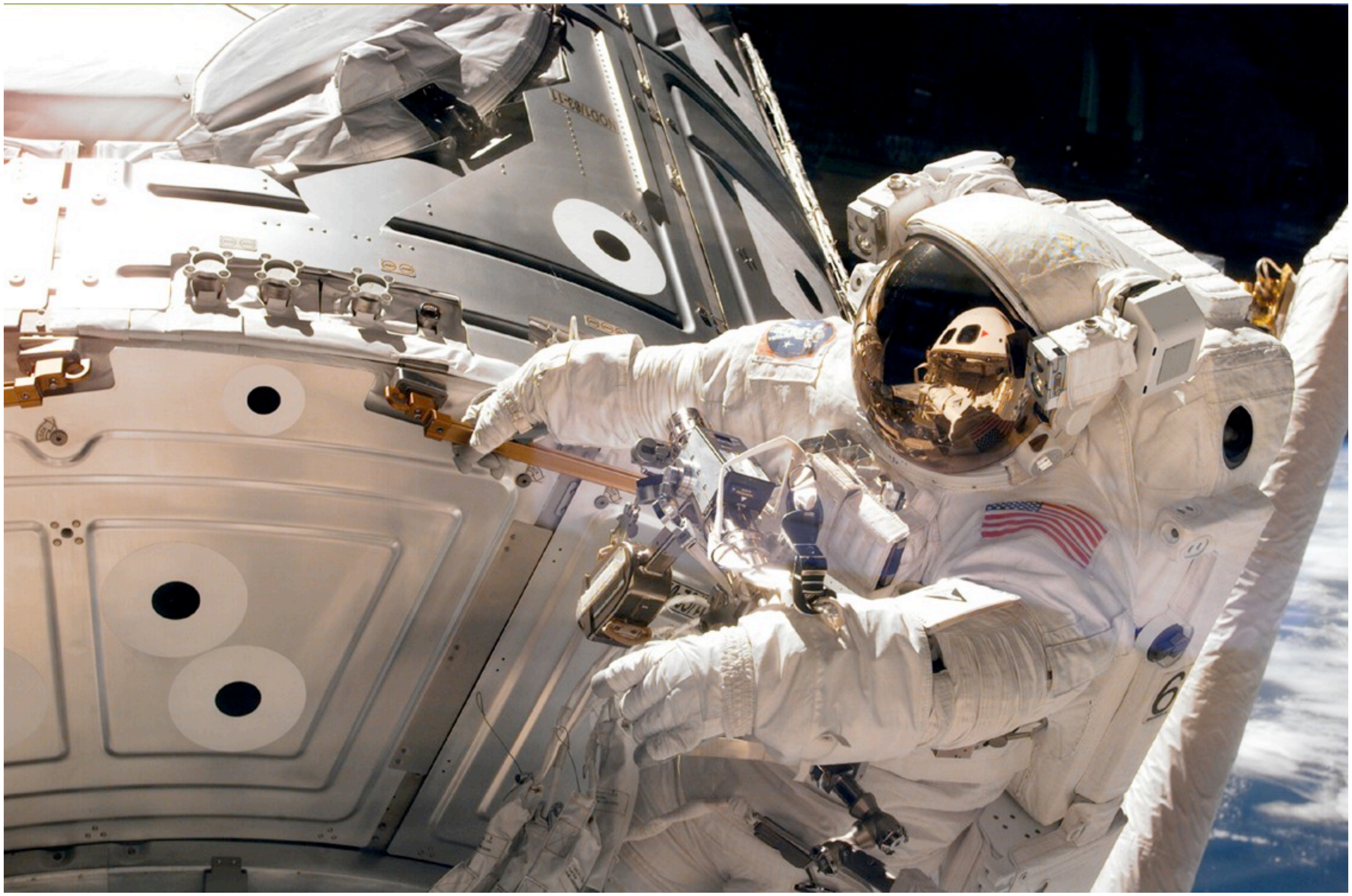
Past, Present, and Future of In-Space Servicing of Major Scientific Facilities

Building Upon the $100 Billion ISS and HST Expertise



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Thank you to P. Burch, F. Cepollina, D. Lester, M. Livio, H. P. Stahl, and loads of GSFC colleagues.

Military and Aerospace Programmable Logic Devices Conference

September 17, 2008

See http://futureinspaceoperations.com

Current Context of In-Space Operations

The astronomy community is identifying major goals for the next 10+ years

- Multiple recent community workshops on future astronomy
- NASA science advisory sub-committees
- National Academy to review NASA astronomy & astrophysics soon

NASA continues to demonstrate extraordinary capabilities in human spaceflight

- 100th EVA on ISS this past January
- Fourth servicing mission to HST in a few weeks
- About *eight times* more free-space EVA time than lunar surface EVA time

Constellation Program identifies major goals and hardware for human spaceflight

- Orion/CEV and Ares 1 to replace Shuttle
- Ares V to enable return humans to the lunar surface
- Altair to land humans on the Moon

Increased robotics capabilities in free space

- Very significant progress at GSFC on robotic servicing of HST in 2004
- "Smart" Orion SVM (GRC, GSFC, JSC) in 2006
- Orbital Express (DARPA, Boeing, *et alia*) in 2007
- ATV (ESA) and SUMO (NRL) in 2008

Does the context offer opportunities?
[This is the stuff to remember]

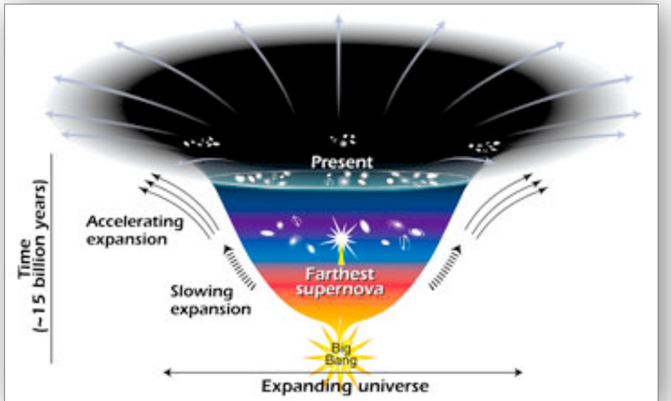
Modest augmentations to the planned future Constellation hardware and building upon nearly <u>two decades</u> of extraordinary success in space operations may enable major scientific goals that would *not be otherwise possible*.

That is,

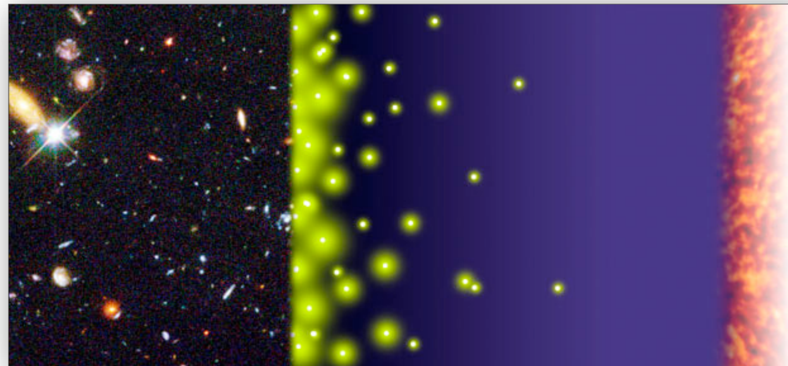
• Existing experience, knowledge, tools, designs, operations, etc. developed for ISS construction and HST servicing.
• New hardware and capabilities intended to carry humans beyond the immediate vicinity of the Earth over the next two decades.
• Generations of robot systems that seem likely to revolutionize how humans -- both astronauts and ground-based operators -- work in complex and challenging environments.
• GSFC has been a leader -- or important partner -- for many programs, much of the hardware, and many of the concepts and goals.
• If humans ever travel to Mars, vastly more free-space experience is going to be necessary than is currently available: propulsion, life support, materials, zero-g EVA, radiation in free space . . .

For the Past Decade, NASA's Astronomy Program Has Concentrated on A Small Number of "Grand Questions," for example . . .

Why is the universe accelerating?



Which astronomical objects were involved in the "first light"?

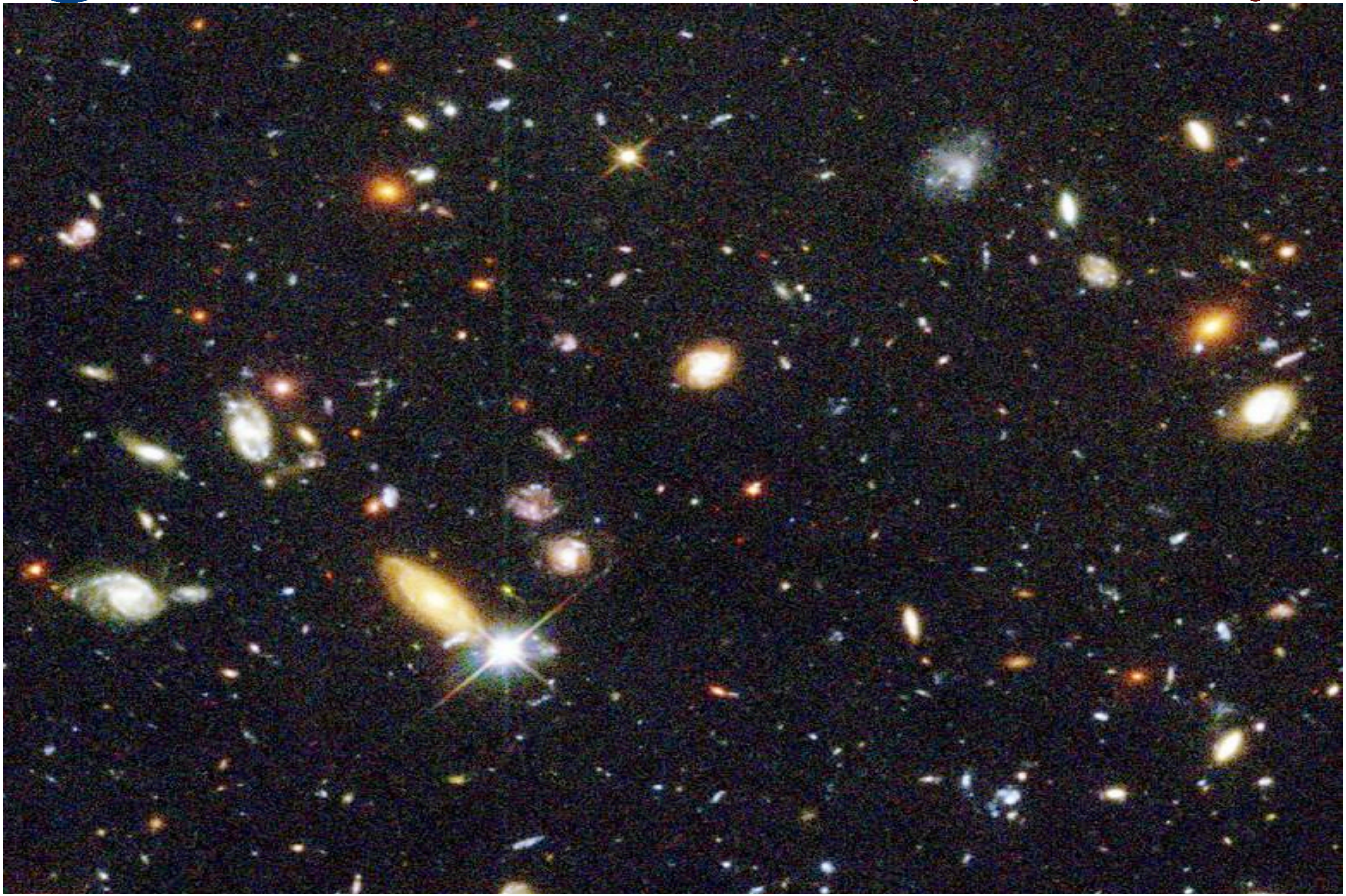


Are we alone?

