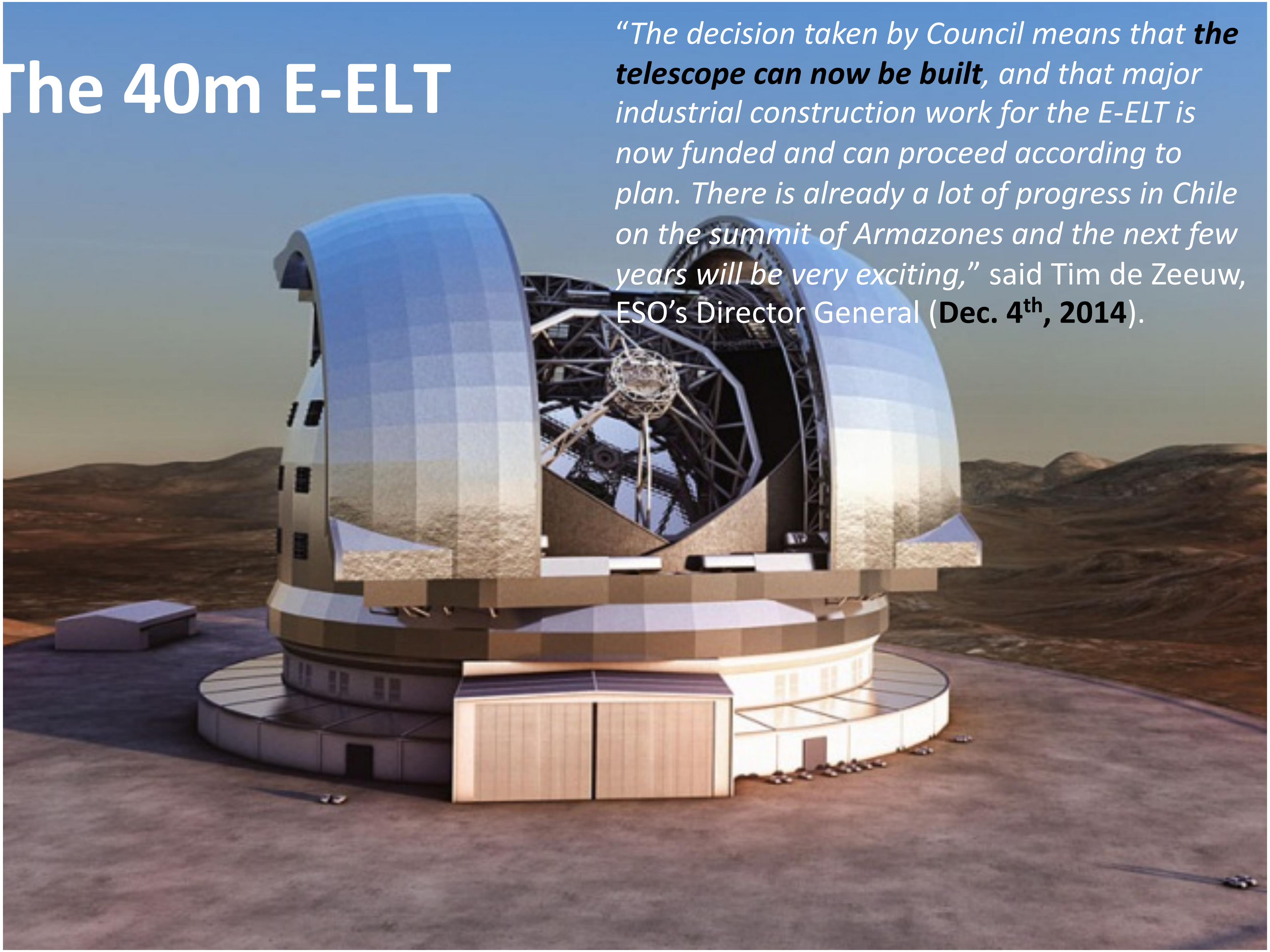
	50m2	400m2	600m2	1200m2	(JWST: 25m2)
2 µm	50mas	18mas	14mas	10mas	(JWST: 68mas)
	8m	25m	30m	40m	

The 25m GMT

The 30m TMT



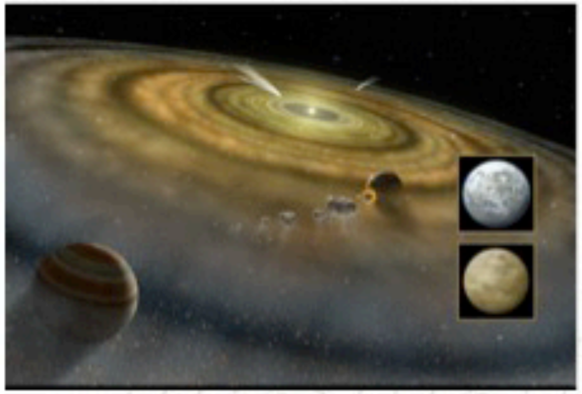
The 40m E-ELT



"The decision taken by Council means that ***the telescope can now be built****, and that major industrial construction work for the E-ELT is now funded and can proceed according to plan. There is already a lot of progress in Chile on the summit of Armazones and the next few years will be very exciting,"* said Tim de Zeeuw, ESO's Director General (**Dec. 4th, 2014**).

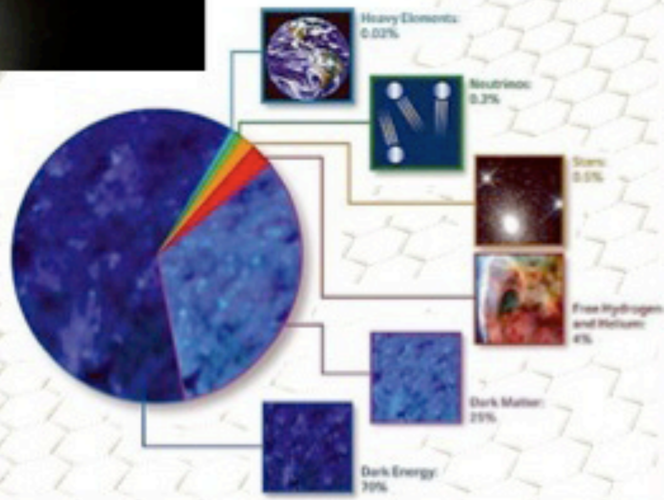
THE DRIVER

- **Planets in other stellar systems**
  - Imaging ***and*** spectroscopy
  - The quest for Earth-like exo-planets

