Radiometric Characterization of a Hyperspectral Image Projector (HIP)

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This presentation includes contributions from many NIST and non-NIST collaborators, including:

Mike Kehoe, Casey Dodge, Casey Smith, Rand Swanson, Resonon (Design/Build of the first non-prototype HIP):

Jorge Neira, Allan Smith, David Allen, Bob Saunders Resonon (Software development, performance characterization, design applications):

James Goodman, University of Puerto Rico

Edward Livingston & Karel Zuzak, U. Texas Southwestern Medical Center

Introduction

Motivation:

- Scene Projector validation tool, SI traceable, for in-car police video cameras
- Scene projector for Fire-fighter Sensor Evaluation
- Scene Projector performance validation artifact for military hardware
- Scene Projector for Quantitative Optical Medical Imaging
- Scene Projector for Multi and Hyperspectral Imaging/Earth-remote Sensing

General solution:

- The Hyperspectral Image Projector (HIP)
  - A 2D scene projector where every pixel has a programmable spectrum

A few optical technologies introduced along the way

- Micromirror (Digital Micromirror Device – DMD) arrays,
- Liquid Crystal on Silicon (LCOS) arrays,
- Supercontinuum sources

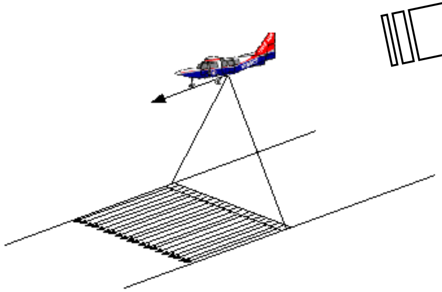
Outline

- Introduction to the concept of a Hyperspectral Image Projector (HIP)
- Show what a realized HIP looks like
- Show some example scenes
  - San Diego Naval Air Station
  - Enrique Reef in Puerto Rico
  - Medical scene of liver/bile duct
- Future Directions

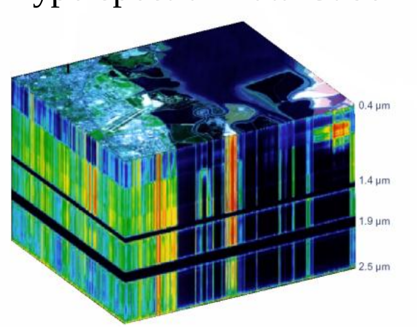
Hyperspectral Image Projector (HIP)

- HIP projects 2-d hyperspectral images
  - Complex spatial scenes with use-defined spectral content
- A source analog to Hyperspectral Image Sensors

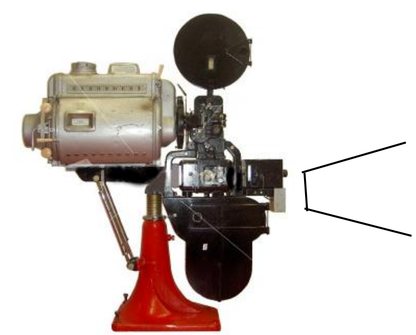
Acquire a Data Set



Hyperspectral Data Cube



Project the data cube to the Instrument Under Test & the Reference Instrument

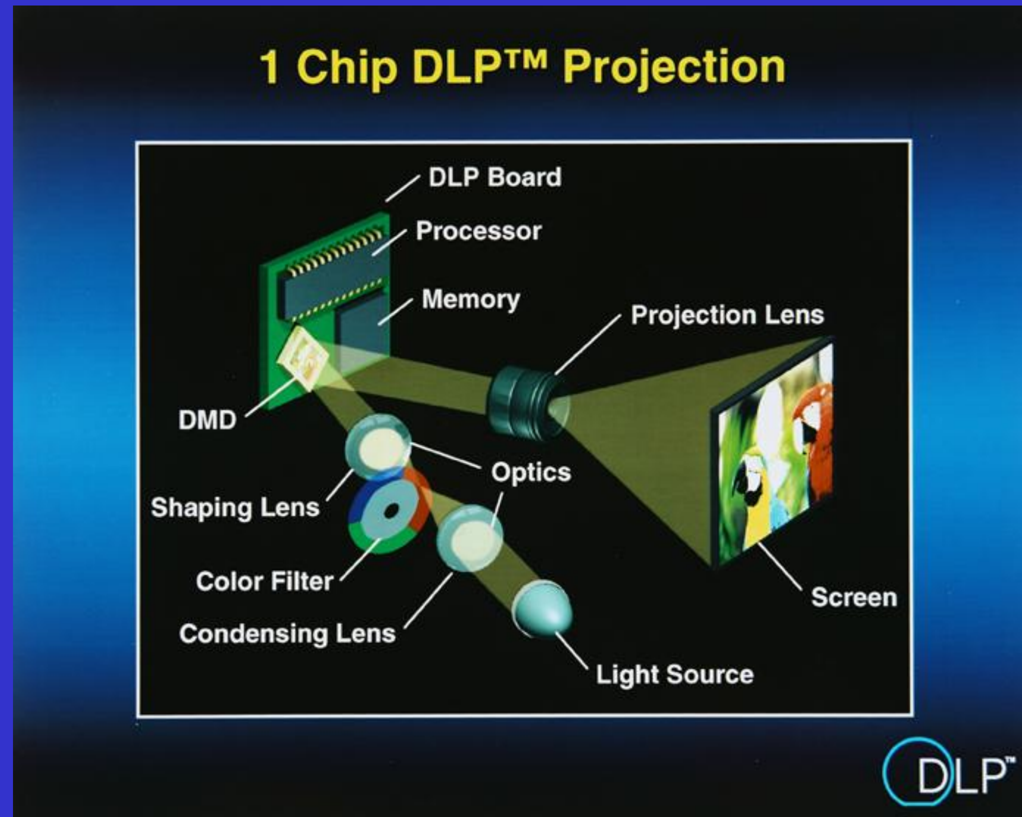


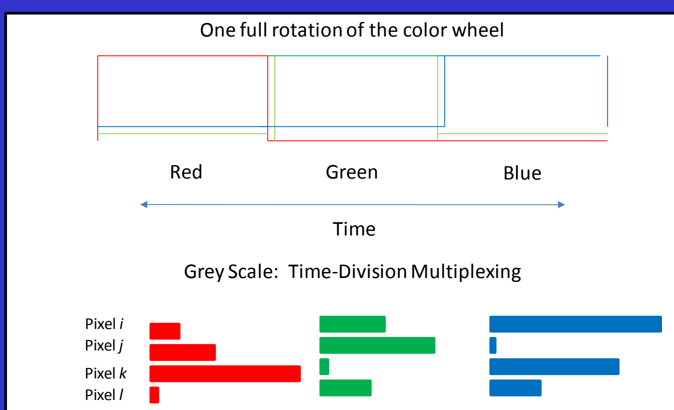
'Reality TV' Projector where user-definable, SI traceable spectral distributions are projected in each pixel.

HIP Basic Concept

HIP replaces the color filter wheel in a conventional DLP projection system.

