

Major Telescopes of the World



Dr. Wm. (Bill) Hrudehy
UCCI Observatory &
Edward Guinan
(Villanova University)
May 23, 2018



University College of the Cayman Islands
Dr. Wm. Hrudehy Observatory

Funded by:

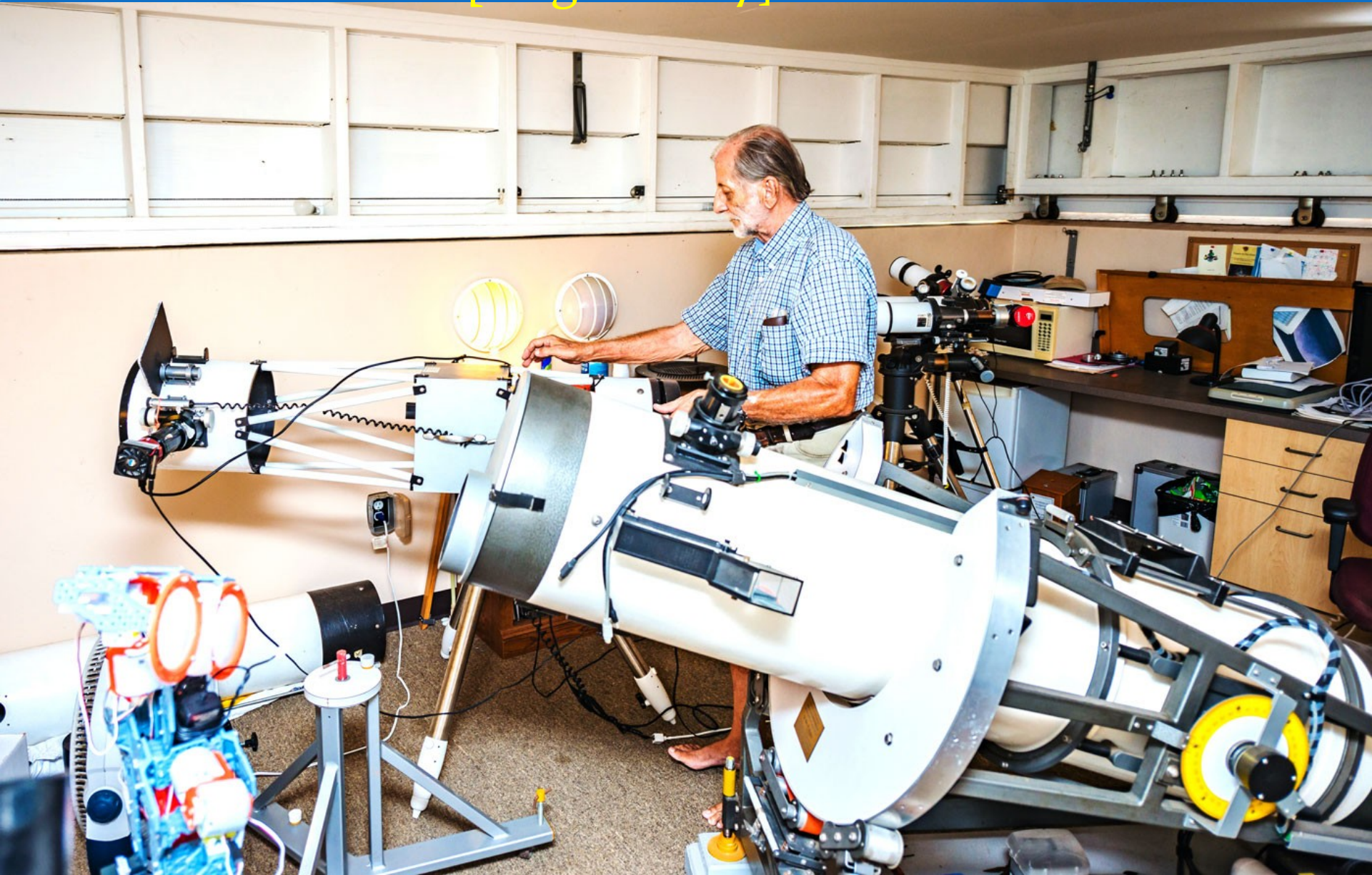
- Greenlight Re
- The Dart Family
- Rotary Club of Grand Cayman
- Caribbean Utilities Company, Ltd.
- Water Authority - Cayman Islands

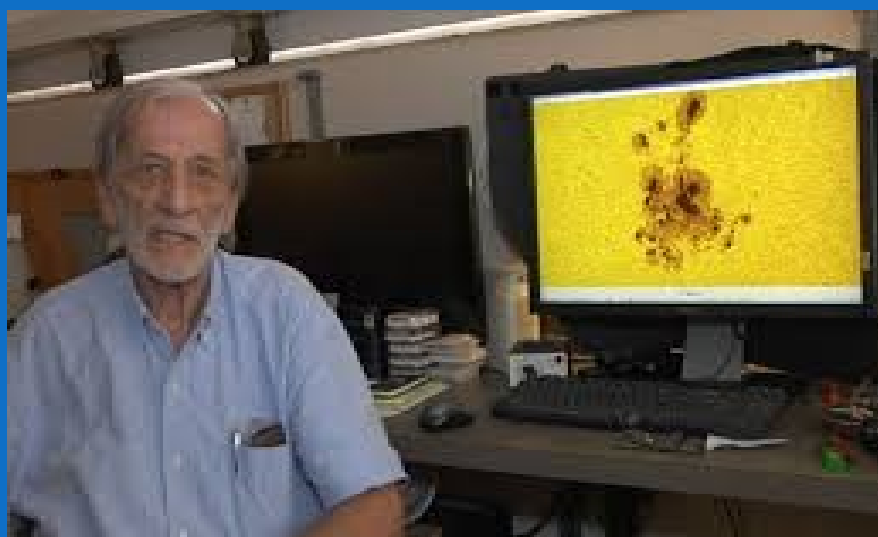
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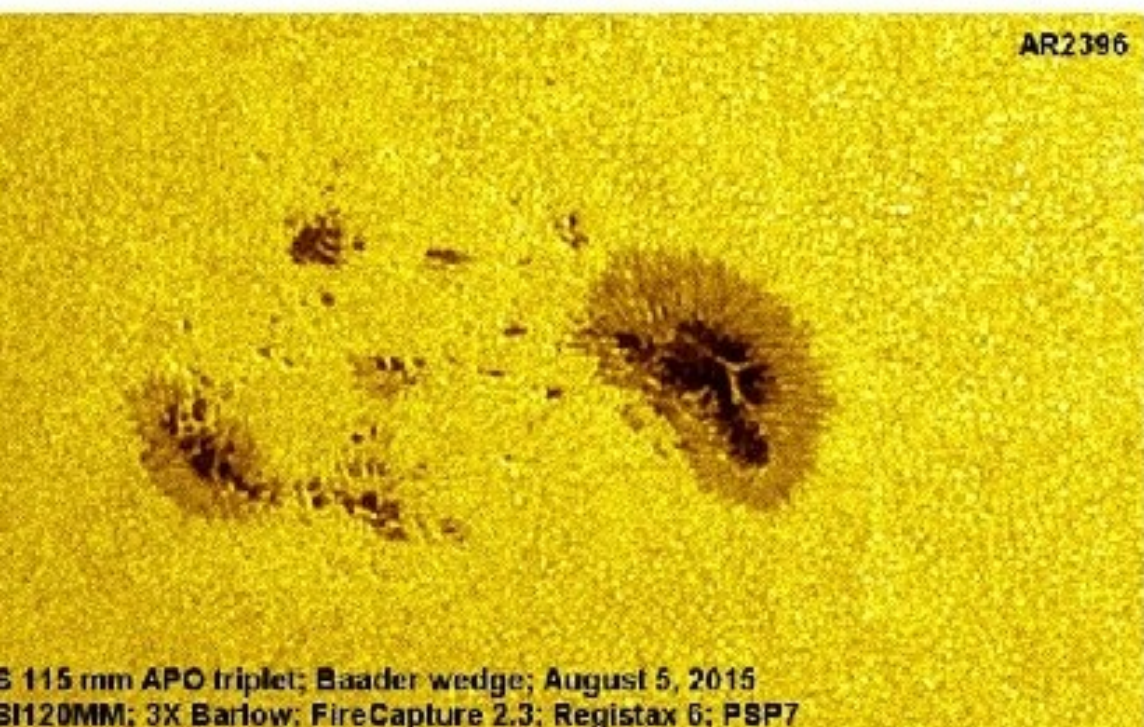
John Doak Architecture	CL Flowers & Sons
Apec Consulting Engineers	The Phoenix Group
Androgroup	Garrison Industries
National Concrete	Evans & Associates
A. L. Thompson's	ElectraTech Services

William Hrudehy Caribbean Astronomy Conference 23-26 May, 2018

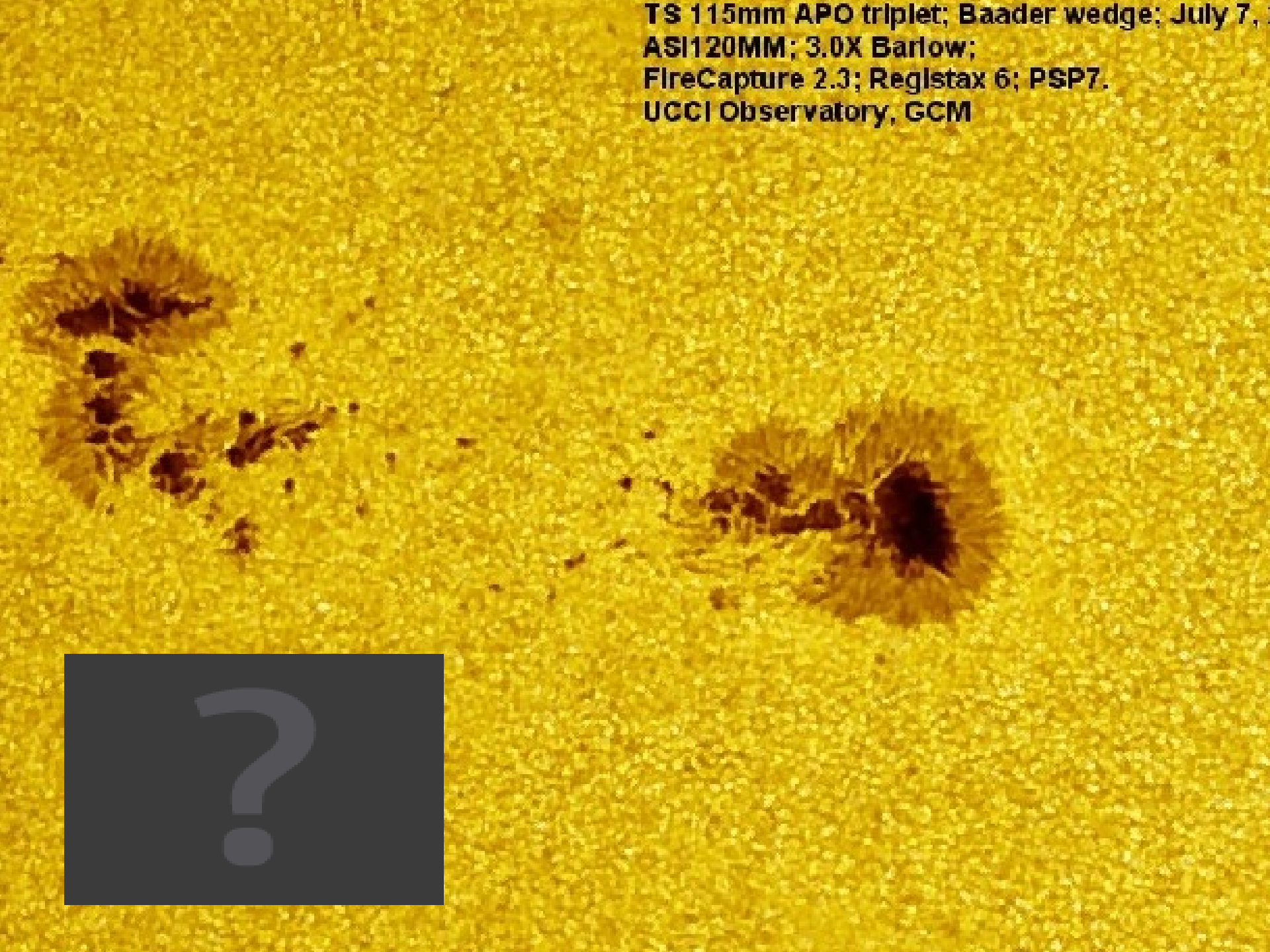
Dr. Bill Hrudehy in UCCI Wm. Hrudehy Observatory [August 2017]







TS 115mm APO triplet; Baader wedge; July 7, 2011
ASI120MM; 3.0X Barlow;
FireCapture 2.3; ReglStax 6; PSP7.
UCCI Observatory, GCM



Sunspot formation Mechanism



STEM-CARIB 2012-2017



SAVE THE DATE!

Featuring an impressive lineup of local and international STEM experts:



Dr. Edward Guinan



Dr. Shirin Haque



Dr. Francois Therrien



Dr. Bill Hruedy



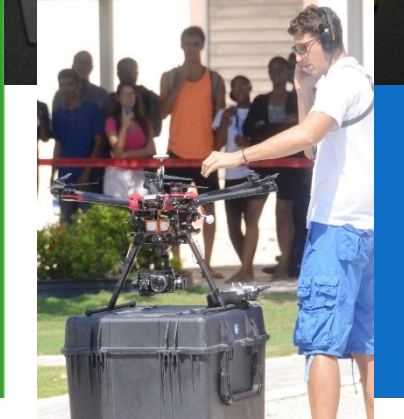
Mr. Jim Schubert



Dr. Marc Lockhart

- Topics include:**
- Forensic Science
 - The Science of Communication
 - Cyber Security
 - Aerodynamics of Helicopter Flight
 - Ballistics
 - Fractal Nature of Sunspots
 - Gravitational Waves
 - Building Bridges
 - Waste Management
 - Nuclear Power
 - Mobile Technology
 - So you wanna be a doctor?
- Other highlights:**
- Presentations by the Science Fair 2016 Winners
 - Demonstrations and Exhibits

REGISTRATION RATES:
 Full Pass: CI\$150 - Regular
 CI\$100 - Students
 One Day Pass: CI\$50 - Regular



The University College of the Cayman Islands

proudly presents

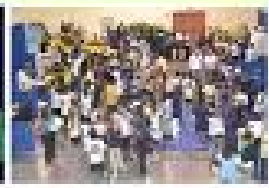


STEM
CARIB 2016

OCTOBER
11 - 14
UCCI Campus



Thank You!





Solar Physics/Digital Solar Imaging Course

UCCI & Harrisburg University

July 23- 30, 2017

One of Bill's favorite
Images (Nov. 11, 2015)

Lunt 60 DSPT; DMK41; 2.5X Barlow; Nov 11, 2015
SharpCap 2.6; AutoStakkert!2/Registax 6; PSP7
UCCI Observatory, GCM

Governor Helen Kilpatrick gives Dr. William Hrudey the MBE medal at Government House, with Mrs. Gigi Hrudey (Jan. 07, 2018)



“I am truly humbled, honoured and delighted to have received an MBE in recognition of my services to the islands,” said Dr. Hrudey. “Science is so important and promoting its many uses, especially to students, has been a key part of my life in Cayman.”

Organized by:

Historical: Galileo to Rosse

Golden age: Lowell to Palomar

Current: Hawaii, las Palmas and Chile

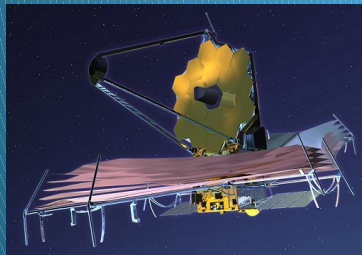
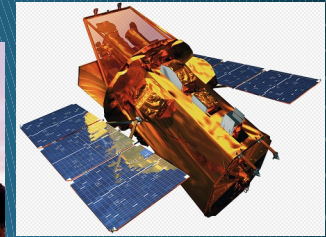
Orbital: Hubble, Herschel and Chandra

Solar: BBSO, SDO, and SOHO

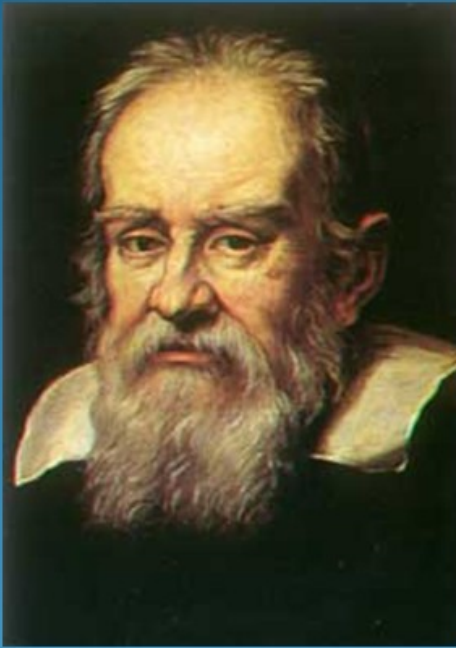
Large Radio: Aricebo and Tianyan (FAST)

Future: JWST, GMT, LSST, TMT and E-ELT

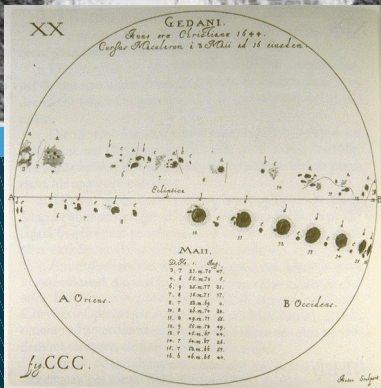
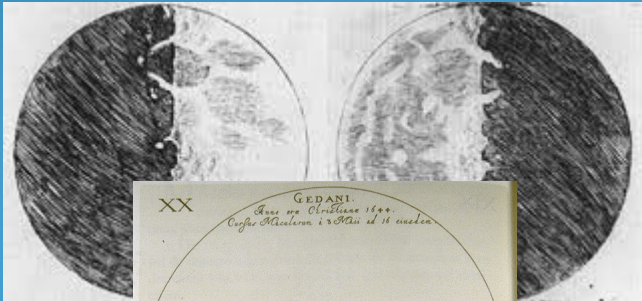
Some of Many !



Galileo's Telescope:

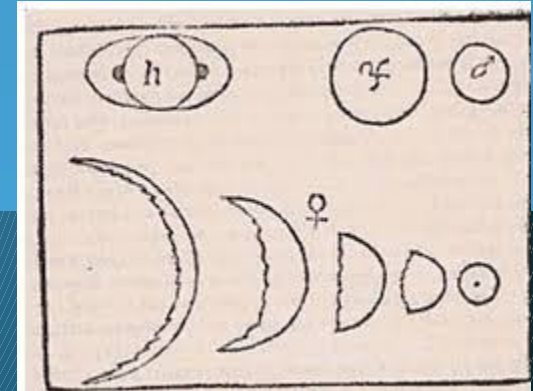


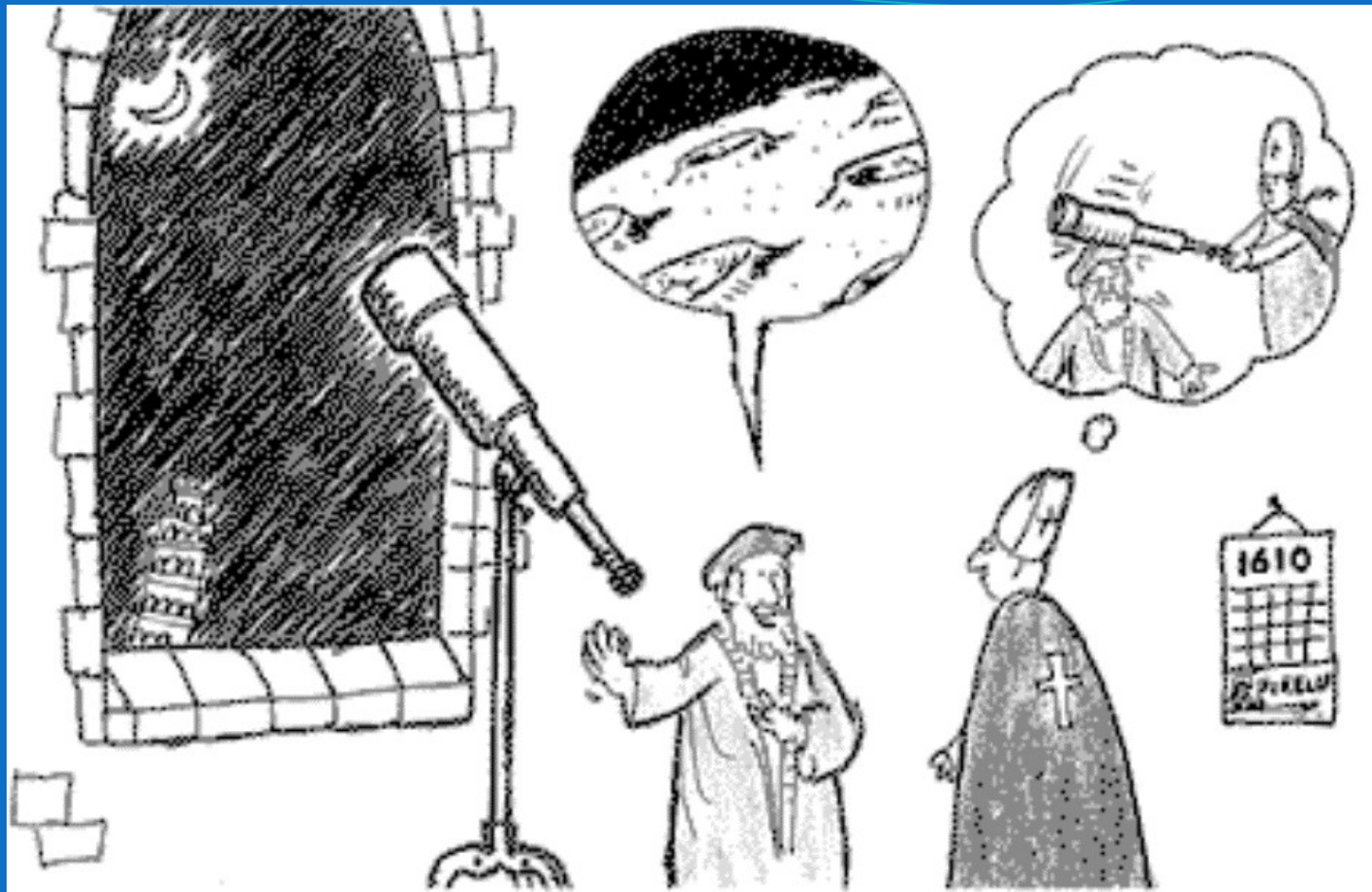
Though the Dutch made the first telescope in 1609, it was Galileo who in 1610 improved the design and generally receives credit as being the first.



