From Superconductors to Satellites: Physics as a Hobby

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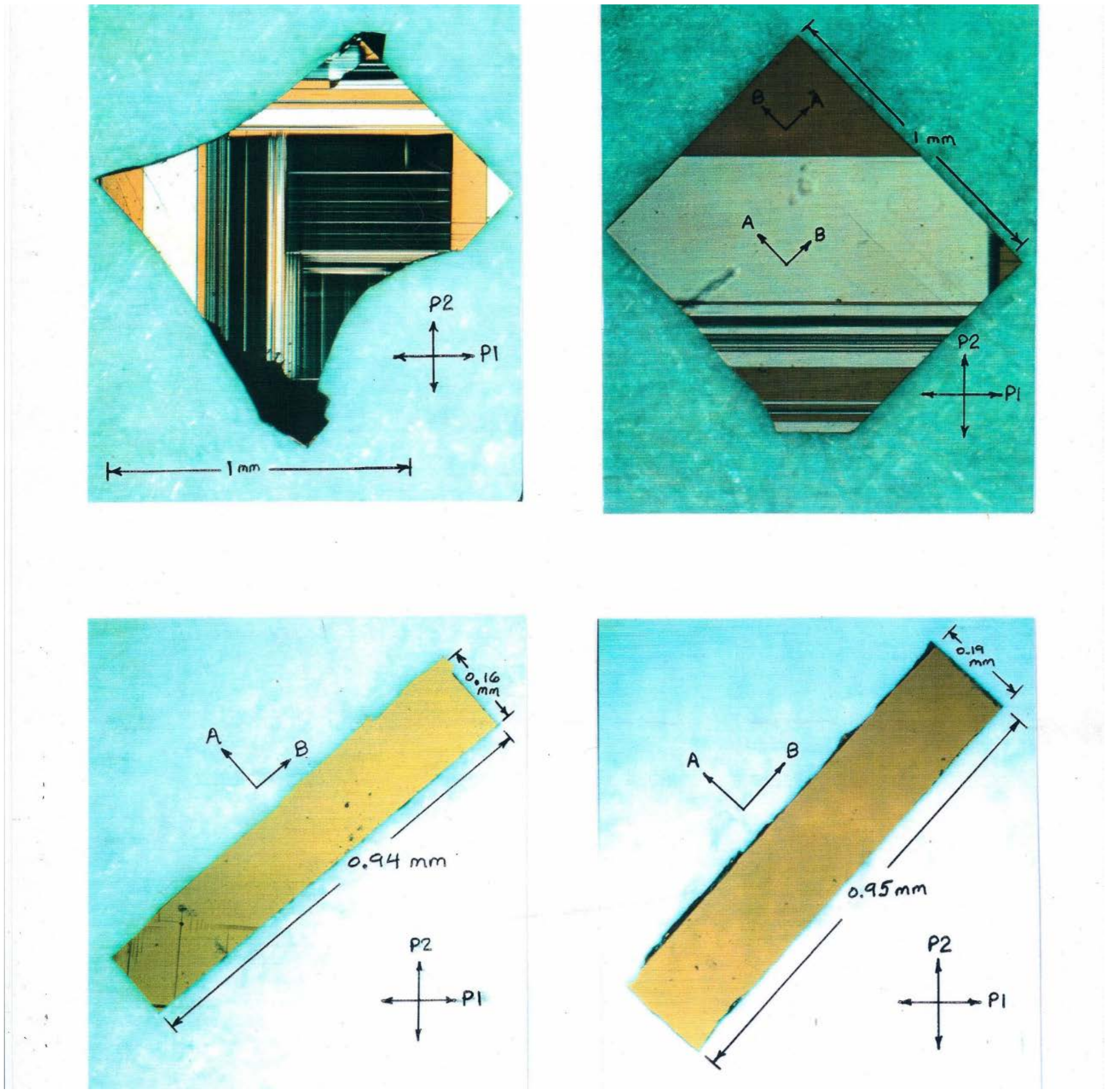
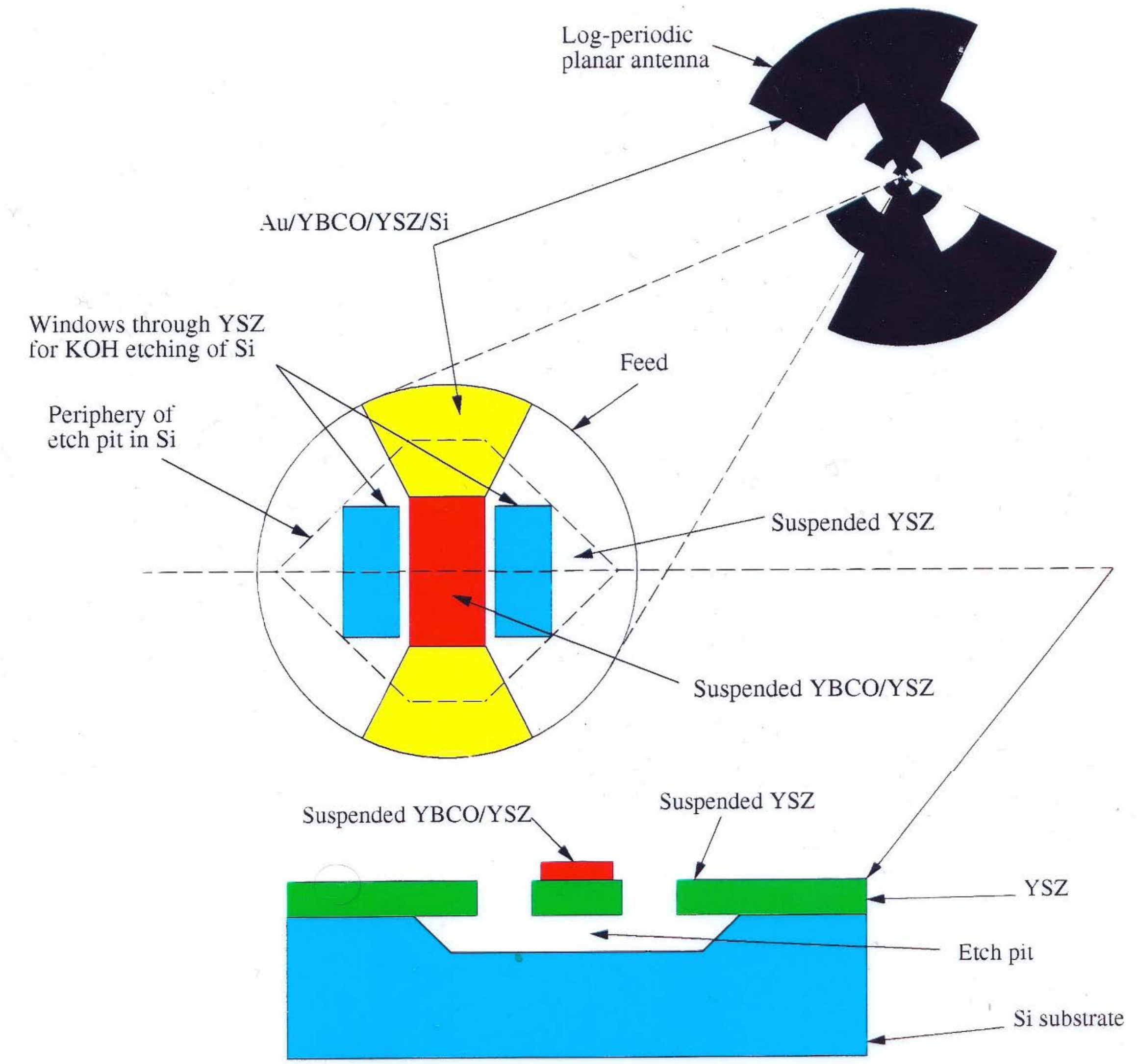
*With many, many collaborators.

Univ. of Illinois, 1987-1992: High-Tc Superconductors



NIST Boulder: NRC Post-doc 1992-1994
Antenna-Coupled High Tc Microbolometer



Earth-Viewing Remote Sensing Satellites

Example Operational Satellites and Sensors (ongoing)

- Joint Polar Satellite System (JPSS) J1 to launch in 2017
  - Advanced Technology Microwave Sounder (ATMS)
  - **Cross-Track Infrared Sounder (CrIS)**
  - **Visible Infrared Imaging Radiometer Suite (VIIRS)**
  - Ozone Mapping and Profiler Suite (OMPS)
  - Cloud and Earth Radiant Energy System (CERES)
  - Radiation Budget Instrument (future – replacing CERES)
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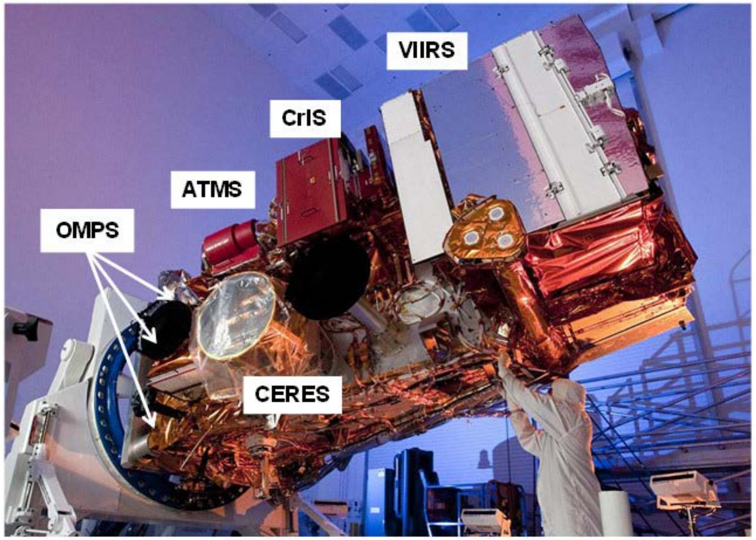
  - Operational Land Imager (OLI)
- Geostationary Operational Satellite System (GOES-R)
  - Advanced Baseline Imager (ABI): To launch Nov. 2016
  - Space weather sensors