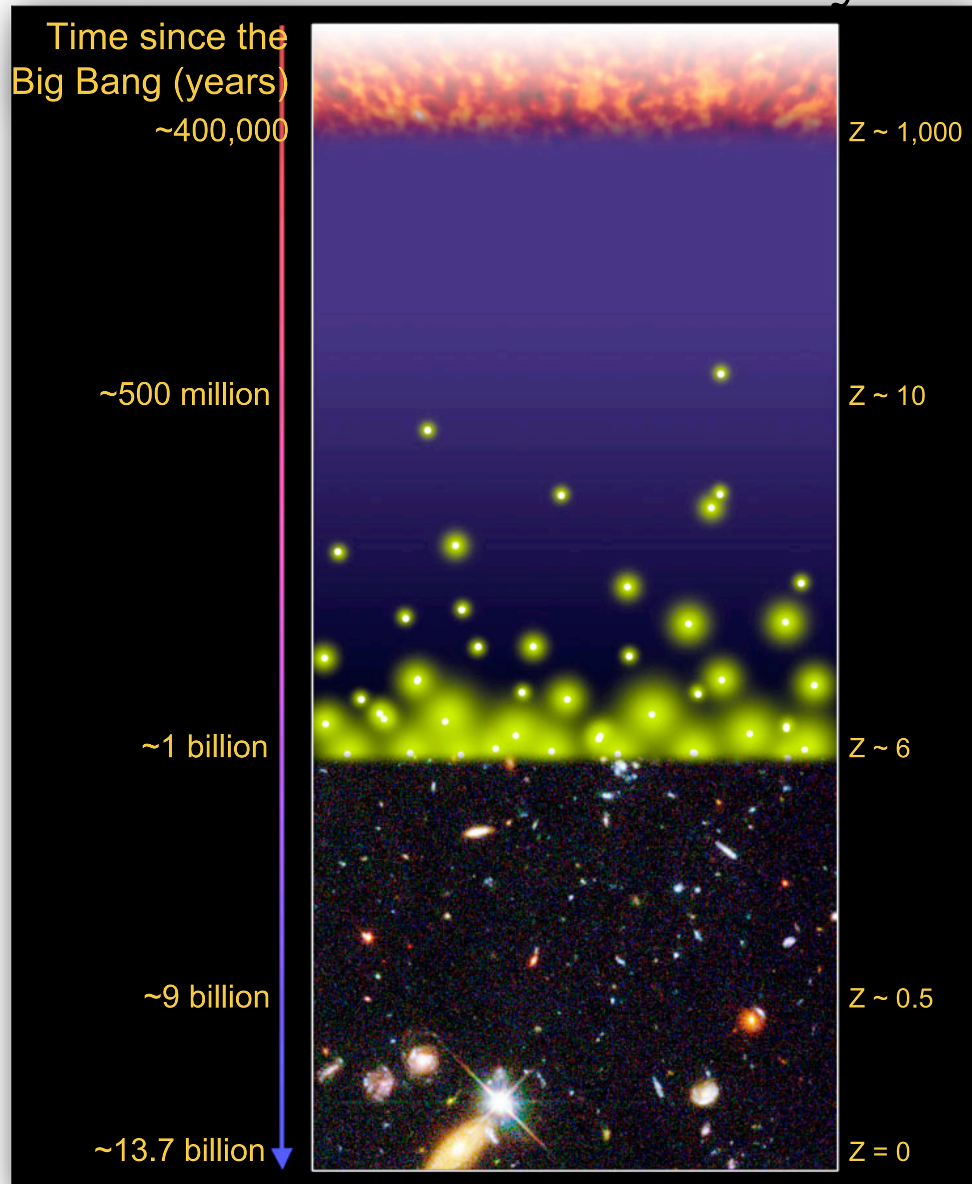
How did galaxies form?

The Hubble "Deep Field"

A "Slice" of the Universe about the Size of Roosevelt's Eye in Dime at Arm's Length



A Brief History of the Universe: Why Go to Space?



Microwave Background (Remnant of the Big Bang)

Atomic H and He: before galaxies form

"The Dark Ages" (Goal of JWST)

Reionization

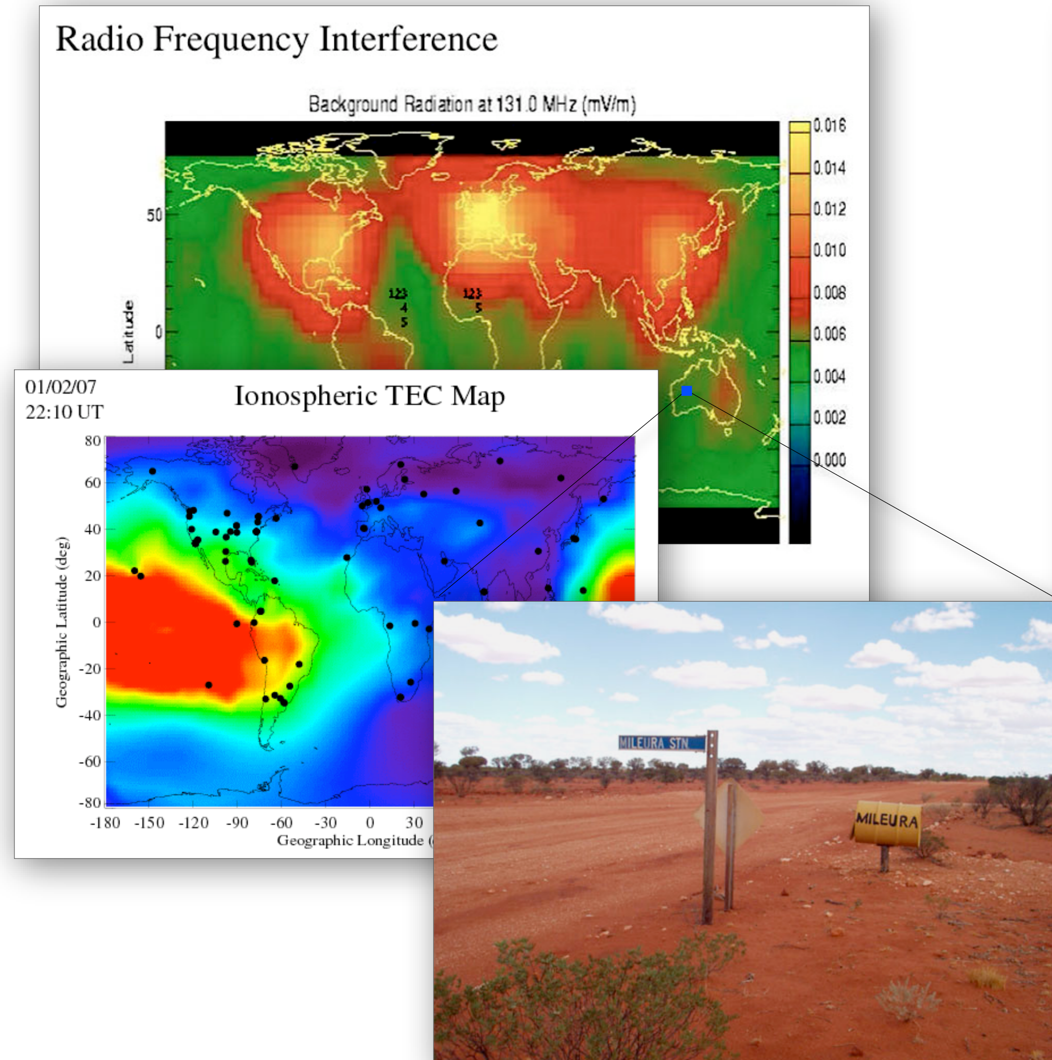
Limit of HST

Limit to ground-based telescopes

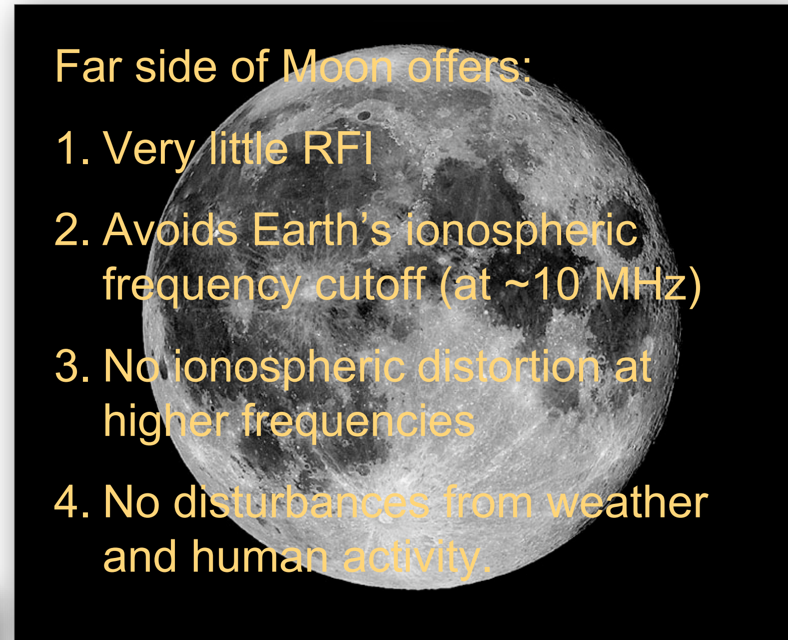
Today

Observations of *redshifted* 21 cm neutral hydrogen emission could investigate $7 \lesssim z \lesssim 100$ (100 million - 1 billion years after the Big Bang)

