Architecture Status

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Human Exploration and Operations Mission Directorate

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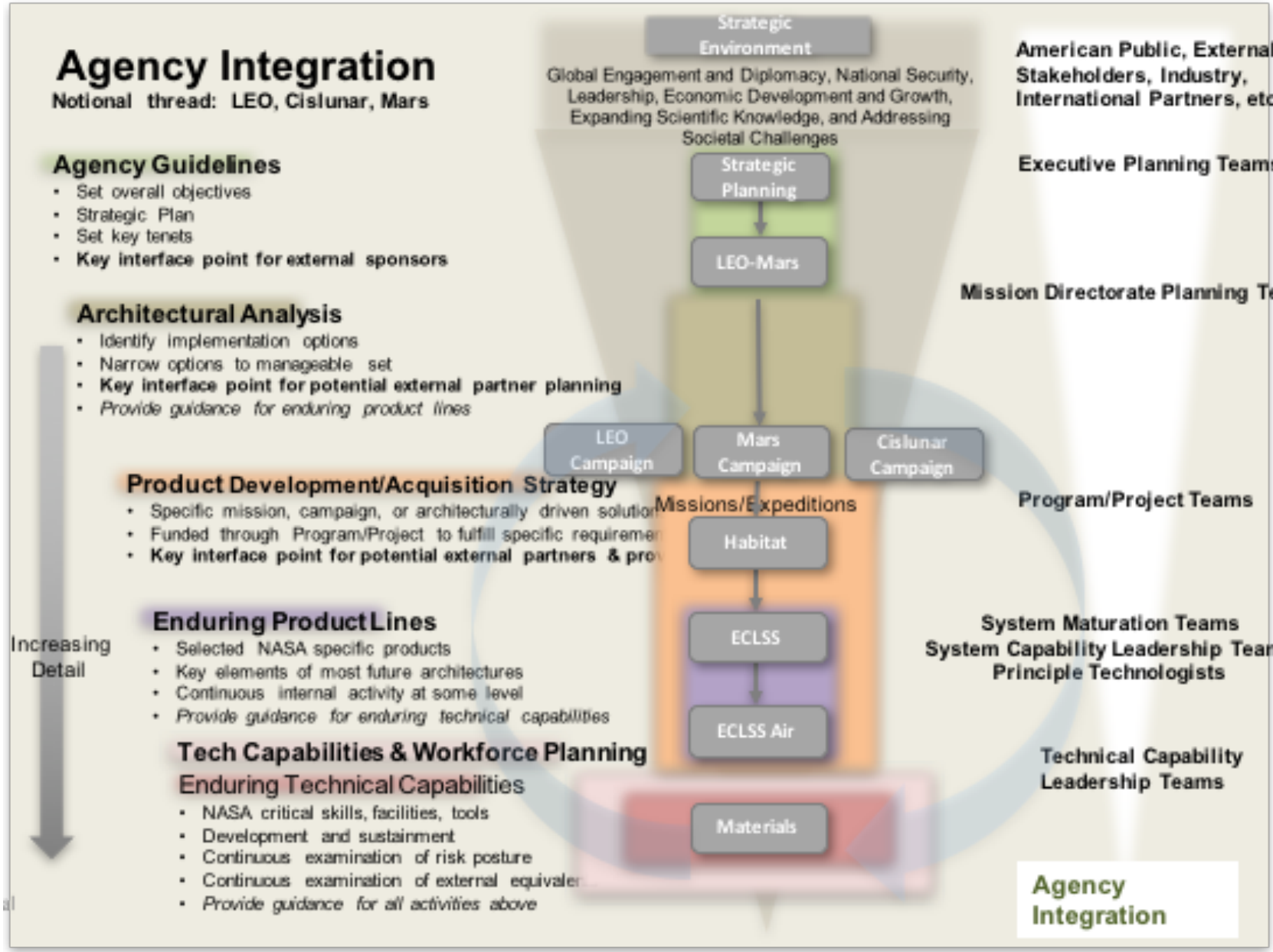
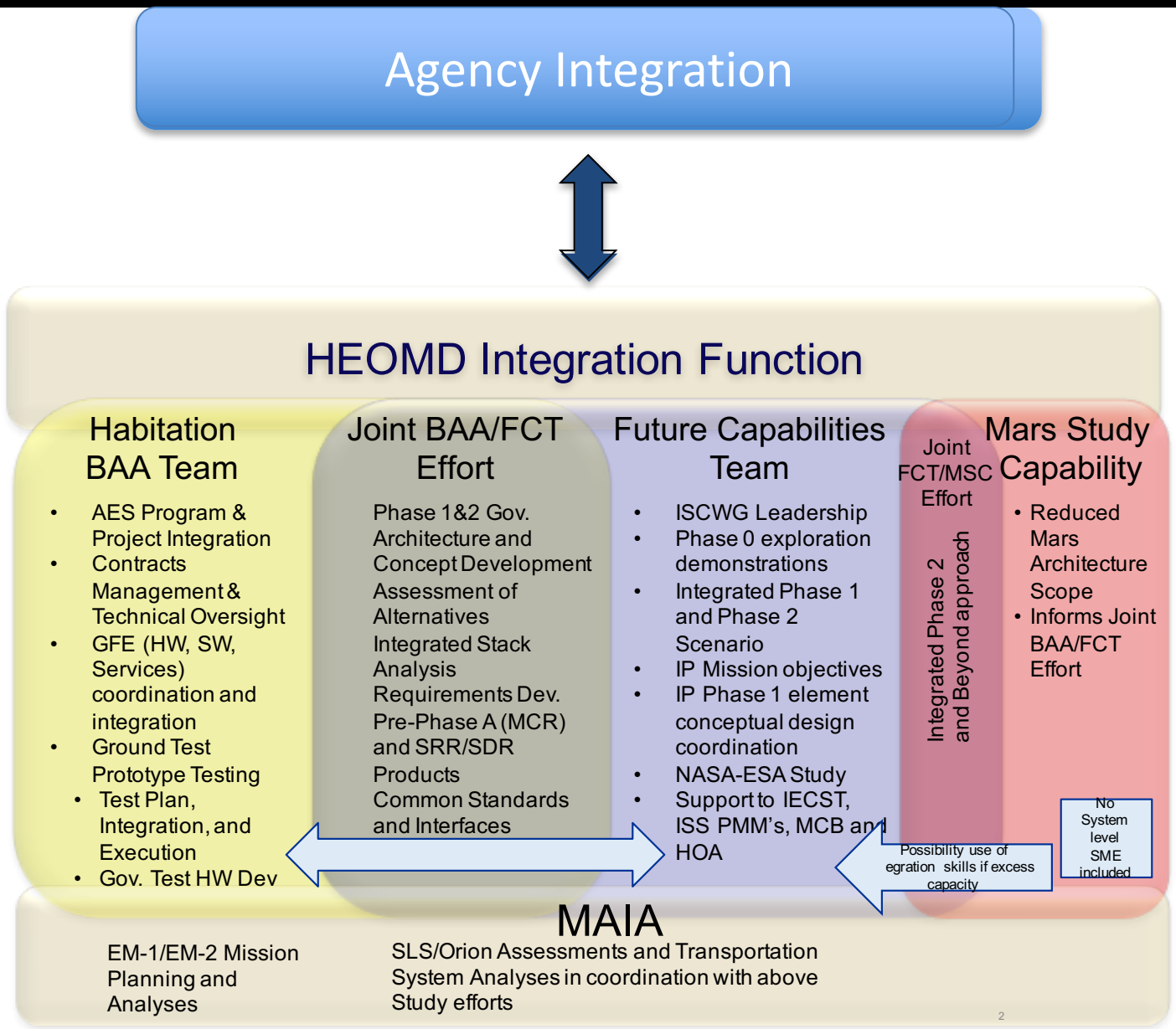
Agency Integration



