In-Pixel Digitization Read Out Integrated Circuit for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission

D. Rider, J-F. Blavier, T. Cunningham, B. Hancock, R. Key,
Z. Pannell, T. Pongetti, S. Sander, S. Seshadri, C. Sun, C. Wrigley

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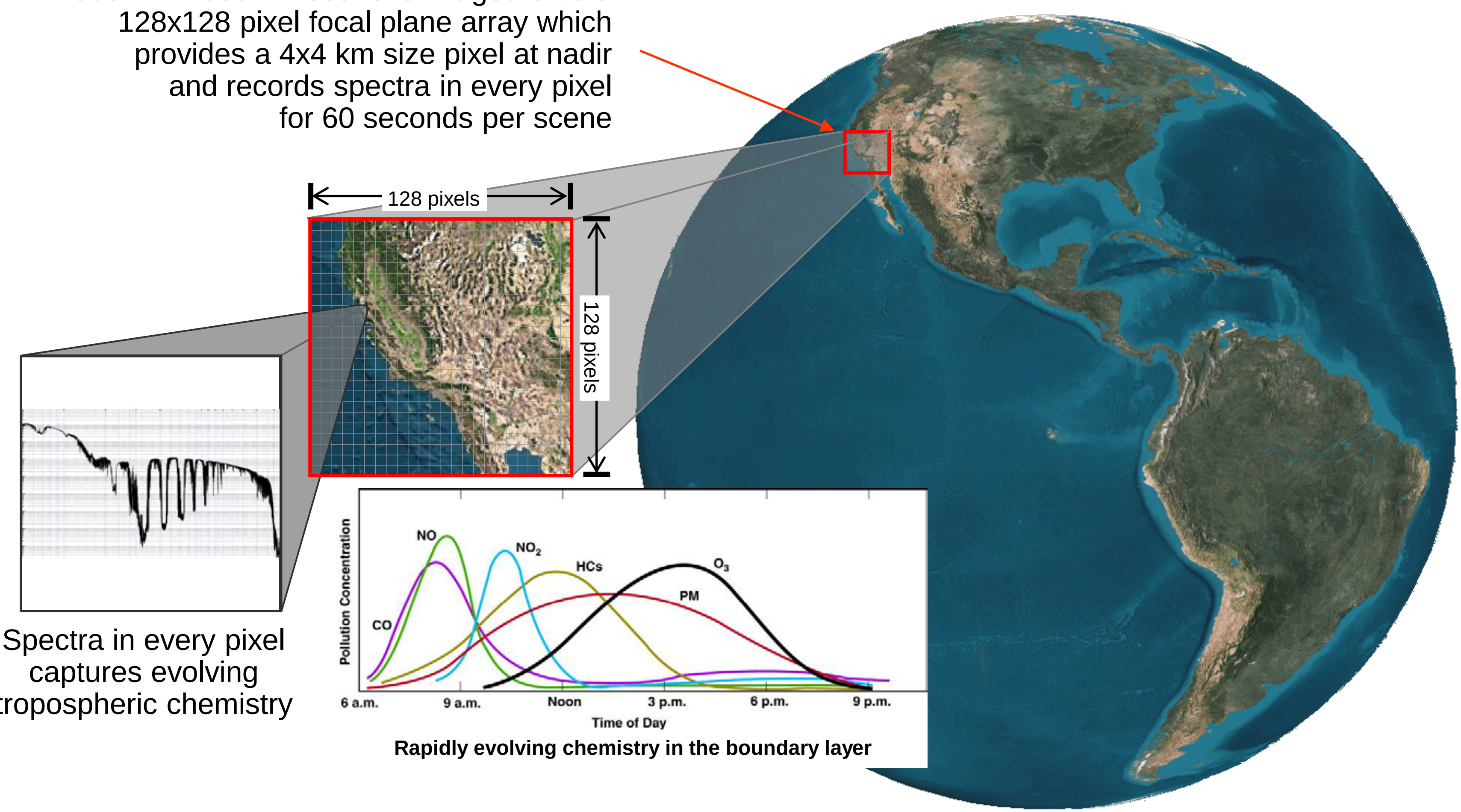
Geostationary Orbit Observing Scenario

