

Development and Implementation of Software Systems for Imaging Spectroscopy



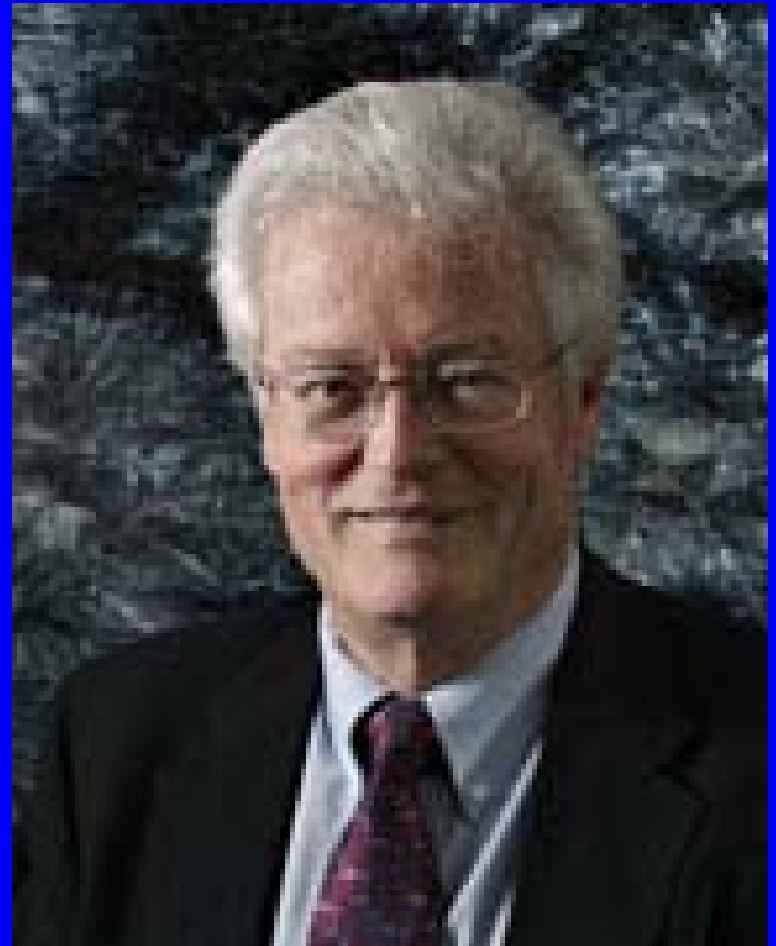
Joseph W. Boardman, AIG
Larry L. Biehl, Purdue
Roger N. Clark, USGS
Fred A. Kruse, HGI
Alan S. Mazer, JPL
James Torson, USGS (ret)
Karl Staenz, U. Lethbridge

Presentation Overview

- **A Few Comments Regarding the Honoree**
- **Development and Evolution of Software for Imaging Spectrometry**
- **Extremely Brief Reviews of Seven Key Historical and Present Day Systems**
- **Concluding Remarks**

Who is the REAL Alexander F. H. Goetz?

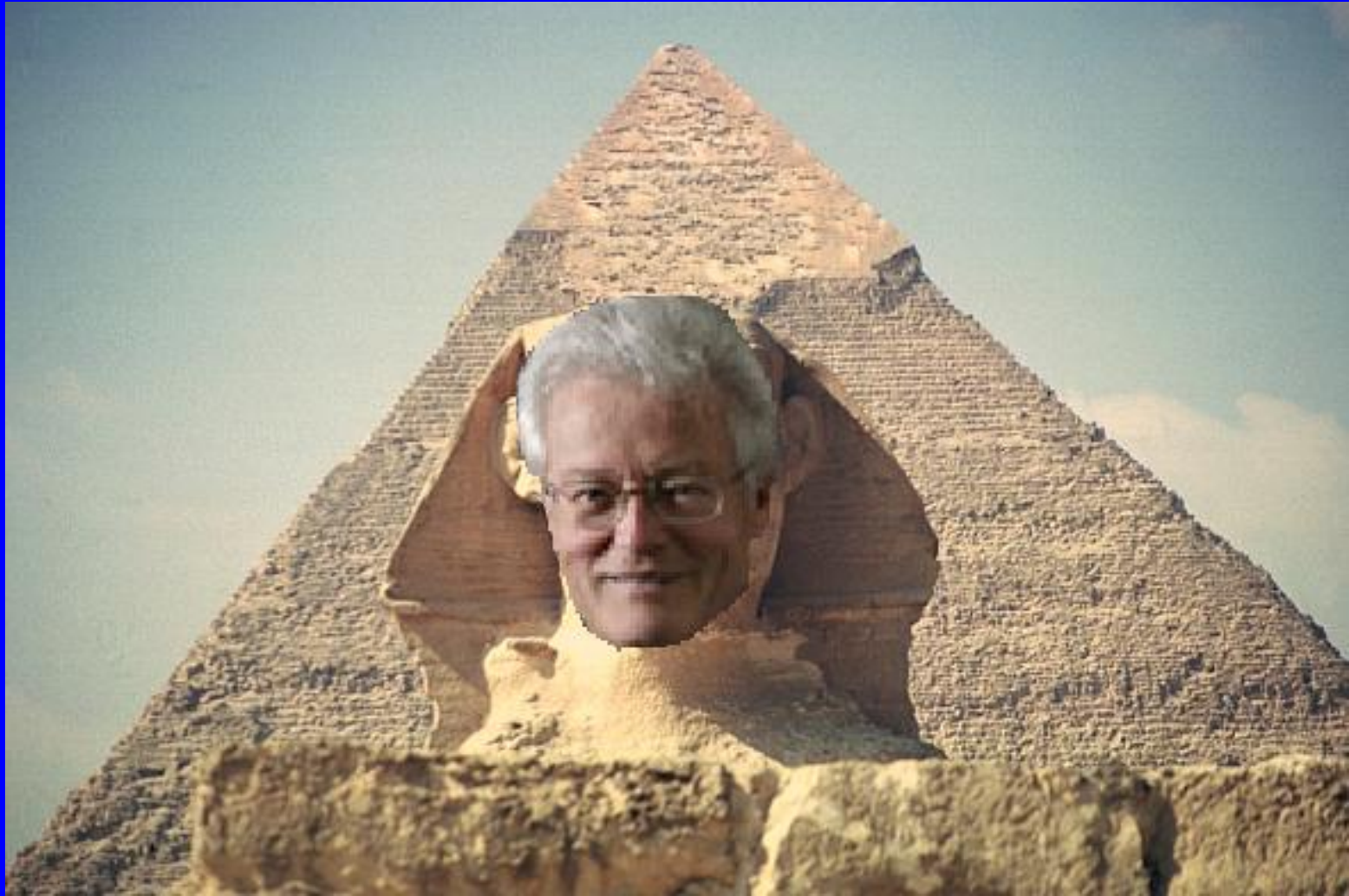
- Award-winning Scientist
- Business Founder
- Chairman of the Board
- Tenured Professor
- High-Tech Inventor
- Cal Tech Born and Bred
- genau und exakt
- Etc, etc, etc...
- But are there other, less well-known, personas?
- Perhaps...





And just for today,
can we all say
“spectrometry”
instead of
“spectroscopy”?

Alex the Pioneer of Imaging
Spectrometry.



*At times, Alex can seem a great and silent
mystery.*



I kid you not, he has a sister named Icy!



He could teach Newton a thing or two
about Opticks!



Captain Alex can sail circles around
Jack Sparrow.



Great son, great daughter -> great Daddy, great job!



A.F.H. Goetz
Did you know the
“F” stands for
Franklin?
As in “Ben”.

Ursus horribilis goeztus coloradoensis betterwatchoutii



Consensus characterization by new grad students and new employees.



Those of you who don't recognize this Alex, go spend more time with him and you certainly will.



