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NASA's Earth Science Technology Office CubeSats for Technology Maturation

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ABSTRACT

NASA's Earth Science Technology Office (ESTO) has been supporting the development of multiple CubeSats to advance various technologies for future Earth Science observations. The goal of this work is to support instrument and information systems technology risk reduction, through flight validation in the space environment, in support of the Earth Science Decadal Survey. Within the next 18 months three CubeSats will have completed system development and testing. Two will launch on GEMSat L-39 planned no earlier than December 2013 while the third will launch no earlier than October 2014. MCubed/COVE-2 (a reflight mission) will take mid-resolution images of the Earth at approximately 200m per pixel while carrying the COVE payload. COVE will validate a real-time high data rate image processing algorithm utilizing the radiation-hardened, space-grade Virtex-5QV FPGA by Xilinx. This is a key capability for the Multiangle Spectropolarimetric Imager (MSPI) instrument planned for the ACE Decadal Survey mission concept. The IPEX CubeSat will validate autonomous science and product delivery technologies demonstrating a twenty-times reduction in data volume for low-latency near real-time product generation. This technology supports the proposed HyspIRI mission concept VSWIR spectrometer and thermal IR imager. Finally, GRIFEX will perform engineering assessments of a state-of-the-art all digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC). Its high throughput capacity will enable the GEO-CAPE mission concept to make hourly high spatial and spectral resolution measurements of rapidly changing atmospheric chemistry and pollution with the Panchromatic Fourier Transform Spectrometer (PanFTS) instrument.

INTRODUCTION

The NASA Earth Science Technology Office (ESTO) is a targeted, science-driven, competed, actively managed, and dynamically communicated technology program that utilizes a peer-review proposal-based approach for technology investment to retire risk for future Earth science missions. Specifically, ESTO develops observation system technologies to provide new instrument and measurement techniques through critical component, sub-system and airborne flight tests as well as information system technologies to develop innovative ground, airborne, and on-orbit capabilities for communication processing, management of remotely sensed data, and science data product generation and knowledge.

ESTO has made substantial investments in the development of multiple CubeSats to advance various technologies for future Earth Science observations in support of the NRC Decadal Survey[1]. This paper will give an update on the system design and launch status of these projects as well as issues resolved associated with advancing toward the successful Mission Readiness Reviews (MRRs) and deliveries. Since the

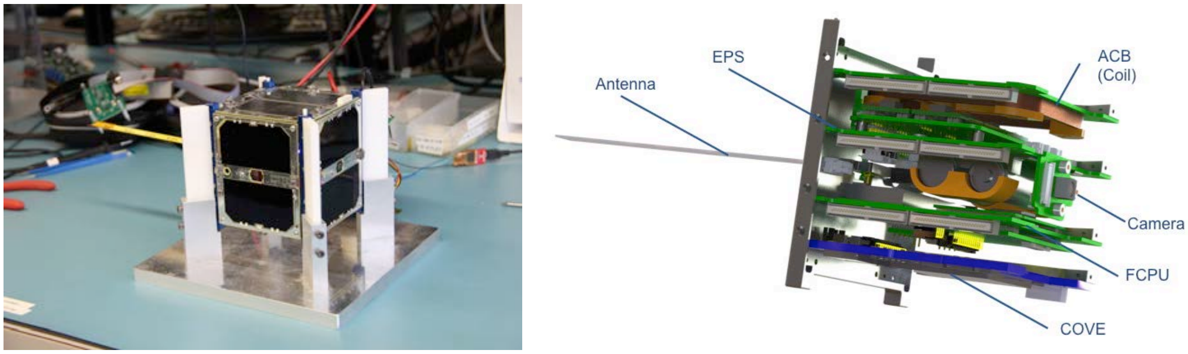

Figure 1: M-Cubed/COVE-2 and avionic redesign for launch and integration.

introduction of the initial projects (M-Cubed/COVE, IPEX, and GRIFEX), ESTO has initiated a new pilot program called In-Space Validation of Earth Science Technologies (InVEST) to support additional flight validation of Earth Science technologies. A brief description of the InVEST program selections will also be provided.

