Jet Propulsion Laboratory
California Institute of Technology

JPL PanFTS

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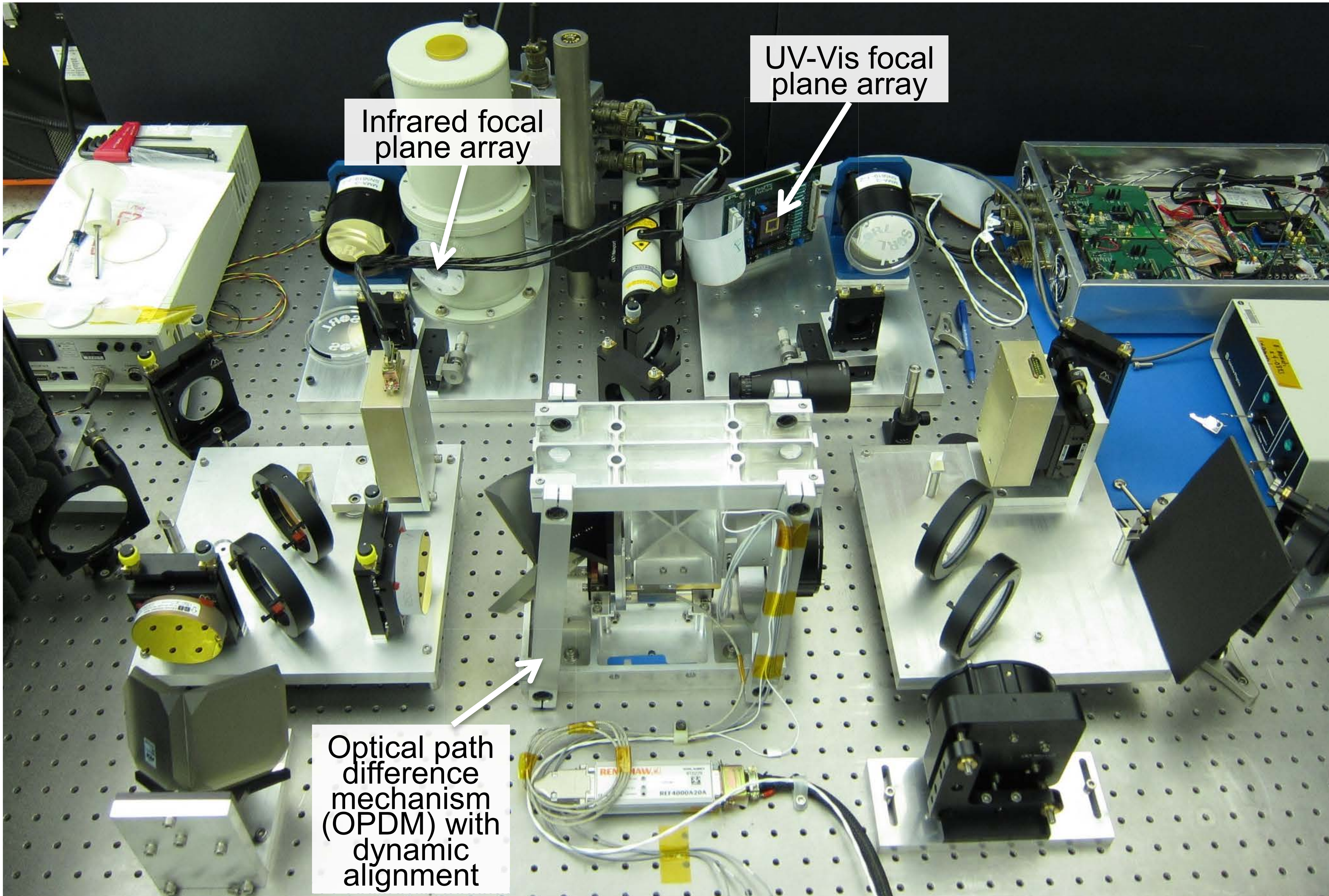
PanFTS IR + Vis Breadboard



