

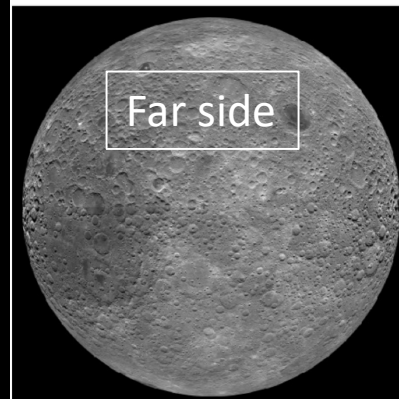
Lunar Exploration

Joseph Silk

January 30 2019

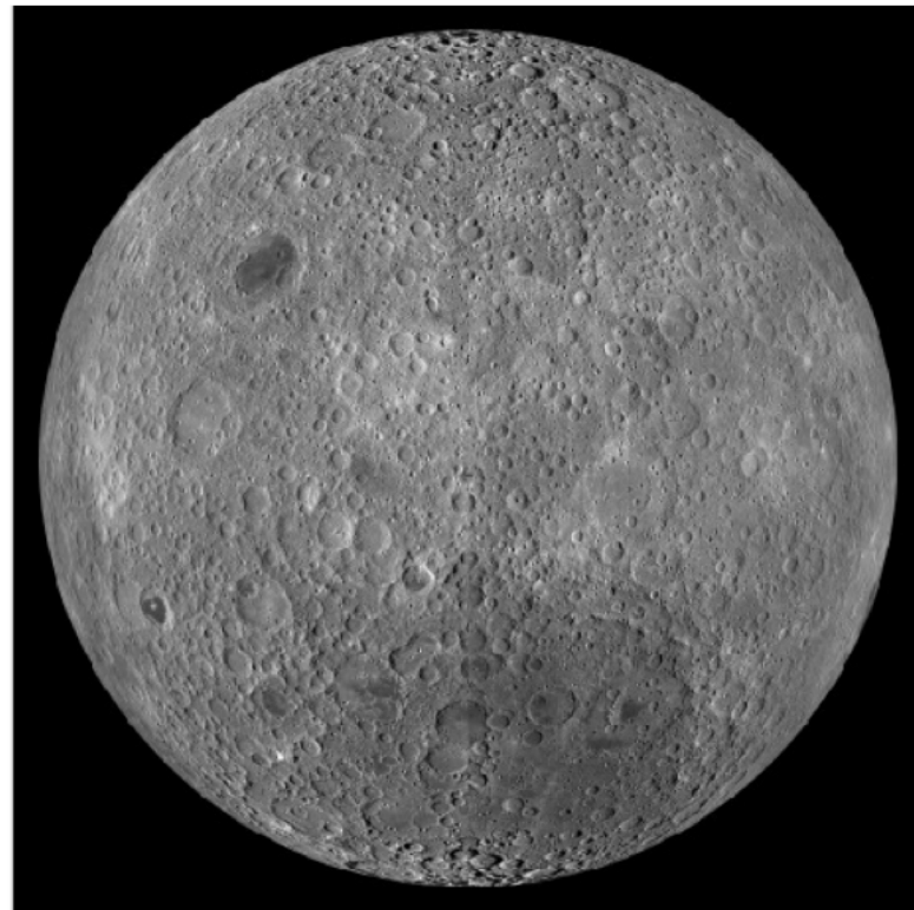
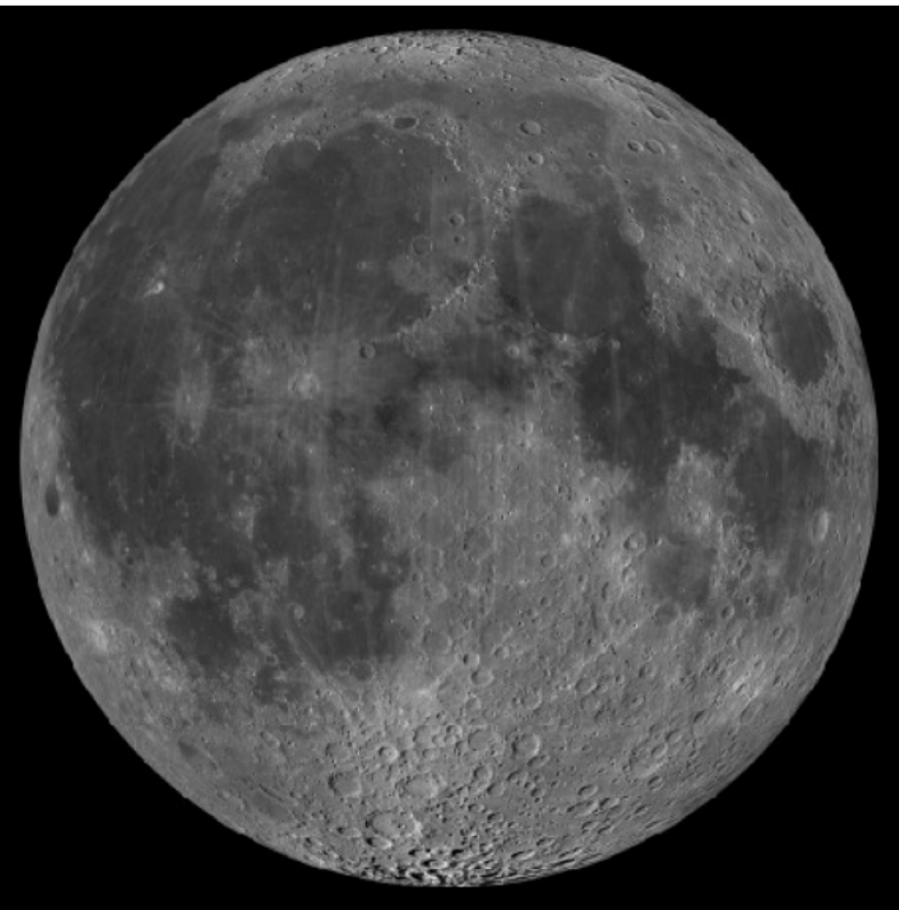
Some facts about the Moon

- Extreme temperatures 260F to -280F
- Rotates in 27 days daytime 13.5 days, night 13.5 days
- Craters near poles in permanent darkness -400F
- Water ice in dark craters
- Diameter 2159 miles, 1/3 Earth
- Mass is 1.2 % earth mass
- Gravity 6 times weaker than on Earth



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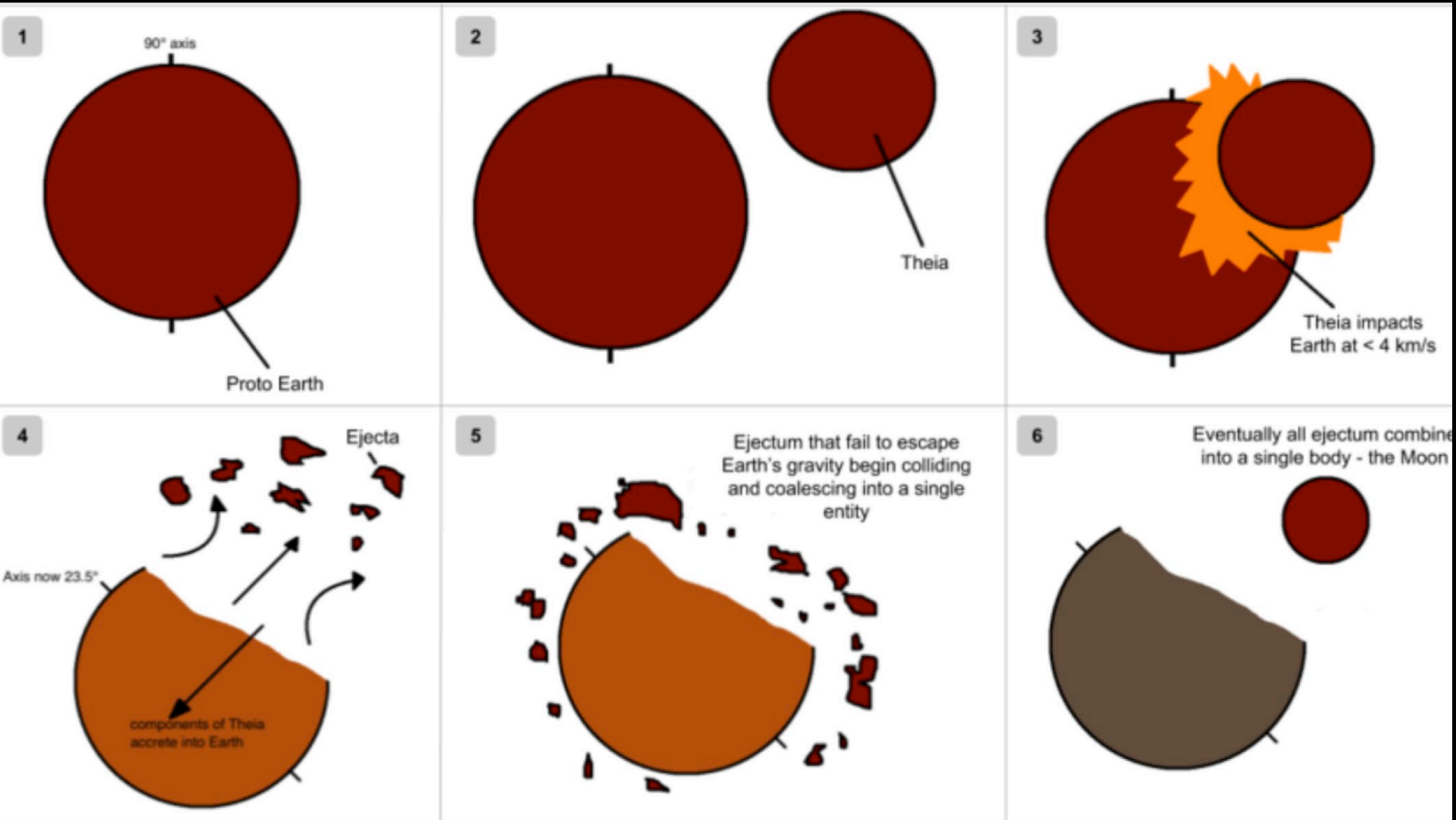
protoplanetary disk





accretion phase

Impact hypothesis



a Mars-size body impacted the earth about 4.5 billion years ago

Why the impact theory works

- the earth has a large iron core, the moon does not
- the iron core of the impactor melted and drained into the earth
- earth has a mean density of 5.5 g cm^{-3} and Moon has a density of 3.3 g cm^{-3}
- Moon and earth have similar oxygen isotope ratios
- The Moon formed from material near earth
- Other planets don't have similar moons (except Pluto)
- Suggestive of a stochastic catastrophic event