Example: JPSS-Type Satellite



Example Current NASA Scientific Satellites

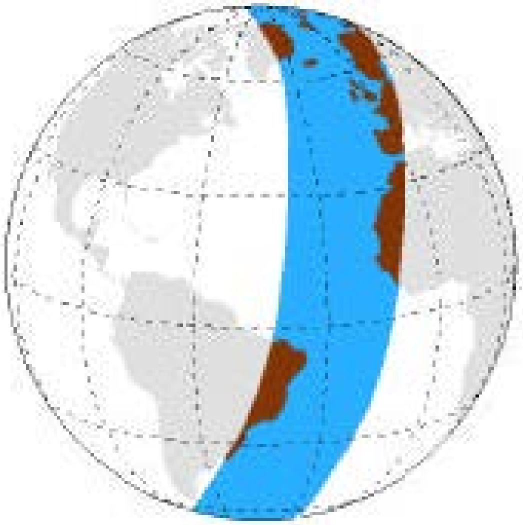
- Earth Observing System (all flying and near end of life – some similar sensors on JPSS)
- Orbiting Carbon Observatory-2 (OCO-2) (Launched July 2, 2014)
- Orbiting Carbon Observatory-3 (OCO-3)
- NIST Advanced Radiometer (NISTAR) and EPIC (On DSCOVR: Launched in 2015 to L-1 orbit)

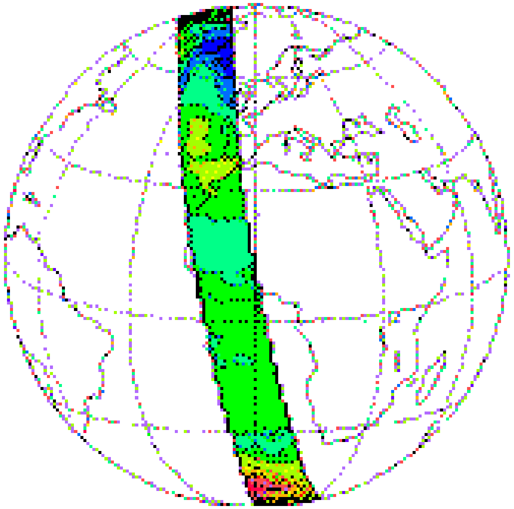
Example Future NASA Satellite Missions

- Ocean Color Instrument (OCI) for PACE and/or ACE missions
- Climate Absolute Radiance and Refractory Observatory (CLARREO)
- CLARREO Pathfinder (to be on International Space Station in future: Reflected Solar Instrument only)
- Hyperspectral and InfraRed Imager (HyspIRI)

Views from Typical Low-Earth Orbits (LEO)

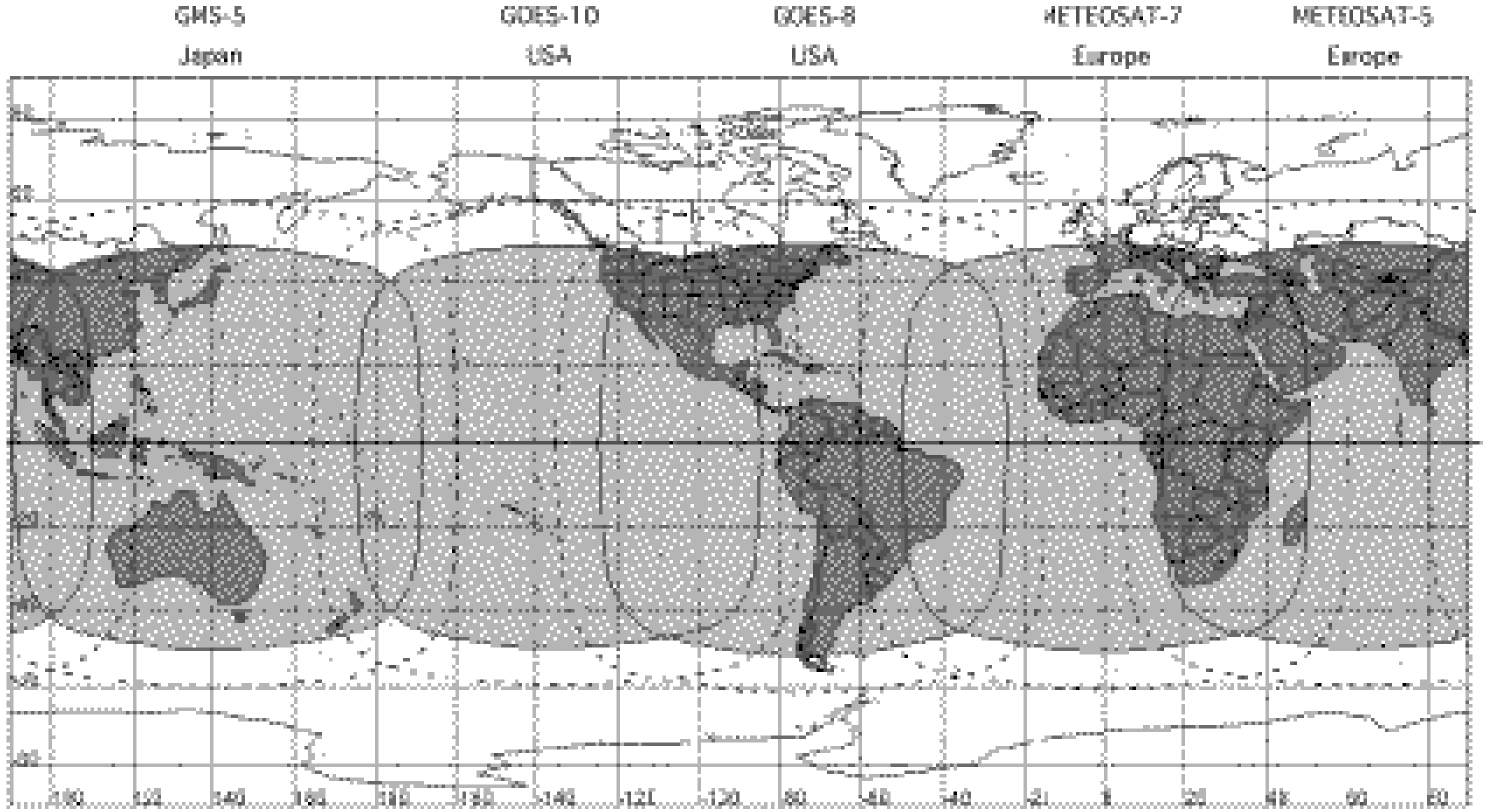
- Usually polar orbiting, typically sun-synchronous
- Altitude typically 600 km to 700 km
- Orbit time typically about 90 minutes
- Takes 24 hours to scan entire sun-lit globe



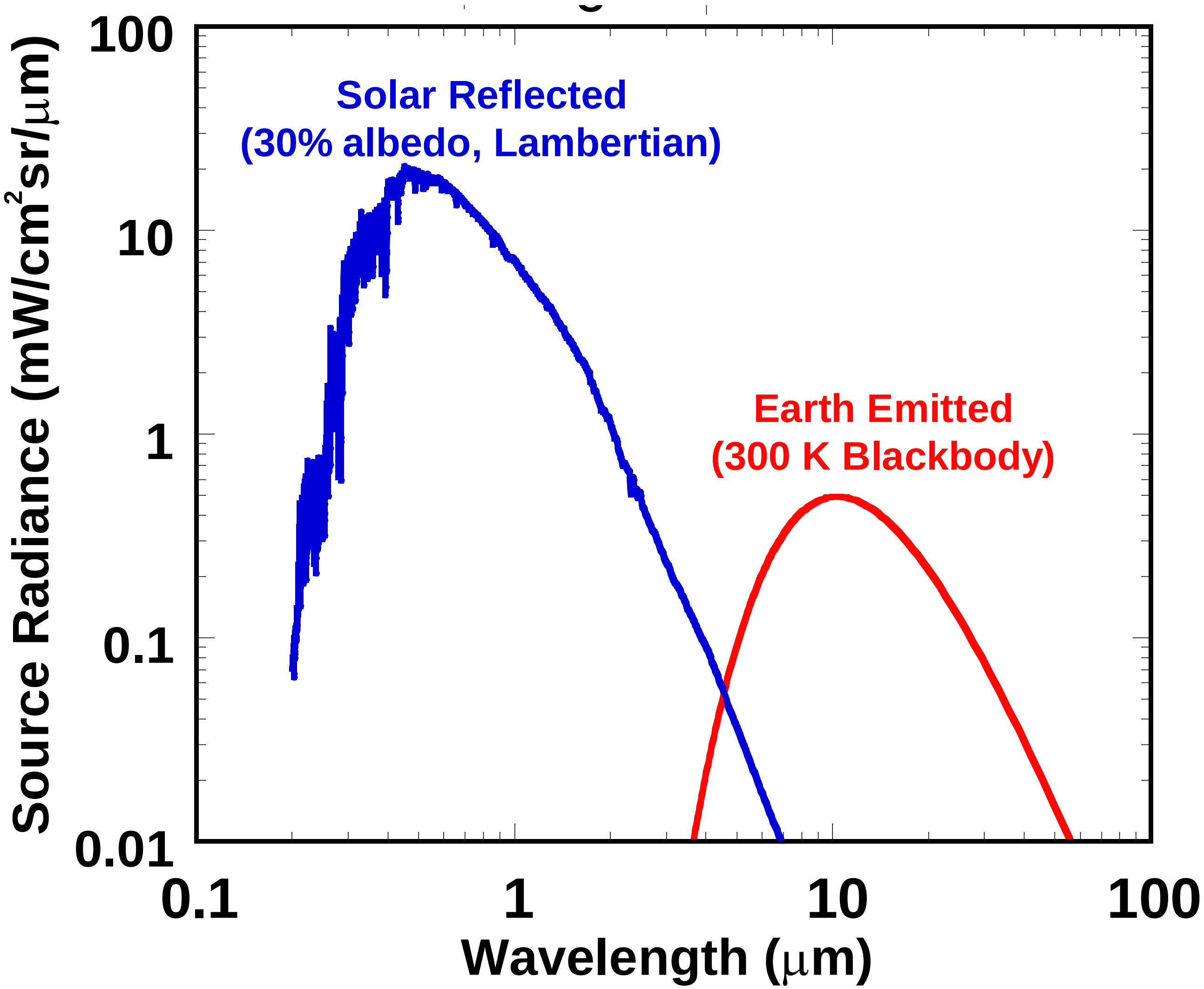


Views from Geostationary Orbits

- Altitude 36,000 km, fixed over equator
- Each looks at the same region of Earth
- Typically scanned within that region

