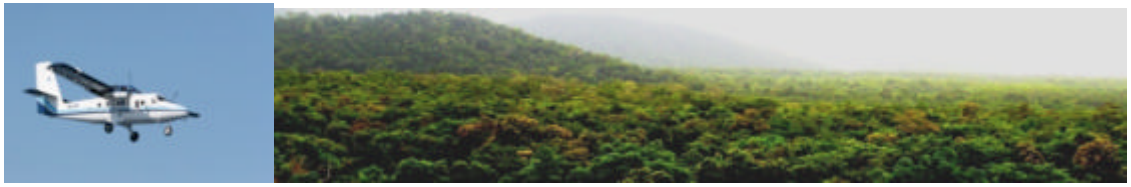


Imaging Spectrometer Science Measurements for Terrestrial Ecology: AVIRIS and the Next Generation AVIRIS Characteristics and Development Status

L. Hamlin, R. O. Green, P. Mouroulis, M. Eastwood, I. McCubbin, D. Wilson, D. Randall, M. Dudik, C. Paine

Jet Propulsion Laboratory, California Institute of Technology

Pasadena, CA, 91109

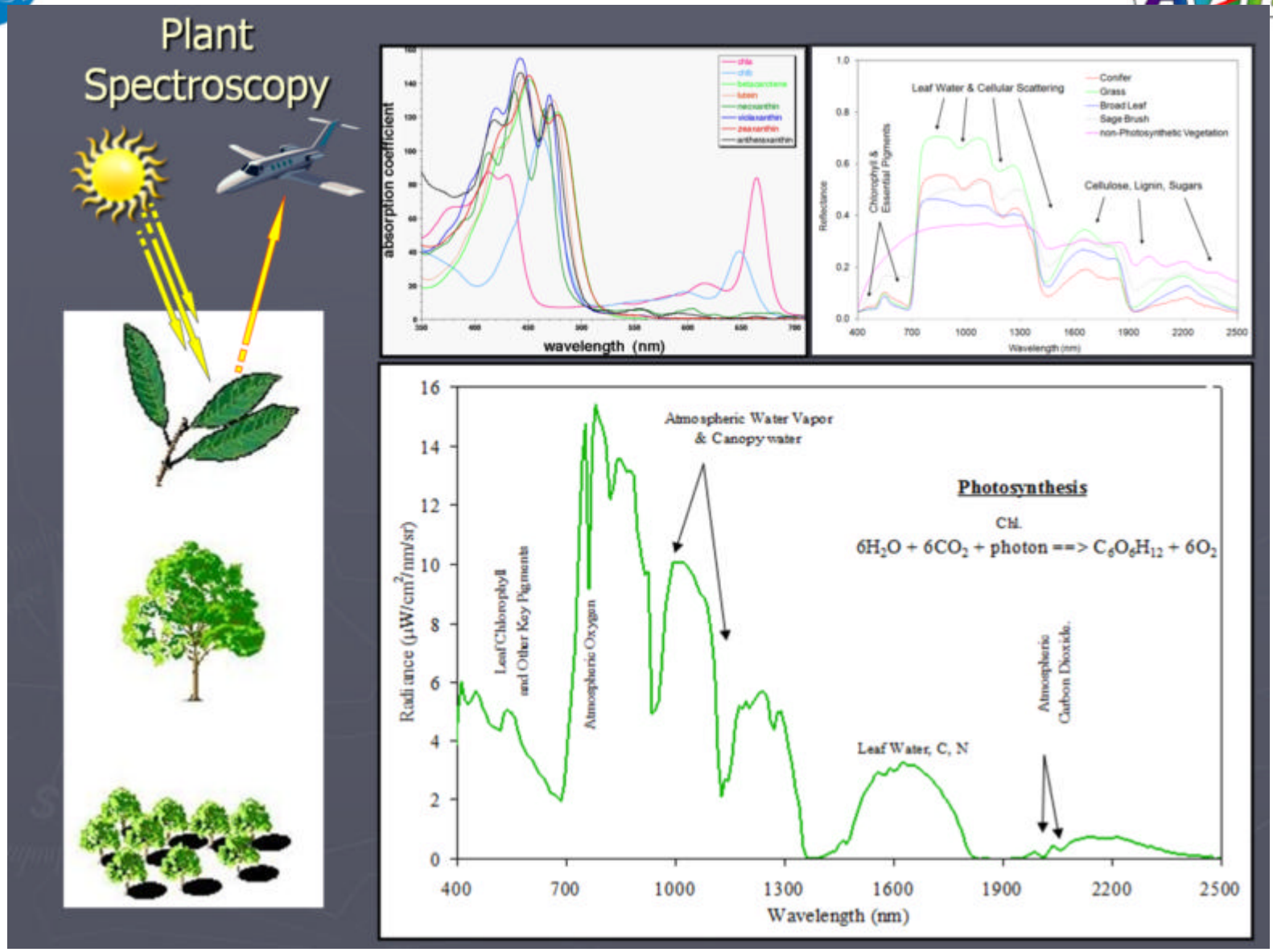
OVERVIEW

- 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

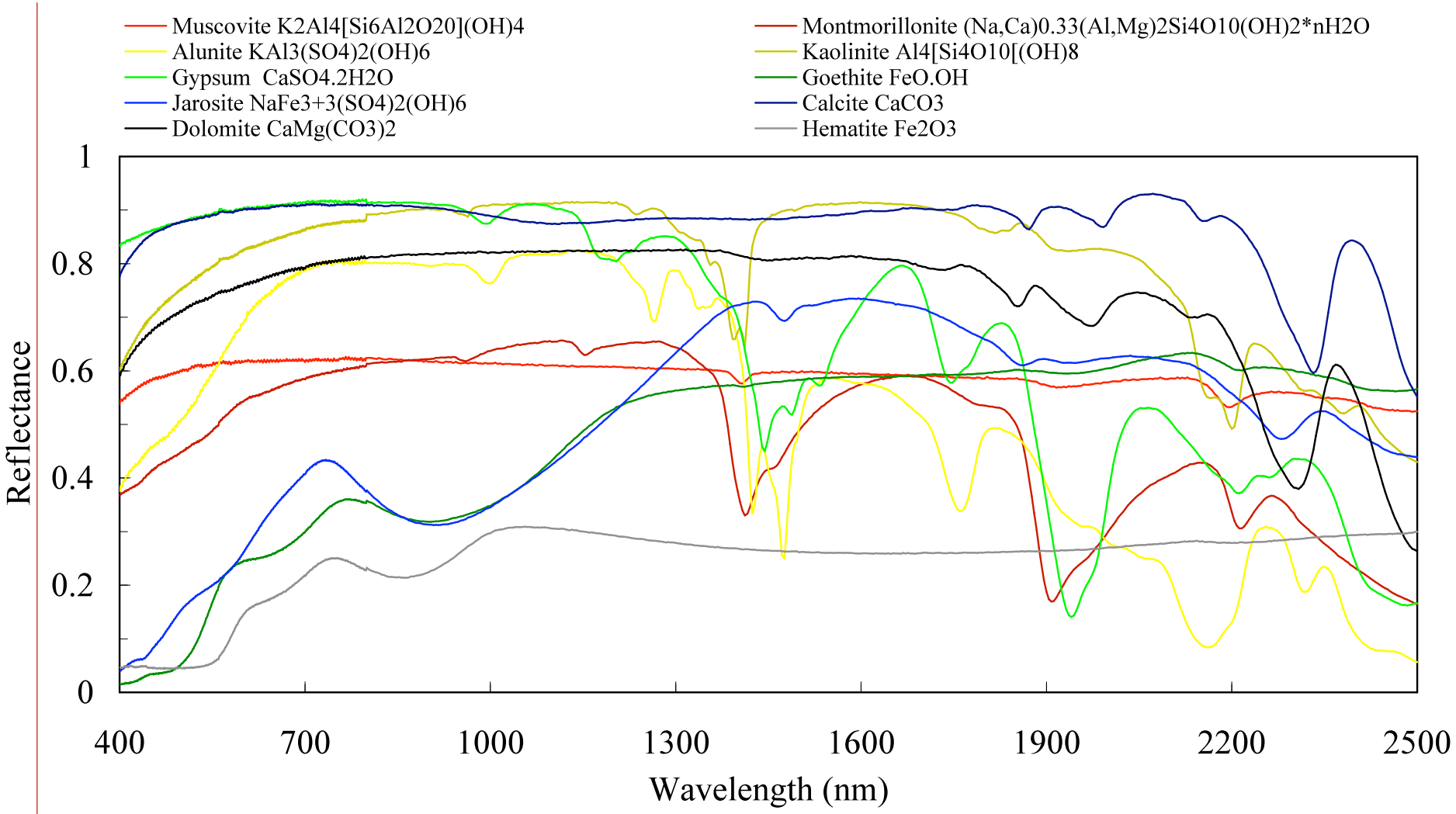
OBJECTIVE

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

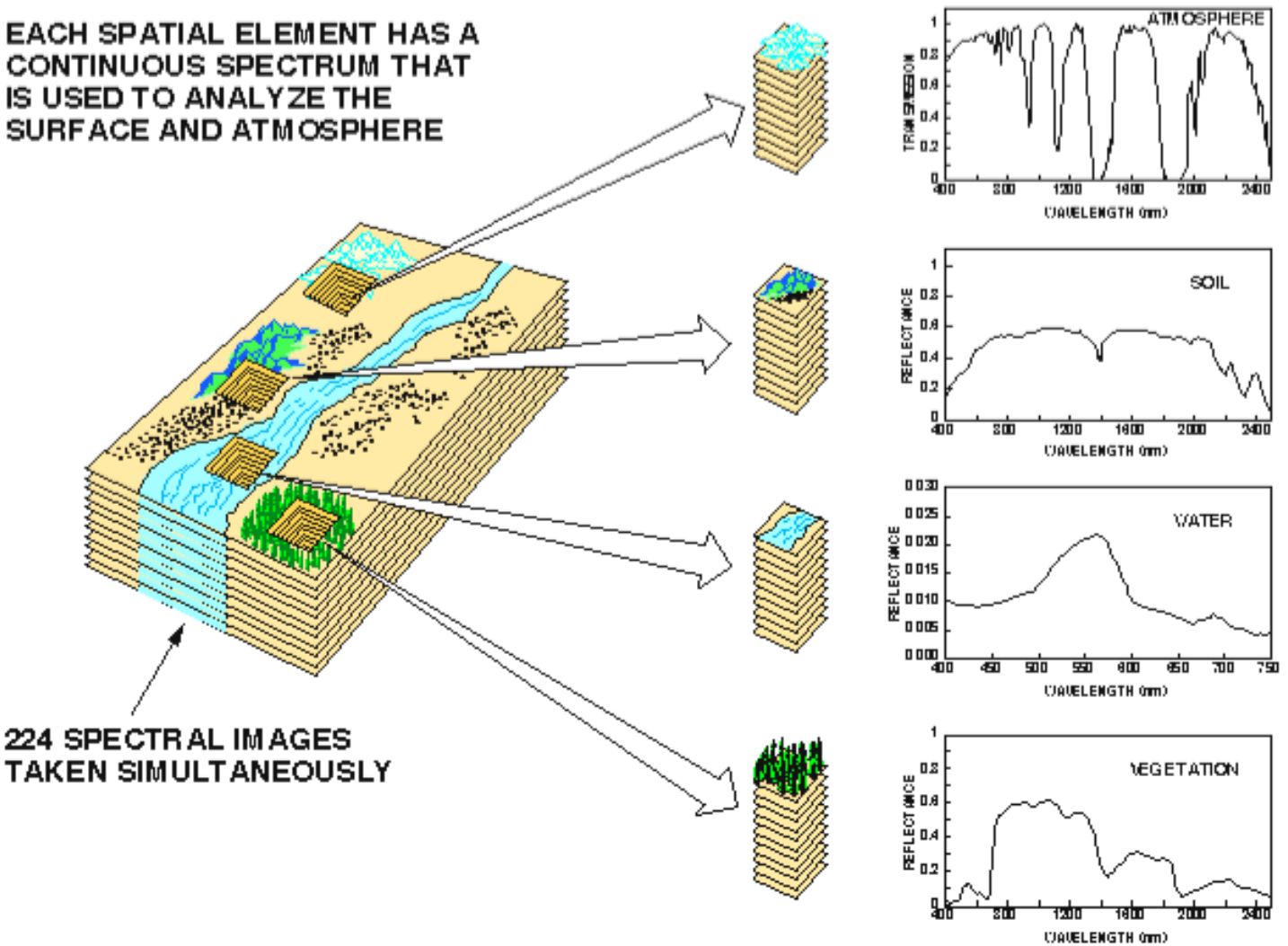
SIGNALS VEGETATION



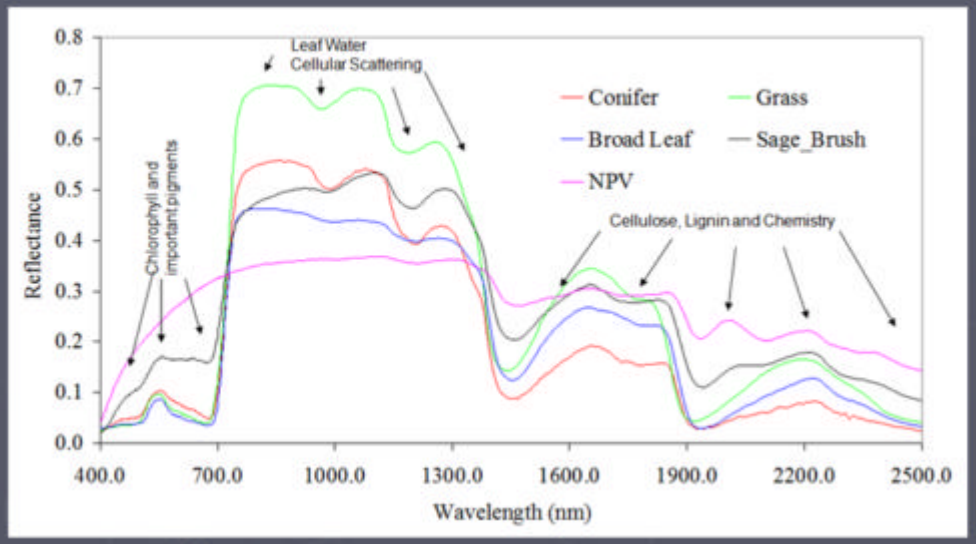
SIGNALS MINERALS



Imaging Spectroscopy Concept

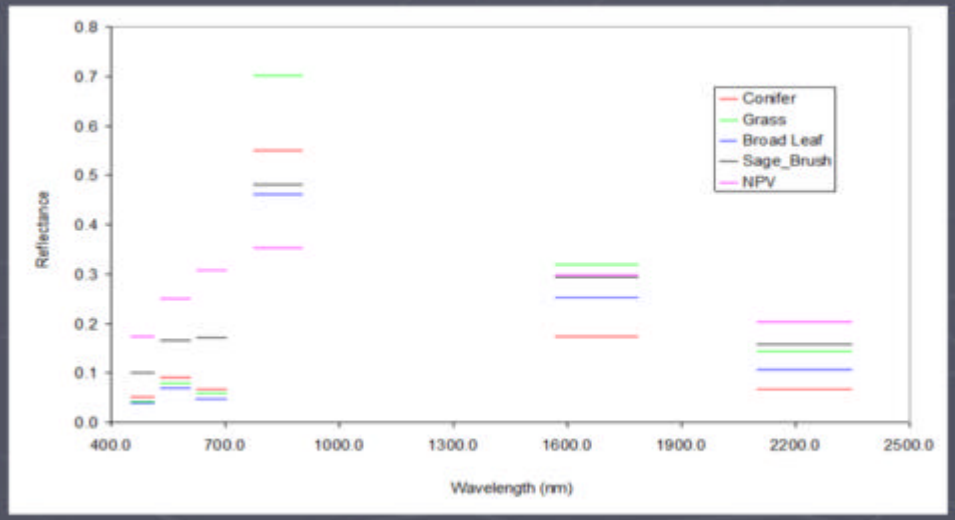


SPECTROSCOPY OR MULTISPECTRAL



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.

