Final Report

1 Summary

This mission was performed by The Johns Hopkins University Applied Physics Laboratory (APL) to develop and fly a balloon-borne gondola with a scientific payload for the observation of Comet ISON and other planetary objects, during a one-day flight demonstration in September 2013. APL performed this task under the direction and sponsorship of the Glenn Research Center (GRC). Specifically, APL defined, developed, delivered, and operated the Balloon Rapid Response for ISON (BRRISON) gondola that would perform a first demonstration flight to make scientific observations of the Comet C2012 S1 (ISON). ISON is a sun-grazing comet that may have freshly emerged from the Oort Cloud on its first, and likely its only, pass through the inner solar system. The balloon-borne platform was designed to make ground-breaking observations to directly address key science questions posed by the planetary decadal survey, “Vision and Voyages for Planetary Science 2013-2022.” APL developed a gondola that used flight heritage from the Stratospheric TeraHertz Observatory (STO) balloon mission, which has already demonstrated capabilities important to a planetary science balloon platform, while at the same time defining a clear and simple evolutionary path resulting in the development of a balloon-borne planetary science platform with broad capability to address decadal survey science questions.

APL developed a balloon platform to observe the comet in the near infrared (2.5 – 5 micron) and in the near-ultraviolet and visible (300 nm – 700 nm) from a nominal 120,000 foot altitude, utilizing the existing STO 0.8 meter telescope and STO gondola subsystems, including pointing, power, command and communications. However, a new gondola structure able to later accommodate a larger, greater than 1 meter diameter, telescope was needed to achieve a significant proportion of decadal survey science. APL subcontracted the development of the ultraviolet and visual (UVVis) payload to Southwest Research Institute (SwRI) in Boulder, Colorado.

To govern a “time is of the essence” project such as BRRISON, APL developed a project plan customized for a rapidly developed balloon-borne project. This BRRISON Project Plan drew upon the experience of APL’s core ballooning team and established a disciplined approach to regulate project management, engineering, product assurance, as well as all other aspects of the project.

The mission was flown on the evening of September 28, 2013, just 11 days after the originally targeted launch date of September 17. The launch operations were conducted by CSBF following a well-rehearsed protocol. The BRRISON flight mission operations center was at the launch site in Fort Sumner. About one hour before launch, the go/no-go decision to inflate the balloon was made. At this point the gondola transitioned to internal power and was raised to launch height. The balloon inflation lasted approximately 45 minutes. Following a final systems check, the go for launch was given and the balloon was released, carrying the gondola. Ascent to float altitude lasted about 2 hours. During the very early phase of commissioning, an anomaly occurred that caused the telescope to rapidly retract to the stowed orientation and become stuck in that orientation. Efforts were made to free the telescope to no avail. The anomaly and its cause will not be discussed in this report. Instead, a full description of the anomaly, its cause, and recommended corrective actions is provided in the “BRRISON Anomaly Investigation Team Final Report.” Following the flight, the gondola was recovered approximately 55 miles east of Lubbock, Texas, and was eventually shipped by truck to APL.

2 Science Goals

The composition and nature of cometary nuclei are key to understanding the condensation and evolution of primitive materials in the early Solar System. The comets are stored in two principal reservoirs, the Oort Cloud and the Kuiper Belt, where the former is a distant reservoir of dormant bodies located approximately 10,000 to 50,000 AU from the Sun, and the latter comprises trans-Neptunian objects from approximately 30 AU to 100 AU from the Sun. The so-called ecliptic comets that have been visited by spacecraft (e.g., Wild 2 and Tempel 1) were all stored in the Kuiper Belt before they evolved onto orbits that entered the inner Solar System. ISON, as an Oort Cloud comet, may have formed in a different source region from the ecliptic comets under distinct physical conditions. Recent dynamical models of the early Solar System suggest that giant planet migration may have disrupted a massive primordial asteroid belt and an outer disk of icy planetesimals (outside 15 AU from the Sun), injecting comets to the Oort Cloud and Kuiper Belt, and contributing much of the mass impacting the Earth-Moon system during the Late Heavy Bombardment which ended about 4 billion years ago. Icy planetesimals formed in, and ejected from, the inner disk (the giant planet feeding zones from approximately five to 15 AU) more likely entered the Oort Cloud and outer disk. Measuring compositions of Oort Cloud comets versus ecliptic comets will constrain models of cometary origins and the dynamical evolution of the early Solar System. In addition, comets in the Oort Cloud may include material and objects captured from neighboring solar systems in the Sun’s birth cluster. Hence compositional studies of Oort Cloud comets, when they fortuitously visit the inner solar system, provide important opportunities to address where and how these comets formed, whether compositional signatures of interstellar materials are preserved, how their birth conditions and histories may differ from those of Kuiper Belt comets, and what volatiles, water and organics were delivered to the early Earth.

Specific comet questions from the planetary decadal survey that were to be addressed with the BRRISON flight demonstration are :

- How does the composition of Oort Cloud comets compare to Kuiper Belt comets?
- What are the chemical routes leading to complex organic molecules in regions of star and planet formation?
- Were there systematic chemical or isotopic gradients in the early solar nebula?
- How did Earth get its water and other volatiles?

An assessment of decadal survey science questions from the Balloon-based Planetary Science Workshop, held January 25-26, 2012, at Glenn Research Center, found that the baseline mission with near-IR and UVVis imaging would address 11 of 45 questions formulated at the workshop, with another 17 of 45 questions addressed in part. The threshold mission, with near-IR measurements only, would address 10 of 45 questions with another five of 45 questions addressed in part.

The BRRISON flight demonstration was planned to observe Comet ISON in the near-infrared and in the near-ultraviolet and visible wavelength ranges. The near infrared camera would have measured the ratio of CO_2 to H_2O emissions from the coma as a vital diagnostic of the comet’s origins. These would have been unique observations that could not have been obtained by any other means. The near ultraviolet and visible camera would have observed at the wavelength of the OH emission from ISON and would test sub-arcsec pointing and characterize the seeing at balloon altitudes. For the BRRISON flight demonstration of Comet ISON, the required observations were measurements of CO_2 and H_2O and the ratio CO_2/H_2O for the comet. The demonstration of sub-arcsec pointing and the seeing measurements were highly desired capabilities but not required for this flight demonstration.

The near infrared camera was to measure the ratio of CO_2 to H_2O emissions from the coma as a vital diagnostic of the comet's origins. The near-IR channel used a commercial off-the-shelf (COTS) camera with an HgCdTe array detector and integrated cryostat and control electronics. The near-IR channel included a cooled filter wheel. The visible channel of the payload observed at the wavelengths of the OH and CN emissions from ISON and it would test sub-arcsec pointing and characterize the seeing at balloon altitudes. The visible channel used two COTS cameras, a CCD camera to make comet observations and a CMOS camera for guiding; it included, in addition to these cameras, a collimator and closed-loop, fast steering mirror system with the goal of demonstrating the ability to obtain diffraction-limited visible imaging on later flights.

Science observations by the BIRC were planned assuming acquiring images in a sequence of filter positions with multiple integration times used at any single filter position. To minimize the amount of time allocated to filter movement, the filters were placed in the wheel so that filters commonly used together occupied adjacent positions. From filter positions one to nine, the filters were: R, 4.60, 4.00, 4.27, 2.73, 2.47, 3.2, 3.05, 2.85. For each planned observation, a range of integration times was calculated for each filter to ensure the highest signal to noise measurement would be obtained. Requiring a couple of seconds on average to rotate between filters, an observation sequence that included all nine filters over an integration time of a few milliseconds to hundreds of milliseconds required less than a minute to complete.

The primary science objective, a Level 1 Requirement, was to observe CO_2 in comet ISON at 4.27 microns and the water vapor band at 2.73 microns. An additional science objective was to measure CO_2 in comet Encke as well. Other objectives were to measure the spectral characteristics and depths of the vibrational OH bands in the surfaces of primitive C-type and similar asteroids and to measure the nature of the OH-related band on the illuminated portion of the Moon. Additionally, evidence for water in the atmosphere of Jupiter was to be explored with the same bands. By measuring the water vapor and CO_2 absorptions, the CO_2/water ratio can be inferred. CO_2 is the most abundant cometary volatile after water and is believed to be a major factor in forming jets at distances from the Sun at which water ice would not yet be mobile. Understanding the CO_2/water ratio in the coma of a comet enables scientists to infer the importance of this volatile in jet formation as well as better understand the degree of compositional heterogeneity in comets. With ISON being a dynamically 'fresh' Oort cloud comet on its first, and probably only, visit to the inner solar system, this information would enable scientists to peer into the formation conditions of such comets. By also measuring the CO_2/water ratio in an evolved short period comet such as Encke, scientists would potentially be able to compare the compositions of the two cometary reservoirs. The measurement of the spectral characteristics of water/OH on asteroids and Moon enables the inference of its physical state as well as abundance. For the Moon, there is the additional objective to measure the thermal stability of this OH, and possibly to test the hypothesis that it originates from the implantation of solar wind particles. Asteroids Kleopatra, Elektra, and Pallas were planned to be targeted. Multiple stars were planned to be targeted as well, for radiometric calibration purposes.

2.1 Scientific Payload Description

The BRRISON scientific payload consisted of a high heritage 80-cm telescope, a near-ultraviolet/visible optical bench and instruments, and an infrared optical bench and instruments were mounted on one side of the UVVis optical bench. The telescope, which flew on prior balloon missions, consisted of a light-weighted f/1.5 hyperboloid 80 cm diameter primary mirror made of honeycombed Ultra Low Expansion titanium silicate glass weighing 50 kg, and a secondary mirror to provide an f/17.5 beam mounted on graphite epoxy spider arms for high thermal stability. The primary mirror surface roughness is of optical quality and the mirror was recoated by Nu-Tek to maximize performance in the 300 – 5000 nm wavelength range required for this flight demonstration. The primary mirror was mounted to a support structure consisting of inner and outer rings. This support structure was modified to accommodate the optical benches and instruments necessary for this flight demonstration. Carbon fiber support struts were designed, built, and mounted on the inner aluminum ring to support the COTS optics bench. This master optics bench is the same as the UVVis optical bench and composed of layered carbon fiber epoxy approximately 5 inch thick, rested just beyond the second outer aluminum ring. A hole bored in the center of optics bench passed the f/17.5 illumination of the telescope that also passed through a field stop and then to a two-position mirror on the optics bench, to direct the illumination either to the UVVis instruments or to the IR instruments. Concurrent visible and IR observations were not planned, nor needed to achieve the science goals of this demonstration. The UVVis instrumentation and IR optics bench was mounted on the far surface of the master optics bench to facilitate integration, alignment and calibration at APL.

