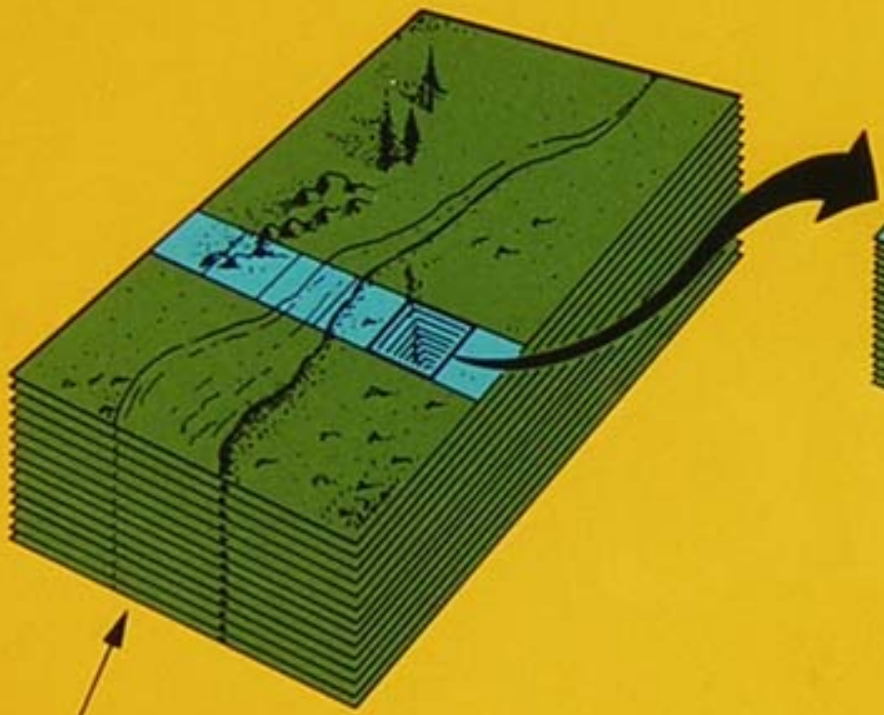
Twenty-Seven Years of Imaging Spectrometry of the Earth

Alexander F. H. Goetz
Analytical Spectral Devices Inc., Boulder
August 2, 2006

Content

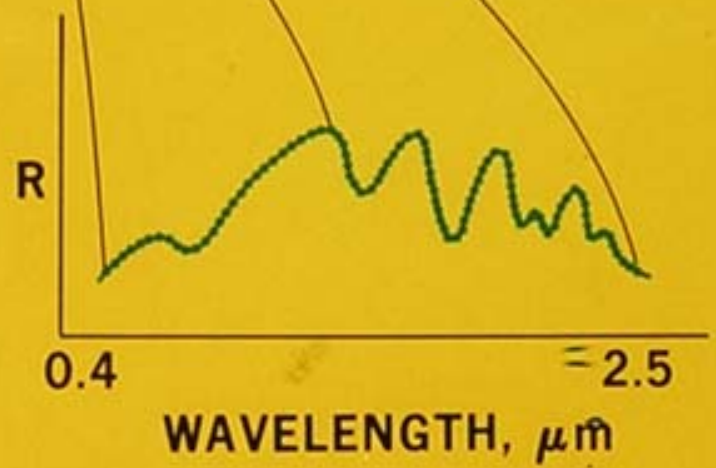
- How did it start?
- What were the drivers?
  - Science
  - Technology
- Development milestones
- Politics

IMAGING SPECTROMETRY CONCEPT



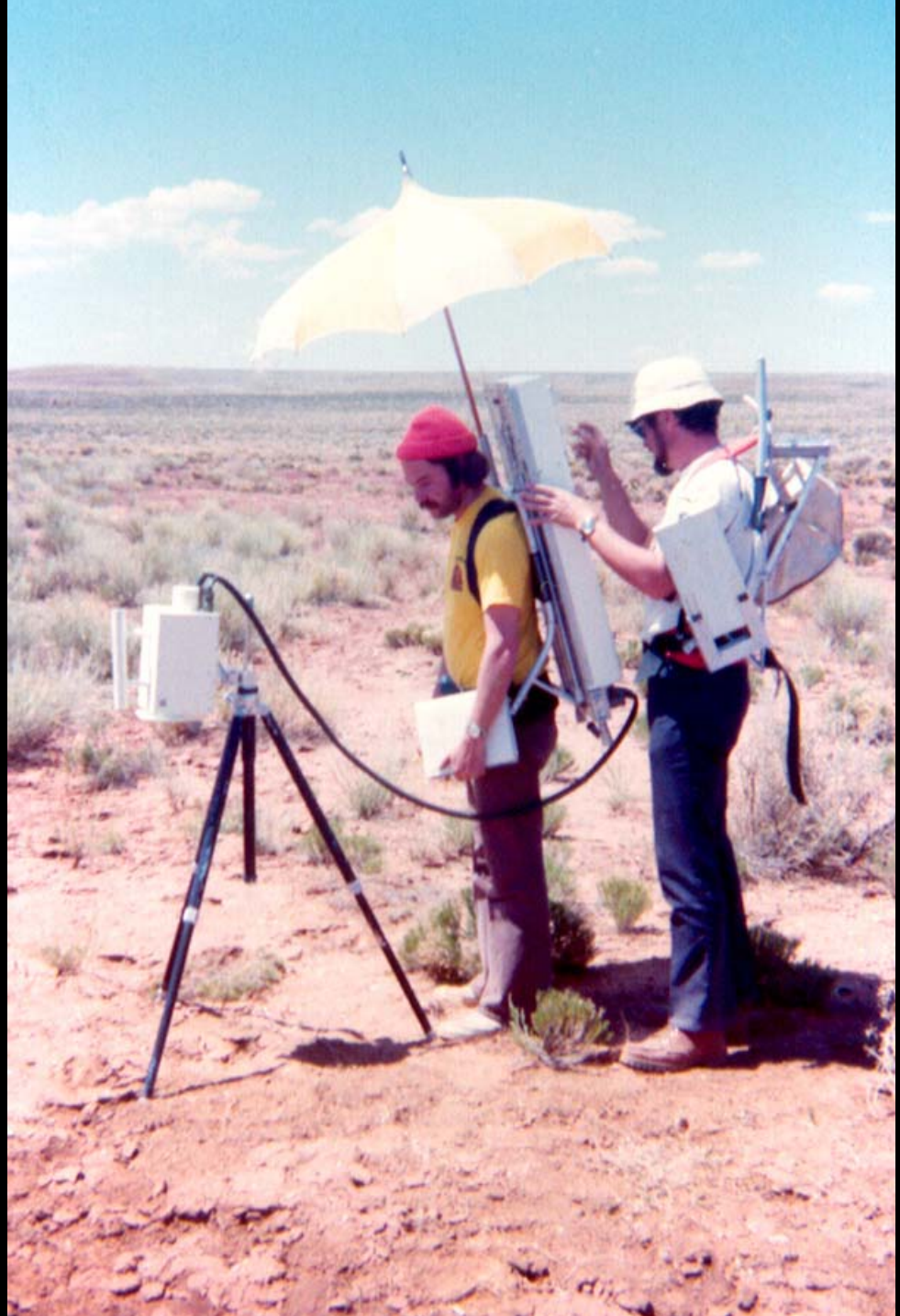
EACH PIXEL HAS AN ASSOCIATED, CONTINUOUS SPECTRUM THAT CAN BE USED TO IDENTIFY THE SURFACE MATERIALS

IMAGES TAKEN SIMULTANEOUSLY IN 100-200 SPECTRAL BANDS, INHERENTLY REGISTERED



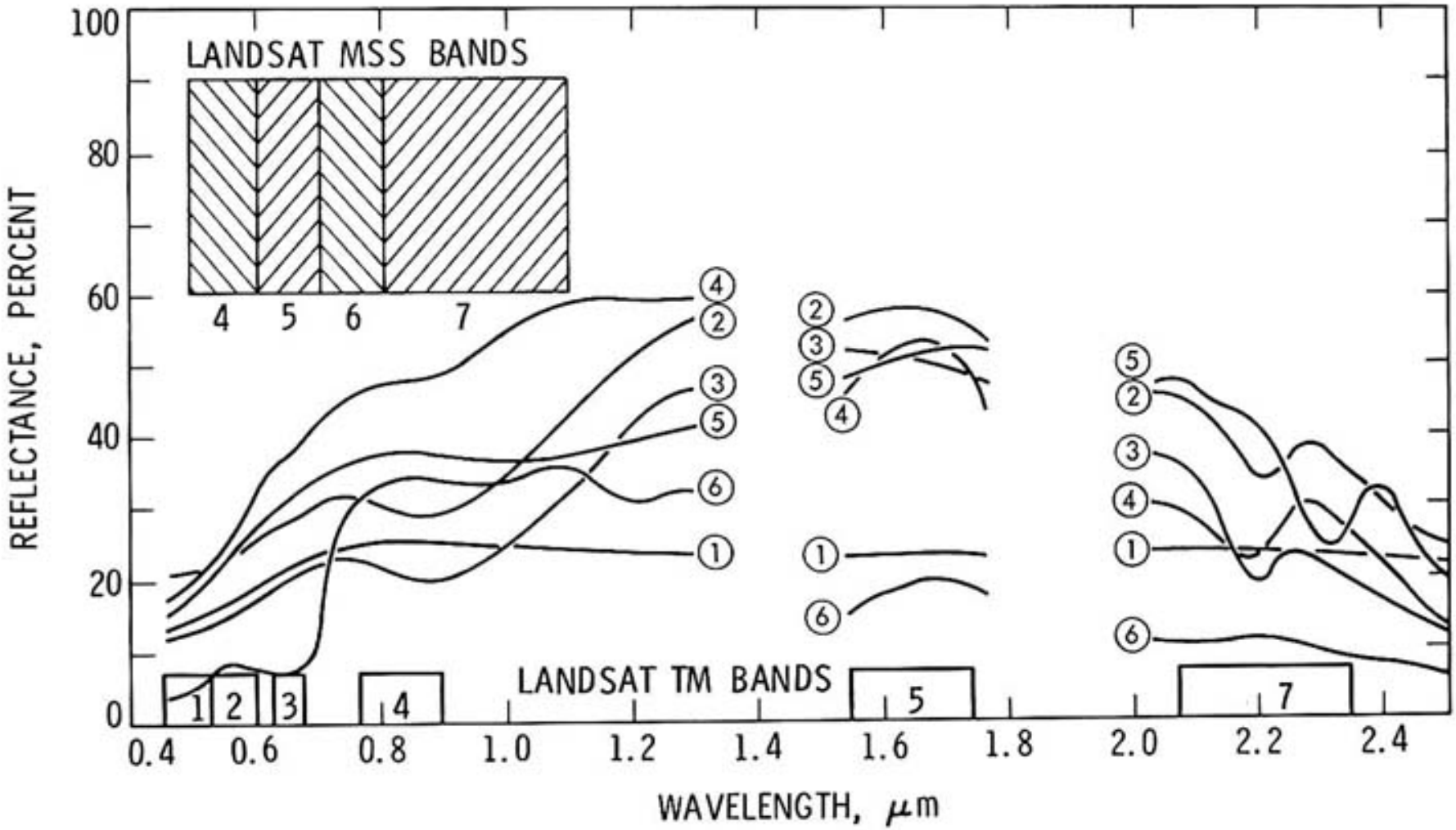
Field Spectroscopy

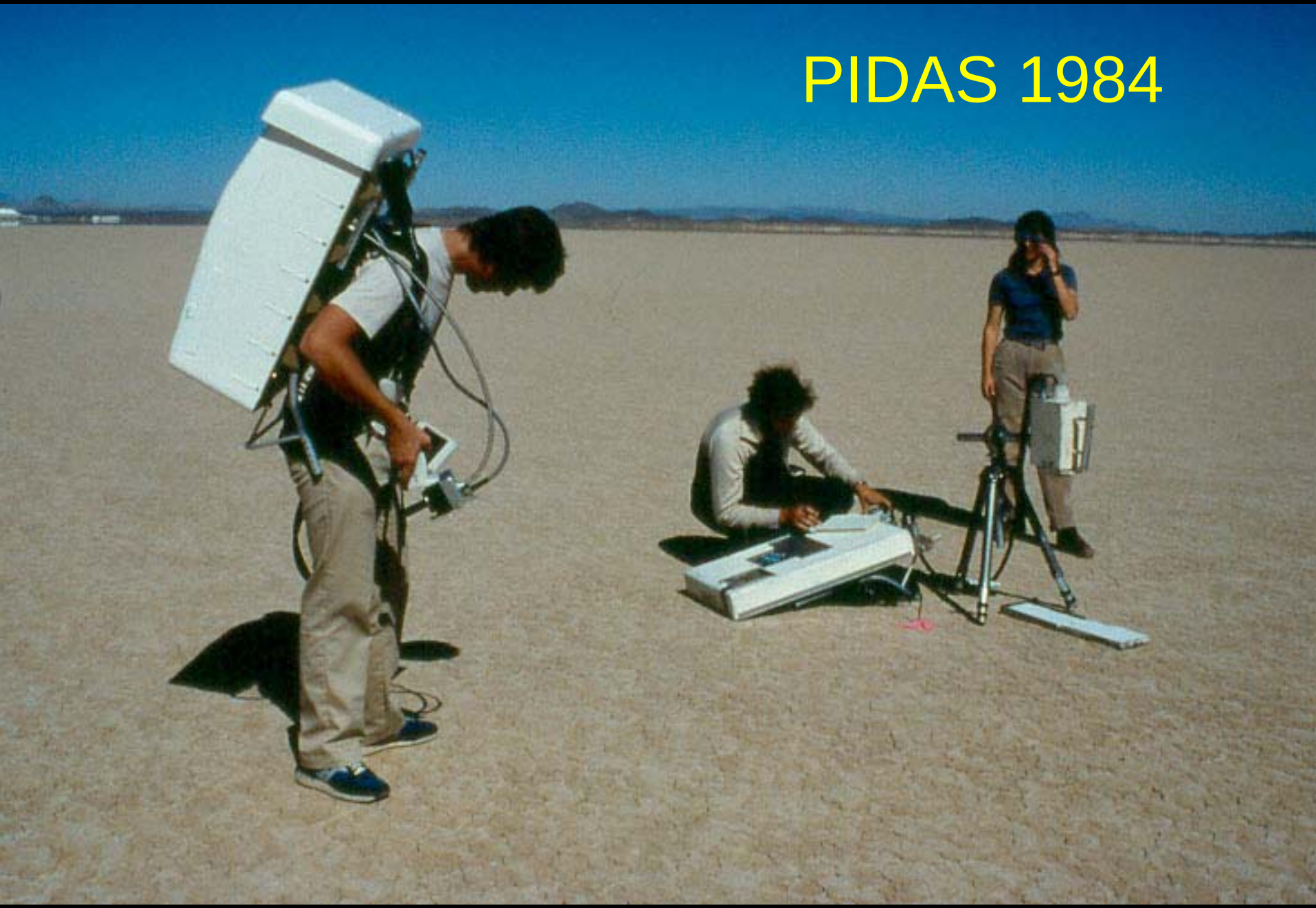
- Started it all
- Advances in instrumentation made on a decadal time scale
- We were way ahead of our time



PFRS
1974

SPECTRAL REFLECTANCE OF ALTERATION MINERALS AND VEGETATION




PIDAS 1984

PS-II
1991


FieldSpec FR 1995


FieldSpec Pro 2004


YAMAHA


FS3
2006
“Look Ma,
no wires!”

