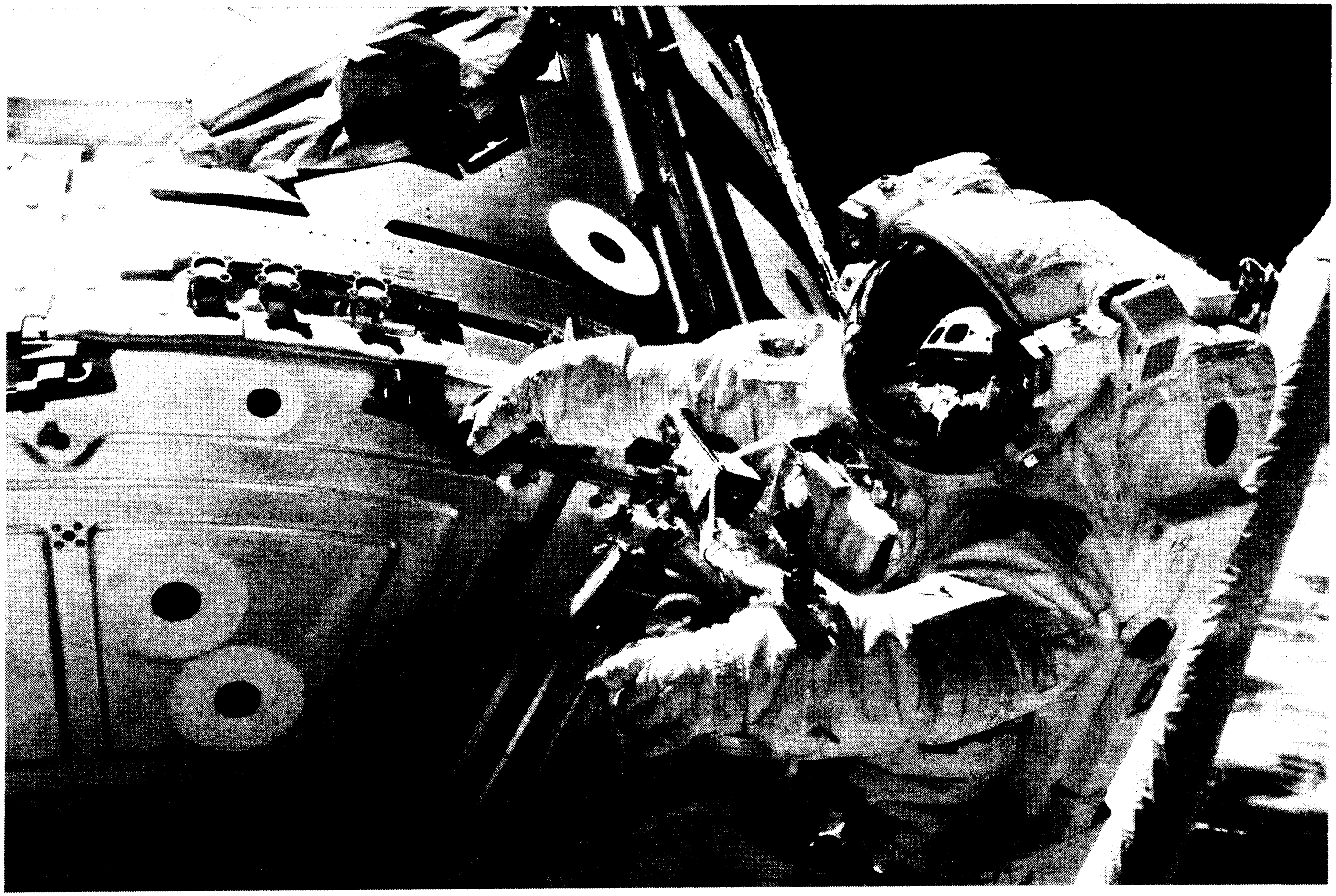
Building Upon the ISS and HST Experience

Science Enabled by Returning Humans to the Moon: An Architectural Overview



Harley A. Thronson

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NASA Goddard Space Flight Center

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

International Space University

February, 2008

See http://futureinspaceoperations.com

A Rare Confluence of Events

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

- STScI 2006, 2007
- NAC science sub-committees (Tempe 2007)
- NAS "Decade Review" in astronomy & astrophysics to start soon

NASA continues to demonstrate extraordinary capabilities in space

- 100th EVA on ISS in early January
- Fourth servicing mission to HST in about a half year

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
- SUMO (NRL) in 2008

Consequently . . .

[This is the stuff to remember]

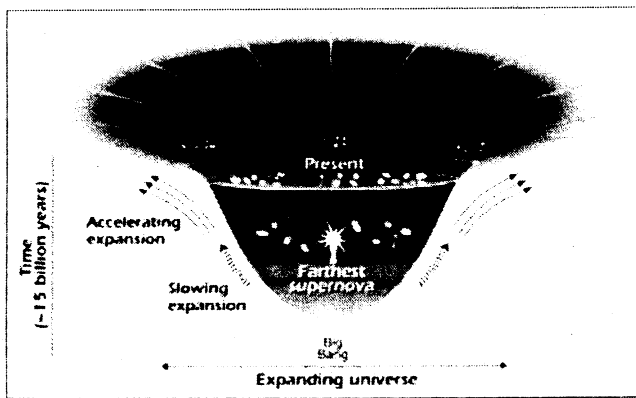
Modest augmentations to the planned future Constellation hardware and building upon nearly two decades of extraordinary success in space operations may enable major scientific goals that would not be otherwise possible.

- 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 operate 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.

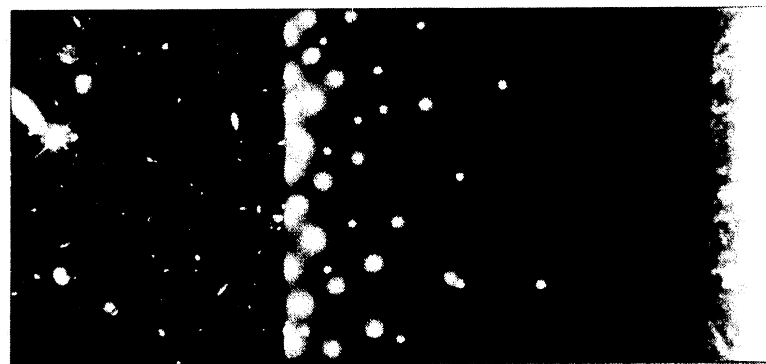
The work presented here was supported by the NASA ESMD Exploration Technology Development Program (ETDP).

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

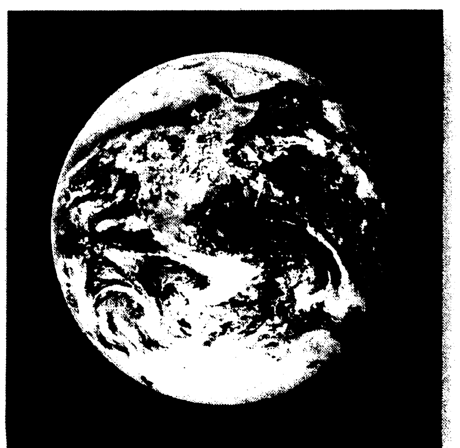
Why is the universe accelerating?



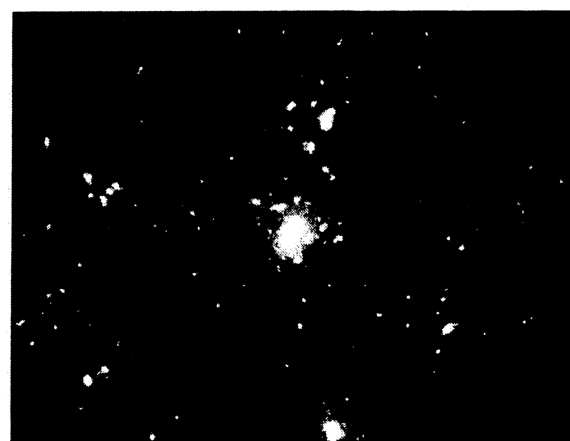
Which astronomical objects were involved in the "first light"?



Are we alone?

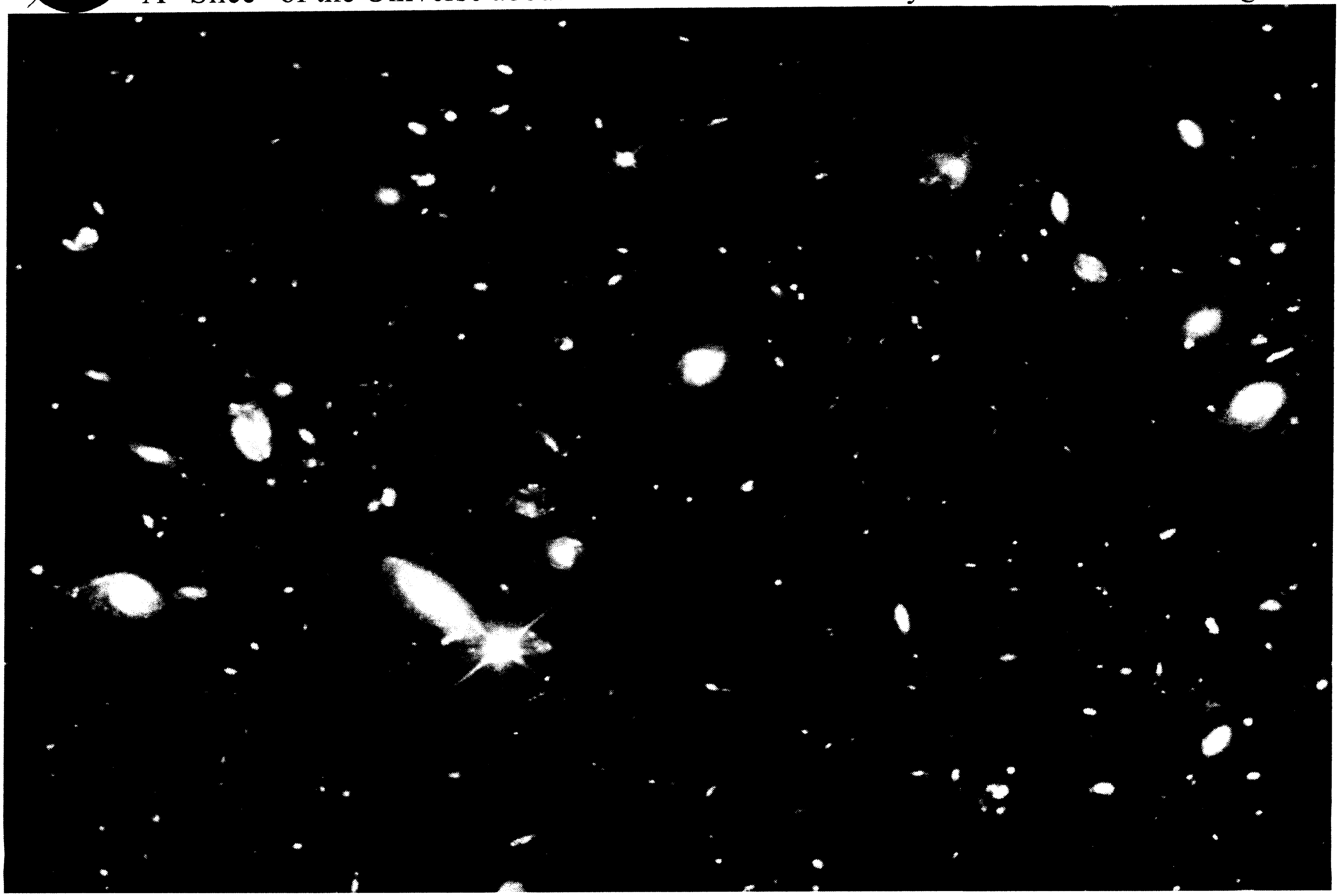


How did galaxies form?

