The Tools of Astronomy

Seeing the whole picture

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What tools do we need?

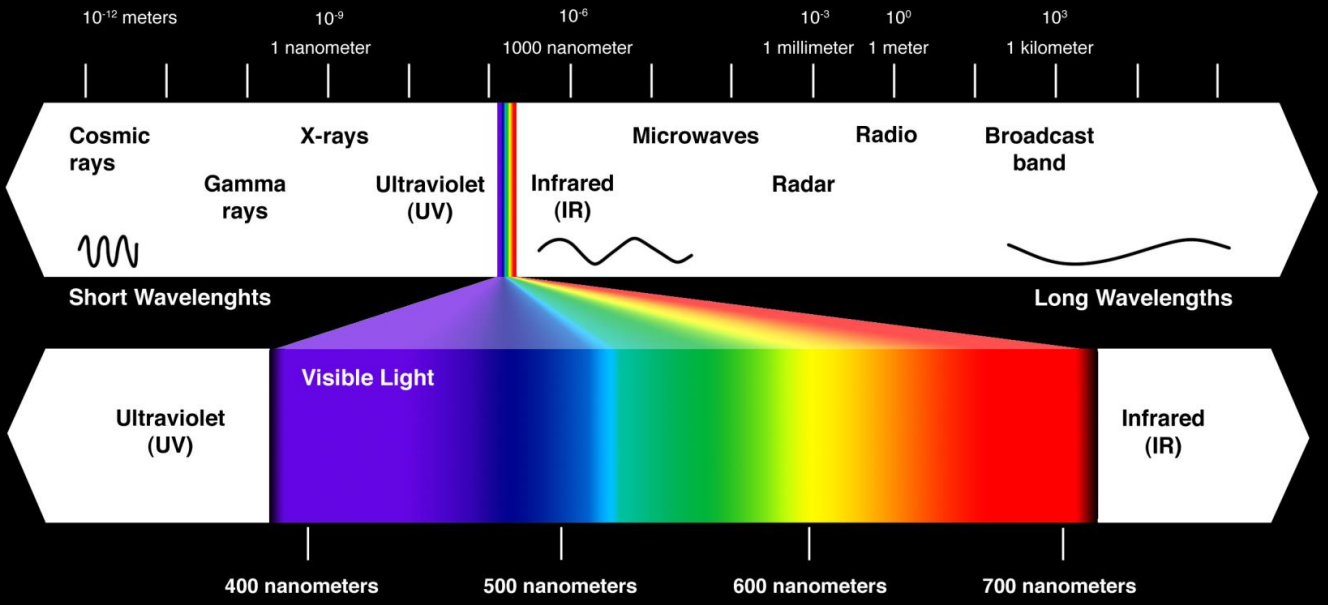
- We need to observe the Universe around us
  - The Solar System
  - The Milky Way
  - Galaxies
  - And beyond
- We need to understand what we see
- We need to predict what is going to happen

The Tools of Astronomy

- The Astronomers Toolkit
  - Ground-based telescopes
  - Space telescopes
  - Spacecraft and probes

  - Computing power

Observing the Universe


10^{-12} meters
10^{-9}
1 nanometer
10^{-6}
1000 nanometer
10^{-3}
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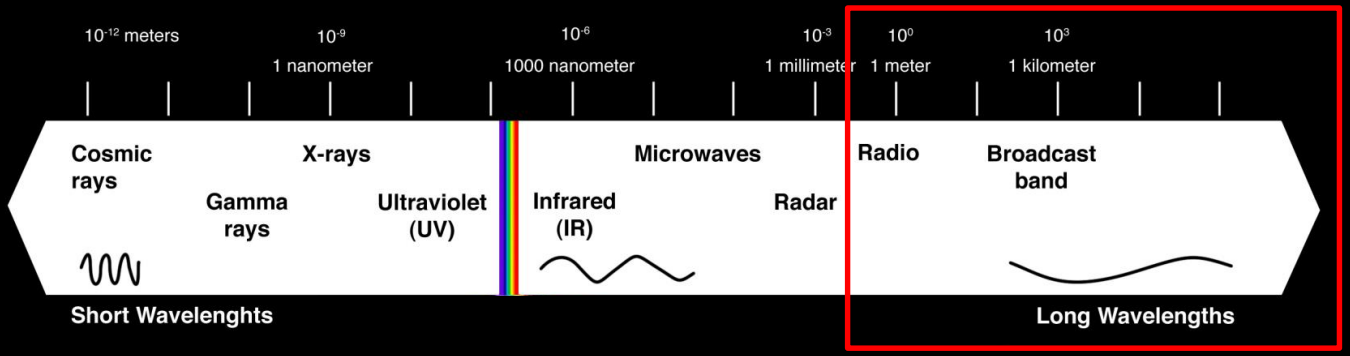
1 meter
10^{3}
1 kilometer
Cosmic rays
X-rays
Gamma rays
Ultraviolet (UV)
Infrared (IR)
Microwaves
Radar
Radio
Broadcast band
Short Wavelenghts
Long Wavelengths
Ultraviolet (UV)
Visible Light
Infrared (IR)
400 nanometers
500 nanometers
600 nanometers
700 nanometers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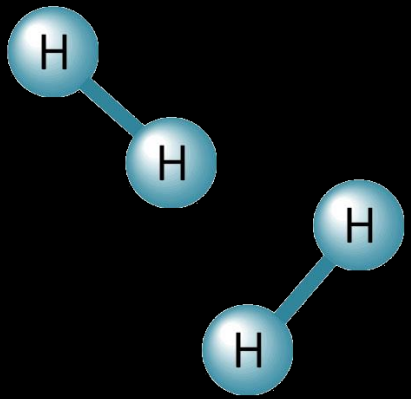
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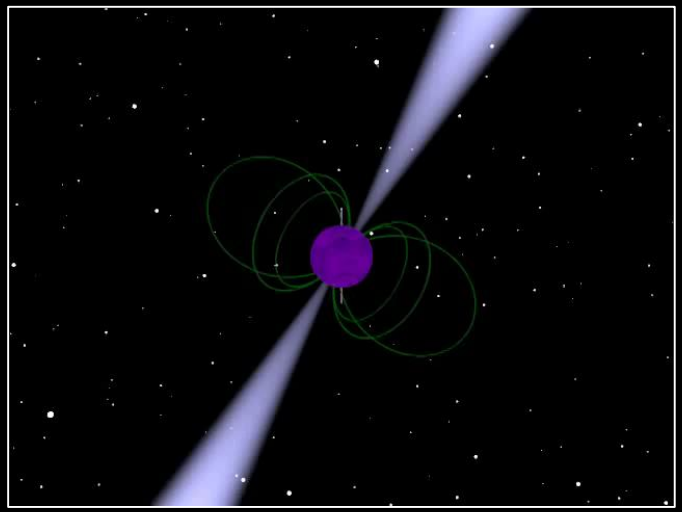

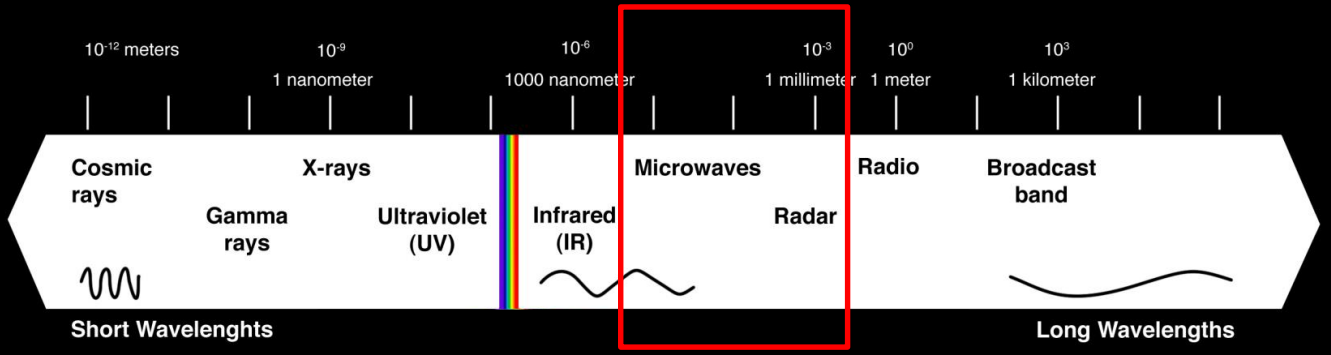
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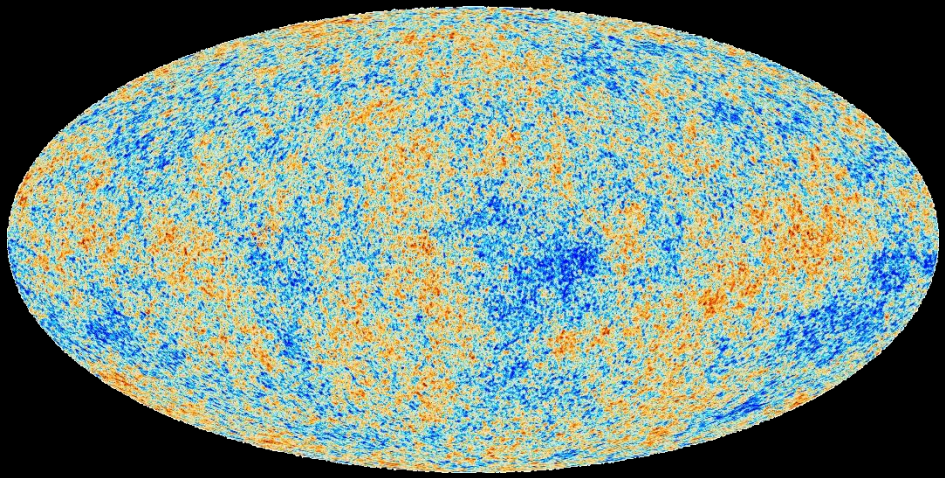

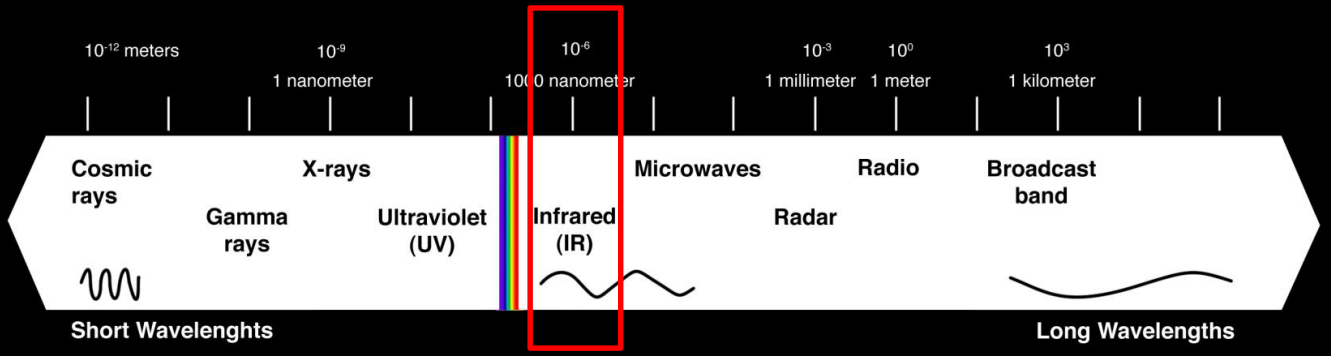
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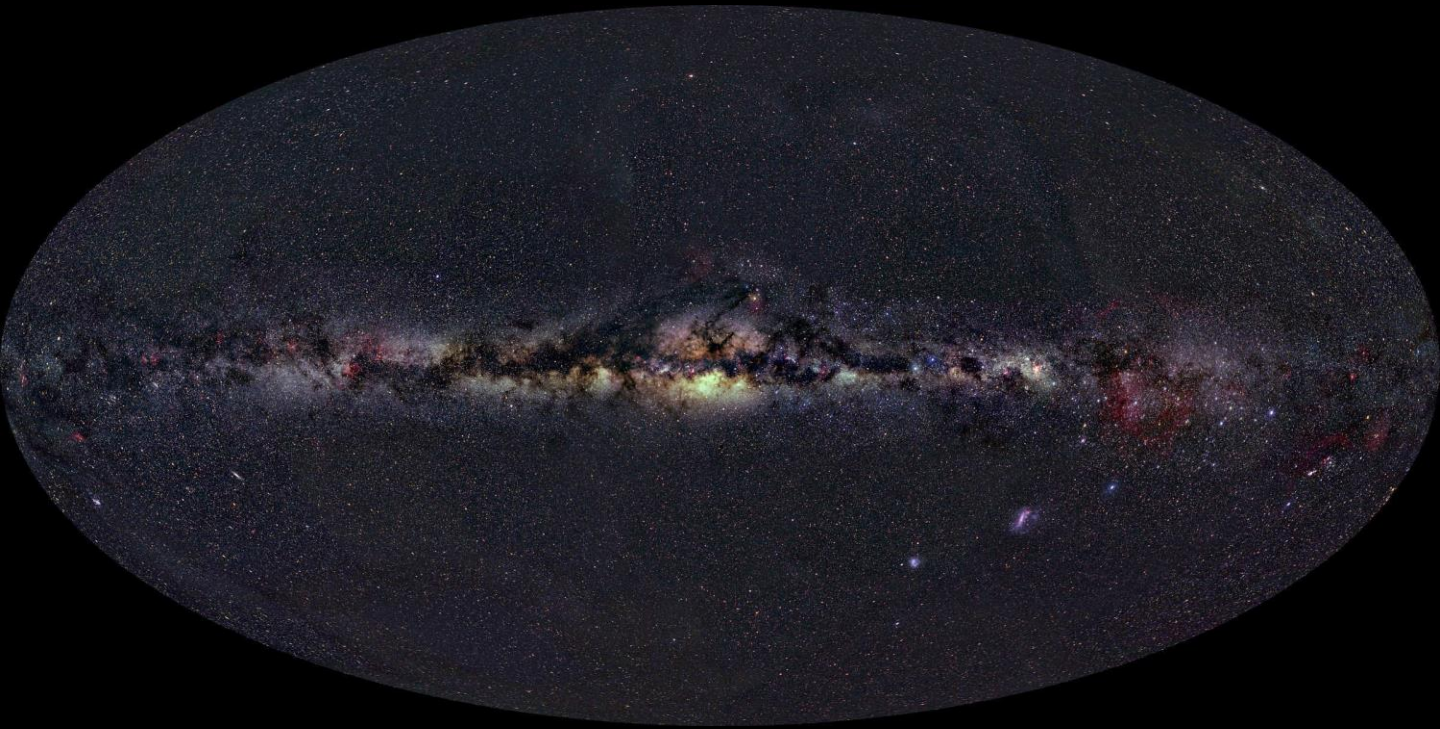

