Remote Sensing and The Signal

NASA JPL AVIRIS Image Data Set

2003 AVIRIS Workshop

Imaging Spectroscopy, AVIRIS, Calibration, & Atmospheric Correction

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Overview

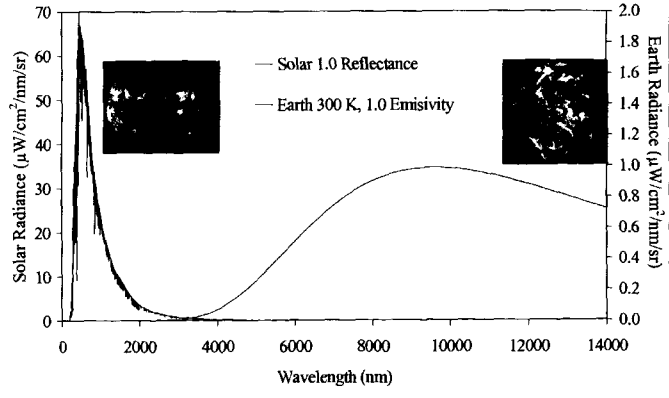
- Remote Sensing and the Signal
- Imaging Spectroscopy
- AVIRIS
- Characterization and Calibration
- Atmospheric Correction
- Summary

Remote Sensing
and The Signal

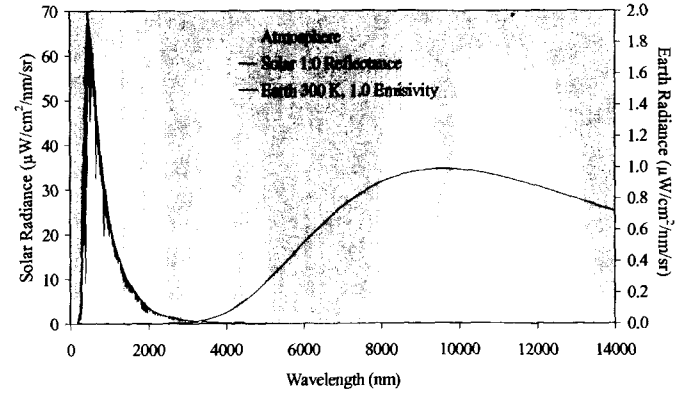
Remote Sensing

- Broad meaning: Deducing the properties of a materials without physical contact.
- Common usage: Deducing the properties and spatial relationships of constituents in the Earth's land, water, and atmosphere environment by measuring electromagnetic radiation.
- Common optical spectrum implementation: Multi-spectral imagers with discrete, broad bands (Landsat, AVHRR, SPOT, etc.)

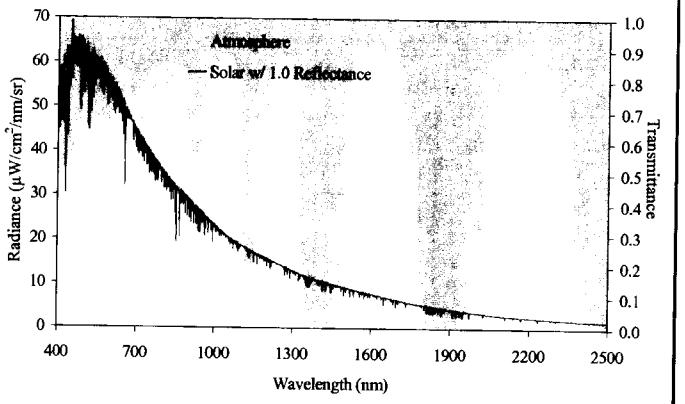
Available Signal in the Optical Spectrum



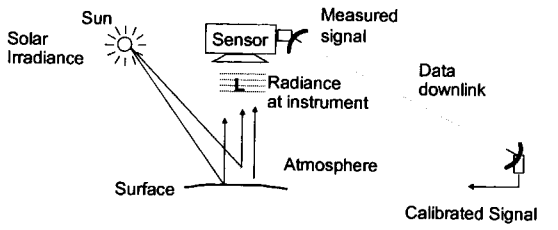
Transmittance of the Atmosphere



Solar Remote Sensing Signal and Transmittance of the Atmosphere

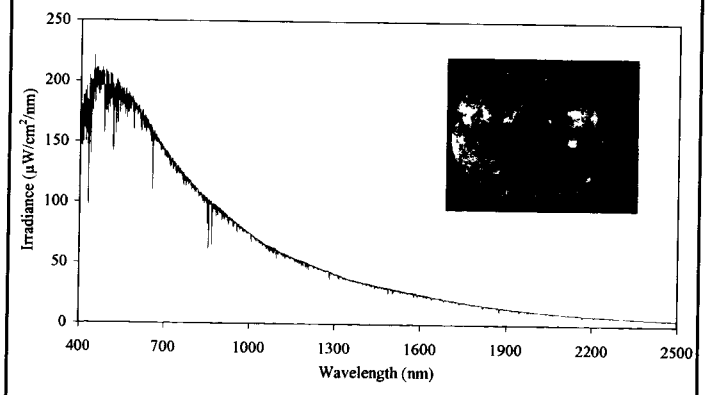


Earth Solar Reflected Energy Remote Sensing

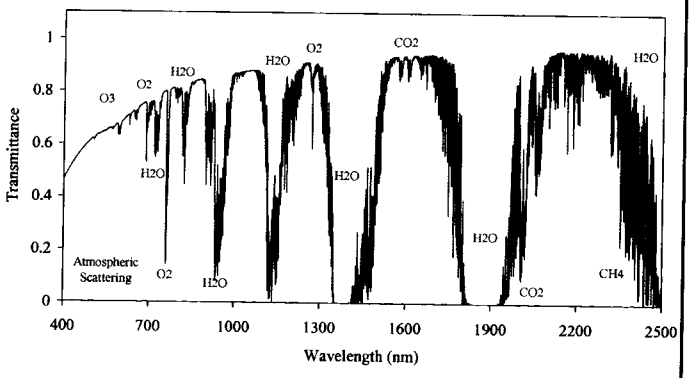


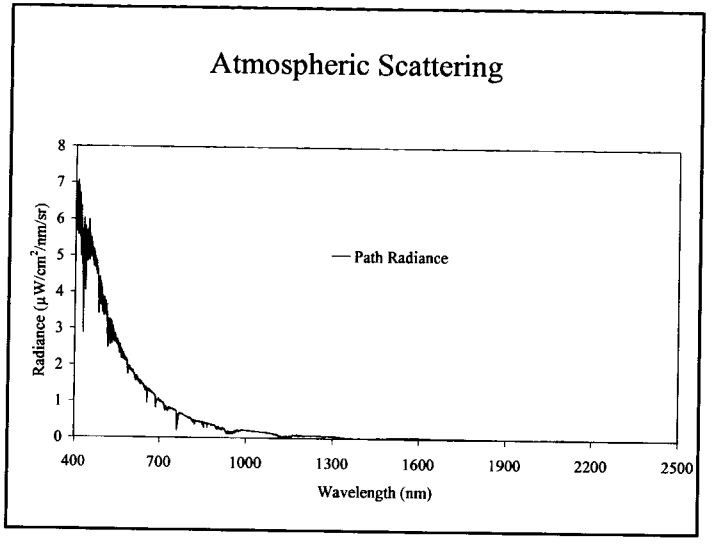
Energy is emitted by the Sun as well as Earth sources (fires, lights, etc)
The energy is transmitted and scattered by the atmosphere and reflected from the surface
The imaging sensor responds to the energy (L) within a field-of-view and spectral range
Sensor signal is digitized and relayed to the ground and recorded
The signal is calibrated, processed, and analyzed to answer the questions of interest

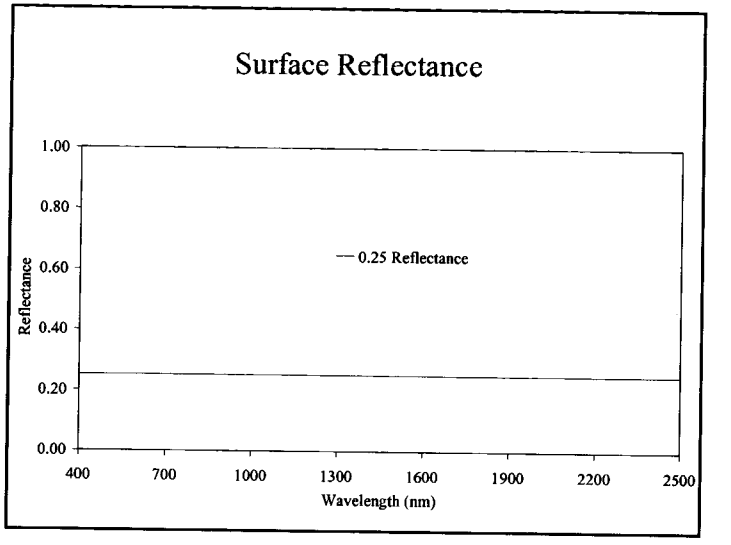
Exo Atmospheric Solar Irradiance (Earth)

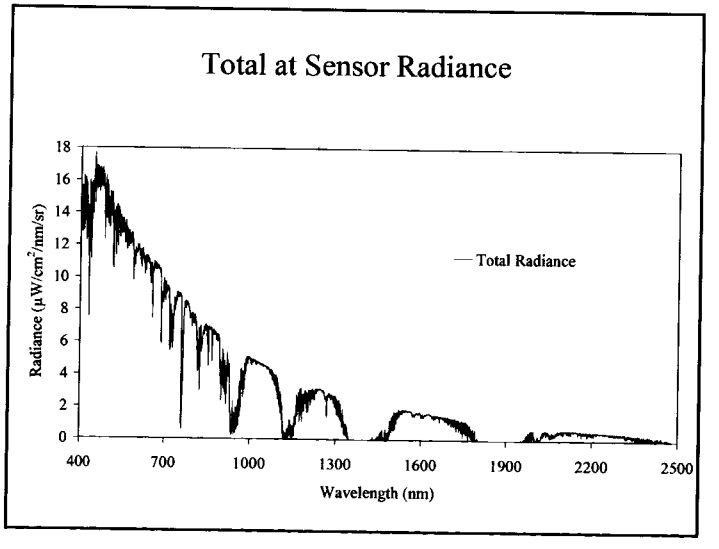


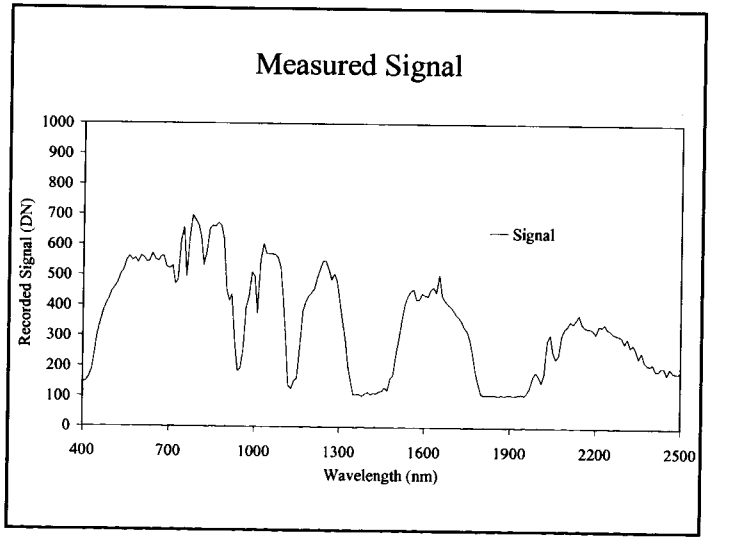
Transmittance of the Atmosphere



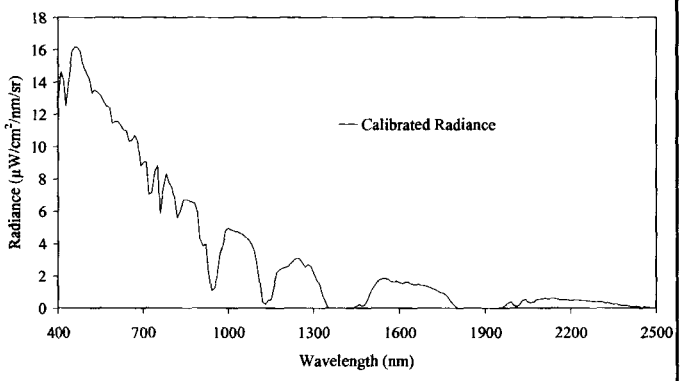

Atmospheric Scattering
Path Radiance
Radiance (μW/cm²/nm/sr)
0
1
2
3
4
5
6
7
8
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)


Surface Reflectance
0.25 Reflectance
Reflectance
0.00
0.20
0.40
0.60
0.80
1.00
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)

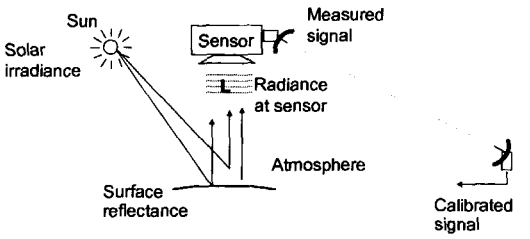

Total at Sensor Radiance
Total Radiance
Radiance (μW/cm²/nm/sr)
0
2
4
6
8
10
12
14
16
18
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)


