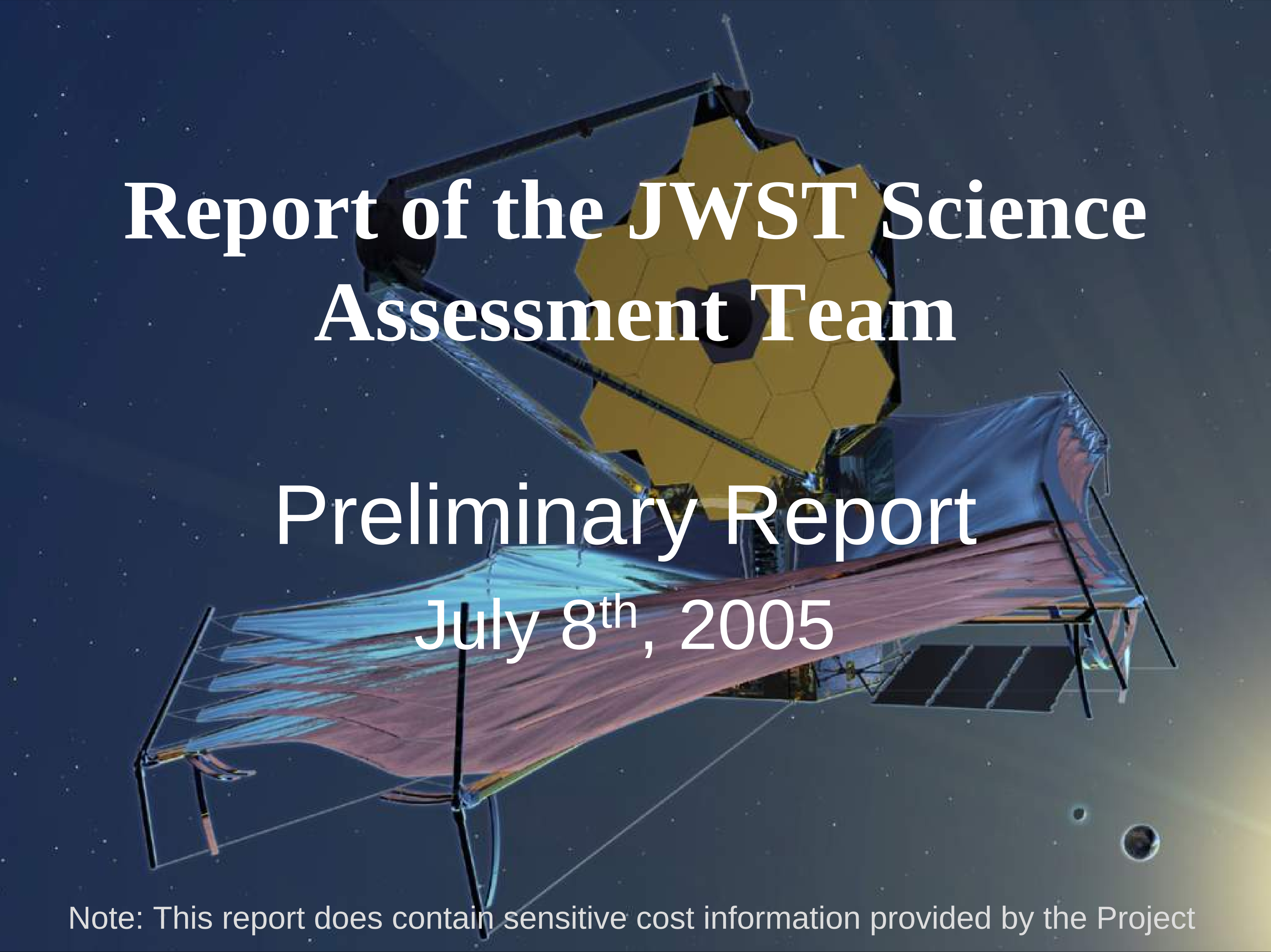


Report of the JWST Science Assessment Team

Preliminary Report

July 8th, 2005

Note: This report does contain sensitive cost information provided by the Project

Contents

Overview 1 of 2

- Astronomy, Astrophysics and Cosmology have undergone a remarkable revolution over the last decade thanks to the enlightened investment in astronomical facilities.
- Central to almost every field of astronomical endeavor has been the outstanding success of the Hubble Space Telescope and now Spitzer is also bringing us into a new realm of extraordinary discovery.
- The **James Webb Space Telescope** is more than worthy successor to these missions and will have a unique role in advancing astrophysical and cosmological understanding.
- The studies carried out by the telescope will span the whole range of profound questions confronting modern astrophysics, from the formation of the first stars to the origin of biological systems in nearby planets.

Overview 2 of 2

- The international scientific community is unanimous in regarding the James Webb Space Telescope as the highest priority facility for the US and the international community to advance astrophysical understanding.

- The European Space Agency and the Canadian Space Agency have joined the project. Both partners are fully committed to the provision of instruments for the telescope, in response to the needs to their national communities.

- We have re-examined the capabilities of the James Webb Space Telescope and have proposed some significant simplifications. Despite these, and substantial advances in current and future ground based capabilities, we conclude since the formulation of the program in 1999, the case for the telescope and its unique capabilities has grown in strength and astronomical significance.
  - This report emphasizes that unique importance of the James Webb Space Telescope for science and society.

- It is very important for the advancement of scientific culture within society that this sense of tremendous discovery that will be enabled by the James Web Space Telescope be communicated very effectively to the wider public through the enlightened investment in public outreach by NASA.

