JWST Science Assessment Team report

M. Stiavelli
SAT History

- The James Webb Space Telescope Project has incurred in very substational cost growth.
- In the attempt to reduce cost NASA HQ asked the JWST Project and Science Working Group to consider a JWST floor mission (4m, 1-5 µm imaging and slit spectroscopy only mission)
  - The JWST Project determined that the cost savings would be modest
  - The JWST SWG declared that such a mission was not worthwhile
- Given that the minimum science requirements of the floor mission were now seen as unacceptable, NASA HQ convened an independent Science Assessment Team. The SAT charter was:
  
  The purpose of this team is to prioritize the science goals and observatory capabilities listed in the JWST Science Requirements Document (SRD) in order to determine a new and enduring set of minimum science requirements. These new requirements will be the foundation for alternate mission development plans to be pursued by the JWST Project, its international partners and the Science Working Group before decisions are made about the future of the JWST Program. The resulting JWST mission must be unique in its capabilities in order to avoid costly duplication with existing astronomical facilities.
SAT Composition and Input

SAT Membership
Dr. C. Matt Mountain, Dr. H. Peter Stockman, co-chairs, Dr. Roberto Abraham, Dr. Alan Dressler, Dr. Kathryn Flanagan, Dr. Robert Gehrz, Dr. Malcolm Longair, Dr. Christopher McKee, Dr. Sara Seager

Process, materials provided and meetings
• Briefings by NASA HQ (Eric Smith, Anne Kinney), Project Manager, Project Scientist and Project technical staff, discussion with SWG, and briefings on groundbased capabilities
• Background Reports

Notes pertinent to recommendations of the SAT
• Several “non-science” factors significantly contributed to projected cost growth: the delay in launcher decision, growing I&T costs, NASA’s inability to fund project to previous plan, and inadequate technical margin in several key areas given the level of project contingencies
• FAD analysis demonstrated that, at stage of the project, significant science de-scopes cannot solve cost problem
  – Reducing telescope area by more than a factor of two, and removing at least two significant instruments, (enabling less than half of the original science goals) be yielded only ~$200M in savings,
• SAT only focused on science capabilities that are: (a) redundant; (b) no longer considered uniquely competitive in 2015-2020; (c) significantly driving mission risk and had the potential for future cost escalation.
This mission and its designed science requirements map directly onto national strategic objectives as outlined in the National Academy of Science Decadal Survey, “Astronomy and Astrophysics in the New Millennium” and NASA’s Strategic Roadmaps “Universe Exploration” and “The Search for Earth-like Planets”

- Decadal Survey, ranked JWST its top priority among all major initiatives, describing it as a “compelling successor to the Hubble Space Telescope”. The NAS stated that JWST’s enormous discovery potential would directly tackle two of the five key questions:
  - Study the dawn of the modern universe, when the first stars and galaxies formed
  - Study the formation of stars and their planetary systems form, and the birth and evolution of giant and terrestrial planets
- NASA’s recent Strategic Roadmaps reaffirmed JWST importance being essential to:
  - Universe Exploration
  - The Search for Habitable Planets.
  - It also will contribute significantly to NASA’s Solar System Exploration Roadmap.

- In the context of modern astrophysics, the four JWST science themes identified by our community are even more relevant today; they recur in every major review of the field since their original formulation in 1999.
  - First light and reionization
  - The assembly of galaxies
  - The birth of stars and protoplanetary systems
  - Planetary systems and the origins of life
- The same JWST themes still challenge and excite us and the public, in our enduring journey to comprehend the Universe and our place in it
Uniqueness and the expansion of “Discovery Space”

- Whenever there is an increase by an order of magnitude or more in observational capability, new discoveries are made:
  - The HST discovery of the silhouettes of proto-planetary disks in Orion
  - The HDF images from Hubble directly revealing the evolution of galaxies
  - The direct detection of an exo-solar planetary atmosphere by HST and Spitzer
  - The discovery (by Hubble) that within galaxies massive black holes are common.
- Comparing the stated goals of the Hubble Space Telescope in 1977 with what it actually achieved, the Hubble Space Telescope has far exceeded the most optimistic expectations of the community.
- With its unique aperture, orbit and current instrument complement, JWST offers one to four magnitudes increase in observational capabilities.
- JWST greatly expands our observational reach, or “Discovery Space” over what will be available in the next two decades.

