# On-board Processing to Advance the PanFTS Imaging System for GEO-CAPE

*Second Year Progress*


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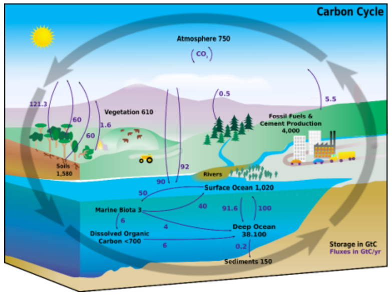
Earth Science Technology Forum

October 28, 2014

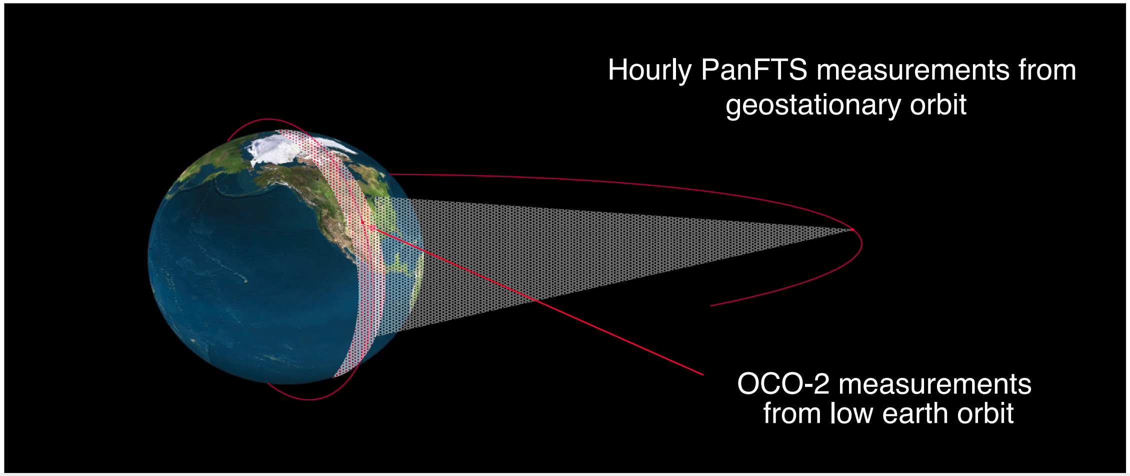
# PanFTS Science Objectives




1. **Atmospheric Composition Science for GEO-CAPE Mission**
   Understand and improve capability for predicting changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition

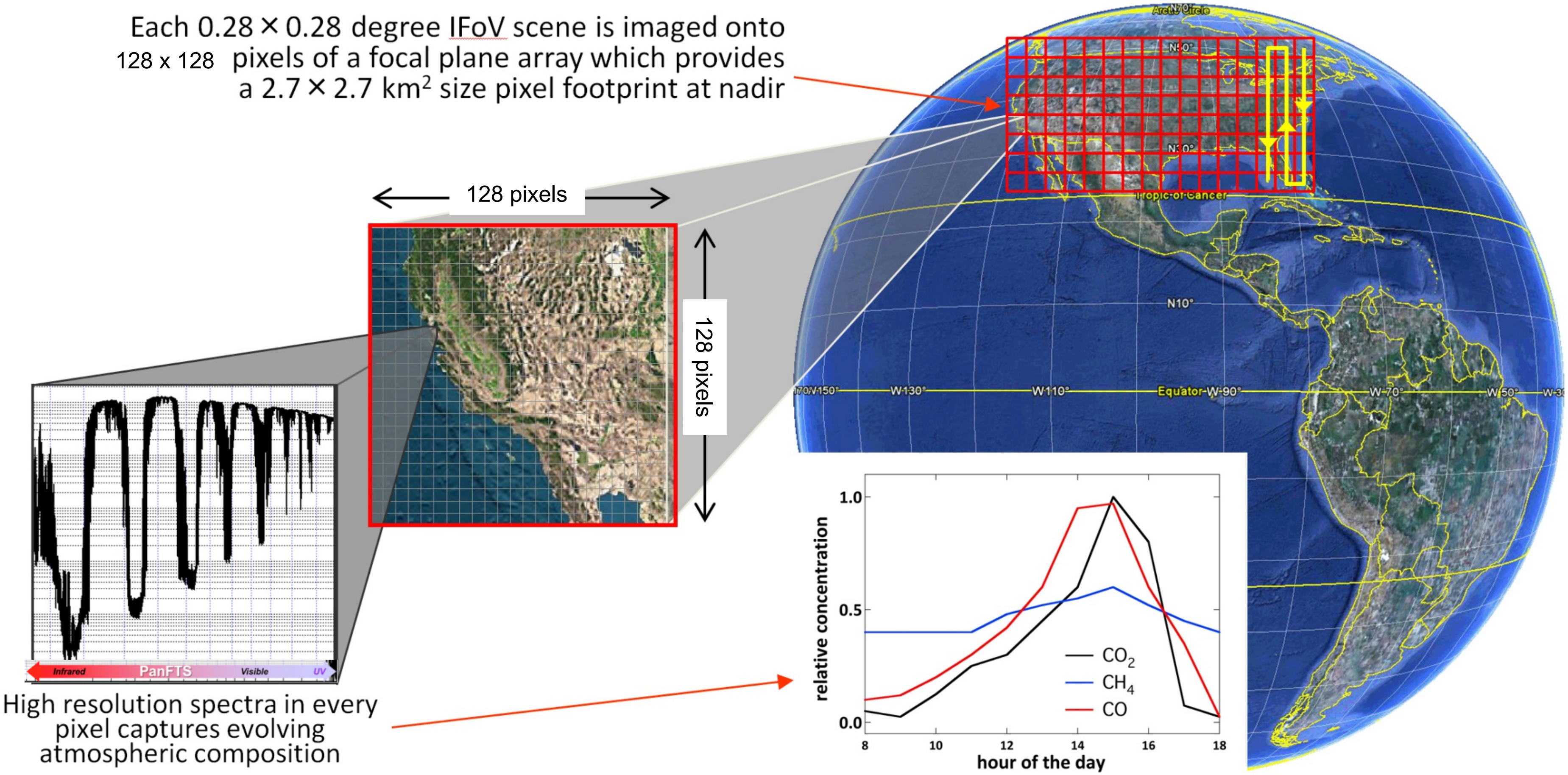
2. **Carbon Cycle Science for NASA Climate Studies**
   Measure profiles of greenhouse gases and transport tracers to quantify carbon fluxes between the atmosphere, land and ocean, and regional scale emissions

3. **Complement science measurements from LEO instruments**




**Panchromatic measurements from geostationary orbit will complement measurements from LEO for quantifying the global carbon budget and monitoring anthropogenic emissions**

# PanFTS Measurement of Atmospheric Chemistry




PanFTS observing capability is totally flexible; observations can be made over the full earth disk in any sequence or pattern

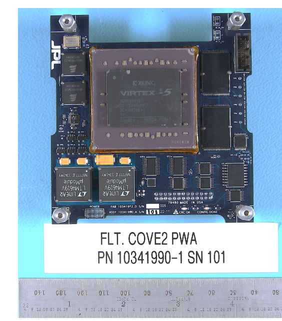
# PanFTS Technology Challenges and Programmatic Investments

