REPORT FROM THE FIRST ORIGINS TECHNOLOGY WORKSHOP
June 4-6, 1996

RECOMMENDATIONS FOR TECHNOLOGY DEVELOPMENT AND VALIDATION ACTIVITES IN SUPPORT OF THE ORIGINS PROGRAM

WORKSHOP CO-CHAIRS

MARY KICZA
Goddard Space Flight Center
National Aeronautics and Space Administration

R. RHOADS STEPHENSON
Jet Propulsion Laboratory
California Institute of Technology

EDITOR

Richard W. Capps
Jet Propulsion Laboratory

WORKING GROUP CHAIRS

Large Space Optics
Jim Bilbro
Marshall Space Flight Center
Dan Coulter
Jet Propulsion Laboratory

Astronomical Sensor Components
Craig McCreight
Ames Research Center
Harvey Moseley
Goddard Space Flight Center

Hyper-Precision and Deployable Structures
Pierre Bely
Space Telescope Science Institute
Bob Laskin
Jet Propulsion Laboratory

Space Interferometer and Telescope Systems
Tim Krabach
Jet Propulsion Laboratory
Bernard Seery
Goddard Space Flight Center

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I. INTRODUCTION

The Office of Space Science (OSS) has initiated mission concept studies and associated technology roadmapping activities for future large space optical systems. The scientific motivation for these systems is the study of the origins of galaxies, stars, planetary systems and, ultimately, life. Collectively, these studies are part of the "Astronomical Search for Origins and Planetary Systems Program" or "Origins Program." A series of at least three science missions and associated technology validation flights is currently envisioned in the time frame between the year 1999 and approximately 2020. These would be the Space Interferometry Mission (SIM), a 10-meter baseline Michelson stellar interferometer; the Next Generation Space Telescope (NGST), a space-based infrared optimized telescope with aperture diameter larger than four meters; and the Terrestrial Planet Finder (TPF), an 80-meter baseline-nulling Michelson interferometer described in the Exploration of Neighboring Planetary Systems (ExNPS) Study. While all of these missions include significant technological challenges, preliminary studies indicate that the technological requirements are achievable. However, immediate and aggressive technology development is needed.

The Office of Space Access and Technology (OSAT)* is the primary sponsor of NASA-unique technology for missions such as the Origins series. For some time, the OSAT Space Technology Program has been developing technologies for large space optical systems, including both interferometers and large-aperture telescopes. In addition, technology investments have been made by other NASA programs, including OSS; other government agencies, particularly the Department of Defense; and by the aerospace industrial community. This basis of prior technology investment provides much of the rationale for confidence in the feasibility of the advanced Origins missions. In response to the enhanced interest of both the user community and senior NASA management in large space optics, OSAT is moving to improve the focus of its sensor, spacecraft, and interferometer/telescope technology programs on the specific additional needs of the OSS Origins Program.

To better define Origins mission technology and facilitate its development, OSAT and OSS called for a series of workshops with broad participation from industry, academia and the national laboratory community to address these issues. Responsibility for workshop implementation was assigned jointly to the two NASA field centers with primary Origins mission responsibility, the Goddard Space Flight Center and the Jet Propulsion Laboratory. The Origins Technology Workshop, held at Dana Point, California between June 4 and 6, 1996 was the first in the series of comprehensive workshops aimed at addressing the broad technological needs of the Origins Program. It was attended by 64 individuals selected to provide technical expertise relevant to the technology challenges of the Origins missions. This report summarizes the results of that meeting. A higher level executive summary was considered inappropriate because of the potential loss of important context for the recommendations.

* Subsequent to the Origins Technology Workshop and prior to publication of this report, NASA Headquarters reorganized the activities of the Office of Space Access and Technology. It appears likely that responsibility for the technology programs recommended in this document will move to the Office of Space Science.

Workshop Structure. The workshop activities were divided into three main sections: a tutorial session that provided background information about the Origins mission concepts and the current plans for supporting technology programs; working sessions for the four working groups; and a final report session. The working groups addressed technology topics in four broad categories: Large Space Optics; Hyperprecision and Deployable Space Structures; Astronomical Sensor Components; and Space Interferometer and Telescope Systems. Because of the overlaps between working group topics and membership expertise, the working groups were encouraged to exchange information and otherwise interact. The final report session provided an opportunity for each group to provide results and recommendations. The final session also included open discussion. Because of the overlap in topics and expertise between the working groups, some of the recommendations also overlap. These repetitions have been retained because the emphasis appears to be valuable.

Report Structure. This report is divided into two main sections that summarize the deliberations of the four working groups. The first contains their recommendations for future technology development in support of the overall Origins Program and the second contains the quantitative technology data developed in response to the needs of the individual Origins mission concepts.

Acknowledgments. We are particularly grateful for the support of the workshop participants whose willing contribution of expertise made the Origins Technology Workshop possible. They are listed in Table 1. JPL's Conference Administration Group is largely responsible for the workshop arrangements and excellent on-site support. Their efforts, along with those of the conference center staff, is greatly appreciated.

Table 1. Workshop Participants

Charles Beichman	JPL
Pierre Bely	Space Telescope Science Institute
James W. Bilbro	NASA/MSFC
John H. Campbell	NASA/GSFC
Richard Capps	JPL
Richard A. Carreras	USAF Phillips Laboratory
Alain Carrier	Lockheed-Martin Missiles & Space
Lester Cohen	Smithsonian Astrophysical Observatory
Dan Coulter	JPL
Robert F. Crawford	AEC-ABLE Engineering Co.
Alok Das	USAF Phillips Laboratory
Don Davies	TRW
Eric Fossum	JPL
Ewing Hackney	Logicon/Phillips Lab
Terry Herter	Cornell University
Murray Hirschbein	NASA/HQ
Alan Hoffman	Santa Barbara Research Center
Jim Huffman	Rockwell Science Center
Gordon Johnston	NASA/HQ
Michael Kaplan	NASA/HQ

Table 1. Workshop Participants (continued)

Mary Kicza	NASA/GSFC
Timothy Krabach	JPL
Michael Krim	Hughes Danbury Optical Systems
Shel Kulick	Composite Optics, Inc.
Mark Lake	NASA/LaRC
Rudolph Larsen	NASA/GSFC
Robert Laskin	JPL
Henry Le Duc	JPL
Jesse Leitner	USAF Phillips Laboratory
Lynn Lewis	Ball Aerospace & Technologies Corp.
Chuck Lillie	TRW
Thomas Livermore	JPL
Richard Lynch	Lockheed Martin
John Mather	NASA/GSFC
Peter Maymon	NASA/GSFC
Craig McCreight	NASA/ARC
David W. Miller	Massachusetts Institute of Technolgy
Harvey Moseley	NASA/GSFC
David Mozurkewich	Naval Research Laboratory
Arthur J. Murphy	JPL
Firouz Naderi	JPL
Robert O'Donnell	MRJ, Inc.
Sherry Olson	NASA HQ/The Mitre Corp
Gary S. Parks	JPL
Steve Prusha	JPL
Gregory Reck	NASA
David Redding	JPL
Harold Reitsema	Ball Aerospace & Technologies Corp.
Paul Robb	Lockheed Martin
Lawrence Robertson	Phillips Labs
Virendra Sarohia	JPL
Karl Schrader	USAF Phillips Laboratory
Bernard D. Seery	NASA/GSFC
Michael Shao	JPL
John Spina	Kodak
Richard Stanton	JPL
R. Rhoads Stephenson	JPL
Brad Tousley	DoD
Peter Ulrich	NASA/HQ
Samuel L. Venneri	NASA/HQ
Barbara Wilson	JPL
Erick Young	University of Arizona
Jeffrey Yu	JPL
Bob Zwissler	TRW

II. WORKING GROUP SUMMARIES AND RECOMMENDATIONS

LARGE SPACE OPTICS WORKING GROUP

The Large Space Optics Panel considered the following technology areas: lightweight telescope mirrors; precision deployment; metrology; control, alignment and phasing; and integrated modeling. It is inevitable that certain technologies span the space of multiple panels and that different disciplines will bring unique perspectives regarding the needs of the Origins Missions in these areas. This is especially true for the Large Space Optics Panel and the Hyper-Precision and Deployable Space Structures Panel. A number of the relevant technologies (e.g., precision deployment, metrology, integrated modeling...) were considered by both panels and the reader is encouraged to review the recommendations of both panels to gain more complete insight into the status of these technology areas as they apply to the Origins Missions. In the future, it will be important to view to the output of the workshops from a systems point of view, examining the assumptions of the various panels for consistency and completeness and working on relevant interpanel issues.

