SHAPING THE FUTURE OF AEROSPACE

AIAA Central Florida

The American Institute of Aeronautics and Astronautics

Space Exploration: Past, Present, and Future

A presentation to Space Rennaissance International

July 15, 2024

Walter E. Hammond
AIAA Central Florida Section
Chair

Key Enablers for Human Space Exploration to 2050

- Launch and In-Space Transportation
  - Launch Systems (Earth, Moon, Mars, Asteroids)
  - In-Space Mobility Systems (Near-Earth, Cislunar, Mars Vicinity)
- Surface Transportation (Moon, Mars, Asteroids)
- Human-Rated Habitats (Cislunar, Moon, Mars Orbit, Mars Surface)
- Infrastructure
  - Cislunar Space
  - Moon Surface
  - Mars Orbit
  - Mars Surface

Key Milestones in Space Exploration*

1950s

- Sputnik 1, 2 (1957)
- Explorer 1 (1958)

1960s

- Yuri Gagarin (1961)
- John Glenn (1962)
- Project Mercury (1961-1963)
- Valentina Tereshkova (1963)
- Project Gemini (1965-1966)
- Project Apollo (1961-1972)
- N1 Lunar Rocket (1969-1972)

1970s

- Almaz/Salyut Space Stations (1971-1991)
- Skylab (1973-1979)

1980s

- Mir Space Station (1986-2001)
- Space Shuttle (1981-2011) 133 successes, 2 failures

1990s

- Hubble Space Telescope (1990-Present)
- Extrasolar Planets Discovered (1995-Present)
- International Space Station (1998-Present)
- Chandra X-Ray Observatory (1999-Present)

2000s

- Shenzhou 5 – Shenzhou 17 Crewed Missions (2003-Present

2010s

- Falcon 2, Falcon Heavy (2010-Present)
- Tiangong-1 Space Laboratory (2011-2018)
- Tiangong-2 Space Laboratory (2016-2019

2020s

- Tiangong Space Station (2021-Present)
- James Webb Space Telescope (2022-Present)
- Space Launch System (SLS, 2022-Present)
- Starship (2023 – Present)

*Excluding Lunar and Planetary Exploration (tabulated elsewhere)

First in Space: Soviet Union

- 1957: First intercontinental ballistic missile, the R–7 Semyorka
- 1957: First satellite, Sputnik 1
- 1957: First animal to enter Earth orbit, the dog Laika on Sputnik 2
- 1959: First firing of a rocket in Earth orbit, first man–made object to escape Earth's orbit, Luna
- 1959: First data communications, or telemetry, to and from outer space, Luna 1
- 1959: First man–made object to pass near the Moon, first man–made object to orbit the Sun, Luna 1
- 1959: First probe to impact the moon, Luna 2
- 1959: First images of the moon's far side, Luna 3
- 1960: First animals to safely return from Earth orbit, the dogs Belka and Strelka on Sputnik 5
- 1960: First probe launched to Mars, Marsnik 1
- 1961: First probe launched to Venus, Venera 1
- 1961: First person in space (International definition) and in Earth orbit, Yuri Gagarin on Vostok 1
- 1961: First person to spend over a day in space, Gherman Titov, Vostok 2 (also first person to sleep in space)
- 1962: First dual manned spaceflight and approach, Vostok 3 and Vostok 4
- 1963: First woman in space, Valentina Tereshkova, Vostok 6
- 1964: First multi–man crew (3), Voskhod 1
- 1965: First EVA, by Aleksei Leonov, Voskhod 2
- 1965: First probe to hit another planet (Venus),Venera 3
- 1966: First probe to make a soft landing on and transmit from the surface of the Moon, Luna 9
- 1966: First probe in lunar orbit, Luna 10
- 1967: First unmanned rendezvous and docking, Cosmos 186/Cosmos 188 (it took until 2006 for the United States to duplicate this major space achievement)
- 1969: First docking between two manned craft in Earth orbit and exchange of crews, Soyuz 4and Soyuz 5
- 1970: First samples automatically returned to Earth from another body, Luna 16
- 1970: First robotic space rover, Lunokhod 1
- 1970: First data received from the surface of another planet (Venus), Venera 7
- 1971: First space station, Salyut 1
- 1971: First probe to orbit another planet (Mars), first probe to reach surface of Mars, Mars 2
- 1975: First probe to orbit Venus, first photos from surface of Venus, Venera 9
- 1984: First woman to walk in space, Svetlana Savitskaya (Salyut 7 space station)
- 1986: First crew to visit two separate space stations (Mir and Salyut 7)
- 1986: First permanently manned space station, Mir, which orbited the Earth from 1986 until2001
- 1987: First crew to spend over one year in space, Vladimir Titov and Musa Manarov on board of TM–4 – Mir

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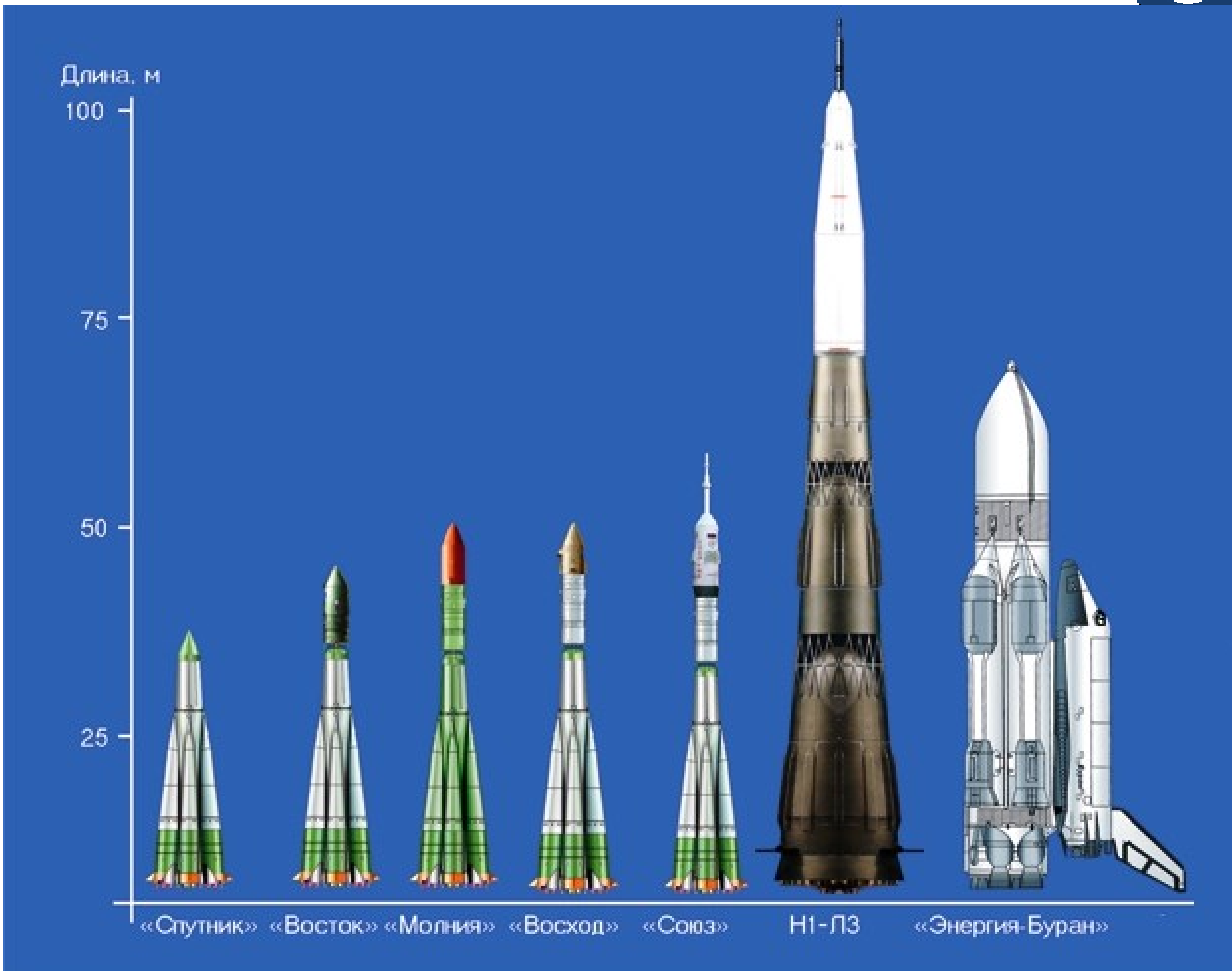
Key Lunar Programs US/USSR 1960s-1970s

Year	United States (Apollo Program)	USSR Manned Lunar Landing Program (N1/L–3)	USSR Zond Manned Lunar Orbital Program (UR–500/L–1)
1961	US launches Alan Shepard into sub-orbital flight nearly 2 months after flight of Vostok 1. US committed to a manned lunar landing before the end of the decade by Pres. Kennedy.	USSR launches first manned spacecraft, Vostok 1, with Yuri Gagarin aboard. Original N1 and N2 launch vehicle programs officially approved.	3-stage Proton booster (in development) designated for circumlunar flight.
1962	Preliminary Apollo mission profile, including lunar orbit rendezvous, approved by NASA.		
1963			
1964	Boilerplate Apollo spacecraft launched by Saturn 1 rocket.	USSR launches first multi-manned spacecraft, Voskhod 1. Lunar landing mission adopted. Preliminary N1/L-3 mission profile established. First lunar landing scheduled for 1967-1968 timeframe.	3-stage Proton/L-1 design and mission profile adopted. Manned lunar fly-by scheduled for 1967.
1965	First flight of multi-manned US spacecraft (Gemini 3). First spacewalk (EVA) by a US astronaut (Ed White, Gemini 4) 3 months after flight of Voskhod 2.	USSR cosmonaut Alexei Leonov completes 1st EVA during Voskhod 2 mission.	Maiden flight of 2-stage Proton. Circumlunar mission modified to utilize 4-stage Proton with Korolyov L-1 spacecraft.
1966	First manned spacecraft docking demonstrated in earth orbit (Gemini 8).	Sergei Korolyov dies during surgery. V. Mishin takes over leadership of USSR space program. N1/L-3 program officially adopted. First lunar landing set for 3rd quarter of 1968.	
1967	Apollo 1 crew killed in flash fire aboard spacecraft during launch pad test. Maiden flight of Saturn V with unmanned Apollo spacecraft (Apollo 4).	Vladimir Komarov killed during maiden (manned) flight of Soyuz spacecraft. Initial N1 flight tests delayed. First automatic spacecraft docking demonstrated in earth orbit (Cosmos 186/188).	Maiden flight of 4-stage Proton and L-1 spacecraft in earth orbit successful (Kosmos 146), but followed by 3 failures. Cosmonaut training for Zond missions begun.
1968	First manned flight of Apollo spacecraft (Apollo 7), modified after death of crew of Apollo 1. Unmanned lunar module tested in earth orbit (Apollo 6). First manned Saturn V/lunar orbital Apollo mission (Apollo 8).	Cosmonaut training for lunar landing missions begun. Yuri Gagarin, 1st human in space, killed during training flight in MiG-15. 1st successful manned flight of Soyuz spacecraft (Soyuz 3), modified after death of Vladimir Komarov on Soyuz 1 mission.	4 unmanned Zond circumlunar missions all end in failure (3 total, 1 partial).
1969	First manned flight of lunar module in earth orbit (Apollo 9). 3 manned missions to the moon, including 2 lunar landings (Apollo's 10, 11, & 12).	Maiden flight of N1 failed after 70 secs. (N1 3L). 2nd flight of N1 (N1 5L) failed immediately after launch - vehicle and launch pad destroyed.	Unmanned Zond mission failed in January. 2nd mission in August (Zond 7) only completely successful mission in program, but program canceled.
1970	Apollo 13 lunar landing mission aborted during trans-lunar coast.	Unmanned prototype of lunar landing vehicle (T2K) successfully tested in earth orbit.	Final unmanned Zond circumlunar mission (Zond 8) partially successful.

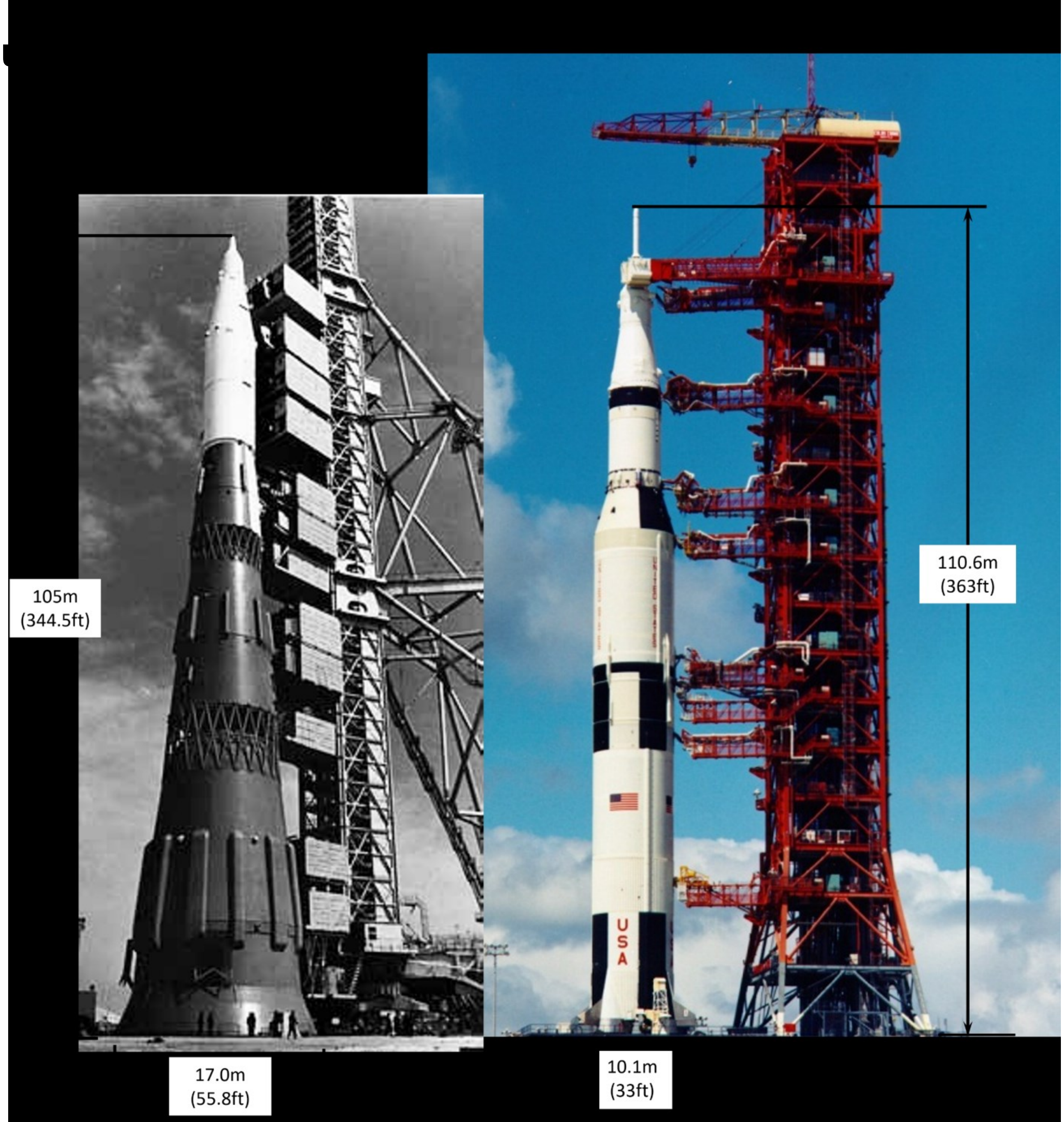
Key Lunar Programs US/USSR 1960s-1970s continued

Year	United States (Apollo Program)	USSR Manned Lunar Landing Program (N1/L–3)	USSR Zond Manned Lunar Orbital Program (UR–500/L–1)
1971	3rd and 4th Apollo lunar landing missions (Apollo's 14 & 15).	3rd N-1 flight failed after 51 secs. (N1 6L) Advanced N1/L-3M program proposed. Crew of Soyuz 11 become 1st humans to inhabit a space station (Salyut 1) but are killed during reentry.	
1972	5th and 6th Apollo lunar landings. (Apollo's 16 & 17). Apollo lunar program concluded. No human has set foot on the moon since then.	4th N1 flight failed after 107 secs (N-1 7L).	
1973	Skylab 1 Orbital Workshop launched unmanned into earth orbit. Extensive damage done to spacecraft during launch. Vehicle manned by successive crews from Skylab's 2, 3, & 4 missions.		
1974		Vasily Mishin replaced by long–time rival Valentin Glushko. All Soviet manned lunar programs cancelled, and official program of denial begins with destruction of all remaining N1 hardware.	
1975	Last manned Apollo mission (ASTP or Apollo 20) docks with Soviet Soyuz spacecraft (Soyuz 19). Another American would not fly in space for 6 more years, until the flight of STS-1.	Soviets continue extensive program of space station missions.	

Soviet Union Launch Vehicles



N1-Satu



N1-Saturn V Failure Comparison

N-1
4 Launches, 4 Failures

February 21, 1969 (69 sec)

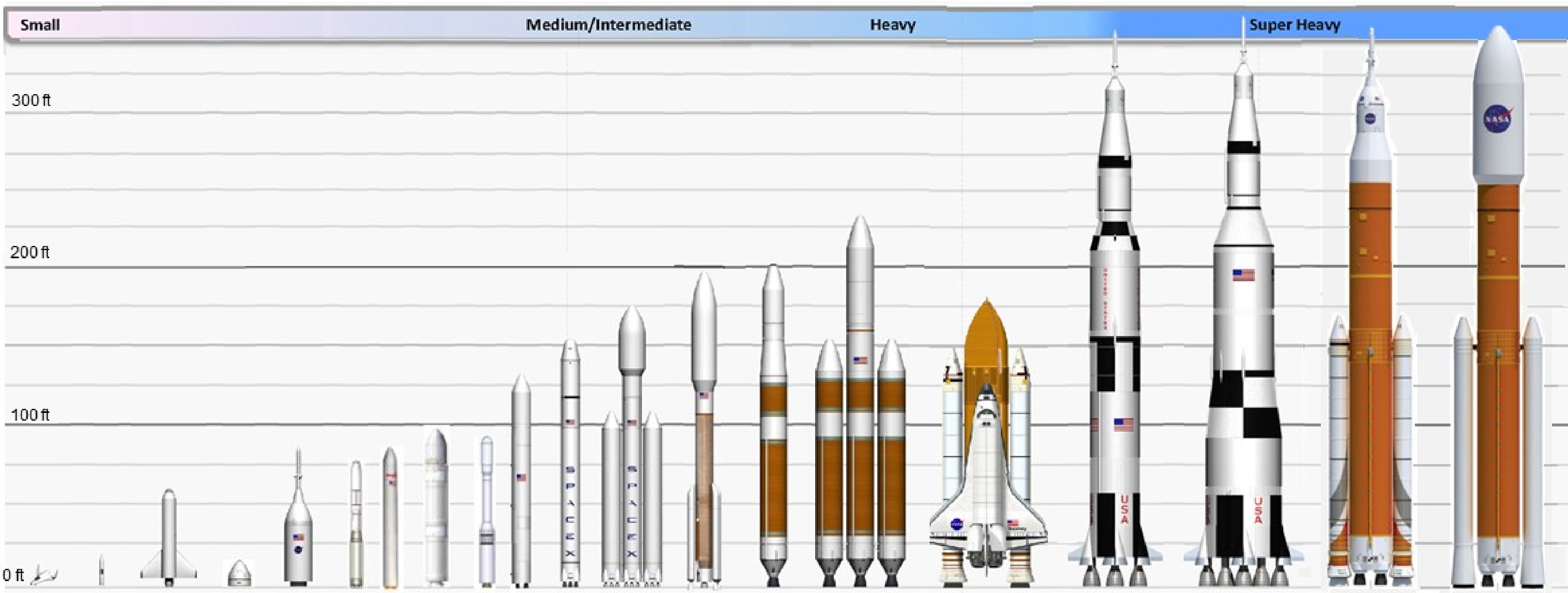
June 27, 1971 (50 sec)

July 4, 1969 (12 sec)

November 23, 1972 (107 sec)

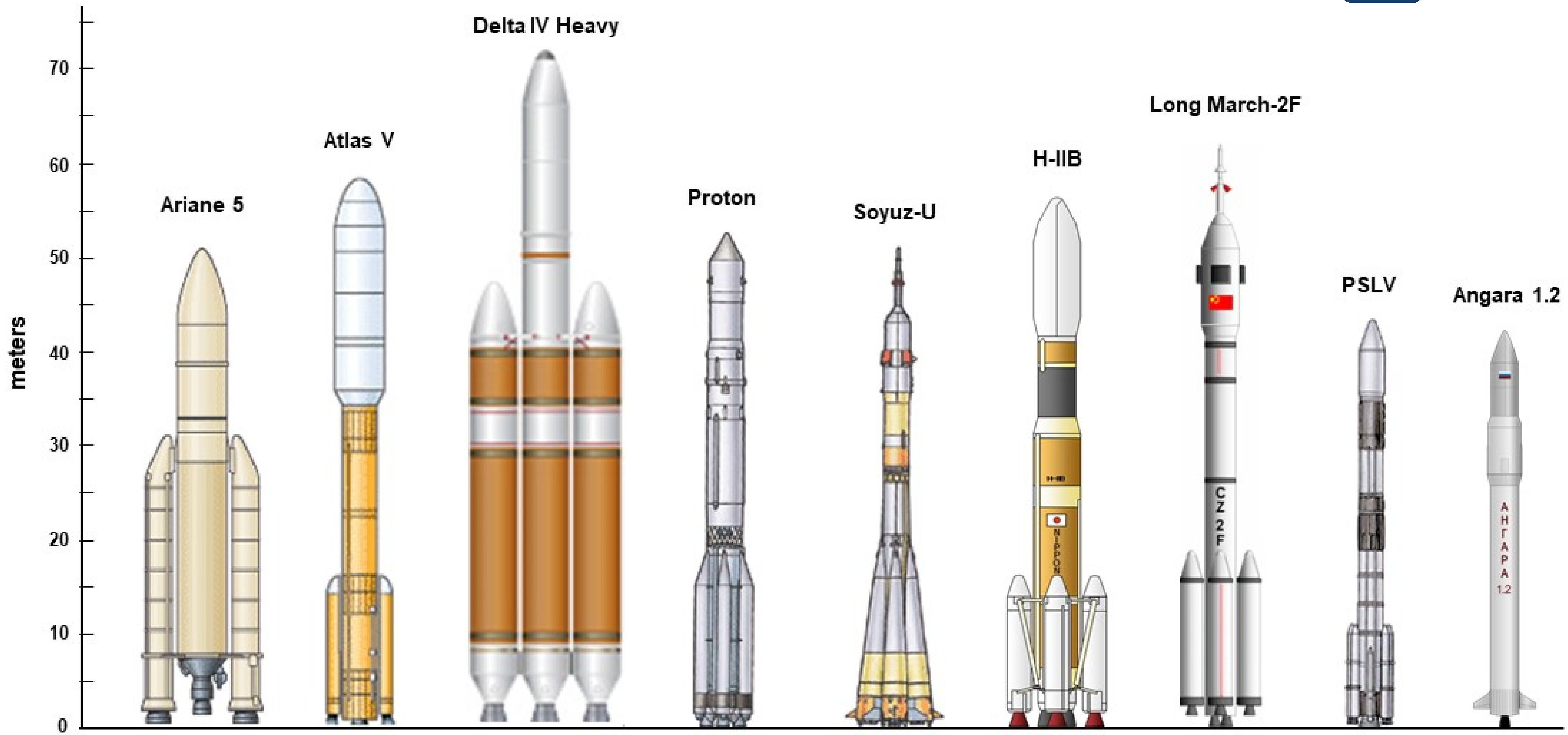
Saturn V
13 Successful Launches, 0 Failures

