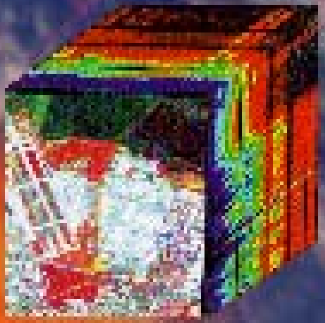
Development and Implementation of Software Systems for Imaging Spectroscopy



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

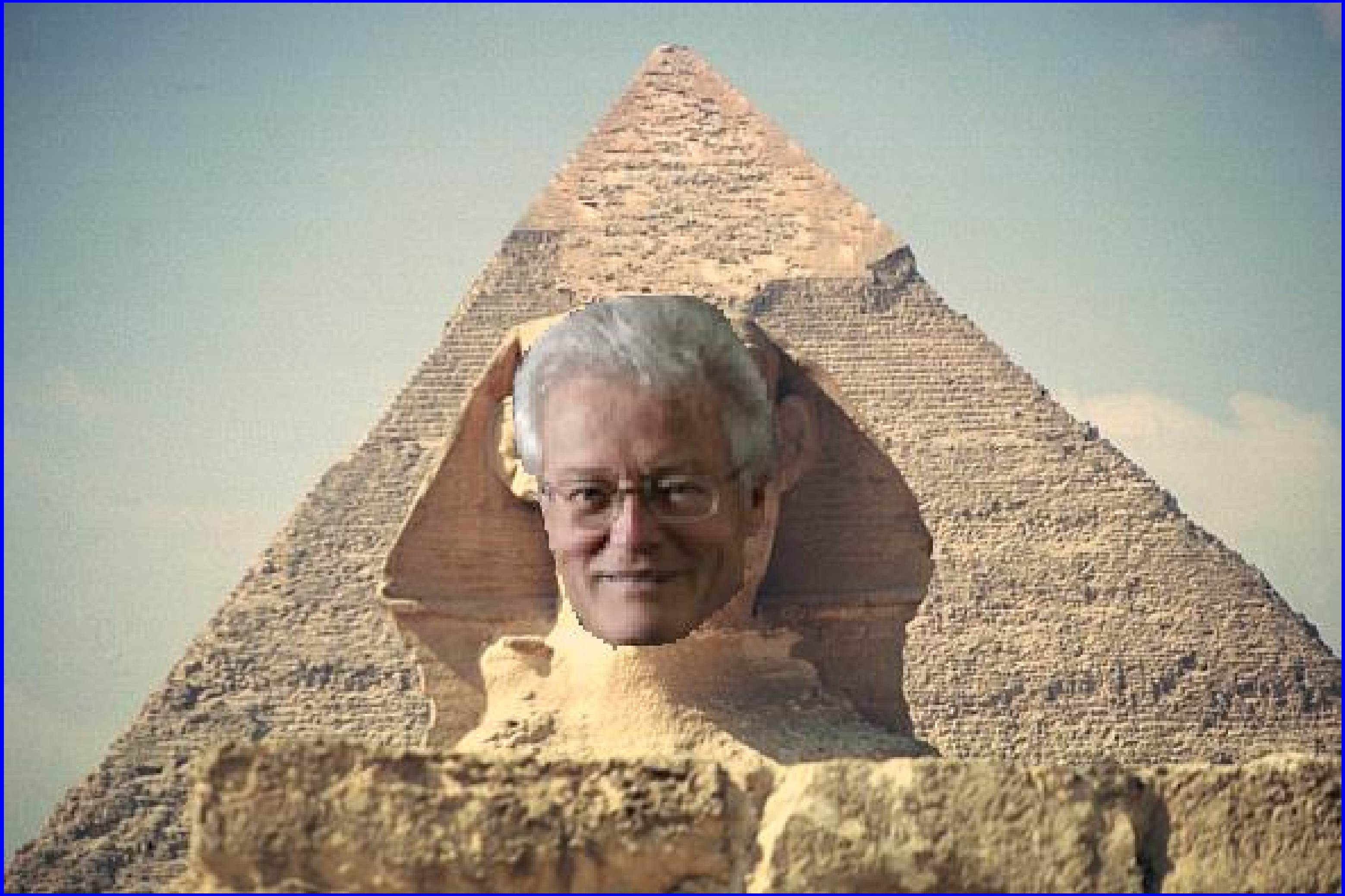
- A Few Comments Regarding the Honoree
- Development and Evolution of Software for Imaging Spectrometry
- Extremely Brief Reviews of Seven Key Historical and Present Day Systems
- Concluding Remarks

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.



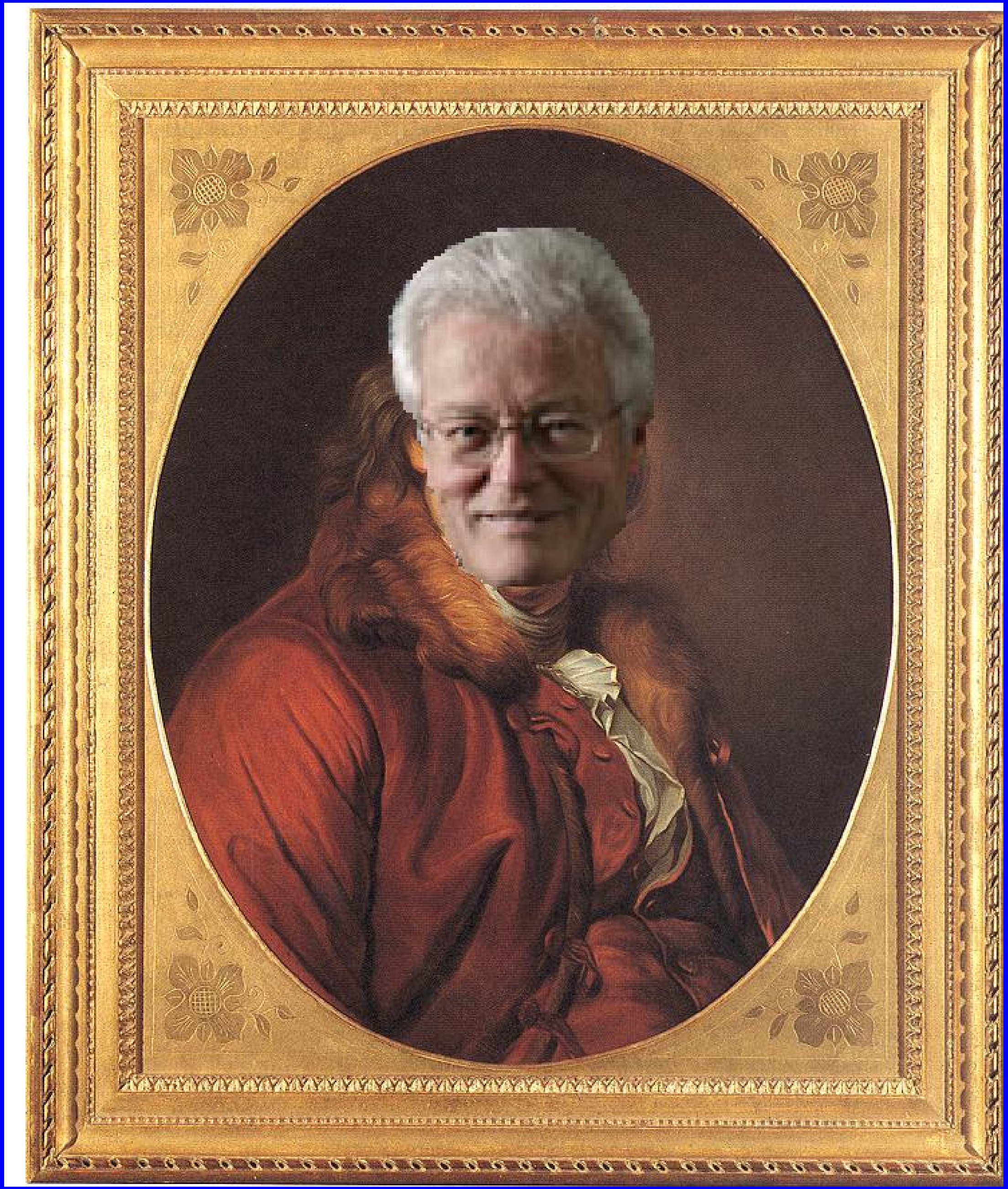
At times, Alex can seem a great and silent mystery.

