


The background of the slide is a composite image of space. In the upper right, the Moon is shown in a full phase. In the lower right, the reddish, cratered surface of Mars is visible. On the left side, the blue and white horizon of Earth is seen. The rest of the background is a dark field of stars.

# **New Frontiers: Multidisciplinary Research Challenges in Space Exploration & Future Communities**

**Josh Arceneaux  
November 9, 2023**


A composite image of Earth, the Moon, and Mars in space. Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark field of stars.

*The views and opinions expressed in this presentation and seminar are those of the author and do not necessarily reflect the official policy, opinion, or position of their employer.*

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A composite image of space exploration. The Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a starry black sky.

**Why is space exploration hard?**



238,900 miles  
6.5 days to get to the moon and back  
6.5 to 30 days surface duration  
Total mission duration of 14 to 36 days

33.9 million to 250 million miles  
15 to 18 months to get to Mars and back  
16+ months on the surface  
Total mission duration of 28 to 34 months



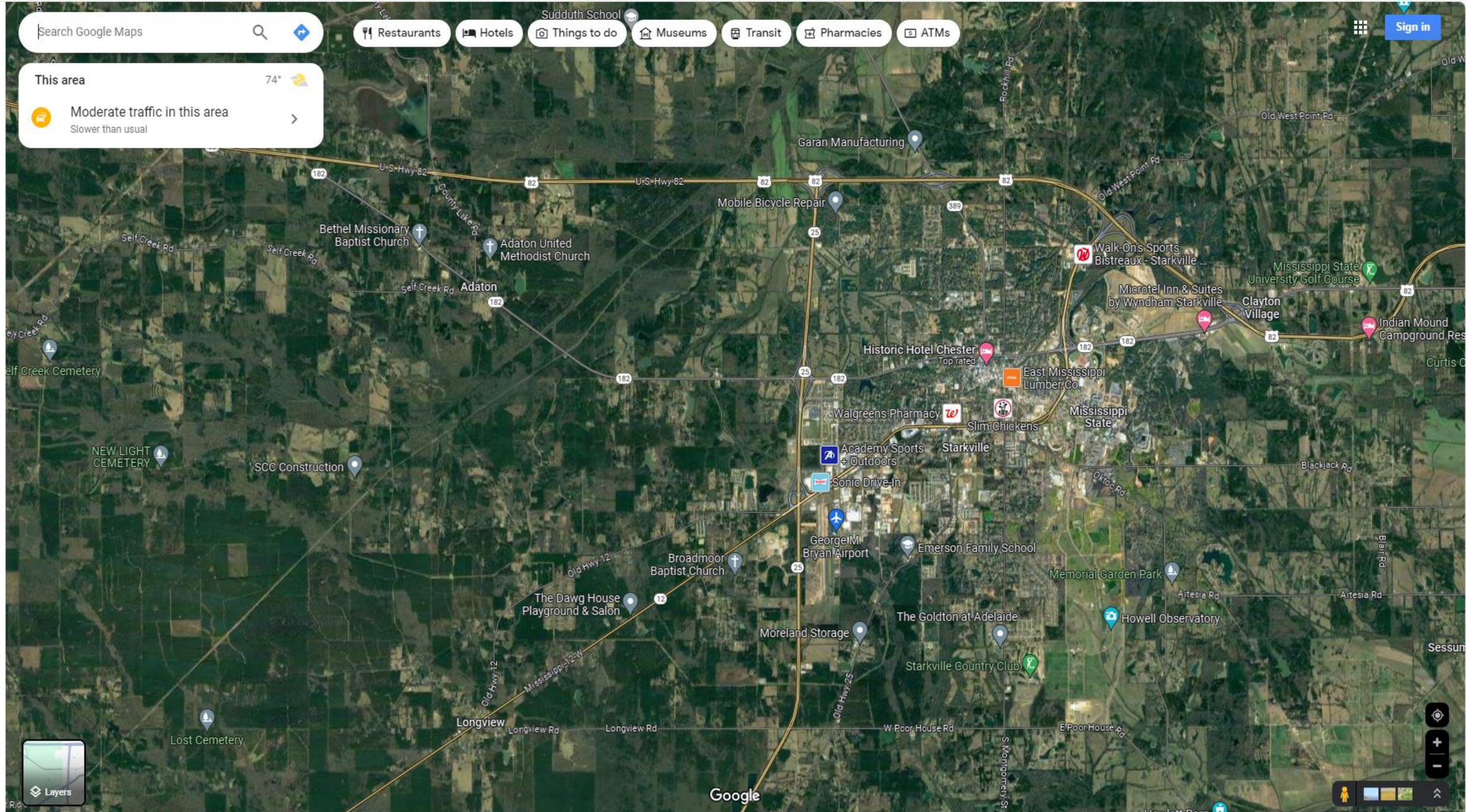
Search Google Maps

- Restaurants
- Hotels
- Things to do
- Museums
- Transit
- Pharmacies
- ATMs

Sign in

**This area** 74°

Moderate traffic in this area  
Slower than usual



Search Google Maps

- Restaurants
- Hotels
- Things to do
- Museums
- Transit
- Pharmacies
- ATMs

This area 74°

Moderate traffic in this area  
Slower than usual

Manufacturing

Garan Manufacturing

Mobile Bicycle Repair

Repair shops

Housing

Restaurants

Recreation

Hunting

Lodging

Materials

Roads

Healthcare

Education

Construction

Recreation and Sporting Supplies

Air Transportation

Water

Storage

Agriculture

SCC Construction

Mississippi State

George M. Bryan Airport

Moreland Storage





Supai, Arizona, USA



- Restaurants
- Hotels
- Things to do
- Museums
- Transit
- Pharmacies
- ATMs

Sign in

- Saved
- Recents

**Supai**  
Arizona 86435

Sunny · 72°F  
10:39 AM

- Directions
- Save
- Nearby
- Send to phone
- Share

- Supai
- New York
- Los Angeles

Supai is a census-designated place in Coconino County, Arizona, United States, within the Grand Canyon. As of the 2010 census, the CDP had a population of 208. The capital of the Havasupai Indian Reservation, Supai is the only place in the United States where mail is still carried in and out by mules. [Wikipedia](#)

### Iconic Supai

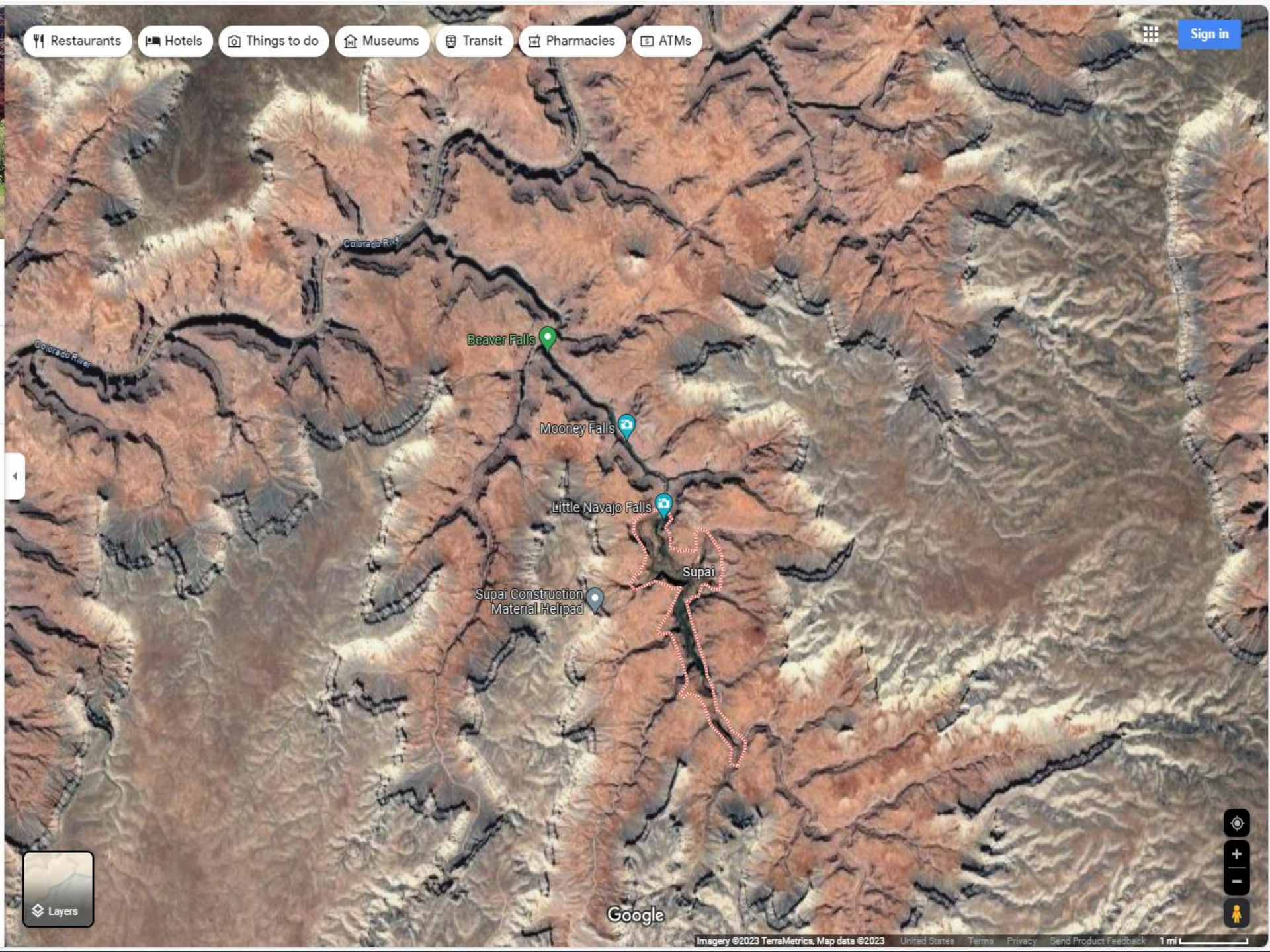
**Havasus Falls**  
4.5 ★ (570)

**Havasus Canyon**  
4.0 ★ (8)

**Havasus Canyon**  
No reviews

**Beaver Falls**  
4.8 ★ (95)

**Fifty Foot Falls**  
4.9 ★ (20)



Google

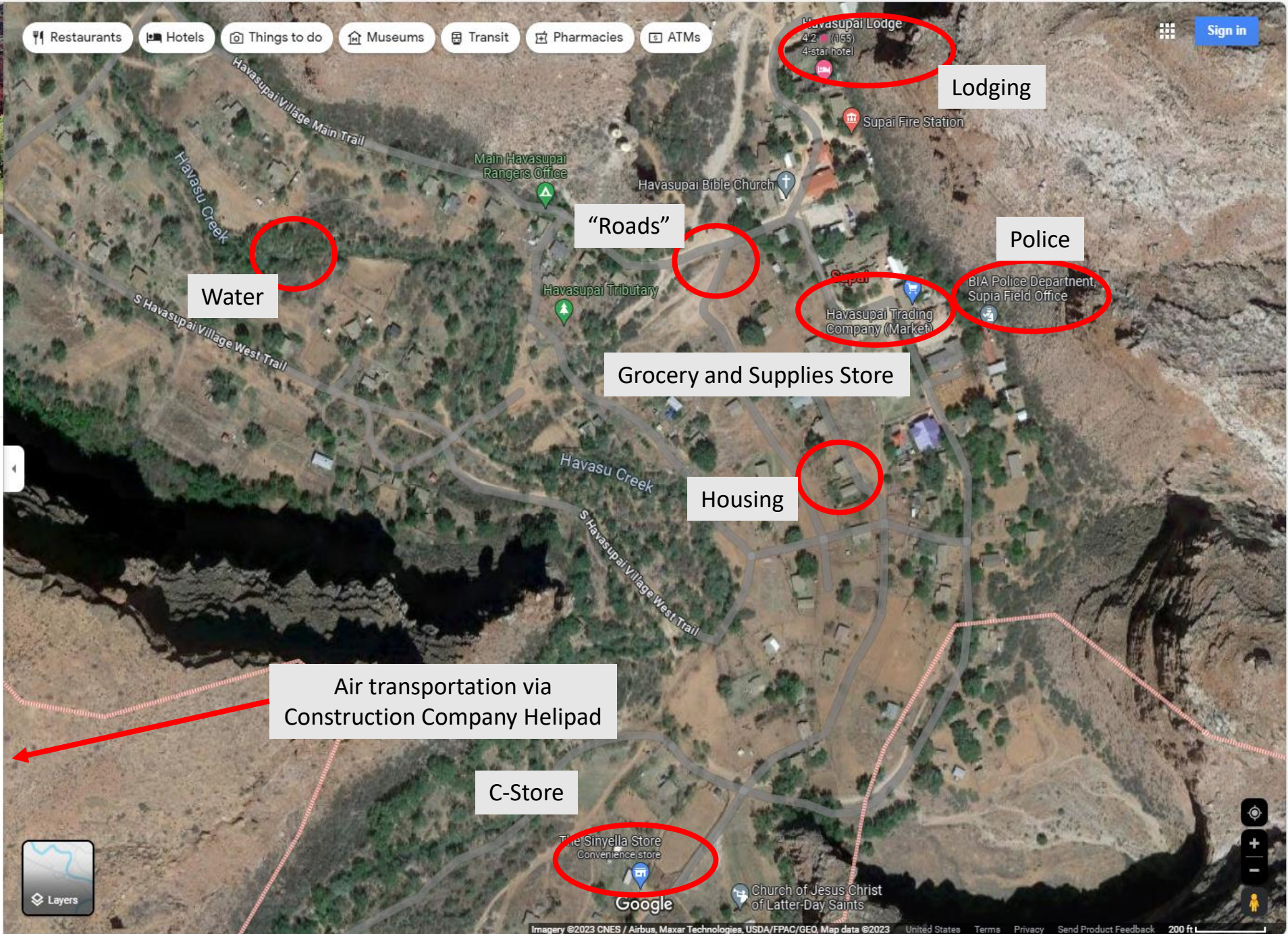
Supai, Arizona, USA

Supai  
Arizona 86435  
Sunny · 72°F  
10:41 AM

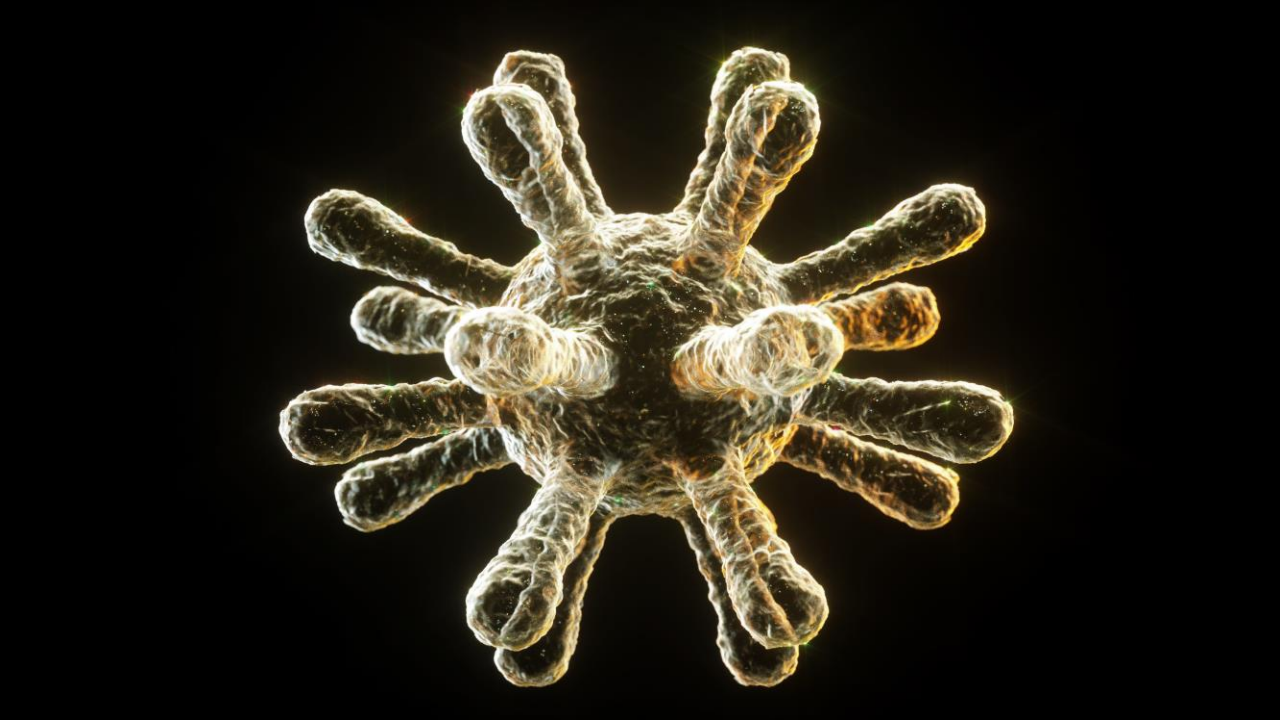
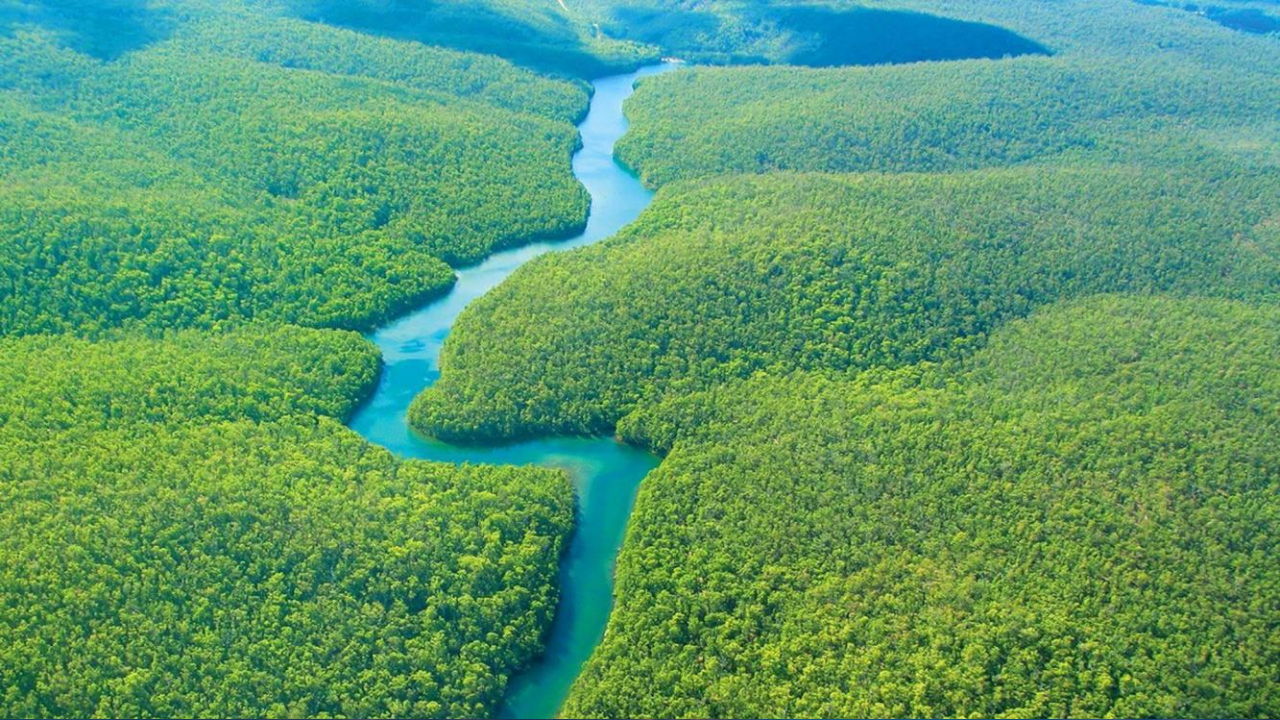
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Iconic Supai

