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ONBOARD AUTONOMY AND GROUND OPERATIONS AUTOMATION FOR THE INTELLIGENT PAYLOAD EXPERIMENT (IPEX) CUBESAT MISSION

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ABSTRACT

The Intelligent Payload Experiment (IPEX) is a cubesat manifested for launch in October 2013 that will flight validate autonomous operations for onboard instrument processing and product generation for the Intelligent Payload Module (IPM) of the Hyperspectral Infra-red Imager (HyspIRI) mission concept.

We first describe the ground and flight operations concept for HyspIRI IPM operations. We then describe the ground and flight operations concept for the IPEX mission and how that will validate HyspIRI IPM operations. We then detail the current status of the mission and outline the schedule for future development.

1. Introduction

Future space missions will produce immense amounts of data. A single image from the HiRise camera on the Mars Reconaissance Orbiter (MRO) spacecraft is 16.4 Gigabits (uncompressed). The future HyspIRI mission under study [1] is proposed to have two instruments - the HyspIRI thermal infrared imager (TIR) instrument producing 1.2 million pixels per second with 8 spectral bands at 4 and 7.5-12 microns per pixel and the HyspIRI visible shortwave infrared (VSWIR) producing 300 thousand pixels per second with 220 spectral bands per pixel in the 0.4-2.5 micron range. Keeping up with these data rates requires efficient algorithms, streamlined data flows and careful systems engineering.

HyspIRI is also considering using Direct Broadcast technology [2] to rapidly deliver this data to application users on the ground. However, in order to leverage the existing DB network, this downlink path is limited to approximately 10 million bits per second. The Intelligent Payload Module (IPM) proposed for HyspIRI is an onboard processing system intended to intelligently decide which data to downlink when, in order to maximize the utility of the DB system.

The HypsIRI IPM concept involves both ground and flight automation. On the ground, users will use Google Earth ™ to specify geographical and seasonal areas of interest. These requests will be automatically combined with predicted overflights to develop a schedule for onboard product generation and downlink [3]. Additionally onboard the spacecraft, the instrument data will be analyzed to search for specific event or feature signatures such as a forest fire, volcanic eruption, or algal bloom. These detected signatures can generate alerts or products that will be merged on a priority basis to drive spacecraft operations.

2. IPEX Overview

IPEX is a 1u cubesat (Figure 1) [4] intended to flight validate technologies for onboard instrument processing and autonomous operations for NASA's Earth Science Technologies Office (ESTO).

