Onboard Mission Planning for the Intelligent Payload Experiment (IPEX) Cubesat

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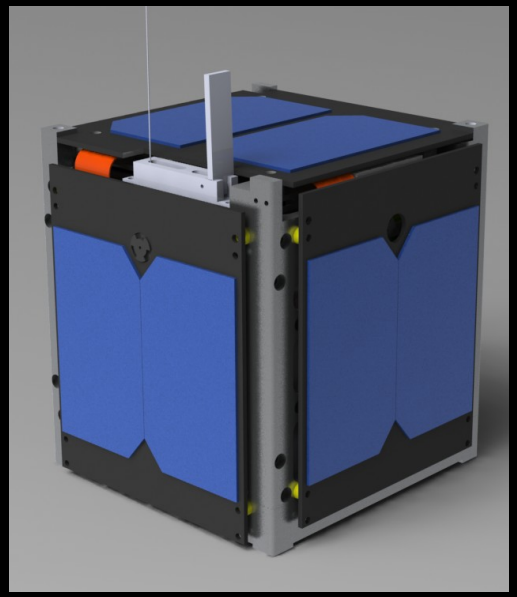
Background

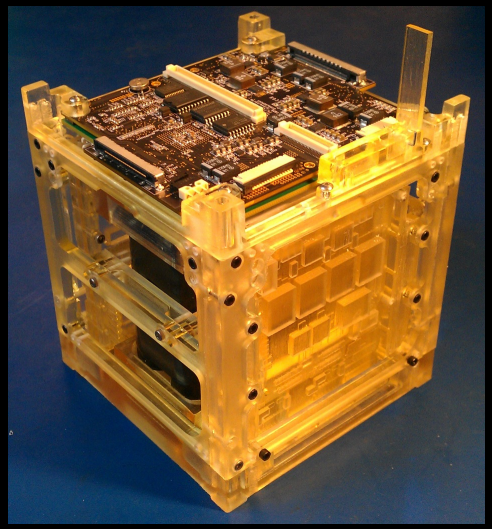
- IPEX is a 1u Cubesat sponsored by NASA Earth Science Technology Office (ESTO)
- Goals
  - Flight validate onboard instrument data processing and product generation software for proposed HyspIRI mission (JPL)
  - Flight validate autonomous operations for instrument processing (JPL)
  - Enhance NASA outreach and University ties (Cal Poly SLO)
    - Cal Poly builds, integrates, operates IPEX cubesat
  - Manifested on Gemsat/L-39
    - October 2013 launch (May 2013 launch integration)

Cal Poly SLO CP-8 spacecraft

- 1u cubesat
- Passively stabilized
  - fixed magnets
- Cal Poly Motherboard
  - 400 MHz Atmel (no HW FPU)
  - 128 MB RAM
  - 512 MB Flash
  - Micro SD card slot (16 GB)
  - Linux OS



rapid prototype



Camera

- 5 x Omnivision OV3642
- <u>Camera Specifications</u>
- Focal Length (f): 4mm
- Integration Time (t_int): 67ms
- Pixel Diameter (d_pixel): 1.75um
- 3 Megapixels (2500x1600)
- FOV = ~50 degrees

2 of 4 Cameras

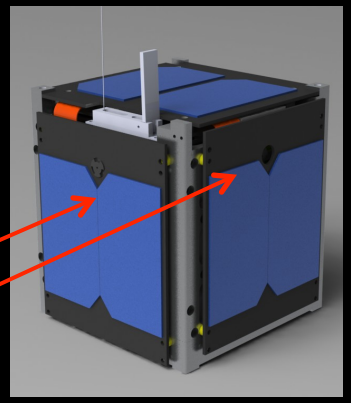


Image from test balloon flight

Payload CPU – Gumstix Earth Storm

- Computer on Module
- Widely used in terrestrial applications
- 800 MHz OMAP (ARM) CPU
- 512MB RAM
- 512MB Flash
- SD card slot (8GB used)
- < 1W typical power
- Runs Linux

Onboard Instrument Processing on IPEX

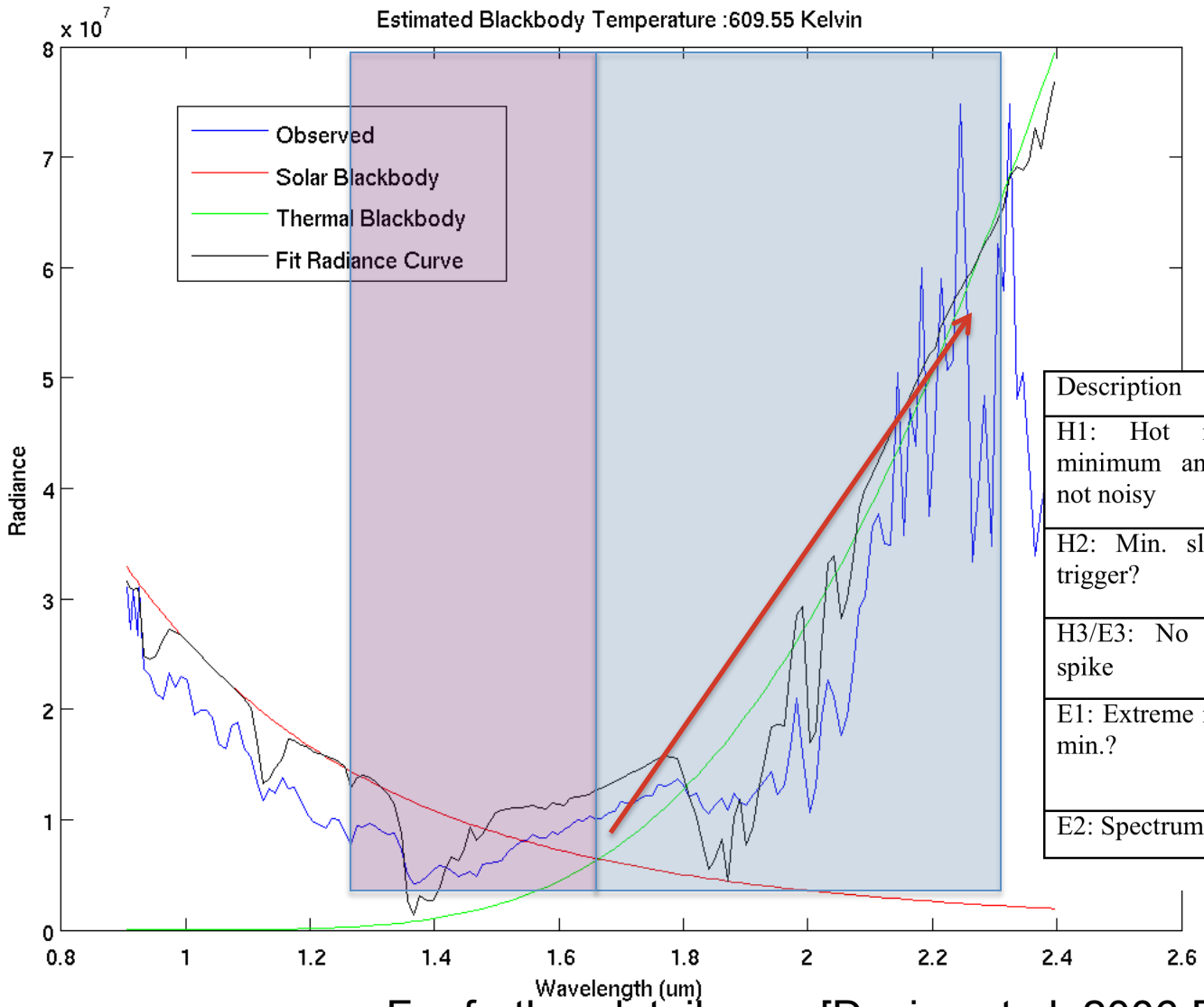
- IPEX will utilize the Gumstix and Atmel to:
  - Demonstrate onboard image correction and bad data rejection
    - image filtering while tumbling
  - Onboard product generation
    - Using both Omnivision 3-color data and Hyperspectral data loaded at launch