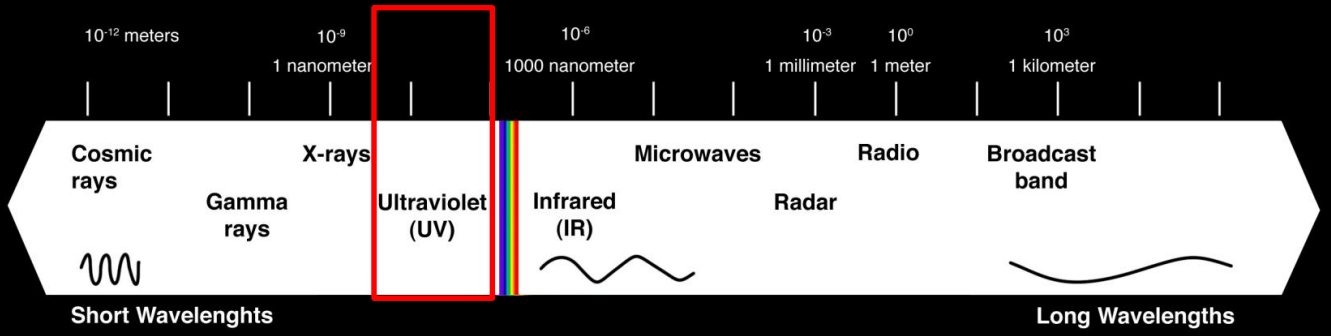
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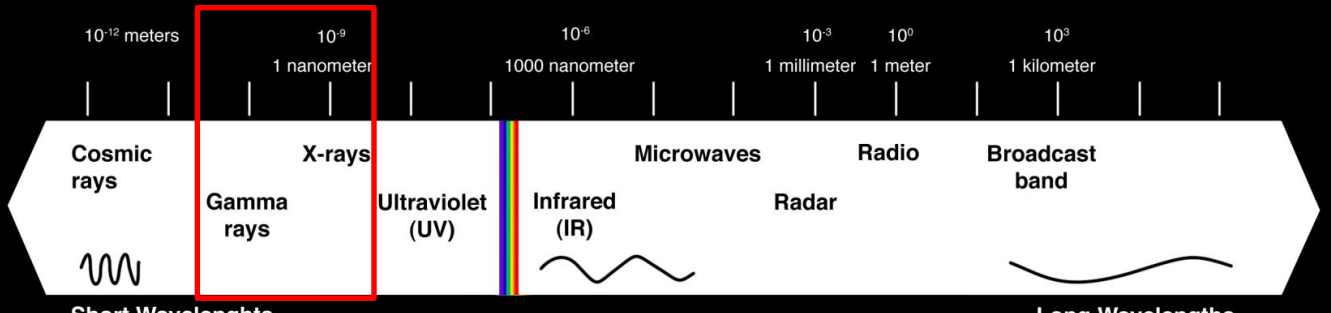
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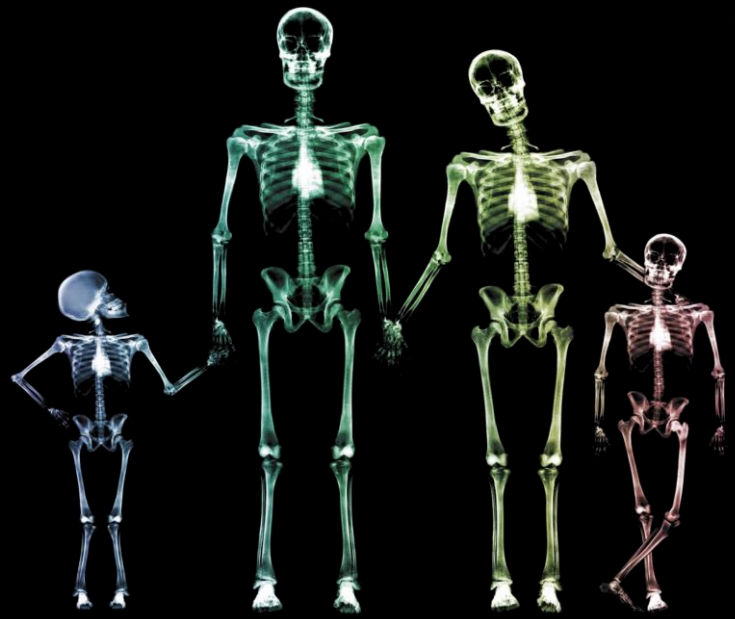
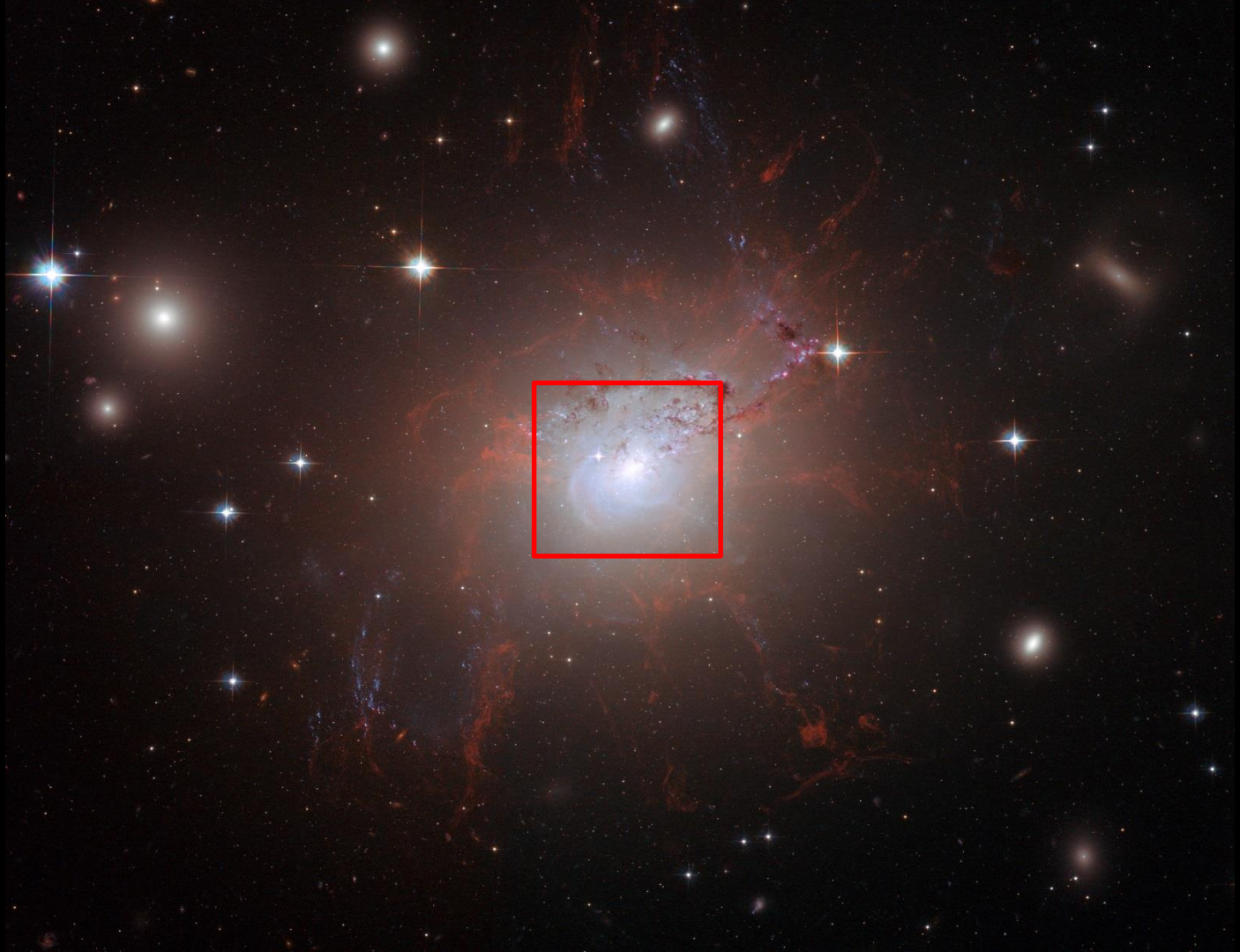


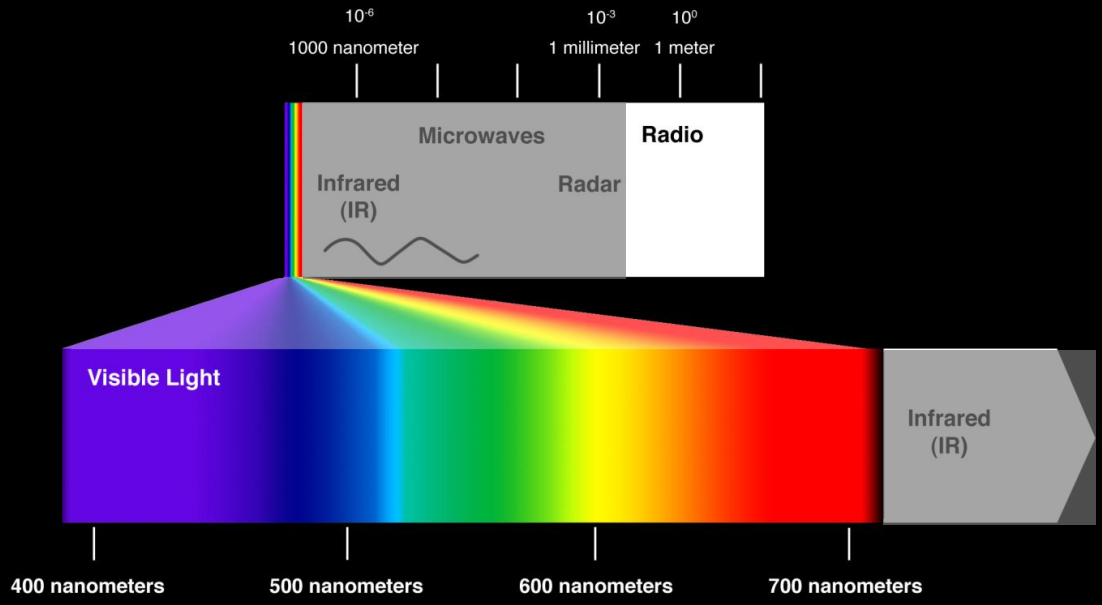


Ground-based telescopes

Ground-based telescopes

1. They're "cheap"
2. They're easier to maintain
3. You can upgrade them
4. You can use different instruments for different types of science

What can we see on the ground?




Lovell Telescope – 76.2m

Why are radio telescopes so large?

- Sensitivity

Why are radio telescopes so large?

- All telescopes are limited in resolution

$$\text{Resolution} = 1.22 \times \frac{\text{Wavelength}}{\text{Telescope Diameter}}$$