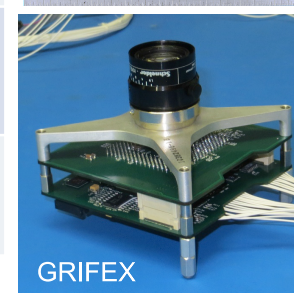
| Program | Technology Area(s) | TRL Advancement |
|---|---|---|
| IIP-07 | • Panchromatic optical design<br>• Digital FPA for imaging FTS (4x4)<br>• Cryogenic, high reliability optical path difference mechanism (OPDM) | 3 → 5<br>3 → 4<br>4 → 6 |
| ACT-08 | • Large format in-pixel digital detector readout (128x128 pixel ROIC) | 3 → 6 |
| IIP-10 | • PanFTS Engineering Model (EM) | 5 → 6 |
| ATI-10 | • CubeSat On-board processing Validation Experiment (COVE) mission using Virtex-5QV FPGA | 5 → 8 |
| ATI-11 | • GRIFEX flight demo of ACT-08 hybridized detector on a CubeSat | 5 → 8 |
| AIST-11 | • On-board interferogram processing for reduction of downlink data rate | 3 → 5 |

COMPLETED (IIP-07, ACT-08, IIP-10, ATI-10)

IN PROGRESS (ATI-11, AIST-11)

Technology Readiness Level (TRL) 6 required at PDR

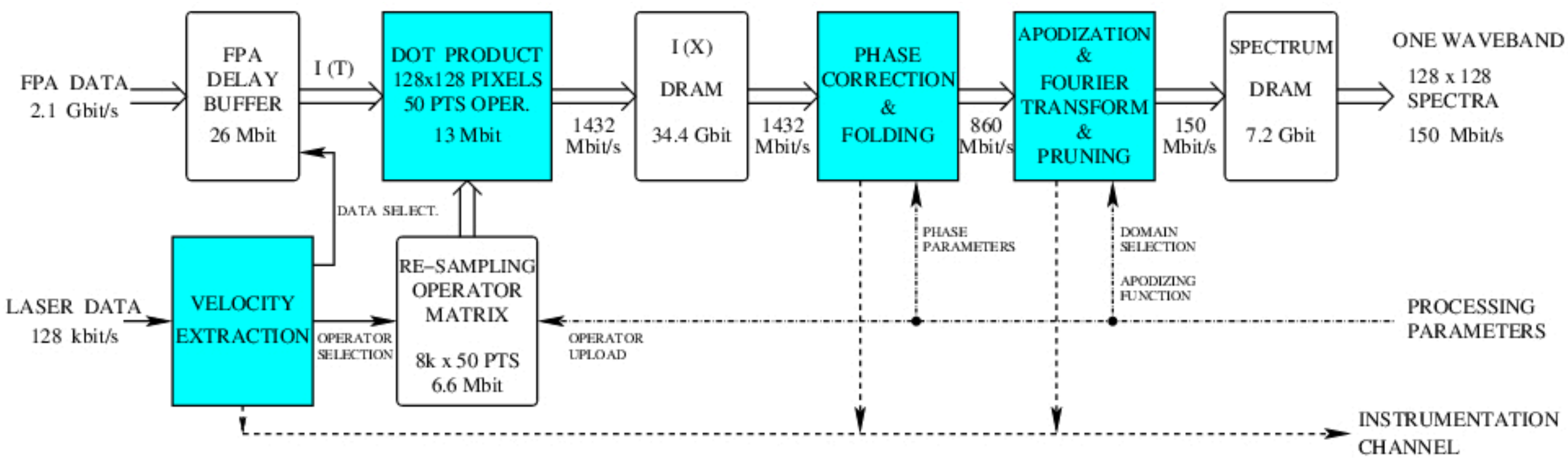


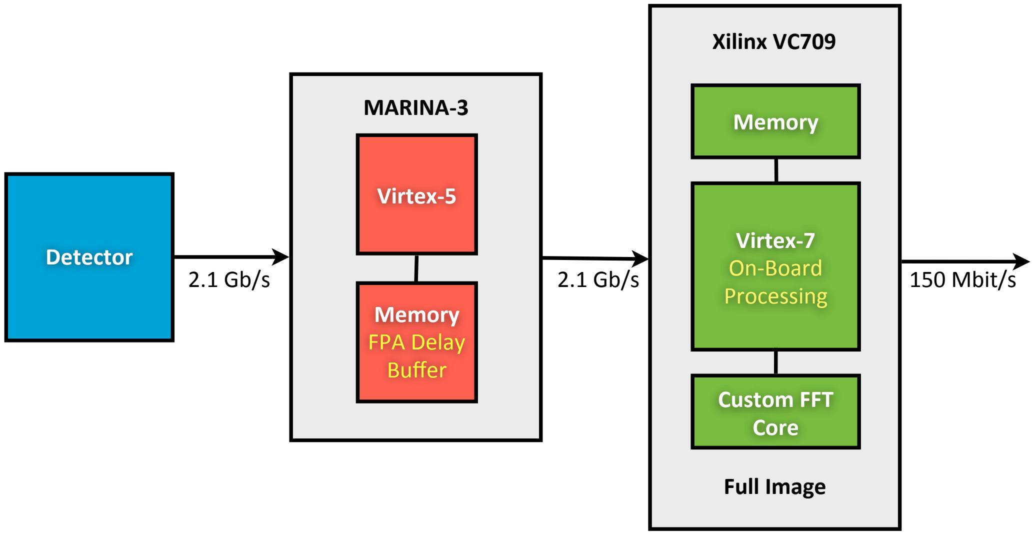
# PanFTS Data Processing Overview

Interferograms produced by the FTS must be converted to spectra before further analysis can take place to derive atmospheric composition. The PanFTS FPAs are sampled at equal time increments to simplify their readout electronics. Processing of such time-domain interferograms follows a method first developed by James Brault. The steps for the conversion to spectra are:

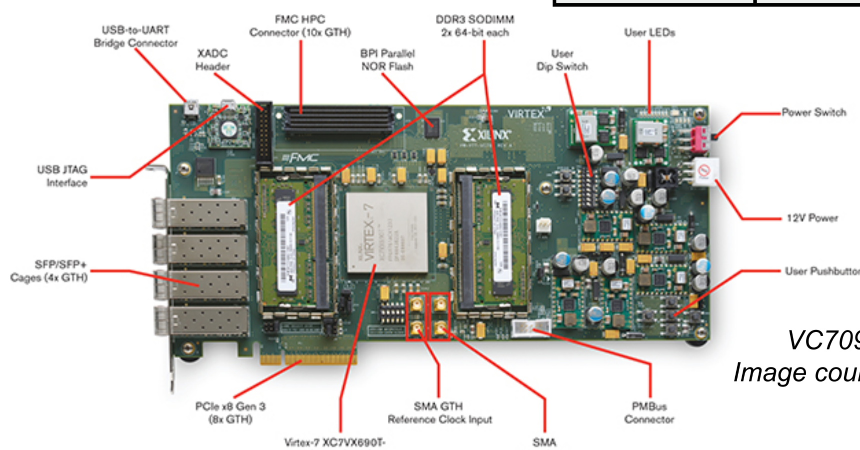
1. Extract scanner position and velocity from the laser signal.
2. Re-sample FPA interferograms from time domain to optical path difference. This step includes digital filtering to remove out-of-band noise that would otherwise fold into the re-sampled bandwidth.
3. Extract phase dispersion from FPA interferograms.
4. Correct FPA interferograms phase dispersion.
5. Compute Fast Fourier Transform (FFT) of the FPA interferograms to produce spectra.



