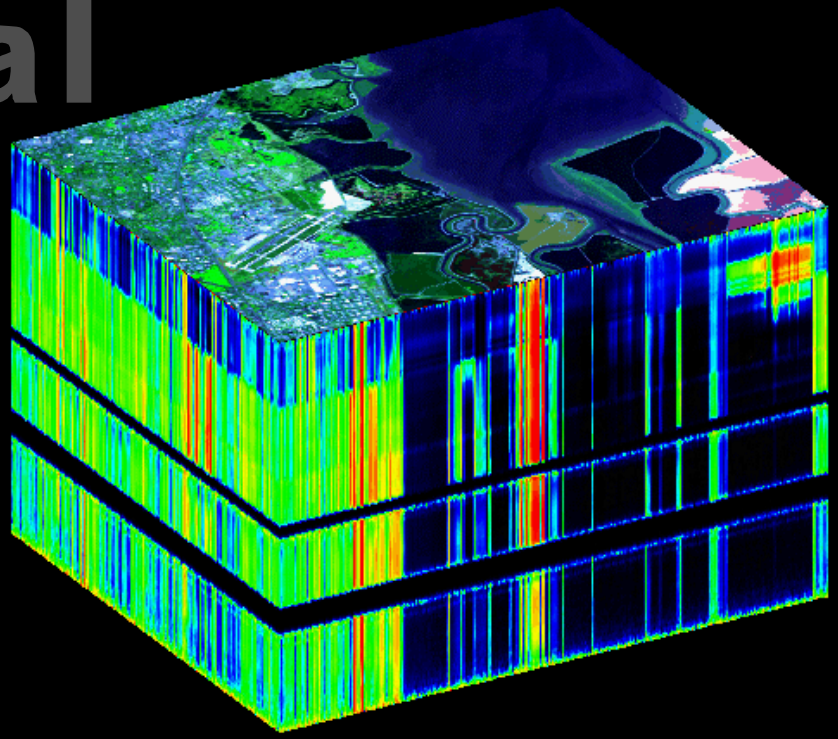
Hyperspectral Challenge Problem



Adapted in part from charts
by R. Taylor, NASA GSFC

With helpful input from
Pankaj Topiwala USC/ISI

Specific Hyperspectral Challenge
Problem: LANL

Jeffrey Bloch

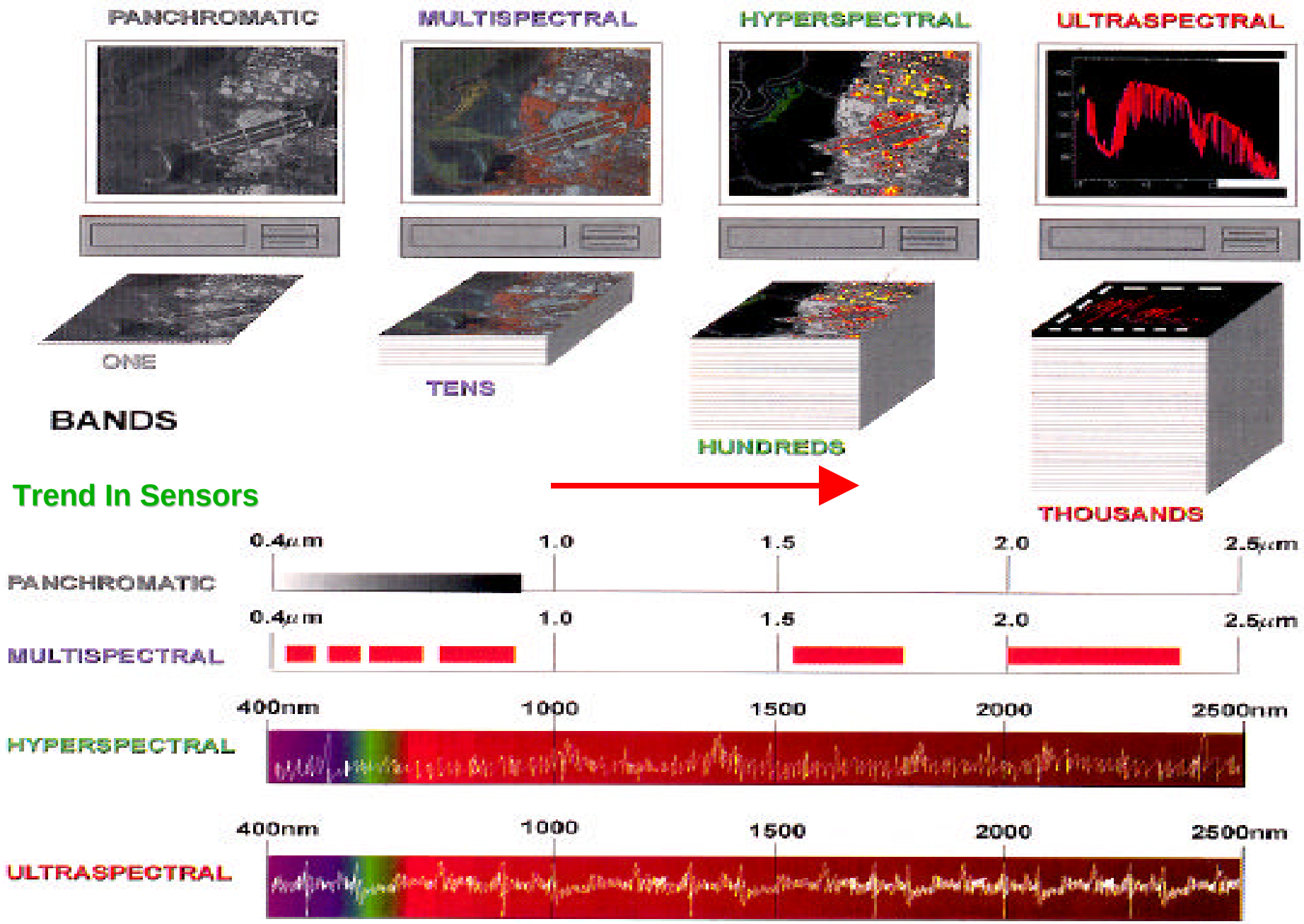
Los Alamos National Laboratory

jbloch@lanl.gov

Objective

