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The Cosmic X-Ray Background NanoSat (CXBN): Measuring the Cosmic X-Ray Background Using the CubeSat Form Factor

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ABSTRACT

The CXBN mission goal is to significantly increase the Cosmic X-Ray Background measurement precision in the 30-50 keV range. The mission addresses a fundamental science question central to our understanding of the structure, origin, and evolution of the universe by potentially lending insight into the high energy background radiation. The CXBN spacecraft will map the Extragalactic Diffuse X-Ray Background (DXRB) with a new Cadmium Zinc Telluride (CZT) detector. The DXRB measurement will pose a powerful tool for understanding the early universe and a window to the far-away universe.

The science objectives were condensed into a novel spacecraft concept characterized by a sun-pointing, spinning spacecraft in LEO with moderate inclination. Launch trajectories allow four nominal passes per day over the primary Earth station at Morehead State University (Morehead, KY). The science mission requirements fortunately allow adoption of the economical CubeSat form factor. The major subsystems comprising the satellite are new — having been developed by the team. Innovative systems include power distribution, command and data handling, and attitude determination and control systems.

The launch is scheduled for August 2012 from Vandenberg AFB through the NASA ELaNa program. CXBN was developed at low cost and on a highly constrained 12 month timeline.

INTRODUCTION

The Cosmic X-Ray Background Nanosatellite (CXBN, Figure 1) is a small satellite mission with the objective to make precise measurements of the cosmic/diffuse X-ray background.[1] The project is based on a low-cost CubeSat form factor and was accepted by NASA's Educational Launch of a Nanosatellite (ELaNa) program for a launch opportunity in 2012. NASA ELaNa is managed by the Launch Services Program to provide secondary payload launch opportunities for science research and technology demonstrations.[2]

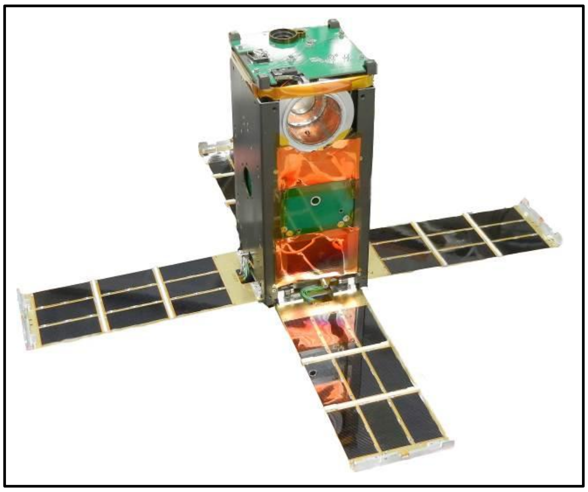

Figure 1: CXBN Flight Unit

The mission team led by PI Malphrus, Project Scientist Jernigan, Project Engineer Brown, and Student Team Lead Rose, consists of members of the following US institutions:

- MSU (Morehead State University), Morehead, KY
- UCB (University of California at Berkeley), Berkeley, CA
- Noqsi Aerospace, Ltd., Pine, CO
- LLNL (Lawrence Livermore National Laboratories), Livermore, CA
- SSU (Sonoma State University), Rohnert Park, CA

CXBN is designed to make measurements of the diffuse X-ray background with a gamma ray detector system based on a CZT (Cadmium Zinc Telluride) array. These measurements have the potential to provide insight into underlying physics of the early universe. The scientific goals, satellite and its subsystems, the concept of operations, ground operations strategies and launch and mission operations plans are described in this paper.

SCIENCE MISSION GOALS

X-ray sky measurements dating back to the 1960s, using sounding rockets, revealed a surprising cosmic background glow of X-ray emission. Subsequent measurements using a variety of platforms, including high altitude balloons and on-orbit X-ray astronomy telescopes revealed many discrete cosmic sources and an unresolved, diffuse background radiation field. In subsequent decades, the sensitivity of detectors increased and the ability to focus X-rays evolved—allowing direct imaging of the discrete X-ray emission associated with celestial objects. Although most types of the discrete, resolved X-ray sources are fairly well understood, astronomers have struggled to understand the origin of the diffuse cosmic X-ray background (DXRB).[3] Despite the enormous observational progress that modern X-ray detectors and telescopes have brought to the study of the DXRB since the emergence of X-ray astronomy, its origin is still uncertain. Ultimately, the energy density of the X-ray sky is dominated by diffuse radiation which is mostly of cosmic origin. The primary scientific issue motivating this mission is to determine the flux of the extragalactic diffuse x-ray background (DXRB) in the hard x-ray band.

The isotropy of the DXRB greater than 3 keV strongly suggests that it is extragalactic. The DXRB in this range is thought to be composed of a very large number of discrete sources. At soft x-ray energies, the nature of these sources is known, namely faint active galactic nuclei (AGN). However, theoretical attempts to synthesize the DXRB spectrum at hard x-ray energies from an AGN population have not been very successful. Part of the difficulty is that the existing measurements are inconsistent with each other, and the one widely considered "best" (made with the A4 instrument on HEAO-1) does not match other measurements.

The hard x-ray band is key to understanding the DXRB because the bulk of the energy is found over this range. The DXRB flux peaks at ~30 keV, so our measurements in the 30-50 keV range cover the peak of the power spectrum. At these energies, genuinely diffuse Galactic emission is small but bright point sources in our galaxy and in the Magellanic Clouds are potential contaminators. The best-measured component of the DXRB spectrum is the 3-300 keV band (i.e. 4-0.04 Å). The HEAO-1 A2 experiment provided the best measurements to date from 3 to about 45 keV. Using archival Swift X-Ray Telescope data Moretti et al. in 2008 produced a new measurement in the 1.5-7 keV band.[4] An analytic description of the DXRB spectrum over a wide (1.5-200 keV) energy band also resulted from this work. Their model was somewhat consistent with HEAO-1 measurements at 20 keV and higher but 30% higher at low energies (2-10 keV).

