High Energy Replicated Optics to Explore the Sun: Hard X-Ray Balloon-Borne Telescope

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Abstract— **Set to fly in the Fall of 2013 from Ft. Sumner, NM, the High Energy Replicated Optics to Explore the Sun (HEROES) mission is a collaborative effort between the NASA Marshall Space Flight Center and the Goddard Space Flight Center to upgrade an existing payload, the High Energy Replicated Optics (HERO) balloon-borne telescope, to make unique scientific measurements of the Sun and astrophysical targets during the same flight. The HEROES science payload consists of 8 mirror modules, housing a total of 109 grazing-incidence optics. These modules are mounted on a carbon-fiber - and Aluminum optical bench 6 m from a matching array of high pressure xenon gas scintillation proportional counters, which serve as the focal-plane detectors. The HERO gondola utilizes a differential GPS system (backed by a magnetometer) for coarse pointing in the azimuth and a shaft angle encoder plus inclinometer provides the coarse elevation. The HEROES payload will incorporate a new solar aspect system to supplement the existing star camera, for fine pointing during both the day and night. A mechanical shutter will be added to the star camera to protect it during solar observations. HEROES will also implement two novel alignment monitoring system that will measure the alignment between the optical bench and the star camera and between the optics and detectors for improved pointing and post-flight data reconstruction. The overall payload will also be discussed. This mission is funded by the NASA HOPE (Hands On Project Experience) Training Opportunity awarded by the NASA Academy of Program/Project and Engineering Leadership, in partnership with NASA's Science Mission Directorate, Office of the Chief Engineer and Office of the Chief Technologist.**

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1. INTRODUCTION

In 2001 the High Energy Replicated Optics (HERO) balloon-borne telescope took the first focused hard X-ray (20-45 keV) images of astrophysical X-ray sources GRS 1915+105, Crab Nebula, and Cyg X-1 [1]. These images were made possible by the development at the NASA Marshall Space Flight Center (MSFC) of novel full-shell electroformed-nickel-replicated high-resolution optics, matched to position sensitive focal plane detectors. Since then, HERO has flown several times with an enhanced payload that included additional optics and detectors. The most recent flight was in 2011 from Alice Springs, Australia, with the goal of observing and mapping the angular extent of astrophysical targets such as the Crab Nebula.

The High Energy Replicated Optics to Explore the Sun (HEROES) mission is a collaborative effort between the MSFC and the Goddard Space Flight Center (GSFC) to further enhance and fly the HERO payload to allow it to make novel solar observations and astrophysical observations during the same balloon flight. As HERO has never before observed the Sun, the focus of the HEROES mission will be on these new measurements. HEROES will be capable of observing solar flares with up to 100 times better sensitivity and 50 times more dynamic range than the best solar observations to date. The most sensitive solar hard X-ray observations are currently provided by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) and are obtained using a non-focusing imaging technique [2]. Such indirect imaging, however, has intrinsically limited dynamic range and sensitivity, while through direct imaging these limitations can be overcome.

The main upgrade to HERO will be the addition of a Solar Aspect System (SAS). The SAS will provide an aspect solution that will allow HEROES to point at the Sun, and will provide a roll aspect for post-flight pointing knowledge. To protect the existing star camera during solar observations, a mechanical shutter will be implemented. Because the star camera is used to obtain an aspect solution during astrophysical pointing, the shutter must be in the open position during this time. Two alignment monitoring systems will also be added; one to monitor the position of the star camera for improved astrophysical pointing knowledge, and a system to monitor the alignment of the main telescope components for improved post-flight data analysis.

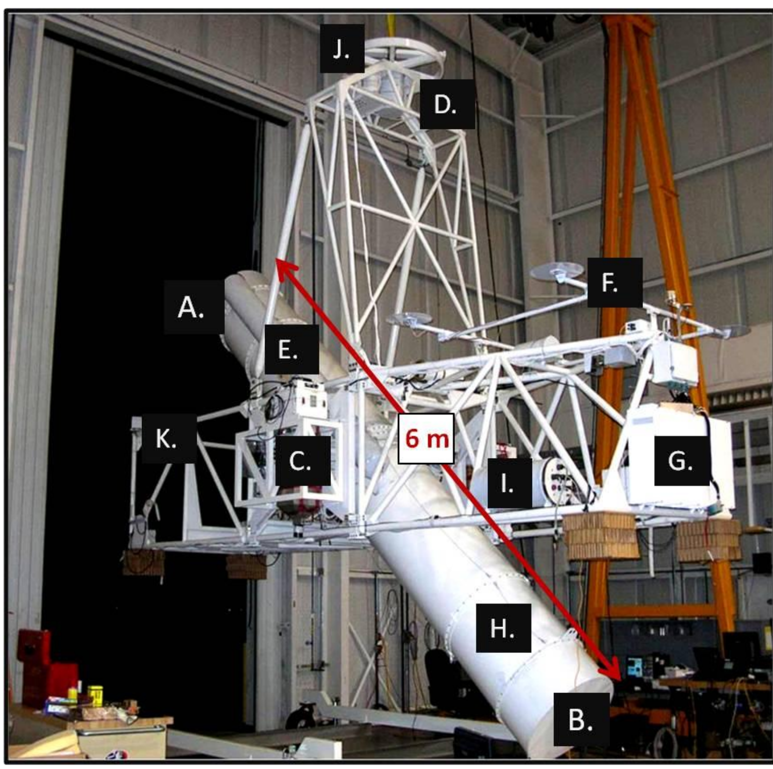
2. HERO CONFIGURATION

The foundation of the HEROES payload is the existing balloon payload HERO. The HERO telescope is capable of high-resolution direct imaging and spectroscopy of hard (20-75 keV) X-ray sources [1,3]. HERO was conceived, designed and fabricated mostly in-house at the MSFC under PI, Dr. Brian Ramsey, and has provided a platform for making high quality observations and for developing and maturing related technologies for over a decade.