PanFTS Imaging Spectroscopy Demo

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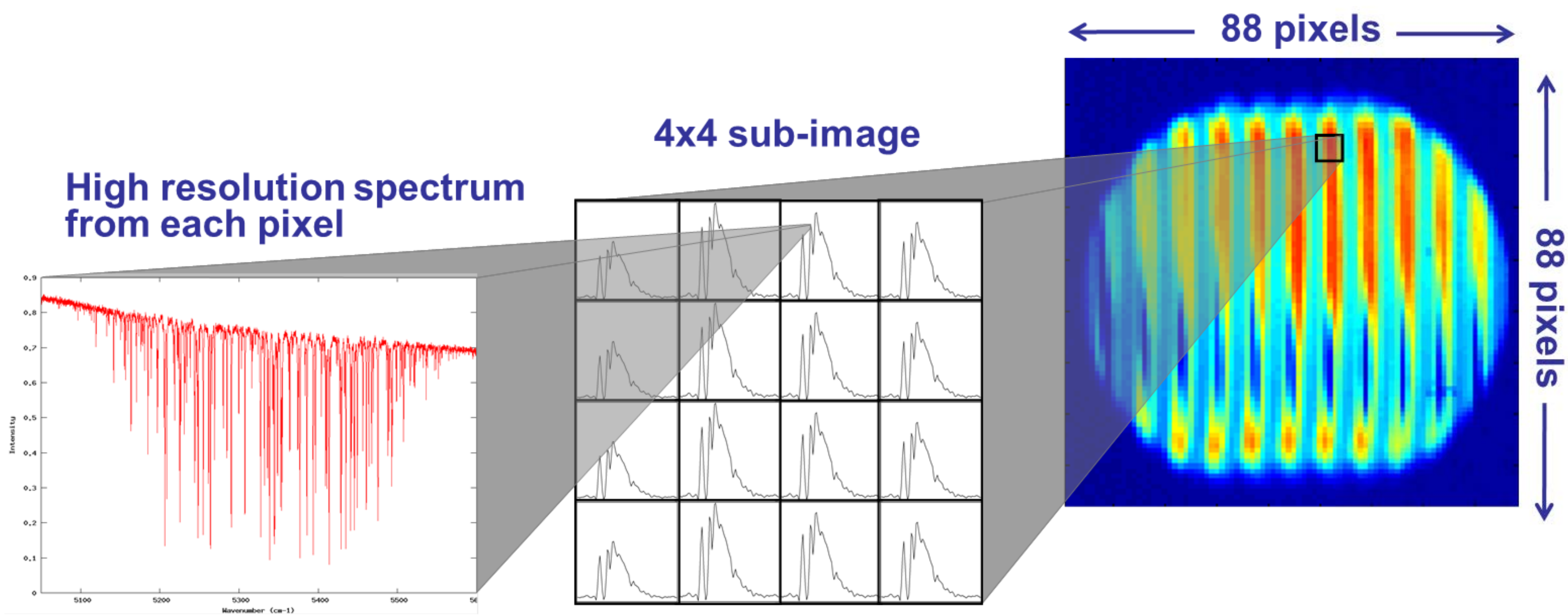
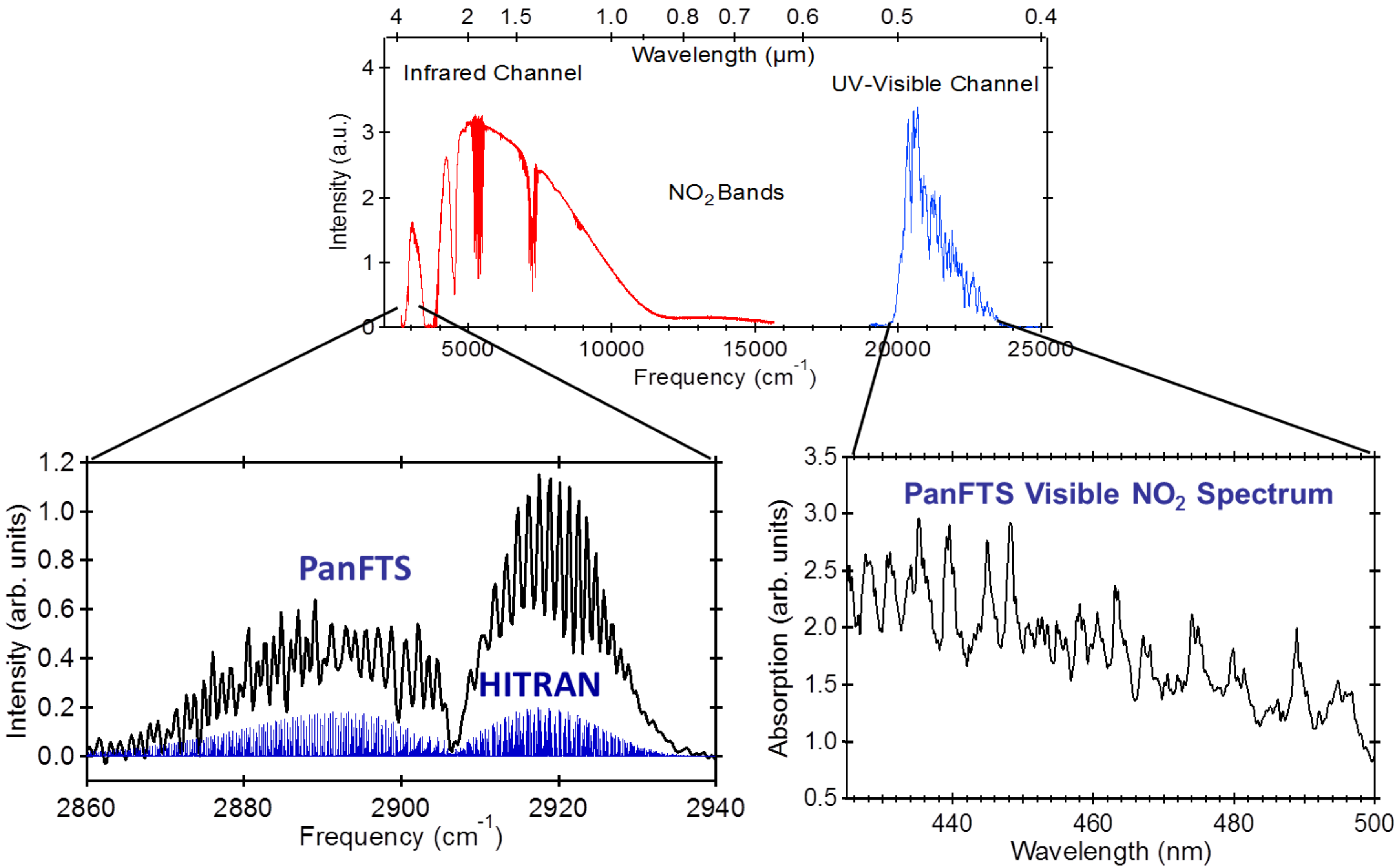
Near-IR image of tungsten lamp filament imaged through PanFTS interferometer: high resolution spectra of atmospheric water vapor

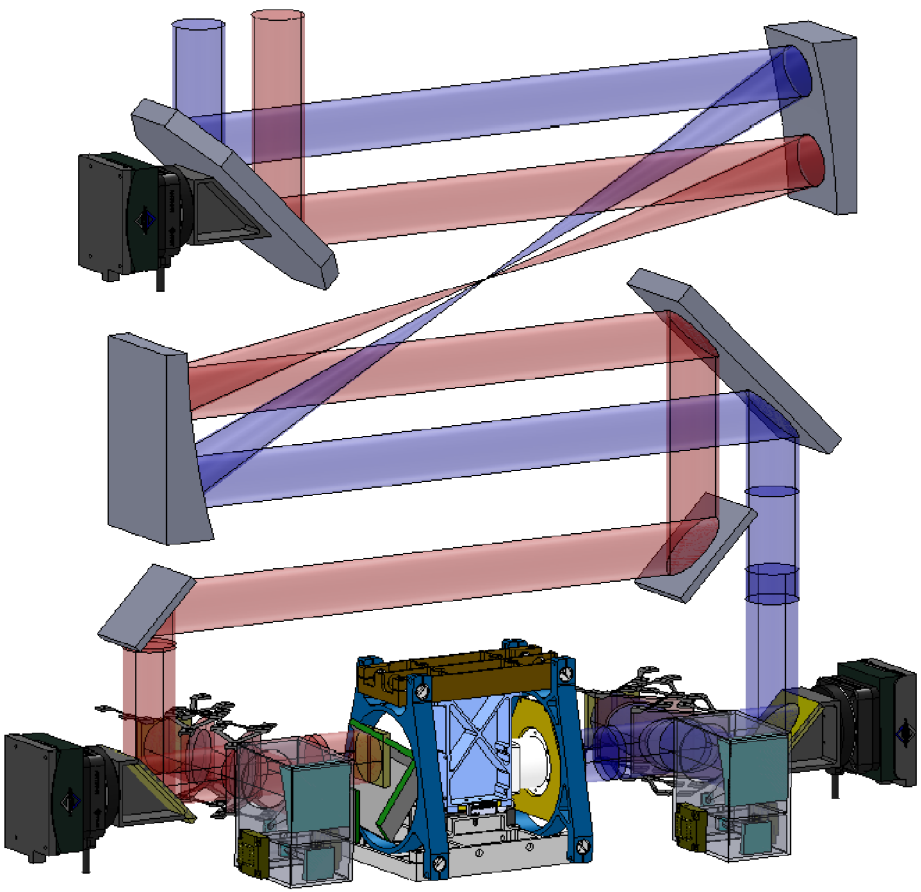


Successful acquisition of a hyperspectral image is equivalent to a scene captured by PanFTS from geo when viewing reflected sunlight and thermal emission from Earth's atmosphere

