HASP Student Payload Application for 2012

Payload Title: High Altitude X-Ray Detector Testbed

Payload Class: (check one) ☑ Small ☐ Large	Institution: University of Minnesota Twin Cities	Submit Date: 12-16-11

Project Abstract

The engineering objective of the proposed experiment is to test and validate the performance of a compact x-ray detector and its associated communication and data-handling (C&DH) computer. The main science objective of the experiment is to characterize the background x-ray noise at the HASP flight altitudes. Payload construction and testing will be performed by Mr. Patrick Doyle as part of his Masters of Science thesis work. Undergraduate students will be recruited to volunteer on the project. The project has one principal investigator, Dr. Demoz Gebre-Egziabher, and one other faculty advisor, Dr. James Flaten. There are also two industry sponsors, Dr. Keith Gendreau from the Astrophysics Science Division at NASA – Goddard, and Dr. Suneel Sheikh, CEO and Chief Research Scientist at ASTER Labs, Inc. Current interface requirements include less than 15 watts of power and less than 1200 baud of downlink bandwidth. There will be minor modifications to the payload mounting plate in order to affix the payload to the plate. The payload will be designed to conform to CubeSat infrastructure standards. All data collected will be stored onboard.

Team Name: University of Minnesota	Team or Project Website: https://wiki.umn.edu/HASP/WebHome

	Student Team Leader Contact Information:	Faculty Advisor Contact Information:
Name:	Patrick Doyle	Dr. Demoz Gebre-Egziabher
Department:	Aerospace Engineering and Mechanics	Aerospace Engineering and Mechanics
Mailing Address:	University of Minnesota 107 Akerman Hall 110 Union St. SE	University of Minnesota 107 Akerman Hall 110 Union St. SE Minneapolis, MN 55455
City, State, Zip code:	Minneapolis, MN 55455	Minneapolis, MN 55455
e-mail:	doyle174@aem.umn.edu	gebre@aem.umn.edu
Office telephone:	612-624-1778	612-624-2305
Cell:	314-276-1944	
FAX:	612-626-1558	612-626-1558

1. Payload Description

The engineering objective of the experiment being proposed is to test and validate the performance of a compact x-ray detector and its associated communication and data-handling (C&DH) computer. The science objective of the experiment is to characterize the background x-ray noise at the HASP flight altitudes. The x-ray detector that will be tested is being developed by NASA-Goddard to support future space communication and navigation concepts of operations. The C&DH computer has been designed and developed by the University of Minnesota for use in small aerospace vehicles. Thus, the HASP flight will give flight heritage to the integrated system consisting of the current x-ray detector and C&DH computer designs. It is noted that the high altitude environment encountered during the HASP flight may not be as harsh or identical to the space environment for which x-ray detector and C&DH computers are ultimately being designed. However, it is believed that the process of building and testing the integrated system for the HASP flight will provide a realistic training scenario for students in the science and art of satellite engineering.

1.1 Background

The work described in this proposal is motivated by the idea of using celestial x-ray sources such as pulsars as beacons for deep space navigation. The impetus for this is that many envisioned future space missions will require spacecraft to have autonomous navigation capabilities. For missions close to Earth, Global Navigation Satellite Systems (GNSS) such as GPS are readily available for use. For missions far from Earth, however, other alternatives must be provided. While existing systems such as the Deep Space Network (DSN) can be used, latencies associated with servicing a fleet of vehicles may not be compatible with some autonomous operations requiring fast updates of the navigation solution.

Recent work has shown that variable celestial x-ray sources such as pulsars can be used as navigation beacons for determining the absolute position of space vehicles [1-9]. This approach is called x-ray navigation (X-NAV). Current X-NAV techniques are applicable to many deep space operations where GPS or other GNSS signals are unavailable or DSN tracking is not possible. While the current demonstrated accuracy of X-NAV is not at the level of GNSS, X-NAV is a nascent technology and it is reasonable to expect future increases in its accuracy. This increased performance will be the result of future improvements in sensors and navigation algorithms. The work described in this proposal is an effort in that direction. It deals with characterizing the performance of small and compact x-ray detectors currently under development [1]. Such detectors placed on envisioned future deep space vehicles could be used to generate an accurate navigation solution at low power levels while taking up little space.

1.2 Technical Challenge

Pulsars are excellent candidates for use as X-NAV beacons. This is because their signals can be used to provide time, range, and phase measurements — key parameters for navigation. It has been demonstrated that the stability of pulsar spin rates compares well to atomic clocks [4]. Furthermore, x-ray signals from pulsars have identifying profiles [5]. However, because the distance to even the closest pulsar is on the order of parsecs, the signal-to-noise ratio (SNR) of the received x-ray signals is small. The low SNR is due to, in part, the background x-ray noise in space. Current methods for detection of these low SNR signals rely on counting a bin number of photons in some known time interval or measuring the energy released by the photons upon striking a detector. Each method records specific peaks according to the pulsar's wavelength, thus allowing the source pulsar to be identified. This implies that accurate range or phase measurements require large x-ray detector areas, long signal collection times, or both. For example, it has been demonstrated that detectors with areas larger than 1 m^2 provide position accuracies that are acceptable for many space-based applications [4]. While detectors of this size can be used on larger space vehicles, they are impractical for smaller ones. The work described in this proposal attempts to characterize the background noise as seen a by small photon detector at altitudes above 30 km, add to the detector's flight heritage, and increase its Technology Readiness Level (TRL).