500 km x 500 km scene is imaged onto a 128x128 pixel focal plane array which provides a 4x4 km size pixel at nadir and records spectra in every pixel for 60 seconds per scene

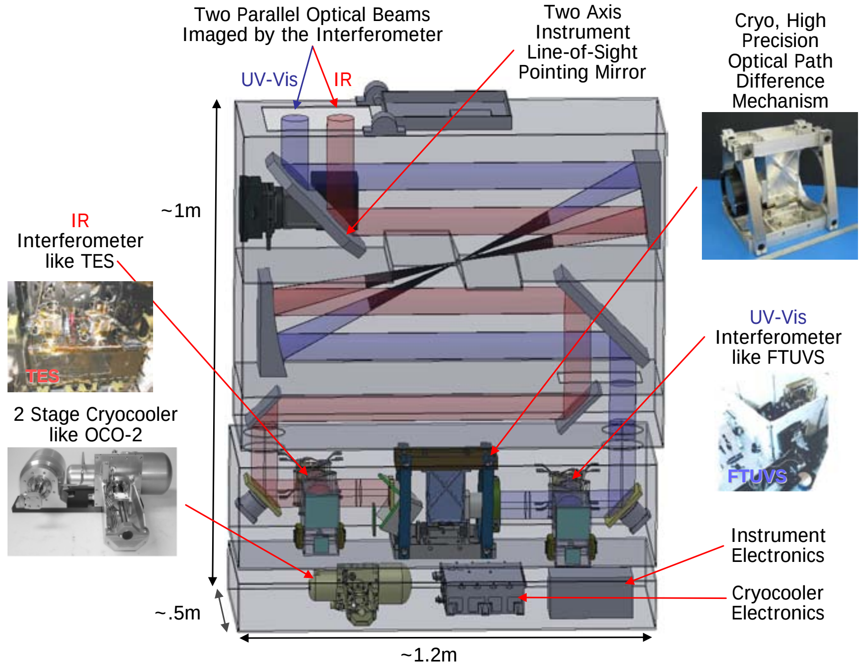


Spectra in every pixel captures evolving tropospheric chemistry

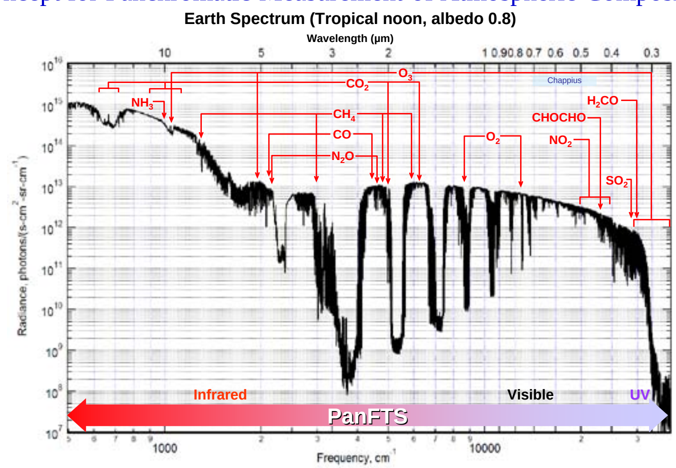
Rapidly evolving chemistry in the boundary layer

From geostationary orbit PanFTS can map all of North and South America hourly with high resolution measurements (temporal, spatial, and spectral) that capture rapidly evolving tropospheric chemistry with planetary boundary layer sensitivity

PanFTS Instrument Concept



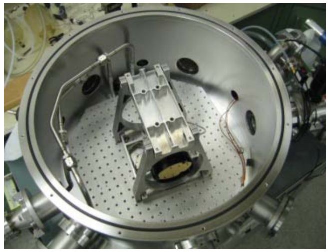
Concept for Panchromatic Measurement of Atmospheric Composition