Near ultra-violet and visible cameras and other optical instruments were integrated to the master optics bench by SwRI. Those instruments consisted of a fine steering mirror (FSM) manufactured by Left Hand Design, which was purchased by APL and provided to SwRI as Contractor Furnished Equipment (CFE), a CMOS high rate camera, also CFE, which was part of the fine steering system, a second CFE camera that was a CCD device for low noise science operation, and a dichroic for splitting the f/17.5 beam between the two cameras. The infrared optics bench and instruments consisted of an optics bench, re-imaging optics and cold stop provided by APL, filter wheel and filters, and an infrared camera that was sensitive over the required wavelengths of 2.5 – 5 microns. The IR optics bench and instruments were enclosed in an aluminum housing designed and built by APL. This housing was cooled through a combination of active and passive means to reduce the thermal background contribution to the IR camera. The IR bench and housing were thermally isolated from the UVVis optics bench. The IR filter wheel, filters, and camera were cooled sufficiently to provide a low noise performance sufficiently sensitive to detect the CO_2 emission from comet ISON. A COTS Linux computer that was kept inside a pressure vessel on the gondola controlled the IR camera filter wheel. A visible channel computer, which controlled the UVVis cameras and FSM, interfaced with the IR computer for command and control. All computers were maintained in a pressurized box. SwRI provided software for interfacing with the UVVis instruments; APL developed the software for controlling the IR instrument. APL also developed the software for interfacing with the existing Command and Control computer.

2.2 BRRISON Infrared Camera

The BRRISON Infrared Camera (BIRC) is a multispectral imager capable of measuring 8 narrow bands between 2.5 um and 5 micron, with an additional astronomical filter at optical wavelengths. BIRC was designed to measure the water and CO_2 emissions from a comet coma and to determine their ratio as an important diagnostic of cometary origins.

BIRC was mounted on an IR optical bench behind the main telescope. This bench was one of two mounted behind the BRRISON main telescope; the UVVis instrument was mounted on the proximal bench and BIRC was mounted on the distal bench. A pick-off mirror either diverts light into UVVis or moves aside to let light pass through to BIRC. The arrangement of the two optical benches is shown in **Figure 1**.

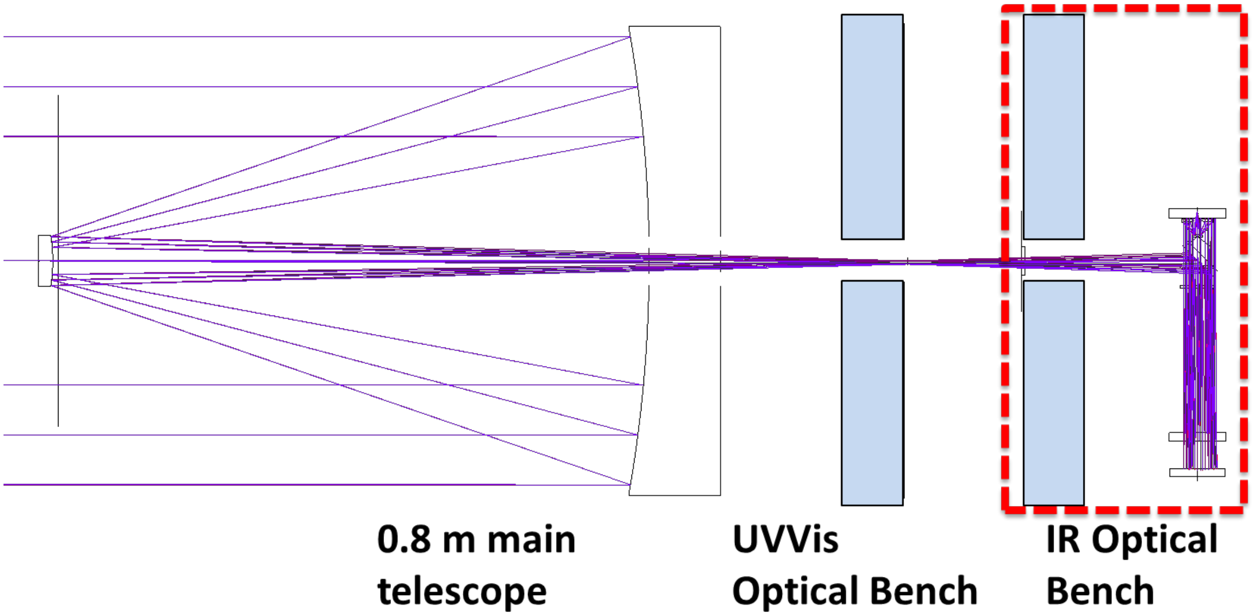

Figure 1. BRRISON optical benches, with ray trace from 0.8 meter main telescope. Prime focus is at the UVVis bench. The IR optical bench mounts relay optics, a filter wheel, and the IR camera.

BIRC used a commercial off-the-shelf camera that had a cryogenic HgCdTe array detector and an integrated cryostat. This camera was integrated with a cooled, 9-position filter wheel and cooled relay optics that couple the camera to the main 80 cm aperture, f/17.5 telescope. Both the filter wheel and relay optics needed to operate near LN2 temperature to reduce the thermal background emission from the instrument itself.

The relay optics include a 50.3 mm, f/4 Ritchey-Chretien (mini-RC) telescope that was mounted within the integrated cryostat and vacuum system of the BIRC camera, immediately in front of the IR focal plane array. The light from the main telescope reached prime focus at the UVVis optical bench, where a field stop is located, and then entered the IR optical bench through a CaF2 window. On the IR optical bench, the relay optics, with three fold mirrors and an aspheric mirror, collimate the light and provided an exit pupil at the mini-RC, at which a cold shield was placed. The cryogenic filter wheel was also near the exit pupil. Two views of the optical layout on the IR optical bench are shown in **Figure 2**.

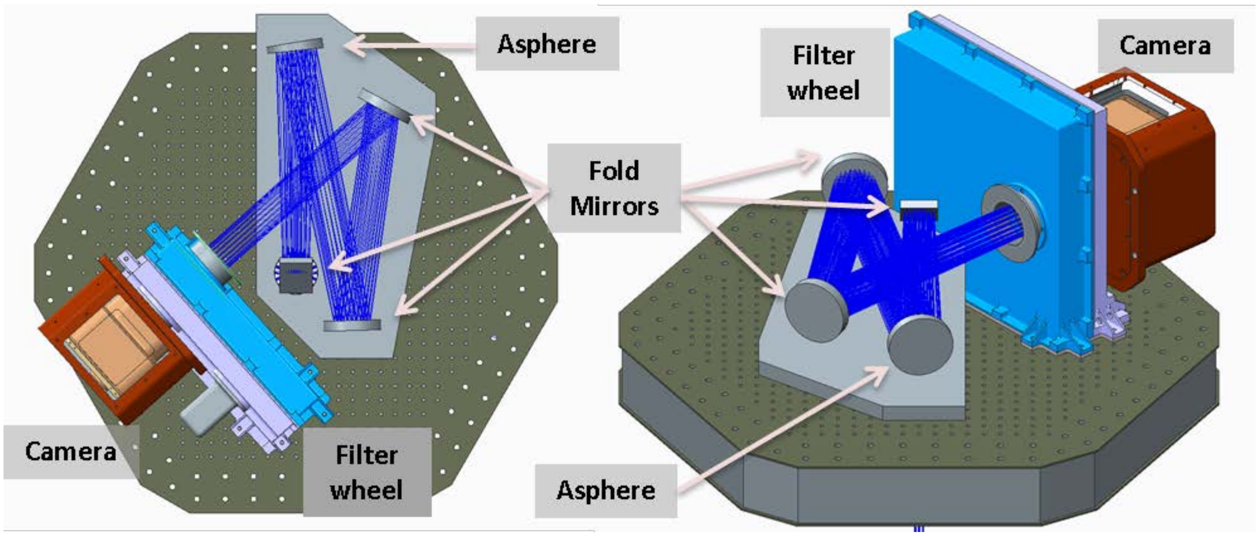

Figure 2. **Two views of the IR optical bench. Light enters at the center of the hexagonal bench, after bypassing the UVVis instrument, and is bent into the plane of the bench at the first fold mirror. Light is then collimated at the Asphere, and after two more fold mirrors, it passes through a CaF2 window, through the nine-position filter wheel, and into the IR camera. The mini-RC telescope is within the IR camera housing.**

The BIRC camera is an integrated system consisting of a Teledyne H2RG 2048 x 2048 HgCdTe array with 5.1 micron cutoff at 77 K, the SIDECAR cryogenic focal plane readout ASIC, and the integral cryostat with its Stirling cryocooler and control electronics. The SIDECAR communicated with an external image acquisition module (SAM card), which was accommodated within an IR Pressure Vessel (IPV). The IPV housed, in addition to the SAM card, a power board, an Ethernet router switch and the IR flight computer. The BIRC camera with its cryocooler is shown on the IR bench in **Figure 3**.

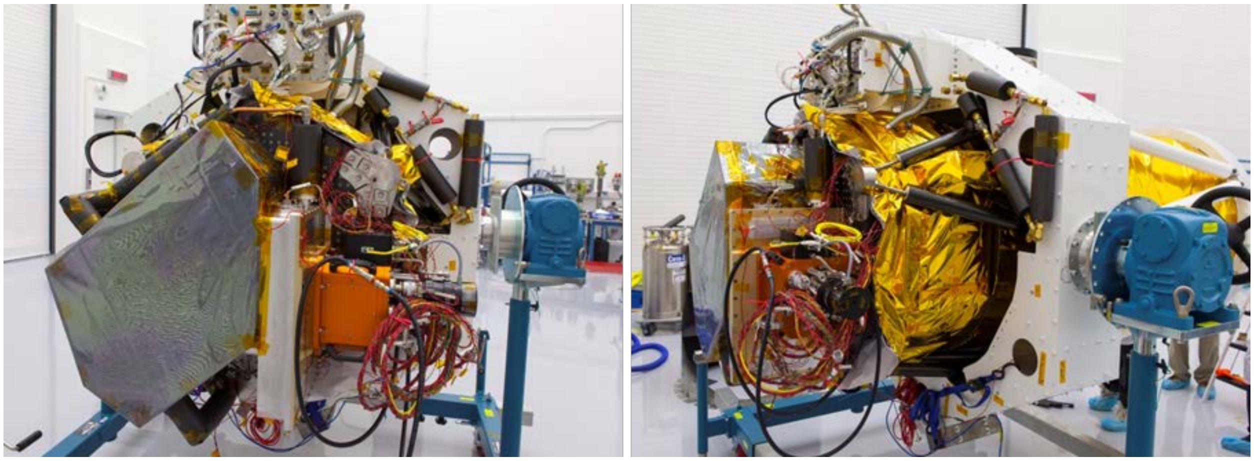

Figure 3. **(left panel) The IR bench, with cold enclosure containing relay optics (gray polygonal box), filter wheel (in aluminum housing), IR camera (orange box), and cryocooler (black cylinder). (right panel, left to right) The IR bench (cryocooler pointing out of page), and the UVVis bench (in thermal blanketing), both mounted on the cradle (white structure) of the main telescope.**

The SAM card in the IPV provided a USB 2.0 interface for image data transfer from the SIDECAR to the flight computer. The flight computer controled image acquisition by the camera via the SAM card, stored image and engineering data on two solid state drives of 512 Gbyte capacity each, provided the command interface and the downlink data interface to the gondola via Ethernet, and managed the thermal control. The temperature and heater controllers in the flight computer managed the IR focal plane fine temperature control and the instrument heaters.

