GeMini Plus: A Versatile Gamma-Ray Spectrometer for Planetary Composition Measurements. Morgan T. Burks[1], Lena E. Heffern[1], David J. Lawrence[2], John O. Goldsten[2], Patrick N. Peplowski[2], [1]Lawrence Livermore National Laboratory, Livermore, CA (burks5@llnl.gov), [2]Johns Hopkins University Applied Physics Laboratory (JHU/APL), Laurel, MD.

Introduction: We are developing a next-generation, high-purity Ge (HPGe) gamma-ray spectrometer (GRS) for planetary composition measurements. This instrument, called GeMini Plus, is unique in that it offers the best available gamma-ray energy resolution in a low-resource package (small size, low mass, low power). GeMini Plus (Figure 1) is thus well suited for resource-constrained missions, including landed and orbital missions, to planets, moons and asteroids.

Fig. 1. GeMini Plus sensor housing including cryostat and miniature cryocooler. Not shown are power supplies and readout electronics.

Gamma-ray spectroscopy is a valuable tool in measuring and quantifying planetary surface composition. This knowledge in turn helps address many science questions including constraining the formation history of the planetary body [1]. GeMini Plus is sensitive to a range of elements commonly found at a planetary surface. These elements include: H, C, O, Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Fe, Th and U. Furthermore, due to the long penetration length of gamma-rays, this technique is sensitive to elements down to several tens of cm below the surface.

GRS instruments have previously flown on planetary missions to the Moon, Mercury, Mars and asteroids, and have made significant contributions to our understanding of these bodies [2-4]. However, most of these instruments had large mass, high power consumption and/or were low energy-resolution scintillator-based systems. The first high-resolution gamma-ray spectrometer that was also small size and low power was the GRS that flew on the MESSENGER mission to Mercury [5]. GeMini Plus is the next generation of the MESSENGER GRS, incorporating lessons learned and updated design to reduce the mass and power, while maintaining the ruggedness and performance.

Figure 2 shows the value of high-energy-resolution for elemental analysis. GeMini Plus was used to measure a Mars soil simulant and compared to a CsI-based scintillator. The soil was bombarded by neutrons to give a gamma-ray signature similar to that expected at Mars. Scintillator detectors are generally less complex and less expensive to deploy than germanium detectors, which have to be cryogenically cooled. However, GeMini Plus provides higher signal to background, better discrimination between gamma-ray lines, and resolves lines that are not resolvable by the scintillator. The result is a higher sensitivity to a wide range of elements.

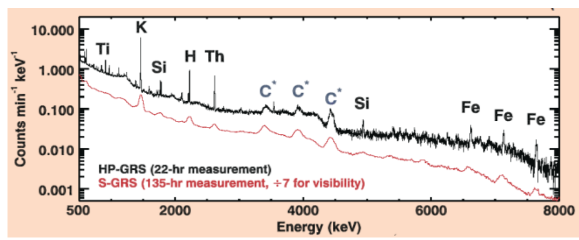

Fig. 2. Measured gamma-ray spectra for the GeMini Plus HPGe spectrometer and a CsI-based gamma-ray spectrometer of Mars soil simulant at the JHU/APL Planetary Gamma-Ray and Neutron Simulation Facility.

GeMini Plus Development: The goal of the GeMini Plus development is to build on the success of the MESSENGER GRS to make the next generation HPGe spectrometer. GeMini Plus incorporates improved infrared shielding, a robust suspension to reduce conductive heat load, and is compatible with the various low-power cryocoolers. The result is a low-resource instrument at Technical Readiness Level 6 or 7 that is suitable for a wide range of planetary missions. Specific development tasks include:

Cryocooler trade study. When the MESSENGER GRS was being designed and built (early 2000's) it was difficult to select a cryocooler that met all the desired specifications of low-mass, low-power, high heat lift, and longevity. However, in the past decade, significant progress in cryocooler technology has been made. GeMini Plus has been designed to work with many different cryocoolers and can be optimized for the needs of a specific mission.