HERO's primary payload (i.e. the telescope) consists of 8 optics modules (each of which contains multiple optics) coupled to 8 focal plane detectors 6 m away, and separated by a carbon-fiber wound- and aluminum optical bench that is connected to the gondola through the elevation drive. In addition to the elevation drive, an azimuth drive that is located at the top of the gondola structure is employed to allow for full pointing capability of the telescope. A co-aligned star camera is used for fine pointing, and is attached to the elevation flange. Figure 1 shows the HERO payload hanging in the high bay of the Columbia Scientific Balloon Facility (CSBF) in Ft. Sumner, NM during pointing tests. These pointing tests allow for a systems check of the star camera algorithm and pointing control system prior to launch.

Gondola System

The gondola is an aluminum frame to which the elevation and azimuth drives, optical bench, star camera, and flight computers are mounted. The on-board attitude control system provides pointing commensurate with the angular resolution of the X-ray optics. A differential GPS system (backed by a magnetometer) is used for coarse pointing in azimuth (to ± 30 arcmins) and a shaft angle encoder plus inclinometer provides the coarse elevation (to better than ± 10 arcmins). A gyroscopically-controlled inertial-mode system with a day/night star camera is used for fine aspect determination and gyro drift compensation. The coarse system is used to roughly orient the optical bench axis and the inertial gyros maintain the gondola pointing. The star camera then acquires fields and matches them to star maps in its database to determine the current pointing direction and to derive offsets needed to slew to the desired position. Further detail on the star camera pointing algorithm can be found in [4]; though it should be noted that the HERO star camera lens has been upgraded since this reference, and will be upgraded again for HEROES to improve the focus movement resolution. Because the star camera has good sensitivity during the day-time (of around a magnitude of ~8, assuming at least a 30° elevation and 5° off-set from the Sun) and excellent sensitivity during the night-time (to fainter than 10^{th} magnitude), pointing solutions can be obtained throughout the balloon flight.



A. Optics
B. Detectors
C. Elevation Drive
D. Azimuth Drive
E. Star Camera & Baffle
F. GPS antennae
G. Battery Box (1 of 2)
H. Optical Bench
I. Flight Data Recorder
J. Reaction Wheel
K. Gondola Structure

- **Focal Length: 6 meters**
- **Total mass: ~ 2.5 tons**
- **Balloon Type: 40 MCF**
- **Launch Location: Ft. Sumner, NM**
- **Typical Flight Duration: 28 hours**

Figure 1: Key components of the HERO payload are labeled. HERO has a 6 m focal length (i.e., the distance from 'A' to 'B'). In this image, HERO is undergoing pointing tests prior to flight in Ft. Sumner, NM.

Just as important as the ability to point at a desired source, are the pointing stability and pointing knowledge. A stable pointing system will allow for maximum throughput of the system and fine pointing knowledge will allow for improved post-flight data reconstruction. HERO's best pointing stability has generally been achieved during night-time observations and is defined by an angular offset between the desired pointing vector along the X-ray axis of the telescope and the calculated pointing vector as determined by the aspect solution/gyros and platform stability. For a particularly stable observation on a past HERO flight, the angular offset was determined to be within ~1 arcmin over 70% of the observation and within 30 arcsecs over 30% of the observation [5]. To complement HERO's pointing stability, HERO's pointing knowledge is ≤ 7 arcsecs, or a couple of pixels (each pixel is 3.5 arcsecs). Single pixel and sub-pixel interpolation are possible depending on the number of stars in the star camera field of view (3º x 2º).

Optics

The HERO optics are conical approximations to a Wolter Type I geometry. These full shell optics were fabricated in-house at MSFC, using an electroformed nickel replication process, and then sputter-coated with iridium. HERO optics fabrication is described in more detail in [1,6,7]. Five of the 8 HERO optics modules contain 14 optics, and the remainder houses 13 optics; for a total of 109 mirror shells. HERO optics average angular resolution is 26 arcsec Half Power Diameter (HPD). This average angular resolution is at least a factor of two better than that of the Nuclear Spectroscopic Telescope Array (NuSTAR), a recently launched satellite-based hard X-ray telescope, which has an angular resolution of around 50 arcsec HPD [8]. Key characteristics of the HERO optics are described in Table 1. The field-of-view corresponds to the diameter at which the effective area for a point source is at least 20% of the on-axis effective area.

Table 1. HERO optics properties are shown

Characteristic	Value
Mirror shells per module	14 (in 5 of the modules) 13 (in 3 of the modules)
Inner, outer shell diameters	50, 94 mm
Total shell length	610 mm
Coating	Sputtered iridium, ~ 20 nm thick
On-axis geometric effective area	~ 90 cm^2 at 40 keV ~ 21 cm^2 at 60 keV
Angular resolution (module)	~13 arcsec FWHM ~26 arcsec HPD
Field of View	9 arcmin at 40 keV 5 arcmin at 60 keV

Each module is mounted in its own tip/tilt mechanism to allow for alignment and to optimize the throughput of the telescope on the ground. The tip/tilt mounts are bolted onto a 1 m diameter flange located at the front of the optical bench (Figure 1, Figure 2). Kapton heaters on each module maintain thermal control throughout the flight and high-density foam is wrapped around each module, along with a sheet of aluminized Mylar. A fiberglass cap covers the assembly.

Detectors

Coupled to the HERO optics are complementary position sensitive, large area detectors responsive in the 20-75 keV range. These detectors are Gas Scintillation Proportional Counters (GSPCs) designed and fabricated at the MSFC, described in detail in [9] and summarized in Table 2.

The performance of the HERO GSPCs is typical for this type of detector: absorption efficiency ranges from 98% at 20 keV to 80% at 70 keV; the energy resolution at 60 keV is < 5% Full-Width at Half Maximum (FWHM); the measured spatial resolution of < 400 μm at 30 keV is sufficient for a 26- arcsec, 6-m-focal length system. These detectors utilize passive shielding, upper and lower thresholds and post-flight rise-time discrimination. Background rates measured during the last Ft. Sumner flight in 2007 were $2x10^{-3}$ counts cm^{-2} sec^{-1} keV at 30 keV. Full details are given in [3]. The HERO detectors are bolted to a flange located at the rear of the telescope. Each detector is aligned to a corresponding optics module located 6 m away (Figure 2). Readout electronics are located in the 4 central cans (2 detectors per can). Each detector is flown with a radioactive calibration source (typically Cd-109).

Table 2. HERO detector properties are shown.