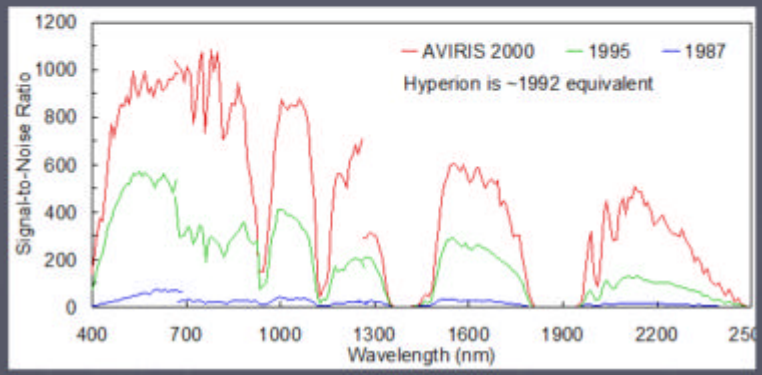
AVIRIS "CLASSIC" SCIENCE MEASUREMENTS

Spectral		
	Range	380 to 2500 nm
	Sampling	10 nm
	Response	10 nm
Radiometric		
	Range	0 to Max Lambertian
	Sampling	14 bit
	Calibration	+/- 1nm
	Signal-to-Noise ratio	>1000 @ 600 nm
		>400 @ 2200 nm
Spatial		
	Field-of-View	34 degrees
	Instantaneous FOV	1 milliradian
	Spatial swath	2.5 to 11 km @ alt (4 to 20 km)
	Spatial resolution	4 to 20 m @ alt (4 to 20 km)
Uniformity		
	Spectral-Cross-Track	>95% Uniform
	Spectral-IFOV	>95% Uniform

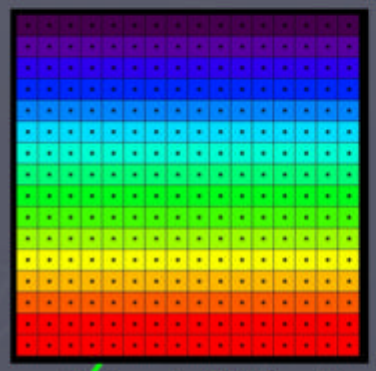
AVIRIS-NG KEY SCIENCE REQUIREMENTS

What is needed in the instrument/measurement:

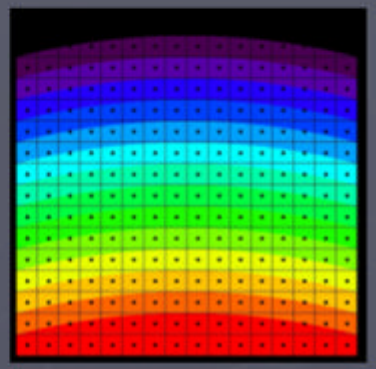
- *High Signal-to-noise ratio required for molecular spectroscopy*



- *Uniformity is required for spectroscopy in the image domain*

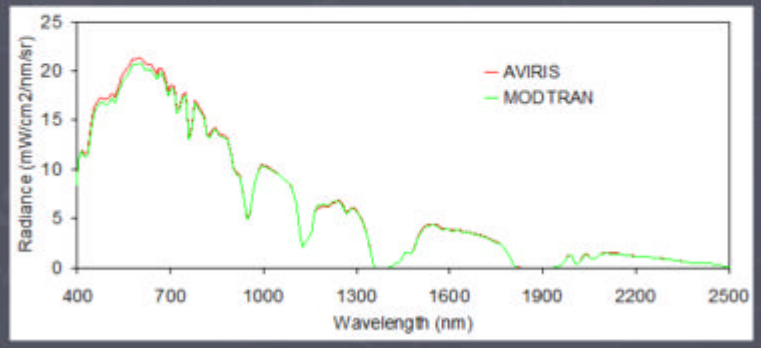


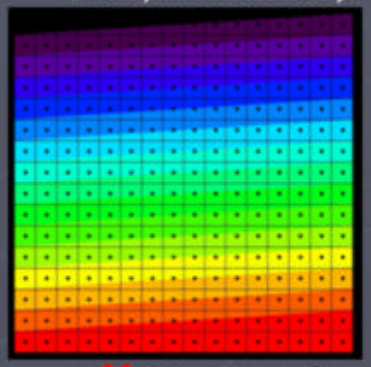
✓ *Required Uniformity*



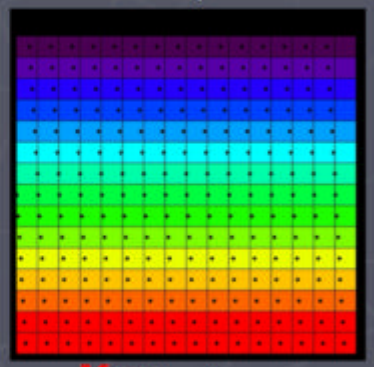
✗ *Failure by "frown"*

- *Excellent calibration for quantitative results (spectral, radiometric, spatial)*





✗ *Failure by twist*



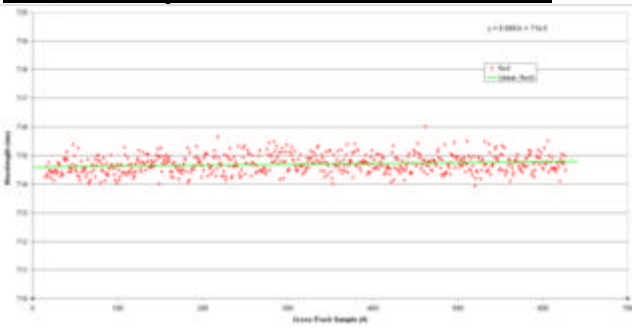
✗ *Failure by Spectral-IFOV-shift*

AVIRIS-NG KEY SCIENCE MEASUREMENTS

Depiction

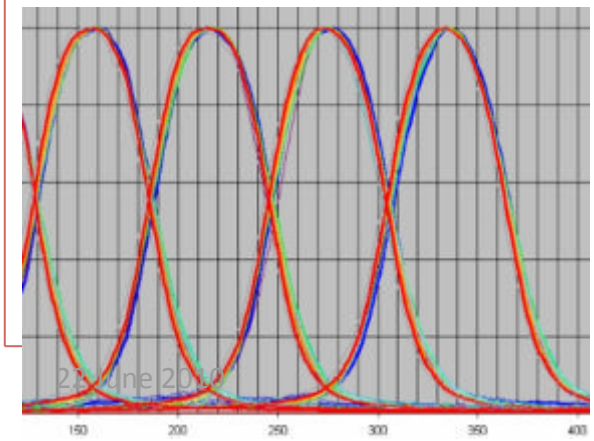
-Grids are the detectors
-Spots are the IFOV centers
-Colors are the wavelengths

>95% spectral cross-track



M3

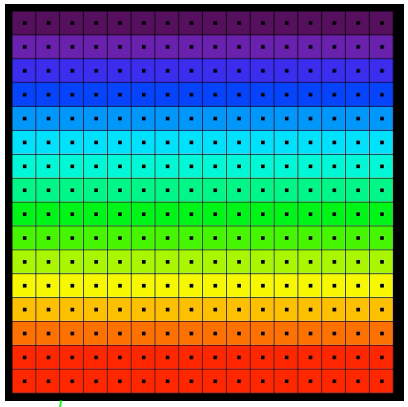
>95% spectral IFOV



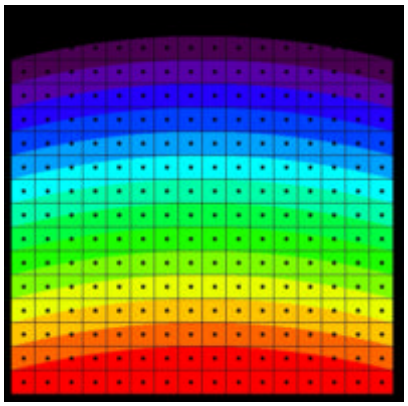
M3

Cross-Track

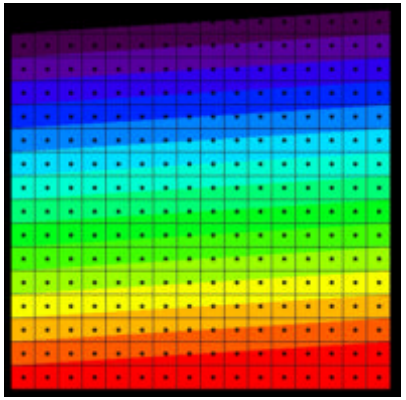
Wavelength (nm)



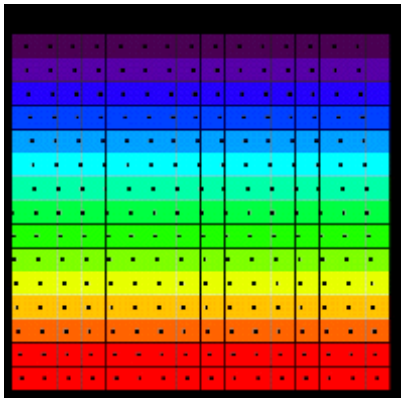
√ Required Uniformity



X Failure by "frown"



X Failure by twist



X Failure by Spectral-IFOV-shift

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 ...

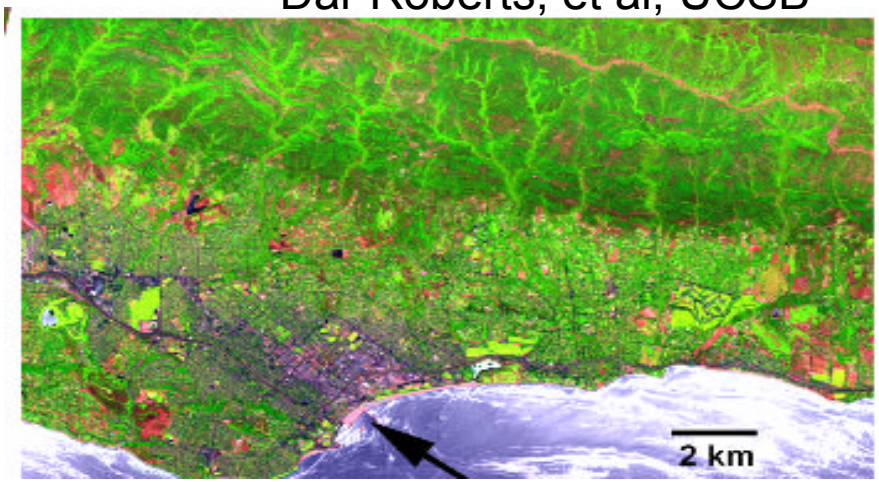
AVIRIS "CLASSIC" 100S OF FLIGHTS OVER 20 YEARS