1.3 Hypothesis

Pulsars that have been investigated for x-ray navigation fall in the 2-10 keV range [1-9], whereas at ballooning altitudes only x-rays above 20 keV are available for detection due to atmospheric absorption [10]. Such energies may be unsuitable for navigation algorithms, but detection of photons at these energy levels still allows analysis of the SNR for small detectors to be performed. A small x-ray detector can also be used for attitude determination. The methods used are akin to using a star camera or tracker [9]. Thus, while characterizing the background x-ray noise and examining possible navigational x-ray beacons, it may also be possible to extract an attitude solution from the x-ray signal when compared to a known attitude solution.

1.3 Payload Systems and Principle of Operation

The payload will consist of a small x-ray detector, a communication and data-handling (C&DH) computer, onboard flash storage, attitude and navigation sensors (IMU and GPS), and a thermal protection system as shown in Figure 1 below. All power is provided by the HASP flight system.

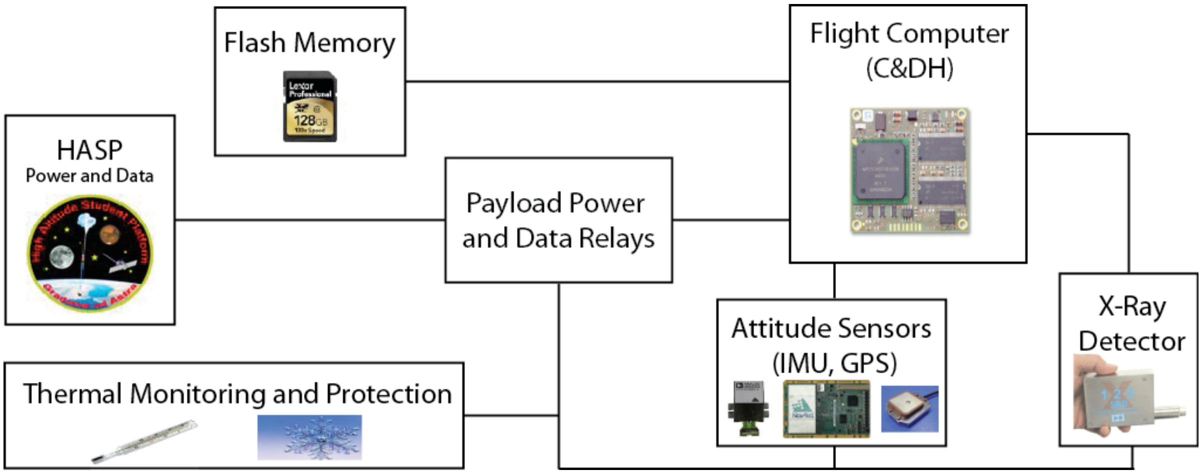

Figure 1. High-level payload system diagram.

The photon data (energy and photon counts) are processed through the C&DH computer and stored in the onboard flash storage for post processing. Included in the payload will be an onboard attitude determination system that uses an IMU/GPS package. The GPS signal will be provided using a Novatel OEMV-3G receiver modified for operation above 80,000 feet. An attitude solution can be obtained by combining angular rates from the IMU with the GPS position estimate. This package has been developed by the Uninhabited Aerial Vehicle (UAV) Research Group at the University of Minnesota, and has a proven flight heritage [13]. The data generated by the attitude determination system will also be placed in onboard storage through the C&DH for post processing.

Once HASP power operations begin, the payload will turn on and remain on while power is being provided through the EDAC 516 connector. It is anticipated that there will be no need to send commands during the flight because the detector will be passively viewing the x-ray sky. Thus a single power up command will be sufficient for payload operation. All data will be stored onboard the payload for post processing, but a periodic checksum will be sent by the C&DH computer to ensure that data collection is proceeding as planned. If the collection is not proceeding properly, then a reset command will be executed.

The interior volume of the payload will be insulated with poly foam or similar material. The temperature of the payload will be monitored and if it is found to be approaching an extrema of the operational range of any component, electrical resistance heaters will be activated or turned off accordingly. The ambient environmental temperature is assumed to be able to provide adequate radiative cooling to avoid reaching maximum operating temperature. Electrical resistance heaters or similar devices will be used to warm the payload as necessary, especially as it passes the tropopause during ascent. Current operational temperature requirements are expected to fall in the -20° C to 150° C range.

2. Team Structure and Management

The student team lead, advisors, and industry partners are shown in Table 1 below.

