Nuclear Spectroscopic Telescope Array (*NuSTAR*) Mission

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Abstract—**The *Nuclear Spectroscopic Telescope Array (NuSTAR)* is a National Aeronautics and Space Administration (NASA) Small Explorer mission that carried the first focusing hard X-ray (6–79 keV) telescope into orbit. It was launched on a Pegasus rocket into a low-inclination Earth orbit on June 13, 2012, from Reagan Test Site, Kwajalein Atoll. *NuSTAR* will carry out a two-year primary science mission. The *NuSTAR* observatory is composed of the X-ray instrument and the spacecraft. The *NuSTAR* spacecraft is three-axis stabilized with a single articulating solar array based on Orbital Sciences Corporation's LEOStar-2 design. The *NuSTAR* science instrument consists of two co-aligned grazing incidence optics focusing on to two shielded solid state CdZnTe pixel detectors. The instrument was launched in a compact, stowed configuration, and after launch, a 10-meter mast was deployed to achieve a focal length of 10.15 m. The *NuSTAR* instrument provides sub-arcminute imaging with excellent spectral resolution over a 12-arcminute field of view. The *NuSTAR* observatory will be operated out of the Mission Operations Center (MOC) at UC Berkeley. Most science targets will be viewed for a week or more. The science data will be transferred from the UC Berkeley MOC to a Science Operations Center (SOC) located at the California Institute of Technology (Caltech). In this paper, we will describe the mission architecture, the technical challenges during the development phase, and the post-launch activities.**

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1. INTRODUCTION

Significant portions of the sky have been mapped in exquisite detail at X-ray energies below 10 keV to depths enabling the study of objects far outside our Galaxy. At energies above this, the lack of focusing telescopes capable of sensitive observations has limited our knowledge of the Universe largely to bright objects within our own Galaxy, and a few dozen nearby extragalactic sources. The *NuSTAR* employs technologies developed over the last decade in a system that extends the inherently low-background, high-sensitivity observations of a focusing telescope to X-ray energies up to 79 keV [1, 2, 3]. *NuSTAR's* primary science goal is to make the first deep maps of regions of the sky in the high-energy X-ray band (band from 6 keV to 79 keV) in order to discover astrophysical objects that primarily radiate at these wavelengths, and to study energetic phenomena uniquely observable there. The *NuSTAR* mission focuses on four key objectives: 1) studying the evolution of massive black holes through surveys carried out in fields with excellent multi-wavelength coverage, 2) understanding the population of compact objects and the nature of the massive black hole in the center of the Milky Way, 3) constraining explosion dynamics and nucleosynthesis in supernovae, and 4) probing the nature of particle acceleration in relativistic jets in active galactic nuclei.

The *NuSTAR* observatory carries a single payload, and achieves its science objectives through a combination of surveys and pointed observations. It was implemented as a NASA Category 3 (per NASA procedural requirements 7120.5D) enhanced Class D (per NPR 8705.4) payload. The *NuSTAR* observatory was launched from Kwajalein on June 13, 2012. After the successful launch and spacecraft checkout, the instrument mast was deployed on June 21, 2012. The first light image of Cygnus X-1 was successfully acquired on June 28, 2012. *NuSTAR* started the science operations phase (Phase E) in August 2012. *NuSTAR* is performing well on orbit and meeting specifications. The planned science observations are underway.

The *NuSTAR* Principal Investigator (PI) is Fiona Harrison at Caltech and Jet Propulsion Laboratory (JPL) manages the mission. Principal project partners include Caltech, JPL, Orbital Sciences Corporation (Orbital), NASA Goddard Space Flight Center (GSFC), ATK-Goleta, Columbia University, UC Berkeley, Lawrence Livermore National Laboratory, Danish Technical University (DTU), and the Italian Space Agency (ASI).

The mission overview is presented in Section 2 of this paper. Sections 3 and 4 describe the *NuSTAR* observatory (X-ray instrument and spacecraft). The mission system is briefly described in Section 5. Two examples of the

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development challenges are discussed in Section 6. The post-launch activities are listed in Section 7. Finally, Section 8 provides a summary.

2. MISSION OVERVIEW

The *NuSTAR* project consists of four major systems: 1) instrument system 2) spacecraft bus system, 3) mission operations system (MOS), and 4) launch vehicle system.

The *NuSTAR* instrument is mounted to a 3-axis stabilized spacecraft and launched into a low Earth orbit (6 degrees inclination, 640km x 621km) [1]. The *NuSTAR* observatory (instrument and spacecraft in the stowed configuration) is shown in Figure 1.