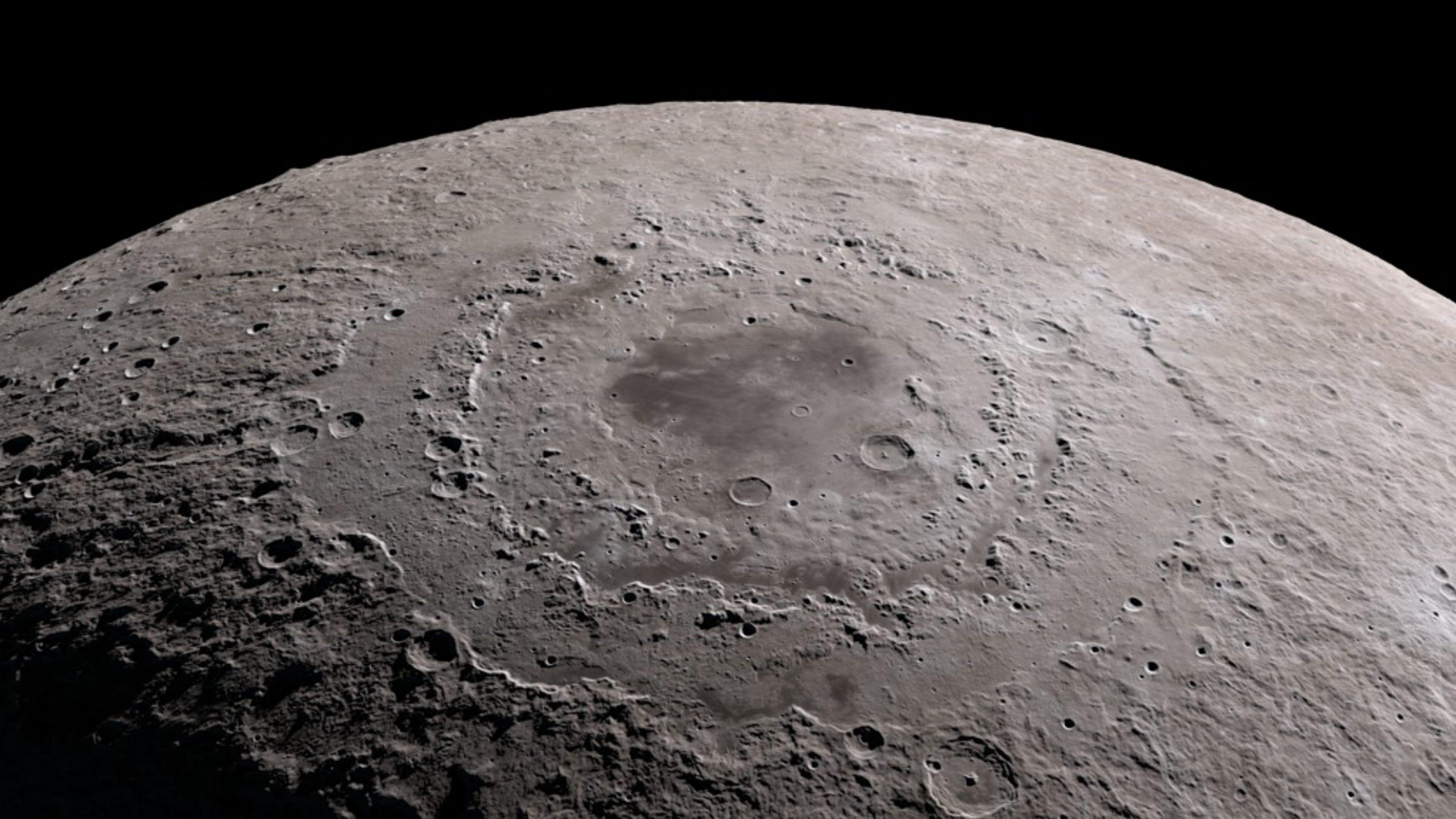
- Recreation
- Havasu Canyon 4.0 ★ (8)
- Havasu Falls 4.5 ★ (570)
- Havasu Canyon No reviews
- Beaver Falls 4.8 ★ (95)
- Fifty Foot Falls 4.9 ★ (20)













Best 41 hr 3 days 42 days 11 days 6 hr

New York

Los Angeles, California

Drag to reorder

Add destination

Leave now Options

Send directions to your phone

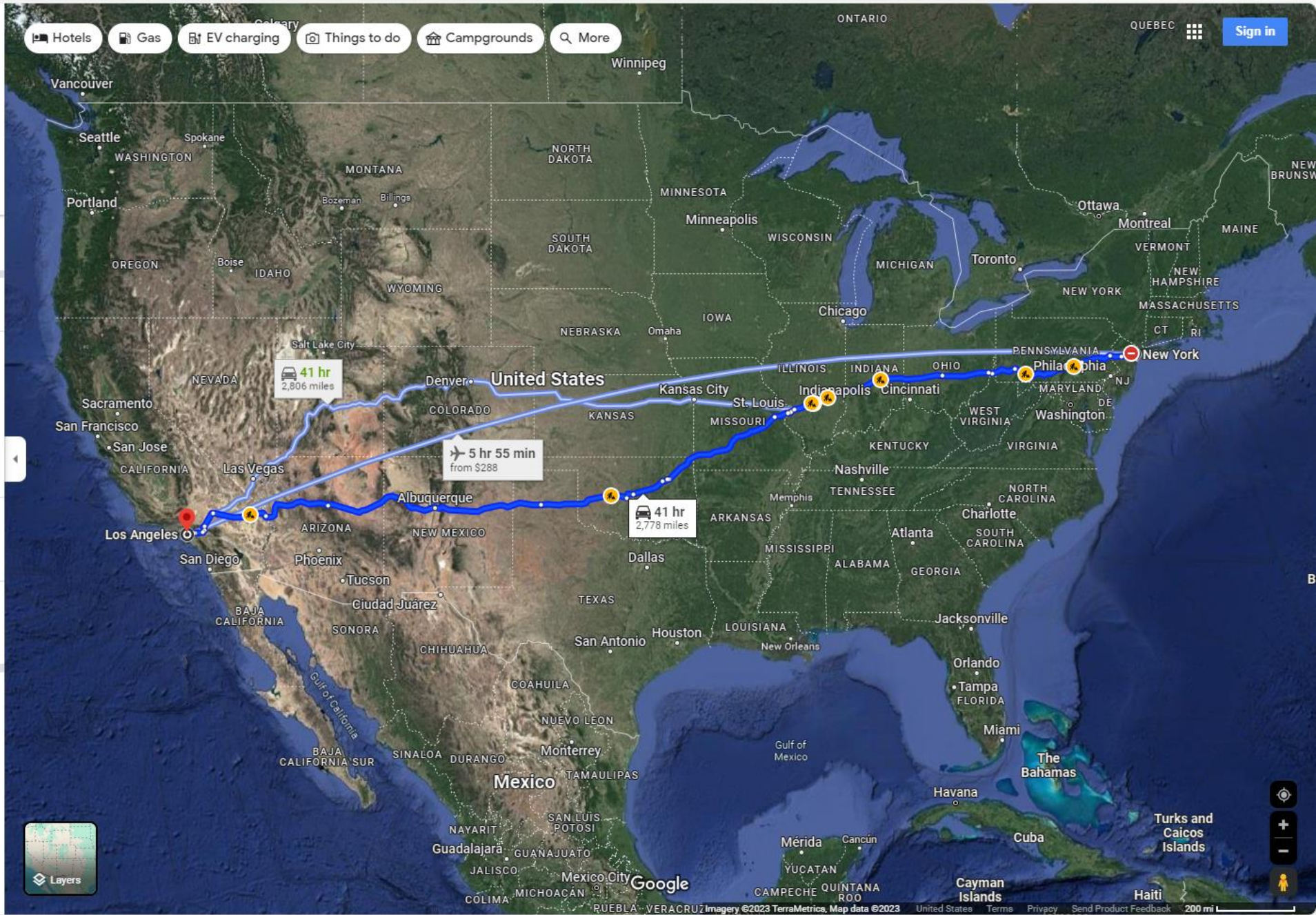
**via I-40 W** **41 hr**  
Fastest route now, avoids road closure on I-280 W  
2,778 miles  
▲ This route has tolls.  
▲ Your destination is in a different time zone.  
Details