The goal of this mission is to create a precise set of CXRB measurements in the 30-50 keV range, thereby constraining models. X-ray spectrum investigations necessitate using space platforms because of the severe attenuation in this frequency range by the Earth's atmosphere. The CXBN will map the Extragalactic Diffuse X-Ray Background with a new breed of Cadmium Zinc Telluride detector. The DXRB measurements will be a powerful tool for understanding the early universe and provides a window to the most energetic objects in the far-away universe.

Specifically, the key goals of the CXBN mission are to:

- Increase the precision DXRB measurement in the 10-50 keV range
- Produce data that will lend insight into underlying physics of the DXRB
- Provide flight heritage for innovative CubeSat technologies
- Provide flight heritage for CZT based X-Ray/Gamma Ray detectors

GEANT4 payload simulations have been performed to determine background rejection and count rates expected on-orbit. These simulations, along with a detailed CZT array description, the detailed science objectives, and initial science data will be presented in a companion paper devoted to CXBN science.^{5}

CONCEPT OF OPERATIONS

The CXBN spacecraft is a 2U CubeSat form factor with a launch size of 10 cm x 10 cm x 20 cm and a mass of 2.4 kg. The concept of operations is summarized as a sun-pointing spacecraft that spins about its Z-axis at 1/6 Hz. Rotation about the Z-axis serves two purposes: 1.) to spin stabilize the satellite and 2.) to facilitate full sky coverage by the science array. The spin rate, along with precession and nutation control, is provided by an ACS system utilizing 3-axis magnetorquers.

The spacecraft will spin about the sun pointing axis, allowing the detector to sweep out its Field of View (FOV) over 360 degrees with each rotation. A study was performed to determine the appropriate detector FOV on the sky and resulting detector collimator design. A FOV of approximately 36° was determined to be ideal. If the FOV is too small, insufficient signal to noise is achieved for weak flux detection. If the FOV is too large, multiple discrete sources would contaminate the data.

As the spacecraft spins, the CZT sweeps the field of view on the sky and, over the course of months will observe the entire sky. Figure 2 illustrates the spacecraft concept of operations. The data is collected and stored on-board and transmitted to a dedicated Earth station at Morehead State University where it will be calibrated, reduced, and analyzed. Discrete sources (X-ray galaxies, X-ray binaries, active galactic nuclei, and pulsars) will be subtracted along with extended sources (the Earth, moon, nearby galaxies) to produce a dataset of the diffuse X-ray background.

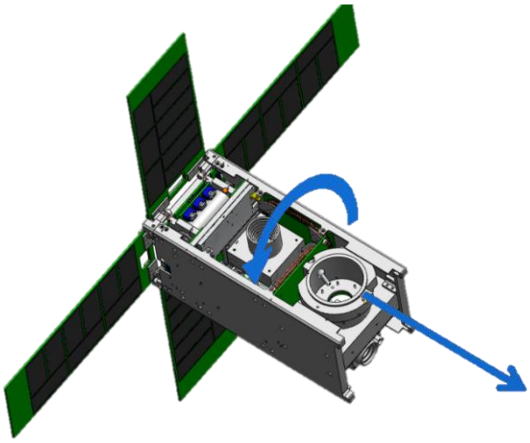

Figure 2: CXBN Concept of Operations

Data collected near the Earth's polar regions and within the South Atlantic Anomaly are expected to be contaminated by trapped particles and secondary gamma rays created as these particles interact with the spacecraft structure. When conservatively estimating the spacecraft to be over the equatorial regions for 10% of the time, ~1 year of operating the science array results in 3 million seconds of good data. A broadband S/N ~250 can be achieved during this time frame. It is expected that the data will reach systematic limits after ~ 16 months of operation. If the goal of S/N of 250 can be achieved for full sky coverage, the mission will lead to significantly increased precision in the DXRB flux in this range. CXBN's goal for measuring flux is less than 5% accuracy.

SPACECRAFT

Overview

The science mission requirements are well suited to a small spacecraft, making this mission ideal for the CubeSat form factor. All of the major subsystems comprising the satellite were designed, built, and tested in-house at the Morehead State Space Science Center.

The spacecraft contains all the necessary subsystems to meet the innovative mission and comply with the internationally-accepted CalPoly CubeSat standards. The bus structures and systems have been ground test proven for the CXBN ELaNa mission and numerous subsystem derivatives have flown on other missions. The heritage systems include: power, communications, attitude determination and control, and bus command and data handling. The spacecraft bus specifications are provided in Table 1. The result from the innovative, yet proven systems is an ideal platform for accomplishing science objectives. A brief description of each of the primary subsystems is provided below.

Table 1: CXBN Spacecraft Bus Specifications

Parameter	***Value***
Launch mass:	2.4 kg
Payload Mass Capability:	1.0 kg
Payload volume:	1.0 U
ADCS	±2.0˚
Payload Power Required:	5W (peak), 3.8 W (OAP)
Prime Power Generated	15 W continuous
Voltages Available to Payload:	600V, 5V, 3.3 V
Dynamics	Sun, Star pointing
Max. Sustainable Current	2.5A @ 5V 1.5A @ 3.3V
Downlink Data Rate	9.6-38.4 kbps
Beacon	CW, 0.1 to 2.5 W
Spacecraft Operational Lifetime:	> 1 year

Structure

The 2-U CubeSat Bus structure is formed by two robust walls matched to a central mounting block. Subsystem enclosures and braces reinforce the structure throughout the length of the body, allowing the frame to hold very tight tolerances. This design provides the rigidity required to maintain integrity during vibration. The structure is also simple to manufacture and assembles easily during test and integration. Additionally, the open-sided concept (shown in Figure 3) provides easy access to subsystems for wiring, improves thermal control, and is designed to meet NASA spacecraft venting standards.

The structure is composed of Aluminum 6061-T6 with a Type III Hard Anodized frame. It serves as a chassis to accommodate a monofilament cutter system that retains four deployable solar panels and blade antennas in the stow configuration. The structures and cutter system also control the deployment in compliance with the NASA LSP secondary payload deployment restrictions.