Characteristic	Value
Number of detectors	8
Fill Gas	56 mm of Xe + Helium (96/4) @ 10^6 pa
Light emitting region	4 mm deep
Exit window	7 mm Suprasil
Position resolution	330 μm (25-35 keV) 400 μm (35-45 keV)
Energy resolution (FWHM)	6% @ 30 keV 4.5% @ 60 keV
Quantum Efficiency	99% (40 keV) 89% (60 keV)

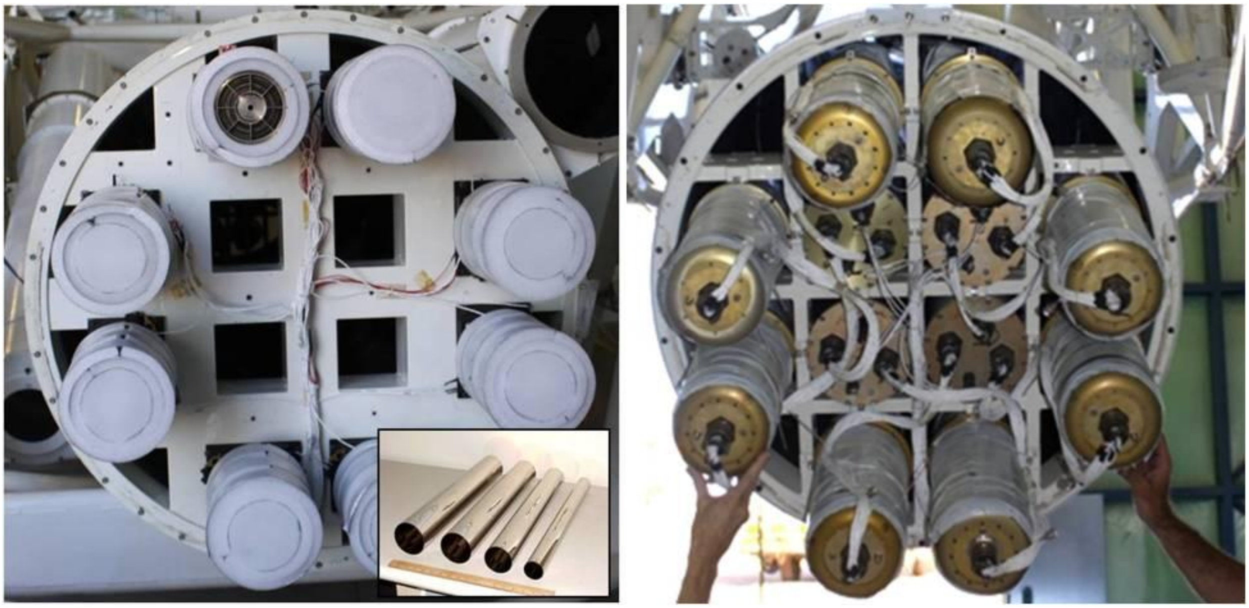


Figure 2: (Left) The image shows the HERO optics modules installed on the optical bench. The inset image shows individual shells before they are nested into a module. The total number of shells for the HEROES telescope is 109. (Right) GSPC detectors that complement each of the 8 optics modules are shown. Detector readout electronics are located in the 4 control cans located at the center of the flange.

3. SOLAR ASPECT SYSTEM

In order to make useful solar observations, HEROES requires a Solar Aspect System (SAS) for solar pointing knowledge in pitch, yaw, and roll. Pointing knowledge will provide the information needed to convert from detector coordinates to solar coordinates such that the resulting HEROES solar X-ray images can be compared with observations in other wavelengths. The required precision of these measurements must be better than the HEROES X-ray resolution of ~15 arcsec FWHM. The HEROES pointing vector is defined by the optics, yet in order to determine solar coordinates on the detectors, the vector between the optics and detectors planes must also be measured. Previous experience has shown that the optical bench, which defines this vector may shift slightly during flight. Therefore, the SAS must be able to measure this vector as well (the alignment monitoring system described below will make this measurement during night-time observations and will provide an independent measurement for the day-time observations). In order to satisfy all of these requirements, SAS consists of the Pitch/Yaw Aspect System (PYAS) and the Roll Aspect System (RAS). Both of these sub-systems are similar to those currently being developed for GRIPS (Gamma-Ray Imaging/Polarimeter for Solar flares), another balloon payload [10].

Pitch/Yaw Aspect System

The PYAS consists of two sub-systems, the PYAS-F (F for front) and the PYAS-R (R for rear) (Figure 3, left). The two sub-systems are nearly identical and can provide solar pitch-yaw aspect independent of each other. Aspect is measured by focusing an image of the Sun, filtered to a narrow wavelength, through a singlet plano-convex lens onto a screen 3 meters away. The focused solar image on the screen is recorded by a 1 megapixel Charge-Coupled Device (CCD) camera. Precise fiducials on the screen provide the locating information for the solar image and decouples the camera pointing from the aspect solutions. The plate scale for the screen is 1.1 arcmin/mm. The PYAS must provide aspect solutions to the control system within 1° of the Sun. Thus, the central portion of the PYAS screens (10.5 cm in diameter) is critical. With the megapixel sensor imaging the screen, each pixel corresponds to ~10 arcsec of sky. Each camera is controlled by a single board computer, and each frame taken is processed onboard to obtain the precise location of the center of the Sun and precise locations of the observed fiducials. From that information, the pointing offset to the desired solar target is calculated and provided to the control system.

The PYAS-F has its lens mounted on a bulkhead at the optics plane and its screen located at the elevation flange on a large bulkhead. The PYAS-R has its lens mounted on the same bulkhead at the elevation flange and its screen at a bulkhead at the detector plane (see Figure 3) Comparing the solar positions between the PYAS-F and PYAS-R provides a measurement of the alignment between the optics and detector plane, and the direct connection between the two systems at the elevation flange's bulkhead reduces alignment error. Both systems will record aspect knowledge during flight but only one system (PYAS-F by default) will provide aspect information to the control system. Higher-accuracy aspect knowledge will be obtained after the flight by processing images from each camera that are recorded to onboard solid-state storage at a rate of up to 10 Hz.

