Astronomy Update

Recent advances and research priorities

Lectures for the
Lifelong Learning Institute
Fall 2024
Session 1

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Former Director, Vassar College Observatory

Prospectus: Astronomy Update

Introduction: Sources of astronomical news

Part 1. Solar system news

Part 2. Exoplanetary frontiers

Part 3. Mapping galaxies, making galaxies.

Part 4. The universe and the biggest questions

Introduction: How astronomical information arrives

Electromagnetic radiation

- Gamma ray
- X-ray
- Ultraviolet light (UV)
- Visible Light (“Optical” =O)
- Infrared (IR, NIR, MIR, FIR)
- Microwave
- Radio

Macroscopic material: Solar system only: Meteorites. Samples returned by spacecraft,

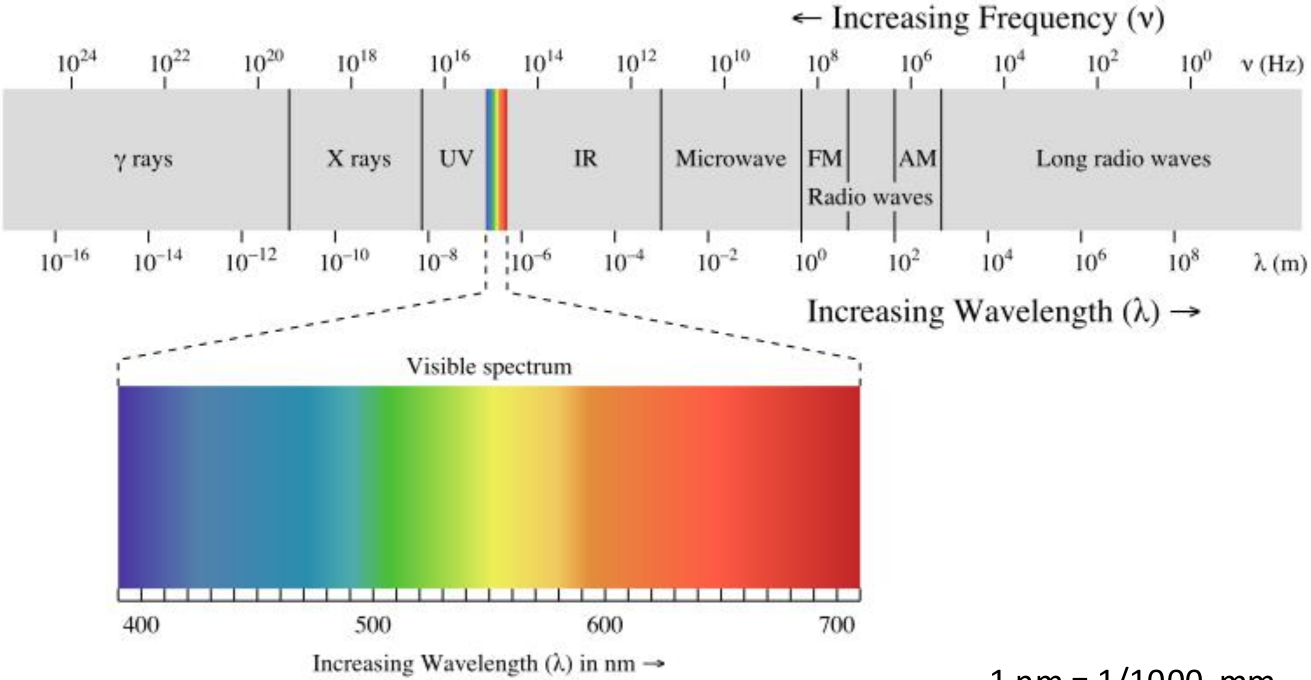
Signals from in situ probes: Solar System (but Voyager I and II at heliopause)

Particles: Cosmic “rays” (electrons, nuclei) and neutrinos: From sun.
From distant sources

Gravitational radiation

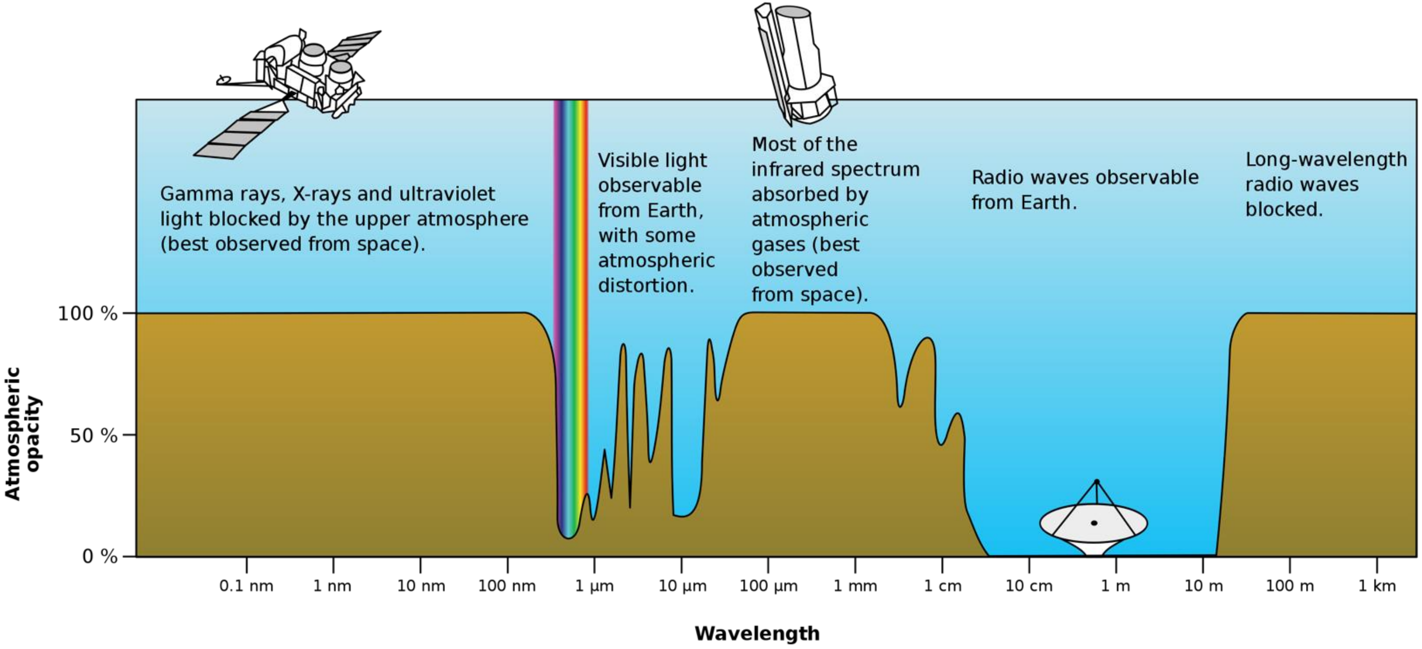
Electromagnetic radiation spectrum

Different frequencies require different detector + telescope technologies



1 nm = 1/1000 mm

Earth's atmosphere limits ground-based observations to visible, near IR and microwave/radio

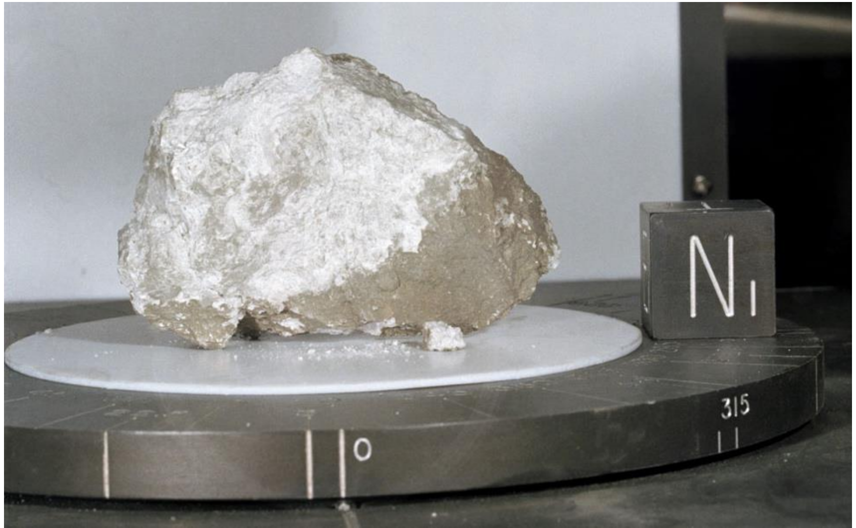


No frequency/wavelength limits for space observatories, BUT costs prohibit building a very large telescope in space (so far).

