The Tools of Astronomy

Seeing the whole picture

Jonathan Crass

UNIVERSITY OF NOTRE DAME

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Science & Environment

Case made for 'ninth planet'

By Jonathan Amos
BBC Science Correspondent

20 January 2016 | Science & Environment

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Ninth planet may have been discovered, researchers say

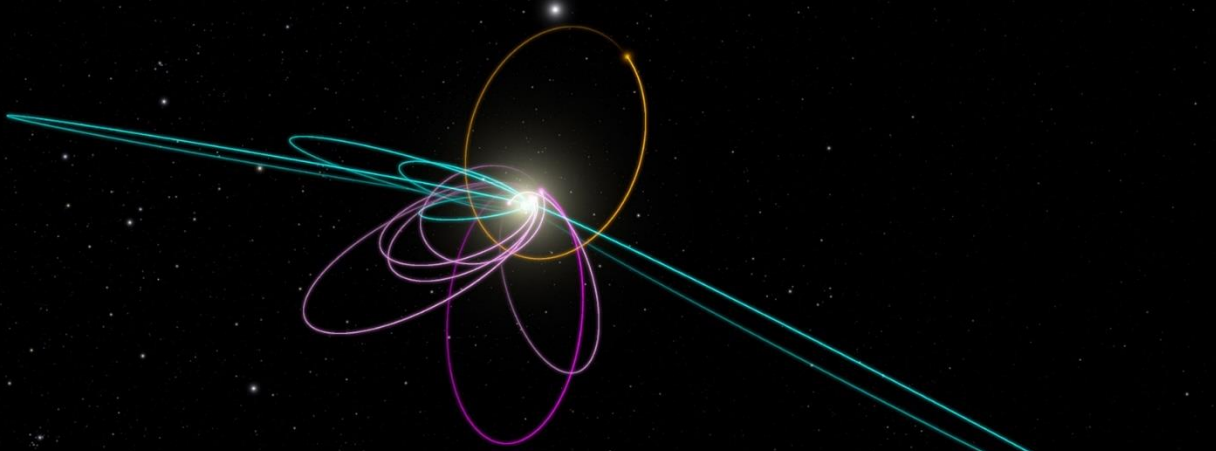
By **Amanda Watts**, CNN
Updated 12:38 PM ET, Thu January 21, 2016

SPACE & COSMOS

The New York Times

Ninth Planet May Exist Beyond Pluto, Scientists Report

By KENNETH CHANG JAN. 20, 2016



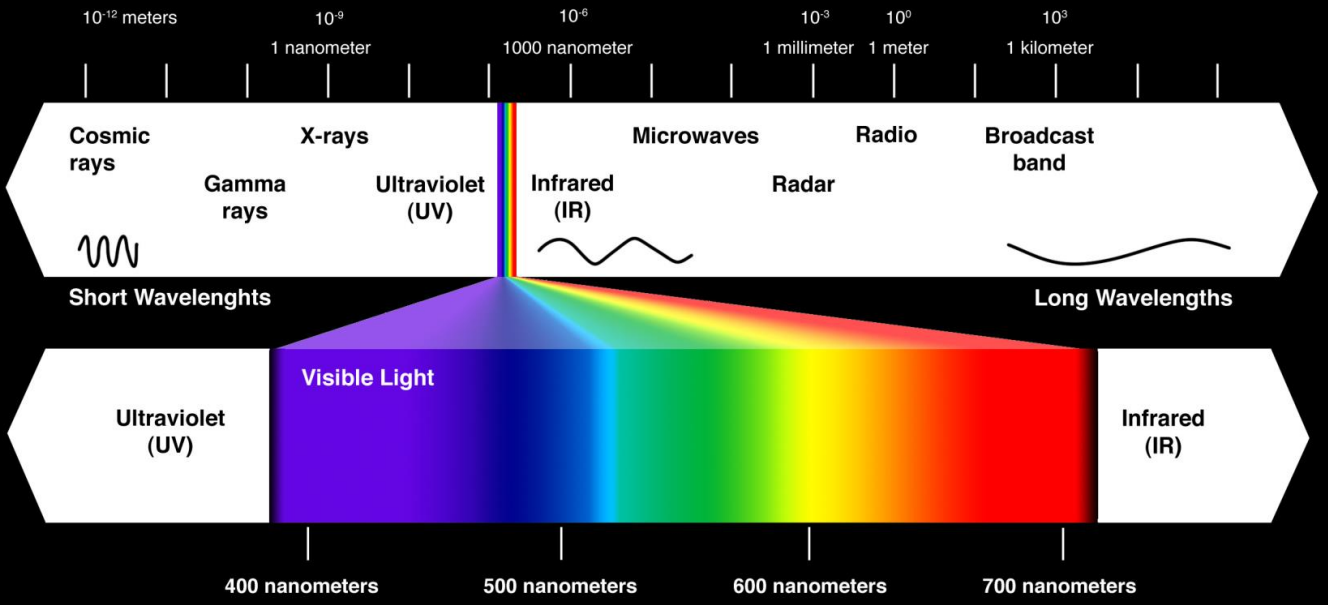
What tools do we need?

- We need to observe the Universe around us
  - The Solar System
  - 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

Observing the Universe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Cosmic rays
X-rays
Gamma rays
Ultraviolet (UV)
Infrared (IR)
Microwaves
Radar
Radio
Broadcast band
Short Wavelenghts
Long Wavelengths
Ultraviolet (UV)
Visible Light
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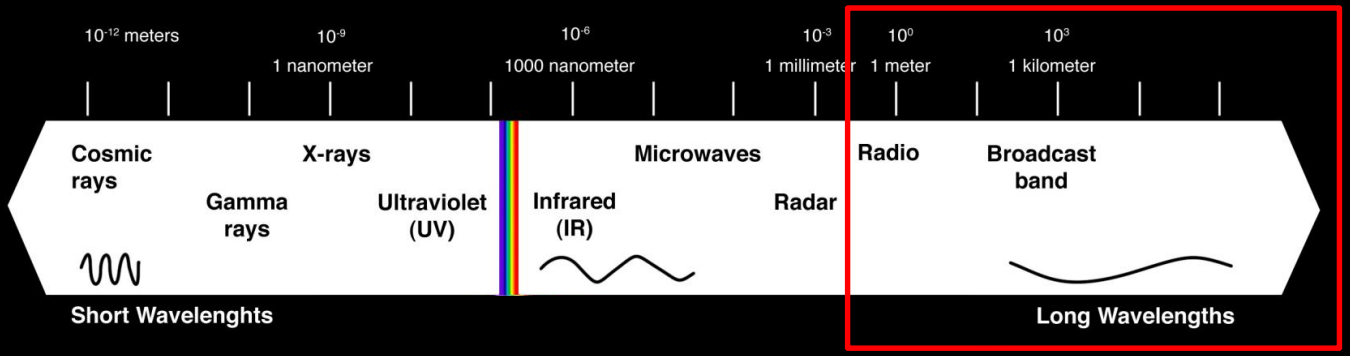
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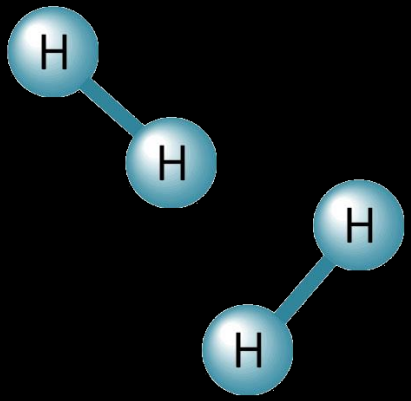
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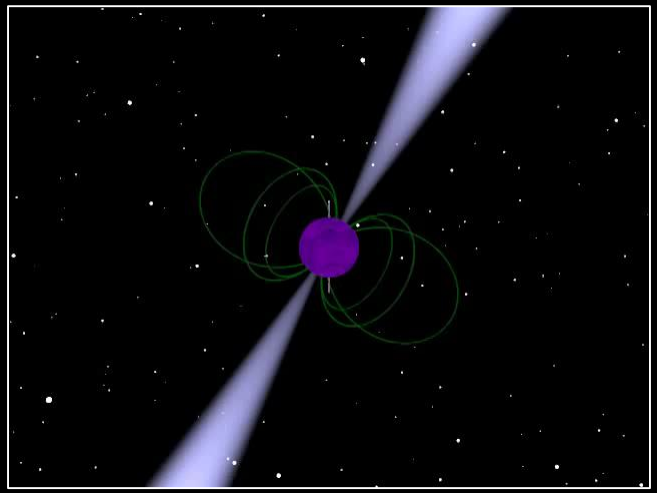

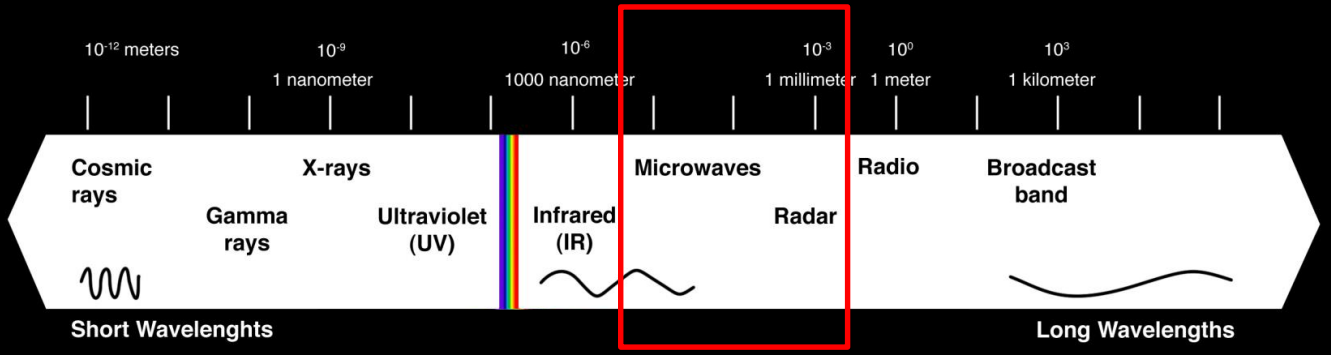
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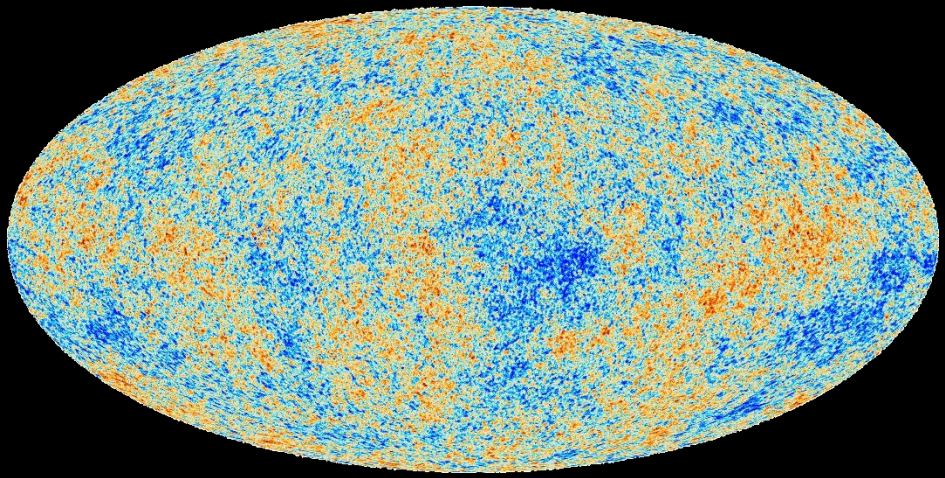

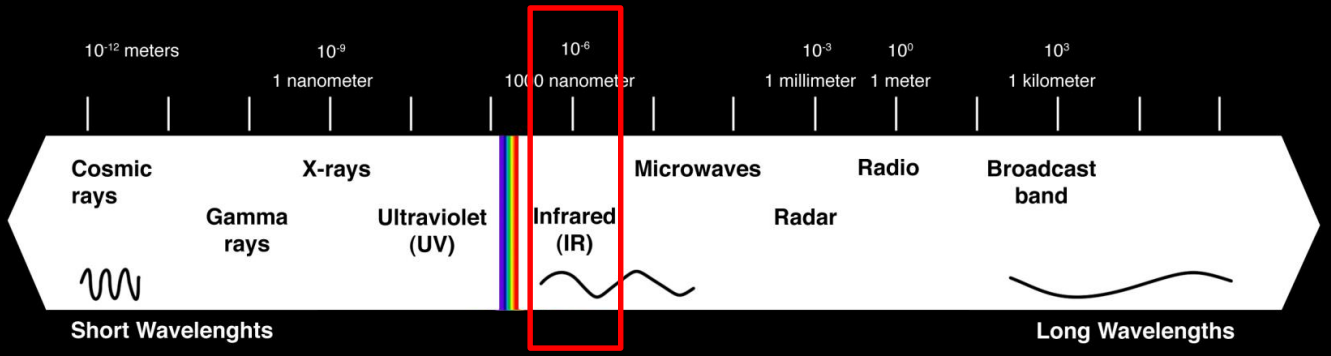
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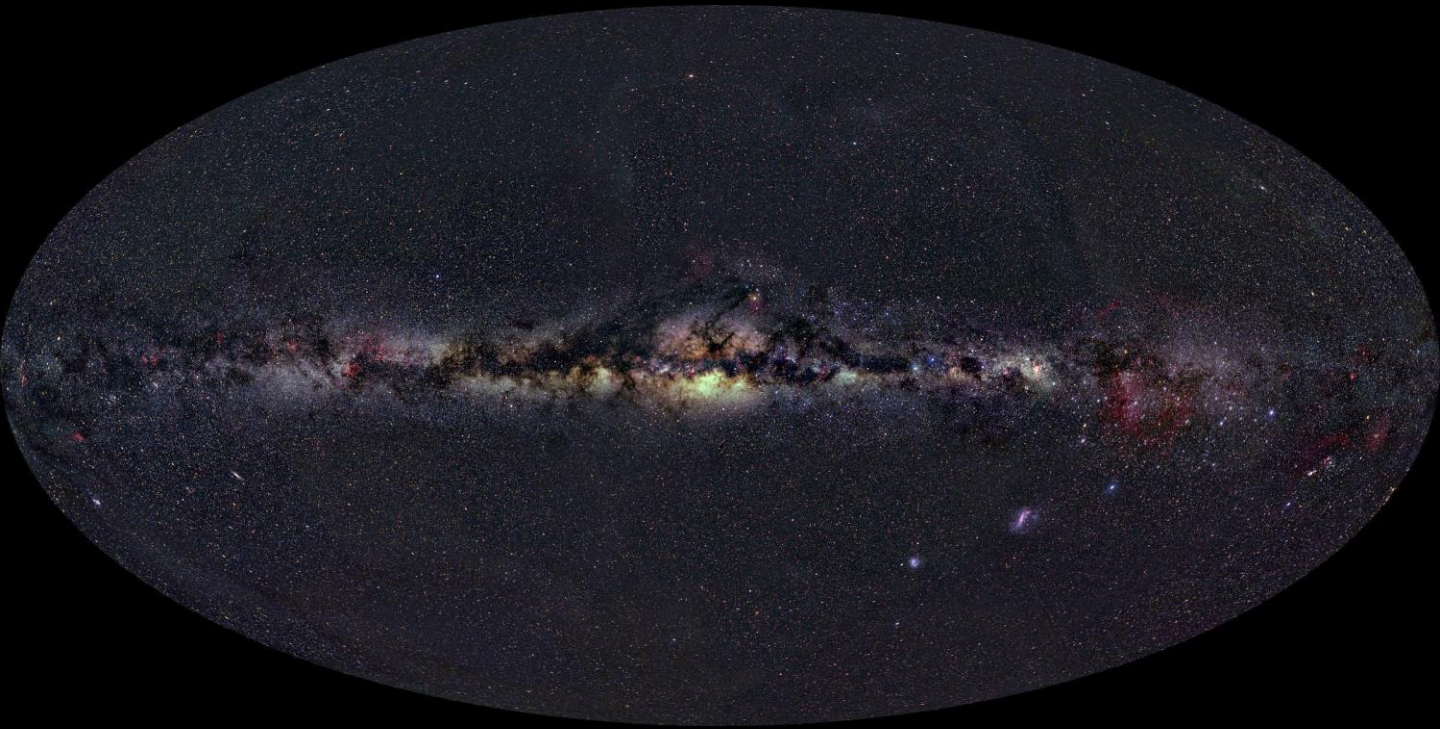

