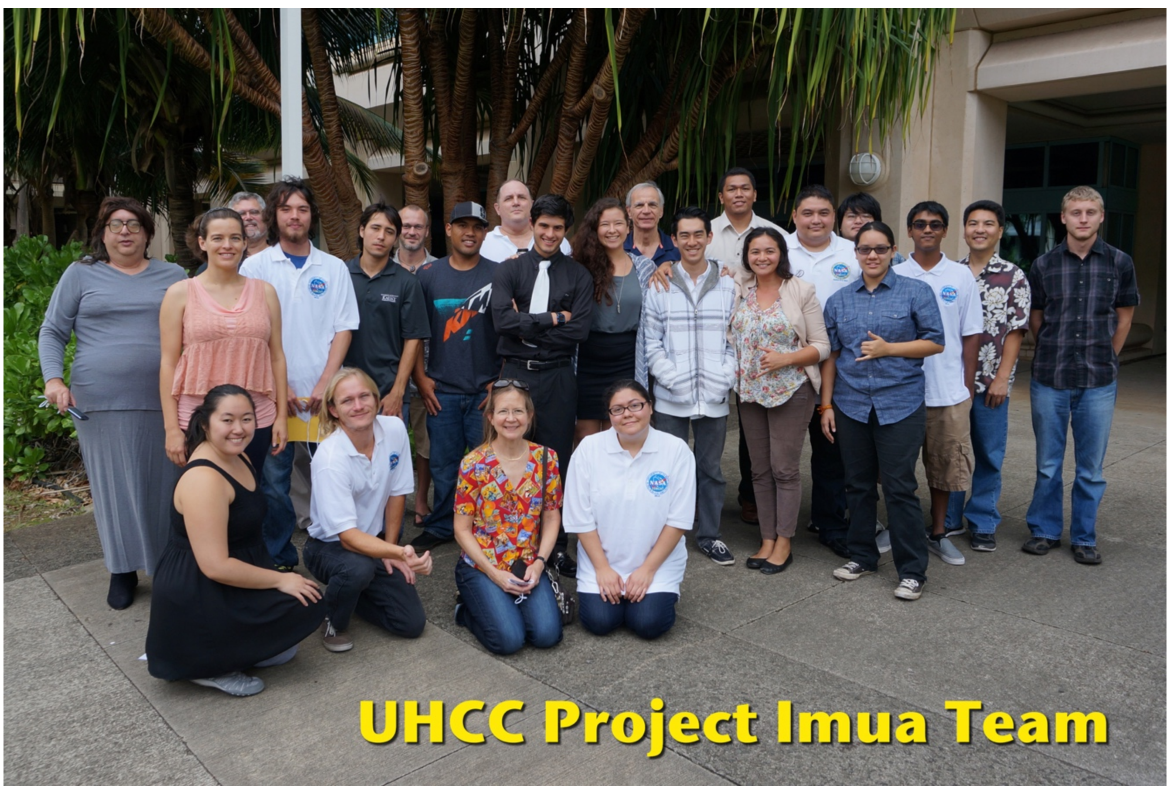
RockSat-X 2015 Final Report

University of Hawai‘i Community Colleges
Project Imua
Hawai‘i Space Grant Consortium

Mission Synopsis: *Project Imua's scientific mission involved the design and fabrication of an UV spectrometer to measure solar irradiance above the earth's atmosphere. The payload also included two engineering experiments involving the design and assembly of an array of photosensors to determine the orientation of the payload with respect to the sun and a 9-axis miniaturized motion detector.*



submitted by

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20 November 2015

RockSat-X 2015 UHCC Payload

Project Imua Payload — PIP

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1.0 Mission Statement

Project Imua (*to move forward* in Hawaiian) is a joint faculty-student enterprise of four campuses within the University of Hawaiʻi Community College system (Honolulu, Kapiʻolani, Kauaʻi and Windward Community Colleges) dedicated to designing, fabricating and testing small payloads for launch into space. This multi-campus project is funded by a two-year $500,000 grant awarded to the Hawaiʻi Space Grant Consortium under the NASA Space Grant Competitive Opportunity for Partnerships with Community Colleges and Technical Schools. This grant includes $200,00 in student internships.

During Year One (AY 2014-15), sixteen UHCC students from four campuses were awarded 43 fellowships (including travel stipends), totally nearly $90,000.

Our recent participation in RockSat-X 2015 strategically supported the primary goals of Project Imua — namely:

- to encourage UHCC students to explore and enter STEM-based careers by engaging in team-oriented, problem-solving activities that emphasize the integration process involved in the design, fabrication, testing and documentation of launch-ready, space-bound payloads supporting scientific and/or engineering experiments.
- to establish and assess the feasibility of a permanent coalition of UHCC campuses for the collaborative development of payloads to be launched by the Hawaiʻi Space Flight Lab and other launch facilities.

Our RockSat-X mission was to design a payload that supports one scientific and two engineering experiments:

1. Scientific Experiment:
   UV Spectrometer. Make direct measurements of the sun's ultraviolet spectral components without atmospheric absorption. Models indicate that variations in UV components of the solar spectrum may directly affect the thermosphere/ionosphere system and ultimately climate. Contribution of UV variation in the 200 to 400nm range is highly uncertain. These data would contribute to an understanding of solar dynamics.

2. Engineering Experiments:
   a. Photometer array. Design and fabrication an array of four photosensors to determine the orientation of the payload housing with respect to the sun around apogee when measurement were being made by our UV spectrometer.
   b. 9-axis Motion Detector. Install an off-the-shelf, non-space rated 9-axis motion detector into the payload and determine its ability to record acceleration, gyroscopic rotation and magnetometer measurements along all three axes.

2.0 Mission Requirements and Description

The scientific objective of this mission, which was assigned to the Kaua'i CC team, was to design a UV spectrometer capable of making direct measurements of solar UV components without atmospheric absorption between 200 and 400nm.

The total solar irradiance spectrum from 10 to 100,000 nm is shown in dark blue in the following graph (Fig. 1). Variability between Solar Maximum and Solar Minimum is shown in green, while the relative transparency of the earth's atmosphere at sea level is shown in light blue. This graph shows that at wavelengths shorter than 300 nm there is a relatively large variation in the sun's extreme UV that exceeds 1%, while the earth's atmosphere is nearly opaque at these wavelengths. To study this variability, one must measure the irradiance from this 200-400 nm wavelength range above the atmosphere.

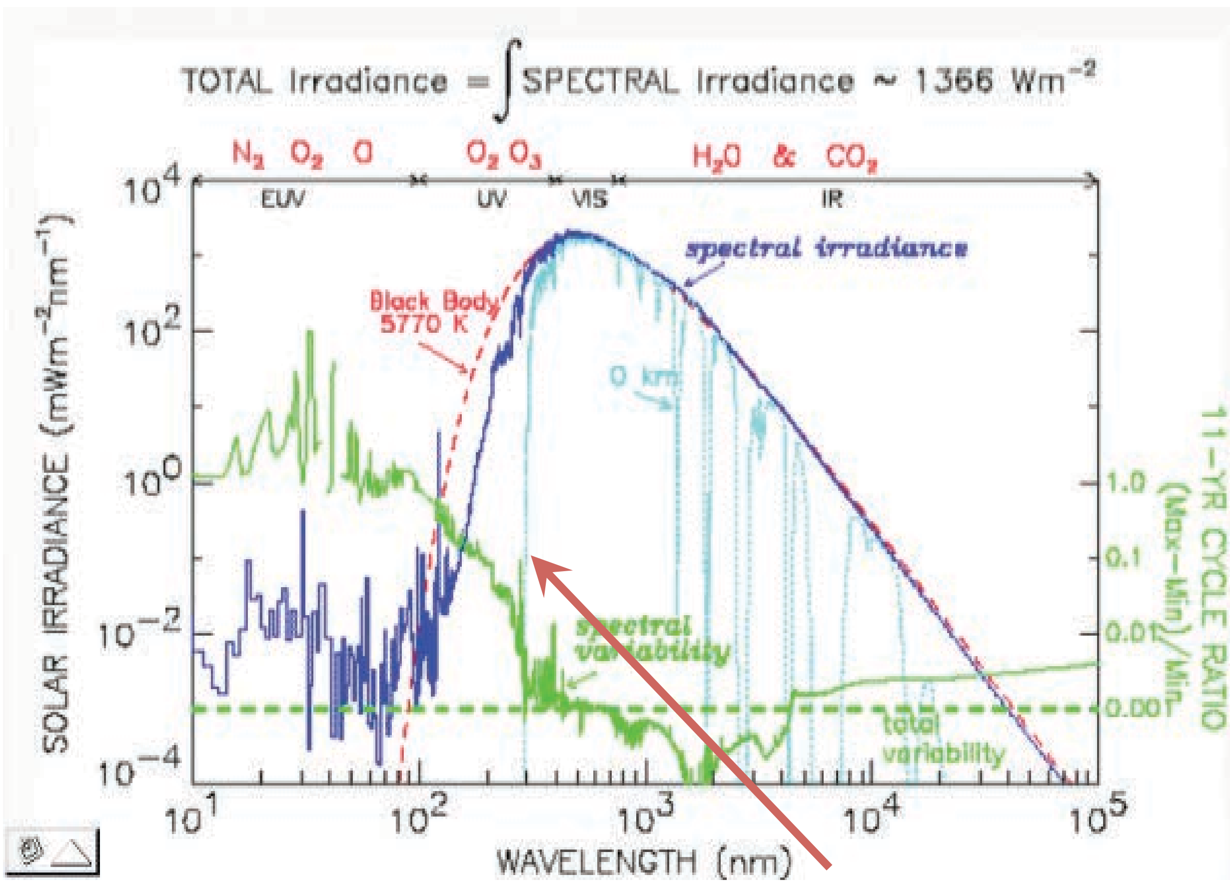


Fig. 1. Solar Irradiance spectrum (courtesy of J. Lean, US Naval Research Laboratory).

The comprehensive success criterion for this experiment was to collect 30 full spectral sweep of data (~123s) between 200-600 nm with 0.4 nm resolution. Each spectral sweep for the selected UV spectrometer took 4.096s plus a 2ms integration time.

The spectrometer was fitted with a cosine receptor that ideally was to be aimed directly at the sun. A fiber optics cable directed the captured sunlight down inside the housing to the UV spectrometer where it was analyzed and data transmitted for storage. The raw data would be converted into a ratio based on the Total Solar Insolation (TSI) that averages 1,367 W/m^2 depending upon time of year across the wavelength range of 300 to 3000 nm. The 200-300 nm range was included in this calculation in order to study its variability. The computed ratio is defined as:

$$\frac{\text{UV total power (200 – 400 nm)}}{\text{TSI}}$$

Data analyzed from these observations would be correlated to SORCE mission solar spectral irradiance (http://lasp.colorado.edu/lisird/sorce/sorce_ssi/).

In order to determine the orientation of this receptor with respect to the sun, an array of four photosensors was installed around the exterior of the aluminum housing as an independent check of the orbital flight parameters that would eventually be provided by Wallops Flight Facility. This photosensor array comprised the first of two engineering experiments on the payload. The sun's relative orientation with respect to the cosine receptor was determined from an analysis of the variation in intensity among the four photodiode sensors.

The second engineering experiment consisted of a miniaturized IMU/accelerometer built from off-the-shelf components. This 9-axis motion-tracking device is capable of recording accelerometer, gyroscopic rotation and magnetic strength. Both engineering experiments were designed and fabricated by the Honolulu CC team.

In a separate engineering exercise that was independent of the payload, the Windward CC team designed a shake table to conduct vibration tests of the payload.

3.0 Payload Design

The Payload for this mission was named PIP (an acronym for Project Imua Payload). Pip also refers to a "seed" — which is representative of the newly established four-campus UHCC enterprise that constitutes Project Imua. Additionally, according to the Urban dictionary, PIP indicates "something that tends to be annoyingly difficult, yet still irresistibly likeable."

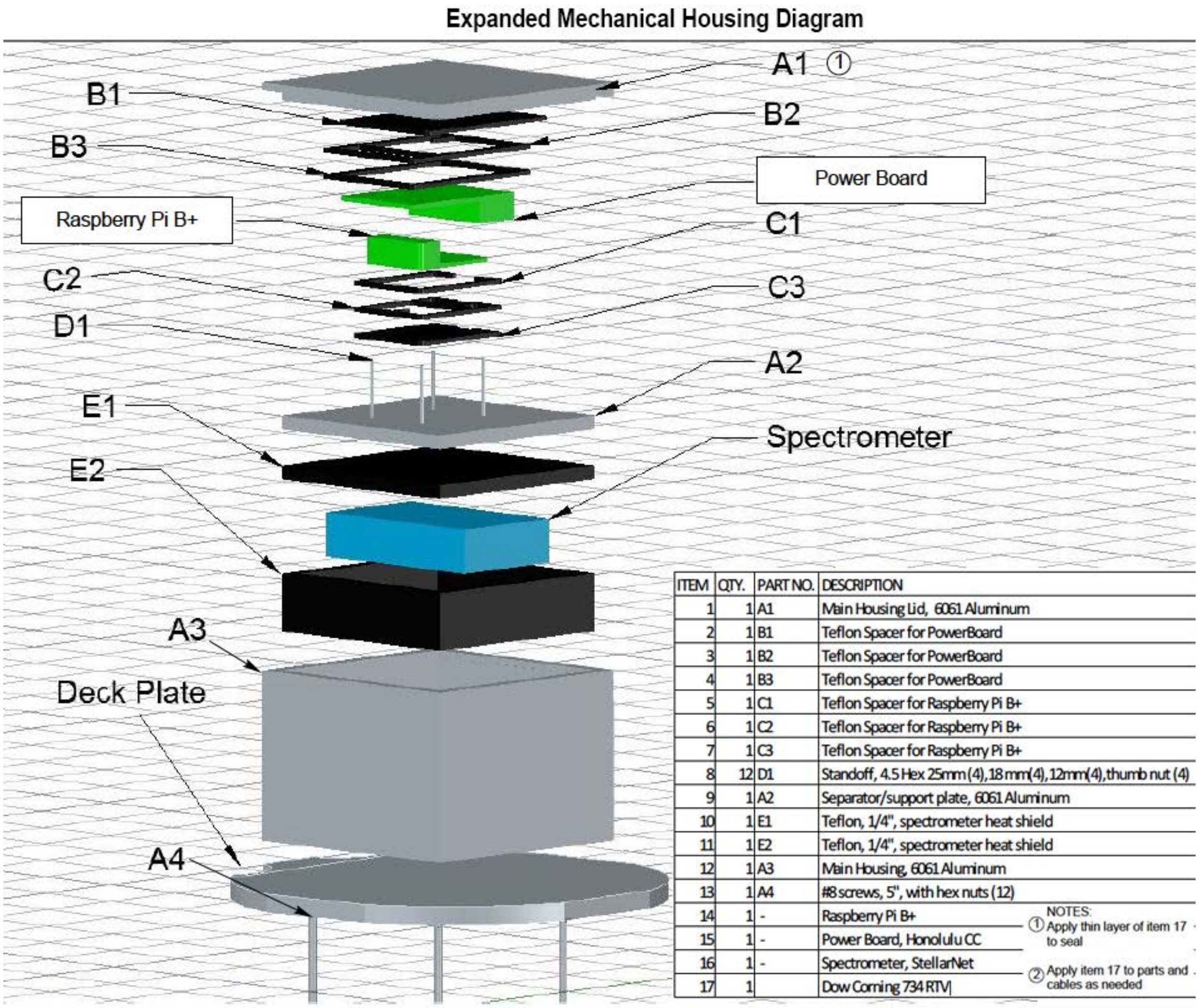
A. Housing

The payload's 6061 aluminum mechanical housing, which measures approximately 8.25" x 8.25" x 4.5", was developed jointly by the Kauaʻi and Windward campuses (see Fig 2). Its total weight including all instruments, electronic components and baseplate was 14.8 lbs. The UV cosine receptor was mounted on the truncated corner and the 4 photosensors were mounted on the top left corner of each vertical sidewall.