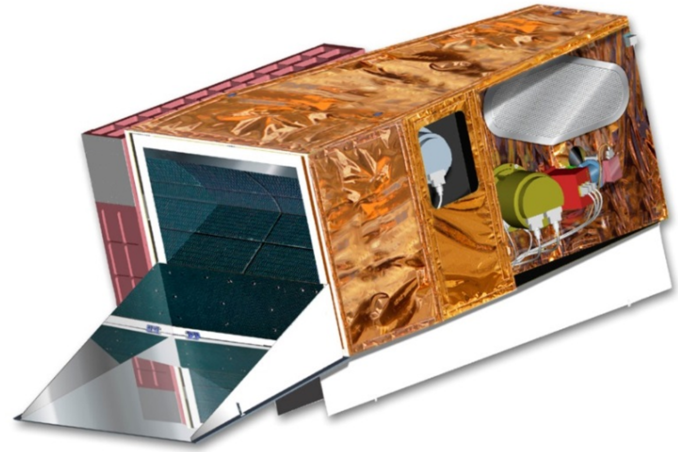


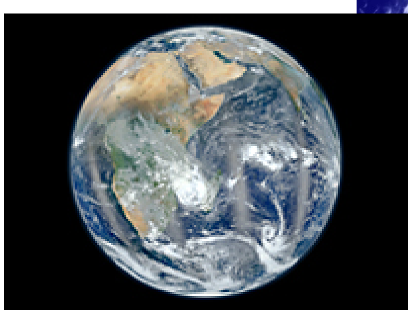
Estimated Spectral Radiance from Earth



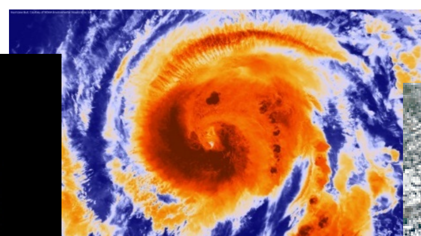
Example: VIIRS Sensor
(Visible Infrared Imaging Radiometer Suite)

- Ocean color (Carbon/Biomass-related)
- Sea surface temperature
- Aerosol characteristics
- Vegetation index (Carbon/Biomass-related)
- Land and Ice temperature
- Fire detection and monitoring

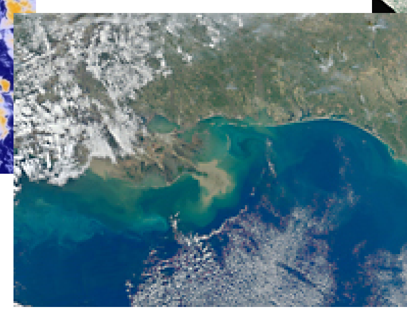




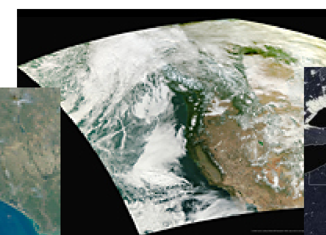
Imagery



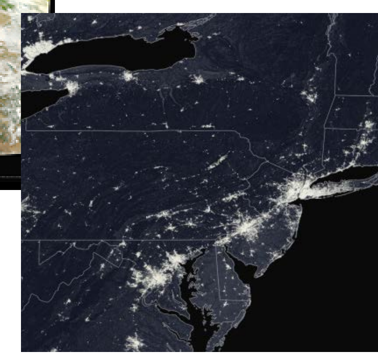
Weather



Ocean Color



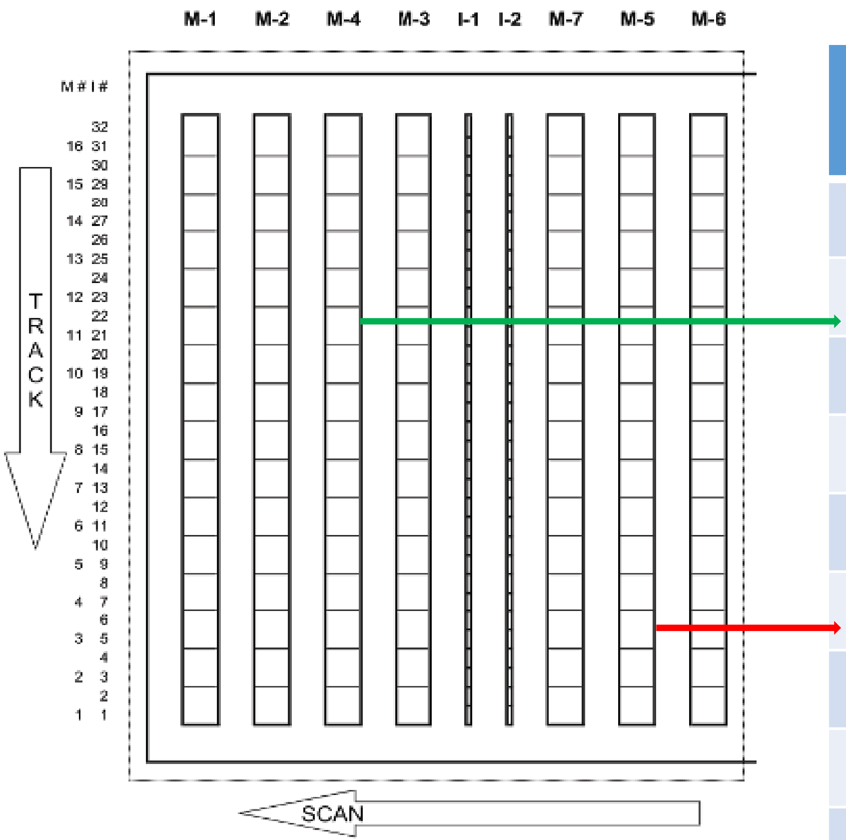
Clouds



Low light Imaging

VIIRS has Detector Arrays with Filters

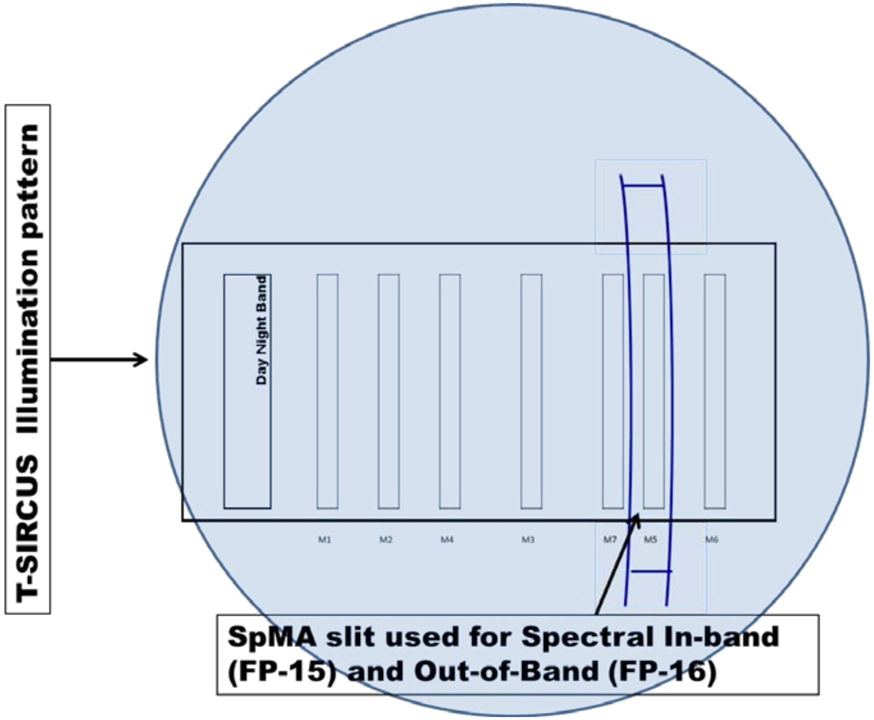
- 16 detectors in a column along satellite track direction
- Each column at a different wavelength band
- Calibration: Determine the responsivity of each detector



Band	Wavelength [nm]
M1	412
M2	445
M4	555
M3	488
I1	640
I2	865
M7	865
M5	672
M6	746

A Typical Sensor Calibration Problem

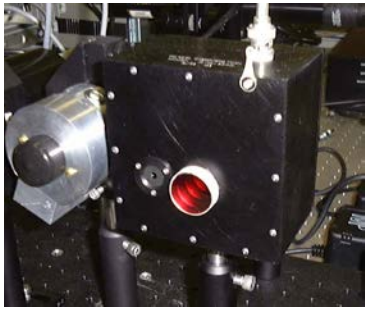
- During use, the Earth scene fills the aperture
- Traditional monochromator method (called theSpMA here) is not full-aperture, leading to errors
- NIST SIRCUS approach (next slide) provides the required full-aperture system-level calibration, solving the problem