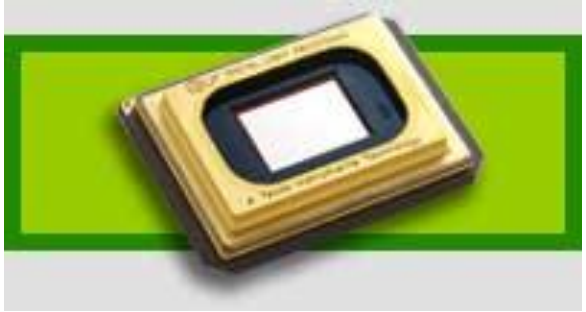
1. Enable user-defined eigenspectra
2. Change the number of different spectra from 3 to an arbitrary, user-defined, number



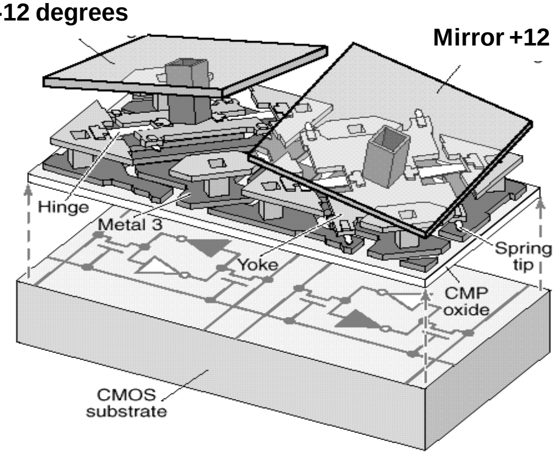


Digital Micromirror Devices (DMD's)

- **An array of (Micro-Electro-Mechanical System) MEMS micromirror elements**
- **Developed by Texas Instruments**
  - 1024 x 768 elements, +/- 12 degree tilt angle
  - Aluminum mirrors
  - 13.68 micron pitch
  - < 24 microseconds mechanical switching time
- **Two nice features**
  - Mirrors don't fail
  - Control software has been developed

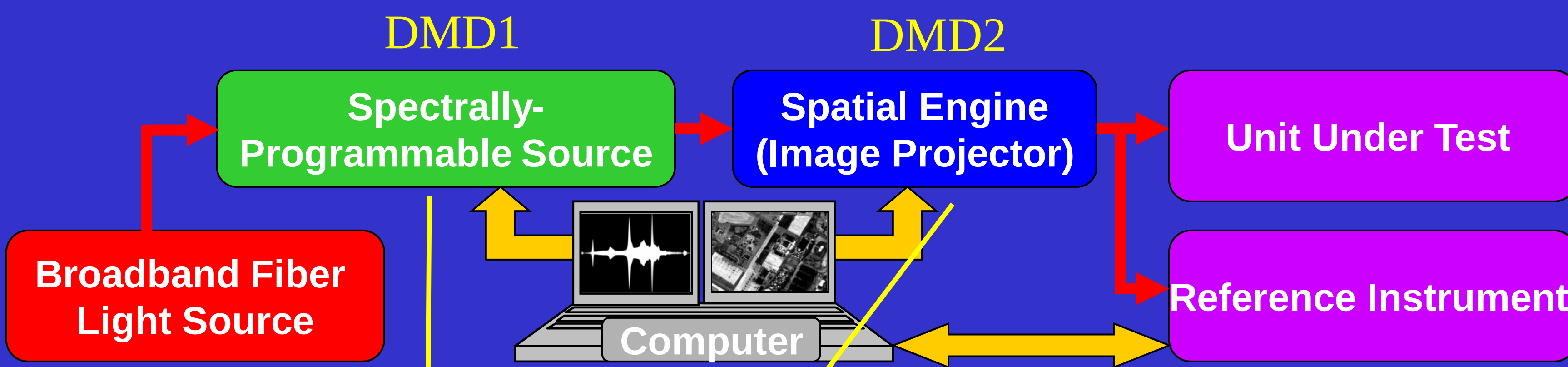


Two Pixels from the DMD Mirror Array:



Liquid crystal technology is also being investigated for the HIP by Boulder Nonlinear Systems, Inc. under SBIR programs