The instrument is composed of three main subsystems: 1) X-ray optics built by Columbia University, GSFC, and DTU; 2) mast and structure manufactured by ATK-Goleta and ATK-Magna; and 3) detector assemblies and electronics provided by Caltech and UC Berkeley. The spacecraft was manufactured by Orbital and is based on the LEOStar-2 heritage design. The observatory was launched in a compact, stowed configuration, and after launch a 10-m mast was deployed to achieve a focal length of 10.15 m. The deployed observatory is shown in Figure 2.

The MOS is composed of the MOC at UC Berkeley and the SOC at Caltech. The calibrated *NuSTAR* data will be available to the community via the High Energy Astrophysics Science Archive Research Center (HEASARC) at GSFC. The high-level mission data flow is shown in Figure 3.

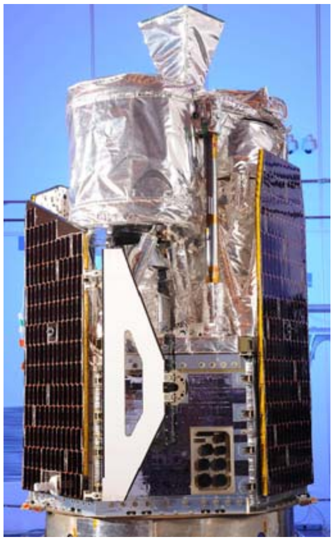

Figure 1. *NuSTAR* Observatory in stowed configuration.

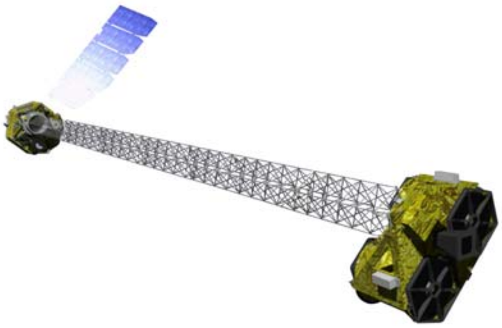

Figure 2. Deployed *NuSTAR* Observatory.

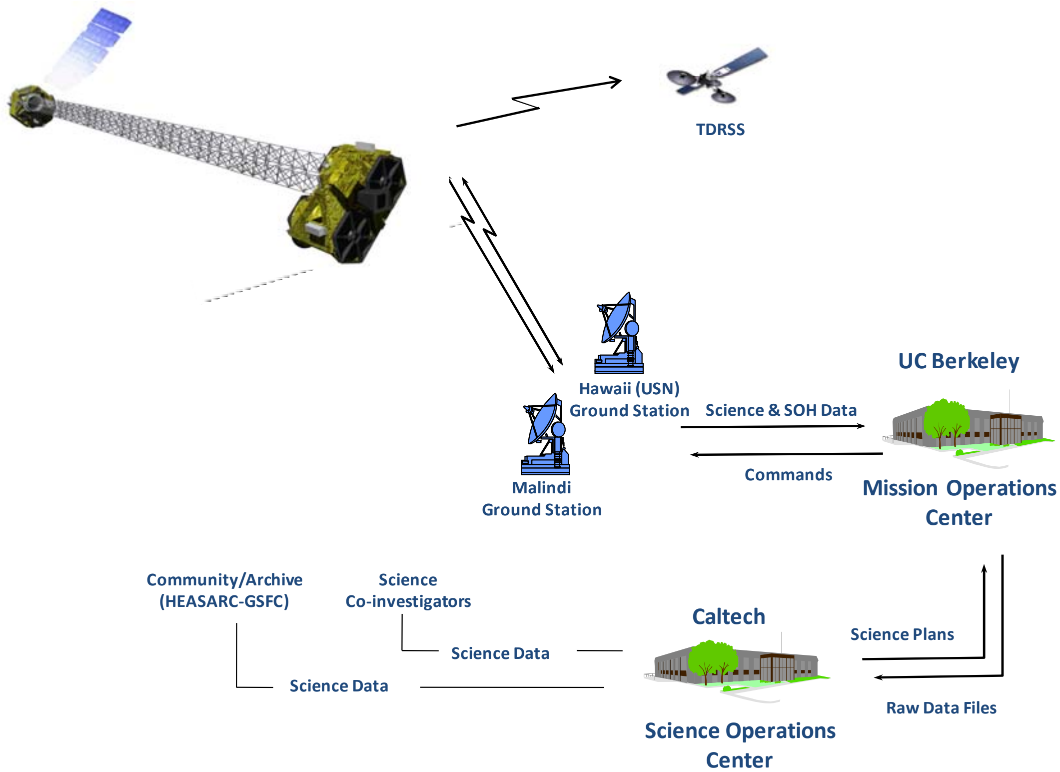

Figure 3. *NuSTAR* High-level Mission Data Flow.

