Report on the 2008-09 VSoE Research Innovation Fund (RIF) Award to Space Engineering Research Center (SERC) of the Astronautics Engineering Division

by

David Barnhart and Joseph Kunc

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GRANT SUMMARY

The Award grant of $10k was used by the Space Engineering Research Center (SERC) of the Astronautics Engineering Department to develop a scientific program to utilize a novel satellite concept called Cubesat. This effort spawned a full proposal to the National Science Foundation (Requested project budget: $583,331 over two years.) on USC's 1st foray into science based satellite missions built entirely at the University. What follows is a short description of the proposed research, part of which was supported by the Grant.

PROJECT SUMMARY

This proposal is directed to demonstrating 1) a Cubesat with sufficiently precise attitude control to allow atmospheric measurements and sufficient power to support telemetry of the measurements made by the payload and 2) a payload to measure ozone concentration, consisting of a small light-weight custom-designed off-axis telescope that fits into one module of a standard Cubesat structure (100x100x100mm), that may be updated to measure the Earth's Albedo or make solar measurements. For OZMOSIS the telescope will provide differential (ultraviolet vs. visible) measurements of atmospheric ozone absorption through solar occultation measurements. As two additional goals, the telescope will observe the atmosphere 'glow' when it is pointed to the day-side limb, and relative reflectivity from below the Cubesat in nadir pointing. To achieve these mission goals with the available Cubesat pointing and telemetry rate, the telescope has two quad-diode detectors (one for visible light and another for UV light) with 8 discrete data channels.

INTELLECTUAL MERIT

The primary goal of the OZMOSIS mission is to obtain ozone absorption data through telescope measurements using a Cubesat. Students will be directly involved in demonstrating a Cubesat with the ability to take optical measurements and will experience firsthand the life cycle of a science-based satellite design, as is used in the majority of NASA and DoD missions today. The key challenges of occultation measurements are achieved on the technical edges of USC's Cubesat performance. These include:

Attitude control: Our Cubesat needs to be centered on the point on the limb where the refracted rays of the rising sun first go through the atmosphere. This in turn necessitates pointing accuracy of 2^0. The satellite has been designed to meet this requirement by the use of active attitude control using MEMS gyros, a simple optical imaging sensor and custom torque rods consistent with a 3U Cubesat structure.

Data flow to ground: Given the general limitations on power available for higher throughput downlink components, an onboard storage and pass-by-pass downlink system must be established. Our telemetry solution uses efficient data compression algorithms with a standard 425 MHz transceiver.

Power: We maximize the power collection with our Cubesat design by having the telescope look out of the front of the Cubesat with deployable panels so that the greatest area faces the sun and provides maximum power available for science collection.

Adaptive software: Onboard satellite GNC software must be developed to allow for in-flight corrections based on sun/limb pointing, as well as ground propagation of the orbit to uplink a pre-determined orientation for sunrise passes. The ground processing software will allow extraction of ozone absorption data and comparison with data from other sources such as MLS, SOFIE and HALOS. The OZMOSIS mission will contribute data to enhance the product of existing satellites. We will complement the much higher-cost missions to-date and prove that Cubesats can be used to augment high quality atmospheric research missions, at fractions of the cost. The telescope is designed for this Cubesat mission but is also applicable to later possible missions to measure the Earth's radiation budget using albedo observations from the Lagrangian-1 point in the Earth-Sun system.

1.0 Relevance of the Research to current space weather research goals.

1.1 Scientific Motivation

The scientific motivation for the proposed mission consists of two distinct directions of research. The first is an important component of climate change measurements and is based on ozone depletion measurements in the solar occultation mode. The second is related to ionosphere measurements of space weather.

The sources of the ozone depletion temporal variations (both latitudinal and seasonal) and the presence and changes of so called 'ozone holes' in the polar regions have the greatest scientific interest and have been addressed by a number of ground systems using Dobson (Brewer) spectrometers and LIDARs, airborne sensors on balloons, rockets, and aircraft, and space measurements (SAGE, TOMS, OMI missions). As all of these measurements detect ozone depletion localized in space and time, the proposed OZone Measurements from Occultation of Solar Ionizing Radiation in Space (OZMOSIS) measurements will add to the database of known temporal and latitudinal variations that are needed to understand the sources of these variations and predict future changes.