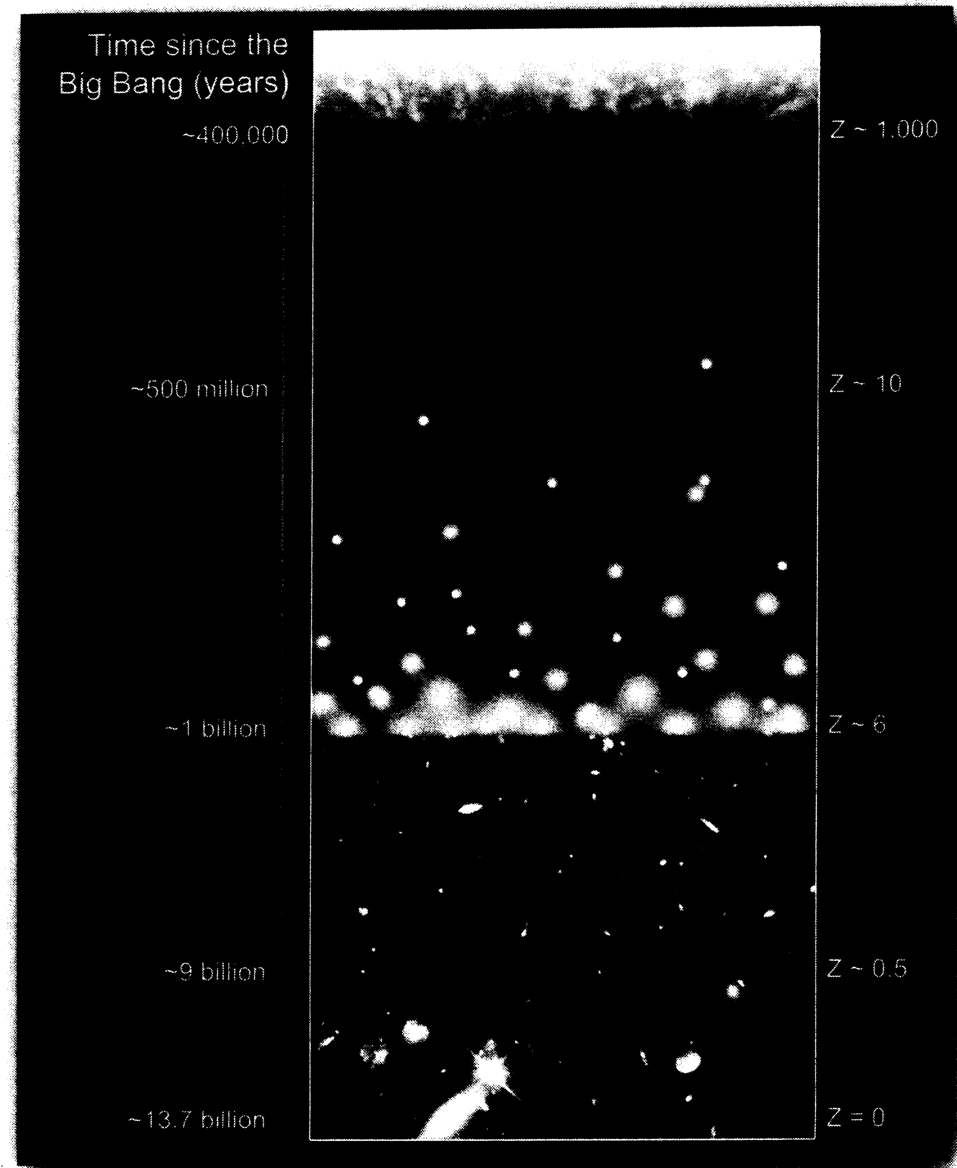


The Hubble "Deep Field"

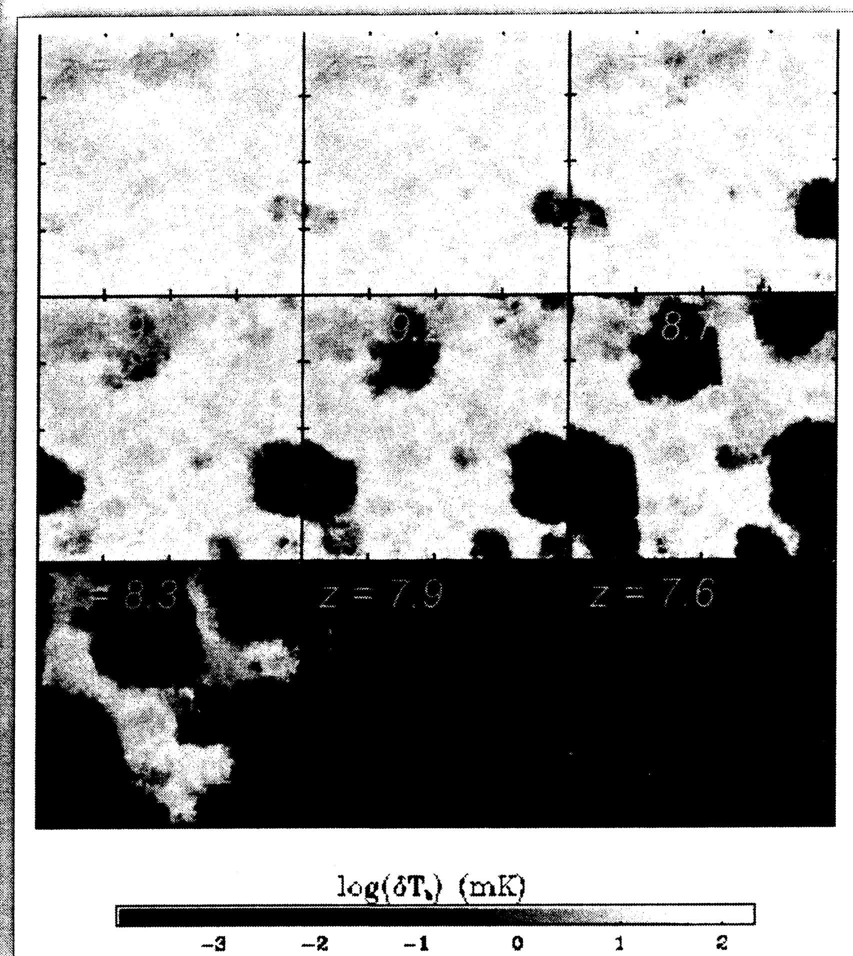
A "Slice" of the Universe about the Size of Roosevelt's Eye in Dime at Arm's Length



The Epoch of Reionization and Beyond



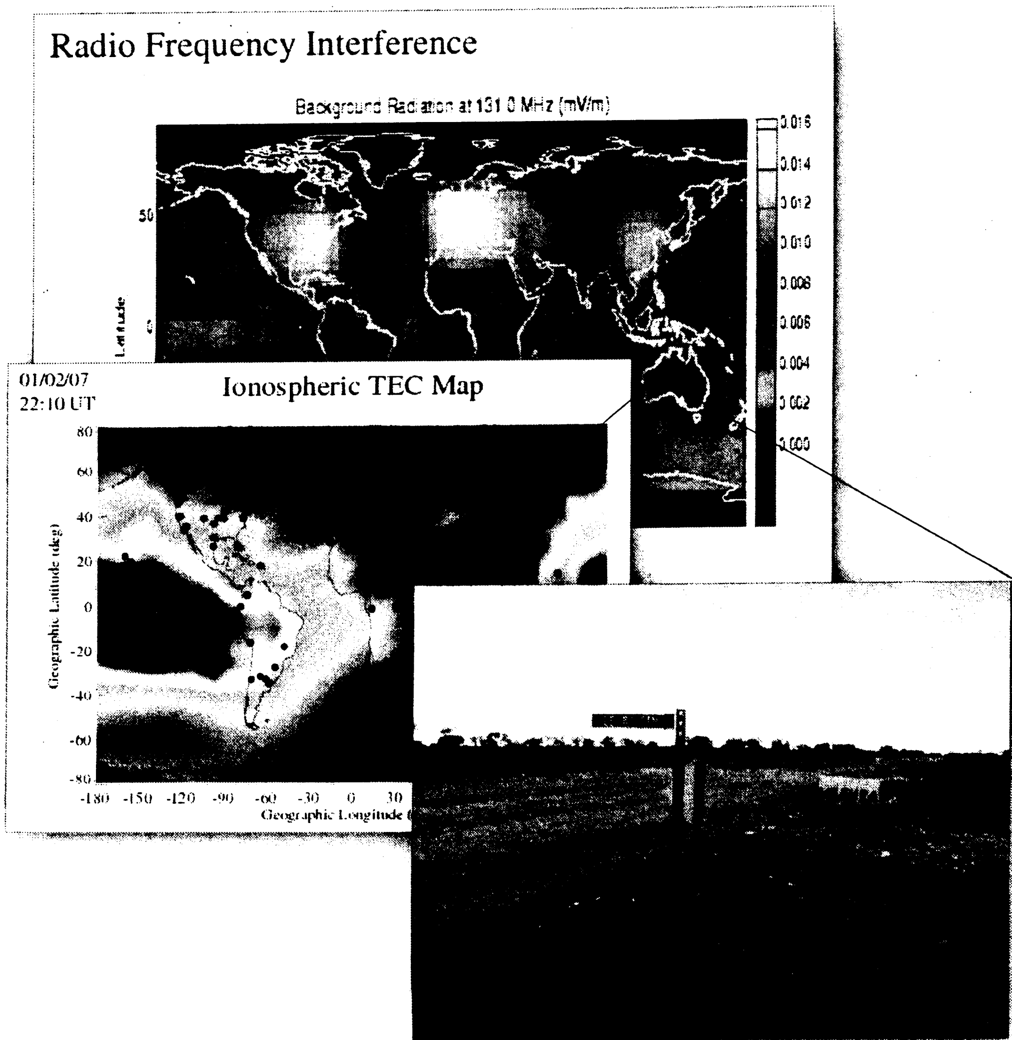
Reionization



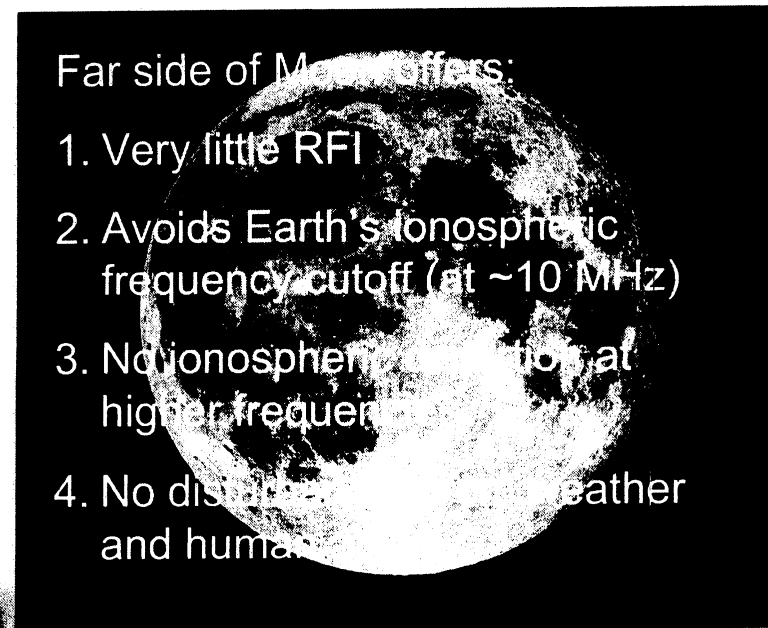
Fluctuations are about 10 mK

Observations of redshifted 21 cm (in the frequency range 10-200 MHz) neutral hydrogen emission could probe $7 \lesssim z \lesssim 100$ (100 million - 1 billion years after the Big Bang)

