Resource-Development and Environmental Challenges for Life on the Space Frontier*

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Editor's note: Please refer to closely related article Search and Discovery Article #70196 (2015)

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Abstract

Successful, safe, and sustainable human habitation of space depends on a host of resource-development and environmental factors. Improved technology in space-transportation systems and in situ resource utilization (ISRU) can support an expanded human presence in the Solar System and beyond. ISRU includes energy sources, metals, as well as water and volatiles. Almost all planets and asteroids in the Solar System possess resources in differing degrees of abundance and accessibility. Helium-3, a potential source of energy for both electricity generation and space transportation, as well as regolith-bonded hydrogen, mainly occurs on airless bodies (the Moon, asteroids, and Mercury). Water ice is superabundant on Mars but is also present in polar regions on the Moon and Mercury, as well as comets and volatile-rich asteroids. M-type asteroids contain a variety of precious metals such as platinum and palladium. Lunar metals such as titanium, magnesium, and iron occur in basaltic mare, and along with helium-3 and hydrogen, can be mined with currently available technology. Environmental constraints on humans in space (microgravity, radiation and temperature flux, absence of atmosphere or atmospheric toxicity, and absence of soil organics) can be overcome through engineered habitation structures and terraforming. Although microgravity on asteroids and comets poses challenges for mining, these problems can be overcome through advanced materials-collection with mass-drivers for moving refined materials into near-earth or Cis-Lunar orbit. Orbital depots for fuel and life-support materials have benefits for the economics of launch and transit missions and can also serve as temporary accumulation areas for materials transport to Earth's surface. Manned depots in orbit can be made more human-friendly by using ice as a counterweight for rotation-induced gravity. Currently envisioned, shallow-subsurface habitations on the Moon and Mars can allow humans to cope with hostile radiation environments on planetary surfaces. Future advances in technology and planetary engineering, involving surficial domed structures and ultimately terraforming, can potentially greatly expand human accessibility to planetary terrains. For each resource or environmental challenge in space there are existing technologies that are fully capable of supporting a sustained human presence in space.

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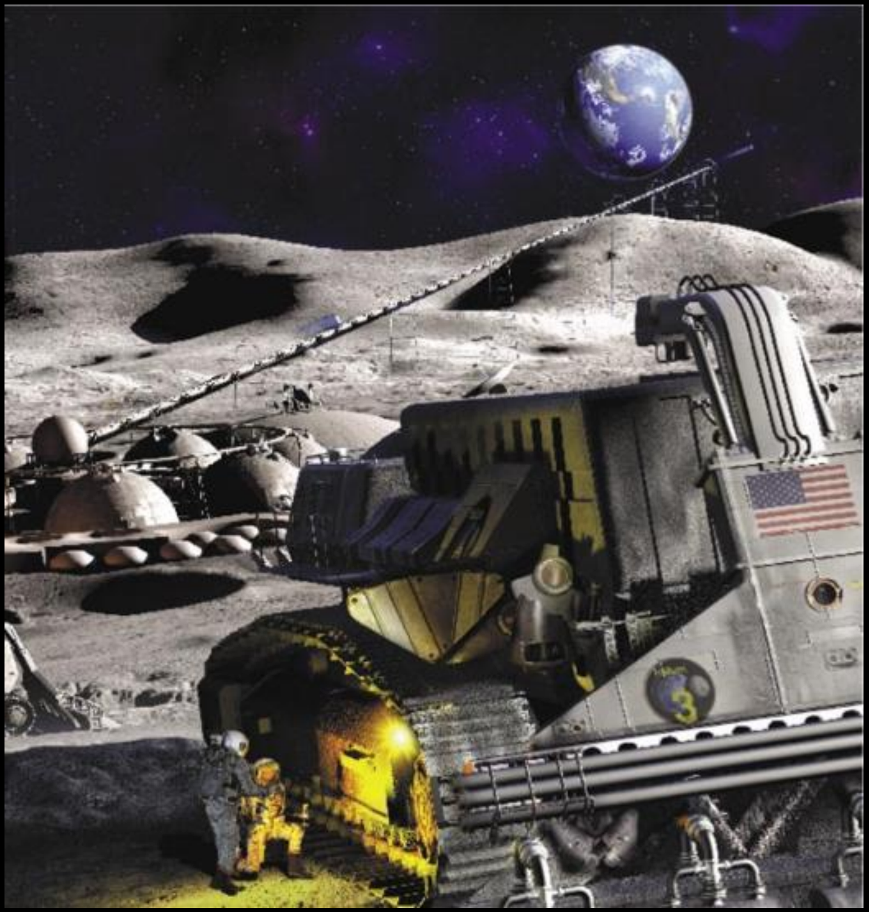
BUREAU OF ECONOMIC GEOLOGY



Schmitt (2004)

Outline

- **Moon**
  - *-Return Mission*
  - *-Resources and Habitation Systems*
- **Asteroids**
  - *-Resources*
  - *-Microgravity*
- **Mars**
  - *-Mission Parameters*
  - *-Resources*
  - *-Terraforming*

Why Return to the Moon?

- **Earth's closest neighbor**
  - *-Three-day trip*
  - *-Technology already exists to return to the Moon*
  - *- Less than 0.1% surface area visited by humans*

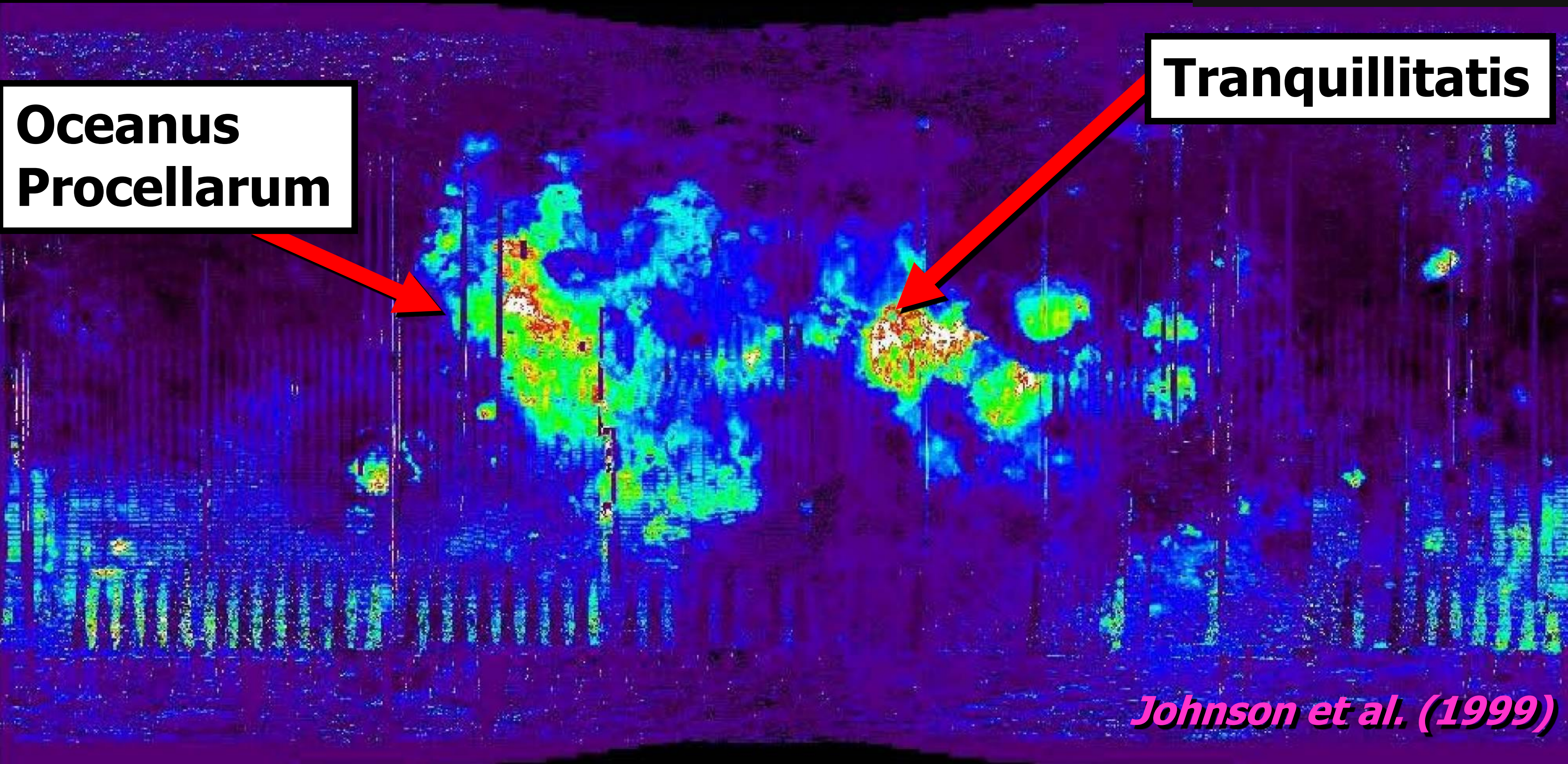
- **Abundant resources**
  - *-Water and volatiles for human settlement and rocket fuel*
  - *-Metals for Moon Base and solar power facilities*