Macroscopic material:

Meteorites: Mainly from inner asteroid belt, some from Moon and Mars

Sample returns: e.g. Moon rocks from Apollo 11-17 and Luna missions 1969-73



Macroscopic material:

Recent samples:

2020-24 – Lunar rocks (Chang’e 5 & 6)

2020 -- 162173 Ryugu (Hayabusa2)

2024 – 101955 Bennu (OSIRIS-Rex)

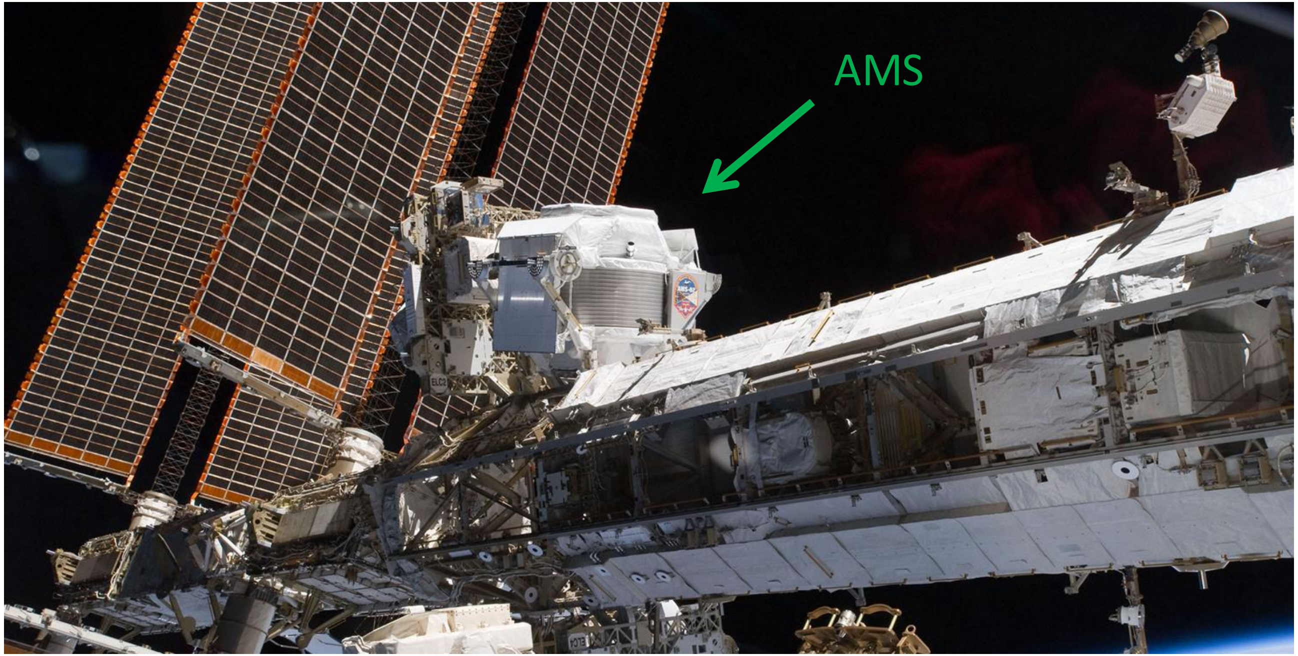
Information from Probes in Situ

GLOBAL PORTRAIT OF THE DWARF PLANET PLUTO

Taken by the New Horizons spacecraft in 2015. It is an enhanced-color view made of three images captured through infrared, red, and blue filters. Surface is primarily nitrogen ice but shows extreme diversity in color and morphology. *NASA / JHUAPL / SwRI*

Particles: Cosmic Ray Astronomy

The AMS cosmic ray detector (2011-present) on the ISS measures the anti-mater component of cosmic rays. Found the positron-to-electron ratio peaked near 275 GeV.

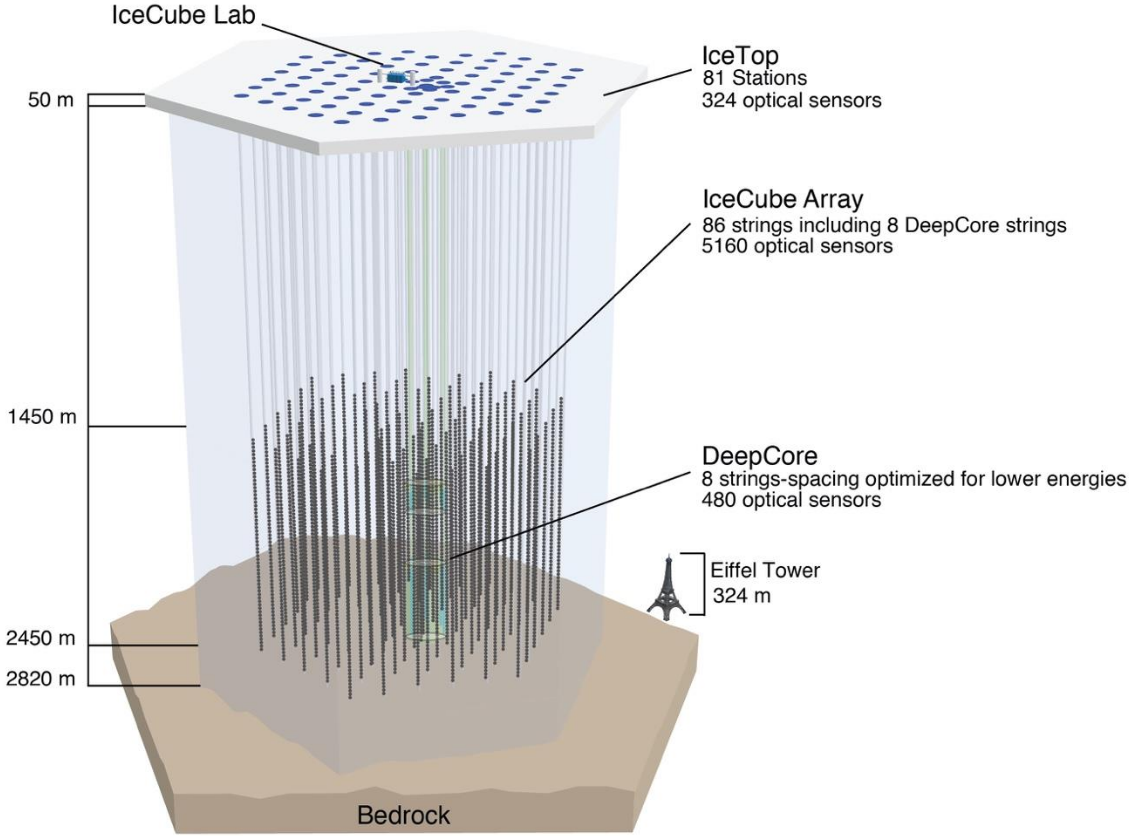


Particles: Neutrino Astronomy

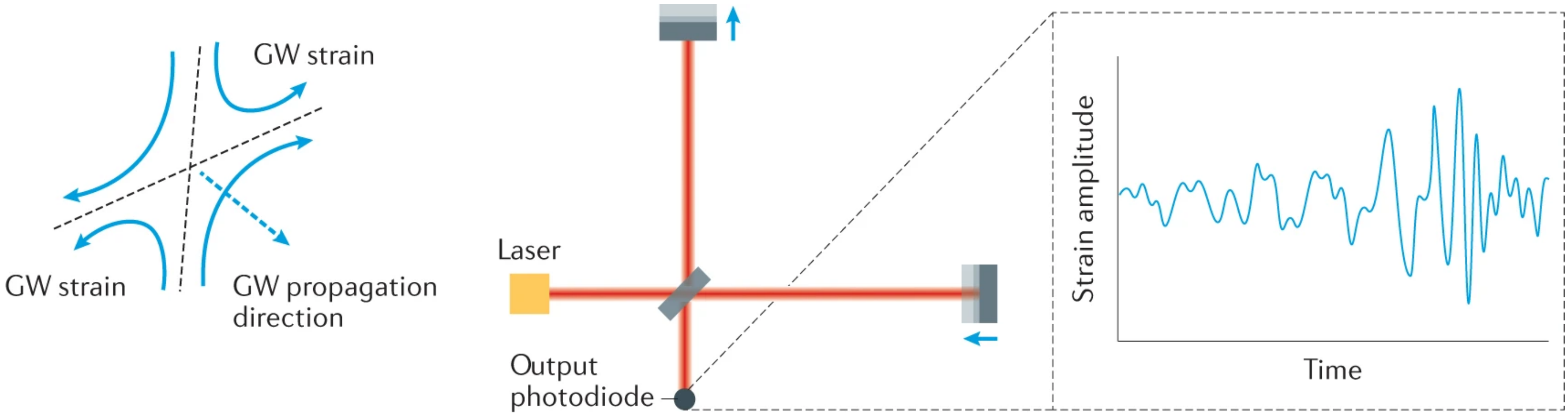
The IceCube Neutrino Observatory

Occupies a volume of about one cubic kilometer of clear ice at the south pole.

86 strings of digital optical sensors record gamma rays produced by neutrino interactions with the ice molecules.

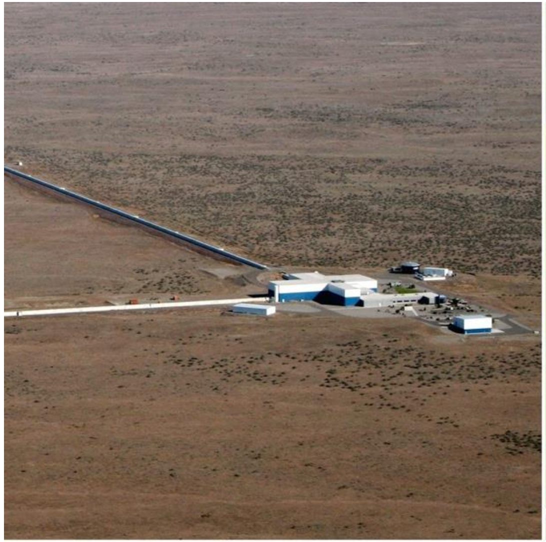


A Gravity Wave Telescope – Two Arms

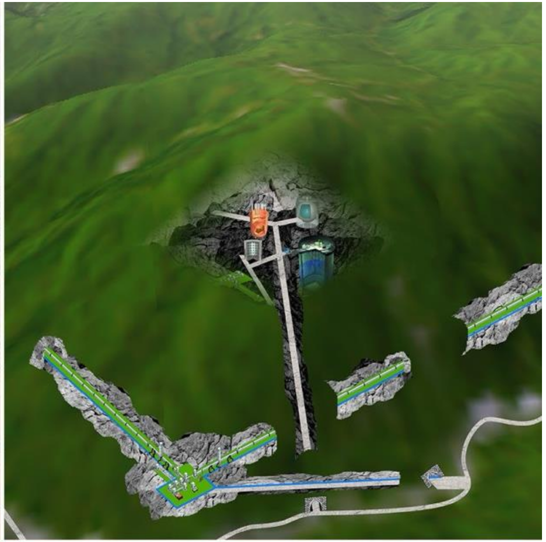


A gravitational-wave (GW) strain shortens one arm while lengthening the other as it passes the detector, resulting in a slight difference in round-trip travel time for the laser light. This, in turn, leads to a phase shift of the light in one arm of the detector relative to the other, creating a change in light intensity at the photodetector. The time-dependent intensity recorded by the photodetector produces a reconstruction of the propagating GW.