On Earth



On the Moon

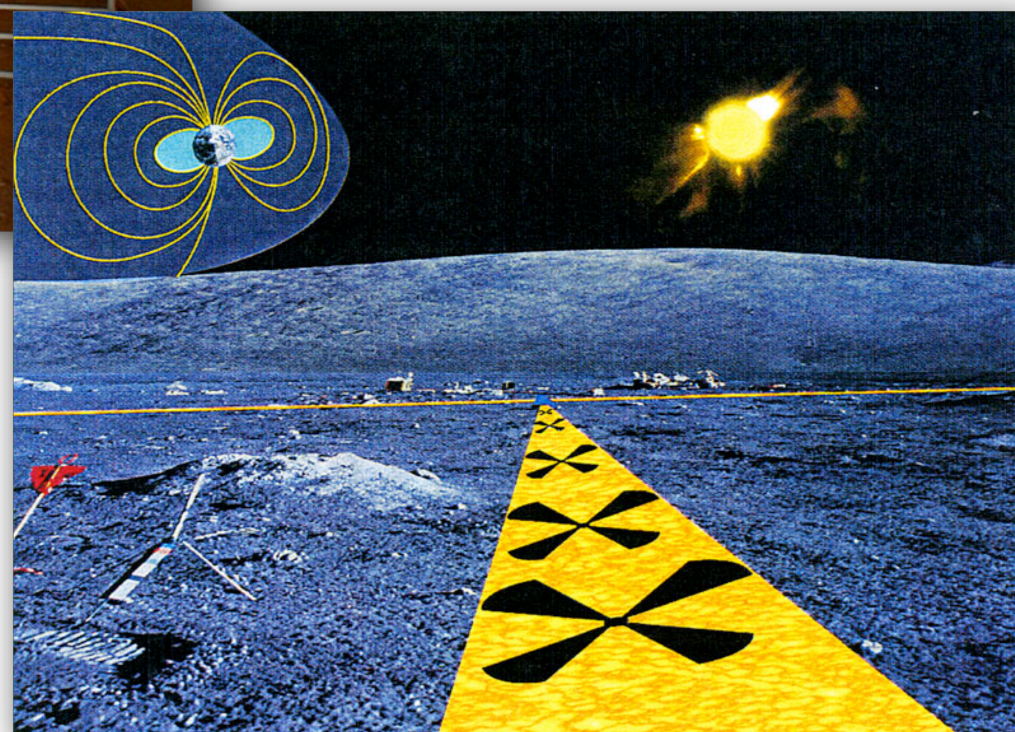


Far side of Moon offers:

1. Very little RFI
2. Avoids Earth's ionospheric frequency cutoff (at ~10 MHz)
3. No ionospheric distortion at higher frequencies
4. No disturbances from weather and human activity.

Precursor and Demonstration Missions Can be Carried out on Earth, but Truly Sensitive Observations Require Space . . . and the Moon?

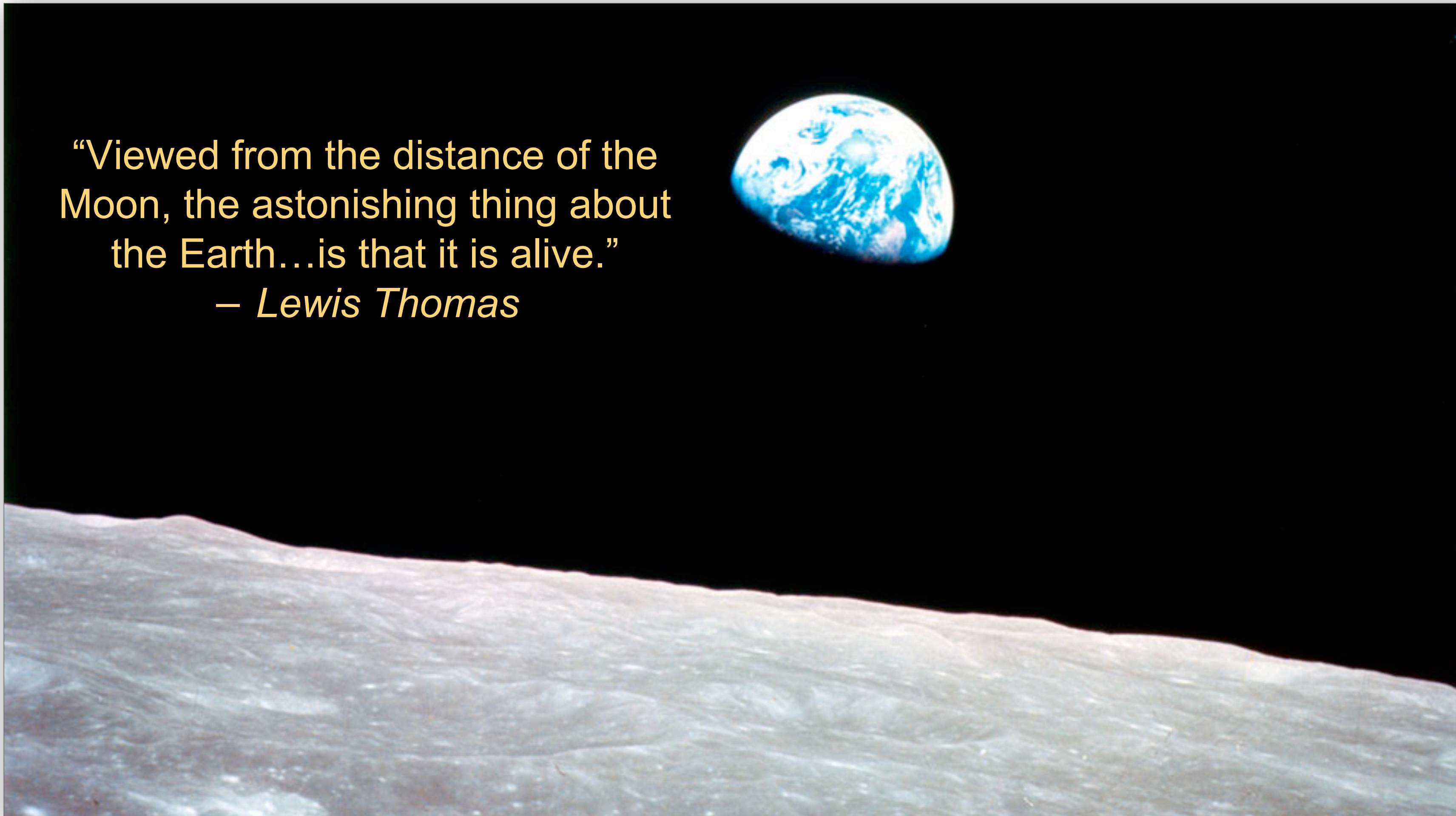
Low frequency radio observations require only lightweight dipoles



Assessment study proposed by U Colorado, NRL, GSFC, others

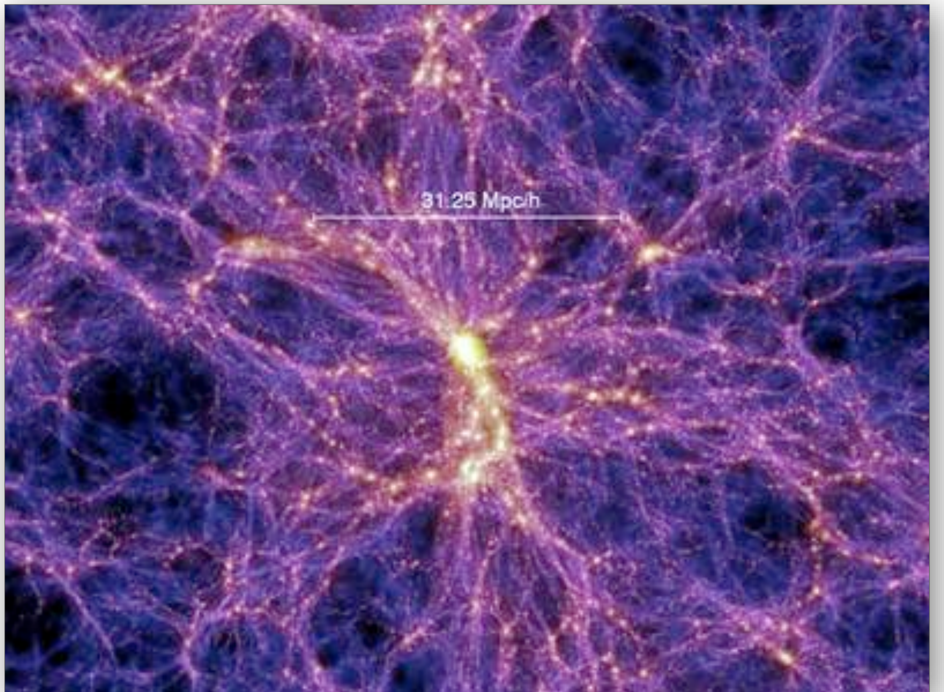
The Search for Earth-like Worlds?

Discovering another "Earth" Would Change Everything!



The Assembly of Structure in the Universe

Potential observations from free space

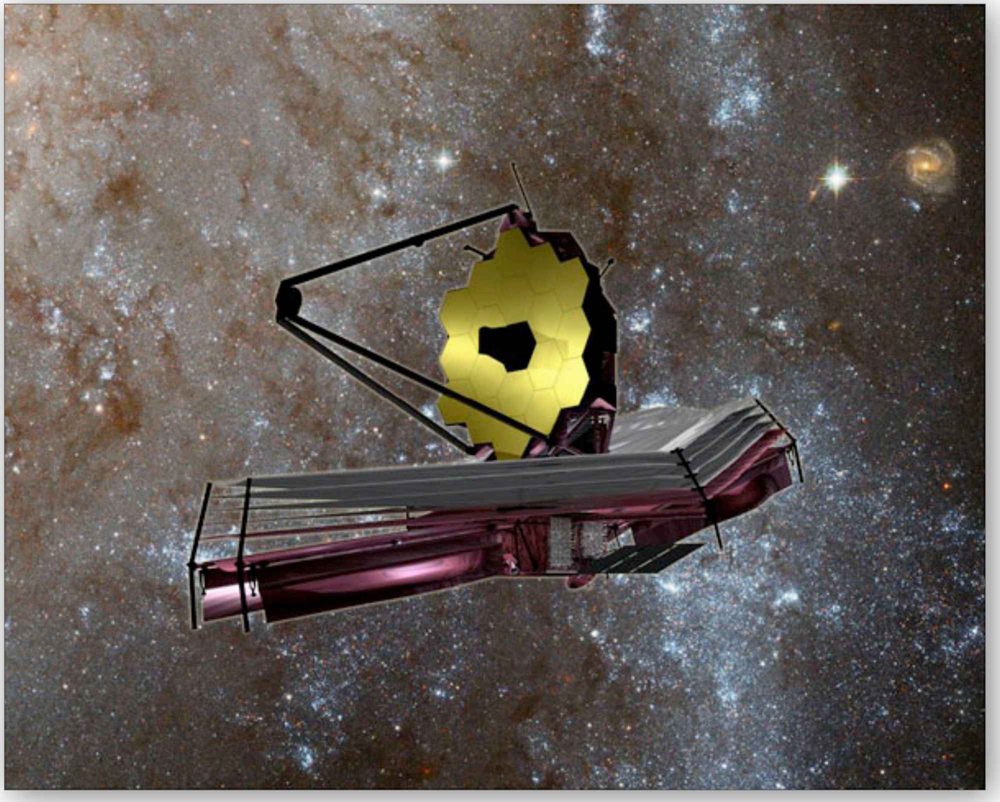


Structure of the 'cosmic web' and the intergalactic medium can be best studied by ultraviolet spectroscopy, which is accessible only outside the Earth's atmosphere.