M-CUBED/COVE-2

M-Cubed/COVE-2 is a 1U CubeSat developed by U. Michgan and JPL as a reflight system of the M-Cubed/COVE mission that experienced an anomaly leading to the post-deployment magnetic conjunction of two CubeSats. The mission of M-Cubed/COVE-2 remains the same, to take mid-resolution images of the Earth at approximately 200m per pixel while carrying COVE. COVE is a payload experiment that will prove an image processing algorithm designed for the Multiangle Spectropolarimetric Imager (MSPI) utilizing the first in-space application of a new radiation-hardened-by-design Virtex-5QV FPGA by Xilinx[2,3]. This experiment will advance the technology required for the future spaceborne implementation of the MSPI instrument required for real-time high data rate instrument processing relevant to future Earth observing missions. MSPI is a multiangle multiwavelength highly accurate polarization camera that will characterize aerosols contributing to an understanding of their effects on cloud formation, and other phenomena. Limited understanding of the complex interactions among clouds and aerosols is one of the largest contributors to uncertainty in climate models.

A detailed analysis was performed of the deployment issue leading to manufacture and recommended use of new separation springs designed to minimize potential conjunction issues (note that this was the first time two CubeSats have conjoined after deployment). In addition, since M-Cubed/COVE-2 is manifested to fly on an Atlas-5 with the NPSCul deployment system on the Aft Bulkhead Carrier (ABC), the flight structure has been re-engineered to sustain the increased launch loads. Additional structural improvements have also been added to ease integration of the overall system as seen in Figure 1.

Some additional enhancements were added to the flight system to test Michigan Exploration Lab (MXL) new hardware on a reliable avionics stack including ADCS sensors, algorithms, and a magnetorquer. The team also addressed all of the required items in the Mission Readiness Review related to system, mechanical, and electrical design, and environments. The spacecraft complies with NASA's end-of-life plans and after the primary mission objectives have been achieved MXL will continue to operate the satellite to continue to assess flight heritage and for educational outreach.

Launch is planned for December 5th from Vandenberg Air Force Base as part of the NRO GemSAT launch. This flight was manifested under the NASA CubeSat Launch Initiative as ELaNa-II. The expected launch parameters will provide good orbital lifetime for the experiment, imaging, and some ability to characterize the potential effects of total ionizing dose exposure on the Virtex-5QV FPGA.

IPEX

The Intelligent Payload Experiment (IPEX) is a 1U CubeSat developed by Cal Poly San Luis Obispo and JPL. IPEX will validate autonomous science and product delivery technologies supporting TRL advancement of the Intelligent Payload Module (IPM) targeted for the proposed HyspIRI Earth Science Decadal Survey Mission providing a twenty-times reduction in data volume for low-latency urgent product generation. As HyspIRI would carry two flight instruments, a VSWIR hyperspectral imaging spectrometer and a thermal infrared imager that would perform global mapping producing approximately 5TB of data per day, the IPEX mission will demonstrate the

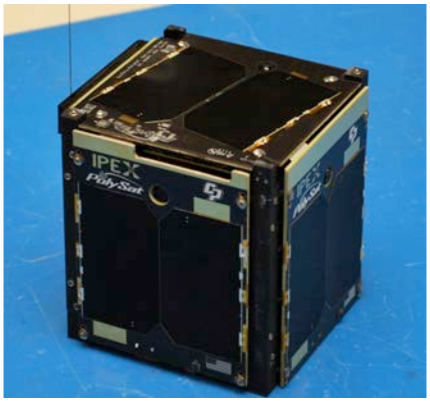

Figure 2: IPEX CubeSat.

support infrastructure needed to produce low-latency near real-time direct broadcast products in advance of the larger science products where the current delivery requirement is two weeks[4]. Figure 2 shows an image of the IPEX CubeSat.