The power board in the IPV implemented power and control functions for a fluorinated liquid cooling loop, the cryogenic filter wheel, and the cryocooler. The liquid cooling loop serviced both the BIRC camera and the two UVVis cameras. The cooling loop removed excess heat from the cameras and transported it to an external radiator on the gondola, maintaining the camera external housings near room temperature. The Ethernet router in the IPV was also the interface to the gondola for the UVVis flight computer and the two BRRISON star cameras.

The BIRC thermal design was divided into multiple zones. The camera focal plane was operated at approximately 70 K, within a structure ("inner sanctum") to which the mini-RC telescope was mounted, all of which was cooled by the cryocooler; the mini-RC was operated at approximately 80 K. The filter wheel mechanism was within the same vacuum enclosure as the camera inner sanctum, but was separately cooled with liquid nitrogen; the filter wheel was operated at approximately 125 K. A separate enclosure, also cooled by liquid nitrogen, was mounted on the BIRC optical bench and contained the three fold mirrors and the collimating asphere of the relay optics; this cold enclosure was separated from the camera and filter wheel vacuum system by a CaF_2 window. The relay optics in the cold enclosure operated at approximately 190 K. Another CaF_2 window was located at the entrance to the cold enclosure on the IR optical bench, where light from the main telescope was passed into BIRC. The optical bench and the main telescope were operated at or above ambient temperatures. Two 50 liter cryogenic dewars were located on the gondola base structure. The dewars contain over 80 kg of LN2 for cooling the filter wheel and optical bench elements. Insulated copper tubing and a vacuum-jacketed flexline across the telescope gimbal carry the LN2 from the dewars to the IR payload. The filter wheel assembly and the mini-RC are shown in **Figure 4**.

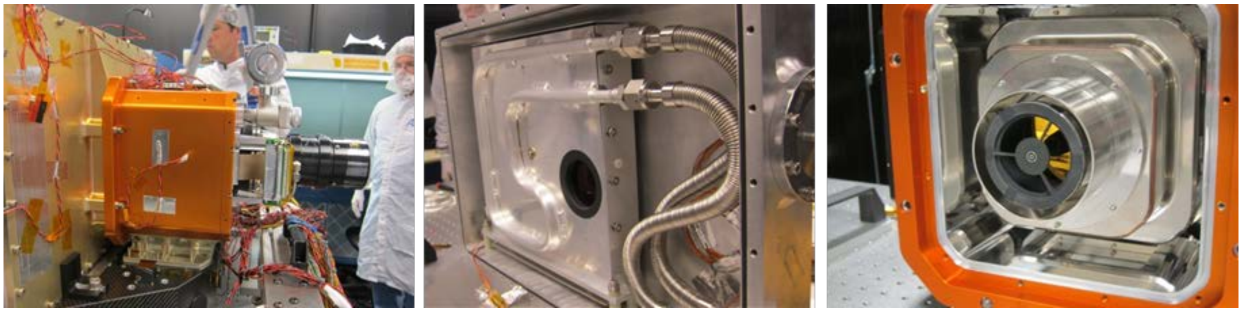

Figure 4. (left panel) the IR camera (orange) and cryocooler (black); (center) the cryogenic filter wheel housing with LN2 cooling loop; (right) the mini-RC telescope within the IR camera.

The cryogenic filter wheel holds 9 filters. There were eight bandpass filters in the near-IR centered at 2.47, 2.73, 2.85, 3.05, 3.20, 4.00, 4.27, and 4.60 microns, each with approximately 3% full width at half maximum. The ninth filter was at visible wavelengths and was primarily for laboratory test and calibration, in the R-band (a broadband filter at 640.7 nm). The field of view (FOV) of the BIRC was approximately 3 arcmin, with a single pixel subtending an instantaneous field of view (IFOV) of approximately 1.16 arcsec. The illuminated field of view was a circle approximately 155 pixels in diameter. The integration time of BIRC could be set from a minimum of approximately 3.45 ms in 3.45 ms increments.

Science observations by the BIRC were planned to observe CO_2 in comet ISON at 4.27 microns and the water vapor band at 2.73 microns. It was also planned to observe these wavelengths in comet Encke. Other objectives were to measure spectral characteristics and depths of OH bands in the surfaces of primitive C-type and similar asteroids and to measure the OH-related band on the illuminated portion of the Moon. Additionally, evidence for water in the atmosphere of Jupiter was to be explored. Multiple stars were targeted for radiometric calibration. However, because of the flight anomaly, science observations were not obtained during the flight.

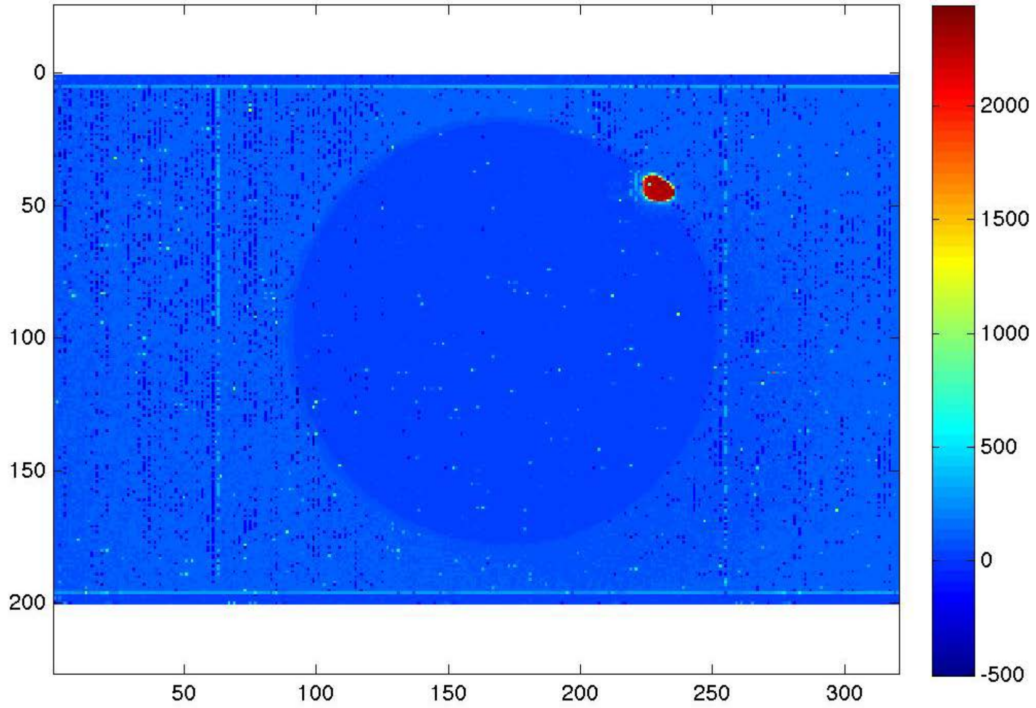

Figure 5. During the flight, BIRC obtained this R-band image of the star Polaris (α Ursae Minoris), which is saturated.

2.2.1 BIRC Test Process

During the brief period of flight near float altitude while the telescope was still responding to pointing commands, an R-band observation of Polaris was obtained as shown in **Figure 5**. As the objective was target acquisition, only observations of the single R-band at 100 msec were obtained, resulting in saturation of the star. This image is shown in **Figure 6** (an artifact of image processing caused the peak of the star image to be suppressed). Calibration measurements were made later, while the telescope was in the stowed position, pointed at the bottom of the gondola penthouse. Those measurements were taken at each of the science filter positions over a wide range of integration times. After several hours of repeated calibration measurements, the IR computer was shut down and an attempted reboot was unsuccessful. The failure to reboot is ascribed to be the result of the hard drive operating at a temperature cooler than its specified range.

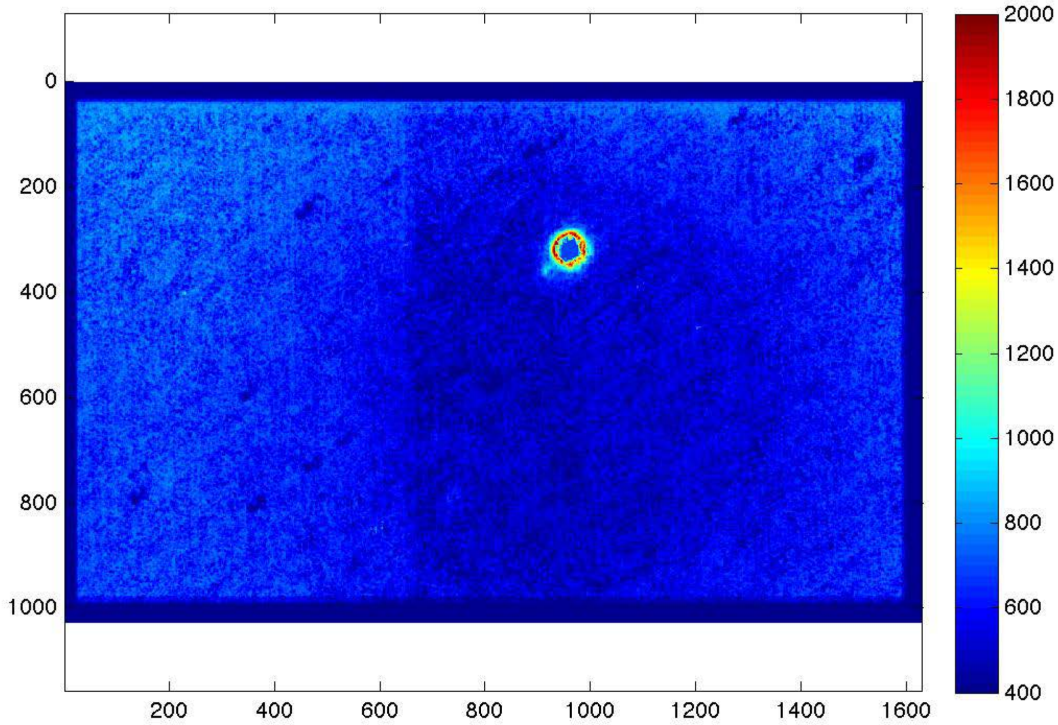

Figure 6. **During a hang test of the pointing control system at Fort Sumner, with the gondola suspended and free to rotate, the IR camera imaged the bright star ζ Perseus and its companion BD+31 666C. The companion star is 8.5 mag fainter and approximately 15 arc sec away (at the 7 o'clock position relative to the bright star, which is saturated).**

The operation of BIRC was tested in the laboratory and at Fort Sumner. The Fort Sumner observations included 2.47 micron and 4.0 micron filter observations of the Moon which clearly showed the expected temperature variations with topography on the illuminated side. Additionally, the Fort Sumner tests included hang tests of the gondola with BIRC imaging star fields. Images of the open star cluster M44 showed that the measured stellar image full width at half maximum was ~4 pixels, including effects of gondola pointing under windy conditions and poor atmospheric seeing.