To answer these questions, new generations of astronomical missions will be required

NASA's astronomical mission to follow the Hubble Space Telescope is the 6.5 m diameter James Webb Space Telescope, scheduled for launch in 2013.

Follow-on major missions will cover other wavelengths, may be larger or fly in constellations, could be spatial interferometers . . .



Large-apertures and/or spatial arrays offer

- Increased sensitivity and
- Increased angular resolution, which

make possible breakthrough discoveries, but which are more costly and complex than more modest missions.

Will there be capabilities in the next ~ 20 years to enable the most ambitious missions?

The Answers to the “Grand Questions” Lie in Space

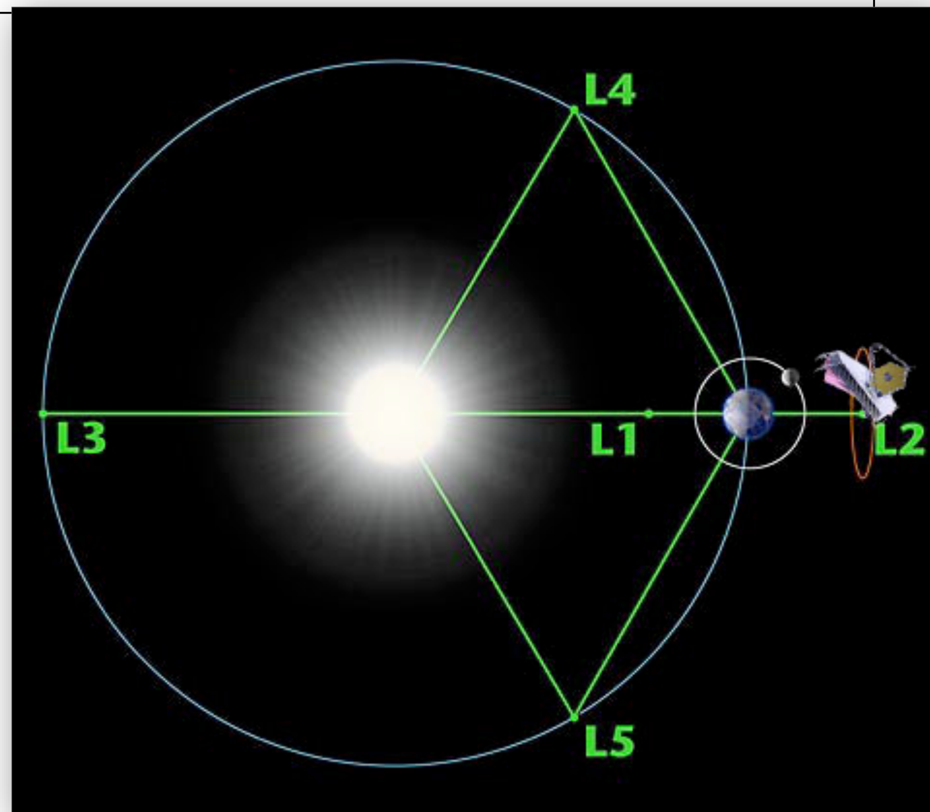
Observations from free space (in particular Lagrange points) offer significant advantages over alternative locations advocated in past years.

Astronomy’s future will include:

- Large and/or complicated optical systems
- Extremely sensitive observations over many wavelengths: x-ray, UV. . .
- The availability of humans and robots
- The availability of new facilities

To answer those ‘grand questions’

And preparing for long human voyages beyond the Earth-Moon system . . . .



Sun-Earth Lagrange points (not to scale)

Access to any libration point opens a profoundly enabling architecture . . .

"If God had meant us to explore the cosmos, He would have created the Moon so that we would have libration points."

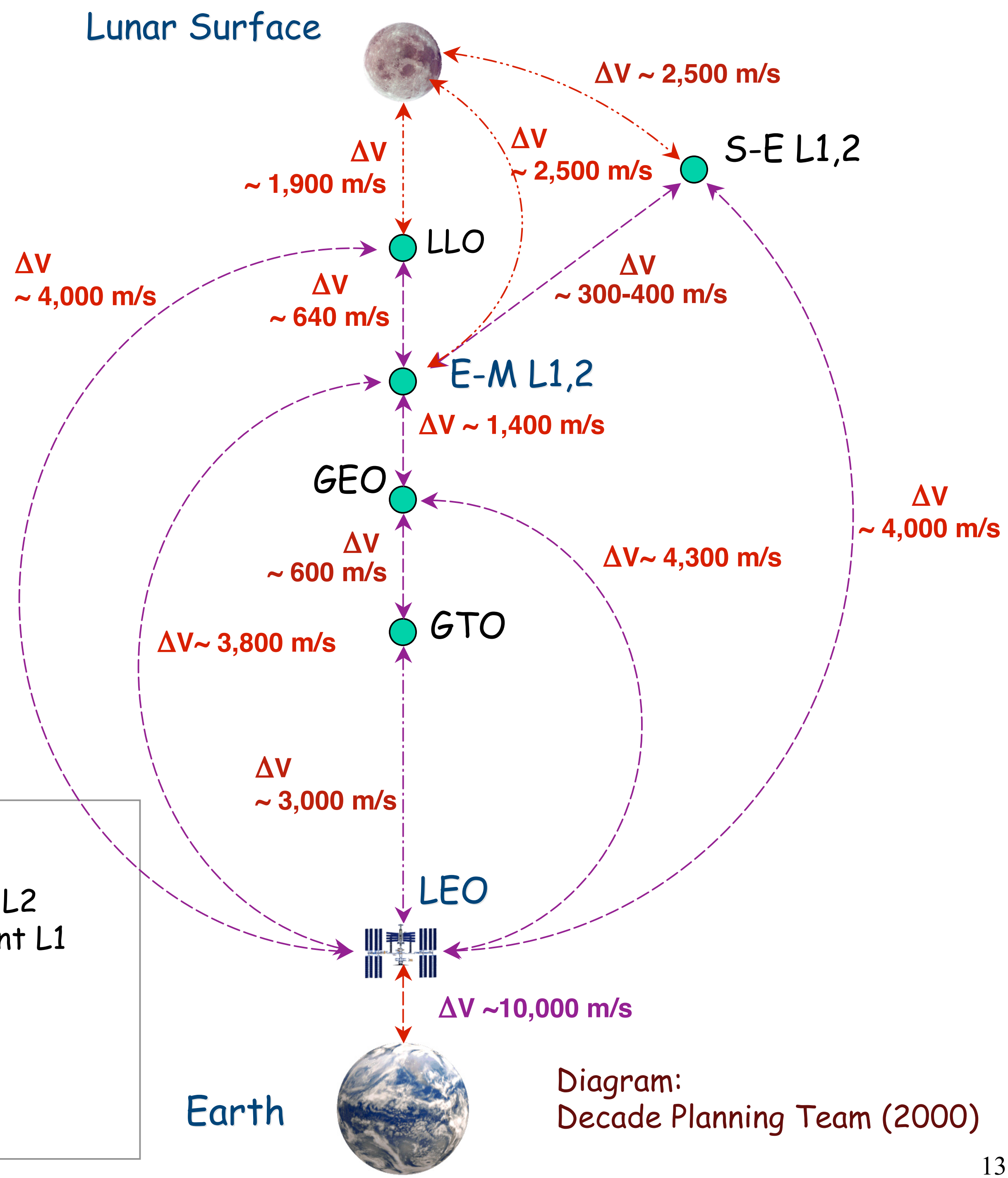


Diagram: Decade Planning Team (2000)

LTO	Lunar Transfer Orbit
LLO	Low Lunar Orbit
SE L2	Sun-Earth Libration Point L2
EM L1	Earth-Moon Libration Point L1
GEO	Geostationary Orbit
GTO	GEO Transfer Orbit
LEO	Low Earth Orbit
Low-T	Low-thrust
High-T	High-thrust

A bit of history:
Genesis of the first space astronomy "vision"

"So many factors favor the Moon as a site for future large-scale space astronomy that planning an observatory there deserves the closest attention in the years ahead."

William Tifft, Steward Observatory
Aeronautics and Astronautics **December 1966**

The world in 1966: Earth-based sites w/1" seeing,
emulsions , photomultipliers
post-Gemini, pre-Apollo,
OAO-2 (point/track ~ 1'/1")