Simultaneous IR and Visible Spectra of NO_2 Using PanFTS Breadboard



PanFTS Engineering Model Instrument



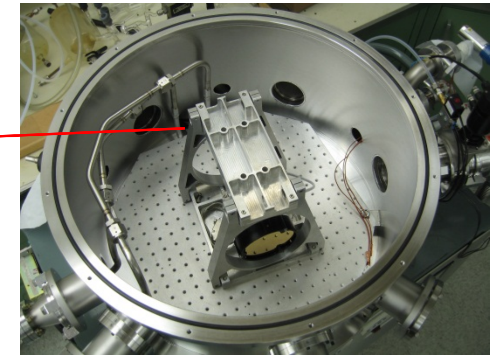
- NASA is funding the development of a PanFTS EM instrument
- The PanFTS EM will be built with flight like optics, optical bench, metrology and alignment system
- The PanFTS EM will cover the spectral range of the flight design (0.28 μm to 15 μm)
- The PanFTS EM performance will be demonstrated in a thermal-vacuum chamber under flight-like conditions

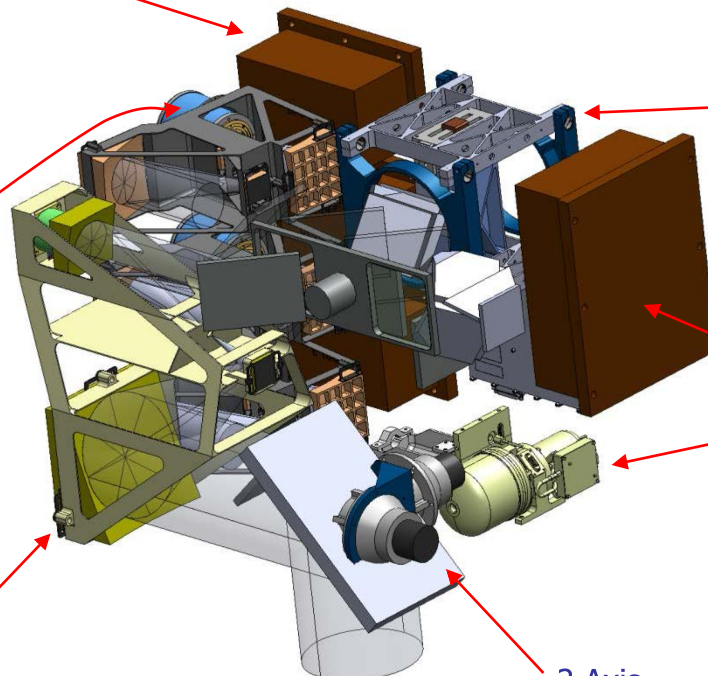
The PanFTS EM will achieve Technology Readiness Level 6 (functional demonstration in a flight-like environment)

PanFTS-NIR Instrument Concept

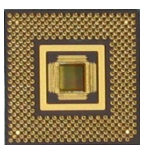
Rad Hard Electronics

Optical Path Difference Mechanism





All digital FPAs



Telescope Optics Module

2 Axis
Line-of-Sight
Pointing Mirror

Single-stage Cryocooler
& Electronics

Size (m)	0.6 H x 0.8 L x 0.7 W
CBE Mass (kg)	133
Data rate (Mb/s)	206
Peak Power (W)	290

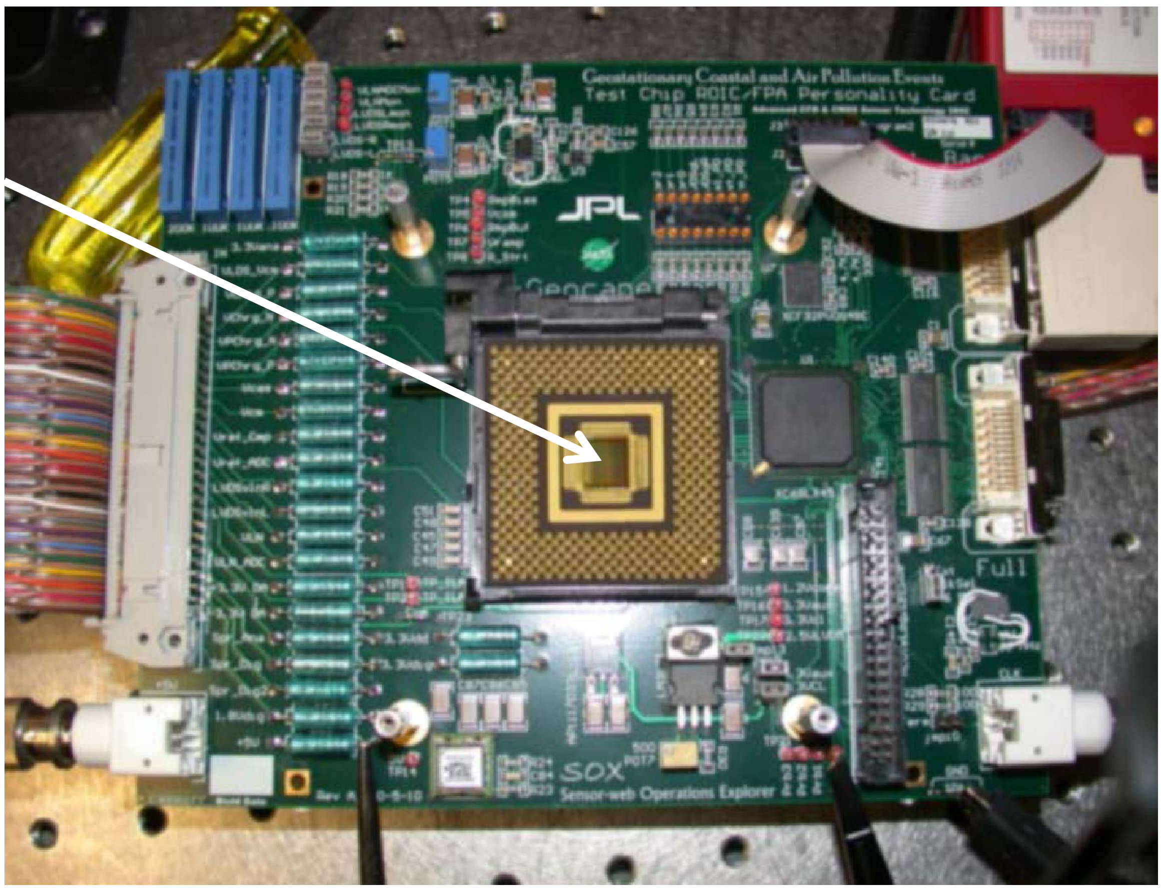
Optical Path Difference Mechanism

Optical Path Difference Mechanism #2 has completed over 1 million cycles (~40% of the 2.5 million cycle life test) in hard vacuum at -100°C with no discernable changes in behavior