# Current OBP Architecture



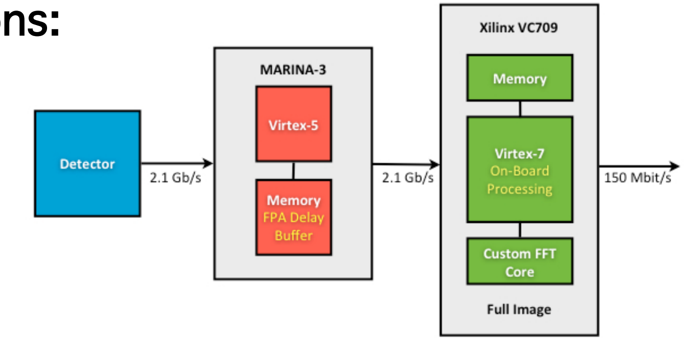

| Parameter | Virtex-7 XC7VX690T |
|---|---|
| Logic Cells | 693,120 |
| CLB Slices | 108,300 |
| Distributed RAM | 10,888 Kb |
| DSP Slices | 3,600 |
| Block RAM | 52,920 Kb |
| Clock Management Tiles | 20 |
| PCIe | 3 |
| XADC Blocks | 1 |
| Total I/O Banks | 20 |
| Max User I/O | 1,000 |
| Configuration Memory | 229.9 Mb |


*VC709 Base Board.*
*Image courtesy of Xilinx, Inc.*

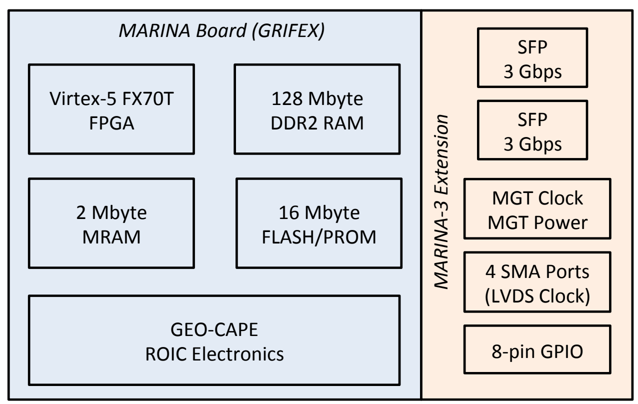
# Custom FPA Interface

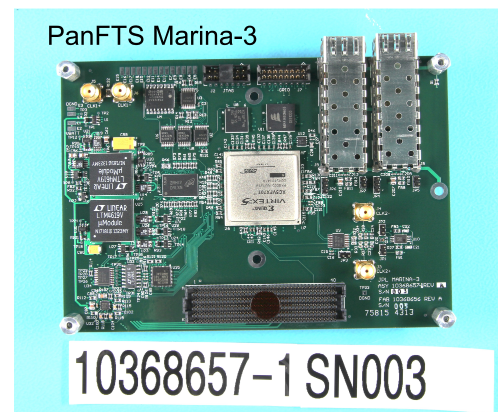
- **Marina-3 board accomplishes the following functions:**
  - Provides timing, control and bias to FPA
  - Controls laser ADCs
  - Receives and buffers FPA and laser samples
  - Receives input from master clock generator
  - Provides optical fiber ports for data output
  - Performs laser processing





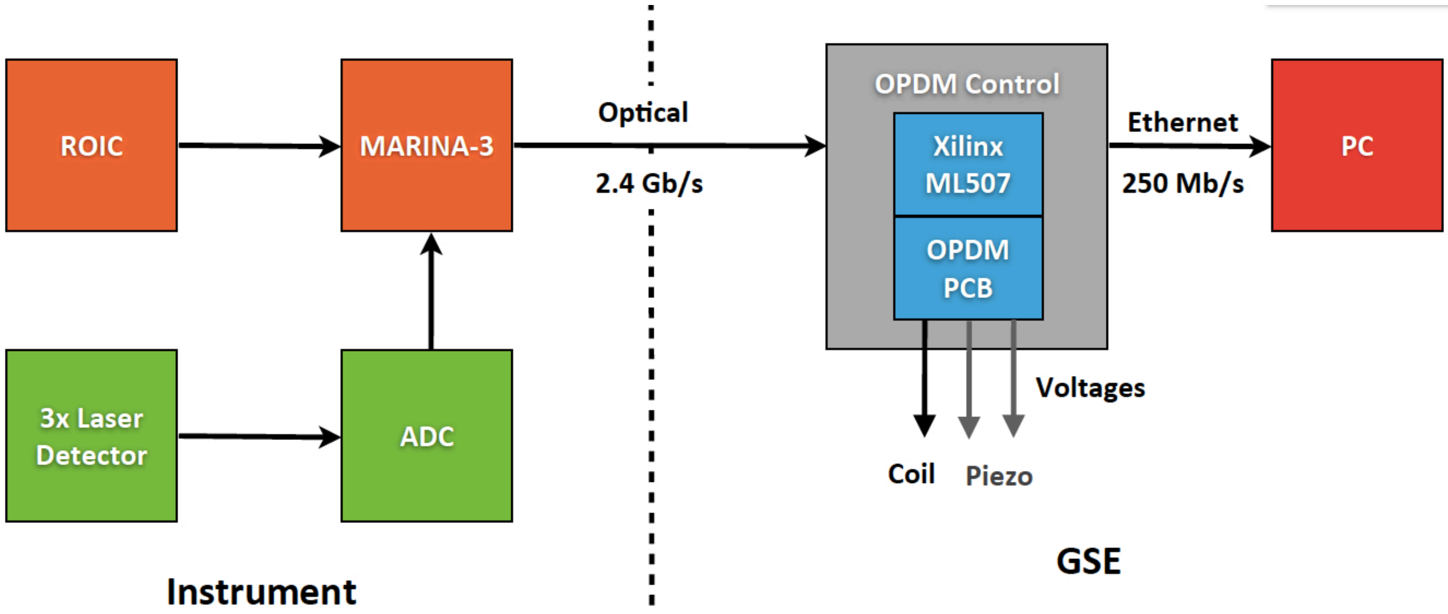
**MARINA-3 BOARD (PanFTS EM)**

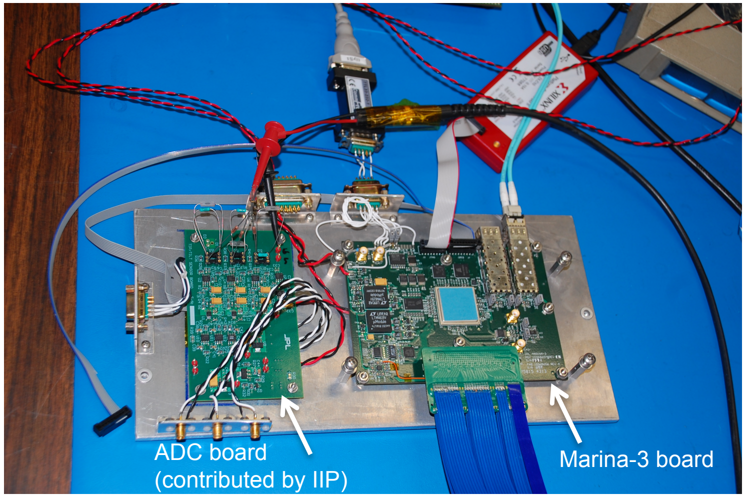



- High-performance Virtex-5 FPGA with many industry-standard interfaces captures high-rate data required for imaging FTS applications
- Extremely flexible: Accommodates a large variety of different focal plane arrays. One-board solution for JPL ROIC (UV-visible), Raytheon SB-410 (MWIR/LWIR), SB-232 (SWIR) and many others