- The SAT believes science case for JWST remains overwhelming, but many of the most important results of the mission may well come from unexpected discoveries.

Comparative performance of JWST with a 30m GSMT and Spitzer

One manifestation of the new “Discovery Space” JWST will enter over the next decade is shown above. Though still under consideration, making reasonable assumptions for the future development of Adaptive Optics, it is possible to compare the performance of a tentative ground-based 30m, scheduled for 2015-2020 with JWST, as well as with Spitzer. The plot shows the relative time gain of JWST compared to a GSMT and Spitzer. The vertical axis is in relative units, where 1.0 means an observation with both JWST and GSMT (and Spitzer) will take the same time to reach the same S/N on a point source; a larger number means JWST is faster.

What is clear is that for the foreseeable future JWST will have an overwhelming advantage for imaging \( \lambda > 1 \)um, and for spectroscopy for \( \lambda > 3 \)um (R=5).
Short wavelength Performance

- In light of the preceding discussions, taking into account the core JWST science case, the possible encroachment from ground-based facilities, and the enormous potential for discovery with JWST, the SAT unanimously gives its highest priority to imaging and spectroscopy over the wavelength range 1.7-28 µm. These capabilities are highlighted in Table 1.

Table 1: JWST Science Capabilities

<table>
<thead>
<tr>
<th>Instrument Capability</th>
<th>Uniqueness</th>
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<tbody>
<tr>
<td>Imaging 0.7-1.7 microns</td>
<td>20-30m MCAO will be comparable</td>
</tr>
<tr>
<td>Imaging 1.7 - 5.0 microns</td>
<td>JWST Unique</td>
</tr>
<tr>
<td>Imaging 5-28 microns</td>
<td>JWST Unique</td>
</tr>
<tr>
<td>Coronagraphy 0.7 - 2.3 microns</td>
<td>Extreme AO on 8-10m superior</td>
</tr>
<tr>
<td>Coronagraphy 2.4 - 5 microns</td>
<td>JWST Unique</td>
</tr>
<tr>
<td>Coronagraphy 5 - 28 microns</td>
<td>JWST in principle unique</td>
</tr>
<tr>
<td>Tunable filter 1.0 - 2.0 microns</td>
<td>8-10m AO &amp; narrow band filters comparable</td>
</tr>
<tr>
<td>Tunable filter 2.4 - 5 microns</td>
<td>JWST in principle unique</td>
</tr>
<tr>
<td>Slit Spectroscopy 0.7-1.7 microns</td>
<td>20-30m MCAO superior</td>
</tr>
<tr>
<td>Slit Spectroscopy 1.6 - 5 microns</td>
<td>JWST Unique</td>
</tr>
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<td>MOS spectroscopy 0.7- 1.7 microns</td>
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<tr>
<td>IFU spectroscopy 1.0- 1.7 microns</td>
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The SAT believes this re-prioritization of JWST’s current capabilities represent a significant de-scoping of the current JWST mission. In some cases the lower priority modes can simply be left untested as long as this does not drive mission cost. However we recognize that to significantly reduce risk and the potential for future cost growth, some modes may have to be eliminated: the SAT would support this.
Summary of Recommendations 1 of 2

1. In light of the preceding discussions, taking into account the core JWST science case, the possible encroachment from ground-based facilities, and the enormous potential for discovery with JWST, the SAT unanimously gives its highest priority to imaging and spectroscopy over the wavelength range 1.7-28 µm. These capabilities are highlighted in Table 1.

2. The SAT fully supports the planning for a greatly simplified “cup-up” test of JWST, which appeared to us to be a far superior, much less costly route to validation than the “cup-down” test (whose chief advantage is lower contamination of the optics). The SAT encourages the SWG to work closely with the Project to identify other areas where a pragmatic approach to I&T could yield other substantial saving without significantly risking the science performance of JWST.

3. The SAT recommends elimination of the 1µm encircled energy requirement and its corresponding stability requirement at both levels while maintaining the 2 µm Strehl requirement of 0.8 as recommended by the Project. It recommends that the stability requirement be replaced with a stability on the Strehl ratio or encircled energy at 2 µm appropriate to obtain 2% photometric stability at 2 µm between mirror adjustments.