The Pegasus XL rocket provided by Orbital was selected competitively as the *NuSTAR* launch vehicle by Kennedy Space Center (KSC). The launch site is the Ronald Reagan Ballistic Missile Defense Test Site located at the Pacific Ocean's Kwajalein Atoll. The *NuSTAR* observatory was launched successfully on June 13, 2012.

3. INSTRUMENT

The *NuSTAR* instrument consists of two independent, identical, co-aligned grazing incidence hard X-ray telescopes [3]. Data from these two telescopes are combined during post-processing on the ground, to increase overall observatory sensitivity. The two X-ray optics modules are mounted to an optical bench, which maintains their co-alignment, and each module focuses X-rays onto a shielded imaging detector module (referred to as a focal plane module). A separate structure maintains the relative position of the shield/detector modules.

The optics and detector benches are fixed to opposite ends of a deployable mast that extends to achieve a 10.15-m focal length after launch. The mast, manufactured by ATK-Goleta, is stowed in a canister during launch with the optics and detector assemblies at opposite ends (see Figure 4). During deployment, the optical bench separates from the canister, and the focal plane modules remain fixed to the canister, and two aperture stops extend along with the mast.

After deployment, and during science observations, the mast maintains the instrument focal length and alignment ensuring that the field of view of the optics is centered on the focal plane array within the required tolerance. Because the absolute deployment location of the mast is difficult to measure on the ground, due to complications associated with complex gravity offloading, an adjustment mechanism is built into the last section of the mast to enable the alignment to optimize the location of the optical axes on the focal plane. A laser metrology system consisting of two lasers and two position sensitive detectors measures cross boresight translation and rotation between the optics and focal plane benches to determine small, time varying displacements that would blur the instrument point spread function. These motions are compensated for during ground data processing. A star tracker head mounted on the optics bench allows the metrology system to distinguish between translation and tilt. As a result, both the translation and rotation of the optics bench can be determined and removed in post-processing.

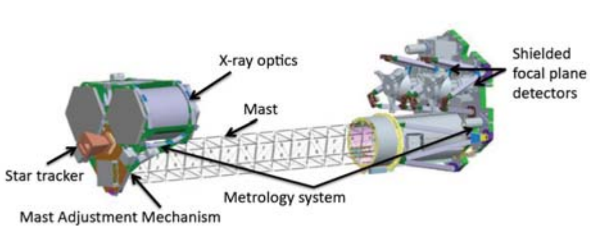

Figure 4. Instrument Configuration.

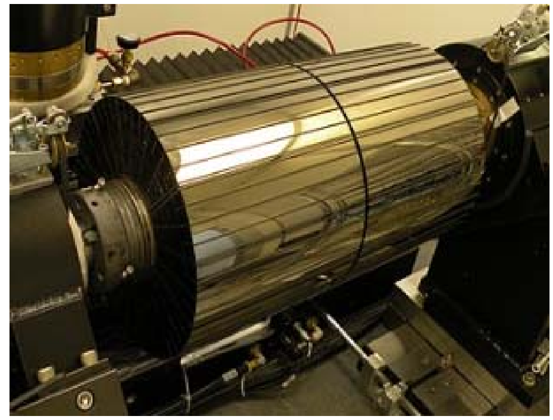

Figure 5. Flight optic module being assembled at Columbia University.

The *NuSTAR* optics utilizes a conical approximation to a Wolter-I design in a highly nested configuration, with 133 shells per each optic. The shells were fabricated from segmented, thermally formed glass produced by GSFC, and the segments are coated with depth-graded multilayers optimized to achieve significant high energy response for the graze angle range. The coatings were performed by DTU and the two *NuSTAR* optics were assembled at Columbia University. A flight optics module is shown in Figure 5.