The entire spacecraft passed environmental testing (including vibe and T-VAC) at 6 dB above the NASA GEVS standards. The MSU CubeSat structure design has consistently proven to survive without deformation or loss of component integrity and to maintain compliance with the CubeSat standard.

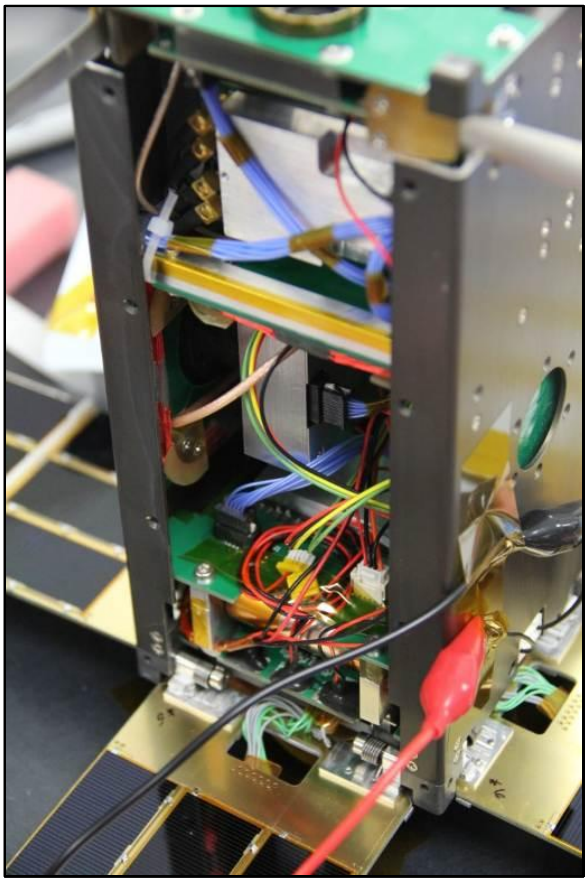

Figure 3: CXBN Flight Model Uses an Open-Sided Structure to Provide Structural Stability and Accessibility to Internal Subsystems

Power Management and Distribution

The electrical power system consists of 4 deployable solar panels for energy generation, 4 lithium ion batteries for energy storage, and a power management and distribution system (PMAD) shown in Figure 4. 36 triple-junction 26% efficient solar cells are utilized on the solar panels which are covered by a protective coating of a proprietary polyimide shown in Figure 5. The PMAD is an innovative, expandable, direct energy transfer system that employs shunt regulation for charging and battery protection. The four Lithium Ion batteries are configured in a 1S4P pack. The power system contains its own dedicated MSP430 processor that supports the ability to be re-programmed during flight.

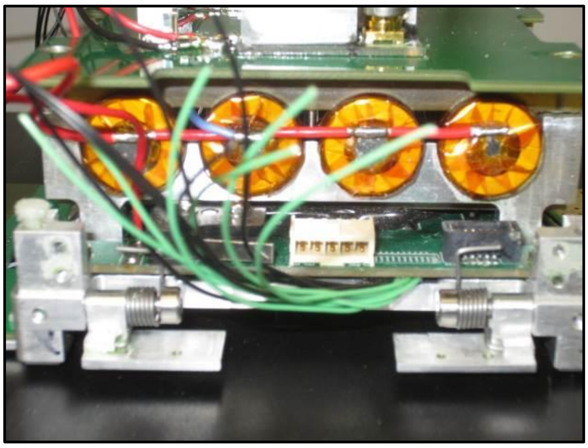

Figure 4: CXBN Power Management and Distribution System

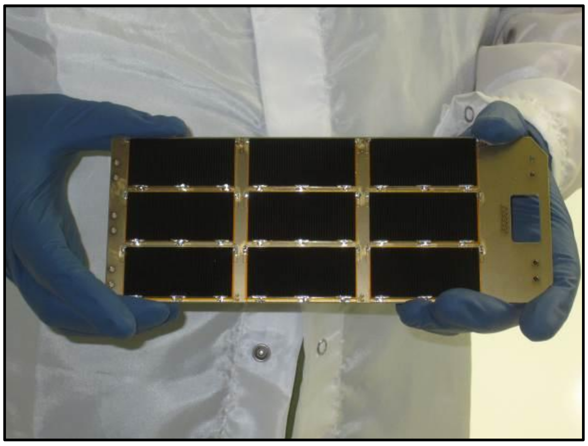

Figure 5: CXBN Deployable Solar Panel

The MSU PMAD is configured with all necessary features to accommodate the mission profile. Simulations show that only 4 orbits are required to fully re-charge the battery pack after 10 minutes of continuous operation of all spacecraft systems (a condition which is not expected to occur). The energy storage architecture will accommodate the science mission operational phases as well as spinning maintenance, and radio transmission during low elevation contacts with significant margin. Main features of the PMAD are provided below in Table 2.

Table 2: CXBN Spacecraft Bus Specifications

Power Generation
▪ Spacecraft point to illumination
▪ 4x deployable solar panels @ 90°
▪ ~15W continuous after sun acquisition
▪ 9 cells per panel – 3 strings of 3 cells
Power Storage
▪ 4x Molicel Lithium Ion 18650 batteries
▪ 1S4P configuration: 8.4V @ 8800 mAh
▪ 18 mm dia. X 65 mm long
▪ Battery protection circuitry
Power Management and Distribution
▪ Direct Energy Transfer system
▪ Shunt regulation for charging
▪ 3.3V, 5V, and 600V
▪ Raw battery voltage available
▪ Maximum sustainable current**
o ~2.5A @ 5V
o ~1.5A @ 3.3V
▪ RBF and Deployment Switch circuitry
▪ Dedicated MSP430
▪ BSL permits reprogramming in flight

Command and Data Handling

The flight computer C&DH system onboard the CXBN spacecraft is responsible for commanding and monitoring all spacecraft subsystems and for commanding and monitoring the payload. The MSU C&DH is designed specifically to work with microprocessor-controlled payloads. The C&DH is based on the Texas Instruments MSP430F543xA series microcontroller. The RISC 16-bit CPU is designed for low cost and, specifically, low power consumption embedded applications. The advantage of this C&DH architecture is its commonality with terrestrial systems and capability to operate at full specification without consuming significant amounts of power.