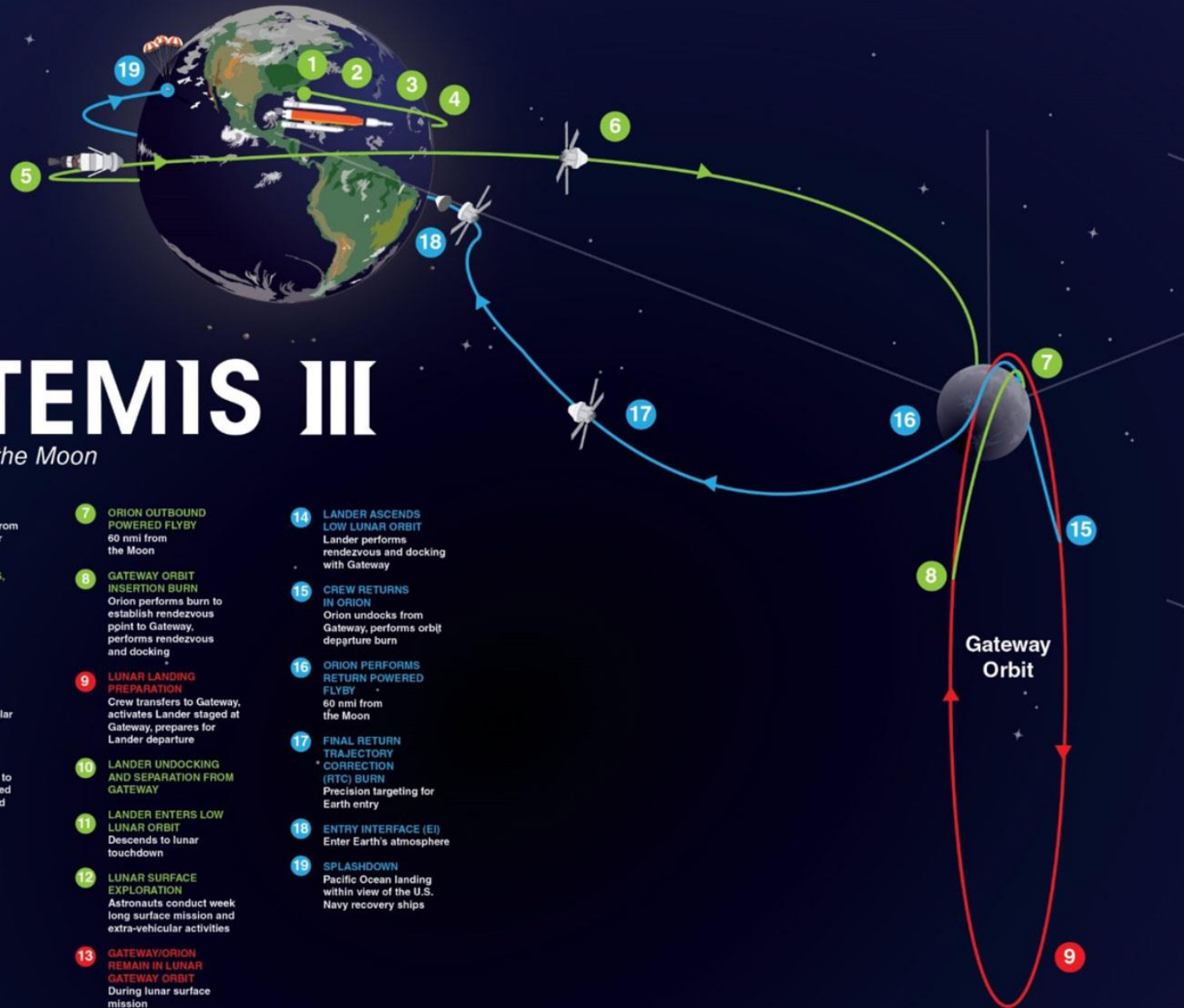
**via I-70 W** **41 hr**  
2,806 miles

**via Airplane** **New York, NY—Los Angeles, CA** **5 hr 55 min**  
from \$287

Explore Los Angeles

Restaurants Hotels Gas stations Parking Lots More

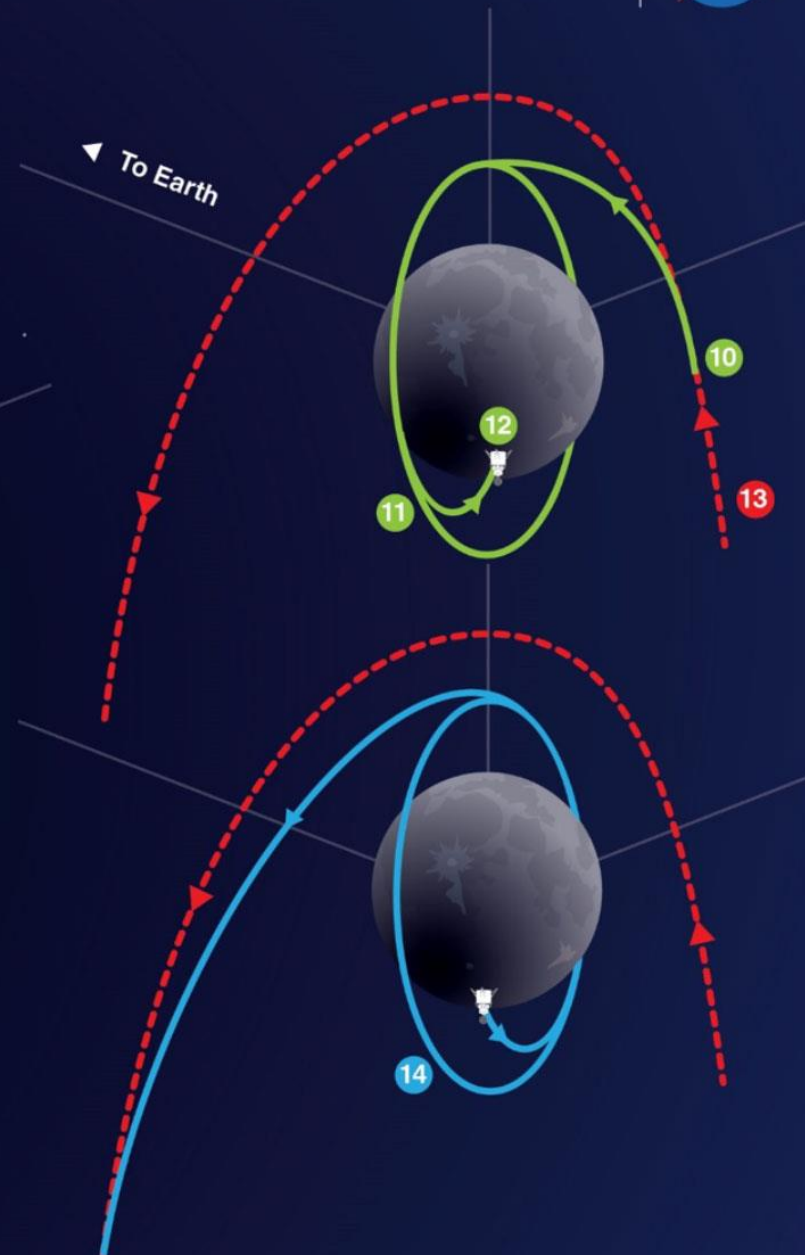




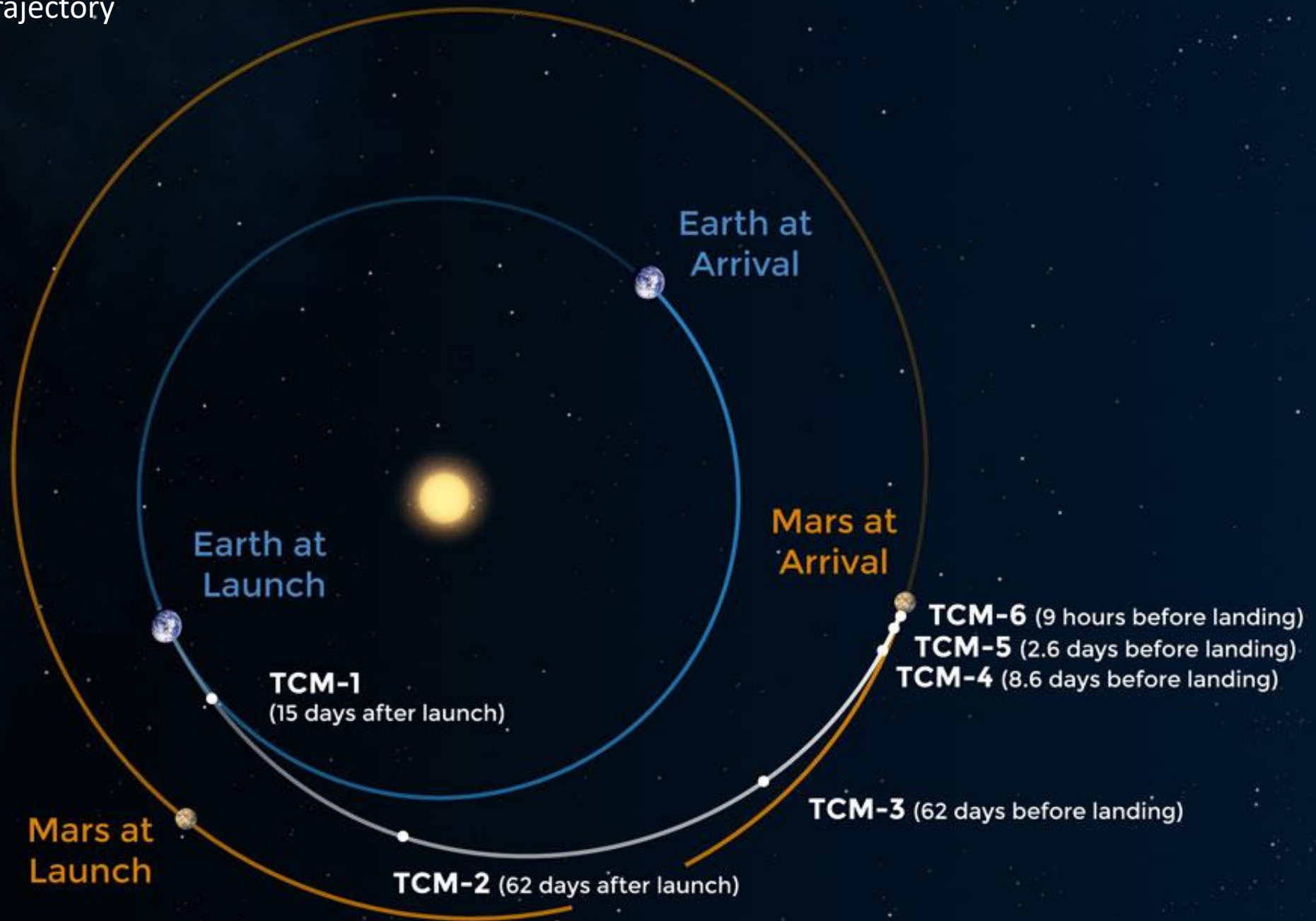
# ARTEMIS III

Landing on the Moon

- 1 LAUNCH**  
SLS and Orion lift off from Kennedy Space Center
- 2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
- 3 CORE STAGE MAIN ENGINE CUT OFF**  
With separation
- 4 ENTER EARTH ORBIT**  
Perform the perigee raise maneuver. Systems check and solar panel adjustments
- 5 TRANS LUNAR INJECTION BURN**  
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal
- 6 ORION OUTBOUND TRANSIT TO MOON**  
Requires several outbound trajectory maneuver burns.
- 7 ORION OUTBOUND POWERED FLYBY**  
60 nmi from the Moon
- 8 GATEWAY ORBIT INSERTION BURN**  
Orion performs burn to establish rendezvous point to Gateway, performs rendezvous and docking
- 9 LUNAR LANDING PREPARATION**  
Crew transfers to Gateway, activates Lander staged at Gateway, prepares for Lander departure
- 10 LANDER UNDOCKING AND SEPARATION FROM GATEWAY**
- 11 LANDER ENTERS LOW LUNAR ORBIT**  
Descends to lunar touchdown
- 12 LUNAR SURFACE EXPLORATION**  
Astronauts conduct week long surface mission and extra-vehicular activities
- 13 GATEWAY/ORION REMAIN IN LUNAR GATEWAY ORBIT**  
During lunar surface mission
- 14 LANDER ASCENDS LOW LUNAR ORBIT**  
Lander performs rendezvous and docking with Gateway
- 15 CREW RETURNS IN ORION**  
Orion undocks from Gateway, performs orbit departure burn
- 16 ORION PERFORMS RETURN POWERED FLYBY**  
60 nmi from the Moon
- 17 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**  
Precision targeting for Earth entry
- 18 ENTRY INTERFACE (EI)**  
Enter Earth's atmosphere
- 19 SPLASHDOWN**  
Pacific Ocean landing within view of the U.S. Navy recovery ships



# Mars Perseverance Trajectory



## A thought experiment

You and three of your best friends want to take a trip from New York to LA. You'll spend a week there seeing the sights before heading back.





# A thought experiment

2,800 miles there  
1 week in town to see the sights  
2,800 miles back

Total Miles = 5,600 miles  
Total trip time = 250 hours or ~10.5 days



# A thought experiment



Seating capacity = 4  
MPG = 18  
28 gal gas tank  
Interior volume = 120 cu.ft.  
Cargo capacity = 45 cu.ft  
Curb Weight: 5562  
Gross Weight: 7260  
Cargo capacity: 1698  
Towing capacity: 9200



Seating capacity = 4  
MPG = 25  
18.5 gal gas tank  
Interior volume = 102 cu.ft.  
Cargo capacity = 14 cu.ft.  
Curb Weight: 3336  
Gross Weight:  
Cargo capacity:

# A thought experiment



Everything you need for the trip you'll need to carry with you:

- 10.5 days of food 150 lbs and 2.8 cu ft.
- 10.5 days of water 42 gallons, 361 lbs, 5.6 cu.ft.
- 10.5 days of air supply 84,000 gallons
- 10.5 days of personal hygiene supplies 1 cu. Ft.
- 10.5 days of garbage storage 206 lbs, 19 cu. ft.
- 10.5 days of human waste storage 40 lbs solid + 22 gallons urine, 2.9 cu.ft.
- 10.5 days of clothes 84 lbs, 8 cu. ft.
- 10.5 days of fuel 224 gallons to 312 gallons  
1,344 lbs to 1,872 lbs  
29.9 cu. ft. to 41.7 cu.ft.



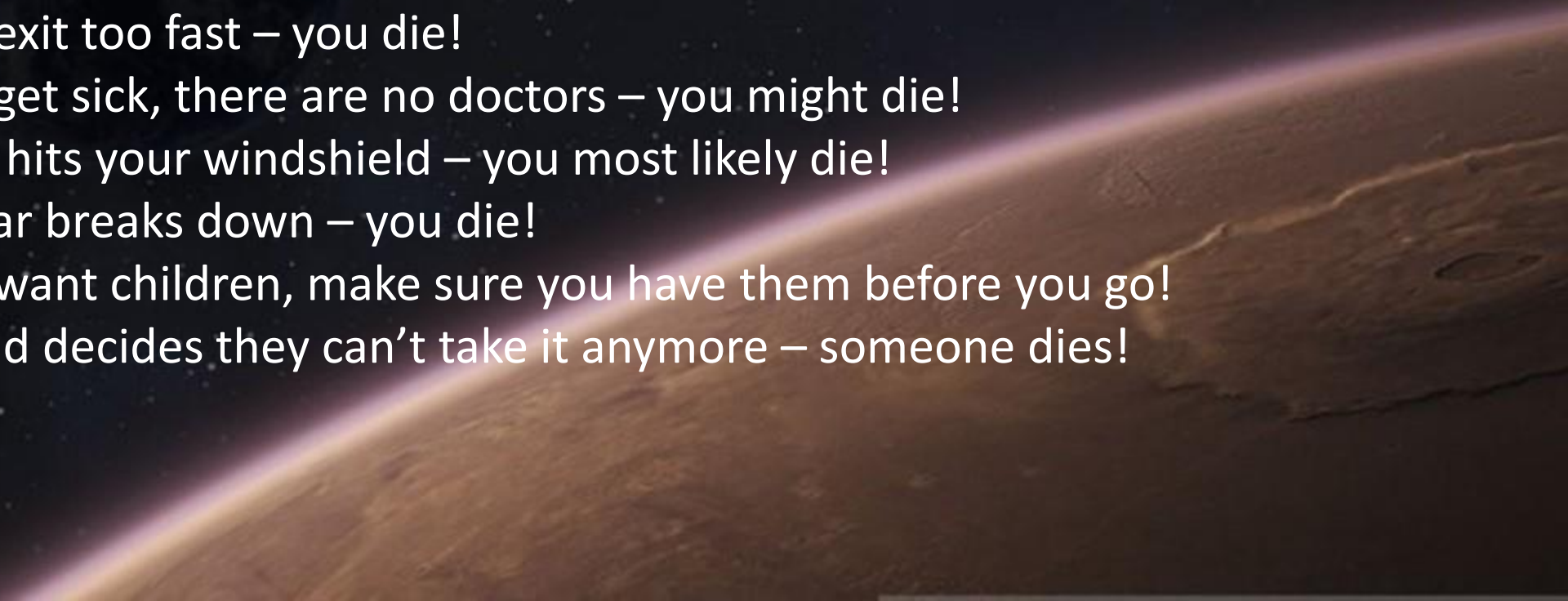
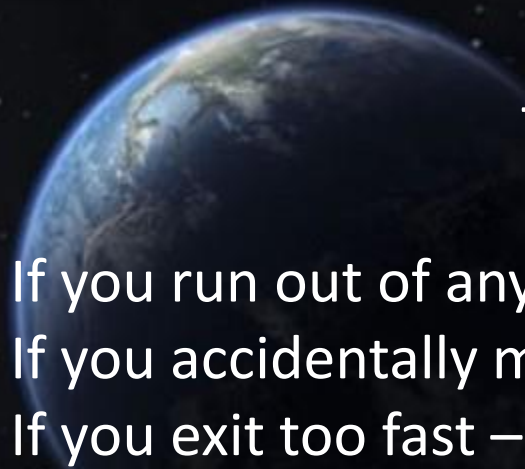
With a trailer and/or pre-emplaced logistics

# A thought experiment



This is a dangerous trip

- If you run out of any of your consumables – you die!
- If you accidentally miss an exit or take a wrong turn – you die!
- If you exit too fast – you die!
- If you get sick, there are no doctors – you might die!
- A rock hits your windshield – you most likely die!
- Your car breaks down – you die!
- If you want children, make sure you have them before you go!
- A friend decides they can't take it anymore – someone dies!

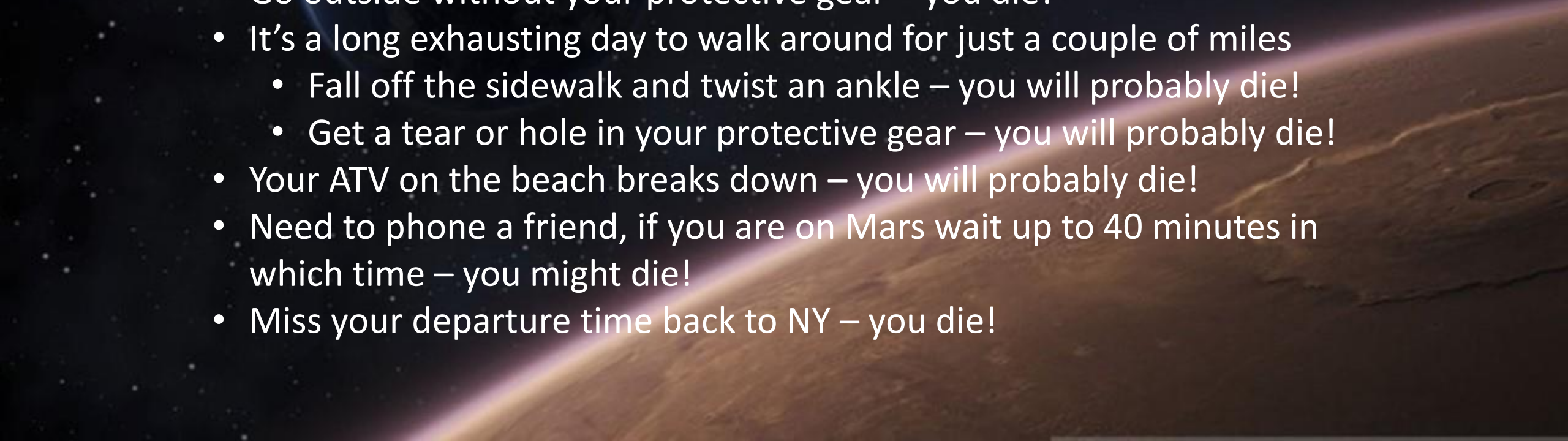
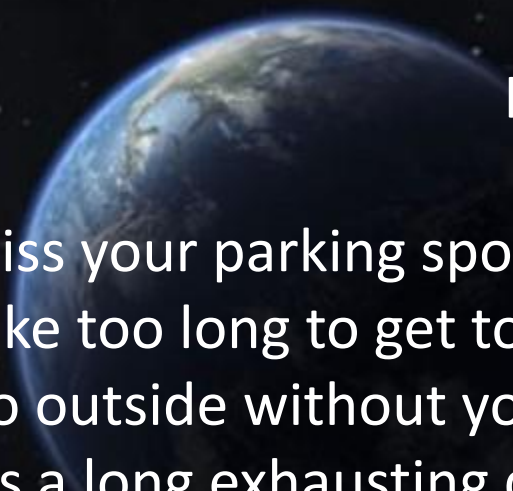