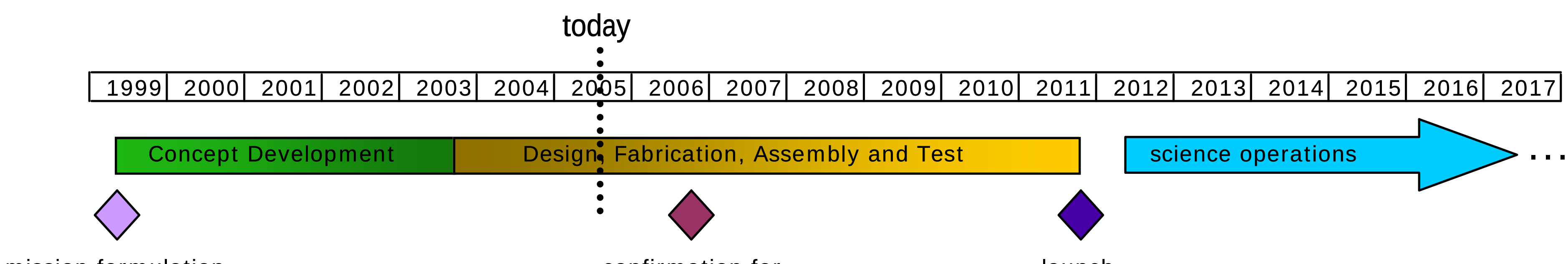
Introduction 1 of 2

History (nominal Project schedule below)

- 2002 Project under goes significant re-plan, reducing aperture from 8m to 6m
  - NASA HQ accepts new cost envelope
- 2003 Mirror selection completed, manufacturing begins.
- 2005 Instruments completing PDR, 20 mirror blanks delivered, figuring and polishing beginning
- NASA HQ projects significant cost growth ~1 billion dollars
  - Analysis of re-scoping to minimum JWST configuration defined in Formalization Authorization Document (FAD), 4m telescope covering 1-5 um, yields insufficient savings, and considered uncompetitive and ***"poorly optimized to maximize the overall capabilities when viewed in the context of other new astronomy facilities"*** by Science Working Group
  - NASA HQ charters Science Assessment Team (SAT)

SAT Charter

- *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.*



Introduction 2 of 2

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 ground based capabilities
- Background Reports
  - NAS Decadal Survey, NASA Strategic Roadmaps, JWST Science Requirement Document, Viability of Formulation Authorization Document (FAD) minimum version of James Webb Space Telescope (by JWST SWG), Assessment of JWST Telescope Cost and Complexity Drivers (by Lee Feinberg, JWST Telescope Manager, NASA), Added JWST Science Cases for the Timeframe 2012-2015 (by Calzetti et al, STScI).
- Meetings:
  - Telecon's 1,7,14,21 June, Face-to-face meeting, Carnegie DTM, 27-28 June, 2005
  - Draft Report finalized by telecon, 6 July, discussed with SWG, 8 July

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 report represents the unanimous recommendations of the SAT

JWST place in the scientific endeavor

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**

Key Science Drivers (example) 1 of 2

First Light and the End of the Cosmic Dark Age - I

“First Light” represents a major transition in our Universes history.

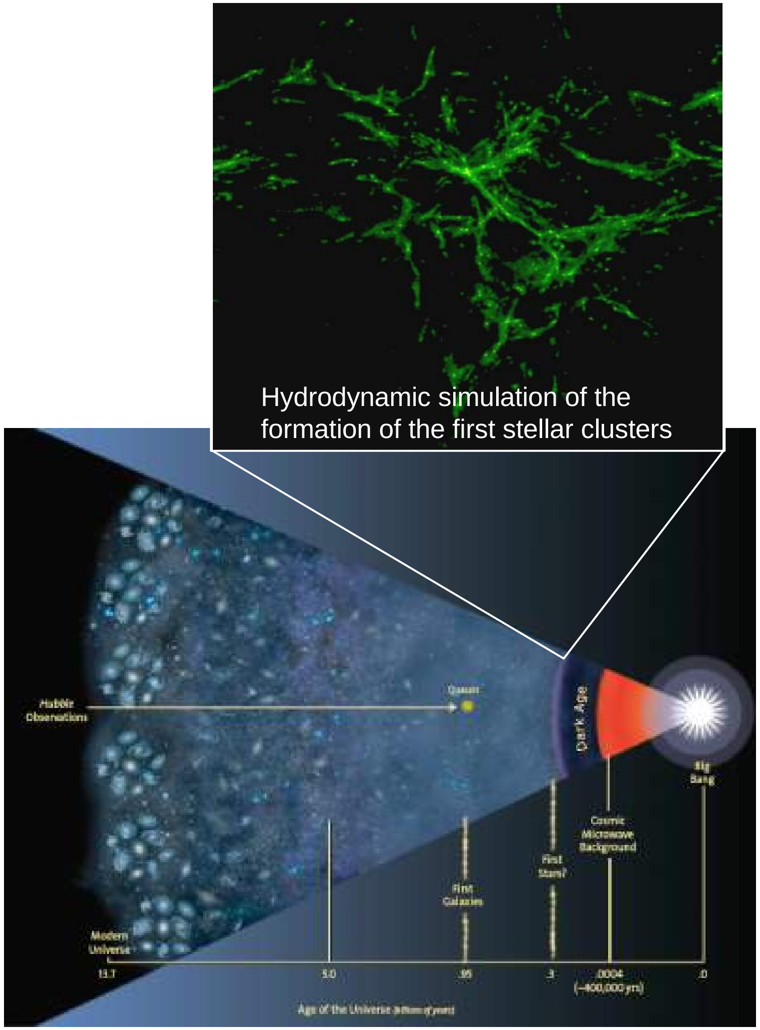
The Cosmic Dark Age was ended by the appearance of First Light, the appearance of the first luminous self-gravitating objects in the Universe.

UV photons from these first objects triggered the rise in the current complexity of our Universe

- Cold, neutral gas fragments on scales much too small to form galaxies, whereas ionized gas naturally fragments into galaxies.

The appearance of these first galaxies set in place the the cycle of stellar birth-death-rebirth that forms the chemical elements in the periodic table.