United States Launch Vehicles



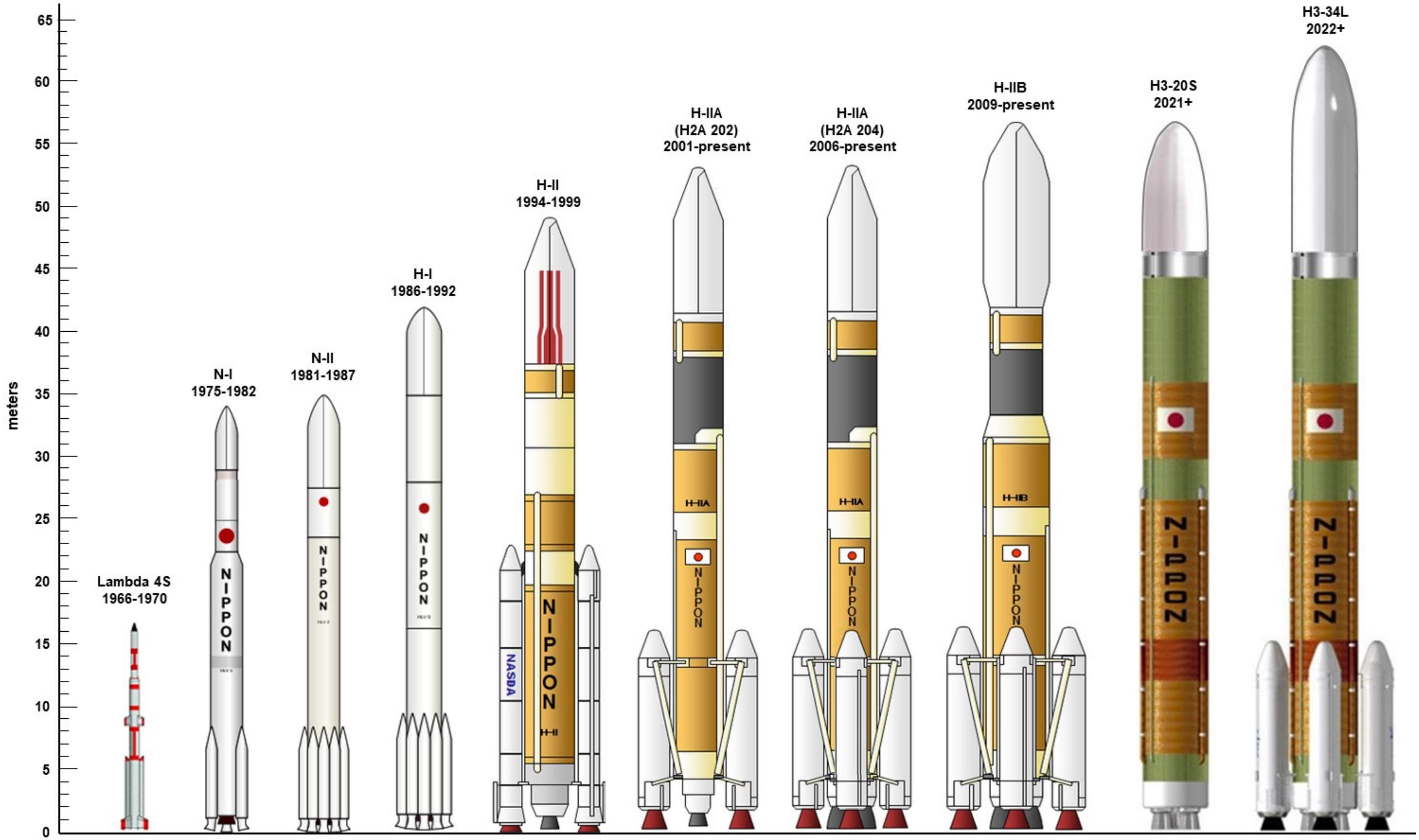
Lynx XCOR	XA-1.0 Masten	RBX Pathfinder AFRL	MLAS NESC	AA-2 OSC	Minotaur IV and V OSC	Athena IIC ATK	Taurus I and II OSC	Falcon 9 and 9H SpaceX	Atlas V SS1 ULA	Delta IV M ULA Delta IV H ULA	Space Shuttle NASA	Saturn V NASA	Nova (Concept Only) NASA	Space Launch System NASA

Present International Launch Vehicles



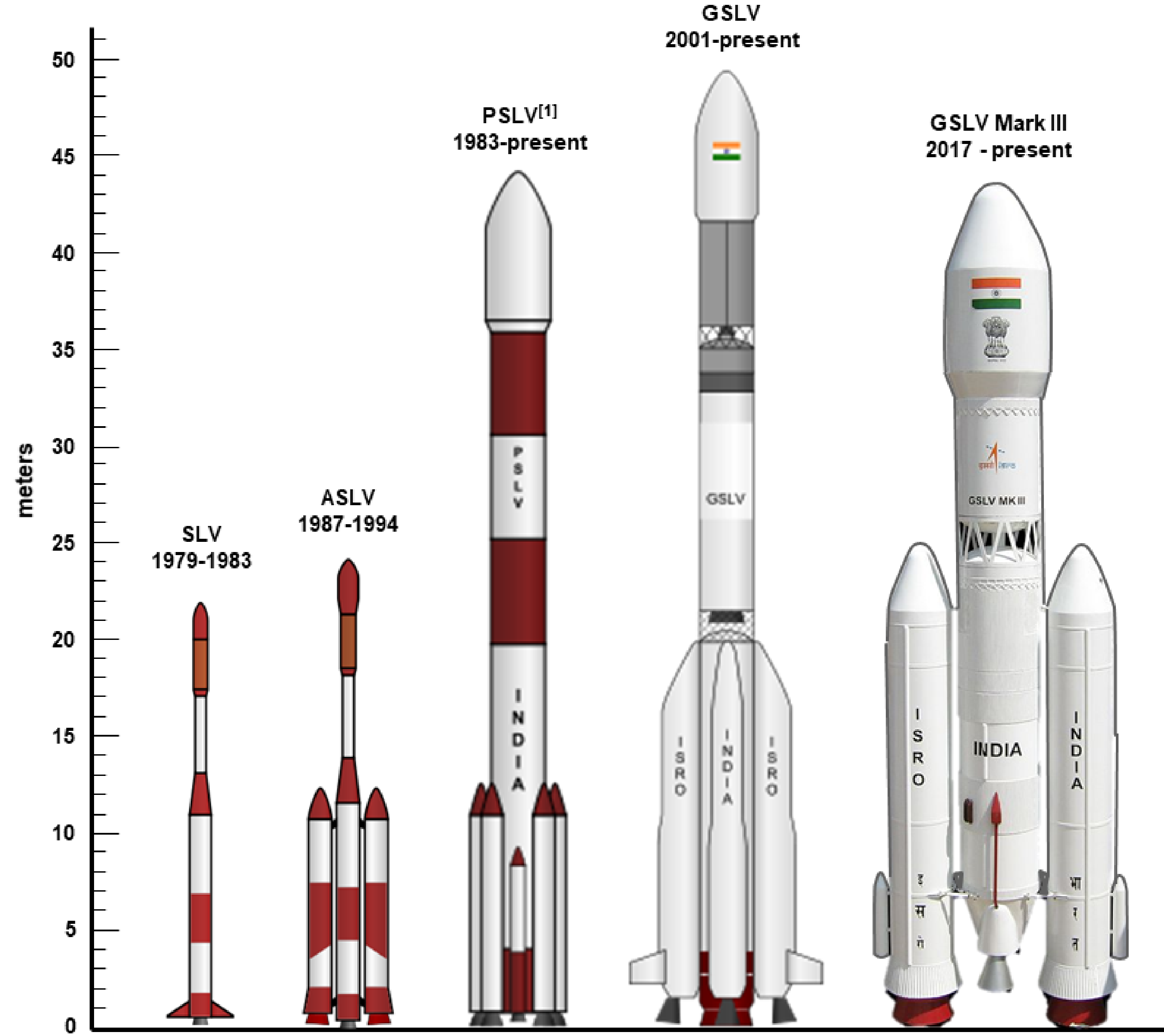
	Ariane 5	Atlas V	Delta IV Heavy	Proton	Soyuz-U	H-IIB	Long March-2F	PSLV	Angara 1.2
Height	51.0 m	58.3 m	72.0 m	53.0 m	51.1 m	56.6 m	62.0 m	44.0 m	42.2 m
Lift Capability	21.0 tonnes	18.8 tonnes	28.8 tonnes	20.7 tonnes	6.9 tonnes	19.0 tonnes	8.4 tonnes	3.3 tonnes	3.8 tonnes
Thrust	15.1 MN	6.4 MN	9.4 MN	10.5 MN	7.2 MN	10.9 MN	5.9 MN	7.9 MN	1.9 MN

Japanese Launch Vehicles



Height	16.5 m	34.0 m	35.0 m	42.0 m	49.0 m	53.0 m	53.0 m	56.6 m	63m	63m
Lift Capability	26 kg	1.2 mt	2.0 mt	3.2 mt	10.1 mt	10.0 mt	15.0 mt	16.5 mt	1.5 mt[2]	18.0 mt[2]
Thrust	? KN	2.3 MN	3.2 MN	3.2 MN[1]	3.9 MN	5.4 MN	9.9 MN	11.0 MN	2.3 MN	12.1 MN

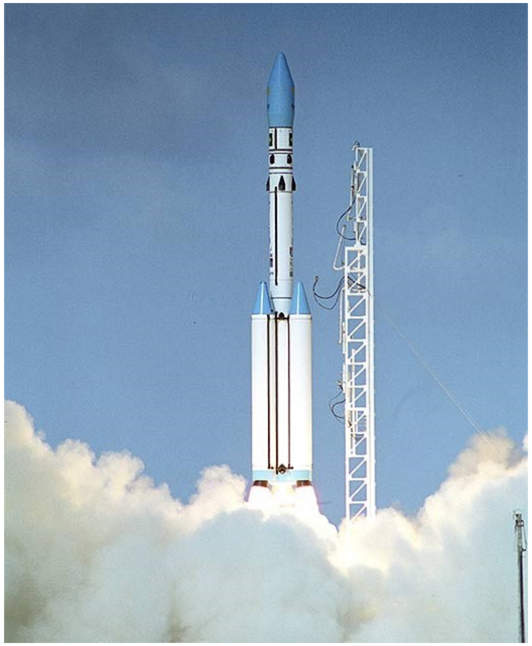
Indian Launch Vehicles



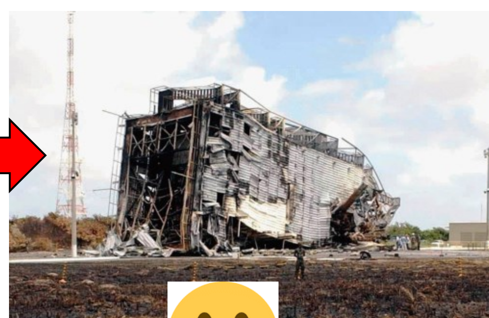
	SLV	ASLV	PSLV	GSLV	GSLV Mark III
Height	22 m	24 m	44 m	49.1 m	43.4 m
Lift Capability	40 kg	150 kg	3.8 mt[2]	5 mt[3]	10 mt[4]
Thrust	0.5 MN	1.0 MN	9.0 MN	7.8 MN	11.8 MN

Brazilian & South Korean Launch Vehicles

Brazil



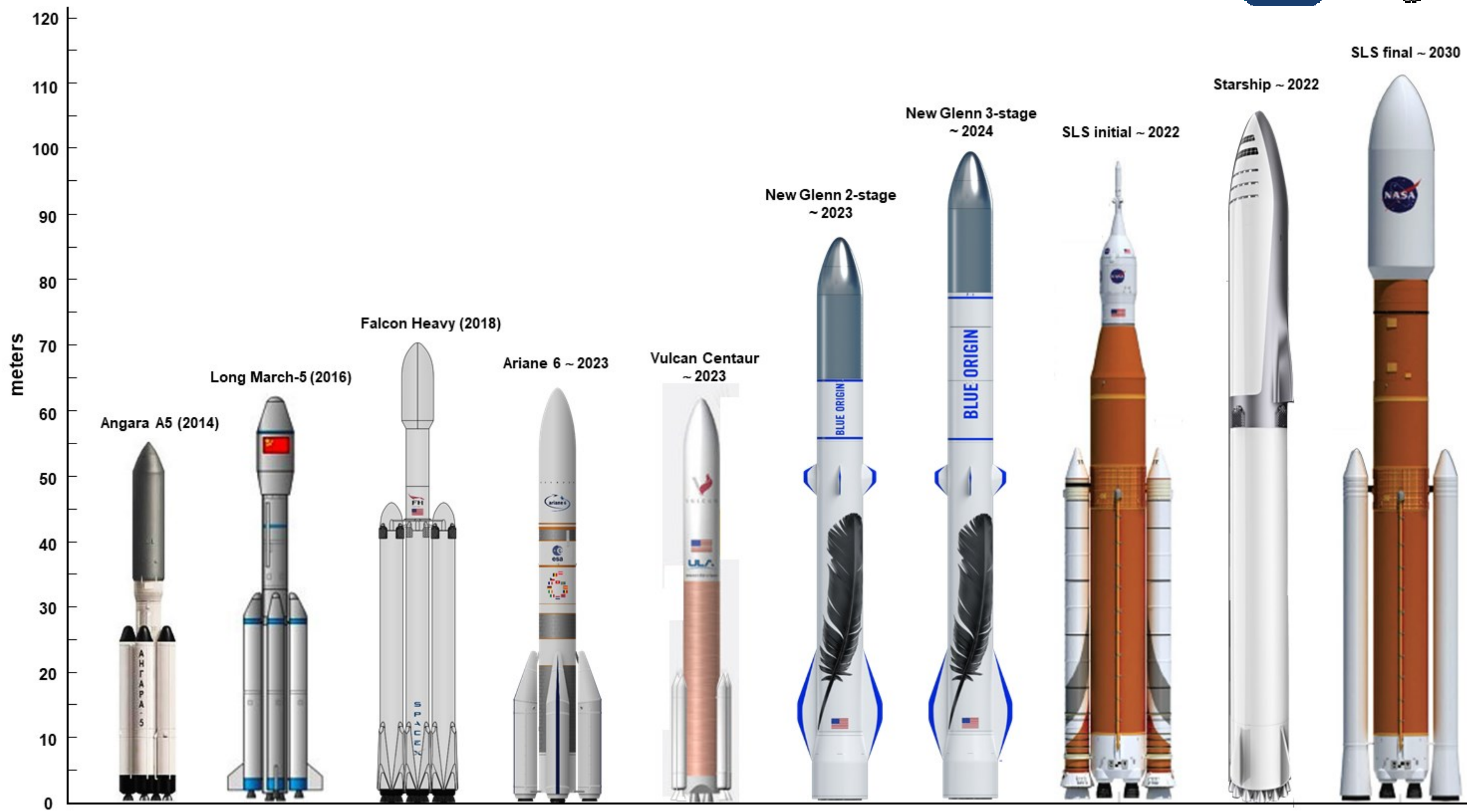
Veículo Lançador de Satélites (VLS)



South Korea

Naro-1

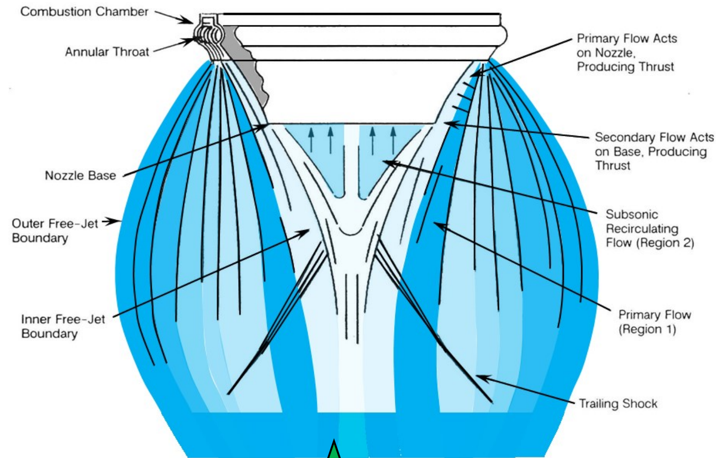
Future International Launch Vehicles



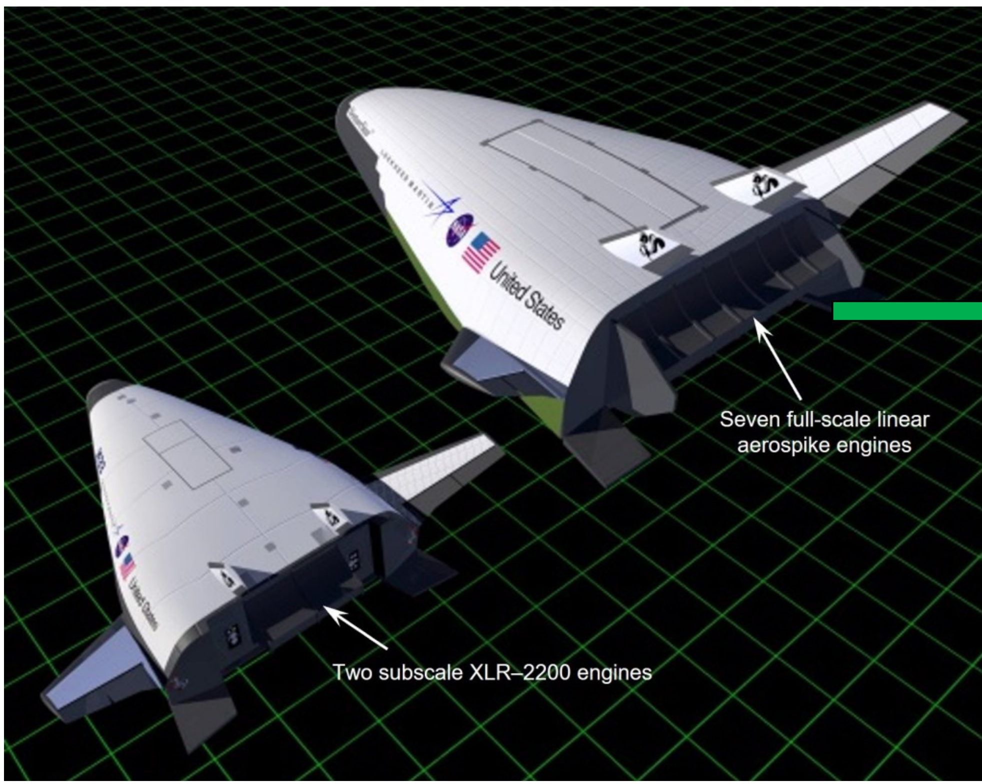
Height	55.4 m	62.0 m	70 m	63 m	61.6 m	86 m	99 m	98.1 m	106 m	111.3 m
Lift Capability	24.5 tonnes[1]	25.0 tonnes[1]	27.6 tonnes[1]	11.5 tonnes[1],[3]	27.2 tonnes[4]	45 tonnes	45 tonnes	70 tonnes	150 tonnes	130 tonnes
Thrust	9.4 MN[2]	10.7 MN	17.6 MN	19.4 MN[3]	18.1 MN[4]	17.1 MN	17.1 MN	37.4 MN	52.7 MN	40.9 MN

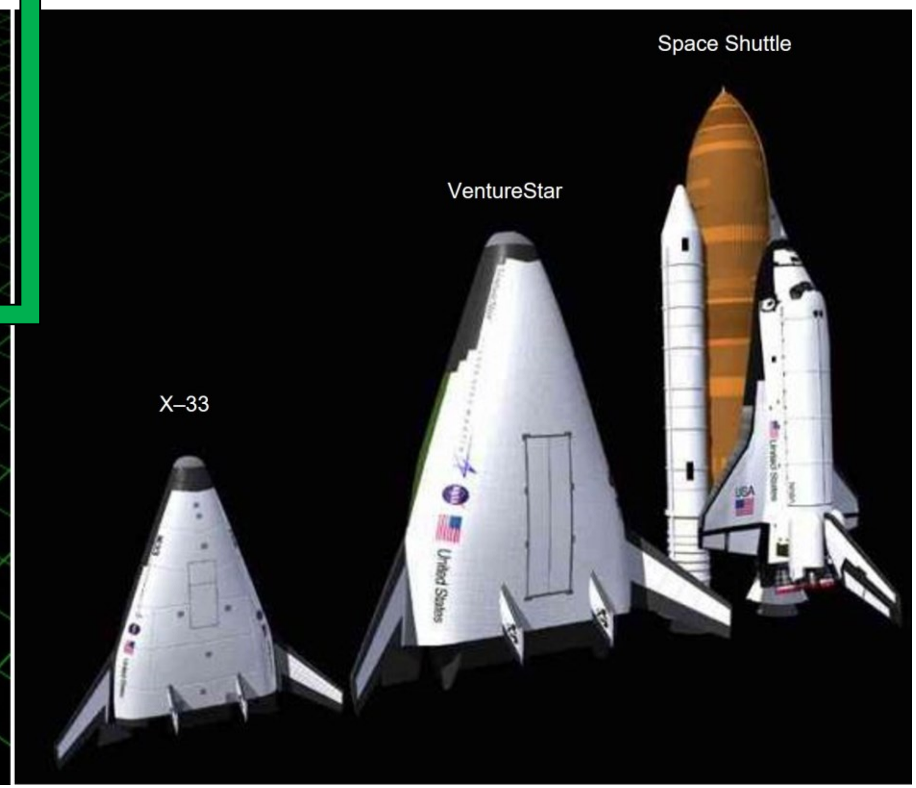
Single Stage to Orbit ?

McDonnell Douglas DC-XA



Lockheed Martin VentureStar





Propulsion for Interplanetary Travel

Video

DragonFly Mission to Titan, Nuclear Thermal & Nuclear Electric Propulsion

00:15 Titan Helicopter Starts to Come Together
https://www.universetoday.com/159611/
02:38 New NIAC Nuclear Rocket Design
https://www.universetoday.com/159599/
05:30

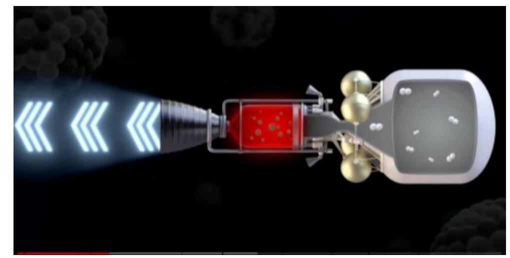
Video

NASA Deep Space Exploration
02:03 Curiosity
6:08 Landing on Mars
8.04 Asteroid Redirect Mission

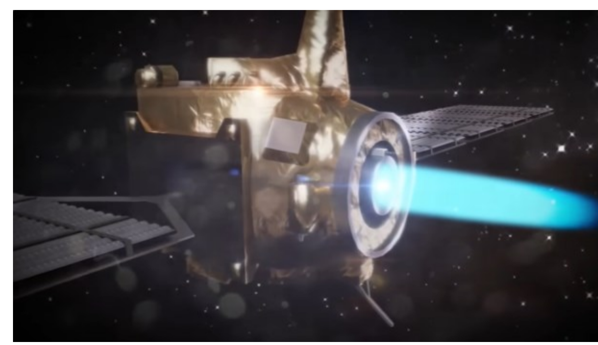
AI

DragonFly

Nuclear Thermal Propulsion (NTR)



Nuclear Electric Propulsion (NEP)



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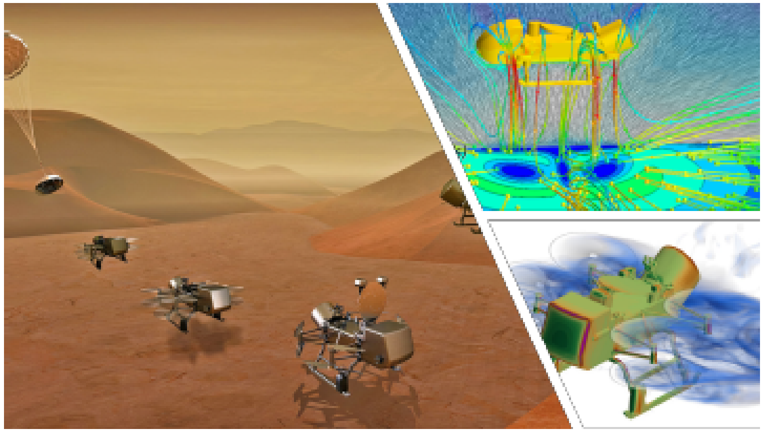
AIAA Central: Monthly BBQ & Seminar
Florida Space Institute
12354 Research Parkway (Partnership 1 Building), Room 209
6:30-8:30pm Thursday, Feb. 15
6:30-7:20, Socialization and BBQ, followed by seminar

Rotorcraft-Lander Aerodynamics in the Titan Environment: Applying Modern Computational Aerodynamics for the Dragonfly lander

Abstract: The Dragonfly mission was recently selected in NASA's New Frontiers program to explore the potential for primitive life forms on Saturn's moon Titan. Flight on Titan is particularly favorable due to the thick atmosphere and low gravity, which are roughly 4.5 and 1/7 that of Earth's, respectively. These favorable flight conditions drive the potential for a lander that explores Titan for life with mobility through powered flight which has the potential to cover more terrain than all the Mars rovers combined. The mission, however, demands assurance of reliable flight operations that includes stable forward flight, sensing for flight and scientific measurements, and extended range. Additionally, the lander involves complex flight scenarios associated with entry-descent and landing and take-off and landing that involve intense interactions that also demand further understanding. Unfortunately, we cannot test the lander in most of these conditions on Earth. Hence, UCF is part of a team that is directly studying these flight and scientific operations for Dragonfly using computational methods. The talk will discuss the Dragonfly flight operations and how UCF is helping to shape the Dragonfly lander to ensure a successful scientific mission on Titan.



