Flight Validating the Proposed HypIRI Intelligent Payload Module: Results from Intelligent Payload EXperiment (IPEX) Cubesat Operations

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*Proposed Mission - Pre-Decisional – for Planning and Discussion Purposes Only

IPEX: Technology Validation of Autonomous Low-Latency Product Generation for HyspIRI* Concept

Intelligent Payload Module (IPM) for HyspIRI* Decadal Survey Mission Concept

- Direct broadcast, autonomous science operations, and product delivery technologies for near real-time product generation
- Proposed spectrometer and thermal IR Imager (TIR) acquire 5 TB/day
- IPM will provide 20x reduction in data volume for low-latency products

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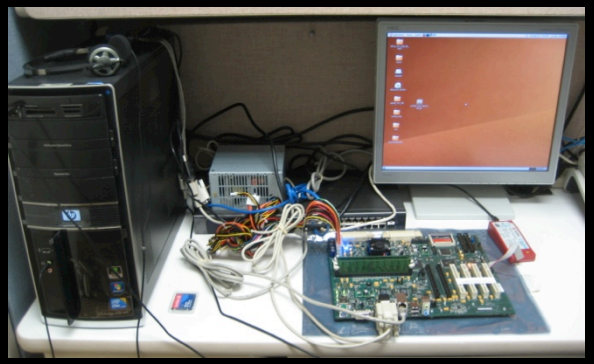
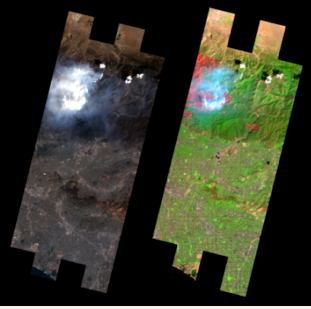


Candidate HyspIRI Low-latency Products

(Burn Scar Data)



200m/pixel with ~50 deg FOV

IPEX flight model carries 5 cameras

Ground Test

Development board with autonomous processing in laboratory environment

Balloon Test

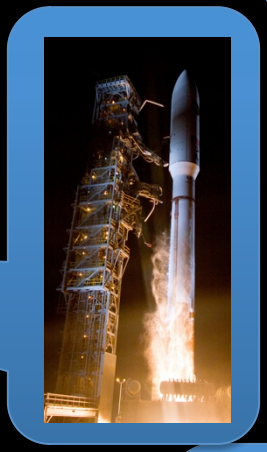
Hundreds of activities scheduled and executed at 100K feet

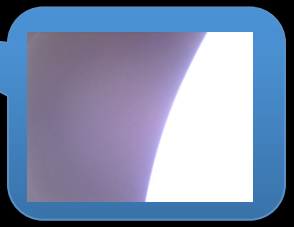
Spaceborne Validation

IPEX CubeSat will verify on-board product selection for HyspIRI objectives

IPEX Timeline

- Balloon Tests July, December 2012
- Launch Integration Delivery June 2013
- Launch 6 Dec 2013
- Level 1 mission success Jan 2014
- Extended Operations