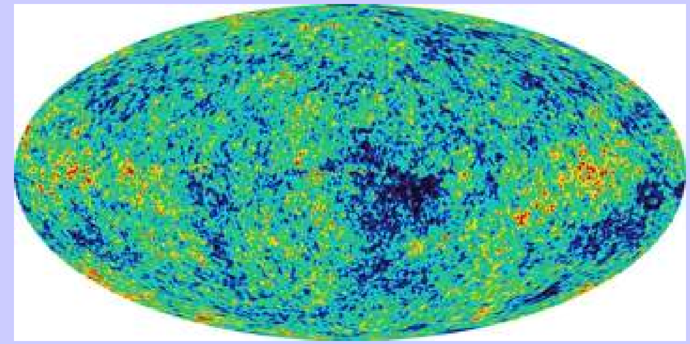
JWST is the only facility planned for the next two decades with the resolution and sensitivity in the thermal infrared needed to address the nature of First Light directly.



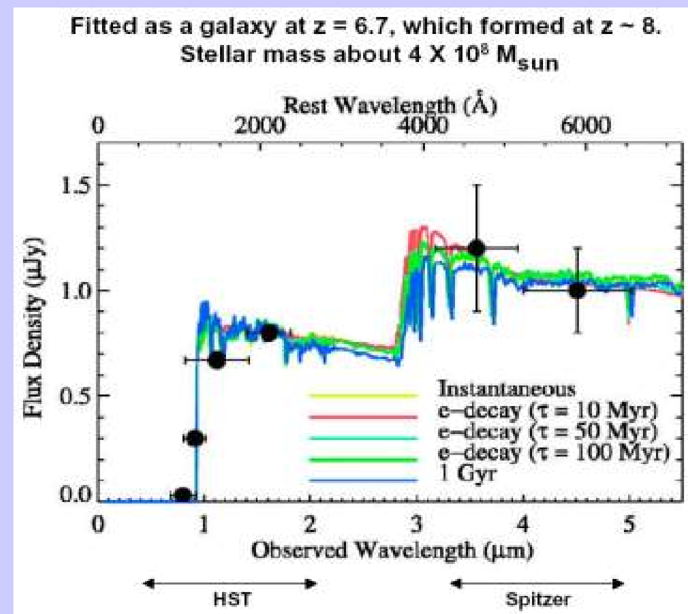
First Light and the End of the Cosmic Dark Age - II

Recent Progress since the Dressler Report "*HST and Beyond*", Goals for the Twenty First Century: Visiting a Time When Galaxies Were Young", 1996

- Quasars at z~6 are indicative that the end of reionization has been found, and "First Light" must be z> 6
- Probing this region has started with Hubble. The Hubble Ultra Deep Field and other Hubble data uncovered an abundant galaxy population z~6.
- Surveys and recent data from *Spitzer* revealed tantalizing evidence of young star forming galaxies at z~6,
  - which means they must have formed z~8.
- Wilkinson-Microwave Anisotropy Probe (WMAP) indicate the Cosmic Dark Age may have ended slowly, with "First Light" beginning z~20
- Sources of First Light within 6 < z < 20 most likely to be associated with the appearance of the first stars: 'Population III', which properties possibly quite unlike those of nearby Populations I and II.



Wilkinson-Microwave Anisotropy Probe (WMAP) indicate the Cosmic Dark Age may have ended slowly, with "First Light" beginning z~20



Deep Hubble and Spitzer observations now probe galaxies at z~6: JWST will be required to probe z > 10

First Light and the End of the Cosmic Dark Age - III

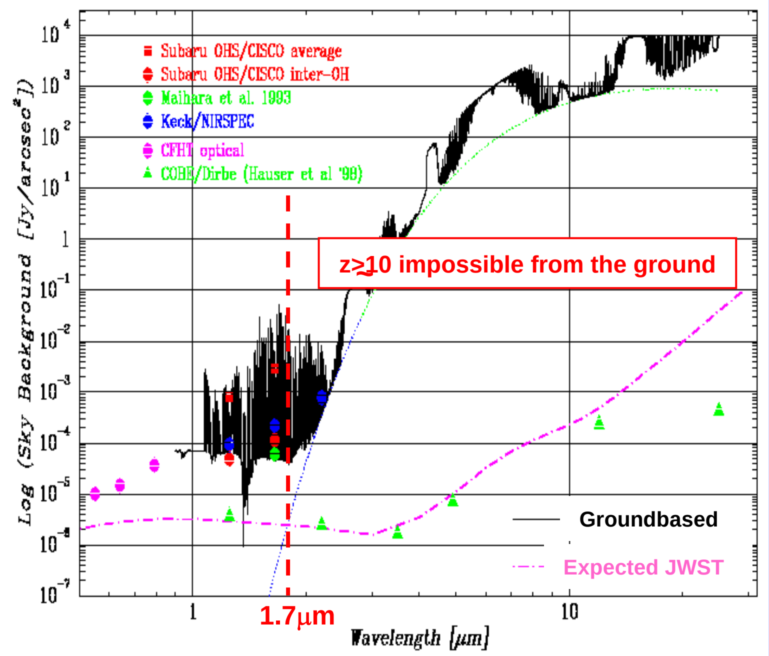
Future Progress

- Because of the inherent physics of the atmosphere studying candidate *First Light* objects beyond z>6 from the ground will be progressively more difficult, and impossible beyond z > 10.

- With its unique combination of low back ground, aperture and angular resolution JWST *will* be able to detect clusters of Population III stars, lighting up massive clouds of Hydrogen: the first emission-line nebulae.

- Given the central importance of discovering First Light, coupled with the little that is known about these systems (and given that little more *can be known* about galaxies at z>10 in advance of JWST), the optimum strategy for JWST is to ensure broad capability red ward of 1.7 µm so that detecting First Light should be possible with at least one of the spacecraft's instruments.

