Commercial Space…

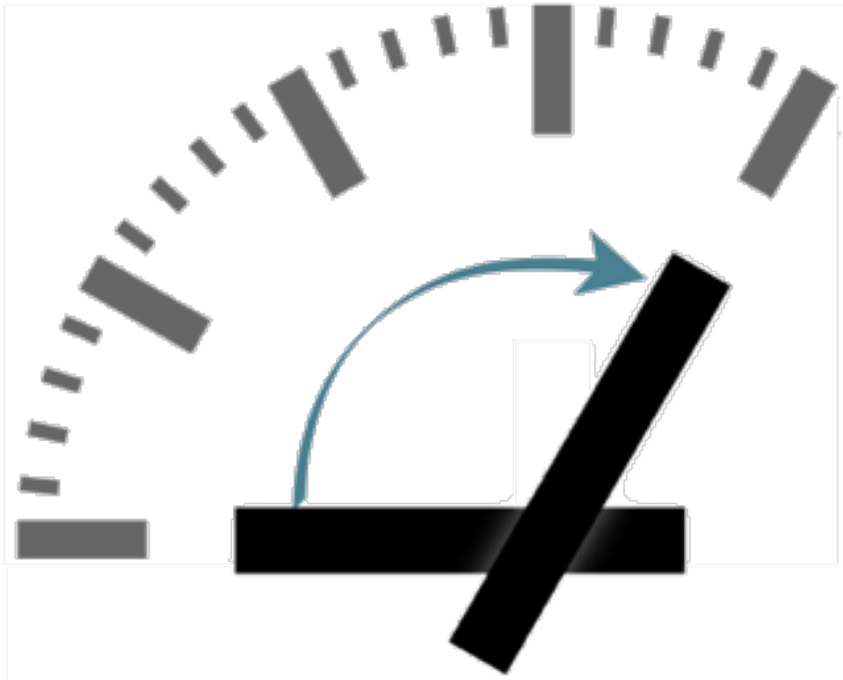
…and the Cislunar Economy

Stephen Fleming

stephenfleming@arizona.edu

@stephenfleming

Agenda



- **Who Am I?**
- Back to the Moon
- Why Return to the Moon?
  - What we can learn there
  - What we can learn how to do there
  - What we can do there
  - Where we can go next from there
- How Are We Going to Get There?
- What About Something Closer to Home?
- Questions & Answers

Who Am I?

Since 2017: University of Arizona. *Founder, Arizona Space Business Roundtable.*

Earlier: Georgia Tech, venture capitalist, telecom executive, and lifetime space enthusiast.

Angel investor in **multiple space startups** since 2000.

Who Am I?

Stephen Fleming
1990

The Washington Post FRIDAY, OCTOBER 12, 1990

Go Get An Asteroid

I am concerned by the tone of Jessica Tuchman Mathews's op-ed piece last week, "The Mars Extravaganza" {Oct. 5}. I am not going to debate whether sending Americans to the Moon and Mars is wise or affordable under current budget restraints. I am not going to deny that there are numerous challenges facing our environment (pollution, deforestation, extinctions, etc.), as Mrs. Mathews points out. But Mrs. Mathews falls into the environmentalist trap of asking, "Why should we spend all that money on space when there are so many problems here on Earth?"

The right question to ask is, "How can we best spend money to solve these problems here on Earth?" The surprising answer is: in space. Only through space-based observations can we understand what's happening to this planet. More important, only through space-based industry can we halt and reverse the trends threatening our environment.

Are messy industrial processes threatening groundwater supplies? Move the industries to orbit and send down only the finished goods. Is open-pit mining erasing huge tracts of wilderness? Go get an asteroid, which contains far more nickel, iron and other metals than humanity has mined to date. Are burning fossil fuels polluting the atmosphere and contributing to CO2 buildup? Put solar power stations in orbit and beam down limitless quantities of safe, clean, unpolluting energy. Are Third World children dying from disease for lack of medicine? Build a pharmaceutical factory in the microgravity of orbit, where we can make life-saving drugs for a tiny fraction of the cost of Earth-based processes.

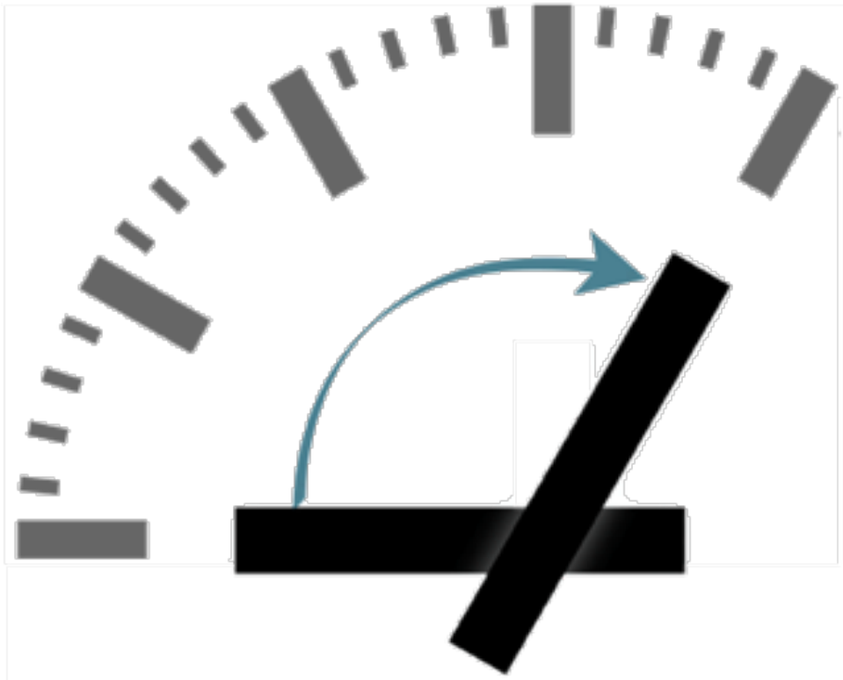
These activities, and hundreds more, do not require a trip to Mars, but they cannot be carried out by machines. Only the intelligence and flexibility of men and women in orbit can break the grip of Earth's gravity and bring the bounty of space to all mankind.

America knows how to carry out these activities quickly, safely and economically. So do Japan, the Soviet Union and the Europeans. But we are hobbled by NASA, a bureaucracy beholden to its unreliable and obsolete Shuttle, its bloated Space Station Freedom and a host of other constituencies. If private industry were encouraged to begin the commercial and profitable use of space without the 1,001 regulations enforced by our government, then we could see astonishing gains in space technology-and in the benefits of space for the first, second and third worlds-by the end of the decade.

A vigorous and independent space program could be the best friend of the entire environmental movement. I encourage Mrs. Mathews to explore its potential benefits for the problems she deplores; she shouldn't throw out this baby industry with NASA's dirty bath water.

STEPHEN FLEMING

Agenda



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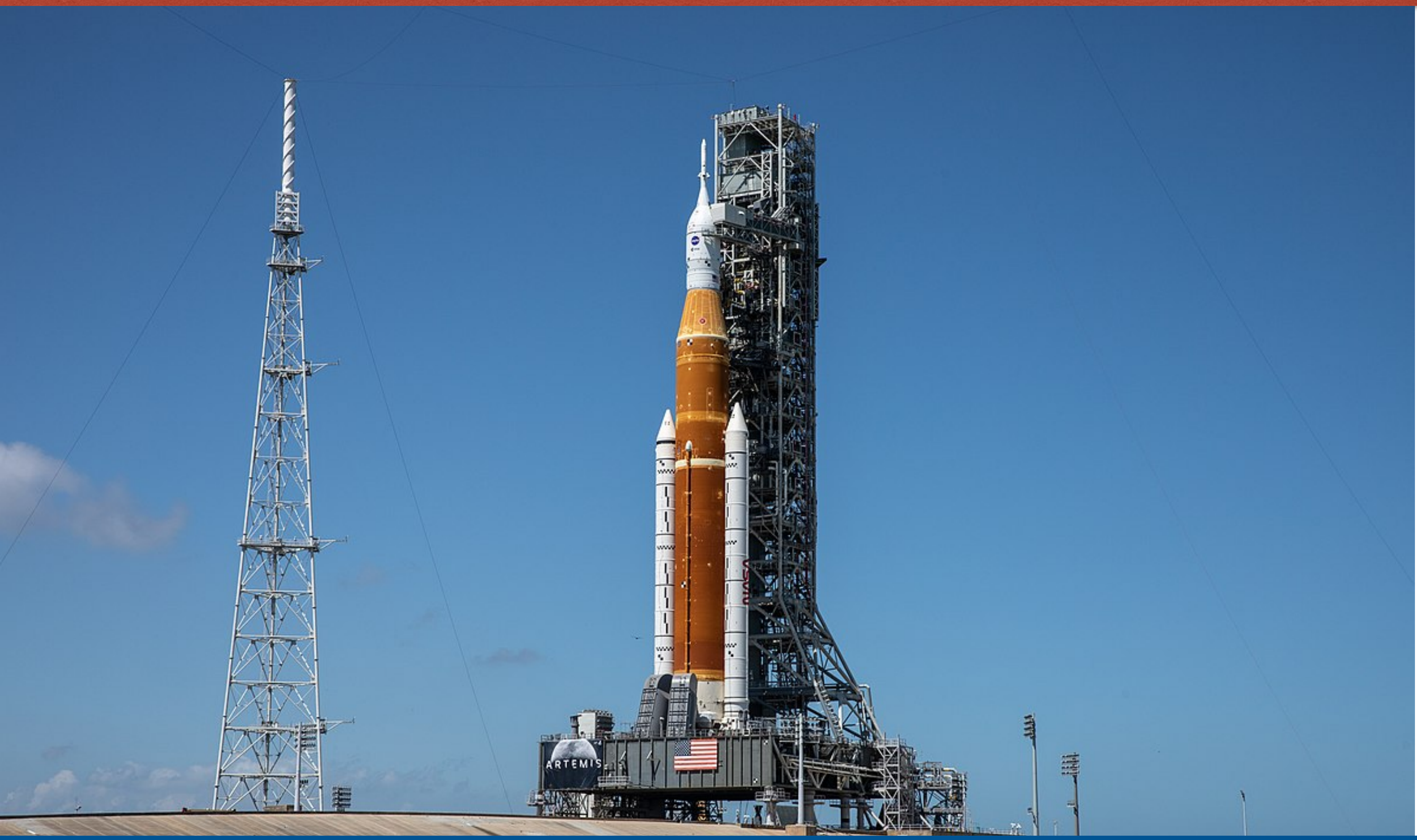
Artemis 1 on the Pad for Launch



Didn’t We Do This Fifty Years Ago?

We Went to the Moon Too Early

...in the wrong way...
...for the wrong reasons...
...and we never went back!

What Happened to Human Flight?

1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

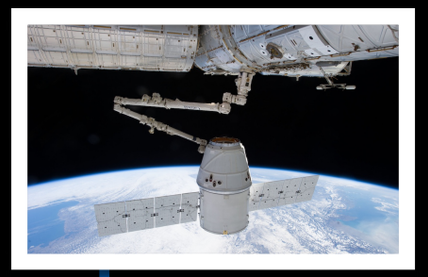
Wright Flyer

DC-3

First supersonic flight

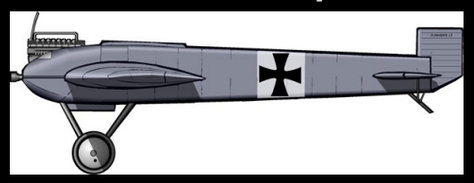
Last Apollo Mission

First Shuttle Launch



First private cargo flight to ISS

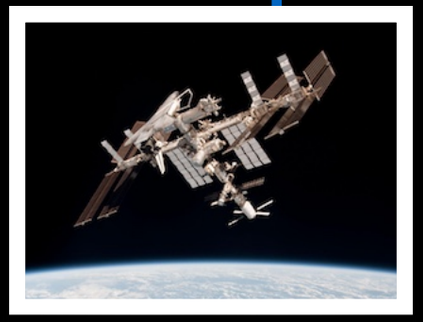
Junkers J-1
First all-metal airplane



Me 262
First jet airplane

Sputnik I

Apollo 11



ISS Continuously Occupied

Crew Dragon test flight

What Happened to Human Flight?

Wright Flyer

First supersonic flight

Last Apollo Mission

Now

1900 | 1910 | 1920 | 1930 | 1940 | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020

44 years

From first flight to breaking the sound barrier.

50 years

From the last Moon landing to… going around in circles.

Earth-Moon System *(to scale)*

At this scale, the Sun is 2.4 screens wide and 250 screenwidths away.

ISS Orbit *(to scale)*

No Humans Past LEO since 1972

We've been going around in circles in Low Earth Orbit for 50 years.

Even Moses Only Wandered 40 Years!

What happened?

Where Did We Go Wrong?

"First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

—Pres. Kennedy, May 1961

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—Pres. Kennedy, May 1961

Decision Made: Flags and Footprints

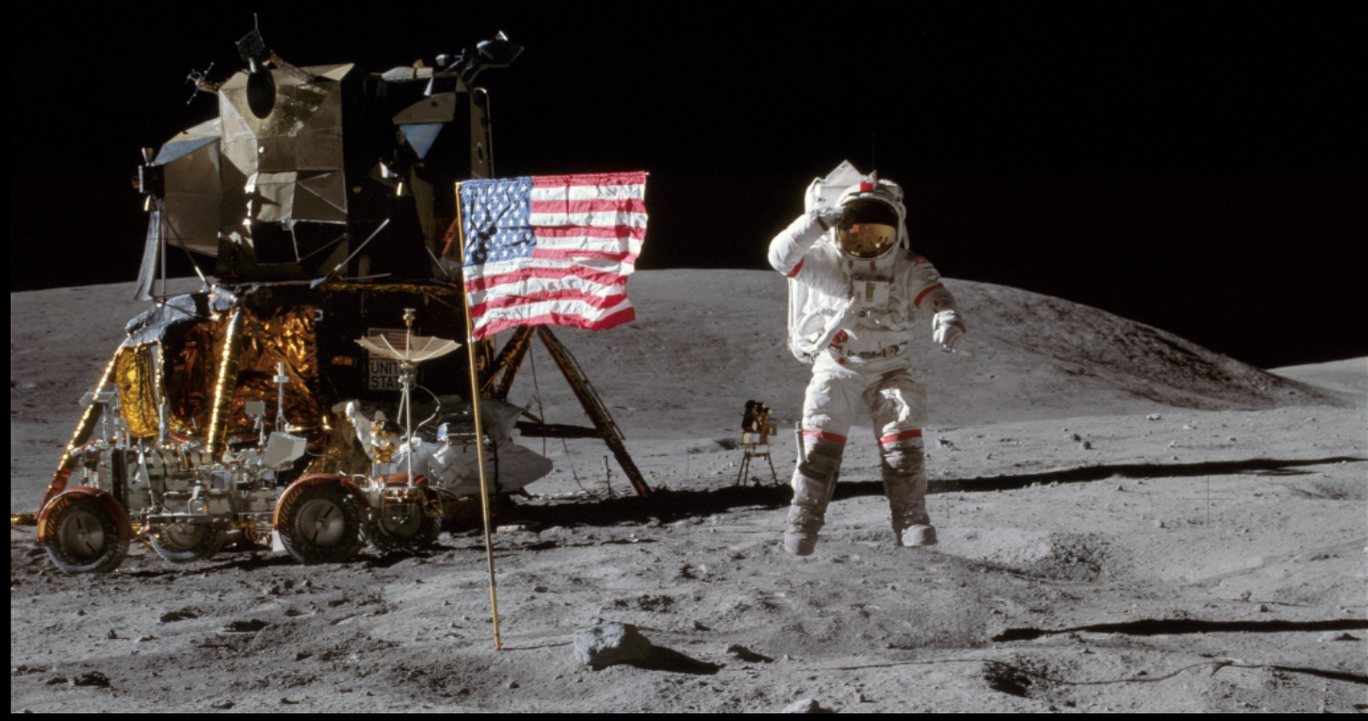
Fifty years later, what remains of the Moon missions?

Zero presence.

Zero industry.

Zero infrastructure.

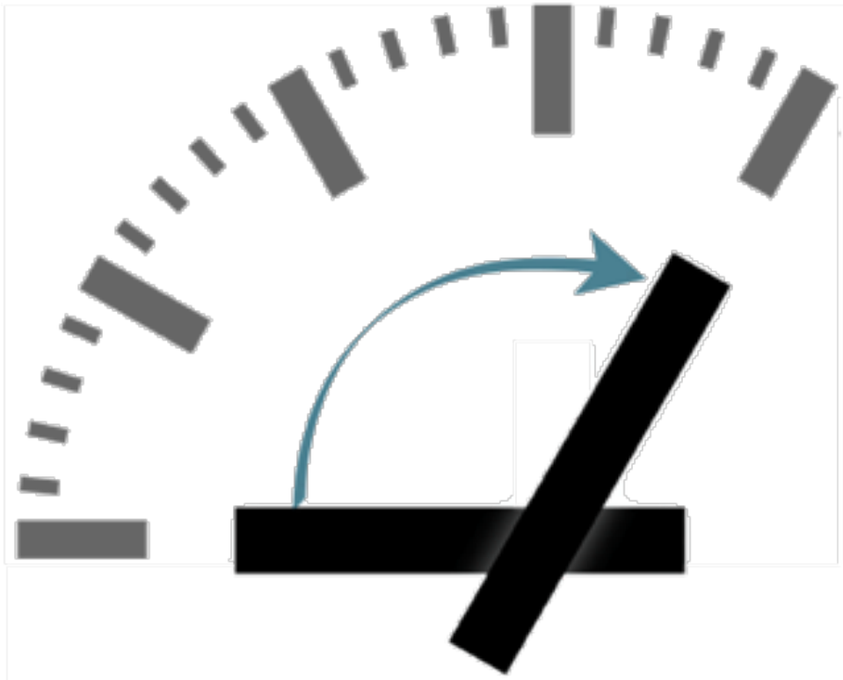
Zero economic value.



From Day One—not a model which could get traction on Wall Street!

What if we tried something different this time?

Agenda



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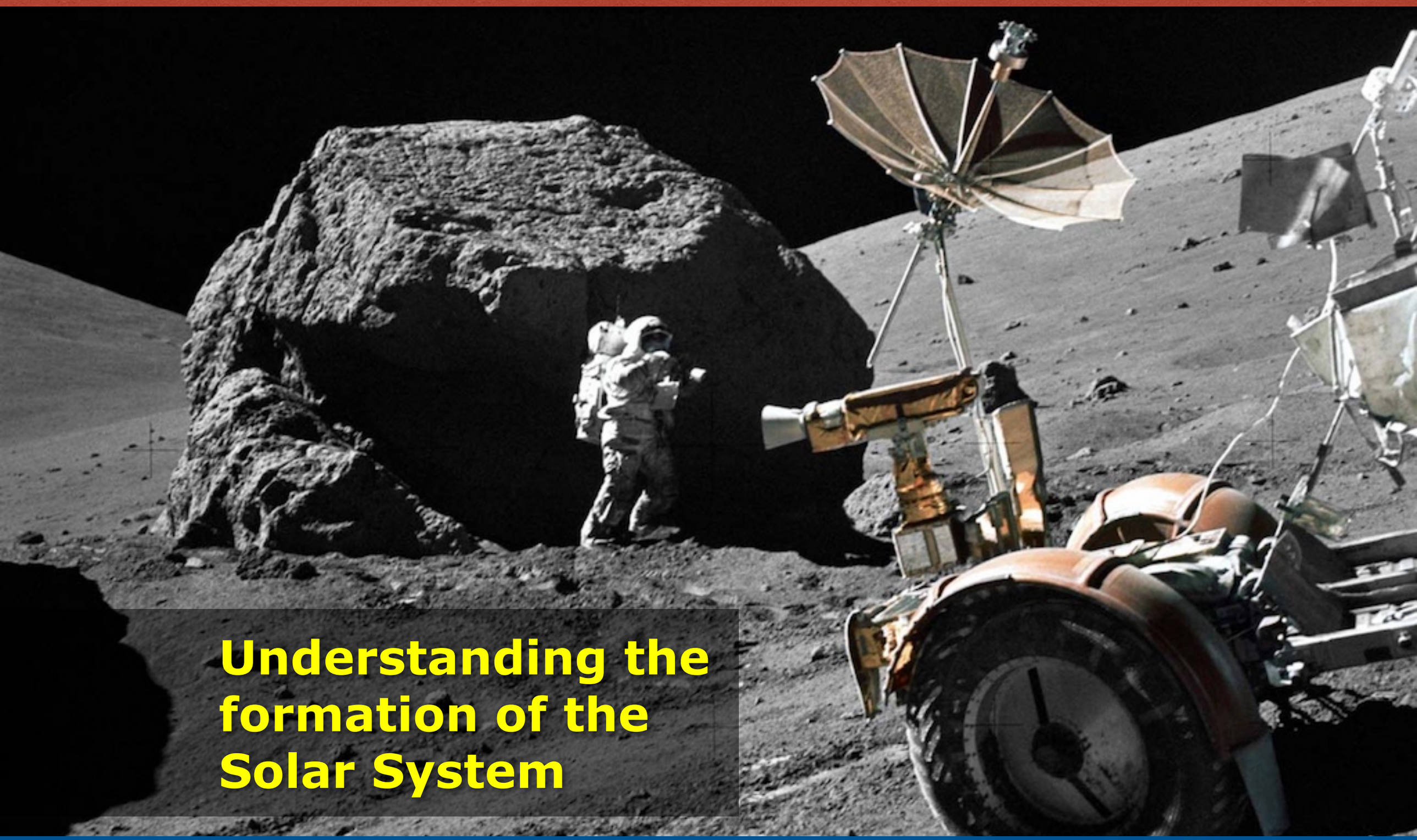
What About Something Closer to Home?

Questions & Answers

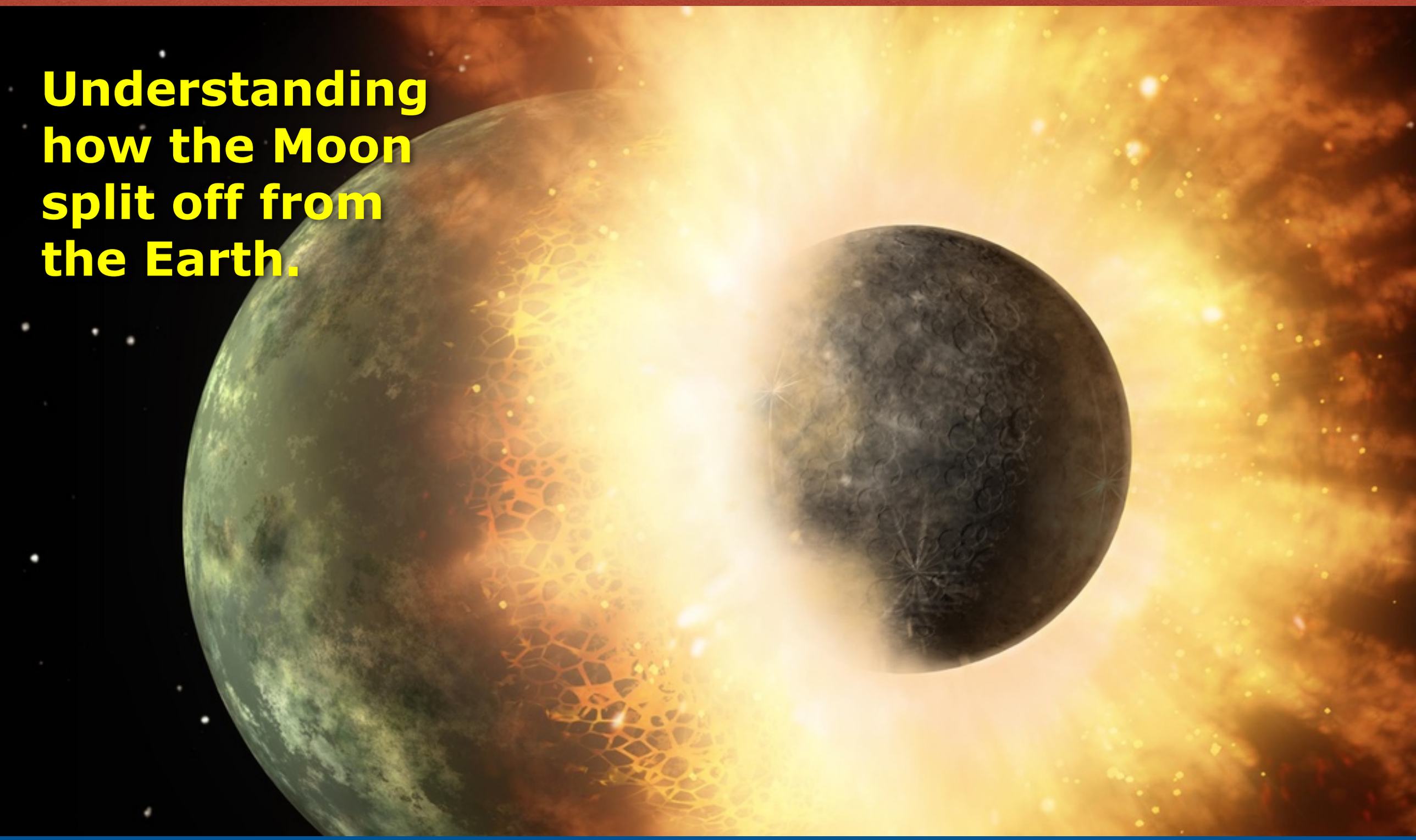
What We Can Learn There



Understanding the formation of the Solar System

What We Can Learn There

Understanding how the Moon split off from the Earth.



What We Can Learn There

Farside Observatory:
Best location in the Solar System for radio astronomy

Illustration

What We Can Learn There

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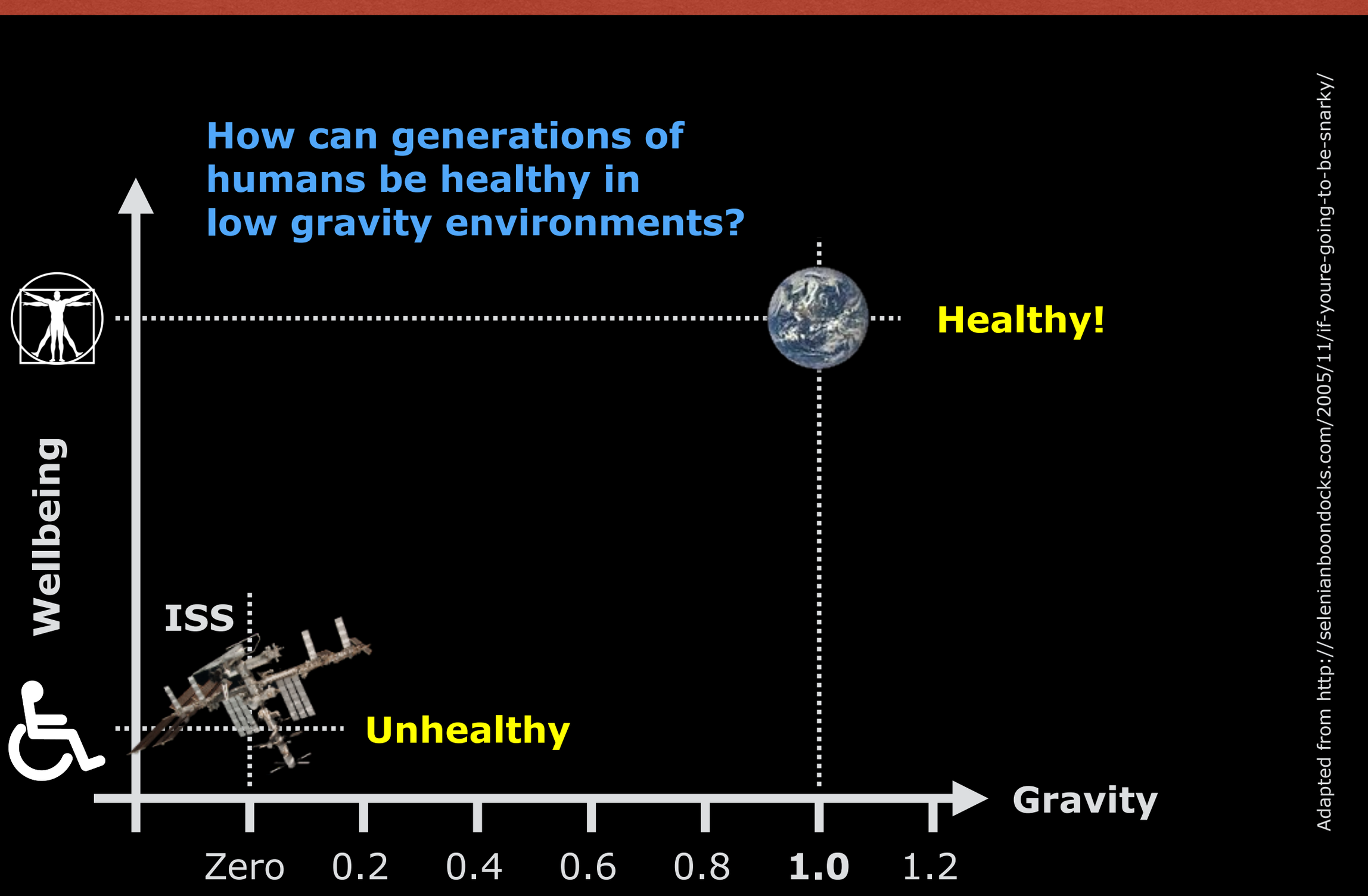
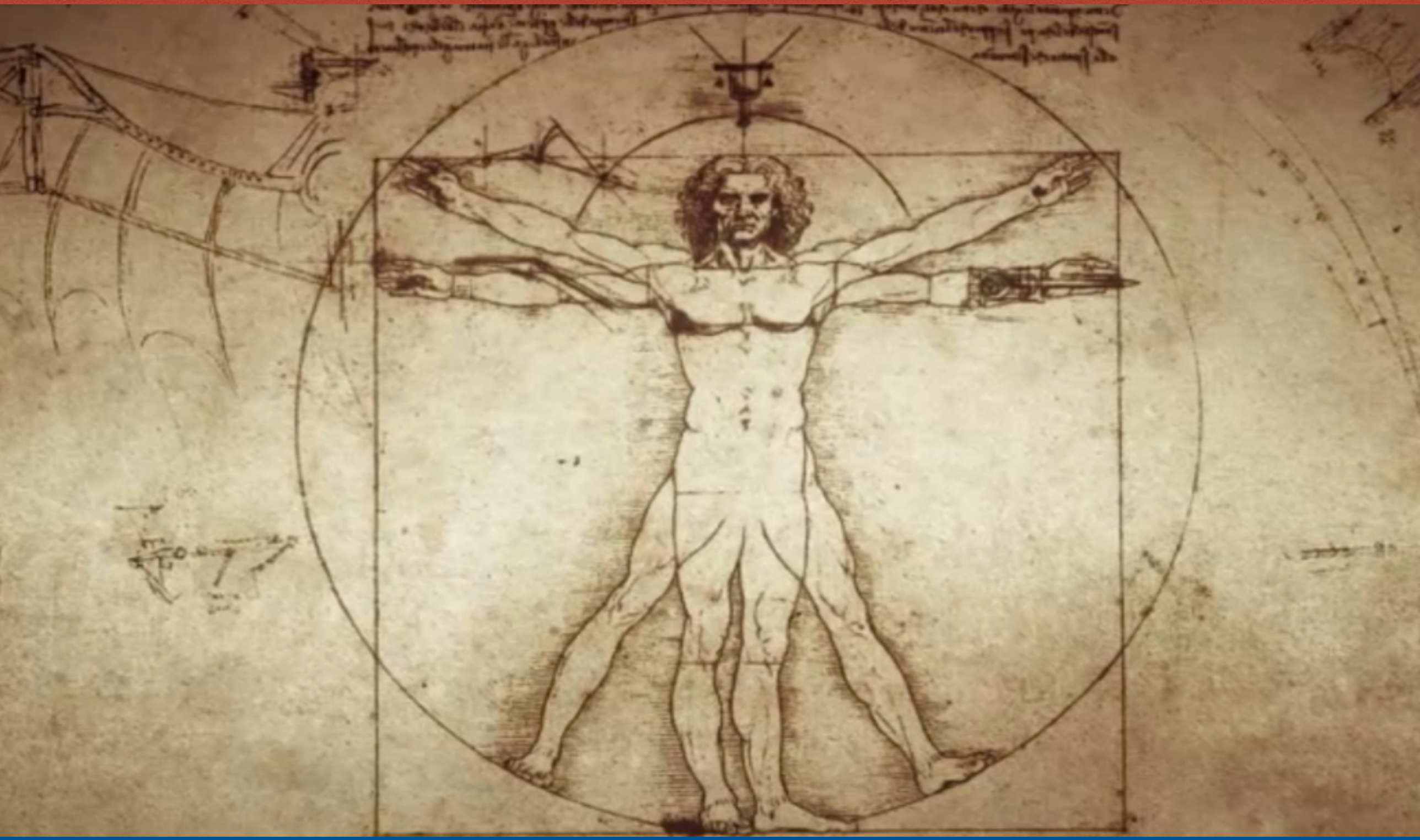
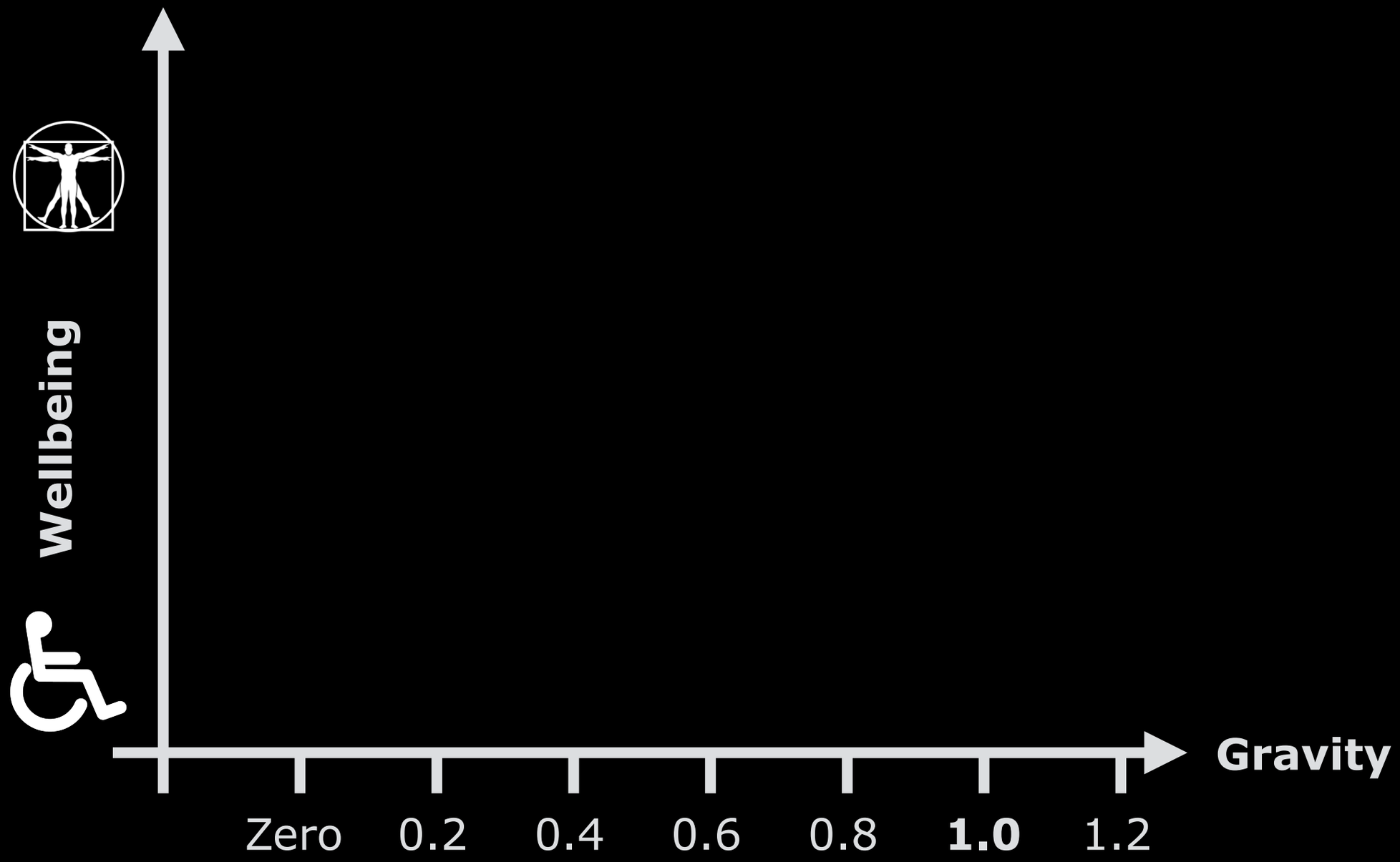
What We Can Learn *How* to Do There