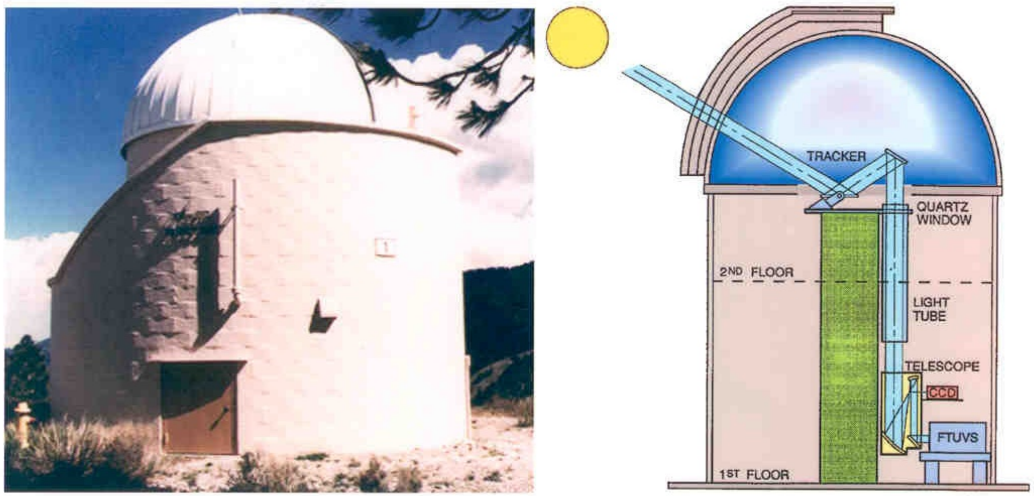
JPL In-Pixel Digitization ROIC

- 128 x 128 pixel Readout Integrated Circuit (ROIC) – designed by JPL
- Charge integration, separate / independent ADC built into <u>each pixel</u>
- High resolution (14 bits), Fast snapshot readout (up to 16 kHz frame rate)
- Can be hybridized with silicon (UV-Vis) or InSb, InGaAs, (IR)

128x128 ROIC



Successful ROIC Operation in the Field

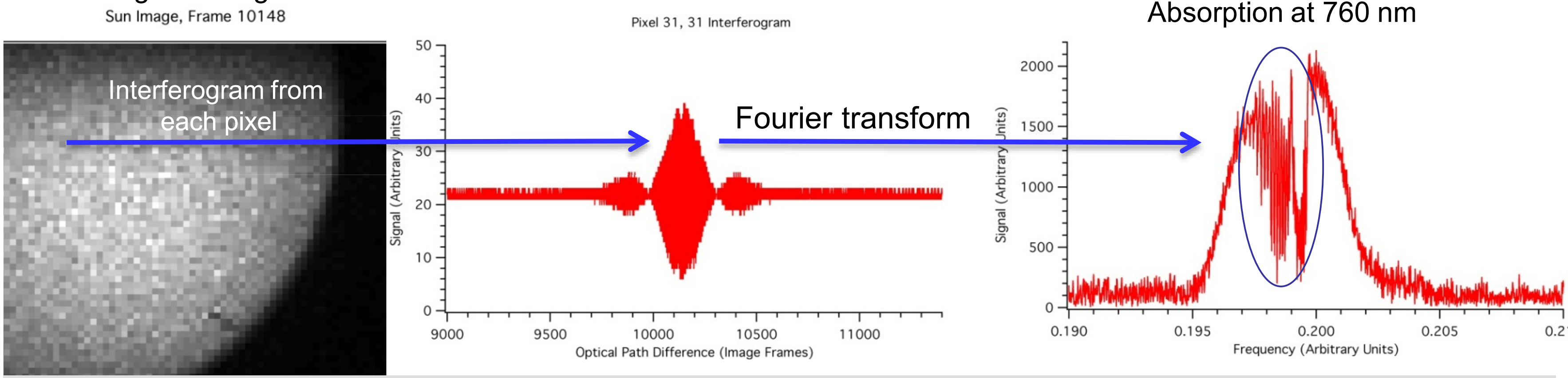


Fourier Transform UV Spectrometer (FTUVS)
at the JPL Table Mountain Facility (TMF)

JPL In-Pixel Digitization ROIC in FTUVS at TMF

Solar disk imaged through FTUVS

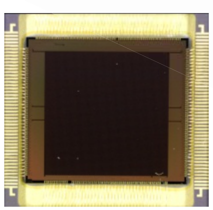
Atmospheric Oxygen (A band)
Absorption at 760 nm



Successful ROIC operation in the FTUVS demonstrated the capability to make scientific measurements of atmospheric composition like those needed for the GEMS mission

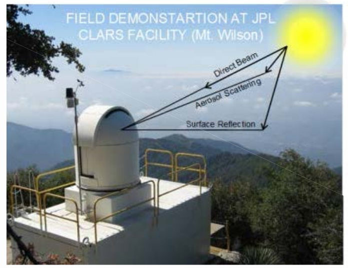
Digital FPA Technology Maturation

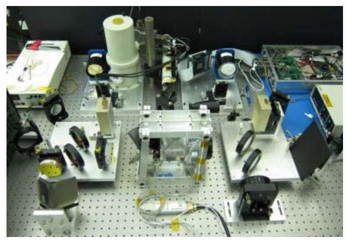
ROIC in FTUVS measuring atmospheric composition

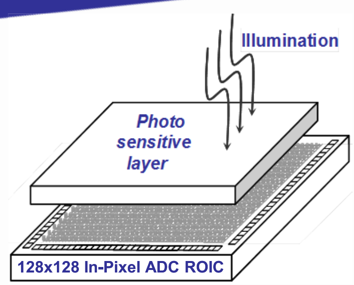


ACT 2008 In-Pixel Digitization ROIC Development and Demonstration

FPA in PanFTS measuring atmospheric composition

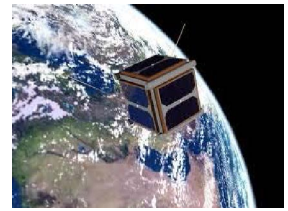


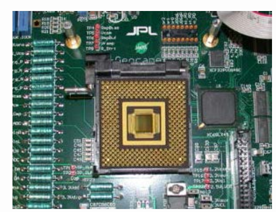




2011 Hybridization of In-Pixel ROIC with SiPIN Detector Array

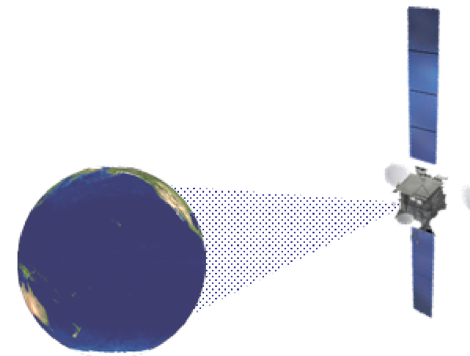
All digital imaging FPA on CubeSat operation in space environment