Onboard Products/Algorithms

Algorithm Name	Description
Generalized Normalized Difference Ratio Normalized Ratios*	Wide range of band ratios for vegetation, burn severity, ice, …
Thermal anomaly detection	Estimation of thermal output to detect volcanic activity, wild fires
Water Depth Calculation	Uses DEM to compute water depth
Support Vector Machine (Machine learned)*	Wide range of classifiers and regressions
Superpixel segmentation	Similar region identification
Sequential Maximum Angle Convex Cone (SMACC) / Endmember Selection	Spectral unmixing, material identification
FLAASH-C	Atmospheric correction
TextureCam*	General classification, decision forests
ICER*	Image compression
Scale Invariant Feature Transform (SIFT)*	Landmark Identification
Maximally Stable Extremal Regions (MSER)	Correspondence detection
Mixture Tuned Match Filter (MTMF)	Signature detection
Shapefile Generation	Region identification from bitmaps

* - routinely run

Volcanic Activity Detection

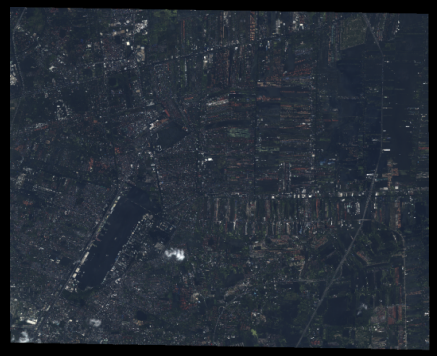


Description	Measure
H1: Hot radiance minimum and pixel not noisy	0.625 < 1.65 µm, 2.25 µm, & 2.28 µm < 750
H2: Min. slope for trigger?	Slope G > 0.13558 G=1.4 for DNs
H3/E3: No 2.28µm spike	(2.28µm+1.65µm)/2< 2.25µm*1.2
E1: Extreme radiance min.?	0.625 < 1.25 µm, 1.65 µm, & 2.28 µm < 750
E2: Spectrum shape	2.28 µm > 1.65 µm/2

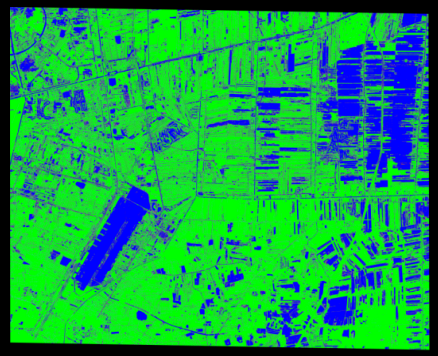
For further details see [Davies et al. 2006 RSE]

Flood Tracking

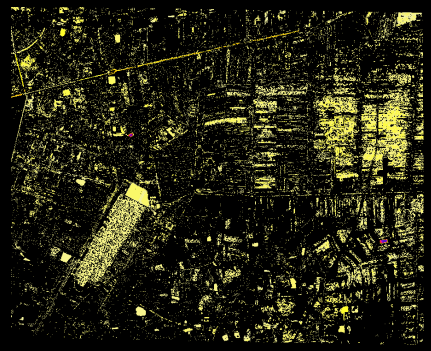
- Integrated WV-2 data (2m spatial resolution)
- Developed algorithms and workflows for water depth and volume estimation (incorporating DEM) – potential algorithms for proposed HyspIRI IPM



Reflectance of WV2 scene of Bangkok w/ flooded Don Muang Airport, acquired 11.3.2011



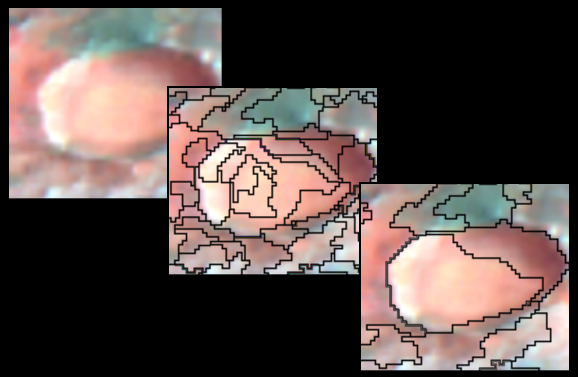
Surface water extent (blue) from SVM classifier using 5th degree polynomial kernel on 8 WV2 bands



Resulting water depth map calculated using SVM-classified surface water extent map and DEM. Total water volume calculated: ~27,872,000 m^3; average flooded pixel depth: 0.64 m.

