PROBING THE SOLAR SYSTEM AND BEYOND

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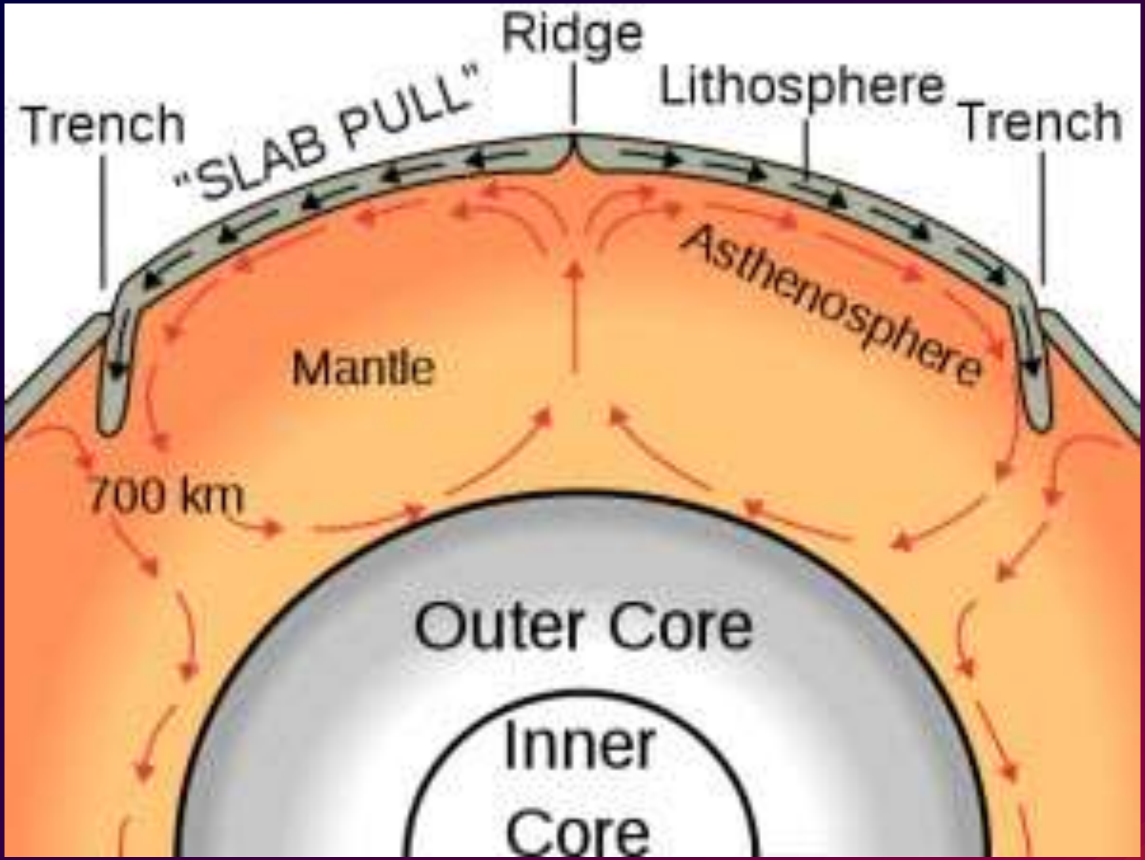
class 6

How do we know about the Earth's interior?

From decades of measuring:

- seismic activity
- heat flow
- gravity anomalies
- geomagnetism on land and at sea
- deep sea cores



the picture of Plate Tectonics emerged.

Earth's internal heat budget is fundamental to the thermal history of the Earth.

The flow of heat from Earth's interior to the surface is estimated at around 50 TW and comes from two main sources in roughly equal amounts:

- **the radiogenic heat produced by the radioactive decay of isotopes in the mantle and crust, and**

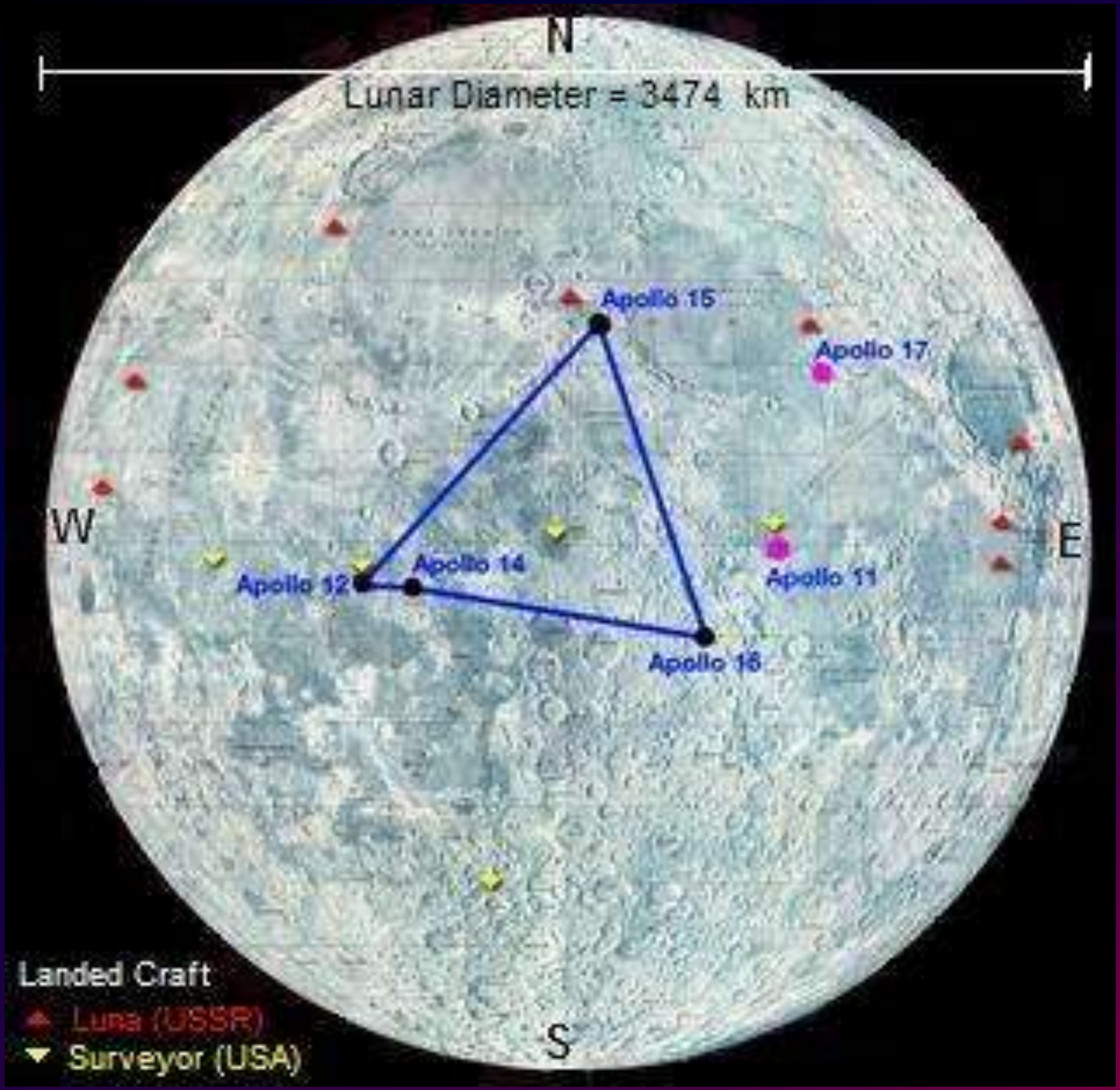
- **the primordial heat left over from the formation of the Earth.**