ALTM
Optech
DELL

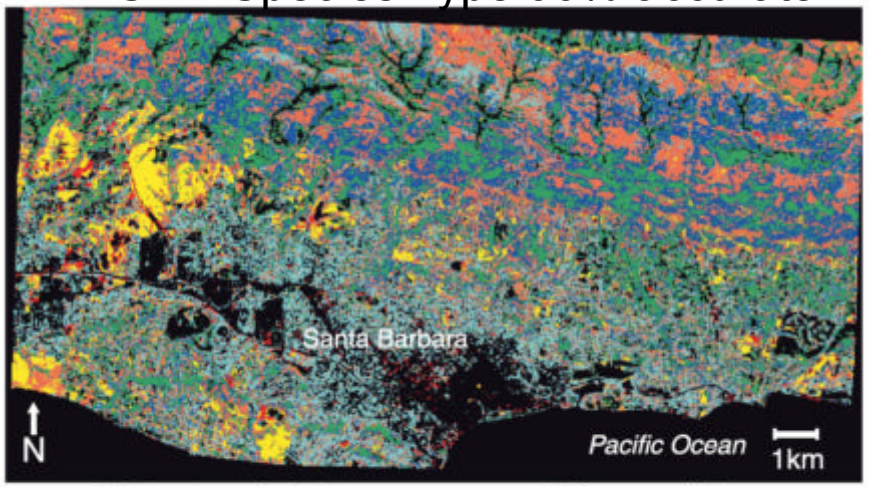
a thoughtful, dedicated JPL team

VEGETATION FUNCTIONAL TYPE ANALYSIS, SANTA BARBARA, CA

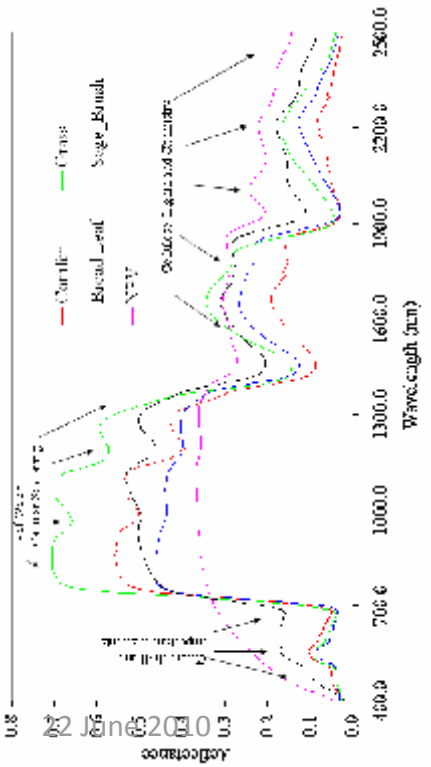
Dar Roberts, et al, UCSB

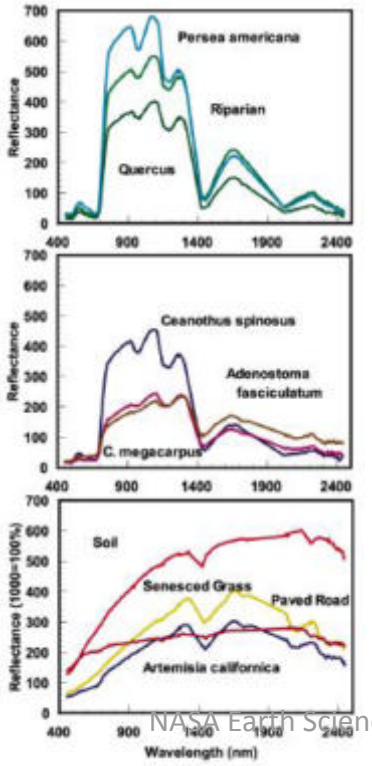


MESMA Species Type 90% accurate

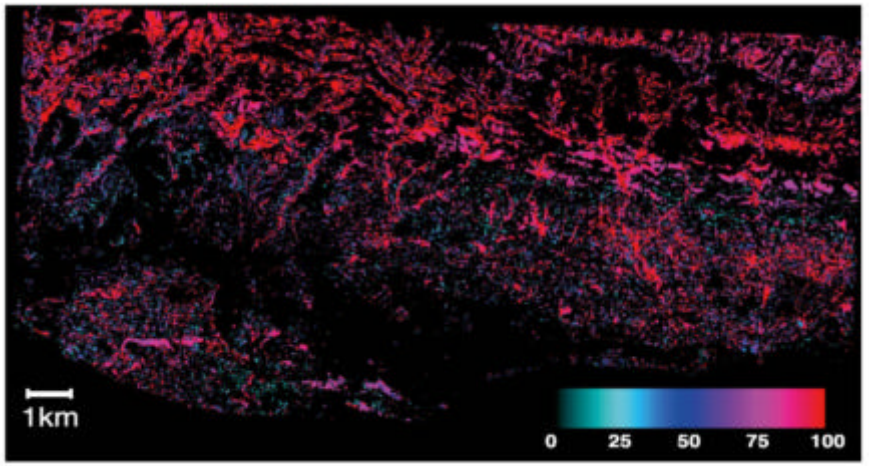


Adenostoma fasciculatum
Ceanothus megacarpus
Arctostaphylos spp.
Quercus agrifolia
Grass
Soil



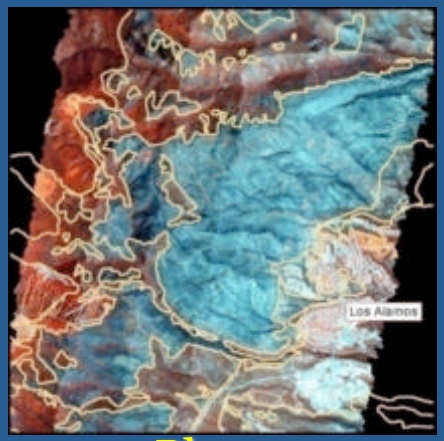


Species Fractional Cover



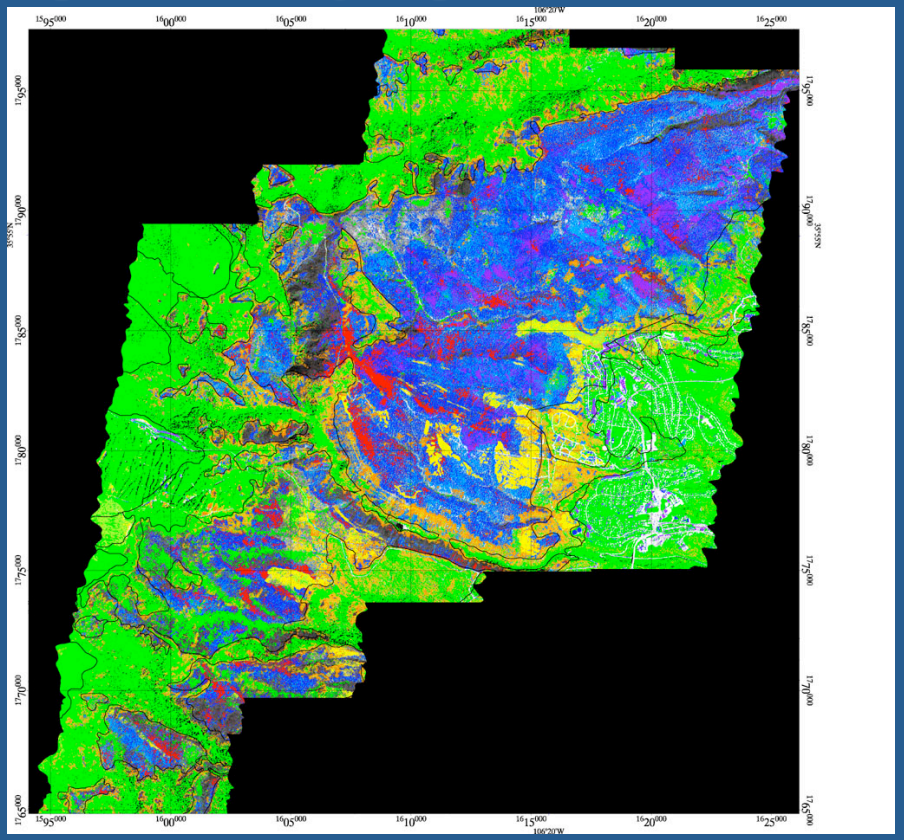
CERRO GRANDE FIRE SEVERITY, LOS ALAMOS, NM, RAY KOKALY

AVIRIS



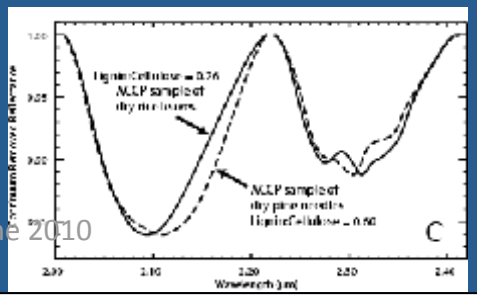
Photo

Spectral Fitting Map

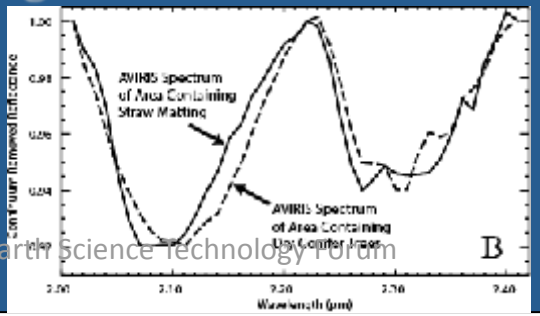


- Ash/Charcoal
- Mineral/Ash
- Mineral-1mm
- Mineral-2mm
- Dry Conifer
- Dry & Green Conifer
- Straw matting
- Straw matting & Green grass
- Green Vegetation

