Imaging Spectrometer Science Measurements for Terrestrial Ecology: AVIRIS and the Next Generation

AVIRIS Characteristics and Development Status


Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA, 91109
OVERVIEW

- Objective
- Spectroscopy or multi-spectral
- Signals
- Imaging Spectroscopy
- Example of Imaging Spectroscopy based Science
- AVIRIS classic measurement characteristics
- Next Generation AVIRIS science measurement characteristics
- Next Generation Design and Status
- Summary
OBJECTIVE

• Answer next generation science questions with calibrated high uniformity and high signal-to-noise ratio imaging spectroscopy measurements
SIGNALS VEGETATION

Plant Spectroscopy

Absorption coefficient

Leaf Water & Cellular Scattering
Conifer
Grass
Broad Leaf
Sage Brush
Non-Photosynthetic Vegetation
Cellulose, Lignin, Sugars

Photosynthesis

6H₂O + 6CO₂ + photon → C₆H₁₂O₆ + 6O₂

Radiance (W/cm²/sr)

Atmospheric Water Vapor & Canopy water
Leaf Water, C, N
Atmospheric Carbon Dioxide
Imaging Spectroscopy Concept

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

224 spectral images taken simultaneously.
SPECTROSCOPY OR MULTISPECTRAL

Spectroscopy is required

Multi-Spectral is Insufficient
JPL EXPERIENCE

- AIS: Retired in AVIRIS lab
- AVIRIS: Now flying in NASA ER-2
- NIMS, VIMS: VIMS orbiting Saturn
- Hydice: Retired
- Hyperion: Orbiting Earth
- [CRISM]: Orbiting Mars
- MaRS: Flying for DOD customer on various aircraft
- MMM (M3): Moon flight mission complete
- ARTEMIS: Orbiting the Earth
- PBTB and ISTB: Ongoing laboratory test bed activities

[ ] = minimal JPL involvement, but important lessons learned.
RED = sensor no longer operating.
## AVIRIS “CLASSIC” SCIENCE MEASUREMENTS

<table>
<thead>
<tr>
<th><strong>Spectral</strong></th>
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<tbody>
<tr>
<td><strong>Range</strong></td>
<td>380 to 2500 nm</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td>10 nm</td>
</tr>
<tr>
<td><strong>Response</strong></td>
<td>10 nm</td>
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<th><strong>Radiometric</strong></th>
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<td><strong>Range</strong></td>
<td>0 to Max Lambertian</td>
</tr>
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<td><strong>Sampling</strong></td>
<td>14 bit</td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>+/- 1nm</td>
</tr>
<tr>
<td><strong>Signal-to-Noise ratio</strong></td>
<td>&gt;1000 @ 600 nm</td>
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<td><strong>Spectral-Cross-Track</strong></td>
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<td><strong>Spectral-IFOV</strong></td>
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AVIRIS-NG KEY SCIENCE REQUIREMENTS

What is needed in the instrument/measurement:

- High Signal-to-noise ratio required for molecular spectroscopy
- Uniformity is required for spectroscopy in the image domain
- Excellent calibration for quantitative results (spectral, radiometric, spatial)

![Graphs and images showing signal-to-noise ratio and calibration requirements.]

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Depiction
- Grids are the detectors
- Spots are the IFOV centers
- Colors are the wavelengths

>95% spectral cross-track

>95% spectral IFOV
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 “CLASSIC” 100S OF FLIGHTS OVER 20 YEARS
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a thoughtful, dedicated JPL team
VEGETATION FUNCTIONAL TYPE ANALYSIS, SANTA BARBARA, CA
Dar Roberts, et al, UCSB

MESMA Species Type 90% accurate

Species Fractional Cover

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CERRO GRANDE FIRE SEVERITY, LOS ALAMOS, NM, RAY KOKALY

AVIRIS Spectral Fitting Map

- Ash/Charcoal
- Mineral/Ash
- Mineral-1mm
- Mineral-2mm
- Dry Conifer
- Dry & Green Conifer
- Straw matting
- Straw matting & Green grass
- Green Vegetation

Lignin-Cellulose Lab

Lignin-Cellulose AVIRIS

Photo

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Remote Measurement via Spectral Fitting