Observationes Jovianae
1610

2. Jovis	max. H. 12	○ **
30. mane		** ○ *
2. Jovis		○ ** *
3. mane		○ * *
3. Ho. J.		* ○ *
7. mane		* ○ **
6. mane		** ○ *
8. mane H. 13.		* * * ○
10. mane		* * * ○ *
11.		* * ○ *
12. H. 4. Jovis		* ○ *
17. mane		* ** ○ *
14. mane		* * * ○ *

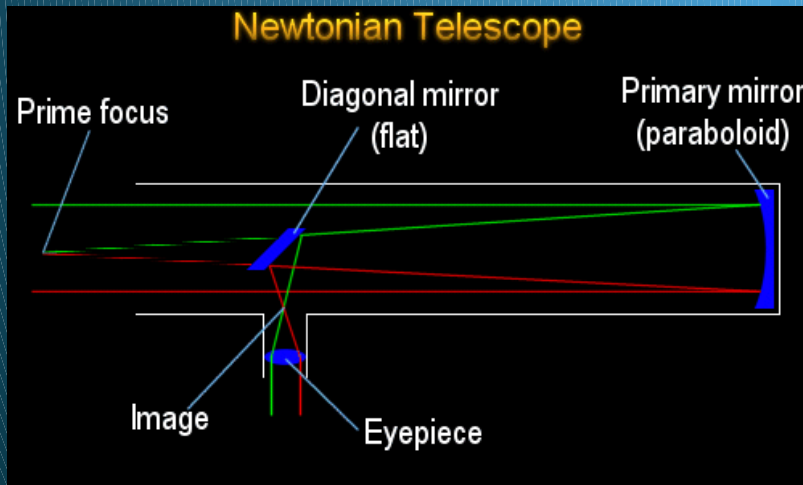




Galileo discusses his discoveries with the church.

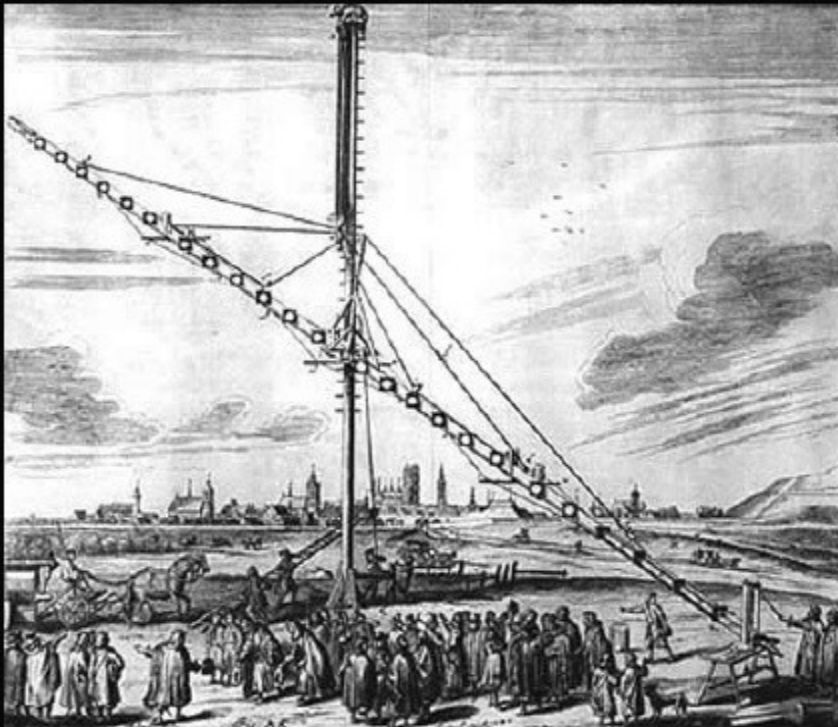
Not in Bill's presentation but I think he would like this cartoon

Newton's reflector 1668



Bill's Newtonian Reflector with a H-alpha Detector at the focus

Johannes Hevelius Scope



Pewaukee Astronomy Club
Harken Observatory

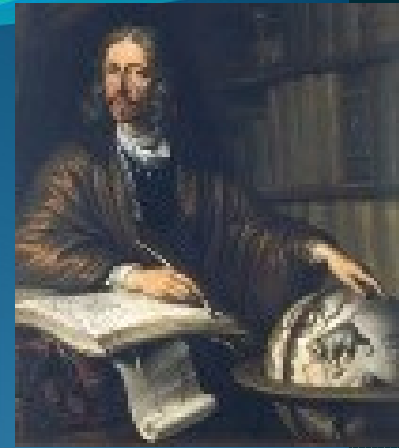
Built 1673

150 ft long

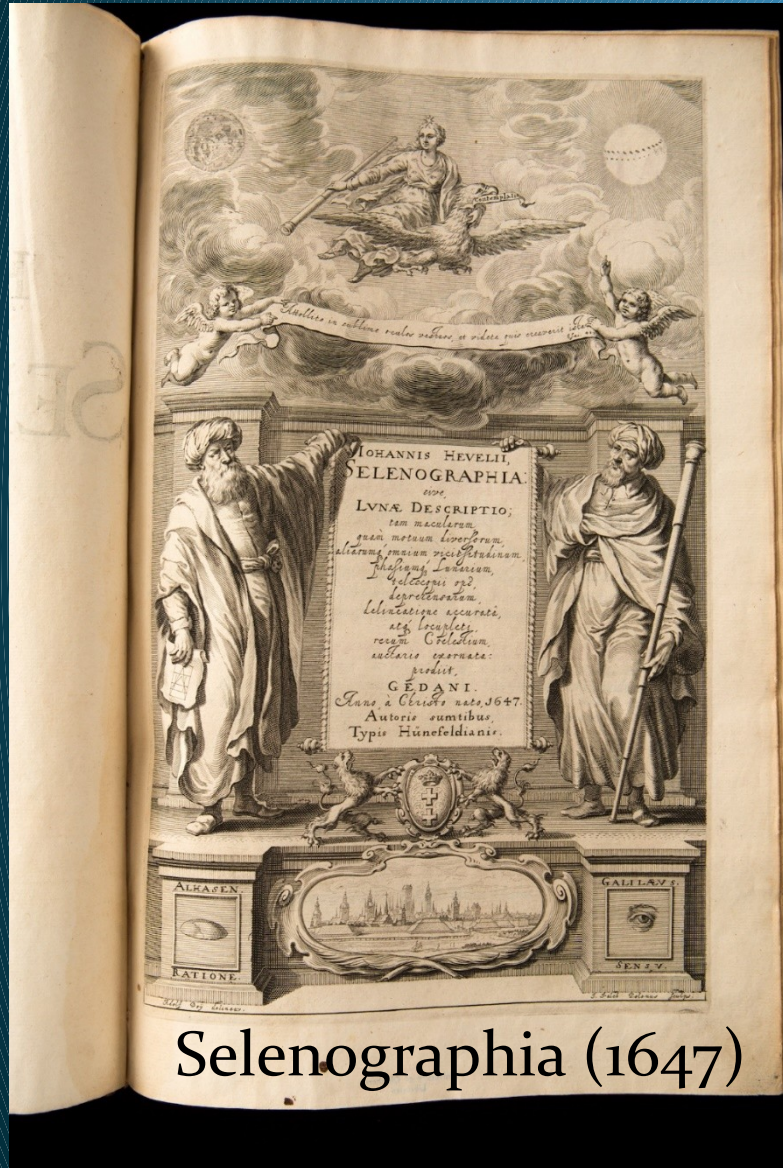
Wooden trough

"The telescope would shake in the smallest breeze, the wooden planks warped, and the ropes had to be constantly adjusted because of stretching and shrinking in the humidity. The unsteadiness also made it difficult to line up the lenses for observations. Due to all these difficulties, this huge telescope was rarely used."

<http://amazing-space.stsci.edu/>



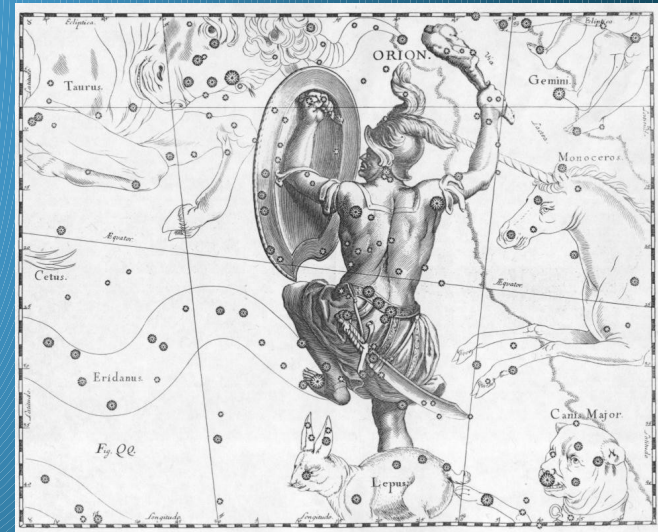
Johannes Hevelius' *Selenographia* and his Star Atlas *Firmamentum*



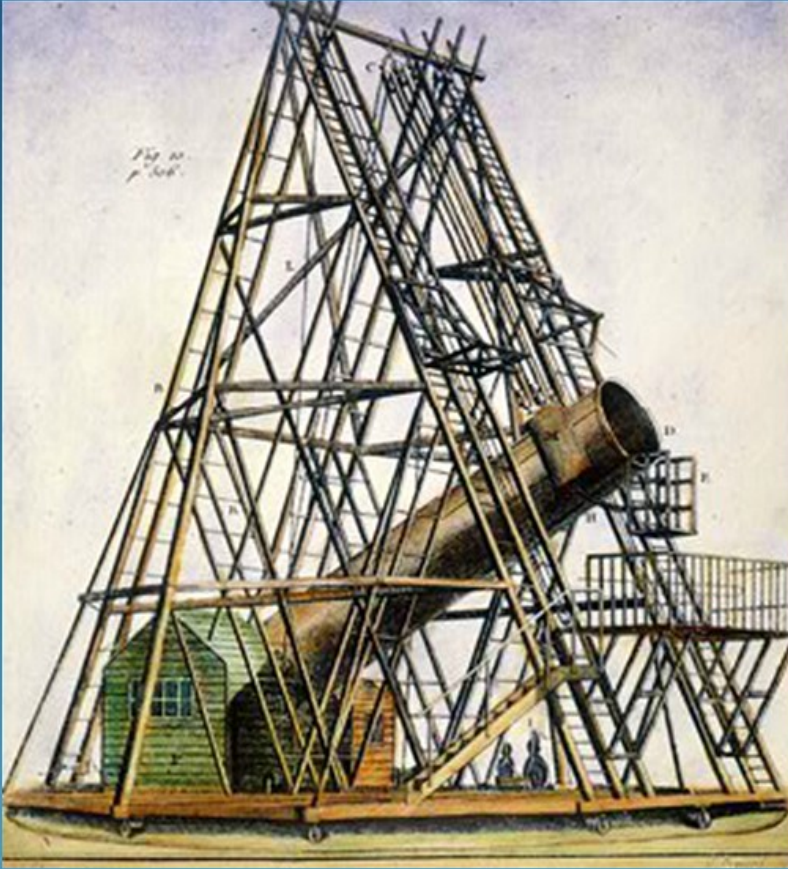
Selenographia (1647)



Discovered a nova in 1670



Sir Wm. Herschel 1789



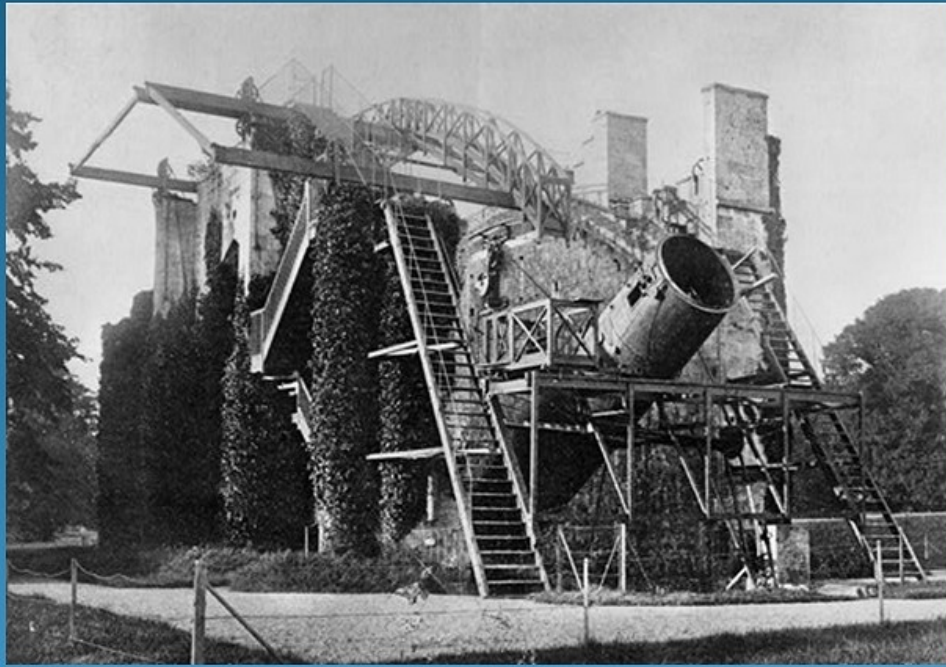
Forty foot long telescope with a 4 foot mirror in Slough, England. It's size and weight limited its use. Nonetheless, Saturn's moons, Enceladus and Mimas, were discovered with it



Discovered Uranus (by accident) in March 1781

Lord Rosse 1845

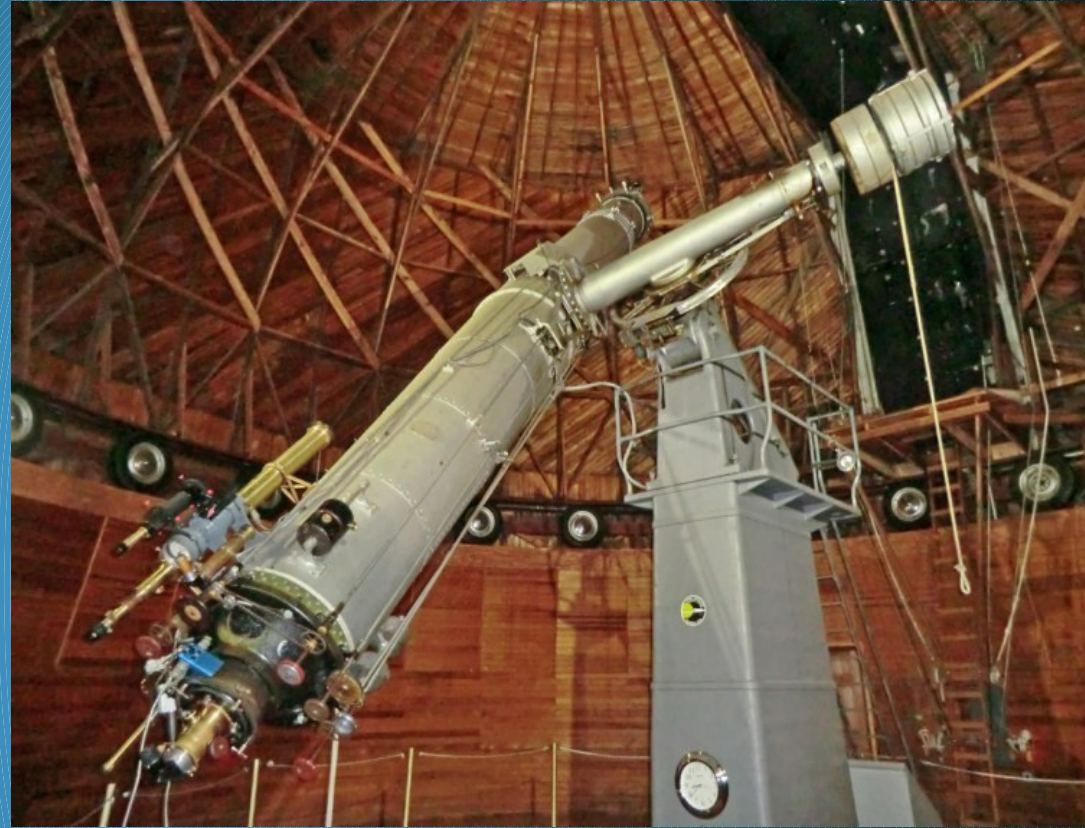
William Parsons, 3rd Earl of Rosse



A 6 foot diameter reflector telescope in Ireland which was used to discover the first spiral galaxy.

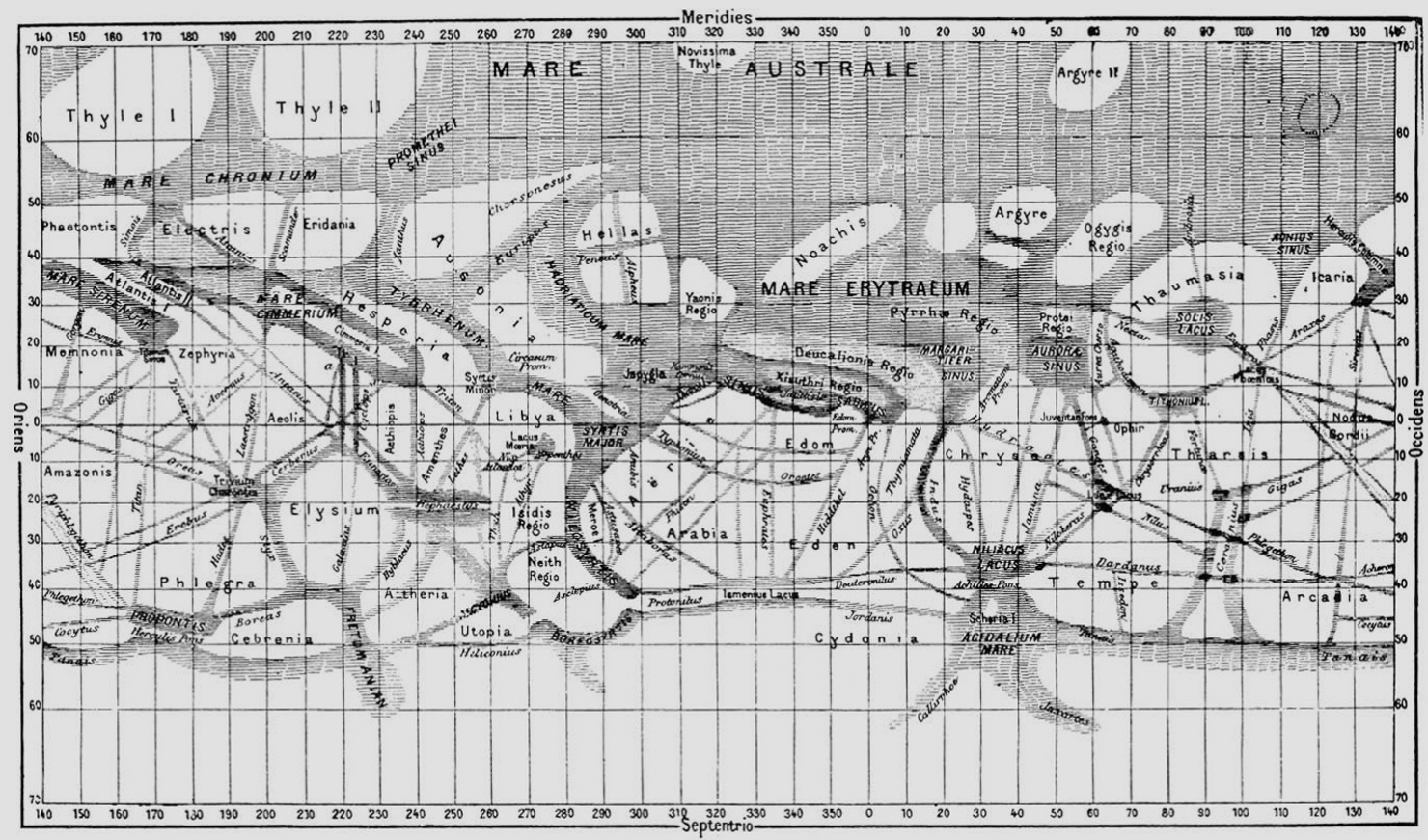


Lowell Observatory – AZ 1895+



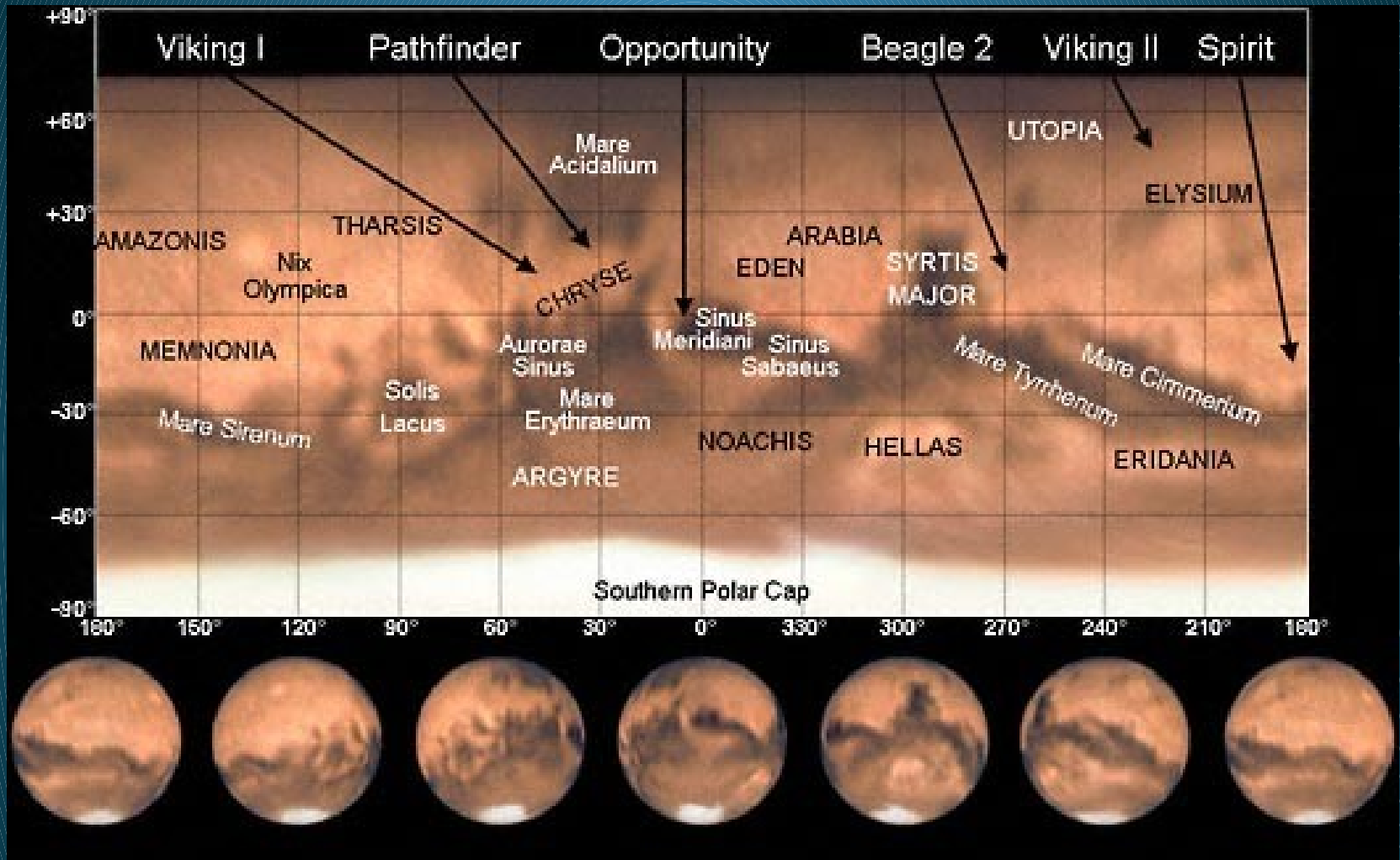
The 24-inch (61-cm) refractor telescope was installed by Percival Lowell in 1895 at a cost of \$20,000 for the purpose of studying Martian “Canals” *. When he died in 1916, he left his estate of \$2,306K “to the furtherance of his studies”. His wife contested this and when the case was settled in 1925, his estate had dwindled to \$1,105K. She still lost though.