For further information see [Mclaren et al. 2012 SPIE, Chien et al. 2012 i-SAIRAS]

Onboard Hyperspectral Analysis

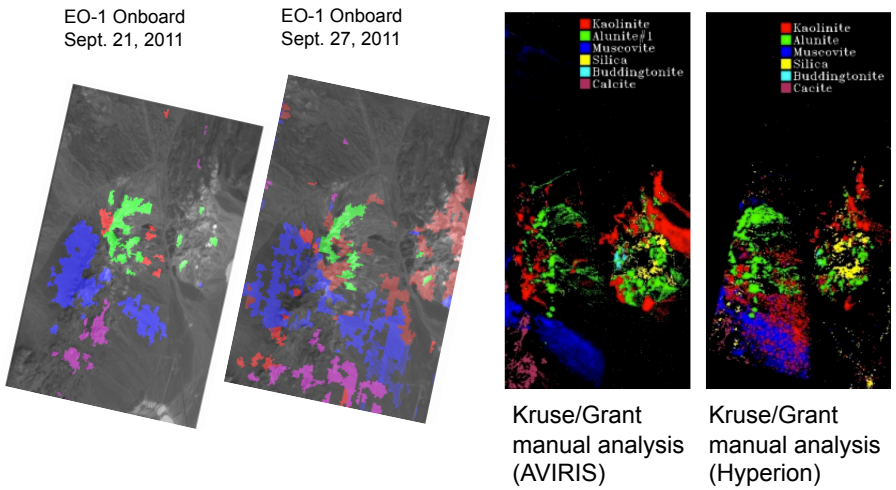


Superpixel segmentation
+
SMACC endmember extraction

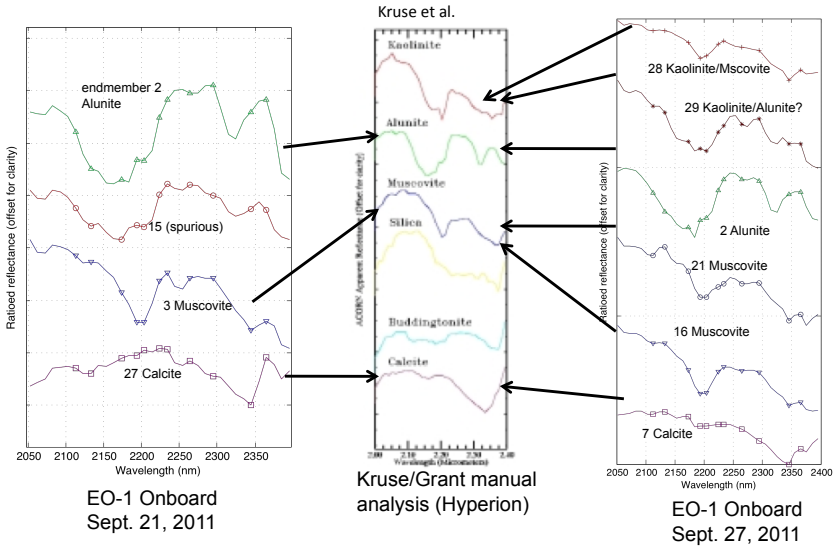
Results from onboard EO-1 (9/2011)

For further details see
[Thompson et al TGARS 2009, 2012]

Repeatability: maps

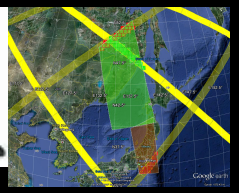


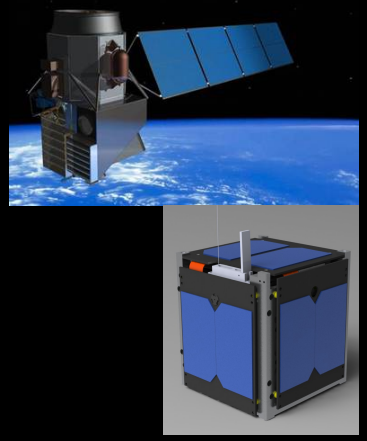
Repeatability: detections



IPEX/Proposed HyspIRI IPM Operations Concept

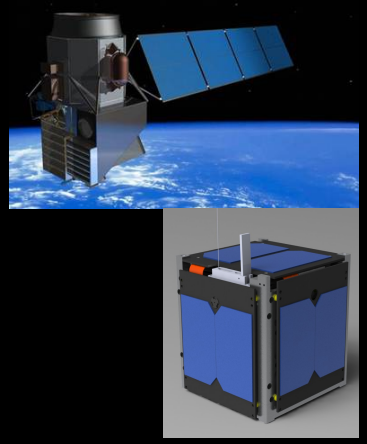
Operations Team enters request regions, products, priorities in Google Earth ™ and CLASP

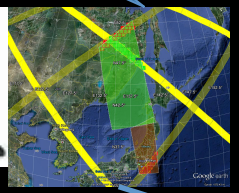


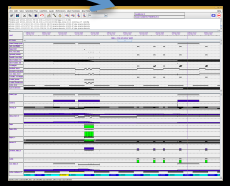


IPEX/Proposed HyspIRI IPM Operations Concept

CLASP uses orbit information to generate time-based goal requests to ASPEN

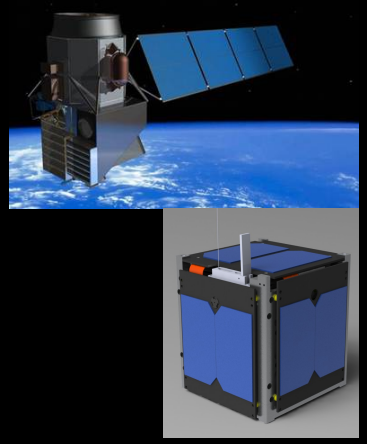


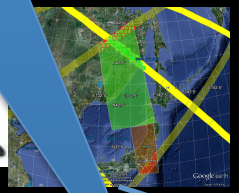


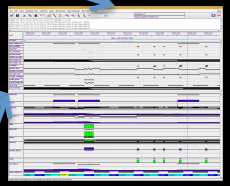


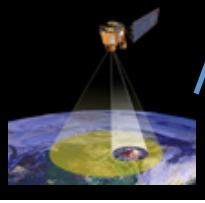
IPEX/Proposed HyspIRI IPM Operations Concept

Other space and in-situ sensorweb assets also electronically submit image and product requests at authorized priorities