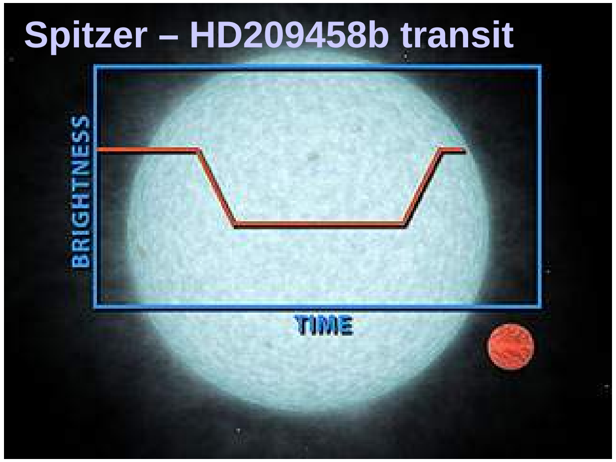
Background: Space vs. Ground



Beyond z ~ 10, the light from First Light sources enters into the thermal infrared, where the night sky glow is no longer dominated by line emission from molecules (whose glow can be masked out), but dominated by continuum emission from the heat in the atmosphere and telescope. *This considerable thermal background poses an insuperable natural barrier which prevents progress in First Light work from ever being taken with optical/near-IR telescopes at z ≳ 10 from the ground*. For example, at 2µm, the apparent sky background of a cooled space telescope like JWST is approaching 1000× darker than excellent ground based telescopes, even at the highest sites. The only path to progress beyond z ≳ 10 with optical/IR telescopes is to place them in space.

Key Science Drivers (example) 2 of 2

Extrasolar Planets and their Environment - I



The discovery of more than 150 planets in orbit around nearby stars has galvanized the field of extra solar planetary science

To date at least eight of these are transiting systems, allowing the direct observation, and characterization

- Spitzer has recently detected the first, direct infrared emission from two extrasolar planetary atmospheres; half a dozen more planets will be observed this GO cycle
- JWST will have the sensitivity to detect transit light curves from Earth-sized planets and atmospheres of giant planets

Following the legacy of the IRAS mission, the Hubble Space Telescope, ground-based telescopes and now Spitzer have revealed a huge diversity debris disks, nascent planetary systems around, many of the nearby young stars.

- This is allowing us to begin to model the early physical process of solar system formation, particularly the era of heavy bombardment, that some 4.5 billions years ago led to the creation of rocky terrestrial size planets such as our own.

JWST, being the only facility planned for the next two decades with its resolution and broad infrared sensitivity, is positioned to uniquely contribute to the great question;

"Throughout the universe, how common are the life generating processes took place almost 4 billions years ago in our solar system?"

Extrasolar Planets and their Environment - II

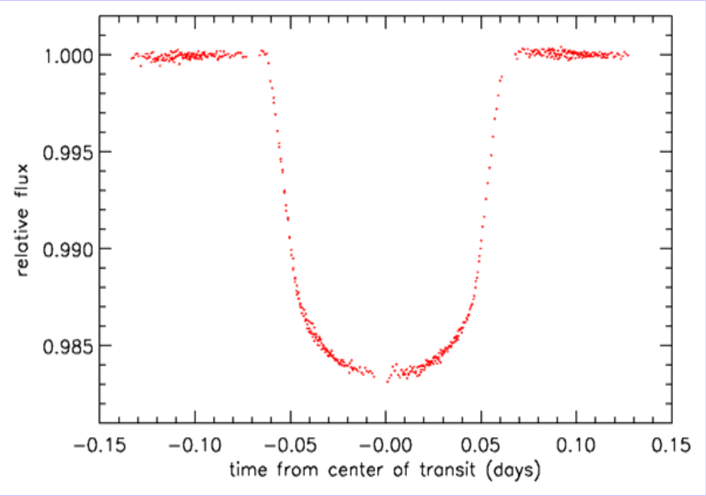
JWST will be the only telescope available to measure density and atmospheric properties of a large number of solar-system-aged extrasolar planets in the next decade.

JWST is uniquely poised to exploit the new discoveries of transiting planets

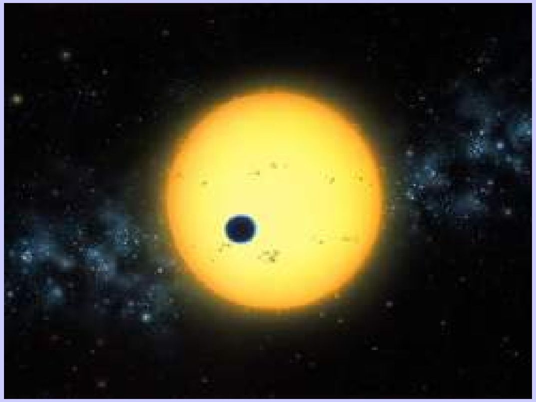
- Only possible with the large aperture and stable space environment, together with the excellent calibration due to the precisely predictable on/off nature of both the primary and secondary eclipses
- Dozens to hundreds of transiting planets will be known from ground-based surveys and Kepler

- JWST will be able to study terrestrial planets
  - The unique capability to confirm the Earth-sized planets detected by Kepler via extremely precise photometry not obtainable from the ground
  - Precise radii (and hence density) of super-Earth-mass planets will help to understand their bulk composition and evolution
  - Potential to detect oxygen in super-Earth-mass planets orbiting small stars
- JWST will characterize giant planets:
  - Light curves for precise radii (and hence density), search for moons and rings
  - Transit transmission spectra for composition (including giant planets at all semi-major axes)
  - Thermal emission spectra for composition is possible for hot planets
  - Reflected light during secondary eclipse for albedos of short-period planets

JWST will therefore be our opportunity to open the window wide to the nature of the fantastically diverse extrasolar planets not found in our own solar system



Brown et al. 2001. HST/STIS photometry of HD209458b with precision of 10^{-4}. By a similar technique JWST will measure transit curves of Earth-sized planets.