and also …

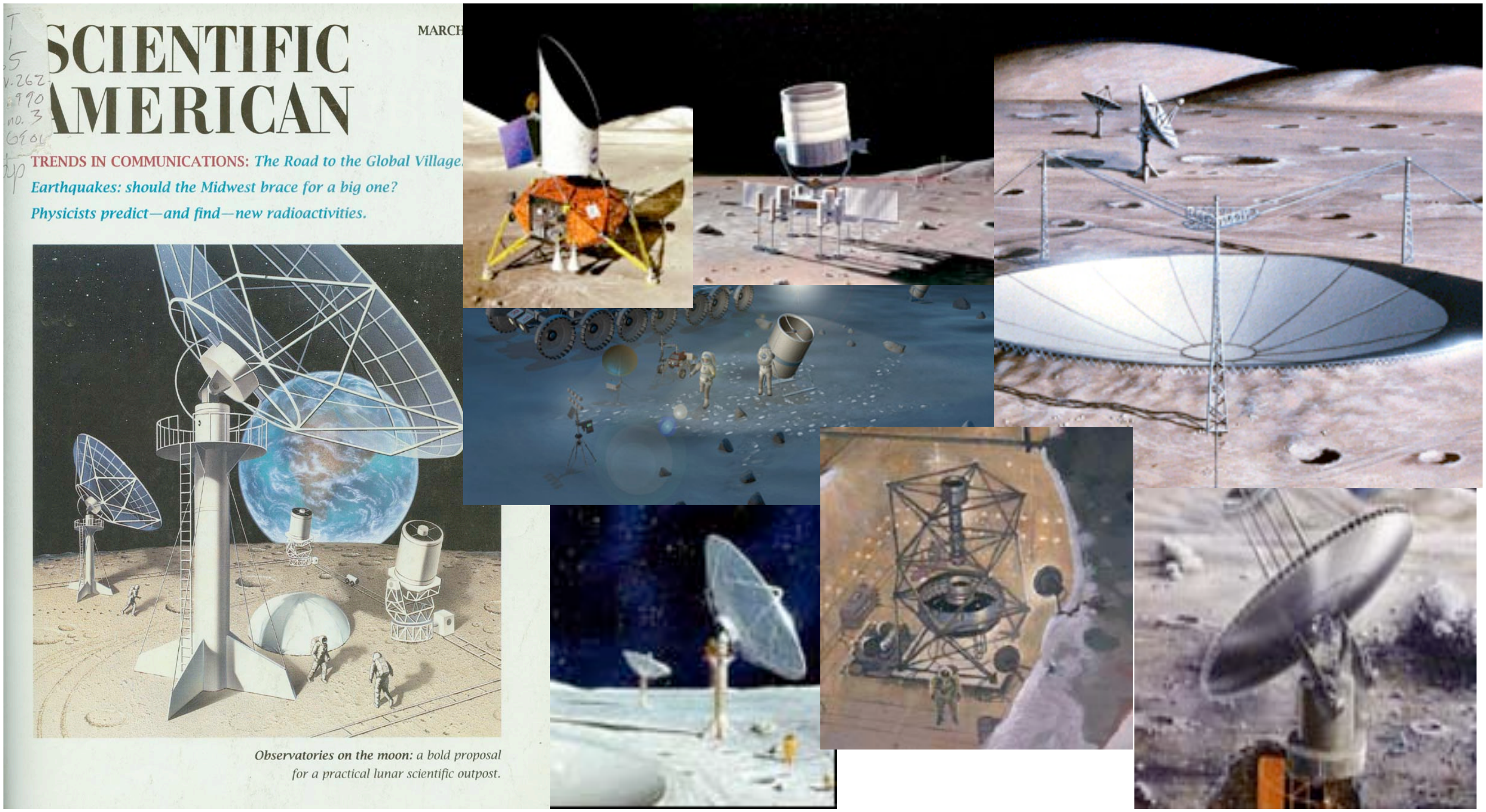
we were actively headed to the Moon!

Advantages of the Moon for Astronomy (c.1966)

- **Vacuum (compared to Earth)**
  - multiwavelength
  - not seeing-limited
- **Radiation isolation (compared to Earth orbit)**
  - no damage to sensitive photographic emulsions
- **Stable surface (compared to free space)**
  - proven tracking technologies
  - no human perturbations
- **Thermal control (compared to low Earth orbit)**
  - long diurnal cycle & lunar polar craters
- **Accessibility (if near an outpost)**
  - service, maintenance

This vision was smart, both scientifically and technologically, and built upon NASA priorities . . . of nearly a half-century ago.

Lunar telescopes were a bold answer to our needs!



Innovative optical, mechanical, thermal, and civil engineering.

But something changed …

… we came to understand that telescopes in free-space could meet our needs, offering advantages previously seen only for the lunar surface . . . with none of the (usually costly) disadvantages.

Which was made possible by . . .

GSFC, NASA's science Center, partnered with JSC, the human spaceflight Center, in 1972 at the start of Space Shuttle development. From this partnership arose breakthrough capabilities …

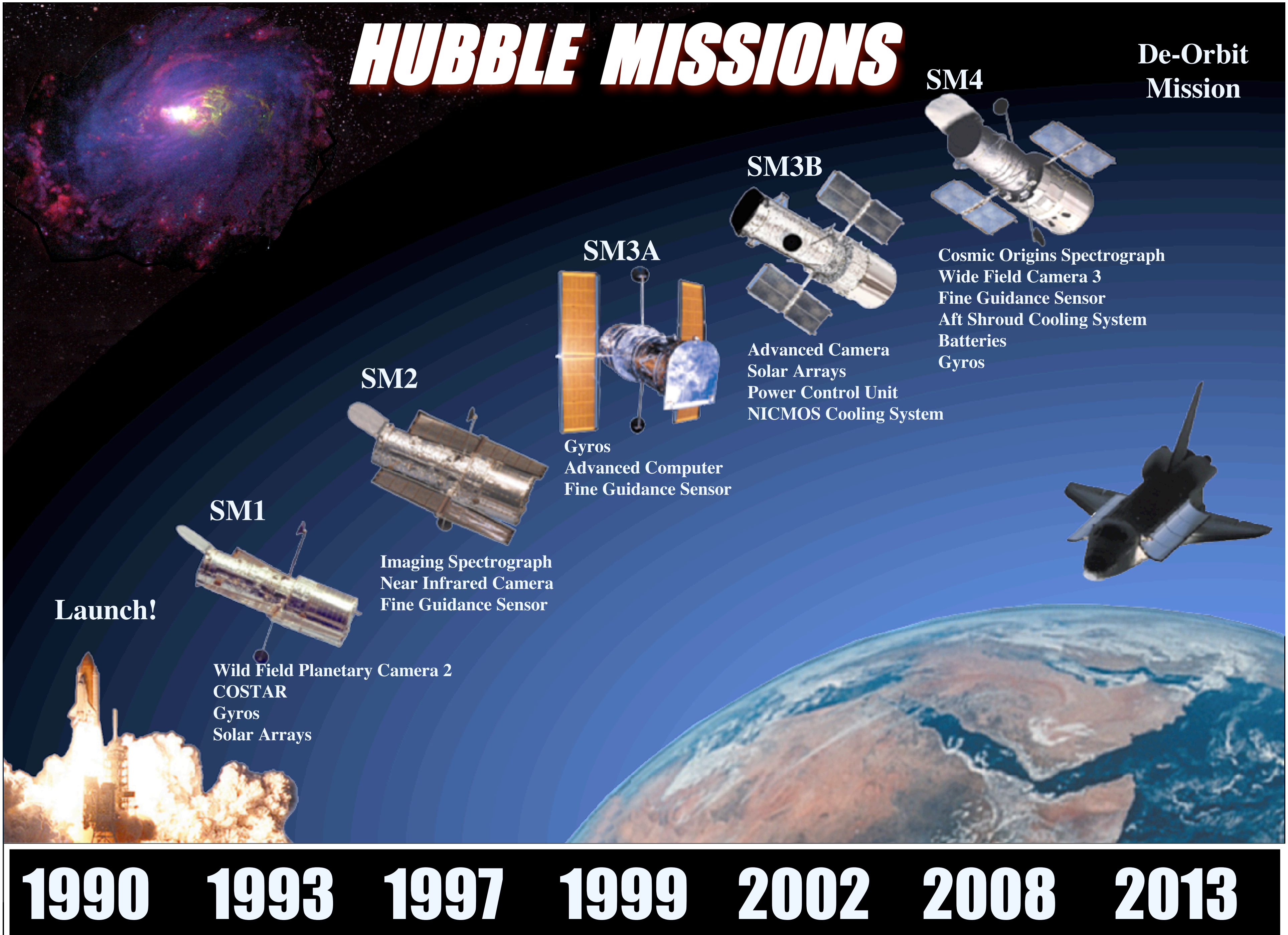
A design that made possible on-orbit servicing:
- More effective cargo bay
- Large robotic arm for capturing and repairing satellites.

Modular spacecraft designed to be approachable, retrievable, and repairable

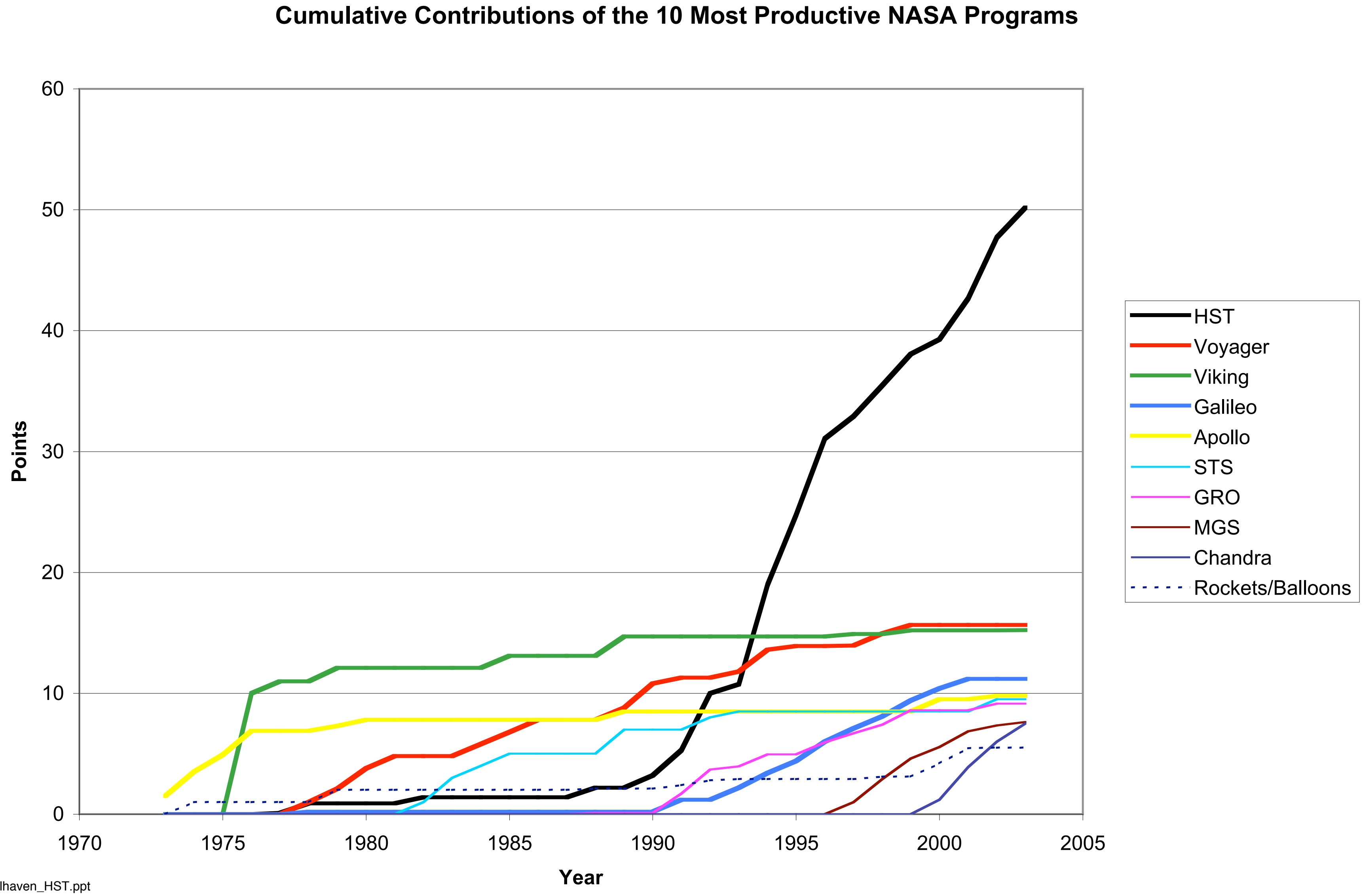
Generic Shuttle-based carriers to berth and service on-orbit spacecraft, not exclusive to one particular vehicle.

