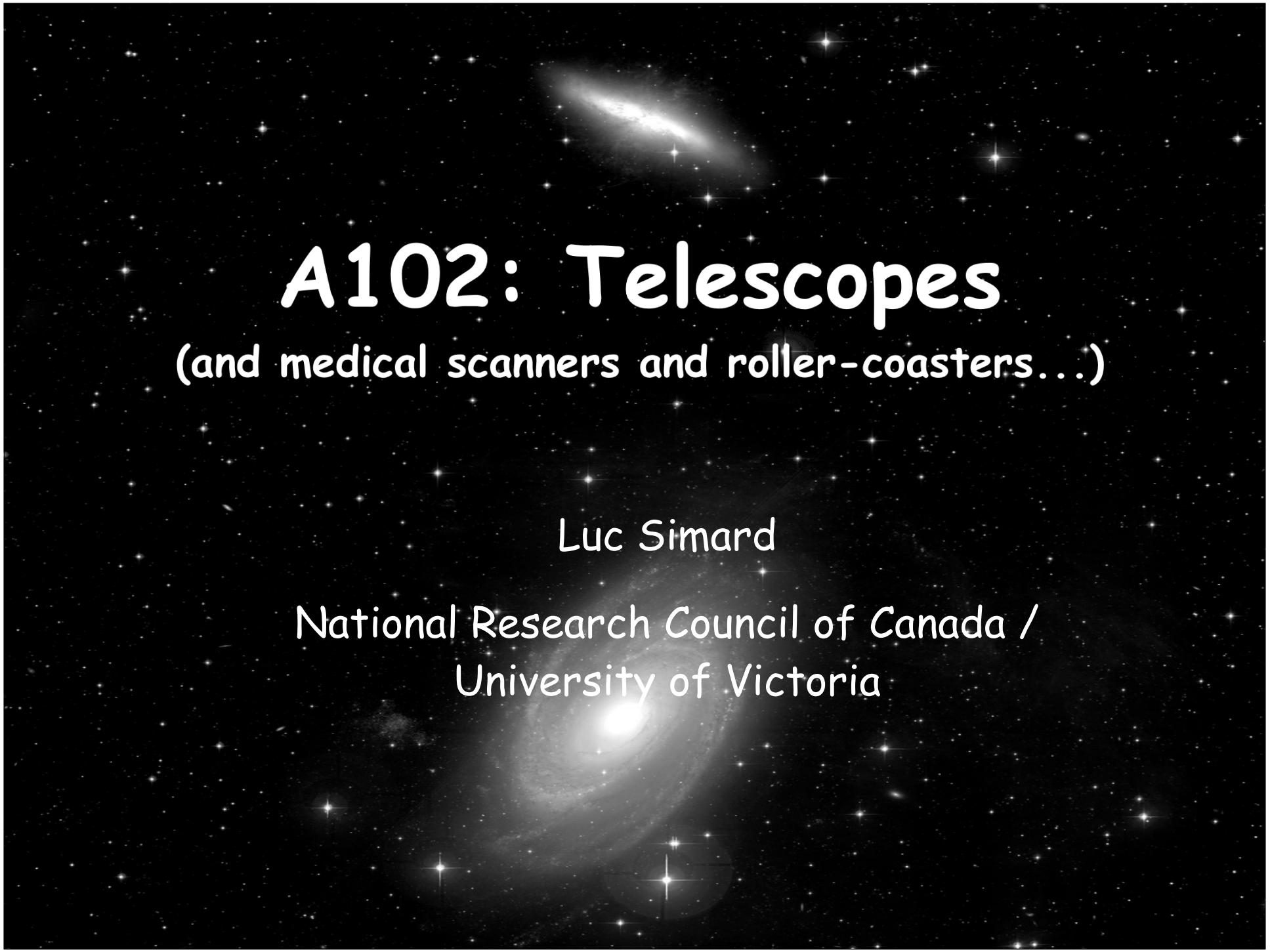
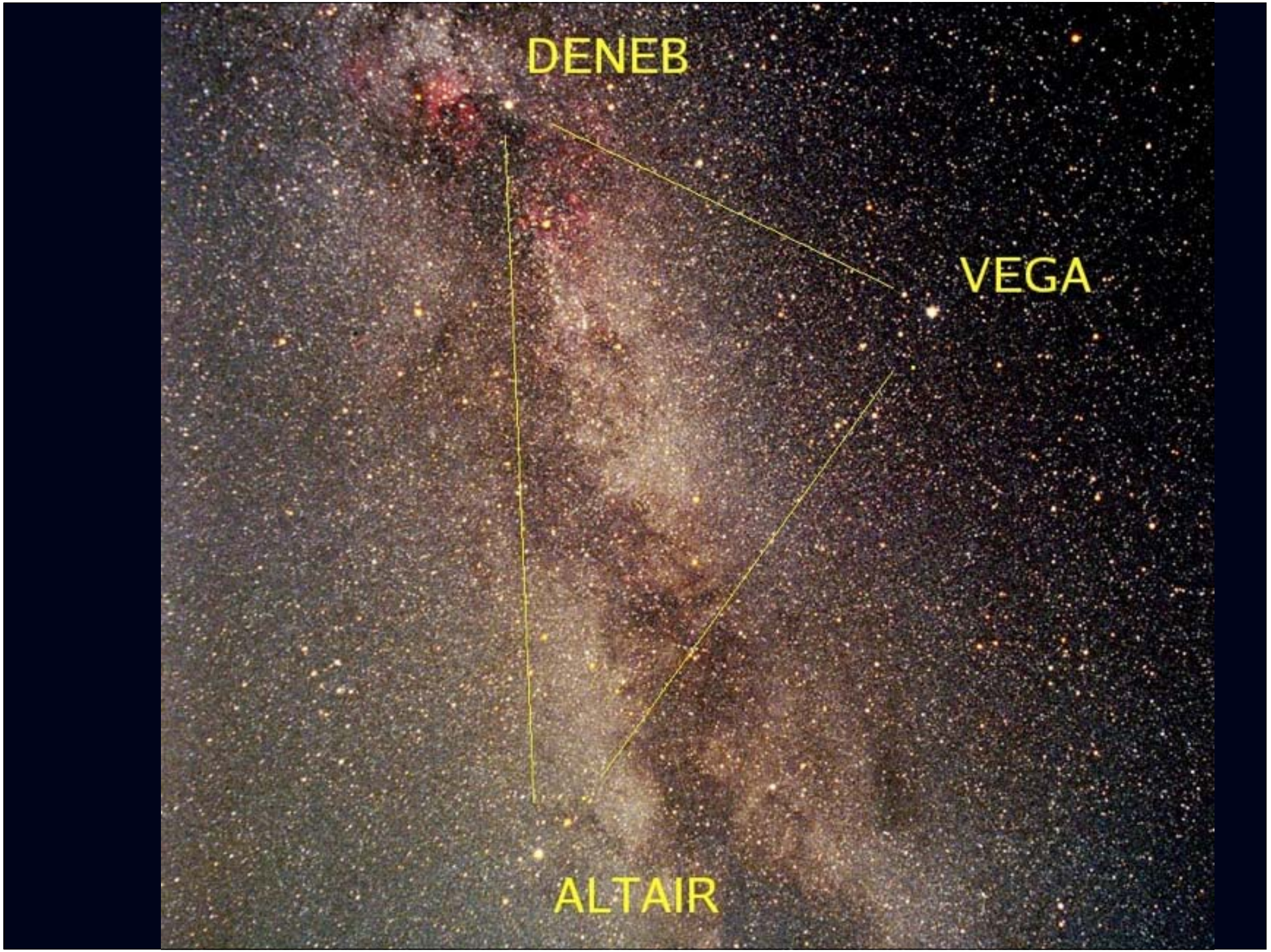

A102: Telescopes
(and medical scanners and roller-coasters...)
Luc Simard
National Research Council of Canada /
University of Victoria

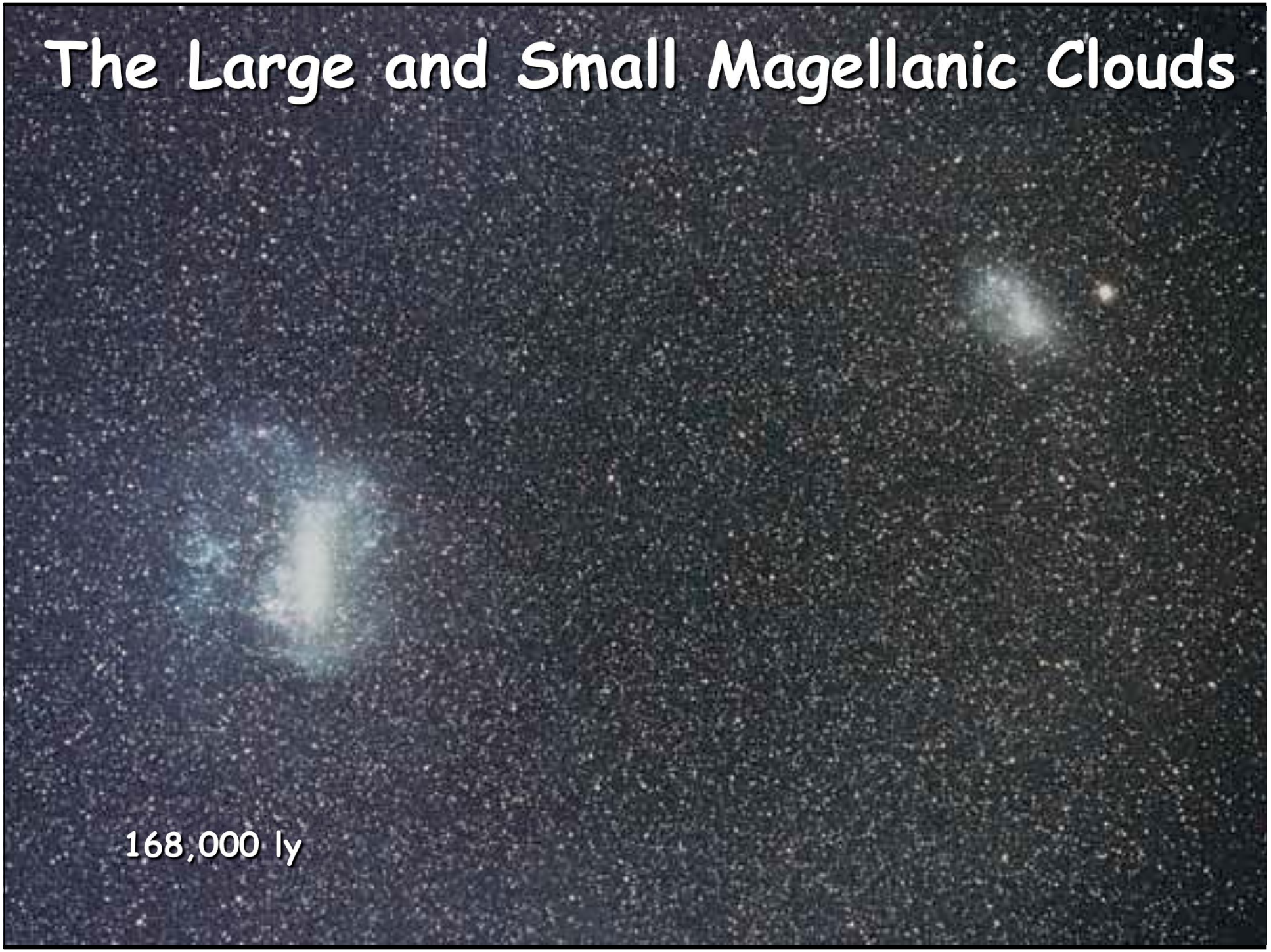
400 years ago!!

Galileo Galilei

Discovery of the Moons of Jupiter in Sidereus Nuncius (1610)


DENEB
VEGA
ALTAIR

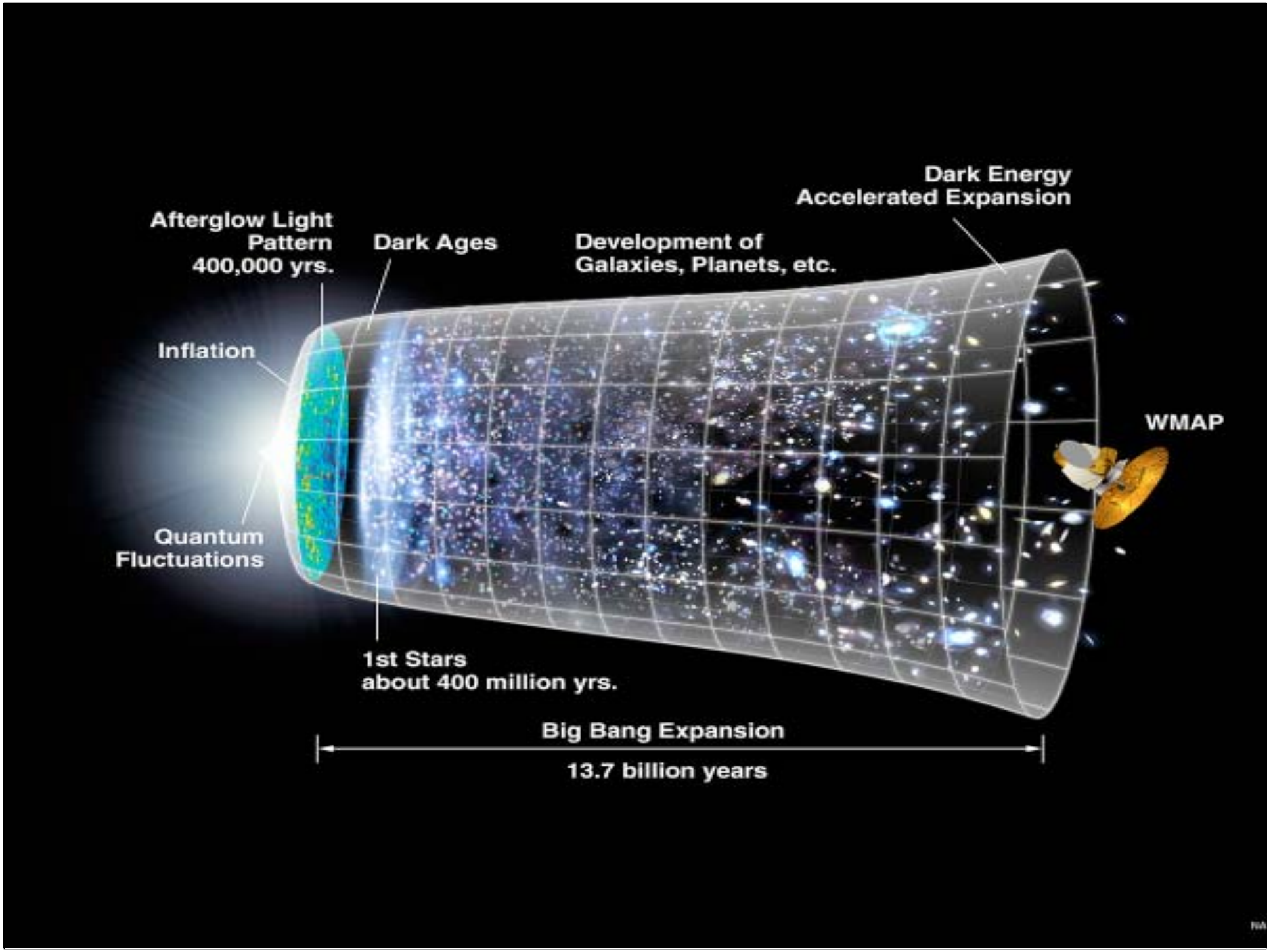
The Large and Small Magellanic Clouds

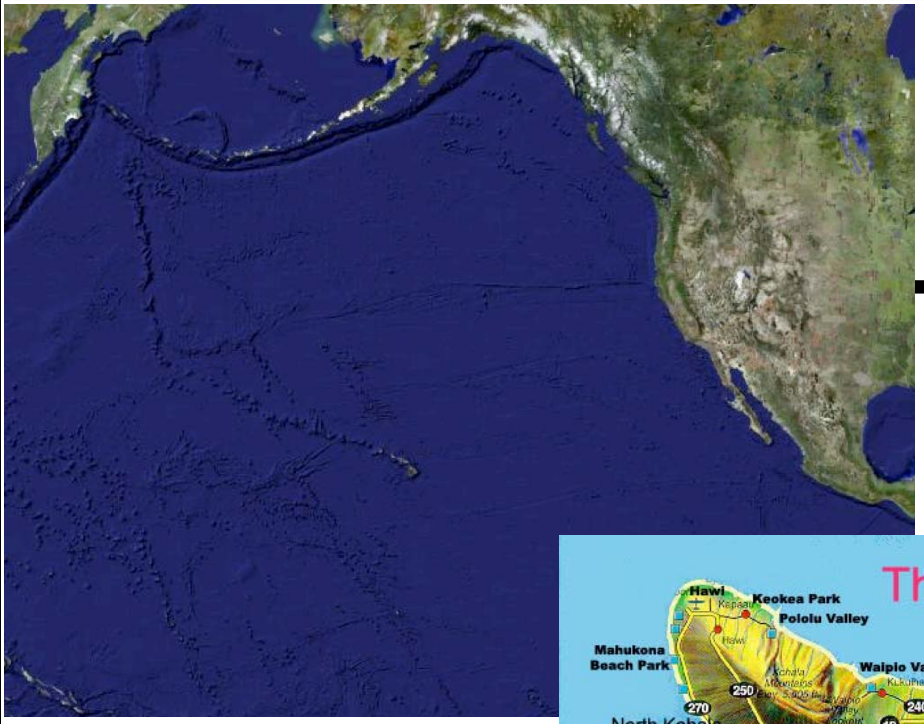



Messier 31
Andromeda Galaxy
2.5 Mly

As far as telescopes can see ...

Credit:
Gemini
Observatory


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years




HAWAII
Kauai
Niihau
Kapaa
Lihue
Kauai Channel
Oahu
Pearl City
Kaneohe
Waipahu
Kailua
HONOLULU
Kaiwi Channel
Molokai
Wailuku
Kahului
Maui
Haleakala N.P.
Lanai
Kahoolawe
Alenuihaha Channel
Hawaii
Mauna Kea
Hilo
Mauna Loa
Naalehu
Hawaii Volcanoes N.P.


