Scientific Assessment of the Descoped Mission Concept for the Next Generation Space Telescope (NGST): Letter Report
National Research Council

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Space Studies Board
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

September 24, 2001

Dr. Edward Weiler
Associate Administrator for Space Science
NASA Headquarters
300 E. Street, SW
Washington, DC 20546-0001

Dear Dr. Weiler:

As you requested in your letter of May 10, 2001, to Space Studies Board Chair John McElroy, the Committee on Astronomy and Astrophysics (CAA) has reviewed NASA's plans for the Next Generation Space Telescope (NGST). NGST is the highest-priority new initiative for astronomy in the recently completed report of the National Research Council's Astronomy and Astrophysics Survey Committee (AASC), *Astronomy and Astrophysics in the New Millennium* (National Academy Press, Washington, D.C., 2001). As described in the AASC's report, NGST was to have been an 8-meter-class, infrared optimized telescope in space. Recently, due to budget and schedule constraints, your office began to consider modifications to the original mission concept and asked the CAA to assess the scientific merits of a descoped NGST with a 6-meter-class mirror.

At its meeting on April 9-10, 2001, the CAA received presentations from the NGST project office; the AASC's Panel on Ultraviolet, Optical, and Infrared Astronomy from Space; Alan Dressler, chair of NASA's Origins subcommittee; and groups involved in large ground-based telescope programs that might have complementary near-infrared capabilities.

The CAA notes that the proposed new baseline plan for the NGST project no longer includes the NEXUS precursor mission that was intended to test the technologies needed for the 8-meter NGST. The NGST project office testified that the plan for a descoped NGST would reduce the technical risk sufficiently that the NEXUS mission would no longer be necessary. The CAA was not asked to consider the engineering and technical risks involved in abandoning NEXUS and cannot offer an expert opinion on the matter. The scientific capabilities of the descoped NGST plan will not be affected by the loss of NEXUS.

The proposed new baseline plan for NGST involves three changes that might have an impact on the scientific performance of the observatory. The first, and most significant, change is the replacement of the 8-meter mirror by a 6-meter mirror. This reduction in mirror size will result in a 25% loss in spatial resolution ($\lambda/2D$ = 0.0344 arcseconds at 2 microns instead of 0.0258 arcseconds) and a ~44% loss in collecting power. As a result, the limiting point source brightness for a fixed observing time will be increased by a factor of ~1.8, while the observing time ($\sim D^4$) required to reach a point source of a given brightness will increase by a factor of ~3. As a result,

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the number of observations that the descoped NGST will be able to make to a given sensitivity limit during its lifetime will be reduced by a factor of ~3. The CAA regards this loss in observing capability as the most serious consequence of the proposed descope.

The second change is the specification of a near-infrared camera detector with 48 megapixels rather than 64 megapixels as planned originally. This cost-saving change is appropriate given the loss of angular resolution inherent in the proposed reduced aperture of the primary mirror. Assuming that the camera will be designed to provide Nyquist sampling at a wavelength of 2 microns, the new detector will provide roughly the same field of view as the original baseline design (~4 arcminutes).

The third change is the specification of a baseline operating temperature of 45 K for the telescope instead of 25 K. This change, according to the NGST project office, will reduce the level of technical risk by permitting active thermal control and improved dimensional stability of the telescope assembly. The increase in operating temperature will not affect the scientific performance of the observatory as specified in the original baseline design. The thermal background of the observatory will be greater than that of the zodiacal light only for wavelengths greater than about 12 microns, but this background is expected to be dominated by stray light from the sunshield rather than the thermal radiation from the telescope itself. The increased temperature proposed for the observatory would adversely affect the observatory's scientific performance at the longer wavelengths only if the thermal background from the sunshield could be reduced by more than an order of magnitude, a reduction that the NGST project office does not regard as likely.

The AASC report (p. 36) outlined five major science goals for NGST: (1) measure the light from the first epoch of star formation in the universe, (2) trace the evolution of galaxies from their birth to the present, (3) observe the birth of stars and planets in our own galaxy, (4) study Kuiper Belt objects in our own solar system, and (5) observe dust emission in galaxies out to redshifts of 3. The report emphasized that the NGST's capability to address the latter three goals will depend substantially on whether its sensitivity in wavelength will extend to 27 microns.

The CAA finds that all these major science goals can be met with the descoped option, despite the substantial loss in observing capability noted above. For detecting faint sources at wavelengths greater than 2.5 microns, the descoped NGST will still be 100 to 1,000 times more sensitive than the Space Infrared Telescope Facility (SIRTF), the most sensitive existing or planned facility for observing in this wavelength band (see the AASC report, Figure 3.2), and it will have nearly an order-of-magnitude better angular resolution than SIRTF. It will, for example, provide a unique capability to observe newborn star clusters at redshifts greater than 5. With the capabilities to achieve this goal and comparable milestones addressing the other major science goals listed above, the descoped NGST retains the priority recommended by the Astronomy and Astrophysics Survey Committee.

In his March 15, 2001, letter to Origins Theme Director Anne Kinney, Alan Dressler, on behalf of NASA's Origins subcommittee, stressed the importance of retaining the mid-infrared (5 to 27 microns) imaging and spectroscopy on NGST. The CAA concurs. The mid-infrared wavelength region offers the greatest potential improvement in sensitivity compared to the wavelength regions accessible to existing and planned telescopes on the ground and in space. At mid-infrared wavelengths, NGST will be able to study dust-enshrouded galaxies, newly forming stars, and planetary systems that may be invisible at shorter wavelengths. It will provide a unique capability for extending the process of discovery that will be initiated with SIRTF. NASA should

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make all possible efforts to preserve the mid-infrared capability and instrument package as described in the current project plan.

In considering the scientific capability of the descoped NGST, the CAA regards the new baseline plan provided by the NGST project team as a sound approach. The CAA did not consider the possible trade-offs among scientific performance and technical capability that led to this plan. If further major adjustments in the baseline capability of NGST are required, however, it will be important to engage the scientific community in considering the necessary scientific and technical trade-offs.