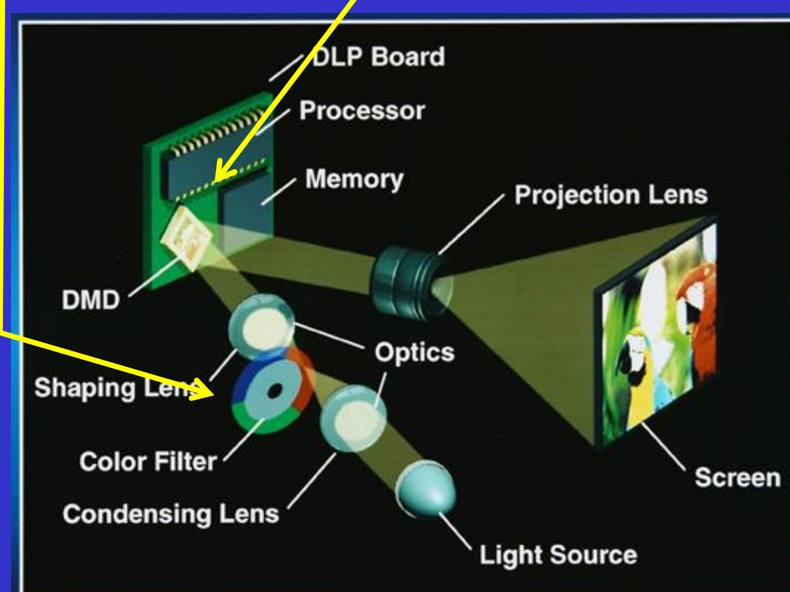
Overview of the NIST HIP



Benefits of the Spectrally Programmable Source

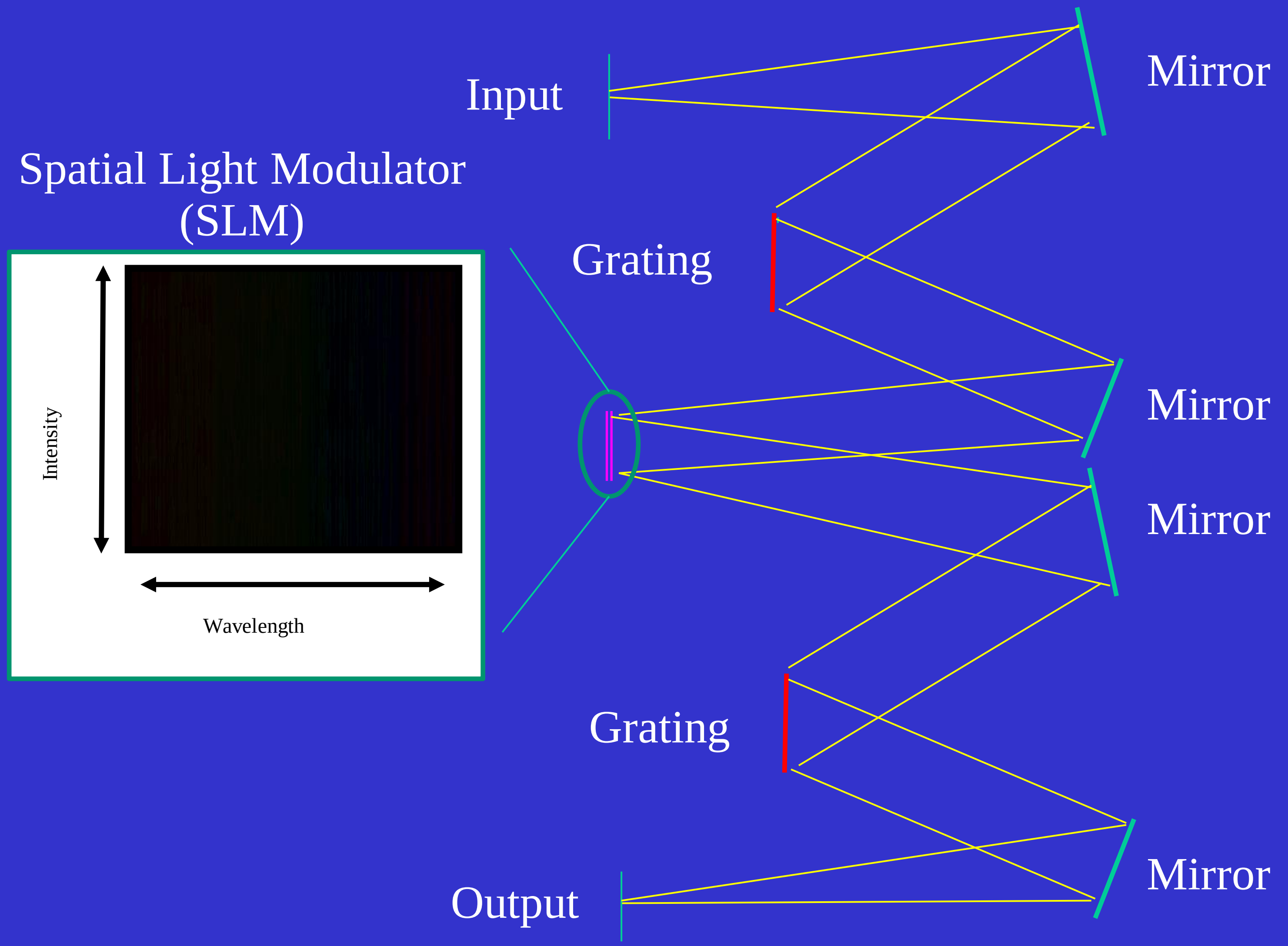
1. More than 3 Eigenspectra

2. These functions now user-defined



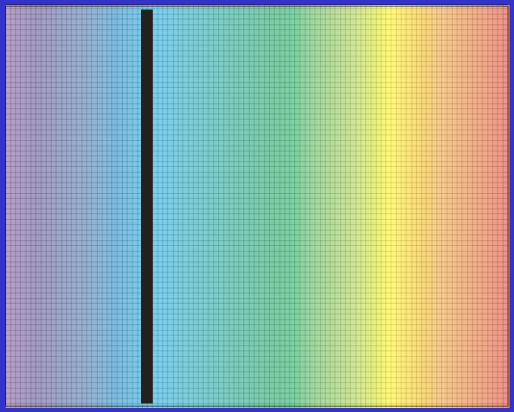
Principle of the Spectrally Programmable Source

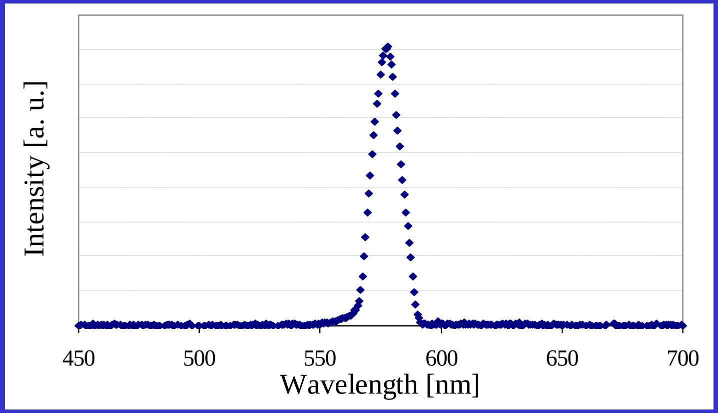
Double subtractive spectrometer



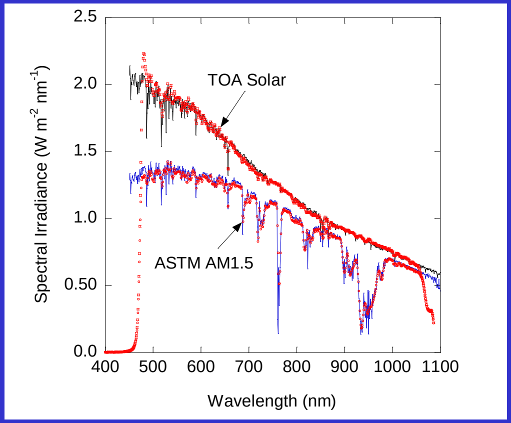
How the DMD is used in the Spectral Engine:

Monochromator Mode

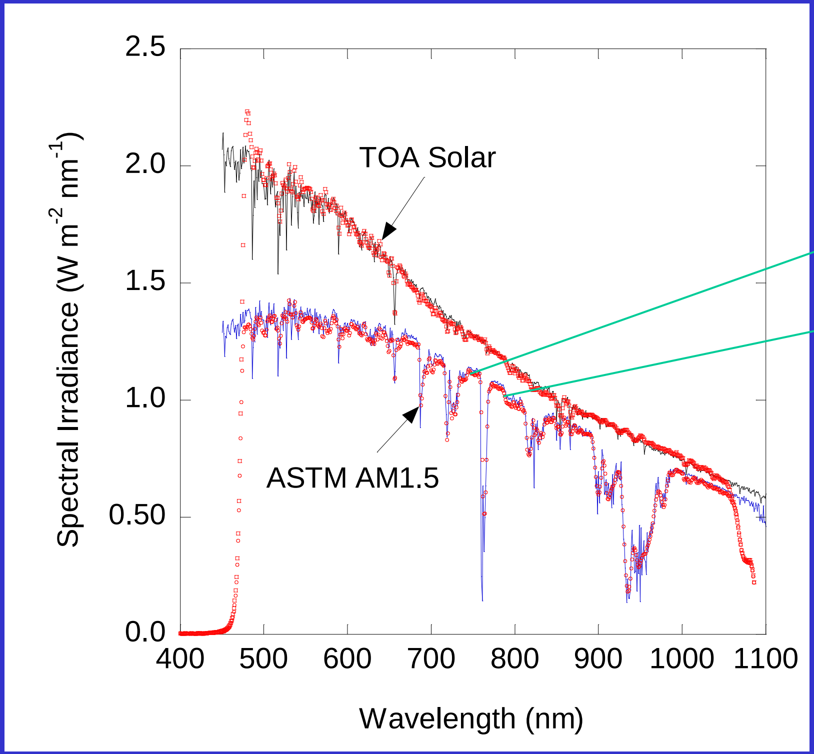


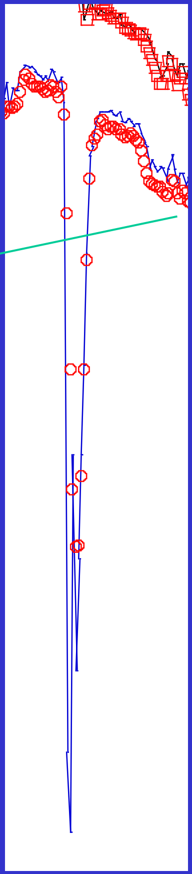


Broad-band Source Mode

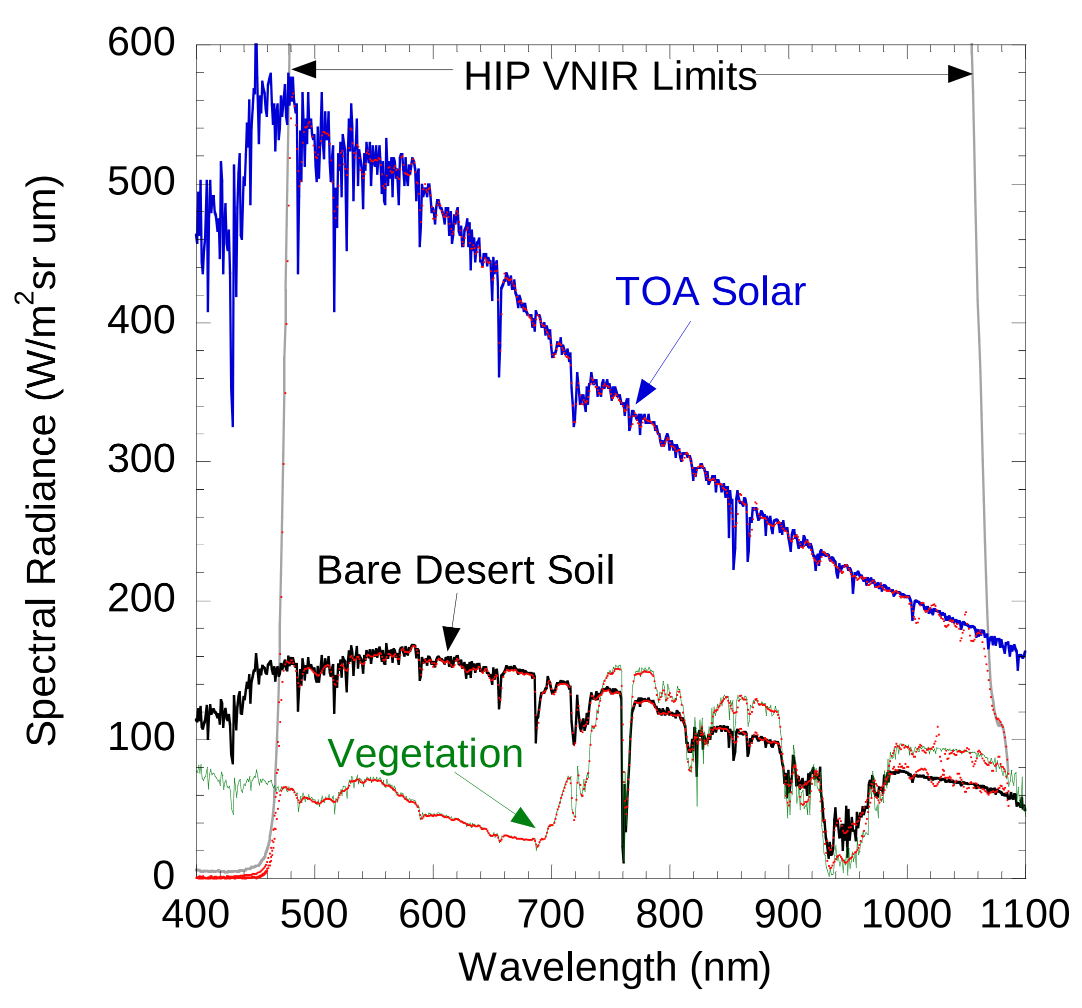


Spectral Matching Examples



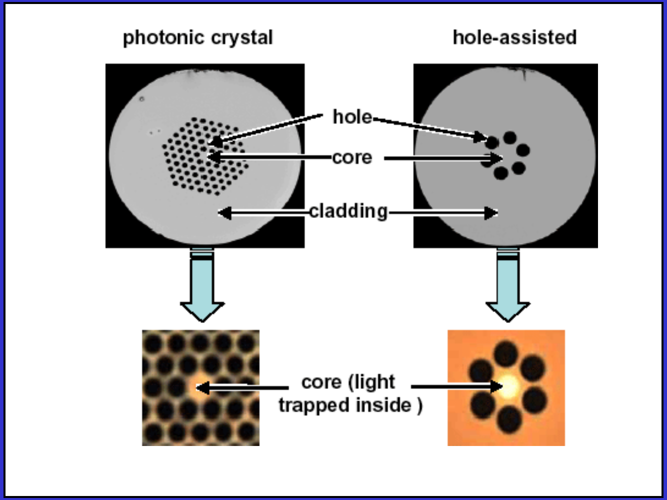


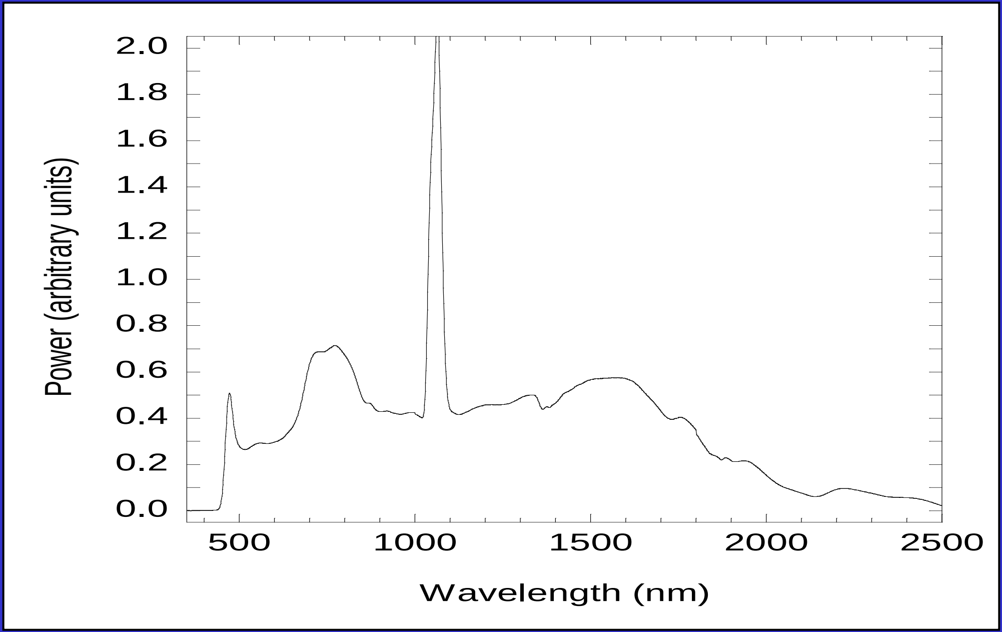
Spectral Matching Examples:



Source: Laser-pumped Photonic Crystal Fiber

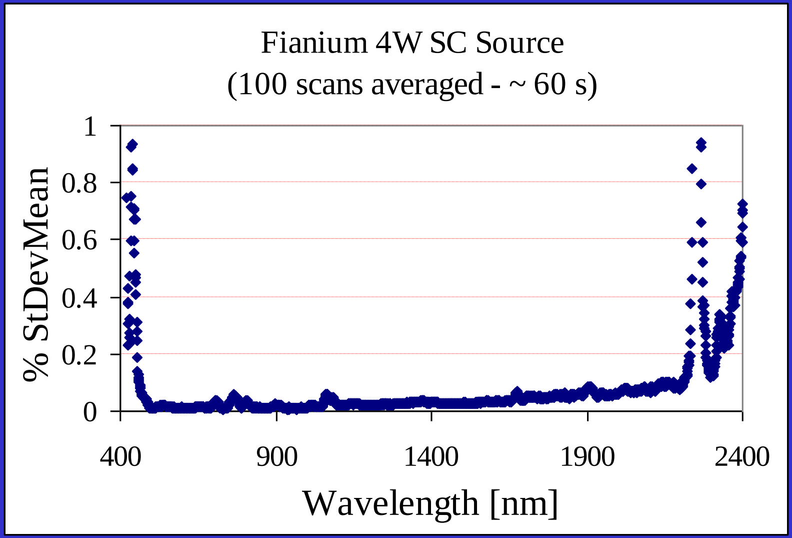
- Utilizes non-linear effects in a photonic crystal optical fiber to greatly broaden the spectrum of a 1064 nm pump laser.
- Broadband light is generated in a single-mode (5 um core diameter) photonic crystal (holey) optical fiber
  - No etendue issues as with lamps or blackbodies.
  - Ideally suited for coupling to a spectral engine.
  - **High radiance, not high power**
- High power and high spectral resolution:
  - 3mW/nm spectral power density from 450 nm to 1700 nm
- Commercially available.