Fig. 2. Payload's mechanical housing consisting of 6061 aluminum

Slots for two D-pin connectors were milled into opposite sides. These provided access to the rocket's power and telemetry lines. The flanged bottom of the housing and four vertical sidewalls were milled from one block of 6061 aluminum. Four bolts flush to the bottom of the deck secured the housing to the baseplate. An aluminum lid with a rabbet joint was secured to the body of the housing with three bolts fastened by nuts.

Figure 3 shows an expanded view of the interior components inside the mechanical housing. The UV spectrometer, which was housed at the bottom of the stack, was surrounded by Teflon spacers. Standoffs supported the remaining components that were installed at the top of the stack. These included the Raspberry Pi and Power Conditioning Board.



ITEM	QTY.	PART NO.	DESCRIPTION
1	1	A1	Main Housing Lid, 6061 Aluminum
2	1	B1	Teflon Spacer for PowerBoard
3	1	B2	Teflon Spacer for PowerBoard
4	1	B3	Teflon Spacer for PowerBoard
5	1	C1	Teflon Spacer for Raspberry Pi B+
6	1	C2	Teflon Spacer for Raspberry Pi B+
7	1	C3	Teflon Spacer for Raspberry Pi B+
8	12	D1	Standoff, 4.5 Hex 25mm (4), 18 mm(4), 12mm(4), thumb nut (4)
9	1	A2	Separator/support plate, 6061 Aluminum
10	1	E1	Teflon, 1/4", spectrometer heat shield
11	1	E2	Teflon, 1/4", spectrometer heat shield
12	1	A3	Main Housing, 6061 Aluminum
13	1	A4	#8 screws, 5", with hex nuts (12)
14	1	-	Raspberry Pi B+
15	1	-	Power Board, Honolulu CC
16	1	-	Spectrometer, StellarNet
17	1		Dow Corning 734 RTV

NOTES:
① Apply thin layer of item 17 to seal
② Apply item 17 to parts and cables as needed

Fig. 3. Expanded view of the mechanical housing

RTV sealant was applied to all exposed joints in an attempt to make the housing waterproof to prevent seawater leakage after post-flight splash down in the Atlantic Ocean.

B. Power Conditioning Board

The Power/Signal Conditioning Board consisted of a GE DC/DC 28v-to-5v step-down converter mounted on a print circuit board. The PCB, which measures 3-1/8" x 3-7/8", was developed by Kapiʻolani CC based on the circuit design of Honolulu CC. Fig. 4 shows the PCB/Power Conditioning Board with the payload's major electronic components attached and labeled.

The Max 3232 breakout with RS232 converter IC interfaces with a Raspberry Pi B+ that controls the UV spectrometer.

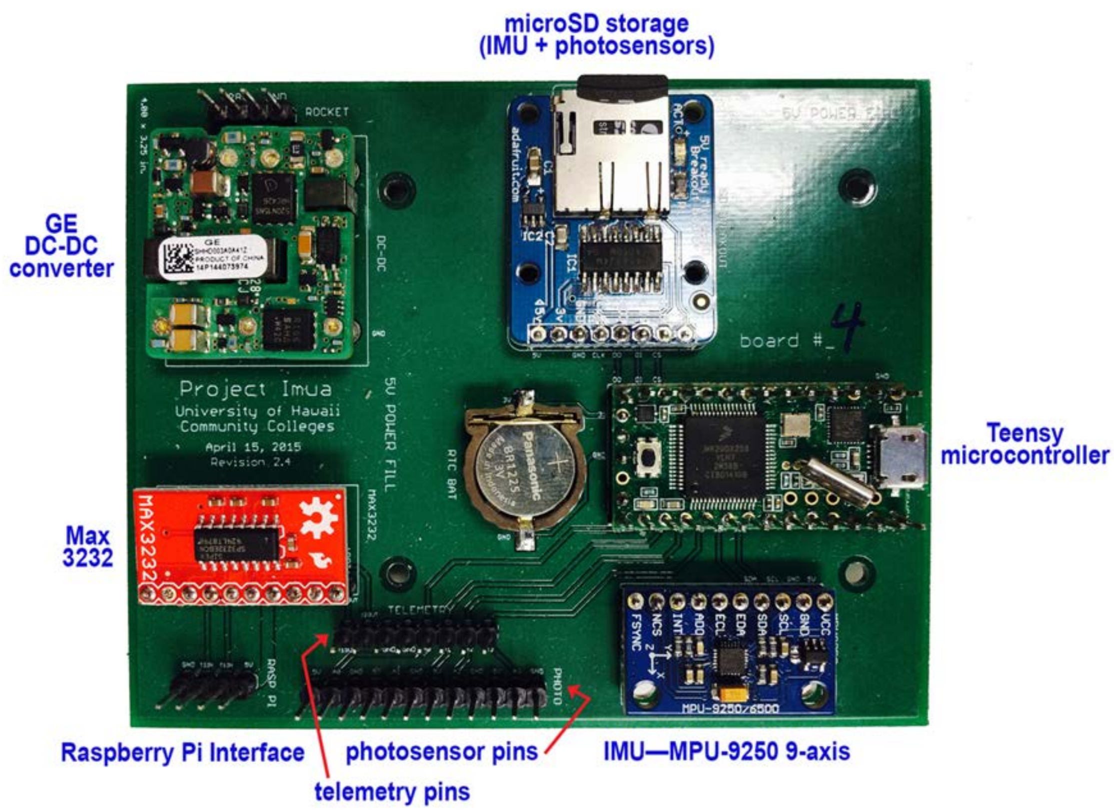


Fig. 4. PCB with major electronic components

Honolulu CC also designed the two engineering subsystems (IMU and photosensor array) that were packaged together in a unit called the Manatee 2.0. Included in this dual subsystem unit are:

• Teensy 3.1 microcontroller, which collected data from the photosensor array and a 9-axis motion tracker (IMU). This microcontroller sent the data from both units to the SD Card reader.

• Four analog diode photosensors (GA1A12S202 Log-scale Analog Light Sensor), which were mounted on the exterior sidewalls of the housing. Their connector pins were located on the PCB.

• HonCCLogger, which consisted of a SD Card reader and microSD card for storage of data from the photosensor array and the 9-axis motion tracker (IMU).

• InvenSense MPU-9250 (IMU), which houses a 3-axis gyroscope and a 3-axis accelerometer on one die. The second die houses a 3-axis magnetometer. The entire unit measures 3x3x1mm. The programmable gyroscope has a full range of ± 250, ±500, ±1000 and ±2000^{o}/sec; a programmable accelerometer with full-range of ±2, ±4, ±8 and ±16g; and a full-scale range of ±4800µT for the magnetometer. The MPU-9250 operates on a dedicated 3VDC Panasonic coin cell that was mounted on the PCB.

C. UV Spectrometer

Kaua‘i CC chose a StellarNet BlueWave miniature spectrometer to serve as the UV instrument (see Fig 5). The specs for this spectrometer are 200-600nm, 2400g/mm, 0.4nm resolution and 1ms-65 sec integration time.

Observations of the sun were made through a CR2 cosine receptor from StellarNet. This miniature UV-Vis-NIR receptor is a ¼” diameter polymer diffuser for 200-1700nm with a 180^{o} FOV. The cosine receptor was attached to an armored solarization resistant 600µm-diameter fiber optics cable.

Data was acquired by a Raspberry Pi B+ controller and formatted for output to the asynchronous telemetry interface.

Fig. 5. StellarNet Blue Wave miniature spectrometer and CR2 cosine receptor

4.0 Student Involvement

Project Imua is a coalition of four campuses in the University of Hawai‘i Community College system. In 2015 the Project Imua team consisted of 16 students across four campuses located on two different islands. Other members of the team included 11 staff members — a project manager, team mentors at each campus, an IT specialist and several advisors.

All students were enrolled as undergraduates in the UHCC system at their respective campuses. Some students were also taking higher division courses at the University of Hawai‘i—Mānoa. Many of the students were enrolled in the pre-engineering Associate of Science Natural Science (ASNS) degree. Several of these students have since gone on to the University of Hawai‘i—Mānoa, where they are enrolled in computer engineering, mechanical engineering, electrical engineering and physics.

The organization chart illustrated in Fig. 6 shows the full team membership with management flow.

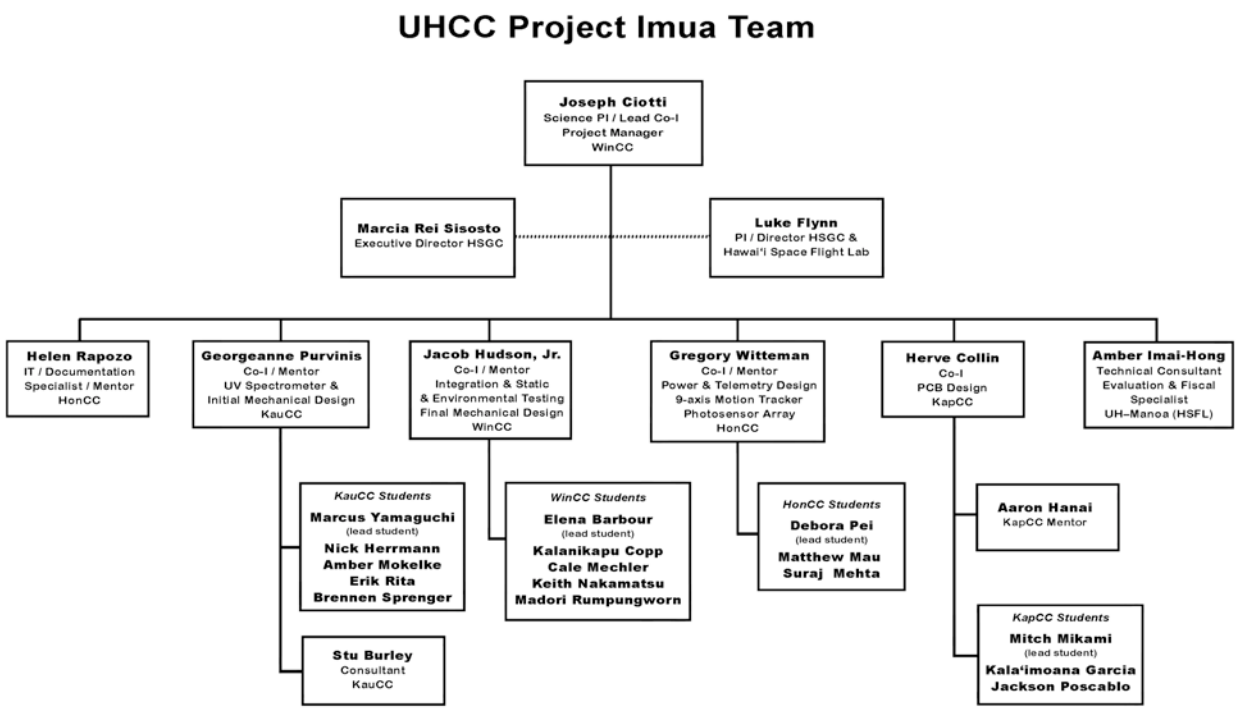


Fig 6. Project Imua UHCC team organization chart for 2015.

5.0 Testing Results

The Windward CC team was responsible for overseeing the Full Mission Simulation tests (including both open and closed bench tests), the integration of the project and the environmental testing of the payload. This required that Windward CC act as host to all other involved campuses, emulate the rocket (with regard to power and signal reception), and implement the designing and construction of a simple shake and spin table (along with an associated diagnostic unit) for the system environmental testing. Whereas the WETT (Windward Environmental Test Table — see Fig. 7) did not become fully functional until after the payload PIP was launched, it did perform adequately enough for subsystem testing. WETT will be used to test future Project Imua payloads.

Fig. 7 Windward CC custom-built Environmental Test Table (WETT)

In order to emulate the rocket Windward CC procured the necessary voltage source along with suitable current output, and built a unit named PITT (Project Imua Telemetry Tester to receive the signal outputs from the payload. Integration, open bench and full mission simulation tests were conducted at the Windward CC campus during the Spring Break (23-29 March 2015). All four campuses participated in these tests (see Fig. 8).