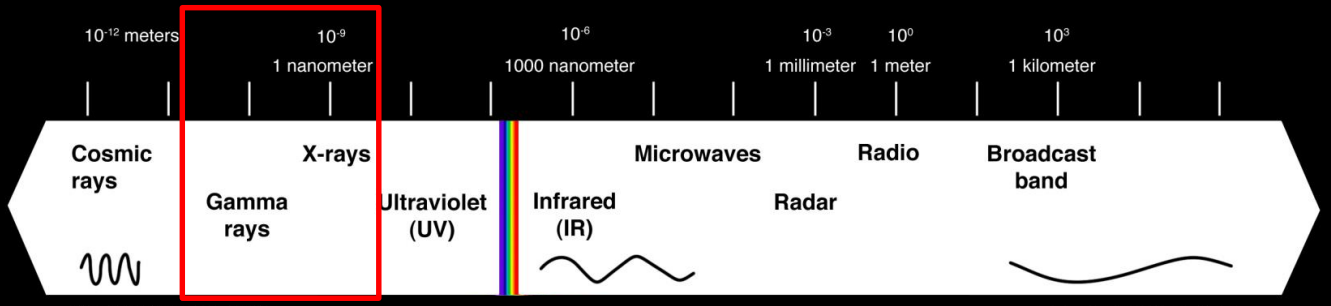
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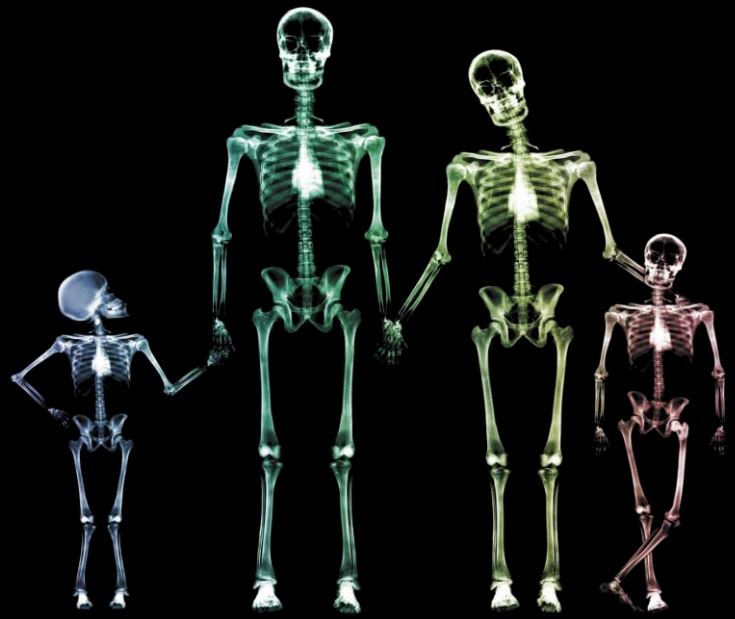
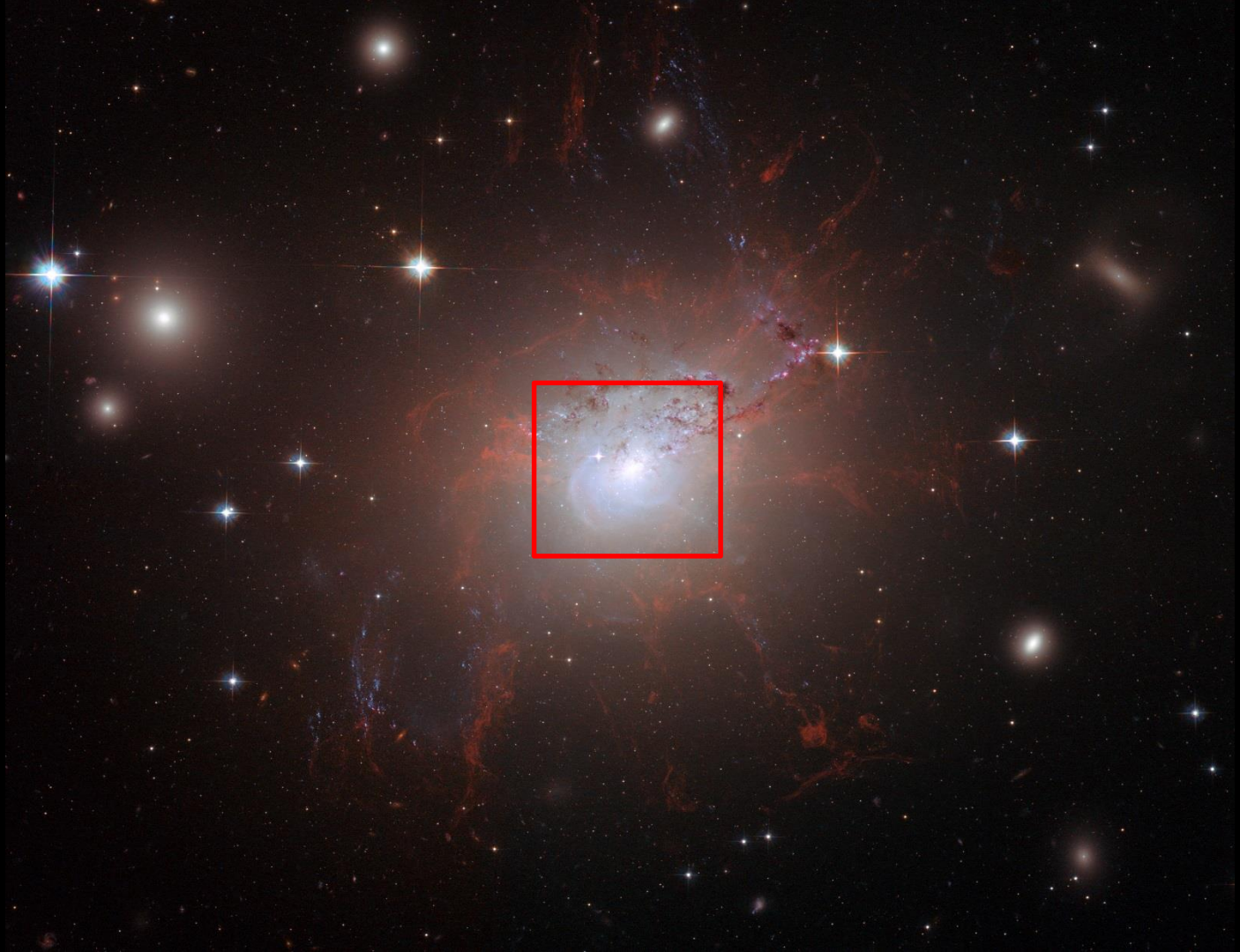


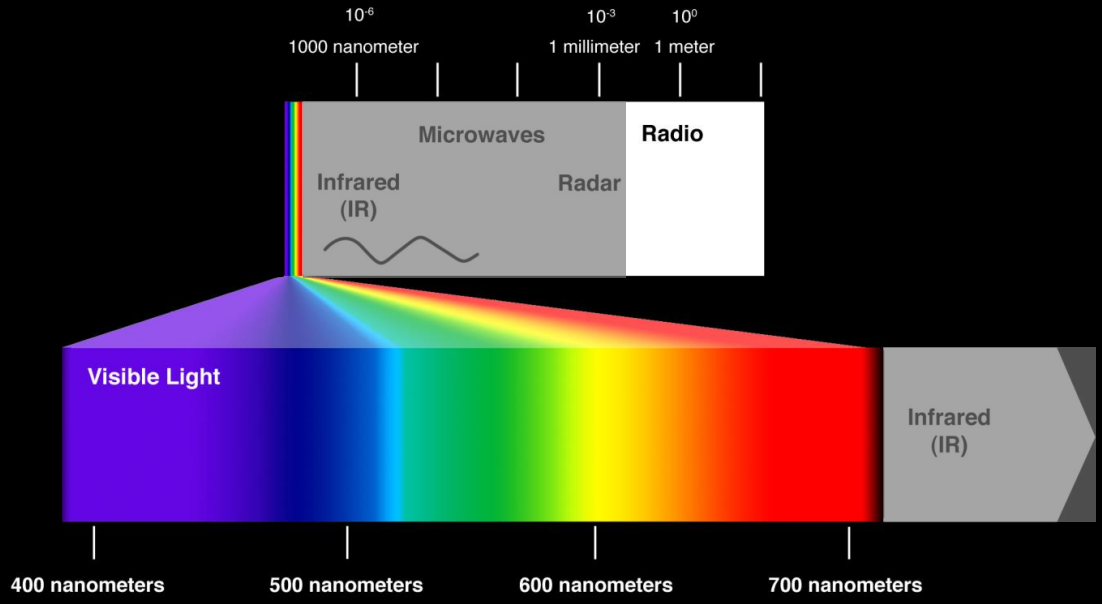


Ground-based telescopes

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?



Radio Telescopes

- First 'detectors' built in 1930s
- First 'dish' telescope - 1937
- Rap
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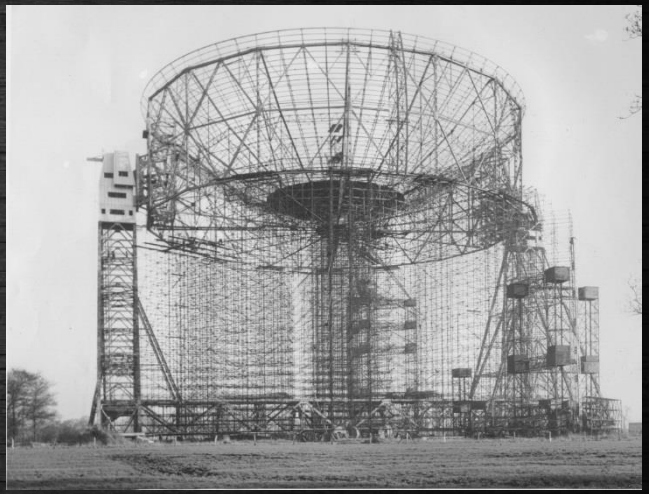
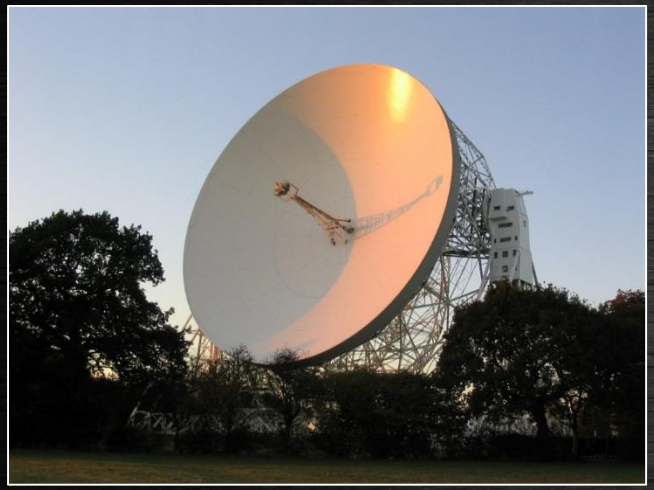
- By
  tele

