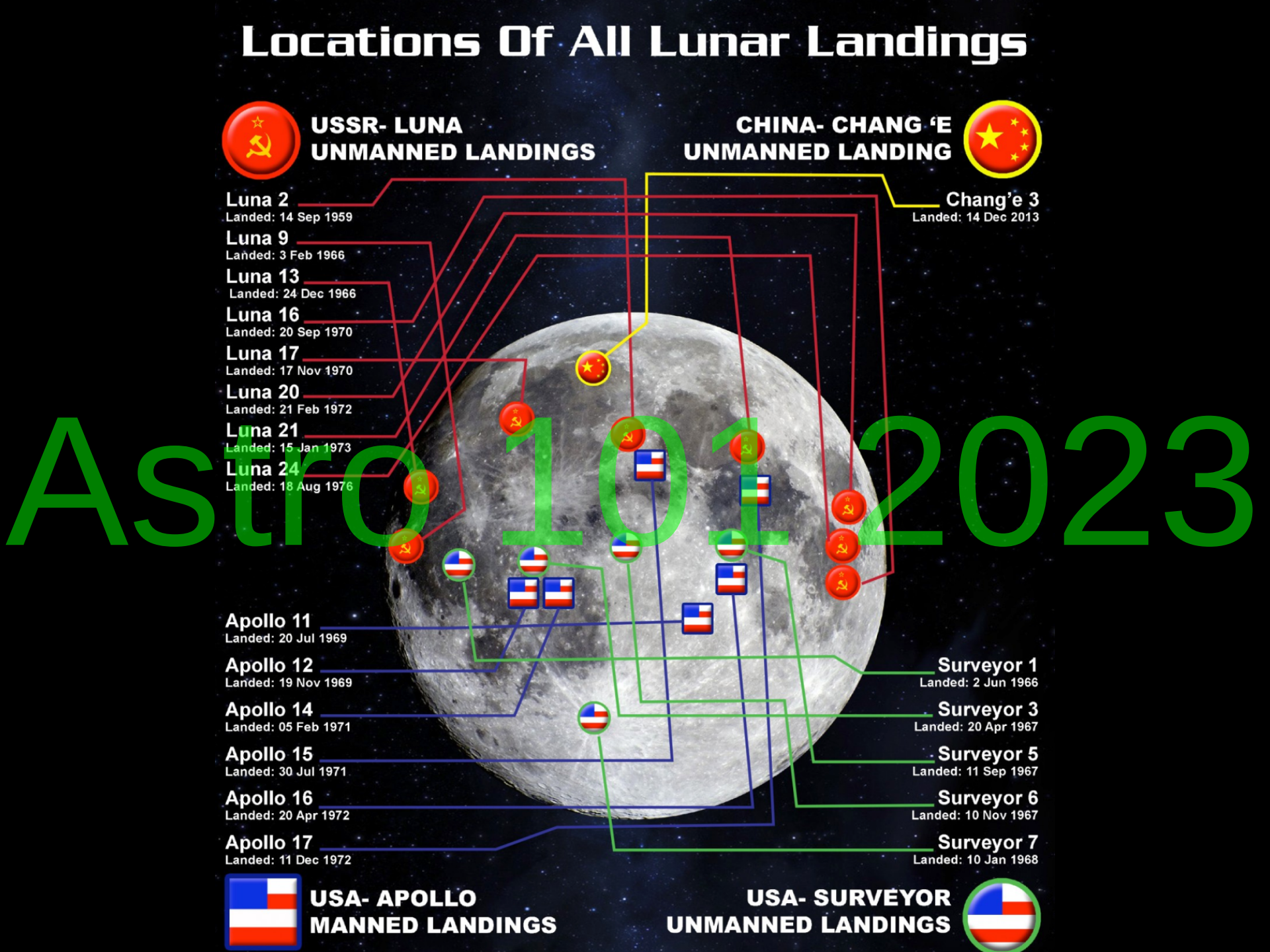
Astronomy 101

Lunar Surface

The Moon (or Luna)

- Earth’s only natural satellite
- fifth largest of the 190+ moons orbiting planets in our solar system.
- relative to host planet, largest in solar system with a diameter of 3475 km (27% of Earth)
- formed 60 million years after the formation of the solar system - 4.53 billion years ago
- in synchronous rotation with Earth (the same side is always facing us)
- mass: 7.35 x 10^{22} kg (1.2 % of Earth’s mass)
- density: 3.34 g/cm^3 (60 % of Earth's density)
- gravity: 1.62 m/s^2 (16 % of Earth’s gravity)
- distance: 365 500 km to 406 700 km (average: 384 400 km)
- orbital period: 27.3 days
- surface temperature: 130°C to -170°C
- 1959 - first unmanned mission to the Moon by Soviet Lunar Program
- 1969 - Apollo 11, first manned landing
- 1972 - Apollo 17, most recent manned mission
- 2019 - Chandrayaan 2 - ISRO (India) Lunar Orbiter, Lander and Rover, latest mission

Locations Of All Lunar Landings



Some of the Missions to the Moon

Current and Past Missions

- Chang'e 5 - CNSA (China) Lunar Sample Return Mission (2020)
- Chandrayaan 2 - ISRO (India) Lunar Orbiter, Lander and Rover Mission (2019)
- Beresheet - Space IL and Israeli Aerospace Industries (Israel) Lunar Lander (2019)
- Chang'e 4 - CNSA (China) Lunar Farside Lander (2018)
- Chang'e 3 - CNSA (China) Lunar Lander and Rover (2013)
- LADEE - NASA Lunar Orbiter Dust Environment Mission (2013)
- GRAIL - NASA Lunar Orbiter Mission (2011)
- Chang'e 2 - CNSA Lunar Orbiter Mission (2010)
- ARTEMIS-P1 and ARTEMIS-P2 - NASA Heliophysics/Lunar Orbiter Mission (2010)
- Lunar Reconnaissance Orbiter - NASA Lunar Orbiter Mission (2009)
- LCROSS - NASA Lunar Impactor Mission (2009)
- Chandrayaan-1 - ISRO (India) Lunar Orbiter Mission (2008)
- Chang'e 1 - CAST (China) Lunar Orbiter Mission
- Kaguya (SELENE) - JAXA Lunar Orbiter Mission
- Deep Impact/EPOXI - NASA Mission to Comet Tempel 1 - Lunar Flyby
- SMART 1 - ESA Lunar Orbiter Mission
- Lunar Prospector - NASA Lunar Discovery Mission
- AsiaSat 3/HGS-1 - Commercial Telecommunications Satellite
- Clementine - DoD/NASA Lunar Mapping Mission
- Hiten - ISAS Lunar Flyby and Orbiter
- Ranger - NASA Lunar Impact Missions
- Luna and Zond - Soviet Lunar Missions

Future Missions

- CAPSTONE - NASA Lunar Navigation and Test Orbiter (2021)
- Peregrine Mission 1 - NASA CLPS Lunar Lander (2021)
- Luna 25 - Roscosmos (Russia) Lunar Lander (2021)
- IM-1 - NASA CLPS Lunar Lander (2021)
- LunaH-Map - NASA Lunar Orbiting CubeSat (2021)
- Lunar Flashlight - NASA Lunar Orbiting CubeSat (2021)
- Lunar Ice Cube - NASA Lunar Orbiting CubeSat (2021)
- LunIR - NASA Lunar Flyby and Technology Test CubeSat (2021)
- Cislunar Explorers - NASA Technology Test CubeSats (2021)
- OMOTENASHI - JAXA (Japan) Lunar Lander CubeSat (2021)
- EQUULEUS - JAXA (Japan) L2 Orbiting Lunar CubeSat (2021)
- SLIM - JAXA (Japan) Lunar Lander (2022)
- Korea Pathfinder Lunar Orbiter - KARI (South Korea) Lunar Orbiter Mission (2022)
- XL-1 Lander - NASA CLPS Lunar Lander (2022)
- Prime 1 - NASA CLPS Lunar Lander (2022)
- VIPER - NASA Lunar South Pole Rover (2023)
- Chang'e 6 - CNSA (China) Lunar Sample Return Mission (2023-24)

Theories of Moon Formation

The Fission Theory: The Moon was once part of the Earth and somehow separated from the Earth early in the history of the Solar System. The present Pacific Ocean basin is the most popular site for the part of the Earth from which the Moon came.