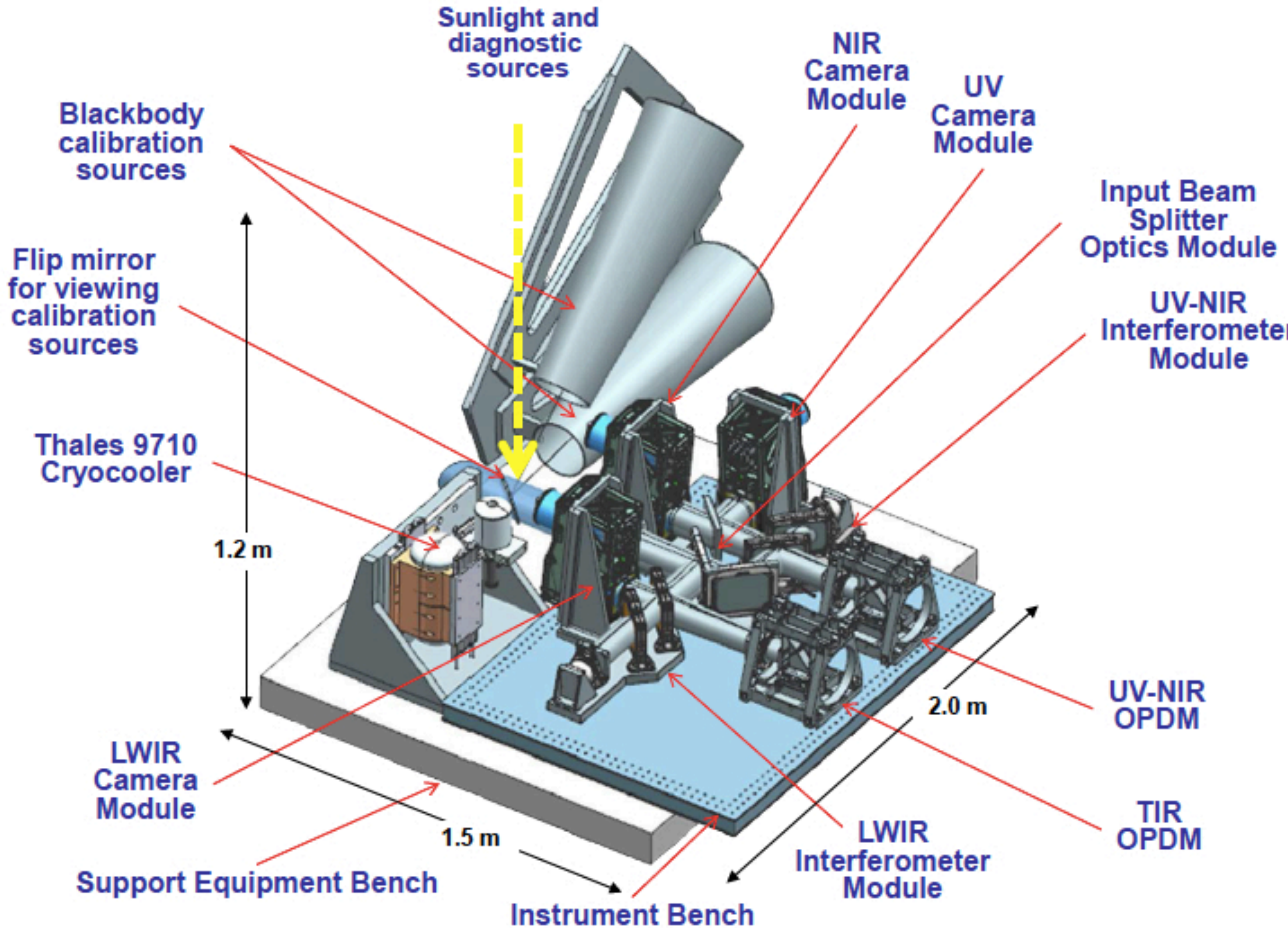
# Existing Instrument System



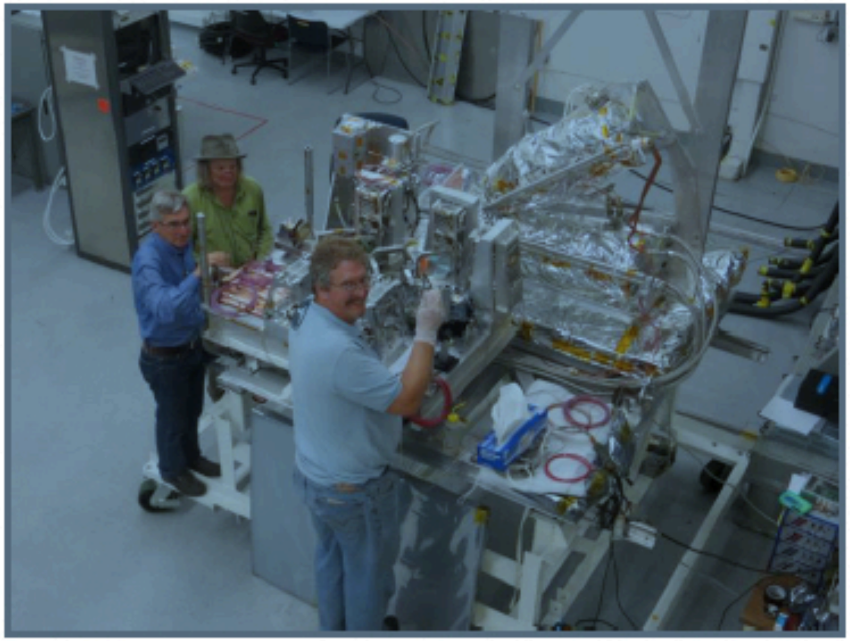



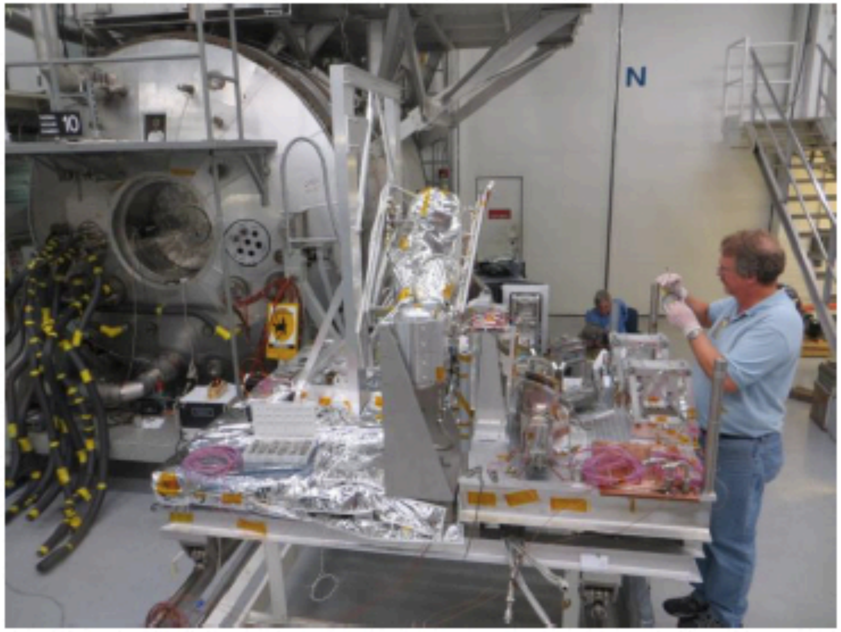

- ✧ OPDM Control keeps up with real-time data processing

