BULK ELEMENTAL COMPOSITION MEASUREMENTS OF THE LUNAR SUBSURFACE WITH BECA.
A. M. Parsons[1], R.D. Starr[2], D. J. Lawrence[3], P. N. Peplowski[3], Luke Perkins[4], [1]NASA Goddard Space Flight Center, Greenbelt, MD, USA (Ann.M.Parsons@nasa.gov), [2]Catholic University of America, Washington D.C., USA, [3]Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, USA, [4]Schlumberger Geoservices –Clamart, France

Introduction: The Bulk Elemental Composition Analyzer (BECA) is a new instrument under development for inclusion on future landed lunar exploration missions. With its technology maturation funded through the Development and Advancement of Lunar Instrumentation (DALI) program, BECA is ideally suited to making high precision *in situ* measurements of the bulk elemental composition of the near-surface of the Moon. With no moving parts, BECA will provide bulk elemental composition information over a volume roughly 1 m radius and 20 cm depth beneath the lunar surface without the need to touch the surface regolith. BECA will therefore be a highly useful tool for answering fundamental lunar science questions and fills a special niche in that it measures the bulk composition of materials beneath the lunar surface. BECA measurements will thus be less sensitive to effects of space weathering and other surface processes. BECA is especially versatile in application, with its ability to produce scientifically important information in static lander, astronaut-deployable and lunar rover configurations.

Instrument Capabilities: BECA's measurements of the local concentrations of both major and minor rock-forming elements such as H, O, Na, Mg, Al, Si, P, S, Cl, Ca, Ti, and Fe and the naturally radioactive elements K, U and Th will provide important geochemical constraints on the thermal and compositional evolution of the Moon. BECA will also answer outstanding science questions about lunar formation through its measurements of the distribution of lunar volatile elements at both polar and middle latitudes. In addition to these scientific contributions, BECA will also provide *in situ* ground truth validation for orbital composition maps obtained by multiple missions. Finally, BECA will also provide extremely useful information about near-surface resources important for future lunar exploration.

The BECA instrument includes a Pulsed Neutron Generator (PNG) which is a high flux, pulsed source of high energy (14 MeV) neutrons that penetrate into the lunar subsurface. These energetic neutrons cause the materials to emit gamma rays with energies characteristic of the elements that produced them. BECA's Gamma Ray Spectrometer (GRS) measures their energies to identify the elements present and their intensities to determine the abundance of each element. Low energy neutrons are also emitted by the lunar surface and measurements by BECA's Neutron Detectors (NDs) allow for a more sensitive and deeper measurement of hydrogen than is available from the gamma rays alone. BECA offers important science and resource detection capability for both static landers, astronaut-deployable instrument packages and rovers. The inclusion of the PNG allows BECA to quickly make scientifically important measurements. For some elements, useful data can be obtained in as little as 15 minutes; complete composition measurements will be achieved in about 2 hours.

Lunar Geochemistry Investigations with BECA: The geological and geochemical diversity of the lunar surface provides numerous opportunities for scientific discovery with BECA. A few of the possible investigations are described below along with specific applications to BECA compositional measurements.

Magnetic Anomalies and Swirls The lunar crust contains numerous locally magnetic areas, ~tens to hundreds of km across, known as magnetic anomalies. The strongest anomalies may be on the order of 1000 nT at the surface. Hypotheses for the formation of lunar magnetic anomalies include magnetized basin ejecta; imprinted magnetization via comet-impact plasma interactions; igneous intrusions; and metallic iron impactor remnants magnetized in the now-extinct lunar magnetic field. Many magnetic anomalies are co-located with reflectance features called swirls. Lunar swirls are irregular, high-reflectance features that appear optically immature, have no topographic relief, and appear depleted in OH relative to their surroundings [1].

Mobile rover-based measurements could map compositional differences across the light and dark patches of the lunar swirls, providing a valuable benchmark for models of regolith processes and weathering on anhydrous airless bodies. BECA's measurements of the elemental composition within a lunar swirl can, for example, test the theory that they are formed via attenuated space weathering due to solar wind shielding by a local magnetic anomaly because this predicts that lower-than-average H content should be observed at these locations.