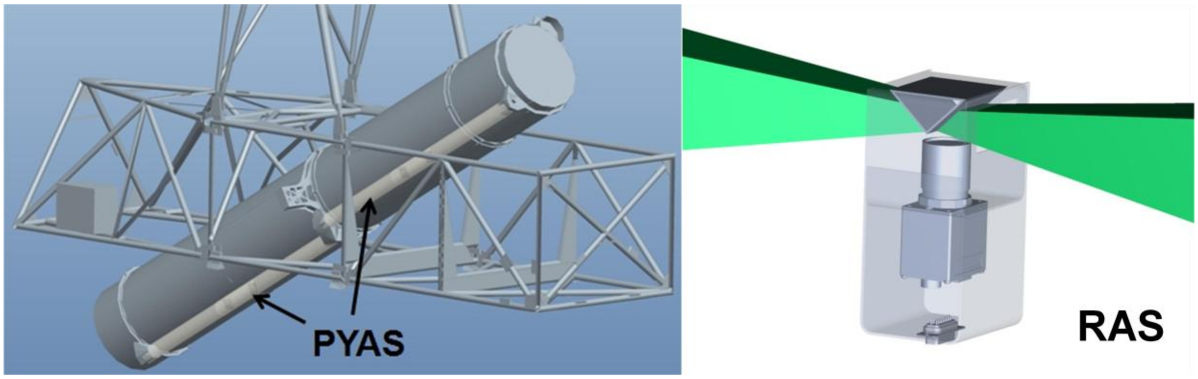


Figure 3: (Left) The Pitch/Yaw Aspect system (PYAS). The two, near-identical sub-systems, PYAS-F and PYAS-R, are mounted along the side of the optical bench and each produces solar images at a focal length of 3 m. (Right) The Roll Aspect System (RAS). The RAS is mounted on the main payload structure and consists of a single camera pointed at two angled mirrors which combine views of the horizon in opposite directions.

Roll Aspect System

The RAS is used to provide only post-flight pointing knowledge because the control system is not able to control the roll of the gondola (which is typically due to wind or other external disturbances). RAS will determine both absolute and relative payload roll by mounting an optical horizon sensor to the gondola. Two mirrors combine views of the horizon in opposite directions into a single CCD camera (Figure 3, right). The bright horizon in one direction is not compromised by the overlaid black sky from the opposite direction. The systematic motion of the combination of the two horizons provides relative roll knowledge with an accuracy of less than a few arcmin. Pendulation is expected to have an amplitude no greater than a degree with a period of around 30 seconds. Aspect knowledge will be obtained by post-flight processing of images from the camera that are recorded to onboard solid-state storage at a rate of up to 10 Hz.

4. ALIGNMENT MONITORING SYSTEMS

Slight misalignment between HEROES star camera and the optical bench, and the optics and detector flanges may occur during flight due to unforeseen mechanical shifts, thermal gradients and gravitational effects. Monitoring these effects will improve night-time pointing and post-flight data reconstruction. A Star Camera Alignment Monitoring System (SCAMS) monitors axial misalignments between the star camera and the optics flange. A second, Bench Alignment Monitoring System (BAMS) monitors misalignments between the optics flange and the detector flange during flight.

Star Camera Alignment Monitoring System

Prior to launch, the star camera is aligned to the optical bench to an accuracy of around 10 arcsecs, and this ground alignment is assumed to stay constant throughout the flight. However, if unforeseen effects (mechanical stress during payload roll-out onto the launch pad, or during launch and/or ascent) occur that shift the position of the star camera from its ground alignment position, an incorrect astrophysical aspect pointing solution will be provided to the pointing control system. A large mechanical shift between the star camera and optical bench (of > 5 arcmins) would result in loss of throughput or loss of source in the telescope field of view. A smaller mechanical shift will have less of an effect, but will still affect throughput.

To monitor misalignments, the SCAMS design employs a visible (green) diode laser with integrated beam focusing optics. This ruggedized laser will be securely mounted to the optics flange. The beam will be directed to a turning mirror mounted on the elevation flange, located at the center of the optical bench. The turning mirror directs the beam upward through a hole in the Optical Bench and through a flat window and onto a flat mirror mounted directly on the camera body. The mount of the flat mirror employs a small angle such that the return beam deviates slightly from the initial beam. This allows the beam to be directed to a CCD camera (1280 x 960 array, 4.65 μm x 4.65 μm pixels) located on the optics flange adjacent to the laser. A neutral density filter will be positioned at the entrance to the CCD to decrease the irradiance at the camera. The position of the CCD camera will be adjusted until the return beam strikes the approximate center of the array (Figure 4). Any additional tilt caused by thermal/mechanical stresses will be seen as a deviation from that initial position determined during ground alignment. Pitch, roll, and yaw of the camera with respect to the optical bench will be detected; however, the sensitivity to pitch may be considerably less, depending on the axis about which the pitch occurs.

At specified intervals, images from the CCD will be transmitted from the payload to the ground system. Each image will be compared to the previous one to determine slight movements of the laser. Based on the distance of the laser movement, a misalignment angle of the star camera will be determined and corrected for during the flight.

