THE LUNAR OCCULTATION OBSERVER (LOCO) - A NUCLEAR ASTROPHYSICS ALL-SKY SURVEY MISSION CONCEPT

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Introduction: The Moon is a unique location for experimental astrophysics. It's dense regolith and lack of an appreciable atmosphere are just two of the characteristics that can be brought to bare on the challenges of high-energy astrophysics.

The Lunar Occultation Observer (LOCO) is a new γ-ray astrophysics mission concept expected to have unprecedented sensitivity in the nuclear regime (~0.02-10 MeV). LOCO will perform an all-sky survey of the Cosmos, and will have the capability to address multiple high-priority science goals in a scaleable and cost effective way. The astrophysics goals include, but are not limited to, Galactic nucleosynthesis, supernovae & novae, potential dark matter annihilation processes, active galactic nuclei, and compact objects. The mission can also be used to perform high-resolution , high-sensitivity orbital geochemistry of the Moon.

LOCO will be a pioneering mission in high-energy astrophysics: the first to successfully employ occultation imaging as the principle detection method. Typically, instruments operating in the hard X-ray or nuclear γ-ray regime are either coded-aperture (~10-500 keV) [1] or Compton telescope (~0.5-10 MeV) imagers [2], respectively. Occultation, however, is a powerful - yet relatively simple - alternative approach, relevant in regimes where traditional imaging approaches are inappropriate, complex, or cost prohibitive.

Placed into lunar orbit, LOCO will use the Moon to occult astrophysical sources as they rise and set along the lunar limb. The encoded temporal modulation will then be used to image the sky thereby enabling spectroscopic, time-variability, point- & extended-source analyses. The benefits of this concept derive from the innovative imaging technique and the lack of a lunar atmosphere & magnetosphere.

By extending the development heritage of planetary orbital-geochemistry investigations with new developments in astrophysical imaging, the LOCO concept will achieve the excellent flux sensitivity, position, and energy resolution required of the next-generation nuclear astrophysics mission. Preliminary modeling of its performance show it to meet or exceed the performance necessary to probe this regime. In addition, the concept is cost effective, requires a minimum of technology development, and has a relatively straightforward and scaleable implementation.

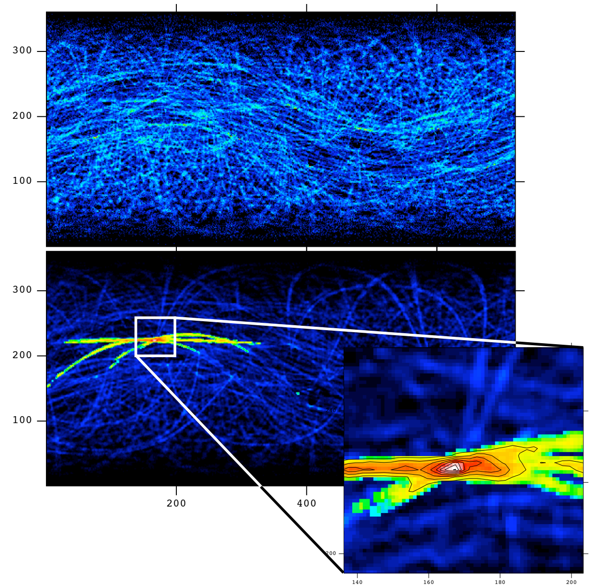

Figure 1. Occultation image generated for one configuration of the LOCO concept. Shown are the lunar limb projections (top), a likelihood weighted image, and the image of a hypothetical astrophysical source at the position of the Crab Nebula (inset).

Occultation Imaging: Conventional imaging techniques, such as the focusing of light with reflecting or refracting optics, are not possible in the hard X-ray or γ-ray regime due to the penetrating nature of the electromagnetic radiation. Imaging, however, has significant advantages over simple measurements of source flux including, but not limited to, the ability to spatially locate astrophysical sources, minimize the contribution of backgrounds, and reduce the effects of source confusion. In short, imaging capabilities translate directly into improved source sensitivity and science return.

Occultation imaging requires astrophysical sources to be repeatedly eclipsed by a natural or artificial object, with the temporal modulation effectively encoded on the acquired data. In its simplest form, occultation image generation requires the identification of rising and setting occultation "edge", as well as knowledge of the ephemerides of the occulting object and detector. Sources can be subsequently identified within the images and analyzed to obtain parameters such as source intensity, variability, and spectrum. A detailed description of the geometry of occultation imaging can be found elsewhere (e.g. [3-6]).