The missions comprising the Origins mission set (SIM, NGST, and TPF) are at various stages of definition as are the knowledge and understanding of their technology needs. SIM has a reasonably well defined architecture, design and technology plan. NGST is currently being studied for feasibility, and a design concept and technology roadmap are being developed. TPF is defined only as in the ExNPS Roadmap based on top level requirements and architectural considerations. As the mission architectures evolve, it will be important to re-evaluate and update the technology plans and on-going technology programs.

Most of the large space optics technology deemed necessary to enable Origins Missions can be demonstrated at the component and subsystem level in suitable ground-based test facilities and testbeds. In addition, system-level testbeds, demonstrating key system-level aspects of interferometers and telescopes, will be necessary. For SIM, demonstrations at room temperature in the laboratory or, where necessary, in a vacuum, are suitable. For NGST and TPF, however, much of the testing must be performed at cryogenic temperatures. Despite the existence of a number cryo-vacuum facilities, it is inevitable that some further modification or development of facilities of this type will be necessary. This is especially true for cryogenic optical testing of large mirrors and mirror segments.

<u>While component and subsystem technology can be adequately validated on the ground, it is strongly recommended that subscale system flight demonstrations incorporating critical capabilities of large space optical systems be implemented</u>. These are complex systems in which the interplay between the various subsystems with each other and the environment must be validated. In particular, it is critical to demonstrate an adequate understanding of the effects of gravity off-loading and the microgravity environment on the optics, the structure and the control/metrology components in order to ensure that the dynamic range of the control/adjustment system is sufficient. It is impossible to adequately simulate the microgravity

environment in ground tests. Such demonstrations should validate precision deployment of optics, metrology and control technology as well as the launch survivability of ultralightweight optics.

It is important for NASA to coordinate and cooperate with the DOD and other government agencies to develop and validate key technologies. The most likely venue for such cooperation appears to be joint in-space technology demonstrations.

Summary recommendations of the panel are given below in each technology area.

Lightweight Telescope Mirrors:

- Initiate development of large (1.5–3 m) ultralightweight (5–15 kg/m^2) cryogenic (30 K–50 K), launch-survivable mirrors and mirror segments suitable for visible and near-IR operation for NGST and TPF.
- Determine fabrication facility upgrades necessary to produce multiple meter lightweight optics for NGST and TPF.
- Perform a study to determine options for cryo-optical testing of large single NGST segments and TPF mirrors including evaluation of prescription retrieval techniques and develop/demonstrate test methodology as required.
- Initiate development of nulling testbed and demonstration of starlight cancellation (nulling) techniques to the level required for SIM (10^{-4}) and TPF (10^{-7}).
- Evaluate launch load alleviation schemes to mitigate the acoustic and dynamic loads on the lightweight mirror/mirror segments during launch for NGST and TPF.

Precision Deployment:

- Initiate a study of the performance of various mechanisms utilized in deployable structures (joints, latches, hinges, drives...) determining their level of precision and stability and their ability to function at cryogenic temperatures for NGST and TPF. Continue/initiate development as required.
- Initiate a ground demonstration program for lightweight, compact, precision deployable booms suitable for SIM, NGST secondary support, and TPF. Evaluate the stability and precision of the structure and the effects of gravity off-loading and mircodynamics. Evaluate function at cryogenic temperatures for NGST and TPF.
- Study the possibility of incorporating active and passive vibration suppression members into deployable structures. Evaluate functions at cryogenic temperatures for NGST and TPF. Initiate development as required.
- Initiate a ground demonstration program for a lightweight, multi-meter diameter, precision deployable truss structure with 50-μm deployment accuracy and 10-nm stability suitable for operation at 30 K–50 K for NGST.

Metrology:

- Continue development of lightweight, low-power, launch-survivable, nanometer-level laser metrology systems for SIM and TPF. For NGST and TPF evaluate cryogenic performance of existing components and initiate development as required.

- Evaluate the necessity of laser metrology and optical trusses for the NGST maintenance system.
- Continue development of lightweight, low-power, launch-survivable, 10–200-pm accuracy laser metrology systems operating at 1-kHz bandwidth for SIM and TPF.
- Initiate development of laser metrology ground testbed.

Control, Alignment and Phasing:

- Initiate a program to develop lightweight, low-power, nonhysteretic actuators that operate at 30–50 K for NGST and TPF. Actuator strokes of microns to multiple millimeters and resolution of 0.1–50 nm are required for various applications, which may necessitate hybrid designs.
- Alignment, steering and deformable mirror technology is essentially in hand, except for the issue of cryogenic performance. Evaluation of the cryo-mechanisms and the deformable mirror at cryogenic temperatures is recommended.
- A trade study is required to determine the optimum technique for wavefront sensing for NGST. Options to be considered include traditional Shack-Hartmann techniques and phase diversity techniques.
- Initiate development of an alignment and phasing ground testbed for NGST.

Integrated Modeling:

- A number of integrated modeling packages are becoming available. A study should be performed to determine missing capabilities, and software should be upgraded as necessary to support SIM, NGST and TPF.
- The results of various integrated models should be checked in a blind comparison test against standard engineering modeling tools (NASTRAN, TRAYSIS, SINDA, CODE 5, etc.).

HYPER-PRECISION AND DEPLOYABLE SPACE STRUCTURES

The panel on hyper-precision and deployable structures considered the following technology areas: metrology, pathlength control, precision pointing, vibration suppression, deployable precision structures, and deployable nonprecision structures. The area of virtual structures, i.e., the technique of doing interferometry with separated spacecraft flying in formation, although assigned to this panel, was not addressed as it was not considered a near term technology priority. A trade study assessing the point (in terms of baseline length) at which this technique becomes cost effective should be conducted prior to serious technology development investment.

Summary recommendations appear below for each area. In many instances it was difficult to reach definitive conclusions regarding technology priorities owing to the immature definition of the NGST and TPF characteristics. Hence, the panel recommends that systems studies be conducted to prioritize technology development. It is already clear, however, that the need for low temperature operation for NGST and TPF (as opposed to SIM) set these missions apart, and will be a strong driver of development needs in the hyper-precision and deployable structure arena.

One technology area was identified as a compelling candidate for space flight experiments: deployable structures. Flight experiments are recommended to assess the microdynamic stability of deployable precision structures as well as to verify the proper deployment of inflatable structures (should inflatables become the choice for large sunshades on NGST or TPF). However, flight experiments are not necessary solely for the purpose of demonstrating deployment reliability for non-inflatable structures. Should flight experiments be undertaken, there are several additional candidates for piggyback payloads discussed below.

Metrology: Further develop the optical truss system for SIM, and possibly NGST, and perform the necessary ground testing to verify the performance of the optical truss.