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 Sepctrometry

- 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

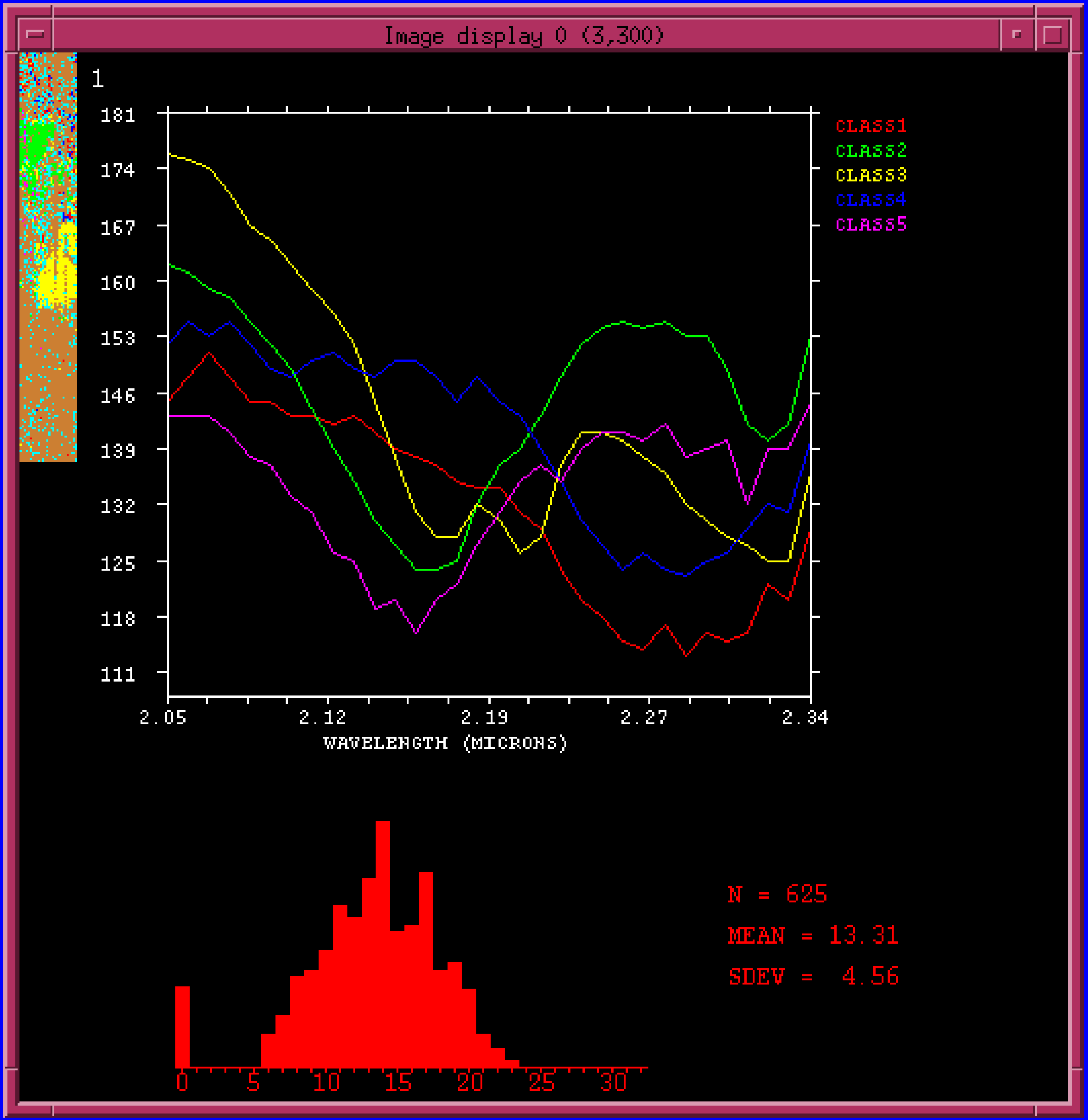


Image display 0 (3,300)
1
181
174
167
160
153
146
139
132
125
118
111
2.05
2.12
2.19
2.27
2.34
WAVELENGTH (MICRONS)
CLASS1
CLASS2
CLASS3
CLASS4
CLASS5
N = 625
MEAN = 13.31
SDEV = 4.56
0
5
10
15
20
25
30

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

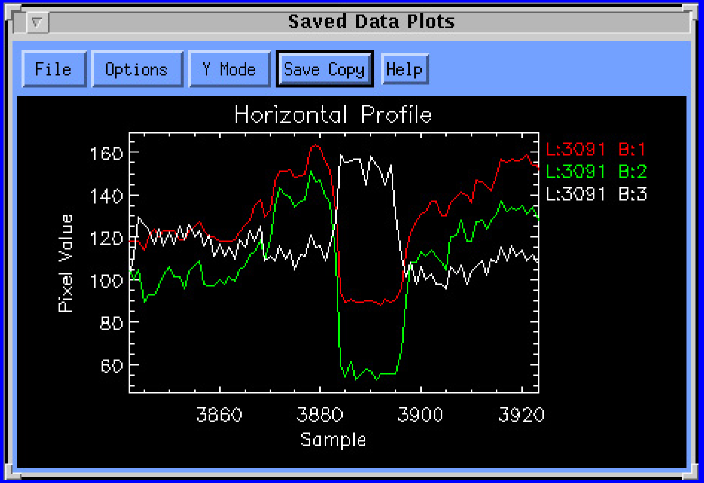
ISIS / Qlook /QL3 by USGS Flagstaff

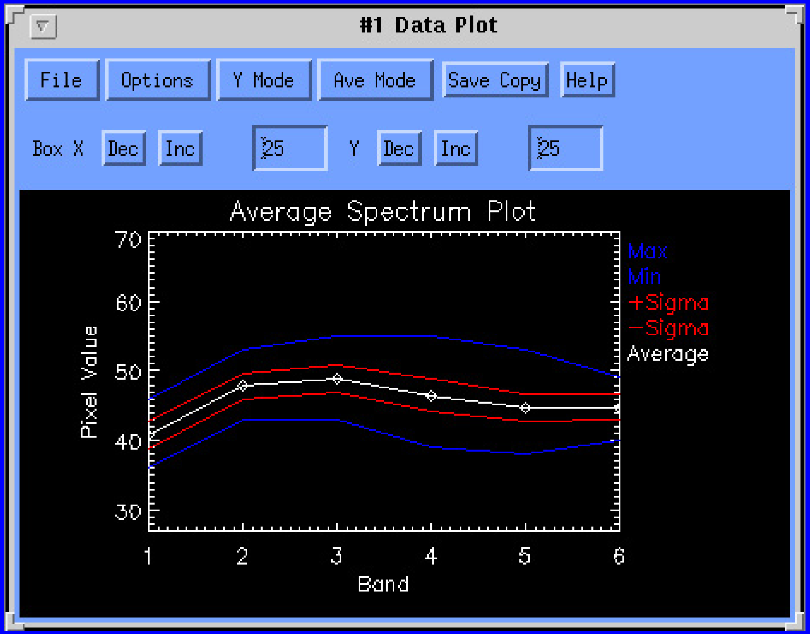
- Integrated Software for Imagers and Spectrometers 2.0 started at USGS Flagstaff 1989, replacing prototype version 1.0
- Originally for NIMS on Galileo Jupiter mission
- VAX/VMS Fortran and C along with TAE
- Early implementation NASA Planetary Data System format
- Supports up to 6-d matrices and numerous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

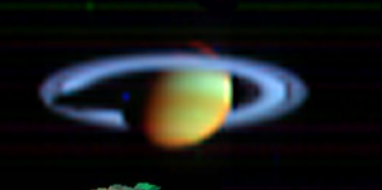
ISIS / Qlook /QL3 by USGS Flagstaff

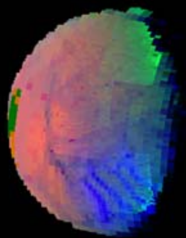
- QL3 interactive display program in ISIS for I2S IVAS displays
- 1993 ISIS 2.1 ported to UNIX from VMS
- Currently an active program in the planetary community for a number of missions and applications
- ISIS 3.0 completely new implementation in C++, for now focused on geometric processing with plans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

ISIS / Qlook /QL3 by USGS Flagstaff










Introduction to Imaging Spectroscopy and Lunar Mapping with Tetracorder

Roger N. Clark

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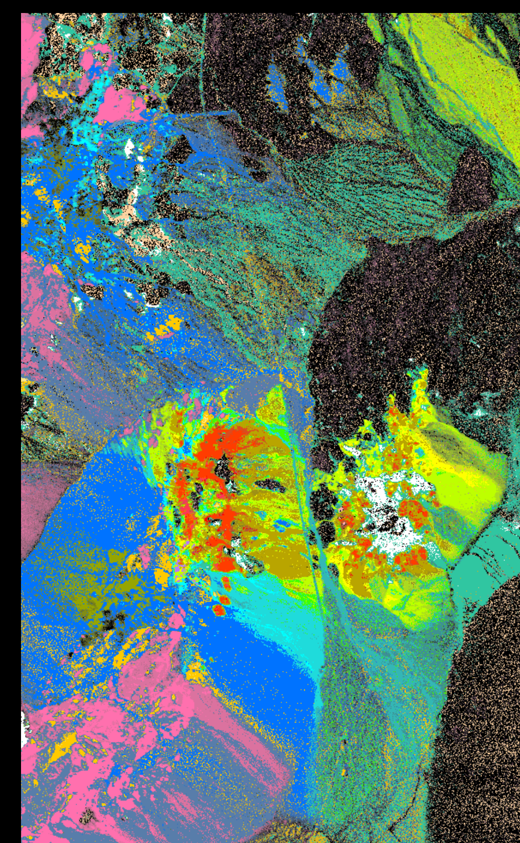
Box 25046 Federal Center
Denver, CO 80225
http://speclab.cr.usgs.gov