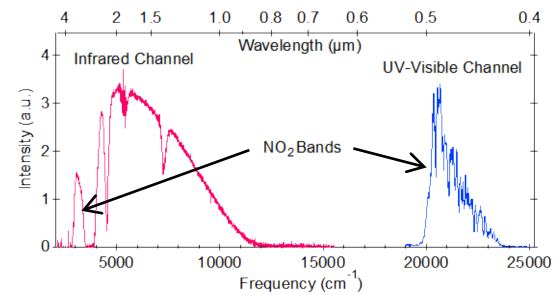
High spectral resolution (0.06 cm^{-1}) and wide spectral sensitivity (15 to 0.26 µm) allows simultaneous measurement of reflected sunlight and thermal emission (day and night) enabling retrieval of several important atmospheric composition species such as Pollutants (O_3, NO_2, NH_3, SO_2, HCHO, CH_3OH, CO), Greenhouse Gases (CO_2, CH_4, N_2O, O_3, H_2O), and Transport Tracers (HDO, N_2O, O_2, O_4)

- The PanFTS design has two separate channels optimized for the infrared and UV-Vis spectral domains, and multiple high speed focal plane arrays (FPAs) which simultaneously capture high-precision interferograms in each pixel for all of the wavelengths in the spectral range
- The IR side of the interferometer is based on the flight proven design of the Thermal Emissions Spectrometer (TES on Aura)
- The UV-Vis side of the interferometer is based on the Fourier Transform UV Spectrometer (FTUVS) which has been operating for over 12 years at the Table Mountain Facility
- The overall design is compact because the two channels share a common fore optics, and a single common interferometer optical path difference mechanism (OPDM)
- Design Life: 3 years (goal 5 years)

- **TRL_{in} = 3 $TRL_{current}$ = 4**
- Engineering Model PanFTS will advance instrument maturity to TRL 6



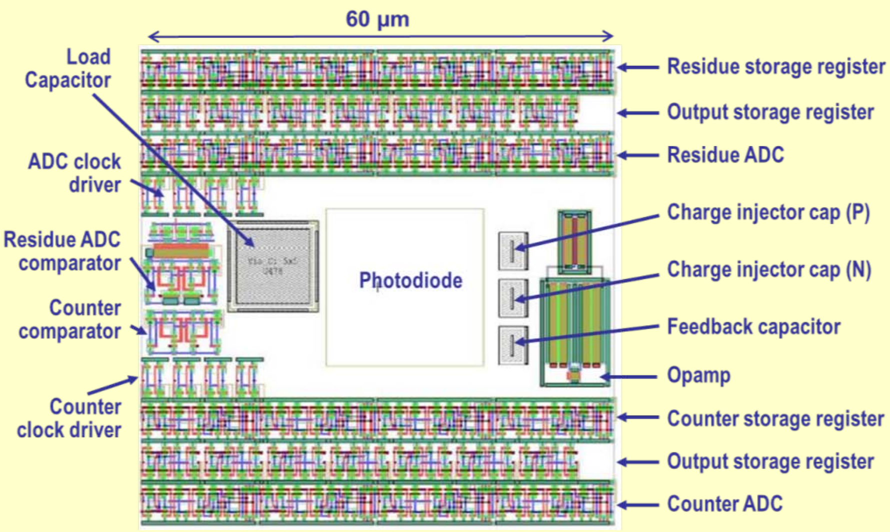
OPDM life test in flight-like thermal-vac conditions



Simultaneous IR + Vis measurement of NO_2 demonstrates functional capability for panchromatic measurements

