

Multi-Slit Offner Spectrometer Development to Support GEO-CAPE Event Imager Science

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Abstract— The Multi-Slit Offner Spectrometer (MOS) is a spatial multiplexing imaging spectrometer directed at geostationary remote sensing of coastal ocean color. Simultaneously generating hyperspectral data cubes from multiple locations enables a smaller sensor with faster revisit times compared to traditional spectrometer concepts. The GEO-CAPE Oceans mission embodied in the Event Imager benefits from this architecture by reducing the payload mass, risk and mission cost. The MOS Instrument Incubator Program (IIP) planned to begin midyear 2011 will design, build, and characterize a prototype MOS satisfying critical requirements for the Earth Science Decadal Survey GEO-CAPE Oceans mission. The spectrometer will be vibration tested to launch levels and performance characterized in a relevant thermal vacuum environment. In collaboration with Oregon State University three studies supported by characterization data will validate MOS's ability to produce coastal products required for GEO-CAPE Ocean science. This paper outlines the driving requirements, the MOS concept, technical challenges, and the IIP goals.

I. INTRODUCTION

One objective of the NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission, an Earth Science Decadal Survey [1] Tier II mission focuses on the dynamics of coastal ecosystems, river plumes, and tidal fronts. The event imager sensor will collect hyperspectral data on the science of short-term processes, land-ocean exchange, impacts of climate change and human activity, and episodic events and hazards. The GEO-CAPE website [2] expands on these ocean science objectives, noting the sensor needs to:

- Quantify the response of marine ecosystems to short-term physical events such as the passage of storms and tidal mixing,
- Assess the importance of high temporal variability in coupled biological-physical coastal-ecosystem models,
- Monitor biotic and abiotic material in transient surface features such as river plumes and tidal fronts,
- Detect, track and predict the location of sources of hazardous materials, such as oil spill, waste disposal and harmful algal blooms, [and]
- Detect floods from various sources, including river overflows.

Moderate spatial resolution imagery, 250 to 375 m meets these objectives adequately resolving tidal fronts, river plumes and

phytoplankton patches in the coastal ocean [3, 4]. Temporal resolution of 1 to 3 hours resolves the dynamics of coastal processes (e.g., tides, wind-driven currents, storm surges, and algal blooms); for hemispherical coverage this is optimally achieved from a geostationary orbit. Achieving the required short revisit times, spatial, and spectral resolutions at a high signal-to-noise-ratios (SNR) using a conventional spectrometer leads to complex, large, and heavy sensor. This paper outlines the plans for a NASA Instrument Incubator Program (IIP) investigation of a Multi-Slit Offner Spectrometer that by virtue of spatial multiplexing, the simultaneous hyperspectral imaging of multiple locations offers significant reductions in system complexity and mass. The multiplex scaling is proportional to the number of slits projected from geostationary orbit onto the Earth. The realized temporal efficiency can be reallocated to a reduced aperture decreasing the overall sensor complexity, envelope, mass and subsequent mission risk.

The MOS IIP, midyear 2011 start will design, build, and characterize a prototype multi-slit spectrometer satisfying a relevant subset of the requirements for the Earth Science Decadal Survey GEO-CAPE Event Imager mission. In collaboration with Oregon State University, three defined studies will validate MOS's ability to generate data products required for GEO-CAPE Ocean science. Specifically, we will investigate the impact on coastal water (CW) products by spectral sampling, out-of-band response, and signal to noise ratio. MOS characterization data, Hyperspectral Imager for Coastal Ocean (HICO) data sets, and the studies will inform the validation of the multi-slit spectrometer concept for the GEO-CAPE Event Imager mission. This combined effort will parameterize the CW product's uncertainty arising from the spectrometer performance traceable to the slit number selection, the multiplex scaling. The spectrometer will be vibration tested to launch levels and the performance characterized in a relevant operational thermal vacuum environment. The planned activities will raise the hardware's technology readiness level to 6.

