Hyperspectral Image Projector (HIP)

•A scene projector for in-lab testing of imaging sensors using spectrally-realistic scenes

Additional information and publications available from:
joe.rice@nist.gov

Or go to the NIST website (www.nist.gov) and search “HIP”

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Laboratory sources do not match reality very closely

We calibrate with uniform sources…

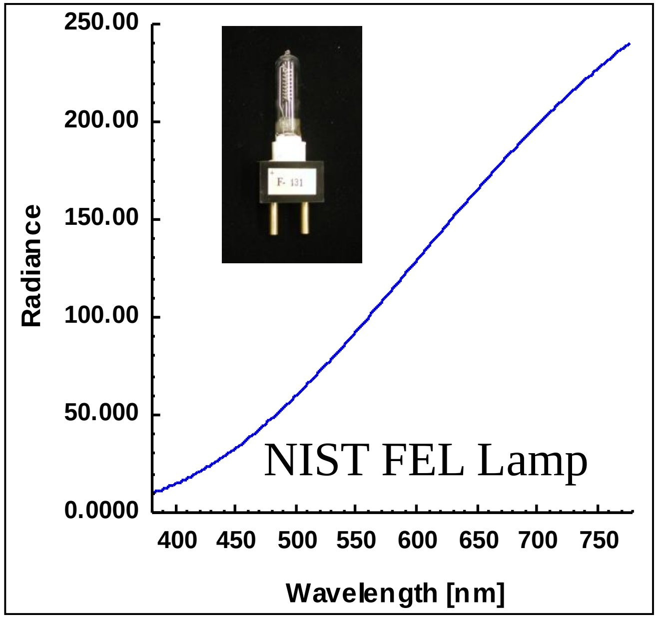
Example: lamp-illuminated integrating sphere for reflective bands, (or blackbody for IR emissive bands)

But reality is spatially non-uniform:

Example: AVIRIS image of North Island Naval Air Station, San Diego, CA

The same situation applies spectrally

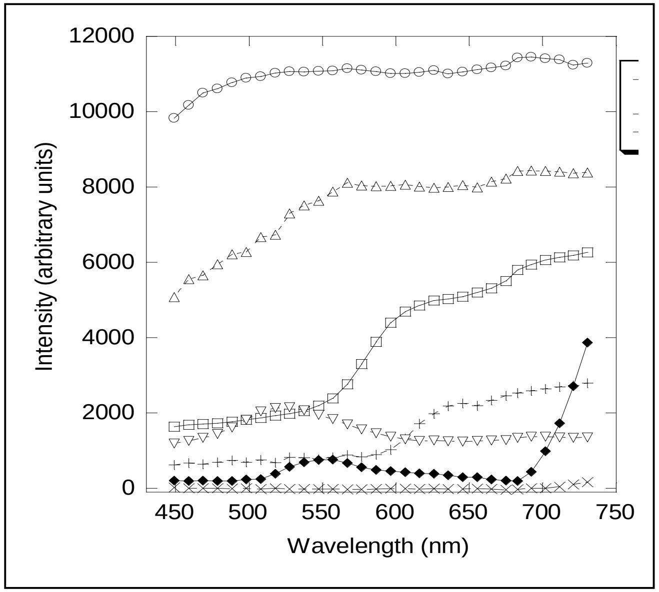
Lamps standards and blackbodies offer only a Planckian-shaped spectrum.



But reality has many different spectra…

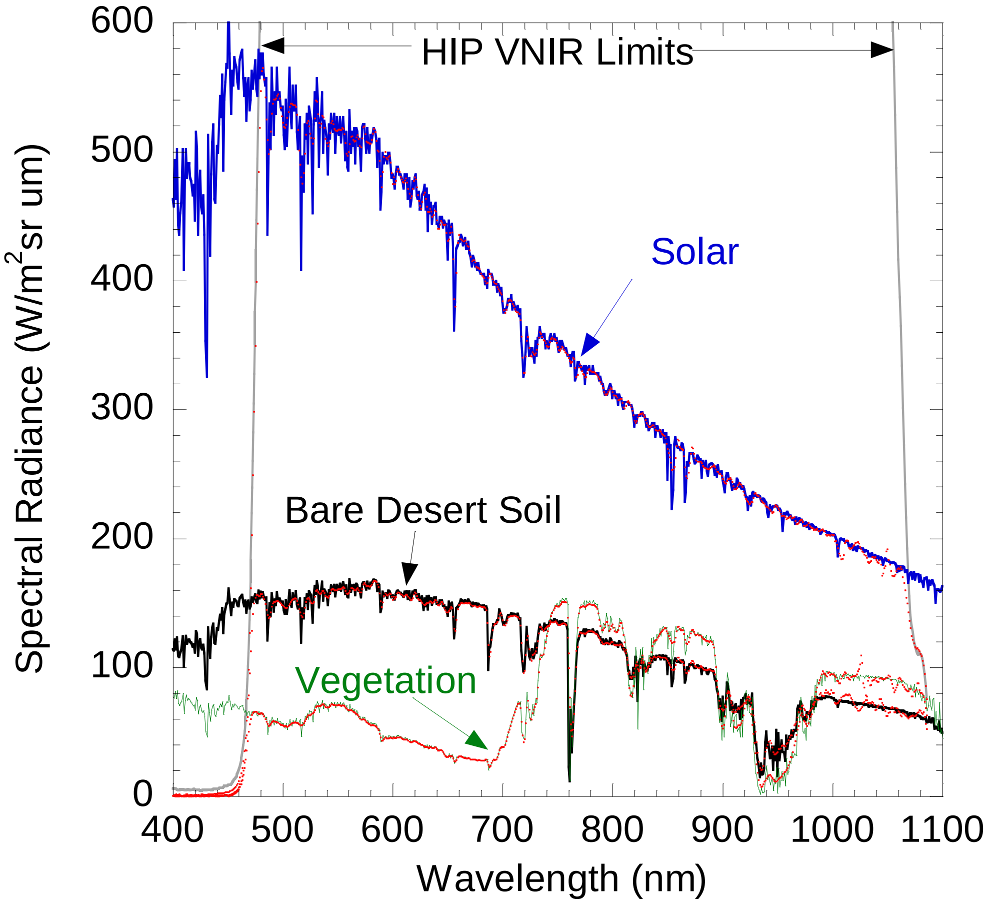
Example: ENVI/SMACC was used to find these 7 endmember spectra from the San Diego Naval Air Station data cube.

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).

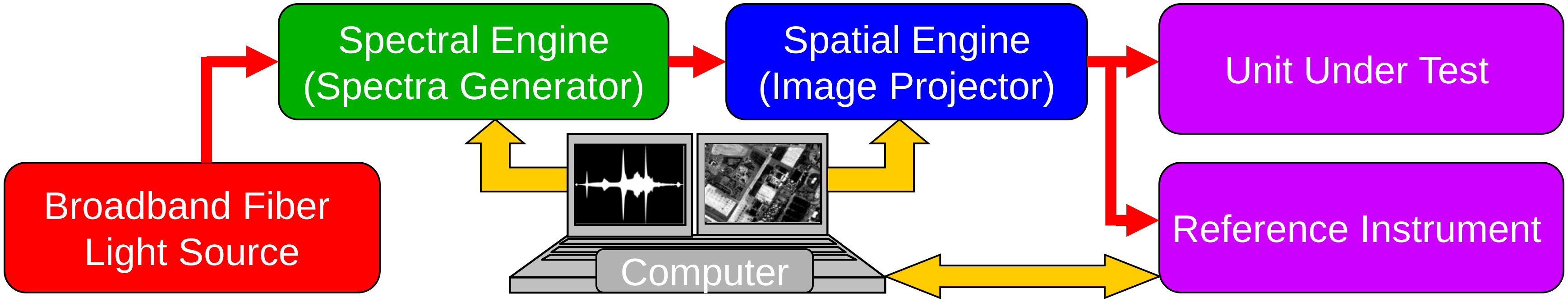


The Hyperspectral Image Projector (HIP) Can Match Typical Reflected-Solar Radiance Spectra

- 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



HIP Prototype Overview



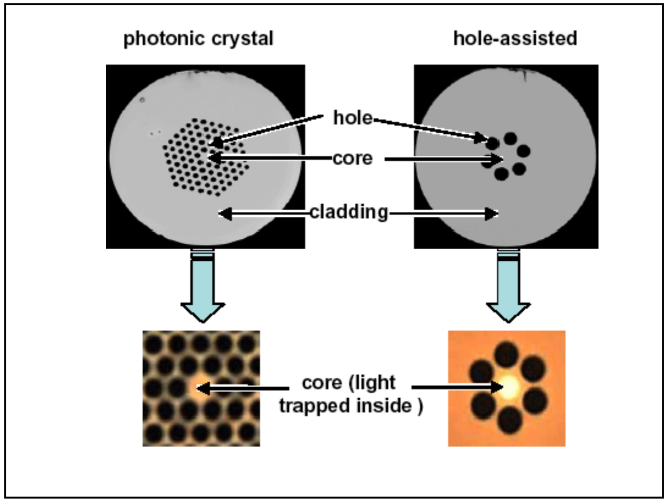
- **Broadband Fiber Light Source**
  - Provides high brightness in a small spot for high spectral resolution
  - Fused-silica fiber supercontinuum source for VNIR/SWIR
- **Spectral Engine**
  - Fiber source light is spectrally dispersed across a digital micromirror device (DMD)
  - Image reflected from on-pixels of DMD is spatially integrated and determines spectrum
- **Spatial Engine**
  - Uses another DMD to project spectra into customer's Unit Under Test (UUT) per 2D spatial abundance images, through a collimator, in sync with spectral engine
- **Reference Instrument**
  - Well-calibrated imaging spectrometer to measure the spectrum of each spatial pixel at the output, relative to NIST reference standards, to provide truth data