Historically Critical Developments

- Science drivers
  - Qualitative nature of multispectral imaging
  - Need for mineralogical identification
- Technology
  - Detectors
  - Optics
  - Platforms
  - Calibration

Critical Developments (2)

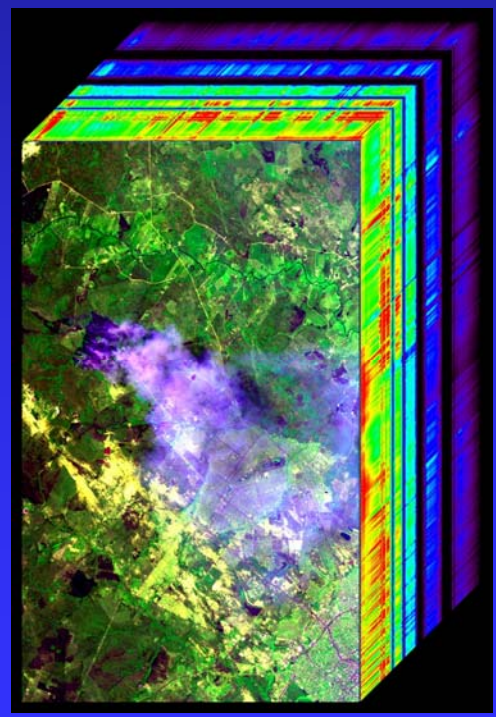
- Equipment
  - Computing hardware advances
  - Commercially available field spectrometers
- Data analysis
  - Software
    - Atmospheric correction
    - Commercially available analysis packages

Milestones in Earth Imaging Spectroscopy

- 1974 PFRS, JPL
- 1979 First composite detector, HgCdTe on Si, North American (Rockwell)
- 1981 SMIRR flight on STS-2
- 1983 AIS flight over Cuprite, NV
- 1984 Buddingtonite discovery at Cuprite
- 1986 Science paper, Goetz,et al.

Milestones (2)

- 1986 GER Imaging Spectrometer
- 1987 AVIRIS
- HIRIS proposed for EOS
- 1989 ITRES CASI
- 1989 First image cube
- 1992 SIPS

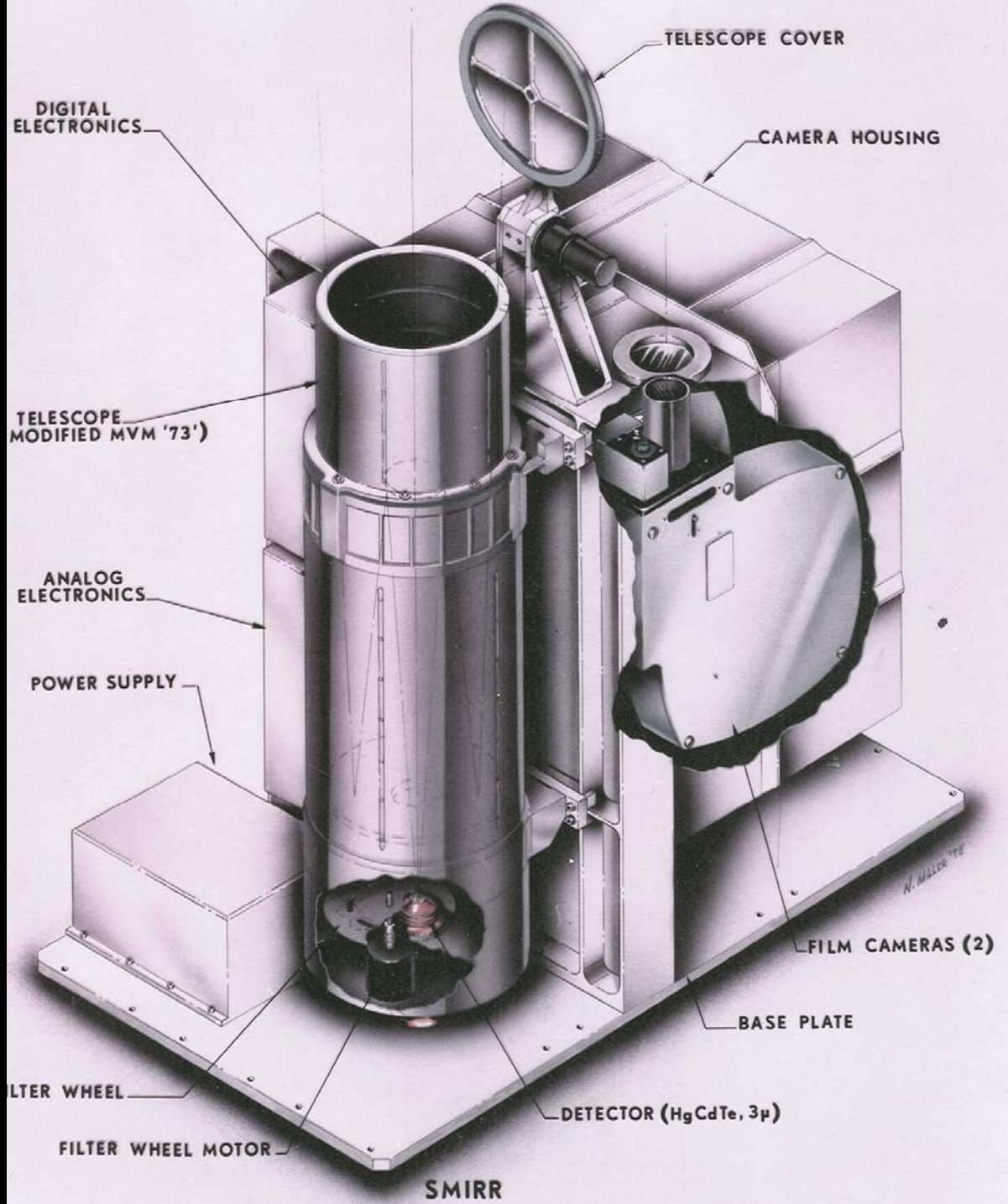


Milestones (3)

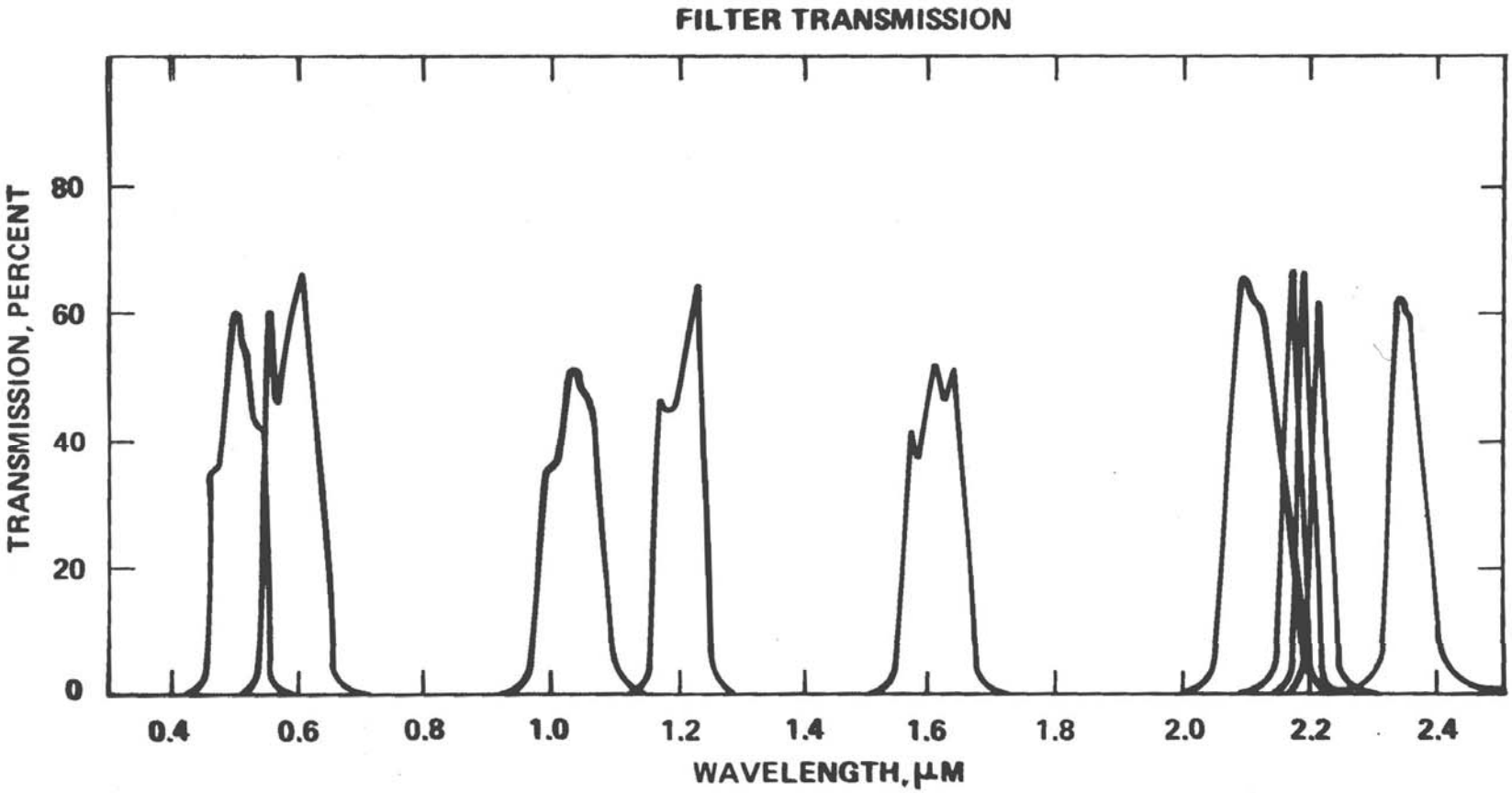
- 1993 ATREM
- 1994 ENVI
- 1995 FieldSpec
- 2000 Hyperion on EO-1
- 2005 M^3 approved
- 2006 EnMAP in Phase B

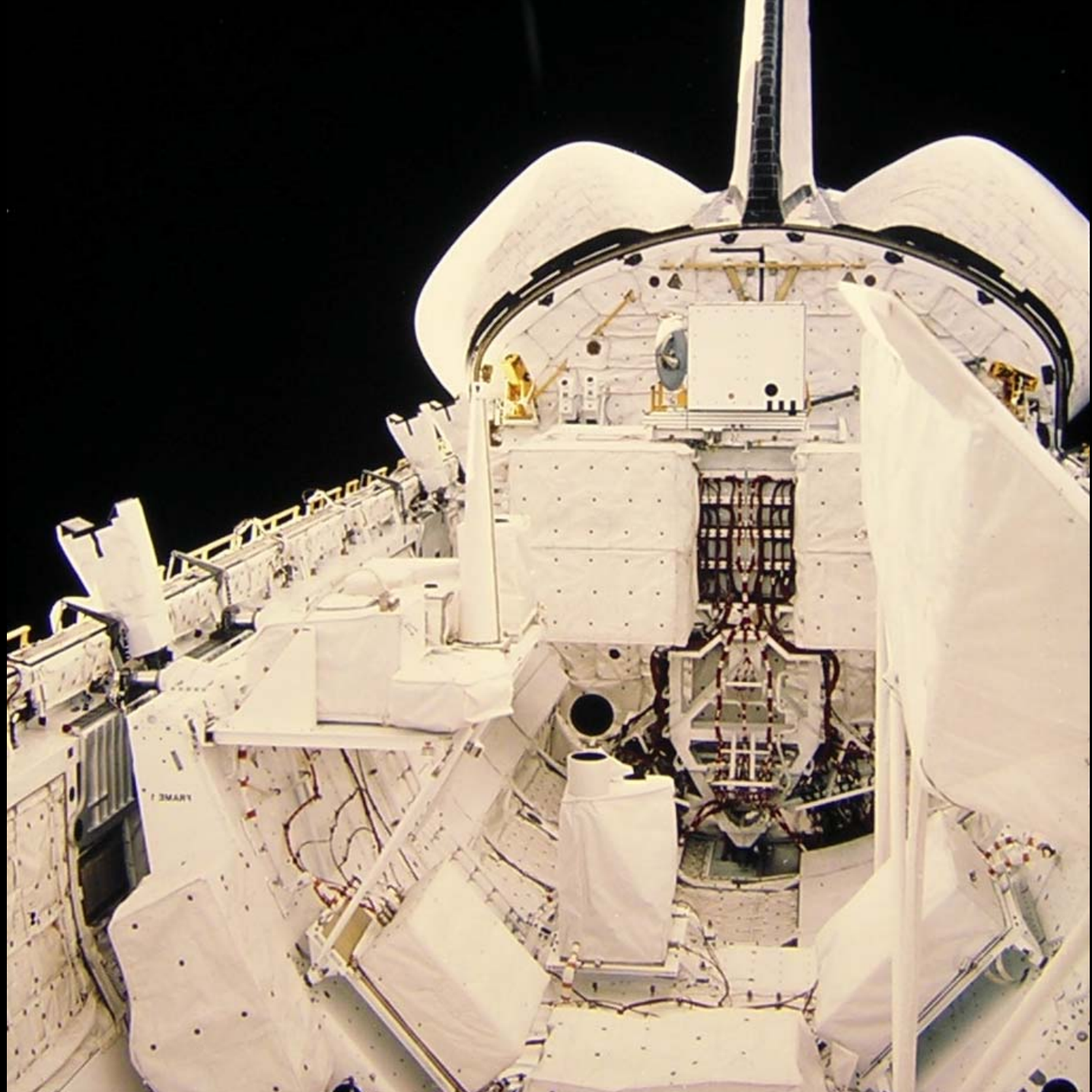
Selling Spectroscopy from Orbit

- Shuttle Multispectral Infrared Radiometer (SMIRR)
- Flew on STS-2 in 1981 along with SIR-A and 3 other instruments