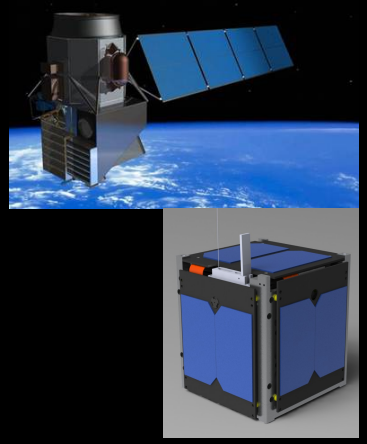


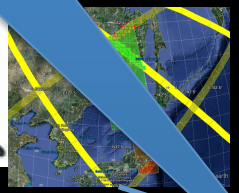


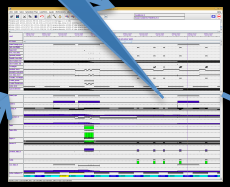
Pre-decisional – for Planning and Discussion Purposes Only

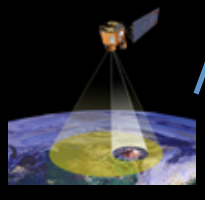
IPEX/Proposed HyspIRI IPM Operations Concept

ASPEN generates operations schedule respecting CPU, RAM, SSR, downlink volume, power, thermal,… constraints









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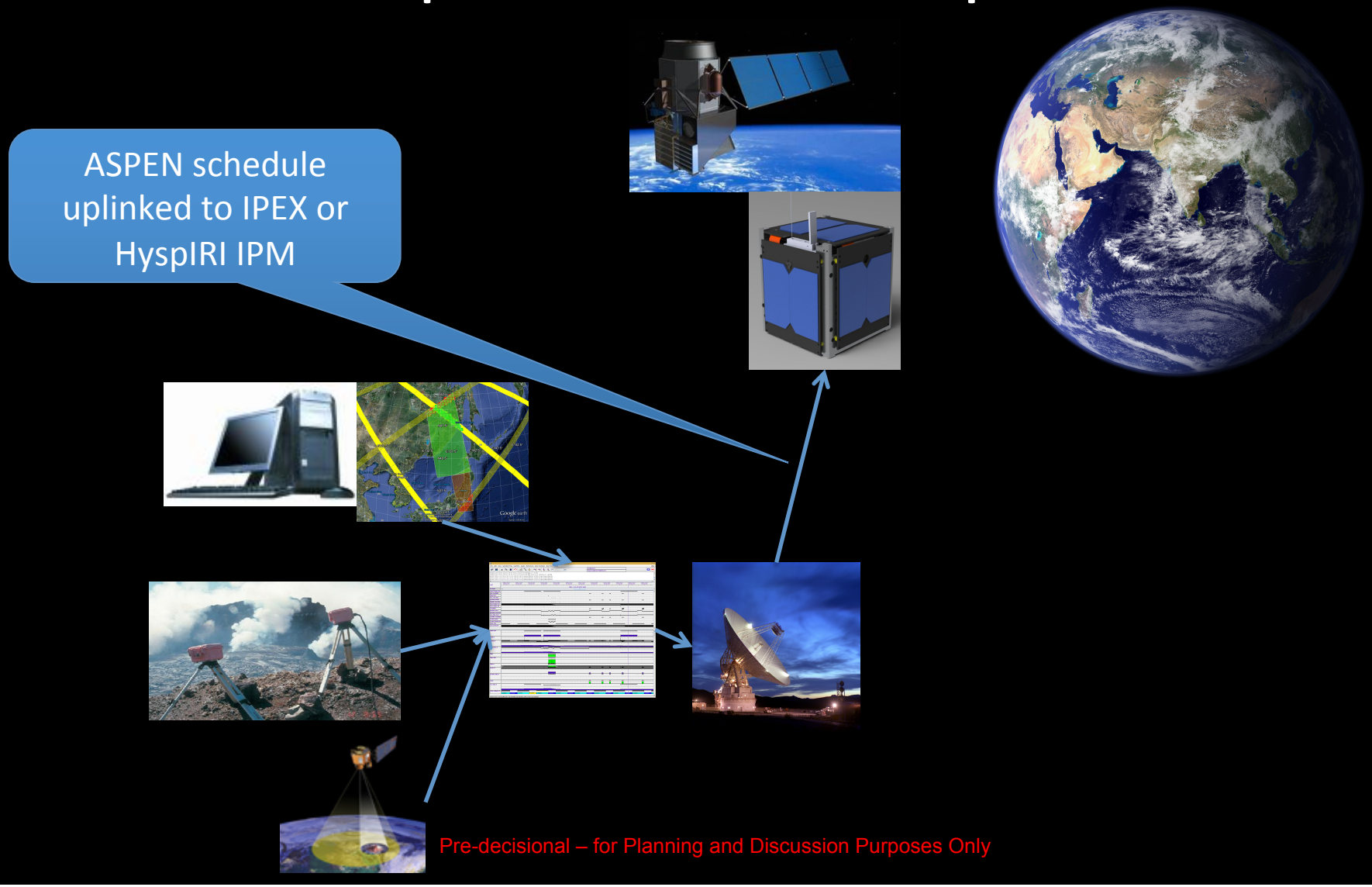