Mk I Telescope – Jodrell Bank



Mk I Telescope – Jodrell Bank



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

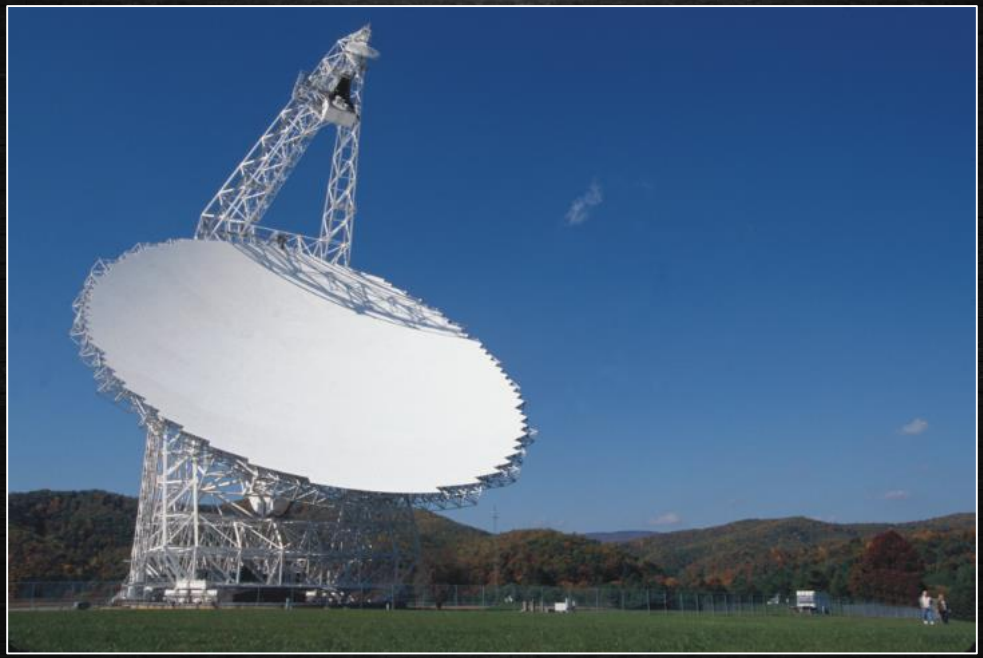
The Biggest Radio Telescopes

- Largest Filled Aperture

Arecibo Radio Telescope – 305m

The Biggest Radio Telescopes

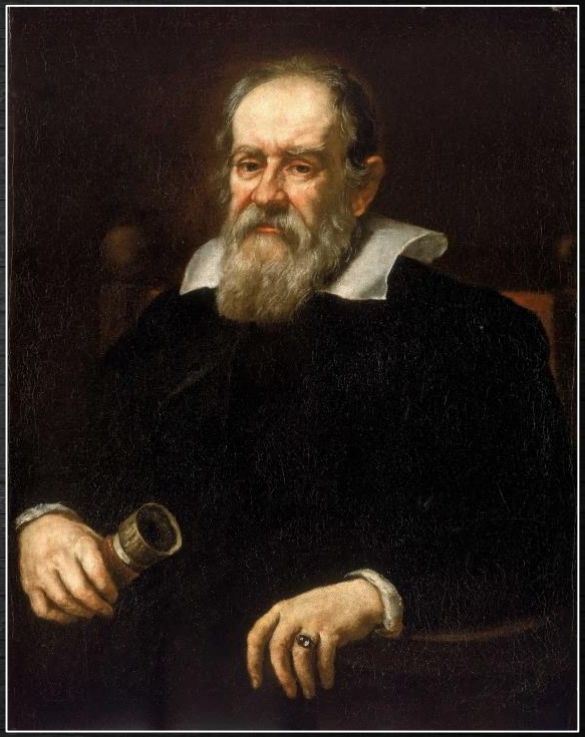
- Largest Fully Steerable

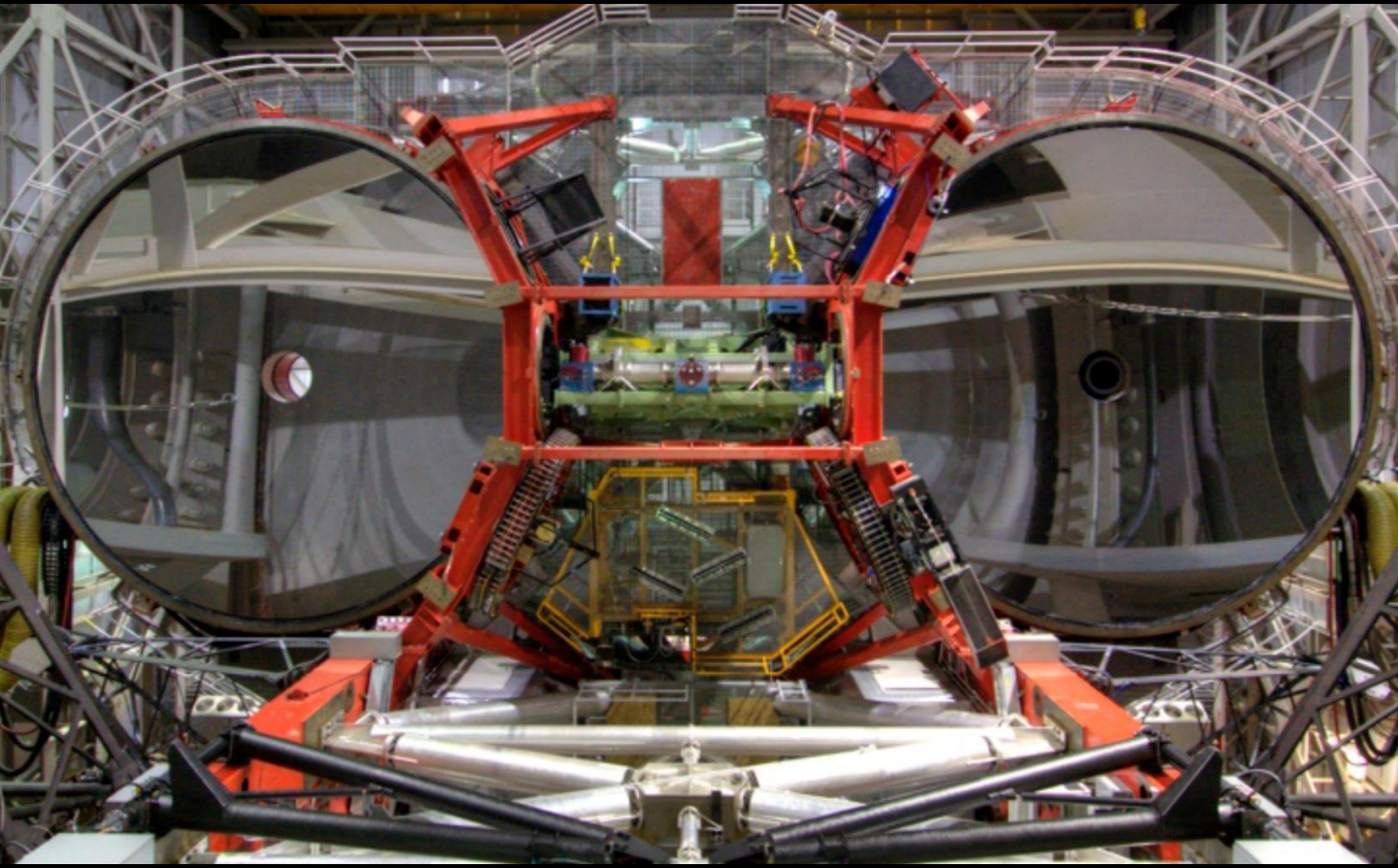


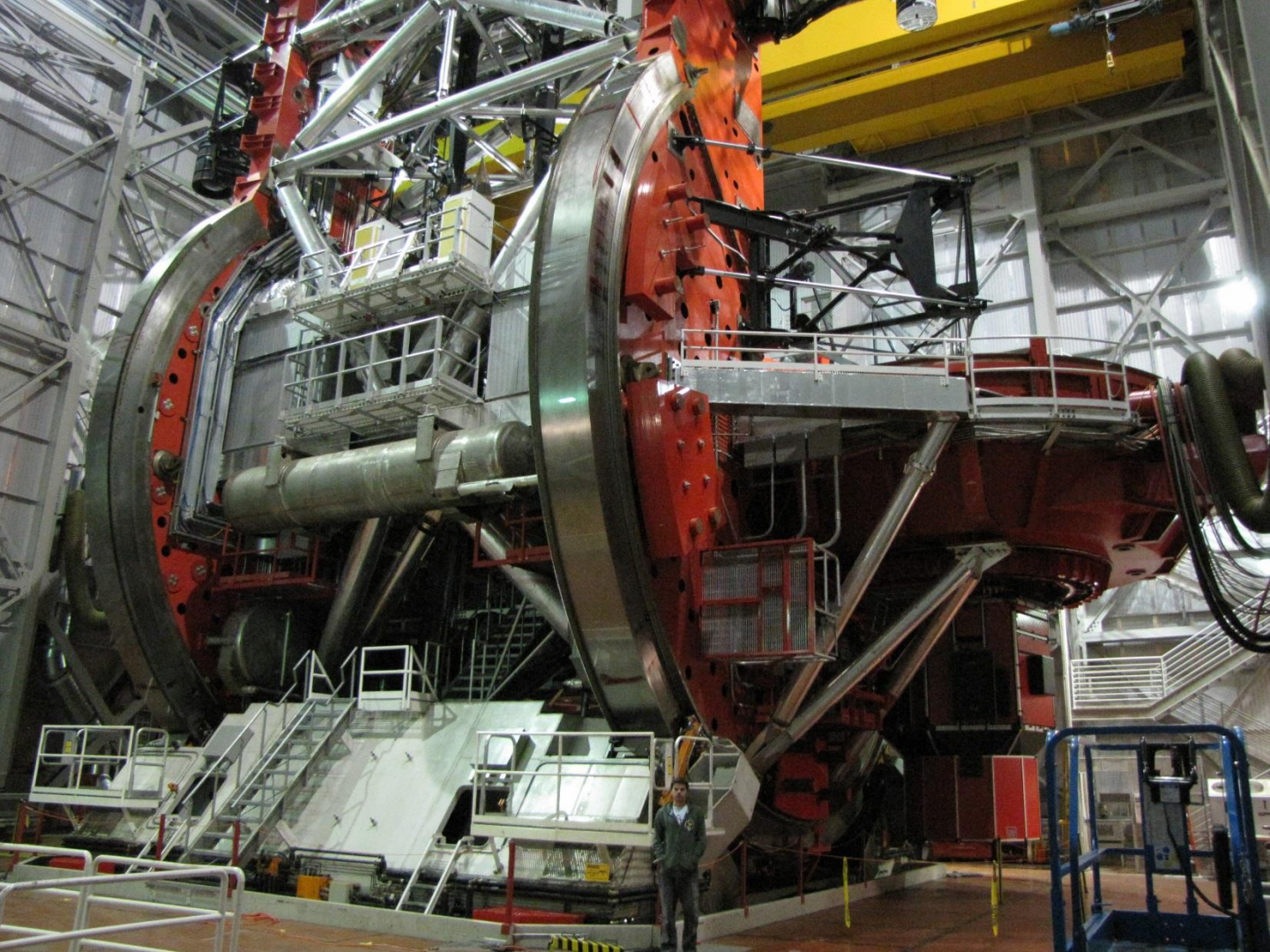
Green Bank Telescope – 100x110m

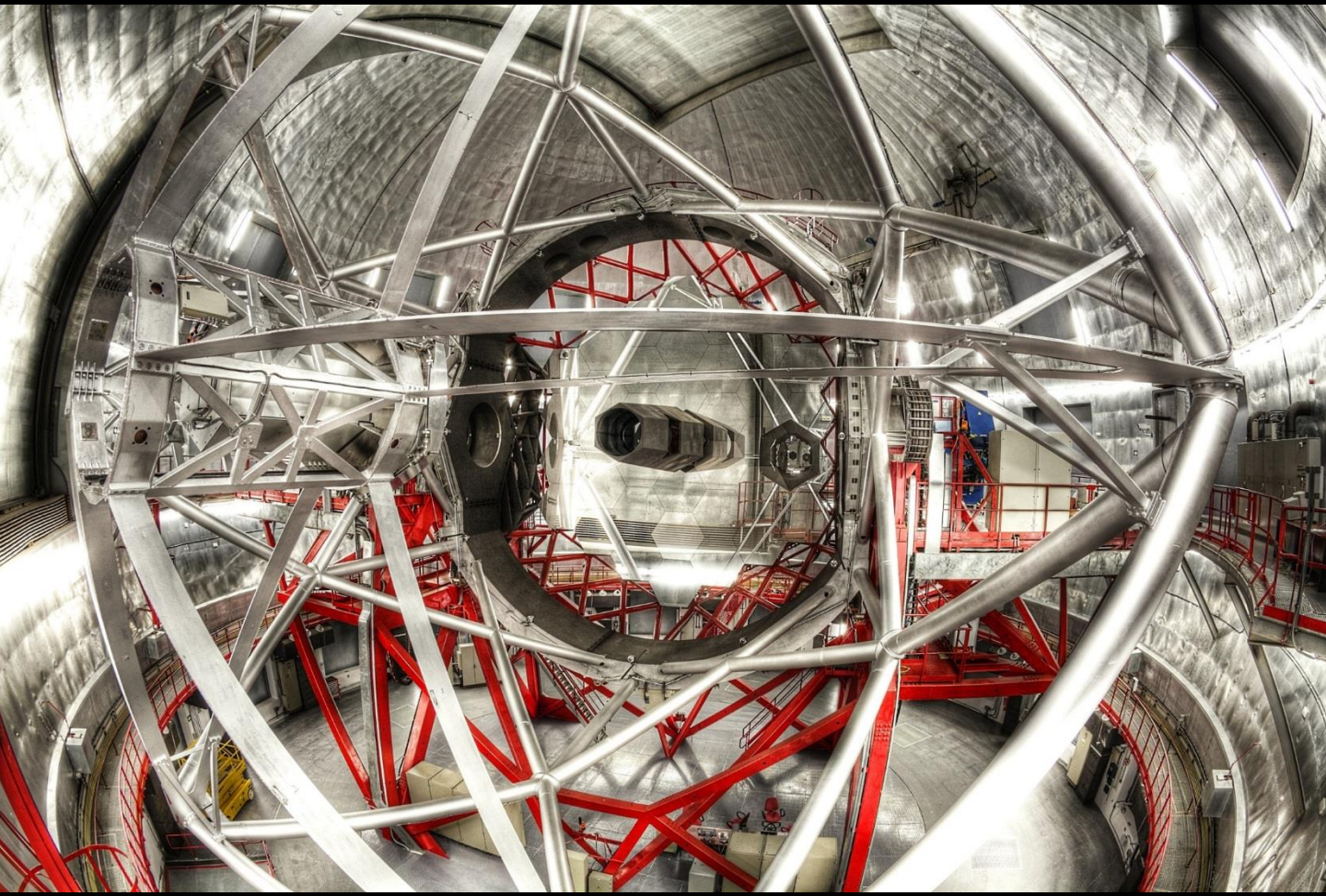
Optical Telescopes

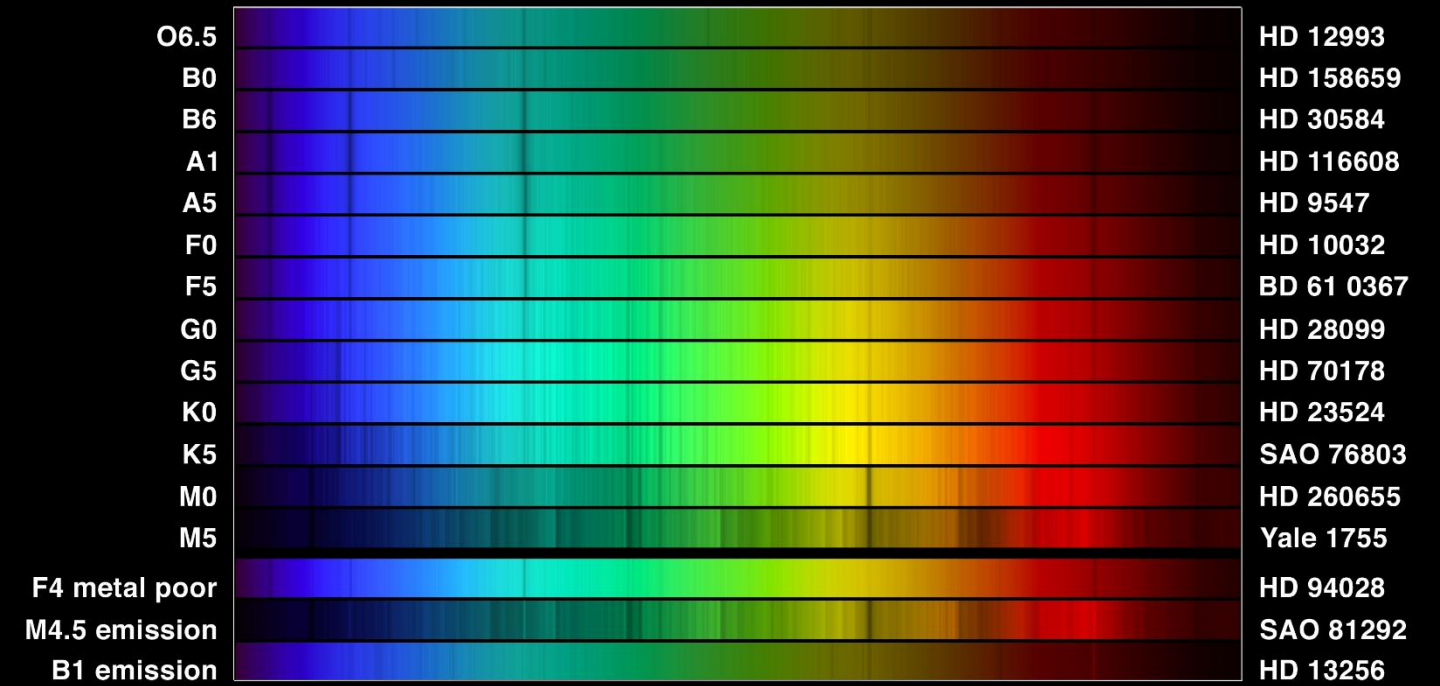
- Galileo – 1609










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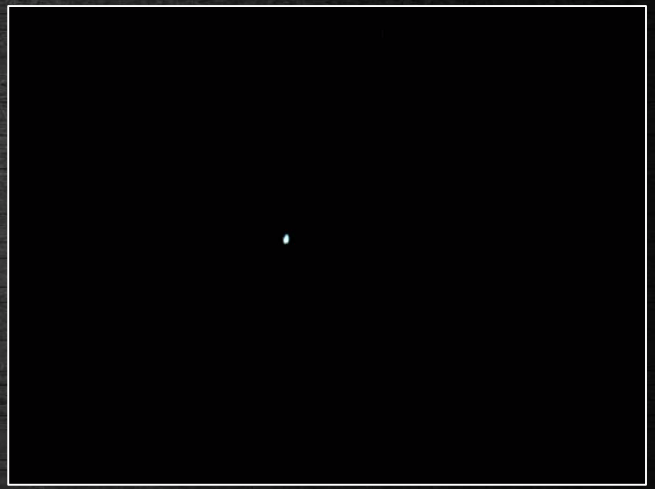
F5
G0
G5
K0
K5
M0
M5
F4 metal poor
M4.5 emission
B1 emission
HD 12993
HD 158659
HD 30584
HD 116608
HD 9547
HD 10032
BD 61 0367
HD 28099
HD 70178
HD 23524
SAO 76803
HD 260655
Yale 1755
HD 94028
SAO 81292
HD 13256