Sincerely,

/s/

John H. McElroy, *Chair*
Space Studies Board

/s/

John P. Huchra, *Chair*
Board on Physics and Astronomy

Attachments:

Letter of request from E. Weiler to J. McElroy
Letter from A. Dressler to A. Kinney
Presentation to CAA by NGST Project Office

cc: Richard M. McCray, Co-chair, CAA
Wendy L. Freedman, Co-chair, CAA
Joel R. Parriott, Study Director, CAA
Joseph K. Alexander, Director, Space Studies Board
Donald C. Shapero, Director, Board on Physics and Astronomy

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National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

MAY 10 2001

Reply to Attn of: S

Dr. John McElroy
Chair
Space Studies Board
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

Dear Dr. McElroy:

As you know, modern astrophysics has been revolutionized by a series of increasingly powerful space observatories. Consistent with recommendations of the 2000 National Research Council report, *Astronomy and Astrophysics in the New Millennium*, for a follow-on mission to the Hubble Space Telescope, NASA is studying the capabilities and implementation challenges of a Next Generation Space Telescope (NGST). As these studies have progressed, we have obtained improved insight into the formidable challenges presented by this mission. In order to maintain the project's cost and technical feasibility, we have recently completed a rescoping exercise that resulted in changes to the observatory's design and enabled elimination of two precursor technology demonstration flights. The Space Studies Board's Committee on Astronomy and Astrophysics was recently briefed on the rescoped mission concept. I would like to request that the Board provide a review of the scientific capabilities of the rescoped design. Similar reviews were conducted and reported by the Board for Cassini (letter to Dr. L. Fisk dated October 19, 1992) and Chandra (letter to Dr. W. Huntress dated April 28, 1993) missions.

Specifically, I would like to ask that the Committee on Astronomy and Astrophysics and Space Studies Board assess the science capabilities of the new mission concept. A key question for the Board and Committee is whether they believe that the rescoped mission would retain the top flight mission priority that was assigned to the original NGST concept by the community in the 2000 survey. It would be helpful if we could receive the results of the assessment during September 2001.

If you have any questions about the NGST project or our plans and requirements, please contact Dr. Anne Kinney, who is responsible for the NASA Origins program.

Sincerely,

Edward J. Weiler
Associate Administrator
for Space Science

March 15, 2001

Dr. Anne Kinney
Origins Theme Director
NASA Headquarters
300 E. Street, SW
Washington, DC 20546-0001

Dear Dr. Kinney,

The Origins Subcommittee (OS) met at JPL on March 6 and at the Carnegie Observatories on March 7. We appreciated the briefing provided by you through Rick Howard on developments within Origins since our October meeting, and are grateful that Associate Administrator Ed Weiler was able to review the health of OSS missions in general. As at our last meeting, all three of you stressed the substantial progress and great enthusiasm for Origins missions tempered by the concerns of difficult schedules and budgets. In this connection we thought it particularly important to make time during our second day to review the Origins Theme architecture from the perspective of scientific directions, schedules, and budgets now that Origins is maturing. We append to this letter a summary of our thoughts on these broad-reaching concerns.

SIM - Space Interferometry Mission

The OS was apprised by Tom Fraschetti (SIM Project Manager) of how the SIM team plans to address the recent SIM replan imposed by the OSS. This replan entails a $930 M cost cap, the requirement that terrestrial planet detection be a key mission goal, and the requirement that SIM identify potential targets for TPF. Fraschetti summarized three design options, the Shared Baseline SIM, ParaSIM, and Sonata, that meet the new requirements. Shao and Fraschetti both advocated the Shared Baseline option over the other two as still cost-effective, while maintaining most of the original science capabilities of the SIM reference design. The OS commends the SIM team for it impressive efforts in redesigning SIM to meet the new requirements of OSS and for its continuing and steady technological progress towards meeting the current SIM metrology and astrometry goals.

The Shared Baseline SIM would still retain an unmatched single observation accuracy (~100 times better than FAME), and would be the only astrometry mission in the near-term that might detect large terrestrial planets. We note that the ability to make wide-angle astrometric measurements is essential if SIM is to find and characterize planets in Jupiter-like orbits, i.e., analogs to our own solar system. We are gratified that this same wide angle capability also enables a robust program of general astrophysics with strong community support, and note that it does not appear to impact significantly the cost of SIM.

The problems they are addressing are difficult, but the SIM team is making steady progress: the project is close to achieving the milestone of picometer metrology and has positive momentum. However, the OS believes that their charter should not be

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open-ended. ***We recommend that the SIM team be given approximately two years to develop the required component technology for picometer metrology (using the MAM-1 testbed) and then to integrate that technology into a systems-level testbed that validates SIM's error budget and performance at the level necessary to detect (large) terrestrial planets. These demonstrations should be prerequisites to initiating the Non-Advocate Review and entering into Implementation Phase. If at that time (early in Phase B) they are not able to demonstrate such performance, then a significant restructuring of the program or cancellation should be considered.***

NGST - Next Generation Space Telescope

The OS was briefed by Project Manager Bernie Seery and Project Scientist John Mather on the project's proposed rescope, aimed at returning NGST to the intended budget and schedule and at eliminating the need for a full-up technology demonstration (the proposed Nexus). The plan calls for a reduced aperture, a warmer telescope (about 50K), and some reductions in focal plane instrumentation, in particular a proposal for a reduction in the number of pixels of the near-IR camera. The OS believes that even with any or all of the proposed changes the NGST would remain the immensely powerful facility that was given first rank by the McKee-Taylor Decadal Survey.

The OS was pleased to hear of the Project's progress on various fronts; there seems to be a steady march toward technology readiness in all phases so as to allow NGST to move into its next phase on schedule. The OS does, however, share the concern of the ISWG --- apparently also felt at Headquarters ---- about the complexity of proposed instrument collaborations among US, Canadian, and European instrument builders and their respective space agencies. We strongly favor agreements which place the responsibility of the near-IR camera wholly or primarily with US scientists and institutions, and similarly clean, workable interfaces for US participation with foreign partners in the other instruments, as appropriate. The OS agrees with the ISWG that the success of these negotiations can have a huge impact, positive or negative, on the future of NGST.

The OS discussed the priority of mid-IR capability on NGST. Mid-IR science was ranked highly by both the ASWG and ISWG, with three of the six identified core science topics requiring this waveband. The OS also wishes to stress the importance of mid-IR imaging and spectroscopic capability on NGST.

