Role of Technology Development for Space Telescopes

Science Experiments in Space Panel Discussion

Workshop on Role of Optics in Space and Space-based Astronomy

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Florida Tech at The Center for Aeronautics and Innovation (CAI)

Melbourne, Florida United States

H. Philip Stahl

PhD from University of Arizona Optical Sciences Center, 1985

36-years of Space Optics Experience:

NASA 1999 to Present

- 1999 to 2006 – Responsible for developing technology to manufacture and test JWST primary mirror segments to TRL-6.
- 2006 to 2011 – Responsible for insight/oversight of manufacture and test of JWST primary mirror segments and secondary mirror.
- 2011 to present – Developing technology to manufacture, test and operate mirrors for future large UVOIR space telescope.
- 2016 to present – Leading team that is designing optical telescope assembly for potential Habitable Exoplanets Observatory mission.

Raytheon Optical Systems Inc. (Danbury CT) 1994 to 1999:

- Responsible for manufacture & test of Spitzer secondary mirror
- Lead team that demonstrated 4-m 7-segment active mirror telescope for SBL

Stahl Optical Systems (consulting 1991 to 1997):

- Designed Ronchi measurement system for STDCE-2 that flew in Oct 1995.
- Member of both STDCE-2 Science & Engineering teams.

Breault Research Organization (1983 to 1990)

- Straylight analysis of multiple space telescope systems.

Question #1

What are the major highlights from past and current space-optics missions in terms of scientific discovery and technology development?

HPS Answer

All space telescopes have been enabled by the same technologies.

Technology development lessons-learned from past and current space-optics missions

<u>All space telescopes have been enabled by the same technologies:</u>

- CTE and CTE homogeneity of mirror substrate materials
  - Hubble – invented ULE and Zerodur
  - Webb – O-30 Beryllium
  - Future – tunable CTE with ultra uniform homogeneity
- Assembly of robust, stiff, lightweight mirror substrates
  - Hubble – high temperature fusion
  - WFIRST – frit bonding or low temperature fusion
  - Webb – CNC machining
  - Future – additive manufacturing
- Optical Metrology
  - Hubble – short exposure vacuum testing
  - Hubble – invented Phase-Measuring Interferometry & DMs
  - Webb – invented PhaseCAM Interferometer & ADM
  - Future – picometer position sensing
- Computer Controlled Optical Polishing – Hubble to Webb
- Launch Vehicle (deferred to Question 3)

Question #2

How can we effectively bring together researchers, engineers, the federal government, and the private sector to overcome the mid-TRL gap that can frustrate the rapid development of technologies relevant to future space-optics missions?

HPS Answer

Technology Development requires:

- Advanced Planning and Time
- Money
- Competition

Technology development lessons-learned from past and current space-optics missions

Technology Development requires advanced planning and time:

- Copernicus
  - Tech Development started in 1959, 13 yrs before launch in 1972.
  - ‘Freeze’ date was 1963 – 9 yrs before launch.
- Hubble
  - Tech Dev started in 1963 – 27 yrs before launch
  - Freeze date was 1978 – 12 yrs before launch
- Webb
  - Tech Dev started in 1996 – 25 yrs before launch
  - Freeze date was 2006 – 15 yrs before launch

Technology Development requires money:

- Need to invest at least 20% of projected initial cost in technology development and maturation.
- Webb invested $50M in technology to make primary mirror assembly. Investment reduced PMA cost by 2X to 3X to final cost of ~$125M.

Technology Development requires competition:

- Competition is the fastest and most cost effective method to achieve technology Development.

Question #3

In the era of commercial launch services, how will new approaches to getting mass into suborbital, orbital and transfer orbits impact future space optics mission capablities?

HPS Answer:

Launch Vehicle Volume Capacity is the most important factor that drives mission risk and cost.

Launch Vehicle Mass Capacity is the second most important factor that drives mission risk and cost.