giant impact

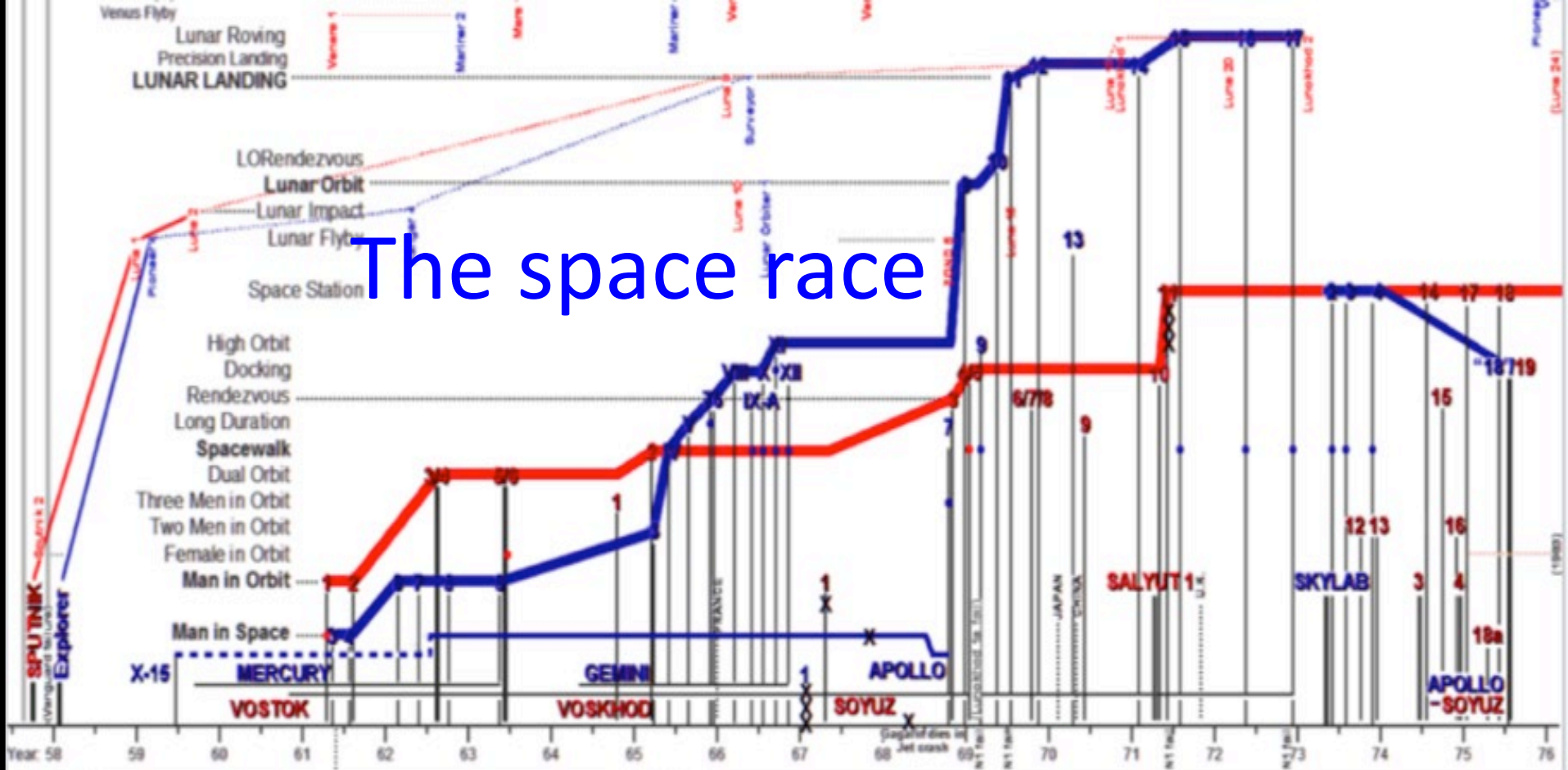




We choose to go to the Moon! We choose to go to the Moon...We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win, and the others, too.

Sep 12 1962

The space race



Context

UK's first hydrogen bomb test starts 24/7 nuke bomber alert at Age (continuous until 1991)
R unilateral nuke test moratorium (followed by US and UK)
thor IRBMs deployed in the UK
A starts after like signs Space Act
astro overthrows Batista in Cuba

George Washington launched
Hawaii becomes fiftieth state
France's first nuclear bomb test
Jupiter IRBMs deployed in Italy
J-2 Pilot Gary Powers shot down
elin
Sino-Soviet Split
aunch Pad Disaster (kept secret)
proposes Bay of Pigs Fiasco
commitment to land on the Moon
Shelters/Berlin Wall constructed
er IRBMs 50MT Tsar Bomba
oyed in Turkey detonated

tar relays first live TV by satellite
CUBAN MISSILE CRISIS
ear Test Ban Treaty
signed by US, USSR & UK
roposes cooperation on Apollo
eech) JFK Assassinated

U.S. Civil Rights Act
China's first nuclear bomb test
U.S., U.S.S.R., U.K. & France)
Winston Churchill dies (stroke)
U.S. invades Dominican Republic

Malcom X Assassinated
Sergei Korolev dies after surgery
Color TV becomes popular

er Space Treaty signed
uper Bowl In US, USSR & UK
lin's daughter defects to the U.S.
racial marriage legalized for U.S.
reform (stopped by Warsaw
vasion & occupation thru 1990)
Trousers MLK Assassinated
accepted RFK Assassinated
for Women's everyday wear
oncorde Eisenhower dies(heart)
FOBS deployed Chappaquiddick
Mylai Massacre

uclear Non-Proliferation Treaty
3 Jets bound for NY Hijacked
Kent State war protesters killed

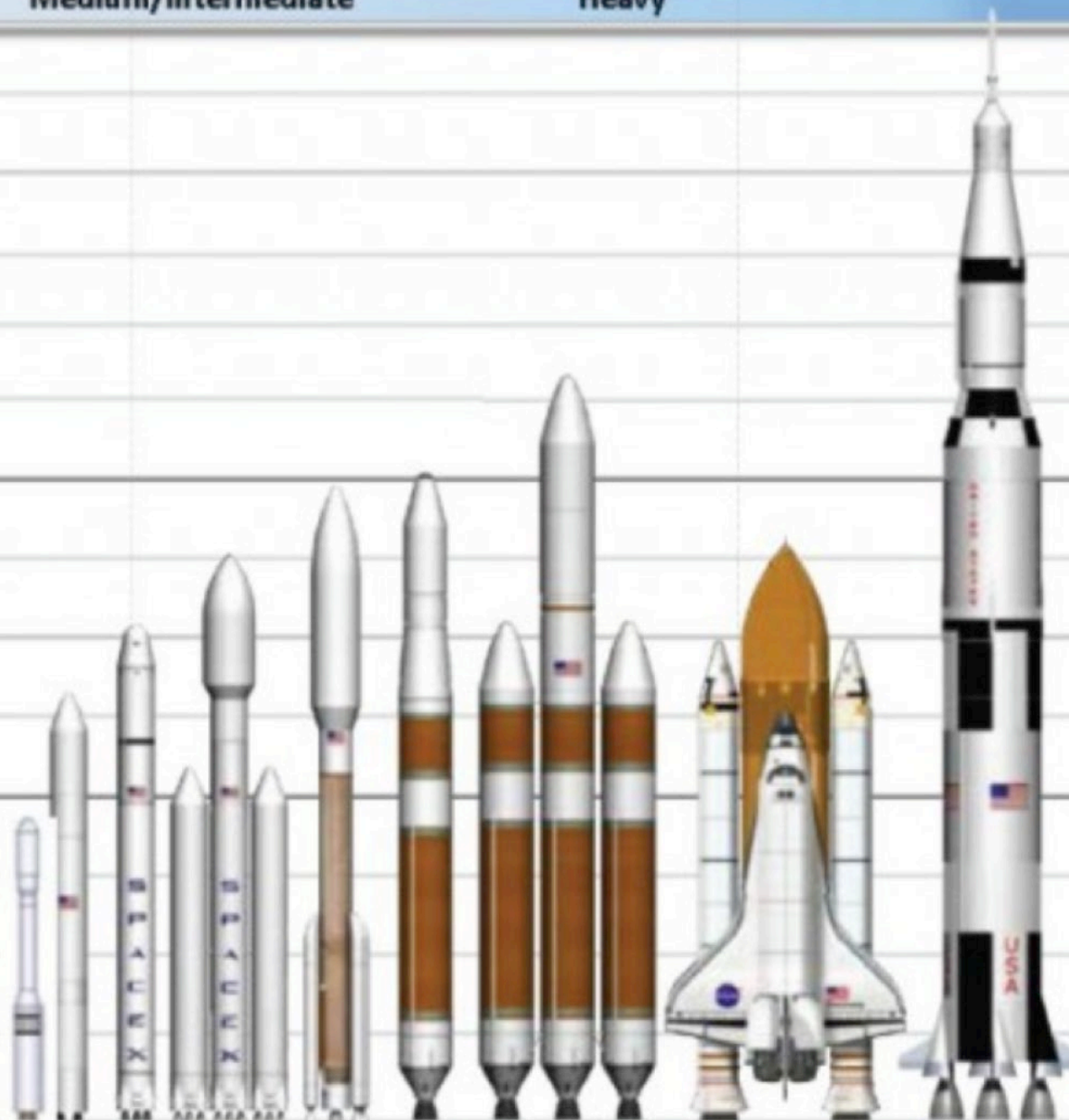
art failure) Intel 4004
chev dies first microprocessor
5, first scientific pocket calculator
Nixon visits China and Russia
marks beginning of DETENTE
r beats Spassky in Chess Match
Munich Olympic Terrorism
es (heart failure) Oil Crisis
u-144 crashes at Paris Air Show
e Jean King beats Bobbie Riggs

India's first nuclear bomb test
resigns after Watergate Scandal
asso elected as female governor

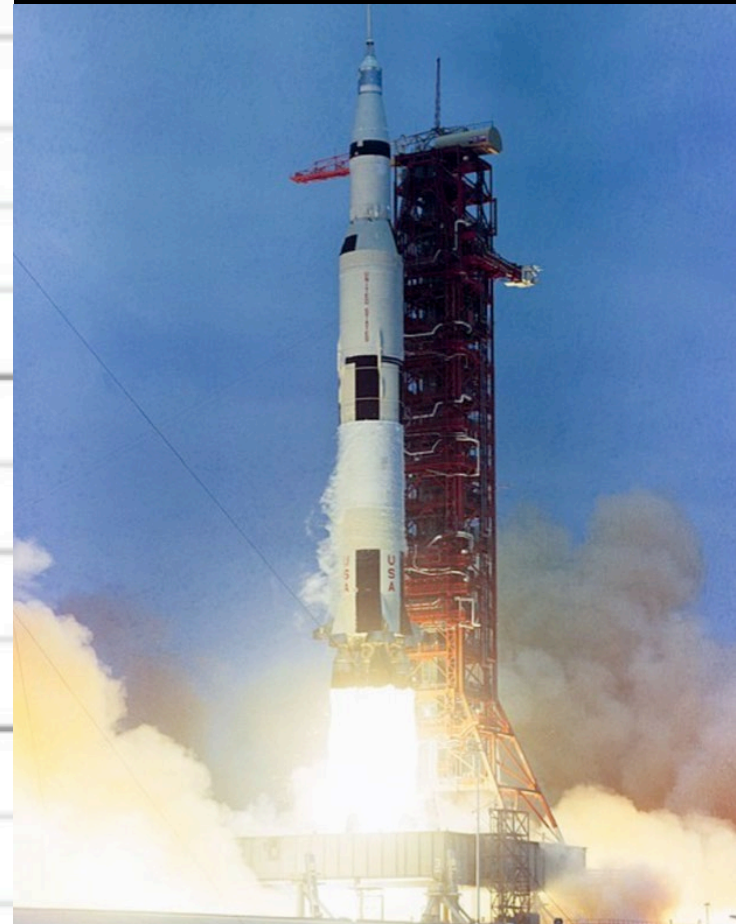
Sony markets Betamax
ari markets Pong home console

Medium/Intermediate

Heavy



Orbital Taurus I & II	SpaceX Falcon 9 & FH	ULA Atlas V 551	ULA Delta IV M	ULA Delta IV H	NASA Space Shuttle	NASA Saturn V
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The launch of [Apollo 10](#) on Saturn V AS-505,
May 18, 1969