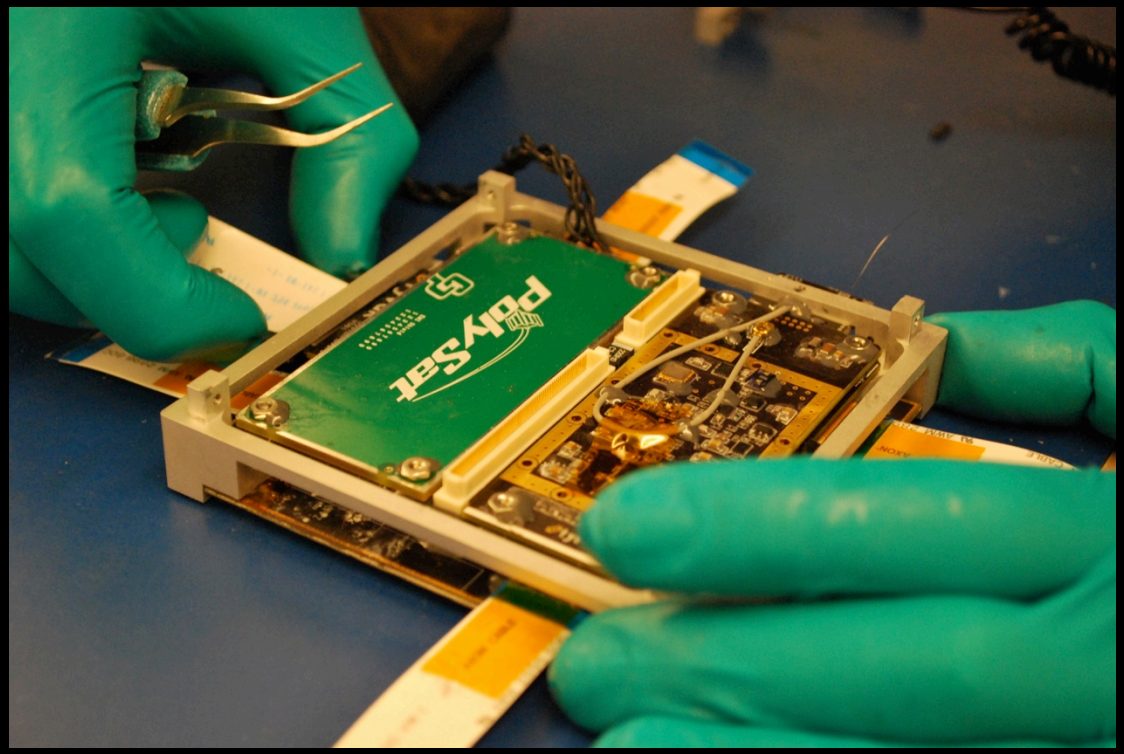
PolySat

- Project-based learning and applied research
- Satellites designed & operated in-house by engineering BS and MS students; Cal Poly SLO
  - EE
  - ME
  - CPE
  - Aero

- 40+ students participated in IPEX via Cal Poly and JPL

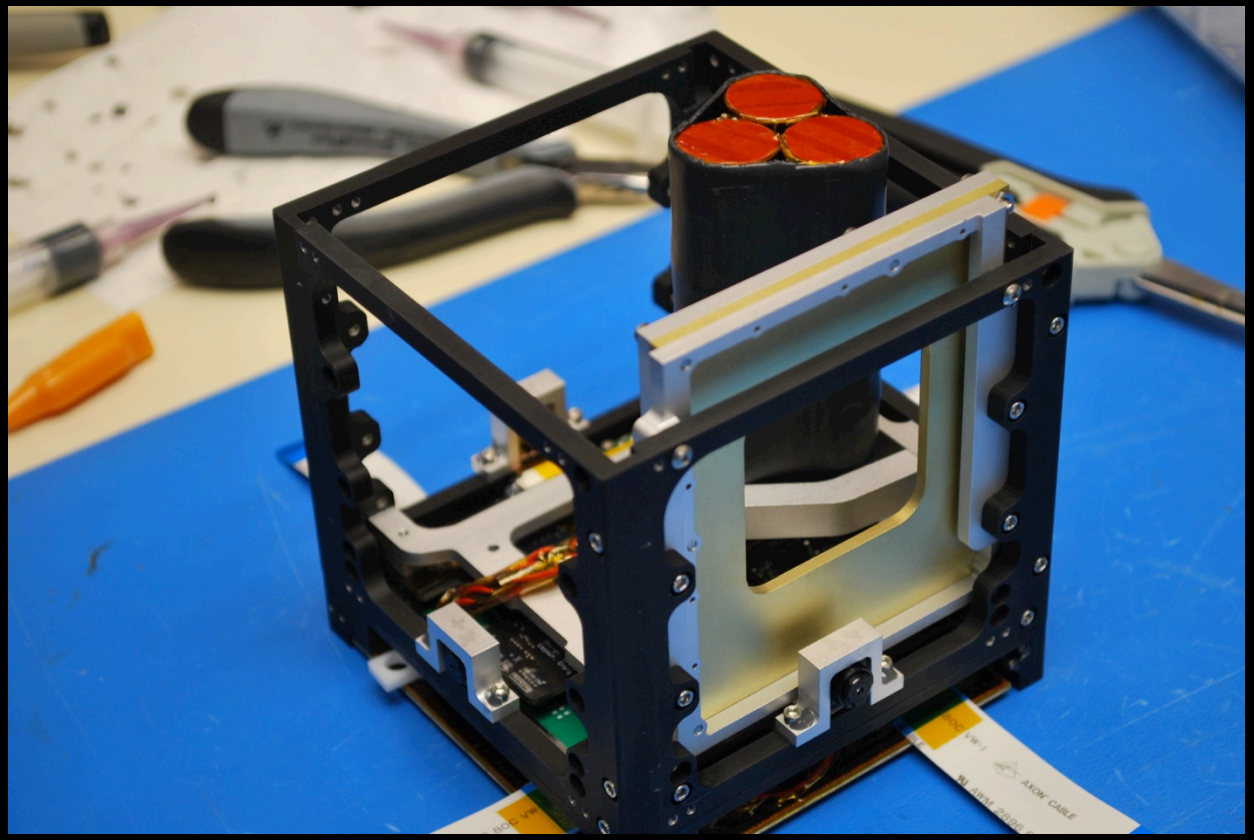
Compact Computing
Cal Poly Intrepid Board

- 20 mm board stack
- ~400 mW
- 400 MHz ARM CPU
- 128 MB RAM
- 512 MB Flash
- 8 GB SD card



