

Report of the HST-JWST Transition Panel

Executive Summary

We were charged “to evaluate the scientific impact of the current NASA plan for ending HST operations and beginning JWST operations,” and we were asked to “provide conclusions that NASA may consider in order to maximize the overall scientific contribution.”

Based upon the material that we have read, the oral presentations that we have heard, and the discussions we have had with scientific and engineering experts, the panel has reached a number of conclusions.

Our conclusions and recommendations primarily concern how to achieve the best science program for the Hubble Space Telescope (the HST), consistent with our understanding of the constraints and the uncertainties. The HST has made enormous contributions to science and human culture and the James Webb Space Telescope (the JWST) has the potential to make a similarly large impact. Our goal is to be helpful to NASA in the complex process in which NASA weighs all of the factors and makes a final plan.

Our principal conclusion is that the options for achieving the HST-JWST transition can be prioritized as follows, with the most preferred option listed first.

1. Two additional Shuttle servicing missions, SM4 in about 2005 and SM5 in about 2010, in order to maximize the scientific productivity of the Hubble Space Telescope. The extended HST science program resulting from SM5 would only occur if the HST science was successful in a peer-reviewed competition with other new space astrophysics proposals.
2. One Shuttle servicing mission, SM4, before the end of 2006, which would include replacement of HST gyros and installing improved instruments. In this scenario, the HST could be de-orbited, after science operations are no longer possible, by a propulsion device installed on the HST during SM4 or by an autonomous robotic system.
3. If no Shuttle servicing missions are available, a robotic mission to install a propulsion module to bring down the HST in a controlled descent when science is no longer possible.

We describe in the following eleven sections the principal facts and reasoning that led to this prioritized list of transition options and also present additional conclusions. We include in appendices the panel’s membership and charter.

1. Input to the panel

The panel has received and studied engineering and science data from NASA sources and from the Space Telescope Science Institute. Among the items received by the panel (prior to the public meeting) were 55 thoughtful, individual emails from members of the scientific community, as well as 40 well-reasoned and fact-filled documents from NASA sources and other informed groups. In addition, the panel heard important oral testimony from a number of experts including the Director of the Astronomy and Physics Division at NASA (Anne Kinney), the Director of the Space Telescope Science Institute (Stephen Beckwith), the James Webb Space Telescope (JWST) Senior Project Scientist (John Mather), the Director of the SIRT Science Center (Tom Soifer), the Hubble Space Telescope (HST) Propulsion Module Study Manager (David Stephenson), Associated Universities, Inc. President and former Director of the Space Telescope Science Institute (Riccardo Giacconi), and NASA Associate Administrator for Space Science (Edward Weiler). The panel also benefited from volunteered oral presentations containing significant relevant information and stimulating insights. Those contributing in this way included: C. Beichman, R. Fienberg, H. Ford, J. Green, J. Grunsfeld, J. Huchra, B. McCandless, J. Morse, G. Rieke, and R. Thompson. Nearly all of the oral presentations were accompanied by carefully reasoned documents made available for study by the panel well before our public meeting. The panel reviewed about 200 email messages from the general public submitted through the panel's website.

Rarely has a scientific panel's activities attracted so many valuable contributions from such a wide range of interested scientists and non-scientists. We thank all those who have given so generously of their time to educate us.

We are grateful to distinguished colleagues who agreed to serve as anonymous referees on extremely short notice. Their comments significantly improved the clarity and focus of this report.

The panel is especially grateful to the NASA Office of Space Science Division Director of Astronomy and Physics, Dr. Anne Kinney, for sharing her deep knowledge and understanding of the facts and constraints related to the transition from the HST Observatory to the JWST Observatory. We are also deeply grateful to Dr. Eric Smith, the JWST Program Scientist and the HST Program Scientist for innumerable important services to the panel in organizing and facilitating our work.

We believe that we speak for the entire astronomical community when we express our admiration for the effective and articulate manner in which the Associate Administrator for the Office of Space Science (OSS), Edward Weiler, has enabled and implemented the scientific priorities of the scientific community as articulated in the Astronomy and Astrophysics Decade Survey Reports. Dr. Weiler has provided valuable insights to this panel.