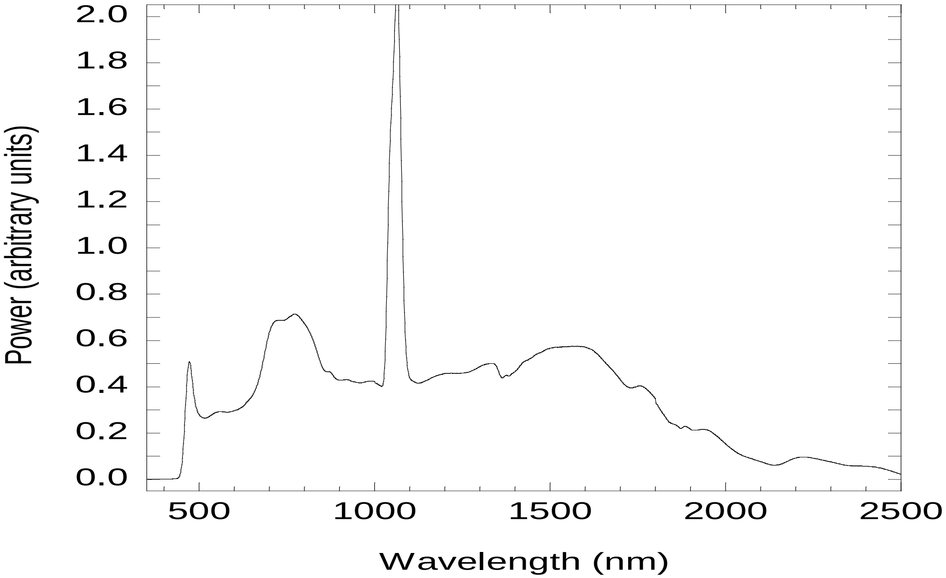
Supercontinuum Fiber Laser: A "White" Broadband Laser

- 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 spectral engine.

- High power and high spectral resolution:
  - 3mW/nm spectral power density from 450 nm to 1700 nm

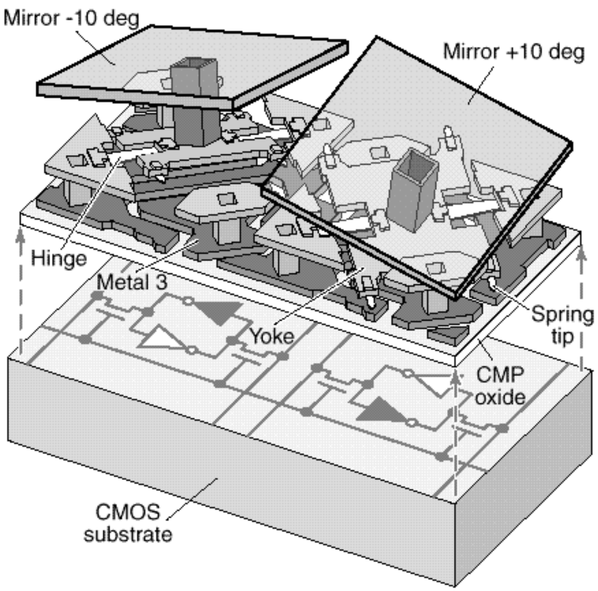




Digital Micromirror Device (DMD)

- **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 visible to 2500 nm applications we have used:**
  TI Discovery 1100 electronics board with an Accessory Light Processor (ALP) electronics board
  (see dlp.com).
- **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.**
- **For the prototypes in this proposal, we plan to use the TI Discovery 3000 and ALP3.**

MEMS = Micro-Electro-Mechanical System
MAPS = Micromirror Array Projection System



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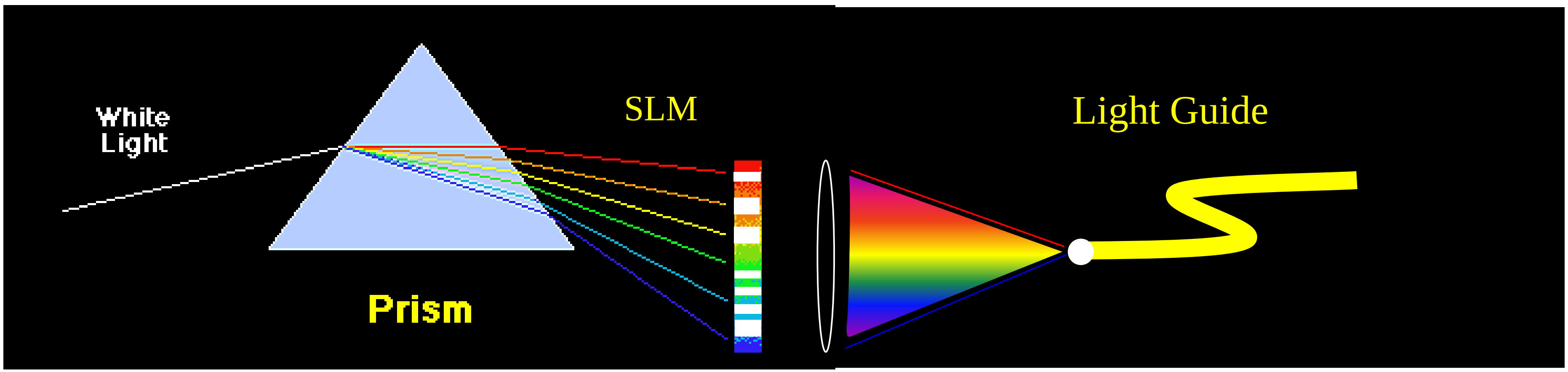
Principle of the Spectrally Programmable Source (also called the Spectral Engine)

Dispersing element

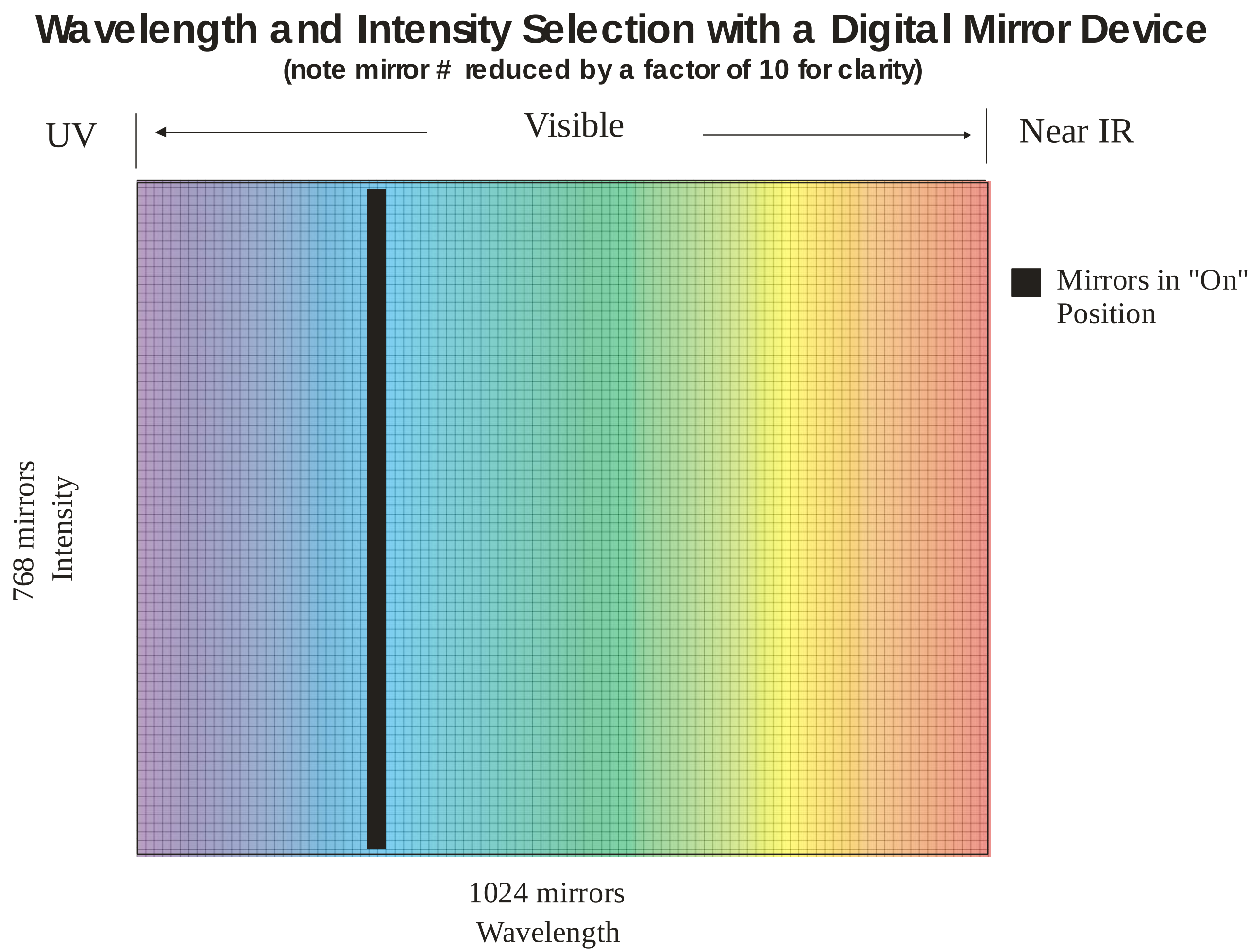
Spatial Light Modulator (SLM)