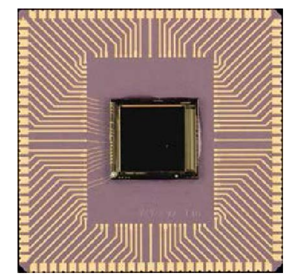


2012 All Digital FPA and Signal Chain Demonstration

Hourly global mapping of atmospheric composition

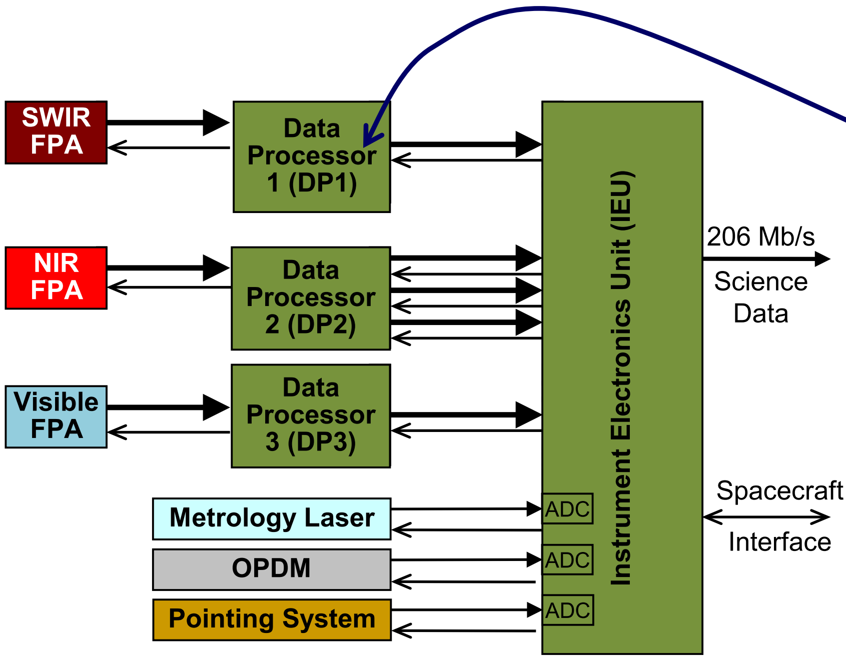


PanFTS on GEMS

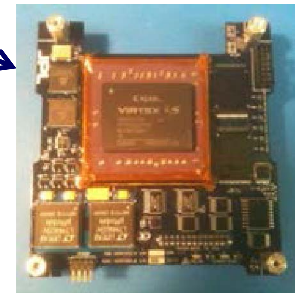


2013 High Throughput Flight FPA Fabrication and Qualification

Rad Hard Flight Electronics



V5QV FPGA based data processing board



A V5QV FPGA based data processing board will fly on the CubeSat On-board processing Validation Experiment (COVE) mission scheduled to launch Oct. 2011

Flight Electronics

- Data Processor assemblies, one for each FPA
  - Three V5QV FPGAs (1 per data processing board)
  - Radiation tolerant (built in s/w self test / reset)
  - Custom designed memory (8-16 GB per FPA)
  - Error correcting code protects DRAM contents
- Instrument Electronics Unit for command, control & data handling
  - Rad750 processor for Instrument FSW
  - Applies 2:1 compression and multiplexes processed data packetized to spacecraft telecom system
  - Digitizes reference laser and forwards data to other processing units
  - Controls OPDM, pointing system, and housekeeping
- SpaceWire (200 Mbps) links transfer data to control unit

FPA Data Handling

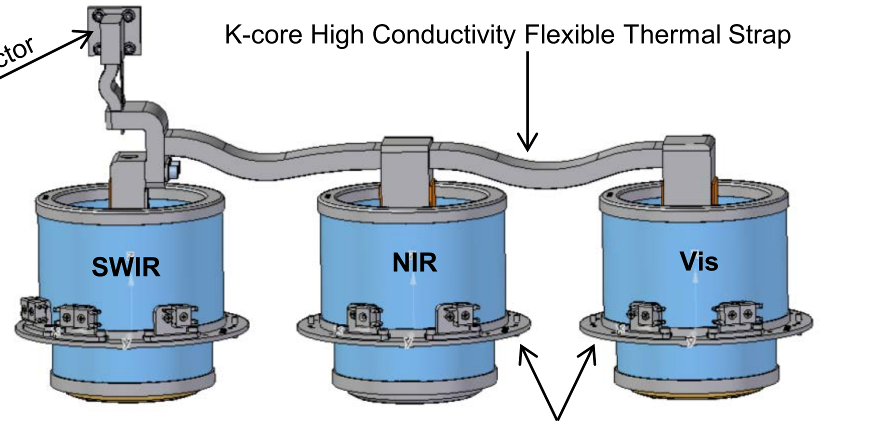
- FPA data are interferograms which are converted from time domain to path difference domain
- Phase correction and Fourier transform are then performed to produce spectra
- Wavelengths regions where detectors are not sensitive are discarded
- ADCs are in-pixel and part of the ROIC

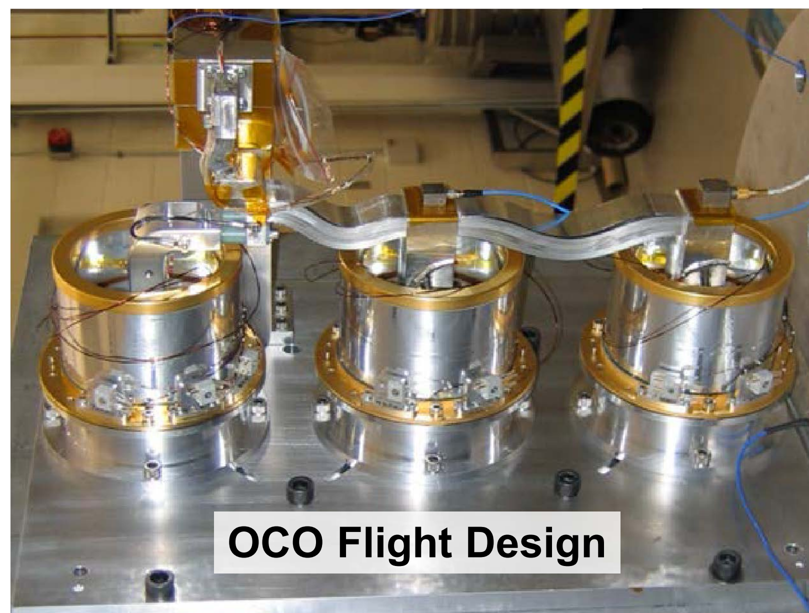
Flight Heritage Thermal System

NGST HEC Pulse Tube Cryocooler (GOES-R ABI cryocooler)