Lignin-Cellulose Lab

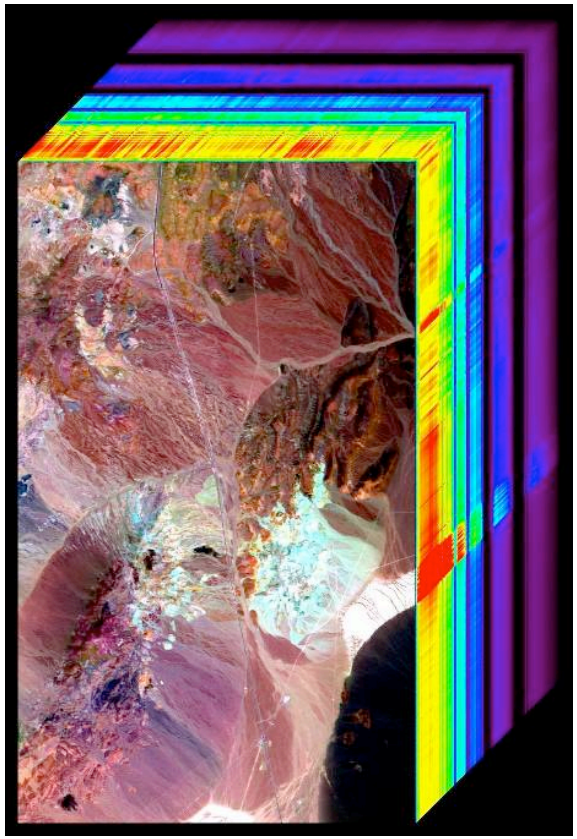


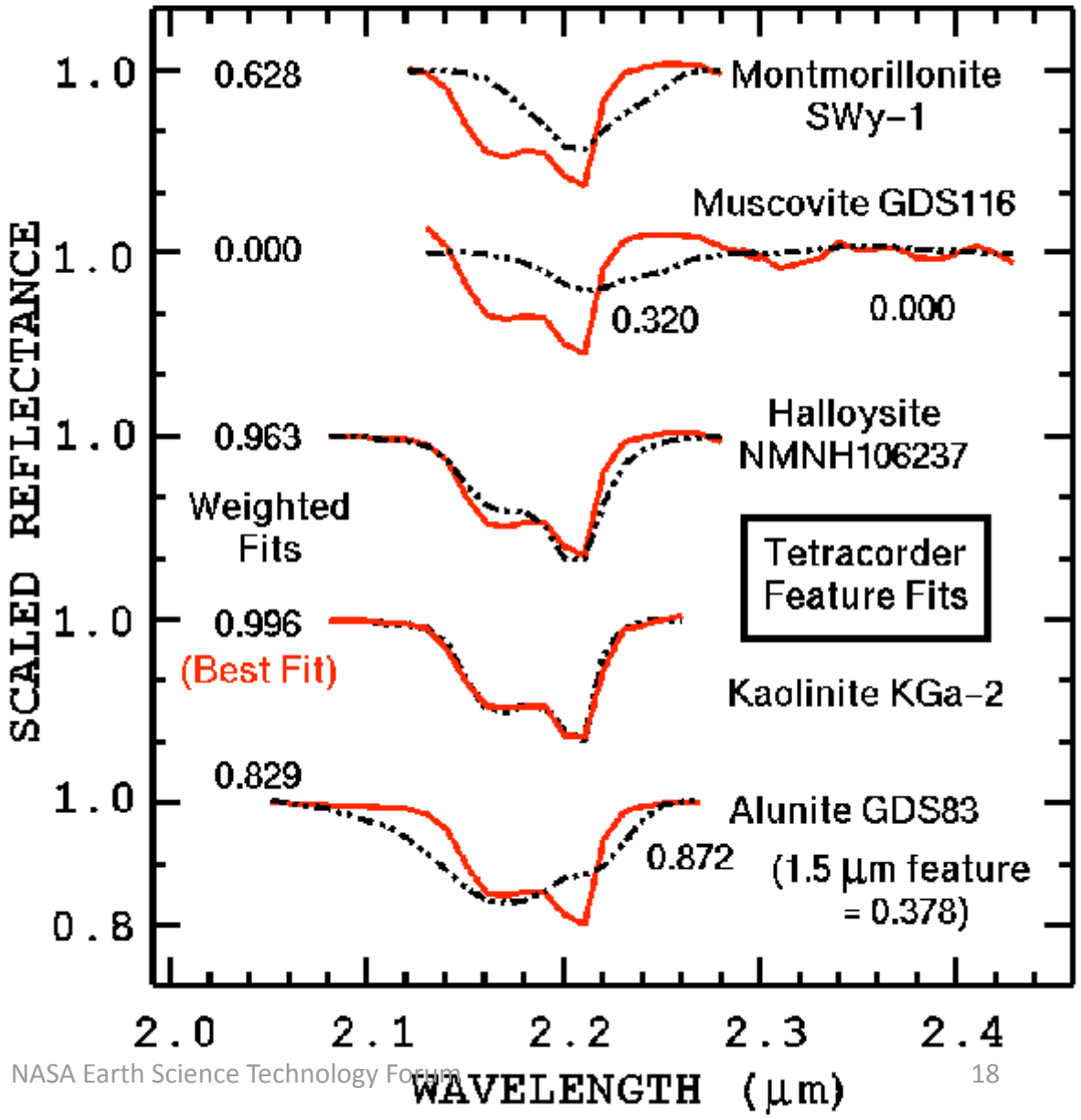
Lignin-Cellulose AVIRIS



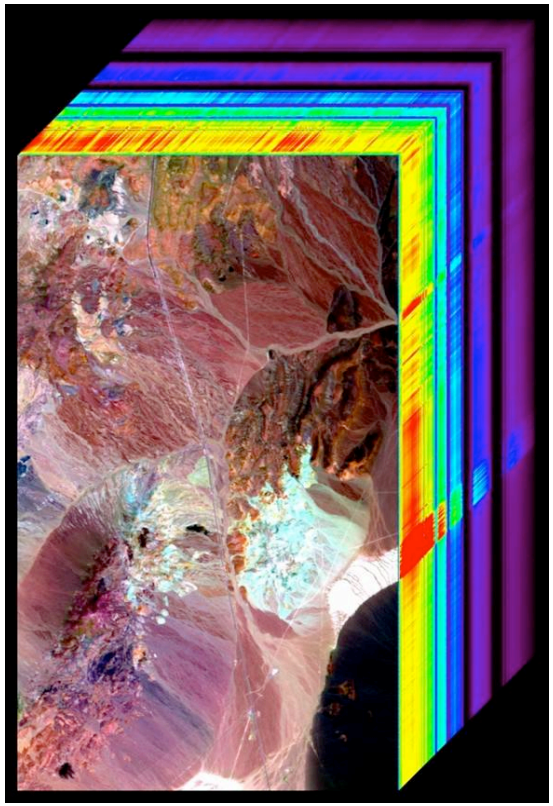
Remote Measurement via Spectral Fitting

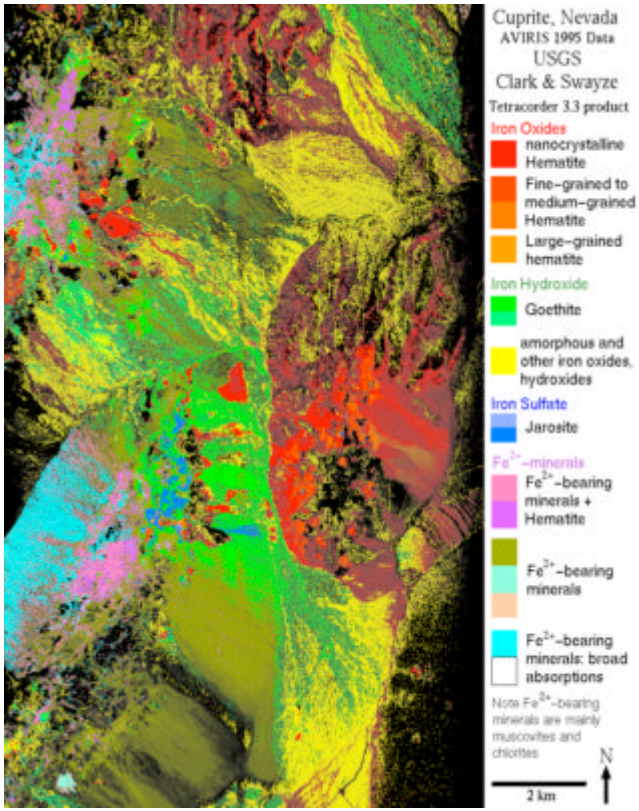
Surface mineralogy
Cuprite, NV

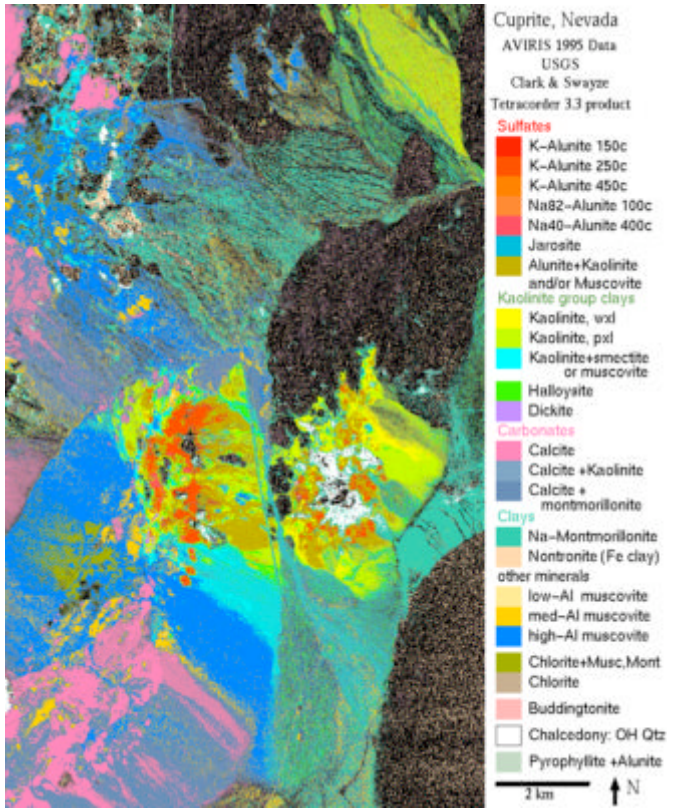




SURFACE COMPOSITIONAL DERIVED WITH IMAGING SPECTROMETER MEASUREMENTS (AVIRIS)

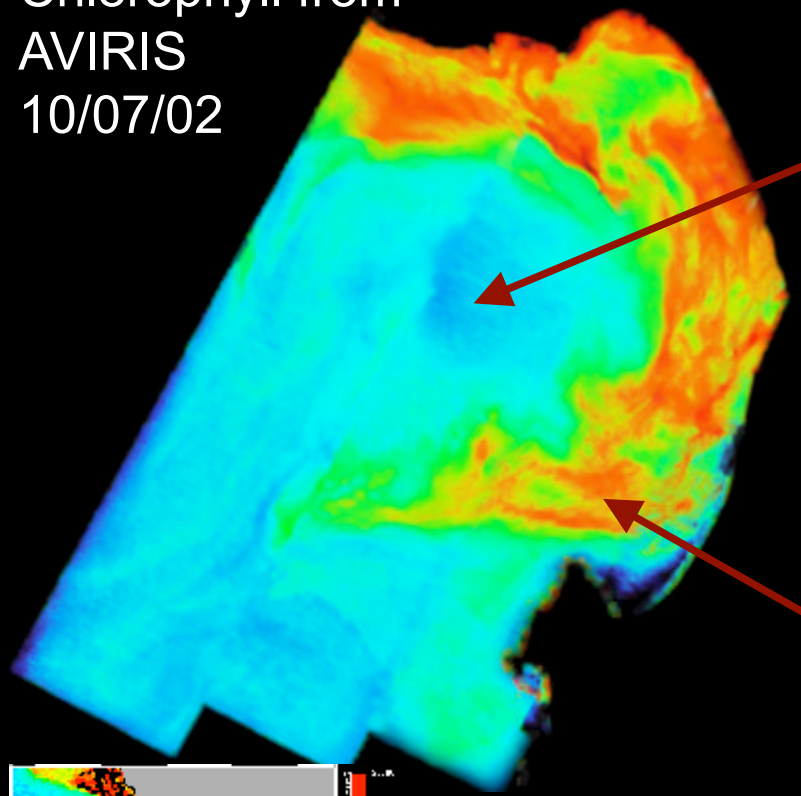


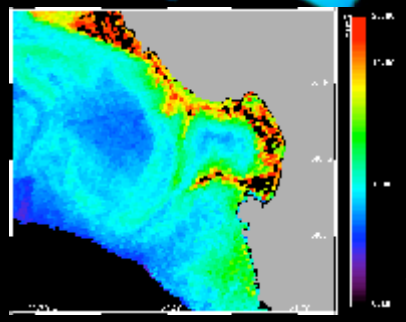




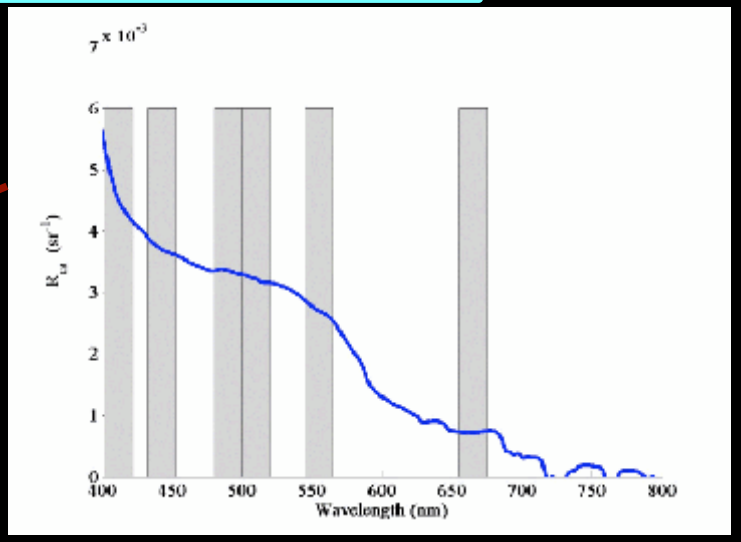
A red-tide bloom in Monterey Bay

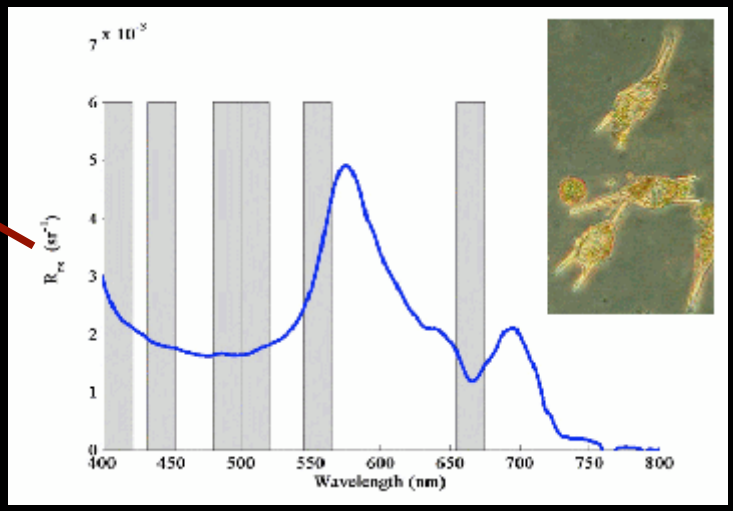
Surface Chlorophyll from AVIRIS 10/07/02