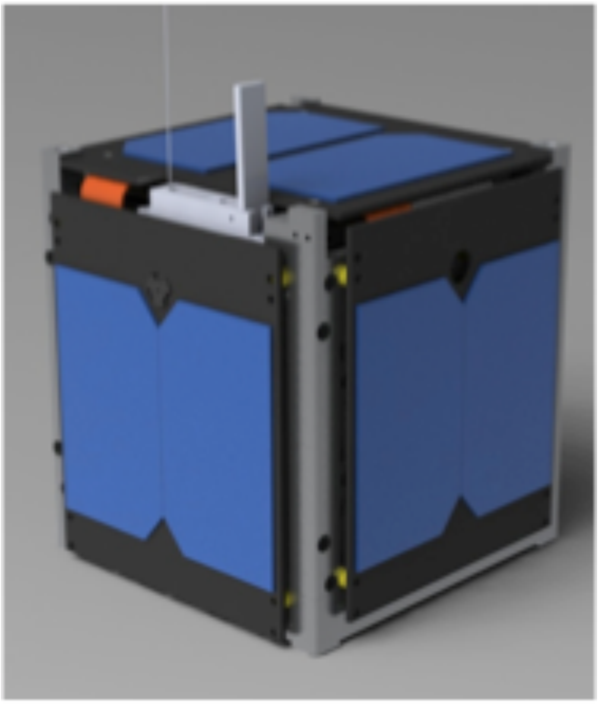

Figure 1: Intelligent Payload Experiment (IPEX) Model 1u Cubesat

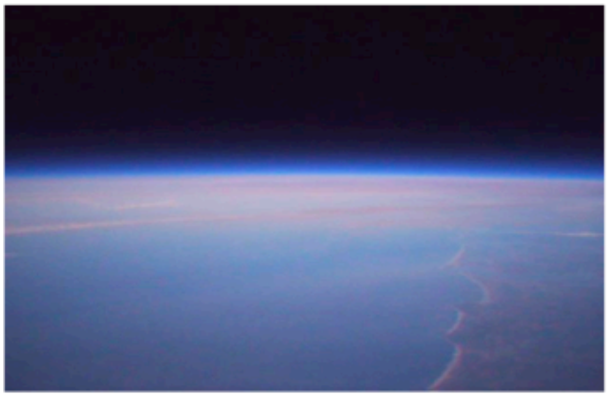

Figure 2: Image from balloon flight of same Omnivision family as IPEX camera (image courtesy A. Behar/PAUSE project/Caltech/JPL/NASA)

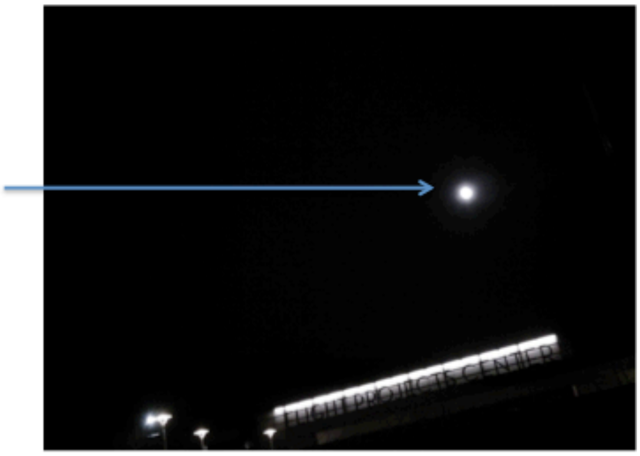

Figure 3: Image of moon taken from ground using IPEX flight model camera

As a 1u cubesat, IPEX is approximately 10cm x 10cm x 10cm. To support it's primary flight software, IPEX carries a 200MHz Atmel ARM9 CPU with 128MB RAM, 512MB flash memory, a 16 GB Micro SD card, and utilizes the Linux Operating System. All six sides of the IPEX spacecraft will have solar panels for electrical power generation and is anticipated to have 1-1.5W power generation. The IPEX spacecraft will use aligned magnets for passive stabilization in its low-earth orbit. The spacecraft carries several batteries to enable operations in eclipse and continuous processing modes. IPEX will carry four Omnivision OV3642 cameras, each producing images at approximately 2048 x 1536 pixel resolution, 3 Megapixels in size, with an instantaneous field of view of 0.025 degrees. With our currently manifested orbit we hope to get approximately 20m/pixel imagery of the Earths surface. Figure 2 shows image from a ballon flight of a similar camera and Figure 3 shows imagery acquired of the moon at night from our flight camera.