The mid-IR waveband is an important probe of galaxy formation and evolution at high redshift, NGST's core mission. Stellar populations older than ten million years have spectral energy distributions which peak at a rest wavelength of 1.6 microns, which is redshifted into the mid-IR for the likely first epoch of star formation. In addition, there is abundant evidence that dust plays a major role in the energy distributions of a substantial fraction of high-z galaxies, so coverage in the mid-IR could be crucial. This also could be relevant to the direct detection of the epoch of re-ionization, which might be more easily observed through observations of redshifted H-alpha than Lyman-alpha if the absorption of the latter by dust or neutral hydrogen is very important.

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Circumstellar disks, another key component of the Origins program, are also a prime target for the mid-IR, and high-resolution imaging can detect small disks with gaps, rings, and warps, all of which may be dynamical signatures of the presence of planets. Mid-IR spectroscopy of these disks can measure the evolution from an active accretion disk to a planetary debris disk. In addition, there are spectroscopic signatures of both the chemical and physical mineralogy of the solid material in these disks, providing important diagnostics to the planet formation process.

The OS heard from Bernie Seery that mid-IR instrumentation is not driving the cost of NGST (a concern expressed in the HST & Beyond Report), for example, by requiring a lower telescope temperature. (Of course, we recognize that each additional instrument adds not just its own cost but also the expense of integrating it into the system, but this to us does not qualify as "driving the cost.") From the point of view of continuity within the Origins program, NGST with mid-IR capability would provide a powerful scientific descendant of SIRTF, with an improvement of a factor of 7.5 in angular resolution and two orders of magnitude in sensitivity, and also provide a technology precursor for the proposed nulling interferometer design for TPF. ***Putting it all together, the OS believes that mid-IR science is very important for NGST, a substantial increase in science for a modest increment in cost. We think it premature to consider giving up this capability before an in-depth investigation of possible tradeoffs at the instrument complement level and at the systems level. We were glad to learn that the Project could present to the ISWG a number of similar cost options that retain the mid-IR instrument, an approach we strongly endorse.***

SIRTF - Space Infrared Telescope Facility

The OS thanks Mike Werner for an update on progress towards the launch of SIRTF in July, 2002. We learned of the cryostat over-pressure problem during testing and the progress toward recovery. Despite the regrettable cost implications, we look forward to a successful fix and the likelihood of the mission staying on schedule.

It was exciting and gratifying to have the SIRTF Legacy programs reviewed by Tom Soifer. The breadth and depth of these early programs re-emphasize the powerful scientific potential of SIRTF that we are all anticipating.

SOFIA - Stratospheric Observatory for Infrared Astronomy

We thank Cliff Imprescia and Eric Becklin for bringing us up to date on SOFIA. Although optimism was expressed about the state of technology development, the OS remains concerned that the Program can be brought to a successful conclusion with the available resources. ***This notwithstanding, we support your decision to attempt to accommodate the projected cost overruns within the SOFIA Program budget.***

This committee has previously stressed the importance of ensuring that SOFIA data be easily and quickly available to the larger scientific community. While we understand the project's current concern with completing the observatory and initial suite of instruments, we encourage the project to continue to press forward its data handling development program as rapidly as possible. Particularly with the now-anticipated delay of order two years in the start of observatory operations, it is of great importance that the data processing, analysis tools, and archival access be available to the science community at the beginning of observatory operations, at least for facility instruments

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and preferably for PI instruments as well. ***We request, again, a detailed description of the plans for data processing and distribution from the SOFIA project at our next meeting.***

The OS feels that it is very important that the difficulties SOFIA is encountering not adversely affect other Origins programs, which suggests regular updates until the program has demonstrated it is on the road to a successful implementation within the budget envelope. ***Accordingly, the OS requests a detailed briefing on the new budget, schedule, and management structure at our next meeting.***

Starlight

The OS appreciated the opportunity to hear from Leslie Livesay about the progress of the Starlight technology demonstration mission (formerly known as ST-3) and to view the experimental testbed in the laboratory. We were impressed to see the progress made in proving the viability of the innovative design change that allows the mission to achieve its goals using only two spacecraft instead of the original three. The two technologies to be demonstrated, precision formation flying and separated spacecraft interferometry, are necessary for development of a multi-spacecraft architecture --- one possible option for Terrestrial Planet Finder (TPF) --- and are of importance for several other proposed Code S missions. However, given the uncertainty of the TPF technology path, the OS is concerned about the large and growing investment in this particular technology demonstration mission.

Kepler and Eclipse

Bill Borucki and John Trauger briefed the OS on the status of the proposed Kepler and Eclipse science missions, respectively. Both missions seek to answer important and complementary Origins questions regarding the statistics of habitable planets and solar system analogs. The results from these missions or missions like them would doubtless influence the design of TPF. Each received high marks for science in the recent Discovery AO process. Because the OS also strongly endorses their scientific goals, we are pleased that the Kepler program has been approved for Phase A study and that you have provided funding for technology development of the high contrast imaging required for a coronagraphic study of the nearest stars, as has been described in the Eclipse proposal. ***Given the renewed interest in using coronagraphy in the TPF mission, and the potential for excellent and relatively rapid science return in a mission like Eclipse, the OS recommends that the Origins theme continue to invest in developing this and related technologies.***

We append to this letter a summary of our discussion, made at your request, about the current state of the Origins program. We look forward to continuing the discussion on this and the items mentioned above at our next meeting at NASA HQ July 11-13.

Sincerely,

Alan Dressler, for the Origins Subcommittee

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Next Generation Space Telescope (NGST)

A Presentation to the National Academy of Sciences Committee on Astronomy and Astrophysics

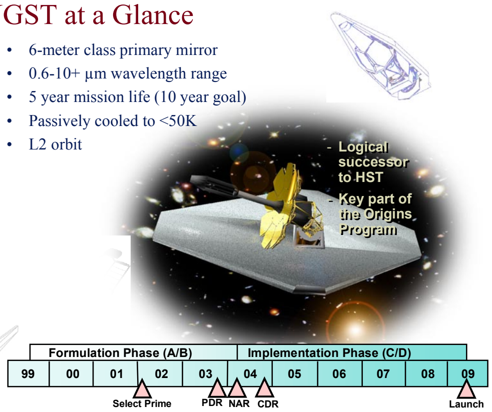
Bernard D. Seery
John C. Mather
April 9, 2001