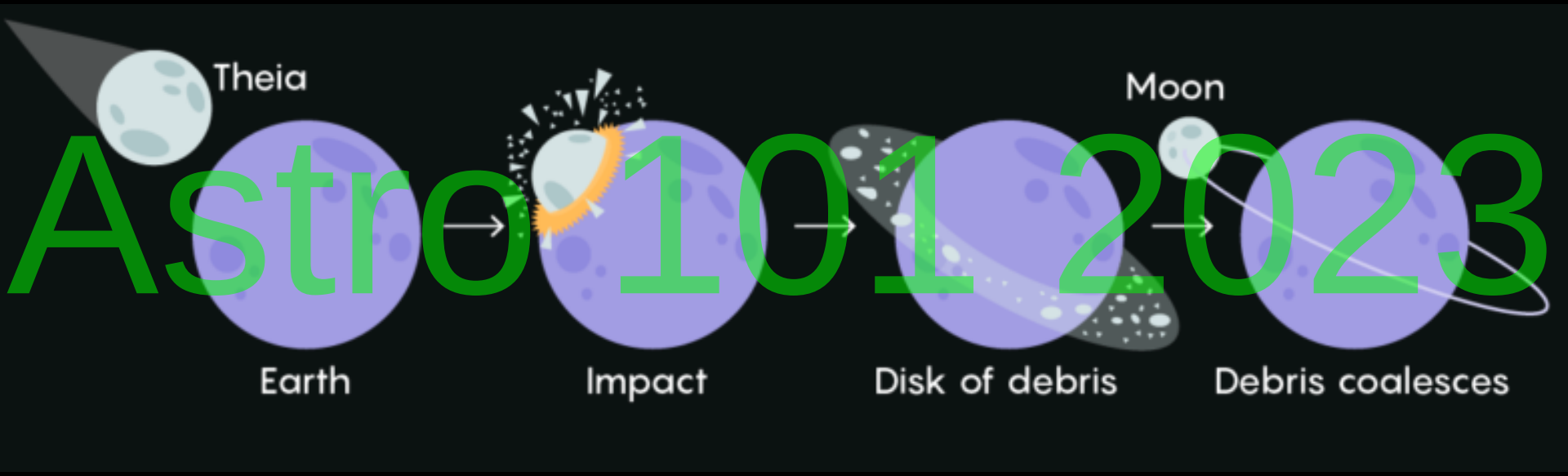
The Capture Theory: The Moon was formed somewhere else, and was later captured by the gravitational field of the Earth.

The Condensation Theory: The Moon and the Earth condensed together from the original nebula that formed the Solar System.

The Colliding Planetesimals Theory: The interaction of earth-orbiting and Sun-orbiting planetesimals (very large chunks of rocks like asteroids) early in the history of the Solar System led to their breakup. The Moon condensed from this debris.

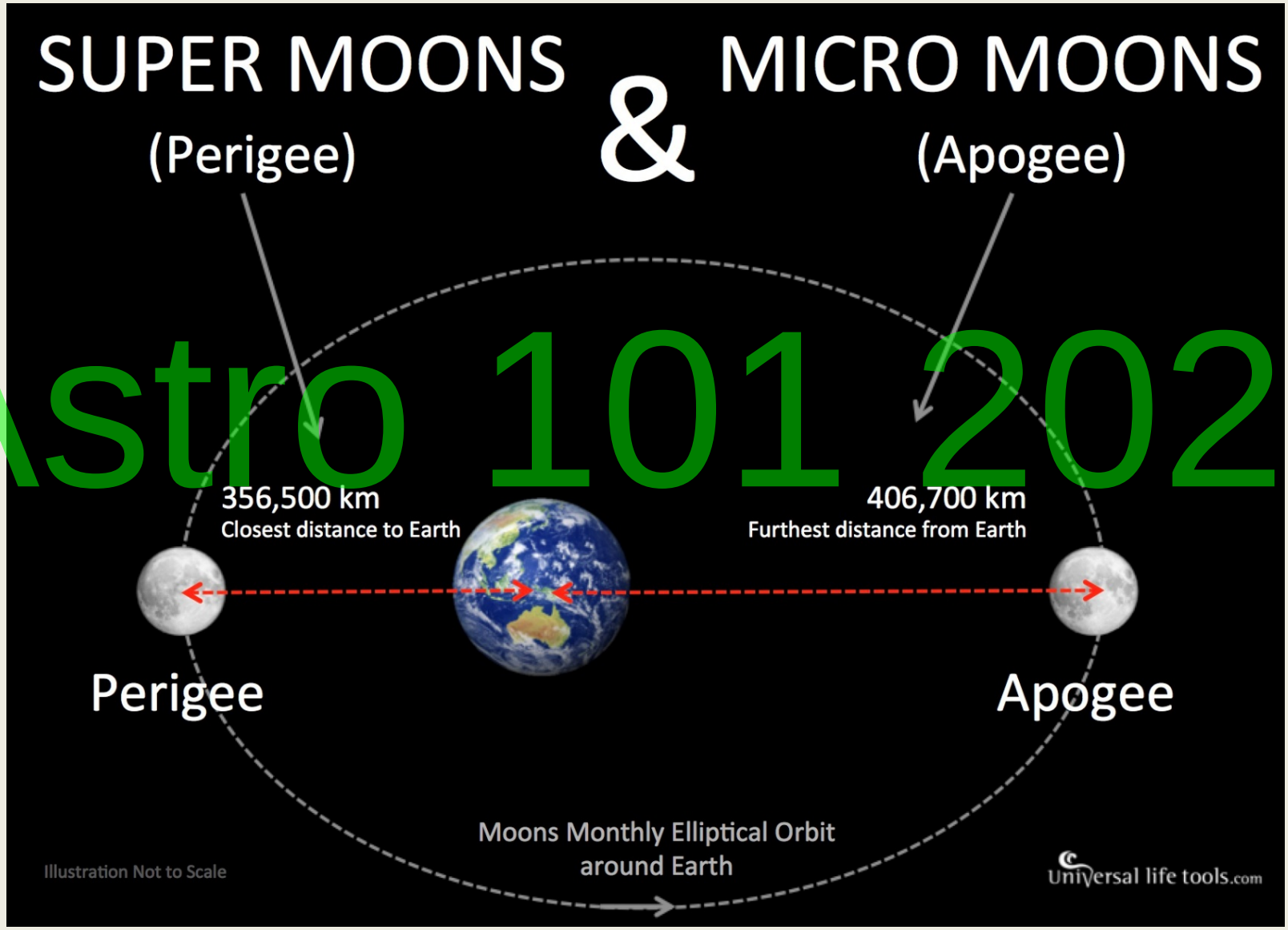
The Ejected Ring Theory: An object the size of Mars, named Theia, struck the earth, ejecting large volumes of matter. A disk of orbiting material was formed, and this matter condensed to form the Moon.