HEO Architecture Starting Point



Human Exploration and Operations Integration

- HEO Integration is guided by and feeds into Agency Integration functions and needs
- In order to tie, across HEO, the top level goals, strategic principles and objectives together there needs to be an HEO integration function
- Integration of elements across Human Exploration:
  - Allows consistent assumptions
  - Publishes common guidelines
- What is being integrated?
  - Habitation: BAA and International
  - System Maturation Teams to Systems Capability Teams
  - Architecture Teams
  - EVA future plans and suit development
  - In-space Propulsion
  - International feed
  - Commercial including and beyond CCP
- Product: Common and documented guidelines, assumptions and design parameters against which elements can be evaluated and considered
- Format
  - Implementation Principles
  - Architecture Guidelines

Exploring Space In Partnership

Now

Using the International Space Station

2020s

Operating in the Lunar Vicinity

2030s

Leaving the Earth-Moon System and Reaching Mars Orbit

Advancing technologies, discovery and creating economic opportunities

Phase 0

Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available

Phase 1

Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport

Phase 2

Complete Deep Space Transport and conduct Mars verification mission

Phases 3 and 4

Missions to the Mars system, the surface of Mars

HEO Strategic Principles for Sustainable Exploration

- FISCAL REALISM: Implementable in the *near-term with the buying power of current budgets* and in the longer term with budgets commensurate with economic growth*;*
- SCIENTIFIC EXPLORATION*: Exploration enables science and science enables exploration;* leveraging scientific expertise for human exploration of the solar system.
- TECHNOLOGY PULL AND PUSH: Application of high TRL technologies for near term missions, while focusing sustained investments on *technologies and capabilities* to address the challenges of future missions;
- GRADUAL BUILD UP OF CAPABILITY: *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;
- ECONOMIC OPPORTUNITY: Opportunities for *U.S. commercial business* to further enhance their experience and business base;
- ARCHITECTURE OPENNESS AND RESILIENCE : Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;
- GLOBAL COLLABORATION AND LEADERSHIP: Substantial *new international and commercial partnerships,* leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and
- CONTINUITY OF HUMAN SPACEFLIGHT*: Uninterrupted expansion of human presence into the solar system* by establishing a regular cadence of crewed missions to cislunar space during ISS lifetime.

Human Space Exploration Phases From ISS to the Surface of Mars
as of November 2016

Today

Phase 0: Exploration Systems ***Testing on ISS***

Ends with testing, research and demos complete*

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 1: ***Cislunar Flight Testing*** of Exploration Systems