The Big Island Hawaii
Hawi
Keokea Park
Pololu Valley
Mahukona Beach Park
Waipio Valley
North Kohala
Kawaihae Harbor
Spencer Beach Park
Hapuna Beach St Park
Waimea
South Kohala
Hamakua District
Akaka Falls State Park
Mauna Kea
Hilo District
North Kona
Hilo
Rainbow Falls
Saddle Road
Kona
Holualoa
Keahou
Kainaliu
Kealakekua Bay
Puna/Pahoa
Pahoa
Isaac Hale Beach Park
South Kona
Mauna Loa Volcano
Park Headquarters
Volcanoes National Park
Volcano
City Of Refuge
Miloli'i
Ka'u District
Punalu'u-Black Sand Beach
Whittington Beach Park

Driving to the Sky

Driving to the Sky

Members of the Canadian Family

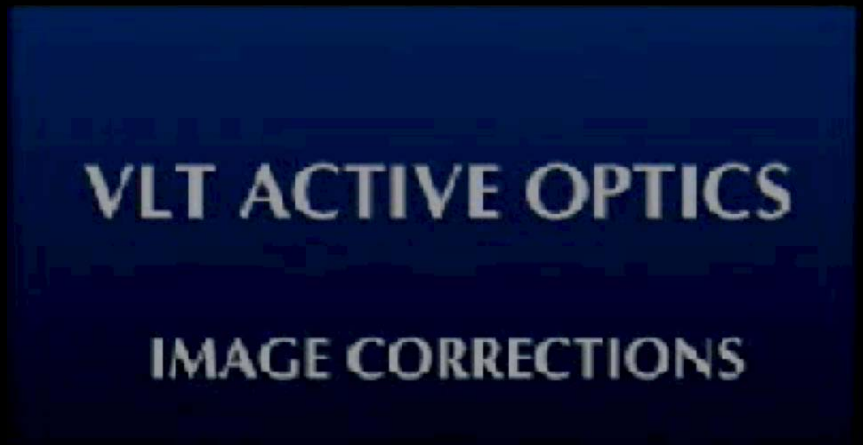
Canada-France-
Hawaii Telescope
3.6m

Gemini North
Telescope
8.1m

Getting Ready to Hunt Starlight


Warning: Telescope At Work

Goodbye Twinkle, Twinkle Little Star



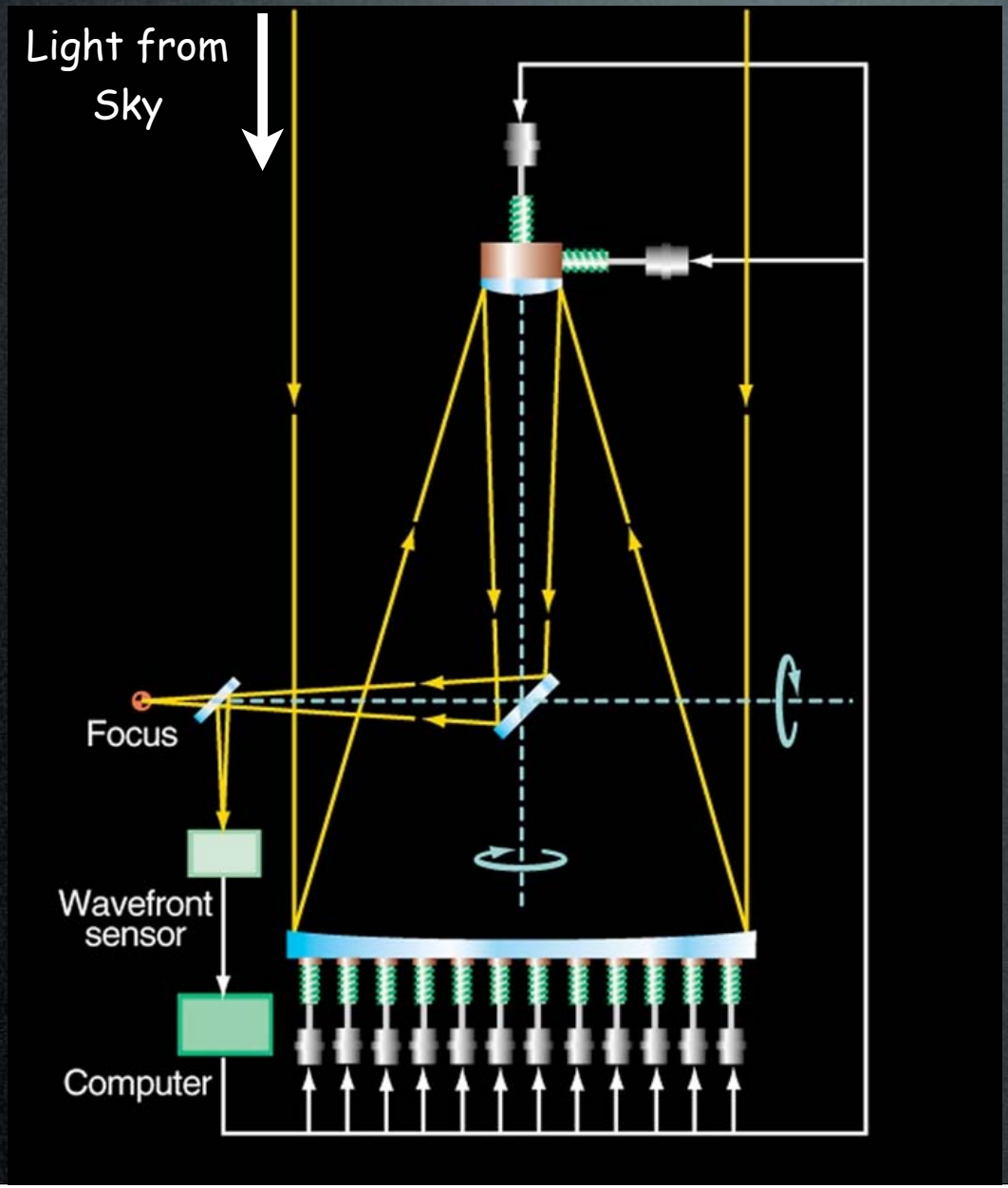
Painting Stars On The Sky

Credit:
Gemini
Observatory

A New Constellation is Born!

Credit:
Gemini
Observatory

Light Path Through a Telescope



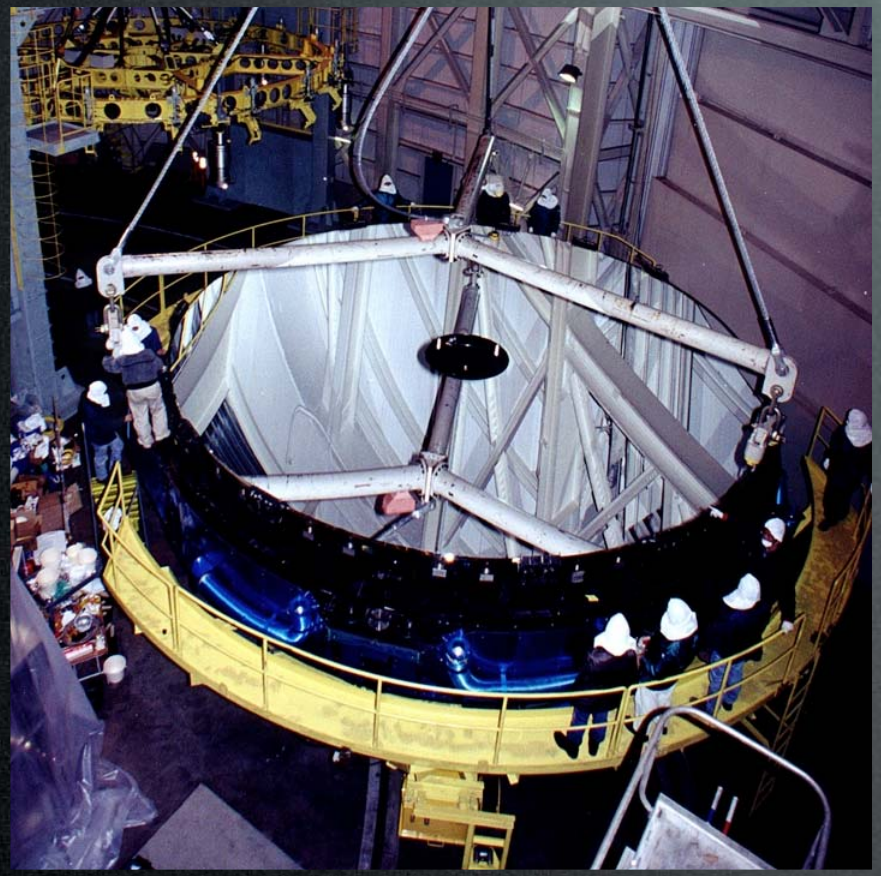
Secondary Mirror

Tertiary Mirror

Primary Mirror (with actuators to maintain its shape)

Monolithic versus Segmented Primary Mirrors

Monolithic

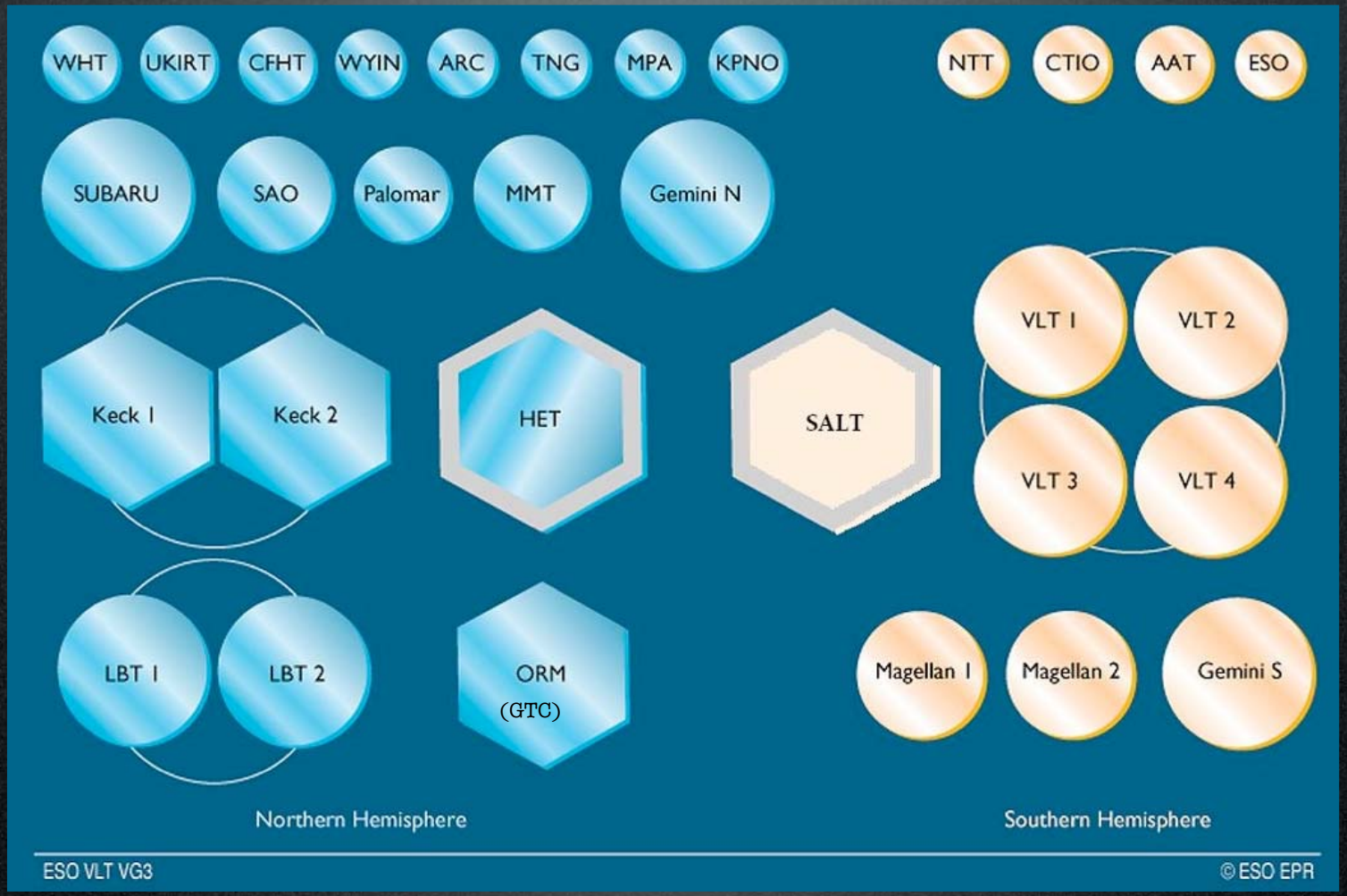


Subaru Telescope

Segmented

Keck Telescope
(36 segments. Each segment is as large as the Plaskett Telescope on West Saanich Rd)

Collecting Area of the Large Telescopes



All 4-meter class primary mirrors are monolithic

8-10-meter class primary mirrors are either monolithic or segmented - dividing line is between 8 and 10 meters.

There are mirrors and then there are telescope mirrors!

Parkes

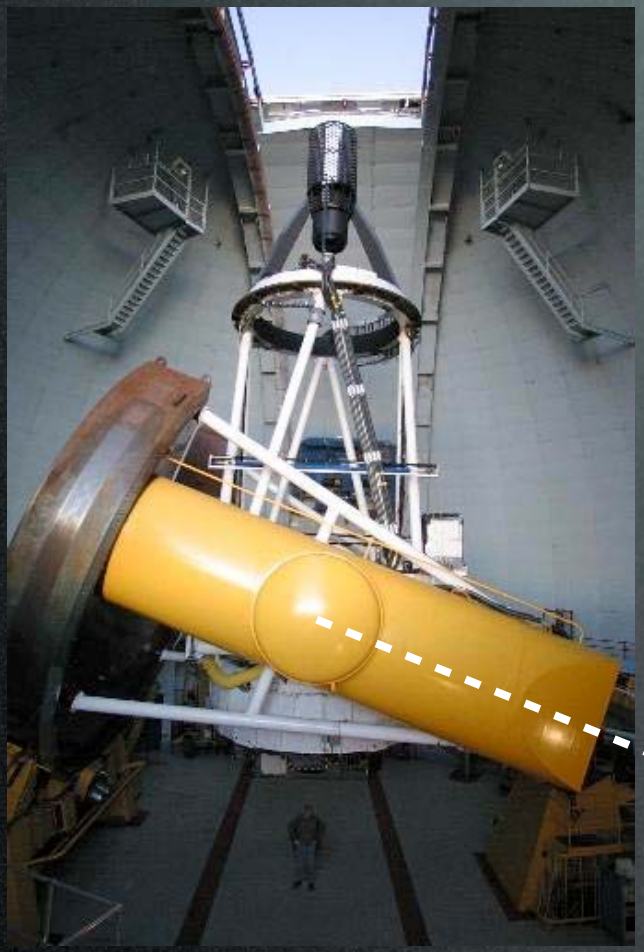
Plateau du Bure

HST

The quality of a telescope mirror is dictated by the observing wavelength, and it is usually quoted as a fraction of the observing wavelength. For example, the HST primary mirror had to meet a tolerance of 1/70λ. For an observing wavelength of 500 nanometers (nm), this means that the "bumps" on its surface had to be less than 7 nm (The diameter of human hair is at least 17,000 nm ...). The HST mirror is one of the most precise polished surface ever produced. It just had the wrong figure.

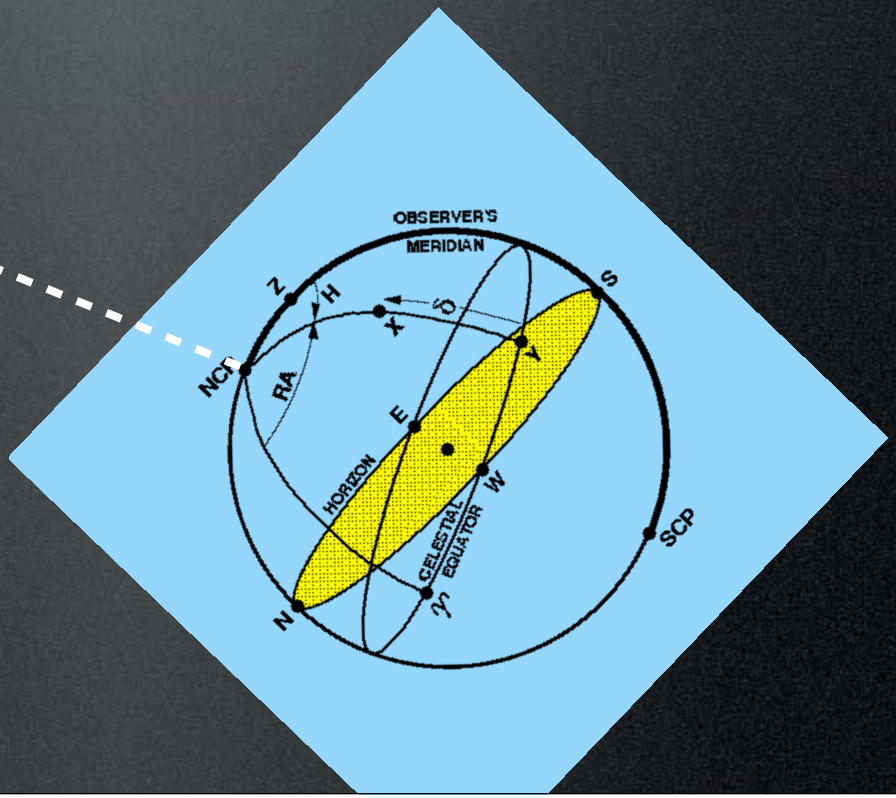
In comparison, a radio telescope dish would have to have bumps smaller than 3 mm to be of equal optical quality. This requirement is a factor of ~500,000 times looser! This is why one can build 100-m radio dish, but an optical mirror of that size is a completely different story.

Telescope Mounts -Equatorial



3.6-m Canada-France-Hawaii Telescope (Horseshoe)

- Pro: Follows the "natural" coordinate system of the sky
- Con: Heavy



Telescope Mounts - Altitude-Azimuth

Altitude

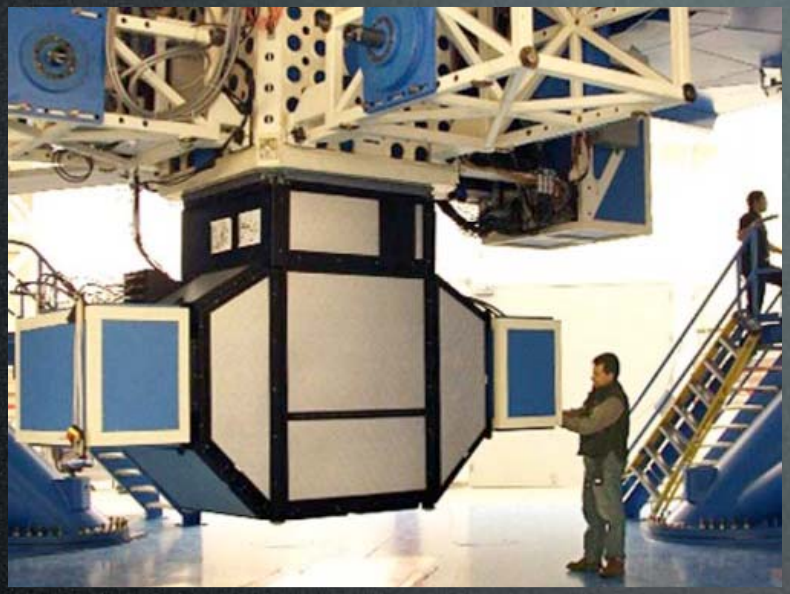
Azimuth

Every large (> 4m) telescope!