- **Technology Development**
  - *-Settlements: Learning experiences for Mars*
  - *-Mining*
  - *-Space-power systems*

Lunar He-3 Distribution

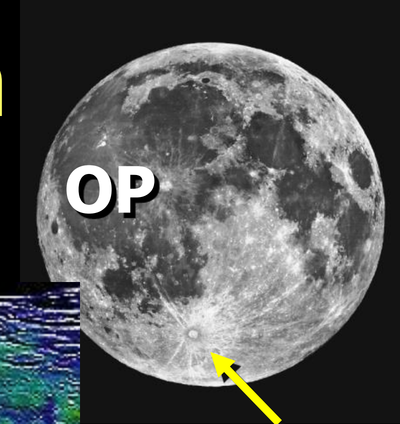
>270,000 km² minable (high- and medium-grade)

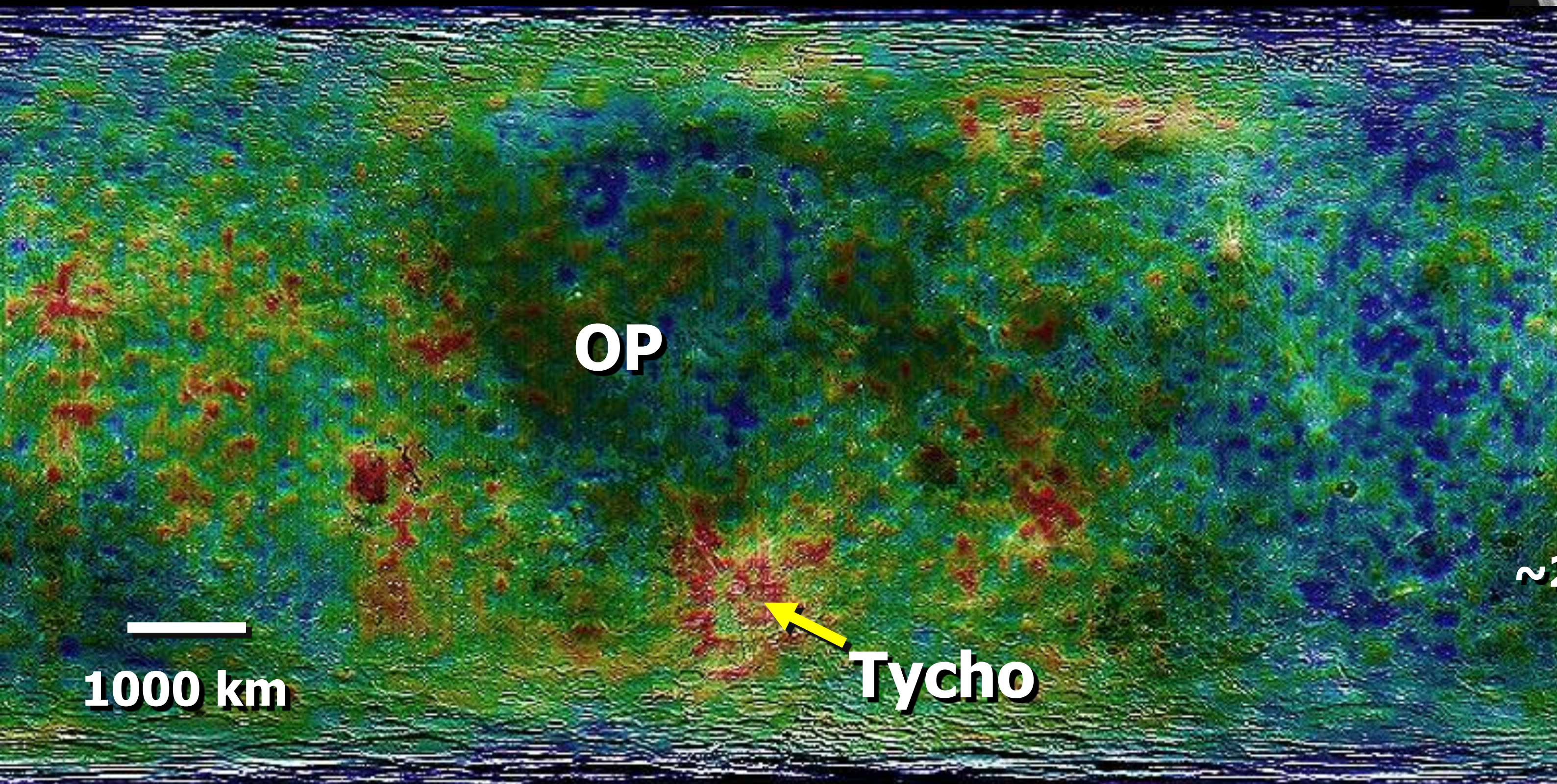
Lewis (1996)



Surficial Hydrogen Distribution

Implantation from Solar Wind





A ~0.4-mi^2 (1-km^2) area of mare regolith at 40-ppm hydrogen could be mined to a depth of ~3.3 ft (1 m) to extract an equivalent amount of hydrogen for launching the Space Shuttle (Spudis, 1996).

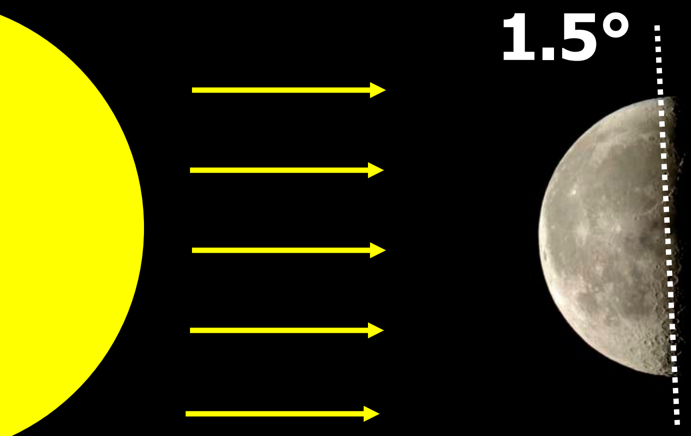
Volatiles at the Poles

Impacts from Comets

10^{13} kg water: past 2 Ga (Arnold, 1979)

North Pole: ~600 Mt of ice:

Daily launches of a space shuttle
For 2,200 years

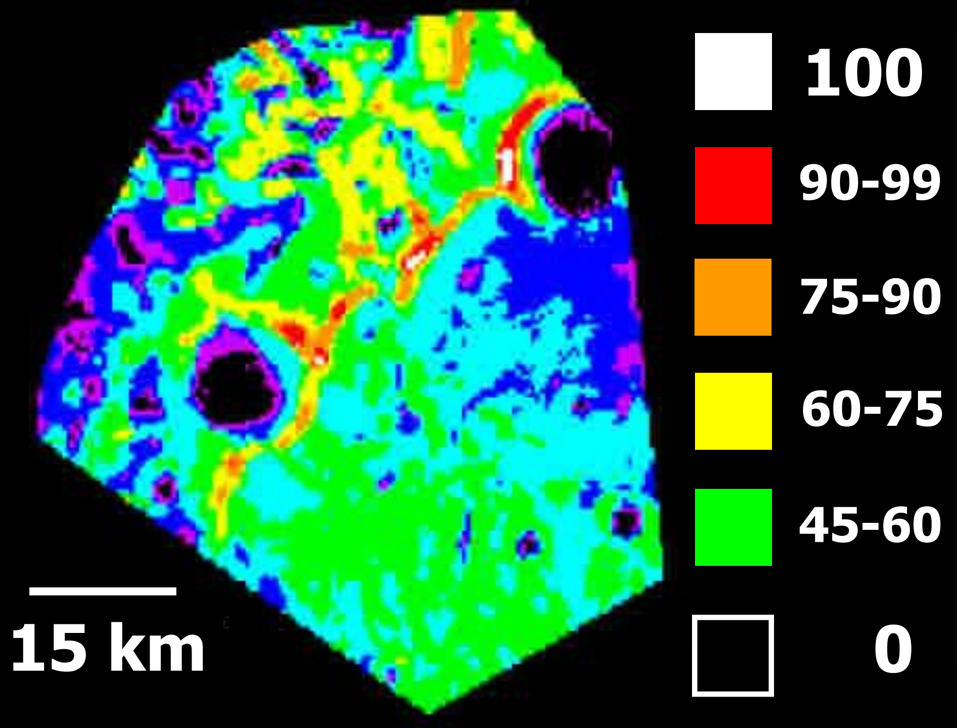


Bussey and Spudis (2006)