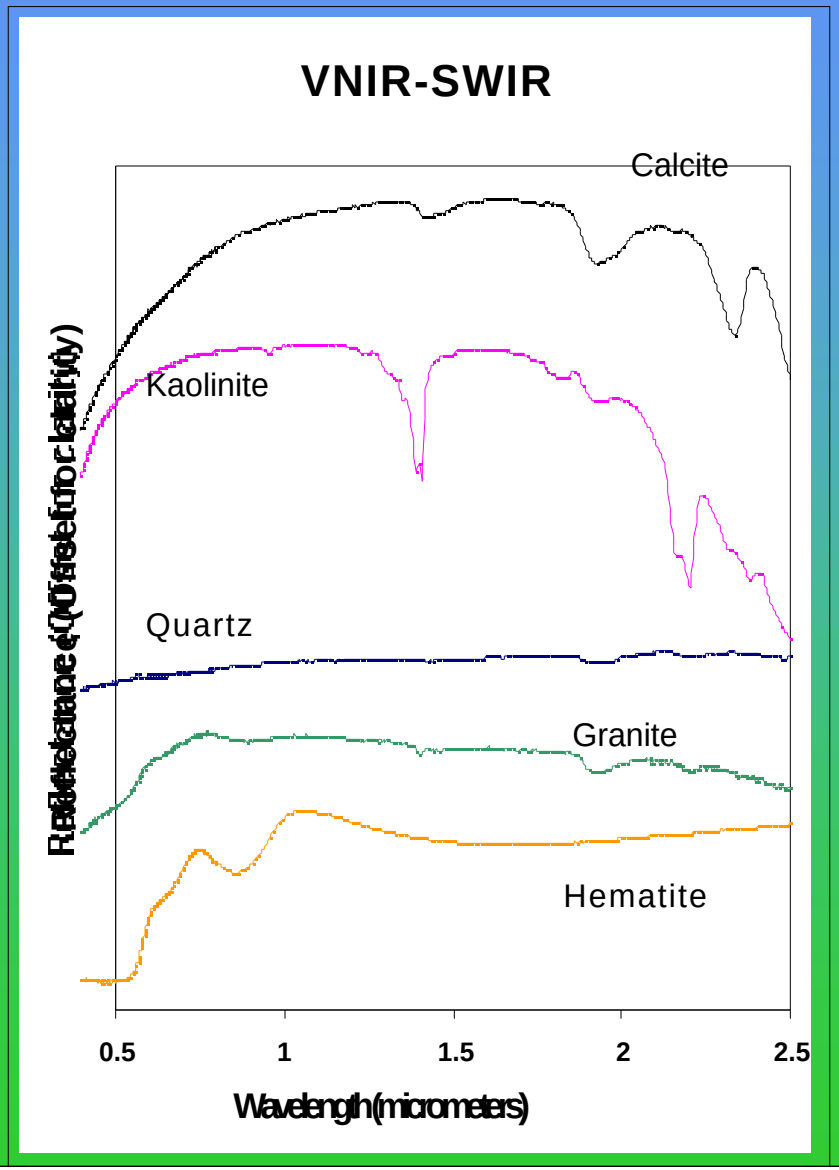
- Present the motivation and a long-term vision for high-resolution spectral imaging

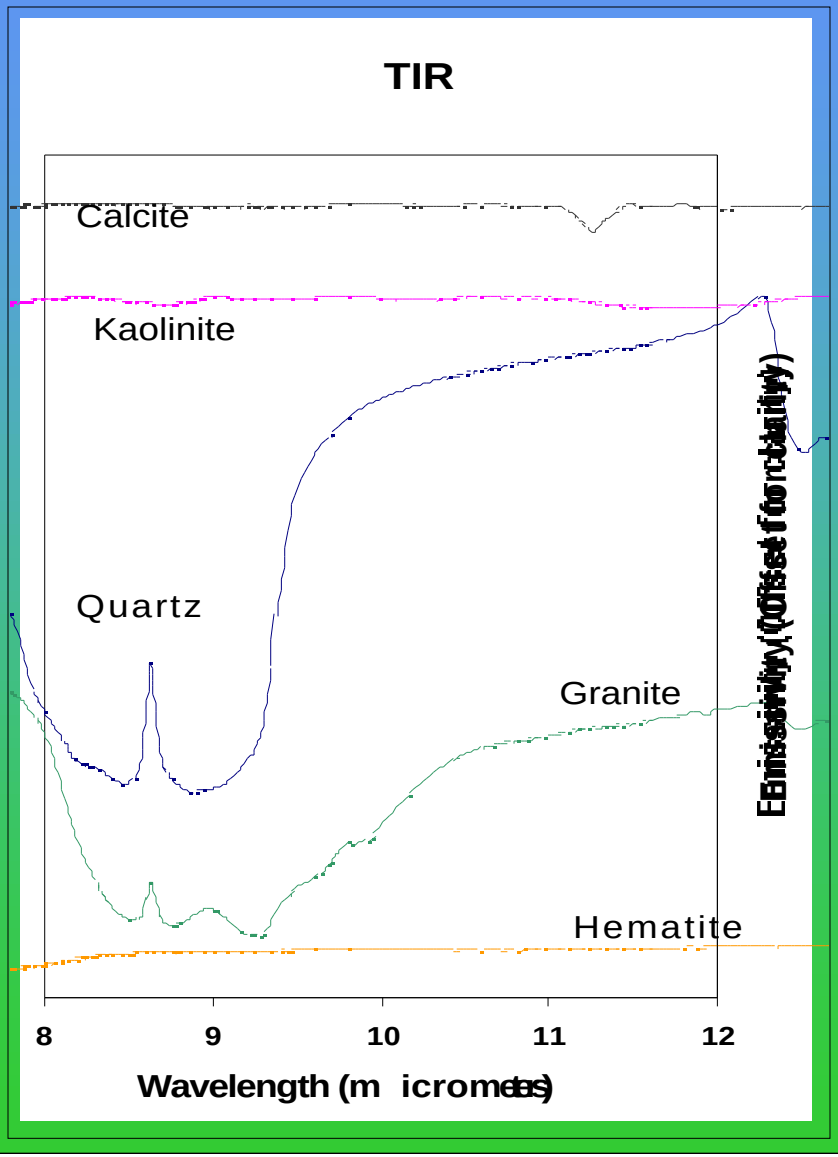
- Present a detailed challenge problem for onboard, hyperspectral product generation using reconfigurable computing



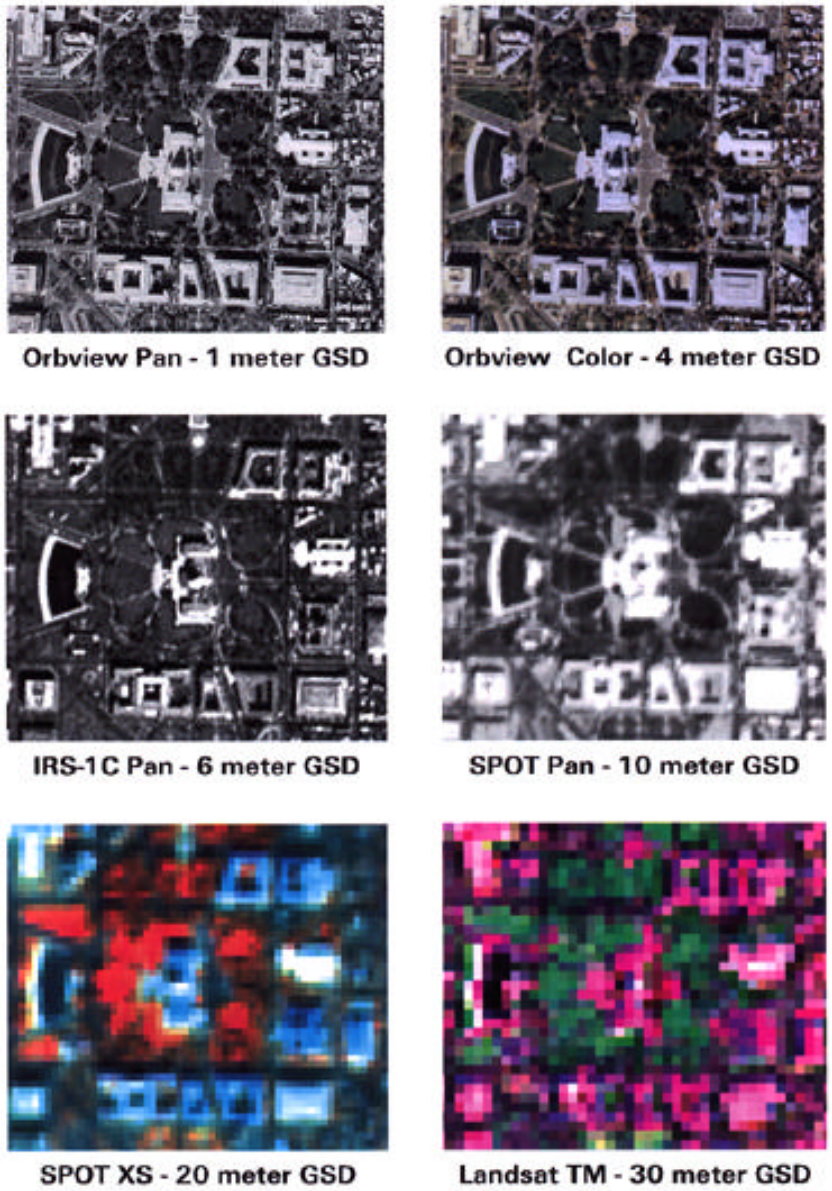
Source: Multispectral Imagery Guide, Logicon

