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NGST Science Instruments and Process

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Abstract. Possible NGST instruments have been studied by NASA, ESA, and CSA teams, and their reports were presented at this meeting and published on the NGST web sites. The instrument capabilities will be evaluated by the Ad Hoc Science Working Group and the technical readiness will be reviewed by a technical panel. Recommendations will be made to the NASA Project Scientist, who will present a report for public comment. NASA, ESA, and the CSA will then allocate instrument responsibilities in early 2000. NASA will choose its scientific investigations with instruments in 2002.

1. Introduction

The first concept for the NGST instrument complement was originally developed for the Yardstick mission study in 1996 by the NASA - STScI team and spelled out in the 1997 NGST project report "Visiting a Time when Galaxies were Young," edited by H.S. Stockman. It comprised four instruments: a near IR camera, a near IR multiobject spectrograph based on the micromirror array being developed by Texas Instruments, a mid IR camera, and a mid IR spectrograph. For this study, near IR was defined as 1 - 5 μm, and mid IR as 5 - 30 μm. The possibility of a coronagraph was discussed, but it was not included in the Yardstick mission study.

These instrument concepts were developed to respond to the scientific objectives described in the 1996 report "HST and Beyond," prepared by an AURA committee chaired by Alan Dressler. This report outlined several top priority objectives in extragalactic astronomy, including seeing the first luminous objects to form after the big bang, understanding the structure of the universe through analysis of the distance scale using supernovae, and learning about the clustering of matter. Infrared capabilities are essential because the expansion of the universe redshifts the primary starlight from the UV into the near IR. Wavelengths grow as $(1+z) = R_{\rm now}/R_{\rm then}$, where z is the redshift and $R_{\rm now}$ and $R_{\rm then}$ are the radius of the universe now and at the time that a photon was emitted. The report also included objectives in the areas of star and planet formation and evolution, which can be studied with infrared light because it penetrates the obscuring dust clouds where the early history of stars and planets occurs.

The NGST is unique in different ways at each available wavelength.

- 0.5 - 1 μm wide band photometry and wide field high quality imaging. On the ground, adaptive optics is not yet fully effective, but ground-based spectroscopy is very competitive. Telescopes even larger than the 10 m Keck are being discussed and would be perfect complements to the NGST, just as the Keck complements the Hubble Space Telescope. It is important to see the Lyman break, which falls in this wavelength range for fairly high redshifts. This wavelength range offers the best angular resolution, but will probably require some image processing because the NGST mirror will not be diffraction limited here.

- 1 - 2 μm imaging and multiobject spectroscopy at moderate resolution. Adaptive optics is very effective on the ground, and may become even better with multiconjugate versions. Numerous atmospheric spectral lines limit sensitivity for low spectral resolution, and airglow is still brighter than the zodiacal light even between the lines.

- 2 - 5 μm imaging and multiobject spectroscopy. In this band, thermal emission on the ground is severe. NGST will observe highly redshifted older fainter cooler stars.

- 5 - 30 μm imaging and spectroscopy (zodi-limited to 10 μm). Thermal emission on the ground is severe, and there is a premium on aperture for angular resolution. The SIRTF (Space Infrared Telescope Facility) will observe in this region but has only 85 cm aperture. The NGST will see interstellar material (near and far), solid bodies, and obscured star formation.

- Coronagraphs at all wavelengths. NGST will be unique in its potential for discoveries of planetary systems, and protoplanetary dust disks. It may also show galactic nuclei and black holes better than ever before.

Scientific leadership of the NGST project is provided by the four Study Scientists and their deputies. John Mather is the NASA study scientist, with deputies Matthew Greenhouse, Eric Smith, and Richard Burg. Peter Stockman, Simon Lilly, and Peter Jakobsen are the STScI, CSA, and ESA Study Scientists. They are supported by an Ad Hoc Science Working Group (ASWG), originally populated by the winners of a NASA competitive selection, and augmented by special appointments for particular research areas, and by representatives nominated by ESA and CSA. The main task for the ASWG is the creation and prioritization of representative science programs and capabilities for the NGST. The ASWG members are tabulated in Table 1 below.