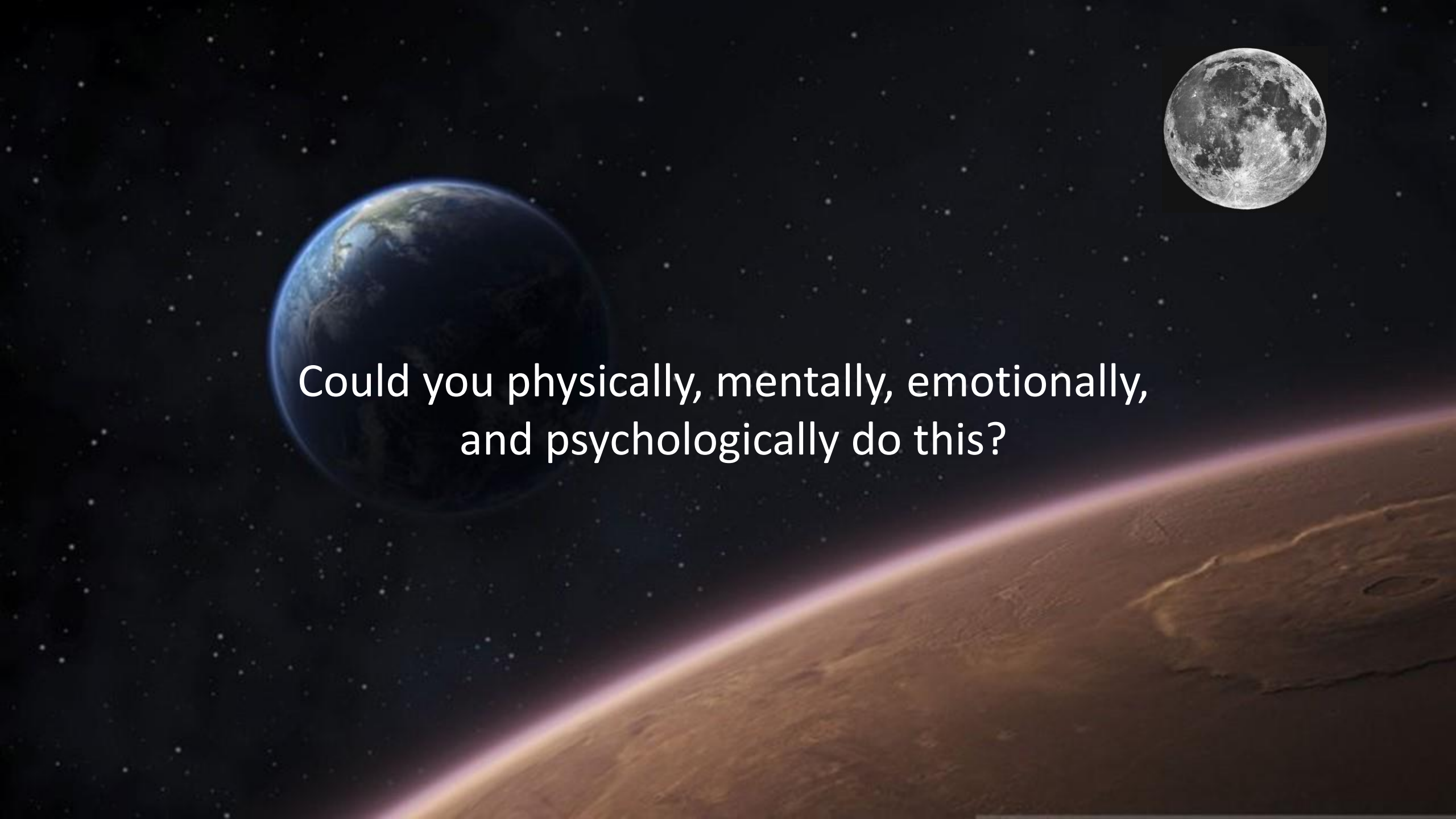
# A thought experiment



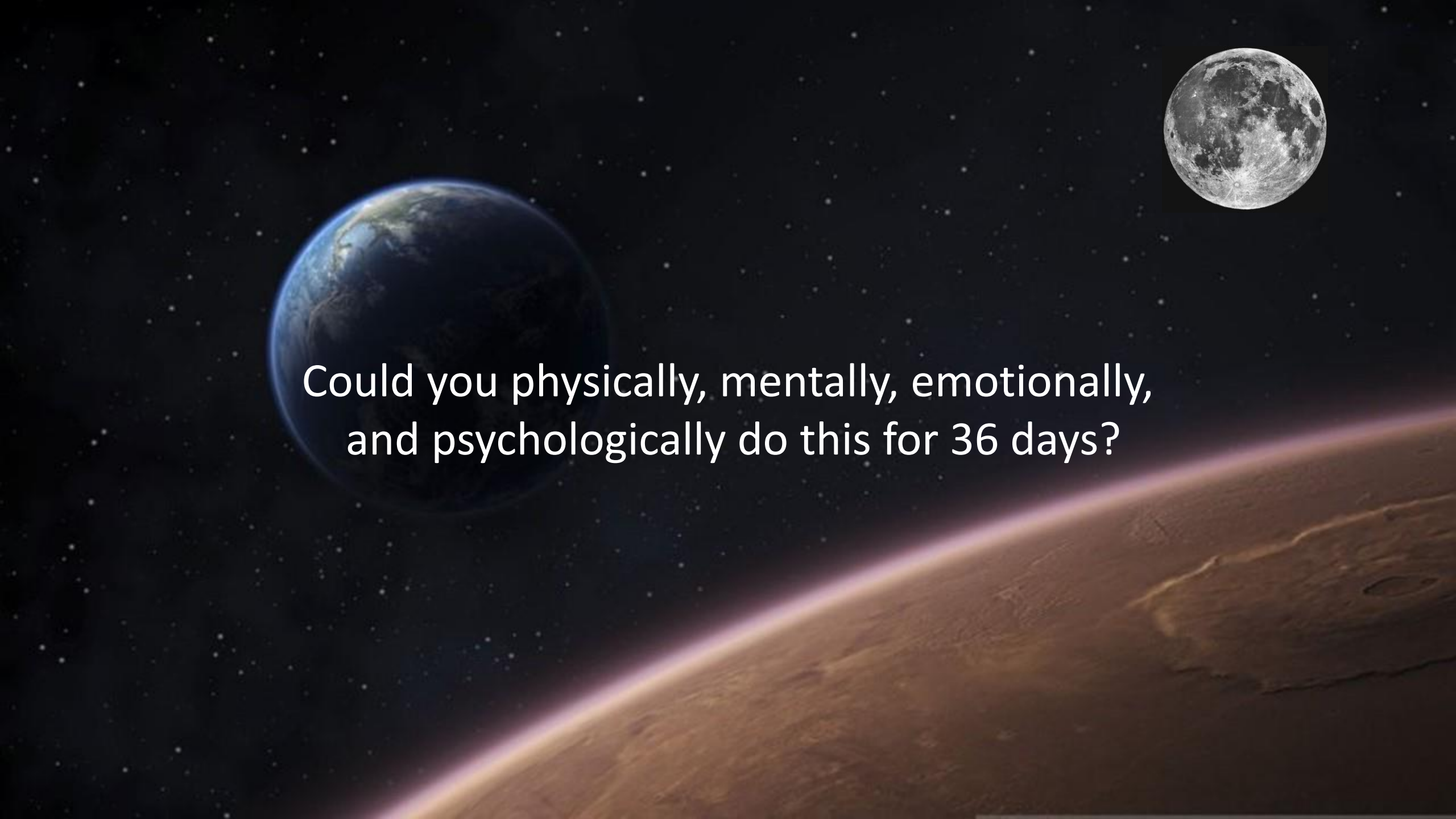
In LA exploring the town

- Miss your parking spot – you die!
- Take too long to get to your parking spot – you die!
- Go outside without your protective gear – you die!
- It's a long exhausting day to walk around for just a couple of miles
  - Fall off the sidewalk and twist an ankle – you will probably die!
  - Get a tear or hole in your protective gear – you will probably die!
- Your ATV on the beach breaks down – you will probably die!
- Need to phone a friend, if you are on Mars wait up to 40 minutes in which time – you might die!
- Miss your departure time back to NY – you die!



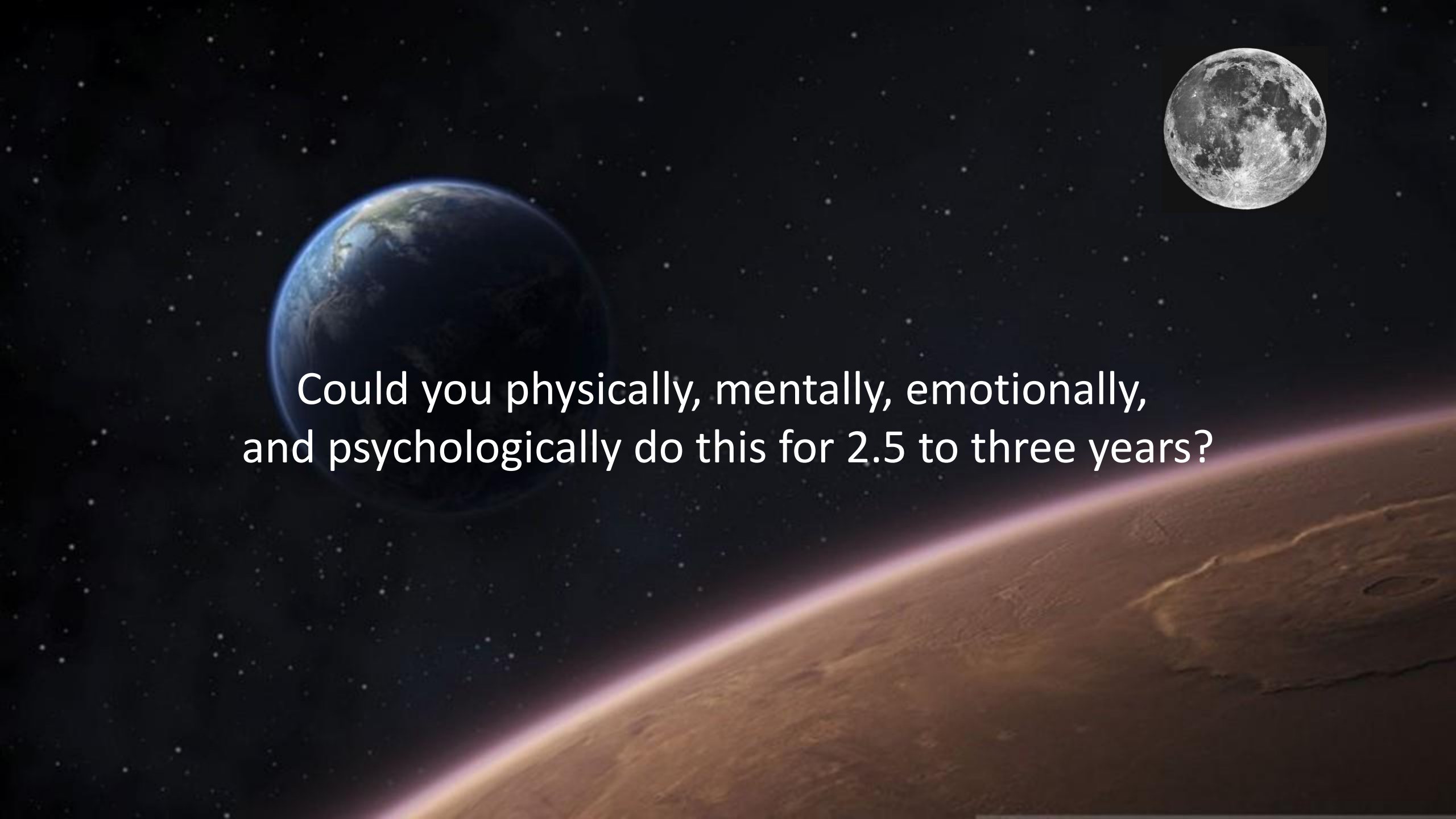
A composite image of space featuring Earth, the Moon, and Mars. Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark starfield.

Could you physically, mentally, emotionally,  
and psychologically do this?


A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is on the right, and the horizon of Mars is at the bottom. The background is a dark starry sky.

Could you physically, mentally, emotionally,  
and psychologically do this for 36 days?



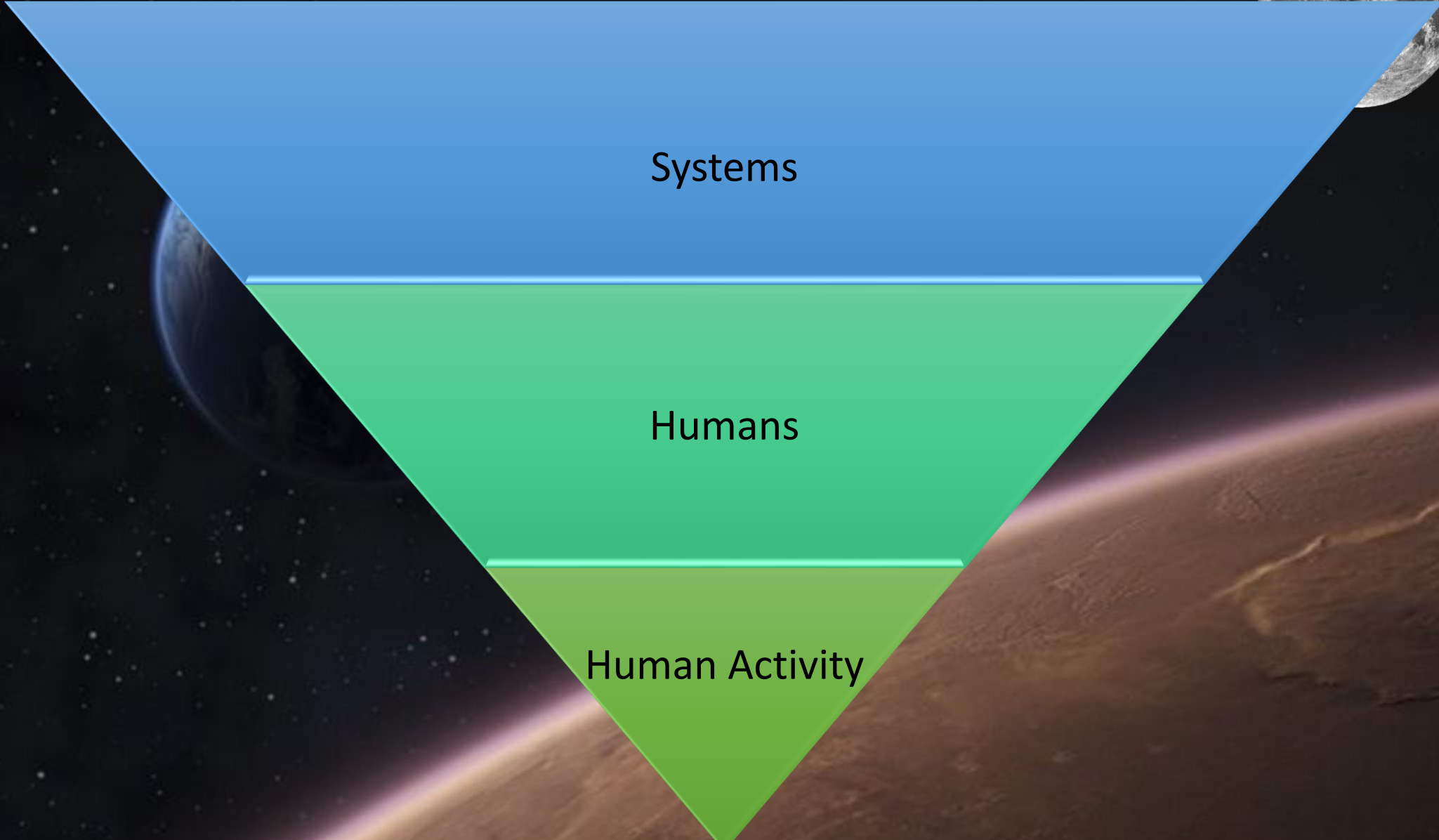
A composite image of space. In the upper left, a blue and white Earth is visible. In the upper right, a full, grey Moon is shown. In the lower right, the reddish, cratered surface of Mars is seen in the foreground. The background is a dark field of stars.

Could you physically, mentally, emotionally,  
and psychologically do this for 2.5 to three years?

A composite image of Earth, the Moon, and Mars in space. Earth is on the left, the Moon is on the right, and the horizon of Mars is at the bottom. The background is a dark starfield.

We need an inflection point in how we approach exploration.

# Current Paradigm



Systems

Humans

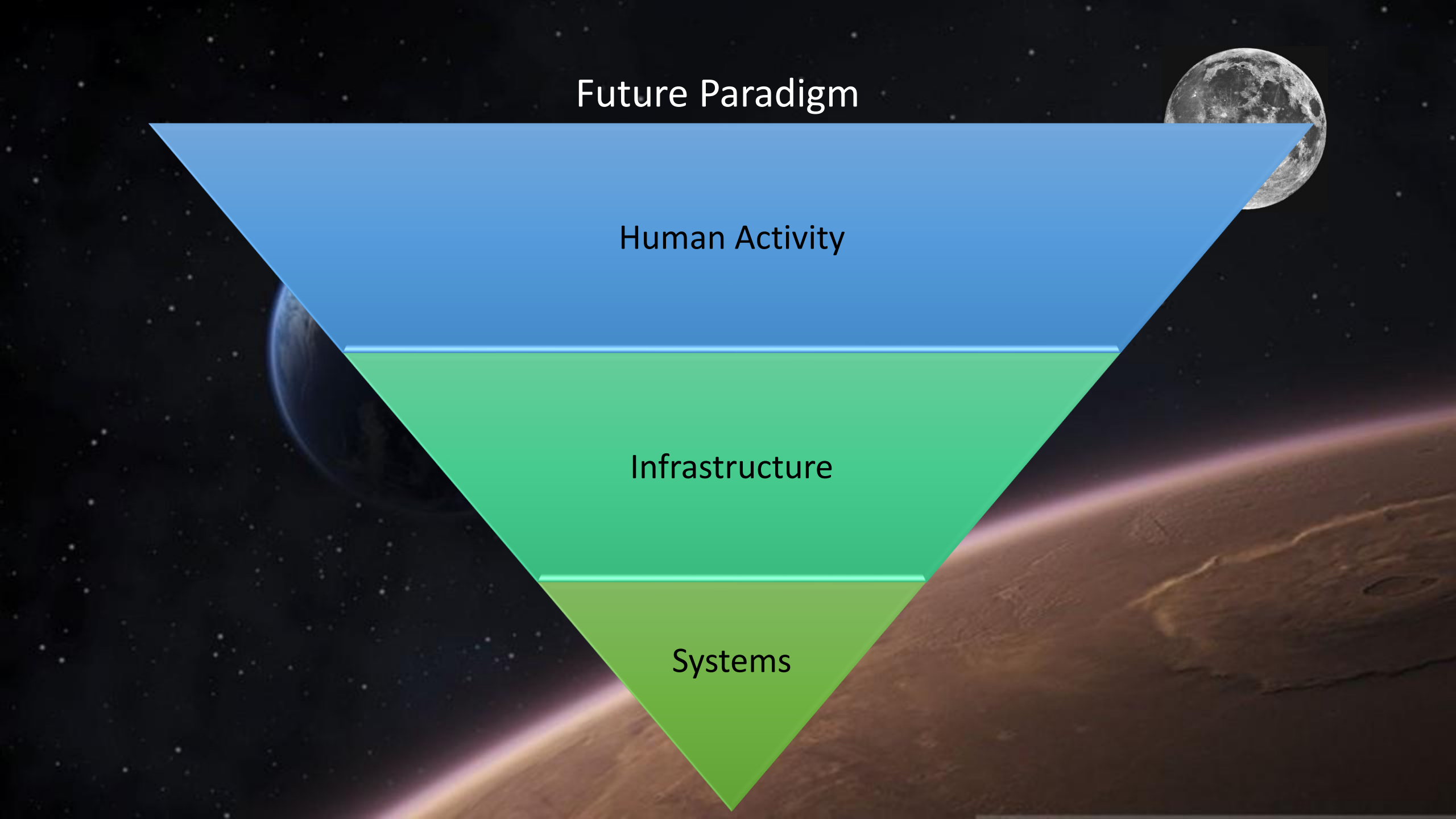
Human Activity

# Future Paradigm

Human Activity

Infrastructure

Systems



# Some Fundamental Tradeoffs

## Mass and Energy

$\Delta v$  (vehicle + payload mass vs propellant mass)