2.2.1.1 Thermal Self Emission Problem/Solution

During thermal altitude testing of the BIRC instrument, a cold plate was used to perform radiometric calibration. This plate was controlled to different temperature set points and the radiometric response of the instrument was characterized. During initial testing it was discovered that the background level in the measured data was much higher than expected. In addition, there was little variation between filters, much less than expected.

This behavior of the camera suggested that there was thermal source in the camera, between the filters and detector that was causing the detector background to be much larger for all the filters. The possibility of this was analyzed using ray-tracing of the mechanical layout and a stray light path from the warm camera exterior to the detector via a reflection off the backside of the filter was discovered. Furthermore, the data was analyzed to determine that the addition background in the camera would be large enough (factor of 100 times) to cause the data to be compromised.

To resolve the problem, an additional cold baffle was installed inside the vacuum enclosure and thermally tied to the filter wheel housing for cooling. The instrument was then run through thermal altitude testing again. The new cold baffle resolved the issue seen during the initial thermal testing. The background in the camera matched predicted levels, and the anomaly was resolved.

2.2.1.2 Solenoid Problem/Solution

During the altitude chamber test on TBD, an observed anomaly involving the cryogenic solenoid valve occurred. The instrument computer indicated that the valve was commanded to actuate; however, no current was being drawn by the valve, and the temperature response indicated the valve had not opened. After the altitude test completed, and the chamber door was open, a command to open the valve was issued and the valve opened normally. Subsequent attempts to re-create the anomaly in a thermal chamber were unsuccessful. The solenoid valve, and harnessing were replaced, and no solenoid valve anomalies occurred during the subsequent altitude chamber test, pre-flight ground operations, and flight.

2.2.1.3 Hard Drive – Solid State Drive Problem/Solution

The BIRC Control Computer, on a limited number of occasions, displayed a problem communicating to one of its two attached drives. In all cases observed, this resulted in the root partition of the boot drive being automatically placed into read-only mode, for system safety, but with subsequent access to the partition steadily degrading. Following the initial failure, the primary flight software, principally aligned with the secondary drive, has been able to run without fault for as long as 5 hours (first Altitude Chamber test).

This failure mode has been observed across a wide temperature range, from hot to cold, and despite replacing the motherboard and the rotating media with solid state drives, though it appears that excessive cold (below 0 C) provides the most reliable trigger.

All failure instances have occurred with the motherboard and drives installed in the IPV, though not necessarily with it sealed. Testing of these computer components in a thermotron resulted in the secondary drive communication consistently failing at ambient temperatures of -15 C to -20 C, but never the boot drive. Observations of a similar failure on a different system also suggests the possibility that USB may be involved. No tests have yet been able to discriminate whether the fault is generated by the drives, the motherboard, or something in between.

In benign conditions, the system has been run for many weeks (total uptime) without the problem manifesting. Increasing the trip point to the survival heater for the IPV to a case temperature of 5 C apparently enabled the second Altitude Chamber test to be uneventful. Apparently this was still not sufficient for the much colder conditions experienced by the IPV during the Fort Sumner flight, where operations were uneventful until about 8 hours after launch, when a reboot was attempted as a consequence of the elevation drive recovery activities, and was apparently unsuccessful.

2.2.2 UVVis Payload

The UVVis instrument was designed to meet two diverse goals:

- *Demonstrate a fine pointing capability*. The error signal was to be determined at the 10 – 20 mas level at a cadence of 20 Hz. The pointing corrections made by the FSM were to be at the same angular level at a cadence of 5 Hz.

- *Observe celestial targets in four UV filters*. Two filters are centered on OH and CN emission regions (near 310 and 385 nm, respectively), with two other filters at nearby continuum wavelengths.

The UVVis optical bench consists of two cameras (a Guide Camera and a Science Camera), two actuators (a fold mirror and a filter wheel), a fine steering mirror (FSM), and various optical elements (three off-axis paraboloids, a dichroic and baffles). The two cameras and two motors are housed in separate pressure vessels. The UVVis electronics are housed in a large pressure vessel (PV) located about 1 m away from the UVVis optical bench. The UVVis PV contains three main elements: the FSM controller board, the CPU (a consumer i7 processor and motherboard with six 500 MB SSDs), the electronics power supply (EPS), consisting of boards that supply power to the FSM, the CPU, the cameras, the actuators and some heaters on the UVVis bench. The UVVis optical bench is a 1-m hexagon made of two carbon fiber face sheets separated by 4-in of aluminum honeycomb. The UVVis optical bench is enclosed in Dupont “Styrofoam” to help provide an isolated and stable thermal environment. A block diagram if the UVVis Payload is shown in **Figure 7**. **Figure 8** displays the UVVis as attached the the BRRISON telescope cradle.

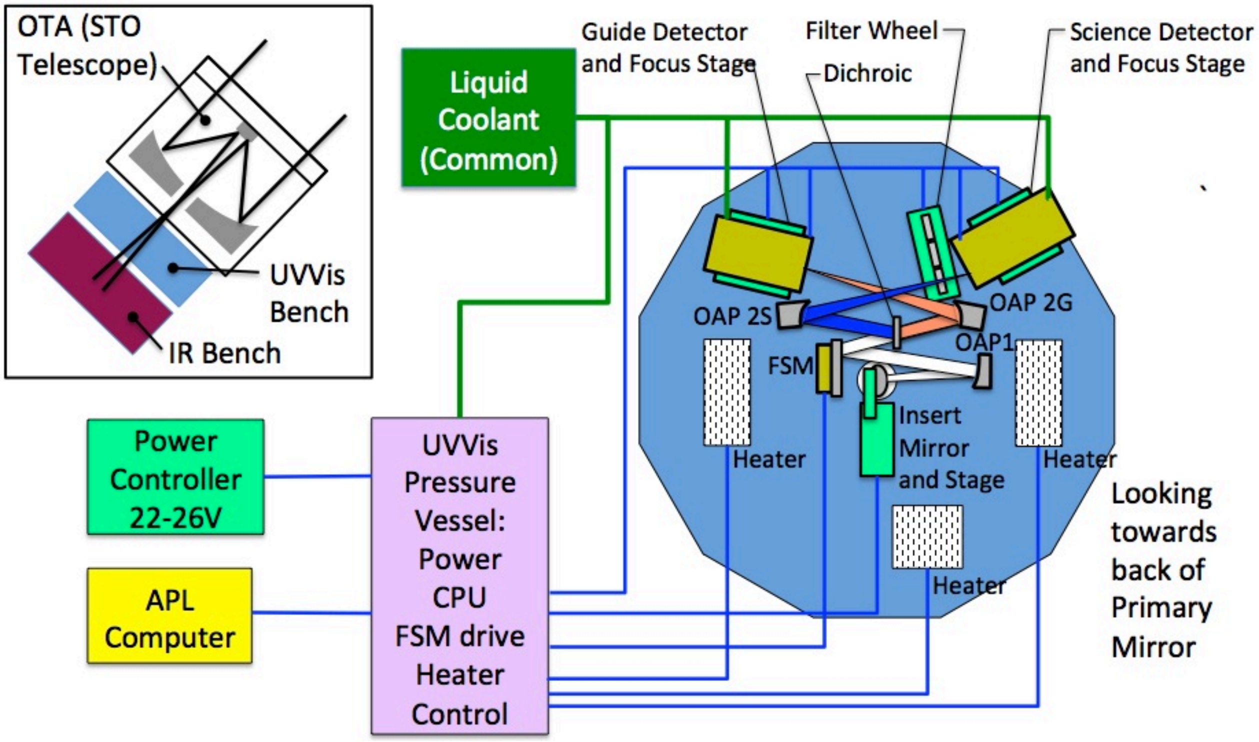

Figure 7 UVVis Block Diagram

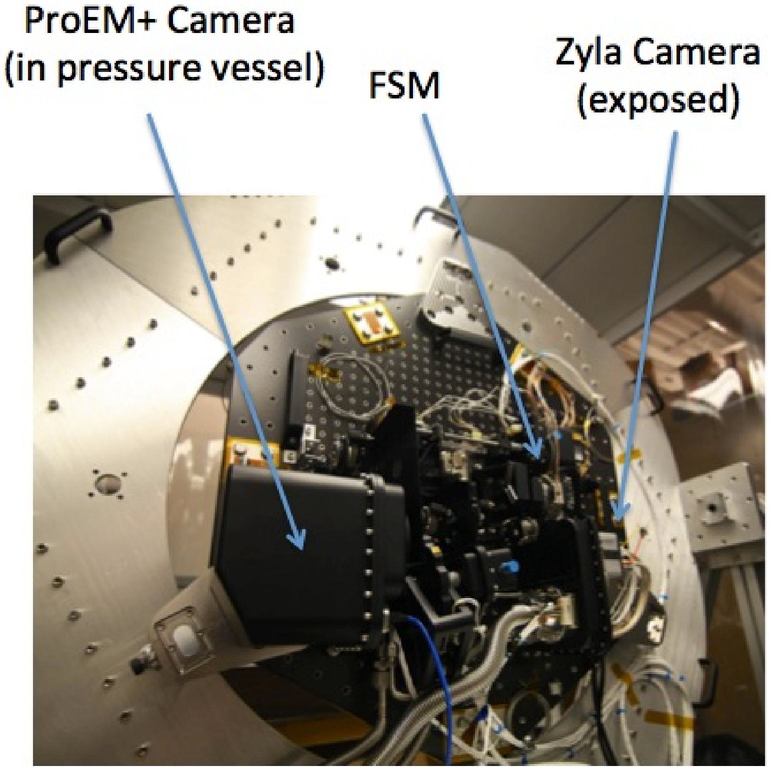

Figure 8 UVVis attached to the BRRISON Telescope Cradle

2.2.2.1 Test Process

Each component on the UVVis optical bench (the two cameras, the two actuators, the FSM and the heaters) was exercised through a 180-step *full-functional test*. The full-functional tests were normally undertaken in an ambient environment (room temperature and 760 torr pressure). In addition, the UVVis bench underwent a 24-hour thermal/high-altitude test in a walk-in thermal/vacuum chamber at APL. This thermal/high-altitude test attempted to simulate the passage through the cold troposphere and subsequent day/night cycles in the 3-4 torr stratosphere. Several full functional tests were performed successfully at different stages of the thermal/high-altitude test. Over two dozen thermal sensors were deployed throughout the UVVis payload and monitored during the test. All temperatures remained within operating limits and all pressure vessels demonstrated hermetic integrity. The optical alignment and PSF characterization of the Science Camera and Guide Camera focal planes were demonstrated with a simulated star (a pinhole located to mimic the f/17 beam from the STO telescope). The simulated star was also used to map the precise relation between control voltages sent to the FSM x and y tilt actuators and the resulting displacements on the camera focal planes.