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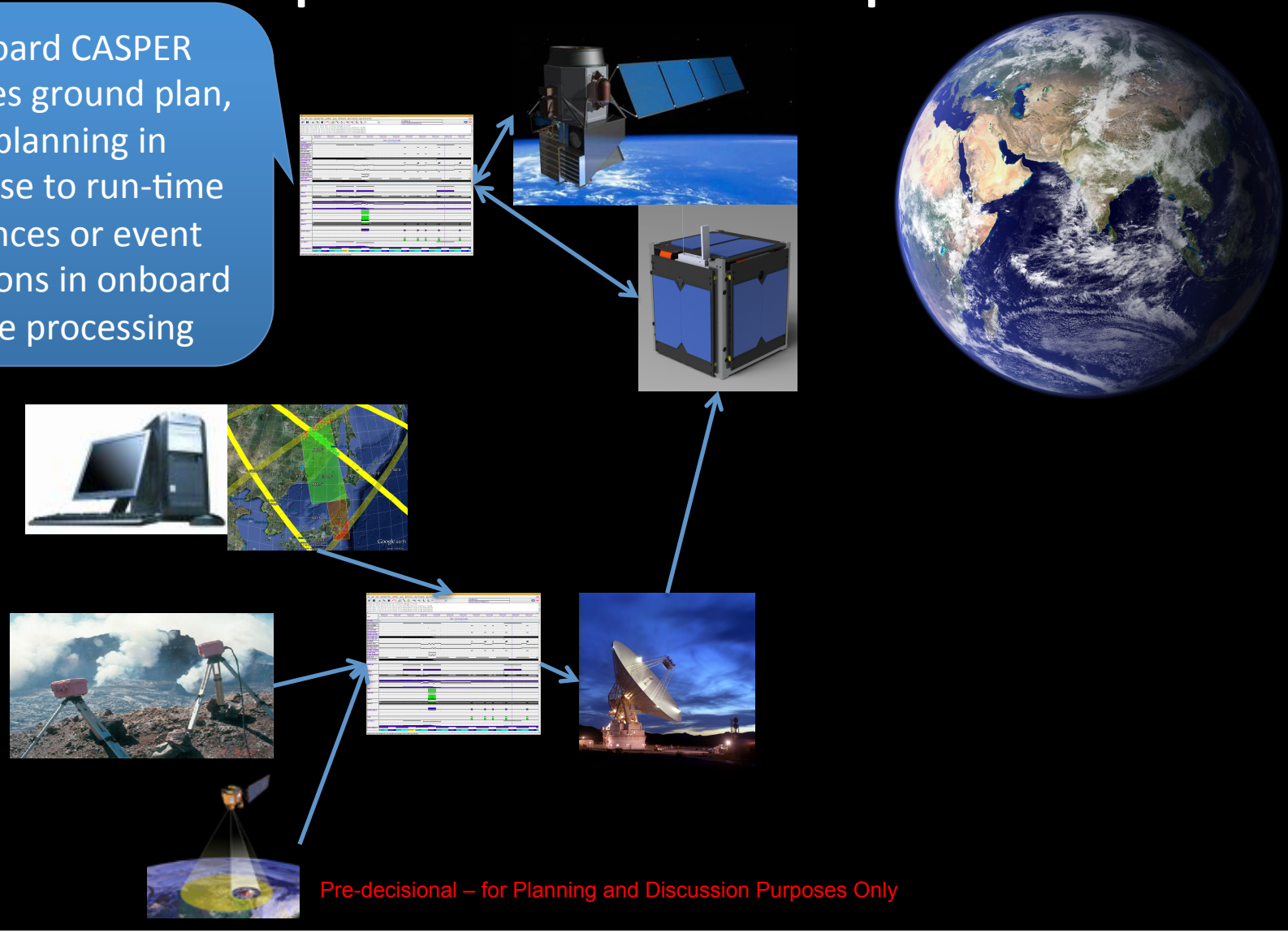
IPEX/Proposed HyspIRI IPM Operations Concept

Onboard CASPER executes ground plan, re-planning in response to run-time variances or event detections in onboard image processing



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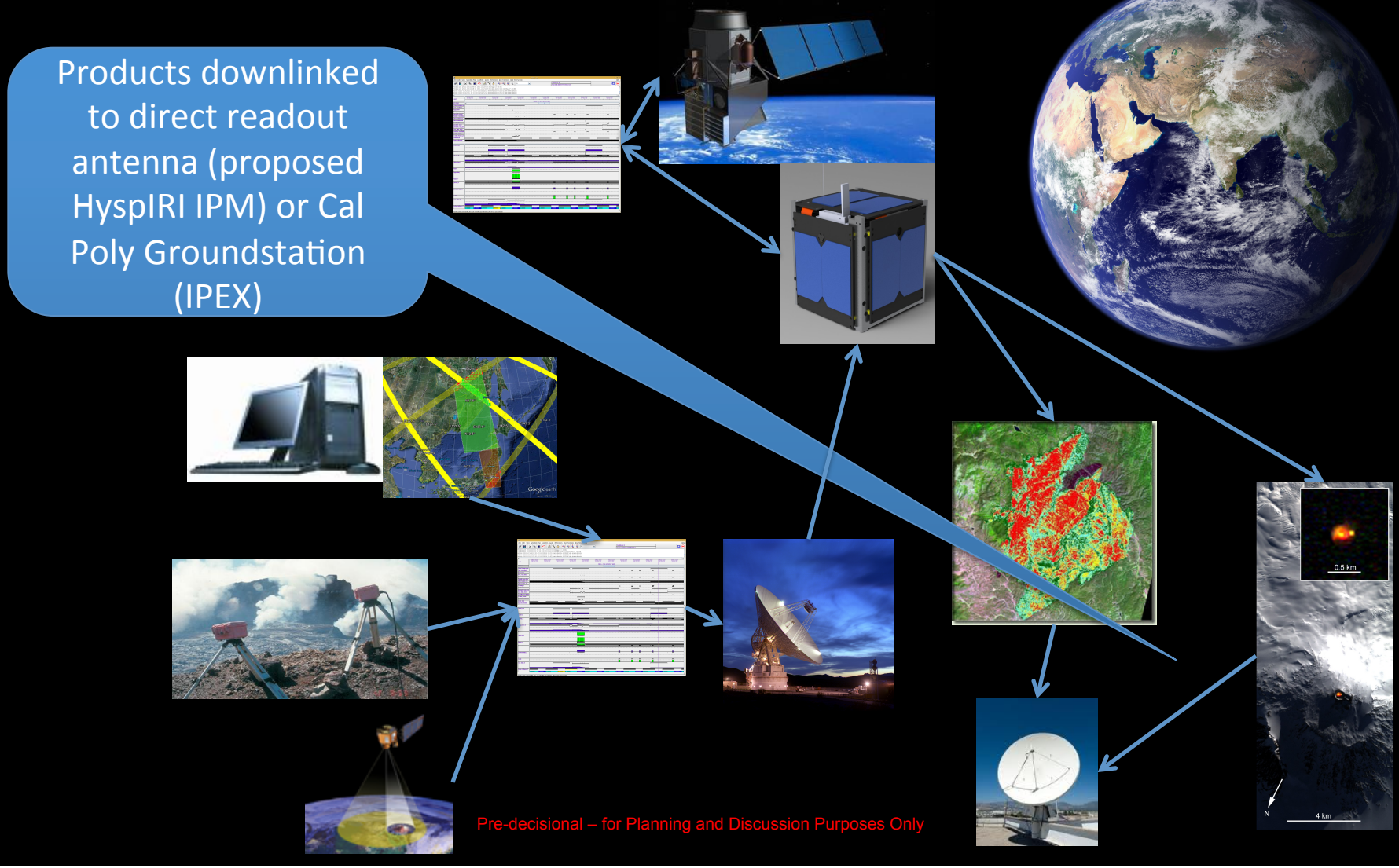
IPEX/Proposed HyspIRI IPM Operations Concept