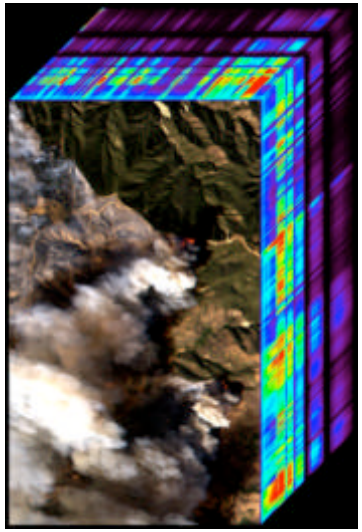
Surface Chl from SeaWiFS 10/08/02

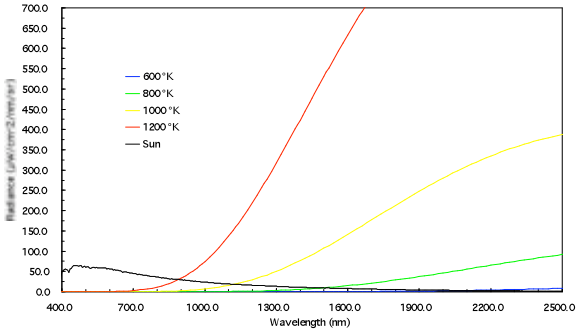


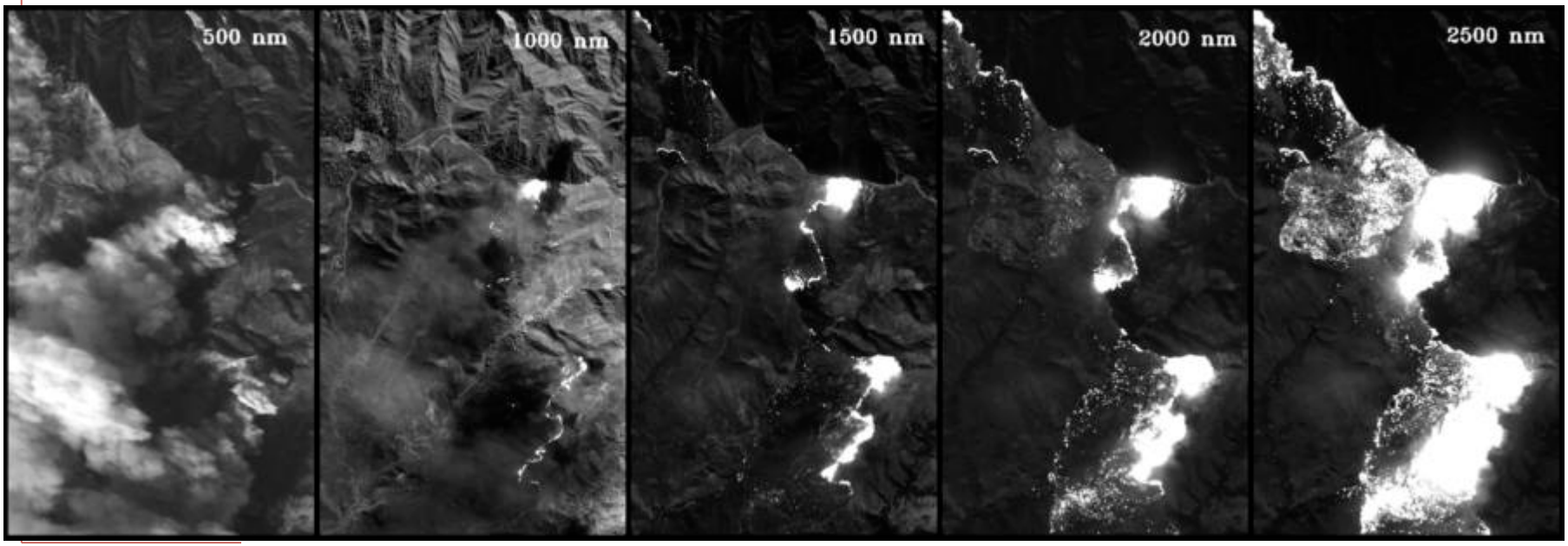


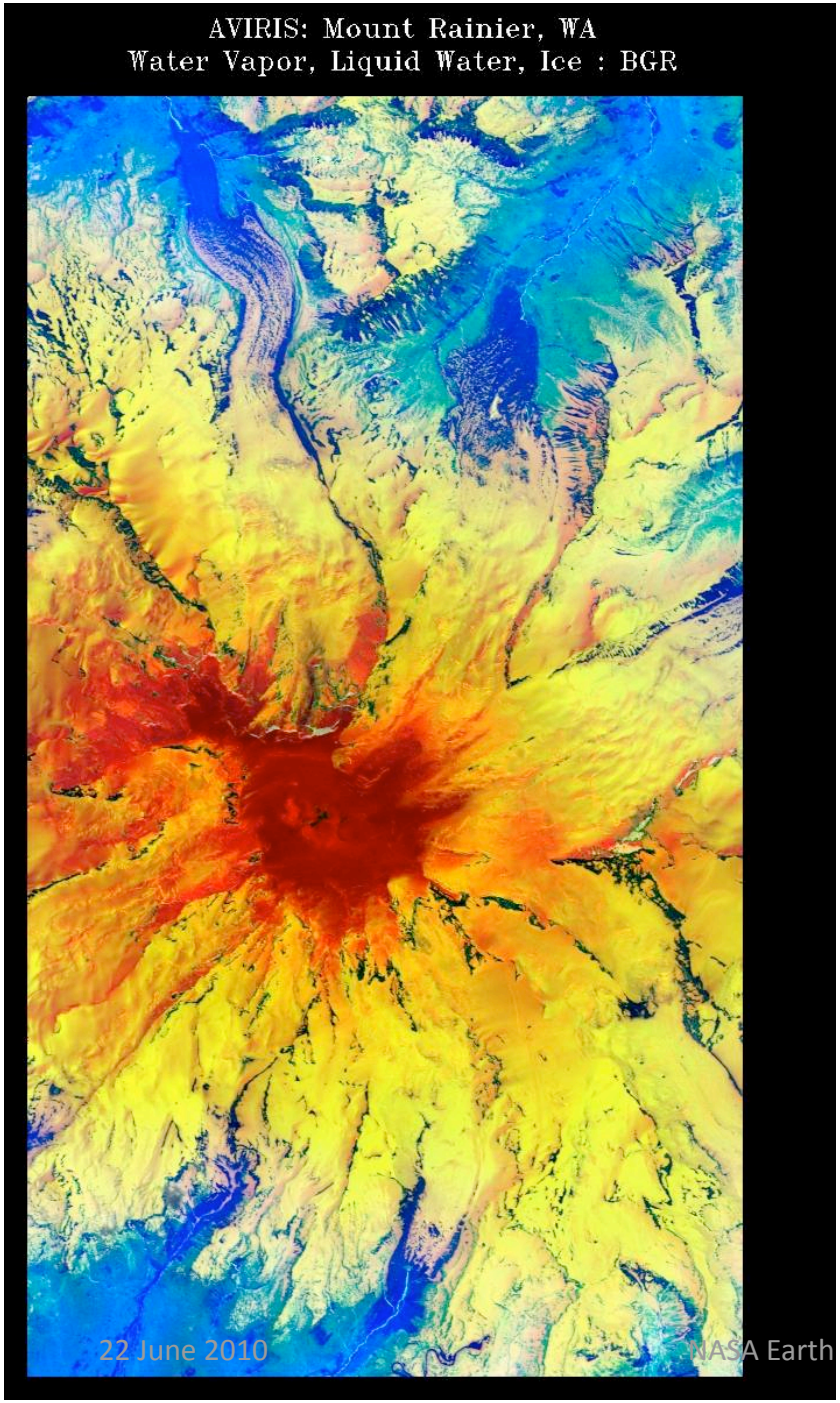
SeaWiFS bands miss signal

SIMI VALLEY,CA WILD FIRE

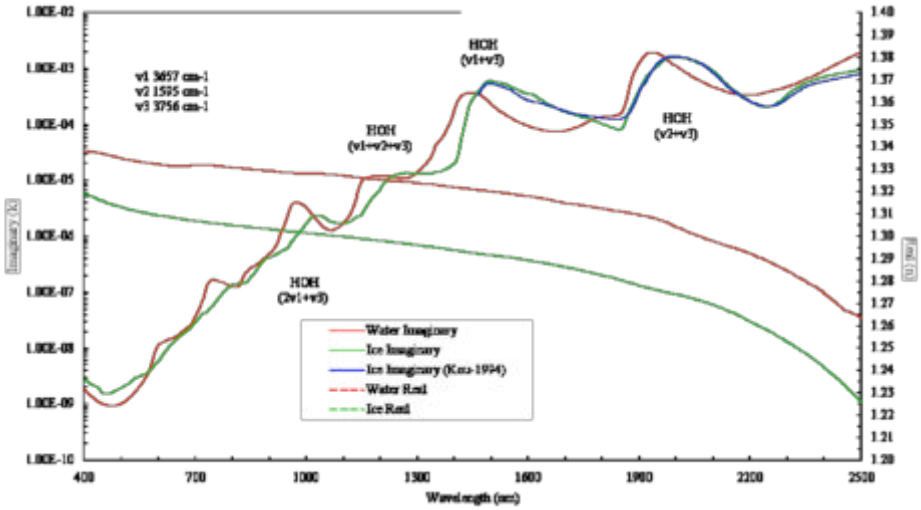


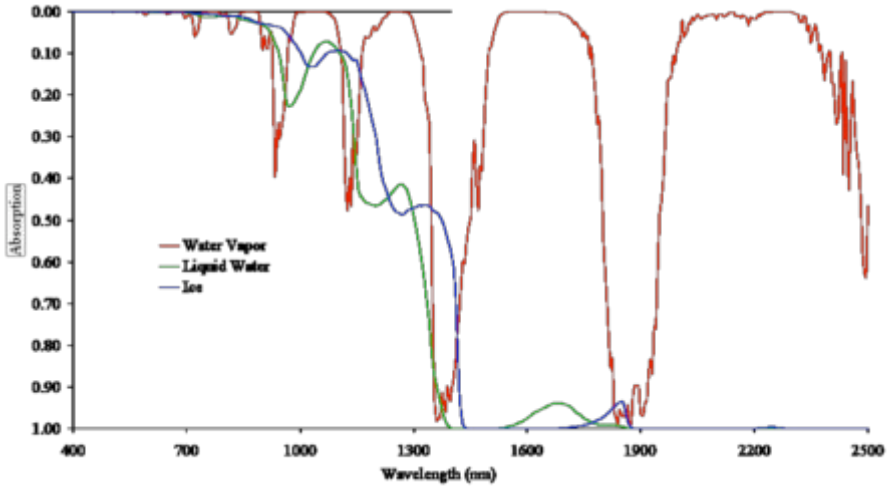






Mount Rainier derived three phases of water (Vapor: blue, Liquid: green, Ice: red) in melting snow environment

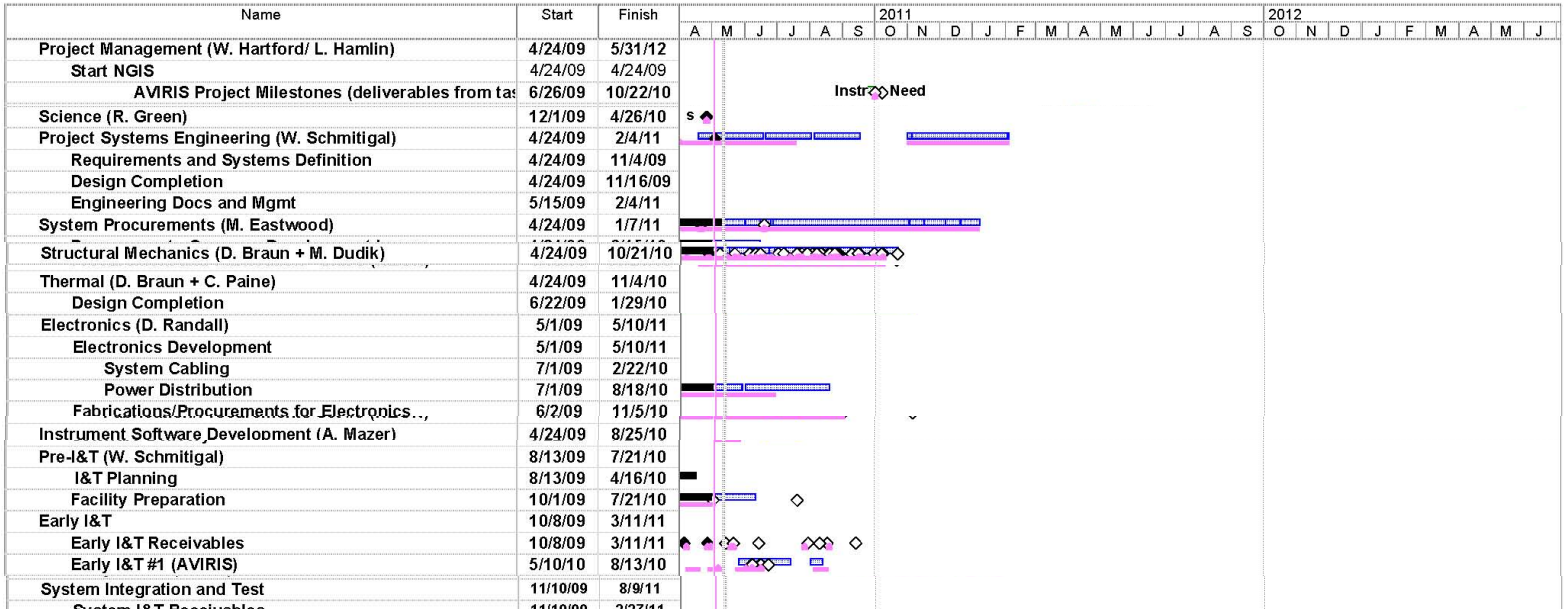




NEXT GENERATION AIRBORNE VISIBLE / INFRARED IMAGING SPECTROMETER (AVIRIS-NG) AMERICAN RECOVERY AND REINVESTMENT ACT (ARRA)

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

- Task Budget: $5M
- Task Schedule: September 1, 2009 – October 1, 2010



Name	Start	Finish
Project Management (W. Hartford/ L. Hamlin)	4/24/09	5/31/12
Start NGIS	4/24/09	4/24/09
AVIRIS Project Milestones (deliverables from tas	6/26/09	10/22/10
Science (R. Green)	12/1/09	4/26/10
Project Systems Engineering (W. Schmitigal)	4/24/09	2/4/11
Requirements and Systems Definition	4/24/09	11/4/09
Design Completion	4/24/09	11/16/09
Engineering Docs and Mgmt	5/15/09	2/4/11
System Procurements (M. Eastwood)	4/24/09	1/7/11
Structural Mechanics (D. Braun + M. Dudik)	4/24/09	10/21/10
Thermal (D. Braun + C. Paine)	4/24/09	11/4/10
Design Completion	6/22/09	1/29/10
Electronics (D. Randall)	5/1/09	5/10/11
Electronics Development	5/1/09	5/10/11
System Cabling	7/1/09	2/22/10
Power Distribution	7/1/09	8/18/10
Fabrications/Procurements for Electronics..,	6/2/09	11/5/10
Instrument Software Development (A. Mazer)	4/24/09	8/25/10
Pre-I&T (W. Schmitigal)	8/13/09	7/21/10
I&T Planning	8/13/09	4/16/10
Facility Preparation	10/1/09	7/21/10
Early I&T	10/8/09	3/11/11
Early I&T Receivables	10/8/09	3/11/11
Early I&T #1 (AVIRIS)	5/10/10	8/13/10
System Integration and Test	11/10/09	8/9/11

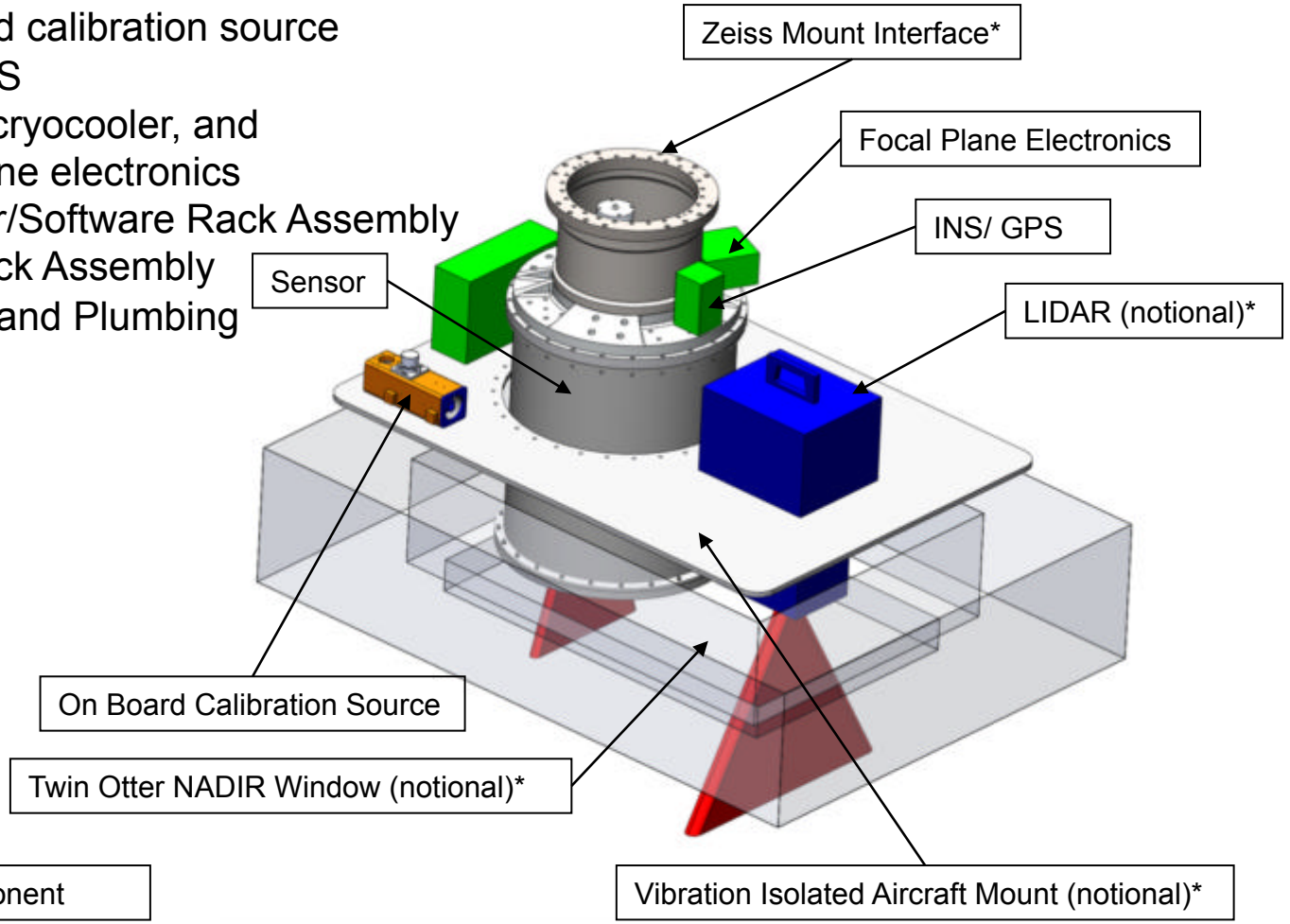
AVIRIS NEXT GENERATION SCIENCE MEASUREMENTS

Spectral		
	Range	380 to 2500 nm
	Sampling	~~10 nm~~ 5 nm
	Response	~~10 nm~~ 5-7 nm
Radiometric		
	Range	0 to Max Lambertian
	Sampling	14 bit
	Calibration	~~+/- 1 nm~~ +/- 0.1 nm
	Signal-to-Noise ratio	~~>1000~~ @ 600 nm >2000
		~~>400~~ @ 2200 nm >1000
Spatial		
	Field-of-View	34 degrees
	Instantaneous FOV	1 milliradian
	Spatial swath	2.5 to 11 km @ alt (4 to 20 km)
	Spatial resolution	4 to 20 m @ alt (4 to 20 km)
Uniformity		
	Spectral-Cross-Track	>95% Uniform
	Spectral-IFOV	>95% Uniform