2.2.2.1.1 Guide Camera Problem

The Guide Camera was a Zyla 5.5 camera from Andor. The Zyla camera was based on a 5.5 megapixel sCMOS array. The Zyla camera provided low read noise (1.3 e-/read advertised) and very fast read-out rates (100 fps sustained read rates). The Zyla camera ordered for use on the UVVis optical bench exhibited a problem: although the CPU could talk to the camera and receive an “I’m here” handshake, no image data was a received from the Zyla camera. Andor sent a loaner camera that did provide image data. Andor replaced the flight Zyla camera with one that worked correctly. Andor performed an investigation of the non-working Zyla camera. They reported that the original flight Zyla unit had broken solder joints on the CameraLink connector. The problem was closed when a new camera received, tested in thermal-vacuum and integrated into the UVVis experiment.

2.2.2.1.2 Science Camera Problem

The Science Camera was a ProEM+ CCD camera from Princeton Instruments. The ProEM+ camera as received from Princeton Instruments did not work under their Linux SDK. Rob Allen at Princeton diagnosed the problem stemming from a firmware revision on a board from Pleora. Pleora fixed and upgraded the firmware on a board for the ProEM cameras. Princeton Instruments tested our camera with the new Pleora board in it and verified that it worked with RedHat 6.4 and Ubuntu 12.10. The issue was closed when the ProEM+ camera had been used successfully in-house since Rob Allen sent us a camera with the upgraded Pleora board.

2.2.2.1.3 Fold Mirror Problem

The UVVis optical bench had a retractable fold mirror that either bent the incoming beam from the telescope (i.e., sends it to the UVVis instruments) or retracted and allowed the beam to continue to the infrared bench. The fold mirror was designed to retract in case of a power-off situation; it was outfitted with a spring that retracted the mirror when power is off. The fold mirror failed to retract during initial bench top checkout. The initial spring was too weak. A stronger spring was installed and the mechanism was successfully tested in ambient conditions and during the high-altitude/thermal test. The issue was closed when the fold mirror mechanism successfully tested in thermal-vacuum chamber and in flight.

3 Gondola

The BRRISON gondola, composed of an Aluminum frame that carried and protected the science payload and subsystems, and was the link with the balloon flight train. The gondola subsystems are shown in the simplified block diagram on **Figure 9**. They were composed of a Command & Control subsystem, a Pointing Control subsystem, a Power subsystem, and a Balloon Control and Telecommunications subsystem. All subsystems had high TRL and were a reuse from the STO balloon gondola that in a 2012 balloon flight has demonstrated the capability to precisely point an 80-cm telescope with a stability of about 1 arcsec.

3.1 Gondola Frame

For BRRISON, a new gondola frame was designed and built. For this effort the gondola was sized to hold the existing 80 cm aperture STO telescope. Its basic design was similar to the successful STO gondola frame but with a number of functional improvements. The frame was designed to be scalable to accommodate up to a 1.5-meter class telescope. Structural and frequency analysis of the new frame were performed to ensure that the structure was strong enough to support up to 5000 pounds even under the 10g shock experienced at the end of the flight when the parachute was released, and stiff enough to guarantee the pointing stability required for the BRRISON flight demonstration.

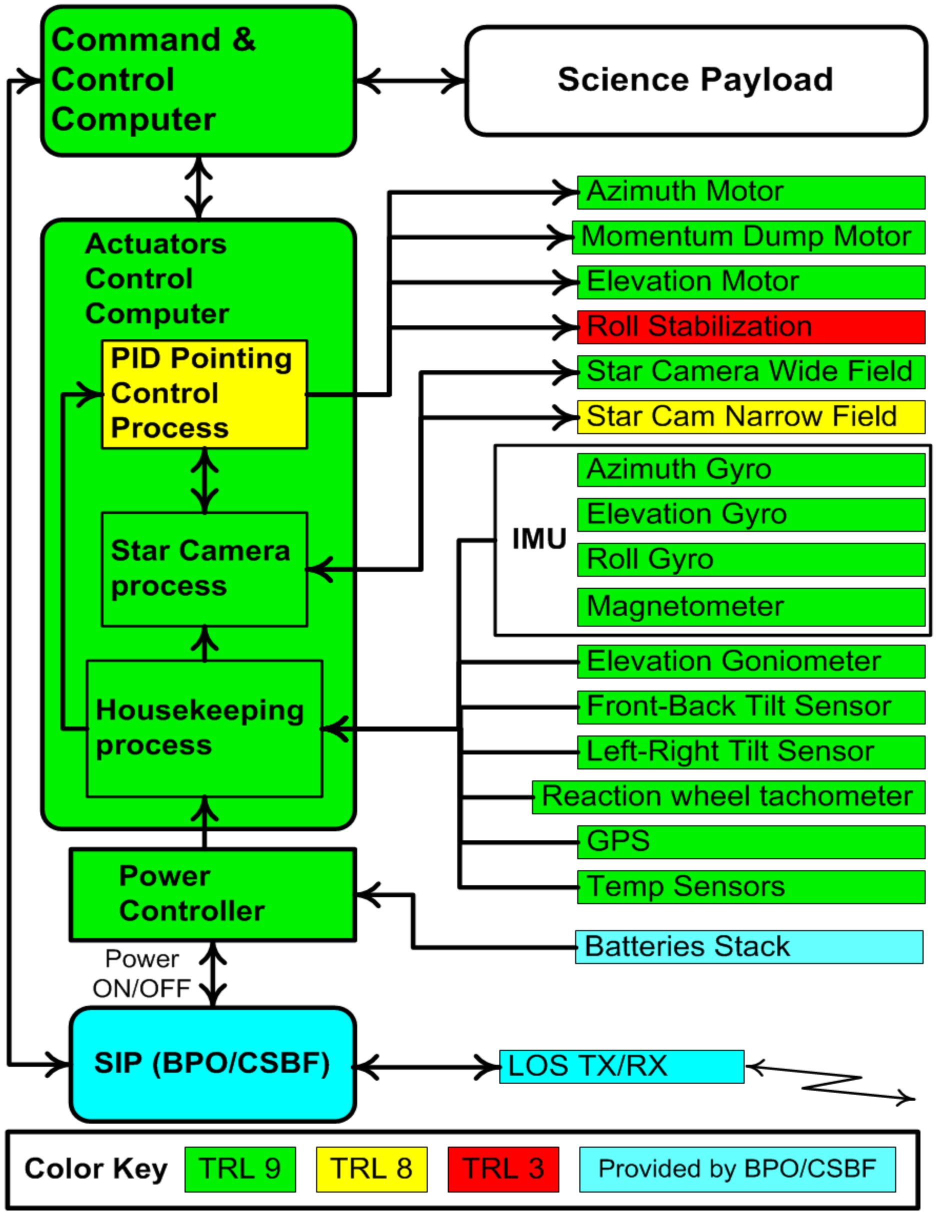

Figure 9 This BRRISON block diagram shows use of high heritage as a result of reuse of equipment from STO and prior missions.

3.2 Pointing Subsystem

The pointing system employed the same hardware and software used for STO with the addition of a roll stabilization system, and a consolidation of the three single-axis optical gyroscopes into a single inertial unit that was installed on the telescope cradle. The two star cameras from STO were refurbished; new star camera baffles were manufactured since the STO baffles were destroyed at landing of STO. To improve star tracker performance, a commandable lens focusing mechanism was added to the narrow field of view star camera. The mechanism is simple and uses high TRL components. The digital control system uses a Proportional-Integral-Derivative (PID) controller to determine motor drive current entirely from position error sensors. Each pointing mode has four control coefficients per axis that can be adjusted in flight for optimum performance. For BRRISON there was only one modification related to the inertial measurement unit (IMU). New algorithm and software was implemented to handle the IMU. The azimuth and elevation control mechanisms were removed from the existing STO gondola, refurbished and installed on the new gondola. The pointing control computer was refurbished, tested and installed on the new gondola.

3.3 Command & Control Subsystem

The Command & Control subsystem (C&C) used the same hardware and software flown on STO. The only modification to the software was the adaptation of the instrument control commands that are forwarded from the ground to the instrument control computer via the C&C computer. The C&C computer was refurbished, tested and installed on the new gondola.

3.4 Power Subsystem

The power subsystem was a reuse of the existing hardware previously flown on STO. The STO charge controller was refurbished, tested and installed on the new gondola. The subsystem was a battery-only system. Twenty-six lithium batteries provided by the Columbia Scientific Balloon Facility (CSBF) provided about 20 kW of power at a voltage between 26 and 24 V for a predicted flight duration of 24 hours. Two insulated battery boxes built for STO contained the batteries.

3.5 Telecommunications Subsystem

The telecommunication subsystem for BRRISON was the same as used for STO. It relies entirely on the CSBF provided mini-SIP (Support Instrument Package). The mini-SIP has a line-of-sight (LOS) link to the ground using UHF radios. The gondola C&C computer interfaced to the mini-SIP and on the ground the ground computers interfaced with the CSBF ground equipment in the same way done for STO. The ground software was primarily a reuse of the STO ground software with modifications related to the BRRISON specific scientific payload needs.

3.6 Harness

A new harness was built to fit the new gondola structure and payloads. The harness design is the same as the STO harness but since the gondola was different in shape and the payloads were different a new harness is needed.

4 Flight Preparation, Launch and Flight Operations

4.1 Integration and Test (I&T)

The BRISSON Observatory I&T was performed in the high bay of APL’s new integration facility. The I&T flow was setup to take a methodical hierarchical approach designed to verify requirements and uncover potential problems. BRISSON was the first NASA balloon mission tested at APL, therefore the Space Department I&T group recognized the need to relax typical spacecraft protocols and prepared a customized observatory test plan to meet the critical mission requirements and the launch date window. Like most of BRISSON’s program, the development and execution time-line was very tight for the Observatory I&T phase and was success oriented. **Figure 10** gives an overview of the actual I&T flow at APL.