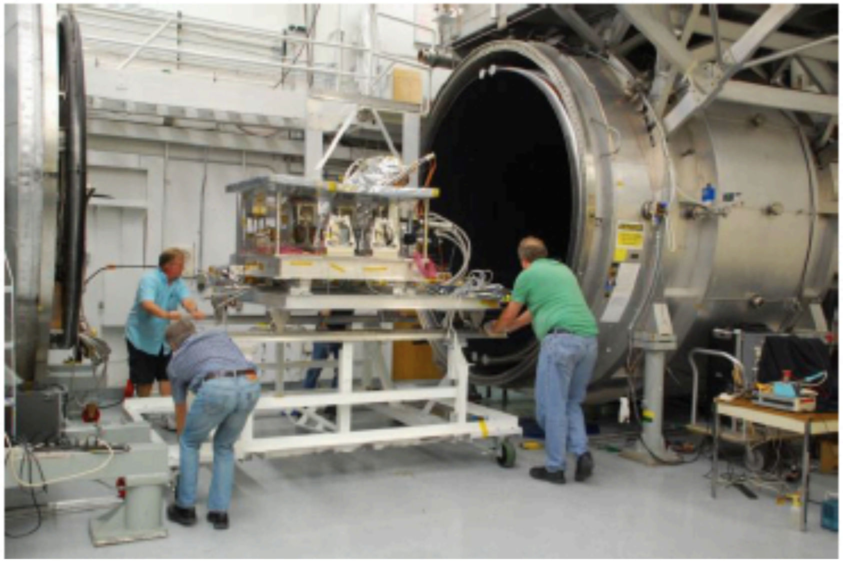
# PanFTS EM T-Vac Test Configuration

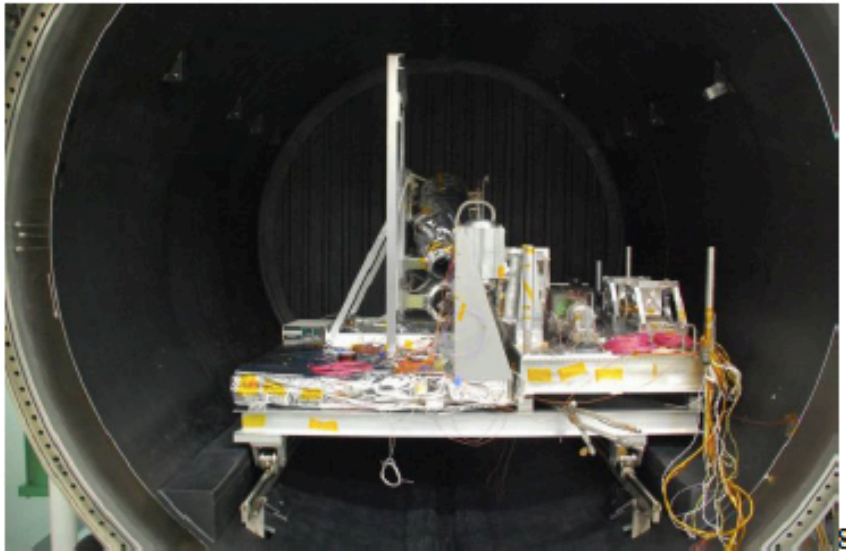


# PanFTS EM TVac Test
## Preparation and Chamber Insertion

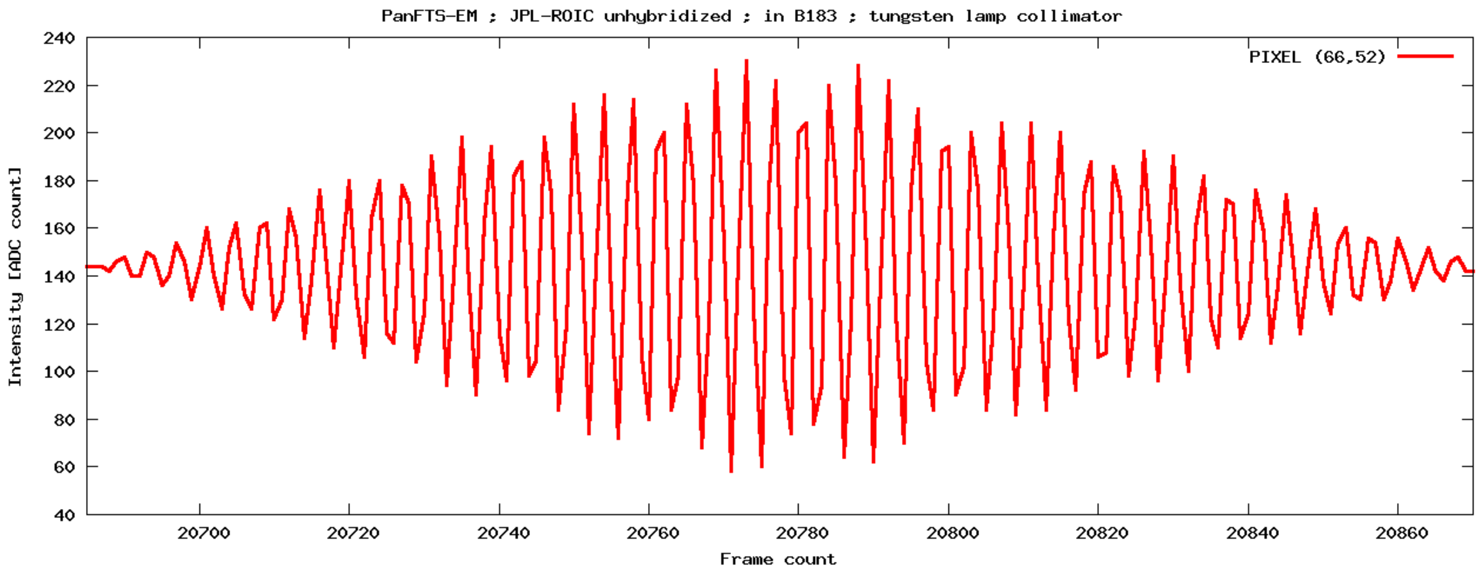