-- Outline --

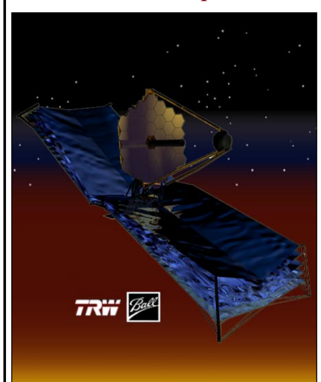
- NGST at a glance
- Rescope process
- Rescope summary
- Instruments and Science
- International partnership concepts
- Schedules and major procurements
- NASA-funded technology development status update
- Wrap up and discussion

NGST at a Glance

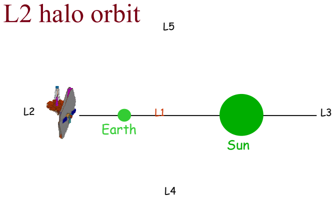
- 6-meter class primary mirror
- 0.6-10+ µm wavelength range
- 5 year mission life (10 year goal)
- Passively cooled to <50K
- L2 orbit



NGST Concepts



NGST at L2 halo orbit



- **Single sunshield protects from Earth and Sun**
- **8-16 hour visibility from single ground station**
- **Simple operations compared to HST**
- **0.01 AU away, but not serviceable by astronauts**
- **Halo orbit around L2 avoids Earth shadow**
- **Unstable orbit requires ~ 3 m/sec/year corrections**

Rescope Process

- Driven by procurement process and design to cost - must have resources consistent with the purchase plan
- Initiated by Project Office last summer with detailed in-house cost estimates of all parts of project, with schedules, PERT charts, test plans, risk management plans, and budget and schedule targets
- Based on US-only cost analyses, but ESA and CSA have agreed in the past that our methods were close enough to theirs
- Main technical changes were to meet the following objectives:
  - Risk reduction without Nexus flight demonstration
  - Launch by 2009
    - Hold schedule
    - robustness
  - Compatible with more than one launch vehicle
  - Stay with core instrument complement and ASWG priorities- preserve science program

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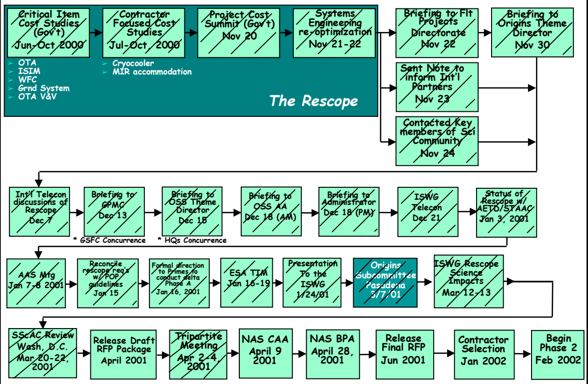
Rescope Process Flow



Re-scoped NGST Reduces OTA Risk

Re-Scope	Specific Impact	Risk Assessment
PM Diameter: 8m class ➡ 6m class; *Dressler minimum - 4m*	• Reduces total optics fab time • Frees up mass & vol allocation, can be applied to other critical elements	• Reduces schedule risk • Increased structural rigidity, reduced 1G off-loading complexity
Areal Density: 15 kg/m² ➡ >20 kg/m²; *Hubble was 180 kg/m²*	• Reduces risk in PM segment development (segment design trade space less restricted) • Reduces 1G sag (more rigid backplane)	• Reduces tech & programmatic risk associated with most critical NGST new technology • Reduces 1G off-loading complexity, reduces risk in system level WFS/C testing
OTA Temperature: 30K/passive ➡ up to 45K/active	• Enables OTA active thermal control • Reduces dependence on material properties and environmental effects	• More robust telescope architecture • Reduces risk associated with opto-thermal stability
WFS/C Update 1 month ➡ 1 day	• Increase bandwidth of sensing & control loops • Reduces thermal & structural stability requirements	• Adds robustness & design margin to OTA subsystems
1-g Testability: Limited subaperture testing vs full aperture plane wave (TBR)	• Enables system-level optical tests with "star-like" source • Allows control system to see substantial portion of full aperture	• Critical step in integrated model validation and observatory-level performance confirmation

Rescoped NGST Eliminates Need for Nexus

Nexus Risk Mitigation	Re-scope Risk Mitigation
WFS/C performance in the space environment	Increased WFS/C bandwidth & more robust design
Observatory long-term imaging stability in space	Raise operating temperature to enable active thermal control
Validation of integrated models and I &T approach	Pre-launch system-level optical testing (designed for 1-G testing)
Establish cost curve and develop mirror fabrication & production processes for ultra-low mass segmented telescope	Increase areal density & reduce mirror area, thereby reducing cost & schedule uncertainty of primary mirror development

Next Generation Space Telescope
NGST
A NASA Origins Mission

ASWG Prioritized Instrument Metrics

- Sensitivity Over Wide Fields of View
  - Discover faint new objects
  - Support General Observer science

Wavelength Range
Fully utilize discovery space
Ensure widest possible redshift coverage

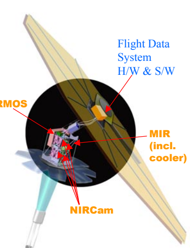
Spectral & Spatial Resolution for DRM Science

- Surveying Efficiency
  - Spatially multiplexed spectroscopic capability
  - Statistics of galaxies & lenses; guide stars
  - Accomplish DRM in 2.5 years

Next Generation Space Telescope
NGST
A NASA Origins Mission

ASWG recommended Instrument Suite

- 4´ x 4´NIR Camera
  - Nyquist sampled at 2 µm, 0.6-5 µm, *R*~100 grism mode
- 3´ x 3´ NIR *R*~1000 Multi-Object Spectrograph
  - Simultaneous source spectra(" 100), 1-5 µm
- 2´ x 2´ Mid IR Camera/*R*~1500 Spectrograph
  - Nyquist sampled at ~10 µm, 5-28 µm, grisms & slit



Next Generation Space Telescope
NGST
A NASA Origins Mission

4th Instruments rec. by ASWG (not in plan)

- NIR R=3000-5000 psf-sampled spectrometer
  - "0.1´´ angular resolution, ~2´´ x 2´´ FOV
  - 2d for single, extended object spectroscopy
- 0.6 - 1 µm camera (sampling diffraction spike)
  - ~0.01´´ angular resolution, 1´ x 1´ FOV
  - (Note-- assumes NIRCAM has 0.6 µm capability)
  - stellar pops/WD cooling curve, circumstellar disks, high z gal. Morphology
- MIR R=3000-5000 psf-sampled spectrometer
  - "0.3´´ angular resolution, " 2´´ x 2´´ FOV, 5-28.3 µm
  - Instead of R~1500 add-on spectrograph to MIR camera

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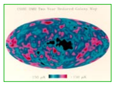
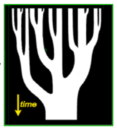
NGST & the Early Universe

ASWG: Simon Lilly

$\Delta\rho/\rho \sim 10^{-5}$



Galaxy assembly



Galaxies, stars, planets, life

- Early evolution of stars and galaxies:
  - What were the first sources of light in the universe?
  - How were galaxies assembled?
  - What is the history of star birth, heavy element production, and the enrichment of the IGM?
  - How were giant black holes created and what is their role in the universe?