The problem with big telescopes

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

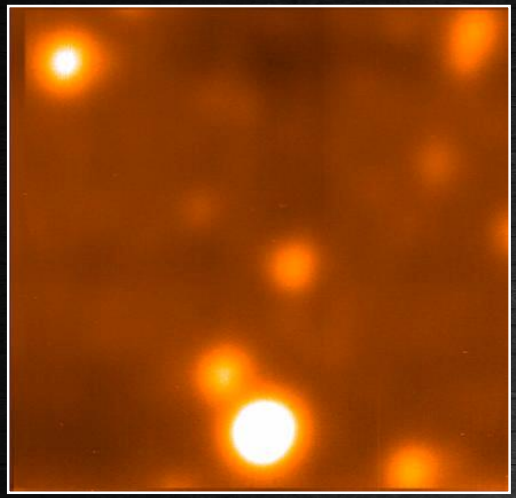
Atmospheric Turbulence

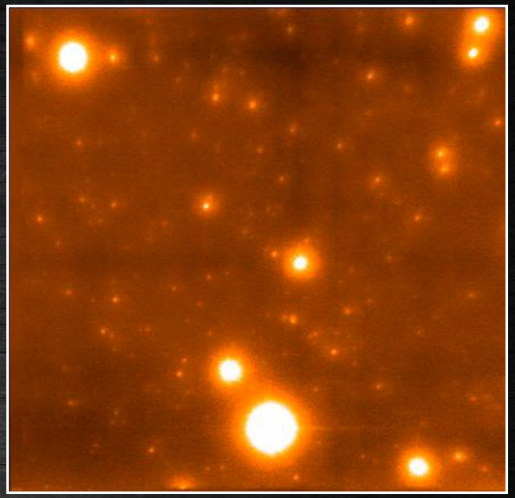


Correcting for the atmosphere

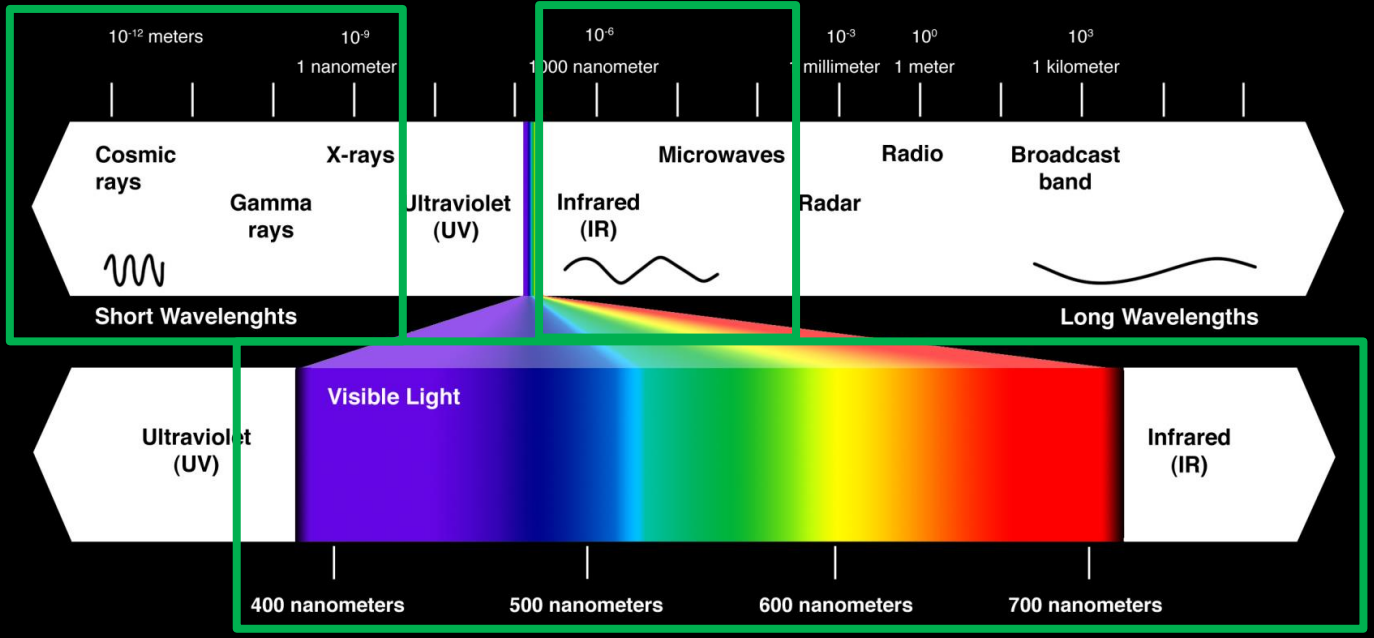
- The simple option:
  - Go to space!
- Correct for the effects on the ground

$ £ €





Space Telescopes


10^{-12} meters
10^{-9}
1 nanometer
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1 kilometer
Cosmic rays
X-rays
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Ultraviolet (UV)
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Long Wavelengths
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Visible Light
Infrared (IR)
400 nanometers
500 nanometers
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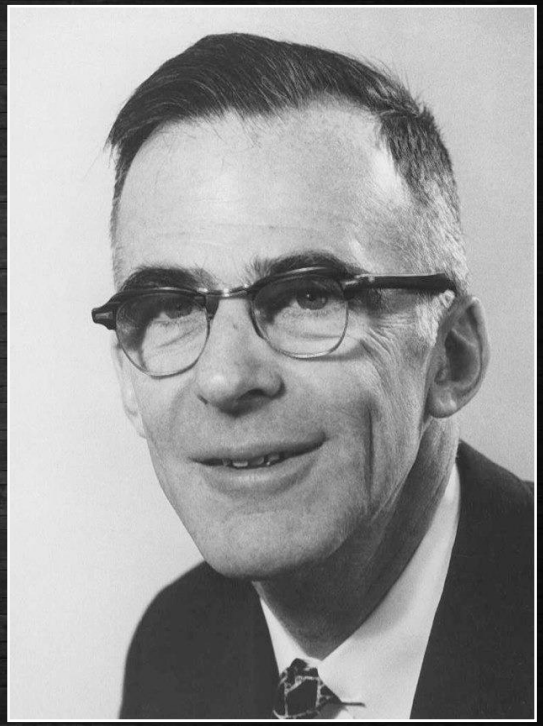
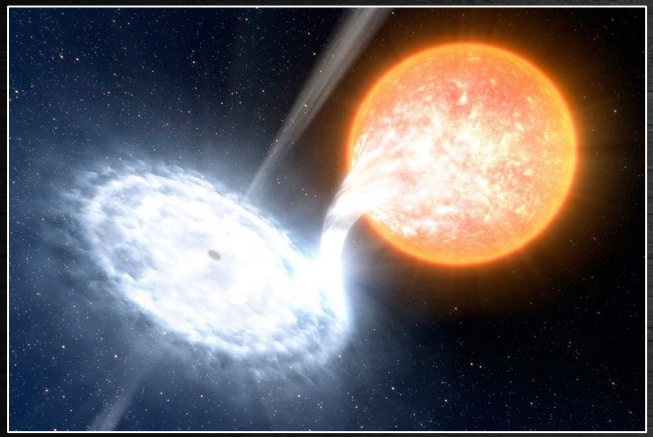
700 nanometers

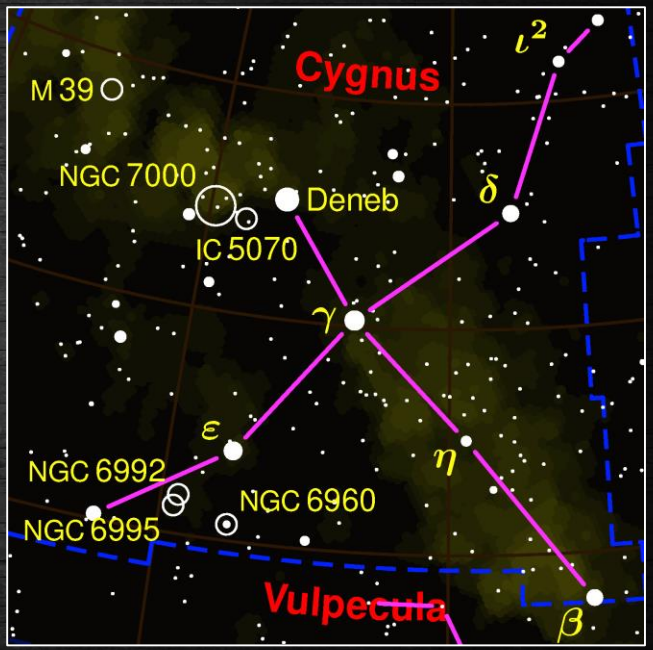
The beginnings of space telescopes

- First proposed by Hermann Oberth in 1923
- Lyman Spitzer, 1946
  - "Astronomical Advantages of an Extra-Terrestrial Observatory"

