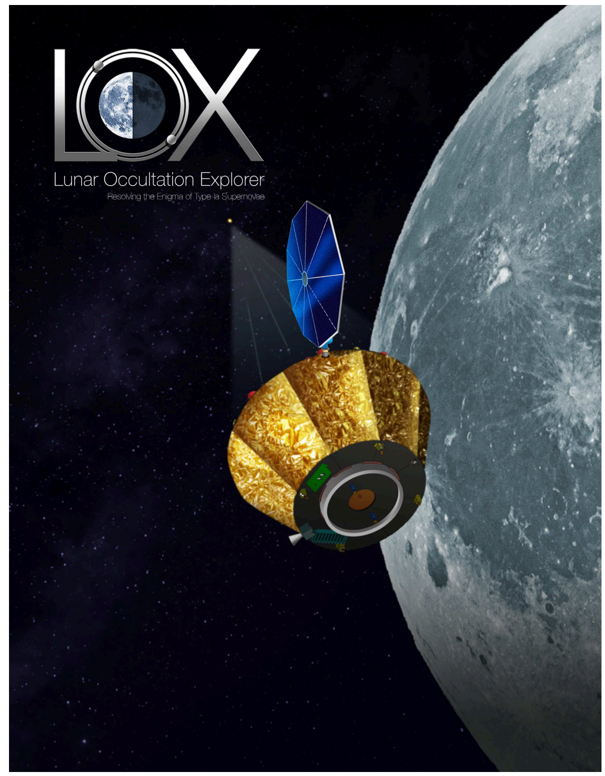
The Lunar Occultation Explorer (LOX): Establishing the Moon as a Platform for Next-Generation Nuclear Astrophysics Investigations. R. S. Miller[1], M. Ajello[2], J. F. Beacom[3], P. F. Bloser[4], A. Burrows[5], M. Errando[6], J. O. Goldsten[7], D. Hartmann[2], P. Hoeflich[8], A. Hungerford[9], D. J. Lawrence[7], J. C. Leary[7], M. D. Leising[2], P. Milne[10], P. N. Peplowski[2], L-S. The[2], [1]University of Alabama in Huntsville, OPB300H, Huntsville, AL 35899, richard.s.miller@uah.edu, [2]Clemson University, Clemson, SC 29631, [3]The Ohio State University, Columbus, OH 43210, [4]University of New Hampshire, Durham, NH 03824, [5]Princeton University, Princeton, NJ 08544, [6]Washington University in St. Louis, St. Louis, MO 63130, [7]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, [8]Florida State University, Tallahassee, FL 32309, [9]Los Alamos National Laboratory, Los Alamos, NM 87545, [10]University of Arizona-Steward Observatory, Tuscon, AZ 85721.

Introduction: The Lunar Occultation Explorer (*LOX*) will leverage the power of a new observational paradigm to transform our understanding of the nuclear cosmos (0.1–10 MeV) and establish the Moon as a platform for astrophysics. Originally developed as a standalone Explorer-class mission, *LOX*'s straightforward implementation strategy and operation profile make the Deep Space Gateway an attractive alternative platform for deployment.

LOX will operate from lunar orbit, using the Moon as a natural occulting disk to temporally modulate cosmic sources of nuclear gamma-rays as they repeatedly rise and set over the lunar limb. The modulation signatures imprinted on acquired gamma-ray time-series data contain *all* the information necessary for source characterization and localization. This innovative use of the Moon, combined with *LOX*'s wide-field-of-view and continuous all-sky monitoring, provides an effective way of addressing multiple Decadal Survey questions in the nuclear gamma-ray regime. The *LOX* approach achieves high sensitivity with a simple instrument design, while also taking advantage of the relatively benign, easily characterized, and slowly changing background environment of the Moon. These capabilities give *LOX* a transformational capacity for discovery.

The tremendous potential of nuclear astrophysics measurements is currently unrealized for the simple reason that instrument sensitivity has been inadequate for nuclear gamma-ray measurements. To date, observational techniques have solidified around a single detection methodology—Compton scatter tele- scopes—that require complex implementation, development, and operational resources to advance their capabilities. The associated technology and cost constraints have limited significant progress in astrophysics at MeV energies for almost a quarter century [1,2]; in fact, from 1980 until today, sensitivity has improved by only a factor of ten. This contrasts markedly with advances in soft X-ray, hard X-ray, GeV gamma-ray, and TeV gamma-ray astrophysics.

LOX directly challenges this paradigm to provide a unique set of time-domain nuclear astrophysics capabilities. *LOX* eliminates the need for complex, position-sensitive detectors, kinematic event reconstruction, masks, or other insensitive detector mass, while also mitigating technology development and implementation complexity as well as their associated costs (e.g., [3]).



Lunar Occultation & the Case for the Moon: Astronomical investigations from the Moon afford new opportunities to advance our understanding of the cosmos. The foundation of *LOX* is the lunar occultation technique (LOT), an observational paradigm uniquely enabled by the Moon and well suited to the all-sky monitoring demands of nuclear astrophysics investigations [4], including uniform and continuous monitoring of the sky at full sensitivity. Temporal modulation is the foundation of the lunar occultation approach.