The MSP430 on the C&DH has a 25 MHz clock rate and 256 KB of flash. It utilizes independent 16-bit timers for task synchronization. The C&DH breaks out into four UART and SPI interfaces and has expandable flash chips (96 Mb utilized for this mission). Another significant factor in the adoption of the processor was its internal bootstrap loader (BSL) that permits reprogramming in flight and provides entry to other systems' BSLs. The BSL feature significantly mitigates risk by accommodating on-orbit software upgrades of the spacecraft and payload flight software. An overview of the C&DH and communication interfaces on CXBN is illustrated in Figure 6.

The payload interface is a combination of analog to digital and digital capture circuitry to support X-Ray energy level capture. The interfaces required a dedicated MSP430 processor to control the timing and mode operations of the payload.

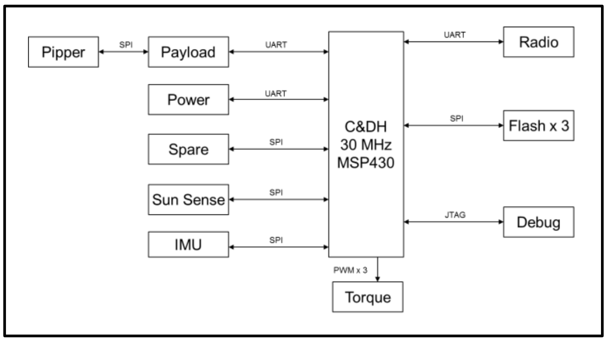

Figure 6: CXBN C&DH Communication Interface Diagram

Attitude Determination and Control

At the systems level, mission objectives define the attitude determination and control systems (ADCS). The unique mission of CXBN can collect scientific data through a spin-stabilized configuration. Multiple sensors were used on CXBN to produce orientation knowledge. Previous CubeSats have favored magnetometers, sun sensors, MEMS gyroscopes, and star constellation trackers for scientific attitude knowledge. The added complexity and development can overrun a short program effort. For CXBN, a novel method was sought to reduce system complexity while maintaining reliability and schedule.

The result is a combination of MEMS gyros (Figure 9) and a star sensor (‘pipper’) to generate an absolute position pulse as a star transits the viewing area. After stabilization the combination of these two systems allows one to back out the roll orientation when clocked from a common time reference.

The basic concept is characterized by the spacecraft entering a slow spin that is controlled with 3 magnetic torquers, shown in Figure 8. Using magnetometers, the torque coils are actuated in proper sequence to maintain the angular momentum vector in alignment with the sun vector, minimizing the sun angle. The sun angle is measured using a dual Sun sensor (DSS), shown in Figure 7, along the -Z spacecraft face.

The spacecraft also deploys four solar panels with weighted ends at a 90° angle relative to the X-axis providing better body inertial properties. The ADCS system is estimated to provide pointing control to 2° Specifics of the ADCS system are provided below in Table 3.

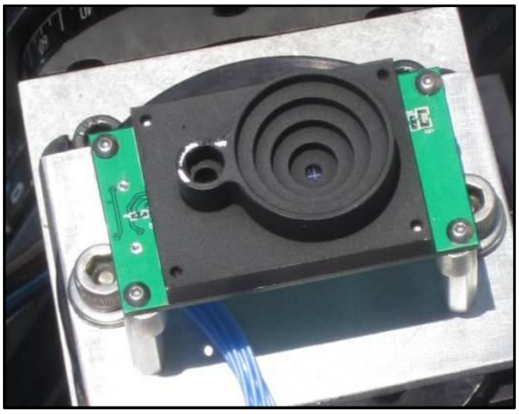

Figure 7: CXBN Dual Sun Sensor

Table 3: ADS and ACS Systems

Determination:
▪ Dual Sun Sensor (DSS) system
○ Dedicated MSP430
○ Power consumption: less than 500 mW
○ Quadrature photodiode system
○ Pitch and yaw knowledge when sun-pointing
○ Medium Sun Sensor (45° half angle)
▪ Tri-Axis Accelerometers
○ Dynamic Range: ±18 *g*
○ Sensitivity: 3.33 m*g*/LSB
▪ Tri-Axis MEMS Gyroscopes
○ Dynamic Range: ± 75, 150, or 300 °/s
○ Sensitivity: 0.0125, 0.025, or 0.05 °/s/LSB
○ Average power consumption: 2.5W
▪ Tri-Axis Magnetometers
○ Dynamic Range: ±3.5 gauss
○ Sensitivity: 0.5 mgauss/LSB
Control:
▪ 3x Magnetic torque coils
○ Driven from C&DH via PWM signal
○ Helmholtz coil measurement at construction
○ Average power consumption: 2.5W