- Depends on:
  - Telescope diameter
  - Wavelength

Largest Filled Aperture

Arecibo Radio Telescope – 305m

Largest Filled Aperture

Five hundred meter Aperture Spherical Telescope – 500m

Largest Fully Steerable

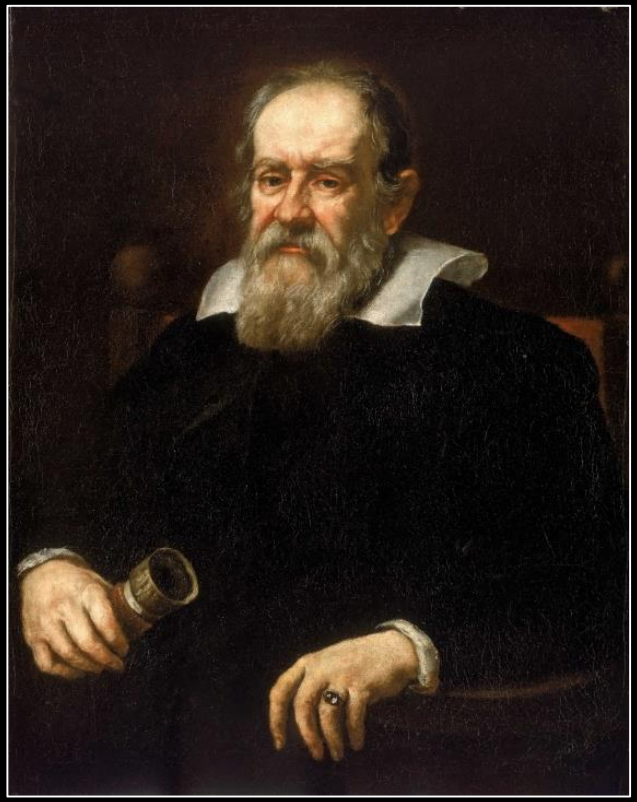
Green Bank Telescope – 100x110m

Largest Overall

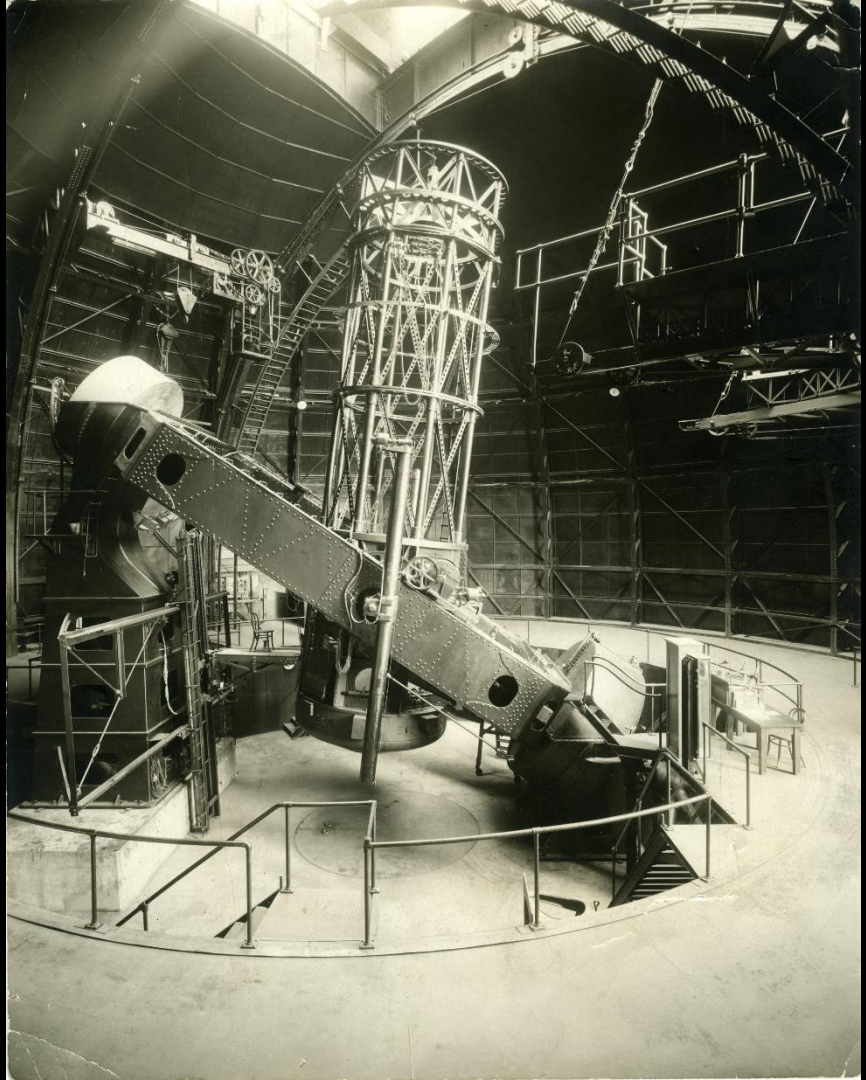
RATAN-600 – 576m

Optical Telescopes

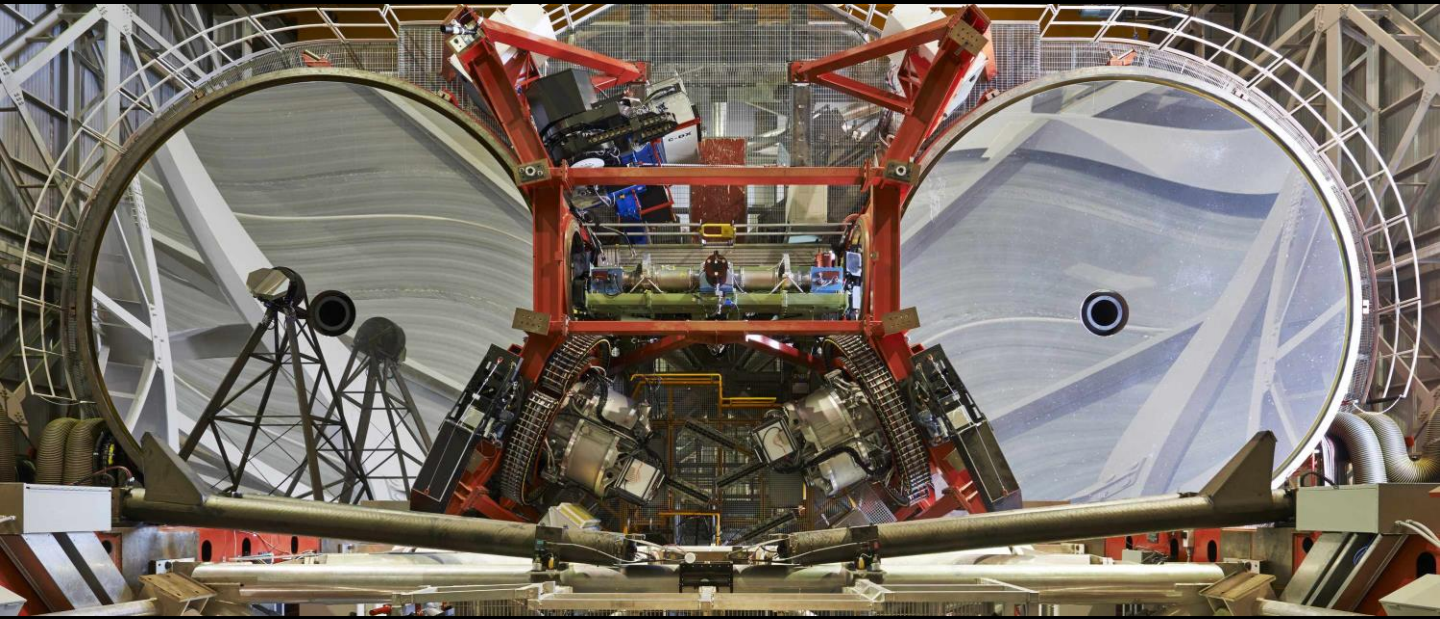
- Galileo – 1609



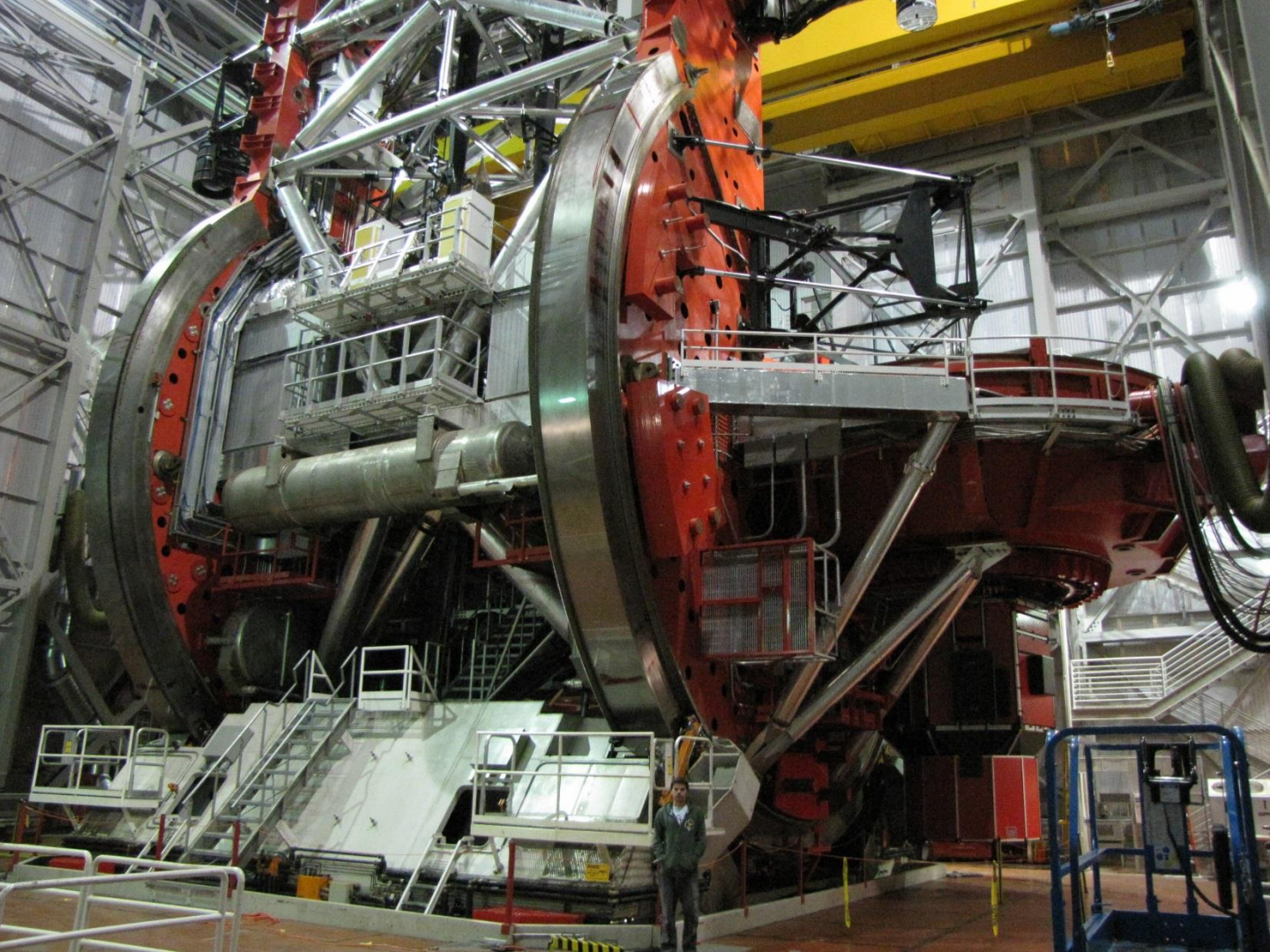
Northumberland Telescope,
University of Cambridge, 11.6in