The Making of Our Moon



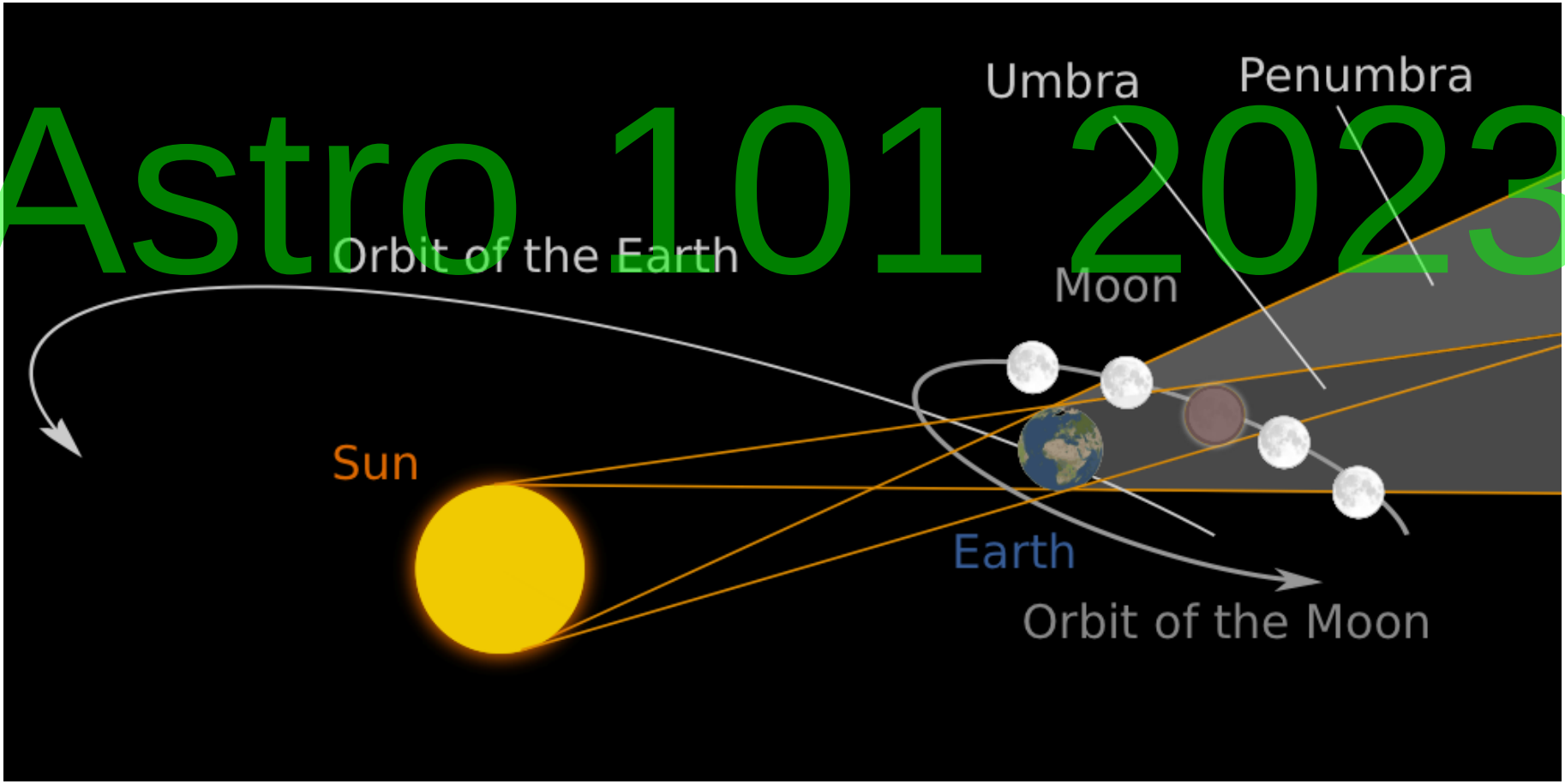
The lunar maria (singular: mare) are large, dark, basaltic plains on Earth's Moon, formed by ancient volcanic eruptions 3 to 3½

The Moon's Orbit



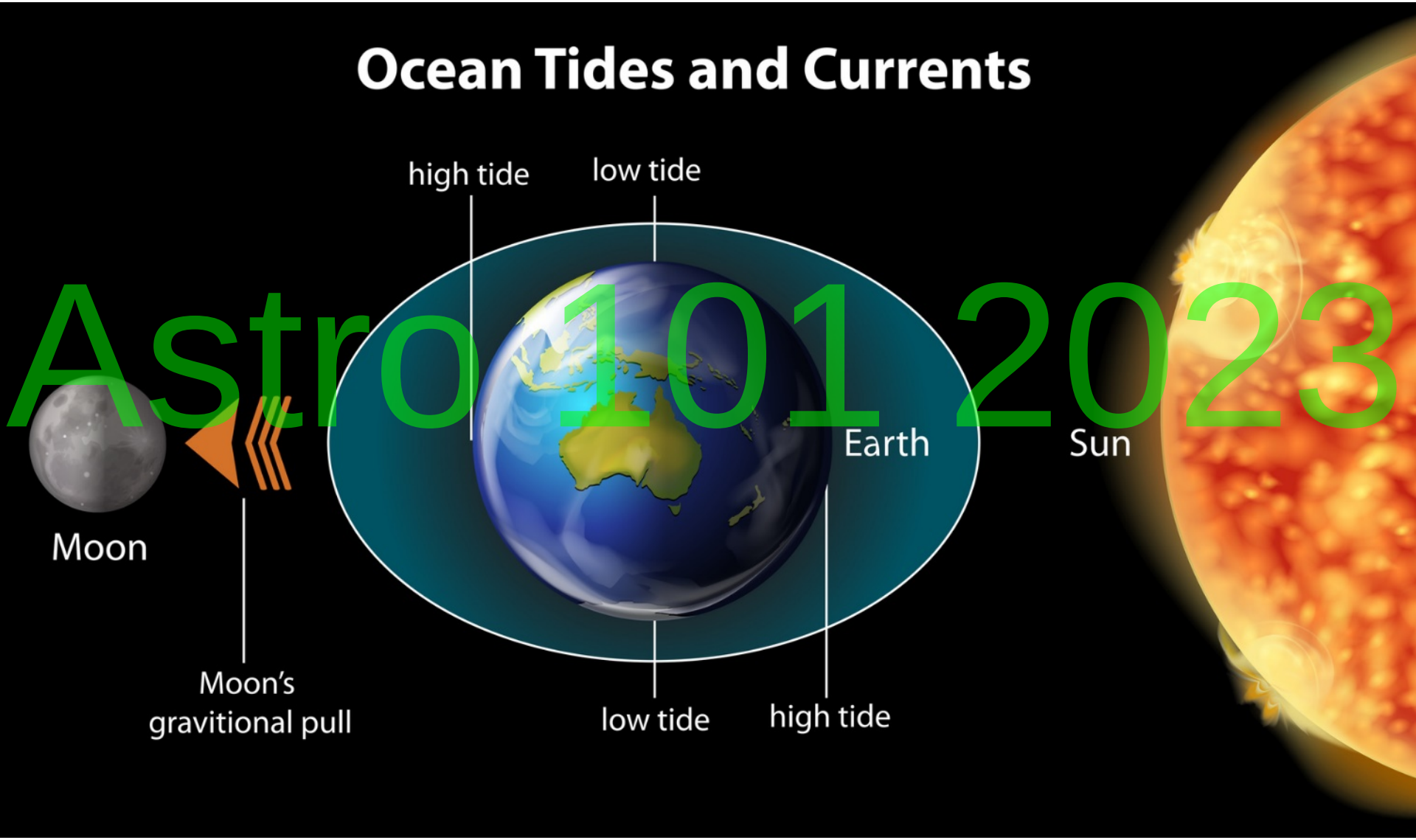
The Moon’s Orbit

Lunar and solar eclipses.