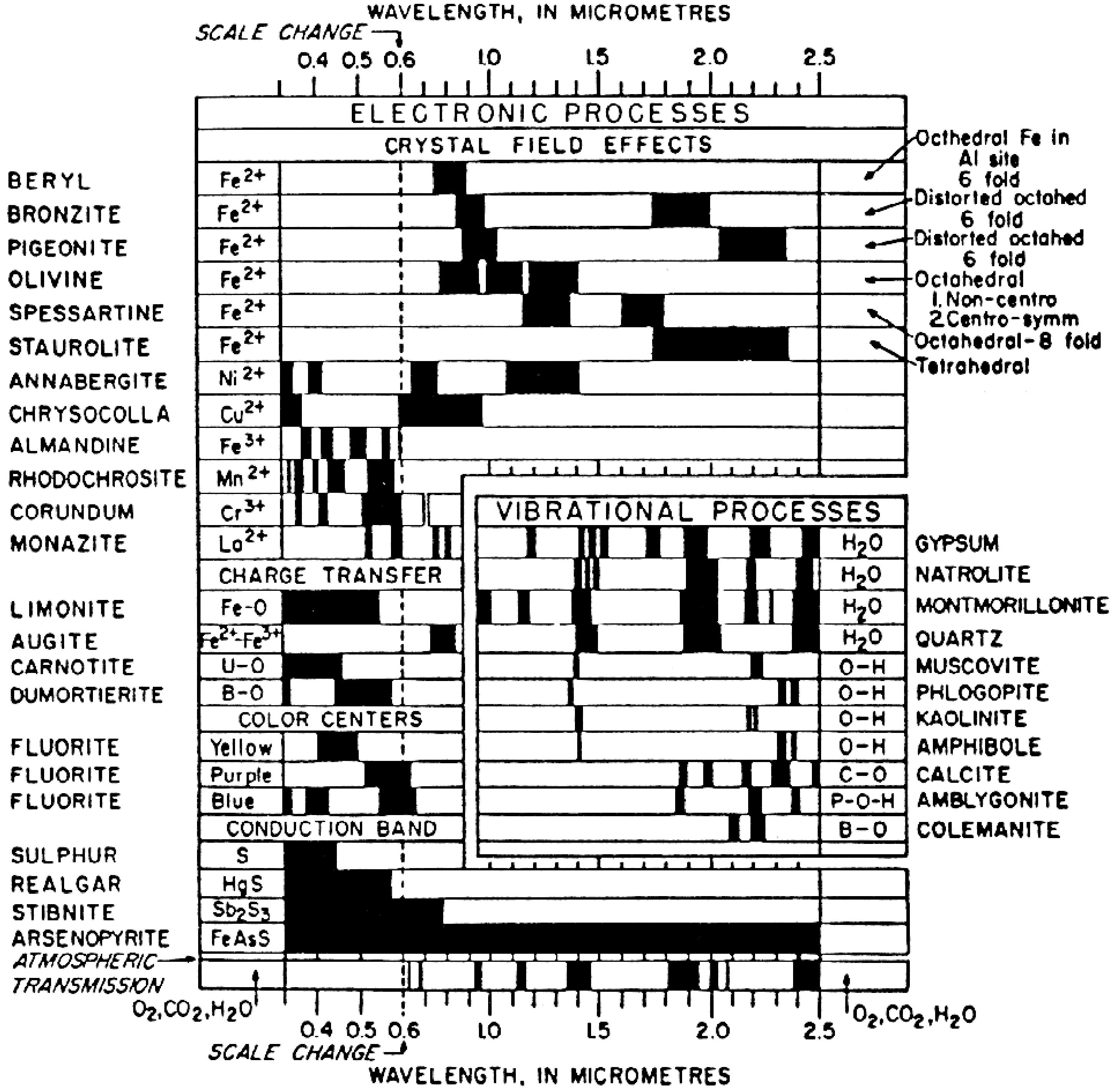



May, 2006

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

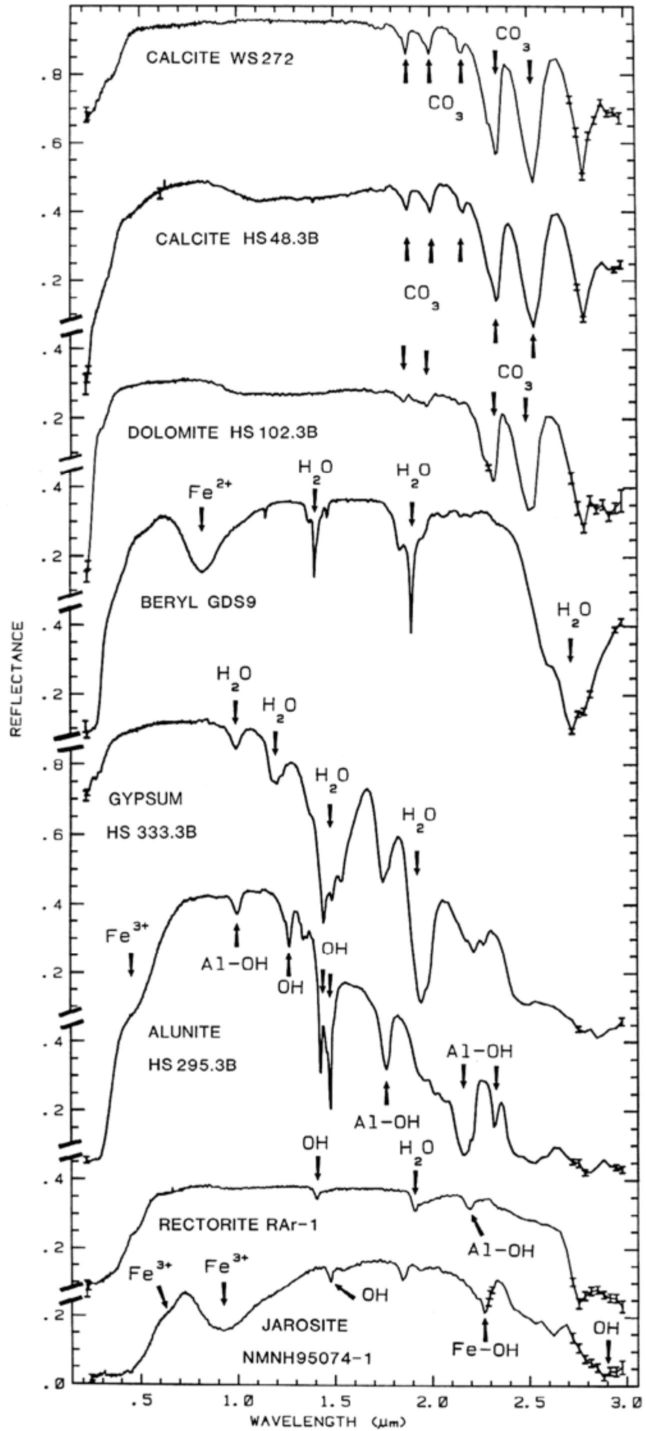
- We will us the Tetracorder system described in Clark *et al*., *JGR*, v.108, p5-1, 2003, plus refinements.
- Tetracorder is an is an expert system where multiple algorithms are applied to analyze a spectrum.
- The results of those algorithms can be tested and are compared, and identifications made.

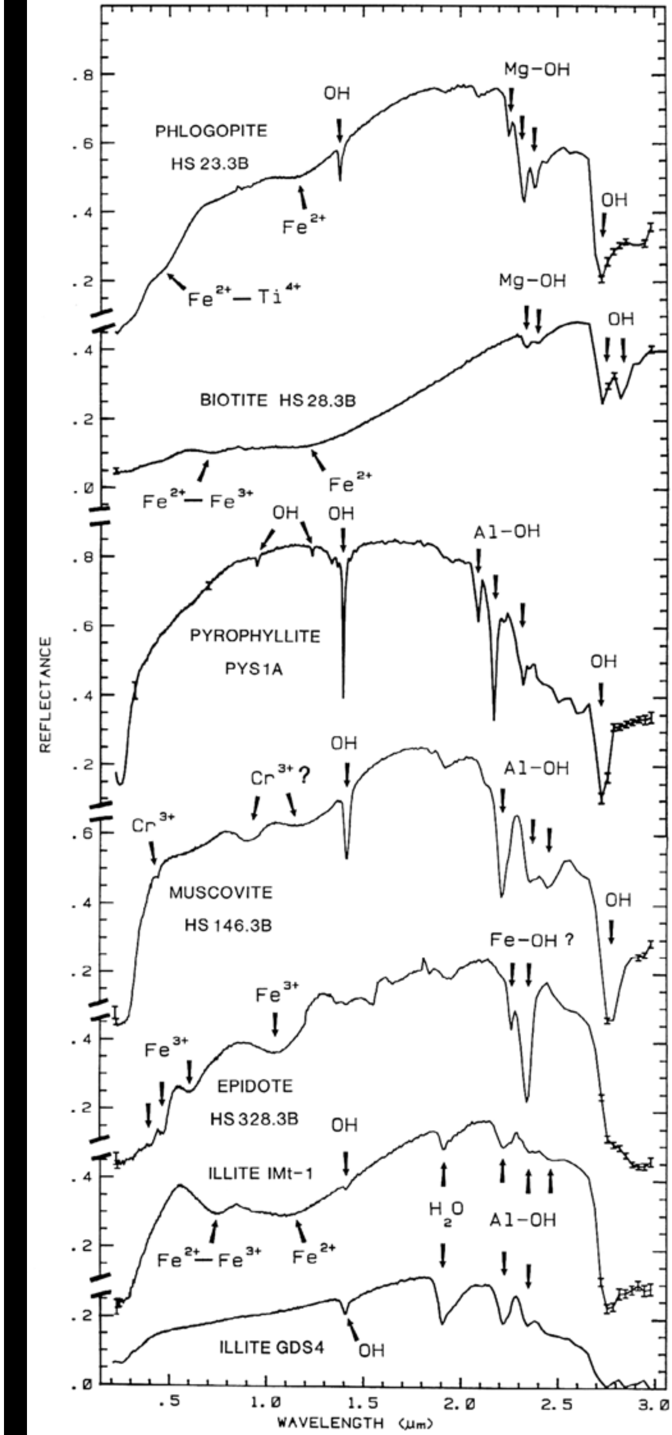
The variety of absorption processes and their wavelength dependence allows us to derive information about the chemistry of a mineral (or material) from its reflected or emitted light.