Measured Signal
Signal
Recorded Signal (DN)
0
100
200
300
400
500
600
700
800
900
1000
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)

Calibrated Radiance



Earth Solar Reflected Energy Remote Sensing



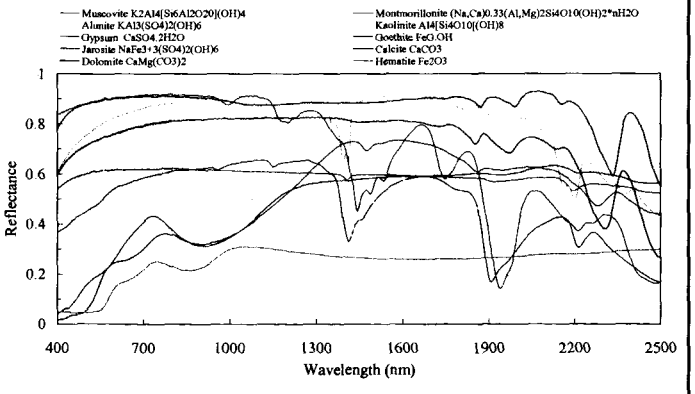
KEY POINTS

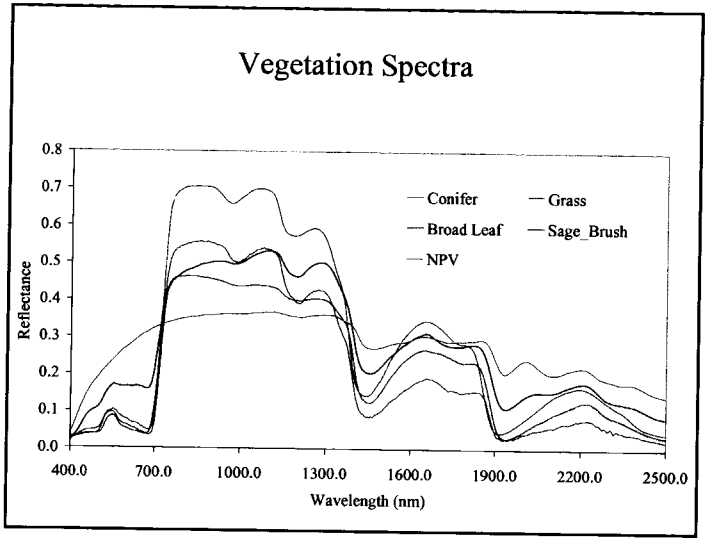
1) Remote sensing instruments measure radiance
2) The solar spectrum and the atmosphere dominate
3) The atmosphere contains fine spectral structure and is variable
4) Fortunately the transmittance of the atmosphere is greater than 1 over much of the solar reflected range

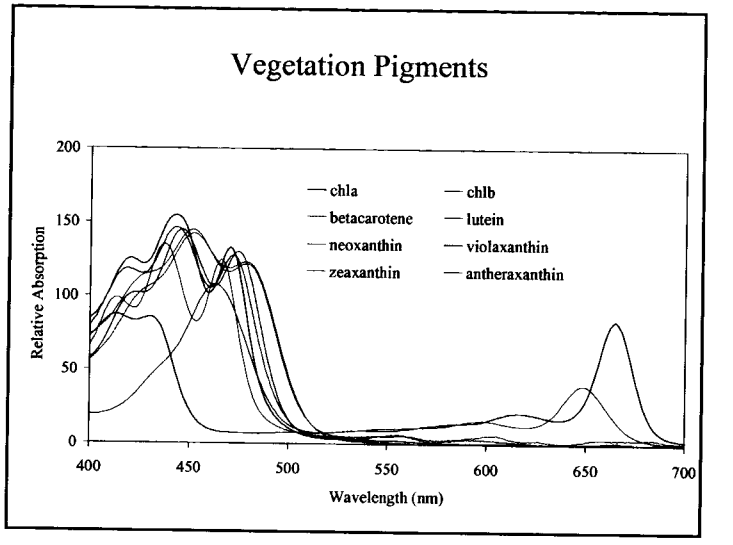
Surface Spectral Signatures

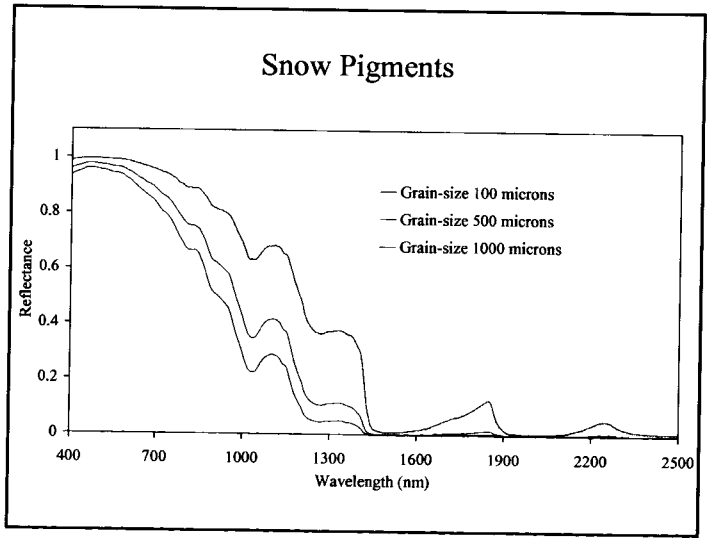
- The constituents of the land, water, and atmosphere environments possess spectral signatures that derive from molecular absorption and particle scattering characteristics
- Materials with different molecular and/or scattering characteristics have different spectral signatures
- In general, surface liquids and solids do not have fine spectral structure (5 nm and smaller) because of the inter-molecular bonds that make them liquid and solid

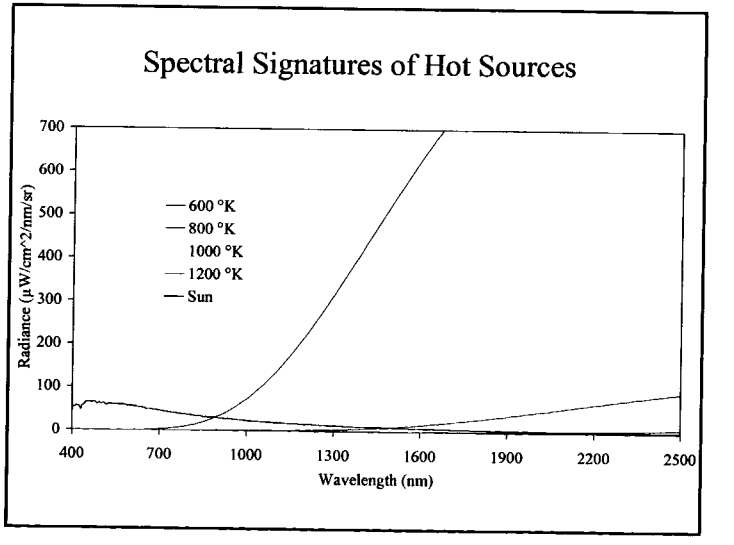
Mineral Spectra




Vegetation Spectra
Reflectance
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Conifer
Grass
Broad Leaf
Sage_Brush
NPV
400.0
700.0
1000.0
1300.0
1600.0
1900.0
2200.0
2500.0
Wavelength (nm)

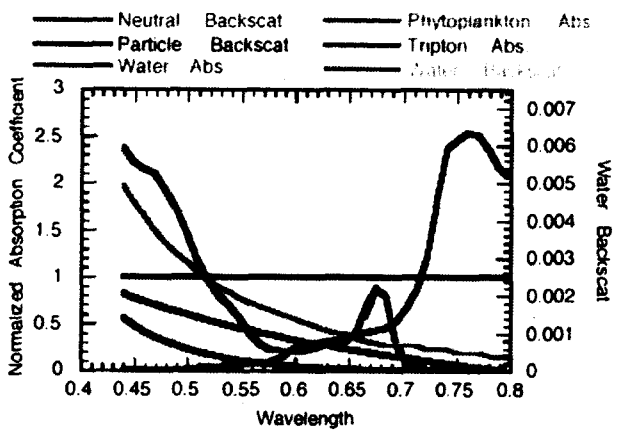

Vegetation Pigments
Relative Absorption
200
150
100
50
0
chla
chlb
betacarotene
lutein
neoxanthin
violaxanthin
zeaxanthin
antheraxanthin
400
450
500
550
600
650
700
Wavelength (nm)


Snow Pigments
Reflectance
1
0.8
0.6
0.4
0.2
0
Grain-size 100 microns
Grain-size 500 microns
Grain-size 1000 microns
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)


Spectral Signatures of Hot Sources
Radiance (µW/cm^2/nm/sr)
700
600
500
400
300
200
100
0
600 °K
800 °K
1000 °K
1200 °K
Sun
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)

Spectral Signatures of Water Constituents

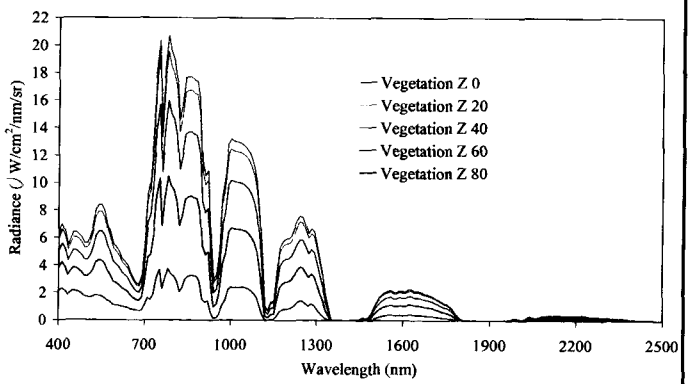
(from John Mustard)



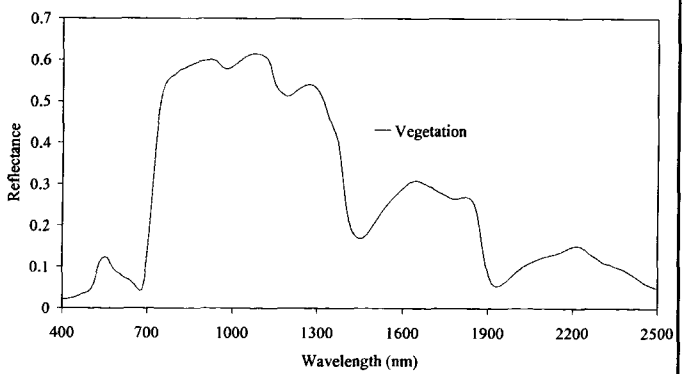
Concept for the Ocean Remote Sensing Communty Apparent versus Inherent Optical Properties

- Apparent optical properties vary as a function of illumination, observation, and surface geometries as well as with atmospheric conditions. Upwelling radiance is an apparent optical property.
- Inherent optical properties are tied to the molecular absorption and constituent scattering characteristics of a material. Reflectance is an inherent optical property.
- The inherent optical properties are need to rigorously pose and answer science research and application questions.

Upwelling Radiance of Vegetation at Different Illumination Zenith Angels



Vegetation Reflectance Spectrum Common to all Radiance Spectra



Summary: Remote Sensing and The Signal

- Earth-looking optical remote sensing instruments measure radiance through atmospheric windows. Landsat, SPOT, AVHRR, your eye, etc.
- The measured signal is a function of the solar source, atmosphere, surface, geometry, and instrument.
- Surface liquids and solid have unique spectral signatures related to molecular and structural composition.
- Radiance is an apparent optical property. Reflectance is inherent to the material. To pose and answer research and application questions with remote sensing, inherent properties are needed.