Biosketch: Dr. Michael Kinzel is an Associate Professor at the University of Central's Mechanical and Aerospace Engineering Department and runs the Computational Fluids and Aerodynamics Laboratory (CFAL). Kinzel's research spans basic and applied research for multiphase fluid flows and aero/hydrodynamics using computational fluid dynamics (CFD). His experience spans a wide range of applications that includes: aircraft (V/STOL, ice accretion), wind turbines, marine vehicles, atmospheric flows, chemical reactors, nuclear waste processing, food processing, biomedical and acoustics.

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Lunar and Planetary Exploration

https://nssdc.gsfc.nasa.gov/planetary/chronology.html

- 1957
- Sputnik 1 - 4 October 1957 - Earth Orbiter
- Sputnik 2 - 3 November 1957 - Earth Orbiter
- Vanguard TV3 - 6 December 1957 - Attempted Earth Orbiter (Launch Failure)
- 1958
- Explorer 1 - 1 February 1958 - Earth Orbiter
- Vanguard 1 - 17 March 1958 - Earth Orbiter
- Pioneer 0 - 17 August 1958 - Attempted Lunar Orbit (Launch Failure)
- Luna 1958A - 23 September 1958 - Attempted Lunar Impact? (Launch Failure)
- Pioneer 1 - 11 October 1958 - Attempted Lunar Orbit (Launch Failure)
- Luna 1958B - 12 October 1958 - Attempted Lunar Impact? (Launch Failure)
- Pioneer 2 - 8 November 1958 - Attempted Lunar Orbit (Launch Failure)
- Luna 1958C - 4 December 1958 - Attempted Lunar Impact? (Launch Failure)
- Pioneer 3 - 6 December 1958 - Attempted Lunar Flyby (Launch Failure)
- 1959
- Luna 1 - 2 January 1959 - Lunar Flyby (Attempted Lunar Impact?)
- Pioneer 4 - 3 March 1959 - Lunar Flyby
- Luna 1959A - 16 June 1959 - Attempted Lunar Impact? (Launch Failure)
- Luna 2 - 12 September 1959 - Lunar Impact
- Luna 3 - 4 October 1959 - Lunar Flyby
- Pioneer P-3 - 26 November 1959 - Attempted Lunar Orbiter (Launch Failure)
- 1960
- Luna 1960A - 15 April 1960 - Attempted Lunar Flyby (Launch Failure)
- Luna 1960B - 18 April 1960 - Attempted Lunar Flyby (Launch Failure)
- Pioneer P-30 - 25 Sept 1960 - Attempted Lunar Orbiter (Launch Failure)
- Mars 1960A - 10 October 1960 - Attempted Mars Flyby (Launch Failure)
- Mars 1960B - 14 October 1960 - Attempted Mars Flyby (Launch Failure)
- Pioneer P-31 - 15 December 1960 - Attempted Lunar Orbiter (Launch Failure)
- 1961
- Sputnik 7 - 4 February 1961 - Attempted Venus Impact
- Venera 1 - 12 February 1961 - Venus Flyby (Contact Lost)
- Ranger 1 - 23 August 1961 - Attempted Lunar Test Flight
- Ranger 2 - 18 November 1961 - Attempted Lunar Test Flight

Sputnik 1
84 kg (185 lb)

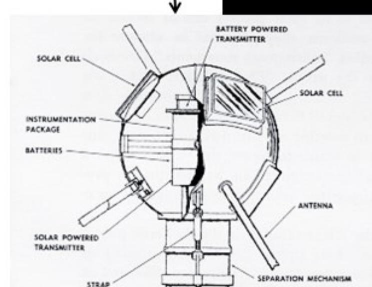
0.6m (23in)

Sputnik 2
508 kg (1121 lbs)
4m (13 ft)

2m (6.6 ft)

Vanguard 1
< 1.5kg (3.25 lbs)

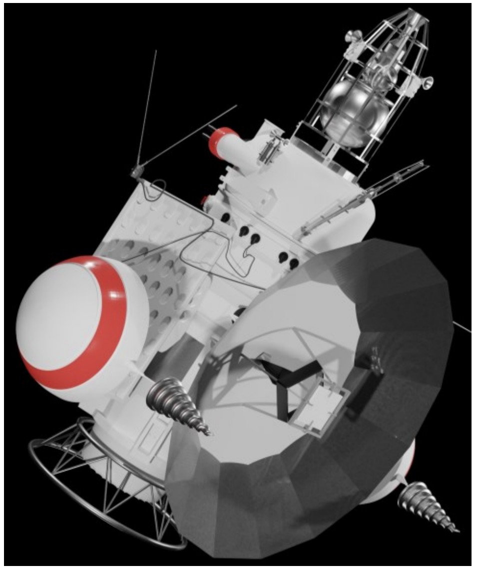
0.15m (6 in)



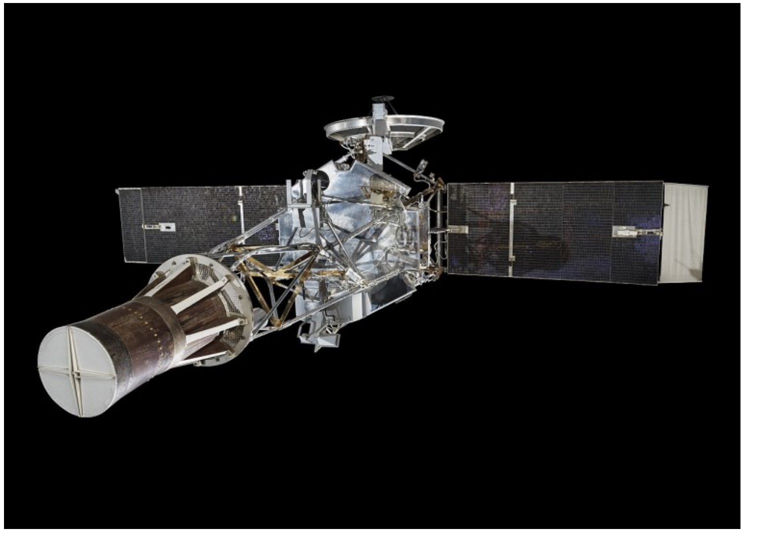
Lunar and Planetary Exploration

- 1962
- Ranger 3 - 26 January 1962 - Attempted Lunar Impact
- Ranger 4 - 23 April 1962 - Lunar Impact
- Mariner 1 - 22 July 1962 - Attempted Venus Flyby (Launch Failure)
- Sputnik 19 - 25 August 1962 - Attempted Venus Flyby
- Mariner 2 - 27 August 1962 - Venus Flyby
- Sputnik 20 - 1 September 1962 - Attempted Venus Flyby
- Sputnik 21 - 12 September 1962 - Attempted Venus Flyby
- Ranger 5 - 18 October 1962 - Attempted Lunar Impact
- Sputnik 22 - 24 October 1962 - Attempted Mars Flyby
- Mars 1 - 1 November 1962 - Mars Flyby (Contact Lost)
- Sputnik 24 - 4 November 1962 - Attempted Mars Lander
- 1963
- Sputnik 25 - 4 January 1963 - Attempted Lunar Lander
- Luna 1963B - 2 February 1963 - Attempted Lunar Lander (Launch Failure)
- Luna 4 - 2 April 1963 - Attempted Lunar Lander
- Cosmos 21 - 11 November 1963 - Attempted Venera Test Flight?
- 1964
- Ranger 6 - 30 January 1964 - Lunar Impact (Cameras Failed)
- Venera 1964A - 19 February 1964 - Attempted Venus Flyby (Launch Failure)
- Venera 1964B - 1 March 1964 - Attempted Venus Flyby (Launch Failure)
- Luna 1964A - 21 March 1964 - Attempted Lunar Lander (Launch Failure)
- Cosmos 27 - 27 March 1964 - Attempted Venus Flyby
- Zond 1 - 2 April 1964 - Venus Flyby (Contact Lost)
- Luna 1964B - 20 April 1964 - Attempted Lunar Lander (Launch Failure)
- Zond 1964A - 4 June 1964 - Attempted Lunar Lander (Launch Failure)
- Ranger 7 - 28 July 1964 - Lunar Impact
- Mariner 3 - 5 November 1964 - Attempted Mars Flyby
- Mariner 4 - 28 November 1964 - Mars Flyby
- Zond 2 - 30 November 1964 - Mars Flyby (Contact Lost)

Mars 1



Mariner 2



Lunar and Planetary Exploration

- 1965
- Ranger 8 - 17 February 1965 - Lunar Impact
- Cosmos 60 - 12 March 1965 - Attempted Lunar Lander
- Ranger 9 - 21 March 1965 - Lunar Impact
- Luna 1965A - 10 April 1965 - Attempted Lunar Lander? (Launch Failure)
- Luna 5 - 9 May 1965 - Lunar Impact (Attempted Soft Landing)
- Luna 6 - 8 June 1965 - Attempted Lunar Lander
- Zond 3 - 18 July 1965 - Lunar Flyby
- Luna 7 - 4 October 1965 - Lunar Impact (Attempted Soft Landing)
- Venera 2 - 12 November 1965 - Venus Flyby (Contact Lost)
- Venera 3 - 16 November 1965 - Venus Lander (Contact Lost)
- Cosmos 96 - 23 November 1965 - Attempted Venus Lander?
- Venera 1965A - 23 November 1965 - Attempted Venus Flyby (Launch Failure)
- Luna 8 - 3 December 1965 - Lunar Impact (Attempted Soft Landing?)
- 1966
- Luna 9 - 31 January 1966 - Lunar Lander
- Cosmos 111 - 1 March 1966 - Attempted Lunar Orbiter?
- Luna 10 - 31 March 1966 - Lunar Orbiter
- Luna 1966A - 30 April 1966 - Attempted Lunar Orbiter? (Launch Failure)
- Surveyor 1 - 30 May 1966 - Lunar Lander
- Explorer 33 - 1 July 1966 - Attempted Lunar Orbiter
- Lunar Orbiter 1 - 10 August 1966 - Lunar Orbiter
- Luna 11 - 24 August 1966 - Lunar Orbiter
- Surveyor 2 - 20 September 1966 - Attempted Lunar Lander
- Luna 12 - 22 October 1966 - Lunar Orbiter
- Lunar Orbiter 2 - 6 November 1966 - Lunar Orbiter
- Luna 13 - 21 December 1966 - Lunar Lander

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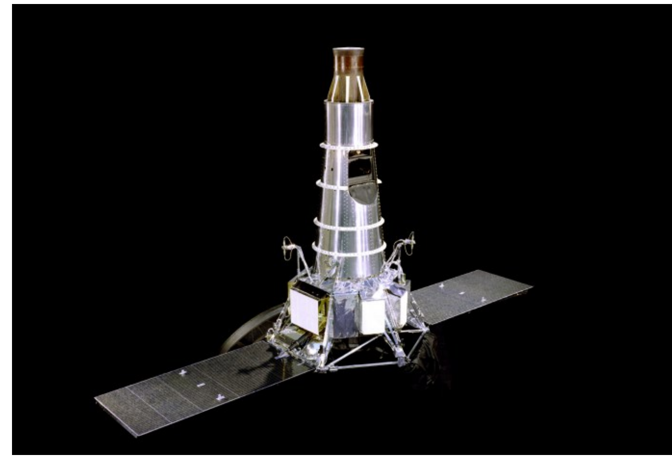
Ranger 9



Luna 10

Lunar and Planetary Exploration

1967

- Lunar Orbiter 3 - 4 February 1967 - Lunar Orbiter
- Surveyor 3 - 17 April 1967 - Lunar Lander
- Lunar Orbiter 4 - 8 May 1967 - Lunar Orbiter
- Venera 4 - 12 June 1967 - Venus Probe
- Mariner 5 - 14 June 1967 - Venus Flyby
- Cosmos 167 - 17 June 1967 - Attempted Venus Probe
- Surveyor 4 - 14 July 1967 - Attempted Lunar Lander
- Explorer 35 (IMP-E) - 19 July 1967 - Lunar Orbiter
- Lunar Orbiter 5 - 1 August 1967 - Lunar Orbiter
- Surveyor 5 - 8 September 1967 - Lunar Lander
- Zond 1967A - 28 September 1967 - Attempted Lunar Test Flight (Launch Failure)
- Surveyor 6 - 7 November 1967 - Lunar Lander
- Zond 1967B - 22 November 1967 - Attempted Lunar Test Flight (Launch Failure)

1968

- Surveyor 7 - 7 January 1968 - Lunar Lander
- Luna 1968A - 7 February 1968 - Attempted Lunar Orbiter (Launch Failure)
- Zond 4 - 2 March 1968 - Test Flight
- Luna 14 - 7 April 1968 - Lunar Orbiter
- Zond 1968A - 23 April 1968 - Attempted Lunar Test Flight? (Launch Failure)
- Zond 5 - 15 September 1968 - Lunar Flyby and Return to Earth
- Zond 6 - 10 November 1968 - Lunar Flyby and Return to Earth
- Apollo 8 - 21 December 1968 - Crewed Lunar Orbiter

1969

- Venera 5 - 5 January 1969 - Venus Probe
- Venera 6 - 10 January 1969 - Venus Probe
- Zond 1969A - 20 January 1969 - Attempted Lunar Flyby and Return (Launch Failure)
- Luna 1969A - 19 February 1969 - Attempted Lunar Rover? (Launch Failure)
- Zond L1S-1 - 21 February 1969 - Attempted Lunar Orbiter (Launch Failure)
- Mariner 6 - 25 February 1969 - Mars Flyby
- Mariner 7 - 27 March 1969 - Mars Flyby

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Surveyor 7

Venera 6

Lunar and Planetary Exploration

- Mars 1969A - 27 March 1969 - Attempted Mars Orbiter (Launch Failure)
- Mars 1969B - 2 April 1969 - Attempted Mars Orbiter (Launch Failure)
- Luna 1969B - 15 April 1969 - Attempted Lunar Sample Return? (Launch Failure)
- Apollo 10 - 18 May 1969 - Crewed Lunar Orbiter
- Luna 1969C - 14 June 1969 - Attempted Lunar Sample Return? (Launch Failure)
- Zond L1S-2 - 3 July 1969 - Attempted Lunar Orbiter (Launch Failure)
- Luna 15 - 13 July 1969 - Lunar Orbiter (Attempted Lunar Lander?)
- Apollo 11 - 16 July 1969 - Crewed Lunar Landing
- Zond 7 - 7 August 1969 - Lunar Flyby and Return to Earth
- Cosmos 300 - 23 September 1969 - Attempted Lunar Sample Return?
- Cosmos 305 - 22 October 1969 - Attempted Lunar Sample Return?
- Apollo 12 - 14 November 1969 - Crewed Lunar Landing
- 1970
- Luna 1970A - 6 February 1970 - Attempted Lunar Sample Return? (Launch Failure)
- Luna 1970B - 19 February 1970 - Attempted Lunar Orbiter? (Launch Failure)
- Apollo 13 - 11 April 1970 - Crewed Lunar Mission (Landing Aborted)
- Venera 7 - 17 August 1970 - Venus Lander
- Cosmos 359 - 22 August 1970 - Attempted Venus Probe
- Luna 16 - 12 September 1970 - Lunar Sample Return
- Zond 8 - 20 October 1970 - Lunar Flyby and Return to Earth
- Luna 17/Lunokhod 1 - 10 November 1970 - Lunar Rover
- 1971
- Apollo 14 - 31 January 1971 - Crewed Lunar Landing
- Mariner 8 - 9 May 1971 - Attempted Mars Flyby (Launch Failure)
- Cosmos 419 - 10 May 1971 - Attempted Mars Orbiter/Lander
- Mars 2 - 19 May 1971 - Mars Orbiter/ Attempted Lander
- Mars 3 - 28 May 1971 - Mars Orbiter/ Lander
- Mariner 9 - 30 May 1971 - Mars Orbiter
- Apollo 15 - 26 July 1971 - Crewed Lunar Landing
- Luna 18 - 2 September 1971 - Attempted Lunar Sample Return
- Luna 19 - 28 September 1971 - Lunar Orbiter

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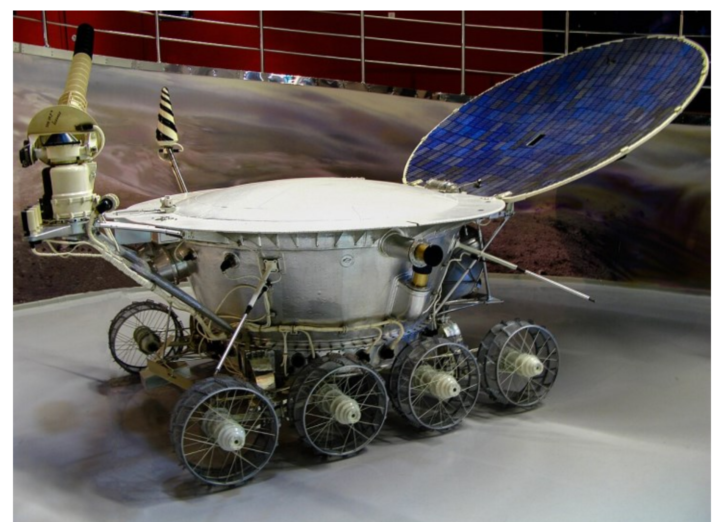
Apollo 11

Lunokhod 1



Lunar and Planetary Exploration

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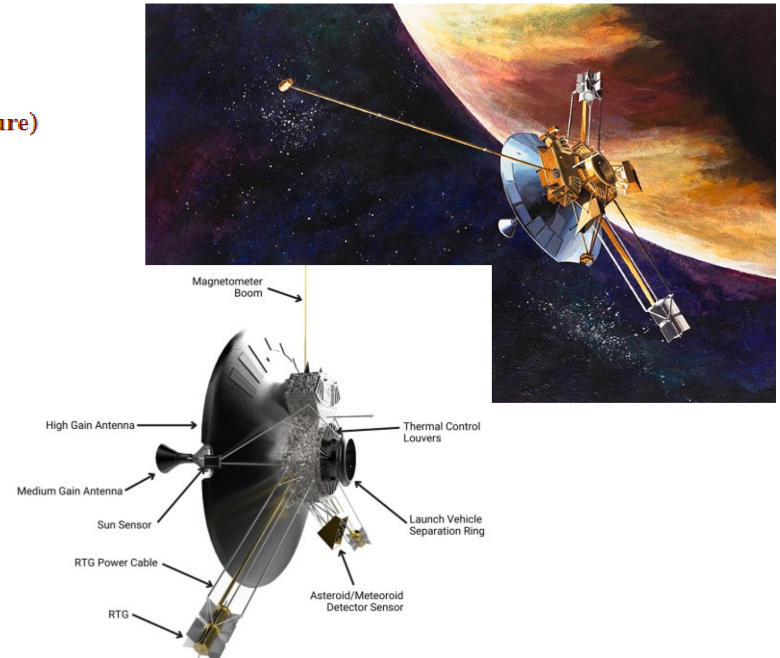
- 1972
- Luna 20 - 14 February 1972 - Lunar Sample Return
- Pioneer 10 - 3 March 1972 - Jupiter Flyby
- Venera 8 - 27 March 1972 - Venus Probe
- Cosmos 482 - 31 March 1972 - Attempted Venus Probe
- Apollo 16 - 16 April 1972 - Crewed Lunar Landing
- Soyuz L3 - 23 November 1972 - Attempted Lunar Orbiter (Launch Failure)
- Apollo 17 - 7 December 1972 - Crewed Lunar Landing
- 1973
- Luna 21/Lunokhod 2 - 8 January 1973 - Lunar Rover
- Pioneer 11 - 5 April 1973 - Jupiter/Saturn Flyby
- Skylab - 14 May 1973 - Crewed Earth Orbiter
- Explorer 49 (RAE-B) - 10 June 1973 - Lunar Orbiter/Radio Astronomy
- Mars 4 - 21 July 1973 - Mars Flyby (Attempted Mars Orbiter)
- Mars 5 - 25 July 1973 - Mars Orbiter
- Mars 6 - 5 August 1973 - Mars Lander (Contact Lost)
- Mars 7 - 9 August 1973 - Mars Flyby (Attempted Mars Lander)
- Mariner 10 - 4 November 1973 - Venus/Mercury Flybys
- 1974
- Luna 22 - 2 June 1974 - Lunar Orbiter
- Luna 23 - 28 October 1974 - Attempted Lunar Sample Return
- 1975
- Venera 9 - 8 June 1975 - Venus Orbiter and Lander
- Venera 10 - 14 June 1975 - Venus Orbiter and Lander
- Viking 1 - 20 August 1975 - Mars Orbiter and Lander
- Viking 2 - 9 September 1975 - Mars Orbiter and Lander
- Luna 1975A - 16 October 1975 - Attempted Lunar Sample Return?
- 1976
- Luna 24 - 9 August 1976 - Lunar Sample Return

Pioneer 11



Viking 2

Courtesy Fine Art America

Lunar and Planetary Exploration

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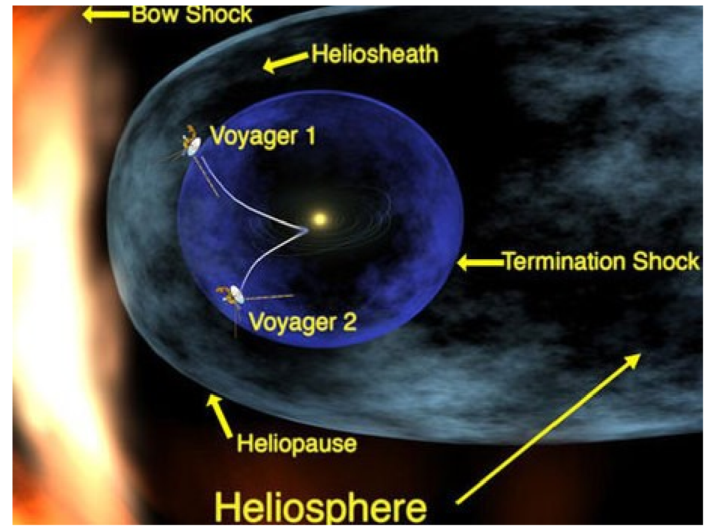
- 1977
- Voyager 2 - 20 August 1977 - Jupiter/Saturn/Uranus/Neptune Flyby
- Voyager 1 - 5 September 1977 - Jupiter/Saturn Flyby
- 1978
- Pioneer Venus 1 - 20 May 1978 - Venus Orbiter
- Pioneer Venus 2 - 8 August 1978 - Venus Probes
- ISEE-3/ICE - 12 August 1978 - Comet Giacobini-Zinner and Halley Flybys
- Venera 11 - 9 September 1978 - Venus Orbiter and Lander
- Venera 12 - 14 September 1978 - Venus Orbiter and Lander
- 1979
- 1980
- 1981
- Venera 13 - 30 October 1981 - Venus Orbiter and Lander
- Venera 14 - 4 November 1981 - Venus Orbiter and Lander
- 1982
- 1983
- Venera 15 - 2 June 1983 - Venus Orbiter
- Venera 16 - 7 June 1983 - Venus Orbiter
- 1984
- Vega 1 - 15 December 1984 - Venus Lander and Balloon/Comet Halley Flyby
- Vega 2 - 21 December 1984 - Venus Lander and Balloon/Comet Halley Flyby
- 1985
- Sakigake - 7 January 1985 - Comet Halley Flyby
- Giotto - 2 July 1985 - Comet Halley Flyby
- Suisei (Planet-A) - 18 August 1985 - Comet Halley Flyby
- 1986
- 1987
- 1988
- Phobos 1 - 7 July 1988 - Attempted Mars Orbiter/Phobos Lander
- Phobos 2 - 12 July 1988 - Mars Orbiter/Attempted Phobos Lander

Viking 1 & 2



Vega 2

Courtesy Fine Art America

Lunar and Planetary Exploration

- 1989
- Magellan - 4 May 1989 - Venus Orbiter
- Galileo - 18 October 1989 - Jupiter Orbiter and Probe
- 1990
- Hiten - 24 January 1990 - Lunar Flyby and Orbiter
- Hubble Space Telescope - 25 April 1990 - Earth Orbiting Observatory
- Ulysses - 06 October 1990 - Jupiter Flyby and Solar Polar Orbiter
- 1991
- 1992
- Mars Observer - 25 September 1992 - Attempted Mars Orbiter (Contact Lost)
- 1993
- 1994
- Clementine - 25 January 1994 - Lunar Orbiter/Attempted Asteroid Flyby
- 1995
- 1996
- NEAR - 17 February 1996 - Asteroid Eros Orbiter
- Mars Global Surveyor - 07 November 1996 - Mars Orbiter
- Mars 96 - 16 November 1996 - Attempted Mars Orbiter/Landers
- Mars Pathfinder - 04 December 1996 - Mars Lander and Rover
- 1997
- Cassini - 15 October 1997 - Saturn Orbiter
- Huygens - 15 October 1997 - Titan Probe
- AsiaSat 3/HGS-1 - 24 December 1997 - Lunar Flyby
- 1998
- Lunar Prospector - 7 January 1998 - Lunar Orbiter
- Nozomi (Planet-B) - 3 July 1998 - Mars Orbiter
- Deep Space 1 (DS1) - 24 October 1998 - Asteroid and Comet Flyby
- Mars Climate Orbiter - 11 December 1998 - Attempted Mars Orbiter
- 1999
- Mars Polar Lander - 3 January 1999 - Attempted Mars Lander
- Deep Space 2 (DS2) - 3 January 1999 - Attempted Mars Penetrators
- Stardust - 7 February 1999 - Comet Coma Sample Return