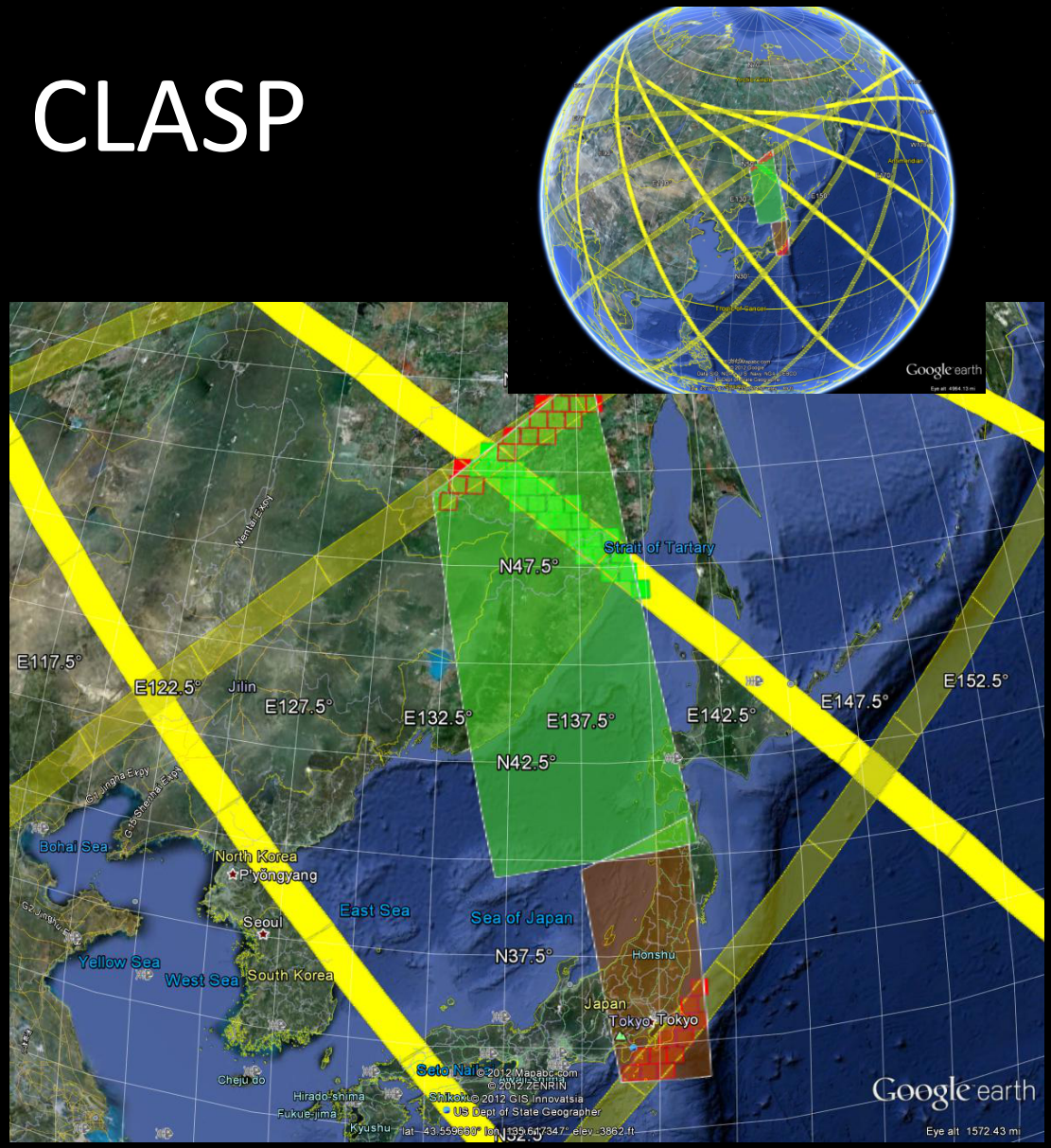
Pre-decisional – for Planning and Discussion Purposes Only

Autonomous Instrument Operations

- Region-based imaging and product requests input using Google Earth
- Ground:
  - CLASP planner used to collect image requests and impose region/overflight/timing of requests based on orbital ephemeris
  - ASPEN generated time-sequences schedule based on request priorities, resources, contention
- Flight:
  - CASPER modified ground schedule based on flight resources and onboard requests due to onboard image analysis

CLASP

- Schedule planner for spacecraft spatial coverage
  - Been used for DESDynI mission concept studies
  - Outputs a nominal plan under some operational constraints, e.g. downlink bandwidth
  - Can output an ASPEN compatible schedule for further refinement
- On right, a sample output with 120° inclination orbit (Gemsat L-39)