ISS: Gravity and Physiology

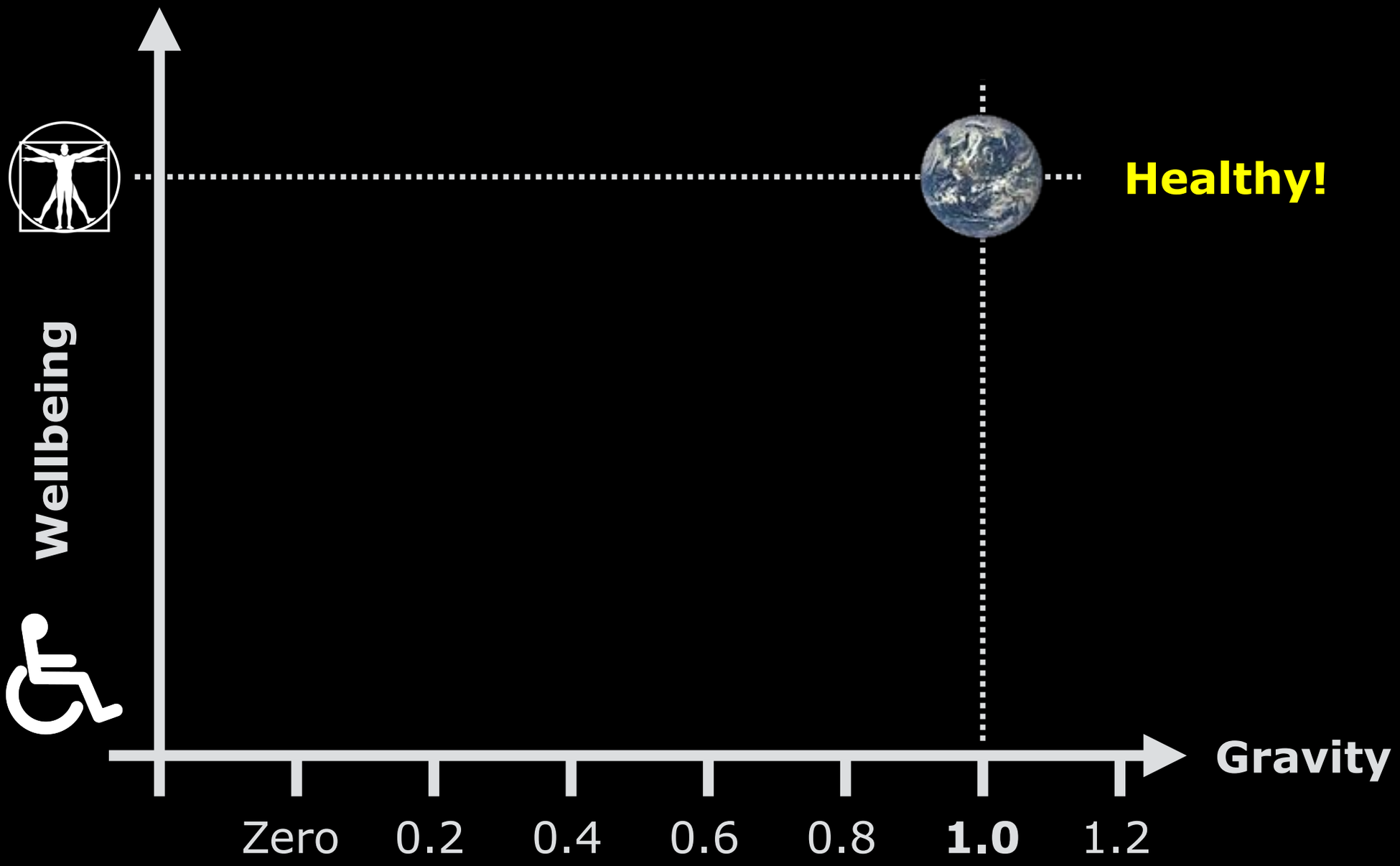


Gravity and Physiology



Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

Earth: 1.0 G

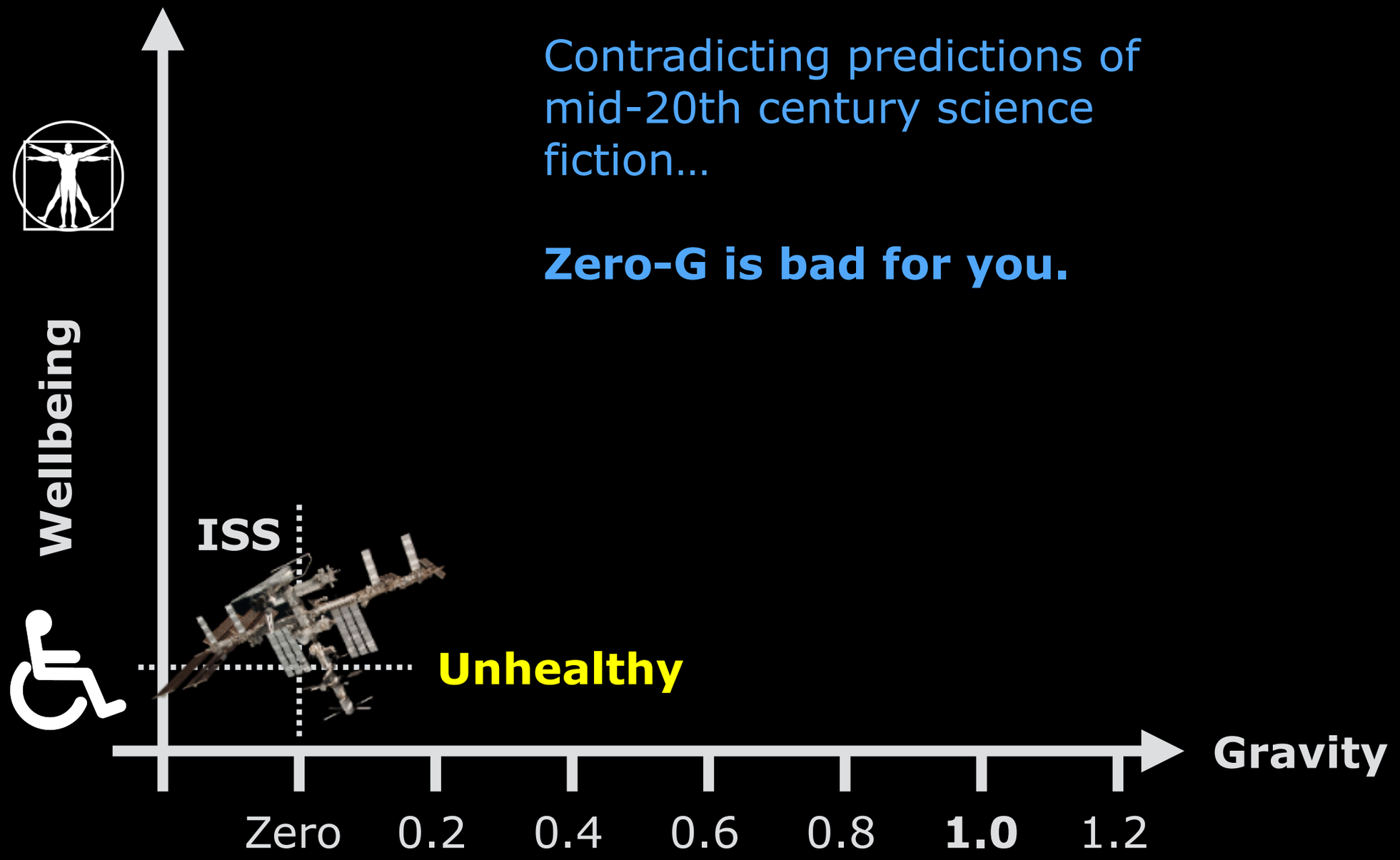


Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

Free Fall: "Zero Gravity"

Contradicting predictions of mid-20th century science fiction…

Zero-G is bad for you.



Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

The Reality

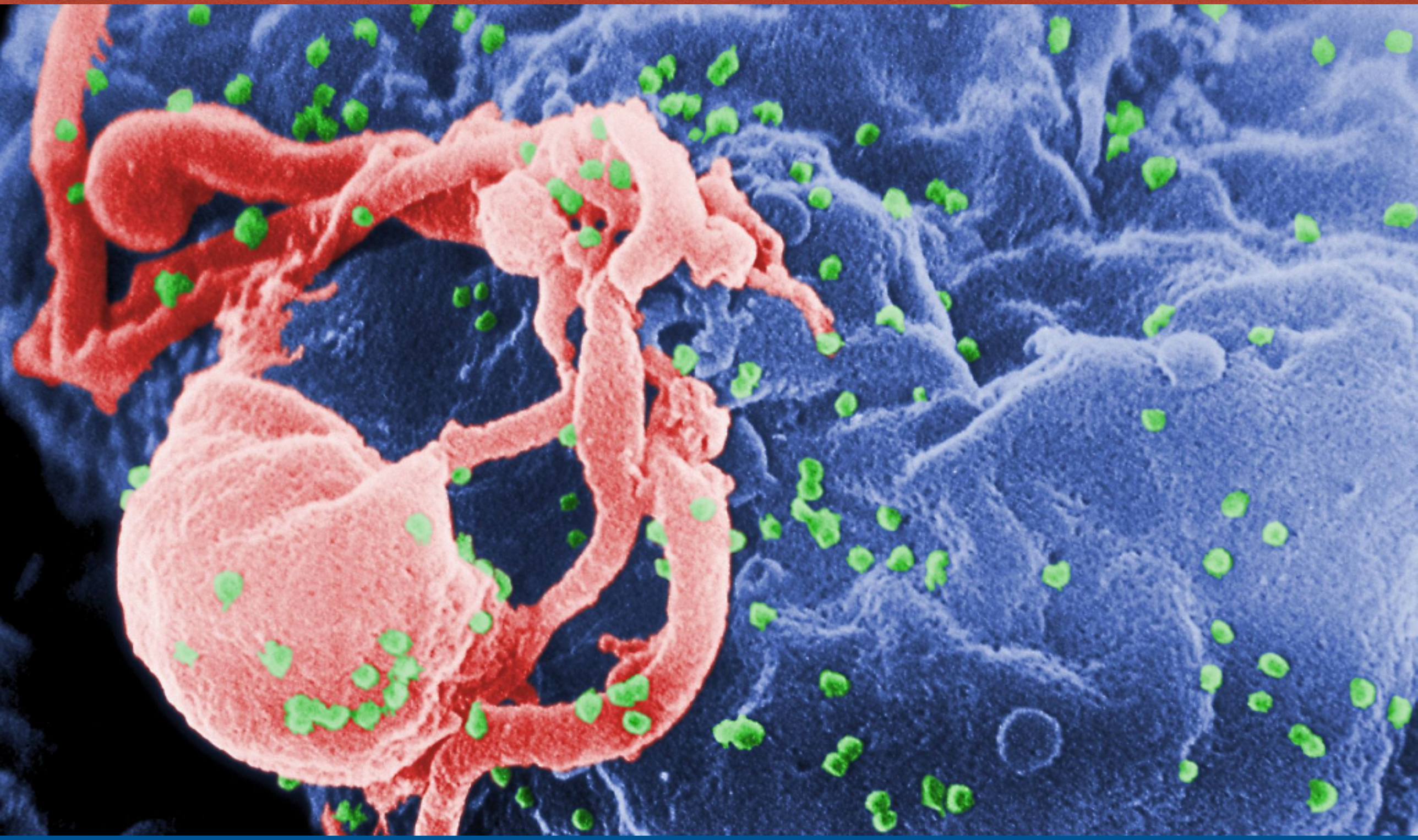
Muscular Atrophy

Bone Loss

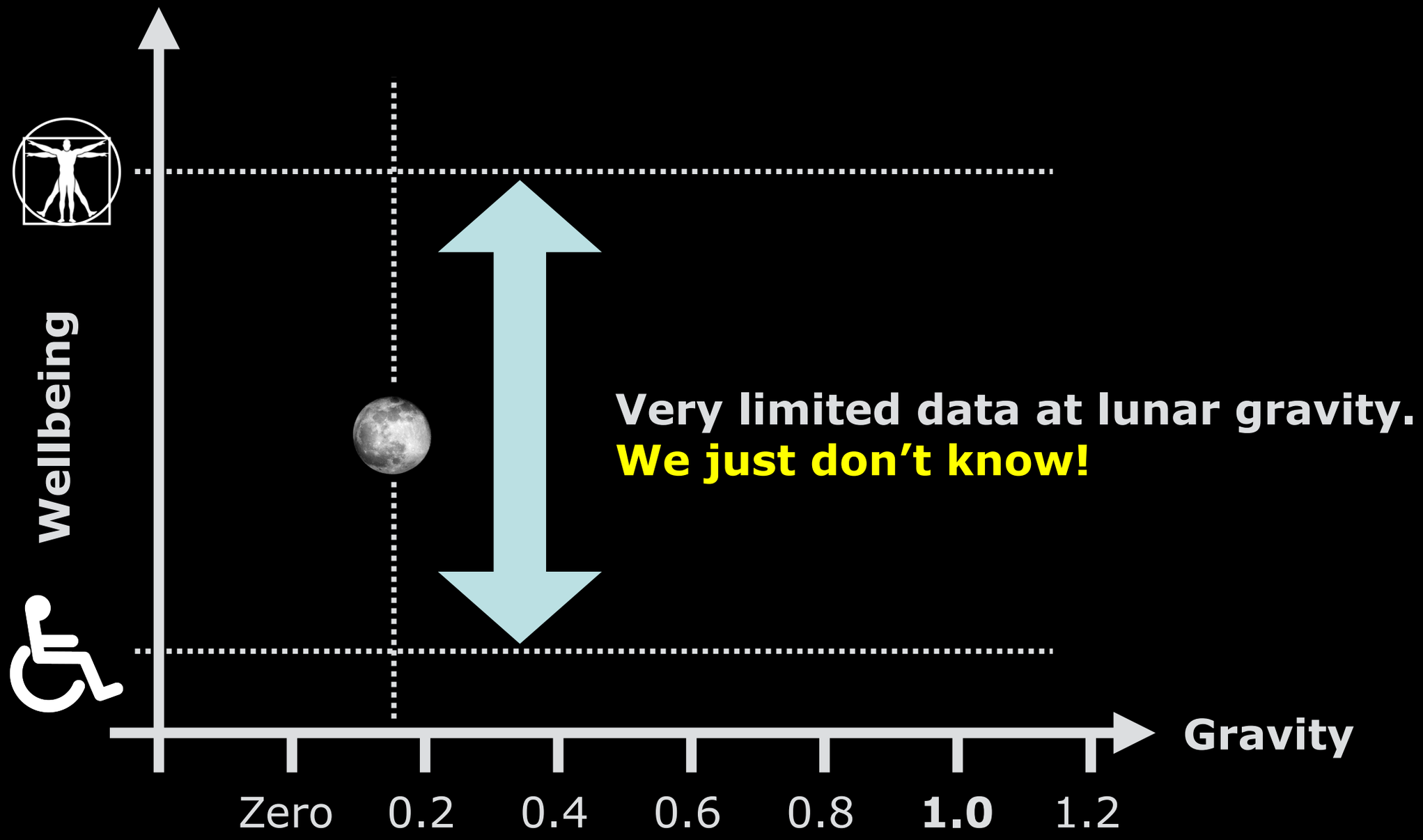
Vision Changes

Lowered Blood Pressure

T-Cell Immunodeficiency



Moon: 0.17 G



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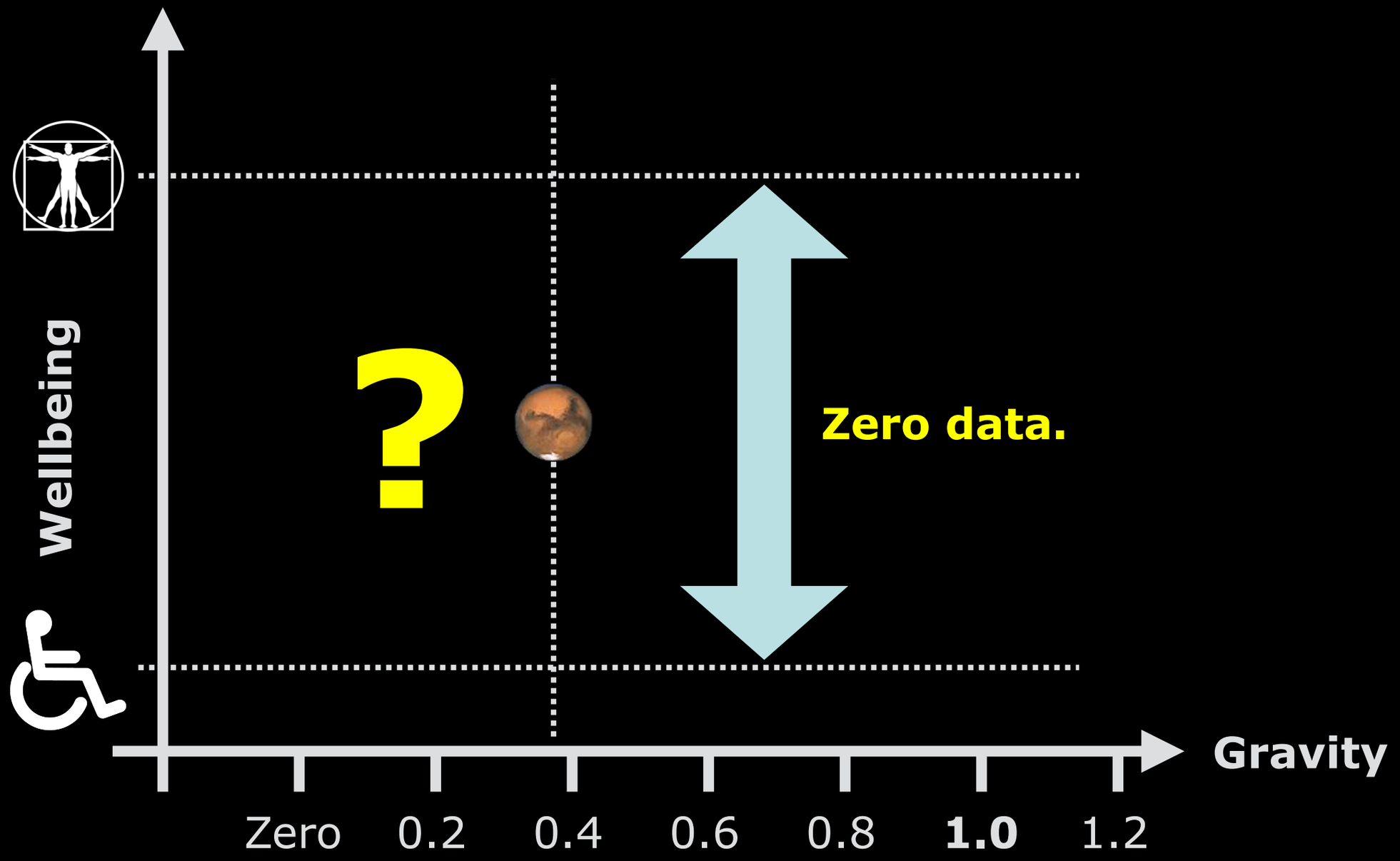
Mars: 0.38 G



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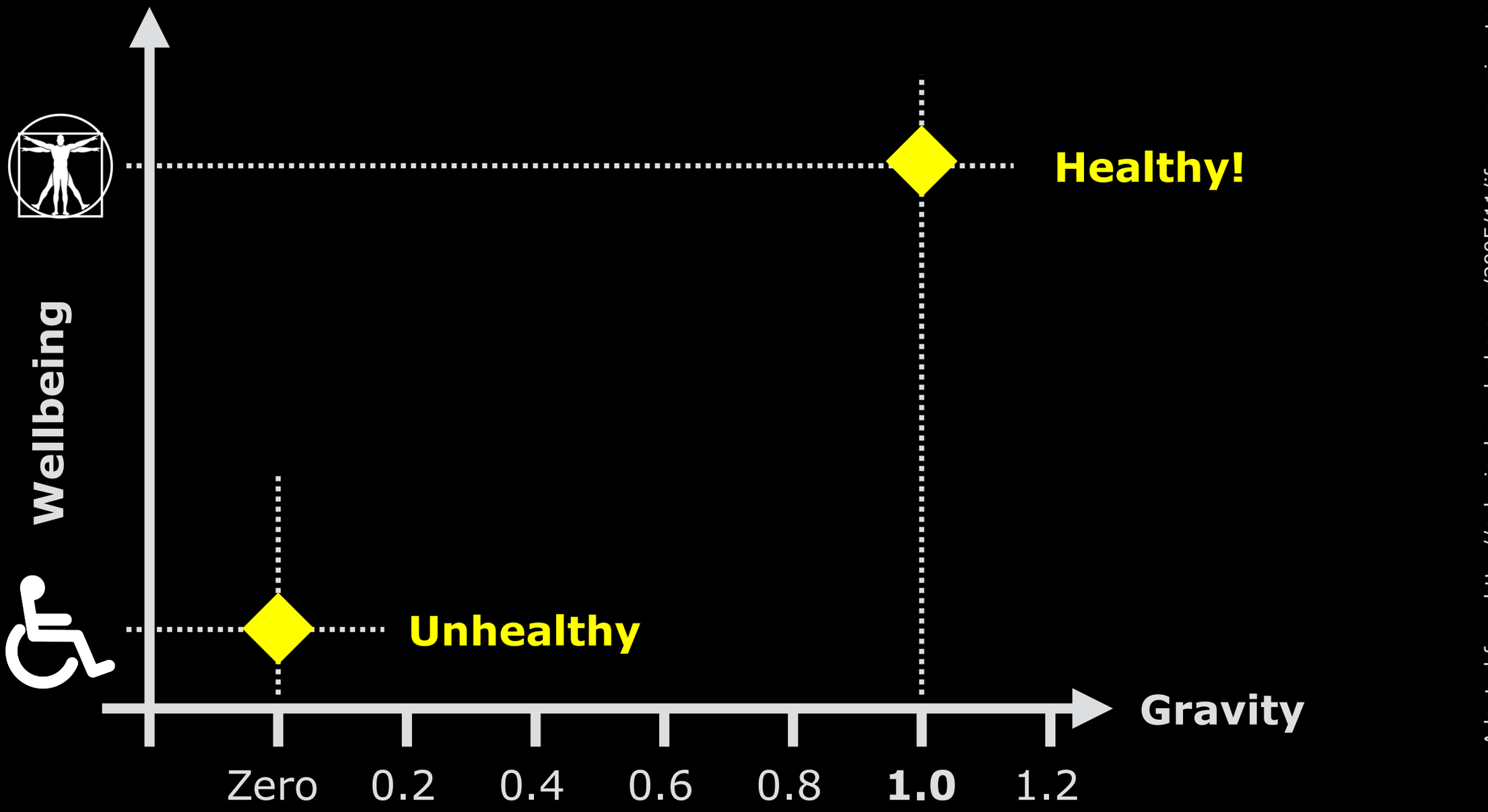
We Only Have Two Data Points!



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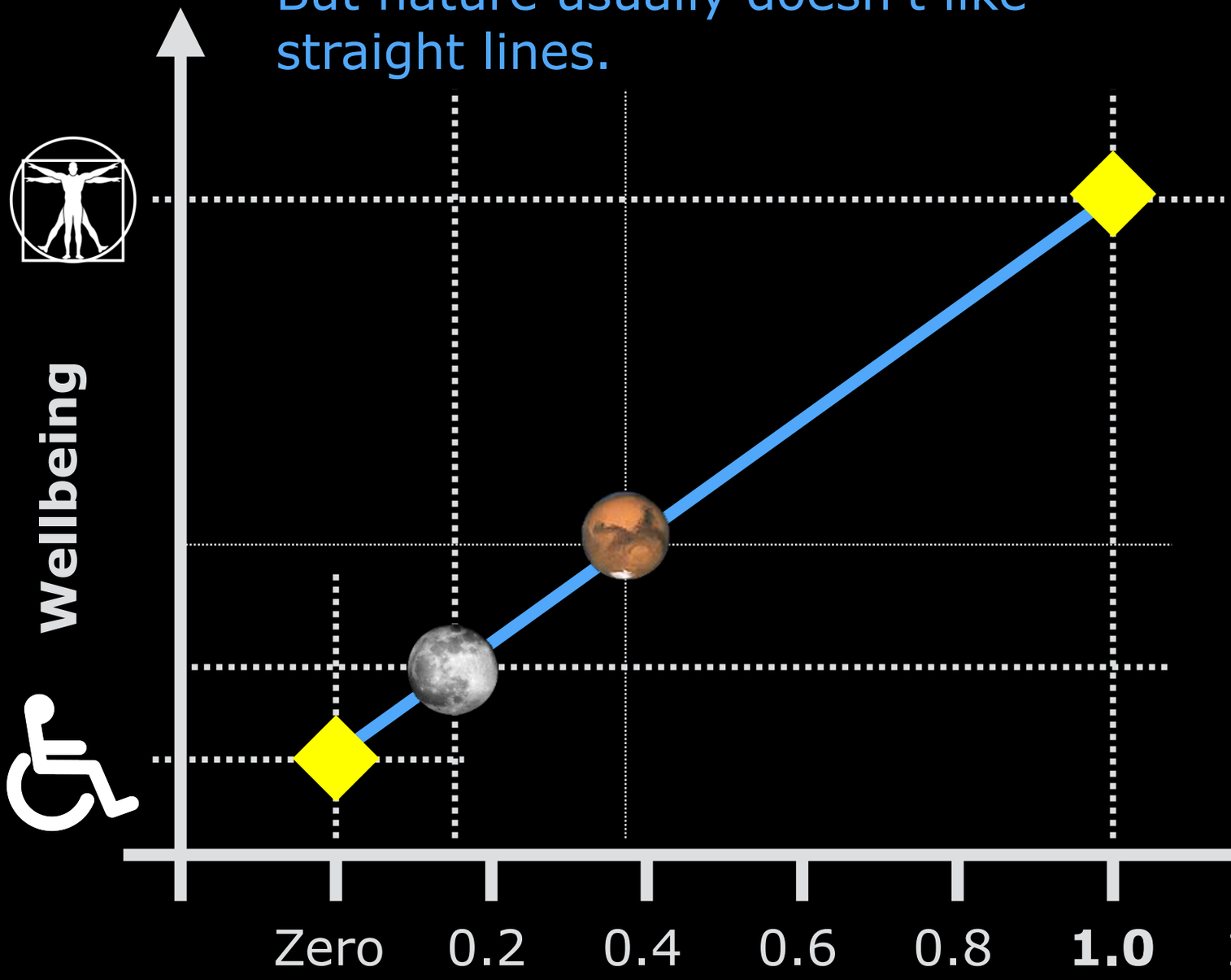
Straight Line Interpolation?

Simple interpolation.

But nature usually doesn't like straight lines.



1

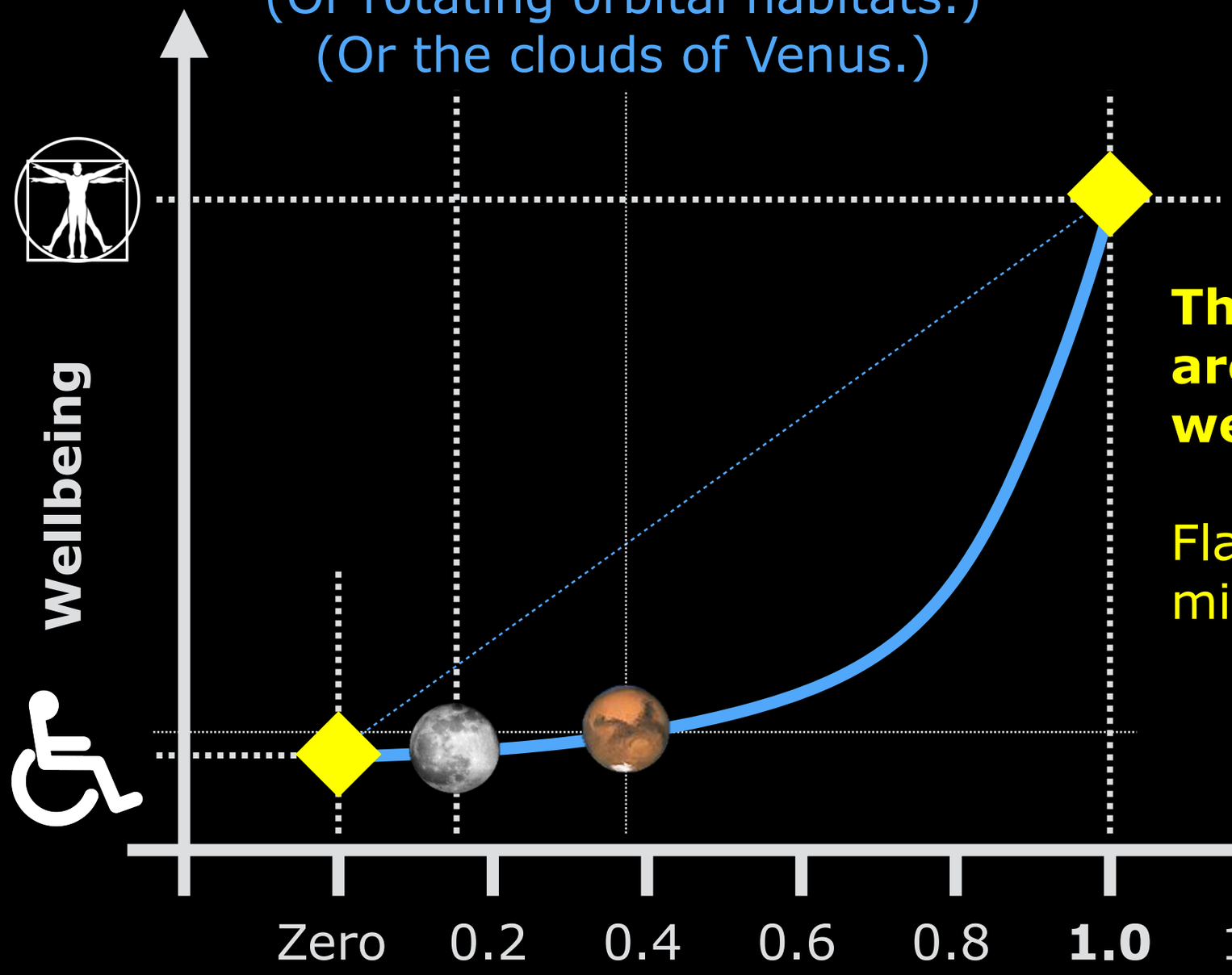
The Moon and Mars are not healthy. Outposts, but not human worlds,

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

What If We *Need* Earth Gravity?