The Moon’s Orbit

Tides on earth



The Moon’s Orbit

Light at night

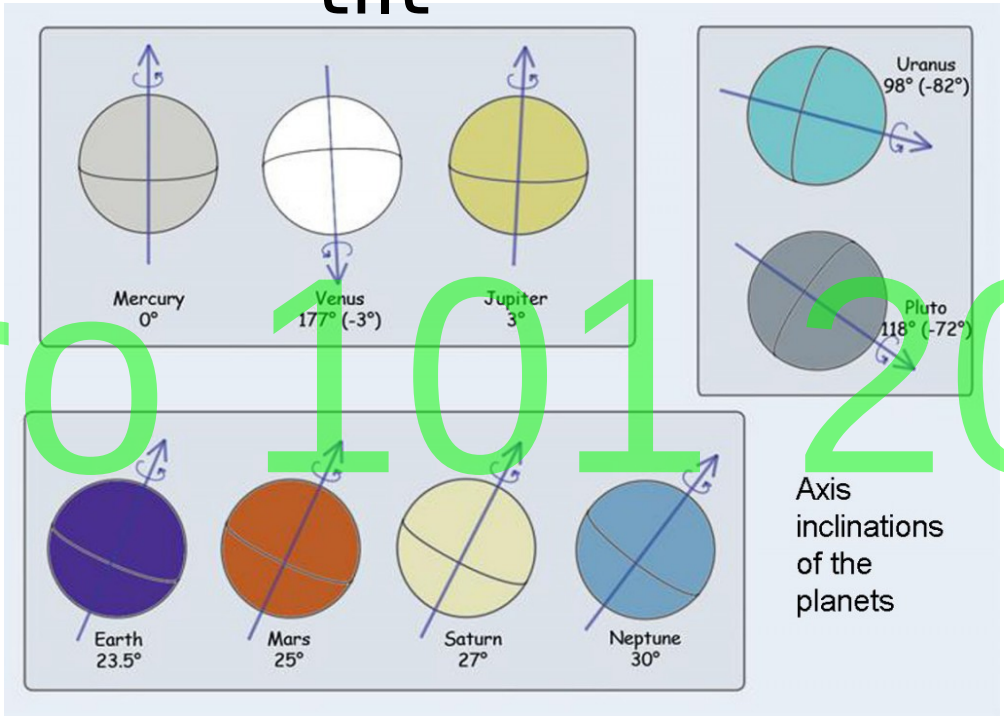
The Moon's Orbit

Longer
Days

- Earth's rotation slowing
- Moon's speed increasing
- Earth – Moon distance is increasing by 3.8 cm per year

The Moon’s Orbit

Axial tilt



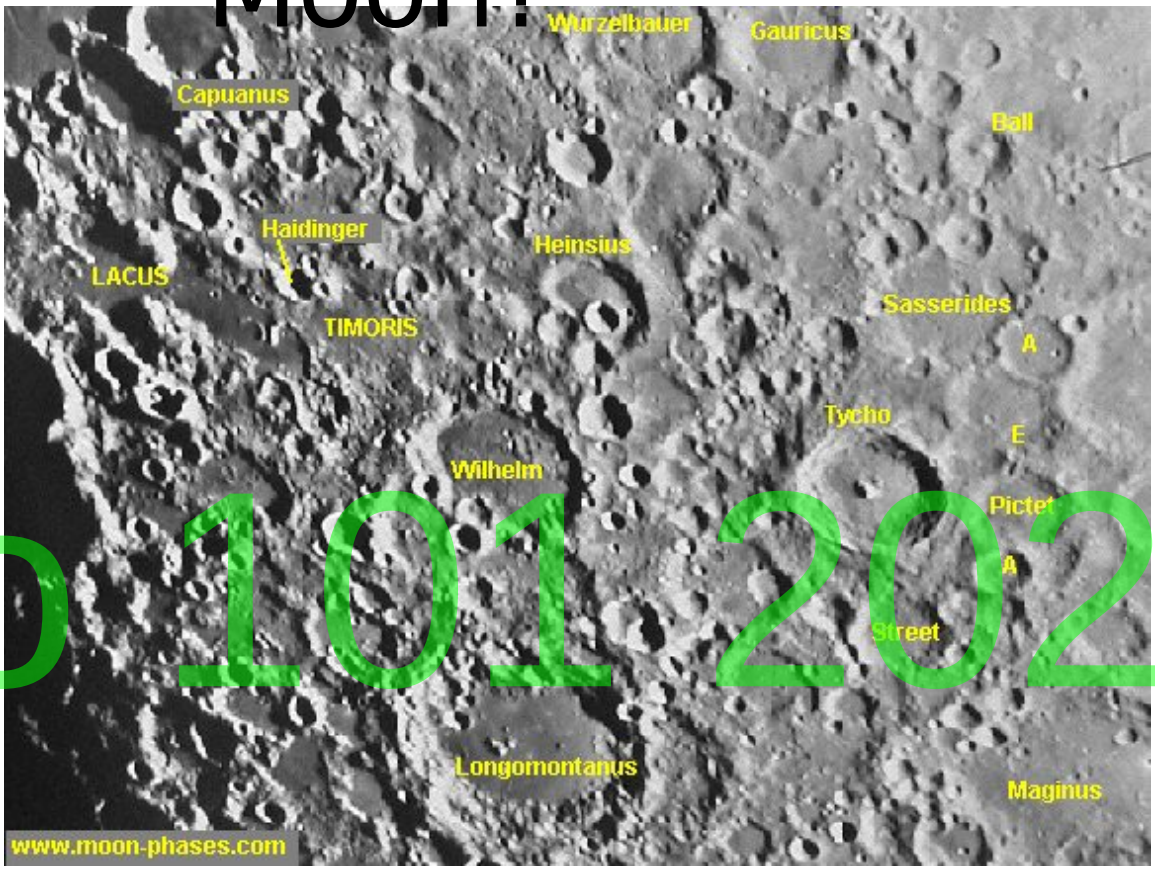
Earth's axial tilt **varies** over a 41,000-year period from 22.1 to 24.5 degrees and currently resides at about 23.4 degrees. The axial tilt angle is currently decreasing.

Without the moon’s stabilizing effect, models have predicted that Earth’s tilt could vary as much as 85 degrees. The limited tilt range is thought to be caused by the gravitational attraction between the

A NASA camera aboard the Deep Space Climate Observatory captured a unique view of the Moon on July 16, 2015 as it passed between the spacecraft and Earth.
Image released on Aug. 5, 2015. (NASA / NOAA)

Craters on the Moon

Why do craters remain on our Moon?



No erosion
- no rain
- no wind

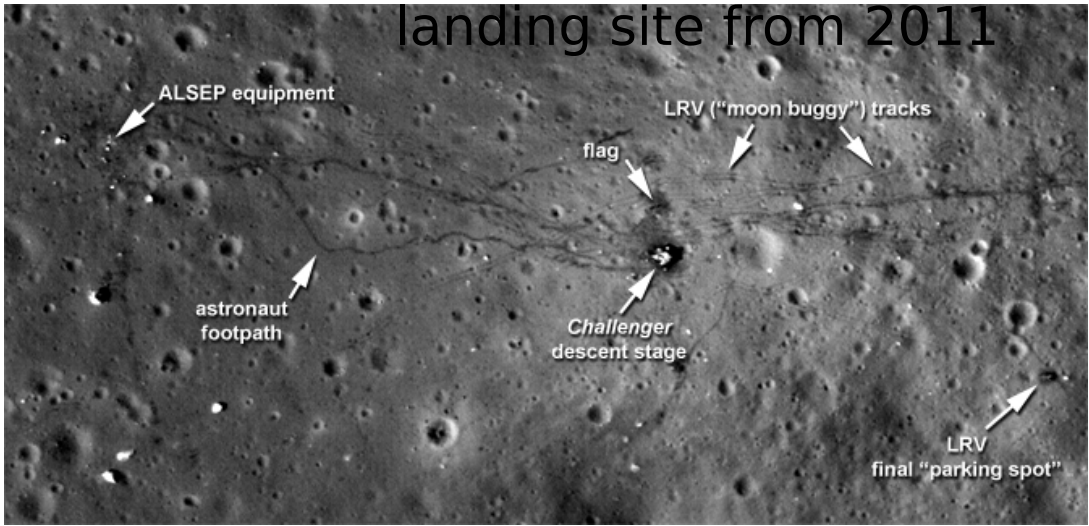
No significant geological activity

No significant atmosphere
- 10^6 molecules/cm^3 (a good vacuum) compared to 10^{19} molecules/cm^3 at sea level on earth
- Primarily neon, helium, and hydrogen, in roughly equal amounts with small amounts of methane, carbon dioxide, ammonia, and water vapour