Surface Distance Traveled vs Time

## Crew Time

Human vs Robotic

Crew and/or Ground vs Automation

## Service Life

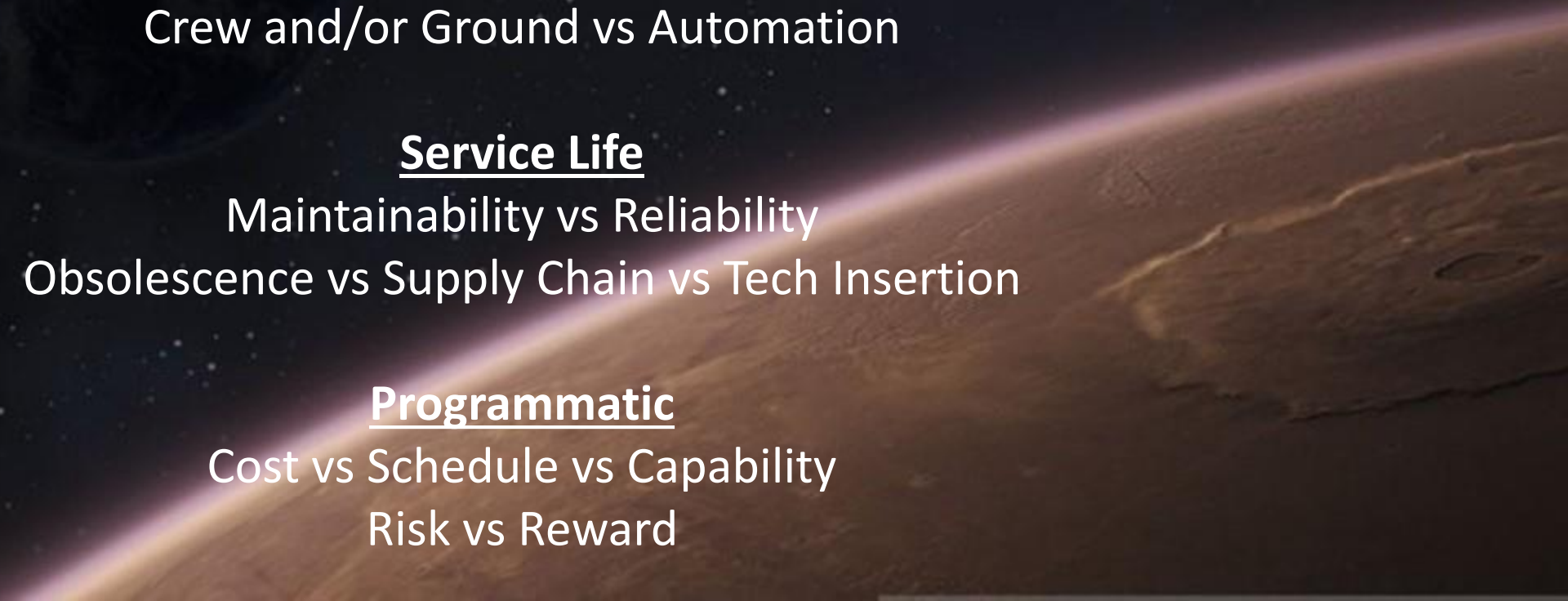
Maintainability vs Reliability

Obsolescence vs Supply Chain vs Tech Insertion

## Programmatic

Cost vs Schedule vs Capability

Risk vs Reward



A composite image of space. In the upper left, the Earth is shown as a blue and white sphere. In the upper right, the Moon is shown as a grey, cratered sphere. In the lower right, the curved horizon of Mars is visible, showing its reddish-brown surface and some craters. The background is a dark field of stars.

# **The Systems, The Humans, The Environments**

LEO Access  
Communications and PNT  
Earth Orbital Habitats  
Logistics  
Cyber



Mission Control  
Resource Utilization  
Supply Chain  
Cyber

In Space  
Manufacturing  
and Assembly

Crewed Mars Orbit  
and Surface Access

Surface Transportation  
Surface Habitats  
Resource Utilization and Manufacturing  
Communications and PNT  
Lunar Orbital Habitats  
Logistics



Crewed Lunar Orbit  
and Surface Access

Edge Services

- Mission Management
- Healthcare
- Cyber
- Compute and Storage
- Analytics, AI, ML

Communications and PNT  
Surface Transportation  
Surface Habitats  
Resource Utilization and Manufacturing  
Logistics

A composite image of space. On the left is a view of Earth from space, showing blue oceans and white clouds. On the right is a full moon. In the foreground at the bottom is the curved horizon of Mars, showing its reddish-brown surface and some craters. The background is a dark field of stars.
$$\Delta v = v_e \ln(M_o/M_f)$$

$v_e$  = effective exhaust velocity

$M_o$  = initial total mass including propellant

$M_f$  = final total mass



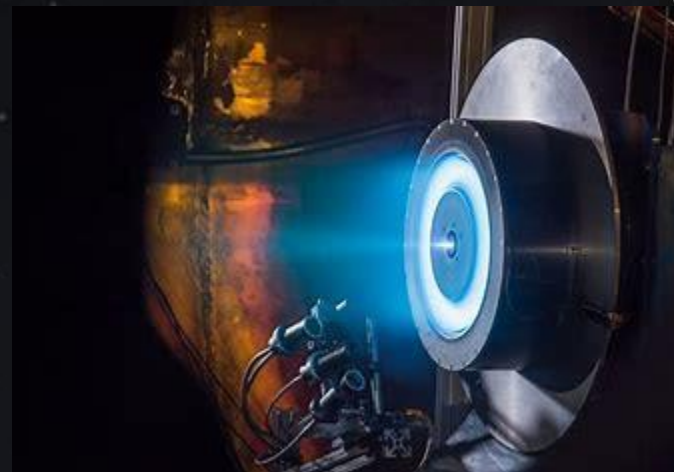


## Chemical Rocket Engines

RS-25 Space Shuttle Main Engine

High Thrust: RS-25  $\sim 2.3$  MN

Low Isp: RS-25 452s vacuum, 366s SL



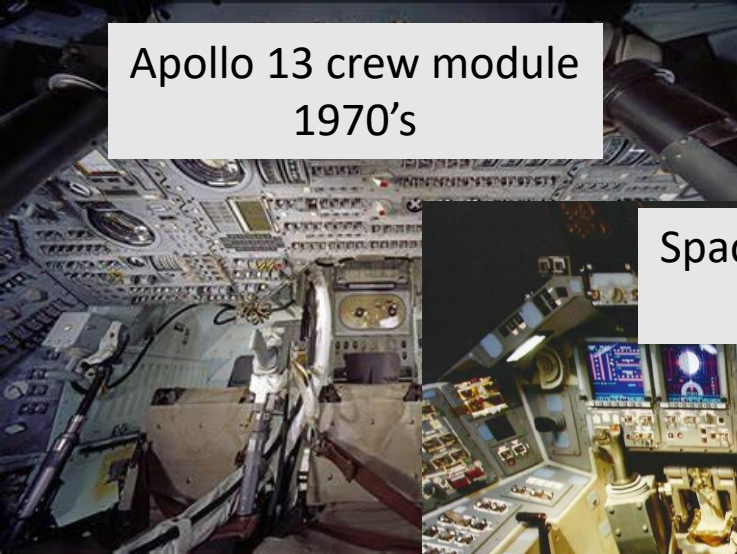
## Solar Electric Propulsion

Engineering unit testing for Gateway

Low Thrust:  $\sim 1.8$  N

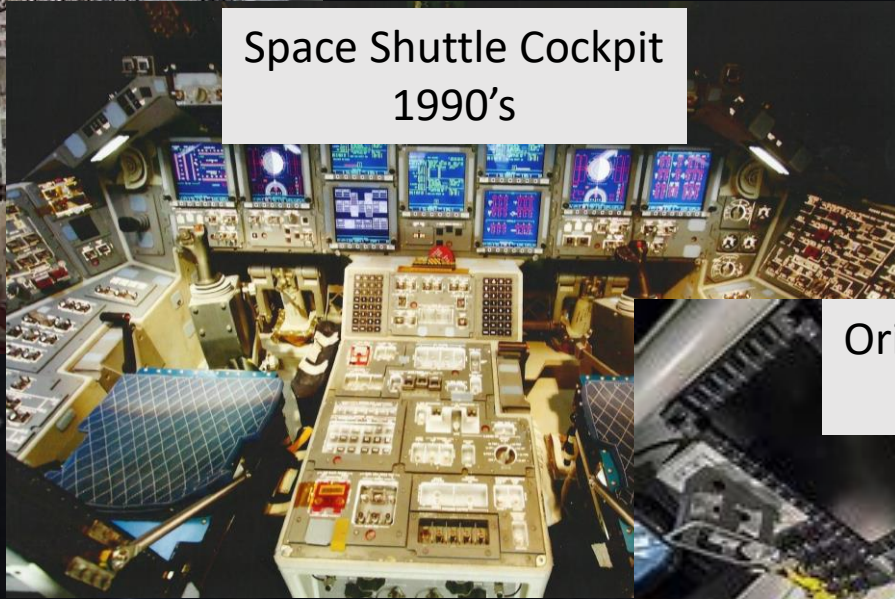
High Isp:  $\sim 2,900$ s

Apollo 13 crew module  
1970's



Complex

Space Shuttle Cockpit  
1990's



Orion Crew Module  
2020's



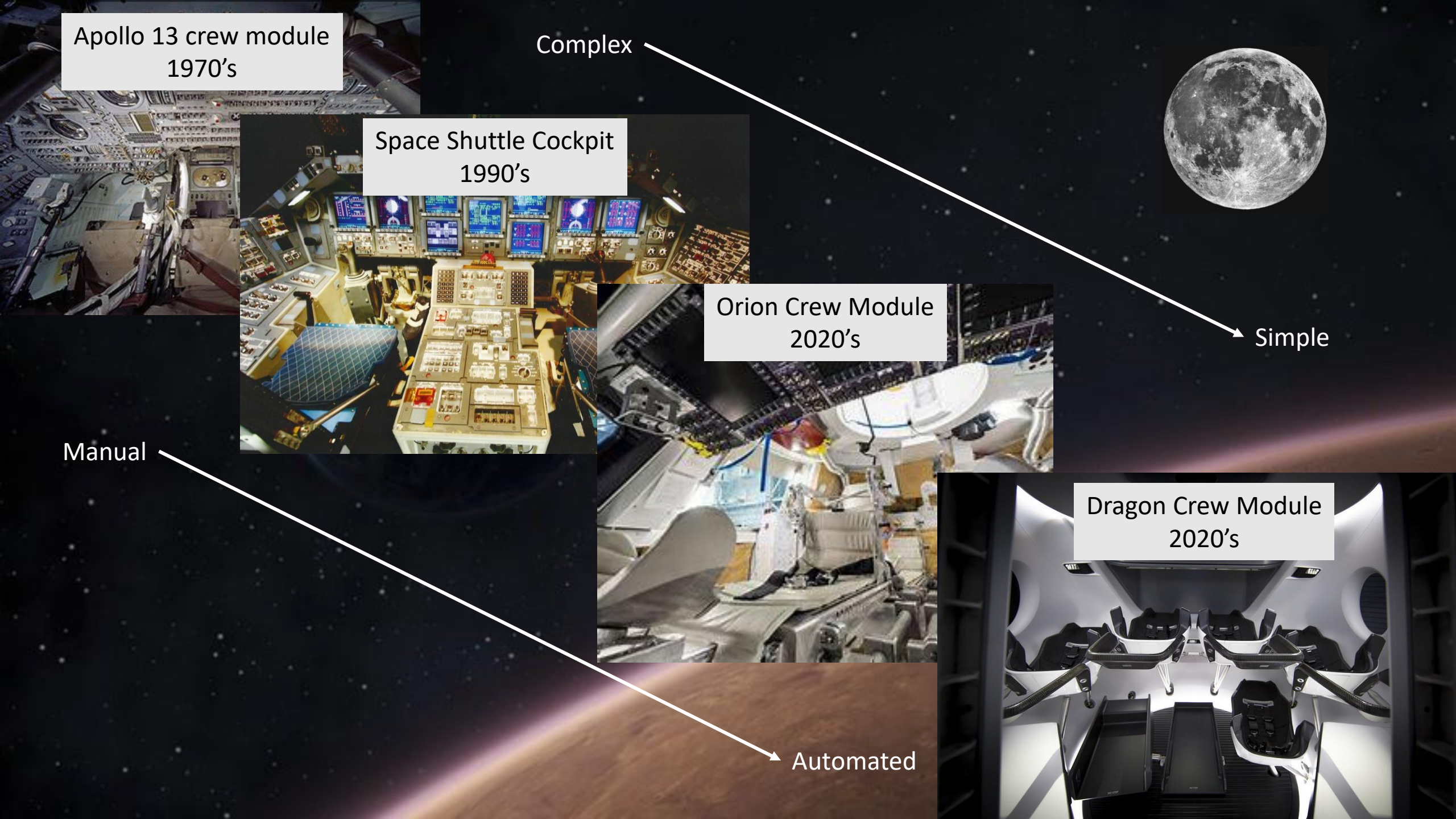
Simple

Manual

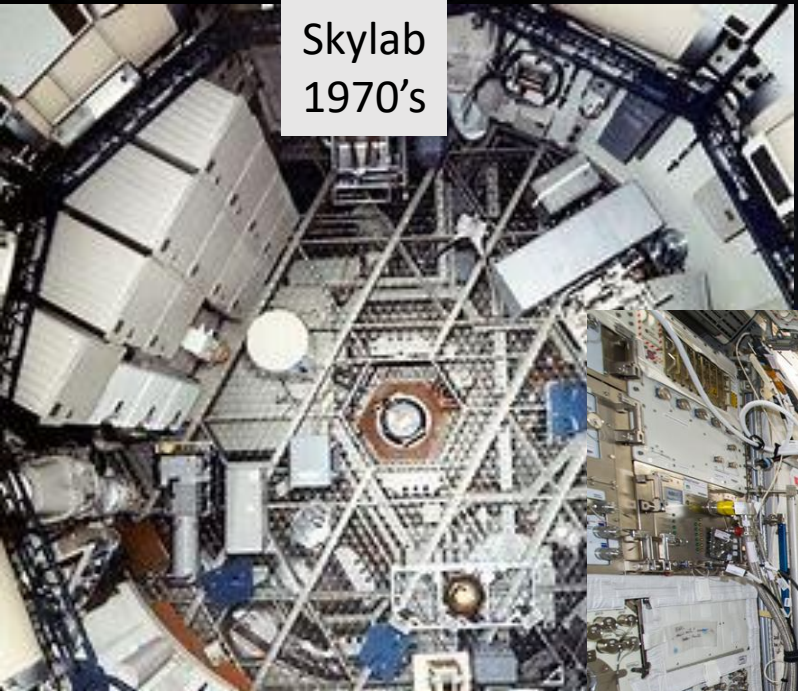
Dragon Crew Module  
2020's



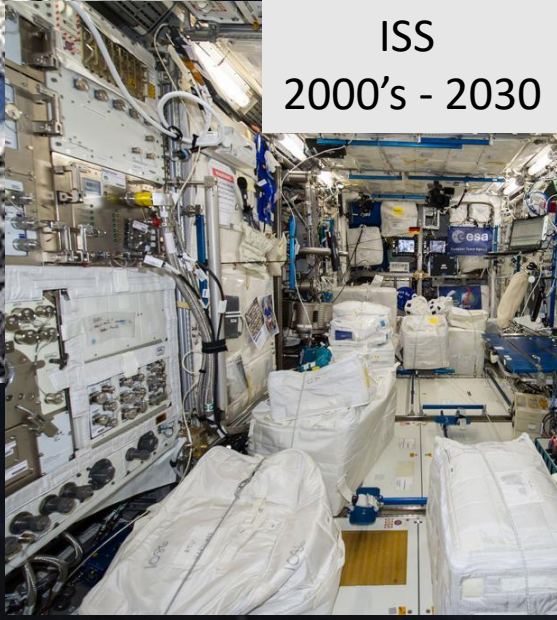
Automated



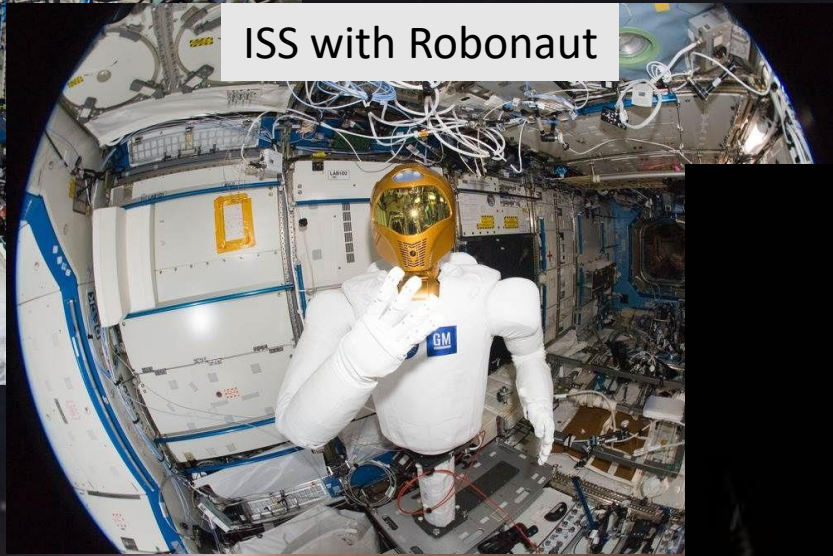
Skylab  
1970's



ISS  
2000's - 2030



ISS with Robonaut



Gateway  
2020's+



Apollo Control Room  
1970's



Space Shuttle Control Room  
1990's



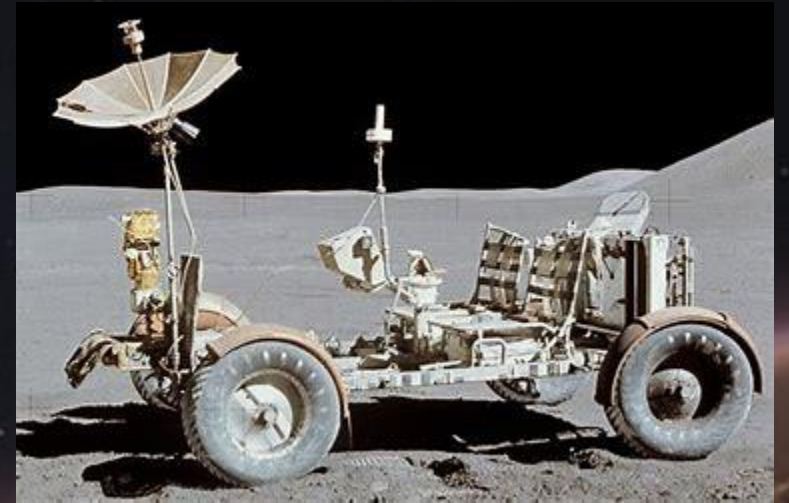
ISS Control Room  
2000's - 2030's




SpaceX Control Room  
2010's +




Human mobility in a lunar environment is a key part of the Moon to Mars Program.