Renaissance Man & More

Software for Imaging Spectrometry

- **Hyperspectral data truly demand specialized software to come to life, to be understood and to be useful**
- **Remarkable pioneer packages as well as remarkable advances in current systems**
- **Computer hardware revolution has made it possible, software has evolved along with hardware**
- **Imagers/data and software/algorithms have played leap-frog, with at least three iterations**
- **Currently the software/algorithm side needs to lift its game**

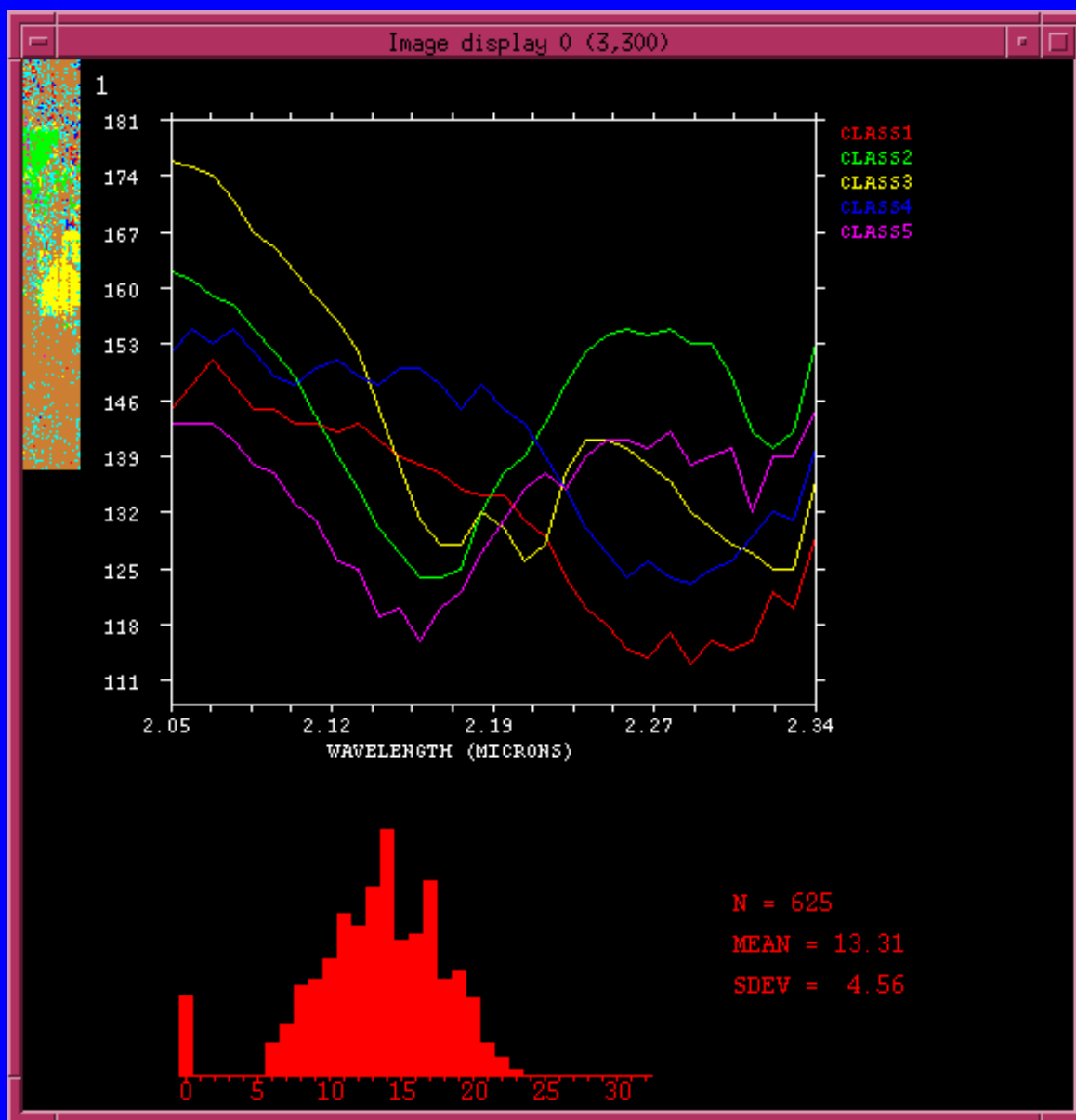
Decades of HSI Software Development

- SPAM by JPL
- ISIS/QL3 by USGS Flagstaff
- Tetracorder by USGS Denver
- SIPS by CSES/CU
- MULTISPEC by LARS/Purdue
- ENVI by BSC/AIG, RSI, Kodak, ITT
- ISDAS by CCRS
- And, of course, others...

SPAM (SPectral Analysis Manager) by JPL

- Developed in 1983
 - Designed for Airborne Imaging Spectrometer (8-bit data)
 - For 68000 Unix processor, with frame buffer and dot matrix printer (processor was slow)
 - Command-line interface
 - Rastertek frame buffer

SPAM by JPL



SPAM Binary Encoding

- Most algorithms built around “binary encoding”
 - Image spectra converted to bit streams, with each bit indicating whether corresponding DN value was above or below spectral mean
 - Approach was fast on 68000 processor and less sensitive to albedo variations than other encodings

SPAM Features

- Spectral matching
- Automatic clustering of image spectra
- Spectral identification using laboratory data
- Spectral “movies”
- Spectral filtering and arithmetic
- Linear mixture analysis
- User-defined spectral libraries

ISIS / Qlook /QL3 by USGS Flagstaff

- Integrated Software for Imagers and Spectrometers 2.0 started at USGS Flagstaff 1989, replacing prototype version 1.0
- Originally for NIMS on Galileo Jupiter mission
- VAX/VMS Fortran and C along with TAE
- Early implementation NASA Planetary Data System format
- Supports up to 6-d matrices and numerous “backplanes”

ISIS / Qlook /QL3 by USGS Flagstaff

- QL3 interactive display program in ISIS for I2S IVAS displays
- 1993 ISIS 2.1 ported to UNIX from VMS
- Currently an active program in the planetary community for a number of missions and applications
- ISIS 3.0 completely new implementation in C++, for now focused on geometric processing with plans for further development

ISIS / Qlook / QL3 by USGS Flagstaff

CV - Cube Visualization

File Display Functions Cursor Functions Help Quit All Displays

#1 pg-PR1A0000-2000121101_005_007

Front View V Band 2

Cursor D S.L,B,W,DN:	2104	1867	2	2,0000	39,0000
Cursor V S.L,B:	2104	1867	2		
Slice D S.L,B,W,DN:	2227	2100	2	2,0000	34,0000
Slice V S.L,B:	2227	2100	2		

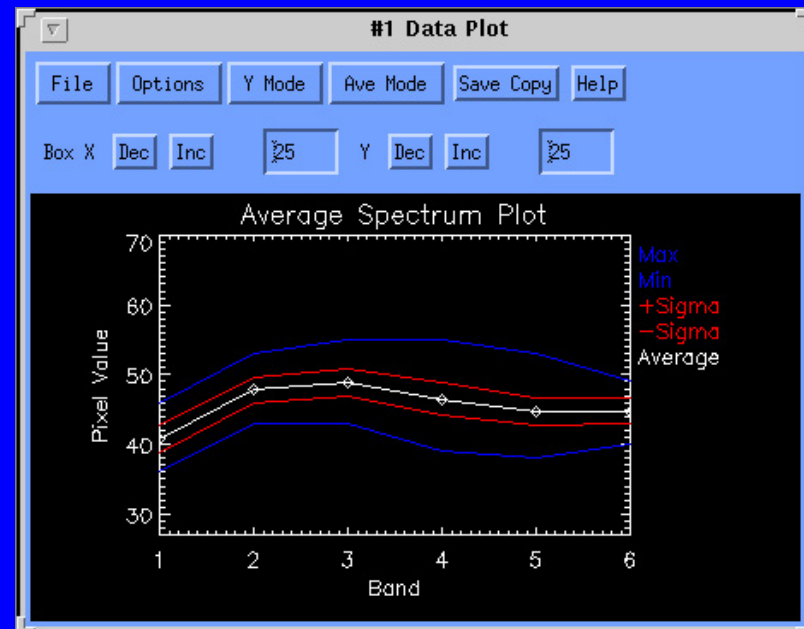
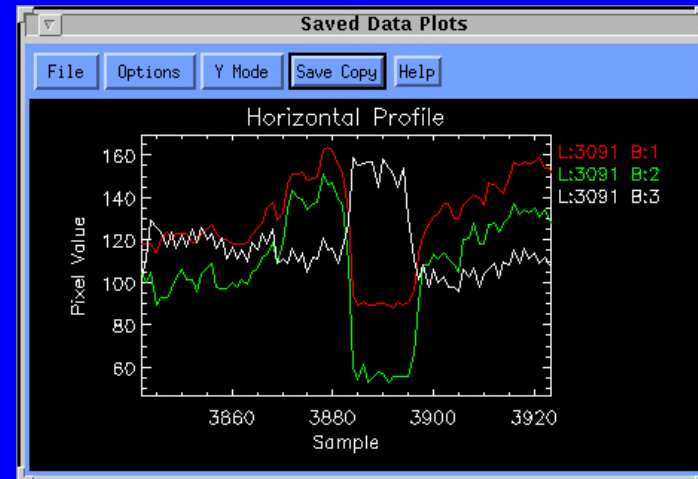
Slice Profile Slice +/-