Student Team Lead	Patrick Doyle	University of Minnesota 107 Akerman Hall 110 Union St. SE Minneapolis, MN 55455	doyle174@umn.edu 314-276-1944
Faculty Advisor	Dr. Demoz Gebre-Egziabher Principal Investigator	University of Minnesota 107 Akerman Hall 110 Union St. SE Minneapolis, MN 55455	gebre@aem.umn.edu 612-624-2305
Faculty Advisor	Dr. James Flaten Assistant Director Minnesota Space Grant Consortium	University of Minnesota 107 Akerman Hall 110 Union St. SE Minneapolis, MN 55455	flaten@aem.umn.edu 612-626-9295
Project Consultant	Dr. Keith Gendreau Research Astrophysicist	NASA GSFC X-Ray Astrophysics Lab Mail Code 662.1 Greenbelt, MD 20771	keith.c.gendreau@nasa.gov 301-286-6188
Project Consultant	Dr. Suneel Sheikh CEO and Chief Research Scientist	ASTER Labs 155 East Owasso Lane Shoreview, MN 55126	sheikh@asterlabs.com 651-484-2084

Table 1. Mailing addresses, affiliations and contact information of key personnel.

The payload will be constructed by Patrick Doyle as part of his Masters of Science thesis work on x-ray navigation. Student participation will be managed by Mr. Doyle and will be offered to undergraduate volunteers. Mr. Doyle will provide weekly progress reports to Dr. Gebre-Egziabher and monthly status reports to the HASP program.

Dr. Flaten is supervisor for the University of Minnesota ballooning team and provides expert advice in balloon flight operations. Dr. Gendreau developed the x-ray detector package we will be using, and provides technical expertise in the integration of the x-ray detectors into the system. Dr. Sheikh is an expert in x-ray navigation and provides ongoing consultation in the development of this payload system. Funding is provided by the Minnesota Space Grant Consortium.

It is anticipated that Mr. Doyle and perhaps 2 undergraduate volunteers will participate in integration at CSBF and flight operations. It is unclear at this time if any advisors or mentors will be able to make the trip. Table 2 below shows the anticipated timeline and milestones for this project (milestones in bold).

Month of 2012	**Description of Work**
January	Hardware acquisition. Undergraduate recruitment. **Structure development and preliminary drawings.**
February-March	Wiring and fabrication of power regulation systems. **Electronics testing and power budget finalization.**
March-April	**Design of flight configuration.** Data format testing. Mounting, vibration and shock testing. **Final dimensioned mechanical drawings.**
April 20	**Preliminary PSIP document deadline.**
April-June	Full systems integration and software testing. **Construction of payload prototype** (completion anticipated in May, testing throughout June**).**
Mid – Late June	Payload testing at NASA/GSFC x-ray interferometer facility.
June 22	**Final PSIP document deadline.**
July	Finalize flight operations plan. Verify all systems go for launch.
July 27	**Final FLOP document deadline.**
July 30 – Aug. 3	**Student payload integration.**
August	Correct unforeseen issues found during payload integration
September	**Launch**

Table 2. Preliminary timeline.

3. Payload Specifications

The payload will be designed to conform to CubeSat infrastructure standards, based on one or more cubes with internal dimensions of 10 cm x 10 cm x 10 cm. A single cube is known as a 1-u, or unit volume, configuration. The payload will likely be a 2-u configuration due to x-ray detector and GPS receiver sizes as listed in Table 4. With an expected structure maximum thickness of 2.5 cm on top and bottom, the 2-u configuration is 25 cm high. The configuration falls within the HASP guidelines for a height of not more than 30 cm for the **small payload** classification. The CubeSat infrastructure supports several future envisioned X-NAV/HASP missions as well, including onboard x-ray attitude control and x-ray communications (X-COM). The anticipated mounting plate footprint is shown in Figure 2 while the preliminary payload structure drawing is given in Figure 4.

At this time there are no serial uplink or additional discrete commands anticipated for the payload. However, some downlink bandwidth will be required for system health monitoring. The serial port will be used to periodically communicate system health to the HASP platform for transmission, with a telemetry rate less than 1200 baud. However, the exact value is undetermined at this time. If the data received via the downlink indicates that data collection is not proceeding as planned, a reset command will be executed through the provided discrete channels by the ground station. The analog download interface is currently not expected to be used but may be incorporated for payload monitoring as construction of the thermal protection system progresses. All collected data will be stored for post-processing.

The C&DH computer, IMU, and GPS receiver and antenna listed in Table 3 have either been flown [13] or tested at the University of Minnesota. The Novatel OEMV-3G GPS receiver that is anticipated to fly on HASP can be modified to remove CoCom restrictions. The University of Minnesota has done these modifications in the past as part of an AFOSR sponsored project. The high altitude capabilities will be tested and verified on a Spirent GSS7700 GPS simulator or similar before operation at HASP flight altitudes.

