SPACEBORNE FLIGHT VALIDATION OF NASA ESTO TECHNOLOGIES

Charles D. Norton [1,3], Michael P. Pasciuto [2,3], Paula Pingree [1], Steve Chien [1], and David Rider [1]

[1]Jet Propulsion Laboratory
California Institute of Technology, Pasadena, California USA
Charles.D.Norton@jpl.nasa.gov

[2]National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, Maryland USA

[3]National Aeronautics and Space Administration
Earth Science Technology Office, USA

ABSTRACT

Small satellites flight experiments, using CubeSats, are growing rapidly as a low-cost and quick turn-around platform for education, focused science observations, and advanced technology validation. This talk will describe recent investments by NASA's Earth Science Technology Office (ESTO) to rapidly advance the TRL of various hardware and software technologies targeted for future Earth Science Decadal Survey Instruments via the CubeSat platform.

Index Terms— CubeSat, ESTO, COVE, IPEX, GRIFEX

1. 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 observational 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 is making significant investments in the U.S. National Research Council Earth Science Decadal Survey that recommends that NASA pursue a set of 15 on-orbit missions, implemented across a 3-tiered timeline, to measure fundamental Earth system science parameters essential to monitoring and data record enhancement of the forcings and responses related to climate change [1]. ESTO programmatic lines generally advance technologies to TRL-6. Given recent and rapid advancements in Small Satellites (including CubeSats), increased access to space, emerging standards, and cost effectiveness, ESTO is now pursuing mechanisms to flight qualify various technologies through successful spaceborne demonstrations to TRL 8 and/or 9. As non-validated technology is generally acknowledged as a primary source of mission delays and cost overruns a new technology flight validation line would directly address this concern. While these activities also include technology validation on the International Space Station we will address CubeSat flight experiments in this paper.

2. ESTO TECHNOLOGY FLIGHT VALIDATION EXPERIMENTS

ESTO's current approach is based on identifying existing technologies that can significantly impact Decadal Survey mission concepts and that are sufficiently mature for rapid enhancement and integration into 1U (10 cm x 10 cm x 10 cm) and 3U (30 cm x 10 cm x 10 cm) CubeSats. The payloads are developed by existing ESTO Principal Investigators, whom also lead the efforts, with spacecraft bus design, development, and integration led by university partners with significant experience in CubeSat development. The launches are acquired via the competitive NASA CubeSat Launch Initiative (CLI) where NASA Launch Services identifies launch integration and test requirements, mission readiness reviews, and launch vehicle integration. Communication is generally via UHF/VHF amateur radio bands, although S-Band is also being pursued, where HAM radio operators around the world participate in identification and tracking of the spacecraft. Operations and commanding are handled at the university partner institution with data analysis performed as a joint activity among the PI
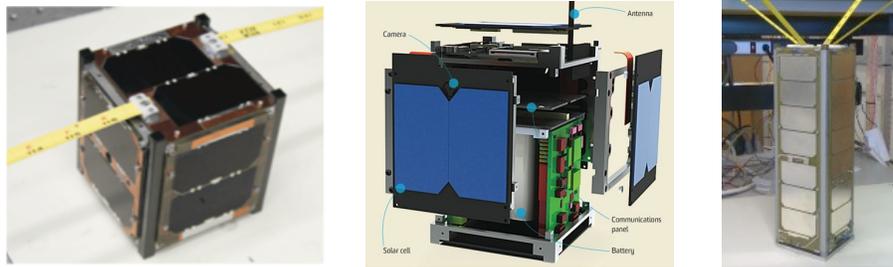
Figure 1. *ESTO CubeSat Projects Flown and In Development*. M-Cubed/COVE, IPEX, and GRIFEX CubeSats flight validating technologies for the Aerosol-Cloud-Ecosystems (ACE), Hyspectral Infrared Imager (HyspIRI), and Geostationary Coastal and Air Pollution Events (GEO-CAPE) proposed Decadal Survey Missions.

institution and participating partners. To date, ESTO has made investment in three technology validation activities relevant to the proposed ACE, HyspIRI, and GEO-CAPE Decadal Survey Missions to advance both hardware and information systems technologies.