Solar Illumination North Pole

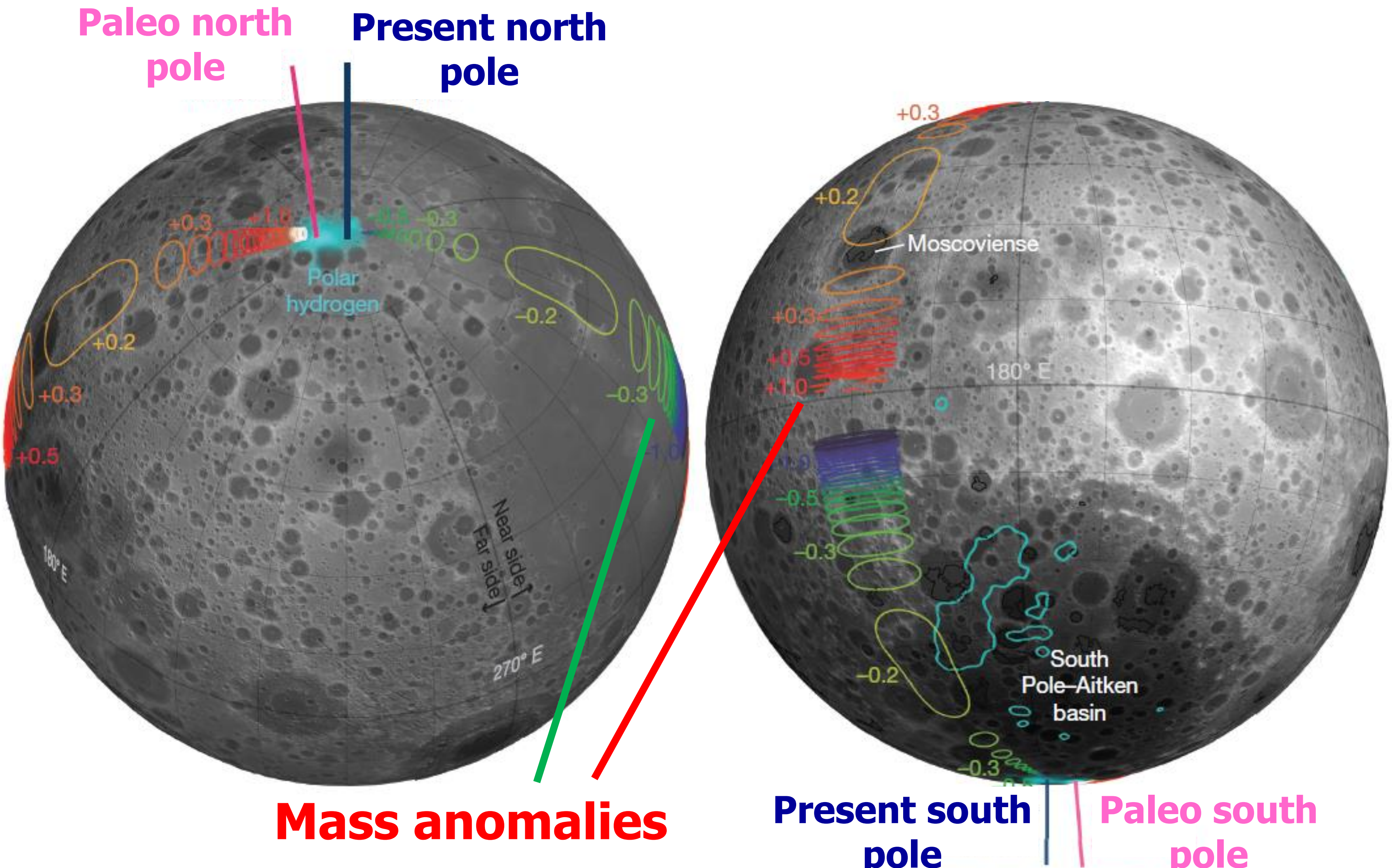
Solar power

% Illumination



Bussey and Spudis (2006)

Off-axis Polar Hydrogen



Modified from Siegler et al. (2016)

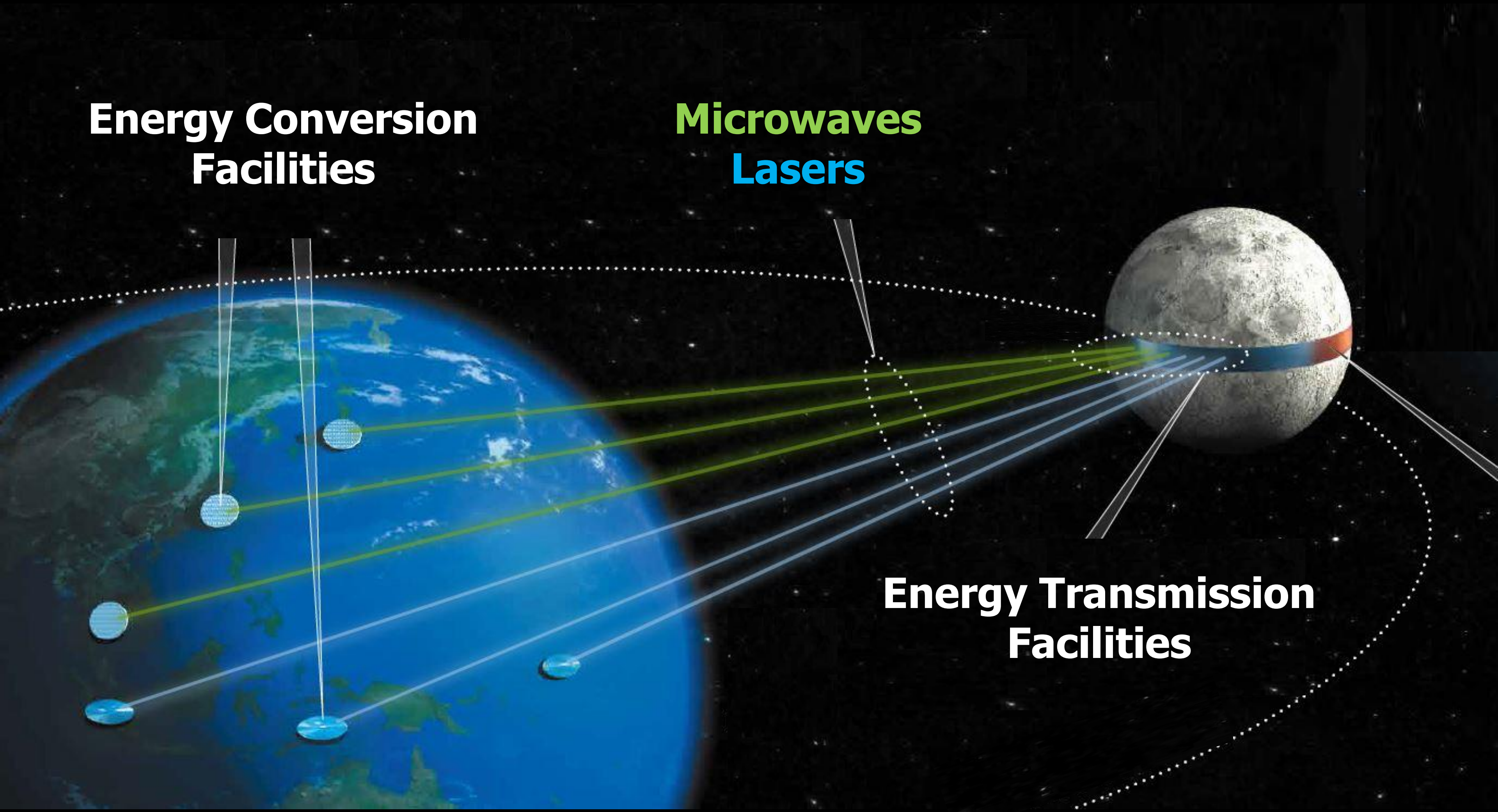
Shackleton Energy Company

Located in Del Valle, Texas (Bill Stone, Founder)