Each focal plane module consists of four CdZnTe pixel sensors coupled to a custom low-noise application-specific integrated circuit (ASIC) as shown in Figure 6. Each hybrid contains a 32 x 32 array of 600 μm pixels, so that the mirror point spread function is over-sampled. The total field of view is 12 arc-minutes. The sensors are placed in a two-by-two array with a minimal (about 500 μm) gap. To achieve a low energy threshold and good spectral performance, the detector readout is designed for very low noise. The electronic noise contribution (including detector leakage current) to the energy resolution is 400 eV, and the low-energy threshold is 2.5 keV for an event registering in a single pixel. Over most of the energy range the detector spectral resolution is limited by charge collection uniformity in the CdZnTe crystal. The focal plane is passively cooled in flight to between 0 and 5 degrees C. The passive cooling is enabled by the low-power dissipation of the detector readout chip. The readout of each focal plane module is controlled by a field-programmable gate array– (FPGA-) embedded microprocessor. The focal plane is surrounded by an active

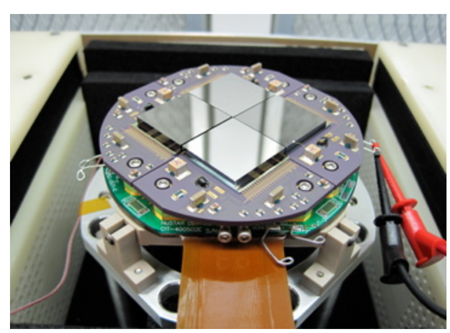

Figure 6. Four CdZnTe pixel sensors coupled to a custom low-noise ASIC.

2-cm thick CsI(Na) shield and incorporates a deployable aperture stop. The CsI shield extends 20 cm above the detector, and has an opening angle of 16 degrees, while the passive aperture stop defines a much narrower opening of 4 degree diameter.

4. SPACECRAFT

The spacecraft bus, procured from Orbital Sciences Corporation, is the seventh in their series of LEOStar-2 spacecraft, and it draws heritage from missions including AIM, SORCE, and GALEX. The avionics architecture and structure design have flown on a Pegasus launch vehicle several times in the past, but the *NuSTAR* telescope design presented new challenges. The volume and mass allocated to the bus were less than typical, while the deployed optics created inertias that were significantly larger than typical for a bus of this size. The *NuSTAR* spacecraft is shown in Figure 7.

The bus structure includes six aluminum honeycomb panels in a hexagonal configuration, with an aft panel included as part of the bus, and the instrument focal plane bench serving as the top of the bus. Nearly all bus components are within the bus cavity, with the following exceptions. One of the Magnetic Torque Bars (MTBs) is on the outer surface of the aft deck because there was no space available within the bus cavity. The Three Axis Magnetometer is located on the mast canister to minimize magnetic interactions with the MTBs. The star tracker Camera Head Units (CHUs) are located with the instrument components on the focal plane bench, due to field of view requirements and volumetric constraints within the bus. While all three CHUs are on the focal plane bench, one of them has its baffle going through the spacecraft bus cavity caused by the volumetric constraints around the instrument components. The bus is mostly a single string configuration, due to mass and volume constraints as well as the mission cost constraint. Some of the unique features of the *NuSTAR* spacecraft required to meet the mission requirements are described in the following paragraphs.

All of the previous LEOStar-2 spacecraft have flown Nickel Hydrogen batteries, but the *NuSTAR* mass constraints required a switch to mass efficient Lithium Ion batteries. The solar array wrapped around the bus while stowed (as shown in Figure 1), and is articulated in one axis while deployed.

Figure 7. *NuSTAR* Spacecraft.

This one axis of rotation, along with the freedom to roll the telescope around its boresight, provides the ability to always point the solar array directly towards the sun. The *NuSTAR* spacecraft has a five-panel solar array supported by a single yoke arm. Although more complex, the single array was used due to space limitations for a second solar array drive. While stowed, each solar array panel is constrained by a single Hold Down and Release Mechanism (HDRM). A mission specific HDRM was used to provide a smaller mechanism and consume less space on the focal plane bench than the standard unit. The Command and Data Handling (C&DH) subsystem is based on the RAD6000 processor, with a 1553B interface to a backup processor. The C&DH subsystem is similar to that used on previous LEOStar-2 spacecraft.

The attitude control subsystem (ACS) provides three axis control with a zero momentum bias. The configuration of the spacecraft presented a challenge for the ACS design. Since the mass of the deployed optics is nearly half the observatory mass, the deployed inertias are very large. Also, the 10-meter boom can cause large gravity gradient torques. A tradeoff between the desire for high torque margins with large ACS actuators and overall mass constraints was required. Actuator sizing was selected based on torque margins that were small but positive at end of life; however, the resulting actuators were still large enough to present packaging and compatibility challenges. The requirement to point in any direction for long periods of times drove the need for multiple CHUs oriented with care to ensure at least one is always unocculted under any conditions. The simplicity of keeping the bus design isolated from the instrument design is always desired, but the volumetric constraints and potential for thermal distortions drove the need to mount the CHUs on the focal plane bench with the other instrument components.