- Further the study of phasing a retrieval solution for NGST (viz., no optical truss) and determine if the structure is stable enough for that method to work upon initialization and during normal operation (days between measurements). If the answer is no, then develop an NGST optical truss.
- Perform the necessary ground testing to verify the performance of the SIM optical truss.
- Continue the flight qualification of the optical metrology components.
- Keep an eye on the video metrology system being developed by the University of Colorado.

Pathlength control: Bring the current JPL pathlength control development to maturity and assess the impact of low-temperature operation.

- Current state of the art is close to the goals but needs to be further developed in terms of accuracy and low-temperature operation.
- System-level analysis is required to guarantee that the supporting structure has no vibration with amplitudes >0.2 nm at frequencies > 100 Hz. If this is not the case, study the use of active damping or local metrology to control the structure to that level .
- Keep an eye on mag-lev solutions being developed for the European Southern Observatory. Mag-lev may be more adapted to low temperature operation.

Precision pointing: Technology is mature and the only area in need of further development is momentum compensation.

- Precision pointing is obtained by steering the optical beam with fast-steering mirrors and gimbal mirrors. Technology is mature (20 years experience) and little additional development is required. Low-temperature operation is not an issue (actuators need to be selected accordingly, e.g., electromagnetic). However, heat dissipation needs to be studied through systems analysis.
- Perform a system-level analysis to determine the amount of momentum compensation required for the Fast Steering Mirror (in terms of force and torque). However this is not a high risk area.
- Need to verify lifetime (5 years for SIM, 10 years for NGST). Establish the need for redundant units.

Systems studies:

- Develop the analysis and subsystem trade tools to ensure that the different elements work well together and that the requirements imposed on the various subsystems are appropriately levied.
- Develop thermal design/concepts.
- Examples of trades include phasing retrieval vs optical truss for NGST, optical pathlength control vs structure control, isolation vs vibration suppression.

Cryogenic operation: While many mechanisms work to requisite accuracy at room temperature, devices need to be developed for cryogenic operation and their thermal impact needs to be assessed.

ASTRONOMICAL SENSOR COMPONENTS

The panel for astronomical sensor and instrument technologies considered development needs in the following technology areas: infrared (IR) detector arrays (near- and thermal-IR), visible detector arrays, cryocoolers, readout and signal-processing electronics, and sensor-level mechanisms and optics. The identified instrument requirements for SIM, NGST, and TPF were considered in detail. In general, these requirements seemed reasonable to the panel, although in some cases they were very ambitious and in need of further study and definition.

Among the various sensor technology options, the level of maturity spans the range from fully established to extremely visionary. In the challenging IR array area, the detector and readout technologies developed for the SIRTF & WIRE missions provide a very useful and directly relevant starting point for Origins. At the other extreme, the areas of visible arrays, mechanisms, and focal plane packaging appeared to be rather adequately covered by the state of the art. The rating scale defined here was used to rate the various options. These ratings are shown as a superscript notation in the following sections and in the summary tables.

Definitions of Technology Development Categories

O - Already meets requirements for Origins.
I - Evolutionary development. Existing technology base.
II - Significant promise, but major advances needed.
III - Speculative. High risk, but high payoff.
IV - Not promising for Origins.

The panel developed a prioritized list of recommended development items. On the list of eight key items, the first four dealt with the extremely challenging levels of IR focal plane performance desired for NGST and TPF. (In the discussion of categories which follows below, the highest-priority items are listed first.) Tightly coupled to the thermal-IR detector technology issue is the matter of cryogenics design, in particular, the heat loads and temperatures needed. It was clear that fundamental trade-offs, between scientific capability and the complexity, maturity, and expense of the IR array/cryogenics technology options, must be made in this area. For the thermal-IR arrays, the panel recommended intentionally overlapping goals; the temperature goals for the cryo systems (6 K) and for the thermal IR arrays (8 K), if both achieved, would provide a highly useful performance margin at the system level.

A precursor demonstration in space is warranted for the cryogenics system. Key issues include fluid management, internal contamination, and lifetime. Considered individually, focal planes and other sensor components probably do not justify a flight experiment; they can be adequately demonstrated on the ground. The panel believed that space radiation effects could, and must, also be thoroughly characterized on the ground. However, if a cryogenics system were selected for flight demonstration, there would be tremendous additional value in including detector arrays, mechanisms, filters, and advanced cold-warm cabling interface elements to validate and test the overall sensor concept. This activity would be extremely valuable in flushing out instrument problems, which are often very subtle and often not apparent in focused lab tests.

The panel strongly recommends that candidate technologies be demonstrated in both laboratory and ground-based astronomical settings, and that the scientific community be directly and heavily involved in both the development and demonstration phases of this work. Teams of scientists, technologists, and industrial partners should be formed early in this process, and their progress, against a clear development plan, should be regularly reviewed.

IR Detector Arrays: <u>Develop near- and thermal-IR array technologies, with initial emphasis on increasing sensitivity (dark current, noise).</u>

Thermal (5–20 μm) IR

- Develop improved Si:As impurity band conduction (IBC)(I) arrays. Identify and overcome limiting mechanisms.
- Revisit prospects for developing Si:Ga IBC (II) arrays; with ~18 μm cutoff, these might operate ~ 2 K warmer than Si:As arrays.
- Evaluate whether quantum well IR photoconductors (QWIPs)(III) can provide low dark currents at 10 K.
- As progress is made in lowering noise and dark current, scale up to 512×512 or larger formats.

Near (1–5 μm) IR

- Improve dark current of InSb(I). Identify and overcome limiting mechanisms.
- Consider improving dark current of HgCdTe(II–III) (5 μm cutoff, for broadband imaging applications)
- As progress is made in lowering noise and dark current, scale up to 2 k×2 k formats.

Ultra-low background characterization technology (~0.01 photons/s-pixel)

- Develop research approaches, and supporting equipment and "standard detectors," to allow realistic evaluation of NGST and TPF IR focal plane technologies. NGST and TPF arrays require characterization at extraordinarily low flux levels, at least 10 times lower than SIRTF.

Cryocoolers: Develop a cryogenics system or a hybrid concept to provide reliable cooling down to ~6 K without vibration.

Active

- Develop hydrogen sorption cooler with Joule-Thomson (J-T) stage(I). Compressor technology and potential contamination are concerns.
- Develop Turbo-Brayton cooler with He gas(II). Reduced efficiencies at lower temperatures are a concern.
- If previous two approaches encounter a hard limit at ~10 K, develop adiabatic demagnetization stage(II) for 5–10 K.

Passive

- Evaluate system implications of solid hydrogen cooler(I). (Note: 100 liters of solid H_2 could provide 10 years of cooling, at 10 mW load. The WIRE and SPIRIT III missions will demonstrate solid H_2 on orbit.)
- Evaluate He II cryostat for low-heat load performance(I). Hybrid LHe II systems, e.g., ones guarded by solid H_2, could prove very efficient. [Need to monitor performance of the AXAF/XRS cryostat, designed for very low (~0.7 mW) loads.]

Readout and Processing Electronics: Sensors for all Origins missions will require low-noise, low-dissipation, stable readouts and processing electronics (e.g., A/Ds). Define and conduct a broadly based program to address these needs.

- Utilize improved readout processing techniques for lower noise and lower dissipation, improved stability, and negligible "glow."
- Develop and evaluate innovative, alternative unit-cell circuit designs.
- Develop new overall architectures and operational modes, to reduce clocking noise.
- Monitor state of superconducting A/D converters(I), for possible use on Origins IR missions.