Tallest, heaviest, most powerful



Luna 16 USSR
sample return 1970

Proton launcher

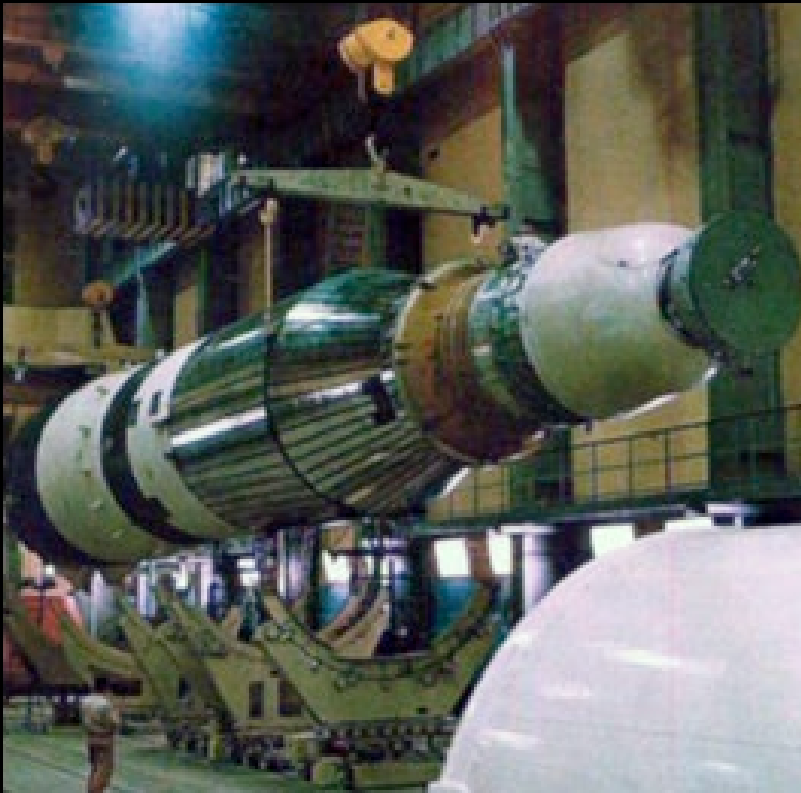
Height 174 ft

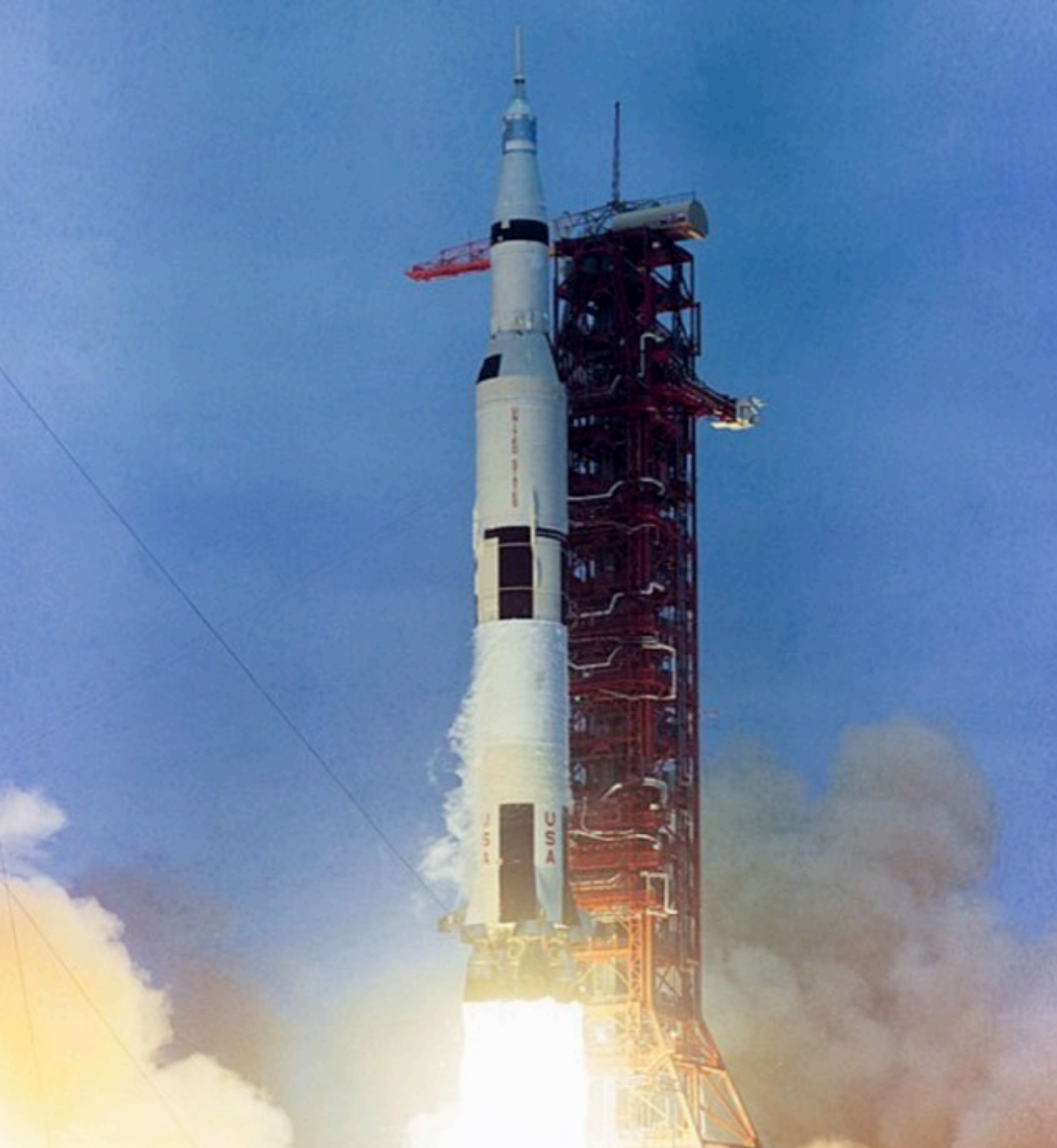
Diameter 23 ft

Mass 694 tonnes

Zond 5 lunar orbiter 1968

2 tortoises, worms, flies, seeds, bacteria





Saturn V launcher

Height 334 ft
Diameter 33 ft
Mass 3000 tonnes

Manned lunar landings
1969-1972