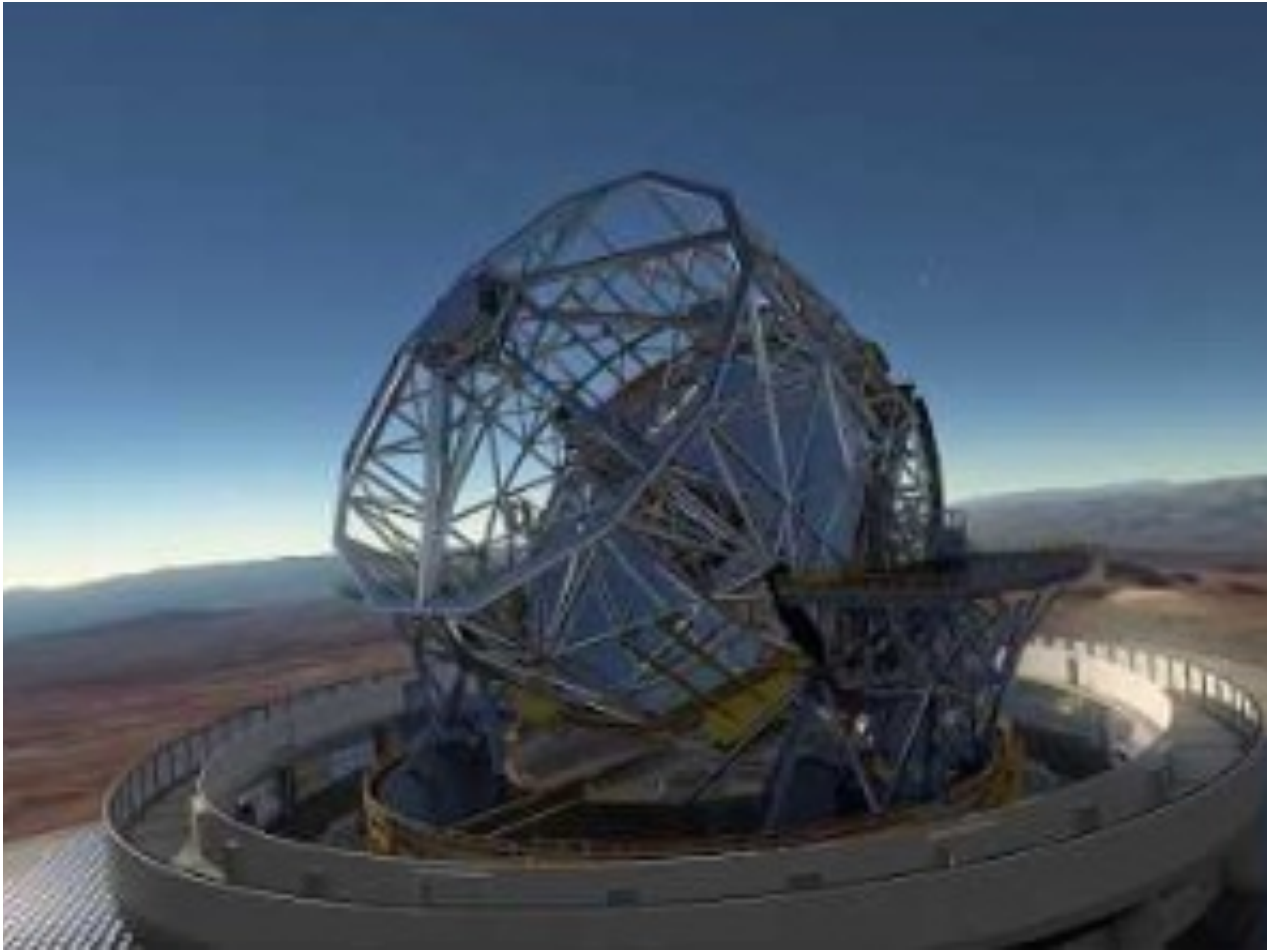


- **Stellar populations**
  - In galaxies inaccessible today (e.g. ellipticals in Virgo cluster)
  - Across the whole history (i.e. extent) of the Universe

- **Cosmology**
  - The first stars/galaxies
  - Direct measure of deceleration
  - Evolution of cosmic parameters
  - Dark matter, dark energy