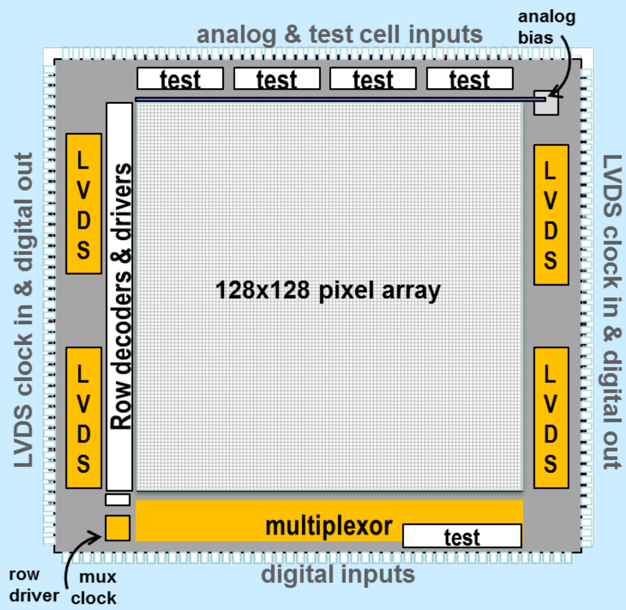
ROIC Design Challenges

Single Pixel Design



- High readout rate (16 kHz)
- High resolution readout (16 bits)
- Mixed analog/digital signal circuit elements
- Pixel footprint size limited to 60 µm
- Low power draw at full speed
- Design for testability

128x128 Pixel Array Design



- High speed full frame (snapshot) readout
- Robust power distribution and signal flow
- Layout that minimizes pixel-to-pixel crosstalk
- Minimal sensitivity to manufacturing limitations
- Low power draw (slow clock rates)
- Design for testability and hybridization

In-Pixel digitization ROIC encompasses two tightly coupled design challenges: (1) pixel design, and (2) array design

ROIC Testability Options Incorporated

Single Pixel Testability

- **Charge generation/collection**
  - Float deep n-well
  - Increase and/or focus source illumination
  - Charge injector test cell w/ source follower output
- **Opamp**
  - External bias/reference controls to vary bias points
  - Pixel test cell with direct voltage inputs & buffered output
- **Injector**
  - Externally-driven injector in test cell
  - Separate external input injector voltage, timing and reset duration control
  - Test cell w/ multiple monitors at critical nodes
  - Injector test cell with photodiode & source follower for basic characterization
- **Comparator**
  - Transparent latches to see comparator output
  - Pixel test cell with direct input via opamp & reset switch
- **Counters & registers**
  - Transparent output signal chain

