CAPABILITY DEMONSTRATION OF AN AMBIENT-TEMPERATURE IMAGING GAMMA-RAY SPECTROMETER FOR HIGH-SENSITIVITY PLANETARY ELEMENTAL MAPPING. S. Abraham[1,2], Y. Zhu[2], P. Bloser[1], J. Berry[2], B. Sandoval[3], G. Duran[3], S. Lanctot[3], M. Petryk[2], D. Anderson[2], J. Deming[4], A. Klimenko[1], S. F. Nowicki[1], and Z. He[2]. [1]ISR-1: Space Science and Applications, Los Alamos National Laboratory (Los Alamos, NM, 87545, snowicki@lanl.gov), [2]Department of Nuclear Engineering and Radiological Sciences, The University of Michigan (Ann Arbor, Michigan 48109-2104, abrasara@umich.edu, hezhong@umich.edu), [3]ISR-5: Space Instrument Realization, Los Alamos National Laboratory (Los Alamos, NM, 87545), [4]ISR-4: Space Electronics and Signal Processing, Los Alamos National Laboratory (Los Alamos, NM, 87545).

Introduction: Gamma-ray instruments have been used for decades in planetary science to help determine the subsurface elemental composition of planetary bodies. Galactic cosmic rays (GCRs) bombard the surface of planetary bodies that have little or no atmosphere. The interactions of GCRs with planetary materials produce gamma rays that provide information about the planetary composition. This has been demonstrated at the Moon [1], Mars [2], Mercury [3], Venus [4], and asteroids Eros [5], Vesta and Ceres [6][7]. For planetary bodies with thick atmospheres, an alternative source of activation (i.e. pulsed neutron generator) is needed because GCRs are absorbed before reaching the surface.

The elemental composition mapping provided by gamma-ray spectrometers complements mineralogical data acquired by other methods (i.e. X-ray diffraction, infra-red spectroscopy). Currently, mineralogical data typically have better spatial resolution than can be achieved with gamma-ray spectroscopy. A gamma-ray spectrometer with energy resolution comparable to that of High Purity Germanium (HPGe) and imaging capabilities would allow for the synthesis of elemental and mineralogical data at finer spatial scales.

To advance the state-of-the-art of planetary gamma-ray spectroscopy, instruments with high energy resolution, high signal-to-noise ratio, high efficiency, low mass, low volume, and no cryogenic cooling are desirable. Pixelated CdZnTe (CZT) gamma-ray instruments are very suitable due to their high energy resolution, high density, high atomic number, ambient-temperature operation (0˚-60˚C), lack of intrinsic background, and the ability to reject GCRs and gamma-rays from spacecraft without using an anti-coincidence shield (ACS).

High energy resolution can be achieved with HPGe, but due to its narrow bandgap (0.7 eV), cryogenic cooling is required to reduce thermal excitation. CZT has a wide bandgap (1.6 eV) that results in a lower probability of thermal excitation at room temperature, allowing for good energy resolution without cooling. The electrode configuration of pixelated CZT detectors and advancements in the development of low noise electronics has allowed the energy resolution of CZT to approach that of HPGe. Pixelated CZT detectors have demonstrated an energy resolution of 0.5% FWHM at 662 keV [8], similar to that achieved by the MESSENGER HPGe gamma-ray spectrometer and greatly superior to that of NaI(Tl) scintillators. Because a CZT instrument does not require a cryogenic system or ACS like HPGe, it can have reduced mass, volume, power, and risk.

A CZT-based gamma ray spectrometer can detect energies from ~0.1 to ~10 MeV. With this energy range, gamma-ray spectra can be analyzed to identify key elements such as H, C, N, O, Na, Mg, Al, Si, S, Cl, Ca, Ti, Fe, and Ni as well as naturally radioactive elements such as K, Th, and U. Pixelated CZT can perform 4π Compton imaging for gamma rays with energies between ~0.5 and ~6 MeV. This enables higher spatial resolution of planetary elemental maps and improved background rejection. Employing Compton imaging does not require the extra mass of a coded aperture mask or heavy collimators.

Since pixelated CZT technology is commercially available for multiple relevant terrestrial applications, it is at Technical Readiness Level (TRL) 4 for space applications. To raise the TRL, pixelated CZT technology needs to be tested in a near-space environment. Thus, in collaboration between Los Alamos National Laboratory and the University of Michigan, we have designed and built an ambient-temperature imaging gamma-ray spectrometer, named Orion Eagle, using pixelated CZT detector technology. Orion Eagle is intended to be a prototype for future CZT instruments for planetary space applications. Orion Eagle was tested on a high-altitude balloon to demonstrate pixelated CZT technology can operate in a near-space environment and can detect gamma rays while identifying/rejecting galactic cosmic rays.