2. The scientific importance of the HST and the JWST

The HST has been NASA's flagship for more than a decade. It has spectacularly extended our knowledge of the cosmos -- from nearby planets to the most distant galaxies. From the HST's vantage point above the absorption and blurring of Earth's atmosphere, this unique

'space observatory' has attained unprecedented sensitivity and yielded brilliantly sharp images.

Because it can be serviced by the Shuttle, the HST's suite of instruments can be regularly updated to take advantage of fast moving technology. It has thereby maintained an unflagging rate of cutting-edge scientific discovery over an extended lifetime.

By any standards the HST has been a spectacular success—one of the most remarkable facilities in the entire history of science. The HST has enabled thousands of astronomers in the U.S. (and also in Europe through partnership with ESA) to study an immense variety of cosmic phenomena. Moreover its marvelous images have captivated the imagination of a broad public, especially offering scientific inspiration to young people.

As often happens in science, each advance raises new questions that are tantalizingly beyond present capabilities. A fundamental new challenge is to probe still deeper into space and further back in time --to the era when the very first groups of stars, the 'ancestors' of galaxies like ours, started to form. This is the prime mission of the JWST, a major new telescope which goes beyond the capabilities of the HST, as well as being in some respects complementary to it. The 6-meter mirror of JWST will have 5.8 times as much collecting area as the HST's. Moreover, it will be optimized for the infrared, the waveband in which light from highly-redshifted distant objects reach us. The JWST's suite of instruments will offer unprecedented sensitivity from 0.6 microns to almost 30 microns. (It will not, however, have the HST's capability in the shorter wavelength visual or ultraviolet part of the spectrum.). Placed in a location permanently in Earth's shadow, the JWST will be about 1.5 million kilometers away. JWST is a collaboration with Canada and ESA. Several European nations contribute additionally to one instrument.

The JWST will have optimal properties for studying the cooler and more distant object within our Galaxy, and for probing regions shrouded by dust. Its unprecedented sensitivity and infrared imaging will be directed at asteroids, protostars, and planets as well as objects at the furthest reaches of the cosmos.

We conclude that the HST is—and that JWST will be—a great observatory whose achievements will be written large in the history of science and whose impact will enrich human culture.

3. The life cycle of the HST

Servicing missions have continually rejuvenated Hubble since its launch in 1990. After the first servicing mission in 1993 corrected a flaw in the optics, subsequent missions have maintained the health of the spacecraft and provided ever more powerful instruments to study the cosmos.

Like any device, HST's capabilities gradually diminish with age. Fortunately, there is no evidence for degradation of the optics to date. The instruments on the HST have design lifetimes of 5 years, but experience has shown that this is generally a conservative lower limit to their lifetimes. Most of the spacecraft systems, with the exception of the gyroscopes, have also demonstrated long lifetimes. Four of the six gyroscopes are currently operating.

Except for the gyroscopes, only the thermal insulation and one of the Fine Guidance Sensors are presently degraded. SM4 is scheduled to repair the thermal insulation and replace the faulty Fine Guidance Sensor. Informed engineering estimates show that the HST must be revitalized by the Shuttle every 3 to 5 years in order to maintain its scientific capabilities.

The two primary factors that limit the lifetime of the HST are the gyroscopes and orbital decay. The HST carries a complement of 6 gyroscopes, and at present 3 are needed for successful operation of the telescope (although operation with 2 gyroscopes is anticipated). These gyroscopes are among the most sensitive ever built, but in the past they have lost their accuracy within a few years. The net result is that recent engineering estimates show that the HST has only a 50% chance of being able to carry out scientific observations more than 5 years after the 6 gyroscopes have been replaced.

Even at an altitude of more than 300 miles, Hubble feels the drag of the atmosphere. Without a reboost by the shuttle, its orbit will decay and it could return to Earth as early as 2013. A re-boost during SM4 could extend the in-orbit lifetime of the mission by a number of years; were it to be reboosted around 2010, then its orbital lifetime could be extended to 2020 or beyond.

We conclude that the HST, while in principle capable of a very long lifetime, requires for its continued scientific viability servicing missions by the Space Shuttle. HST servicing missions, like all shuttle missions, are expensive and risky.