Imaging Spectroscopy

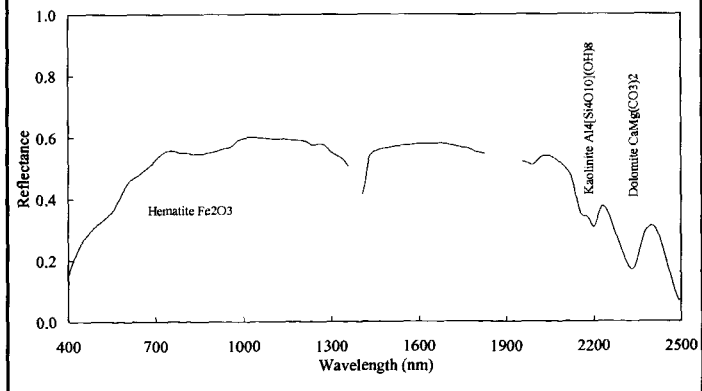
Electromagnetic Spectroscopy

- Physics and chemistry that deals with the interactions between matter and electromagnetic radiation as observed by contiguous wavelength dispersed measurements

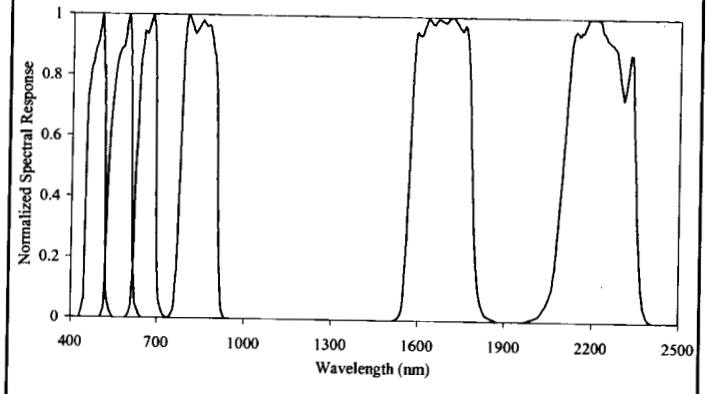
Imaging Spectroscopy

- Measuring spectra as images

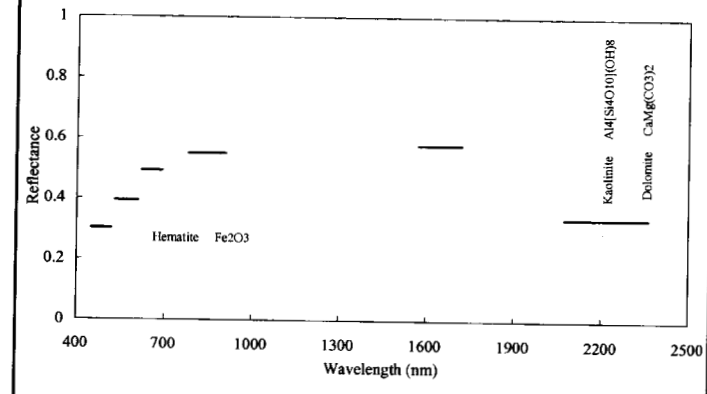
Three Mineral Spectrum



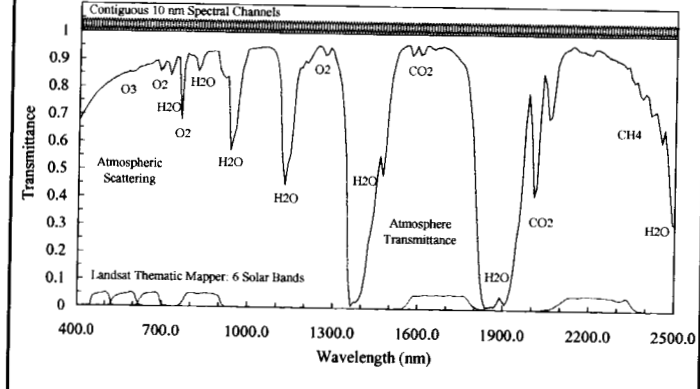
Multispectral Measurement



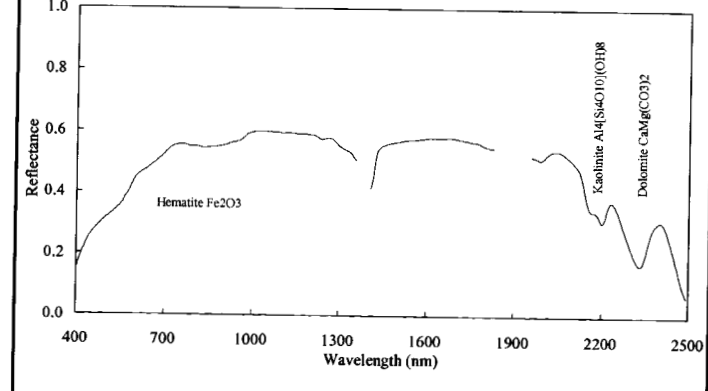
Three Mineral Spectrum Convolved to Landsat TM Bands



Earth Imaging Spectroscopy



Three Mineral Spectrum



Cuprite, NV

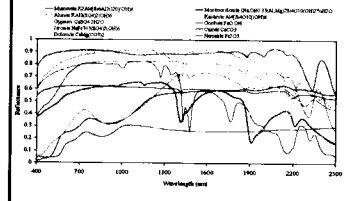
- Single band image

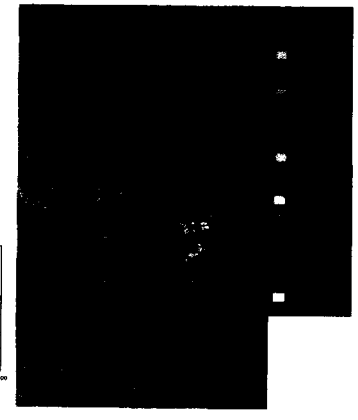
Delineate regions of different brightness

Cuprite, NV

- Imaging Spectroscopy

Identify full range of surface materials and delineate the distribution

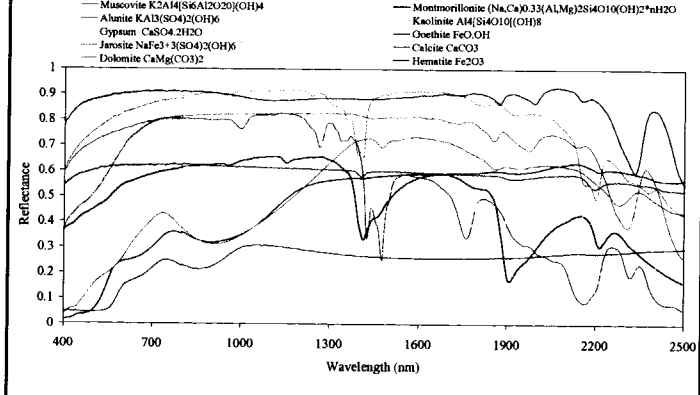




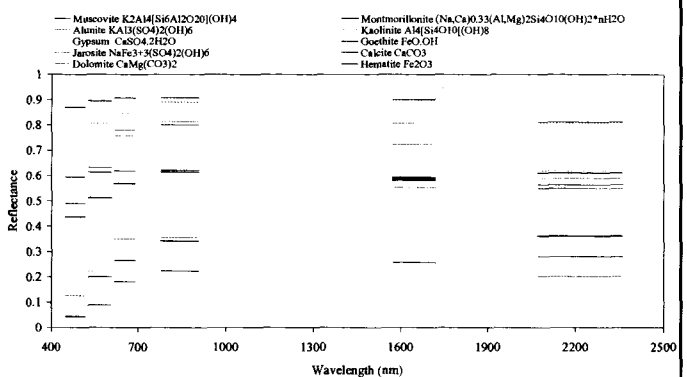
Imaging Spectroscopy Approach

- Three materials are detected
- Three minerals are identified based on molecular absorption characteristics
- The expressed concentration of the three minerals may be derived

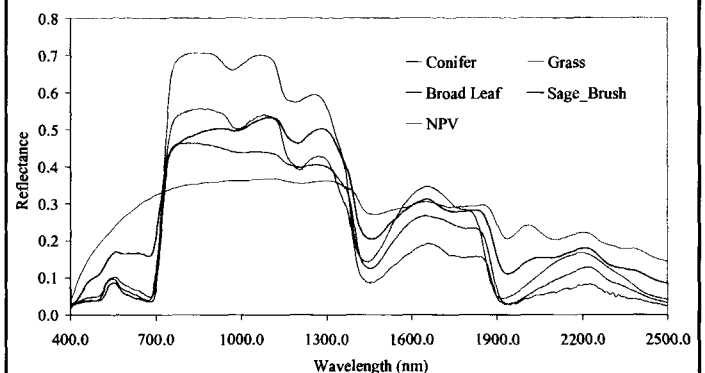
Mineral Spectra



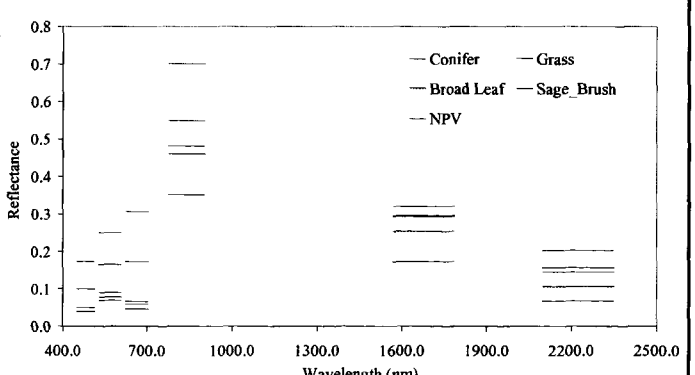
Minerals Multispectral



Plant Spectra



Plants Multispectral



IMAGING SPECTROSCOPY CONCEPT
Scientific Basis

- Determining the composition and inferring processes on the Earth surface by counting photons at the top of the atmosphere is an improbable objective.
- Spectroscopy provides a framework based in physics and chemistry to achieve this remote measurement (not sensing) objective in the context of the interaction of photons with matter.
- The physics, chemistry and biology of spectroscopy have been validated through more that 100 years of laboratory and astronomical research and applications. (Fraunhofer 1814)

IMAGING SPECTROSCOPY CONCEPT
Mathematical Basis

- An alternate view of the imaging spectroscopy concept hinges on the general problem of solving for unknowns from measurements.
- If one has fewer measurements than unknowns, then the problem is underdetermined. Six or Ten measurements (e. g. bands) are almost never enough to account for the unknowns effecting the radiance at the top of the atmosphere.
- Furthermore, one can not simply solve for the a single unknown of interest (the magic band). One must solve for all the unknowns that may effect the expression of the unknown of interest.
- If there are more measurements than unknowns (Imaging Spectroscopy) then the problem is likely over determined and solvable.

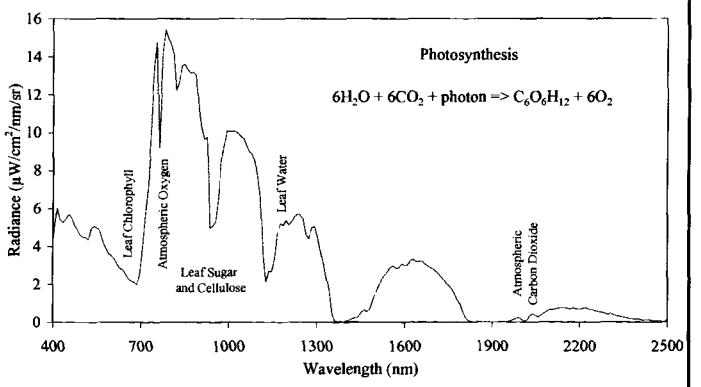
IMAGING SPECTROSCOPY CONCEPT
Technological Basis

- Imaging Spectroscopy takes advantage of advances in:
  - Optical, detector, and design technology
  - Computer communication, analysis and storage technology
  - Satellite onboard processing and downlink technology
  - Science research and applications algorithms
- Imaging Spectrometers are becoming easier to build than 20 band and greater multispectral sensors

H. G. Wells, The Outline of History

"The telescope has released the human imagination as no other implement has ever done. If there is any other apparatus worthy to be compared to its enlarging influence, it is the spectroscope, which was developed after the discoveries of Fraunhofer, the glass-worker, in 1814. Since man has lived on earth he has seen rainbows, but who could have told him that those bands of color held in them a promise that one day he should be able to analyze the stars? But the spectroscope receives the rays from any luminous source, passes them through prisms and breaks them up into rainbow-like bands. These bands reveal under examination transverse lines of brightness and darkness which vary with the heat and the chemical composition of the source of light and of any intervening vapour. So that men can now sit in observatories and learn the composition and take the temperature of stars incalculable billions of miles away."

Biology and Chemistry Revealed in Spectroscopy



Imaging Spectroscopy Definition

- Imaging spectroscopy is the measurement and analysis of spectra acquired as images.
  - A spectrum is generally the measurement of more than 100 contiguous spectral channels (or bands)
  - An image generally has more than 100 spatial elements in the line and sample direction.

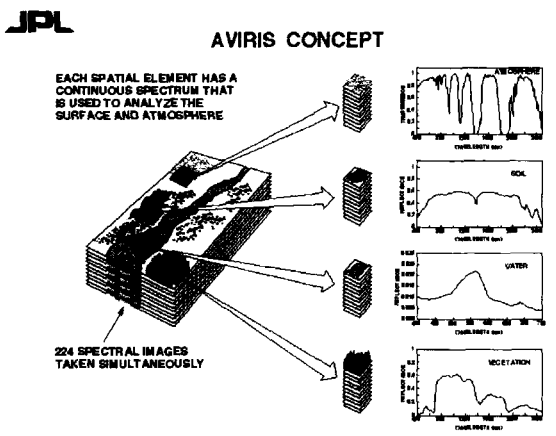
Imaging Spectroscopy Approach

- Measure the calibrated upwelling radiance spectra as images.
- Based upon the molecular absorptions and constituent scattering characteristics expressed in the spectra:
  - Detect multiple materials in each spectrum
  - Identify the specific surface and atmospheric constituents present
  - Assess and measure the expressed constituent concentrations
  - Assign proportions to constituents in mixed spatial elements
  - Delineate spatial distribution of the constituents
  - Monitor changes in constituents through periodic data acquisitions

Summary: Imaging Spectroscopy

- Imaging Spectroscopy:
  - The measurement and analysis of spectra acquired as images
  - The next advance in remotes sensing beyond multispectral
- Imaging Spectroscopy
  - Identifies materials based on resolved molecular absorptions
  - Identifies more than one material per spectrum (mixtures)
  - Assesses concentration through spectroscopic analysis of expressed absorption and scattering
- Imaging Spectroscopy
  - Based in physics, chemistry and biology
  - Based in the mathematics of solving for unknowns from measurements
  - Based in advanced instrument, computer, and algorithm technology

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)



History: AVIRIS at JPL

- Earth Imaging Spectroscopy was conceived at JPL under the leadership Alex Goetz and Gregg Vane in the mid 1970s as the next logical step from multi-spectral remote sensing. Many other contributed.
- The Airborne Imaging Spectrometer (AIS) was developed as a technology test bed at JPL using discretionary funds. AIS first flew in 1982.
- AVIRIS was proposed to NASA in 1983 based on the success of AIS.
- AVIRIS has flown in every year since 1987

History: AVIRIS at JPL

- AVIRIS was designed with 1980s detector technology. This meant AVIRIS needed to have large detectors and high optical throughput.
- In the 1995 the detectors were upgraded to current technology. These large modern detectors in conjunction with the high optical throughput resulted in exceptional signal-to-noise ratio perfomance.
- The base design of AVIRIS has enabled a series of subsystem refurbishments that have allowed AVIRIS performance to continue to improve over the years.