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Lunar and Planetary Exploration

- 2000
- 2001
- 2001 Mars Odyssey - 7 April 2001 - Mars Orbiter
- Genesis - 8 August 2001 - Solar Wind Sample Return
- 2002
- CONTOUR - 3 July 2002 - Fly-by of three Comet Nuclei
- 2003
- Hayabusa (Muses-C) - 9 May 2003 - Asteroid Orbiter and Sample Return
- Mars Express - 2 June 2003 - Mars Orbiter and Lander
- Spirit (MER-A) - 10 June 2003 - Mars Rover
- Opportunity (MER-B) - 8 July 2003 - Mars Rover
- SMART 1 - September 2003 - Lunar Orbiter
- 2004
- Rosetta - 2 March 2004 - Comet Orbiter and Lander
- MESSENGER - 3 August 2004 - Mercury Orbiter
- 2005
- Deep Impact - 12 January 2005 - Comet Rendezvous and Impact
- Mars Reconnaisance Orbiter - 12 August 2005 - Mars Orbiter
- Venus Express - 09 November 2005 - ESA Venus Orbiter
- 2006
- New Horizons - 19 January 2006 - Pluto/Charon and Kuiper Belt Flyby
- 2007
- Phoenix - 04 August 2007 - Small Mars Scout Lander
- Kaguya (SELENE) - 14 September 2007 - Lunar Orbiter
- Dawn - 27 September 2007 - Asteroid Ceres and Vesta Orbiter
- Chang'e 1 - 24 October 2007 - CAST (China) Lunar Orbiter
- Lunar-A - Cancelled - Lunar Orbiter and Penetrators
- 2008
- Chandrayaan-1 - 22 October 2008 - ISRO (India) Lunar Orbiter

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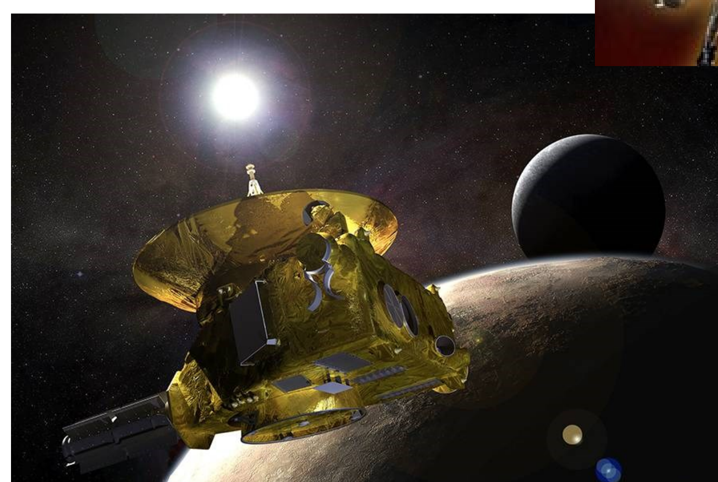
Galileo

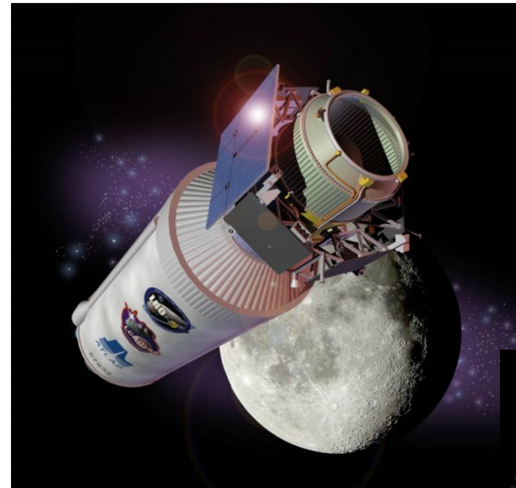
New Horizons



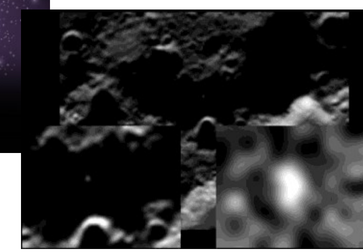
Lunar and Planetary Exploration

- 2009
- [Kepler] - 7 March 2009 - Extrasolar Terrestrial Planet Detection Mission
- [Lunar Reconnaissance Orbiter] - 18 June 2009 - Lunar Orbiter
- [LCROSS] - 18 June 2009 - Lunar Impactor
- 2010
- [Akatsuki/Planet-C] - 20 May 2010 - ISAS Venus Orbiter
- [Chang'e 2] - 1 October 2010 - CAST (China) Lunar Orbiter
- 2011
- [Juno] - 5 August 2011 - Jupiter Orbiter
- [GRAIL] - 10 September 2011 - Lunar Orbiter
- [Phobos-Grunt] - 08 November 2011 - Attempted Martian Moon Phobos Lander
- [Yinghuo-1] - 08 November 2011 - Attempted Mars Orbiter
- [Mars Science Laboratory] - 26 November 2011 - Mars Rover
- 2012
- 2013
- [LADEE] - 06 September 2013 - Lunar Orbiter
- [Mangalyaan] - 05 November 2013 - ISRO (India) Mars Orbiter
- [MAVEN] - 18 November 2013 - Mars Scout Mission Orbiter
- [Chang'e 3] - 01 December 2013 - Lunar Lander and Rover
- 2014
- [Chang'e 5 Test Vehicle] - 23 October 2014 - Lunar Flyby and Return
- [Hayabusa 2] - 3 December 2014 - JAXA Asteroid Sample Return
- [PROCYON] - 3 December 2014 - JAXA (Japan) Asteroid Flyby Mission
- 2015
- 2016
- [ExoMars 2016] - 14 March 2016 - ESA Mars Orbiter and Lander
- [OSIRIS-REx] - 8 September 2016 - Sample Return Mission to Asteroid Bennu
- 2017

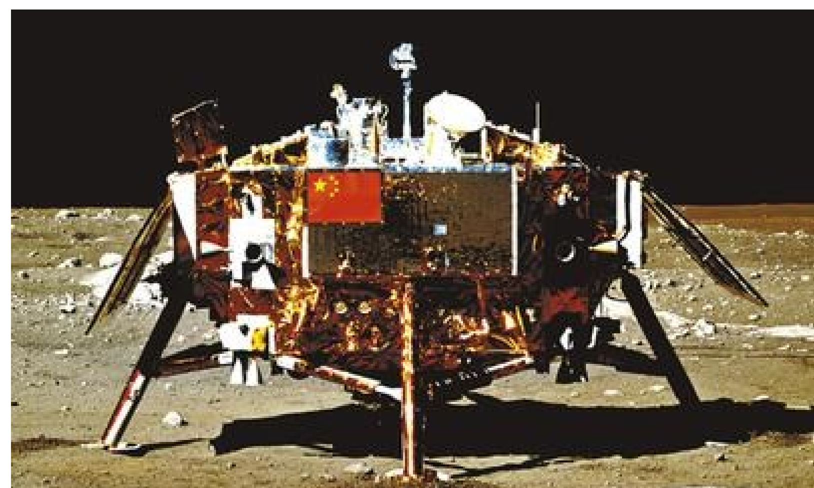
Lunar Crater Observation and Sensing Satellite (LCROSS



Centaur Spent Upper Stage Impact



Chang'e 3



Lunar and Planetary Exploration

- 2018
- InSight - 5 May 2018 - Mars Lander
- Queqiao - 20 May 2018 - CNSA (China) Lunar Relay Satellite
- Parker Solar Probe - 12 August 2018 - Solar Orbiter - Venus Flybys
- BepiColombo - 19 October 2018 - ESA and JAXA Mercury Orbiters
- Chang'e 4 - 7 December 2018 - CNSA (China) Lunar Farside Lander and Rover
- 2019
- Beresheet - 22 February 2019 - SpaceIL and IAI (Israel) Lunar Lander
- Chandrayaan 2 - 22 July 2019 - ISRO (India) Moon Orbiter, Lander, and Rover
- 2020
- Solar Orbiter - 10 February 2020 - ESA solar orbiting mission
- Hope - 19 July 2020 - United Arab Emirates Mars Orbiter
- Tianwen 1 - 23 July 2020 - CNSA (China) Mars Orbiter and Rover
- Mars 2020 - 30 July 2020 - Mars Rover and Rotorcraft
- Chang'e 5 - 23 November 2020 - CNSA (China) Lunar Sample Return Mission
- 2021
- Q-PACE - 17 January 2021 - Microgravity Particle Collision Study CubeSat
- Lucy - 16 October 2021 - Trojan Asteroid Flybys
- Double Asteroid Redirection Test (DART) - 24 November 2021 - Asteroid Dimorphos Impactor
- LICIACube - 24 November 2021 - Asteroid Dimorphos Imaging Cubesat
- James Webb Space Telescope - 25 December 2021 - L2 Orbiting Infrared Observatory
- 2022
- CAPSTONE - 28 June 2022 - Lunar Navigation Test Orbiter
- Korea Pathfinder Lunar Orbiter (Danuri) - 4 August 2022 - KARI (South Korea) Lunar Orbite
- LunaH-Map - 16 November 2022 - Lunar Orbiting CubeSat
- Lunar Ice Cube - 16 November 2022 - Lunar Orbiting CubeSat
- NEA Scout - 16 November 2022 - Asteroid Flyby CubeSat

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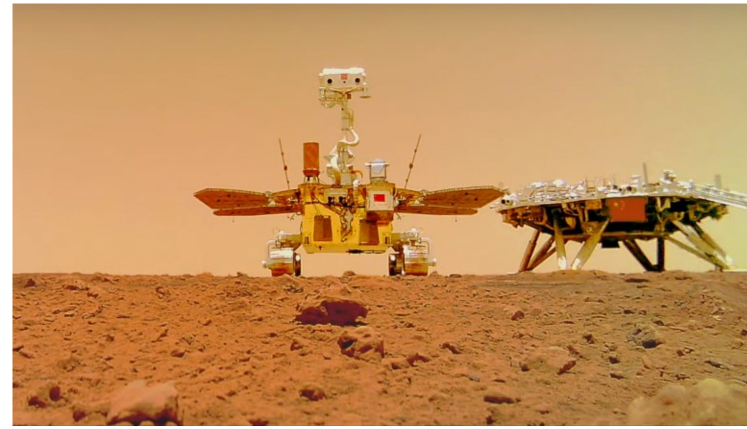
Tianwen-1



Chandrayaan 2

Lunar and Planetary Exploration

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2022 continued

- Lunar InfraRed imaging (LunIR) - 16 November 2022 - Lunar Flyby and Technology Test CubeSat
- OMOTENASHI - 16 November 2022 - JAXA (Japan) Lunar Lander CubeSat
- EQUULEUS - 16 November 2022 - JAXA (Japan) L2 Orbit Lunar CubeSat
- Artemis 1 - 16 November 2022 - Lunar Test Flight
- Lunar Flashlight - 11 December 2022 - Lunar Orbiter CubeSat
- Hakuto-R M1 - 11 December 2022 - Lunar Lander

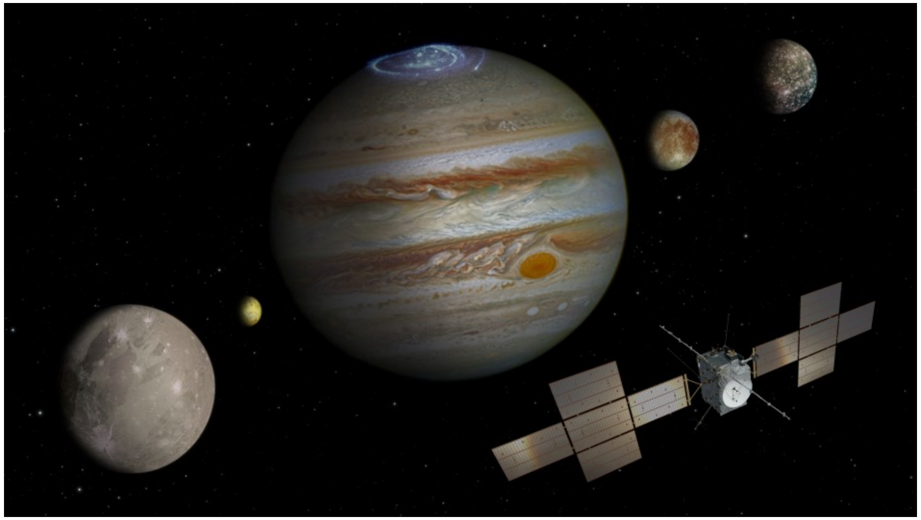
2023

- JUpiter ICy moons Explorer (JUICE) - 14 April 2023 - ESA Ganymede-Callisto-Europa multiple flyby mission
- Chandrayaan 3 - 14 July 2023 - ISRO (India) Lunar Orbiter, Lander, and Rover
- Luna 25 - 10 August 2023 - Russian Lunar Lander
- SLIM - 6 September 2023 - JAXA (Japan) Lunar Lander
- Psyche - 13 October 2023 - Main Belt Asteroid Orbiter

2024

- Peregrine Mission 1 (Astrobotic) - 8 January 2024 - Lunar Lander
- Intuitive Machines 1 (Odysseus) - 15 February 2024 - Lunar Lander
- Chang'e 6 - May 2024 - CNSA (China) Lunar Sample Return Mission
- Europa Clipper - 10 October 2024 - Jupiter Orbiter - Multiple Europa Flybys
- Hera - October 2024 - ESA mission to asteroids Didymos and Dimorphos
- Griffin Mission 1 (VIPER) - 2024 - Lunar South Pole Rover
- Intuitive Machines 2 (PRIME-1) - 2024 - Lunar Lander
- Lunar Trailblazer - 2024 - Lunar Orbiting Small Satellite
- Blue Ghost 1 (Firefly) - 2024 - Lunar Lander
- EscaPADE - 2024 - Dual Mars Orbiting Spacecraft
- Chang'e 6 - 2024 - CNSA (China) Lunar Sample Return Mission
- Intuitive Machines 3 (PRISM) - TBD - Lunar Lander and Rovers

JUICE

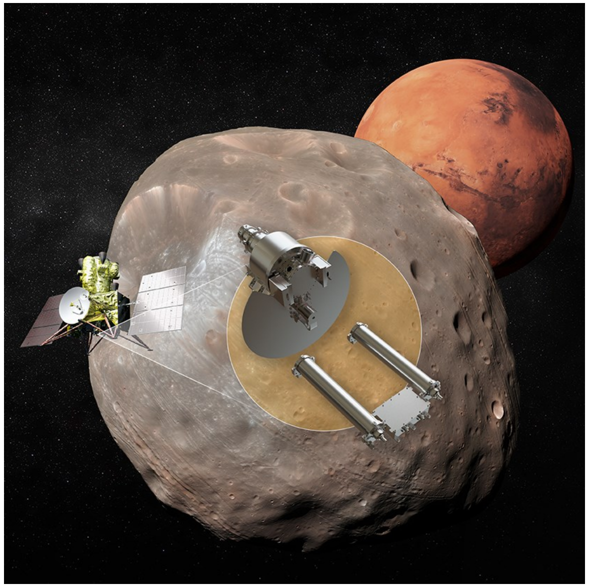


Intuitive Machines 1 (Odysseus)

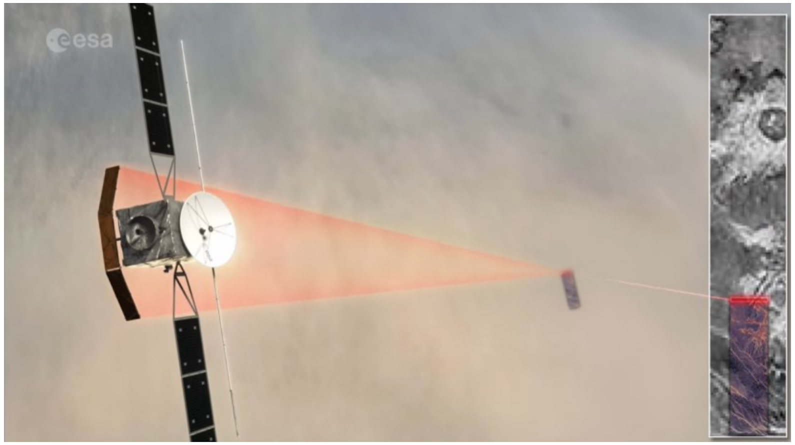
Lunar and Planetary Exploration

- 2025
- Draper Lunar Lander - 2025 - Lunar Lander
- Blue Ghost 2 (Firefly) - 2025 - Lunar Lander
- Lunar Pathfinder - 2025 - Lunar Orbiter
- 2026
- Chang'e 7 - 2026 - CNSA (China) Lunar Survey Mission
- Martian Moons eXploration (MMX) - 2026 - JAXA (Japan)
  Phobos Sample Return Mission
- 2027
- 2028
- Dragonfly - 2028 - Quadcopter Mission to Titan
- ExoMars Rover - 2028 - ESA Mars Rover, Rosalind Franklin
- Chang'e 8 - 2028 - CNSA (China) Lunar Technology Test
- 2029
- DAVINCI - 2029 June - Venus Flyby and Atmospheric Probe
- 2030
- 2031
- VERITAS - 2031 - Venus Orbiter
- EnVision - 2031 - ESA Venus Orbiter
- 2032

Martian Moons eXploration (MMX)

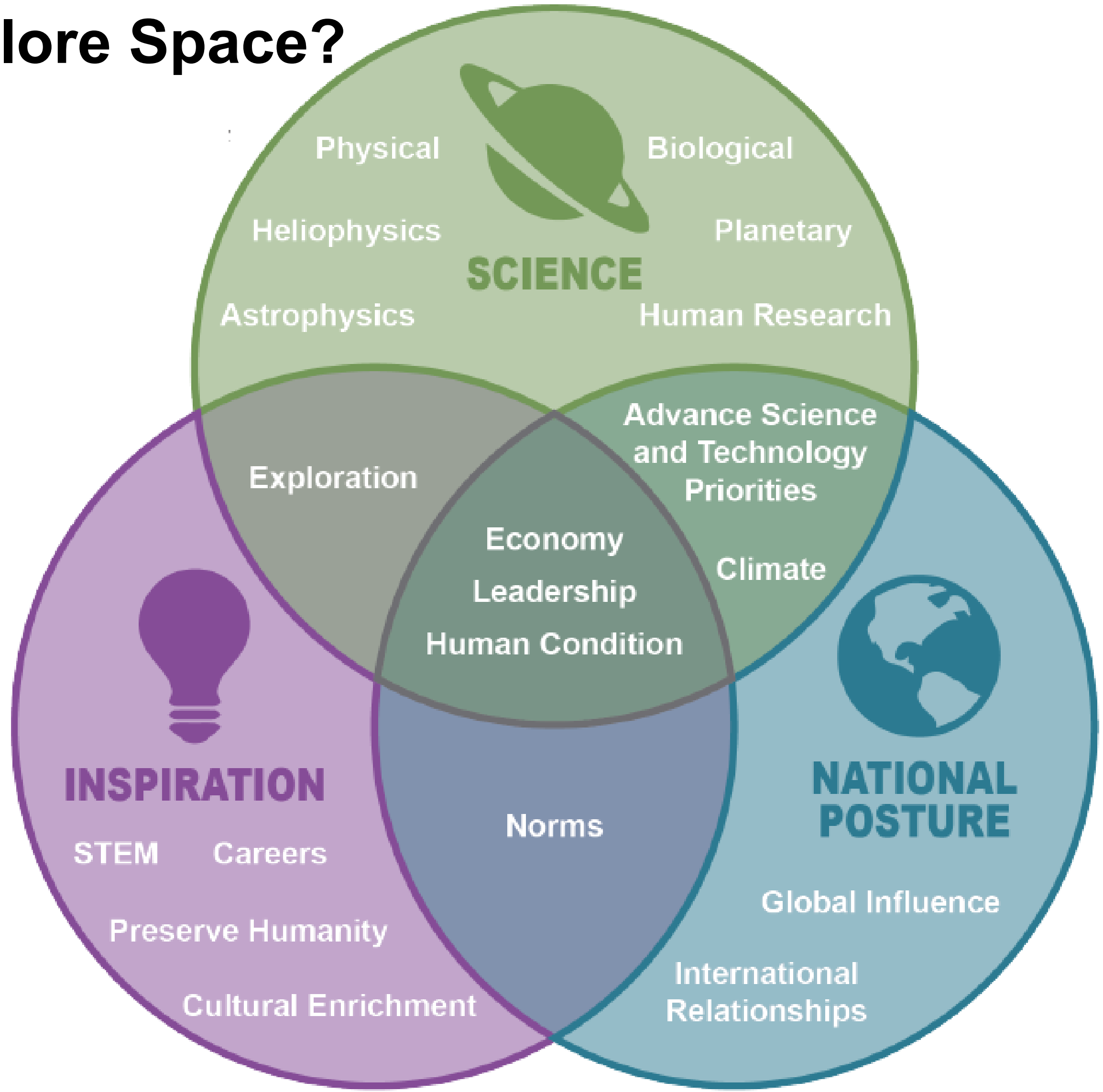


EnVision



Why Explore Space?

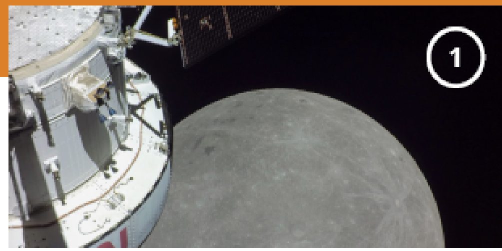
GOVERNMENT VIEW



Crewed exploration of the Moon and Mars will strengthen these three pillars, leading to a new era of science and discovery. **The Moon to Mars Objectives define NASA's ambitions; the Moon to Mars Architecture shows how to realize them.**

Architecture Segments

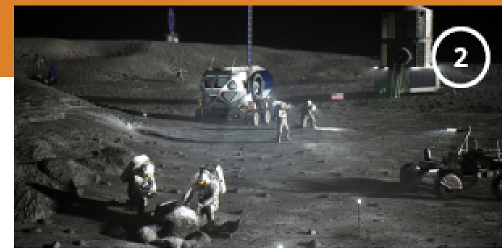
The architecture segments below capture the evolutionary nature of NASA's Moon to Mars exploration strategy, growing in complexity over time to meet more of NASA's Moon to Mars Objectives.



Human Lunar Return

Includes the inaugural Artemis missions which will return humanity to the Moon for the first time since the Apollo missions of the 1960s and 70s. This segment will demonstrate and validate core systems and capabilities for the Moon to Mars effort.

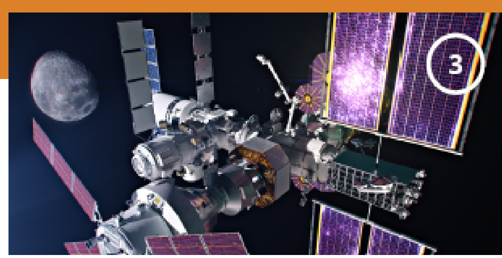
This segment will test crew and cargo transportation systems, deploy lunar communications relays, demonstrate technologies, and land the first woman and first person of color on the lunar surface. Missions pursued in this segment will lay the groundwork to achieve the Moon to Mars Objectives.



Foundational Exploration

Will prepare for future segments by expanding operations, capabilities, and systems supporting crewed missions to lunar orbit and the Moon's surface. It will build on initial Human Lunar Return capabilities and validate exploration systems for future Mars missions.

Surface missions in this segment will feature increased duration, expanded mobility, and regional exploration of the lunar South Pole. Orbital operations will also increase in duration. The needs of future missions will influence this segment's activities, which may include reconnaissance, Mars risk reduction, and initial infrastructure for long-term lunar evolution.



Sustained Lunar Evolution

Will aim to build future economic opportunity and greater participation in lunar science and exploration. The segment will increase our science capability, mission duration, and the production of goods and services derived from lunar resources.

This segment is an "open canvas," embracing new ideas, systems, and partners to realize a long-term presence on the Moon and grow the lunar economy. This sustained architecture could achieve existing science objectives and address new science objectives identified through discoveries in previous segments.

Humans to Mars

Will establish a human presence on Mars and empower new science on its surface. Since the earliest days of spaceflight, the Red Planet has captivated humanity. The Moon to Mars Architecture sets a course to finally step foot on a planet beyond humanity's own.

Building on previous segments, this segment will include the initial capabilities and systems necessary to safely travel to Mars, land on its surface, and return safely to Earth. Following this initial journey to Mars, NASA will prepare for progressively longer and more complex missions there.