AVIRIS-ng Instrument Configuration

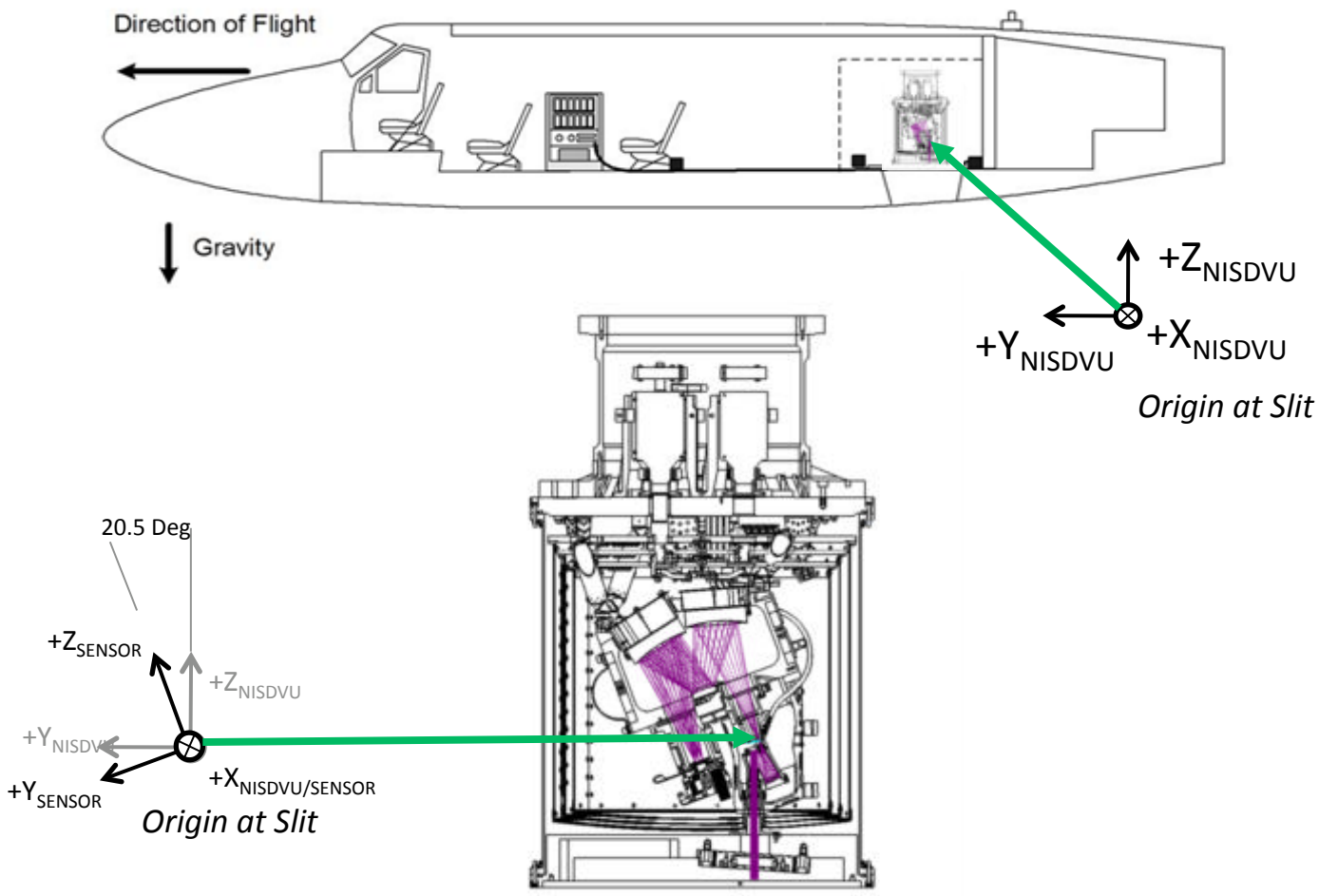
AVIRIS-ng consists of:

- 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

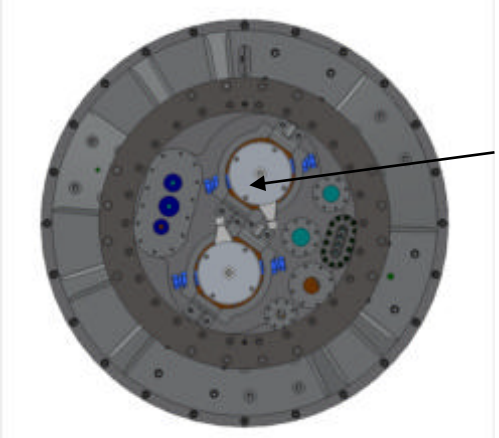
AVIRIS-NG COORDINATES



Sensor Configuration

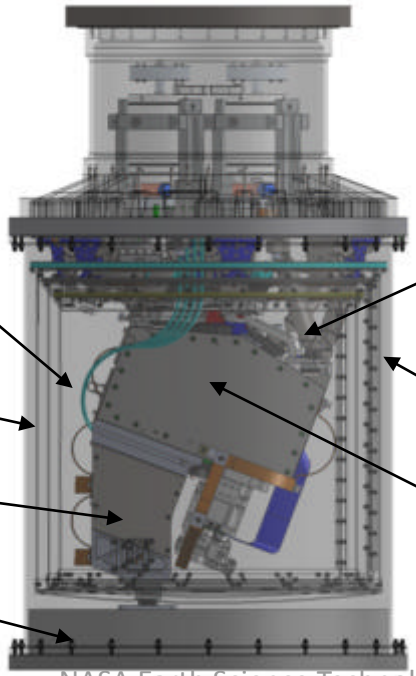
Operator Rack

- Power Switches
- Blank Panel
- KVM Drawer
- Blank Panel
- Aux Camera Control
- LIDAR Operator Computer
- Power Switches
- NGIS Data Computer w/CL-SAS DVR
- Sensor Data RAID Array



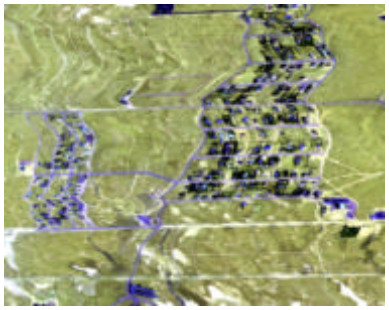
Environmental Control Rack

- LS 332 TC | LS 332 TC
- Lakeshore 340 Thermal Controller
- cRIO & TCP/IP Hub
- Cryocooler Pwr & Cntrl
- OBC Pwr, Cntrl, & Thermal Cntrl
- FPIE Power Supplies
- Ion Pump Controller | Aux Therm Ctrl
- Power Dist / Conditioning / Switching
- Thermorack Chiller

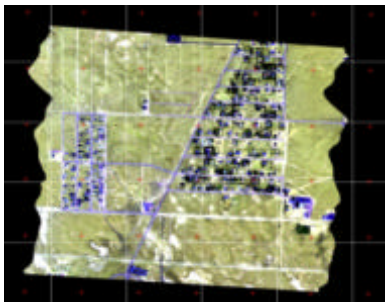


System Operation

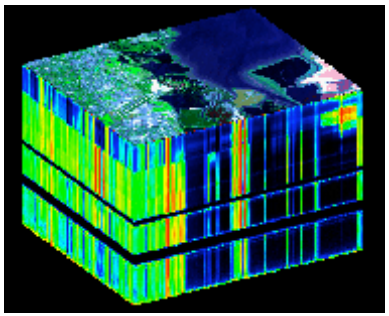
- Pushbroom imager collects image “lines”
- Image lines are collected into data “cubes”. Typical cubes are taken over 20 minute runs.
- Image “swath” is the width of the data cube. Swath dimensions are a function of altitude.
- Cube data are geo-rectified using GPS/INS data to correct for platform motion
- 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



Raw Spatial Data



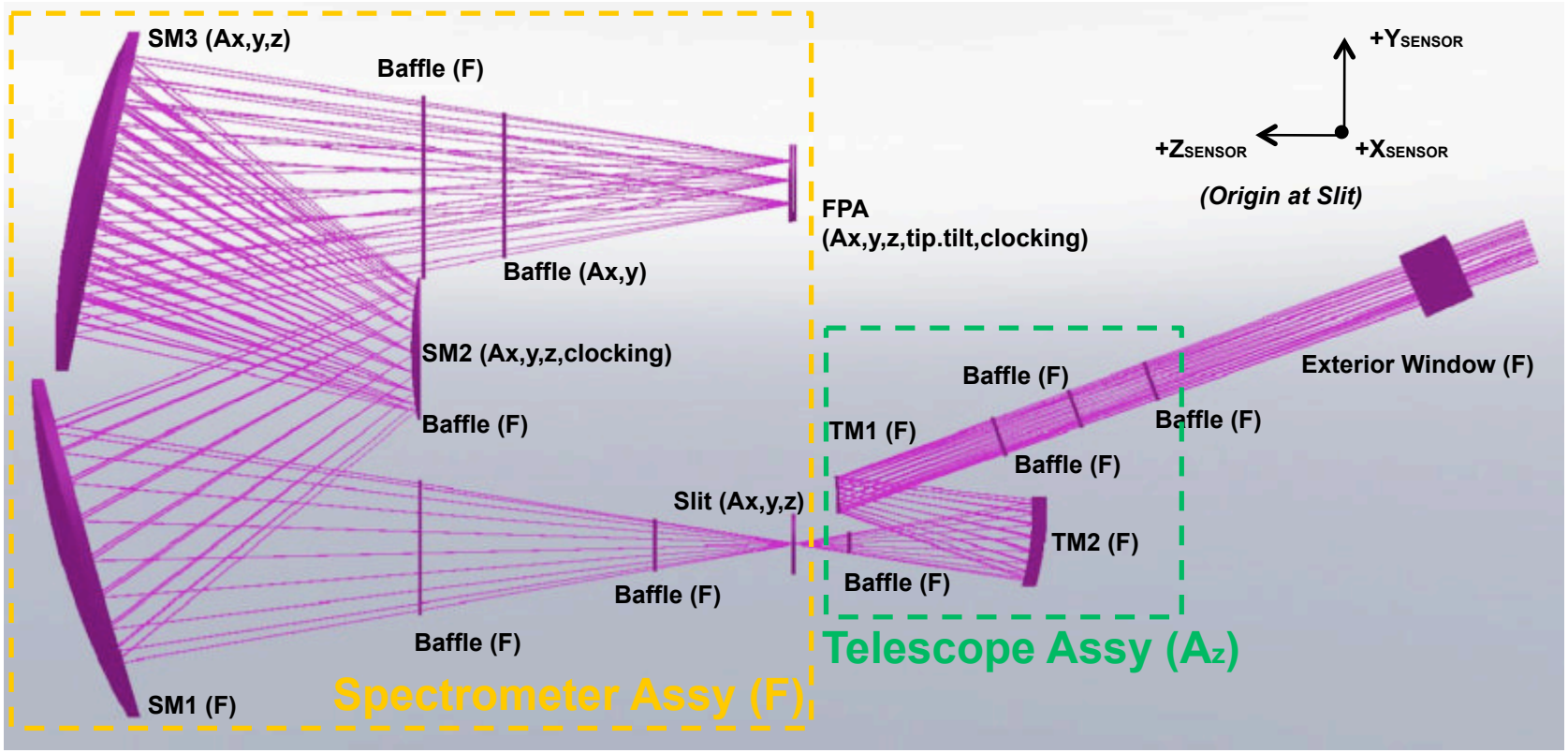
Geo-rectified Data



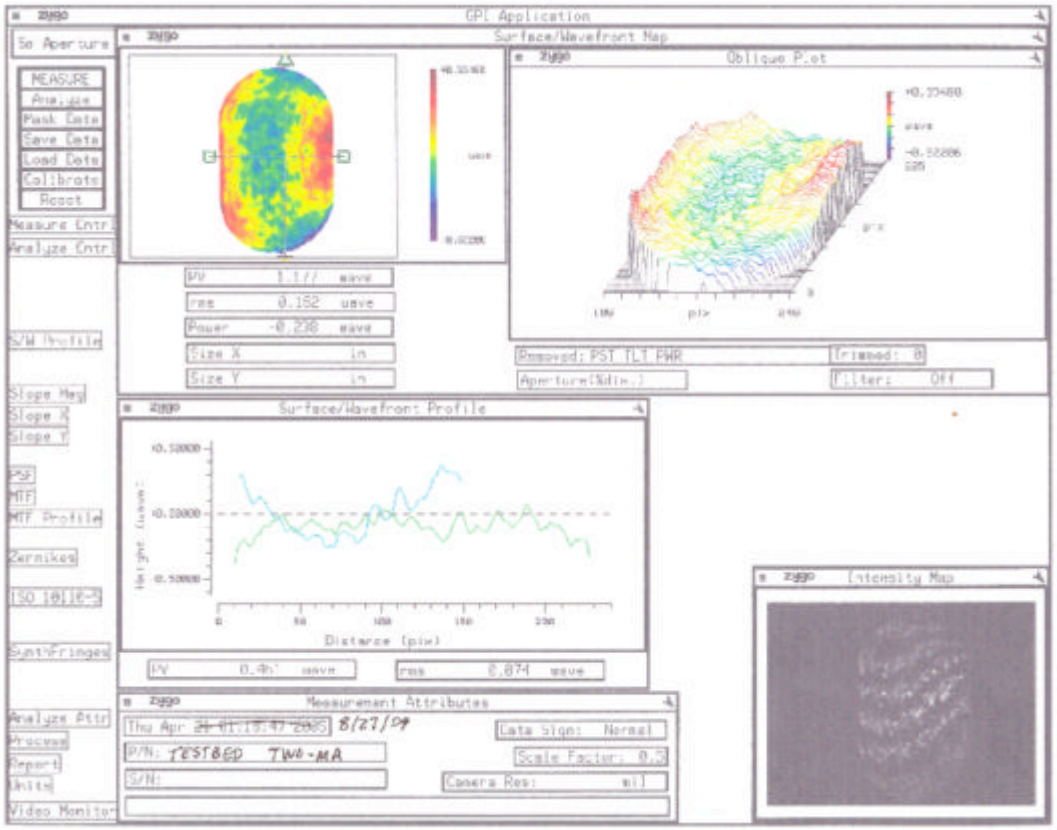
The NISDVU Data Cube

Instrument Optical Architecture

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.

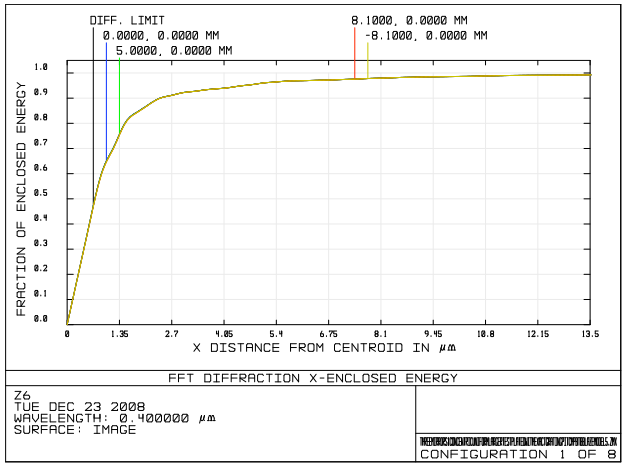
Notice non-circular pupil shape.

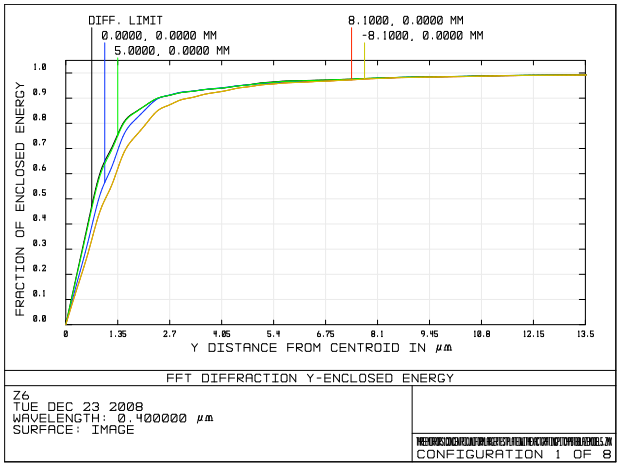
Post-polished aluminum mirrors produced by Axsys.