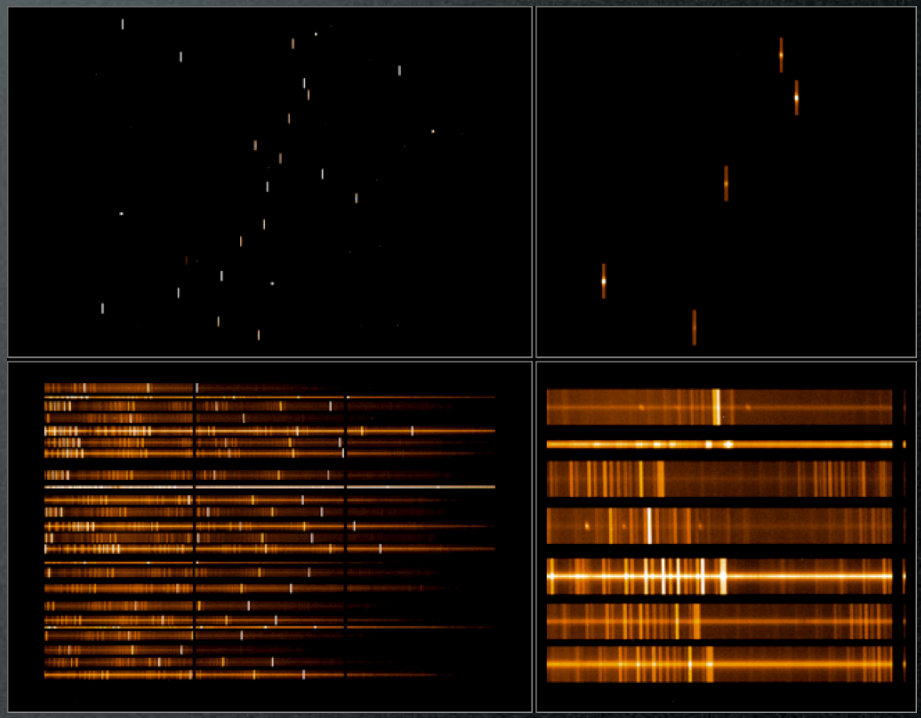
Gemini Telescopes

- Twin telescopes to cover both hemispheres: Mauna Kea, Hawaii and Cerro Pachon, Chile
- Primary = 8.1-m, 22.2 T
- Effective focal length = 128.1 m
- Moving mass = 342 tons
- Dome diameter/height = 36m/46m
- First light = 1999 (North), 2000 (South)

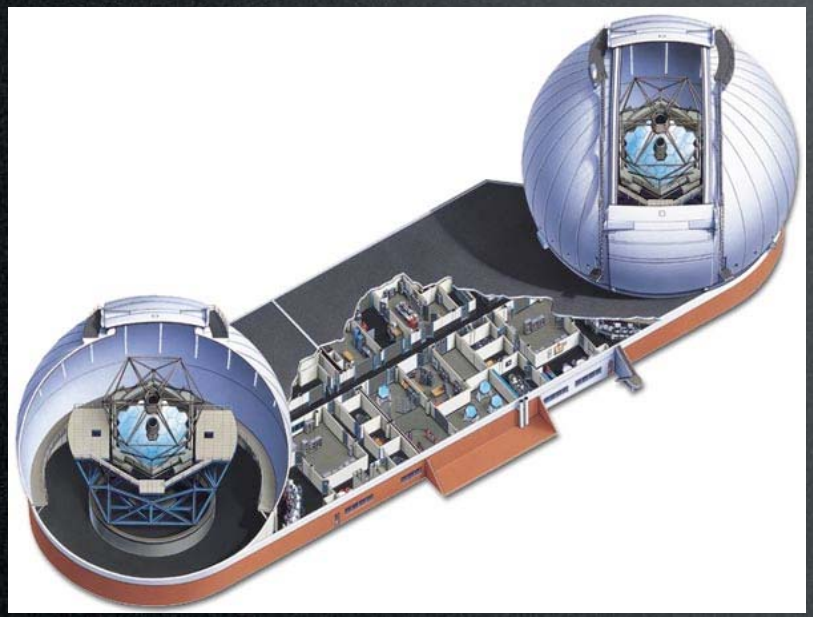
Gemini-North Multi-Object Spectrograph (GMOS)-N



- Designed and built in Victoria!
- Same size as a small car
- Records spectra of hundreds of objects in a single exposure



Keck Telescopes

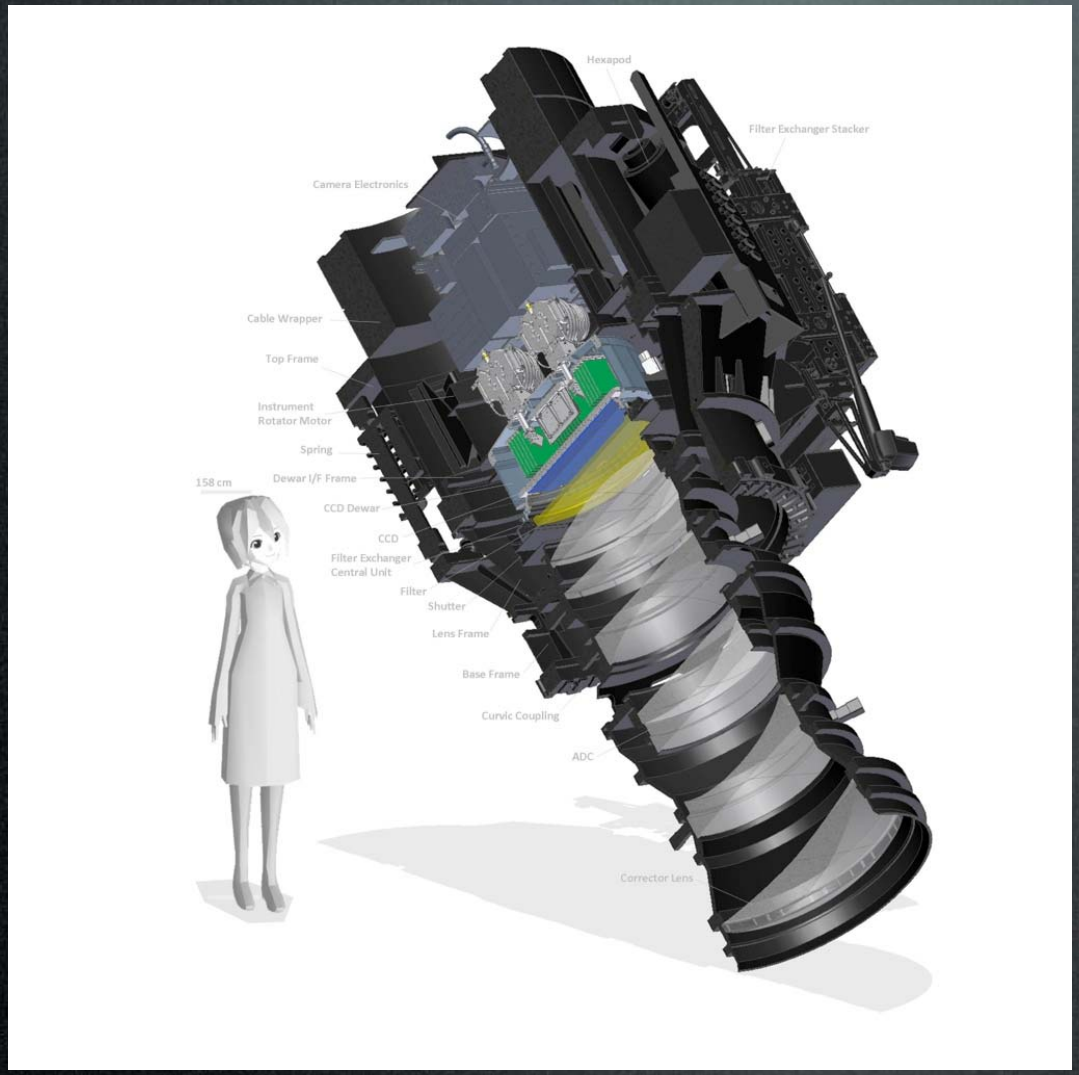


- Twin telescopes on Mauna Kea, Hawaii
- Can be linked interferometrically to create a 85-m baseline
- Telescope:
  - 10-m segmented primary mirrors - light collecting area of 76 m^2
  - Overall height = 24.6m
  - Moving weight = 270 T
  - Total weight of glass = 14.4 T
- Dome:
  - Height = 30.8m
  - Width = 37m
  - Moving weight = 635T

Subaru Telescope

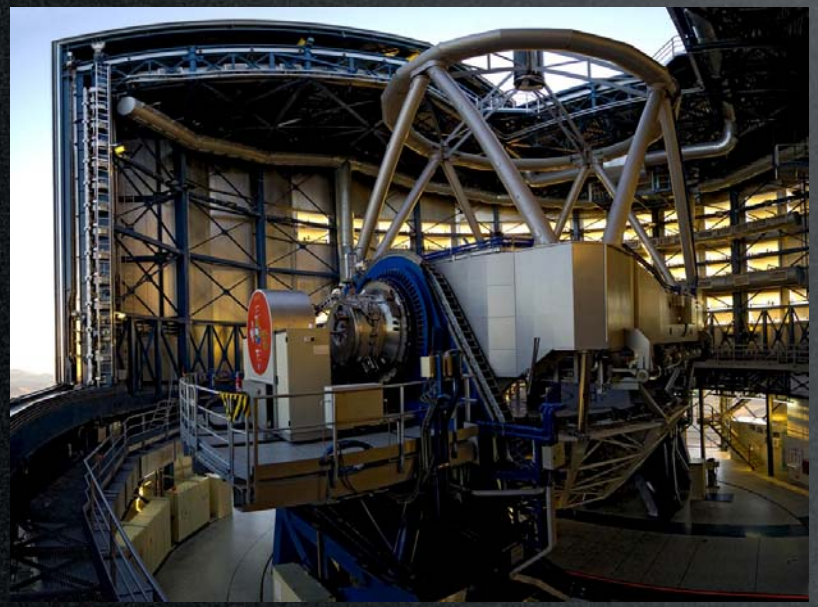
- Located on Mauna Kea, Hawaii
- Telescope:
  - 8.3-m, 20-cm thick monolithic mirror
  - Overall height = 22.2m
  - Moving weight = 555 T
  - Total weight of glass = 22.8 T
- Dome:
  - Cylindrical
  - Height = 43m
  - Diameter at base = 40m
  - Moving weight = 2000T
- First Light = January 1999

Subaru HyperSuprimeCam



- Largest wide-field mosaic camera in the world with a total of 870 megapixels (your puny cell phone is no match for the power of HyperSuprimeCam)
- Field of view with a diameter of of 1.5 degrees (~3 full Moons)
- On-sky testing going on now!

Very Large Telescopes



- European Southern Observatory
- Located on Cerro Paranal, Northern Chile (2635m)
- 4 Unit Telescopes (UT) and 4 Auxiliary Telescopes (AT)
- UT telescopes:
  - 8.2-m, 17.5-cm thick monolithic mirror
  - Overall height = 22.2m
  - Moving weight = 430 T
  - Total weight of glass = 23 T
- Dome:
  - Cylindrical fixed base + upper rotating part
- First Light = 25 May 1998 (UT1), 4 September 2000 (UT4)

Synthesizing a Super VLT

- Auxiliary telescopes:
  - 1.8-m diameter (same as Plaskett telescope)
  - Total mass = 30T
- 30 different stations with relocate time between stations < 3 hours
- Baselines up to 200 meters long for milli-arcsecond angular resolution (full moon = 1.8 million milli-arcseconds)
- Tolerance is 0.05 micrometers over distances of 120 meters

Extremely Large Telescopes (ELTs)

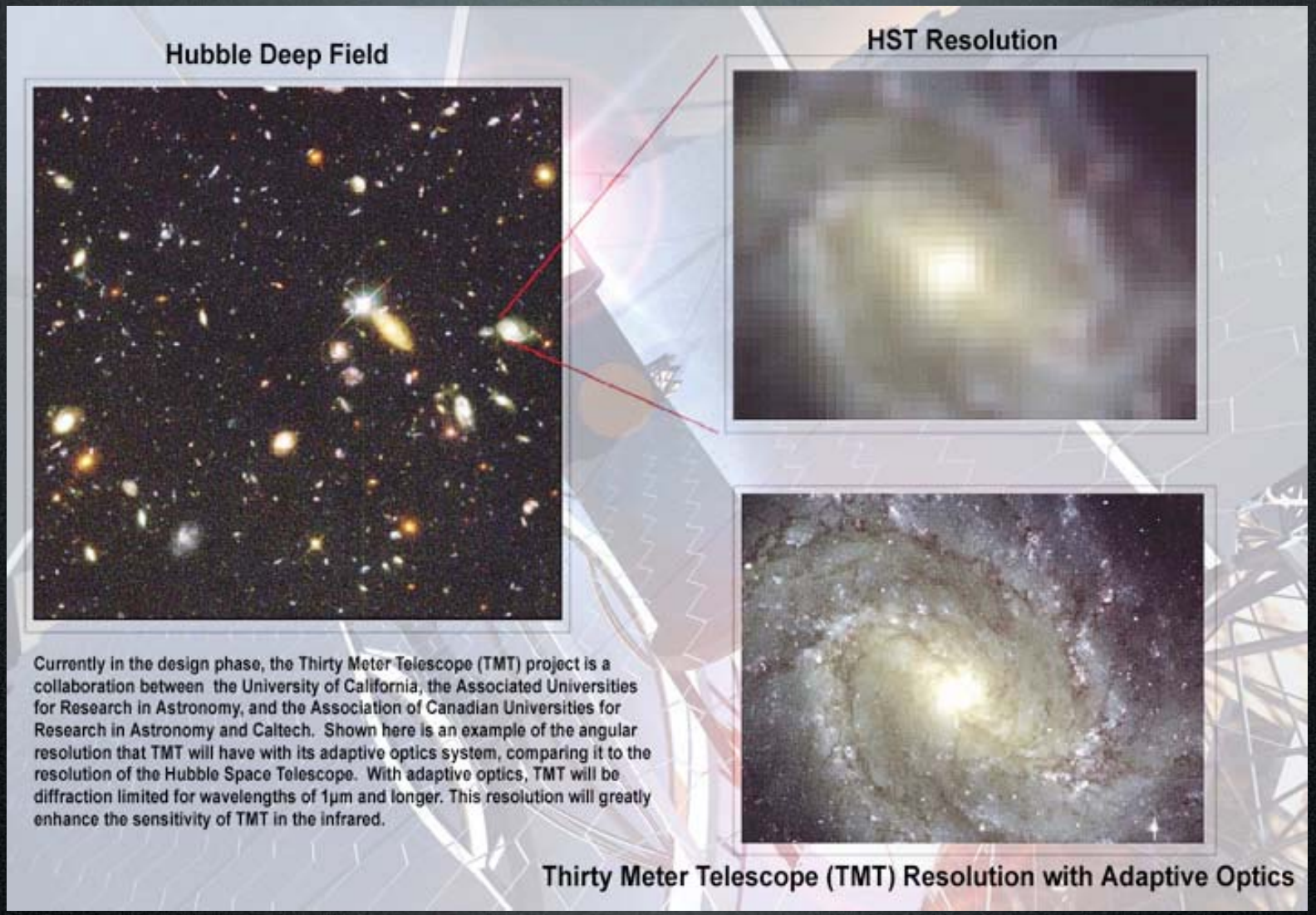
A Useful Measurement Unit for ELTs … The Boeing 747-8I

Wingspan of 68.5m

Empty operating weight of 215 tons

Seating capacity of 605 passengers

Amazing Angular Resolution

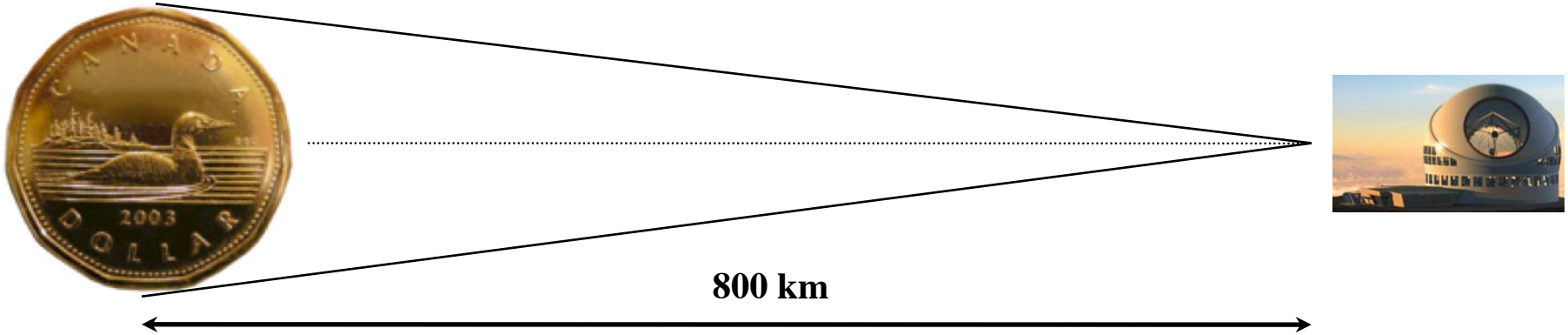


(Credit: Mike Bolte, UCO/Lick)

The Hubble Space Telescope is only 2.4 meters in diameter after all - All ELTs will have 10x its angular resolution

NRC·CNRC
Herzberg Institute of Astrophysics

Seeing a loonie from really far, far away ...