2. Design Reference Mission

The scientific implications of this general direction were developed into a Design Reference Mission. The first DRM was reported by Stiavelli et al. (1997) at the STScI, and was a list of proposed observing programs with desired fields of view, sensitivities, and numbers of objects to be measured. The DRM provides the basis of a numerical metric for the performance of the instruments and spacecraft, and the observations outlined could become key observational projects when the NGST scientific programs are finally chosen. DRM Version 2.1 represents the current best parameterization and prioritization following the

Table 1. Ad Hoc Science Working Group (ASWG)

Jill Bechtold, Steward Obs.	Mike Fall, STScI
Harry Ferguson, STScI	Robert Fosbury, ESO/STECF
Jon Gardner, GSFC	James Graham, UC Berkeley
Tom Greene, NASA Ames	Matt Greenhouse, GSFC
Don Hall, Univ. Hawaii	Avi Loeb, Harvard
Peter Jakobsen, ESTEC	Bob Kirshner, Harvard
Simon Lilly, Univ. Toronto	Bruce Margon, Univ. Washington
John Mather, GSFC (Co-Chair)	John MacKenty, STScI
Michael Meyer , Steward Obs.	Harvey Moseley, GSFC
Phil Nicholson, Cornell Univ.	Takashi Onaka, U. Tokyo
Marcia Rieke, Steward Obs.	Mike Rich, UCLA
Peter Schneider, Max Planck Inst.	Gene Serabyn, JPL
Massimo Stiavelli, STScI	Peter Stockman, STScI (Co-Chair)
John Trauger, JPL	Ewine van Dishoeck, Leiden

June 1999 ASWG meeting. In this version the yardstick can be completed in 2.52 years. The ASWG added two new themes to the original: Nearby Planet detection, and Astrochemistry/Astrobiology. Neither requires a completely new instrument capability. The DRM programs fall into five major themes:

- Cosmology and the Structure of the Universe (21%)
- The Origin and Evolution of Galaxies (33%)
- The History of the Milky Way and its Neighbors (15%)
- The Birth and Formation of Stars (16%)
- The Origins and Evolution of Planetary Systems (15%)

The current versions are available online at the NGST web site with descriptions at `http://www.ngst.stsci.edu/drm/programs.html`, and a numerical spreadsheet at
`ftp://ngst.gsfc.nasa.gov/drm.xls` (Netscape) or
`http://www.ngst.nasa.gov/cgi-bin/doc?Id=435` (Internet Explorer). The Project recognizes the need to balance stability of requirements with scientific accuracy and relevancy. The prime DRM documents (NGST-SCI-SPEC-0004 [Excel], 0013 [ASCII]) are now under configuration control. Major version changes (e.g., version 2 to 3) will only be made when authorized by the ASWG.

The contents have been discussed extensively by the ASWG, and ranked in order of priority. The ranking confirmed the original approach of the Yardstick mission, in which the near IR instruments are both essential and the mid IR instruments are very important. The mid IR includes specific DRM goals and provides a very large "discovery space," in the sense that the NGST capabilities so far exceed all prior missions that important new types of objects and phenomena might well be found. The ASWG also showed that extension of the wavelength range down to 0.6 μm is critically important to cosmology, since the 0.1216 μm Lyman α line (the longest wavelength at which the intergalactic hydrogen becomes opaque) remains at wavelengths below 1 μm for redshifts out to $z = 7.2$, and the Lyman break does not reach 1 μm until $z = 10$. This line and the Lyman continuum break are the strongest markers for high redshift sources. Extension to longer wavelengths was not judged as critical, but the Phase A observatory study contractors have been asked to study mission concepts that would provide sensitivity limited by the zodiacal light out to 10 μm. This plan is the result of an engineering trade study, which showed that a 30 K instrument chamber can be readily achieved with radiative cooling, and that the observatory designs that allow this temperature are naturally capable of reaching the zodiacal limit at 10 μm.