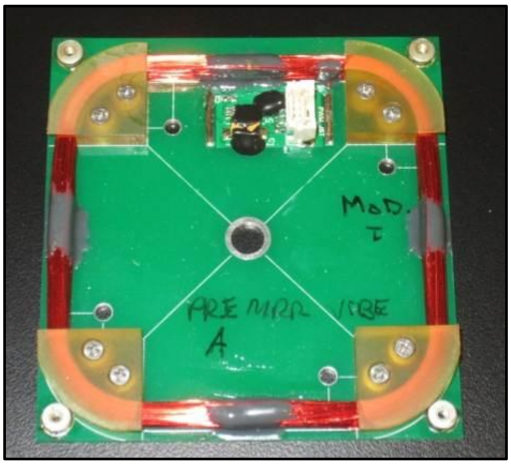

Figure 8: CXBN Magnetic Torquer

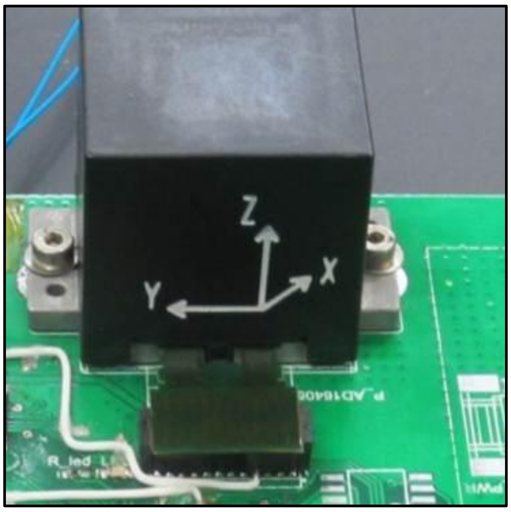

Figure 9: CXBN IMU with MEMS Gyros

Canopus Pipper

For CXBN, a novel idea was proposed by John Doty to use a very similar concept as a Digital Canopus Tracker[6] used in the 1970s, excluding unnecessary and overcomplicated systems. This idea, coined the Canopus Pipper, uses the star Canopus to detect roll position.

Canopus, or Alpha Carina, is the second brightest star in the sky with an apparent magnitude of -0.72 (11). Canopus is located about 300 light years away at a right angle (RA) of 06h23m57s and a declination (DEC) of -52°41'44".[7] The brightness and position in the sky make Canopus an ideal choice for star sensor systems.

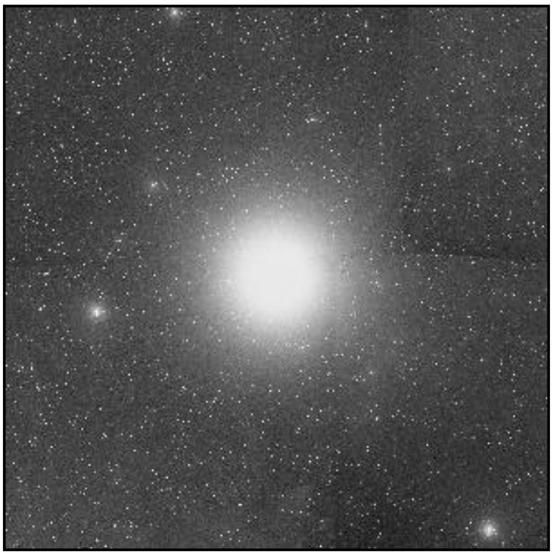

Figure 10: *SkyView* Image of Canopus

Star sensors vary significantly from star trackers. Instead of using imagers, some star sensors operate by using a photo detector to produce pulses when stars transit the detector's FOV. The concepts were first introduced with dissector tubes in the 1960s to produce a system that could determine when a specific star was reached and then track it with feedback to the ACS.[8]

A difficulty presented when using star sensors is correlating the magnitude of the star with the pulse amplitude during transit. While functional testing in the earth environment can reasonably be performed in very dark geographic locations and good weather conditions, magnitude calibration must be based upon on orbit characterization. While difficult, the simplicity of the sensor alleviates many other systems level challenges where power, size, budget, and schedule become dominant. Star pippers provide a much more appealing solution than a star tracker in this application.

The star sensor is mounted in CXBN orthogonal to the spin-axis. By sweeping out the sky as CXBN spins, the Canopus Pipper produces a voltage pulse when star light enters its aperture. Since the Canopus Pipper alone only produces a reference pulse, it needs to be paired with a roll rate to deduce complete roll knowledge. On CXBN, MEMS gyroscopes are used to measure the roll rate. The end result is not an actively tracking ADCS, but a solution for roll determination that can be implemented with minimal impact on mission schedule.

The Canopus Pipper also links to the science payload to correlate position in the sky. The Pipper measurements are routed through the payload processor where it is sampled and time stamped.

Figure 11 below depicts this operational concept of the Canopus Pipper from starlight to data read by a microprocessor and Figure 12 shows the final flight model.

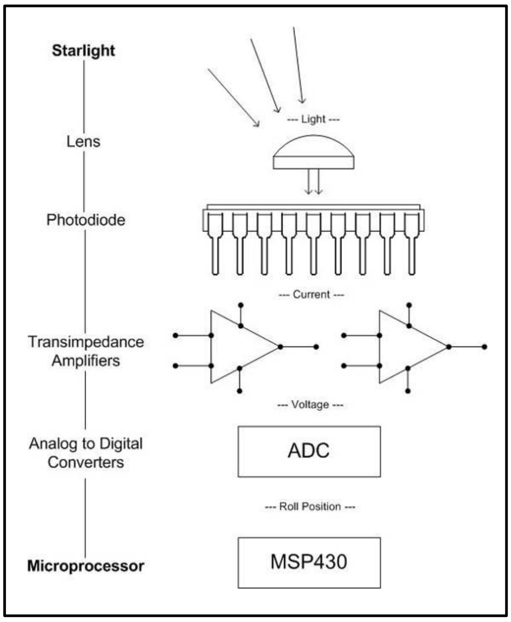

Figure 11: Block Diagram Concept of Canopus Pipper

Starlight passes through a lens, to a photodiode. Then the current is converted into a voltage, where it is sampled by analog to digital converters (ADCs). Lastly, the signals from the ADC are sent to a microprocessor for integration into telemetry.