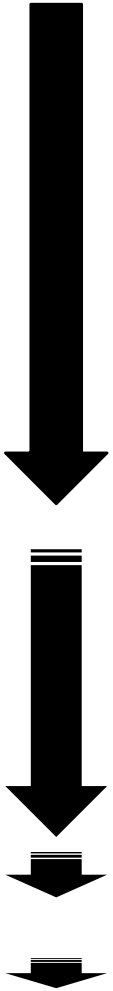


Victoria - Calgary = 728 km

Ottawa - Washington DC = 733 km

San Francisco - San Diego = 737 km

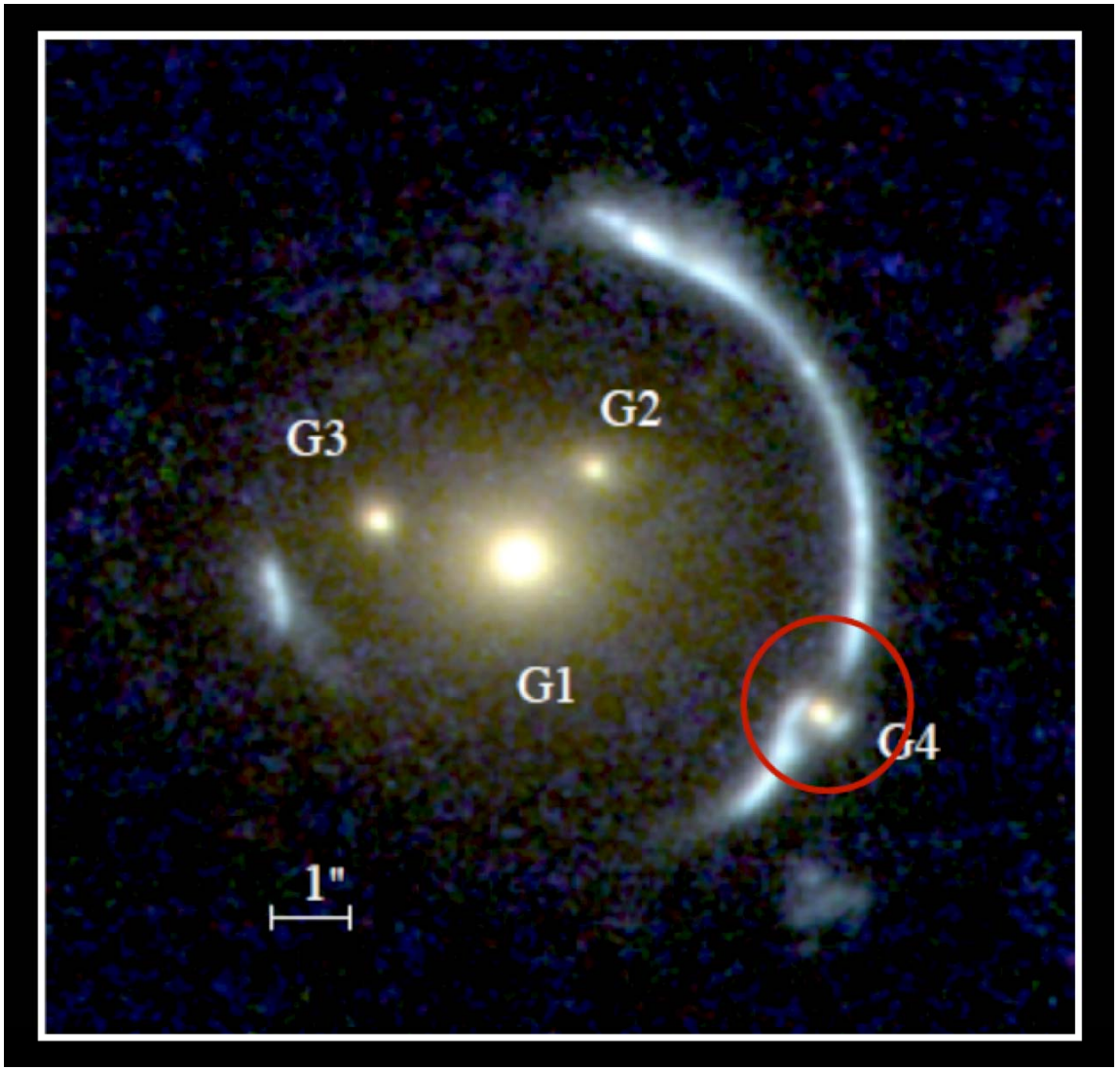
TMT's Angular Resolution is a few millionths of the Moon's Diameter

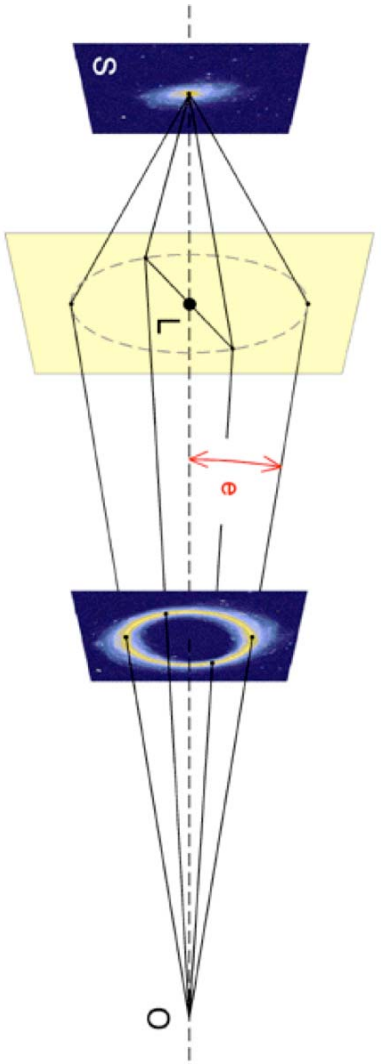


If one were to divide the diameter of the Moon into two million parts, then TMT could see seven of these parts …

TMT
THIRTY METER TELESCOPE

Probing Dark Matter with Gravitational Lensing





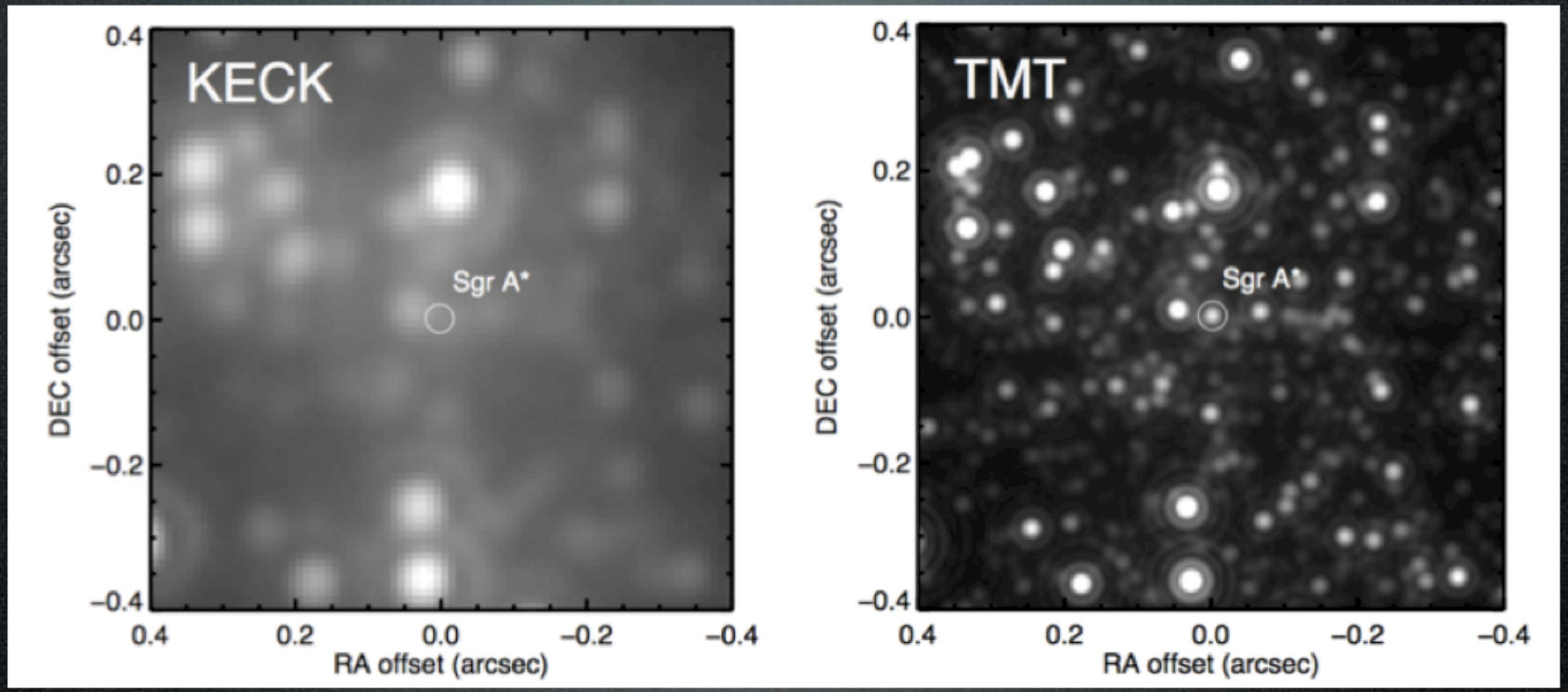
TMT
THIRTY METER TELESCOPE

Probing Dark Matter with Gravitational Lensing

Dark Matter And Not Stars!

TMT will “see” dark sub-structures at least 10x less massive than currently possible - Better constraint on nature of dark particle

Einstein and The Galactic Center

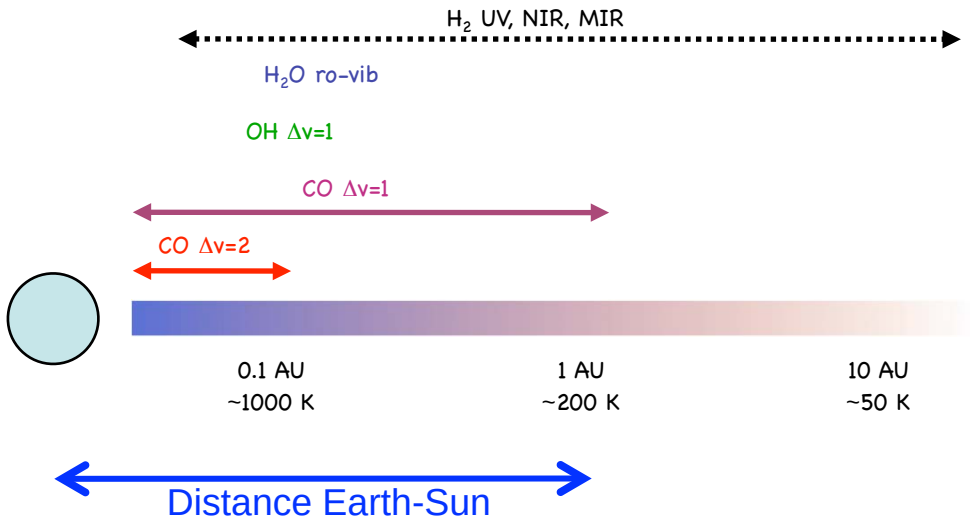


(Credit: Leo Meyer / Andrea Ghez, UCLA)

The center of our Milky Way harbors a supermassive black hole with a mass of four million times the Sun!

Time to put Einstein through a new test ...

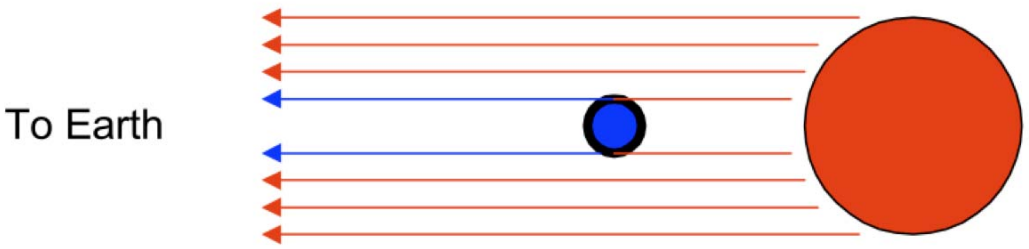
Molecules of Life and Newly-Formed Planets around Other Stars

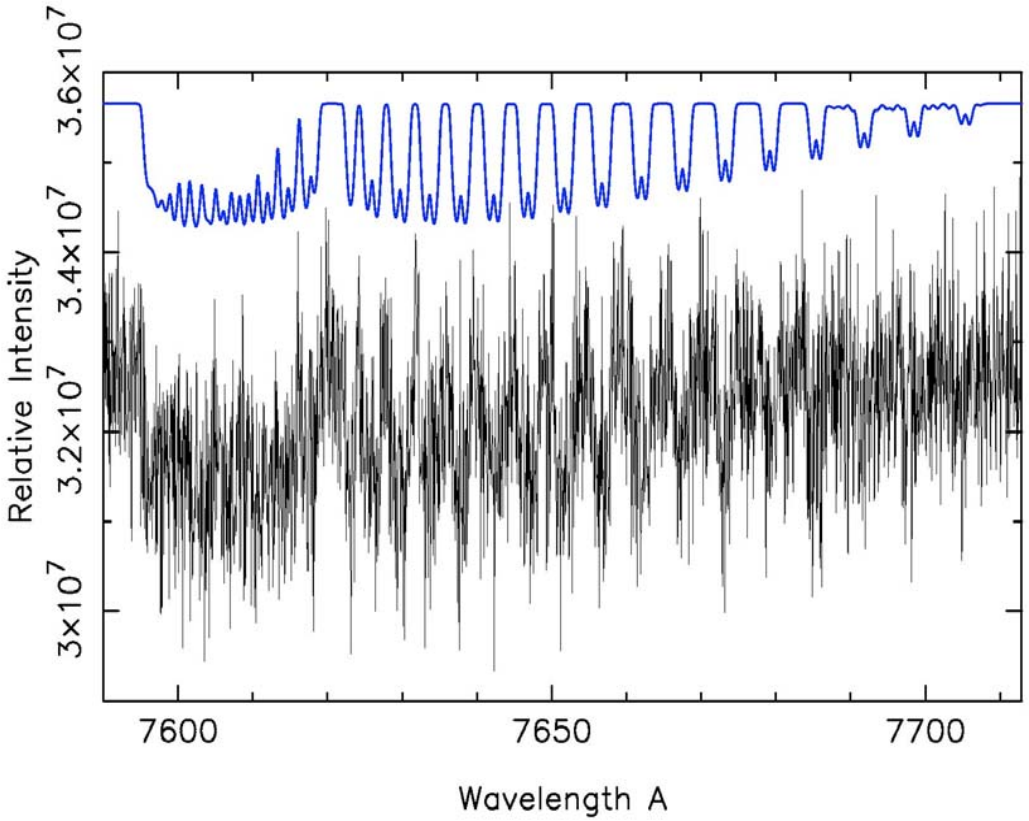


The angular resolution of TMT will make it possible to probe the space around other stars on scales comparable to the Earth-Sun Distance.

Powerful spectrographs will let us identify the complex molecules of life around these other stars and study how these molecules are deposited onto the surfaces of newly formed planets.

Atmospheres of Earth-Like Planets



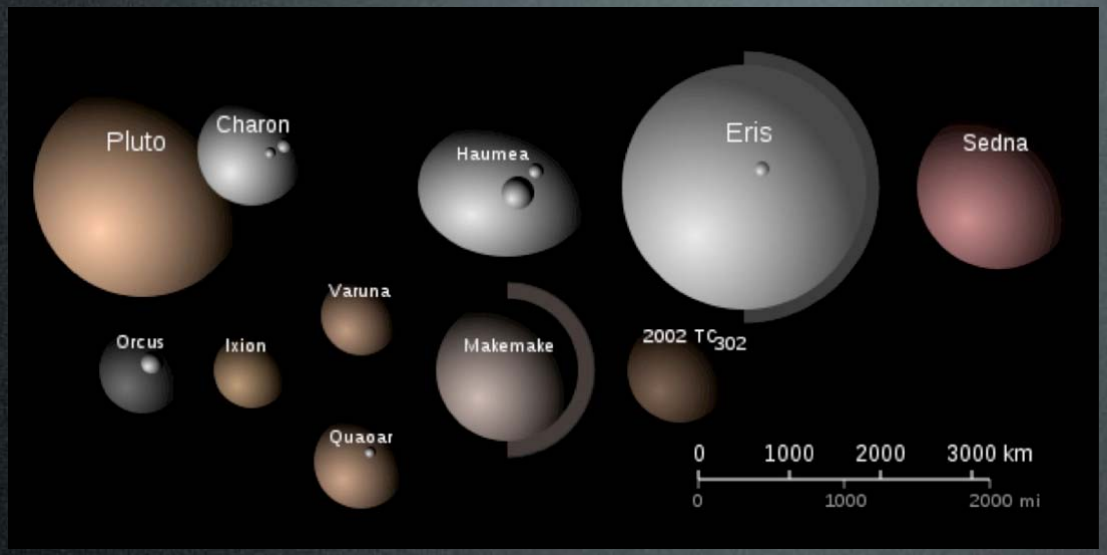


Oxygen

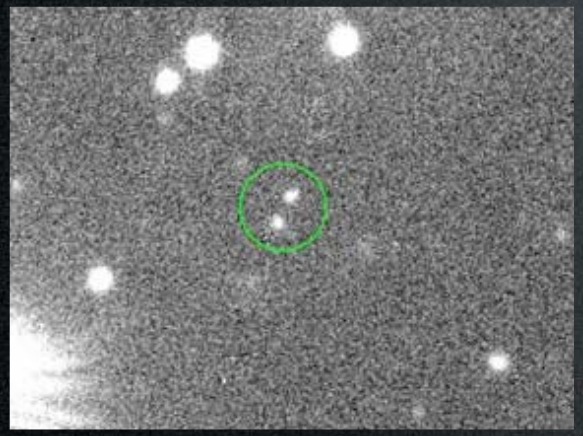
LIFE!

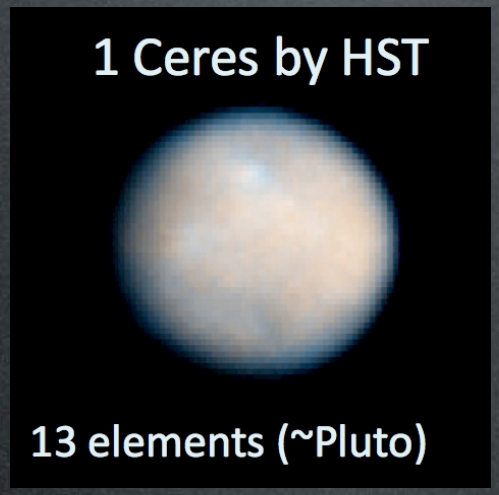
(It should take 3 hours ...)

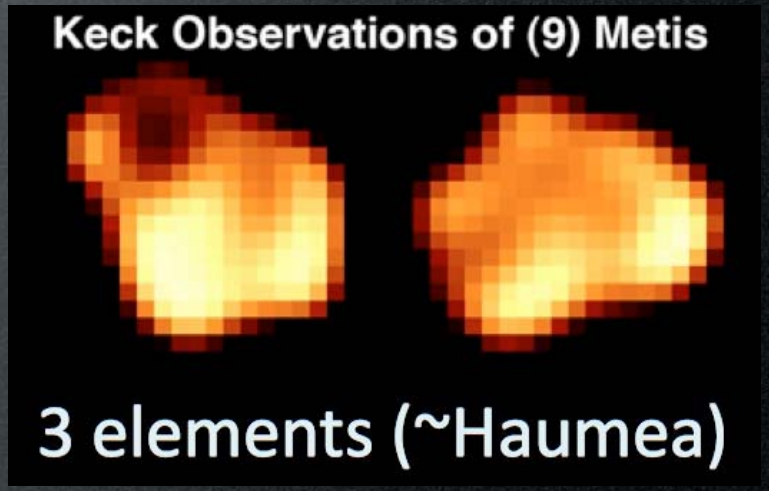
Mapping the Surface of Kuiper Belt Objects



Sorry Pluto,
but you are
not a planet ...