Apollo10 lunar module
rehearsal

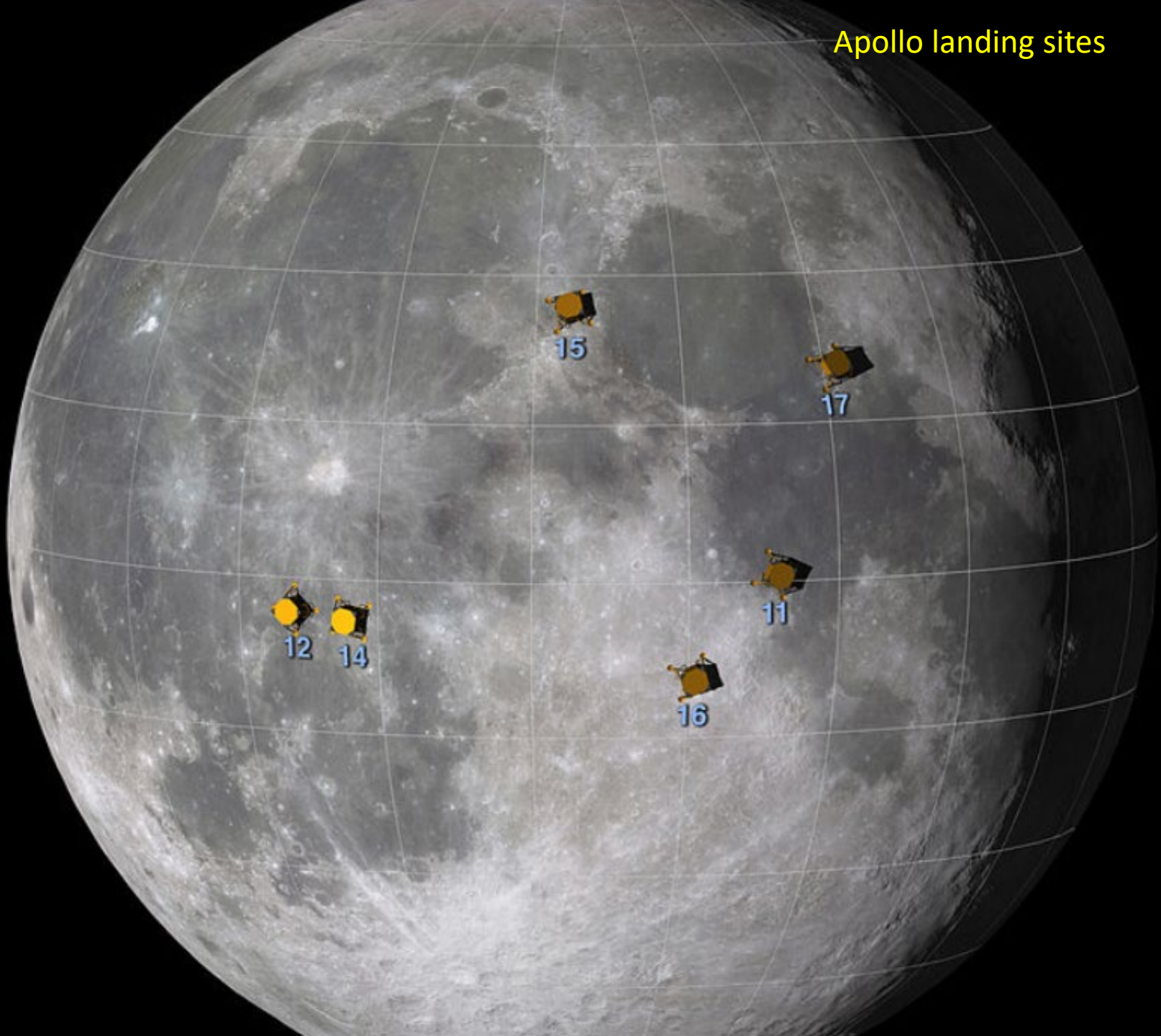




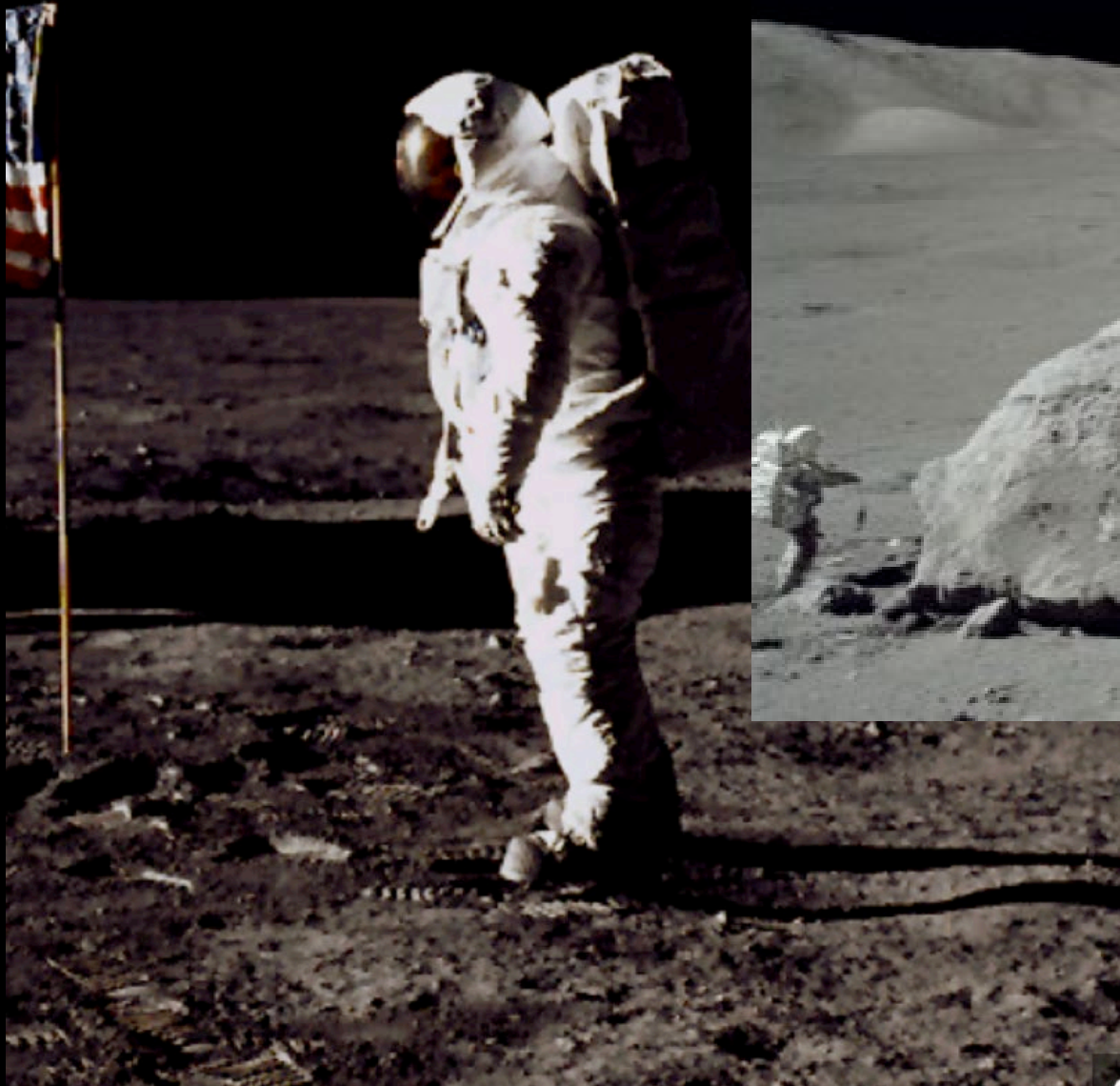
world record speed 24791 mph
on May, 26, 1969 during return
of Apollo 10



Apollo landing sites



Buzz Aldrin
Apollo 11



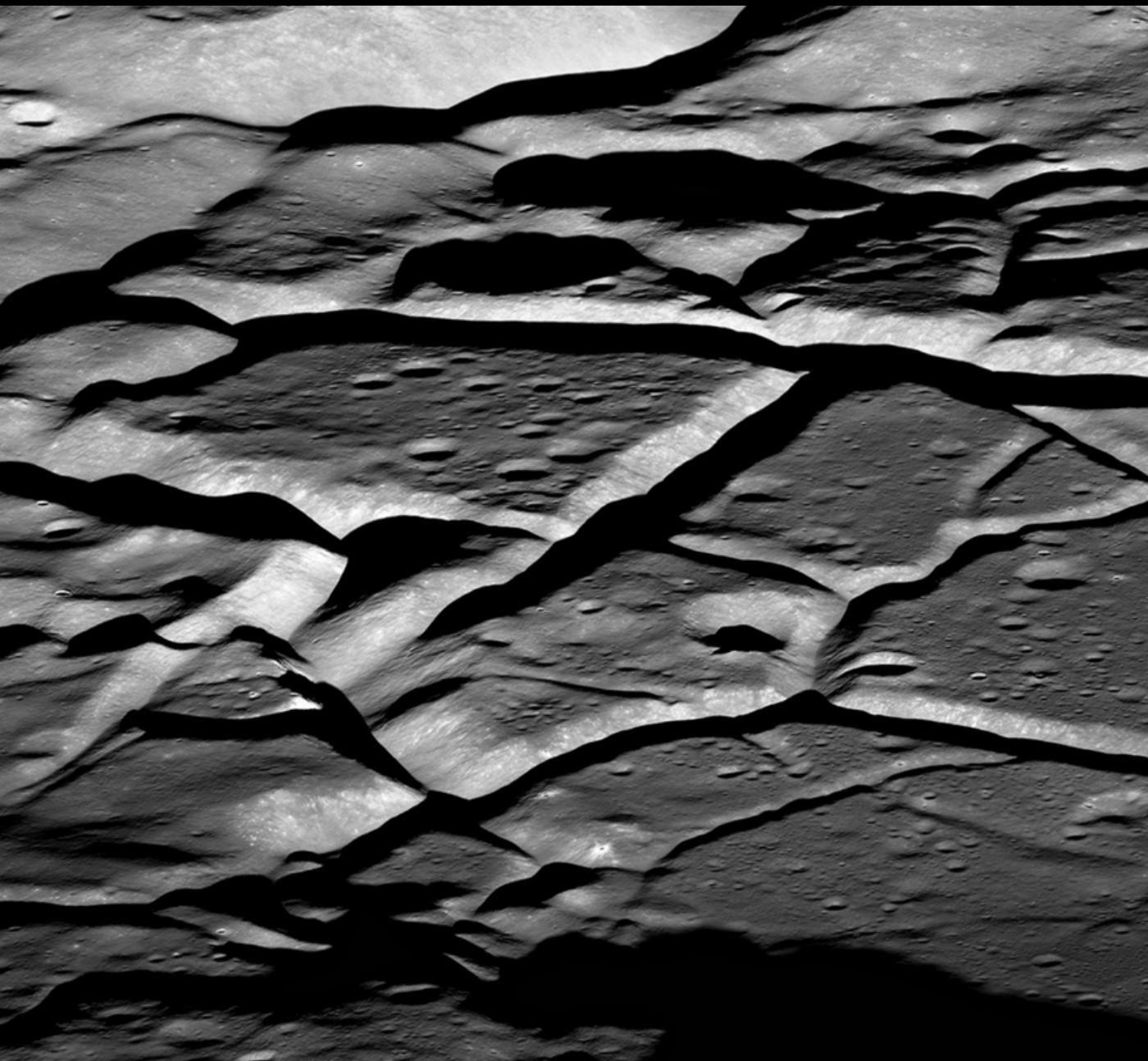
Harrison Schmitt
Apollo 17



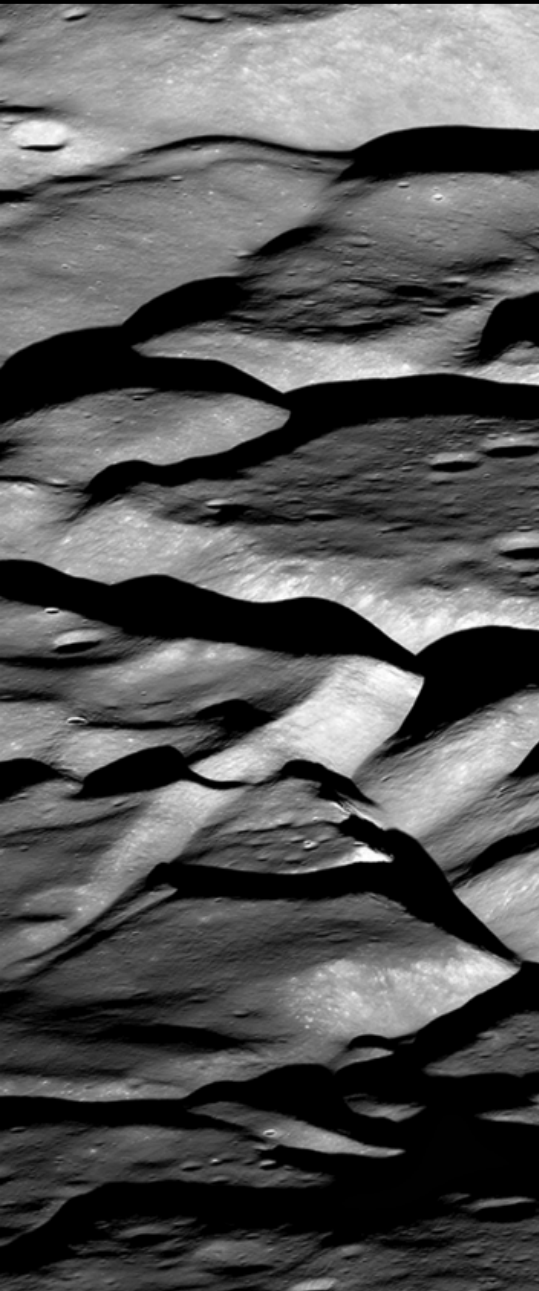
NASA's Lunar Reconnaissance Orbiter,
launched 2009