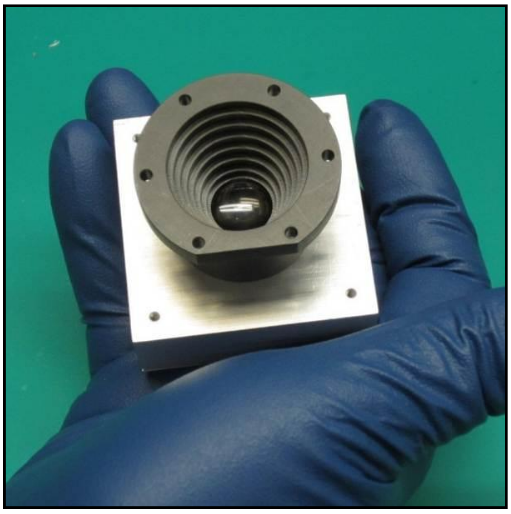

Figure 12: CXBN Canopus Pipper

Communications Systems

The mission requires a very low uplink command rate and telemetry at as high as possible rate, the main restriction being licensable bandwidth. The CXBN communication system consists of an AstroDev Li-1 radio (Figure 13), antennas, and an antenna phasing network. Baseline configuration provides command uplink at 9.6 kbps and telemetry downlink at 9.6 kbps with up to 38.4 kbps (reconfigurable in flight). Table 4 provides specifications for the on-board radio systems utilized for this mission.

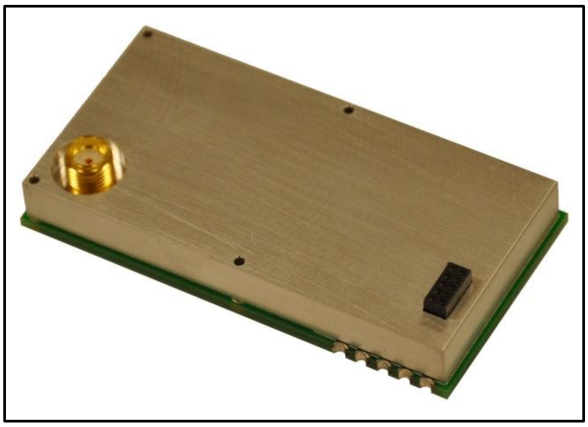

Figure 13: CXBN Transceiver

Table 4: CXBN Transceiver

AstroDev Lithium-1 Transceiver
▪ UHF: 400 – 450 MHz
▪ Half duplex
▪ AX.25 packet protocol
▪ Operates on 3.3V and 5V
▪ Variable transmit power: 250 mW – 4 W
▪ 9.6 kbps (base), 115.2 kbps (max)
▪ CW Beacon
▪ Ping (with or without telemetry)
▪ Backdoor reset
▪ Provides BSL entry to C&DH

SCIENCE PAYLOAD

The DXRB flux measurements to be made during this campaign utilize a direct bandgap semiconductor detector developed by a team including the Project Scientist (G. Jernigan) [17]. The detector is based on a Cadmium zinc telluride, (CdZnTe or CZT) pixelated array. The instrument is used in a variety of applications including as radiation detectors in the gamma ray and X-ray spectra. Radiation detectors using CZT can operate in direct-conversion (or photoconductive) mode at room temperature. Advantages of this technology include high sensitivity to X-rays and gamma-rays due to the high atomic numbers of Cd and Te, and better energy resolution than scintillator detectors. The CZT array payload is a novel, 16x32grid, low-power sensor with 600x600 micron pixels and 1keV energy resolution at an energy of 60keV. A 5 mm thickness provides a very ample interaction volume for incoming gammas. Figure 15 shows the detector array along with a high-Z multi-layered shielding box and field of view collimator. The collimator aperture was designed to define the appropriate field of view on the sky (approximately 18° half angle) and contains two X-ray calibration sources (totaling two μ-Curies of Americium 241). Placement of the calibration sources within the collimator is shown in Figure 14.

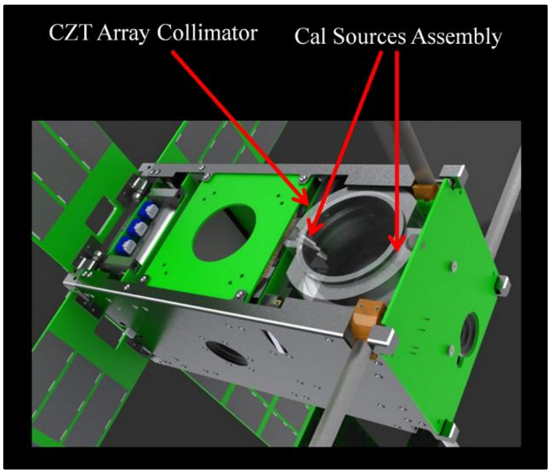

Figure 14: CZT Array Collimator and Calibration Sources

Shielding materials, thicknesses, and placement were carefully selected based on numerical simulations of the collimator interaction with high energy cosmic rays that produced secondary particles including gamma rays in the energy range of interest. These simulations are described in the companion science paper.[9]

The DXRB has a flux of ~1 sec^{-1} cm^{-2} sr^{-1} in a band from 20-50 keV for a field of view ~0.25 ster and a 4 cm^2 area. Therefore for every second of high quality data we expect to detect ~1 DXRB count in this band and also typically ~1 particle background event. If we conservatively assume that we are over the equator for 10% of the time with low background then in ~1 year of operation we would have 3 million seconds of good data. In ~1 year of operation we reach a broadband S/N ~250. We expect to be systematic limits after ~ 16 months of operation. The team continues do extensive modeling including GEANT simulation to refine the estimates of the S/N. The goal is to measure the absolute level of the DXRB to <5% accuracy.