LIGO – USA, WA



KAGRA-Japan
Mt. Ikenoyama

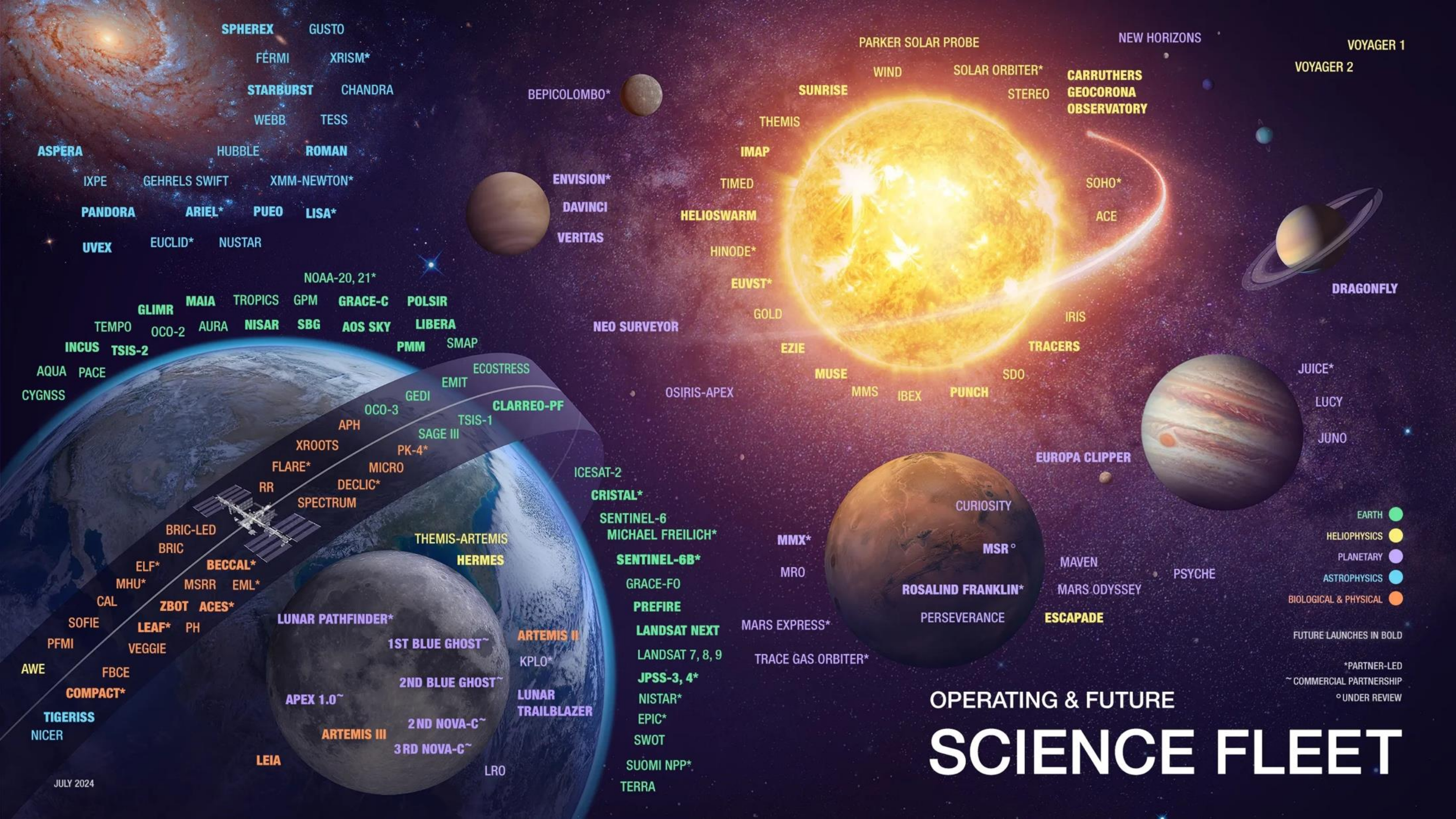


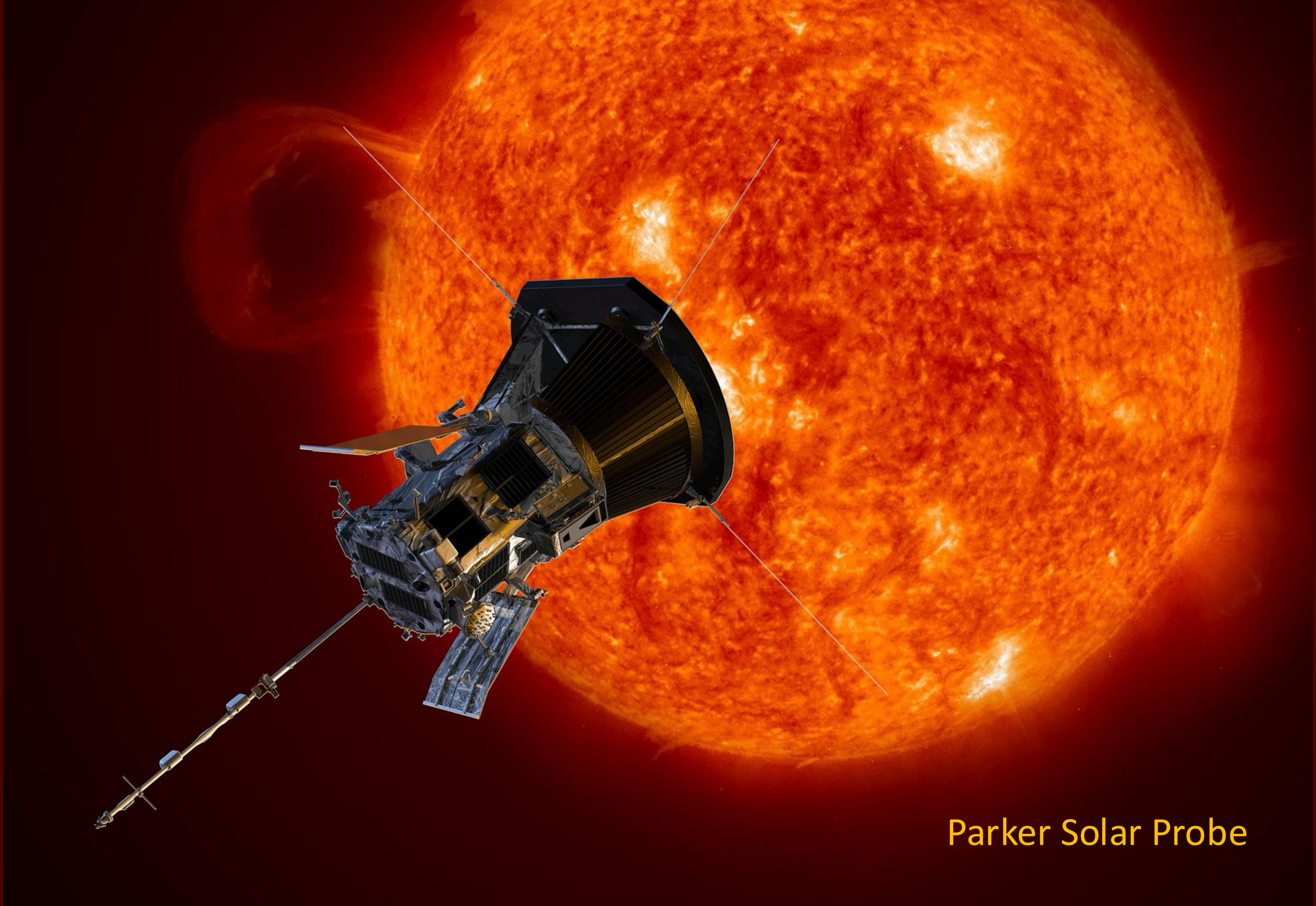
VIRGO –
Europe, Italy

LIGO-USA, LA

PART 1
Solar System Update

The Sun
Mercury
Venus
The Moon
Mars
Asteroids
Europa and the Outer Planets


SPHEREX
GUSTO
FERMI
XRISM*
STARBURST
CHANDRA
WEBB
TESS
ASPERA
HUBBLE
ROMAN
IXPE
GEHRELS SWIFT
XMM-NEWTON*
PANDORA
ARIEL*
PUEO
LISA*
UVEX
EUCLID*
NUSTAR
NOAA-20, 21*
GLIMR
MAIA
TROPICS
GPM
GRACE-C
POLSIR
TEMPO
OCO-2
AURA
NISAR
SBG
AOS SKY
LIBERA
INCUS
TSIS-2
PMM
SMAP
AQUA
PACE
ECOSTRESS
CYGNSS
EMIT
GEDI
CLARREO-PF
OCO-3
APH
TSIS-1
SAGE III
XROOTS
PK-4*
FLARE*
MICRO
RR
DECLIC*
SPECTRUM
BRIC-LED
BRIC
ELF*
BECCAL*
MHU*
MSRR
EML*
CAL
ZBOT
ACES*
SOFIE
LEAF*
PH
PFMI
VEGGIE
AWE
FBCE
COMPACT*
TIGERISS
NICER
JULY 2024
THEMIS-ARTEMIS
HERMES
LUNAR PATHFINDER*
1ST BLUE GHOST~
ARTEMIS II
KPLO*
2ND BLUE GHOST~
APEX 1.0~
LUNAR TRAILBLAZER
2ND NOVA-C~
ARTEMIS III
3RD NOVA-C~
LEIA
LRO
ICESAT-2
CRISTAL*
SENTINEL-6 MICHAEL FREILICH*
SENTINEL-6B*
GRACE-FO
PREFIRE
LANDSAT NEXT
LANDSAT 7, 8, 9
JPSS-3, 4*
NISTAR*
EPIC*
SWOT
SUOMI NPP*
TERRA
BEPICOLOMBO*
ENVISION*
DAVINCI
VERITAS
NEO SURVEYOR
OSIRIS-APEX
PARKER SOLAR PROBE
WIND
SOLAR ORBITER*
SUNRISE
STEREO
CARRUTHERS GEOCORONA OBSERVATORY
THEMIS
IMAP
TIMED
SOHO*
HELIOSWARM
ACE
HINODE*
EUVST*
GOLD
IRIS
EZIE
TRACERS
MUSE
SDO
MMS
IBEX
PUNCH
NEW HORIZONS
VOYAGER 1
VOYAGER 2
DRAGONFLY
JUICE*
LUCY
JUNO
EUROPA CLIPPER
CURIOSITY
MMX*
MSR °
MRO
MAVEN
PSYCHE
ROSALIND FRANKLIN*
MARS ODYSSEY
PERSEVERANCE
ESCAPADE
MARS EXPRESS*
TRACE GAS ORBITER*
EARTH
HELIOPHYSICS
PLANETARY
ASTROPHYSICS
BIOLOGICAL & PHYSICAL
FUTURE LAUNCHES IN BOLD
*PARTNER-LED
~ COMMERCIAL PARTNERSHIP
° UNDER REVIEW
OPERATING & FUTURE
SCIENCE FLEET