Volatiles in South Pole PSRs Although the Moon was once presumed "dry", the presence of volatiles, namely hydrogen and possibly water, has been determined in a variety of ways. Clementine bi-static radar and Lunar Prospector neutron spectroscopy measurements from lunar orbit provided the first evidence that enhanced amounts of water ice exist at the lunar poles [2, 3]. Permanently Shadowed Regions (PSRs), locations on the Moon that do not see the sun for geologically long periods of time, have very cold temperatures (<~120 K) and can therefore trap water and other volatiles. PSRs exist within craters at both poles because the Moon's axis of rotation is nearly perpendicular to the plane of its orbit around the sun. Follow-up studies of the initial Lunar Prospector results suggest that the enhanced hydrogen mostly located within PSRs [4] is likely in the form of water ice [5], has an average abundance of 1.5 ± 0.8 wt.% water equivalent hydrogen within the PSRs [6], and is likely covered by tens of centimeters of less volatile-rich material in many locations but may reach the surface in some PSRs [7]. A variety of types of measurements made by instruments on the Lunar Reconnaissance Orbiter (LRO), launched in 2009, have also shown evidence of the presence of water within many PSRs [8,9,10].

While there is substantial evidence for the presence of volatiles at the lunar poles, there is much that is unknown about their chemical species and spatial distribution. BECA would be a very exciting tool for exploring the distribution of volatiles in and near PSRs. A rover is helpful in this instance because a lander only allows measurements at the landing location and given that the targeted volatiles are in or near the PSRs, the landing location is not likely to contain the largest concentration of volatiles. Because the PSRs are, by definition, areas where solar power is unavailable, it is important that the PSR volatile composition measurements be made very quickly. BECA's PNG allows scientifically useful measurements in 15 minutes – 2 hours.

South Pole Aitken Basin The 2500 km diameter South Pole Aitken (SPA) Basin is the largest, deepest and perhaps the oldest impact crater on the Moon. SPA was called out specifically as a high priority target for a future mission in the current Planetary Decadal Survey [11]. SPA is unique in the inner solar system because of the magnitude of the SPA impact that potentially excavated lunar crust and upper mantle materials. The SPA basin may thus provide a glimpse into the Moon's early interior composition. While a diverse range of mafic impact melts and basalt materials are represented within the SPA basin, the dominant material is Mg-rich pyroxene. SPA also hosts anomalous concentrations of thorium near its northern rim and a central geochemically distinct "Mafic Mound" region, with relatively higher Fe and Ca concentrations as compared to the surrounding basin.

BECA is uniquely suited to directly measure the bulk near-surface heterogeneity of the major rock forming elements of the SPA basin. A BECA study of locations within the SPA interior would baseline the geochemical composition of the lunar interior. If onboard a rover, BECA could provide insight into the early solar system evolution. With knowledge of SPA's geochemical composition, a direct comparison to Apollo samples can be made to better understand the interior of the near and far sides of the Moon. BECA could also be deployed in SPA's high-thorium regions to better define the Th distribution and could test whether this Th enrichment is due to distinct impacts or it is of intrusive origin. Such data would provide valuable information for studies of lunar differentiation and thermal evolution.

Technology Maturation Progress: In addition to describing the science that BECA will enable, we will report the current progress in the instrument maturation effort. The BECA Team represents a close collaboration between personnel at NASA Goddard Space Flight Center (NASA/GSFC) who are adapting the PNG controller electronics to spaceflight applications, the Johns Hopkins Applied Physics Laboratory who will be providing the Data Processing Unit (DPU) and the sensors and our industrial partner Schlumberger Technology Corporation who will be providing the PNG. While the BECA instrument currently contains components ranging from TRL 4 to TRL 9, we are working to bring these individual components to at least TRL 6 and then test BECA in both static lander and rover configurations to verify the maturation of the entire BECA instrument system. BECA's performance in both the static lander and small rover configurations will be tested at the Gamma ray Neutron Test Facility (GNTF) at NASA/GSFC.

References: [1] Jawin, E. R *et al.,* (2018), Findings Report for the *Lunar Science for Landed Missions Workshop*, NASA Ames Research Center. [2] Nozette, S., *et al.,* (1996), *Science*, 274, 1495–1498. [3] Feldman, W. C. et al., (1998), *Science*, 281, 1496-1500. [4] Eke, V. R. *et al.,* (2009), *Icarus*, 200, 12–18. [5] Feldman, W.C. *et al.,* (2001), *J Geophys Res.:Planets,* 106, 23231–23251. [6] Feldman, W.C., *et al.,* (2000), *J. Geophys. Res.,* 105, 4175–4196. [7] Miller, R.S., *et al.,* (2014), *Icarus*, 233, 229–232. [8] Lucey, P. G. *et al.,* (2014), *J. Geophys Res: Planets,* 119, 1665–1679. [9] Hayne, P. O. *et al.,* (2015), *Icarus*, 255, 58–69. [10] Sanin, A. B., et al., (2017), Icarus, 283, 20-30. [11] Squyres, S.W., *et al.,* (2011), Vision and Voyages for Planetary Science in the Decade 2013-2022. *National Academies Press*, 1–410.