Spectral Signatures





Spatial Vs. Spectral Resolution



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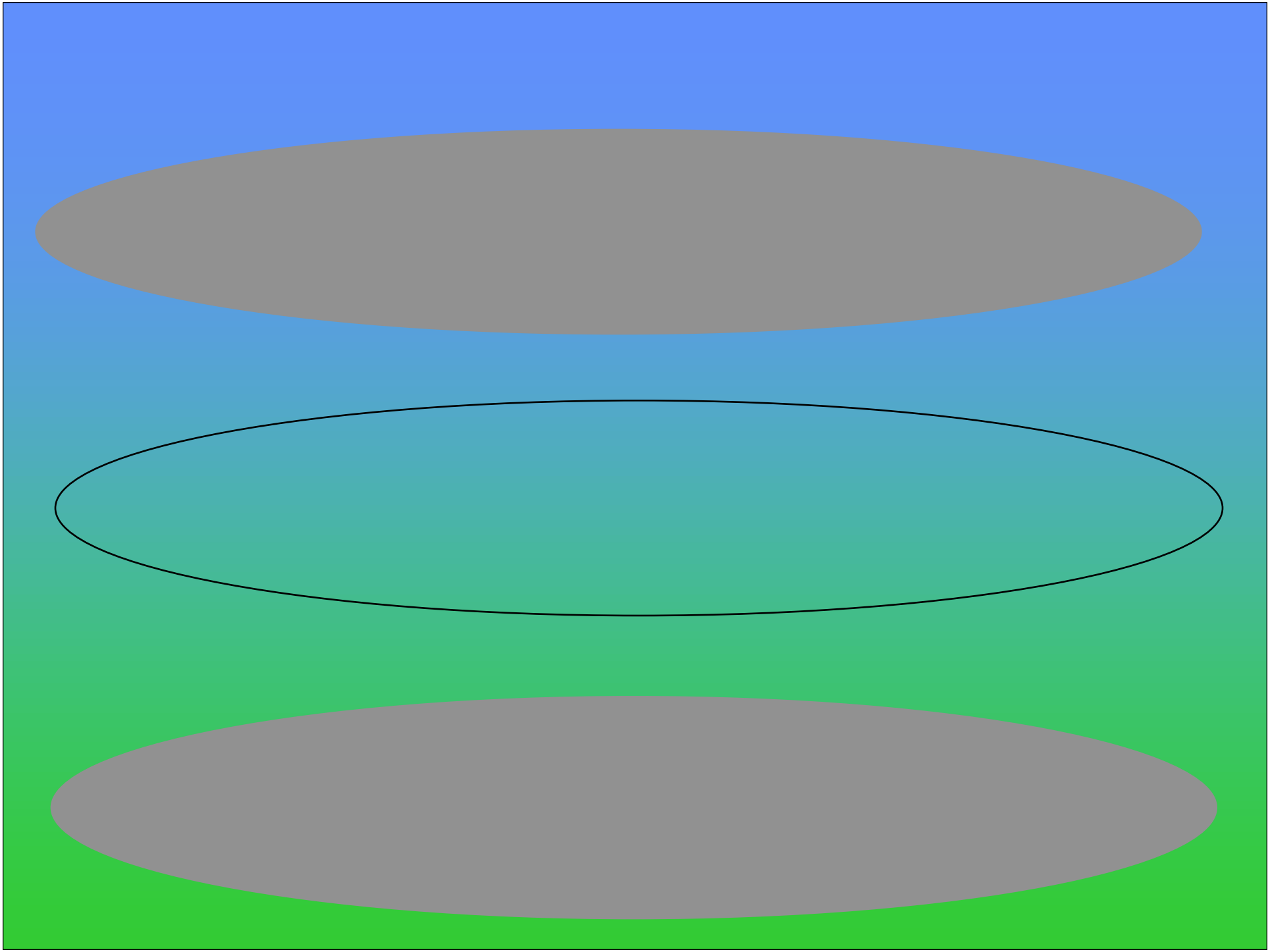
Source: Multispectral Imagery Guide, Logicon

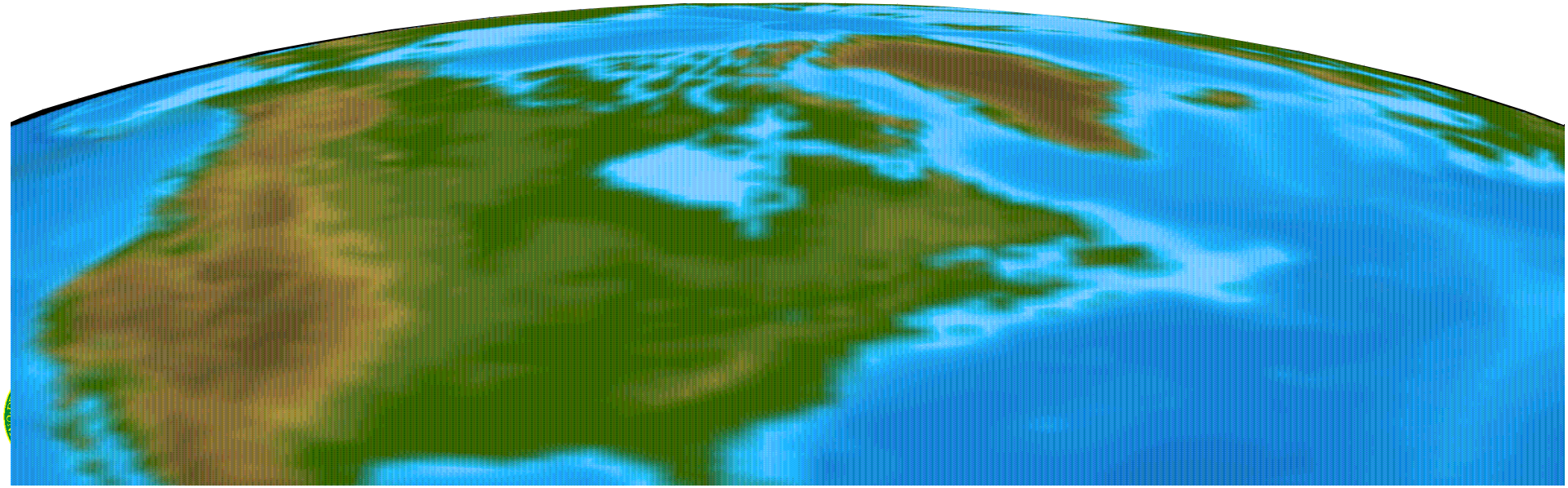
- Sensors can trade spatial vs spectral resolution
- Planned sensors have high spatial AND spectral resolution
- Exploitation is processor/storage intensive