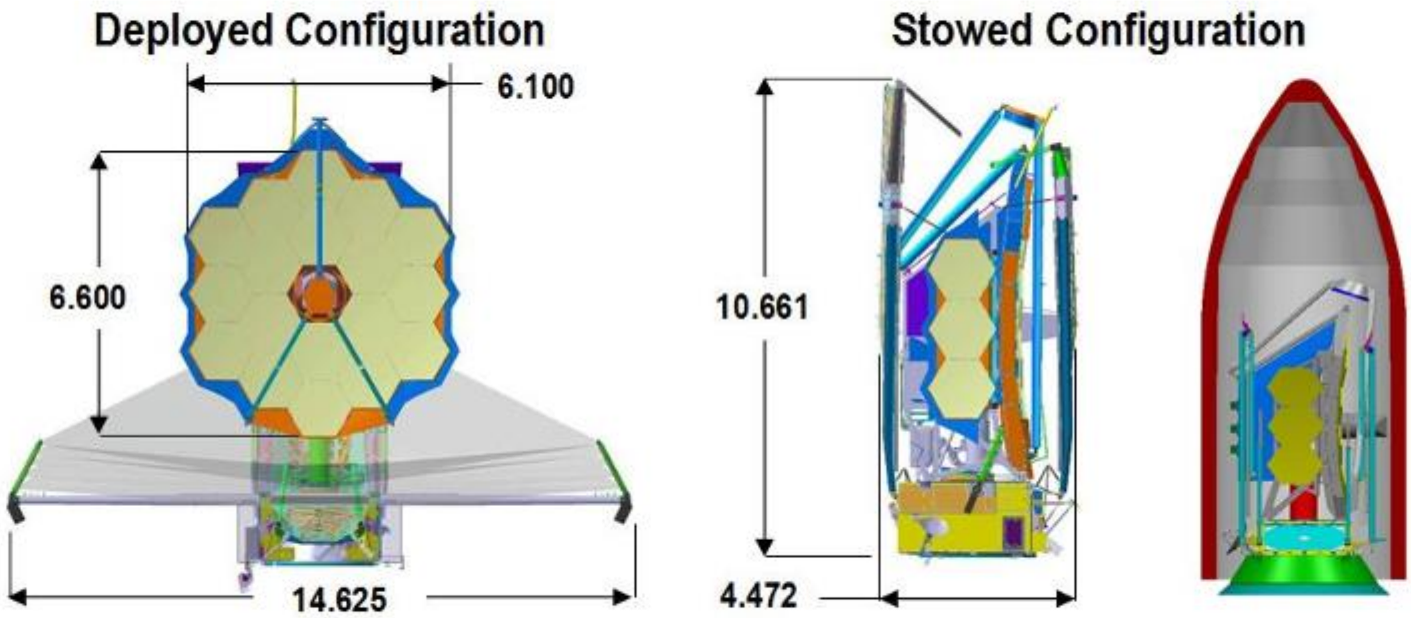
Great Observatories designed for Shuttle

Hubble, Compton and Chandra were specifically designed to match Space Shuttle's payload volume and mass capacities.

	Launch	Payload Mass	Payload Volume
Space Shuttle Capabilities		25,061 kg (max at 185 km) 16,000 kg (max at 590 km)	4.6 m x 18.3 m
Hubble Space Telescope	1990	11,110 kg (at 590 km)	4.3 m x 13.2 m
Compton Gamma Ray Observatory	1991	17,000 kg (at 450 km)	
Chandra X-Ray Telescope (and Inertial Upper Stage)	2000	22,800 kg (at 185 km)	4.3 m x 17.4 m
Spitizer was originally Shuttle IR Telescope Facility (SIRTF)			

Webb designed to fit in Ariane 5

	Payload Mass	Payload Volume
Ariane 5	6600 kg (at SE L2)	4.5 m x 15.5 m
James Webb Space Telescope	6530 kg (at SE L2)	4.47 m x 10.66 m



Future Missions enabled by Future Launch Vehicles

- Most important need for future large space observatories is large volume launch vehicle fairing.
- Up mass is also important.
- SLS Block-2 with 8.4-m fairing has 7.5-m dynamic envelop and can launch 40 mt to SE-L2.
- National Academy identified missions enabled by large LV.