Astronaut Buzz Aldrin deploying the seismometer

The Apollo 11 Passive Seismic Experiment was the first seismometer placed on the Moon’s surface. It detected lunar "moonquakes" and provided information about the internal structure of the Moon

Heat flow probes drilled around 2 meters into the surface by Apollo 15, 16, and 17.

Heat flow of of around 20 milliwatts per square meter. This is around 20% of Earth’s heat flow at the surface.



Network of seismometers placed on the Moon by Apollo Missions 11, 12, 14, 15, and 16.

Those left by Apollo Missions 12, 14, 15, & 16 were used to triangulate epicenters of lunar quakes.

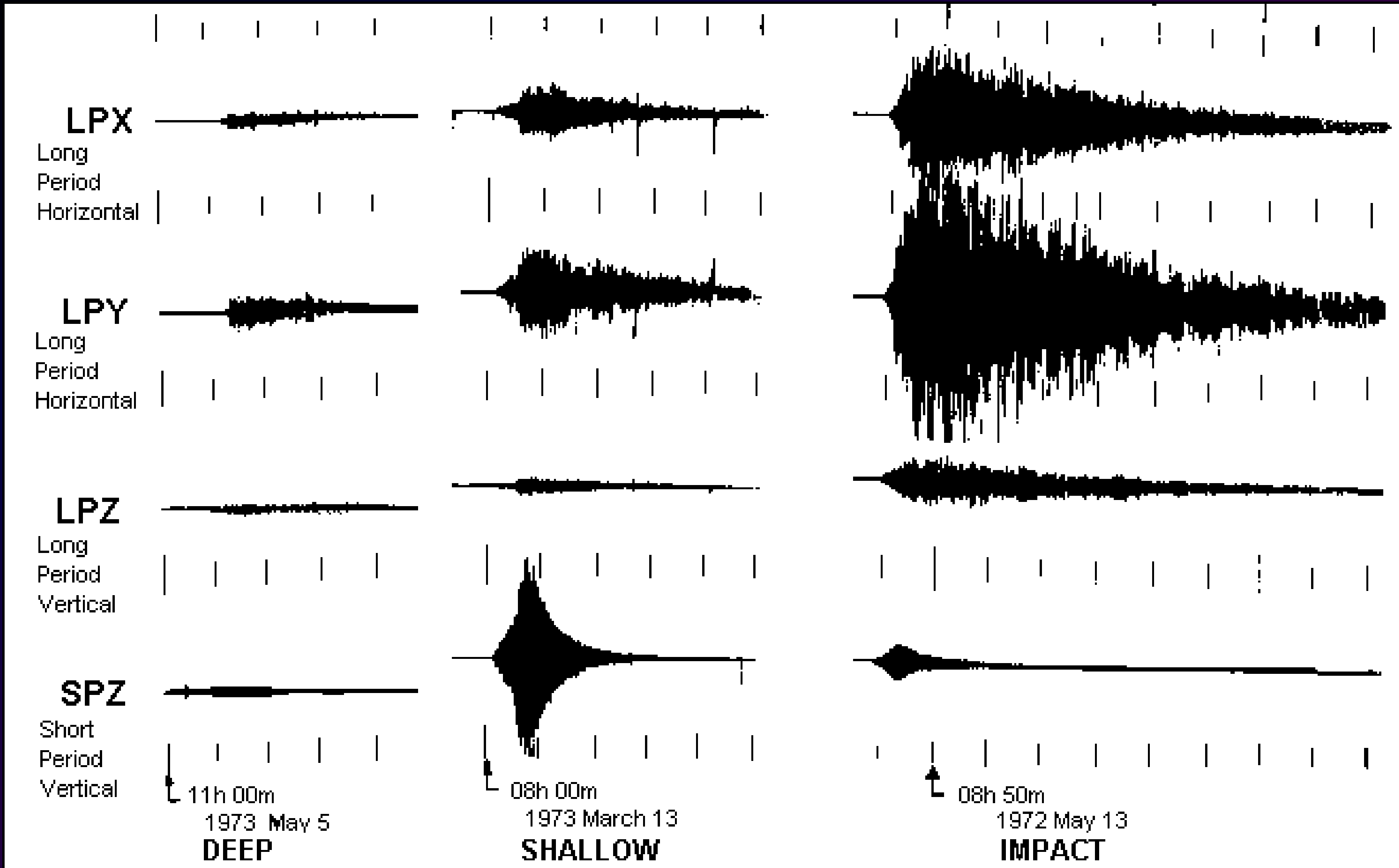
Four types of seismic events found on the Moon:

Thermal Events – small, local, occur around sunrise and sunset, believed to come from abrupt temperature changes, causing small-scale cracking and slumping of the surface.

Deep Quakes – Occur at 700 – 1,000 km, low energy release, come from a limited region of the lunar mantle. Periods of 14 and 206 days. Believed to come from deep shifting due to tidal forces between Moon and Earth and Moon and Sun.