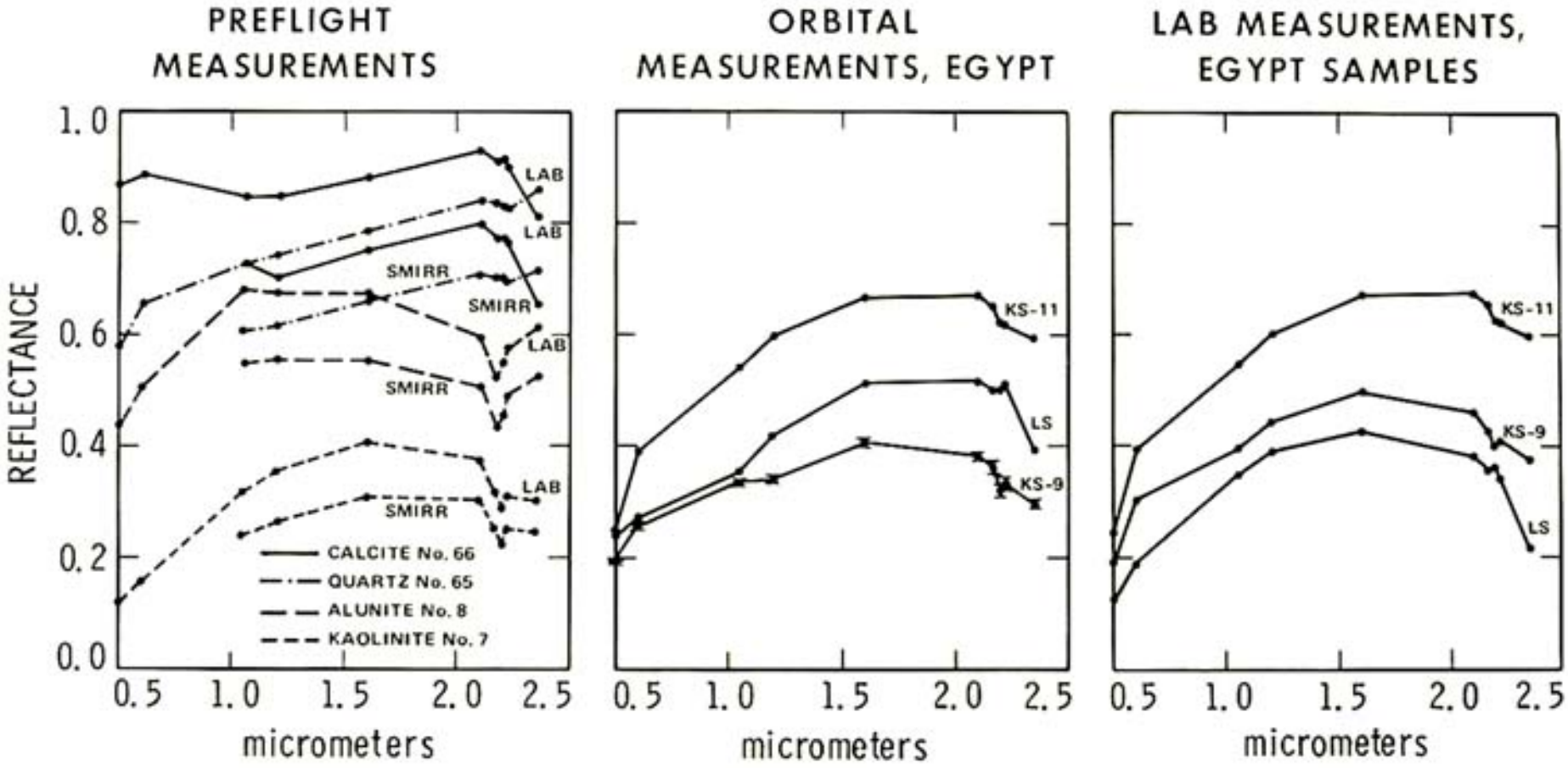

TELESCOPE COVER
DIGITAL ELECTRONICS
CAMERA HOUSING
TELESCOPE MODIFIED MVM '73')
ANALOG ELECTRONICS
POWER SUPPLY
FILM CAMERAS (2)
BASE PLATE
LTER WHEEL
DETECTOR (HgCdTe, 3μ)
FILTER WHEEL MOTOR
SMIRR

SMIRR FILTERS



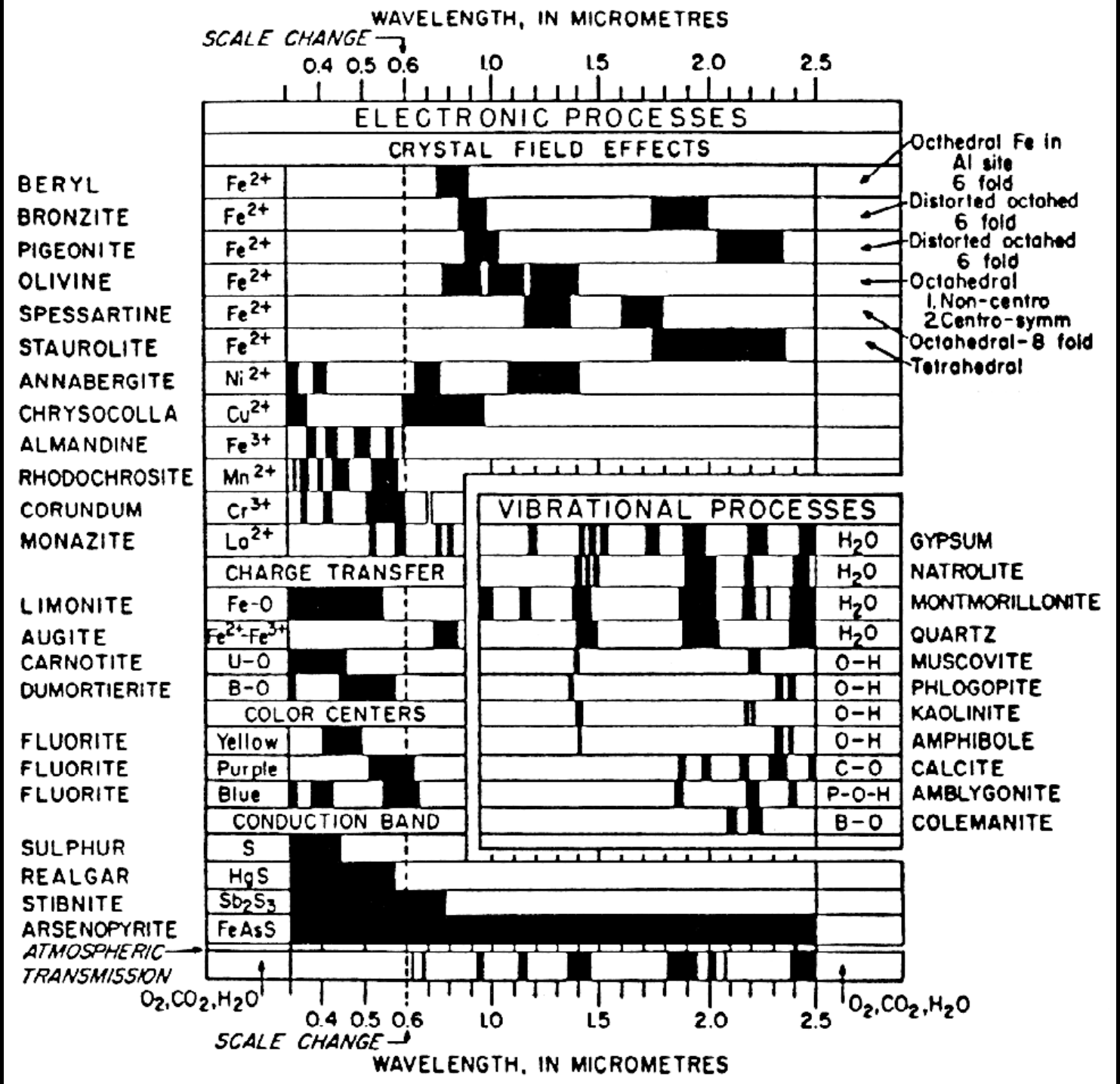


SMIRR RESULTS



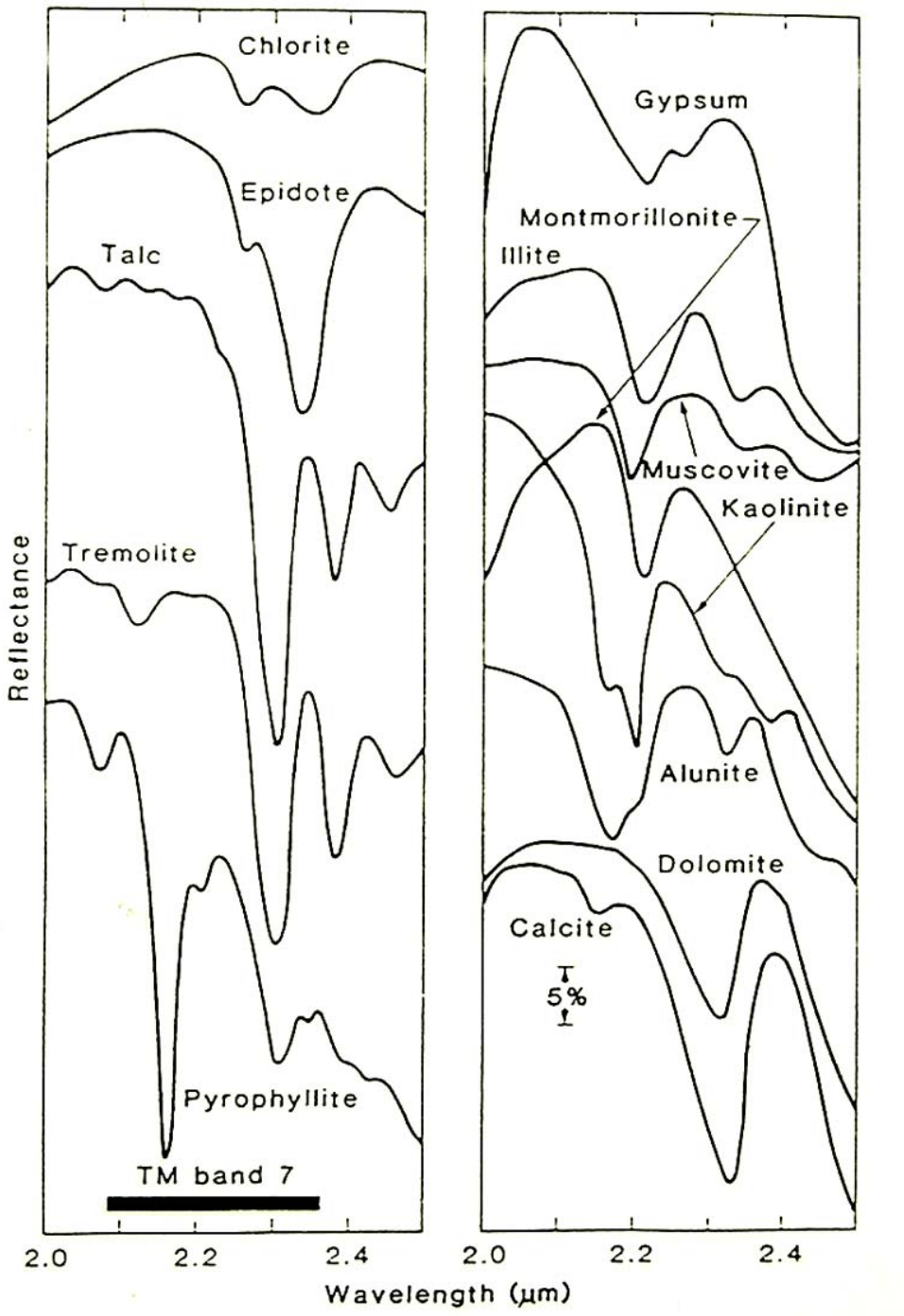
Wavelength Range

- 0.4 – 2.5 μm based on
  - Hunt diagram
  - Solar output crossover
  - Atmospheric transmission
  - Available detectors


WAVELENGTH, IN MICROMETRES
SCALE CHANGE
0.4 0.5 0.6 1.0 1.5 2.0 2.5
ELECTRONIC PROCESSES
CRYSTAL FIELD EFFECTS
BERYL Fe2+
BRONZITE Fe2+
PIGEONITE Fe2+
OLIVINE Fe2+
SPESSARTINE Fe2+
STAUROLITE Fe2+
ANNABERGITE Ni2+
CHRYSOCOLLA Cu2+
ALMANDINE Fe3+
RHODOCHROSITE Mn2+
CORUNDUM Cr3+
MONAZITE Lo2+
CHARGE TRANSFER
LIMONITE Fe-O
AUGITE Fe2+-Fe3+
CARNOTITE U-O
DUMORTIERITE B-O
COLOR CENTERS
FLUORITE Yellow
FLUORITE Purple
FLUORITE Blue
CONDUCTION BAND
SULPHUR S
REALGAR HgS
STIBNITE Sb2S3
ARSENOPYRITE FeAsS
ATMOSPHERIC TRANSMISSION
O2,CO2,H2O
Octhedral Fe in Al site 6 fold
Distorted octahed 6 fold
Distorted octahed 6 fold
Octahedral 1. Non-centro 2. Centro-symm
Octahedral-8 fold
Tetrahedral
VIBRATIONAL PROCESSES
H2O GYPSUM
H2O NATROLITE
H2O MONTMORILLONITE
H2O QUARTZ
O-H MUSCOVITE
O-H PHLOGOPITE
O-H KAOLINITE
O-H AMPHIBOLE
C-O CALCITE
P-O-H AMBLYGONITE
B-O COLEMANITE
O2,CO2,H2O
0.4 0.5 0.6 1.0 1.5 2.0 2.5
SCALE CHANGE
WAVELENGTH, IN MICROMETRES