Komarov crater

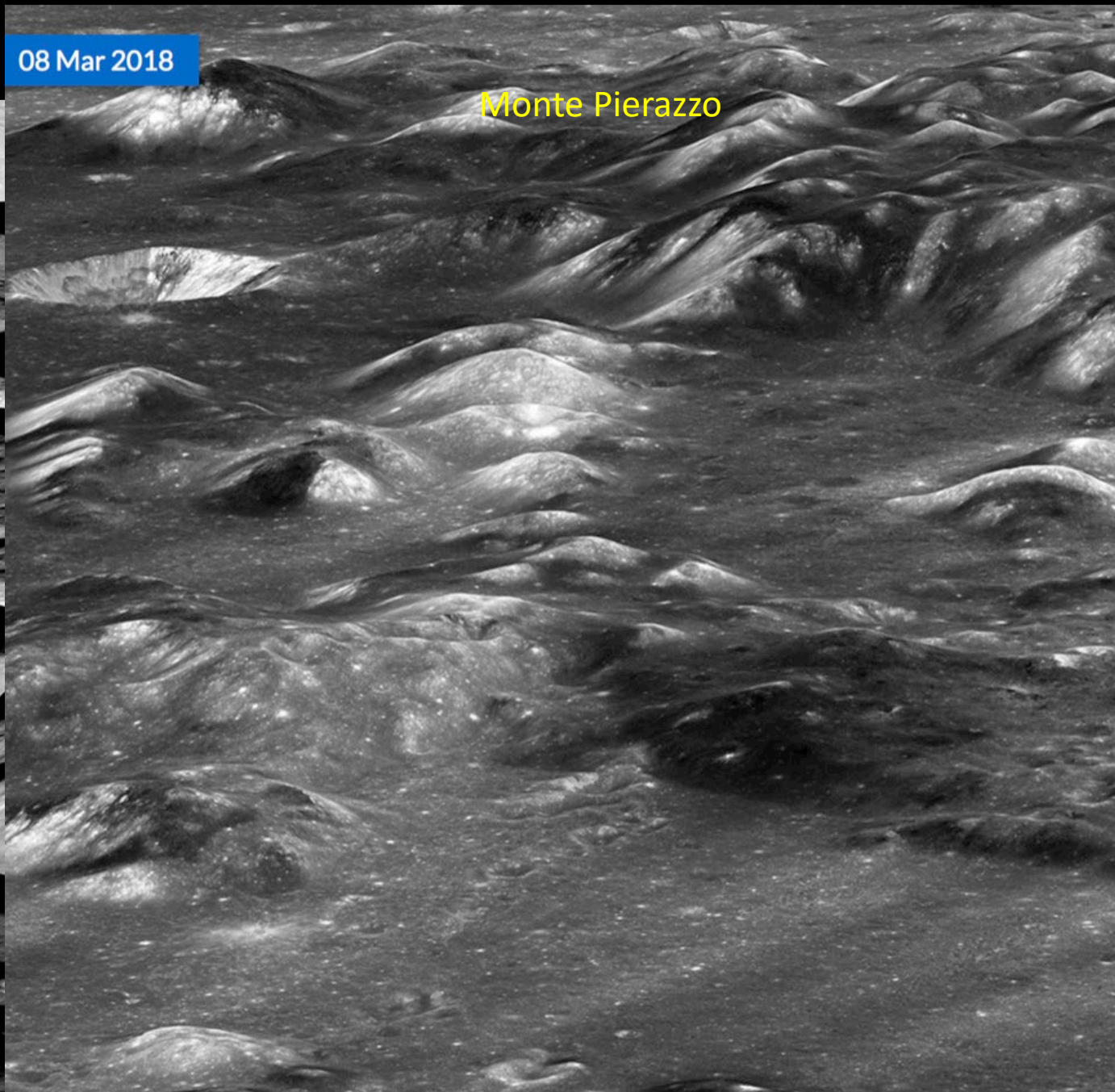


Komarov crater

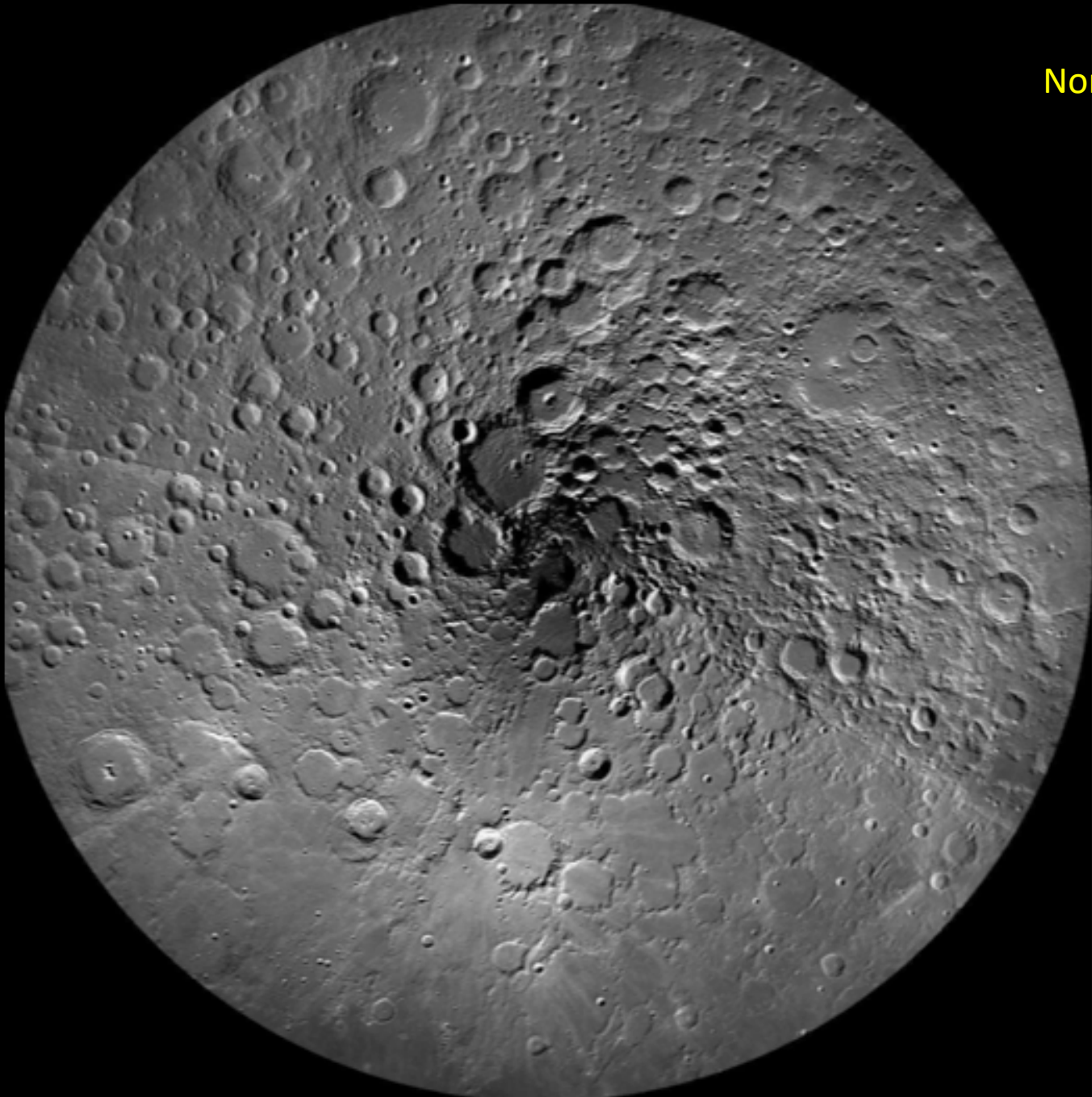


08 Mar 2018

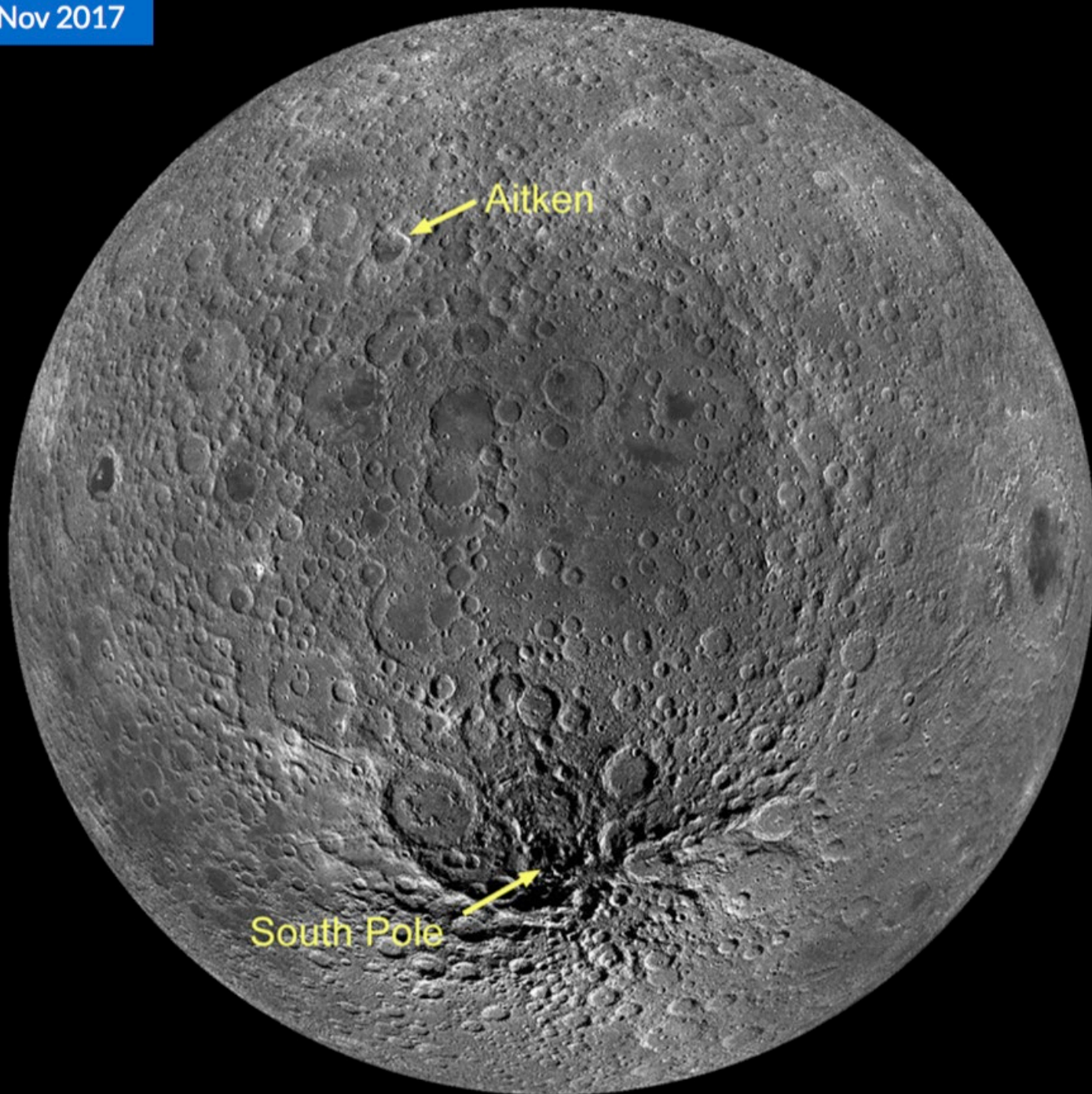
Monte Pierazzo

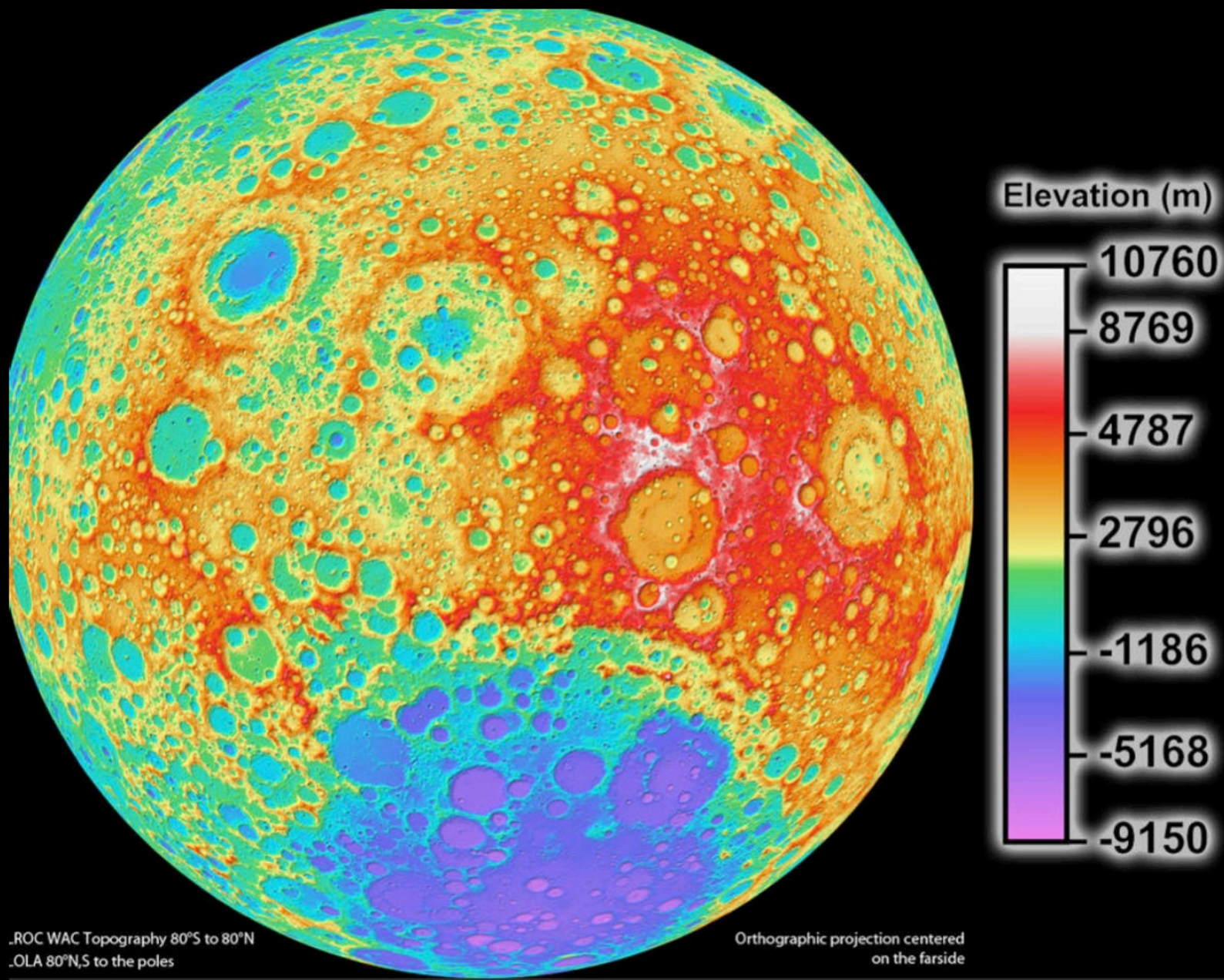