Autonomous Operations

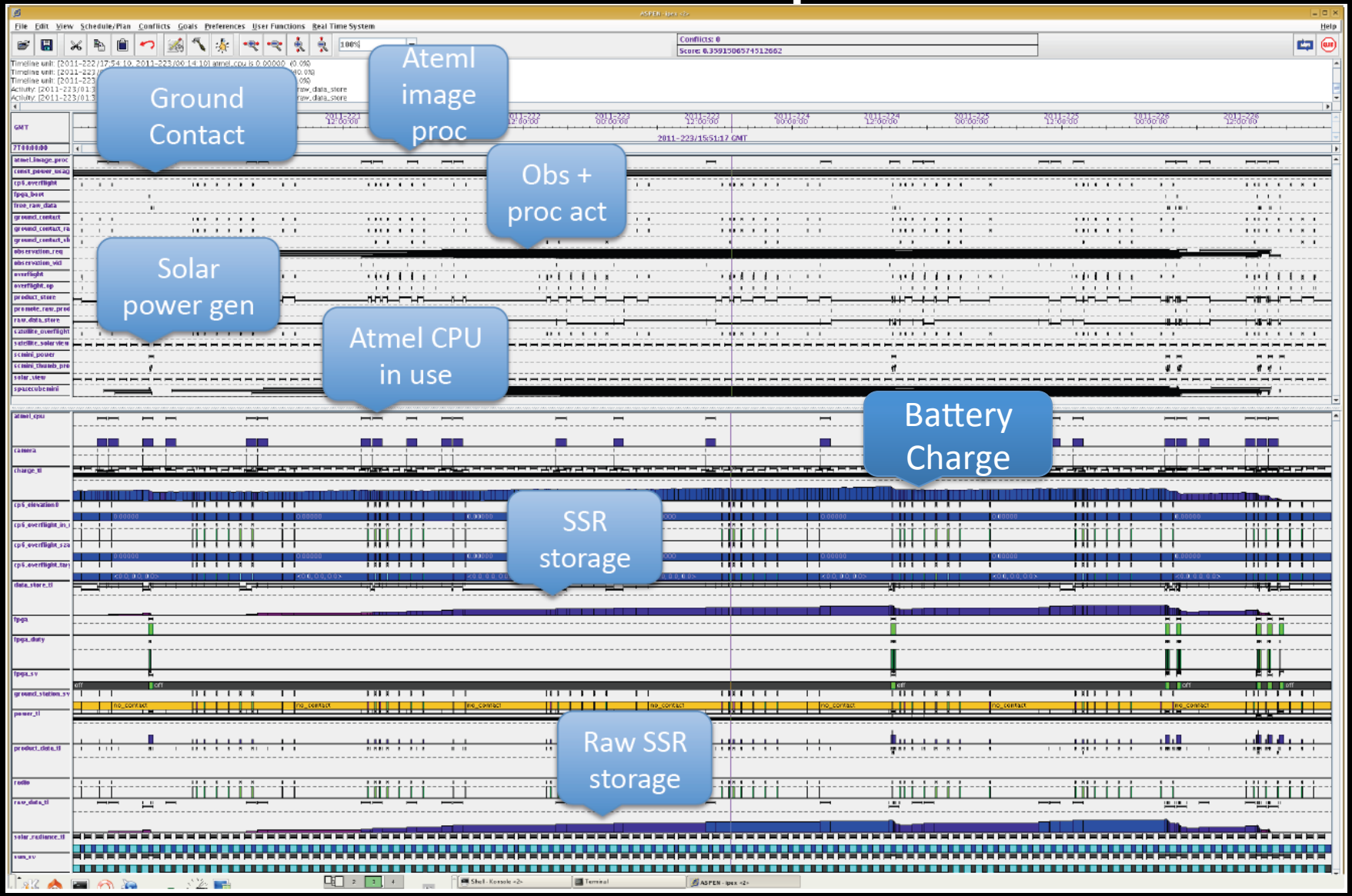
- Baseline Schedule created on ground using ASPEN
  - Observation keep-in window
    - Use of Gumstix or cameras hampers uplink to spacecraft
  - Eclipse schedule
  - Observation Activities + processing
  - Ground initiated processing experiments
- Constraints:
  - CPU usage
  - Data storage: raw images, processed images, summary products < flash storage capacity (e.g. 4GB)
  - Energy capacity of battery: ~50 Whr
  - Solar generation: <~1.5 Watt
- CLASP capable of modeling above constraints, ground ASPEN used for flight CASPER compatibility

CASPER Onboard Safety Analysis

- Informal methods safety analysis of known risks to spacecraft; here we focus on those enforced by CASPER

Subsystem	Example Risk
Power (14,3)	Battery SOC run too low
	Solar cell failure
	Battery degradation failure
Pointing(4,1)	Spin rate too high
Instrument (6,4)	Image acquisition flooding
Software (23, 13)	Hanging process, blocks other processes
	System memory exhaustion
	CDH CPU oversubscription
SD Card (3,1)	Write beyond SD card capacity
Communications (6,1)	Payload card noise interferes with uplink