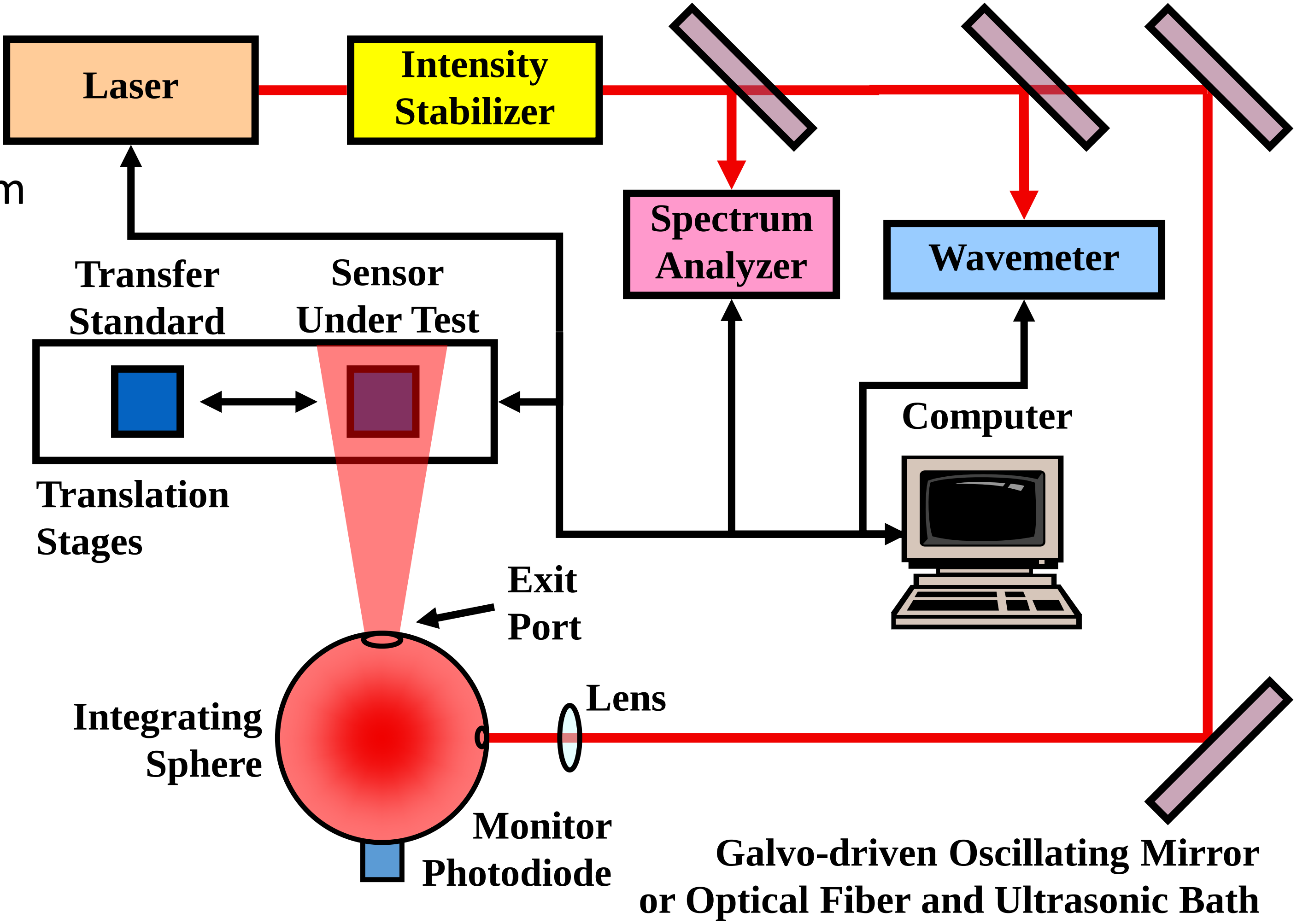


NIST

NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) Facility

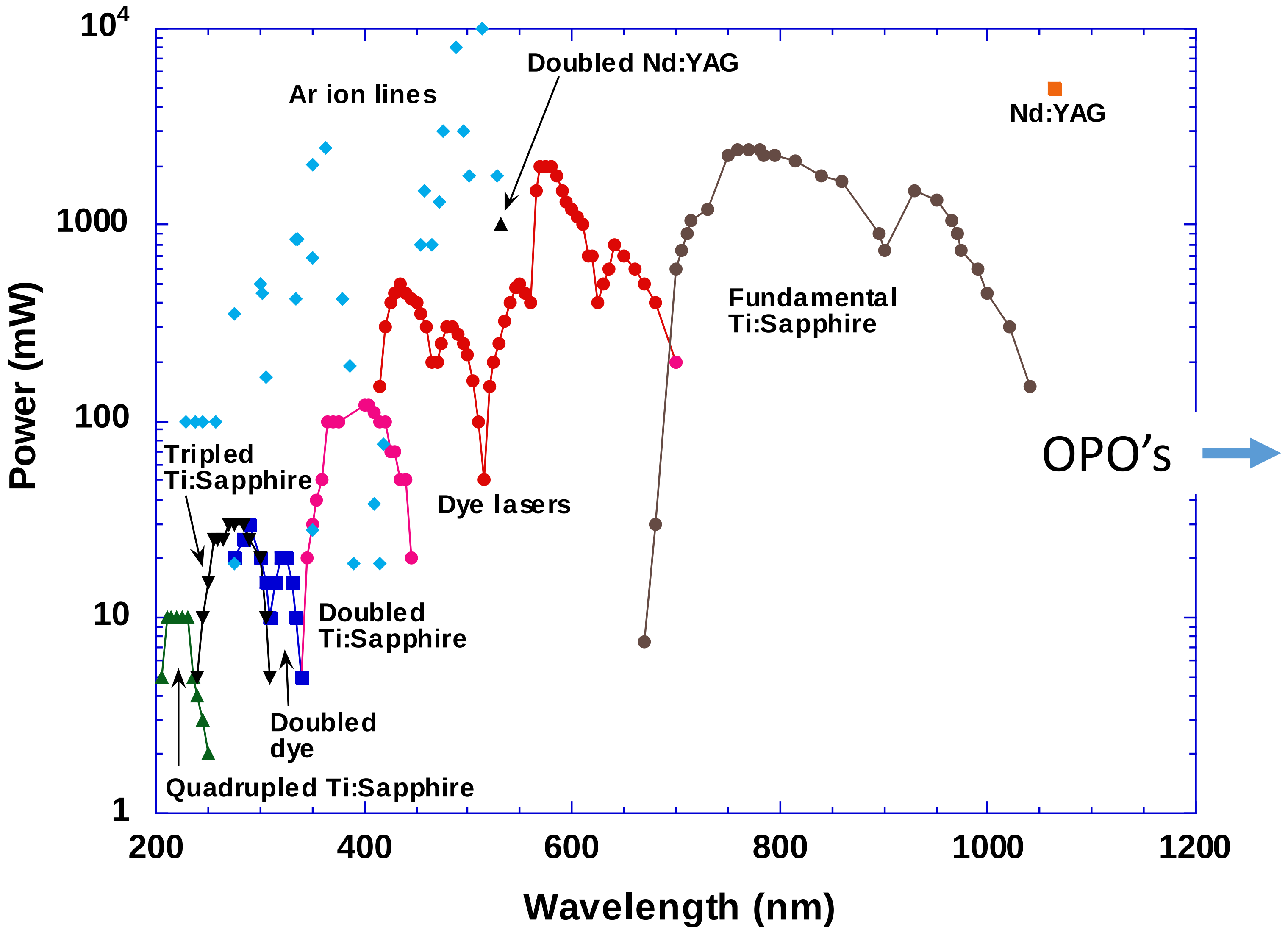
SIRCUS has used tunable lasers from 210 nm to beyond 5300 nm





NIST

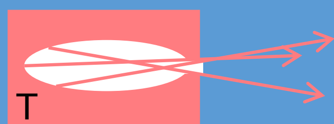
Some SIRCUS Lasers



Fundamental Radiometric Standards: Ways to Measure Amount of Light from Scratch

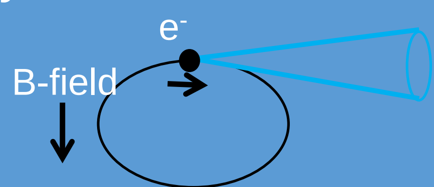
Sources

Blackbody



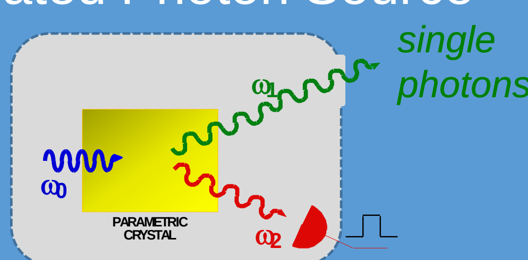
Temperature ⟶ Radiance

Synchrotron



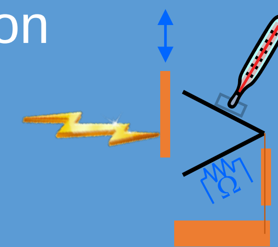
B-field, current, energy ⟶ Radiance

Correlated Photon Source



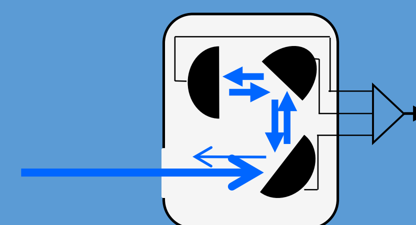
Detectors

Electrical Substitution Radiometer



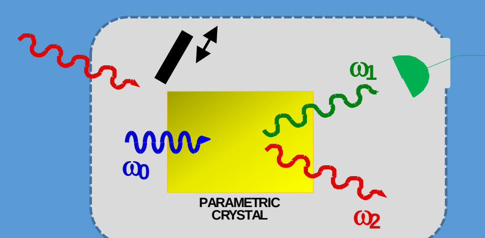
Optical power

Trap Photodiode



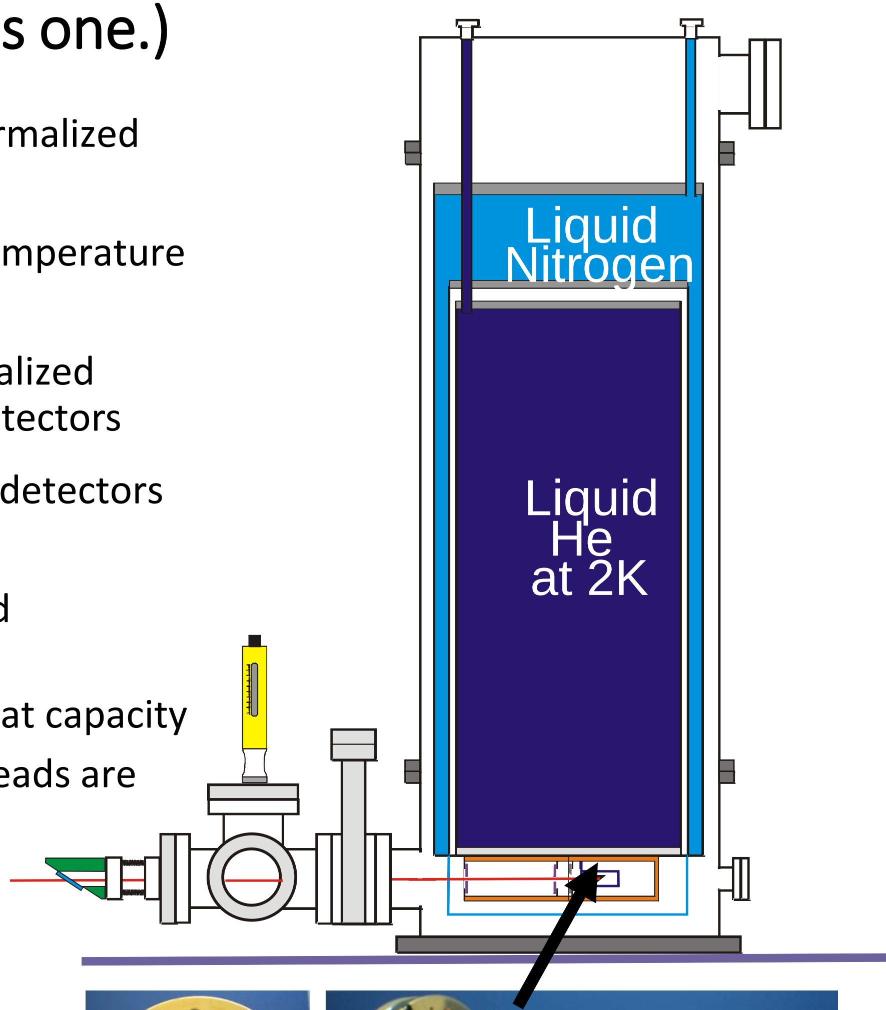
Optical power

Photon Counting Radiance

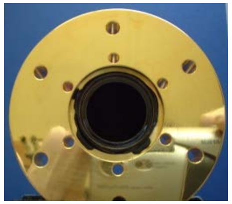


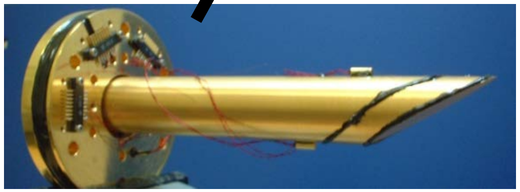
Cryogenic Electrical Substitution Radiometry (I built this one.)