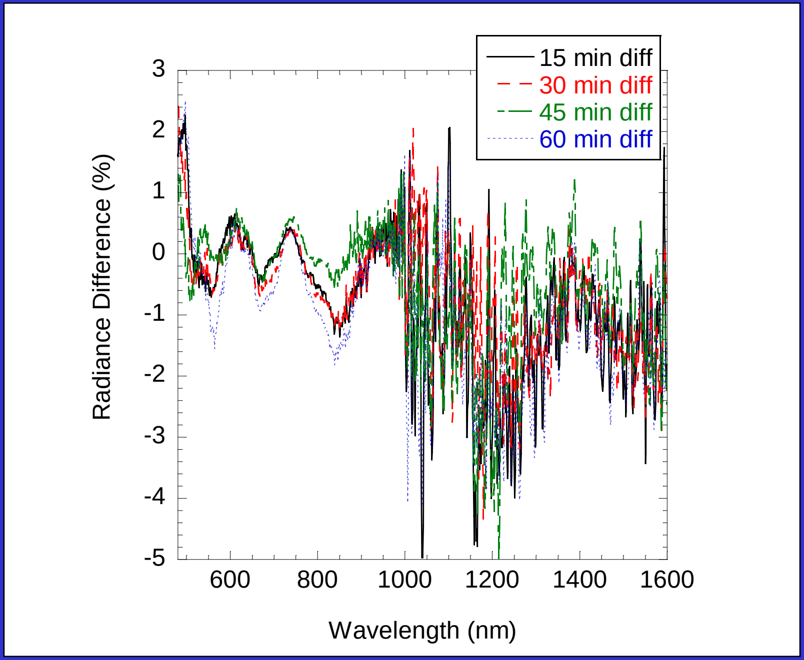


Supercontinuum Source Stability

Short term: 60 seconds

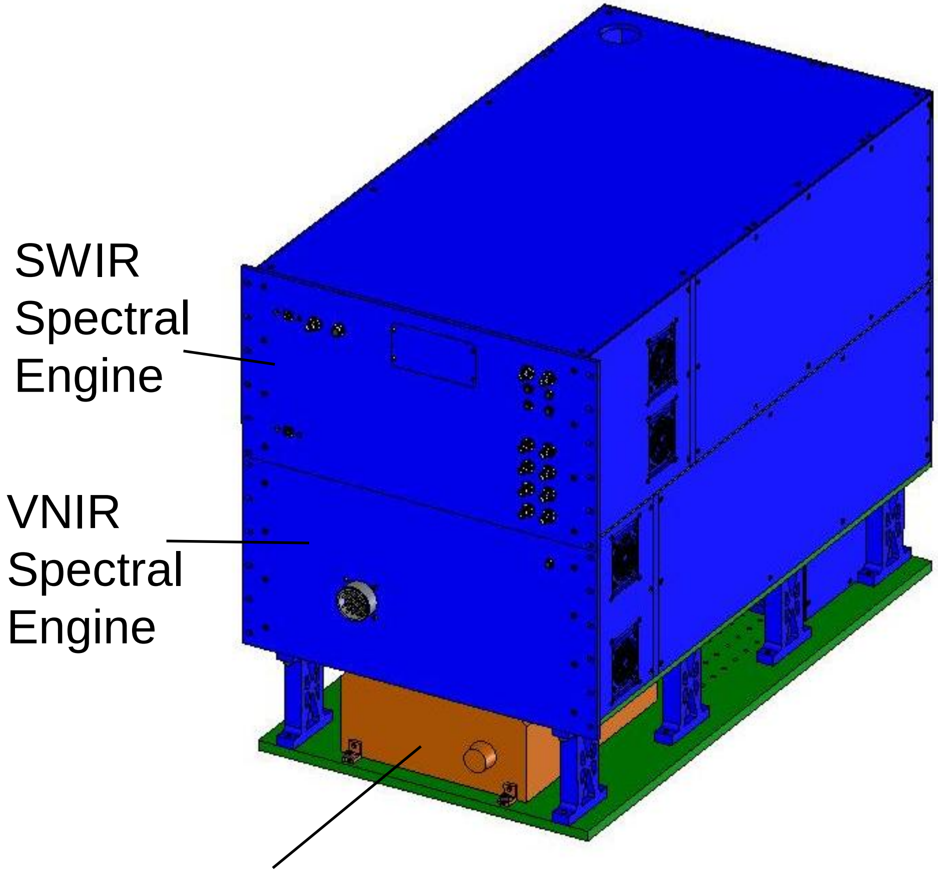


Longer term: 60 minutes

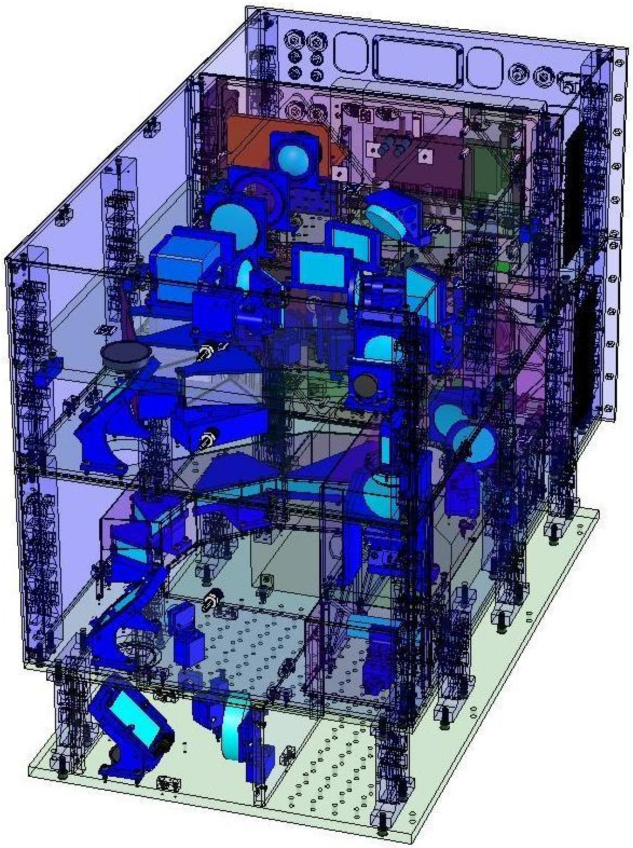


NIST/Resonon Prototype HIP VNIR-SWIR Spectral Engine

Outside view from front:

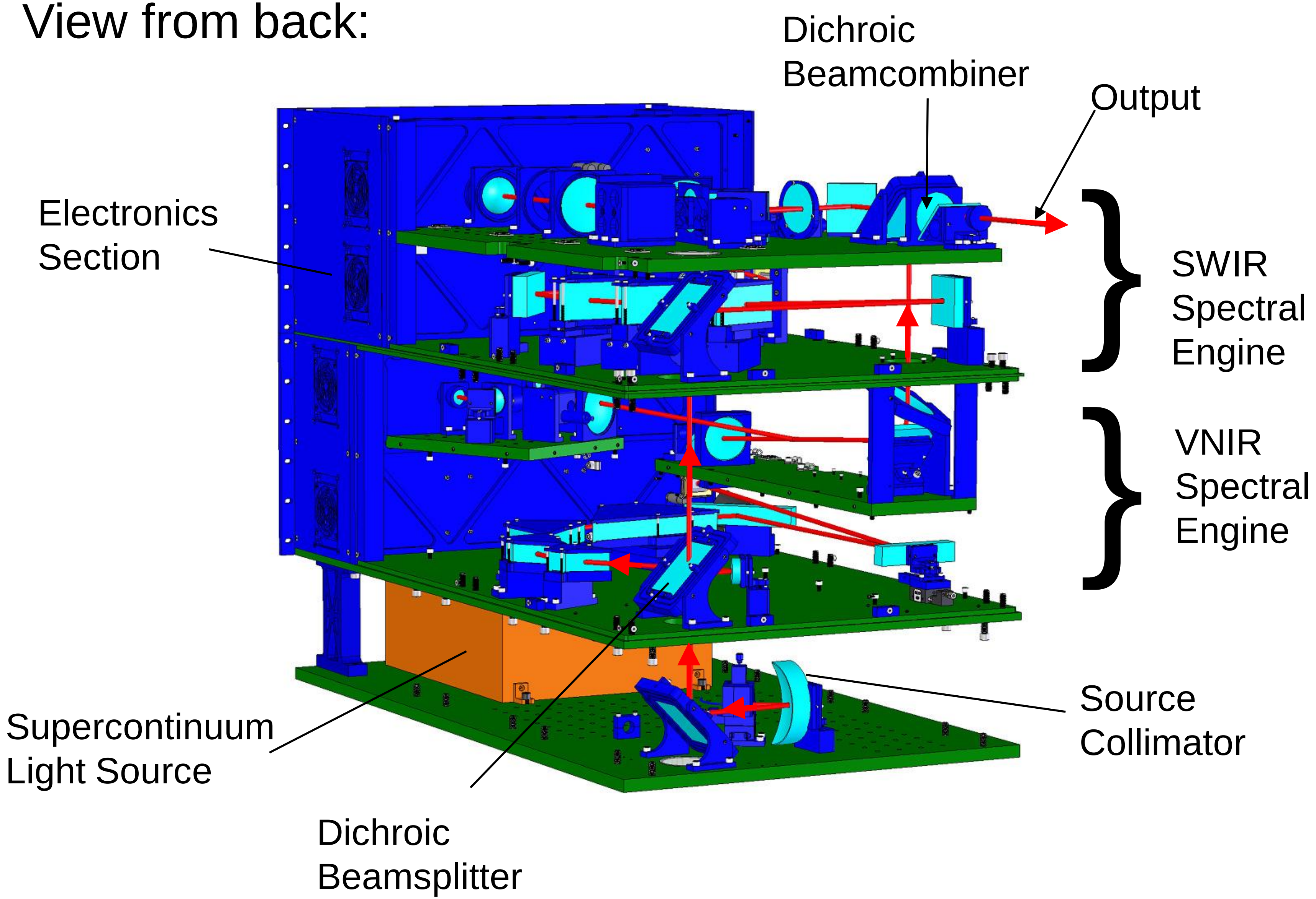


Inside view from back:

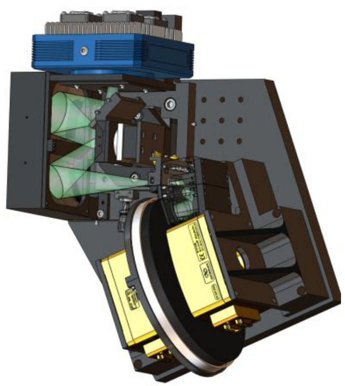


HIP VNIR-SWIR Spectral Engine

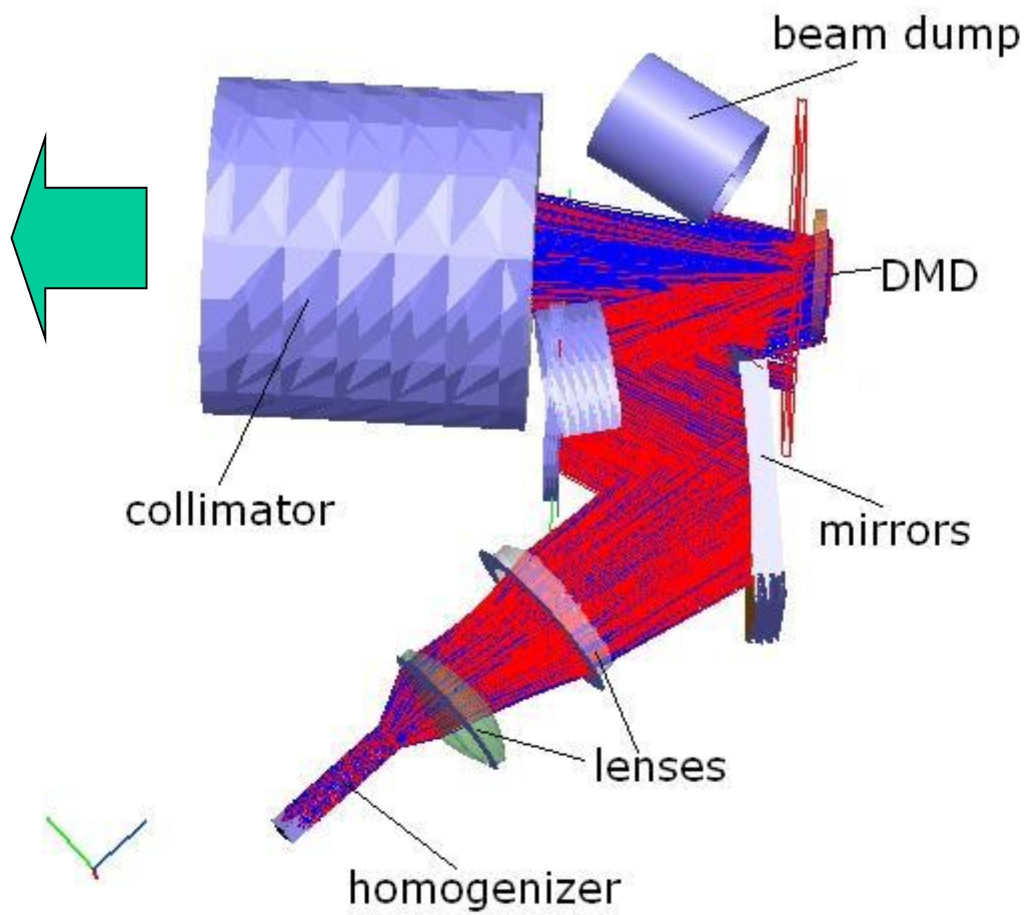
View from back:



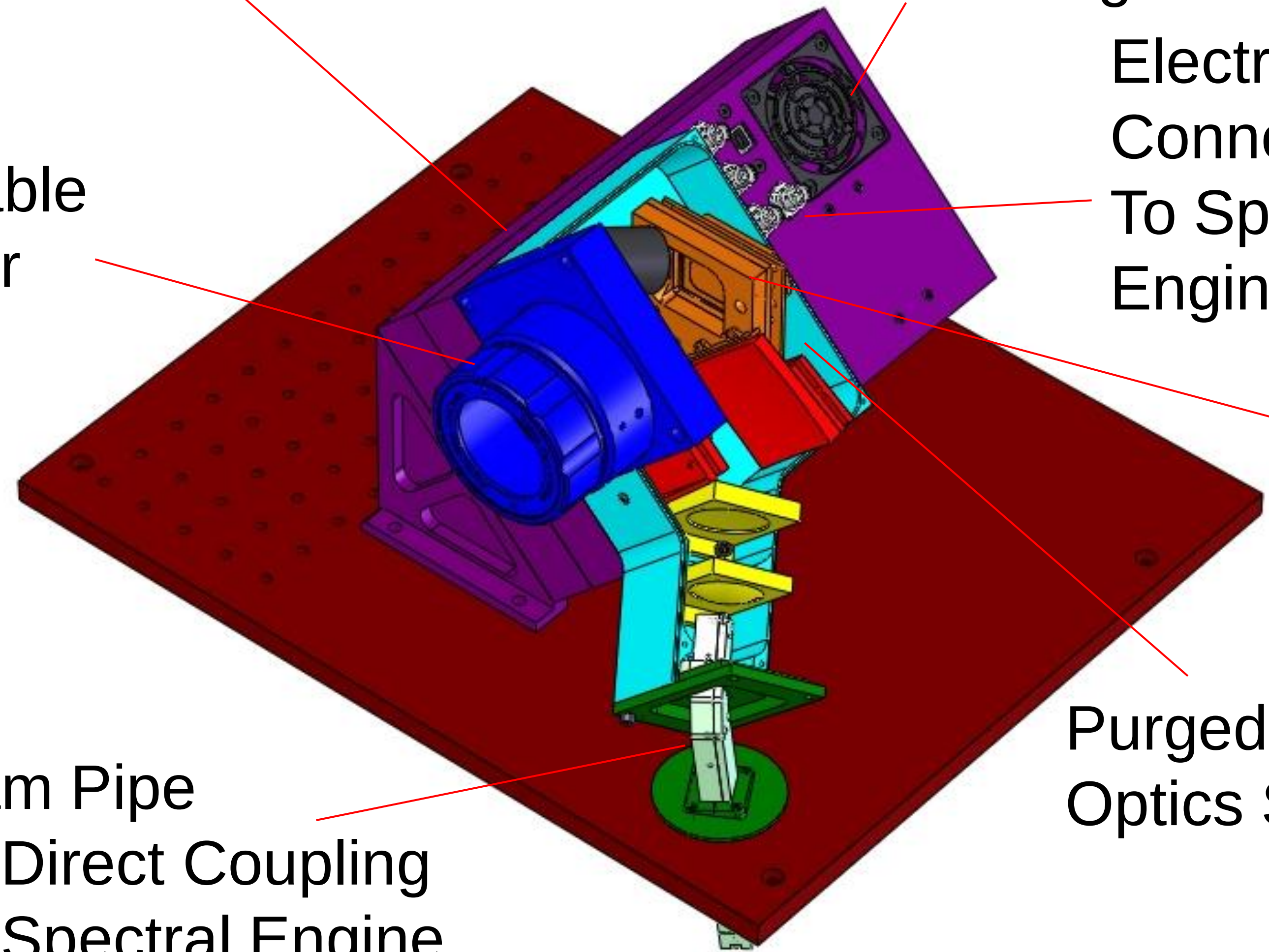
VNIR-SWIR Spatial Engine
Optical Design



Sensor



VNIR-SWIR Spatial Engine
Mechanical Design



NIST/Resonon VNIR-SWIR HIP Prototype System

SWIR Spectral Engine

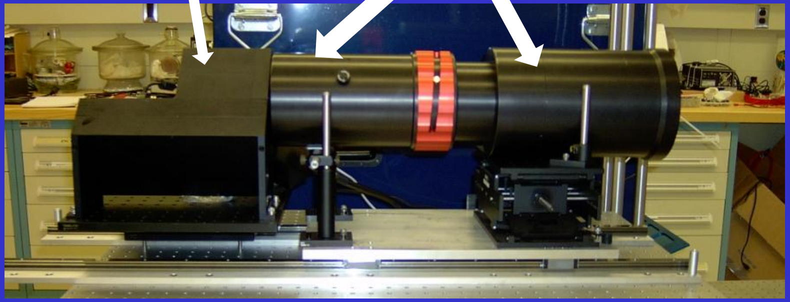
VNIR Spectral Engine

Super-continuum Source

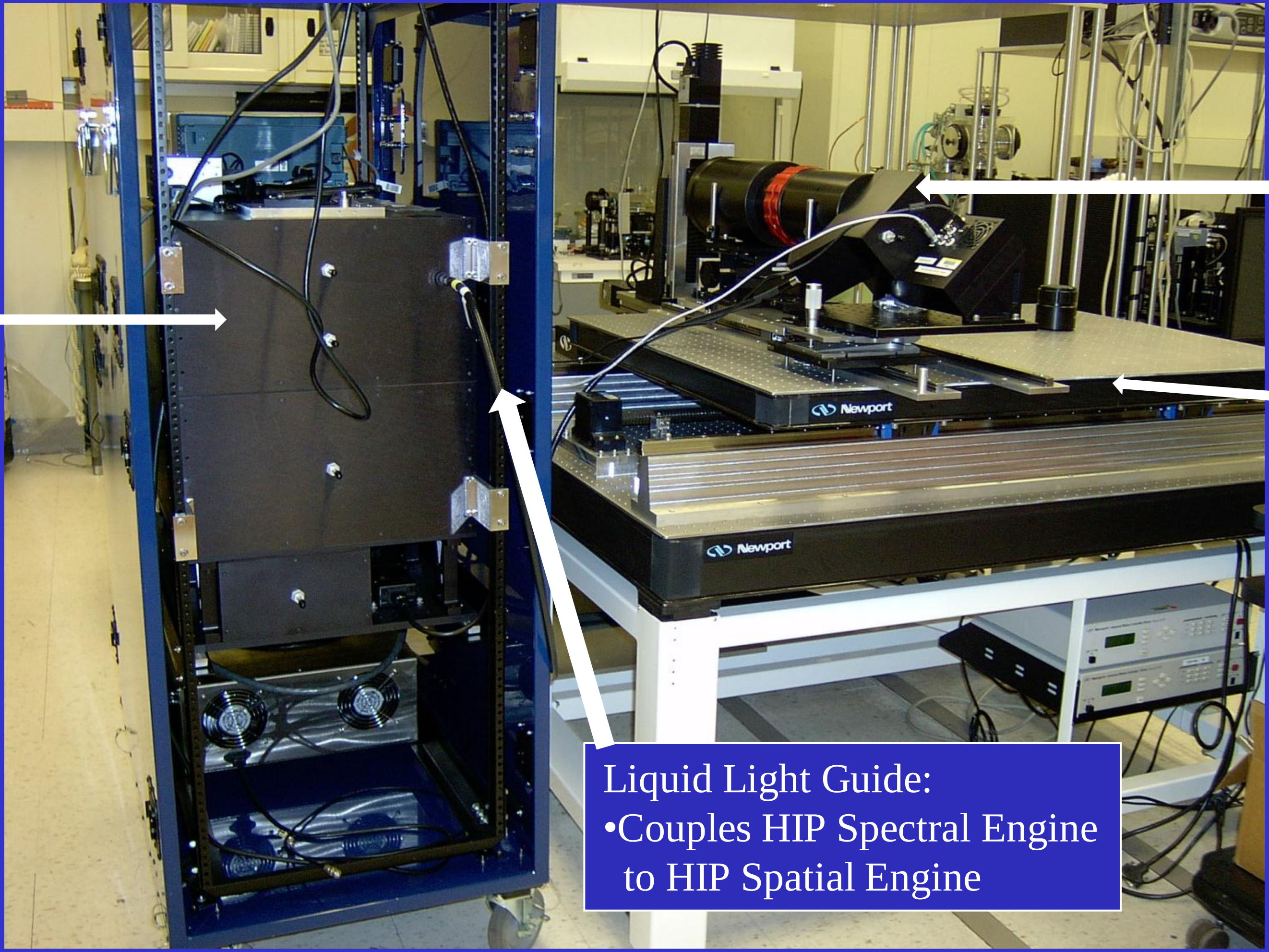
Power Supply

Spatial Engine

Collimator For Projection to UUT



NIST/Resonon VNIR-SWIR HIP Prototype System



Reference Instrument

PIXIS camera with a liquid crystal tunable filter