Drag: Slider Zoom Box



#1 Subsampled

#1 Zoom



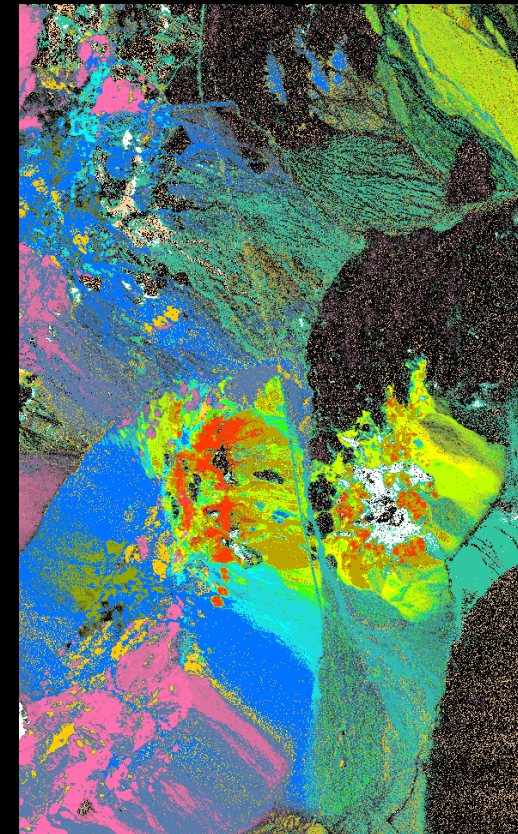
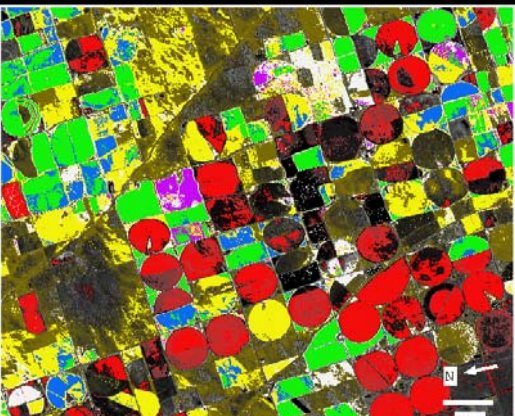
Introduction to Imaging Spectroscopy and Lunar Mapping with Tetracorder

Roger N. Clark

U.S. Geological Survey
Box 25046 Federal Center
Denver, CO 80225

<http://speclab.cr.usgs.gov>

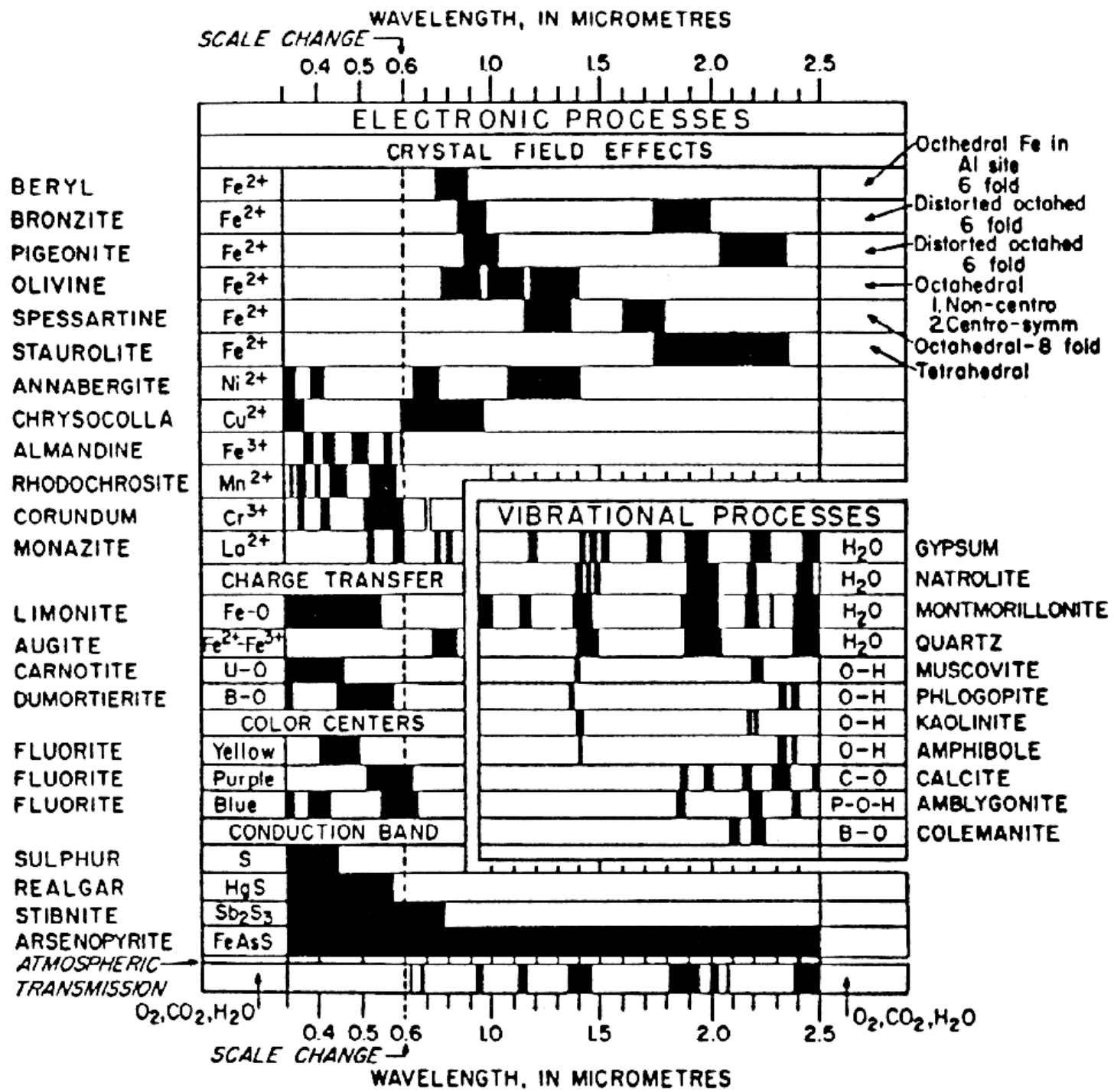
May, 2006



The Challenge of mapping minerals on any moon or planet with imaging spectroscopy is detection and discrimination of diagnostic spectral features from thousands of possibilities