Fig. 8. Open bench test at Windward Community College's NASA Flight Training Lab

The open bench test evaluated the electrical and payload subsystems on an open platform. A 28-DCV-power supply simulated the power source from the rocket. All data collection and transmission was verified for each subsystem during two full mission simulation runs of 5.6 minutes each. All power remained within limits. Center-of-gravity tests were also conducted confirming that the payload CG was within 1” of center.

On May 19, 2015 a pressure test was conducted at the Hawai‘i Space Flight Lab (HSFL) to check for leaks. This was followed up with a 5-minute water submersion test. This process was repeated on May 22. Some leakage was detected through the cosine receptor joint, which was resealed with RTV. Since the UV spectrometer was designed for use in a future project, integration required sufficient vibrational suppression and waterproofing. While Windward CC spent considerable time customizing the Teflon layers to immobilize the UV unit, a better choice of gasket sealant might have to be made.

On June 11, 2015, a longitudinal g-force test was conducted with the shake table at the HSFL (see Fig. 9). This table was identical to the shake table at WFF. Subsequent tests of the electronic components and subsystems verified that they had survived this vibration test and were able to collect data and store data.

Fig 9. Shake Test at HSFL in June 2015

Extensive environmental tests were undertaken at the Wallops Flight Facility during late June 2015. Five students and two mentors participated in the GSE, Environmental and Integration tests at WFF. After passing the GSE checkout on June 23, the PIP payload was transported to WFF for integration and further tests. These included a power-back-up test that simulated what would happen should the rocket spontaneously ignite prematurely; an all fire test that simulated a full mission with power sequentially being brought up to the transponder, ACS, skirt deployment (inhibited), CarRoLL and recovery system; and a no fire test that simulated what would happen should the first stage ignite as planned, but the second stage fail.

On the next day, a shake test was conducted using a vibration table identical to the table at HSFL. This test ended with a 10-second random shake, which exposed the payload to over 10g. This test was done for each of the three axes. Finally, after the aft skirt deployment test was conducted, a power-up test was performed.

On June 26, the last day of testing at WFF, the CarRoLL underwent a GPS rollout test to obtain a complete RF mapping of the CarRoLL section to insure nothing would interfere with the transponder frequency.

Since the UHCC Project Imua payload had passed all tests at WFF and was deemed flight certified, the payload PIP was stored at WFF in preparation for the upcoming launch in August.

6.0 Mission Results

Seven students and two mentors attended the weeklong preparations for the August 11, 2015 launch. Additional tests were conducted, similar to those performed during the June Environmental Testing period. Weather and sea conditions on the scheduled launch day forced a one-day delay. On August 12, 2015 the Terrier-Improved Malemute sounding rocket carrying the RockSat-X 2015 CarRoLL was successfully launch at 6:04 am EDT (Fig. 10). The rocket reached an apogee of 96 miles on a 15-minute sub-orbital flight.

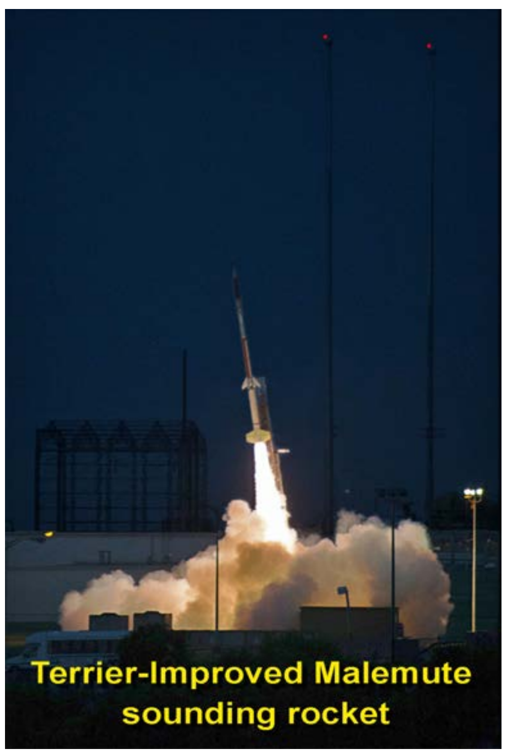


Fig. 10. RockSat-X 2015 launch on 12 August 2015 at 6:04 am EDT.

Figure 11 shows the ground trace of flightpath from launch at Wallops Flight Facility in Virginia to a splash down in the Atlantic Ocean approximately 263 miles down range.

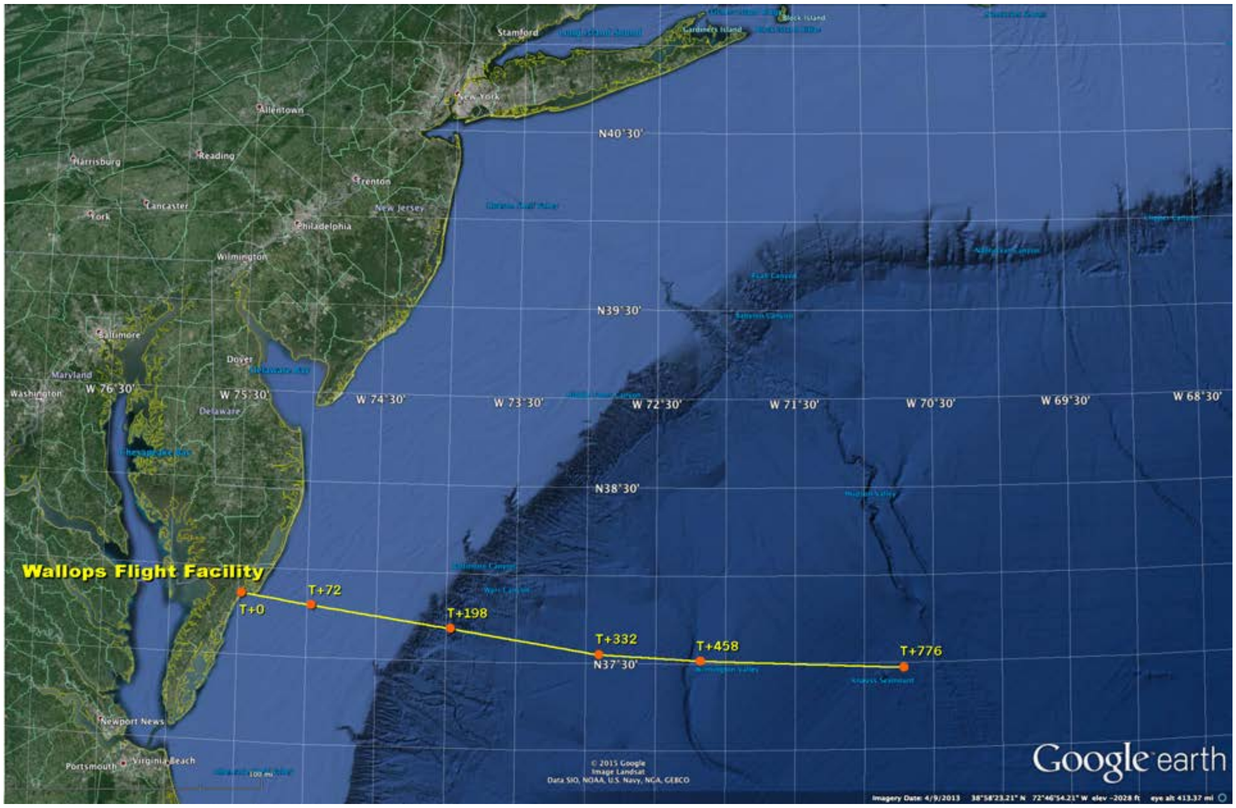


Fig. 11. Ground trace of the RockSat-X 2015 flight from launch at WFF to recovery 263 miles down range.

After its recovery and return to Building F-10 at Wallops Flight Facility, the payload was inspected, photographed and disassembled following the Post Flight Protocol outlined in Appendix D. The housing was found to have suffered seawater leakage despite the RTV sealant. As a result, the UV spectrometer and microSD cards on the Raspberry Pi B+ and the HonCCLogger Card Reader were thoroughly cleaned with an alcohol solution. The data from both microSD cards were fully retrievable.

A. Photosensor Array — Establishing the Payload's Orientation to the sun

Fig 12 illustrates the azimuth/elevation coordinate system used in determining the position of the sun with respect to the payload PIP. The cosine receptor defines 0^o azimuth (Φ). Azimuth is measured counterclockwise around the baseplate. The elevation (Θ) of the sun is measured as positive above the baseplate and negative below it.

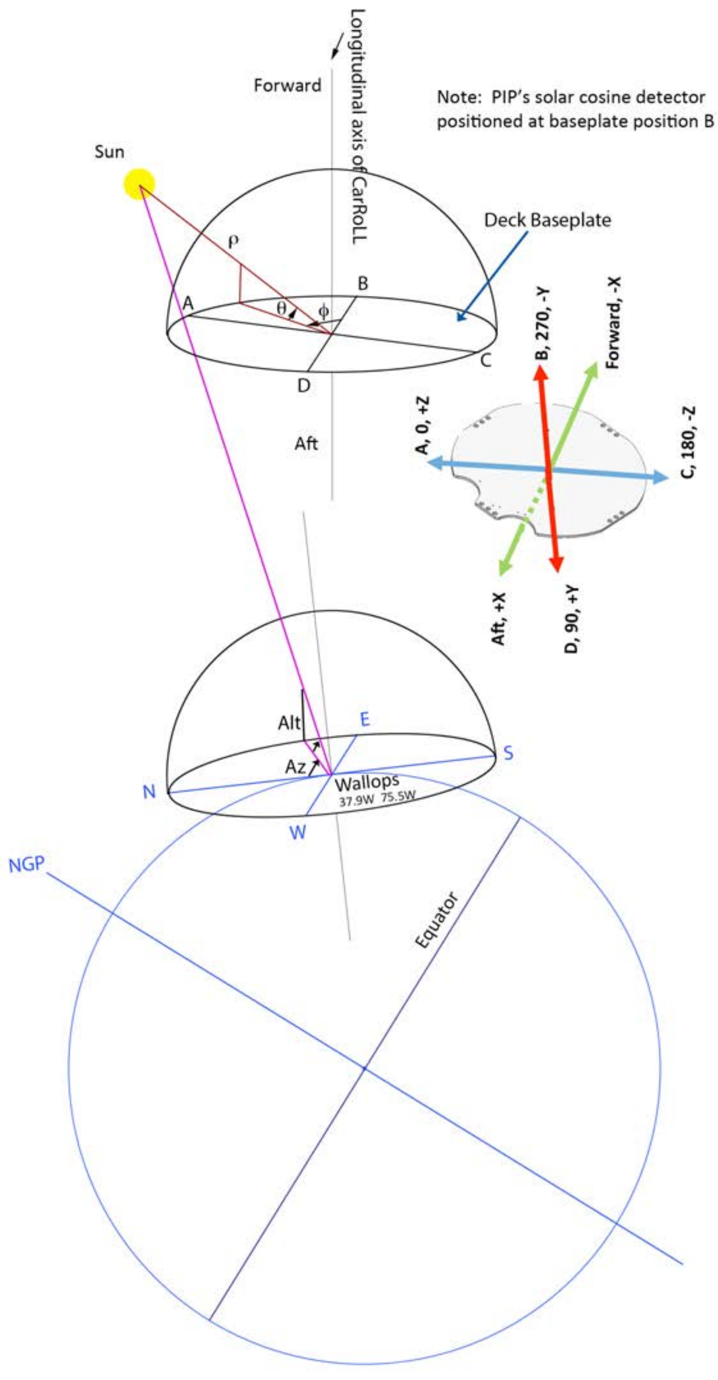


Fig. 12. Coordinate system of payload/baseplate with respect to sun

Since WFF assigned the B quadrant of the baseplate as sun-pointing for this flight, the cosine receptor was oriented on the baseplate along that direction, thus defining 0° for azimuth (see Fig 12).

A calibration profile of the photosensor array was made on a precision rotation table at a laboratory on the Windward CC campus in June 2015 (Fig. 13). The four photosensors were labeled and color-code as A0 (blue), A1 (red), A2 (orange) and A3 (green). An incandescent light source was kept at an elevation of 0° with respect to the baseplate throughout the calibration runs.