Humans need gravity. We're trapped on Earth.

(Or rotating orbital habitats.)
(Or the clouds of Venus.)



2

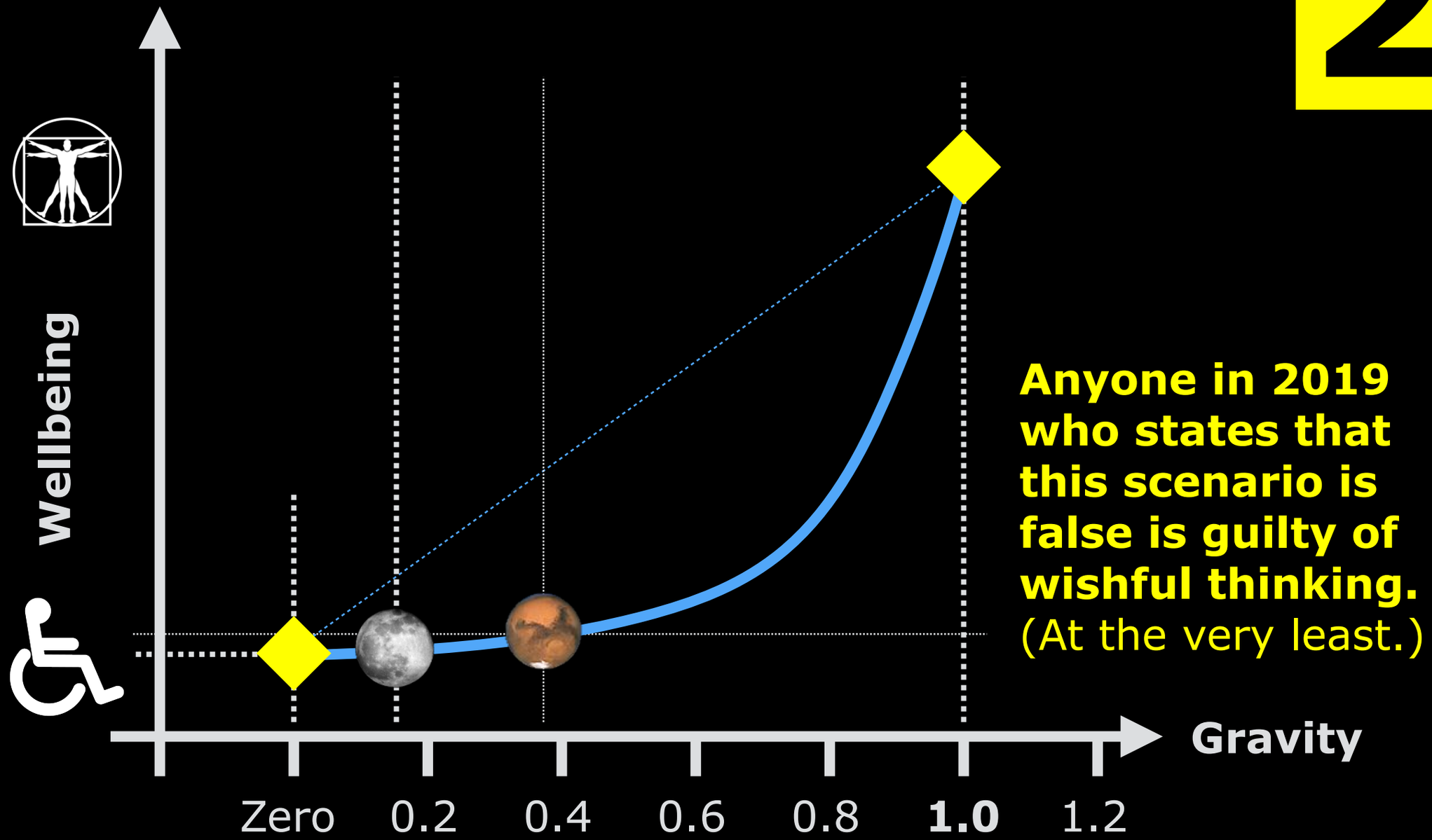
The Moon and Mars are hostile to human wellbeing.

Flags and footprints missions only.

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

The Target Shifts from Mars to Venus

What If We *Need* Earth Gravity?



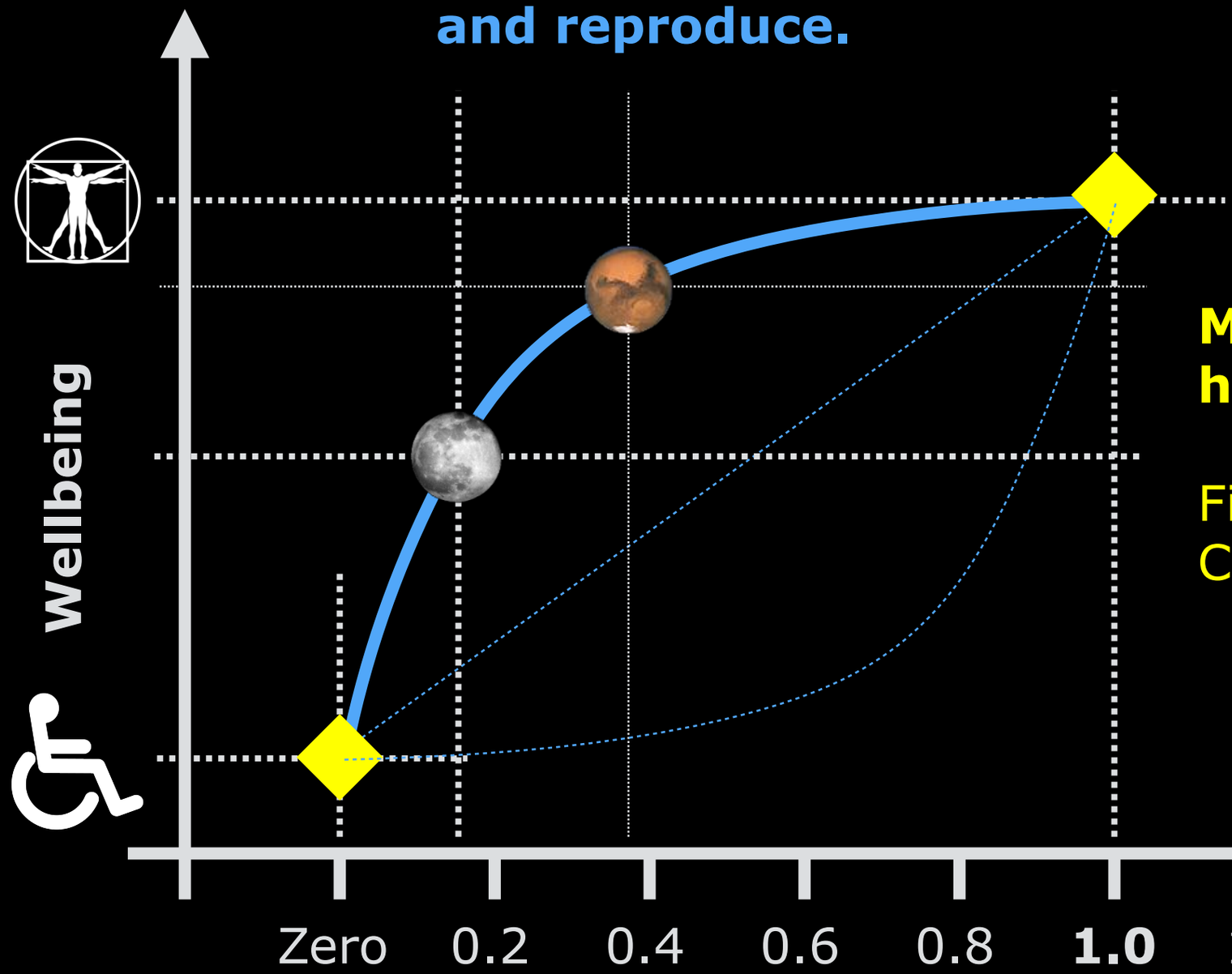
2

Anyone in 2019 who states that this scenario is false is guilty of wishful thinking.
(At the very least.)

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

What If A Little G Goes a Long Way?

1/3 G is enough to thrive and reproduce.



3

Mars is the next human world.

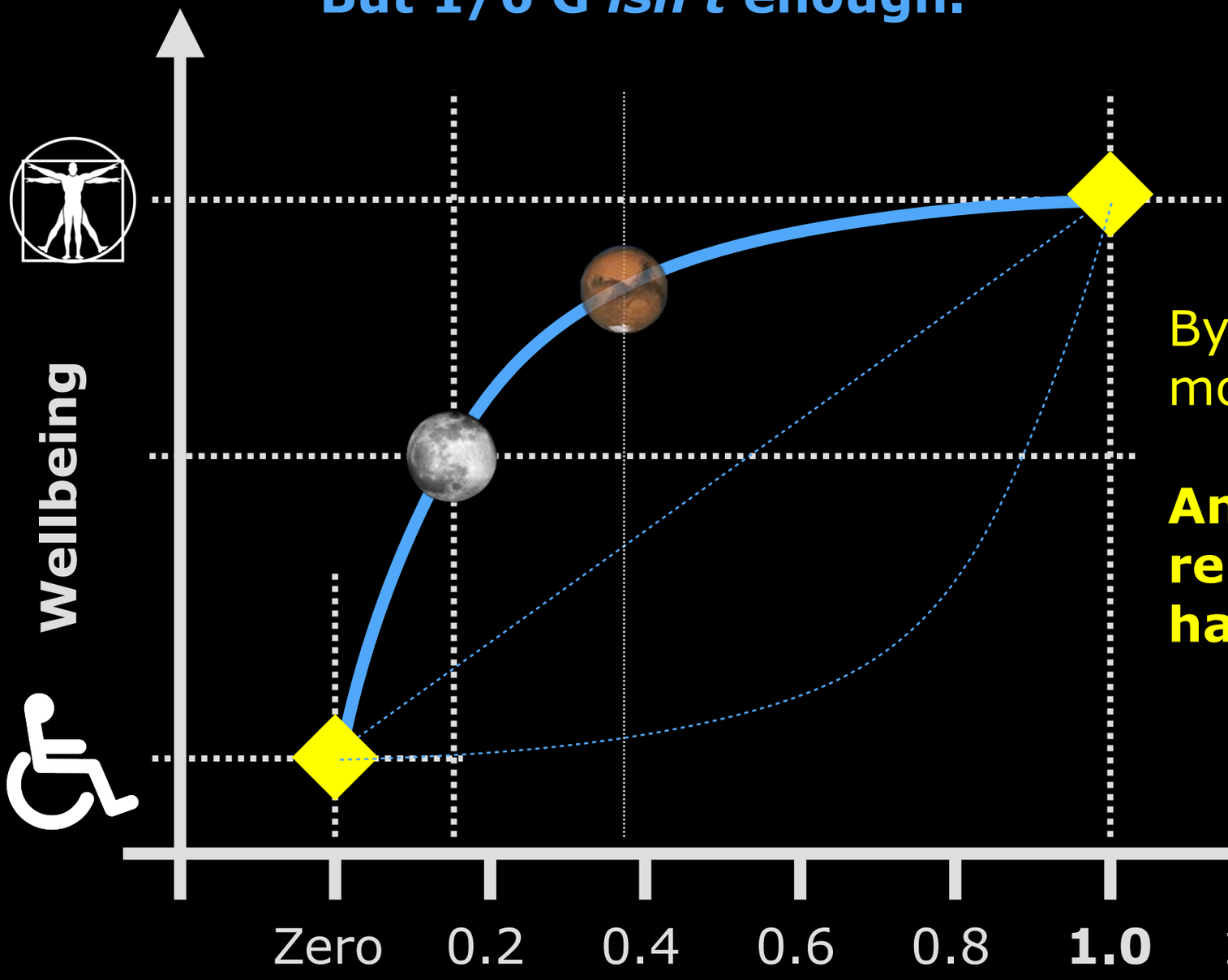
Fire up the Mars Colonial Transporter!

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

What If A Little G Goes a Long Way?

But 1/6 G *isn't* enough.

3



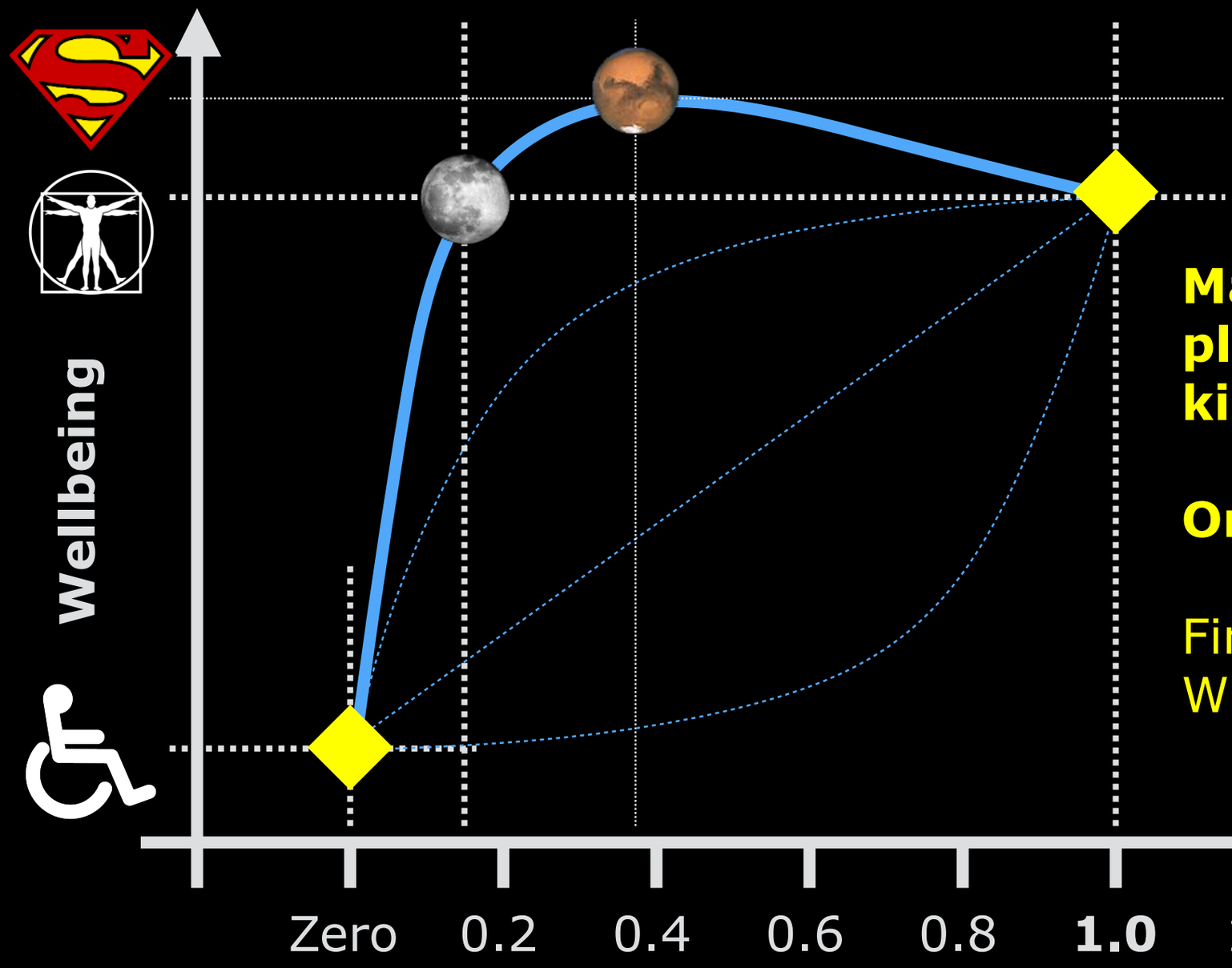
Bye bye, Luna, Jovian moons, Titan, etc.

And the Moon remains a temporary hardship post.

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

The Martian Superman Scenario

Low-but-not-zero-G turns out to be *good* for joints, circulatory system, etc.



4

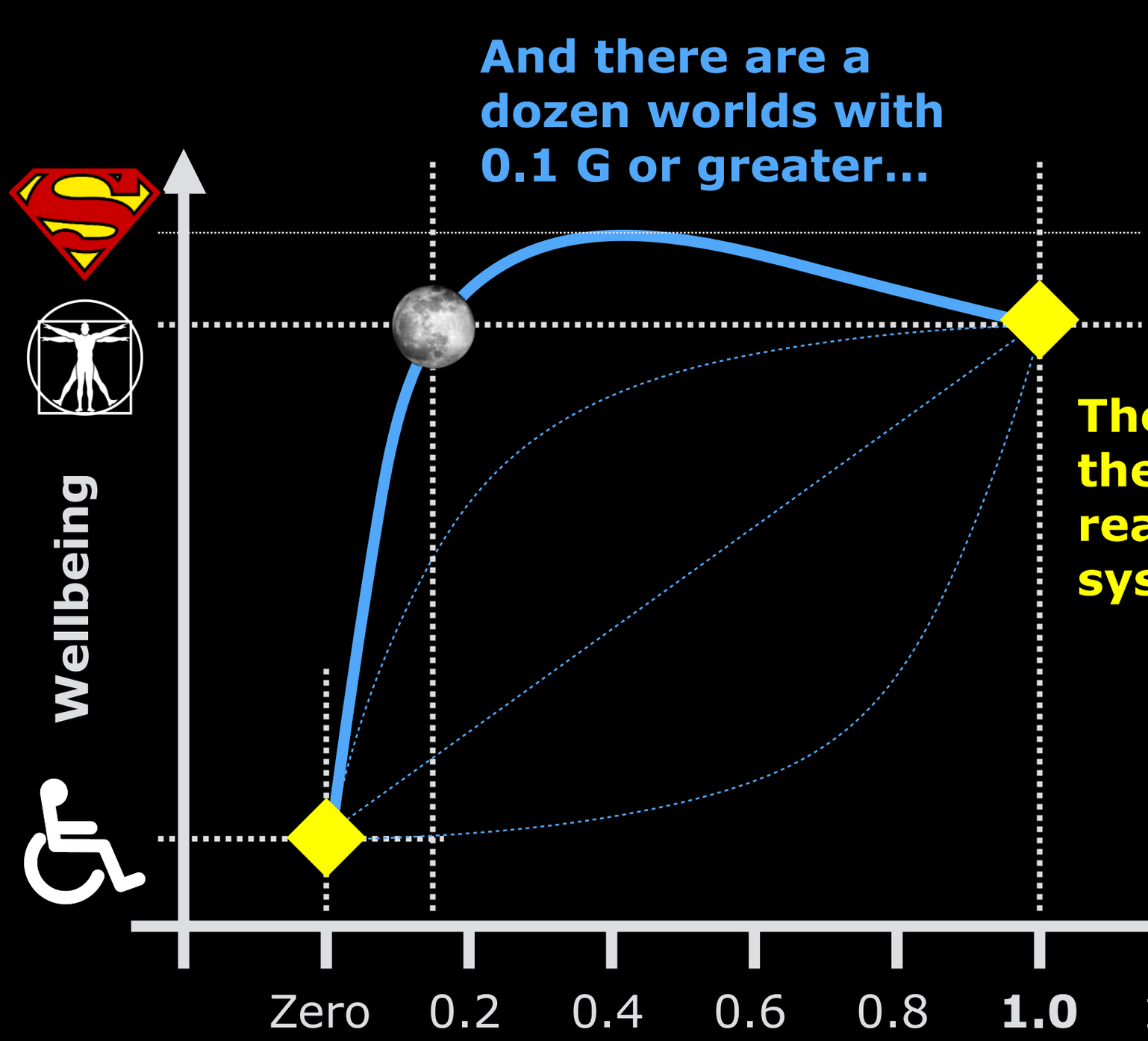
Mars IS the kind of place to raise your kid!

Or to retire…

Fire up the Space Winnebagos!

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

The Human Solar System



4

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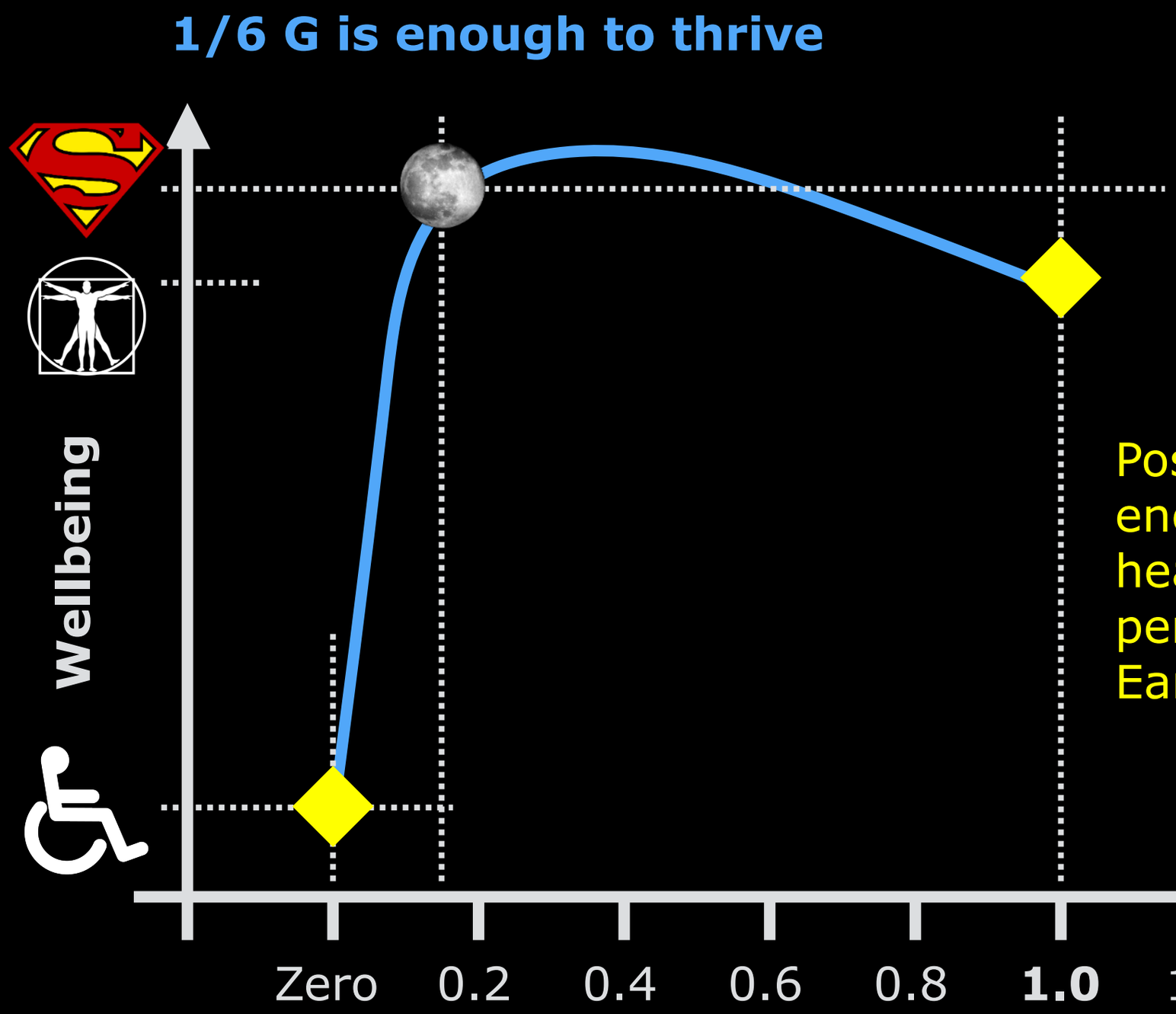
The Lunar Superman Scenario

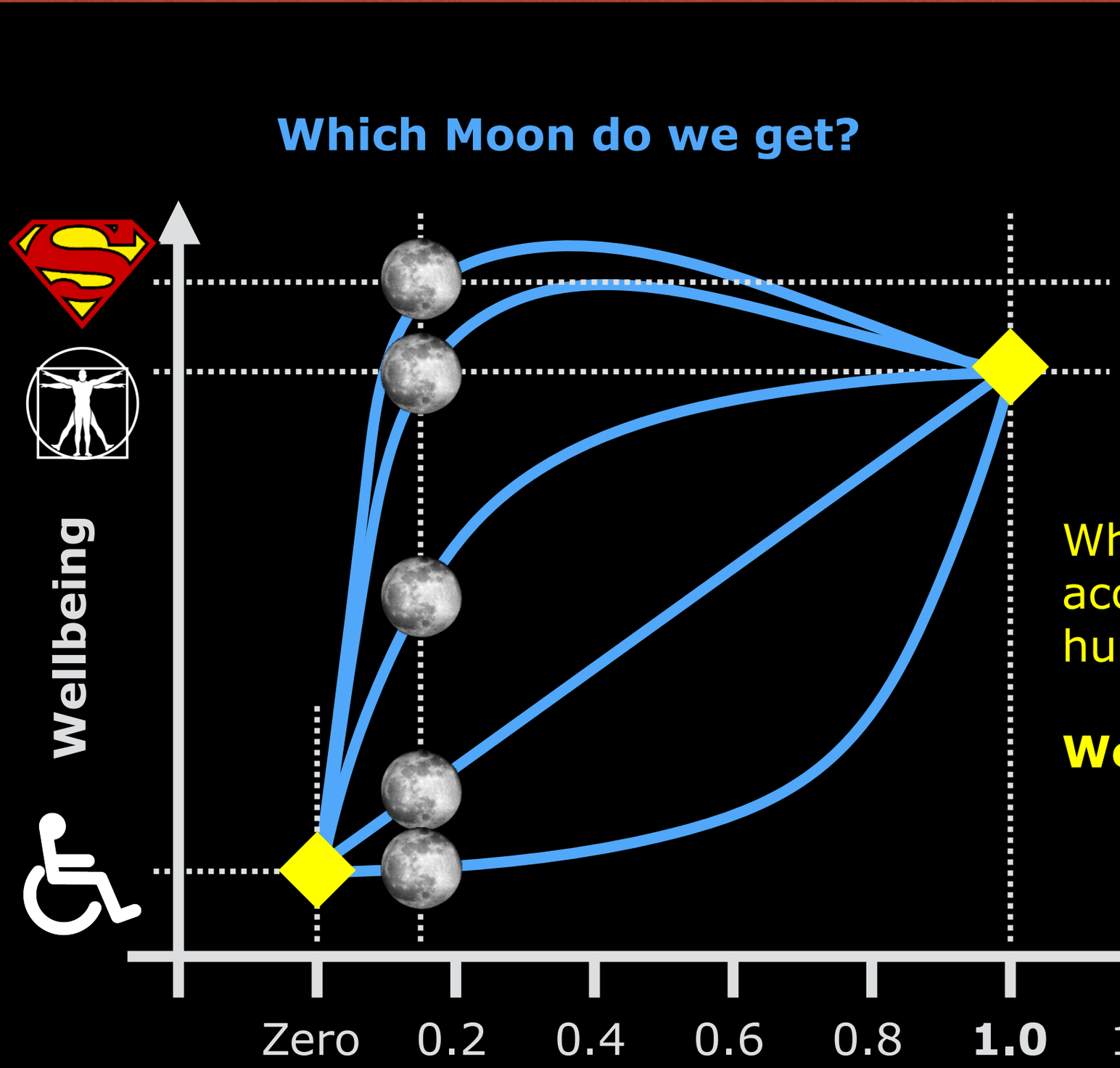


5

Possibly, 1/6 G is enough to support health and well-being, perhaps even beyond Earth standards!

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

We Only Have Two Data Points!



?

Which of these curves accurately represents human physiology?

We just don't know.