AVIRIS at JPL

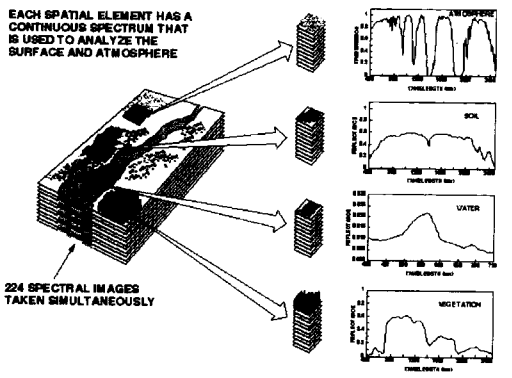
- All AVIRIS data from 1992 to present are maintained in the JPL AVIRIS archive.
- AVIRIS was originally designed to fly on the ER-2 with 20 meter spatial resolution.
- Since 1998 AVIRIS has also flown on the Twin Otter platform with 4 meter spatial resolution. A georectification capability was added for the Twin Otter data.
- In the last three years AVIRIS has flown about 80 times each year and collected about 1 terrabyte of data a year

AVIRIS at JPL

- Given the heavy usage, AVIRIS is put through a maintenance period for about 4 months each year.
- The AVIRIS workforce functions in a team approach to keep AVIRIS working and to try to anticipate issues before they become problems.
- All data flown for investigators are distributed to the principal investigator and designated co investigators.
- Requests for previous years data are handled as well.
- About 1 terabyte of AVIRIS data are distributed each year.

JPL

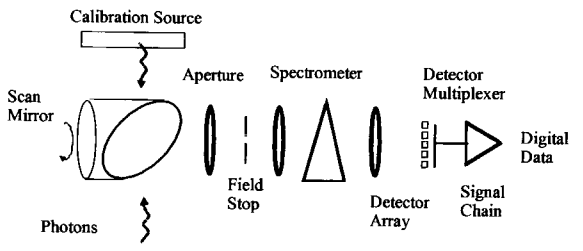
AVIRIS CONCEPT



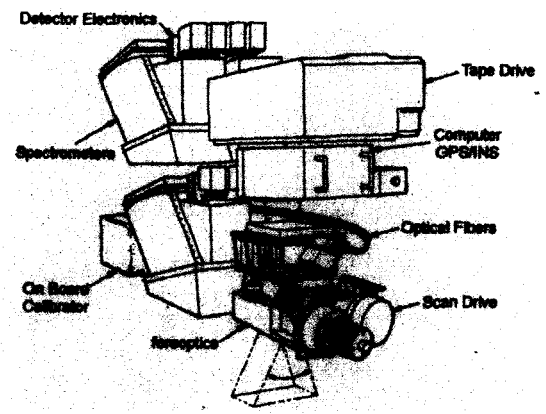
Instrument System Requirements

- High Precision (SNR)
  - Identification of materials based on spectroscopy
- Stability (spectral, radiometric, spatial)
  - Makes calibration possible
- Uniformity (spectral, radiometric, spatial)
  - Enables spectroscopy across the image
- Calibration (spectral, radiometric, spatial)
  - Required for the physics, chemistry, and biology of spectroscopy
  - Allows compensation for the atmosphere

Generic Whiskbroom scanner

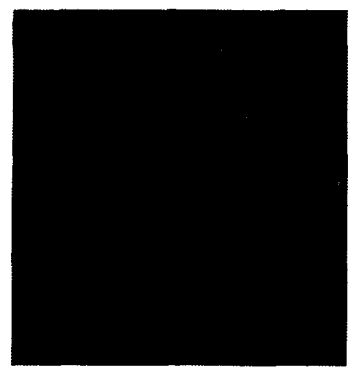


AVIRIS Instrument

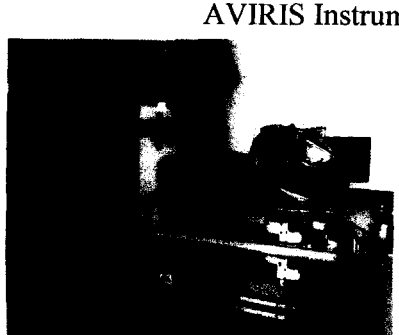


One of four AVIRIS spectrometers

Photons are dispersed into the spectrum and converted to electrons, amplified, digitized and recorded



AVIRIS Instrument



AVIRIS Technology Status
- Thermal control 1997
- Low Altitude 1998
- INU/GPS 1998
- Geo rectification 1998
- Onboard calibrator 1999
- Detector arrays 2000
- Digital signal chain 2001
- Onboard data storage 2001
- Scanner and fore optics 2002

AVIRIS is designed with 200 μm detectors and F/1 optics.
It is hard to imagine larger detectors or faster optics.
The AVIRIS design is in the advanced technology zone of the physics of spectroscopic measurements

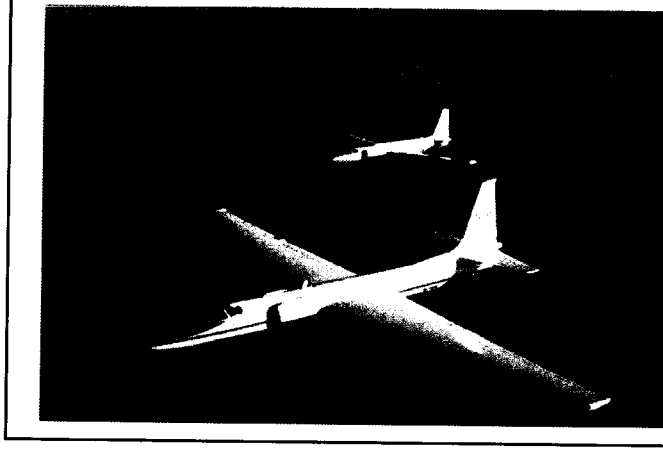
AVIRIS Throughput is the Key

- Instrument optical throughput is a function of
  - Integration time
  - Spectral channel width
  - Detector size (linear dimension squared)
  - Focal length over aperture (F/1 is 100 times better than F/10)
- AVIRIS is designed with 200 μm detectors and F/1 optics.
  - It is hard to imagine larger detectors or faster optics.
  - The AVIRIS design is in the advanced technology zone of the physics of spectroscopic measurements

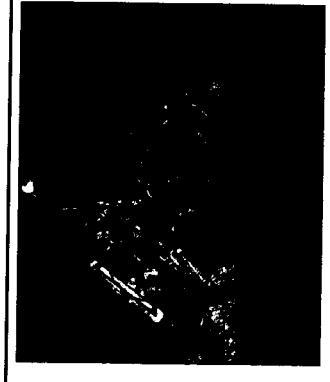
AVIRIS Characteristics

• Imager type	Whiskbroom scanner (12 hz)
• Dispersion	Four grating spectrometers (A,B,C,D)
• Detection	224 detectors (32,64,64,64) Si and InSb
• Digitization	12 bits
• Data rate	20.4 mbits/second
• Spectrum rate	7300 spectra/second
• Data capacity	>35 gigabytes (>10,000 km^2)
• Flights	>80 per year

ER-2 Platform



AVIRIS: PEARL HARBOR, HAWAII



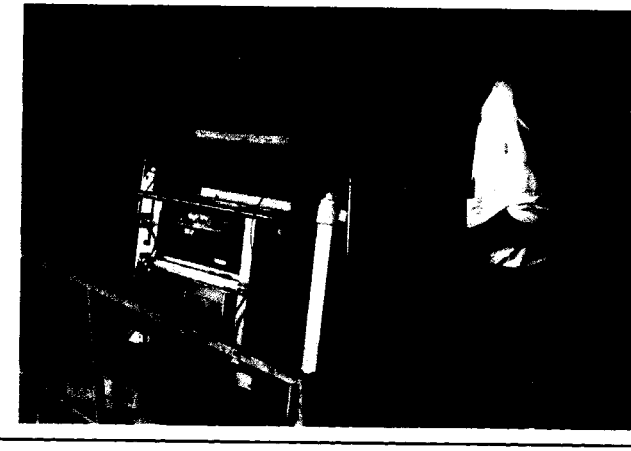
Spectral
- Range: 370 to 2500
- Sampling: 9.8 nm
- Accuracy: 0.5 nm

Radiometric
- Range: 0 to Max Lambertian
- Sampling: 12 bits
- Accuracy: 96 percent

Spatial (ER-2 / Twin Otter aircraft)
- Swath: 11 / 2.2 km
- Sampling: 20 / 4 m
- Accuracy: 20 / 4 m

Full INU/GPS geo rectification

AVIRIS Installation Preparations

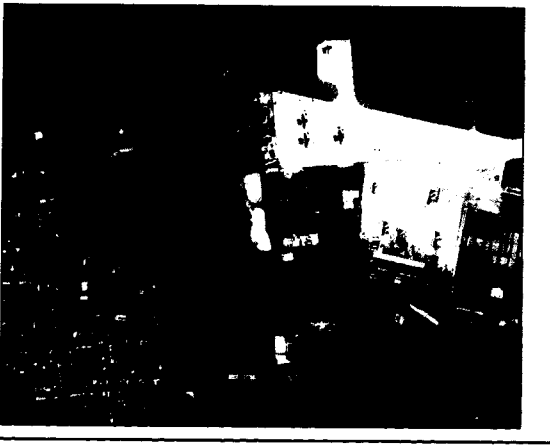


Twin Otter Platform

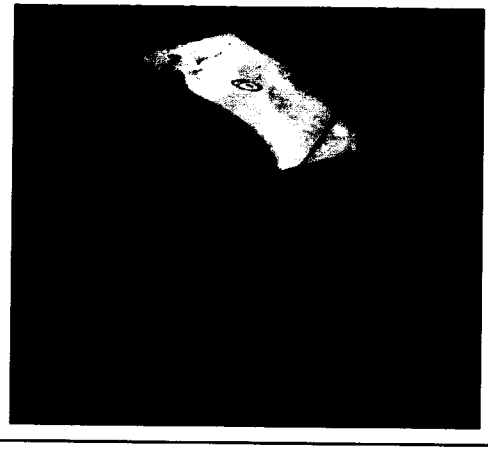
AVIRIS Installation

Twin Otter In Flight

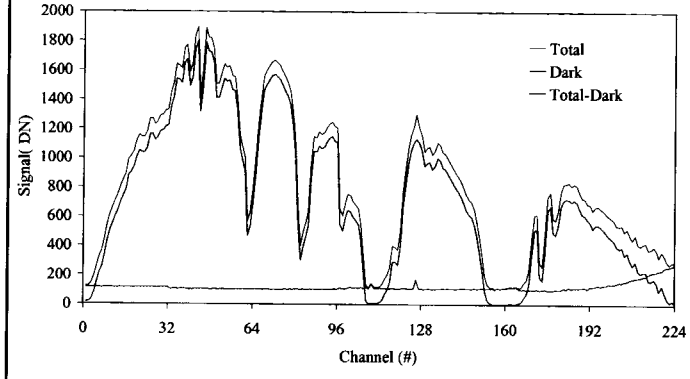
AVIRIS Low Altitude Capability



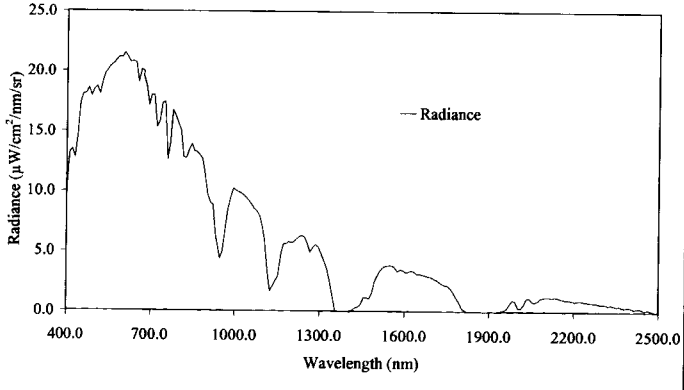
AVIRIS Data Example



Raw Data



Calibrated AVIRIS Spectrum



AVIRIS Science Data Acquisition

	FY98	FY99	FY00	FY01	FY02
Months of Maintenance	4	5	4	4	5
Months of Science Data	8	7	8	8	7
Flights ER-2/Twin Otter	35/29	45/31	58/30	40/40	40/45
Flight Lines	429	517	589	600	650
Gigabytes	647	840	906	1000	1500
Scenes Acquired**	2757	3579	3860	4260	4686
Scenes Delivered	3249	5206	5734	6000	6500

**Scene: 512 lines by 614 samples

AVIRIS Task Structure at JPL

- The AVIRIS task at JPL has all the following elements
  - Task Leadership and Outreach
  - Calibration and Validation Science
  - Mission Planning and Experiment Coordination
  - Instrument Operations, Calibration, and Maintenance
  - Data Quality, Archiving, Calibration, Distribution
- These include all the elements of a satellite remote sensing instrument.