260mm (W) x 115mm (D) x 310mm (H)
Mass = 4.1kg

235mm (W) x 205mm (D) x 85mm (H)
180W Max power output
Mass = 3.3kg





PanFTS-NIR Accommodation on GEMS

All specifications are preliminary

Pointing

PanFTS views a 2-dimensional iFoV mapped onto a 128x128 pixel FPA

Nadir Pixel Ground Footprint: 4 km x 4 km
Instantaneous Field of View: 512 km x 512 km
IFoV Swath Angle (full): 0.82 deg.

Step-Settle Interval: 10% of stare time
Stare Interval: 30 sec.
Line-of-Sight Pointing Accuracy: 50% of nadir pixel
Line-of-Sight Pointing Stability: 25% of nadir pixel
Line-of-Sight Pointing Knowledge: 10% of nadir pixel
Geo-Location Reconstruction: 10% of nadir pixel

- Pointing Pattern: Nominal pointing pattern is boustrophedonic ("as the ox plows")
- Pattern can be "intelligently guided" for cloud avoidance based on imagery
- PanFTS incorporates a fine steering mirror for pointing correction based on data from spacecraft stellar inertial reference package

PanFTS-NIR Accommodation on GEMS

All specifications are preliminary

Thermal

PanFTS will likely have two radiators for pulse tube cooler and electronics
Require cold space view.

Vibration

Instrument moving parts:

- Optical Path Difference Mechanism (OPDM): Extremely slow, uniform motion: 10-20 sec scan over 1-2 cm. Mechanism is frictionless.
- Main pointing mirror: executes 0.8 deg. slew every 10-20 sec. 45 degree slew to diffuse reflector every 30-60 min.
- Fine pointing mirror: flexure-based piezo-driven tip/tilt stage – very small steps
- NGST pulse-tube cryocooler – same unit used on ABI

PanFTS-NIR Accommodation on GEMS

All specifications are preliminary

Data Rate

- Three focal plane arrays will be used for 0.76 μm, 1.6 μm and 2.3 μm spectral bands
- On-board processing of FPA and metrology laser data will reduce the raw interferogram data rate by a factor of 15-30 from 3 Gb/sec to 100-200 Mb/sec
- Instrument will acquire data continuously for solar zenith angles ± 70 deg.
- Assumed duty cycle is 50% (alternates with ocean color instrument) on 30-min period.

Space Radiation Environments for GEO and Environment Monitoring Sensor Package

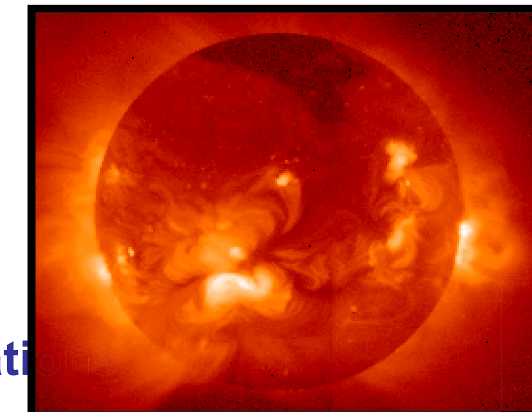
Dr. Insoo Jun

August 2011

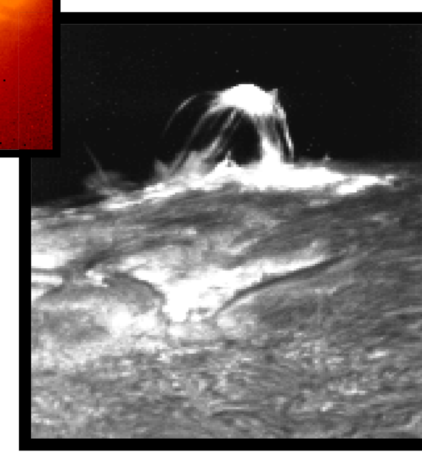
Jet Propulsion Laboratory
California Institute of Technology

Introduction: The Space Environment

- The space environment is extremely dynamic. Its can vary dramatically from minute to minute due to factors such as:
  - Solar flares
  - Coronal mass ejection (CME)
  - Geomagnetic storms
  - Magnetic sub-storms
  - Cosmic rays
  - Meteoroid showers
  - Orbital debris
  - Trapped radiation
  - Magnetic and electric field fluctuations



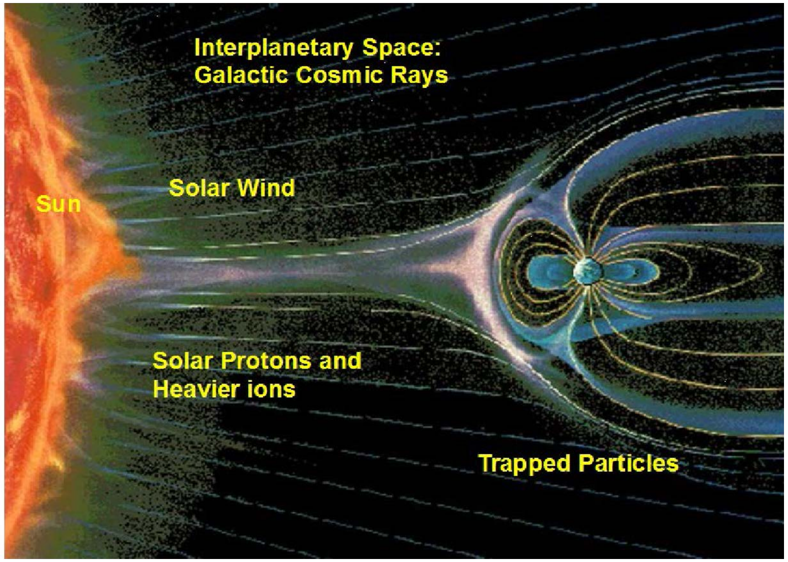
Sun in X-ray



Solar Flare

Components of GEO Natural Radiation Environment

Environment	Models (*) Available for Environment Specification
Trapped electrons/protons	AE8/AP8 model POLE model
Low energy plasma	SCATHA, ATS-6, and ATS-6 data Rice's theoretical model
SEP - Protons	JPL Model ESP model JSC model
SEP – Heavy Ions	CREME96
GCR – Protons and Heavy ions	CREME96 Badhwar-O'Neill Model Nymmik model
Magnetic Field	Tsyganenko, IGRF