4. Revised End of Mission Scenarios

The Columbia tragedy has raised new questions about astronaut safety, and the original plan to return the HST to Earth is no longer considered an option by NASA. Instead, plans are being developed to deorbit the HST in a controlled fashion to ensure that it lands safely in the ocean.

We note that recent events have initiated a revision of end of mission scenarios, and we conclude that implications for continued HST science operations should be examined. This report is an initial step in the re-examination.

5. Uncertainties

Formulating a strategy for the HST-JWST transition is difficult because of uncertainties regarding the availability of the Space Shuttle, the JWST launch schedule, the need for developing a mode for de-orbiting the HST with at present unknown characteristics and time of availability, and because one cannot be sure when vital components of the HST will fail.

We conclude that it is prudent for NASA to be prepared for a range of possibilities from the most pessimistic (no future Shuttle servicing missions) to the most optimistic (two future servicing missions). We therefore describe our further conclusions in a series of options that depend upon the availability of the Shuttle and the development of a practical and approved de-orbiting strategy.

We urge NASA to maintain flexibility in the development of plans for the transition from the HST to the JWST since the facts and the context in which decisions are made may change in the future.

6. No SM4?

The congress or the executive branch could decide for policy reasons that there will be no further service missions to the HST, ruling out the possibility of implementing the plans for SM4. If there is not an SM4 servicing mission, the HST science program will be aborted prematurely with a major loss of science opportunity. Moreover, citizens worldwide would be deprived of an important source of inspiration and of cultural enrichment. Outside support for NASA could be weakened.

In this worst case scenario, the HST project should be prepared to maximize the scientific return from the observatory in the absence of new servicing missions. This might require changes in the operational or scientific strategies.

Moreover, a decision to discontinue servicing would make available two outstanding science instruments that have already been built and tested, COS and WFPC-3, as well as significant undesignated funding in the years 2004-2009. NASA could consider a dedicated new mission featuring a fast-track 2-meter class telescope with COS and/or WFPC-3 in the focal plane, instruments that are built and could be adapted at minimum cost to a stand-alone mission. Such a mission could conceivably be launched into geosynchronous orbit by 2010, in time to overlap significantly with JWST.

We conclude that the STScI and NASA should develop backup plans to cover the worst-case scenario that there are no further servicing missions to the HST.

7. Only SM4

The panel is impressed with the careful scientific and engineering preparations for the repair mission SM4. We urge continuing efforts to maximize the productive scientific lifetime of the HST under the assumption that SM4 will be the last HST servicing mission. In this connection, we applaud the efforts to make possible scientific operations with only two gyroscopes and to extend operation with a reboost. Since SM4 is likely to be delayed significantly, we believe that a study should be commenced as soon as possible to investigate the likely increase in operational lifetime from installing a complete set of six gyroscopes that are produced with the best technology presently available. Current estimates suggest that the expected duration of science operations is limited by the robustness of the gyro design. Because of the need to consider possible robotic de-orbiting of the HST, a careful study should be initiated to consider the possibility of attaching a device to the telescope during SM4 that would make robotic de-orbiting easier.

We conclude that an inter-disciplinary group should be formed from experts at the GSFC, the STScI, and the MSFC, augmented as appropriate by contractors, astronauts, European representatives, other outside experts, etc., to explore all plausible approaches to lengthening the scientific lifetime of the HST within realistic

mission and budgetary constraints. If possible, SM4 should occur in 2005 and no later than 2006. Timely servicing and installation of the new instruments are essential to take full scientific advantage of SM4.

8. The JWST Launch date

Many astronomers have written to the panel emphasizing the importance of an overlap in the operation of the HST and the JWST. We agree that this would be desirable since there will likely be a number of objects studied by the JWST for which it would be important to obtain optical and uv images with the HST. If there is a gap between the cessation of HST observations and the beginning of the JWST, it should be kept to a minimum. Even though financial support may be available during this time, a substantial gap in which no orbiting space telescope is available could erode scientific teams and decrease interest in the design of equipment that is essential for progress in the field.

In the original NASA transition plan, a three year overlap in HST and JWST operations was scheduled. In the present OSS plan, a gap of one year is scheduled, with a planned cessation of HST operations in 2010 and the launch of JWST in 2011.

The panel was impressed by the progress that has been made by the JWST team and was encouraged by the fact that there are no recognized problems that would prevent meeting the 2011 launch deadline.