Parker Solar Probe

Parker Solar Probe (launched August 2018, orbit adjusted by Venus gravity assist) Update

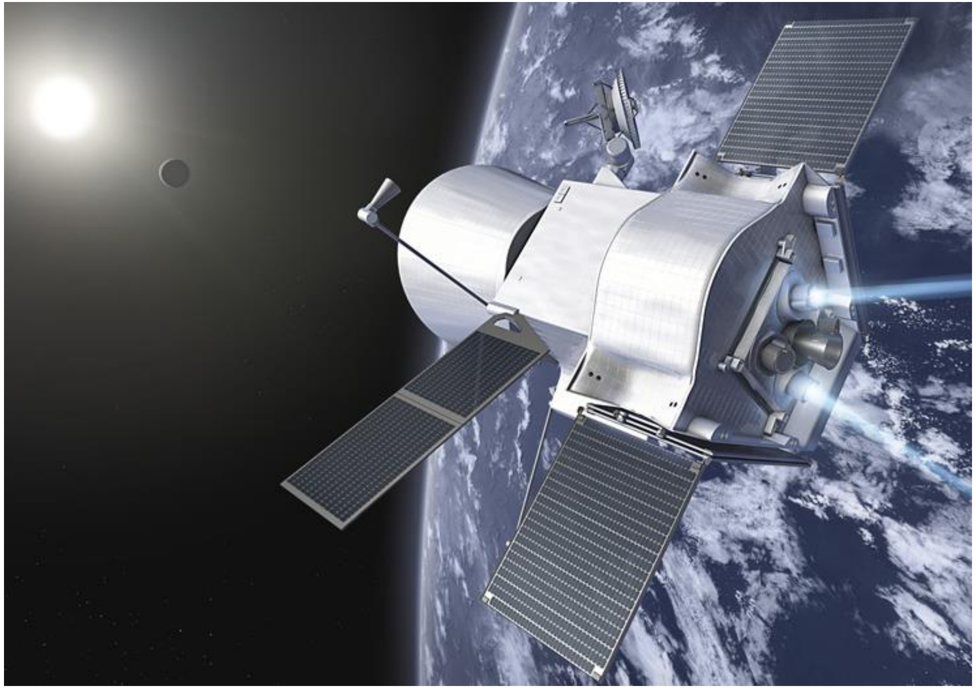
Records: Fastest spacecraft ever ($400{,}000^{+}$ mph).
Closest approach to sun (3.8 million miles) on 12/24/2024
Heat shield/radiator working (sunlight 500x brighter)

Problems to be addressed: Coronal Heating (3 million K vs 5500°)
Solar wind acceleration

Science: Measured local material velocities, magnetic field structure
Crossed the Alfven Surface (sonic/supersonic boundary)
Discovered magnetic field switchbacks
Flew through coronal mass ejections
Coordinated with other observatories during the 4/08/24 eclipse

Mercury

BepiColombo Space Probe (ESA, JAXA)



- **Launch:** 20 October 2018

- **Mercury flybys:** 1 Oct 2021, 23 June 2022, 19 June 2023, 4 Sept 2024, 1 Dec 2024, 8 Jan 2025

- **Arrival at Mercury:** November 2026

- **Beginning of routine science**
- **operations at Mercury:**
  Early 2027

- **Components:** Mercury Transfer Module – provides power and support during 8-yrs prior to orbit
  Mercury Planetary Orbiter – dormant until inserted into tight orbit, Mercury
  Magnetospheric Orbiter – dormant until inserted into eccentric orbit

Planet Mercury

Smallest Planet (R=2439 km = 0.39 R_{earth} = 1.4 R_{moon})

Highest uncompressed density 5.3 g/ml ➔Large iron core

3:2 Spin/orbit synchronization. Solar day = 176 earth days = 2 sidereal orbits

Uniform cratered surface

Messenger spacecraft image 2008

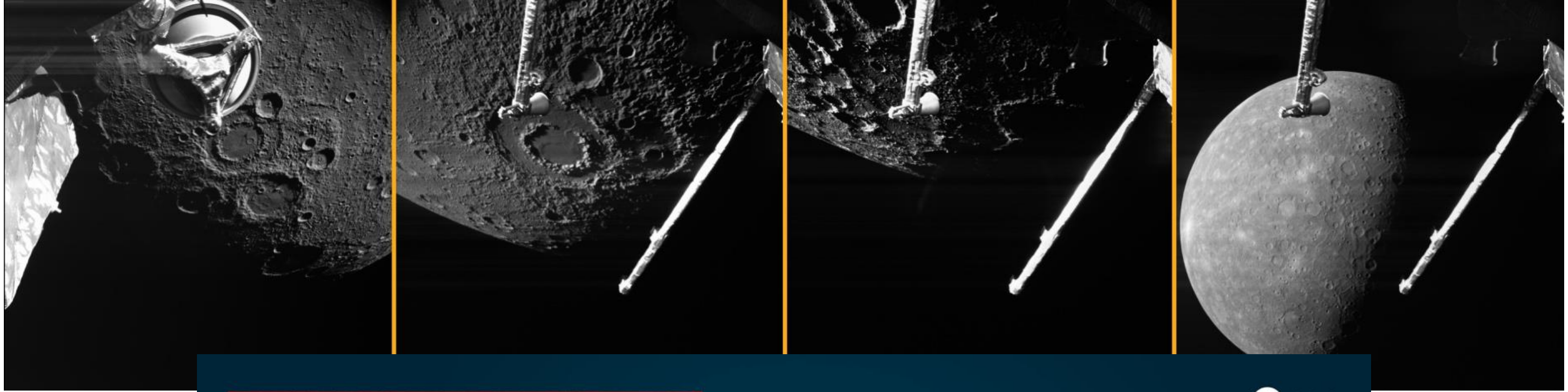
Mercury significant issues (2008-present) :

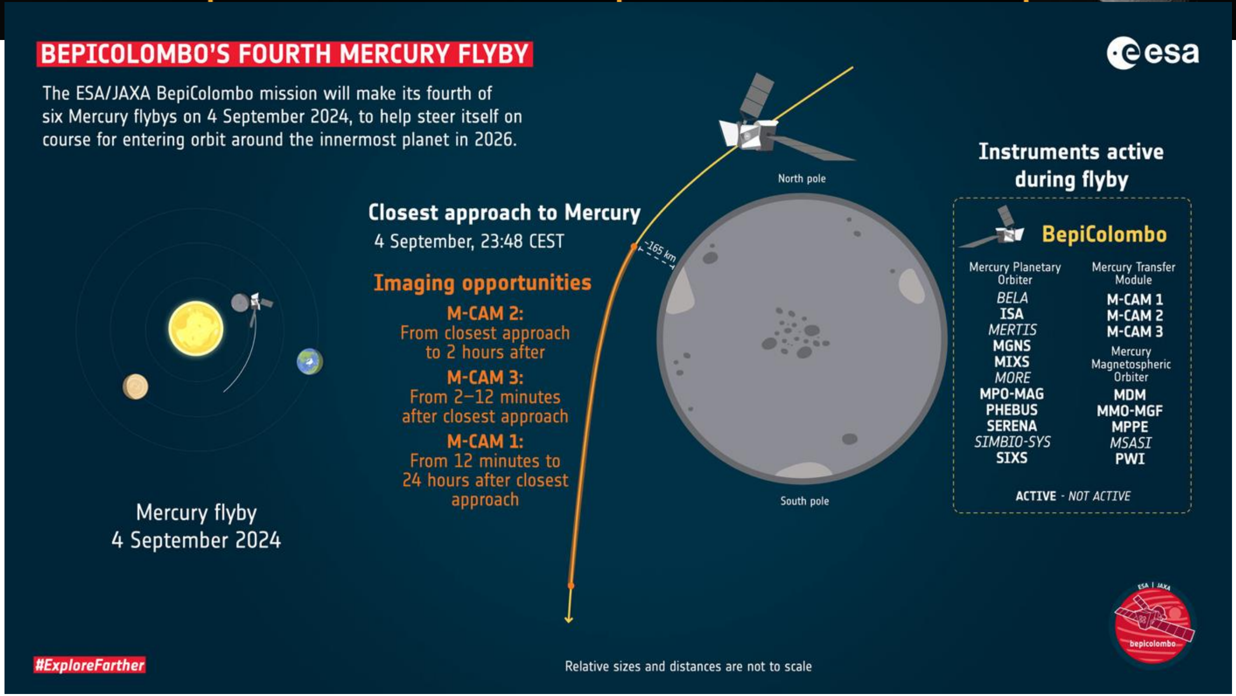
Magnetic field (1% Earth's) → liquid metal core! Complex interaction with solar wind. Bipolar magnetic field offset 400 km north of planet equator

Exosphere of O, H, He, and K produced by sputtering of surface material.