Near-Term Vision: Hyperspectral Imaging System

DATABASE-IN-THE-SKY

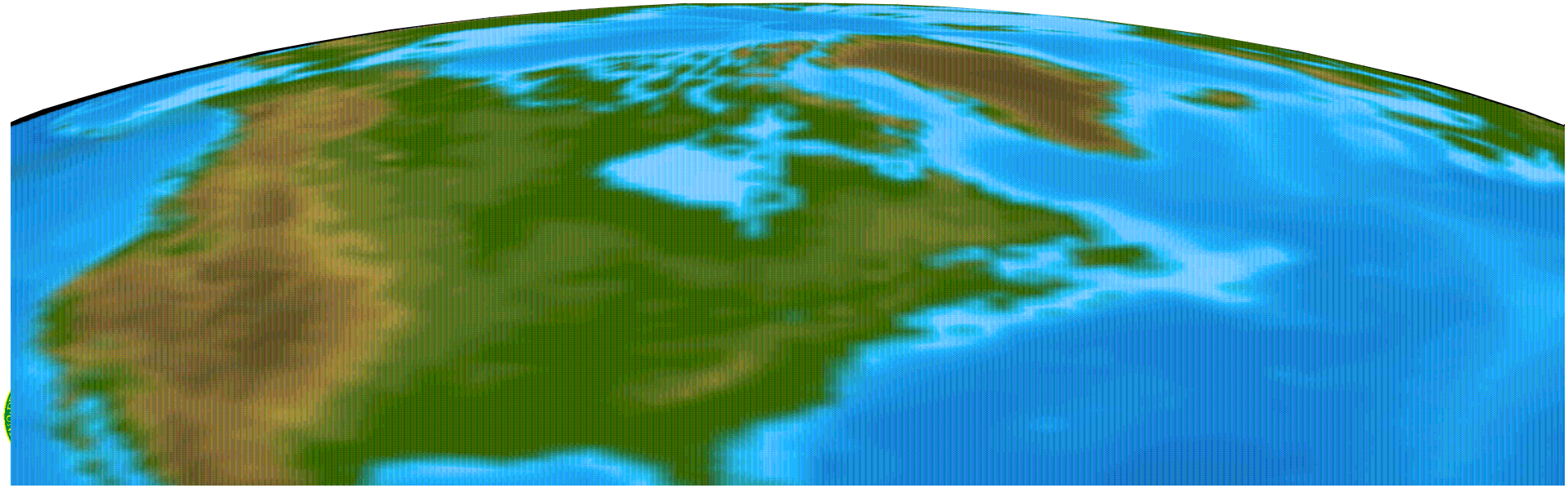
- ***Users Request Hypercube Slices***
- ***Direct Delivery of Derived Products***
- ***Large Area Coverage per Orbit***
- ***Full Spectrum Coverage (VNIR - TIR)***
- ***Pointable for Revisit / Calibration***



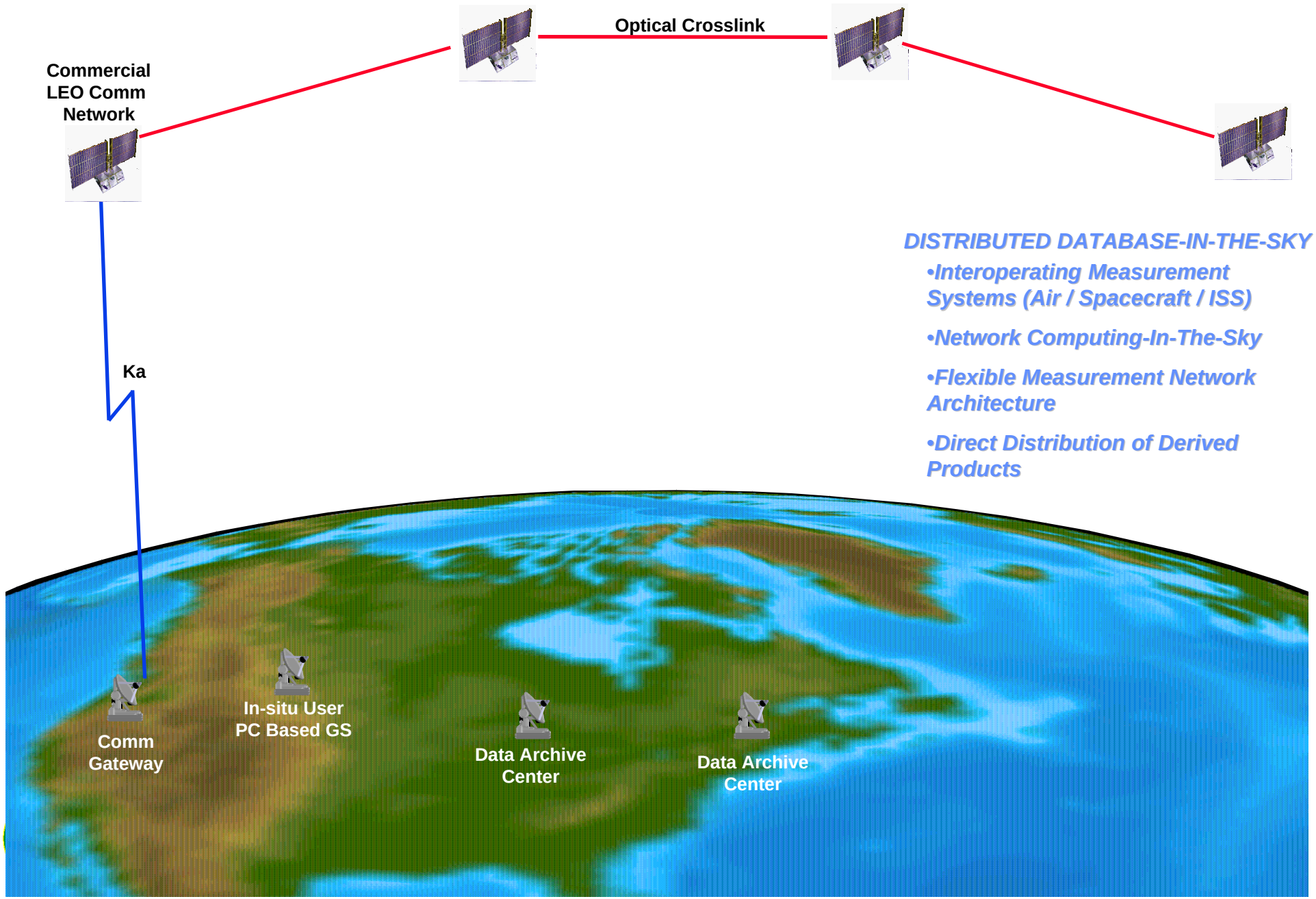
Near-Term Vision: Hyperspectral Imaging System

SYSTEM SPECIFICATIONS

- ***Orbit period: 90 min***
- ***Swath width: 5 km - 500 km***
- ***Spatial Resolution: 2.5 m - 250 m***
- ***Spectral Resolution: 200 bands***
- ***Dynamic Range: 12 bpp***
- ***Data Rate: up to 2 GB/s***



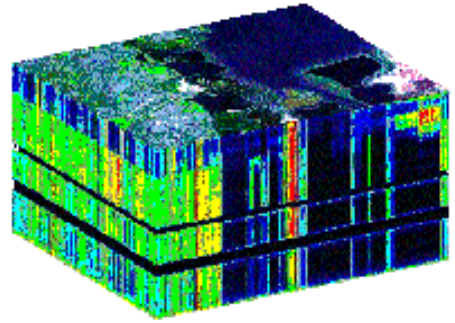
Long-Term Vision: Distributed Hyperspectral Imaging Systems



DISTRIBUTED DATABASE-IN-THE-SKY

- ***Interoperating Measurement Systems (Air / Spacecraft / ISS)***
- ***Network Computing-In-The-Sky***
- ***Flexible Measurement Network Architecture***
- ***Direct Distribution of Derived Products***

Generic Characteristics of a Hyperspectral Image Processing Pipeline



HSI Sensor

2kx2k
12 bpp
200 bands

1.3 GB

8-12 GFLOPs
3 GB Mem

Preprocessing
- Spect-Spatial Registration
- Gain Control
- Calibration
- Data Format.
- Atmospheric Cor. (Modtran, etc.)
- Geocoding
- Band Grouping

10-15 GFLOPs
3 GB Mem

Spect. Unmixing
- Anal. of Variance
- Regression
- Hypoth. Testing
- Endmember Sel.
- Terrain Analysis

!5-10 GFLOPs
2 GB Mem

Image Fusion
- Material Map Sharpening
- HR Panchro. + LR Spec. Regis.
- Image Data Fusion

5-7 GFLOPs
2 GB Mem

Anomaly Detection
- Spectral Match Filtering
- Adaptive CFAR
- Hypoth. Testing
- Cluster Analysis
- Outlier Detection
- Object Attributes/ Preclassification

Cue Other Sensors

Target Handoff
- Geolocation
- Attributes/Class.