Consequences of no erosion

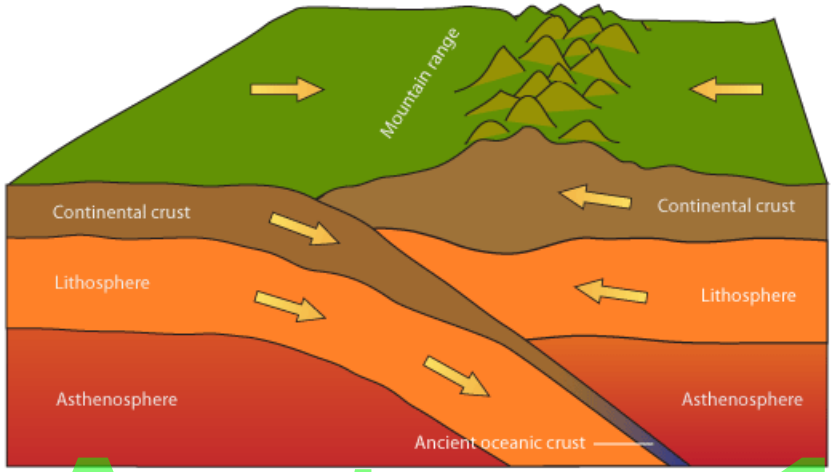
Footprints on the moon will likely be there for 100 million years

LRO images of the Apollo 17 (1972) landing site from 2011



Approximately 80% of Earth's surface is less than 200 million years old, while over 99% of the Moon's surface is more than 3 billion years old.

Craters on the Earth

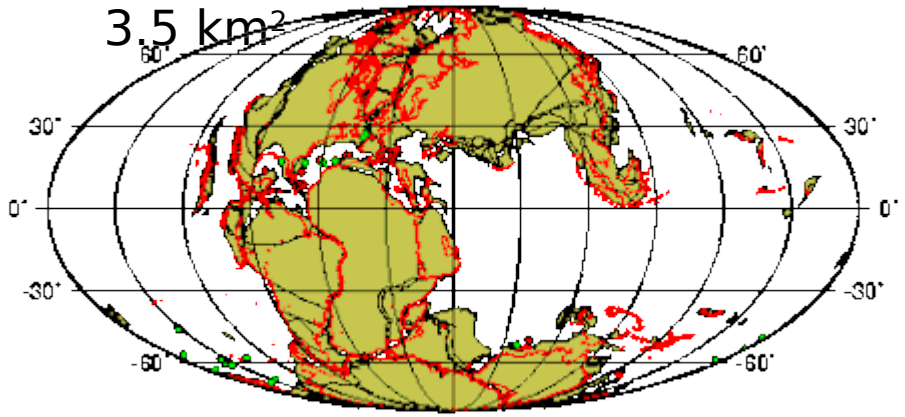


Subduction zones cause loss of land mass.