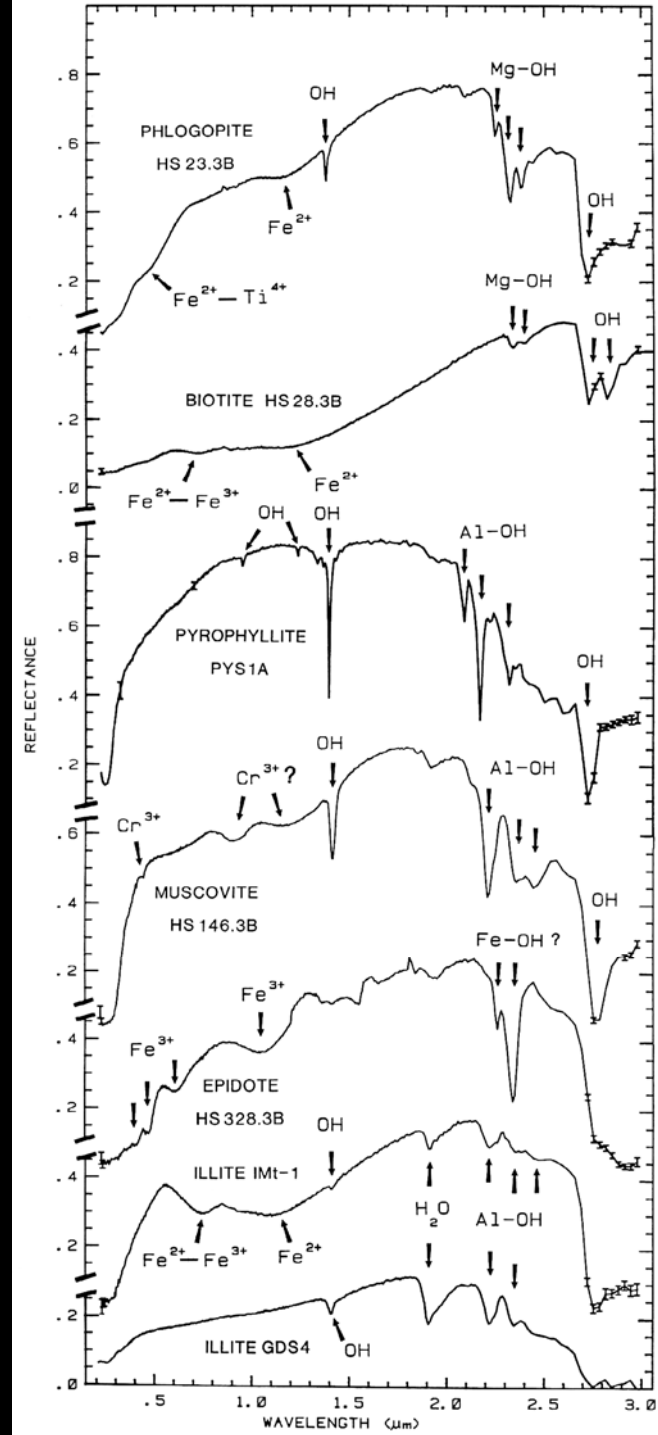
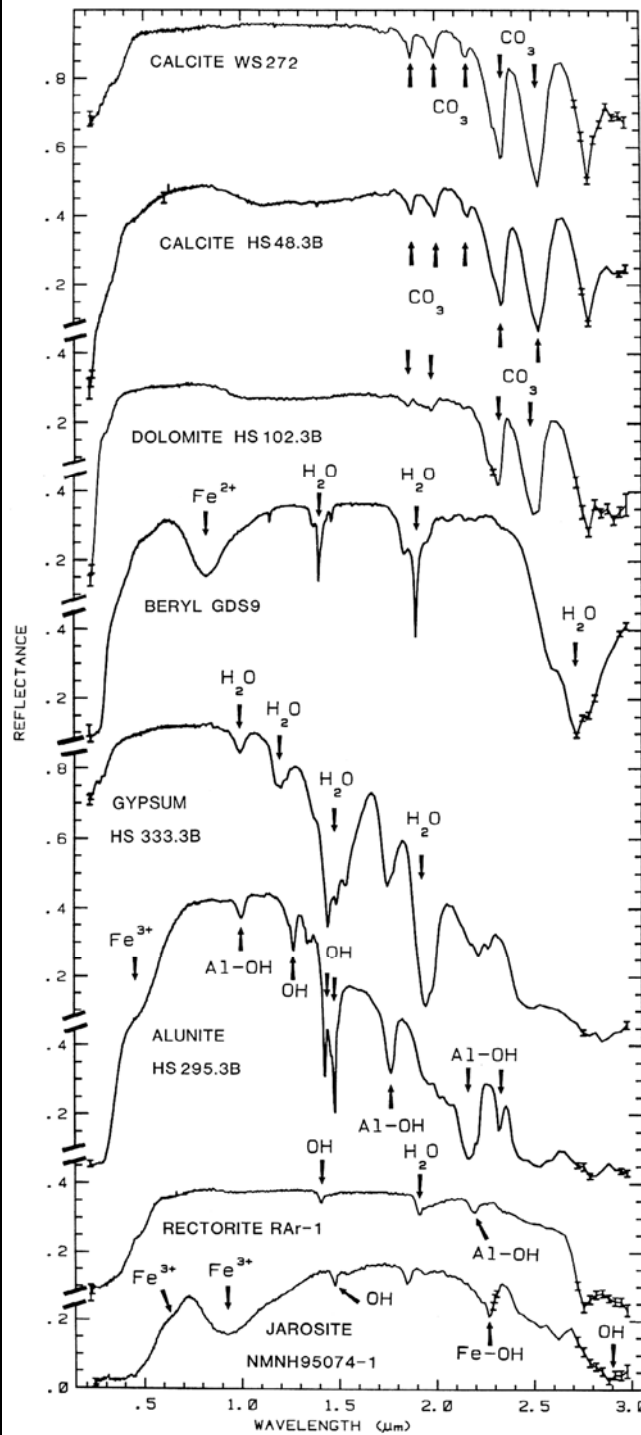
- **We will use the Tetracorder system described in Clark *et al.*, *JGR*, v.108, p5-1, 2003, plus refinements.**
- **Tetracorder is an expert system where multiple algorithms are applied to analyze a spectrum.**
- **The results of those algorithms can be tested and are compared, and identifications made.**

The variety of absorption processes and their wavelength dependence allows us to derive information about the chemistry of a mineral (or material) from its reflected or emitted light.

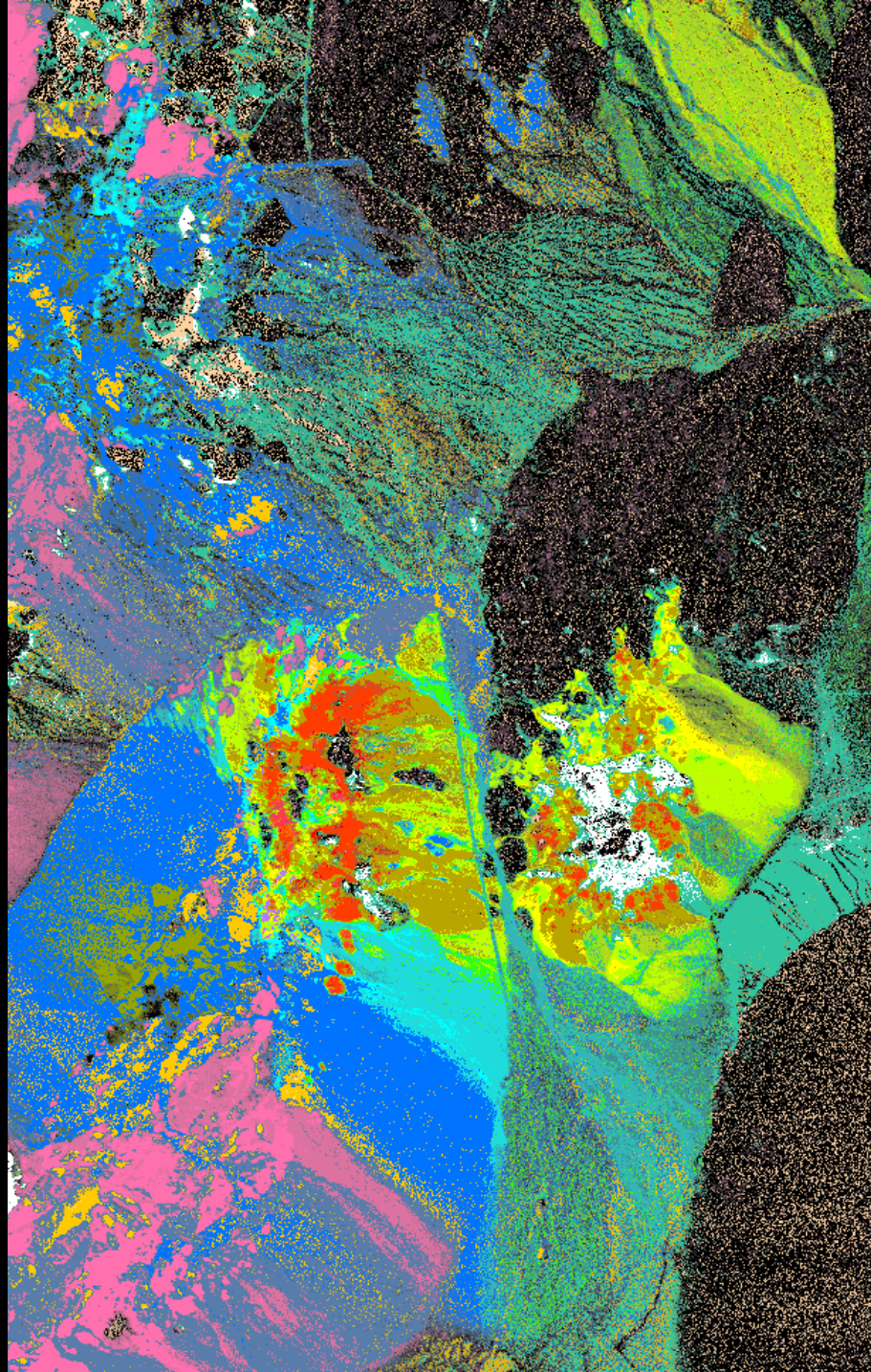


The spectrum of each material produces a “fingerprint” which allows it to be Identified.

Tetracorder identifies multiple materials, including effects of mixtures, grain size, and coatings.



Example Tetracorder results



Cuprite, Nevada

AVIRIS 1995 Data

USGS

Clark & Swayze

Tetracorder 3.3 product

Sulfates

- K-Alunite 150c
- K-Alunite 250c
- K-Alunite 450c
- Na82-Alunite 100c
- Na40-Alunite 400c
- Jarosite
- Alunite+Kaolinite
and/or Muscovite

Kaolinite group clays

- Kaolinite, wxl
- Kaolinite, pxl
- Kaolinite+smectite
or muscovite

Halloysite

Dickite

Carbonates

- Calcite
- Calcite +Kaolinite
- Calcite +
montmorillonite

Clays

- Na-Montmorillonite
- Nontronite (Fe clay)