NGST Deep Imaging: 0.5–10 μm

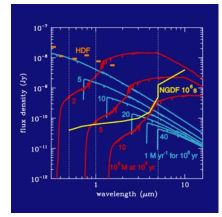
ASWG: Simon Lilly

4'x4' deep survey field

5000 galaxies to AB ~ 28, 10^5 galaxies to AB ~ 34 photometry, morphology & z's

Depth: AB ~ 34 in 10^6 s
Redshifts: Lyman α to z = 40 (?) 4000 Å to z = 10

NGST will detect 1 $M_\odot$ yr^{-1} for 10^6 yrs to z ≥ 20 and 10^8 $M_\odot$ at 1 Gyr to z ≥ 10 (conservatively assuming Ω = 0.2)



Evolution of Planetary Systems

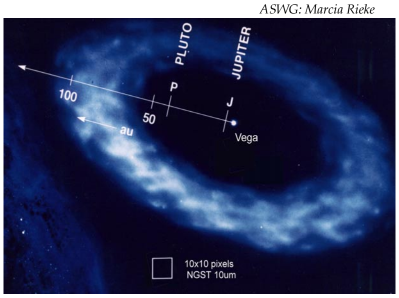
ASWG: Marcia Rieke

Vega Disk Detection

λ (μm)	Flux* (μJy)	Contrast Star/Disk
11μm	2.4	1.5x10⁷
22μm	400	2x10⁴
33μm	1300	3x10³

Reflected & emitted light detected with a simple coronograph.

*per Airy disk



NGST resolution at 24μm = 5 AU at Vega, > 10 pixels across the inner hole

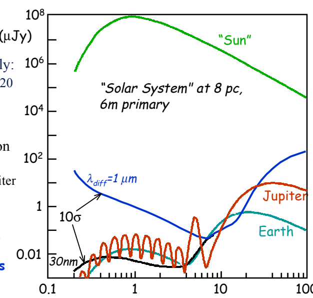
NGST & Extrasolar Planets

From Angel & Woolf 1998, in *Science with the NGST*, ASP, **133**, 172

- Control of primary only:
  - Jupiter at 10 < λ < 20 μm

Active wavefront correction to 30 nm rms
Direct detection of Jupiter λ > 0.4 μm

Not a baseline program, but a natural upgrade issue for future missions such as TPF or an NNGST.



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Design Reference Mission

- DRM contains the Dressler Report science
- DRM does not preempt proposal process
- 23 large, critical science programs that could be carried out in ~2.5 years
- 7 Core Programs
  - 1: Form. & Evol. of Galaxies - Imaging
  - 2: Form. & Evol. of Galaxies - Spectroscopy
  - 3: Mapping Dark Matter
  - 4: Search for Reionization Epoch
  - 5: Measuring cosmological parameters
  - 6: Form. & Evol. of Gals. - Obscured Stars & AGN
  - 7: Physics of Star Formation: Protostars

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7 Core Programs Requirements

- 1: 2 μm diffraction limited imaging, wide FOV, 8m sensitivity, 0.6-5 μm
- 2: 1-5 μm NIR multiplexed spectroscopy, R=100-3000; 5-10 μm spectroscopy, R=3000
- 3: Wide FOV; stable psf
- 4: Very sensitive NIR spectroscopy R=100-300
- 5: Ability to follow fields over months
- 6: MIR (10-28+ μm) imaging/spectroscopy, R=300
- 7: MIR (10-28+ μm) imaging/spectroscopy, R=3000+

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Observing Speed Scaling Laws

- D^2N_{pix} for diffraction limited survey to given depth
- D^4N_{obj} for multiobject spectrograph, detector limited
- 1/(zodiacal light + stray light) for background limited detector sensitivity (R<50 in near IR)
- 1/(physical pixel area) for dark current and cosmic ray limited sensitivity - NGST has funded development of detectors with smaller pixels
- $(\text{exposure time})^2/(\text{read noise})^2$ for read noise limited detectors - sets minimum useful exposure time for spectroscopy
- (optical efficiency * QE * Strehl)^2 for dark current or read noise limit; linear if background limited
- Conclusion for NGST: Design Reference Mission takes about 2-3x as long for 6.5 m, 48 Mpix NIRCAM as for 8 m with 64 Mpix

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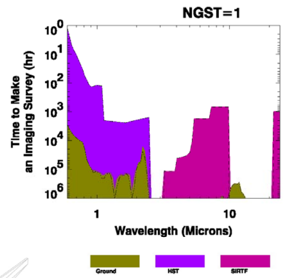
Yardstick Cameras vs. other observatories
(8m, 4´x4´, 64Mpixel NIRCAM, 35K OTA)



Primary:	8m
FOV(arcmin):	4x4
%DRM:	100%
Diff Lim(μm):	1.5
OTA Temp:	35K
MIR:	Yes
EELV	

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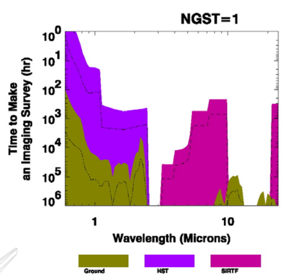
Rescoped Cameras vs. other observatories
(6.5m, 4´x4´ 48Mpixel NIRCam, 50K)



Primary:	6.5m
FOV (arcmin):	4x4
%DRM:	67%
Diff Lim(μm):	2.0
OTA Temp:	50K
MIR:	Yes
EELV	