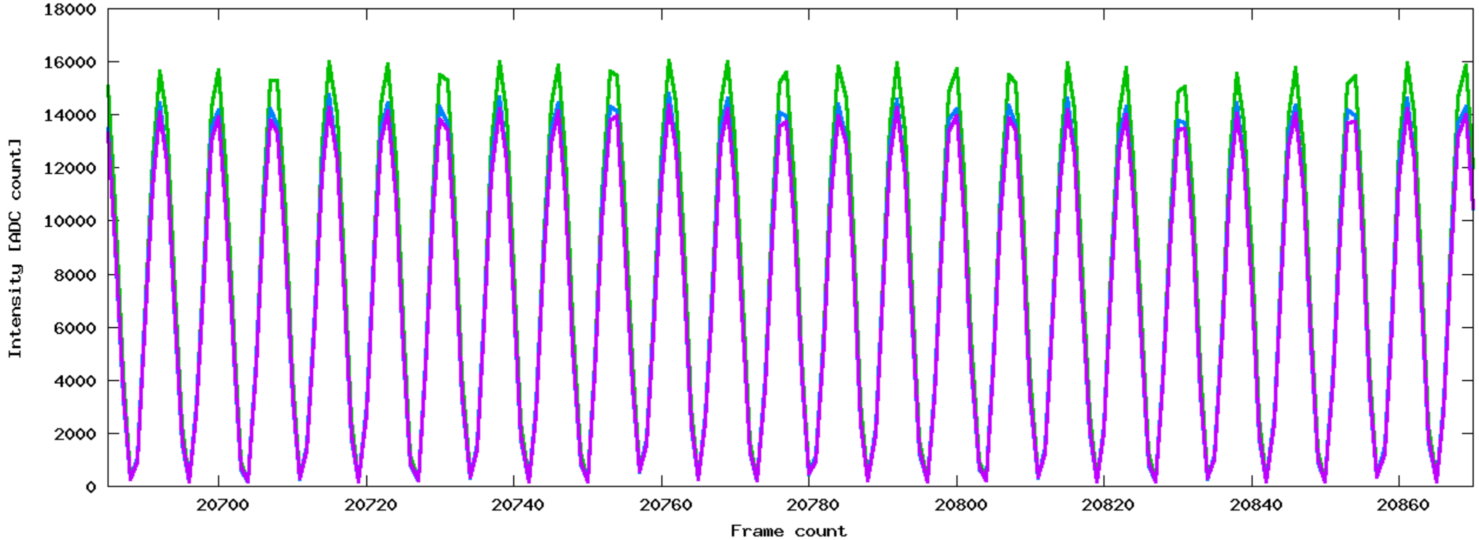




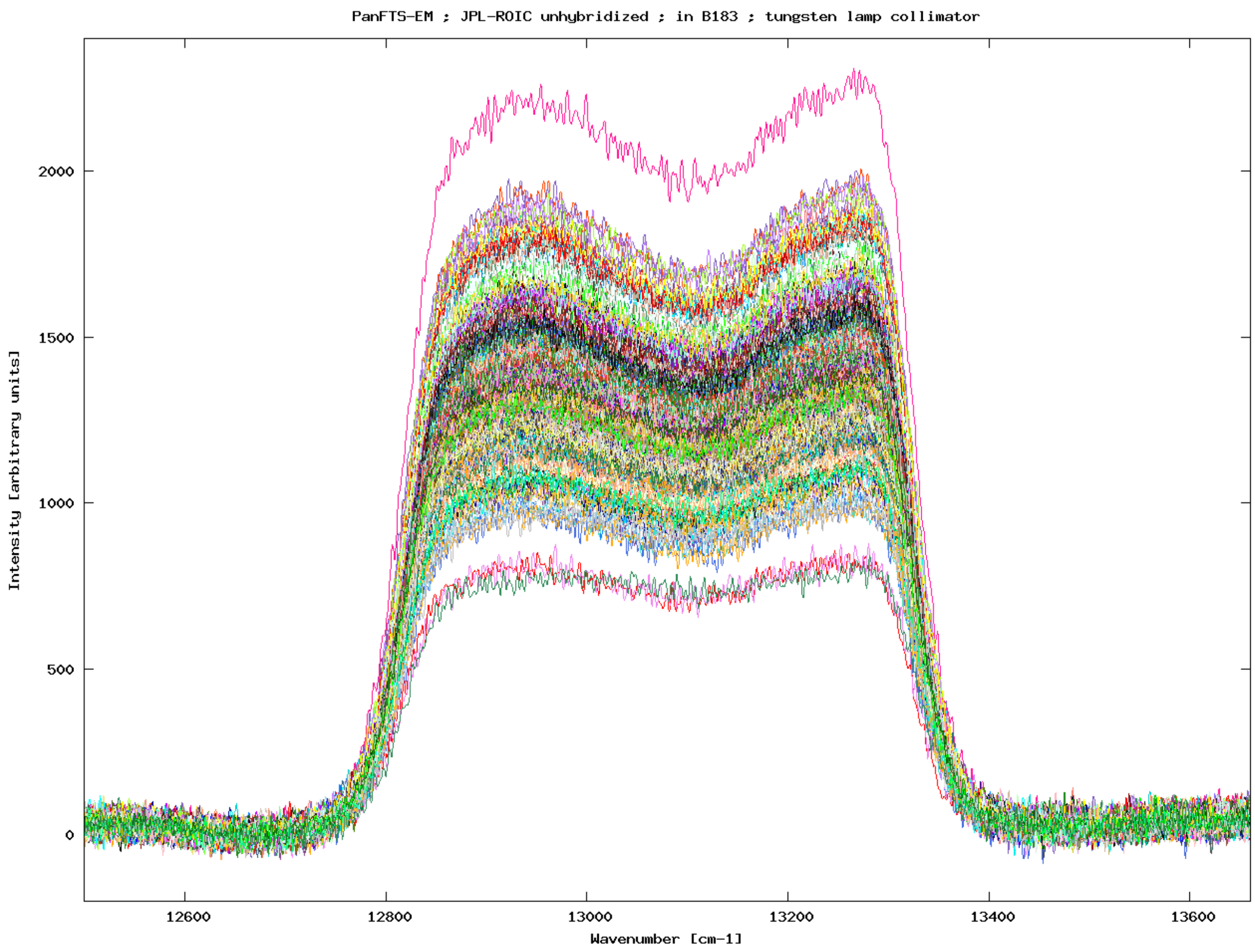
# TVAC Results (1 of 2):
## Time-domain plot of one pixel and the three laser channels