Previous Axsys mirrors fail mid-frequency specification by a factor of 2-3, impact acceptable (see risks and mitigations later).

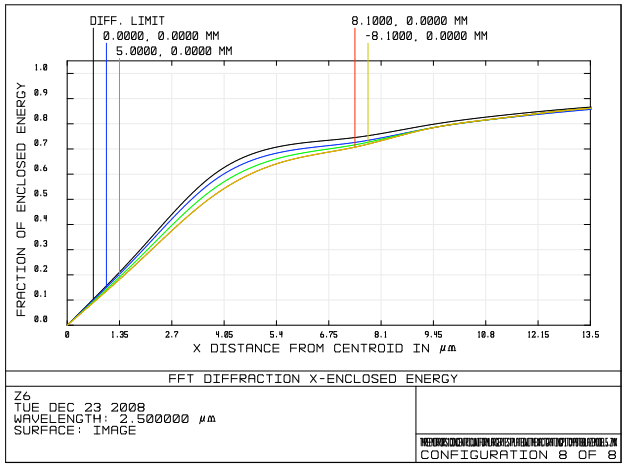
SPECTROMETER PERFORMANCE

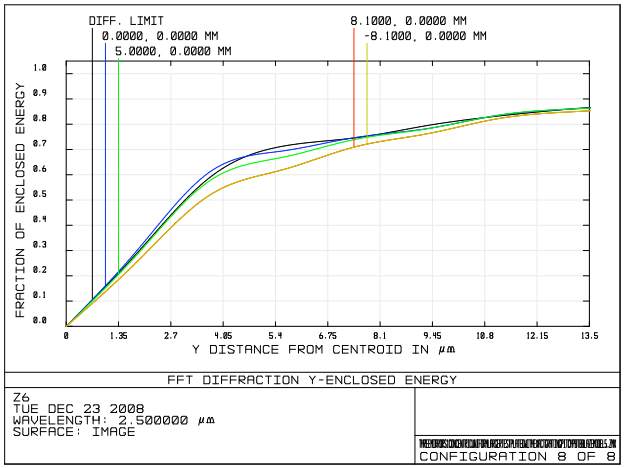
(X- AND Y- ENCLOSED ENERGY IN PIXEL)
(ACCOUNTS FOR APODIZATION)





400 nm

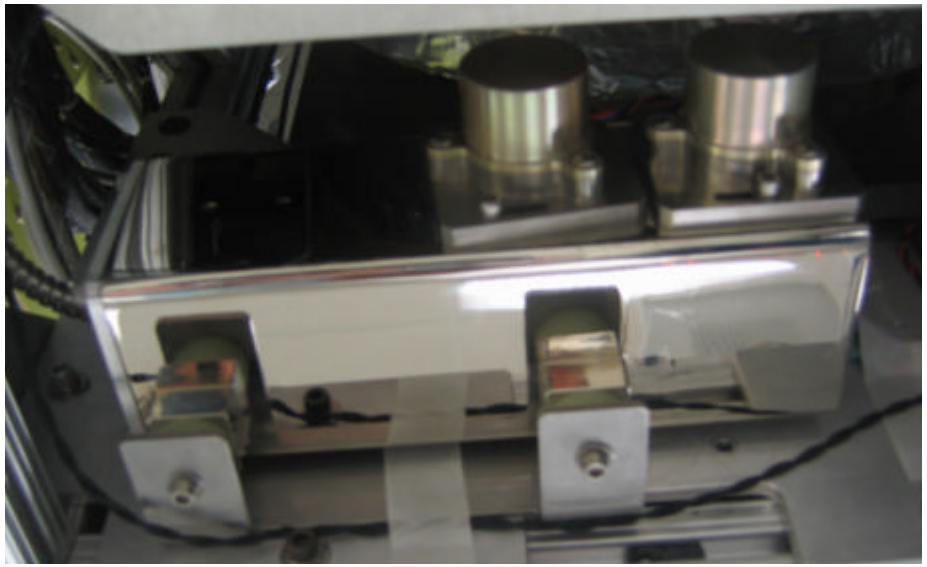




2500 nm

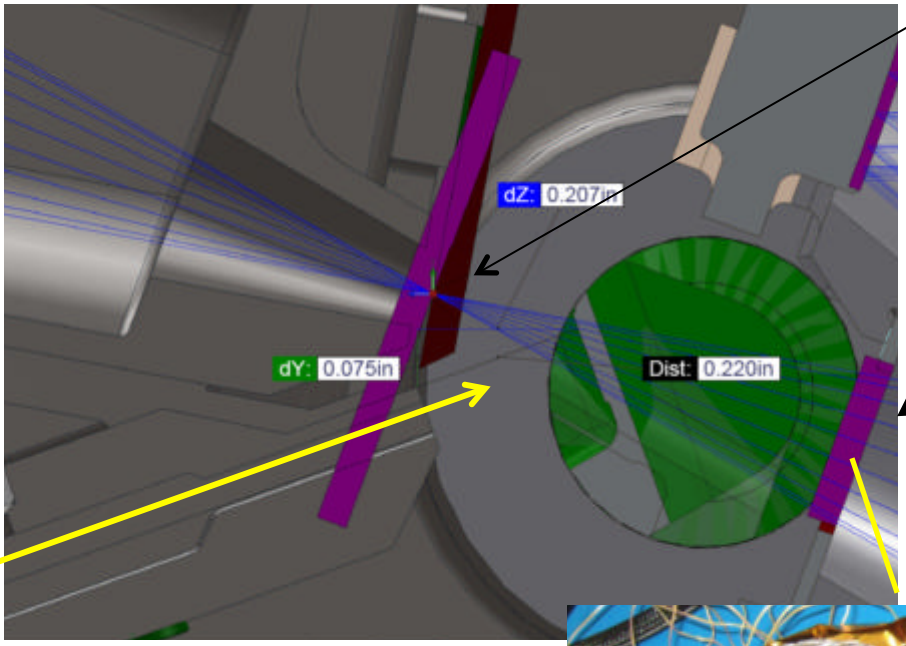
ON-BOARD CALIBRATOR

- 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

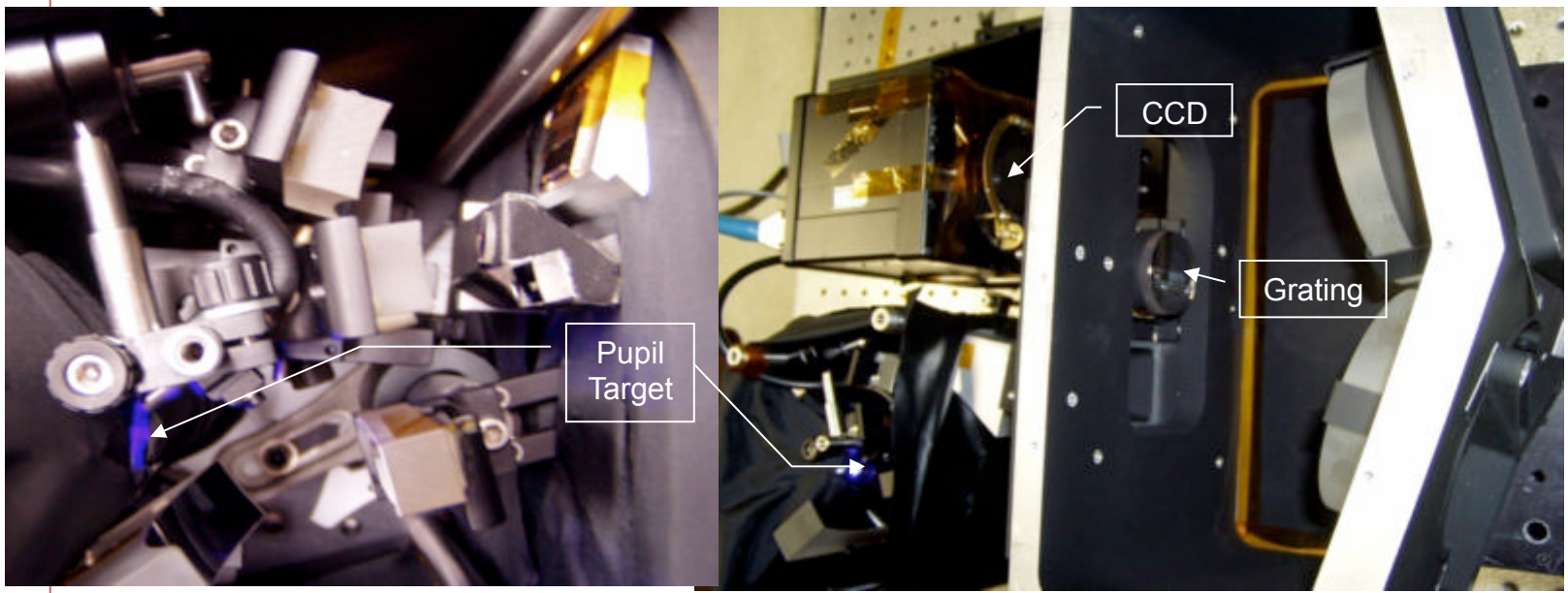


Slit

Target

Fiber
Illumination

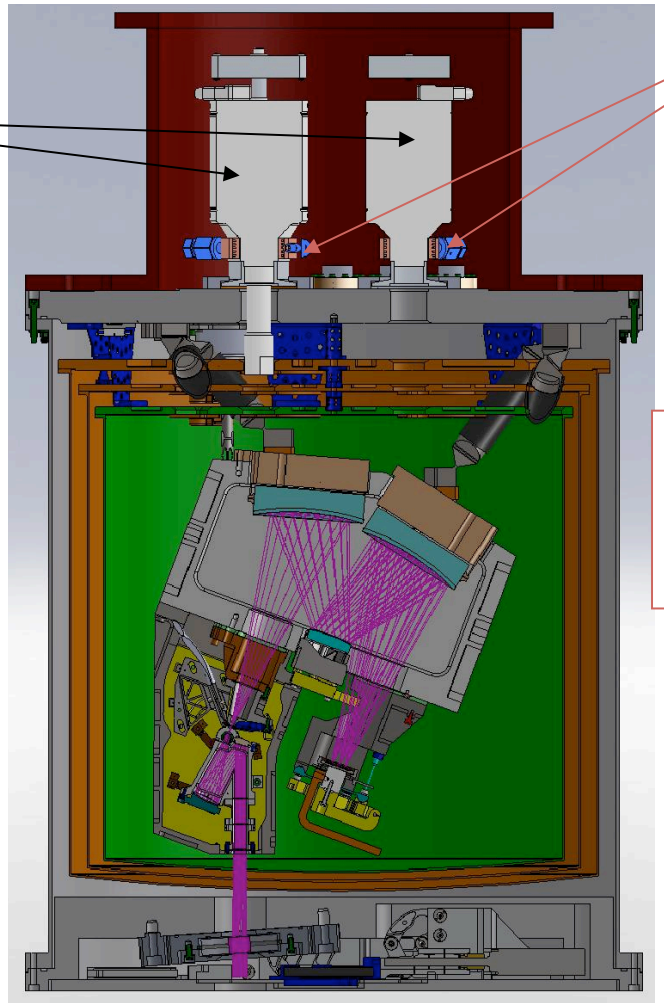
TESTBED OBC TARGET TESTING



- 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



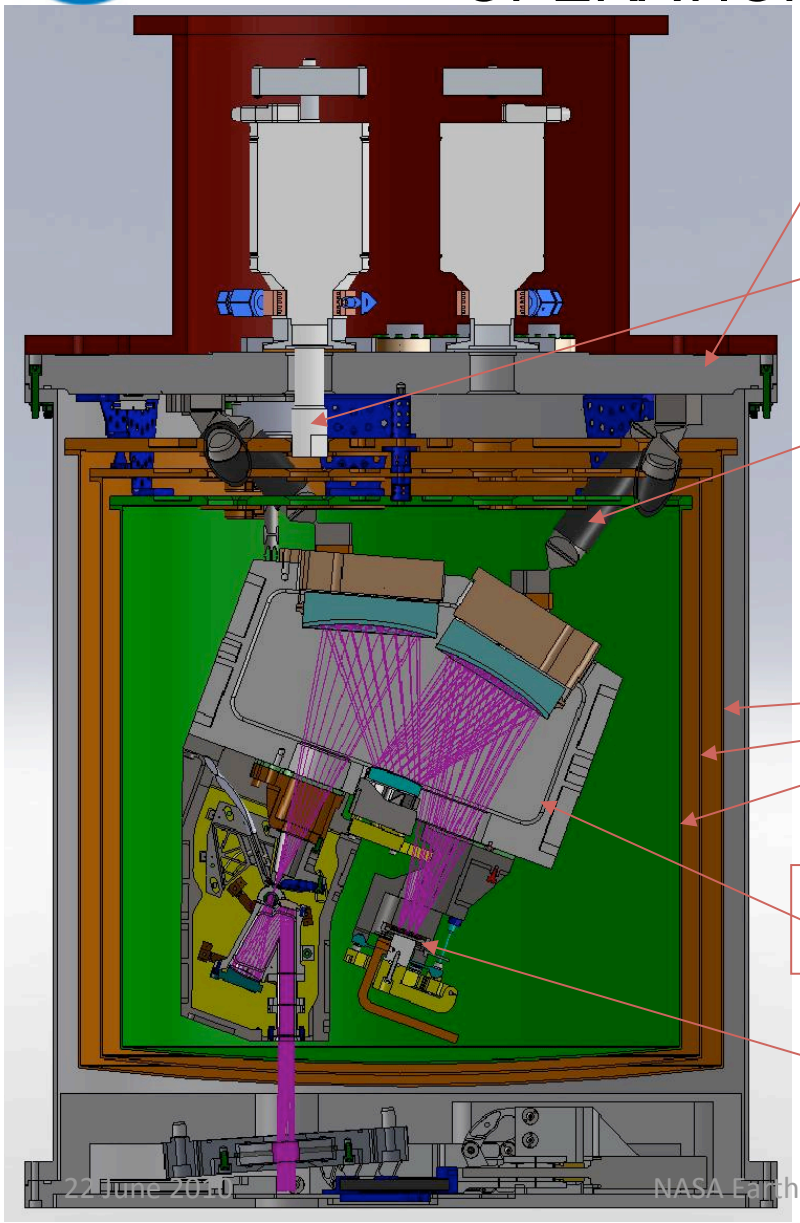
recirculating fluid chiller
removes heat from cryocoolers

vacuum-ion pump and gauge
decision on use of the ion pump is pending system performance evaluation

temperature monitoring and control
maintains FPA temperature stability and optical alignment (multiple locations on instrument)

cryo wiring harness is fabricated in-house; not shown

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)