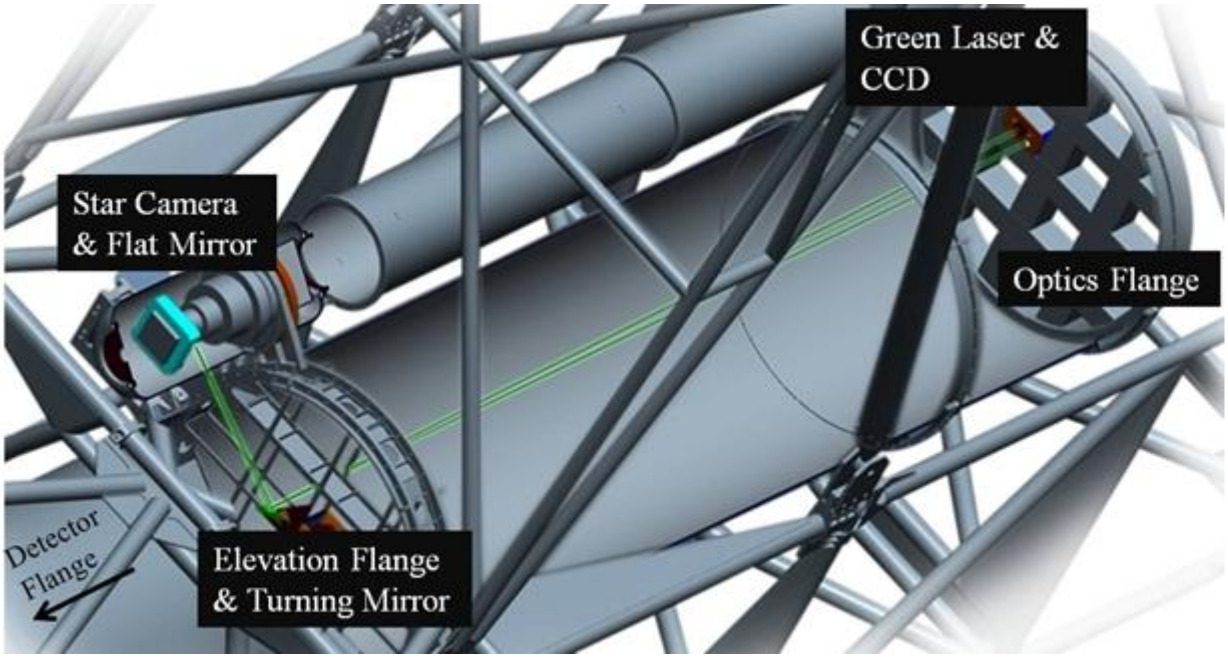


Figure 4: SCAMS conceptual drawing is shown. The green line represents the laser beam reflected off of the turning mirror of the elevation flange, onto the mirror on the star camera and then through a return path and slight angle deviation, into the CCD camera which is located next to the laser on the optics flange. The alignment between the star camera and optical bench is continuously monitored throughout the flight.

Bench Alignment Monitoring System

The HEROES optical bench consists of the optics flange which is attached to a 1 m diameter, 3 m long carbon fiber wound cylinder that is, in turn, bolted onto the elevation flange. The elevation flange is the attachment point for the elevation drive through which the optical bench is connected to the gondola. An additional 3 m long, 1 m diameter aluminum cylinder is attached to the opposite side of the elevation flange, to which the detector flange is mounted; allowing for a 6 m focal length. During flight gravitational and thermal effects may cause a small degree of twisting and bending (banana effect) of the optical bench. These motions would result in a shift of the source position on the detectors that could negatively impact data reconstruction post-flight. Small variations in the position of an astrophysical point source on the detectors can generally be corrected for. However, this is not as easily done with a source that fills the telescope's field-of-view, such as the Sun. HEROES will monitor relative motions between the optical flange and detector flange and will also monitor any movement of the optics modules in their tip/tilt mounts.

The BAMS will use 2 CCDs that are mounted in a thermal enclosure on the elevation flange, and pointed in opposing directions to image pre-determined patterns of infrared light emitting diodes (LEDs). These LEDs will be affixed to the optics and detector flanges and to the optics modules themselves and monitored throughout the flight. The CCDs will be equipped with visible-light filters to block any stray light; improving the signal to noise of the detection. HEROES collaborators at the University of Alabama in Huntsville (UAH) have developed an algorithm to calculate millimeter or finer displacements using these images.

The lens chosen to image the ring of infrared diodes is a 12 mm focal length f/1.4 matched to the ½ inch format of the CCDs. Experimentally, it has been determined that the field of view at the required 3 m distance is about 1 m with an excellent focus at that distance. The 1 m image fills the ½ inch imager very well. This results in a magnification of approximately 0.013. This means that a 2 mm diameter LED will occupy a diameter of about .025 mm (25 microns) on the CCD. This corresponds to roughly 5 pixels x 5 pixels, which is an ample number of pixels for the UAH algorithm to be implemented.

If it is assumed that the minimum detectable movement of the spot is the diameter of the spot, a 0.002 m movement of the LED over a distance of 3 m, then the tracker will detect an angular movement of $\theta = (0.002/3) = 6.7 \times 10^{-4}$ radians, or 2.3 arcmin. However, it has been demonstrated in software that this method can reliably detect a 1 pixel shift which corresponds to a movement of the LED pattern of 0.4 mm. This results in a resolution of 1.3×10^{-4} radians or ~28 arcsecs.

5. STAR CAMERA SHUTTER

In order to observe the Sun during the day and still be able to observe astrophysical objects during the night, a shutter must be added to protect the existing star camera from prolonged solar radiation exposure. The HEROES shutter will operate by a hinged door mechanism that covers the end of the star camera baffle to stop any direct light from entering the CCD. The shutter is not required to be 'light-tight' considering the fact that in the closed position, any remaining stray light will enter the star camera baffle at sufficiently large angles to be stopped by the baffle plates prior to entering the camera lens.

HEROES will make use of the existing HERO star camera and linear focusing mechanism. The star camera is an Apogee U9 Alta series camera with 3072 x 2048 pixels, utilizes a USB 2.0 interface, has dual 12/16 bit digitization to 32 Mbyte memory and runs on a 12 V supply. The star camera lens will be upgraded to a Takahashi FSQ-106ED with improved focus movement. The camera-lens system is mounted inside of the star camera housing, to which a ~9' baffle is attached, to limit scattered light. The star camera housing is attached and co-aligned to the optical bench.

Modified Commercial Off-The-Shelf components will be used to open and close the hinged door. The Ball Drive Actuator 85915 from Motion Systems has been chosen for this operation. This actuator has a 5 in. high precision stroke and 40 lbs maximum dynamic load and 240 lbs static load; which are more than adequate for this application. While the actuator is not rated for vacuum, modifications will be made to prepare the system for operation in the balloon environment. The primary modification will be removing the existing grease in the actuator and motor, and replacing is with a suitable low off-gassing alternative. The Ball Drive Actuator will be tested in a vacuum prior to launch of the balloon. Figure 5 shows the shutter attached to the HEROES star camera baffle in various positions.