Lynette Cook artist's conception shows the planet transit including the small atmosphere. JWST can detect giant planet atmospheres.

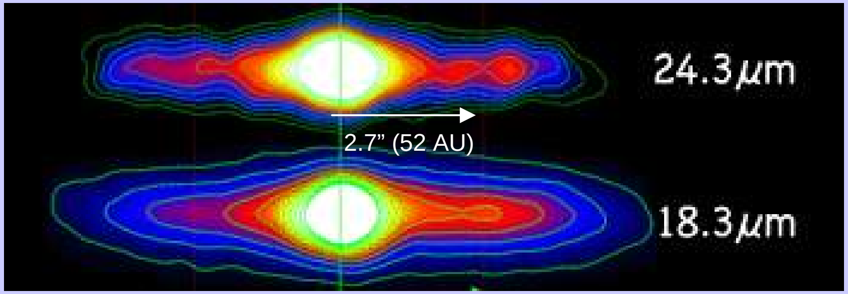
Extrasolar Planets and their Environment - III

JWST will make outstanding contributions to the study of circumstellar and debris disks because of three key advantages over HST and ground-based telescopes: outstanding sensitivity in the near-to mid-infrared and capability for high dynamic range IR imaging

- In nearest sites of ongoing low-mass star formation in the Taurus and Ophiuchus a diffraction limited 6m telescope provides a resolution at 2 microns of 10 AU.
  - to distinguish between the processes that formed the majority of the solar system planets from those at work in the Kuiper Belt and Beyond
- Spectroscopy, or narrow filter imaging with a coronagraph, will allow identification *and location* of biogenically of useful molecules such as water ice, and molecular gas in various parts of the disk.

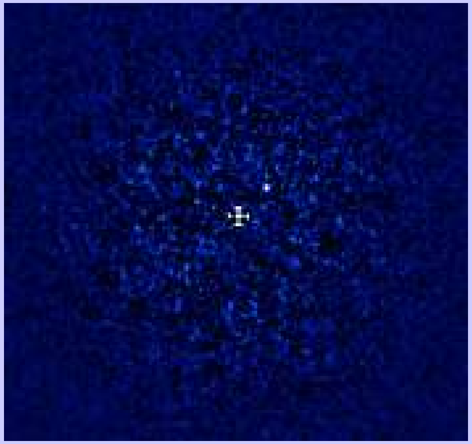
JWST directly complements TPF

- Only JWST can access the many key biogenic markers from 1 – 5 microns
- JWST will have the field of view to study the outer reaches of circumstellar and debris disks
- JWST will have the angular resolution to identify the footprints of planets in debris disks
- With a launch date of ~2019 for TPF-I, JWST offers the only IR mission capable of studying extra solar planetary systems this decade



Groundbased 8m thermal infrared imaging of one of few debris disks observable today (around Beta Pictoris) demonstrates the spatial structure in these systems during the era of heavy bombardment (courtesy Gemini Observatory).

Recent observation by Spitzer have shown that protoplanetary disks are both extremely common yet varied: JWST will uniquely deliver this type of data routinely on the plethora of debris disks recently discovered by Spitzer



The SAT does believe JWST's near IR (1 – 1.5 um) coronagraphic capabilities will be challenges by groundbased systems by 2012.

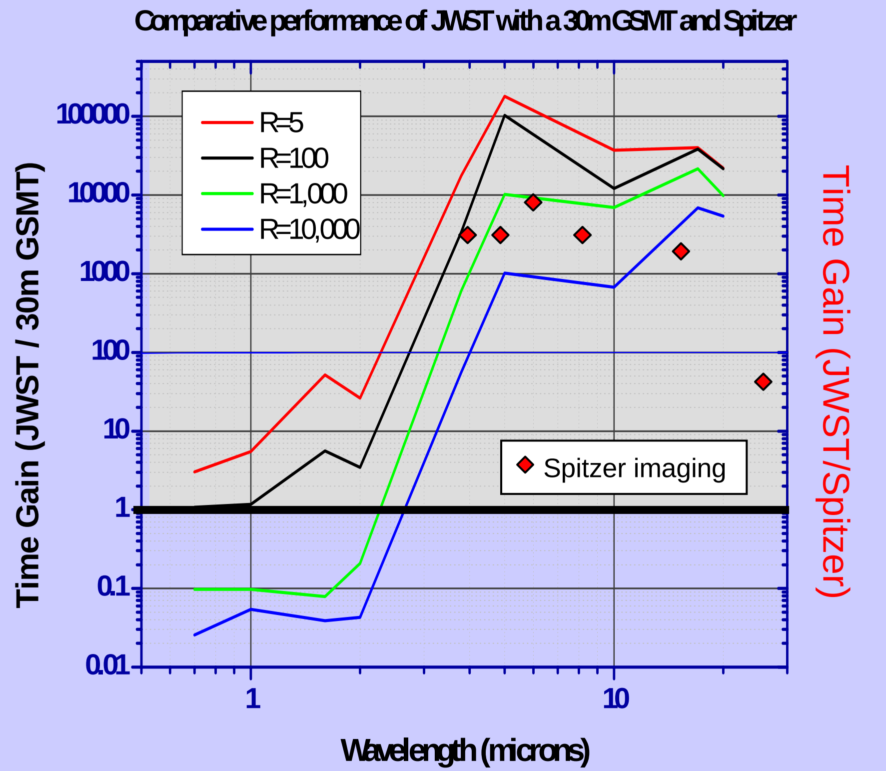
This is a simulated, differential coronagraphic detection of a 5 Jupiter mass planet 0.5 " from a H=5 mag. K0V star imaged through a high-order "extreme AO system" on an 8m ground-based telescope planned for 2008-2009.

Courtesy R. Doyon

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 a extra 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.