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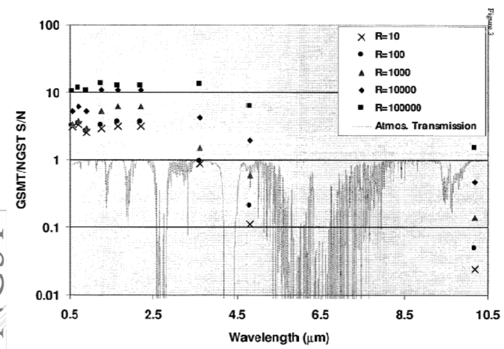
25 m GSMT / 8 m NGST: spectroscopy



Decade Survey Draft, p. 107

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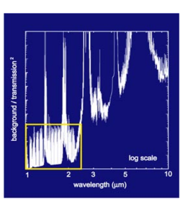
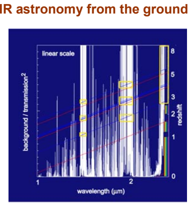


IR astronomy from the ground



The outlook for NGST in the Near IR

ASWG: Simon Lilly

It is reasonable to be pessimistic about ground-based observations for:
(a) all deep observations at λ > 2.2 μm
(b) systematic multi-line spectroscopy at 1 < λ < 2 μm (OH emission and H_2O absorption)
(c) anything requiring diffraction limited imaging at λ < 1 μm or (wide-field) imaging at 1 < λ < 2 μm (c.f. AO)

i.e. modest progress in programs involving:
(d) the very highest redshifts
(e) systematic diagnostic spectroscopy
(f) stellar (CO-bandhead) masses at high z
(g) the energy sources in all except the most luminous high *z* ULIRGs (c.f. SIRTF)

These are the central goals of NGST program on the formation and evolution of galaxies, which are therefore likely to remain current

What's Changed since 1996?

- Discovery of cosmic far IR background and its sources shows dust re-emits half the luminosity of the universe (COBE, SCUBA, ISO)
- Discovery of large numbers of high redshift AGN and dusty Chandra X-ray sources shows black holes are significant part of total luminosity
- Discovery of many unexpected planetary systems shows planetary formation is very important problem
- Theoretical predictions that first objects in the universe were at redshift 20-30 ups the ante for sensitivity and wavelength range
- Multi-Conjugate Adaptive Optics and proposed 20-30 m ground based telescope complement NGST (like Keck and HST), and reduce NGST advantage at λ < 2.5 μm, especially for spectroscopy

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Scientists think Mid IR is worth the cost

- **Dressler 1996 - yes: "Extension of this telescope's wavelength range shortward to about 0.5 µm and longward to at least 20 µm would greatly increase its versatility and productivity. The Committee strongly recommends this course, if it can be done without a substantial increase in cost."**
- **ASWG (Ad Hoc Science Working Group): yes (unanimous vote on core instrument complement, and wavelength range was 2nd priority after sensitivity)**
- **Decadal Survey: yes: "Extending NGST's sensitivity deeper into the infrared, from the 10 µm currently planned to 30 µm, would substantially improve its ability to study Kuiper Belt Objects (KBOs) in our solar system, the formation of planets in our Galaxy, and the dust emission from galaxies out to redshifts of 3."**
- **ESA advisory system: yes (was basis for selection for F mission funding)**
- **ISWG (Interim Science Working Group): yes**
- **Origins Subcommittee - yes: "Putting it all together, the OS believes that mid-IR science is very important for NGST, a substantial increase in science for a modest increment in cost."**

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Engineers think the mid IR cost is reasonable

- Telescope design not driven by mid IR
  - Shortest wavelength drives accuracy spec
- Test program not driven by mid IR
  - Telescope can be regulated at 50 K to stabilize it
- Passive cooling design not driven by mid IR
  - Needed for InSb to run at 30 K
  - Mid IR system gets its own sub-cooler
- Detectors not major cost
  - SIRTF sensitivity already adequate, small number of chips
- Mid IR instruments not major consumers of services (data rate, mass, power)
  - All dominated by the Near IR camera

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Could the First Objects be seen in the Mid IR?

- UV objects re-ionized the universe - but was most of the UV and Ly α absorbed by the IGM? Or by dust? Which came first?
- Massive objects and AGN **could** form dust very rapidly (10 Myr) if the dust stays near the objects, so the first objects **might almost immediately become MIR bright** too
- At z = 20, Ly α is 2.6 µm, but H α is 13.8 µm - we'd like to see it
- To know something is primordial, we need to **show** it has **NO** metals or dust
  - [O III] 5007 A is strongest metal line expected for z > 9, falls beyond 5 µm for z > 9

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Origins of Planets - Primary Mid IR NGST Science

- History of metal abundances as raw materials over age of Universe - when could life first form?
- Direct view of protoplanetary and planetary debris disks
  - Temperature, density, chemistry, orbital resonances with planets
  - Relation to formation of binary stars
  - Organic chemistry - astrobiology
- First direct view of planetary-mass objects
  - Easy shot for objects separated from bright stars
  - Scientific precursor for TPF
- Comparative planetology - Solar System objects versus observed disks, "loose planets"

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International Partnership Concept

- ESA ~$200M (FY96) value of effort, gains 15% observing time on HST and NGST; ESA has approved funding subject to successful detailed plan
- CSA ~$50M (FY96) value of effort, gains 5 observing time on NGST
- Initial goal 50-50 split of instrument/non-instrument contributions
- Exploring ESA contribution to spacecraft bus, based on Herschel (FIRST)/Planck bus contract to be announced shortly
- CSA contribution probably fine guidance sensor and contribution to near IR camera
- CSA and ESA would fund staff at STScI

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Instrument Partnership Concepts

- Current favorite idea, from Tripartite meeting 4/4/01:
  - NASA to provide shared instrument services (electronics, thermal, data system, …) and integration and test
  - NASA AO to provide NIRCAM
  - ESA to provide NIRSPEC, based on US detectors and multiobject selector
  - NASA/ESA/member nations to develop detailed partnership plan for Mid IR instrument, using Mid Infrared Steering Committee to define the concept and work breakdown structure. US to provide detectors and their electronics.
  - CSA to provide separate fine guidance sensor, and contributions to NIRCAM