LOX's location in lunar orbit provides many advantages over traditional, Earth-orbiting gamma-ray observatories. The LOT provides long observing periods, and the correspondingly large number of occultations gives long on-source exposure times. Additionally, the gamma-ray backgrounds from the lunar surface provide an in-situ calibration source that reduces associated systematics to the level of a few percent [5]. The variations in this background, the result of variability in the cosmic-ray flux and lunar composition, are understood and correctible [5]. The irreducible cosmic diffuse gamma-ray flux is also well understood. In contrast, Earth-orbiting observatories must contend with dynamic and complex background environments that change on orbital timescales and are not easily characterized [6].

All aspects of the occultation technique— including source-analysis methodologies [4,7,8], operation of instrument components [9-12], and systematics driven by the lunar background environment—have been validated from lunar orbit.

Implementation: The *LOX* science objectives are achieved using a single-instrument payload consisting of a large array of identical gamma-ray detector modules. *LOX* combines established detector technology with heritage electronics in a straightforward way that minimizes both implementation and operational risk. Our proposed approach meets all science requirements with ample margin.

LOX will place a large-area gamma-ray spectrometer array into lunar orbit and continuously acquire broadband spectra. As *LOX*'s orbit evolves with respect to the celestial sphere, large swaths of the sky are surveyed. Although spectra are acquired continuously, they will be divided into (artificial) observing periods to facilitate the identification of transient gamma-ray signatures and monitor evolving astrophysical light curves.

The instrument will be pointed to the nadir (i.e., toward the center of the Moon), and sources will repeatedly rise and set along the lunar limbs. This low-resource implementation has modest operational demands and currently adopts a large-area (~1.5 m^2) gamma-ray spectrometer as its single instrument. Rather than being monolithic, the *LOX* instrument is an array of individual gamma-ray spectrometer modules that operate as a single instrument (BAGEL, Big Array for Gamma-ray Energy Logging). The instrument's top-level design and functionality are simple and well-established, leveraging design and operational heritage from multiple planetary and astrophysics science missions.

Simplicity is a hallmark of the *LOX* concept. It requires only a non-imaging spectrometer in lunar orbit. Operations are simple because there are no slewing or onboard data-processing requirements; data-analysis protocols are based on flexible and established time-series analyses of acquired spectra [4,5,7]. Flux sensitivity, spectral resolution, field of view (FoV), and source localization are governed by implementation parameters such as spectrometer size, detector type, orbit altitude, and spectrum integration times (i.e., mission-level rather than technology-driven solutions). The *LOX* concept is also highly scalable, limited only by resource constraints such as mass and power.

All elements of *LOX* are high-heritage, and most have operated in-situ from lunar orbit for extended periods of time. Mission operations and operating conditions are proven and well-established, and recent proof-of-principle efforts led to the first high-energy astrophysical source detection from the Moon. These features establish *LOX* as a low-risk, cost-effective, and competitive venture that will address several Decadal Review findings, provide new insights into the lifecycle of matter and energy throughout the cosmos, and resolve the enigma of thermonuclear supernova, the beacons of the cosmos.

Summary: *LOX* is a low-risk, cost-effective, and competitive astrophysics mission concept that challenges established paradigms in nuclear astrophysics investigations, will provide new insights into the lifecycle of matter and energy throughout the cosmos, and establish the Moon as a platform for high-energy astrophysical sciences.

Estimated Mass: 350-500 kg
Estimated Volume: ~20 m^3
Estimated Power Requirement: 100-300 W
Estimated Data Volume: 100-200 Mbyte/day
Location on DSG: External, lunar nadir pointing
Preferred Orbit: Lunar (altitude tbd)
Crew Interaction: None

References: [1] Schönfelder, V., et al. (1992), in *Data Analysis in Astronomy IV*, New York: Springer, p. 185. [2] Schönfelder, V., et al. (2000), *Astron. Astrophys. Suppl. Ser.*, 143:145–179. [3] Boggs, S. E., et al. (2006), arXiv:astro-ph/0608532v1. [4] Miller, R. S., and D. J. Lawrence (2016), *Ap. J. Lett.*, 823:L31. [5] Lawrence, D. J., S. Maurice, and W. C. Feldman (2004), *JGR*, 109:E07S05. [6] Harmon, B. A., et al. (2002), *Astrophys. J. Suppl. Ser.*, 138:149–183. [7] Miller, R. S. (2012), J*GR*, 117:E00H19. [8] Miller, R. S., G. Nerurkar, and D. J. Lawrence (2012), *JGR*, 117:E11. [9] Lawrence, et al. (1998), *Science*, 281:1484–1489. [10] Lawrence, et al. (2002), *JGR*, 107:5130. [11] Feldman, W. C., et al. (1999), *NIM. A*, 422:562–566. [12] Feldman, W. C., et al. (2004), *JGR*, 109:E07S06.