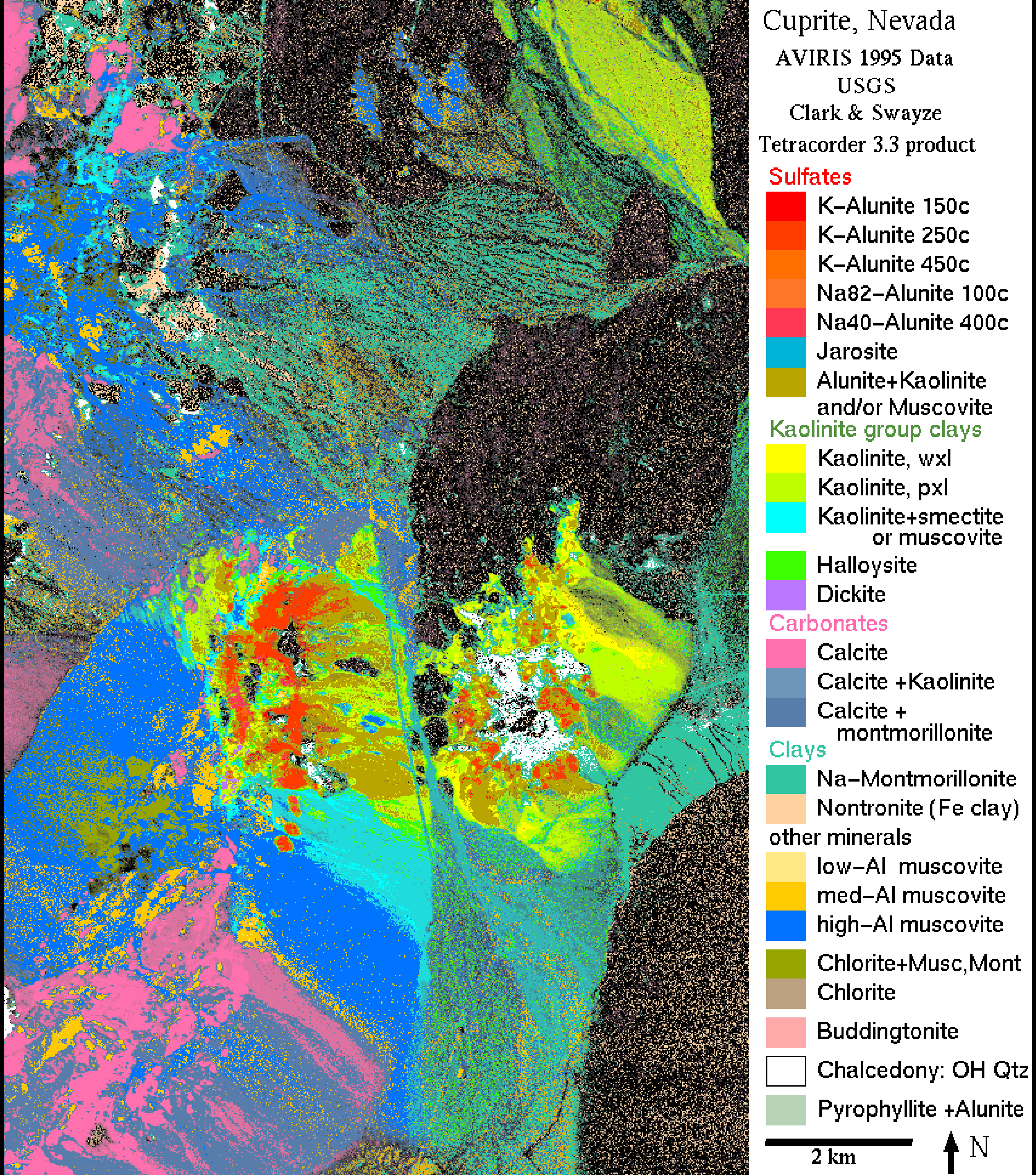
The spectrum of each material produces a “fingerprint” which allows it to be Identified.