One cryocooler currently being tested is from Lockheed Martin (Figure 3) with a mass of 450 grams, 750 mW heat lift at 77K, and an expected lifetime of ~10 years of continuous operation.

Fig. 3. Lockheed Martin cryocooler. This cryocooler is low mass (450 grams), has a long life expectancy (10 years) and has sufficient heat lift (500 mW heat lift at 77 K). It is well suited for integration with GeMini Plus

Radiation damage and annealing. Although germanium-based spectrometers give the highest resolution of any competing technology, the resolution degrades over time due to radiation damage from cosmic ray bombardment. These effects are seen at a fluence around 10^8/cm^2, which is about a year in space (depending on Solar cycle and proximity to planetary bodies). Fortunately this damage can be repaired *in situ* by annealing the detector to 100 ^{o}C for several days.

GeMini Plus will be irradiated at the NASA Space Radiation Laboratory with GeV protons to reproduce the damage expected in space. The instrument will then be annealed under various conditions in order to optimize annealing time and temperature. This will allow us to verify the performance of GeMini Plus for long duration missions in harsh radiation environments.

Vibration and shock tests. The GeMini Plus sensor housing has been mounted on a shake table and subjected to vibration loads mimicking rocket launch. Testing includes

- Sinusoidal strength test: 35 G at 42 Hz
- Random vibe: 14 G rms from 20 to 2000 Hz
- Shock: up to 2500 G at 2000 Hz.

These tests were performed an all three axes and showed that any resonances are well outside the measurement bandwidth. Thus the design is well-suited for rocket launch.

Design flight electronics. A flight-heritage data processing unit (DPU) has been developed for GeMini Plus (Figure 4). The DPU minimizes mass and allows quick reuse of standard flight-proven designs. Four modular "slices" are coupled together to form a compact electronics stack without the need or added mass of a backplane. These slices include a Low Voltage Power Supply, a High Voltage Power Supply, a Processor board containing the central FPGA, and a Cryocooler Controller capable of driving several types of cryocoolers. All-digital filtering algorithms have been implemented within the FPGA and shown to achieve similar performance to a commercial laboratory analyzer (Figure 5).

Fig 4. Digital Processing Unit (DPU) showing two "slices".

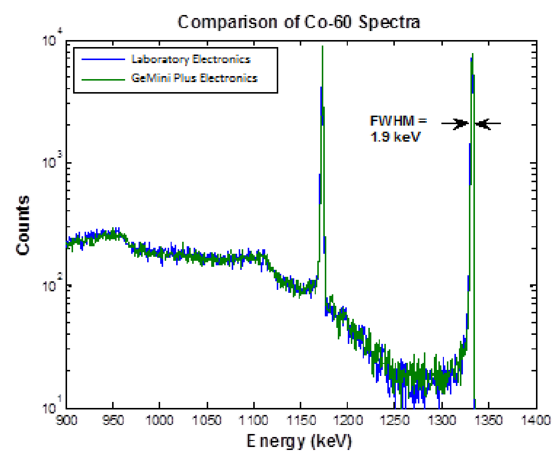

Fig 5. Energy resolution performance of the DPU compared to standard laboratory electronics for a germanium detector and a ^{60}Co point source.

References: [1] Evans, L. G. et al. *Remote Geochemical Analysis: Elemental and Mineralogical Composition* 167198 (1993); [2] Peplowski et al. (2011) *Science*, *333*(6051), 1850-1852; [3] Boynton et al., *Space Science Reviews*, *110*(1-2), 37-83 (2004); [4] Goldsten et al. In *The Near Earth Asteroid Rendezvous Mission*, pp. 169-216. Springer Netherlands, 1997; [5] Goldsten et al. *Space Science Reviews* 131, no. 1-4 (2007), 339-391; [6] Burks, M. (2008), *IEEE Nuc. Sci. Symp*., 1375.