Understanding Worlds through 30 years of Infrared Imaging Spectroscopy

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Overview

• Remote Sensing or Remote Measurement
• Imaging Spectroscopy
• Earth Measurements Examples
• Other Planets and the Moon
• Instrument Evolution and Next Generation Measurements
• Conclusions
Remote Sensing or Remote Measurement
Remote Sensing or Remote Measurement

Reflected sunlight visible to short wavelength infrared
The Origin of Spectroscopy

• Newton generated a rainbow with a prism and described many characteristics of light in Opticks, 1704

• Fraunhofer developed a spectroscope in 1814 and used the observation of dispersed light to understand glass composition as well as to discover the absorption lines in flames and the solar spectrum

• Edwin Hubble used spectroscopy to understand the expanding nature of our universe in 1929

• Spectroscopy is a powerful analytical method that enables remote measurement for scientific discovery and other applications
Imaging Spectroscopy

Each spatial element has a continuous spectrum that is used to analyze the surface and atmosphere.

Early conceptual figure

Requires advanced: detectors, optical designs, computation, etc.
The Pushbroom Imaging Spectrometer Approach

Many Parallel Spectrometers

Detector Array

Spectrometer

Slit

Telescope

Reflectance

Wavelength (nm)

0 400 700 1000 1300 1600 1900 2200 2500

0.2 0.4 0.6 0.8 1.0

NASA
The Airborne Imaging Spectrometer
Proposed at JPL in 1979 (IRAD)

AIS-1982

32x32 HgCdTe Detector
Rockwell Scientific
AIS First Flight Discovery
Buddingtonite Occurrence at Cuprite, NV

\[(\text{NH}_4)\text{AlSi}_3\text{O}_8\]
The Airborne Visible-Infrared Imaging Spectrometer (AVIRIS)

- Proposed 1983 and first flew in late 1986
- F/1 optics; Si, InGaAs, InSb detectors; 200 µm class detectors
- 87 µs integration time; ≥1 M electrons in 10 nm channels for bright targets
- 8700 spectra per second; > 100 Terabytes of data and products
- AVIRIS is mentioned in more than 850 refereed journal articles
- Flew the RIM Fire, CA on the 13th of September 2013 (28 consecutive years)
AVIRIS Image Cube, San Jose, CA

NASA ER-2
Collects images from 20 km (65,000 ft) altitude
Earth Measurement Examples
Cuprite, NV for Mineral Mapping
Field Checking the Spectroscopy at Cuprite, NV
Spectroscopy Enables Sub-pixel Detection

- Grapevine Mountains 20m x 20m AVIRIS measurements

3m x 1m Dolomite discovered with 20m x 20m AVIRIS imaging spectrometer measurement

Boardman and Kruse
Spectroscopy of Vegetation

- Nitrogen & Chemistry
- Leaf Water & Cellular Scattering
- Chlorophyll & Ancillary Pigments
- Cellulose, Lignin, Sugars

Reflectance vs. Wavelength (nm)

- Grassland
- Dryland Vegetation
- non-Photosynthetic
- Conifer
- Broadleaf
Mapping Vegetation Species with Imaging Spectroscopy

Dar Roberts, et al, UCSB

MESMA Species Type 90% accurate

Species Fractional Cover  Quercus agrifolia

Airborne Imaging Spectroscopy, Santa Barbara, CA
Species/Functional-type Map
Shenandoah National Park, USA

- Pinus virginiana
- Pinus virginiana / deciduous mix
- Pinus rigida
- Pinus strobus
- Pinus strobus / Quercus mix
- Tsuga canadensis

- Quercus rubra
- Quercus rubra - Quercus spp. - Carya
- Quercus prinus - Quercus coccinea
- Quercus coccinea / mix
- Quercus velutina / mix
- Quercus alba
- Quercus prinus - Quercus spp. / mix
- Quercus prinus - Acer rubrum / mix
- Quercus prinus
- Carya sp.
Crop type, Crop health, Nitrogen, Leaf water, Soil Composition, Soil Salinity, Soil Carbon, etc.
Photosynthesis Revealed via Spectroscopy