II. MUTLI-SLIT OFFNER SPECTROMETER (MOS)

A. GEO-CAPE Mission Driving Requirements

The GEO-CAPE Ocean Science Traceability Matrix (STM) [5] provides the instrument requirements flowdown from the science objectives. Table I lists the driving requirements

TABLE I.
GEO-CAPE Oceans Science Traceability Matrix: Instrument Requirements

Parameter	Threshold	Goal
Spectral Range	345-900 nm	340-1100 nm
Spectral Resolution (FWHM)	0.5 nm	0.25 nm
Spatial Resolution (nadir)	375x375 m ²	250x250 m ²
Field of Regard	±9° E/W	
Temporal Resolution: Targeted Events	1 hr	0.5 hr
Temporal Resolution: Routine Coastal U.S.	≤ 3 hrs	0.5 hr
Solar Zenith Angle	±70°	±75°
SNR for 10 nm FWHM over 380-800 nm range	1000	1500

for the oceans sensor that the MOS concept impacts. The spatial and spectral resolutions directly limit the number of received photons while the temporal resolution over the field of regard restricts the dwell time at one location; the solar zenith angle and solar radiance determine the scene radiance. Since the effective focal length and detector pixel size are used to achieve the spatial resolution, the entrance aperture is the final instrument parameter that can be adjusted to meet the signal to noise requirement.

B. The MOS Concept

The Multi-Slit Offner Spectrometer takes advantage of the high quality imaging and low distortion over the large two dimensional field afforded by the Offner spectrometer design form [6]. A conventional Offner Spectrometer comprises three spherical surfaces: a primary mirror, a convex diffraction grating, and a tertiary mirror all with a common center of curvature. Conventionally there is a single entrance slit. MOS extends this basic design by having multiple entrance slits displaced in their width direction; Fig. 1 shows this for the case of two slits. Each slit produces a full spectrum on the focal plane but originating from displaced ground samples. A large area focal plane array collects the hyperspectral imagery from multiple ground pixels simultaneously amounting to spatial multiplexing as suggested in Fig. 2.

Fig. 2 shows the instantaneous projection of three slits onto the scene and the dispersed spectrum from each slit imaged onto the focal plane. To generate the hyperspectral image cube over the field of regard from geostationary orbit, a scan mirror moves from East to West covering the gap between the instantaneous slit images. This generates an “image block”. Two “image blocks” are shown in Fig. 2, one yellow and one red. After generating the first “image block” (yellow) the scan mirror jumps to the start of the next “image block” (red). The scan repeats for the next “image block” (red). For a geostationary payload with an agile scan mirror, image blocks could be anywhere in the hemisphere making the instrument capable of both routine coastal coverage and high revisit monitoring of coastal events. A Multi-Slit Offner Spectrometer based instrument accommodates the GEO-CAPE Event Imager temporal resolution, field of regard, and event monitoring requirements.

For a fixed signal to noise ratio, spatial multiplexing enables MOS to cover the field of regard faster than a single slit spectrometer with the same basic parameters. As an

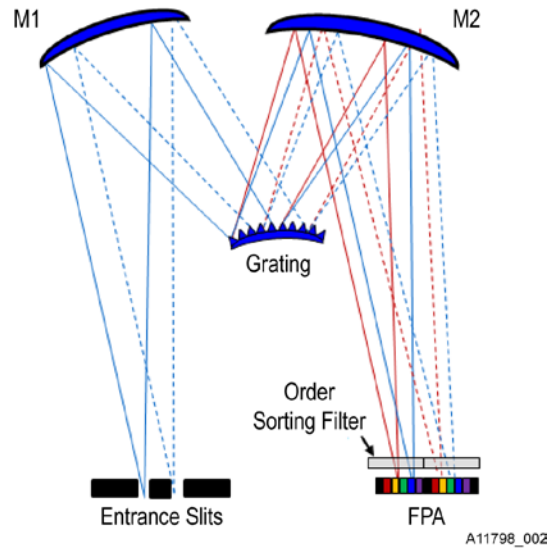


Fig. 1. Schematic representation of the operation of a two slit MOS. The deviation from a standard Offner spectrometer is the introduction of two displaced slits at the input to the spectrometer. A full spectrum is dispersed across the focal plane assembly (FPA) for each slit. The out-of-band performance controlled by order sorting filters and slit displacement is central to this study.

