National Aeronautics and Space Administration

Returning to the Moon: Plans for Distributed Simulation in the Artemis Program

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Overview

- The Artemis Program
- Artemis Base Camp (ABC)
- Integrated Mission Simulations
- Simulation ABC
- Simulation Interoperability Standards
- SpaceFOM
- Take-Aways
- Questions

The Artemis Program

Artemis is the twin sister of Apollo and goddess of the Moon in Greek mythology. She now personifies our path to the Moon as the name of NASA's program to return astronauts to the lunar surface by 2024.

When they land, Artemis astronauts will step foot where no human has ever been before: the Moon's South Pole.

With the horizon goal of sending humans to Mars, Artemis begins the next era of exploration.

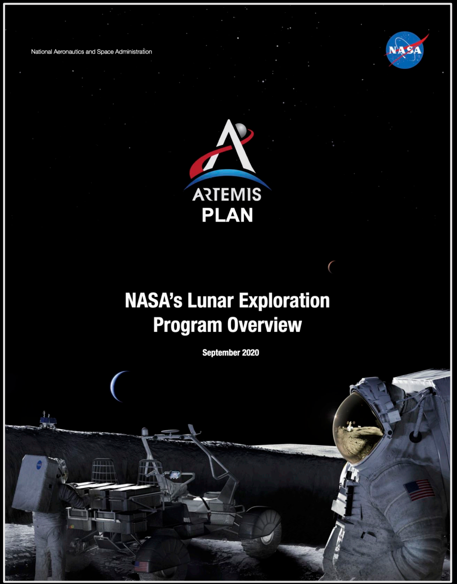
The Artemis Program

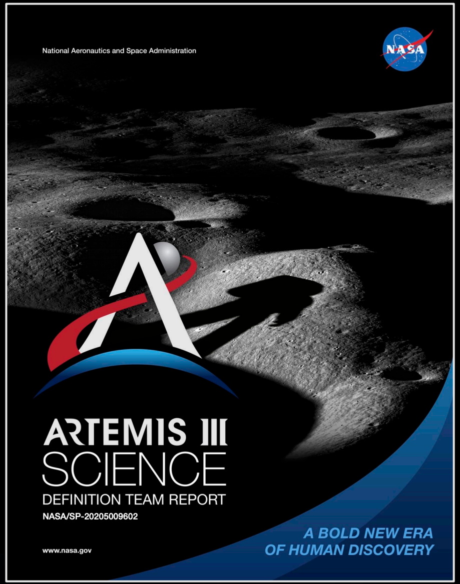
NASA Movie - Why The Moon?: https://www.youtube.com/watch?v=bmC-FwibsZg

NASA Movie – We Are Focused: https://www.youtube.com/watch?v=OsIhTw0CK8U

The Artemis Program

- Key Objectives:
  - Setting Humanity on a Sustainable Course to the Moon
  - Landing Human on the Moon in 2024
  - Extending Lunar Missions and Preparing for Mars
- Key Artemis Documents:
  - The Plan: https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf
  - The Science: https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf
  - The Accords: https://www.nasa.gov/specials/artemis-accords/index.html





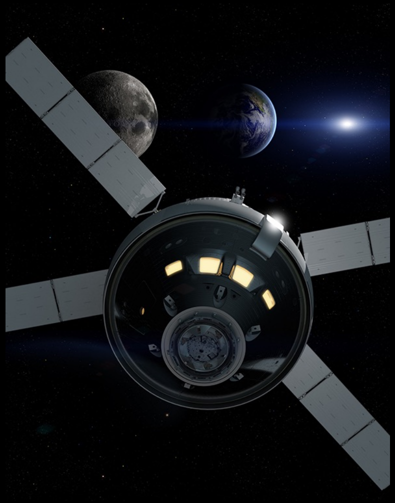
The Artemis Program: Elements

Ground Systems

The structures on the ground necessary to support launch and recovery of returning astronauts.

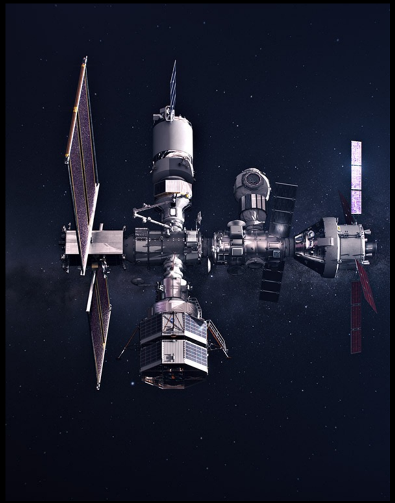
Space Launch System

The only rocket that can send Orion, astronauts, and cargo to the Moon on a single mission. Upon launch, the SLS will be the most powerful rocket in the world.



Orion Spacecraft

The NASA spacecraft that will carry astronauts from Earth to lunar orbit and back.



Gateway

The spaceship in lunar orbit where astronauts will transfer between Orion and the lander on regular Artemis missions. Gateway will remain in orbit for more than a decade, providing a place to live and work, and supporting long-term science and human exploration on and around the Moon.