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Sub-Architectures

Each sub-architecture represents a task, technology, or process that NASA must master to achieve the Moon to Mars objectives. The first eight of the sub-architectures listed below were included in the first edition of the Architecture Definition Document, with the last four added as part of the 2023 Architecture Concept Review process.

Communications, Navigation, Positioning, and Timing Systems
Enable transmission and reception of data, determination of location and orientation, and acquisition of precise time.

Habitation Systems
Ensure the health and performance of astronauts in controlled environments.

Human Systems
Execute human and robotic missions; this includes crew, ground personnel, and supporting systems.

Logistics Systems
Package, handle, transport, stage, store, track, and transfer items and cargo.

Mobility Systems
Move crew and cargo around the lunar and Martian surfaces.

Power Systems
Generate, store, condition, and distribute electricity for architectural elements.

Transportation Systems
Convey crew and cargo to and from Earth to the Moon and Mars.

Utilization Systems
Enable science and technology demonstrations.

New for 2023

Data Systems and Management
Transfer, distribute, receive, validate, secure, decode, format, compile, and process data and commands.

In-situ Resource Utilization (ISRU) Systems
Extract resources in space or on the Moon or Mars to generate products.

Infrastructure Support
Includes facilities, systems, operations planning and control, equipment, and services needed on Earth, in space, and on planetary surfaces.

Autonomous Systems and Robotics
Employ software and hardware to assist the crew and operate during uncrewed periods.

New for 2023

6

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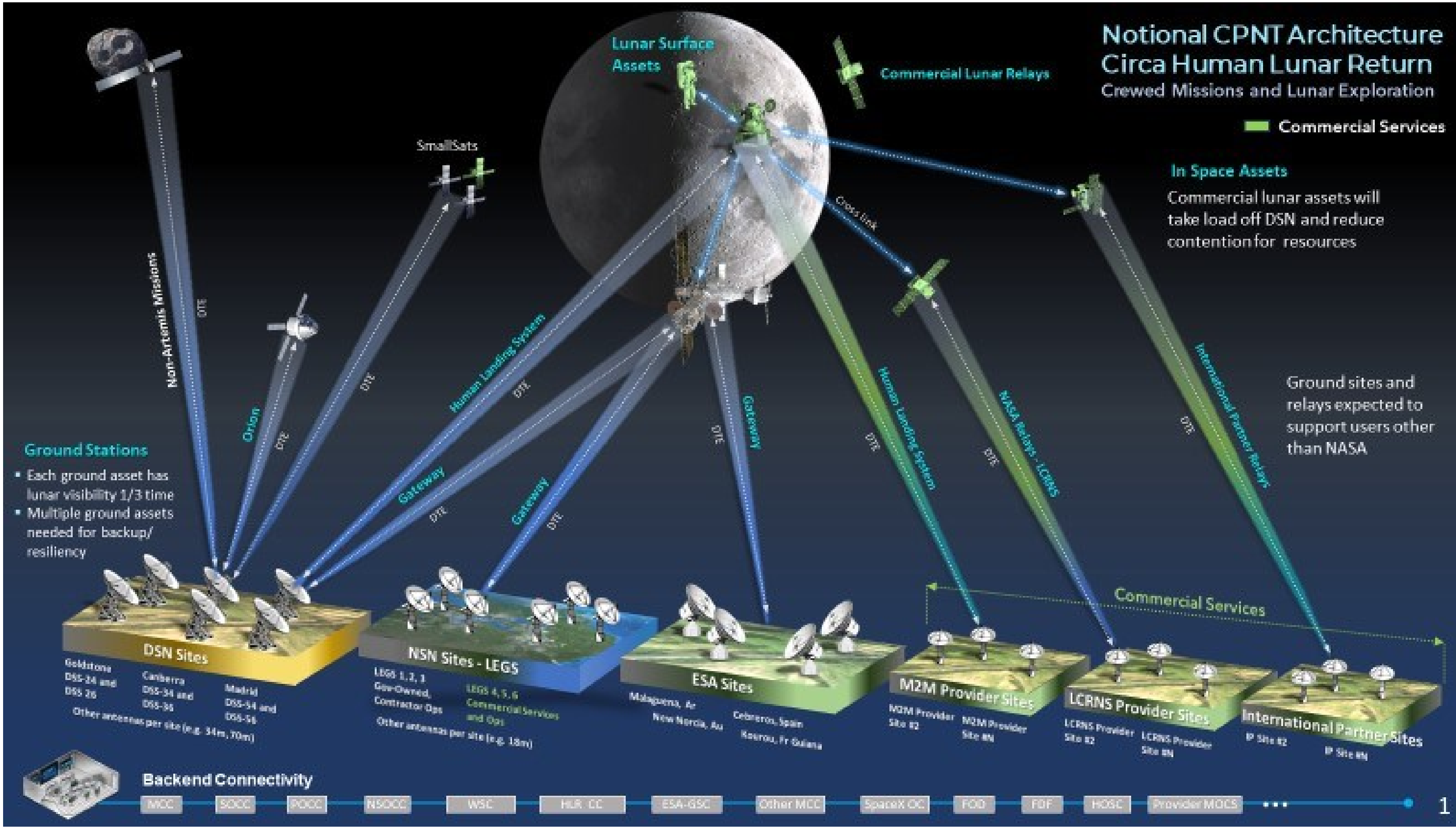
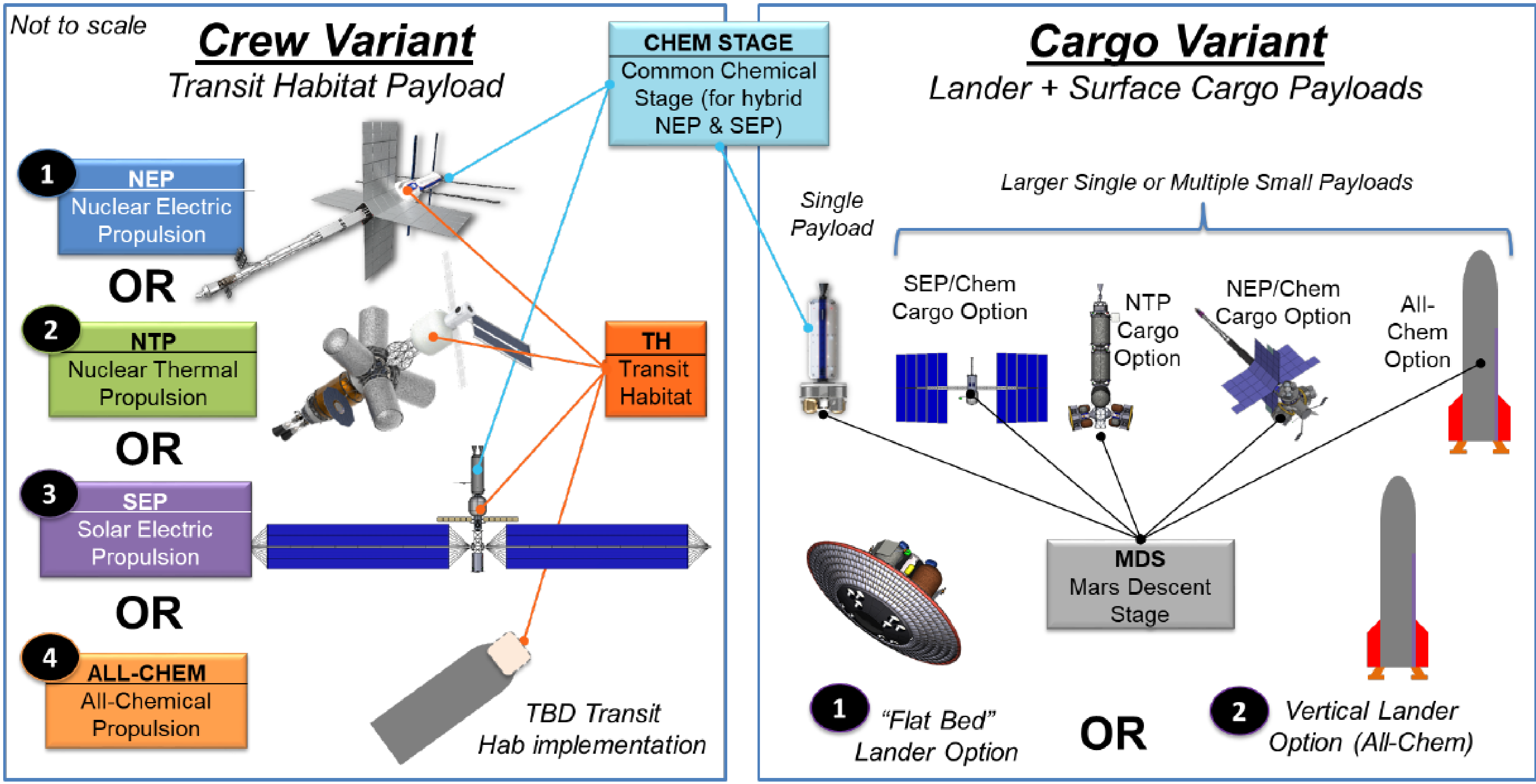
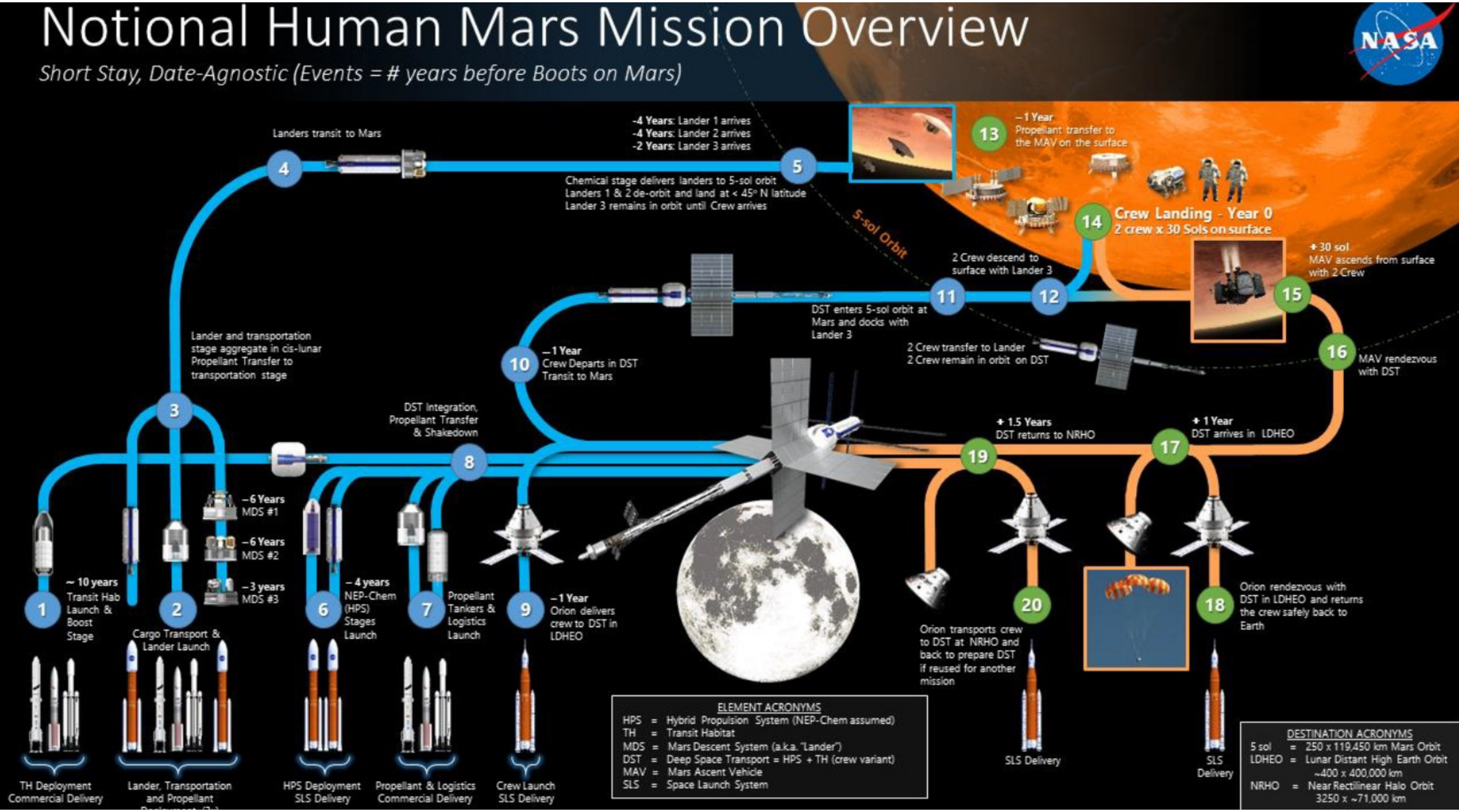
Lunar Mission Communication Network

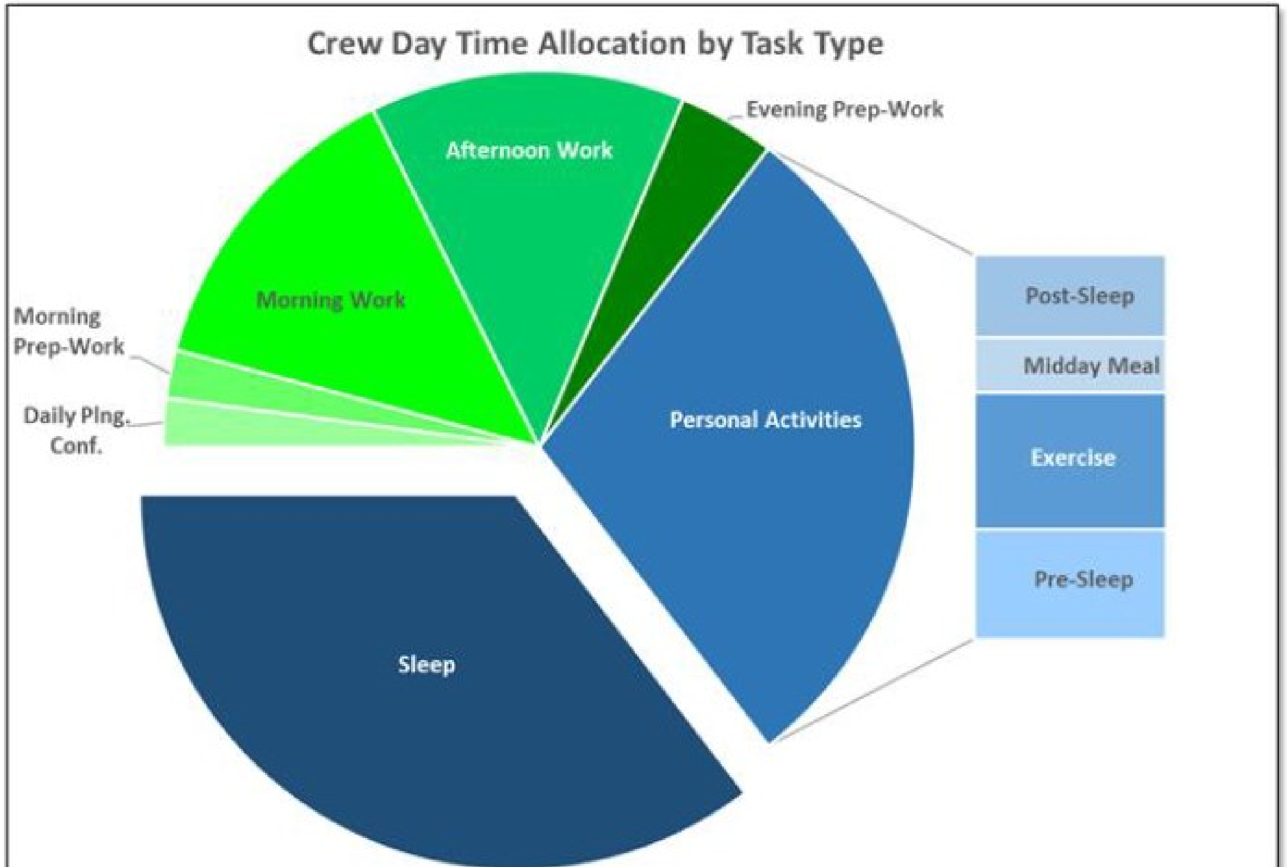


"How" to Get to Mars and Back?




Notional Human Mars Mission Overview
Short Stay, Date-Agnostic (Events = # years before Boots on Mars)
NASA
Landers transit to Mars
-4 Years: Lander 1 arrives
-4 Years: Lander 2 arrives
-2 Years: Lander 3 arrives
Chemical stage delivers landers to 5-sol orbit
Landers 1 & 2 de-orbit and land at < 45° N latitude
Lander 3 remains in orbit until Crew arrives
5-sol Orbit
~1 Year
Propellant transfer to the MAV on the surface
Crew Landing - Year 0
2 crew x 30 Sols on surface
+30 sol
MAV ascends from surface with 2 Crew
2 Crew descend to surface with Lander 3
DST enters 5-sol orbit at Mars and docks with Lander 3
2 Crew transfer to Lander
2 Crew remain in orbit on DST
MAV rendezvous with DST
Lander and transportation stage aggregate in cis-lunar Propellant Transfer to transportation stage
~1 Year
Crew Departs in DST
Transit to Mars
DST Integration, Propellant Transfer & Shakedown
+1.5 Years
DST returns to NRHO
+1 Year
DST arrives in LDHEO
~6 Years
MDS #1
~6 Years
MDS #2
~3 years
MDS #3
~10 years
Transit Hab Launch & Boost Stage
Cargo Transport & Lander Launch
~4 years
NEP-Chem (HPS) Stages Launch
Propellant Tankers & Logistics Launch
~1 Year
Orion delivers crew to DST in LDHEO
Orion transports crew to DST at NRHO and back to prepare DST if reused for another mission
Orion rendezvous with DST in LDHEO and returns the crew safely back to Earth
SLS Delivery
SLS Delivery
TH Deployment
Commercial Delivery
Lander, Transportation and Propellant
HPS Deployment
SLS Delivery
Propellant & Logistics
Commercial Delivery
Crew Launch
SLS Delivery
ELEMENT ACRONYMS
HPS = Hybrid Propulsion System (NEP-Chem assumed)
TH = Transit Habitat
MDS = Mars Descent System (a.k.a. "Lander")
DST = Deep Space Transport = HPS + TH (crew variant)
MAV = Mars Ascent Vehicle
SLS = Space Launch System
DESTINATION ACRONYMS
5 sol = 250 x 119,450 km Mars Orbit
LDHEO = Lunar Distant High Earth Orbit ~400 x 400,000 km
NRHO = Near Rectilinear Halo Orbit 3250 x ~71,000 km

Mars Surface Crew Time Allocation

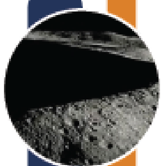


Activity	Hours/Day
Sleep	8.50
Post-Sleep (incl. Meal)	1.50
Daily Planning Conference	0.50
Morning Prep-Work	0.50
Morning Work	3.25
Midday Meal	1.00
Afternoon Work	3.25
Evening Prep-Work	1.00
Exercise	2.50
Pre-Sleep (incl. Meal)	2.00
Total	24.00

Total Hours/Day per Category:	
Personal Activities	*7.00*
Sleep	*8.50*
Conferences, Prep	*2.00*
Available Work Hours	***6.50***

Moon to Mars Objectives

NASA's Moon to Mars Objectives seek to expand humanity's frontiers in space science and exploration. The objectives fall into the overarching goals below:



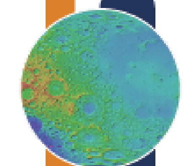
Lunar and Planetary Science
Answer questions about the formation of our solar system, the geology and chemistry of planetary bodies, and the origins of life.

Heliophysics
Advance our study of the Sun and our ability to observe, model, and predict space weather.

Human and Biological Science
Grow our understanding of how the lunar, Martian, and deep space environments affect living things.

Physics and Physical Sciences
Investigate space, time, and matter in the unique environments of the Moon, Mars, and deep space.

Science Enabling
Develop integrated human and robotic techniques that address high-priority scientific questions around and on the Moon and Mars.



Applied Science
Conduct science utilizing integrated human and robotic techniques to inform the design of exploration systems.

Lunar Infrastructure
Create an framework for government, industry, academia, and international partners to participate in a robust lunar economy and facilitate science.

Mars Infrastructure
Develop the power, communications, navigation, and resource utilization capabilities to support initial human Mars exploration.

Transportation and Habitation
Create the systems necessary for humans to travel to the Moon and Mars, live and work there, and return to Earth safely.

Operations
Conduct crewed missions to gradually build technologies and capabilities to live and work on planetary surfaces other than Earth.

FLORIDA

AEROSPACE KEY FACTS AND FIGURES

AIAA — Shaping the Future of Aerospace

#2 State in aviation, aerospace, and space establishments.

7 Major Airports

9 *Aerospace Engineering Programs

MAJOR INDUSTRY EMPLOYERS

- Aerojet Rocketdyne
- Airbus
- BAE Systems
- Blue Origin
- The Boeing Company
- Embraer
- Flight Safety International
- General Dynamics
- Harris Corporation
- L-3 Crestview Aerospace
- Lockheed Martin Corporation
- Northrop Grumman Corporation
- Pratt & Whitney
- Raytheon
- Rockwell Collins
- Sikorsky
- SpaceX
- United Launch Alliance

MAJOR MILITARY INSTALLATIONS

- Cape Canaveral Air Force Station
- Eglin Air Force Base
- Homestead Air Force Base
- Hurlburt Field Air Force Base
- Jacksonville Naval Air Station
- Key West Naval Air Station
- MacDill Air Force Base
- Patrick Air Force Base
- Pensacola Naval Air Station
- Whiting Field Naval Air Station

11,600+ Aerospace-related companies call Florida home, contributing **$17.7 billion** in revenues to Florida's economy

85,000+ Floridians work in state's aviation and aerospace industries

$5.2 billion Annual aviation and aerospace business exports, making Florida the national leader in these sectors

Every major aviation and aerospace company in the world has significant operations in the Sunshine State.

Florida's Space Coast is a hub for the growing commercial space industry with small, medium, and large companies involved in everything from rocket engine research to satellites setting up shop.

Florida is the birthplace of commercial aviation and the air transport hub of the Western Hemisphere; the state is also home to more than 100 public use airports.