Adapted from http://selenianboondocks.com/2005/11/if-youre-going-to-be-snarky/

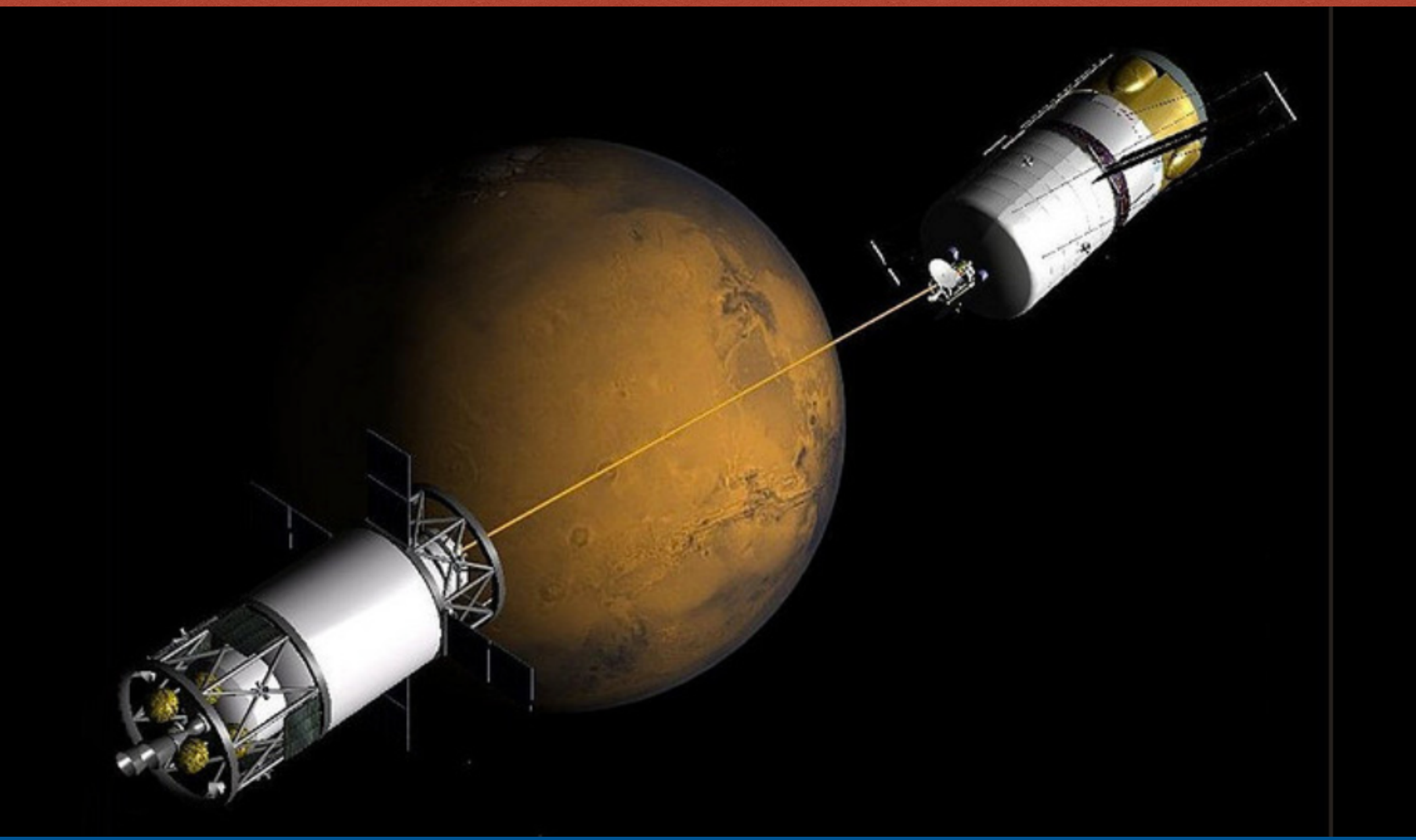
G-Lab: Orbital Centrifuge Lab

Free-flying crew-tended station near ISS

5m dia. x 15m long
Approx. cost: $100M

http://ssi.org/ssi-update-april-2012-introduction-to-g-lab/

Centrifugal Tethers



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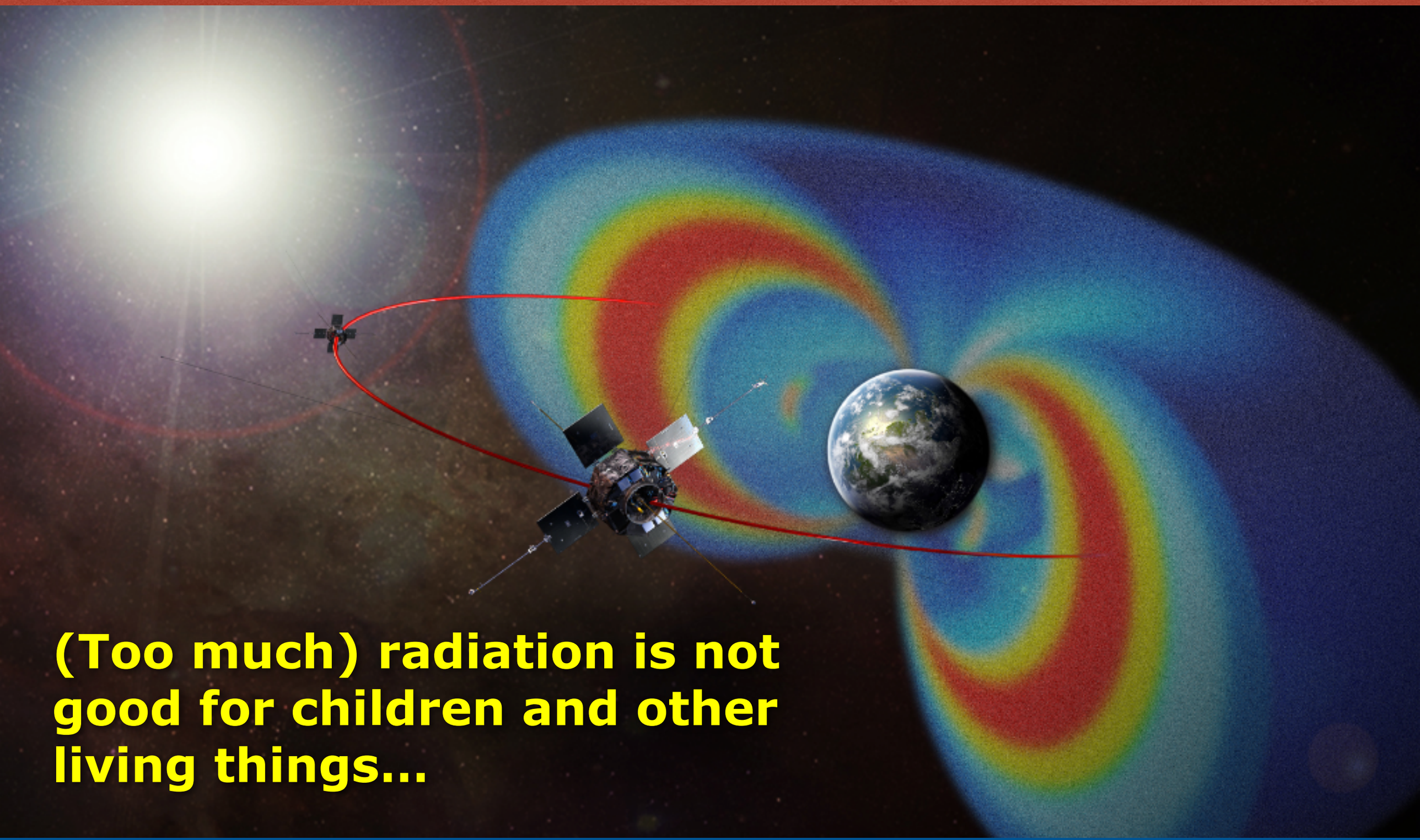
What We Can Learn *How* to Do

Closing the loop on life support

Water-only recycling: 93% efficient

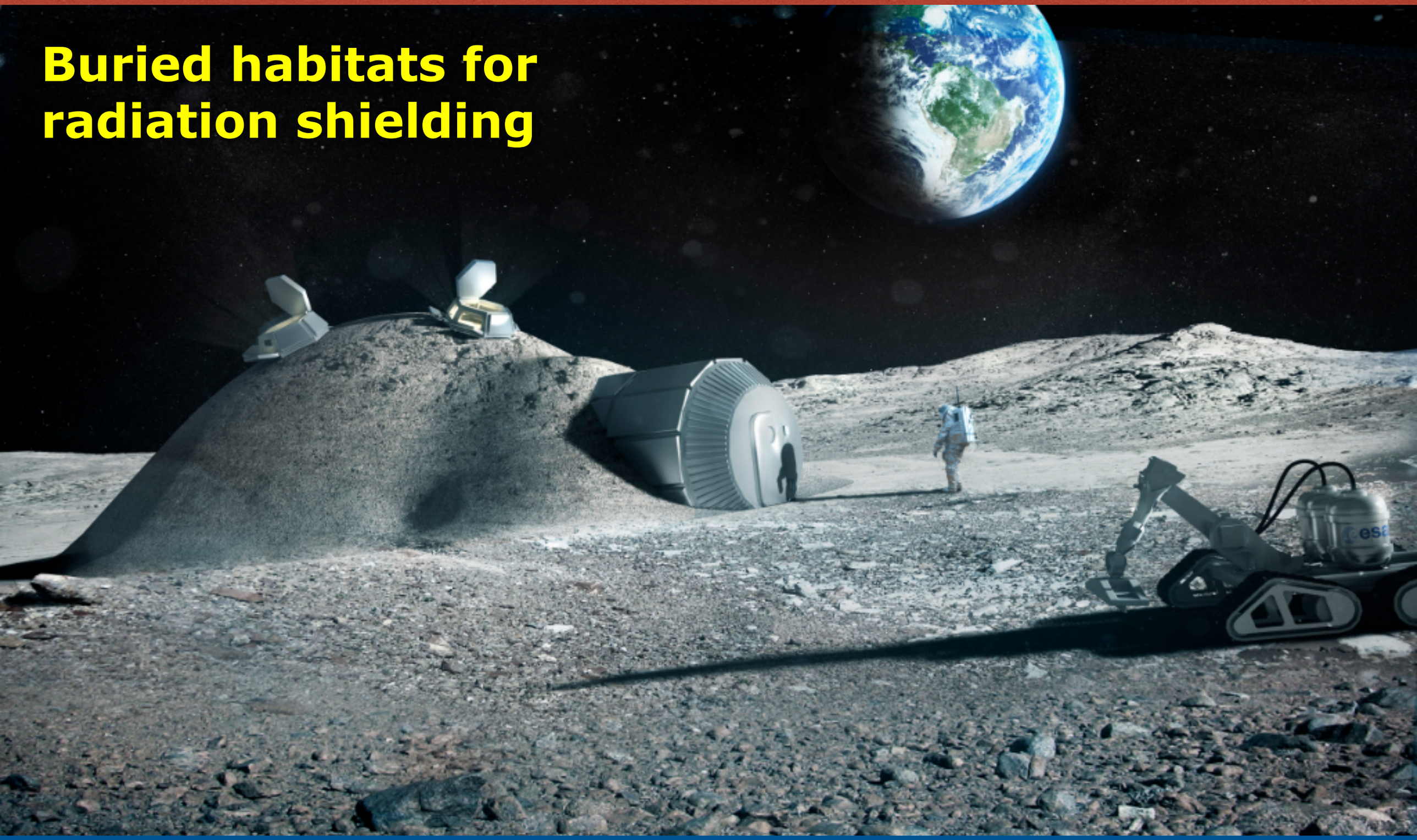
Space is Radioactive!



(Too much) radiation is not good for children and other living things…

What We Can Learn *How* to Do There

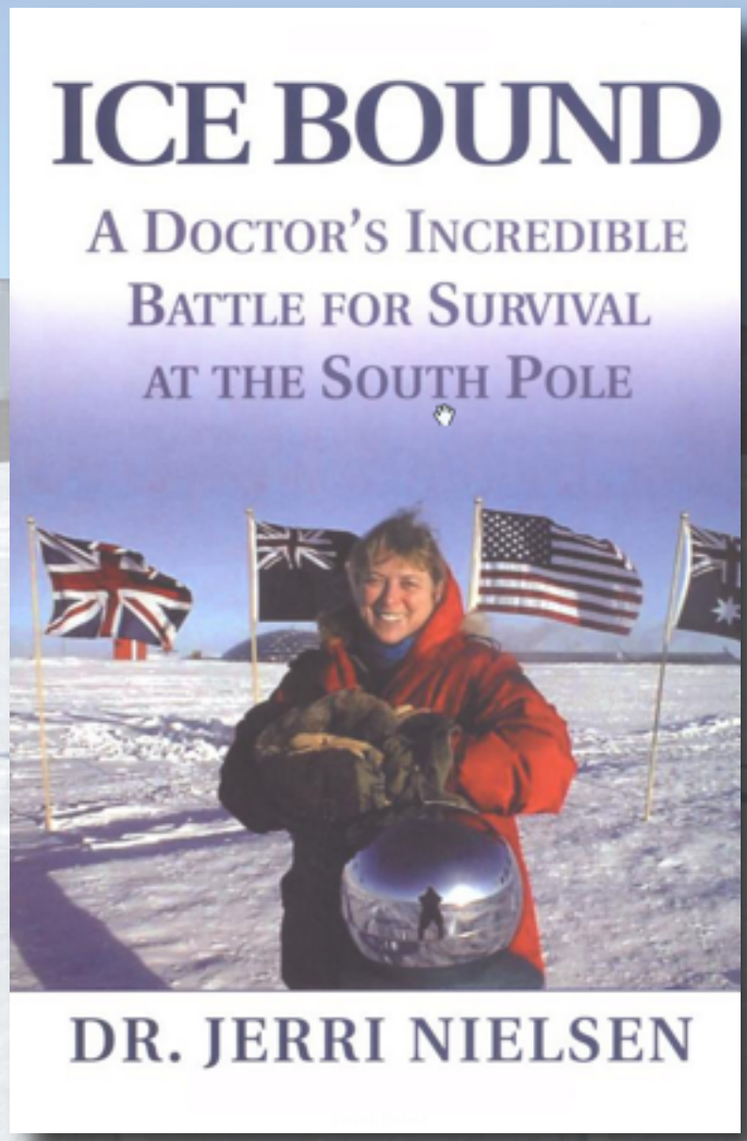
Buried habitats for radiation shielding



What We Can Learn *How* to Do There

Truly isolated operations
(but only 3 days from Earth)

Dr. Jerri Nielsen, 1999



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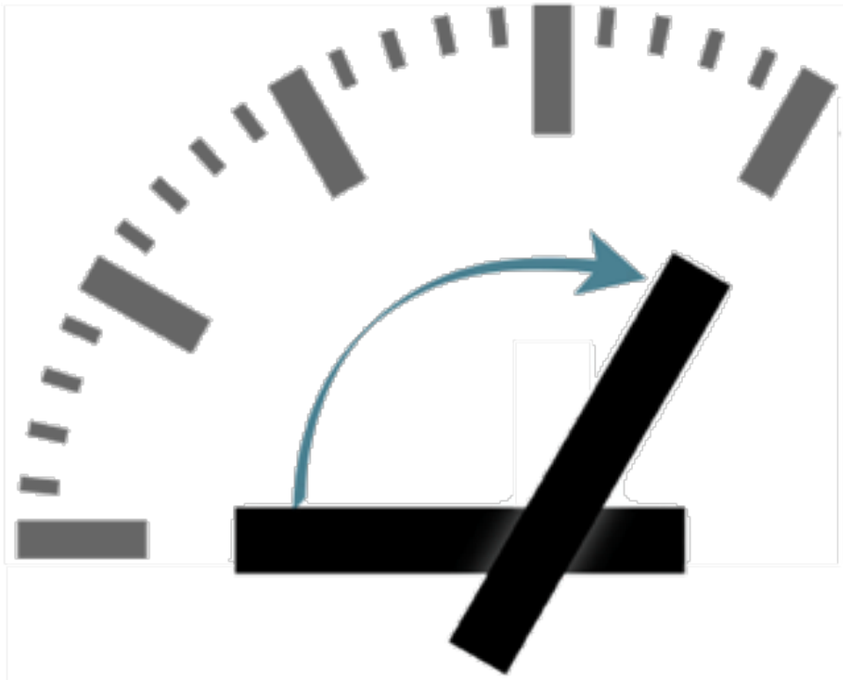

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What We Can Do There

A new world to explore…

The Moon is Earth's Eighth Continent!

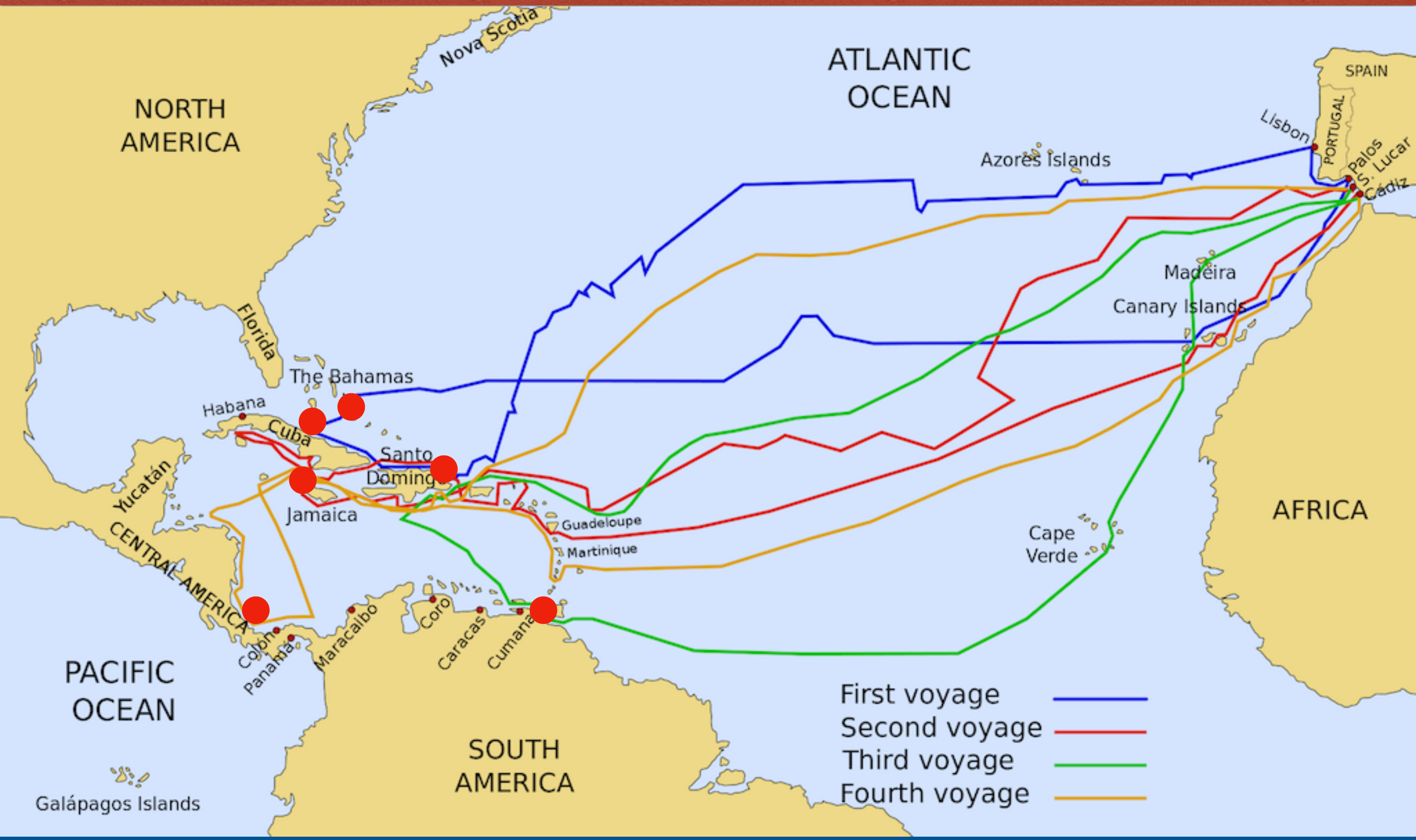
Landmass	Area (sq km)
Asia	43,820,000
Moon	37,900,000
Africa	30,370,000
North America	24,490,000
South America	17,840,000
Antarctica	13,720,000
Europe	10,180,000
Australia	9,008,500

Total of Six Apollo Landing Sites

Six football fields, in a land bigger than Africa.

Apollo:
Equatorial orbits, easy ΔV for rendezvous, nothing on Farside at all.

Voyages of Columbus



What We Can Do There

What We Can Do There

International Treaties

Outer Space Treaty
(1967)

"The exploration and use of outer space shall be… the province of all mankind."

The Moon and other celestial bodies [are] "not subject to national appropriation."

Military bases are forbidden.

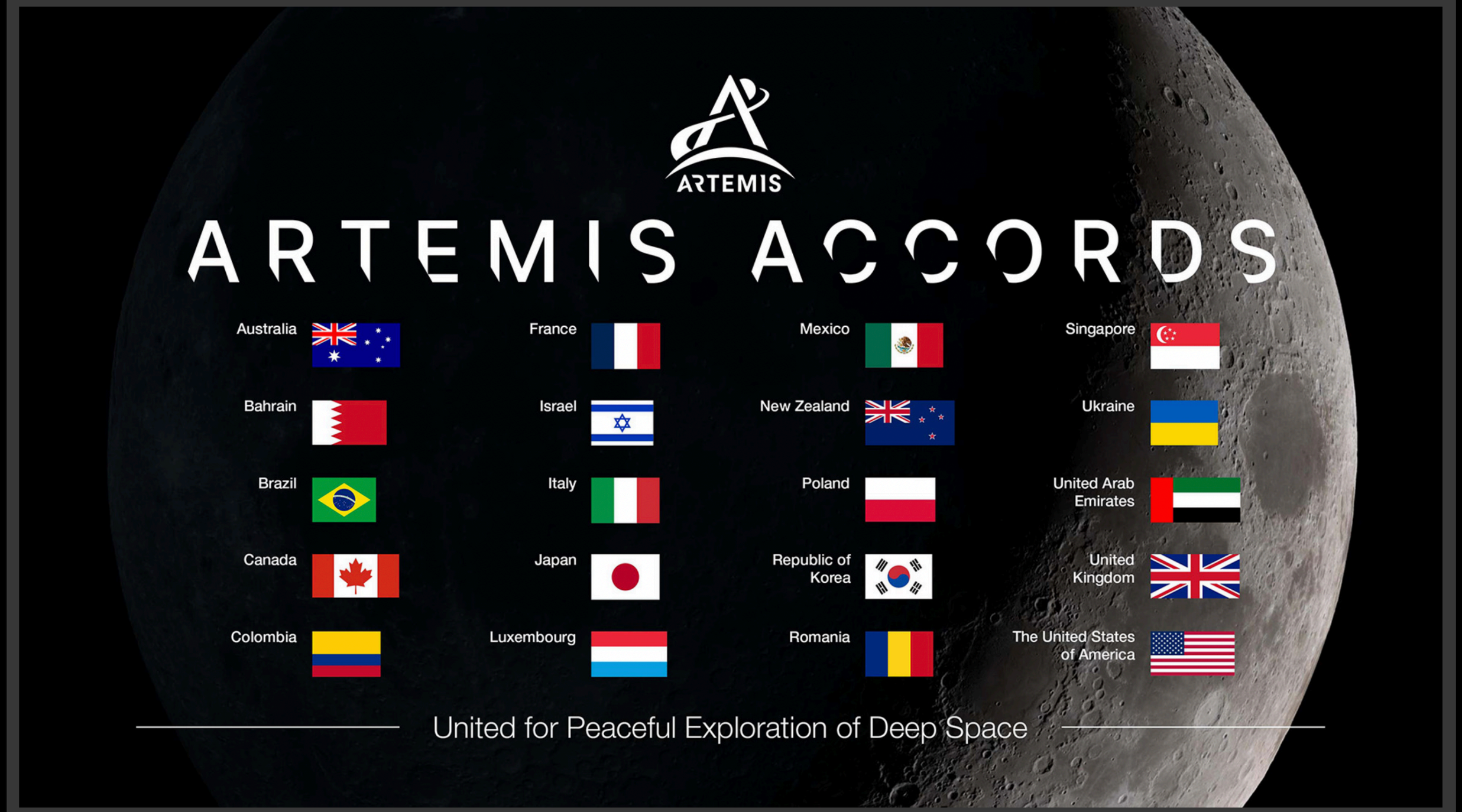
Moon Agreement
(1979)

"The moon and its natural resources are the common heritage of mankind."

Bans private ownership of any lunar resources by any company or individual.

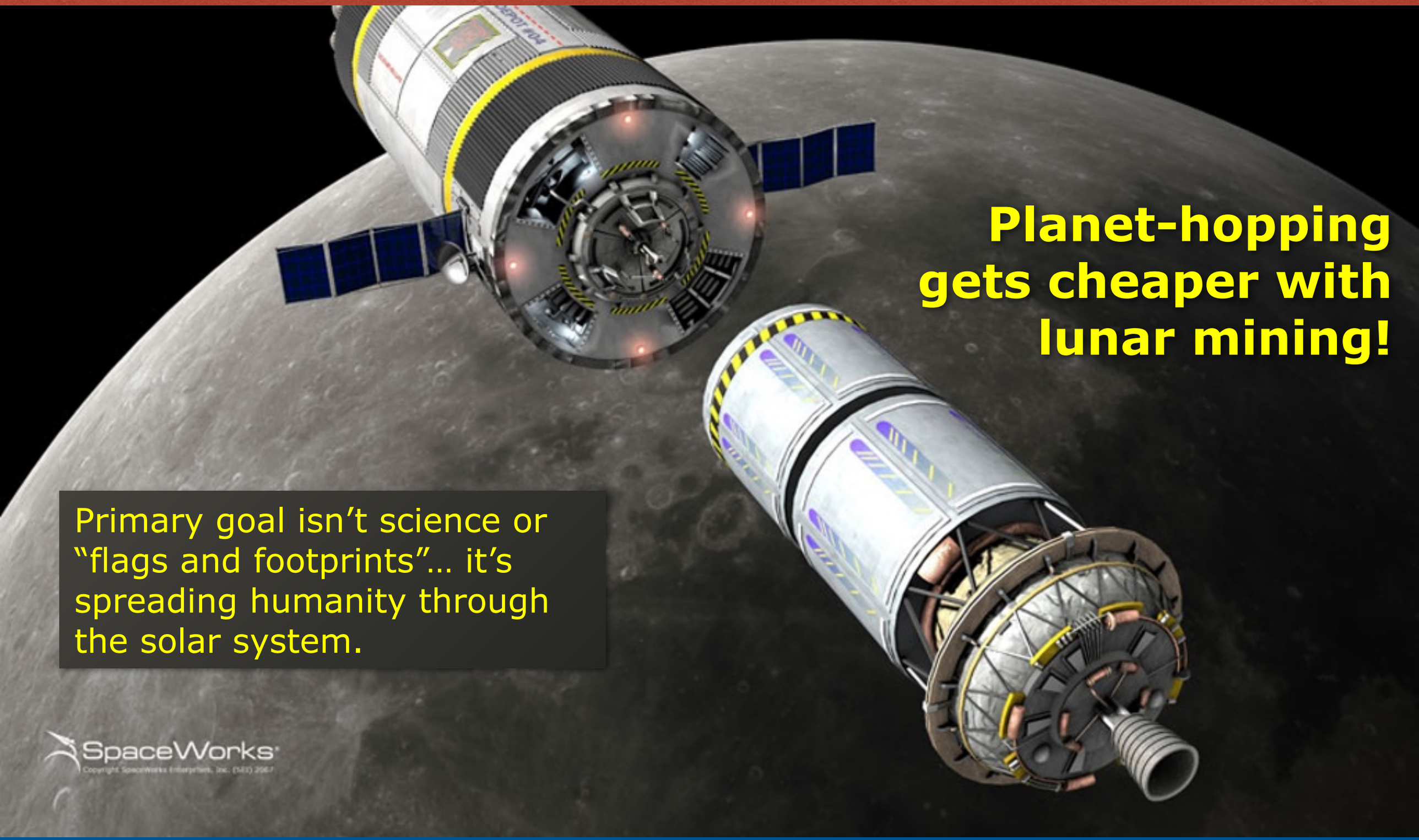
Requires international regime for sharing benefits.

The Artemis Accords



https://www.nasa.gov/specials/artemis-accords/index.h

What We Can Do There



What We Can Do There

Lunar mining:

In Situ Resource Utilization
Effective teleoperations
Vacuum chemistry
Dust control

What We Can Do There

Beresheet-1 launched 2019
Privately funded!

Resource prospecting

What We Can Do There

They came so close!

What We Can Do There

Water to drink and
irrigate crops
Hydrogen for fuel
Oxygen to breathe
Chemical feedstock

Ice!

Malapert Mountain

C

B

A

Shackleton

D

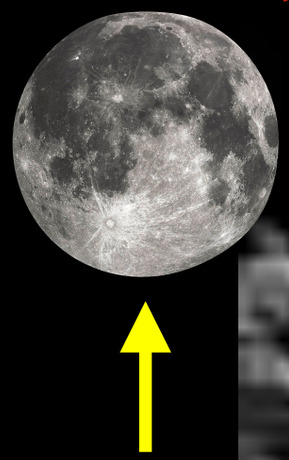
de Gerlache

© JAXA/NHK

The Lunar South Pole is Unique

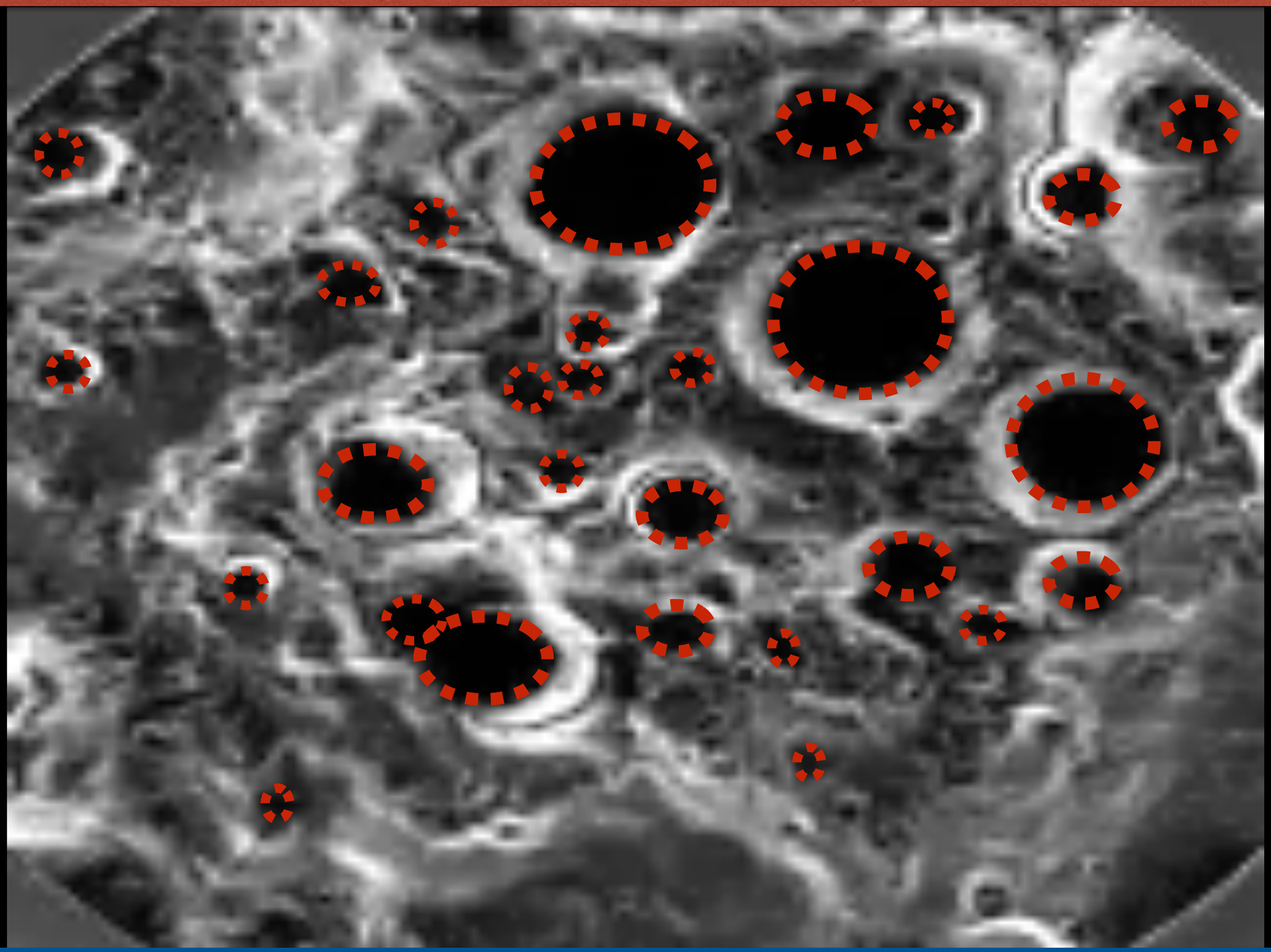
JAXA KAGUYA video

Permanently Shadowed Craters



JAXA KAGUYA video

Permanently Shadowed Craters



The Moon Gets Hit… A Lot!

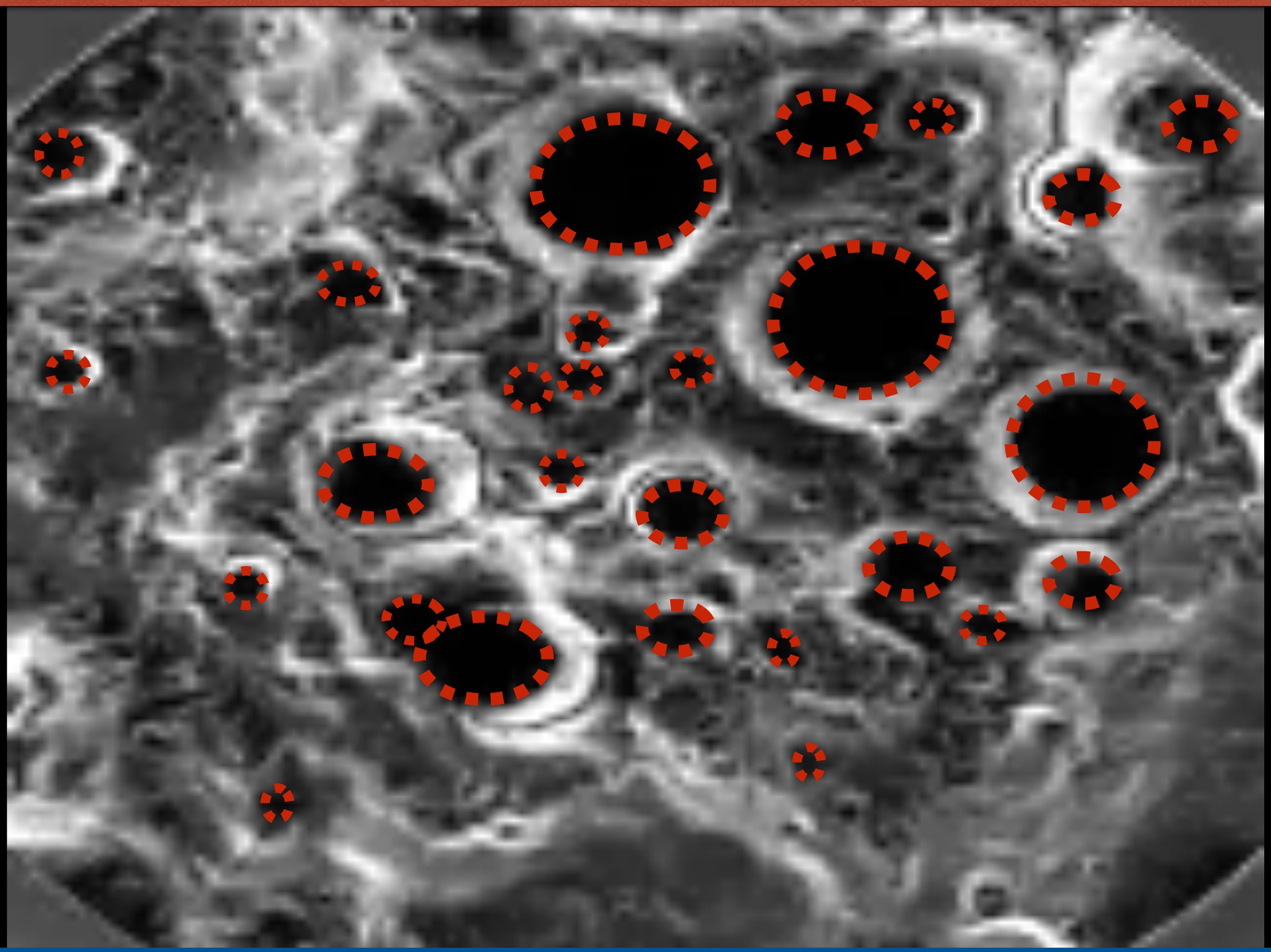
All those craters came from somewhere!