North Pole

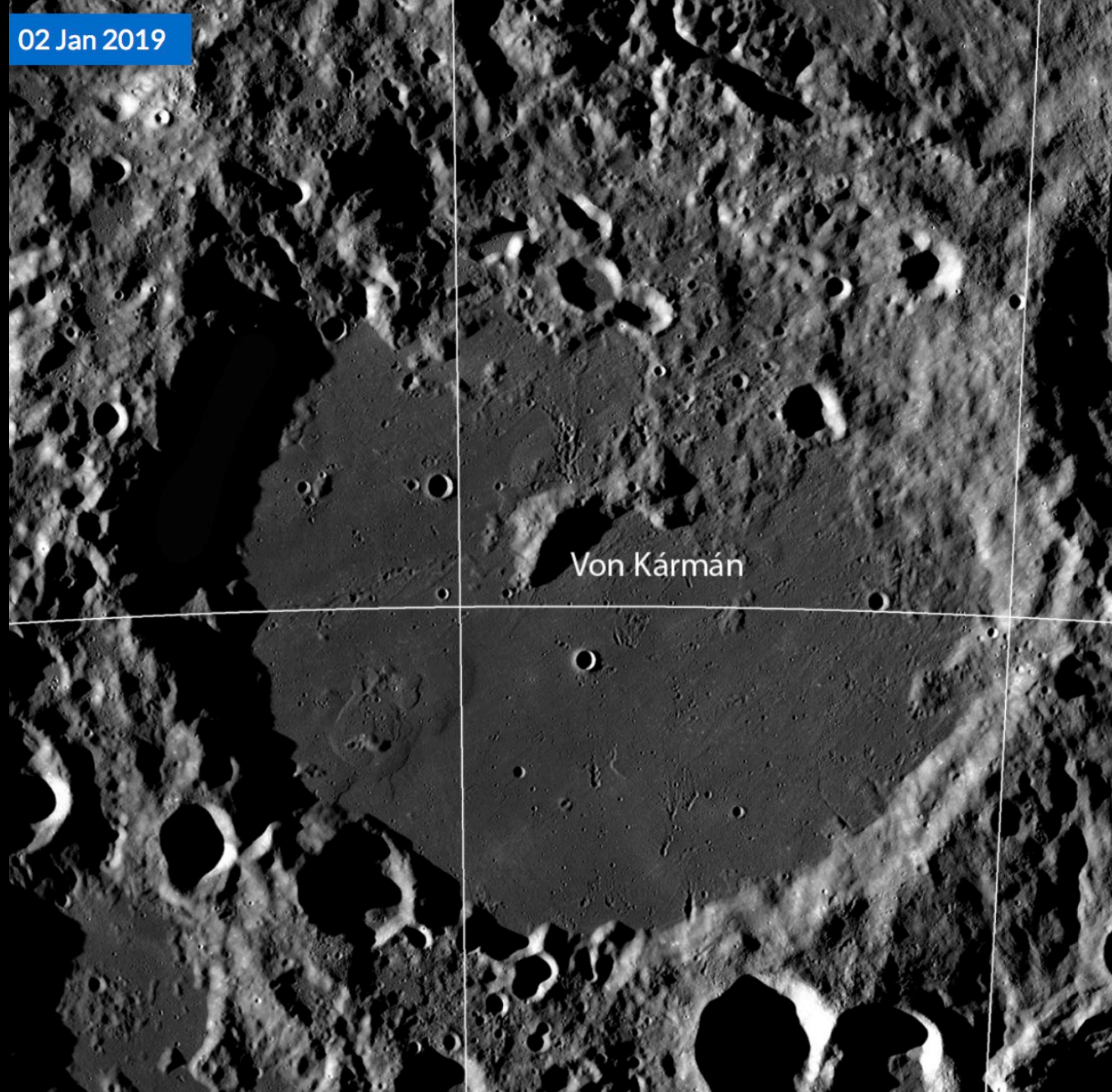


02 Nov 2017

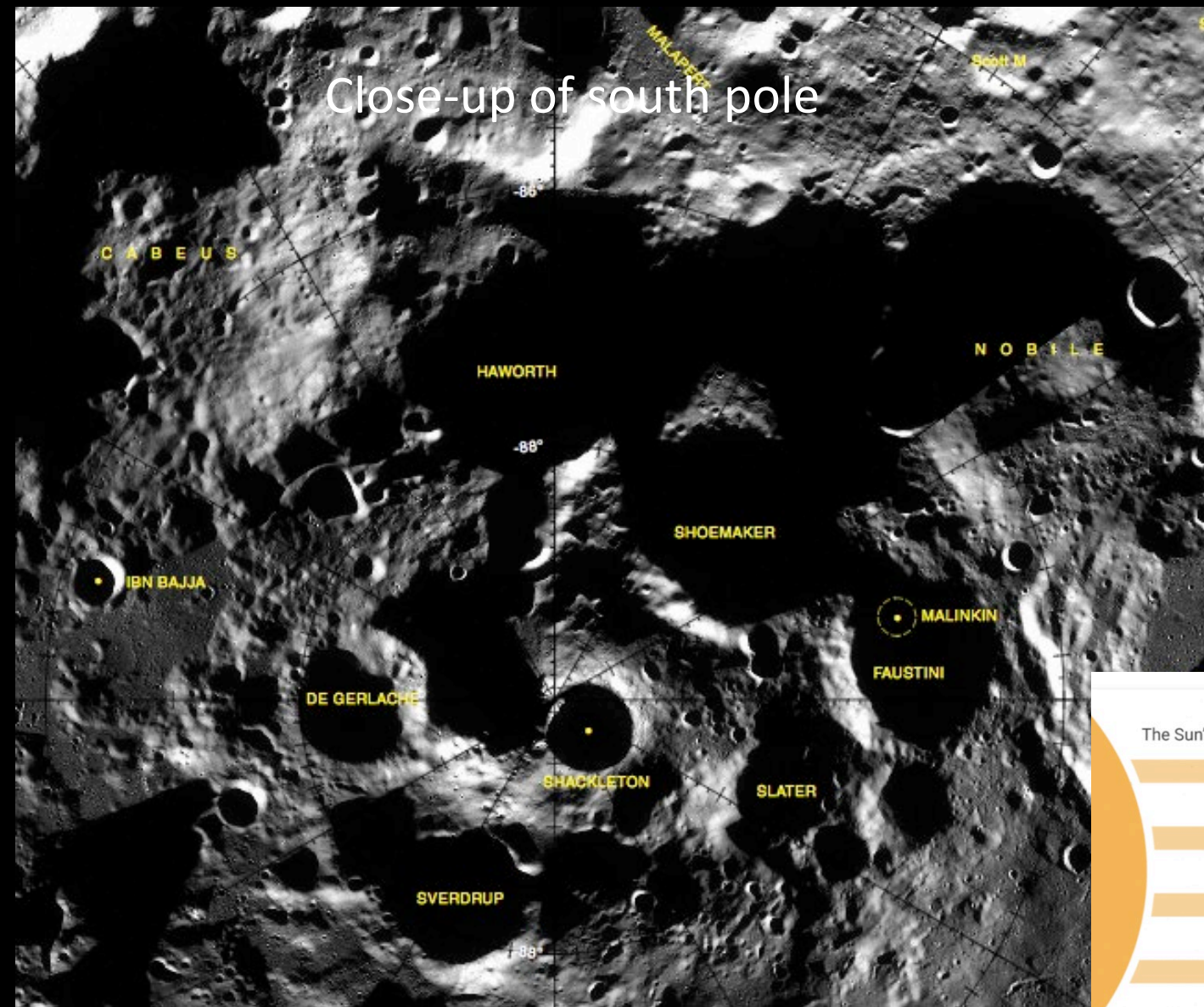




02 Jan 2019



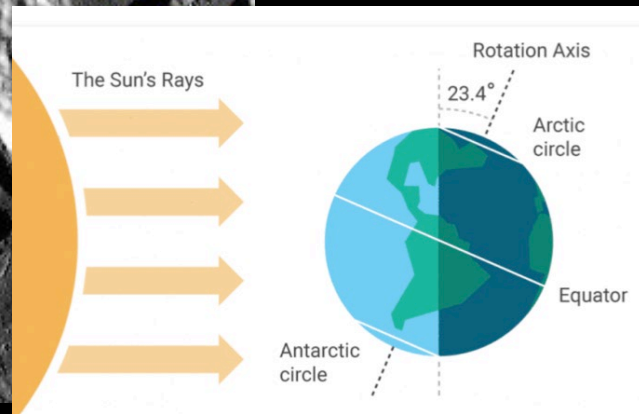
Dark cold craters with nearby solar power ideal for telescopes