3. Instrument Plans

NASA's Goddard Space Flight Center (GSFC) is managing the NGST mission, and will be responsible for the Integrated Science Instrument Module (ISIM). GSFC will provide the supporting structure, thermal environment, and electrical interface to the cold optics and detectors of the various instruments, along with the data system and the flight software and ground support equipment (GSE). International contributions of instrumentation will be received by GSFC. GSFC will integrate and test the modules and provide a complete integrated package as Government Furnished Equipment (GFE) to the observatory prime contractor. GSFC will lead an Integrated Product Team (IPT) for the development of the ISIM, and its members will include the STScI, ESA, CSA, the prime contractor, and the flight instrument principal investigators when they are chosen.

The international allocation of responsibility for the instruments is planned for April 2000, based on a technical feasibility report from a technical panel, and a scientific priority report from the ASWG, presented by the NASA Study Scientist, J. Mather. We have received approximately 18 study reports, including 6 funded by NASA, one offered by the University of Colorado, and 11 funded by ESA and CSA, and the report on the yardstick instrument package developed by NASA. These reports are available at `http://www701.gsfc.nasa.gov/isim/science.html` and from the main NGST web site document archive. In addition, the STScI chartered a committee chaired by John Huchra to compare the generic capabilities of near infrared spectrographs. There will be a series of ASWG meetings, scheduled for Nov. 3 - 5, and Nov. 22 - 23, and a meeting of the Technical panel Oct. 14 - 15. The Technical Panel will develop parametric cost models to enable a design-to-cost approach, so that the ASWG will be able to choose a consistent set of instrument capabilities. The final ASWG report will be prepared by a subgroup chosen to have minimal conflict of interest with the various instrument teams.

The NASA, ESA, and CSA management will consider the recommendations and develop an allocation of international responsibilities by April 2000. Budget targets for the three teams are approximately $100M for NASA, $100M for ESA, and $25M for CSA. The NASA budget has to cover the ISIM support systems as well as the NASA instruments. ESA will solicit its instrument package from industry, with a separate scientific team. NASA will solicit complete investigations, including both scientific programs and instruments, in 2001, with a selection planned for 2002. The CSA budget is not sufficient for an entire instrument so a partnership with NASA or ESA is expected.

NASA plans to issue a NASA Research Announcement (NRA) in early 2000, to cover instrument technology development. Examples of topics to be covered include: instrument technologies for multi-object and integral field spectroscopy, conventional and MEMS cryogenic infrared tunable filters, laboratory and ground-based demonstrations of NGST science instrument concepts, laboratory demonstration of long life flight cooling systems for 6 K IR focal plane arrays, and techniques for characterization and operation of detectors under ultra-low background conditions.

4. Instrument Possibilities and Studies

The generic possibilities for instruments include:

- Cameras with filters and tunable filters
- Dispersive spectrographs using prisms, gratings, grisms, or echelles
- Fourier spectrographs (cameras with adjustable cosine filters)
- Multiobject spectrographs, using micromirrors, microshutters, multiple discrete slits, or movable fibers on actuators
- Dispersive integral field spectrographs, using image slicers, fibers, or microlens arrays
- Coronagraphs, using graded Lyot stops, dark spots, phase masks, and high order deformable mirrors
- Combinations of all sorts (filters and gratings, filters and Fourier, Fourier and dispersive, beam switches for shared detectors, etc.)

The goals of the NASA Baseline ISIM Design Study were to: demonstrate mission science feasibility, assess ISIM engineering and cost feasibility, identify ISIM technology challenge areas, and enable smart customer procurement of NGST instruments. The yardstick architecture was constrained to be consistent with the yardstick mission concept, an 8 m telescope with a particular design. In this plan, the ISIM must provide accommodation for wavefront sensors, fine guidance sensors, and fast steering mirrors. Ongoing progress can be monitored at the ISIM web site:
http://www701.gsfc.nasa.gov/isim/isim.htm.