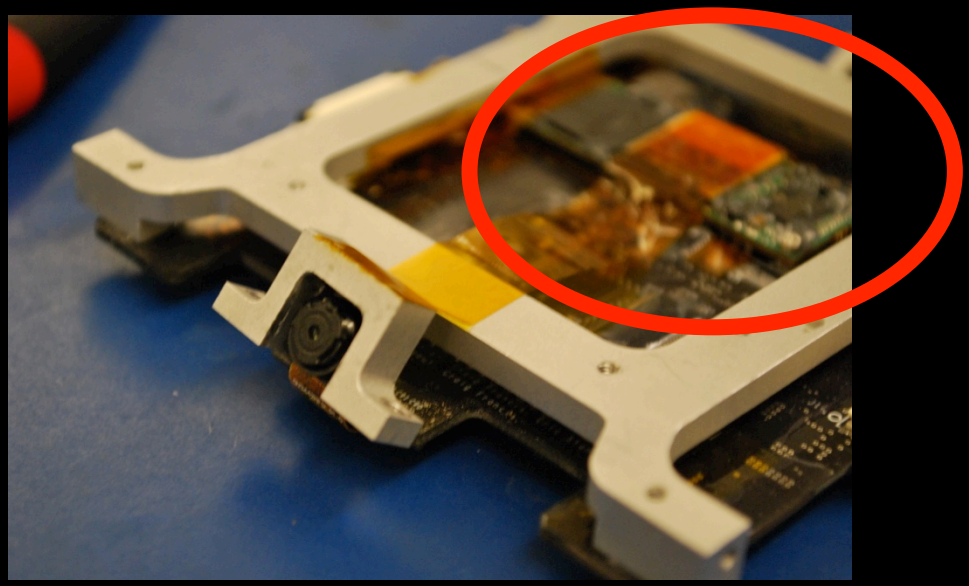
Favorable Payload Budgets

- 80% of spacecraft volume left for payload
- ~1 W continuous power in 1U



Gumstix Payload Processor

- SCMini encountered fabrication difficulties (Pioneer)
- SCMini Fabrication delays and launch schedule required switch to Gumstix Earth Storm
  - 800 MHz CPU
  - 512 MB RAM
  - 512 MB SSR



5 x 3-MegaPixel Cameras

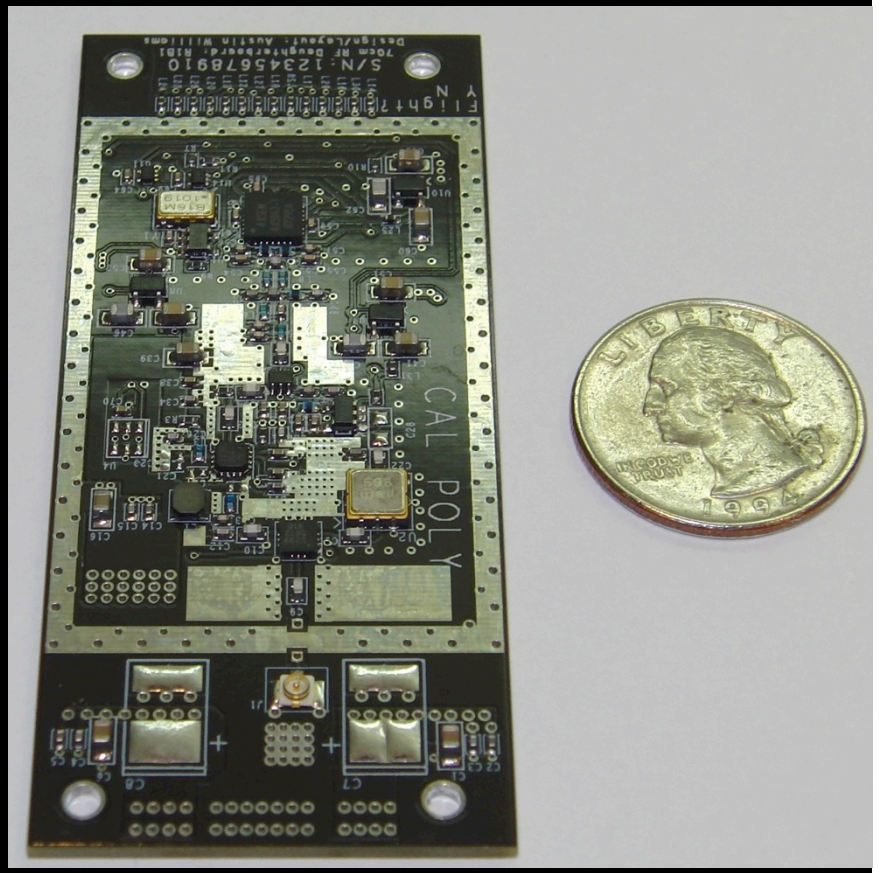
- Cell phone COTS parts
- Provide input data to onboard image processing algorithms