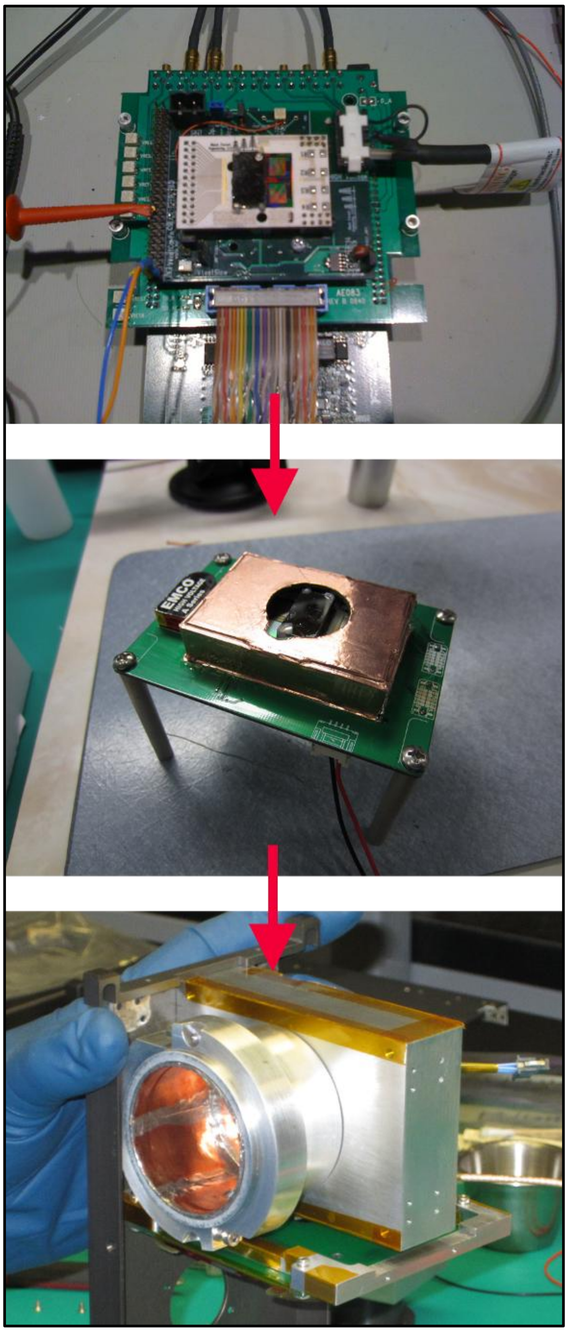

Figure 15: CZT Array and High Voltage Power Supply on Development Board (Top) Housed in multi-layer High Z Shielding (Middle) mounted in an Aluminum Structure with a Collimator (Bottom) lined with High Z Shielding

ENGINEERING DEVELOPMENT

The engineering development of CXBN followed a spiral engineering approach that was undertaken by faculty, undergraduate, and graduate students working closely together, Figure 16. The design process incorporated typical engineering reviews including: requirements review, specifications review, preliminary design review, critical design review, and mission readiness review. All electronics and mechanical systems were iteratively designed in 3D modeling programs then prototyped and tested. In the case of the electronics systems, boards were designed, manufactured, populated, and tested in quick succession. Numerous iterations allowed for skills building and minimized white wires on the final system. The mechanical development followed a similar path, first being designed in 3D, then rapid prototyped in plastic models (3-D printing). The models were fit checked and verified before engineering and flight models were produced in their end material. As an example, the CZT array collimator design process is illustrated in Figure 17. A CAD view of the CZT detector collimator was first produced (top left) followed by a rapid prototyped (3-D printed) model of the collimator (top right). Engineering (bottom left) and flight (bottom right) models were then produced from the final materials – in this case 6061 Aluminum with a graded-Z shield (a particle filtering window formed by layers of Pb, Sn, and Cu). These images illustrate the rapid design-prototype process employed for many of the CXBN subsystems.

Overall, the development effort consisted of 1) identifying, modifying, and bench-testing of all bus subsystems, 2) development of two engineering models (EM) in near-flight configuration, and 3) the development of the flight model (FM). The engineering development approach – based on evolved subsystems from internal engineering training and rapid prototyping – facilitated the spacecraft design, assembly, and testing within a 12 month timeframe. Therefore, the team was able to take advantage of the flight opportunities in 2012.

Figure 16: Undergraduate Students and Faculty Worked Together to Fabricate Electronic and Mechanical Systems and to Assemble Engineering and Flight Models of CXBN

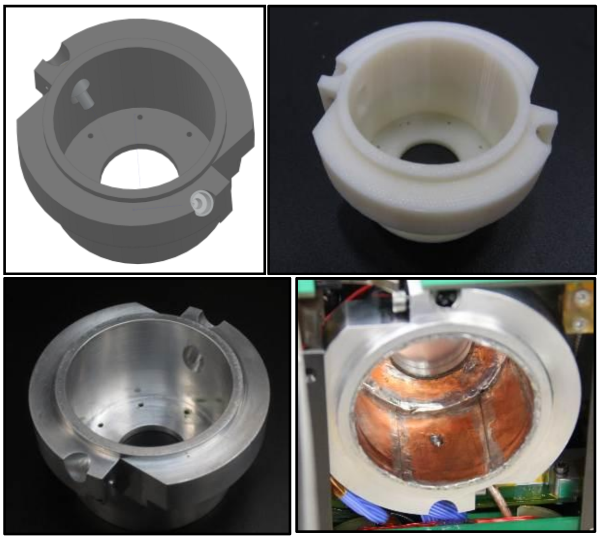

Figure 17: Mechanical Design Process Illustrated

Verification and Pre-flight Testing

CXBN was subjected to a rigorous testing regime to verify compliance with all requirements specified by the ELaNa VI mission ICD Rev 1.0 and NASA LSP-REQ-317.01. These tests included empirical measurements (vibration, thermal bake-out, vacuum testing, physical dimension and protrusion adherence, mass properties, transmission, power on and deployable exclusions, and "Day in the Life" testing) and derived and modeled values (second order mass properties, orbit debris analyses, venting models, structural survivability, and hardware cleanliness). Test reports and compliance verification was documented in the CXBN Verification and Compliance summary submitted on November 17, 2011.[10] Most of the pre-flight testing was performed on site at the Morehead State University Space Science Center Spacecraft Verification facility. The facility includes vibration analysis (shaker table) system (shown in Figure 18), EM anechoic chambers (Figure 19) and a screen room for RF characterization, and a solar simulator.

Delivery and PPOD Integration

The flight model of the satellite subsystems of CXBN passed pre-flight verification in November 2011 and was delivered to the launch integrator, CalPoly on January 4, 2012. CXBN, along with CP-5 was integrated into a PPOD on January 5 (Figure 20) and subsequently delivered to Vandenberg Air Force Base (VAFB).