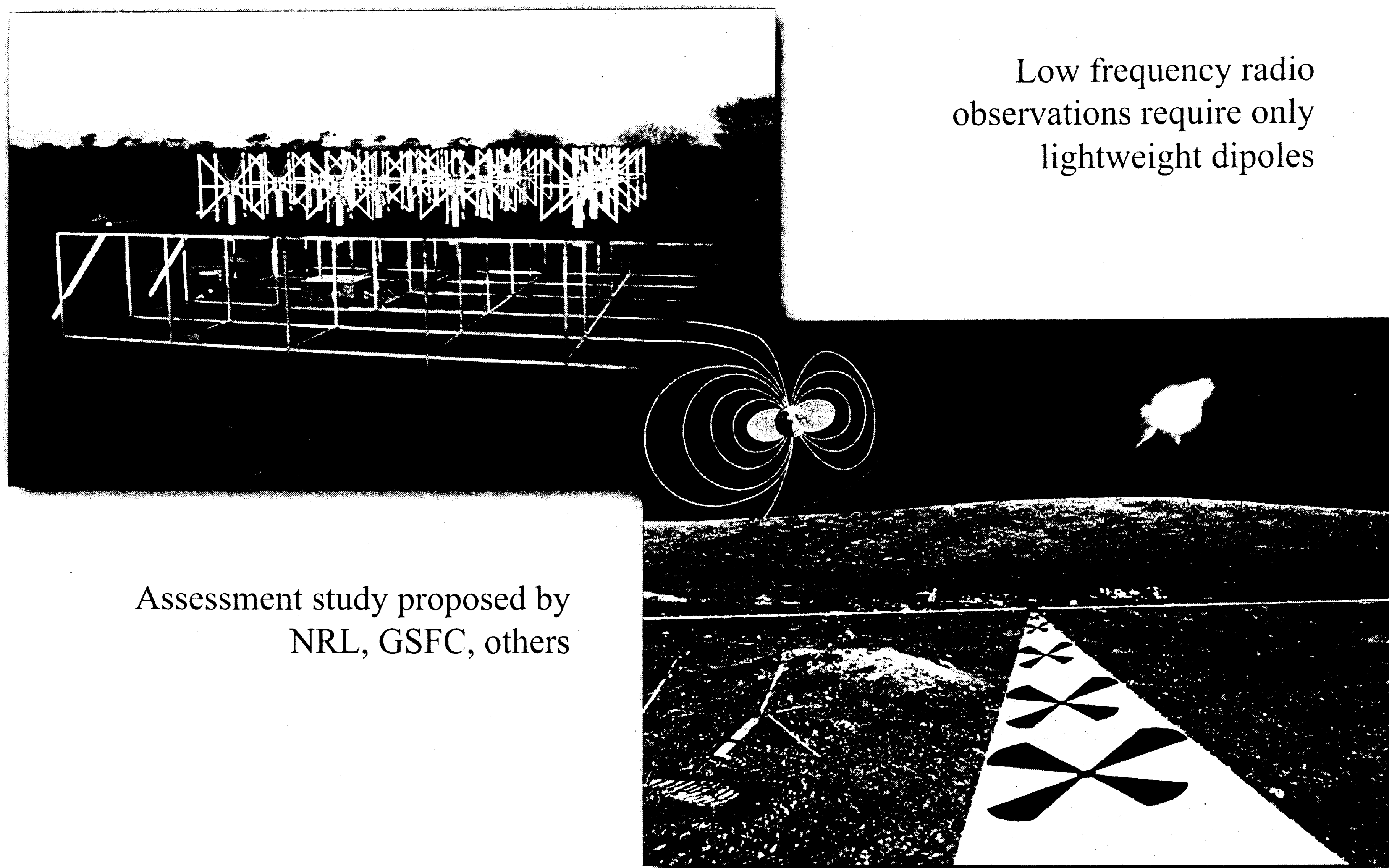
On Earth



On the Moon



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

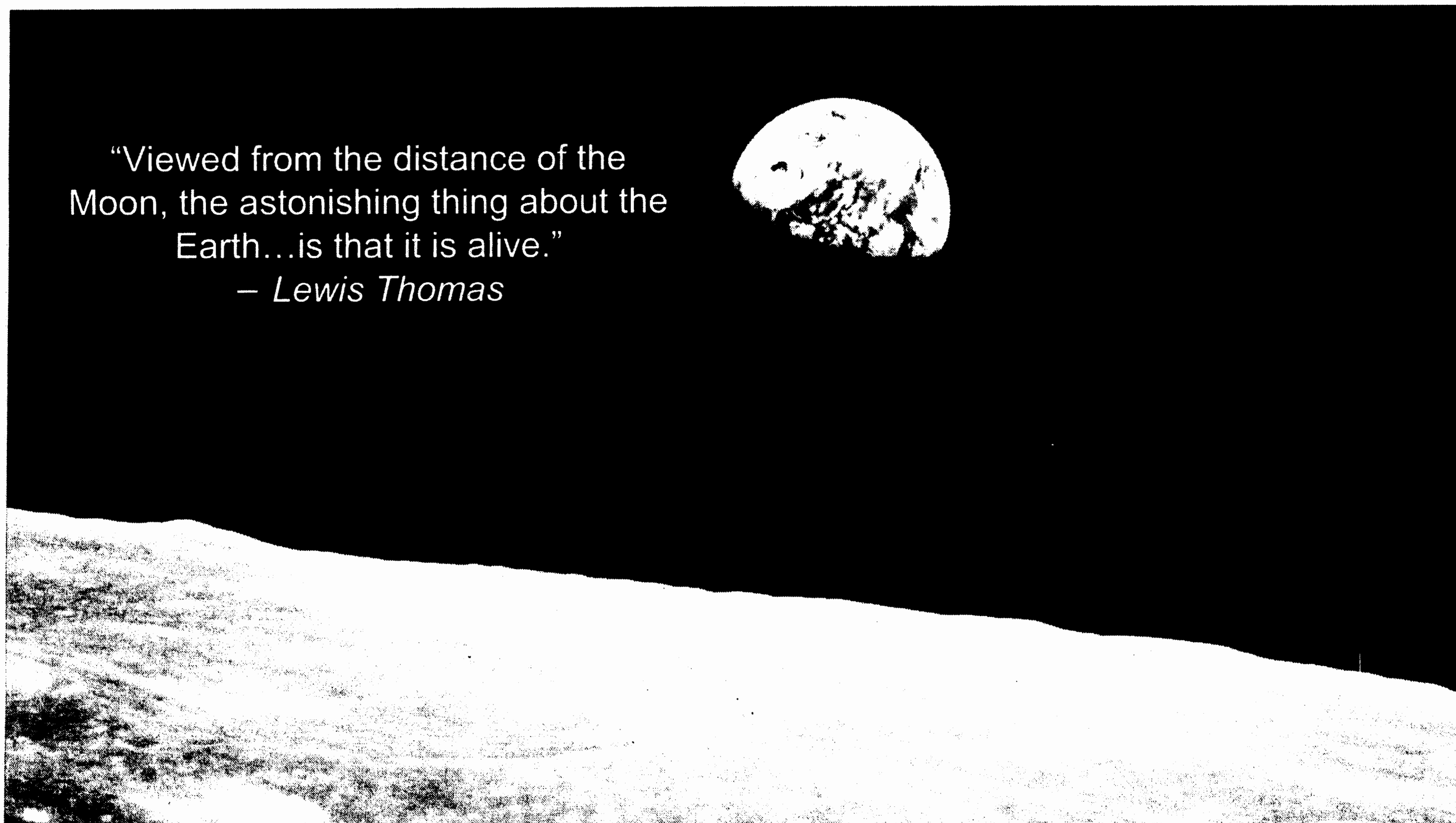


Low frequency radio observations require only lightweight dipoles

Assessment study proposed by NRL, GSFC, others

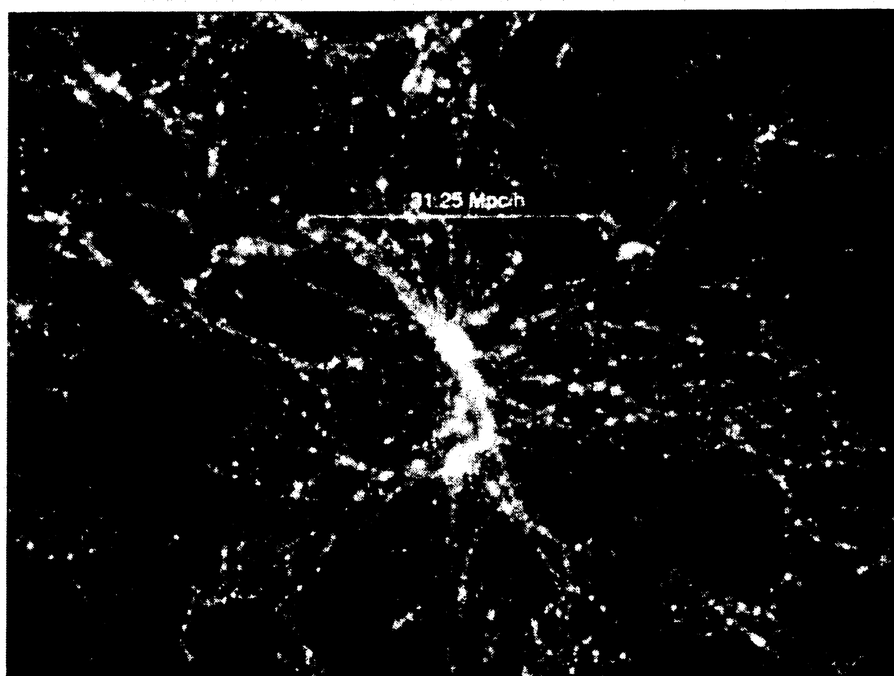
The Search for Earth-like Worlds?

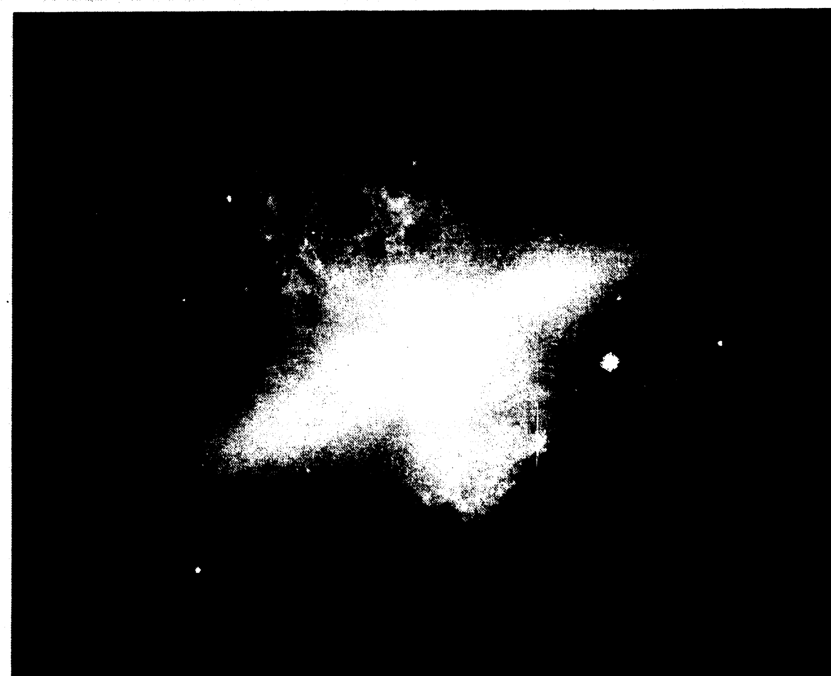
Discovering another "Earth" Would Change Everything!



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.

The Answers to the "Grand Questions" Lie in Space

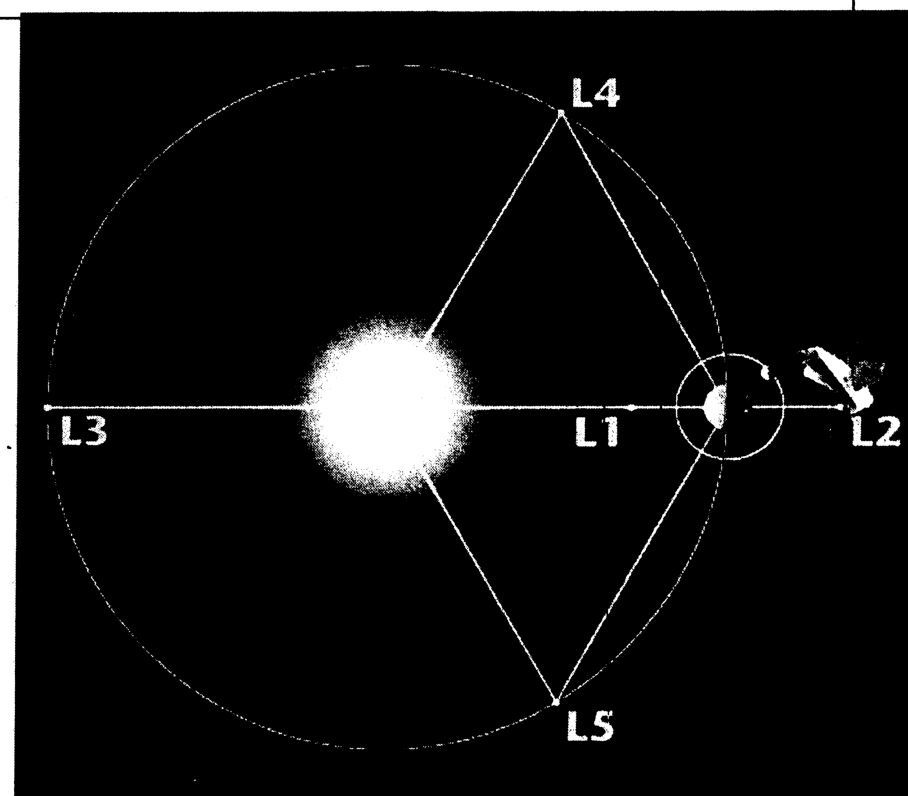
Observations from free space (in particular Lagrange points) offer the most promise for broad areas of astrophysics.