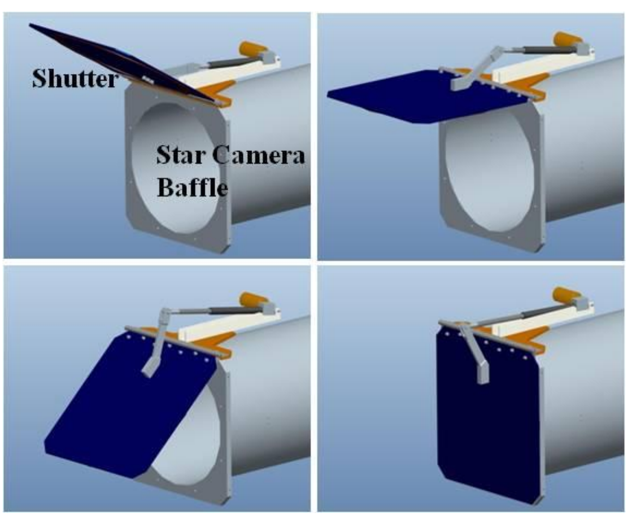


Figure 5: Conceptual design of the HEROES star camera shutter is shown. The upper left-hand picture shows the shutter in a fully open position and the lower right image shows the shutter in its closed position.

6. FLIGHT

HEROES will maximize its science output by leveraging both day-time solar observations and night-time astrophysical observations on the same balloon flight. HEROES's scientific objectives are: (a) Investigate the acceleration and transport of energetic electrons in solar flares using hard X-ray imaging spectroscopy. (b) Investigate the scale of high energy processes in a pulsar wind nebula by mapping the angular extent of hard X-ray emission. (c) Investigate the hard X-ray properties of astrophysical targets such as X-ray binaries and active galactic nuclei. (d) Investigate electron acceleration in the non-flaring solar corona by searching for the hard X-ray signature of energetic electrons.

HEROES will launch from the Columbia Scientific Balloon Facility in Ft. Sumner, NM, during the Fall 2013 campaign. The payload will fly on a 40 MCF balloon. Assuming a typical ~33 hour (Conventional) flight with an early morning launch, HEROES is expected to take a few hours to reach a float altitude of at least 37 km. Once at float altitude, HEROES will begin observing its primary target, the Sun, until it falls below about 30º in elevation, the minimum elevation angle (maximum atmospheric attenuation) at which HEROES can make useful observations. Then HEROES observations will switch to astrophysical targets. Because HEROES primary astrophysical target, the Crab nebula, will not be observable until several hours after sunset, HEROES will observe other astrophysical targets. These targets will be selected by the HEROES team through an internal announcement of opportunity (AO) within MSFC and GSFC. Target selections can be changed during the flight if needed, if for example, a new transient X-ray source is observable during the flight. Near midnight local time, HEROES primary astrophysical target, the Crab nebula, becomes observable. HEROES will observe it until the Sun becomes visible again on the second day. During the second day, once sunset approaches or the batteries have been exhausted (whichever comes first), the HEROES flight will be terminated by CSBF. Figure 6 illustrates this flight profile. HEROES members will accompany CSBF to retrieve the gondola and payload from its landing site.

It is worth mentioning that the HEROES team is performing extensive thermal simulations. This includes complete 3-D modeling of the new subsystems and their relative thermal environment. Modeling of existing systems that may have risk with extended solar pointing are also being performed. The simulation will include the environment for the entire float profile, including the position of the payload with respect to the Sun for the different observations planned, along with worst case environmental conditions. Also any component that has a risk during ascent will be analyzed. Preliminary data from these models indicate that extended solar pointing will not require additional thermal mitigation over that of the existing HERO payload.

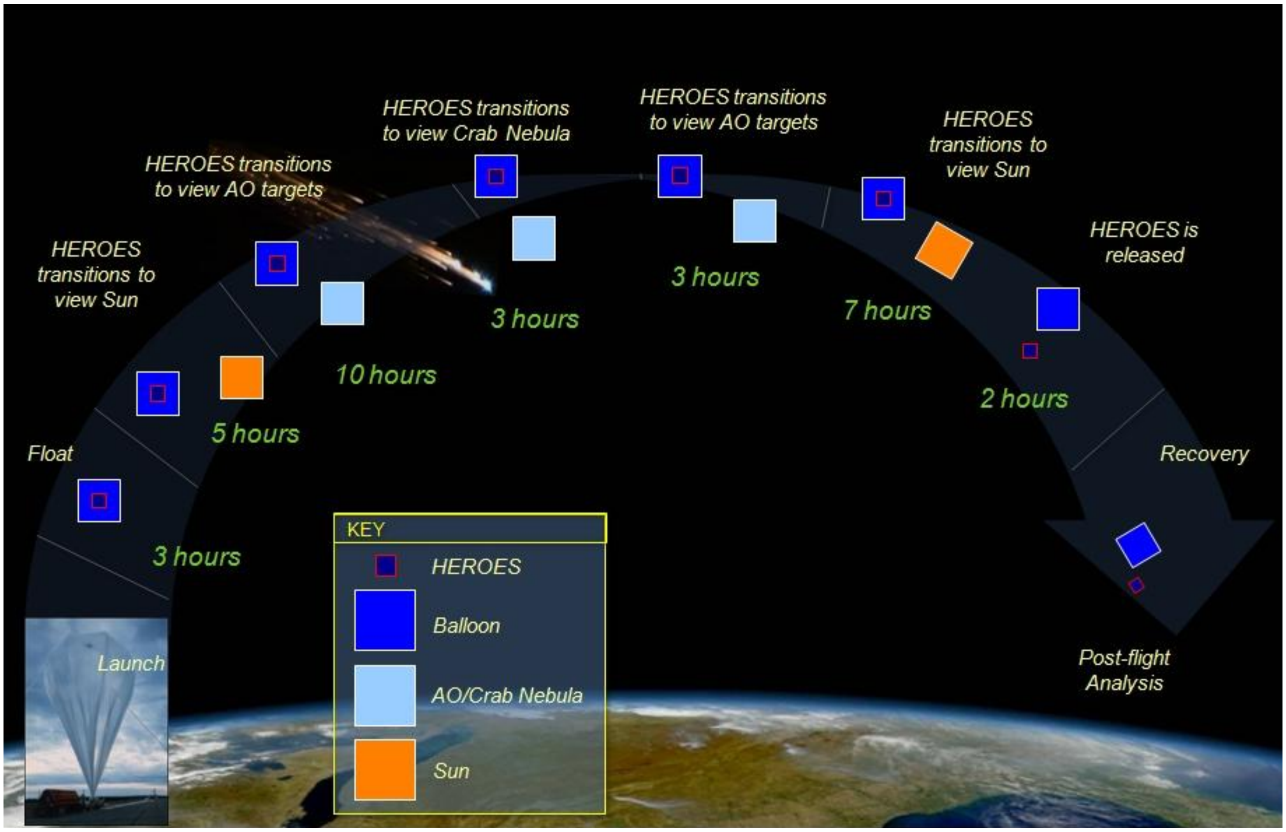


Figure 6: A diagram of an example flight profile is shown. It takes around 3 hours from launch for the payload to reach float (max. altitude). HEROES will observe the Sun for ~5 hours until it is no longer visible. Astrophysical observations will then take place during the night-time, until the Sun is visible again on the second day. HEROES will observe the Sun until CSBF requires the flight to be terminated or no more useful science can be obtained.