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 its clear that for the foreseeable future JWST will have an overwhelming advantage for imaging $\lambda >$ 1um, and for spectroscopy for $\lambda >$ 3um (R>5) (Mountain & Rieke 2005)

Recommendation 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.*

Table 1: JWST Science Capabilities

Instrument Capabilty	***Uniqueness***
Imaging 0.7-1.7 microns	20-30m MCAO will be comparable
Imaging 1.7 - 5.0 microns	JWST Unique
Imaging 5-28 microns	JWST Unique
Coronagraphy 0.7 - 2.3 microns	Extreme AO on 8-10m superior
Coronagraphy 2.4 - 5 microns	JWST Unique
Coronagraphy 5 - 28 microns	JWST in principle unique
Tunable filter 1.0 - 2.0 microns	8-10m AO & narrow band filters comparable
Tunable filter 2.4 - 5 microns	JWST in principle unique
Slit Spectroscopy 0.7-1.7 microns	20-30m MCAO superior
Slit Spectroscopy 1.6 - 5 microns	JWST Unique
MOS spectroscopy 0.7- 1.7 microns	20-30m MCAO superior
MOS spectroscopy 1.7 - 5 microns	JWST Unique
IFU spectroscopy 1.0- 1.7 microns	20-30m MCAO superior
IFU spectroscopy 1.7 - 5 microns	JWST Unique
(IFU) spectroscopy 5-28 microns	JWST Unique

Key

- (green) High priority
- (yellow) Unique, but science case requires more study
- (white) Low priority

The SAT believes this prioritization of JWST's current capabilities enable a significant de-scoping of the current JWST mission. In some cases the low priority modes can simply be left untested as long as this does not drive mission cost. However, the SAT would support the actual elimination of low-priority modes provided that this would significantly reduce risk and the potential for future cost.

Reducing Cost and Risk

- **In searching for significant costs savings the SAT were given a number of presentations discussing the Integration and Test (I&T) philosophy of such a challenging mission in light of fears of repeating the "Hubble error". The SAT commends the Project on its new and pragmatic approach to I&T that *are reliant on a number of significant relaxations of key mission requirements.***

- **The JWST Mission Requirements Document (MRD) was derived from early studies of the JWST mission concepts. NASA used the earliest controlled version of the MRD as an essential element of the procurement process for selecting the prime contractor. As NGST and the Project have refined the design and testing approaches for the Observatory, an important set of science-related MRD requirements are found to drive much of the cost of mission development. Based upon briefings by Project engineering and the SWG analyses, the SAT provides the following recommendations with regard to relaxing MRD requirements.**

- **These relaxations or de-scopes are consistent with our belief that the core of the JWST science mission can still be realized, and provide NASA and the community with a unique capability for the foreseeable future.**

Integration & Test Approach 1 of 3

- JWST is a space telescope of unprecedented aperture, expected to deliver diffraction limited performance, but it is also cryogenic and passively cooled, a challenging combination.
- As a science community we are haunted by the experience of Hubble, where the primary mirror was figured to the errant radius-of-curvature, which resulted in serious spherical aberration.
- Consequently the desire for a true “end-to-end” test of JWST is understandable.
- A ground-test verification that JWST will perform as planned on-orbit involves not only accommodation of the difference between 1-g and 0-g, but also a thermal environment that is very difficult to replicate.
  – Being passively cooled, in orbit at L2 it will have a large (e.g, 30 degree Kelvin) frozen in gradient across its primary mirror, an uncertainty on it’s bulk temperature of several degrees, and a high sensitivity to changes in the gradient due to slewing (roughly 0.5K over the Field of of Regard which moves primary mirror segments and effects the encircled energy and Strehl).
- Demanding a full-up demonstration of JWST’s performance on-orbit could involve test equipment that rivals the sophistication and complexity of JWST itself, potentially adding substantially to the capital cost and the time line to become one of the major expenses in the mission.
  – Though the telescope can be mounted with the mirrors horizontal, and the zero-gravity effects can be calibrated or removed to some level of precsion, to simulate the thermal environment would require moving the “solar load” around the telescope at cryogenic temperatures.

Integration & Test Approach 2 of 3

- However, it is easy to take the wrong lesson from the HST experience. Ironically, the incorrect radius-of-curvature would have been spotted in even a crude end-to-end test, one that would have been affordable.

- It is agreed by all that JWST needs to be tested fully-assembled for some performance aspects – component level tests and reliance on modeling alone to predict how the system will perform is in no way adequate.

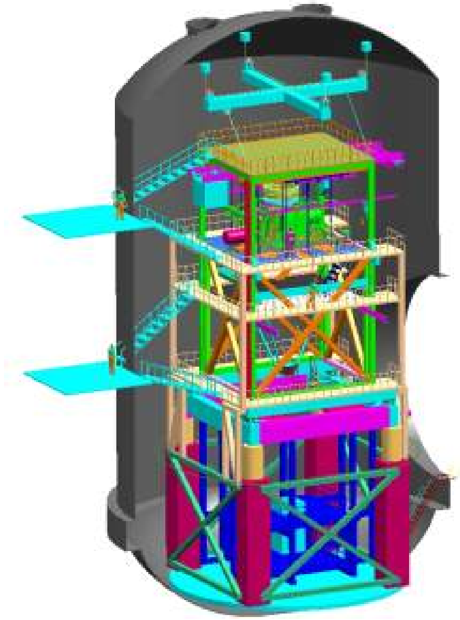
- By carefully selecting the elements that must be checked in the fully-assembled stage (and adding more only as an option if schedule permits), we believe substantial cost savings can be achieved over the original proposal, and the risk for even greater cost growth could be minimized or eliminated.
  - We concur with the Project that it will be more important to verify that the components are all within specification (for example, radii of curvature of the optical components), that the desired control of moving elements is as expected, and that the thermal performance is at least consistent with what models predict (ruling out, for example, thermal leaks and shorts), then it will be to demand that all these pieces work together as they would on-orbit to produce and hold the diffraction-limited image.