Shallow Quakes – Shallow depths, infrequent, similar to terrestrial intra-plate tectonic events. Origin not known, but can be up to magnitude 5.

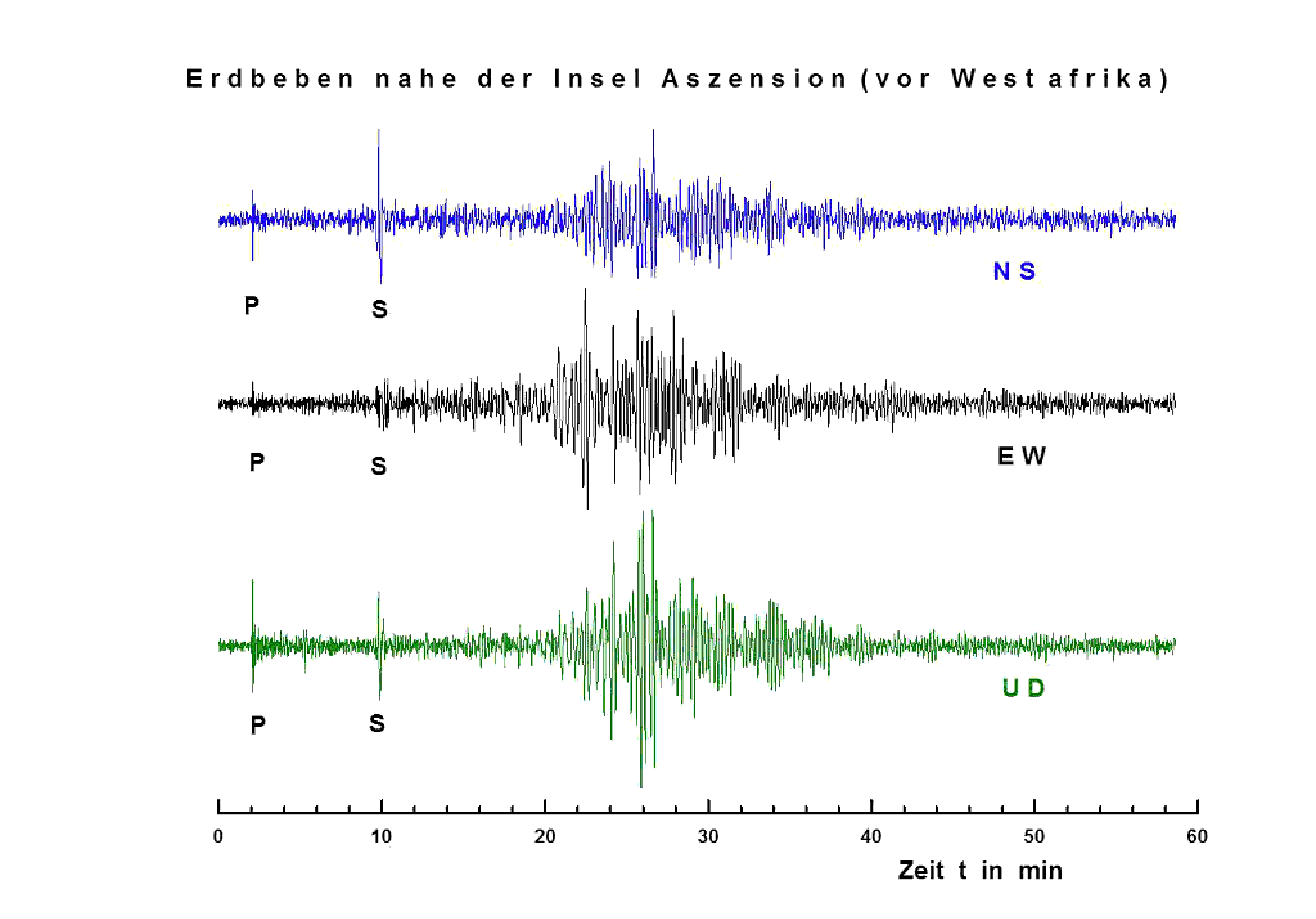
Impact Events – Due to crashing of meteorites and lunar landing modules of human origin.