The original design had a single S-band transceiver for up and down link communications, using a component inherited from the ST-8 program. Two omni antennae are used to provide nearly spherical coverage, and the downlink operates in high rate mode for ground contacts and low rate mode for Tracking and Data Relay Satellite System (TDRSS) return link compatibility. The receiver portion of the transceiver experienced several issues during component level production and test; therefore, the flight spare transceiver from the LRO program was transferred to *NuSTAR* and modified for the *NuSTAR* spacecraft. The entire component did not fit in the space available, so the receiver portion was separated and flown to provide a redundant uplink path. Along with redundancy, this second receiver also provided TDRSS forward link compatibility.

5. MISSION OPERATIONS SYSTEM

The *NuSTAR* MOS is composed of the MOC at UC Berkeley and the SOC at Caltech. The *NuSTAR* MOC shares the same multi-mission facility that already supports the FAST, RHESSI, CHIPS, and THEMIS missions. Secure NASA IONet network connections link the MOC to NASA's Near Earth Network (NEN) stations, and the Space Network (SN).

A dedicated tail circuit was installed between NASA Johnson Space Center (JSC) and UC Berkeley to provide connectivity via ASINet to the Malindi, Kenya ground station, operated by the Italian Space Agency. The MOC processes the Level 0 data and passes it to the SOC, which performs all Level 1 and 2 processing and immediately after validation makes the calibrated data available to the community via the High Energy Astrophysics Science Archive Research Center (HEASARC) at GSFC.

The mission operations functions for *NuSTAR* are closely modeled after those for RHESSI and THEMIS. The spacecraft command and control system is the Integrated Test and Operations System (ITOS), which is already used for FAST, RHESSI and THEMIS [4]. Spacecraft engineering data is also processed and archived by the Berkeley Trending Analysis and Plotting System (BTAPS), a MySQL based database system that allows real-time as well as post-mission queries and analyses of system trends, and aids with anomaly investigation and resolution. The Berkeley Emergency and Anomaly Response System (BEARS) is used to monitor telemetry streams from multiple spacecraft and performs error checking and paging of operations personnel in case limit violations or other error conditions are detected. The SatTrack Suite provides all flight dynamics aspects for *NuSTAR* as well as the backbone of the MOC automation and data flow management functions.

The science team selects the targets to observe based on availability within given constraints and generates a pointing file. This file is sent to the MOC at UC Berkeley to be communicated to the spacecraft. All science data along with selected spacecraft engineering and orbit data is received by the SOC within 48 hours of each station pass. The SOC processing is performed automatically with minimal operator oversight. Level 1 and Level 2 products and calibration files are generated and made available to the science team on a local web server. Level 1 data in Flexible Image Transport System (FITS) format is archived at the HEASARC at GSFC along with appropriate documentation and HEAsoft compatible software to allow the production of higher level data products. The SOC is responsible for coordinating the generation of observation requests by the science team and the delivery of pointing sequences and instrument parameter files to the MOC.

6. Development Challenges (Two Examples)

Although the *NuSTAR* project encountered numerous technical challenges during the development phase, only two major challenges are presented in this section.

Mass and Momentum Margins

One of the most significant technical challenges that the *NuSTAR* project had to deal with was the mass and attitude control subsystem (ACS) margins. Both of these margins were tight from the beginning of the project. The ACS momentum is driven by the large deployed inertias and gravity gradient torques. The instrument mass is higher than a typical Small Explorer (SMEX) instrument due to the optics mass. Throughout the development phases, these two resources were traded back and forth and tracked closely as the system matured.