Flight Software

- Linux-based
  - Custom code to add expected satellite functionality
- Standards compliant
  - Smaller learning curve for Poly students, others
- Standard communication protocols
- Facilitates On-orbit software updates
- Linux is a viable for payload processing applications that do not have hard real-time constraints

Communication

- Custom UHF radio hardware
  - 1W output power
- Amateur radio
  - 437 Mhz
  - 9600 bps



Autonomy Overview

- **Onboard Image Processing**
- Autonomous management of image processing and operations
  - Ground planning, onboard autonomy

Validation Methodology

- Image Processing Validation methodology
  - Generate products on CDH and Gumstix
    - Checksum comparison
      → conclude successful product generation
  - Ground pre-loaded imagery
    - check against pre-loaded checksum → success
- Operations Validation
  - Execute specific scenarios to validate each autonomy capability
    - Priority-based scheduling
    - Resource-based scheduling
    - Geographically-based image and product request

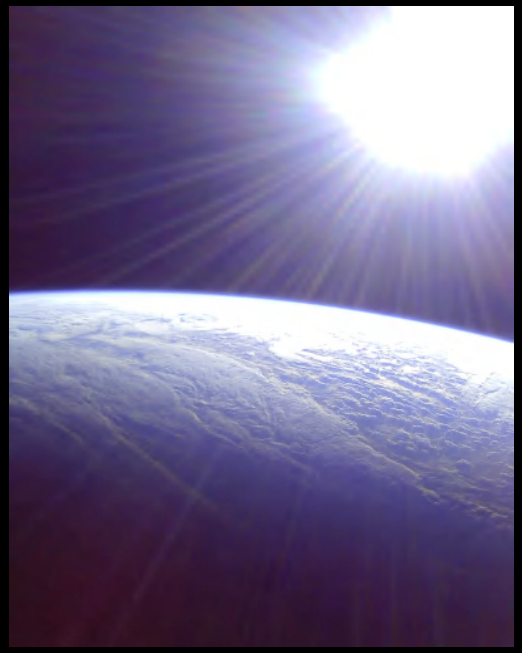
Onboard Products/Algorithms

Algorithm Name	Description
Generalized Normalized Difference Ratio Normalized Ratios*	Wide range of band ratios for vegetation, burn severity, ice, …
ICER*, JPEG2000*	Image compression
FLAASH-C	Atmospheric correction
Superpixel segmentation	Similar region identification
Sequential Maximum Angle Convex Cone (SMACC) / Endmember Selection	Spectral unmixing, material identification
TextureCam*	General classification, decision forests
Landmark Salience map	General image/computer-vision processing
Maximally Stable Extremal Regions (MSER)*	Correspondence detection
Scale Invariant Feature Transform (SIFT)	Correspondence detection
Support Vector Machine (Machine learned)*	Wide range of classifiers and regressions

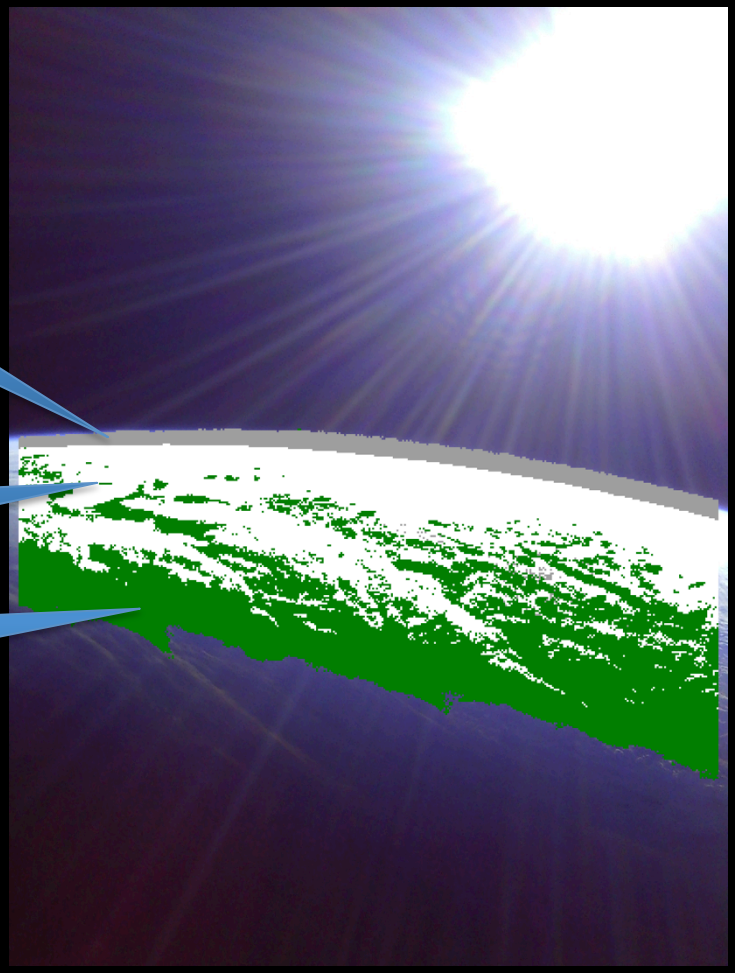
* - routinely run

For further information see [Chien et al. IGARSS 2010, JSTARS 2013]