4. The SAT recommends that the scattered light requirements be relaxed to the CL720/CL630 level recommended by the Project. Since the contamination plan is still being developed, the SAT recommends that the Project explore post I&T cleaning as a method to maintain the performance of the observatory while utilizing achievable clean-room and launch standards.
Summary of Recommendations 2 of 2

5. The SAT concurs with the Project recommendation that the stability requirement be relaxed to mirror adjustments every 7-10 days. The committee finds that the negative effect on observatory efficiency (estimate loss ~1%) acceptable. Efficiency effects of this order would be acceptable to eliminate heroic design or testing activities.

6. The SAT recommends that as long as the current telescope configuration is maintained, the anisotropy requirements on image quality should be significantly relaxed to ensure they do not drive missions costs. The SAT suggests the SWG examine the need for retaining any anisotropy requirement.

7. The SAT believes that a five-year reduction in the science mission to address mass concerns would significantly compromise the scientific legacy of JWST, and should be considered only as a last resort.

The SAT would as an alternative recommend that the Project build up sufficient mass margin (contingency) within the mission, even if in the final analysis of mass, this means the removal of science capabilities rated as not “high priority” in Table 1, to ensure the requirement to remove 20kg of propellant should never arise.

The SAT also notes that many if not all of the relaxations of requirements, and simplifications recommended in this report have been on the Project’s “radar screen” in some cases for several years. We urge that in future the Project, Contractors and SWG find a more effective way to tackle such outstanding issues in a more efficient and timely manner. A far tighter, two-way coupling between the guardians of the science requirements (the SWG) and the implementers of this complex mission, (the Project and Contractor Team) is urgently required.
What next

- Preliminary report delivered to NASA HQ on July 8\textsuperscript{th}. Final report will be identical in content.
- JWST SWG essentially concurs with the SAT recommendations.
- NASA HQ needs to find the money.
Integration and Test

Recommendation 2

The SAT fully supports the planning for a greatly simplified “cup-up” test of JWST, which appeared to us to be a far superior, much less costly route to validation than the “cup-down” test (whose chief advantage is lower contamination of the optics). The SAT encourages the SWG to work closely with the Project to identify other areas where a pragmatic approach to I&T could yield other substantial saving without significantly risking the science performance of JWST.

This change would be enabled by a significant relaxation of allowable contamination levels.

The SAT commends the Project on its innovative approach to I&T and believes the costs saving of this approach to be significant and includes a slide from the presentation to the SAT (27th June) by the JWST Optics Manager, L. Feinberg as an example of the possible current and future savings.
Encircled Energy at 1 \(\mu m\)

- The encircled energy requirement of 74% at 1 \(\mu m\) in a 0.15 arcsec radius and stellar source affects the point source sensitivity and capability to derive accurate photometric and morphological information for faint galaxies (\(m_{ab} > 28\)) at wavelengths < 1 \(\mu m\).

- The engineering ramifications of the requirement fall on the accuracy of the manufacturing and test of the primary mirror segments and the yet-to-be-determined mid-scale stability of the backplane. Because this requirement is so difficult to meet, even larger scale accuracies and tests are affected.
  - It was noted by the Project that as a consequence of this requirement several error budget allocations for mid-frequency wavefront errors fall in the 2-5nm range, which will be difficult to impossible to verify.

- It is also clear the NIRCam pixels under sample the 1um point spread function (see figure), as does NIRSpec slits. Consequently the point sources sensitivity at these wavelengths is not a sensitive function of the 1um encircled energy requirement.

Recommendation 3

The SAT recommends elimination of the 1\(\mu m\) encircled energy requirement and its corresponding stability requirement at both levels while maintaining the 2 \(\mu m\) Strehl requirement of 0.8 as recommended by the Project. It recommends that the stability requirement be replaced with a stability on the Strehl ratio or encircled energy at 2 \(\mu m\) appropriate to obtain 2% photometric stability at 2 \(\mu m\) between mirror adjustments.

Cost & Risk Savings

According to Project presentations, the potential cost savings are high: ~$10M in near-term costs, plus the potential for recovering schedule margin in the mirror fabrication (1 month on this critical path costs~$25M) and potential savings of $150M+ per cryo-figuring cycle that is no longer necessary.
Scattered Light Requirements

- The scattered light requirements are intended to limit the background contributed by scattering of zodiacal, galactic, and sunshade emission to significantly less than the natural backgrounds.