A significant milestone in a space science mission is the Announcement of Opportunity (AO) for proposals for instruments, which signifies that the scientific goals and the optical design of the telescope are well enough established that more detailed design of instruments should be undertaken. The AO to launch intervals for the four Great Observatories are: the Compton Gamma Ray Observatory (14 years), the Hubble Space Telescope (13 years) , the Chandra X-Ray Observatory(16 years) , and the Space Infrared Telescope Facility (19 years).

The JWST AO for instruments was released in November 2001. If JWST takes as long from AO to launch as the average Great Observatory, then the JWST launch date would be in 2017. We are impressed by the care and detail which has led to the more optimistic schedule determined by the JWST project and recognize that JWST may succeed in meeting schedule milestones better than previous observatories of comparable complexity.

We conclude that the JWST launch date might be delayed substantially beyond 2011. Appropriate planning should take into account the possibility that the JWST launch could be later than indicated by the current schedule.

9. Servicing and End of Mission

In the absence of a re-boost, the HST orbit will decay and the vehicle will re-enter and breakup in an uncontrolled manner as early as 2013 to 2020, depending on solar activity. A re-boost would postpone the reentry date by a few years. In any event, NASA policy is that the HST will not be allowed to reenter in an uncontrolled manner. Therefore, plans for the

HST science program must include an intervention that allows an acceptable end to the mission.

The continued vitality of the HST science program requires Shuttle service missions. Full exploitation of the HST would require two service missions during the period before the end of mission, SM4 in about 2005 (or not later than 2006) and SM5 in about 2010.

The SM4 mission is presently being considered for 2005 and is necessary for normal servicing of the HST, but especially for replacement of the gyros and for installing improved instruments. At the conclusion of SM4, Hubble's complement of scientific instruments will consist of two spectrographs and three cameras (as well as a Fine Guidance Sensor useful for astrometry). This will produce a vigorous science program prior to a possible final servicing mission.

10. Options for Ending the Mission

There are two options under consideration for enabling the end of mission. (The return to earth via the shuttle, the original plan, is no longer under consideration.) These two options are:

- Installation of a propulsion module on the HST during a Shuttle mission;
- Robotic installation of a propulsion module.

In both methods, the propulsion module installation can either be followed by continuing science operations or be the final mission to terminate the HST. The conceptual plans for implementing either method are preliminary. We believe strongly that attaching the propulsion module to the HST should not result in the premature termination of the science operations. This strategy requires either a propulsion device that can be attached to HST without degrading essential HST operational capabilities or the installation of a propulsion device after science operations are terminated. Preliminary discussions suggest to us that a technical solution is achievable in which a propulsion device is installed on HST without disrupting science operations provided appropriate tradeoffs are made between some science and engineering requirements.

The Shuttle could be used to attach the de-orbiting device and at the same time provide an additional servicing mission, SM5. This combined propulsion and service mission could greatly extend HST useful science lifetime. The committee prefers a Shuttle mission for this purpose because the same mission will also improve the performance of the HST before it is brought down to Earth.

In order to solve the technical issues that would allow the continued science operations the trade-offs of requirements and what is achievable technically must be reconciled. There is no demonstrated evidence that the robotic solution would be less expensive and the opposite might be the case. Either the robotic or shuttle option could enable termination,

but only the shuttle method would also provide the benefit of full scientific exploitation of the HST.

In a related point, we note the very significant cost of maintaining a full servicing staff at GSFC to support the potential for future servicing missions of the HST. To minimize this cost, we think innovative ways should be sought to try to involve some of this staff in the support of other missions, such as the JWST. We understand that it may be difficult to reassign contract personnel at GSFC who are expert at tasks related to servicing missions to other tasks, but we think that this issue merits thorough study.

We conclude that it would be desirable to form a joint team of experts in propulsion engineering, spacecraft operations, and science operations in order to develop the best solution for servicing and ending the mission of HST, while taking into account safe termination, servicing requirements, and the possible trade-off of requirements to continue the science program. This team would presumably include scientists from the STScI, HST servicing and engineering experts from GSFC, and propulsion experts at MSFC, and might include astronauts or other relevant experts.