4 km deep, 21 km wide
eternal darkness

perpetual light

Shackleton crater



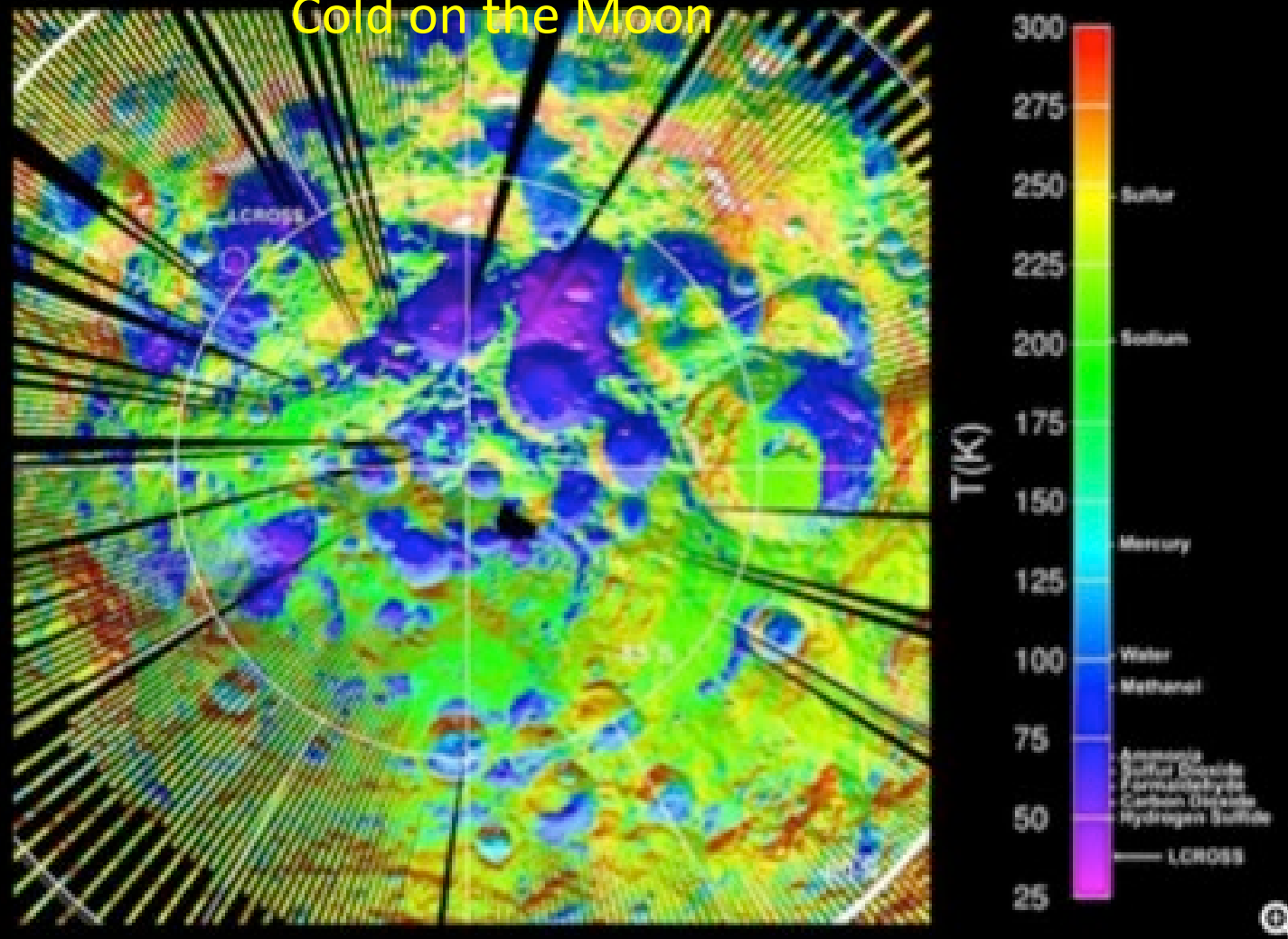
Water on the moon

**Chandrayaan-1
IR spectrometer
hydration signature
(OH)**



Blue = water absorption strength

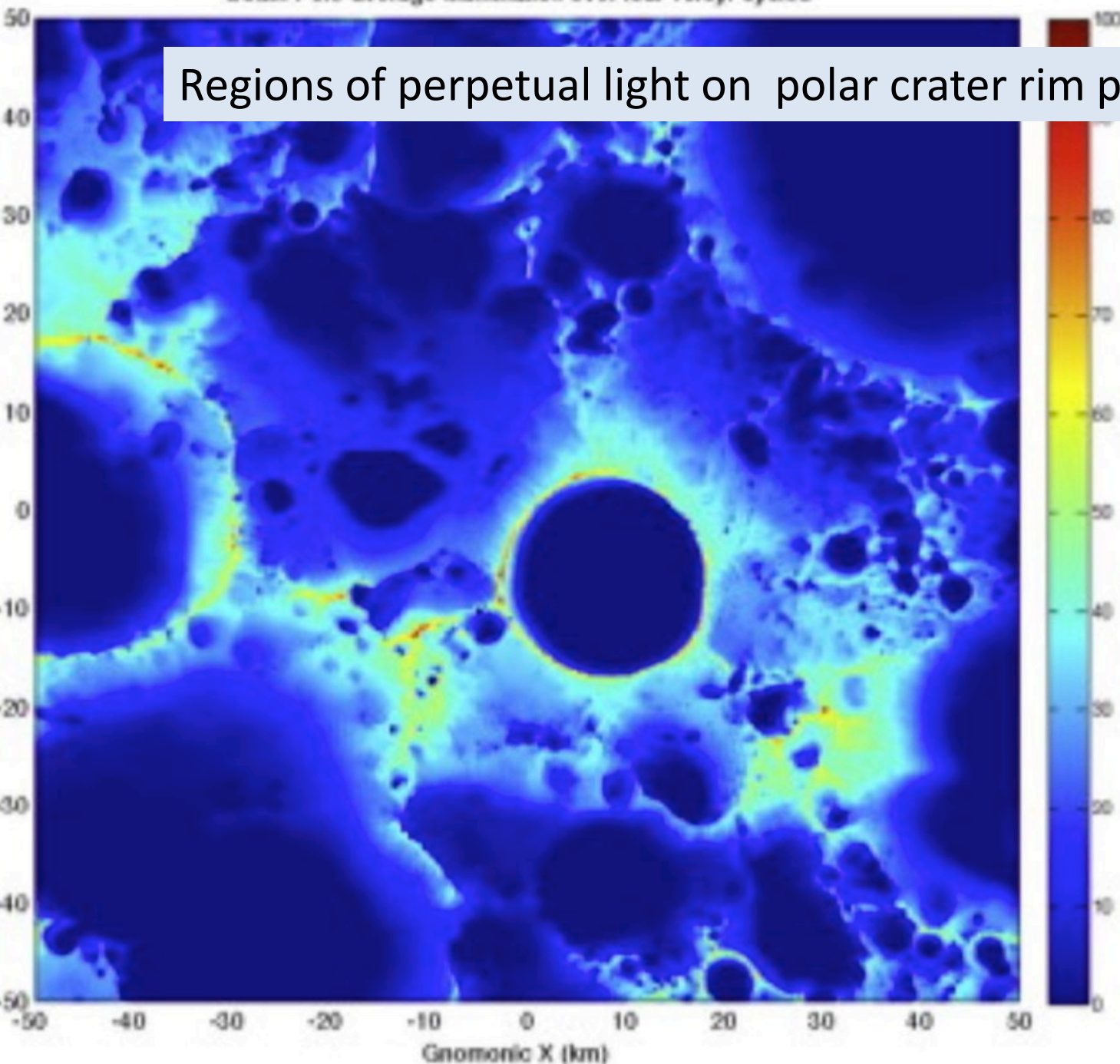
Cold on the Moon



LRO Diviner Lunar Radiometer Experiment surface temperature map of the south polar region of the Moon. The data were acquired during September and October 2009, when south polar temperatures were close to their annual maximum values. The map shows the locations of several intensely cold impact craters that are potential cold traps for

South Pole average illumination over four 18.6yr cycles

Regions of perpetual light on polar crater rim peaks



Shackleton crater rim



ESA concept: Moon Village at lunar south pole



Aims: business and tourism in 2035+

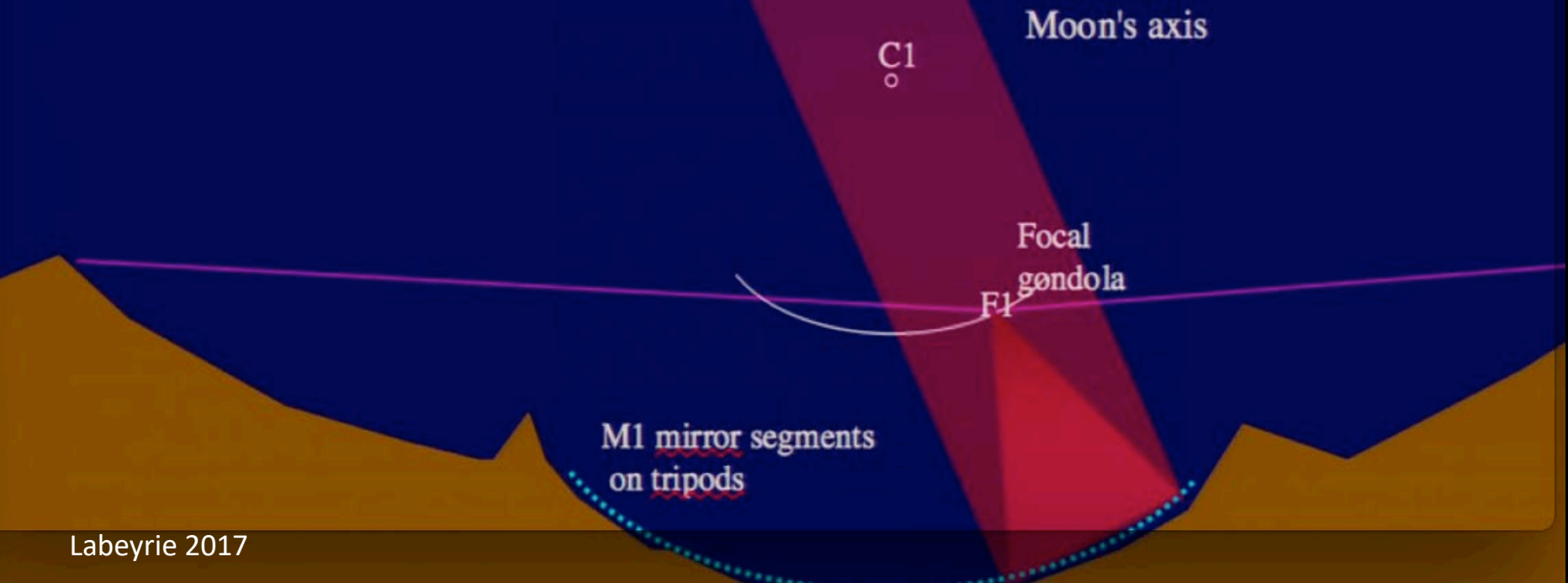
ESA concept: Moon Village at lunar south pole



Aims: business and tourism in 2035+

10 km NIR hypertelescope

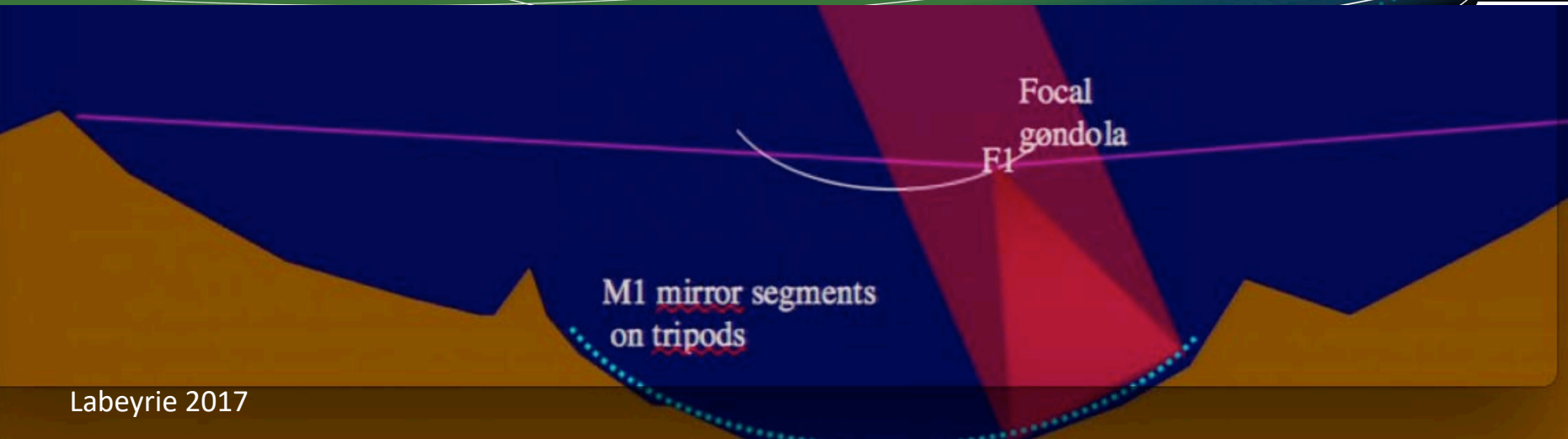
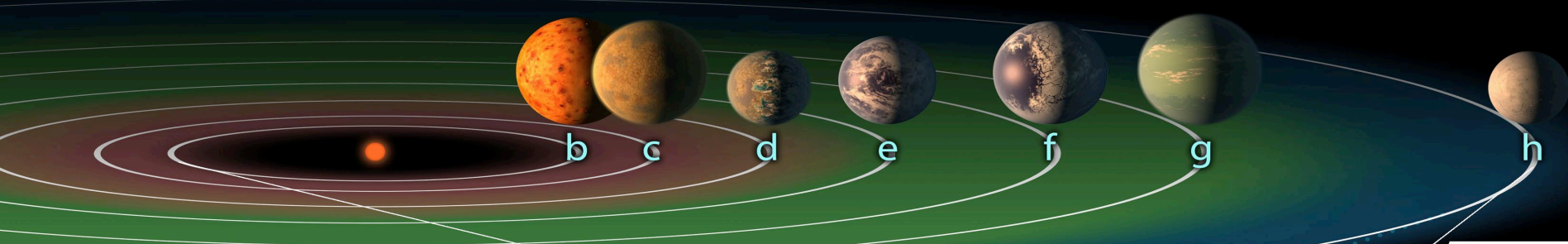
- Fixed segmented primary mirror, 5-10 m size
- Meta-aperture size: 5 km, limited by crater depth
- Focal camera suspended from cable, actively pendulated
- Resolution: 20 to 5 microarc-seconds in visible (500nm)
4 to 1 microarc-seconds in UV (100nm)
- Sky coverage : yearly: $\pm 45^\circ$ from ecliptic (about 65 % of sky)



10 km NIR hypertelescope

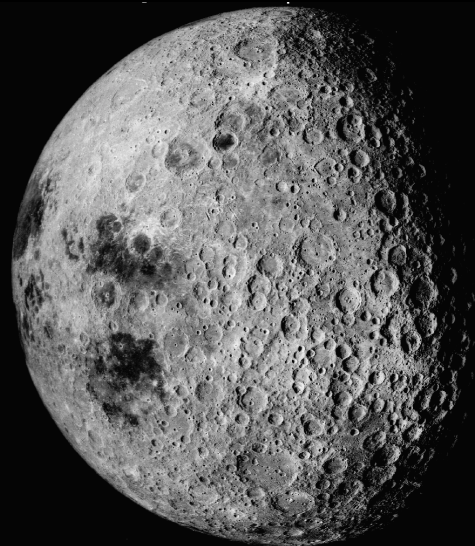
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TRAPPIST-1 System



far side of MOON for low frequency radio astronomy

most radio-quiet environment
in inner solar system



JPL concept

21cm hydrogen absorption against CMB

probe redshift =50 @ 30 MHz
or wavelength 10m

optimal array is $D \sim 10-100$ km

need millions of antennae



SKA-LOW 10^5 antennae in 2025

Chang'e

When we will return?