- **The unknown**
  - Open new parameter space



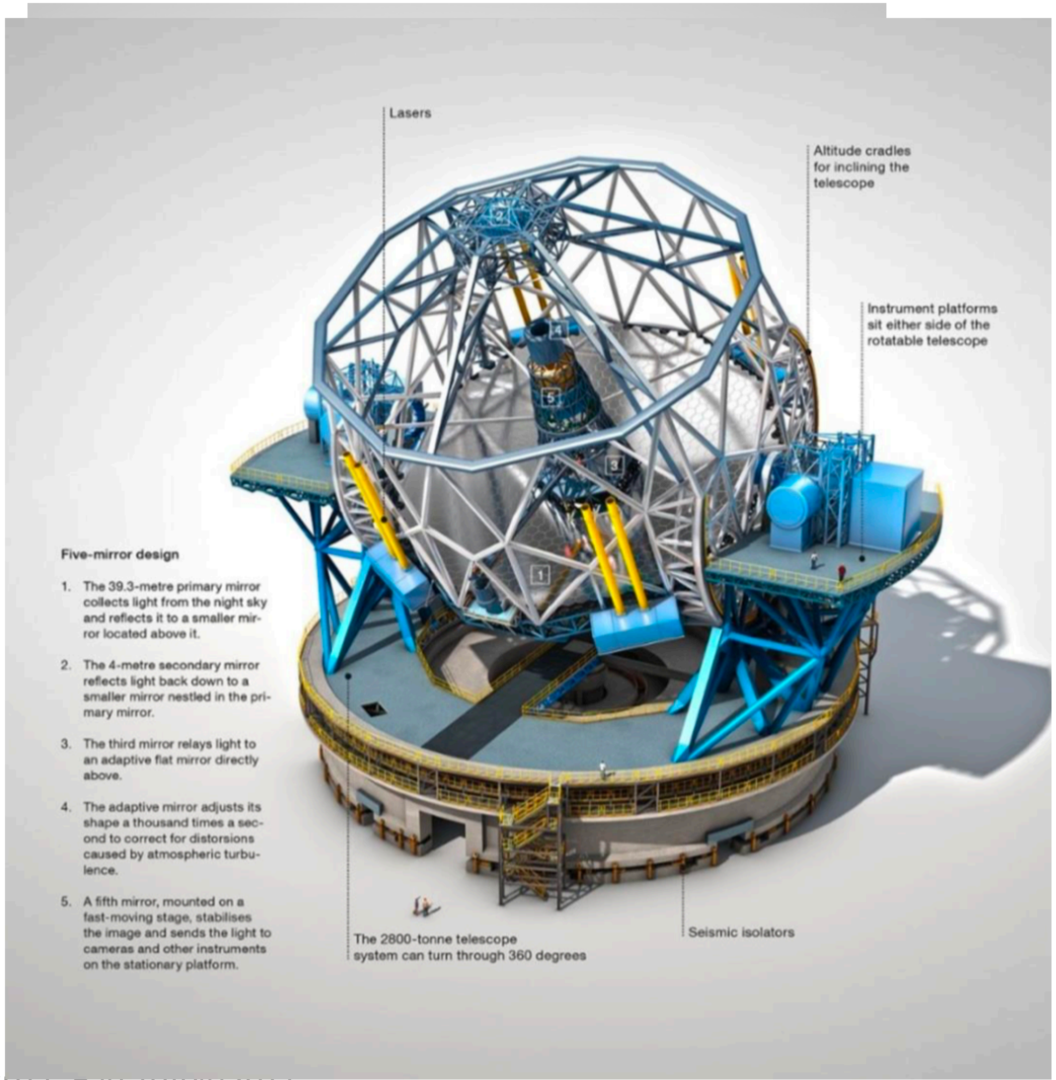
The E-ELT Project

The Telescope

- **40-m class telescope**: largest **optical-infrared** telescope in the world.
  (GMT = 25m; TMT = 30m)

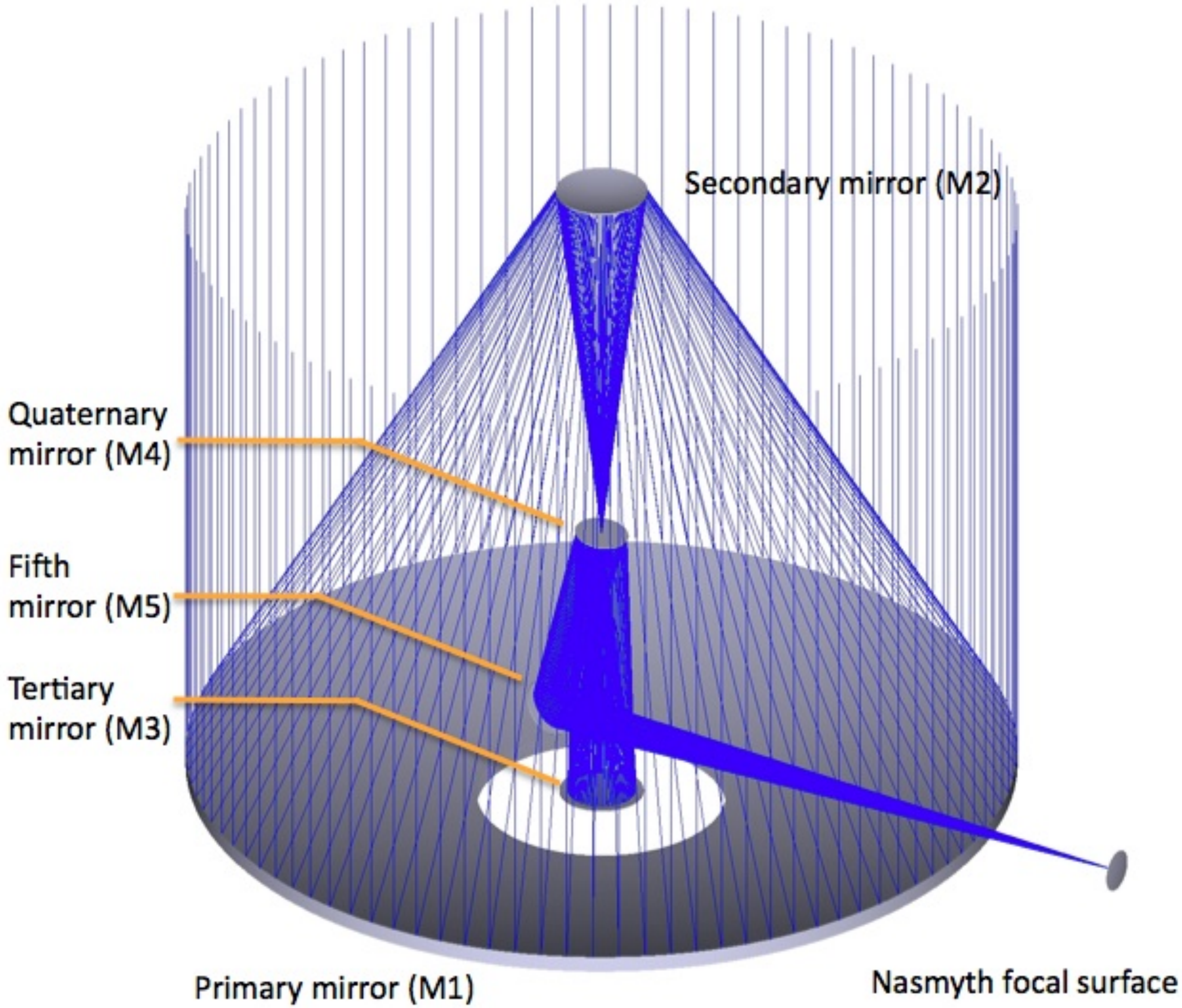
- **Segmented** primary mirror.
  798 segmenti 1.4m
- **Adaptive optics** assisted telescope.
  M4 & M5 adaptive
- Diffraction limited performance:
  12mas@K-band
  Wide field of view: 7arcmin.

- Mid-latitude site (Amazones/Chile).
  Fast instrument changes.
  VLT level of operations efficiency.

