Title: GreatOWL, a space-based mission to realize charged-particle and neutrino astronomy

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Science Drivers: The sources of the most energetic particles in the Universe, the Ultra-High Energy Cosmic Rays (UHECRs), still remain a mystery. What object(s) can accelerate a particle to > 10^{20} eV? This is more than a factor of 10^7 times the energy of a 7 TeV LHC beam. What is the nature of the acceleration mechanism? What is the composition of this radiation and how does it evolve at the highest energies? What is the flux of UHE neutrinos? The acute need for measurements to address these questions has been explicitly described in the past two NAS Decadal Surveys of Astronomy and Astrophysics [1,2], and "How do Cosmic Accelerators Work and What are They Accelerating?" was one of the top eleven science questions for the 21st century listed in the Turner Report [3]. The uncertainty in the nature of UHECRs and their sources still remain even with about a decade of operation of each of the largest ground-based UHECR experiments, the Pierre Auger Observatory (PAO) and the Telescope Array (TA). Based upon the results of these ground-based experiments, the existence of the Greisen-Zatsepin-Kuzmin (GZK) suppression above 4 $\times 10^{19}$ eV suggests that most UHECR originate in astrophysical objects. Higher energy particles must come from sources within about 100 Mpc and are deflected by ~1 degree by predicted intergalactic/galactic magnetic fields. While PAO [4] and TA [5] have reported areas of ~3 σ excess of events in the southern and northern hemispheres respectively, the sources remain unresolved. Thus the potential for charged-particle astronomy and UHE neutrino astronomy (using GZK neutrinos) exist, but only if an experiment has the exposure (in a reasonable time frame) to overcome the paltry overall UHECR rate of ~ 1 event per km^2 century above ~$10^{19.5}$ eV. Space-based UHECR experiments provide a mechanism to overcome the exposure limitations of ground-based experiments and can survey both the northern and southern skies. Around 2000, the free-flying Orbiting Wide-angle Light Collectors (OWL) mission (see Figure 1) [6] and the ISS-based Extreme Universe Space Observatory (EUSO) [7] were designed to obtain the needed, large exposure on a few year timescale and to operate above $10^{19.5}$ eV. EUSO has evolved into JEM-EUSO [8], which will be the pathfinder experiment demonstrating the technique of space-based UHECR measurements. Here we discuss the GreatOWL mission [9], which is based upon OWL but with significantly improved performance to perform charge-particle astronomy, to determine the nuclear composition evolution of UHECR above 10^{19} eV, and to have enough exposure to measure the flux of GZK-induced neutrinos. Specifically, GreatOWL will have the following UHECR and UHE neutrino science reach:

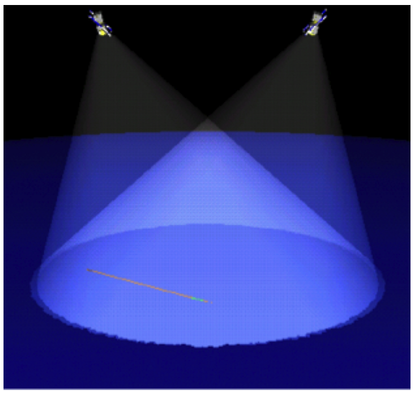

Figure 1: The OWL concept: two 'eyes' stereoscopically viewing an extended air shower from low-Earth orbit. The FOV and common atmospheric volume are highlighted.

- With the GreatOWL 'eyes' in 3300 km orbits, in 5 years with 10% duty cycle the exposure will be ~10^7 km^2 sr yr (~290 times the exposure for Auger in 5 years) for UHECR above 10^{19} eV with an angular resolution of ~1 deg and with ~20% energy resolution.
- With the GreatOWL 'eyes' in 1000 km orbits, in 5 years with 10% duty cycle the exposure will be ~10^6 km^2 sr yr for UHECR above 10^{18} eV, will have the sensitivity to measure ~40 GZK neutrino events/yr, and will be able to measure the nuclear composition evolution of UHECR above 10^{19} eV.