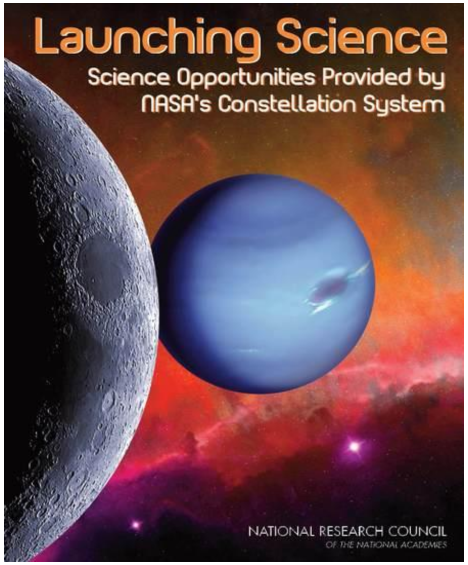


TABLE S.1 Summary of Mission Concepts Evaluated by the Committee

Mission	Cost Estimate[a] (billions of current-year [2008] $)	Technical Maturity[b]	Worthy of Further Study as a Constellation Mission?	Notes
Advanced Compton Telescope (ACT)[c]	~1	Medium	No	This mission does not benefit from the Constellation System. It can fit in an existing Evolved Expendable Launch Vehicle (EELV).
Advanced Technology Large-Aperture Space Telescope (ATLAST)[d]	>5	Low for mirror technology (including mass) Medium for detectors and thermal control	Yes	The 16-meter folded telescope design can only fit in an Ares V payload fairing.
Dark Ages Lunar Interferometer (DALI)[d]	>5	Medium for rovers and interferometrics Low for reducing mass and for deploying and operating in a remote location	Yes	The large antennas must be landed on the lunar farside. This requires both the Ares V launch vehicle and the Altair lunar lander.
8-Meter Monolithic Space Telescope[d]	1-5	High for mirror and structure Low for coronagraphic observation	Yes	The 8-meter-diameter telescope can only fit inside an Ares V payload fairing.
Exploration of Near Earth Objects via the Crew Exploration Vehicle[d]	>5	High for instruments Low for human factors such as radiation	Yes	The Orion vehicle is the only U.S. spacecraft envisioned that will be capable of operating beyond low Earth orbit. The mission also will require substantial payload capability. This mission fits better within the purview of the Exploration Systems Mission Directorate than as a mission of the Science Mission Directorate.
Generation-X (Gen-X)[c]	>5	Low for mirror development and operations	Yes	One Ares V launch of one 16-meter telescope is significantly simpler than the early proposed configurations. The cost estimates are weak. The additional mass capability could significantly reduce mirror development costs.
Interstellar Probe[c]	1-5	High for science, instruments, and mission concept	Yes	Further study is needed of the benefits of Ares V—in particular, of alternative propulsion options.
Kilometer-Baseline Far-Infrared/ Submillimeter Interferometer[c]	>5	Low	No	This mission should be able to fit on an existing EELV; therefore the need for Constellation is questionable, except for human servicing.
Modern Universe Space Telescope (MUST)[c]	>5	High for instruments Low for coronagraph and mirror assembly	Yes	A large, one-piece central mirror rather than a robotically assembled mirror is possible with Ares V.
Neptune Orbiter with Probes[c]	>5	High for mission concept and instruments Low for propulsion and possibly lander	Yes	Ares V could possibly obviate the need for aerocapture and/or nuclear-electric propulsion.
Palmer Quest[c]	>5	Low	No	This mission does not benefit from Constellation. It can fit in an existing EELV.

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Single Aperture Far Infrared (SAFIR) Telescope[c]	>5	Medium for mission concept Low for cooling and detectors	No	This mission does not benefit from Constellation. It can fit in an existing EELV. However, it could benefit from human servicing.
Solar Polar Imager[c]	~1	High for instruments Propulsion not studied in sufficient detail	Yes	Propulsion options enabled by Ares V should be considered.
Solar Probe 2[d]	1-5	High for science, instruments, and mission concept	Yes	Ares I and Ares V launch vehicles could enable spacecraft to be placed in an orbit that could bring it close to the Sun, accomplishing the major science goals.
Stellar Imager[c]	>5	Low for formation flying	Yes	Larger mirrors (2 meters versus 1 meter) and a second hub could be launched on a single Ares V launch.
Super-EUSO (Extreme Universe Space Observatory)[d]	1-5	Low for mirror	No	This mission does not benefit from Constellation. Significant advances in this science can be made using ground-based and alternative approaches.
Titan Explorer[c]	>5	High for instruments Medium for blimp	Yes	Launch on Ares V may enable propulsive capture rather than aerocapture and may shorten transit time.

NOTE: The mission concepts are listed in alphabetical order. All of the missions listed are robotic missions, with the exception of the proposal for Exploration of Near Earth Objects via the Crew Exploration Vehicle.
[a]Cost estimates are based on data estimates provided to the committee, with modifications based on expertise within the committee.
[b]Technical maturity is based on data provided to the committee.
[c]This is 1 of 11 Vision Mission studies initiated by NASA between 2004 and 2006.
[d]This study proposal was submitted in response to the committee's request for information.

Launching Science: Science Opportunities Enabled by NASA's Constellation System, Space Studies Board, National Research Council, 2009 The National Academies Press. https://doi.org/10.17226/12554.

Habitable Exoplanet (HabEx) Imager Mission

HabEx is designed to take advantage of SLS Block 1B capacities:

- 8.4-m fairing volume enables a simple low-risk 4-meter monolithic-aperture off-axis telescope with no deployments.
- Mass capacity of 44-mt to SE-L2 is 3X more than needed for HabEx's projected total mass (with 30% reserve) of 14 mt.