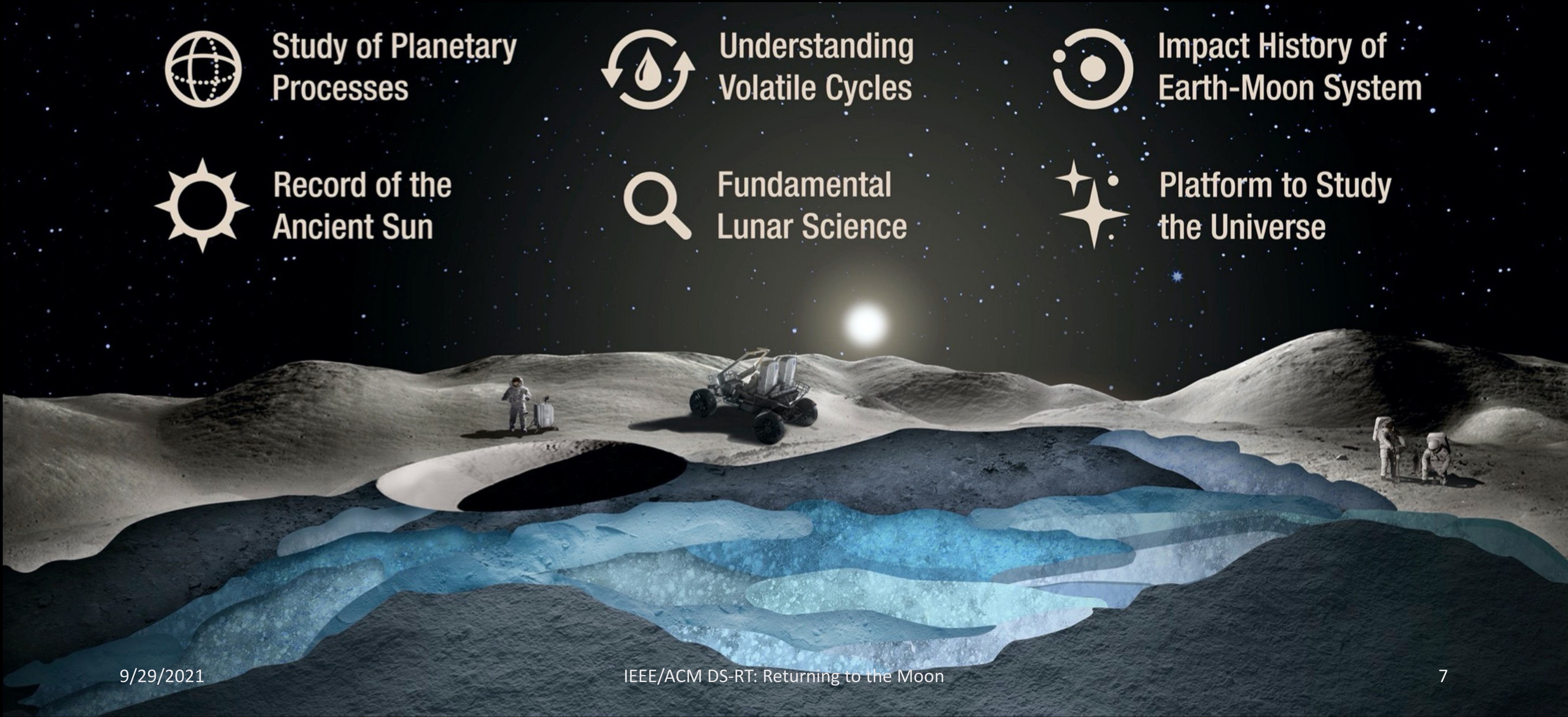
Human Landing System

Built by American companies, human landing systems are the final mode of transportation that will take astronauts from lunar orbit to the surface and back to orbit.

Artemis Base Camp

To give astronauts a place to live and work on the moon, the Artemis Base Camp concept includes a modern lunar cabin, a rover, and a mobile home.