7. SUMMARY

The HEROES project is a 15-month program to upgrade and fly the existing HERO astrophysics balloon-borne payload to make new observations of the Sun and view astrophysical sources at high energies. Prior to the balloon flight from Ft. Sumner, NM scheduled for the Fall of 2013, HEROES will add a Solar Aspect System, Star Camera shutter, an Alignment Monitoring System for the Star Camera and an Alignment Monitoring System for the optical bench.

A follow-on payload to HEROES and the focus of future work is SuperHERO. SuperHERO will be designed for a Long Duration Balloon flight mission (typical flights are 2 to 4 weeks long) and will take advantage of improved Technology Readiness Level for the SAS and AMSs afforded by HEROES. SuperHERO will enhance the resolution of the existing optics through mirror-shell realignment and the GSPC detectors will be upgraded to CdTe pixelated detectors being developed by Paul Seller and Matt Wilson at the Rutherford Appleton Laboratory in the UK [11]. These detectors will provide better spatial resolution (250 μm pitch), oversampling the response of the HEROES optics for improved angular resolution, as well as provide higher energy resolution and higher quantum efficiency over all energies. The addition of anti-coincidence shielding will further enhance performance of these detectors through improved background rejection. Improved pointing and pointing stability will be achieved through the integration of the SuperHERO optical bench onto the Wallops Arc-Second Pointer (WASP) system currently under development [12].

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BIOGRAPHIES

Dr. Jessica Gaskin *is a physicist in the X-Ray Astronomy Group at NASA Marshall Space Flight Center in Huntsville, AL. She has characterized multiple types of solid state detector systems for X-Ray Astronomy and has supported the High Energy replicated Optics (HERO) hard X-ray balloon-borne telescope; offering flight support and detector calibration support. Over the past few years, she has focused her research on Planetary/In-Situ based instrumentation, concentrating on the mini-SEM. She has a B.S. in Physics (specializing in Astrophysics) from New Mexico Tech, an M.S. in Astronomy from Case Western Reserve University, and a Ph.D. in Physics from the University of Alabama in Huntsville. Dr. Gaskin is the MSFC PI for HEROES.*

Dr. Steven D. Christe *is a Research Astrophysicist at the Solar Physics Laboratory, located at GSFC. Dr. S. Christe received his Ph.D. from the University of California, Berkeley (UCB), at the Space Sciences Laboratory under Prof. R.P. Lin. During his graduate studies, working with Dr. S. Krucker, Dr. Christe developed a sounding rocket program to study solar microflares. The FOXSI program, short for the Focusing Optics X-ray Solar Imager, is a partnership between the Space Sciences Lab UCB, MSFC, and the Japanese Astro-H mission. As a postdoctoral researcher at the Space Sciences Lab, Dr. S. Christe oversaw the FOXSI program as the project manager/project scientist. These responsibilities have continued after he joined the GSFC in the Fall of 2009. Dr, Christe is the GSFC PI for HEROES.*

Dr. Albert Shih *joined the Solar Physics Laboratory at GSFC in 2010. His research interests focus on X-ray and gamma-ray observations of particle acceleration in solar flares. He is currently serving as the Deputy Mission Scientist for RHESSI, and is the project manager and project scientist for Gamma Ray Imager/Polarimeter for Solar flares (GRIPS). Dr. Shih is the Solar Project Scientist for HEROES.*

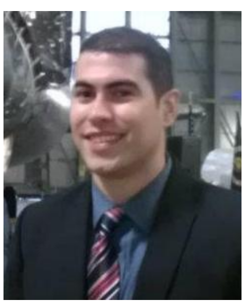
Dr. Colleen Wilson-Hodge *began her NASA career as a Cooperative (Co-Op) Education student in 1989, and in 1999 she completed her Ph.D. She has led/co-authored more than 40 refereed journal* articles *and has led 14 observing proposals. Since 2005, Dr. Wilson-Hodge has been a Co-I on the Gamma-ray Burst Monitor (GBM) onboard Fermi. She is Astrophysics Project Scientist for HEROES.*

Dr. Katherine Stevenson Chavis *Is a systems engineer in the Space Systems Department at NASA MSFC in Huntsville, AL. Over the past few years, she performed many aspects of the systems engineering discipline while supporting several projects such as Orbital Express, Ares I-X, Ares I, Ares V and SLS. She currently serves as Lead Systems Engineer for HEROES.*

Ms. Leigh Smith *is the Project Manager for the HEORES Project. She has worked for NASA MSFC since 2000. She graduated from the University of Alabama in Huntsville with B.S. degree in Electrical Engineering and a M.S. Degree in Engineering Management.*

Mr. Brian O'Connor *joined MSFC as a Co-Op in 2006. He is a Thermal Engineer in the Thermal & Mechanical Analysis Branch of the Space Systems Department. He has worked on a number of projects supporting the thermal subsystem team. For the ILN, he performed an extensive analytical trade of radiator designs. Mr. O'Connor is the Thermal Engineer for HEROES.*

Mr. Jonathan Pryor is *an electrical engineer with work experience in imagery systems and scientific balloon payload avionics. He received his electrical engineering degree from Tennessee Technological University in December of 2011 and now works at NASA MSFC. Mr. Pryor is the Avionics Engineer for HEROES.*



Mr. Marcello Rodriguez *started at GSFC as a Co-Op in 2005 and became a full- time employee in 2007. He has worked on the Lunar Reconnaissance Orbiter (LRO) spacecraft purification system. And has been on detail in the science division working on instrumentation. Mr. Rodriguez is the SAS Systems Engineer for HEROES.*