Ends with one year crewed Mars-class shakedown cruise

Phase 2: ***Cislunar Validation*** of Exploration Capability

Phase 3: Crewed Missions Beyond Earth-Moon System

Phase 4a: Development and robotic preparatory missions

Phase 4b: Mars Human Landing Missions

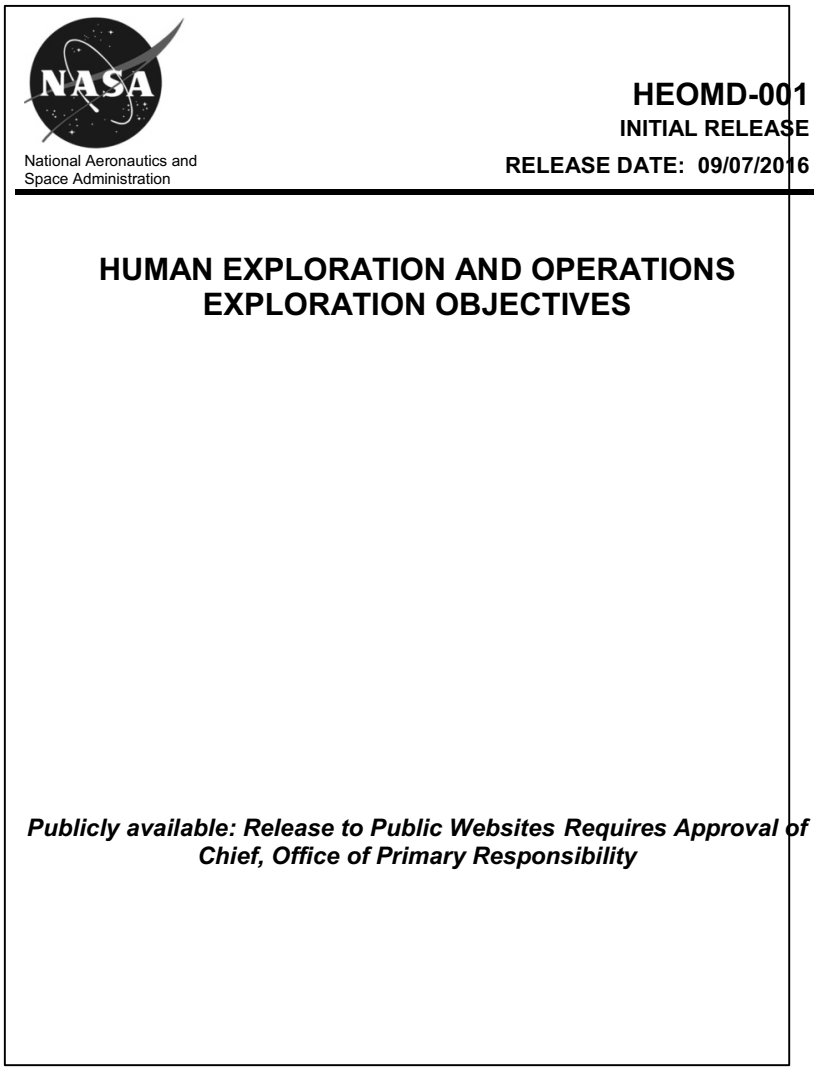
Planning for the details and specific objectives will be needed in ~2020

* There are several other considerations for ISS end-of-life

Mid-2020s

2030

HEO Exploration Objectives Baselined for Phase 0/1/2
Planned update in work to reflect evolving exploration strategy