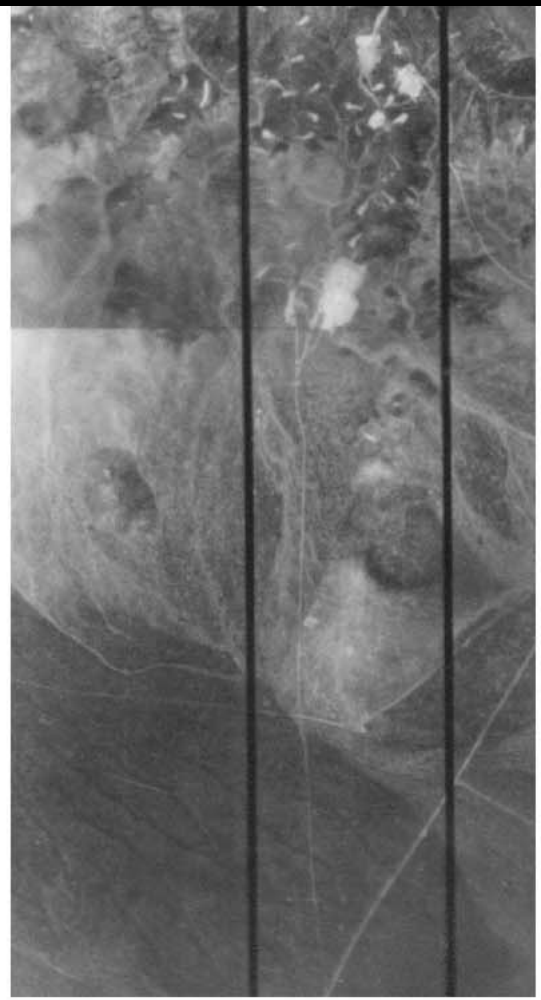
Spectral Resolution Requirement

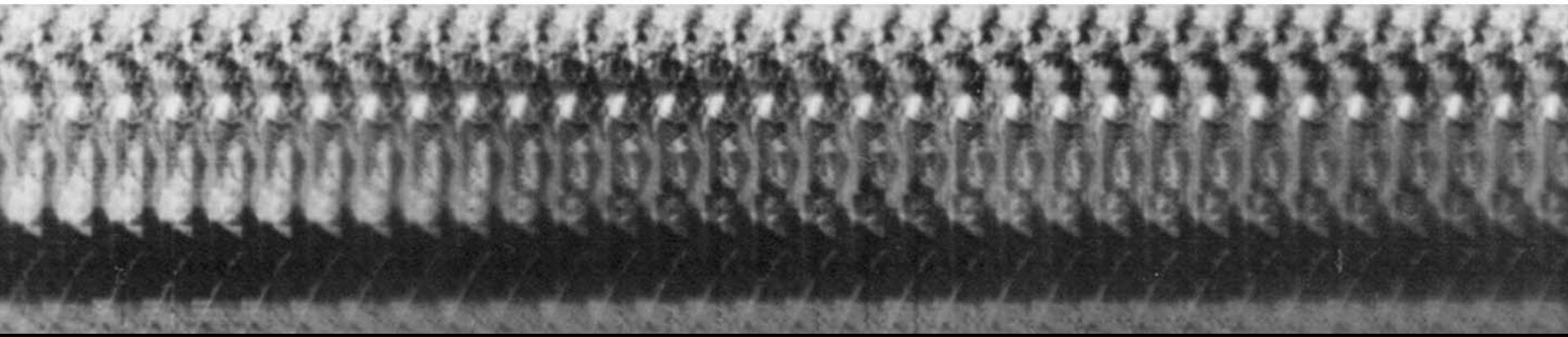
- Based on the FWHM of pyrophyllite
- Two samples per resolution element led to the 10 nm “resolution” value

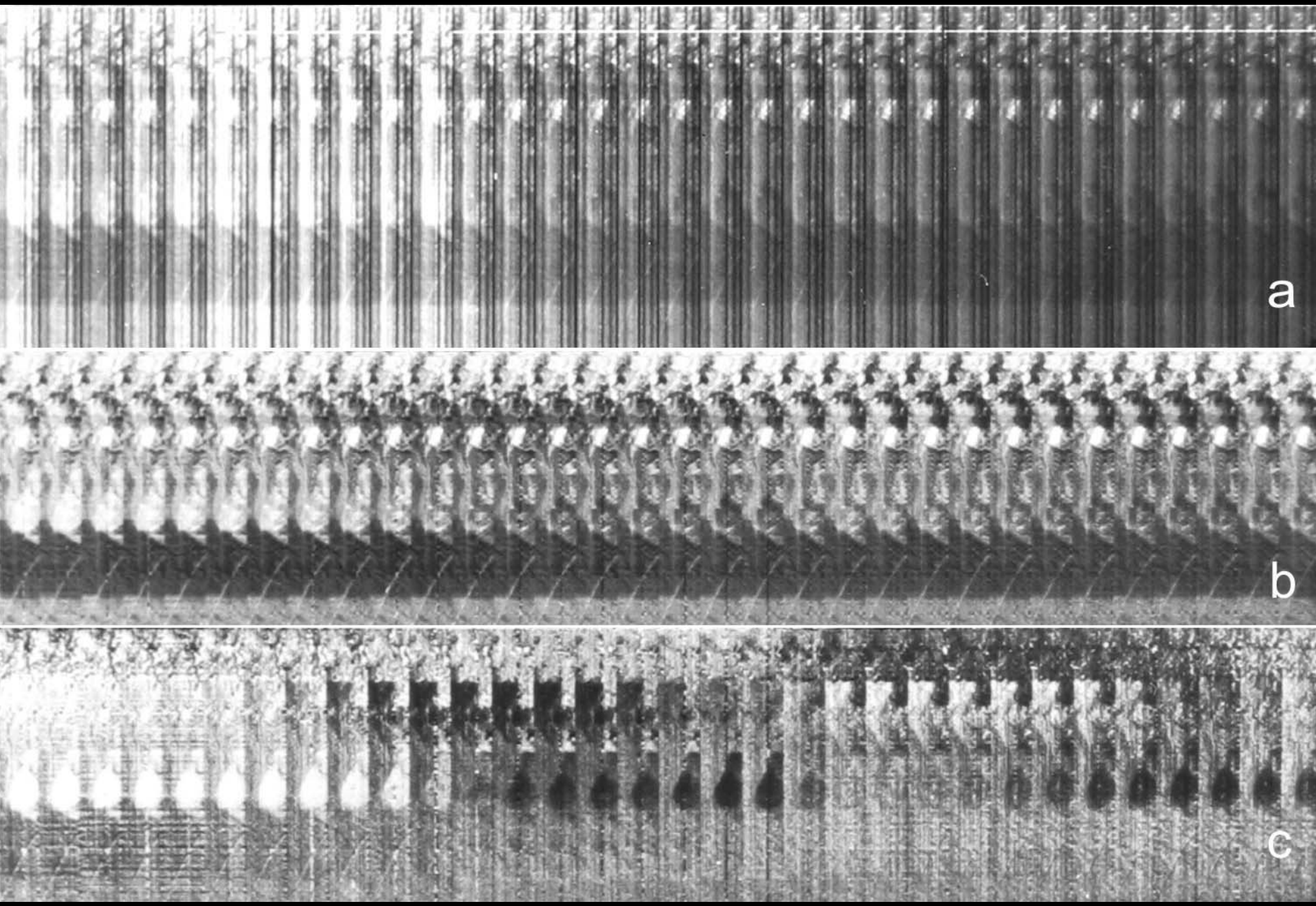

Chlorite
Epidote
Talc
Tremolite
Pyrophyllite
TM band 7
Gypsum
Montmorillonite
Illite
Muscovite
Kaolinite
Alunite
Dolomite
Calcite
5%
Reflectance
2.0
2.2
2.4
2.0
2.2
2.4
Wavelength (μm)

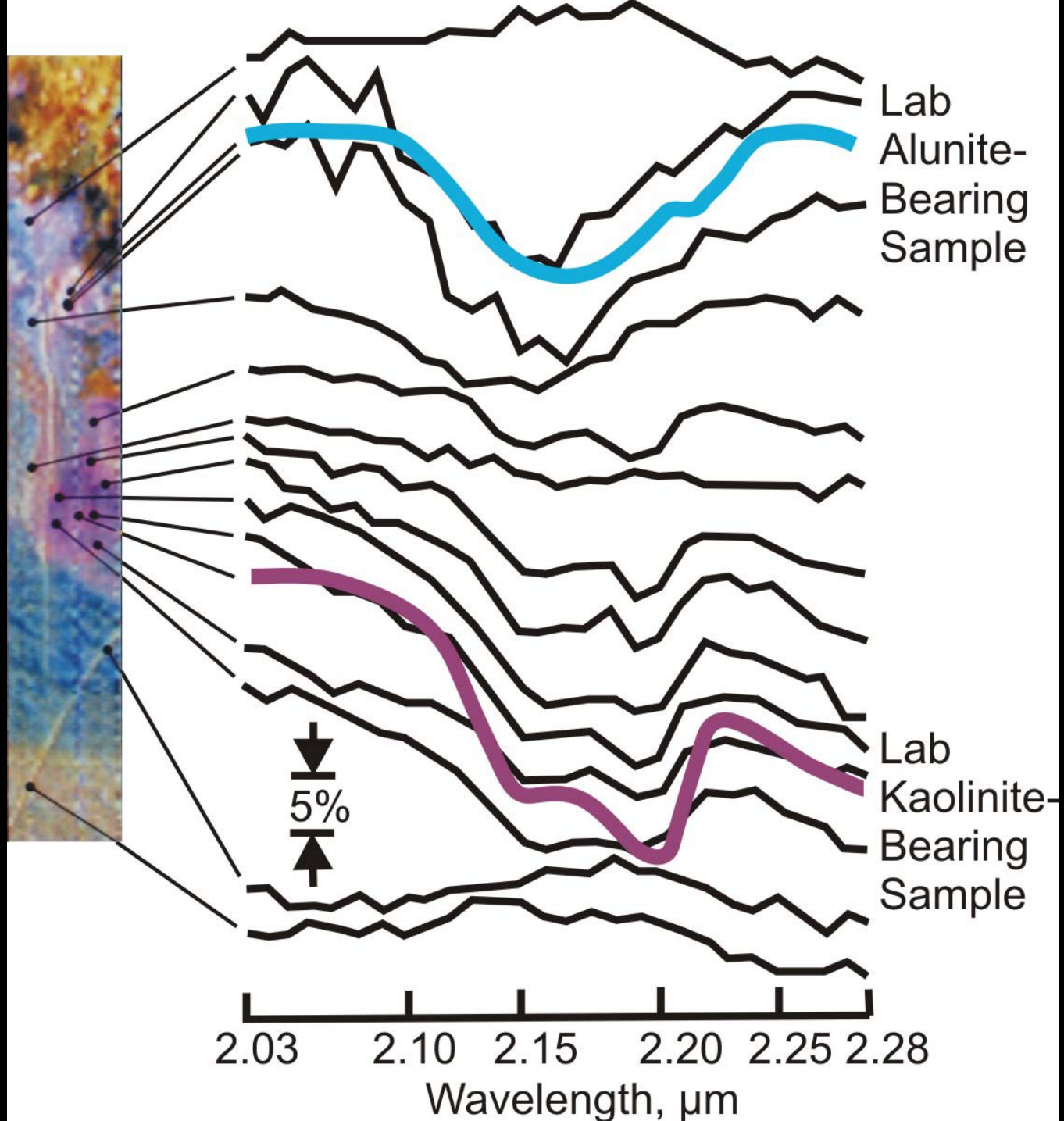
AIS 1983


NASA
707
N707NA





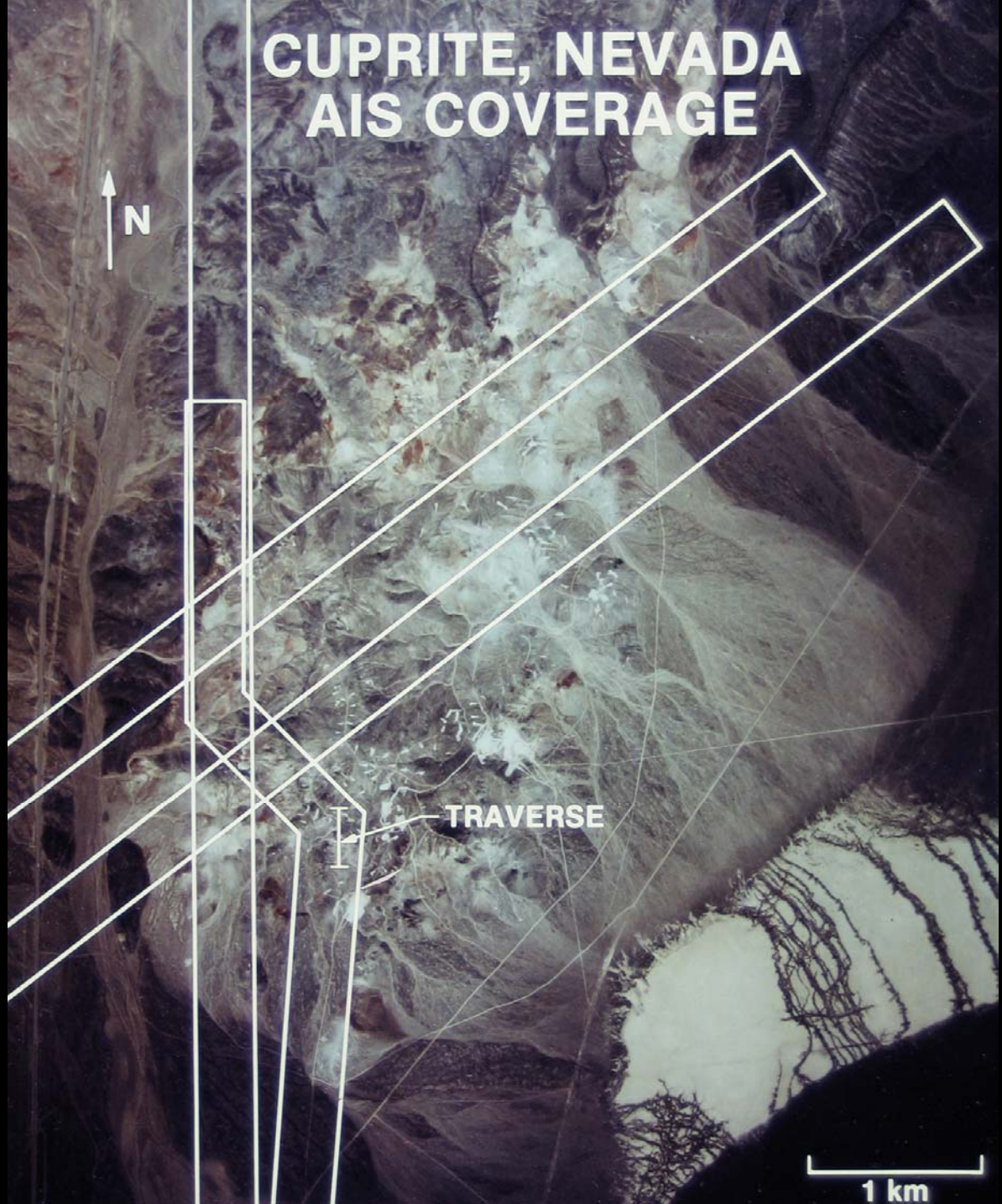

a
b
c


Lab
Alunite-
Bearing
Sample
Lab
Kaolinite-
Bearing
Sample
5%
2.03
2.10
2.15
2.20
2.25
2.28
Wavelength, μm