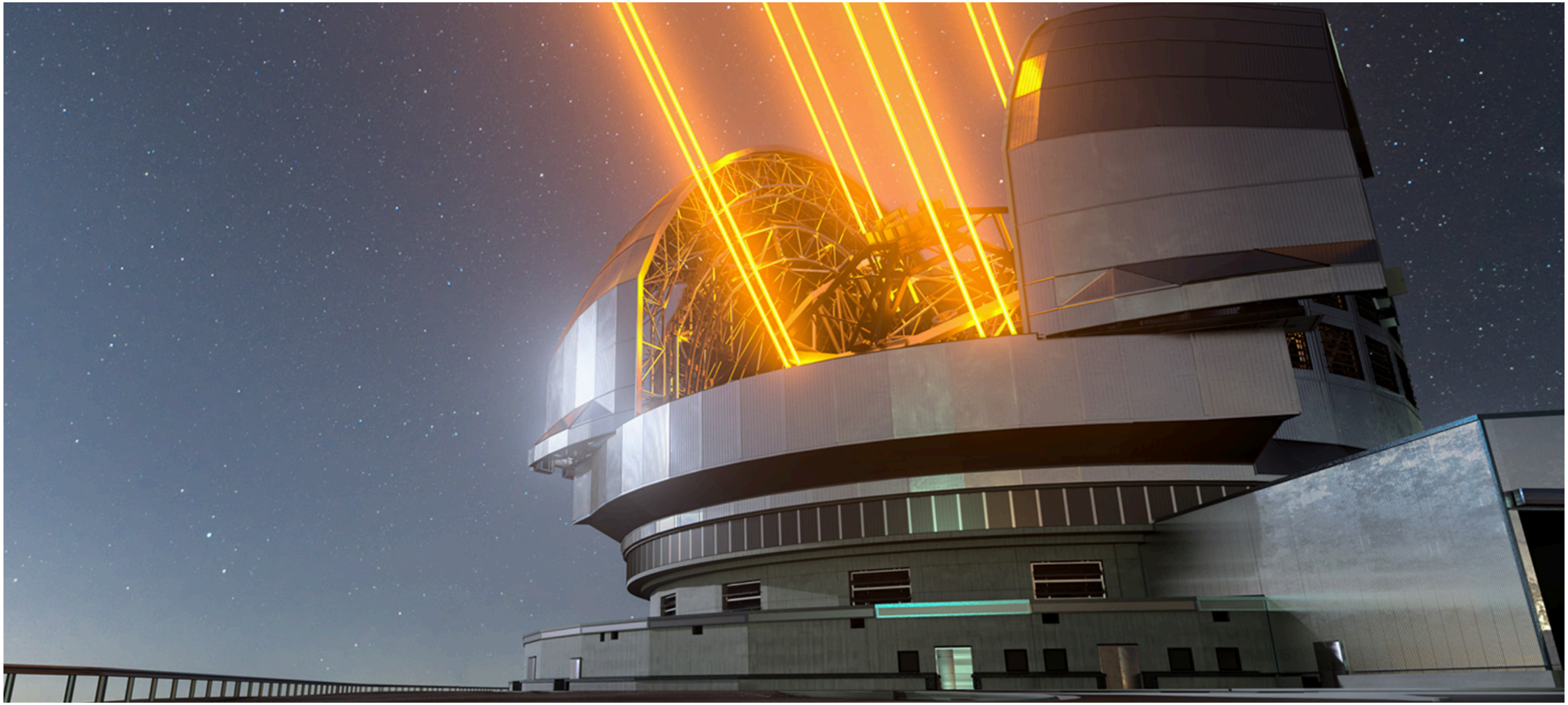


E-ELT optical design

3-Mirror anastigmat: un telescopio che ha tre specchi con potere ottico che permettono di minimizare sferica, coma e astigmatismo. Ha un campo di vista corretto ancora più grande dei 2-mirror telescopes come il Ritchey-Cretien dove sono corretti sferica e coma.