2.1. M-Cubed/COVE

M-Cubed/COVE is the University of Michigan built 1U Michigan Multipurpose Mini-satellite (M-Cubed) that is carrying a JPL-developed payload called the CubeSat On-Board Processing Experiment (COVE) [2,3,4]. M-Cubed's mission is to take mid-resolution images of the Earth at approximately 200m per pixel while carrying COVE (Fig. 1). COVE will fly an experiment to prove an image processing algorithm designed for a proposed Decadal survey instrument called MSPI, the Multiangle Spectropolarimetric Imager (Fig. 2), utilizing the first in-space application of a new radiation-hardened-by-design Virtex-5 SIRF FPGA by Xilinx. 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.
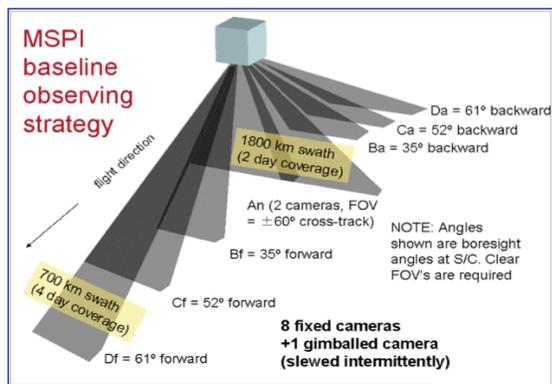

Figure 2. *MSPI Design*. MSPI will measure cloud and aerosol properties with 1 fixed and 8 gimbaled cameras.

A single camera for MSPI must processing ~100 MB/s of raw video data, where the future instrument will carry 9 cameras. This work will demonstrate how the COVE payload can move ground-based processing to space reducing the downlink requirements by two-orders of magnitude reducing risk for future instrument development and the Aerosol-Cloud-Ecosystems (ACE) Decadal Survey mission concept. M-Cubed/COVE successfully launched from Vandenberg Air Force Base on October 28, 2011 as a secondary payload on the NPP Mission under the CubeSat Launch Initiative (CLI) Program as part of ELaNa-3.

2.2. IPEX

The Intelligent Payload Experiment (IPEX) is a 1U CubeSat in development with Cal Poly San Luis Obispo that will carry a processing payload developed by NASA Goddard Space Flight Center (GSFC) with advanced web-based autonomous payload operations and processing software developed by NASA JPL (Fig. 1). IPEX will validate, in an on-orbit environment, autonomous science and product delivery technologies supporting TRL advancement of the Intelligent Payload Module (IPM) baselined for the proposed Hyperspectral Infrared Imager (HyspIRI) Earth Science Decadal Survey Mission concept providing a twenty-times reduction in data volume for low-latency urgent product generation. As the HyspIRI mission imaging spectrometer (VSWIR) and thermal infrared imager (TIR) will acquire roughly 5.5 TBytes of data per day during global imaging with 19-day and 5-day repeat intervals respectively IPEX will validate the role of the Intelligent Payload Module (IPM) to produce targeted reduced bandwidth data products that can be readily available to the community while the research science quality products are processed over a longer time period.

The CASPER onboard planning software, currently used on EO-1, will demonstrate the integration into the planning schedule new activity goals based on image processing results. It will also integrate onboard telemetry with the schedule to resolve conflicts. On the ground, the ASPEN software will generate weekly schedules of primary science payload activities such as image acquisition and
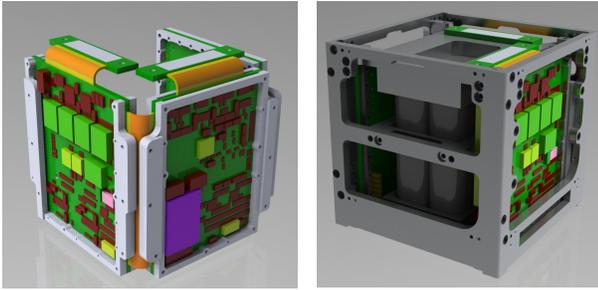
Figure 3. *SC-Mini Design*. Spacecube-Mini board design with integration into IPEX CubeSat bus structure.

Figure 5. *GRIFEX Payload Model*. Payload design including camera, data processing and ROIC/FPA.

processing based on candidate algorithms planned for the HyspIRI mission concept. One of the new technologies introduced will be the Spacecube-Mini (SC-Mini) designed for the CubeSat form-factor as a 3-part flexible integrated circuit board design (Fig. 3).

2.3. 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) (Fig. 1). 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. This ROIC has an unprecedented frame rate of up to 12 kHz while consuming less than 2W of power where the design of analog-to-digital converters (ADCs) in each pixel enables the all-digital design. The GRIFEX mission will assess the engineering performance of the ROIC in the space environment to reduce the integration risk for many future instruments, such as PanFTS, where extremely high frame rates for imaging are required.