The SAT believes that the Project is moving ahead in the right spirit to reduce the costs associated with integration and testing and to prevent the possibility of significant cost overruns associated with it.

Integration and Test 3 of 3

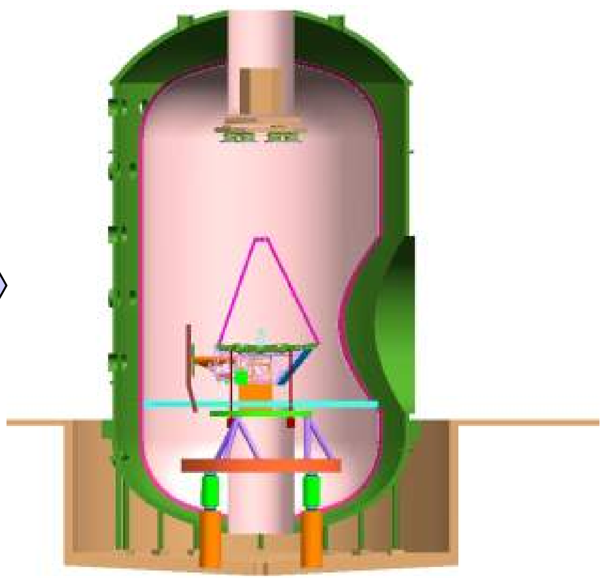
Recommendation 2

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



"Cup-down" test configuration within Johnson Space Flight Center (JSC) cryogenic test chamber

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



"Cup-up" test configuration within Johnson Space Flight Center (JSC) cryogenic test chamber

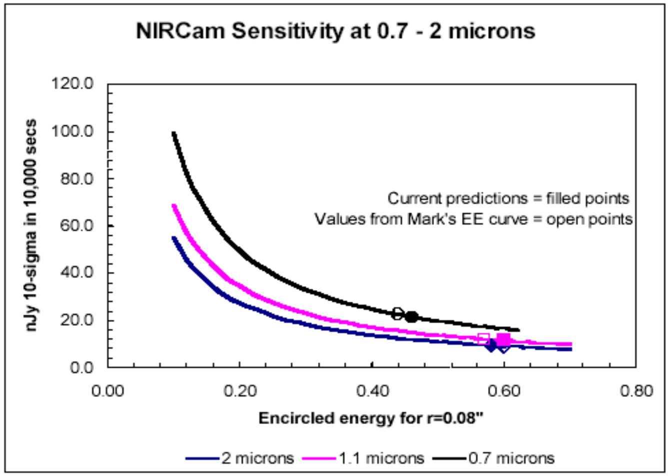
The SAT commends the Project on its innovative approach to I&T and believes the costs saving of this approach to be significant and includes a slide from the presentation to the SAT (27th June) by the JWST Optics Manager, L. Feinberg as an example of the possible current and future savings

Encircled Energy at 1 μm

- The encircled energy requirement of 74% at 1 μm 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 (mab > 28) at wavelengths < 1 μm.
- 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 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.



Current performance at 0.7μm = 0.46 EE, 21.5 nJy

Degraded performance = 0.42 EE, 23.4 nJy

Used 0.060MJy/sr as scattered background (extrapolated from 1μm)

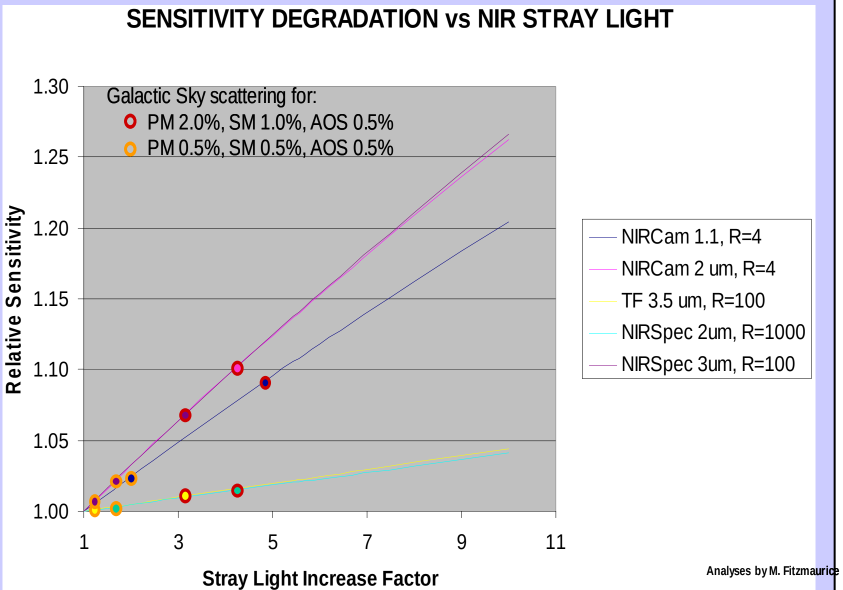
A preliminary analysis of the effects of relaxing The 1um encircled energy requirement on NIRCam sensitivity is shown above.

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.



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.

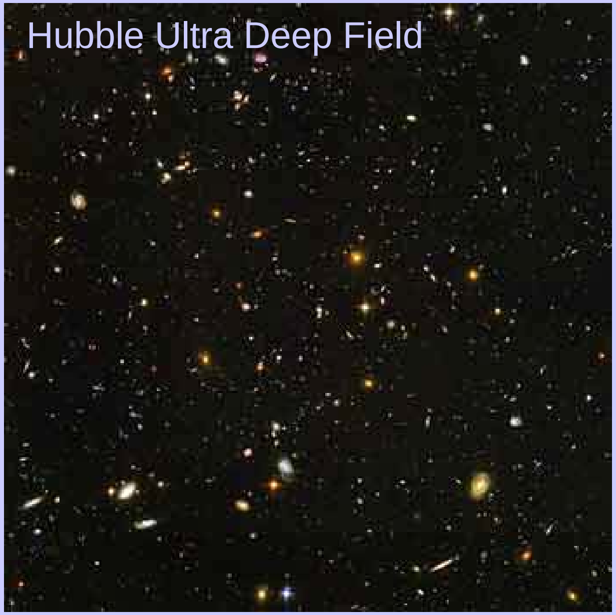
Given the huge gains of JWST over existing and foreseeable facilities the SAT considers this an acceptable loss in sensitivity given the potential for significant simplifications in the Integration and Test (I&T) phase through the adoption of the "cup-up" test configuration

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

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 through-out 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 ~4nm, and low frequency errors to ~ 16nm 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.