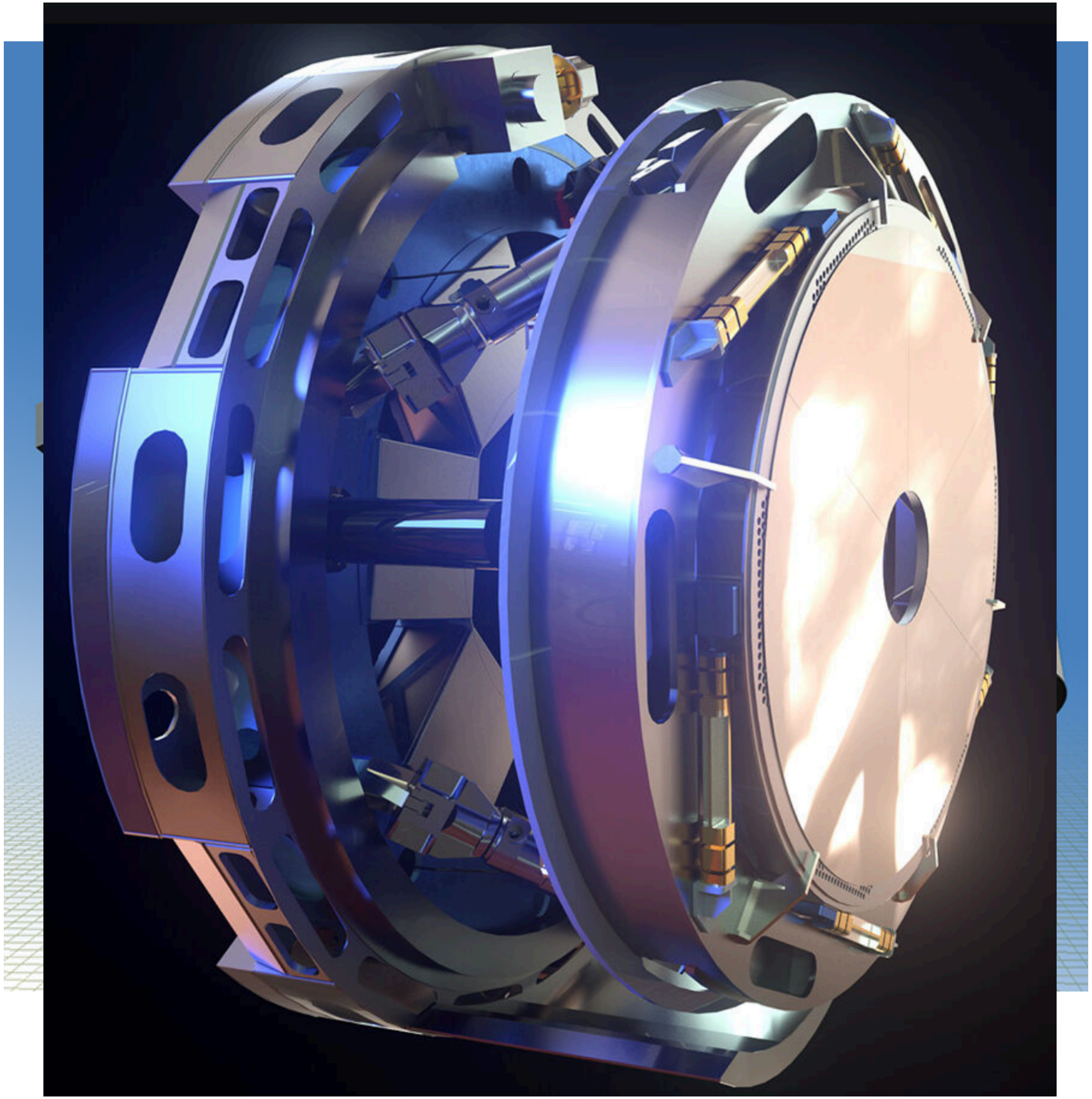


ELT & Adaptive Optics

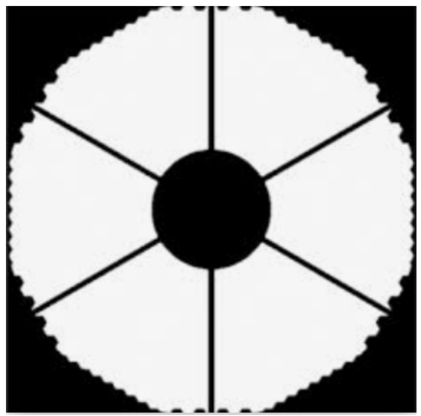


https://elt.eso.org/telescope/

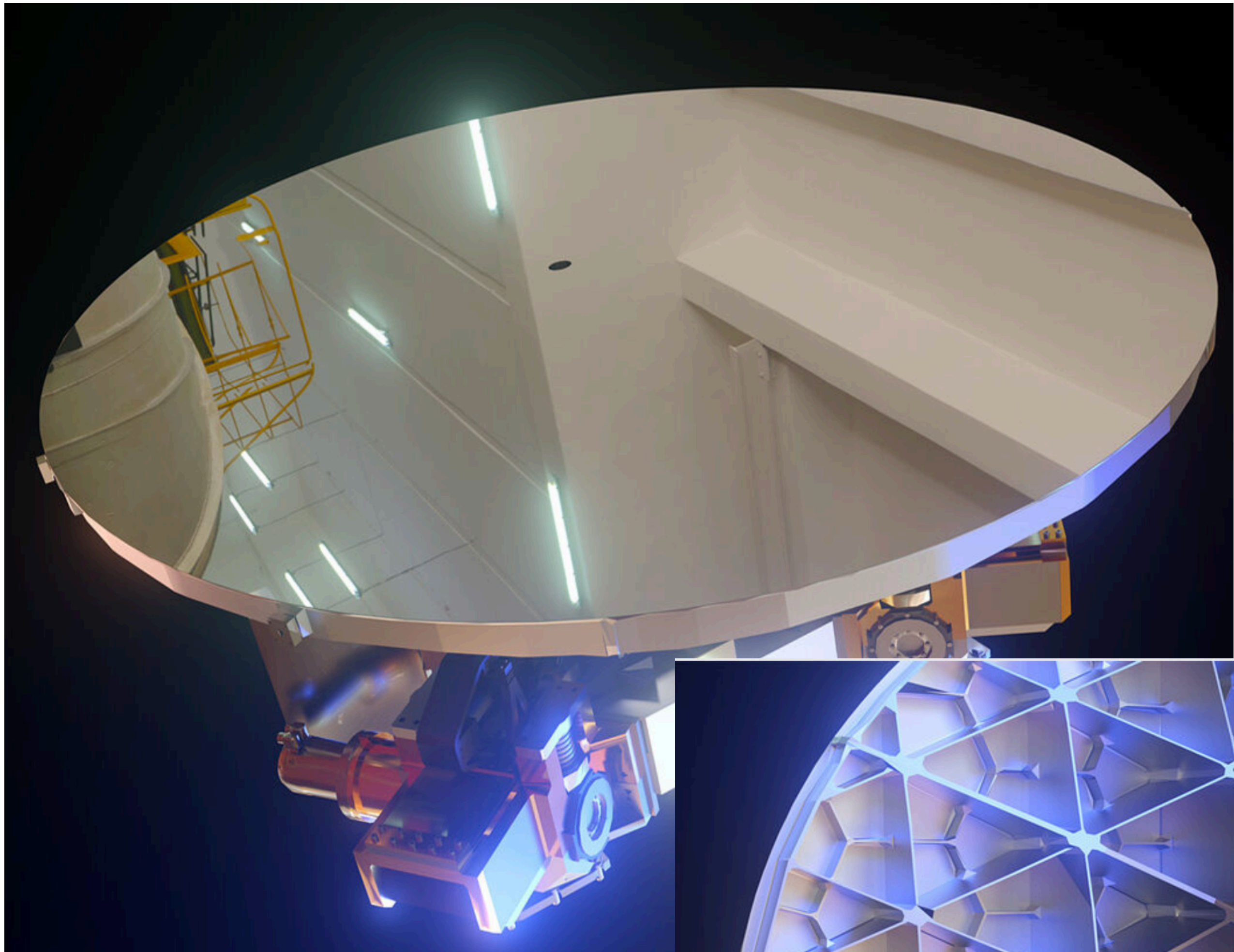
The E-ELT deformable M4

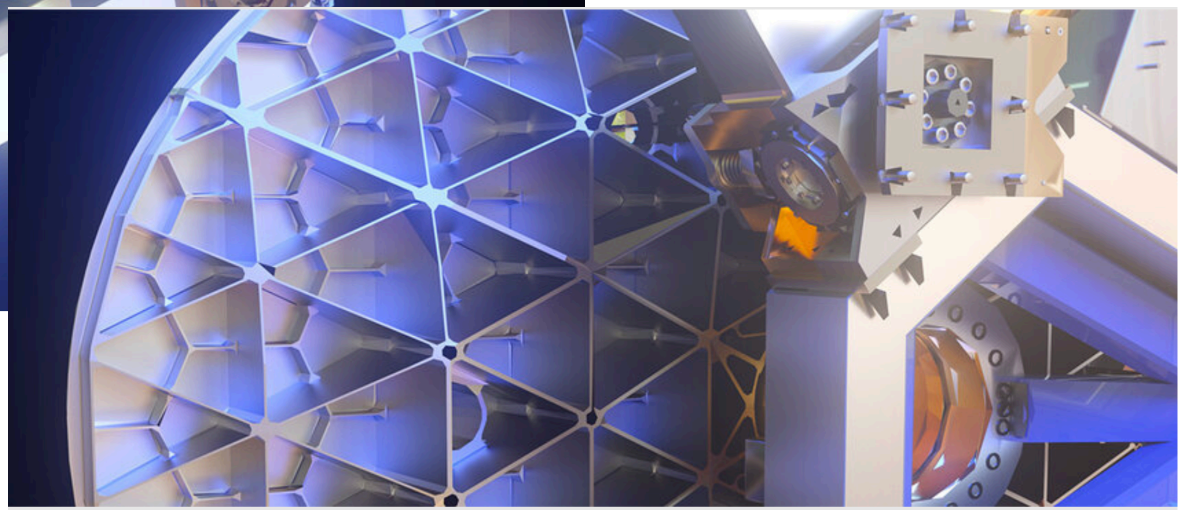


Il piu grande specchio adattivo mai costruito, 2.4m di diametro e ~5300 actuators!!! Deriva dagli specchi secondari di LBT, una tecnologia completamente italiana!!!



Il piu piccolo specchio di ELT (!).