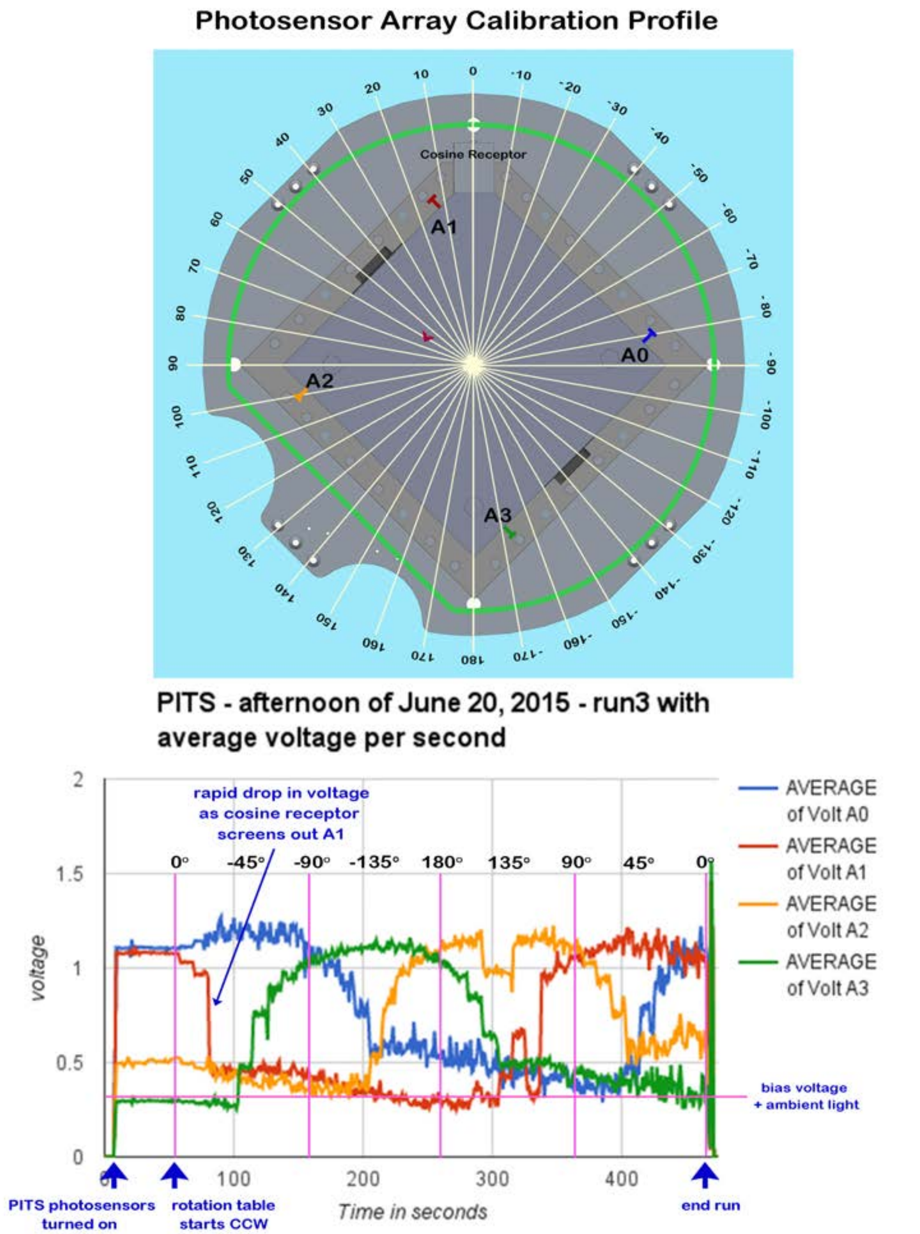


Fig. 13. Calibration profile for the four-photosensor array. Light source at elevation 0°.

According to the flight orientation parameters provided by WFF, the sun was effectively on-target and remained fairly fixed to the cosine detector during the time interval between T+87s and T+161s (see Fig. 14). During this on-target phase, which occurred prior to apogee, the azimuth (Φ) remained relatively fixed at approximately -24° with elevation (Θ) at -18°.

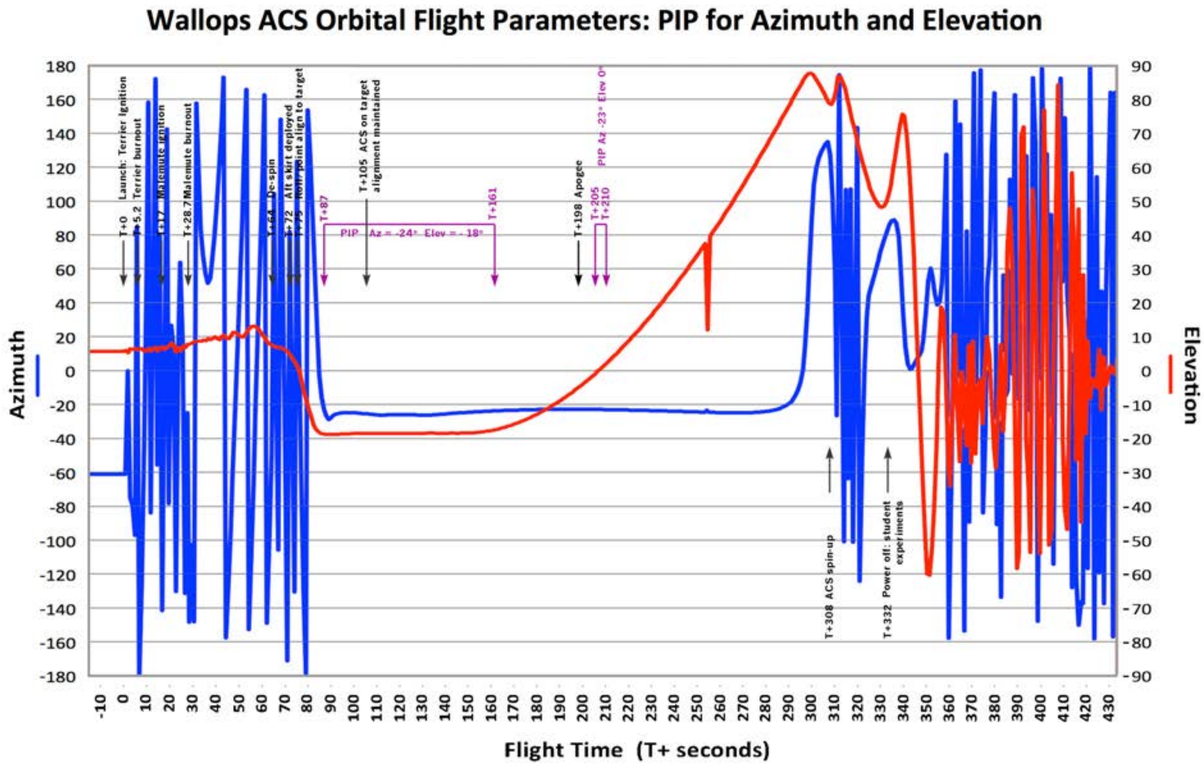


Fig. 14. WFF ASC flight orientation parameters for PIP (azimuth and elevation) —12 August 2015

The 5-second interval between T+205 and T+210, as shown in Fig. 14, was of special benefit for making comparisons with the calibration profile, since the sun was at an elevation of 0° — matching the elevation of the calibration's light source. The cosine receptor's azimuth of 23° was also relatively fixed during this interval.

Figure 15 shows the voltage readings from the four photosensors that were transmitted to WFF during the flight. Similar voltage readings were stored on the microSD onboard the payload. While the WFF readings were based on a 5-volt range, the on-board readings were referenced at 3.3 volts — and so occasionally clipped. In addition, the on-board voltage readings were not recorded until approximately 1-2 seconds after launch, resulting in the loss of 1-2 seconds of data. All voltage readings were averaged over 1-second intervals. Significant timeline events are identified on this graph. The readouts of these four photosensors are color-coded to match those of the calibration profile: A0 (blue), A1 (red), A2 (orange) and A3 (green).

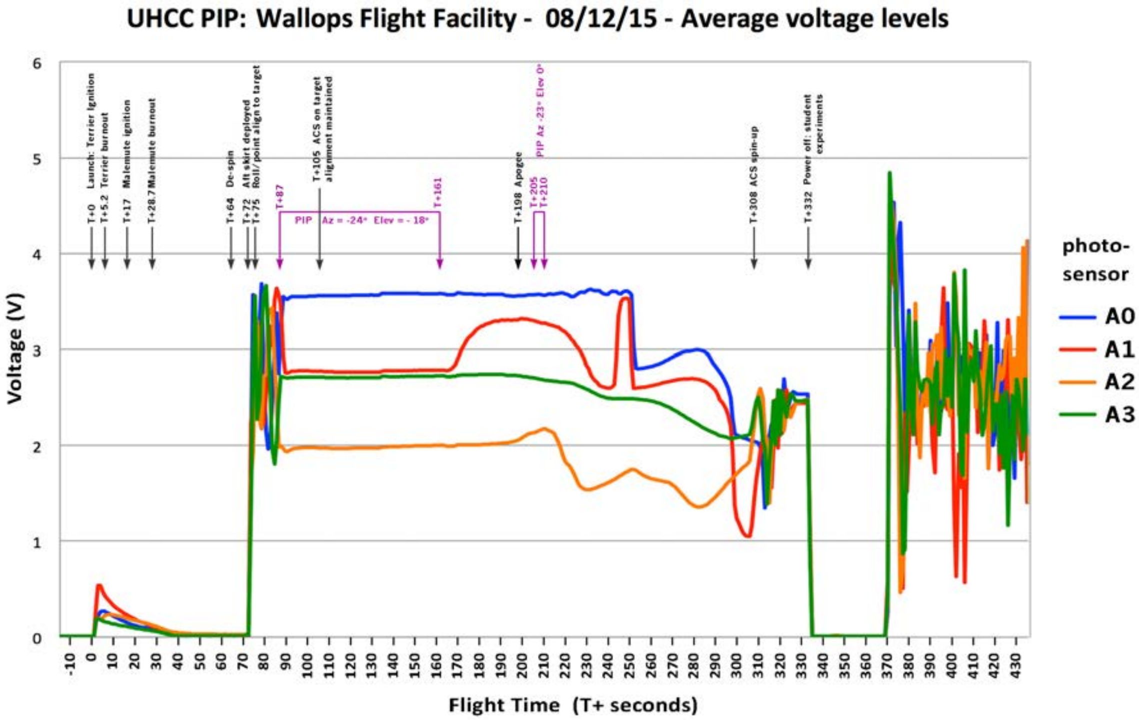


Fig. 15. Voltage readouts of photosensors A0 (blue), A1 (red), A2 (orange) and A3 (green) — 12 Aug 2015. Graph is annotated with significant flight timed events [see Appendix C for mission timeline events].

Analysis of the voltage readings from the four photosensors (A0, A1, A2 and A3) during this specific on-target phase of the flight closely matched the calibration profile for an azimuth of -24^o even though the sun was below the baseplate at an elevation of -18^o. This differed slightly from the calibration's light source, which was kept at 0^o elevation. As expected for this particular -24^o azimuth position, photosensor A1's readings were only slightly higher than those of photosensors A2 and A3, due in part to the screening effect caused by the cosine receptor's aluminum block extension (see annotation in Fig. 13). Photosensor A1 also yielded a lower voltage reading than expected from the calibration profile since the sun was 18^o below the baseplate.

Compared to the readings shown for an azimuth of -23^o on the calibration curve (Fig 13), the in-flight readings for photosensor A3 yielded higher voltage values than for photosensor A2 despite being at the same -23^o azimuth. In the lab, the backlight on the opposite side of the light source was controlled. This suggests that during flight sensor A3 may have observed a higher albedo of the earth's atmosphere/clouds than sensor A2.

Immediately after apogee, the CarRoLL slowly pitched, bringing the sun to an elevation of 0^o for approximately 5 seconds (T+205s to T+210s), while its azimuth remained fixed at -23^o. This interval provided ideal comparison with the calibration profile— showing that photosensors A0 and A1 yielded similar voltage ratios as the calibration profile.

This analysis supports the use of this four-photosensor array for tracking the sun's orientation during flight.

B. UV Spectrometer —Solar Irradiance above the Earth's Atmosphere

After returning to its campus, the Kaua'i CC team analyzed the data acquired near apogee by the StellarNet BlueWave spectrometer. WFF's orbital parameter data of the flight verified that the cosine receptor was pointed towards the sun. During the time interval of primary data acquisition (T+87s through T+161s), the sun remained fairly fixed with respect to the cosine receptor — holding at -24^o azimuth (Φ) and -18^o elevation (Θ).

The post-flight analysis of the spectral data demonstrated that this UV spectrometer was capable of making measurements of the solar spectrum. The requested on-target pointing at the sun was achievable over a span of 1-2 minutes. Figure 16 shows that the solar irradiance obtained during the flight (red plot) was highly attenuated as compared to solar data taken outside at the Kaua'i CC campus (green plot). For reference purposes, the Fraunhofer G (430.7 nm) is indicated on this graph.

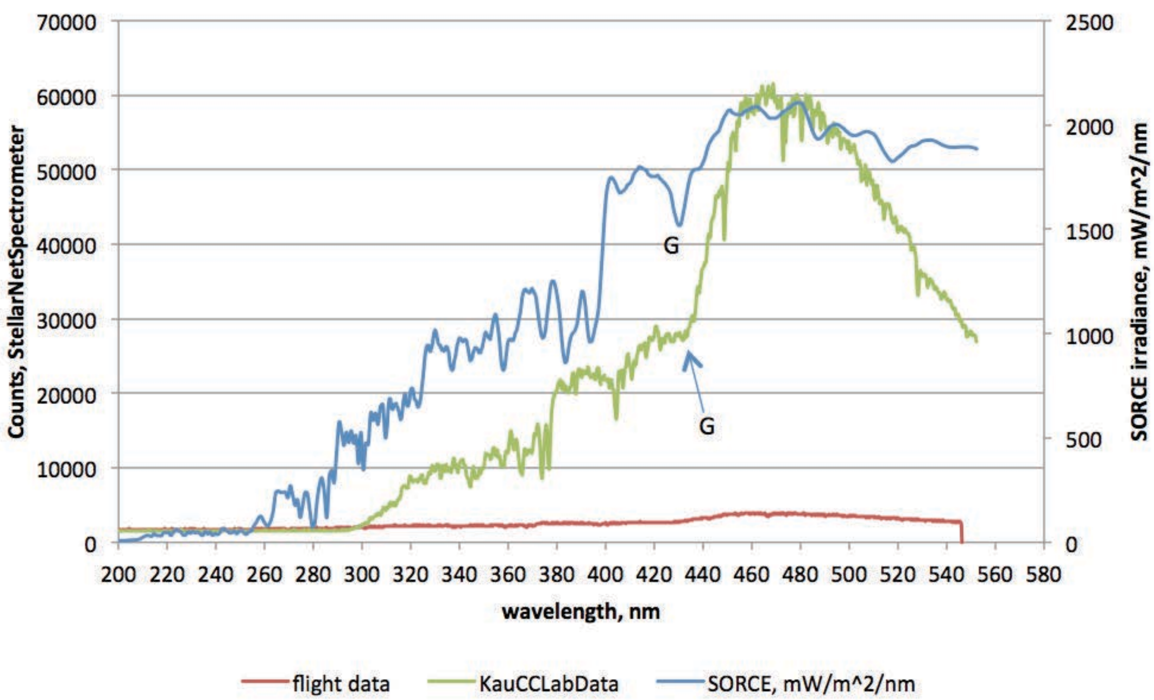


Fig. 16. Flight Data for UV spectrometer versus SORCE data and data collected at Kaua'i CC campus

Scans #5 through #19 were made near apogee with the sun directed approximately at the cosine receptor (azimuth of -24^o and elevation of -18^o with respect to the baseplate). While the general profile of counts was as expected, significant attenuation was observed in all sweep recordings (see Fig. 17).