Procedures at integration are anticipated to include testing that the payload interfaces with HASP are set up properly, that power is being delivered, and that the payload collects, transmits, and stores data without issue. Thermal response of the payload enclosure to near vacuum down to -100°C will then be tested. If the insulation and heaters are able to keep the payload enclosure above -20°C then the remaining components will be placed within the payload and tested to ensure flight readiness. It is also anticipated that vibration and shock testing will be conducted during integration. Assuming success at integration, procedures at flight operations are anticipated to consist solely of making sure the payload is connected properly, but will otherwise be ready to fly.

3.1 Payload Weight and Power Budget

The payload will use the EDAC 516 connector to provide power to all systems. Voltage will be regulated and distributed according to each system's power requirements and its maximum current draw allowed.

Expected hardware components and their power and weight budgets are given in Table 3 below. Note that thermal protection is specified as a complete system and has yet to be determined component-wise. Structural components include outer thermal insulation, mounting nuts and bolts, and any mounting brackets remaining to be designed. Both structural and thermal components are largely unknown at this time and are thus given a large amount of uncertainty compared to other known hardware components. Both power and weight uncertainties meet the specifications of +30 VDC at 0.5 amps (15 Watts) and 3 kg respectively for the small payload classification.

3.2 Payload Location and Orientation

The experimental goals are independent of physical location on HASP but the x-ray detector must be facing outwards as indicated on Figure 5. Thus any small payload location is suitable but the x-ray detector must be oriented such that it is pointing away from the main HASP payload.

	Mass (g)	Mass Uncertainty (g)	Power (W)	Power Uncertainty (W)
C&DH Computer 32-bit PowerPC Phytec MPC5200B-tiny SoM [11]	200	50	2.0	0.2
X-Ray Detector AMPTEK X-123SDD [12] or similar device	200	50	2.5	0.2
IMU Analog Devices ADIS16405 [14] or similar	20	5	0.5	0.2
GPS Receiver / Antenna Novatel OEMV-3g [16] / San Jose Technology SA-60C [16] or similar	105	5	2.5	0.5
Thermal Protection	500	100	5.0	1.0
Structural Components	1000	700	-	-
TOTAL	2025	910	12.5	2.1

Table 3. Mass and power budget.

4. Preliminary Drawings

Included below are drawings and figures for the mounting plate footprint (Figure 2), anticipated mounting plate modifications (Figure 3), a sketch of the mounting structure (Figure 4), desired payload location and orientation (Figure 5), flight computer (Figure 6), IMU (Figure 7), GPS Receiver (Figure 8), GPS antenna (Figure 9), and an x-ray detector similar to that which will be provided by NASA/GSFC (Figure 10). A table of component dimensions is also provided in Table 4.

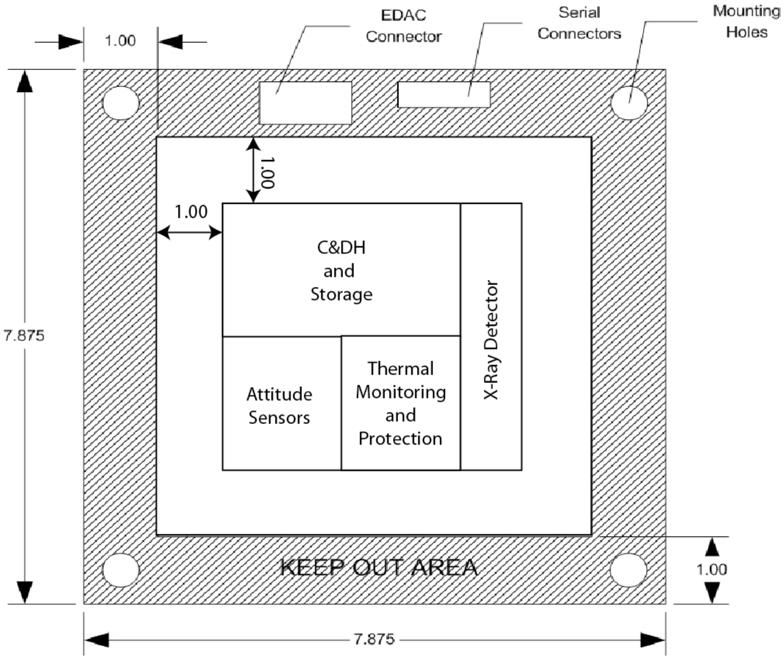

Figure 2. Anticipated mounting plate footprint. There are one-inch margins left for thermal poly foam protection around the CubSat infrastructure. This drawing is contingent on volumetric space allocation and is subject to change accordingly.