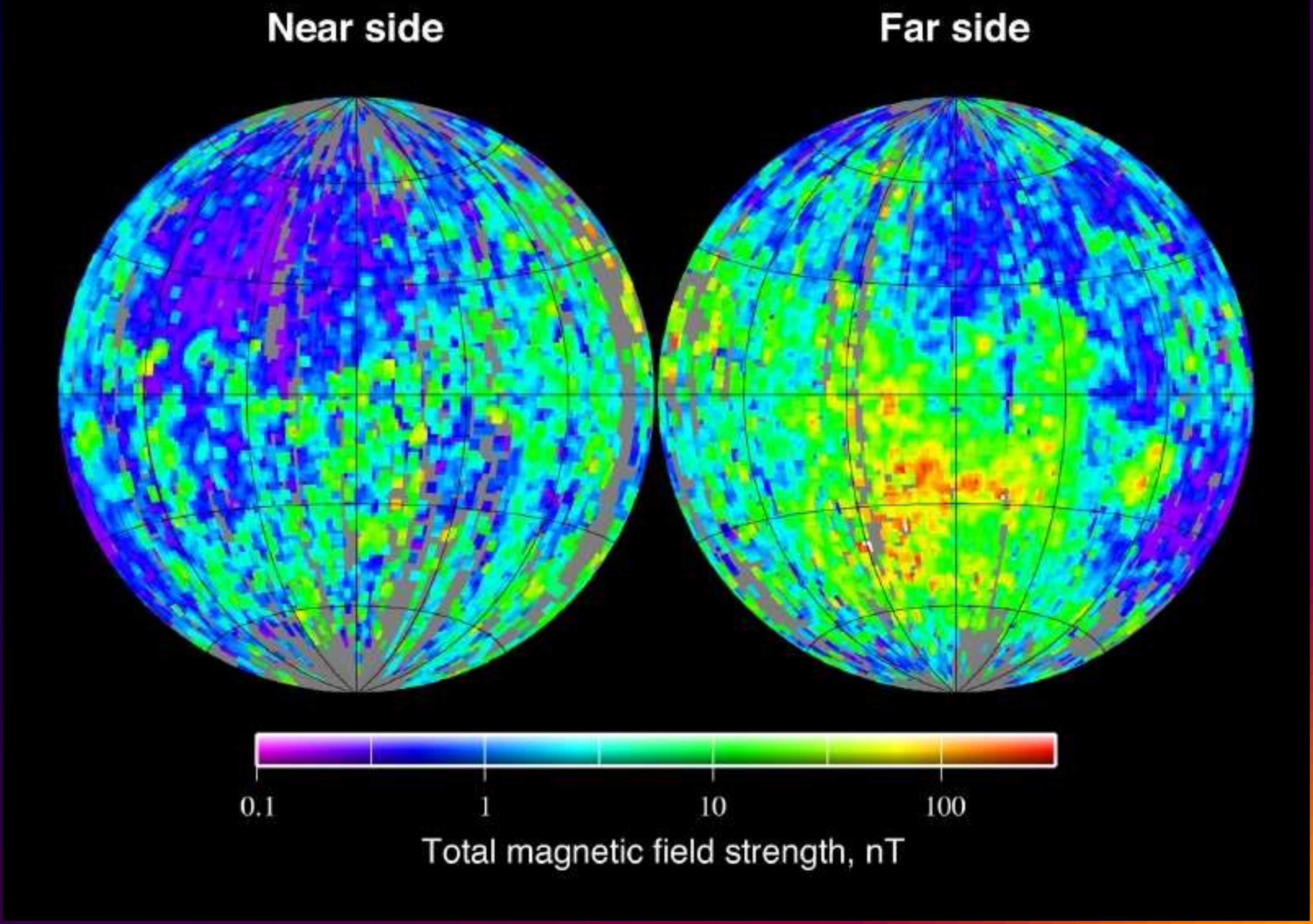
seismograms from the Apollo network

Moonquakes look different from earthquakes on seismograms.

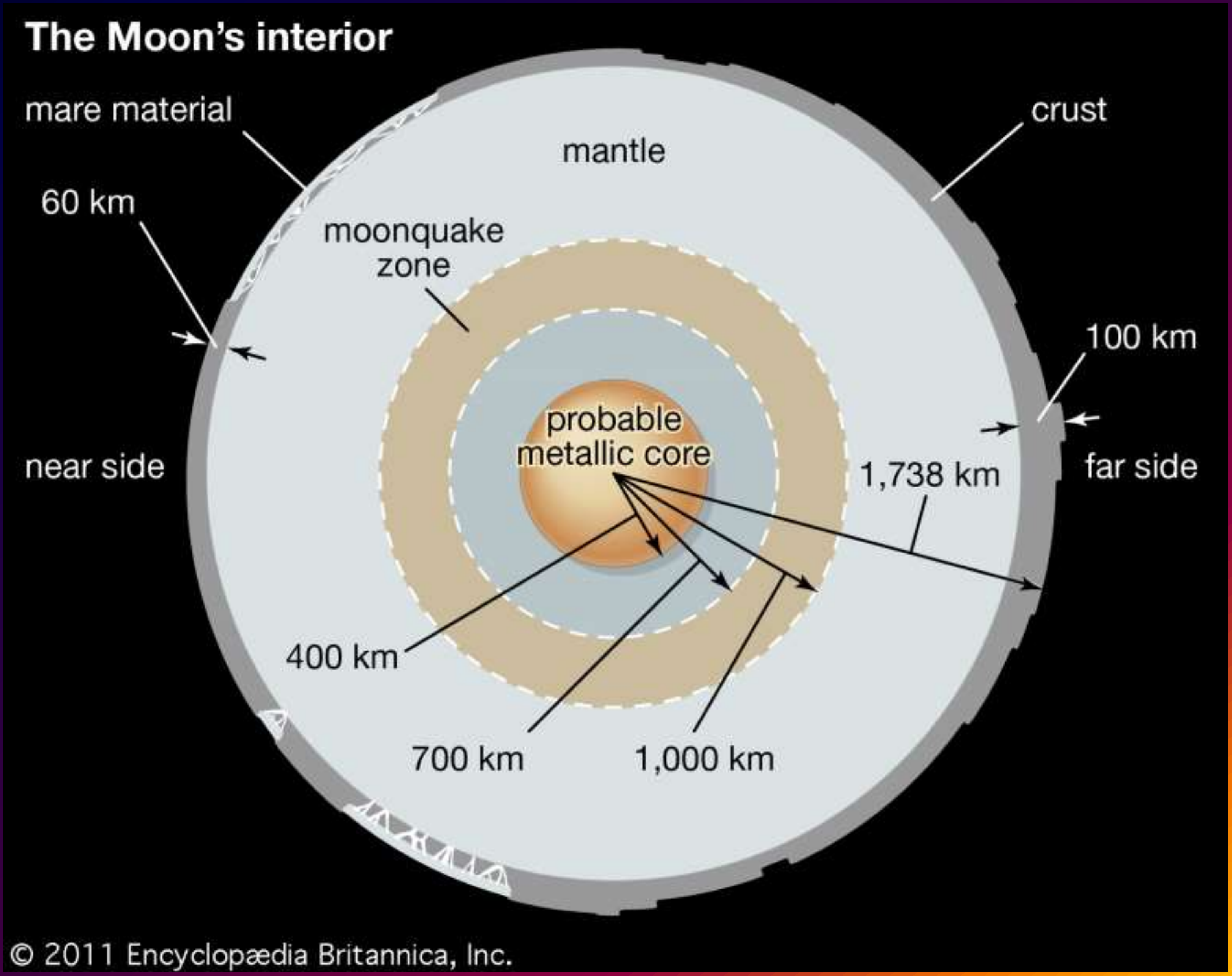
Example of recording of a terrestrial earthquake. Note the sharp onset of the P and S, and the surface wave train.



Magnetic field strength at the surface of the Moon from NASA probes.
The Moon no longer has a dipole field, but apparently it did around 4 Gy ago.



From measuring moon quakes, lunar heat flow, gravity and magnetics, we have a mental picture of the differentiated interior of the Moon.