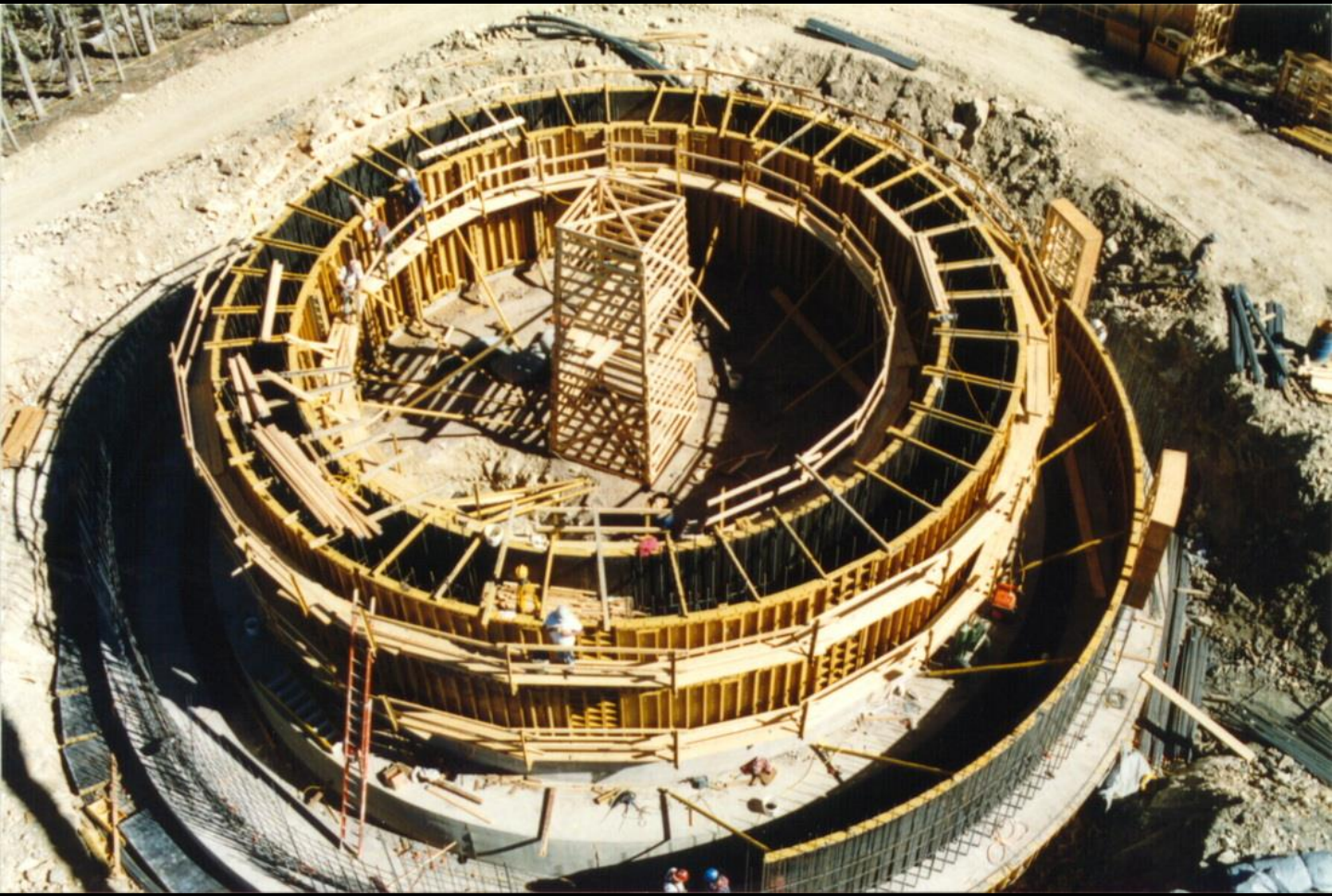


Hale Telescope,
CA, USA – 60in

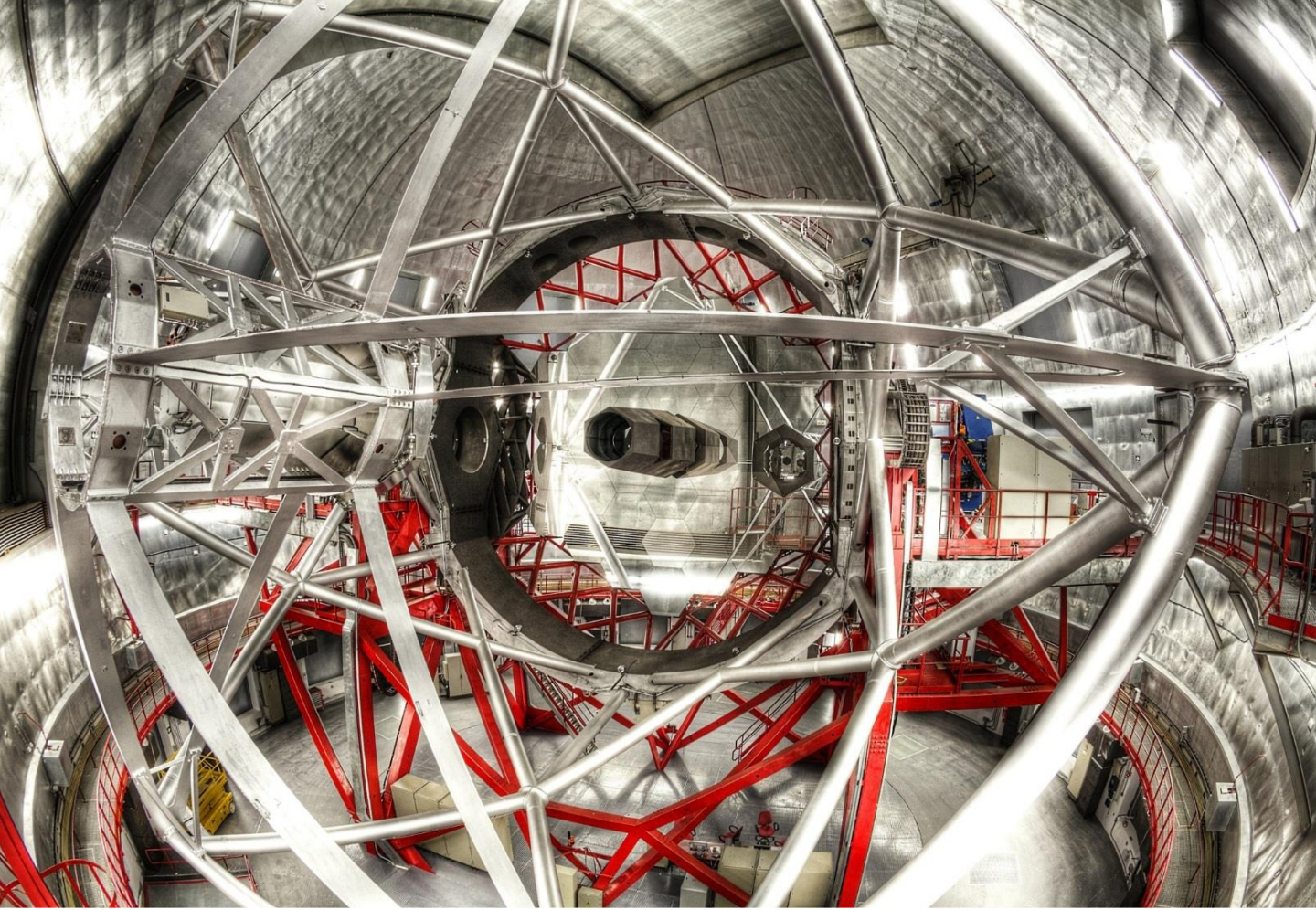


Large Binocular Telescope, AZ, USA – 2 × 8.4m

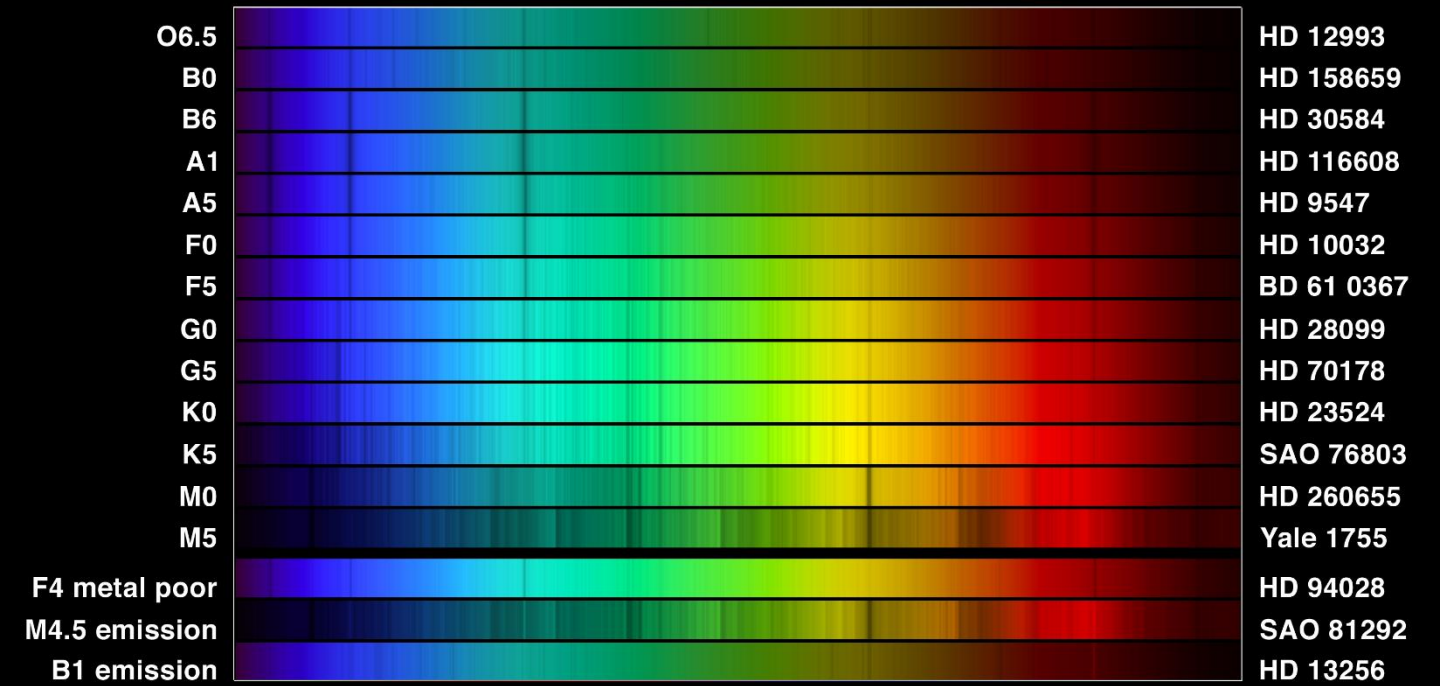





OVERSIZE LOAD



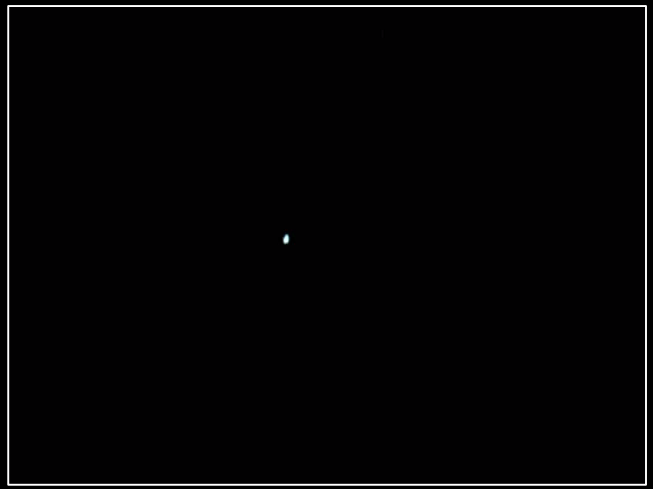
Gran Telescopio Canarias – 10.4m


O6.5
B0
B6
A1
A5
F0
F5
G0
G5
K0
K5
M0
M5
F4 metal poor
M4.5 emission
B1 emission
HD 12993
HD 158659
HD 30584
HD 116608
HD 9547
HD 10032
BD 61 0367
HD 28099
HD 70178
HD 23524
SAO 76803
HD 260655
Yale 1755
HD 94028
SAO 81292
HD 13256