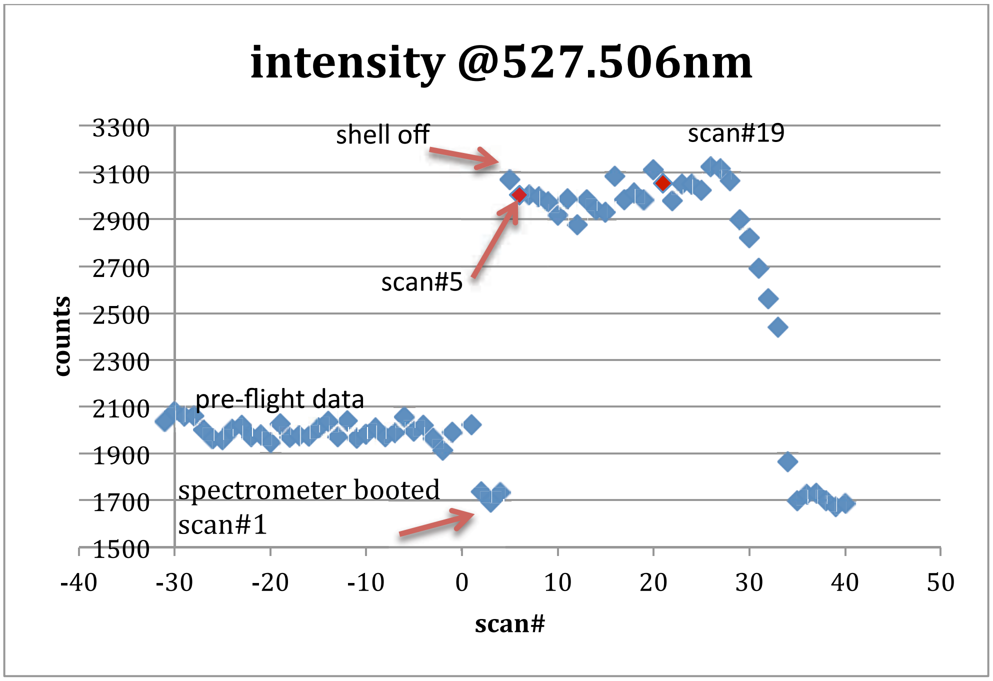


Fig. 17. UV spectrometer raw intensity data for wavelength 527.506 nm

Sweeps #5, 15 and 19 — as well as an average of sweeps recorded near apogee — show identical profiles across the wavelength range from 200 to 560 nm (Fig. 18).

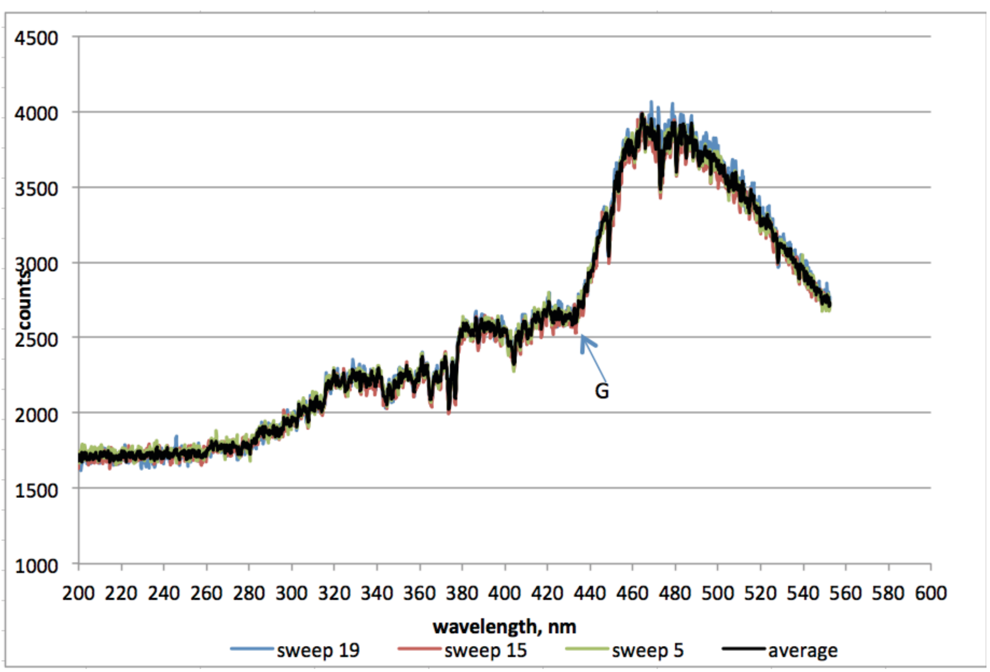


Fig. 18. UV-Vis spectral profiles for apogee recorded sweeps 5, 15, 19 and average.

The cause for the attenuation remains unknown. Possible causes could be a dirty fiber optic connector. During the disassembly of the payload after recovery, it was noted that the fiber connector that mates with the spectrometer was visibly dirty. Dirt on fiber optic connectors can easily cause a factor of 100 reduction in received power. It is possible that a dirty connector may have caused the severe reduction in power that was observed. The low light levels received makes obtaining useful results between 200-300nm impossible.

Subsequent inspection of the fiber optics cable and cosine detector at the Windward CC campus did not uncover any signs of dirt on the connectors.

Analysis of photographs of payload assembly at Wallops, and analysis of the videos in space of the mission confirm that the payload was oriented correctly. Even if the sun were oriented at an angle of 33^{o} relative to the normal of the cosine receptor, that would result only in a 16% reduction in intensity. Even with the presence of atmospheric absorption, the test plots made at the Kaua‘i CC campus prior to flight peak intensities of 60,000 counts— making the 93% reduction of intensity observed in the flight data difficult to account for.

The Windward CC team also conducted a basic light transmission test with a Vernier light intensity meter to check the transmission of the fiber optics cable and the cosine receptor *in situ*. With a 480 lux incandescent light source, the fiber optics cable — which was wound up in the payload section identical to its flight configuration, but without receptor — yielded 180 lux (37.5% transmission). The throughput of cosine receptor, however, was found to be only 14 lux (3% light transmission). Together with the cable this would yield a final transmission of 1.1%.

Another possible cause for the low light throughput may have been the shortening of the fiber optics cable prior to launch. Since the original cable was deemed too long to wind into the housing, a shorter cable was purchased in consultation with the vendor. The shorter cable was first inserted at FMSR, but no pre-flight test was conducted to verify that this replacement cable provided sufficient transmission. According to StellarNet representatives contacted after the flight, this “spectrometer is calibrated to a NIST traceable source with a specific fiber optic cable and cosine receptor combination. Any deviation from the combination can hypothetically cause problems or deviate your readings from normalized values.”

Additional issues could have arisen if the fiber optics cable were tied too tightly onto the standoffs inside the housing. This could cause the phenomenon of micro bending with resultant attenuation. At the other extreme, if the fiber optics cable were tied too loosely, g-forces at launch could have caused permanent damage to the cables. Figure 19 shows the interior of PIP after recovery at sea following the August launch. It is difficult to determine from this post-flight photograph if the fiber optics cables were inadequately secured to the standoffs.

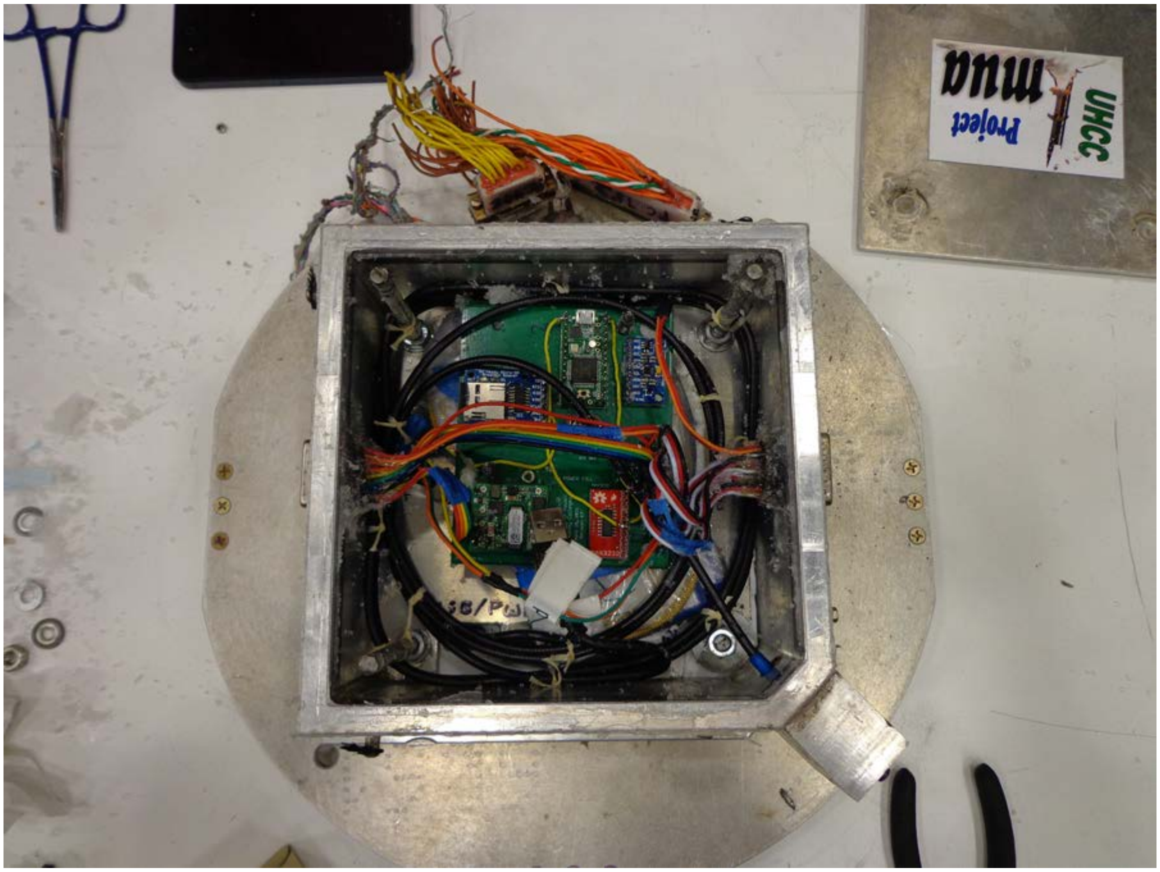


Fig 19. Interior of PIP after ocean recovery following August launch

It is also possible that the cosine receptor may have suffered physical damage under direct exposure to the intense, unfiltered sunlight at apogee. This cause is difficult to verify since any loss in transmission by the cosine receptor that was observed in the post-flight test may have resulted from thermal damage occurring during re-entry.

Since pre-launch tests were never conducted on the spectrometer after the new fiber optics cable was installed for the FMSR, the ultimate cause of this attenuation remains undetermined.

C. 9-axis Motion Sensor — Acceleration, Gyroscopic Rotation and Magnetic Field

Analysis of the InvenSense MPU-9250 9-axis motion sensor verified that this off-the-self miniaturized IMU is capable of being used in space flight. Figure 20 is a plot of the acceleration in all three directions for the first 5 minutes of flight. The vertical axis is given in raw count units. The z-axis lies along the longitudinal direction of the CarRoLL with the x/y axes in the plane of the baseplate.

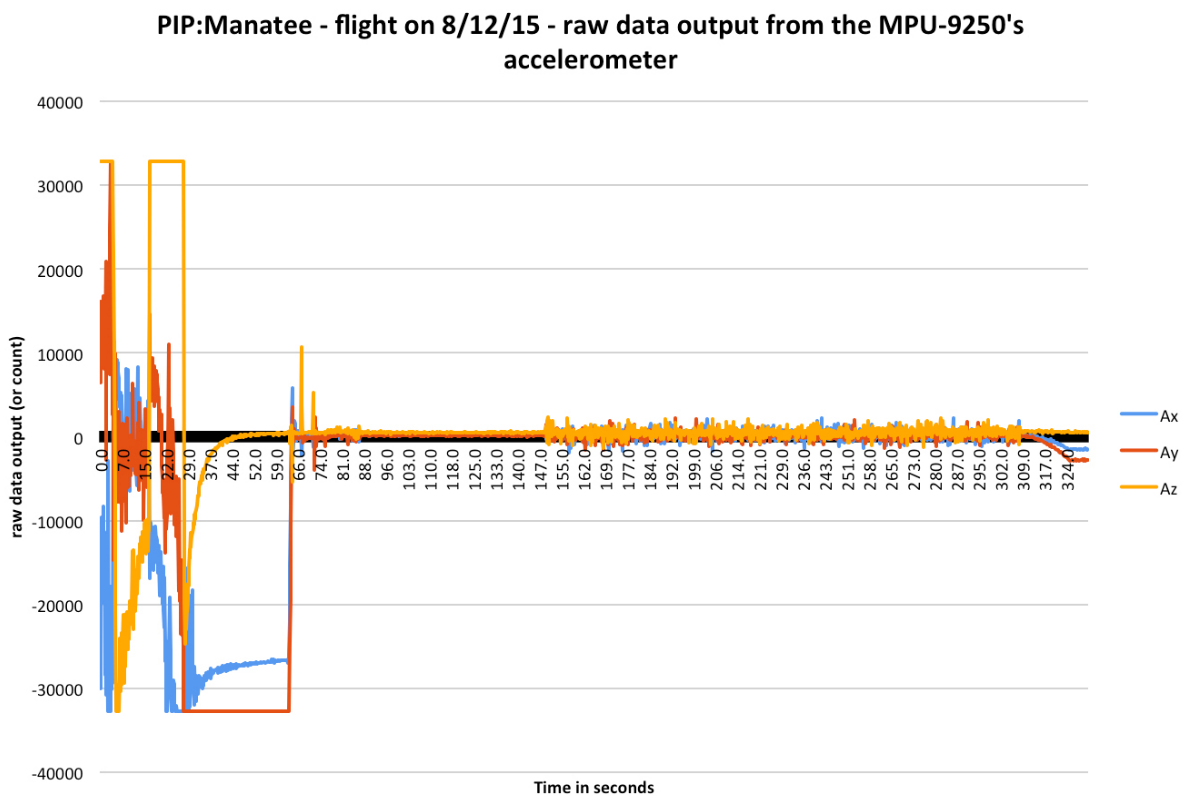


Fig. 20. Acceleration along x, y and z axes during the first 5 minutes of flight.