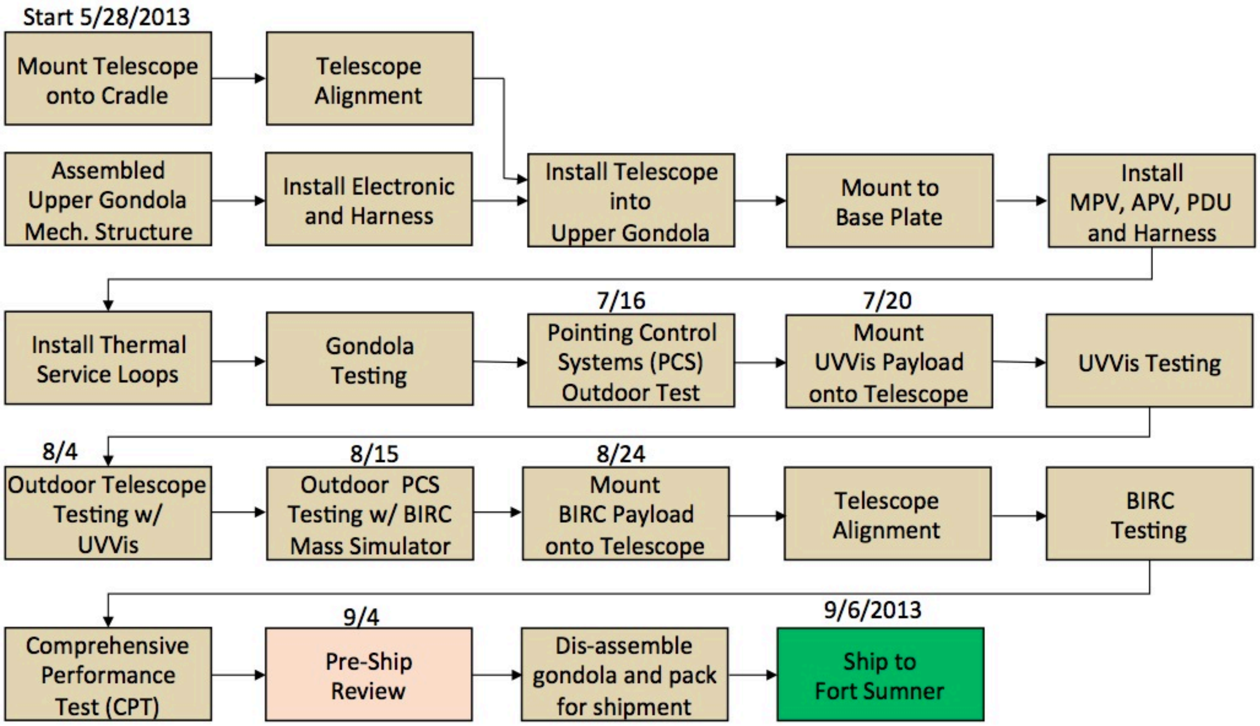

Figure 10 APL Gondola I&T Flow

The new gondola structure was the first to arrive in I&T having three sections: penthouse, double H, and baseplate. Next, the telescope was received after it had been refurbished and aligned at the Nu-Tek facility, an optics vendor. The telescope was then mounted onto a new BRISSON cradle designed for the gondola mechanical interface. An optical verification check before mounting the telescope into the upper gondola structure (i.e. penthouse and double H assembly) discovered that it had become misaligned either during transport from Nu-Tek or while being mounted onto the cradle. Subsequently, Nu-Tek realigned the telescope again at APL prior to its installation into the upper gondola structure.

The science benches, gondola electronics, thermal components, and harness were assembled and tested in parallel to the start of I&T. This approach provided those subassemblies milestone need dates for installation onto the gondola within the planned I&T flow. The harness fabrications were paced to meet the subsystems' test dates. Due to APL's thermal chamber volume limitations, the full observatory system could not be tested together. Instead, the baseline plan was to thermally test individual electronic units, subsystems, and science bench payloads in the walk-in (5 ft. x 7 ft. x 7 ft.) altitude chamber prior to observatory integration.

The Gondola integration had three milestone installations with their associated testing being completed prior to full observatory system tests. Each milestone, built in succession; first the telescope, then the UVVis that was attached to the telescope, and finally the BIRC was stacked onto the telescope over the UVVis. The I&T team performed three outdoor pointing control tests to verify system operation at each stage of development maturity:

- Installation of telescope into gondola; performed subsystem integration tests
- UVVis bench mounted to telescope and installed into gondola; performed subsystem integration tests

- BIRC bench mounted to telescope; performed subsystem integration tests

After the installation of both the telescope and UVVis bench into the gondola, separate outdoor pointing tests (dates 7/16/13 & 8/4/13) were performed. However, due to the late delivery of the BIRC bench that particular outdoor test (8/15/13) was completed using a mass model.

The late arrival of the BIRC bench required that the I&T team attempt to efficiently optimize the remaining test time at APL. As stated above, a BIRC mass simulator was installed to perform the last outdoor pointing test. The Comprehensive Performance Test (CPT) and the Requirements Verification & Validation (V&V) matrix were completed in stages, as the subsystems became finalized. The complete telescope assembly with both flight science payloads attached was never installed into the gondola at APL while being tested as a complete system. This was due to the rapidly approaching launch window and the program decision to perform any required remaining tests with the fully assembled gondola in the field at Fort Sumner.

4.2 Shipping

The gondola and supporting GSE equipment were transported cross country in two enclosed air ride trucks. The telescope with the mounted science benches were separated from the gondola structure and secured in a custom designed shipping fixture illustrated in **Figure 11**.

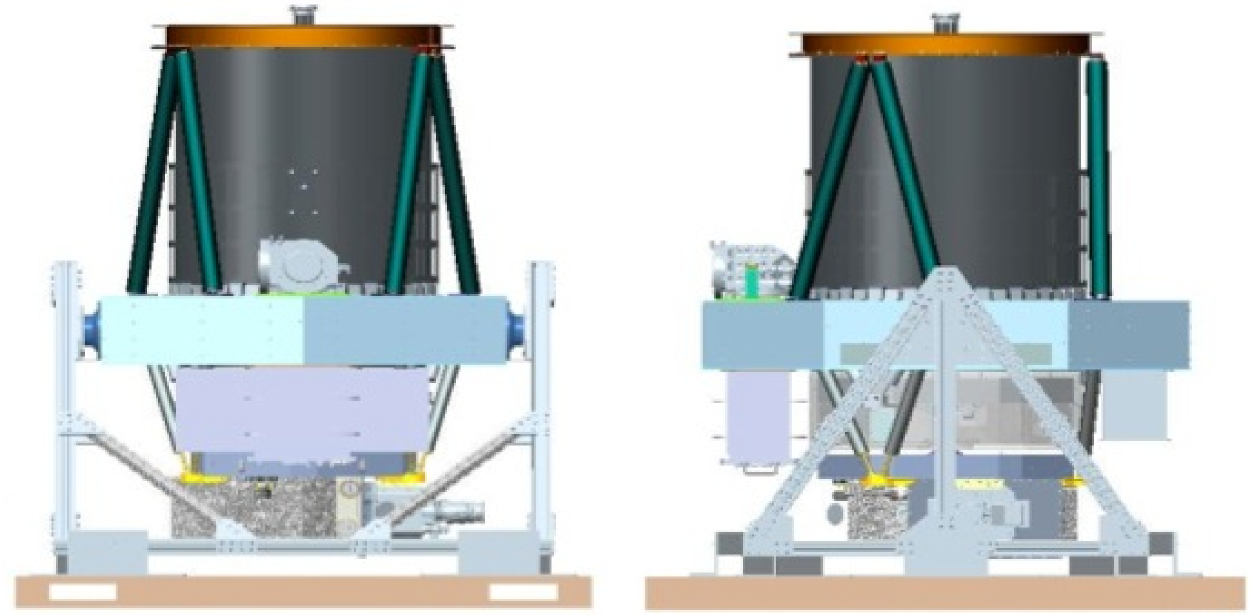

Figure 11. Telescope Shipping Fixture

The entire telescope payload was then enclosed with small bags of desiccant in a giant Llumalloy protective bag to maintain cleanliness. The truck carrying the telescope and flight electronics was climate controlled. This precaution was taken to reduce the risk of moisture buildup on the payload optics that could obscure images or damage electrical circuits. Another precautionary measure was to fit a shock recorder to the shipping fixture that continuously monitored the shock in all three-axis throughout the duration of the trip.

Following the flight (that is described in subsequent sections) the gondola and test equipment were returned to APL by truck following initial damage inspection that occurred at Fort Sumner. Trucks departed Fort Sumner on October 3, 2013 and arrived at APL on October 8, 2013. Upon arrival at APL the trucks were directed to Building 30 where they were unloaded and the gondola and test equipment were placed into Building 30 and placed into quarantine at the direction of the Anomaly Investigation Team.

4.3 Fort Sumner Launch Preparations

-September 27, 2013 at the NASA/CSBF balloon integration facility in Fort Sumner (NM). Here follows a summary of the daily activities performed during this period:

Monday, September 9: Gondola, payload, and supporting GSE equipment was delivered to the NASA/CSBF balloon I&T facility via truck (**Figure 12**). After the equipment was unloaded and inspected set-up of the work area as well as the MOC and SOC stations took place.

Figure 12 BRRISON gondola arrives in Fort Sumner in sections

Tuesday, September 10: Transfer of the payload from the shipping fixture to the Flotron test fixture occurred (**Figure 13 - Left**). This was followed by the setup of payload alignment and calibration optical system. Then the gondola upper structure was mated to the gondola baseplate and the gondola flight computers were installed on the baseplate **(**Figure 13 - **Right).**

Wednesday, September 11: The PDU and GSE batteries were installed on the baseplate and the first gondola power-up test was completed. Communication between the gondola flight systems and the MOC computers was tested. An alignment check of the telescope secondary mirror with respect to primary mirror was successfully completed. Additional thermal blanketing was installed. CSBF delivered 27 flight batteries and their performance tests were completed.

Figure 13 (Left) Installation of the telescope/instruments assembly on the Flotron. (Right) Gondola upper structure is installed on top of gondola baseplate.

Thursday, September 12: BIRC and UVVis calibration (focus sweeps) was performed. Then communication between the BIRC and UVVis flight computers and gondola flight C&C computer was established. The communication loop between the MOC and SOCs and the BIRC and UVVis instruments was also established. The light shade, known as the *sugar scoop*, was covered with thermal blankets. The battery boxes were populated with the flight batteries.

Friday, September 13: The BIRC instrument geometric calibrations were completed and focus sweeps were performed. The pointing offset between BIRC and UVVis were measured (**Figure 14).** Activities for calibrating the UVVis instrument continued. The installation of the Mini-SIP inside the SIP cage at the bottom of the gondola was completed (**Figure 15**).

Saturday, September 14: This was a rest day. No major activities were performed.

Sunday, September 15: Payload alignment and calibrations were completed. The telescope and instruments were thermally dressed for flight. The telescope sugar scoop and star cameras baffle tubes were installed in the telescope cradle. Both the gondola and the payload were prepared for the installation of payload within the gondola.

Figure 14 APL optical engineers performing BIRC alignment calibrations.