Primary Goals:

- ***Mine lunar water ice and other volatiles***
- ***Produce and deploy rocket propellant***
- ***Provide space-based fuel depots***
- ***$25 B investment for infrastructure development***

Luna Ring: Shimizu Corporation



Modified from Shimizu Corporation (2016)

Golden Spike: Transportation & Lander

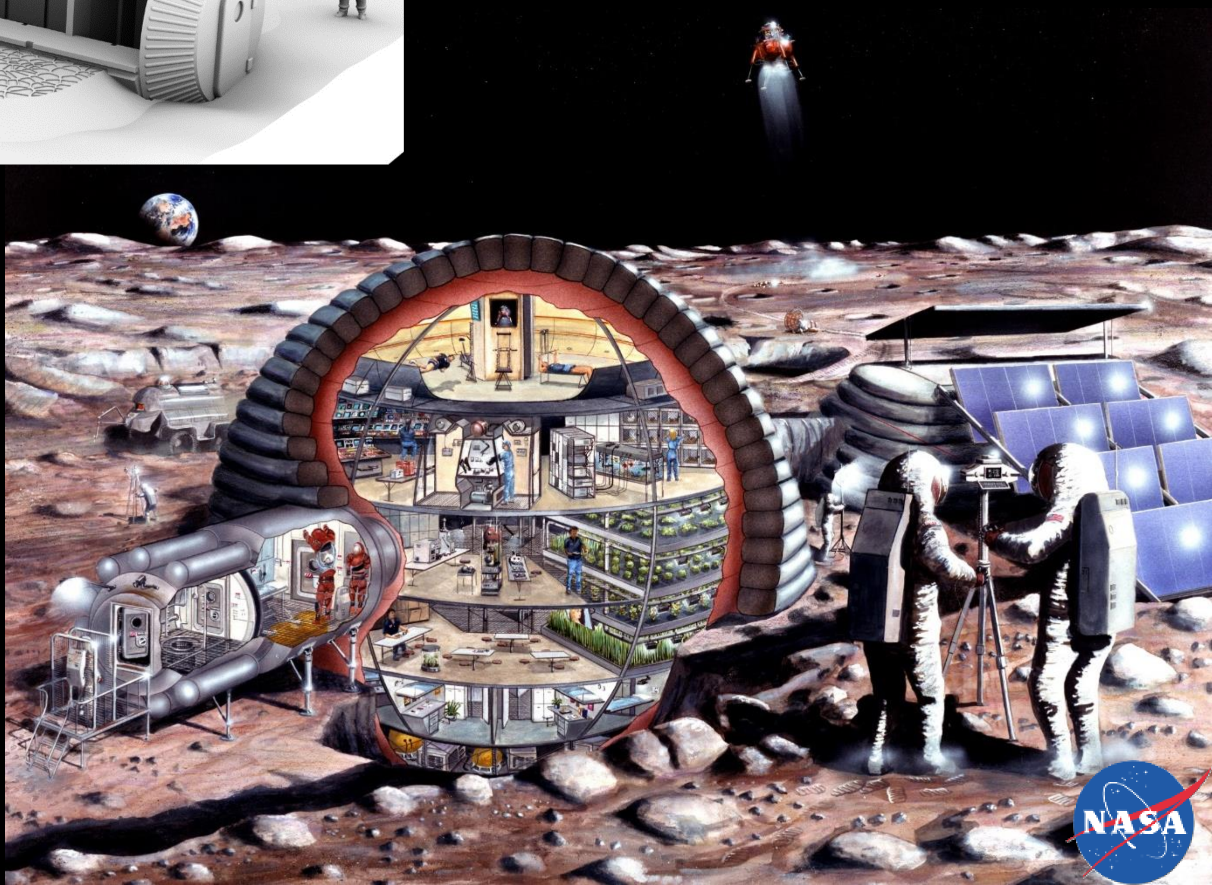
Golden Spike (2016)

Lunar Base Designs

Sinterhab

ESA/Foster + Partners (2013)

