AMBIENT-TEMPERATURE IMAGING GAMMA-RAY SPECTROMETER (TIGRS) FOR HIGH-SENSITIVITY PLANETARY ELEMENTAL MAPPING. S. N. Nowicki[1], Z. He[2], Y. Zhu[2], A. M. Parsons[3], T. H. Prettyman[4], S. A. Storms[5] and S. A. Wender[6], [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, hezhong@umich.edu, zhuyuef@umich.edu), [3]Astrochemistry Laboratory (Code 691), NASA Goddard Space Flight Center (Greenbelt, MD, 20771, ann.m.parsons@nasa.gov), [4]Planetary Science Institute (1700 East Fort Lowell, Suite 106, Tucson, AZ 85719-2395, prettyman@psi.edu), [5]ISR-5: Space Instrument Realization, Los Alamos National Laboratory (Los Alamos, NM, 87545, sstorms@lanl.gov), [6]P-2: Applied and Fundamental Physics, Los Alamos National Laboratory (Los Alamos, NM, 87545, wender@lanl.gov).

Introduction: Gamma-ray instrumentation has long been used in planetary science to determine the bulk elemental composition of the solid subsurface of planetary bodies to depths of a few decimeters. Gamma-ray spectrometers have been successfully used at the Moon, Mars, Mercury, Venus, and asteroids Eros, Vesta, and Ceres to extract planetary composition information from the gamma rays they emit. For planetary bodies with thin or no atmosphere, gamma rays are produced from the interactions of galactic cosmic rays (GCRs) with planetary materials. For bodies with thick atmospheres, such as Titan, GCRs are absorbed before they can reach the surface. In this case, landed missions can obtain elemental composition information by including an alternative source of activation such as a pulsed neutron generator (PNG) along with the gamma ray spectrometer.

Elemental composition mapping complements mineralogical data acquired by infra-red spectroscopy, X-ray diffraction and many other methods. Such mineralogical data are usually acquired with much higher spatial resolution than can currently be achieved by gamma-ray spectroscopy. An imaging gamma-ray spectrometer (GRS) with energy resolution similar to that of High Purity Germanium (HPGe) would enable synthesis of elemental and mineralogical data at finer spatial scales, enabling detailed analyses at the scale of geologic units. To accomplish this, we have designed the ambient-Temperature Imaging Gamma-Ray Spectrometer (TIGRS) as a GRS ready for planetary science applications based on the maturation of pixelated CdZnTe (CZT) gamma-ray detector technology.

A GRS with high energy resolution, high efficiency, low mass, low volume and high signal-to-noise ratio without the need for cryogenics would significantly advance the state-of-the-art for planetary gamma-ray spectroscopy technology. Pixelated CZT detectors can fulfill these requirements because they have: 1) high density and atomic number, 2) high energy resolution made possible by the electrode configuration. For example, pixelated CZT detectors have shown 0.5% FWHM at 662 keV [1], similar to that achieved by the MESSENGER HPGe GRS, 3) room-temperature operation (0˚- 30˚C; no cryogenic cooling requirement), 4) no intrinsic background, and 5) rejection of GCRs and gamma-rays from spacecraft without the need for an anti-coincidence shield (ACS).

Since CZT arrays are used in multiple relevant commercially-available terrestrial applications, they are now at Technical Readiness Level (TRL) 4 for space applications. In addition, TIGRS' imaging capability will allow for significantly improved planetary elemental maps. These CZT detector arrays can function in a manner similar to previous HPGe GRS instruments and can be deployed in orbit, on a static lander or a moving platform (such as a rover or drone) for future-landed planetary exploration missions.

TIGRS can detect gamma rays in the energy range of 0.1 to 10 MeV. Gamma-ray spectra can be analyzed to identify the elements that make up planetary materials and will provide important geochemical constraints on the planetary body's thermal and compositional evolution. These elements include: H, C, O, N, Na, Mg, Al, Si, S, Cl, Ca, Ti, Fe, and Ni and the naturally radioactive elements K, U and Th. Gamma-rays detected between ~0.5 and ~6 MeV can also be used to perform imaging, thus enabling higher spatial resolution planetary maps and improved background rejection. The gamma rays not used for imaging are still acquired and stored for spectroscopy use, with improved sensitivity over past HPGe spectrometers due to TIGRS' large volume.

TIGRS' many planetary science applications include providing geochemical context for future sample-return missions such as from a comet, or the lunar South Pole-Aitken basin. The chemical data acquired by TIGRS also supports the geochemical characterization of primitive bodies (asteroids and comets), Mars, and the icy moons. TIGRS can also be used with a PNG to study the geochemistry of the surface of Venus.