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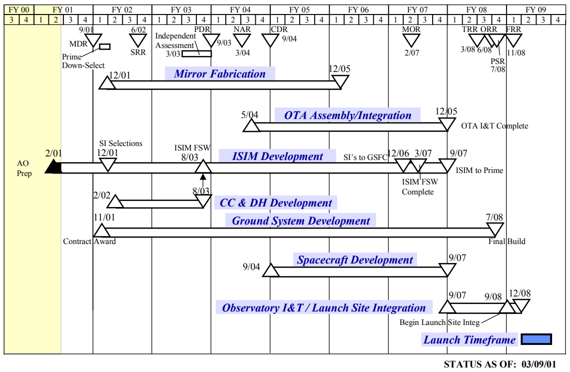
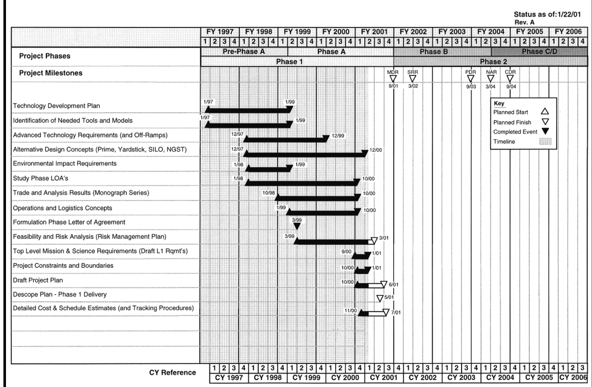
NGST Top Level Observatory Schedule



STATUS AS OF: 03/09/01

NGST Phase A Products



Technology Development Progress

Technology	TRL in early 2000	TRL Currently
Sunshield	4	5-
WFS&C	3	4
Mirrors	3	4
Actuators	4	5
MEMS	3	4
Cryo DM	4	5
Deployables	3	4
Detectors	3	4

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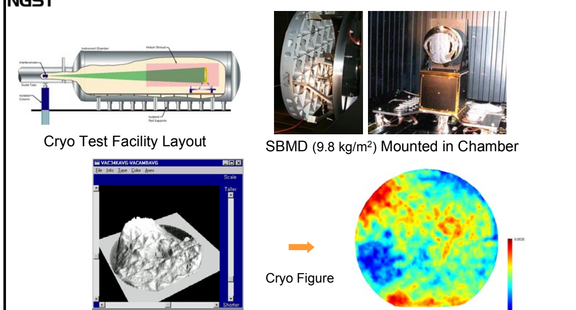
Cryo Testing of SBMD at MSFC



Cryo Test Facility Layout

SBMD (9.8 kg/m²) Mounted in Chamber

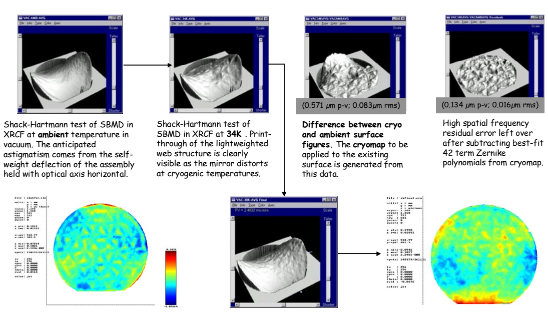
Cryo Deformation

Surface error: 34K - 288K (571 nm p-v; 63 nm rms)

Cryo Figure

Final Surface @ 35K (17 nm rms) Gravity Corrected

Validation of SBMD Cryo-Null Figuring



Shack-Hartmann test of SBMD in XRCF at ambient temperature in vacuum. The anticipated astigmatism comes from the self-weight deflection of the assembly held with optical axis horizontal.

Shack-Hartmann test of SBMD in XRCF at 34K. Print-through of the lightweighted web structure is clearly visible as the mirror distorts at cryogenic temperatures.

(0.571 μm p-v; 0.083μm rms) Difference between cryo and ambient surface figures. The cryomap to be applied to the existing surface is generated from this data.

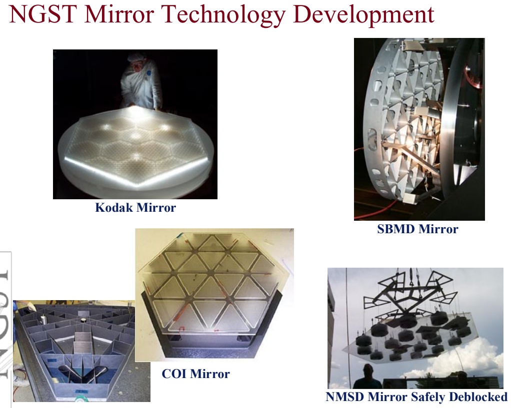
(0.134 μm p-v; 0.016μm rms) High spatial frequency residual error left over after subtracting best-fit 42 term Zernike polynomials from cryomap.

Ambient temperature measurement of SBMD with cryomap applied, ready for final test.

At 38K, web print-through and center dimple are significantly reduced compared to cryo map at 34K prior to cryofiguring.

Final surface of SBMD at cryogenic temperatures, with gravity effects removed by averaging of multiple rotations.

NGST Mirror Technology Development



Kodak Mirror

SBMD Mirror

COI Mirror

NMSD Mirror Safely Deblocked

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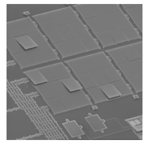
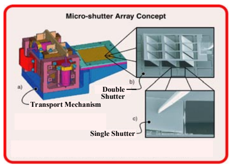
Microdevice Test Arrays for NGST

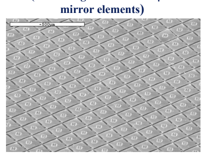
- Objective: Develop technology to allow selection of >100 targets per/FOV for NIR spectroscopy
- Pursuing both micromirror and microslit selector technologies
- Major focus for NRA 2 funding
  - Issue: Riskiest instrument technology, offramps to be pursued by ESA



Sandia National Lab

(Both designs feature 100 µm mirror elements)





GSFC 256x256 array

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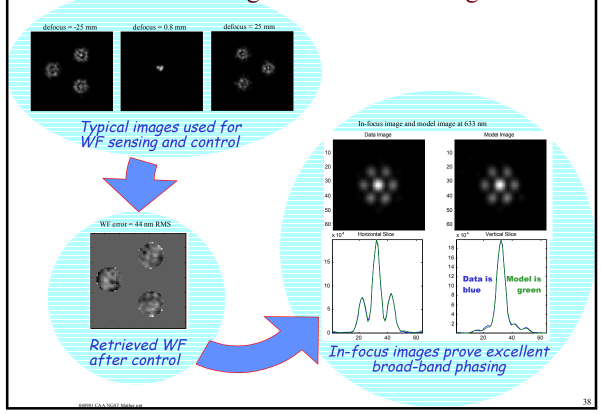
WCT- 2 Segment Mirror Phasing