(*) References can be provided upon request

- **The long-term (>6 month) averaged GEO radiation flux levels are relatively well defined from GOES and other satellites – within a factor of 2**
- **However, these models (and even the GOES data) are inadequate to address problems that might occur to a specific satellite → See the next three charts**

Characteristics of GEO Radiation Environment (not prioritized) 1/3

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- **Strong temporal variations**
  - Large storm or injection event (e.g., CME-compressed magnetosphere in March 1989) and Polar Cap Absorption (PCA) events can significantly modify the GEO environment in minutes
  - Current models do not address short term (minutes to hours to days) temporal variations (AE9/AP9 are stating to address this issue)
  - Suggestion: Need to measure time variations of low energy plasma and high energy trapped particles at the satellite location
- **Strong longitudinal and local time dependences**
  - The trapped environment can differ by an order of magnitude at different locations around the geosynchronous orbit
  - The GOES data have limited applications to satellites located at different longitudes (e.g., what was the actual flux at a given satellite location?)
  - Suggestion: Measure energy spectra of electrons, protons, and heavy ions at the satellite location

Characteristics of GEO Radiation Environment (not prioritized) 2/3

- **High energy trapped electrons**
  - Internal ESD is a common cause for GEO satellite failures or anomalies
  - No direct, in-situ measurements of the IESD charge deposition are available
  - Suggestion: Measure characteristics (i.e., charge deposition rates, arc pulse shape, energy, electric field, etc.) of IESD pulses
    - Along with simultaneous knowledge of the external electron energy spectrum, this will be extremely helpful for understanding conditions for IESD
- **No geomagnetic shielding**
  - Relatively free access of SEP and GCR → Good place to measure high energy (>100 MeV) protons from SEP
  - Suggestion: Measure high energy protons from SEPs
    - I've recently suggested, per my role as a National Academies NRC committee member, this as the number one priority for NASA's future SPE modeling efforts. This is needed to better define the SPE energy spectra for accurate radiation risk assessment for astronauts.

Characteristics of GEO Radiation Environment (not prioritized) 3/3

- GOES and other spacecraft proton and electron data are available and extensive GEO communication satellite flight experience
  - The AP9/AE9 statistical models (beta version) are just now becoming available. It is hoped that they will help reduce uncertainty.
    - The human space flight architecture team (HAT) requires improvements in GEO statistical estimates to enable future servicing missions to GEO
  - Additional data are always valuable to data archive and can be used to reduce the uncertainty of environment models
- GEO science missions have been relatively limited to date
  - Real time sensor and detector degradation and transient response such as radiation induced noise in the GEO radiation environment are not well quantified
    - Note: This is particularly true for new microelectronic technologies in the complex, combined environmental conditions at GEO
  - Suggestion: Measure sensor degradation responses in real time
    - Degradation rates along with real time environment measurements would be very useful in understanding the behavior of materials and sensors under specific environment conditions

So…. We propose an experiment to address the issues discussed in the previous charts

Title/Name of the experiment:

CREAM-GEO (Compact Reconfigurable Environment & Assurance Monitor for GEO)

- What is it supposed to do?

  Measure the local environments, including ionizing radiation (TID), ionospheric plasma, surface charging and/or internal charging, SEU monitoring, and temperature.

  Measure the energy spectra of electrons and protons.

  Measure in-situ sensor degradation and radiation induced noise.

- Brief architecture (list main components)

  (Refer to the diagram on the next page.) The main components are the sensors (e.g., dosimeter, SEU detector, charging monitor, electron/proton spectrometers, etc.), the data and power interface between CREAM and the main spacecraft.

- How do they integrate and work together with the host spacecraft?

  Interface: TBD (we are considering RS422, but can accommodate other interfaces if, for example, a plug-and-play interface is needed)

  power needs: 10 W*

  size: 10 x 10 x 3 cm*

  weight: 1 kg*

  data needs: 100 ~ 1000 bps*

- A notional "Day in the Life" description of how this will operate on the spacecraft. (also include how data gets back to you)

  CREAM will communicate with the main spacecraft every minute, then the spacecraft dumps the data to the ground at a rate which could range from every minute to every day. The data will provide in-situ information on the local GEO environment impacting the other electronics and sensors.