Surface mineralogy
Cuprite, NV

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SURFACE COMPOSITIONAL DERIVED WITH IMAGING SPECTROMETER MEASUREMENTS (AVIRIS)
A red-tide bloom in Monterey Bay

Surface Chlorophyll from AVIRIS 10/07/02

Surface Chl from SeaWiFS 10/08/02

SeaWiFS bands miss signal
SIMI VALLEY, CA WILD FIRE

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Mount Rainier derived three phases of water (Vapor: blue, Liquid: green, Ice: red) in melting snow environment.
NEXT GENERATION AIRBORNE VISIBLE / INFRARED IMAGING SPECTROMETER (AVIRIS-NG) AMERICAN RECOVERY AND REINVESTMENT ACT (ARRA)

Design and build follow-on to AVIRIS (higher sampling, high signal-to-noise)

• Task Budget: $5M
• Task Schedule: September 1, 2009 – October 1, 2010
## AVIRIS NEXT GENERATION

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AVIRIS-ng Instrument Configuration

AVIRIS-ng consists of:

- Sensor
- On board calibration source
- INS/ GPS
- Heater, cryocooler, and focal plane electronics
- Operator/Software Rack Assembly
- ECS Rack Assembly
- Cabling and Plumbing

* Not an AVIRIS-ng component
AVIRIS-NG COORDINATES

Origin at Slit

Direction of Flight

Gravity

20.5 Deg

Origin at Slit

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Sensor Configuration

- Cryocoolers (2X)
- Thermal Shields, Active Thermal Control
- Thermal Shields, Passive (2X)
- Telescope
- Window
- Vacuum Chamber
- Spectrometer
- Kinematic Struts, Active Thermal Control

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System Operation

• Pushbroom imager collects image “lines”
• Image lines are collected into data “cubes”. Typical cubes are taken over 20 minute runs.
• Image “swath” is the width of the data cube. Swath dimensions are a function of altitude.
• Cube data are geo-rectified using GPS/INS data to correct for platform motion
• Cubes are radiometrically calibrated against a stable on-board source before and/or after each run
• The NISDVU is designed to be easily integrated with LIDAR
OFFNER SPECTROMETER, 2 MIRROR ANASTIGMAT HIGH-THROUGHPUT TELESCOPE
SIMPLE SYSTEM: 4 MIRRORS, 1 GRATING, 1 DETECTOR
ASSEMBLED TESTBED TELESCOPE

Achieved 1.1 wave p-v wavefront error over entire aperture and field with minutes of assembly time.

Notice non-circular pupil shape.

Post-polished aluminum mirrors produced by Axsys.

Previous Axsys mirrors fail mid-frequency specification by a factor of 2-3, impact acceptable (see risks and mitigations later).
SPECTROMETER PERFORMANCE
(X- AND Y- ENCLOSED ENERGY IN PIXEL)
(ACCOUNTS FOR APODIZATION)

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ON-BOARD CALIBRATOR

• Maintain absolute radiometric calibration within 95% across all spectral channels within the FOV

• As designed will also
  – Allow image specific flat fielding to control small radiometric variability and deviations
  – Allow trend monitoring to detect performance issues early

• To meet the requirements we will use a refinement of the on-board calibrator source currently flying and meeting these requirements in AVIRIS and MaRS.
OBC TARGET

• OBC target in front of slit
• Mature OBC approach with extensive heritage
• We have tested the use of the OBC target at the slit entrance
• OBC now in testing for installation into AVIRIS-ng
INSTRUMENT CRYOVACUUM ARCHITECTURE

- Cryocoolers, power supplies, and drive electronics
- Recirculating fluid chiller removes heat from cryocoolers
- Temperature monitoring and control maintains FPA temperature stability and optical alignment (multiple locations on instrument)
- Vacuum-ion pump and gauge
  
  Decision on use of the ion pump is pending system performance evaluation
- Cryo wiring harness is fabricated in-house; not shown

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CRYOVACUUM SUBSYSTEM
OPERATIONAL CONDITIONS

Vacuum enclosure carries window, cryocoolers, all electrical and vacuum feedthroughs, all mechanical loads

cryocooler cold ends ~110 K steady-state
Both coolers run for cooldown, then one switches off.
(Straps to inner shield and spectrometer are not shown)