2013

Europe's space
moon village
the end of the

ESA said the Moon was the
Said immediate goal was
the next decade

By AFP

PUBLISHED: 11:36, 28 September 20

Trump will
astronauts

WASHINGTON (Reuters)

An exclusive look at Jeff Bezos' plan to set up Amazon-like delivery for 'future human settlement' of the moon

By **Christian Davenport** March 2, 2017 [Email the author](#)



NYT, Nov 20, 2018

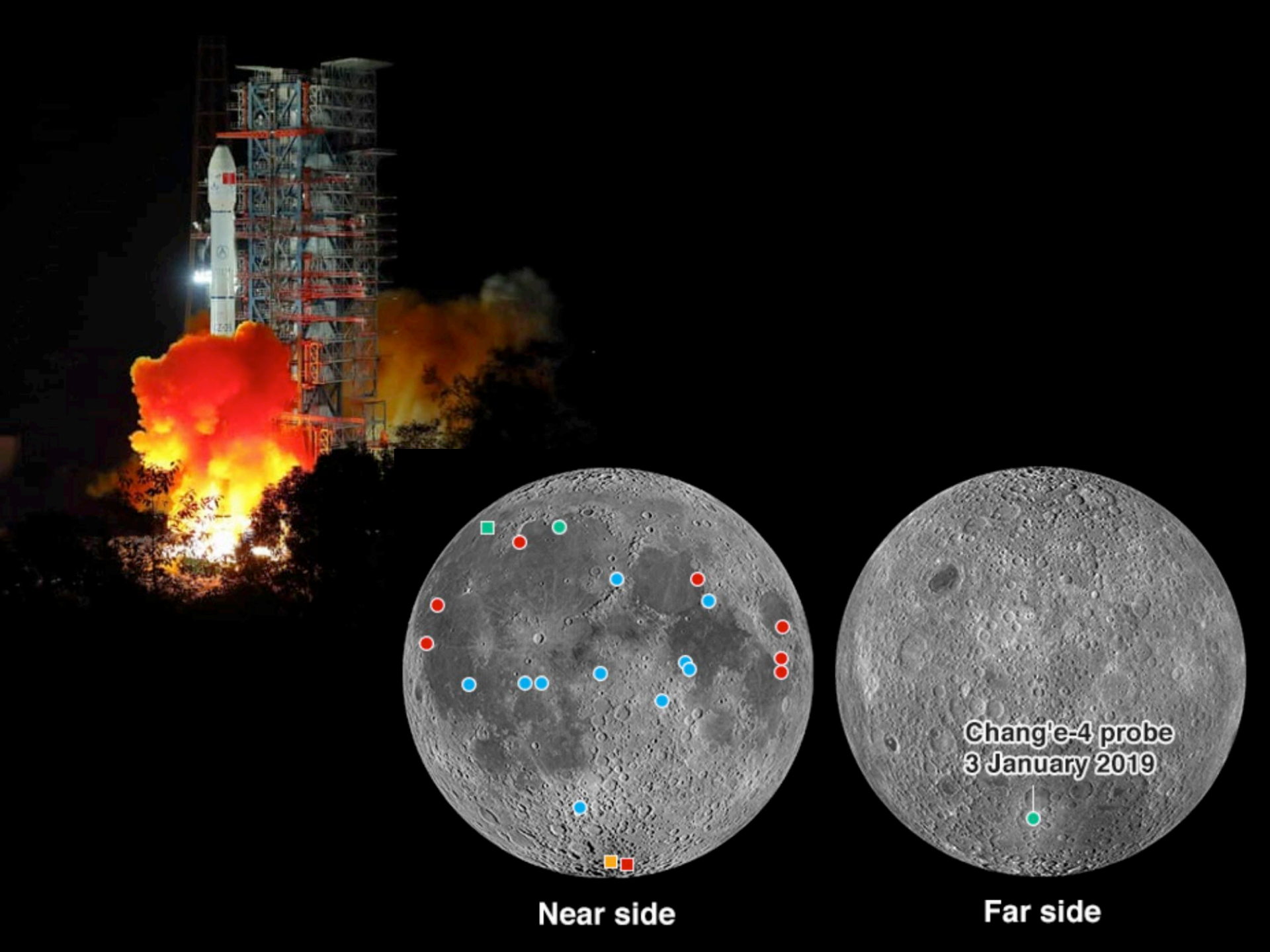
NASA Chooses Private Companies for Future Moon Landings

Nine companies will vie for more than \$2 billion dollars to build small landers to carry science experiments to the lunar surface.

build a
base by

it, by the end of

Recall: HST +++ was 5-10% of cost of ISS + Space Shuttle
Strong commercial interest in lunar tourism, mining, fuel...



Near side

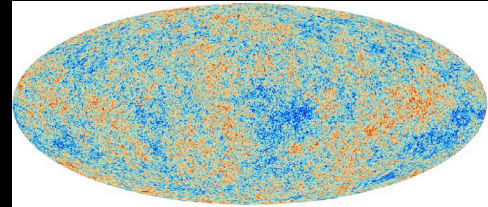
Far side

The future of cosmology

Dark energy? No prediction for $w \neq -1$

Dark matter? No detection yet!

Probing inflation via CMB? No lower bound



$N \sim 10^6$ modes: 0.1% CMB at precision $N^{-1/2}$

We must pursue B, we may get lucky!



$N \sim 10^8$ 0.01% with galaxies

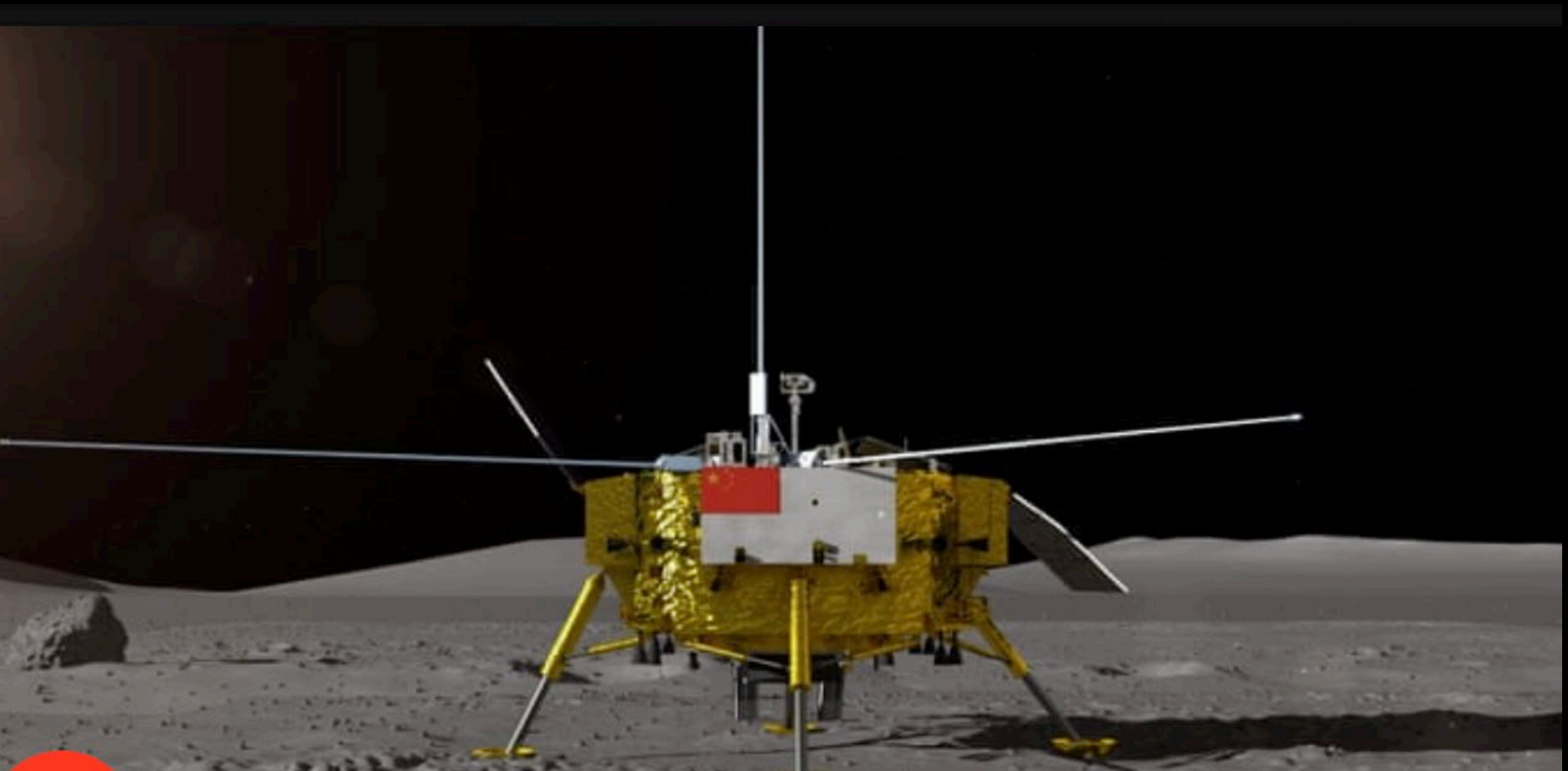
$N \sim 10^{12}$ in the dark ages
0.0001% with HI in 1st clouds



Back to the moon!

Chang'e lander with radio dipole antennae

Landed on far side of Moon: Jan 3 2019



Issues for the future of lunar exploration

- International treaties
- Pollution
- Property law
- Mineral rights
- Criminal law

Outer Space Treaty United Nations 1966

principles governing the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies

Article IX, second sentence:

State Parties shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination

Article I, OST 1967

All states shall have equally free access to Outer Space including the Moon and other celestial bodies....outer space is not subject to expropriation by claim of sovereignty, by means of use or occupation

Article IV expressly allows the use of military personnel for peaceful space activities

Article XXII IGA 1988: Partner States may exercise criminal jurisdiction over nationals of a partner state whose misconduct in orbit affects the life or safety of a national of another partner state.