The problem with big telescopes

- We have an atmosphere…
- There's a finite size single telescope we can build

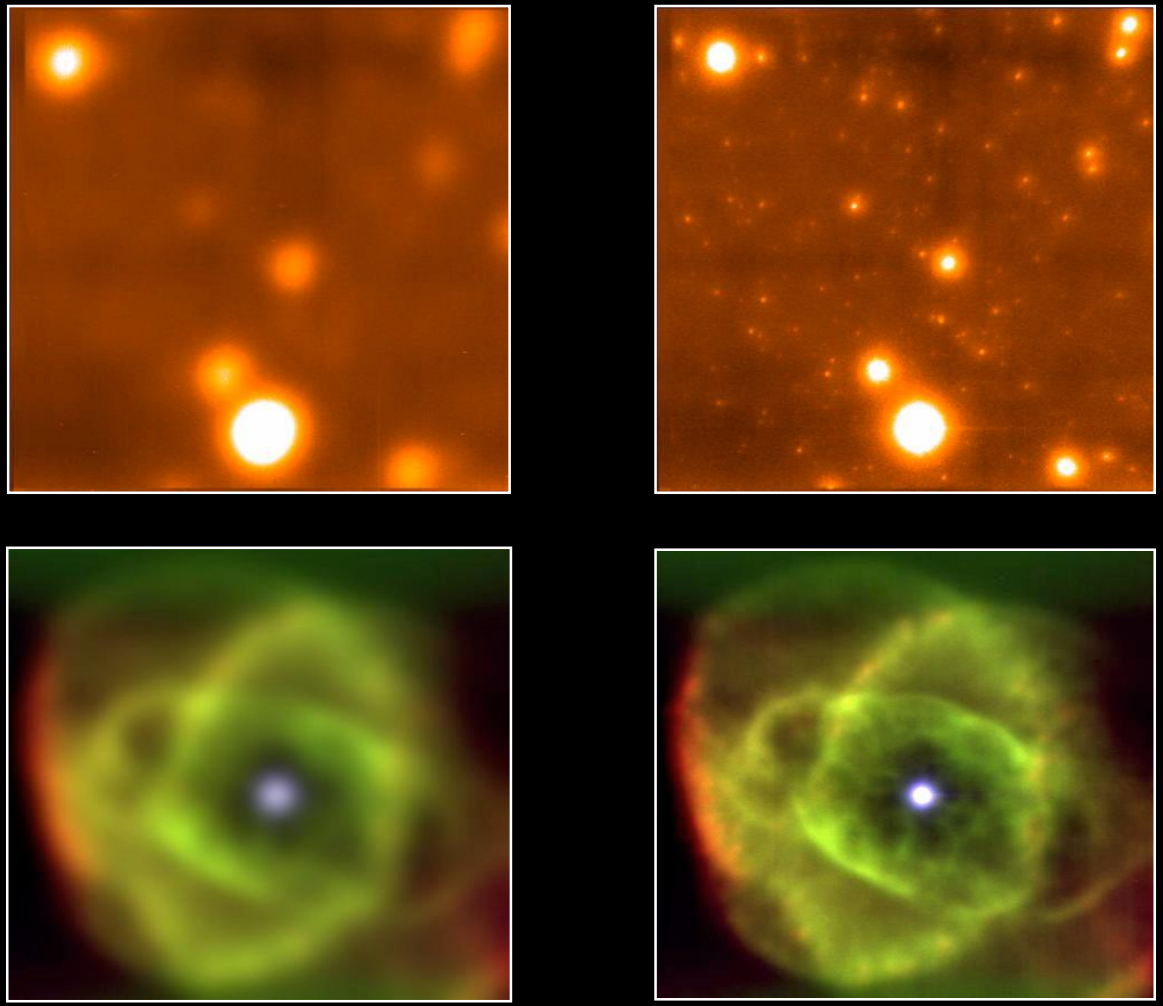
Atmospheric Turbulence



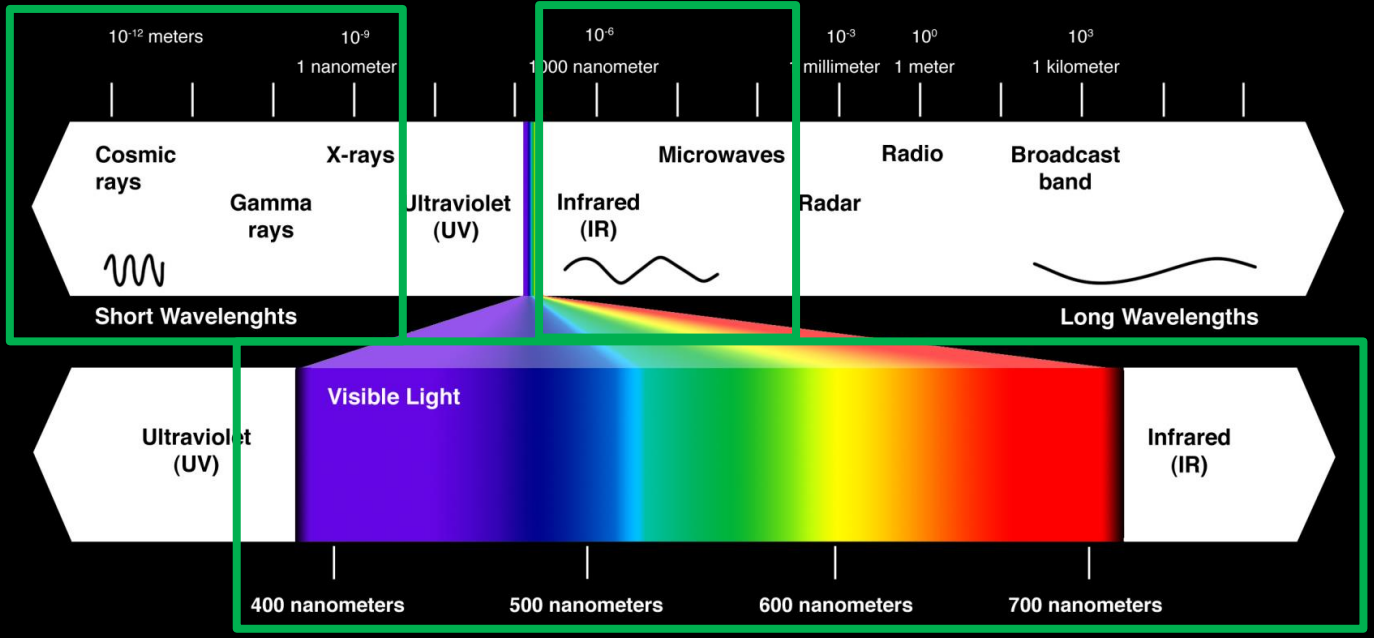
Correcting for the atmosphere

- The simple option:
  - Go to space!
- Correct for the effects on the ground

$ £ €



Space Telescopes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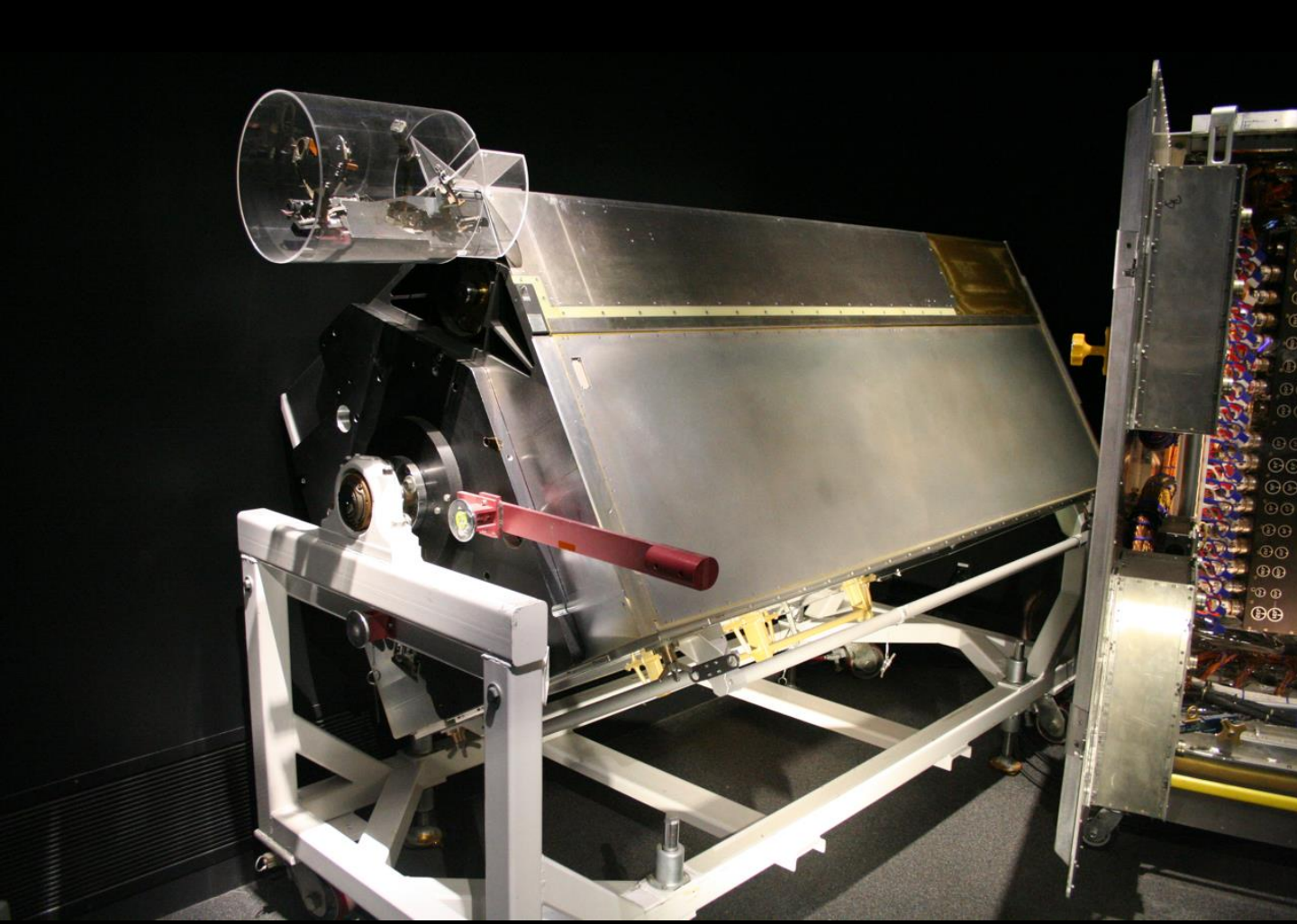
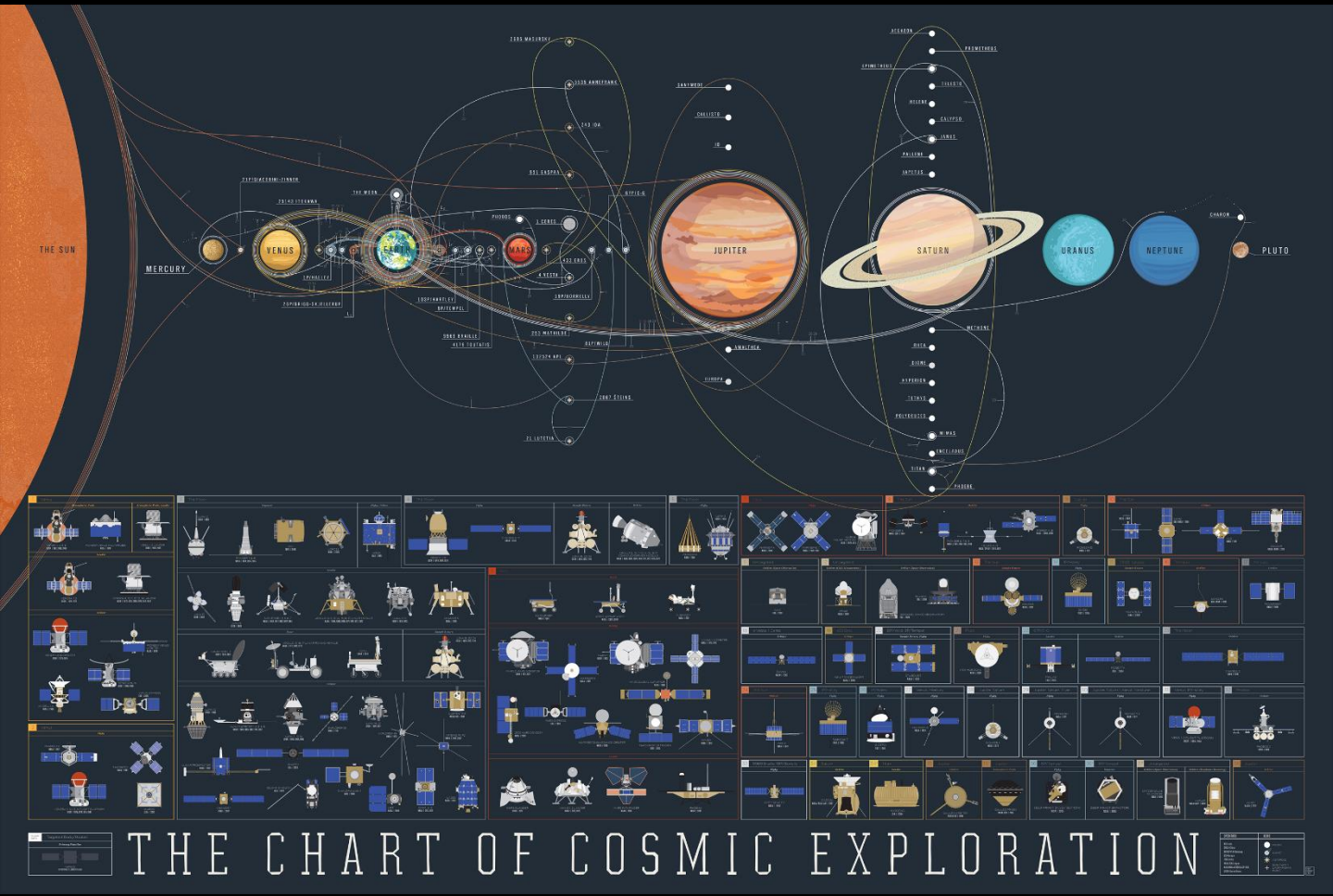
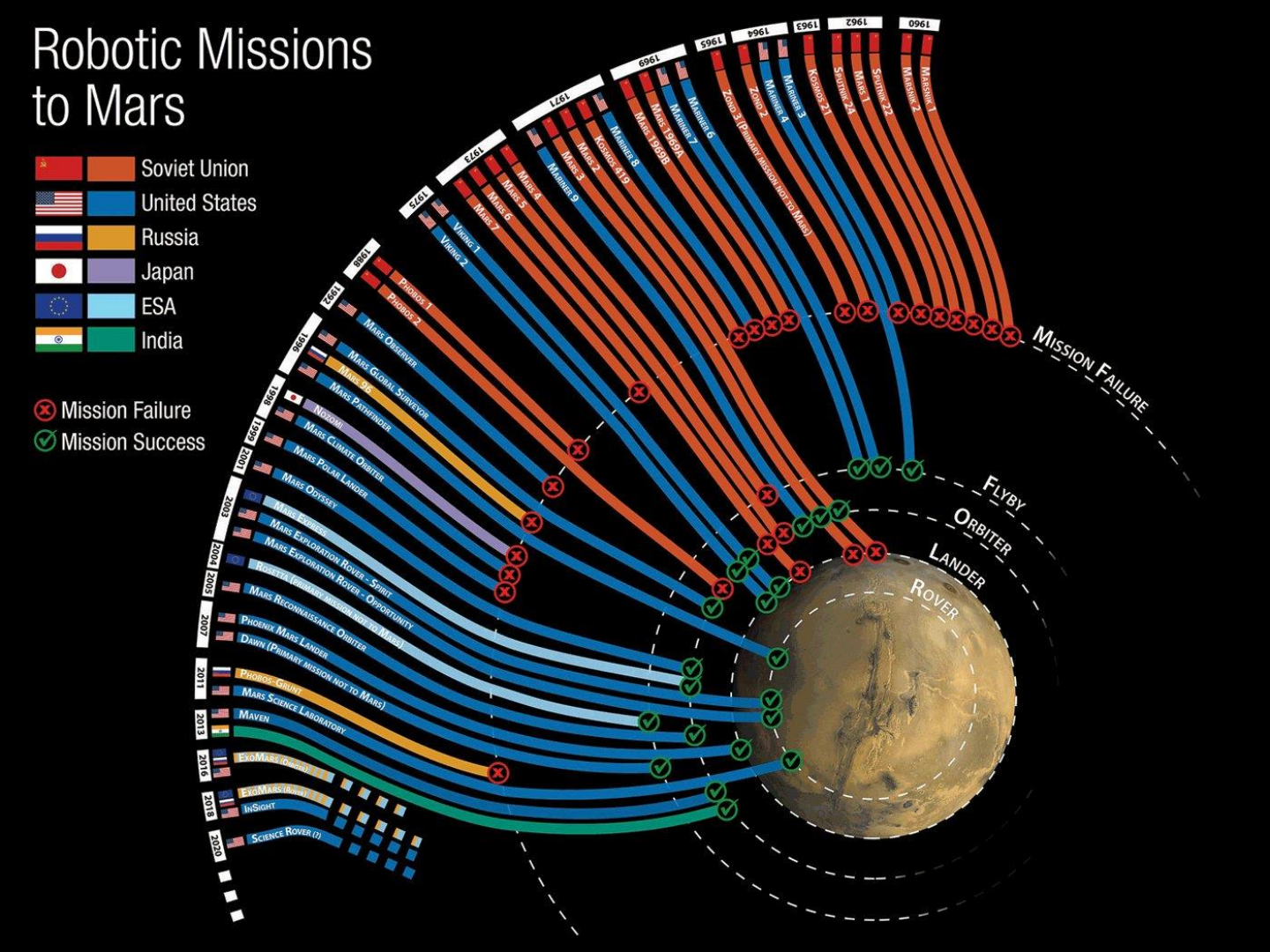
Pix Nixed as Hubble Sees Double