On-Orbit Satellite Servicing Concept, 1975

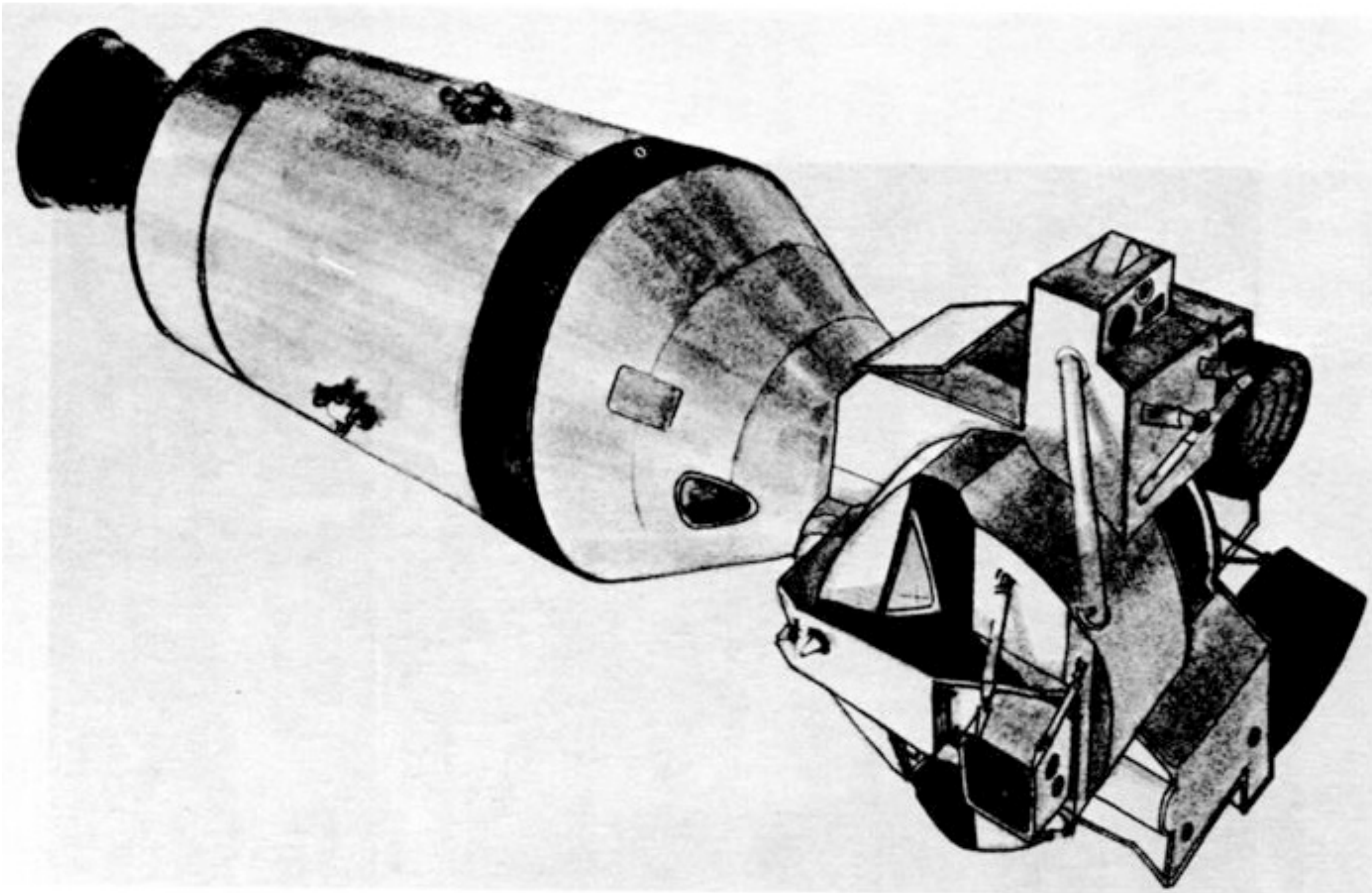
Interesting concepts, but have they resulted in results for science?


HUBBLE MISSIONS
De-Orbit Mission
SM4
Cosmic Origins Spectrograph
Wide Field Camera 3
Fine Guidance Sensor
Aft Shroud Cooling System
Batteries
Gyros
SM3B
Advanced Camera
Solar Arrays
Power Control Unit
NICMOS Cooling System
SM3A
Gyros
Advanced Computer
Fine Guidance Sensor
SM2
Imaging Spectrograph
Near Infrared Camera
Fine Guidance Sensor
SM1
Wild Field Planetary Camera 2
COSTAR
Gyros
Solar Arrays
Launch!
1990 1993 1997 1999 2002 2008 2013

HST's Dominance of *Science News* "Annual Discoveries" List Reflects the Effectiveness of Regular Servicing by Astronauts and Collaborative Work with Science Community

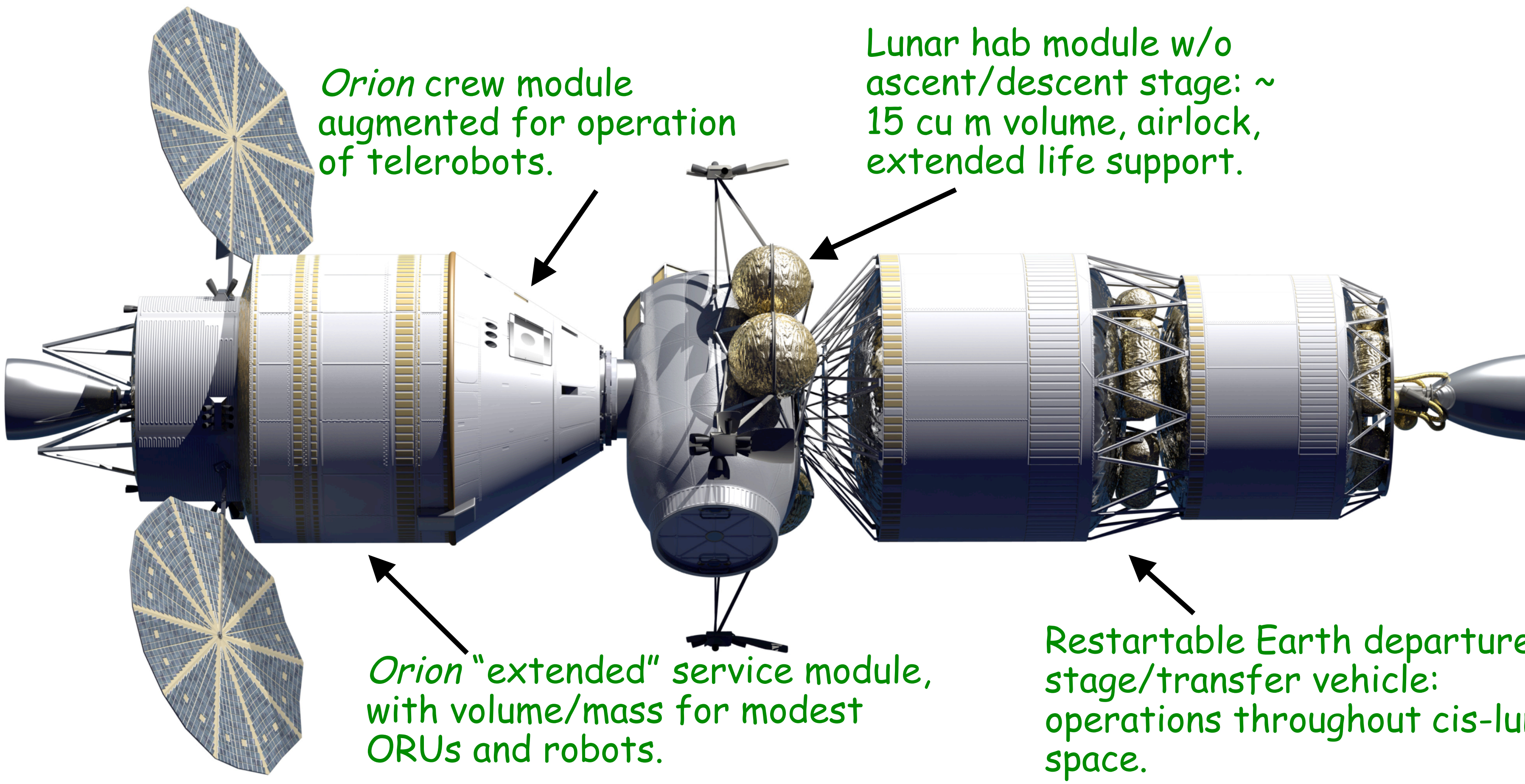


Adapting human spaceflight hardware to achieve multiple goals is nothing new and predated the Shuttle by about a decade: the Apollo Applications Program. This particular concept was never built, aspects of the design evolved into the Apollo Telescope Mount in Skylab.