Photosynthesis revealed in the spectrum:

\[
6\text{H}_2\text{O} + 6\text{CO}_2 + \text{energy} \rightarrow \text{C}_6\text{O}_6\text{H}_{12} + 6\text{O}_2
\]
Atmospheric Water Vapor

Water Vapor Absorption

Pasadena Imaging Spectrometer Image

Spectral Fitting 15.92 mm

Water Vapor Map
Shallow Water Spectroscopy
Corals

- Composition
- Condition
- Productivity
- Bathymetry
- Water quality

AVIRIS Image of Kaneohe Bay, HI
Classification of the bottom of coastal zones and coral reef types
A red-tide bloom in Monterey Bay, CA

Surface Chlorophyll from AVIRIS 10/07/02

Surface Chl from SeaWiFS 10/08/02

SeaWiFS bands miss signal
Three Phases of Water
Mount Rainier, WA
Snow and Ice: Albedo, Dust, Melting

- Water availability
- Melting of the Earth’s glaciers.

Nepal Himalaya

Upper Colorado River Basin (T. Painter, JPL)
San Juan Mountains, CO
15 June 2011

\[
\frac{dU}{dt} + Q_m = (1 - \alpha)S + L' + Q_s + Q_r + Q_g + Q_a
\]

Kaspari et al. in prep
World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001
NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS Imaging Spectroscopy
Tetracorder 4.0wpc2 product

Spectral Shape Map
The map assigns materials whose spectra are similar to the reference materials below. It is not a map of the identification of these materials. A similarity map is analogous to a map of materials with similar colors viewed with your eyes. The colors may indicate similar compositions.

- concrete (WTC01–37B)
- concrete (WTC01–37Am)
- cement (WTC01–37A)
- dust (WTC01–15)
- dust (WTC01–26)
- dust (WTC01–36)
- gypsum wall board

Image sampling: 1.7 meters/pixel

Asbestos
2005 Hurricane Katrina Response

OBJECTIVE
- Assess impact of flood and hazards via imaging spectroscopy
- Examples: Flood water composition, particulate distribution, oil contamination, methane leaks, environmental damage, fires, etc.

COLLABORATORS
- Delivery to FEMA
- Roger Clark, Trude King, et al., USGS
- Prof. Susan Ustin, UC Davis
- Prof. Dar Roberts, UC Santa Barbara
- Prof. Greg Asner, Carnegie (CIW) & Stanford
- Robert Green, JPL
- Joseph Boardman, AIG
NASA AVIRIS used by USGS, NOAA and NASA science team to estimate the thickness and volume of the surface oil. Example result: High values at 131 liters/pixel*.

NASA AVIRIS used by a broad government and university science team to map vegetation species and physiological condition (health) before and after oil impact.

*A Method for Quantitative Mapping of Thick Oil Spills Using HySpIRI; Roger N. Clark¹, Gregg A. Swayze¹, Ira Leifer², K. Eric Livo¹, Raymond Kokaly¹, Todd Hoefen¹, Sarah Lundeen³, Michael Eastwood³, Robert O. Green³, Neil Pearson¹, Charles Sarture³, Ian McCubbin⁴ Dar Roberts⁵, Eliza Bradley⁵, Denis Steele⁶, Thomas Ryan⁶, Roseanne Dominguez⁶, and AVIRIS Team³; ¹USGS, ²UCSB, ³NASA, ⁴DRI
Other Planets and the Moon
1989 Near Infrared Mapping Spectrometer (NIMS) to Jupiter

Europa Future?