Figure 21 is a scaled up plot for the acceleration in the z direction for the first 32 seconds of flight. Rocket staging events are indicated in the graph.

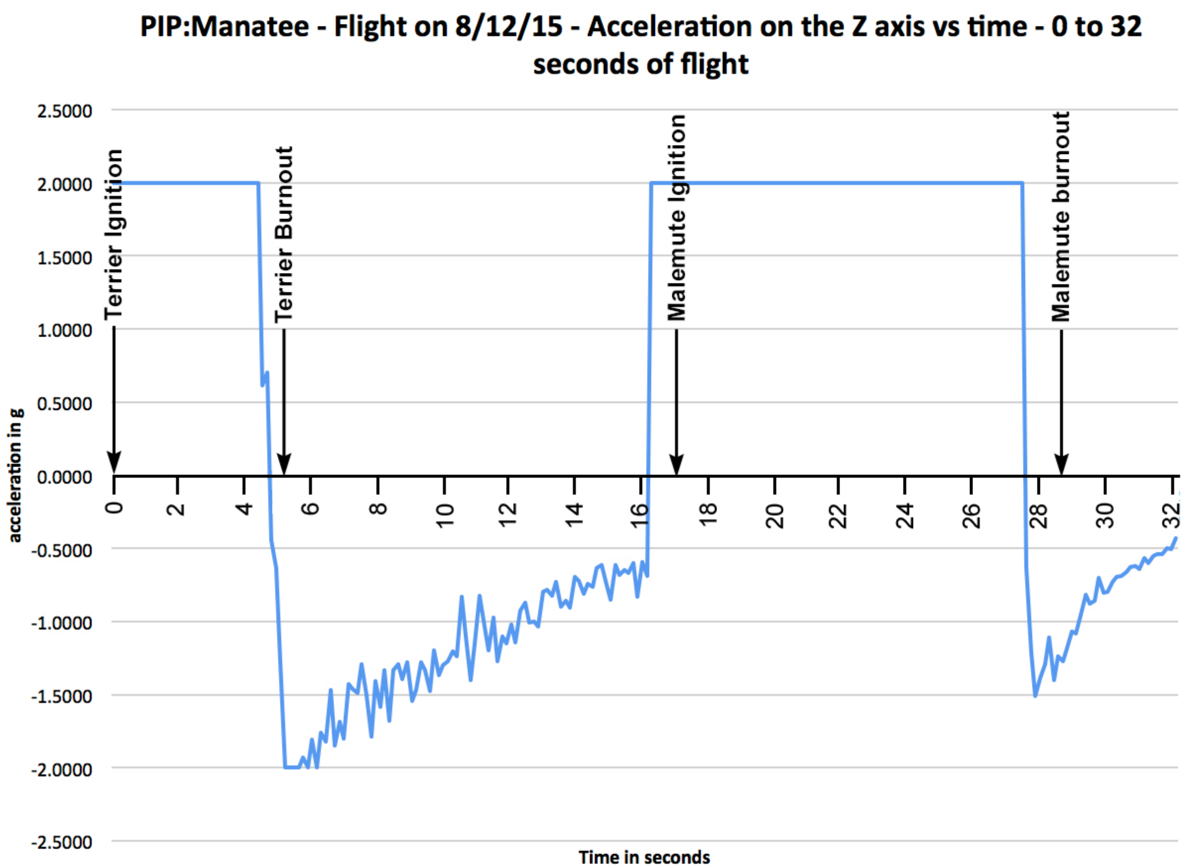


Fig. 21. Acceleration along the longitudinal z-axis from T+0 to T+32 second.

Figure 22 plots the gyroscopic rotation along the three axes. De-spin was initiated at T+64 . The CarRoLL reached its fixed on-target orientation at T+75. The vertical axis is given in raw data output. ASC spin was re-initiated at T+308 in preparation for re-entry. The de-spin and spin events are clearly shown by the gyroscope's data as plotted on this graph.

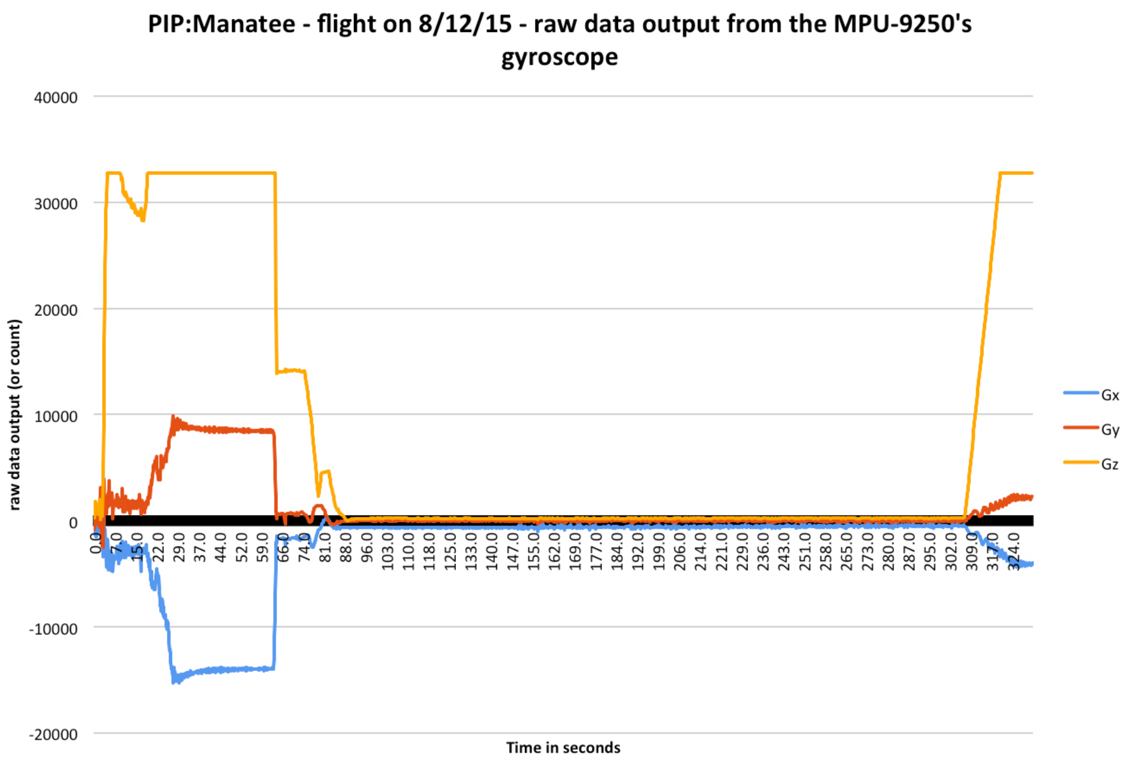


Fig. 22. Gyroscopic rotation along all three axes for the first 5 minutes of flight.

Figure 23 is a plot of the magnetic field strength recorded by the MPU-9250's magnetometer. Time runs from launch through approximately 5 minutes into the flight.

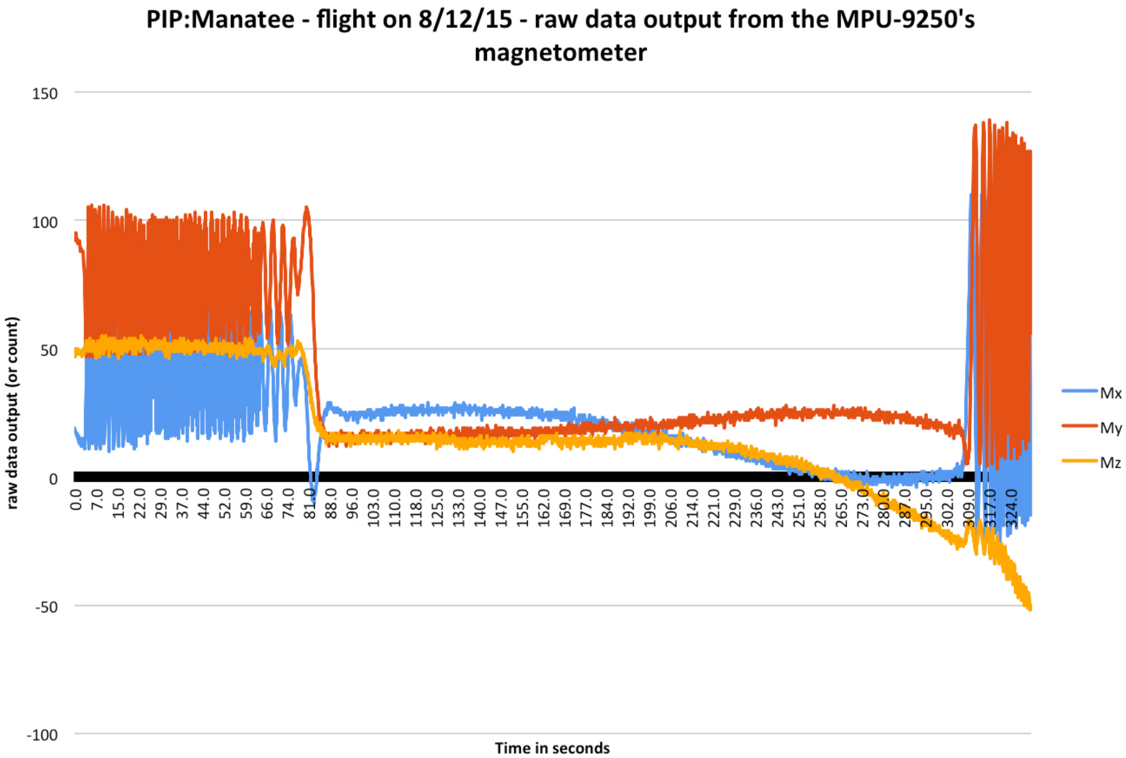


Fig. 23. Magnetometer readings along the three axes during the first 5 minutes of the flight.

7.0 Conclusions

1. The successful launch of Project Imua's payload PIP is an historic first for the University of Hawai'i Community College system. This is the first payload fully developed by the UHCC campuses to be flown in outer space. This notable achievement has captured the attention of the local community and media. To date, Project Imua has been featured in over 70 television, radio and newspaper stories with a total estimated audience of more than 1 million people.

2. All three equipment onboard PIP (UV spectrometer, photosensor array and 9-axis motion tracker) successfully collected data.

3. Forty-three (43) undergraduate fellowships were awarded to community college students at the four UHCC campuses during this first year of Project Imua. Several of these students have since graduated and transferred to UH-Mānoa where they are pursuing STEM education in computer science, mechanical engineering, electrical engineering and physics. This outcome is strong testimony to the succesful attainment of Project Imua's first of two primary objectives — to promote student engagement in STEM-related fields by providing opportunities to participate in payload design, fabrication, testing, delivery and launch.

4. Furthermore, the successful completion of this first space launch of a UHCC-developed payload supports the second main objective of Project Imua — to serve as a pilot test for establishing a joint enterprise of UHCC campuses for developing and launching small space payloads, especially in collaboration with the Hawai'i Space Flight Lab.

8.0 Potential Follow-on Work

There are tentative plans for installing the UV spectrometer in a CubeSat for orbital flight at a later date.

The experience gained from launching the InvenSensor MPU-9250 into sub-orbital flight is being used in outfitting the payload currently under development for Project Imua's mission onboard RockSat-X 2016. A more accurate 9-axis device (VN100-T) will be substituted for the MPU-9250. This newer unit, which measures 33x36x9mm, is larger than the MPU-9250, but more robust.

9.0 Benefits to the Scientific Community

Information regarding the amount of solar UV irradiance received above the earth's atmosphere is critical in understanding solar dynamics. The total solar irradiance in this spectral range is expected to have a major influence on the heat budget of the earth's thermosphere and ionosphere.

The variations in total solar flux from sunspot maximum to sunspot minimum are not well known. Until this variation is well-documented, models of the impact of UV irradiance on climate will remain uncertain.

10.0 Lessons Learned

Among the lessons learned from this mission were:

1. Communications: The establishment of various communications modes such as Google Hangouts was adopted more than a month into the early phases of the project. Especially for a multi-campus/multi-island coalition such as UHCC Project Imua, frequent and robust methods of communication are essential and need to be initiated immediately.

While there have been past joint projects between two UHCC campuses in the HSGC — notably between WinCC and HonCC as well as between WinCC and KapCC — this is the first time that a coalition of four campuses has joined forces on a major aerospace engineering project. The communication and logistic challenges increase exponentially and are compounded by the fact that one of the campuses (KauCC) is located on a different island. The success of this year's mission is largely due to the establishment of a well-defined organizational structure that incorporates a Project Manager, campus faculty mentors, and support and advisory personnel. During the beginning phase of the mission, communication among the campuses was tenuous and inconsistent. Over the project's year-long period, a stronger communication network was established that incorporated multiple venues, such as, teleconference phone calls, video chat technology like Google Hangouts, on-line collaboration like Google Drive, Google Groups and Google Calendar, social media and face-to-face meetings. These were done both on an intra-campus and inter-campus approach to facilitating communications. This formal joint enterprise has also allowed students from different campuses to become more acquainted with each other than has been in the past. The students gained a better understanding of the iterative nature of engineering, as well as experience working as a cohesive team in a diverse group.