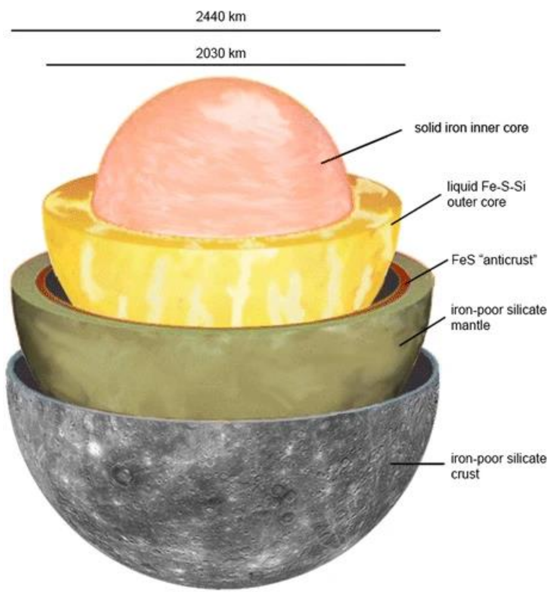
T_{day} = 430° C, T_{night} = -180° C, Possible ice in polar craters in permanent shadow

Messenger found a high abundance of volatiles on the surface (elements such as sulfur, carbon, potassium, chlorine and sodium more abundant than on the Moon)




BEPICOLOMBO'S FOURTH MERCURY FLYBY
esa
The ESA/JAXA BepiColombo mission will make its fourth of six Mercury flybys on 4 September 2024, to help steer itself on course for entering orbit around the innermost planet in 2026.
Mercury flyby
4 September 2024
Closest approach to Mercury
4 September, 23:48 CEST
Imaging opportunities
M-CAM 2:
From closest approach to 2 hours after
M-CAM 3:
From 2–12 minutes after closest approach
M-CAM 1:
From 12 minutes to 24 hours after closest approach
~165 km
North pole
South pole
Instruments active during flyby
BepiColombo
Mercury Planetary Orbiter
BELA
ISA
MERTIS
MGNS
MIXS
MORE
MPO-MAG
PHEBUS
SERENA
SIMBIO-SYS
SIXS
Mercury Transfer Module
M-CAM 1
M-CAM 2
M-CAM 3
Mercury Magnetospheric Orbiter
MDM
MMO-MGF
MPPE
MSASI
PWI
ACTIVE - NOT ACTIVE
ESA | JAXA
bepicolombo
#ExploreFarther
Relative sizes and distances are not to scale

Questions about Mercury for Bepi-Colombo



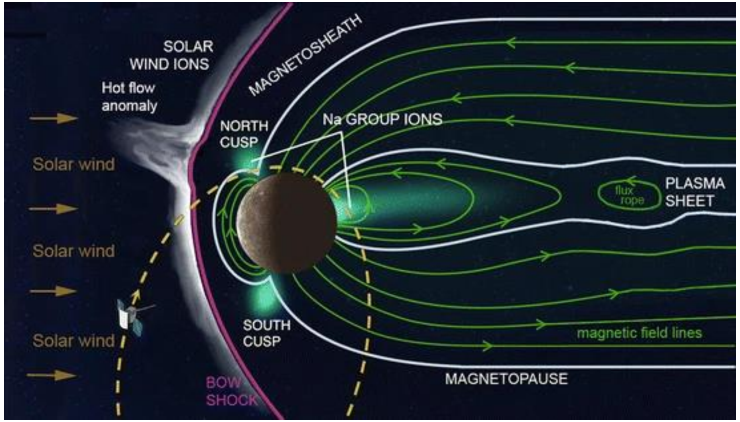
Where did Mercury form? Why such a large core?

Is there water? How much? Where from?

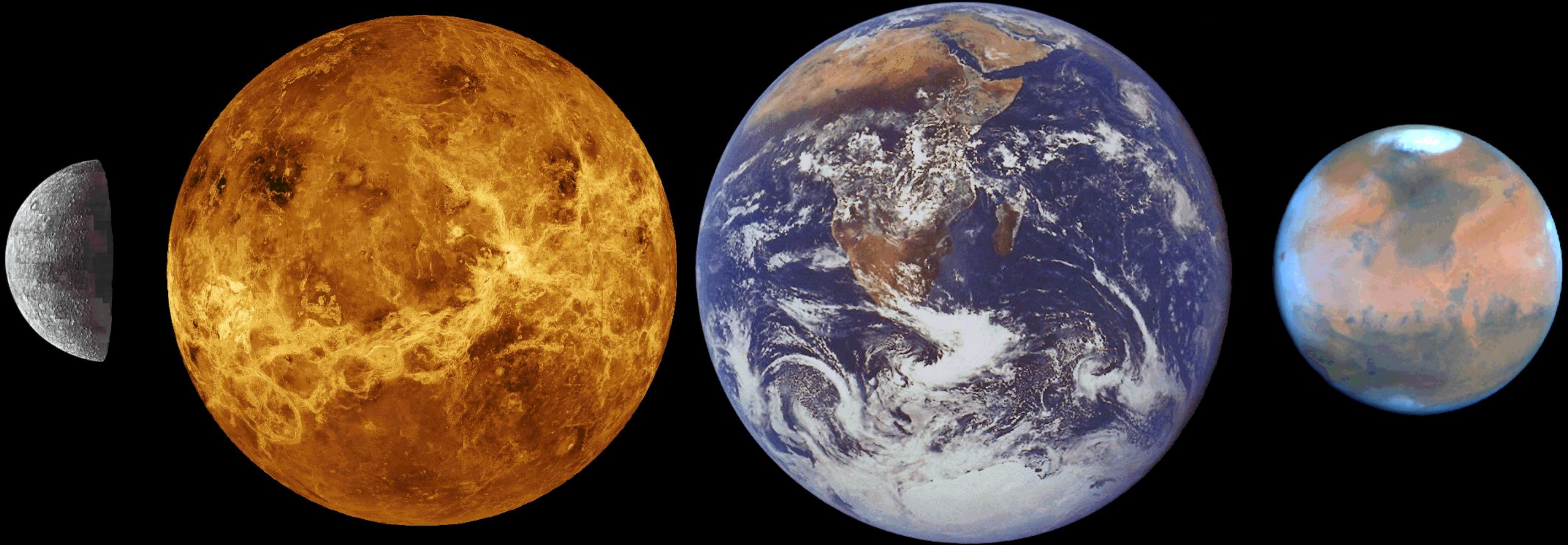
Is there surface activity? Is it due to volatiles?

Why so dark?

Why so magnetic?
Does the offset vary?
How can such a small world remain molten in its interior?



Venus



Exploration

Arecibo – Radio/radar telescope

Mariner 2 (first planetary flyby, 1962), 5, 10. Venera 1-3.

Venera landers: 7 (1970), 8, 9(first pictures,), 10, 13, 14 17,18

Pioneer Venus orbiter & surface probes (radar altimeter, 1978),
Venera 15,16 (1983, synthetic aperture radar)

Magellan (arrived Aug '90, radar resolution 120 meters)
Vega 1, 2 (1985 flyby)

Venus Express (arrived 2005, still orbiting)
IR imaging (Heat-map of surface)
study of atmospheric composition

Venus is Earths “twin:”