Inflatable Lunar Base

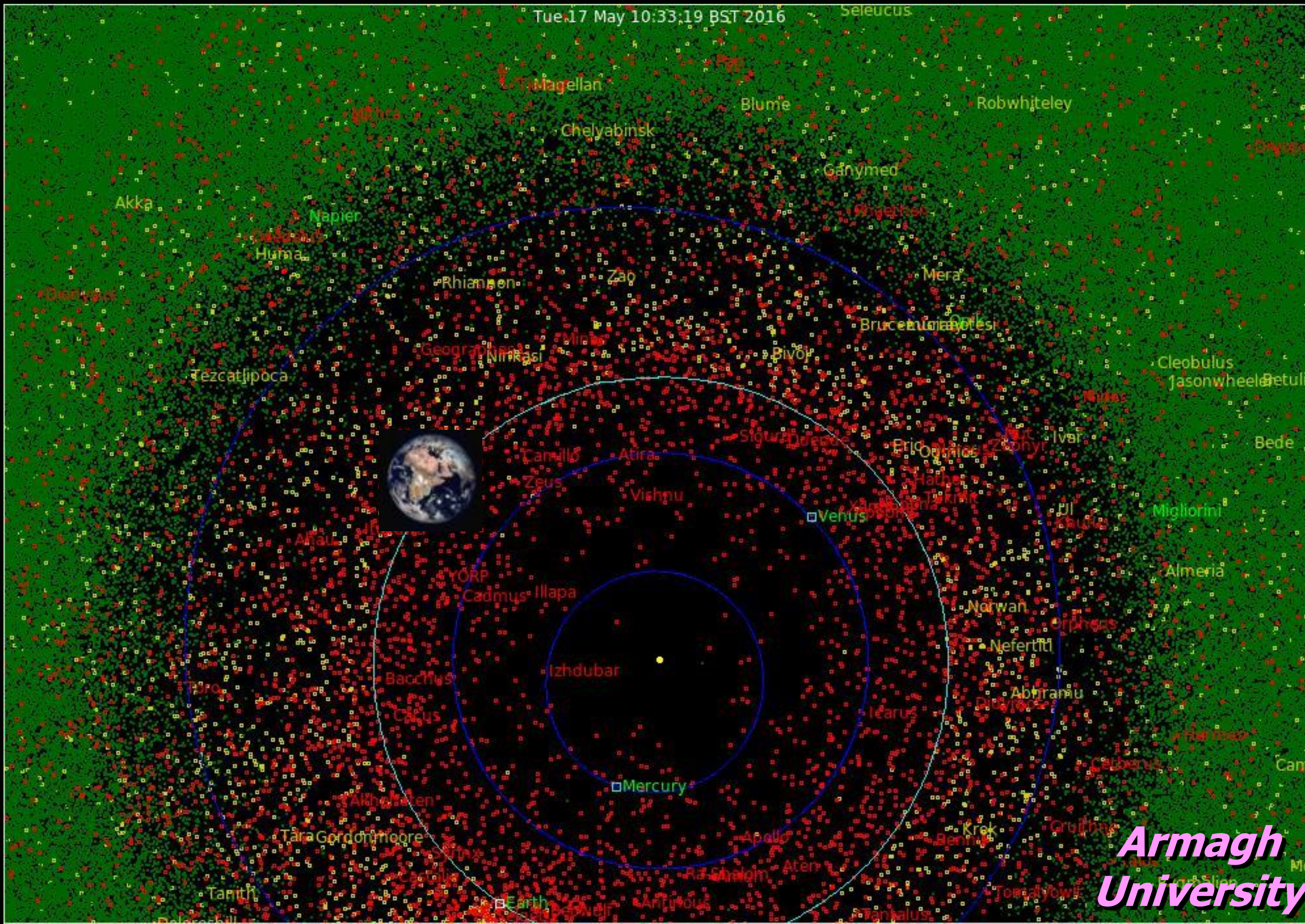


NEAs
May 17, 2016

Non-Earth approaching

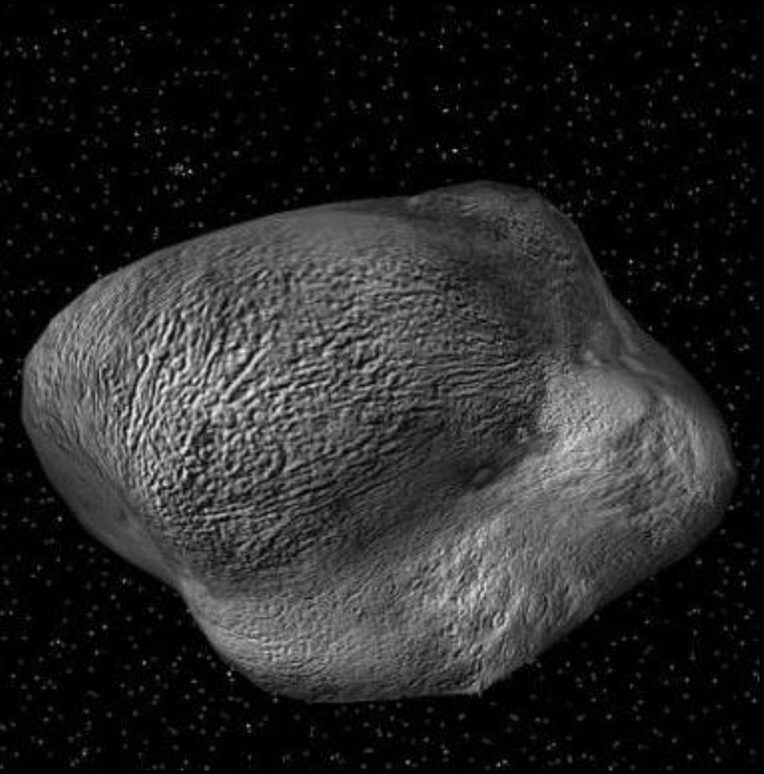
Amors

NEA's



3554 Amun–NEA

Smallest known M asteroid—300× metal in lunar regolith


Codrin Bucur

~2 km diameter (size of a
typical open-pit mine)

Mass: 30 billion tons

Market value
- Fe and Ni: $8,000 billion
- Co: $6,000 billion
- Pt-group: $6,000 billion

Equivalent asset $10 million per ton to launch from Earth, or $300,000,000 billion

Asteroid-Mining Technology

Strip mining

Bonsor (2000)

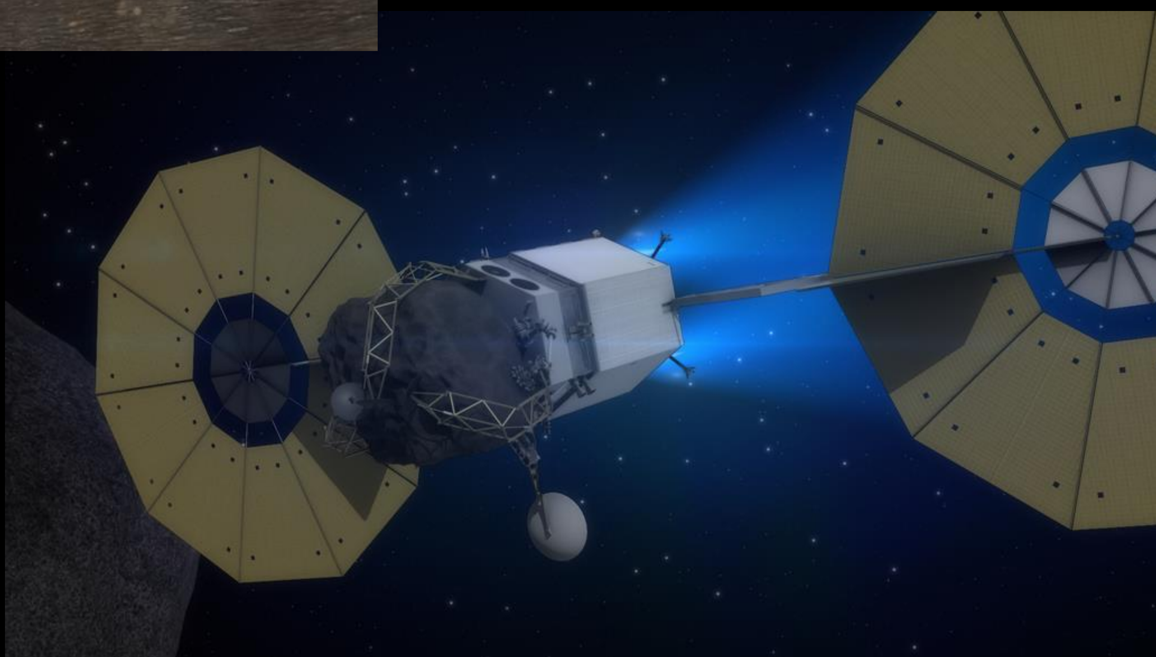
Orbital transfer

Ames Research Center

Asteroid Redirect Mission

Capture

Transit

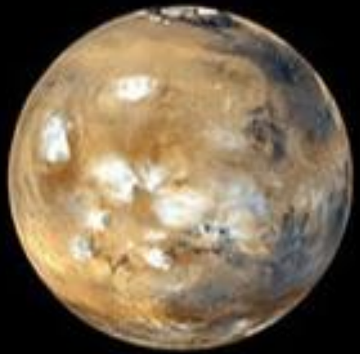


NASA (2016)