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)

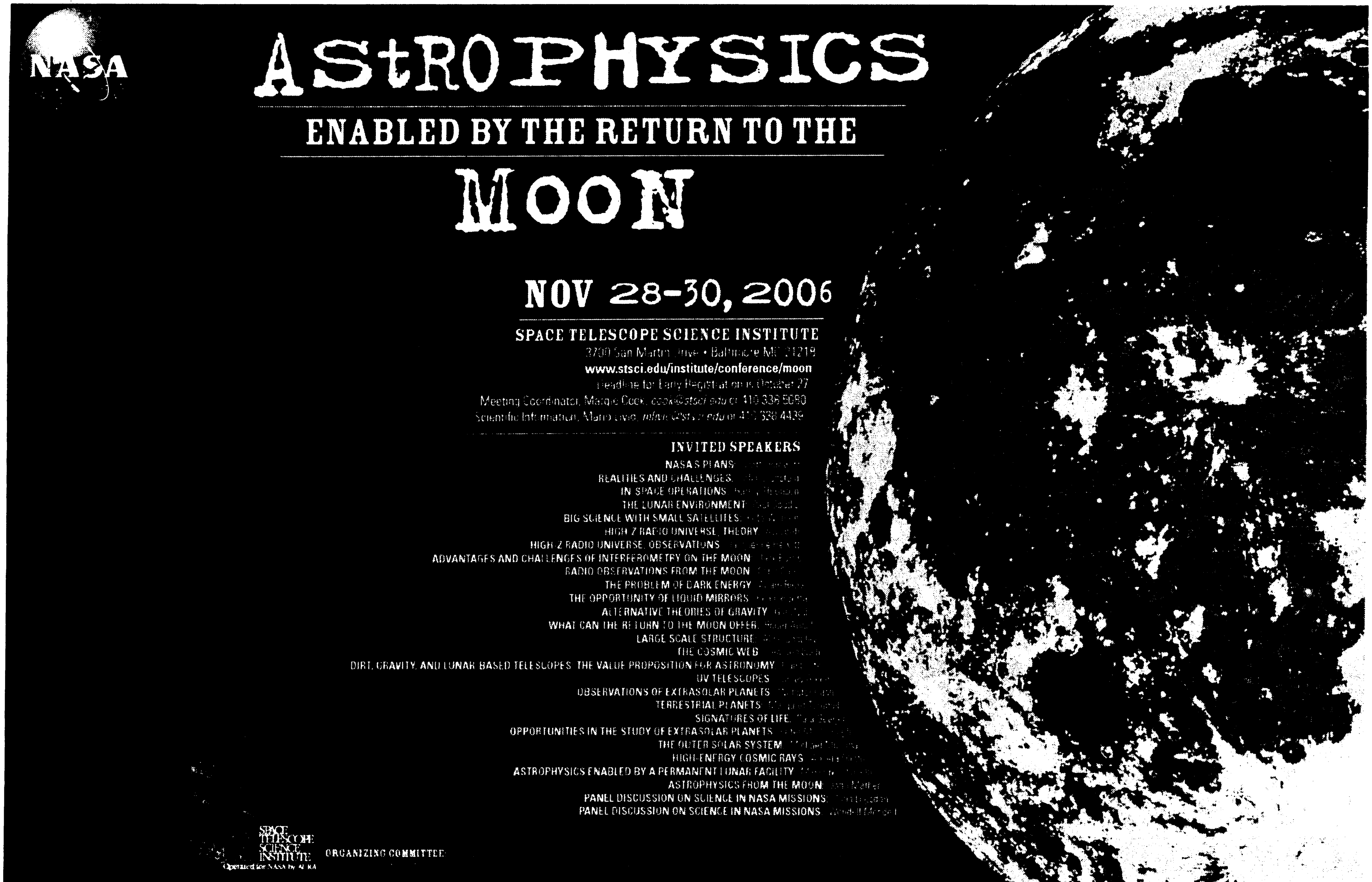
To answer these questions, new generations of astronomical missions will be required

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 . . .

Identification and priorities will be developed in the coming couple years via the long-established NRC "decade review" in astronomy & astrophysics.

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



The meeting was organized by STScI in collaboration with JHU, AURA, and NASA, with about 160 participants and led to . . .

NAC Astrophysics Subcommittee Recommendations (J. Mather, Chair)

(March 2007: *Not In Priority Order*)

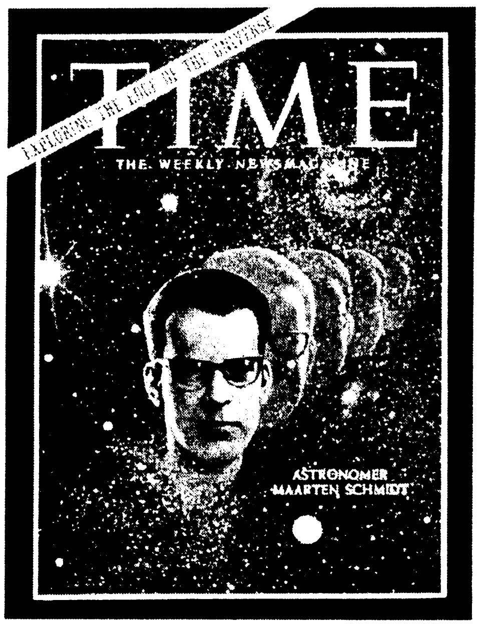
- **Radio-quiet (RFI) environment and infrastructure on lunar farside, or near Shackleton site, for low-frequency observatory (atmosphere and electronic density goes up significantly for a month with every landing)**
- **Large launch vehicles capabilities - VSE will include large launch vehicles like the Ares V, and the community should be part of dialogue in crafting its capabilities (e.g. volume, large mass capability, aspect ratio).**
- **Capability for secondary payload of small or medium science instruments (on lunar orbiters, or for transportation to lunar surface – Ares system, CEV)**
- **In-space Operations - potential for assembly, servicing, and deployment (trade studies).**
- **Large area lunar access - Autonomous and/or human-assisted mobility (depending on trade studies)**

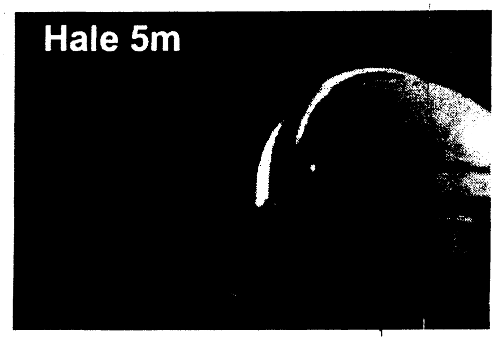
A bit of history:
Genesis of the first lunar astronomy vision

"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**

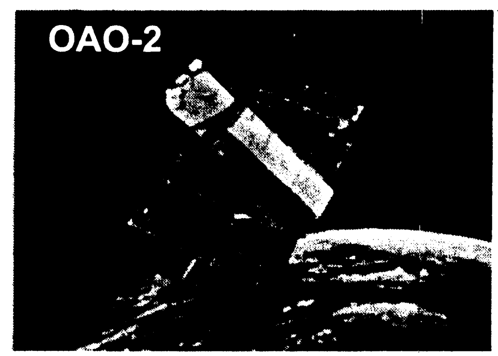
The world in 1966: Earth-based sites w/1" seeing,
emulsions , photomultipliers
post-Gemini, pre-Apollo,
OAO-2 (point/track ~ 1'/1")





and also ...

we were ***actively*** *headed to the Moon!*

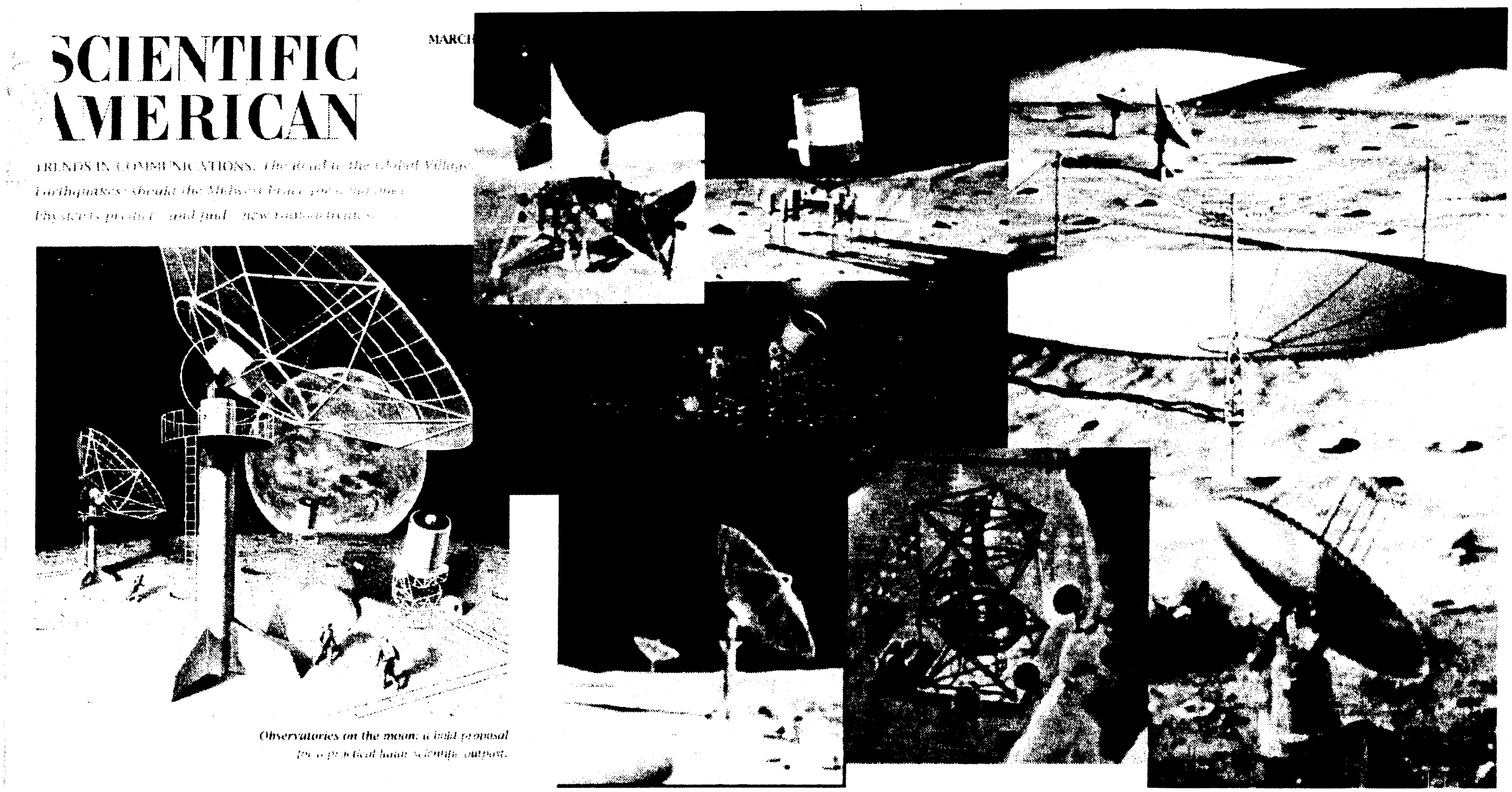


Advantages of the Moon for Astronomy c.1966

- **Vacuum (compared to Earth)**
  - multiwavelength
  - not seeing-limited
- **Radiation isolation (compared to Earth orbit)**
  - no damage to sensitive 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

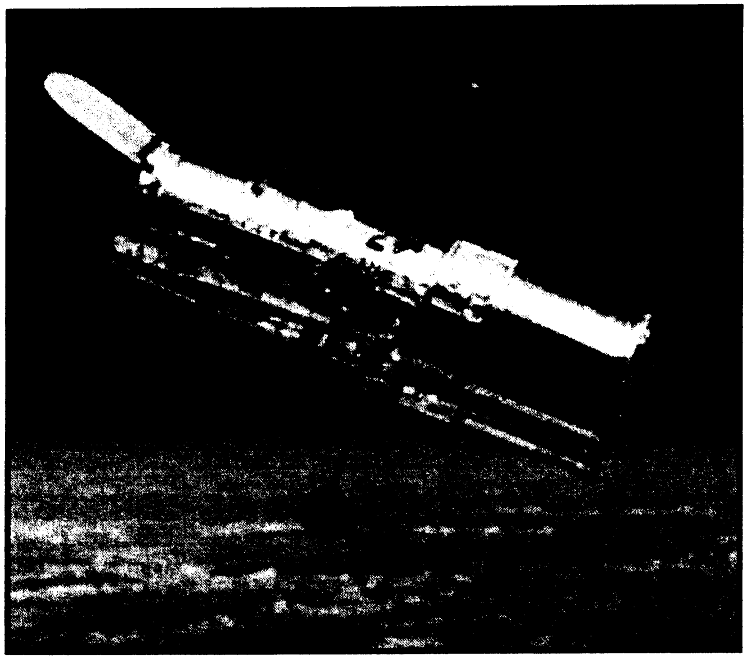
This vision was smart, both scientifically and technologically, and built upon NASA priorities of the day.

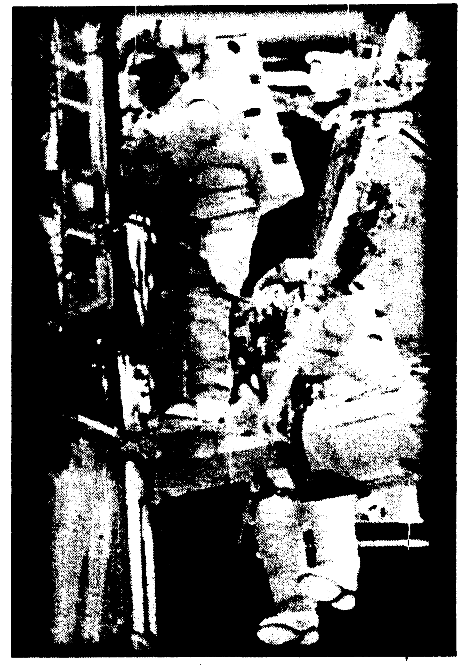
Lunar telescopes were a bold answer to our needs!



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 (many) disadvantages.