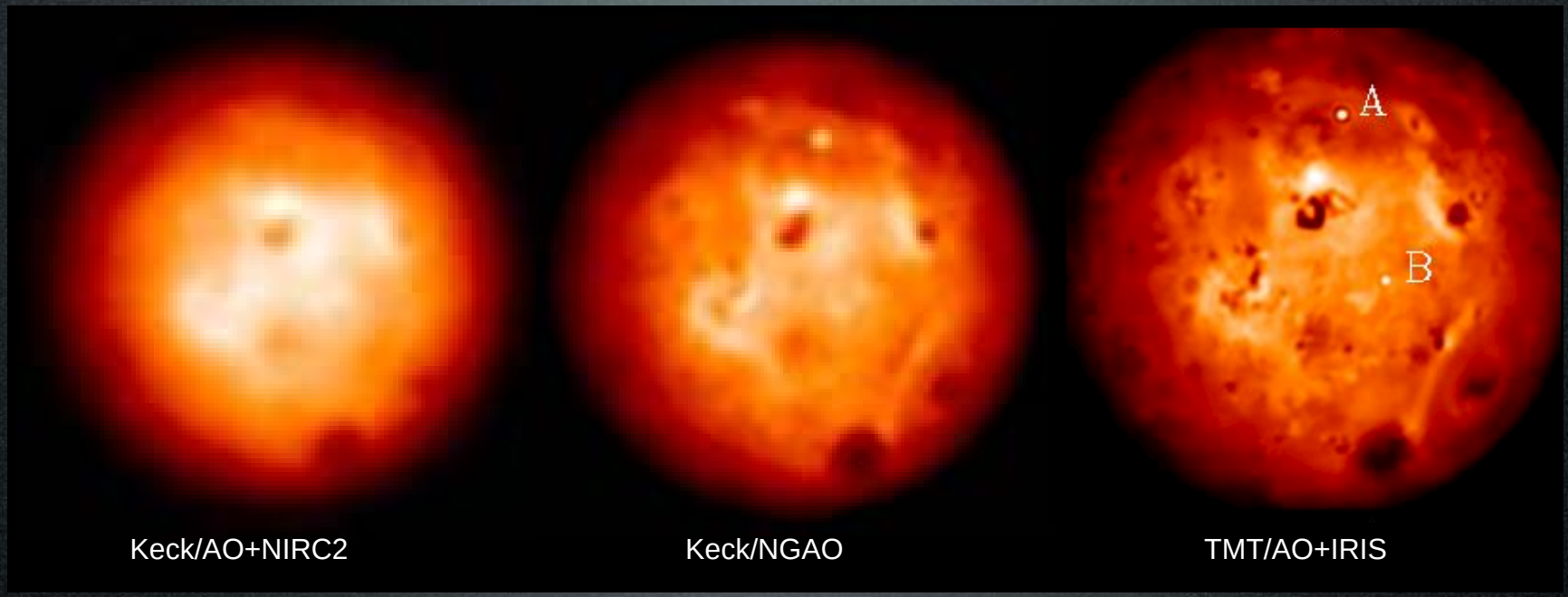






(Credit: Franck Marchis, UC Berkeley/SETI)

Observing Jupiter's Io with AO on an ELT

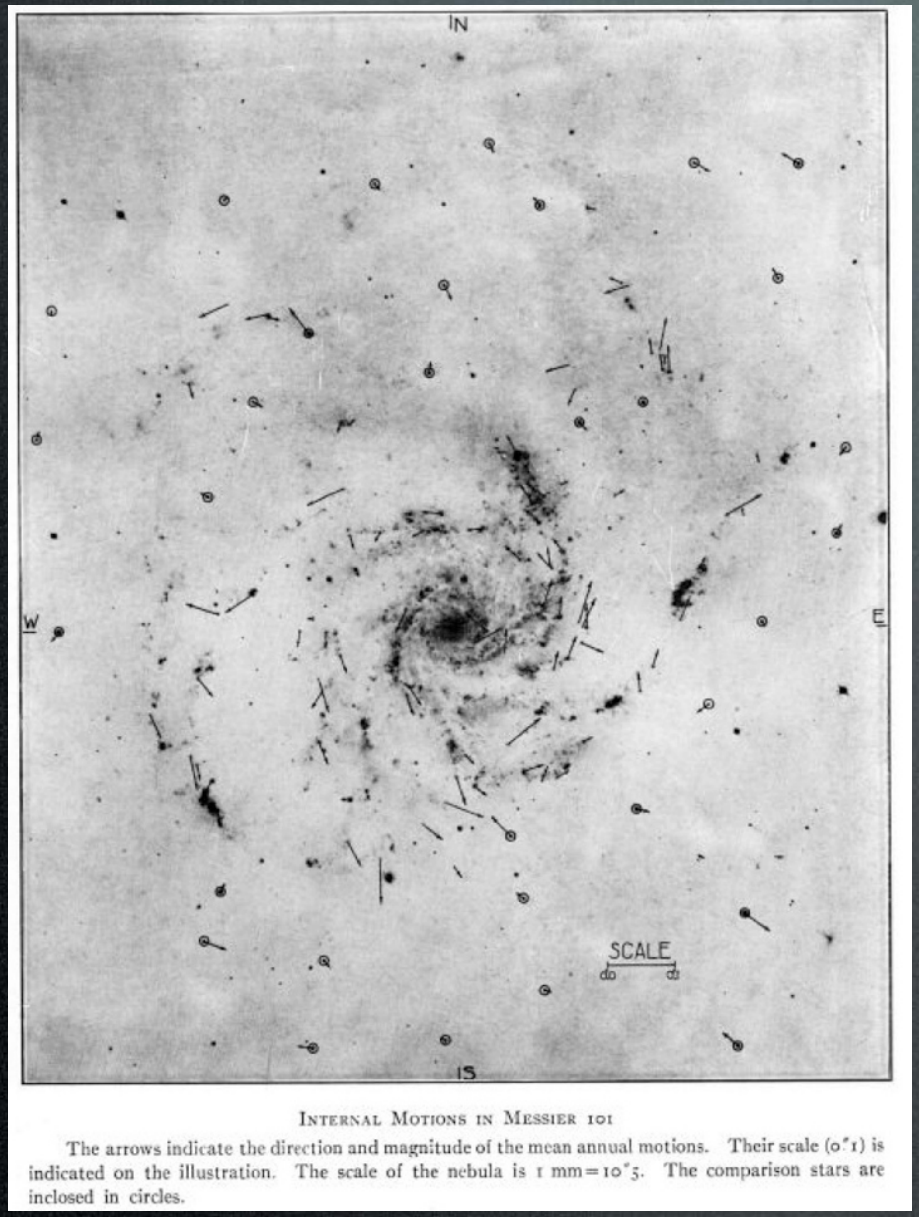


(Credit: Franck Marchis, UC Berkeley/SETI)

Remember Galileo's log book? He would be proud!

Hold on for a second … Space probes have been there and done that, so why bother?

van Maanen's Dream



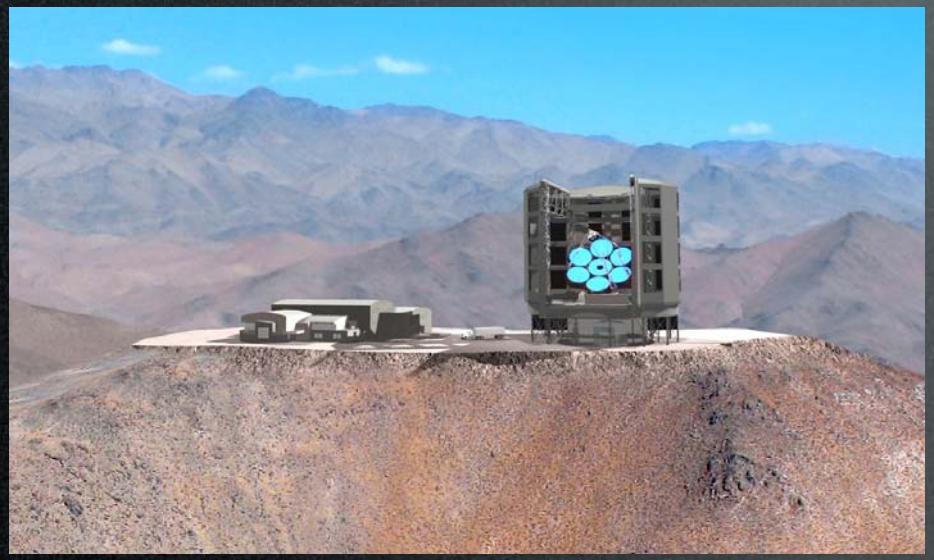
INTERNAL MOTIONS IN MESSIER 101

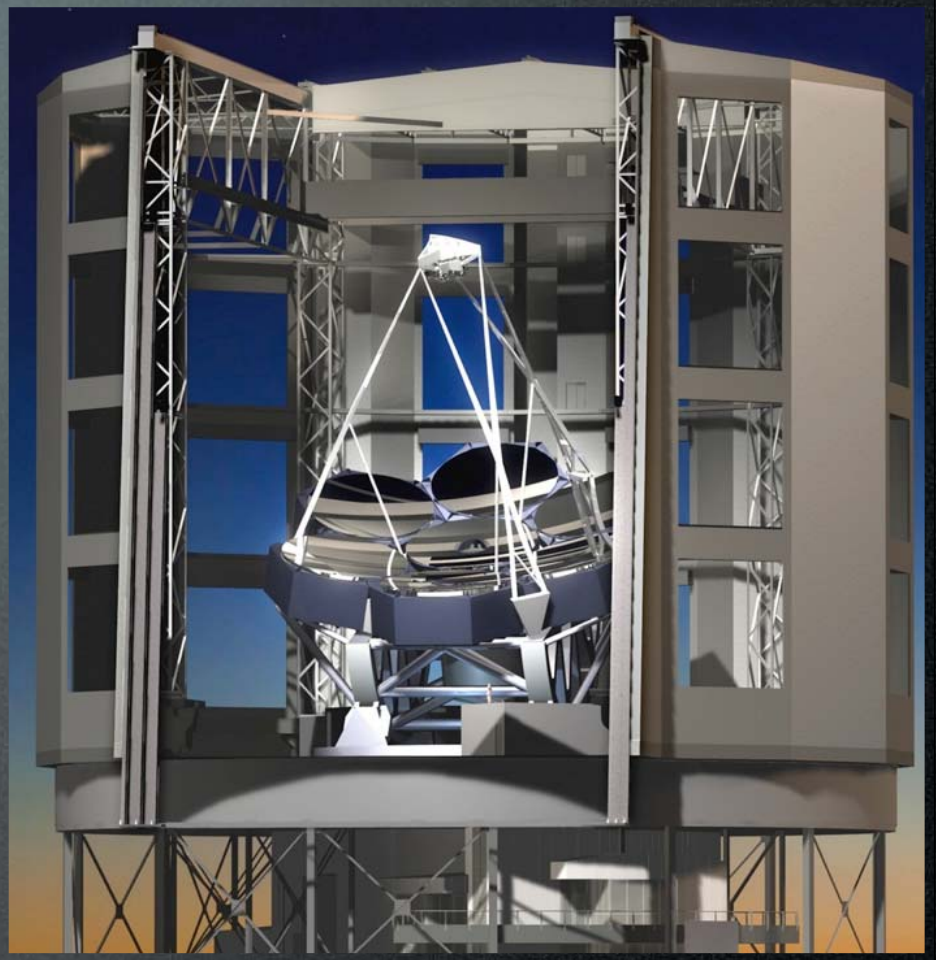
The arrows indicate the direction and magnitude of the mean annual motions. Their scale (0".1) is indicated on the illustration. The scale of the nebula is 1 mm = 10".5. The comparison stars are inclosed in circles.

"Preliminary Evidence of Internal Motion in the Spiral Nebula Messier 101" - van Maanen et al. 1916, ApJ, 44, 210

An ELT will allow us to measure the rotation of the Andromeda galaxy disk (60 micro-arcseconds / year) over a few years

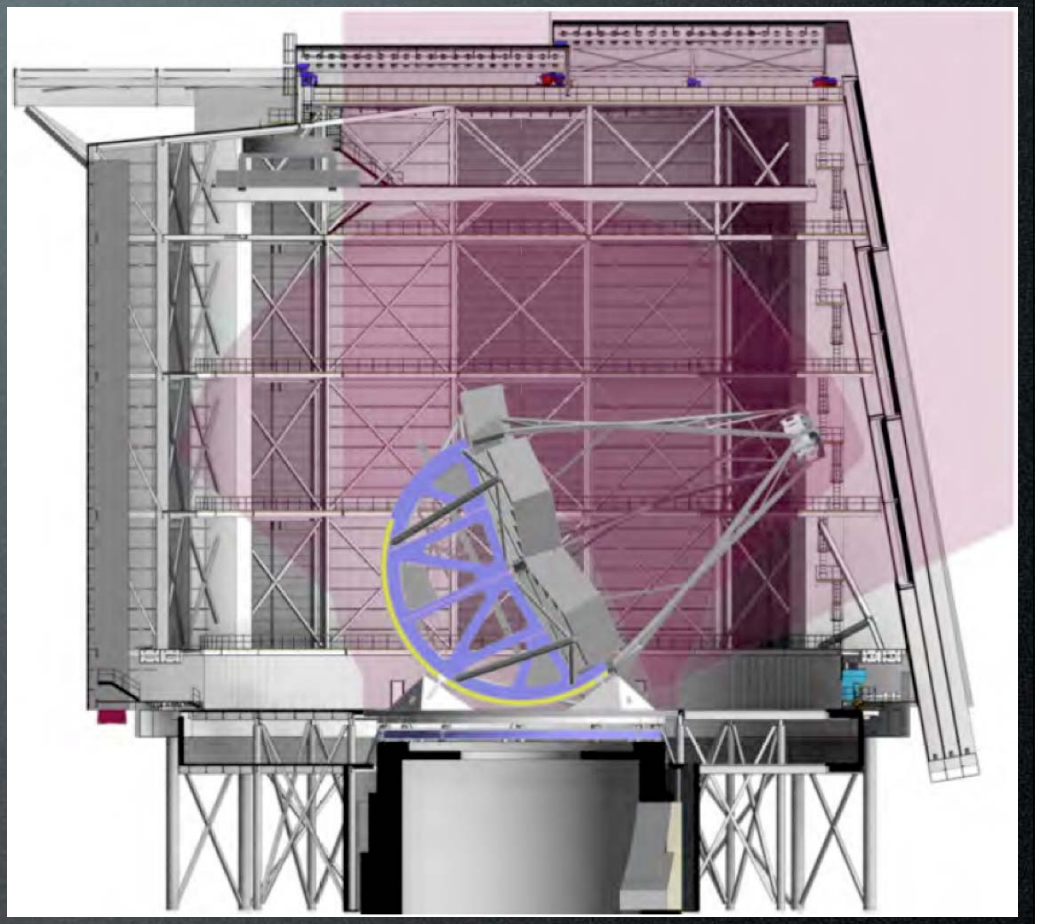
Giant Magellan Telescope (GMT)





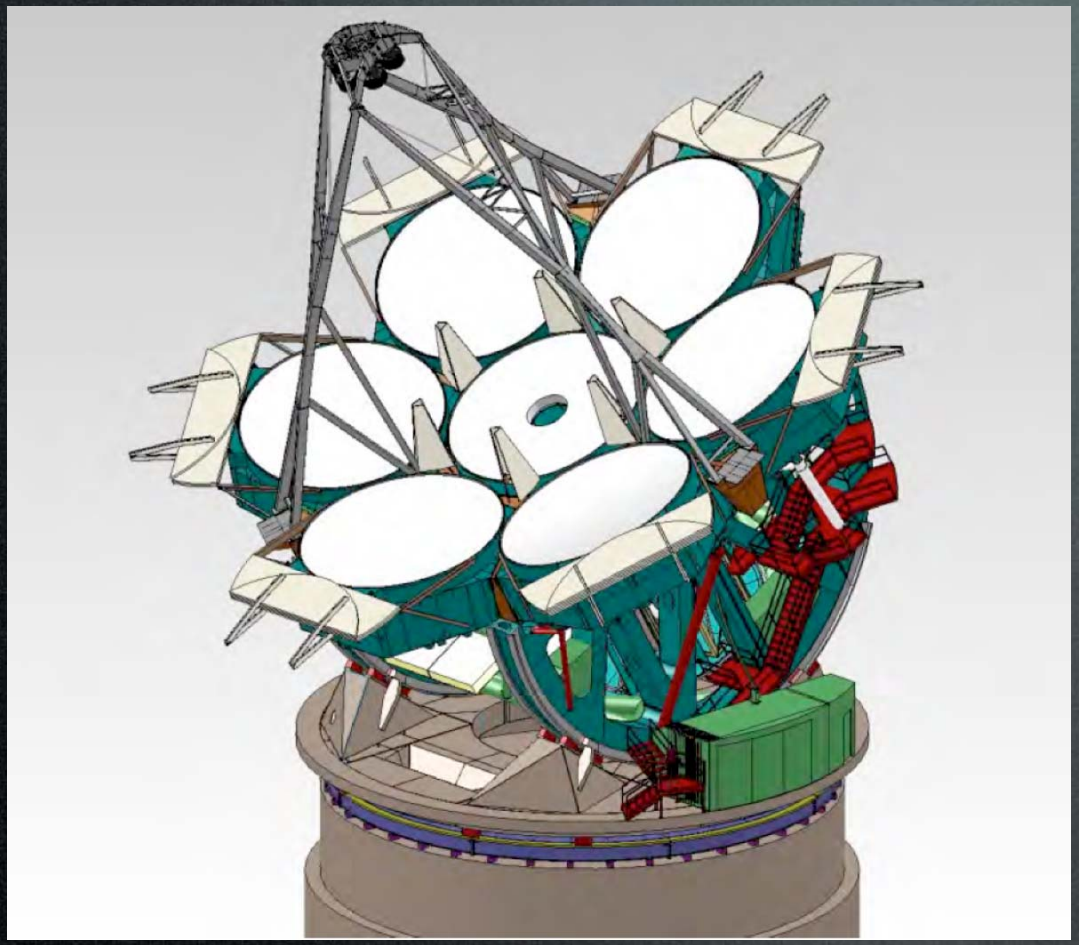
- Astronomy Australia Ltd
- Australian National University
- Carnegie Institution for Science
- Harvard University
- Korea Astronomy &Space Science
- Smithsonian Institution
- University of Texas at Austin
- Texas A&M University
- University of Arizona
- University of Chicago

GMT - Enclosure



- "Quasi-cylindrical" (Cannot really call it a dome!)
- Overall height: 65 m
- Diameter: 55 m
- Mass: 2200 tons
- Retractable top and front shutters
- Side vents for maintaining inside temperature close to ambient