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

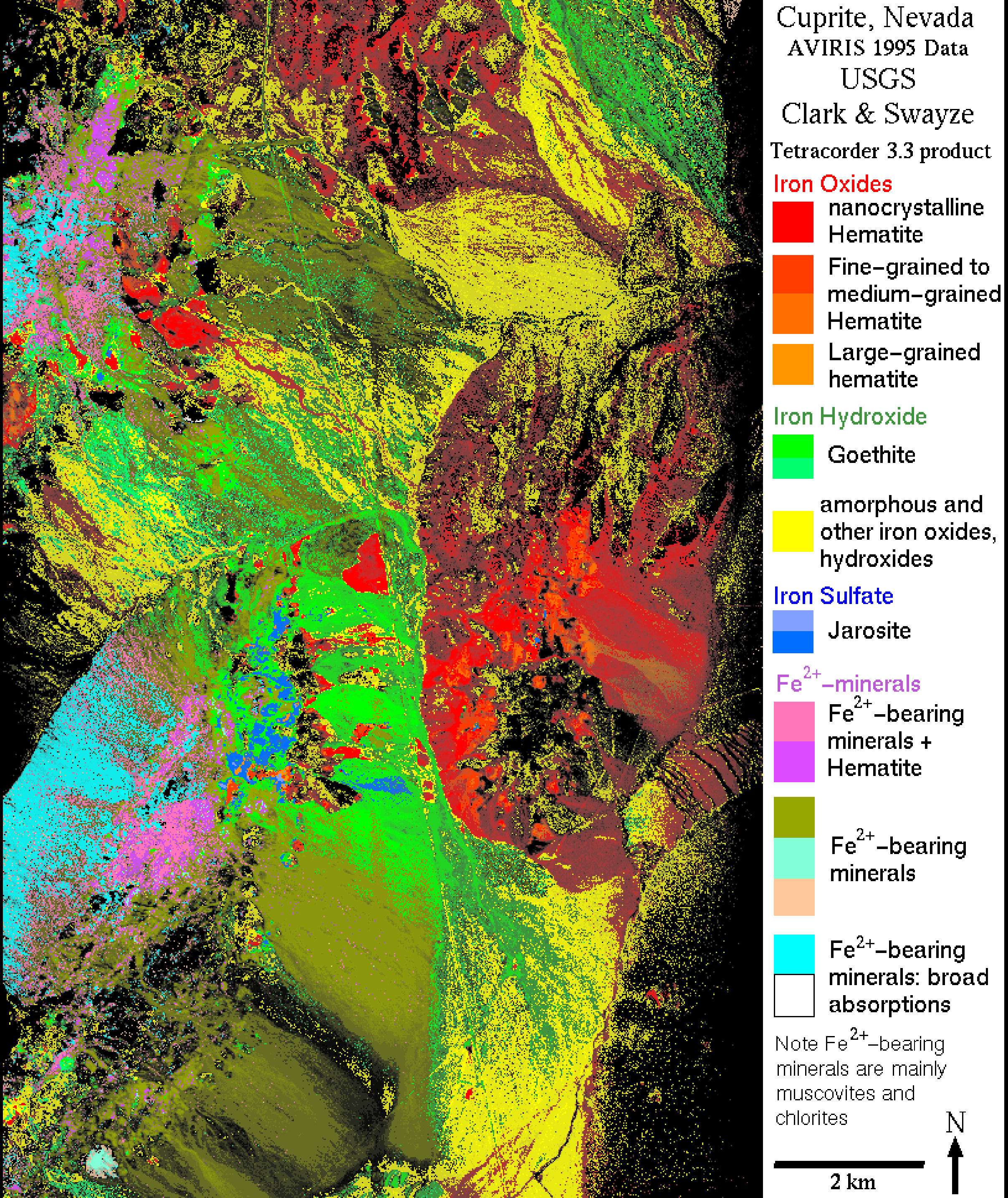




Example Tetracorder results



Example Tetracorder results



Conclusions

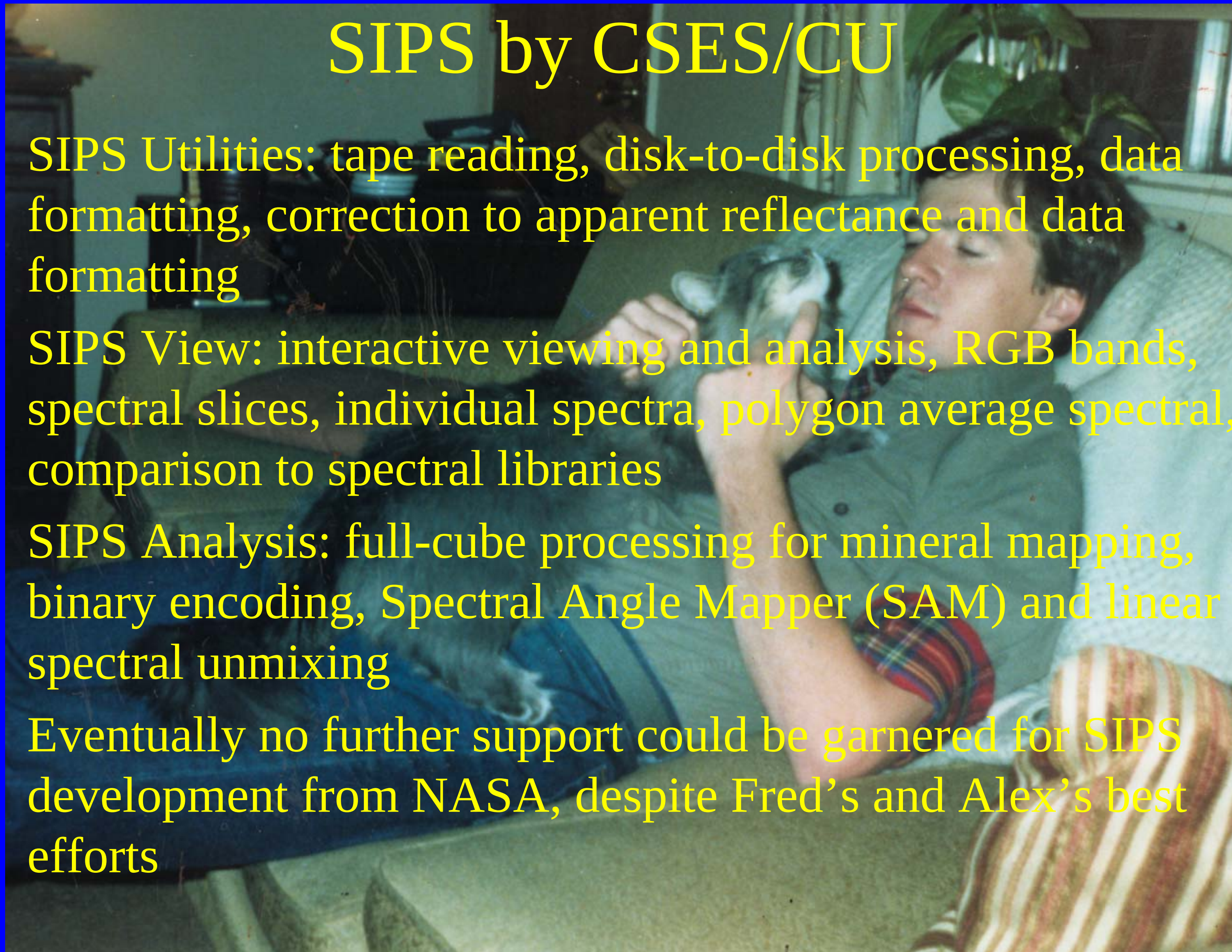
- Tetracorder runs at a rate of ~1,000 spectral features per MFLOP meaning hundreds of minerals can be searched for in lunar M3 data.
- The USGS Spectroscopy Lab has 1.6 tera-FLOPs available, enabling extensive analysis of M3 data.
- Reference reflectance spectral libraries are mature for the search 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

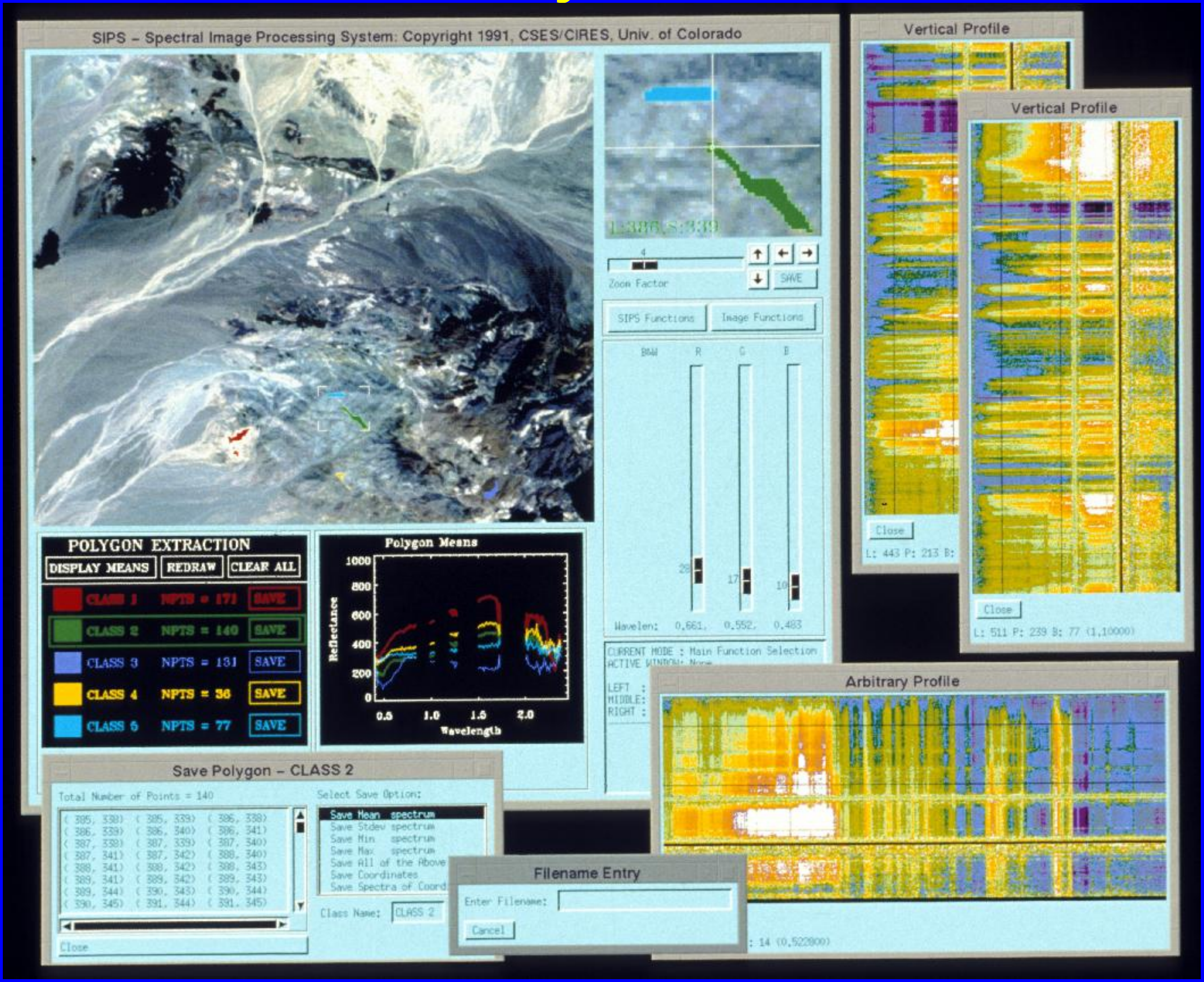
- "Processing imaging spectrometry data will be like drinking from a firehose", AFHG c. 1988.
- So we started with "SIPS" in 1990 at CSES
- Builds on previous work, especially ISIS and SPAM as well as Fred Kruse's experience at USGS
- NASA funded as a tool for viewing and processing AVIRIS data, written 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