- Thermalized optical laser power is compared to thermalized electrical power in a black cavity
- Generally, active cavity radiometers in vacuum at temperature of 2 K to 5 K
- Primary standard at NIST and in most other industrialized nations for optical power responsivity of transfer detectors
- Intercompared internationally via portable transfer detectors at 0.02% (k=2) uncertainty
- Advantages of cryogenic temperatures for improved performance:
  - ➢ Larger cavity can be used due to decreased heat capacity
  - ➢ Reduced lead heating since superconducting leads are used
  - ➢ Reduced temperature gradients between
  - ➢ electrical and optical heating
  - ➢ Reduced background radiation



Primary Optical Watt Radiometer (POWR)





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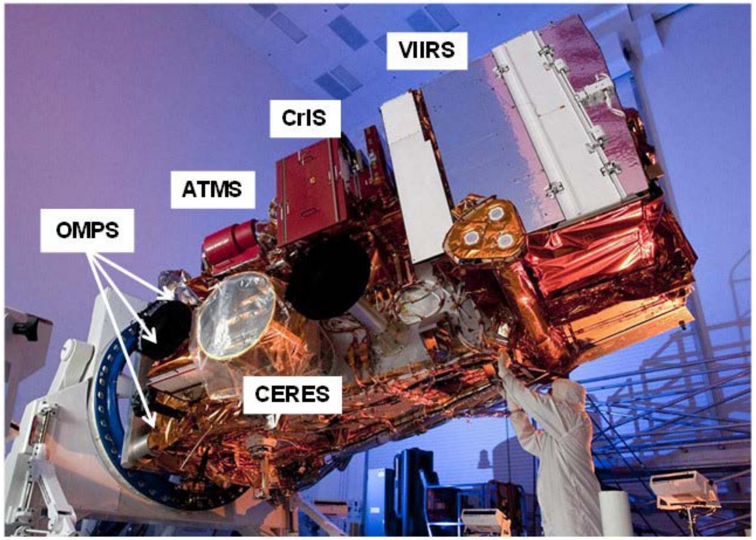

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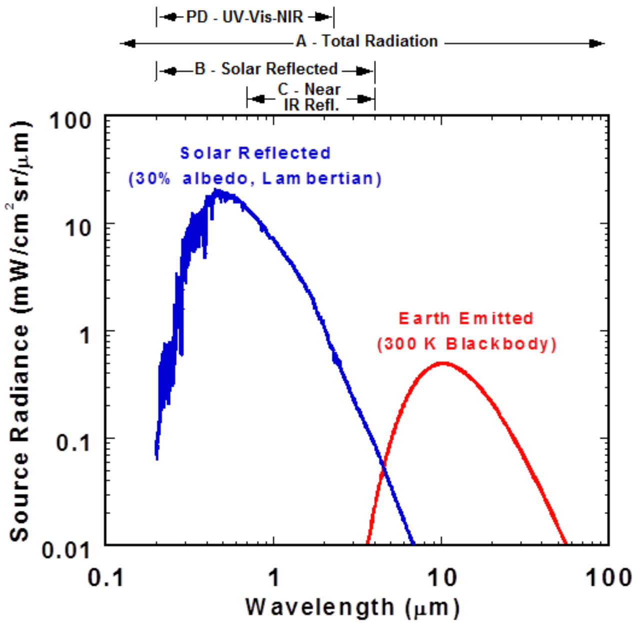
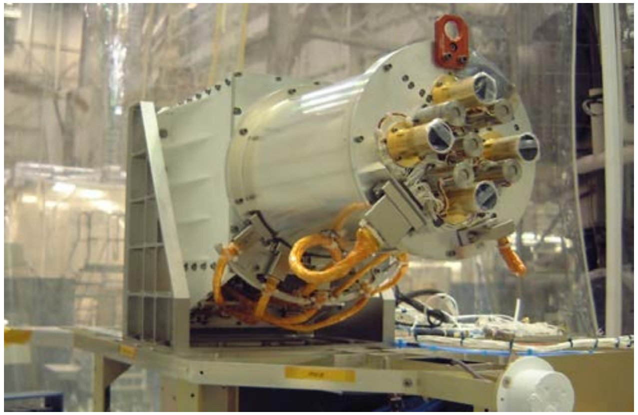
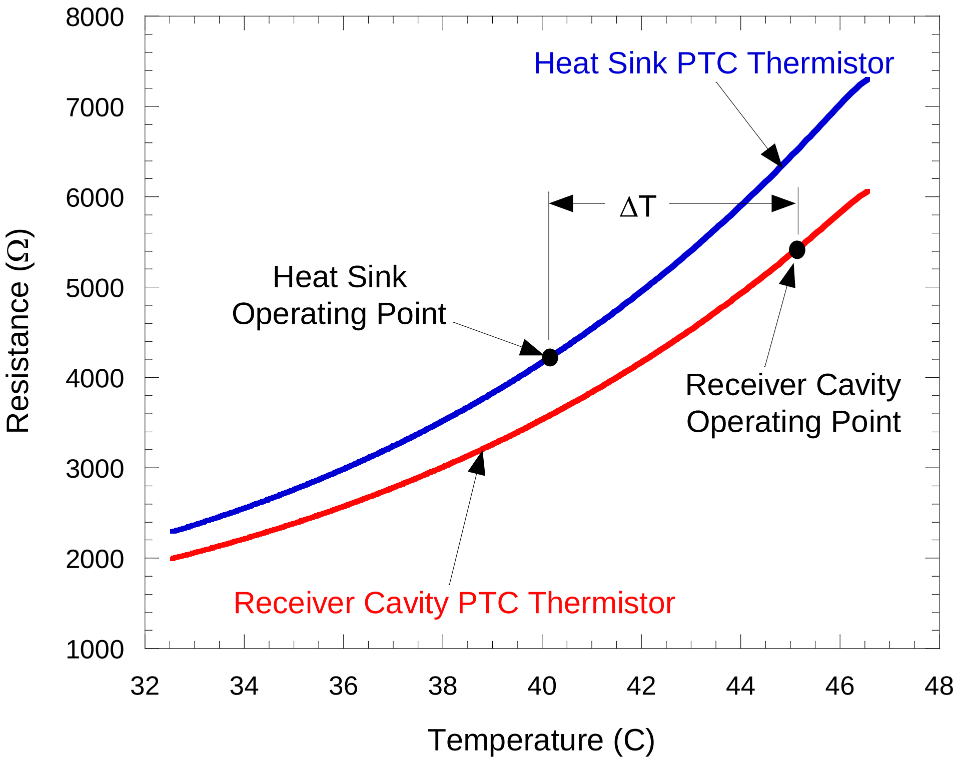
NISTAR: NIST Advanced Radiometer (I helped)

Measures the absolute irradiance (solar reflective and Earth emitted) over entire sunlit face of Earth, from L-1 orbit, in four broadband channels. On DSCOVER satellite.





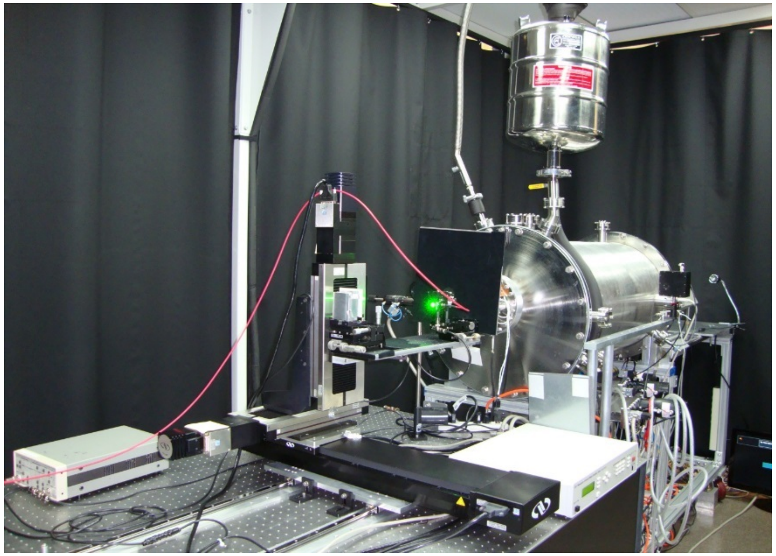
NISTAR uses PTC Thermistors:
Barium Strontium Titanate doped with Silicon

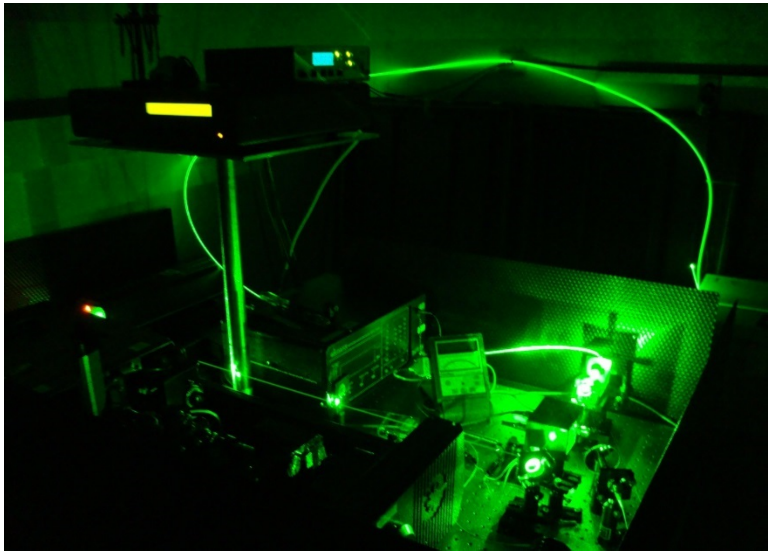


(PTC = Positive Temperature Coefficient)