Comet Shoemaker-Levy, 1994

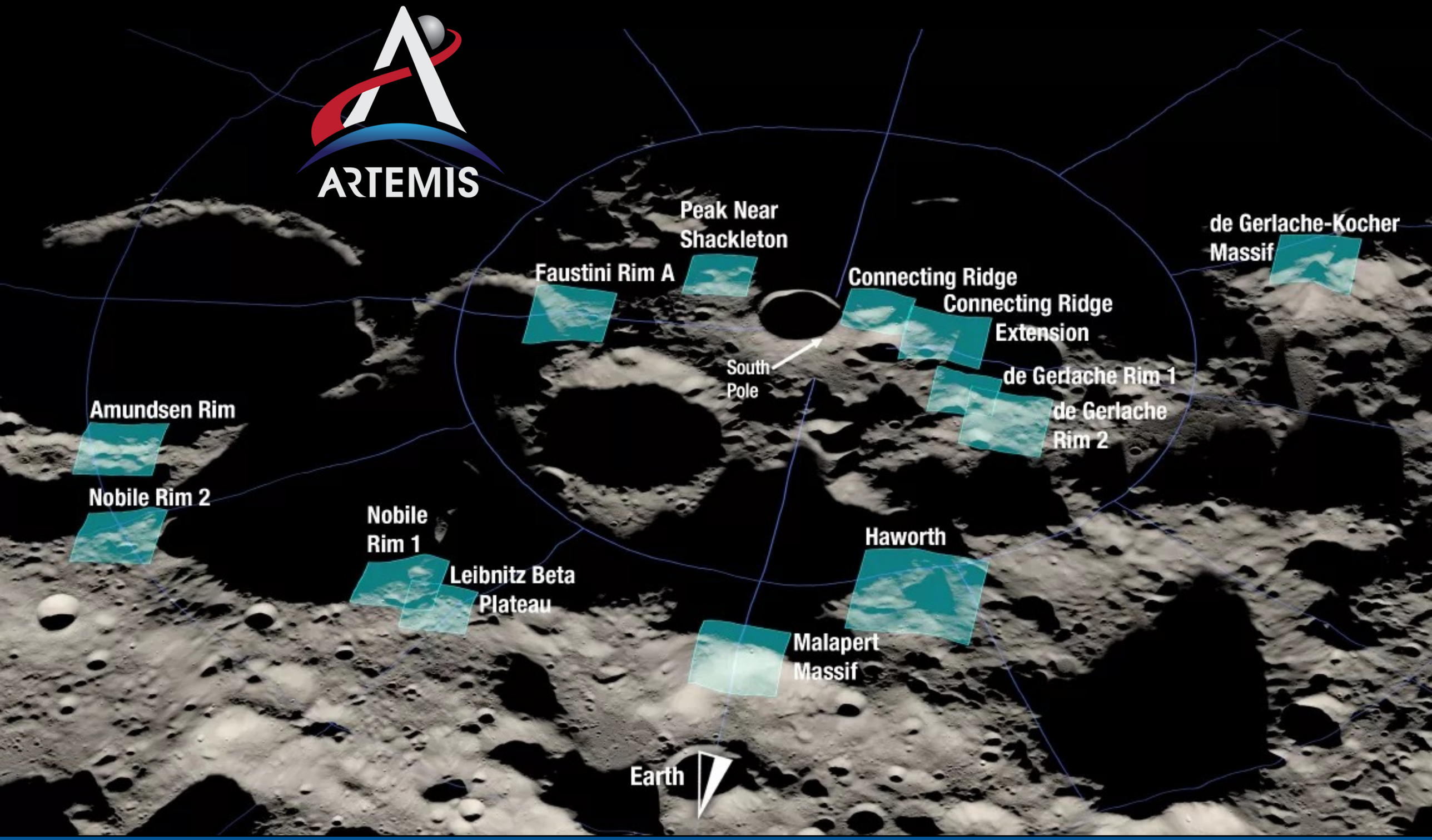
Remember?

Comets are Dirty Snowballs

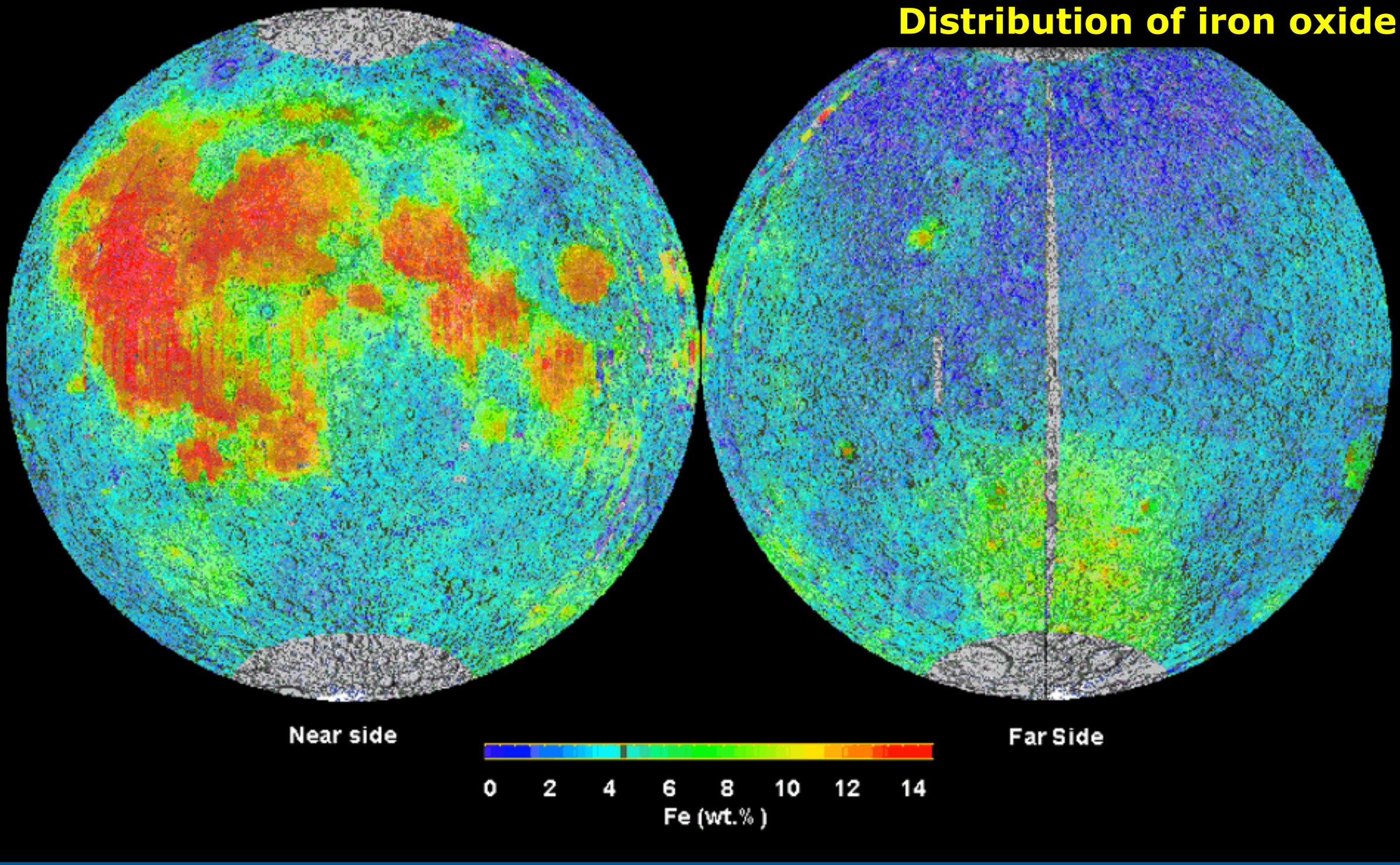
Shadowed Craters Act as "Cold Traps"



NASA Just Announced Landing Targets



Lunar "Geology" is Complex



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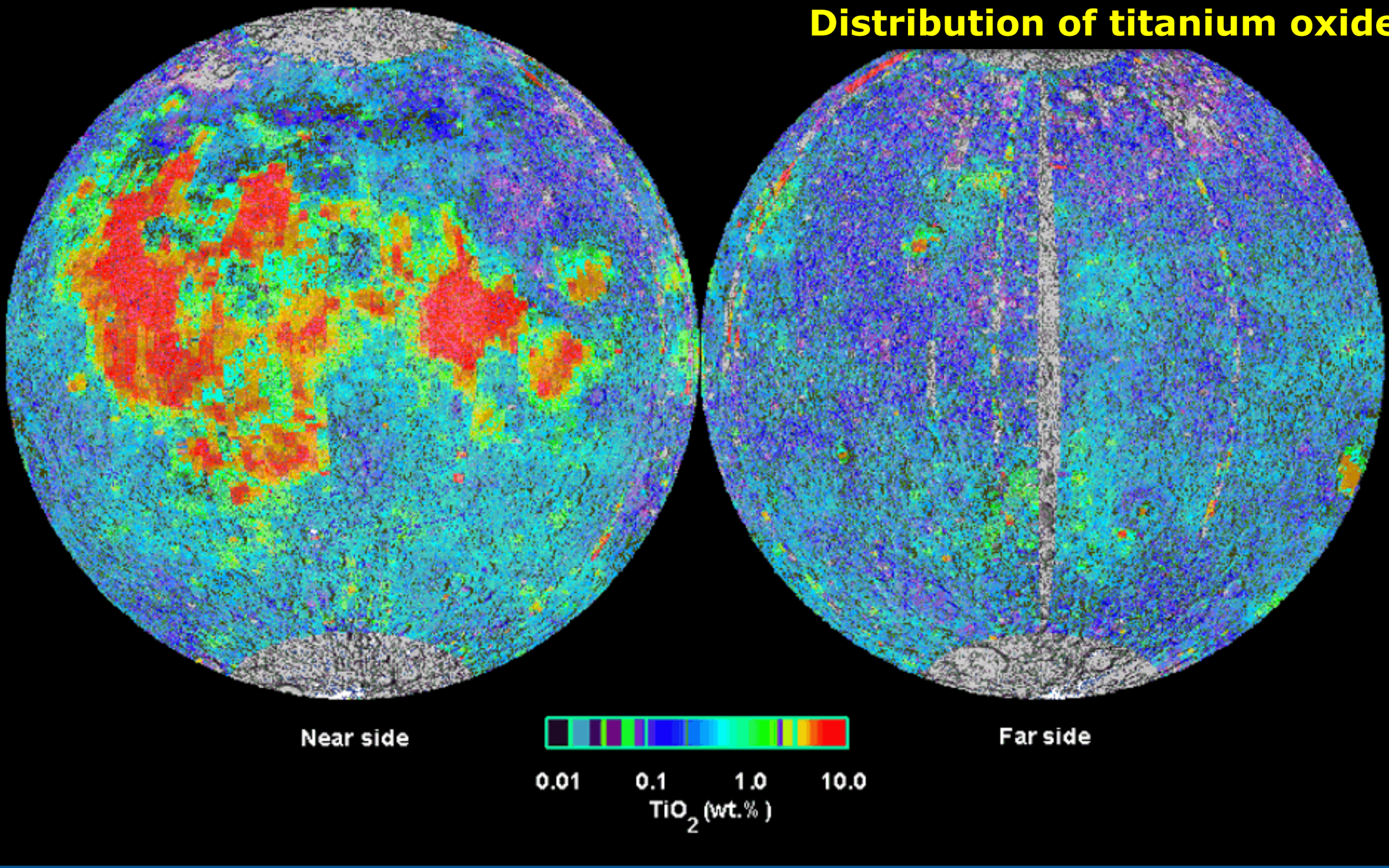
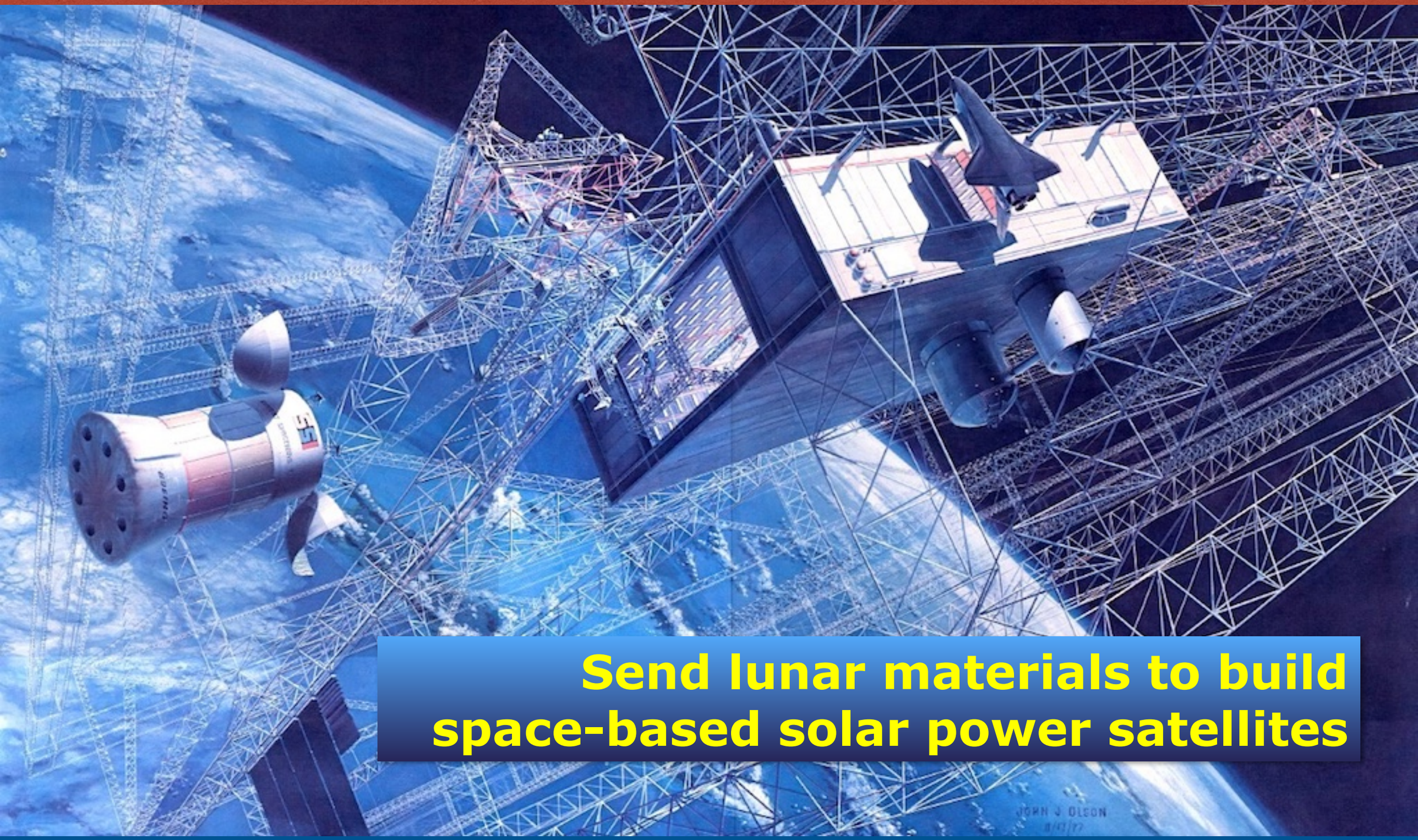


What Can You Mine/Make on the Moon?

Iron
Aluminum
Titanium
Silicon
Glass

Oxygen
Hydrogen
Regolith
…and more

What We Can Do There



We've Gotten Good at Orbital Assembly

...but at $10,000/pound from Earth, it doesn't matter.

What We Can Do There

Extract Helium-3 (*double* maybe!)

Mining the Lunar Dust

Regolith, the loose soil on the moon's surface, contains more than 1 million tons of helium 3. In theory, this nonradioactive isotope could provide an abundant source of clean nuclear energy. How it might be done:

3 Heater: Brings regolith to 700° C by flowing it over solar-heated pipes. This causes the helium 3 and other gases to be released from the regolith.

2 Fluidized chamber: Removes all grains larger than 100 microns. Excess regolith is returned to the surface.

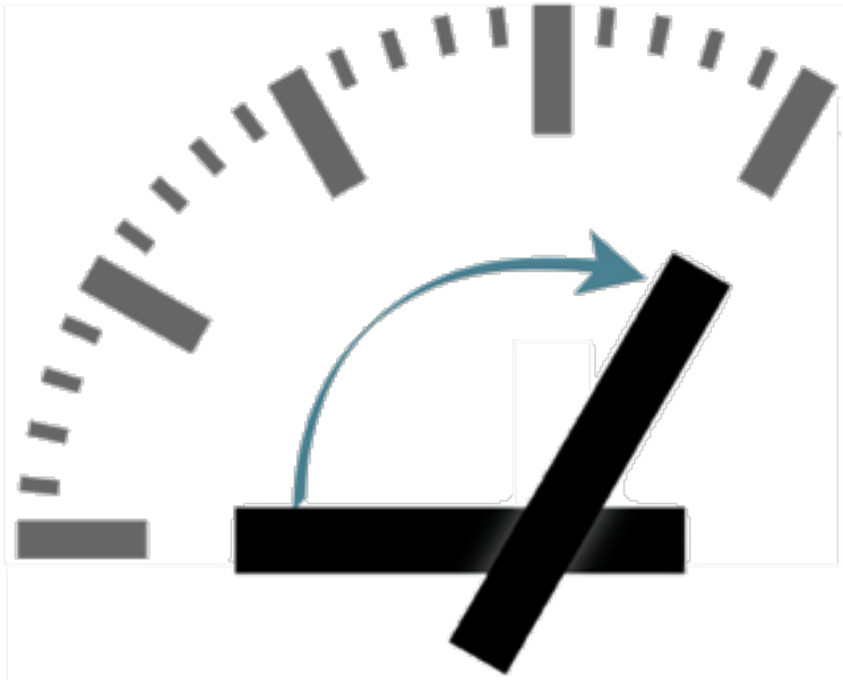
1 Bucket wheel: Moves the regolith onto a lifting belt to sift out large stones and keep only grains smaller than one millimeter in diameter.

4 Gas storage: Collects the helium 3 and other gases for transport to a moon base where the gases are separated. The helium 3 is shipped to Earth.

Solar collector
Solar power
Depleted regolith
Electrostatic separator
Gas storage tanks
Pivoting arm
Heater
Fluidized chamber
Lunar regolith
Bucket-wheel excavator

SOURCE: UNIVERSITY OF WISCONSIN-MADISON FUSION TECHNOLOGY INSTITUTE
GRAPHIC BY STANFORD KAY—NEWSWEEK

Agenda



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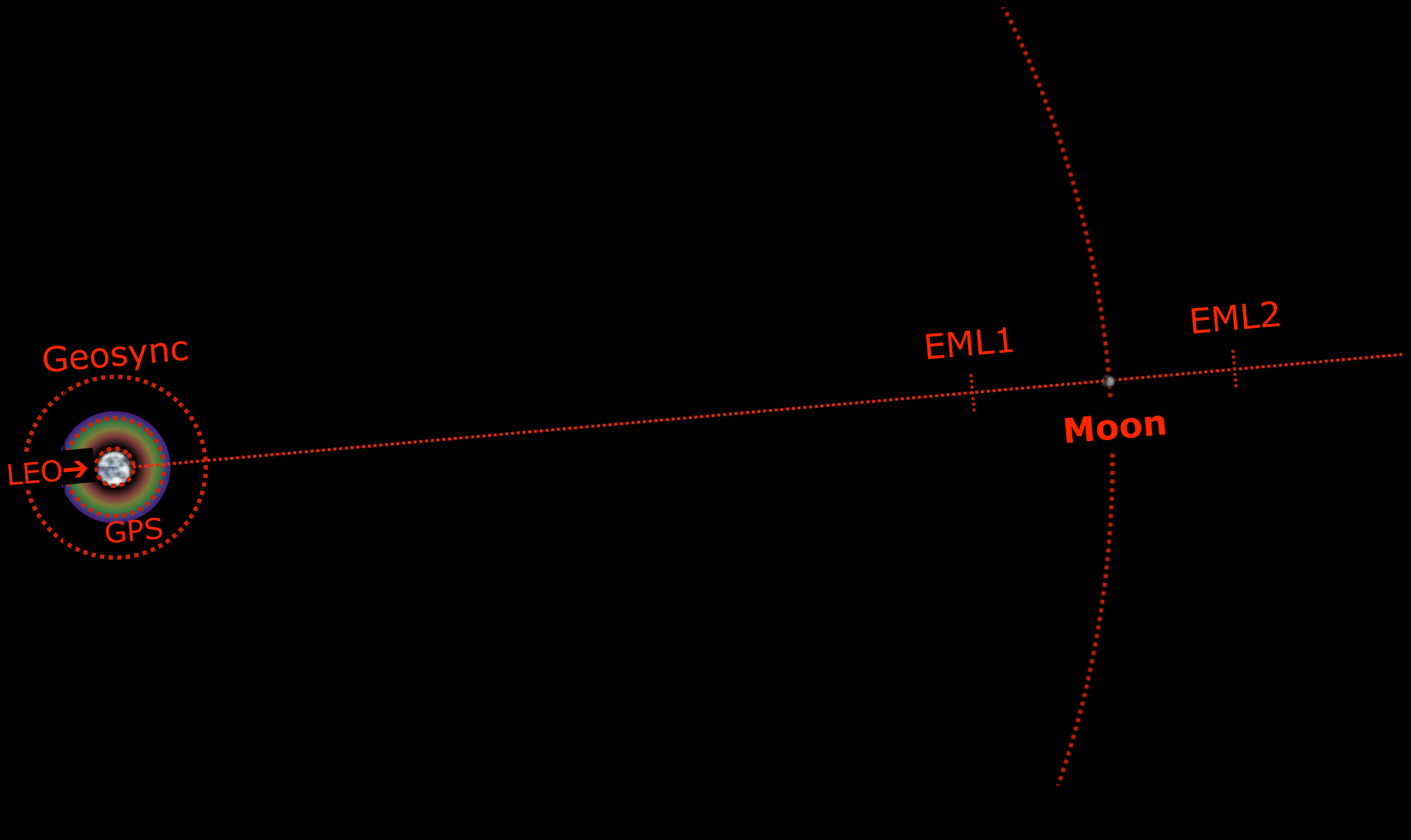
- Questions & Answers

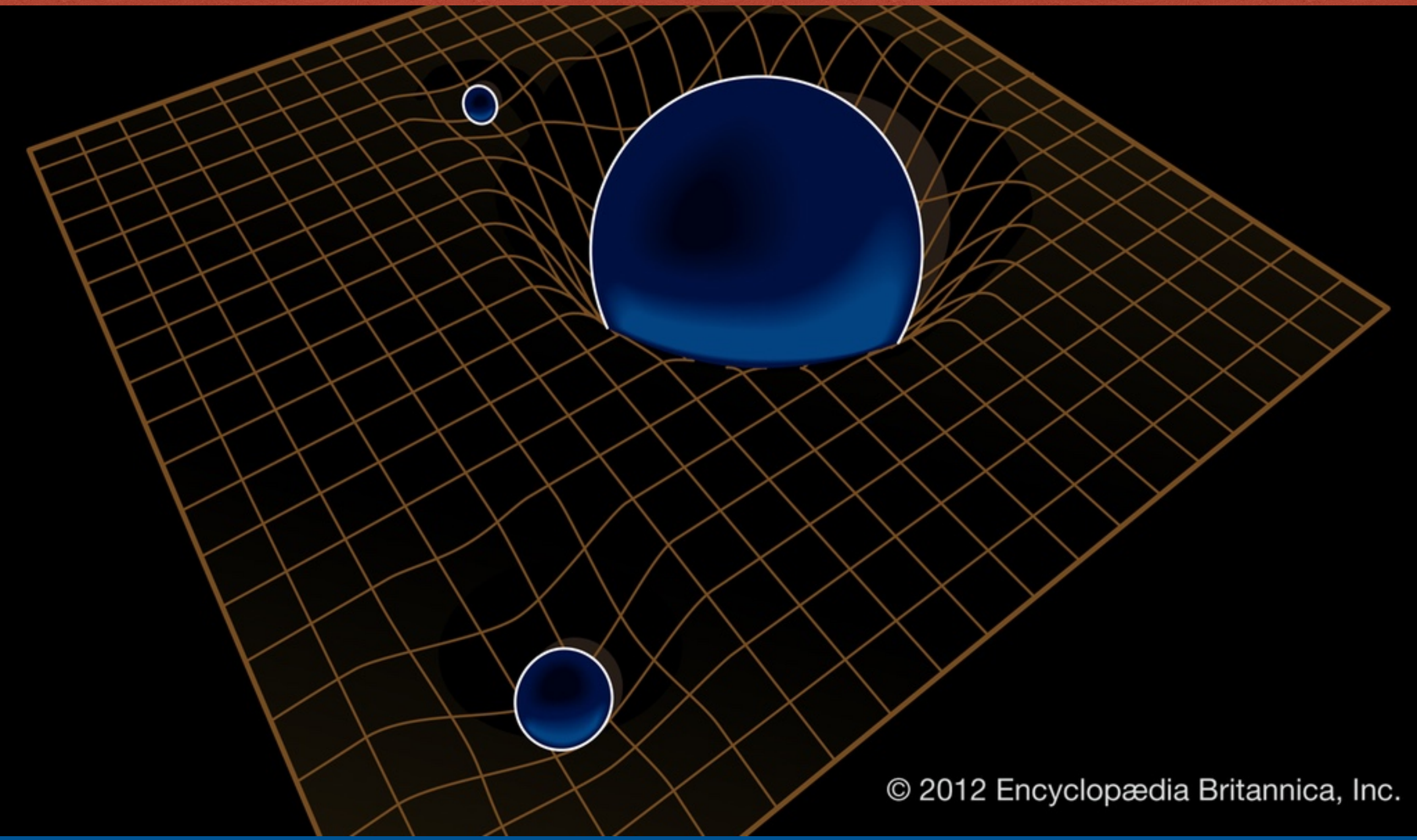
Earth-Moon System *(to scale)*

At this scale, the Sun is 2.4 screens wide and 250 screenwidths away.

Earth-Moon System *(to scale)*



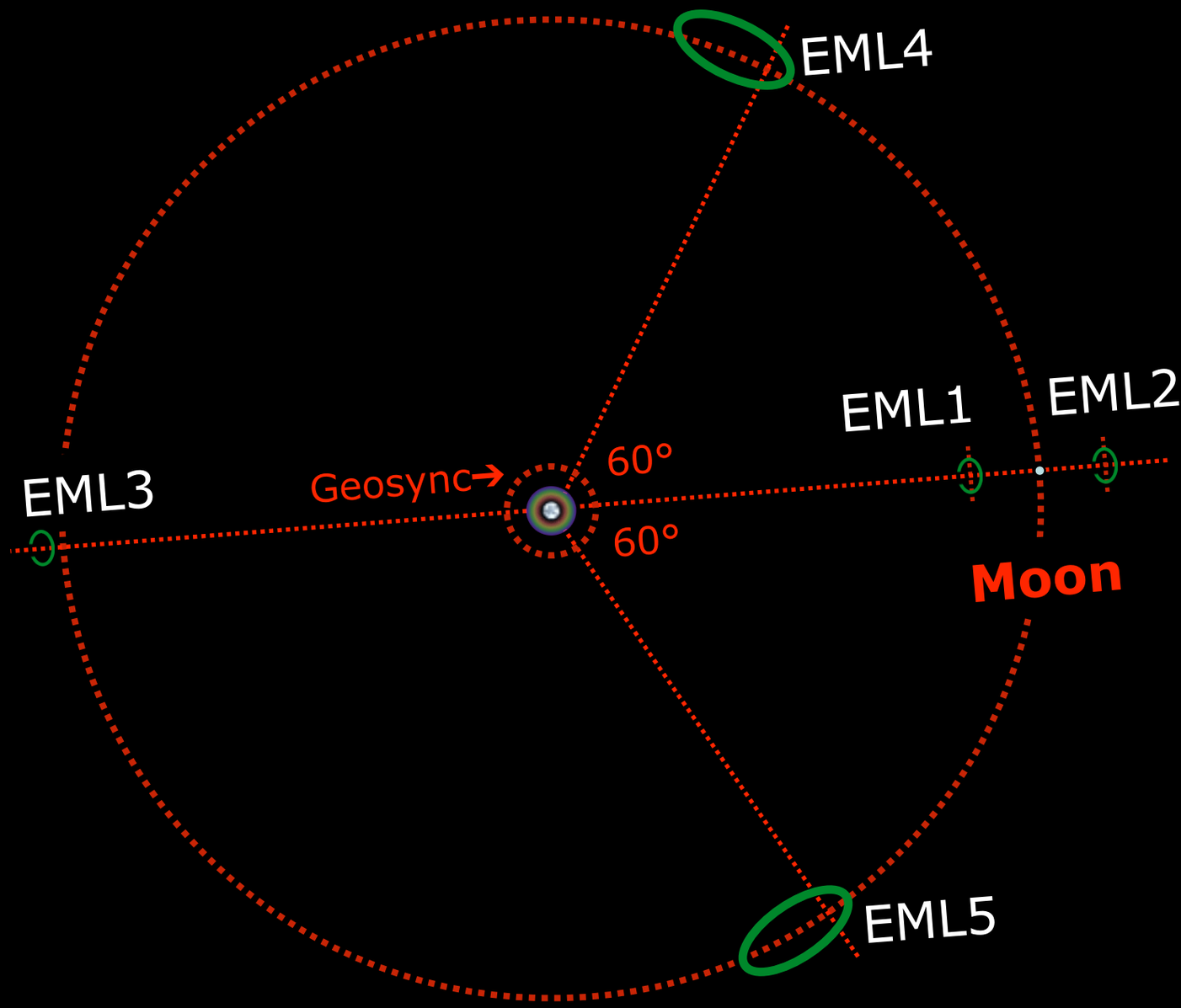
Rubber Sheet Model of Gravity



In space, transport costs are measured in ***energy***, not time or distance.

(Unless you have passengers.)