The *NuSTAR*'s launch mass was constrained by Pegasus launch vehicle to an orbit of at least 550km x 600km. The orbit altitude was chosen to have a high confidence of achieving a two-year mission without requiring a propulsion system. Figure 8 shows the *NuSTAR* mass compared to the launch vehicle allocation. The project spent the majority of the time with a mass margin of approximately 10% and

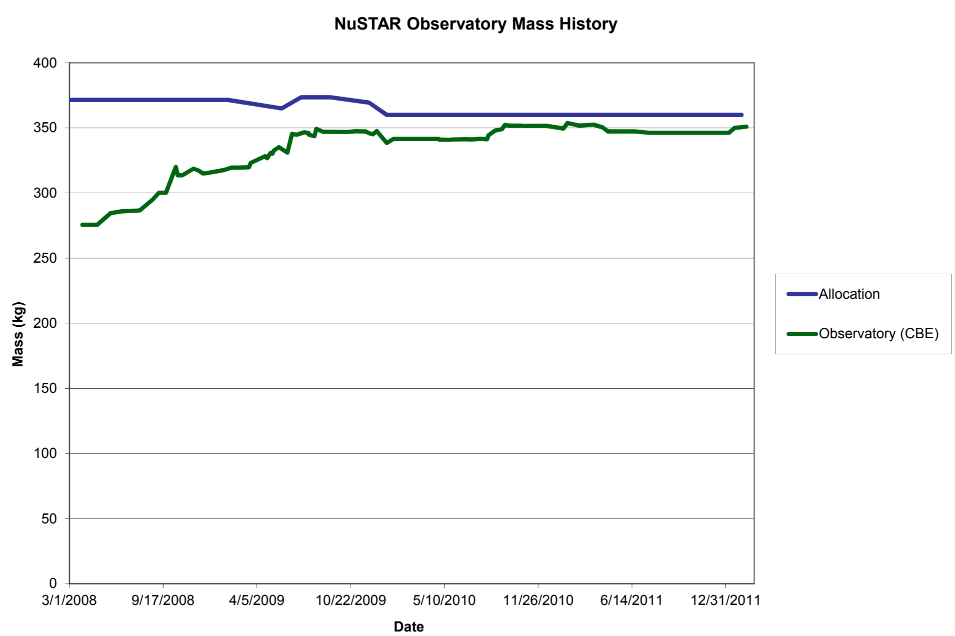

Figure 8. Mass Margin History.

launched with approximately 3%.

The system momentum margin was driven by the large inertia of the system on two of three axes (a result of the long mast length) and the large gravity gradient torques that act on the system. In addition to the disturbances, the low inclination of the orbit reduced the variation in the magnetic field around the orbit, which reduced the effectiveness of the magnetic torque bars for unloading the momentum that builds up in the reaction wheels.

It was clear in Phase B that it will be a challenge to meet typical control margins (about 100%). Throughout the development phase, this margin was traded against several other resources, most of the time mass. Below are the series of trades that the project proceeded through to maintain the margins and acceptable risks.

a. Maximum geomagnetic storm level—When there is a geomagnetic storm, the atmosphere expands, increasing atmospheric drag. The level of severity of a storm is described by the Kp number which ranges from 1–9. Since a Kp=9 storm only occurs ~4 times per solar cycle and was a significant driver of the ACS design at the end of mission life, the project decided to only size the system for a Kp=8 for nominal operations and only utilize Kp=9 for safing cases. In essence the project was trading a slight reduction in operational availability to avoid driving the ACS component sizing and hence mass unnecessarily. Since the drag is higher at the lower altitude, the project mitigated this risk by increasing the orbit insertion altitude using optimized launch vehicle control algorithms.

b. Reaction wheel selection—The project inherited a single Goodrich Type B wheel from the ST-8 project. This wheel in combination with three additional Goodrich wheels was the baseline in Phase B. During the fall of 2008 it was clear that these would not provide the amount of momentum storage necessary to maintain pointing at all attitudes late in mission life. Based on this, the wheels were changed to the Honeywell HR12-series wheels although these wheels had never been flown on a LEOStar-2 bus. Although the heritage interface and software associated with the reaction wheel had to be changed, the project changed to the Honeywell HR-12-37 to obtain the required momentum storage capacity for the available mass.

c. Magnetic torque bar sizing—The *NuSTAR* torque bar sizing was driven by the low inclination orbit, which limits the amount of variation in the earth's magnetic field and hence the effectiveness of the torque bars. The initial design utilized 350 Am^2; larger bars were considered; however, the additional mass was too much to justify the small increase in momentum control margins. Although the momentum margins were always tight throughout the development phase, this risk was mitigated by the tradeoff that allowed graceful degradation of the ability of the observatory to point in certain locations of the sky late in the mission.

d. End of life (EOL) altitude increase—The end of life altitude requirement was originally 425 km and was one of the main drivers of the momentum margin. As the altitude decreases, the atmospheric disturbance torque increases. To increase the margin with the existing torque bars, the EOL altitude was increased. Also, after launch vehicle selection, the project was able to effectively increase the probability of a higher orbit by tweaking the guidance algorithm.