Calibrating NISTAR at SIRCUS

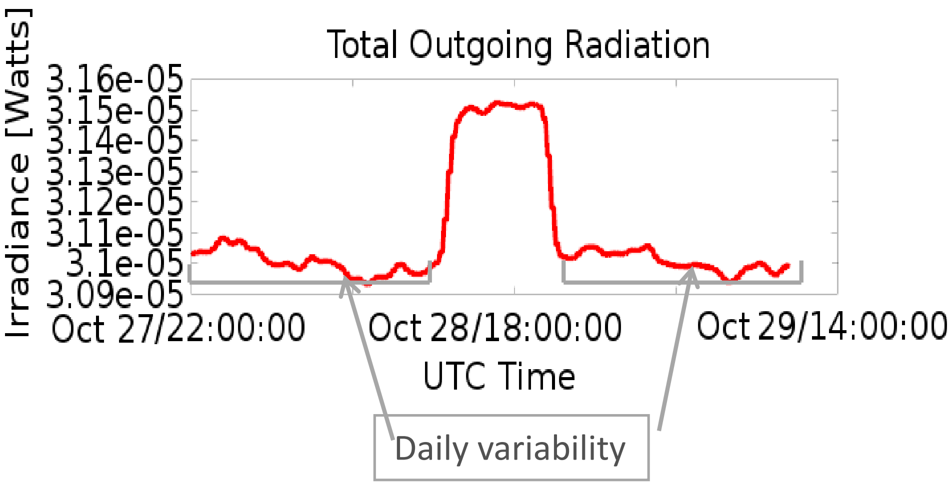
- During the 2010 calibration of NISTAR using the SIRCUS facility, the instrument was in a thermal-vacuum chamber to simulate the space environment.
- It viewed the output of a laser-illuminated integrating sphere coupled to an off-axis parabolic mirror collimator, simulating the geometry of the view of Earth from L-1.

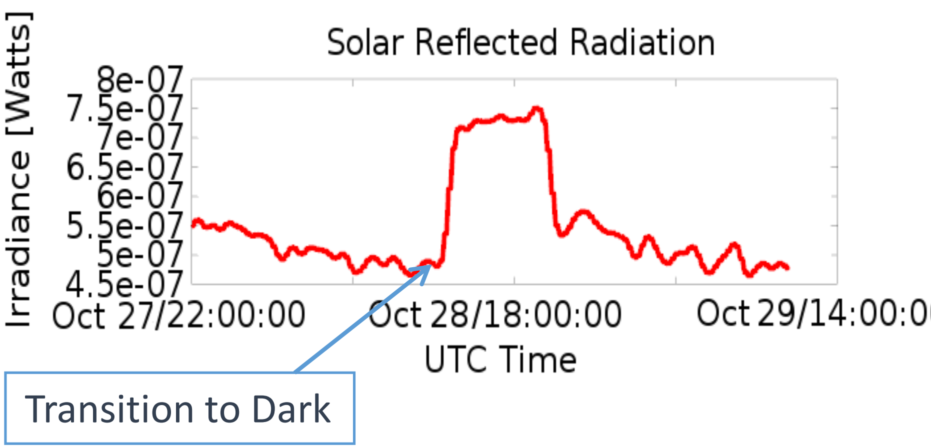




•The integrating sphere and collimator were on a translation stage, and the laser was fiber-optically fed.
•This enabled the source to be moved relative to the large, fixed vacuum chamber that contained NISTAR
•A silicon photodiode trap detector served as the irradiance responsivity standard

NISTAR Actually Works!





Nominal Operation

Vast majority of time looking at Earth, but occasionally slew to dark space to find:

- Zero offset in irradiance measurement
- Signal noise level

Transition to Dark Space

Difference between Earth-pointed and dark responses gives actual Earth signal.

Dark Space-Pointed

Noise levels are within 1.5% requirements for Bands A and B.

Band	Earth Signal (nW)	Noise Percent of Daily Mean
A (Total)	505.14	0.782 %
B (Solar Reflected)	217.99	0.902 %

Laboratory sources do not match reality

- We calibrate with uniform sources…

Example: lamp-illuminated integrating sphere

- But reality is spatially non-uniform:

Example: AVIRIS image of

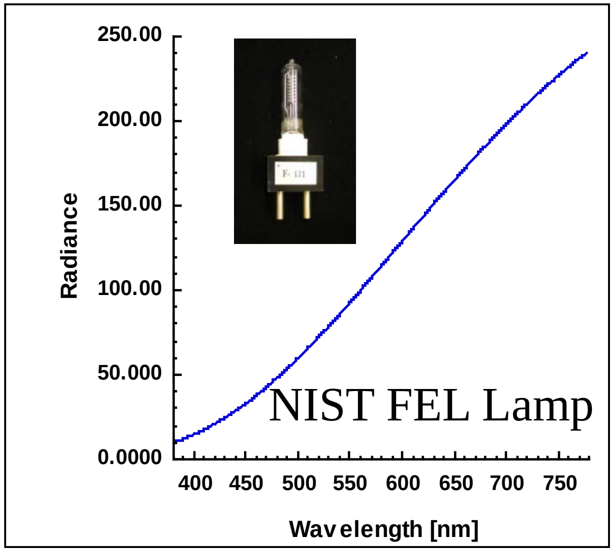
North Island Naval Air Station,

San Diego, CA

NIST

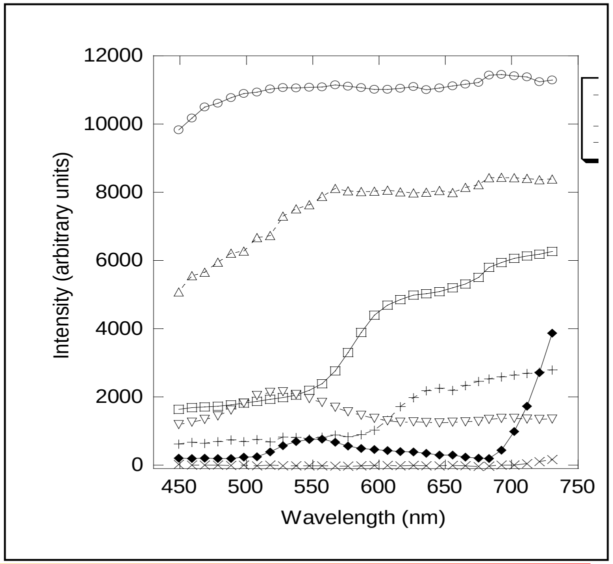
The same situation applies spectrally

- Lamps standards and blackbodies offer only a Planckian-shaped spectrum.



- But reality has many different spectra…

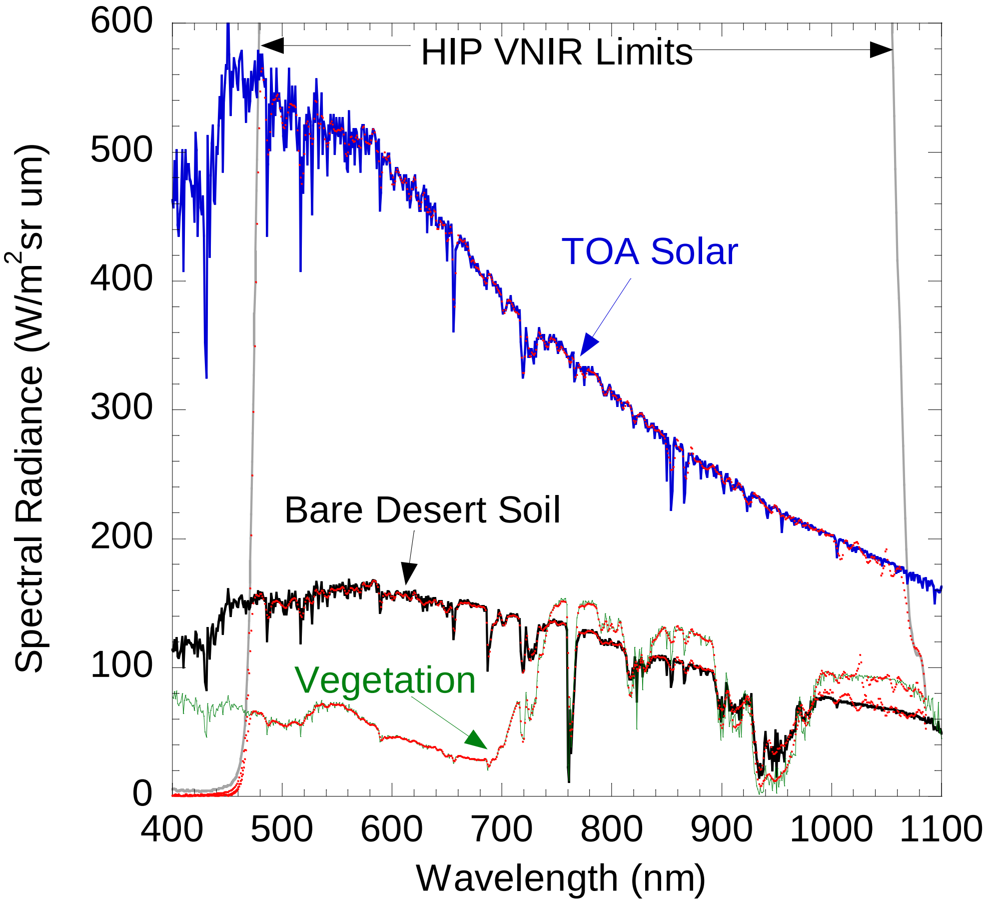
Example: ENVI/SMACC was used to find these 7 eigenspectra from the San Diego Naval Air Station data cube.