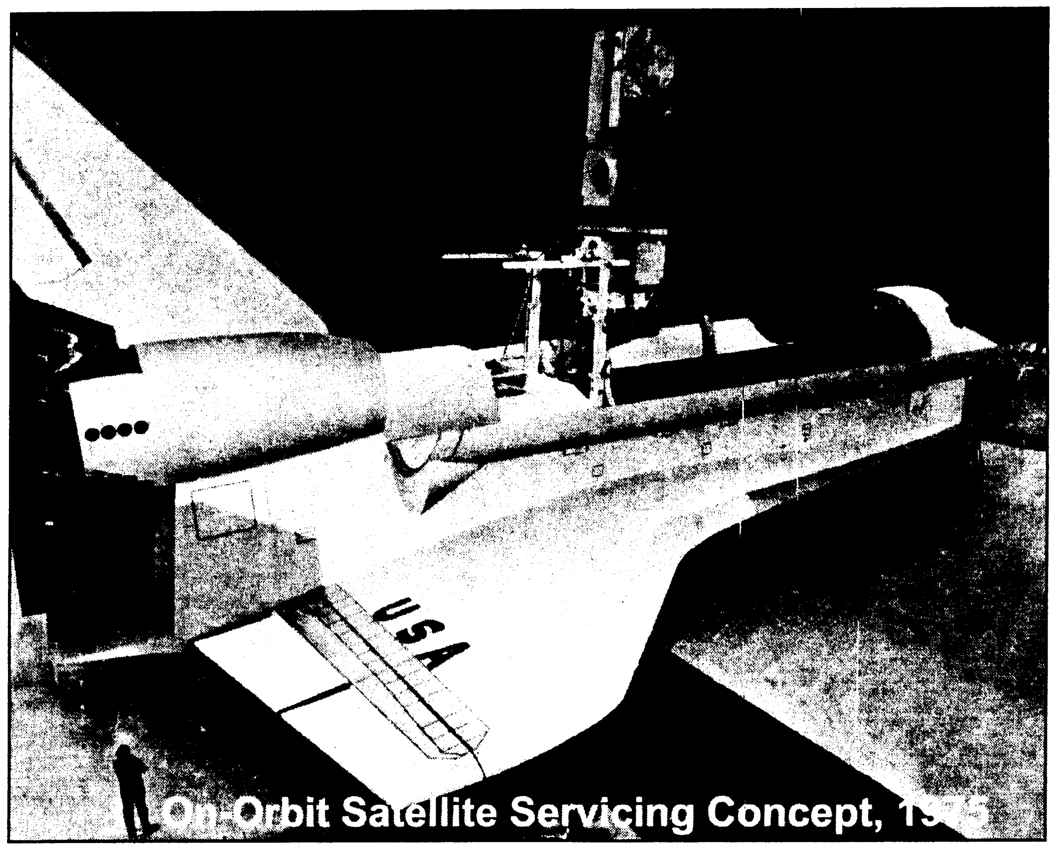
Which was made possible by . . .

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 <u>breakthrough</u> 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

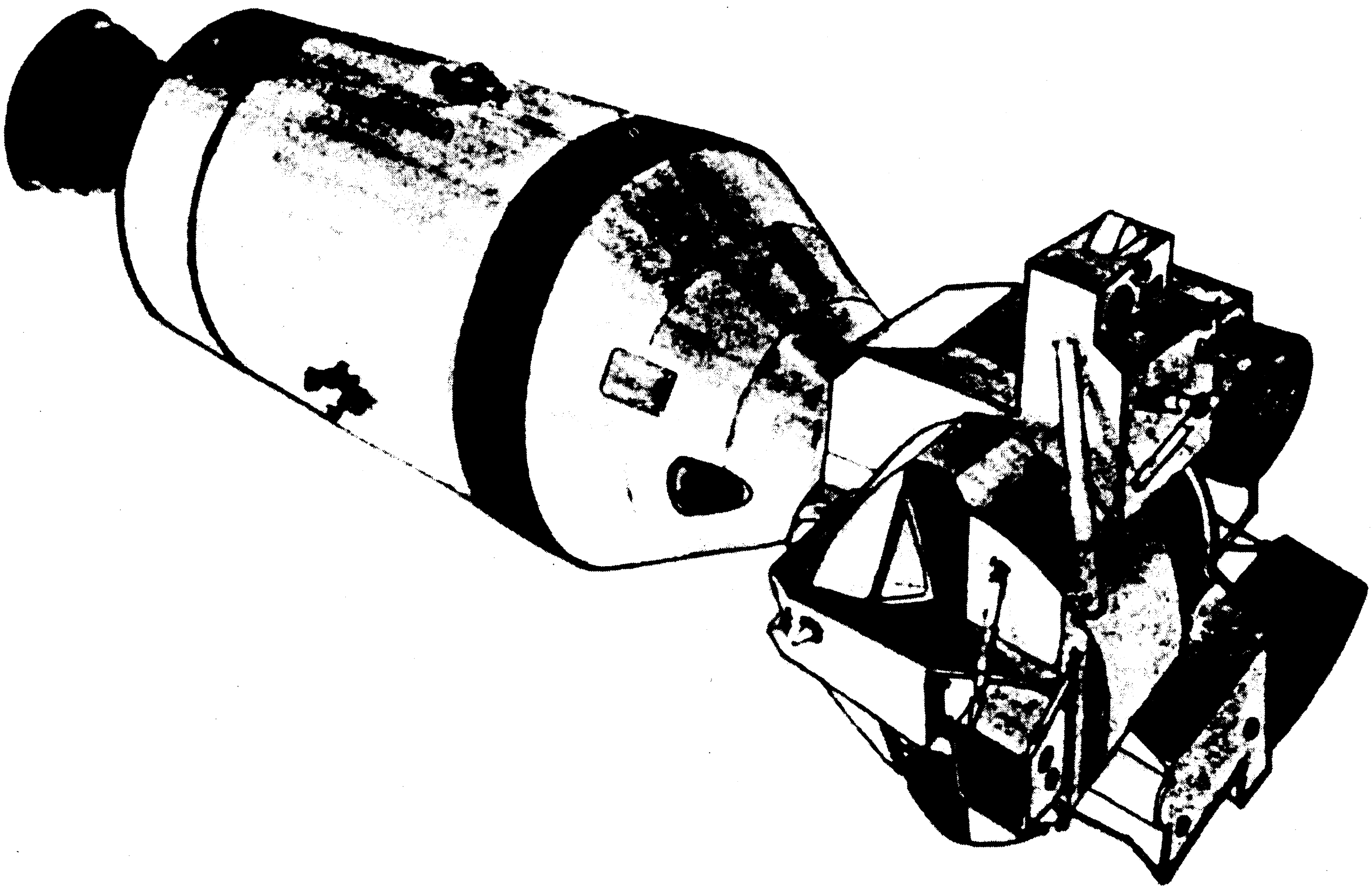
Generic Shuttle-based carriers to berth and service on-orbit spacecraft, not exclusive to one particular vehicle.



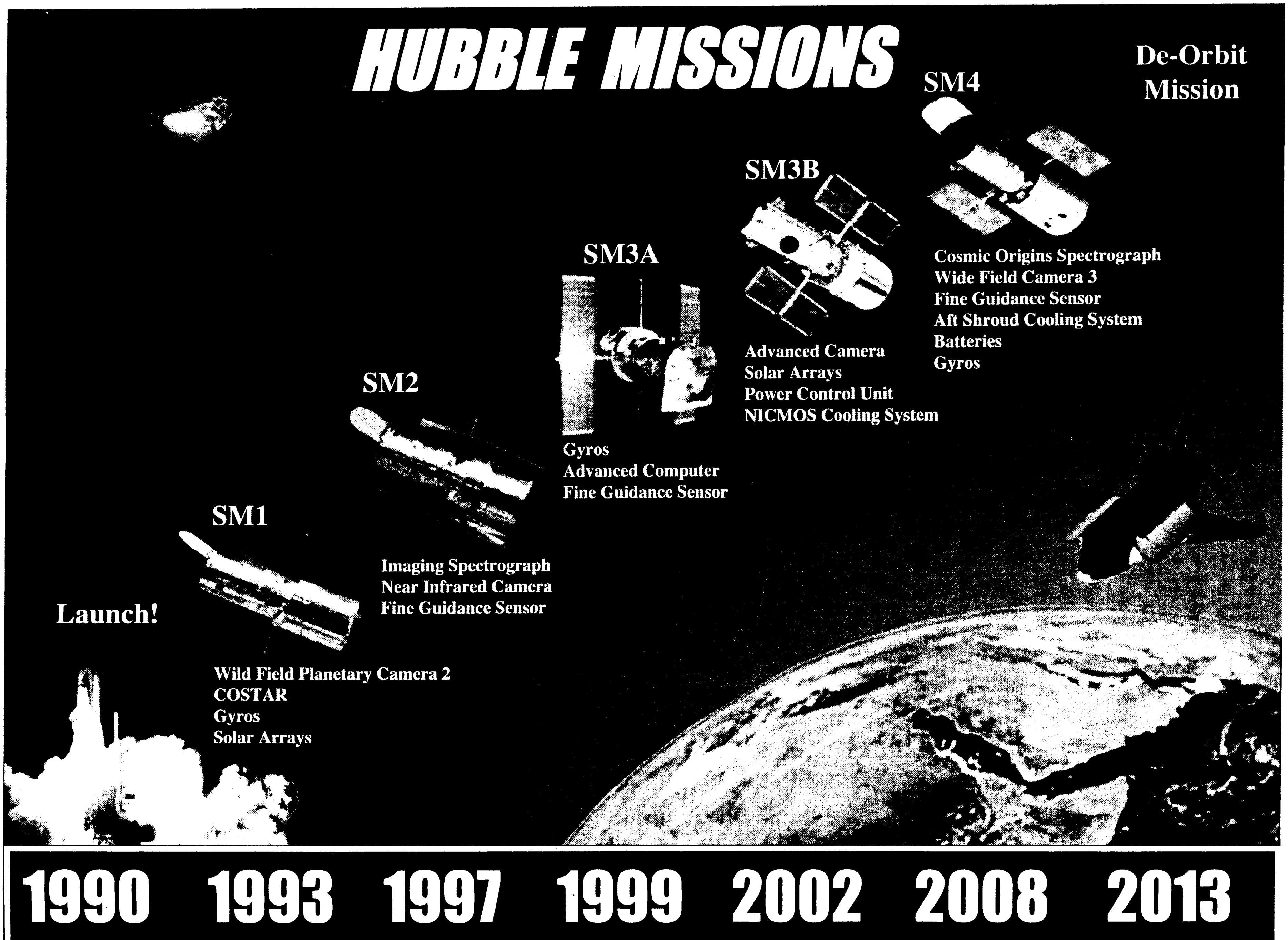
On-Orbit Satellite Servicing Concept, 1975

Interesting concepts, but have they resulted in substantiated goals for science?

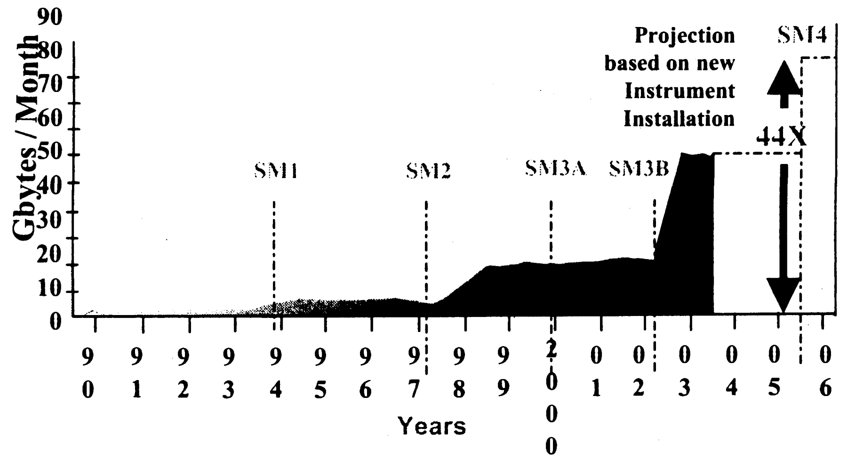
Although adapting human spaceflight hardware to achieve multiple goals predated the Shuttle by about a decade: the Apollo Applications Program. This particular concept was never built, aspects of the design evolved into the Apollo Telescope Mount in Skylab.



