The Development of a Highly Integrated Imaging Payload for Space Weather and Maritime Monitoring. H. N. Lerman[1], I. B. Hutchinson[1], N. P. Bannister[1], M. McHugh[1], R. Ingley[1], M. Lester[1], D. Wright[1], S. Milan[1], C. Brunskill[2], D. Garton[2], [1]University of Leicester (Space Research Centre, University of Leicester, Leicester, UK, LE1 7RH, hnl4@le.ac.uk), [2]Satellite Applications Catapult (Satellite Applications Catapult, Harwell, UK, OX11 0QR).

Introduction: CubeSats have very challenging resource limitations (e.g. power, mass, volume and communication) but enable exciting opportunities to develop creative and innovative scientific experiments. Subsystems are required to be compact and efficient whilst being capable of achieving high levels of performance and reliability for various commercial, security and scientific applications.

The CubeSat payload development and optimization presented here is a multi-purpose imaging payload with powerful onboard processing capability that significantly reduces telemetry requirements. The camera is closely integrated with other subsystems to improve autonomy. The primary applications for this payload are space weather monitoring and maritime situational awareness, which both benefit from the acquisition of data at UV wavelengths.

Here, we discuss the results of initial experimental test and describe the optimization and capabilities of the CCD based, UV enhanced camera system, which is highly suitable for use in a compact and efficient CubeSat payload.

Space Weather Monitoring: The interaction of the Solar Wind with the Earth's magnetosphere produces characteristic signatures at UV and optical wavelengths in the auroral ovals of the Northern and Southern hemispheres. Measurements of these emissions provides an opportunity to monitor the magnetosphere activity and morphology, giving an insight into the physical nature of the processes involved. The energy exchange which results from such interactions between the Earth and Sun causes disruption to power transmission systems, causes damage to expensive spacecrafts in LEO, degrades GPS signals, and is a source of danger to astronauts. Hence it is advantageous to observe magnetospheric changes across a variety of timescales and to associate the activity with particular locations in the magnetosphere. For these measurements, the camera system is used in conjunction with a Microchannel Plate (MCP) Optic in a similar configuration to that used for the Mercury Imaging X-Ray Spectrometer onboard ESA's BepiColumbo mission.

Maritime Situational Awareness: The current methods utilized to track and identify vessels at sea are far from perfect. For example, the maritime Automatic Information System, a broadcasting signal which identifies identity and position of a vessel, can be switched off or altered to send incorrect information. Moreover, optical monitoring from space, although useful for spatial resolution and target discrimination, lacks reliability due to the changeability of the weather. However, the imager concept presented here is able to overcome some of these issues, as reported by Bannister and Neyland (2015) [1]. In order to achieve this, the imaging system utilizes data from both optical and near infra-red (NIR) wavelength channels, obtaining using a conventional lens/mirror based system.

Imaging Payload: The multi-purpose imaging payload incorporates a spherical MCP optic and a UV-sensitive CCD focal plane sensor with transmissive filters deposited on a CaF_2 window in front of the CCD. The optic consists of a spherically curved glass plate containing millions of precisely aligned hollow channels whose walls act as grazing-incidence mirrors, and is the key to realizing a low mass, compact instrument [2]. The detector is a full frame imaging device, which is UV enhanced/coated and compromises 2048x512, 13.5μm pixels. A thermal cooling and stabilization system is used to optimize dynamic range and overall performance. The selected detector exhibits a detection efficiency of greater than 50% across the UV wavelength range of interest, ideal for space weather monitoring. It also performs well within the range required for use in maritime domain awareness applications.

Camera Design: In order to facilitate rapid development and optimization of a range of different possible payload configurations, a 3D printer was used to manufacture suitable test environments for the detector/cooling system and optical benches for the lenses, filters and mirrors (see Figure 1, which shows the first re-configurable optical system that was used to verify the UV performance of the camera). The modular system is compact, low mass, light proof and cheap to fabricate. The FPGA based detector system generates all of the necessary biases and clocks required to operate the CCD and incorporates a CDS ASIC for sampling the output from the detector (a space qualified version is available). Low level data processing is performed on an FPGA in order to compress the data stream and generate the various data products that are required to provide appropriate control over the other subsytems. The FPGA is also used to provide closed loop control over the thermal cooling/stabilization system and control over the various calibration sources used to characterize detector performance.

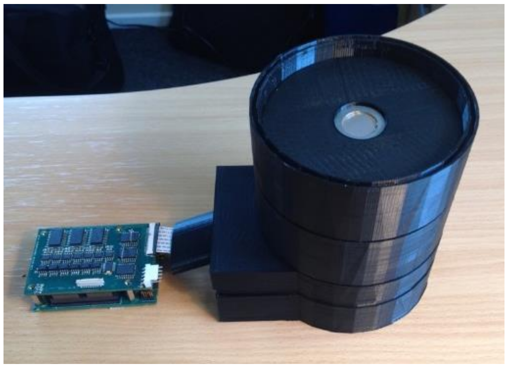

Figure 1: Camera electronics and detector enclosure. The mesh can be seen at the top of the enclosure.

Camera Performance: Initial tests focused on the verification of UV performance. A light-tight enclosure was fabricated and a UV filter and mesh were used along with a Cathodeon v03 deuterium lamp to deliver an appropriate intensity of wavelength constrained light at the focal plane. Dynamic range and detection efficiency measurements were made with the focal plane stabilized at a temperature of 290K. The data obtained were also used to verify the data processing algorithms developed in order to enable autonomous control of the platform. The optical performance of the UV optic was also investigated using the detector/camera system.

A number of different detector operating modes have been investigated during the tests, including on-chip binning, windowing and frame transfer. Early results indicate good UV response and overall instrument dynamic range. We have also investigated the overall performance of particular instrument configurations using instrument radiometric models in conjunction with a detector simulator. The software accounts for specific operating modes and detector noise sources and simulates the expected output given a particular operating scenario and input light field. A typical image obtained with the camera system is shown in Figure 2. The low intensity bands on the left and right of the image are calibration pixels that are not associated with light sensitive parts of the detector. The image incorporates two, 100 row windows on the surface of the detector. Light intensity increases from the bottom to the top of each window and can be used to generate a photon transfer curve for the system (verifying the gain and noise of the system).

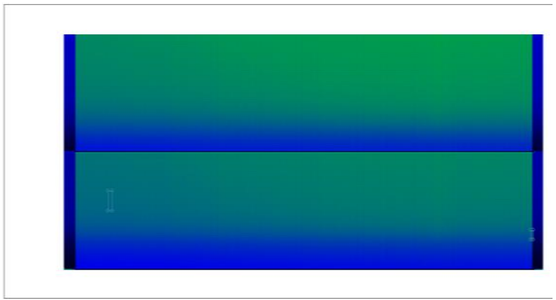

Figure 2: Camera image obtained with the detector/drive electronics, illustrating windowed operation.

References: [1] Bannister N. P. and Neyland D. L. (2015) *IJRS, 36*, 211-243. [2] Bannister N. P. et al. (2007) *Ann.Geophysicae* 25, 519-532.