Mass = .815 Earth,

Radius: 6200 km (.95 Earth),

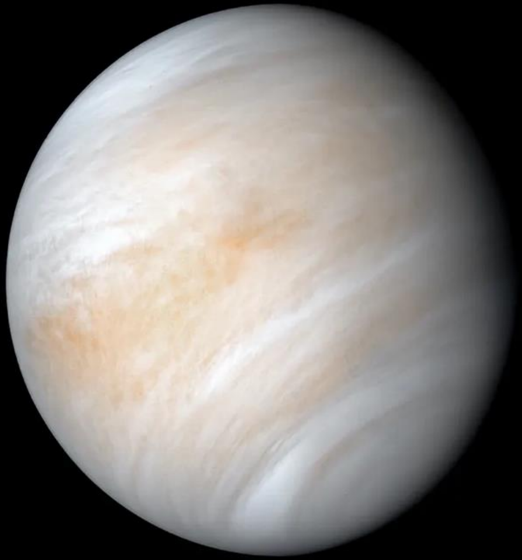
Density: 5200 kg/m^3

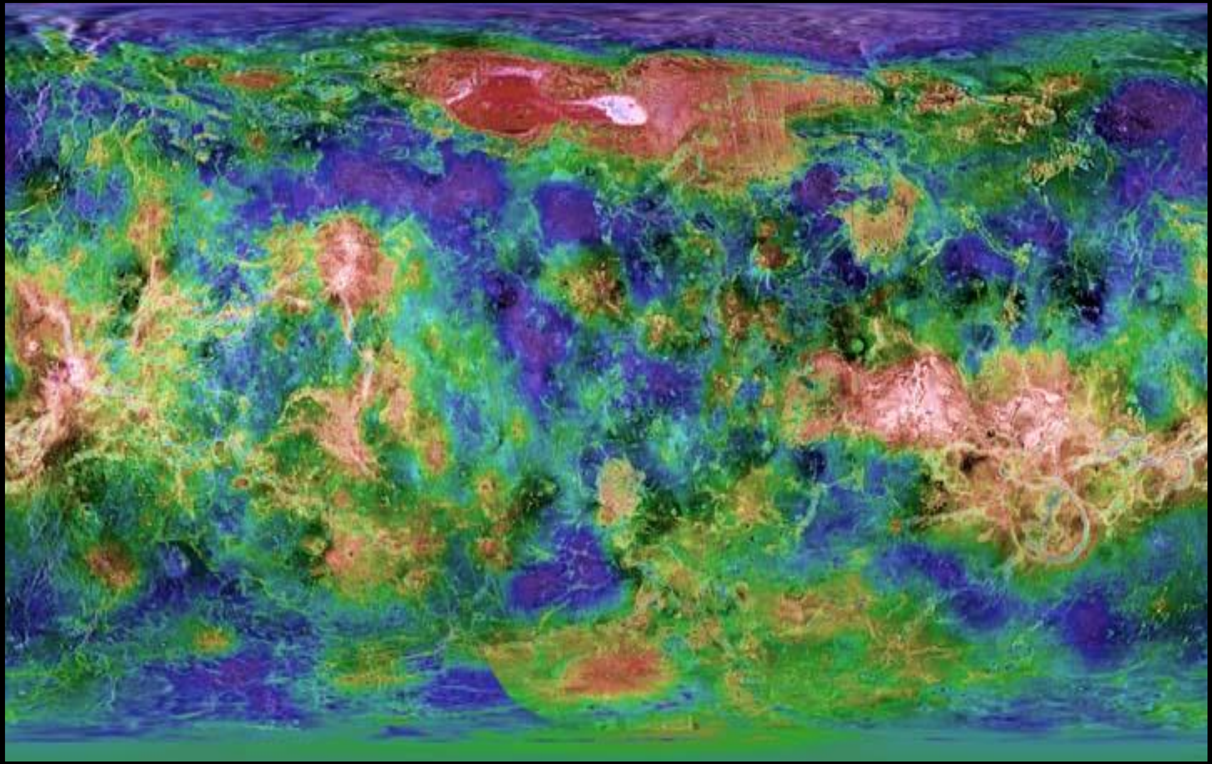
BUT

No magnetic field (maybe due to slow 243.01 day retrograde rotation)

Massive atmosphere of CO_2, 90x Earth, clouds of suphuric acid

Average surface temperature: 730 K = 460° C = 900° F



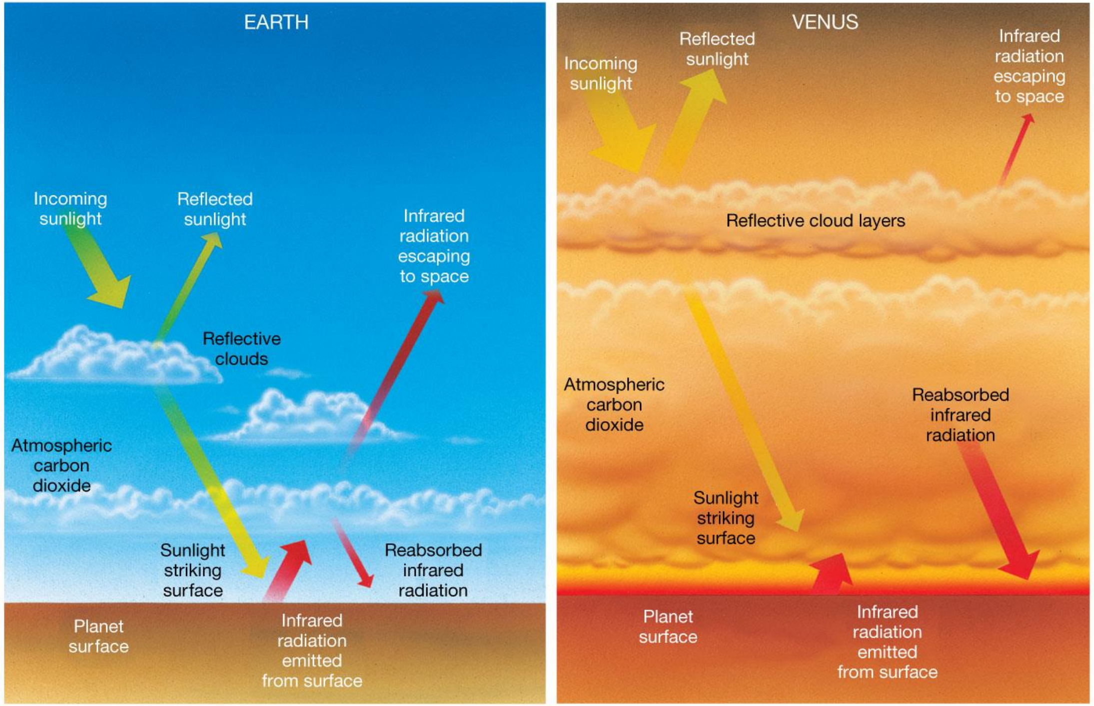


Venus in visual (left) from Mariner 10 in 1974

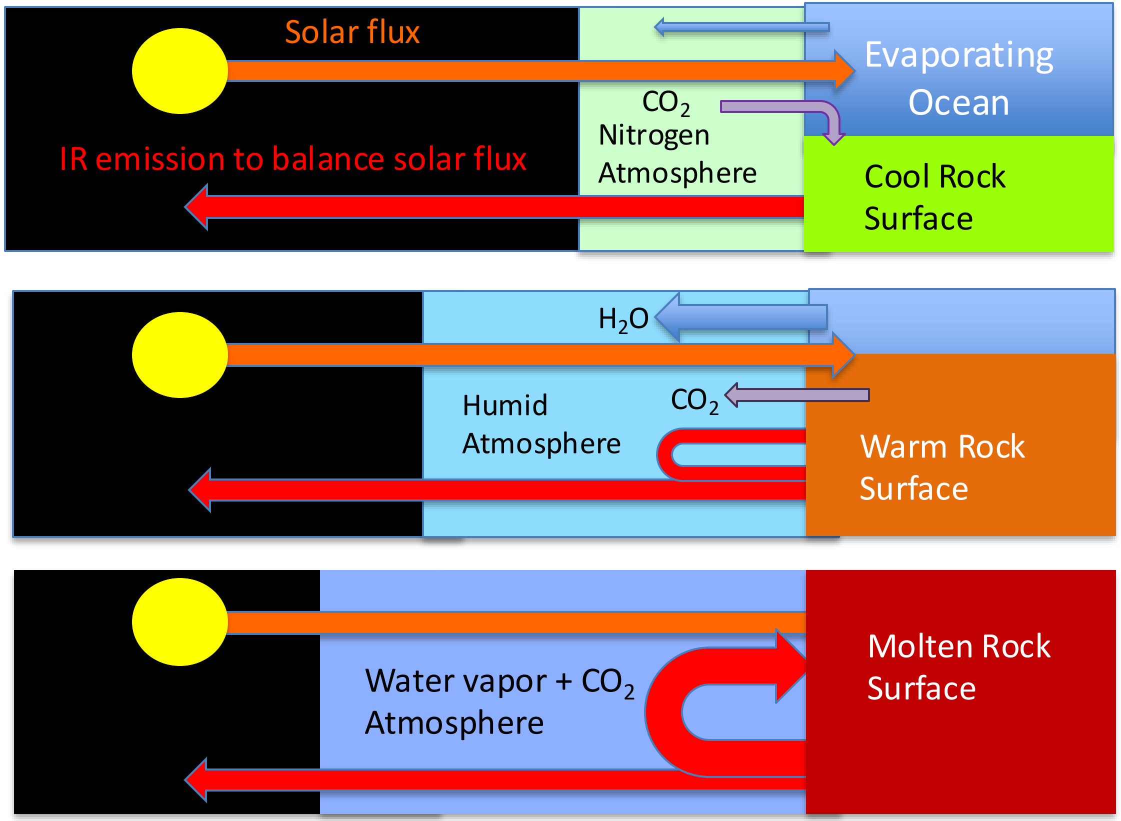
Surface elevation map from Magellan in 1994

The Atmosphere of Venus

Venus is the "victim" of a runaway greenhouse effect— surface just kept getting hotter and hotter as infrared radiation was reabsorbed and more CO_2 was released



Atmospheric evolution onVenus – Runaway greenhouse effect



4.3 Gyr— Atmosphere similar to early Earth, but warmer.

4.1 Gyr— H_2O vaporizes, CO_2 extracted from carbonate minerals. Increasing greenhouse

4.0 Gyr—super-greenhouse.
Steam eventually dissociated by sunlight, H escapes, O reacts with surface.

Venus should be a burning warning for anyone on a similar planet

Venus is what happens if CO_2 emission runs unchecked

Except for *Venus Express*, little recent investigation of Venus

– 40 missions 30-50 years ago

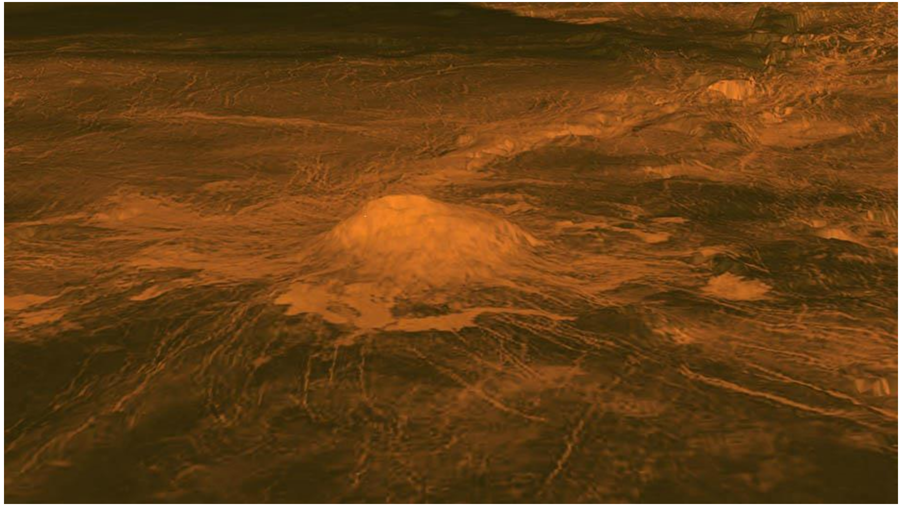
Several planned missions, but none in the near future

(NASA missions VERITAS and DaVINCI in perhaps 10 years)