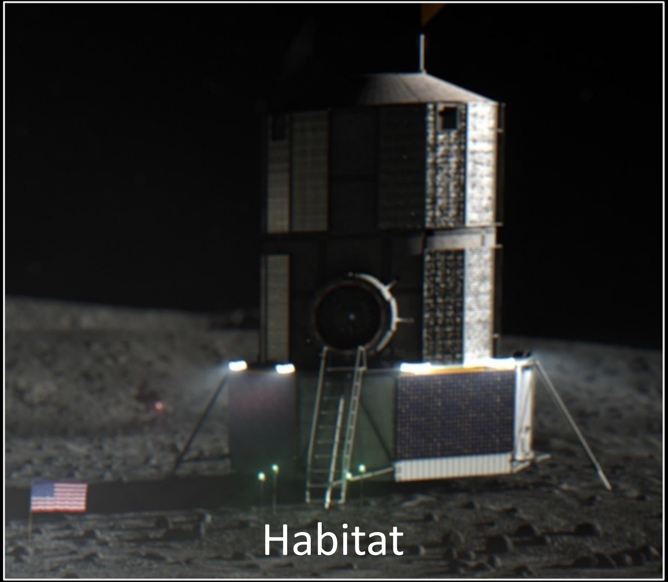
The Artemis Program: Science Objectives



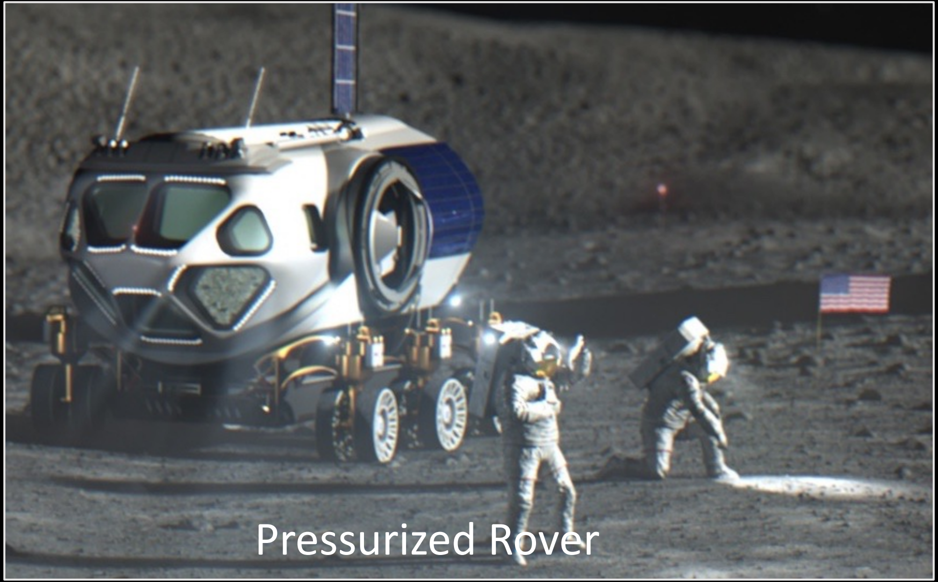
Artemis Base Camp (ABC)

Artemis Base Camp: Elements

- A place for Astronauts to live on the Moon
  - A modern lunar cabin (Habitat)
  - A way to get around (Unpressurized Rover)
  - A mobile home (Pressurized Rover)
  - Other support elements (Power, Water, Comm, etc.)

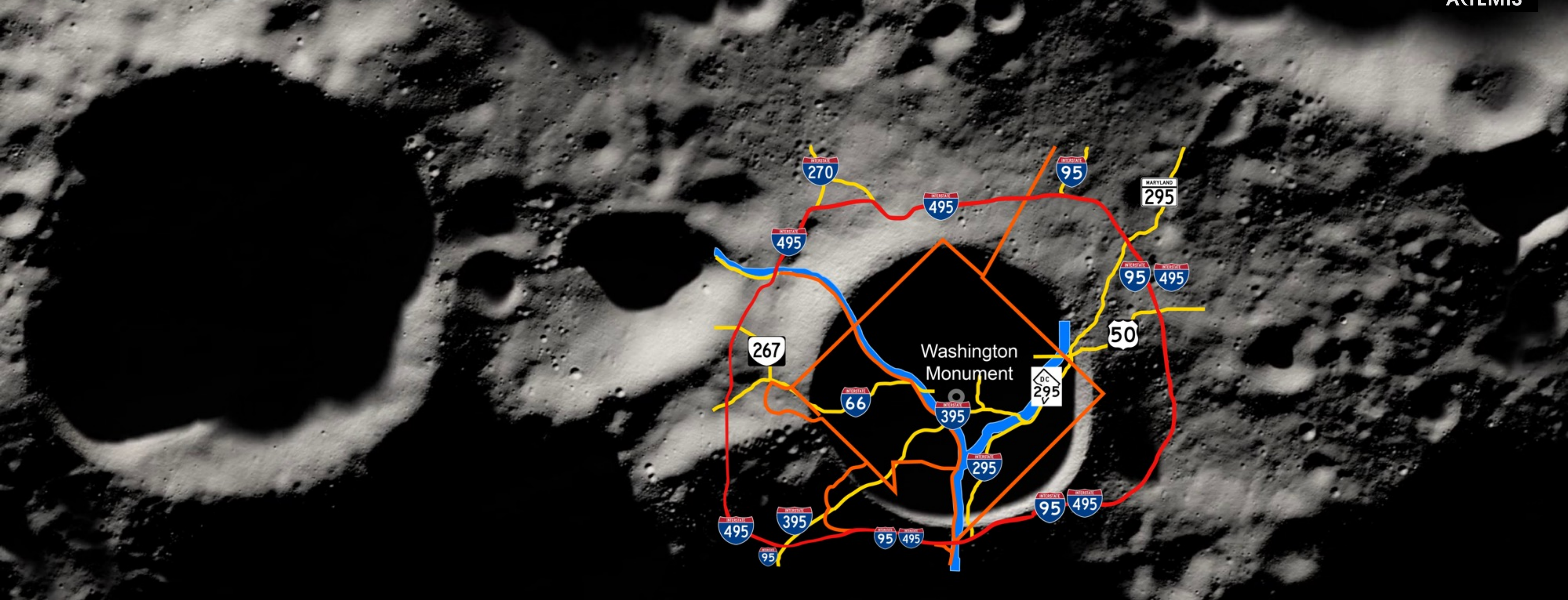

Habitat


Unpressurized Rover


Pressurized Rover


Surface Support Elements

ABC: The Scale of Shackleton Crater



~20 km in diameter, ~4 km deep and ~3x deeper and wider than the Grand Canyon

(*and approximate size of the Capitol Beltway as depicted above*)