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* ABET accredited school and/or AIAA Student Branch

AVIATION/AEROSPACE & DEFENSE

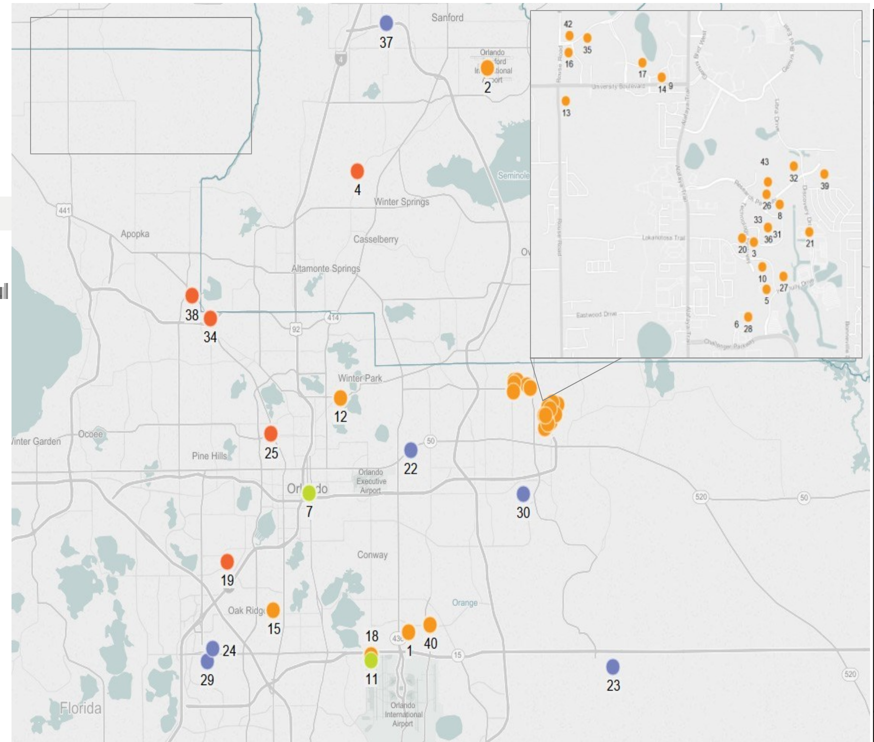
AIAA Central Florida Section

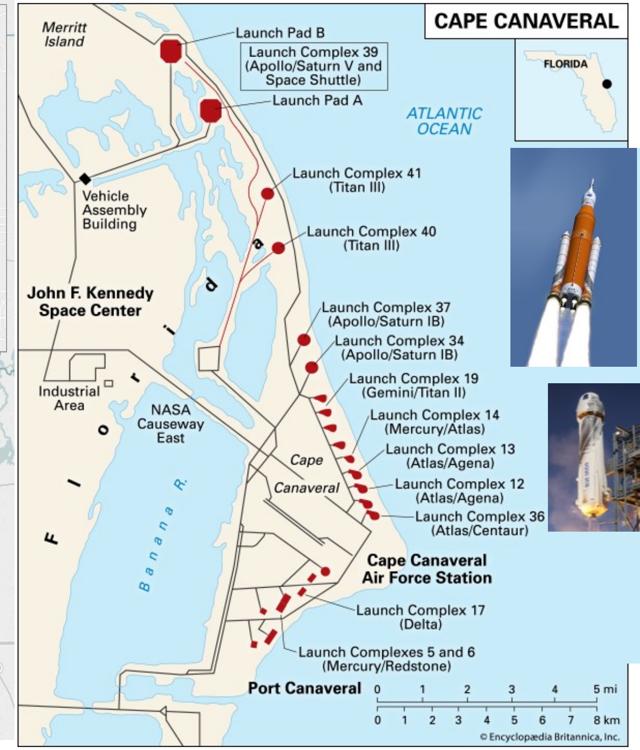
Leading Employers-Orlando MSA

Leading Employers-KSC Area

ORLANDO ECONOMIC DEVELOPMENT COMMISSION

Sector
- Defense Industry
- Maintenance, Repair & Overhaul
- Modeling Simulation & Training
- Optics and Photonics





1 Adacel Systems
2 Aerosim Flight Academy
3 Air Force Agency for Modeling and Simulation
4 Analog Modules
5 Astronics DME
6 AVT Simulation
7 BBA/ Signature Flight Support Corporation
8 CAE Systems Flight & Simulation Training
9 Camber Corporation
10 Carley Corporation
11 Cessna Citation Service Center
12 Coalescent Technologies Corp
13 Cole Engineering Services
14 Corsair Engineering, Inc.
15 Cubic Defense Applications
16 Dignitas Technologies, LLC
15 Engineering & Computer Simulations, Inc.
18 FlightSafety International, Inc.
19 Gooch and Housego
20 Intelligent Decisions
21 JHT, Inc.
22 Kaman Precision Products, Inc.
23 Kratos Training Solutions
24 L-3 Coleman Aerospace
25 L-3 Communications
26 L-3 Communications
27 Leidos
28 Lightpath Technologies, Inc.
29 Lockheed Martin-MFC
30 Lockheed Martin-MST
31 Marine Corps System Command
32 Metters Industires, Inc.
33 Naval Air Warfare Center
34 Northrop Grumman - Apopka
35 Northrop Grumman - Orlando
36 Army Program Executive Office
37 Primal Innovation
38 Qorvo
39 Raytheon Technical Services Company
40 SimCom International, Inc.
41 The DiSTI Corporation
42 U.S. Army - R&D & Engineering Command

Blue Origin, LLC
SpaceX
United Launch Alliance
Boeing Defense & Space
Lockheed Martin
Northrop Grumman
Harris Corporation

NASA/KSC
NASA/MSFC
U.S. Air Force
Jacobs Engineering
Test & Operations
Support Contract

Private Investment Capital in Central Florida

- The five-year average annual investment level as of the end of 2022 was $8.2 billion, an increase from the 2021 five-year average figure of $7.1 billion. There was an 82% increase in start-up space venture investment from 2020 to 2021.

24 Infrastructure Elements Developed by the AIAA SPST*

Definitions of the 24 Infrastructure Elements for the Table of Space Laws

1. Develop a fully reusable two stage to low earth orbit space transportation system (ES-EO Vehicle) with advanced reliable technology that maximizes operability and is truly 'airline operational'.
2. Provide new mission functions for NASA to develop and perform maturation of new technologies required to provide true 'airline operations' required for affordability and sustainability.
3. Develop a low earth orbiting space outpost complex (LEO Station), that has much like ground operations capability today. (Remote or occasional staffing)
4. Develop an in-space transportation system for transfer from the earth orbiting complex to other locations such as Lunar orbit (EO-LO Vehicle) or in-space satellite servicing including repair. This in-space system shall be based at the earth orbiting complex and must transfer its cargo to the earth-to-orbit system for return to the ground.
5. Develop a lunar orbiting platform complex (LO Station) that shall provide a home for a lunar transportation system, (surface to lunar orbit), and used for transferring cargo between the lunar transportation system and the in-space transportation system at this platform complex.
6. Develop a fully reusable lunar orbit to lunar surface transportation system (LO-LS Vehicle) that shall be space based at the lunar orbit platform.
7. Develop an initial lunar base for harvesting and processing material resources for use on the lunar surface, in-space, or transferred back to earth.
8. Develop a lunar surface transportation system to be used for exploring the moon to identify the location of resources to be mined and transferred back to the lunar base. This system shall be based at the lunar base.
9. Develop a plan for adding life support to the in-space facilities.
10. Develop habitation concepts and select best for development on the orbiting outpost at earth and the moon.
11. Develop rotational artificial gravity required to support long term habitation for personnel in-space first for use at Earth orbit and Lunar orbit.
12. Develop in-space parts manufacturing capability to be used at both orbital outposts and at the Lunar surface base. This is needed to support the space-based transportation systems and orbiting outposts, as well as the Lunar base and transportation.
13. Develop Power Stations on the lunar surface to support lunar operation on the surface, (include Nuclear and Solar in the selection trade).
14. Develop habitation concepts and select best for development on the lunar surface, including shielding requirements for long term habitation and with consideration for life support functions including their food production.
15. Develop a control center needed to manage space activities. Location of this post is not yet determined.
16. Develop a comprehensive system for assuring space situational awareness in all the areas of operations.
17. Develop a lunar communication system to be used for communication from any location on the lunar surface back to the lunar base or to the earth and to the space in-orbit outposts.
18. Develop a rescue service to return crew stranded on the Lunar surface to the Lunar base.
19. Develop a lunar research and development facility for testing new techniques and to perform lunar science investigations.
20. Develop lunar production facilities (e.g., rocket propellant etc.) as needed.
21. Develop lunar production facilities for life support (food) at the lunar surface.
22. Demonstrate in-space fabrication and construction processes for large-scale structures to be used in-space.
23. Develop a high efficiency nuclear/electric propulsion system to explore deep space, out to the main asteroid belt, where key raw materials may be found.
24. Develop space-based solar power systems for specific needs.

*** Space Propulsion Synergy Team (SPST)**

18 Categories of Space Laws Developed by the SPST

AIAA Central Florida

Introduction to Space Law

On Earth, the rule of law has been a foundational element for the growth of thriving and peaceful civilization on every inhabited continent of our planet. The SPST fully expects that space law will be equally instrumental in the thriving and peaceful growth of human activities in space. Below is an example set of 18 types of space laws, together with a table of their applicability to the 24 infrastructure elements.

Brief Descriptions of Areas of Space Laws, Regulations and Standards:

1. Traffic Management Regulations:
   - a. Registration requirements:
   - b. Updates for alternate missions and orbital changes
   - c. Launch vehicle disposal and launch debris prevention
   - d. Collision avoidance requirements
   - e. De-orbiting or disposal requirements post-mission
   - f. Stricter regulation of launches of high-risk or damaging payloads
2. Orbital Debris Regulations:
   - a. Launch debris avoidance requirements
   - b. Safing requirements to avoid explosions post-mission
   - c. Debris removal requirements for existing debris
   - d. Anti-satellite testing regulations
3. Liability Law:
   - a. Liability for damage:
     - i. Damage to space assets
     - ii. Damage to Earth surface assets
     - iii. Damage to Lunar assets
     - iv. Safety Zone regulations, as in Artemis Accords
   - b. Liability for debris removal
   - c. Enforcement measures for liability
4. Civilian Jurisdiction Law:
   - a. Define jurisdiction first, via citizenship or owner of spacecraft:
     - i. Each craft must display national ID, or multiple ID's if joint
   - b. Add unique law for space as required:
     - i. Contract law
     - ii. Interpersonal law
     - iii. Family law
     - iv. Tort law
     - v. Criminal law
     - vi. Other legal areas
     - vii. Later, independent settlements may develop separate law
5. Lunar Surface Law:
   - a. Property law or Exclusive Use law:
     - i. May require amendment to Outer Space Treaty
     - ii. May be temporary
     - iii. See Extraction and Mining Law, below
   - b. Governance law
   - c. Rights of access
   - d. Surface communications sharing and frequency allocation
6. Waste Regulations:
   - a. Regulations for LEO disposal for re-entry
   - b. Regulations to control in-space disposal beyond LEO
   - c. Regulations for gaseous and molecular contamination
   - d. Regulations for disposal on Lunar surface
7. Extraction and Mining Law:
   - a. Mining claims registration law
   - b. Conflicting claims adjudication law
   - c. Resource sharing accords for limited resources (e.g., Shackleton Crater ice)
   - d. Surface restoration regulations
8. Building Codes and City Planning:
   - a. For 'urban' locations, such as multinational Lunar Village
   - b. Planning accords for shared roads and utilities
   - c. Safety regulations for pressurized structures
   - d. Property rights within shared development areas
   - e. Governance structure for building registration and permits
9. Nuclear Law for Power and Propulsion:
   - a. Safety regulations for nuclear systems
   - b. Radiation regulations for nuclear systems:
     - i. Both for operators and for community radiation:
   - c. Transparency avoiding concealment of nuclear weapons or materials
   - d. Construction and operating licensing:
     - i. When used in 'urban' locations, see above
   - e. Shutdown regulations for post-mission nuclear systems
   - f. Disposal regulations for nuclear and radioactive waste

18 Categories of Space Laws (continued)

10. Standards:
    a. Electric utility standards
    b. Docking port standards for multiple sizes
    c. Grappling fixture standards
    d. Power pack standards for vehicles and for space suits
    e. Electrical for powering up externally and recharging:
        i. Including for human emergencies
    f. Refueling fittings
    g. Deorbiting systems, such as tethers
    h. Tool standards
        i. Fastener standards
11. Co-operation Framework:
    a. Standard documents for co-operation on space stations
    b. Standard documents for co-operation on Lunar stations
    c. General documents for ad hoc unplanned co-operation
    d. Co-operative troubleshooting and repair
12. Rescue Accords for Human Emergencies:
    a. Accords for when rescue is required
    b. Accords for allocating resources for rescue attempt
    c. Standard procedures for rescue in-space
    d. Standard procedures for rescue on Lunar surface
    e. Standard rescue port
    f. Standard rescue vehicle
    g. Standard (inflatable?) 'lifeboat' for rescue in-space by any nation:
        i. Standards for safe haven shelter, pre-positioned on Lunar surfac
13. Data Ownership Law:
    a. Intellectual property law
    b. Agreements on sharing of safety-related IP
    c. Agreements on privacy of proprietary economic IP
14. Telecommunication Regulations:
    a. Frequencies for shared communications, safety
    b. Standard Assignment of private frequencies for specific users
    c. Limits on radiated power, interference
    d. Rules for sharing telecom relay satellites
    e. Provisions for handling voice, data, control differently
15. Criminal Law, Policing (Code of Conduct, Dangerous Misbehavior):
    a. Define jurisdiction first, via citizenship or owner of spacecraft
    b. Add unique law for space as required
        i. Consider maritime and aviation law for precedents
    c. Establishment of police powers and organizations
    d. Laws setting conditions for arresting, detaining, and confining
    e. Procedures for remote justice courts, based on Earth
    f. Use of force regulations
    g. Rights of residents when facing policing enforcement
16. Planetary Protection Clarifications:
    a. Contamination and environmental protection, (not Planetary Defense)
    b. Based on existing NASA and other standards
    c. Enforcement on private companies to be based on the country of their HQ on Earth
17. Inflammables and Explosives:
    a. Examples: Propellants, energy storage media, mining explosives
    b. Primarily needed at multinational 'village' or 'urban' locations
18. Military Clarifications:
    a. Based on existing Outer Space Treaty and 'customary international law'
    b. Military aggression prohibited
    c. Military offensive weapons prohibited (dual-use systems regulated):
        i. Include definitions of prohibited weapons
        ii. Missiles and conventional and nuclear weapons
        iii. Laser weapons and other new generation weapons
        iv. Cyber weapons and aggression

Space Laws Cross Reference Table

Table of Space Laws, Regulations, and Standards Required for Each of the 24 key Infrastructure Elements

Infrastructure Element #	Traffic Management	Orbital Debris	Liability	Civilian	Lunar	Waste	Extraction	Building	Nuclear/Power/ Propulsion	Standards	Co-operation	Rescue	Data Ownership	Telecommunication	Criminal, Policing	Planetary Protection	Inflammables and Explosives	Military Clarifications
1 LEO launcher	Y	Y	Y	Y					Y[5]	Y	Y	Y		Y				Y
2 NASA tech									Y	Y			Y					
3 LEO station	Y	Y	Y			Y			Y[5]	Y	Y	Y		Y			Y	Y
4 EO-LO vehicles	Y	Y	Y						Y[5]	Y	Y	Y		Y				Y
5 LO station	Y	Y	Y			Y			Y[5]	Y	Y	Y		Y			Y	Y
6 LO lander	Y	Y	Y						Y[5]	Y	Y	Y		Y		Y		Y
7 Lunar base			Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y
8 Lunar transport			Y		Y	Y			Y	Y	Y	Y		Y		Y		Y
9 Add life support			Y	Y		Y				Y		Y						
10 Space habitats	Y	Y	Y	Y		Y			Y	Y	Y	Y	Y	Y	Y		Y	Y
11 Rotating gravity			Y							Y	Y							
12 Parts manufacturing			Y							Y	Y							
13 Lunar power			Y		Y	Y		Y	Y	Y	Y					Y		
14 Lunar habitats			Y	Y	Y	Y				Y	Y	Y	Y	Y	Y	Y	Y	Y
15 Control center	Y	Y	Y		Y[3]					Y	Y	Y		Y	Y			Y
16 Sit. awareness	Y		Y							Y	Y					Y		Y
17 Lunar communication	Y	Y	Y		Y					Y		Y		Y		Y		
18 Lunar rescue	Y[1]		Y		Y					Y	Y	Y		Y				Y
19 Lunar R&D			Y	Y	Y	Y	Y			Y			Y				Y	
20 Lunar production			Y	Y	Y	Y	Y	Y		Y			Y	Y	Y	Y	Y	
21 Lunar farming			Y	Y	Y	Y	Y	Y					Y	Y	Y	Y		
22 Large structures	Y	Y	Y	Y				Y[4]		Y	Y			Y	Y	Y		Y
23 Nuclear propulsion	Y	Y	Y						Y	Y				Y			Y	
24 Space solar power	Y	Y	Y	Y[2]						Y				Y				

LEGEND

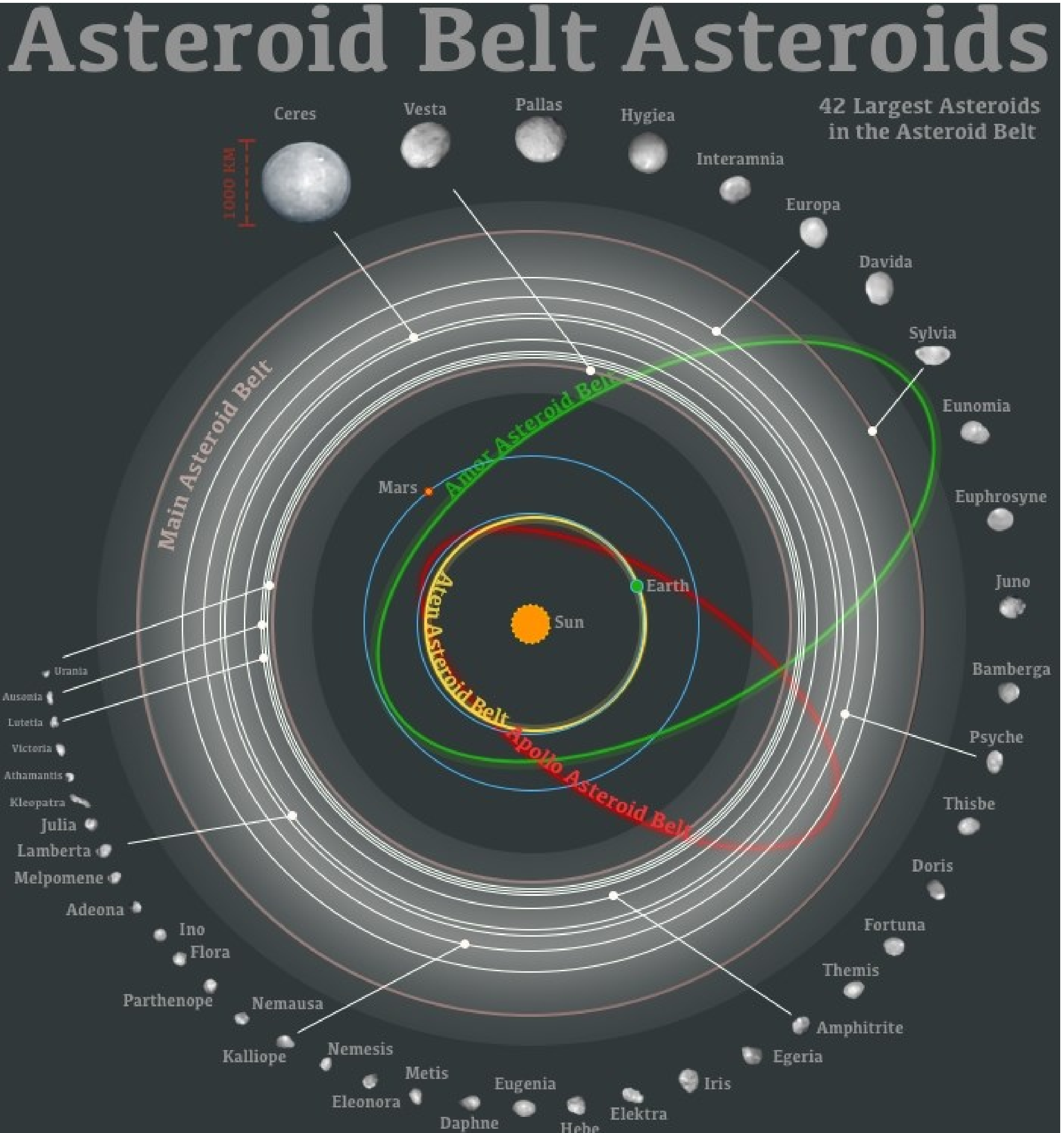
Y = Yes, required

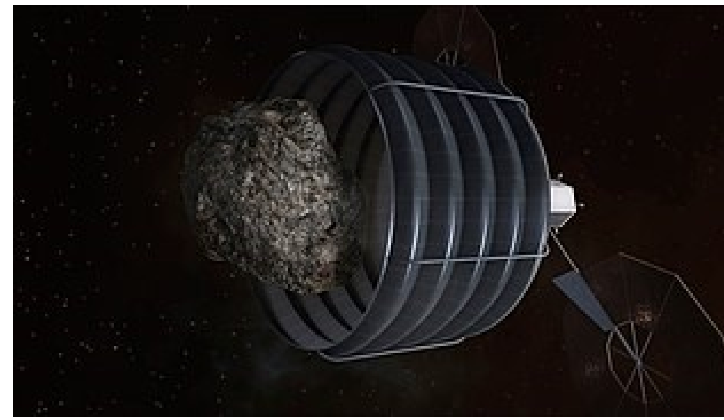
Superscript Legend

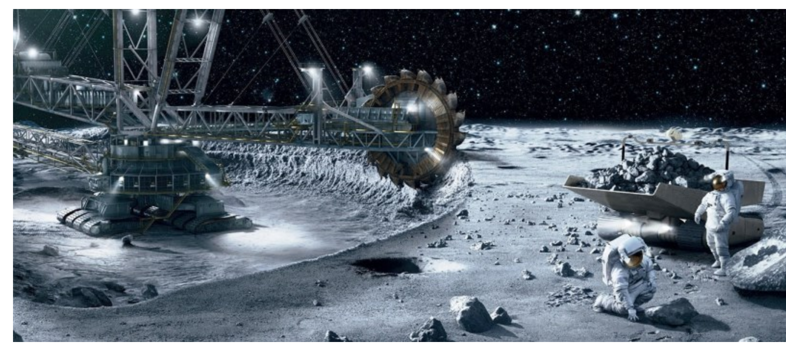
1. Only if flying rescue vehicle included
2. Only if system is staffed in space
3. Only if local field center on the Lunar surface
4. Only if demo on Lunar surface
5. Only if transporting nuclear cargo

Why Exploit Space?

Private Enterprise View – Asteroid Mining $$





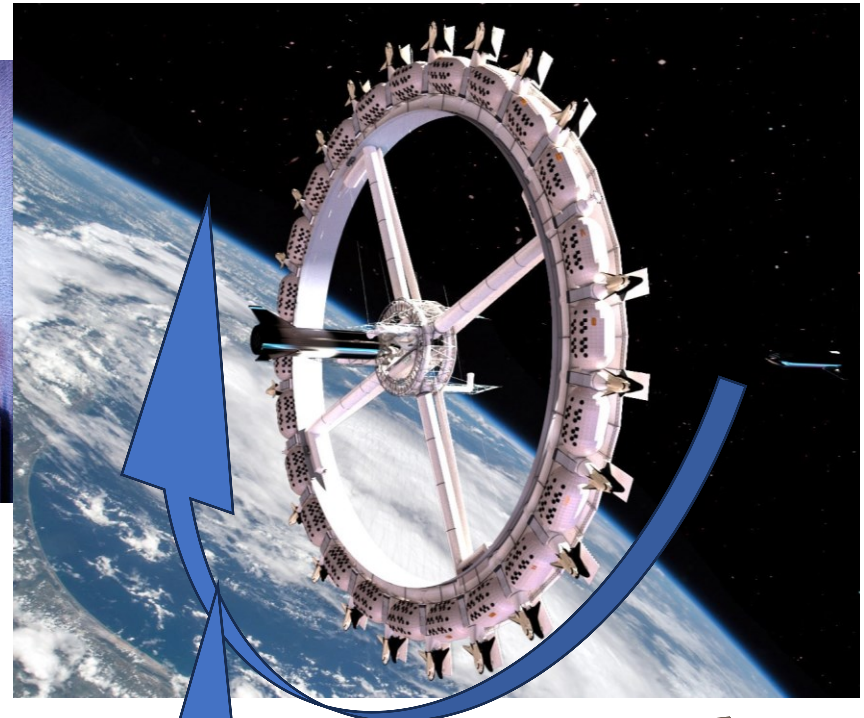


Why Exploit Space?

Private Enterprise View – Space Hotels $$

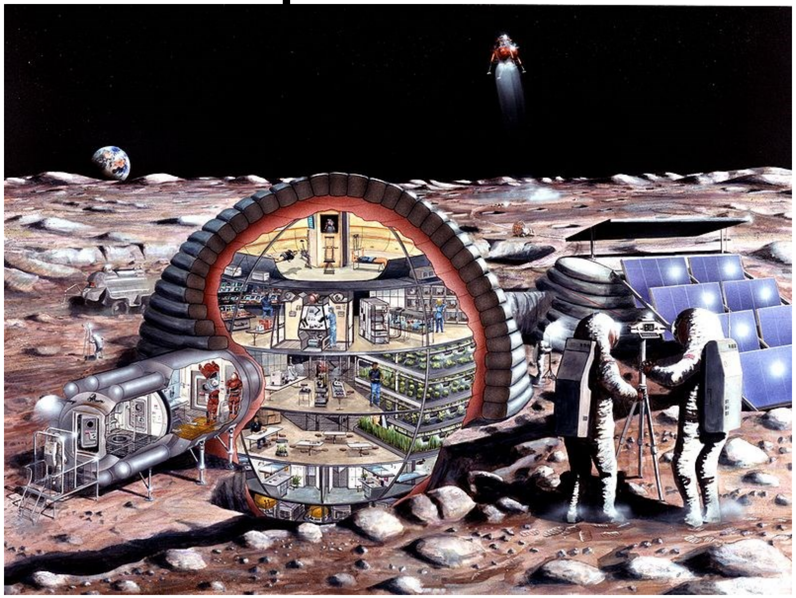
Actual Implementation

Wishful Thinking



Why Exploit Space?