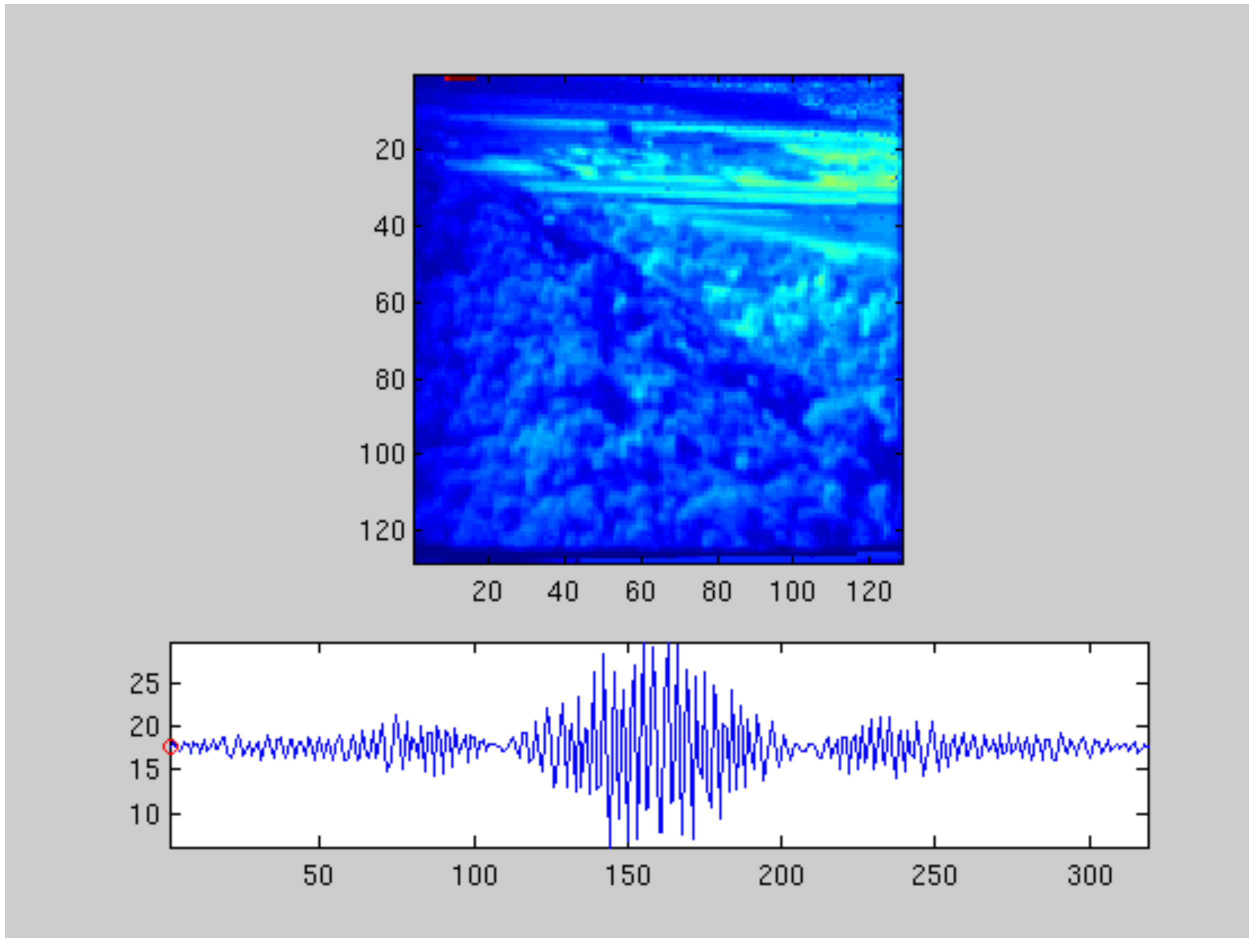
# TVAC Results (2 of 2):

324 spectra showing the response of the optical filter used for the oxygen A-band channel



# Recent PanFTS Activity

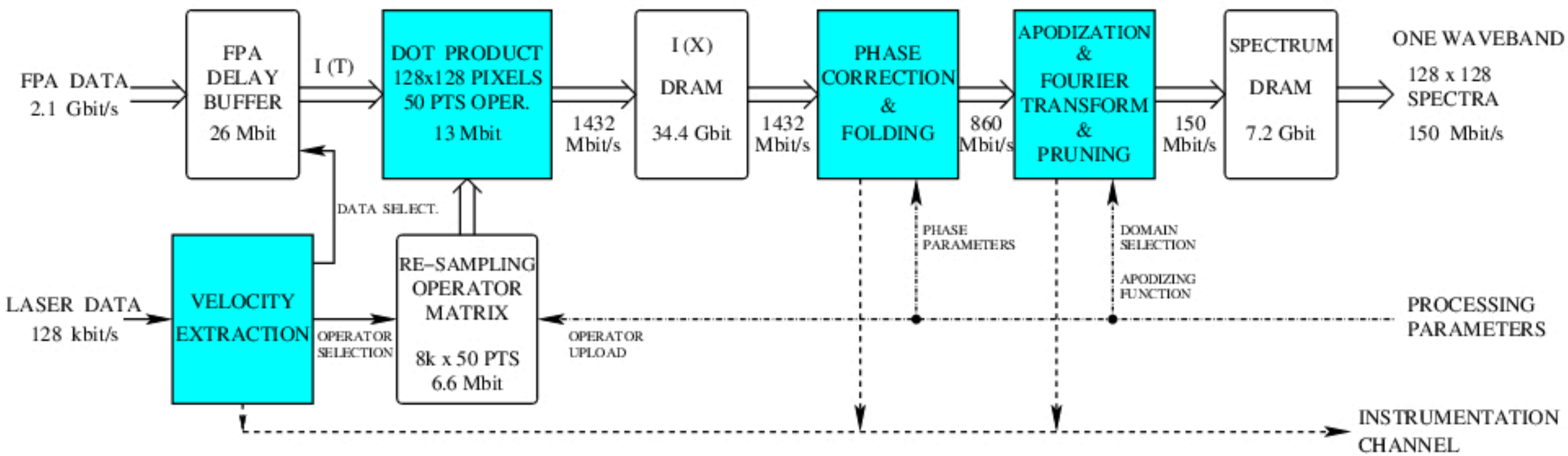
A derivative of the EM PanFTS instrument focused on wavebands relevant to OCO-2 is installed at CLARS (California Laboratory for Atmospheric Remote Sensing) on Mount Wilson.




- Each pixel in the image gives a spectrum of the oxygen A-band slant column density: 16,384 total spectra – never before done in the NIR.