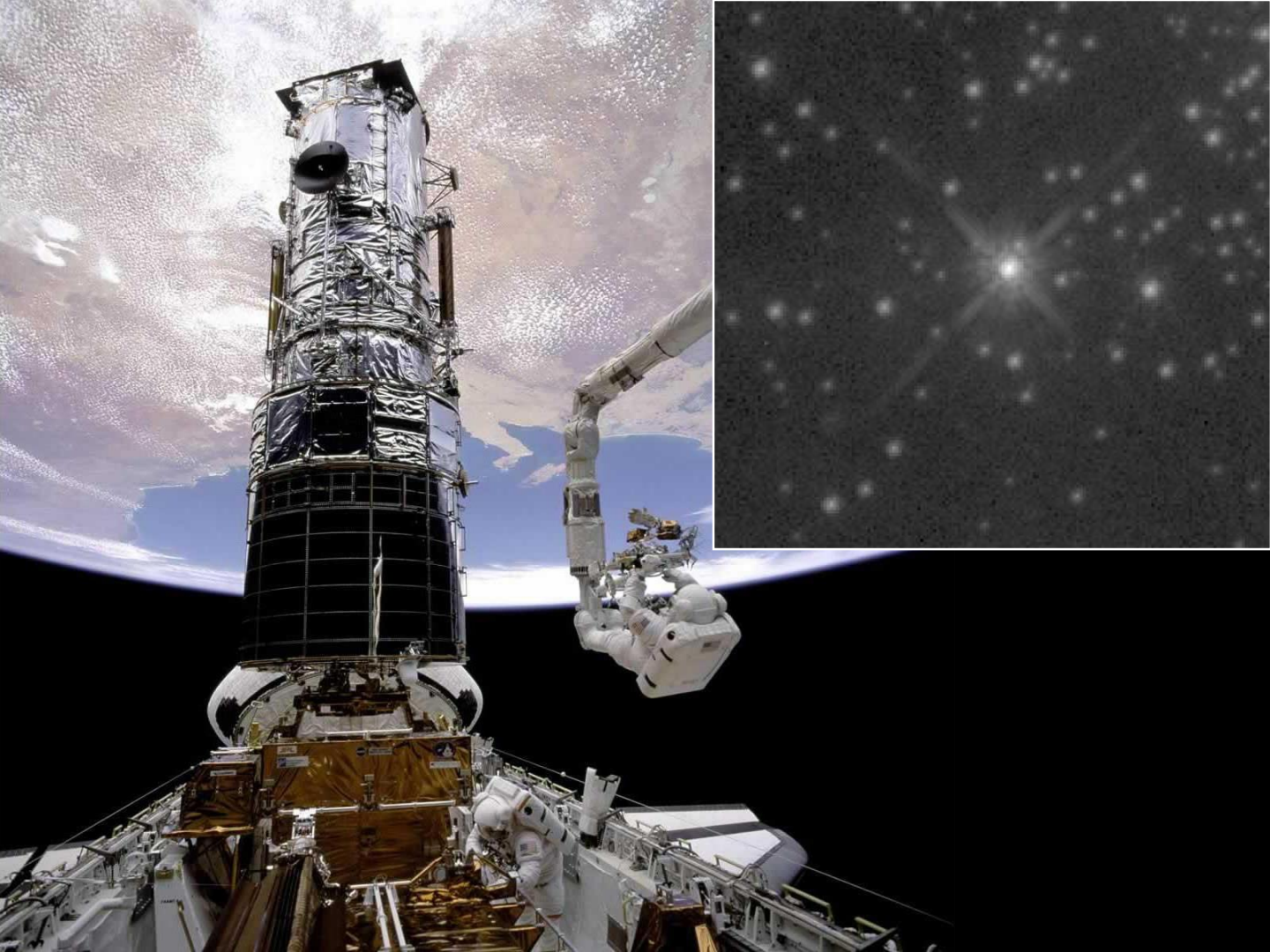


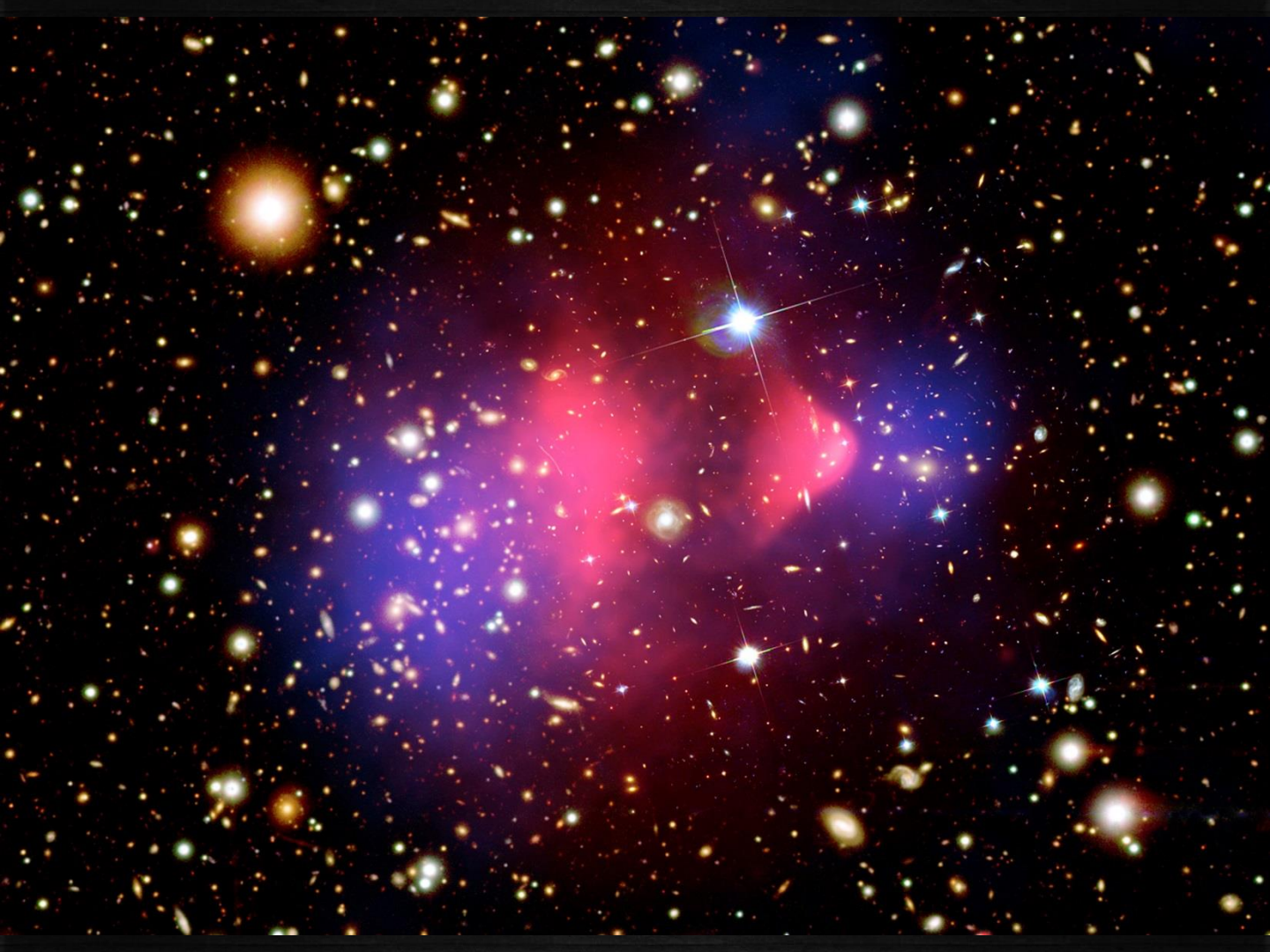
The First X-ray satellite - Uhuru



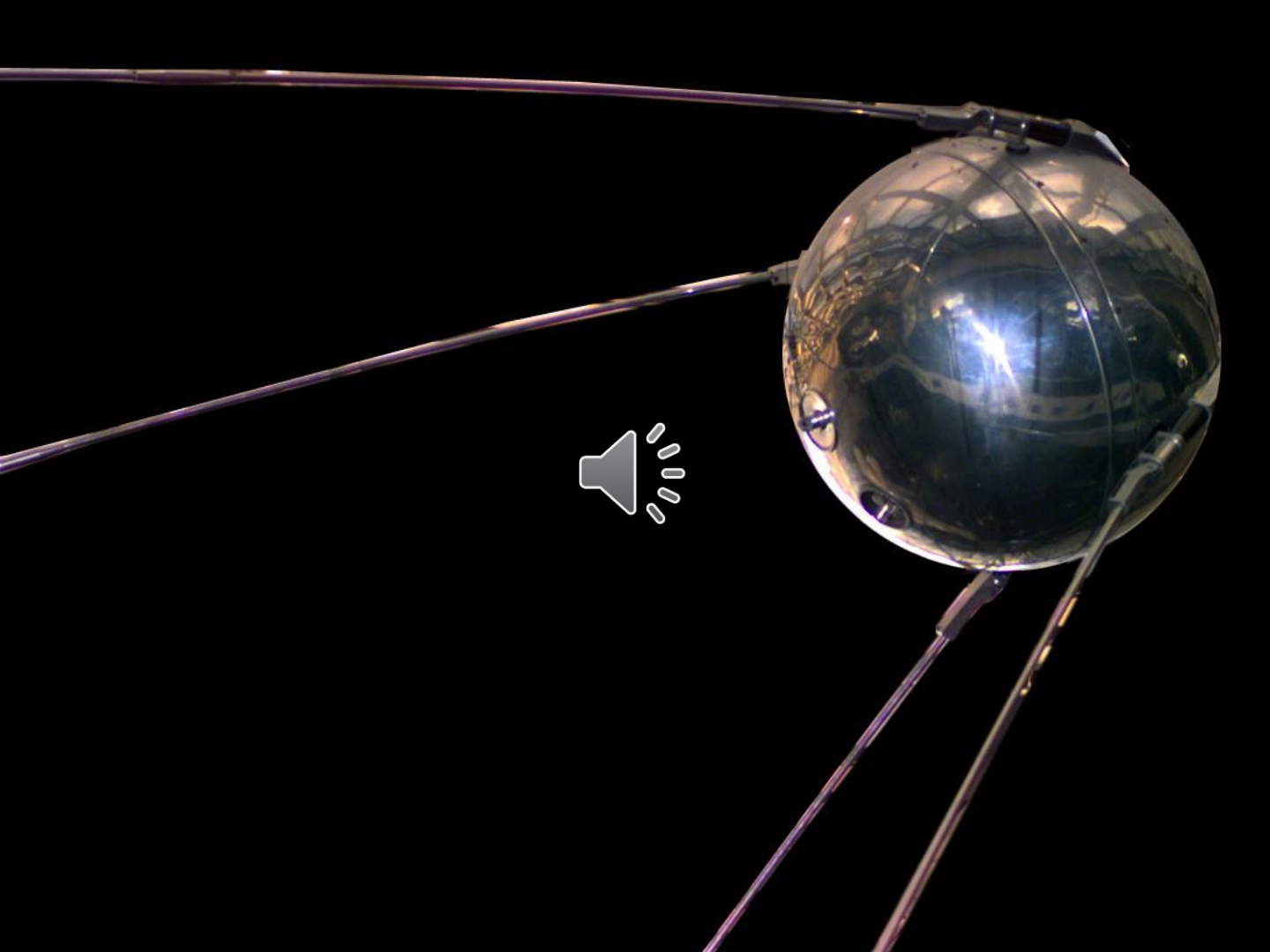


Pix Nixed as Hubble Sees Double



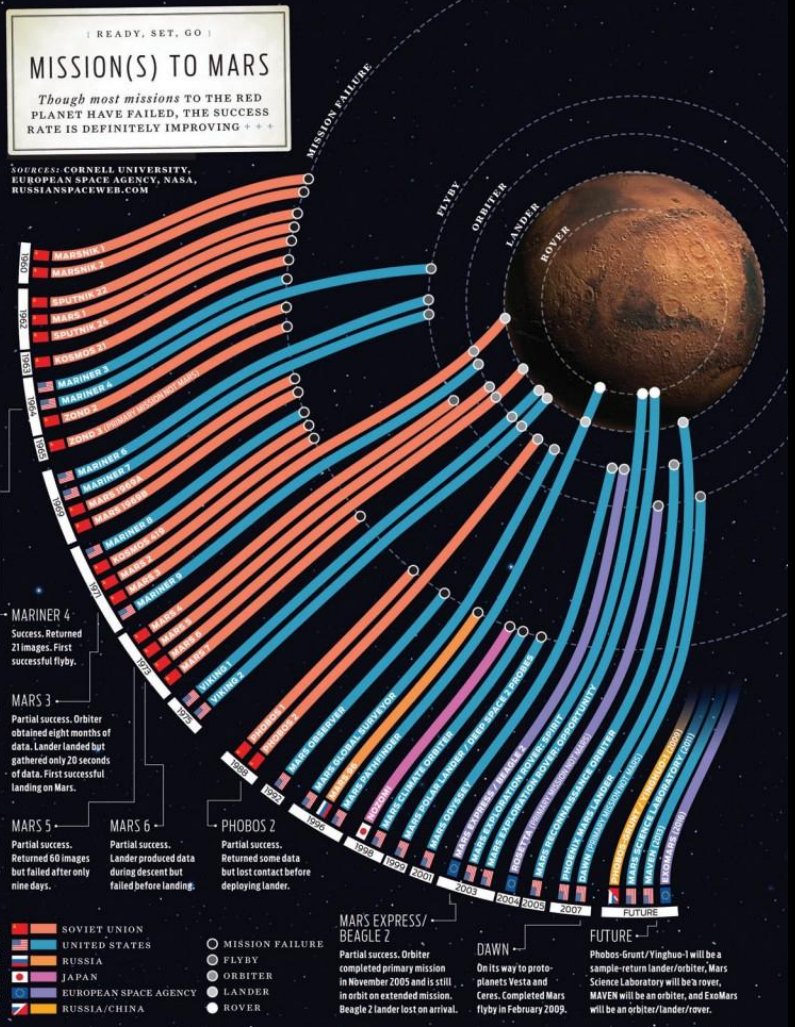


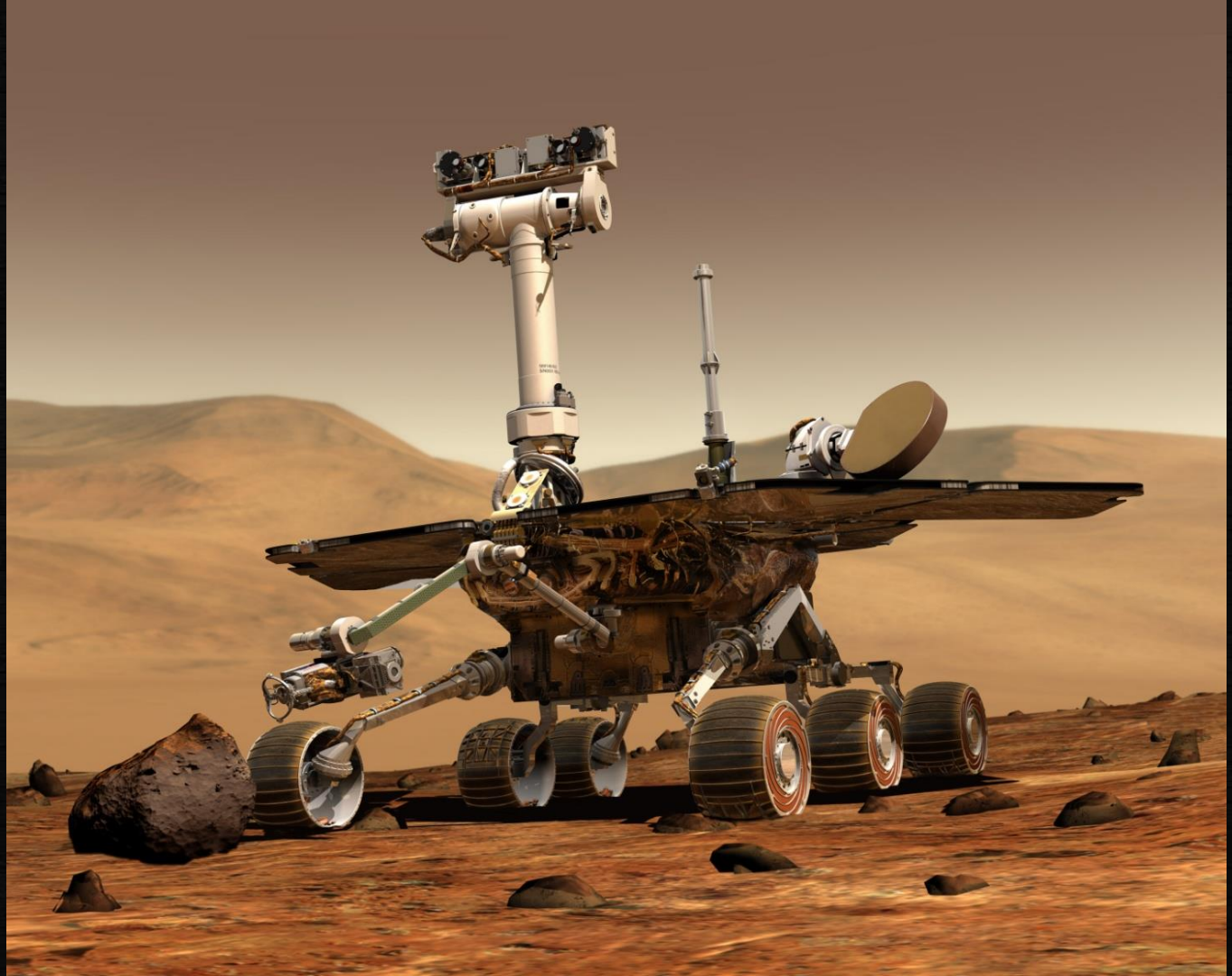
Spacecraft & Probes

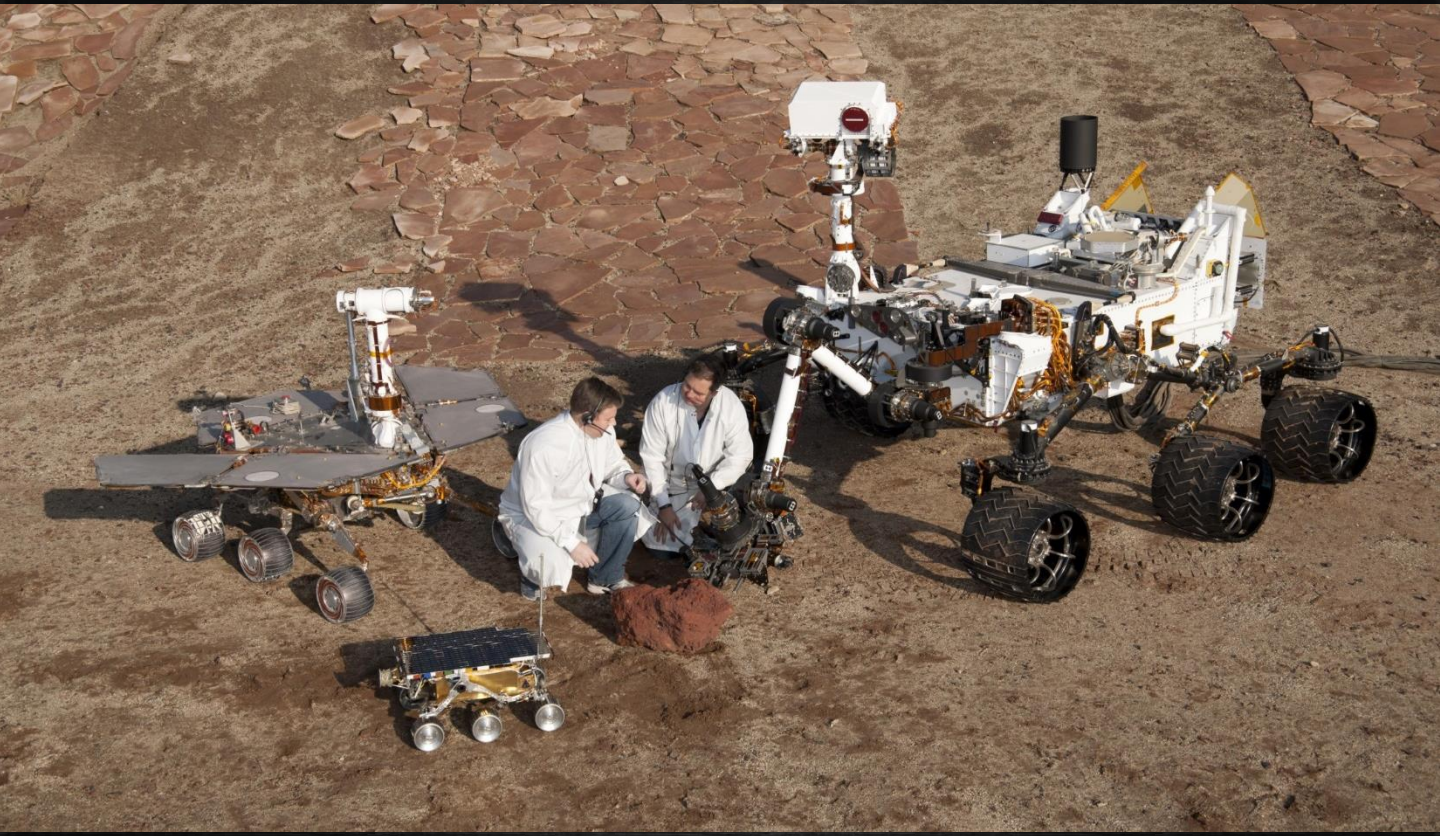


Solar Dynamics Observatory

- Launched: 11th February 2010 from Cape Canaveral Air Station

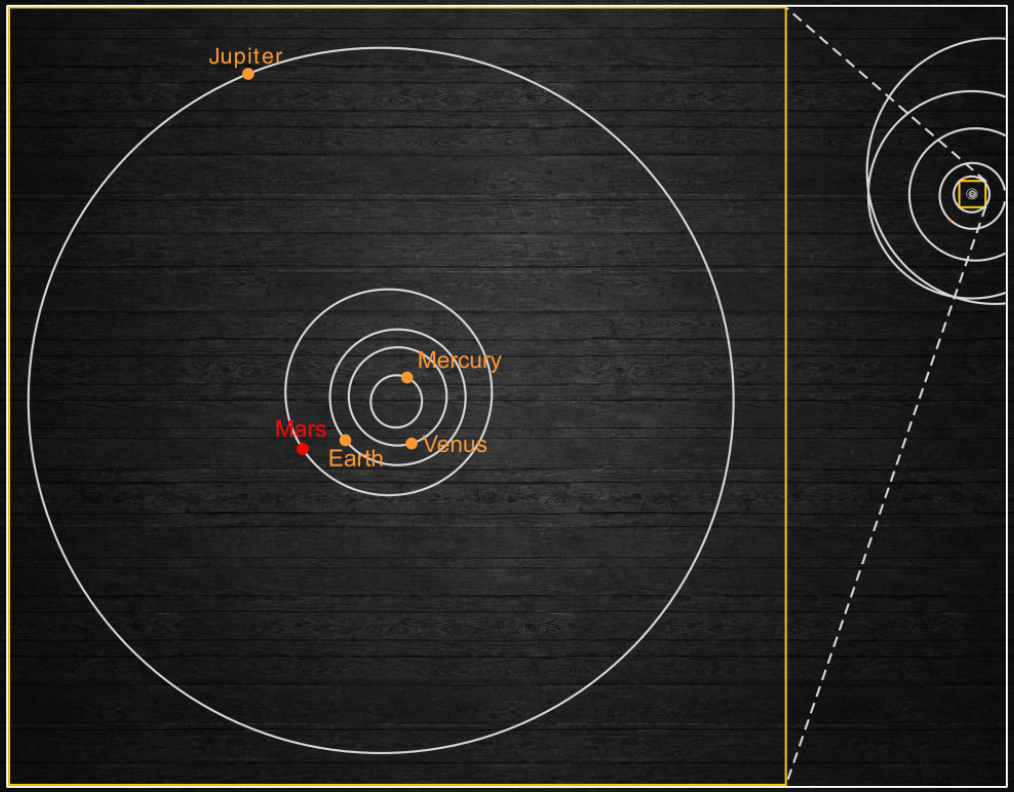

READY, SET, GO
MISSION(S) TO MARS
Though most missions TO THE RED PLANET HAVE FAILED, THE SUCCESS RATE IS DEFINITELY IMPROVING
SOURCES: CORNELL UNIVERSITY, EUROPEAN SPACE AGENCY, NASA, RUSSIANSPACEWEB.COM
MISSION FAILURE
FLYBY
ORBITER
LANDER
ROVER
1960
1964
1965
1966
1969
1971
1973
1975
1988
1992
1996
1998
2001
2003
2004
2005
2007
FUTURE
MARSNIK 1
MARSNIK 2
SPUTNIK 22
MARS 1
SPUTNIK 24
KOSMOS 21
MARINER 3
MARINER 4
ZOND 2
ZOND 3
MARINER 6
MARINER 7
MARS 1969A
MARS 1969B
MARINER 8
KOSMOS 419
MARS 2
MARS 3
MARINER 9
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 / DEEP SPACE 2 PROBES
MARS ODYSSEY
MARS EXPLORATION ROVER: SPIRIT
MARS EXPLORATION ROVER: OPPORTUNITY
MARS RECONNAISSANCE ORBITER
PHOENIX MARS LANDER
MARS SCIENCE LABORATORY (MSL)
MARS ORBITER MISSION (MOM)
MAVEN
EXOMARS
MARS SCIENCE LABORATORY (MSL)
MARS ORBITER MISSION (MOM)
MAVEN
EXOMARS
MARINER 4
Success. Returned 21 images. First successful flyby.
MARS 3