Apollo was the last time we had human mobility off planet.

A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark starry sky.

**What doesn't kill you, doesn't always make  
you stronger.**

A composite image of space. In the upper left, a portion of the Earth is visible, showing blue oceans and green landmasses. In the upper right, the Moon is shown in a full phase, displaying its characteristic grey and white surface features. The lower half of the image is dominated by the curved horizon of Mars, showing its reddish-brown surface with some darker patches and a thin atmosphere. The background is a dark field of stars.

Today we mitigate human health and performance risk in two ways:

- 1) Countermeasures
- 2) Most impactful; selecting astronauts that represent peak human physical and mental condition.







Space Radiation



Isolation and Confinement



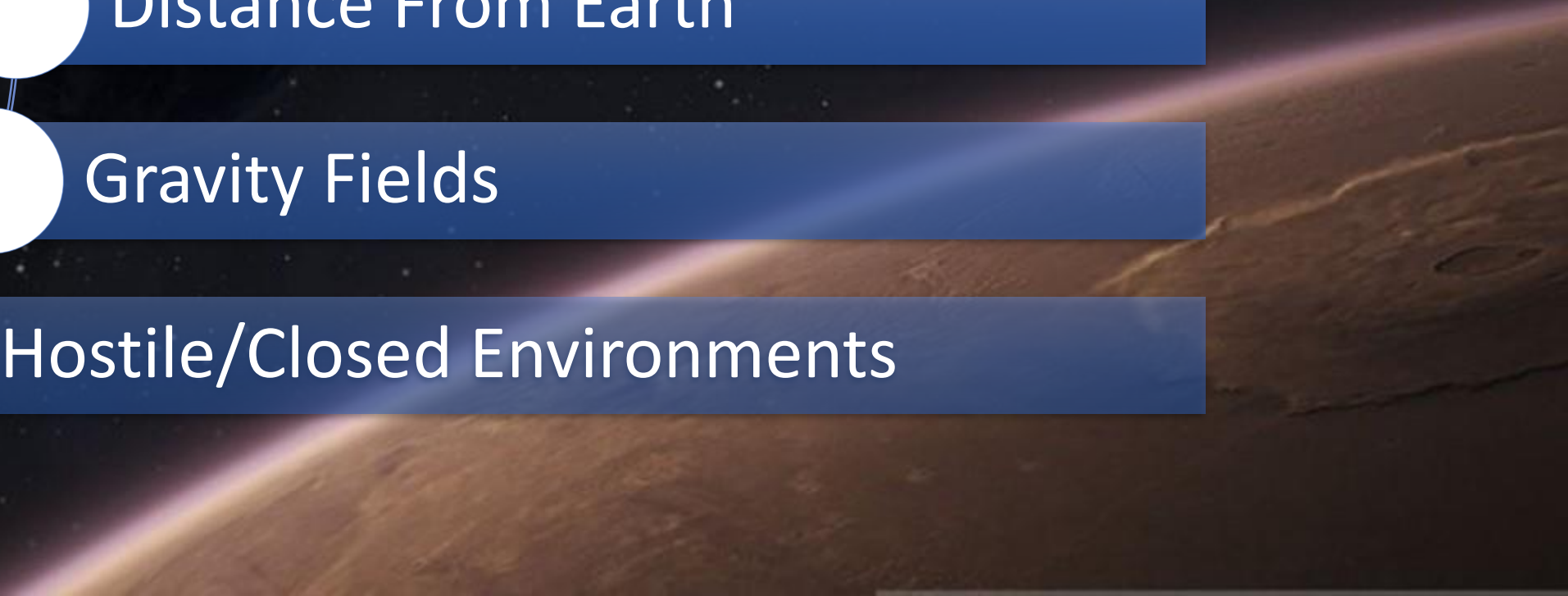
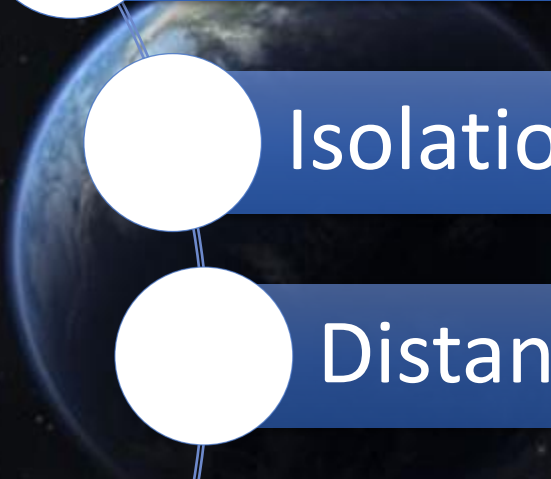
Distance From Earth



Gravity Fields



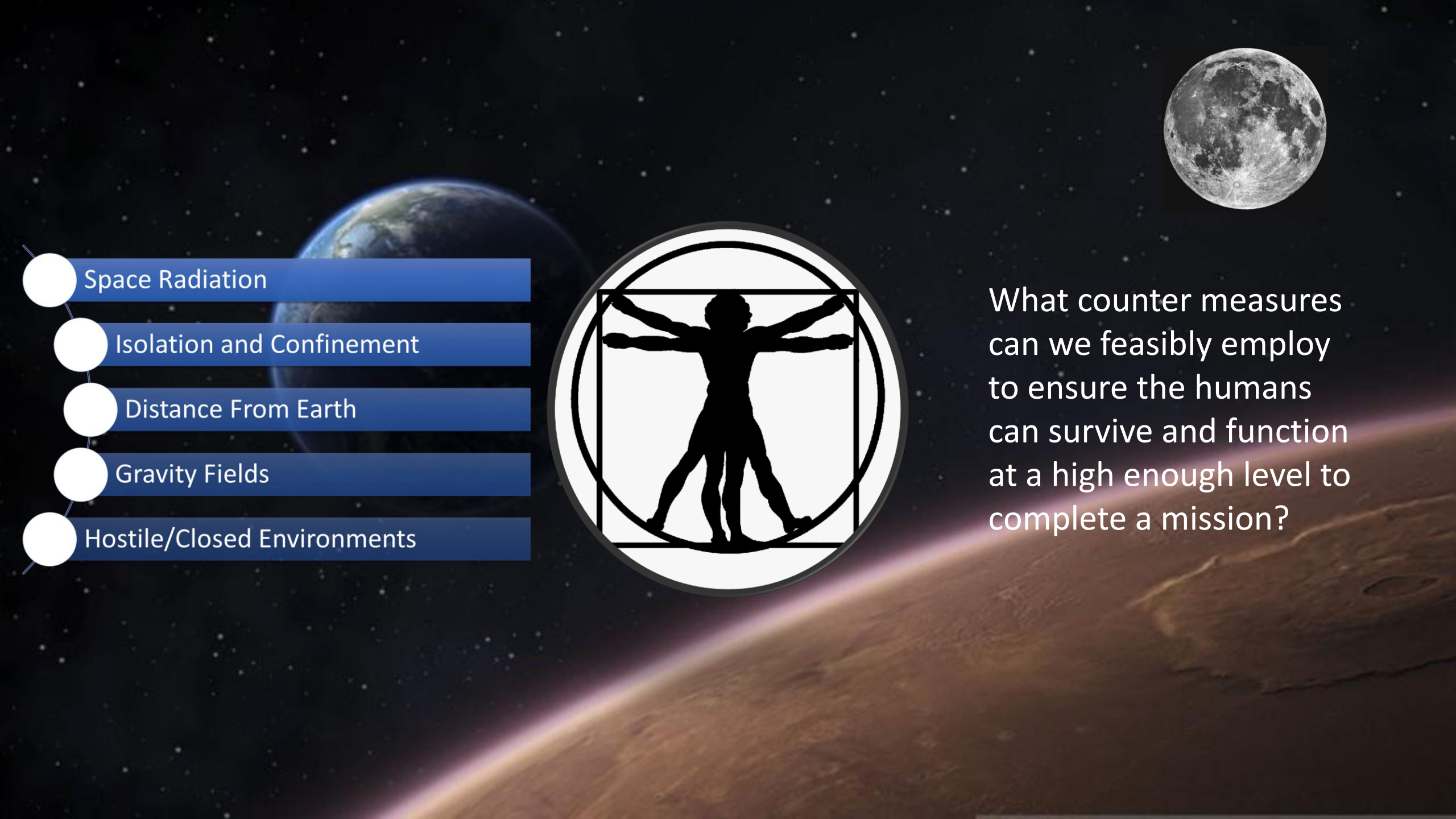
Hostile/Closed Environments



- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments



What counter measures can we feasibly employ to ensure the humans can survive and function at a high enough level to complete a mission?



A composite image of space. On the left, a portion of the Earth is visible, showing blue oceans and green landmasses. In the upper right, the Moon is shown in a full phase, displaying its characteristic grey and white surface features. The bottom right corner shows the reddish-brown horizon of Mars. The background is a dark field of stars.

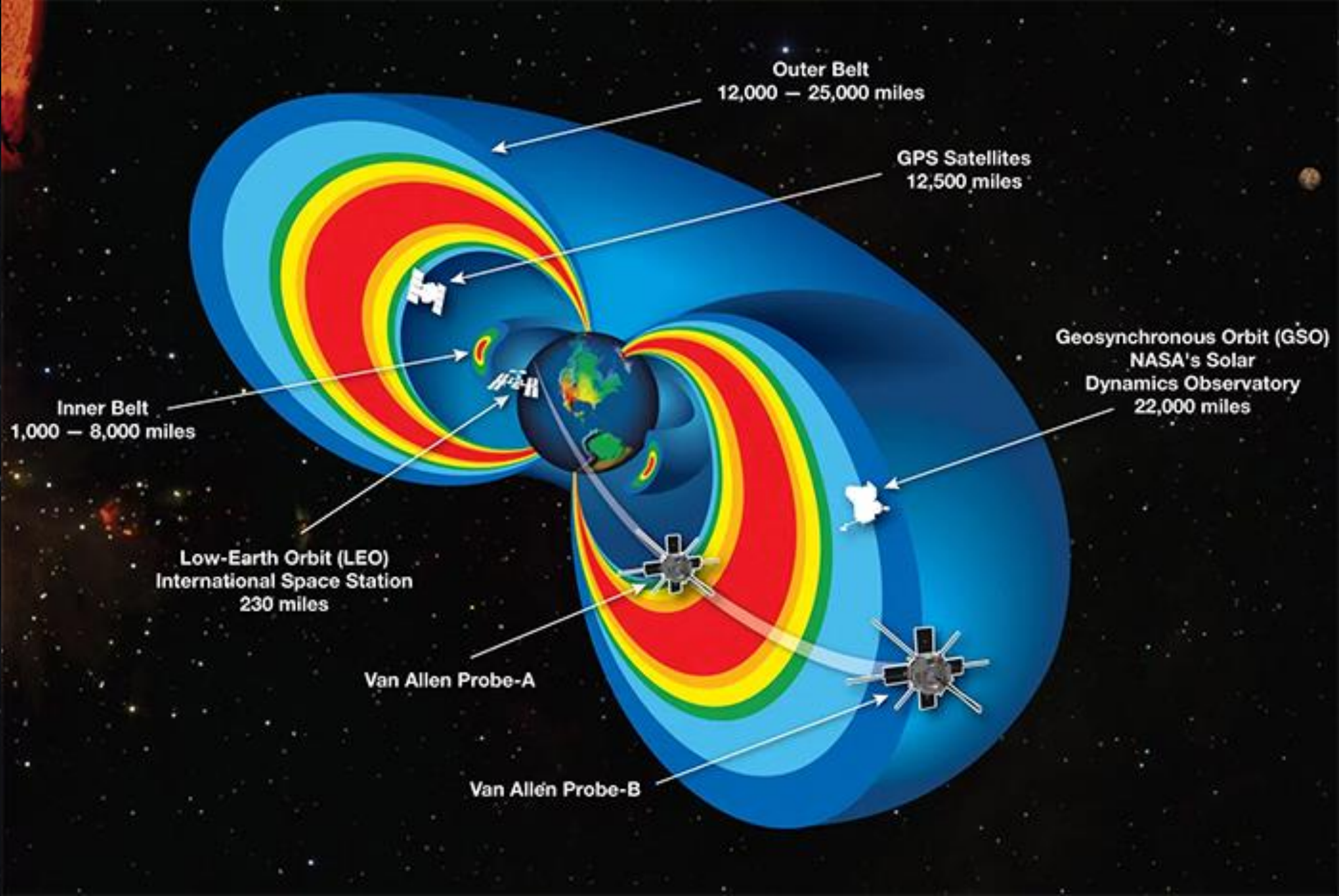
## Radiation exposure:

- increases cancer risk
- damages the central nervous system
- can alter cognitive function
- reduces motor function
- prompts behavioral changes

- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments

LEO exploration and communities are somewhat protected by the Van Allen Belts

Lunar and Mars exploration will not have this protection



Space Radiation

Isolation and Confinement

Distance From Earth

Gravity Fields

Hostile/Closed Environments

# Humans are social animals



- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments



- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments



1/6 gravity



After 30-days in zero or micro-G, astronauts are considered deconditioned to gravity:

- Weight-bearing bones lose on average 1% to 1.5% of mineral density per month during spaceflight.
- Muscle mass atrophies and strength is lost
- Fluids redistribute in the body and can cause vision impairment and other issues.

How much time is needed to adjust to gravity fields after landing on the Moon or Mars before astronauts can perform mission activities?

What's the increased risk if these task are mission critical tasks?