Project Imua's second year in RockSat-X has already benefited significantly by utilizing the various modes of communication that were identified in year one.

2. Housing sealant: Saltwater leakage were detected as a result of the water recovery phase of the launch despite previous water-proof tests and use of RTV sealant on all joints, including the cosine receptor. On a related note, whereas Windward CC did spend a large fraction of time customizing the Teflon layers to immobilize the UV unit, a better choice of gasket sealant needed to be made.

3. Fiber optics cable and attenuation issue: Additional tests should always be conducted after introducing new components into a subsystem regardless of whether the involved change is minor and/or vendor consultation suggests the alteration would meet the specs of the instrumentation involved.

4. Photometer and IMU/9-axis motion detector: To avoid clipping of data at its high values, the appropriate parameter range needs to be selected when setting switches and choosing voltage settings. For the IMU the maximum g-force range should have been selected. For the photosensors, a voltage range of 0-5VDC would have been more appropriate than the 3VDC that was used by the Manatee system. Fortunately, WFF's 5VDC records of this photosensor data eliminated the clipping experienced by the Manatee. Future onboard recording methods need to insure that recording begins before launch rather than at T+0 to avoid the loss of any initial data, as occurred with the Manatee's design.

11.0 Appendices

Appendix A: Project Imua Partners

Project Imua consists of the following partners:

1. **University of Hawai‘i Community College (UHCC)** — the following four of the seven UHCC campuses are equal partners in Project Imua:

• **Honolulu Community College (HonCC)**: During project Year One, the HonCC team was comprised of one Project Imua Co-I/faculty mentor, one staff member (Project Imua IT specialist) and three students. The HonCC team was responsible for designing and assembling the payload power and telemetry circuitry. In addition, this team designed and constructed the payload's two engineering experiments: a 9-axis motion tracking device (accelerometer, gyro and magnetometer) and an array of photo sensors for determining the orientation of the sun to the payload.

• **Kapi‘olani Community College (KapCC)**: During project Year One, the KapCC team consisted of one Project Imua Co-I, one faculty mentor and three students. The KapCC team was responsible for designing the Print Circuit Board (PCB) for the power and telemetry circuits.

• **Kaua‘i Community College (KauCC)**: During project Year One, the KauCC team consisted of one Project Imua Co-I/faculty mentor, one adjunct consultant and five students. The KauCC team was responsible for designing and assembling the payload's UV spectrometer for measuring solar irradiance above the atmosphere. In addition, this team designed the payload's aluminum mechanical housing.

• **Windward Community College (WinCC)**: During project Year One, the WinCC team was comprised of one Project Imua Co-I/Project Manager, one Project Imua Co-I/faculty mentor and five students. The WinCC team was responsible for integrating the payload subsystems together, revising the design of and assembling the mechanical housing, performing the required full mission simulation static and pressure environmental tests, and coordinating the environmental and integration tests at Wallops Flight Facility. WinCC also acted as the lead campus for this project through the responsibilities assigned to Project Imua's Program Manager.

2. **Hawai‘i Space Grant Consortium (HSGC)**: The Director of HSGC (UH Mānoa) serves as Project Imua's PI and advisor. The Executive Director of HSGC also acts as an advisor to Projector Imua and provides support with the program's budgetary matters.

3. **Hawai‘i Space Flight Laboratory (HSFL)**: The HSFL avionics engineer acts as Project Imua's engineering consultant and evaluator, and also assists with student travel accommodations. HSFL supported Project Imua by making its vibration table and pressure chamber available for static testing.

4. **Colorado Space Grant Consortium (COSGC)/ RockSat-X**: The RockSat-X program, which is sponsored through COSGC in cooperation with **Wallops Flight Facility (WFF)**, provides the space launch facilities for the Project Imua's payload. The sub-orbital flight was conducted onboard a Terrier-Improved Malemute rocket at WFF — with launch occurring on August 12, 2015.

Appendix B: UHCC Project Imua Timeline for RockSat-X 20

Project Imua's timeline was dictated by the established protocols and schedule mandated by the RockSat-X program. A summary of the activities follows:

• August 2014: An Executive Directors meeting of Project Imua (comprised by the Project Manager, campus faculty mentors, consultants and advisors) identified the payload experiments for Year One's mission — an UV spectrometer and a 9-axis motion tracker. The photo sensor array was added to the payload at a later date. RockSat-X was identified as the preferred launch system. Campus assignments were designated. Student applications to Project Imua were solicited and awarded.

• September 2014: The RockSat-X Intent to Fly Form was submitted to COSGC. Additional student fellowships were awarded. The KauCC team began the design of the UV spectrometer. HonCC started designing the 9-axis motion tracker. The WinCC team began its design of a vibration table for on-campus static environmental tests.

• October 2014: KauCC acted as the lead campus in preparing the project's Conceptual Design (CoD) phase. On October 14, the first of seven teleconference review sessions (CoDR) was held between the Project Imua teams and COSGC/RockSat-X coordinators. A deposit of $2,000, which constituted the first installment for the RockSat-X launch fee, was submitted for a shared deck on the 2015 launch vehicle.

• November 2014: KauCC acted as the lead campus in preparing the project's Preliminary Design Review (PDR) phase. On November 4, a PDR teleconference review was held between the Project Imua teams and COSGC/RockSat-X coordinators. At this stage, an additional engineering experiment was suggested — an array of photo sensors to determine the orientation of the sun with respect to the UV spectrometer's detector. On November 22, the Project Imua students presented their mission objectives and designs at the Fall 2014 HSGC Fellowship Symposium.

• December 2014: HonCC acted as the lead campus in preparing the project's Critical Design Review (CDR) phase. On December 4, a CDR teleconference review was held between the Project Imua teams and COSGC/RockSat-X coordinators. At this stage, after a re-examination of the mechanical housing's design, changes were made to improve the method of securing the housing onto the spacecraft deck plate. Based on the exemplary presentation made at this CDR session, the RockSat-X coordinator canceled the program's scheduled Post-CDR for the Project Imua team. At this stage, the UHCC Project Imua teams began fabricating the subsystems assigned to each campus.

• January 2015: The KapCC Project Imua student team was selected. On January 7, UHCC Project Imua was official selected onto the RockSat-X 2015 manifest. The UHCC payload was assigned to a shared deck with Capitol Technology University (CTU). Fabrication and initial tests of each team's subsystem continued.

• February 2015: KapCC acted as the lead campus in preparing the project's Subsystem Testing Review (STR) phase. On February 27, an STR teleconference review was held between the Project Imua teams and COSGC/RockSat-X coordinators. The second, non-refundable installment of $6,000 was submitted for the RockSat-X launch fee.

• March 2015: WinCC assumed the role of lead campus in preparing for the upcoming integration phase. WinCC re-designed the payload housing to ensure that the UV spectrometer's detector was not screened out by our shared partner's deck. Subsystem fabrication entered its final stages. KapCC finalized the design of the PCB, which was submitted to a mainland vendor for processing. All four campuses met at the WinCC campus during the Spring Break to conduct open bench tests on the integrated subsystems.

• April 2015: WinCC acted as the lead campus in preparing the project's Integrated Subsystem Testing Review (ISTR) phase. An Executive Directors meeting was held on April 4 to assess the status of the project. The WinCC begin the integration process on the subsystem components. On April 24, the ISTR teleconference was held between the Project Imua teams and COSGC/RockSat-X coordinators. On April 25, the Project Imua students presented their mission plans and subsystem designs at the Spring 2015 HSGC Fellowship Symposium. The final installment of $6,000 was submitted for the RockSat-X launch fee.

• May 2015: WinCC continued as lead campus in preparing the project's Full Mission Simulation Review (FMSR) phase. KapCC revised the payload's PCB. WinCC fabricated the housing's internal support structure and re-designed the housing's lid. Two full mission simulation tests were conducted at the WinCC campus. On May 29, the FMSR teleconference was held between the Project Imua teams and COSGC/RockSat-X coordinators.

• June 2015: On June 11, WinCC coordinated a vibration test on the payload at HSFL facilities on the UH-Mānoa campus. WinCC further modified the exterior of mechanical housing to bring the payload's total mass within the tolerance as specified by WFF. During the period of June 23 through 28, Project Imua sent a team of two mentors and five students to Wallops Flight Facility to conduct a Ground Support Equipment (GSE) test on the payload. After integrating the payload onto the rocket's main payload structure (called the CarRoLL), various environmental tests (including vibration, center of gravity, moment of inertial and GPS rollout) were conducted. The Project Imua payload passed all its tests and was fully certified for space flight. According to RockSat-X coordinators, this was the first time in the program's five-year history that a payload has been fully certified and ready to fly at the Environmental Test in June. As a result, the payload was stored at WFF for the upcoming August launch.

• July 2015: WinCC developed the protocols for handling the payload prior to launch and immediately after recovery, and served as lead campus for the Launch Readiness Review (LRR) session. On July 20, the LRR teleconference was held between the Project Imua teams and COSGC/RockSat-X coordinators. In addition, five weekly teleconferences were held between the COSGC/RockSat-X coordinators and all seven university teams assigned to the upcoming August launch. On July 31, an Executive Directors meeting was held to discuss the payload for Year Two. As in Year One, it was decided to design three experiments—one scientific experiment involving a neutron/gamma ray detector and two engineering experiments, including an improved version of the 9-axis motion tracker and an innovative sublimation rocket motor to be ejected from the payload bay.

• August 2015: During the period of August 4 through 12, Project Imua sent a team of two mentors and nine students to Wallops Flight Facility for the launch originally scheduled on August 11. Prior to launch, a final Ground Support Equipment (GSE) test and integration were conducted by the UHCC team. Due to weather condition, the launch was postponed to August 12, when a Terrier-Improved Malemute carried the RockSat-X payloads on a 15-minute sub-orbital flight to an apogee of 96 miles. The payload was successfully recovered and returned to WFF, where the UHCC team conducted its post-flight protocol of retrieving the data and securing the payload for transportation back to Hawai‘i.

• September – November 2015: Compilation and analysis of the data collected from the two engineering experiments (9-axis motion detector and array of photosensors) and the scientific instrument (UV spectrometer). Analysis was made in conjunction with the orbital parameter data provided by WFF.

Appendix C. Mission Time Line

Mission Time Line
46.012/Koehler Rev- F
Weight: 868.4 lb. QE: 84.0 deg. AZ: 97.0deg.

7/20/15

Event	Time (sec)	2 sigma Low Altitude (km)	Nominal Altitude (km)	2 sigma High Altitude (km)	Nominal Range (km)	Velocity (m/s)	Nominal Q (psf)	Mach NO.	Flight Elevation (deg)	Event Control	Timer Type	Dwell Time (sec)
Terrier Ignition	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	Ground Fire	-	-
XHD: Launch Signal	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
CTU:Signal to Turn On System	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	1
UHCC: Power to Experiment	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
VT: Power to Printer Motors, Instruments, and Camera	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
VT: Notify Flight Computer of Launch	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
UPR: Launch Signal, Power	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
UPR: Add more power	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	332
Backup Power to Student Experiments On	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.0	TM	UMFT	1
Rail Release	0.5	0.0	0.0	0.0	0.0	45.0	25.9	0.1	84.0	-	-	-
Terrier Burnout	5.2	1.5	1.6	1.6	0.2	561.0	3473.8	1.7	82.9	-	-	-
Improved Malemute Ignition	17.0	6.4	6.5	6.6	0.9	307.1	627.9	1.0	80.7	CDI	Elec	1
Improved Malemute Burnout	28.7	16.8	17.2	17.6	2.8	1685.0	4283.7	5.7	79.2	-	-	-
XHD: Signal to Turn On Cameras	50.0	47.5	49.3	51.1	9.3	1427.8	26.8	4.4	77.9	TM	UMFT	282.0
Heat Shield Enable	60.0	60.4	62.8	65.1	12.2	1333.3	4.3	4.3	77.1	TM	UMFT	740.0
Despin to 0.0 Hz	64.0	65.2	67.9	70.5	13.4	1295.8	2.0	4.4	76.8	CDI	UMFT	1
Motor Separation	68.0	70.0	72.9	75.7	14.6	1258.5	0.9	4.3	76.4	CDI	Elec	1
UPR: Signal Flag for Aft Skirt deployment	70.0	72.3	75.3	78.3	15.2	1239.8	0.6	4.3	76.2	TM	UMFT	262.0
Aft Skirt Separation	72.0	74.5	77.7	80.8	15.7	1221.2	0.4	4.3	76.0	TM	UMFT	1
XHD: Deploy Cameras	72.0	74.5	77.7	80.8	15.7	1221.2	0.4	4.3	76.0	TM	UMFT	260.0
ACS1: Roll and pointing allgn to target	75.0	77.8	81.2	84.5	16.6	1193.4	0.2	4.3	75.7	ACS	Elec	-
NNU: Power ON H-Bridge and Drive Motor Deploy	75.0	77.8	81.2	84.5	16.6	1193.4	0.2	4.3	75.7	TM	UMFT	257.0
Nosecone Separation	76.0	78.9	82.4	85.7	16.9	1184.1	0.2	4.3	75.6	TM	UMFT	1
300 kFt Upleg	84.2	87.5	91.4	95.3	19.3	1108.8	0.0	4.2	74.7	-	-	-
ACS: On Target, maintain alignment	105.0	106.4	111.7	116.8	25.2	919.4	0.0	2.8	71.7	ACS	Elec	-
CUB: Induction Heater ON	130.0	123.7	130.5	137.2	32.3	699.2	0.0	1.8	65.8	TM	UMFT	60
ACS: Gas Nozzles DISABLED	150.0	133.3	141.4	149.3	37.9	533.3	0.0	1.3	57.8	ACS	Elec	-
UNL: Power Linear Actuators for Crystallization	175.0	140.1	149.8	159.2	44.8	357.4	0.0	0.9	37.6	TM	UMFT	5
Apogee	**198.4**	141.1	**152.4**	163.2	51.3	282.8	0.0	0.7	0.0	-	-	-
XHD: Signal to Retract Cameras	290.0	96.2	113.3	129.8	76.8	902.6	0.0	2.6	-71.3	TM	UMFT	42.0
NNU: Power ON H-Bridge and Drive Motor Retract	290.0	96.2	113.3	129.8	76.8	902.6	0.0	2.6	-71.3	TM	UMFT	42.0
ACS: Gas Nozzles ENABLED	307.0	79.2	97.4	115.0	81.7	1056.5	0.0	3.9	-74.0	ACS	Elec	-
ACS Spin-up	308.0	78.1	96.4	114.0	82.0	1065.7	0.0	4.0	-74.1	ACS	Elec	-
300 kft Downleg	312.7	72.9	91.4	109.4	83.3	1108.8	0.0	4.2	-74.7	-	-	-
UPR: Signal Flag for 30 seconds to Power Off	302.0	84.5	102.3	119.6	80.2	1011.0	0.0	3.6	-73.3	TM	UMFT	30.0
XHD: Signal for Pre-power Loss Sequence	315.0	70.2	89.0	107.1	84.0	1129.9	0.1	4.2	-75.0	TM	UMFT	17.0
CUB: Clear SD card Buffer, Prep for Shutdown	325.0	58.2	77.6	96.3	86.9	1222.3	0.4	4.3	-76.1	TM	UMFT	5
ACS: Begins Pulsed Venting	330.0	51.9	71.5	90.6	88.3	1268.5	1.2	4.3	-76.6	ACS	Elec	-
Power to Student Experiments Off	332.0	49.3	69.0	88.2	88.9	1286.5	1.7	4.3	-76.8	TM	UMFT	1
Ballistic Impact (nominal)	426.7	0.0	0.0	2.5	101.6	172.8	381.8	0.5	-88.5	-	-	-
ACS: Off	440.0		8.5		101.6	118.5	74.0	0.4	-83.9	ACS	Elec	-
Chute Deploy	457.8		6.3		101.6	112.9	85.5	0.4	-85.1			
Payload Impact (on chute)	919.5	0.0	0.0	0.0	101.6	9.8	1.2	0.0	-90.0	-	-	-