Instrument System Requirements

- High Precision (SNR)
  - Identification of materials based on spectroscopy
- Stability (spectral, radiometric, spatial)
  - Makes calibration possible
- Uniformity (spectral, radiometric, spatial)
  - Enables spectroscopy across the image
- Calibration (spectral, radiometric, spatial)
  - Required for the physics, chemistry, and biology of spectroscopy
  - Allows autonomous compensation for the atmosphere

Summary: AVIRIS

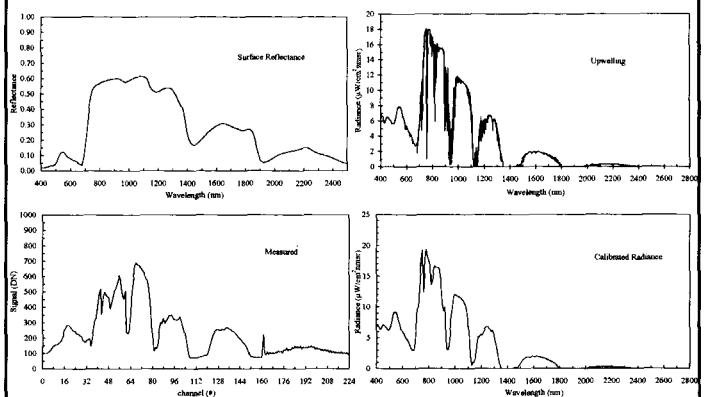
- AVIRIS has spectral, radiometric, and spatial properties
- Sensor Priority
  - High Precision (SNR)
  - Stability (spectral, radiometric, spatial)
  - Uniformity (spectral, radiometric, spatial)
- The large detectors and fast optics of AVIRIS give it an edge in the physics
- There must be a total system to acquire and deliver data

CALIBRATION

CALIBRATION

- Requirement
- Laboratory
- Inflight
- Issues

Calibration and the Signal



CALIBRATION REQUIREMENT

- Imaging spectroscopy data must be spectrally, radiometrically and spatially calibrated in order to:
  - Extract information from measured radiance
  - Compare information acquired from different regions and different times
  - Compare and analyze imaging spectroscopy measurements with measurements provided by other instruments
  - Extract information from spectral image measurements using physically based computer models

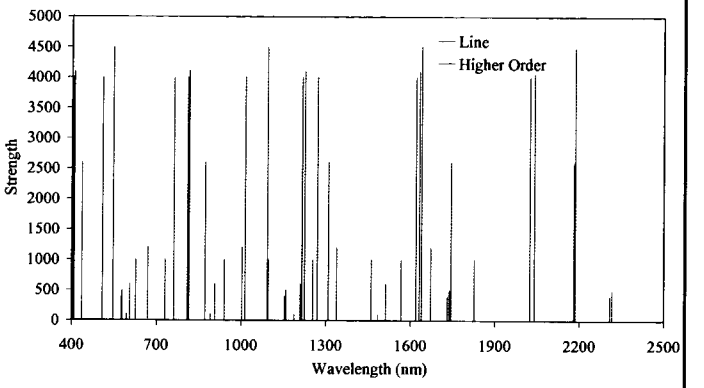
Laboratory Calibration

- Spectral
- Radiometric
- Spatial

Laboratory Spectral Calibration

- Parameters
  - Range
  - Sampling and uncertainty
  - Response Function and Uncertainty
- Standards
  - Atomic emission lines
    - Hg or Ne spectral lines, for example
    - Laser lines
  - Spectrally featureful materials
    - Doped Spectralon
    - Plastics

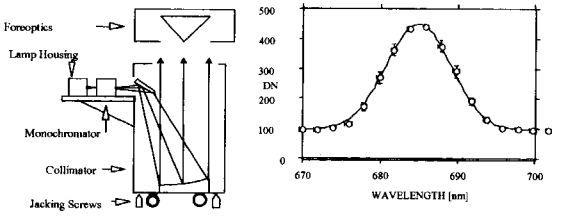
Mercury Vapor Lamp Spectral Calibration Standard



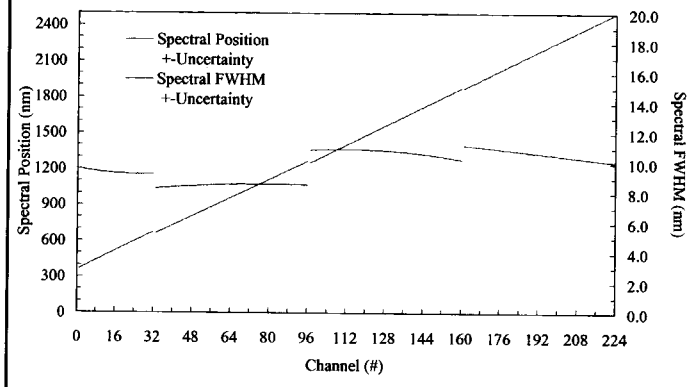
Laboratory Spectral Calibration

- Approach
  - Calibrate scanning monochromator to Hg or Ne spectral lines
  - Fill the aperture with collimated monochromatic light from the monchromator
  - Measure each channel response as monochromatic light is scanned through the spectrum
  - Analyze the measurements to a generate a spectral position and response function for each channel

Spectral Calibration Apparatus and Result



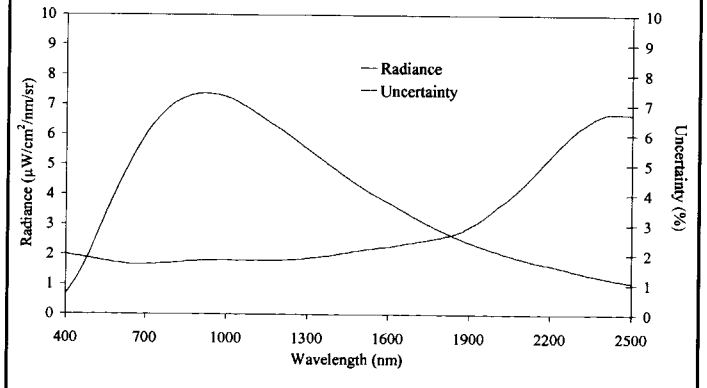
Spectral Calibration Parameters



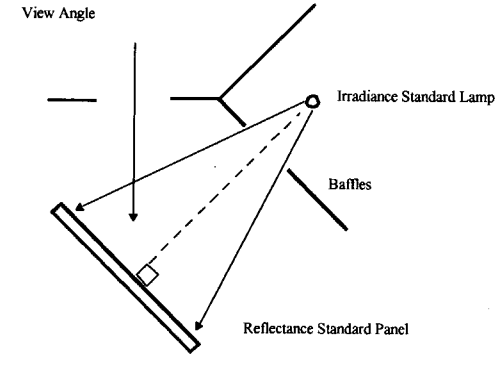
Laboratory Radiometric Calibration

- Parameters
  - Radiometric Calibration Range
  - Radiometric Calibration Sampling
  - Radiometric Calibration Accuracy
  - Radiometric Calibration Precision
- Standards
  - NIST Irradiance Lamp
  - Fixed point blackbody source
  - Quantum efficient detector
  - Detector stabilized integrating sphere
  - 3000C blackbody source

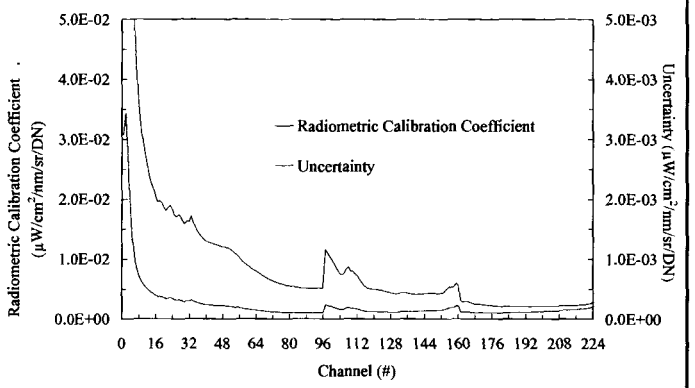
Radiometric Standard



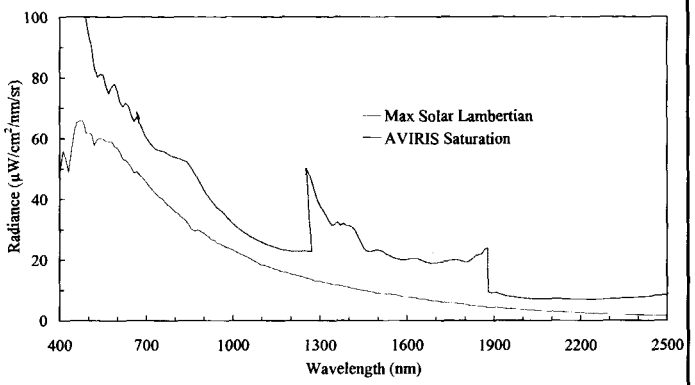
Radiance Source



Radiometric Calibration Coefficients



AVIRIS Saturation Levels (12 bits)



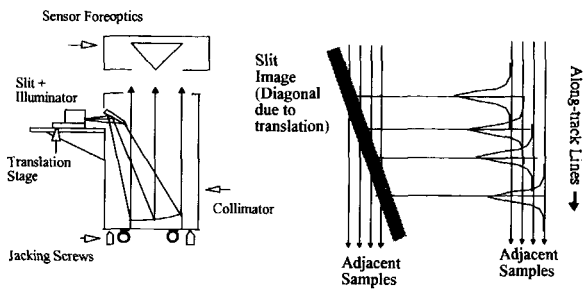
Laboratory Spatial Calibration

- Parameters
  - Cross-track Sampling and uncertainty
  - Along-track Sampling and uncertainty
  - Cross-track Response and uncertainty
  - Along-track Response and uncertainty
- Standards
  - Known illuminated slit

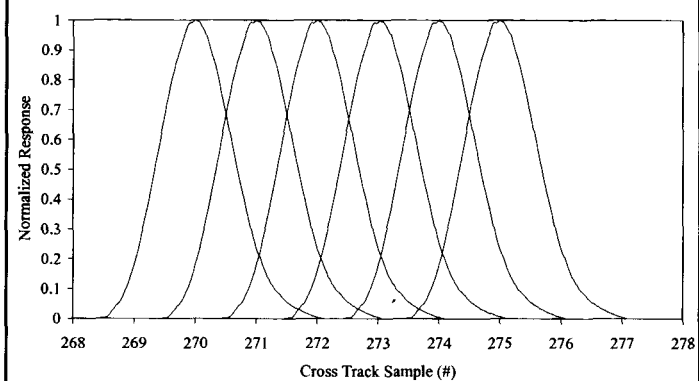
Laboratory Spatial Calibration

- Approach
  - Scan a point source in the focal plane of a collimator
    - Alternately, use slit source or knife-edge source
  - Observe the scanned point source with the sensor
    - Cross-track
    - Along-track
  - Measure sensor response
  - Analyze measurements to determine the spatial calibration parameters
  - Fourier transform of point spread function is MTF
  - Spatial sampling interval is distance between adjacent PSF

Slit Response Function Measurement



Spatial Response Functions



Laboratory Calibration

- Imaging Spectrometers have spectral, radiometric, and spatial characteristics
- Each calibration characteristic has response, range and corresponding uncertainty factors
- With 100s of spectral channels, imaging spectrometer present special challenges for calibration

Calibration Conundrum

- Three or more months may be spent calibrating a sensor in the laboratory, and yet the inflight data are NOT calibrated.
- This is largely because the inflight environment is vastly different than the laboratory environment.
- **Calibration in the flight environment is the only calibration that counts.**

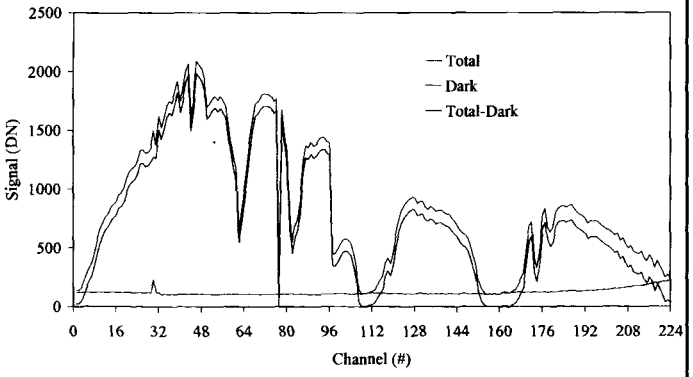
Inflight Calibration Experiment

- Objective
  - Establish that the imaging spectrometer data are calibrated in the flight environment
- Approach
  - Measure the surface and atmosphere at a homogeneous ground target and independently predict the upwelling spectral radiance at the time of imaging spectrometer data acquisition
  - Use the predicted upwelling radiance spectrum to validate the spectral and radiometric calibration of the imaging spectrometer in the flight environment