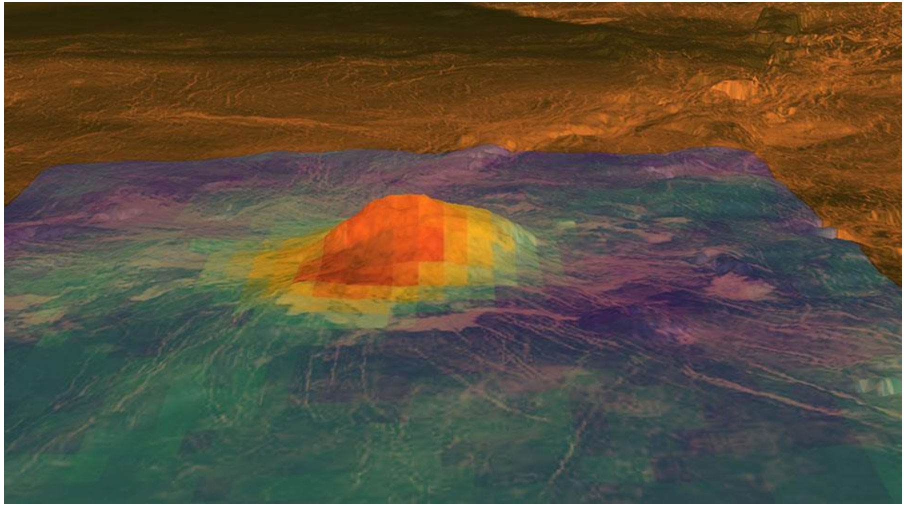
Continuing analysis of older data produces some advances:

Evidence for active volcanism continues to accumulate: SO_2 variation, surface changes, thermal mapping

Evidence for resurfacing due to tectonic activity without drifting crustal plates.

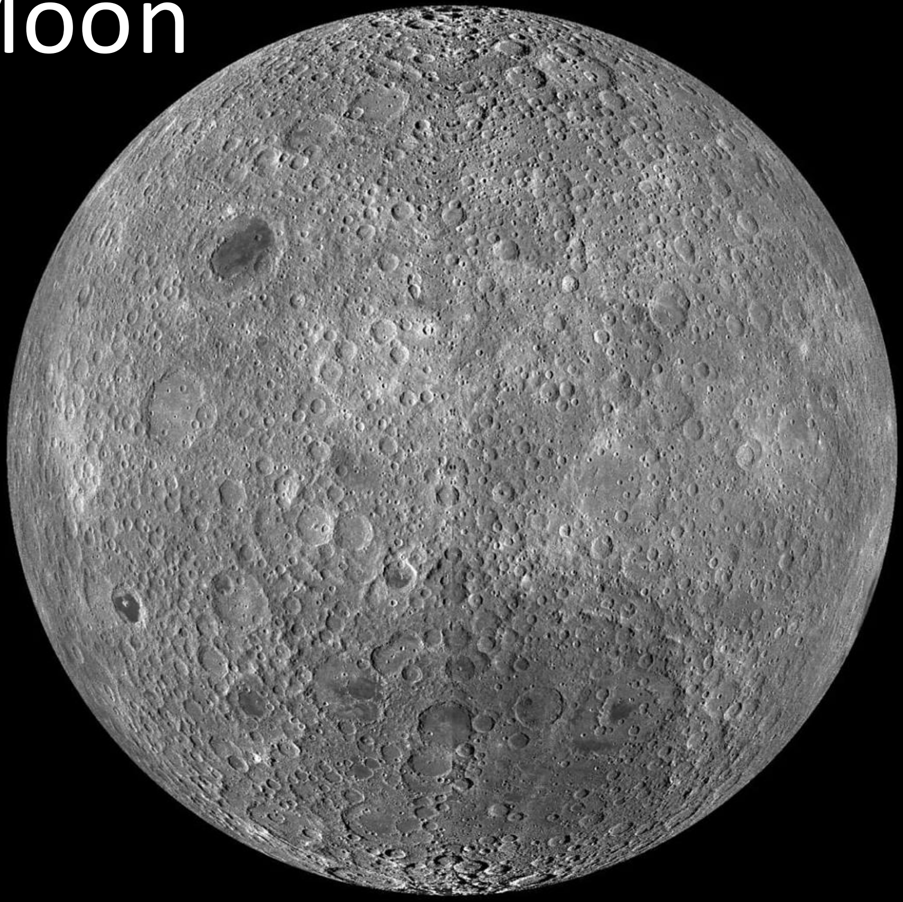


Idunn Mons from Magellan radar altimeter and roughness imaging



Same image with IR temperature data from Venus Express overlayed in color

The Moon



Apollo (1962-72) science results

Distance: From retro reflectors: moon receding 3.8 cm/yr

Seismography: Dense, small (iron?), core, but mainly rock.

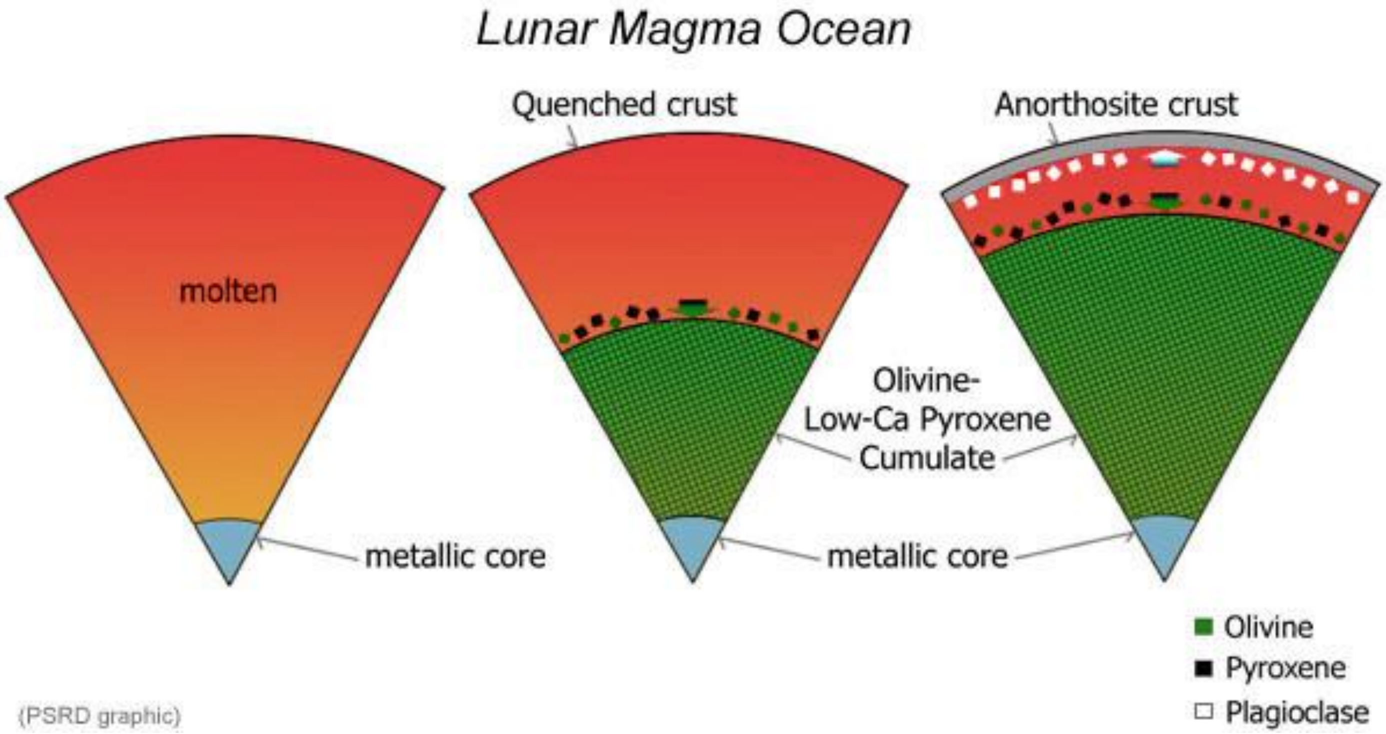
Surface composition from returned samples:

Similar to Earth, basalt and feldspar, but deficient in volatiles,
Age 3.1-3.9 Gyrs (maria) 3.8-4.2 Gyrs (Highlands),
oldest rocks 4.4 Gyrs

Theory of origin: Impact/ejection/hot re-accretion

Evolution: Magma ocean cools to form feldspar crust, maria flooded with lava over 800 million years. Inspires general theory of

Hot Evolution of Planets



The idea that the Moon melted substantially (probably completely) when it formed, nicknamed the magma ocean concept, is an important theory in lunar and planetary science. The basic idea is that as the molten Moon (left) crystallized (center and right), minerals less dense than the magma floated and the heavier ones sank. The lighter minerals (plagioclase feldspar) formed the primary crust of the Moon.