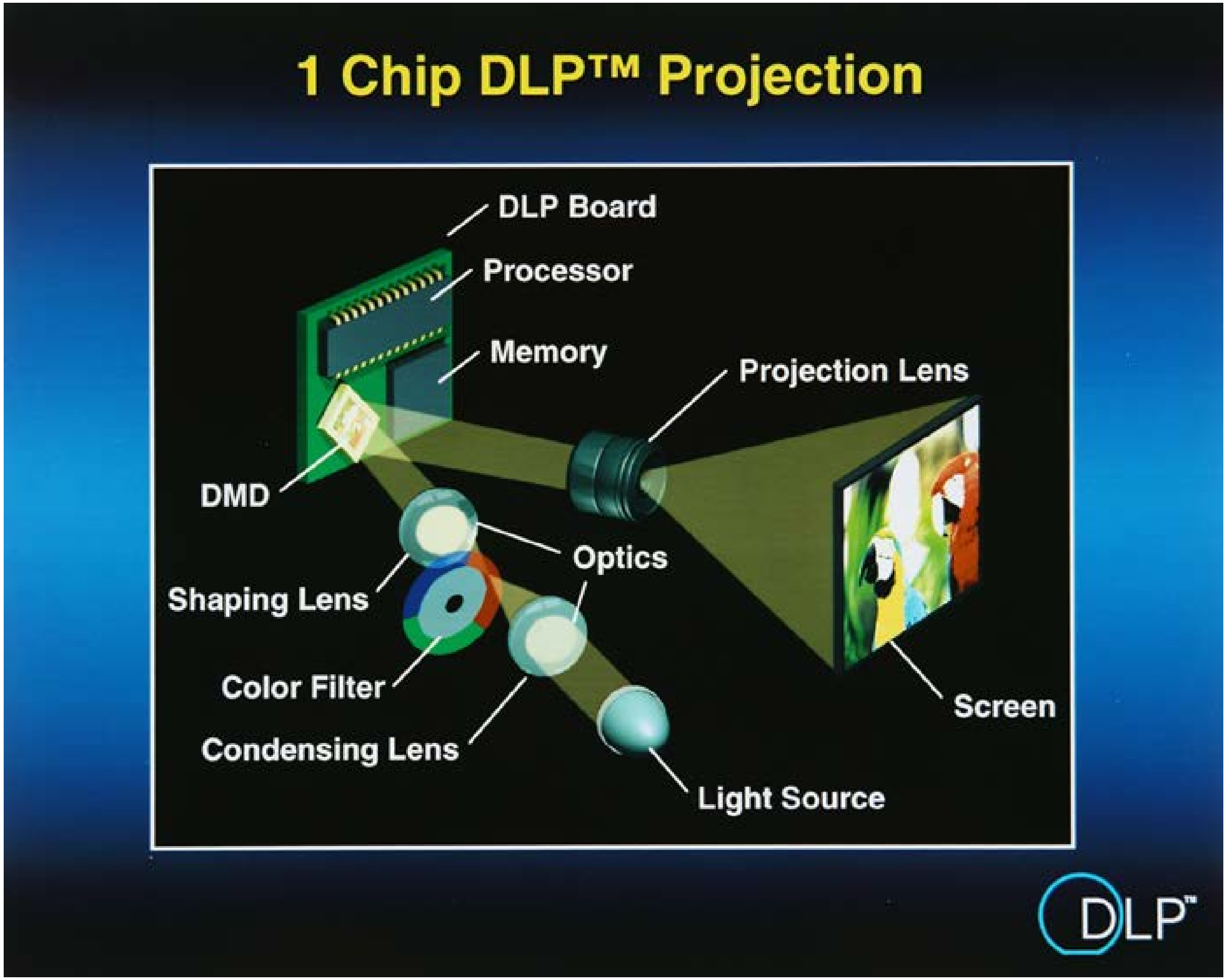
SMACC Reference: J. Gruninger, A. J. Ratkowski, and M. L. Hoke, "The sequential maximum angle convex cone (SMACC) endmember model," *Proc. SPIE* **5425**, 1-14 (2004).

So I developed a Hyperspectral Image Projector (HIP) to Match Typical Reflected-Solar Radiance Spectra

- The HIP provides enough light to simulate a bright sunny day outside
- Red data plots below show how well the HIP simulates different real-world spectra



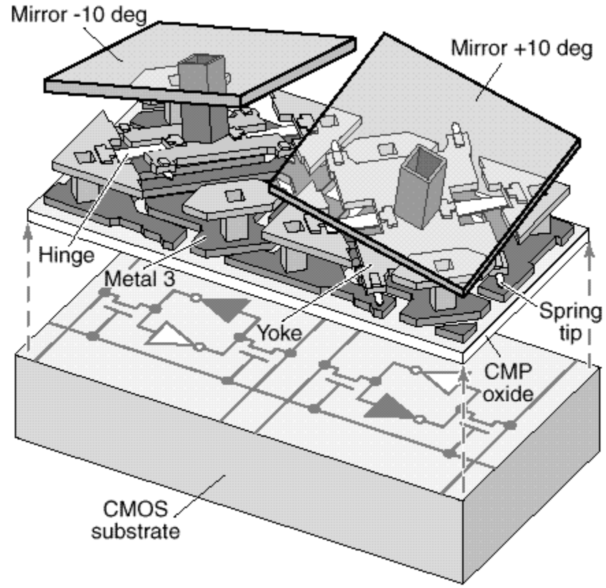
Background: Digital Light Processing (DLP) Projectors



www.dlp.com

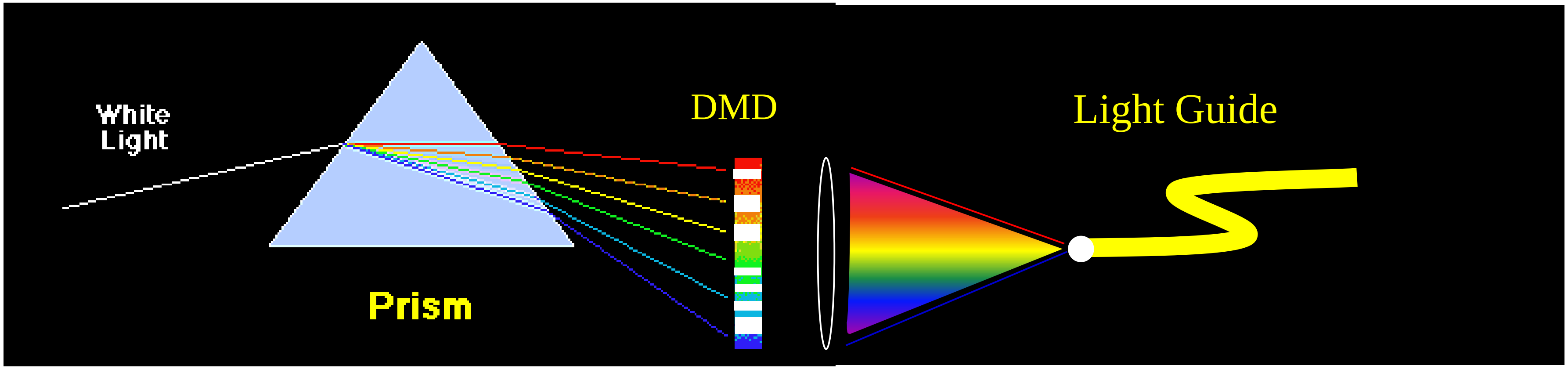
Digital Micromirror Device (DMD)

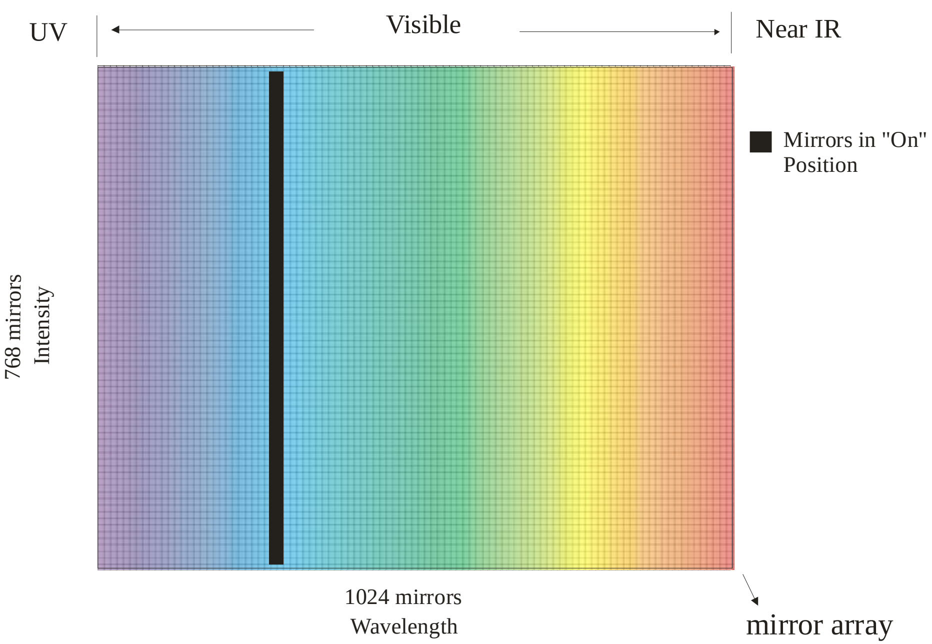
- An array of MEMS micromirror elements
- Developed by Texas Instruments (TI)
  - 1024 x 768 elements, +/- 12 degree tilt angle
  - Aluminum mirrors
  - 13.7 micron pitch
  - < 24 microseconds mechanical switching time.
- For longer wavelength infrared developments we are using DMDs where the glass window is replaced by a ZnSe window.
- Control algorithms are being written by us using LabVIEW with a USB interface to a standard PC.
- I used the TI Discovery 3000 and ALP3.