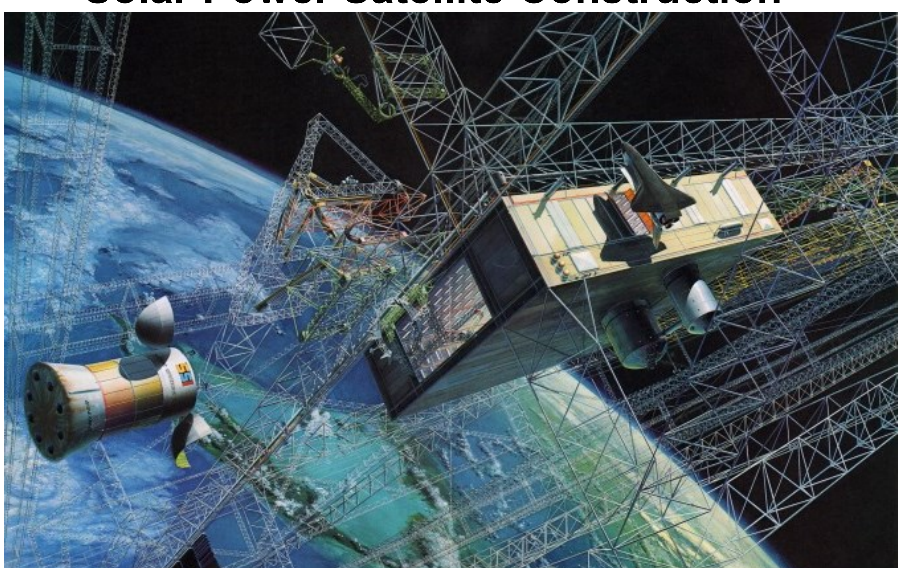
Private Enterprise View – Construction & Logistics Support $$



Advanced Lunar Base Construction

Refueling Depot

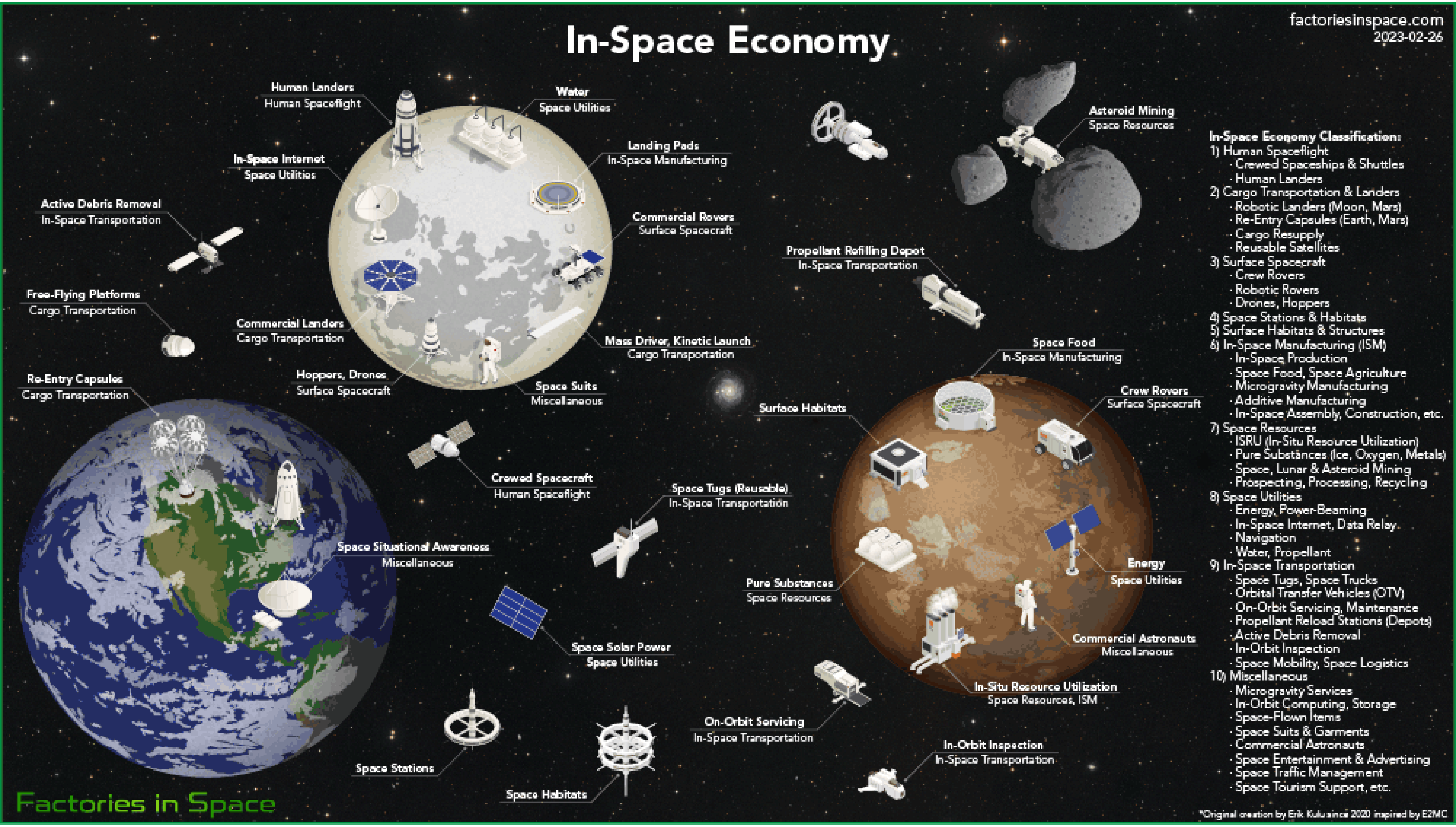
Solar Power Satellite Construction



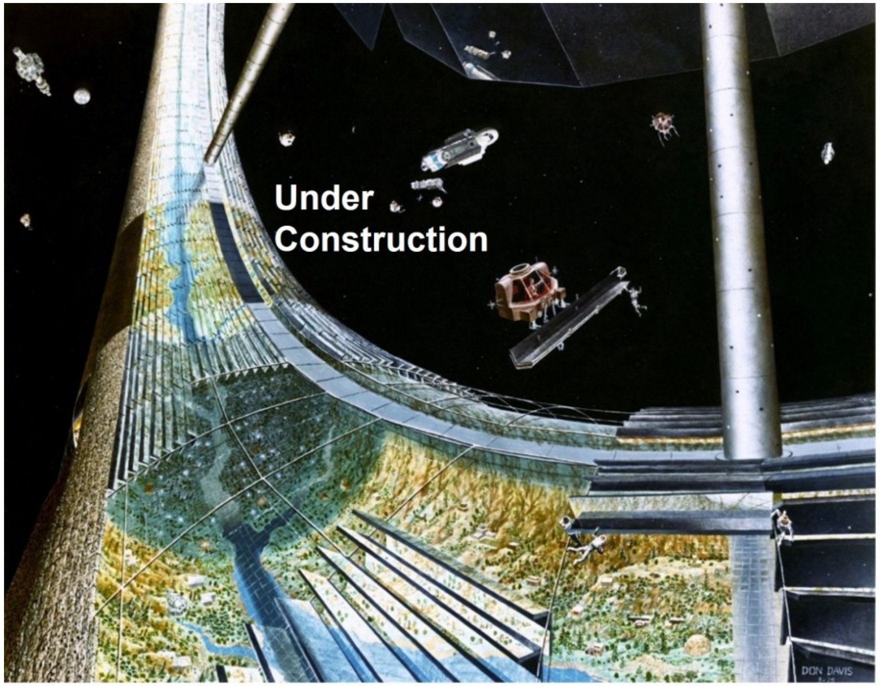
Courtesy: The Boeing Company

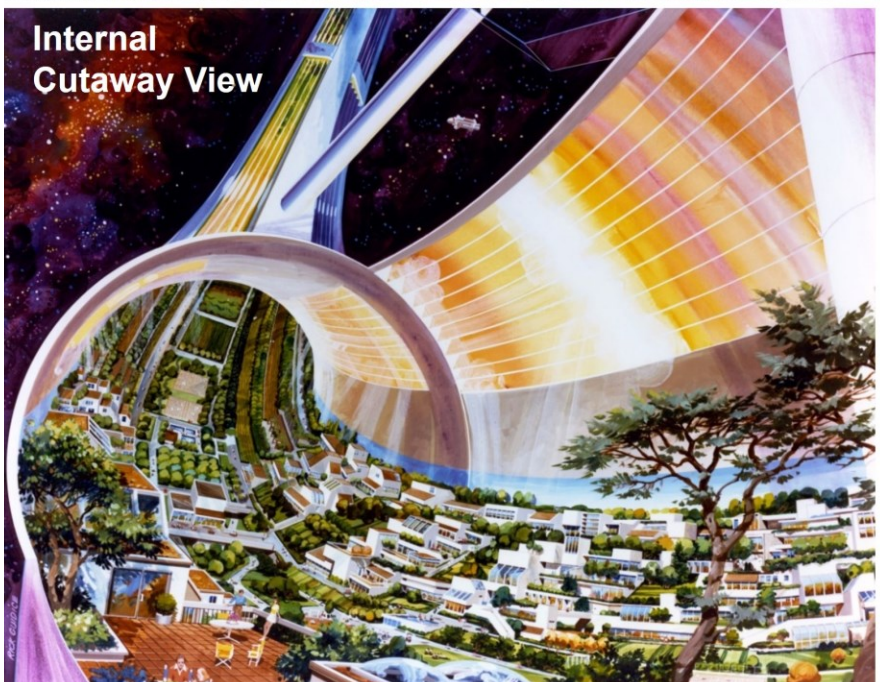
Why Exploit Space?

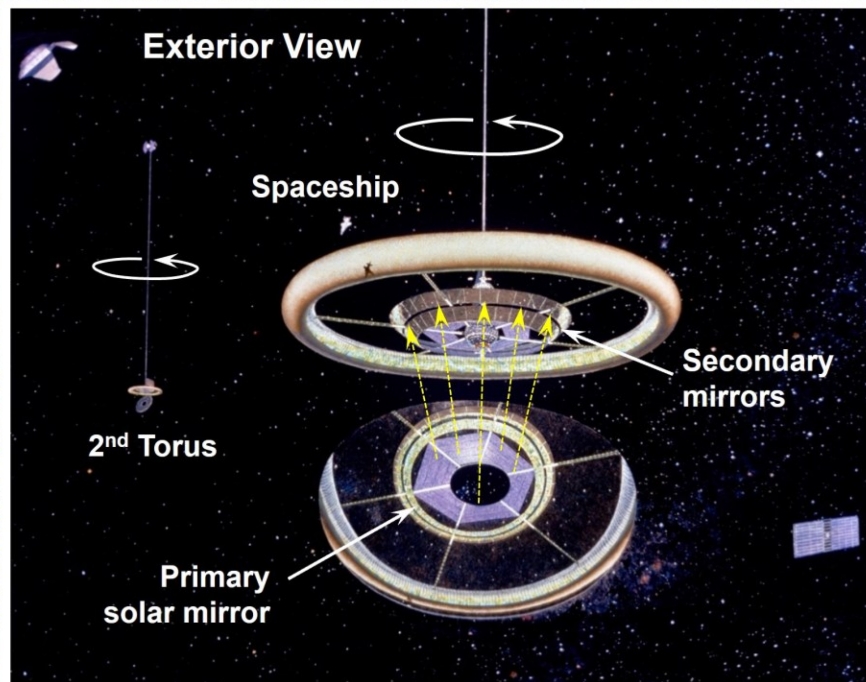
Private Enterprise View – Manufacturing $$