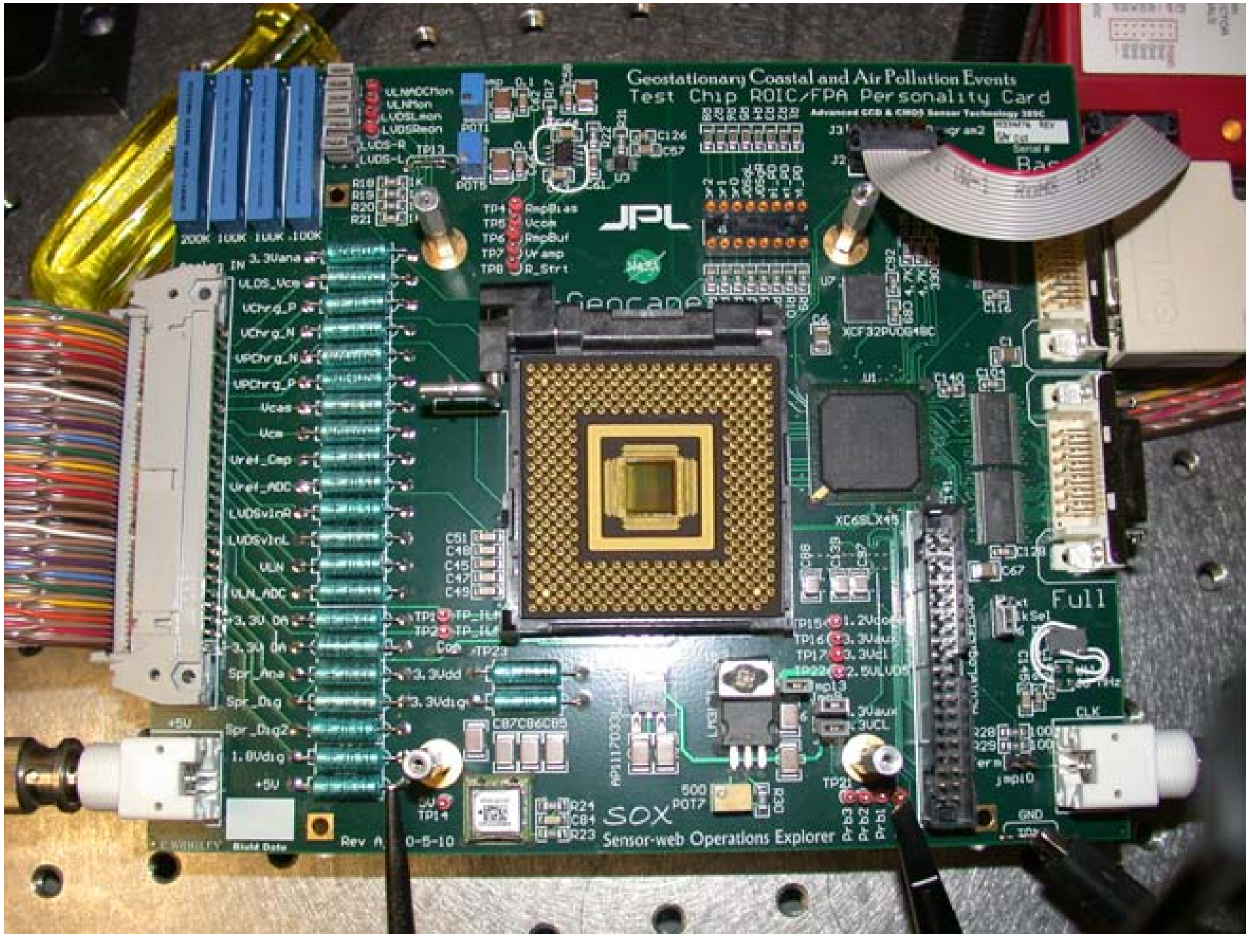
128x128 Pixel Array Testability

- **Operationally adjustable inputs**
  - Clocks
  - Reference voltages
  - Bias currents
  - Test cells driven by external current source
- **Selective power down**
  - Can limit output to specific 2^n rows, where n=0 to 4
  - Separation of power to window sections possible
- **Illumination**
  - Calibration via variable flat field illumination
  - Spot image on single or few pixels
  - Transistor glow can be tested via source follower & select switch in injector test cell
- **Pixel operation**
  - Transparent gates at both row and column outputs to monitor signal delays and settling
  - Test cells probe/characterize charge injector, opamp, comparator & counter