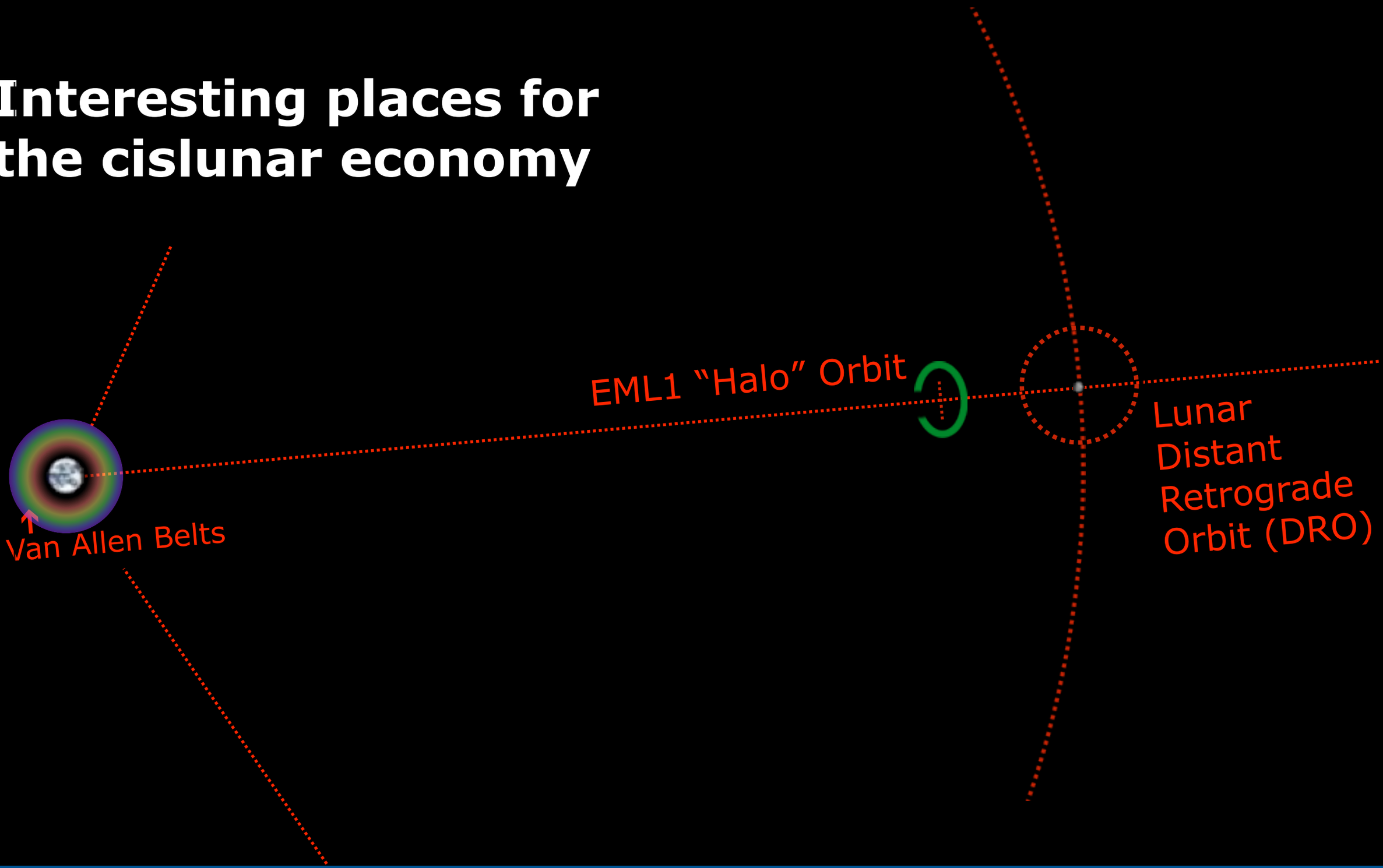
Lagrange Points *(to scale)*



Gravitationally semi-stable for small bodies
(like space stations)

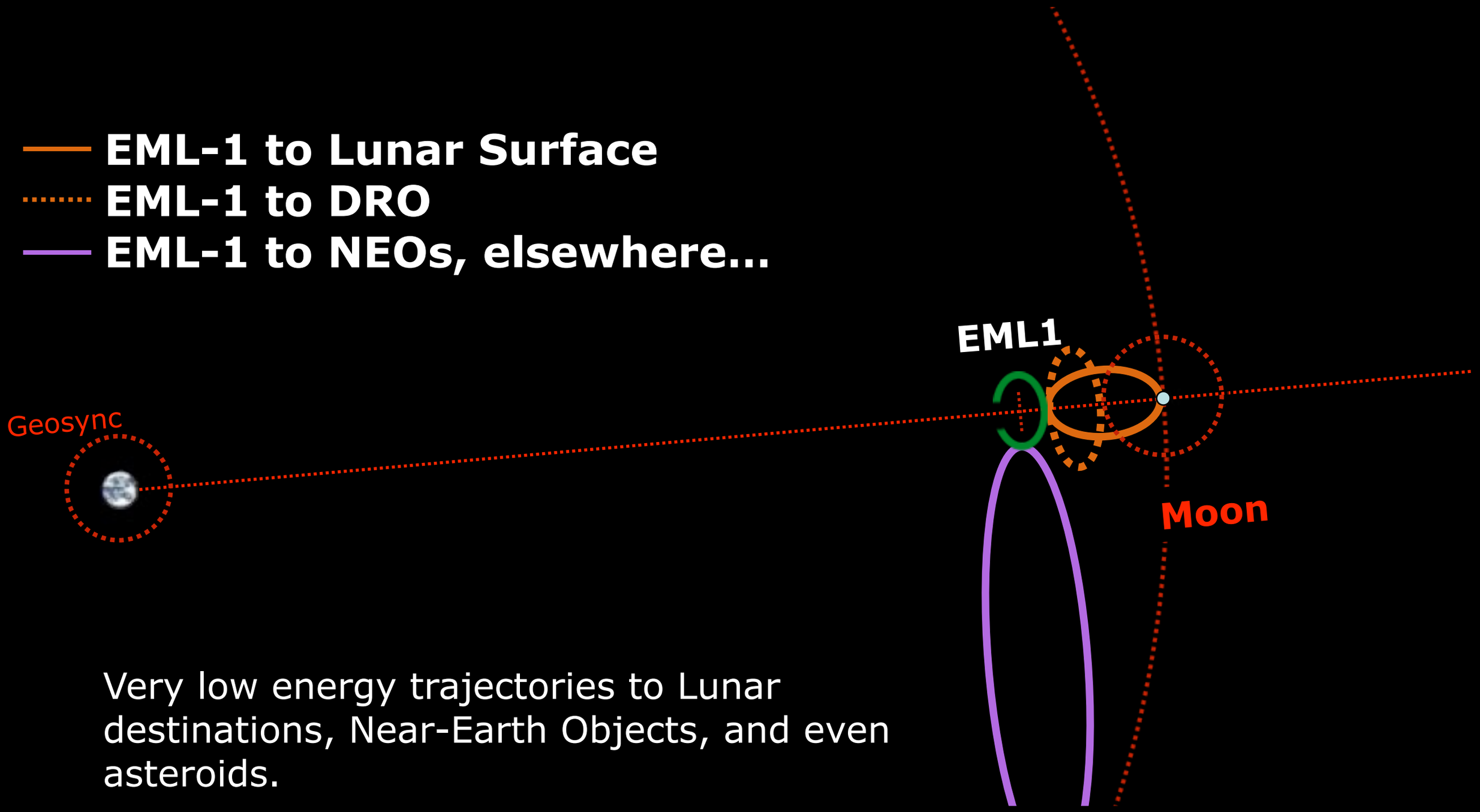
Earth-Moon System *(to scale)*

Interesting places for the cislunar economy



Cislunar Trade Routes

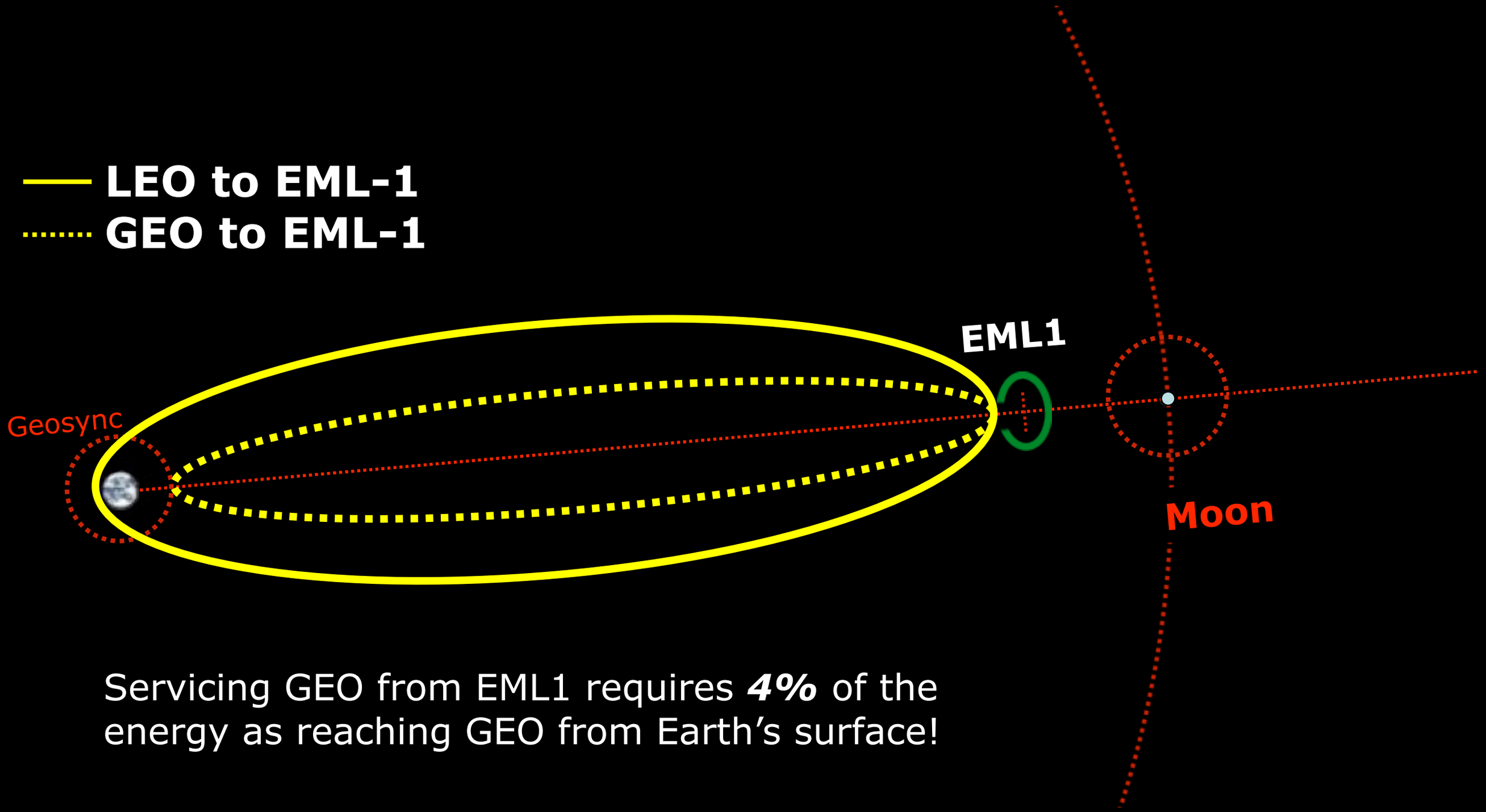
- EML-1 to Lunar Surface
- EML-1 to DRO
- EML-1 to NEOs, elsewhere…



Very low energy trajectories to Lunar destinations, Near-Earth Objects, and even asteroids.

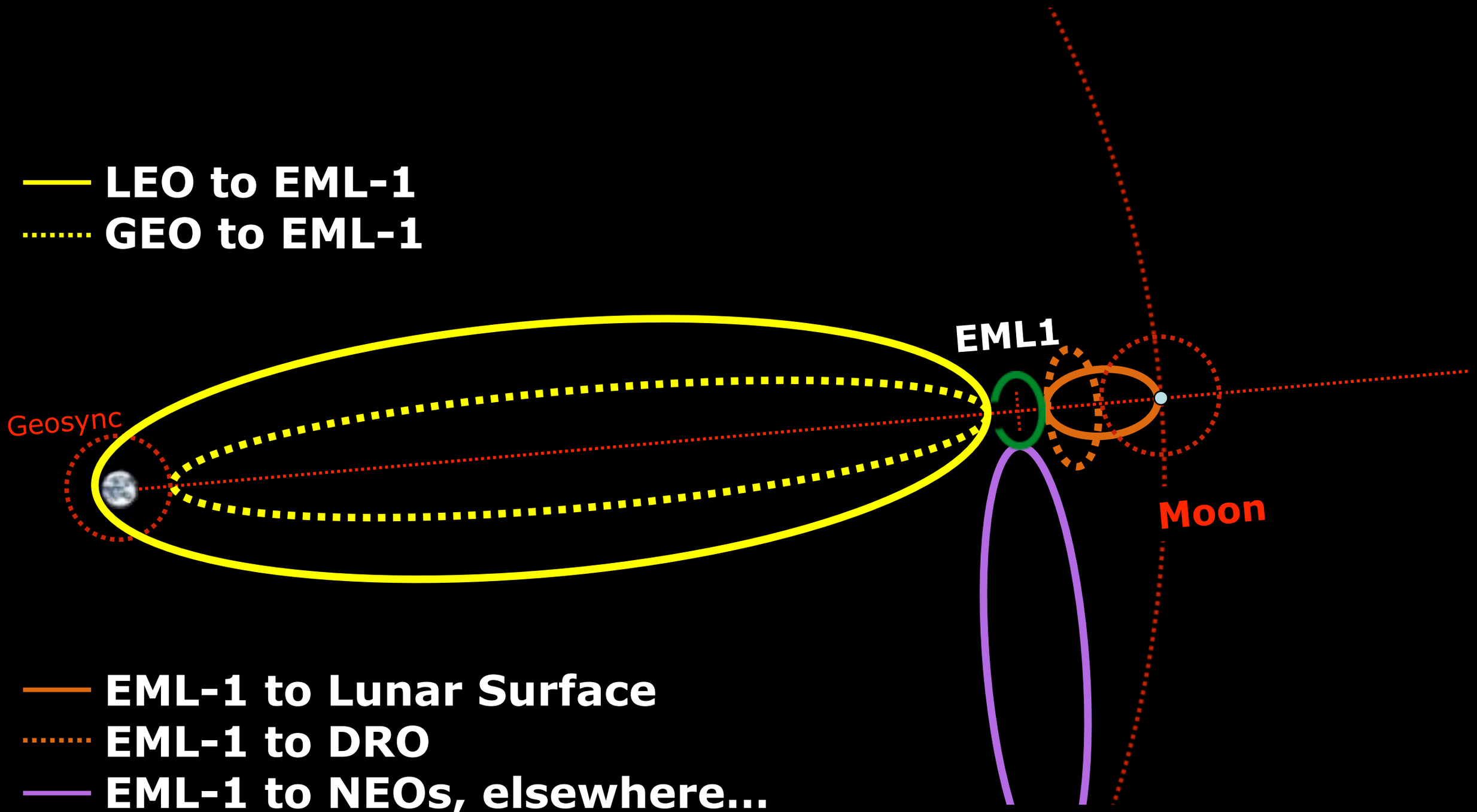
Cislunar Trade Routes

LEO to EML-1
GEO to EML-1



Servicing GEO from EML1 requires ***4%*** of the energy as reaching GEO from Earth's surface!

Cislunar Trade Routes



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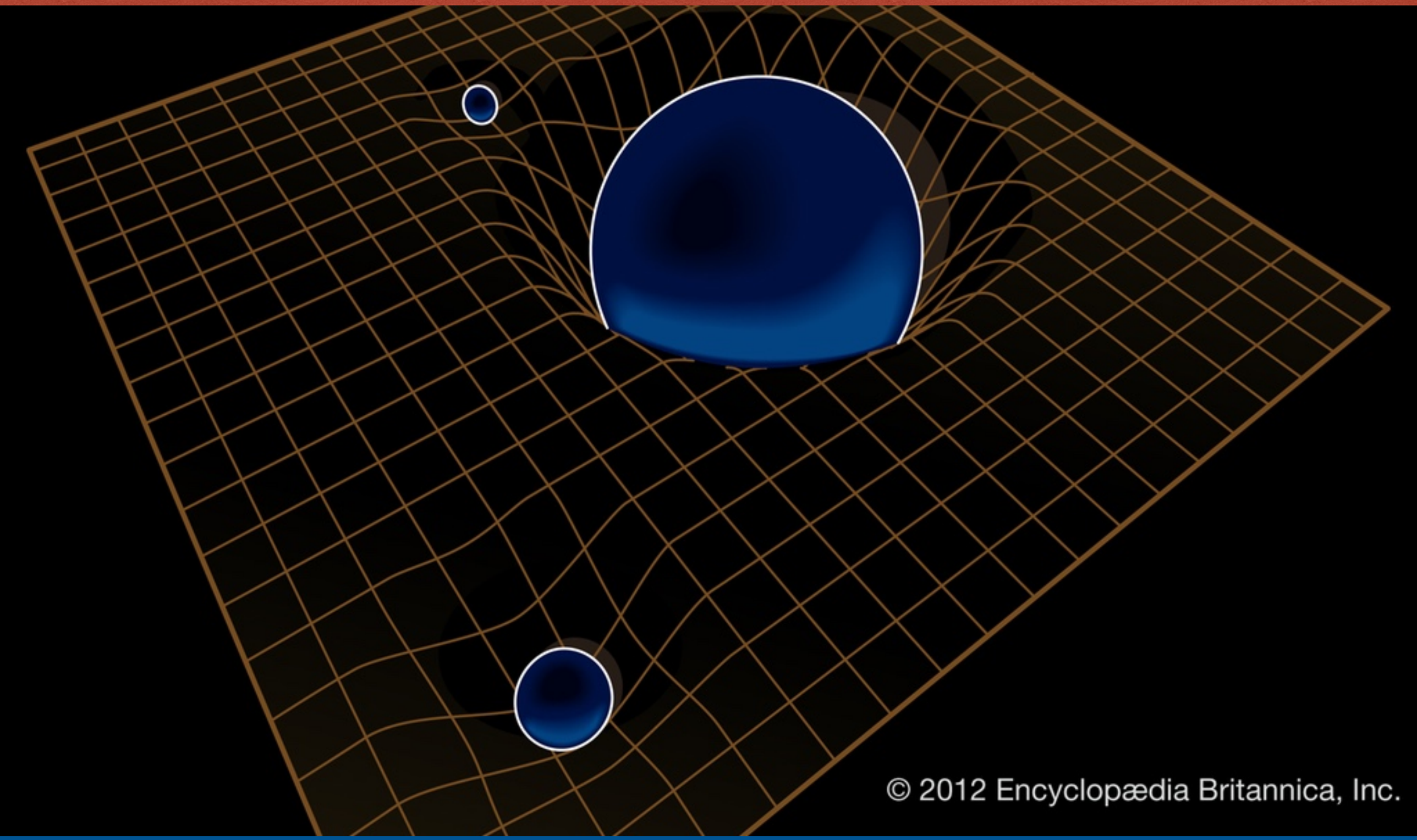
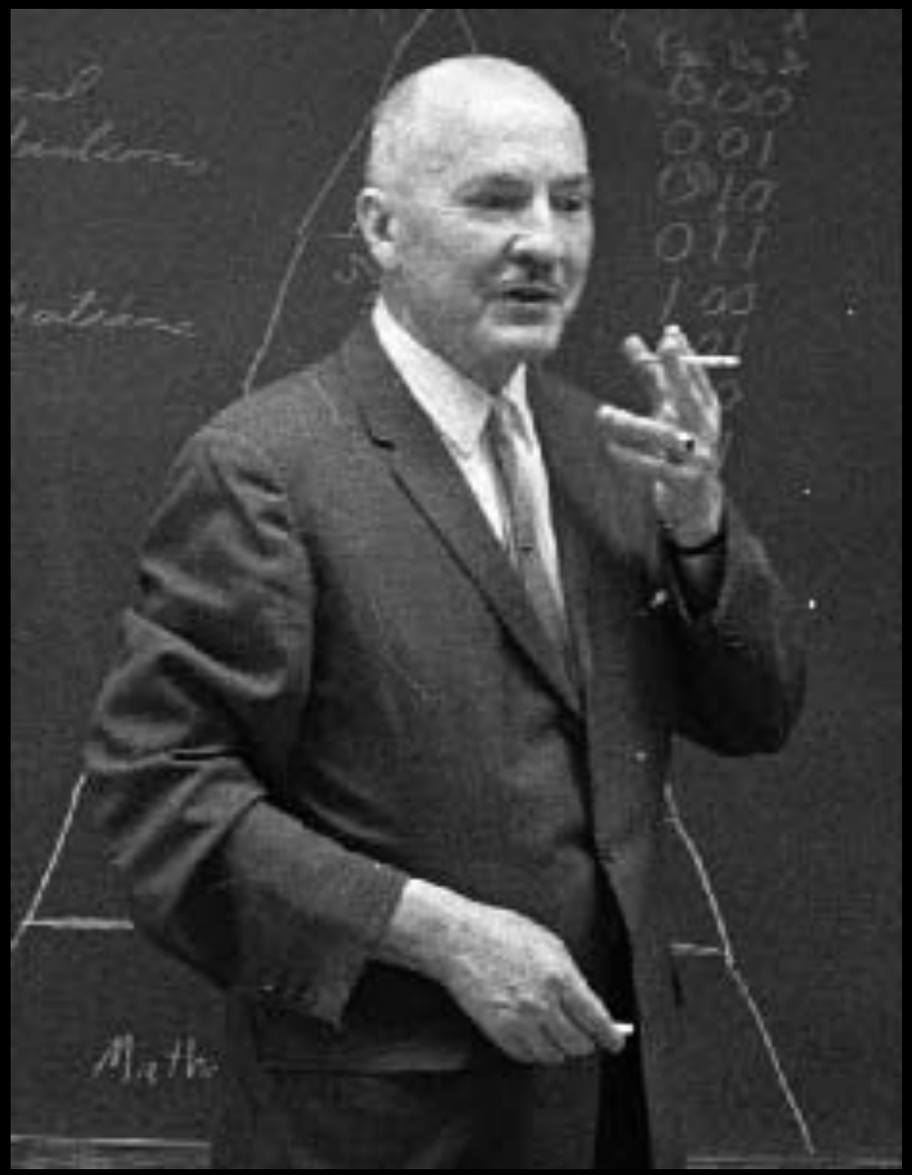


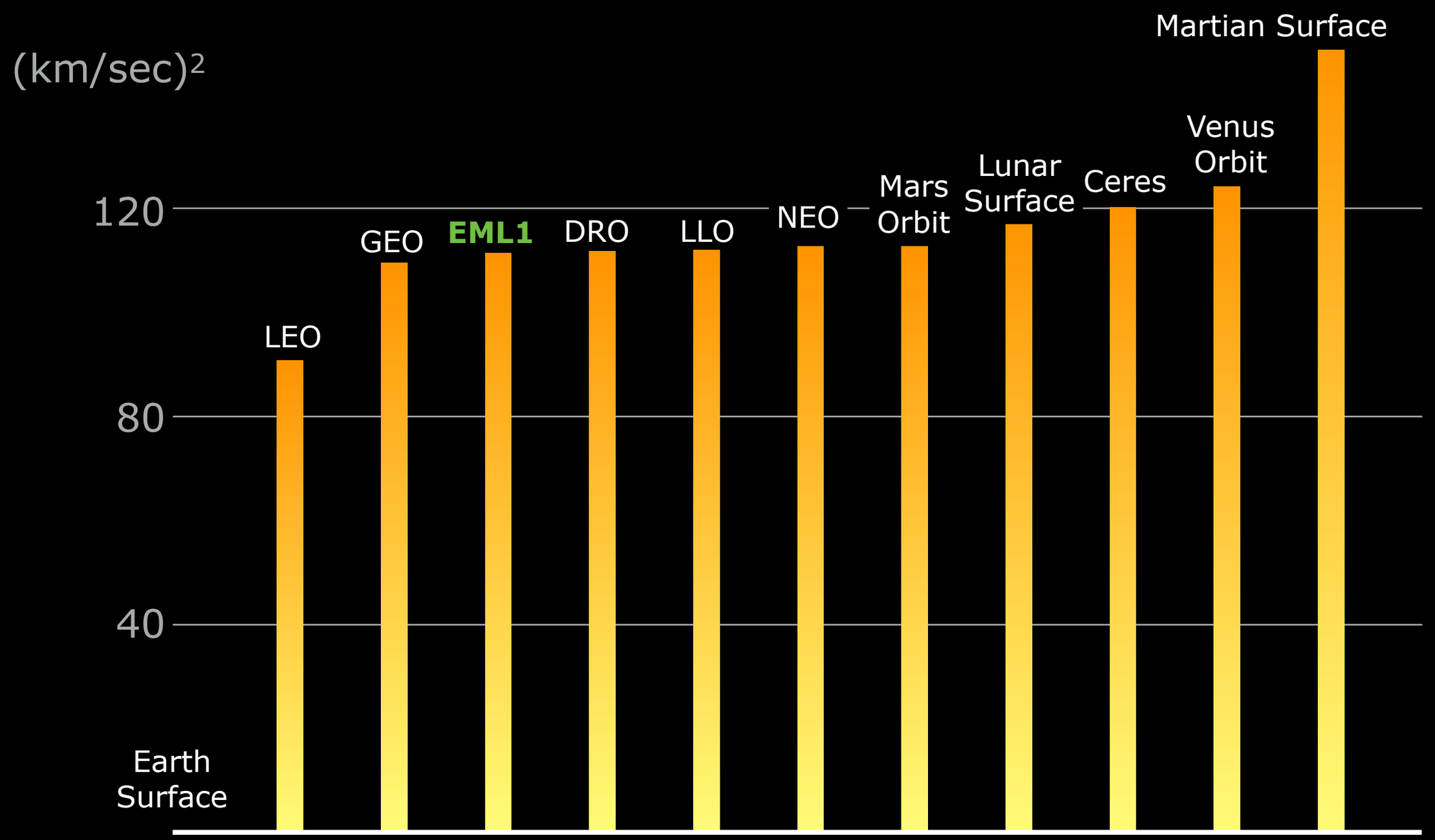
Halfway to Anywhere



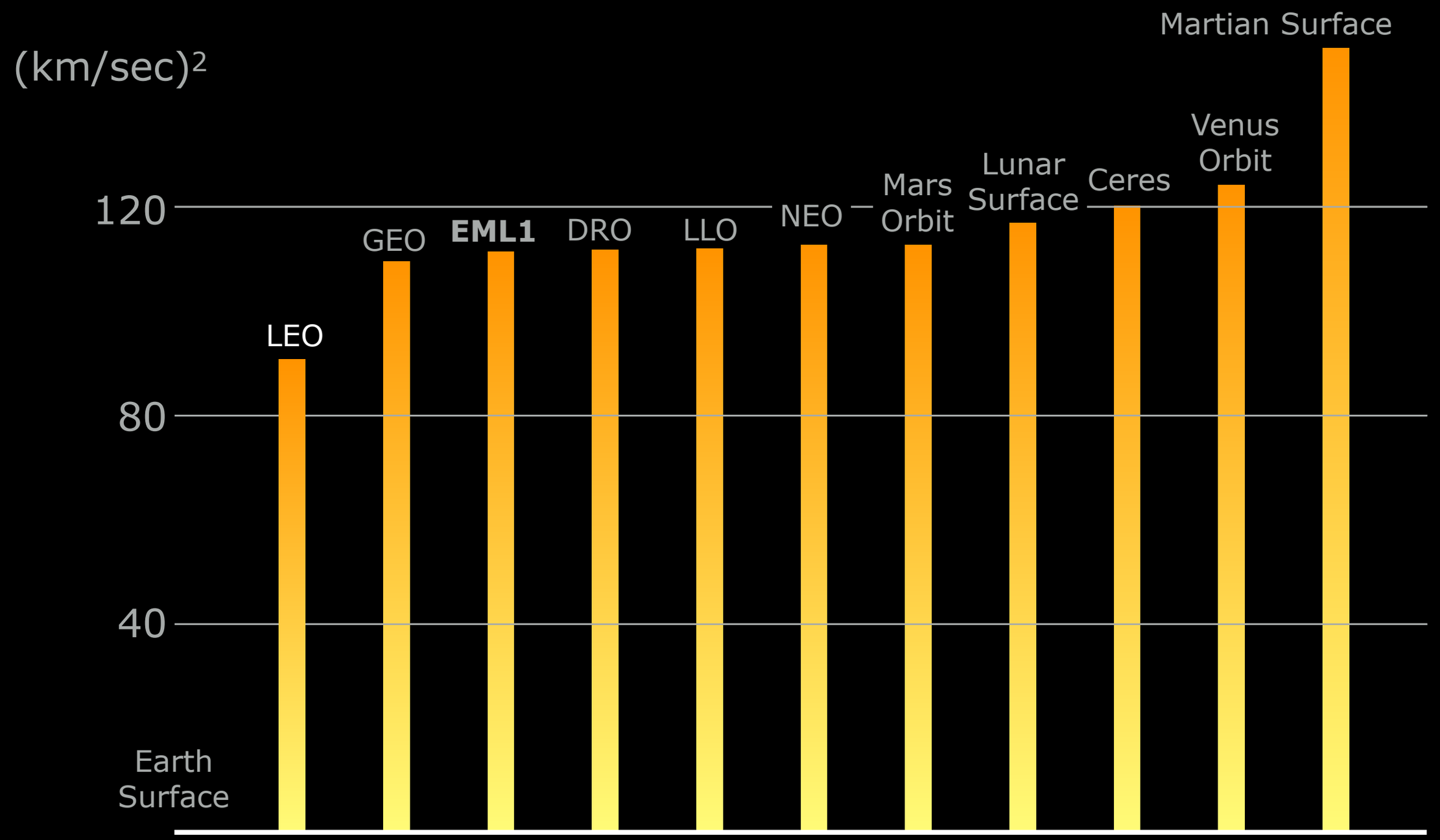
"Reach low orbit, and you're halfway to anywhere in the Solar System."

—R.A. Heinlein

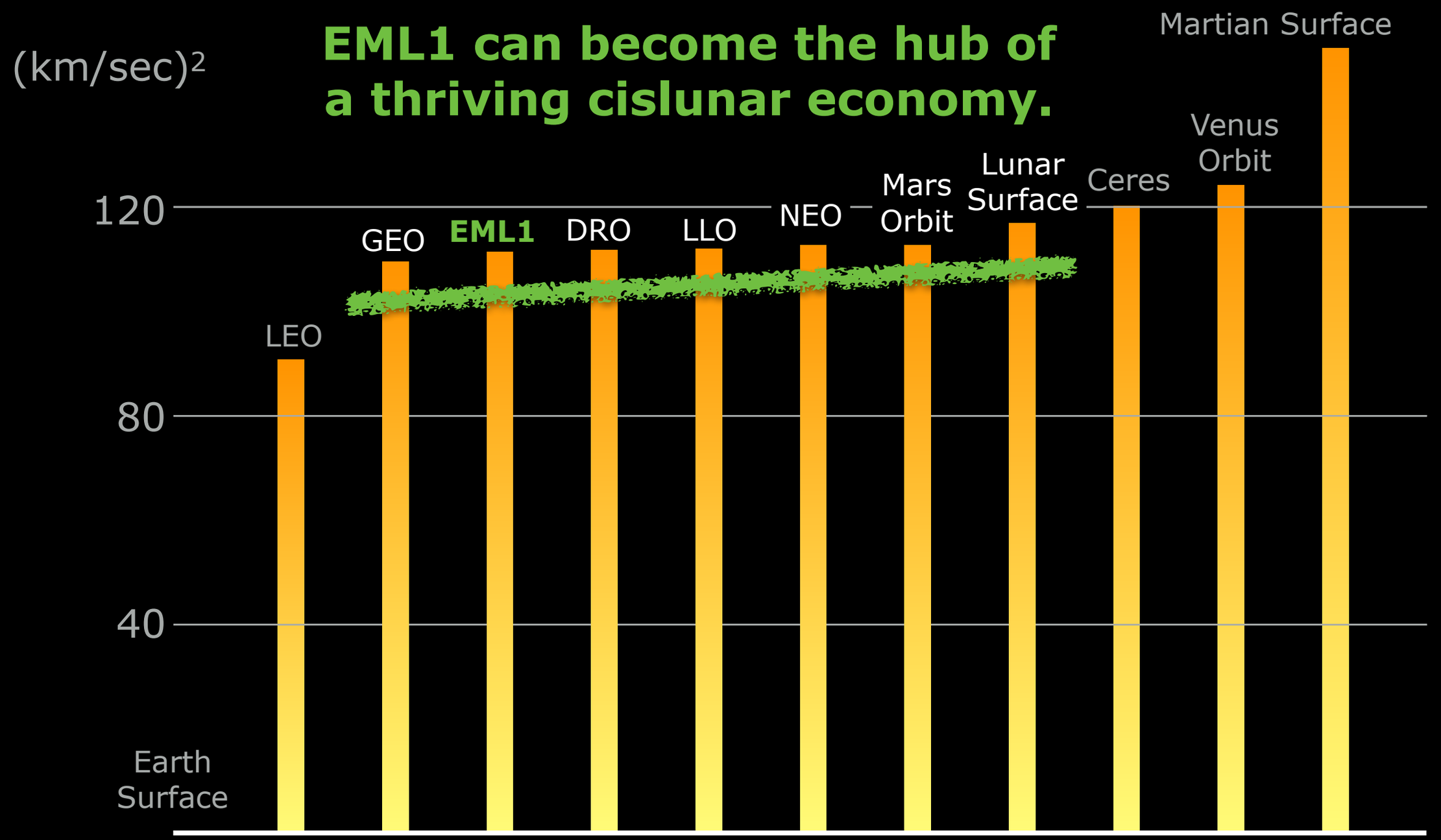
Orbital Energy Requirements: ΔV^2



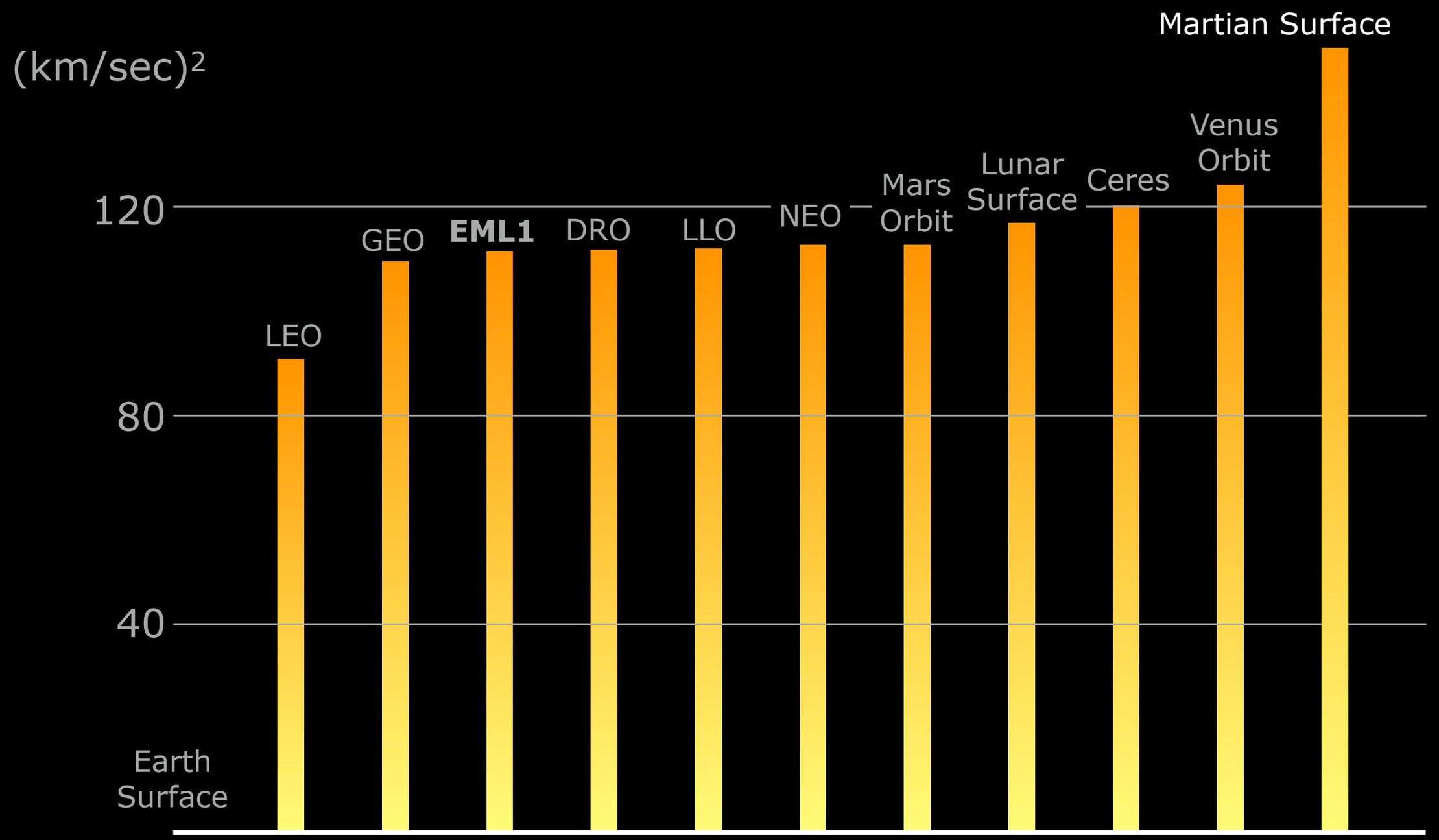
The First Step is a Doozy!