Lowell Observatory - Arizona



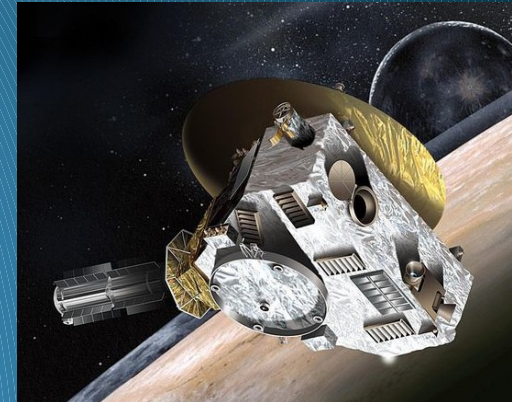
Lowell's drawing of Martian "Canals"

Modern Map

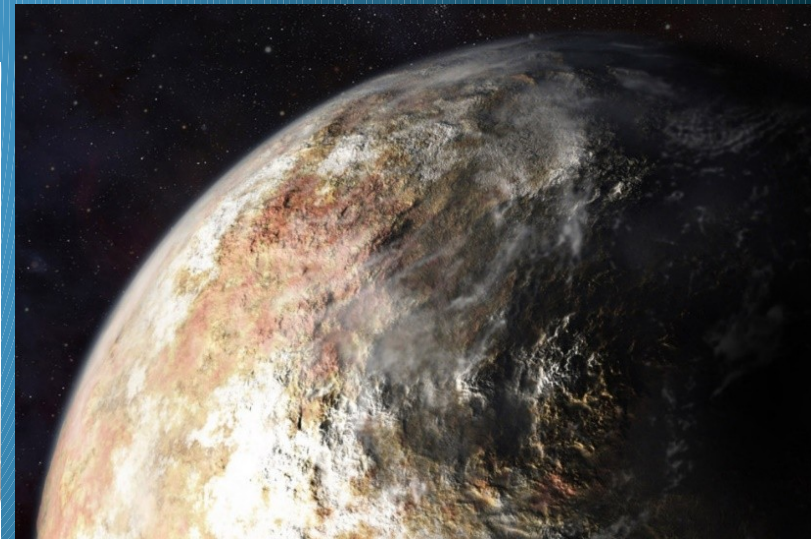
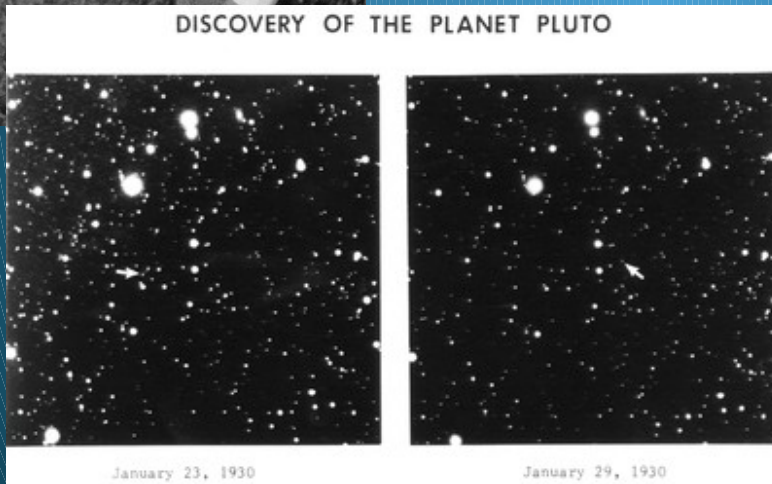


Lowell Observatory – Arizona

Clyde Tombaugh's discovery of Pluto in 1930



His ashes were sent to Pluto aboard the New Horizons's Mission.



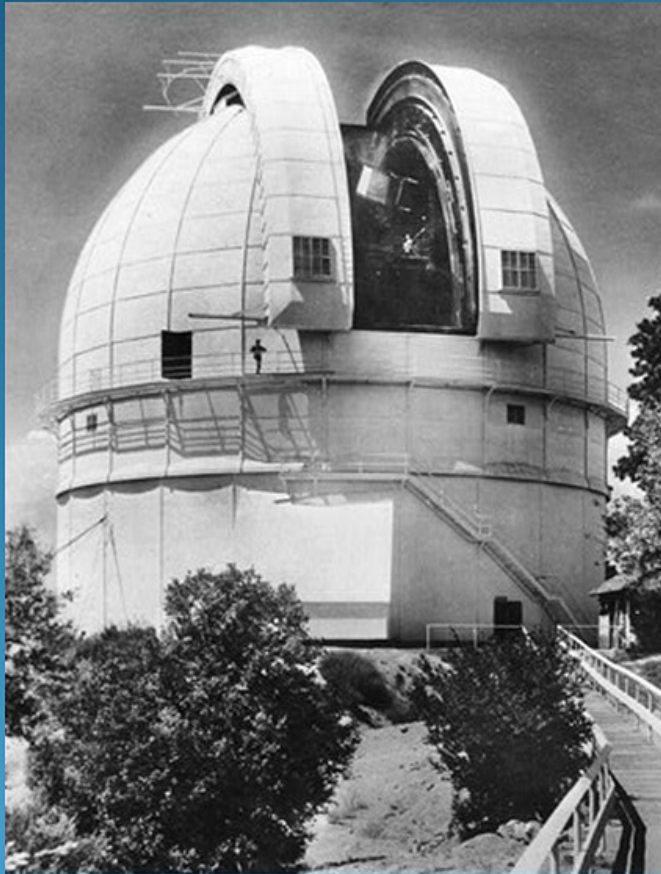
Yerkes 40 inch refractor



Maintained by the University of Chicago and completed in 1897, the Yerkes 40 inch refractor telescope remains the largest refractor telescope in the world.

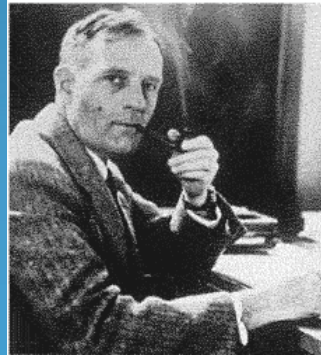


Mount Wilson 100 inch reflector

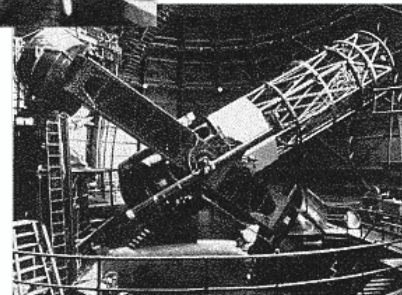
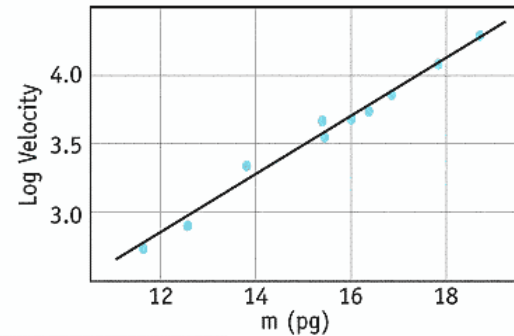


The Mount Wilson 100 inch reflector telescope was completed in 1917. Edwin Hubble's work in 1924 on the Andromeda galaxy and subsequent studies regarding expansion of the universe were done here.

DISCOVERY OF EXPANDING UNIVERSE



Edwin Hubble

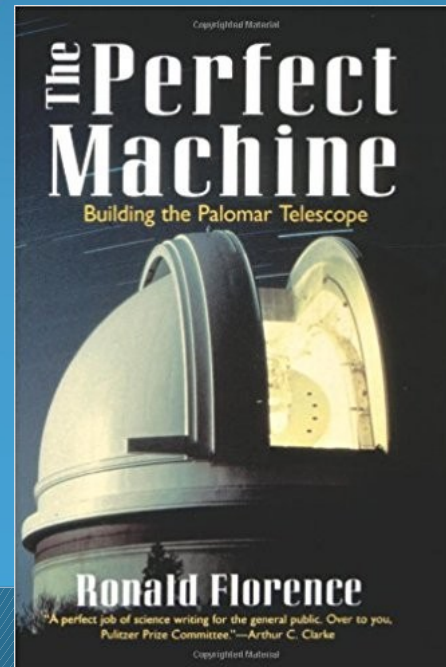


Mt. Wilson
100 Inch
Telescope

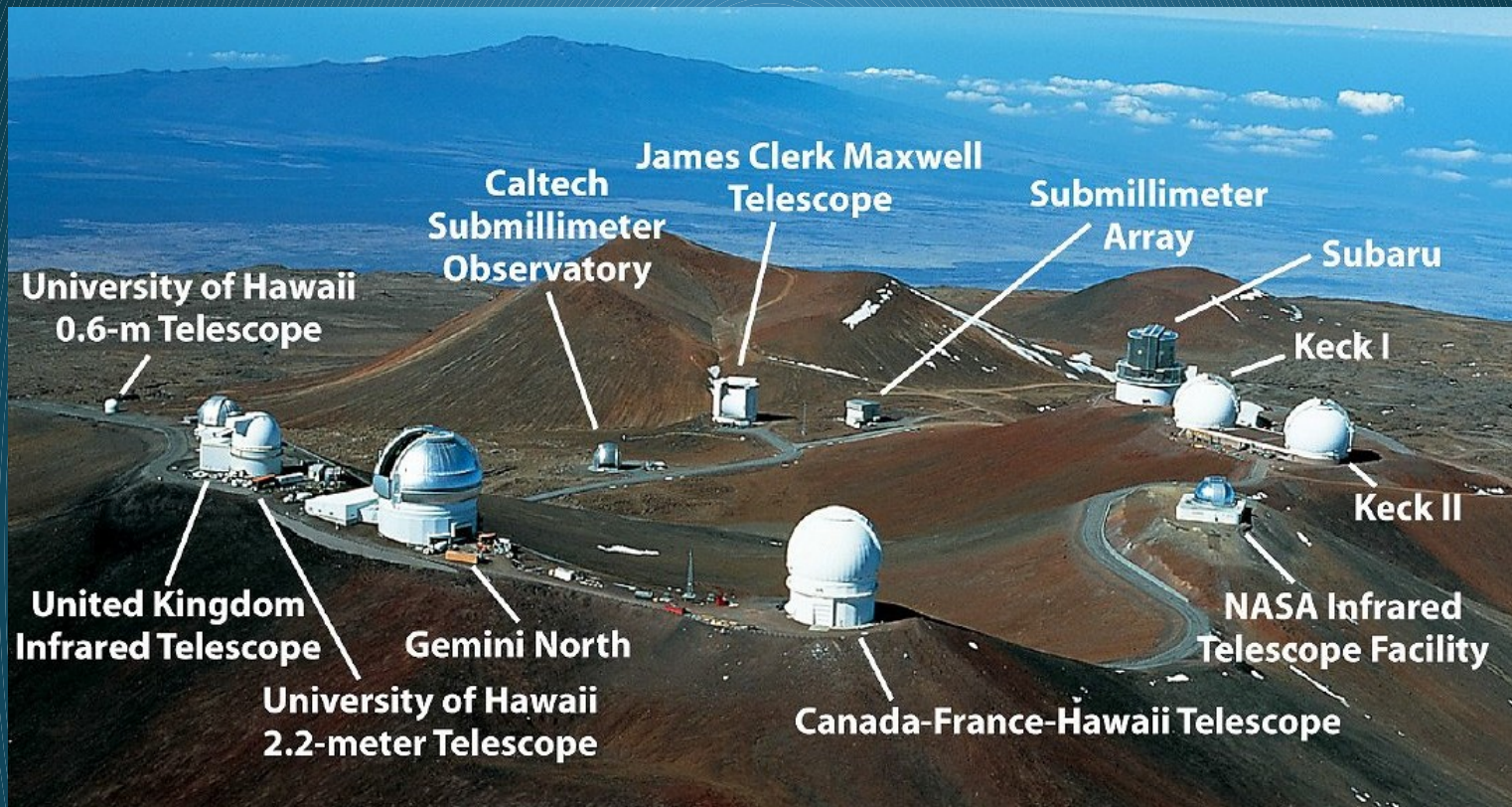
Palomar (Hale) 200 inch



Opened in 1948, the Hale (Palomar) 200 inch telescope was a modern marvel of engineering – read *The Perfect Machine* by Ronald Florence.



Mauna Kea, Hawaii



Mauna Kea is a large installation of independent scopes atop a dormant volcano on the “Big Island” at 13,796 feet. First light for the U of H 2.2 M scope was 1970. Others followed with there now being some 12 scopes.

Kilauea Volcano Eruption as seen from Mauna Kea



May 2018 Eruption of Kilauea Volcano

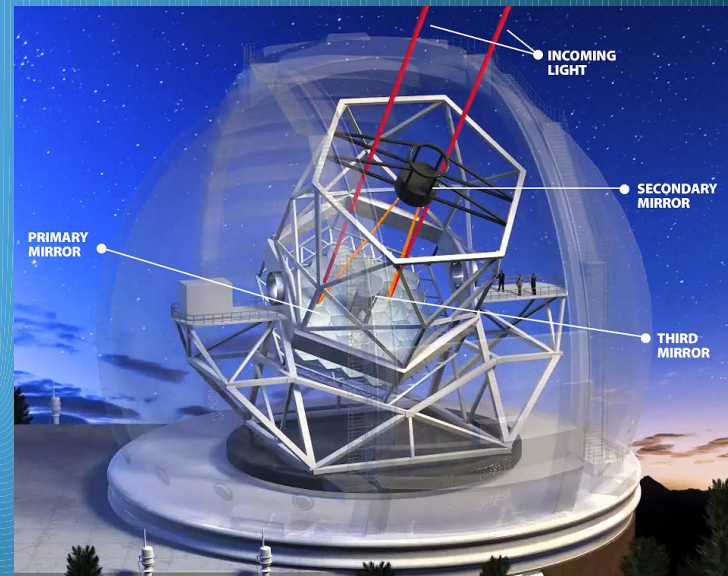
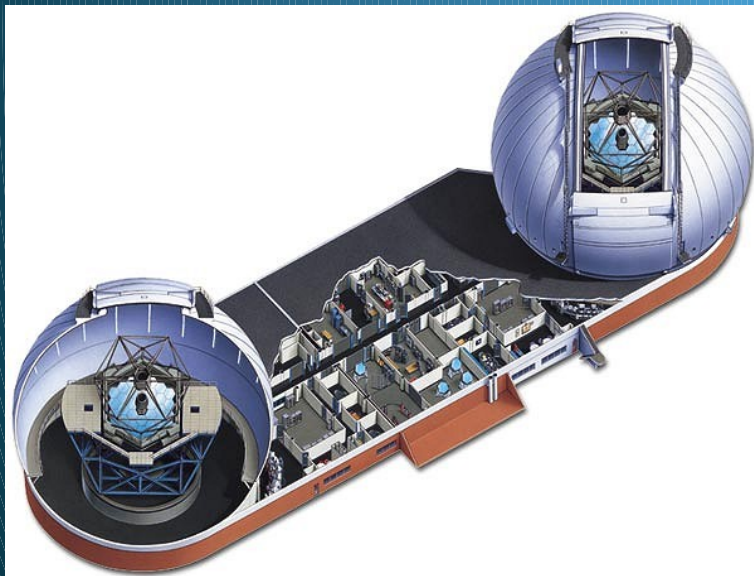
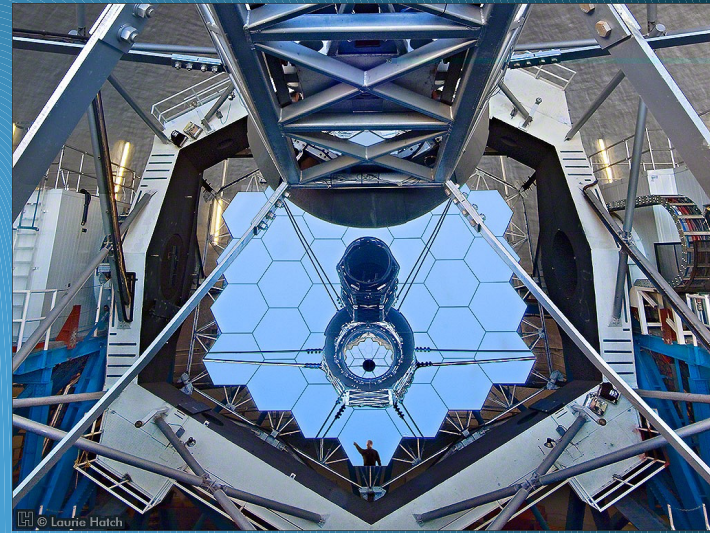
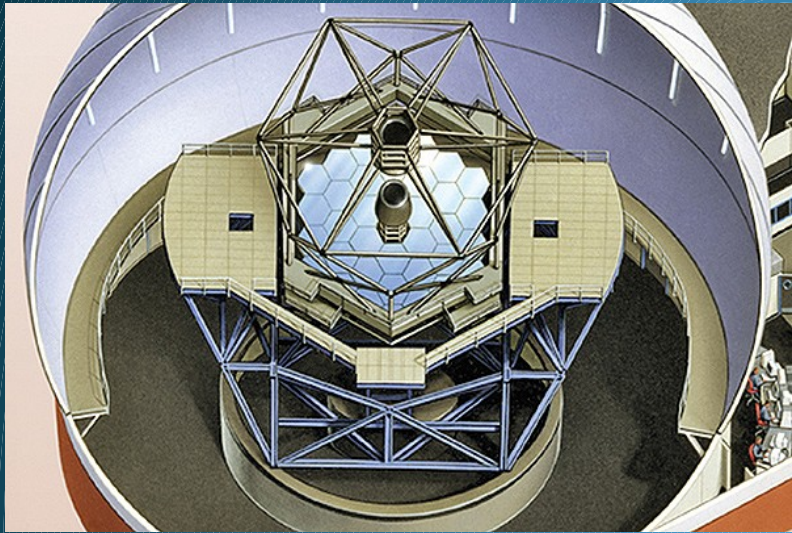


Keck I and II (13,600 ft.)

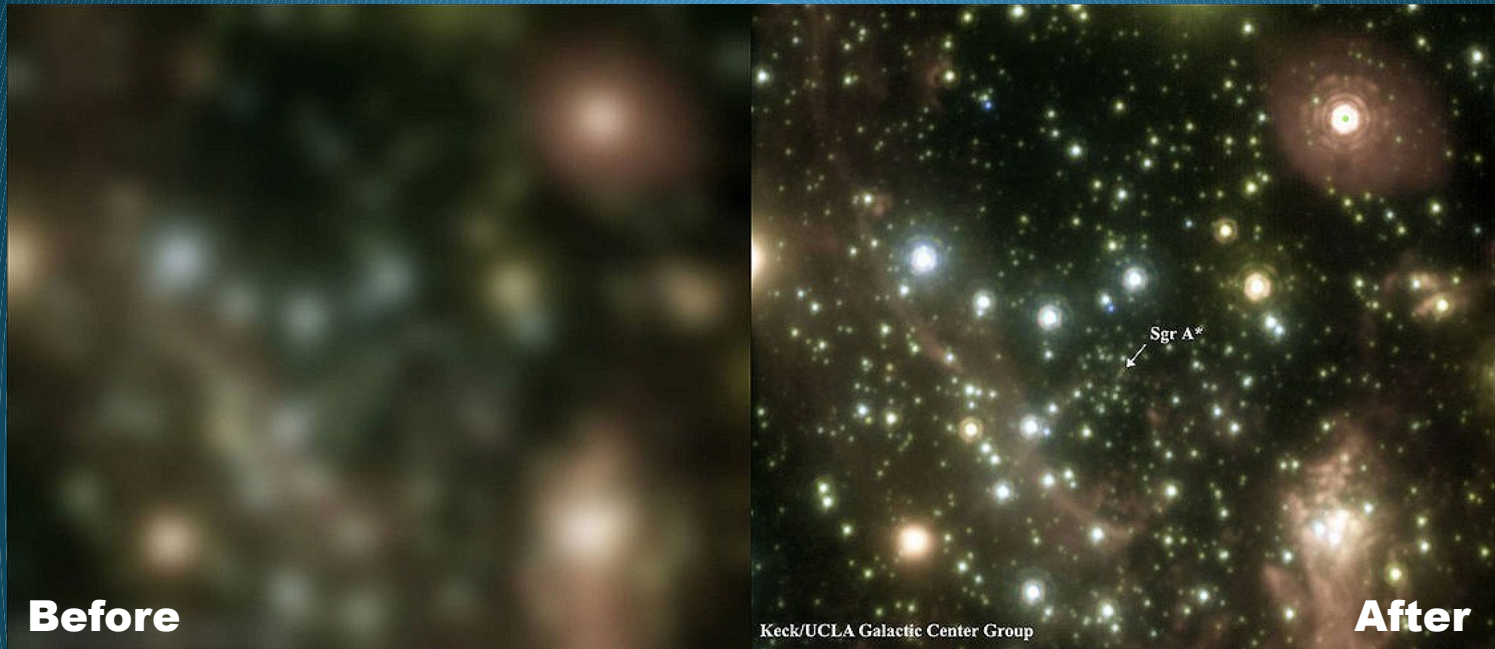


Keck I (Nov. 1990) and Keck II (Oct. 1996) are both optical scopes with 33 ft. mirrors composed of 36 hexagonal segments. Each segment is adaptively controlled and, each scope is Alt/Az mounted.

Additional images:



Adaptive Optics (AO):



A method of correcting for atmospheric turbulence in optical telescopes. Conceived in the 1950's but refined in the 1970's through JASON/DARPA and "Star Wars", the method is routinely used with major telescopes providing images often better than with Hubble..