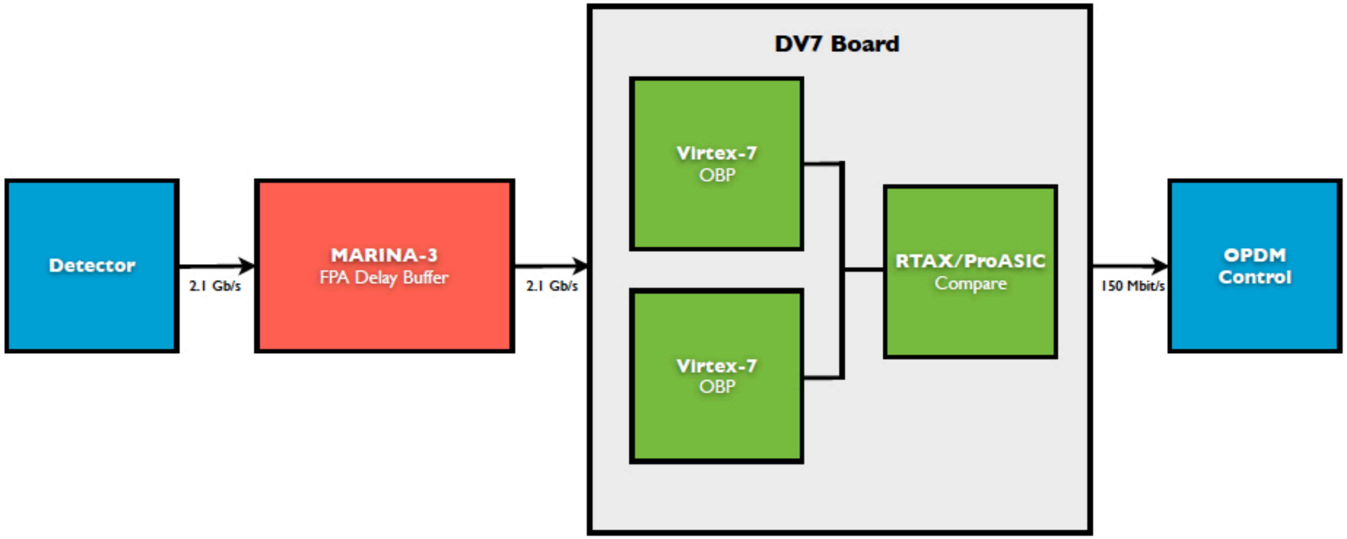
# OBP Algorithm Status

- Complete: velocity extraction (demonstrated in TVAC), FFT core (being tested)
- In development: re-sampling, dot product, DRAM access/storage
- Future work: phase correction and folding, integration of all modules, testing, demonstration with EM PanFTS instrument



# Future OBP Hardware Architecture

- Selection of Virtex-7 FPGA over Virtex-5 FPGA for OBP
  - One V7 vs. six V5s is a significant power savings for each FPA
  - V7 may become flight qualified for instrument development
  - Cost savings: V5QV @ $80K each vs. commercial/military-grade V7 at $8-10K each
- Dual Virtex-7 (DV7) board
  - Two V7s, each running OBP algorithm in parallel
  - V7 data outputs compared by rad-hard FPGA
  - If data miscompare or V7 latch-up (non-destructive) occurs, reset board to clear fault and continue next observation



# Summary

- MARINA-3 custom board designed, built, and successfully demonstrated with EM PanFTS in TVAC

- PanFTS OBP algorithm development is performed on the Virtex-7 FPGA-based VC709 platform

- Final milestone is to integrate VC709 board with full OBP into EM PanFTS instrument for 2.1 Gbit/s to 150 Mbit/s data rate reduction demonstration at Mt. Wilson by the end of May 2015.

- Virtex-7 algorithm development and FPGA component maturity is driving the DV7 custom hardware architecture for future PanFTS OBP implementation

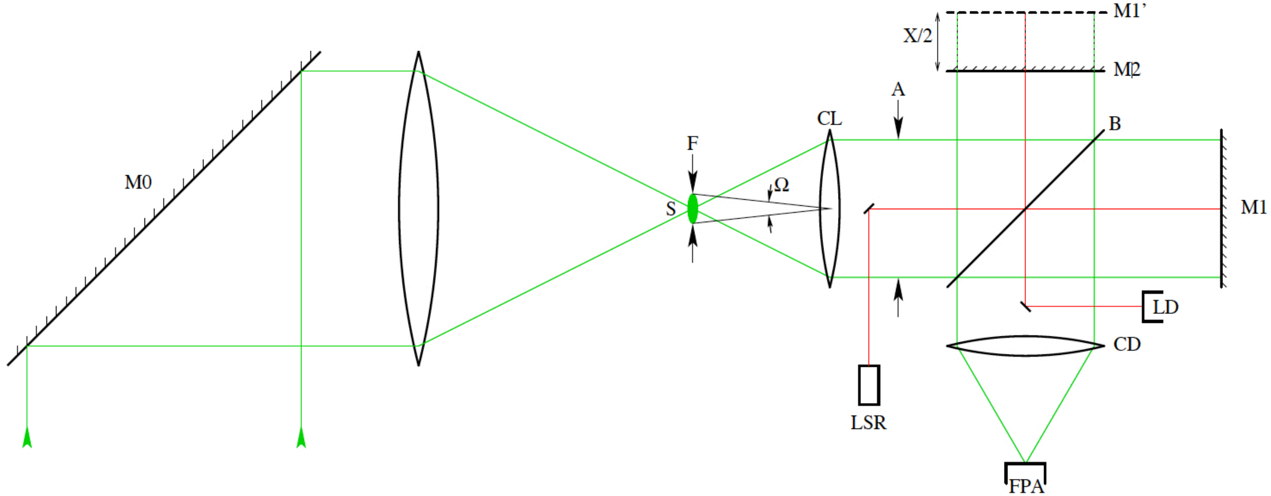
# Backup Material

# GEO-CAPE Measurement Requirements

GEO-CAPE measurements requirements from the science traceability matrix (STM) circa the GEO-CAPE Community Workshop May 2011

| Species | Precision | Spectral region |
|---|---|---|
| $O_3$ | Stratosphere: 5%<br>2 km-tropopause: 15 ppb<br>0-2 km: 10 ppb | UV, Vis, TIR |
| CO | 2 km – tropopause: 20 ppb<br>0-2 km: 20 ppb | SWIR, TIR |
| $NO_2$ | $1 \times 10^{15}$ $cm^{-2}$ | Vis |
| HCHO | $1 \times 10^{16}$ $cm^{-2}$ | UV |
| $SO_2$ | $1 \times 10^{16}$ $cm^{-2}$ | UV |
| $CH_4$ | Troposphere: 20 ppb | SWIR, TIR |
| $NH_3$ | 0-2 km: 2 ppb | TIR |
| CHOCHO | $4 \times 10^{14}$ $cm^{-2}$ | Vis |
| Aerosol (AOD) | 0.05 | Vis |
| Absorbing aerosol (AAOD) | 0.02 | UV |
| Aerosol index (AI) | 0.1 | UV |
| Aerosol centroid height (AOCH) | 1 km | Vis, NIR |

# PanFTS Optics Overview




- JPL has extensive experience in designing and operating FTS instruments for a variety of platforms (ATMOS, MkIV, TES, FTUVS, CLARS).
- An FTS has a wide spectral range, independent of the detector array size. This wide bandwidth enables simultaneous measurement of several gas species.
- An imaging FTS 2-dimensional field of view maps directly to the observed scene.
- The FTS spectral resolution is primarily set by the optical path difference of the interferometer, not the critical slit alignment of a grating instrument.
- The spectral frequency scale of an FTS is linear, set by a stable reference diode laser metrology system eliminating wavelength drift from small temperature changes suffered by grating instruments.
- An FTS has a highly stable instrument line shape (ILS).
- The FTS interferometer modulates light at frequencies which are above the 1/f scintillation of the Earth, so that source of noise is rejected.
- The FTS is less sensitive to stray light generated after the interferometer as that participates only in the photon noise, not in the recorded signal.