Onboard Product: TextureCam Classification



Original Image

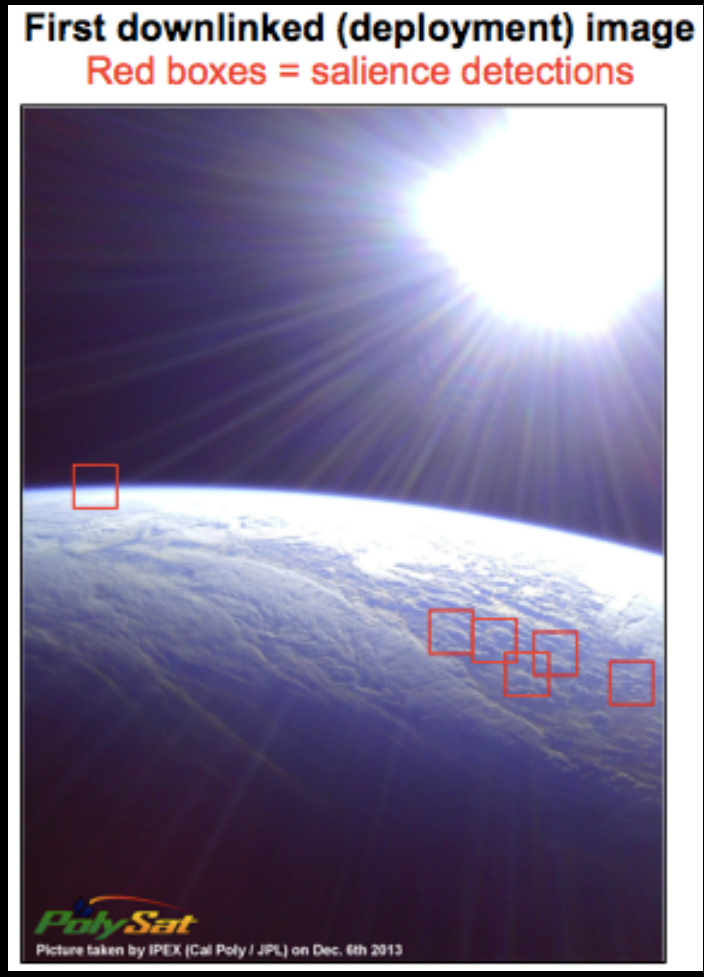


Original Image showing onboard product as generated on ground.

Onboard Product: Landmark Salience

- Landmark Salience
  - An image analysis algorithm that automatically selects sub-regions of high visual salience (exceptional or high-contrast features) for prioritized downlink.

Original Image



Ground processing showing product as would be generated onboard

Technology Validation – Product Generation

Metric	Score
Imaging Requests - preloaded	260
Imaging Requests - acquired	138
Imaging Requests fulfilled: TOTAL	398
Band Ratio - Histograms	13818
Band Ratio - Images	3290
Band Ratio - TOTAL	17108
Salience Thumbnails	3290
TextureCam Thumbnails	~5920
Checksums validated against ground (pre-loaded images)	~12300
Total image products validated	31256

Autonomy Overview

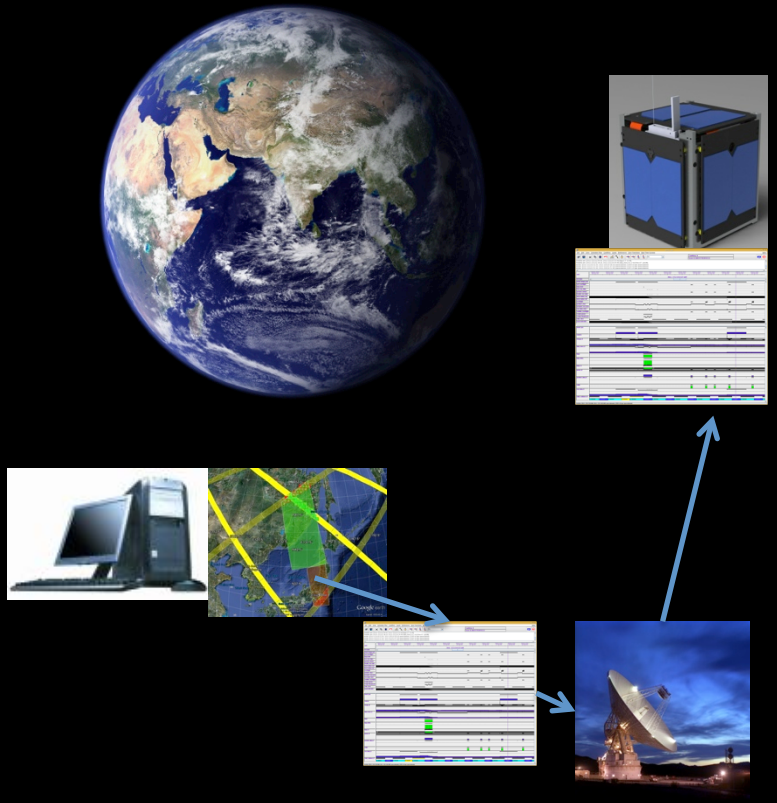
- Onboard Image Processing
  - Families of image analysis algorithms
  - Examples of data products
- **Autonomous management of image processing and operations**
  - **Ground planning, onboard autonomy**