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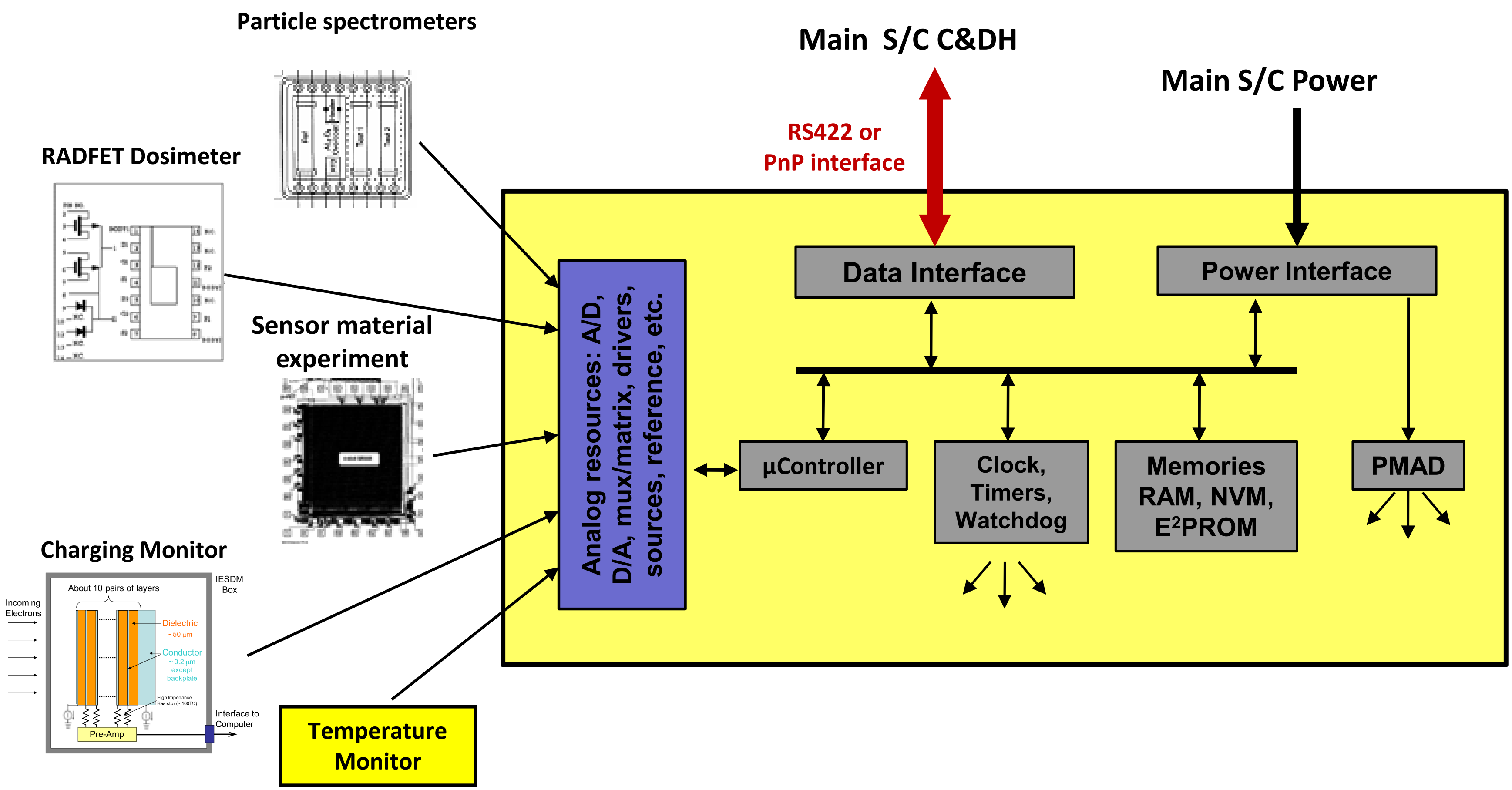
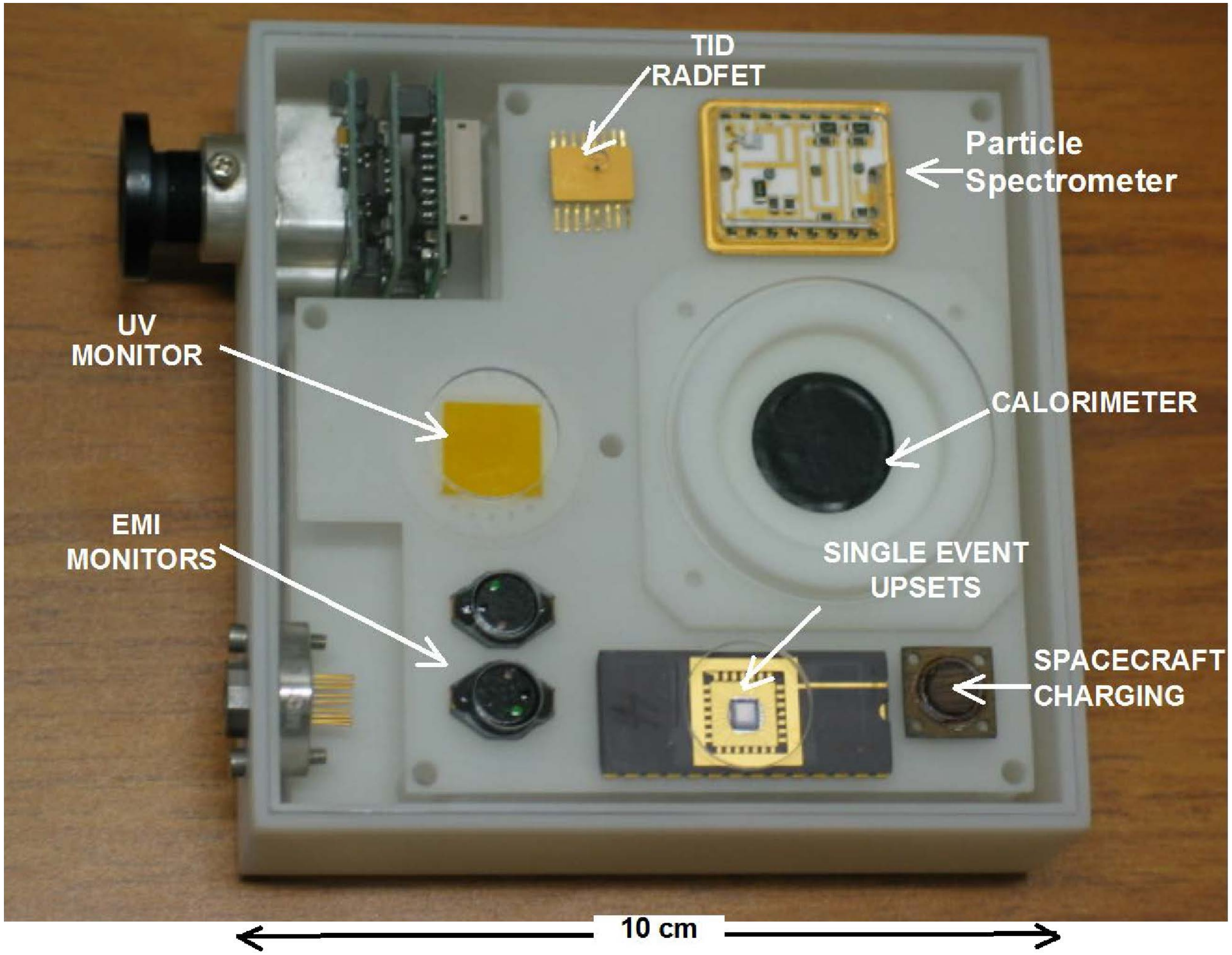
*All quantities are dependent on the final selection of sensors.

NOTIONAL Block-Diagram of CREAM-GEO



The final selection of sensors and their specific measurement requirements will be determined later after discussions with the host spacecraft and based on science investigation requirements.

Mock-up of CREAM-GEO (Illustration only)



JPL is building a similar environment monitoring sensor package for International Space Station. We can leverage from this experience in building a GEO sensor package.

Things to Do if We Decide to Go Forward…

- Define the measurement requirements
  – That is, what do we want to measure with the environment sensors that will yield the maximum return on investment?
- Decide sensor types and develop functional requirements. This will determine
  – Power
  – Mass
  – Data rate
- Develop operational scenarios
- Understand S/C physical constraints
- And many other programmatic and technical discussions

BACKUP

Radiation and Effects

- **Total Ionizing Dose**
  - **Cumulative long term ionizing damage mainly due to protons and electrons**
- **Displacement Damage Dose**
  - **Cumulative long term non-ionizing damage mainly due to protons, electrons, and neutrons**
- **Single Event Effects**
  - **Event caused by a single charged particle (heavy ions and/or protons) traversing the active volume of microelectronic devices**
- **Internal or Surface Charging**
  - **Electrons deposit charges in material which induces electrostatic discharge**
- **Radiation dose to *astronauts for future servicing missions to GEO***