Power, Control, and Signal Interfaces for Focal Planes: Sensors for all Origins missions will require high-performance cabling to the cryogenic focal plane subsystems. The panel recognized the significant complexities and costs involved in integrating present-day cabling and power approaches for bridging the cold-warm interface. Advances in this area could dramatically reduce noise and pickup problems, and allow subsystem tests to accurately predict final integrated-system performance.

- Through modest extensions of technology and innovative changes in architecture (including on-chip generation of functions), develop means to reduce wire count, from ~25 presently, to ~3, in an advanced IR or visible array.
- Through more radical approaches, develop technologies to allow an all-optical interface to the focal plane. This would be based exclusively on optical fibers, and would require timing generators, A/Ds, optical drivers and receivers, and fibers, all of which operate efficiently at cryogenic temperatures.

Visible Detector Arrays: The existing state of technology appears capable of meeting SIM and (potentially) NGST needs.

- Build and demonstrate visible CCD arrays(0) for SIM and NGST (incl. rad-hardness tests).
- Pursue alternative technologies—active pixel sensors(I), avalanche photodiodes(0), Si p-i-n arrays(I)—should problems arise.

Sensor Mechanisms: Origins missions will require some sensor-level mechanisms, but existing art appears to be adequate.

- Previous space flight experience, especially from the ISO mission, has established an adequate foundation for Origins.

Sensor Optics (mirrors, filters, gratings, lenses): Origins missions will require instrument-level optics, but present capabilities appear to be sufficient, apart from the issue of size.

- A single-mode spatial filter (for 7–17 μm) will be needed for TPF. The panel felt this important requirement could be met with existing technologies and careful engineering. Such a prototype device must be fabricated and tested.
- Adequate commercial sources exist for interference filters, gratings, lenses, dichroics, etc.
- The physical size requirements (especially to match large NGST instruments) present some challenge. The panel recommended a modest program to design, fabricate, and test large (10–12 cm diameter) optical elements and filters.

SPACE INTERFEROMETER AND TELESCOPE SYSTEMS

The systems working group addressed two large topic areas. First, the technology readiness needed in spacecraft subsystems that will be part of any Origins mission and, second, how higher-level systems issues will impact technology choices and system costs in lower-level hardware implementations. The panel strongly recommends that the Origins program begin a continuing effort to better define the mission architectures of NGST and TPF, to provide higher confidence that the mission profiles being used to guide the technology choices are correct. For example, if TPF is implemented as a 1-AU mission instead of 3–5 AU, the overall system impacts would be enormous, and the focus of technology efforts would be radically altered.

System-Level Issues:
Among the higher-level systems considered by the panel were the following:

- Concern about the strong linkage between technology requirements and overall mission architecture. Until the architecture is firm, important technology issues cannot be resolved.
- Role of ground testing: What types of affordable ground tests will be possible to verify system performance in SIM, NGST and TPF? The size of these missions (TPF in particular) makes end-to-end ground tests difficult, if not impossible.
- Contamination: For NGST, questions were raised about whether station keeping at the L-2 location has unique contamination issues. The panel recognized that optical path length errors caused by contamination buildup is a major concern for the nulling interferometer (TPF). Active cleaning could become a requirement unless careful contamination control is part of the TPF program.
- Greater utilization of autonomy: The highly complex nature of these missions, combined with the distances of the spacecraft from the Earth and the cost caps under which the programs will be operating, will require system autonomy to a much greater level than previous NASA missions.
- Role of simulations: to reduce risk, meet the cost caps, provide a framework for technology decisions, and lower the need for extensive hardware testing.
- Overall system implications of vibration: Understanding how disturbances in one area of the spacecraft will be transmitted throughout the structure will be critical in assigning vibration damping and isolation budgets on the various subsystems.

Conclusions and Recommendations
High-risk, high-priority technologies that the panel identified are suited for ground testing in existing facilities. These include:

- High-bandwidth, low-mass communication systems (optical and Ka)
- Cryogenic electronics
- Low-mass power systems (both advanced solar arrays and lightweight batteries)
- Autonomous control

High-risk, high-priority technologies that will require space-based testing and validation. These include:

- Inflatable sunshields of the size needed by NGST (and any 1-AU TPF mission)
- Measurement of contamination and thermal effects can be carried out with small instrumentation packages on flights of opportunity (MAP was specifically called out)
- Coolers should be flown on the Space Shuttle or Space Station to investigate micro-gravity effects

Strong Need for hybrid simulation activities for these missions

- To reduce risk, simulation activities should include "hardware in the loop" as part of the simulation testbed. This approach is often weakly exploited because it takes significant resources to integrate the simulator and protoflight hardware. The panel believed that this level of simulation is critical for carrying out these missions, especially given the cost and schedule constraints that will be imposed.

- An integrated modeling and simulation activity should be established sooner rather than later, with an emphasis on facilitating data exchange across the various tools that exist in the aerospace community

Contamination issues

- We must improve our understanding of the basic physics of contamination. This research should include line-of-sight effects, scattering, etc; it should lead to development of better contamination models to be incorporated in the mission design studies
- Conduct small-scale experiments on orbit wherever possible
- Influence the choice of subsystems that will be inherently lower sources of contamination

Incorporation of "cold" electronics

- To reduce extremes in the thermal effects on these spacecraft (i.e., very cold payloads attached to 300 K spacecraft buses) more extensive use of cold electronics in the spacecraft should be strongly considered. These include low-temperature CMOS, superconducting inteconnects and electronics, and extensive use of fiberoptic elements. The reduction in thermal gradients may produce large gains in the long-term stability of the payload platforms.
- Implications for low-temperature operation on the power subsystems will be severe, however. The panel noted that for TPF at 5 AU, the choice for solar panels may need to be silicon instead of GaAs because of the changes in efficiencies due to lower temperatures. These types of effects need to be seriously considered in any systems-modeling activity and technology rating.

Make use of synergies between Origins programs needs and Mission to the Solar System technology roadmap.

- Many of the spacecraft subsystems in the Origins missions will have a significant amount of commonality with developments called for in the solar system exploration technology roadmap, since both sets of missions will be conducted outside of earth orbit. Coordination and cost-sharing of these common technology developments, along with the greater advocacy, will help ensure the timely development of these critical items.

APPENDIX

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Short description of required technology capability for Origins missions **Priority is defined as follows** **High-** Critical to the mission and must be developed **Medium** Very enhancing and should be developed **Low** Enhancing and worthy of development		Quantitative performance metrics that define the required technology capability		Performance levels required for SIM, NGST and TPFA			Description of known or anticipated technology options that respond to the capability requirement	Current State-of-the Art in the context of overall mission environment	Ultimate performance limits if known	Requirements for performance validation and demonstration