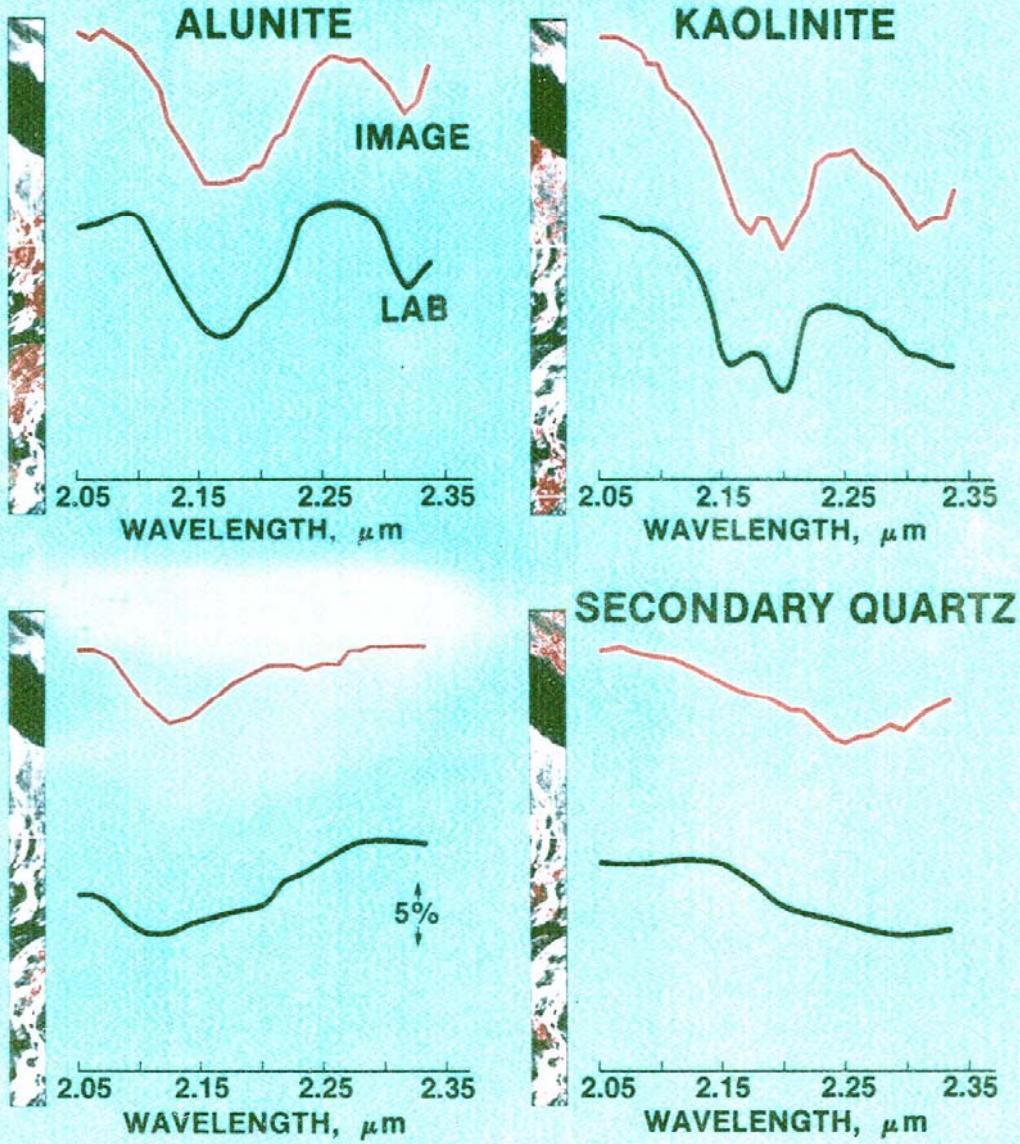
First Publications

- Vane, G., A.F.H. Goetz and J. Wellman, 1984, Airborne Imaging Spectrometer: a new tool for remote sensing, *IEEE Transactions on International Geoscience and Remote Sensing*, vol. GE-22, 546-549

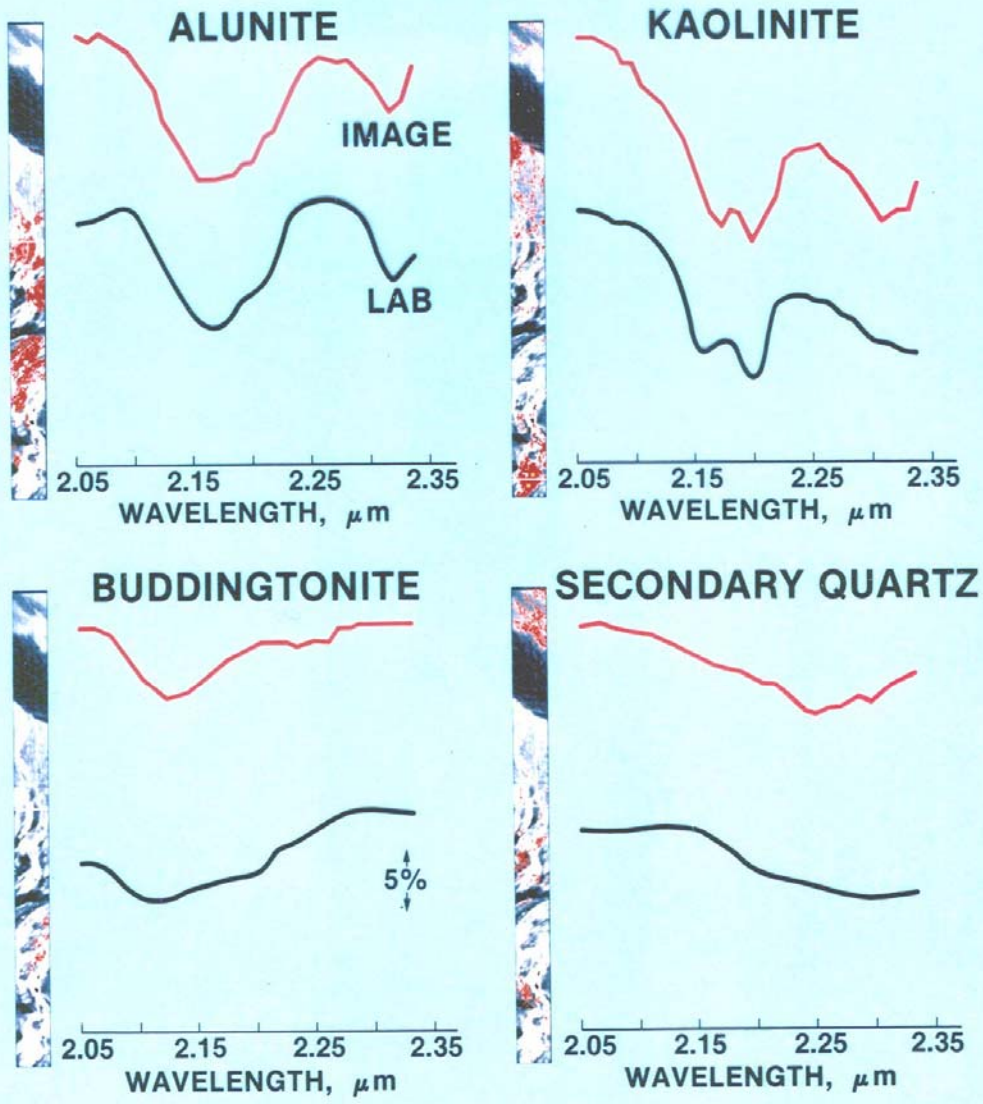
- Goetz, A.F.H., G. Vane, J. Solomon and B.N. Rock, 1985, Imaging spectrometry for Earth remote sensing, *Science,* vol. 228, 1147-1153.
  - First mention of the term “hyperspectral”

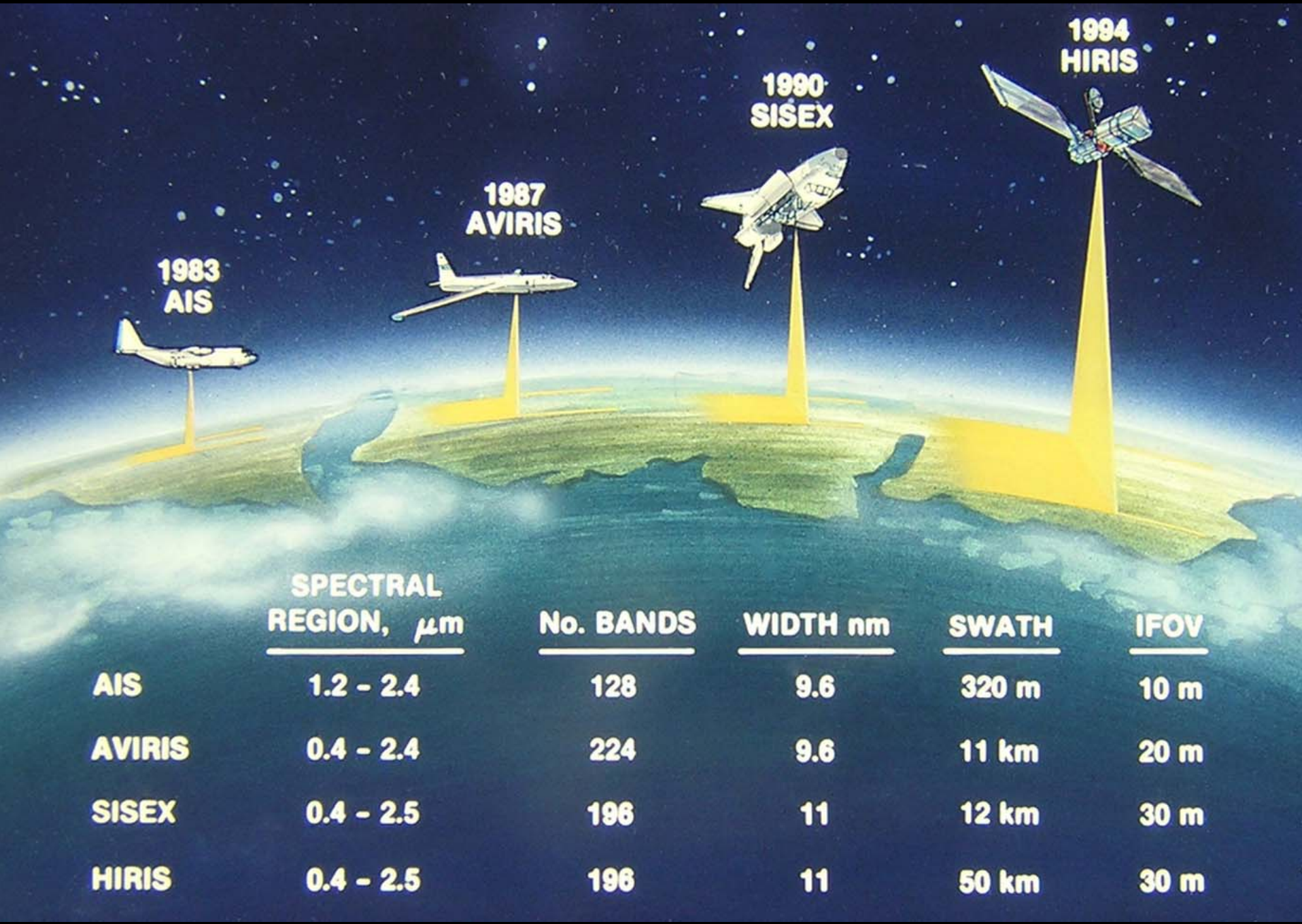

CUPRITE, NEVADA
AIS COVERAGE
N
TRAVERSE
1 km

CUPRITE MINING DISTRICT, NEVADA



CUPRITE MINING DISTRICT, NEVADA





	SPECTRAL REGION, μm	No. BANDS	WIDTH nm	SWATH	IFOV
AIS	1.2 - 2.4	128	9.6	320 m	10 m
AVIRIS	0.4 - 2.4	224	9.6	11 km	20 m
SISEX	0.4 - 2.5	196	11	12 km	30 m
HIRIS	0.4 - 2.5	196	11	50 km	30 m

JPL IMAGING SPECTROMETER SENSORS

	SPECTRAL REGION, μm	No. BANDS	WIDTH nm	SWATH	IFOV
AIS	1.2 - 2.4	128	9.6	320 m	10 m
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SISEX	0.4 - 2.5	192	11	12 km	30 m
HIRIS	0.4 - 2.5	192	11	50 km	30 m

HIGH RESOLUTION IMAGING SPECTROMETER (HIRIS)

TEAM LEADER

Alexander F. H. Goetz, University of Colorado

TEAM MEMBERS

John Aber
University of New Hampshire

Kendall L. Carder
University of South Florida

Roger N. Clark
U.S.G.S., Denver

Curtiss O. Davis
Jet Propulsion Laboratory

Jeffrey Dozier
University of California, Santa Barbara
and Jet Propulsion Laboratory