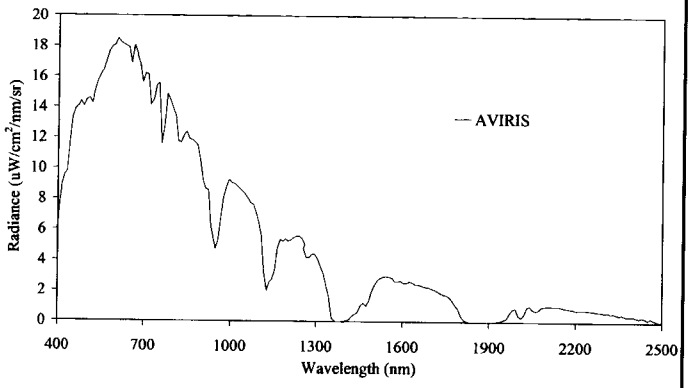
Calibration Site Leoncito, Argentina

AVIRIS Image Calibration Target, Leoncito, Argentina

AVIRIS Signal from Calibration Target



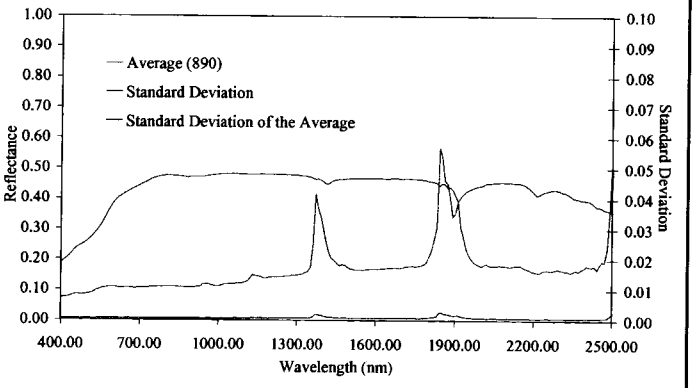
AVIRIS Calibrated Radiance



Leoncito, Team Argentina

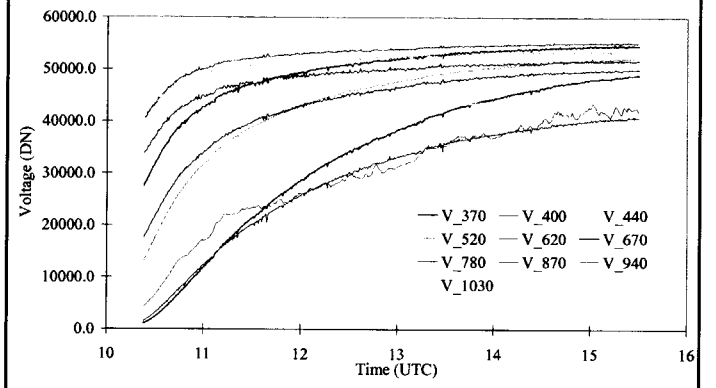
Leoncito Reflectance Measurements

Calibration Target Spectral Reflectance

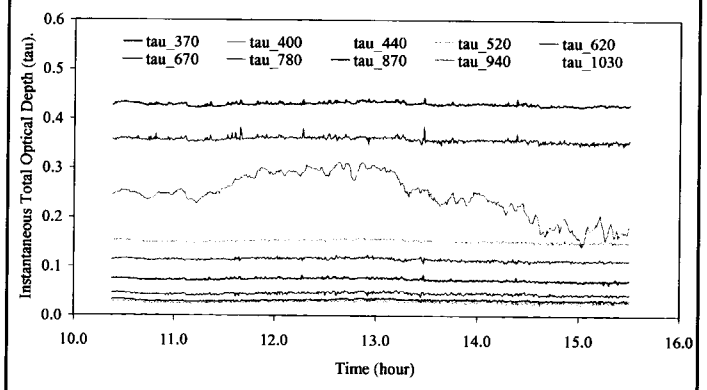


Leoncito, Team Argentina

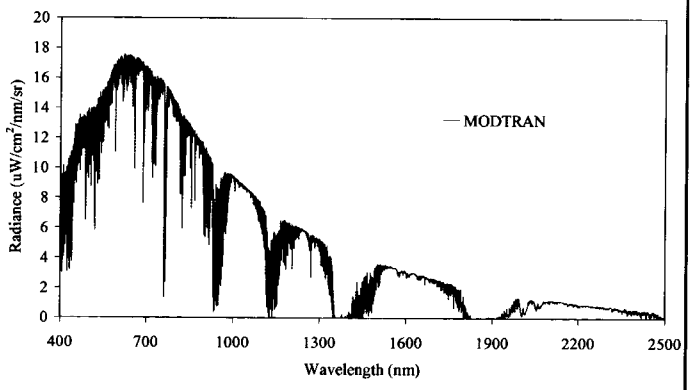
Measured Sun Photometer Voltages



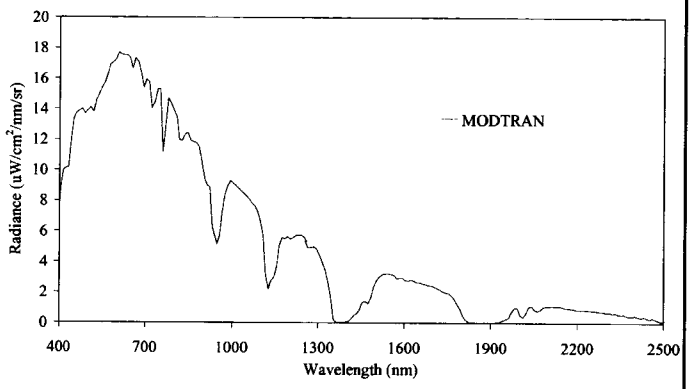
Measured Optical Depths



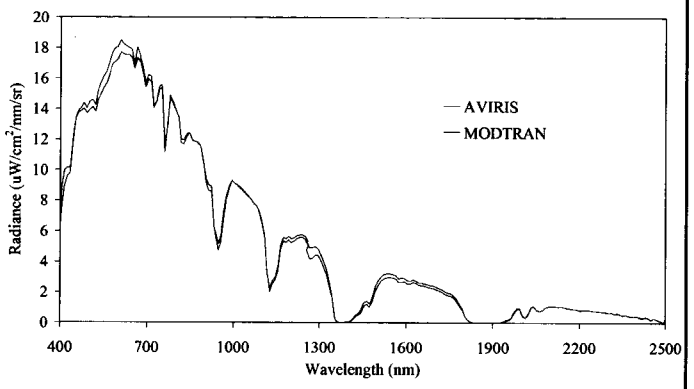
MODTRAN Predicted Radiance



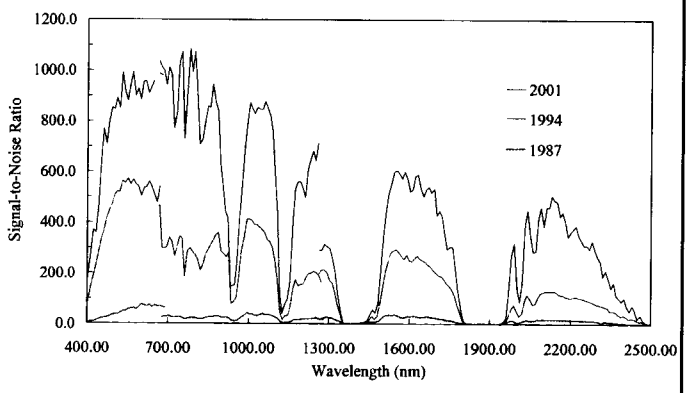
Predicted Radiance Convolved to AVIRIS



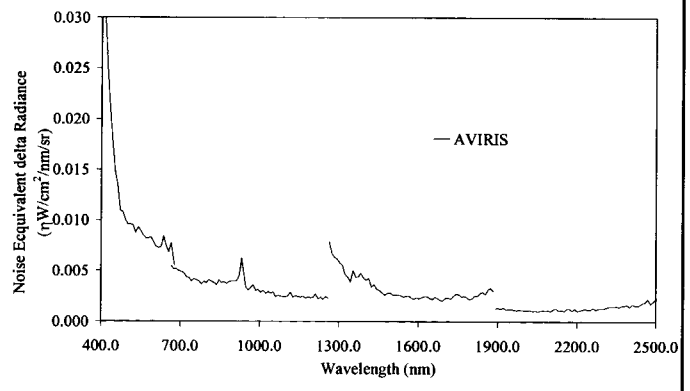
Predicted Compared to Measured



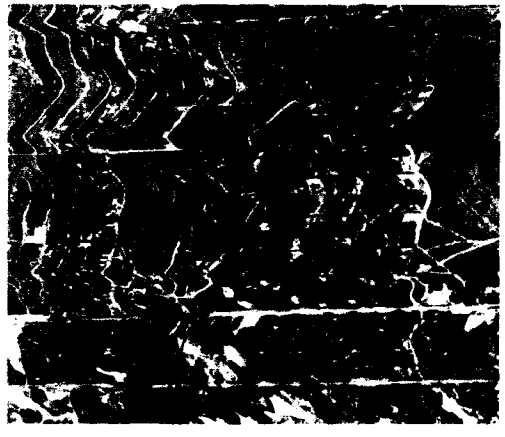
Signal-to-Noise Ratio at AVIRIS Reference Radiance



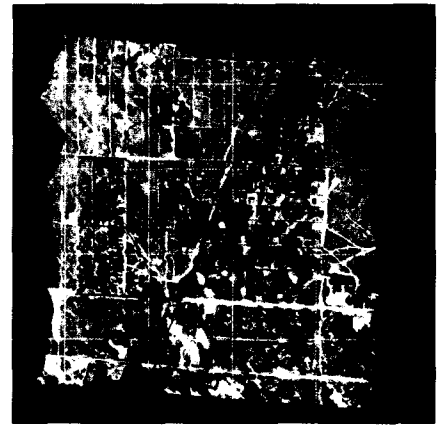
Noise Equivalent delta Radiance (dark signal)



Spatial Error from Roll, Pitch, Yaw



Spatial Correction with INS/GPS Input

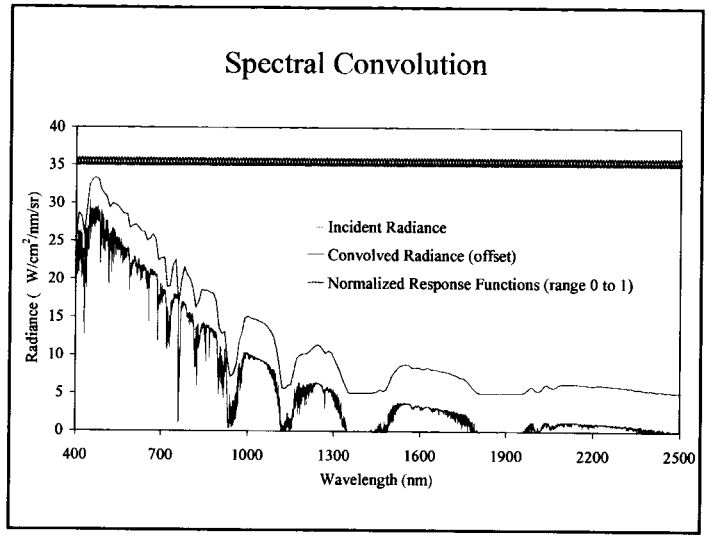


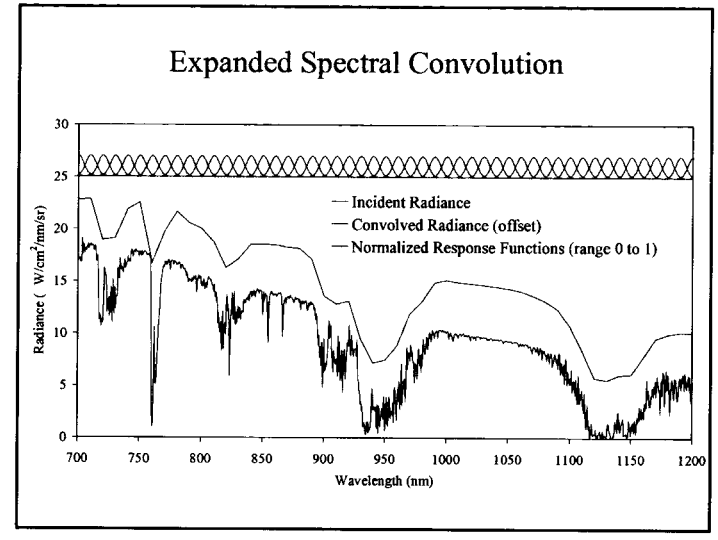
Critical Calibration and Instrument Factors