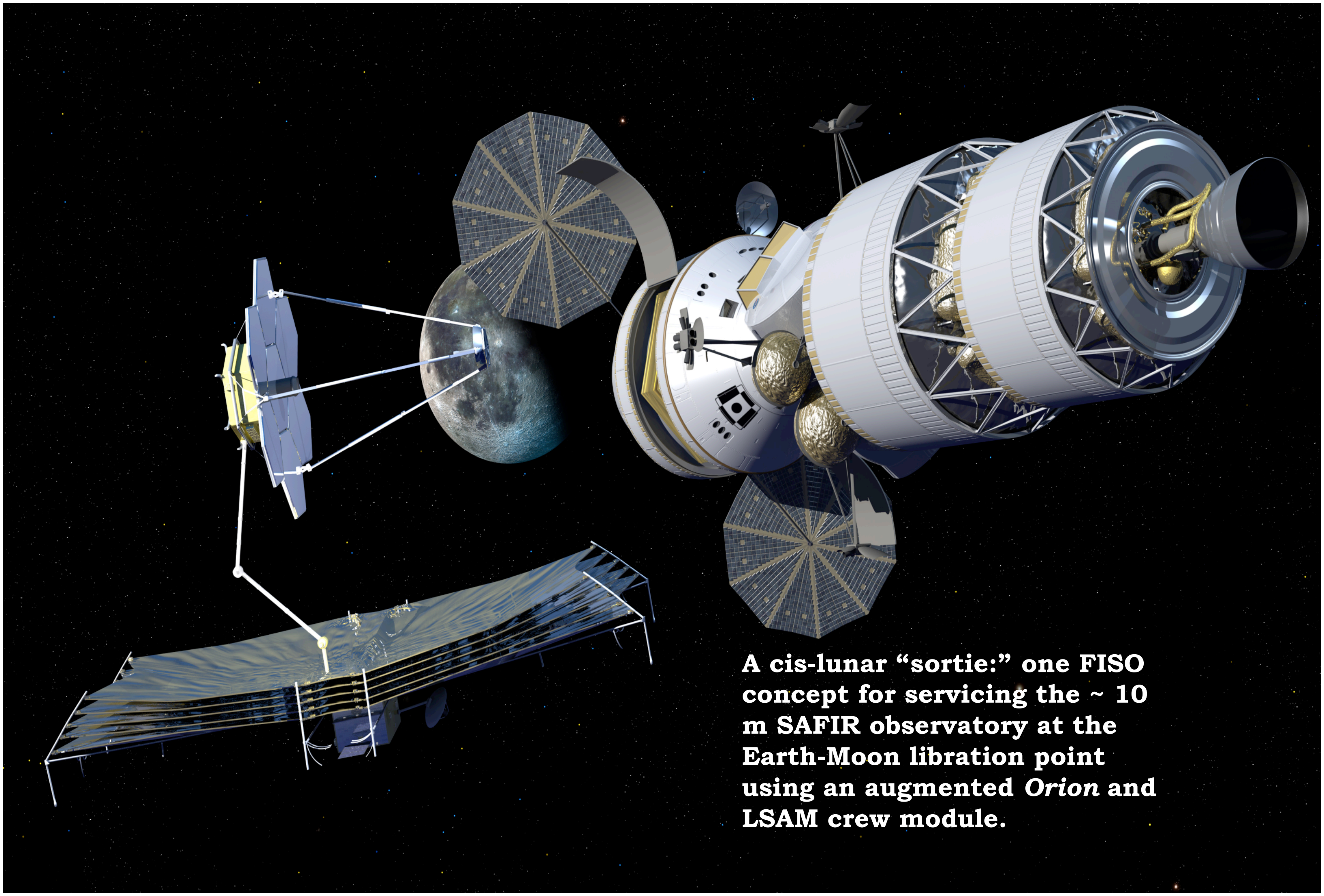


Lunar module adapted for astronaut-tended solar and astrophysics observations (ca. 1967)

Similarly, human spaceflight vehicles of the 21st Century may enable major in-space science missions not otherwise possible.



This Orion "stack" may simultaneously serve as a precursor/demo in preparation for long human voyages beyond the Earth-Moon system.



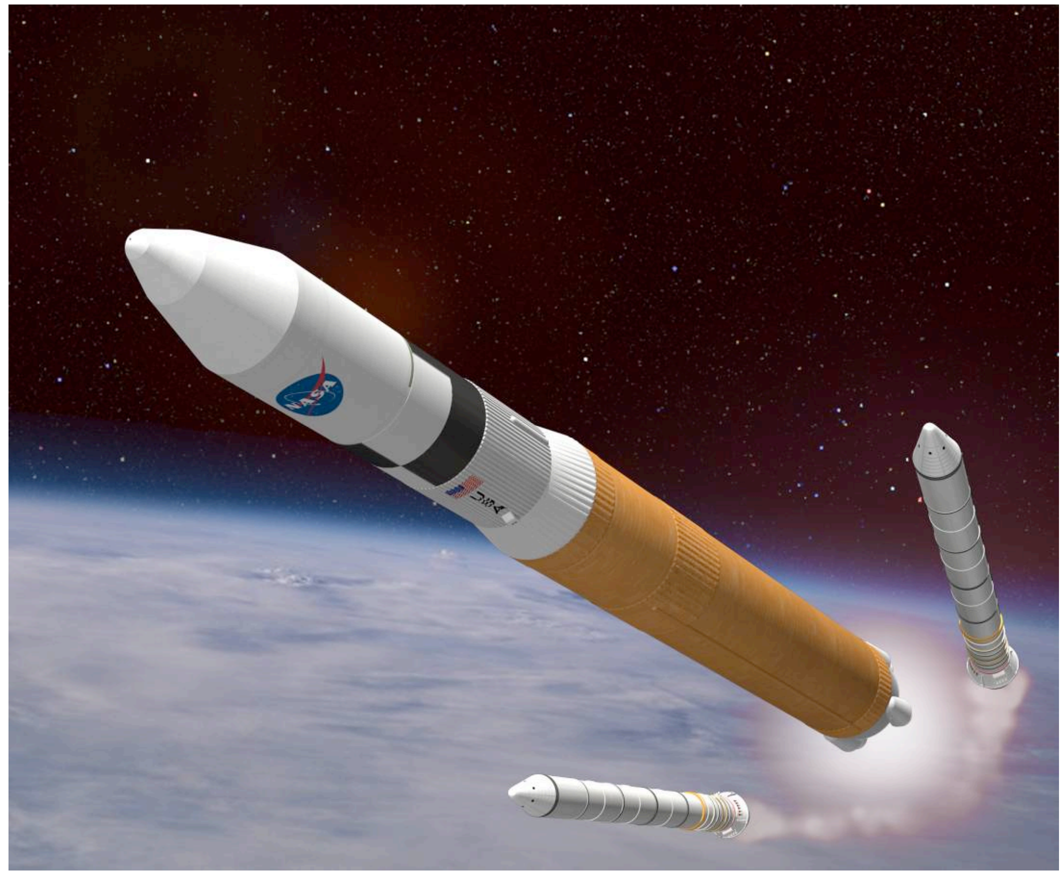
The “grand questions” of astronomy may require large, complex optics that cannot be operated on the Earth’s surface.

As was the case with Hubble, will astronauts be the key enabling capability to realize these goals? And with robotic partners?

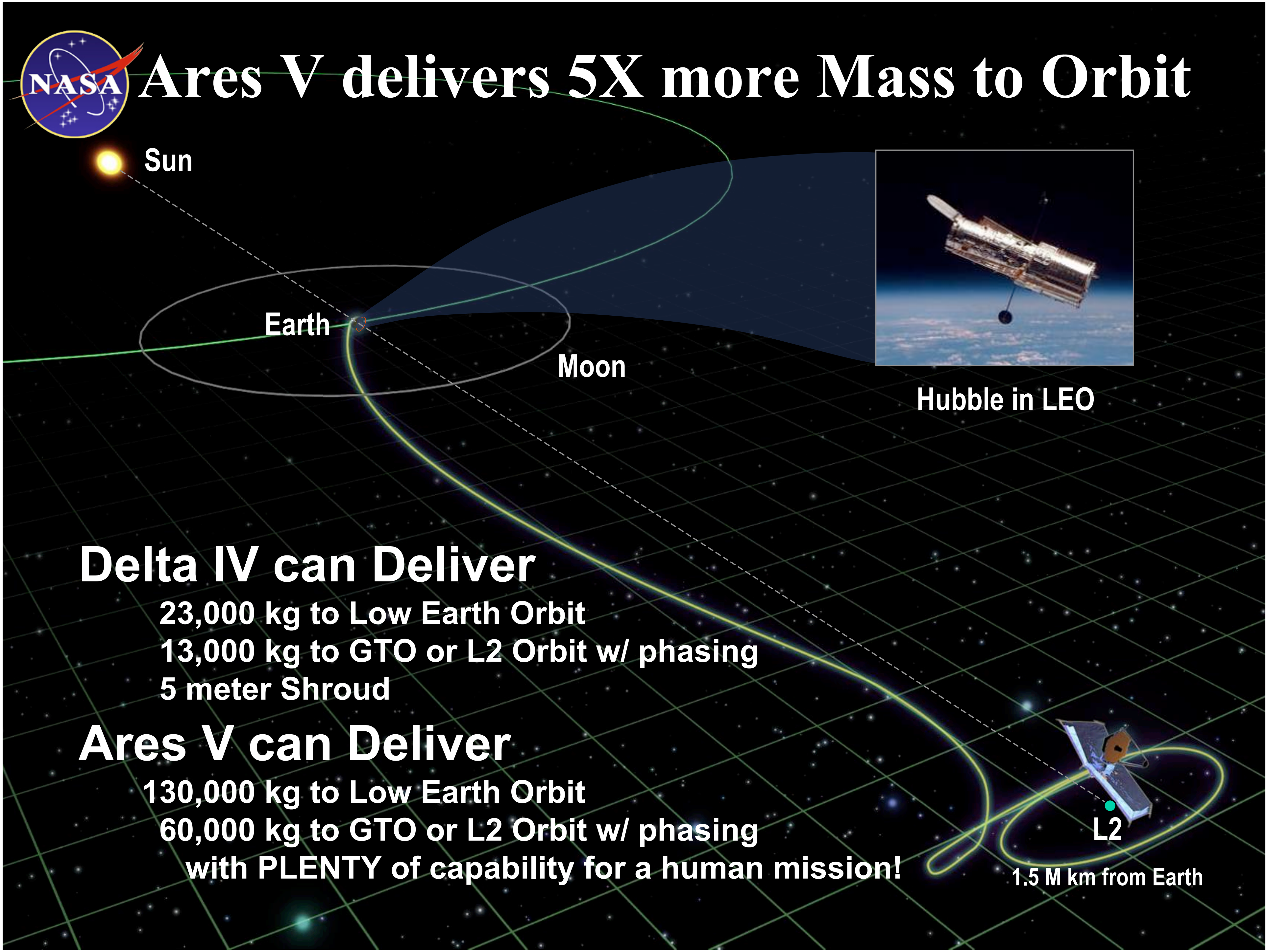
But, wait! There’s more!!

Ares V: an Enabling Capability for Future Space Astrophysics Missions

NASA’s Constellation vehicles: Ares I crew launch vehicle with Orion crew exploration vehicle (right) and Ares V cargo launch vehicle (left).