Siegfried A. W. Gerstl
Los Alamos National Laboratory

Carol A. Wessman
University of Colorado

Hugh Kieffer
U.S.G.S., Flagstaff

David A. Landgrebe
Purdue University

John M. Melack
University of California, Santa Barbara

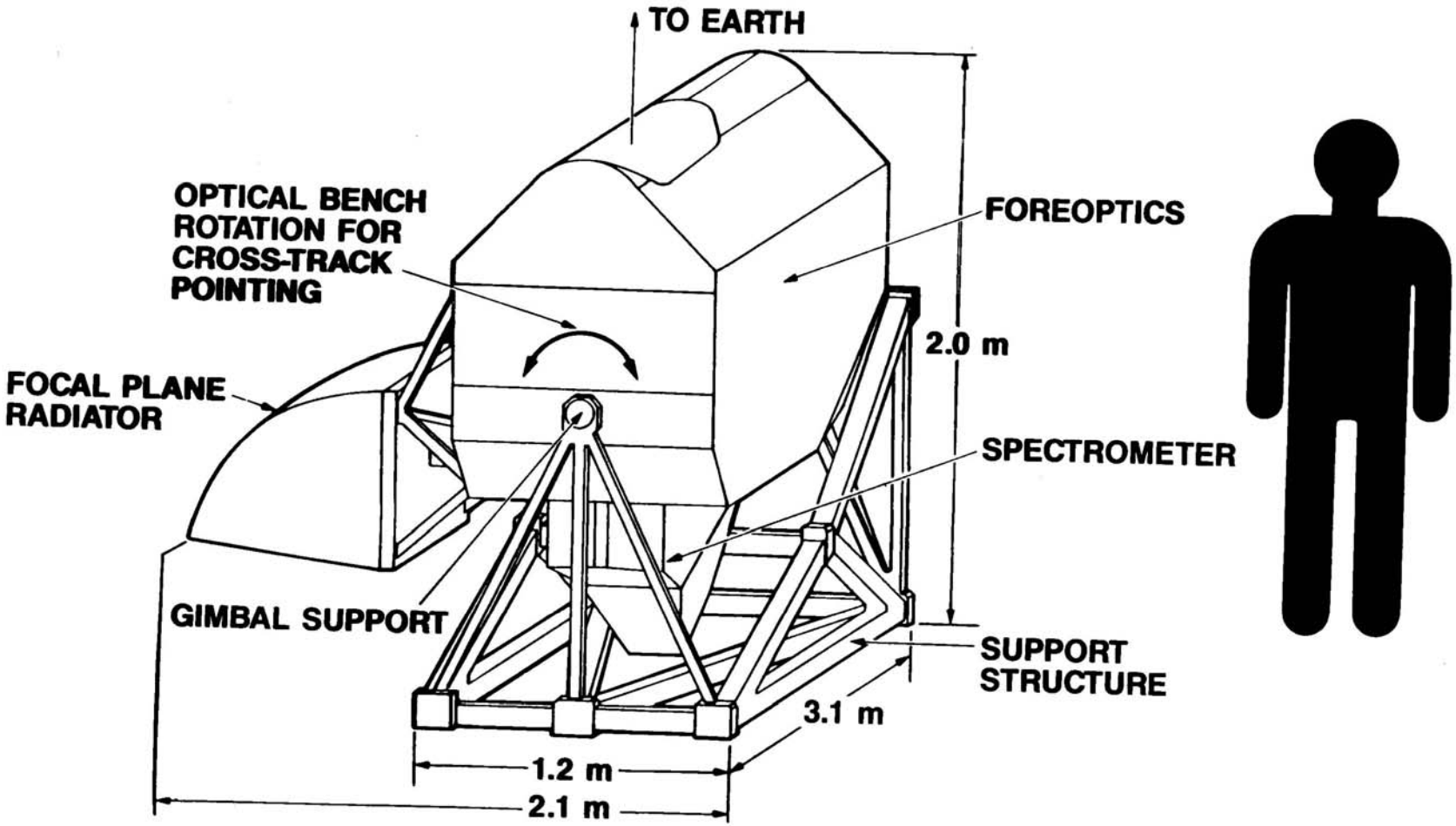
Lawrence C. Rowan
U.S.G.S., Reston

Susan L. Ustin
University of California, Davis

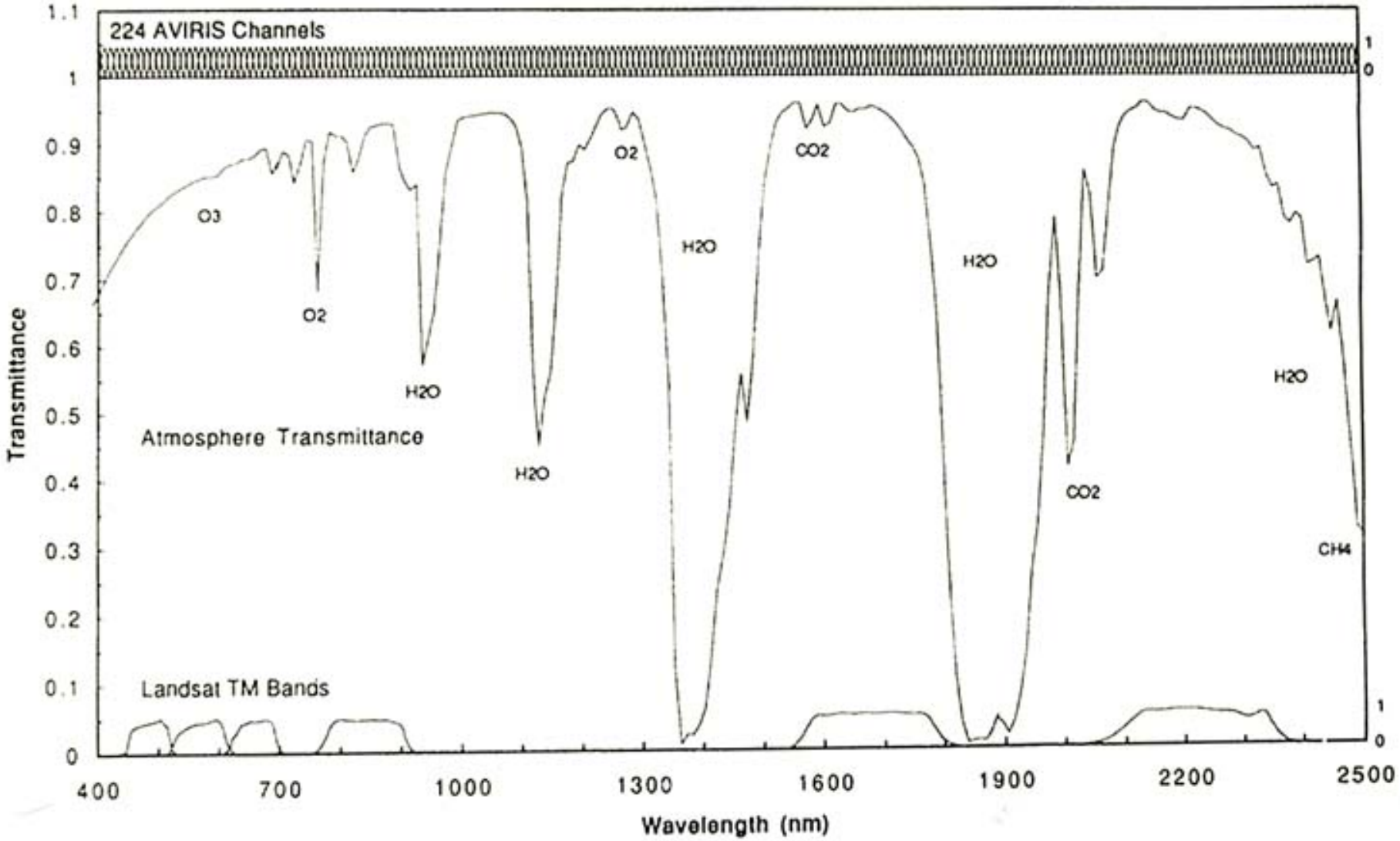
Ronald M. Welch
South Dakota School of Mining
and Technology

JPL

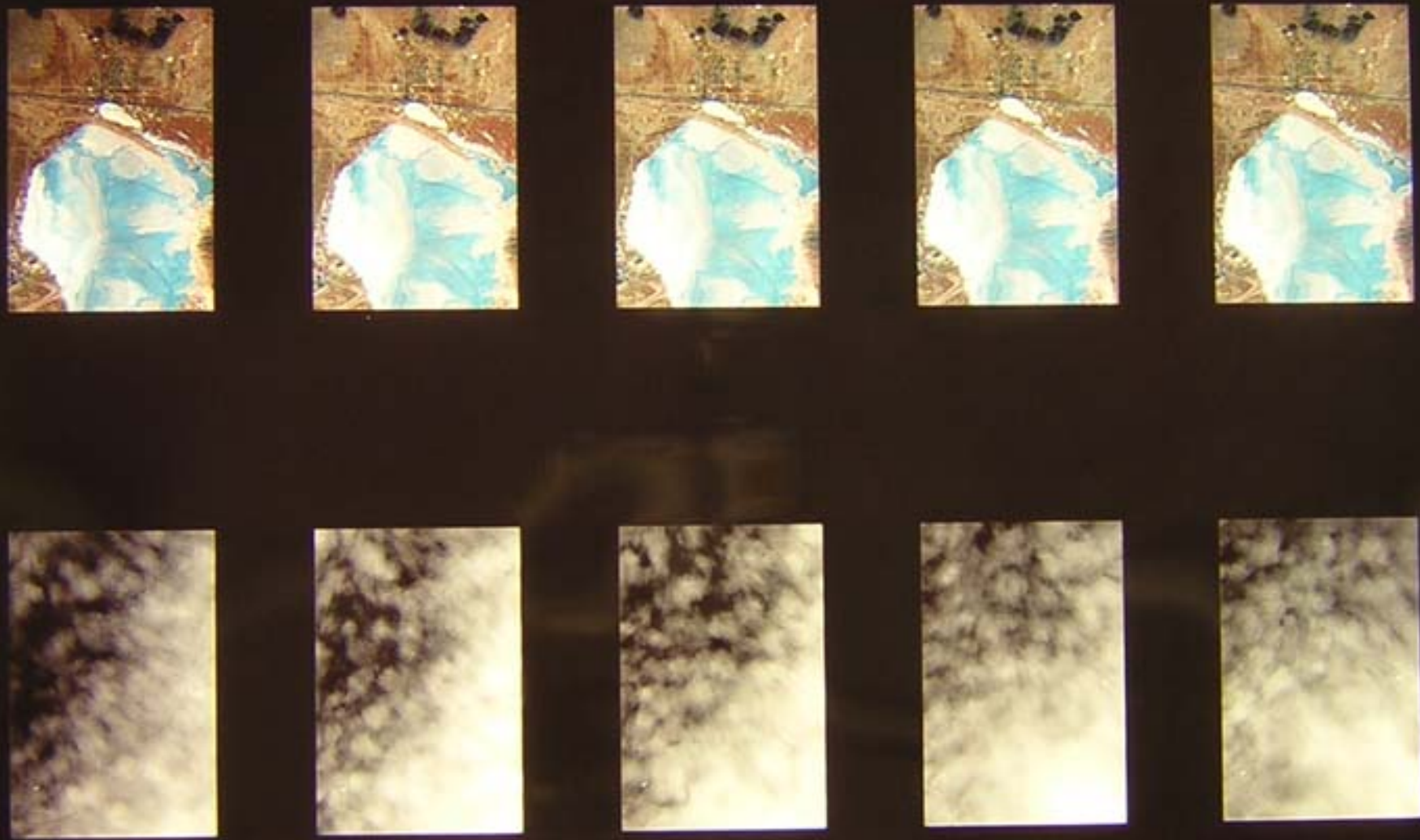
HIRIS
CONCEPTUAL LAYOUT



AVIRIS, TM Spectral Measurements



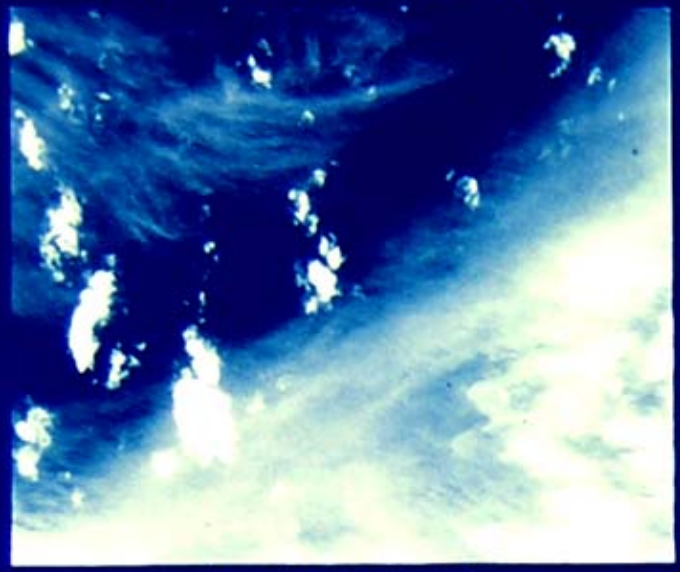
AVIRIS: Water Vapor 15 Minute Interval Time Series Over Rogers Dry Lake, CA on 18 May 1993



Water Vapor Retrieval and Correction

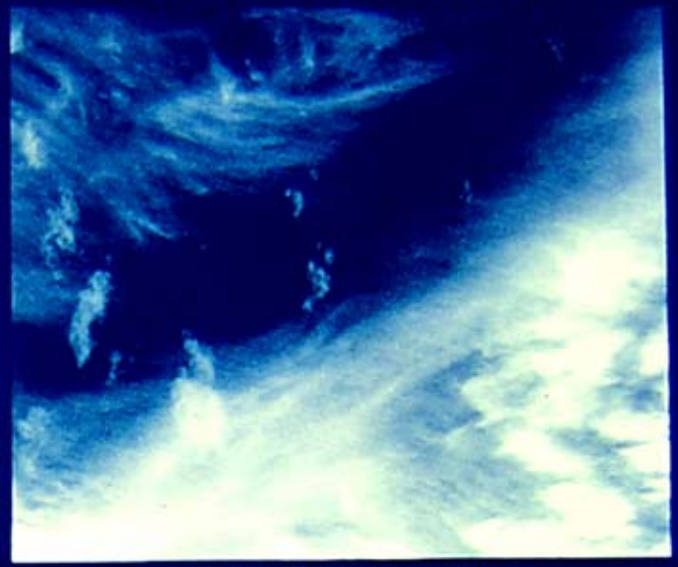
- First paper on calculating water vapor in1988 AVIRIS Proceedings by Jim Conel, Rob Green et al.
- Gao & Goetz, 1990 JGR paper on water vapor and liquid water retrievals
- Gao, Heidebrecht & Goetz 1993 RSE paper describing ATREM

CLOUD IMAGE OVER GULF OF MEXICO (12/5/91)
(0.56 um, B17, RUN: 03, SEG: 04)



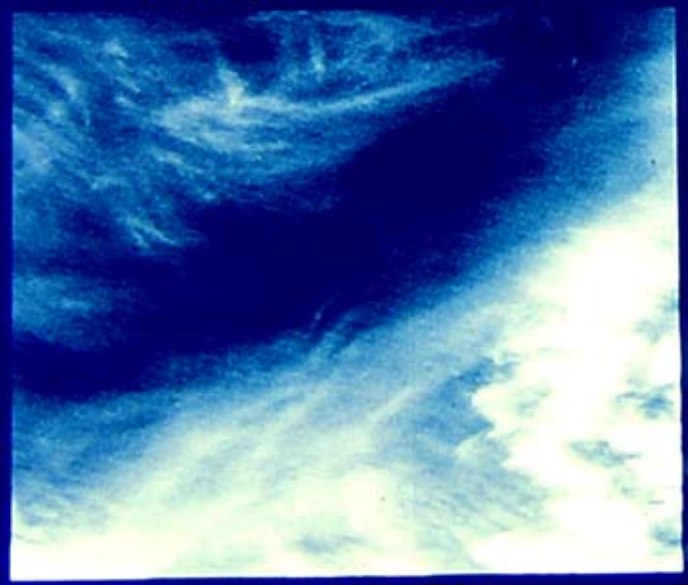
(CSES/U. OF COLORADO)

CLOUD IMAGE OVER GULF OF MEXICO (12/5/91)
(1.35 um, B108, RUN: 03, SEG: 04)



(CSES/U. OF COLORADO)

CLOUD IMAGE OVER GULF OF MEXICO (12/5/91)
(1.38 um, B111, RUN: 03, SEG: 04)