Autonomous Operations

- Onboard software autonomously fulfills imaging and product generation requests
  - Take an image at *specified time* with *specified camera*
  - Execute *specified product generation workflow* or *default product generation workflow*
    - E.g., “image Australia and generate a flood map”
    - Generate requested products from acquired image.
    - Generate products redundantly on CDH and Gumstix board

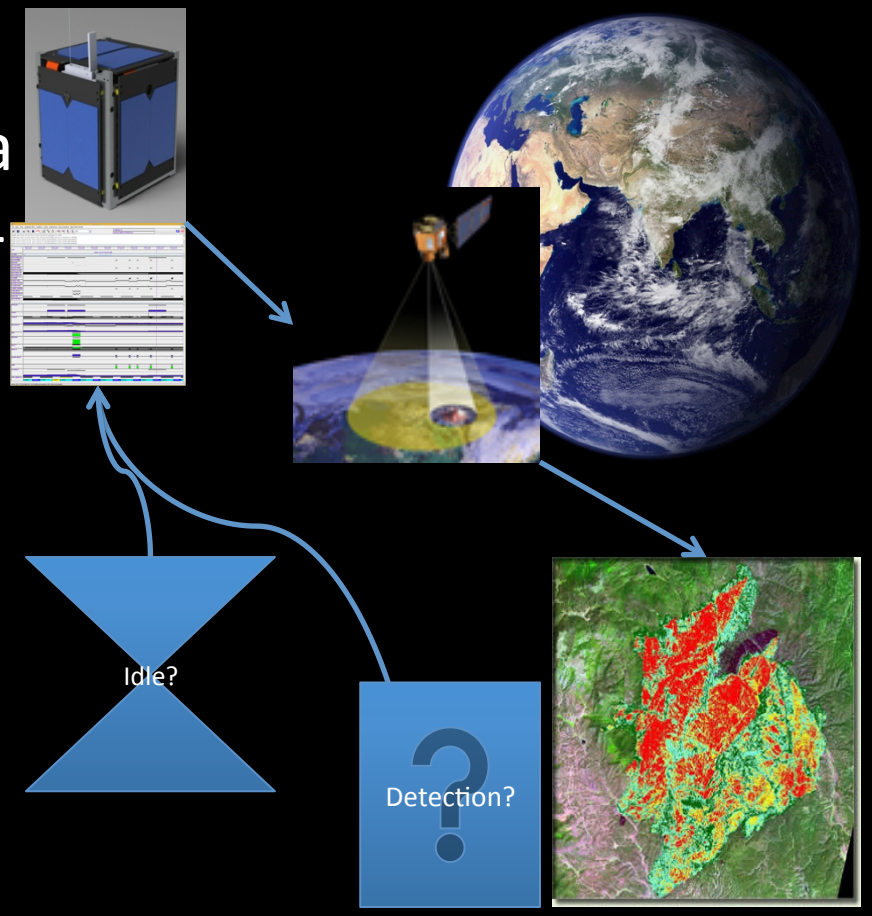
Observation Request Generation

- **<u>Geographic based image and product requests</u>**
  - Web-based ground planning tool to generate observation requests for uplink to spacecraft
  - Generates schedule of radio contacts to avoid operational conflicts