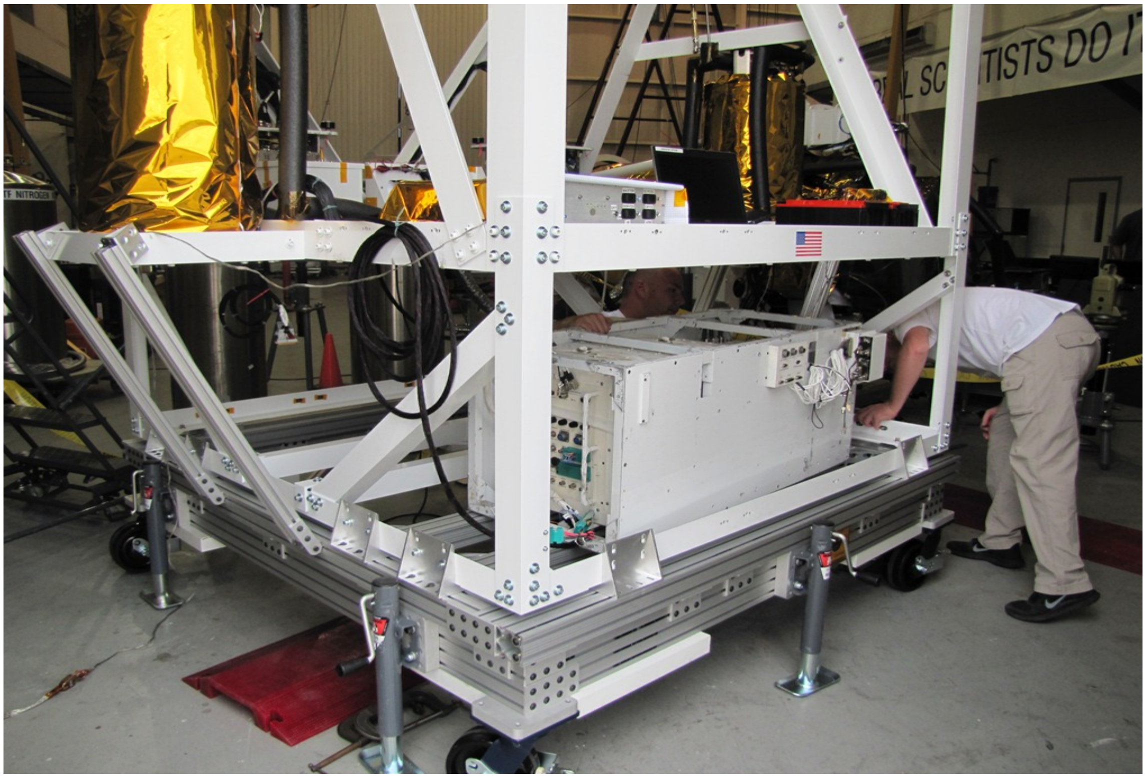

Figure 15 The Mini SIP is installed in the SIP cage below the gondola baseplate.

Figure 16 (Left) Telescope is installed into gondola upper structure and reassembled on top of baseplate. (Right) First session of night time testing by suspending the gondola from the overhead crane and peeking out of the East high bay door

Monday, September 16: The payload (telescope and IR/UVVis instrument assembly) was installed on the elevation mount of the gondola (**Figure 16 - Left**). This was the first time that all five segments of the gondola, the telescope and both the IR and UVVis payloads were united together as a single assembly. The harness and cooling loops connection was performed between the gondola and payload. The initial telescope balance was also performed.

Tuesday, September 17: Installation of the thermal system was completed. Preparations began for the first night sky hang test scheduled for the coming night.

Wednesday, September 18: In the early morning hours a night time hang test (**Figure 16 Right**) was conducted. For the first time star light from the BIRC instrument occurred through the main telescope. Successfully pressure tested the APV and MPV pressure vessels.

Thursday, September 19: Work with CSBF began to determine how accommodate the ballast box and crush pads to the gondola lower structure. Work to close-out the penthouse assembly was initiated. The GoPro camera on the GPS mounting bracket was installed.

Friday, September 20: A Helmholtz coil was set-up to create a controlled magnetic field around BRRISON to calibrate the magnetic field sensitivity of the gyros. The narrow field of view star camera light shade was removed to allow improvement in the focus on this star camera.

Saturday, September 21: The telescope balance was improved; the ballast box support beams were removed for modification to support the alternate ballast box. A hang test with both the UVVis and IR payloads was performed. Despite poor viewing conditions due to clouds the test was very successful as the pointing and thermal control systems worked very well and very good imagery was collected from all three cameras.

Sunday, September 22: Some improvements to the telescope balance were made and another night sky hang test was performed. During this test the sky was clear; however, moderate gusting winds challenged the pointing system which met the challenge. This also proved to be a good test of the Fine Steering Mirror that is used to improve pointing performance.

Figure 17 Gondola suspended outdoors from the launch vehicle during the compatibility test.

Monday, September 23: The flight batteries were mounted to the structure, blanketing was installed, system testing occurred. Another night sky hang test was performed, again achieving good performance of the gondola systems and payload instruments.

Tuesday September 24: A close-out review was held to disposition open action items, anomaly reports and problem reports that were not closed at the time. The mini-SIP position was changed to provide better gondola balance and fixed to the structure with hard fasteners. The CSBF team came to do fit checks of the ballast hoppers and crush pads. Another night sky hang test was performed.

Wednesday September 25: Electrical work on the mini-SIP was performed to check the communications and ballast controls, final balance on the telescope occurred, standard definition video cameras were installed to image the stow latch and sundial, and CSBF came in the afternoon to weigh the vehicle. Another night sky test was conducted that allowed pointing and IR instrument procedures to be further refined.

Thursday, September 26: In the early morning hours another short night sky hang test was conducted taking advantage of clear skies and low ground winds. After sunrise the CSBF Compatibility Test was performed. CSBF brought the launch vehicle known as "Big Bill" to the high bay and carried BRRISON out to the tarmac for a full top-to-bottom functional test to demonstration compatibility of all systems with CSBF provided equipment, the ability to perform all functions and to communicate, i.e. uplink commands and downlink telemetry as if in flight (**Figure 17**). All tests were fully successful.

Friday September 27: During the night yet another short sky test was performed to test the UVVis system one last time.

Early in the afternoon the Flight Readiness Review (FRR) with CSBF was conducted. At the FRR, CSBF announced that the Sunday morning launch conditions had deteriorated to MARGINAL and that the weather front that would make Sunday morning GOOD would arrive earlier and now Saturday evening was expected to be GOOD. CSBF offered this rare evening launch opportunity. The team gathered and consulted with team members back at APL to determine the effects of launching roughly 12 hours earlier than had ever been planned. Evening launches although routine at other launch sites, are a rarity from Fort Sumner. It was determined that a revised timeline could be developed that would meet the level one mission requirements and a thermal analysis showed that the nighttime ascent would not be problematical. However, due to the change in launch time, the light shade would need to be rotated 119 degrees to allow the optimal viewing time of ISON without interference from the Sun. CSBF affirmed that changing the light shade rotation angle would not require a new hang test. In consultation with NASA project management and APL senior management the decision was made to make the necessary preparations for the first evening launch in memory from Fort Sumner at 6:00 pm MDT Saturday.

So beginning Friday afternoon, the science team began working on a new operations plan (see Section 4.4.2). Meanwhile the mechanical team removed, rotated and reinstalled the telescope nightshade. The light shade blanketing was reattached and taped. Subsequently the telescope was carefully rebalanced to account for the asymmetric shape of the nightshade.

4.4 *Saturday September 28: Launch and flight operation*

4.4.1Prelaunch preparations

The launch was planned for 6 pm. In the morning final preparations of the BRRISON gondola/payload were conducted. Namely the final balance of the gondola was performed by shifting the position of the two battery boxes and the APV and MPV pressure vessels. Then holes were drilled in the baseplate floor the APV, MPV and the two battery boxes were secured with bolts. The CSBF personnel finished dressing wiring of the Mini-SIP harness. The two LN2 tanks were then topped-off.

At 1:30 pm the launch vehicle “Big Bill” arrived to pick-up the gondola and moved it outside. CSBF personnel installed the ballast hoppers and crush pads (**Figure 18**). The LN2 purge line and GSE power supply were transferred from ground to Big Bill. Meanwhile health of the gondola and payload systems was constantly monitored

At 3:25 pm the GO for moving to the launch pad is issued. During taxi the up-down motion of the launch vehicle causes the telescope to be released from its lath and deploys. Telescope is manually commanded back to the stow position and some constant drive towards the latch is applied to prevent the reoccurrence. Same thing happened again before reaching the launch line.

Figure 18 BRRISON gondola suspended from launch vehicle being readied for launch.

After reaching the flight line, adjustments to the stow latch position were performed in an attempt to prevent the reoccurring of the uncommanded release of the telescope and do a final top off of the LN2 dewars. Meanwhile CSBF personnel attached the parachute and deployed the balloon.

Just before balloon inflation starts the GSE LN2 purge line was removed and transferred to internal power. Then the gondola is raised to launch height.

At about 5:10 pm the GO for balloon inflation is given.

At 6:10:16 the balloon was released, it rapidly raised above the launch vehicle which in turn moved slightly to follow the balloon direction. When the balloon was straight above the launch vehicle the launch director opened a pin that was keeping the gondola connected to the launch vehicle, and the gondola was released and started to climb rapidly (**Figure 19**). During the release of the gondola from the launch vehicle there was a large vertical jump that caused the telescope to be spontaneously released from the latch. This event was immediately noticed and it was attempted to immediately restow the telescope but the strong downdraft pushing on the telescope while the gondola was ascending prevented us to do so. So the telescope was left deployed. While ascending the telescope bounced several times on the lower elevation stop, but it was not deemed to be an issue.

From launch to when the threshold altitude of 90,000 feet was reached control of the telescope attitude was not attempted. The gondola/payload health was monitored through telemetry.

The next two sections describe the flight timeline planned before flight and what actually happened in flight.

4.4.2 Planned Flight timeline

The planned flight timeline is shown in **Figure 20**. This timeline is vastly different from what was originally planned because of the drastic change in the time of launch. The original target launch time on any given day was 7 am, but the new actual launch time was 6 pm implying a different schedule for the observing targets. In the original timeline the first target would have been the comet ISON itself, but with the new launch time ISON could not be observed until it rose at about 4:15 am local time. So it was planned to first observe other targets and also to start observations with the UVVis instrument instead of with the IR instrument. The targets planned before observing ISON and the sequence of observations is listed on the top part of **Figure 20**.

Figure 19 The BRRISON gondola starts ascending.

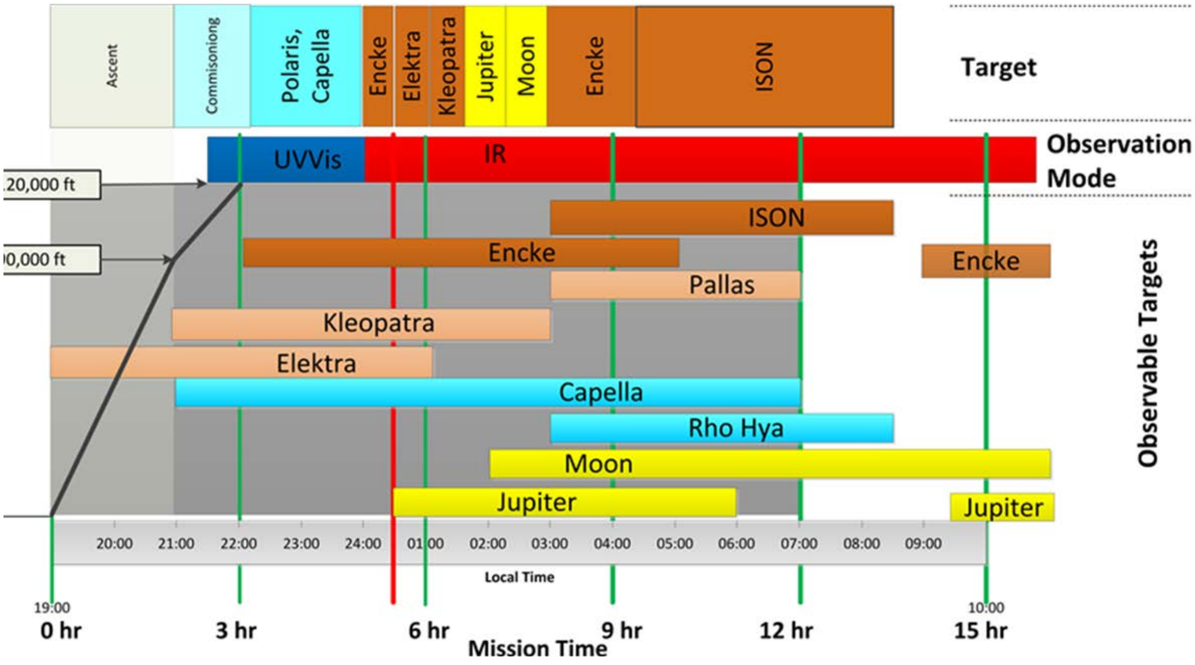

Figure 20 Planned flight timeline based on a target launch time at 7pm local time.