The ionosphere measurements of space weather research direction requires nadir pointing of the proposed instrument, which will measure solar radiation reflected (backscattered) from the ionosphere and high clouds. Such measurements will provide additional data that will be compared with the data obtained from similar satellite UV backscatter measurements (TOMS), as well as microwave and infrared measurements on LIMS and ISAMS, and will thus be important additions to another form of ionosphere map based on the GPS Total Electron Content measurements. As solar occultation measurements in the first research area are relatively short during a normal orbit, our mission proposes to increase flexibility of the instrument by evaluating nadir pointing modes to potentially significantly increase the efficiency of the mission.

1.2 Overall Project Scope & Goals

A prioritized list of the top OZMOSIS **science goals** are listed below:

- Development of a technology for space applications using a small and lightweight off-axis telescope that has potential to be scaled up to provide high spatial resolution (using CCD detectors as an example) in a wide spectral band (from UV to FIR) for significant Climate Change and Space Weather measurements. **(PRIMARY)**
- The actual use of this telescope in a scaled down version on a Cubesat that has two (UV and visible) bands to provide ozone depletion measurements in a solar occultation mode. These measurements are important to track the ozone variations in location and amount. **(SECONDARY)**

- Measurements of reflectivity with nadir pointing using this telescope, on a Cubesat, during the course of a defined orbit mission after occultation measurements are taken. The reflectivity data will have implications for Climate Change analysis (cirrus amount and cloud heights) and for Space Weather applications (ionosphere reflectivity). **(TERTIARY)**

The top OZMOSIS **engineering goals** are listed below:

- Building a Cubesat that supports occultation measurements for an optical telescope able to operate in the velocity vector. **(PRIMARY)**
- Provide for attitude control and pointing to support both (a) occultation measurements and (b) nadir pointing during normal orbit operations. **(SECONDARY)**

2.0 Description of the science objectives and measurements planned for the proposed mission.

2.1 Spectral bands for ozone depletion measurements

The spectral bands for the OZMOSIS mission were chosen based on the lowest cost approach to realize measurements of ozone depletion as a difference in UV and VIS absorption. Ozone absorption is strongest in the UV Hartley spectral band, about 200 to 300 nm, centered at 255 nm. One method of supporting this band is to coat the Primary Mirror with UV enhanced aluminum, which would increase reflection of the solar irradiance at wavelengths longer than about 200 nm. **We propose an original solution to create a UV bandpass by using both a UV enhanced Al coating for the PM and a thin-film multi-layer coating for the Secondary Mirror (SM) on the OZMOSIS telescope.** This thin-film coating reflects the light (to the UV detector) at wavelengths below 300 nm, and thus, this combination of coatings creates the required Hartley spectral band without using expensive spectrographs and/or filters. Figure 5 shows the absorption cross sections for ozone. The probability of absorption of the light and ionization of oxygen molecules is proportional to the cross-section.

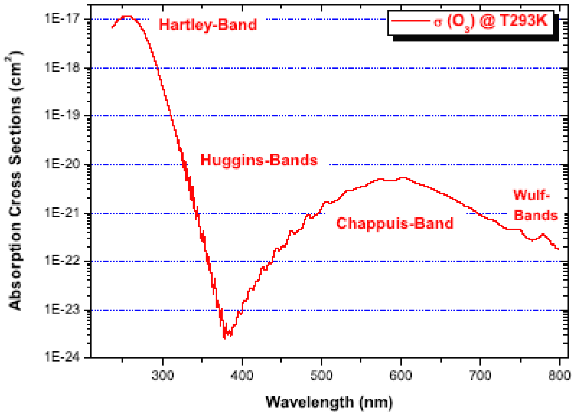

Figure 5. *Absorption cross section as a function of wavelength. The strongest ozone absorption is observed in the Hartley band centered around 255 nm..*

The second (visible light) bandpass is created by placing a diagonal aluminum mirror in the focal plane of the PM. This mirror has a number of small holes (related to a large ± 2 deg Field Of View, FOV) to transmit the light through the holes to the SM and to reflect a portion of sunlight in visible band to the visible detector. Visible light bandpass is created by using a blue or green glass filter placed on the visible light detector. This cheap glass filter limits the longer wavelengths, e.g. in red and IR spectral bands and together with the diagonal metal aluminum mirror creates an effective visible light bandpass of about 400 – 600 nm. **The absorption of ozone in this VIS bandpass is more than three orders of magnitude weaker than in the Hartley UV bandpass, providing excellent self-calibrating differential ozone measurements by the proposed OZMOSIS telescope.**