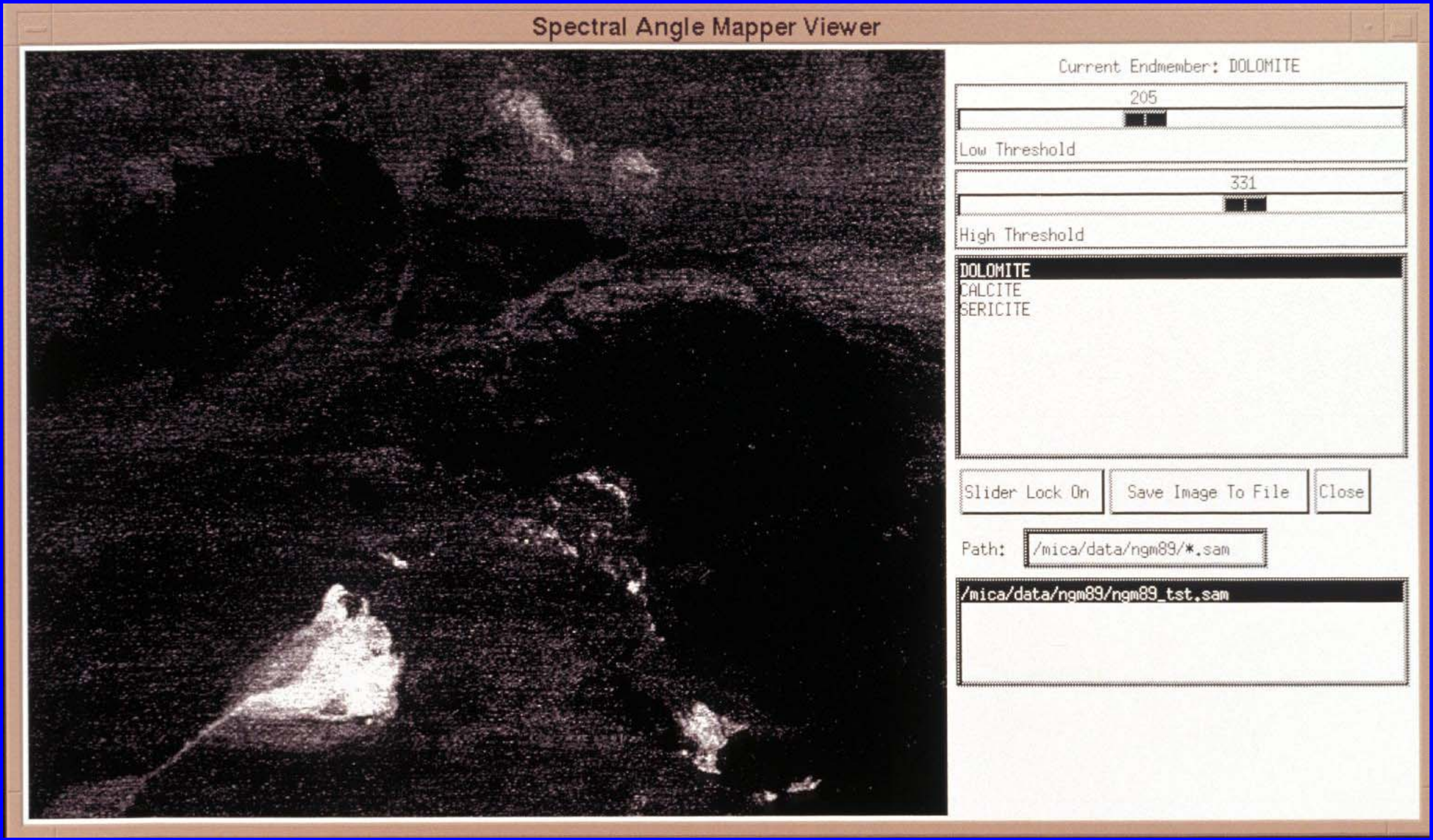


- SIPS Utilities: tape reading, disk-to-disk processing, data formatting, correction to apparent reflectance and data formatting
- SIPS View: interactive viewing and analysis, RGB bands, spectral slices, individual spectra, polygon average spectral, comparison to spectral libraries
- SIPS Analysis: full-cube 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



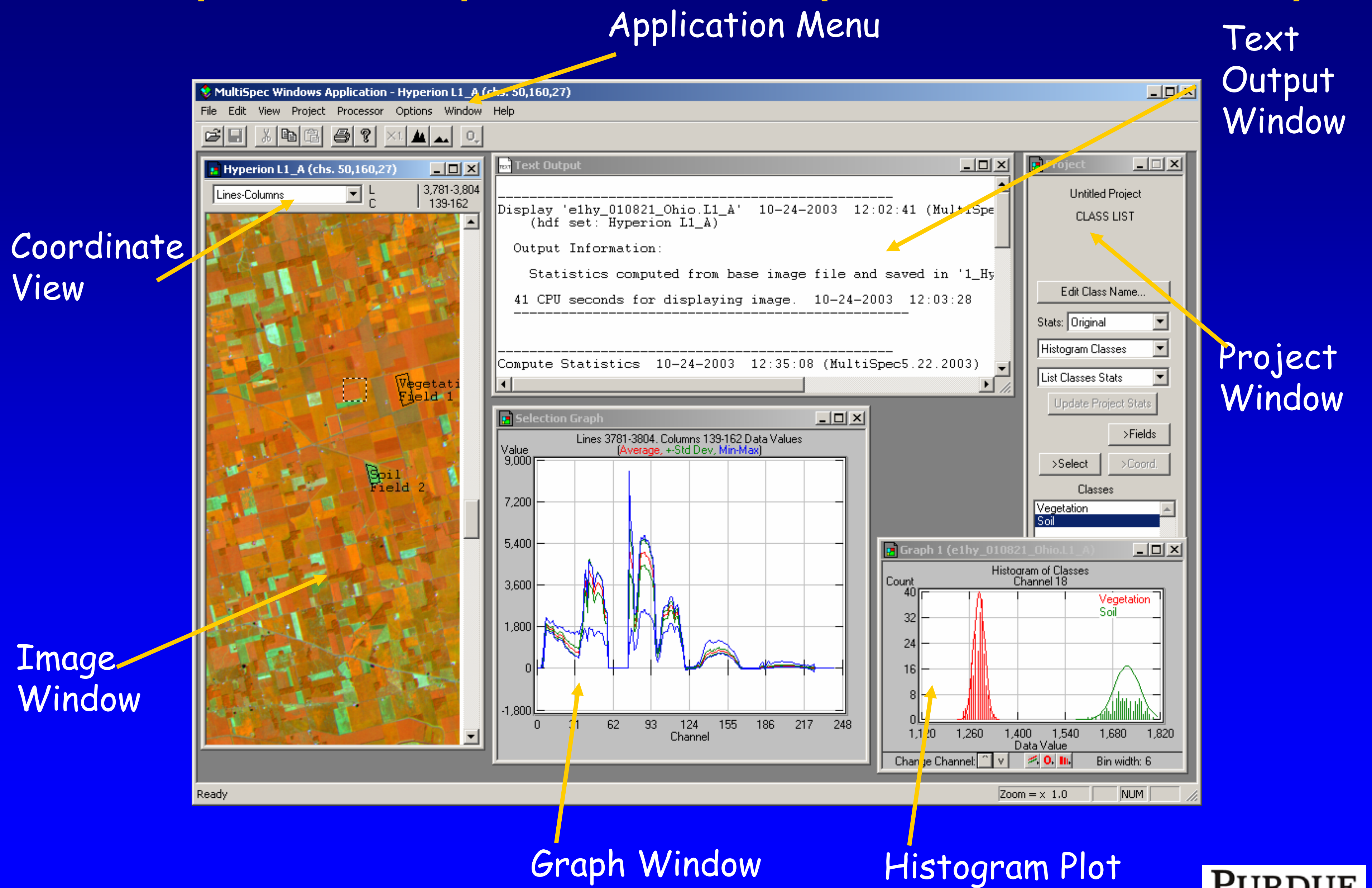
SIPS by CSES/CU



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)



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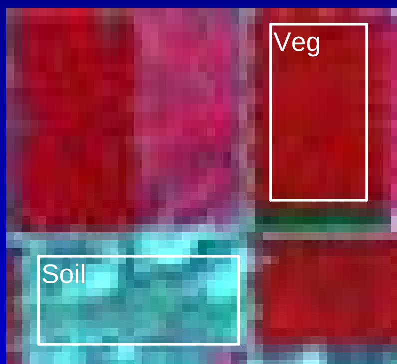
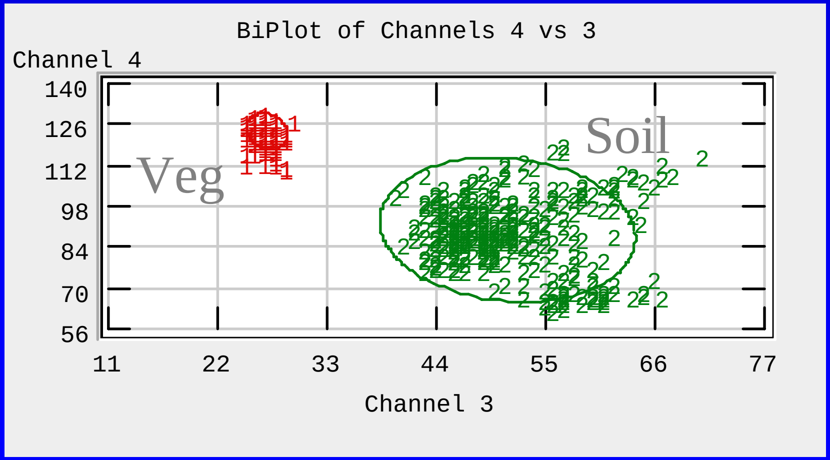
Comparison of Classes

Image Space



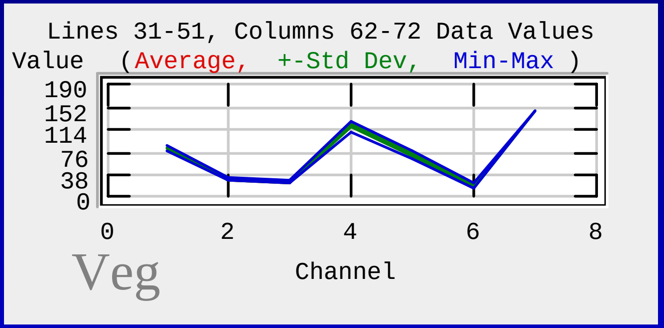
Geographic Orientation

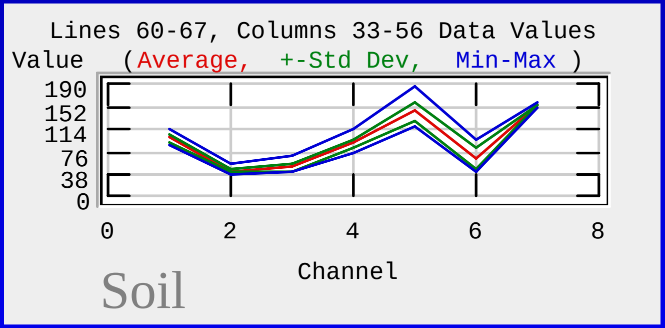
Feature Space



For Use in Pattern Analysis

Spectral Space





Relate to Physical Basis for Response

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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