Technology Summary Field Descriptions

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Lightweight Telescope	High						**Beryllium (near net shape HIP process)**			ground test
Mirror Technology		aperture size	m	0.33	4-8	1.5-3	• Large CTE			cryo-optical
		segmented (seg. si	Y/N (m)	N	Y (1.4-3.3)	N	• HIP process size limit			vibration
		areal density	kg/sq.	<30	8	<15	• Surface quality?			
		operating temperat	K	300	30-50	30	aperture size	0.85m	2m?	
		wavelength range	μm	0.4-1.0	0.5-20	6-17	segmented	N	Y/N	
		figure (WFE)	μm rms	DL @ 0.4μ	0.025 (λ/20)	DL @ 2μm	areal density	20kg/sq.m	15kg/sq.m	
		microroughness	Å rms	<10	<20	<10	operating temperature	5K-300K	5K-300K	
		fabrication cost	H,M,L	Low	Moderate	Low	wavelength range	6.5-200μm	1μm?	
		launch survivability	G,M,P	Good	Good	Good	figure (WFE)	DL@6.5μm	DL@1μm?	
							microroughness	25Å rms	10Å rms	
							fabrication cost	High-Moderate	Moderate?	
							launch survivability	Good	Good	
							Silicon Carbide (CVD-replication, rxn bonded)			ground test
							• CVD material warps			cryo-optical
							aperture size	1.2-1.5m	3m?	vibration
							segmented	N	Y/N	
							areal density	15-20kg/sq.m	<10kg/sq.m	
							thin sheet	3-10	1?	
							operating temperature	77K-300K	5K-300K	
							wavelength range	visible	UV	
							figure (WFE)	DL@0.5m	DL@0.1μm	
							microroughness	1Å (CVD), 10-50Å(RXB)	1Årms	
							fabrication cost	Moderate-Low	Low	
							launch survivability	Moderate	Good?	
							Glass (ULE, Fused Silica, Zerodur)			ground test
							• Fragile			cryo-optical
							• Can be ion figured			vibration
							aperture size	10m	?	
							segmented	Y (N@8M)	Y/N	
							areal density	20kg/sq.m	20kg/sq.m	
							thin sheet	4.5(2mm)	2?	
							operating temperature	5K->300K	5K->300K	
							wavelength range	UV-submm	UV-submm	
							figure (WFE)	DL in UV	DL in UV	
							microroughness	1Årms	1Årms	
							fabrication cost	Moderate	Moderate	
							launch survivability	Poor (lightweight)	Moderate?	

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Lightweight Telescope Mi	High						**Aluminum**			
		aperture size	m	0.33	4-8	1.5-3	• Bare Al surface is too rough, coating possible			ground test
		segmented (seg. si	Y/N (m)	N	Y (1.4-3.3)	N	aperture size	2		cryo-optical
		areal density	kg/sq.	<30	8	<15	segmented	N	Y/N	vibration
		operating temperat	K	300	30-50	30	areal density			
		wavelength range	μm	0.4-1.0	0.5-20	6-17	thin sheet	5(2mm)	<5	
		figure (WFE)	μm rms	DL @ 0.4μ	0.025 (λ/20)	DL @ 2μm	operating temperature	5K-300K	5K-300K	
		microroughness	Å rms	<10	<20	<10	wavelength range			
		fabrication cost	H,M,L	Low	Moderate	Low	figure (WFE)			
		launch survivability	H,M,L	Good	Good	Good	microroughness			
							fabrication cost	Low	Low	
							launch survivability	Good	Good	
							Composite			
							• Replication tool up to 3.5m			ground test
							• CTE mismatch with structre, Moisture			cryo-optical
							aperture size	1-4	10?	vibration
							segmented	Y	Y	
							areal density	5-10	1?	
							thin sheet	1-1.5	<1	
							operating temperature	150K-300K	5K?-300K	
							wavelength range	>50μm	x-ray?	
							figure (WFE)	2μm	DL in Vis?	
							microroughness	1000Å	100Å?	
							fabrication cost	Low	Low	
							launch survivability	Good	Good	
							Vanasil (high silica Al alloy)			
							aperture size	<0.5	2	ground test
							segmented	N		cryo-optical
							areal density			vibration
							thin sheet	5(2mm)	<5	
							operating temperature	?	?	
							wavelength range			
							figure (WFE)			
							microroughness			
							fabrication cost	Low	Low	
							launch survivability	Good	Good	

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Lightweight Telescope Mirror Technology	High						**Nickel**			
		aperture size	m	0.33	4-8	1.5-3	• Very high mass density penalty			ground test
		segmented (seg. si	Y/N (m)	N	Y (1.4-3.3)	N	• Excellent for diamond turning			cryo-optical
		areal density	kg/sq.	<30	8	<15	aperture size	2-8		vibration
		operating temperat	K	300	30-50	30	segmented	Y	Y/N	
		wavelength range	µm	0.4-1.0	0.5-20	6-17	thin sheet	8-9 (1mm)	8-9	
		figure (WFE)	µm rms	DL @ 0.4µ	0.025 (λ/20)	DL @ 2µm	areal density			
		microroughness	Å rms	<10	<20	<10	operating temperature	?	?	
		fabrication cost	H,M,L	Low	Moderate	Low	wavelength range			
		launch survivability	G,M,P	Good	Good	Good	figure (WFE)	vis		
							microroughness	7Å		
							fabrication cost	Low	Low	
							launch survivability	Good	Good	
Lightweight Cryogenic Telescope Structures	High						**Beryllium**			
		aperture size	m			1.5	aperture size	.85m	2m?	ground test
		geometry				off axis	geometry	R-C Cass		cryo-optical
		mass	kg			50	mass	29		vibration
		operating temperat	K			30	operating temperature	5K	5K	
		wavelength range	µm			6-17	wavelength range	6.5-200µm	1µm?	
		figure (WFE)	µm rms			DL @ 2µm	figure (WFE)	DL@6.5µm	DL@1µm?	
		fabrication cost	H,M,L			L	fabrication cost	High	Moderate?	
		launch survivability	H,M,L			H	launch survivability	Good	Good	
							Silicon Carbide			
							aperture size	0.5	3m?	ground test
							geometry	3-mirror cass		cryo-optical
							mass	15		vibration
							operating temperature	220K	5K	
							wavelength range	SW/MWIR	UV-IR	
							figure (WFE)	0.7µm rms	DL@0.1µm	
							fabrication cost	Low	Low	
							launch survivability	Good	Good	
Starlight Cancellation (coating implications)	High	Nulling		10E(-4)		10E(-7)	**Metallic Coatings**			ground test
		Strehl		high	N/A	High				cryo-optical
		amplitude mismatch		<10E(-2)		<10E(-4)	amplitude mismatch	.01-.05		vibration
		phase mismatch		<1.7 x 10E(-2)		<1.7 x 10E(-4	phase mismatch	.01-.05		
		polarization mismatch		<10E(-2)		<10E(-4)	polarization mismatch	.01		
							Contamination issues, figure mismatch	.01		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Precision Deployable Structures	High	deployment accura	mm	5	0.5	5	**Extendible Booms**			flight
		stability over tempe	mm	5	0.5	5	• joint dominated structure			
		microdynamic stabi	nm	1*	100	1*	• susceptible to microdynamics			
		scale of deployment	m	10	8	75	• very large structures			
		operating temperat	K	280	40	35	• high part count			
		deployment temper	K	280	TBD	TBD	deployment accuracy	3 mm	0.3 mm	
		packaging efficienc	%	TBD	TBD	TBD	stability over temperature	3mm	0.3mm	
		deployed frequency	Hz	5	5	0.5	microdynamic stability	TBD nm	TBD nm	
		mass	kg/sq.m	low	5-7	<10	scale of deployment	12 m	150 m ??	
							operating temperature	TBDK	TBD	
							deployment temperature	TBDK	TBD	
							packaging efficiency	5%	5%	
							deployed frequency	depends on size and form factor		
		* function of frequency: 1 nm > 100 Hz					mass	low		
		100 nm @ 10 Hz								flight
		10 um @ 1 Hz					**Fold-out Booms**			flight
							• microdynamics concentrated in latch			
							• smaller structures than extendible			
							• low part count			
							deployment accuracy	3 mm	0.3 mm	
							stability over temperature	3mm	0.3mm	
							microdynamic stability	TBD nm	TBD nm	
							scale of deployment	10 m	25 m ??	
							operating temperature	TBDK	TBD	
							deployment temperature	TBDK	TBD	
							packaging efficiency	100%	100%	
							deployed frequency	depends as above		
							mass	low		
							Areal Structures			
							• back-up structures			
							• approach to packaging			
							• latches			
							• approach to unfolding			
							deployment accuracy	3 mm	0.3 mm	
							stability over temperature	3mm	0.3mm	
							microdynamic stability	TBD nm	TBD nm	
							scale of deployment	none flown	25 m ??	
							operating temperature	TBDK	TBD	
							deployment temperature	TBDK	TBD	
							packaging efficiency	100%	100%	
							deployed frequency	depends as above		
							mass	TBD		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Precision Deployable Structures	High	deployment accura	mm	5	0.05	5	**Deployment Latches, Hinges**			ground test
		stability over tempe	mm	5	0.05	5	• preload technique			
		microdynamic stabi	nm	10	100	10	accuracy (latches)	50µm	25µm?	
		scale of deployment	m	10	8	75	accuracy (hinges)	1-2µm	Š1µm?	
		operating temperat	K	280	30	35	temperature	300K	30K?	
		deployment temper	K	280	TBD	TBD				
		mass	kg/sq.m	low	5-7	<10	**Deployable Full Apertures**			flight
							• composite, SiC, Be structures			ground
							• approach to packaging			
							• approach to unfolding			
							deployment accuracy	<50µm	25µm?	
							stability over temperature	<50µm	??	
							microdynamic stability	??	??	
							scale of deployment	5m	??	
							operating temperature	??	??	
							deployment temperature	??	??	
							mass	??	??	