Kilauea volcano, Luana Street, 2018

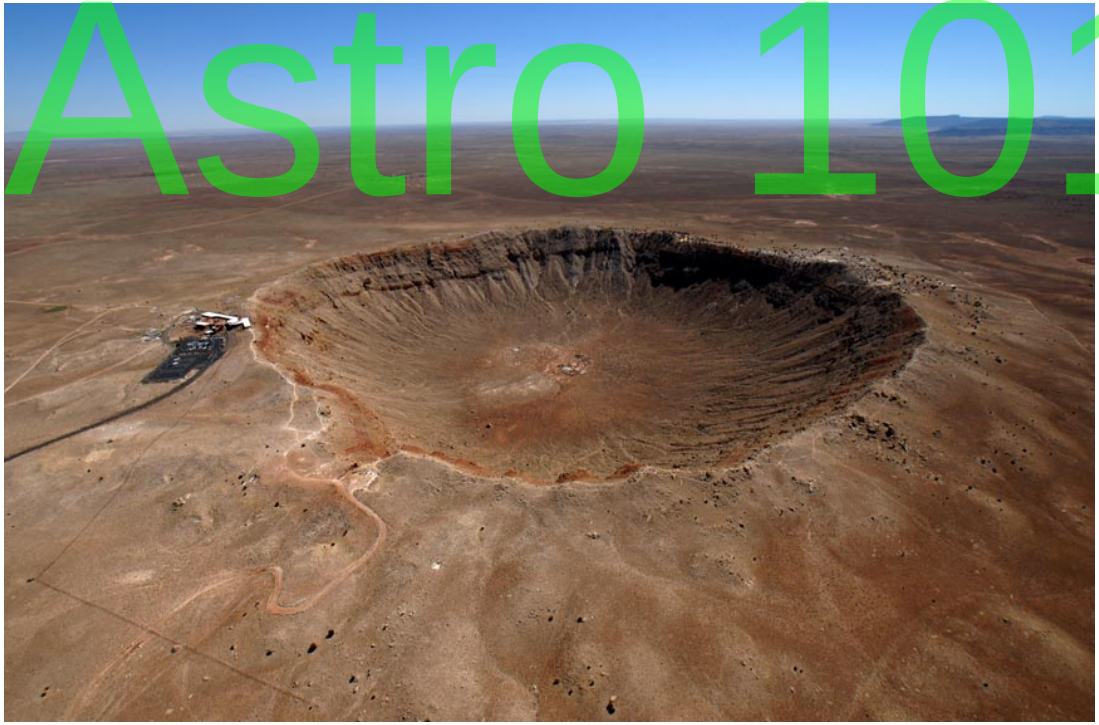
Hawaii expanded by about 3.5 km^2

Mid ocean ridge spreading

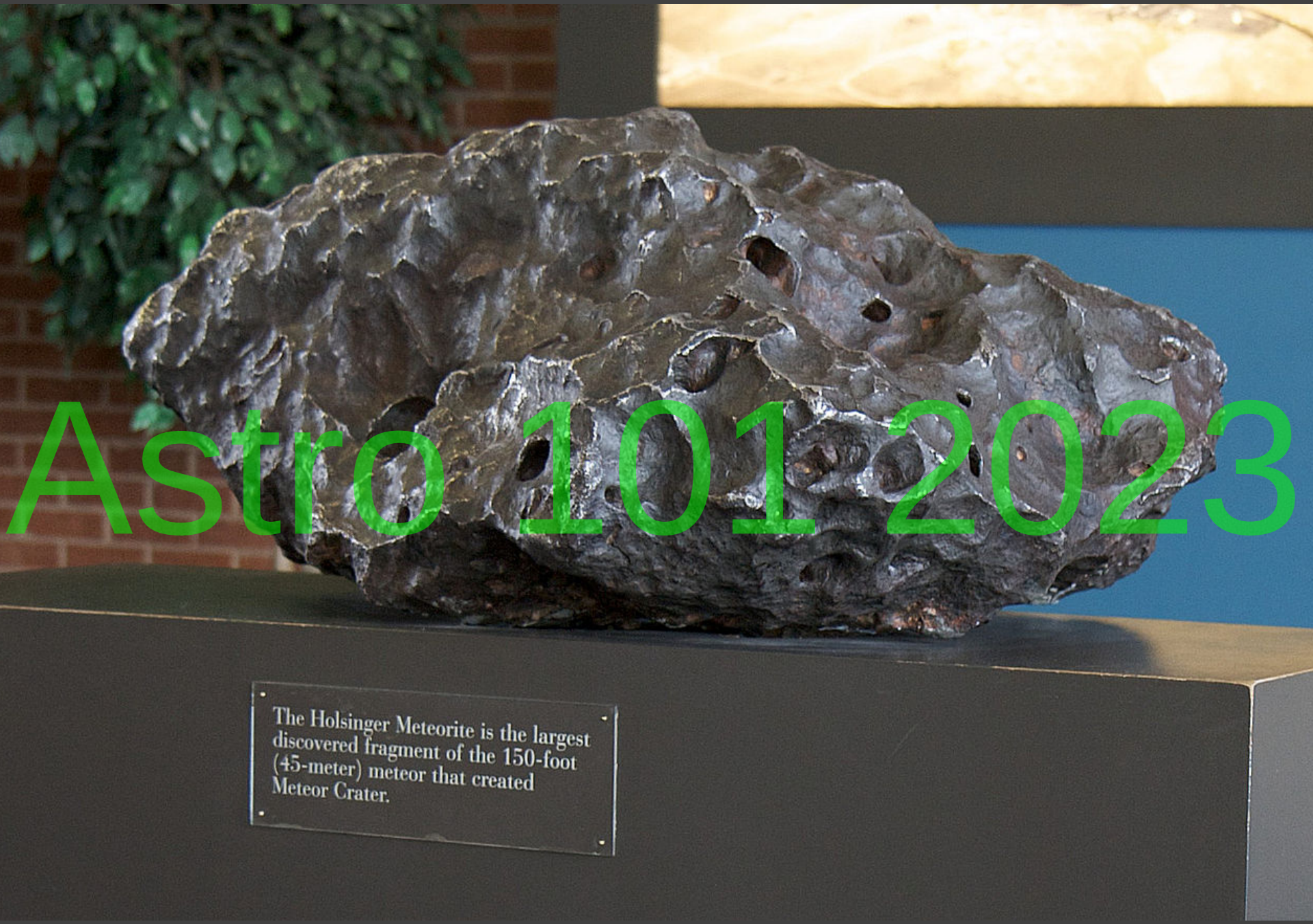


150 My of continental drift

Barringer Crater



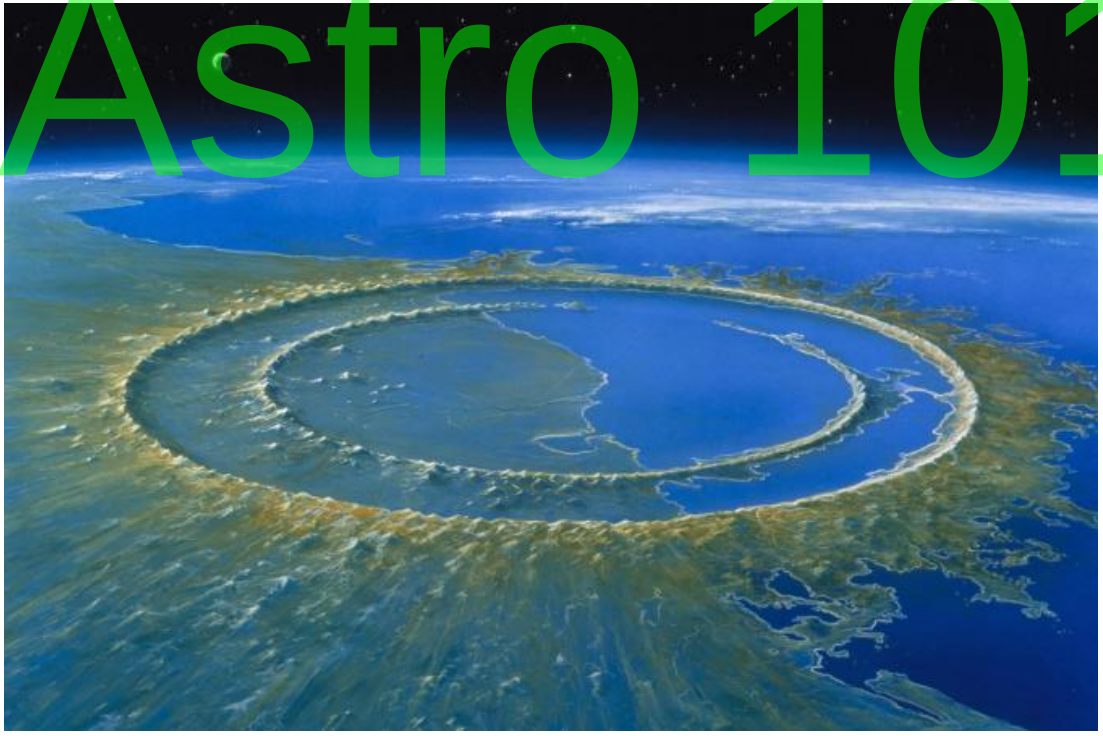
- Located outside Flagstaff, Arizona
- The crater is about 1.6 km wide and 175m deep.
- Created 50,000 years ago by a 45m diameter, 270 000 metric ton, nickel-iron meteorite traveling about 20 km/s
- Evidence of an impact include
  - overturned rock layers around the crater
  - rocks that have been deformed by extreme temperature and pressure
  - specific minerals created by meteoritic impacts
- Scientists now believe that most of the meteorite vaporized on impact
- Small meteoritic fragments have been found scattered around the crater.



Manicouagan Crater

- located about 300 km (190 mi) north of Baie-Comeau, Quebec
- 215 million years old
- multiple-ring structure
  - about 100 km across
  - 70 km diameter inner ring with annular lake,
- it is the earth's sixth-largest confirmed impact crater according to rim-to-rim diameter.
- may have been part of a multiple impact event
  - Rochechouart crater in France,
  - Saint Martin crater in Manitoba
  - Obolon' crater in Ukraine
  - Red Wing crater in North

Chicxulub Crater



- Buried underneath the Yucatán Peninsula in Mexico.
- The crater is more than 180 kilometers in diameter and 20 km in depth
- The impactor was at least 10 km in diameter
- Discovered by geophysicists who had been looking for petroleum in the Yucatán during the late 1970s.
- Impact associated with the crater is implicated in the Cretaceous–Paleogene extinction event 66 million years ago, including the worldwide extinction of non-avian dinosaurs.

Definitions

- **Asteroid** – A relatively small object composed of rock, carbon or metal, which is orbiting the Sun. It formed early in the solar system about 4.5 billion years ago close to the Sun, where it was too warm for ices to remain solid.
- **Comet** - A relatively small object which is composed of dirt and ices (water, carbon dioxide, ammonia, methane) as it formed away from the sun. Comets are characterized by dust and gas tails when in proximity to the Sun. (Far from the Sun it is difficult to distinguish an asteroid from a comet.)
- **Meteoroid** - A small particle from an asteroid or comet orbiting the Sun.
- **Meteor** - A meteoroid that is observed as it burns up in the Earth's atmosphere – a shooting star.
- **Meteorite** - A meteoroid that survives its passage through the Earth's atmosphere and impacts the Earth's surface.
- **Near Earth Object (NEO)** - Near Earth Objects are asteroids

Size and Frequency of Bombardment

Daily: Earth is bombarded with more than 100 tons of dust and sand-sized particles.

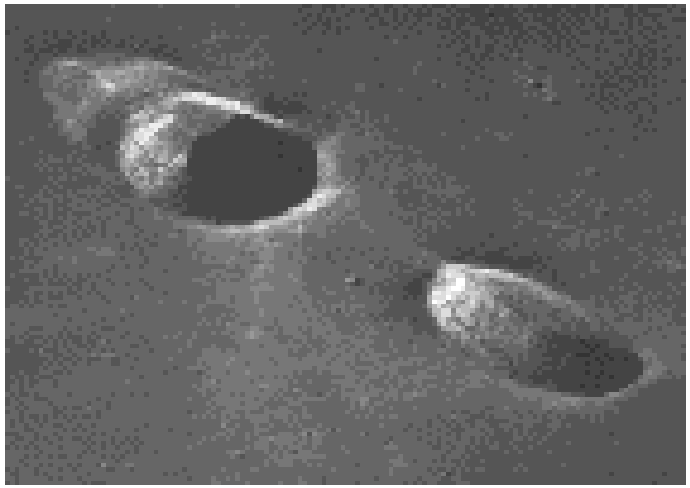
Yearly: diameter < 25 meters hits Earth's atmosphere, creates an impressive fireball but burns up before reaching the surface.

2000 years: 25 meters < diameter < 1 km hits Earth and causes significant damage to the local area.

Few million years: an object large enough to threaten Earth's civilization. Impact craters on Earth, the moon and other planetary bodies show evidence of these occurrences.