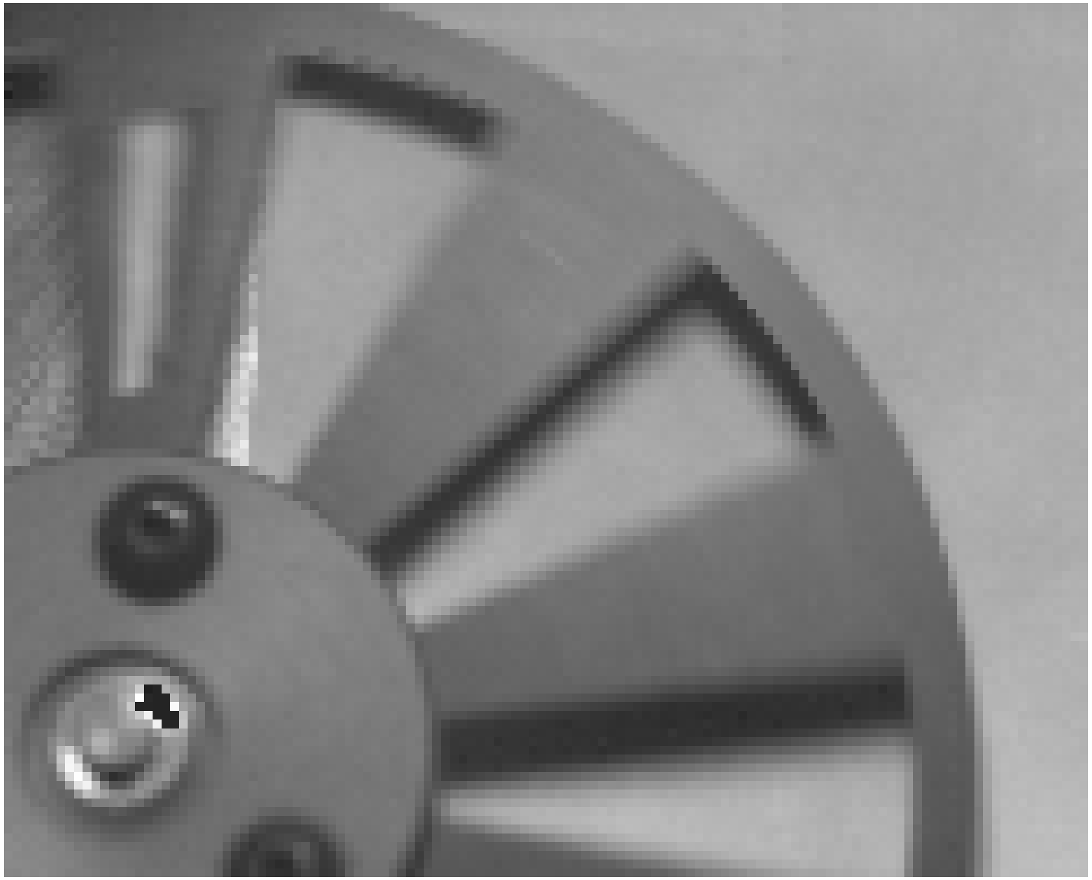
ROIC design incorporated numerous features to enable detailed performance characterization testing / analysis

128x128 Pixel Array Lab Test Set-up

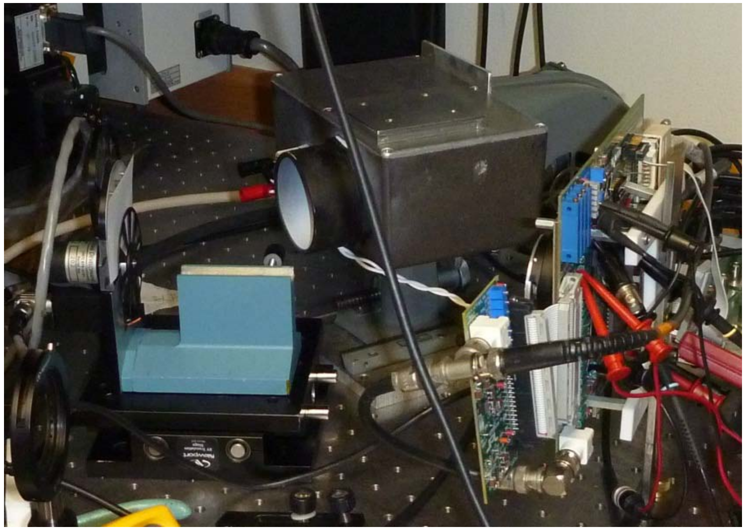
- 391 pin ROIC socket mounted on custom designed circuit board
- Camera-link s/w captures 3.6 Gbps ROIC output data stream
- 2 Tb RAID array hard drive storage system records data