Recombine the Light

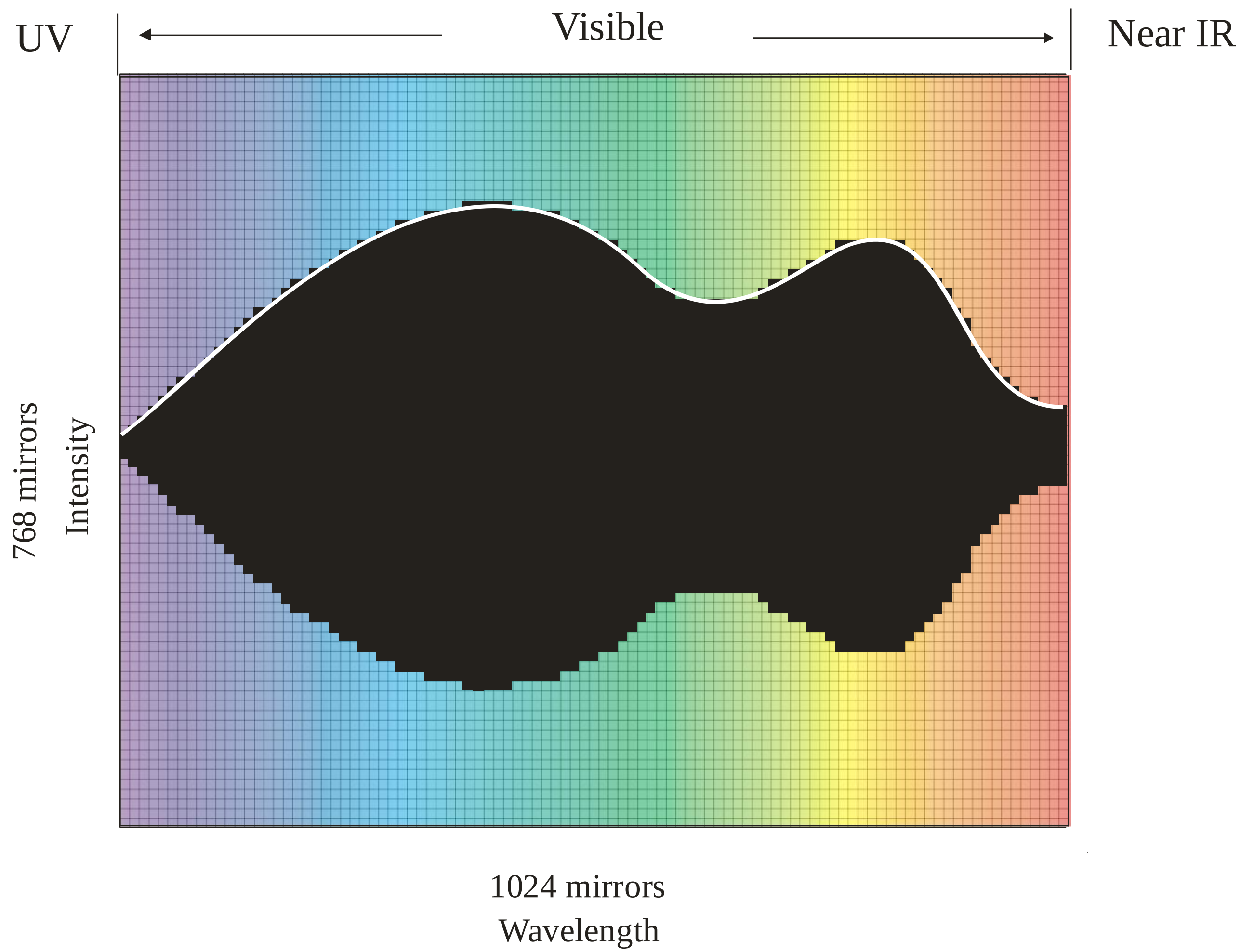


- Enabling Technology: SLM
  - Digital micromirror devices (DMDs)
  - Liquid crystal on silicon arrays (LCOS arrays)

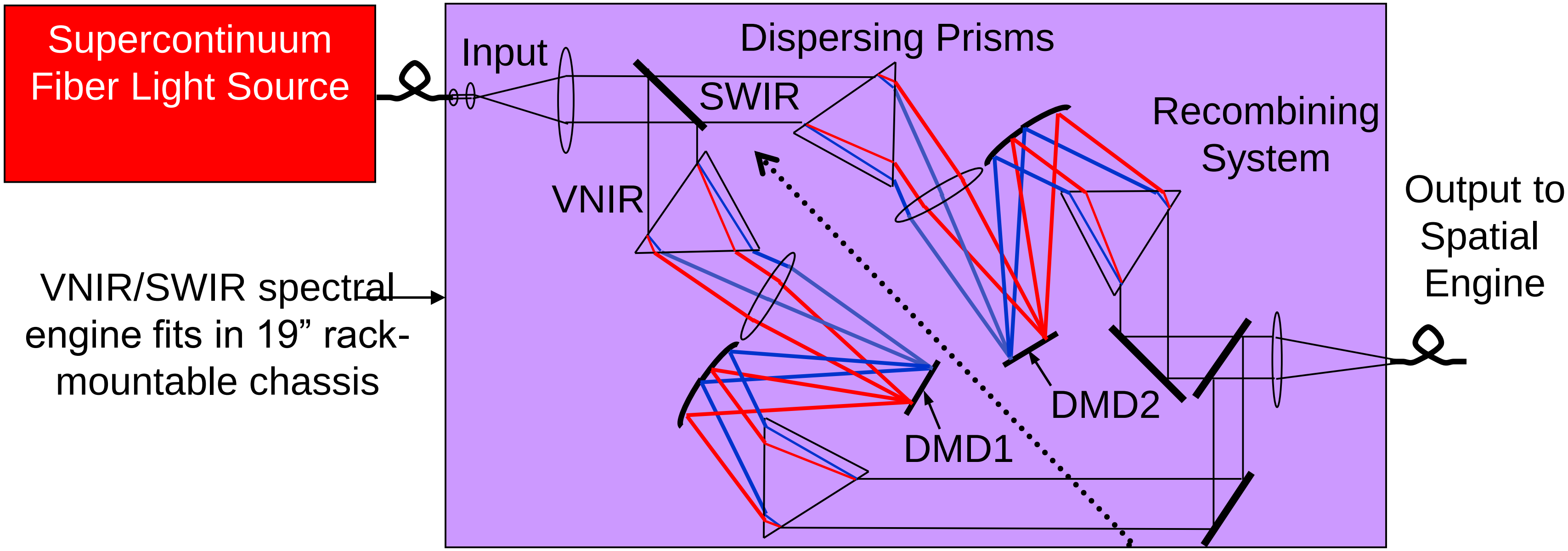
How the DMD is used in a spectrally tunable source: Monochromator Mode



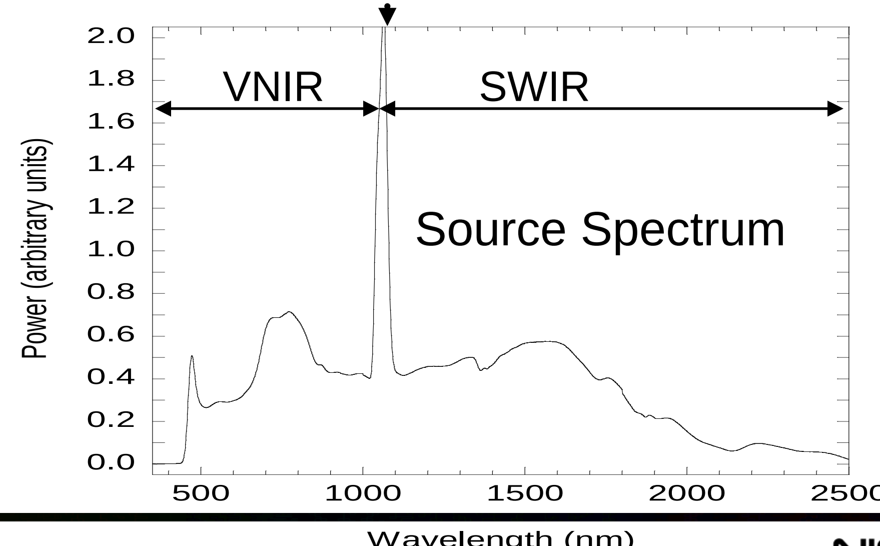
How the DMD is used to create an arbitrarily programmable spectrum