LO specchio di tip tilt di ELT in silicon-carbide (M5) ha una forma ellittica con dimension 2.2x2.7m. Puo correggere il tip tilt fino a frequenze di 10 Hz.

The E-ELT Project

Instrument Roadmap

- 1st Light Instruments

Instruments - First Light	AO	Mode	λ (µm)	Resolution	FoV / Sampling	Add. Mode
E-CAM – 2023	**SCAO, MCAO**	**- IMG - MRS**	**0.8 – 2.4**	**BB, NB 3000**	**53.0” / 3 mas**	**Astrometry 40mas Coronography**
E-IFU – 2023	**SCAO, LTAO**	**- IFU**	**0.5 – 2.4**	**4000 10 000 20 000**	**0.5×1.0” / 4mas 5.0×10.0” / 40mas**	**Coronography**
E-MIDIR – 2024/2028	SCAO, LTAO	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18” / 12 mas 0.4”×1.5” / 4 mas	Coronography Polarimetry
E-HIRES - 2024/2028	SCAO	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82” 0.027”×0.5”	Polarimetry
E-MOS - 2024/2028	 MOAO	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8” / 0.1” 420’ / 0.3” 2” / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS - 2027/2030	XAO	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0” / 2.3 mas 0.8“ / 1.5 mas	Coronography Polarimetry

SCAO: single-conjugated AO **MCAO:** Multi-Conjugated-AO **LTAO**: Laser-Tomographic AO

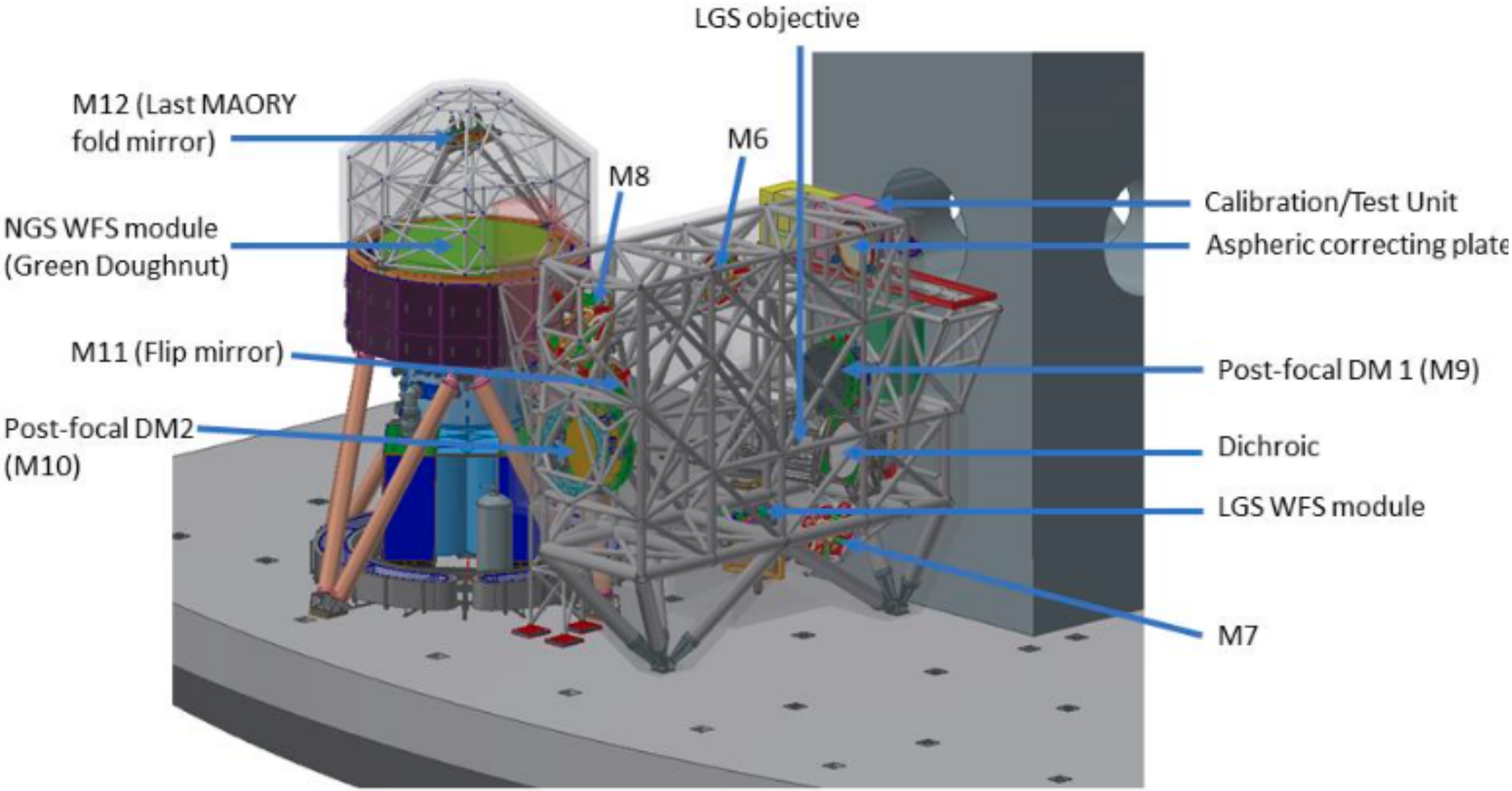
MOAO: Multi-Object AO **XAO**: Extreme-AO

Strumenti “*italiani*”per E-ELT

MAORY, sistema Adattivo multiconiugate
(PI P. Ciliegi);

HIRES, High Resolution spectrograph
(PI A. Marconi);