Appendix D. Protocol for Handling PIP for Pre/Post August 2015 Launch

ADVISORY: Breaching the housing of PIP could result in altering the mass distribution that was established at the June Environmental Testing sessions. As Jesse Austin stated, *it is now very important that you do not drastically change your experiment mechanically.* If such changes are even suspected of being made, Jesse should be notified and a determination will be made if this has any significant implications on the entire payload section. As a result, any breach of our PIP payload should be treated as an absolute last resort for salvaging only major flaws that would render our mission a complete failure.

A. Pre-Launch Handling Protocol

The seal of PIP may only be breached and the payload lid opened under the following circumstances:

- UV spectrometer is not transmitting data during the GSE checkout/power on test in August.
- Three (3) of the photosensors are not transmitting data during the GSE checkout/power on test in August. These three malfunctioning sensors must include **both** A0 and A1, which straddle the cosine receptor. If either A0 or A1 is functioning, then the housing may not be breached to repair this subsystem, even if it is the only sensor operating.

IMPORTANT. The following steps must be strictly adhered to in the event that the seal must be broken and repair work undertaken:

1. All exterior components must first be fully inspected and tested for possible correction of the subsystem failure by the student team whose equipment is malfunctioning.
2. If the exterior checks yield negative results, the team must request permission from Project Imua lead mentor at WFF (Georgeanne Purvinis) to breach the housing to conduct the necessary repair work.
3. Georgeanne Purvinis must concur that all possible exterior tests have been conducted by the students without success and immediately contact the Integration/Static Test mentor (Jake Hudson) with the diagnostic report.
4. Jake Hudson must confer with Project Manager (Joe Ciotti) and both must concur that the situation requires breaching the housing. Upon agreement, the Project Manager will immediately contact Georgeanne to proceed with the necessary repair work.
5. Photographs will be taken during all stages of the repair session.
6. The WinCC integration team present at the August launch will be in charge of opening and resealing the housing.

SAFETY: A facemask and eyewear should be worn to protect against the fiber particles that may be ejected when the absorbent material is removed. An antistatic wrist strap (ESD) should be worn.

7. The campus team whose equipment is malfunctioning will be responsible for making the necessary repairs.
8. Upon resealing of PIP, Jesse must be informed that the housing was breached.

B. Post-Launch Handling Protocol — Decommissioning PIP

After PIP's water recovery and its subsequent return to the Project Imua team, PIP's housing should be opened to remove any water that may have leaked inside. At this time, the two micro SD cards (on PCB and Raspberry Pi) and the campus patches will be retrieved and securely stored in a separate container. Special care should be taken to insure that PIP is not exposed to stray voltage, including electrostatic.

1. All sides (including bottom) of PIP must be photographed.

2. Once the housing is opened, photographs will be taken at each stage prior to any component or electronic layer being disturbed or removed.

3. The WinCC integration team present at the August launch will be in charge of opening the housing, draining any water, disconnecting, unmounting and cleaning the interior electronic components, removing the two micro SD cards and retrieving the enclosed campus patches. **SAFETY:** A facemask and eyewear should be worn to protect against fiber particles that may be ejected when the absorbent material is removed. An antistatic wrist strap (ESD) should be worn.

4. **Disassembly procedures:**
   a. remove three hex nuts on lid.
   b. break RTV seal and pry open lid by inserting a narrow bladed tool such as a flat-head screwdriver under the lid.
   c. drain any water and remove the water absorbent material.
   d. remove Raspberry Pi by disconnecting the jumper cables and removing the standoff nuts.
   e. remove the micro SD card from the Raspberry Pi. If water entered the housing, clean the micro SD card with alcohol and let dry.
   NOTE: Duplicate data contents as soon as possible. Also upload the data to the **PIP Flight Data** folder located on Google Drive → project-imua.
   f. remove the PCB by disconnecting the jumper cables and removing the standoff nuts.
   g. remove the micro SD card from the PCB. If water entered the housing, clean the micro SD card with alcohol and let dry.
   NOTE: Duplicate data contents as soon as possible. Also upload the data to the **PIP Flight Data** folder located on Google Drive → project-imua.
   h. remove the campus patches. If water entered the housing, replace plastic bag after ensuring patches are dry.
   i. remove the two RS-232 interface connectors prior to removing the metal spacer.
      - remove the external barrel-head nuts (2 each)
      - sever the RTV seals around each of the RS232 units
   j. remove the metal spacer plate by removing the standoff nuts.
   k. remove the cosine extender by unscrewing the two screws and breaking the RTV seal. This will allow the fiber optics cable to freely rotate while it remains attached to the extender and spectrometer.
   l. remove the Teflon layers one layer at a time, allowing the fiber optics cable to unwind
   m. remove the UV spectrometer and disconnect the fiber optics cable from the spectrometer. Clean the spectrometer as needed.
   n. clean and dry off the interior of the housing.
   o. re-screw the cosine extender onto the housing. Do not use RTV sealant. Stow fiber optics cable inside the housing.
   p. re-secure the Teflon and metal spacers inside the housing
   q. re-screw two RS-232 interface connectors onto housing
   r. clean/replace lid and re-secure with hex nuts. Do not seal.

5. **Distribution of PIP components for transportation back to Hawaii**

a. **PCB and PCB's micro SD card** will be given to the HonCC team for transportation to Hawaii. If water entered the housing, the micro SD card should be cleaned with alcohol to remove any residue of seawater. Contents of this card should be duplicated and both data storage devices stored safely in separate locations for return to Hawaii. Also upload to data to the **PIP Flight Data** folder located on Google Drive → project-imua.

b. **Raspberry Pi card** will be given to the WinCC team for transportation to Hawaii. The **Raspberry Pi's micro SD card** will be given to the KauCC team for transportation to Hawaii. If water entered the housing, the micro SD card should be cleaned with alcohol to remove any residue of seawater. Contents of this card should be duplicated and both data storage devices stored safely in separate locations for return to Hawaii. Also upload to data to the **PIP Flight Data** folder located on Google Drive → project-imua.

c. **Campus patches** will be given to the WinCC team for transportation back to Hawaii and returned to the Project Manager for attachment to the campus award plaques.

d. **UV Spectrometer** will be given to the KauCC team for transportation back to Hawaii

e. **PIP Housing** will be given to the WinCC team for transportation back to Hawaii. A letter advising TSA of PIP's purpose should be included with the packing. Explanation of any visible singing due to thermal heating upon re-entry should also be noted in the letter.

C. Distribution of PIP and contents after completion of mission

1. Upon arrival in Hawaii, PIP should be immediately returned to WinCC's NASA Flight Training AEL for further inspection, photography and removal of any remaining payload contents.

2. Contents of PIP will be distributed as follows:
    - UV spectrometer will be returned to KauCC
    - PBC board will be returned to KapCC
    - IMU and other electronic components mounted on the PCB will be returned to HonCC.

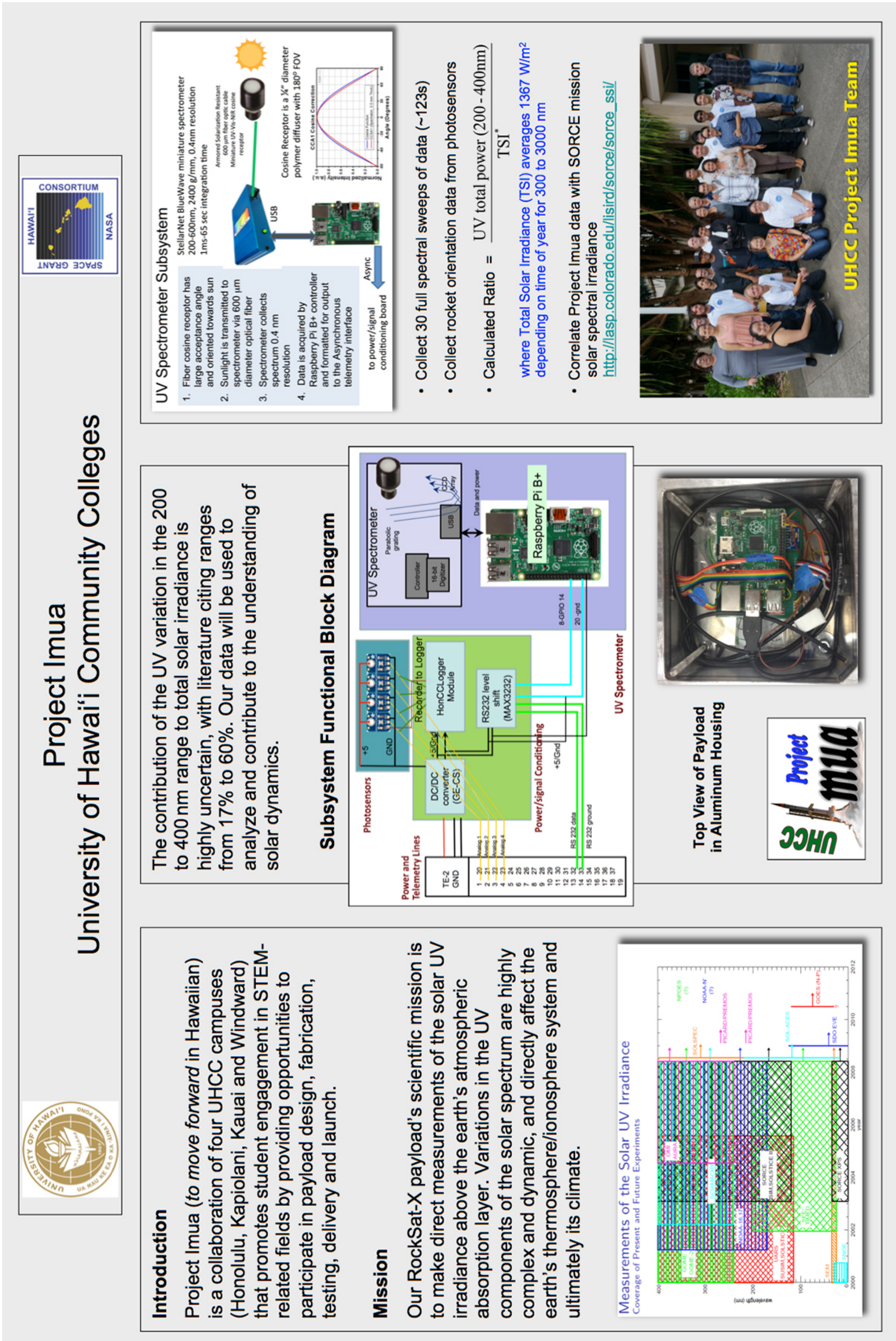
Note: HonCC will remove these components from the PCB upon return to Hawaii and return the PCB to KapCC.
- PBC board will be returned to KapCC (see note above)
- Raspberry PI B+ will be returned to WinCC
- photosensors will remain on the exterior of the housing
- PCB's micro SD card will be returned to HonCC
- Raspberry Pi's micro SD card will be returned to KauCC

3. Upon removal of the interior components, PIP will be circulated among the four UHCC campuses for periods of three (3) months per campus. A detailed schedule will be determined in August when PIP is returned to Hawaii. In order to accommodate a possible ceremony at the Legislature or Governor's Office in late August or September, one of the O'ahu campuses will assigned the first in the tour cycle.

NOTE: Depending upon the re-entry conditions of the housing's exterior components (photosensors, wires, decals and fasteners), a decision will be made whether to replace some or all these components for display purpose.

(revision date: 29 July 201)

Appendix E: Project Imua Poster



Appendix F. Promotion and Recognition Ceremonies

Project Imua has garnered over 70 public relations reports, including newspaper and magazine articles, TV interviews, radio broadcasts and other promotion opportunities with a total estimated audience of more than 1 million people.

On 23 October 2015, the Project Imua team was recognized by Hawai‘i State Governor David Ige at the Governor's Office in the Hawai‘i State Capitol.

Appendix G. Project Imua Logo

Appendix H. Selected Photos