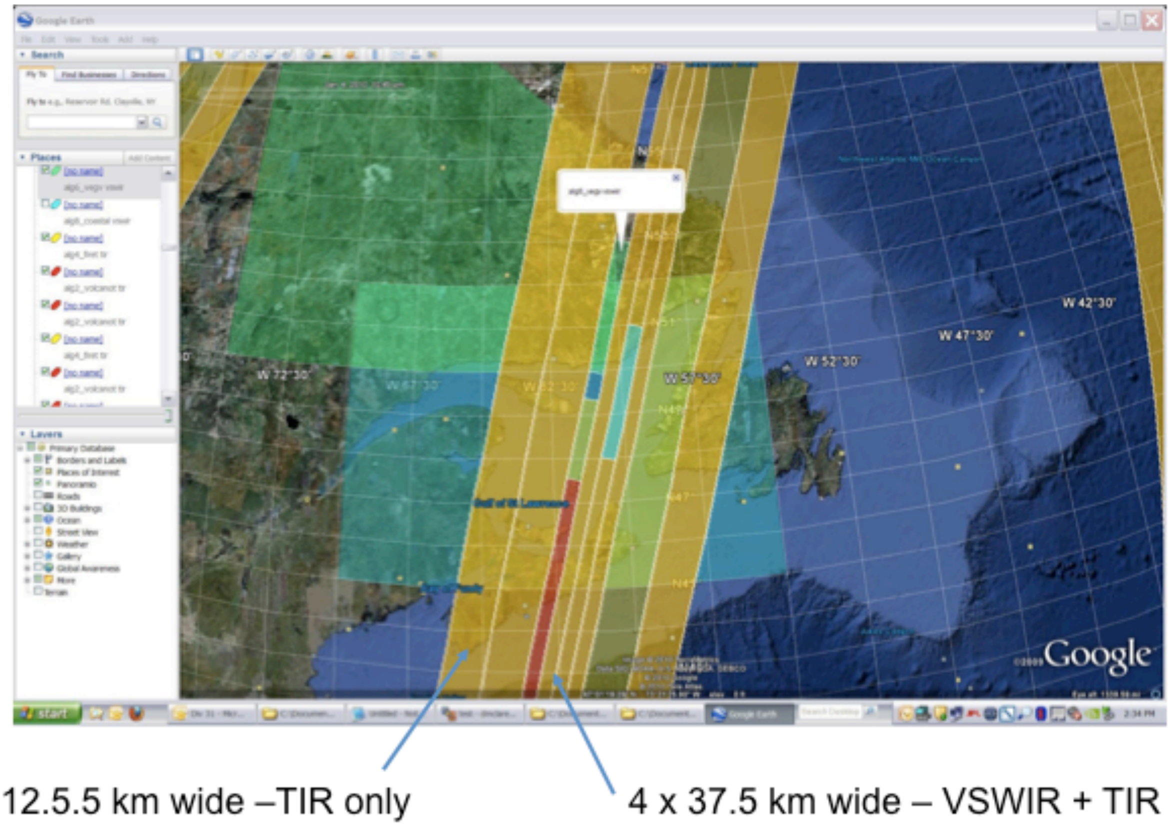

Figure 4: Google Earth ™ display of proposed HyspIRI instrument ground swaths

A key part of IPEX is the SpaceCube Mini (SC Mini) processor, developed by the Goddard Space Flight Center [5]. This is a compact processing package carried by IPEX in addition to the above Atmel. The SC Mini includes 2 PPC 440 non rad-hardened processors, over 100M FPGA gates, 2x256MR RAM, and 64 Gb flash RAM. The SC Mini runs a version of linux called SC linux. Because the SC mini will use over 10W power, it's duty cycle will be extremely limited (5% duty cycle). Because of thermal constraints most of this SC mini operations time will be during eclipse.

3. IPEX Ground and Flight Operations

IPEX is intended to demonstrate automated ground and flight operations of onboard autonomous processing of instrument data. In order to achieve this end, a range of capabilities and software are required.

The ground mission planning software for IPEX uses the CLASP [6-8] planning system to determine the processing and downlink requests based on the projected overflight of the spacecraft.

These requests are then handled in a priority-based fashion by the ASPEN [9] system to generate a baseline schedule for several days operations in advance. ASPEN must manage the ground contact schedule, eclipse schedule, observation activities, and onboard image processing activities. The onboard image processing activities can involve a range of constraints including CPU usage, RAM usage, and downlink product size. The primary activities of image-acquisition and image-processing can also require significant data storage resources based on when the image is acquired versus when the SC mini can be powered on (thermal & power constrained) to process the image.