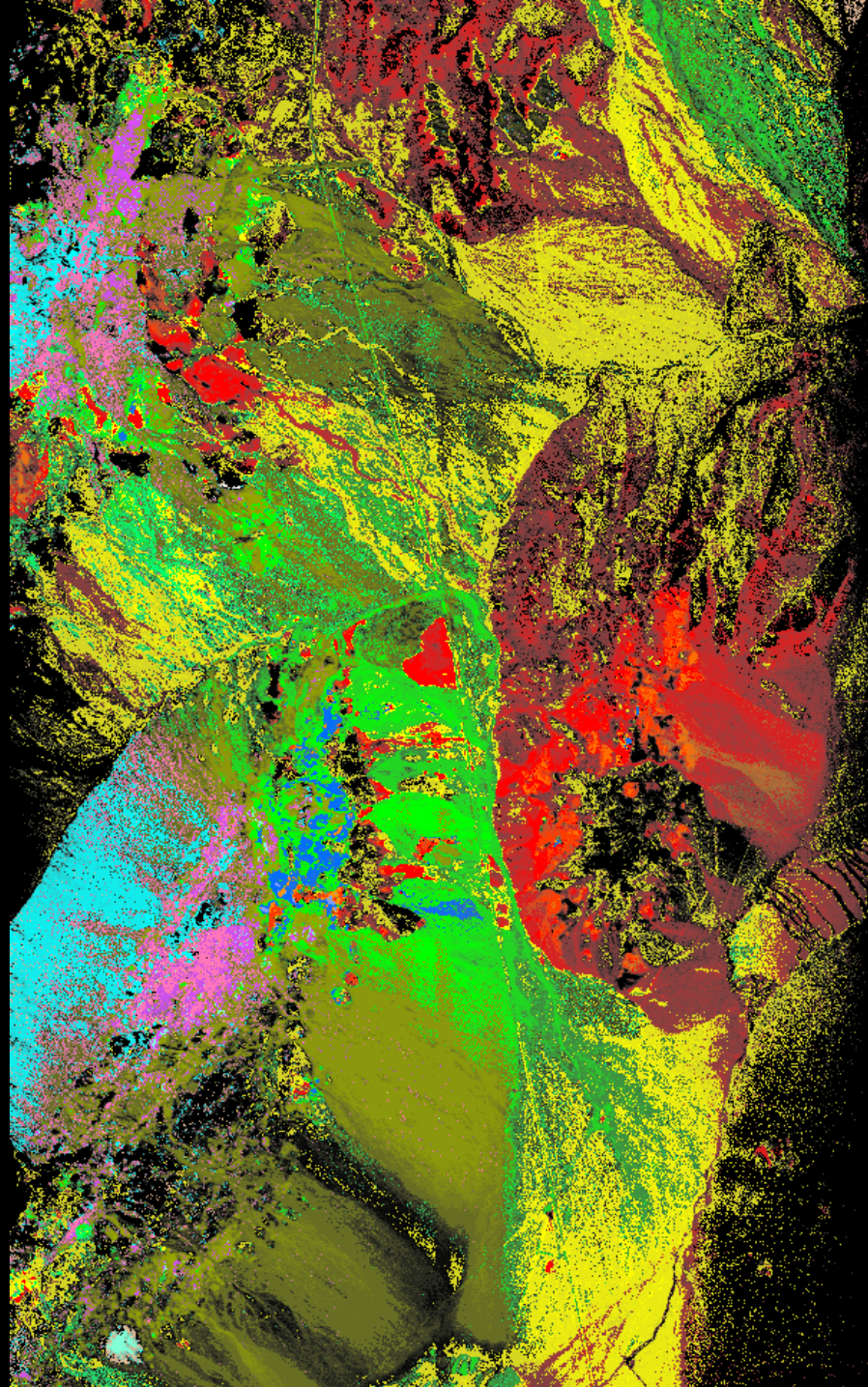
other minerals

- low-Al muscovite
- med-Al muscovite
- high-Al muscovite
- Chlorite+Musc, Mont
- Chlorite
- Buddingtonite
- Chalcedony: OH Qtz
- Pyrophyllite +Alunite

2 km






Example Tetracorder results





Cuprite, Nevada
AVIRIS 1995 Data
USGS
Clark & Swayze
Tetracorder 3.3 product


Iron Oxides

-  nanocrystalline Hematite
-  Fine-grained to medium-grained Hematite
-  Large-grained hematite





Iron Hydroxide

-  Goethite
-  amorphous and other iron oxides, hydroxides

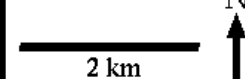
Iron Sulfate

-  Jarosite

Fe²⁺-minerals

-  Fe²⁺-bearing minerals + Hematite
-  Fe²⁺-bearing minerals
-  Fe²⁺-bearing minerals: broad absorptions
- 

Note Fe²⁺-bearing minerals are mainly muscovites and chlorites



Conclusions

- Tetracorder runs at a rate of ~1,000 spectral features per MFLOP meaning hundreds of minerals can be searched for in lunar M3 data.
- The USGS Spectroscopy Lab has 1.6 tera-FLOPs available, enabling extensive analysis of M3 data.
- Reference reflectance spectral libraries are mature for the search for lunar volatiles.
- Tetracorder mapping will include detection and mapping of organics, water and OH-bearing minerals, hundreds of other minerals, and temperature anomalies.



**More information at:
<http://speclab.cr.usgs.gov>**



SIPS by CSES/CU

- “Processing imaging spectrometry data will be like drinking from a firehose”, AFHG c. 1988.
- So we started with “SIPS” in 1990 at CSES
- Builds on previous work, especially ISIS and SPAM as well as Fred Kruse’s experience at USGS
- NASA funded as a tool for viewing and processing AVIRIS data, written in IDL
- Distributed under MOU free of charge from CSES to over 200 sites
- Later became basis of HYDICE Starter kit for DoD community program

SIPS by CSES/CU

- SIPS Utilities: tape reading, disk-to-disk processing, data formatting, correction to apparent reflectance and data formatting
- SIPS View: interactive viewing and analysis, RGB bands, spectral slices, individual spectra, polygon average spectral, comparison to spectral libraries
- SIPS Analysis: full-cube processing for mineral mapping, binary encoding, Spectral Angle Mapper (SAM) and linear spectral unmixing
- Eventually no further support could be garnered for SIPS development from NASA, despite Fred's and Alex's best efforts

SIPS by CSES/CU

SIPS - Spectral Image Processing System: Copyright 1991, CSES/CIRES, Univ. of Colorado

The interface displays a satellite image of a mountain range. A zoomed-in view of a specific area is shown in the top right, with a green line indicating a profile. Below the main image is a 'POLYGON EXTRACTION' panel with buttons for 'DISPLAY MEANS', 'REDRAW', and 'CLEAR ALL'. It lists five classes with their respective point counts and 'SAVE' buttons:


- CLASS 1 NPTS = 171
- CLASS 2 NPTS = 140
- CLASS 3 NPTS = 131
- CLASS 4 NPTS = 36
- CLASS 5 NPTS = 77

To the right of the polygon extraction is a 'Polygon Means' graph showing Reflectance vs. Wavelength (0.5 to 2.0). Below this is a 'Save Polygon - CLASS 2' dialog box with a list of coordinates and a 'Select Save Option:' menu. A 'Filename Entry' dialog box is also present, asking for a filename.

On the right side, there are two 'Vertical Profile' windows showing spectral data across different wavelengths. Below them is an 'Arbitrary Profile' window. At the bottom right, there is a 'CURRENT MODE : Main Function Selection' and 'ACTIVE WINDOW : None' status bar.

SIPS by CSES/CU

Spectral Angle Mapper Viewer



The interface displays a grayscale image of a landscape on the left. The right side contains a control panel with the following elements:

- Current Endmember: DOLOMITE
- Slider for value 205
- Low Threshold
- Slider for value 331
- High Threshold
- List of endmembers: DOLOMITE, CALCITE, SERICITE
- Buttons: Slider Lock On, Save Image To File, Close
- Path: /mica/data/ngm89/*.sam
- Selected file: /mica/data/ngm89/ngm89_tst.sam

MultiSpec: A Tool for Multispectral-Hyperspectral Image Data Analysis

- Background: Origin in LARSYS (Purdue University)
- Purpose:
 - Technology Transfer (Provide ability for other researchers to try new techniques without having to program the algorithms)
 - Teaching (Use in remote sensing courses; significant use now in K-12)
 - Research (Grad students use in research)
- Platforms: Macintosh and Windows
- Software type: Freeware

Sample MultiSpec Window (Windows Version)