e. Reaction wheel size reduction—When the launch vehicle was selected, it was clear that the project needed to add a softride system at a mass cost of ~10 kg. One of the primary changes to the spacecraft to accommodate this additional mass increase was to reduce the size of the reaction wheels. The smaller reaction wheels reduced momentum margins; however, at this point based on the mature models, it was clear that the magnetic torque bars were the driver for the margin.

f. Harness mass reduction—The harnessing initially came in significantly over the estimate by about 5 kg. Due to this mass problem, the project reviewed the possibility of reducing the shielding of wires to reduce weight. Shielding was removed on noncritical lines but was maintained on critical lines to prevent switching noise from interfering. This added a small risk of electromagnetic interference / electromagnetic compatibility (EMI/EMC) problems later in test, but given the relative insensitivity of the instrument to this type of noise, it was decided this was an acceptable risk.

In the end, the project came in 10 kg under the launch allocation. Momentum margins never made it to the desired value, but *NuSTAR* was launched with about a 50% margin at end-of-life at the worst-case attitude. The project accepted this risk given the semi-graceful degradation of sky availability (our ability to point to any point in the sky) at the end of mission life.

Instrument Thermal Design

Throughout the project, the thermal design of the instrument was a significant challenge. Two major reasons are:

1) The instrument thermal design was distributed among 4 different organizations:
   a. JPL (Instrument systems/Optics)
   b. ATK (Structures)
   c. UC Berkeley (Instrument components)
   d. Orbital (Instrument mounted spacecraft components)
2) The observatory has a requirement for almost full sky availability, which provides a significant driver on the thermal design to deal with a large array of solar aspect angles on a very large structure.

Due to the large number of organizations involved, the thermal design of the instrument was always lagging the rest of the system design. This led to a number of issues including the incorrect temperatures used for the mast diagonal qualification testing.

The *NuSTAR* project was lacking overall thermal systems engineering to coordinate the four organizations. Due to the scope of the effort and the number of people/organizations involved, the project would have been better served to have a thermal systems engineer in the project office with overall authority over the four organization efforts. One of the problems encountered was that the instrument thermal performance was affected due the metrology laser thermal blanket inconsistency between the model and as-built flight configuration. However, operation changes after launch was able to minimize the impact of this performance degradation.

7. POST-LAUNCH ASSESSMENT

After the successful ferry flight to Kwajalein, *NuSTAR* completed all required launch site activities. The carrier aircraft dropped the observatory inside the drop box at 16:00:37 (UTC) on June 13, 2012. The Pegasus launch vehicle performed nominally. The observatory was placed in a 621km x 640km orbit at 6 degrees inclination. Throughout the powered flight, the team had access to launch vehicle and observatory telemetry in real-time. Following separation from the launch vehicle, the observatory powered on the transmitter and the reaction wheels. Telemetry was acquired almost immediately and the observatory had indicated even before separation that it had a lock on the TDRSS command carrier. The solar array was deployed nominally. Once the array was deployed, the observatory found the sun and proceeded to damp out the launch separation rates and acquire a sun-pointing attitude.

The rate damping and sun acquisition were achieved although these activities took slightly longer than expected. At this point, the post-launch vehicle performance was reviewed. All systems were nominal with the exception of the system momentum, which seemed higher than expected for the stowed configuration. Approximately 60 minutes after launch, the system momentum started to grow, at the same time the magnetic torque bars also started to saturate. The torquer bars were turned off and once this was done the system momentum stopped growing. Over the course of the next 36 hours, it was determined that the behavior was caused by errors in transformation matrices in the attitude control system. Subsequently, this anomaly was corrected by a software update.

The ACS components and performance were then checked out, in preparation for mast deployment. The mast deployment occurred on the morning of June 21, 2012. The deployment was done with the ACS control system disabled to avoid any unexpected control interactions with the deployment. Following the final set of optics bench releases, the instrument was commanded to deploy the mast. The mast deployment was nominal and all 55 bays were successfully deployed (one bay launched latched for a total of 56 bays in the mast). Following the deployment, the spacecraft ACS system control was re-enabled and it successfully captured the observatory and attained a sun-pointing attitude. The internal alignment of the instrument with the mast adjustment motor was accomplished to shift the optics bench orientation so that both metrology system lasers were aligned with their respective detectors. The instrument team also checked out the performance of the focal plane detectors and found these to be in perfect working order. In parallel with the ACS checkout the instrument team started the rough alignment process as the ACS slew/alignment targets were chosen to be bright X-ray targets.