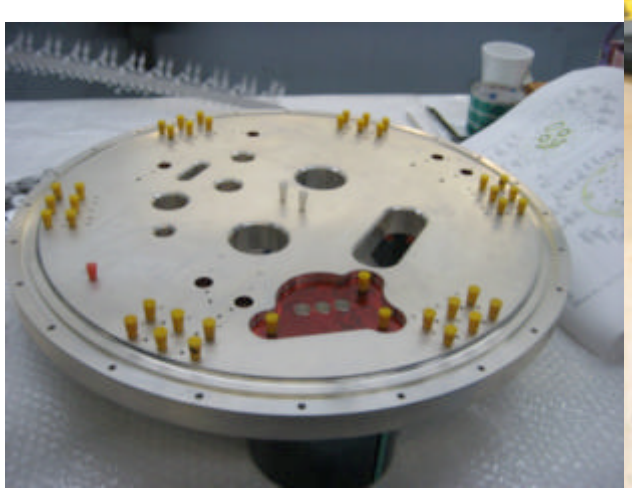
Two “floating” and one actively-cooled radiation shields reduce heat input to spectrometer:
1st shield ~288 K, floating
2nd shield ~235 K, floating
actively-cooled shield ~125 K, controlled

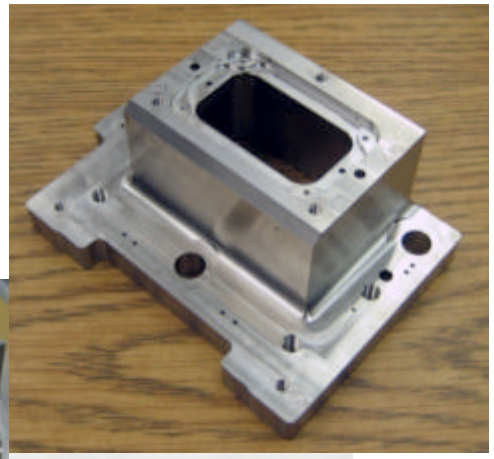
Spectrometer and telescope temperature are actively controlled to <50 mK variation

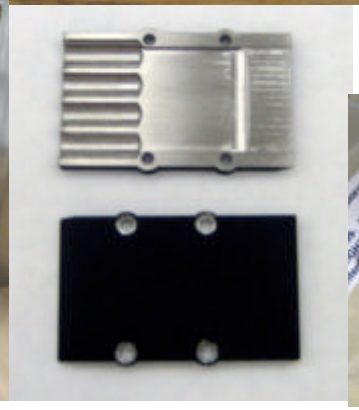
FPA is cooled to ≤140 K and actively controlled. (Dedicated high-conductance strap to cold sink not shown.)

DESIGN /FABRICATION STATUS

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

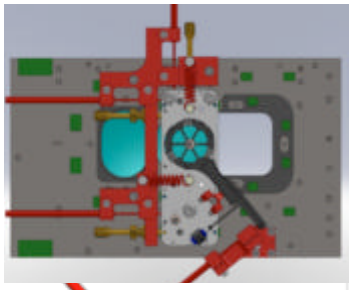


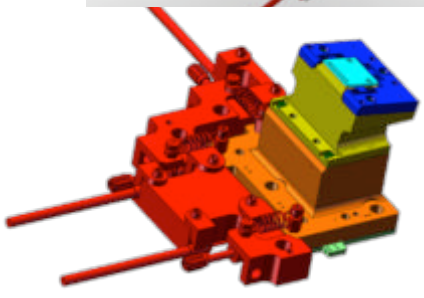


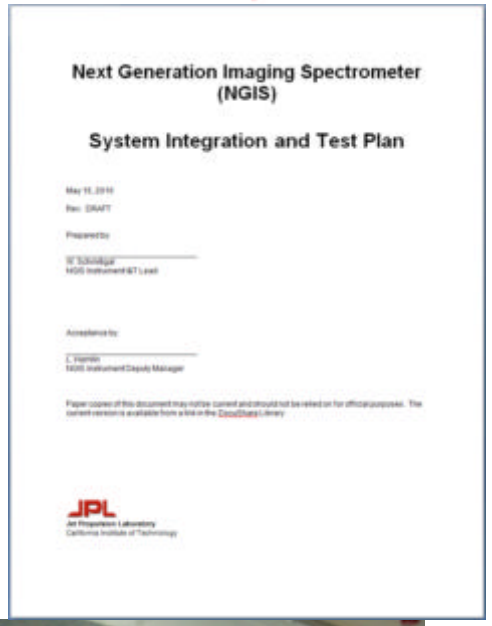


I&T STATUS

- 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

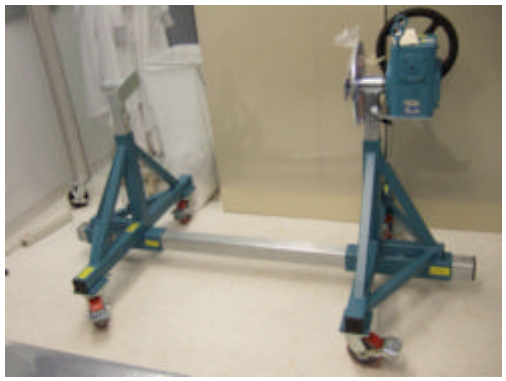





Next Generation Imaging Spectrometer
(NGIS)

System Integration and Test Plan

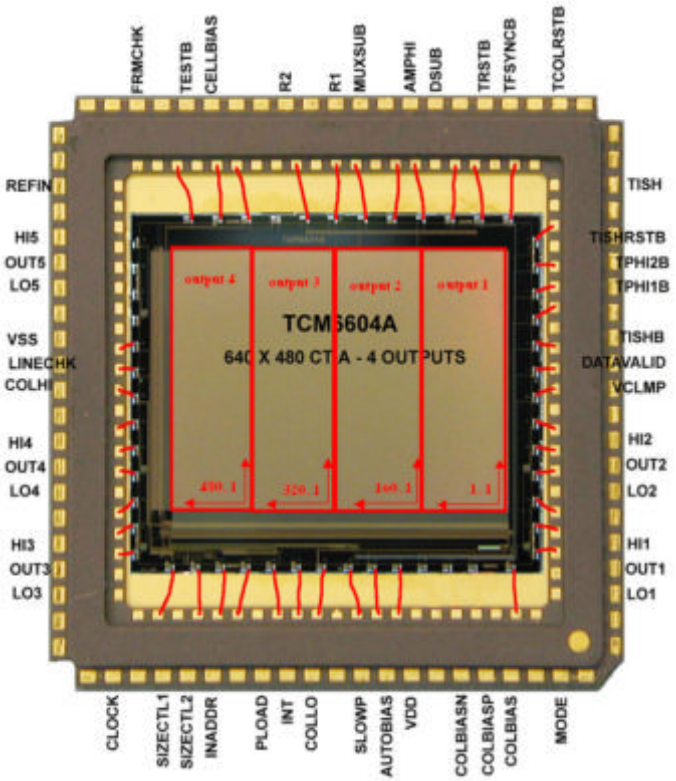
JPL



ELECTRONICS DESIGN- MARS HERITAGE

- 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

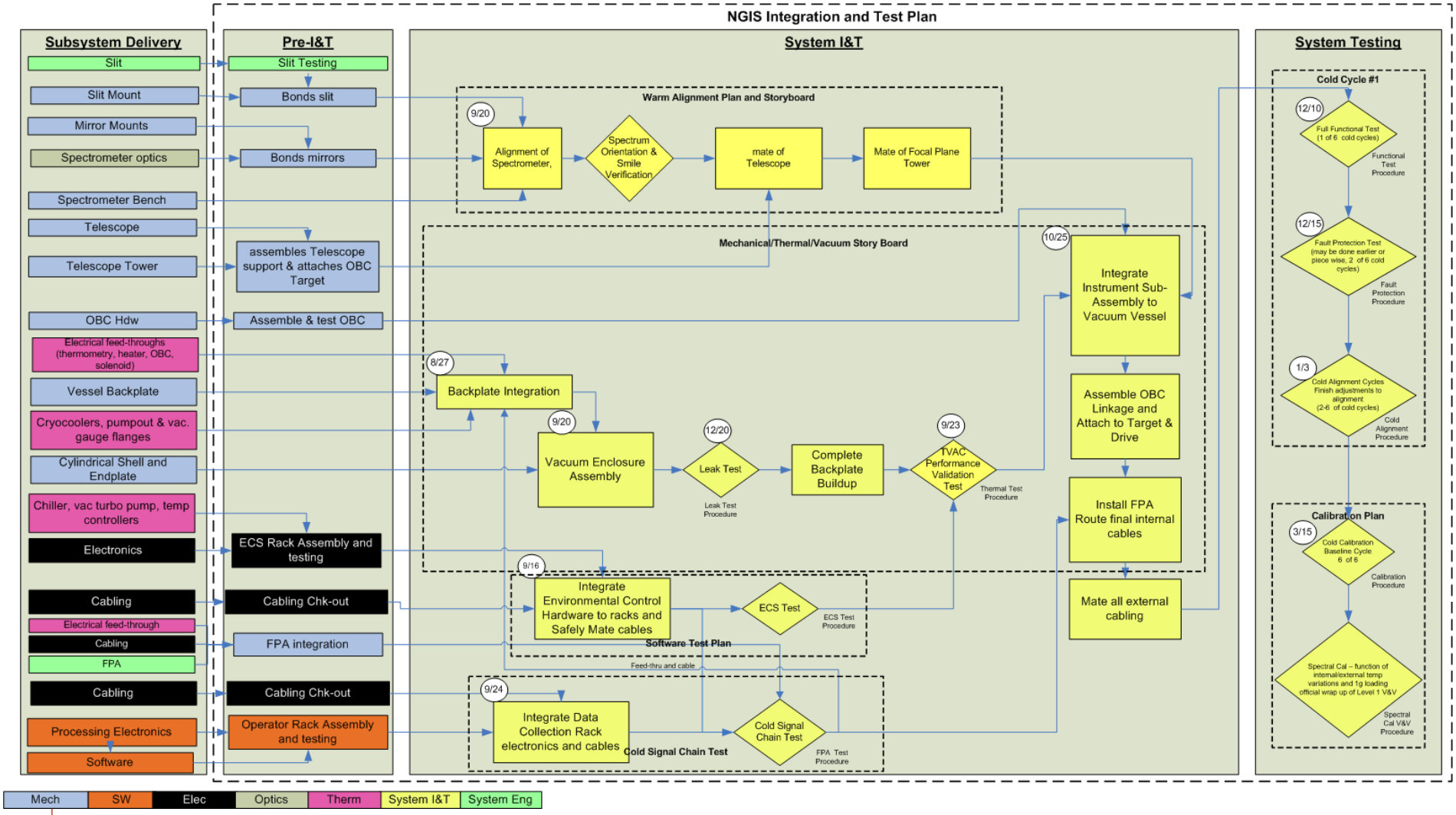
FOCAL PLANE ARRAY



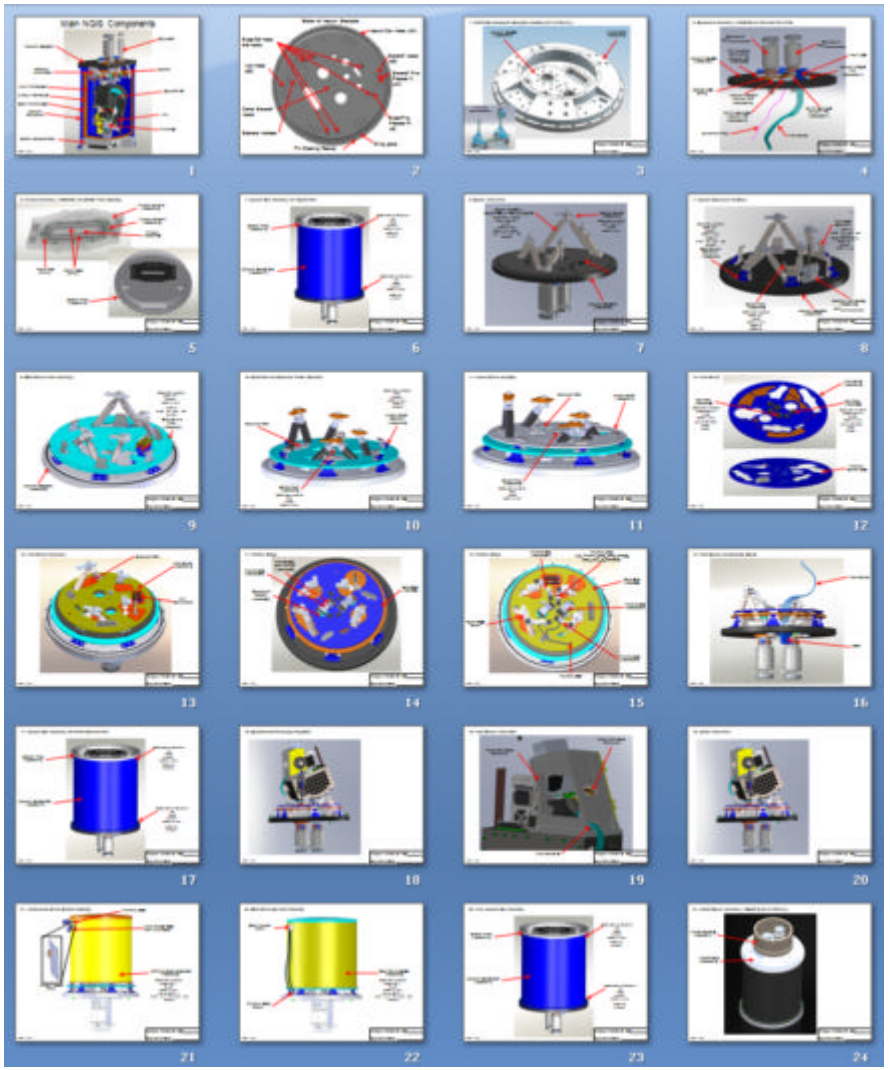
TELEDYNE PROPRIETARY INFORMATION

- Well-known Teledyne TCM6604A
- Capacitive transimpedance amplifier
- Snapshot imaging
- 4 video outputs, 1 ref output (unused)
- 4 clocks, 7 bias voltages
- Power dissipation: ~ 60mW
- Read noise: 120 e- [rms]
- Amplifier glow: ~ 100 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



MECHANICAL/THERMAL/OPTICAL INTEGRATION PROCEDURE



- 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

WARM ALIGNMENT STORYBOARD

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

Note: Slides above represent only a portion of the full document

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