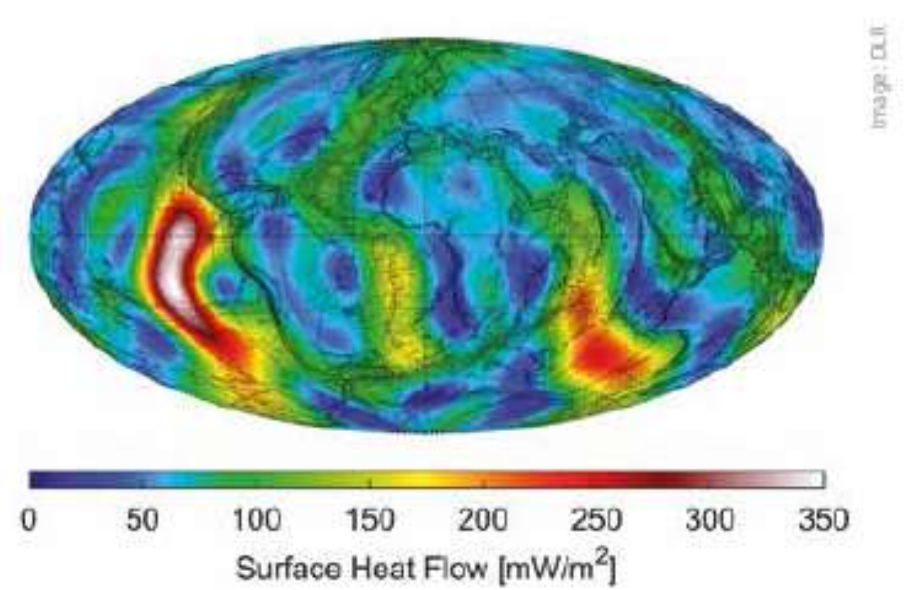


Figure 4: A spherical harmonics model of the Earth's surface heat flow based on 38,374 measurements, plotted on a shaded relief topographic map.

Earth's heat flow at the surface

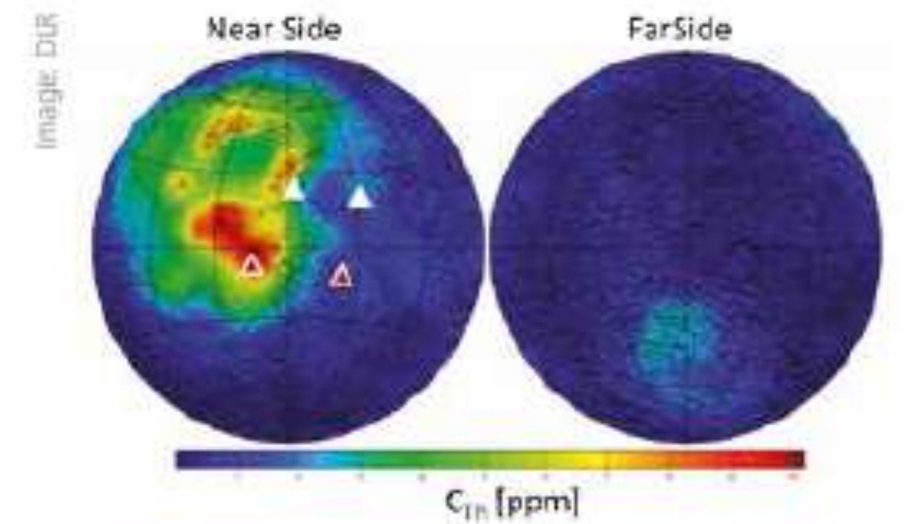


Figure 6: Color coded map of near-surface thorium abundance as measured by the Lunar Prospector Spacecraft. On the lunar nearside, a strong enrichment of Th is visible in a region termed the Procellarum KREEP terraine (PKT). Thorium is also enriched in the Southpole-Aitken basin (SPA) on the lunar farside. Apollo 15 and 17 landing sites are indicated by white triangles, while the Apollo 14 and 16 sites are indicated with red triangles. Apollo 14 retargeted the Apollo 13 site, located in the center of the thorium anomaly.

Moon's heat flow at the surface

In Situ Heat Flow Measurements on the Earth, Moon, and Mars
https://elib.dlr.de/115935/1/Kap_2_Grott_20170928.pdf
by M. Grott and A. Hagermann Sep 28, 2017