Application Menu

Text Output Window

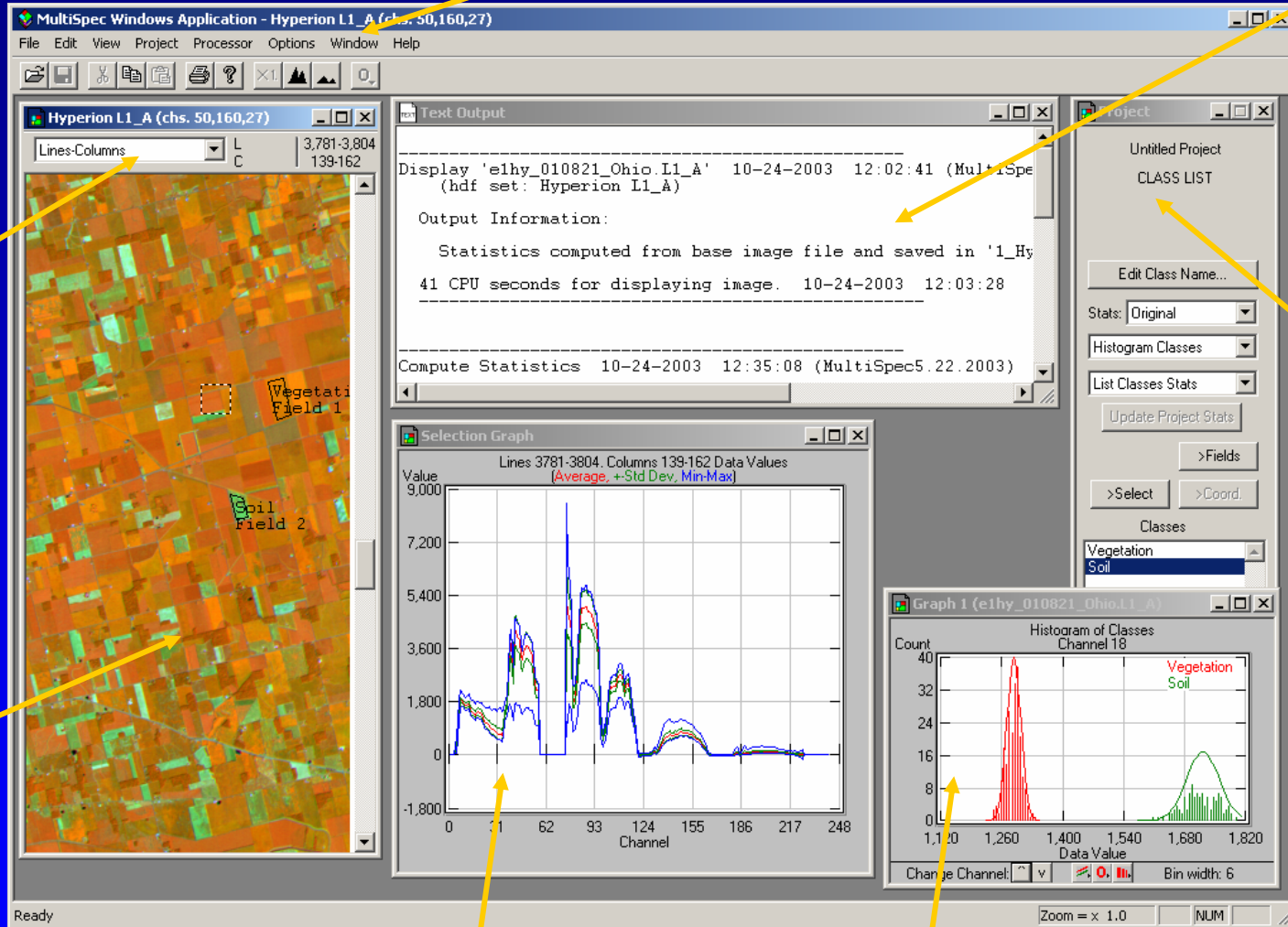
Project Window

Coordinate View

Image Window

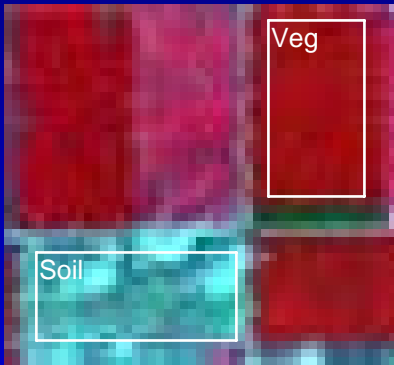
Graph Window

Histogram Plot



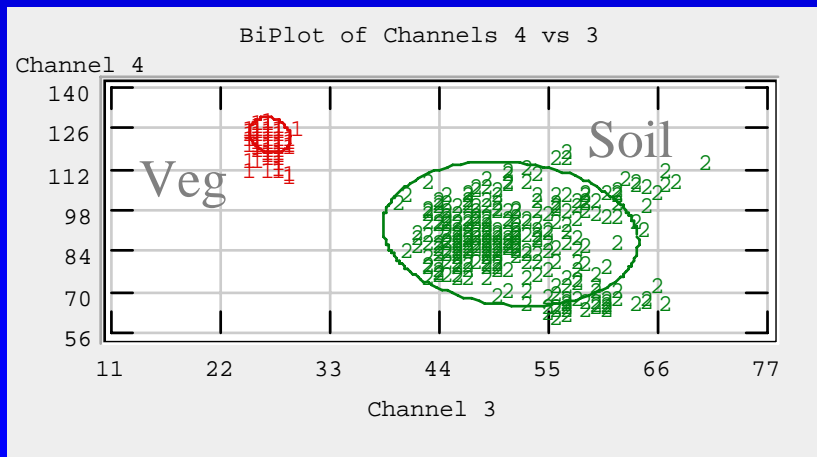
Comparison of Classes

Image Space



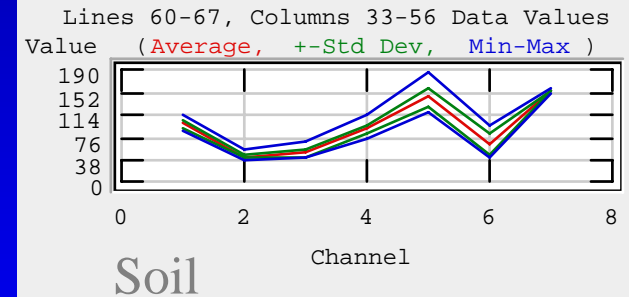
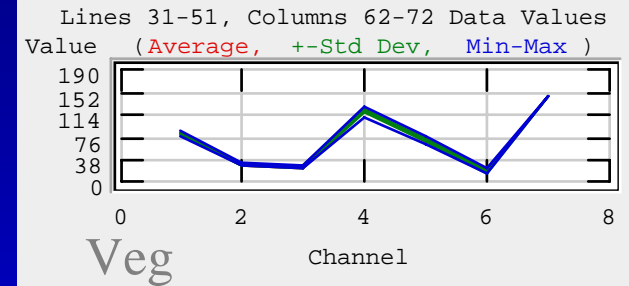
Geographic Orientation

Feature Space



For Use in Pattern Analysis

Spectral Space



Relate to Physical Basis for Response

Access to MultiSpec

- <http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/>
- Documentation & Tutorials available on web site

Acknowledgements

- Funding for the research leading to the development of MultiSpec was provided by NASA
- The Globe Program provided the support for the initial Windows versions of MultiSpec

ENVI by BSC/AIG, RSI, Kodak and ITT

- ENVI never would have happened without Alex
- Each BSC/AIG partner was either a student or employee of CSES at one time or another
- 1993 programming begun in IDL by BSC/AIG partners
- 1994 first version for sale through RSI under license
- 2000 Eastman Kodak buys ENVI from BSC and RSI from David Stern, consolidating the product
- 2004 ITT buys Kodak Commercial and Gov't Systems
- 2006 RSI becomes ITTVIS

ENVI by BSC/AIG, RSI, Kodak and ITT

Jim Young, Adam Lefkoff, Kathy Kierein Young,
Joe Boardman and Fred Kruse



ENVI by BSC/AIG, RSI, Kodak and ITT

- ENVI developed to serve AIG R&D needs and that of our science colleagues
- Focused on two aspects:
 - Innovative hyperspectral algorithms (ours and others): MNF; PPI; scatterplots; linked spectral, spatial, scatter views; n-d Visualizer; Mixture Tuned Matched Filter etc.
 - Easy-to-use intuitive Graphical User Interface
- Now branching out to be more than an HSI tool