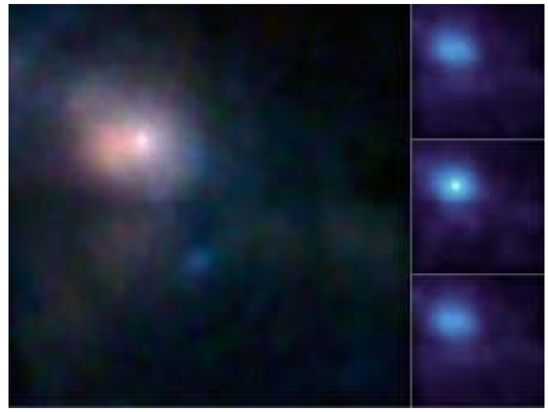

Figure 9. *NuSTAR* image of the area surrounding the supermassive black hole, called Sagittarius A*, at the center of the Milky Way. The three images (right) show the X-ray observations during the middle of a flare-up.

Once the ACS checkouts were complete and the instrument rough alignments performed, the observatory was pointed at the first light target Cygnus X-1. This was performed nominally and the initial image was acquired. A second week-long commissioning phase was added in early August to make finer updates to attitude system in order to improve the pointing performance of the spacecraft. Coordinated observations with Chandra, XMM, Swift, Suzaku, and INTEGRAL were scheduled to cross-calibrate *NuSTAR* with the other observatories.

In July 2012, *NuSTAR* teamed up with NASA's Chandra X-ray Observatory and the W. M. Keck Observatory (Mauna Kea in Hawaii) to observe Sagittarius A* at the center of the Milky Way. As shown in Figure 9, *NuSTAR* captured an outburst from Sagittarius A*. When black holes consume fuel, they erupt with extra energy. These *NuSTAR* data will help astronomers better characterize this process when combined with the simultaneous observations taken at other wavelengths.

8. SUMMARY

In this paper, we presented the overview of the *NuSTAR* observatory. In addition, we discussed two examples of the technical challenges encountered during the development phase. The *NuSTAR* observatory was successfully launched on June 13, 2012. *NuSTAR* is performing well on orbit and meeting specifications. The planned science observations are underway and the project is on track to meet the level 1 requirements and produce outstanding scientific results.

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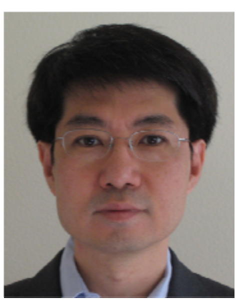
BIOGRAPHIES



Yunjin Kim *received his Ph.D. in electrical engineering from the University of Pennsylvania (Philadelphia, Pennsylvania) in 1987. From 1987 to 1989, he was with the Department of Electrical Engineering, New Jersey Institute of Technology (Newark), as an assistant professor. Since 1989, Yunjin Kim has been with the Jet Propulsion Laboratory (JPL), California Institute of Technology. He was the NuSTAR project manager from Phase B to Phase D.*

Jason Willis *holds both a B.S. and M.S. degree in Aerospace Engineering Science from the University of Colorado at Boulder where he specialized in spacecraft systems. In 1998 he joined JPL as a Spacecraft Systems Engineer on several projects leading up to his involvement on the Mars Exploration Rover Project starting in 2000. He was a flight systems engineer and Entry Descent and Landing Flight Director for both of the MER landings. From 2004 through 2008, he was the Multimission System Architecture Platform Lead Systems Engineer. From 2007 through the end of commissioning, Jason was the NuSTAR Project Systems Engineer.*

Fiona Harrison *received a Ph.D. in physics from UC Berkeley. She spent two years as a Robert A. Millikan Prize Fellow in Physics at Caltech, and in early 1996, she joined the faculty there as an Assistant Professor, and was promoted to Professor of Physics and Astronomy in 2005. She has combined experimental and observational work in high energy astrophysics. In 1996, she began developing instrumentation for focusing high energy X-rays, and successfully proposed to NASA to build the balloon-borne High Energy Focusing Telescope (HEFT). She is the NuSTAR Principal Investigator.*

Karl Forster *attended Columbia University in New York, receiving a Ph.D. in Astronomy in 1998. After two years as a post-doctoral scholar at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, he moved to southern California and was a staff scientist at the Caltech working as team lead for GALEX science operations for which he received a NASA exceptional public service medal in 2008. Karl joined the NuSTAR team in 2011 as manager of the NuSTAR Science Operations Center.*

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