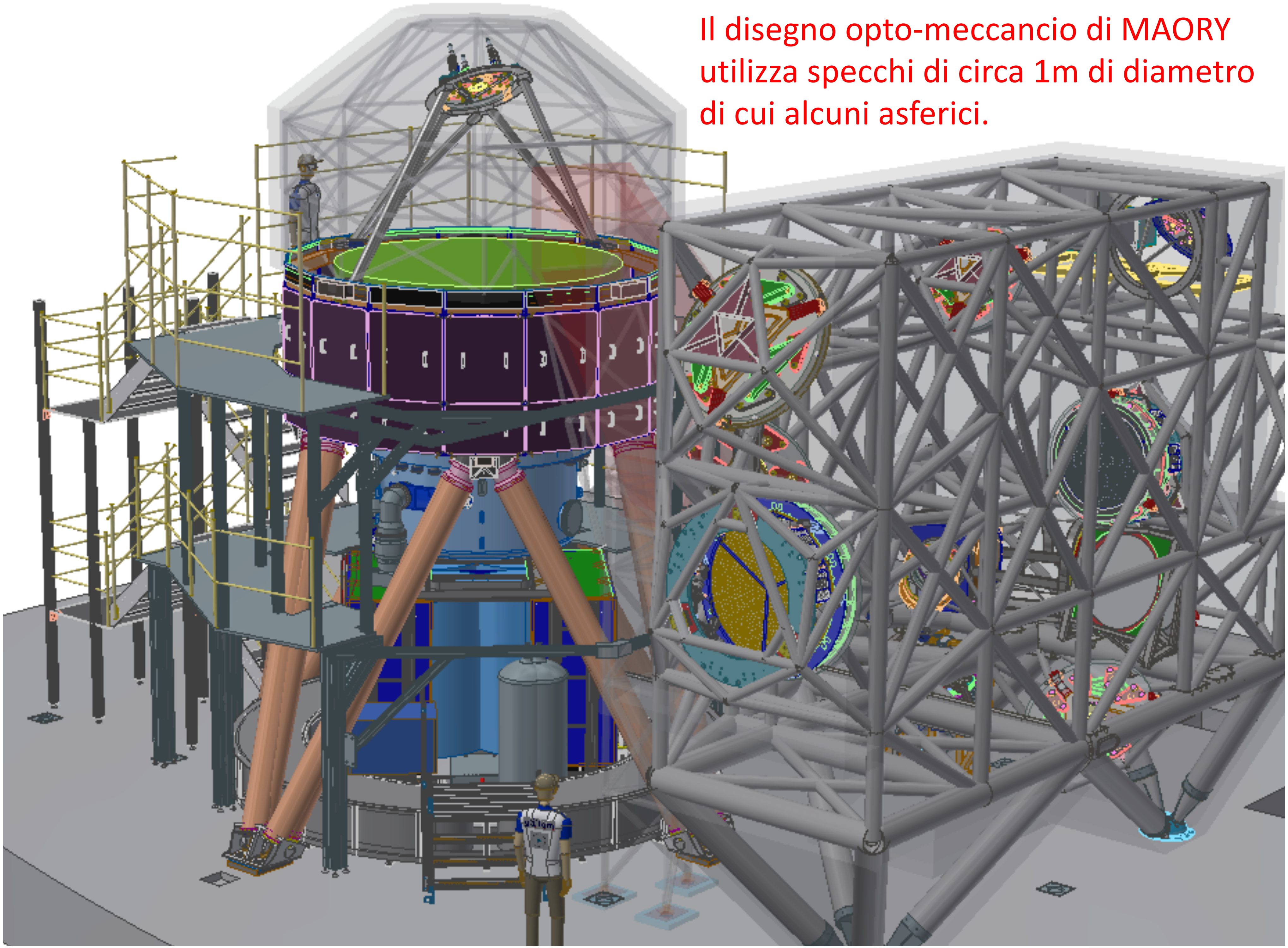
MAORY: una vista d'insieme



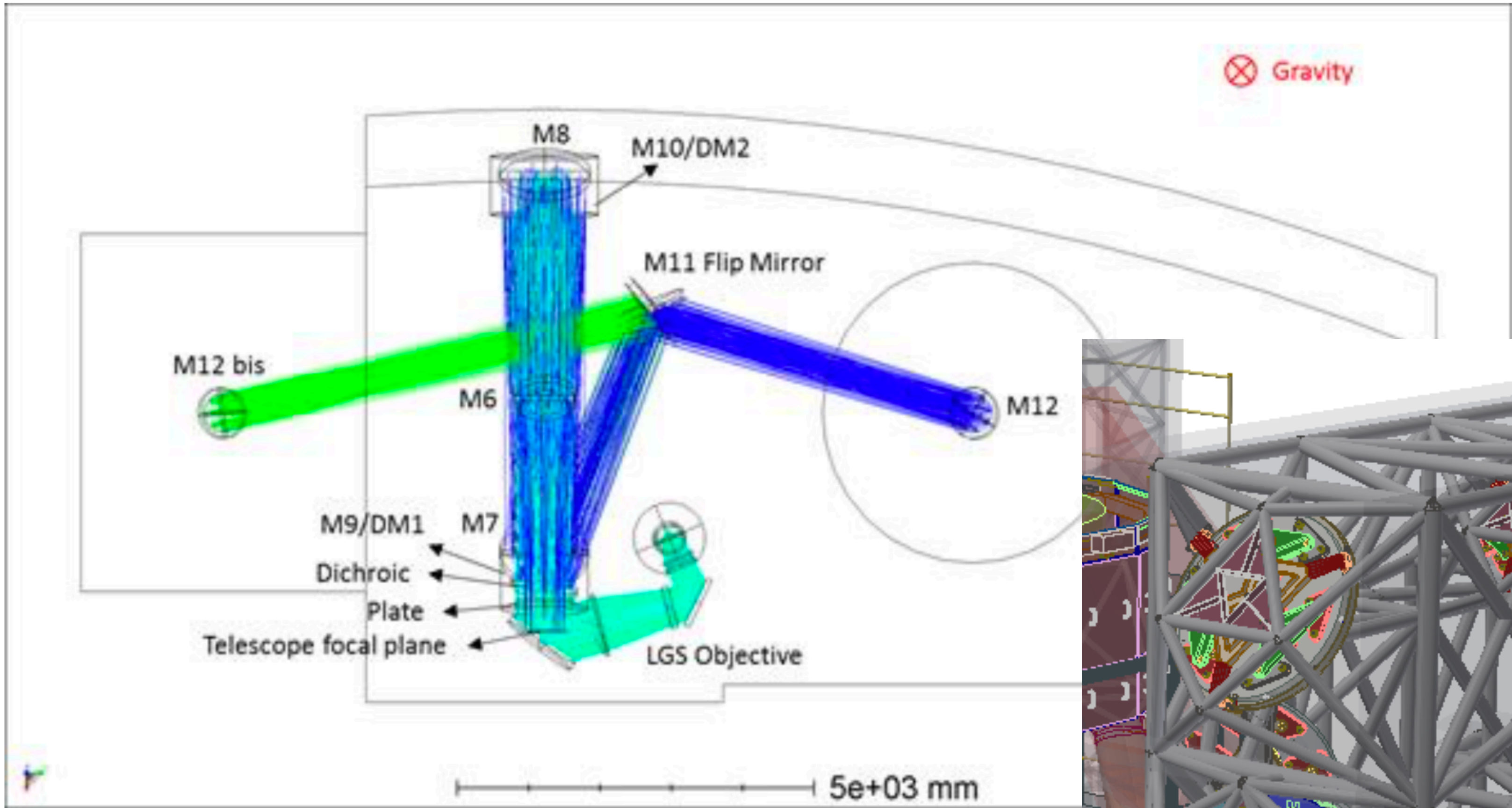
MAORY: dati principali

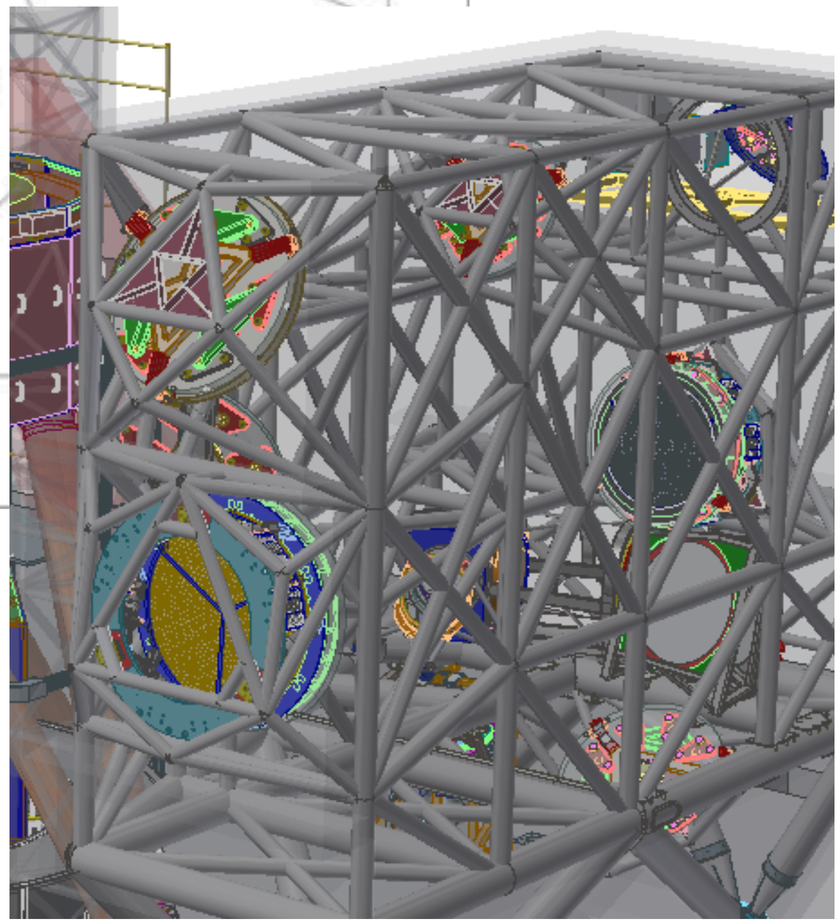
- 3 DMs: M4 and 2 post focal DMs. Post-focal DMs are fixed with Nasmyth (rotating wrt to pupil/M4)
- 8 LGS WFS: fixed asterism (45") integral with telescope, 15" FoV, 500Hz, conj. at M1
- LGS WFS unit has derotator to track pupil rotation and focus stage to follow Na layer distance
- 3 NGS LOR (Low Order and Reference) units patroling with 2D stages 160" ⌀ technical field (half each)
- LOR units are field-derotated by MICADO
- LO WFS: 2x2 SH – H band – 1" FoV – 100-500Hz
- R WFS: 10x10 SH – R+I band – 4" FoV – 0.1-10Hz
- Each of the 8 LGS and 3 LOR WFS has pupil recentering capabilities (xy)

Il disegno opto-meccancio di MAORY utilizza specchi di circa 1m di diametro di cui alcuni asferici.



MAORY Optical-mech. design





TOP VIEW

Il disegno ottico di MAORY utilizza specchi di circa 1m di diametro di cui alcuni asferici.

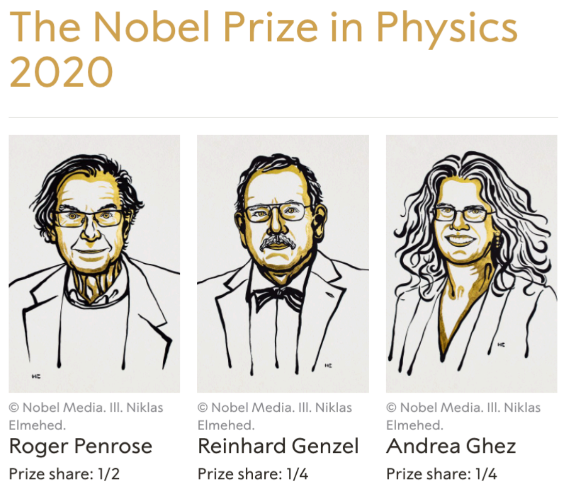