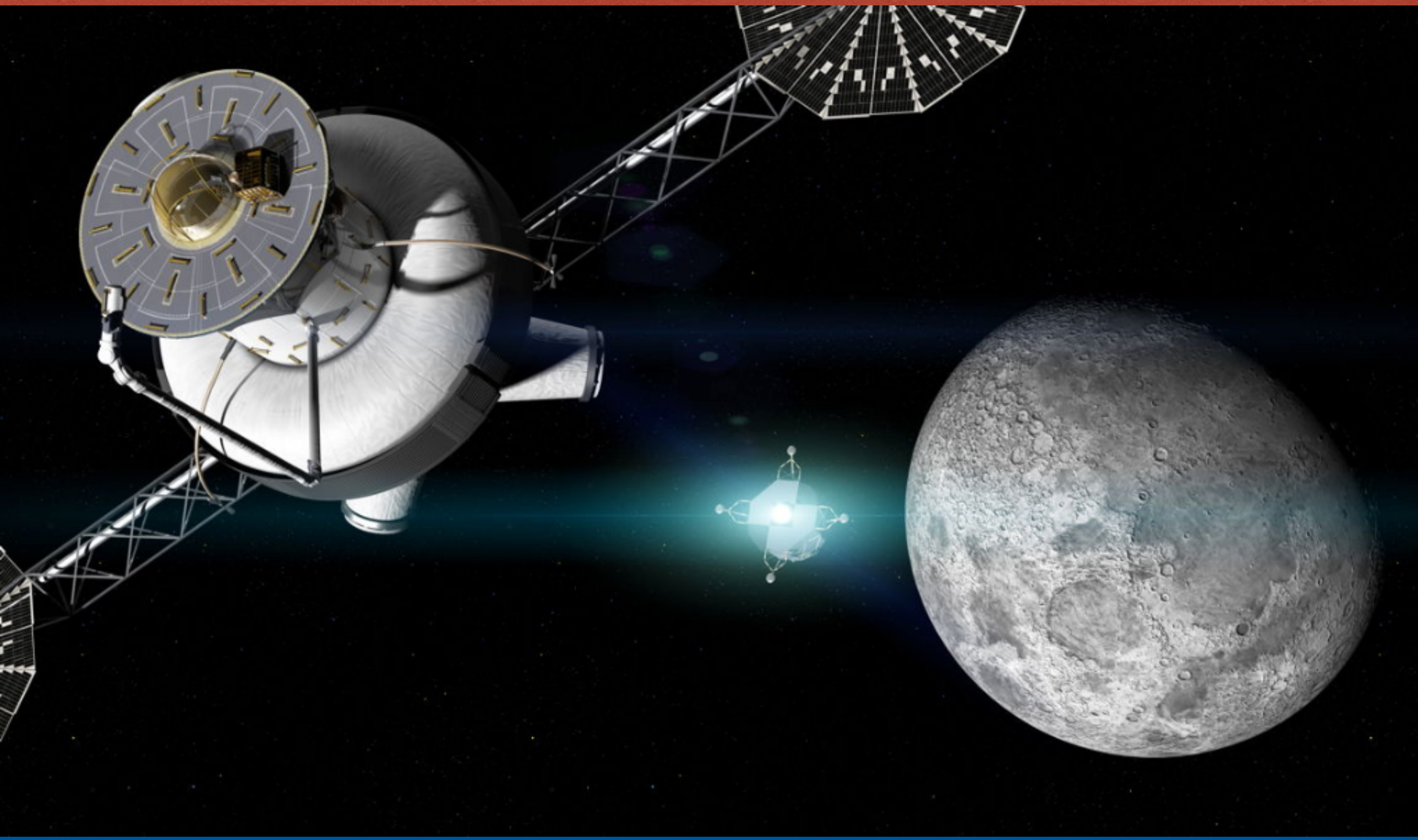
The Flat Spot is the Sweet Spot!



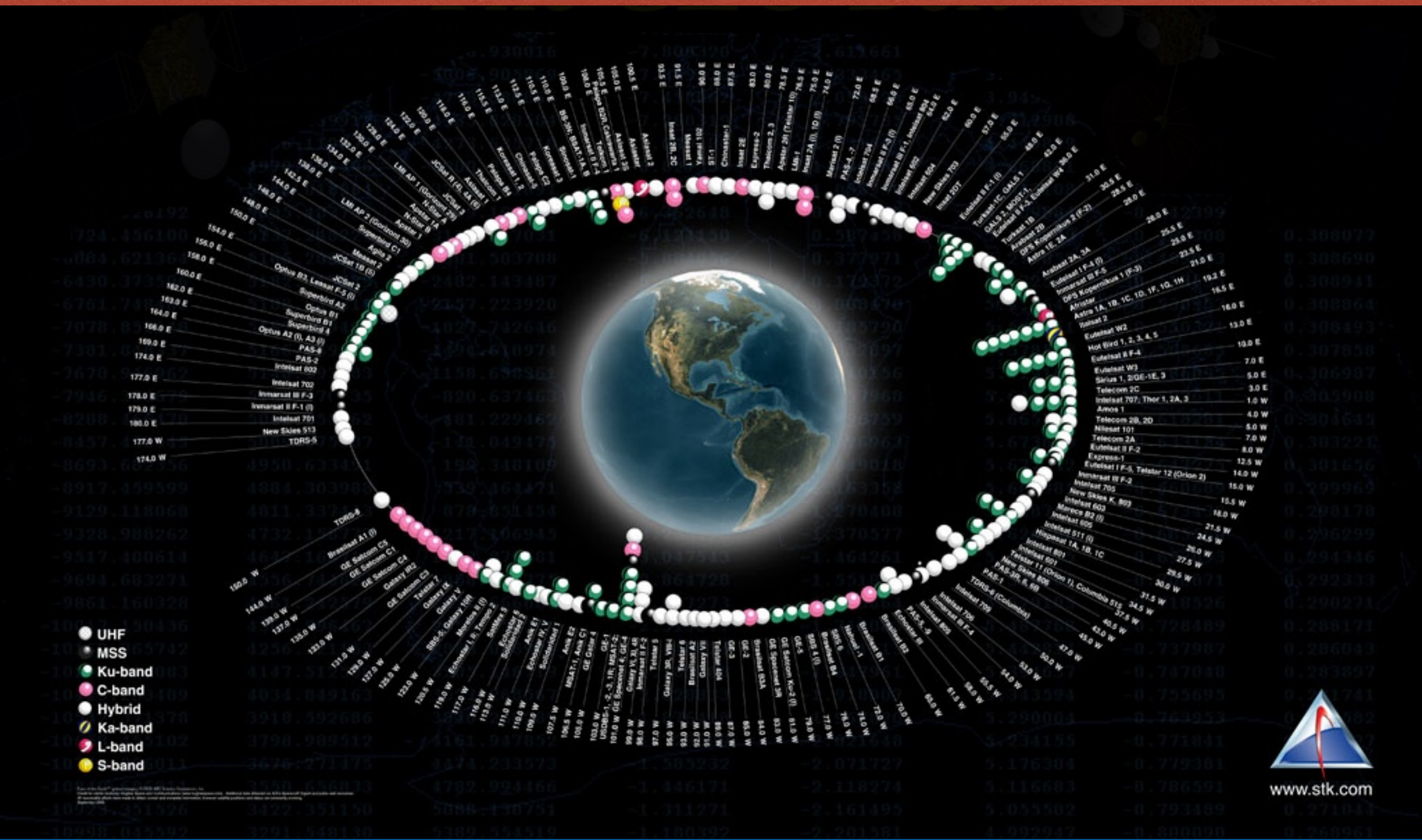
Why Mars Landings Should Wait…



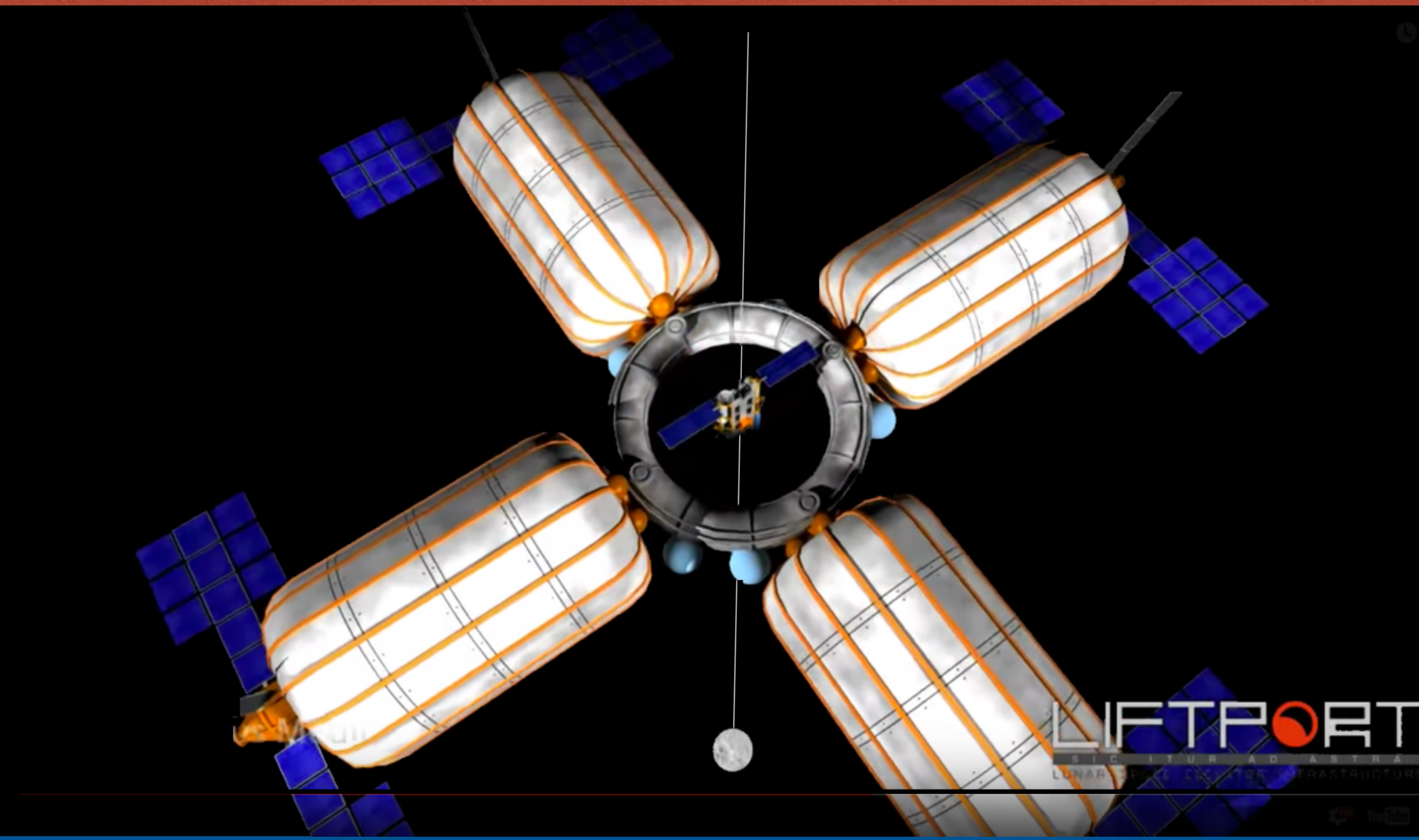
EML1 Station: Access to Deep Space



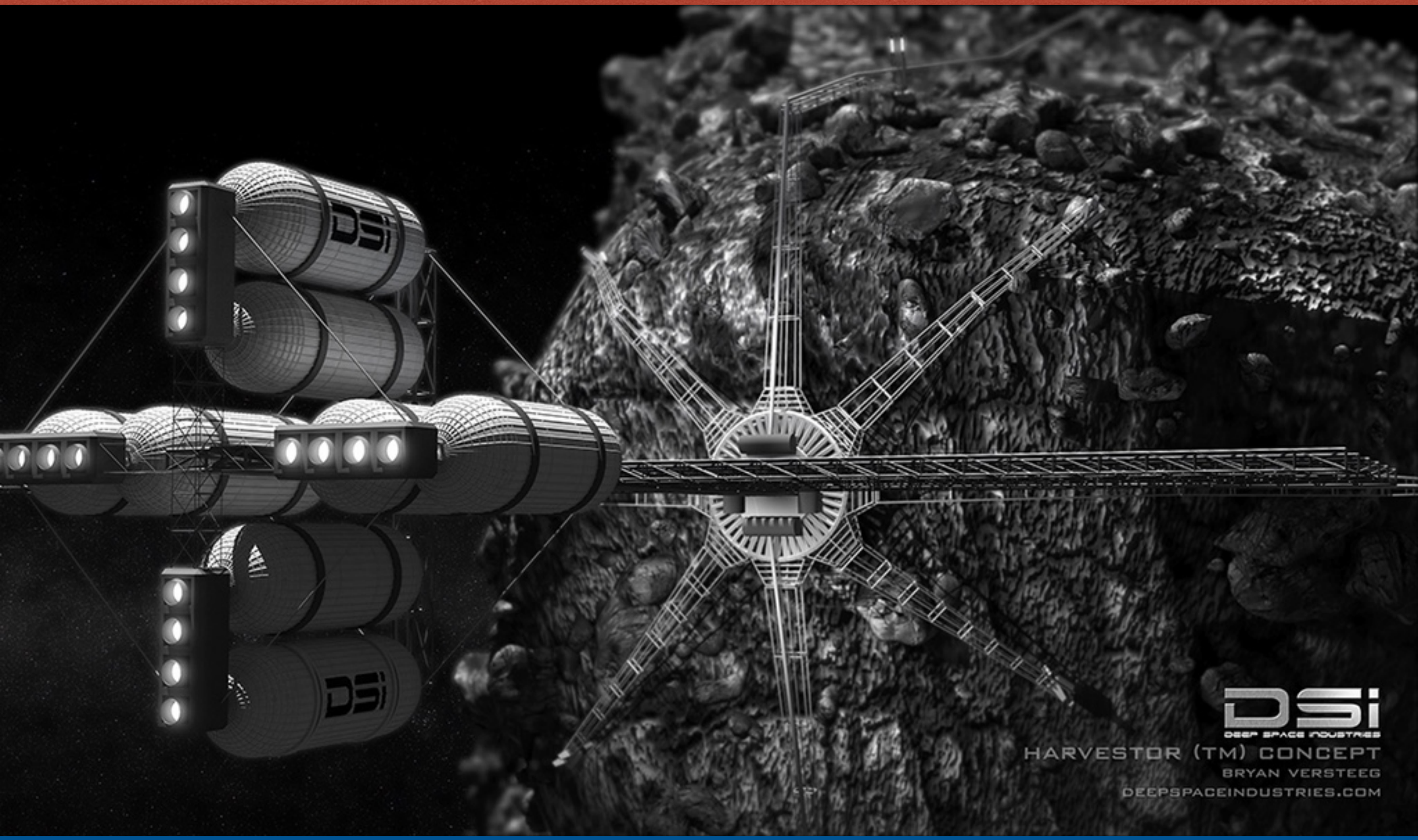
EML1: Geosync Satellite Servicing



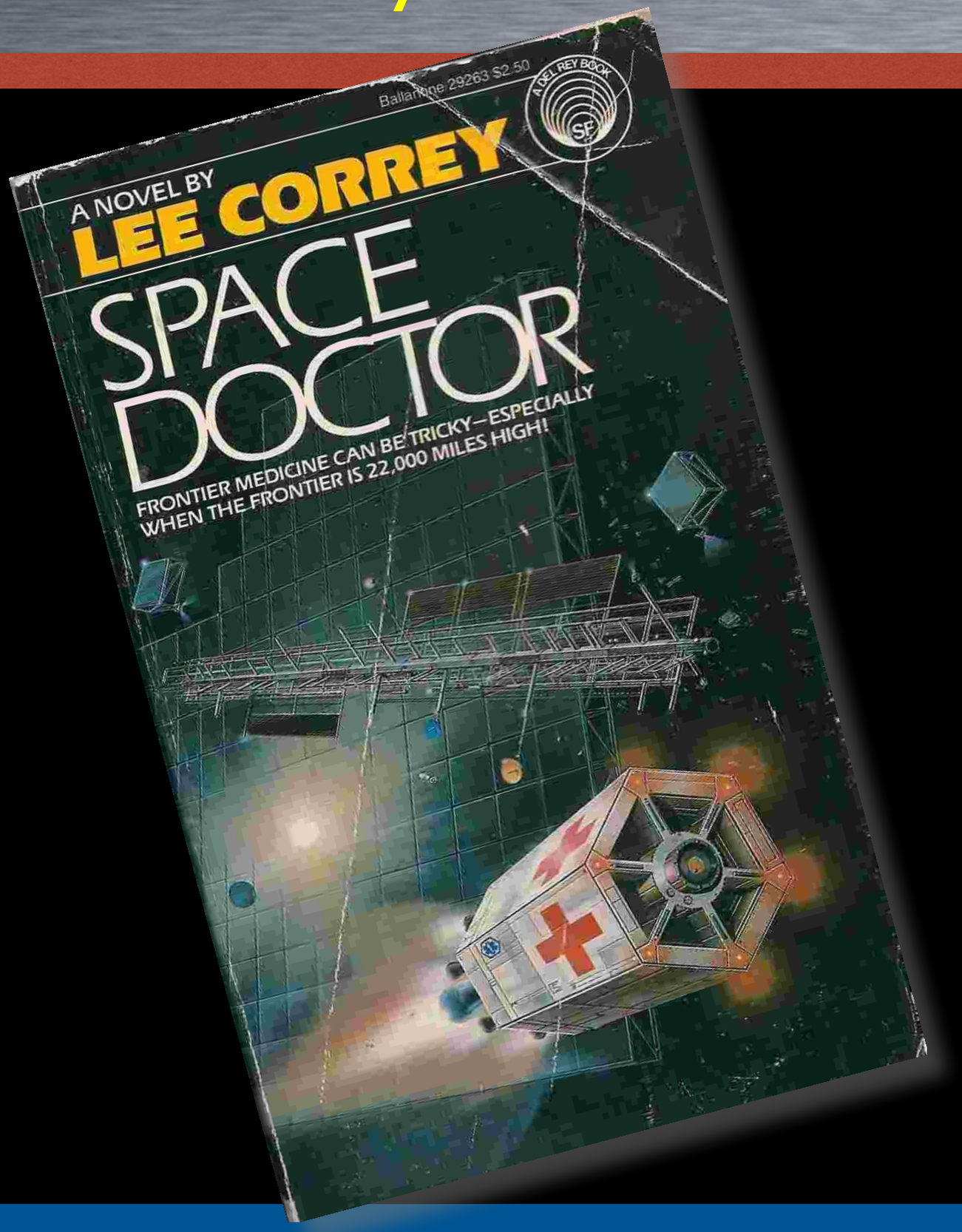
EML1: Midpoint for Lunar Elevator



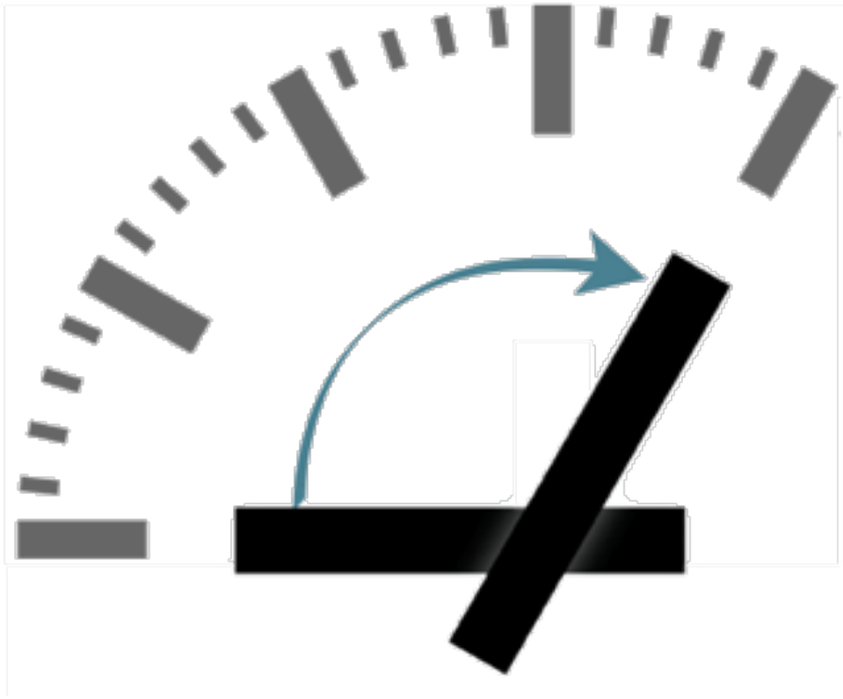
EML1: Staging Point for Asteroids



EML1: Three Days from Home!



Agenda



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NASA Space Launch System (SLS)

Between $2-5 billion per launch

Hopefully launching next week! (Aug 2022)

NASA Altair Lander *(cancelled)*

NASA Lunar Gateway

Purpose: **to give SLS someplace to go**

Falcon Heavy *(first launched 2018)*

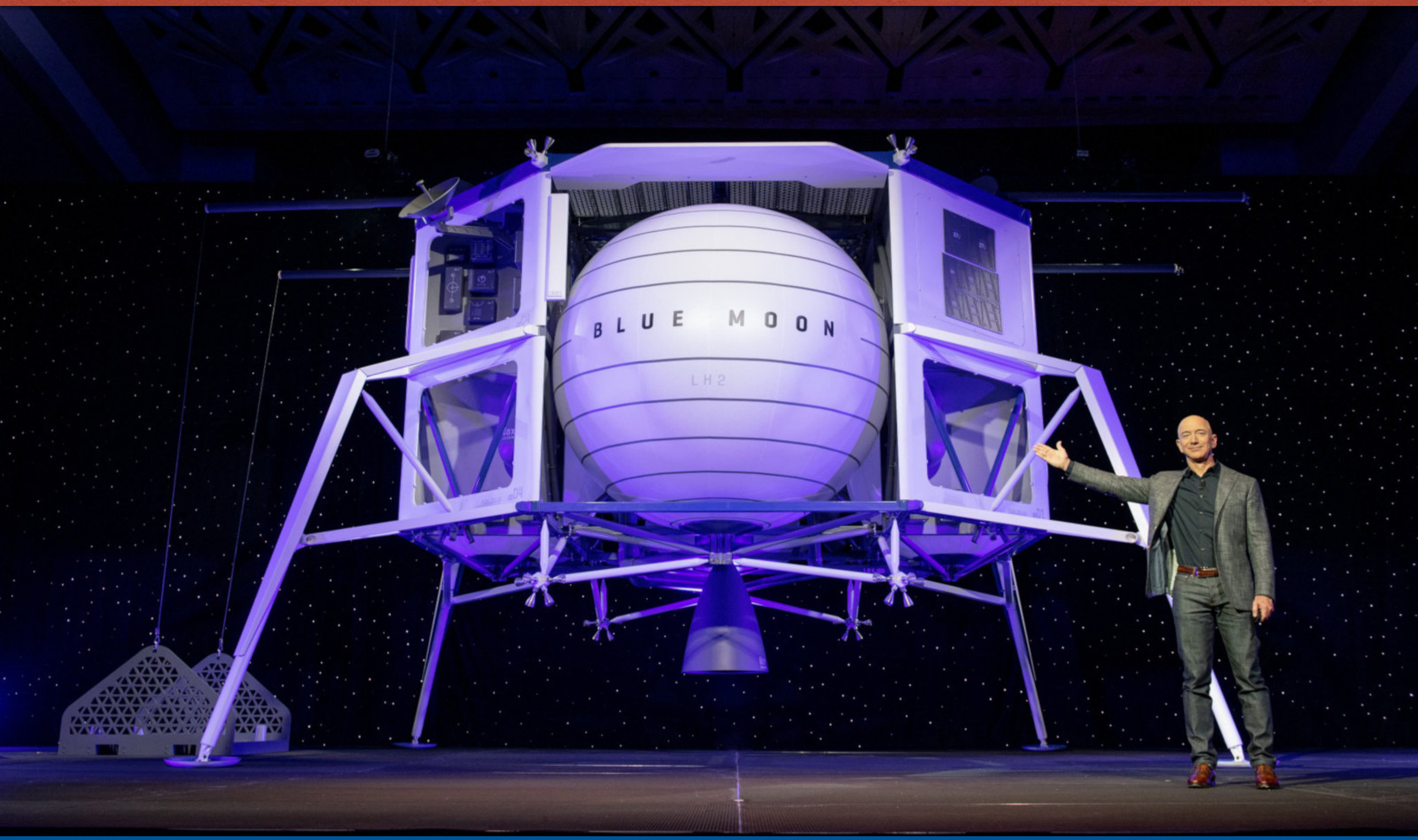
Approx. $90 million per launch

Falcon Heavy *(first launched 2018)*

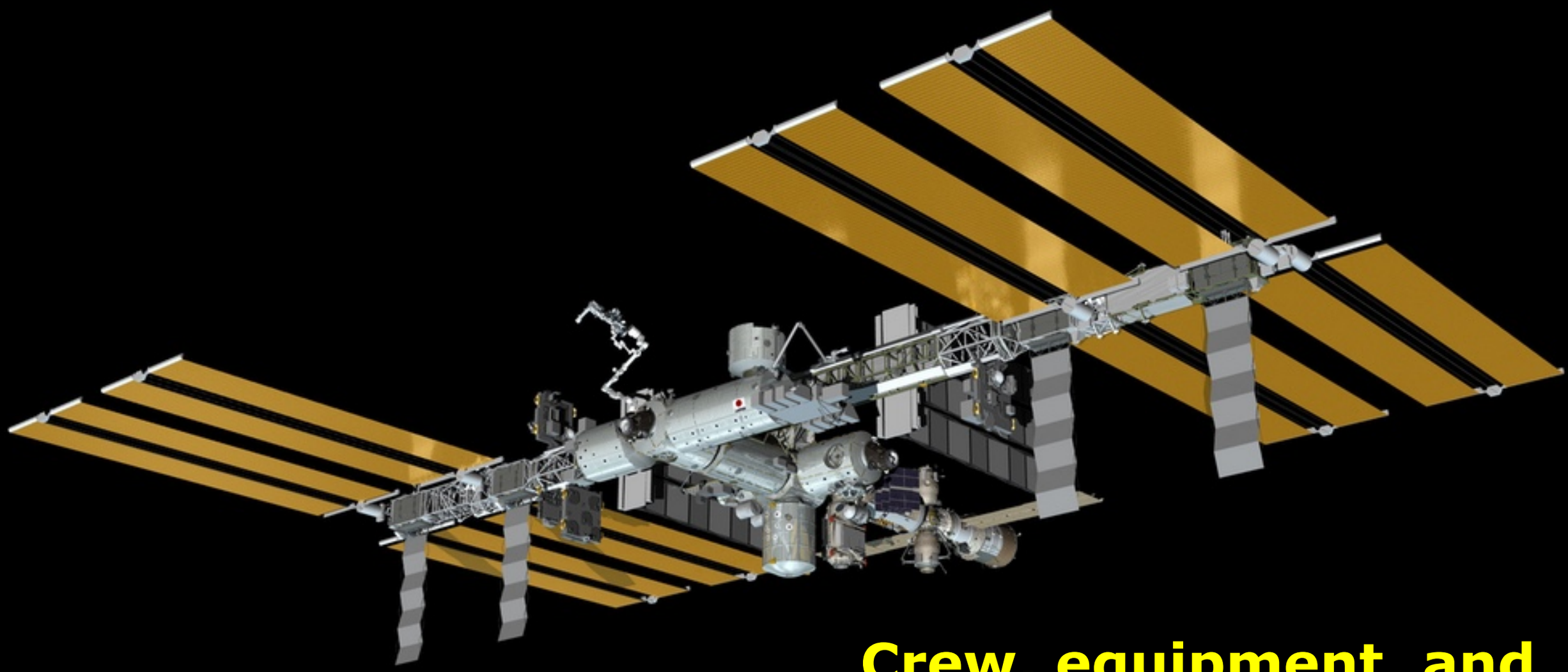
SpaceX Starship

New Glenn *(first launch in 2023?)*

Blue Moon



Assemble Missions in Orbit



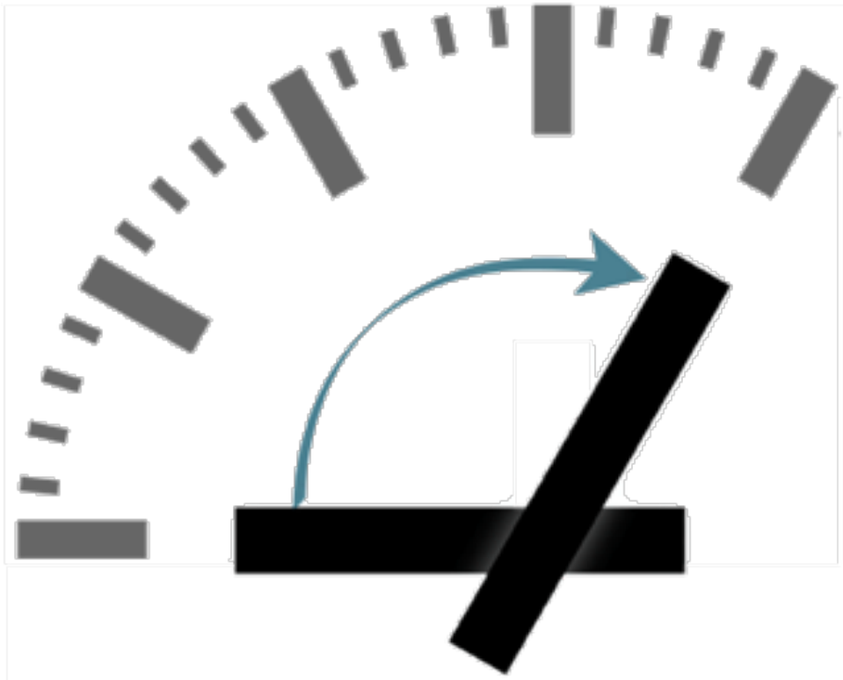
Crew, equipment, and propellant may all be launched separately.

We Need to Go Back to the Moon!

If God wanted man to become a spacefaring species, He would have given Earth a moon.