Advanced Concepts Beyond 2050

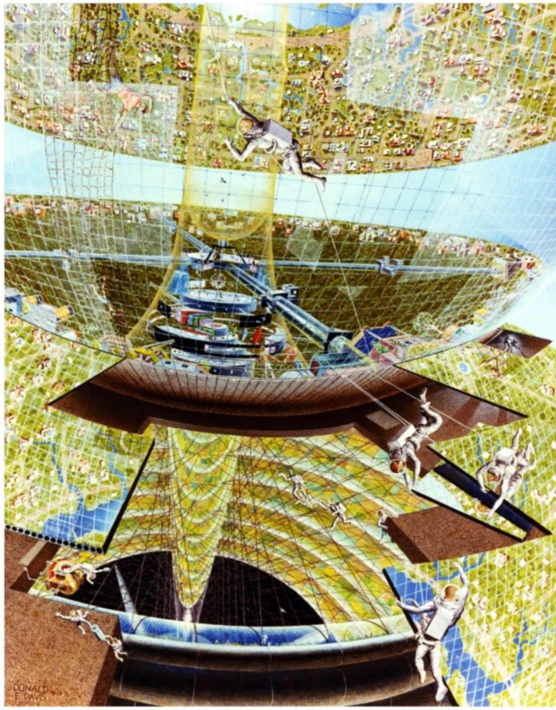




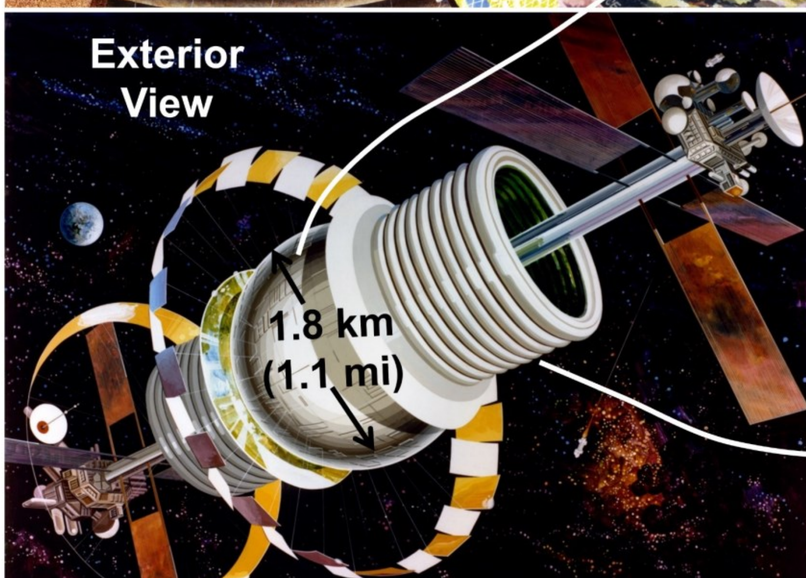


Advanced Concepts Beyond 2050

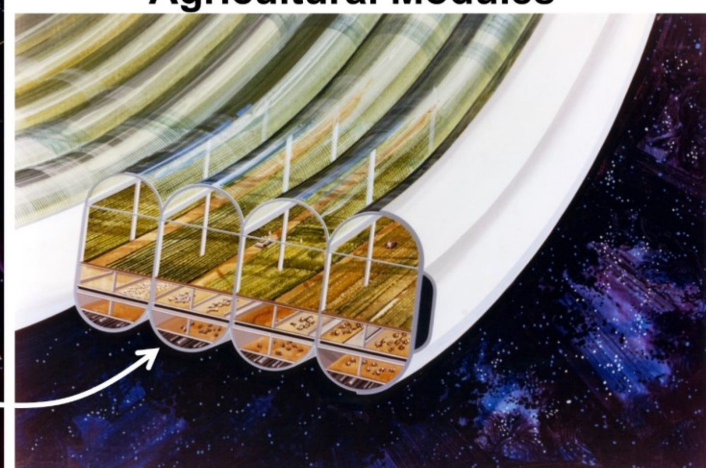
Under Construction



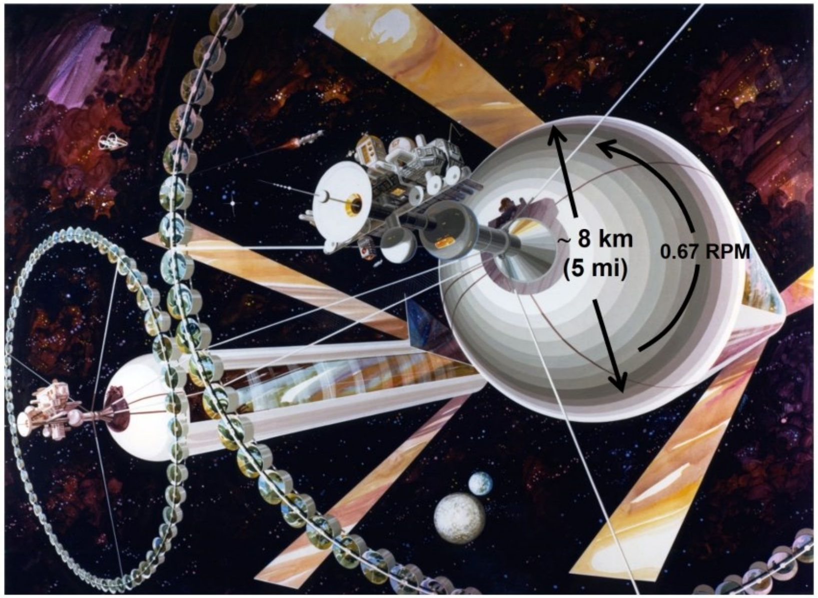
Interior View

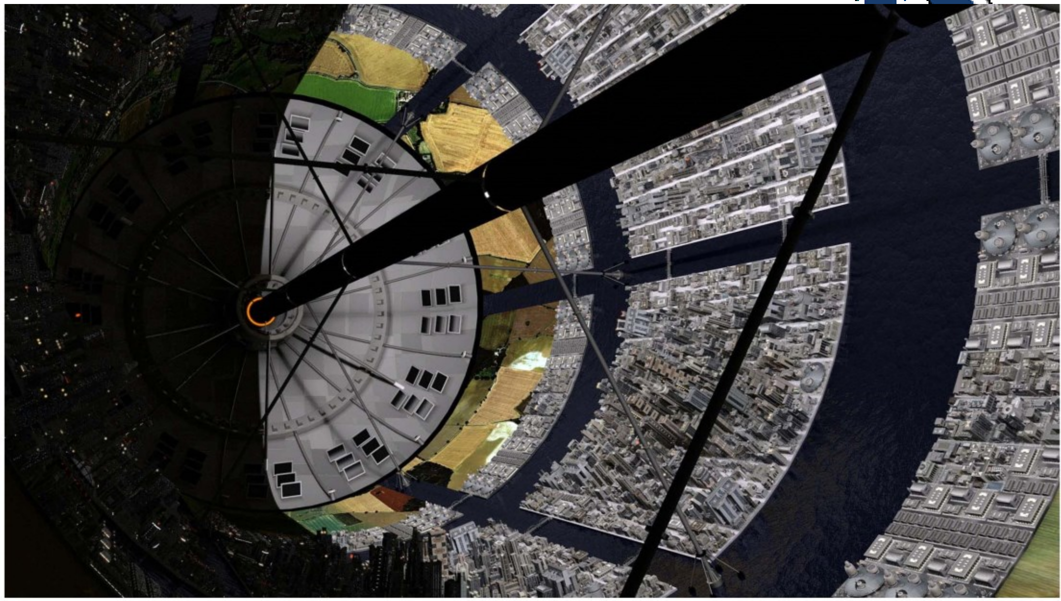


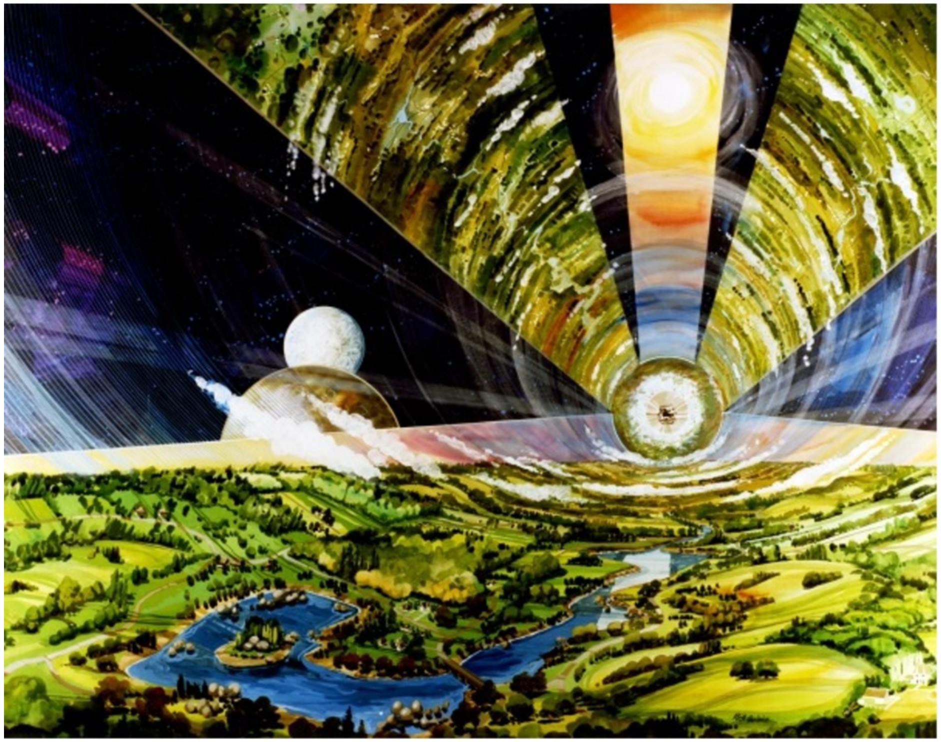
Agricultural Modules

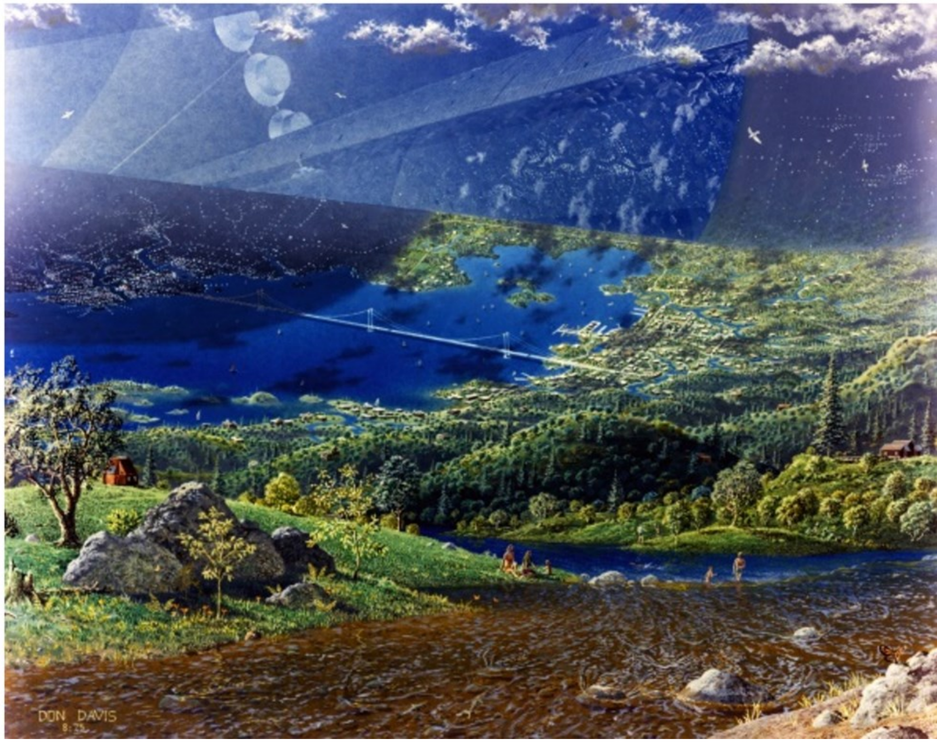


Advanced Concepts Beyond 2050

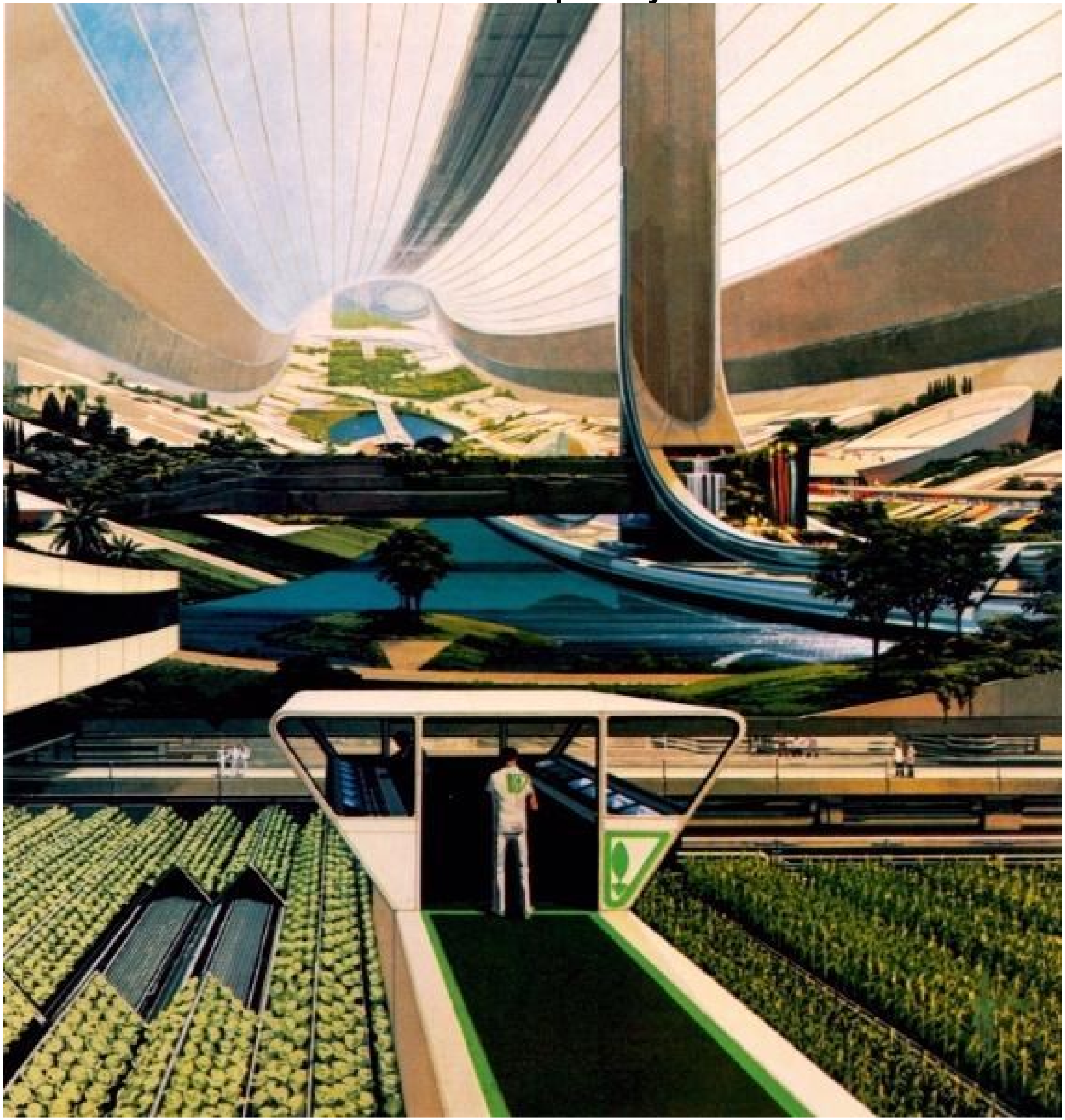






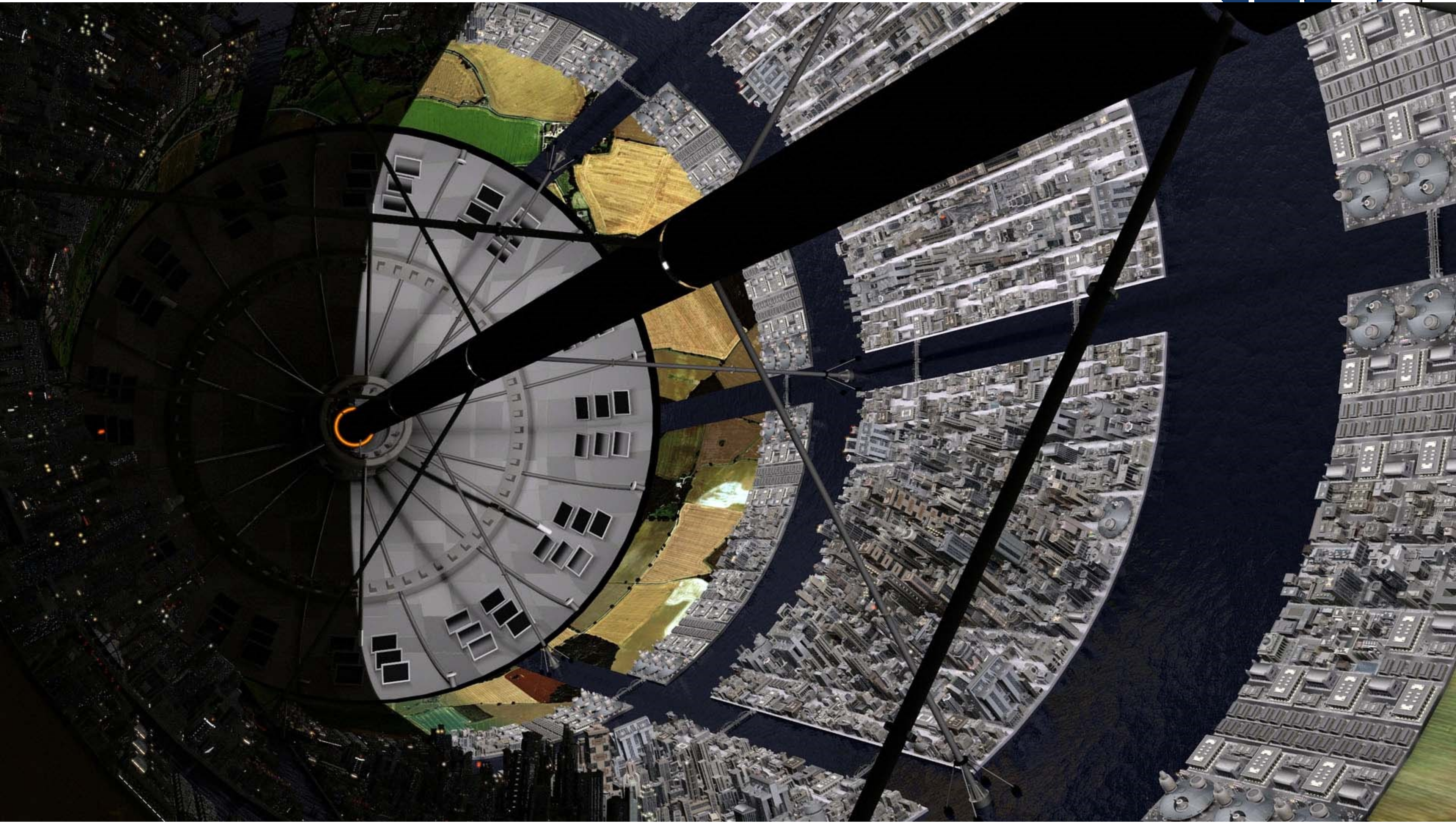


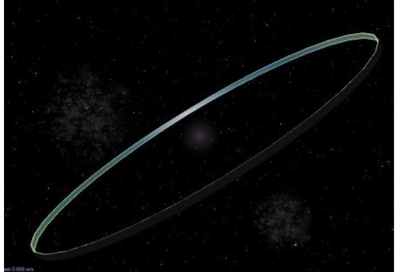
Advanced Concepts Beyond 2050



AIAA Central Florida

Advanced Concepts Beyond 2050

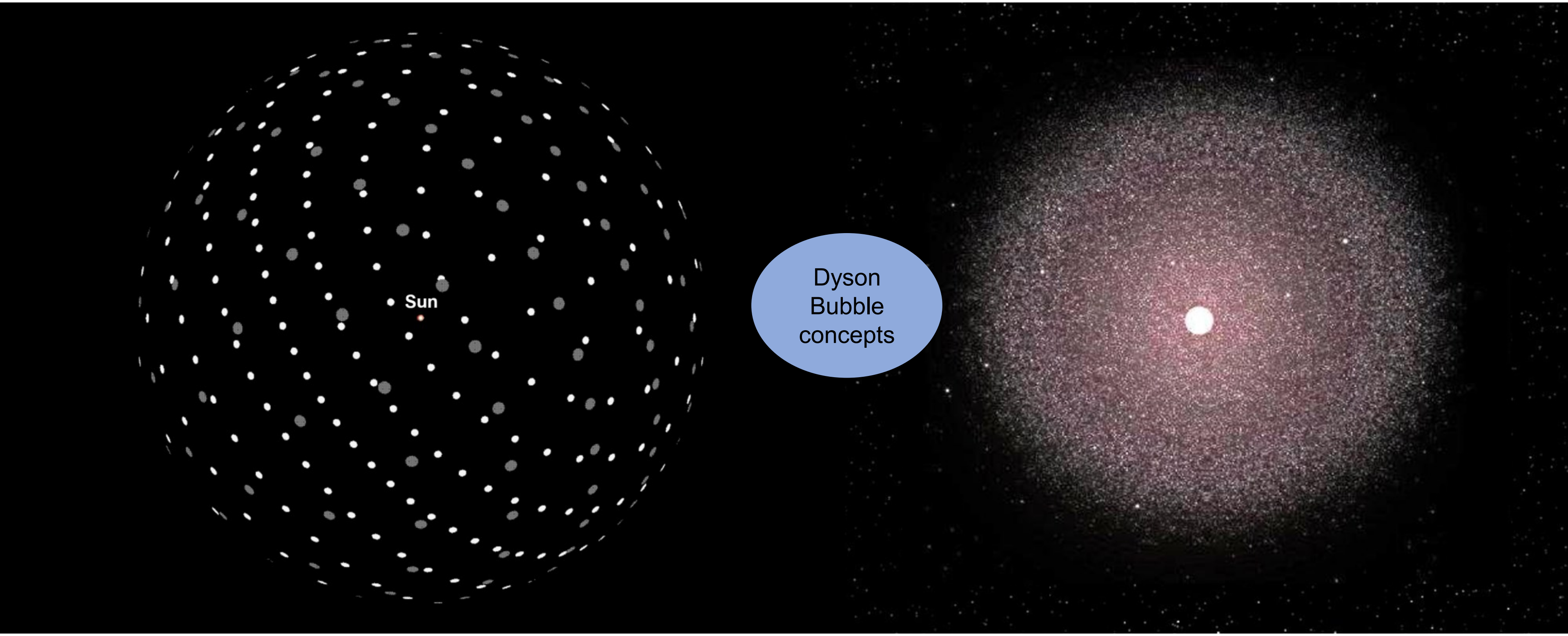




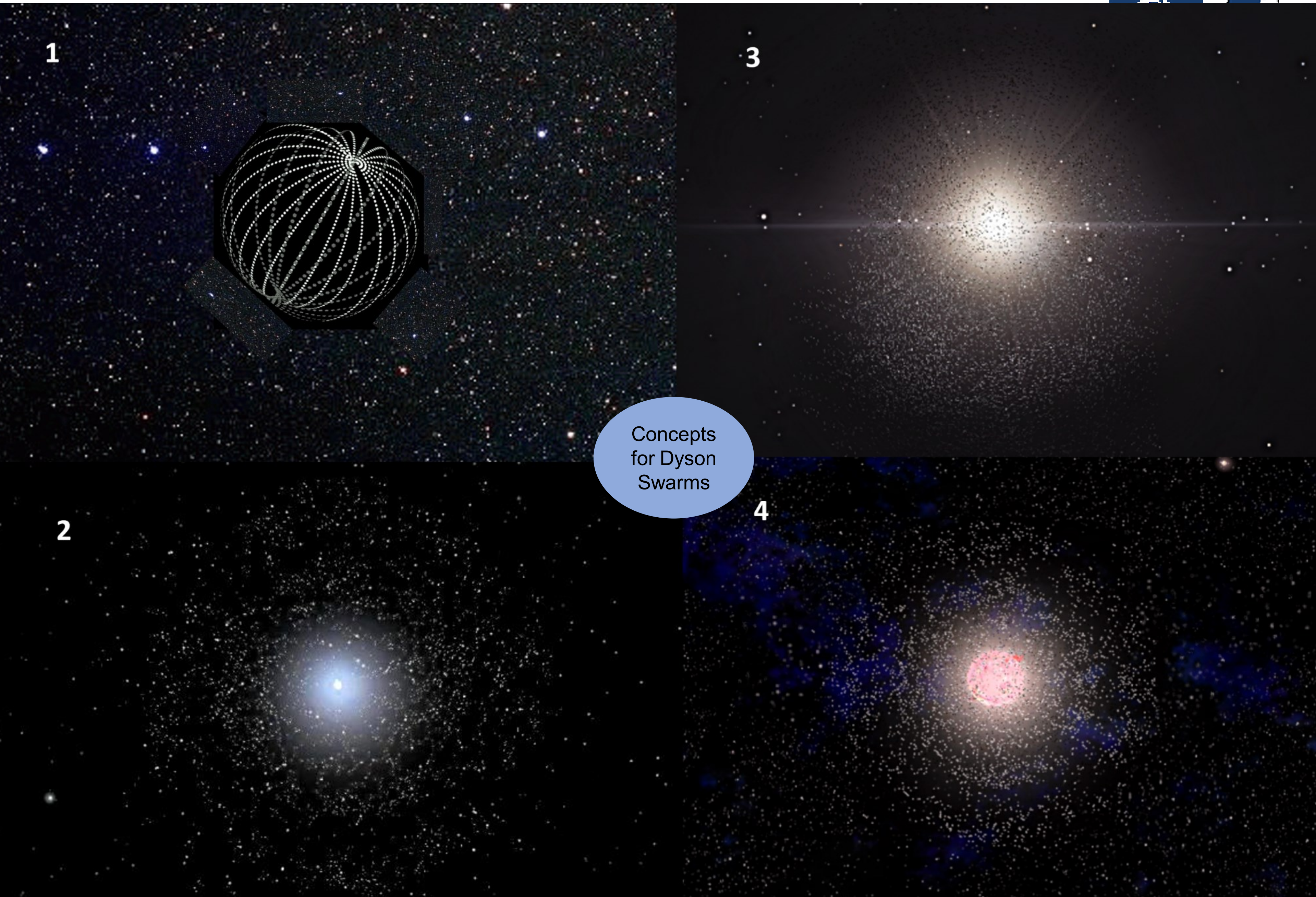
Really Far Future Concepts

Really Far Future Concepts

Really Far Future Concepts



Really Far Future Concepts



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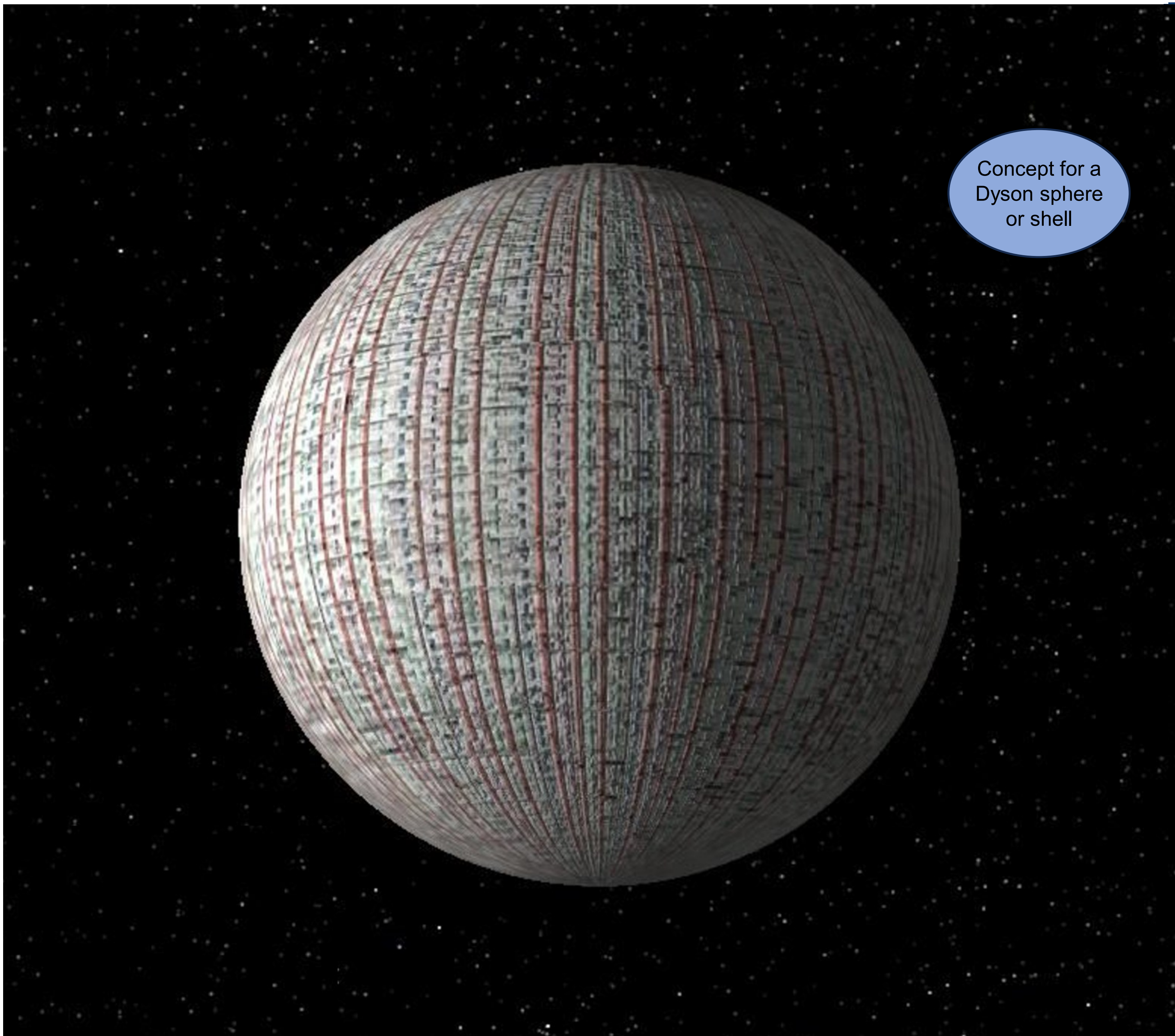
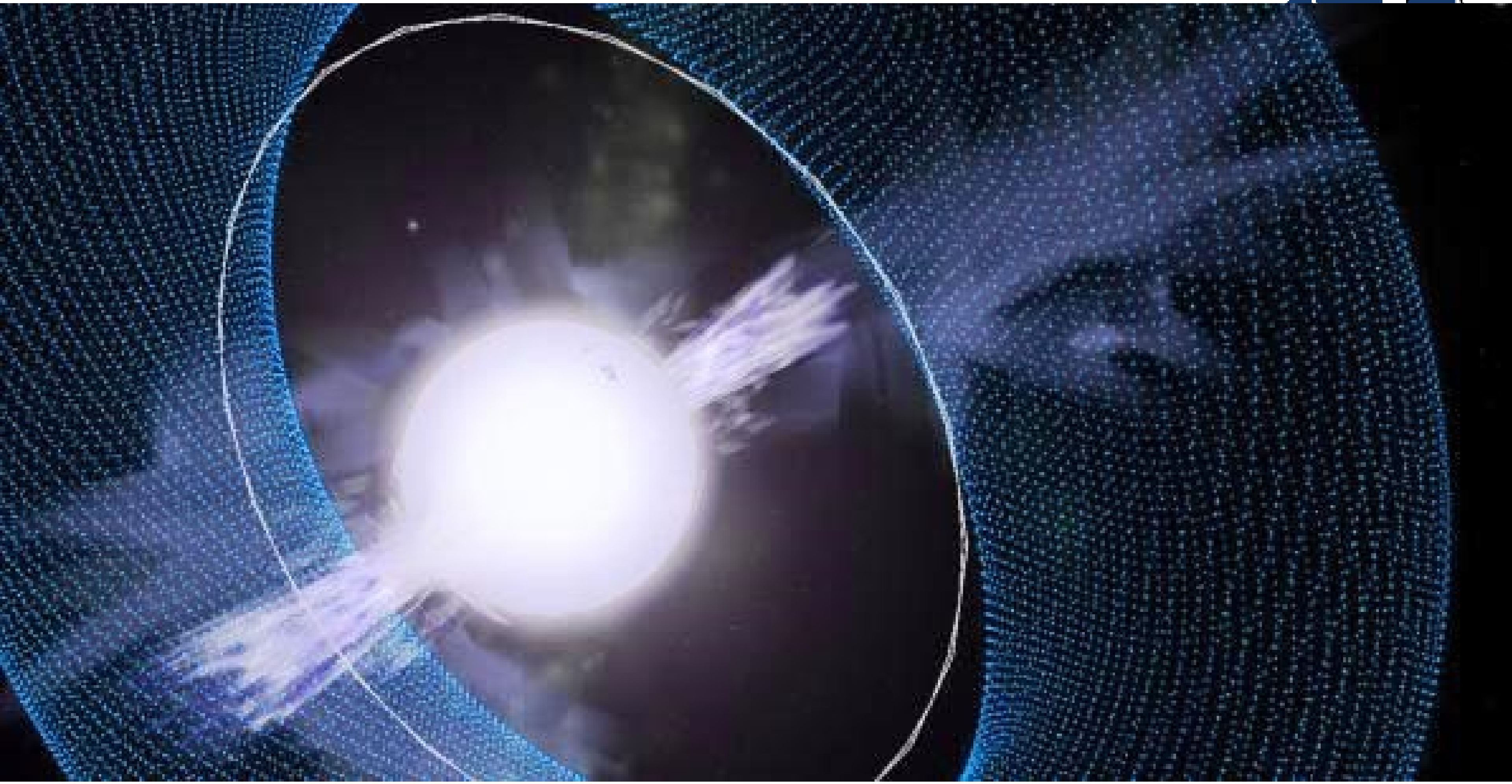


Really Far Future Concepts



Example of "starlifting" by a Type III civilization. A toroidal swarm of satellites in mutually inclined orbits generates intense magnetic fields, in effect "squeezing" the star so that it expels matter from the polar regions. The energy required for starlifting is extracted from the star's own radiation. A side benefit is that by removing the outer layers the pressure on the core is relieved, extending this star's life.

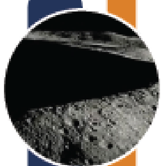
(Nikolai) Kardashev scale
- Type I harnesses the energy of an entire planet (~5 $x10^{16}$ watts)
- Type II can harness the energy output of its host star (~4 $x10^{26}$ watts)
- Type III can access the energy of an entire galaxy (~4 $x10^{37}$ watts)

Stages of technological evolution of mankind, which far outpace the glacial pace of natural Darwinian evolution. A caveman would be born with almost the same innate intelligence as the young boy at the bottom, it's what happens after one is born that makes all the difference: better nutrition, life-long education, cultural/sociological factors, etc. Each generation is as bewildered as the one before.

BACKUP

Moon to Mars Objectives

NASA's Moon to Mars Objectives seek to expand humanity's frontiers in space science and exploration. The objectives fall into the overarching goals below:



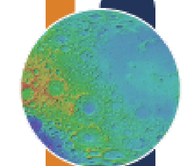
Lunar and Planetary Science
Answer questions about the formation of our solar system, the geology and chemistry of planetary bodies, and the origins of life.

Heliophysics
Advance our study of the Sun and our ability to observe, model, and predict space weather.

Human and Biological Science
Grow our understanding of how the lunar, Martian, and deep space environments affect living things.

Physics and Physical Sciences
Investigate space, time, and matter in the unique environments of the Moon, Mars, and deep space.

Science Enabling
Develop integrated human and robotic techniques that address high-priority scientific questions around and on the Moon and Mars.



Applied Science
Conduct science utilizing integrated human and robotic techniques to inform the design of exploration systems.

Lunar Infrastructure
Create an framework for government, industry, academia, and international partners to participate in a robust lunar economy and facilitate science.

Mars Infrastructure
Develop the power, communications, navigation, and resource utilization capabilities to support initial human Mars exploration.

Transportation and Habitation
Create the systems necessary for humans to travel to the Moon and Mars, live and work there, and return to Earth safely.

Operations
Conduct crewed missions to gradually build technologies and capabilities to live and work on planetary surfaces other than Earth.

Decomposition of Objectives

Lunar/Planetary Science

Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moon and Mars.

Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.

Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.

Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have coevolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.

Decomposition of Objectives

Heliophysics Science

Goal: Address high priority Heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.

Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.

Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.

Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.

Human and Biological Science

Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, support safe, productive human space missions and reduce risks for future exploration.

Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.

Evaluate and validate progressively Earth independent crew health & performance systems and operations with mission durations representative of Mars-class missions.

Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.

Decomposition of Objectives

Physics and Physical Science

Goal: Address high priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.

Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.

Enable Earth-based scientists to remotely support astronaut surface and deep space activities using advanced techniques and tools.

Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.

Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.

Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.

Enable long-term, planet-wide research by delivering science instruments to multiple science-relevant orbits and surface locations at the Moon and Mars.

Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.

Decomposition of Objectives

Applied Sciences

Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.

Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.

Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.

Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.

Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems.

Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.

Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.

Decomposition of Objectives

AIAA Central Florida

Lunar Infrastructure

Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.

Develop a lunar surface, orbital, and Moon-to- Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.

Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.

Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.

Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.

Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.

Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.

Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

Decomposition of Objectives

Mars Infrastructure

Goal: Create essential infrastructure to support initial human Mars exploration campaign

Develop Mars surface power sufficient for an initial human Mars exploration campaign.

Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.

Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign..

Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.

Decomposition of Objectives

Transportation and Habitation

Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human exploration missions to the Moon and Mars, while living and working on the lunar and Martian surface, with safe return to Earth.

Develop cislunar systems that crew can routinely operate to and from lunar orbit and the lunar surface for extended durations.

Develop system(s) that can routinely deliver a range of elements to the lunar surface.

Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.

Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.

Develop transportation systems that crew can routinely operate between the Earth-Moon vicinity and Mars vicinity, including the Martian surface.

Develop transportation systems that can deliver a range of elements to the Martian surface.

Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.

Develop systems that monitor and maintain crew health and performance throughout all mission phases, including during communication delays to Earth, and in an environment that does not allow emergency evacuation or terrestrial medical assistance.

Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during lunar missions.

Develop systems capable of returning a range of cargo mass from the lunar surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.

Develop systems capable of returning a range of cargo mass from the Martian surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.

Decomposition of Objectives

Operations

Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign..

Optimize operations, training and interaction between the team on Earth, crew members on orbit, and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.

Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.

Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.

Operate surface mobility systems, e.g., extravehicular activity (EVA) suits, tools and vehicles.

Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.

Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.

Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.

Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit..

Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms.

Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.

Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.