Figure 18: Morehead State University Space Science Center Spacecraft Verification Center Shaker Table

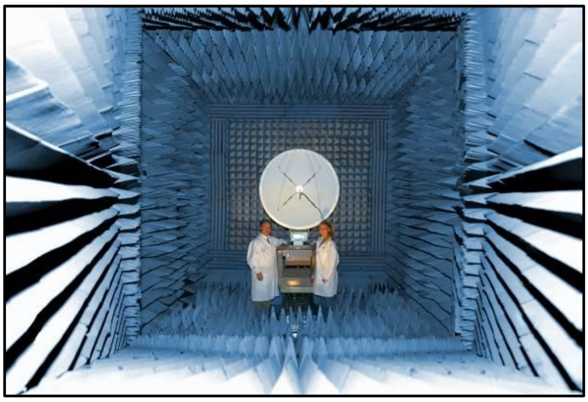

Figure 19: Morehead State University Space Science Center EM Anechoic Chamber

GROUND OPERATIONS

All ground operations supporting CXBN from launch, to early operations (LEOP) through primary mission operations and de-orbit procedures will be managed by the Morehead State University Space Operations Center (SOC).

The center operates several ground stations, including low bandwidth VHF/UHF systems and a 21-meter diameter, parabolic dish antenna system (Figure 22), to support small satellite missions. The 21-m has the capacity to track satellites in low earth orbit (LEO) with extremely low transmission power, as well as satellites at geostationary, lunar, and Earth-Sun Lagrangian orbits. The system currently operates at UHF, L-, S-, C-, X- and Ku-bands. Table 5 outlines the basic performance characteristics of the 21-m.[11]

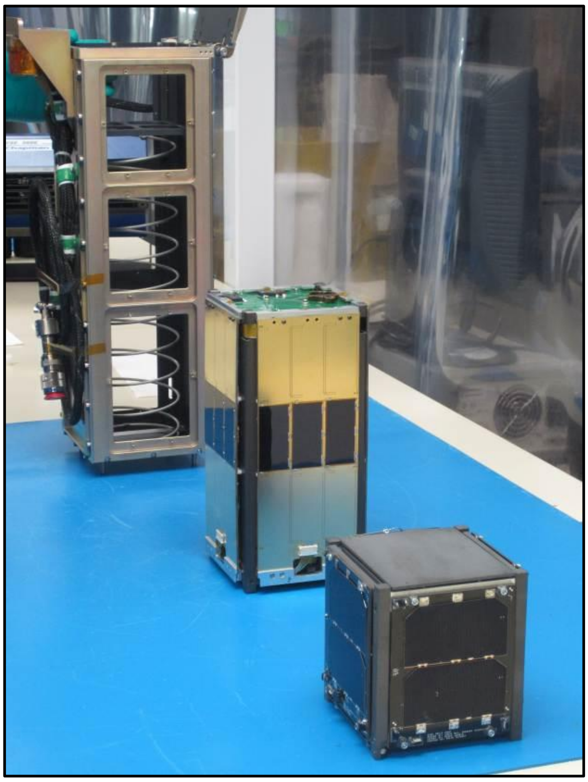

Figure 20: CXBN (Center) and CP5 (Front) in the Clean Room at CalPoly (San Luis Obispo, CA) Prior to Integration into the P-POD (Background)

The MSU SOC will be utilized for scheduling, command sequence generation, satellite housekeeping, orbit tracking, and science data acquisition. Scheduling and commanding of the satellite will be carried out by ground station personnel that include a significant student workforce component.

CXBN has several different modes of operation. They include failure recovery beacon, standby beacon/uplink, downlink, and full science acquisition modes. The failure recovery mode is the most conservative mode which attempts to minimize power usage by emitting a low power beacon with health and status information. The standby beacon/uplink mode will broadcast a beacon with a complete telemetry set with current science data interleaved. In downlink mode the spacecraft will send historical science data. Finally the science mode will collect and store data as scheduled for later retrieval. Once the science mission is completed the spacecraft will be full time dedicated to the amateur community for repeater service.

Figure 21: Morehead State University 21 Meter Ground Station

Table 5: 21 Meter Antenna Performance Characteristics

Feature	***Performance***
Antenna Diameter	21 Meter
Optics	Prime Focus
F/D Ratio	0.363
Receive Polarization	RHCP,LHCP,VERT,HORZ
Travel Range	AZ +/- 275 degrees from South EL -1 to 91 degrees POL +/- 90 degrees
Velocity	AZ Axis = 3 deg/sec EL Axis = 3 deg/sec
Acceleration	AZ = 1. 0 deg/sec/sec min EL = 0.5 deg/sec/sec min
Display Resolution	AZ/EL = 0.001 deg POL = 0.01 deg

LAUNCH

The launch of CXBN as a secondary payload in NASA's ELaNa-6 mission is scheduled for August 2012 from VAFB, CA. The launch vehicle will be an Atlas-5-411 vehicle from ULA (United Launch

Alliance). The secondary payloads on the rocket expect an altitude of 770 km x 480 km and an inclination of 64°. The primary payload on this flight, referred to as NROL-36, are two NRO/MSD (Mission Support Directorate) classified spacecraft (NRO-36, namely NOSS-36A and NOSS-36B).[12] The eight PPODs on NROL-36 are contained within a NPSCuL (Naval Postgraduate School CubeSat Launcher). This new CubeSat deployment platform was designed and developed by students of NPS (Naval Postgraduate School) in Monterey, CA, to integrate/package P-PODs as secondary payloads.[13]. NRO refers to all 11 secondary CubeSat payloads on NROL-36 as the OUTSat (Operationally Unique Technologies Satellite) mission. The launch will mark the NPSCuL's maiden voyage.[14] The launch of OUTSat is nominally scheduled for August 2, 2012.

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Kentucky Space provides funding for student support allowing undergraduate students to gain invaluable space systems development experience on this and other initiatives. Publication references are included within the text.

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