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Pathlength Control and Actuators (primary segment phasing for NGS	High	range	mm	2000	6	10	**Multi-Stage Delay Lines**			ground test cryo
		accuracy	nm	0.2	50/1?	0.2	• piezo vernier stage			
		jitter during slew	nm	10	?	10	• voice coil middle stage			
		operating temperat	K	280?	30	35	• motor drive on track outer stage			
		bandwidth	Hz	100	< 1	100	range	20 mm stroke	TBD	
		heat dissipation	mW		very low	very low	accuracy	1 nm acc	TBD	
		hysteresis		?	low	?	jitter during slew	5 nm jitter	TBD	
							operating temperature	293K	TBD	
							bandwidth	500 Hz BW	TBD	
							heat dissipation	low	low	
							Mag-Lev Delay Line			ground test
							range	TBD	TBD	cryo
							accuracy	TBD	TBD	
							jitter during slew	TBD	TBD	
							operating temperature	TBD	TBD	
							bandwidth	TBD	TBD	
							heat dissipation	TBD	TBD	
							Air Bearing Delay Line			ground test
							Multi-Stage Segment Phasing			ground test
							• vernier stage- needs cryo development			cryo
							- magnetostrictive			
							- electrostrictive			
							- piezoelectric			
							• lead screw for outer stage			
							range	1.5 mm	> 6mm	
							accuracy	25nm	<10nm?	
							jitter during slew	TBD	TBD	
							operating temperature	293K	TBD	
							bandwidth	< 1Hz BW	TBD	
							heat dissipation	TBD heat	TBD	

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Fast Steering Mirrors	High	aperture size	cm	4	10	10	**Electrodynamically Actuated Mirrors**			ground
		range	mrad	0.3	10	0.2	• Voice Coils or attractive magnetics			cryo
		accuracy	nrad	20	1200	6	aperture size	TBD cm		
		bandwidth	Hz	100	30	100	range	TBD mrad		
		momentum compe	%	90?	99	90?	accuracy	TBD nrad		
		operating temperat	K	280?	30	35	bandwidth	1 K Hz BW		
		heat dissipation	mW	N/A	very low	very low	momentum compensation	> 90%		
		reliability			very high		operating temperature	293K		
							heat dissipation	TBD mW		
							reliability	TBD		
Alignment Mirrors	High	aperture size	cm	4		4	**Solid State Actuated Mirros**			ground
		range	mrad	170		17	• piezoelectric			cryo
		accuracy	urad	50		50	• electrostrictive			
		bandwidth	Hz	1		1	• magnetostrictive			
		momentum compe	%	90?		90?	• SIRTF PSMA (HDOS)			
		operating temperat	K	280?		35	aperture size	10cm		
		heat dissipation	mW	N/A		very low	range	TBD mrad		
		reliability		high		high	accuracy	TBD nrad		
							bandwidth	1 K Hz BW		
							momentum compensation	> 90%		
							operating temperature	293/5K	5K	
							heat dissipation	TBD mW	low	
							reliability	low	high	
Wavefront Corrector	High	aperture size	cm		15-30		**Deformable Mirror**			ground
		# actuators			1000?		aperture size	30		cryo
		speed	Hz		<10?		# actuators	900		
		correction range	µm		0.1-5µm		speed	1KHz		
		operating temperat	K		30-50K		correction range	5		
		mass			low		operating temperature	300K		
		cost			low		mass	high		
		reliability			high		cost	moderate		
							reliability	moderate		

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REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Metrology	High	accuracy 1-D	pm	10	10000	200	**Sample Point - Heterodyne**			ground test
Relative Laser Gauge		accuracy 3-D	pm	135	10000	N/A	accuracy 1-D	< 1pm 1-D	TBD	
(Optical Truss)		sampling rate	Hz	1000	100	1000	accuracy 3-D	TBD 3-D	TBD	
		beam length	m	10	20	75	sampling rate	1000 hz?	TBD	
		number of beams	unitless	40	>40??	10	beam length	1 m	200 m ??	
							Sample Point - Amplitude			ground test
							accuracy 1-D	5 nm	< 1nm	
							accuracy 3-D	3-D TBD	TBD	
							sampling rate	TBD hz	TBD	
							beam length	TBD m	TBD	
							Laser Backscatter Radar			
							Dyson Interferometer			
Metrology	High	accuracy 1-D	um	1	1	0.1	**Frequency Scanning**			ground test
Absolute Laser Gauge		accuracy 3-D	um	10	10	1	accuracy 1-D	10 um 1-D	1 um 1-D	
(Optical Truss)		ambiguity distance	m	1	1	1	accuracy 3-D	TBD 3-D	TBD	
							ambiguity distance	no ambig	no ambig	
							Dual Heterodyne			ground test
							accuracy 1-D	100um 1-D	TBD	
							accuracy 3-D	TBD 3-D	TBD	
							ambiguity distance	1 m ambig	TBD	
							Laser Ranging			flight
							accuracy 1-D	100 um 1-D	TBD	
							accuracy 3-D	TBD 3-D	TBD	
							ambiguity distance	no ambig	no ambig	

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REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Metrology - Lasers	High	wavelength	um	1.3	0.5	0.5	**Nd:YAG**			ground test
		power	mW	30	10	10	wavelength	1.3 um	N/A	
							power	200 mW	TBD	
		stability (after stabil	part in	10 billion	TBD	10 billion				
							Semiconductor Lasers			flight
							wavelength	1.3 or 1.5	N/A	
							power	> 1 watt	TBD	
							Er-doped Fiber Lasers			
							Stabil. via Pound Drever Hall	> 10 to 14		ground test
							Stabil. via Acousto-optic Mod	TBD		ground test
Metrology Frequency Shifters	High	frequency separatio	MHz	0.1	0.1	0.1	**Bragg Cells**			ground test
		throughput	dB	3	3	3	frequency separation			
							throughput			
							Acousto-Optics Tunable Filters			ground test
							frequency separation			
							throughput			
							Electro-Optic Modulators			ground test
							frequency separation			
							throughput			
							PZT Fiber Stretchers			ground test
							frequency separation			
							throughput			
Segment Control Algorithms	High	Speed			moderate		Co-alignment			ground test
		fidelity			high		Co-phasing			
							Phase Deversity			