Given the success of the Ultra-Deep Field imaging in not reaching a limit dictated by systematic errors which occur at the 2% level, a similar stability requirement of 2% for the 2μm Strehl ratio should be appropriate for JWST

Recommendation 5

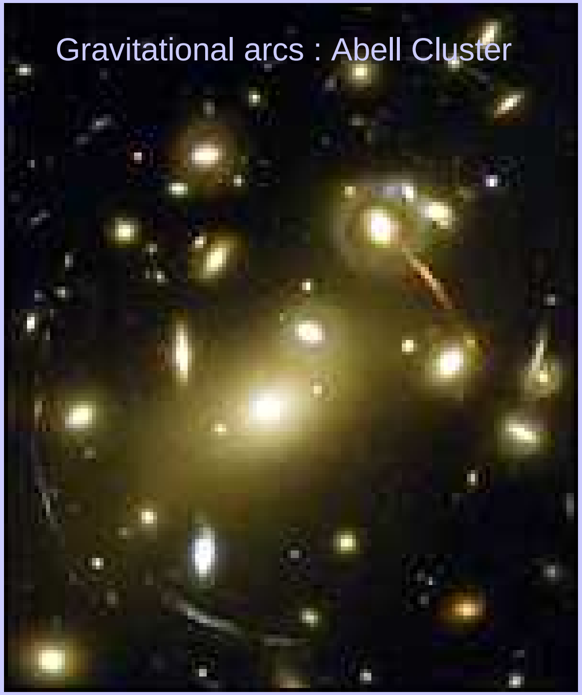
The SAT concurs with the Project recommendation that the stability requirement be relaxed to mirror adjustments every 7-10 days. The committee finds that the negative effect on observatory efficiency (estimate loss ~1%) acceptable. Efficiency effects of this order would be acceptable to eliminate heroic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

Mission Lifetime

- The requirements on the duration of the JWST science mission (post commissioning) are five years from the perspective of redundancy and ten years in terms of expendables (station-keeping fuel).
- One of the suggested JWST mass reductions is to reduce the requirement on expendables to five years in order to reduce mass by 20 kg.

Recommendation 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 to ensure the requirement to remove 20kg of propellant should never arise. If in the final analysis of mass, the only option remaining is the removal of science capabilities rated as not "high priority" in Table 1, the SAT would support this rather than lose five years of mission life.

Future Work

- The SAT believes this process is far from complete, several studies need to be completed:
  - Can NIRSpec achieve the stability requirements to measure the atmospheric properties of transiting extrasolar planets?
  - What is the detailed science case for the tunable filters beyond 2μm, could this capability be achieved though other observing techniques (such as narrow band filters) or innovative uses of other JWST capabilities?
  - What is the quantitative science case for the mid-IR coronagraphs, what suppression ratio's will be achieved, how many actual planetary systems are likely to be observed in this waveband with JWST, and are there other compelling but quantitative science arguments for retaining these coronagraphs?
  - The SWG should examine the need for retaining the anisotropy requirement in the current mission. Would the careful design of observing and planning strategies for maintaining optical performance (e.g. minimizing coma) be sufficient?
  - What is the actual Field of Regard (FoR) required in order to operate JWST properly, can the FoR be modified in a way that would save significant development costs and still enable efficient operations?
  - Are there further simplifications in the I&T approach which could yield significant future cost saving with perhaps minimum impact on the current science requirements?
  - Are there further simplifications in the current instrument suite possible? We note that experience with Spitzer showed removing filter wheels and other mechanism greatly reduced cost, risk and verification time.

- There is now an urgent need to fully understand the detailed cost savings of the proposed recommendations made in this report, and the SAT would like to be kept appraised of the results of this analysis.

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.

Conclusions

- The economies to be achieved by concentrating upon the wavebands longer than 1.7 microns have to be determined by the project in collaboration with Northrop Grumman Space Technologies. It is expected that relaxing a number of key requirements on the telescope and instrumental specifications will result in both significant cost savings and substantially reduce the risk of future cost growth. We have also prioritized the scientific instrument package to satisfy the scientific requirements of the mission. If further economies are necessary, the cost and schedule impacts of removing instrumental capabilities need to be assessed taking account of both the cost savings and the potential to improve the mass and risk margins of the mission. Ballpark estimates would indicate the possibility of finding about half the requested savings to be made

- Those projected overruns which have been driven by external circumstances rather than by changes in the program of technical development for the JWST and its instruments are outside the remit of the science assessment of the SAT. We have sought economies which should shorten the development program and enable the slippage costs to be minimized. There should be knock-on effects in the size of the contingencies needed to complete the project. These need to be costed with urgency since the clock is running and our conviction is that every effort should be expended to maintain an aggressive approach to the implementation of our recommendations so that the schedule is maintained.

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.*

   The SAT believes this prioritization of JWST's current capabilities enable a significant de-scoping of the current JWST mission. In some cases the low priority modes can simply be left untested as long as this does not drive mission cost. However, the SAT would support the actual elimination of low-priority modes provided that this would significantly reduce risk and the potential for future cost.

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 mission costs. The SAT suggests the SWG examine the need for retaining any anisotropy requirement.*

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