High Speed Imaging Demonstration



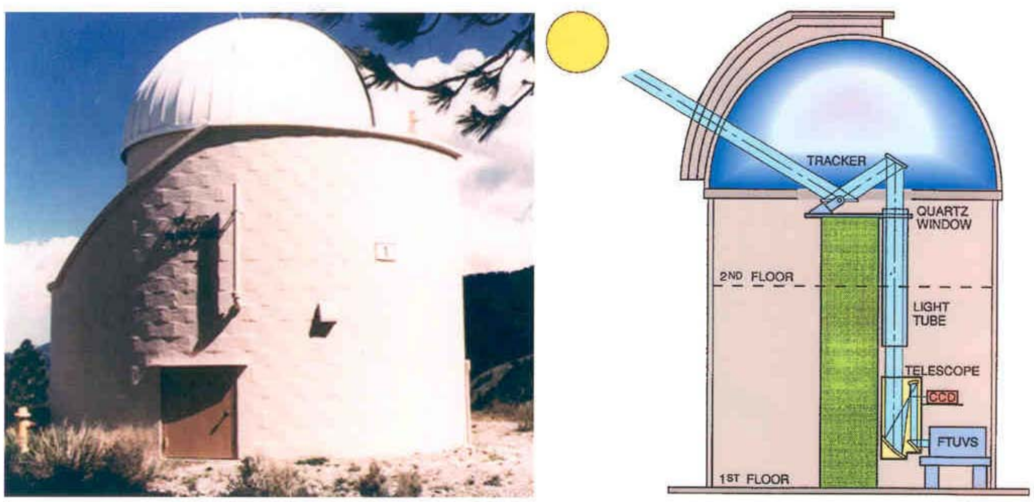
- Chopper used for high speed target
- Slot passes by every 2 milli-seconds
- Image captured by the ROIC every 180 micro-seconds



High speed imaging test set-up

Stop action experiment demonstrated ROIC capability for the high speed imaging needed to make rapid measurements of atmospheric composition

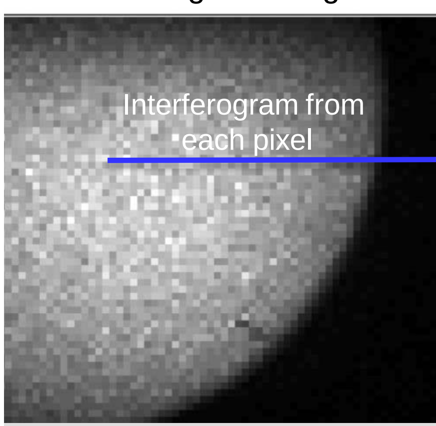
Successful ROIC Operation in the Field

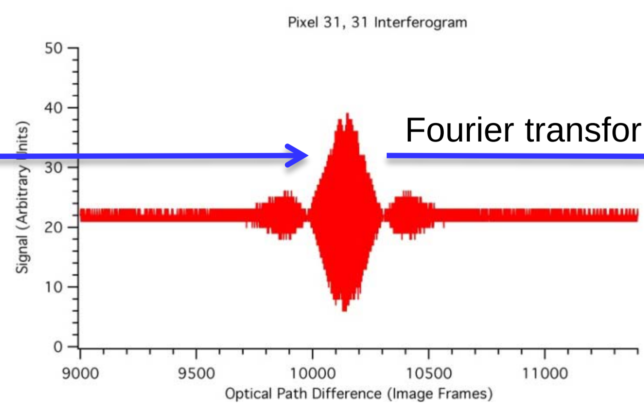


Fourier Transform UV Spectrometer (FTUVS)
at the JPL Table Mountain Facility (TMF)

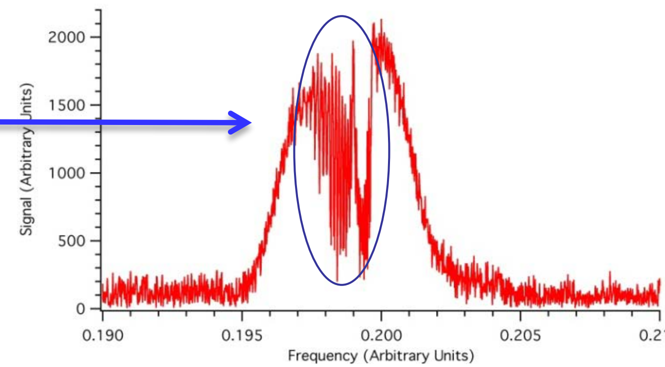
JPL In-Pixel Digitization ROIC in FTUVS at TMF