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JPL Phase Retrieval Camera

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Report Card for Last Year - Accomplishment Metrics

Last Year's Goals	Status to Date	Comments
• System Studies		
- ISIM Delta formulation studies/cost estimates	- Formulation and cost studies complete in October 2000	- Revisiting weight margin and investigating cryo-materials issues
- OTA cost model development	- New, joint NASA/DoD telescope cost curve developed in October 2000	- Based on AMSD developments
- Cryocooler vs cryostat trade	- Trade study by both primes complete in September 2000	- Project to proceed with cryostat due to near term cost pressures, and push cryocooler development off on LTSI
- International agreements and Phase A/B studies	- Agreements on the non-instrument components put on hold till after rescope; signed annexes to the Letters of Agreement in place	- Agreement on the MIR TBD - Bilaterals in March/Tripartite in April
• Pathfinder Flights - ISIS	- Cancelled due to shuttle manifest delays of flight until 2002	- Cost overruns projected to continue on the ILC Dover shield contract
- Nexus	- Cancelled due to budget shortfall in 2001-2002 and mirror delivery schedules longer than originally anticipated	- Large-scale OTE testbed pulled forward in the program - LTS may enable SIM STS launch strategy

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Report Card for Last Year - Accomplishment Metrics

Last Year's Goals	Status to Date	Comments
• Programmatic		
- Phase 2 Downselect	- SEB on track to release RFP in June	- Original target of March 2001 delayed 3 months by rescope
- NRA 2 Instrument Tech Awards	- 6 awards made in January 2001	
• Technology - Advanced Mirror Systems Demonstrator Phase 2	- Phase 2 underway and hardware being developed	- Traceability/manufacturing process review held in January 2001
- NGST Mirror Systems Demonstrator Phase 2 complete	- COI hybrid glass mirror completed 2 of 3 cryo figuring cycles; U of A mirror actuator fab behind schedule and 2nd deblocking took longer than advertised	- Completion determined by XRCF testing schedule
- Focal plane development	- Hardware scale-up continues with first SCA deliverables in July 2006	- Technology downselect in June 2003
- Wavefront Control Testbed completion	- WCT 3 complete; PRC complete by May 2001	- Gov't will continue to further refine the testbed until NAR
• Science - Revitalize Science Advocacy Group	- ISWG replaced ASWG in November/December of 2000	- First face-to-face meeting in January 2001

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Cost Growth Since Pre A Studies

Cost growth since the Pre A estimate:

- Nexus startup had been delayed twice in the last 2 years due to budget shortfalls
  - Schedule delays precluded the original early risk mitigation intent
  - Flight test by mission CDR was deemed too late
    - Contributed to cost growth in early Phase C as higher fidelity testbeds were required early
  - New agency risk posture drove up verification costs in Phase D
- Instrument module growth due to:
  - Increased requirements to improve performance above SIRTF
  - Need to develop key instrument technologies like MEMs
  - Desire to reduce development risk through a more conservative (more expensive) model philosophy
  - Inability to achieve planned level of integration due to international agreements
- International agreements have not yielded dollar-for-dollar savings

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Goals for Next Year (2002)

- Programmatic
  - Phase 2 Contract Award
  - ST ScI under separate NGST contract
  - International agreements in place and MOUs drafted
- Technology
  - Detector technology downselect
  - AMSD cryotesting underway
  - Wavefront algorithms demonstrated with PRC and both high/low authority cryo mirrors
- Science
  - ISWG review of the degree to which science program has been preserved in rescope

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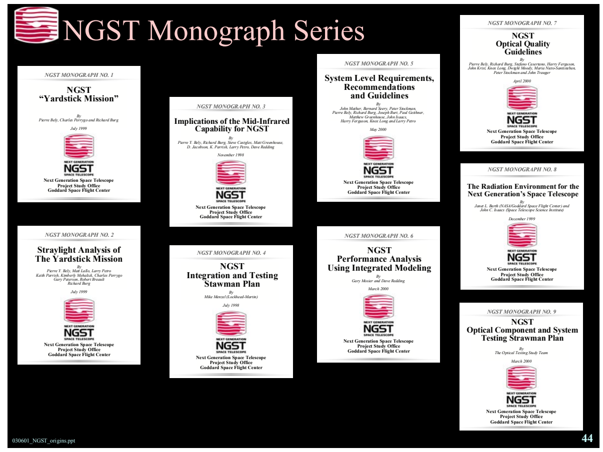

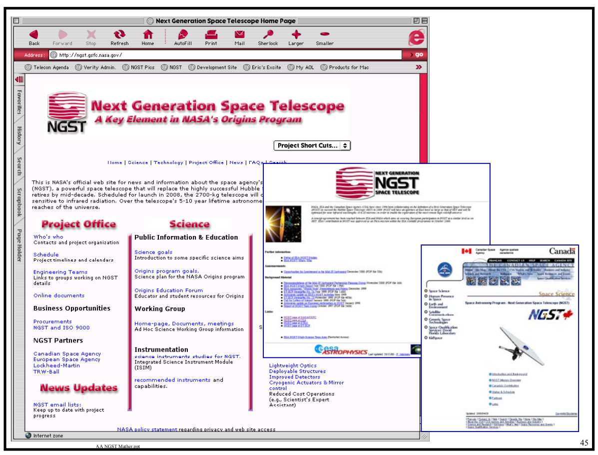

Biggest Worries

- Cost growth in Phase B after teams are selected
  - Unknown unknowns
  - Would have to rescope again to meet budget
- Bureaucratic obstacles
  - International collaboration difficulties
  - ITAR regulations
- But:
  - NAS says this is top priority
  - Strong international desire to cooperate
  - Large Phase A technology investment by NASA
  - Adequate time to get ready for NAR

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Points to Remember

- Rescope restores an affordable program while preserving most of science program
- NGST still essential 5 years after start, but advantage shifts to longer wavelengths
- Phase A Studies complete and cost estimates sufficiently mature to warrant commencing Phase B immediately after downselect

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