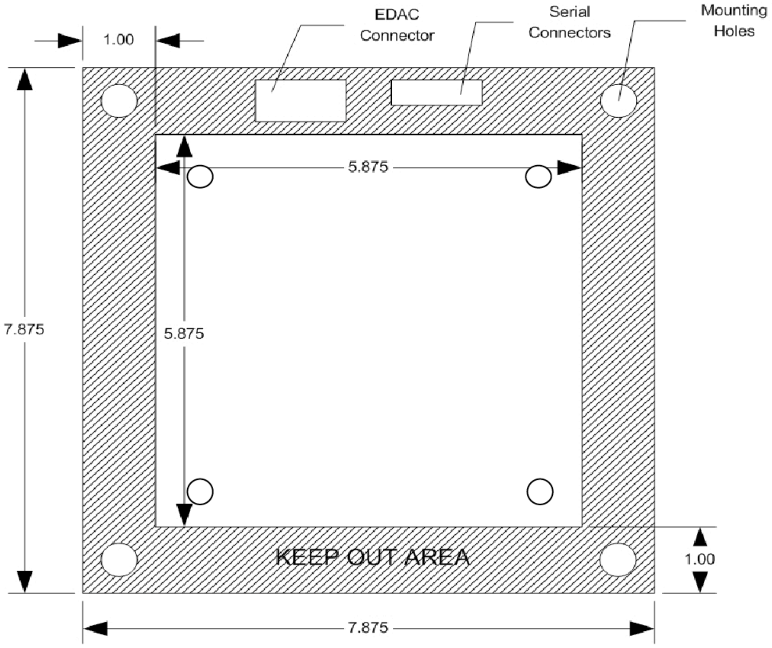

Figure 3. Anticipated modifications to the mounting plate. Holes will be drilled to affix payload structure to mounting plate. The holes will be offset from each edge by about 2.5 cm (subject to change due to structural uncertainties in insulation thickness at this time). These anticipated holes are not shown to scale.