GMT - Telescope Design



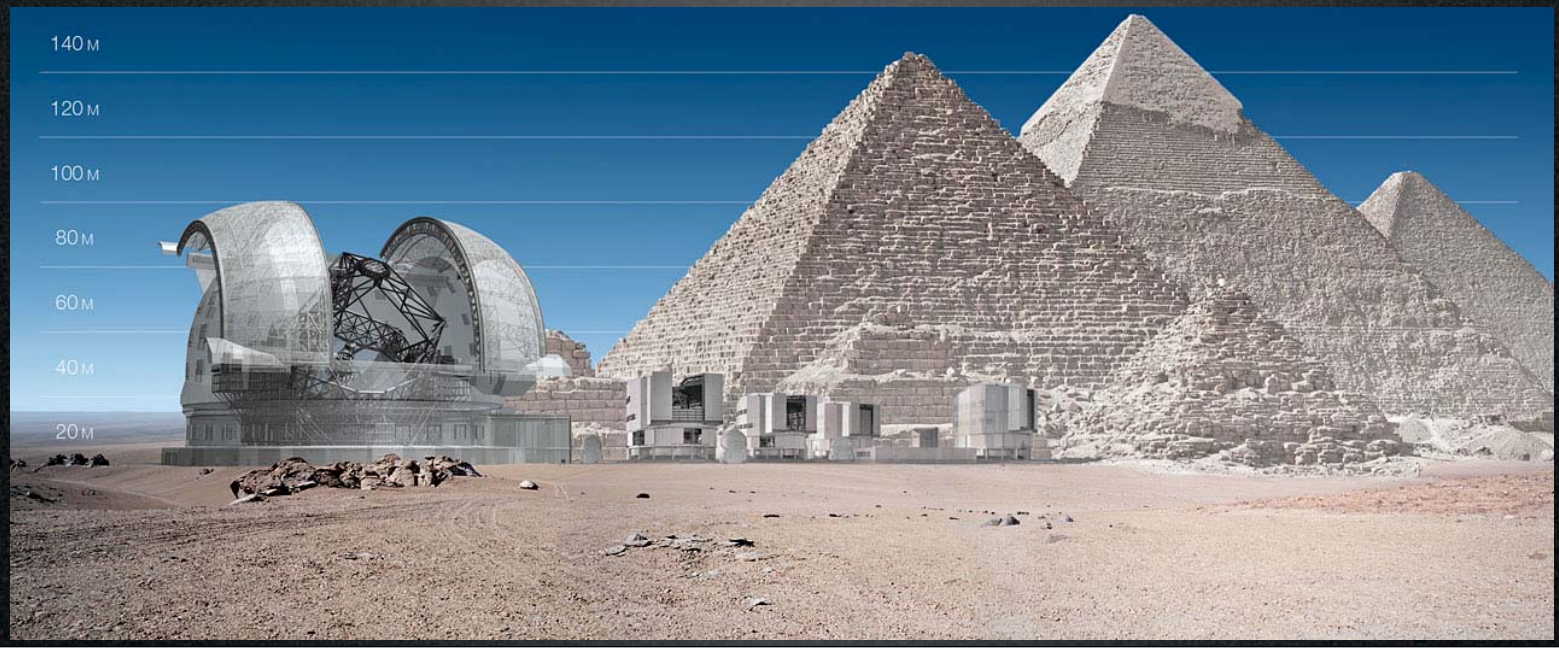
(Credit: Johns et al. SPIE 2012)

- Seven 8.36-m segments - each segment is as large as some of the largest telescopes in the world today!
- Largest diameter: 25.4 m
- Collecting area = 368 m^2
- Total rotating mass = 1250T
- Height = 40 m

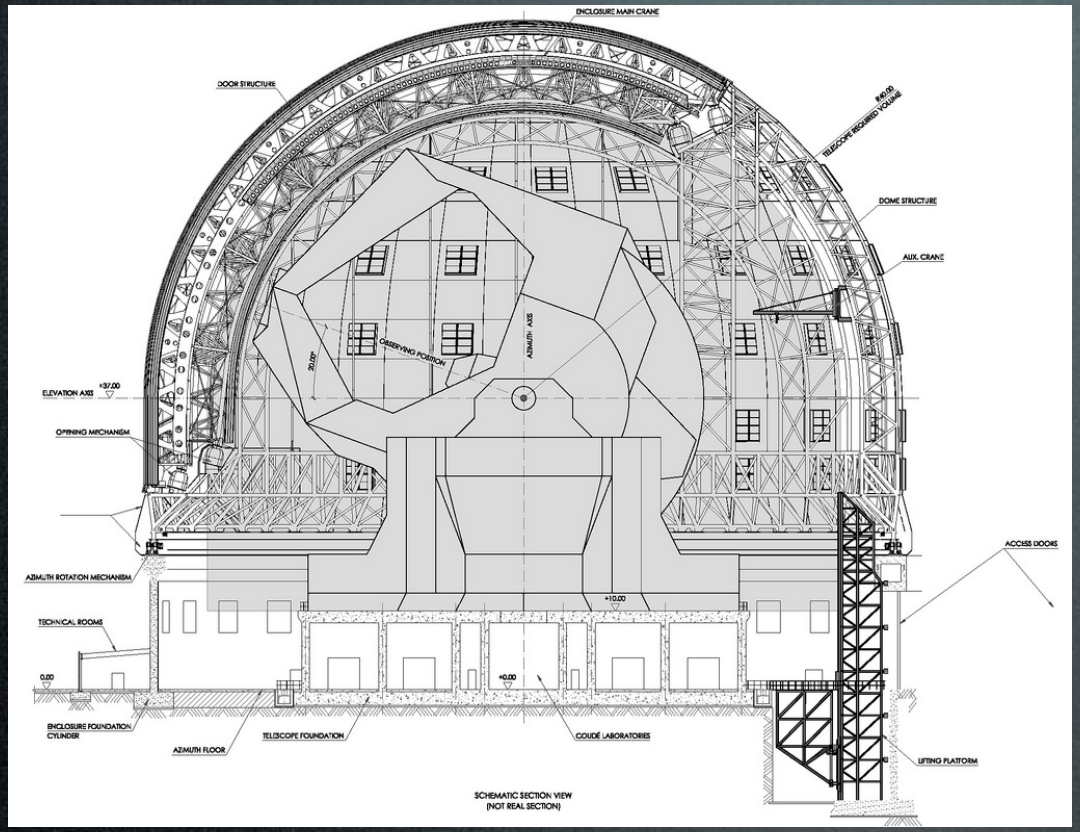
European Extremely Large Telescope

Located on Cerro Armazones - 20 km from the VLT at Cerro Paranal

(Credit: ESO)

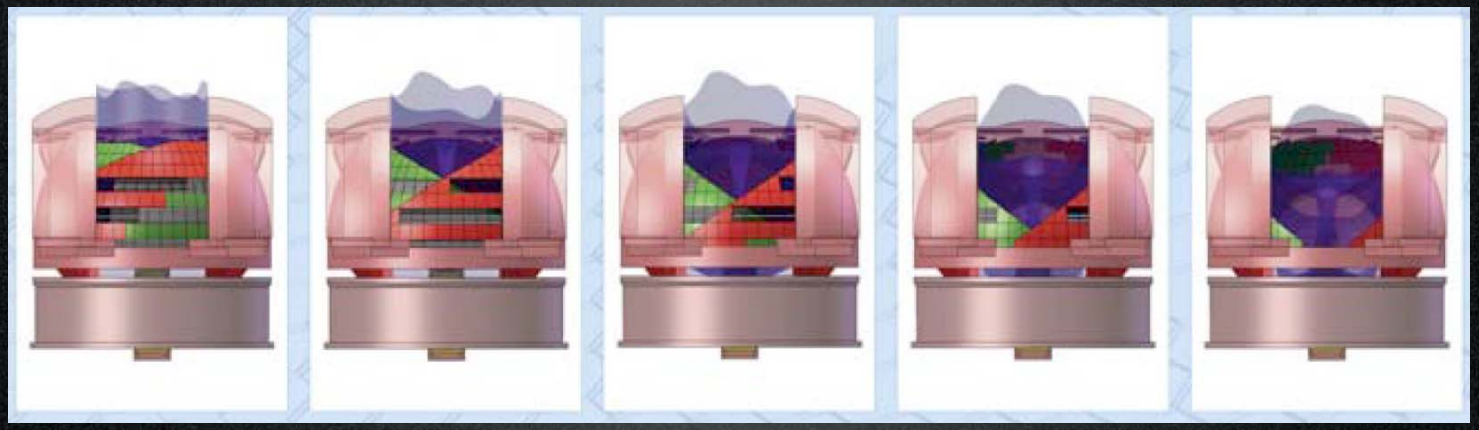


E-ELT - The Dome

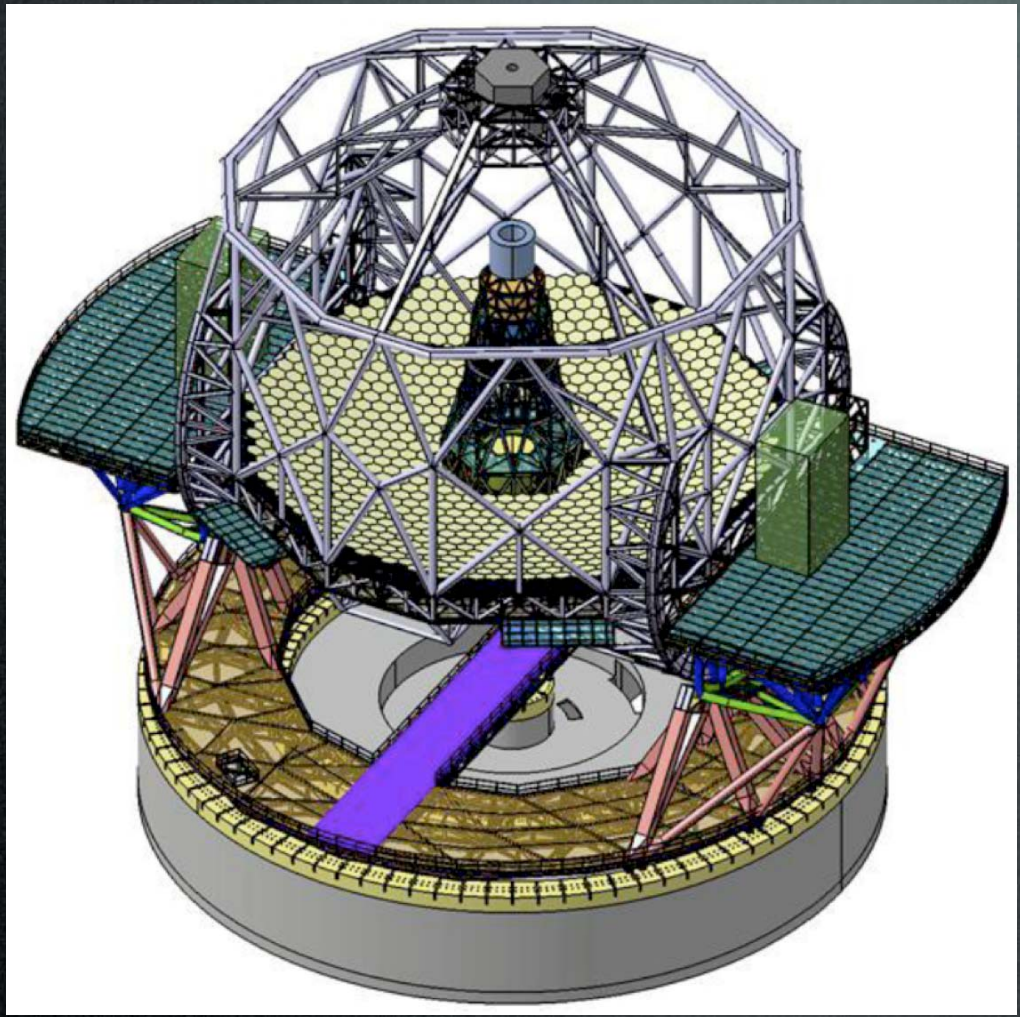


- 74-m height (!)
- 86-m diameter (!)
- 3000 T of steel
- Doors have total width of 45.3 m
- Adjustable screens provide wind protection

(Credit: ESO)



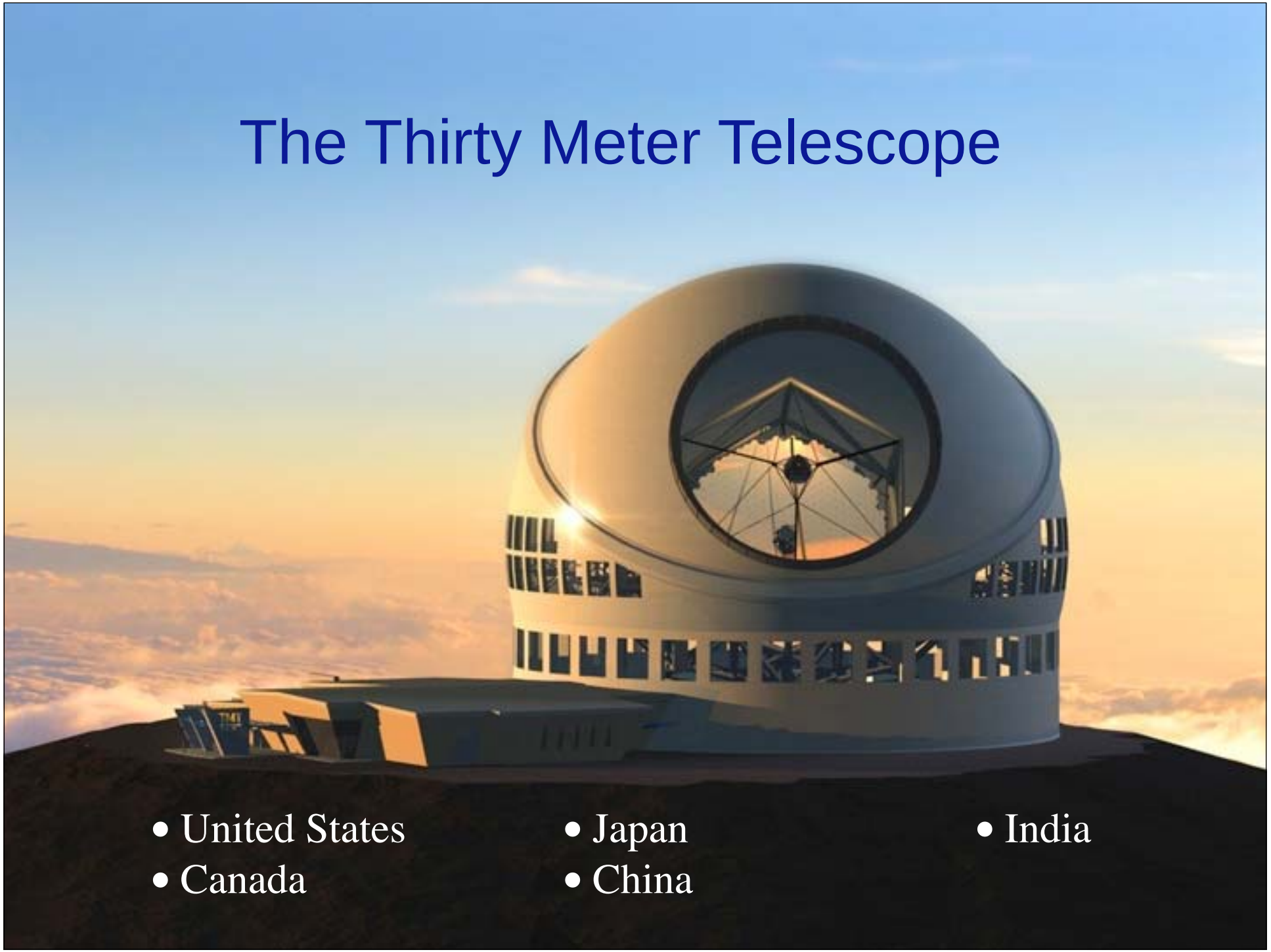
E-ELT - The Telescope



(Credit: E-ELT Construction Proposal)

- Pier diameter = 51.5 meters
- Total telescope mass = 2786T
- Height above observatory floor = 65 m
- Full width including platforms = 71m
- Primary mirror with a diameter of 39 meters
- A total of 798 segments