- Higher fidelity models of the JWST open-telescope structure show that these requirements, particularly in the NIR, require a cleanliness that exceeds that of the Hubble (<0.5% dust coverage on the primary mirror). Such levels require great care and world-class clean-room operations (550).

- Moreover, the Project has been unable to determine what level of contamination control can be provided with the Ariane 5, particularly during launch.

- The Project recommends relaxing the contamination specification to a 2% coverage on the primary mirror, and 1% on the secondary mirror (CL720/CL630) to permit “cup-up” testing during I&T and facilitate negotiations with Ariane concerning launch cleanliness.

**Recommendation 4**

*The SAT recommends that the scattered light requirements be relaxed to the CL720/CL630 level recommended by the Project. Since the contamination plan is still being developed, the SAT recommends that the Project explore post I&T cleaning as a method to maintain the performance of the observatory while utilizing achievable clean-room and launch standards.*

From presentation to SWG, Oct. 2004

Analysis of the potential loss of sensitivity for JWST instruments as a function of increased scattered light over the original baseline is shown above. Changing the specification corresponds moving from the orange circles to red circles along each instrument capability line (multi-colored lines – see key). As can be seen the greatest loss come for imaging at short IR wavelengths.

Given the huge gains of JWST over existing and foreseeable facilities the SAT considers this an acceptable loss in sensitivity given the potential for significant simplifications in the Integration and Test (I&T) phase through the adoption of the “cup-up” test configuration.
Encircled Energy Stability & Observatory Efficiency

- As JWST is designed as a large, passively stable telescope. However its mirror figure, and delivered image quality, has to be maintained throughout the life of the mission by wavefront sensor measurements of bright stars, and subsequent mirror position updates, and hence is also an “active telescope” (abet with a very low update rate).
- The current mission requirement, expressed as an encircled energy stability requirement (2% between mirror adjustments) is that this stability be preserved for a minimum of 30 days between wavefront sensor updates.
- According to the Project this 30 day requirement has become a significant stressing requirement on the telescope stability performance.
  - For example recent modeling has shown the mid-spatial frequency errors across the telescope back-plane must be maintained to \(\sim 4\text{nm} \), and low frequency errors to \(\sim 16\text{nm} \) between updates.
  - A more frequent WFSC update rate would “help enormously” on the structural stability challenges and though the Project has a fairly aggressive risk management mitigation plan aimed at subscale demonstrations, the expectation is that the stability issue will be a major challenge throughout the program including verification.
- The update rate also has an effect of mission efficiency. However in practice, the operations of the observatory will be modified to achieve an optimum balance of productivity and optical quality. The SWG should recommend the best parameter to measure.

**Recommendation 5**

The SAT concurs with the Project recommendation that the stability requirement be relaxed to mirror adjustments every 7-10 days. The committee finds that the negative effect on observatory efficiency (estimate loss \(\sim 1\%)\) acceptable. Efficiency effects of this order would be acceptable to eliminate heroic design or testing activities.
Anisotropy Requirements

- The 2μm anisotropy requirement (absolute and stability) on the PSF are intended to provide a stable shape of the PSF for photometric reductions and analysis of high-redshift galaxy morphologies.
- Recent analyses of the JWST architecture suggest that the absolute requirement is generally met (e.g. the 18 segment mirror and obscuring struts are sufficiently symmetric) but that the stability requirement may be very difficult to achieve.
- As the Project and STScI become more knowledgeable of the optical performance of the observatory, they will be capable of designing observing and planning strategies for maintaining optical performance (e.g. minimizing coma).

Recommendation 6

The SAT recommends that as long as the current telescope configuration is maintained, the anisotropy requirements on image quality should be significantly relaxed to ensure they do not drive missions costs. The SAT suggests the SWG examine the need for retaining any anisotropy requirement.

We note that Hubble breathing produces changes in image quality of approximately 2%. However careful analysis and calibration allows the full reconstruction of the lensing mass field in these strong lensing cases, however as with HST, weak lensing is unlikely to be possible.

The SAT believes this is an acceptable de-scope to the JWST Science Case