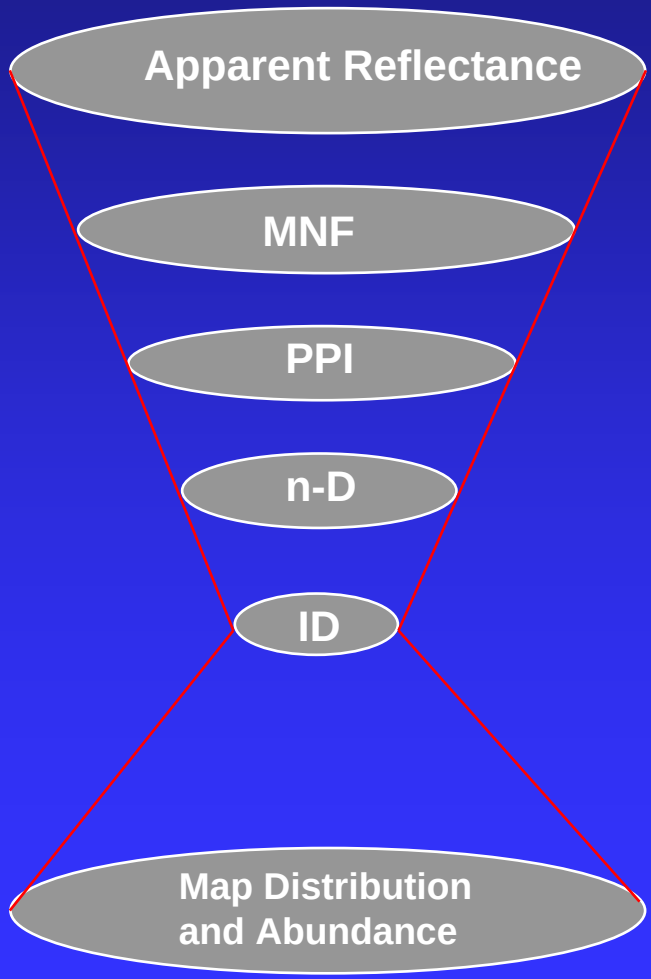
(CSES/U. OF COLORADO)

CLOUD IMAGE OVER GULF OF MEXICO (12/5/91)
(1.60 um, B123, RUN: 03, SEG: 04)

(CSES/U. OF COLORADO)

“Hourglass” Approach

End-to-End Hyperspectral Processing



Spatial/Spectral Browsing

Spectral Data Reduction

Spatial Data Reduction

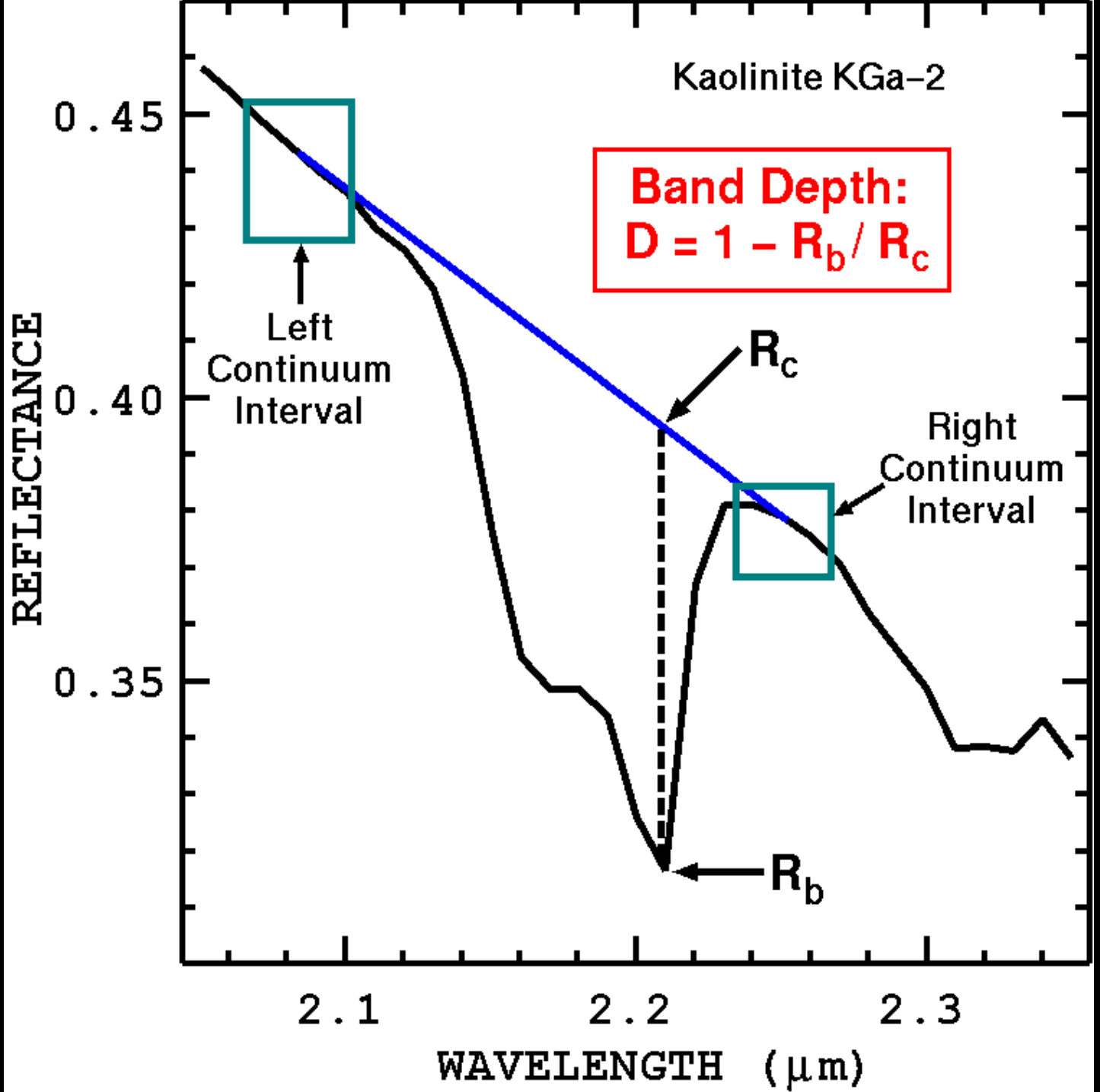
Visualization

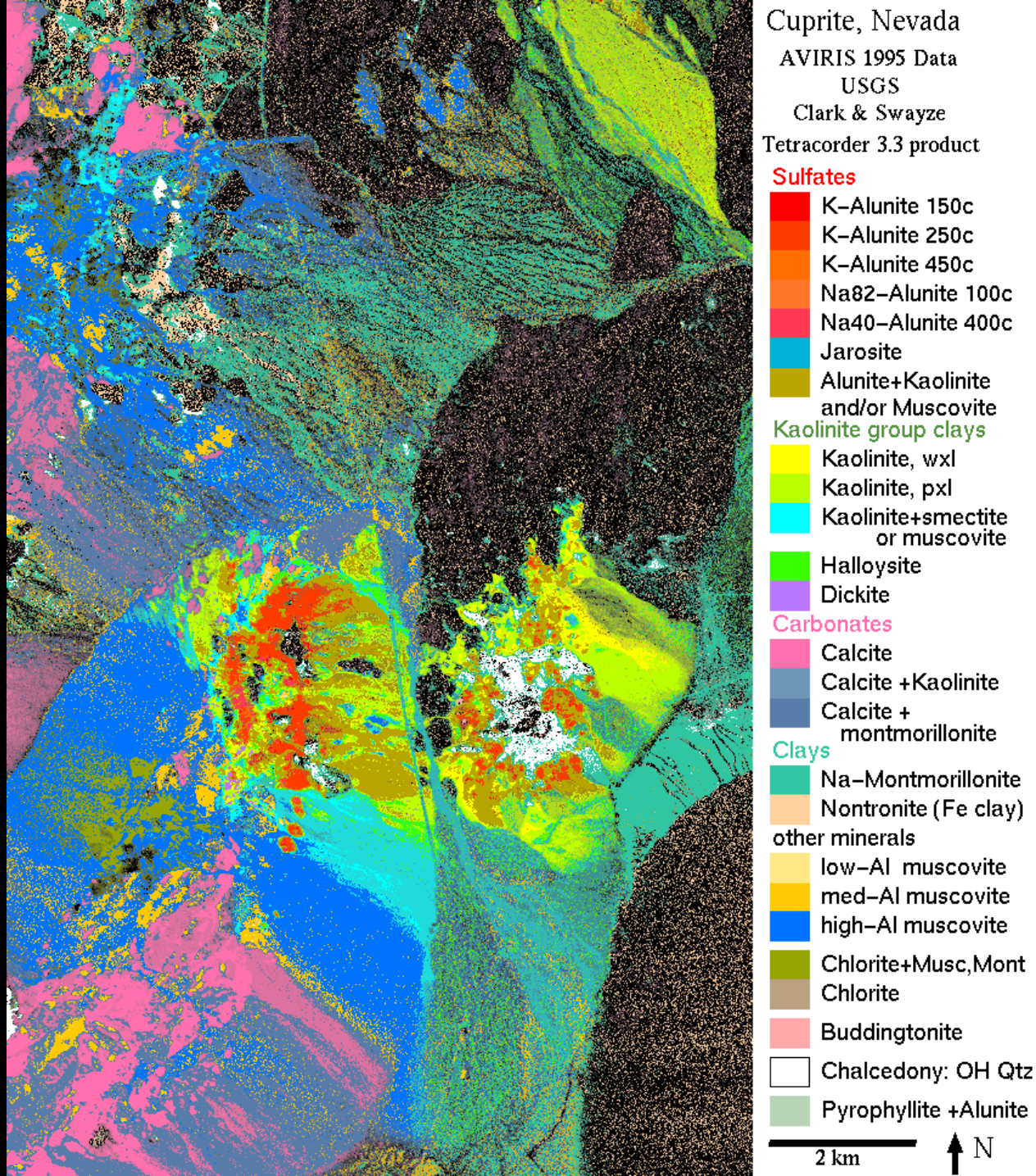
Identification

Mapping

- Binary Encoding
- Spectral Angle Mapper (SAM)
- Linear Spectral Unmixing
- Spectral Feature Fitting
- Matched Filter & MTMF

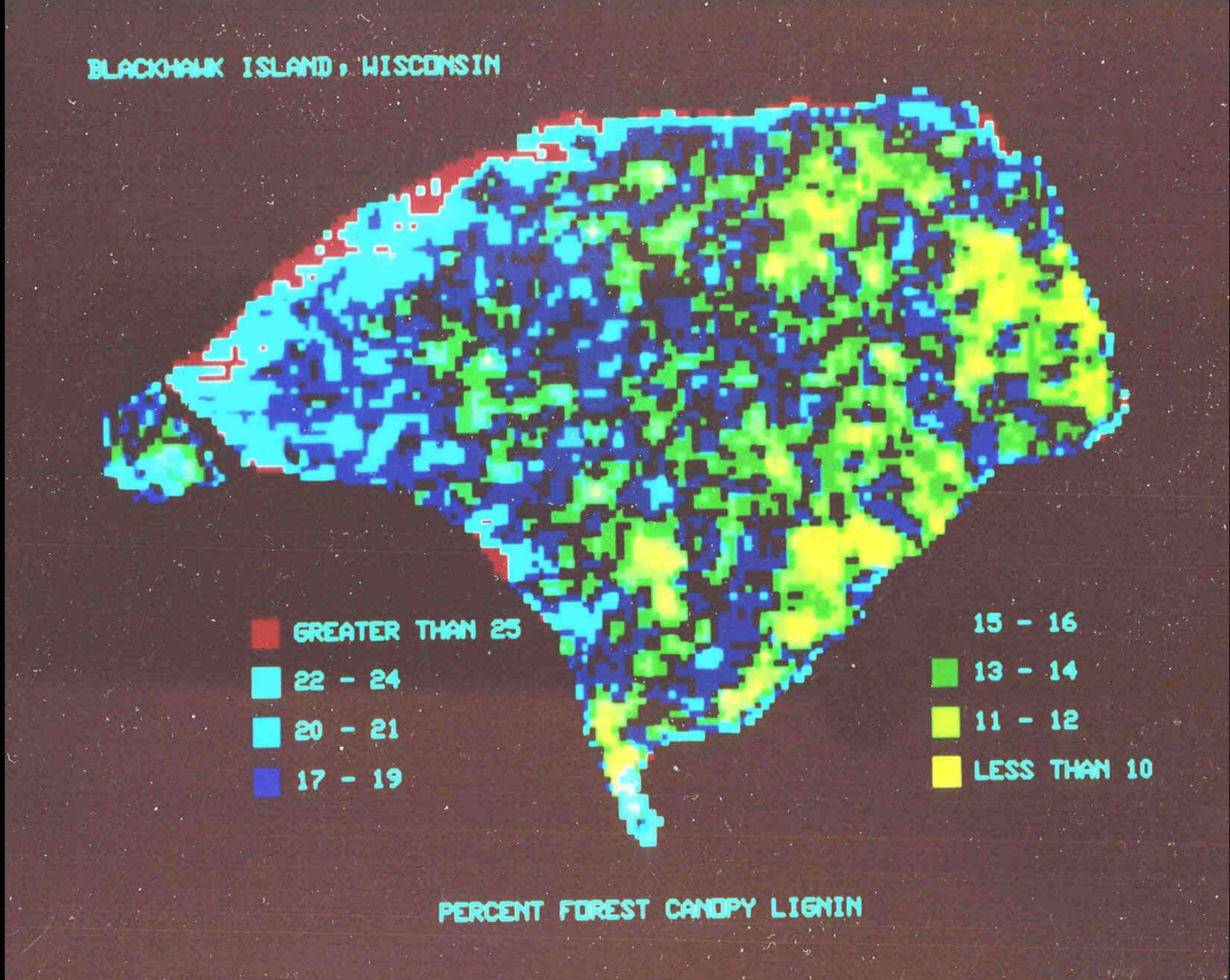
Field Verification: Subpixel Detection and Abundance - 3m x 3m Dolomite


Kaolinite KGa-2
Band Depth:
D = 1 – Rb / Rc
Left
Continuum
Interval
Rc
Right
Continuum
Interval
Rb
REFLECTANCE
0.45
0.40
0.35
2.1
2.2
2.3
WAVELENGTH (μm)


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
N

Regression Techniques

- Wessman CA, Aber JD, Peterson DL, 1988, Remote-sensing of canopy chemistry and nitrogen cycling in temperate forest ecosystems, *Nature,* 335 (6186): 154-156
- Martin, ME, Aber, JD, 1997, High spectral resolution remote sensing of forest canopy lignin, nitrogen, and ecosystem processes, *Ecological Applications,* 7, 431-443

