COUGRS: A Low-Resouce Gamma-Ray Spectrometer for Surface Science Investigations into Planetary Origins and Evolution P. N. Peplowski[1*], J. O. Goldsten[1], D. J. Lawrence[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723, [*]Patrick.Peplowski@jhuapl.edu

Introduction: Gamma-ray spectroscopy is a proven technique for the remote characterization of the elemental composition of planetary surfaces. Planetary gamma-ray emissions, which result from galactic cosmic ray (GCR) induced excitation of nuclei as well as natural radioactive decay, provide element-characteristic signatures that can be used to characterize surface composition. Gamma-rays have the unique ability to probe to depths of 10s of cm, beyond surficial layers altered by space weathering and into more pristine material beneath. Results from planetary gamma-ray investigations, which have been included on the NEAR, Lunar Prospector (LP), Mars Odyssey (MO), MESSENGER, Kaguya, Chang'e, and Dawn missions, have revolutionized our views on the formation and evolution of the terrestrial planets and small solar system bodies (e.g. [1-5]).

The science return of a Gamma-Ray Spectrometer (GRS) largely depends on the technology used for the sensor element. Scintillators, such as those used on NEAR, LP, Chang'e, and Dawn, can provide robust characterization of major (H, C, O, Mg, Si, Al, Ca, Ti, Fe) and some minor (K, Th, U) elements with low operational encumbrances [2,6,7]. Semiconductor sensors, in particular high-purity germanium (HPGe), provide an order-of-magnitude improvement in energy resolution, which facilitates measurements of elements (e.g. Na, Cl) that are difficult to characterize with scintillators [3,8,9]. Unfortunately, HPGe is sensitive to radiation damage, requiring periodic annealing activities, operates at high-voltages (>3000 kV), and requires cryogenic cooling.

For resource-challenged missions, scintillators are the most attractive option. However, showing that they can meet all of the science goals can be a challenge. We present a new scintillator GRS design – the COmpact, Ultra-light Gamma-Ray Spectrometer (COUGRS) – which meets the need for low-resource measurements of bulk elemental composition on small spacecraft, particularly landers.

Instrument Design: COUGRS was designed with the goal of providing a low-cost, low-resource alternative to traditional GRS systems. The design utilizes spaceflight-heritage components in a compact instrument whose mass and power requirements are an order-of-magnitude lower than prior GRS instruments. We selected CsI as our scintillator of choice based on its moderate energy resolution, extensive spaceflight heritage, and most importantly its ability to be read out by a photodiode. The use of photodiodes over traditional photomultiplier tubes greatly reduces the instrument volume and alleviates the need for high voltage.

The COUGRS design uses multiple, small CsI crystals in place of a single large sensor. This maintains the energy resolution of the system, which would otherwise decrease with increasing sensor volume. This modular sensor design allows for the sensitivity of the instrument to be increased to suit mission needs by simply adding additional sensor elements. A three-sensor version of COUGRS is shown in Fig. 1, and its characteristics are detailed in Table 1. A two-sensor version has been built and is a hosted payload on the upcoming Balloon Observation Platform for Planetary Science (BOPPS) high-altitude balloon as a test of its sensitivity to carbon signatures and to raise its TRL.

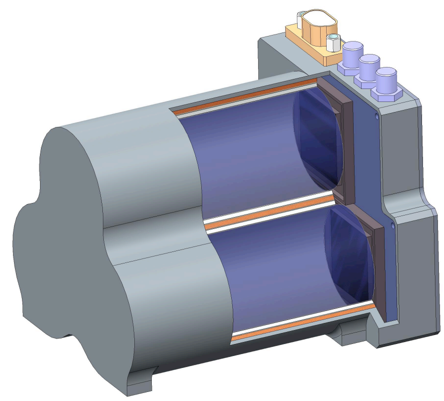

Figure 1. Cut-away of the three-sensor COUGRS design.

Table 1. Summary Specifications:

Sensor:	Three 2.5x6 cm CsI crystals
Energy Range:	300 keV to 9 MeV
Energy Resolution:	5.8% @ 661 keV
Intrinsic Efficiency:	40% @ 661 keV
Total Mass:	700 g
Volume	10 cm x 8 cm x 5 cm
Power Dissipation:	<1 W
Data Rate:	< 100 bps

Because gamma-ray spectroscopy is an inherently count-rate-restricted technique, and sensitivity tracks directly with sensor volume, compact systems are not well suited to orbital measurements - particularly those acquired at altitudes >1 body-radius away. As a result, COUGRS is intended for surface science operations. On the surface, the gamma-ray continuum is dominated by scattering within the surface, not from galactic cosmic rays backgrounds in the sensor, and therefore an anticoincidence shield (ACS) is not needed. This further reduces the mass of the instrument. NEAR GRS measurements using the raw outer detector signal were recently used to associate Eros with the L and LL chondrites [6], and demonstrate that surface GRS measurements do not require an ACS.