National Aeronautics and Space Administration

HEOMD-001
INITIAL RELEASE
RELEASE DATE: 09/07/2016

HUMAN EXPLORATION AND OPERATIONS
EXPLORATION OBJECTIVES

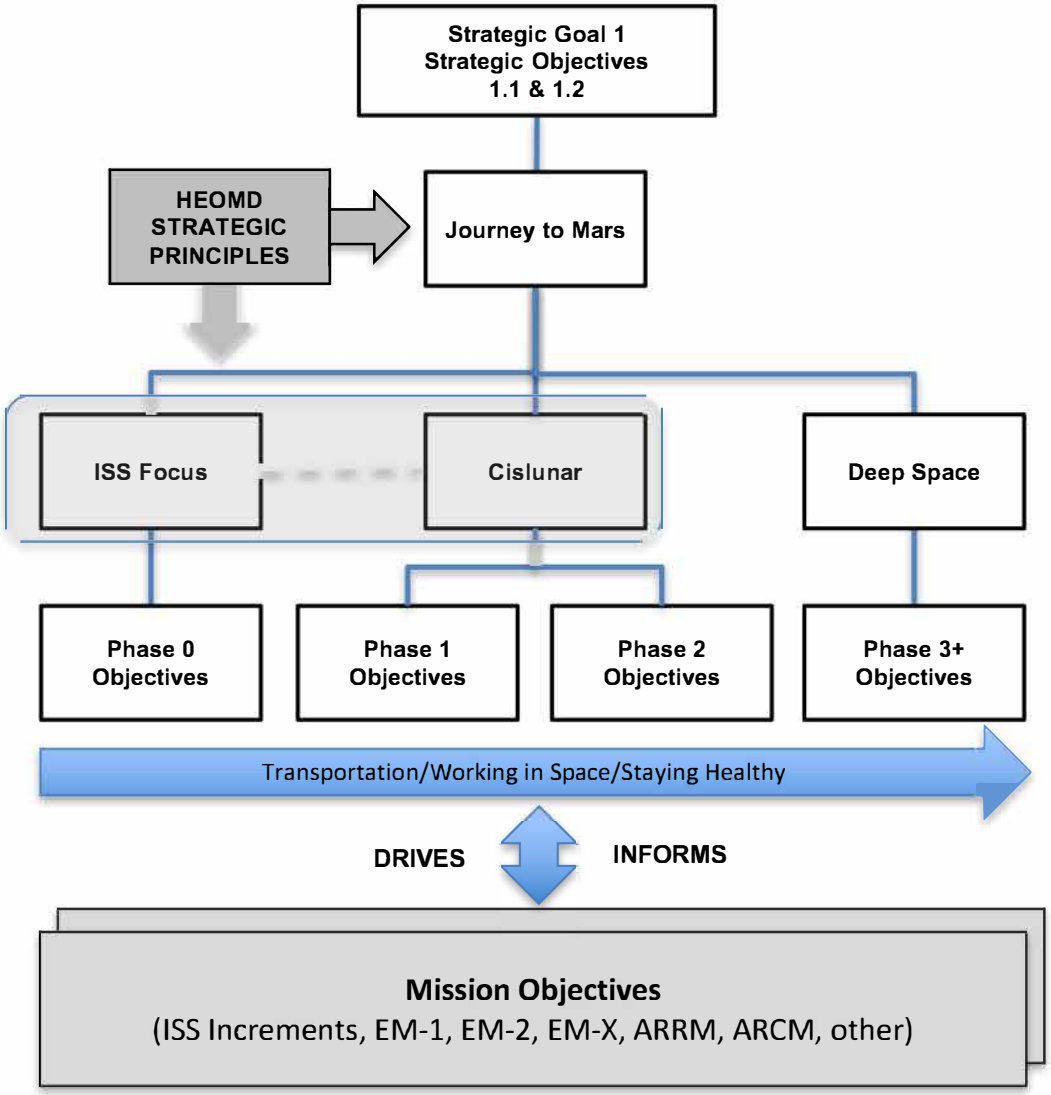
Publicly available: Release to Public Websites Requires Approval of Chief, Office of Primary Responsibility

Phase 0: Exploration Systems Testing on ISS and in LEO (17 objectives)
"Leverage the ISS as a test bed to demonstrate key exploration capabilities and operations, and foster an emerging commercial space industry in LEO."