10-15 GFLOPs
2 GB Mem

Compression
- Spectral KLT
- Bit Allocation
- Band Coding

130 MB

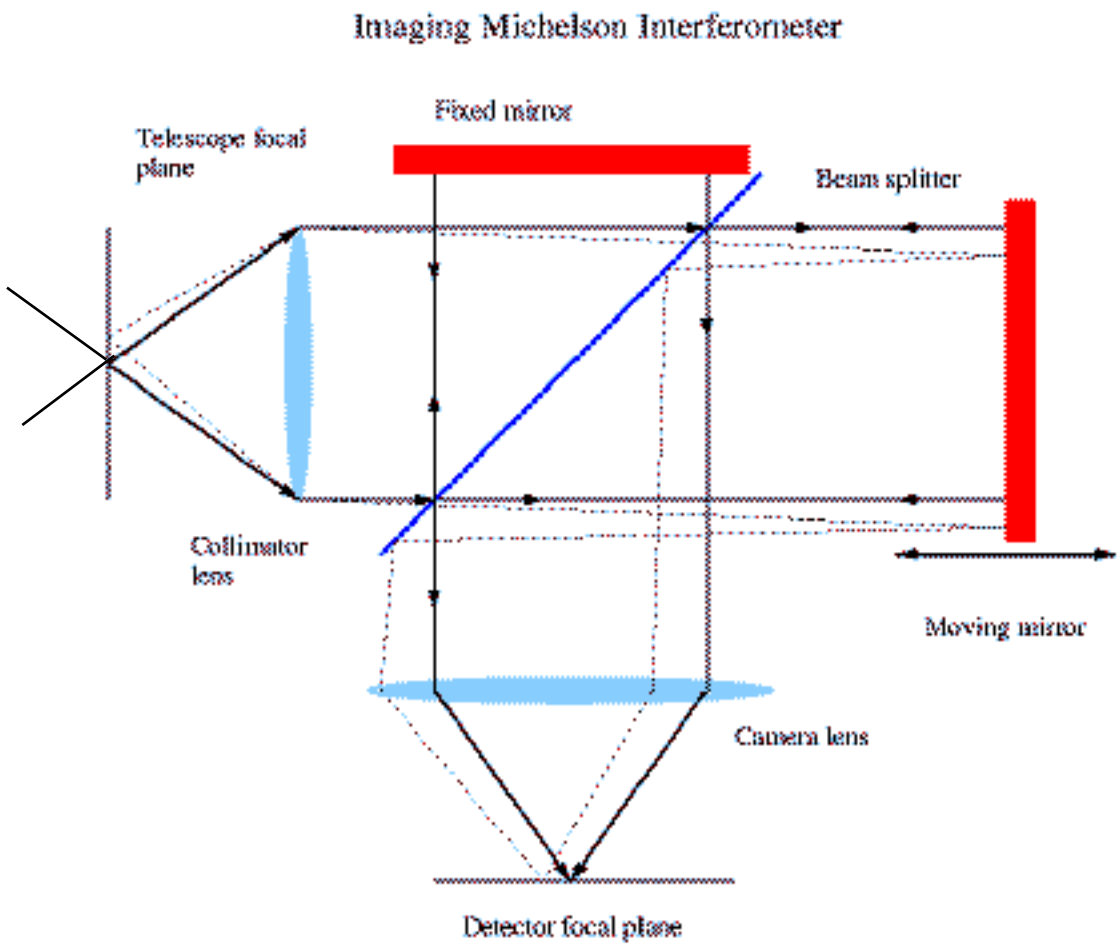
XMTR

The Challenge Problem:
Real-Time Continuous Hyperspectral Surveillance

- **Assumptions:**
  - **Fourier Transform Imaging Instrument**
  - **Datacube axes: X, Y, and F.T. of optical spectrum**
  - **New image cube collected every 3 seconds**

- **Real Time Processing Requirements:**
  - **Recover pixel spectra**
  - **Search for multiple spectral features of interest**
    - **(32 Maximum using matched filters)**
  - **Final output: Broadband and spectral feature images**
  - ***Extra Credit:* Image slice motion correction**
  - ***Extra Credit:* Pixel Clustering in real time**

Challenge Problem Data Source: Fourier Transform Imaging Spectrometer



Instrument Data Characteristics:

- Spatial Resolution: 128x128 pixels
- 14 Bits of data per pixel
- Mirror Positions: 4000+
- Number of mirror positions not necessarily a power of 2
- Mirror Scan Time over all locations: 3 seconds
- Each spatial image is collected before the mirror is moved again.
- Image Data cube of contains an *Interferogram* of the optical spectrum at each spatial pixel.
- The FOV of the instrument *may* move slightly between image collections. Such translations need to be removed, preferably at the sub-pixel level

Raw Data Rate: 67 Megasamples/second

Algorithm Overview

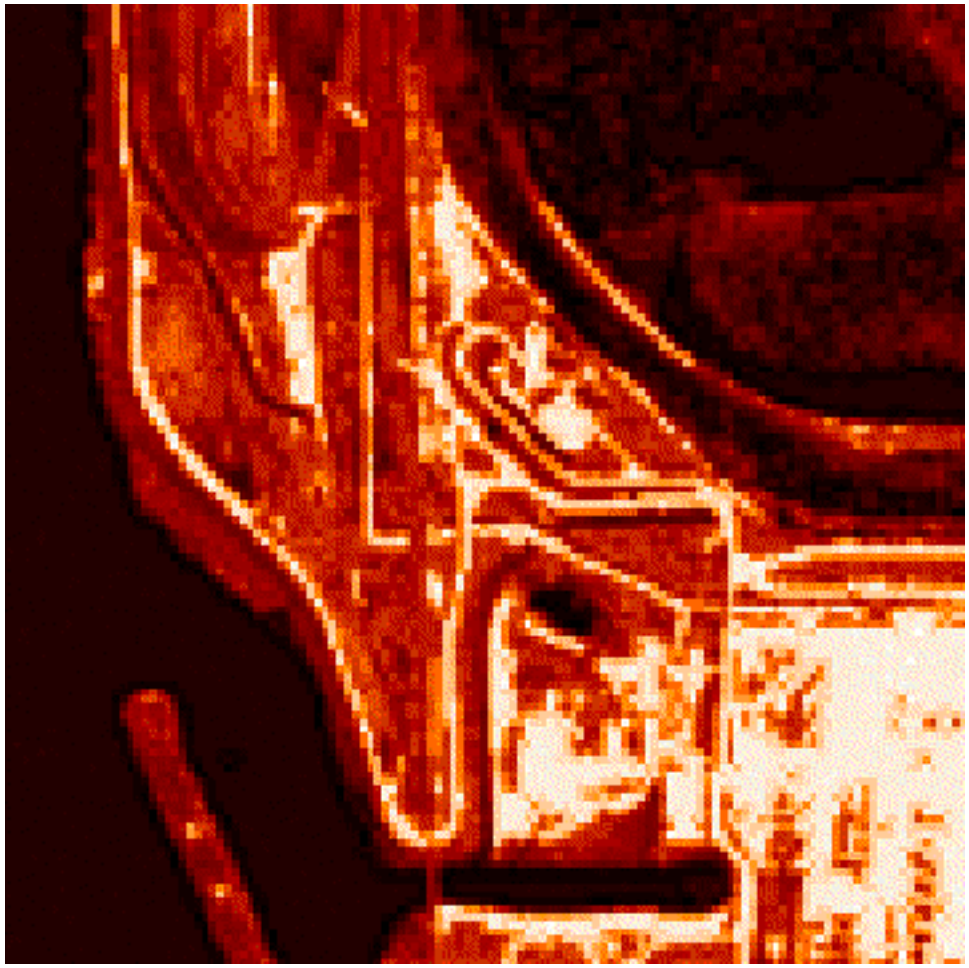
All of the following must be performed in less than 3 seconds:

- **Step 1A: Extra Credit: Register each image slice with the next**
- **Step 1: Perform a FT on each pixel's Interferogram**
    - **-> 1634 4096 pt FTs**
- **Step 2: Combine and average symmetric portions of transforms**
    - **Actual number of valid wavenumber bins is 251**
- **Step 3: Apply wavelength and pixel dependent gains and offsets**
    - **Calibration table supplied as part of the challenge problem**
- **Step 4: Sum the datacube in the wavenumber dimension and produce a broadband image**
- **Step 5: Compute the Covariance Matrix of the image background**
- **Step 6: Use the covariance matrix on 32 library spectral templates to produce 32 matched filters.**
- **Step 7: Produce 32 images by performing a spectral dot product of the matched filters on the datacube.**
- **Step 8: Extra Credit: Perform a "k-means" cluster assignment algorithm on the spectral datacube, classifying each pixel, and reporting the mean class vector for each cluster as well as an image with the assignments.**

NOTE: Steps 5+6 can be bypassed in a first implementation.

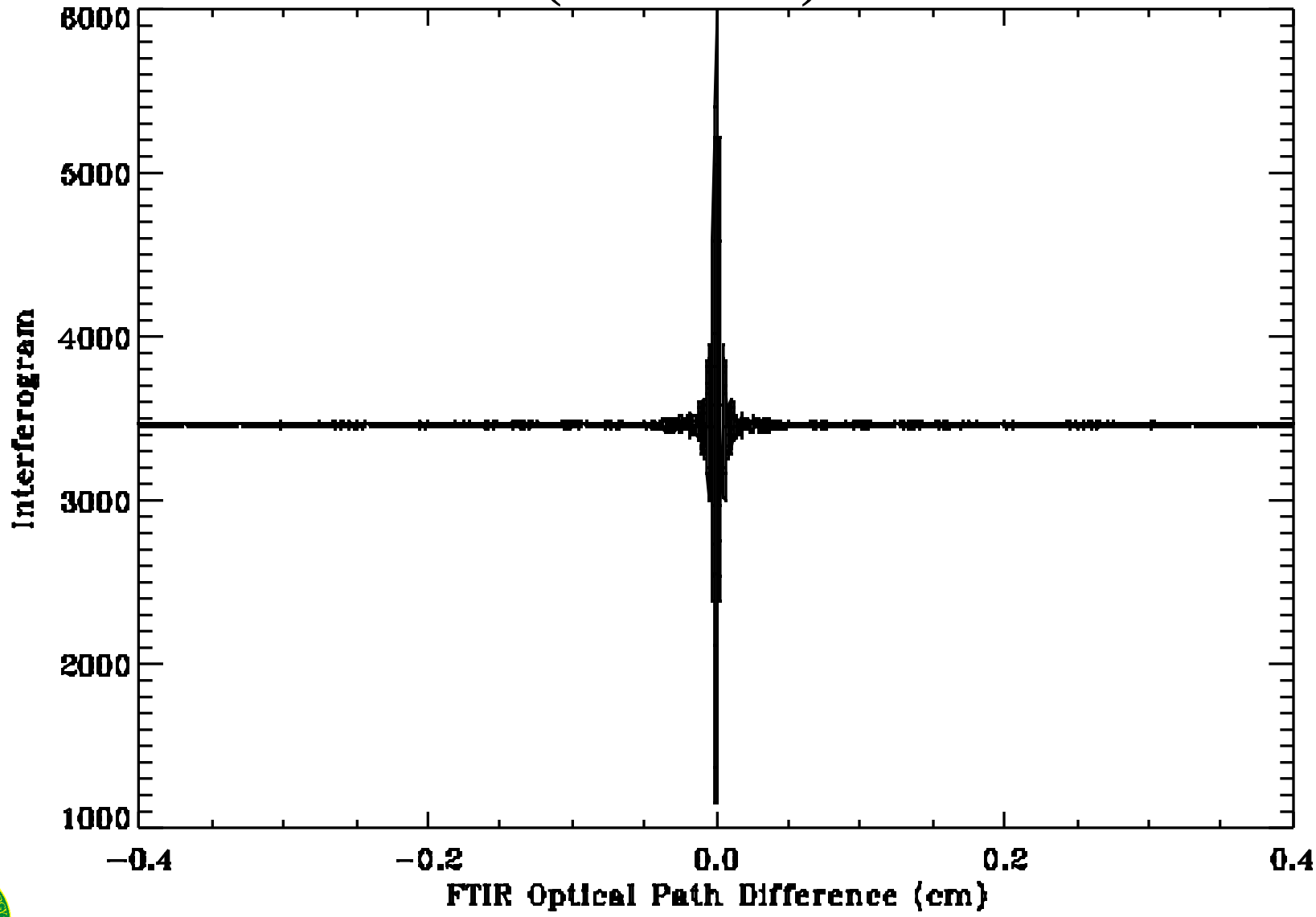
Broad Band Image

(All Spectral Channels Summed Together)