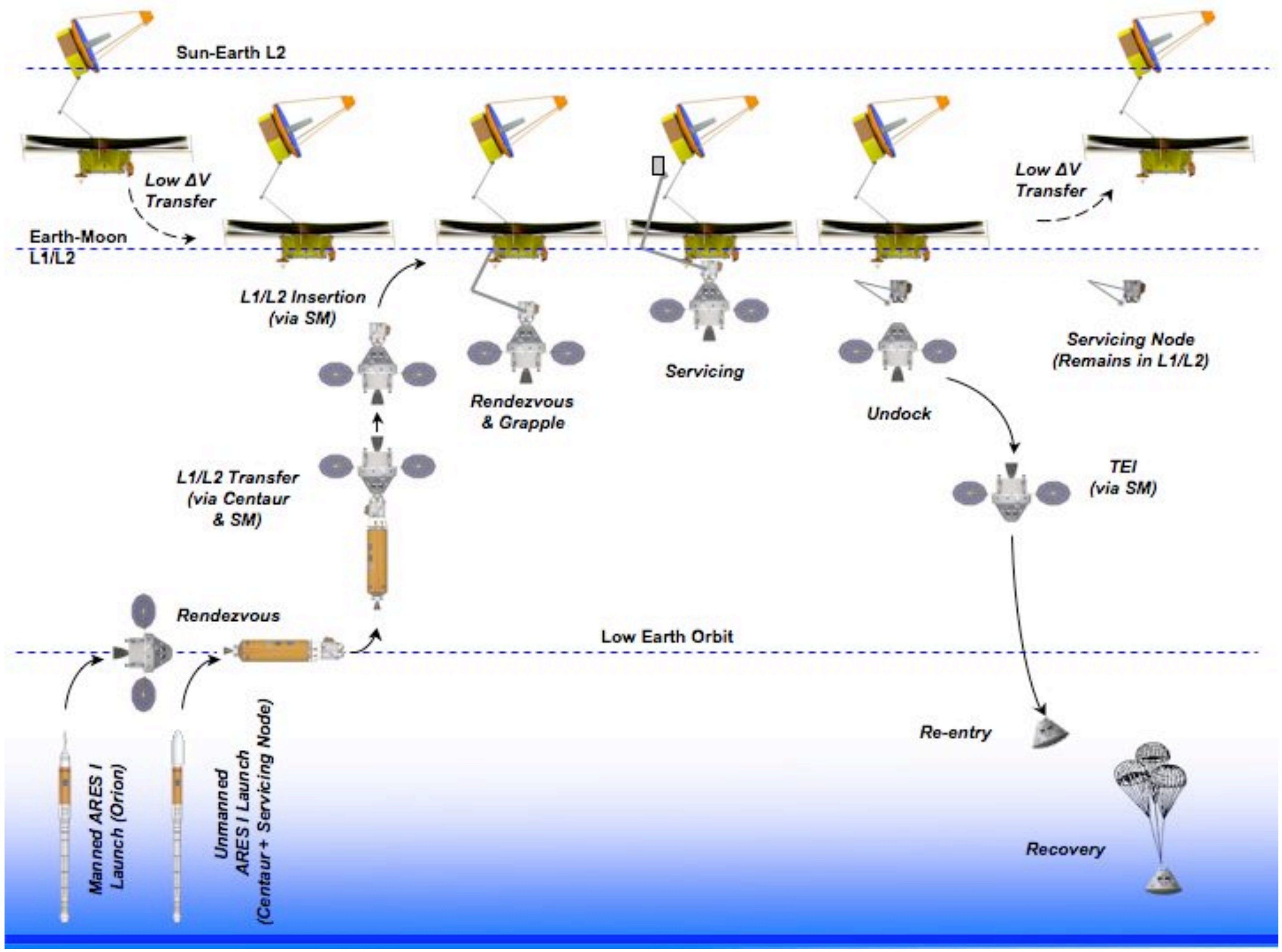


Ares V: capable of placing 60,000 kg into a Sun-Earth L2 point, with a ~10 m diameter fairing. (Courtesy: H. Philip Stahl (NASA MSFC))


Ares V delivers 5X more Mass to Orbit
NASA
Sun
Earth
Moon
Hubble in LEO
Delta IV can Deliver
23,000 kg to Low Earth Orbit
13,000 kg to GTO or L2 Orbit w/ phasing
5 meter Shroud
Ares V can Deliver
130,000 kg to Low Earth Orbit
60,000 kg to GTO or L2 Orbit w/ phasing
with PLENTY of capability for a human mission!
L2
1.5 M km from Earth

Although Ares V has Impressive Capabilities, It is 10+ Years in the Future

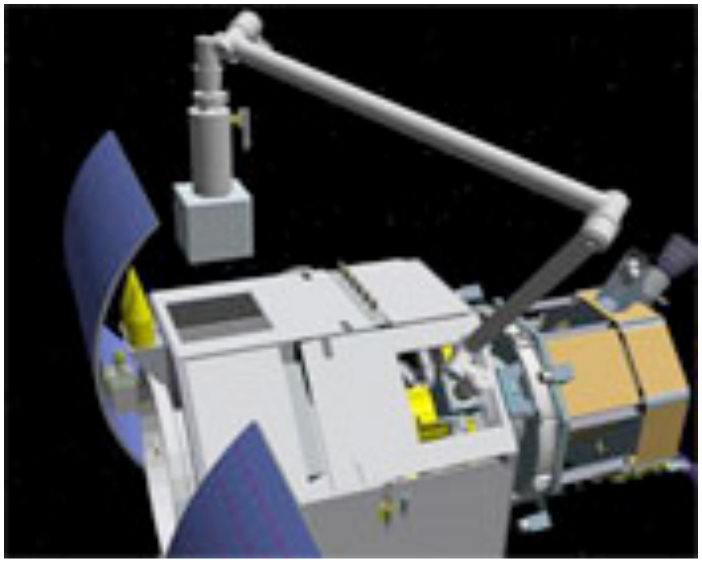
Are There Other Elements of NASA's Constellation Architecture that Could be Used to Enable Astronaut-based Servicing?

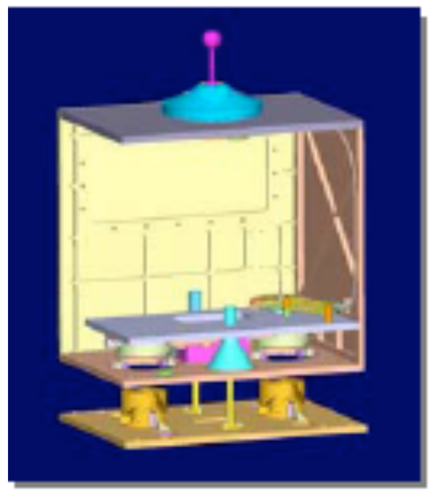


Concept of operations to use a pair of Ares I vehicles to carry astronauts to Earth-Moon L1,2 "jobsites" within 5 - 10 years.

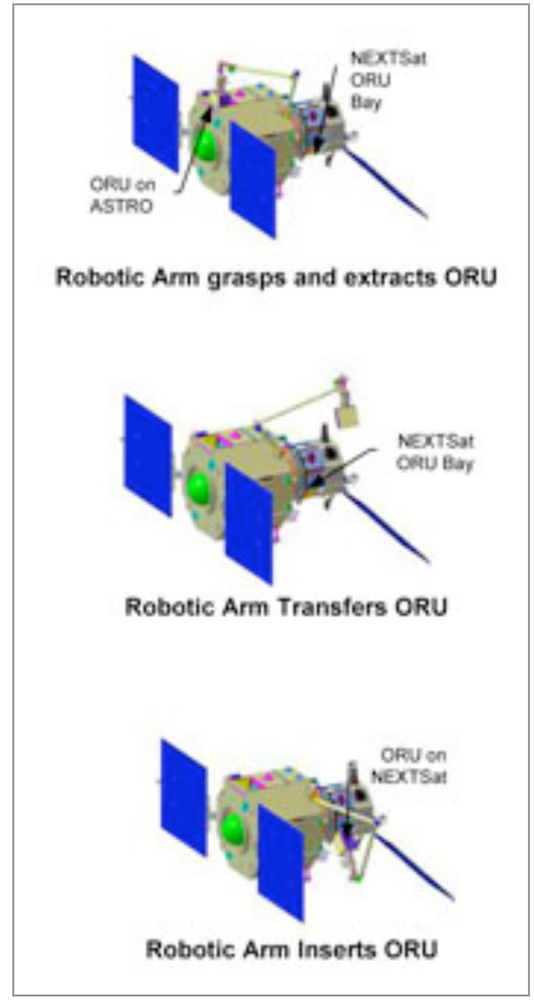
But wait! There’s still more!

DARPA’s Orbital Express (2007)





ORU



http://sm.mdacorporation.com/what_we_do/oe_3.html

http://www.boeing.com/ids/advanced_systems/orbital/pdf/arcss_briefing_2006-02-04.pdf

http://sm.mdacorporation.com/what_we_do/oe_4.html

Orbital Express Overview

- Orbital Express (OE) Demonstration System is to demonstrate the operational utility, cost effectiveness, and technical feasibility of autonomous techniques for on-orbit satellite servicing
- The specific objectives of OE are to develop and demonstrate on orbit:
    - An autonomous guidance, navigation, and control system
    - Autonomous rendezvous, proximity operations, and capture
    - Orbit fluid transfer between a depot/serviceable satellite and a servicing satellite
    - Component transfer and verified operation of the component
    - A nonproprietary satellite servicing interface specification

http://www.boeing.com/ids/advanced_systems/orbital/pdf/orbital_express_demosys_03.pdf

Possible Future Assessment and Trade Studies

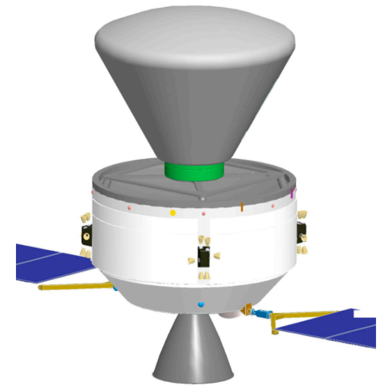
Space robotics:

Surface or in-space ops, human-robot interaction
=> AR&D and inspection of ISS, Shuttle, *Orion*; space tugs and remote cargo transfer; refueling;

***Orion* + robots + astronaut EVA:**

manipulation, upgrade, construction with astronauts on-site
=> complex assembly, rescue, servicing etc. possible only with astronauts and advanced robotics; cost trades

Tug rescue of stranded CEV



In-space support for lunar surface ops:

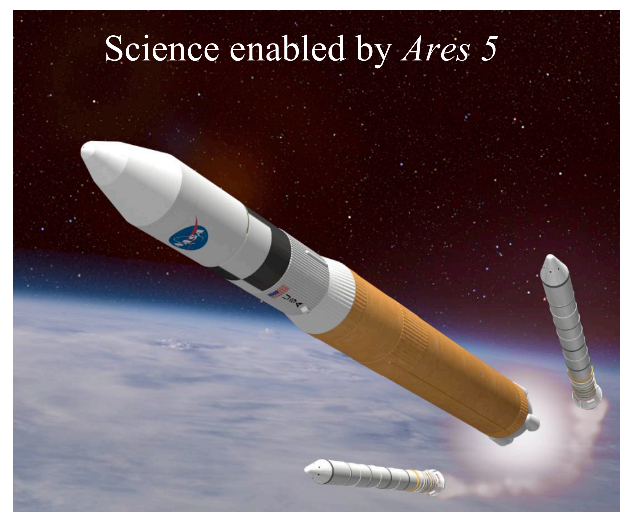
Application of in-space capabilities to lunar surface ops and vice versa

=> Depoting, refueling in space; contingency and medical support for surface humans operations; preparations for long human space voyages

Robotic servicing of complex satellite

***Ares 5*: heavy lift and very large optical systems:**

=> very large apertures, multiple payloads, etc. Design study coordinated among GSFC, ARC, MSFC, JSC, NRO, academia, industry; costs



Concluding . . .

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Roll the video . . . .see http://futureinspaceoperations.com