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Integrated Modeling	High	Disciplines Covered					**IMOS (JPL)**			
		> Optics	Y/N	Y	Y	Y	Optics	COMP/MACOS		
		focal plane	Y/N	Y	Y	Y	focal plane	COMP/MACOS		
		> Structures	Y/N	Y	Y	Y	Structures	NASTRAN		
		> Thermal	Y/N	Y	Y	Y	Thermal	TRAY/SINDA		
		> Control	Y/N	Y	Y	Y	Control	MATLAB		
		> Multi-body Dyna	Y/N	Y	?	?	Multi-body Dynamics	N		
		Number DOF's	unitless	6000	6000	6000	DOF	multiple		
		Number DOF's	unitless	6000	6000	6000	Runtime	fast		
		Runtime on Sparc	min				Interface	mod erate		
		User Interface								
							TAOS (BALL)			
							Optics	Y		
							focal plane	?		
							Structures	Y		
							Thermal	Y		
							Control	Y		
							Multi-body Dynamics	?		
							DOF	multiple		
							Runtime	moderate		
							Interface	standard		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Precision Pointing Gimbals	High	aperture size	cm	40	N/A	N/A				
		range	mrad	340	N/A	N/A				
		accuracy	nrad	150	N/A	N/A				
		bandwidth	Hz	10	N/A	N/A				
		momentum compe	%	90	N/A	N/A				
		operating temperat	K	280?	N/A	N/A				
		degrees of freedom		2	N/A	2				

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	TPFA	DESCRIPTION	SOA	LIMIT	DEMO?
Non-precision	High	deployment accura	mm	N/A	10 cm	10 cm	**Inflatable Membranes**			flight
Deployable Subsystems		stability over tempe	mm	N/A	TBD	TBD	• unpredictable deployment (now)			
		microdynamic stabi	nm	N/A	N/A	N/A	• need space rigidization			
		scale of deployment	m	N/A	15	75	• low parts count			
		operating temperat	K	N/A	40	35	deployment accuracy	TBD	TBD	
		deployment temper	K	N/A	TBD	TBD	stability over temperature	TBD	TBD	
		packaging efficienc	%	N/A	high	high	microdynamic stability	TBD	TBD	
		deployed frequency	Hz	N/A	TBD	TBD	scale of deployment	15 m	150 m ??	
		areal density	kg/m	N/A	low	low	operating temperature	TBDK	TBD	
		thermal isolation		N/A	TBD	TBD	deployment temperature	TBDK	TBD	
							packaging efficiency	1%	1%	
Comment: Critical for NGST Sunshield							deployed frequency	depends on size and form factor		
							areal density	TBD	TBD	
							thermal isolation	TBD	TBD	
							Extendible Membranes			ground
							• predictable/controllable deployment			
							• ground testable			
							• based on unfurlable booms			
							• high parts count			
							deployment accuracy	1 cm?		
							stability over temperature	1 cm?		
							microdynamic stability	TBD nm		
							scale of deployment	10 m?		
							operating temperature	TBDK		
							deployment temperature	TBDK		
							packaging efficiency	<5%		
							deployed frequency	depends on size and form factor		
							areal density	TBD		
							thermal isolation	TBD		

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REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
IR Detectors							**InSb (1 - 5 um) (I)**			
Near Infrared (1-5um	High	DQE	%		~80		DQE	~80		
		Read Noise	e-		3		Read Noise	~7		
		Dark Current	e-/sec		0.01 - 0.1		Dark Current	0.1 (27 K)		
		Operating Temp	K		30-40?		Operating Temp	5 to 30		
		Format	nxm		1k x 1k		Format	1k x 1k (high bkgrnd)		
					4k Mosaic					
		Pixel Size	um		TBD		Pixel Size	~20		
							HgCdTe (5um cutoff) (II+)			
							DQE	~80		
							Read Noise	~30?		
							Dark Current	~80		
							Operating Temp	20-30?		
							Format	256 x 256; 1 k x 1 k in 2.5 um HgCdTe		
							Pixel Size	~20		
Thermal IR (5-20um)	High						**Si:As IBC (NGST & PF) (I)**			
		DQE	%		~50	~50?	DQE	40-50		
		Read Noise	e-		~3	<8	Read Noise	30		
		Dark Current	e-/sec		0.05, R=1E3	<2	Dark Current	1 to 2		
					<10, R=3		Operating Temp	4 to 6		
		Operating Temp	K		~6, or 30-40	~10 (6?)	Format	256 x 256		
		Format	nxm		512x512	18x50	Pixel Size	30		
					1K Mosaic		Wavelength	5 to 27		
		Pixel Size	um		TBD	TBD				
		Wavelength	um		5-20	7 to 17	**Si:Ga IBC (NGST & PF) (II)**			
							Operating Temp	10?		
							Wavelength	5 to 18		
							HgCdTe (17um Cutoff) (III)			
							DQE	60 - 70?		
							Read Noise	<100		
							Dark Current	~1E6		
							Operating Temp	20-40		
							Format	256 x 256		
							Pixel Size	50		
							Wavelength	5-~14		
							QWIP (NGST & PF) (III)			
							DQE	10 to 15		
							Read Noise	?		
							Dark Current	100000		
							Operating Temp	25		
							Format	256 x 256		
							Pixel Size	38		
							Wavelength	9, 15		

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REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Visible Detector Arrays	High	•High-speed, low-noise CCD					**Improved Si CCD (0)**			
(NGST may use only near-IR arrays)		QE	%	>80	>80?		QE	>80		
		Read Noise	e-	<5	3		Read Noise	3		
		Dark Current	e-/sec	0.1	0.01		Dark Current	0.01		
		Operating Temp	K	~300	30		Operating Temp	~120-300		
		Format	nxm	128 x 128 or 256x256	2k or 4k		Format	2 k x 2 k		
		Pixel Size	um	<30	15		Pixel Size	~12		
		Frame Rate	Hz	1000	30		Frame Rate	~0.1		
							Improved Active Pixel Sensor (I)			
		•APD for SIM					QE	60		
		rad-tolerance	rad	TBD			Read Noise	80		
							Dark Current	?		
							Operating Temp	40		
							Format	256 x 256		
							Pixel Size	15		
							Frame Rate	15		
							APD (SIM) (0)			
							QE	60		
							Read Noise	n/a		
							Dark Current	2 to 3		
							Operating Temp	220		
							Format	1		
							Pixel Size	100		
							Si p-i-n Array (I)			
							QE	85 - 90		
							Read Noise	30 - 50		
							Dark Current	650 @ 300K		
							Operating Temp	10K --> 300K		
							Format	512X512		
							Pixel Size	25		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Analog Readout Electronics	High						**Si Cryo CMOS (I)**			
		Temperature	K	300	30, 5	~6	Temperature	1.5		
		Read Noise	e-	3	3, 8	<8	Single-Sample Read Noise	30		
		Power	mW	TBD	~1	~1	Multiple-Sample Read Noise	6		
		"Glow" Level	ph/s	TBD	TBD	TBD	Power	0.3 (array)		
		Detector Bias Stabil	%	5?	~5	~5	Leakage Current	~0.1		
		Integration Time	s	TBD	100?	TBD				
		Leakage Current	e-/s	TBD	0.01 - 0.1	<2	**GaAs JFET (II)**			
							Temperature	<4		
							Single-Sample Read Noise	~100?		
							Multiple-Sample Read Noise	n/a		
							Power	?		
							Leakage Current	?		
							Photoelectron Counter (III)			
Analog-Digital Converters	High	ADC's					**Conventional ADC (0)**			
		Bits	#	?	?	?	Bits	13		
		Speed	Hz	?	?	?	Speed	200k		
		Power	mW	?	?	?	Power	1 mW/Mbps		
							Temperature	65		
							Superconducting ADC (I)			
							Bits	14		
							Speed	50k		
							Power	0.5		
							Temperature	4.2		
Focal Plane Packaging	Low						**Mosaic Focal Plane**	2,3,4 close-packed?		
(Believe that NGST can tolerate alleys between arrays in mosaics.)							gap	few pixels		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Mode Filter	High	Wavelength Transmission Loss Modal Purity	um %			10	**10 um hollow sapphire fiber**			
Beam Combiner Optics for Nulling	High	?								
Filters/Gratings Dichroics/Lenses	High	Diameter Transmittance, etc. Wavelength	cm % um	pres SOA 0.4-1	up to12 pres SOA 0.5-20	pres SOA 7 to 17	**Filters/Gratings/Dichroics/Lenses (0)** Diameter (Develop larger optical elements, with performance equal to or better than SOA)	~3-5		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Mechanisms (Linear and Rotary)	High						**Cryo mechanisms (e.g., ISO) (0)**			
		Temperature	K	300	30-40	6-10?				
		Number of Cycles	#	?	?	?				
		Rotation	degrees	?	?	?				
		Travel	cm	?	?	?				
		Power or Energy	mW, m	?	?	?				