Solar disk imaged through FTUVS





Atmospheric Oxygen (A band)
Absorption at 760 nm

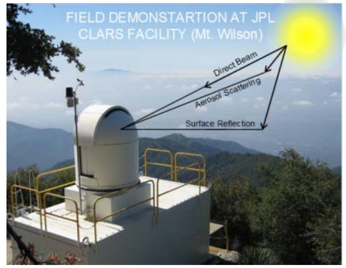


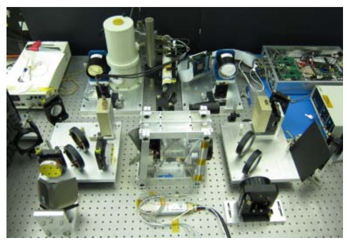
Successful ROIC operation in the FTUVS demonstrated the capability to make scientific measurements of atmospheric composition like those needed for the GEO-CAPE mission

In-Pixel ROIC Technology Infusion

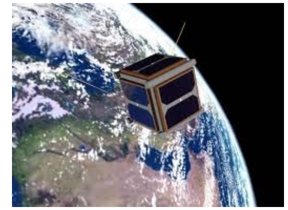
ROIC in FTUVS measuring atmospheric composition

FPA in PanFTS measuring atmospheric composition

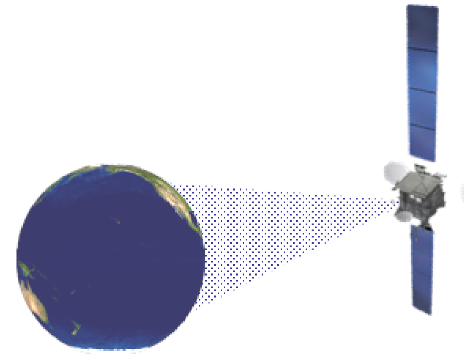




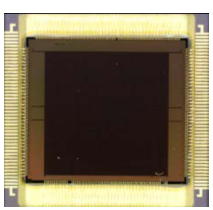
All digital imaging FPA on CubeSat operation in space environment



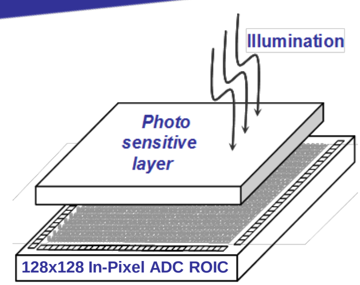
Hourly global mapping of atmospheric composition



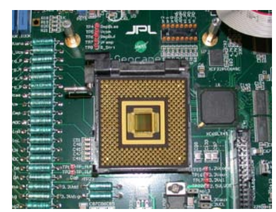
PanFTS on GEO-CAPE



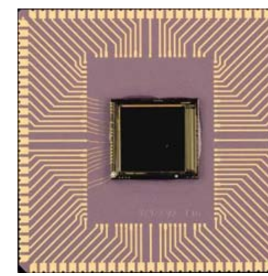
ACT 2008 In-Pixel Digitization ROIC Development and Demonstration



ACT 2010 High Throughput FPA Development and Demonstration



CubeSat 2011 In-Pixel Digitization FPA and Signal Chain Demonstration



2013 High Throughput Flight FPA Fabrication and Qualification

Summary

- Innovative in-pixel digitization ROIC has been developed that enables all digital FPAs (photons in produces bits out proportional to the intensity of the incident light)
- First run success developing brand new, unique ROIC design and fabrication
- Stop action experiment demonstrated ROIC capability for the high speed imaging needed to make rapid measurements
- Overall ROIC performance is outstanding and can be improved with array design refinements
- The ROIC array was successfully operated in the Fourier Transform Ultraviolet Spectrometer (FTUVS) which is an operational instrument at JPL's Table Mountain Facility which makes routine measurement of atmospheric composition. Over a period of several days the ROIC was able to acquire a series of spectra over a wide range of conditions, demonstrating the ROICs capability to make atmospheric composition measurements like those needed for the GEO-CAPE mission.
- Operation in a relevant environment (an operational imaging FTS measuring atmospheric composition) advanced the ROIC technology maturity to TRL 5