Initial Characterization of the GeMini Plus, a High-Resolution Gamma-Ray Spectrometer for Planetary Composition Measurements. Lena E. Heffern[1], Morgan T. Burks[1], David J. Lawrence[2], John O. Goldsten[2], Patrick N. Peplowski[2]; [1]Lawrence Livermore National Laboratory, Livermore, CA (heffern1@llnl.gov), [2]Johns Hopkins University Applied Physics Laboratory (JHU/APL), Laurel, MD.

Introduction: Johns Hopkins University Applied Physics Laboratory (APL) and Lawrence Livermore National Laboratory (LLNL) are collaborating to develop a high-resolution, gamma-ray spectrometer (GRS) for planetary composition measurements. This instrument, called GeMini Plus (Fig. 1), is unique in that it offers laboratory-quality resolution in a low-resource package (low mass, low volume, low power). GeMini Plus is well suited for resource-constrained missions, including landed and orbital missions to planets, moons and asteroids. GeMini Plus is funded under the Maturation of Instruments for Solar System Exploration (MatISSE) NASA program.

GeMini Plus is the descendant of the MESSENGER GRS that successfully flew to the planet Mercury [1]. Lessons learned from the MESSENGER GRS and LLNL hand-held terrestrial GeMini spectrometer [2] have been incorporated into GeMini Plus. This has resulted in a low-resource and rugged design. GeMini Plus has been fully assembled in the laboratory and will undergo initial characterization that will include energy resolution, sensor efficiency, thermal & cryocooler efficiency, radiation damage testing (simulated space radiation damage), and annealing techniques.

Fig. 1. GeMini Plus sensor, including a Ricor cryocooler. Not shown are the power supplies and readout electronics.

Planetary Nuclear Spectroscopy: Gamma-ray spectroscopy enables the measurement and quantification of planetary surface composition; this knowledge helps to address many science questions, including constraining the formation history of the planetary body [3]. GeMini Plus is sensitive to a range of elements commonly found at the surface of a planetary body.These elements include: H, C, O, Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Fe, Th and U.

Because gamma-rays are highly penetrating GeMini Plus is sensitive to materials from the surface to tens of cms below the surface. This allows for the characterization of elemental composition below the regolith which is less dependent on weathering effects.

GeMini Plus Gamma-Ray Spectrometer: GeMini Plus measures gamma rays with a cryogenically cooled, 5cm diameter by 5cm height, n-type, high-purity germanium (HPGe) crystal. Gamma-ray spectrometers are characterized by two principal parameters: intrinsic energy resolution and sensor efficiency. Intrinsic energy resolution quantifies the spectral resolving power of the GRS, allowing specific gamma-ray energy lines to be resolved from other lines and distinguished from background counts. Sensor efficiency quantifies the ability of the sensor to convert incident gamma rays into measureable counts. The physical size of a GRS sensor affects its efficiency: high-volume, high-density sensors provide a higher efficiency than low-volume, low-density sensors.

Energy Resolution Measurements: Previously flown planetary GRS have been either inorganic scintillators (NaI, BGO, CsI, LaBr) or cryogenically cooled HPGe sensors [4-6]. The energy resolution for scintillators is quoted as a percentage at 662 keV, with values ranging from 3 to 15%. In contrast, the energy resolution for HPGe spectrometers at 662 keV is < 0.5%. Fig 2. shows the difference between the two types of sensors (CsI and HPGe) via gamma ray spectra; the superior energy resolution of the HPGe sensor is shown.

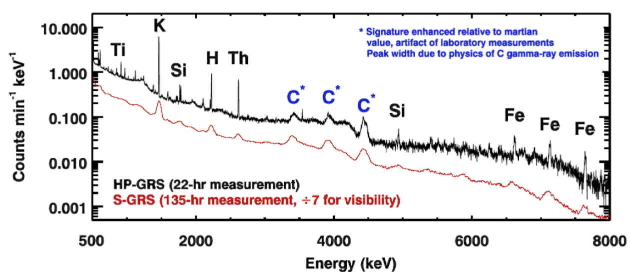

Fig. 2. Comparison of gamma-ray spectra for the GeMini Plus HPGe spectrometer and a CsI-based gamma-ray spectrometer. The measurement was made with Mars soil simulant at the JHU/APL Planetary Gamma-Ray and Neutron Simulation Facility.