Exploring Our Own Solar System



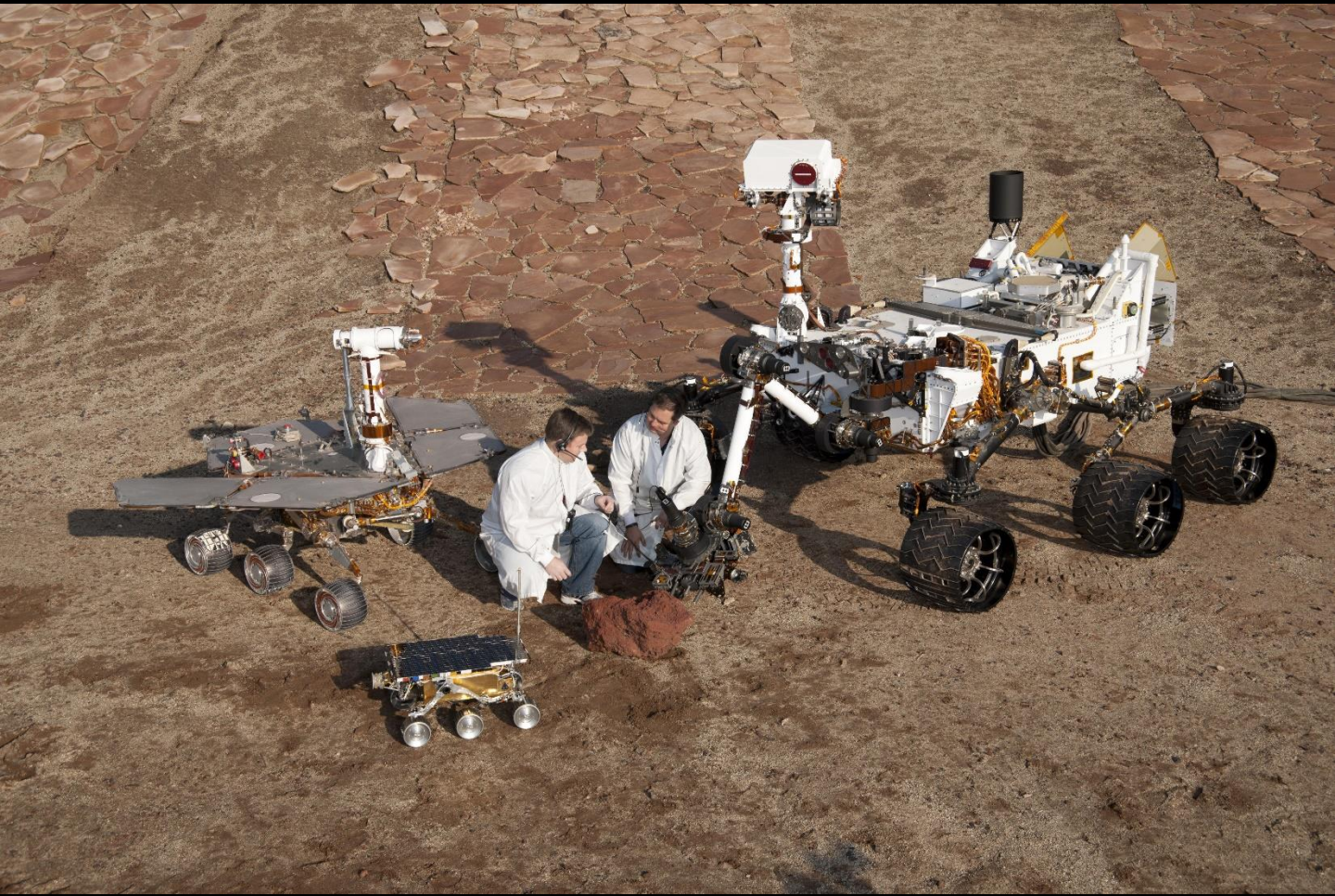
THE CHART OF COSMIC EXPLORATION

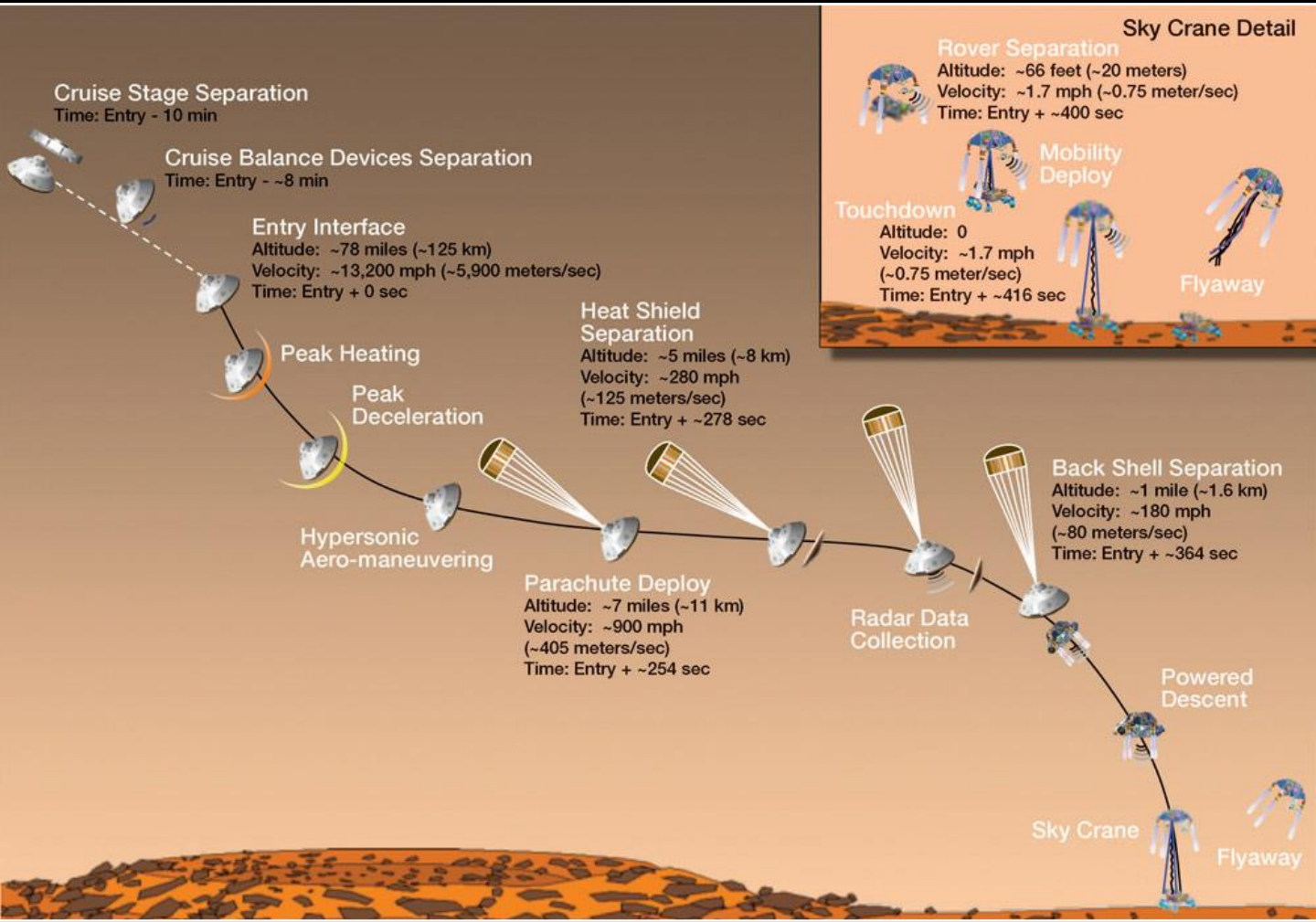

Robotic Missions to Mars
Soviet Union
United States
Russia
Japan
ESA
India
Mission Failure
Mission Success
1960
1962
1963
1964
1965
1969
1971
1973
1975
1988
1992
1996
1998
1999
2001
2003
2004
2005
2007
2011
2013
2016
2018
2020
Marsnik 1
Marsnik 2
Mars 1
Sputnik 22
Sputnik 24
Kosmos 21
Mariner 3
Mariner 4
Zond 2
Zond 3 (Primary mission not to Mars)
Mariner 6
Mariner 7
Mars 1969A
Mars 1969B
Kosmos 419
Mariner 8
Mariner 9
Mars 2
Mars 3
Mars 4
Mars 5
Mars 6
Mars 7
Viking 1
Viking 2
Phobos 1
Phobos 2
Mars Observer
Mars Global Surveyor
Mars 96
Mars Pathfinder
Nozomi
Mars Climate Orbiter
Mars Polar Lander
Mars Odyssey
Mars Express
Beagle 2 (Primary mission not to Mars)
Mars Exploration Rover - Spirit
Mars Exploration Rover - Opportunity
Mars Reconnaissance Orbiter
Phoenix Mars Lander
Dawn (Primary mission not to Mars)
Phobos-Grunt
Mars Science Laboratory
Maven
ExoMars Orbiter
ExoMars Rover
InSight
Science Rover (?)
Mission Failure
Flyby
Orbiter
Lander
Rover

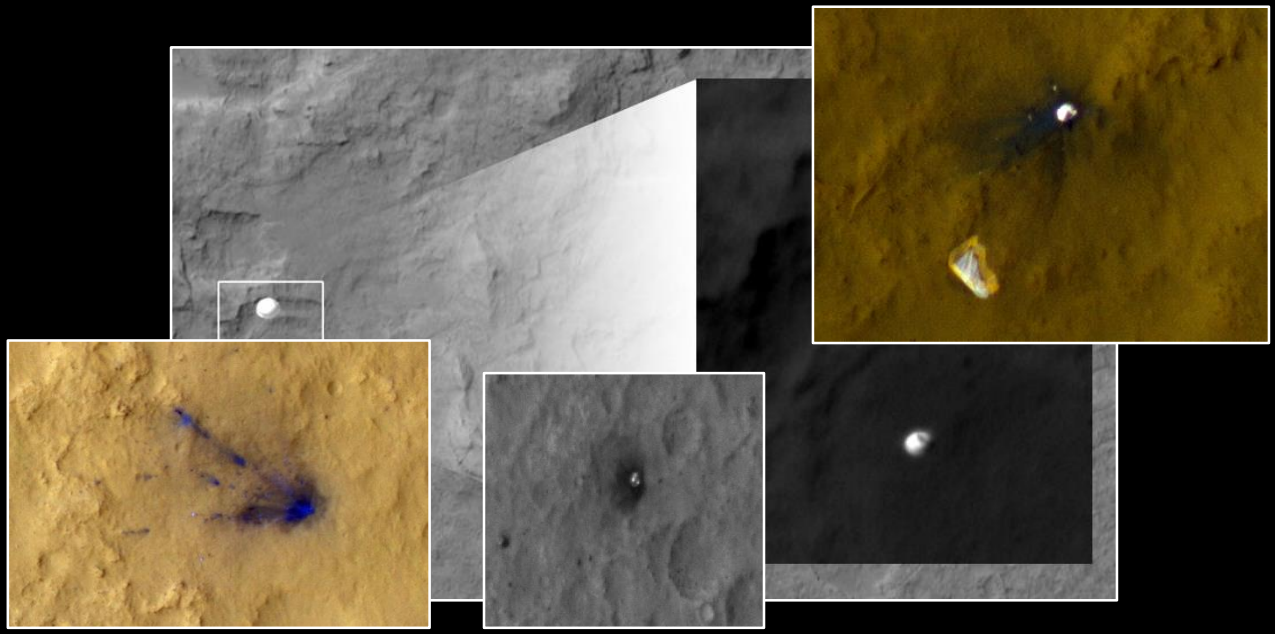
Recent and Current Missions

- Curiosity Rover
- Cassini Mission
- New Horizons

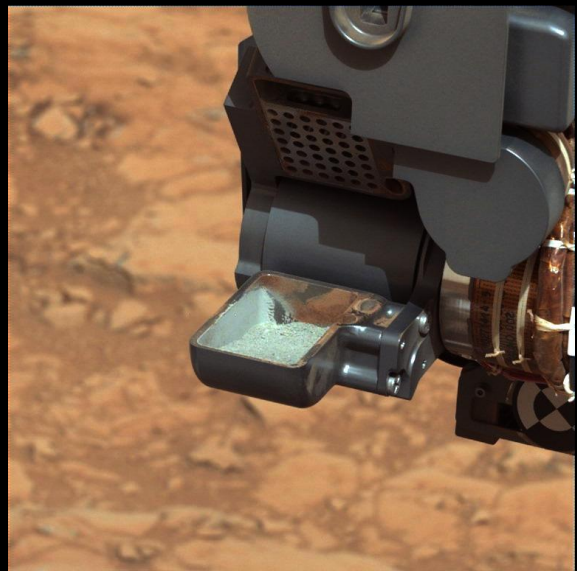

HD



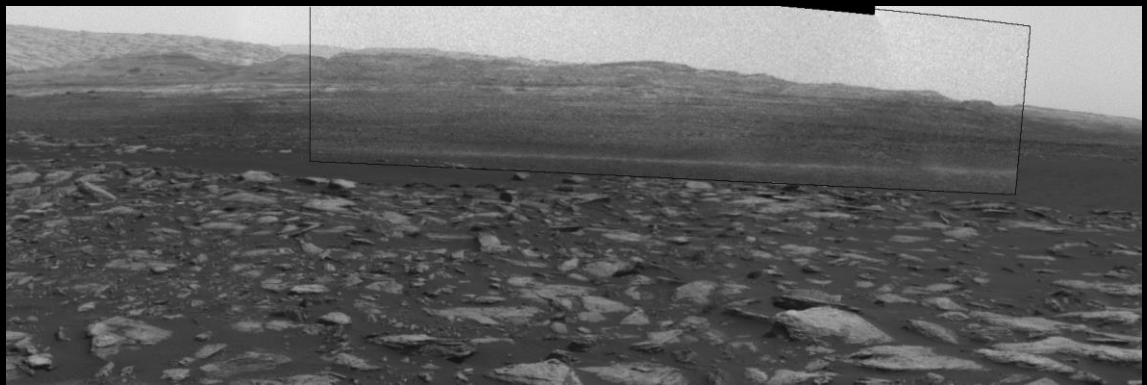

Cruise Stage Separation
Time: Entry - 10 min
Cruise Balance Devices Separation
Time: Entry - ~8 min
Entry Interface
Altitude: ~78 miles (~125 km)
Velocity: ~13,200 mph (~5,900 meters/sec)
Time: Entry + 0 sec
Peak Heating
Peak Deceleration
Heat Shield Separation
Altitude: ~5 miles (~8 km)
Velocity: ~280 mph
(~125 meters/sec)
Time: Entry + ~278 sec
Hypersonic Aero-maneuvering
Parachute Deploy
Altitude: ~7 miles (~11 km)
Velocity: ~900 mph
(~405 meters/sec)
Time: Entry + ~254 sec
Radar Data Collection
Back Shell Separation
Altitude: ~1 mile (~1.6 km)
Velocity: ~180 mph
(~80 meters/sec)
Time: Entry + ~364 sec
Powered Descent
Sky Crane
Flyaway
Sky Crane Detail
Rover Separation
Altitude: ~66 feet (~20 meters)
Velocity: ~1.7 mph (~0.75 meter/sec)
Time: Entry + ~400 sec
Mobility Deploy
Touchdown
Altitude: 0
Velocity: ~1.7 mph
(~0.75 meter/sec)
Time: Entry + ~416 sec
Flyaway