11. Is an additional servicing mission for the HST scientifically worthwhile?

The panel has received much insightful advice on this question. Two conclusions are clear. First, extraordinary science could be enabled by an additional servicing mission, SM5, with the Shuttle. Two, the resources that would be used for the support of a science-enabling SM5 could instead support other extraordinary space science projects.

Although there are qualitative descriptions of attractive science programs that could be done with an extended HST mission, there is no definitive proposal which the panel could evaluate.

The panel has great confidence in the Office of Space Science peer review system and great admiration for what this system has produced in the past.

We therefore conclude that the best way to determine the value of a future science-enabling SM5 is for NASA to issue as soon as possible a fast-track AO permitting scientists to propose a science program, which could include new instrumentation, to be performed with the HST dedicated to performing the observations described in the proposal. In the AO, prompt release of the data to the community should be encouraged, as well as robust and simple science operations, and the relevant experts at STScI and GSFC should assist in drawing up the AO.

If more than one competing SM5 proposal is submitted, NASA should have a peer reviewed competition to select the best HST proposal or proposals within total budgetary, programmatic and operational constraints. The successful proposal, which may include a new instrument, should then be peer evaluated in competition with other comparably sized new scientific proposals such as those within the Explorer or Discovery programs. In this way, no already approved science project would be adversely affected. It is our intention that this process should maintain the relative priorities of the Decade Surveys.

We understand that it will be difficult to release an AO and select an instrument in time for a service mission in about 2010. However, the Office of Space Science is highly respected for its ability to create original solutions for new problems. We note the possibility of a pre-AO public meeting, or a written information release, that might allow prospective proposers to begin work in the near future. We also note that there may be science proposals that do not include any new instruments, but instead rely on the post-SM4 instruments. In any event, only proposals that meet the time constraints should be considered for the peer review competition.

A fast-track AO will permit a science program that, for example, could provide spectacular images in the ultraviolet, optical, and infrared, coupled with information-laden spectroscopic measurements.

If the combined propulsion and service program is successful in the peer review competition, and if the NASA Administrator approves an additional Shuttle flight for this purpose, then we believe that the Administrator should find a way to fund the required Shuttle-related costs out of the entire NASA budget (not just out of the OSS budget). This special treatment of the Shuttle costs seems appropriate to us because of the enormous outreach benefits of HST science.

Appendix A: Panel Membership.

John N. Bahcall, Institute for Advanced Study (Chair)

Barry C. Barish, Linde Professor of Physics, California Institute of Technology

Jacqueline N. Hewitt, Professor of Physics and Director, Center for Space Research, MIT

Christopher F. McKee, Chair, Physics Department, UC Berkeley

Martin Rees, Royal Society Research Professor, U. Cambridge

Charles Townes, Professor in the Graduate School, UC Berkeley

Appendix B: Charter

The Office of Space Science (OSS) charters the *HST-JWST Transition Plan Review Panel* to evaluate the scientific impact of the current NASA plan for ending HST operations and beginning JWST operations. The panel should solicit input from the scientific community and other experts. In the course of its general review, the panel should present answers to the following questions:

- Does the current plan provide for the best scientific use of unique HST abilities in the context of the overall NASA program?

- Is there sufficient flexibility in the plan to respond to, for example, unforeseeable failures of HST instruments, for limitations on shuttle servicing missions, and for possible delays in the JWST program?

The panel should produce a brief report summarizing their findings with respect to the charge and providing conclusions that NASA may consider in order to maximize the overall scientific contribution. NASA will provide the following items as initial input to the panel for their consideration:

OSS Plan for HST – JWST transition
The HST Post-SM4 Science Review Panel Report
HST Propulsion Module Study Report (Interim)
Origins Roadmap 2003

During their discussions the panel may seek additional technical details or clarifications through the OSS and the HST Program Office. On July 31, 2003 the panel will hold an open meeting (Washington, DC [additional details]) at which interested parties can provide input related to the HST-JWST transition plan. The panel will additionally consider comments from the community received via a web site (<http://HST-JWST-transition.hq.nasa.gov/>).

Panel Composition: The Panel shall consist of 6 members, inclusive of the panel chair

Panel Products: The panel should produce a brief report for the Office of Space Science summarizing their findings with respect to the charge and providing conclusions that NASA may consider in order to maximize the overall scientific contribution