Technical Capabilities: Figure 1 illustrates the original OWL concept: two orbiting near-UV (330 – 400 nm) imaging telescopes, flying in a loose formation in 1000 km orbits, stereoscopically measure the nitrogen fluorescence signal during moonless nights from Extended Air Showers (EAS) induced by UHECRs interacting in the Earth's atmosphere. The co-measurement allows for a straightforward reconstruction of the incidence direction, distance from the EAS to each instrument, and provides a cross-check of the measurement of the EAS profile, required to measure the energy and identity of the UHECR primary particle, in order to miminize the effects of atmospheric variability. Each OWL 'eye' is an f/1 Schmidt camera with a 45° full FOV and the highly-pixelated focal plane samples the near-UV signal at 10 MHz. The optical performance is quite modest, the optical angular needed is ~1 milli-radian, over 10^4

away from the diffraction limit. Thus each OWL 'eye' is more like a 'light bucket' with performance requirements closer to a microwave dish. An illustration of a deployed OWL 'eye' is shown in Figure 2.

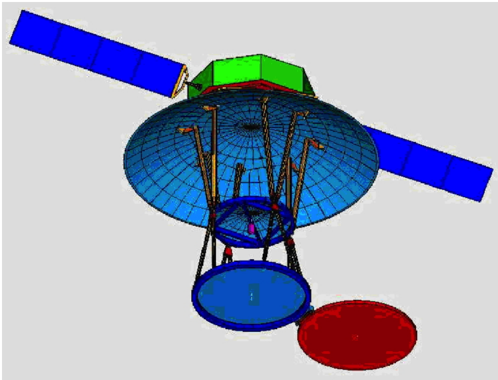

Figure 2: A Fully deployed OWL instrument with the light shield removed for clarity.

GreatOWL extends the performance of OWL by increasing the UV light-collection capability by a factor of 70 to yield a full aperture energy threshold of 10^{18} eV for a configuration with the GreatOWL 'eyes' in a 1000 km orbits, while another configuration using 3300 km orbits increasing the exposure by ×10 assuming for the same time span of operation. The increase in light collection is based on incorporating UV sensitive SiPMs as the focal plane detector and scaling the optics by ×6. This leads to a GreatOWL instrument with a 42 m diameter mirror, an 18 m diameter optical aperture, and a 13.8 m diameter focal plane array. This would be prohibitively massive and complex using conventional, rigid structures such what was assumed for the original OWL. However, rigidized inflatable structures could form the mirror and other structures a relatively lightweight spacecraft with a relatively lightweight and compact stowed design, allowing for easier launch vehicle accommodation. In 1996, the Space Shuttle mission STS-77 deployed the 14 m diameter Inflatable Antenna Experiment, and a picture of the deployed antenna is shown in Figure 3. Since then there has been progress on developing inflatable structures, such as that used in the Spartan 208 Shooting Star telescope and the Bigelow Expandable Activity Module (BEAM) that will be launched to the ISS in 2016. The technology development needed for GreatOWL would leverage off of these.

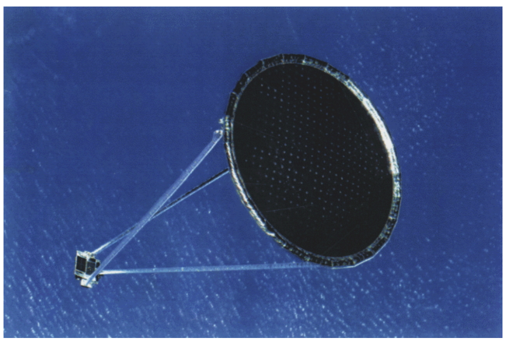

Figure 3: NASA's deployed 14 m diameter Inflatable Antenna Experiment (IAE).

New Technologies: Significant/5 years. R&D is needed to develop the inflatable optics and structures, a foldable large-area focal plane array, and mechanical engineering to assemble these into a spacecraft in a stowed then deployed configuration.

Reasons why a probe-class mission is needed: A 2002 GSFC ISAL & MSAL runs developed the OWL baseline instrument and mission designs and determined a mission cost to be $360 M (not including launch vehicle). Like OWL, GreatOWL requires two instruments and a dual-manifest launch. Assuming 3% yearly inflation, the FY2016 cost places this above the cost-cap for a MIDEX.

Cost Estimate: Based on inflating 2002 OWL mission cost by 3% inflation, this yields a mission cost estimate of $540 M, not include the launch vehicle.

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