The Thirty Meter Telescope



- United States
- Canada
- Japan
- China
- India

TMT

THIRTY METER TELESCOPE

TMT on Mauna Kea

TMT
THIRTY METER TELESCOPE

TMT on Mauna Kea

TMT and Keck I & II

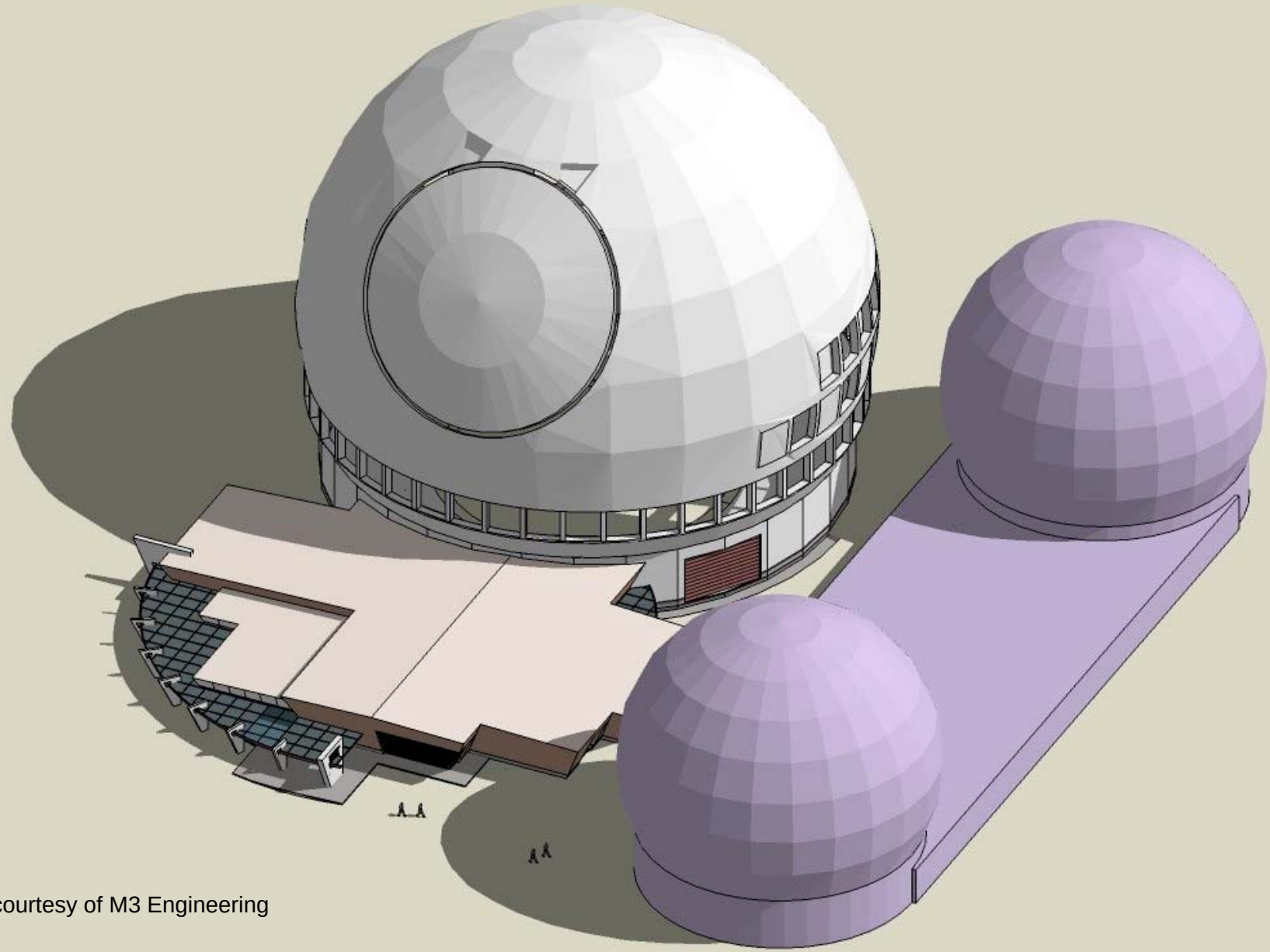
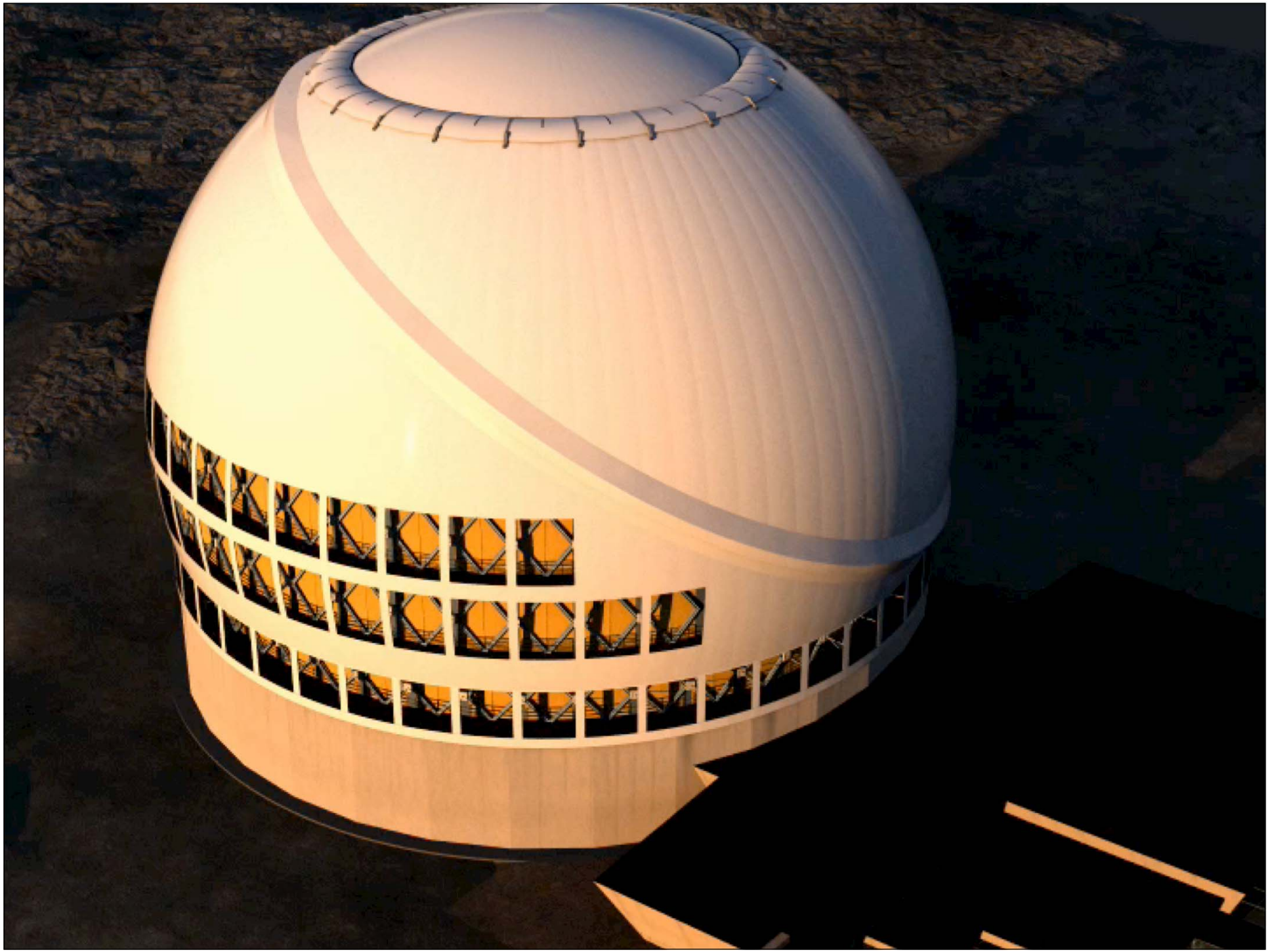
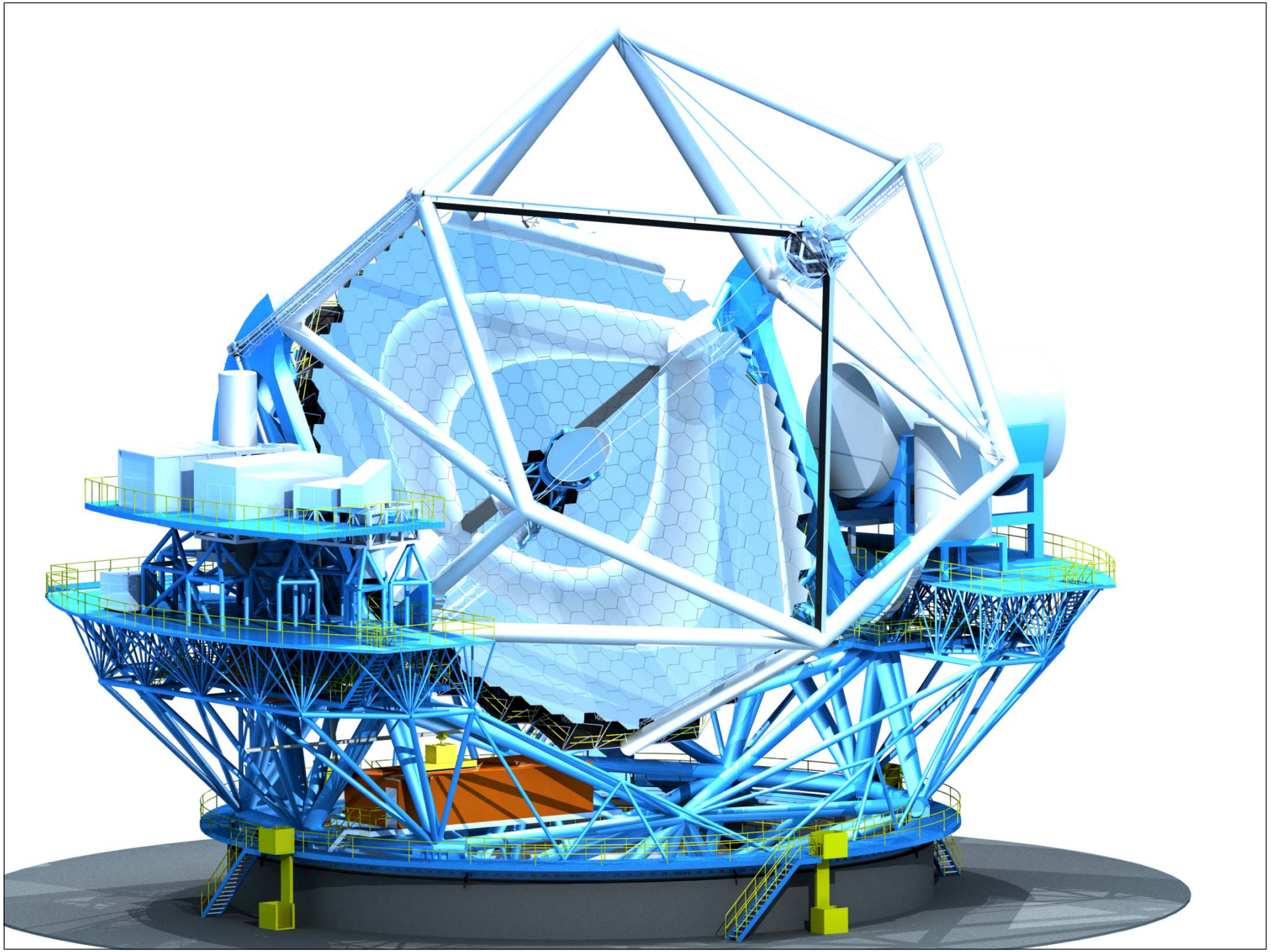
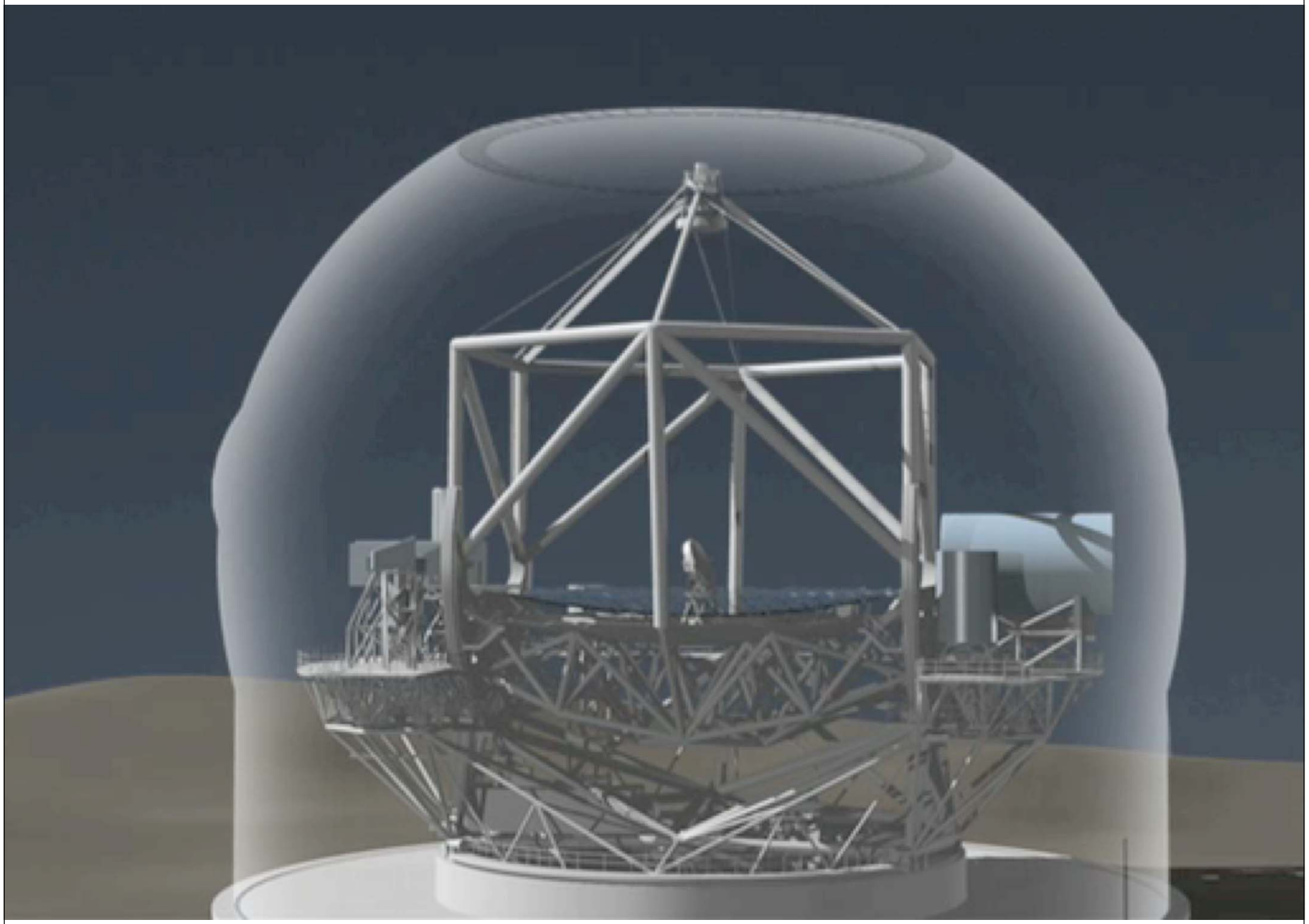