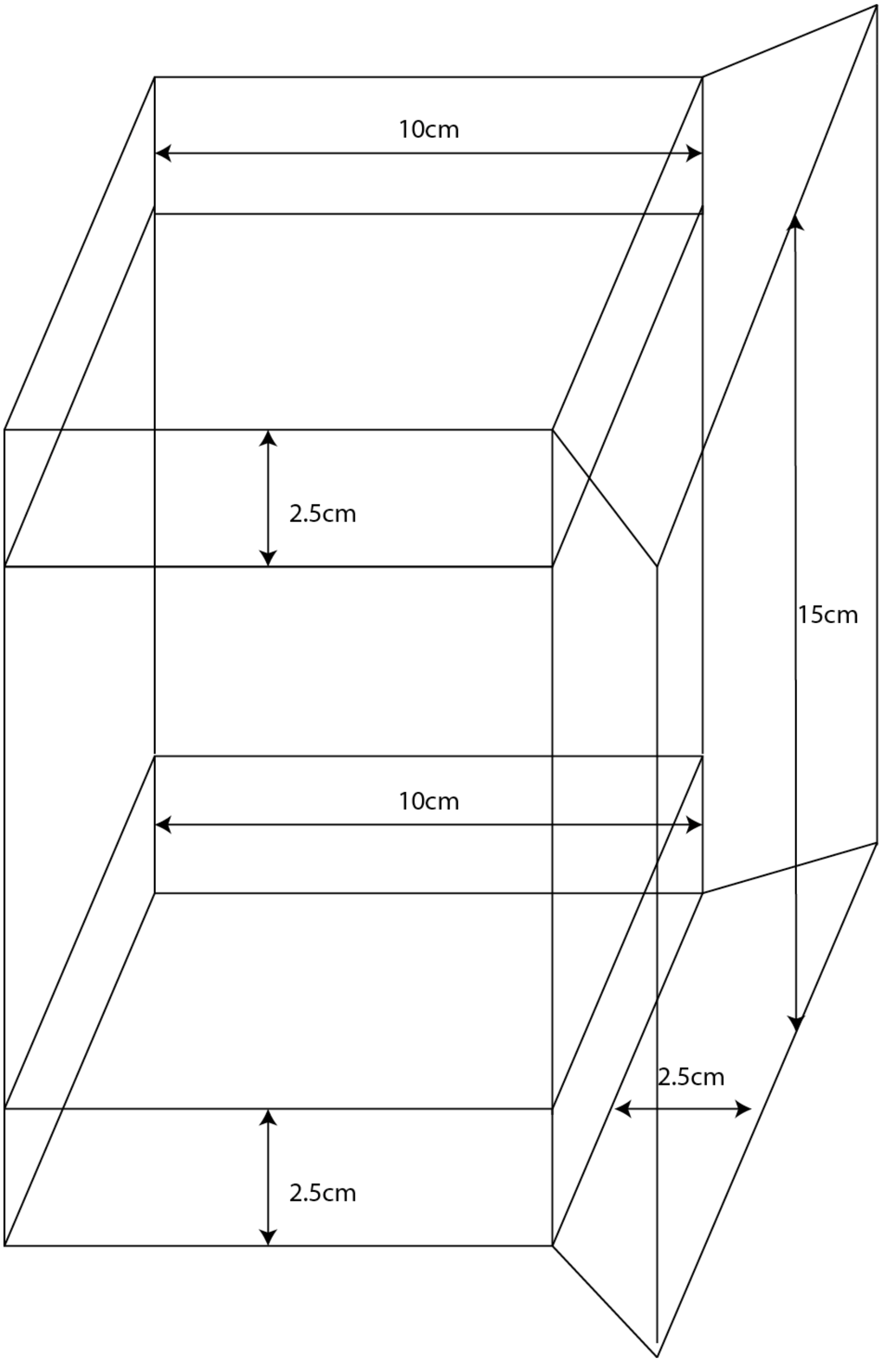

Figure 4. Preliminary sketch of mounting structure (not to scale). Shown is a 1-u configuration. For the 2-u configuration, the 10 cm interior height will double to 20 cm, thus raising the height to 25 cm instead of the 15 cm shown. Only one face of the outer wall is shown while there will be 4 walls and the top as shown to enclose the payload. The outward-pointing side will have an opening for the x-ray detector's photon collector. A GPS antenna will also be mounted on the exterior of the structure. The outer dimensions for the 1-u configuration as shown are 15 cm x 15 cm x 15 cm.

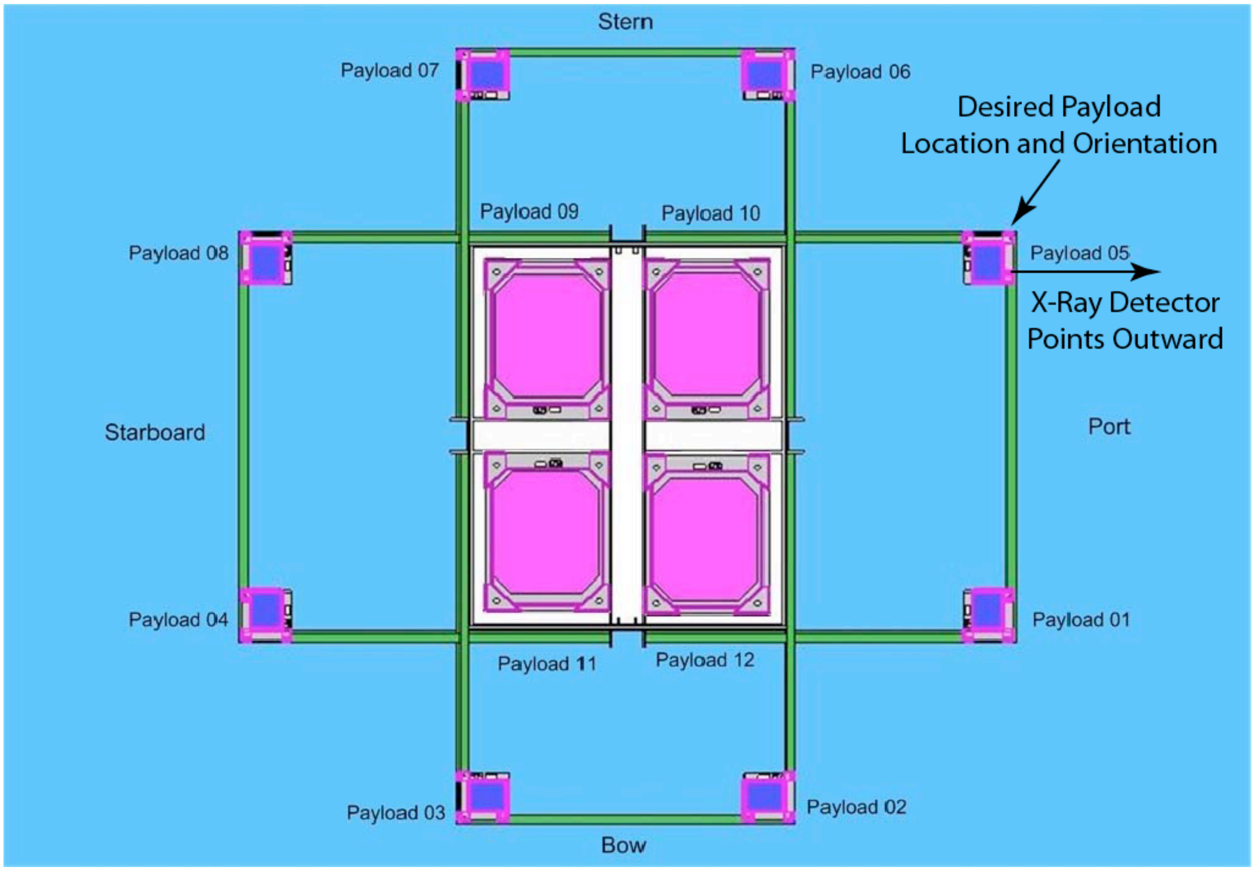

Figure 5. Desired payload location and orientation on HASP. Any small payload location is acceptable as long as the x-ray detector points away from the main HASP payload body.

Figure 6. Flight computer (32-bit PowerPC Phytec MPC5200B-tiny SoM [11]).

Figure 7. IMU (pictured is Analog Devices ADIS16405).

Figure 8. Novatel OEMV-3g GPS receiver [15]. Altitude CoCom restrictions will be removed.