IPEX had planned to carry a new device called SpaceCube-Mini (SC-Mini) which was a high performance CubeSat form-factor processing unit, but vendor manufacturing issues in fabrication of the multilayer PCB board microvias created open circuits in the design. These were precise laser drilled microvias

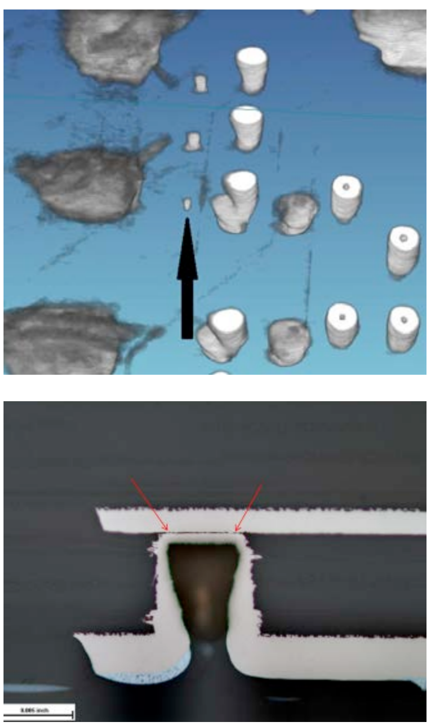

Figure 3. Microvia separation in SC-Mini board shown by computer tomography (top) and PCB board slicing (bottom).

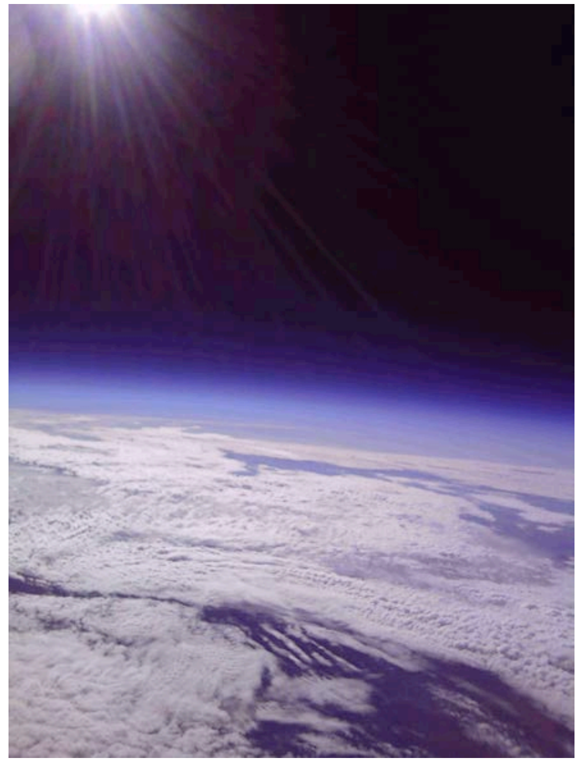

Figure 4: IPEX balloon flight imagery testing avionics systems at 100,000 feet.

that require a minimum of 11 weeks for board manufacture, more time than would be available to maintain the delivery schedule, so the decision was made to switch to a GumStix processor for payload processing. The flight avionics system has been tested on high altitude balloon flights where communication with the system, autonomous scheduling and planning, and imagery have been successfully taken showing good progress on the final flight system design. Figure 3 shows images of the microvia problem identifying the microvia size issue along with contact separation. Figure 4 shows an image from a past balloon test flight of the avionics and communications system.

GRIFEX

The GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX) is a 3U CubeSat in development with the University of Michigan that will perform engineering assessment of a JPL-developed all digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC). Its high throughput capacity will enable the proposed GEO-CAPE mission to make hourly high spatial and spectral resolution measurements of rapidly changing atmospheric chemistry and pollution with the Panchromatic Fourier Transform Spectrometer (PanFTS) instrument also developed by ESTO. ROICs have been fabricated and tested with good results for imaging representing a major accomplishment for the detector work. The control and data acquisition processing board design is based on the COVE board design, but it contains additional components and capability and has been named MARINA. The CubeSat mechanical design will utilize heritage from the NSF-sponsored Radio Aurora Explorer (RAX) and M-Cubed/COVE-2 systems.

The optical assembly to be flight validated will be housed in a 1U section of the 3U CubeSat as illustrated in Figure 5. The image size is 128x128 pixels with an 850m ground pixel spot at 500 km. At this time, the ROICs have been fabricated and tested and the MARINA boards (engineering and flight models) have been built. Good progress has been made on the spacecraft bus development. The team expects to have a flight model completed by November 2013, roughly 1 year before the expected launch date from VAFB.