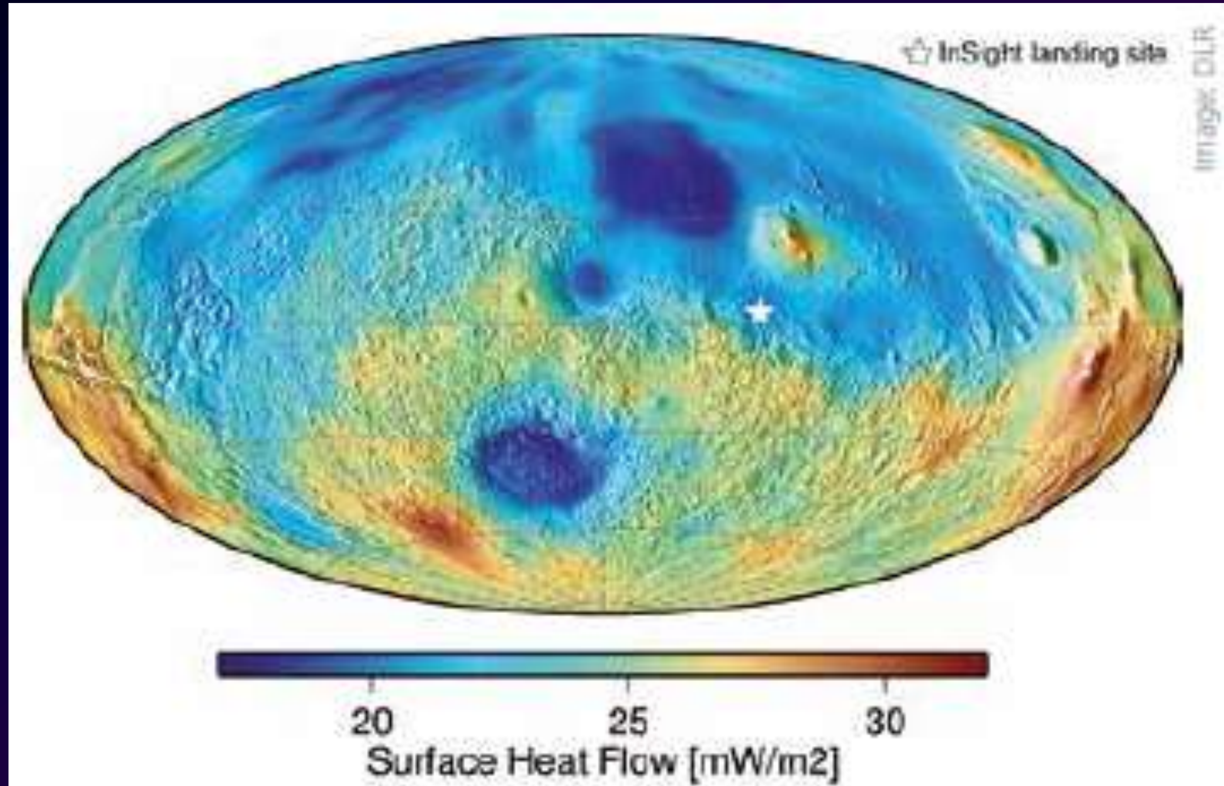


Figure 7: Theoretical Model of the Martian surface planetary heat flow as predicted by a thermal evolution model. A Wänke and Dreibus bulk composition of heat producing elements (Wänke and Dreibus, 1994) has been assumed. Models of the present-day crustal thickness (Neumann et al., 2004) as well as the distribution of heat producing elements between crust and mantle (Taylor et al., 2006) have been used as model inputs. The targeted landing site of the InSight mission is also indicated.

Model of predicted Martian surface heat flow

INSIGHT probe, launched May 5th, 2018; landed on Mars Nov. 26th 2018
Interior Exploration using Seismic Investigations, Geodesy and Heat Transport

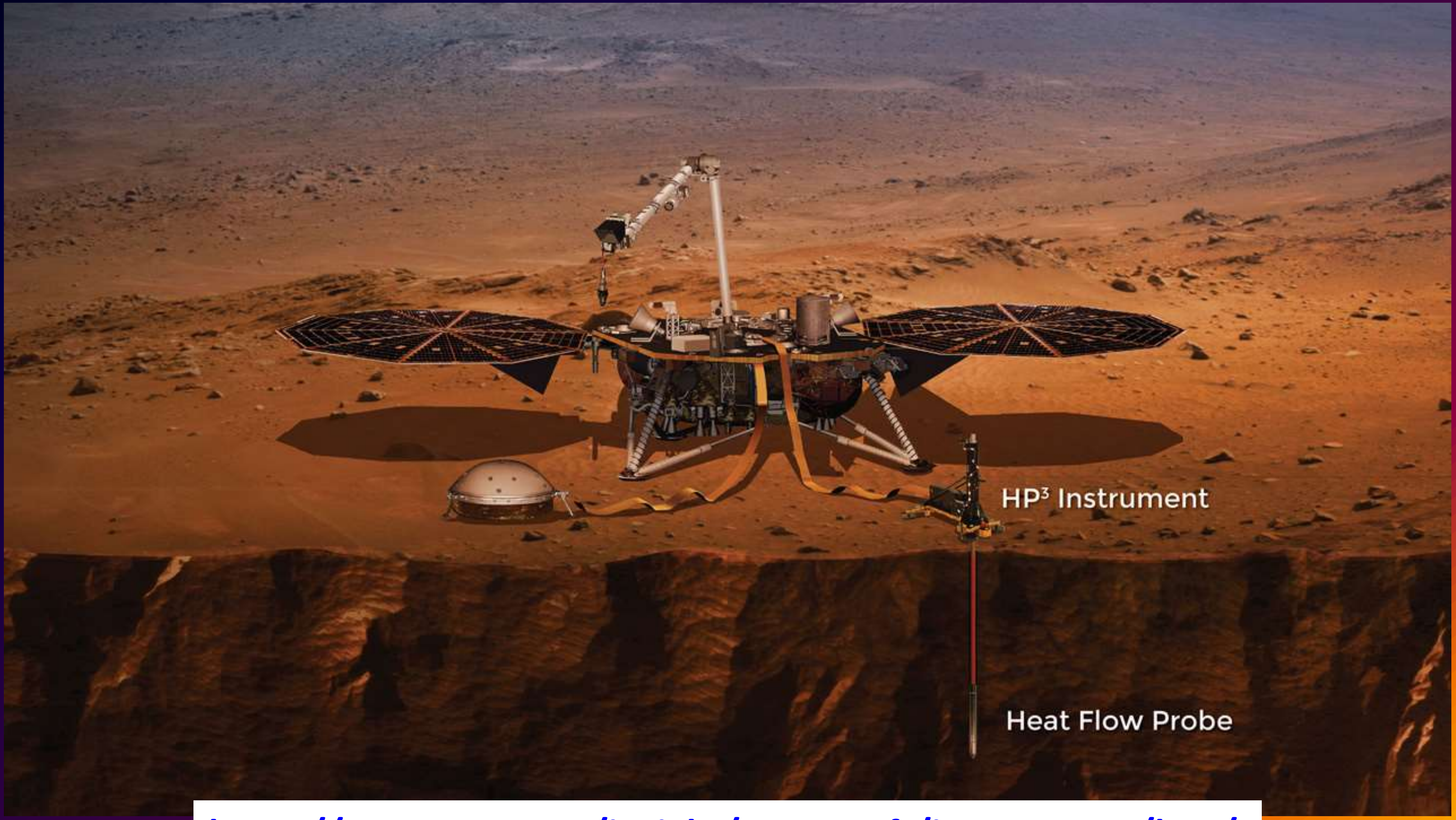
InSight Science Goals:

To uncover how a rocky body forms and evolves to become a planet by investigating the interior structure and composition of Mars.

The mission will also determine the rate of Martian tectonic activity and meteorite impacts.