Partial success. Orbiter obtained eight months of data. Lander landed but gathered only 20 seconds of data. First successful landing on Mars.
MARS 5
Partial success. Returned 60 images but failed after only nine days.
MARS 6
Partial success. Lander produced data during descent but failed before landing.
PHOBOS 2
Partial success. Returned some data but lost contact before deploying lander.
MARS EXPRESS/ BEAGLE 2
Partial success. Orbiter completed primary mission in November 2005 and is still in orbit on extended mission. Beagle 2 lander lost on arrival.
DAWN
On its way to proto-planets Vesta and Ceres. Completed Mars flyby in February 2009.
FUTURE
Phobos-Grunt/Yinghuo-1 will be a sample-return lander/orbiter, Mars Science Laboratory will be a rover, MAVEN will be an orbiter, and ExoMars will be an orbiter/lander/rover.
SOVIET UNION
UNITED STATES
RUSSIA
JAPAN
EUROPEAN SPACE AGENCY
RUSSIA/CHINA
MISSION FAILURE
FLYBY
ORBITER
LANDER
ROVER
JENNA CHRISTIE ROBSON



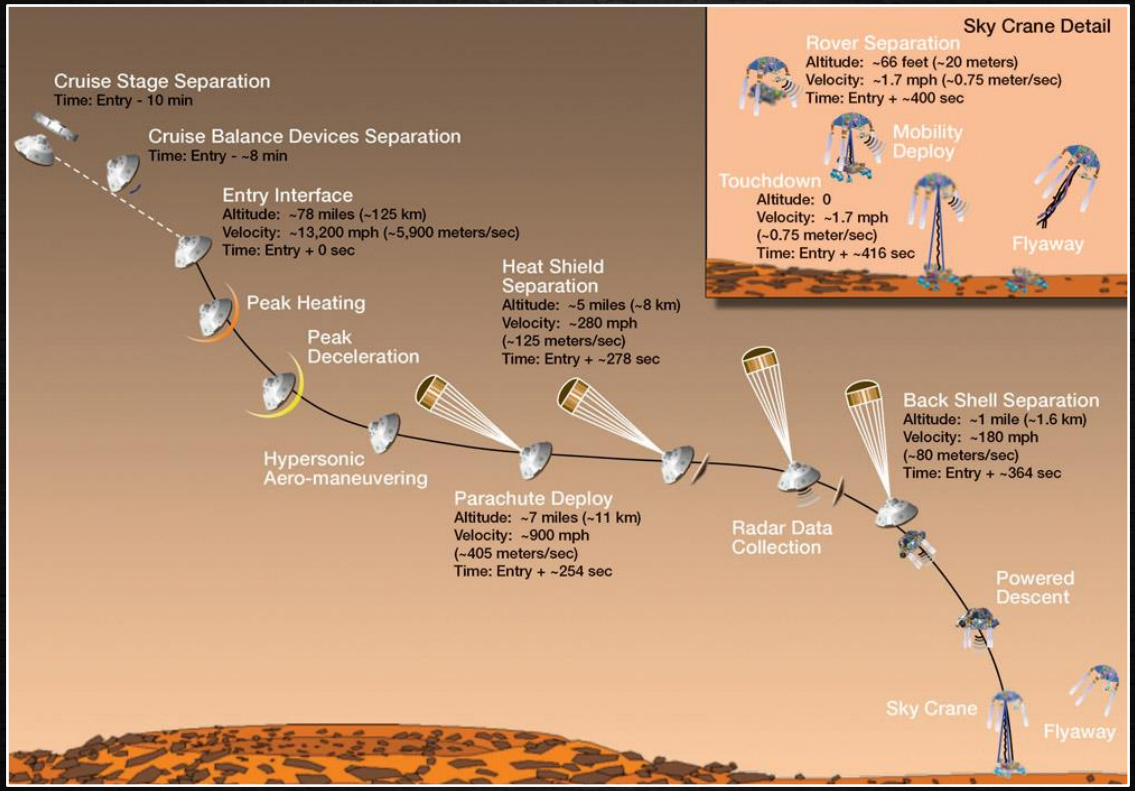


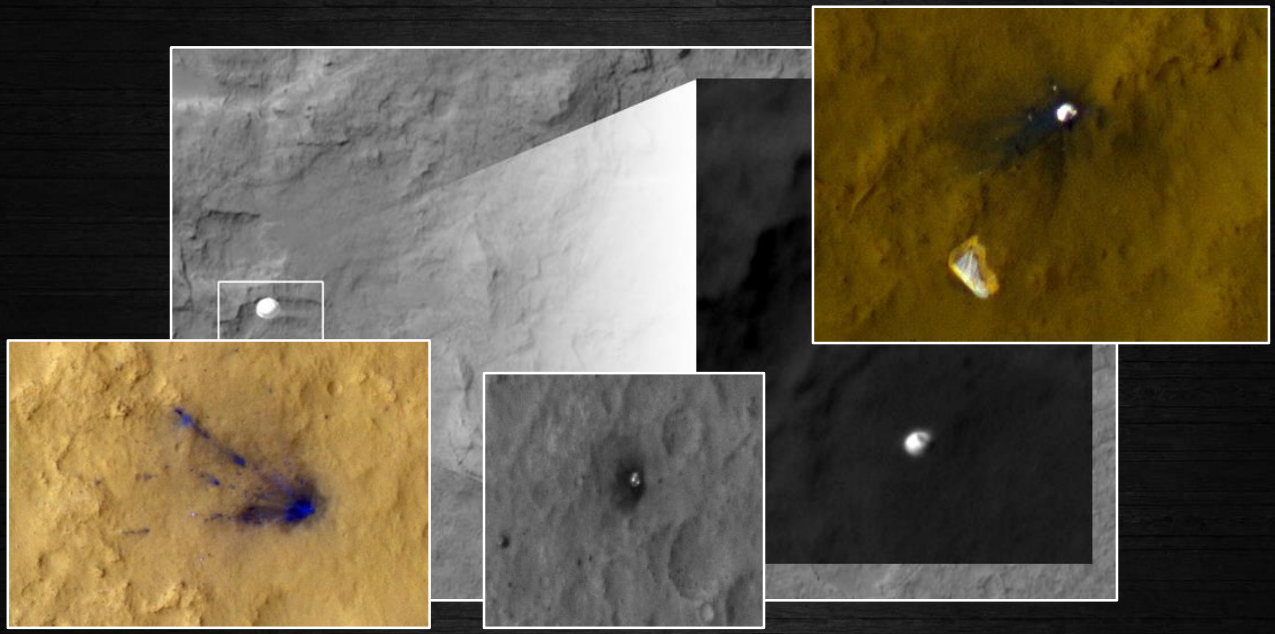

HD

Getting to Mars



Landing Curiosity





“The overall scientific goal of the mission is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present.”


meters
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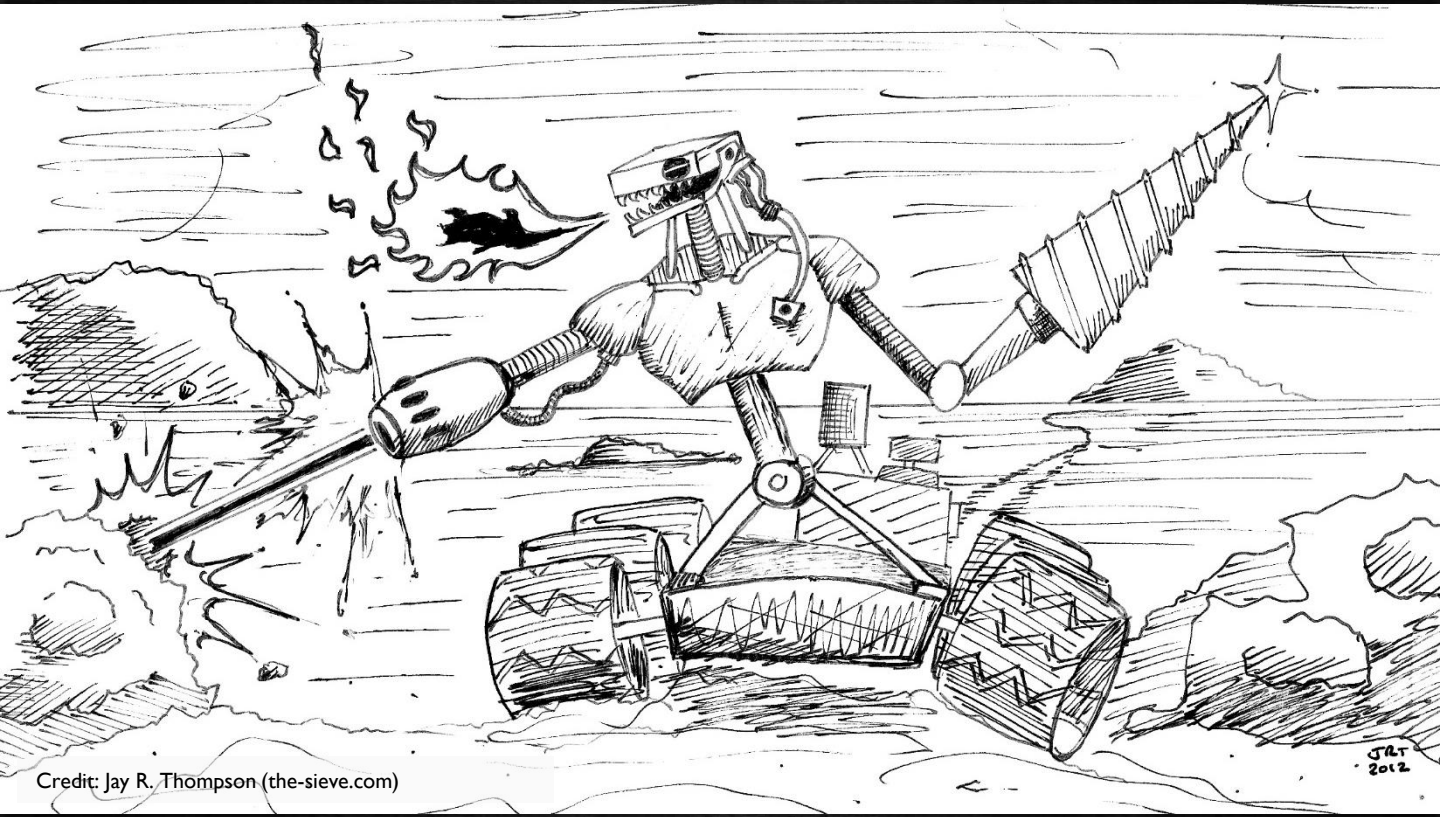
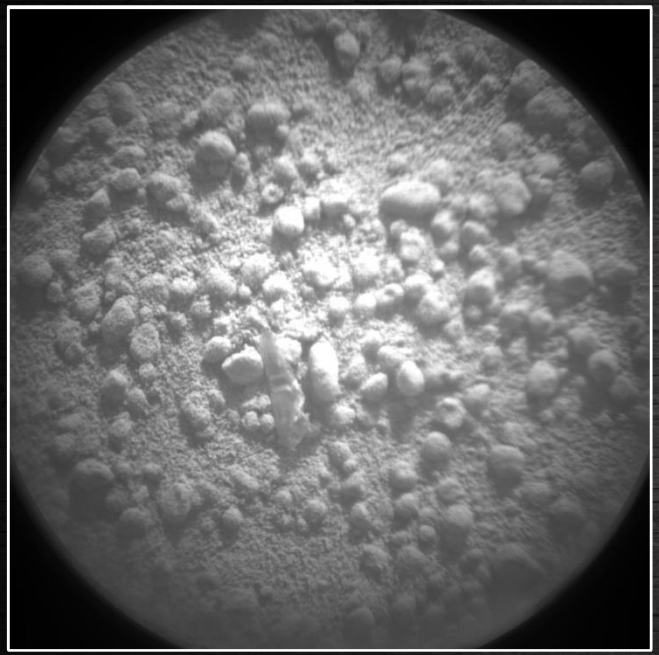
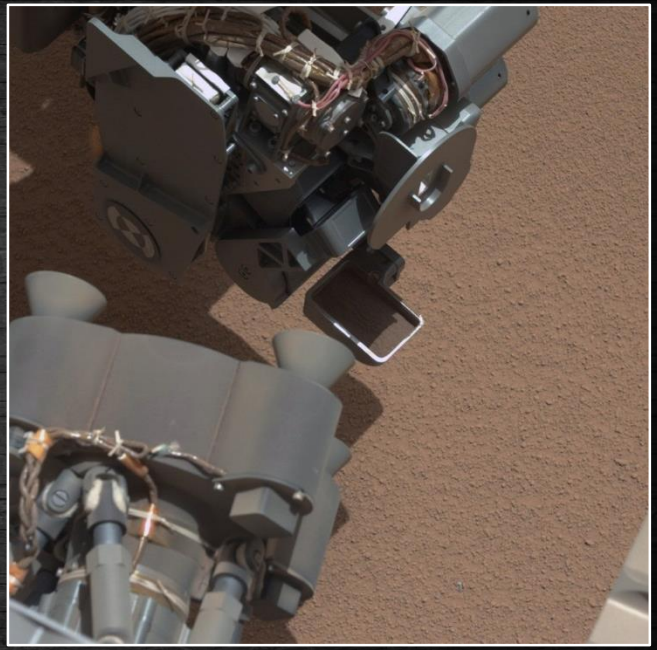
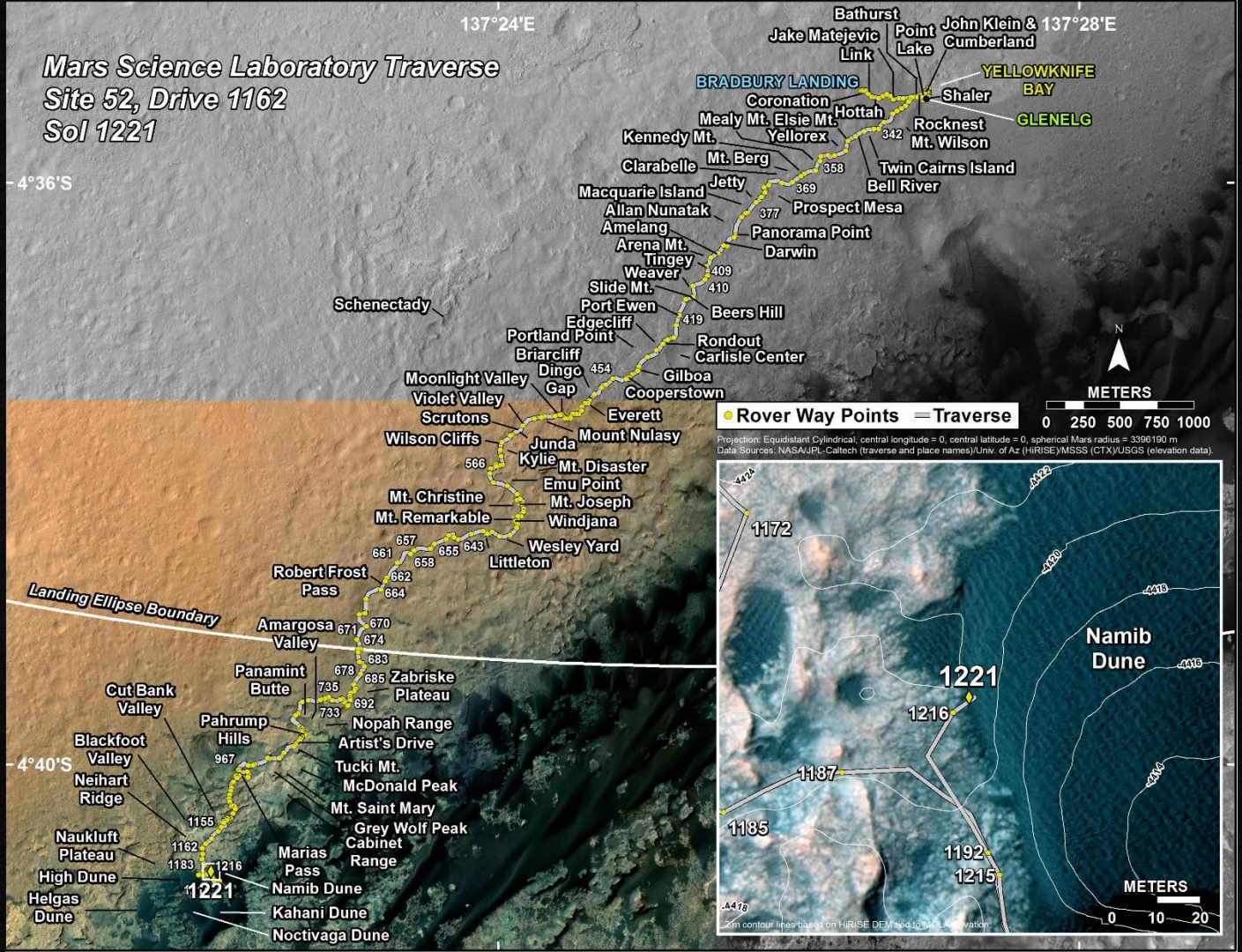
2