Energy Resolution: CZT has a wide bandgap (1.6 eV) that results in a low probability of thermal excitation of electrons from the valance band to the conduction band at room temperature that results in excellent energy resolution. Better energy resolution can be achieved with HPGe, which has a narrower bandgap (0.7 eV), but requires the use of cryogenic cooling to reduce the thermal excitation. Figure 1 compares the response of NaI(Tl), HPGe and pixelated CZT detector to a ^{152}Eu source and shows that the energy resolution of CZT approaches that of HPGe and is greatly superior to NaI(Tl) scintillator GRSs. The mass, volume, power and risk of a CZT instrument will be less than HPGe since it does not require the cryogenic system or ACS needed for HPGe.

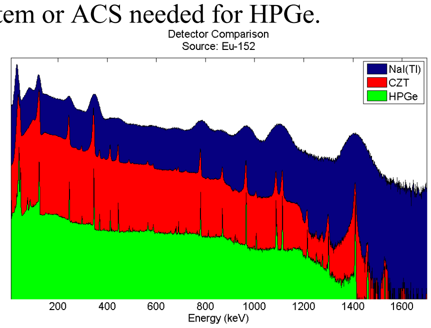

Figure 1. Gamma-ray spectral performance of NaI(Tl) (blue), CZT (red), and HPGe (green). The spectral performance of CZT approaches that of HPGe without the need for a cryogenic cooler.

Compton Imaging: We propose to use the Compton imaging techniques available to pixelated CZT detectors to improve the spatial resolution of current state-of-the-art neutron and gamma-ray detectors. Unlike using a coded mask aperture [2] and heavy collimators [3], employing Compton imaging techniques does not require the extra mass.

A commercially available CZT imager was used in combination with a D-T PNG (14.1 MeV neutrons) to produce a gamma-ray image of a bucket of water (Fig. 2) using the 2.223 MeV characteristic line of hydrogen. Measurements of H could determine the location, thickness, concentration, and depth of buried water-ice, as well as the chemistry of associated mineral alteration and salts which are important for understanding the current climate and past climate cycles on Mars.

The ability to measure the position of energy-absorbing events within the volume of a pixelated CZT detector can also be used to identify background due to charged particles. Unlike discrete gamma ray interactions, charged particles deposit energy continuously along their path. They can therefore be identified as charged particle background by their specific spatial signature within the CZT detector, making an ACS unnecessary. Figure 3 is an illustration of muon interactions in a pixelated CZT detector.

Volume: TIGRS consists of two layers of pixelated CZT detector arrays. Each layer is a 2 × 2 array of detectors and the dimensions of each detector is 4 cm × 4 cm × 1.5 cm. Figure 4 shows the simulated effective area as a function of energy for TIGRS, the HPGe on Mars Odyssey and MESSENGER, as well as Polaris, which is a commercially-available CZT instrument. Figure 4 shows that TIGRS has a higher effective area than the state-of-the art HPGe for planetary science.

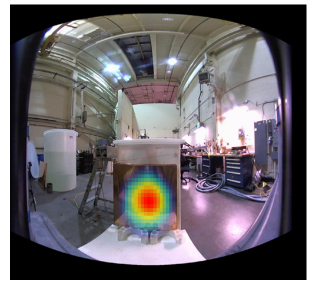

Figure 2. Compton image of irradiated water produced by a CZT array in the laboratory superimposed on a context image. The source is a D-T PNG placed inside a large bucket of water. An image was produced using the characteristic 2.223 MeV line of H.

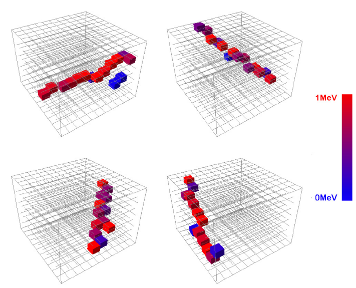

Figure 3. Four examples of muon tracks passing through a pixelated CZT detector. The passage of energetic particles through the detector makes a linear ionization trail, which can be distinguished from the discrete interactions of gamma rays.

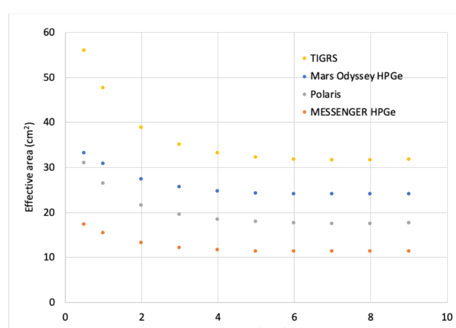

Figure 4. Effective area of TIGRS compared to the state-of-the-art detectors in planetary science. With a volume of 192 cm^3, it has a higher effective area than the Mars Odyssey HPGe.

References: [1] Streicher, M. et al, (2016) *IEEE TNS,* 63(5), 2649-2656. [2] Barthelmy, S. D. et al. (2005) *SSR*, 120(3-4), 143-164. [3] Chin, G. et al. (2007) *SSR*, 129(4), 391-419.