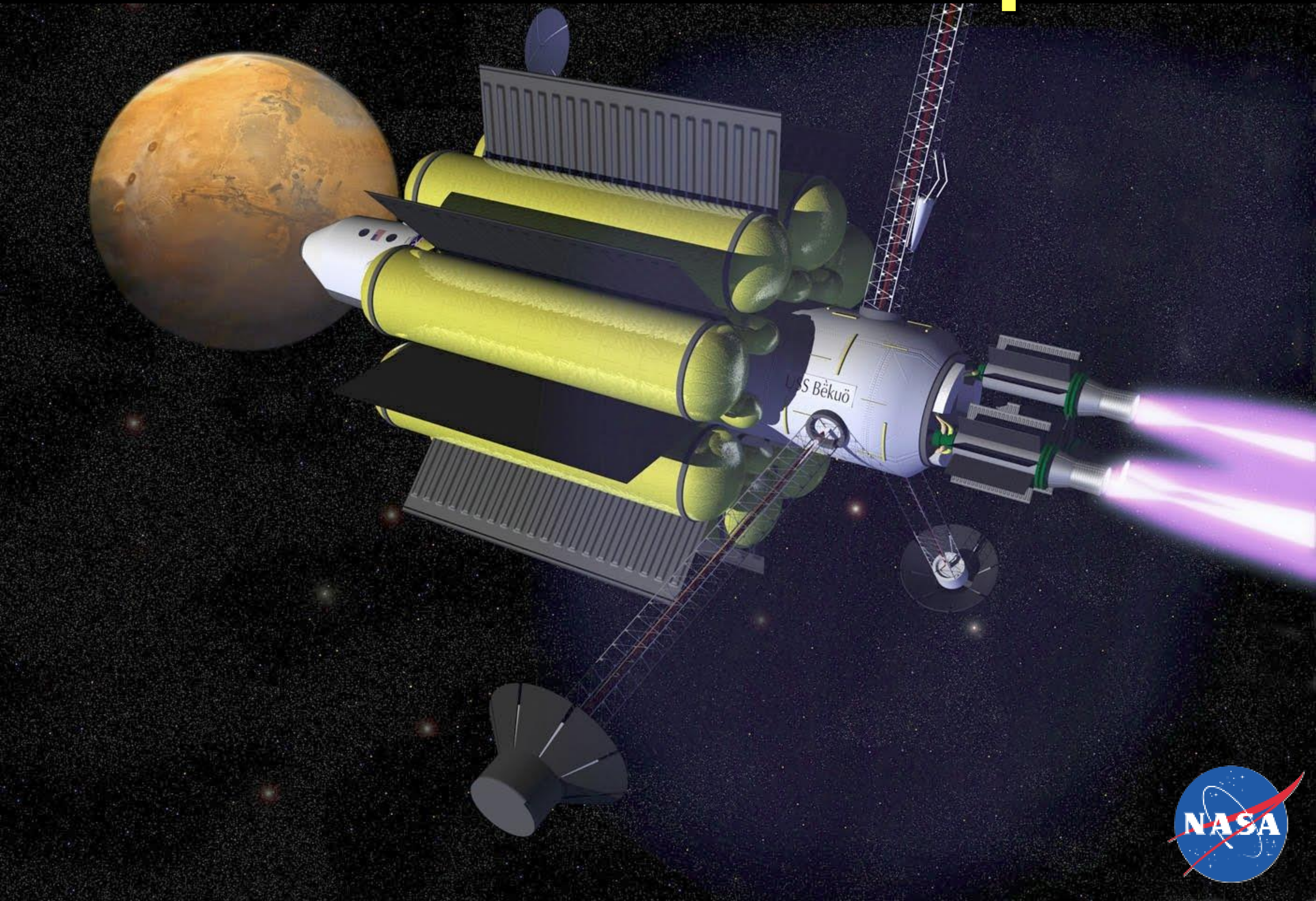
Destination: Mars

Most Earth-Like Planet

-Second-closest planet (>200-d trip with conventional rocket)
-Earthlike seasons; Day = 24 hours, 37 minutes
-As much land surface as the Earth



VASIMR Plasma-Ion Propulsion



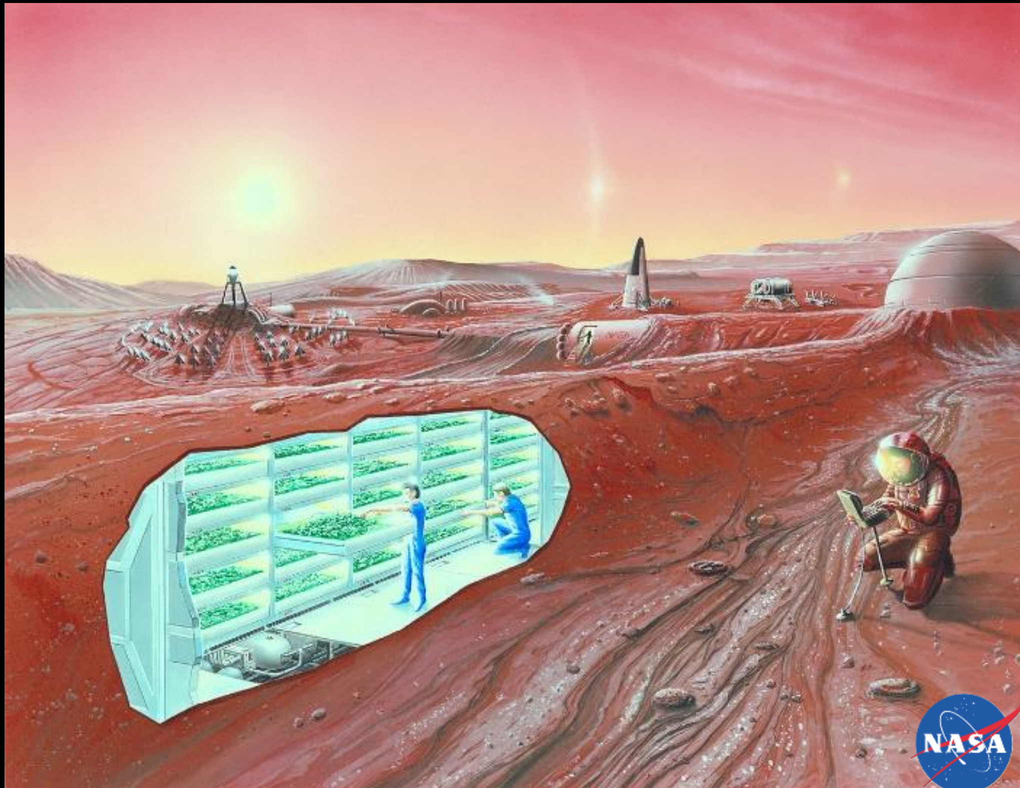
Mars: Surface Radiation Risks

RAD on Mars Curiosity

Galactic Cosmic Rays, Solar Particle Events

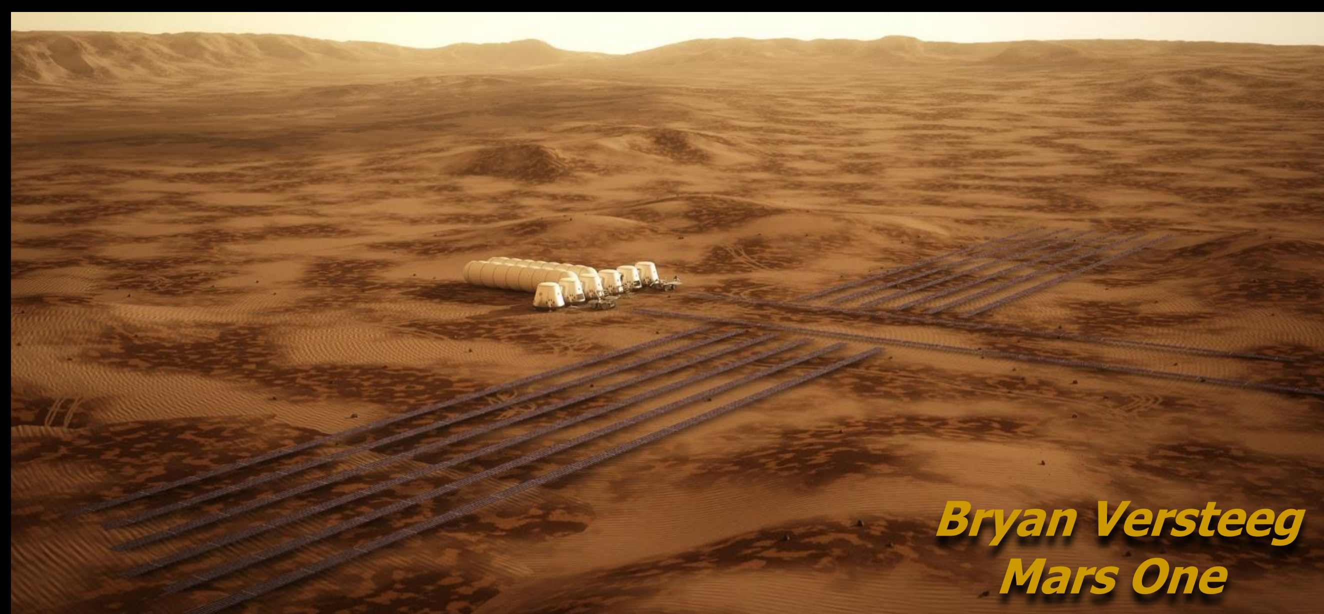
Radiation equivalent to whole-body
Computed Axial Tomography (CAT) scan every 5 days
Lifetime cancer risk increase of 5%