—Krafft Ehricke

Agenda



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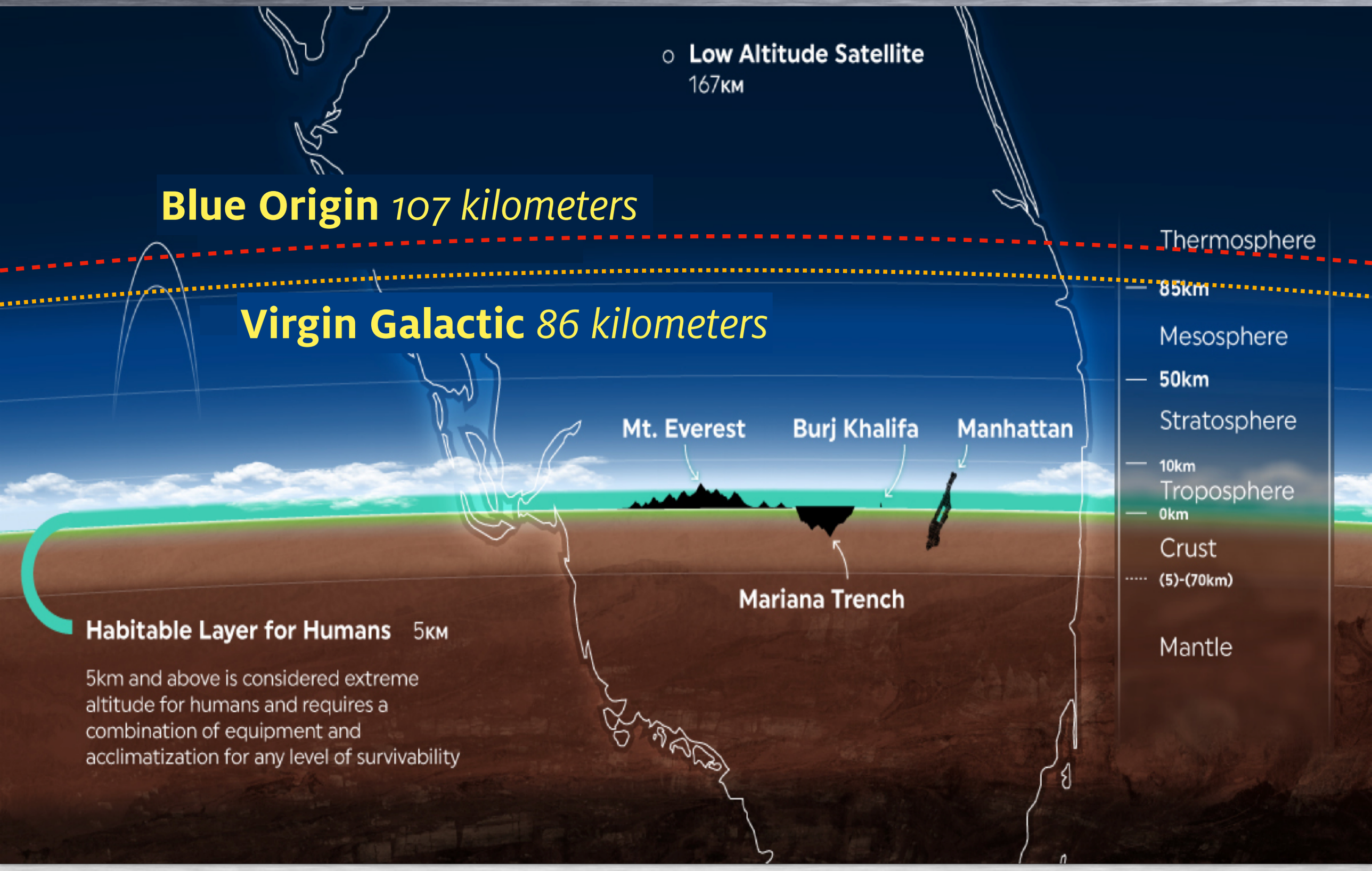
Virgin Galactic *12 July 2021*

Blue Origin *20 July 2021*

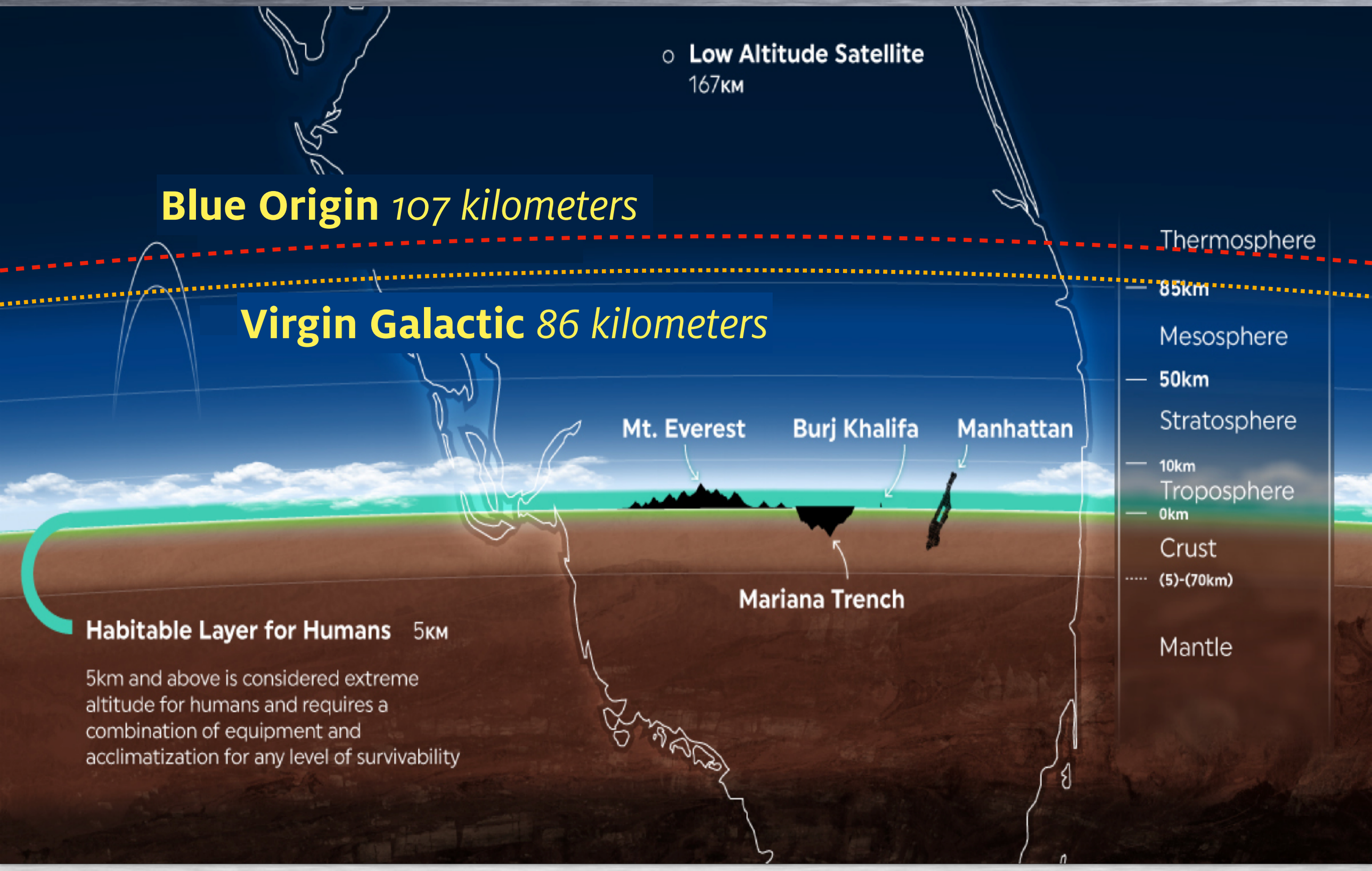
Did They Go to Space?



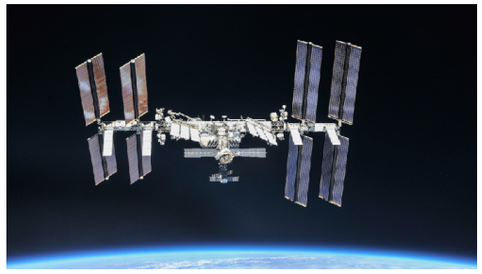
Did They Go to *Orbit?*

Blue Origin *107 kilometers*

Virgin Galactic *86 kilometers*



Comparison of Velocities



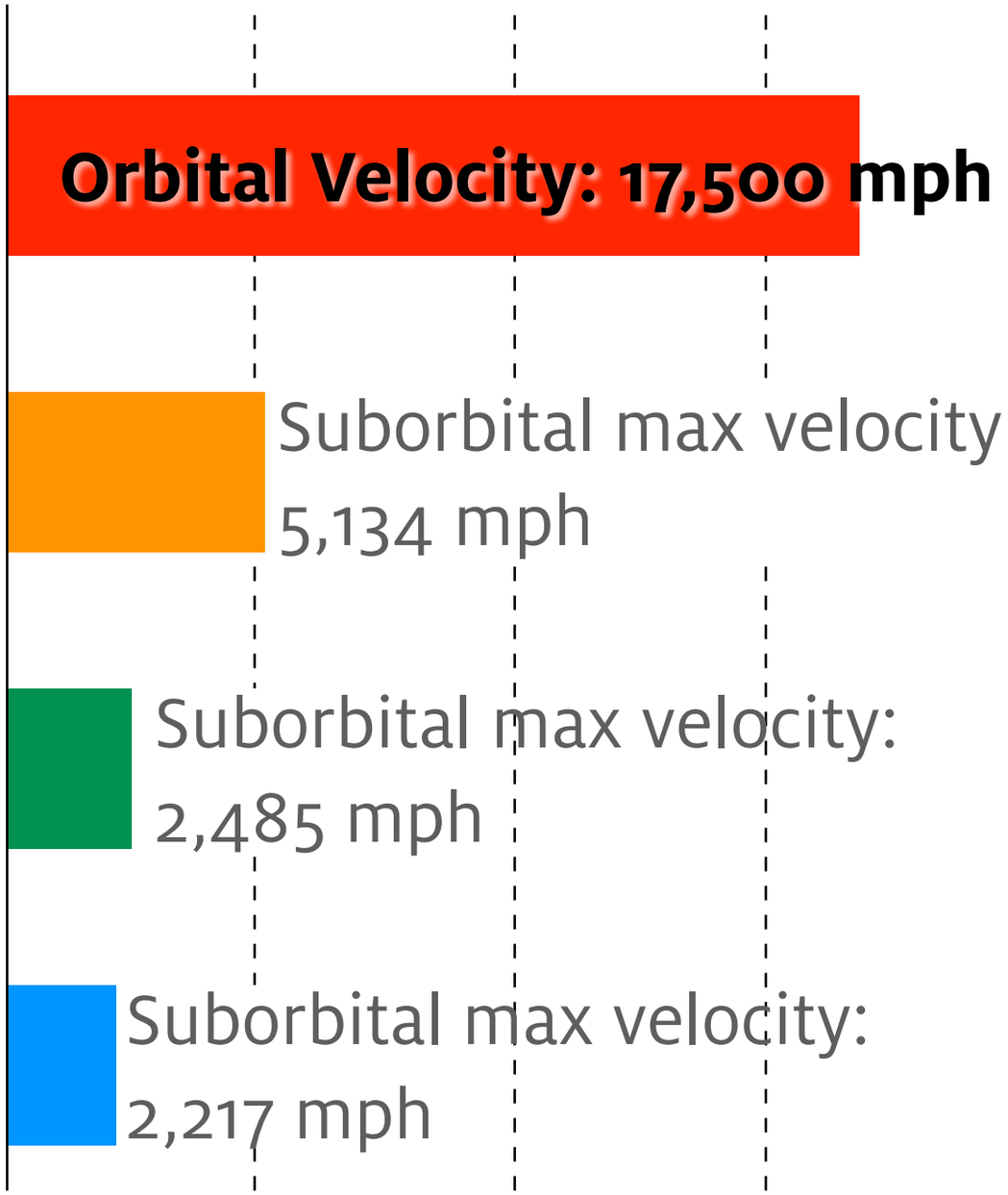
International Space Station

Alan Shepard, suborbital flight, 1961

Virgin Galactic "Spaceship Two"

Only ~14% of orbital velocity

Blue Origin "New Shepard"

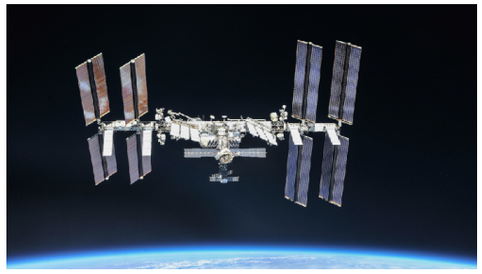


But… what about Kinetic Energy?

$$KE = \frac{1}{2} mv^2$$

Kinetic energy grows as the *square* of the velocity!

Comparison of Kinetic Energies



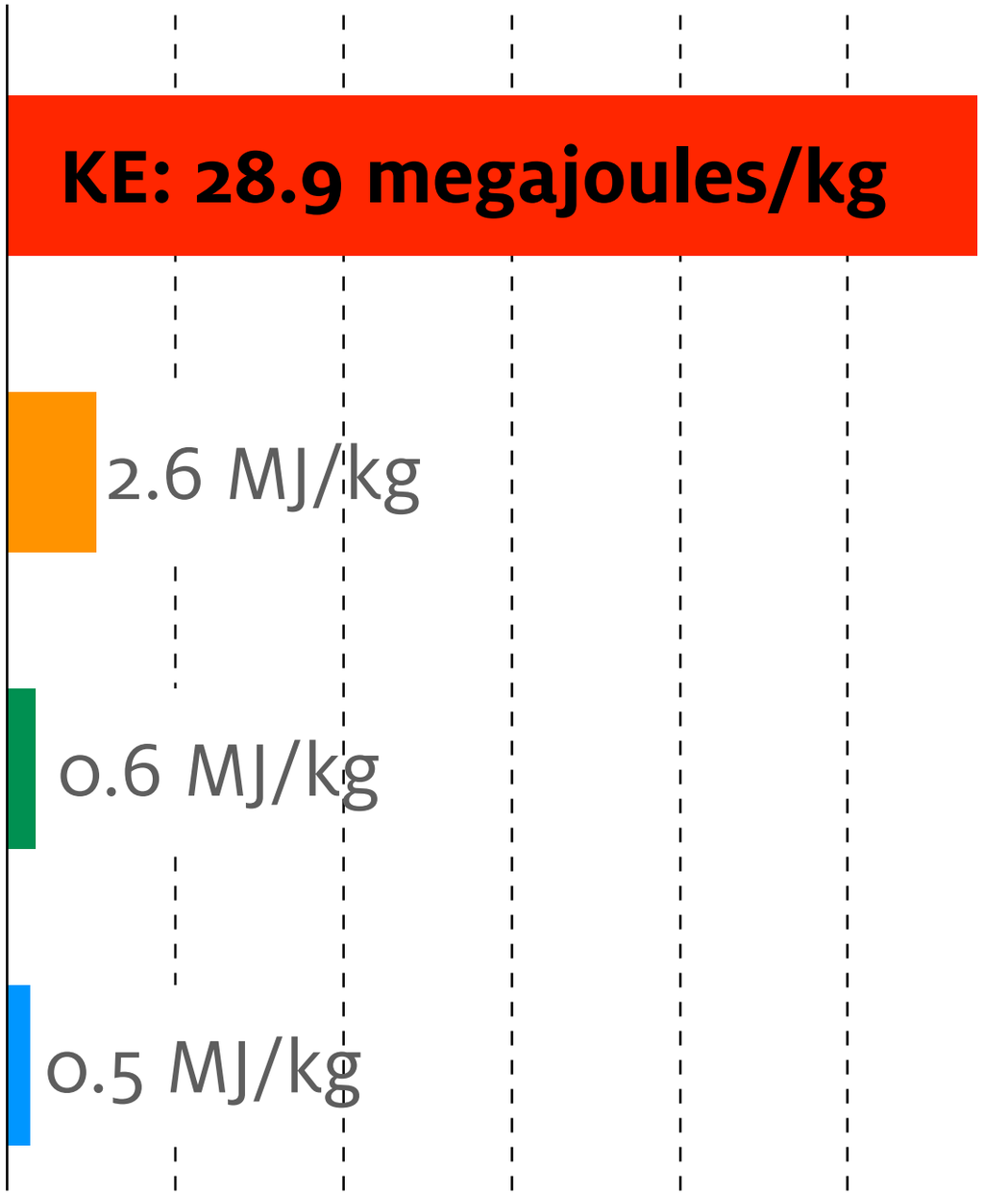
International Space Station

Alan Shepard, suborbital flight, 1961

Virgin Galactic "Spaceship Two"

Only ~2% of orbital ***energy***

Blue Origin "New Shepard"



Inspiration 4: *First private crew to orbit*

Inspiration 4

Inspiration 4 Crew

Dr. Sian Proctor

Hayley Arceneaux

Jared Isaacman

Chris Sembroski

Axiom Space: *First Private Visit to ISS*

SpaceX Makes it Look Routine

173 flights, now flying about 1/week

Demonstrated 12x reuse on three different boosters

Starship Launch…

Starship Returning…

TESLARATI
Richard Angle

...and Starship Landing

Booster Stacked and… Ready to Fly?

Starship

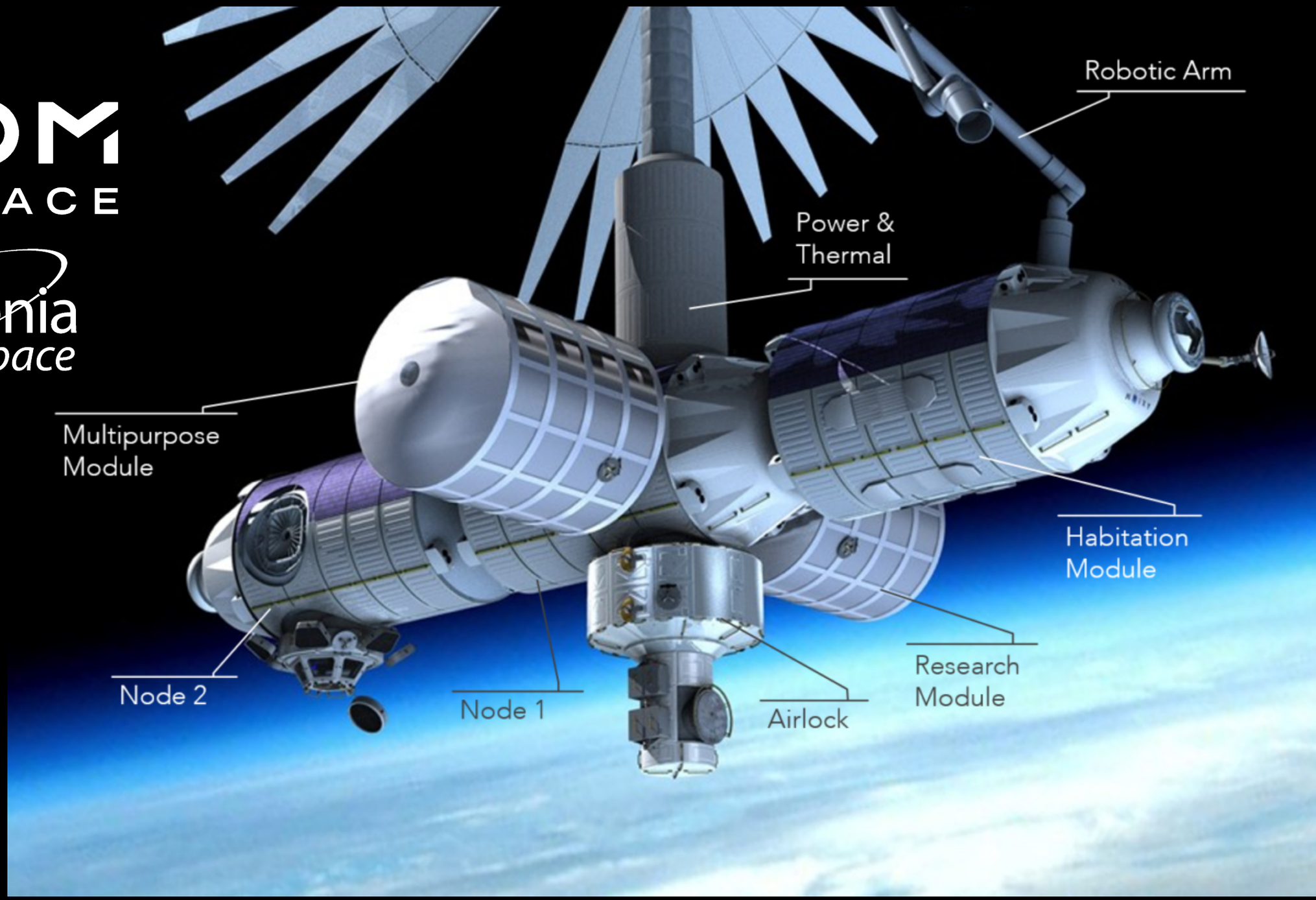
Sierra Space DreamChaser

Axiom Station

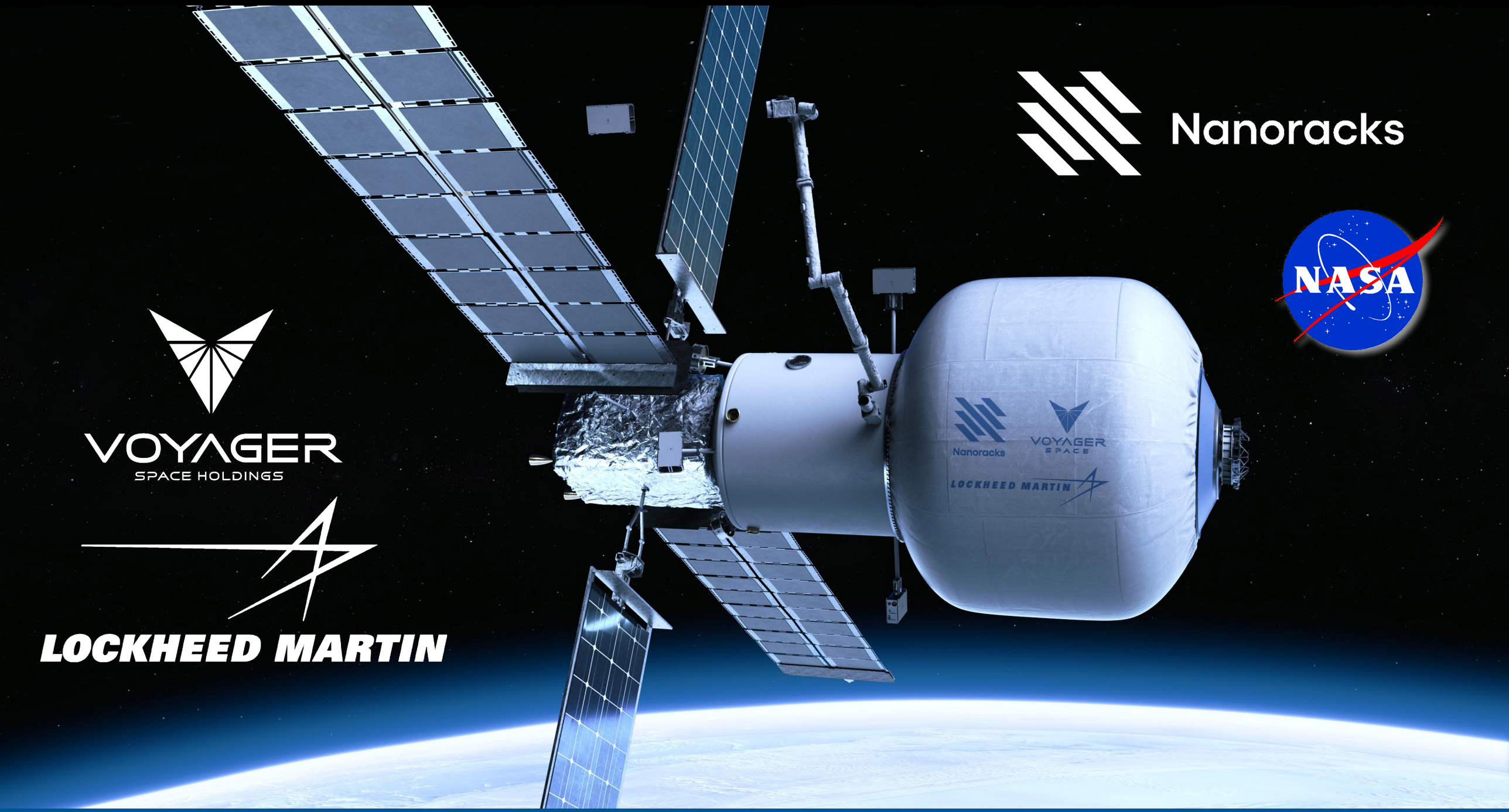
AXIOM SPACE

ThalesAlenia Space
A Thales / Finmeccanica Company

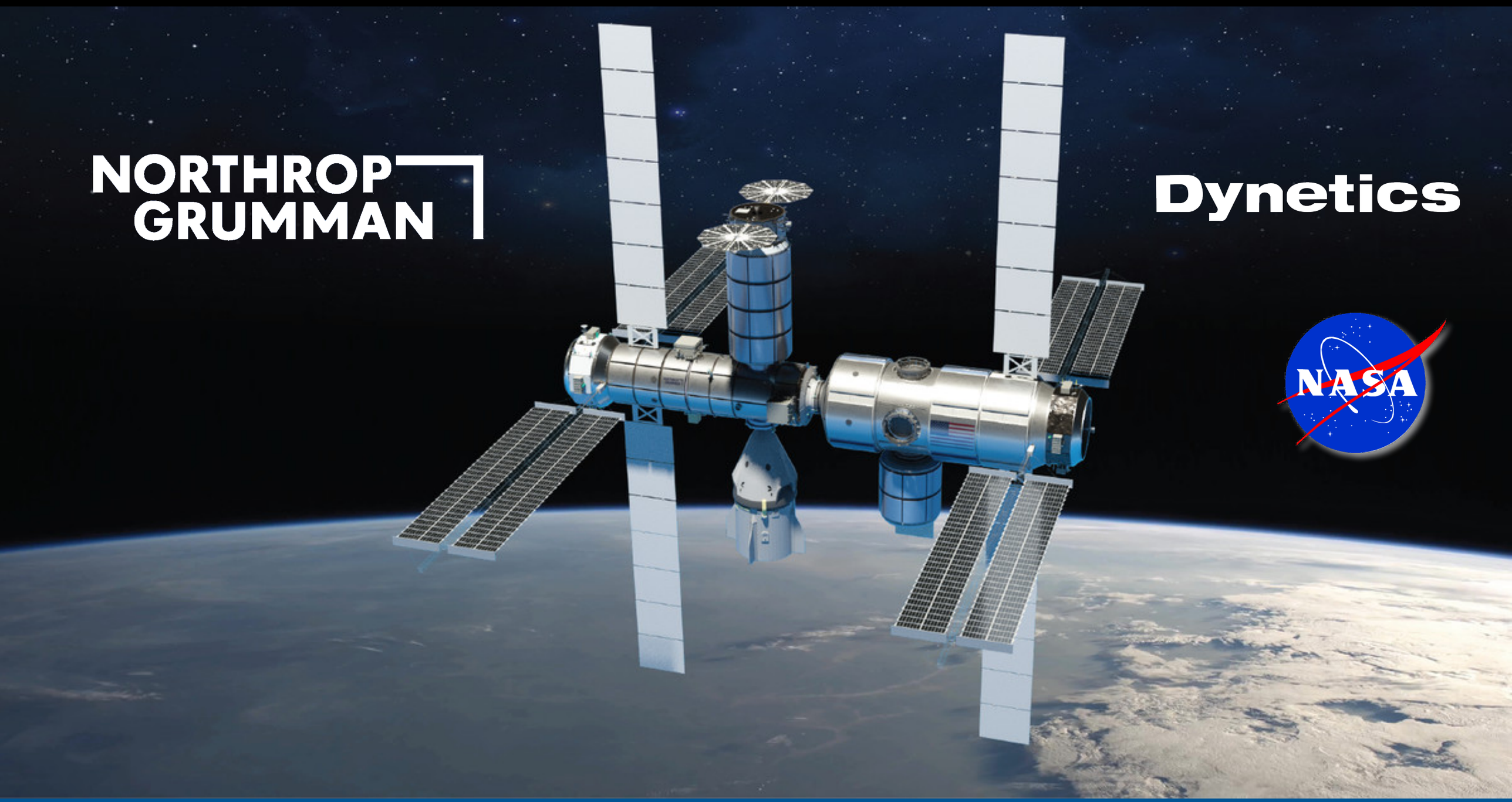
NASA



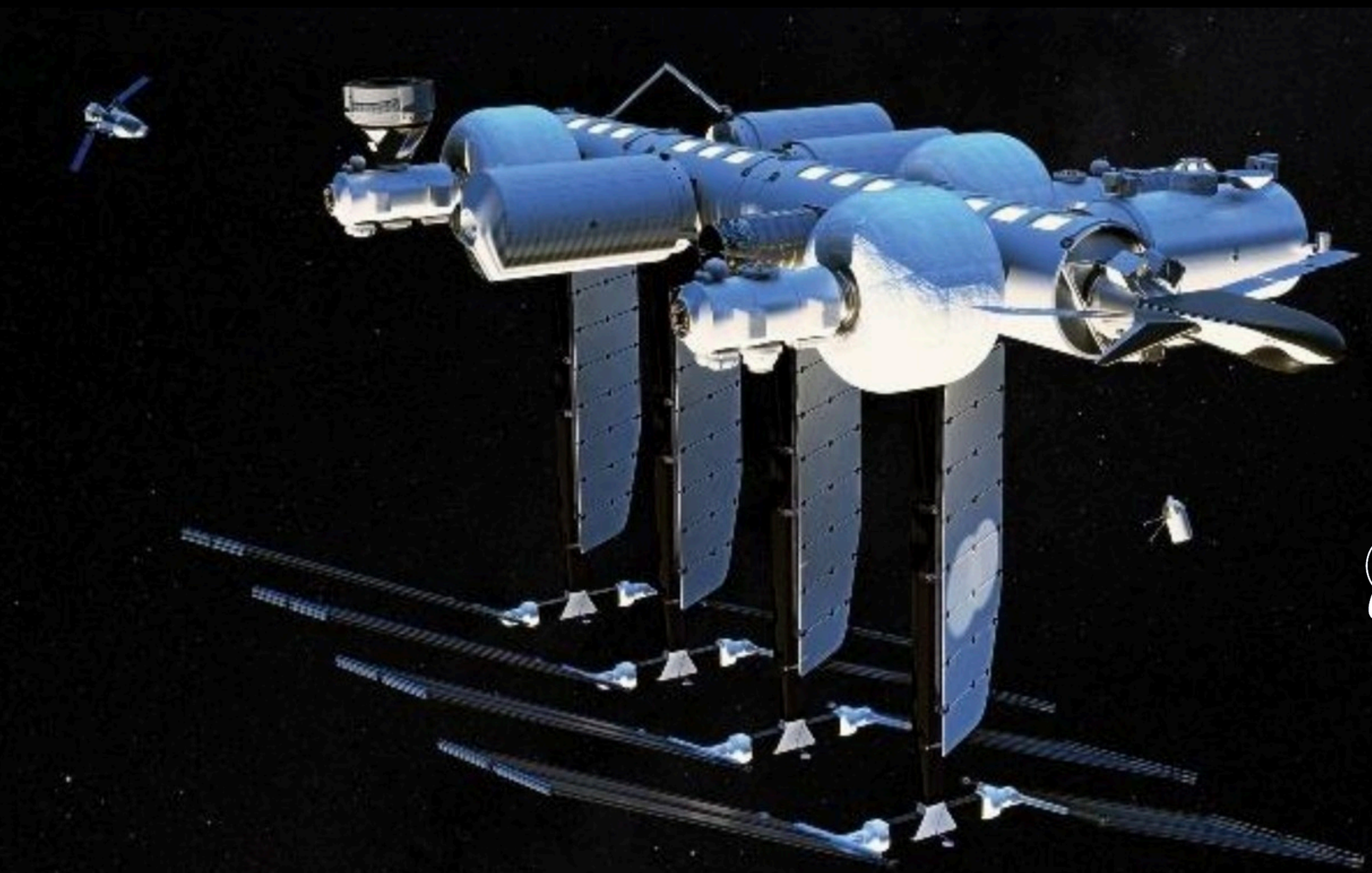
Nanoracks Starlab



Northrop Grumman Commercial Station



Orbital Reef



SIERRA

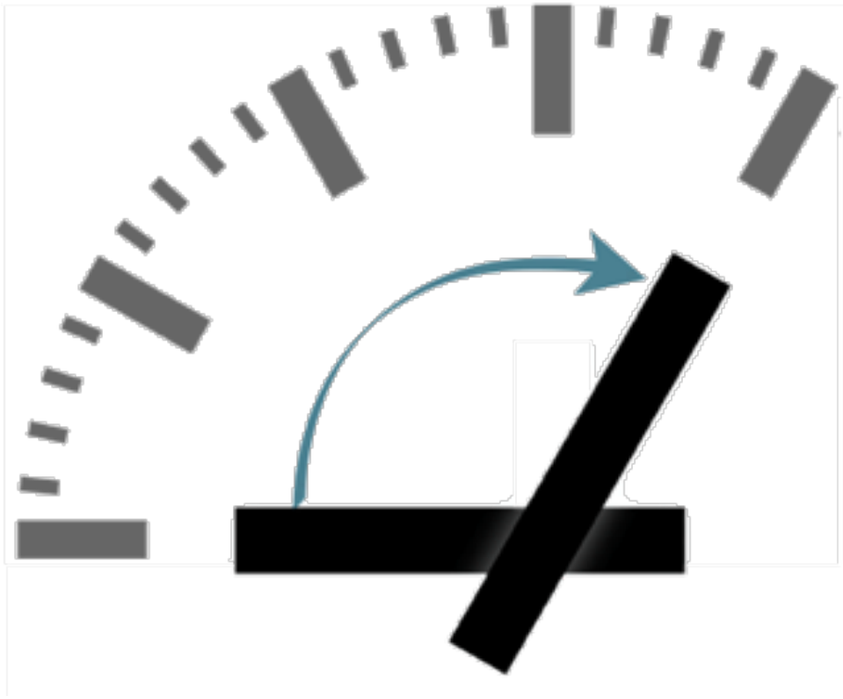
REDWIRE

BLUE ORIGIN

BOEING

MITSUBISHI HEAVY INDUSTRIES

Agenda



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Thank You!

Stephen Fleming
University of Arizona

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Twitter @stephenfleming