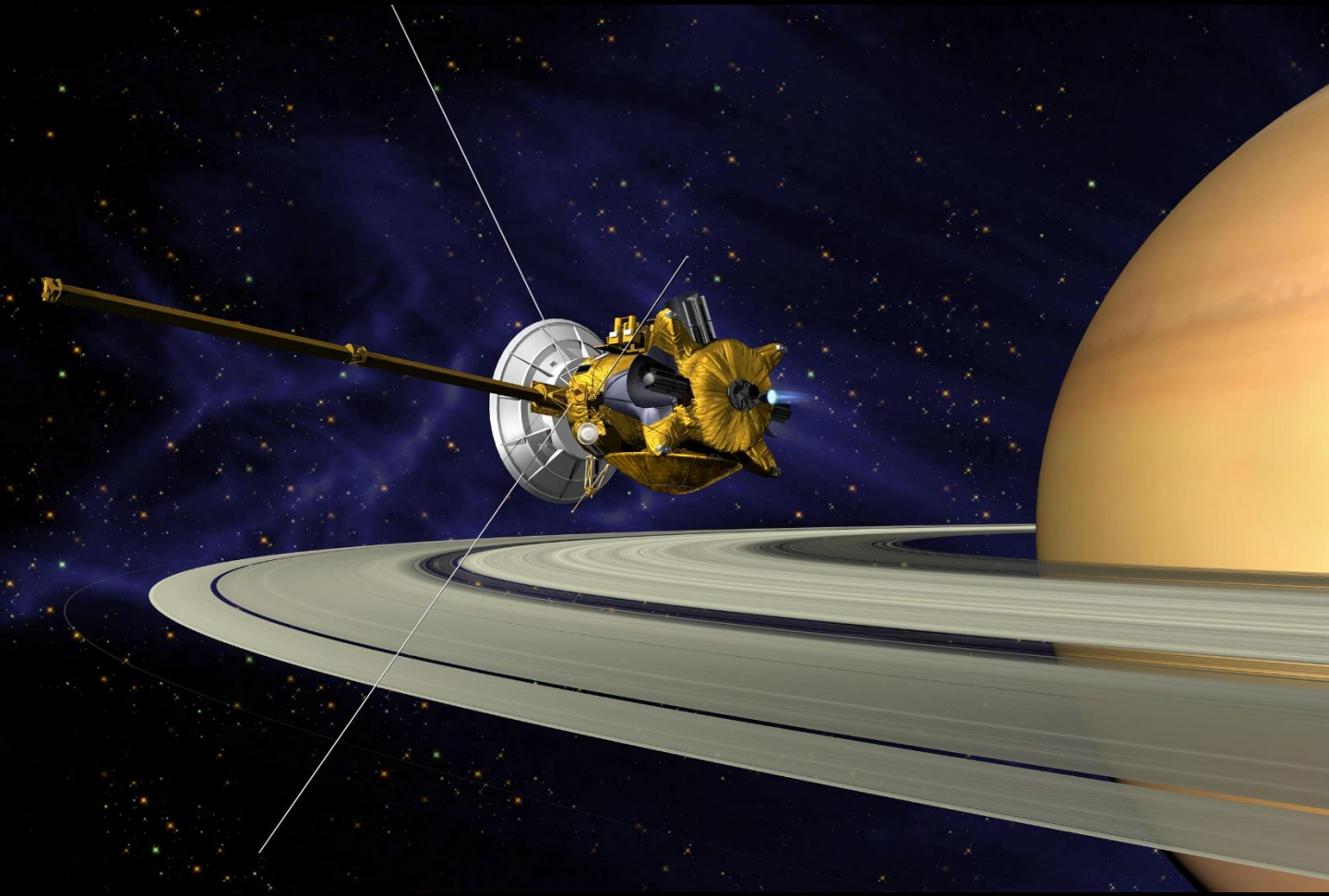


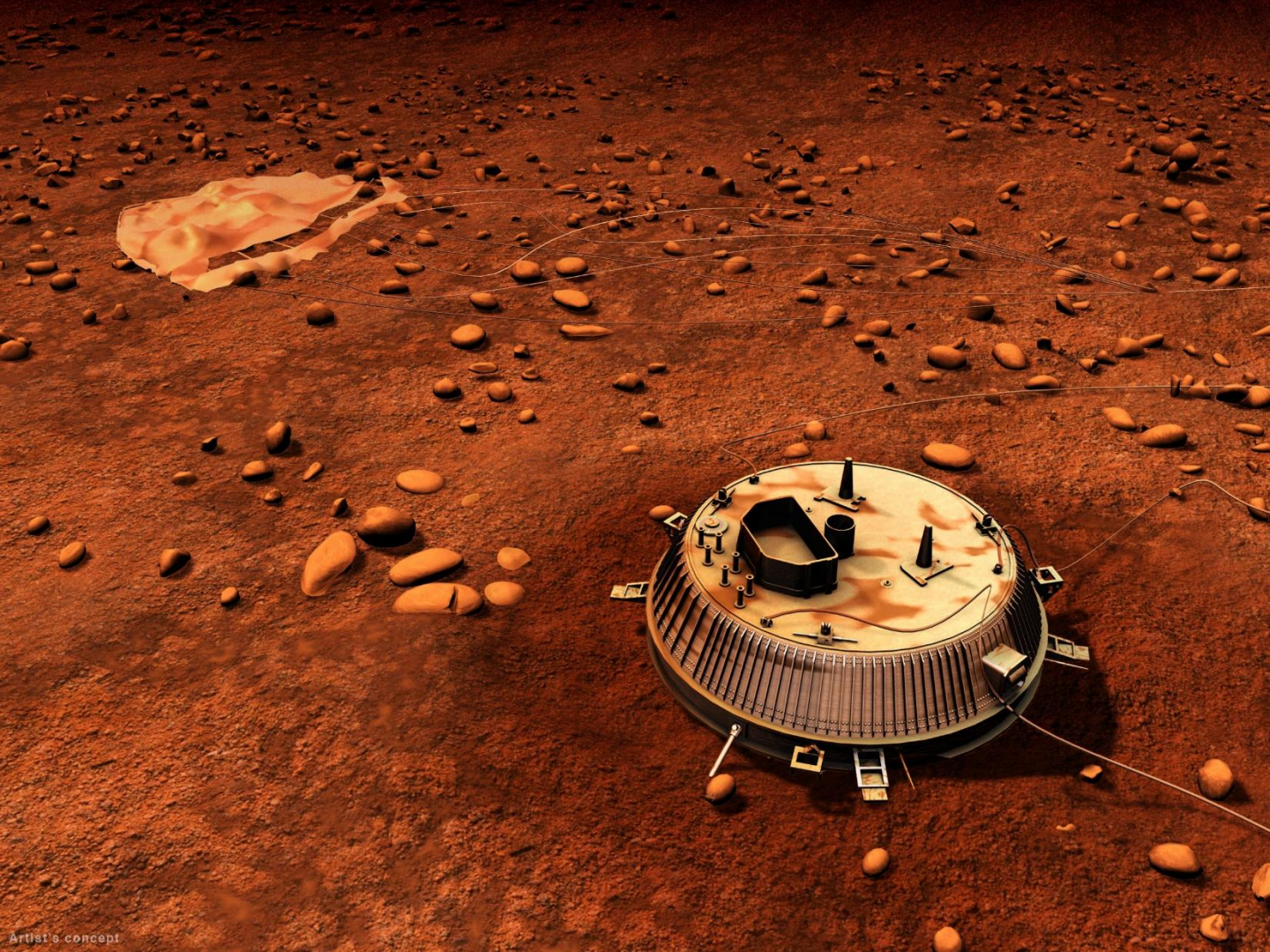

2 mm

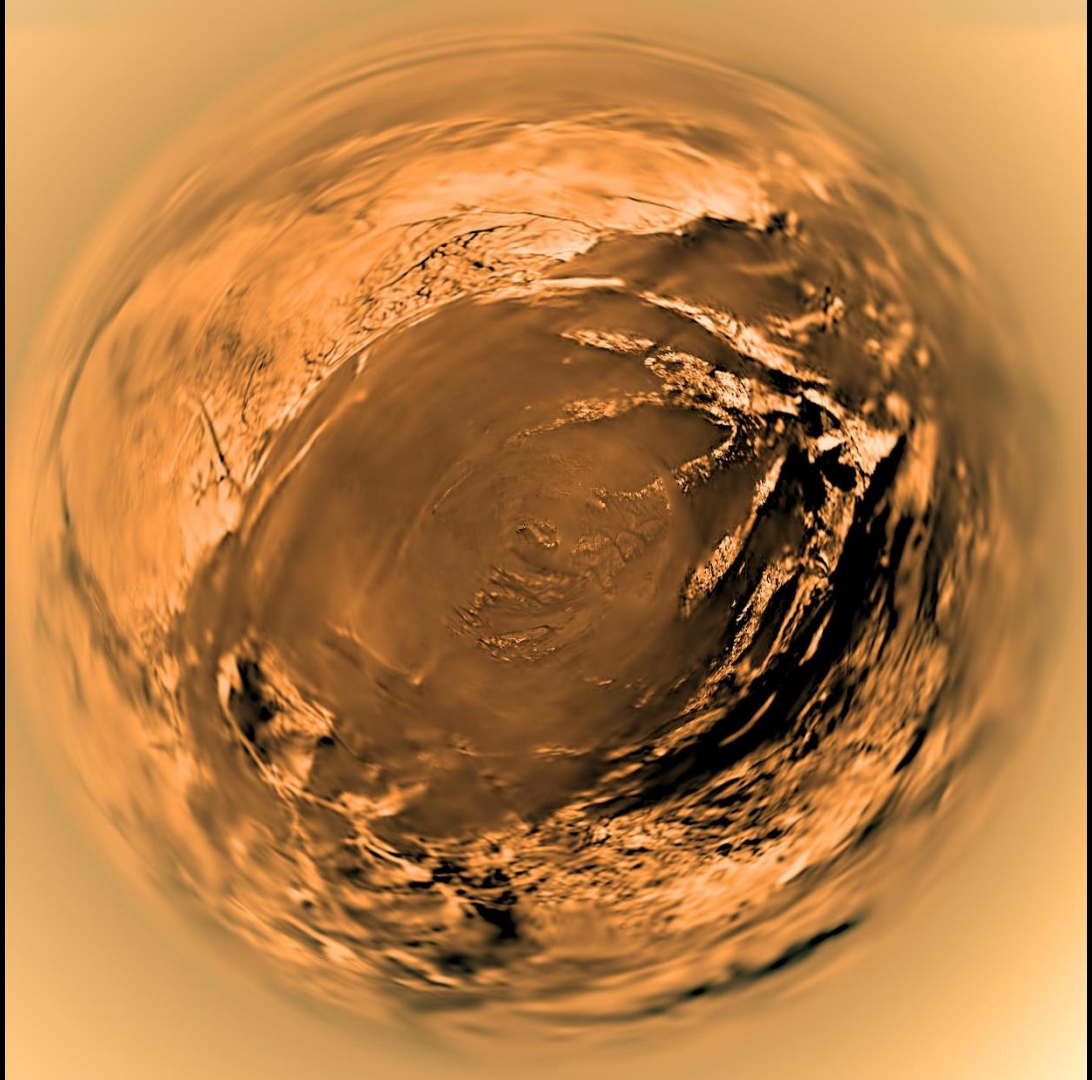


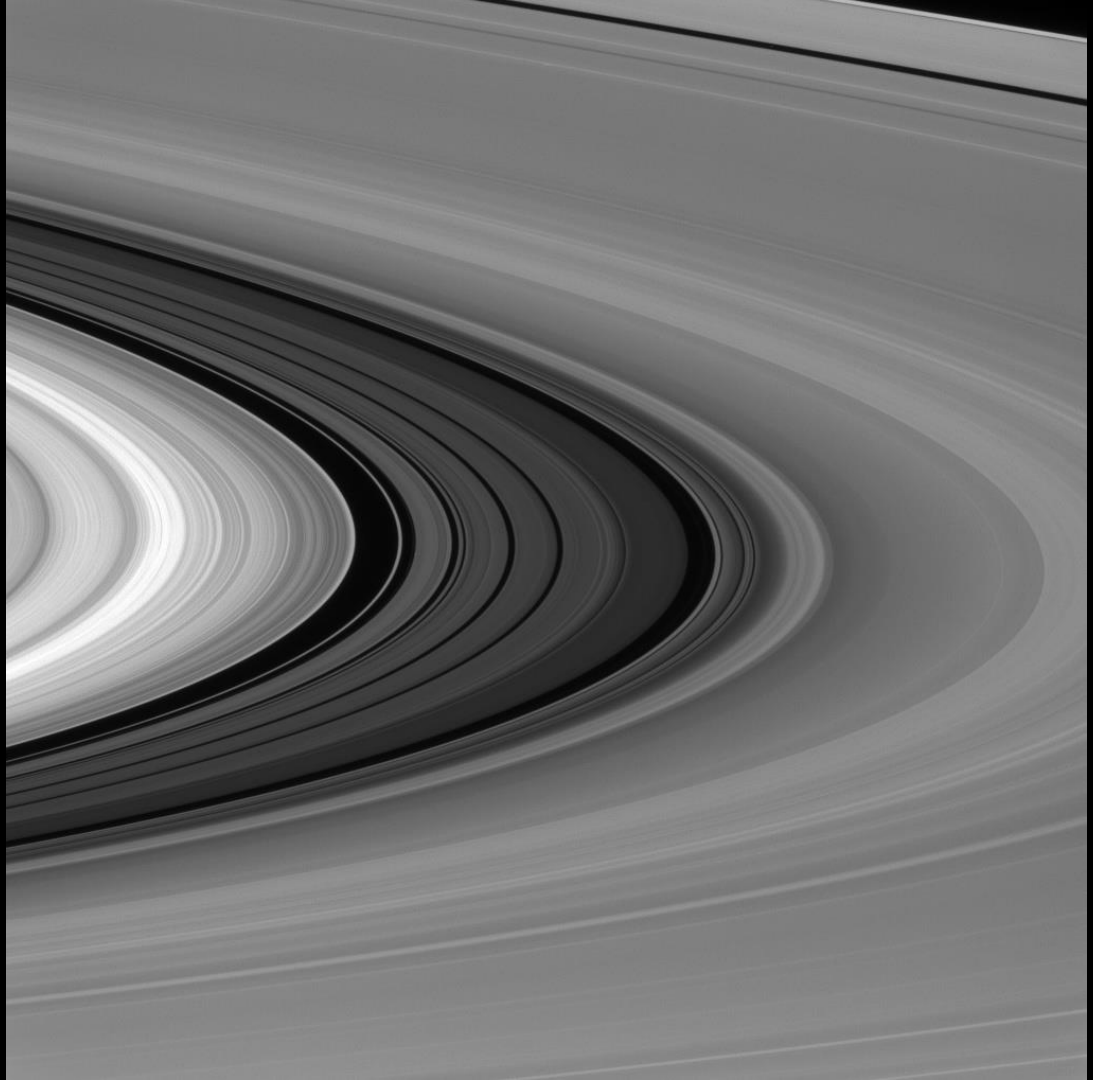
January 23, 2017

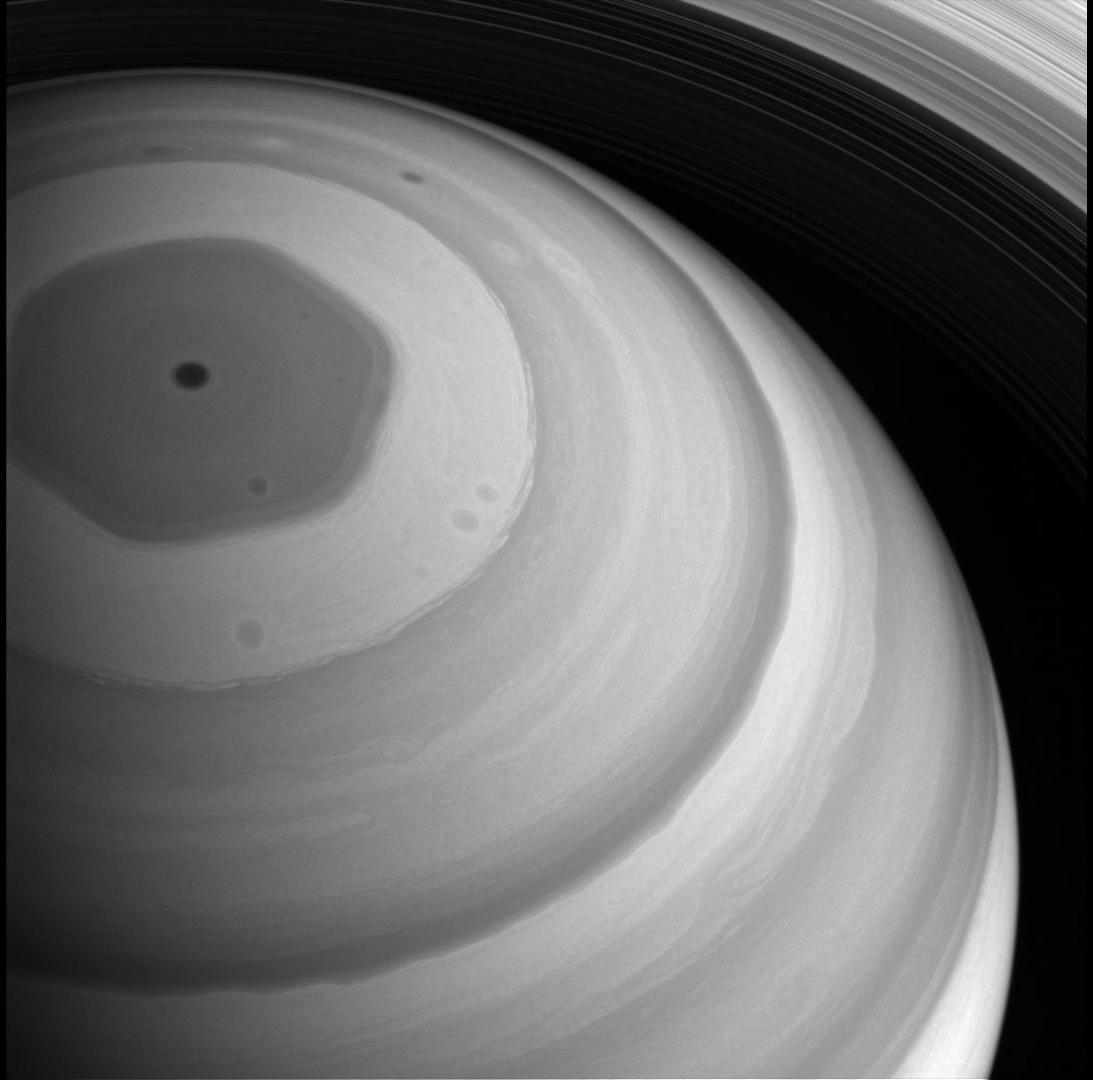