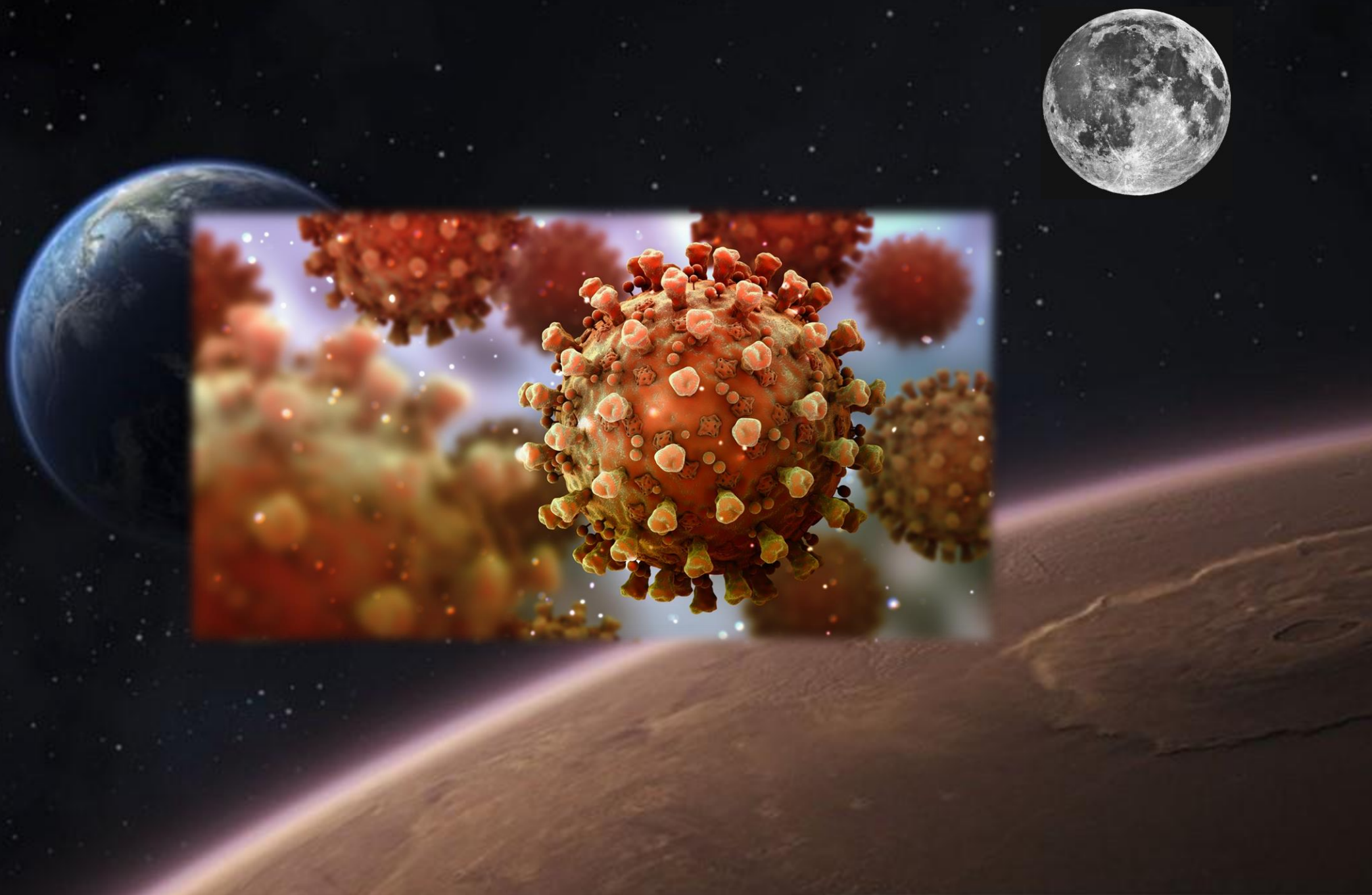
1/3 gravity



- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments




- Space Radiation
- Isolation and Confinement
- Distance From Earth
- Gravity Fields
- Hostile/Closed Environments



Analog mission can help determine impacts on some aspects of long duration space missions.




A composite image of space featuring Earth, the Moon, and Mars. Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark field of stars.

It's not enough to choose the "best athlete"

We need capabilities to ensure humans can perform physically, mentally, emotionally, and psychologically in the most isolated, distant, and extreme environments we have ever come across.

A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark starry sky.

**The Politicians, The Bankers, The Businesses**

A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is on the right, and the horizon of Mars is at the bottom. The background is a dark starry sky.

Politicians make policy that drives exploration, or not

## The Artemis Accords

Non-binding multilateral arrangement between the United States government and other world governments participating in the Artemis program.

Sets the foundation for Moon to Mars exploration.

### Key Tenants:

- Transparency
- Interoperability\*
- Emergency Assistance
- Registration of Space Objects
- Release of Scientific Data\*
- Protecting Heritage
- Resource Extraction\*
- Deconfliction of Activities
- Orbital Debris and Spacecraft Disposal\*

\* Key areas for research engagement



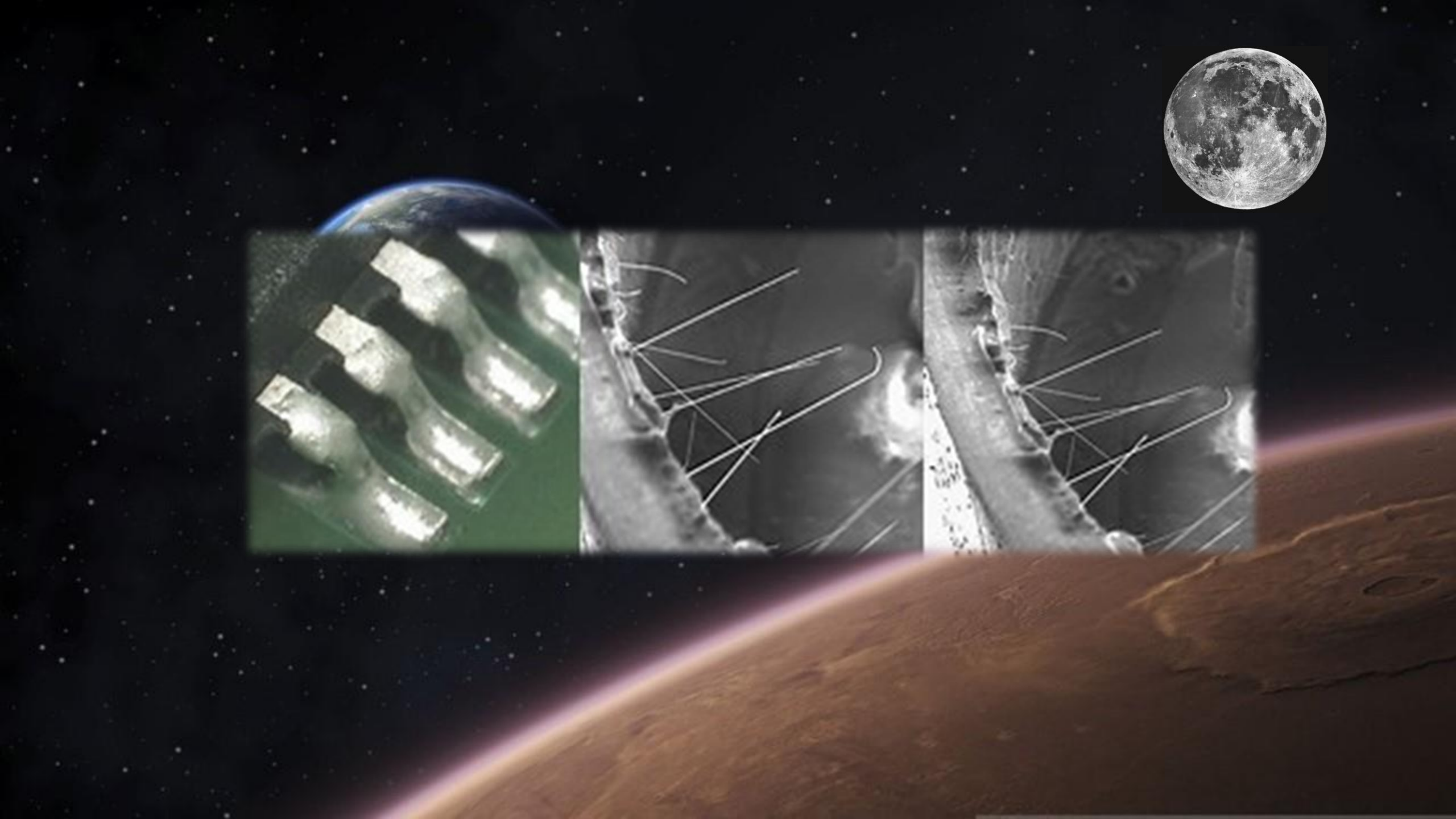



# ARTEMIS ACCORDS



United for Peaceful Exploration of Deep Space

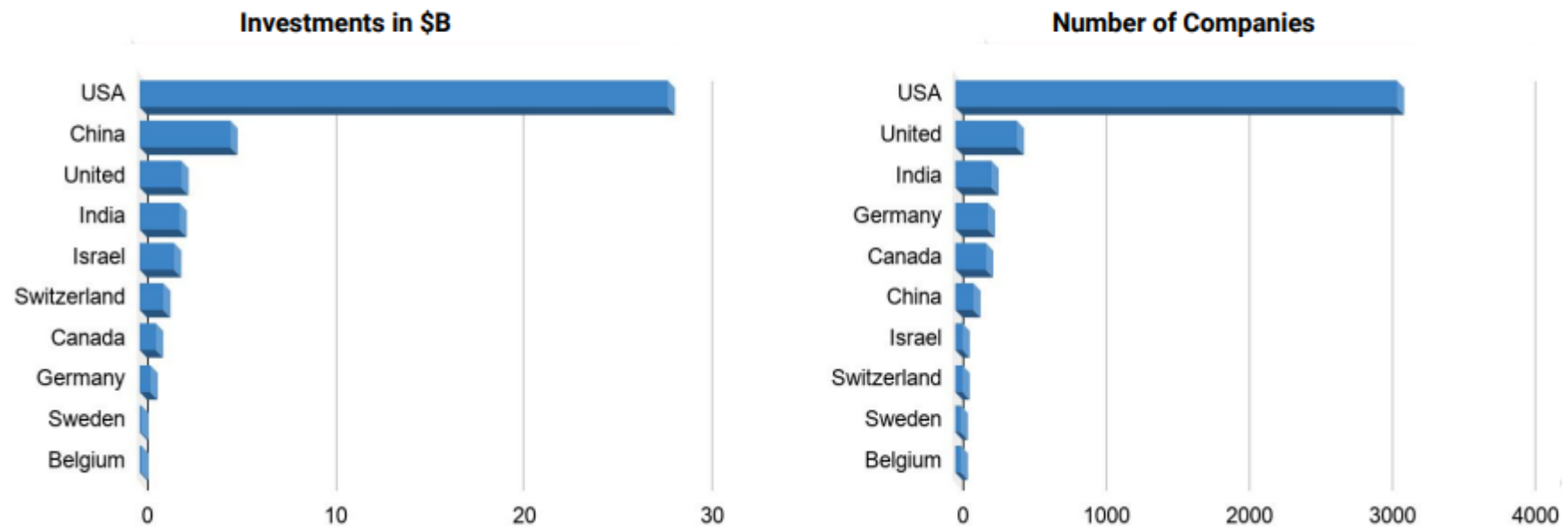




A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is on the right, and the horizon of Mars is at the bottom. The background is a dark field of stars.

The power of vision, private-public collaboration, and profit

## Top 10 Countries in SpaceTech Sector in 2021



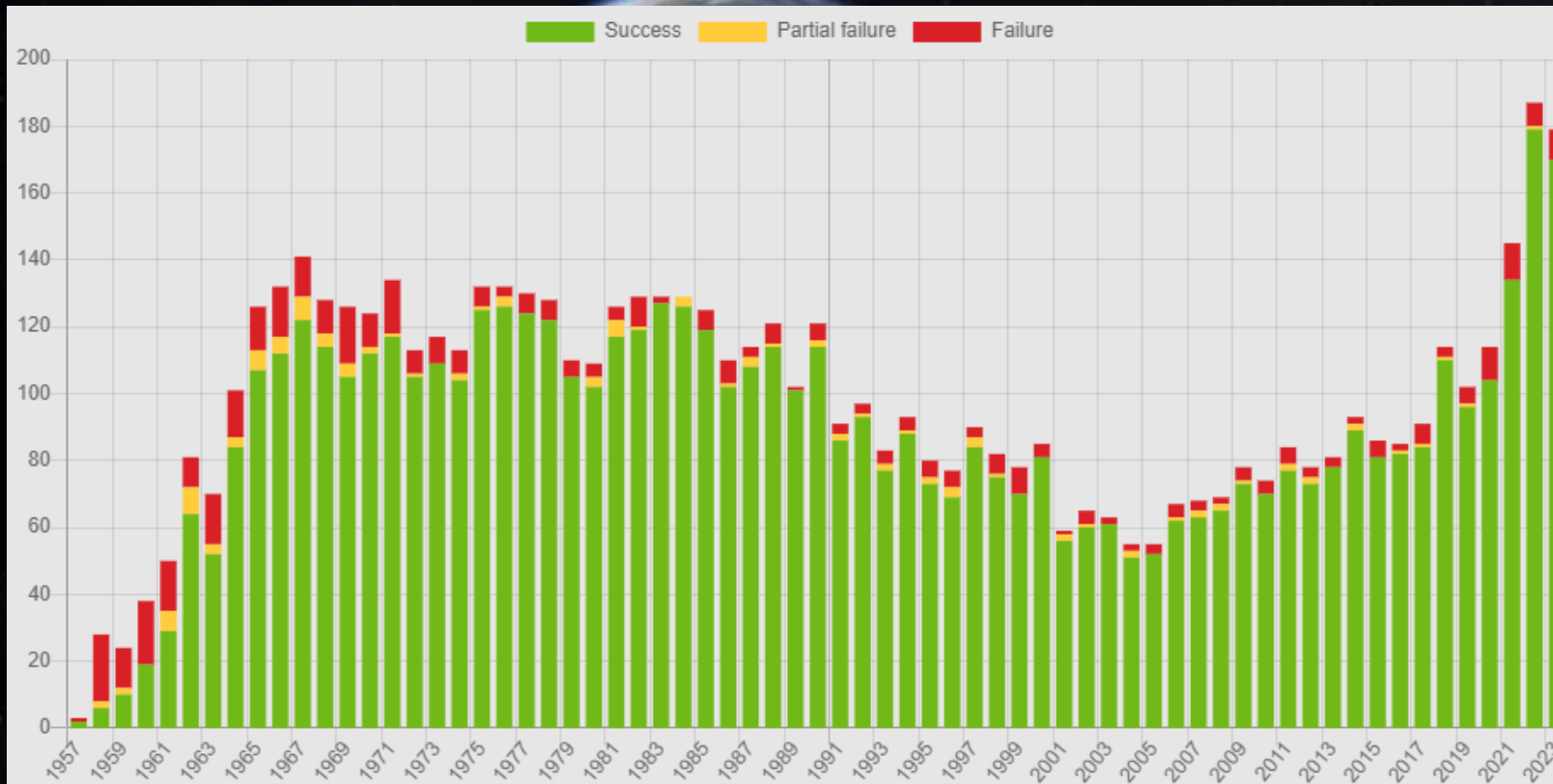
Source: World Economic Forum

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Space economy (M\$)	180,603	188,077	190,613	197,111	197,891	199,244	197,974	206,397	203,587	211,575
Private industries	151,275	158,593	160,298	165,691	165,884	167,280	164,171	168,691	165,232	170,772
Government	29,328	29,484	30,315	31,420	32,007	31,964	33,804	37,707	38,355	40,803
Y/Y Growth		4.0%	1.3%	3.3%	0.4%	0.7%	-0.6%	4.1%	-1.4%	3.8%
% Gov Dollars	16%	16%	16%	16%	16%	16%	17%	18%	19%	19%

Source: Bureau of Economic Analysis



## Number of launches per year



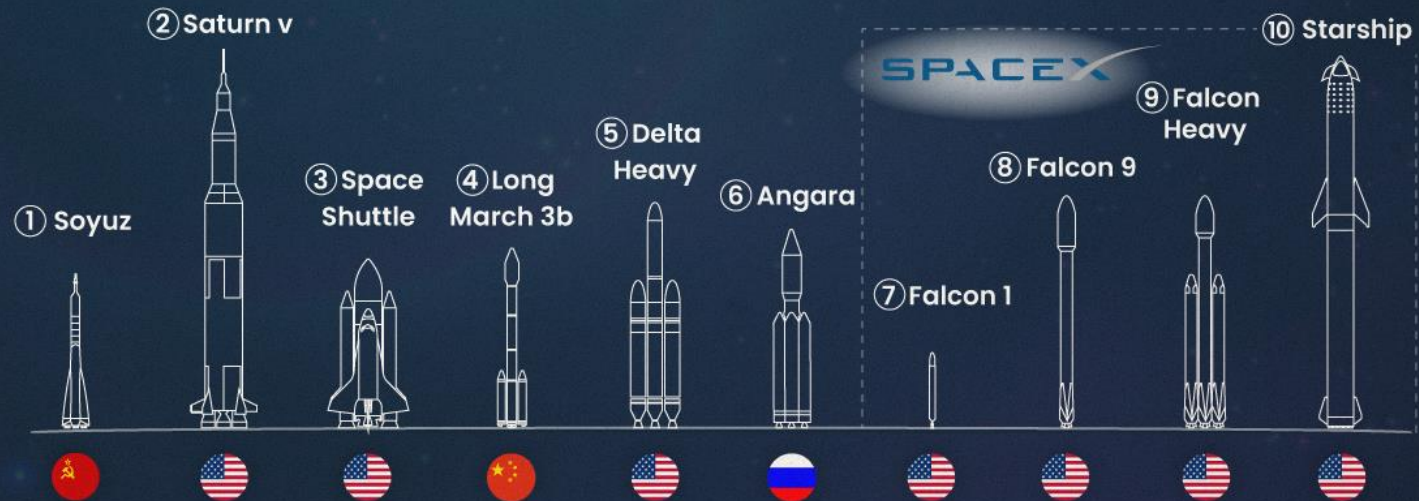
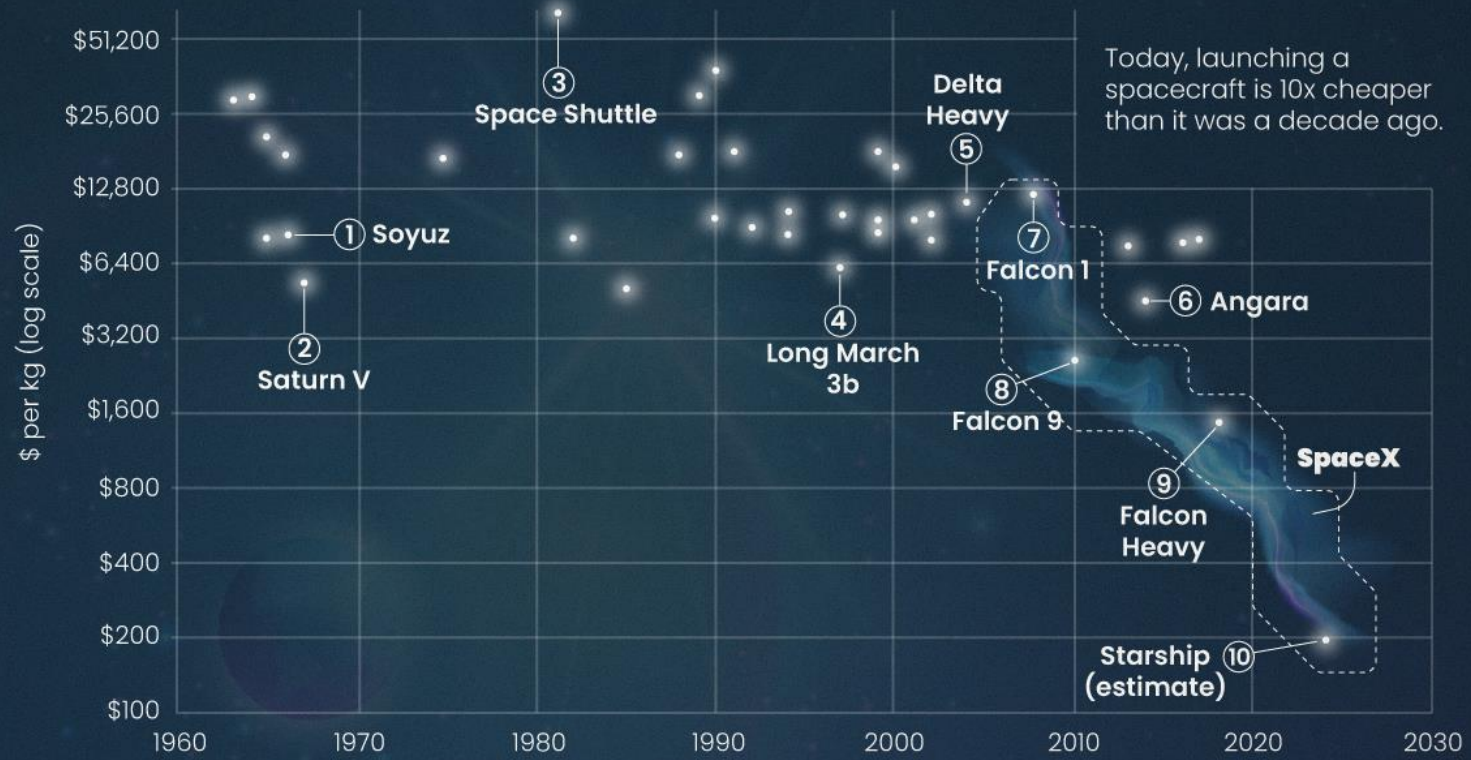
source: spacestatsonline