The GEO-CAPE ROIC will be hybridized with SiPIN diode arrays to make a complete FPA (Fig. 4). The SiPIN diode arrays are being manufactured by Raytheon Vision Systems in Goleta, CA. The hybrid detector will be built into a simple camera and interfaced to a Xilinx Virtex-5 FPGA for detector control and data handling at the Jet
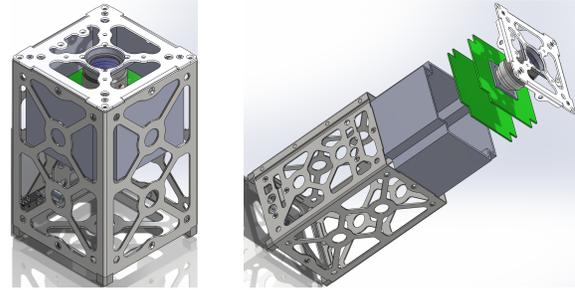
Propulsion Laboratory (Fig. 5). The camera and data system will be integrated into the student built 3U CubeSat at the University of Michigan.

The ROIC works with a broad class of detectors commonly used to make Earth science measurements. For GEO-CAPE, ESTO is also investing in the Panchromatic Fourier Transform Spectrometer (PanFTS) where the GEO-CAPE FPA is a key component of the interferometer used for high-resolution measurements (temporal, spatial, and spectral) to capture rapidly evolving tropospheric chemistry from geostationary orbit on an hourly basis for all of North and South America.

3. FUTURE PLANS

Now that ESTO has completed a first launch and operations phase with M-Cubed/COVE, with launches for IPEX and GRIFEX planned for the near future, the office is in the process of requesting technology development topics of interest via a Request for Information (RFI) solicitation. ESTO's focus will remain fixed on technology validation to reduce the risk of incorporating advanced technology into future science instruments and missions. Our future efforts to advance these technologies through space qualification will continue to extend the reach of ESTO's work into future Earth science missions.

4. ACKNOWLEDGEMENTS

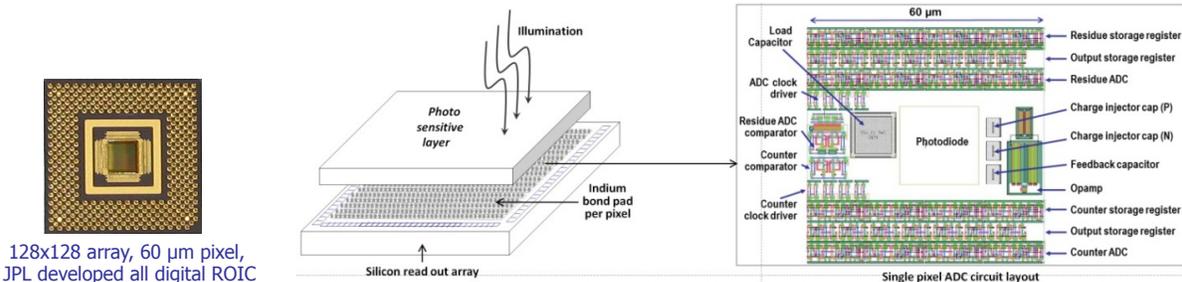128x128 array, 60 μm pixel, JPL developed all digital ROIC

Figure 4. *ROIC/FPA Design*. GEO-CAPE In-Pixel digitization packaged ROIC and detector design for flight validation on the GRIFEX CubeSat mission.

5. REFERENCES

[1] National Academy of Sciences, Earth Science and Applications from Space; National Imperatives for the Next Decade and Beyond, The National Academies Press, Washington, D.C., 2007.

[2] A. Craddock and J. Cutler, "Radio Aurora Explorer (RAX-2) and Michigan Multipurpose Minisatellite (M-Cubed): Two CubeSats from the Michigan Nanosatellite Pipeline Launch Together," *Space Times*, Vol. 50, No. 6, AAS, pp. 4-7, November/December 2011.

[3] D. Bekker, P. Pingree, T. Werne, T. Wilson, and B. Franklin, "The COVE Payload – A Reconfigurable FPGA-Based Processor for CubeSats,"25th Annual AIAA/USU Conference on Small Satellites, August 2011.

[4] P. Pingree, T. Werne, D. Bekker, T. Wilson, J. Cutler, M. Heywood, "*The Prototype Development Phase of the CubeSat On-board processing Validation Experiment (COVE),*" IEEE Proc. 2011 Aerospace Conference, Big Sky, MT.