Adaptive optics input:



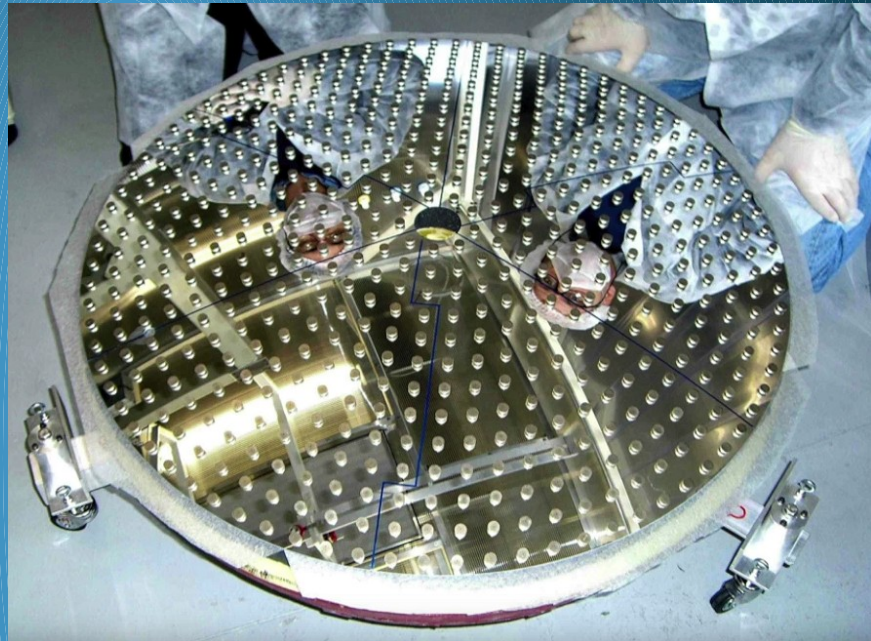
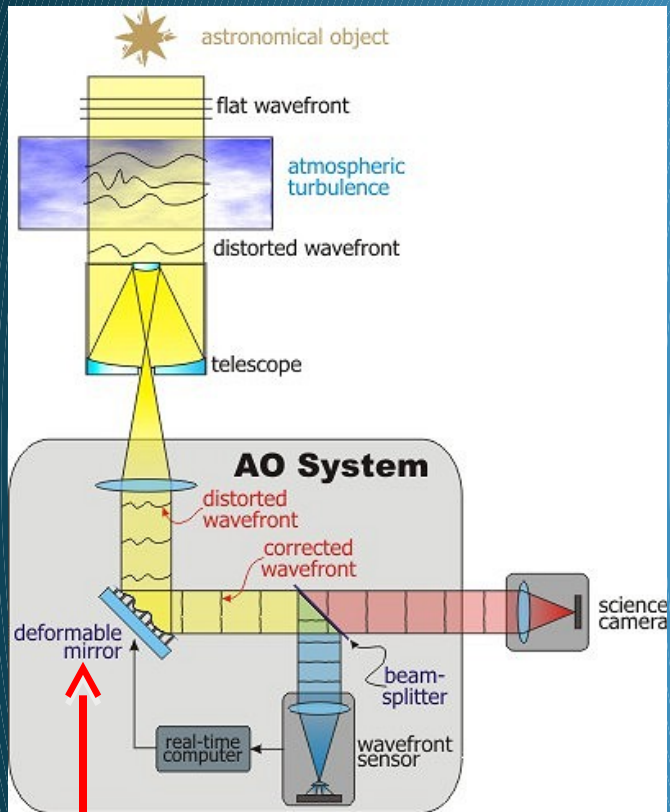
Wave front sensing – samples incoming light 10 – 100/sec., feeds to a deformable mirror and real time computer which calculates correction, adjusts mirror and sends to imaging device.

Natural star – as above but uses natural star if bright enough.

Artificial laser star – as above but uses Na (589nm) lasers to create artificial “stars” in the mesosphere.

Lenslets

Adaptive optics:



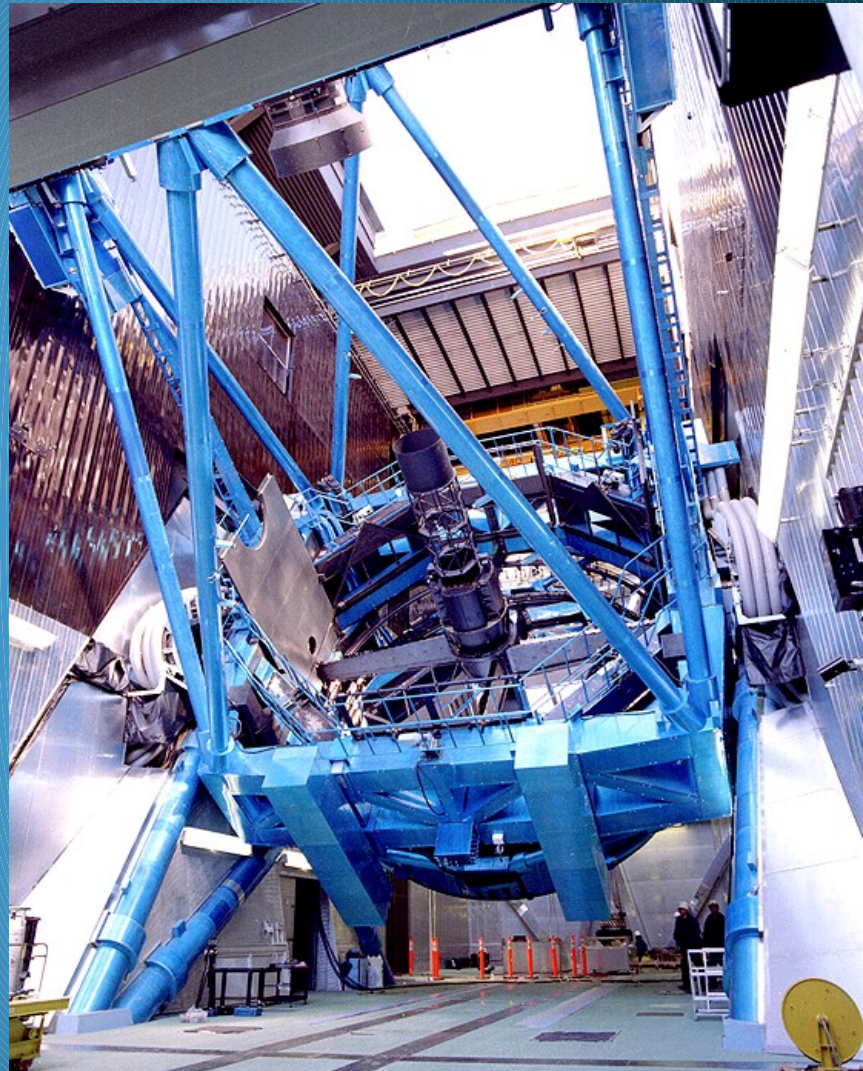
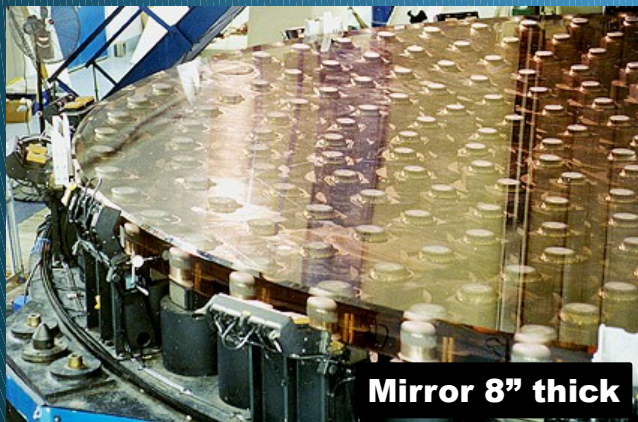
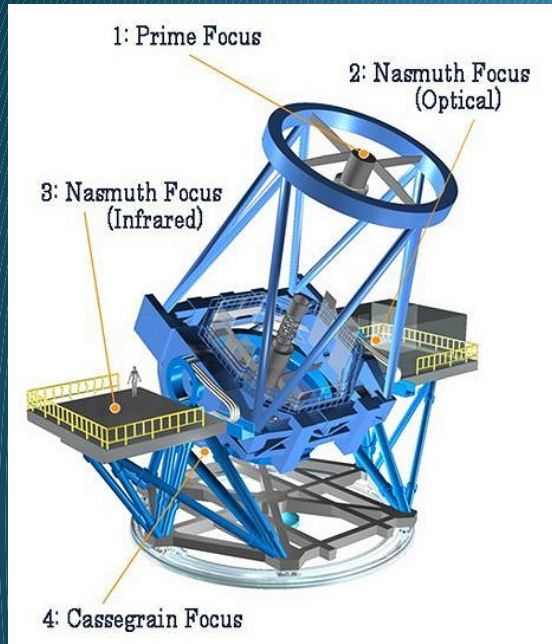
Subaru (13,579 ft.) - no relation the Subaru car



Operated by the NAOJ, this Alt/Az scope with a 27 ft. solid mirror (the largest in the world), was completed in 1998. Some 261 computer controlled actuators correct for any distortion with different orientations.



Additional images:

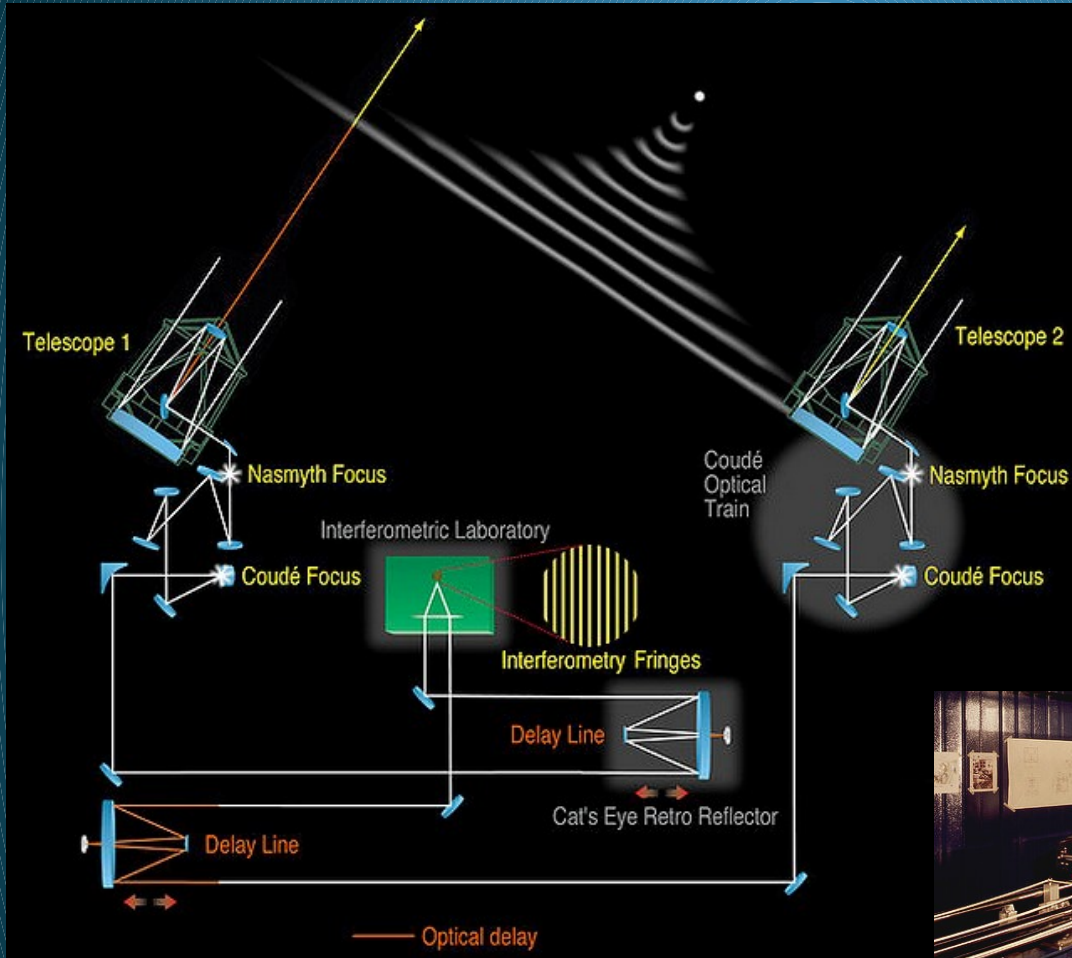


Very Large Telescope (VLT) Interferometer: Paranal, Chile

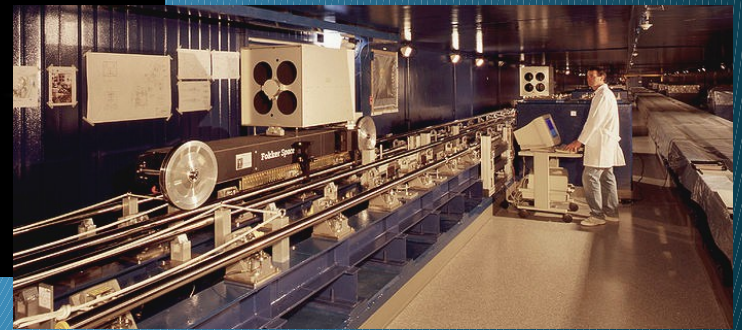


Operated by the ESO and consisting of 4 identical VLT scopes using 27 ft. solid mirrors, they can be linked for optical interferometry using a delay line system in an underground tunnel. Four other 6 ft. auxiliary scopes on tracks can be used as well. (Altitude 8,645 ft). Many exoplanets discovered via spectra.

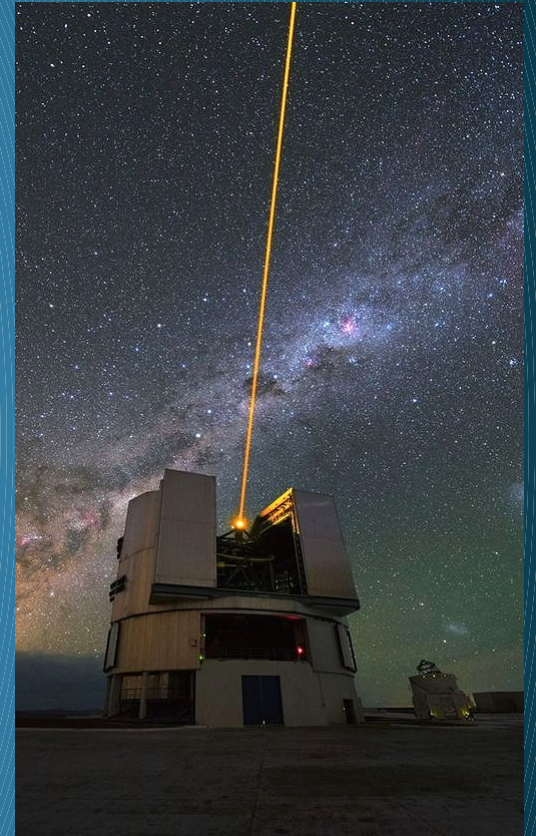
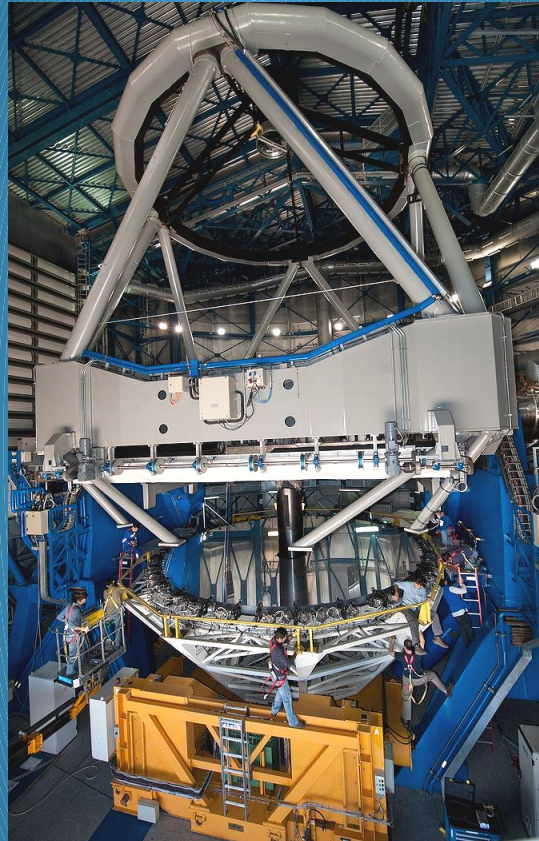
Additional images:



Optical interferometry involves coupling two or more of the scopes together to improve resolution. Currently, 2 are paired but, in the future, more will be considered. To ensure phase alignment, a Delay Line is used.



Additional images:



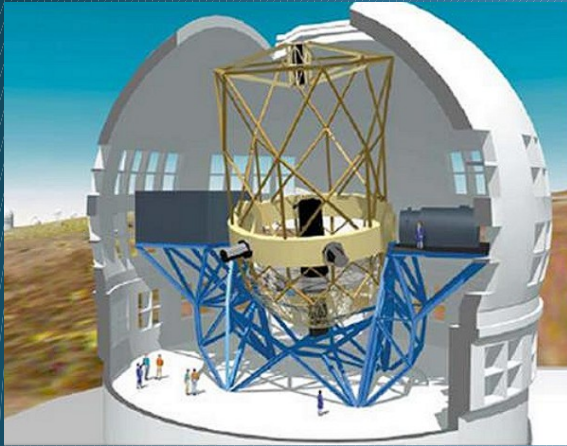
La Palma, Canary Islands

(7,861 ft.)

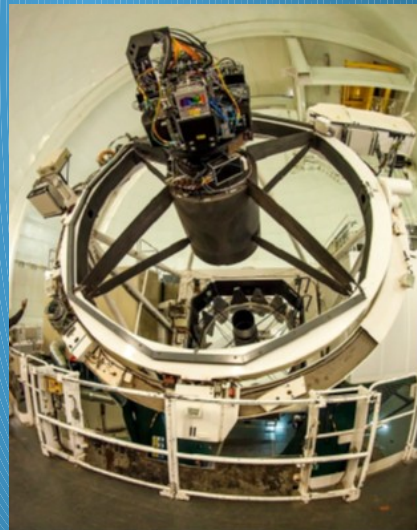


The La Palma Observatory complex was begun in 1985 and has grown to some 12 instruments led by the 34 ft. segmented GTC and 14 ft. Wm. Herschel Telescope. La Palma is second only to Mauna Kea for ideal viewing conditions.

Additional images:



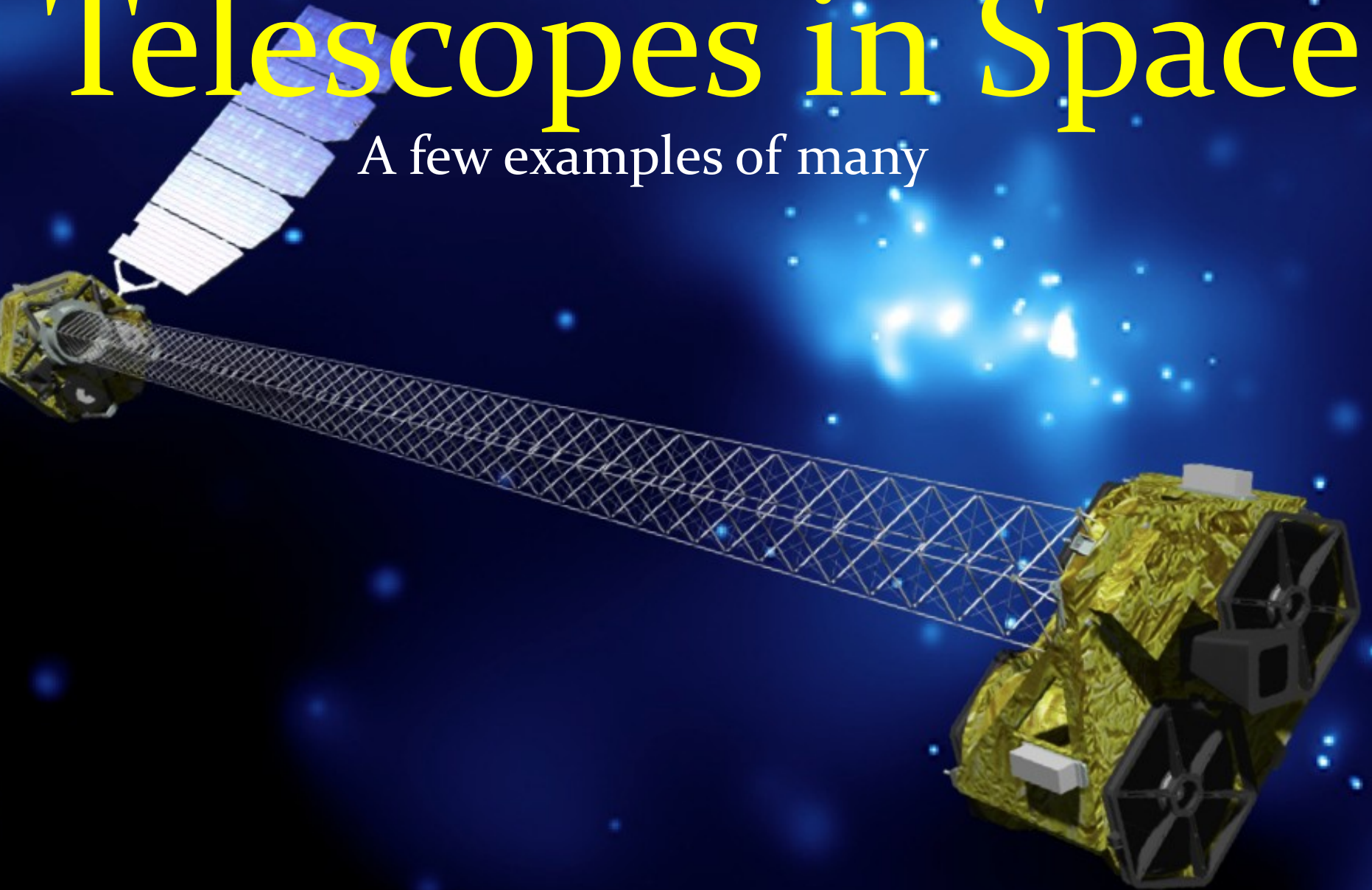
GTC – said to be the largest optical telescope in the world presently.



WHT was opened in June of 1987 and claims to be one of the most productive scopes in the world.