Onboard the spacecraft the CASPER [10] planner will be used to manage spacecraft resources. CASPER will model all of the same resources and constraints as ASPEN but will be able to modify IPEX operations in response to deviations from the ground predicted plan such as: using more or less power than expected; activities taking longer or shorter than expected; or image products being larger or smaller than expected. CASPER will also be able to respond to onboard analysis of instrument data such as detection of features or events in imagery. Onboard processing will also be used to detect data of little value (e.g. images of dark space) early in processing activity. This analysis will save processing time, data-storage, and energy that would have been spent processing these less interesting images. In response, CASPER can schedule followon acquisitions from event or feature detection, or previously unscheduled lower priority data acquisition goals.

The IPEX spacecraft will have a number of driving operations constraints. IPEX is extremely power limited. The solar power generation will be approximately 1/10th of the maximum power draw (when the SC mini is powered on). The peak power of

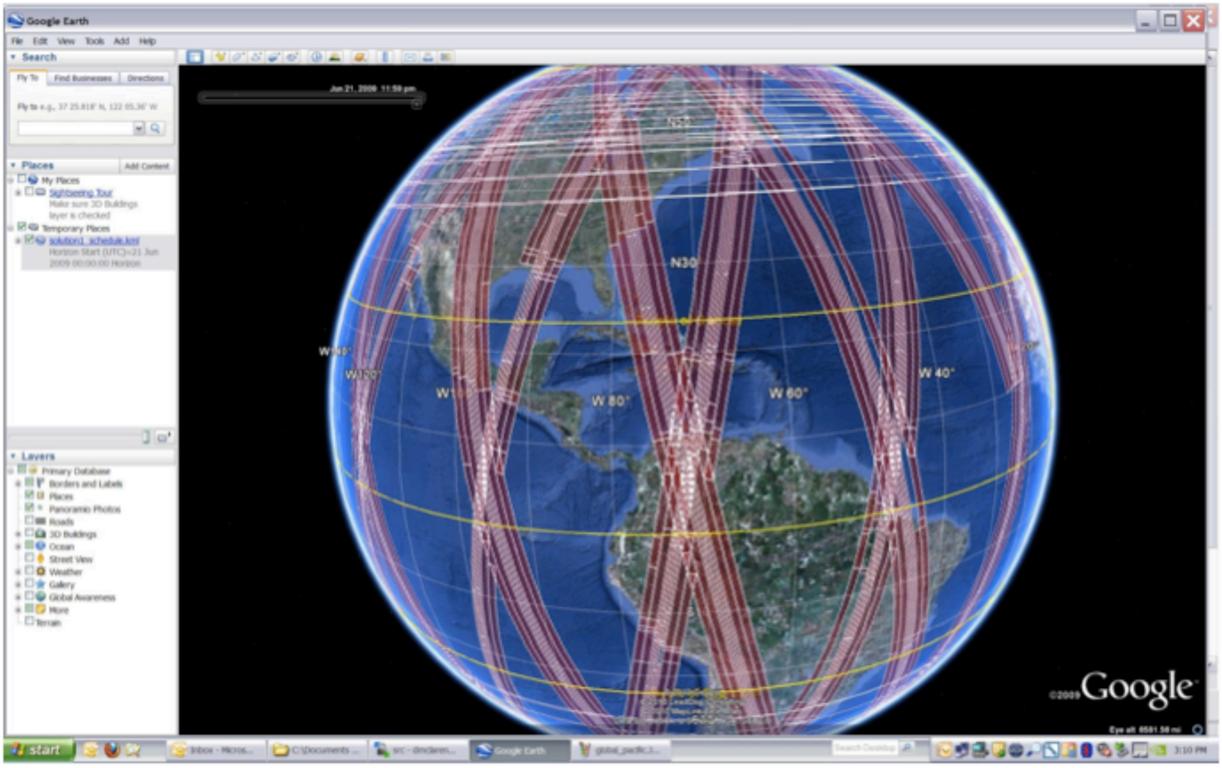

Figure 5: Google Earth ™ display of proposed HyspIRI instrument processing plan

the SC mini also limits its use to times of eclipse for thermal reasons.