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Instrument Cryocooler	High-Med						**He Turbo-Brayton (II)**			
		Temperature	K		6 - 10?	6 - 10?	Temperature	8		
		Heat Load	mW		~2+	~1	Heat Load	40 @ 8K		
		Power	W/W				Power	? (poor eff below 20 K)		
		Vibration	mN		~0	~0	Vibration	low		
		Lifetime	yrs		10	10				
		Sink Temp = flight system passive temp ~ 30-40K					**Hydrogen J-T Sorption (I)**			
							Temperature	10		
							Heat Load	scalable		
							Power			
							Vibration	very low		
							He Stirling J-T Hybrid (IV)			
							Temperature	5		
							Heat Load			
							Power			
							Vibration	mod to high		
							Solid Hydrogen (I)			WIRE
							Temperature	<7	vap press	
							Heat Load	<8mW		
							Power	0		
							Vibration	0		
							Magnetic (ADR) (II)			
							Temperature	<2 or higher		
							Heat Load	1 @ 5 K		
							Power			
							Vibration	0		
							LHe (0)			IRAS, COBE, SIRTF
							Temperature	<2		
							Heat Load	5-100		
							Power	0		
							Vibration	0		

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Communications										
High Rate Data Downlink	High	Data rate Weight Power Pointing	Mbps kg W deg		> 10 < 10 < 10 ± 25	> 1 < 10 < 5	**high bandwidth Ka**	> 1Mbps	~1Gbps	space
							small deep space transponder		3kg 15W	DS-1
Low rate command uplink/downllink	Med	Data rate Weight Power	kbps kg W		< 10 < 5 < 5	< 1 < 5 < 5	**DSTT**		< 1 kg	ground
							Ka band inflatable antenna - issues of rigidization - surface quality - contamination	L'garde	10m for Ka	space
							optical comm	> 1Mbps	> 1Gbps 3kg	space
Mass Storage System (MSS)		Capacity Power	Gb W		100 10	100 1	**CMOS DRAM** - 256 Mb and 1Gb die - requires refresh power	> 200 Gb 200W	> 1 Tb < 20 W	none
							Magnetic Disk array - based on COTS devices - non volitile storage	> 100 Gb	> 1Tb	lab
							Non volatile solid state devices - VBL - FRAM - holographic	< 1Gb	?? > 1Tb > 1 Tb	space
Communication Codes		Efficiency Robustness					**Turbo codes**			ground
Ground stations		Sensitivity Cost Operational Autonomy					**Ka band** - 34m DSN dish for Cassini, DS-1		70m	
							Optical - 3.5m telescope at Starfire		10m	

Comments:
Common need with solar system exploration roadmap for high data rate, low mass and power communication subsystem
Should explore multi use capability of communication systems to reduce mass and power further:
- optical comm combined with star tracker guidance functions
- inflatable antenna with power system (solar collector) and propulsion (soalr sail)

Comments:
Large mass storage systems on board NGST and TPFA permit store and forward operation
Coupled with high s/c autonomy, this permits greatly reduced ground operations, with lower costs
It will also alleviate outage issues with Ka and optical communication systems

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Propulsion Systems										
Orbit Insertion	High	Isp	sec		1500		**Solar thermal**			Lab
		Efficiency			15%					
		Power	W		300					
		Mass	kg							
							Ion Thruster (NSTAR)	3350 sec 2.5kW		DS-1
Station-keeping	High	Isp	sec		500		**Stationary Plasma**			Lab
		Efficiency			30					
		Power	W		300					
		Mass	kg				**microwave electric thruster**			
							solar sail			
Momentum managmen	High	Isp					**Inert Gas arcjet**			
		Efficiency								
		Power					**Solar sail**			
		Mass					**Pulsed plasma thruster**	1000s	2500s	
							stationary plasma			

Comments:

Major concern, especially for TPFA, that propellant systems do NOT contribute to optics contamination

High efficiency Ion Thrusters, or possibly solar sail, are absolutely neceesary for TPFA to get out to 5AU

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Power Systems										
Solar Arrays	High	Efficiency	%				**Silicon**	14%	18%	
		Power per Mass	W / kg				**GaAs**	19%	21%	
		op. temp	K			35K	**Multi-junction**	22%	27%	SSTI
							InP	13%	18%	
							Bandgap - engineered		38%	
							solar panel structure			
							APSA	> 50 W/kg	>150 W/kg	
							Ultraflex			
Batteries	Med	specific energy	Whr/kg							
		Op. temp.	K		50K	35K	**NiCd spec. eng.**	28		
		cycles					**Super NiCd**	24		
							IPV NiH2	33		
							CPV NiH2	38		SSTI
							Li-ion	90		DS-1

Comments:

Concern voiced about possible need for low operating temperature power systems - or need for high thermal isolation between ~250K power bus and cold telescope

Efficiencies quoted for typically for near earth operation - lower temp operation will reduce efficiency in some cells
- Advanced Si may be best choice for TPFA

Also need effort on low mass structures supporting solar cells

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Data busses & Electronic Packaging	Med	throughput circuit density mass power rad hardness	Mb/s gates/cm kg W krad				**AS 1773** - SCI developed	20 Mb/s		Lab
							Ring FODB - TRW developed, joint NASA/DOD program	1Gb/s		
							Chip on Board - GSFC Code X activity			
							3D and space cube architectures - JPL NM activity			

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Autonomy										Lb
Autonomous GNC Operations	High									
Onboard Resource Management	High									
Anomaly Detection and Correction	High									
On - board analysis of scienc data	Med									
Simulation	High									

Harware in the loop simulation necessary for phase C/D testing and validation of subsystems and operations that cannot be demonstrated with ground testing

Comments:

Autonomous operation is key to reducing mission lfecycle costs
Autonomy critcial to TPFA due to long comm delays

ORIGINS TECHNOLOGY SUMMARY

REQUIRED CAPABILITY		PERFORMANCE GOALS					TECHNOLOGY OPTIONS			
DESCRIPTION	PRIORITY	METRICS	UNITS	SIM	NGST	PF	DESCRIPTION	SOA	LIMIT	DEMO?
Structures	High									
Advanced Composites		cost reduction Modulus CTE CME								
Multifunctional structures										
Active release devices		low shock low contamination initiation timing	g NVR ms				shape memory alloy systems			

Non-precision Structures