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

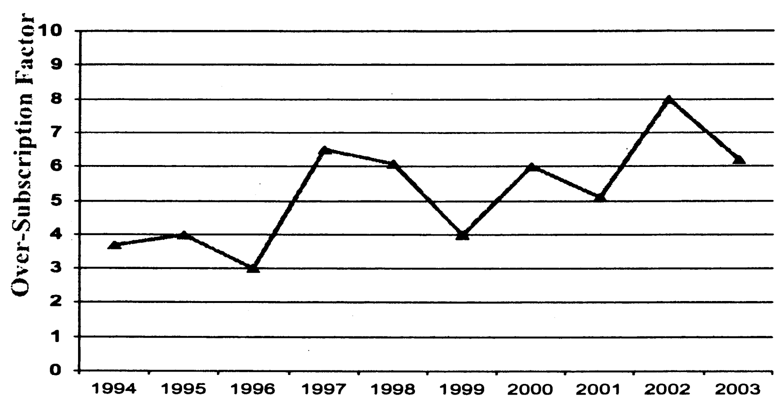

HUBBLE MISSIONS
Launch!
SM1
Wild Field Planetary Camera 2
COSTAR
Gyros
Solar Arrays
SM2
Imaging Spectrograph
Near Infrared Camera
Fine Guidance Sensor
SM3A
Gyros
Advanced Computer
Fine Guidance Sensor
SM3B
Advanced Camera
Solar Arrays
Power Control Unit
NICMOS Cooling System
SM4
Cosmic Origins Spectrograph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

HST Demand, Productivity, Cost-Effectiveness



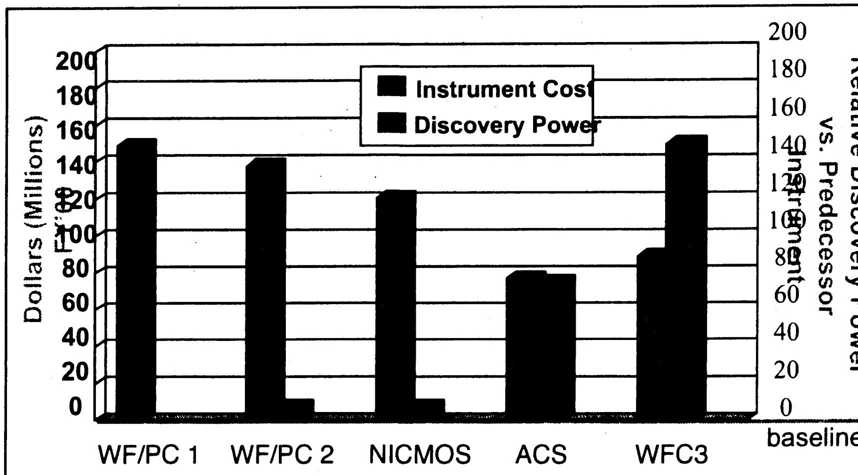
- Major advances in detector technology yield more sensitive instruments with wider fields-of-view and higher resolution producing more useful data per image
- Major improvements in operational scheduling efficiency yield more images per observing week and more scientific opportunities

- Demand for observing time on Hubble by the international astronomical community is consistently very high.



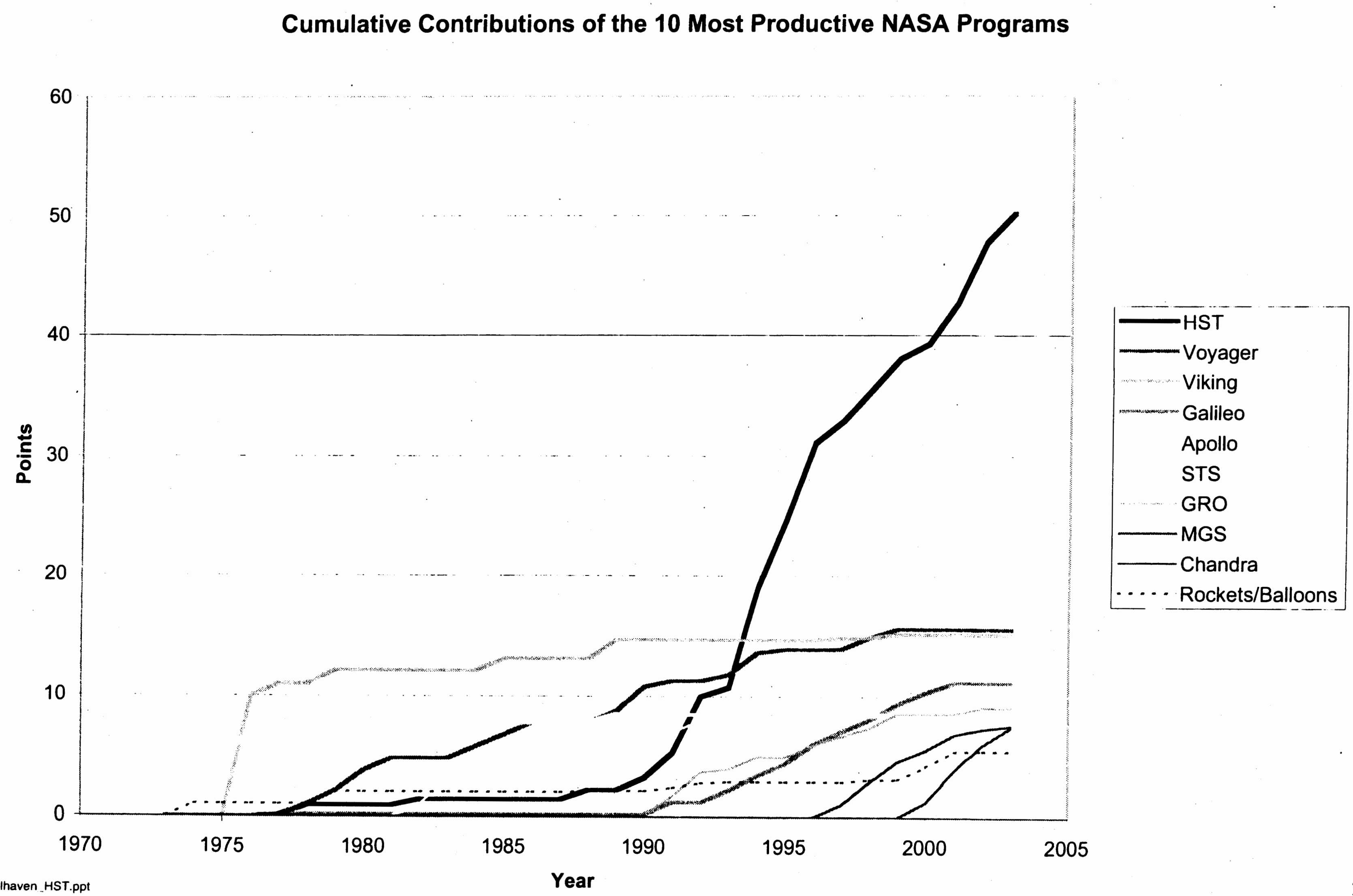
Requests for Scientific Observation Time on HST Beyond Availability

Note: HST observation proposals are restricted to that science which *cannot* be gathered from ground-based observatories.

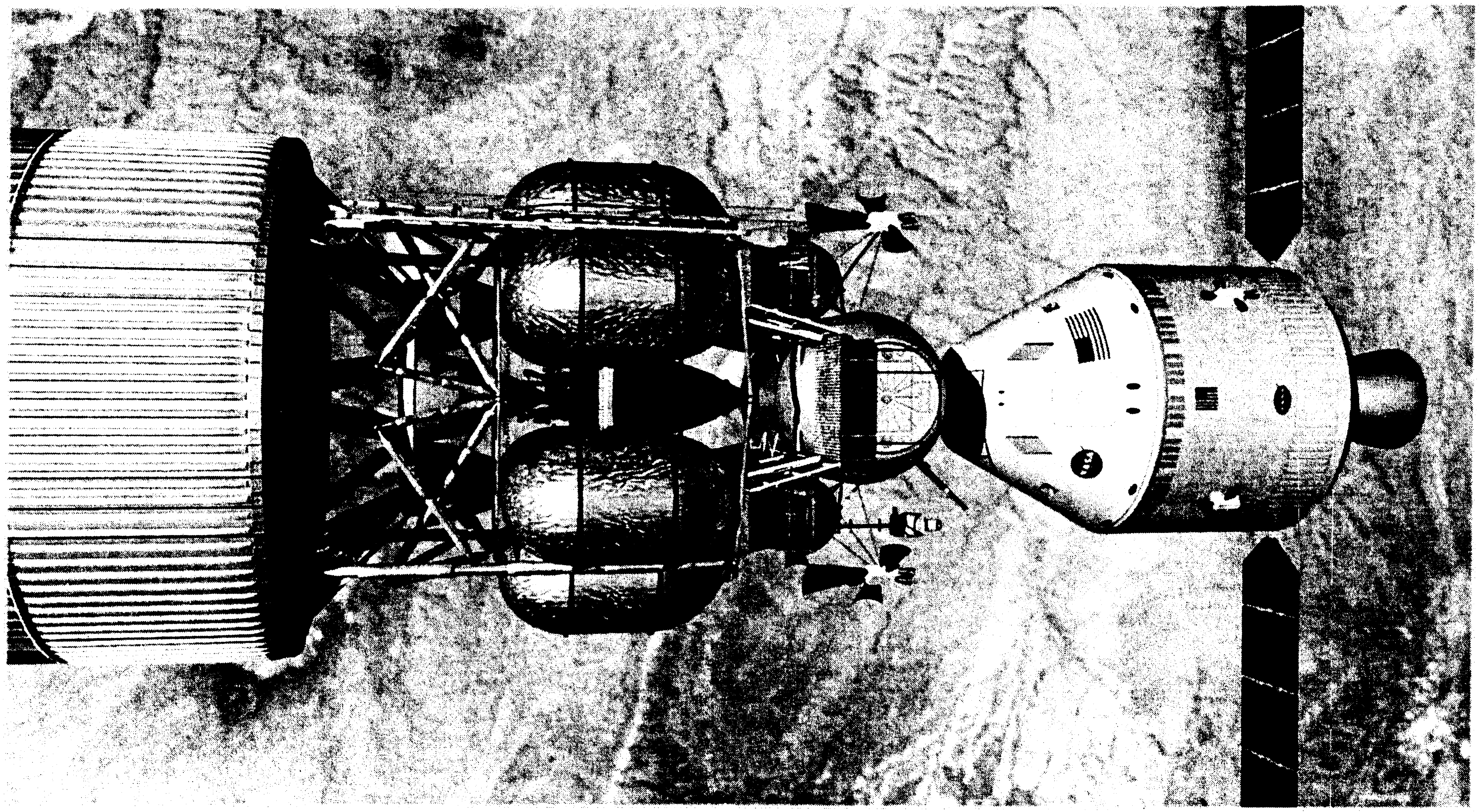


- New detector technology yields order-of-magnitude gains in the power of Hubble instruments over time
- Reuse of flight hardware and prior designs yields major cost reductions per instrument
- At the conclusion of SM4 Hubble will be at the apex of its capabilities and very cost-effective

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

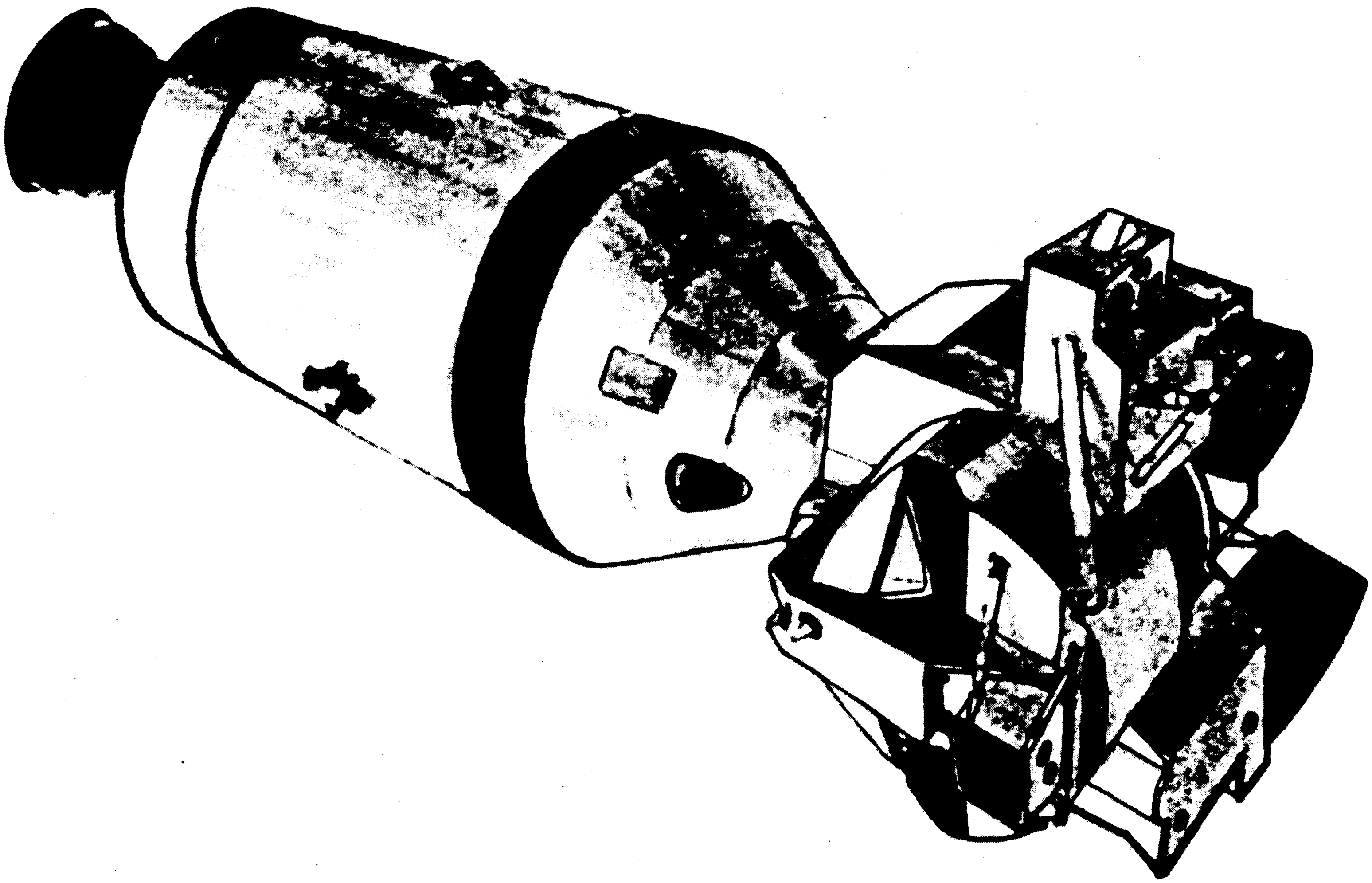


To replace the Space Shuttle, NASA is designing the *Orion* Crew Exploration Vehicle . . .