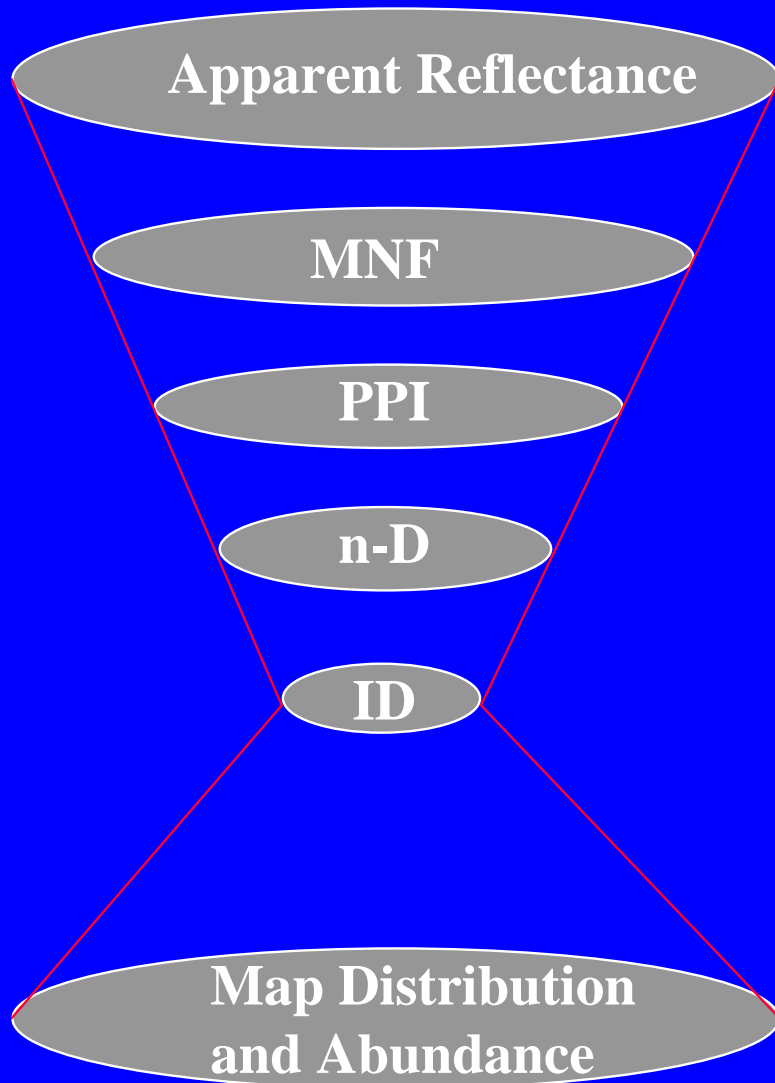
ENVI by BSC/AIG, RSI, Kodak and ITT

The screenshot displays the ENVI 4.2 software interface with several windows open:

- #1 (R:Band 189,G:Band 193,B:Band 208):eff_...:** A false-color satellite image of a landscape with a red rectangular region of interest.
- #1 Spectral Profile:eff_masked:** A line graph showing 'Value' (150-350) vs 'Wavelength' (2.0-2.4). A vertical red line is at approximately 2.15.
- #2 PPI (mnf_masked):ppi_masked:** A dark image showing the results of Principal Component Analysis (PCA).
- #3 MF Score (n_D Class #1 [Red1] [8 points]):b...:** A dark image showing the results of Maximum Likelihood Classification.
- #1 Zoom [4x]:** A zoomed-in view of the region of interest from the first window.
- #1 Scatter Plot:** A scatter plot of 'MNf Band 2 (eff_masked):mnf_masked' vs 'MNf Band 1 (eff_masked):mnf_masked'.
- #3 Band-MF Score (n_D Class #1 [Red1] [8 points]):budmfmf:** A window for applying a stretch, showing 'Input Histogram' and 'Output Histogram'.
- #3 Zoom [4x]:** A zoomed-in view of the MF Score image.
- n-D Visualizer:** A window showing 'n-D Selected Bands' (a table of 50 bands) and a scatter plot of the selected bands.
- n-D Controls:** A control panel for the n-D Visualizer with 'Speed' set to 50 and 'View' set to 21/31.
- #3 Scatter Plot:** A scatter plot of 'Infeasibility (n_D Class #1 [Red1] [8 points]):budmfmf' vs 'MF Score (n_D Class #1 [Red1] [8 points]):budmfmf'.
- Scatter Plot Mean: eff_masked:** A line graph showing 'Value (Offset for clarity)' vs 'Wavelength' (2.0-2.4) with multiple colored lines.
- Available Bands List:** A list of available bands including 'budmfmf1', 'MF Score (n_D Class #1 [Red1] [8 points])', 'Infeasibility (n_D Class #1 [Red1] [8 points])', 'ppi_masked', 'PPI (mnf_masked)', 'mnf_masked', and 'MNf Band 1 (eff_masked)' through 'MNf Band 5 (eff_masked)'. It also shows 'Selected Band' as 'MF Score (n_D Class #1 [Red1] [8 points]):b' and 'Dims' as '400 x 350 [Floating Point] [BSQ]'.

The Windows taskbar at the bottom shows the Start button, taskbar icons for Calculator, Eudora, Windows Task Manager, Boardman_HSI_Soft..., tetracorder-mapping..., and 15 IDL. The system tray shows the time as 12:41 AM.

ENVI by BSC/AIG, RSI, Kodak and ITT



- Empirical Methods
- Model-based Methods

- MNF transform
 - Minimum Noise Fraction
- Pixel Purity Index

- n-D Visualizer

- Spectral Analyst

- Classification and subpixel classification
 - SAM, linear spectral unmixing, matched filtering, and MTMF