Mars Habitations

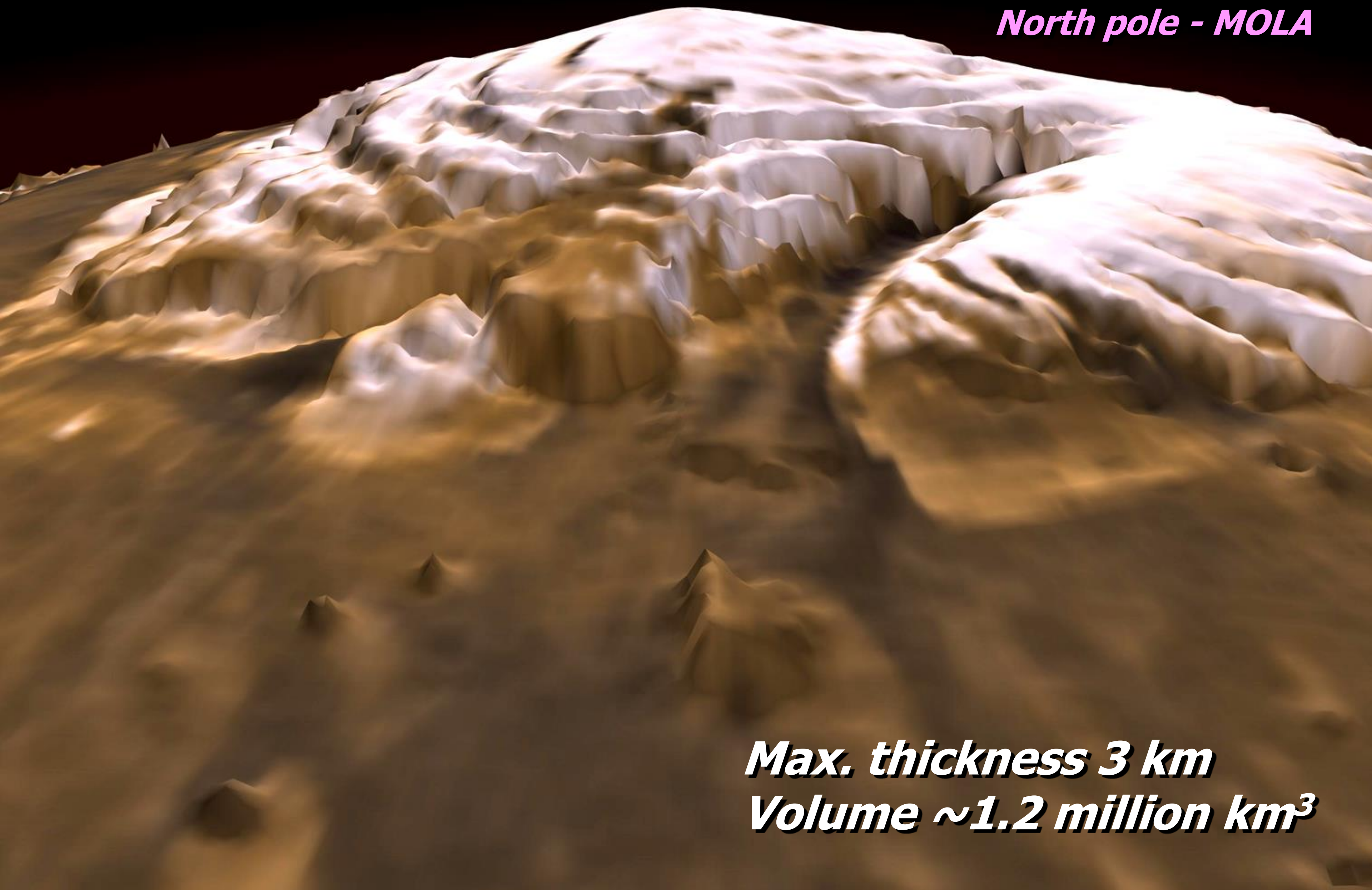


Underground facilities

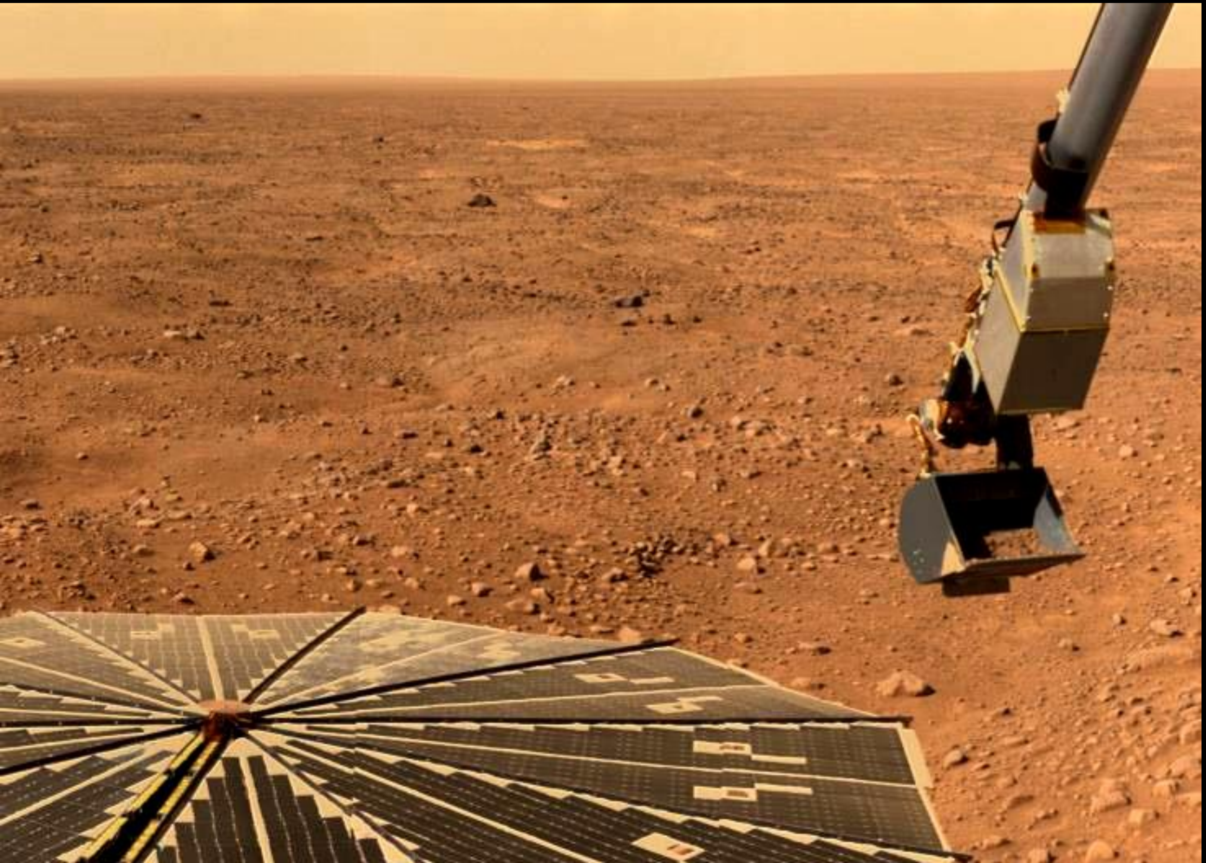
Surface facilities with solar panels



Ice Caps

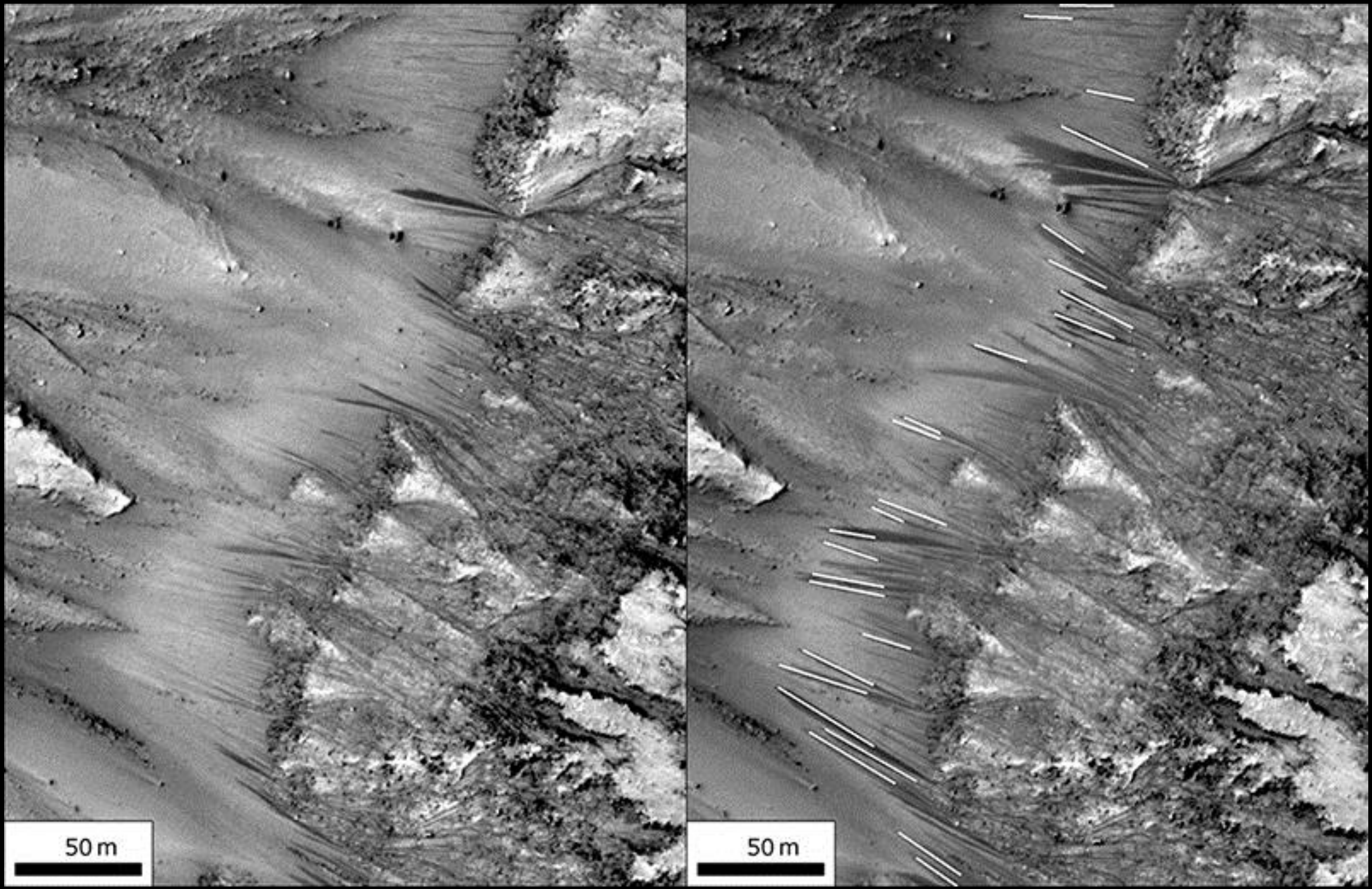


Martian Permafrost
Phoenix Mission



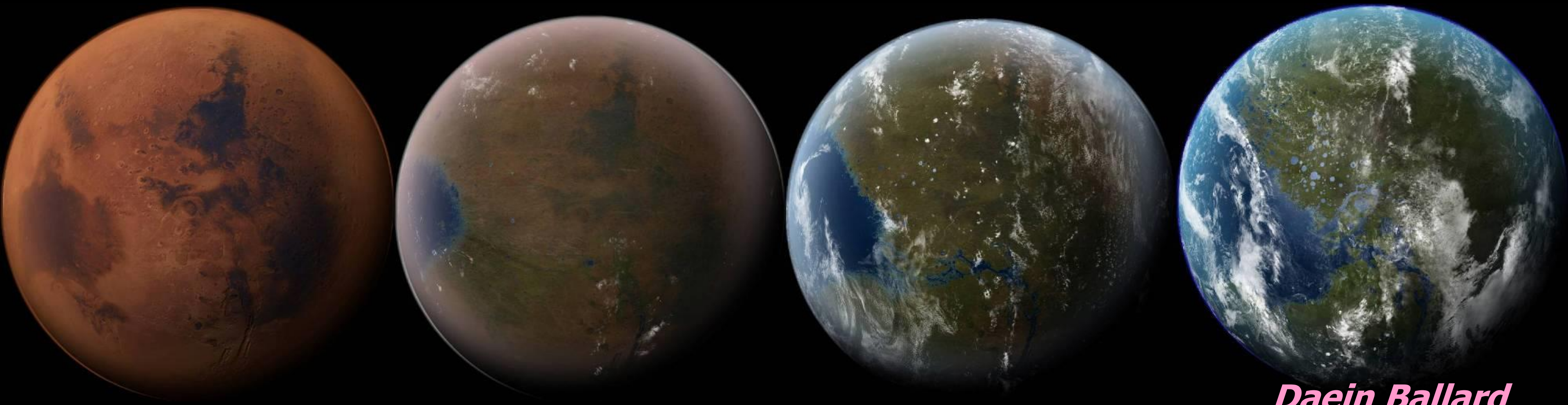
Mars Water Tracks

Recurring slope linae at Palikir Crater



Levy (2014)

Terraforming Mars