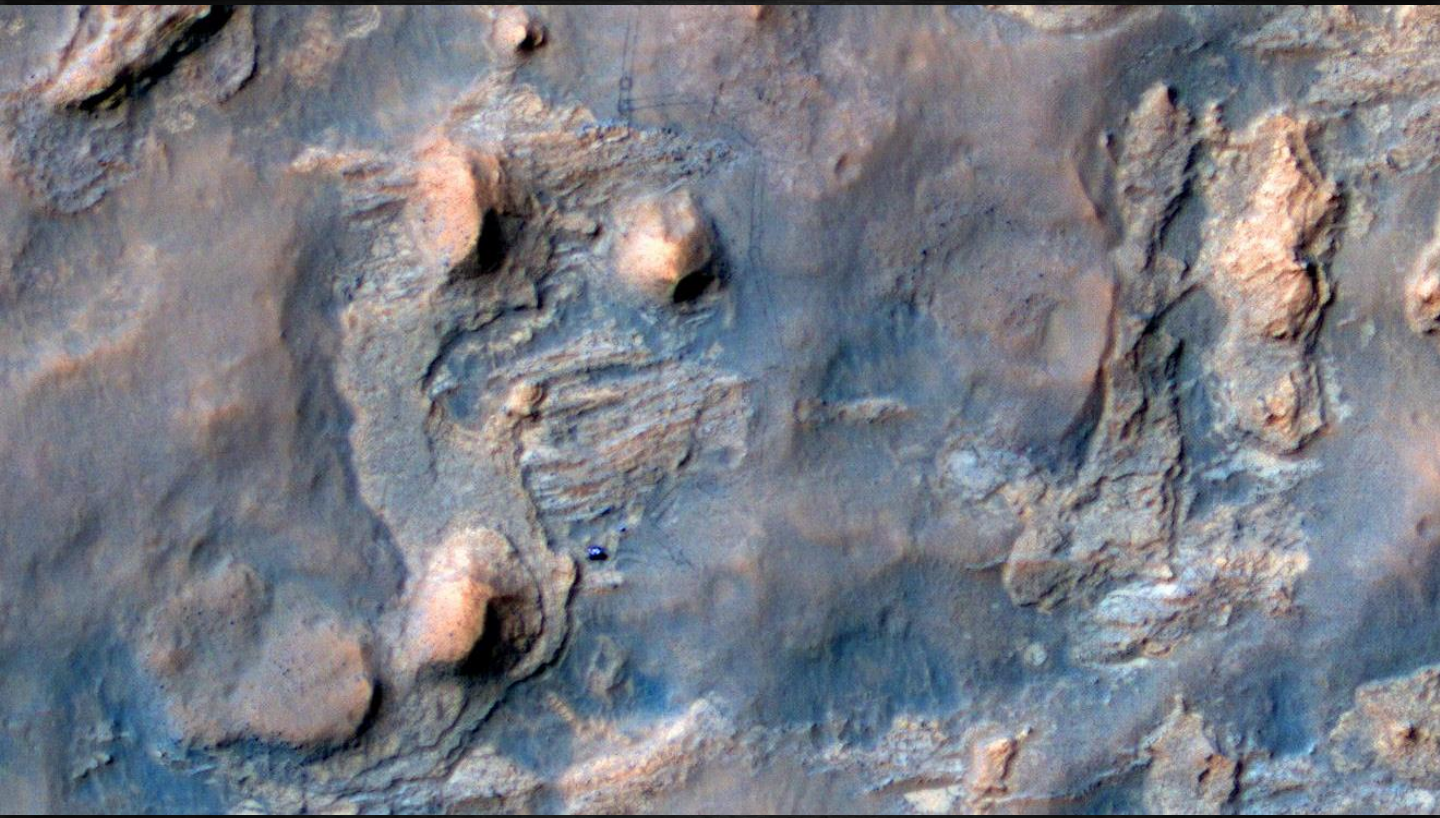


Credit: Jay R. Thompson (the-sieve.com)






Mars Science Laboratory Traverse
Site 52, Drive 1162
Sol 1221
137°24'E
137°28'E
4°36'S
4°40'S
Bathurst
Jake Matejevic
Point Lake
John Klein & Cumberland
Link
BRADBURY LANDING
YELLOWKNIFE BAY
Coronation
Shaler
Hottah
GLENELG
Mealy Mt.
Elsie Mt.
Rocknest
Kennedy Mt.
Yellorex
342
Mt. Wilson
Clarabelle
Mt. Berg
358
Twin Cairns Island
Jetty
369
Bell River
Macquarie Island
Allan Nunatak
377
Prospect Mesa
Amelang
Panorama Point
Arena Mt.
Darwin
Tingey
Weaver
409
410
Slide Mt.
Schenectady
Port Ewen
419
Beers Hill
Edgecliff
Portland Point
Rondout
Briarcliff
Carlisle Center
Dingo Gap
454
Gilboa
Moonlight Valley
Violet Valley
Cooperstown
Scrutons
Everett
Wilson Cliffs
Mount Nulasy
Junda
Kylie
566
Mt. Disaster
Emu Point
Mt. Christine
Mt. Joseph
Mt. Remarkable
Windjana
657
661
655
643
658
Wesley Yard
Littleton
Robert Frost Pass
662
664
Landing Ellipse Boundary
Amargosa Valley
671
670
674
683
678
685
Zabriske Plateau
Panamint Butte
735
692
733
Cut Bank Valley
Pahrump Hills
Nopah Range
Artist's Drive
Blackfoot Valley
967
Tucki Mt.
Neihart Ridge
McDonald Peak
Mt. Saint Mary
1155
Grey Wolf Peak
Naukluft Plateau
1162
Cabinet Range
Marias Pass
1183
1216
High Dune
1221
Namib Dune
Helgas Dune
Kahani Dune
Noctivaga Dune
N
METERS
0 250 500 750 1000
Rover Way Points
Traverse
Projection: Equidistant Cylindrical; central longitude = 0, central latitude = 0, spherical Mars radius = 3396190 m
Data Sources: NASA/JPL-Caltech (traverse and place names)/Univ. of Az (HiRISE)/MSSS (CTX)/USGS (elevation data).
-4424
-4422
1172
-4420
-4418
Namib Dune
-4416
1221
1216
1187
-4414
1185
1192
1215
METERS
0 10 20
-4476
2m contour lines based on HiRISE DEM tied to MOLA elevation




Earth
moon

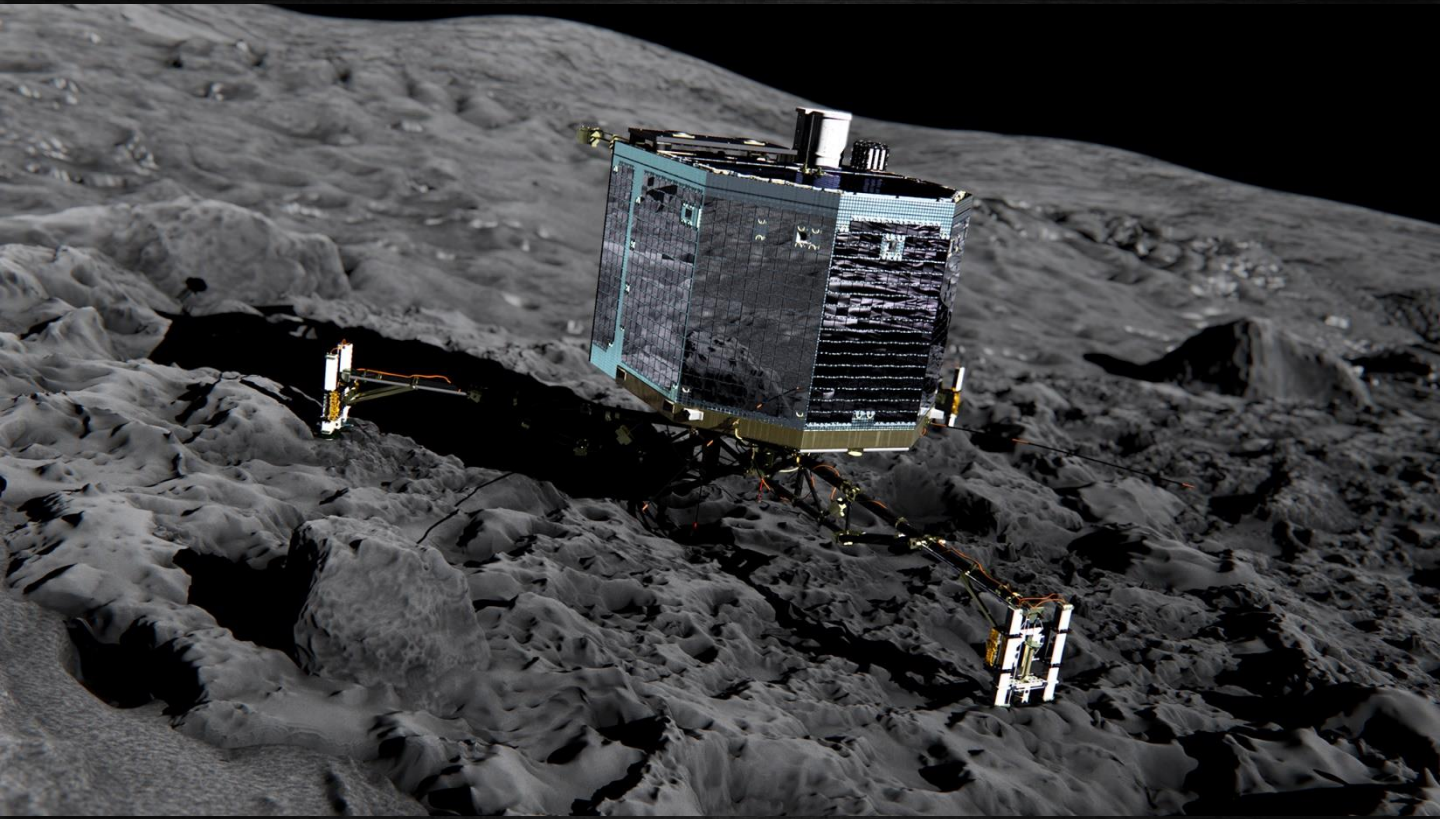
Curiosity

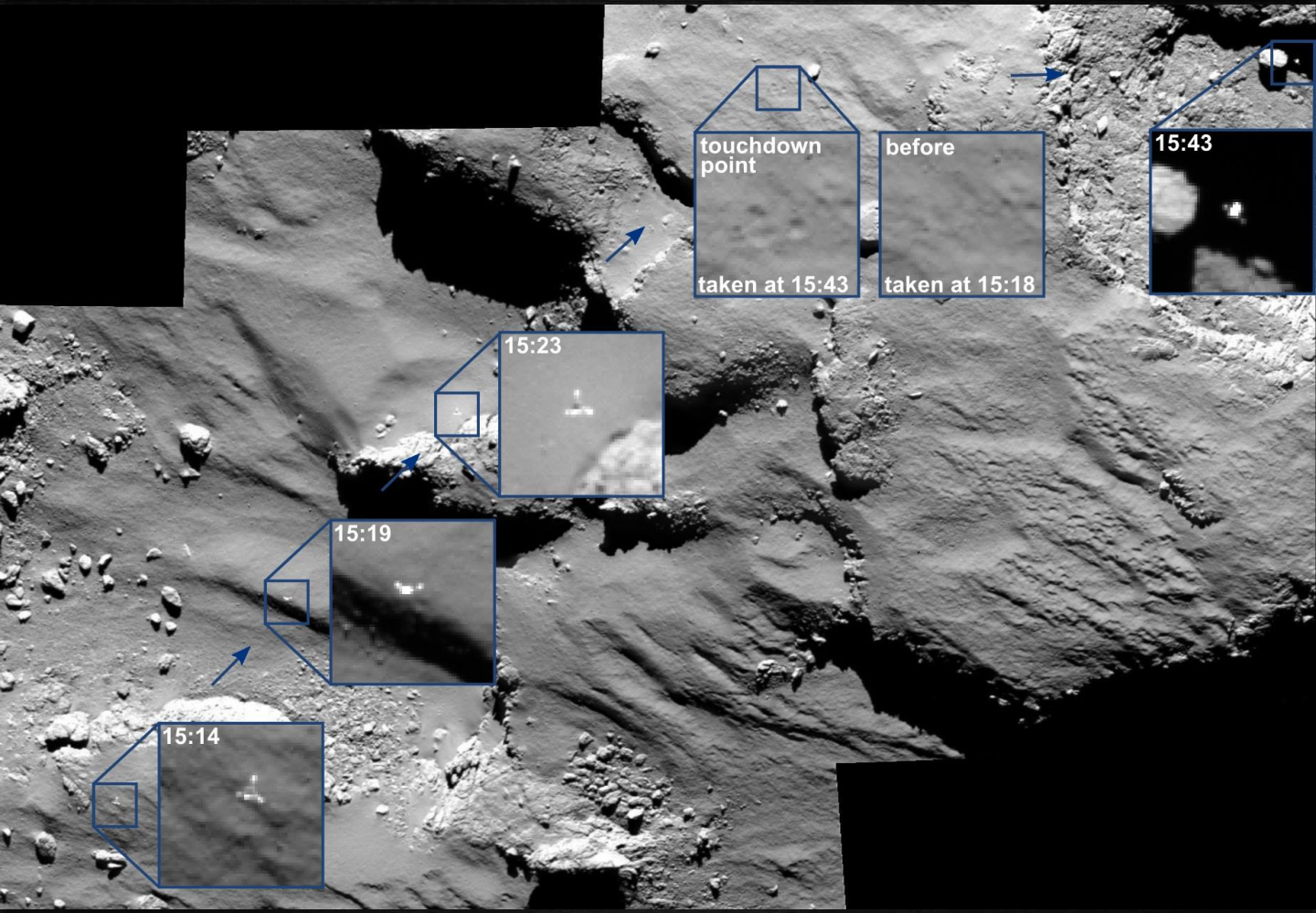
- Minimum mission duration of 1 Martian year
  - Currently on 1230 days = 1.8 Martian years
- Currently driven over 10 km