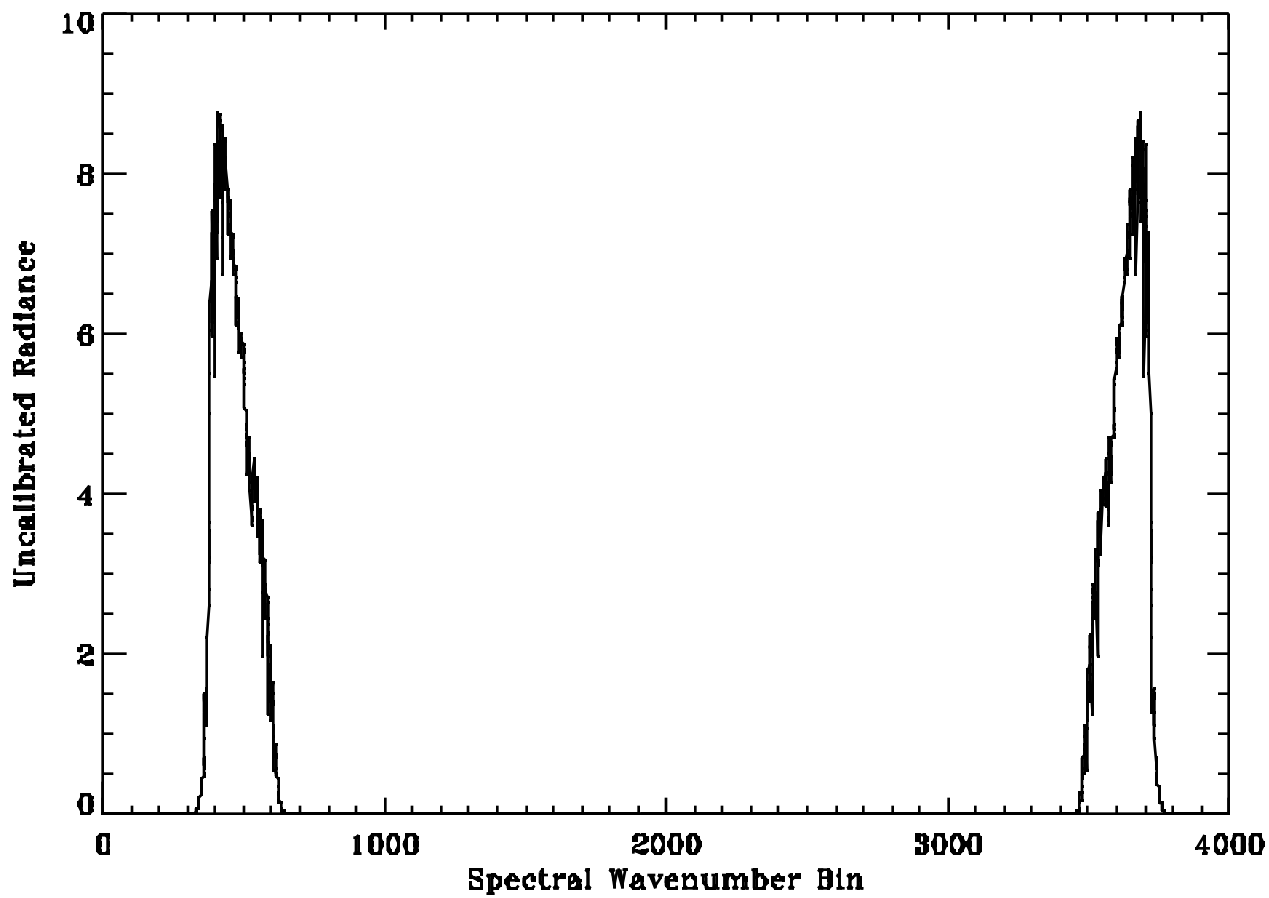


Raw Interferogram

(One Pixel)

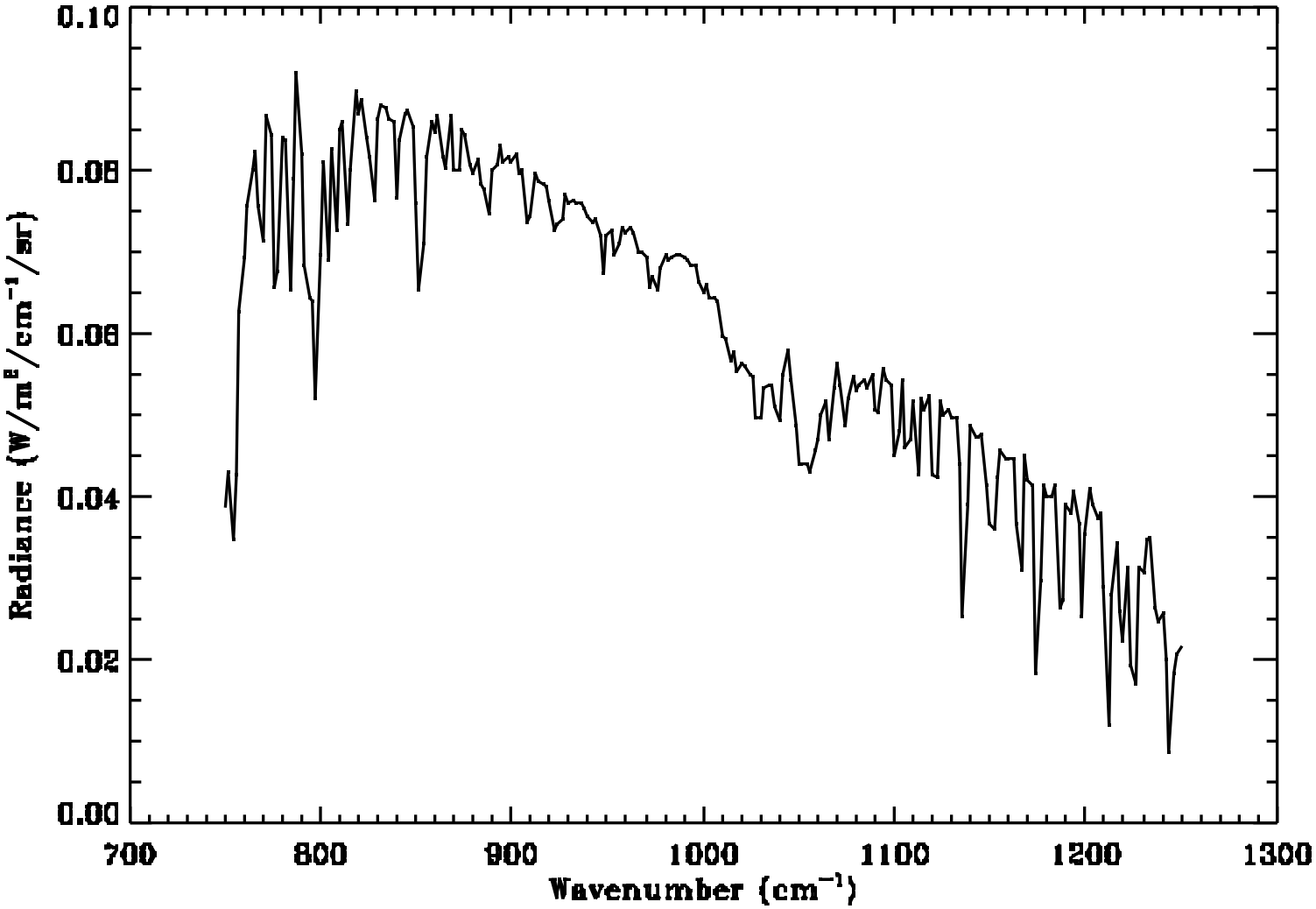


Fourier Transform of Interferogram



Final Calibrated Spectrum

(for one Pixel)



Spectral matched filter

- R = image cube
- b = spectral signature of plume
- $K = RR^T$ = covariance matrix; describes statistics of background clutter