Daein Ballard

Requirements

Raise surface temperature
Increase atmospheric pressure
Change chemical composition of atmosphere
Surface water
Reduce UV flux at surface

Terraforming Mars

Reflection Arrays

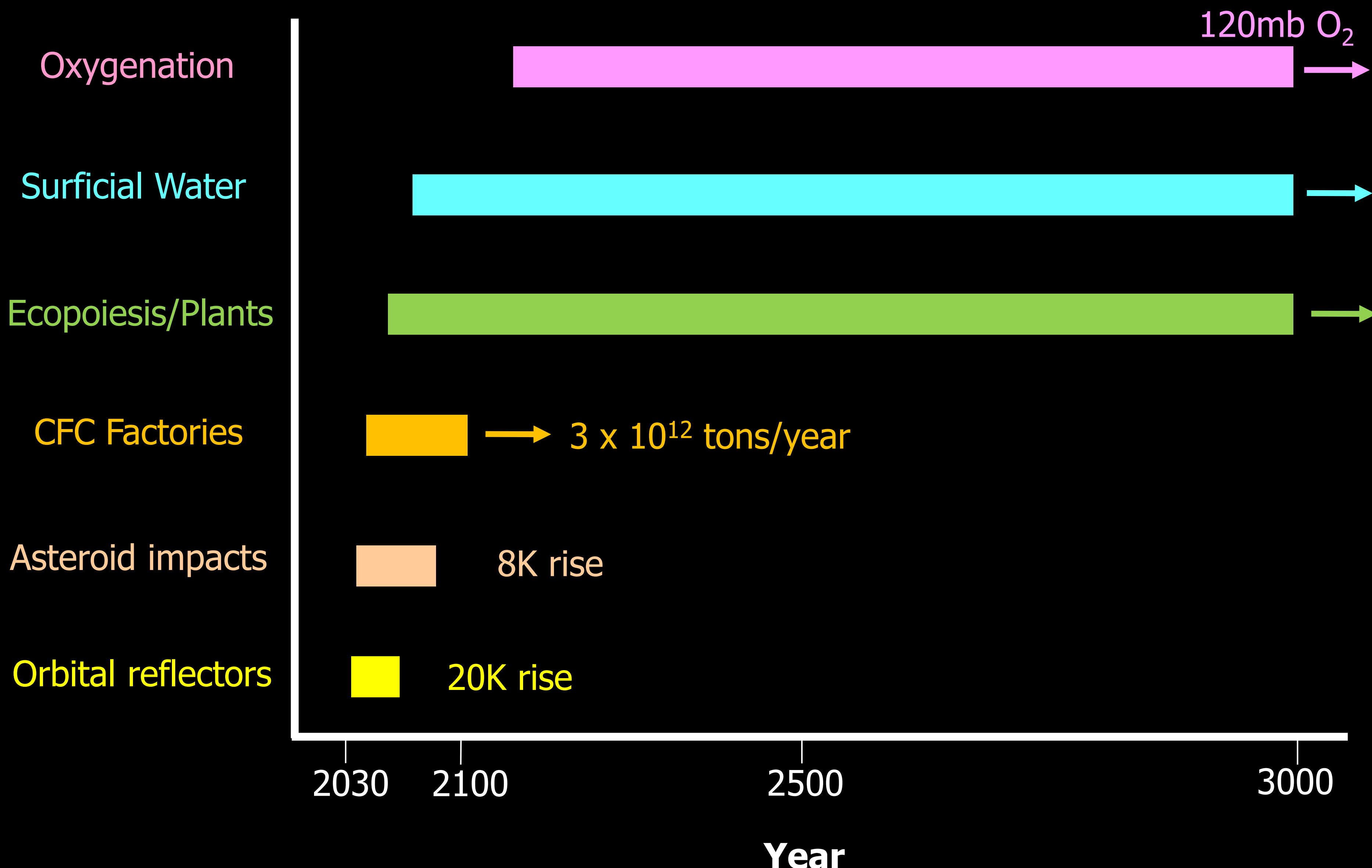
Rigel Woida

Greenhouse Gas Factories

Plant Cultivation

Ice Comet Impacts-NH_3, H_2O

Terraforming Mars: Timeline



Sunset on Mars