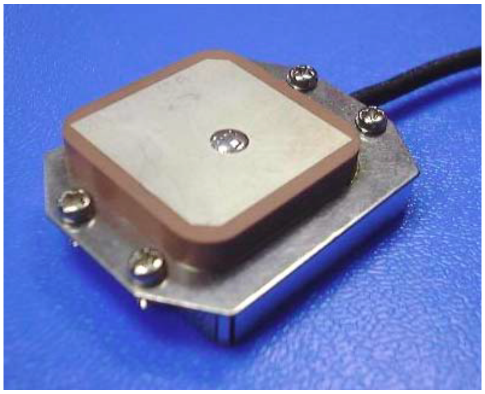

Figure 9. GPS antenna (San Jose Technology SA-60C [16]).

Figure 10. Amptek X123SDD Complete X-Ray Spectrometer with Silicon Drift Detector [12]. The size of this detector is comparable to that which may be provided by NASA/GSFC.

	Length (cm)	Width (cm)	Height (cm)
C&DH Computer and Storage	5.0	5.0	1.0
X-Ray Detector	10	2.5	7
IMU	2.3	2.3	2.3
GPS Receiver	8.5	12.5	17
GPS Antenna	2.9	3.8	1.05

Table 4. Main component dimensions.

References

1. "Next Generation Communications." NASA Goddard Space Flight Center tech sheets, http://gsfctechnology.gsfc.nasa.gov/TechSheets/XRAY_Goddard_Final.pdf
2. Ray, Paul S., et al, "Deep Space Navigation Using Celestial X-ray Sources." ION NTM, 2008, San Diego, CA.
3. Sheikh, Suneel I., et al, "Relative Navigation of Spacecraft Utilizing Bright, Aperiodic Celestial Sources." ION 63rd Annual Meeting, 2007, Cambridge, MA.
4. Sheikh, Suneel I., et al, "Spacecraft Navigation Using X-Ray Pulsars." *Journal of Guidance, Control, and Dynamics*, Vol 29, No 1, 2006.
5. Sheikh, Suneel, I., et al, "Absolute and Relative Position Determination Using Variable Celestial X-Ray Sources." 30th Annual AAS Guidance and Control Conference, 2007, Breckenridge, CO.
6. Graven, Paul, et al, "X-NAV Beyond the Moon." ION 63rd Annual Meeting, 2007, Cambridge, MA.
7. Sheikh, Suneel I., "The Use of Variable Celestial X-Ray Sources for Spacecraft

Navigation." Department of Aerospace Engineering, University of Maryland, Ph.D. thesis, 2005.

8. Woodfork, D. W. "The Use of X-ray Pulsars for Aiding GPS Satellite Orbit Determination." Department of Electrical and Computer Engineering, Air Force Institute of Technology, Master of Science thesis in Astronautical Engineering, 2005.
9. Hanson, John, et. al, "Noise Analysis for X-Ray Navigation Systems." IEEE-ION PLANS, May 2008.
10. Peterson, L.E., et. al, "Techniques in Balloon X-Ray Astronomy." Space Science Reviews, 13:320-336, 1972.
11. Phytec, MPC5200B microcontroller datasheet. URL: http://www.phytec.com/products/sbc/PowerPC/phyCORE-MPC5200B-tiny.html
12. AMPTEK X-123SDD Complete X-Ray Spectrometer with Silicon Drift Detector. URL: http://www.amptek.com/x123sdd.html
13. University of Minnesota, UAV Research Group. URL: http://www.uav.aem.umn.edu/
14. Analog Devices ADIS16400/16405 datasheet. URL: http://www.analog.com/static/imported-files/data_sheets/ADIS16405.pdf
15. Novatel OEMV-3 datasheet. http://www.novatel.com/assets/Documents/Papers/OEMV3.pdf
16. San Jose Technology, Inc., SA-60C datasheet. URL: http://www.sanav.com/gps_antennas/gam/sa-60c.htm

December 12, 2011

Dr. Demoz Gebre-Egziabher
Department of Aerospace Engineering & Mechanics
University of Minnesota,
110 Union St. SE
Minneapolis, MN 55455

Dear Dr. Gebre-Egziabher:

I am writing this letter to document the discussions we had in November 2011 regarding the potential support the Astrophysics Science Division of NASA Goddard Space Flight Center (NASA/GSFC) would provide for your upcoming proposal for an experiment to fly on the High Altitude Student Platform (HASP). We understand the proposal will be to build, test, and validate the performance of a compact X-ray detector and its associated communication and data-handling (CDH) computer. The X-ray detector proposed for this test is one designed and developed by NASA/GSFC. As we indicated in the discussions, we strongly support this proposed mission. Furthermore, if awarded, we are prepared to provide prototype X-ray detector designs that will be incorporated as payload of the HASP experiment.