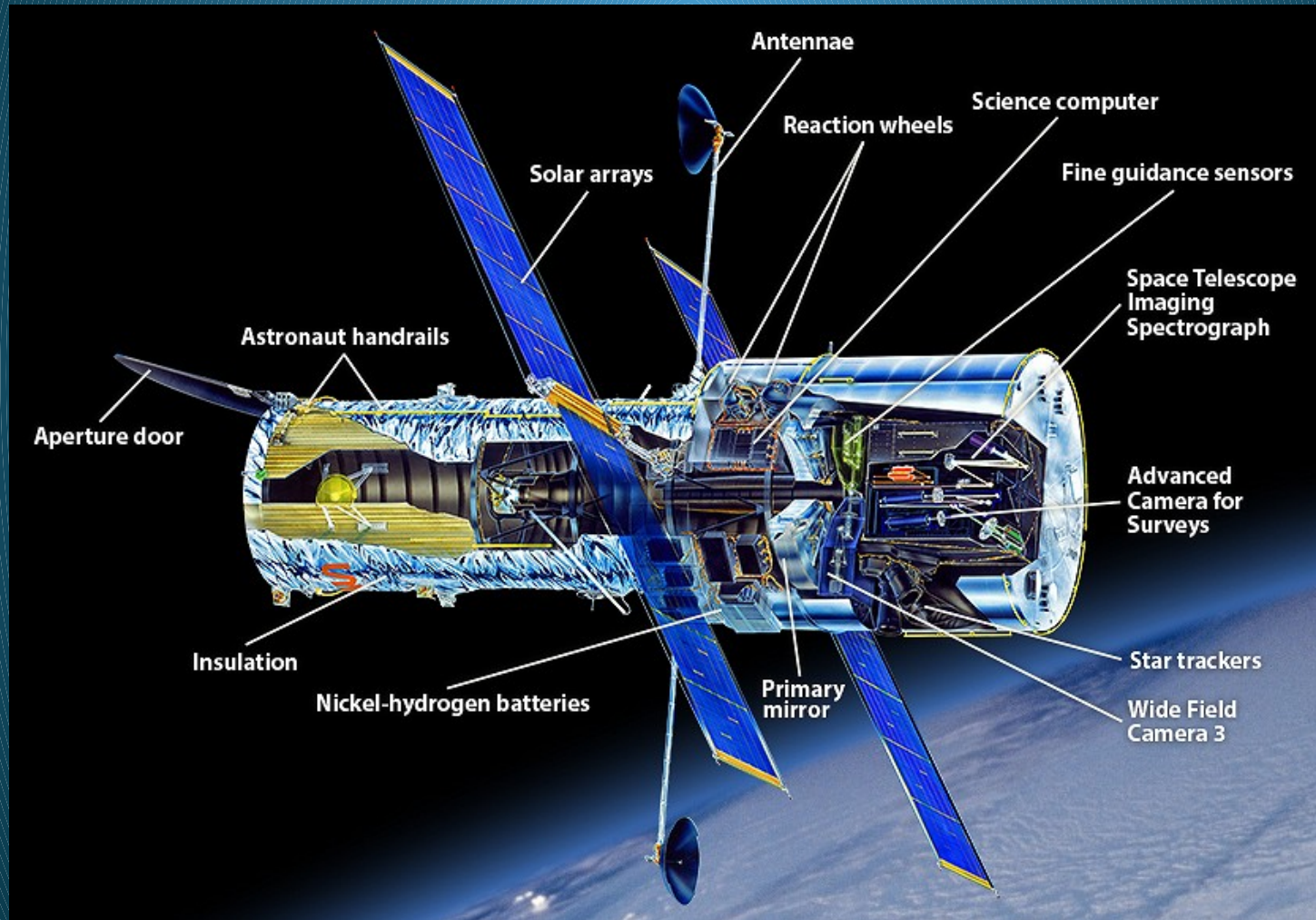
Telescopes in Space

A few examples of many



Hubble Space Telescope

Launched April 1990 in low earth orbit with period of 97 minutes at an altitude of 336 miles and, +/- 28 degrees to the equator



Sample images:

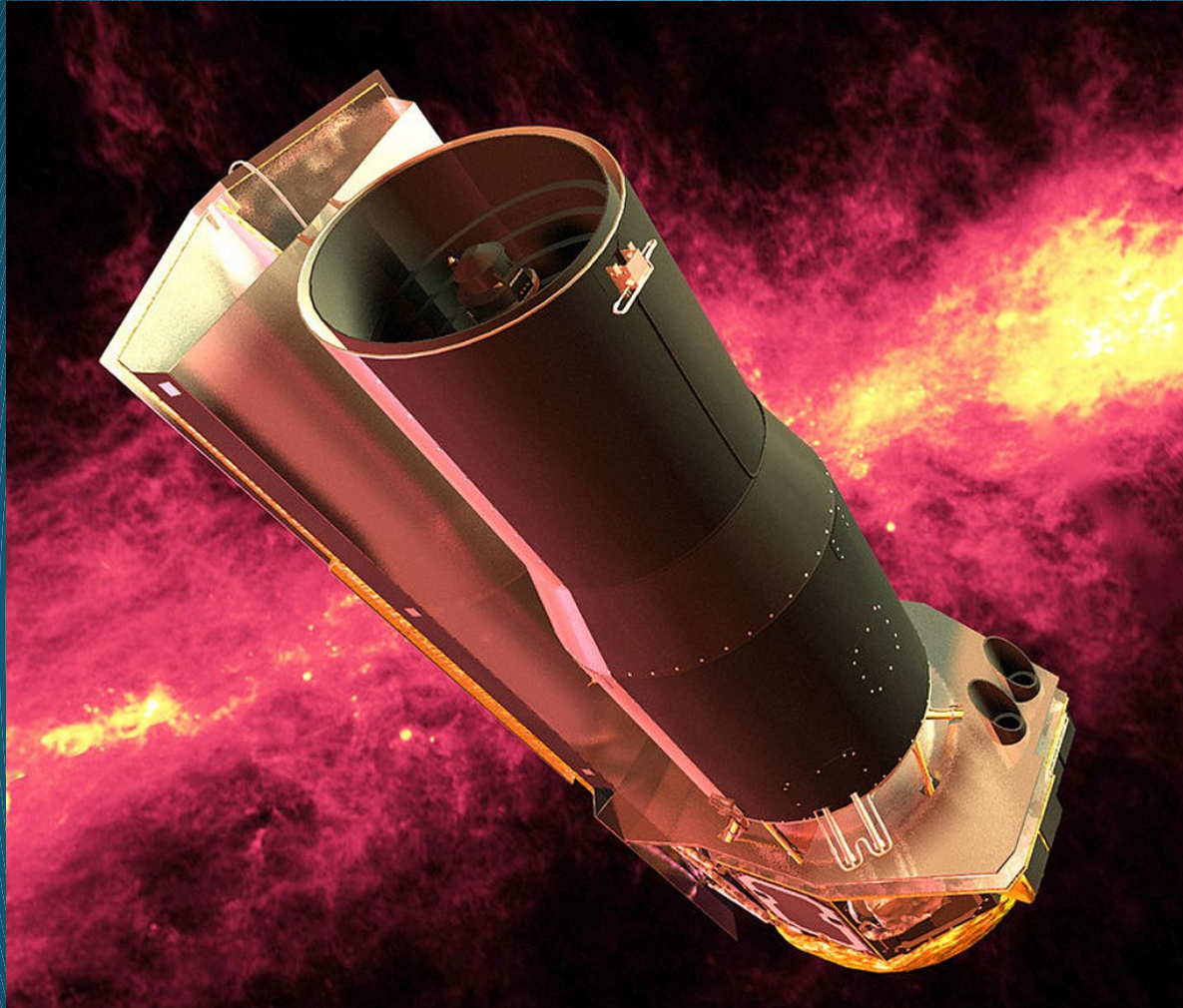


Hubble Extreme Deep Field



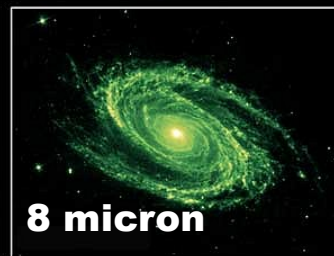
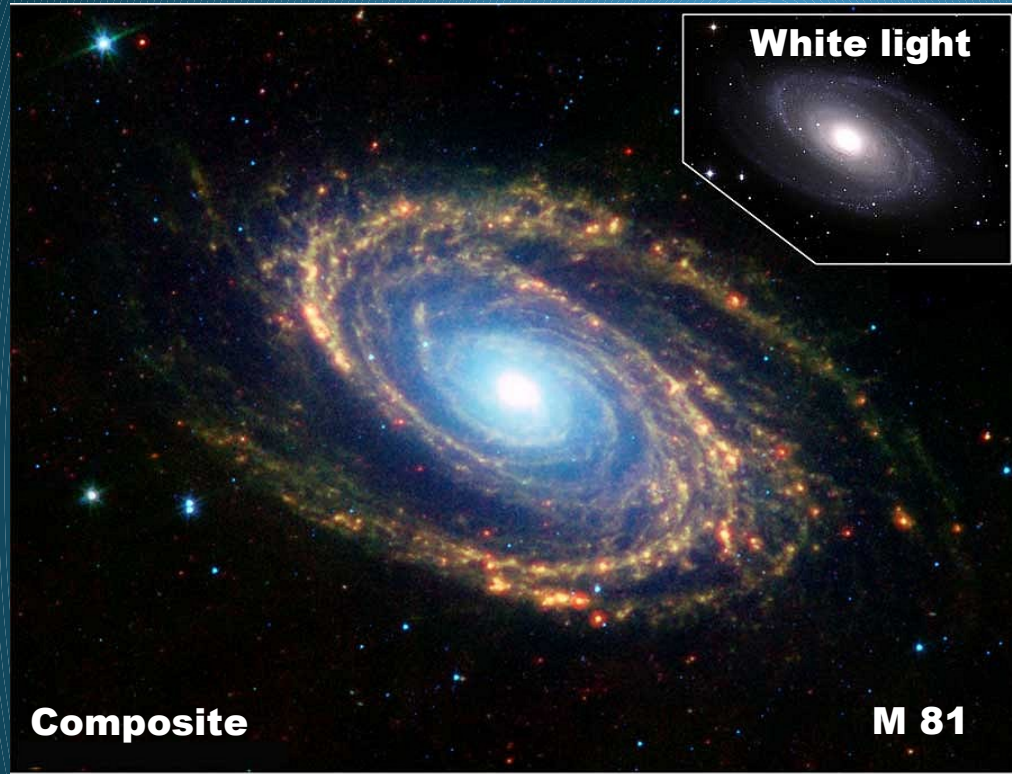
Obtained by combining months of data covering an area representing 1/13 millionth of the sky. Reveals the appearance at some 13.2 billion years ago.

Spitzer Space Telescope SST

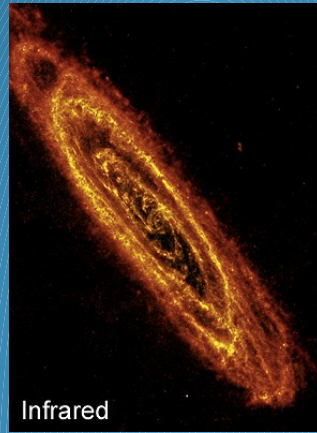


Launched by NASA in August 2003 in an earth trailing orbit, this 2.8 ft. IR scope was decommissioned in March 2017. It was 1/3 the length of Hubble and 1/11th the weight. Currently it is used in searching for exoplanets.

SST sample image:



Herschel Space Observatory:



Infrared



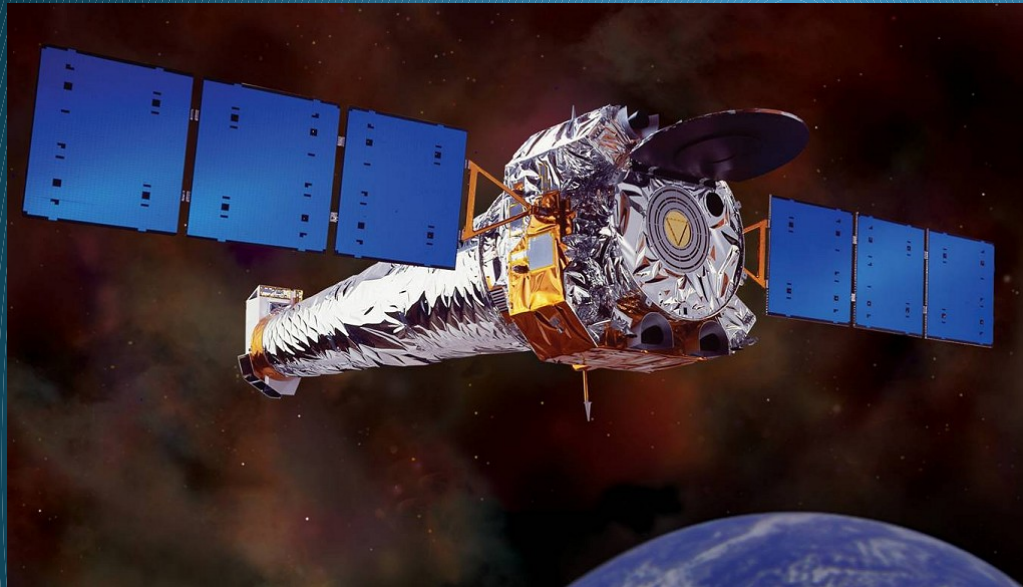
Visible & Infrared



Visible

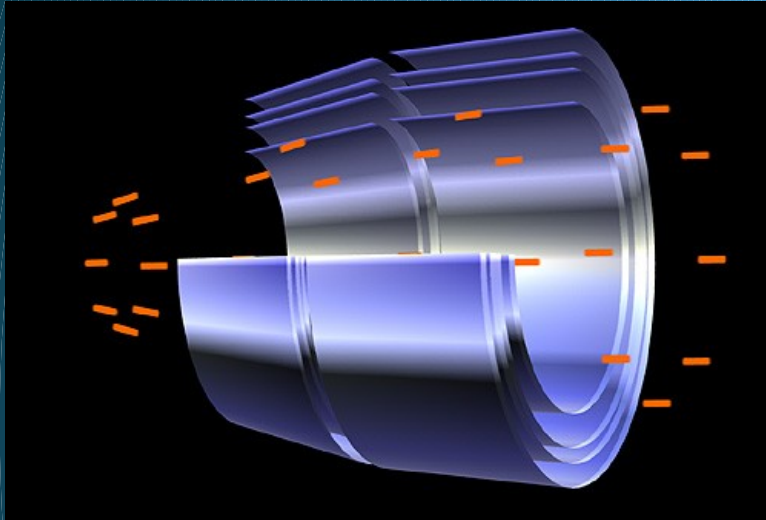
Operated by the ESA, this IR scope was launched in May 2009 and decommissioned June 2013. It is positioned at L2 some 930k miles from earth. With an 11.5 foot mirror, it was the largest orbiting IR scope to date.

Chandra X-ray Observatory



CXO was launched in July 1999 with the Columbia shuttle. It moves in a 64 hour elliptical geocentric orbit ranging from 8,809 to 83,592 miles. It uses 4 pairs of nested parabolic/hyperbolic mirrors for x-rays to glance off of.

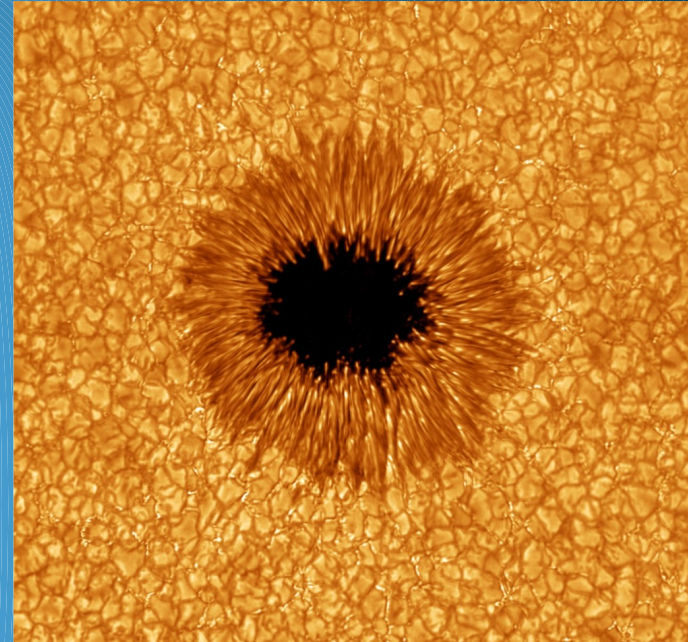
CXO Sample images:



Solar Telescopes

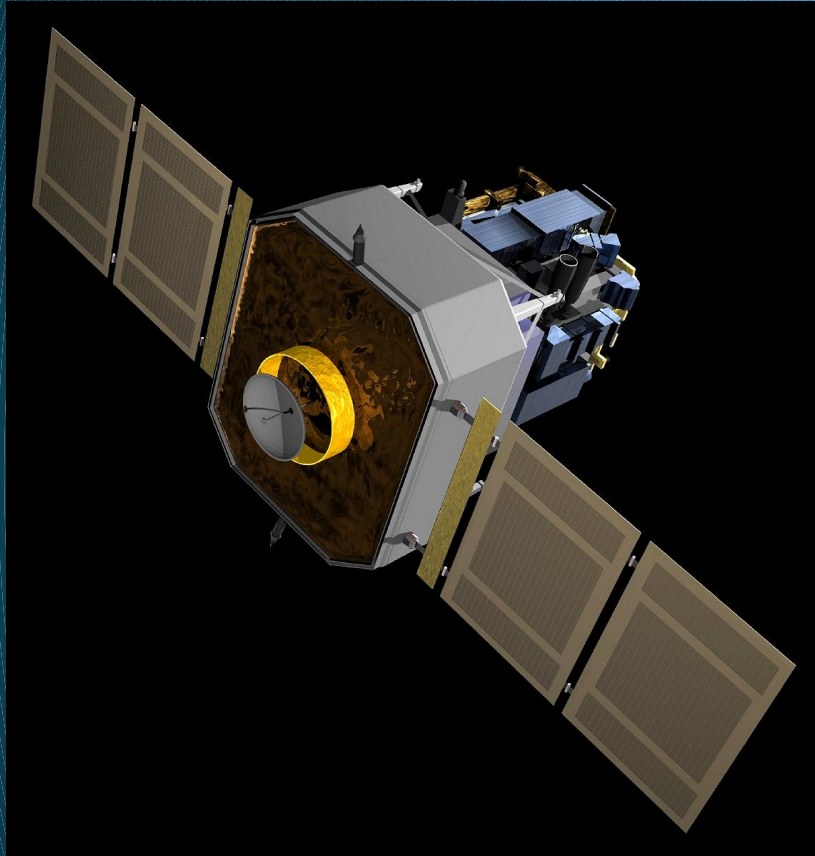


Big Bear Solar Observatory – BBSO



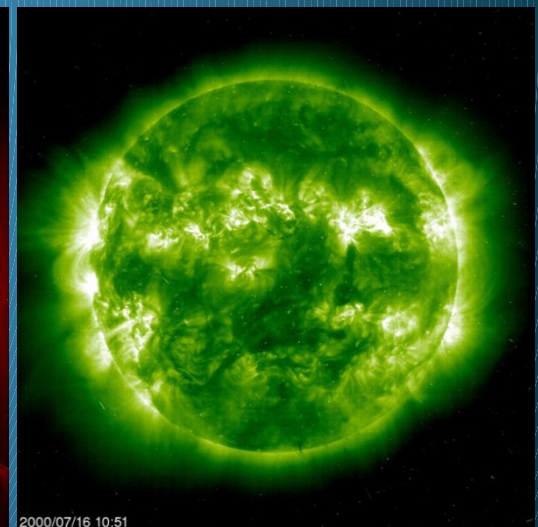
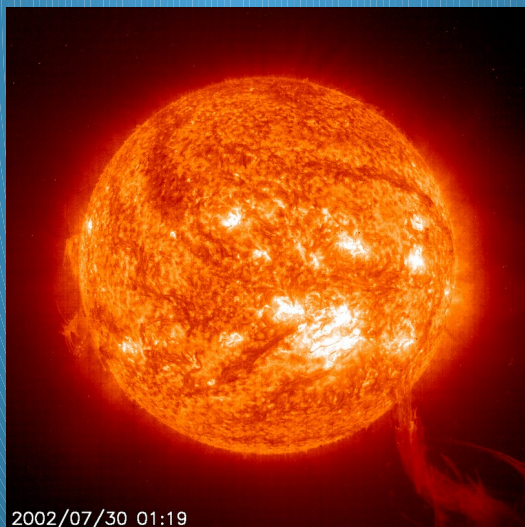
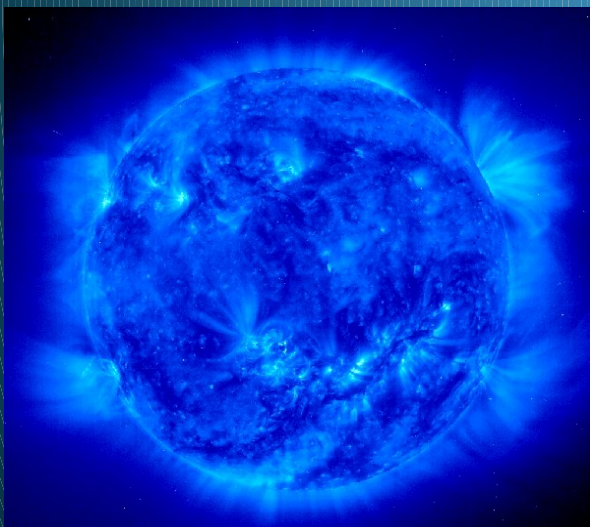
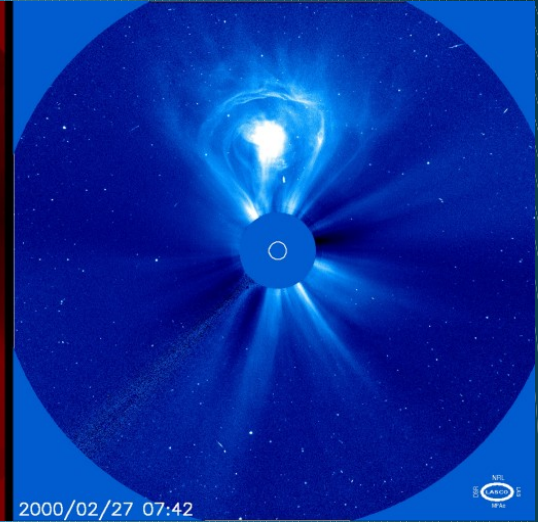
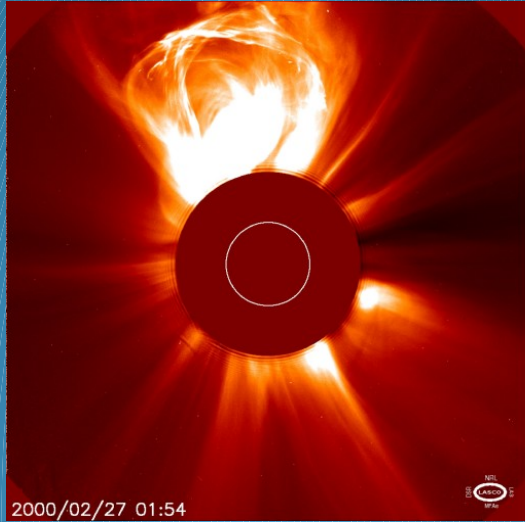
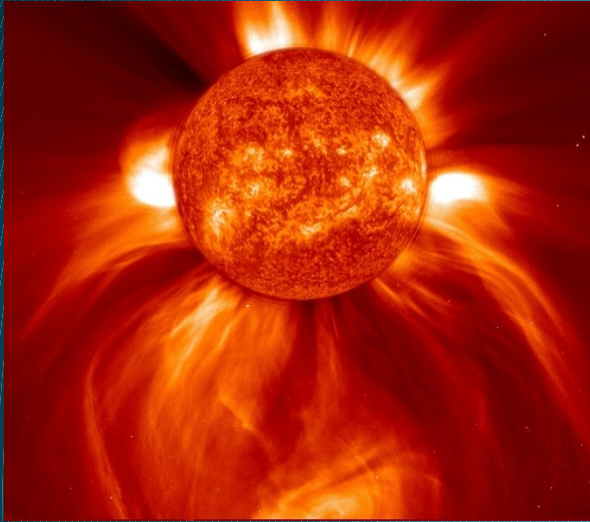
First opened by CIT in 1969, it had a 0.5M mirror which was upgraded to a 1.6M mirror in 2009 after NJIT took over in 1997. Adaptive optics are used providing superb images. It is the largest of its type in the world thus far.