Design Concept for VNIR/SWIR Spectral Engine

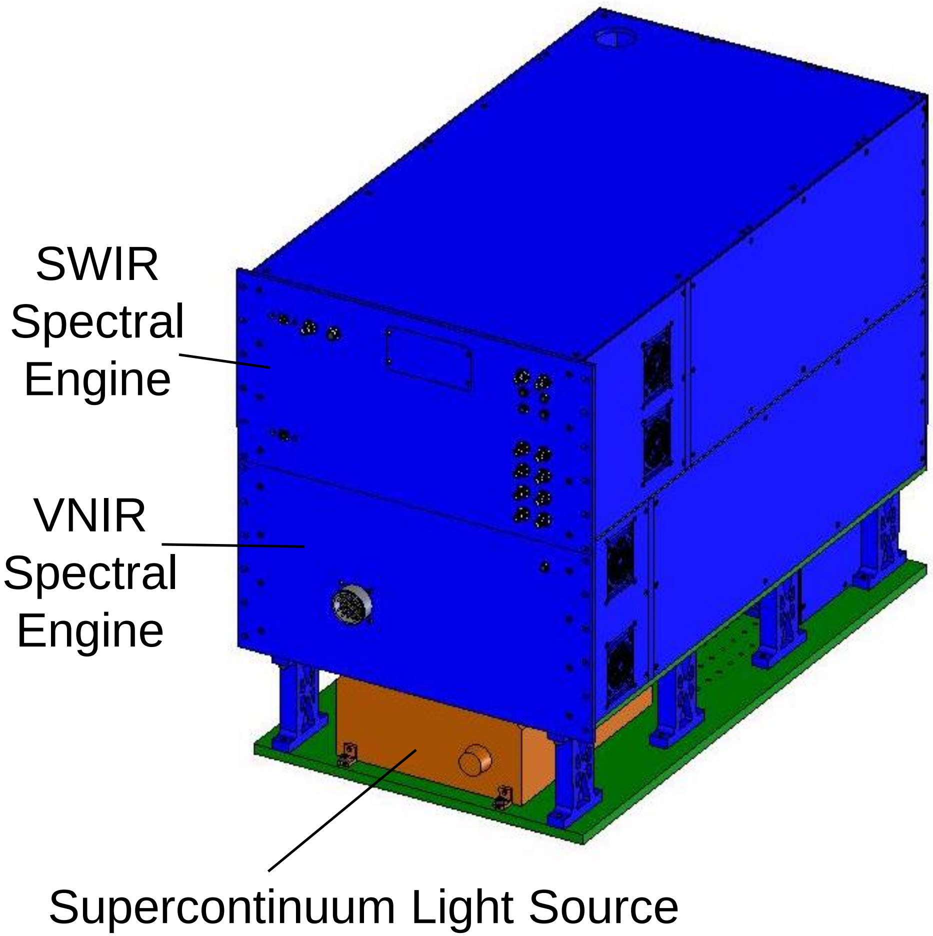


- Splits input into VNIR and SWIR
- One DMD (1024x768) for each range
- Optical modeling in Zemax and FRED
  - Prisms selected
  - Design meets requirements
    - ❖ Spectral range
    - ❖ Transmittance
    - ❖ Spectral resolution
- Mechanical modeling in Solid Works

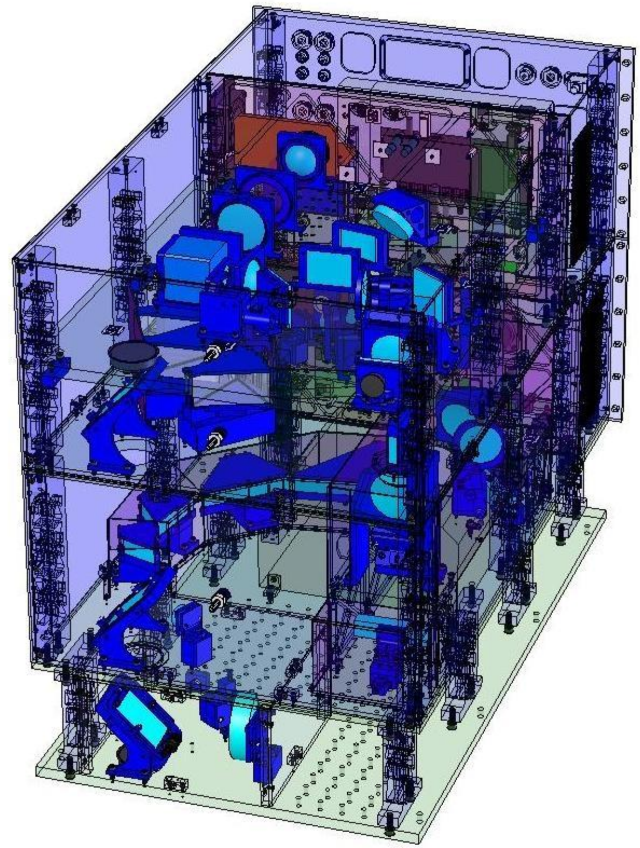


HIP VNIR-SWIR Spectral Engine

Outside view from front:

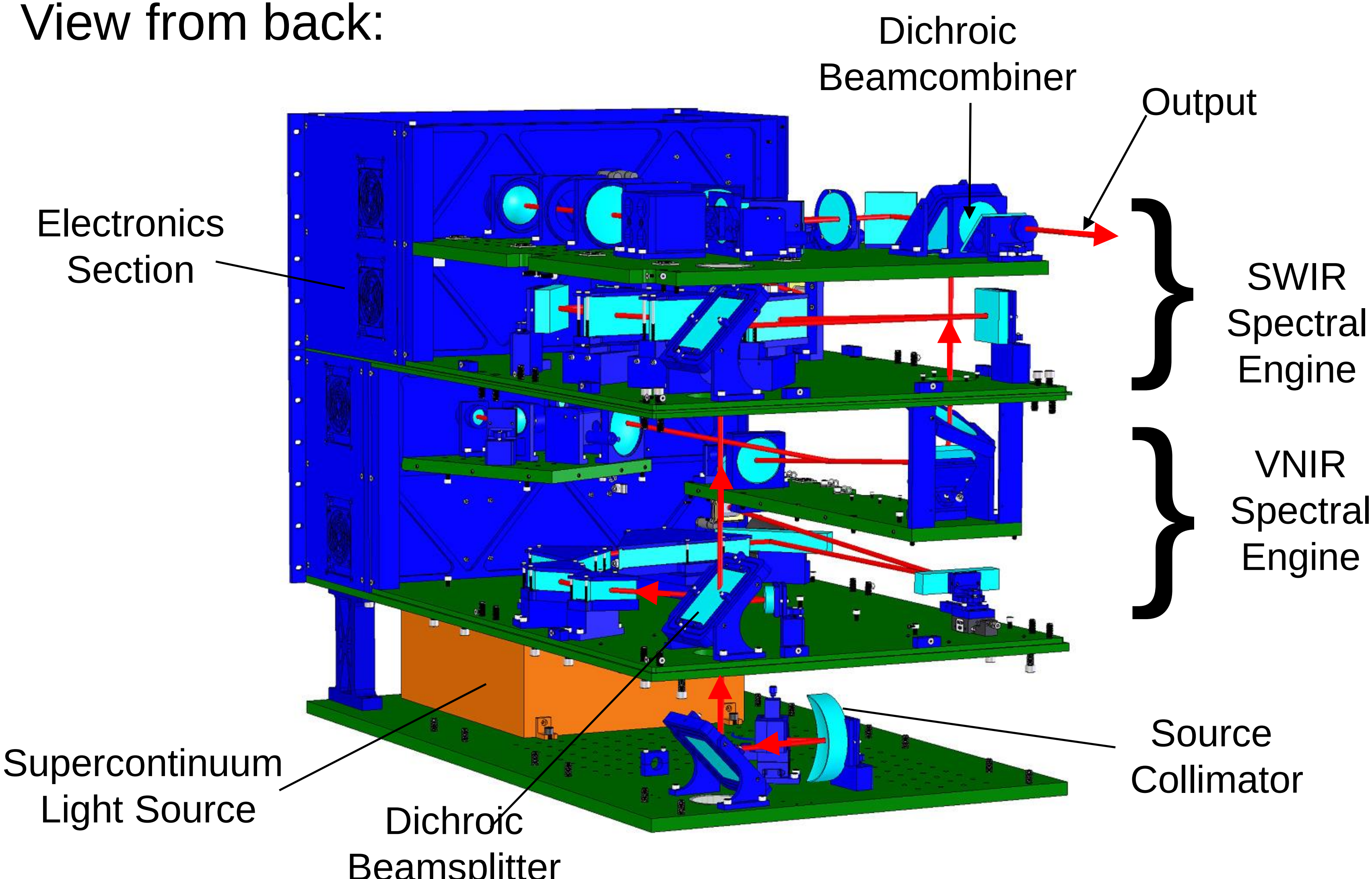


Inside view from back:



HIP VNIR-SWIR Spectral Engine

View from back:



SWIR Spectral Engine

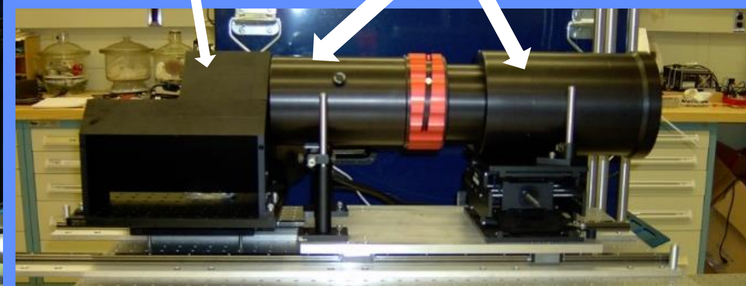
VNIR Spectral Engine

Super-continuum Source

Power Supply

Spatial Engine

Collimator For Projection to UUT



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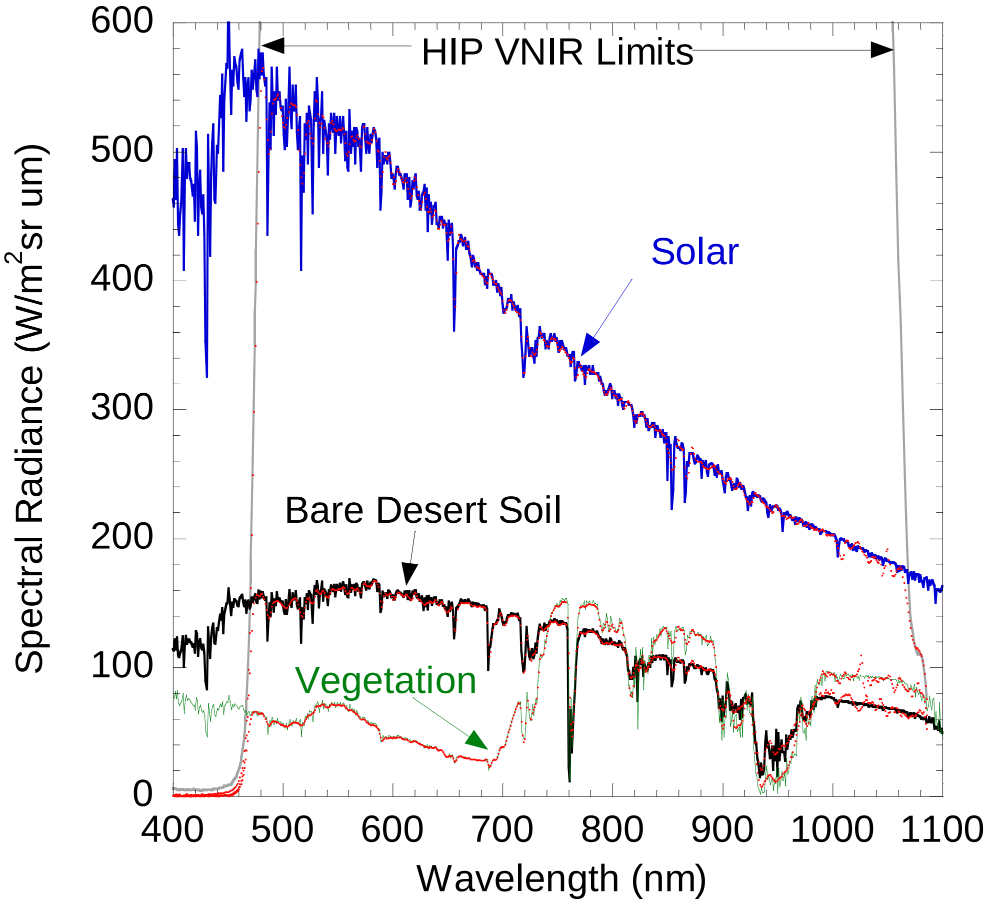
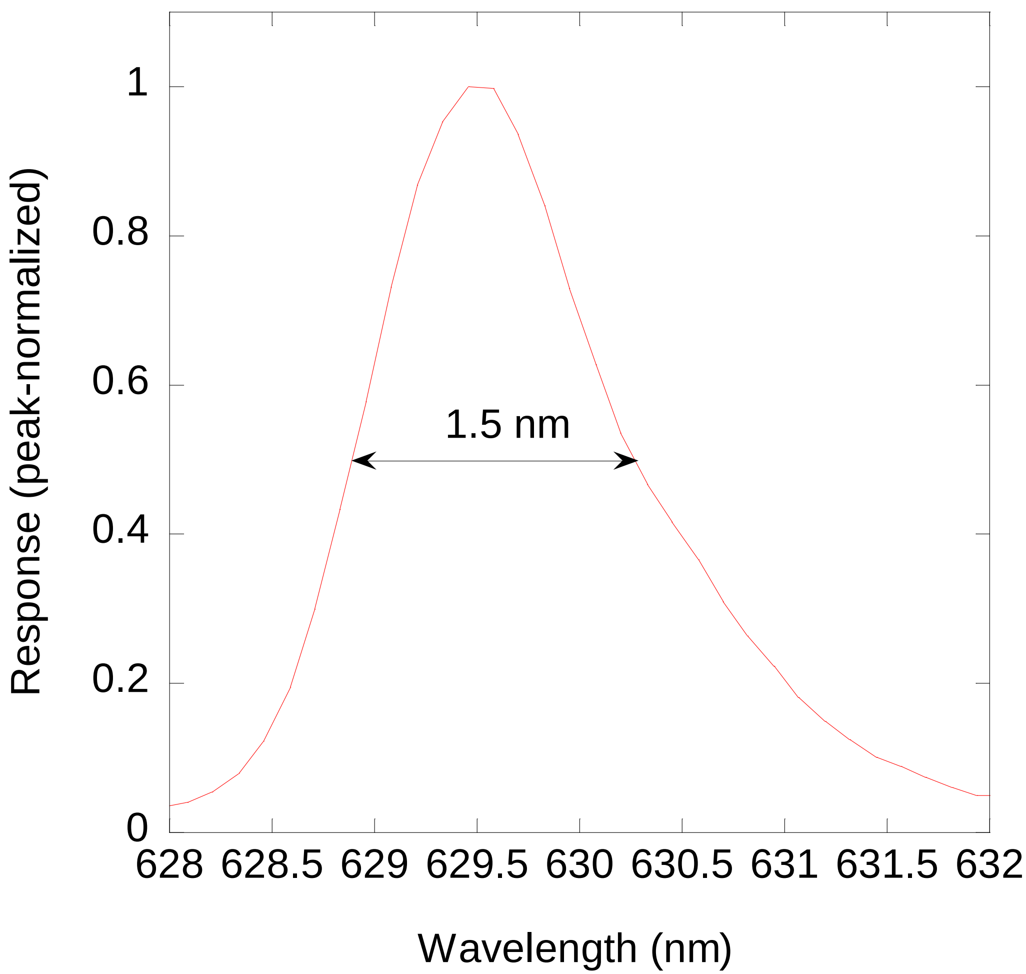


HIP Prototype Specifications

Parameter	Specification
Spectral Range	450 nm to 2500 nm (VNIR-SWIR) (extension to 350 nm in progress)
Spectral Resolution	5 nm VNIR 8 nm SWIR
VNIR/SWIR/MWIR Sync. Accuracy	1 microsecond
Spatial Format	1024 H × 768 V
Projected FOV**	7.9° H × 5.9° V
Spatial Resolution**	0.135 mrad
Average Spectral Radiance	1000 $W/m^2 sr \mu m$
Bit Depth and Frame Rate	12 bits at 250 Hz max; 8 bits per component at180 Hz/*N* typical* 1 Bit at 11 kHz max
Contrast Ratio	1000:1
Wavelength Accuracy	2 nm
Radiance Accuracy	2%

**N* = number of components (i.e. eigenspectra) per frame
**Depends on collimator used. Values shown are for the standard 100 mm collimator. 500 mm collimator also available.