Instrument: The Orion Eagle prototype contains one 2 cm × 2 cm × 1.5 cm CZT detector (shown in Figure 1). Future detector systems could include arrays of CZT to achieve an effective area greater than state-of-the-art HPGe for planetary science [9]. A single detector has an array of 11 × 11 pixelated anodes and a planar cathode. The energy and position (x,y,z) of radiation interactions in the CZT detection volume can be determined due to this electrode configuration [10]. Orion Eagle was designed to work in near-vacuum environments. Potting and careful layout helped mitigate the risk of high-voltage breakdown. Orion Eagle does not employ any cooling, so copper contacts were used to dissipate heat from electronics. Orion Eagle is light (11 lbs), small (contained within a 33.2 cm × 23.3 cm × 11.0 cm box), and has low power consumption (~4W). Orion Eagle was incorporated into a gondola with a flight computer and batteries.

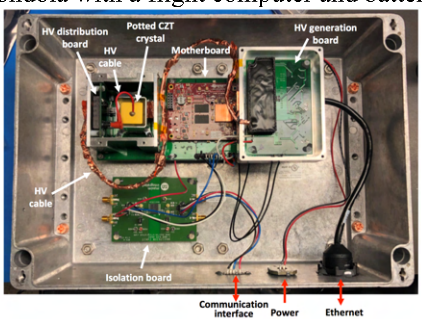

Figure 1. Interior of Orion Eagle with all lids removed.

High-Altitude Balloon Flight: The Orion Eagle payload was hand-launched at NASA Columbia Scientific Balloon Facility in Fort Sumner, NM on September 26th, 2021. Orion Eagle successfully operated throughout the ~9 h flight, including ~5 h at the desired float altitude of ~38 km, and survived the landing. The detector's count rate peaked at the approximate altitude of the Regener-Pfotzer maximum during both the ascent and descent (Figure 2). The 511 keV annihilation-line was observed in the energy spectra (Figure 3), as expected. This demonstrates that pixelated CZT-based instruments can sustain in a near space environment, raising the TRL to 6.

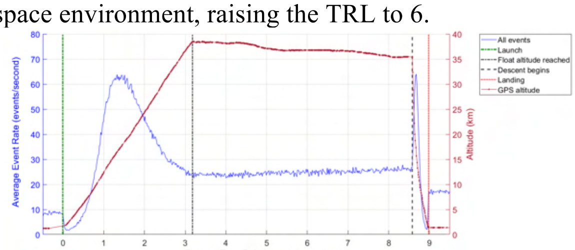

Figure 2. Event rate detected by Orion Eagle during the high-altitude balloon flight.

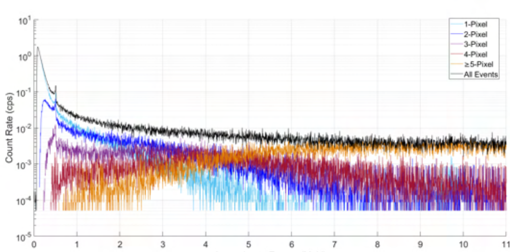

Figure 3. Raw energy spectra from the high-altitude balloon flight, sorted by the number of anode pixels triggered.

Background Rejection: The ability to estimate the 3D position of energy deposition events within the volume of a pixelated CZT detector can be particularly useful to identify background due to charged particles. Energetic charged particles passing through the detector create a linear ionization trail, which can be distinguished from the discrete interactions of gamma rays. They can therefore be identified as charged particle background based on their spatial signature, making background rejection without an ACS possible. Figure 4 shows examples of charged particle tracks detected in the CZT volume during the flight.

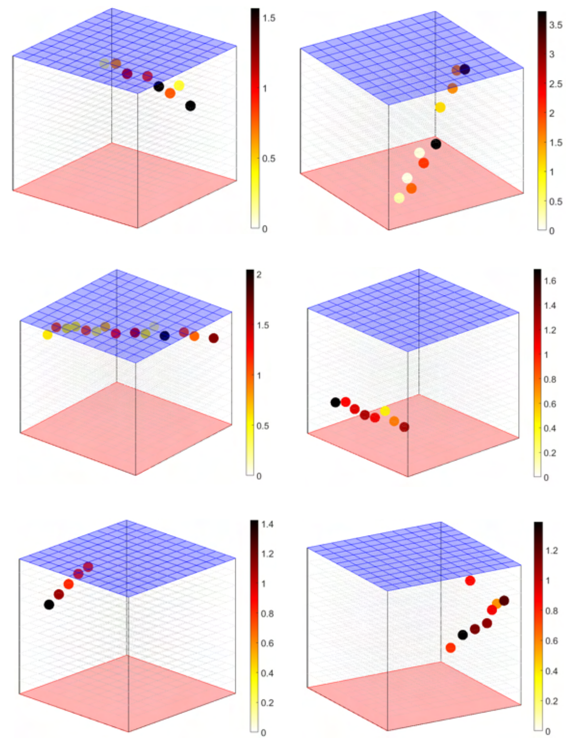

Figure 4. Examples of charged particle tracks passing through Orion Eagle's single CZT detector. The blue 11×11 grid represents the pixelated anodes and the red face represents the planar cathode. The color of each data point represents the energy deposited per pixel in MeV.

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