Science with COUGRS: We have explored the science return of COUGRS for a surface based measurement whose goal is to associate surface composition to meteorite composition. This is similar to the science goals of NEAR, Dawn at Vesta, and a number of missions advocated by the planetary science decadal survey. A 24-hour COUGRS measurement is sufficient to distinguish between achondrite-, ordinary chondrite, and carbonaceous-chondrite-like material with three-standard-deviation precision (Fig. 2). Longer measurements provide additional constraints, for example the 72-hour-long measurement shown in Fig. 3 highlights discrimination between various carbonaceous-chondrite-like materials through measurements of C/Si vs. S/Si. The sensitivity of gamma-ray spectroscopy to C was recently shown by [10]. In addition to Si, Fe, C, and S (Figs 2, 3), COUGRS is also sensitive to H, Mg, Al, K, Ca, and Ti concentrations.

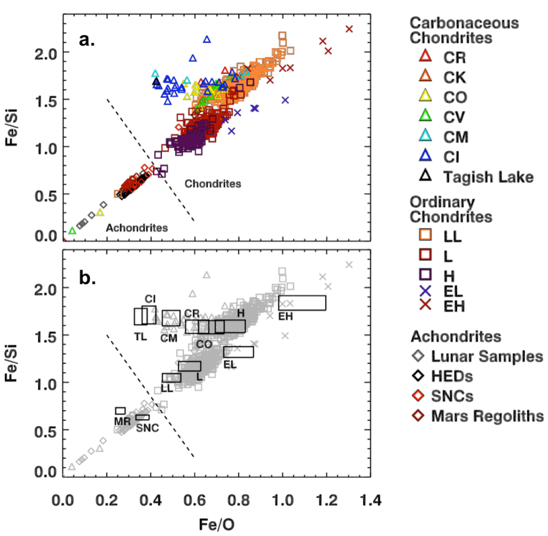

Figure 2. Simulated performance of COUGRS for a 24-hour surface measurement. Boxes highlight 3-standard-devation measurement uncertainties.

Two mechanisms are available for measuring H with COUGRS. For >0.5 wt% H abundances, the 2223-keV gamma-ray provides a direct measure of H. For smaller concentrations, Fe photon ratios are diagnostic of H content. This technique was recently demonstrated on asteroid 433 Eros using NEAR GRS data [6], where the H content of Eros (1000^{+1700}_{-600} ppm) was found be consistent with L and LL chondrite falls, material that had previously been found to be consistent with NEAR geochemical measurements.

Accommodation: The advantages provided by a scintillator GRS can be leveraged to improve the science return of the instrument. For example, the small size and mass of COUGRS greatly expands is accommodation potential, allowing for it to be placed on arms, booms, or legs where the gamma-ray background will be lower. Additionally, its low power and data usage facilitate collecting multiple, long-duration measurements that limit statistical uncertainties.

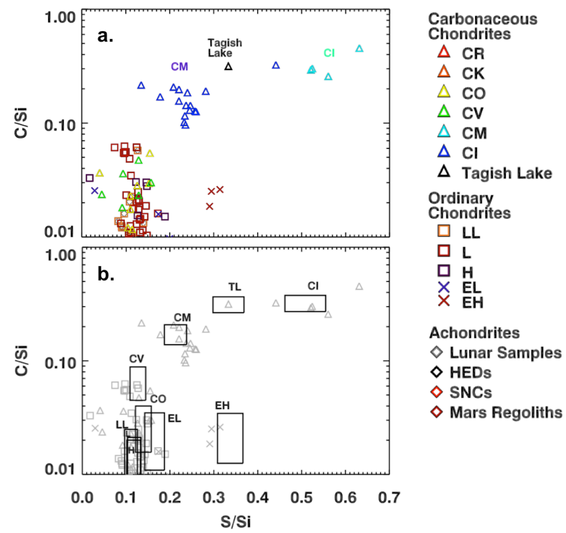

Figure 3. Simulated performance of COUGRS for a 72-hour surface measurement. Boxes highlight 3-standard-devation measurement uncertainties.

Potential Missions: A number of missions identified as high-priority in the 2012 Planetary Science Decadal Survey would benefit from the inclusion of COUGRS. These include sample context measurements for Mars, Comet, or South Pole-Aiken basin sample return mission and surface composition measurements of primitive solar system bodies, like near-Earth, main belt, and Trojan asteroids or the martian moons Phobos and Deimos.

References: [1] Lawrence et al. (1998) *Science, 281, 1484-1498.* [2] Prettyman et al. (2006) *J. Geophys. Res. 111, E12007.* [3] Boynton et al. (2007) *J. Geophys. Res. 112, E12S99.* [4] Peplowski, P. N. et al. (2011) *Science, 333*, 1850-1852. [5] Prettyman et al. (2012) *Science 338, 242-246.* [6] Peplowski et al. (2014) *Meteorit. Planet. Sci. (submitted manuscript)* [7] Zhu et al. (2010) *Planet. Space Sci. 58, 1547-1554.* [8] Evans, L. G. et al. (2012) *JGR 117, E00L07.* [9] Peplowski et al., (2014) *Icarus 228, 86-95.* [10] Peplowski et al. (2014) *Planet. Space Sci. (submitted manuscript).*