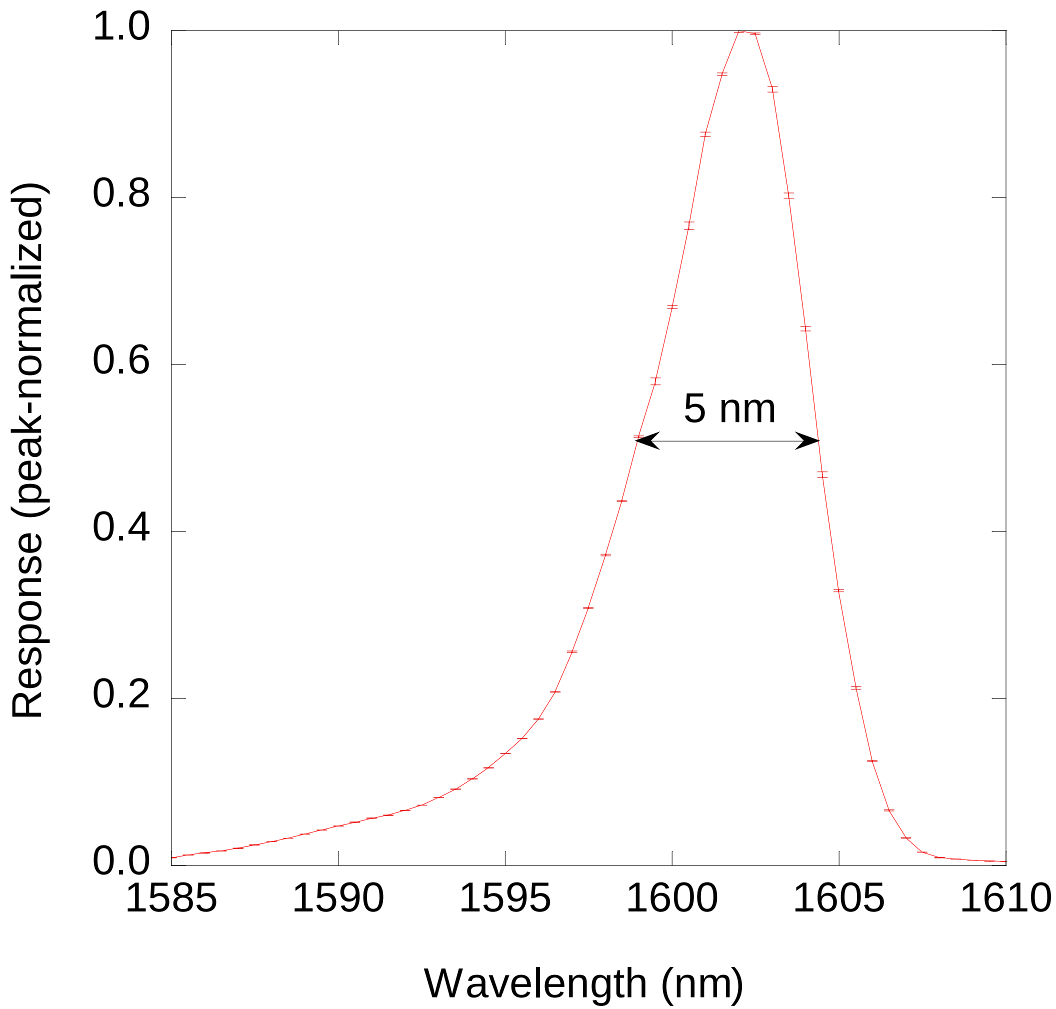
VNIR Spectral Resolution Test Data



Spectral Resolution of Test Instrumentation is 0.2 nm

Meets the < 5 nm spec

SWIR Spectral Resolution Test Data



Spectral Resolution of Test Instrumentation is 0.5 nm

Meets the < 8 nm spec

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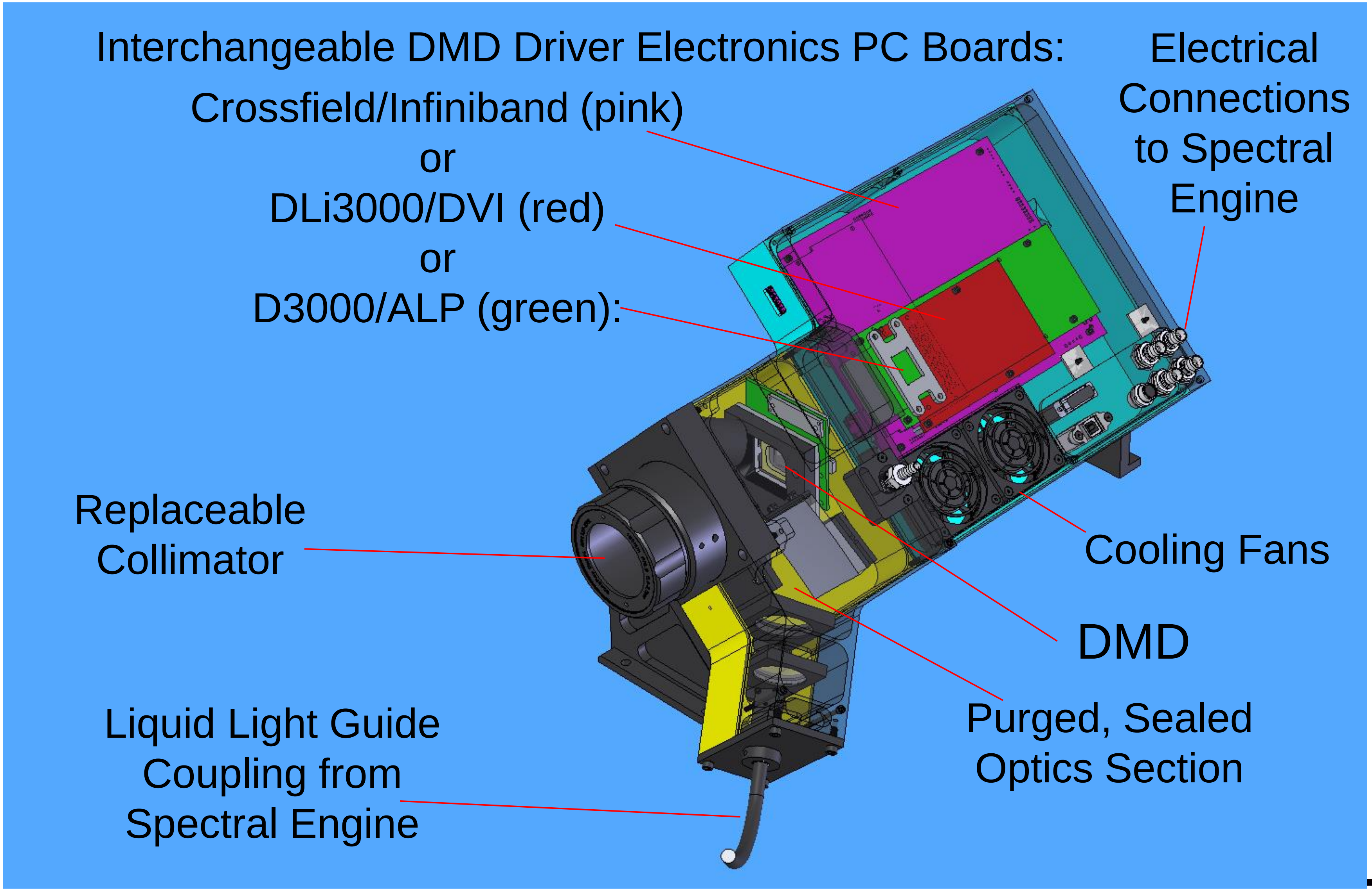
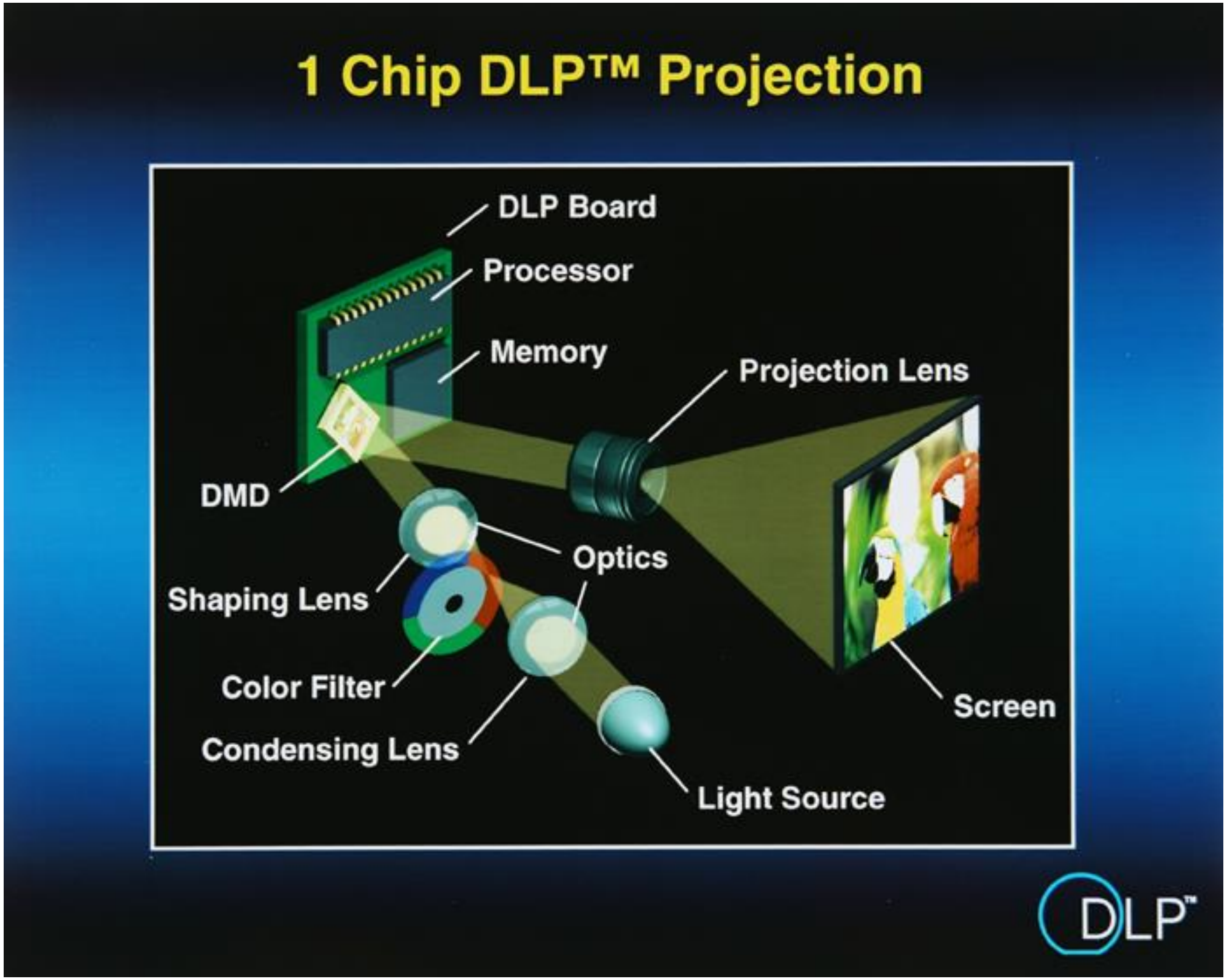
VNIR-SWIR Spatial Engine Prototype Mechanical Design