The ISIM design has evolved considerably since its 1996 first edition. In that study there was a single highly integrated instrument module that performed all the necessary functions. It was felt that this was the only way to meet the cost and mass goals, and indeed beryllium structures were used to help with the mass. By 1999, the design had become modular, with many segments that can be installed as units. This modularity is important for simple assembly, test, and integration, as well as to enable the contributions of multiple organizations to a single whole. The new design also uses an aluminum structure to reduce cost, and it is hoped that the new launch vehicles will have sufficient capabilities to allow this. The ISIM was designed with sufficient detail to support accurate cost and mass estimates.

Specific US instrument studies include:

- J. Bechtold, T. Greene: U. of Arizona & Lockheed Martin Corp. 0.3 - 40 μm imaging, spectroscopy, and ISIM layout
- J. Graham: U. of California & ITT Industries & Lawrence Livermore Labs 1 - 15 μm Fourier transform imaging spectroscopy
- J. MacKenty: STScI/ Ball Aerospace/ GSFC 1 - 5 μm multi-object spectroscopy with MEMS micro-mirrors
- H. Moseley: GSFC MEMS micro-shutter aperture control for multi-object spectroscopy
- G. Serabyn: JPL 5 - 28 μm camera/spectrometer and Sorption cryo-cooler
- J. Trauger: JPL 5 - 30 μm high contrast coronagraph with deformable mirror

The CSA NGST Science Instrument Studies include:

- Near-IR MOS/IFS: David Crampton (HIA/DAO) & CAL (Ottawa)
- Visible Imager: Paul Hickson (UBC) & CAL (Ottawa)
- IFIRS Imaging FTS: Simon Morris (HIA/DAO) & Bomem(Quebec) (collaboration with US Graham/ITT study)

European instrument concept studies include:

- Trade study of integral field and multi-object spectrograph options, including O. Le Fevre (PI), LAS, Marseille, France; R. Bacon, Observatoire de Lyon, France; R. Davies, Durham University, UK; R.S. Ellis, Cambridge University, UK; G. Monnet, European Southern Observatory, Garching, Germany; N. Thatte, MPE, Garching, Germany; and T. de Zeeuw, Leiden Observatory, the Netherlands.
- An image slicer IFS design for detailed study.
- Optical camera study: Martin Ward et al.
- Payload suite study encompassing OTA, ISIM, and instruments awarded to Dornier Satellitensysteme (Munich, Germany) & Alcatel (Cannes, France), including: a wide field filter wheel camera covering the VIS/NIR wavelength range (0.6 - 5 μm), a wide field Fourier Transform Spectrograph, doubling as Wide Field Camera (VIS/NIR), a MIR camera covering 5 μm - 10 μm and 10 μm - 28 μm, and a MIR Integral Field Spectrograph covering 5 μm - 10 μm and 10 μm - 28 μm.

5. Summary and Conclusions

A formal process for evaluating the possible NGST instrument complement and assigning responsibility for portions of it to the three international partners has been developed, with an agreement anticipated in April 2000. Eighteen instrument studies have been completed and will be evaluated by the ASWG and a technical panel. The technical panel will prepare a parametric cost estimate for the instrument concepts and assess technical readiness to enable the ASWG to choose a set of instruments that could fit the budget goal.

Acknowledgments. The NGST project benefits strongly from the support of top NASA management, beginning with the statement made by Dan Goldin, the NASA Administrator, to the American Astronomical Society in 1996. He said the "HST and Beyond" report was much too cautious in requesting a 4 m NGST, and said NASA would build an 8 m NGST. The NGST also benefits greatly from the work of Alan Dressler, who took the "HST and Beyond" report to Dan Goldin and established a relationship of trust. The GSFC ISIM study received scientific leadership from Matt Greenhouse, who is also the main point of contact for the instrument studies funded by NASA. He is the originator of much of the process described above.

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