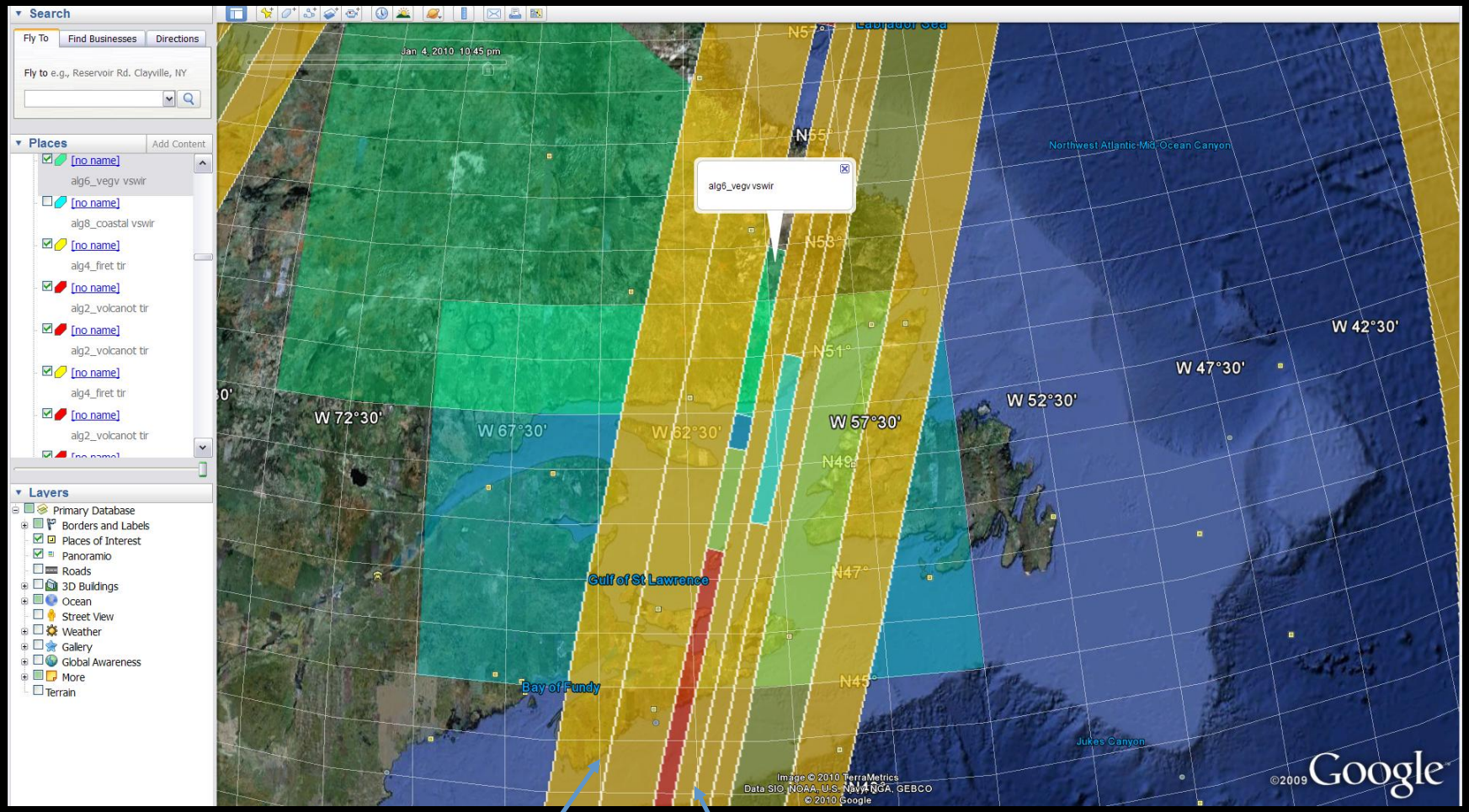
Autonomous Operations



Autonomous Operations for Intelligent Payload Module

- HyspIRI Mission concept is under study which proposes a VSWIR hyperspectral imager and TIR Thermal infra-red imager
- This HyspIRI concept includes a heritage Direct Broadcast concept Intelligent Payload Module which would process the ~800 x 10^6 bits/second raw data stream into ~10 x 10^6 bits/second direct broadcast data stream
- IPEX will demonstrate automated planning and processing of the data as maturation of the prototype HyspIRI IPM operations system
  - Users specify regions of interest, products, and priorities in Google Earth ™
  - System automatically creates priority based plans for onboard processing and downlink

Proposed HyspIRI Instrument Swaths

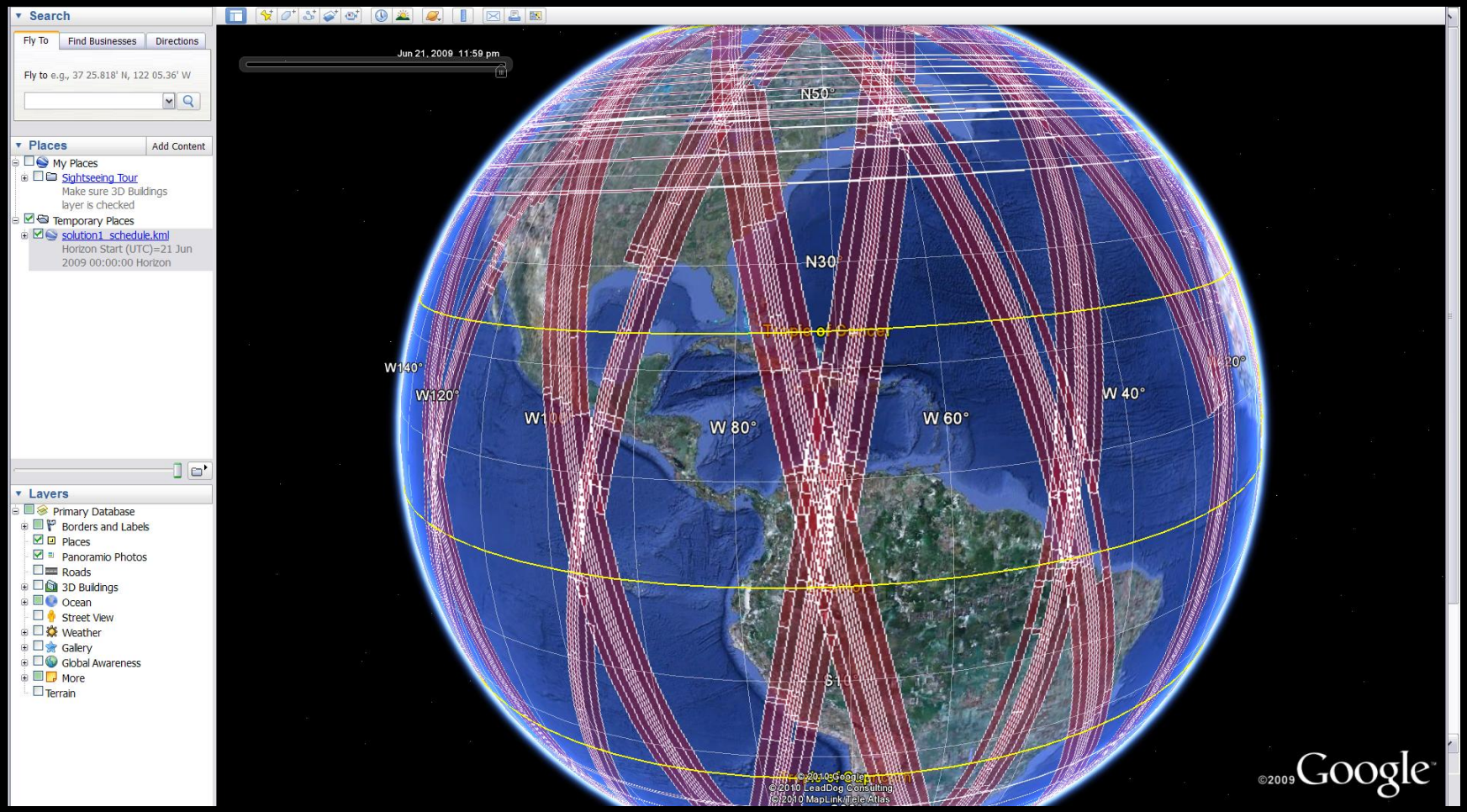


4 x 112.5.5 km wide –TIR only

4 x 37.5 km wide – VSWIR + TIR

Pre-decisional – for Planning and Discussion Purposes Only

Proposed HyspIRI IPM Sample Plans



Pre-decisional – for Planning and Discussion Purposes Only

IPEX Balloon Unit Flight

- Flown 28 July 2012, peak altitude 104,000 feet above sea level
- Flown 09 December 2012, peak altitude 88,000 feet above sea level
- Balloon unit included two CPU “CP top hat” units, each with Atmel CPU, SD card, 4 cameras
- CASPER installed on one “top hat” and planned over 300 activities corresponding to over 3000 commands
- Despite one SD card/file system failure, acquired over 1000 images
- See http://scienceandtechnology.jpl.nasa.gov

Imagery from Balloon Flight

Conclusions

- The IPEX Cubesat will Flight Demonstrate Autonomous Payload Operations for the proposed HyspIRI mission Intelligent Payload Module
  - Onboard Image Processing and Product Generation
  - Onboard Mission planning for dynamic processing and resource management
  - Ground-based automated planning for processing request generation and management
  - IPEX currently manifested to launch 10/13 on GEMSAT L-39, with several year projected mission lifetime