Solar and Heliospheric Observatory - SOHO



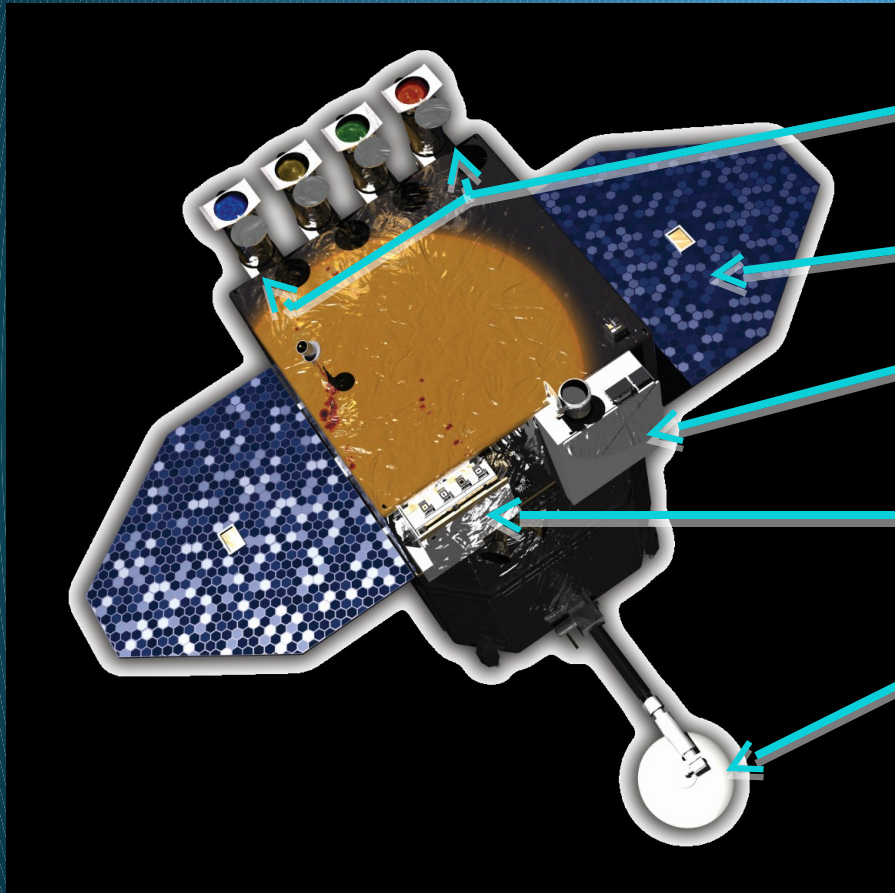
A joint venture between NASA and ESA, SOHO was launched in December of 1995. Its purpose was to study the sun from its core to its solar wind. It is positioned at the First Lagrangian point some 1.5 million miles from the Earth towards the Sun. Upon decommission, its orbit was moved to a heliocentric one and, it won't come near earth for several centuries.

Examples of SOHO Images:



Solar Dynamics Observatory (SDO)

Launched February 2010 in geosynchronous orbit



AIA (Atmospheric Imaging Assembly)

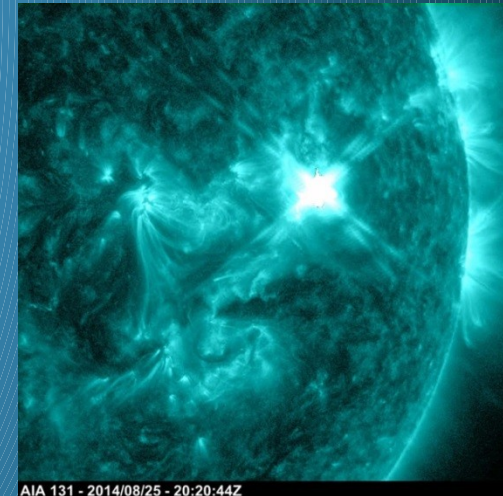
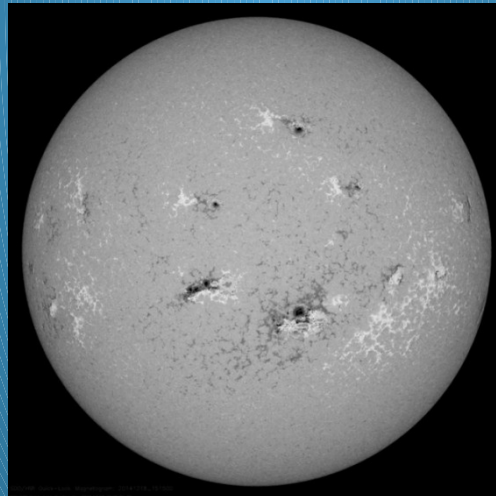
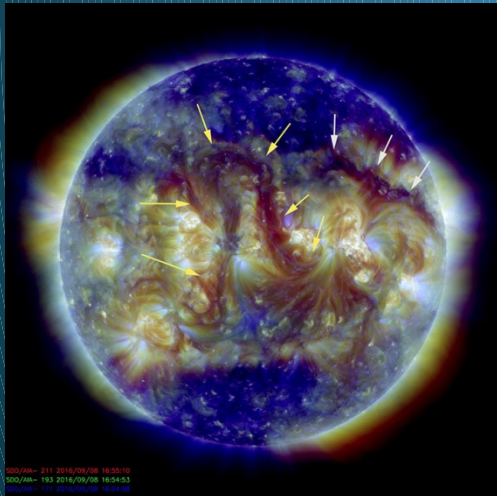
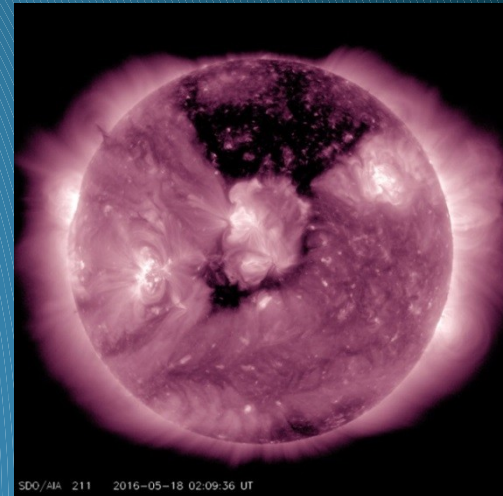
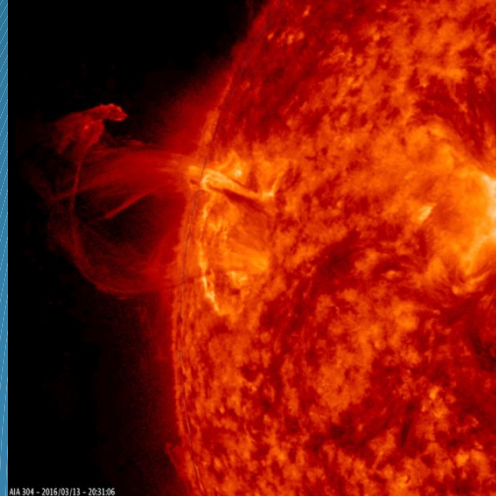
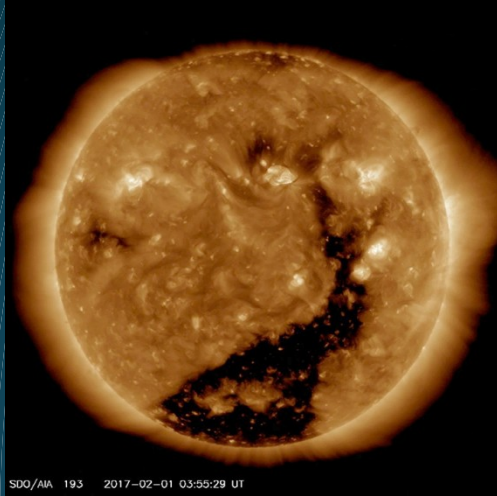
Solar panels

HMI (Helioseismic and Magnetic Imager)

EVE (Extreme Ultraviolet Variability Experiment)

High gain antenna

Examples of SDO images:



Large Radio Telescopes



Arecibo Radio telescope in Puerto Rico



Opened in 1963, the 1,000 foot diameter antenna is composed 38,778 perforated 3x6 foot aluminum panels supported on a spherical cable mesh. The moveable receiver is suspended from 3 towers. Some damage was incurred with Hurricane Maria in 2017

Arecibo Radio Observatory

Largest Radio Telescope in the Caribbean (2nd largest in the World: 1963+)

[-----1,000-ft (305-meter) -----]



FAST Tianyan 500m (really 300m) in China



Though started in 2011, first light was in Sept. 2016. The 500m parabolic antenna is suspended on cables from the rim. Six towers provide cables to suspend the Feed Cabin. The cost was \$180M vs. \$269M to relocate local villages.

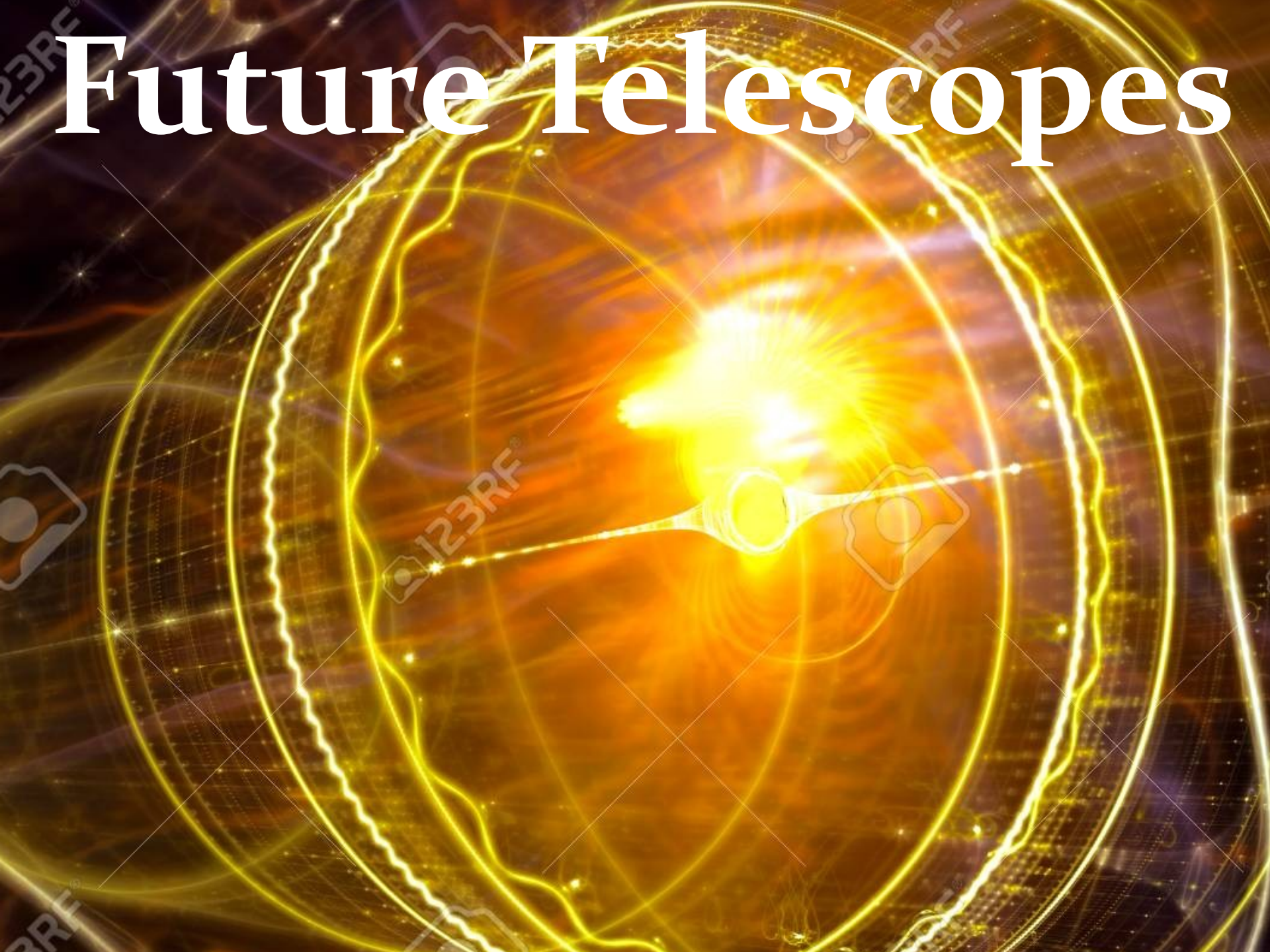
China's New 500-m FAST (Filled Aperture Radio Telescope), among many of its major science goals, will participate in searching SETI radio signals from the nearest Exoplanets



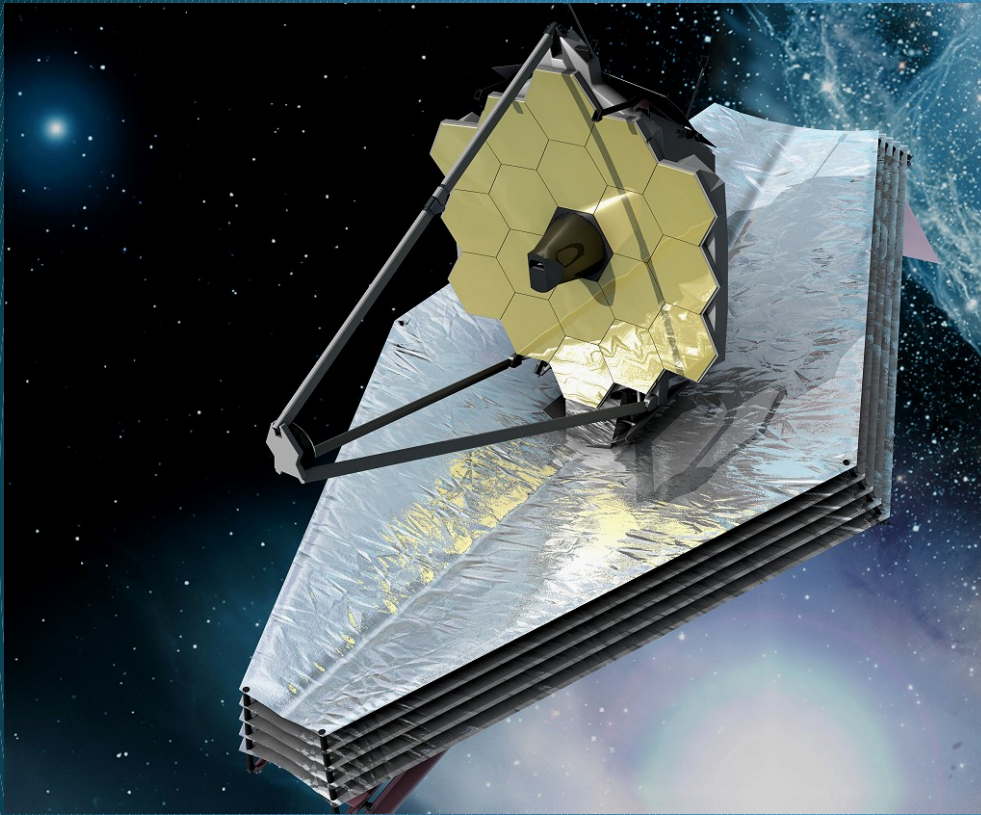
SKA= Square Kilometer Array Africa and Australia (under construction)



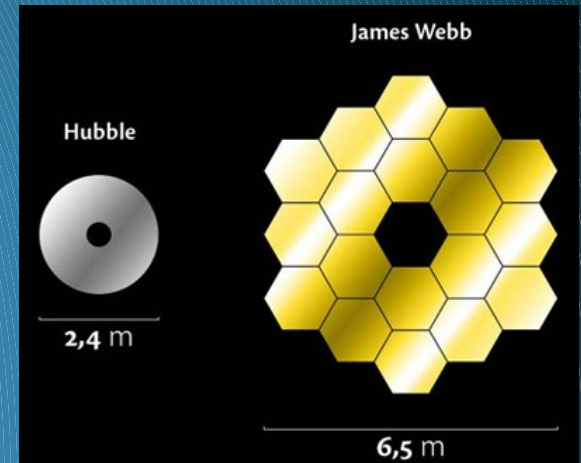
Future Telescopes



James Web Space Telescope:



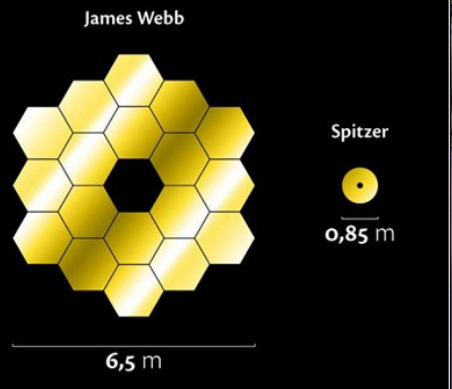
A joint project between NASA, ESA and the Canadian Space Agency.



Due for launch by To be launched by NASA in the spring of 2019, this 21 ft., mirror made of 18 segments will be positioned at L2. It folds up for delivery to fit into the nose cone.

James Webb Space Telescope (JWST)

One of the many uses will be searching for evidence of atmospheres and biosignatures of nearby Habitable Zone Exoplanets



Expected Launch: Spring 2019

Great Paris Exhibition Telescope
 (lens at the same scale)
 Paris, France (1900)

Yerkes Observatory
 (40" refractor lens at the same scale)
 Williams Bay, Wisconsin (1893)

Hooker (100")
 Mt Wilson, California (1917)

Hale (200")
 Mt Palomar, California (1948)

Multi Mirror Telescope
 (1979-1998) Mount Hopkins, Arizona

BTA-6 (Large Altazimuth Telescope)
 Zelenchuksky, Russia (1975)

Large Zenith Telescope
 British Columbia, Canada (2003)

Gala
 Earth-Sun L2 point (2014)



James Webb Space Telescope
 Earth-Sun L2 point (planned 2018)



Tennis court at the same scale

Large Sky Area Multi-Object Fiber Spectroscopic Telescope
 Hebei, China (2009)



Hobby-Eberly Telescope
 Davis Mountains, Texas (1996)



Large Binocular Telescope
 Mount Graham, Arizona (2005)



Very Large Telescope
 Cerro Paranal, Chile (1998-2000)

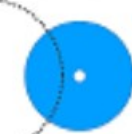


Magellan Telescopes
 Las Campanas, Chile (2000/2002)

Gran Telescopio Canarias
 La Palma, Canary Islands, Spain (2007)



Southern African Large Telescope
 Sutherland, South Africa (2005)



Gemini North
 Mauna Kea, Hawaii (1999)



Gemini South
 Cerro Pachón, Chile (2000)



Giant Magellan Telescope
 Las Campanas Observatory, Chile (planned 2020)

Overwhelmingly Large Telescope
 (cancelled)

Arecibo radio telescope at the same scale

Keck Telescope
 Mauna Kea, Hawaii (1993/1996)



Subaru Telescope
 Mauna Kea, Hawaii (1999)



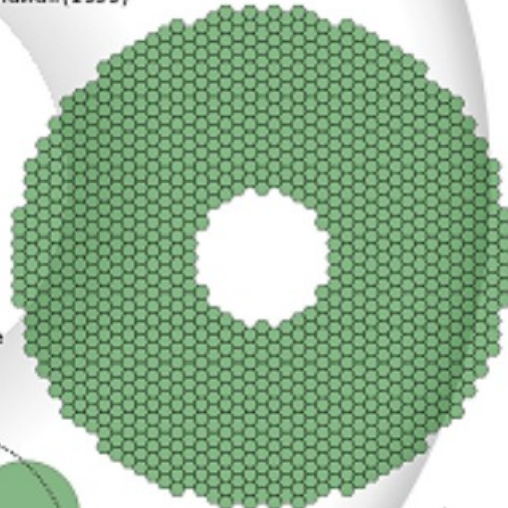
Gemini North
 Mauna Kea, Hawaii (1999)



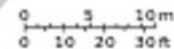
Large Synoptic Survey Telescope
 El Peñón, Chile (planned 2020)



European Extremely Large Telescope
 Cerro Armazones, Chile (planned 2022)

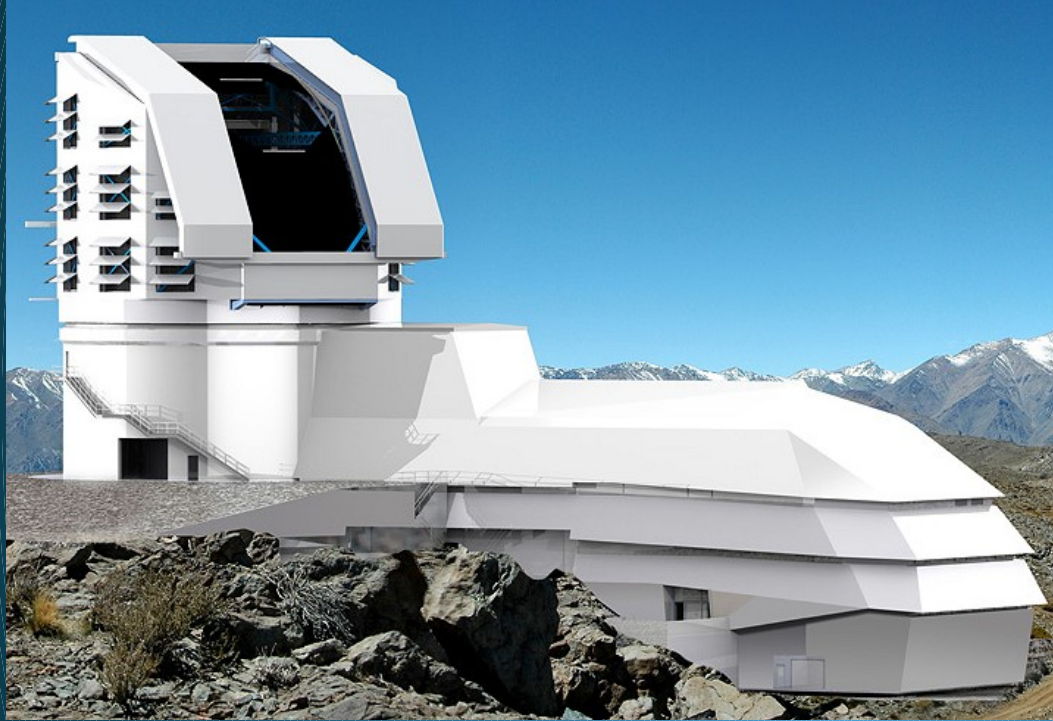


Human at the same scale



Basketball court at the same scale

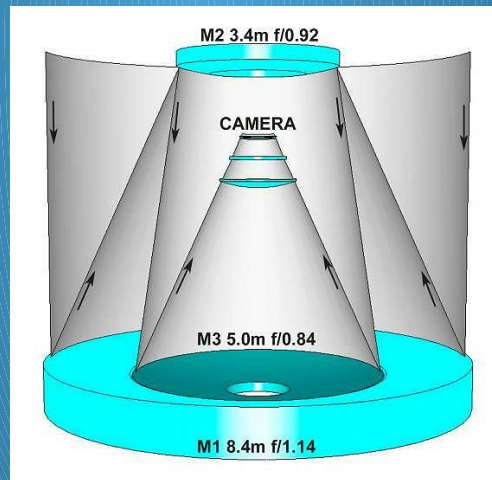
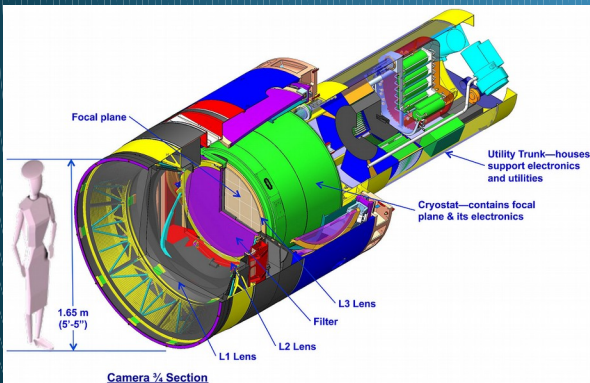
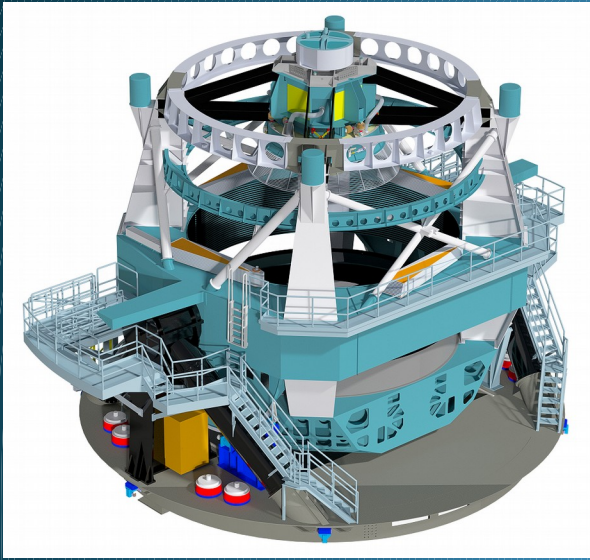
Large Synoptic Survey Telescope (LSST)



This privately funded 27.6 ft. scope will be located in Chile at an elevation of 8737 ft. Completion will be in 2019 and, it will have the largest digital camera at 3.2 Giga-pixels. The 3.5 degree FOV will allow regular imaging of the full sky resulting in 200,000 images per year resulting in some 1028 petabytes of data.