Integrated Mission Simulations

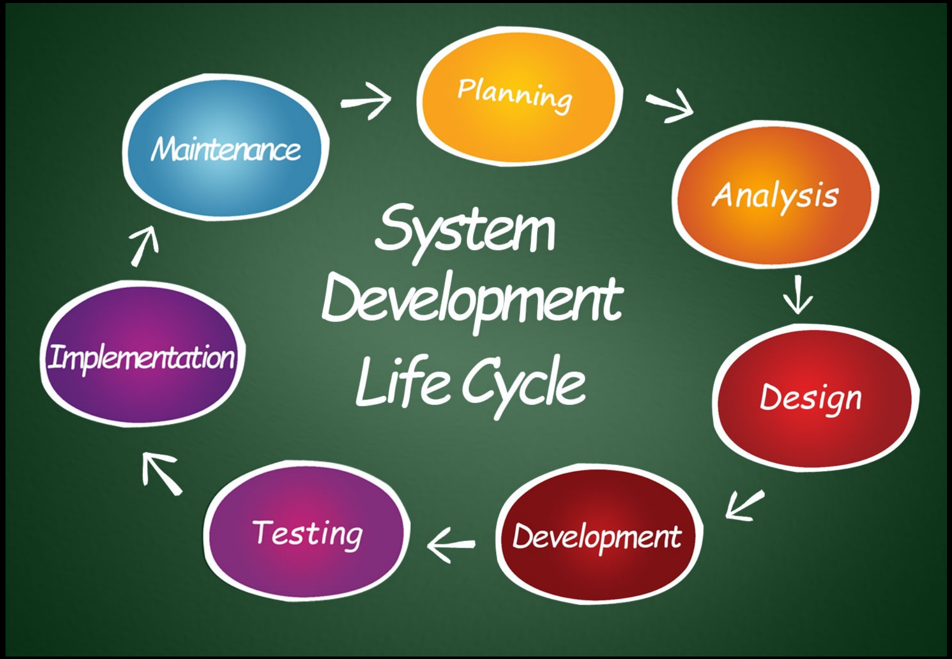
- Supports Systems Engineering and Integration (SE&I)
  - Captures coupled effects throughout the development process
  - Provides insight into design choices
- Supports hardware and software testing in difficult to create conditions
- Supports training and operations

Integrated Mission Simulations: Benefits

- Insight into spacecraft subsystems behavior
  - Facilitates definition of interfaces between subsystems
  - Supports early evaluation of subsystem interactions and responses
  - Reduce design conservatism
- Useful at all levels of project:
  - Provides system level analyses supporting project-level decision making;
  - Informs cross-subsystem trades;
  - Illuminates the effects of design changes on vehicle subsystems

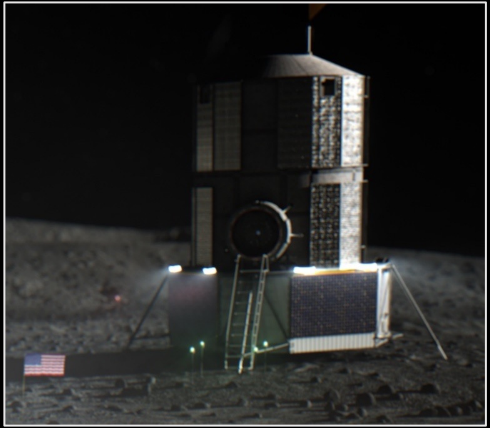
Integrated Mission Simulations: Life Cycle

- NASA develops large scale integrated space systems simulations
  - Significant funds invested in the development
  - Most often for training and operations
  - Typically, at the end of the program life cycle
- Early life cycle development
  - Provides insight into emergent behavior of complex systems
  - Can inform and drive design evolution.
  - Available to support design, development, test, and integration
  - Supports evolutionary maturation of models
  - Funding leveraged throughout the program life cycle



Simulation ABC

- The Artemis program has an evolving complex multi-element architecture.
- The Artemis program needs the ability to model the integrated performance of this complex system of systems.
- The elements will be developed and provided by a variety of international and commercial partners.
- These elements will need to interoperate and so will the element simulations.
- Element providers are likely to have their own, often proprietary, element simulations.