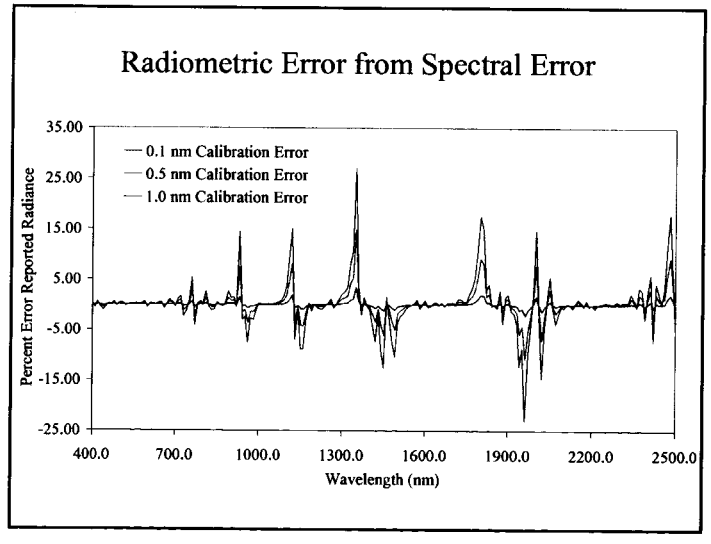
- Spectral Smile (Frown)
- Keystone
- Radiometric Precision

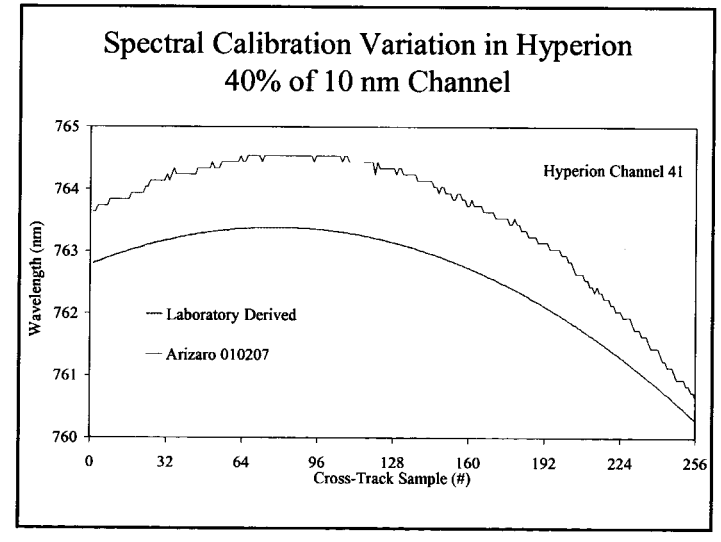
Smile or Spectral Calibration Variability

- Because the upwelling radiance contains fine structure from solar and atmosphere molecules imaging spectrometers are very sensitive to accurate spectral calibration
- A 10% error in spectral calibration can produce a 15% error in radiometric calibration


Spectral Convolution
Incident Radiance
Convolved Radiance (offset)
Normalized Response Functions (range 0 to 1)
Radiance (W/cm²/nm/sr)
Wavelength (nm)


Expanded Spectral Convolution
Incident Radiance
Convolved Radiance (offset)
Normalized Response Functions (range 0 to 1)
Radiance (W/cm²/nm/sr)
Wavelength (nm)


Radiometric Error from Spectral Error
0.1 nm Calibration Error
0.5 nm Calibration Error
1.0 nm Calibration Error
Percent Error Reported Radiance
Wavelength (nm)


Spectral Calibration Variation in Hyperion
40% of 10 nm Channel
Hyperion Channel 41
Laboratory Derived
Arizaro 010207
Wavelength (nm)
Cross-Track Sample (#)

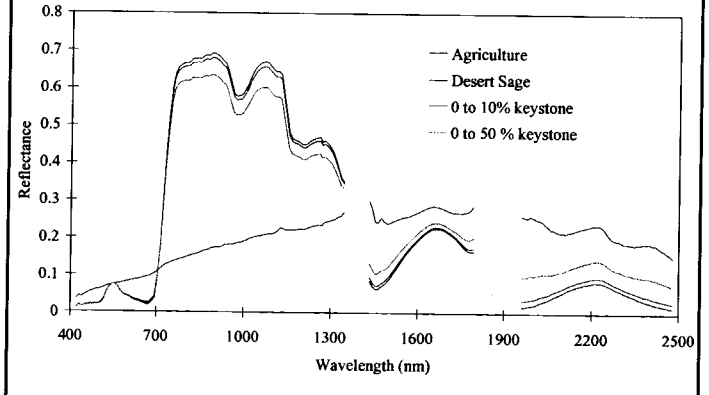
Spectral Smile

- Lack of spectral calibration knowledge induces large spectrally pernicious errors
- Pushbroom spectrometer can (not always) have large cross track spectral variation
- Imaging spectroscopy requires stable, accurately known spectral calibration parameters

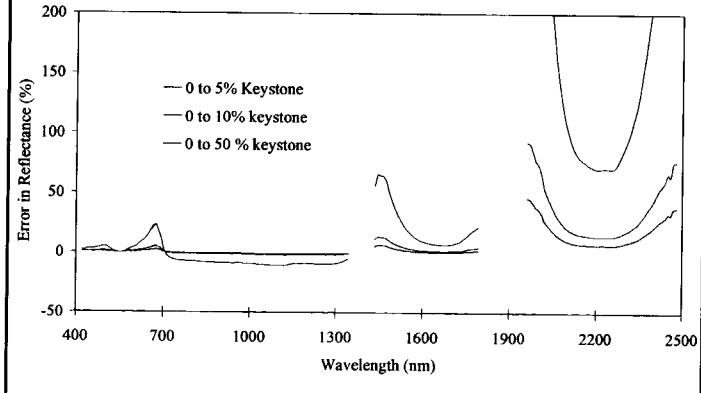
Keystone

- Keystone is a linked spectral and spatial non-unformity
- Effectively different wavelengths are derived different spatial areas on the surface

Spectral-Spatial Keystone



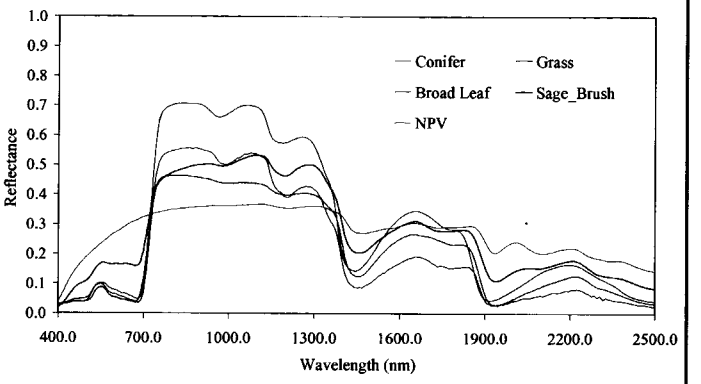
Errors from Kestone



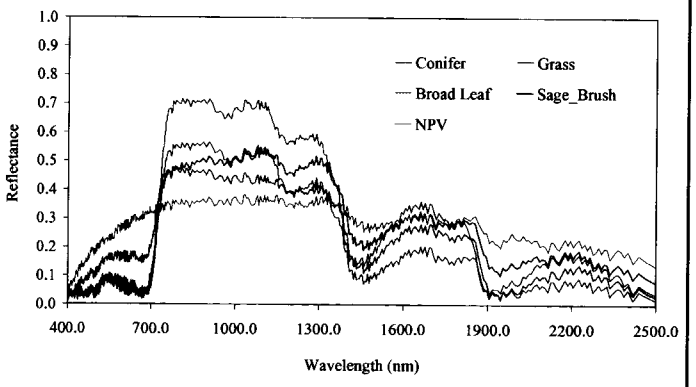
Radiometric Precision

- Radiometric precision is reported as the signal-to-noise ratio or noise equivalent delta radiance
- Radiometric precision establishes the random uncertainty at the single spectrum level

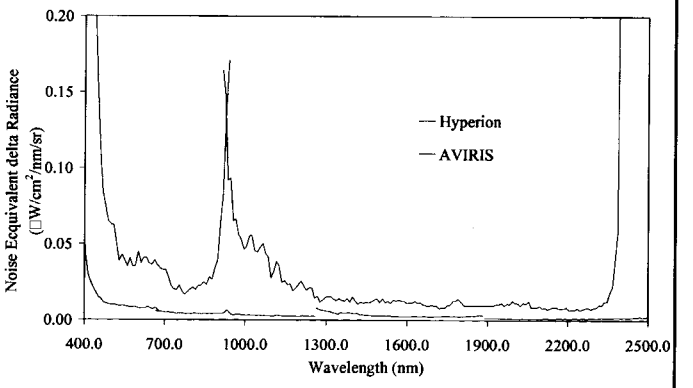
High Precision Spectra



Low Precision Spectra



Precision Comparison of AVIRIS and Hyperion



Hyperion met its technology demonstration goals

Modern Spaceborne Imaging Spectrometers Should Have:

- 5% or less Smile
- %5 of less Keystone
- AVIRIS precision or better
- Excellent stability

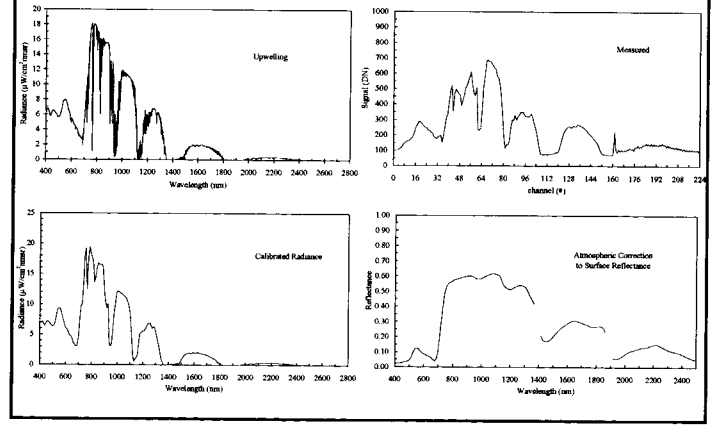
<u>Appropriate designs and lab demonstrations now exist to meet these requirements</u>

Key Points: Calibration

- Imaging spectrometers have spectral, radiometric, and spatial domains
  - Sampling, Range, Stability, Uniformity, Accuracy, Precision
- Calibration in the laboratory is essential
- Calibration in the flight environment is what matters
- The quality of the measurement is linked to the design of the instrument and the quality of the calibration
- Smile and keystone should be avoided and precision embraced

Atmospheric Correction

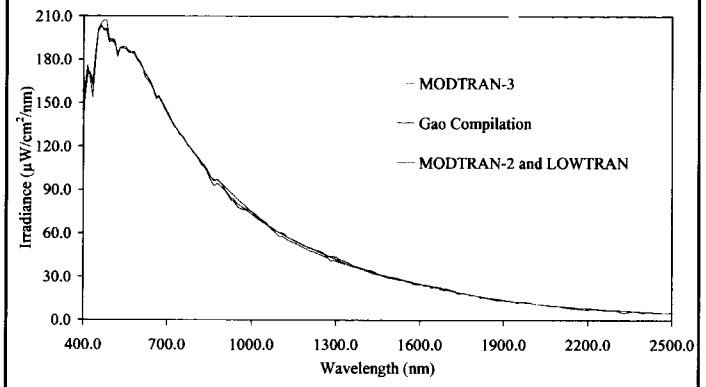
Atmospheric Correction



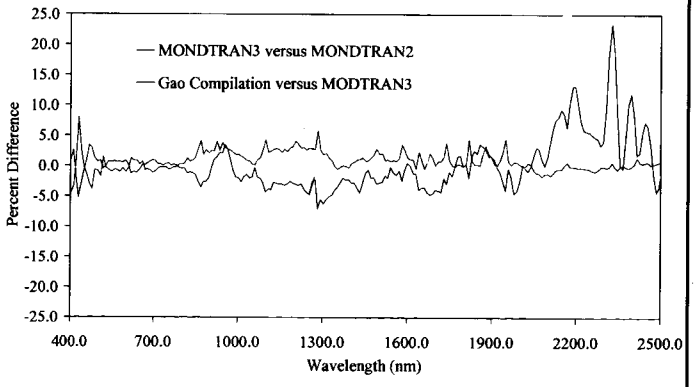
Atmospheric Correction

- Objective
  - Compensate for illumination and atmospheric effect to reveal the surface reflectance
- Approach:
  - Calculate, model, and derive illumination and atmospheric factors
  - Use these factors in a radiance to reflectance inversion
- Factors
  - Solar irradiance
  - Atmospheric absorption and scattering
  - Illumination, surface, and observation geometry