- $q = b$ = ordinary matched filter
- $q = K^{-1} b$ = adaptive matched filter

- $q^T R$ = plume map

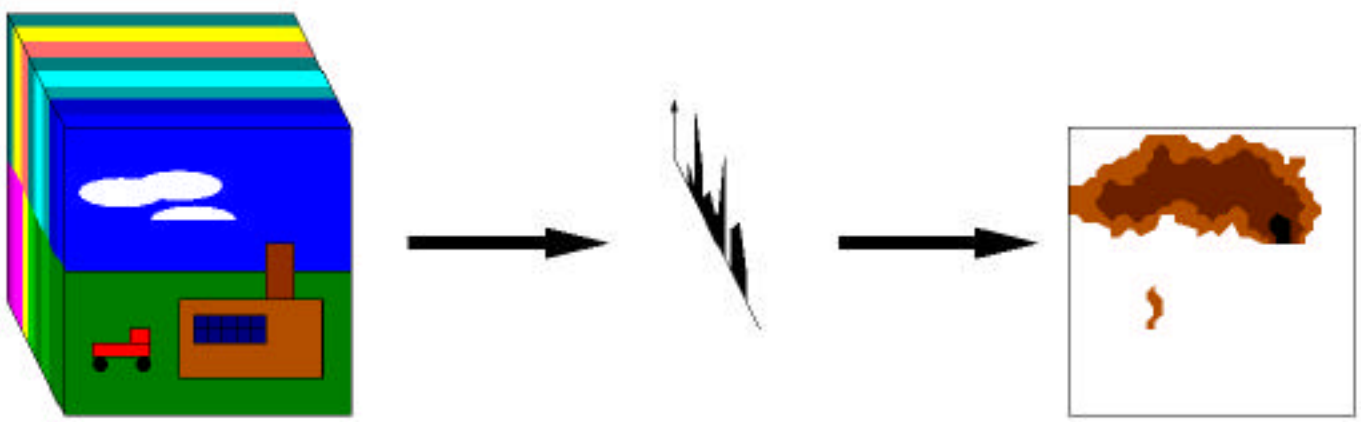
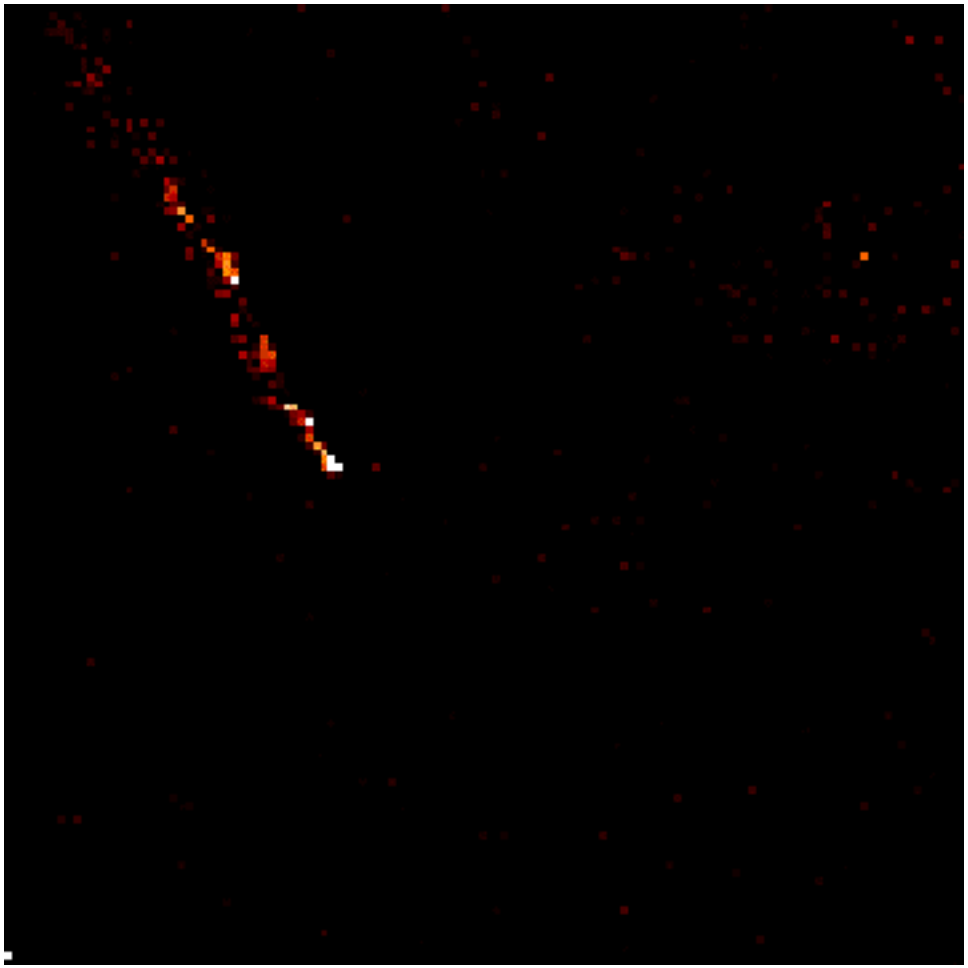


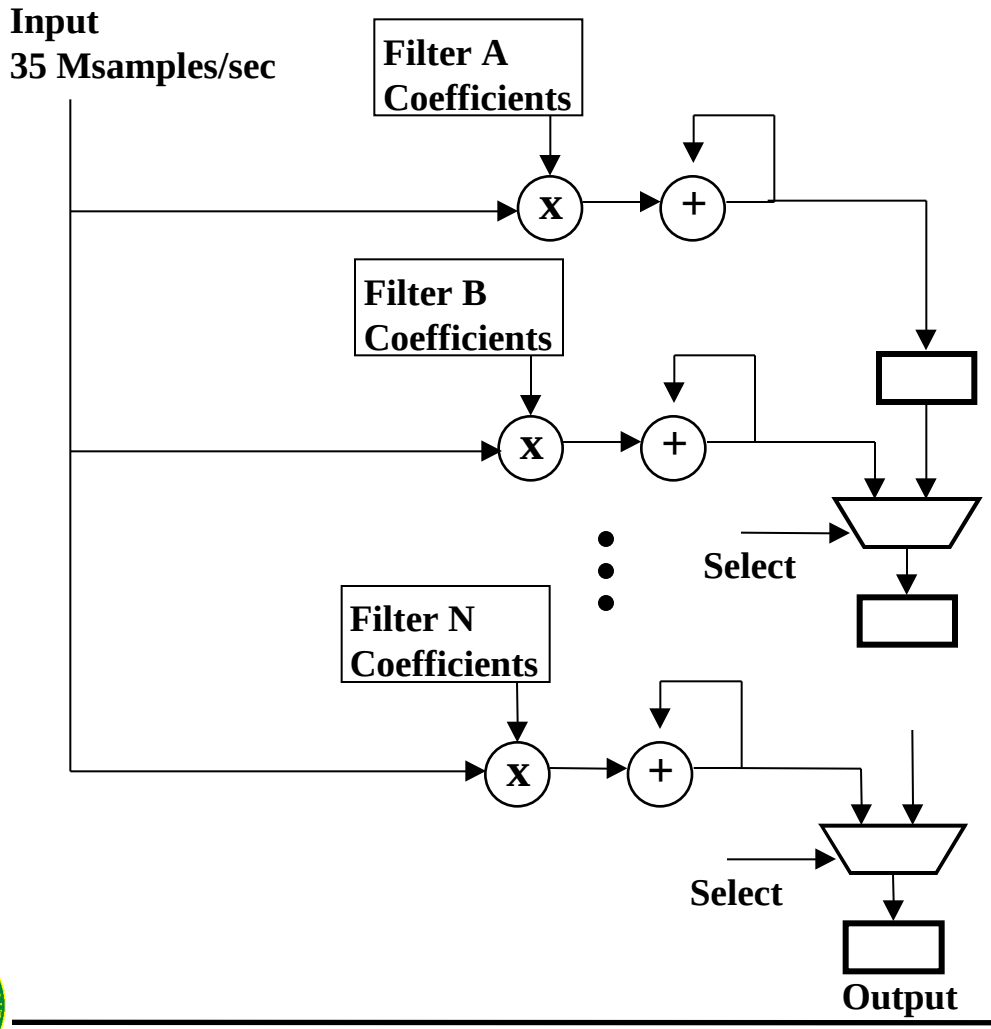
Image Cube → Matched filter → Plume map

Matched Filter Output

Effluent Plume Detected



Spectral Matched Filter on LANL Reconfigurable Computing Board



- **Current Hardware implementation *17x faster* than 400 MHz Intel PII for 12 filters.**
- **Fully populated Hardware implementation *45x faster* than 400 MHz Intel PII for 32 filters.**
- **More processing capacity available for additional operations (classification, thresholding, etc.) in parallel.**
- **Multiple boards can be ganged together, increasing processing while maintaining throughput.**

Challenge Problem on Web

Details of this hyperspectral ACS challenge problem, including the sample raw dataset, calibration constants, sample output, and algorithm descriptions will be available on the web in approximately 3 weeks.

Please send e-mail to:

jbloch@lanl.gov

and you will be notified when the web site is available.