LAUNCH STATUS AND FUTURE DIRECTIONS

M-Cubed/COVE-2 and IPEX are both on track to deliver their flight systems for the December 2013 GEMSat launch from VAFB. After delivery to Cal Poly San Luis Obispo they will be integrated with the NPS CubeSat Launcher (NPSCul) at the Naval Post Graduate School with the seven other GEMSat CubeSat missions. The NASA CubeSat Launch Initiative (CLI) has selected the GRIFEX project for launch on ELaNa X planned for October 2014 from VAFB.

With the experience gained from MCubed, IPEX and GRIFEX, in September of 2012 ESTO released a solicitation for In-space Validation of Earth Science Technologies (NNH12ZDA001N-InVEST). The InVEST solicitation is designed to fill the gap of validating new technologies in space prior to use in Earth science missions. This new program line serves as a risk reduction activity where targeted technologies can rapidly advance the TRLs of instrument subsystems, or small instruments, to TRL-7 through successful spaceborne demonstrations. The objective of InVEST is to support development related to the Decadal Survey and the Climate-Centric Architecture that address a multitude of scientific measurements critical to understanding Earth system processes from space. Four InVEST awards were announced in April of 2013.

The Microwave Radiometer Technology Acceleration (MiRaTA) 3U CubeSat, led by William Blackwell of MIT Lincoln Laboratory, would validate new radiometer and GPSRO technology for an all-weather tri-band sounding capability at 60 Ghz, 183 Ghz, and 207 Ghz. The Advancing Climate Observation: Radiometer Assessment using Vertically Aligned

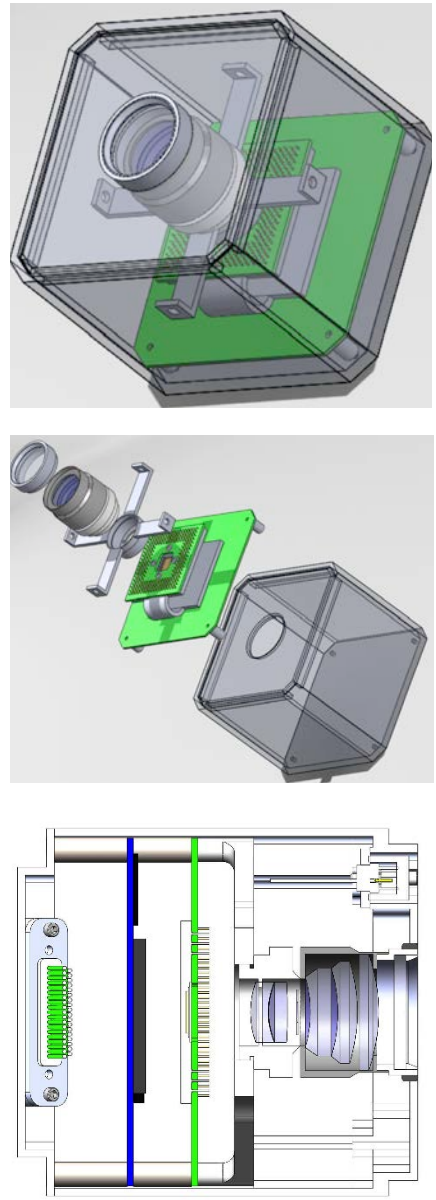

Figure 5. CAD of GRIFEX optical payload with camera, ROIC, and MARINA backend electronics.

Nanotubes (RAVAN), led by PI Lars Dyrud of Johns Hopkins Applied Physics Laboratory, would demonstrate a radiometer that is compact, low cost, and absolutely accurate to NIST traceable standards. The Hyperangular Rainbow Polarimeter (HARP)-CubeSat, led by J. Vanderlei Martins of University of Maryland at Baltimore County (UMBC), would advance technologies toward a highly accurate wide FOV hyperangle imaging polarimeter for characterizing aerosol and cloud properties. Finally, the CubeSat Flight Demonstration of a Photon Counting Infrared

Detector, led by Renny Fields of The Aerospace Corporation, would demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 0.9 to 4.0 microns. The InVEST program is a pilot program where the awards mentioned will be developed over a period of 3 years.

Acknowledgments

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