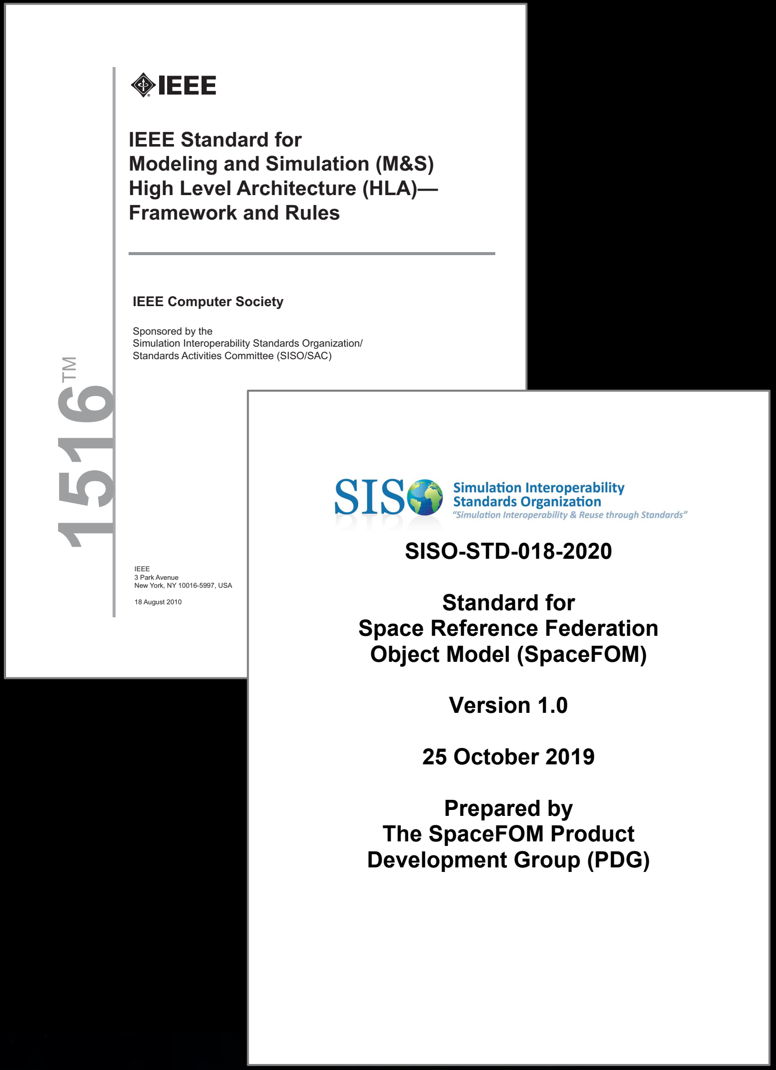
Simulation ABC: Example

Simulation ABC: Construction

- The NASA Exploration Systems Simulations (NExSyS) Team is developing simulations of the Artemis Base Camp.
- Consists of the following principal Artemis elements: Lander, Unpressurized Rover, Pressurized Rover, Surface Habitat, Supplemental Power System, etc.
- Currently focused on resource flow and integrated architecture performance.
- Initially using a collection of NExSyS-based simulations but will transition to partner simulations as they become available.
- Uses HLA and SpaceFOM as the simulation interoperability standards.

Simulation Interoperability Standards

- NASA is using HLA and SpaceFOM for interoperability
- IEEE 1516-2010 - High Level Architecture (HLA):
  - Originally developed by the US DoD;
  - Current version is IEEE 1516-2010, also known as HLA Evolved;
  - Long history with massively distributed simulations used for war games;
  - Only covers the core interoperability requirements.
- SISO-STD-018-2020 - Space Reference Federation Object Model (SpaceFOM):
  - Relatively new standard focused on the the needs of space systems simulations;
  - Provides additional standards specification needed for a priori interoperability.
  - An extension of the HLA (IEEE 1516-2010)
  - Published in January 2020 (relatively new)


IEEE

IEEE Standard for
Modeling and Simulation (M&S)
High Level Architecture (HLA)—
Framework and Rules

IEEE Computer Society

Sponsored by the
Simulation Interoperability Standards Organization/
Standards Activities Committee (SISO/SAC)

1516™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

18 August 2010

SISO Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

SISO-STD-018-2020

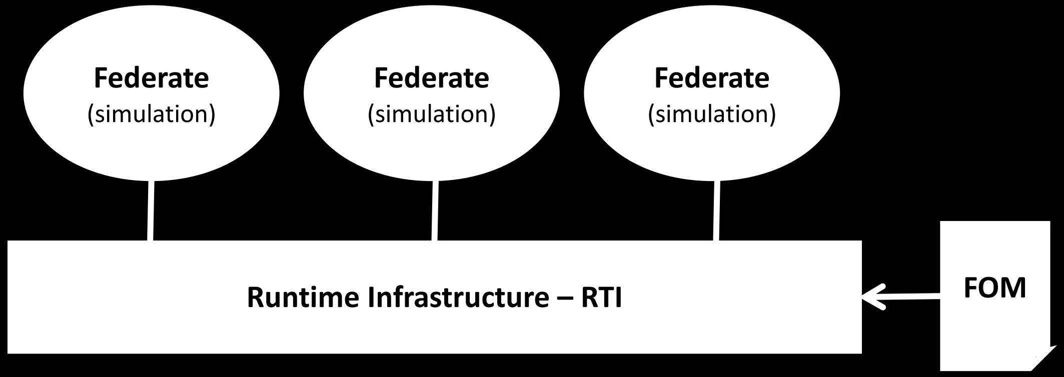
Standard for
Space Reference Federation
Object Model (SpaceFOM)

Version 1.0

25 October 2019

Prepared by
The SpaceFOM Product
Development Group (PDG)