Image courtesy of M3 Engineering

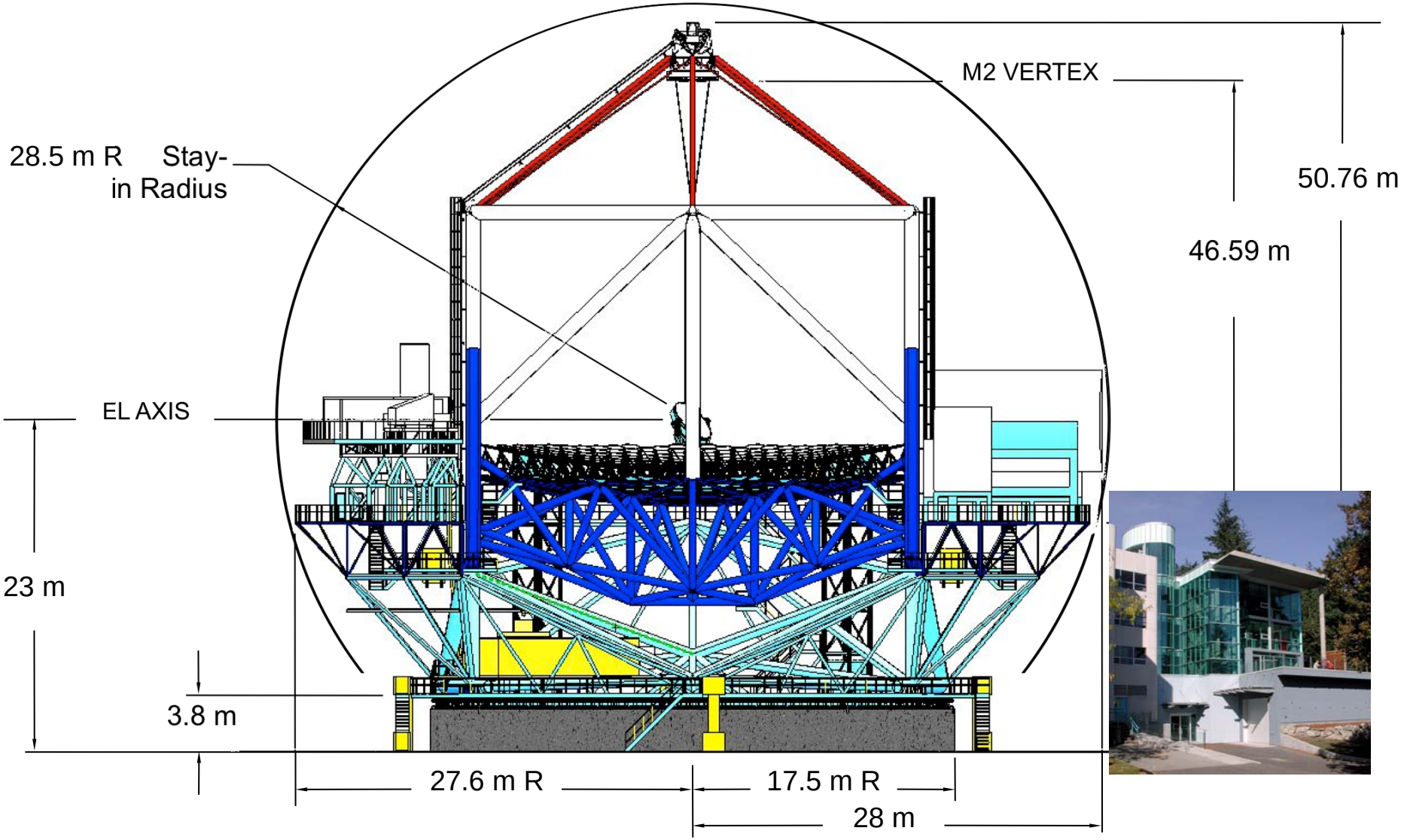


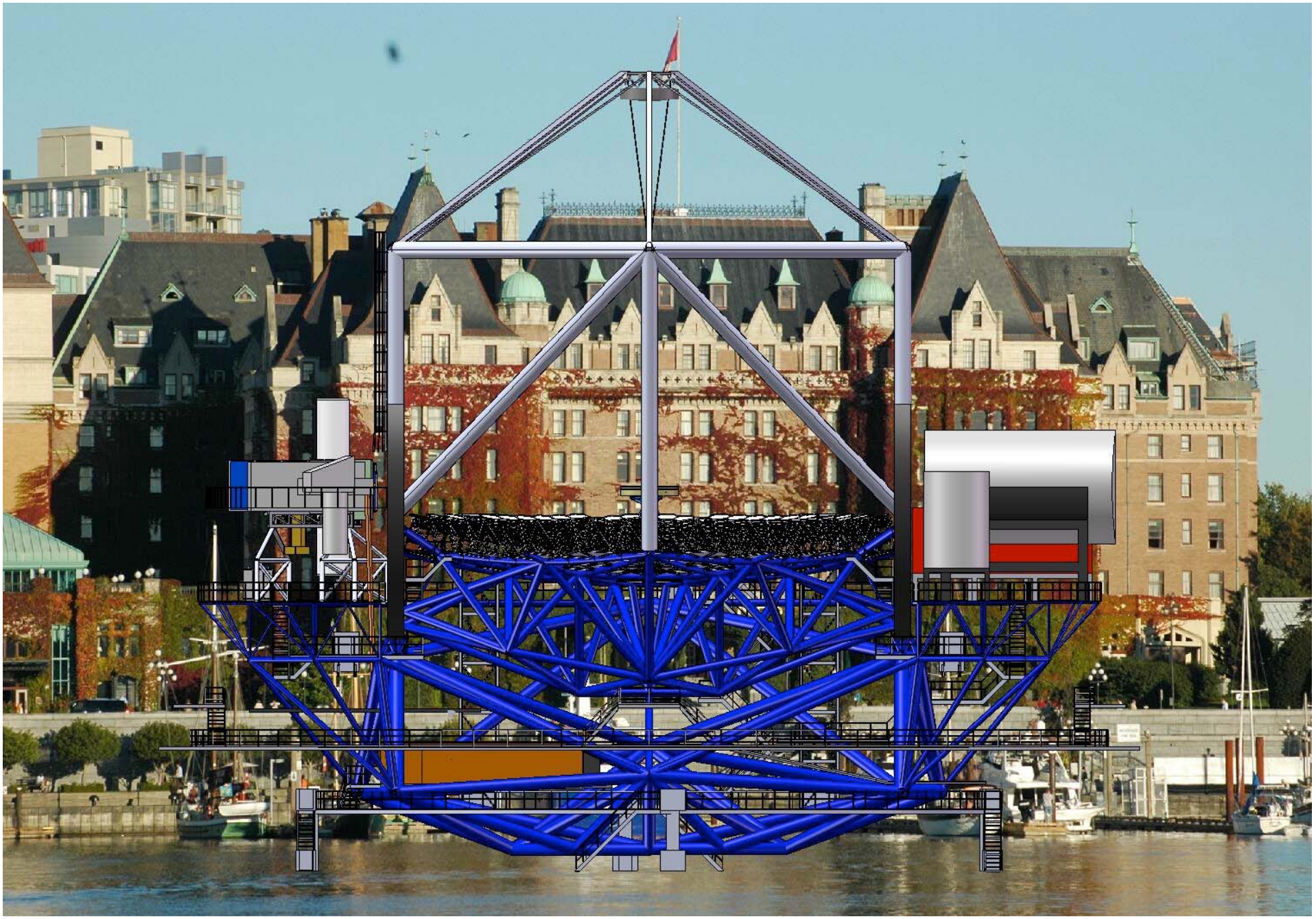




TMT
THIRTY METER TELESCOPE

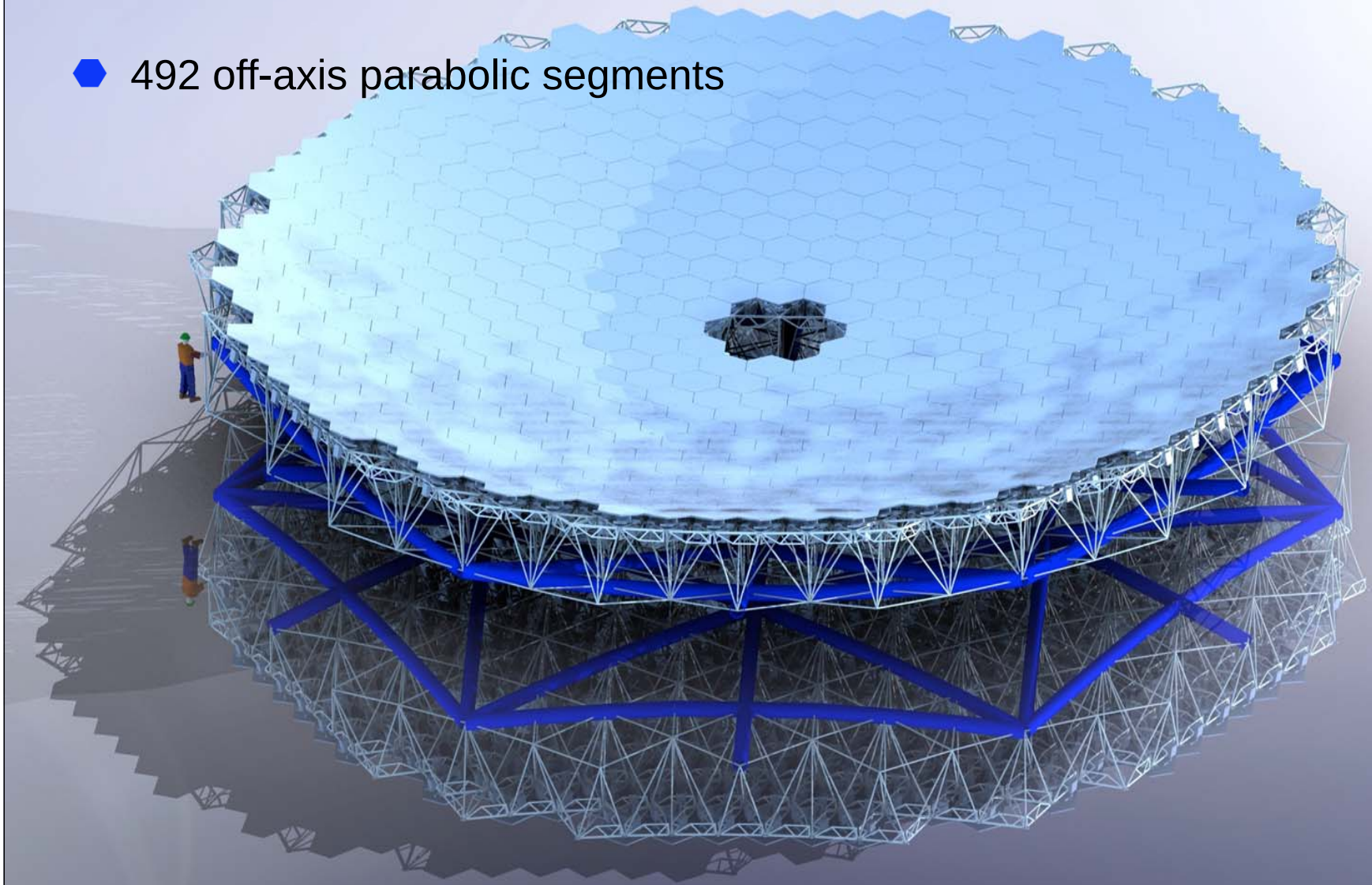
Key Dimensions



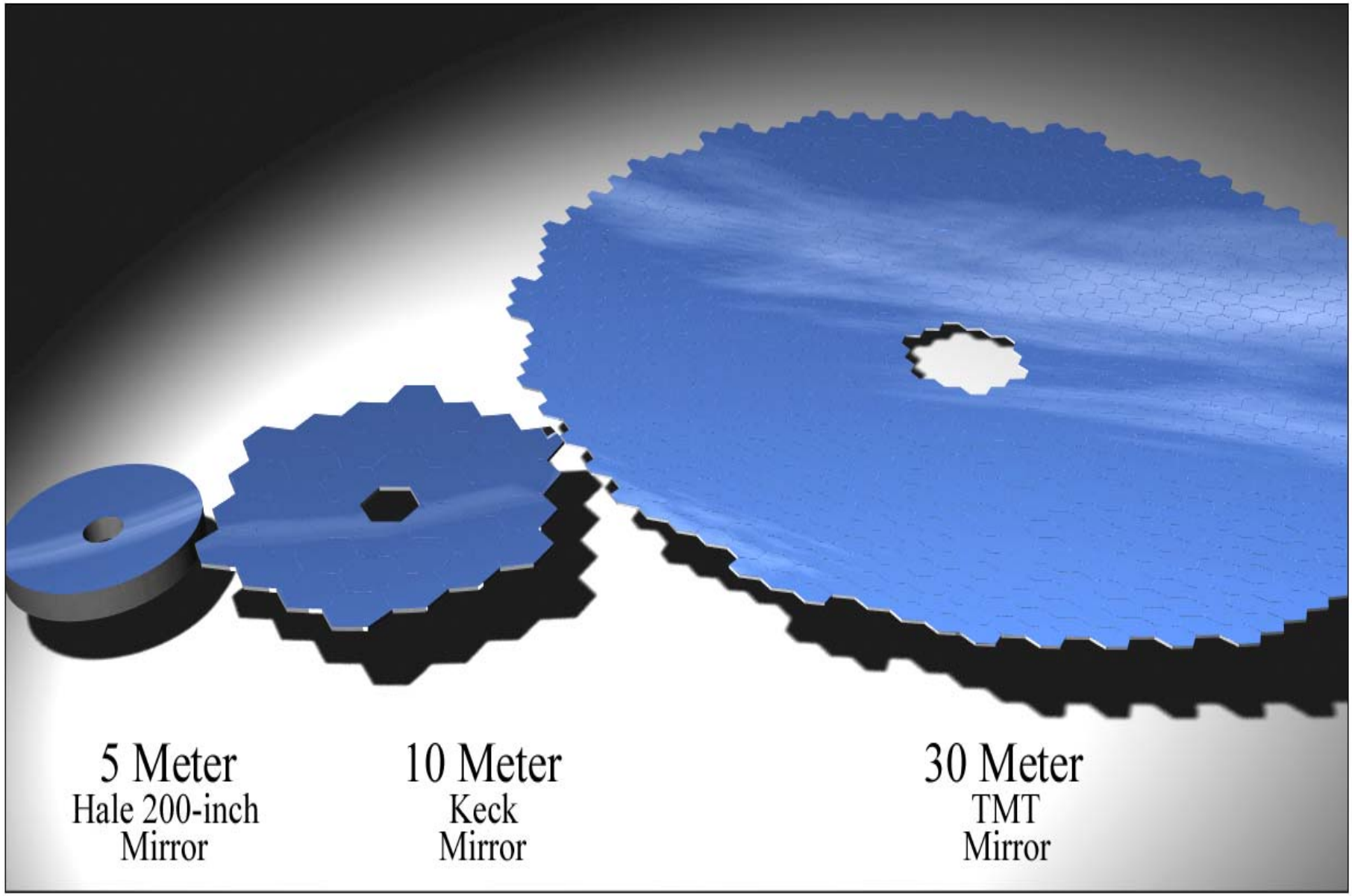


TMT primary mirror

- 492 off-axis parabolic segments

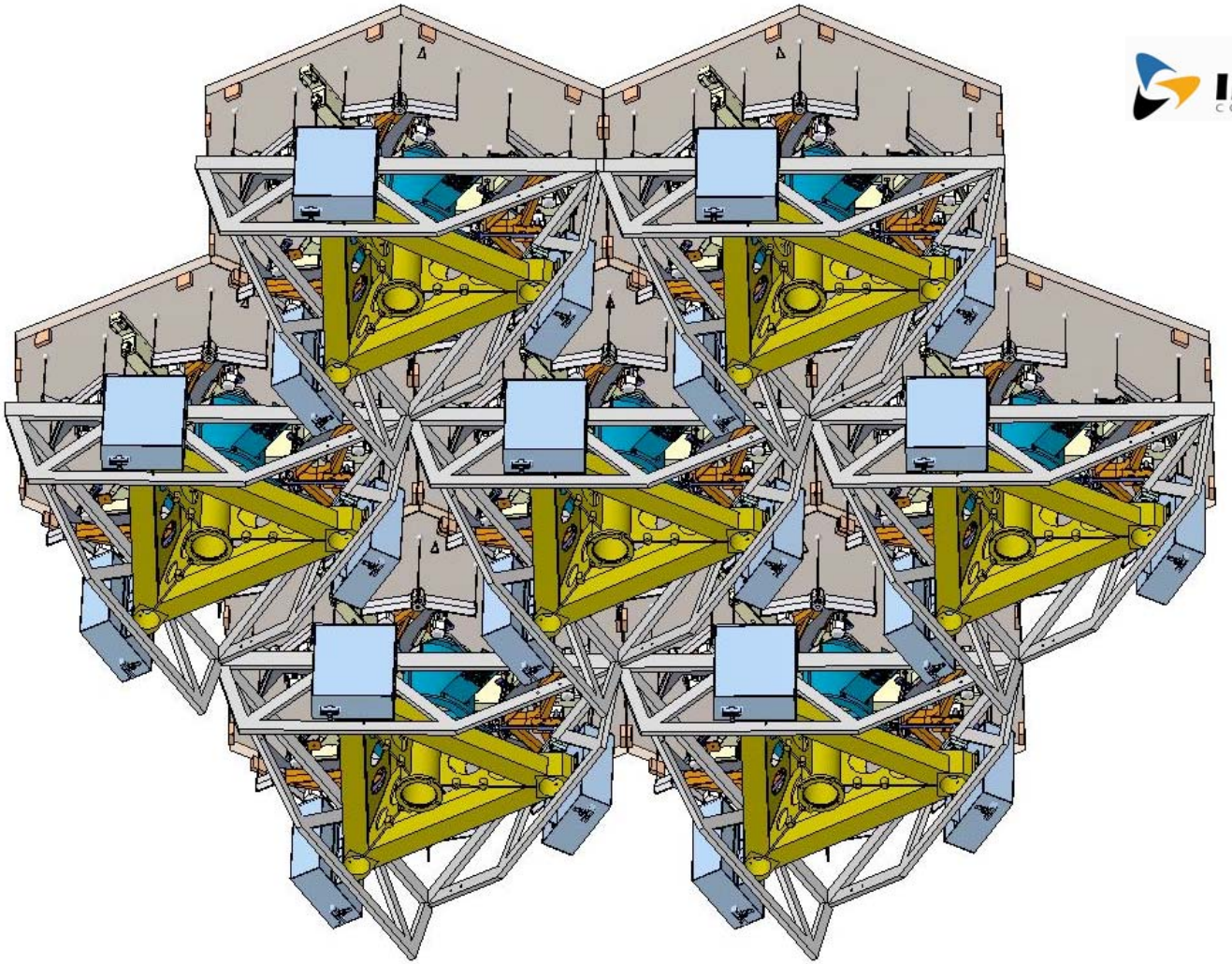


1 TMT segment = 8 Climenhaga telescopes!

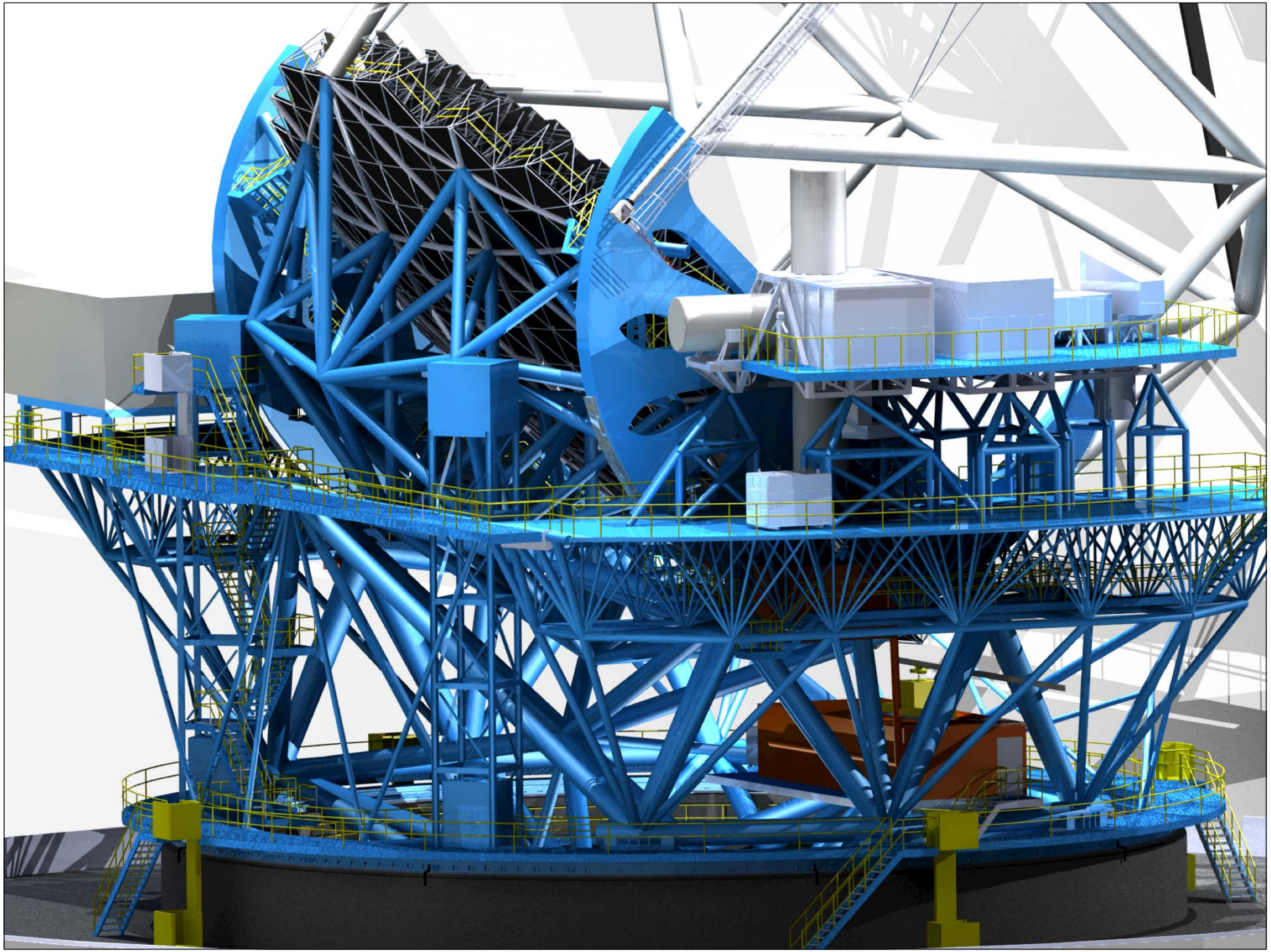

5 Meter
Hale 200-inch
Mirror
10 Meter
Keck
Mirror
30 Meter
TMT
Mirror

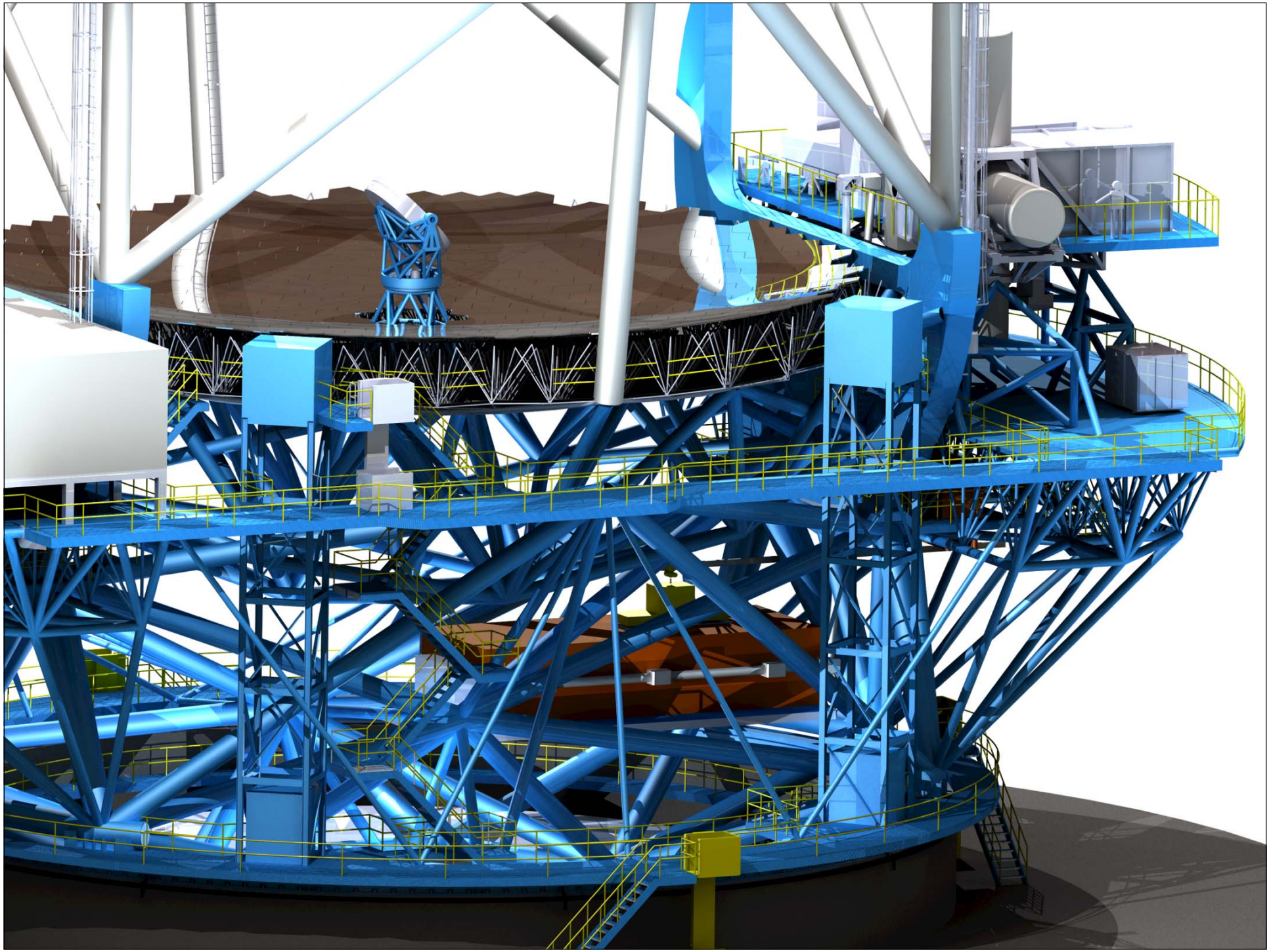
TMT
THIRTY METER TELESCOPE

Each segment is supported and shaped by its own “mechanical hand”



IMTEC CORPORATION





Question:

What do you think the next, next generation of telescope will look like? (And what are we going to call them??)