Lunar Craters (< 15km)

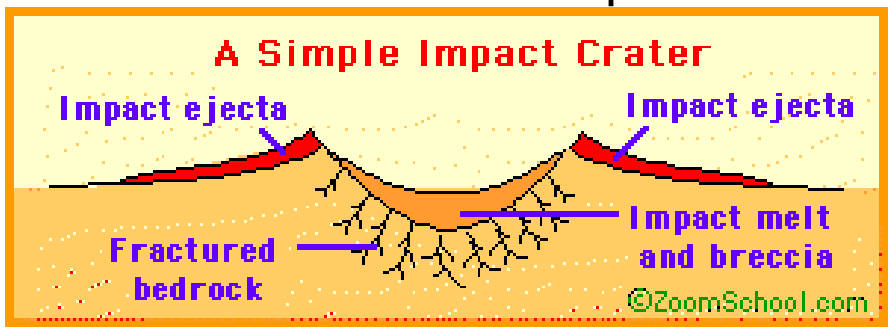
Most craters on the Moon are circular, some are not.

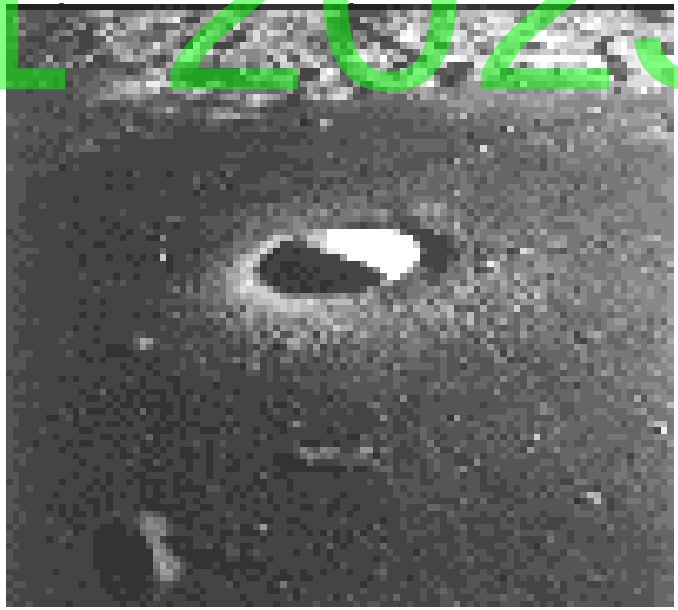


Messier and Messier A craters

Most craters on the Moon that have diameters less than about 15 kilometers.

These craters are simple bowls.

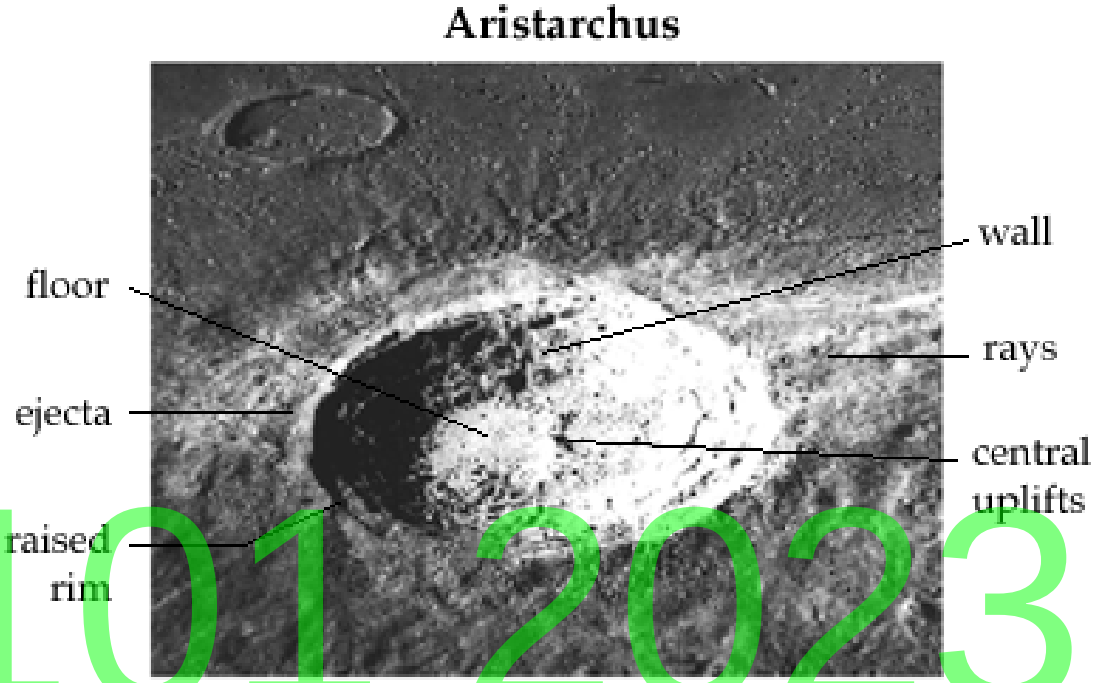


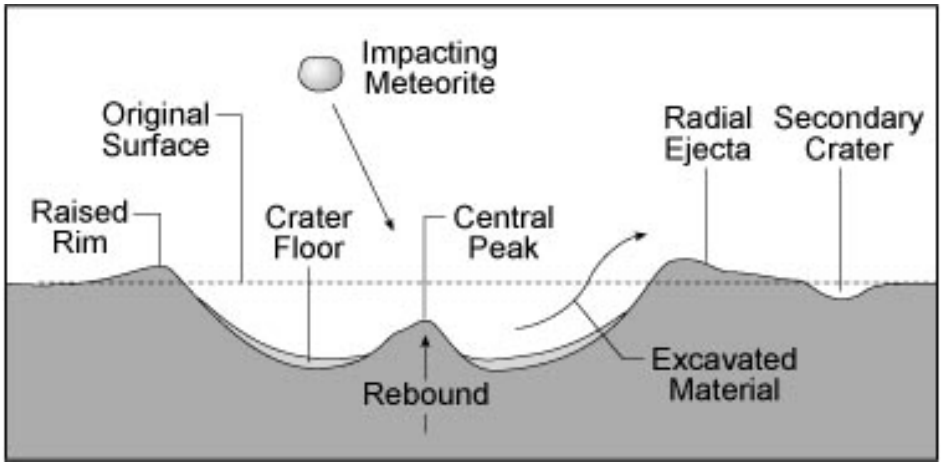


Moltke crater with a diameter of 7 km

Lunar Craters (20km to 175km)

- **Floor -** bowl shaped or flat, characteristically below surrounding ground level unless filled in with lava.
- **Walls -** characteristically steep and may have giant stairs called terraces.
- **Raised rim -** rock thrown out of the crater and deposited as a ring-shaped pile of debris at the crater's edge during the explosion and excavation of an impact event.
- **Ejecta -** blanket of material surrounding the crater that was excavated during the impact event. Ejecta becomes thinner away from the crater.
- **Rays -** bright streaks starting from a crater and extending away for great distances.
- **Central uplifts -** mountains formed because of the huge increase and rapid decrease in