The base flight software on IPEX is based on extensions and adaptation of the Linux Operating System. The well-known System V *init* process is used directly to start, and restart if necessary, the principal components of the flight software: systemManager for health monitoring, watchdog, beacon for real-time distribution of telemetry, datalogger for logging and archiving of telemetry and a sequence execution processes for real-time, time-based, and event-based commanding of the spacecraft.

4. IPEX Onboard Instrument Processing

IPEX will be validating a wide range of onboard instrument processing algorithms. The vast majority are variations of pixel mathematics, e.g. normalized difference ratios, band ratios, and similar products. For example, many flooding (surface water extent) classifications are based on band ratios [11-12]. Snow and ice products also use simple band processing formulae [13]. Thermal anomaly detection algorithms such as for volcano [14-16] and active fire mapping [17] also involve computationally efficient slope analysis of spectral signals. Finally, a wide range of vegetation indicators also involve difference ratios or similar computations.[18]

IPEX will also fly more computationally complex image processing technologies. These include: Suport Vector Machine Learning Techniques [19], spectral unmixing techniques [20], and TextureCam [21] Random Decision forest classification techniques.

IPEX is expected to have an extremely limited downlink data rate (less than 9.6K bits per second). AS a result, most of the IPEX onboard processing validation will come from running algorithms on the same images on the Atmel, PPC, and FPGA, and comparing the results. Only in cases where the results do not compare will full images be likely to be downlinked.

5. IPEX Status

The IPEX spacecraft bus design and development is led by Cal Poly San Luis Obispo and is mostly complete. Many elements of the spacecraft such as the CPU/motherboard and structure are complete. Many other elements such as the payload interface board are mostly complete with minor revisions expected.

The SC Mini design and development is by the Goddard Space Flight Center. SC Mini design has been completed and it is in the process of being fabricated. It is expected to complete testing and be delivered for final flight hardware integration in late 2012. Several versons of the SC linux software have been developed and have been used by the IPEX team for testing on the V5 Pro ML510 cards.