Thermally-isolating kinematic struts support instrument from warm outer vacuum shell (318 K maximum environmental temperature)

Two “floating” and one actively-cooled radiation shields reduce heat input to spectrometer:
1st shield ~288 K, floating
2nd shield ~235 K, floating
actively-cooled shield ~125 K, controlled

Spectrometer and telescope temperature are actively controlled to <50 mK variation

FPA is cooled to ≤140 K and actively controlled.
(Dedicated high-conductance strap to cold sink not shown.)
DESIGN /FABRICATION STATUS

- Design complete
- Mechanical and Cyro-vacuum parts now in fabrication
- 45% of parts now received, complete in August 2010
I&T STATUS

• Facility Ready
• Personnel trained
• GSE design complete – now in build
• Plans, procedures and storyboards in review
• “Pre” I&T now underway
• I&T begins July 2010
• Focal Plane Interface Electronics
  • only 1 analog board (only 1 focal plane assembly)
  • FPGA programming has been modified
    • 1 Focal Plane Assembly (no multiplexing)
    • uses MaRS 14-bit capability (MaRS only used 12 bits)
    • MaRS pedestal shift problem identified and corrected
    • GPS time tag incorporated (requirement)
    • 1st pixel clock extension incorporated (for warmer FPA operation)
    • line buffers enable non-interleaved data output
    • larger FPGA (pin-compatible and EEPROM compatible)
• Camera Link Data Path (to next-generation frame grabber card)
• OBC and control electronics
• C-MIGITS III INS/GPS
FOCAL PLANE ARRAY

- Well-known Teledyne TCM6604A
- Capacitive transimpedance amplifier
- Snapshot imaging
- 4 video outputs, 1 ref output (unused)
- 4 clocks, 7 bias voltages
- Power dissipation: $\sim 60\text{mW}$
- Read noise: 120 e- [rms]
- Amplifier glow: $\sim 100 \text{e-/sec}$
- Recent understanding of a phenomenon affecting blue-end QE stability is yielding processing steps for mitigation
- Devices are straightforward to fabricate using current vendor processes
- Custom JPL drive electronics exist and work extremely well with this FPA
I&T FLOW DIAGRAM

NGIS Integration and Test Plan

System I&T

Warm Alignment Plan and Storyboard

Alignment of Spectrometer

Spectrometer Orientation & Optics Verification

Rate of Telescope

Mate of Fixed Plane Tower

Mechanical-Thermal/Vacuum Story Board

Integrate Instrument Sub-Assembly to Vacuum Vessel

Assemble OBC Linkage and Attach to Target & Drive

Install FPA Route final internal cables

Calibration Plan

Cold Calibration Baseline Cycle 1

Calibration Procedure

Cold Calibration Baseline Cycle 2

Calibration Procedure

Cold Calibration Baseline Cycle 3

Calibration Procedure

Cold Calibration Baseline Cycle 4

Calibration Procedure

System Testing

Cold Cycle 1

Final thermal test (all 4, cold cycles)

Final Pressure Procedure

Final Alignment Procedure

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MECHANICAL/THERMAL/OPTICAL INTEGRATION PROCEDURE

NGIS Integration Procedure

Alfonso Feria
Version 0.6
June 2nd, 2010

- **Purpose**
  - Story board for the integration process
- **Description**
  - Provide hardware information (adhesives, fasteners, parts lists, etc.) to aid during integration
  - Provide installation notes
  - Record bolt torque values
  - Document torque wrench information
  - Collect and document thoughts and notes before, during and after integration
- **Status**
  - Done

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Description:
A step-by-step visual guide to the warm alignment process, including GSE needed and verification steps

Status: Done
Successful peer review 06/09/10
SUMMARY

• The science enabled by a high uniformity and high signal-to-noise ratio imaging spectroscopy is well established
  – AVIRIS referenced in > 600 refereed journal articles

• We understand the key measurement characteristics that are needed

• We have developed the right set of requirements flowing from the science

• Throughout the AVIRIS-ng effort, these science traced requirements will be tracked, balanced, and reported to assure the instruments are ready for the next generation science

• The design is complete and being manufactured

• AVIRIS-ng is being built and will be integrated this summer