4.4.3 Actual Flight timeline

The actual flight timeline followed the planned timeline until the anomaly that kept the telescope stow bar stuck behind the stow latch. Please refer to the Anomaly Investigation Team Report for details on the nature of the anomaly and the causes leading to it. During the ascent trough the dense atmosphere up to 90,000 feet altitude the gondola pointing system was turned off and the gondola was free to spin. Probably because of the telescope being deployed and the sugar scoop asymmetric orientation there was some lateral force acting on the gondola that made it spin quite rapidly at about 9 rpm during the initial part of the ascent. This rotation slowly subsided with altitude. Meanwhile the telescope continued to move up and down and regularly hit the low elevation mechanical stop.

At 7:50 pm (1 hour and 40 minutes after launch) the gondola had passed the 90,000 ft. altitude. By this time the rotation had stopped. Commissioning commenced by turning on the tracking system and stabilize the gondola in azimuth, and then control and stabilize the telescope elevation. Star fixes were commanded to obtain precise pointing knowledge.

At 8:05 pm a command was sent to the telescope to point at the star Polaris. Initially Polaris was not in the field of view of the narrow field star camera (NFSC) and software offsets were applied to bring Polaris in the center of the NFSC field of view. The misalignment was not present during ground testing and it is believe to be due to either the banging of the telescope on the low elevation mechanical stop or to thermal deformations effects.

At about 8:15 pm the fold mirror in the UVVis instrument was activated to direct the light beam coming from the telescope into the UVVis instrument package. Images with the UVVis camera are acquired but the star Polaris was not seen in the field of view. A command was sent to the fold mirror to retract to let the light beam reach the IR camera. The plan was to acquire some images with the BIRC IR camera which has a 3 arc minutes field of view, 3 times larger than the UVVis field of view.

At 8:19:21 pm while images were being taken with the IR camera, the anomaly occurred. This is described briefly below and in more detail in the AIT Report.

The pointing control software does not receive telescope attitude information for several seconds, it enters into an anomalous state and commands the telescope to move to high elevation with great velocity. The stow bar eventually hits the stow latch which bends backwards and let the stow bar pass it. The stow bar remains stuck behind the stow latch assembly preventing the telescope to be redeployed

Between 8:30 pm and 11 pm Several attempts were made to redeploy the telescope by violently hammering the stow bar against the stow latch but this was unsuccessful. Eventually the elevation servo amplifier stopped functioning, likely overstressed by the hammering procedure, and all hopes to redeploy are lost. Without the ability to control the elevation there is nothing that can be done.

At about 11:25 pm a full gondola power cycle is performed as a last ditch attempt to see if the elevation servo amplifiers would come back alive. It did not. As a consequence of the power cycle communication with the BIRC computer is also lost.

The flight continued for several hours during which time testing was conducted on the other systems operations for engineering purposes. Several calibration images were taken with both the BIRC and UVVis cameras. Verification was done of the ability to command the focus mechanism of the NFSC even at low temperatures of about -45 C. The secondary actuator heaters are also activated and a command sent to the secondary actuator focus mechanism, thus verifying the ability to warm the actuator to above -20C and command it to move successfully.

At one point a full gondola power cycle was performed as a last ditch attempt to see if the elevation servo amplifiers would come back alive. It did not. As a consequence of the power cycle communication is lost with the BIRC computer. It is believed that the cold temperatures inside the BIRC pressure vessel prevented the computer to properly reboot, either the computer itself did not reboot or the solid state hard drives stopped and the boot process was not successfully completed.

At about 3 am on September 29 the gondola was commanded for a final shut down and powered the entire observatory down.

The flight continued with the BRRISON gondola powered down until about 6 am when CSBF commanded the termination procedure. All remaining ballast was dropped and the explosive bolts securing the interface between the parachute and balloon were activated. The gondola came back to the ground on parachute and safely landed about 45 minutes after termination.

4.4 Gondola Recovery

The gondola landed in a shallow ravine on a large ranch near Guthrie, Texas. The recovery team was given two strict instructions: to thoroughly photograph the untouched gondola and its surroundings; and focus on preserving any evidence that would assist in assessing the anomaly by limiting the disturbance of the gondola. An image of the gondola as it was found at the landing site is shown in **Figure 21**.

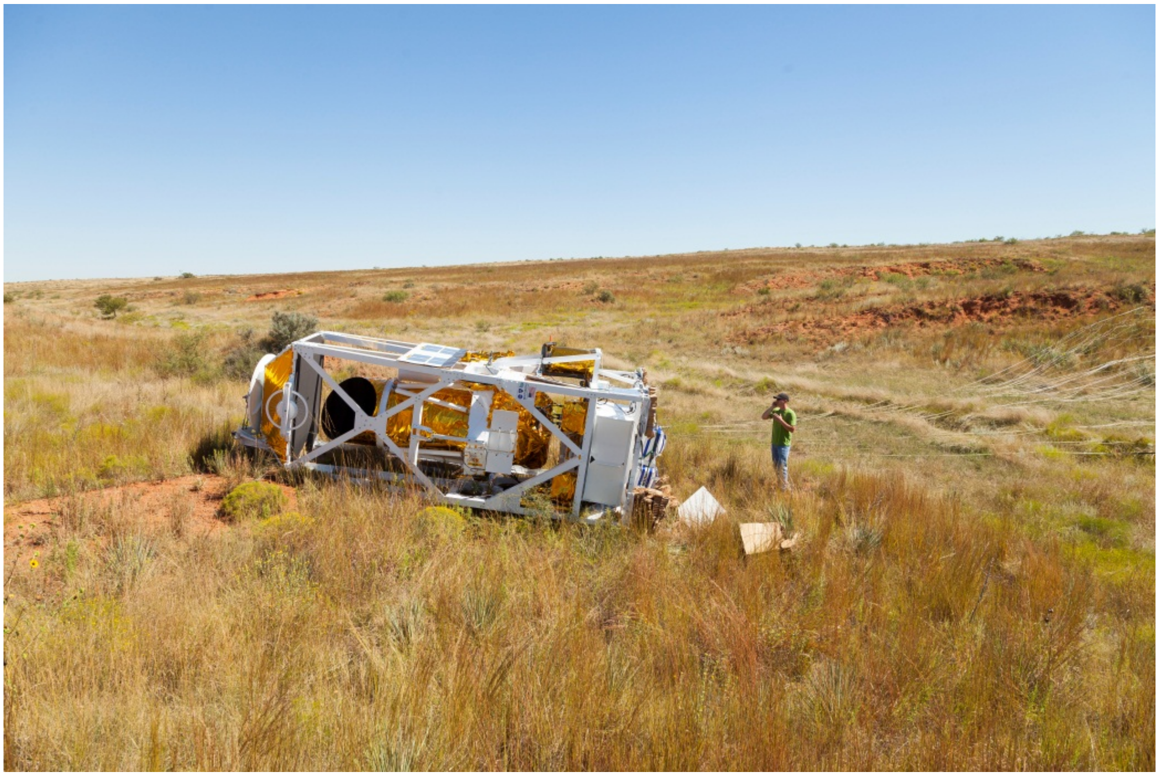

Figure 21 BRRISON Gondola seen as landed approximately 55 miles east of Lubbock, Texas.

After photo cataloging the gondola, the team executed the shutdown and safe procedure (video) disabling the active subsystems as follows:

- Powered off the Power Distribution Unit (PDU)
- Disconnected the batteries and safe the battery terminals
- Stabilized and secured the telescope from movement
- Vented the Dewar cooling system
- Recovered three GoPro cameras; a fourth was not located at the recovery site

4.5 Damage assessment

The Gondola landed in the desired manner, i.e. straight down on the crush pads with the parachute disengaging to prevent dragging and the toppling onto a side that prevented damage to the telescope and payloads. Even more fortuitously, when the gondola toppled, it did so across a ditch which prevented the outrigger-mounted LN_2 dewar from being damaged as well as preventing the dewar from being pushed into the gondola structure that would have resulted in damage to internally mounted components.

4.5.1 Crush Pads and SIP Cage

Because the gondola landed vertically as desired the crush pads absorbed much of the impact energy. In addition to this the SIP cage, which is the lowest section of the structure, was made with lower gauge aluminum than the other parts of the structure. This was intentionally done so that the SIP cage would deform on impact, thus absorbing more of the kinetic energy and preventing distortion of the primary structure. The SIP cage did deform and as expected cannot be reused. However, the deformation was not severe and no damage resulted to the SIP.

4.5.2 Stow Latch Mechanism

The stow latch mechanism and mounting bracket was destroyed upon to the ground. This occurred as a direct result of the inflight telescope anomaly. The stow bar became stuck and moved passed the stow latch. As the gondola struck the ground upon landing, the impact shock thrust the stow bar into the stow latch bracket causing deformation of the bracket and dislodged the stow latch. The entire telescope containment system will be replaced for future flights.

4.5.3 BIRC Struts

Two of the six struts that connect the BIRC to the telescope cradle debonded, i.e. failed in tension, and extended in length. This most likely occurred either on impact to the ground or when the gondola toppled onto its side. This indicates that a high level of stress was imparted to the struts and as such all six struts will need to be replaced for future flights.

4.5.4 Miscellaneous Items

The following items incurred minor damage and will be either repaired or replaced:

- The telescope low elevation stop was cracked
- The star tracker light shade baffles dislodged or broke
- The telescope weight ring deformed

5 Education and Public Outreach

The Education and Public Outreach (EPO) program was intended to be comprised of three components: Formal Education, Informal Education and Public Outreach. However due to changes in NASA’s EPO philosophy brought about by sequestration, most of the proposed EPO program was not executed. The only portion of the EPO program that was executed was the development of public outreach social media websites that were used to inform the public about Comet ISON, the purpose of the BRRISON project and to provide timely status of the project. The URLs of these websites are:

BRRISON Website: http://brrison.jhuapl.edu/index.php
Facebook: https://www.facebook.com/BRRISON
Twitter: https://twitter.com/BRRISON
youtube: http://www.youtube.com/user/BRRISON