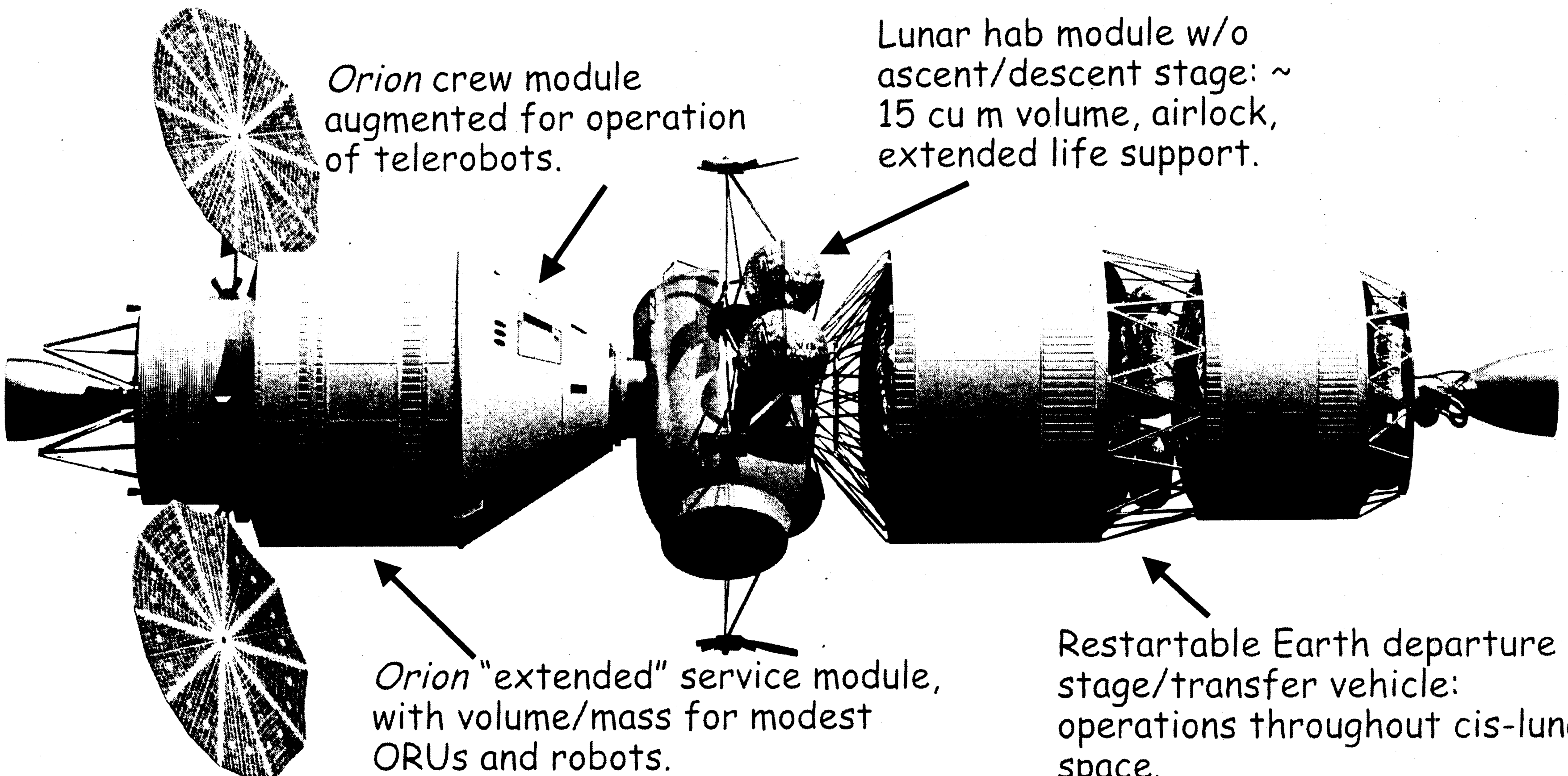


Operational concept for the *Orion* vehicle, docking with the lunar landing module over the US Southwest

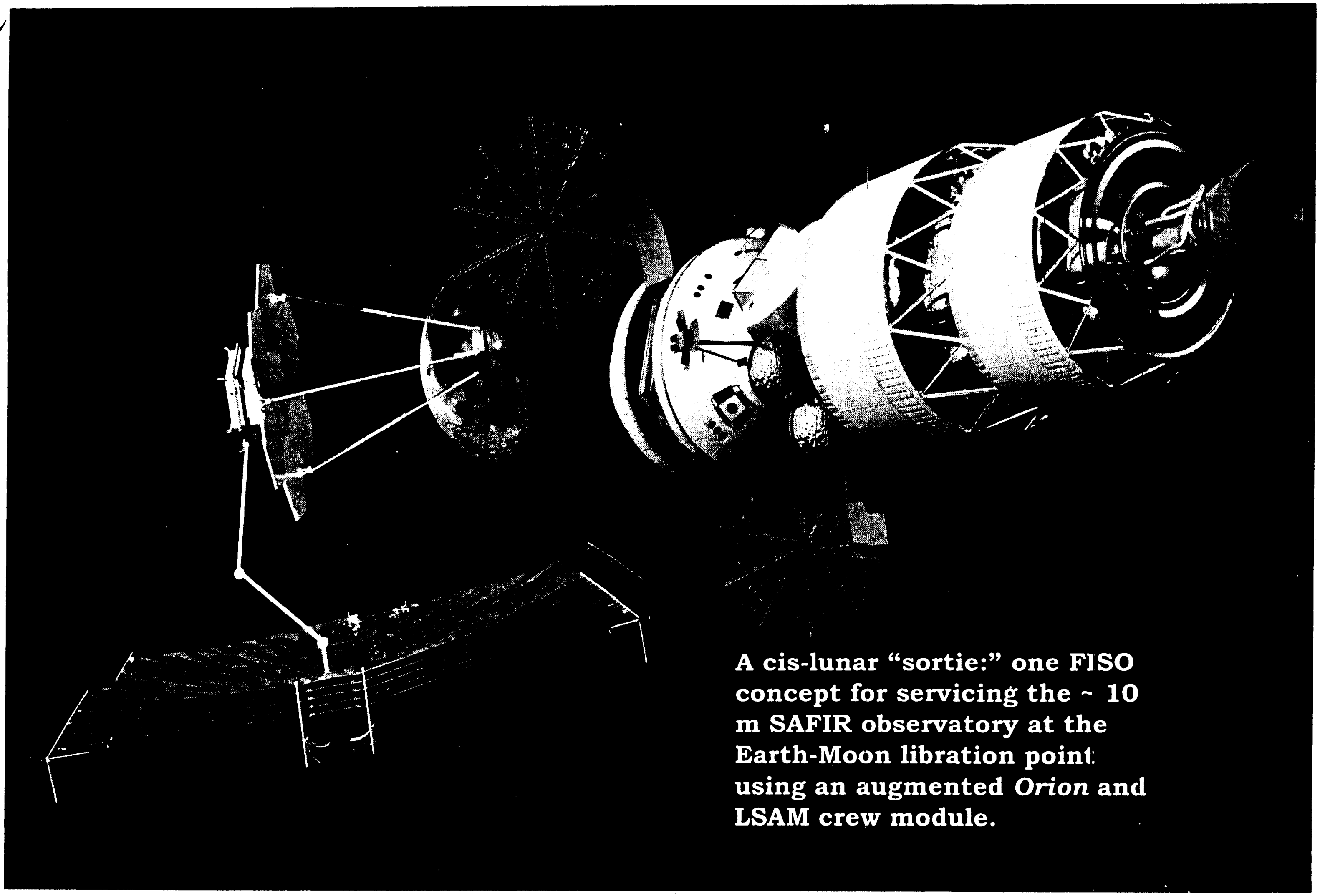
So, again we consider modern versions of concepts developed as part of the Apollo Applications Program



. . 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.


A cis-lunar "sortie:" one FISO concept for servicing the ~ 10 m SAFIR observatory at the Earth-Moon libration point using an augmented *Orion* and LSAM crew module.

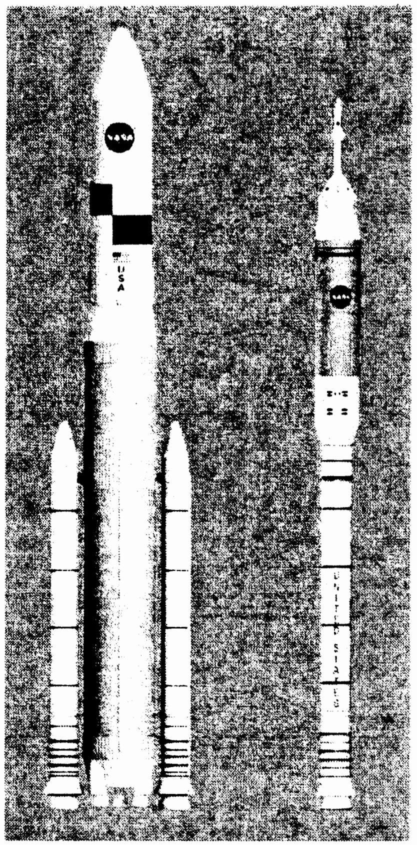
The "grand questions" of astronomy may require large, complex optics that cannot be operated on the Earth's surface.

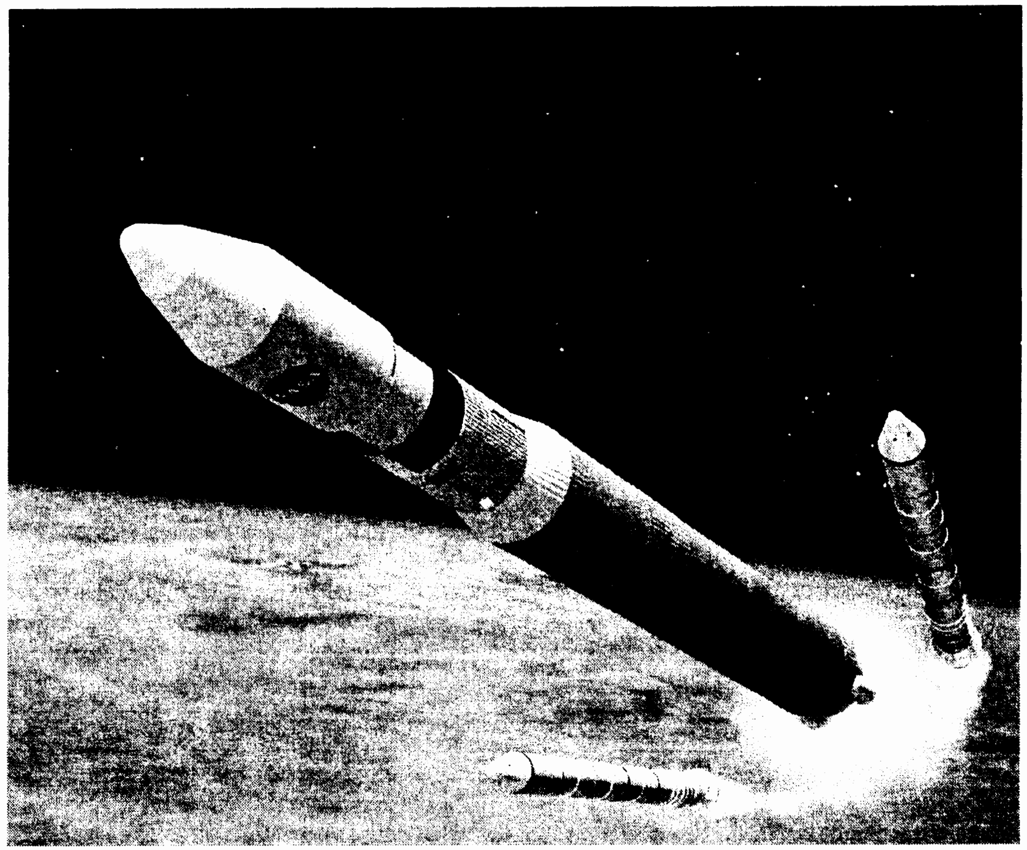
As was the case with Hubble, will astronauts be the key enabling capability to realize these goals? And with robotic partners?

But, wait! There's more!!