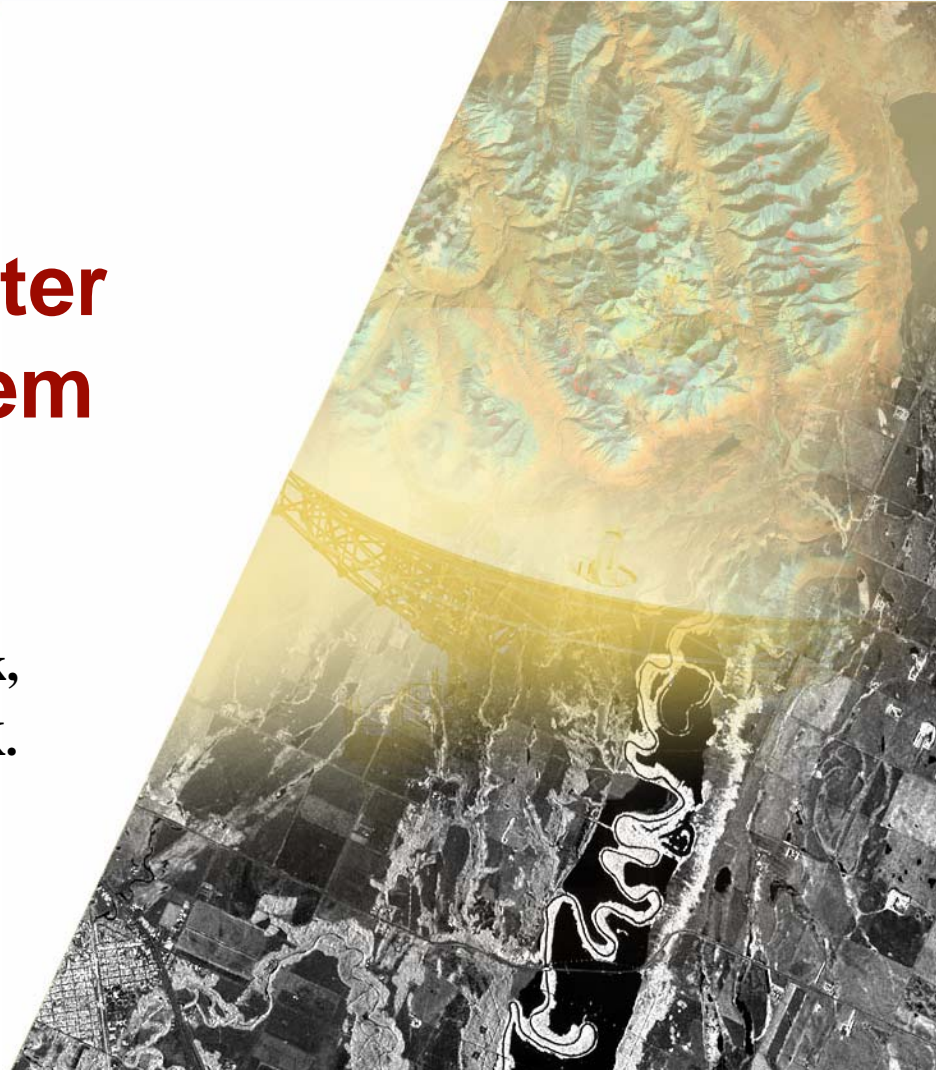


ISDAS

Imaging Spectrometer Data Analysis System

K. Staenz

**A. Abuelgasim, P. Budkewitsch, R. Hitchcock,
R.A. Neville, R. Soffer, J. Schwarz, L. Sun, K.
Omari, H.P. White**



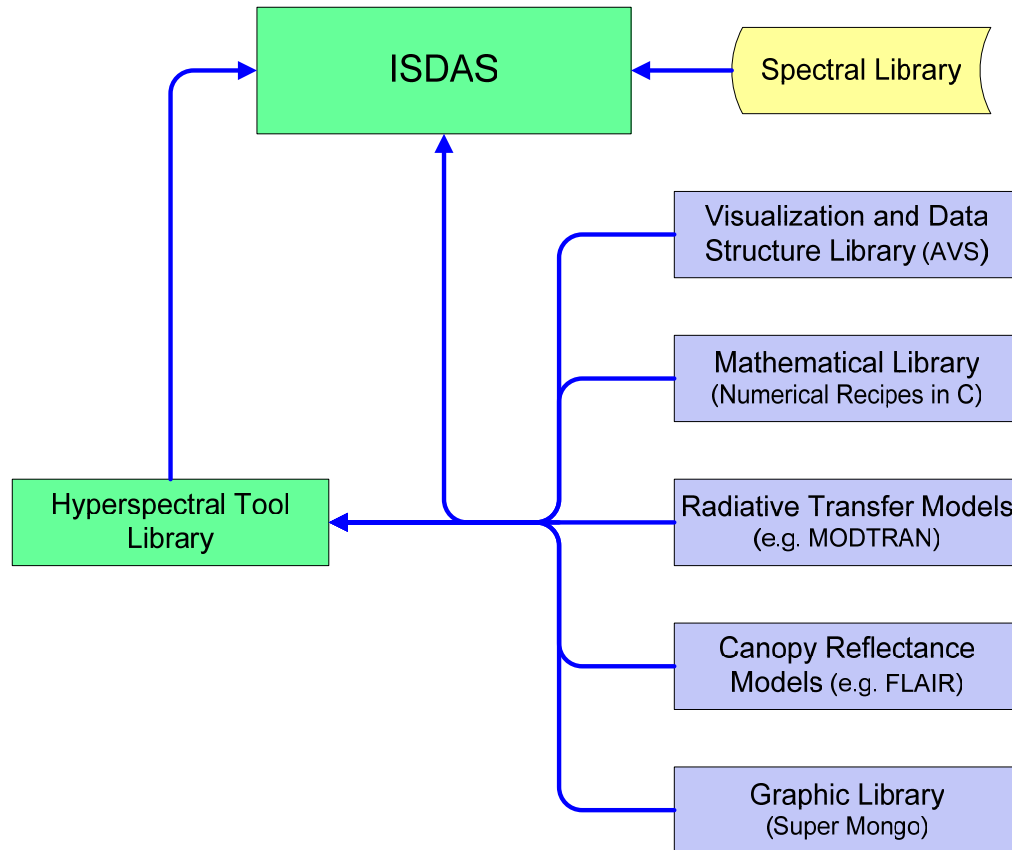


ISDAS - Overview

- **R&D platform for hyperspectral tools development and analysis**
 - rapid prototyping of algorithms and products
 - modular framework for easy addition of new tools
 - processing of data from any hyperspectral imager
- **Runs in Red Hat Linux (PC) environment**
- **Built on the Application Visual System (AVS), a commercial graphics programming and s/w product platform**
- **Tools are coded in C, C++, and Fortran**
- **Incorporates about 60 major tools (e.g., spectral unmixing)**
 - Data handling (e.g., data input/output, format conversion)
 - 1D, 2D and 3D visualization of data
 - Data preprocessing (e.g., calibration, atm. and BRDF correction)
 - Evaluation of the performance of future sensors
 - Qualitative and quantitative information extraction



ISDAS – Software Architecture





ISDAS – Typical Interface

The screenshot displays the ISDAS software interface, which is used for processing satellite data. The main window shows a workflow diagram with the following components:

- Data Input**: The starting point of the workflow.
- Auto Destriper**: A tool used for removing striping artifacts from the data.
- Atm Corr Tool**: A tool for atmospheric correction.
- Smile Corrector**: A tool for correcting smile artifacts.
- 2D Tool**: A tool for 2D processing, which is currently active and showing a topographic map of a region.
- 1D Tool**: A tool for 1D processing, which is currently active and showing a line graph of data values.

The interface also includes several tool panels and configuration options:

- AVS Network Editor**: A panel for editing the workflow network.
- AVS Module Library**: A library of modules including Data Input, Filters, Mappers, and Data Output.
- Filters**: A panel with various filter options like Atm Corr Tool, Auto Destriper, Average Smooth, BRDF Correction, Dark Subtract, Database Tool, Est chloro (RARS), and Fast Atm Corr.
- Mappers**: A panel with options like Masking Tool, Sensor Analyser, and Smile Corrector.
- Data Output**: A panel with options like 1D Plot, 1D Tool, 2D Tool, and 2D Plot.
- Atm Corr Tool**: A panel with options like Atm Create Raw LUT, Atm Convolve LUT, Atm Transform Spectrum, Atm Transform Cube, and link tool.
- Atmosphere**: A panel with options like Haze and Atmospheric Gases.
- Standard atmosphere model**: A panel with options like No gaseous absorption, Tropical, Midlatitude Summer, and Midlatitude Winter.
- Ozone column**: A panel with options like As per model and Specify, and a value of 0.319.
- Water vapor column**: A panel with options like As per model and Specify, and a value of 0.277778.
- Reference for gas columns**: A panel with options like Set altitude and Ground level, and a value of 0.

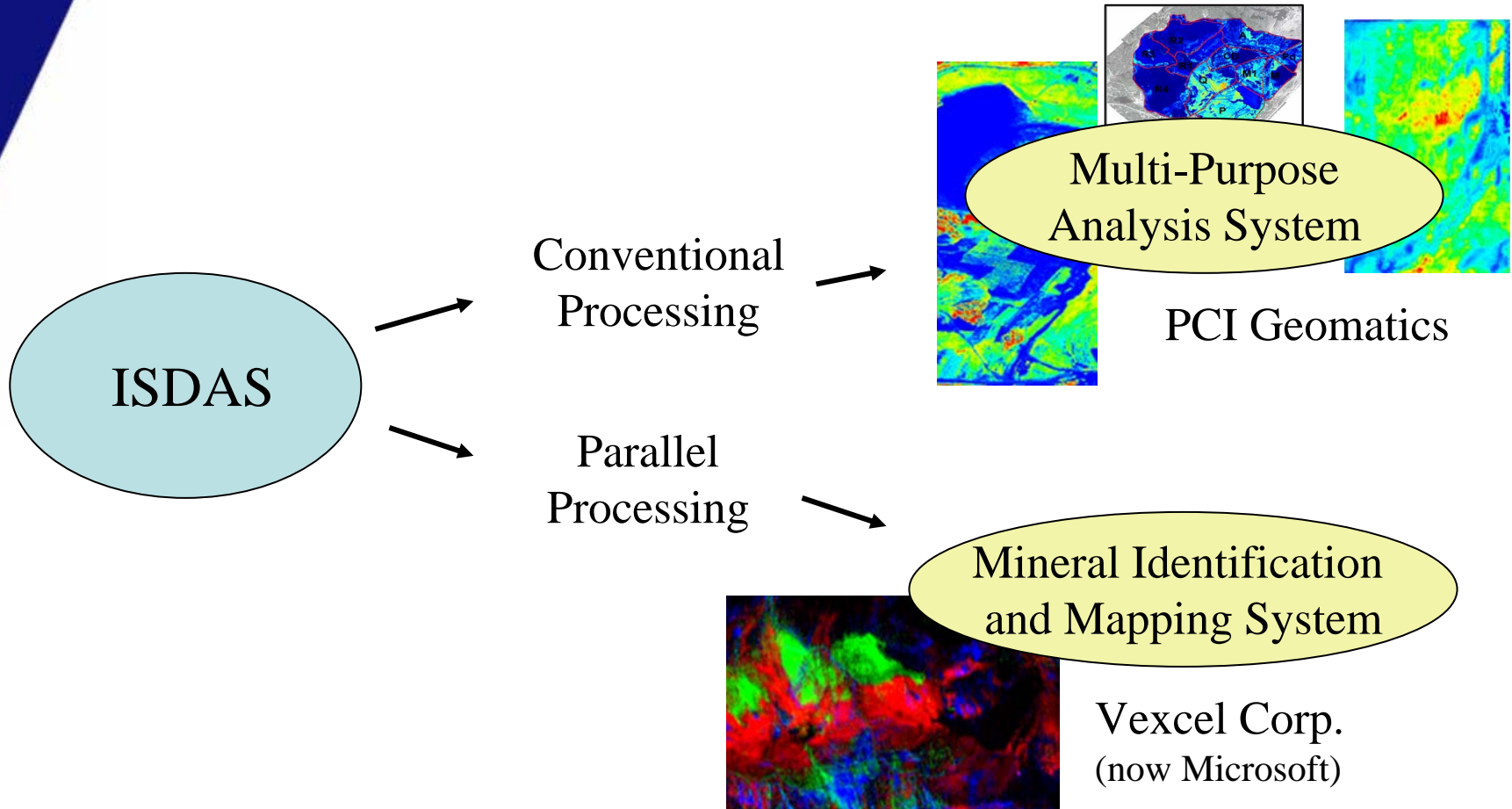
The 1D Tool window shows a line graph with the following data points:

Altitude (km)	Value
4.3	7.9
1450.0	58.0
2462.2	31.4





ISDAS - Commercialization



Some Final Thoughts on HSI Software

- While there has been considerable progress in the past twenty years, we have truly just begun
- The best algorithms are still in our future
- There is a danger that the current easy-to-use tools will stifle creativity and instill a false sense of finality, especially in students and newcomers
- The information content of our data is nearly limitless and virtually untapped
- The onus is on the algorithm and software developers to catch up with the data providers