Autonomous Response and Autonomous Filler Imaging/Processing

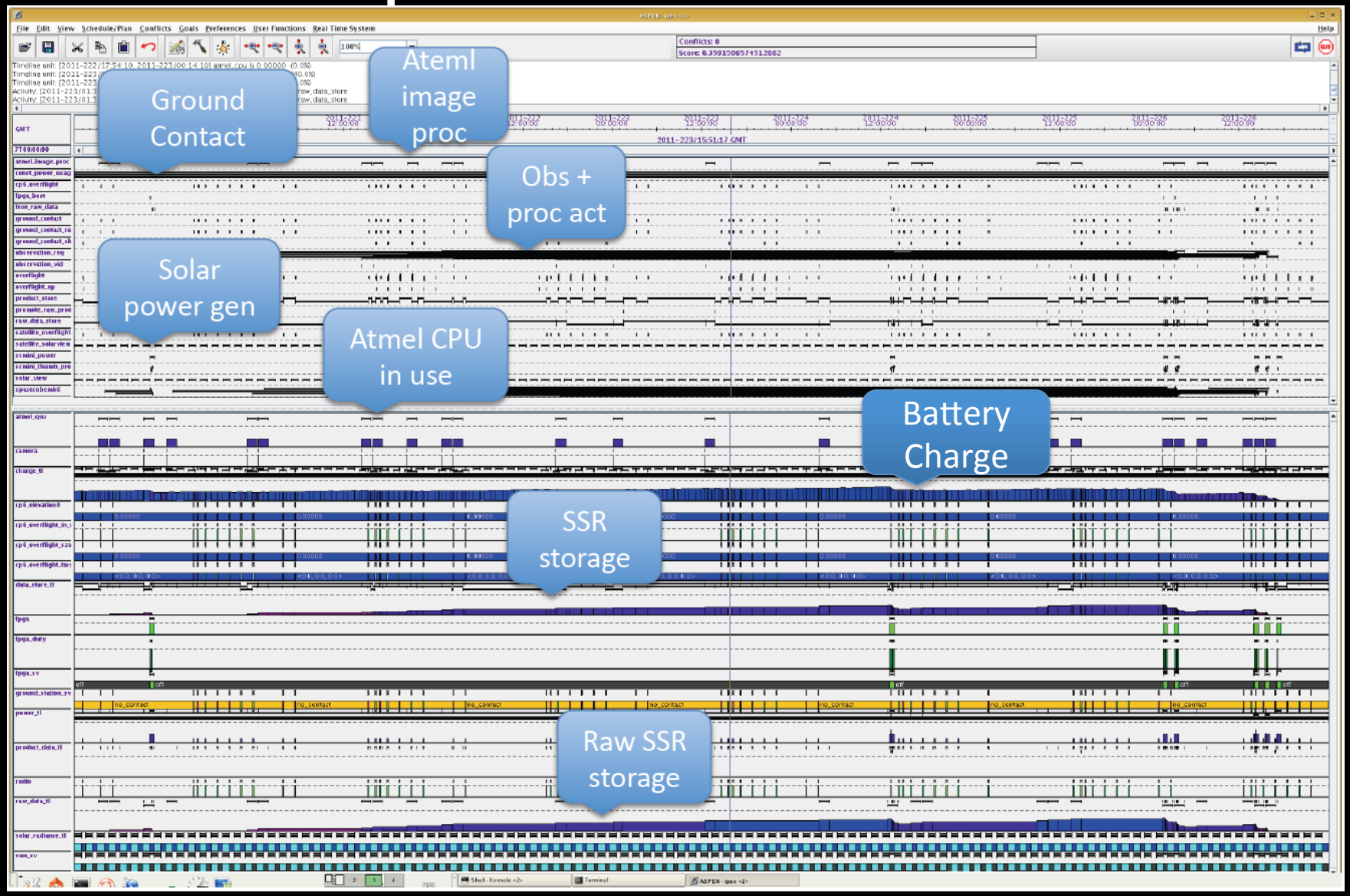
- **<u>Autonomous Response:</u>** analysis of an observation can trigger a "follow on" observation-request or processing
  - at a prescribed priority
- **<u>Autonomous Filler:</u>** Onboard agent issues periodic "idle" observation requests
  - at a low priority



Autonomous Operations:
Automatic operations constraint enforcement

- Onboard IPEX, CASPER monitors current system health and and models future system health: e.g. battery state of charge, CPU usage, Disk resources, Communications schedule
- Observation and processing goals are scheduled automatically:
  - Enforcing all relevant operations constraints
  - Respecting user-defined priorities

Sample CASPER schedule



Technology Validation – Autonomous Operations

Metric	Score
Imaging Requests fulfilled: TOTAL	398
Total image products validated	31256
Autonomous responses executed	94
Geographic based requests requested	3
(limited by uplink issues)	
“idle/filler” agent imaging requests	42

INSPIRE: Onboard Autonomy

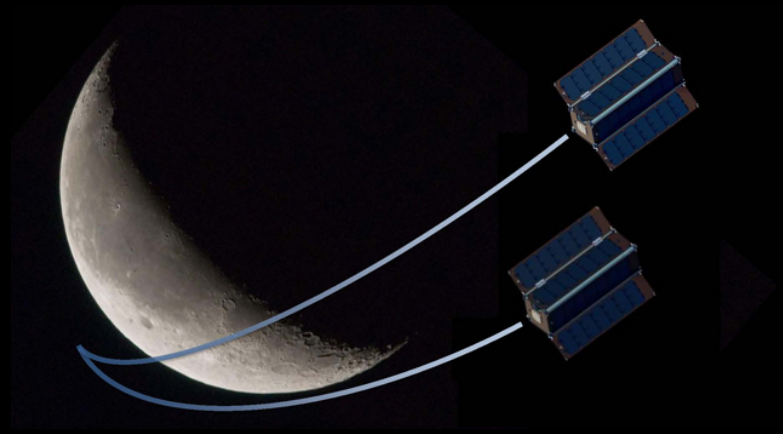
INSPIRE is a 3u interplanetary cubesat under development by JPL. **INSPIRE** will fly the same Intrepid system board and Omnivision 3642 cameras as an onboard science technology validation