Ares V: an Enabling Capability for Future Space Astrophysics Missions

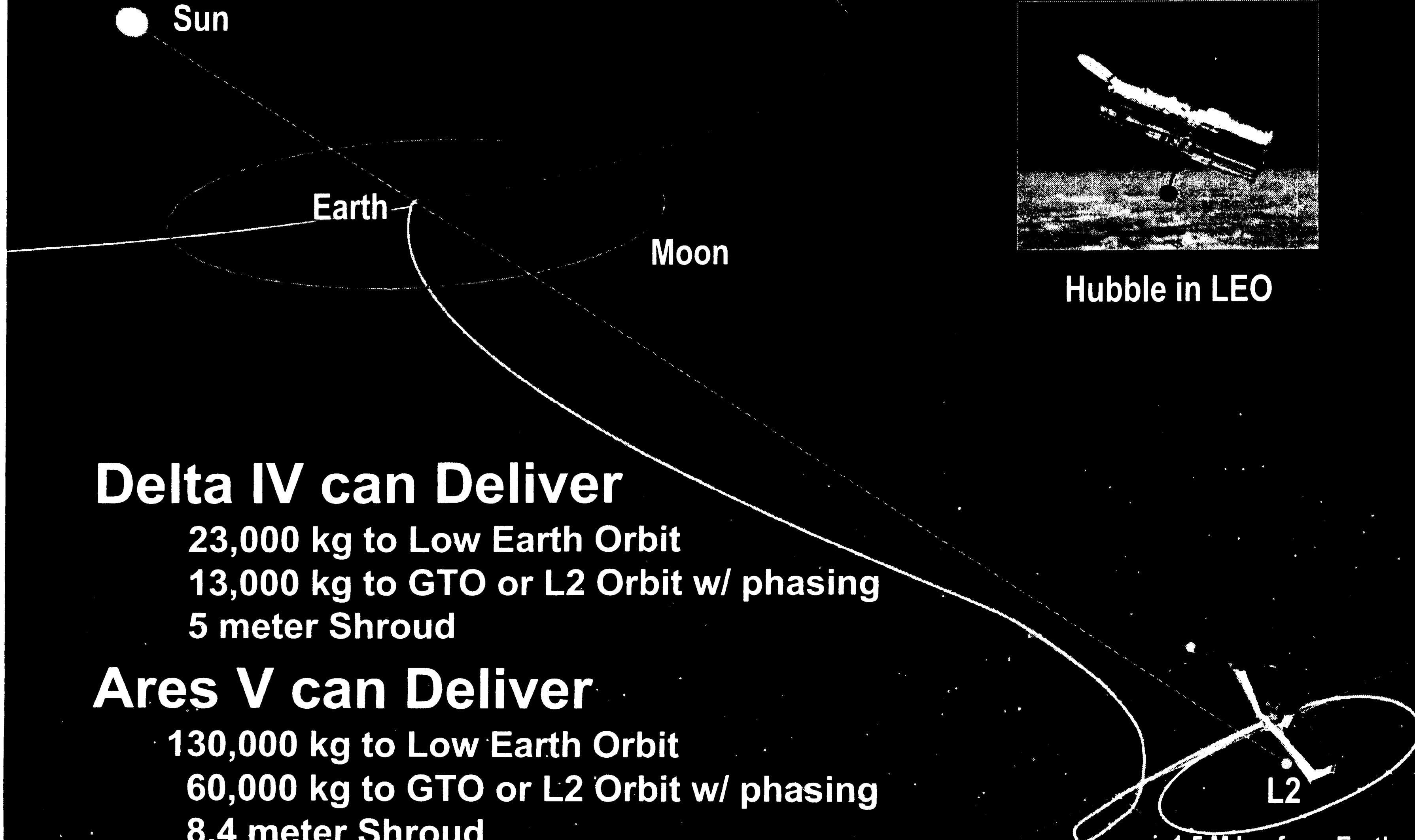
See http://futureinspaceoperations.com





A proposed vehicle 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



Delta IV can Deliver

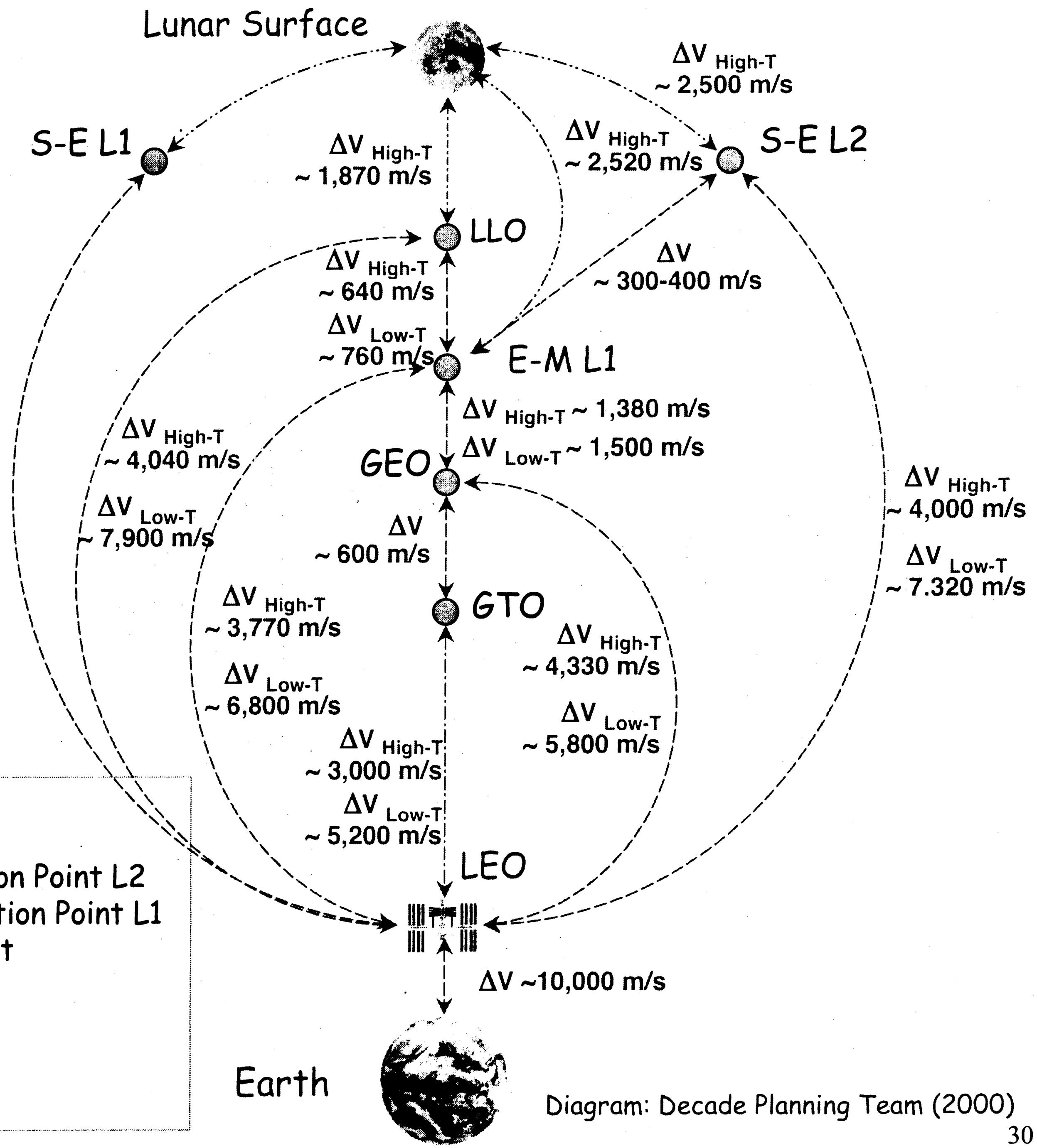
23,000 kg to Low Earth Orbit
13,000 kg to GTO or L2 Orbit w/ phasing
5 meter Shroud

Ares V can Deliver

130,000 kg to Low Earth Orbit
60,000 kg to GTO or L2 Orbit w/ phasing
8.4 meter Shroud
(slightly less with 12 meter Shroud)

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

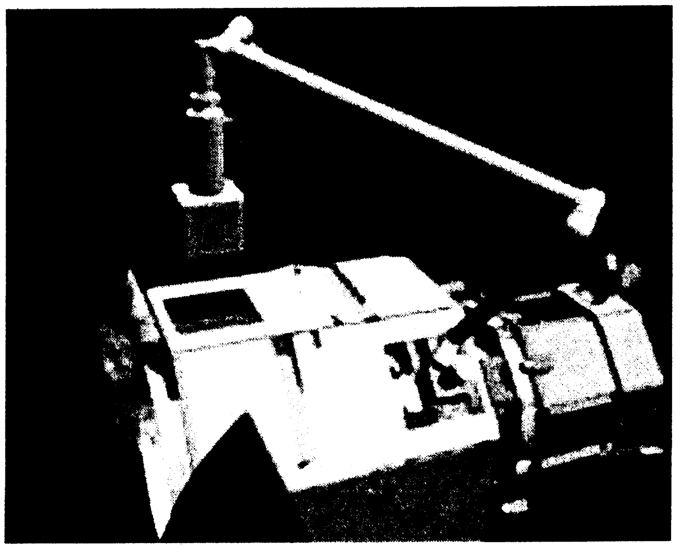
"If God had meant us to explore the cosmos, He would have created the Moon so that we would have libration points."

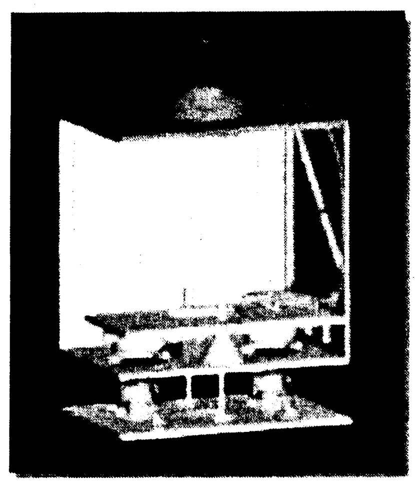


LTO	Lunar Transfer Orbit
LLO	Low Lunar Orbit
SE L2	Sun-Earth Libration Point L2
EM L1	Earth-Moon Libration Point L1
GEO	Geostationary Orbit
GTO	GEO Transfer Orbit
LEO	Low Earth Orbit
Low-T	Low-thrust
High-T	High-thrust

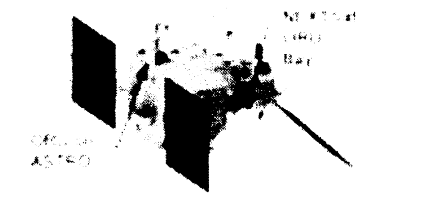
Diagram: Decade Planning Team (2000)

But wait! There's still more!
DARPA's Orbital Express (2007)





ORU



Robotic Arm grasps and extracts ORU

Robotic Arm Transfers ORU

Robotic Arm Inserts 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

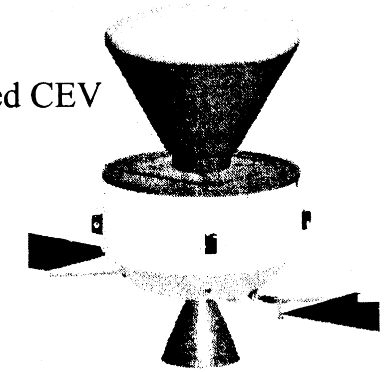
Major Mission Objectives

- On-Orbit demonstration of technologies required to support autonomous on-orbit servicing of satellites
  - Perform autonomous fluid transfer
    - Transfer of propellant in a 0-g environment
  - Perform autonomous ORU transfer
    - Component replacement
      - Battery Transfer
      - Computer Transfer
  - Perform autonomous rendezvous and capture of a client satellite
    - Direct Capture
    - Free-Flyer Capture

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

Proposed Future Assessment and Trade Studies

Tug rescue of stranded CEV



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

In-space support for lunar surface ops:

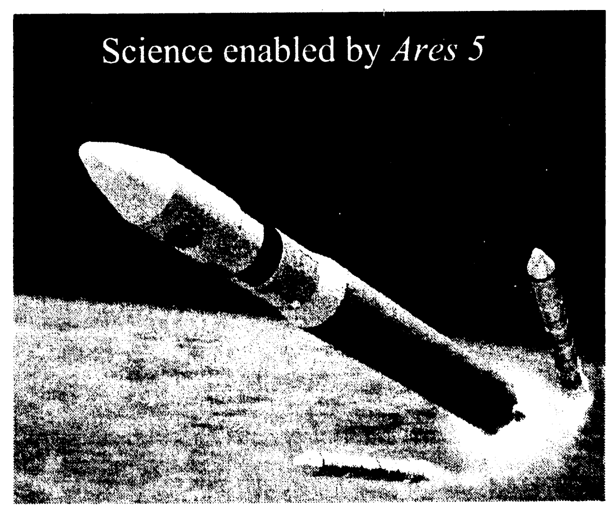
Application of in-space capabilities to lunar surface ops and vice versa

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

***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

Robotic servicing of complex satellite



Concluding . . .

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

- 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 operate in complex and challenging environments.
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Roll the video . . . .