SpaceFOM



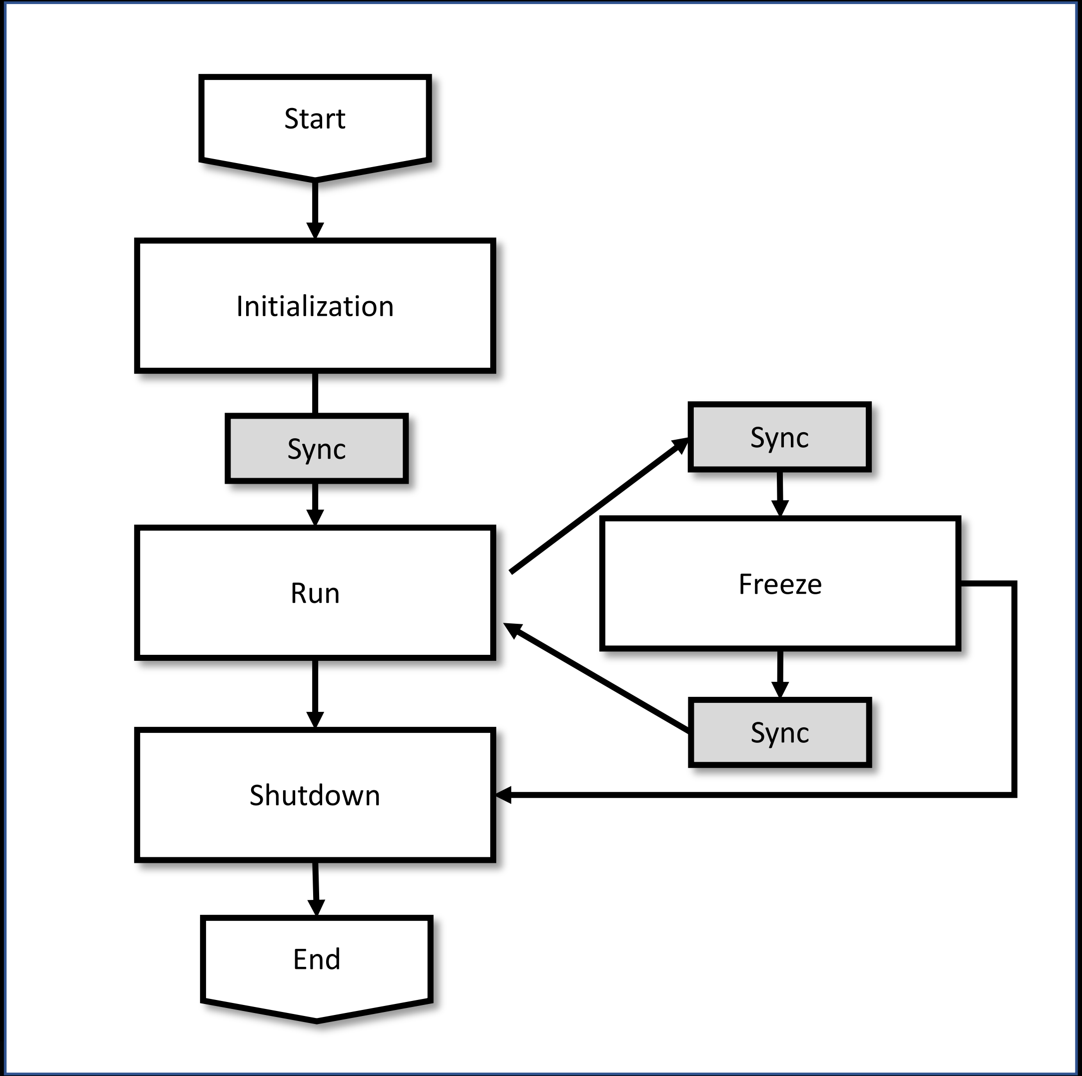
- Based on HLA
- Each system is called a federate
- Federates connect to a Runtime Infrastructure that provides services
- Together they form a Federation
- Data is exchanged based on a Federation Object Model (FOM)
- A session is called a Federation Execution

SpaceFOM: Extension to HLA

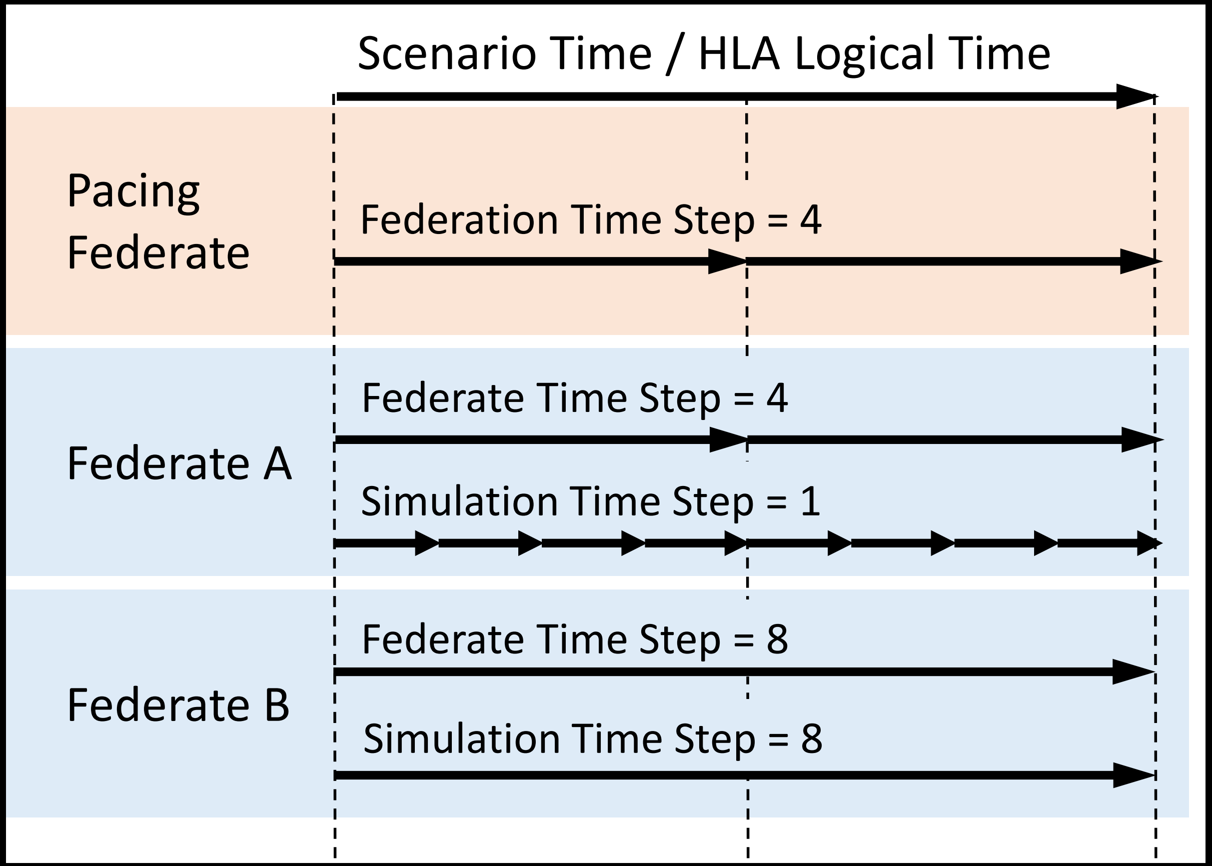
- HLA is not enough to ensure interoperability; a Federation Object Model (FOM) is also needed.
- Existing FOMs did not provide adequate support space systems simulations.
- The SpaceFOM was developed to provide the additional specifications necessary for space-based scenarios:
  - Roles and responsibilities;
  - Common data types;
  - Timelines and time standards;
  - Time-stepped focused time management;
  - Reference frames and references frame trees;
  - Reference frame naming convention;
  - Common base for space entities: entities and interfaces;
  - Well defined execution control definition;
  - Rules for assessing SpaceFOM compliance;
  - Base set of FOM modules.