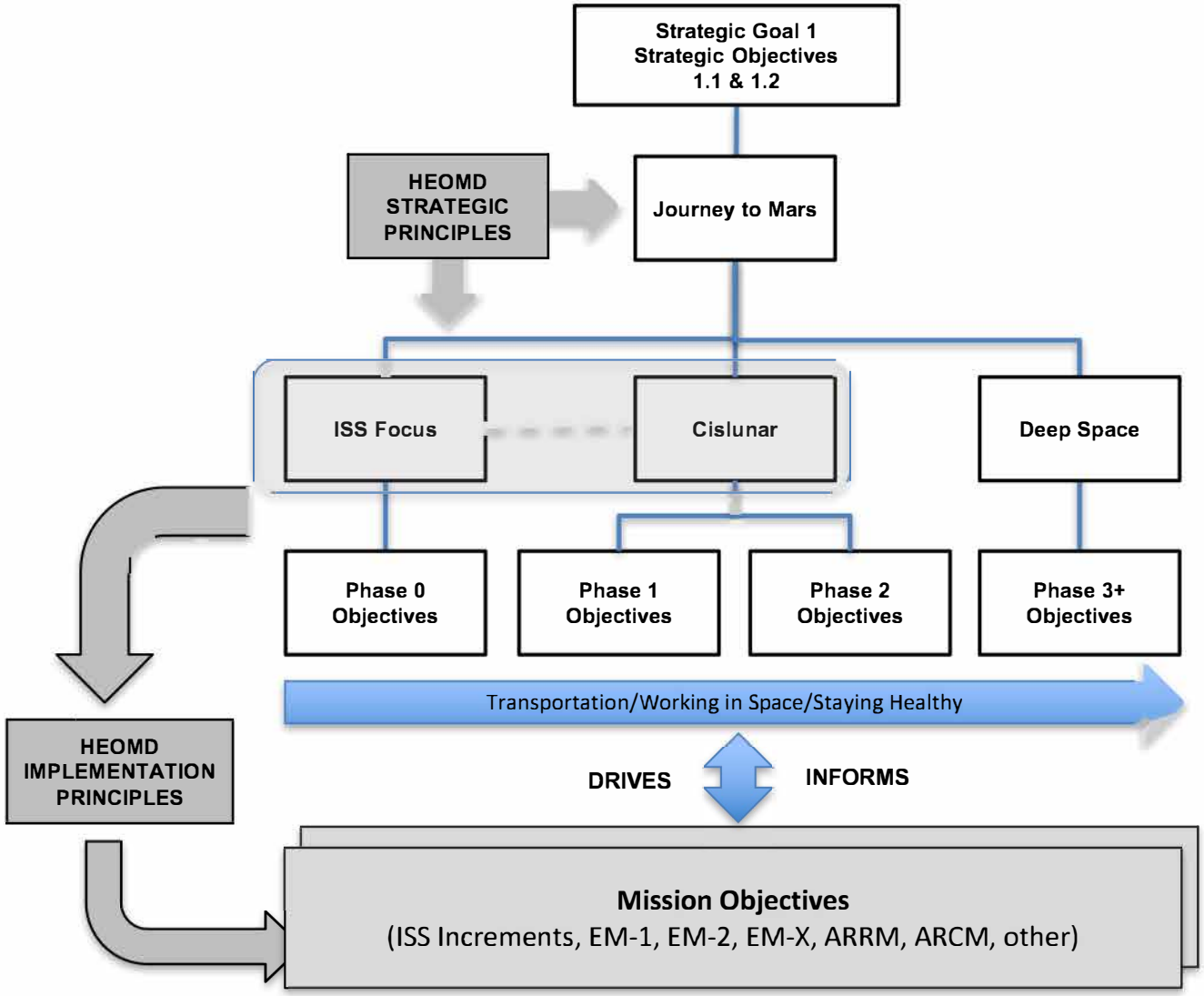
Phase 1: Cislunar Demonstration of Exploration Systems (28 objectives)
Update will reflect buildup of the Deep Space Gateway

Phase 2: Cislunar Validation of Exploration Systems (18 objectives)
Updated will reflect buildup of the Deep Space Transport

Relationship of Agency to HEO Strategy, Principles, and Objectives



HEO Implementation Principles Drive Architecture, Hardware, and Mission Trades and Decisions



Development of HEO Principles and Guidelines

- Development of design guidelines and implementation principles done in series of meeting with Design teams and HEO Senior Management Team

  - Design Team Meeting - Exploration Alignment (30 Jan 2017)
    - Briefing by technical teams across HEO to share study results, assumptions and upcoming decision points
    - Ability to share disconnects and elevate HEO decisions required to complete near term work
    - Established forum for sharing future information and integration topics
    - Set up decisions need to be made by HEO Senior Management

  - HEO Senior Management Meeting (8-9 Feb 2017)
    - Developed Implementation Principles
    - Developed architecture guidelines by phase
    - Discussed partnership strategies
    - Set path for near term decisions