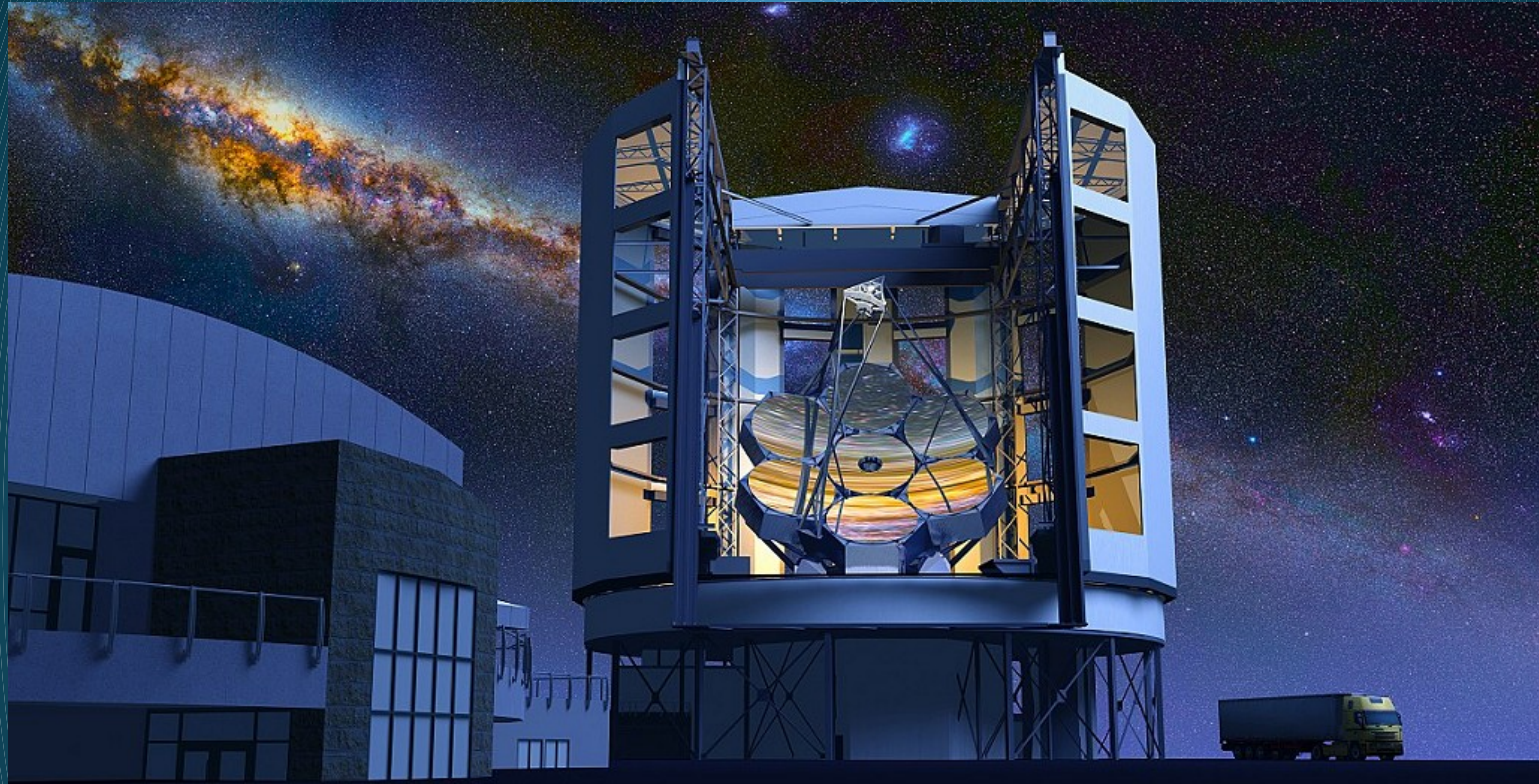
1 Pbyte = 1,024 terabytes

Additional images:



Unique three mirror design with primary center area further hollowed out as a tertiary mirror. M2 is the largest convex mirror ever made.

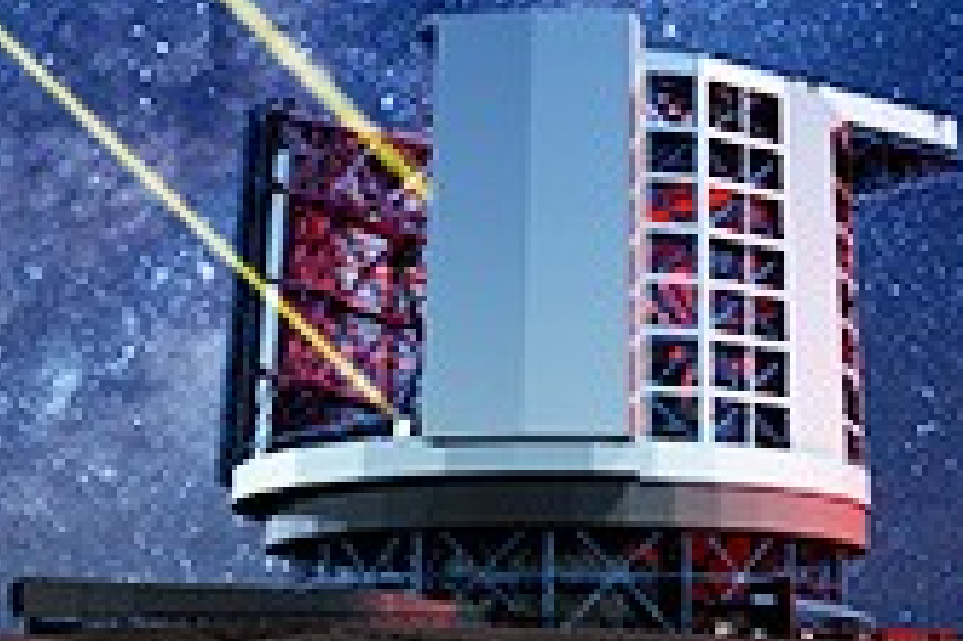
Giant Magellan Telescope (GMT)



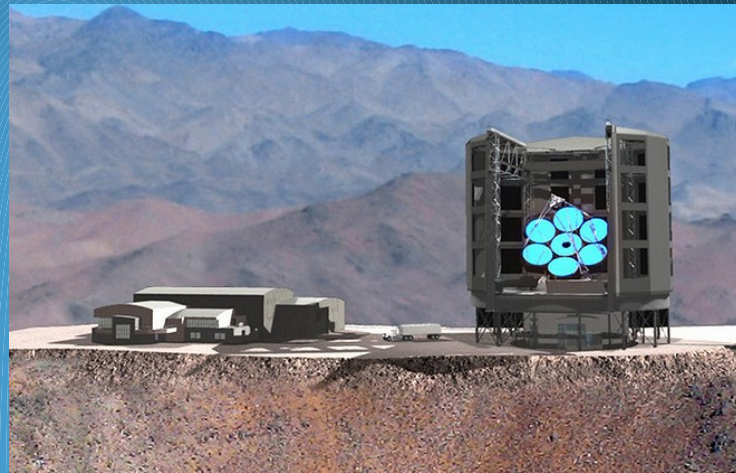
Scheduled for completion in 2022, this 83 foot telescope made of seven 27.6 ft. solid round mirrors will be located in Chile at an elevation of 8255 ft.. A multinational project led by the US, it will be the largest telescope of its kind.

Giant Magellan Telescope (GMT)

~24.5 m (80 ft) - Under construction; First Light ~2022
Resolving power of ~22 mas (could resolve Prox-b)



Additional images:



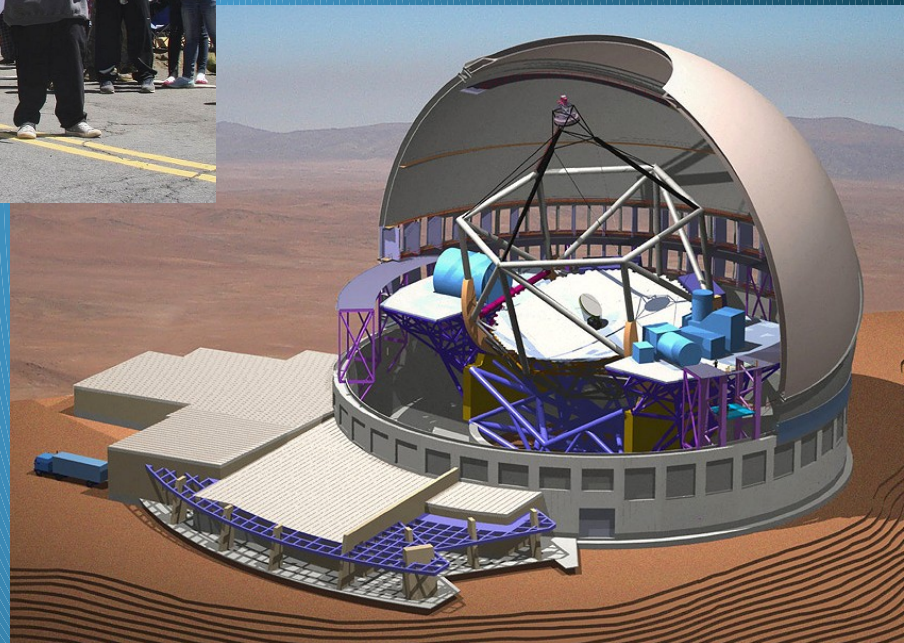
30 Meter Telescope (TMT) - Mauna Kea ?



Supported by the US, Canada, India, China and Japan

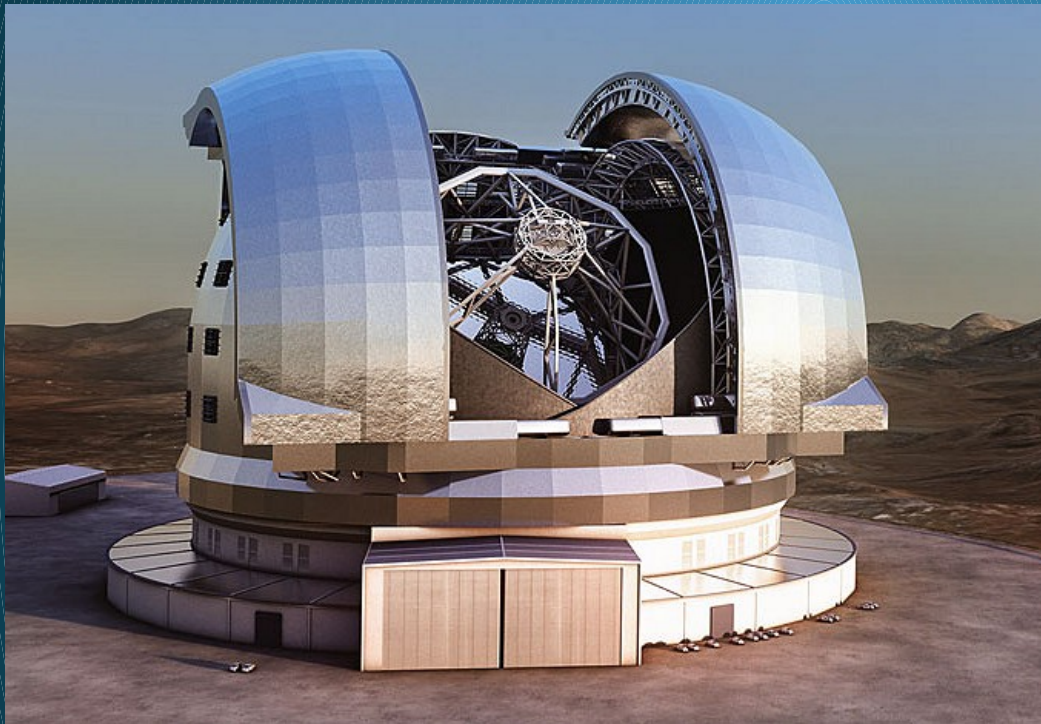
Scheduled for 2023?, this 98 ft. scope made up of 4,921 segments utilizing AO is planned to be located at an elevation of 13,290 ft. on Mauna Kea. A lot of conflict exists over native concerns but, as of October 2017, approval was granted. The alternative site would have been La Palma.

Additional images:

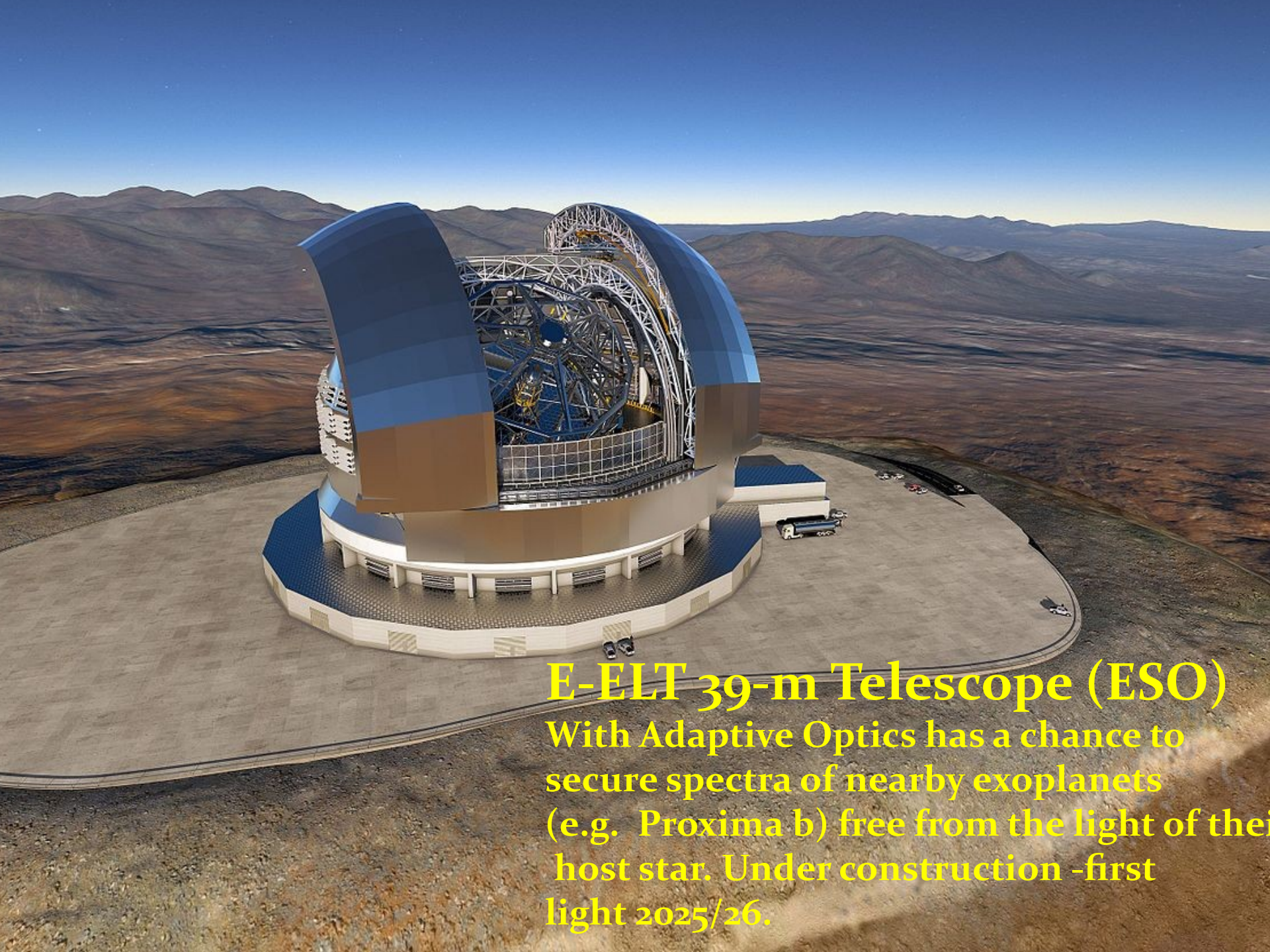


E-ELT

European Extremely Large Telescope



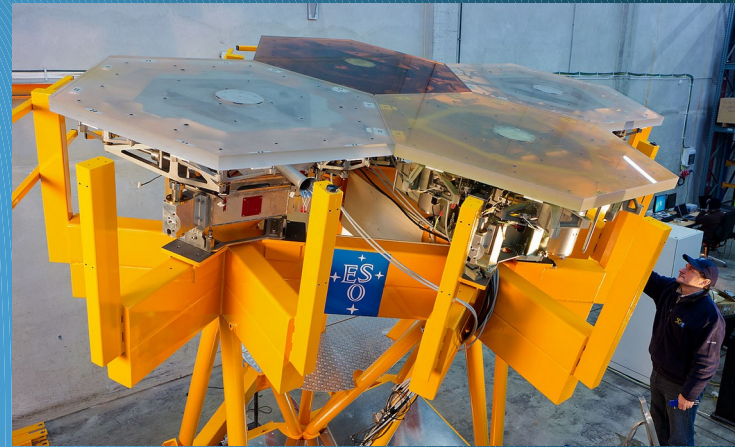
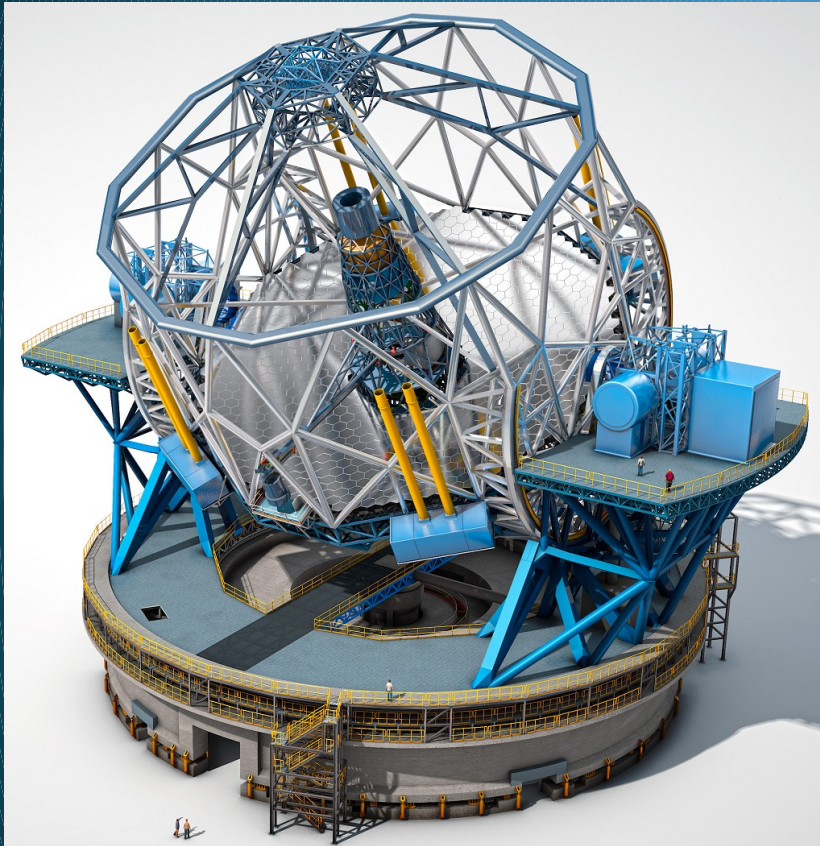
This 128 ft. scope, operated by the ESO will be located in Chile at an elevation of 9,993 ft. AO will be used with 8 laser guide stars. Made of some 798 2" thick segments measuring 4.5 ft. on a side, it will be the largest optical telescope in the world with first light in 2024



E-ELT 39-m Telescope (ESO)

With Adaptive Optics has a chance to secure spectra of nearby exoplanets (e.g. Proxima b) free from the light of their host star. Under construction -first light 2025/26.