Lunar Occultation Technique: To maximize performance and science return, LOCO will utilize the Moon as an occulting object. This Lunar Occultation Technique (LOT) [6] is conceptually similar to previous approaches in Earth orbit, but will lead to increased sensitivity due to the following factors:

- **Dense Regolith vs. Terrestrial Atmosphere** Relative to the tenuous terrestrial atmosphere, the dense lunar regolith is an optimal occultation medium that generates sharp (fast) occultation features. The duration of the occultation edge (rise and/or fall time) translates directly into spatial resolution.
- **Lunar vs. Terrestrial Atmosphere** The lack of an appreciable lunar atmosphere eliminates the energy dependent attenuation of incident X- and γ-rays prior to occultation, translating into improved spatial and spectral resolution relative to the Earth-based approaches.
- **Lunar vs. Terrestrial Magnetosphere** Earth-orbiting spacecraft experience significant variations in charged backgrounds as they move through the various rigidity cutoffs within the terrestrial magnetic field. Activation and dynamic background effects result, generating non-trivial systematic effects. These issues are significantly mitigated (or eliminated) at the Moon.

At nuclear energies, backgrounds at the Moon consist of well characterized and/or easily monitored components such as primary cosmic rays, diffuse X- & γ-ray emission, as well as the lunar albedo. Except for periods of high solar activity, these background components vary on time scales significantly longer (days to months) than a typical spacecraft orbital period (~120 minutes for 100 km orbit altitude). Due to their modest variability, background systematics are easily accounted for, with certain components (e.g. 6.13 MeV γ-rays from lunar albedo ^{16}O de-excitation) used as in-situ calibration sources and proxies for monitoring instrument generated backgrounds.

Spectrometer Concept: The sensitive component of LOCO is a large-area spectrometer. Occultation imaging eliminates the need for a complex position-sensitive science instrument, relying instead on temporal modulation of source fluxes.

Studies related to optimized detector geometries and implementations are ongoing. The spectrometer will record temporal modulations in photon count rate as sources rise and set along the lunar limb during the spacecraft's orbit about the Moon. The key parameter here is the large area necessary to achieve the required flux sensitivity. An array, built up from modest, relatively inexpensive, spectrometers is the most cost-effective (and realistic) approach for the baseline instrument.

Each spectrometer module will incorporate an inorganic scintillator crystal, an associated opto-electronic readout device, and front-end electronics. For individual spectrometers the key design parameters are stopping power, intrinsic energy resolution, and (scintillation) light collection efficiency.

Our current spectrometer design incorporates recent advances in scintillator technology in the form of Cerium-doped Lanthanum Bromide, $LaBr_3$:Ce. This material has great promise, excellent energy resolution (<3% @ 662 keV) and will significantly impact spectroscopic endeavors. We are also evaluating a new detector design combining CsI(Tl) and a new generation of opto-electronic readout devices that are rugged, compact, require only low-bias operation, and are insensitive to magnetic fields. Tradeoff studies are ongoing regarding issues related to performance, detector components, electronics design, and implementation strategy.

Status: A preliminary feasibility study has been completed and fundamental performance capabilities of the LOCO concept have been evaluated. Techniques for image reconstruction of astrophysics point-sources [7], as well as spatially extended sources, have been developed. Detailed mission design, as well as detector evaluation and prototyping, is now ongoing.

Summary: LOCO is a nuclear astrophysics mission concept whose goal is to probe the Cosmos and study the ``fires of creation". Utilizing the unique properties of the lunar environment combined with the lunar occultation technique, is highly cost-effective when compared to other mission concepts [1, 2], yet is competitive with them in terms of sensitivity and science return. LOCO will enable both astrophysical point- & extended-source observations, and lunar studies, to be made with a single instrument from hard X-ray to nuclear γ-ray energies.

References: [1] R. Carter, et al. (2002), "*EXIST Mission Study Report"*, NASA/GSFC. [2] S. Boggs, et al. (2005), "*ACT Mission Concept Study Report"*, NASA. [3] B.A. Harmon, et al. (2002), ApJ. Supp., 138 149. [4] S.E. Shaw, et al. (2004), A & A, 418 1187. [5] R.S. Miller (2008), IEEE Trans. Nucl. Sci. 55, 1387. [6] R.S. Miller (2008), SPIE Conf. Proc, 6686. [7] R.S. Miller & M.R. Orr (2009), Nucl. Instr. Meth. A, submitted.