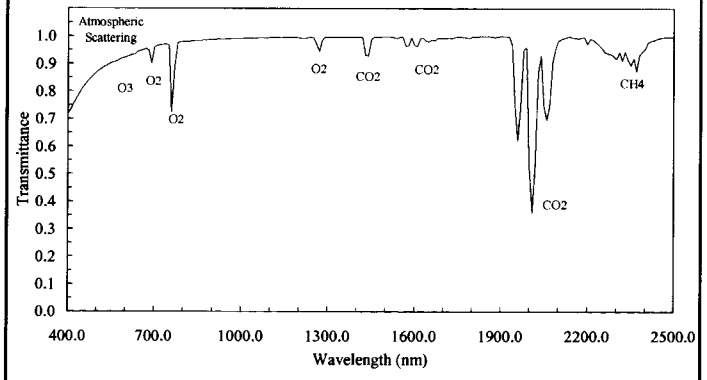
Exo Atmospheric Solar Irradiance



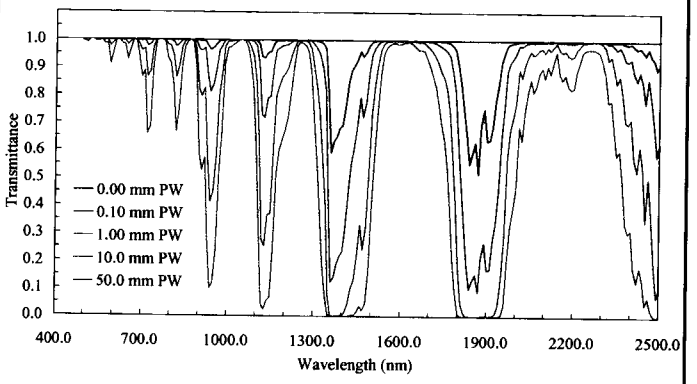
Variability in Solar Irradiance Spectra



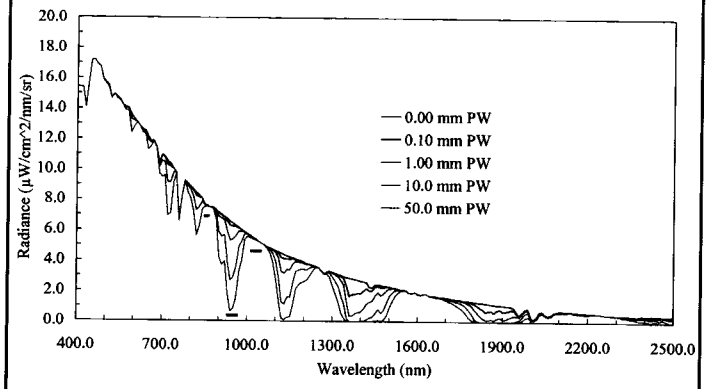
Atmospheric Constituents other that Water



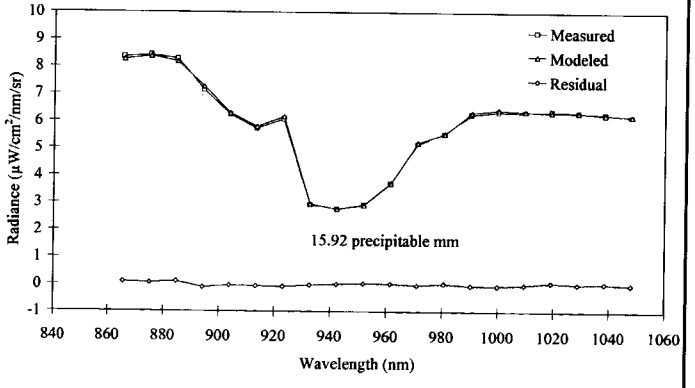
Influence of Water Vapor



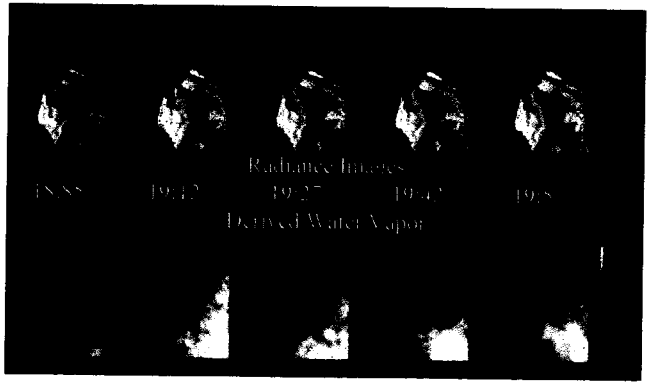
Estimation of Water Vapor
Continuum Interpolated Band Ratio (CIBR)



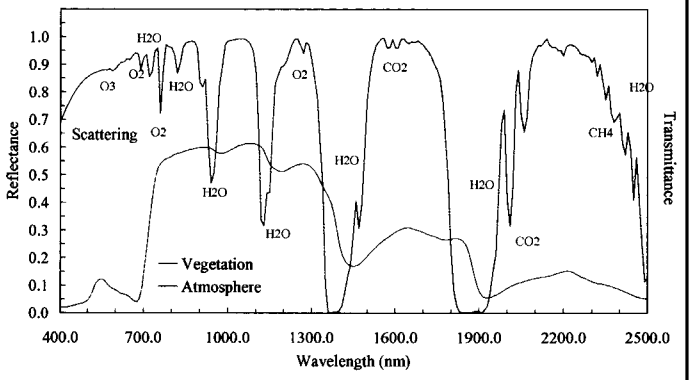
Estimation of Water Vapor
Spectral Fitting



AVIRIS Water Vapor at Rogers Dry Lake, CA



Water Vapor and Vegetation



Radiative Transfer Atmospheric Correction

- With imaging spectroscopy, because the full spectrum is measured, the dominant absorbing constituent of the atmosphere, water vapor may be derived directly.
- The derived atmospheric composition in conjunction with an accurate radiative transfer code may be used to invert from measured radiance to apparent surface reflectance.
- Radiative transfer atmospheric correction is possible with imaging spectroscopy data only if the imaging spectrometer radiance spectra are well calibrated.

Radiance at the Sensor

Simplified equation of the radiance at the sensor

$$Lt = \mu F_0 \rho_a/\pi + \mu F_0 T_d \rho_s T_u/\pi$$

Lt is the at sensor radiance
μ is the cosine of the solar zenith angle
F_0 is the exo atmospheric irradiance
ρ_a is the upward reflectance of the atmosphere
T_d is the downward transmittance
ρ_s is the reflectance of the surface
T_u is the upward transmittance of the atmosphere

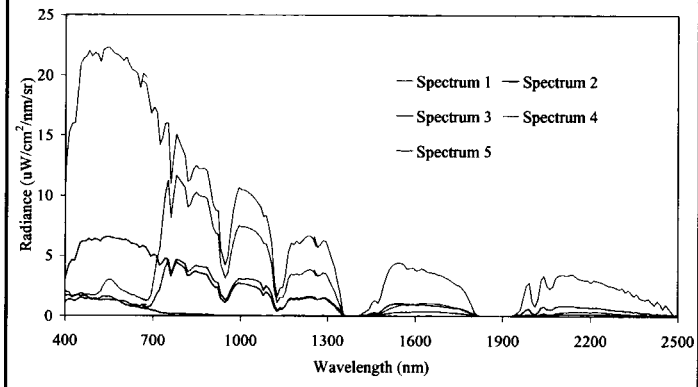
Reflectance Inversion

- The surface reflectance is solved on a spectrum by spectrum basis with atmospheric factors calculated with a radiative transfer code

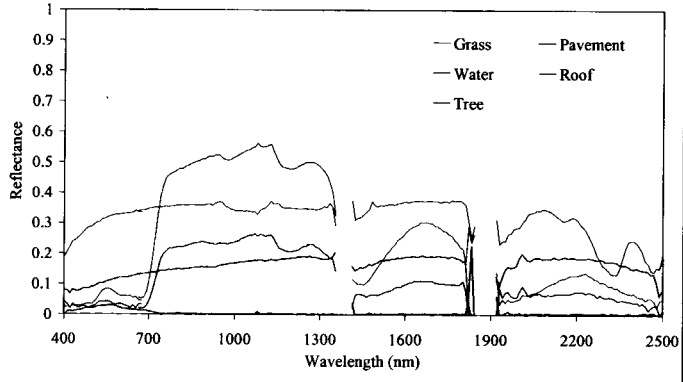
$$\rho_s = (\pi Lt - \mu F_0 \rho_a)/\mu F_0 T_d T_u$$

AVIRIS Image from New York area

AVIRIS Radiance



AVIRIS Reflectance Spectra



Ground Calibration or Single Spectrum Enhancement

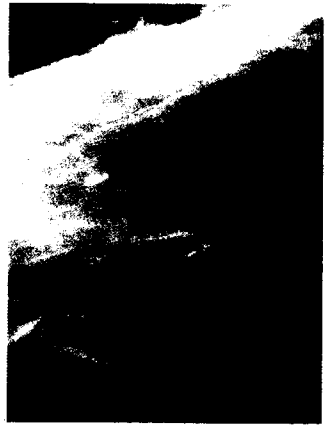
- Because there are systematic errors in
  - Radiative transfer codes
  - In the ability to constrain the atmosphere
  - And in AVIRIS
- Reflectance inversion results contain spectral artifacts
- These artifacts may be addressed through ground calibration or single spectrum enhancement where
  - A correction ratio if formed between the derived reflectance and the measured reflectance of a known area in the image
  - This spectral ratio is applied to the entire image to suppress the artifacts

Cirrus Clouds

- Cirrus clouds are common and perhaps second only to water vapor in there impact on optical remote sensing
- With traditional multispectral remote sensing they are difficult to detect
- There are strategic wavelengths for cirrus cloud detection
- There are evolving strategies to correct for the effects of cirrus clouds

Image of the Mojave Desert, CA

Image of the Mojave Desert, CA at 1380 nm



Cirrus Cloud Detection Basis

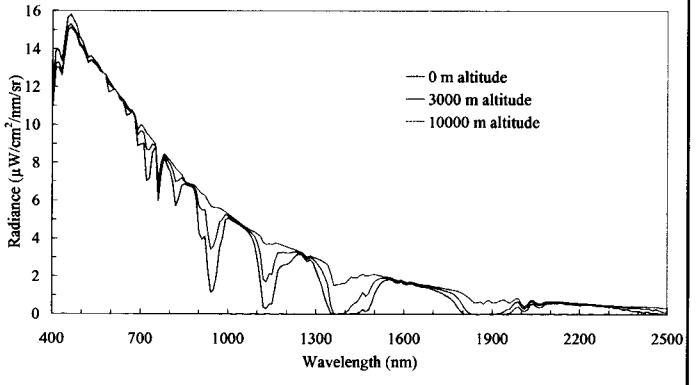


Image of the Mojave Desert, CA at 1380 nm

Summary: Atmospheric Correction

- The Atmosphere is present in every measurement (Landsat, SPOT, AVHRR, your eye)
- Water vapor is largest factor for atmospheric correction
- Other factors:Aerosols, Cirrus Clouds, Well mixed gases, Ozone
- With calibrated imaging spectroscopy data, a radiative transfer based atmospheric correction is achievable

Research and Applications

Research and Applications

- Atmosphere: water vapor, clouds properties, aerosols, absorbing gases...
- Ecology: chlorophyll, leaf water, lignin, cellulose, pigments, structure, nonphotosynthetic constituents...
- Geology and soils: mineralogy, soil type...
- Coastal and Inland waters: chlorophyll, plankton, dissolved organics, sediments, bottom composition, bathymetry...
- Snow and Ice Hydrology: snow cover fraction, grainsize, impurities, melting...
- Biomass Burning: subpixel temperatures and extent, smoke, combustion products...
- Environmental hazards: contaminants directly and indirectly, geological substrate...
- Calibration: aircraft and satellite sensors, sensor simulation, standard validation..
- Modeling: radiative transfer model validation and constraint...
- Commercial: mineral exploration, agriculture and forest status...
- Algorithms: autonomous atmospheric correction, advance spectra derivation...
- Other: human infrastructure...

AVIRIS Literature

- A citation search for "AVIRIS" in titles and abstract shows 285 refereed journal articles currently published.
- The AVIRIS workshops contain over 500 papers. These are available on-line at the AVIRIS web site.
- There are many additional AVIRIS papers in SPIE, IGARSS, ERIM and other conference proceedings

SUMMARY

- Imaging Spectroscopy is a new approach to remote sensing based in the physic, chemistry, and biology of spectroscopy
- Imaging Spectroscopy leads to over determined solutions for the composition of the surface and atmosphere.
- Imaging Spectroscopy requires advanced sensor, computer, and algorithm technology
- Imaging Spectroscopy requires an instrument with high SNR, high stability, high uniformity,

SUMMARY

- Imaging Spectroscopy requires an instrument with
  - High SNR
  - High stability
  - High uniformity
  - Excellent calibration
- With these instrument and corresponding data characteristics atmospheric correction is possible
- With high fidelity imaging spectrometer data, a range of new research and application become possible...

What Next

- It is important for you to contact NASA and let them hear your perspective on Imaging Spectroscopy
  - Flight requests
  - Communicate with NASA managers at appropriate venues
- Communicate with your colleagues about Imaging Spectroscopy
  - Government, Universities, Industry, etc.
- Publish in the journal literature
- Make the case for Imaging Spectroscopy and the next step

What Is Possible

- AVIRIS Class Spaceborne Imaging Spectrometer
  - **AVIRIS level precision**
  - **<5% smile**
  - **<5% keystone**
  - 10 to 30 meter spatial resolution
  - 20 to 180 km swath
  - Access to any point on the Earth in 3 days

Information

- AVIRIS website: http://aviris.jpl.nasa.gov
- Email: rog@jpl.nasa.gov
- AVIRIS Workshop Proceedings: On-line at website
- AVIRIS Workshop: March 2004