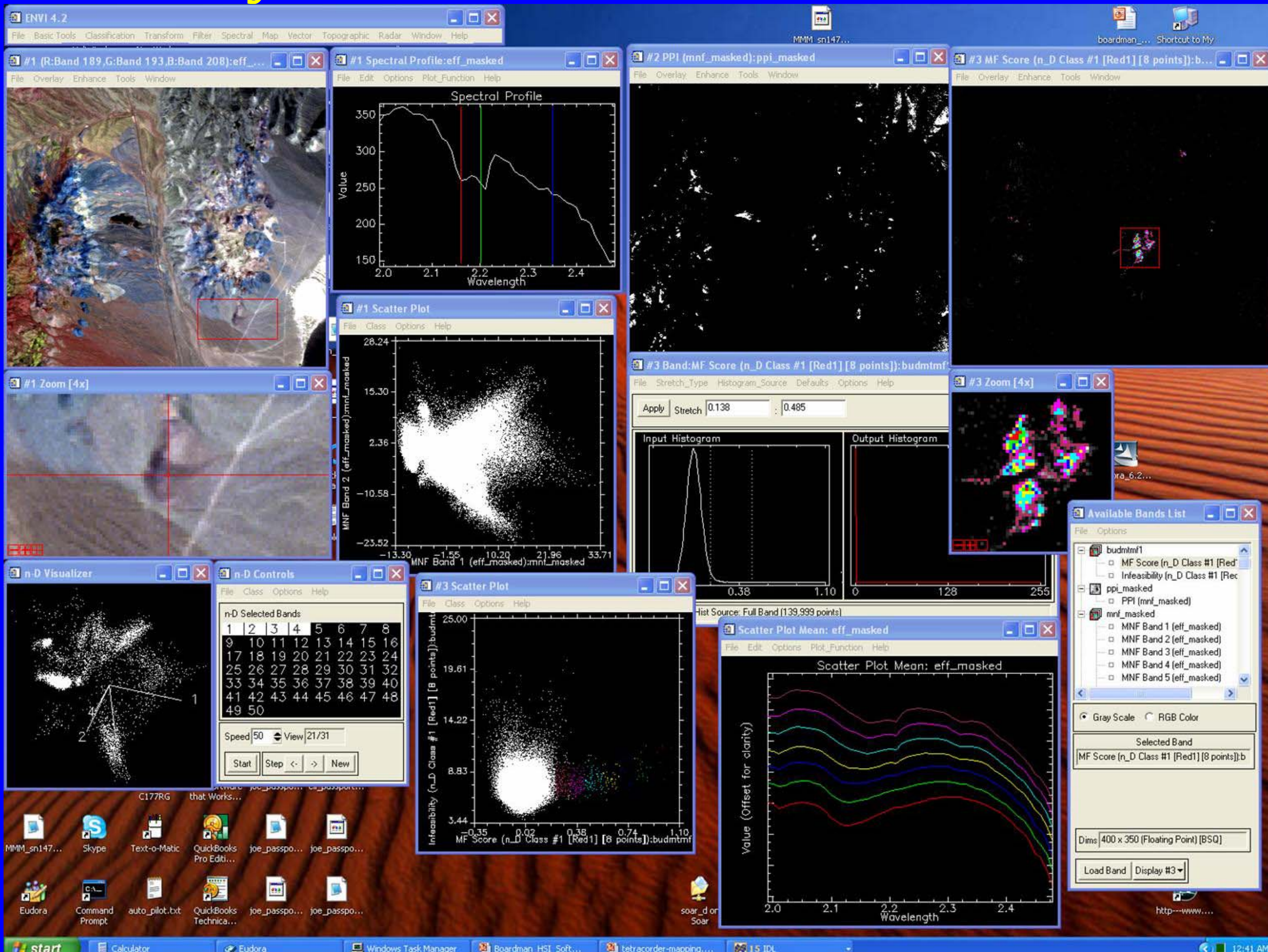
ENVI by BSC/AIG, RSI, Kodak and ITT

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

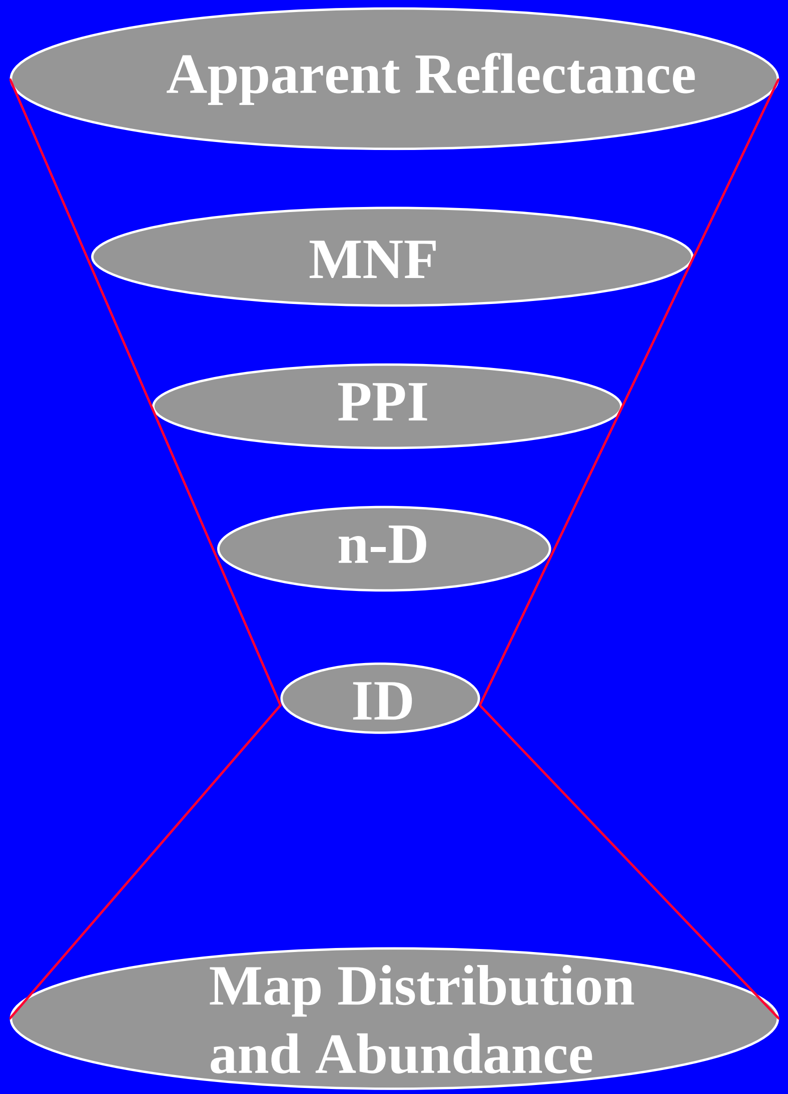
ENVI by BSC/AIG, RSI, Kodak and ITT

- ENVI developed to serve AIG R&D needs and that of our science colleagues
- Focused on two aspects:
  - Innovative hyperspectal 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



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**

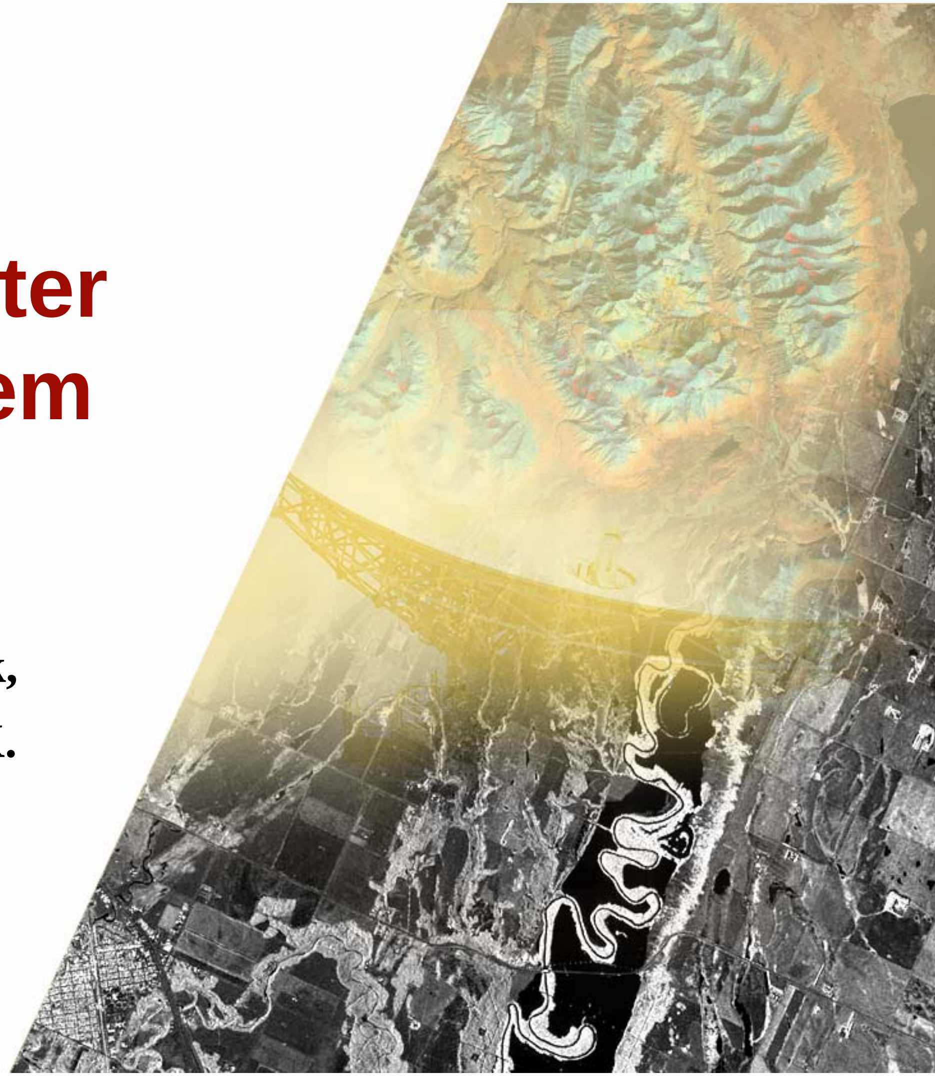
- **Classification and subpixel classification**
  - **SAM, linear spectral unmixing, matched filtering, and MTMF**