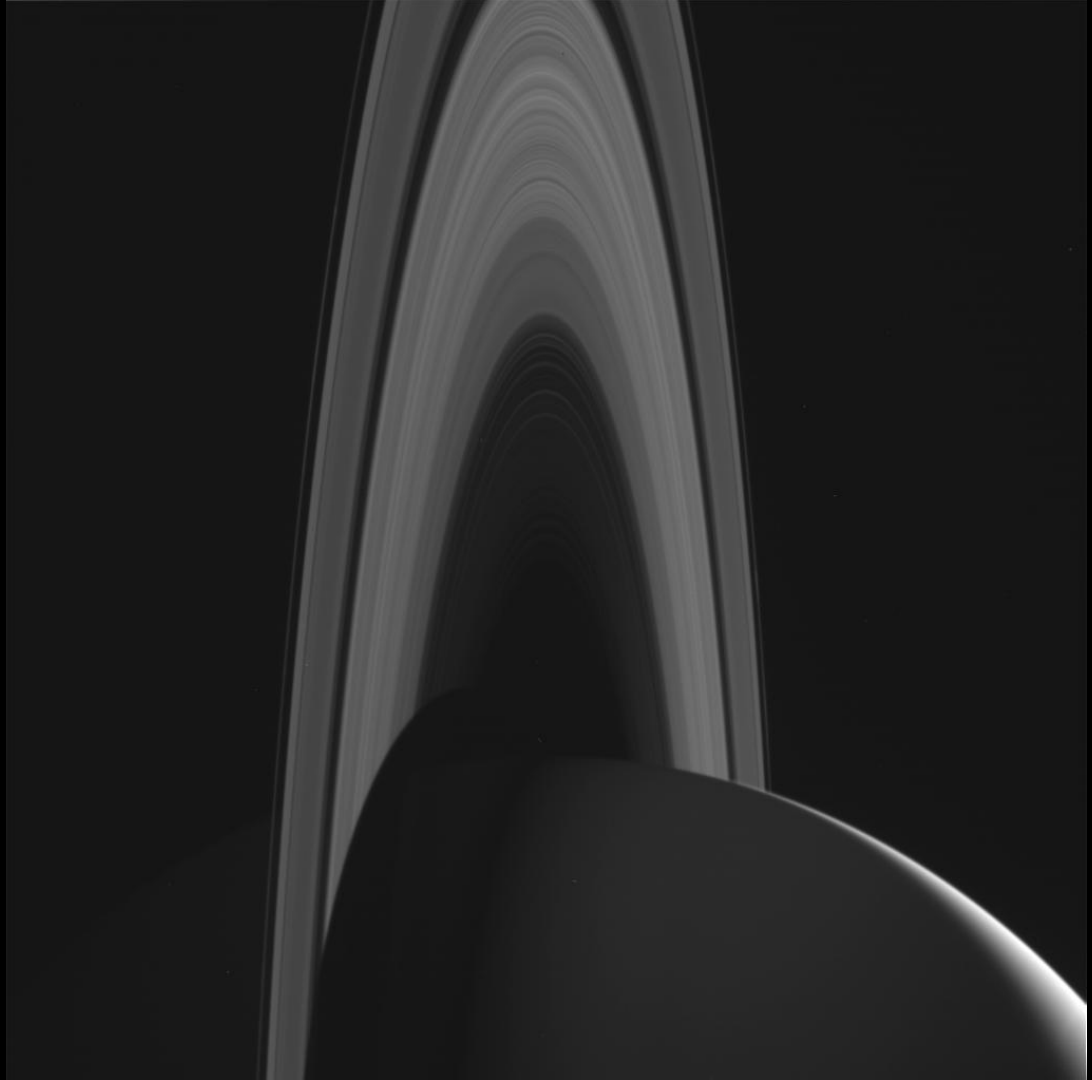


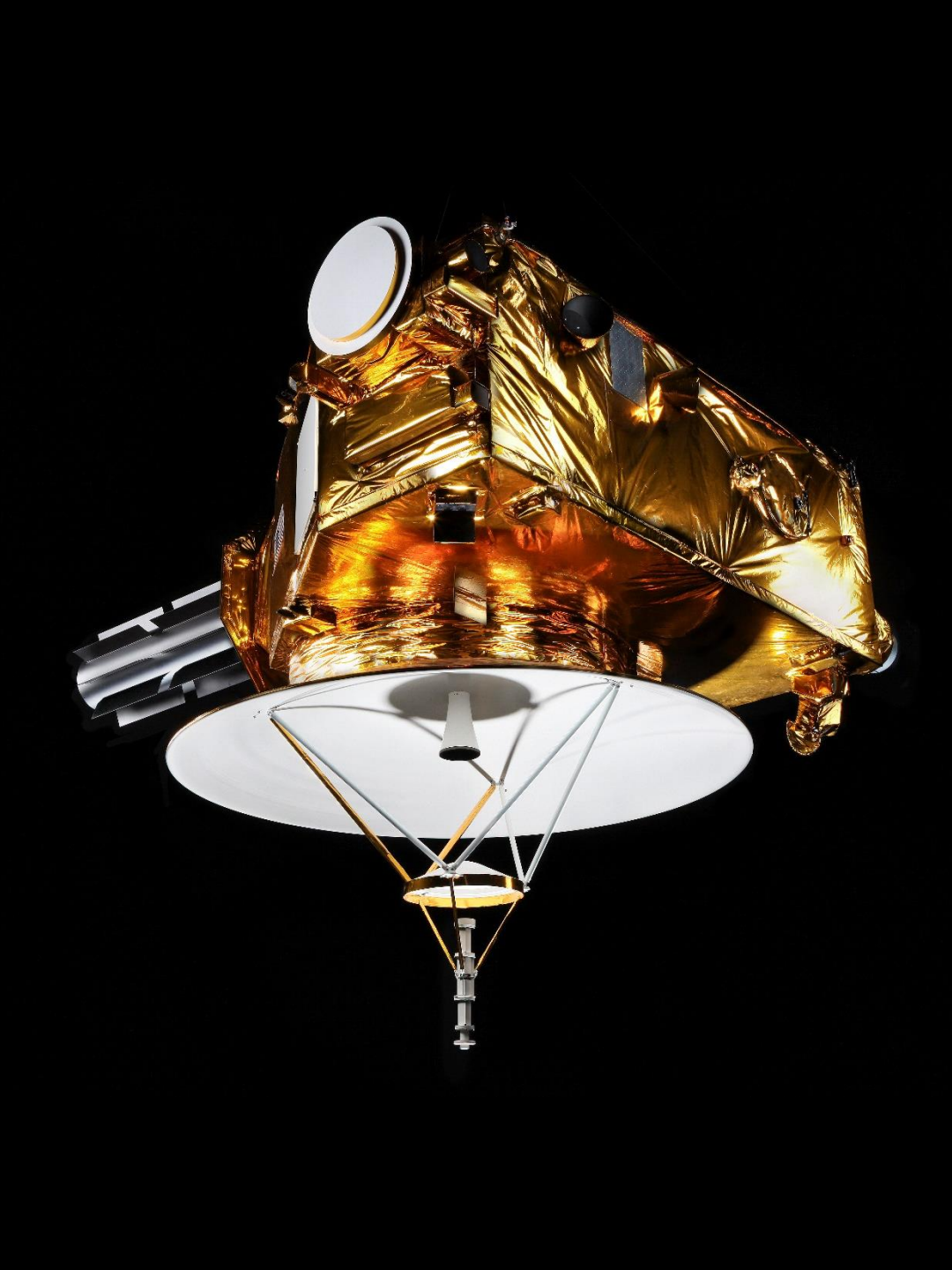

Artist's concept

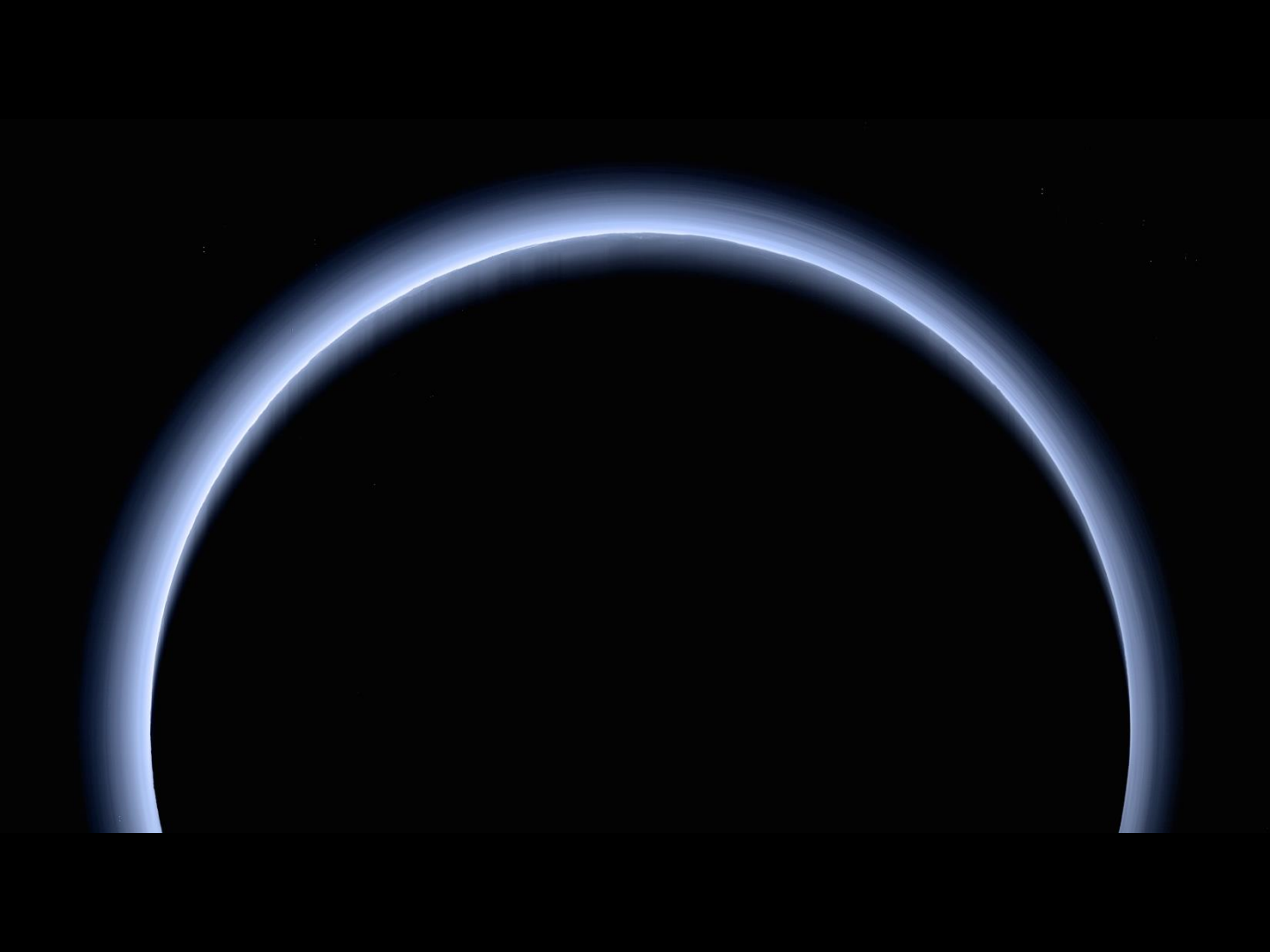


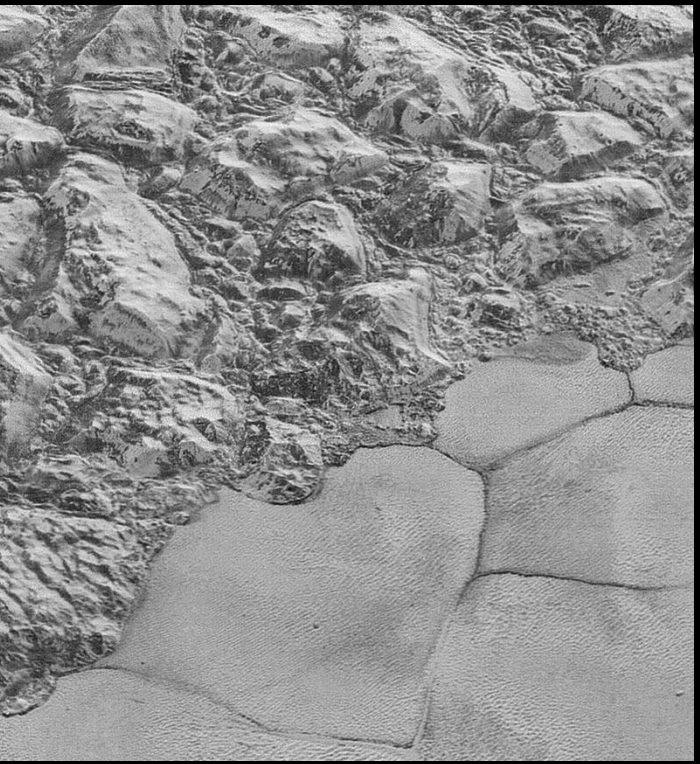


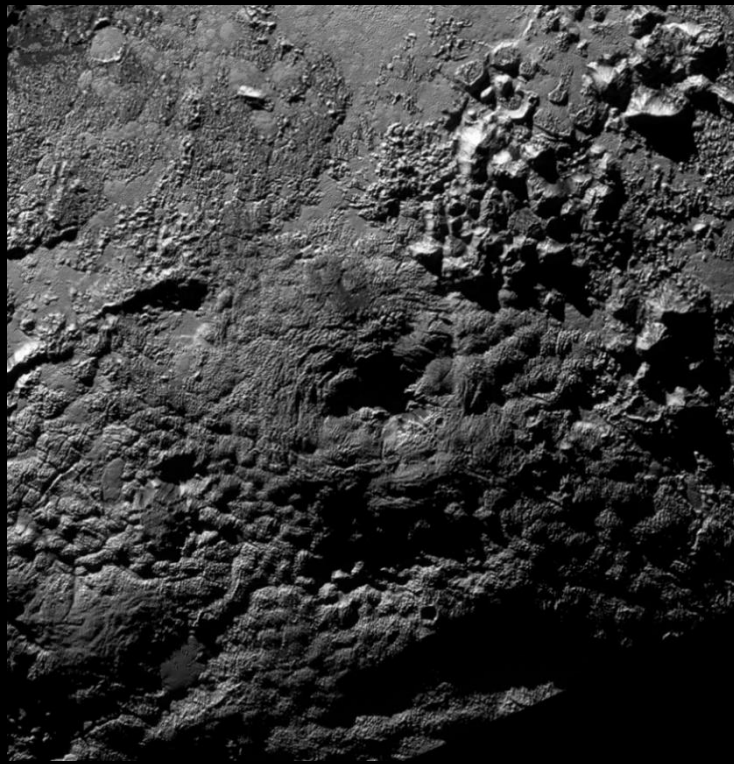













Earth
moon


Thank you