Additional images:



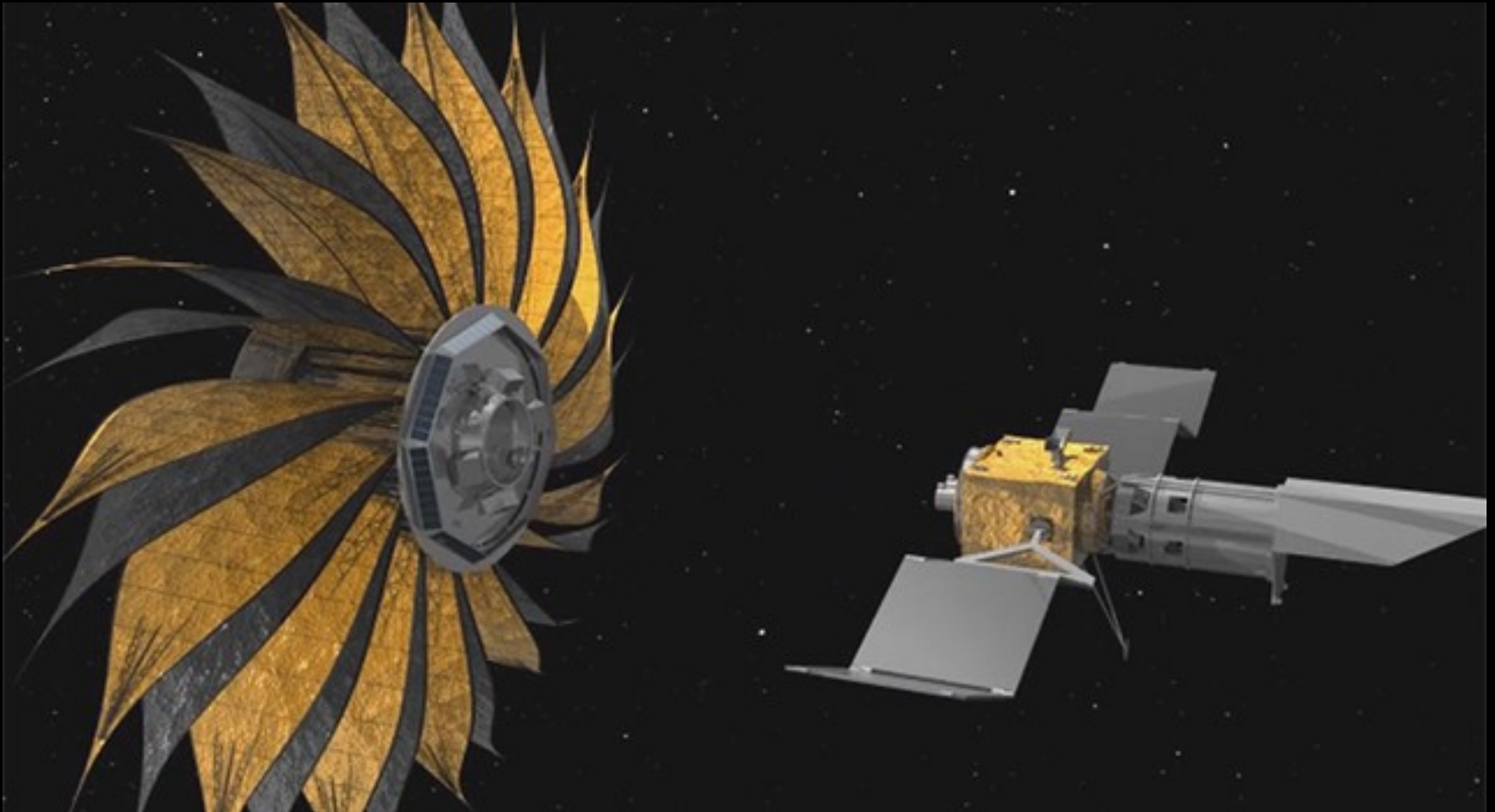
New Worlds Mission (NWM): Hunting for alien life

Exobiology mission

For example-NWM can resolve Prox b from its host star ($\sim 0.039'' = 39 \text{ mas}$ at quadratures) permitting imaging and spectroscopy.

<https://exoplanets.nasa.gov/resources/1015>

Star shade Concept: Occult Star: permit hosted exoplanets to be imaged (being considered by NASA ~2025)

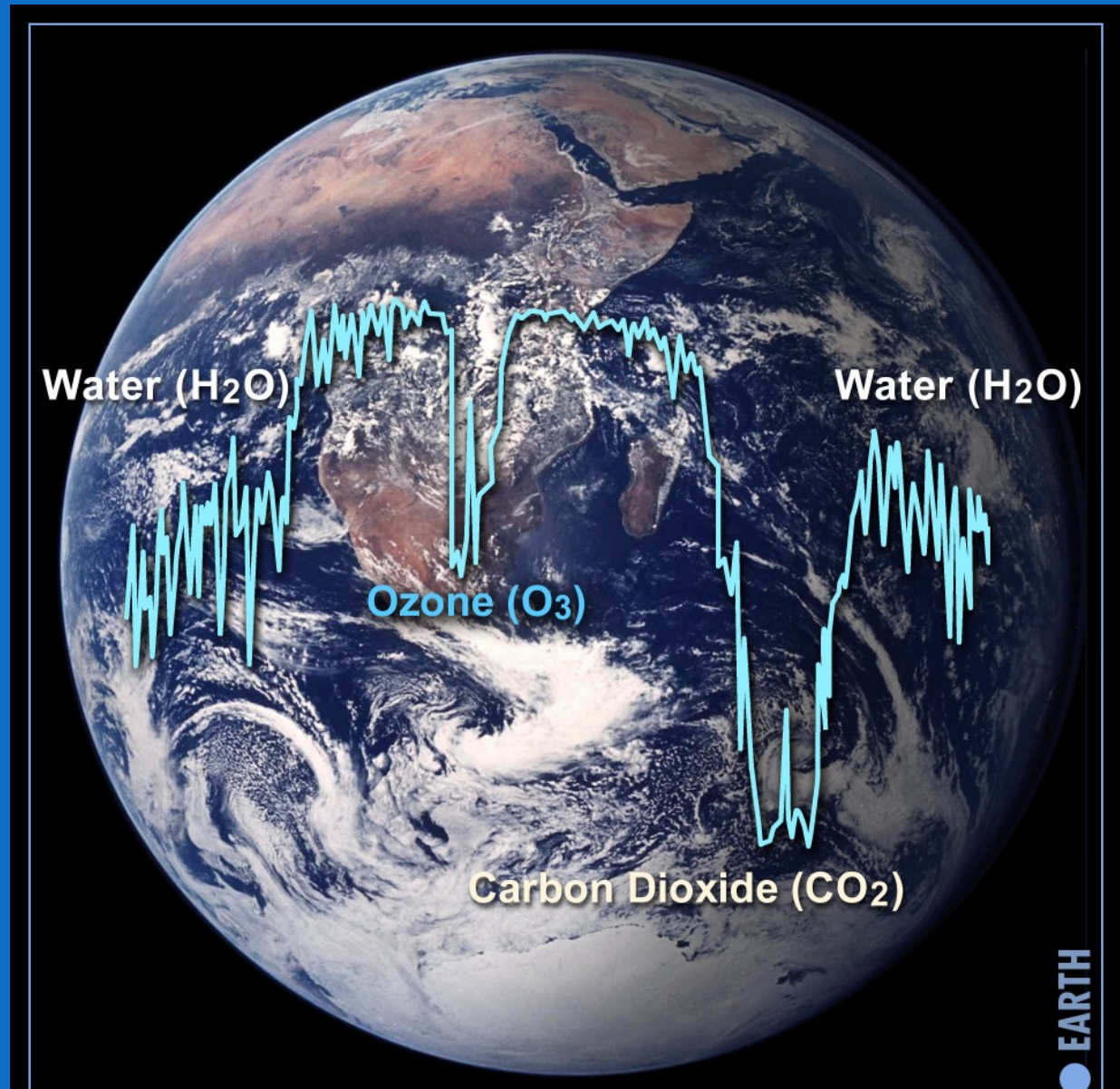


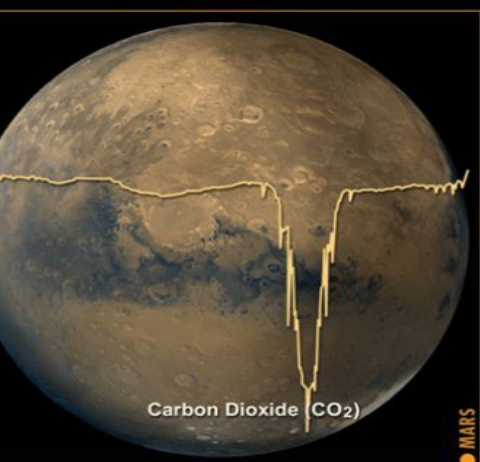
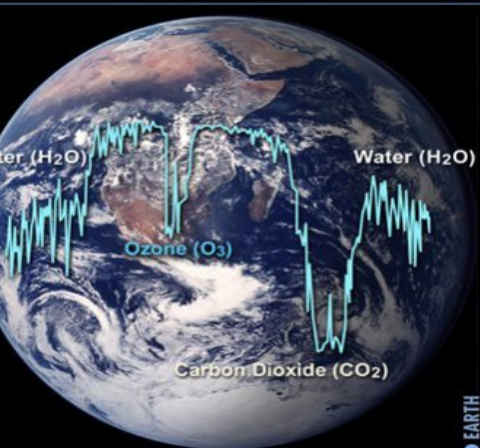
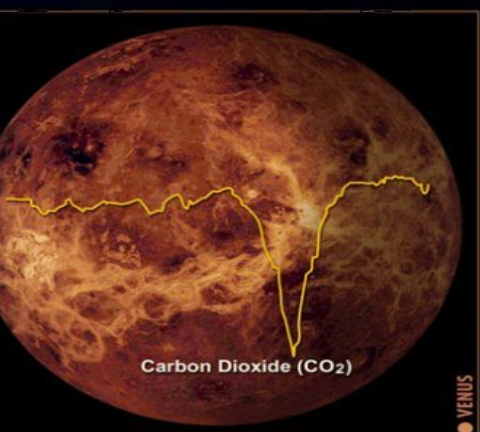
<http://newworlds.colorado.edu/starshade/>

Biosignatures

Oxygen
Ozone
Methane
Water...
Red Edge-
chlorophyll

Photo Courtesy of European Space Agency





Darwin / Terrestrial Planet Finder TPF *IR Interferometers in Space (in 10-15 yrs?)*





So, there's an overview

60 H1a/N15 August 7, 2013
ured with iCap 2.2
ked with Avistack2/Registax 6
l Observatory, GCM

Thank you



Governor Helen Kilpatrick gives Dr. William Hrudey the MBE medal at Government House, with Mrs. Gigi Hrudey (Jan. 07, 2018)



“I am truly humbled, honoured and delighted to have received an MBE in recognition of my services to the islands,” said Dr. Hrudey. “Science is so important and promoting its many uses, especially to students, has been a key part of my life in Cayman.”

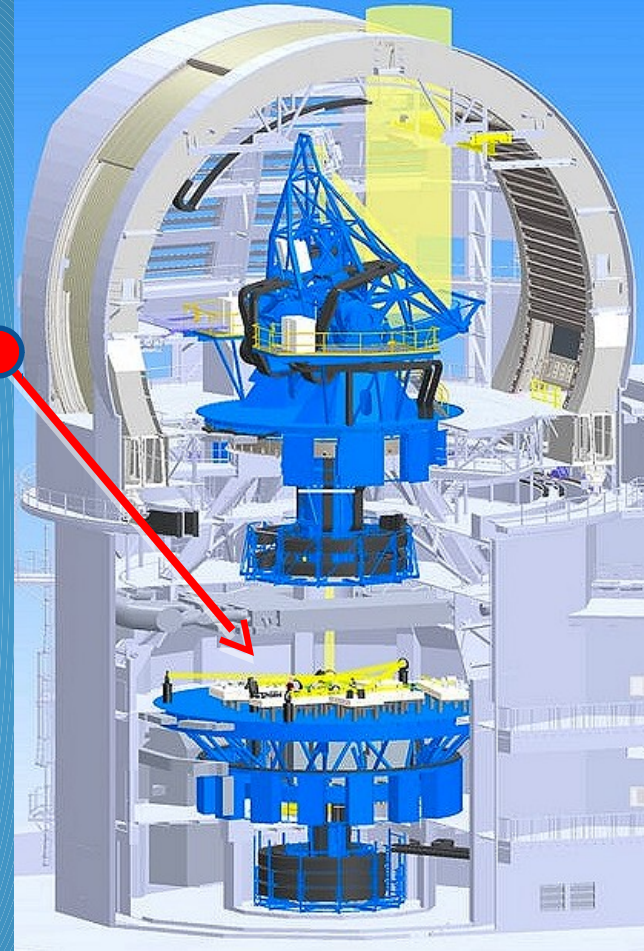
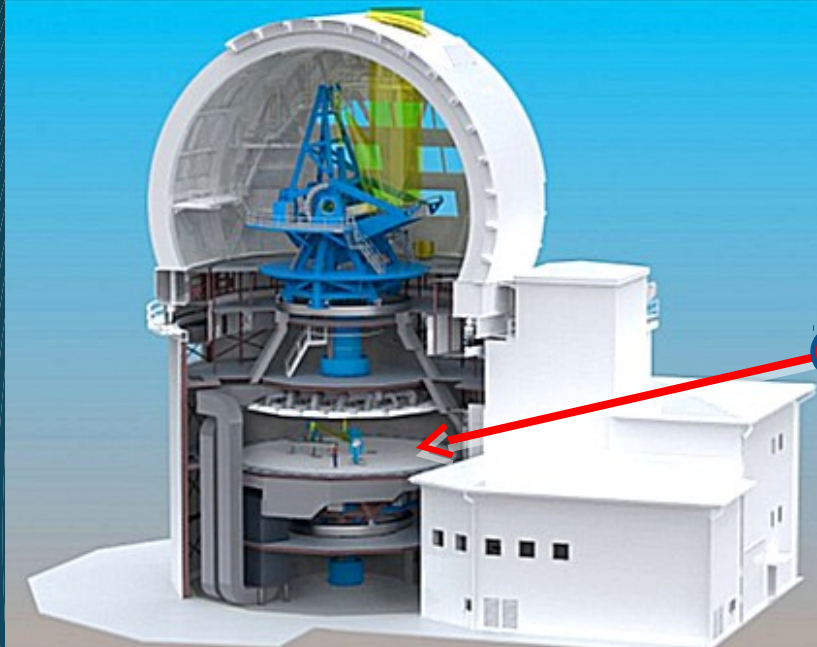
Haleakela, Maui – DKIST (10,118 ft.)



Named, in 2013, after Danial Inouye (1924 – 2012) who was an Hawaiian senator from 1963 to 2012. It is supported by multiple American universities and suffered local from activists opposing its construction.

22 mostly American collaborators

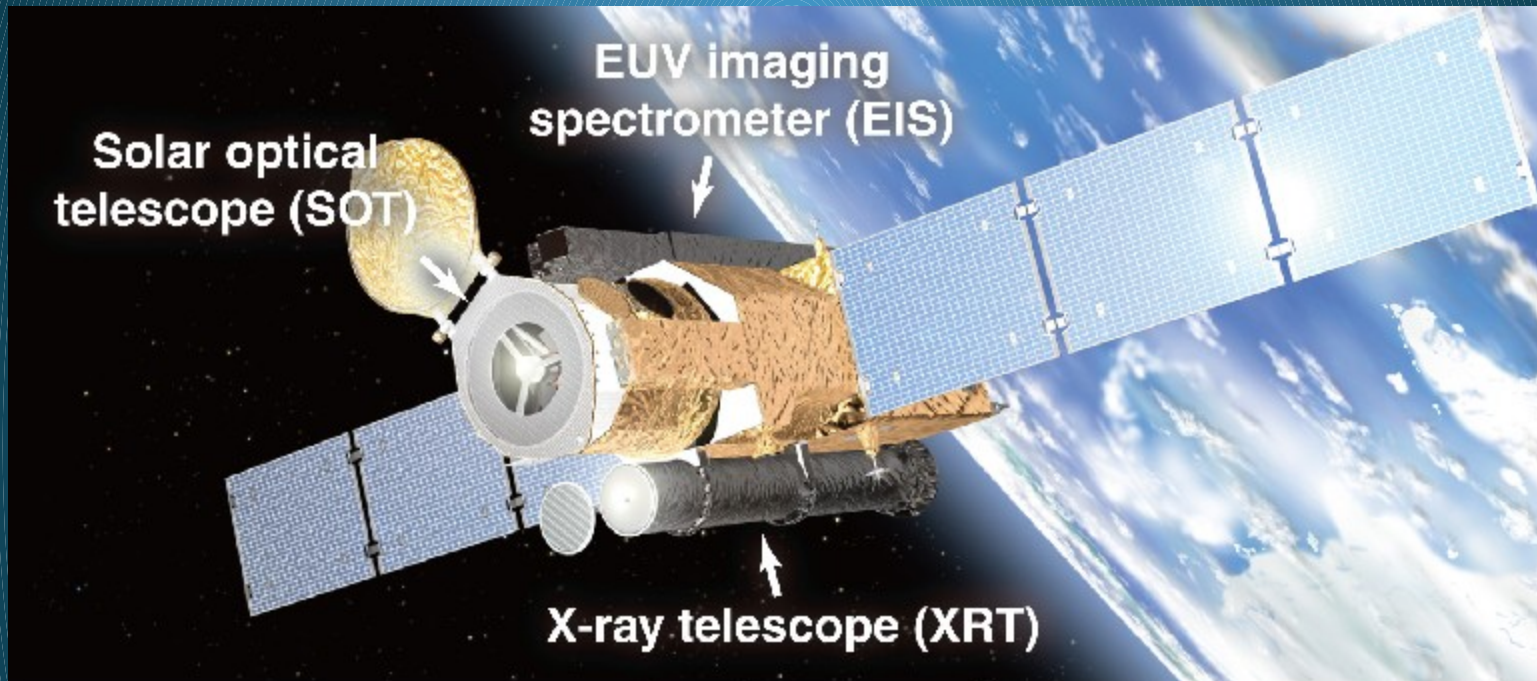
Additional images:



With a 14 ft. off-axis mirror on an Alt/Az mount, light rays are directed down to the Coude level where, on a number of optical benches, studies are carried out.

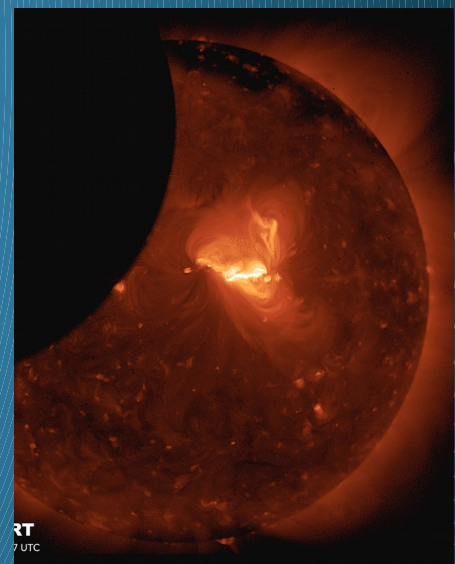
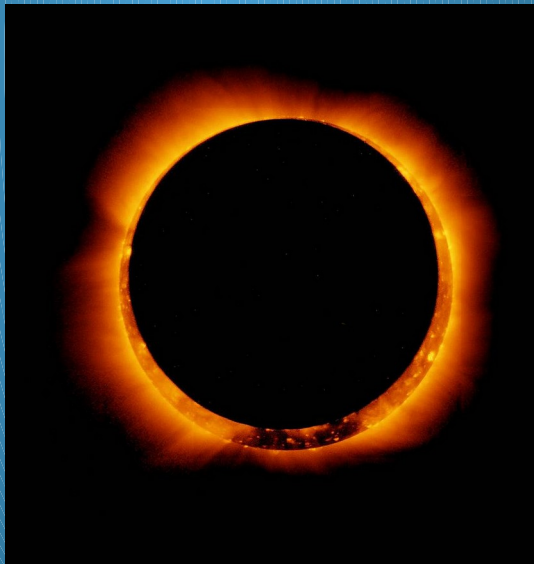
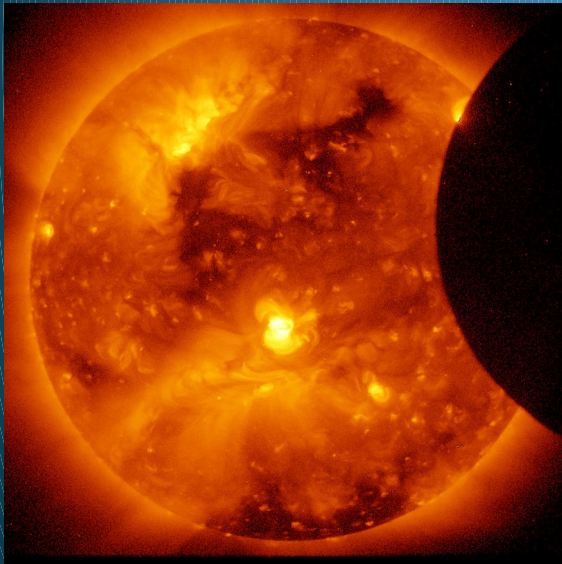
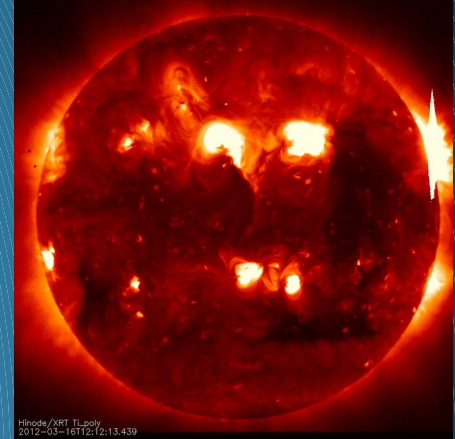
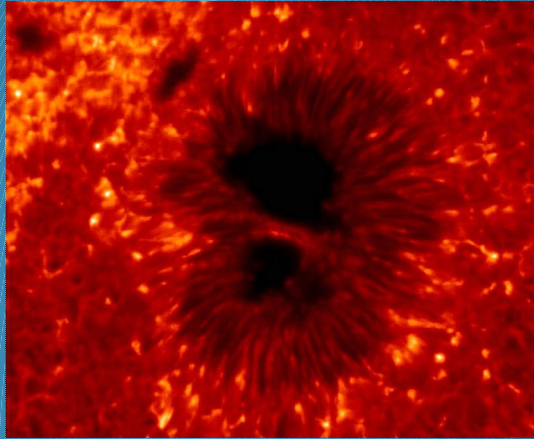
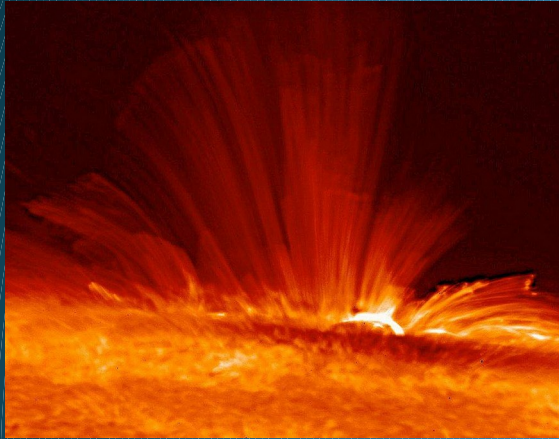
Hinode a joint JAXA & NASA venture

launched September 2006 in a Solar synchronous orbit



Instruments include a Solar optical telescope, an X-ray telescope and an Extreme-ultraviolet Imaging Spectrometer.

Examples of Hinode's images:



Trends to date:

- **Bigger is better** – Newton's 4" to EELT of 128 ft.
- **Segmented mirrors**
- **Alt/Az vs. equatorial** – more practical and cheaper
- **Adaptive optics** – major improvement
- **Locations** – Mauna Kea, Chile and La Palma
- **Multiple types of sensors** - IR, UV, gamma ray,
 - - micro wave, X-ray, visible, particle, radio and gravity