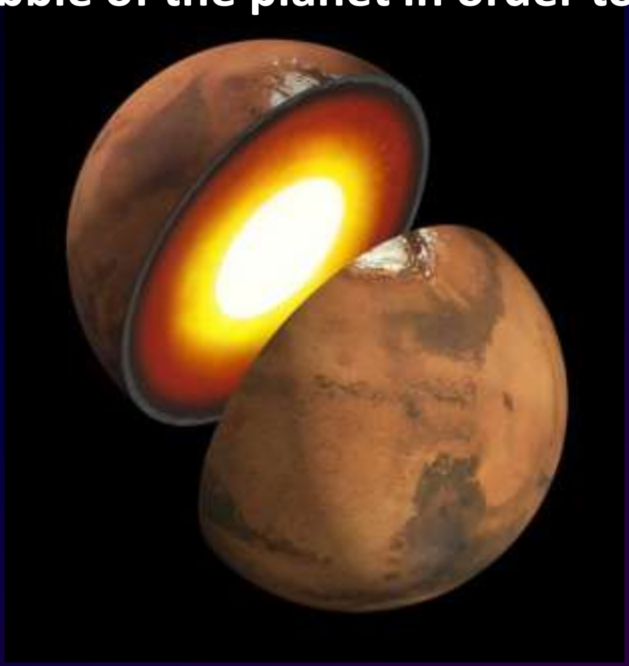
One of the first images of the surface taken by INSIGHT's camera.

The Heat Flow and Physical Properties Probe, HP3 for short, burrows down to almost 16 feet (five meters) into Mars' surface. That's deeper than any previous arms, scoops, drills or probes before it.

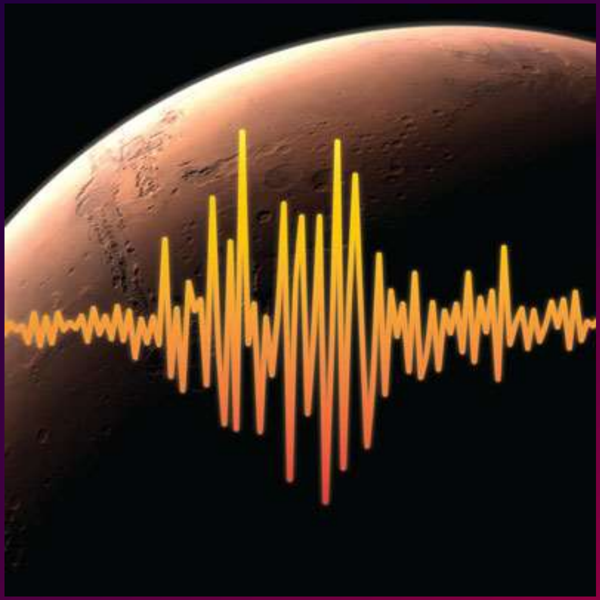


https://mars.nasa.gov/insight/spacecraft/instruments/hp3/

Science Goals: To measure heat flow, seismicity, and slight wobble of the planet in order to determine:

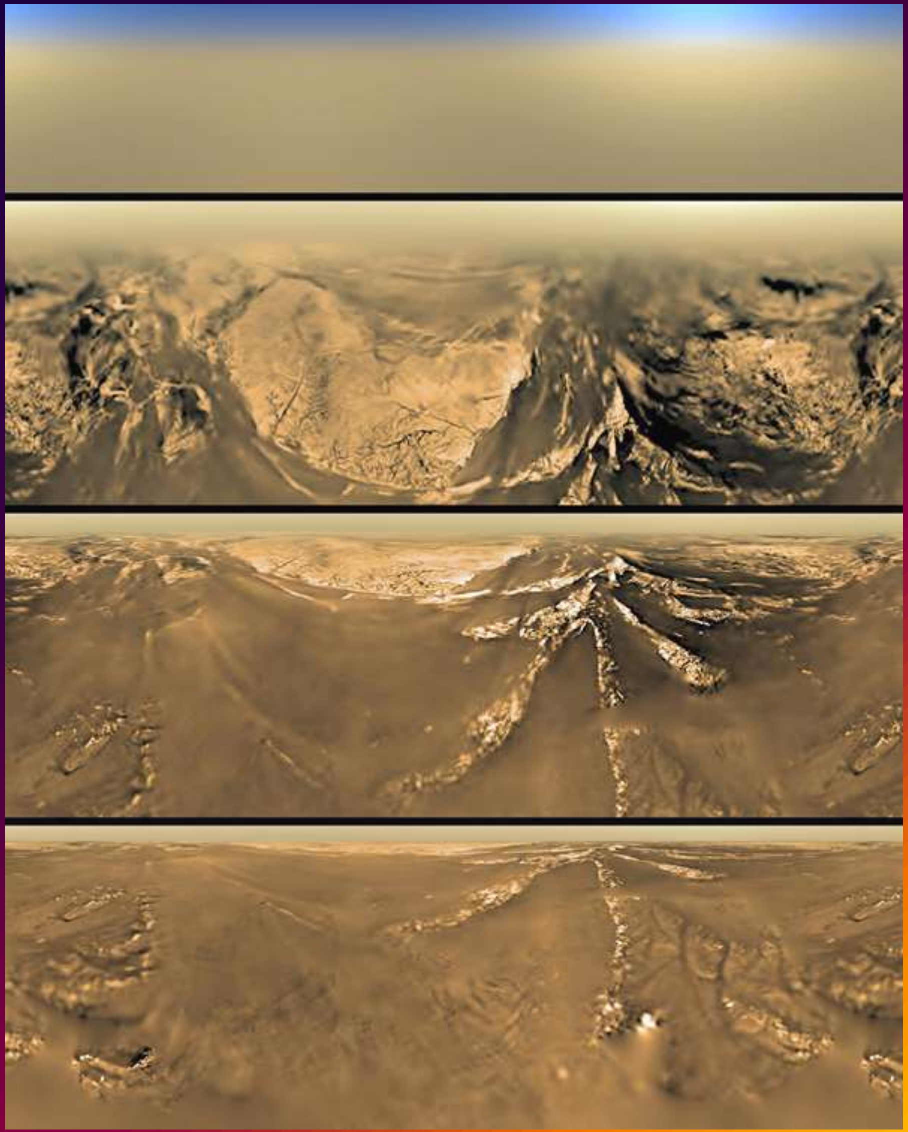


- **The size of the core, what it is made of, and whether it is liquid or solid.**
- **The thickness and structure of the crust.**
- **The structure of the mantle and what it is made of.**
- **How warm the interior is and how much heat is still flowing through.**



- **How powerful and frequent internal seismic activity is on Mars, and where it is located within the structure of the planet.**
- **How often meteorites impact the surface of Mars.**