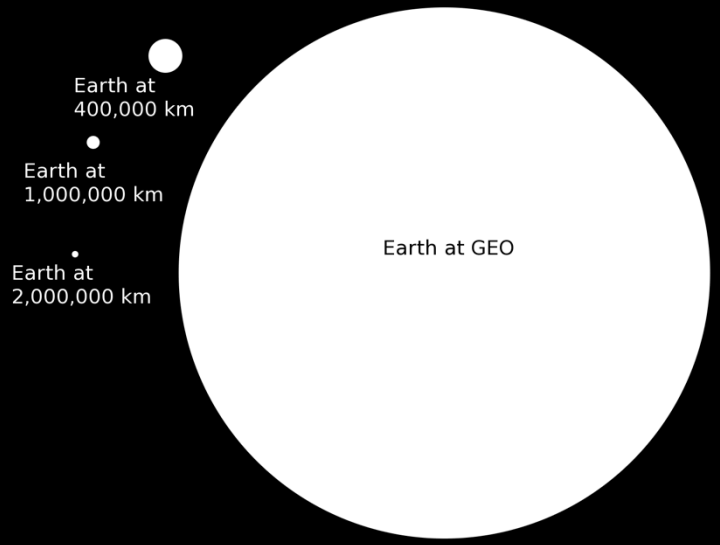
Approach Onboard image analysis will detect Earth against the star field background. Images and subframes containing the planet will be prioritized for downlink.

Expected benefits 20x data reduction for image selection vs. random, >100x or more for subframing

Heritage components include CASPER (downlink resource management), TextureCam (image analysis).

New components to be demonstrated include convex hull horizon detection.

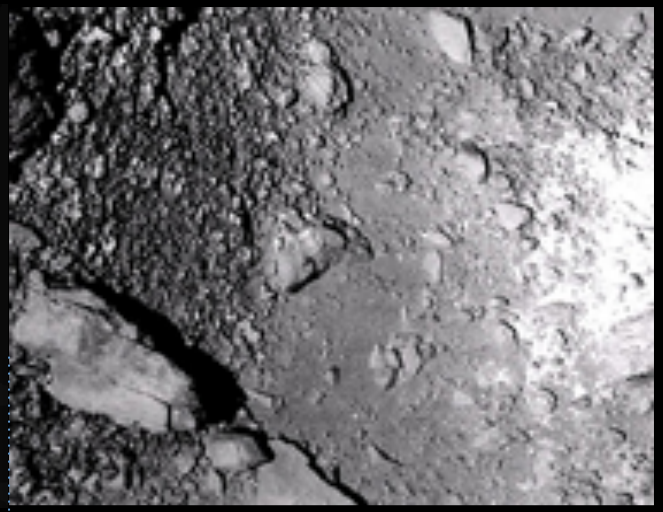




Apparent size of Earth in camera frame
Shown for different mission phases

NEAScout*: Imaging for Detection and Reconnaissance

6U Cubesat
2+ year mission to asteroid @ ~ 0.25 AU



	Target Detection and approach with wide field imaging Ephemeris determination	**Target Reconnaissance with medium field imaging** Shape, spin, and local environment	**Close Proximity Imaging** Local scale morphology, terrain properties, landing site survey
ACTIVITIES			
CHALLENGES	Limited downlink (<5 kbps) Limited camera capability Large target position uncertainty	Limited downlink (<5 kbps) Short flyby time (<4 hr) Uncertain environment	Limited downlink (<5 kbps) Short time at closest approach (<20 min.)
APPROACH	Autonomous sky scanning sequence Image co-adding for SNR increase Compression	Autonomous navigation Autonomous target (re)pointing, Adaptive gain setting Thumbnails, triage, lossless compression, windowing and feature extraction	

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Conclusions

- IPEX has successfully validated several key technologies for HysPIRI* IPM and other future missions
  - Onboard product generation
    - Evolutionary (band ratio, normalized difference) and
    - Revolutionary (machine learning, e.g. TextureCam)
  - Autonomous Payload Operations
    - Autonomous workflow management
    - Autonomous Response imaging and processing
    - Automatic operations constraint enforcement
    - Priority and geographic-based requests
- Future missions (INSPIRE, NEA Scout*) would further use these technologies

*Proposed Missions - Pre-Decisional – for Planning and Discussion Purposes Only

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