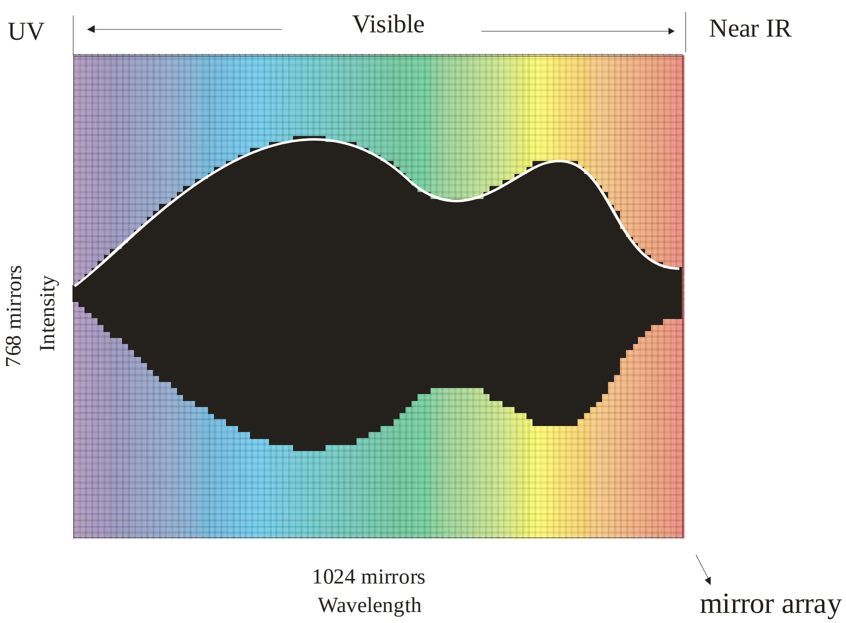


MEMS = Micro-Electro-Mechanical System

How the DMD is used to create an arbitrarily programmable spectrum

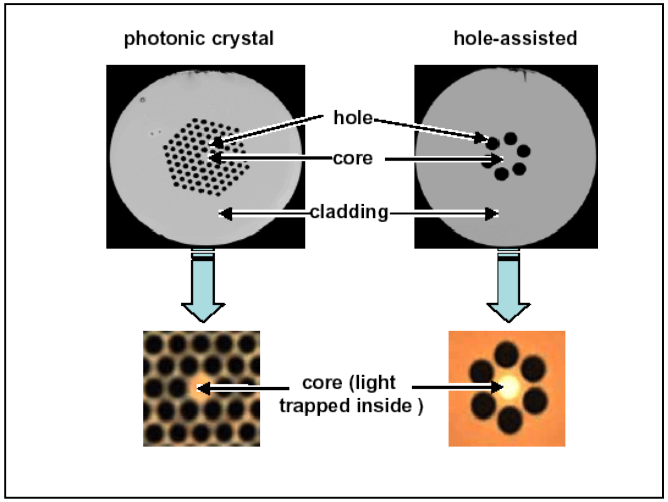


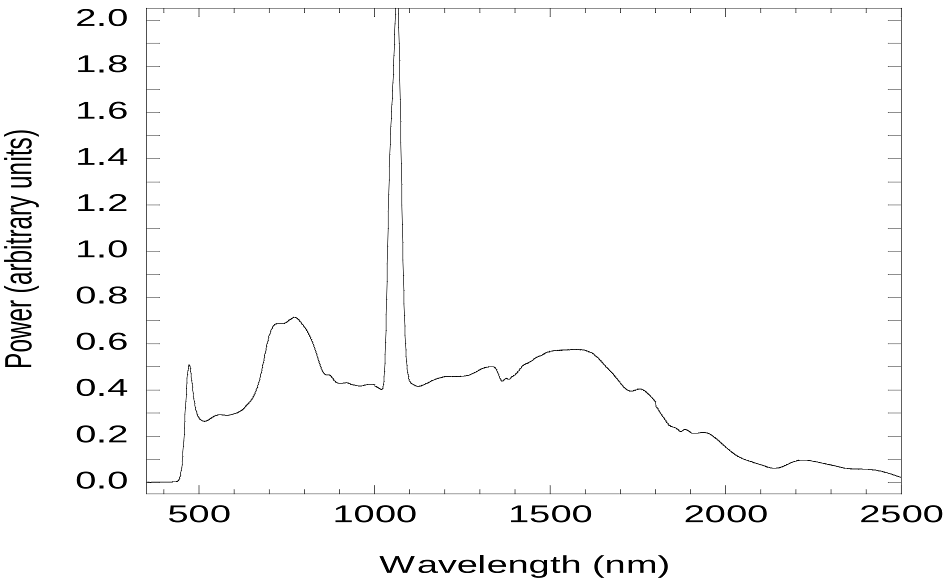




Supercontinuum Fiber Source: A "White" Broadband "Laser"

- Utilizes non-linear effects in a photonic crystal optical fiber to greatly broaden the spectrum of a 1064 nm pump laser.
- Broadband light is generated in a single-mode (5 um core diameter) photonic crystal (holey) optical fiber
  - No etendue issues as with lamps or blackbodies.
  - Ideally suited for coupling to a HIP spectral engine.
- High power and high spectral resolution:
  - 3mW/nm spectral power density from 450 nm to 1700 nm





Compressive Projection is Used to Achieve Higher Brightness

- **First, ENVI/SMACC was used to find these Eigenspectra and their Abundances**

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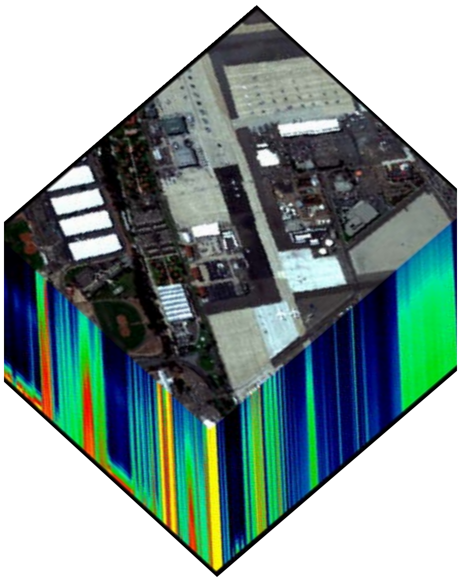
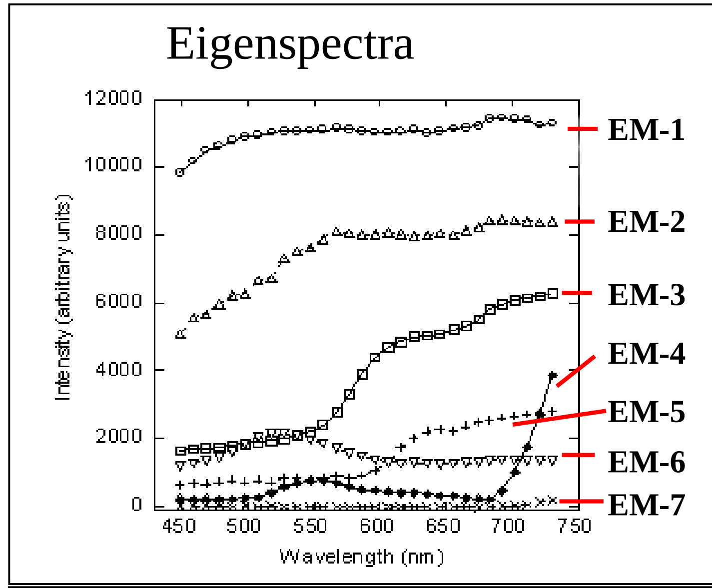
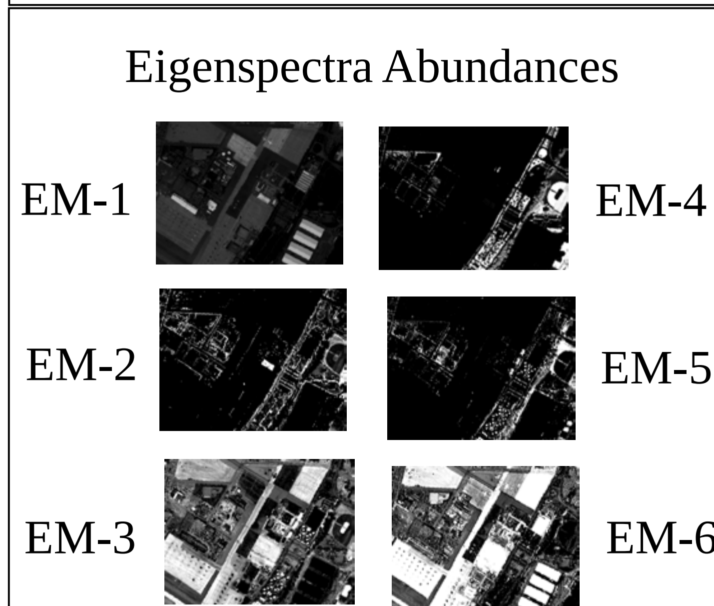


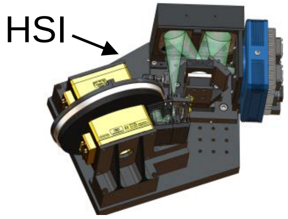




- **Then we need only project N = 6 broadband spectra instead of M = 30+ monochromatic spectra.**

Example Sensor Test at the HIP Facility

- Used a pushbroom Hyperspectral Imager (HSI) from collaborators at University of Colorado – This sensor is prototype instrument for NASA.
- Input data was a real scene collected by HSI
- Projected by the HIP and measured by the HSI.
- HSI scanned HIP to simulate ground track motion



HIP Projected, HSI Measured:

Learning Theoretical Physics as a Hobby

- Reading, Re-reading, and Cross-reading Physics Textbooks.

  Examples (there are too many to list here):

  - Gravity: An Introduction to Einstein's General Relativity Hartle
  - Gravitation, Misner, Thorne, Wheeler
  - Quantum Field Theory, Peskin & Schroeder
  - Introduction to Cosmology, Ryden
  - Spacetime and Geometry: Intro to General Relativity, Carroll
  - A First Course on String Theory, Zwiebach
  - Group Theory, Ramond (It was good to read Tinkham's GT book first)
- Augmenting with video lectures when available.
  - Quantum Field Theory, Tong: FollowsPeskin & Schroeder
  - General Relativity, Alex Flournoy: Follows Carroll
- When?
  - Mon-Fri, 6 am to 8 am (or earlier if I wake up naturally)
  - Sat-Sun: 4 to 6 hours (or more if I can: but this is secondary to faith and family)
  - Retirement?

Summary

- “Before you do an experiment, think about it, but do not think about it too much: Do the experiment.” William Phillips, NIST Nobel Laureate, 1997.
- Think deeper about the fundamentals of quantum mechanics: “This is a good way to end your career.” David Mermin, Physics Colloquium. This, by the way, is exactly how I plan to end my career: as the hobby in which it started.
- When it comes to theoretical physics, I prefer to sip it – like a fine wine, over a very long time period, as opposed to chugging it like a beer as we have to in school.
- Don’t ever believe the myth about being too old: Patience and Persistence
- Don’t let them type-cast you.
- “I hope you never lose your sense of wonder.” Lee Ann Womack
- Be on the lookout for opportunities:

NIST SURF Program: https://www.nist.gov/surf/surf-gaithersburg

NIST/NRC Post-doctoral Fellowships: Search http://sites.nationalacademies.org/pga/rap/

For example, for Remote Sensing: Search advisors: Joseph Rice and others

http://nrc58.nas.edu/RAPLab10/Opportunity/Opportunity.aspx?LabCode=50&ROPCD=506851&RONum=B7541

For example, for Optical Properties of Materials: Search advisors: Eric Shirley and others (theory and experiment)

http://nrc58.nas.edu/RAPLab10/Opportunity/Opportunity.aspx?LabCode=50&ROPCD=506851&RONum=B7542