ISDAS

Imaging Spectrometer Data Analysis System

K. Staenz

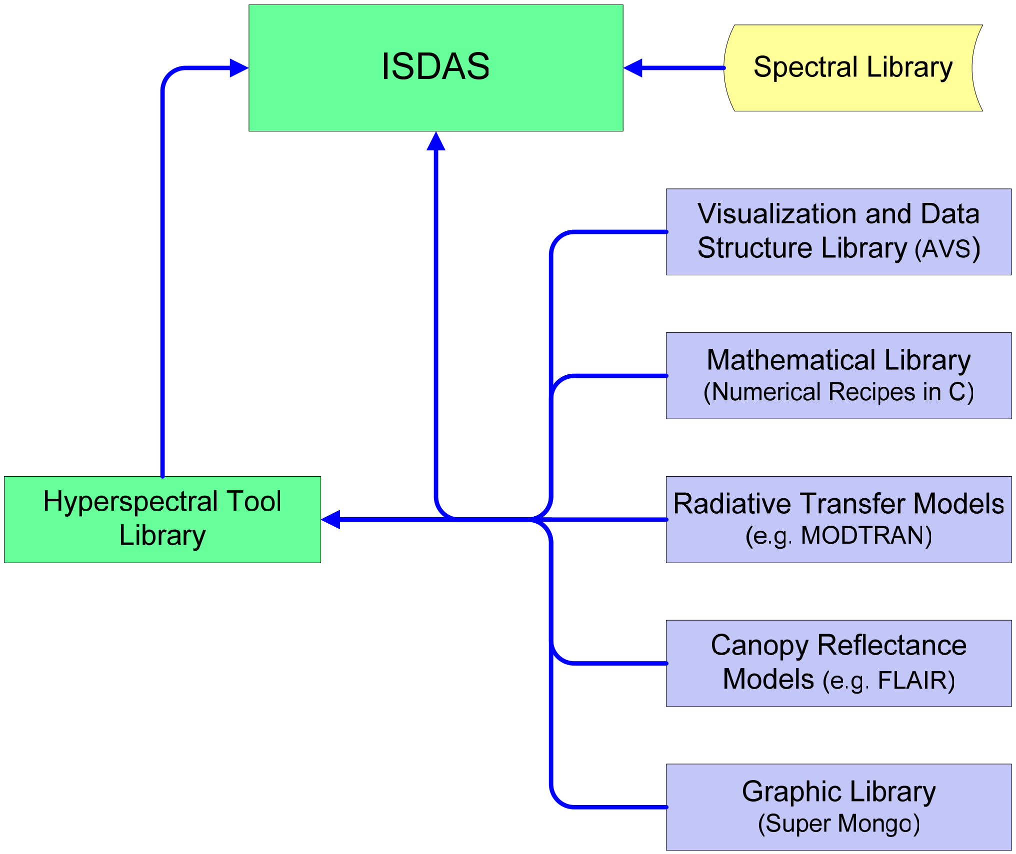
A. Abuelgasim, P. Budkewitsch, R. Hitchcock, R.A. Neville, R. Soffer, J. Schwarz, L. Sun, K. Omari, H.P. White



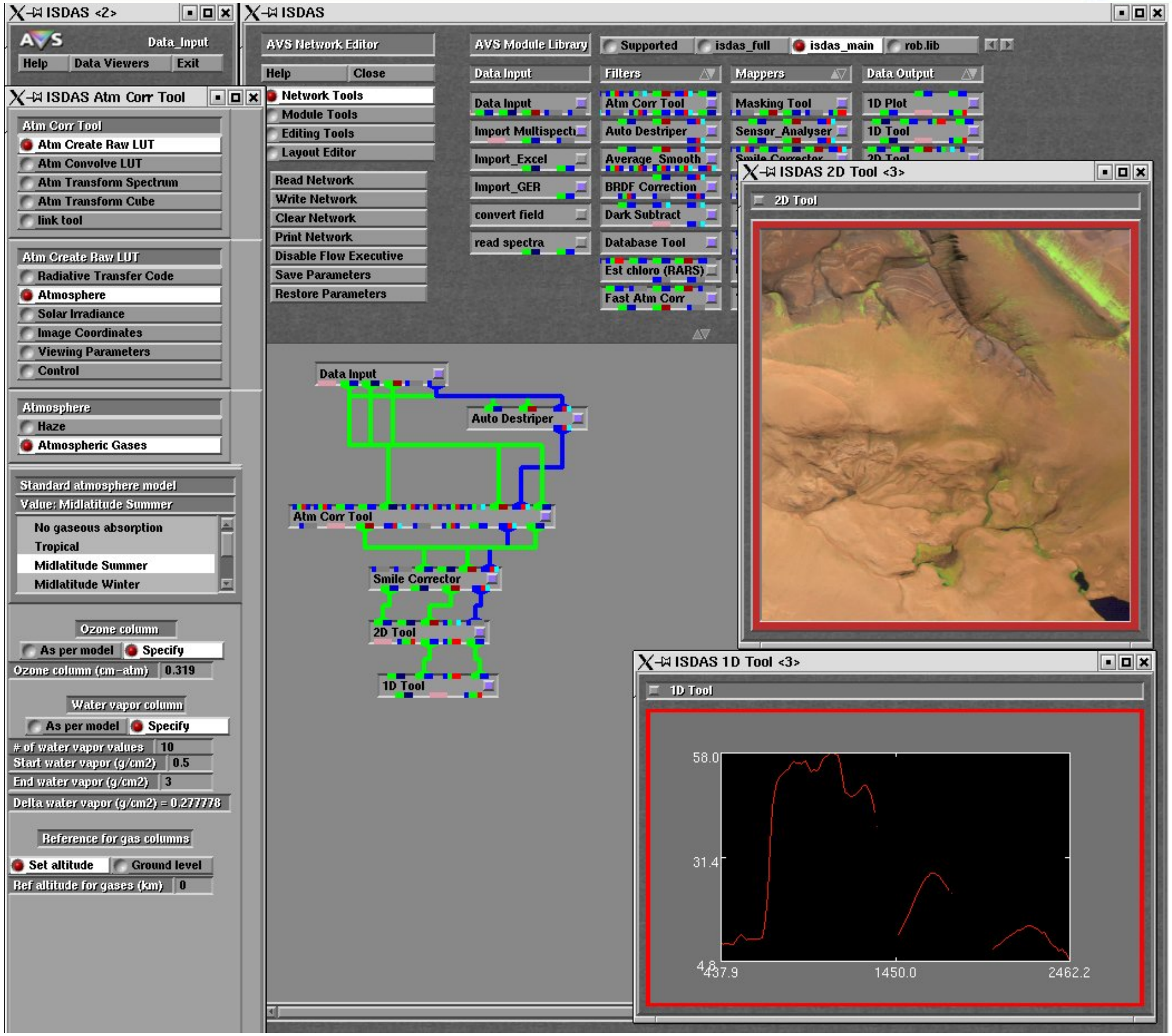
ISDAS - Overview

- **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

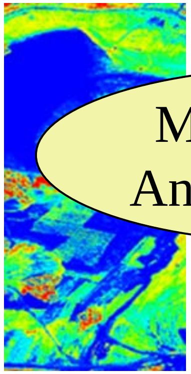


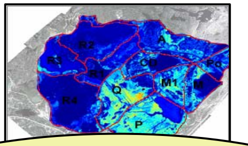
ISDAS - Commercialization

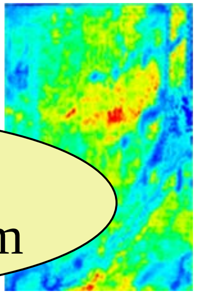
ISDAS

Conventional Processing

Parallel Processing



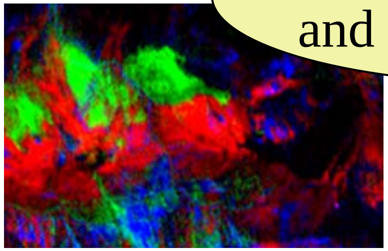




Multi-Purpose Analysis System

PCI Geomatics

Mineral Identification and Mapping System



Vexcel Corp.
(now Microsoft)

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