NASA/GSFC has been developing a Modulated X-ray Source (MXS) and an associated X-ray detector for potential use as space communication link. Communication via X-rays offers significant advantages to both civilian and military space programs. It has the potential to provide high-data rates (several gigabits per second) at low power over vast distances in space. As such, it is ideally suited for small satellite applications where the size, geometry, weight, and power constraints are severe. In addition, such a communication system could penetrate RF shielding on the ground and communicate with hypersonic vehicles during that short period of time when the build-up of heat along a vehicle's surface during reentry blocks traditional RF communication signals. Initial testing of MXS began in 2007 and in the intervening years its Technology Readiness Level (TRL) has increased significantly. It is currently at a point where it could be integrated into a small satellite on the size scale of a Micro- or Nano-satellite. Therefore, the balloon mission you are proposing is a logical next step increasing the TRL of the detector for MXS, possibly followed in future years by balloon-borne testing of the full system. The MXS will be vital to many future NASA missions. We believe it will be vital to for many Department of Defense envisioned satellite applications as well.

In pursuing this collaboration, no funds will be exchanged between the University of MN and our laboratory. We see our collaboration with the University of Minnesota in pursuing the proposed HASP mission progressing as follows: As noted above, we will provide either a prototype X-ray detector, or the design of the detector we have developed. If the latter, we will also provide mentoring and advice while the University of Minnesota builds its own X-ray detector using our designs. In either case, we are aware that the primary purpose of your effort is student training and, as such, students must do the majority of the design and development work. Thus, while we are willing to provide some technical assistance and consultations on how to operate and integrate the detector into the CD& H computer (if required), we will not participate in the day-to-day (or week-to-week) activities of the design group. We will primarily assume the role of the "customer payload" of the mission. As such, we are willing to participate in periodic design reviews.

Finally, we would like to point out that one of the overarching goals of NASA/GSFC is outreach, which may take the form of student training and mentoring. We would, therefore, like to use this particular HASP mission to complement student aerospace hardware projects and outreach activities already going on in the Aerospace Engineering and Mechanics (AEM) Department at the U of MN, especially projects sponsored by NASA's Minnesota Space Grant Consortium (coordinated for the whole state out of the AEM Department). We also see potential for arranging future student internships at NASA/GSFC for U of MN students who become involved in this new HASP project.

In summary, NASA/GSFC supports the University of Minnesota's proposed HASP mission. If the proposal submitted is successful in being selected, we look forward to working with the University of Minnesota in developing a payload to test and validate NASA GSFC's X-ray detector technology.

Sincerely,

Dr. Keith Gendreau,
NASA/GSFC
Astrophysics Science Division
Greenbelt, MD 20771

ASTER LABS

12 December 2011

Dr. Demoz Gebre-Egziabher
Department of Aerospace Engineering & Mechanics
University of Minnesota
110 Union St. SE
Minneapolis, MN 55455

Subject: *High Altitude Student Project (2012)* Proposal Support

Dear Dr. Gebre-Egziabher;

I am writing this letter to document our support for your proposal being submitted to the High Altitude Student Project (HASP) 2012 cycle. To this end, Advanced Space and Technology Research Laboratories, Inc. (ASTER Labs) will work with the University of Minnesota to define methods by which we can collaborate to advance the objectives of the work identified in the above proposal.

As you know, ASTER Labs has been on the forefront of developing technologies for utilizing X-ray sources as range and range-rate measurements for navigation in space. In collaboration with DARPA and other industry partners we have performed extensive studies to evaluate the use of X-rays as communication channels for navigation and ranging applications. In this regard, for example, we have designed a system that will allow using natural X-ray sources, such as pulsars, as beacons for deep space navigation (US Patent No. 7,197,381 and 7,831,341). We believe this approach to navigation will be a new mission enabling technology for many future space applications, including hypersonic and ballistic flight vehicle communications and spacecraft formation flying. However, there is much more work required before an actual system like this can be fielded and we believe that your proposed HASP experiment is one of many crucial steps in this direction. At a minimum, it will provide a vehicle by which the NASA/GSFC compact (i.e., small size, weight and power consumption) X-ray detector designs can be tested and validated in an environment that is close to the final space environment in which it will be used. This will give the existing detector design flight heritage and, thereby, increase its Technology Readiness Level.

In view of this, if your above mentioned proposal is successfully awarded, ASTER Labs is prepared to work with you and your students in designing and developing a HASP payload to accomplish this mission. At a minimum, we are willing to participate in design reviews and consult on issues that may arise as you integrate the X-ray detector into the HASP payload. We are also prepared to provide in-kind support in terms of algorithms and software related to using, evaluating, and testing data collected by the X-ray detector.

We look forward to working with the University of Minnesota in advancing the state-of-art of X-ray navigation and communication as well as training the next generation of engineers that will be developing and fielding these technologies.

Sincerely,

Suneel I. Sheikh

Suneel I. Sheikh Ph.D.
CEO & Chief Research Scientist

ASTER Labs, Inc.
155 East Owasso Lane, Shoreview, MN 55126-3034
Tel: 651-484-2084 Fax: 651-484-2085 www.asterlabs.com