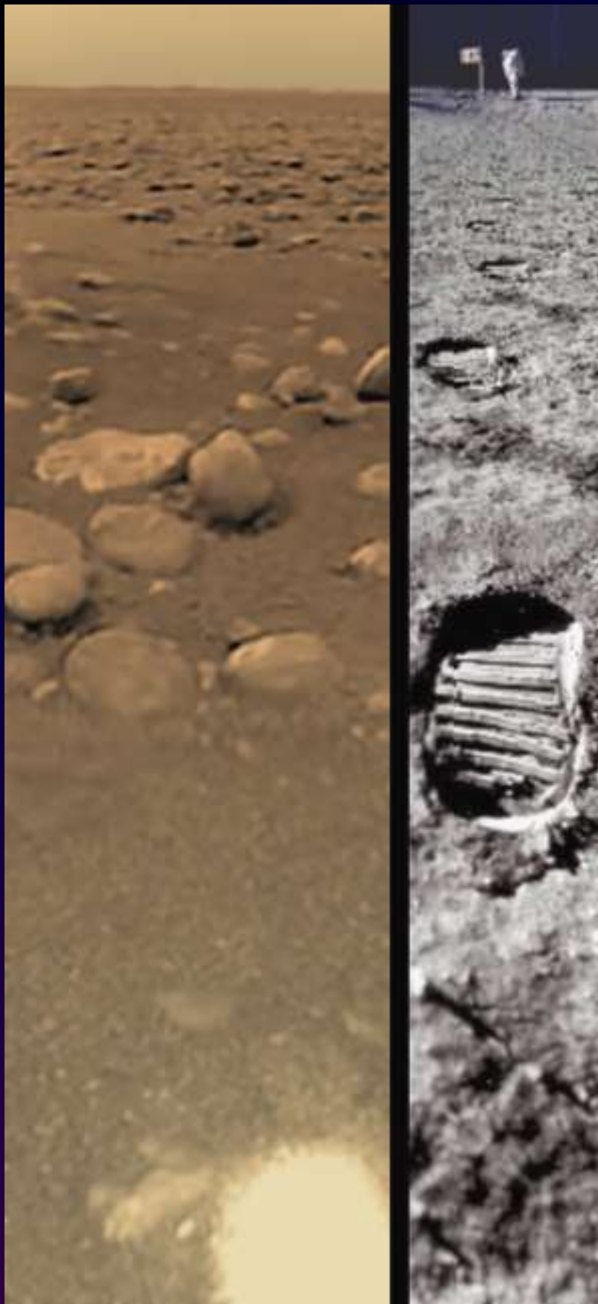
Touchdown on Titan: How we landed a probe on another planet's moon
In 2005, the Huygens probe pierced the shroud of Saturn's moon Titan to reveal a surprisingly Earth-like world.
By Korey Haynes | Published: Friday, October 19, 2018



This progression of vistas from four different altitudes, from highest (top) to lowest (bottom), shows flattened (Mercator) projections of the moon as Huygens punched through Titan's haze to reveal its strangely Earth-like surface features.

ESA/NASA/JPL/University of Arizona
Geronimo!

http://www.astronomy.com/magazine/news/2018/10/touchdown-on-titan-how-we-landed-a-probe-on-another-planets-moon



Huygens' final landing site (left) reveals a bed of water and hydrocarbon ice, dotted with rocks showing smoothed edges and other signs of erosion.
This image was taken with the probe's Descent Imager/Spectral Radiometer and colored based on spectral data to give a true sense of the terrain's appearance.

A familiar image of an astronaut's footprint from the Apollo Moon landings (right) illustrates the scale of Huygens' view.

ESA/NASA/JPL/University of Arizona

in Titan’s haze layers, Huygens detected molecules similar to tholins produced in earthly laboratories. Tholins are thought to be important to the development of life on Earth, and the complex carbon molecules are a source of active research. Their presence on Titan is an encouraging sign that the building blocks of life are not unique to Earth.

Titan’s atmosphere:
98.4% nitrogen
1.6% methane
trace amounts of hydrocarbons, argon and helium

Rosetta space probe built by the European Space Agency, launched on March 2nd, 2004 and reached Comet 67P/Churumov-Gerasimenko on August 6th, 2014. First probe to study a comet.

Comet Churyumov–Gerasimenko in September 2014 as imaged by Rosetta

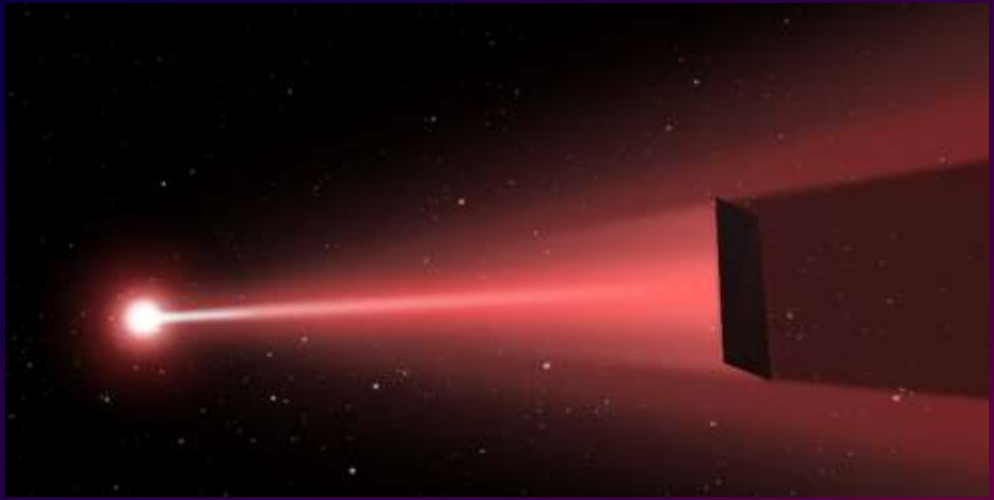
Phillae lander – first time landing a probe on a comet.

Breakthrough Prize Foundation to team with NASA to send a probe to Enceladus

NASA to support initial studies of privately funded Enceladus mission
by Jeff Foust — November 9, 2018, SpaceNews on line

Starlight

Starlight
Directed Energy for Relativistic Interstellar Missions



Future: Sending probes out of the solar system