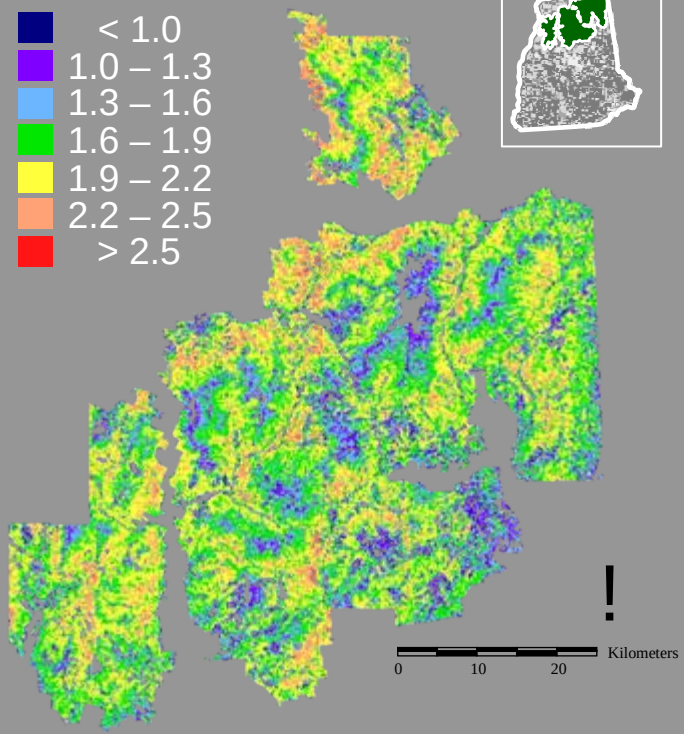

BLACKHAWK ISLAND, WISCONSIN
GREATER THAN 25
22 - 24
20 - 21
17 - 19
15 - 16
13 - 14
11 - 12
LESS THAN 10
PERCENT FOREST CANOPY LIGNIN

Linking leaf chemistry and image data: AVIRIS

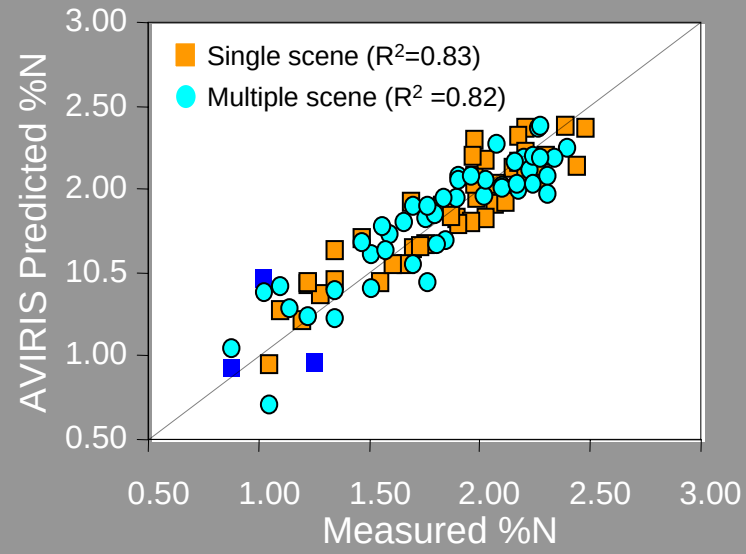
AVIRIS % N estimation using Partial Least Squares regression

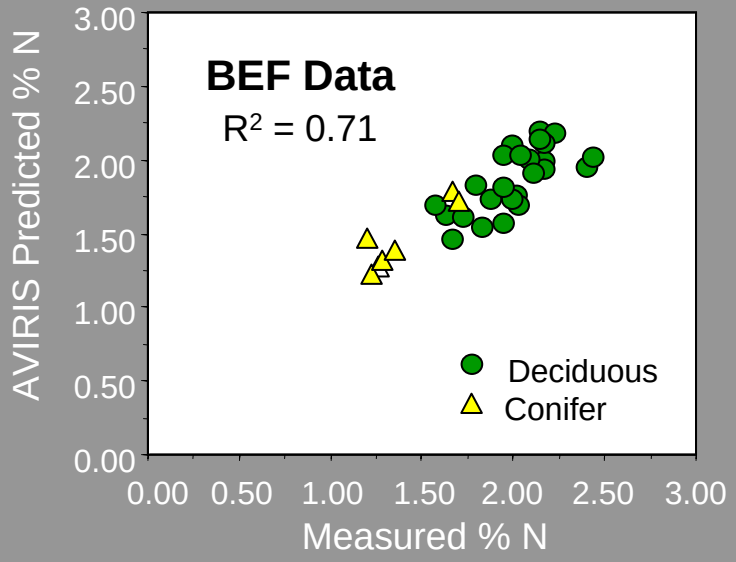
Estimated Canopy % N

1997 AVIRIS Data



Smith, Ollinger et al., Ecol. Appl. (2002)





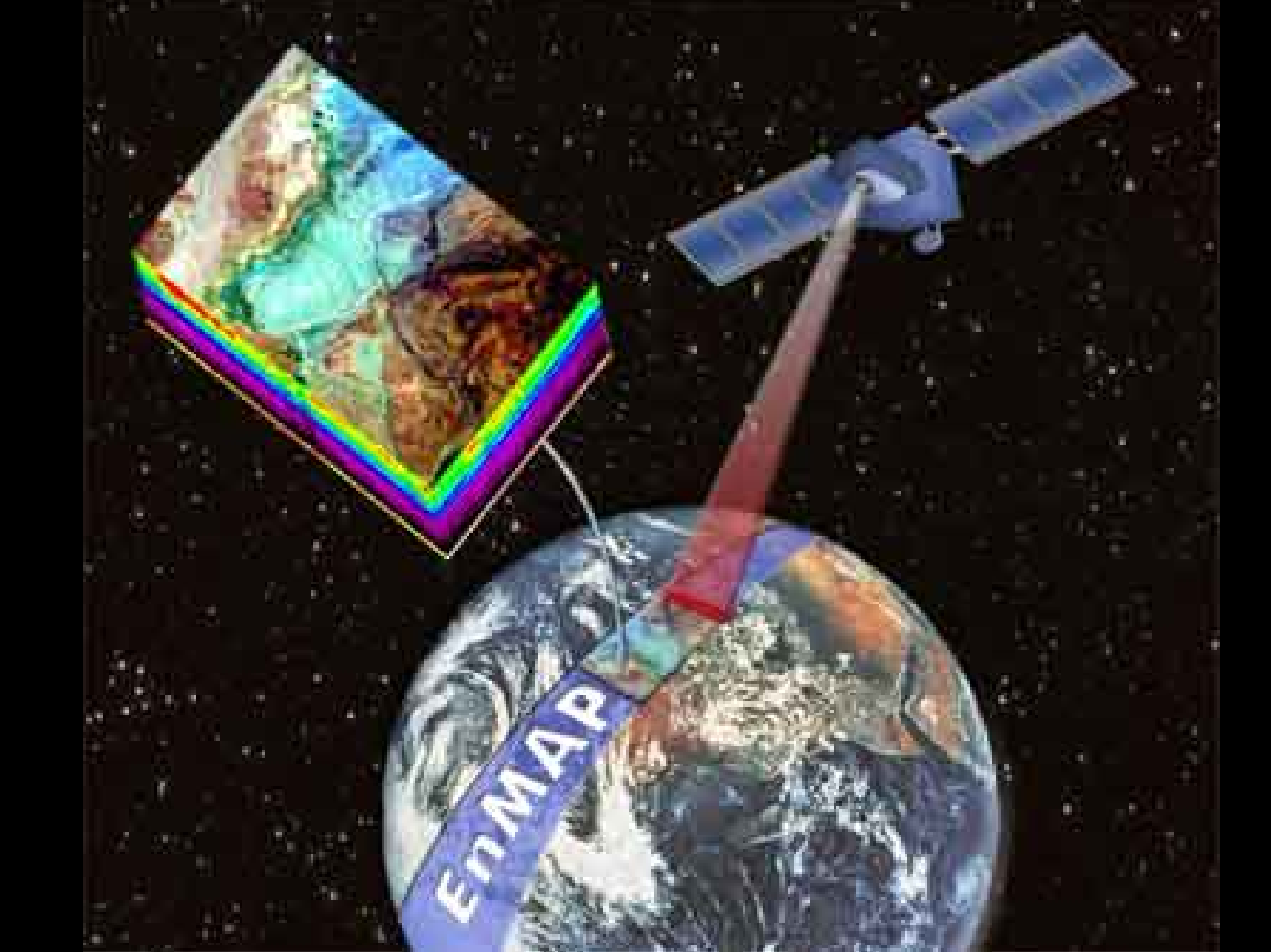
White Mountain National Forest

EO-1

NASA/GSFC

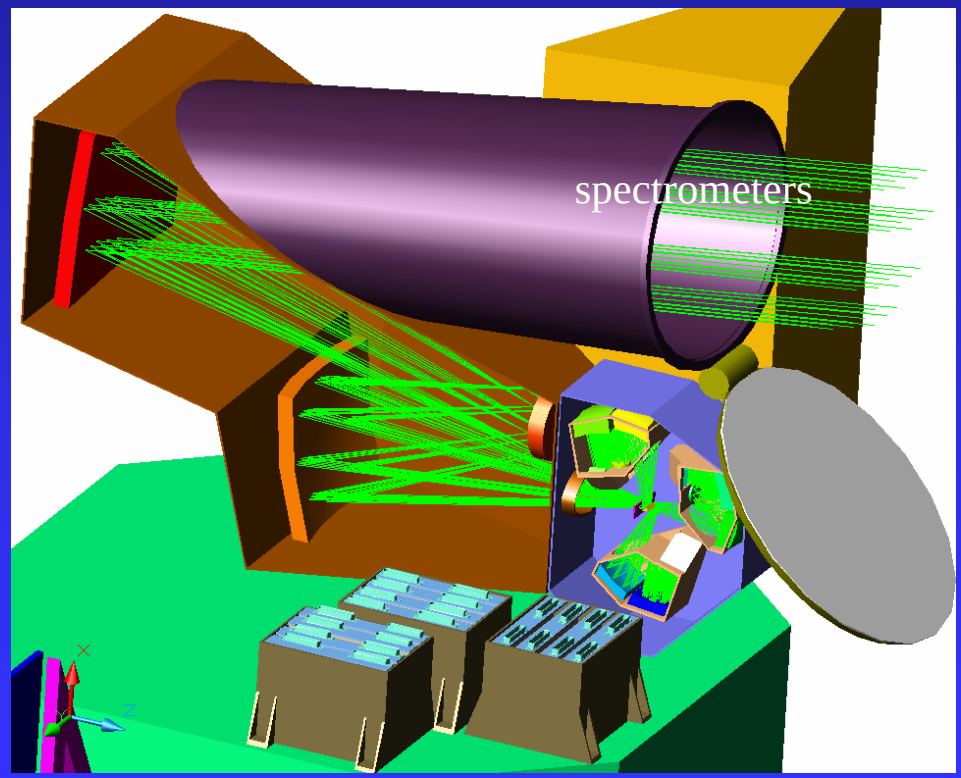
The Future

- Imaging spectrometers for planetary missions
- NASA not planning any for Earth yet
- Hyperion still functioning
- Rest of the world is active
  - Canada – HERO
  - Germany EnMAP
  - Italy – HYPSIO
  - Japan – HYPEREX
  - So. Africa/Belgium - ?


EnMAP

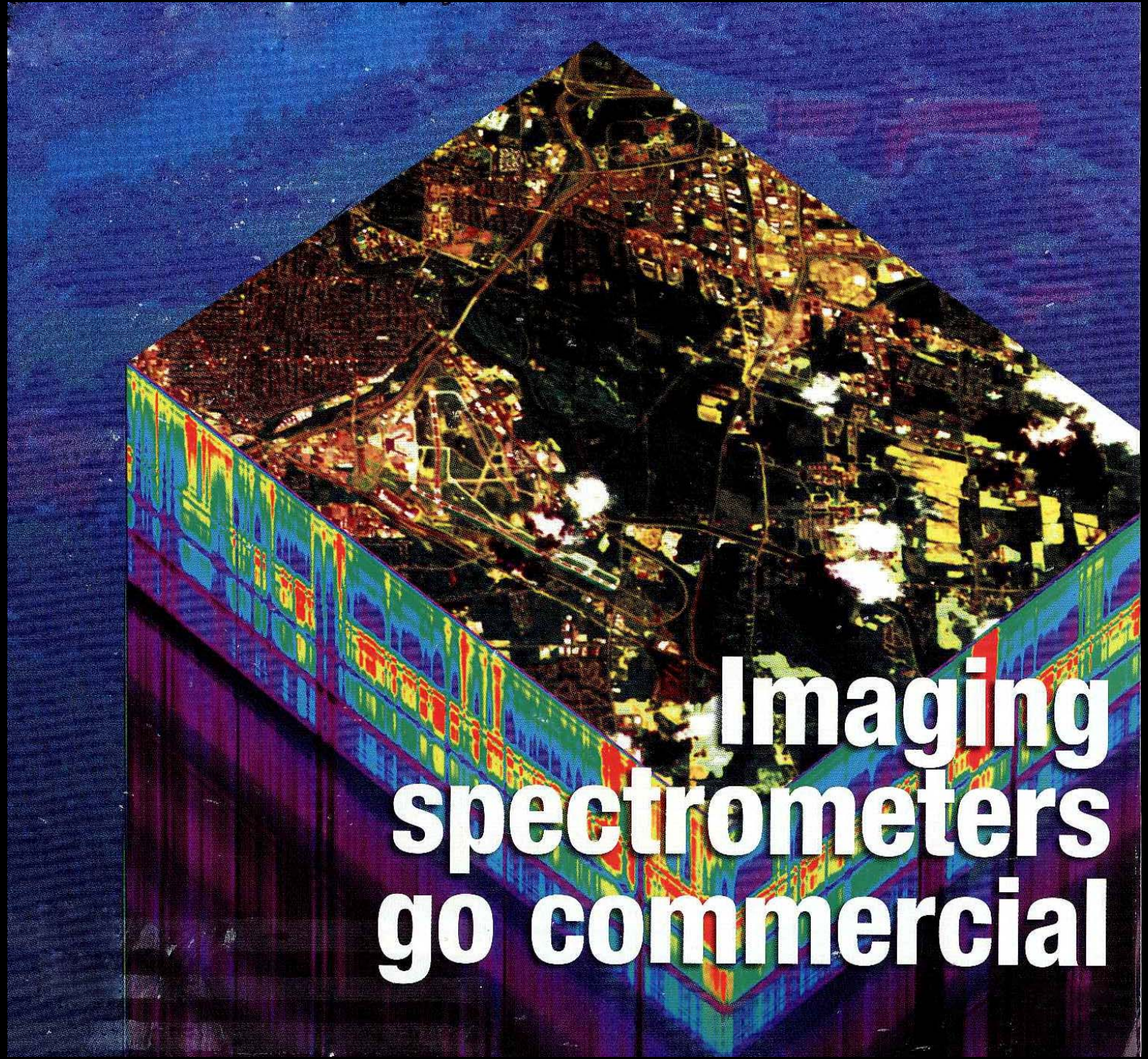
FLORA Spectrometer – 3D Mechanical Rendition

Telescope



Electronics

Telescope door w/ calibration surface



Imaging spectrometers go commercial

Some Observations From the Last 27 Years

- Visionaries are bailed out by technological advances
- Pioneers get shot in the back
- SNR rules!
- New stuff is always too expensive
- Keep plugging. Somebody will make something positive happen just to get you out of their hair