Implementation Principles

HEO Implementation Principles

- Robust international partnerships, among existing and new partners are important
  - Examine utility of building on/adapt/growing partnerships
  - Consider what partners can provide given funding, historic and future interests, and demonstrated commitment to date for hardware development
- Commercial capabilities will be needed in the architecture
  - Preserve an open, competitive environment, and defining and communicating an appropriate risk acceptance posture
- Goal of cislunar is build up and validation of the crewed Mars transit system
  - Shakedown cruise by the end of the 2020s is still the right target
- Humans Mars orbit mission in 2033 (out and back – short stay which may require Venus flyby)
- A minimal, crew-tended gateway remains long-term in cislunar space to facilitate successive crewed Mars missions and sustain mission cadence; this should drive the definition of initial cislunar gateway
  - Stage Mars vicinity missions in cislunar space
  - Could also support lunar surface missions
- Engage in a coordinated dialogue with the agency, external stakeholders, SMD and STMD on cislunar and Mars exploration decisions.

Sample Architecture Guidelines by Phase

Sample HEO Architecture Guidelines

Phase 0: ISS and LEO Transition

- Operate ISS as long as beneficial:
  - Test Mars-class systems (e.g., ECLSS) and operations concepts
  - Promote LEO commercialization
- ISS as a catalyst for the ultimate goal of commercial self-sustainability in LEO without NASA as a primary tenant or landlord

Phase 1 and 2: Cislunar

- **Flight rate**
  - One crewed Orion/SLS exploration mission per-year beginning in 2023
  - One SLS cargo mission per year starting in 2027
- 8.4m fairing for SLS cargo to be provided through innovative procurement methods and industry contributions leveraging other fairing development
- Expanded cislunar habitation capability (i.e. first element of gateway enabling extended-duration operations)
- EVA demonstration via airlock prior to first operational use
- Use STMD-developed 40 kw Solar Electric Propulsion (SEP)
- Exercise device required for missions longer than 14 days
- Balance interests and capabilities of international and commercial partners

Sample HEO Architecture Guidelines – Phase 1

Phase 1: Cislunar Gateway

- **Maintain operations with a crew of 4**
- Extend mission capabilities beyond 21 days
- Self-supporting (power/propulsion, thermal, life support, etc.) for crew (30 days) and uncrewed operations independent of Orion
- Support buildup, departure and return of the Deep Space Transport to/from cislunar space
- Minimalist cislunar gateway; buildup contingent on partnerships
  - NOT a large, permanently crewed facility; much smaller than ISS
  - Can support commercial and international partner interests (e.g. staging for international partner lunar landings) with contributed elements
- Support excursions to different cislunar orbits and destinations

Sample HEO Architecture Guidelines – Phase 2

Phase 2: Deep Space Transport (Mars Transit Vehicle)

- Cislunar gateway continues operations and human missions in parallel with Mars vicinity missions (Deep Space Transport)

- 1,000-day Mars-class transit/orbital vehicle
  - Habitation and logistics for 4 crew (ECLSS and related systems)
  - Compatible with SLS cargo fairing diameter (8.4m)
  - Up to 45mt/SLS cargo TLI (SLS Block 2)

- SLS launching fully assembled 41mt components (Habitat, Propulsion Module)

- Year-long shakedown cruise in cislunar space is acceptable to validate a 1,000-day capability

- Deep Space Transport is reusable and is returned to cislunar space for refurbishment in between Mars vicinity missions
- Evaluate commercial capabilities and bring online when available

- Implement a dual communications capability: optical comm and deep-space Ka-band

Sample Upcoming Decisions

Sample HEO Architecture Guidelines / Decisions

- ISS transition and phasing (LEO commercialization, workforce, operations)
  - As informed by Agency level discussions
- Focus of international contributions
- EM-2, EM-3 Decisions on Co-manifested payload
- Co-manifested payload mass capability
- Habitation planning through LEO and cislunar: what to accomplish via ISS vs cislunar
- Space-to-ground and space-to-space communication

Ongoing/Upcoming Architecture Studies

HEO Architecture Study Examples

- Mars Flyby/Orbital/VGA Mission Analysis
- In-Space Propulsion Boundaries
- ECLSS Strategy Refinement
- Interoperability, Design and Construction Standards
- Mission Design Checkpoint with International Partners
- BAA habitation contract awards