Cryocooler Trade Studies: GeMini Plus uses a miniature cryocooler to maintain a crystal temperature of approximately 77 – 100 K. The previous MESSENGER GRS was equipped with a Ricor K508N cryocooler, which was lightweight and low power, but had a short lifetime. Advances in technology have enabled new, longer-lifetime, separated cold-head cryocoolers to be developed. These new cryocoolers offer increased reliability, as well as a significant reduction in electronic noise, which enables improved energy resolution compared to the Ricor cryocooler (Fig. 3).

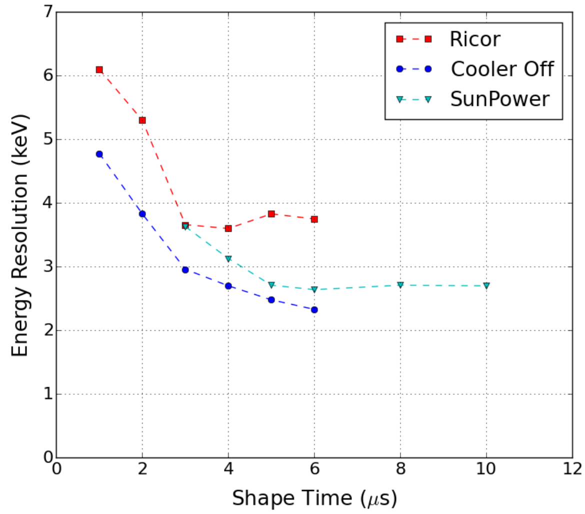

Fig. 3. Measured gamma-ray energy resolution versus signal shaping time for the GeMini Plus prototype using a ^{60}Co source (1332keV). A comparison of resolution was made between a Ricor K508N and a SunPower DS 1.5. A baseline comparison was made with the cooler off to eliminate noise from the cyrocooler (measurements of 5 to 10 minutes are made with cooler off before the crystal heats appreciably).

Currently, three different cryocoolers are being investigated: the Ricor K508N, the SunPower DS 1.5, and the Lockheed Martin Micro Pulse Tube Cyrocooler (Fig. 4). Other micro cryocoolers, from companies such as Thales Cryogenics and Ricor, are also being considered as possibilities for further investigation. The modular design of the GeMini Plus allows for an interchangeable cryocooler, such that it may be switched out depending upon mission requirements (lifetime, cost, weight, etc.).

Fig. 4. The Lockheed Martin Micro Cryocooler has a low mass (450 grams), long life expectancy (10 years) and sufficient heat lift (500 mW heat lift at 77 K)[7].

Thermal Design & Vibration Testing: To survive rocket-launch and maintain an internal crystal temperature of approximately 80K, a rigorous suspension system had to be designed and tested. The internal HPGe crystal is rigidly contained in a gold-plated aluminum capsule. The capsule is suspended and thermally isolated from external cryostat housing by Kevlar strings. The capsule is then cooled to 77 – 100 K by the mechanical cryocooler, which makes a connection to the internal capsule via a flexible copper braid. The Kevlar string mechanism was individually tested and rated to an ultimate tensile strength of 1110 N. The final design of the sensor housing with suspension system was successfully tested on a shake table and subjected to vibration loads mimicking rocket launch. Vibration 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 on all three axes; results demonstrated that any resonances are well outside of the measurement bandwidth. Further experimental testing will be done to evaluate the thermal design (cool-down durations, steady-state power demands, thermal loads).

Radiation Damage & Annealing: HPGe crystals are subject to radiation damage from cosmic ray bombardment, causing degradation of the sensor's energy resolution over time. These effects are seen at a fluence around 10^8 /cm^2, which is roughly a year in space (dependent on solar cycle and proximity to planetary bodies). Fortunately, annealing the HPGe crystal at a temperature of 100 ^{o}C for several days can reverse the effects of radiation damage.

The NASA Space Radiation Laboratory at Brookhaven National Laboratories offers a GeV proton beam line; several germanium crystals will be irradiated at this facility to simulate long duration missions in harsh radiation environments. This will allow us the opportunity to anneal the instrument under various conditions in order to optimize annealing time and temperature.

Flight Electronics: A low mass, MESSENGER flight-heritage data processing unit (DPU) has been developed for GeMini Plus. The DPU consists of four modular slices that are coupled together, forming a compact electronics stack. 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. The FPGA is programmed with all-digital filtering algorithms and has been shown to be comparable to commercial laboratory analyzers.

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