example, a five slit MOS covers the same area five times faster than its single slit counterpart when all else is equal. Alternatively, for fixed coverage time, a five-slit MOS requires an optical aperture roughly half that of a conventional system

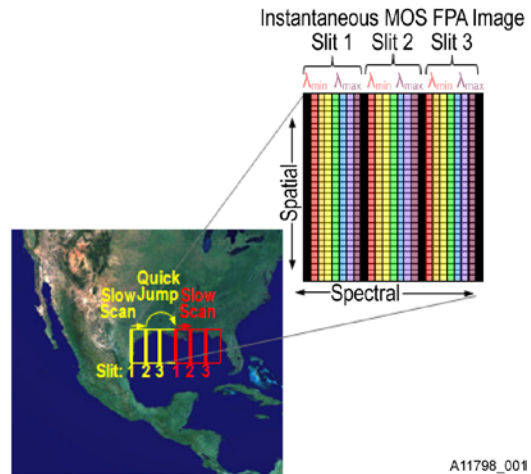


Fig. 2. Three slit MOS operating from a geostationary orbit. Each slit produces three spectra in the image plane. An instrument scan mirror, stepping from east to west generates a block image, the full yellow section; the scan mirror moves the slit image until the image at slit position 1 overlaps with the start position for slit image 2. A complete data cube is created for the yellow block. After completing the scan over the yellow image block, the scan mirror jumps to generate the red and subsequent blocks in a like manner.

with the accompanying mass and volume reductions. Strawman designs suggest the conventional spectrometer requires a payload of the scale 550 kg while the MOS version is roughly 150 kg. Consequently, for the same mission, a MOS is smaller and lighter compared to a single slit design.

The technical challenge of MOS is out-of-band rejection, mitigating the impact of light from adjacent slits contaminating its neighbors. The combination of focal plane order sorting filters and the amount of slit displacement manages the overlap of spectra from adjacent slits. For each image snapshot, the spectrometer yields the spectrum along the three separated N-S lines. For applications where the number of spectral channels is less than the number of spatial channels, the mission benefits from using a Multi-Slit Offner Spectrometer where the payload aperture, mass and volume are reduced. With a single telescope, a single spectrometer, and a single focal plane, MOS performs like multiple single slit spectrometers.

C. MOS IIP Plan

During this IIP we will design, build, and test a Multi-Slit Offner Spectrometer described by the block diagram in Fig. 3. Fig. 4 shows a field view of an Offner spectrometer fed by a telescope and spot diagrams at 610 nm; the design has exceptional performance over the field required by MOS. The hardware enclosed by the thermal vacuum chamber will be subjected to launch vibrations and tested in an operational thermal vacuum environment. This testing will raise the spectrometer opto-mechanical subsystem to TRL 6.

For the IIP, the telescope is replaced by a source relay camera that images illuminated targets through the test chamber window. The electronics and thermal control subsystems are test equipment and not subjected to the relevant environments. Spatial, spectral, and out-of-band performance measurements will be made to assess the impact of a flight-like implementation on operational coastal products. These impact studies will be performed by the Oregon State University Co-I and his team.