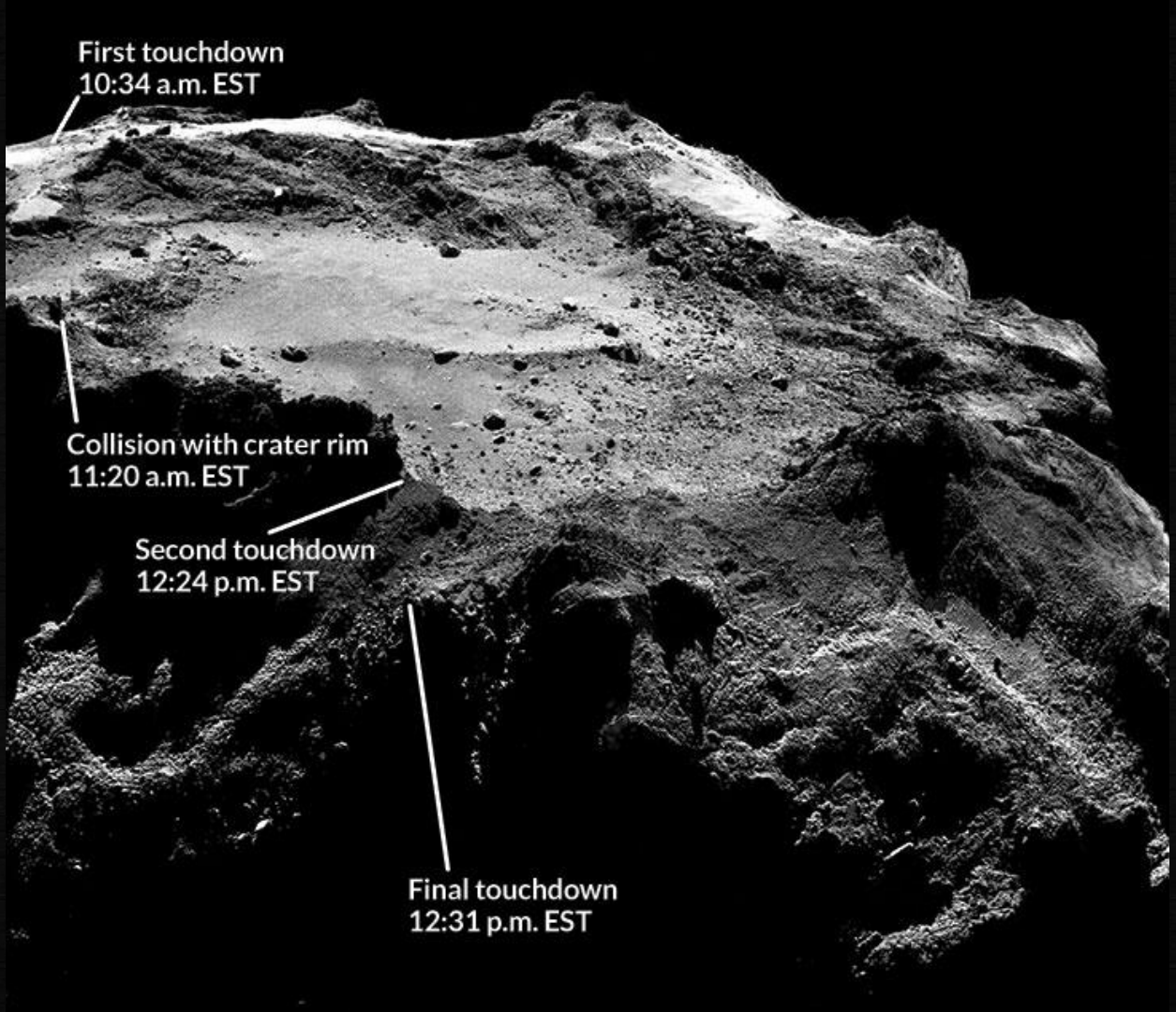
- Lots more to come!

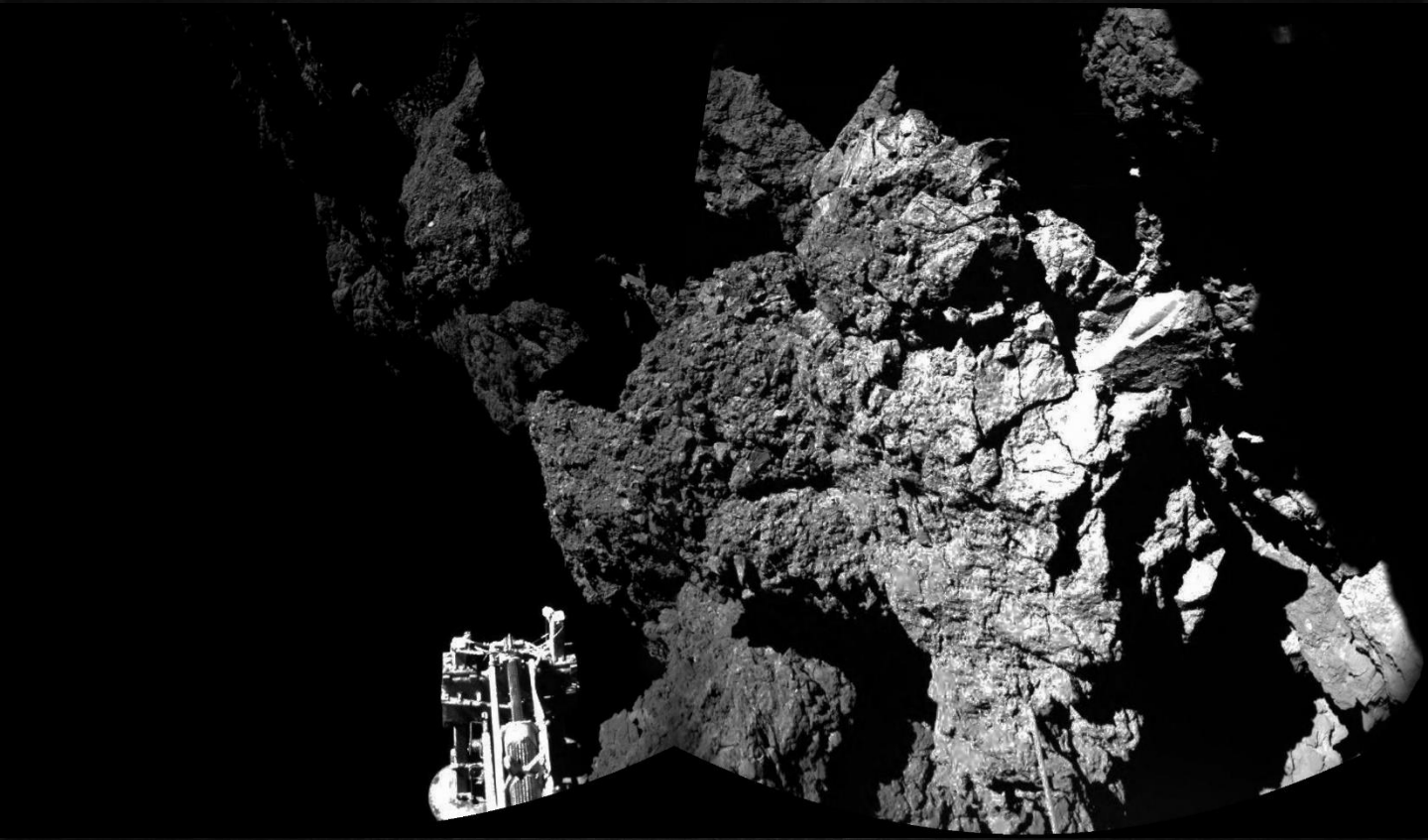
Comets

- Small solar system objects
  - Made of ice and dust
- Have elliptical shaped orbits
  - Brings them close to the sun

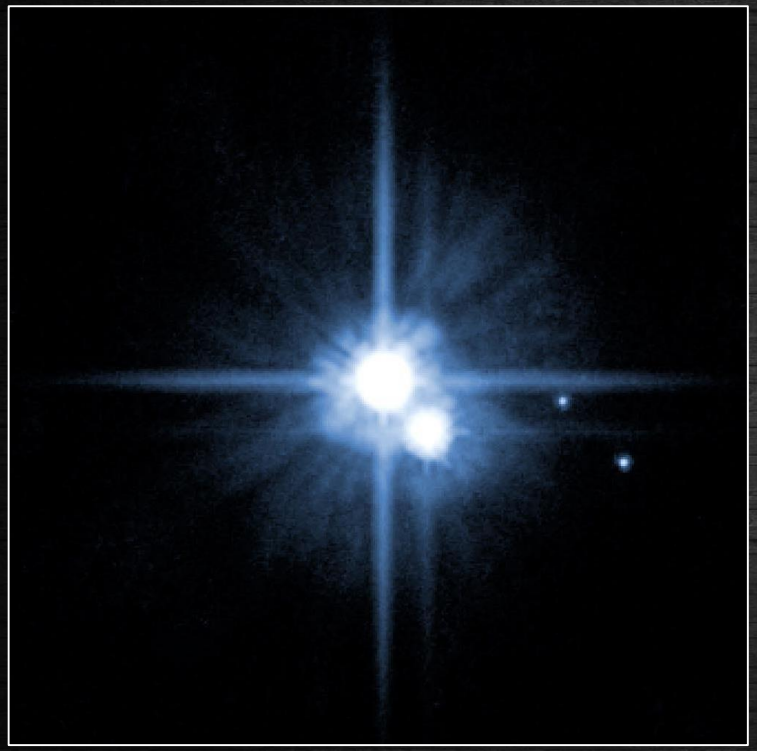



touchdown point
taken at 15:43
before
taken at 15:18
15:43
15:23
15:19
15:14


First touchdown
10:34 a.m. EST
Collision with crater rim
11:20 a.m. EST
Second touchdown
12:24 p.m. EST
Final touchdown
12:31 p.m. EST



Pluto



Distance from the Sun

5,906,440,628km

39.482 × distance to Earth

Size

0.1807 × size of Earth

Mass

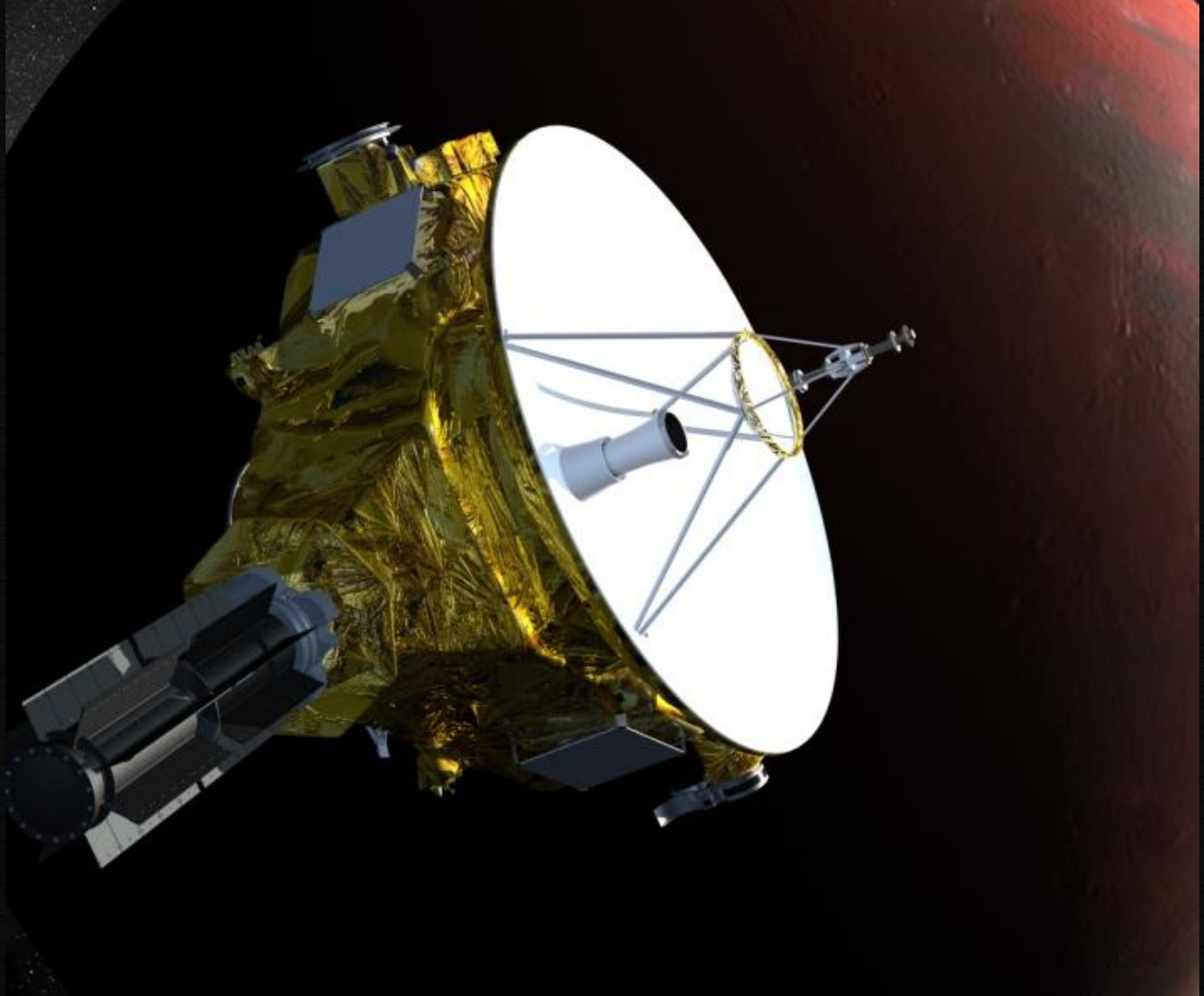
0.002 × mass of Earth

Length of 1 Day

6.387 × Earth days

Length of 1 Year

247.921 × Earth years



New Horizons

- Launched: 19th January 2006
- Arrival at Pluto: 14th July 2015
- Seven instruments on board
  - Three imaging telescopes
  - Two plasma spectrometers
  - A dust sensor
  - Radio science receiver/radiometer