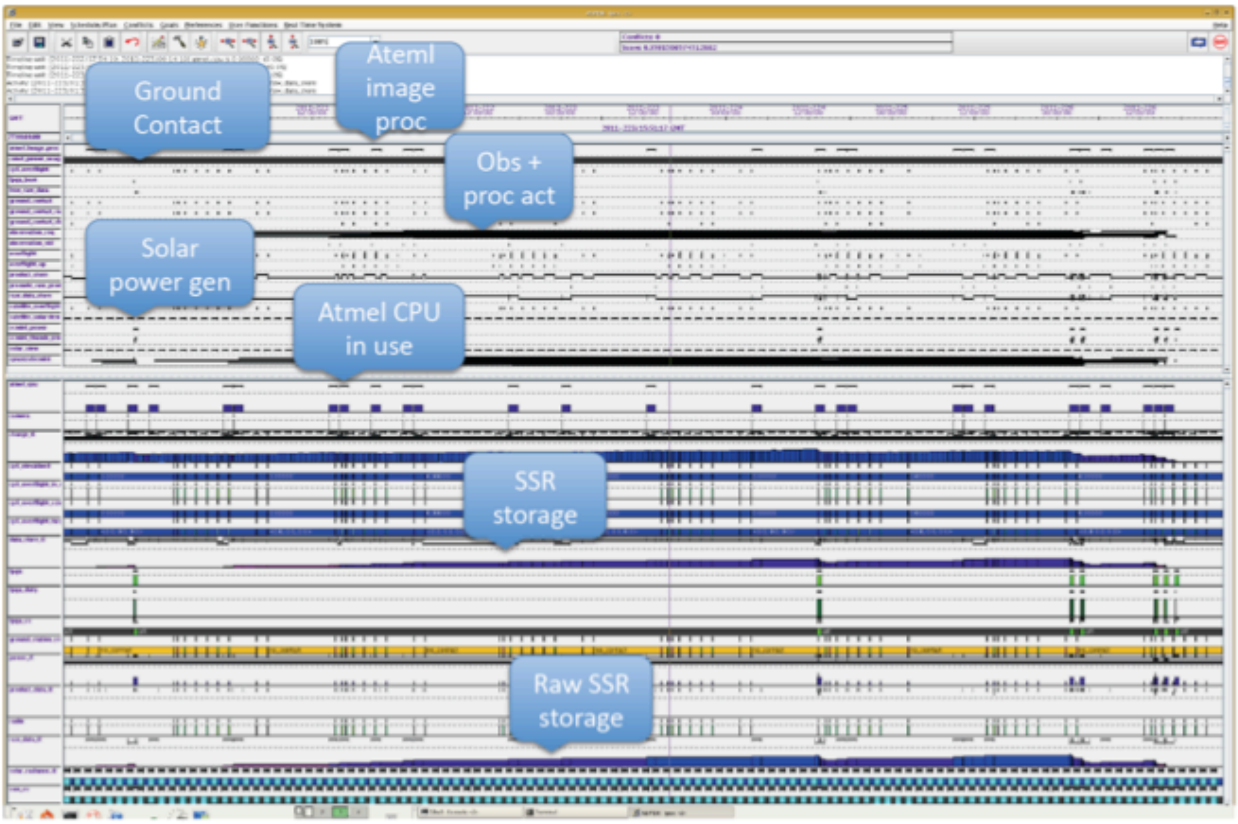

Figure 6: ASPEN display of proposed IPEX Operations Plan

The ground and flight autonomy software is developed by JPL and has been assembled in a set of software spirals. First versions of the ASPEN planning model were developed in the Summer of 2011. An updated version of the CASPER software is being integrated with the Cal Poly flight software in the Summer of 2012. Roughly a dozen of the image processing algorithms are currently operating on the Atmel and SC Mini PPC platforms. Current efforts are focused on increasing the fidelity of the operations models, implementing additional instrument processing algorithms (including on FPGA), and on closer integration with the Cal Poly Flight Software.

We will be testing the basic IPEX hardware and software without the SC mini on a balloon launch the 28th July 2012. This will enable an end-to-end test of the commanding software, image acquisition, telemetry, and hardware in a near space environment. This will also allow us to acquire test imagery in near space like conditions with the flight camera.

IPEX is manifested for an October 2013 launch. This launch has an associated April 2013 launch integration delivery. Currently an engineering test unit will be assembled in late 2012 with the final delivery of the SC Mini flight unit arriving in time for the final flight unit integration and environmental test.

6. Related Work, Future Work, and Conclusions

The Autonomous Sciencecraft on the Earth Observing One (ASE) spacecraft has pioneered onboard instrument data analysis [22]. In particular ASE highlighted onboard product generation for volcanology [23], flooding [24], and cryosphere [25] disciplines. However, ASE did not have to deal with high data rate streams as will challenge IPEX and HyspIRI.

Onboard the Mars Exploration Rovers, the WATCH software enables automatic processing of imagery to track dust devils and cloud features [26]. More recently, the AEGIS software enables onboard retargeting for targets of geological interest [27].

We have described the IPEX mission to flight validate autonomous operations and onboard instrument processing. The IPEX cubesat will flight validate the SpaceCube Mini flight processing unit. The IPEX cubesat will also demonstrate low cost, autonomous ground and flight mission opeartations enabling end users to specify image processing and product requests.

7. Acknowledgements

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