A critical output from this effort will be the understanding of the optimal number of slits, the order sorting filter complexity, and out-of-band rejection that can be achieved while still retrieving the desired ocean data products with the

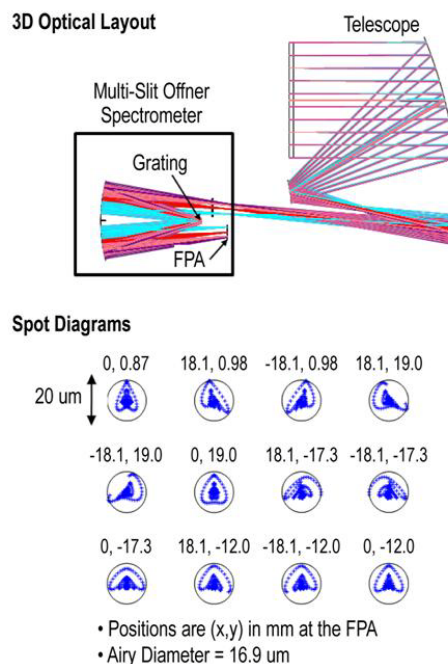


Fig. 4. Field view of an Offner spectrometer showing good imaging performance over a large field, sufficient to accommodate multiple slits. The reflective telescope is not planned as part of the IIP but is shown for completeness.

required uncertainties. The basic trade can be formulated as how many slits can be simultaneously imaged with sufficient out-of-band rejection that the data product retrieval uncertainties are acceptable to the GEO-CAPE Oceans science objectives. Characterization data will support the answering of this question. The OSU team will use the MOS test results, Hyperspectral Imager for Coastal Ocean (HICO) data sets, and airborne hyperspectral data sets to quantify the impact of slit spectral sampling, out-of-band response, and SNR impact to coastal water data products. These studies will inform a mission suitability study with the objective of validating MOS's application to the GEO-CAPE Oceans mission.

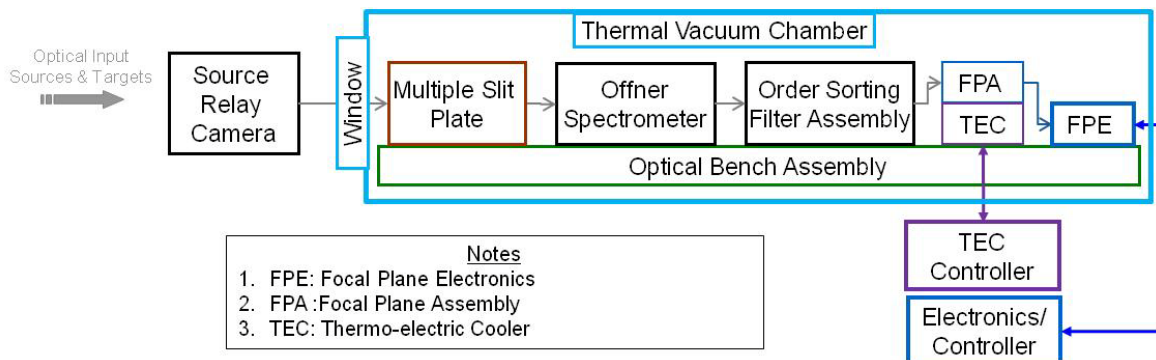


Fig. 3. The Multi-Slit Offner Spectrometer block diagram defines the opto-mechanical subsystem, hardware enclosed in the thermal vacuum chamber as the subsystem whose technology readiness level will be increased by this effort. This distinguishes the spectrometer hardware from the supporting test equipment.

III. CONCLUSION

We have outlined the Multi-Slit Offner Spectrometer concept and its benefits, a comparatively smaller payload with lower risk and mission cost, afforded to the GEO-CAPE Oceans mission. The goals, major tasks and studies planned for the IIP were described. These activities drive to the common outcome of validating the suitability of the MOS for the GEO-CAPE coastal ecosystems mission. In addition the spectrometer subsystem will experience launch vibrations and be tested in a relevant space environment. Upon completion of the IIP the spectrometer subsystem will be at TRL 6.

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