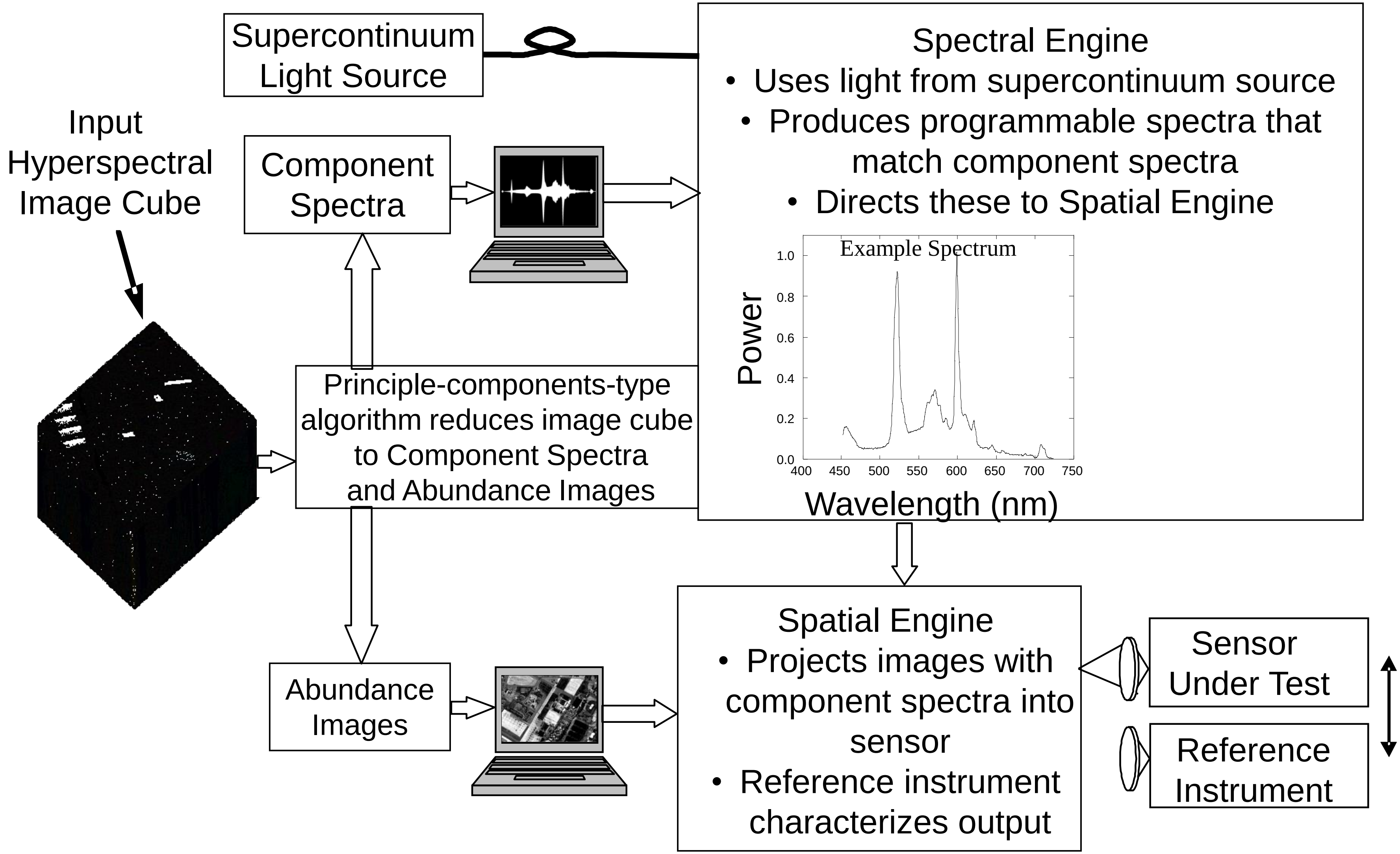


Background: Digital Light Processing (DLP) Projectors



www.dlp.com

HIP Image Cube Projection Concept



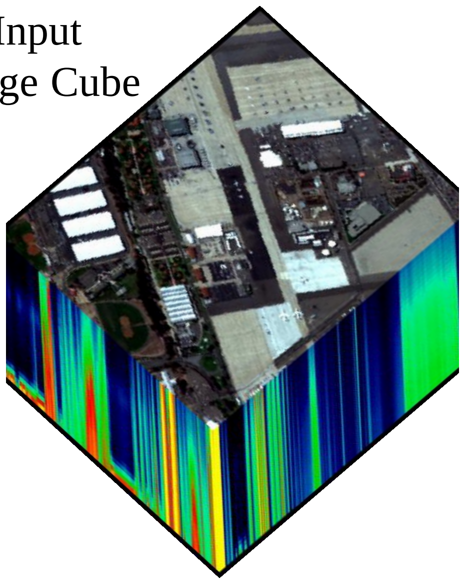
Compressive Projection is Used to Achieve Higher Brightness

First, ENVI/SMACC was used to find these Endmember Spectra and their Abundances

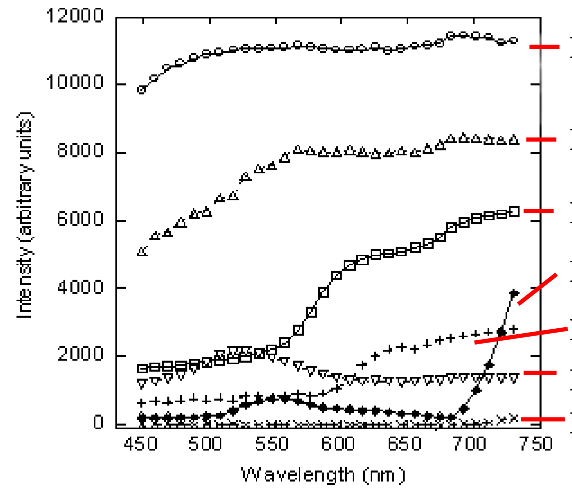
J. Gruninger, A. J. Ratkowski, and M. L. Hoke, “The sequential maximum angle convex cone (SMACC) endmember model,” *Proc. SPIE* **5425**, 1-14 (2004).

Example: AVIRIS Image Cube of San Diego Naval Air Station

Input Image Cube



Eigenspectra

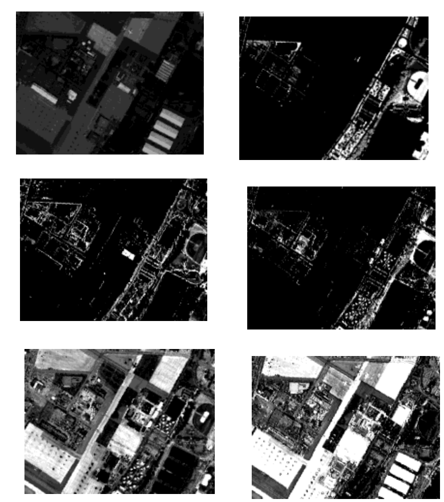


Eigenspectra Abundances

EM-1 EM-4

EM-2 EM-5

EM-3 EM-6

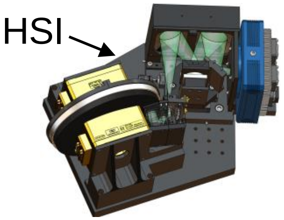


Then we need only project N = 6 broadband spectra instead of M = 30+ monochromatic spectra.

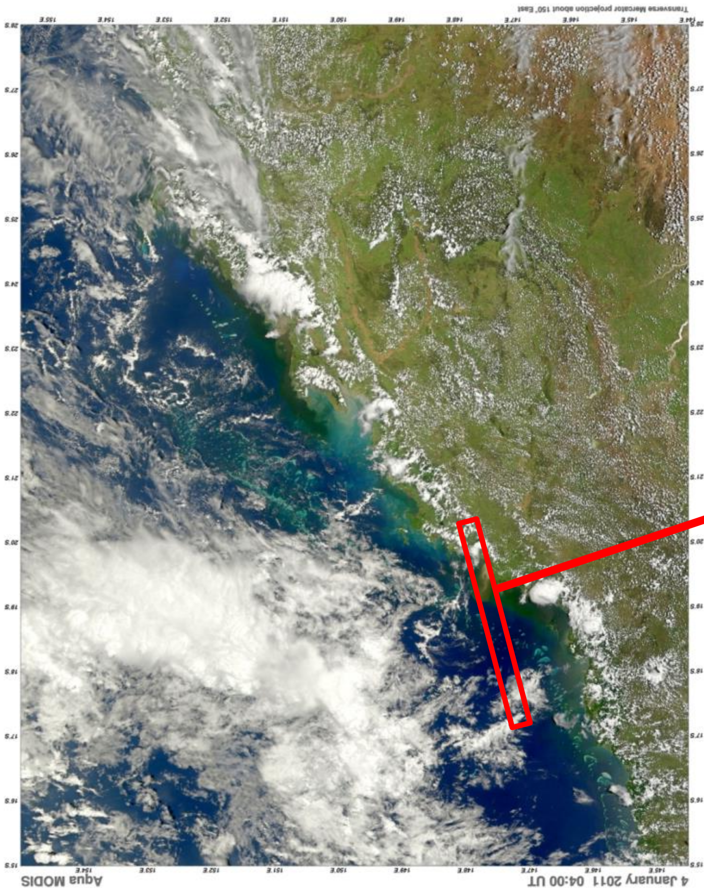
Example Sensor Test at the HIP

- **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:

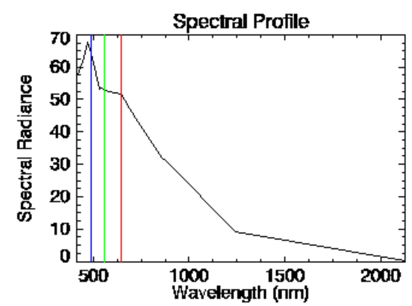


HIP Projection of MODIS Satellite Image Into ORCA Prototype in the Lab

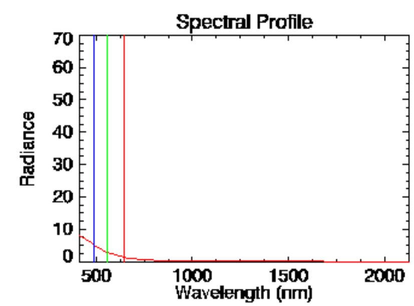


- ORCA (Ocean Radiometer for Carbon Assessment) was a NASA prototype ocean color sensor for the NASA PACE (Pre- Aerosol Cloud Ecosystems) mission.
- Clouds provide stray light that interferes with the ability to measure ocean color and bio-chemistry to quantify carbon processes
- HIP difference images potentially allow measurement of stray light effects with realistic scenes

Typical Cloud Pixel

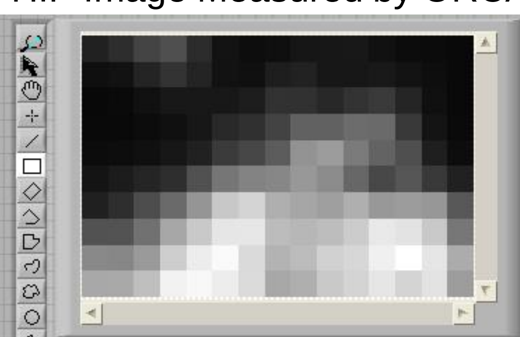


Typical Ocean Pixel

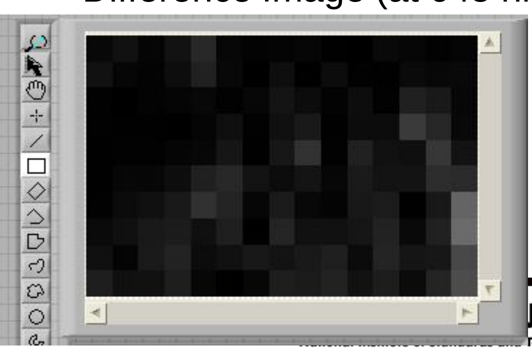


Original Image

HIP Image Measured by ORCA



Difference Image (at 645 nm)



Monochromatic Band Projection

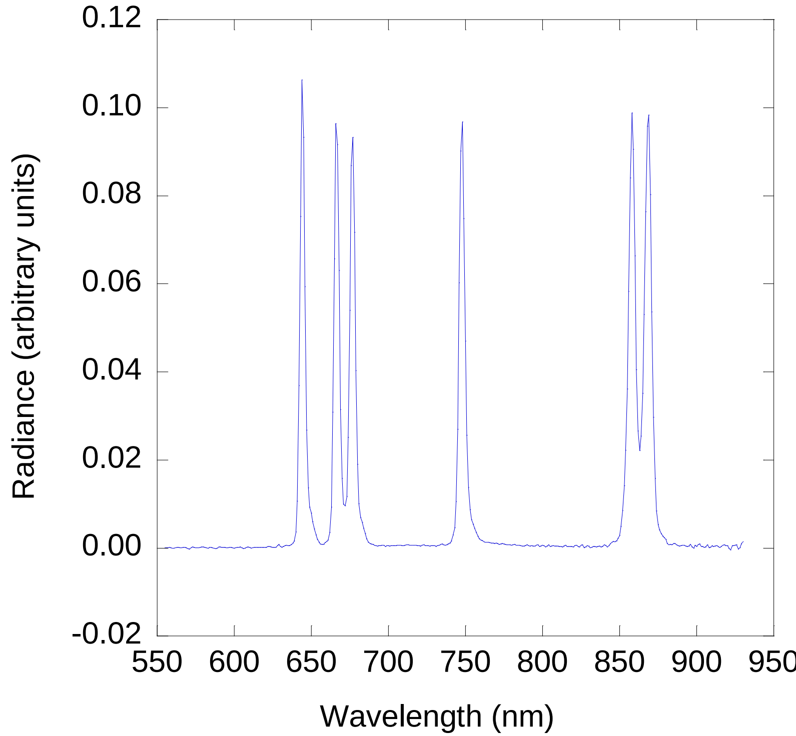
•Using the HIP, we projected six MODIS monochromatic band images into ORCA at the following band center wavelengths:

"Eigenspectrum #"	Wavelength (nm)
1	645
2	667
3	678
4	748
5	859
6	869

•All six images were projected sequentially, but all within the integration time of ORCA

•The radiance levels at each wavelength had been adjusted prior to the test, using a calibrated detector at the output, so that they would have equal radiance levels for a spatially uniform scene

•Measurement of radiance levels of the 6 monochromatic bands from the HIP as made using an ASD spectrometer:

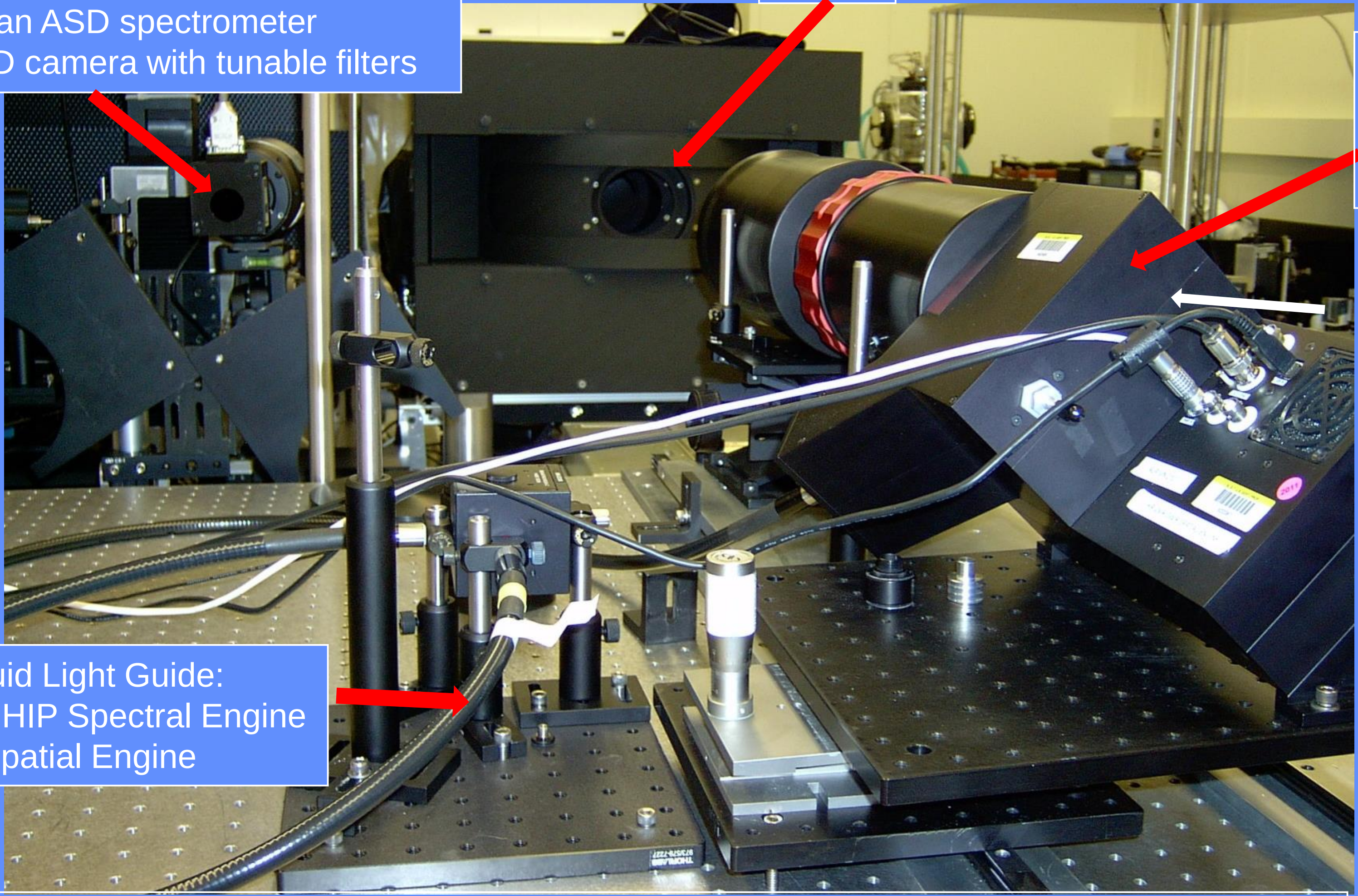


ORCA at the HIP lab at NIST

NIST Reference Instruments:
- Enable measurements of HIP output radiance (ground truth)
- Includes an ASD spectrometer and a CCD camera with tunable filters

ORCA

HIP Spatial Engine



Liquid Light Guide:
- Couples HIP Spectral Engine to HIP Spatial Engine

Translation stage moves HIP between Reference Instruments and ORCA

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