SpaceFOM: Rules, Roles, and Execution Control

- Rules:
  - 103 Compliance Rules
  - Additional guidelines
- Roles:
  - Master
  - Pacing
  - Root Reference Frame Publisher
- Execution Control
  - A well-defined executive cycle
  - Gated to reduce potential deadlocks
  - Supports multi-phase initialization
  - Supports controlled mode sequencing



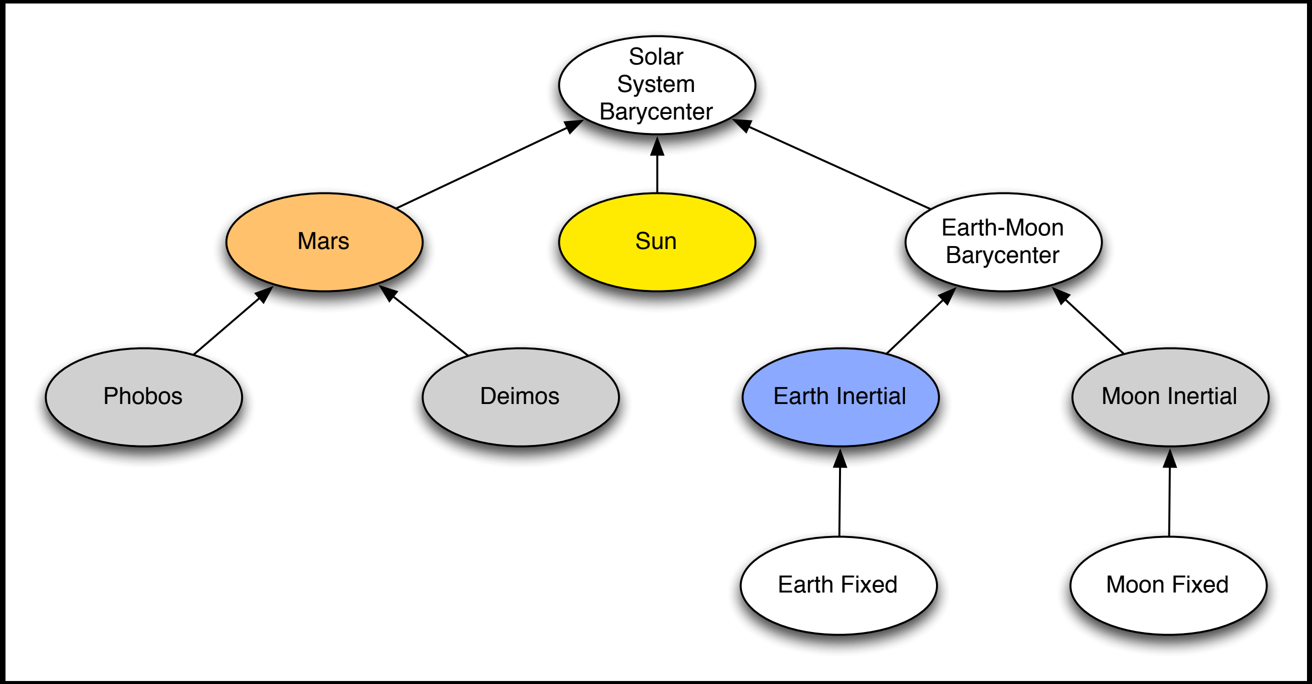
SpaceFOM: Time Standard and Time Lines



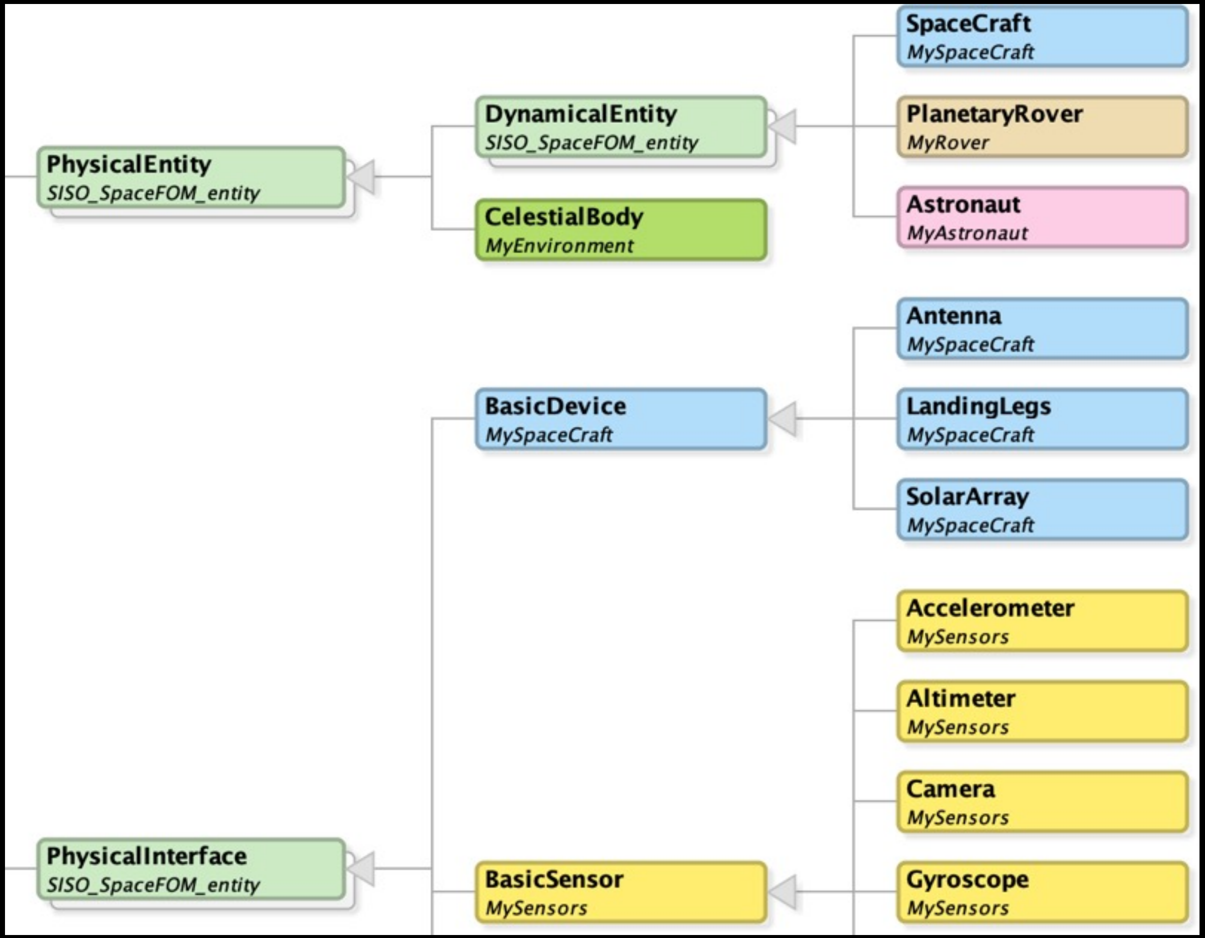
- Defines the Terrestrial Time (TT) standard as the basis for time across the federation execution.
- Defines conversions between other time standards.
- Defines 6 related time lines to support execution control:
  - Physical Time
  - Computer Clock Time
  - Simulation Elapsed Time
  - Simulation Scenario Time
  - HLA Logical Time
  - Federation Scenario Time
- Supports different simulation time steps.
- Support non-realtime and realtime execution.
- Support Central Timing Equipment (CTE).

SpaceFOM: Reference Frames and Trees

- Defines a reference frame tree.
- Supports the computation of a state in one frame with respect to any other frame in the tree.
- Is defined based on the needs of the specific federation execution.
- Proposes a standardized naming convention for reference frames.



SpaceFOM: Objects and Extension



- Builds off of the HLA base objects.
- Provides a small set of common object types tailored to space system needs:
  - Physical Entity,
  - Dynamical Entity,
  - Physical Interface.
- Other space systems can extend from these.
- Provides a set of common unit definitions for object attributes.

Take-Aways

- We are going back to the Moon with the Artemis program.
- NASA is developing a suite of integrated distributed simulations that will be used through all phases of the Artemis program.
  - Integrated simulation has traditionally been used to support operations and training near the end of the development lifecycle.
  - NASA is investing in integrated simulation earlier in the development lifecycle to support Systems Engineering and Integration activities.
  - The more complex the system(s), the greater the benefit of integrated simulation.
- Complex systems with distinct multi-element architectures can effectively be modeled with distributed simulation.
  - These distributed simulations will depend upon a well-defined simulation interoperability infrastructure based on standards, like HLA and SpaceFOM.

Questions?

NASA

ARTEMIS