5,990 total launches  
116 partial failures (1.9%)  
438 total failures (7.3%)

379 launches with humans  
6 have gone to the moon  
0 have gone to Mars

3 manned orbiting outposts in LEO

- Skylab – de-orbited
- Mir
- ISS

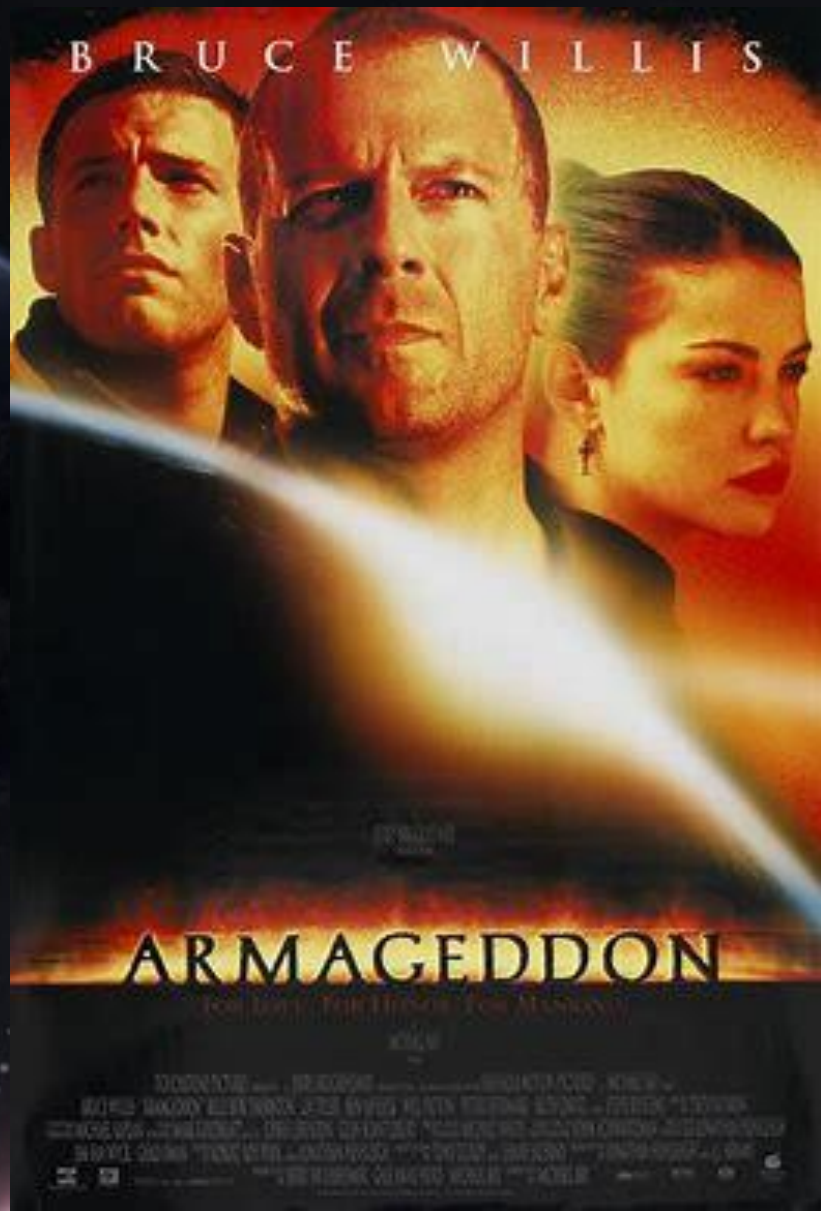


Prices have been adjusted for inflation.  
Source: Center for Strategic and International Studies



A composite image of Earth, the Moon, and Mars in space. The Earth is on the left, the Moon is in the top right, and the horizon of Mars is in the bottom right. The background is a dark field of stars.

**How can we advance under such conditions?**







An epic drama of  
adventure and exploration

Space Station One, your first step in an Odyssey that will take you to the Moon, the planets and the distant stars.



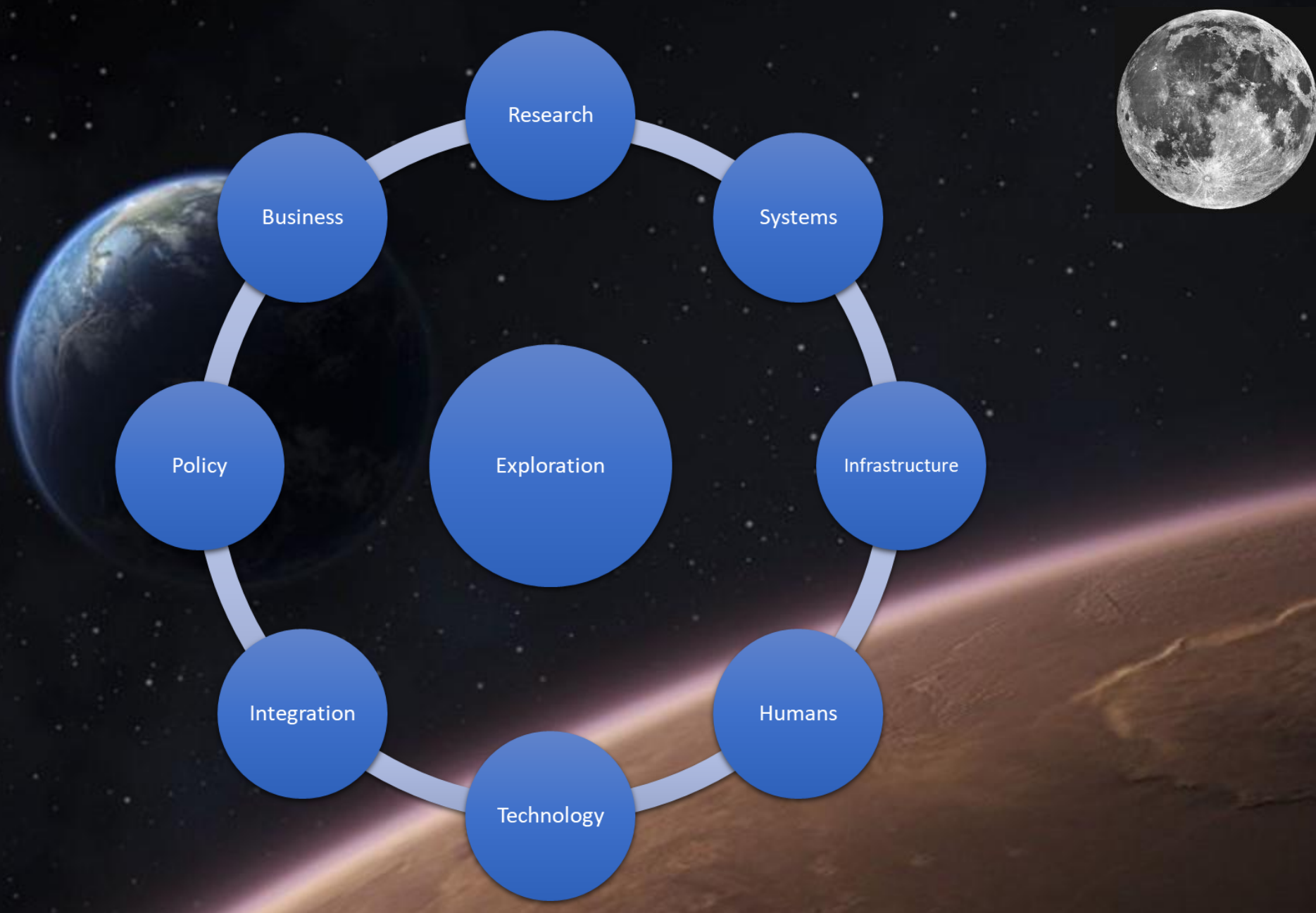
STANLEY KUBRICK'S  
**2001: a space odyssey**

CASTING BY KEIR DULLIEN - CARY LOCKWOOD - STANLEY KUBRICK WITH ARTHUR C. CLARKE  
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## Mass and Energy

V (vehicle + payload mass vs propellant mass)

Surface Distance Traveled vs Time

## Crew Time

Human vs Robotic

Crew and/or Ground vs Automation

## Service Life

Maintainability vs Reliability

Obsolescence vs Supply Chain vs Tech Insertion

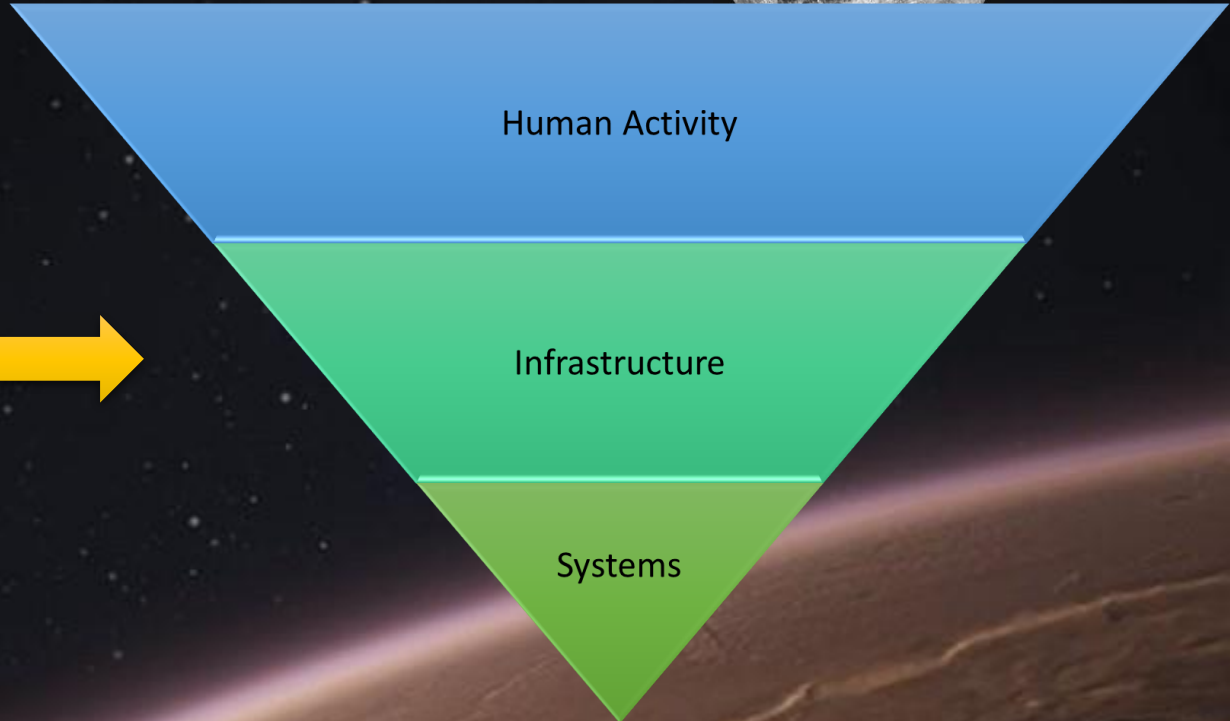
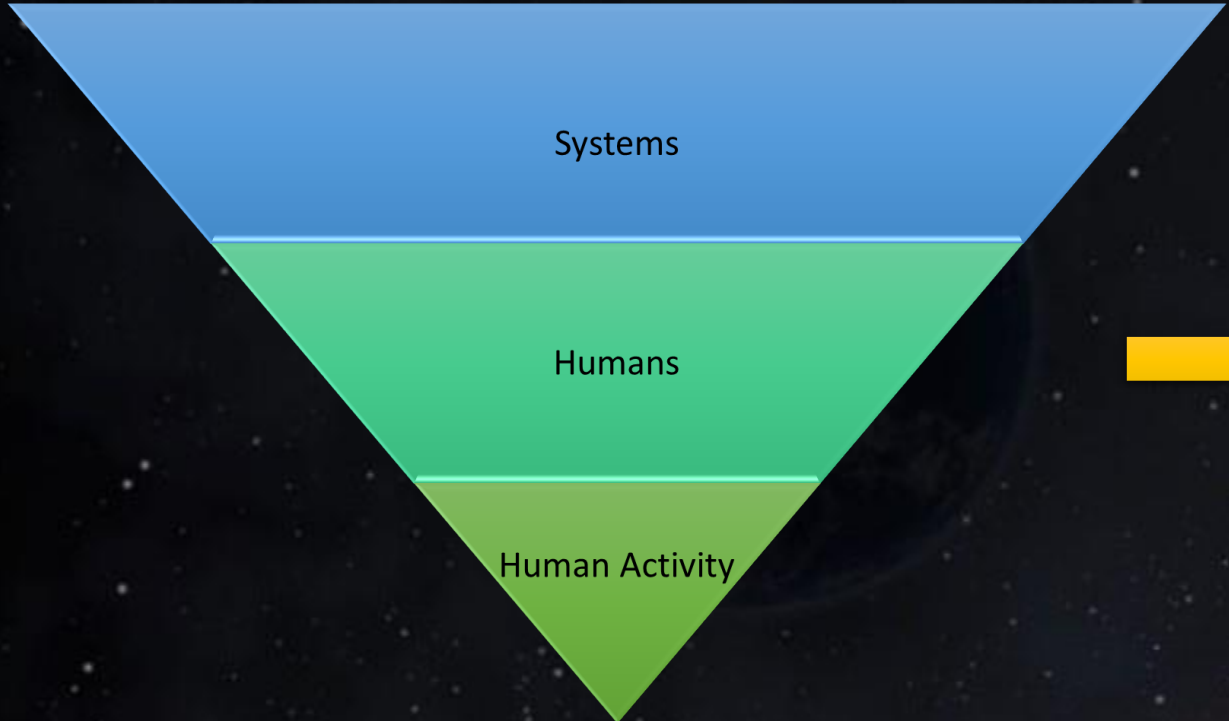
## Programmatic

Cost vs Schedule vs Capability

Risk vs Reward



Big challenges require  
a multi-discipline  
approach to create  
sustainable solutions



# We are at the beginning of the beginning!

A composite image of space featuring Earth, the Moon, and Mars against a starry background. The Earth is on the left, the Moon is in the top right, and the horizon of Mars is at the bottom.

- Space exploration as we know it is going through a fundamental change.
- Once the domain of 2 nations as a strictly government endeavor, it is rapidly transforming to global participation by a multitude of nations, commercial companies, and wealthy individuals.
- Not only is the domain of space increasing in participants, but the number of systems is increasing, each are increasing in complexity, and becoming more dependent on each other.



STAR  
WARS



STAR TREK


Science  
fiction  
could be  
science fact



BATTLESTAR  
GALACTICA



*firefly*

A composite image of space featuring Earth, the Moon, and Mars. Earth is on the left, the Moon is on the right, and the horizon of Mars is at the bottom. The background is a dark field of stars.

# Questions and Answers