La schedula di MAORY

Milestone (Meeting/review)	Date
Kick-Off	02-2016
Preliminary Design Review 1	04-2021
Preliminary Design Review 2 (End Phase B)	07-2021
Final Design Review (End Phase C)	02-2023
Preliminary Acceptance in Europe (End Phase D)	02-2028
MAORY Shipping parts in Chile	04-2028
Instrument Installation Readiness Review in Chile	07-2028
MAORY First Light	09-2028
Provisional Acceptance in Chile	05-2029

Gli strumenti degli ELT hanno un nuovo livello di complessità che si riflette anche nella durata del progetto, dai 7 anni di uno strumento VLT ai 14 di MAORY!!

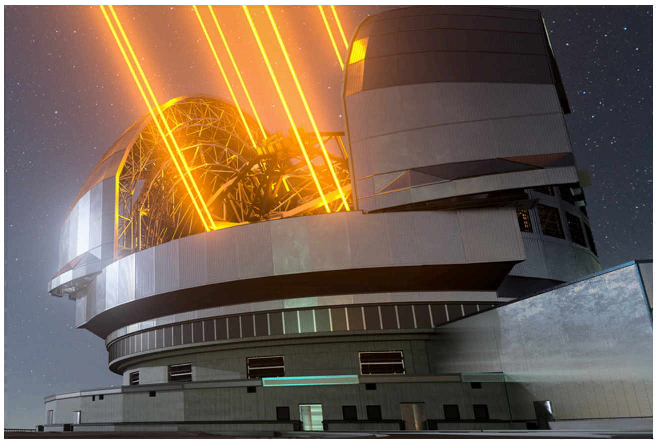
Cosa concludiamo:

I telescopi si sono evoluti in maniera enorme da Galileo ai giorni nostri da 30mm a 40m, un fattore 1000!!!!



L'ottica adattiva ha dimostrato le sue grandi potenzialita' quando utilizzata sui telescopi attuali di classe 4-8m.

L'ottica adattiva e' il componente fondamentale di tutti gli ELT attualmente in progetto !!!



Grazie per la vostra attenzione.....

Il centro galattico visto da NAOS Conica al VLT nel 2002