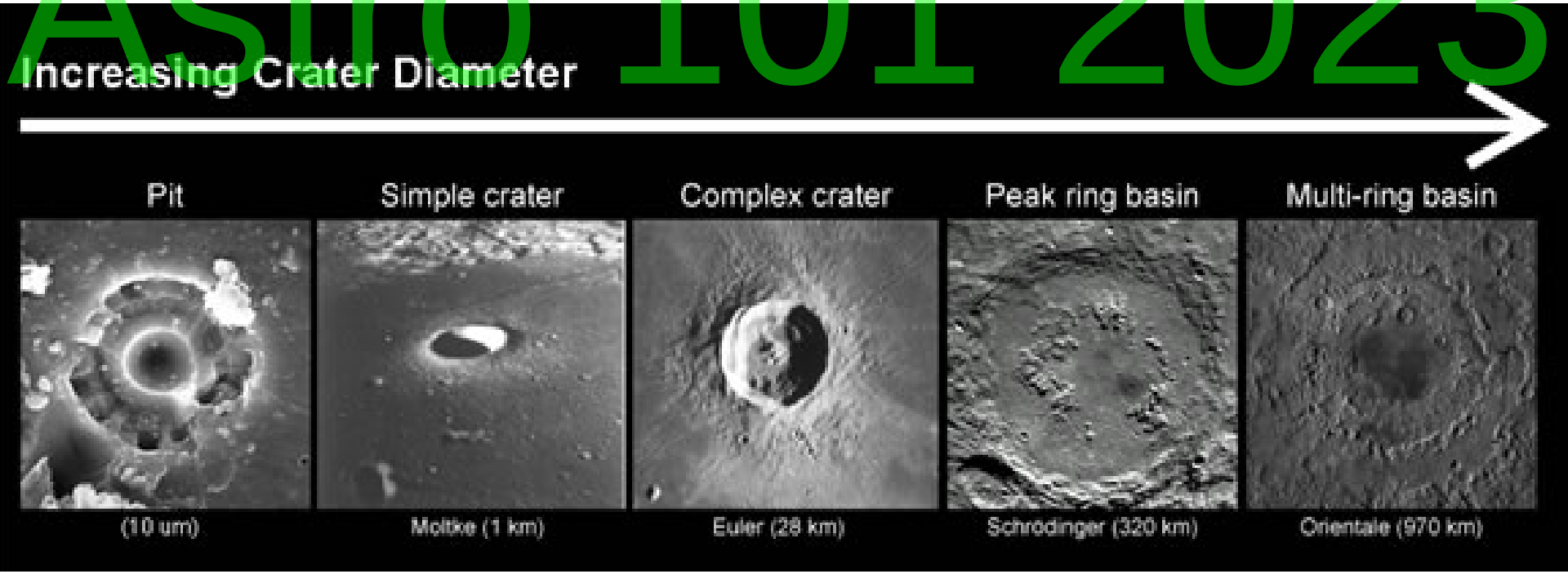


Lunar Craters (> 175km)

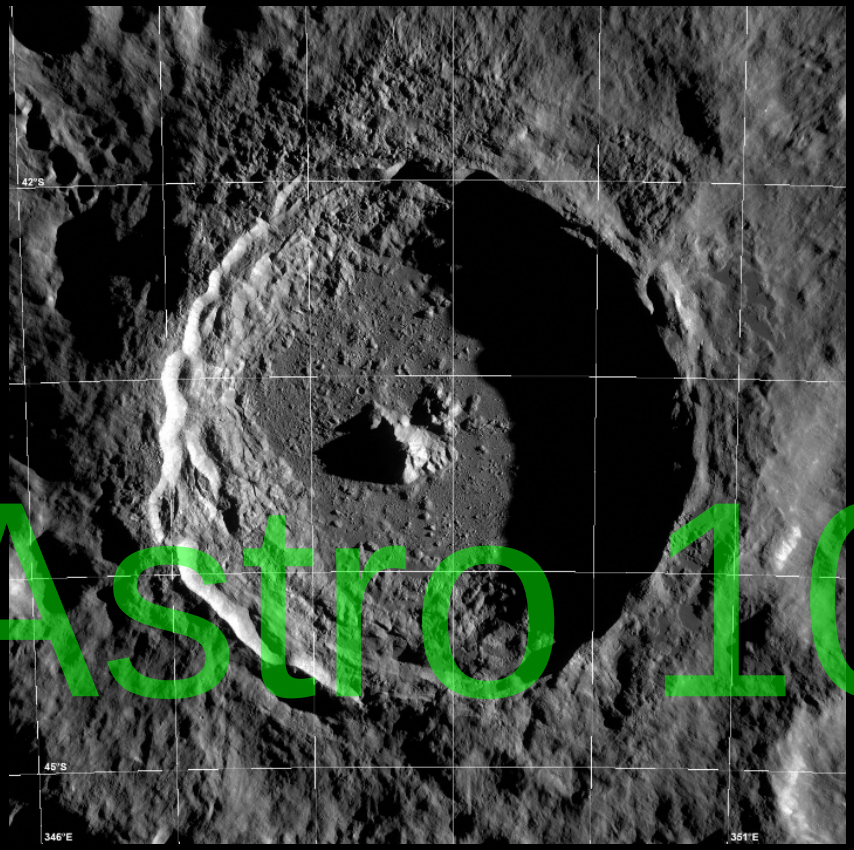
Craters with a diameter over 110 miles (175 km) can have more complex, ring-shaped uplifts within the crater.

These large impacts produce faulting and other crust deformations.

Material ejected from impact basins is distributed over wide areas possibly causing secondary impacts and craters.



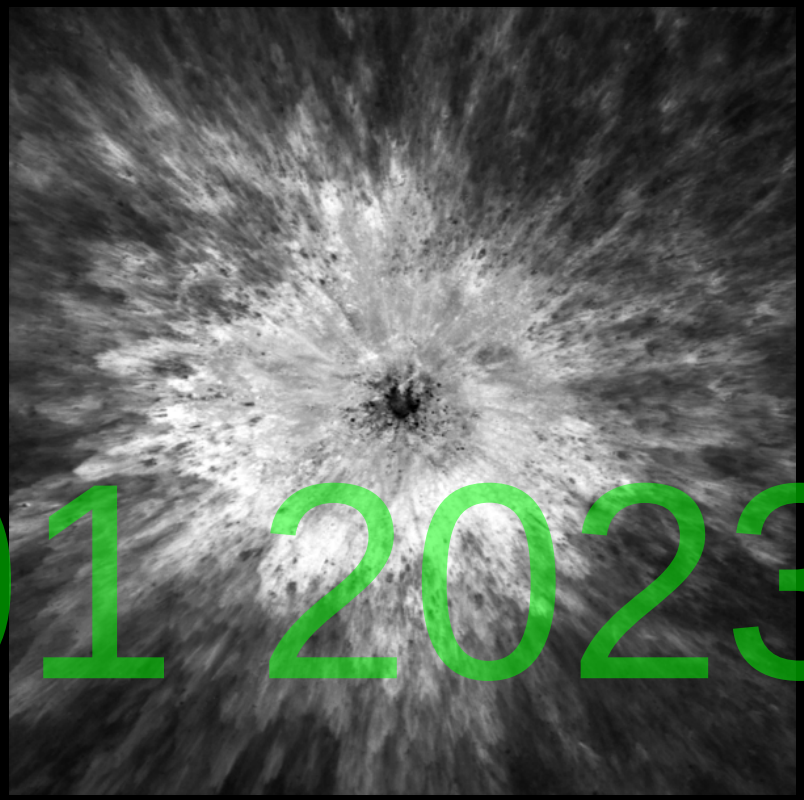
Lunar Craters



Tycho crater showing central uplift.

Diameter 86 km

Depth 4.8 km



An unnamed crater (180 m in diameter) located at the northern edge of Mare Fecunditatis showing strong reflectance contrast between the ejecta deposit and the surrounding background. This suggests that this crater was recently formed.

Craters Formed Before and After a Mare

Astro 101 2023

Russell is a 103km diameter lava-flooded remains of a lunar impact crater.

Calculating the size of a crater

The lunar image is a scaled image

$$\frac{\text{Actual Diameter of Moon}}{\text{Actual Diameter of Crater}} = \frac{\text{Image Diameter of Moon}}{\text{Image Diameter of Crater}}$$

The Scale

$$\frac{\text{Actual Diameter of Moon (km)}}{\text{Image Diameter of Moon (pix)}} = \text{scale in km/pixel} = \text{scale in km/pixel}$$

Size Calculation

Crater size in pixels x Scale in km/pixel = Crater size in km

OR

$$\frac{\text{Crater size in km}}{\text{Scale in km/pix}} = \text{Crater size in pixels}$$