http://www.psrd.hawaii.edu/July19/Apollo11-discoveries.html

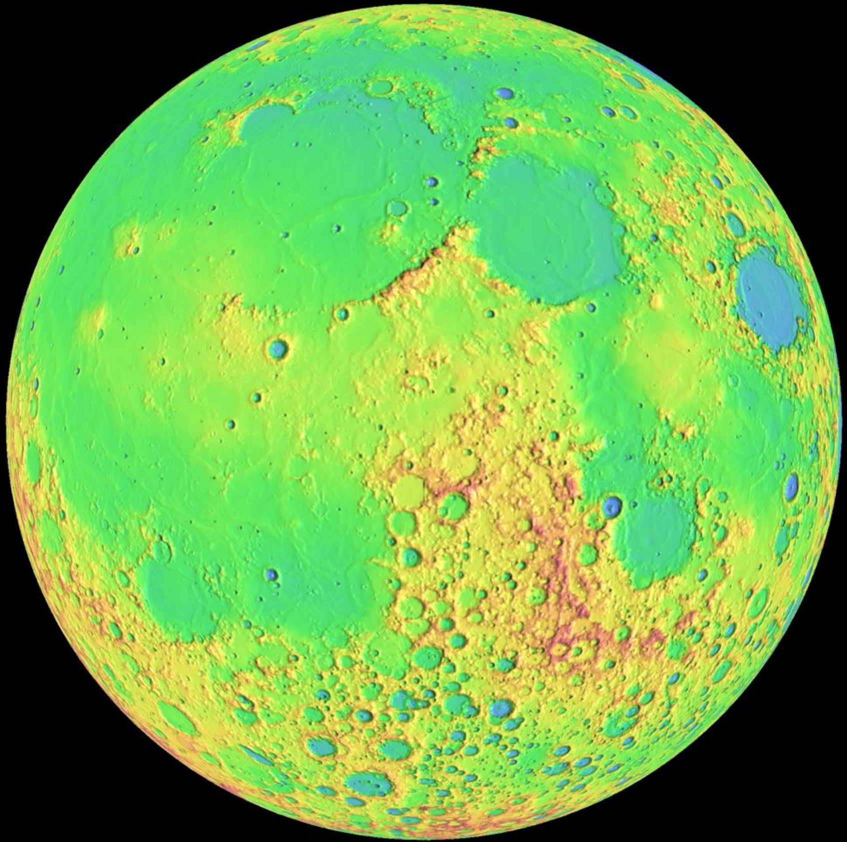
Lunar science since Apollo

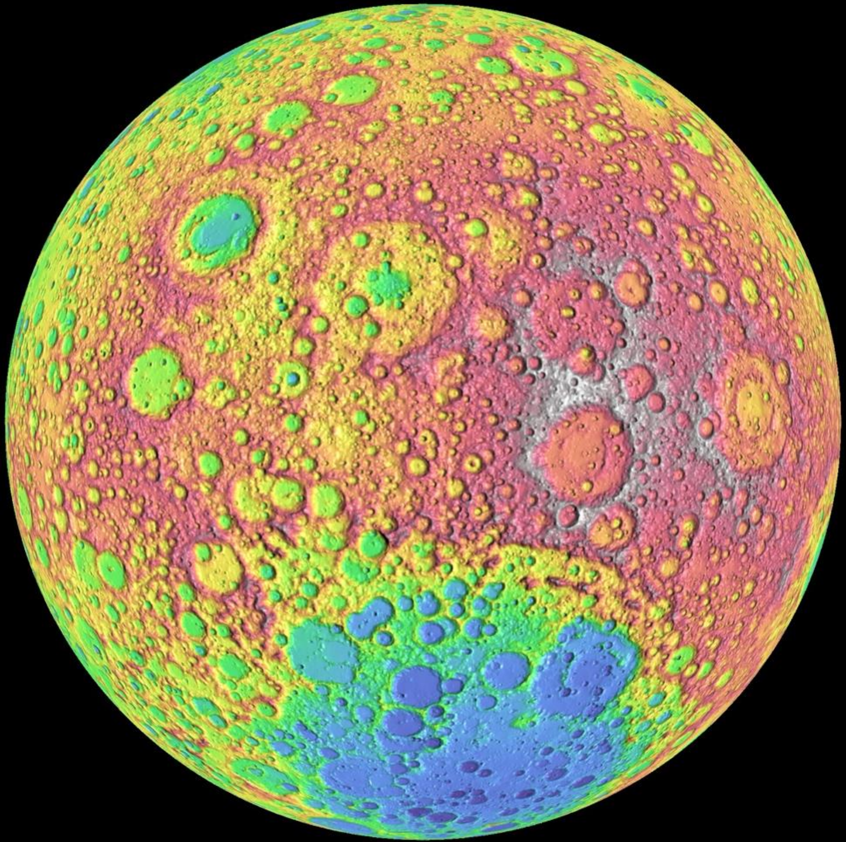
General lull for 40 years – renewed interest in the early 2000's

Focus of current research planning is more exploitation than science:

(a) Water! South pole!
(b) Minerals (^3He ? Oxygen? Economics?)
(c) Habitable base
(d) Waystation for Mars

NASA -- Lunar Reconnaissance Orbiter (LRO) -2009-present: Discovery of extensive subsurface hydrates, mineral mapping, detailed surface elevation mapping. Also GRAIL (2011) – mapping lunar gravity field.





Lunar science since Apollo

China's Chang’e series (1-6) – 3-> lander and rover, 4-> lander and rover on farside, 5-> sample return, 6 (2024) 2 kg sample return from farside

India's Chandrayaan-1 and 2, 2009, 2019-present – “atmospheric” water?
Chandrayaan-3: Vikram lander landed near the lunar south pole Nov 2023.
+ Pragyan rover wheeled and “hopping” – surface material analysis.
Both survived 12 days.

Japan's SELENE orbiter 2007-9, surface environment mapping, detection of trace oxygen. SLIM in Jan-Aug 2024, lander + 2 detached rovers – demo of precise landing system, but landed nose first –limited electric power.
Survived 4 lunar days

South Korea, Pakistan, ESA, all have made minor lunar probes. Many nations collaborate on the ongoing NASA Artemis program.

Key Lunar Science Questions

Interior structure?

Clarify origin by impact?

Details of asymmetry?

Details of environment?

Water and Habitability?

Crewed missions to the moon.

NASA Artemis program (ESA, JAXA, UAE, CSA participating) aims to put people on the lunar surface no sooner than September 2026

China has funded a mission to land a crewed on the moon by 2030.

Artemis facts:

Compared to Apollo:

Very intent on developing foundation for crewed missions to Mars

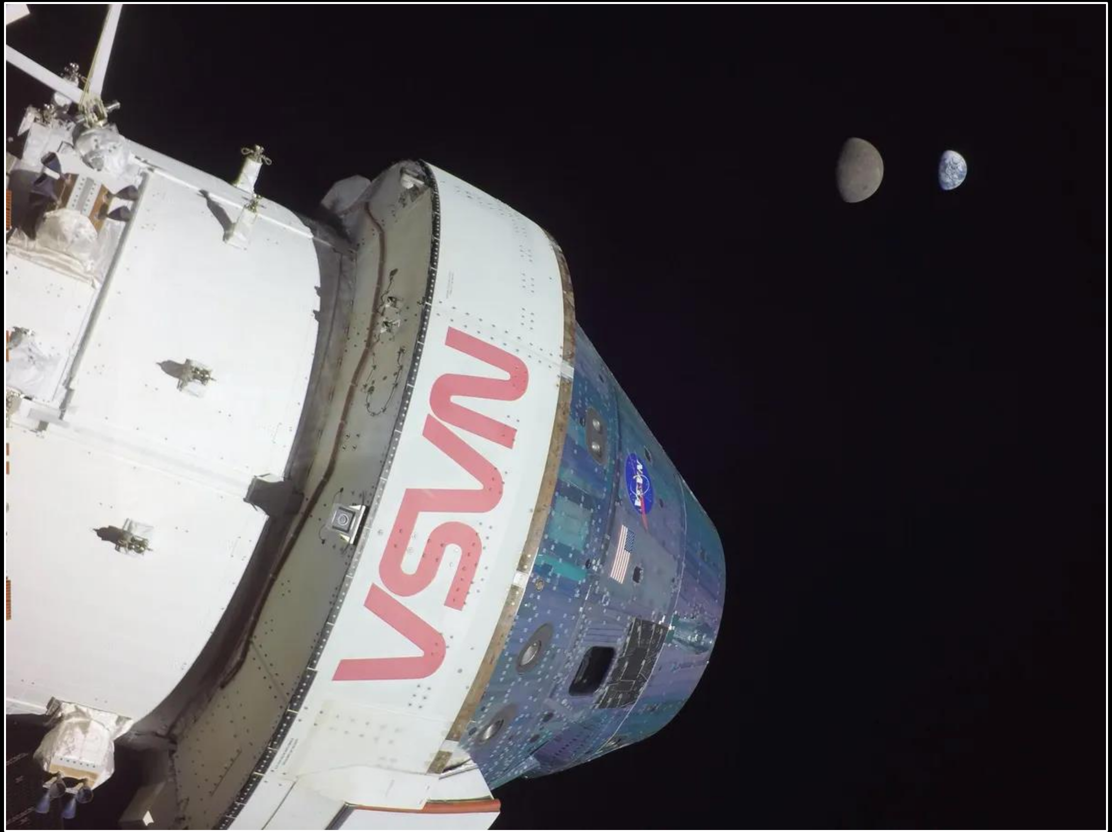
More advanced hardware: safer, more appropriate for deep space.
- New Space Launch System (SLS) rocket (Northrup, Boeing)
- New Orion crewed capsule (Lockheed Martin)
- New Lunar Gateway space station to orbit moon

Cost of 5 missions \$93 B (0.2% of federal budget over 13 years)
  Apollo was \$290 B (2.0% of federal budget over 12 years)

Key Artemis mission objectives:

- **Science**: Missions will retrieve samples more strategically than during the Apollo era.
- **Long-term presence**: The Apollo 17 crew spent three days on the lunar surface, but Artemis aims to establish a base, extending the trips to weeks and possibly months.
- **Resources**: the discovery of water and rare minerals hold promise for both scientific and economic exploration and exploitation.
- **Technology and Mars Missions:** developments are explicitly designed to pave the way for future crewed deep-space missions.
- **Partnerships**: Establish a model for large-scale collaborations with other nations and with commercial companies such as SpaceX and Boeing.
- **Equality**: to land the first woman and first person of color on the lunar surface.

Artemis 1, an uncrewed test flight, orbited and flew beyond the Moon.



Nov 29, 2022, Artemis 1 at maximum distance from Earth. Image from a camera on end of solar panel

The next missions in preparation:

•Artemis 2 will be a crewed flight beyond the Moon (the farthest humans have ever been in space. (2025)

•Artemis 3 will land the first female astronaut and first astronaut of color on the lunar surface. They will spend a week on the Moon performing scientific studies.(2026)

•Artemis 4 will deliver a core part of a new lunar space station (named 'Gateway') into orbit around the Moon and land another two astronauts on the Moon's surface.(2028)

•Artemis 5 will add another important module to Gateway and involve a third crewed lunar landing to undertake further surface science.(2030)