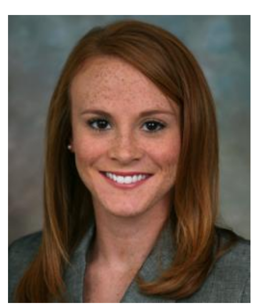
Mr. Alexander Sobey *joined MSFC's Federal Career Intern Program as an Aerospace Engineer. Since then, he has taken on a structural design role for the Pre-Phase-A study of the Energetic X-ray Imaging Survey Telescope (EXIST). Mr. Sobey has also worked on the International Lunar Network (ILN) as well as the Extreme Universe Space Observatory (EUSO) as the structural designer. Mr. Sobey is the lead Mechanical Engineer for HEROES.*

Mr. Tomasz Lis *graduated from the University of Alabama in Huntsville (UAH) with a B.S. in physics in 2011, and currently is working on his masters with a specialization in optics. Mr. Lis is enrolled in the NASA MSFC Co-Op program. His thesis will involve the HEROES Alignment Monitoring Systems development.*

Mr. Alexander Cramer *studied mathematics and electrical engineering as an undergraduate at the University of Maryland, receiving BS degrees in both in 2009. He has worked as an Electrical Engineer at GSFC since 2009. He is currently working toward a PhD in machine vision at the University of Maryland. Mr. Cramer is the Solar Aspect Systems Electrical Engineer.*

Mr. Miguel Rodriguez Otero *joined NASA in 2011 as part of JSC's internship program. He recently joined the Electrical Power Branch at MSFC, and possesses a M.S. from the University of Puerto Rico at Mayaguez, and a B.S. from the Polytechnic University of Puerto Rico. Both degrees are in Electrical Engineering. Rodriguez-Otero supports the Electrical design and Integration of HEROES.*

Ms. Heather Koehler *has a M.S. in Aerospace Engineering from Auburn University and 15 years of experience working for NASA as a contractor and civil servant. Her experiences includes Space Shuttle guidance, navigation and control software development and testing, Shuttle mission support, natural environments analysis and meteoroid environment modeling and analysis in support of program/project risk assessments. Mr. Koehler is the Lead Software Engineer for HEROES.*

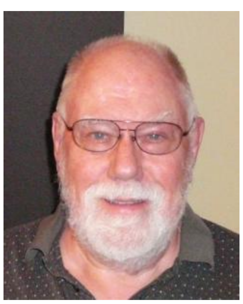


Ms. Maegan Rinehart-Dawson *is a Flight Systems Test Engineer with a B.S. in Aerospace Engineering from Mississippi State University. She currently works for NASA MSFC where she works hardware integration and testing for space station payloads. Ms. Rhinehart-Dawson provides software and mechanical support for HEROES.*

Ms. Melissa Edgerton *is an aerospace engineer for NASA at the GSFC. She earned a B.S. in Mechanical Engineering and is currently pursuing a M.S. in Aerospace Engineering from the University of Maryland in College Park. Melissa spent two years as a co-op student at Goddard before converting to a full-time employee three years ago. She is working in the Electromechanical Systems Branch with a focus on Optomechanics. Ms. Edgerton is the Solar Aspect System Mechanical Engineer.*

Mr. Steve Bohon *is a Master's student at North Carolina State University in mechanical engineering with a focus on thermal sciences. Mr. Bohon has industry experience with the mechanical design of cold-weather regulating systems. In the summer of 2012, Mr. Bohon interned with the NASA Academy leadership development program at the MSFC and assisted with the mechanical design of HEREOS systems.*

Mr. Marlon Holt *joined NASA as a Co-Op. Since then, he has assisted with design, development and testing of power electronic circuits, sub-systems, and power supplies. Mr. Holt has also tested solar cells for Space Systems/Loral and tested the Hubble Space Telescope flight spare battery. Mr. Holt provides Power Systems support for HEROES.*



Mr. John Jasper *has fifty-seven years experience in all phases of software development, integration, and testing. He has designed and implemented radar-tracking software, data link processing software, and distributed air defense system architectures, using C, C++, and Ada languages. Most recently, Mr. Jasper has designed and coded embedded (PC104) applications, providing compression and remote display of FLIR imagery in support of the Chaparral Air Defense System. Under contract to the University of Alabama in Huntsville, Mr. Jasper is currently supporting research in novel tracking techniques for space-based platforms. Mr. Jasper is supporting the software development for the Alignment Monitoring Systems for HEROES.*

Dr. Don Gregory *is professor of physics at the University of Alabama in Huntsville and has more than 100 refereed open literature technical publications in internationally circulated journals in fields ranging from basic physics and optics to materials and advanced propulsion. He has 13 US patents and has been the recipient of the Department of the Army Research and Development Award. Dr. Gregory supports the Alignment Monitoring Systems development for HEROES.*

Dr. Brian Ramsey *obtained his Ph.D. in Astrophysics from Birmingham University in England, in 1978. Since 1983, he has been at MSFC working in the x-ray astronomy group. His areas of interest include x-ray and neutron optics and the development of x-ray detectors for various applications (including astrophysics, planetary, and medical). Dr. Ramsey was responsible for the conception and implementation of the HERO payload. He serves as an advisor to the HEROES team.*

Mr. Kurtis Dietz *received his BS degree in physics and astronomy from the University of Arizona in 1988. He has worked at the MSFC since 1989, currently as a computer scientist specializing in instrument development for scientific payloads. He is the author or coauthor of dozens of papers in instrumentation. Currently, he is responsible for the test, flight, and ground software for several balloon-borne, aircraft-borne, and ground-based instruments used in x-ray astronomy, gamma-ray terrestrial studies, cosmic ray studies, and atmospheric research. Mr. Dietz supports the software development for HEROES.*

Mr. Jeffrey Apple *received his B.S. degree from Tennessee Technological University in Cookville, Tennessee in 1986. Shortly after, he joined MSFC as an Electrical Engineer in the Preliminary Design Office. Mr. Apple has been Lead Electronics Engineer for HERO since 2000 and has served as Lead Electronics Engineer for several other scientific balloon payloads. Mr. Apple provides engineering support for HEROES.*