Reflectance [log]

0.00  0.01  0.10  1.00

800  1800  2800  3800  4800

Wavelength (nm)

0.00  0.10  0.20  0.30  0.40  0.50  0.60  0.70

Scaled Reflectance

0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7

Wavelength (µm)

Icy Plains (2)
Linea (3)
MgSO₄·11H₂O

Ref: Ice Rich
Ref: Ice Poor
1997 Visual and Infrared Mapping Spectrometer (VIMS) to Saturn

Saturn's Rings
Cassini VIMS
S42 Rev 75 latphase
RC17 calibration
10 Degrees Phase Angle
Fill-Factor Corrected

Titan

Reflectance
Wavelength (μm)

Tholin R80MP CH4:N2=90:10 *0.5
Tholin Run103 N2:CH4=90:10 *0.5
Iron Powder < 10 microns
Signa-Aldrich 0115CE 293 K

Scaled Reflectance
Wavelength (μm)

Nickel, Sigma 01509/BW
< 1 micron

Lapetua dark material
S33, rev 40, offset 0.06
VIMS, 2240 pixel average
calibration RC17

Image of VIMS equipment
2005 CRISM to Mars

- Spectral: 400 to 4000 nm
- Spatial: 12 by 12 km @24
Moon Mineralogy Mapper (M3)

- Lunar Mineral Separates
  - Soils
  - Adsorbed Water
  - Olivine
  - Pyroxenes
  - Plagioclase
- Apollo 17 Lunar Basalt Samples
  - 79221 (soil)
  - 75035 (rock)

Human Vision

Light Wavelength (nm)

Reflectance

- Plagioclase
- Olivine
- Cr-Spinel
- Melt-G
- Melt-C
- Pyroxenes
- Adsorbed Water
M3 Pre Ship

Launch 22 Oct 2008, India

Chandrayaan-1

Teledyne 6604a
430 to 3000 nm
Substrate removed

24 Month Build (8 Kg, 15 Watts)
Minerals were mapped within three days of first light.
M3 Hydroxyl/Water on the Moon

Unexpected Minerals

Mineralogy

A three-color mosaic derived from the Moon Mineralogy Mapper (M3) near-infrared spectrometer. Orange and pink colors illustrate the distribution of iron-bearing minerals. Green represents the surface brightness at 2.4 micrometers. Blue indicates the presence of small amounts of surface OH and H2O that are most prominent at these viewing geometries at cooler, higher latitudes. See page 55b.

Image: NASA/ISRO/Brown University/R. Clark, USGS
Chlorophyll

M3 Looking Back at Earth 2009

Projected IFOV: 269 km
Cross-track samples: 47
1009 nm
2497 nm
2816 nm
Instrument Evolution and Next Generation Measurements
Imaging Spectrometer Optical Advances

• An Offner spectrometer enables uniform spectroscopy using a slit, two spherical mirrors, a convex grating, order sorting filter (OSF) and detector array.

• The grating on a convex surface is the key. The slit, optical component mounts, OSF and detector also have critical requirements.

Detectors Advances: Increase in Array Size and Spectral Range

- 32 x 32
- 640 x 480
- 2048 x 2048
- 1280 x 480... Larger
2012 AVIRIS-Next Generation
Substrate removed MCT 380 to 2510 nm

Alignment Complete

>95% cross-track and IFOV uniformity

“Smile”

“Keystone”
2012 Ultra Compact Imaging Spectrometer (UCIS) <3kg < 3W

Substrate removed MCT 500 to 2550 nm
Pisolithic Ironstone with <100 µm spot
Exoplanet Worlds

Spectroscopy of Exoplanets

- Provides access to information about molecules, atmospheric conditions, composition

Imaging strategies exist

Disequilibrium chemistry

- Spectroscopy could provide the first evidence for life beyond Earth

Understanding Worlds with Imaging Spectroscopy
Conclusions

- Spectroscopy reveals physics, chemistry, and biology and related processes
- With advances in detectors, optics, and electronics, imaging spectroscopy became feasible in the late 20th Century (AIS)
- Since its inception, the use of imaging spectroscopy on Earth and throughout the solar system has been proven and expanded extraordinarily
- There are now a suite of compelling science research examples for understanding worlds from the micron scale to exoplanet distances
- Imaging spectroscopy enables remote measurement for the 21st Century
Thank You!

Images raise questions and spectra answer them!