Hyperspectral Image Data Cube

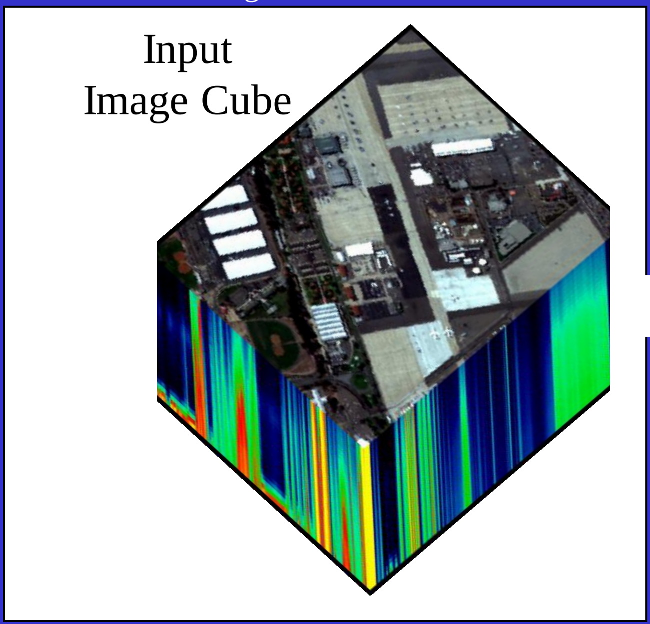
AVIRIS Image Cube of the San Diego Naval Air Station

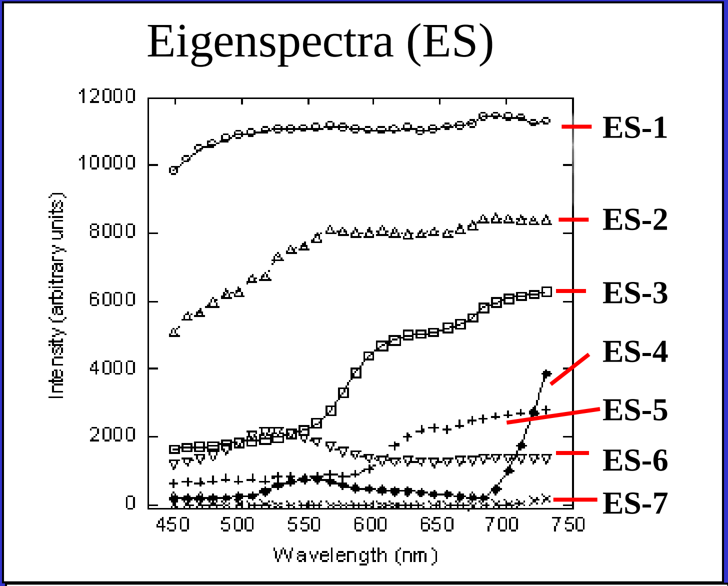
Compressive Projection is Used to Achieve Higher Brightness

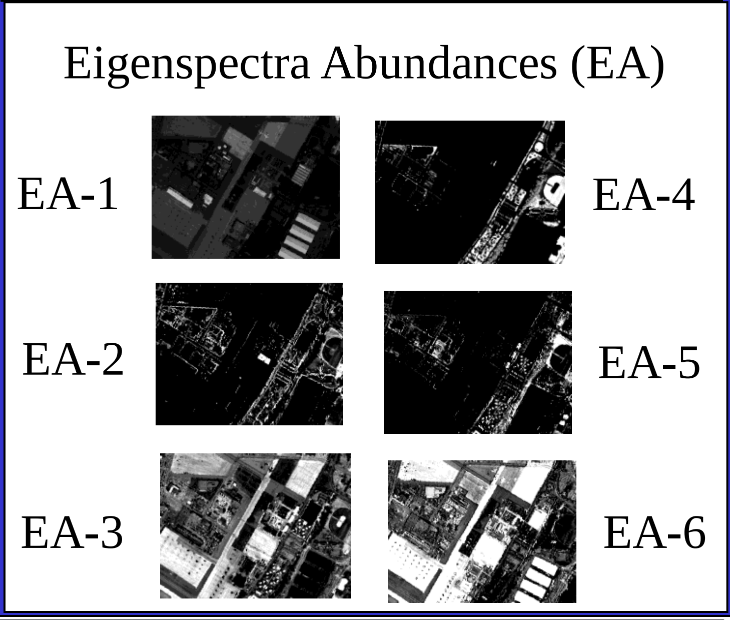
Software such as ENVI/SMACC is used to find the Eigenspectra and their Abundances

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



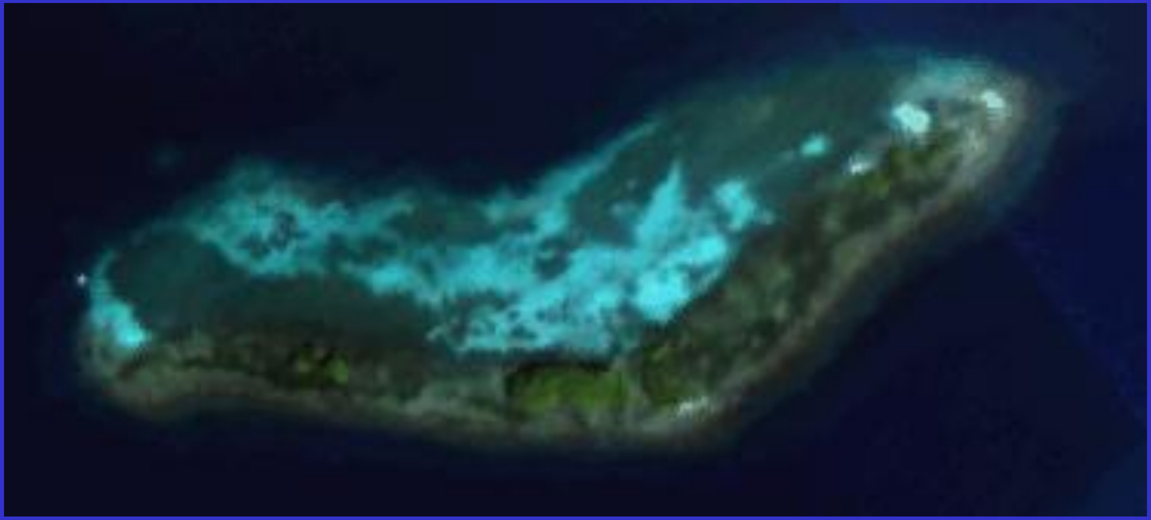




Then we need only project N = 6 broadband spectra instead of M = 30+ monochromatic spectra.

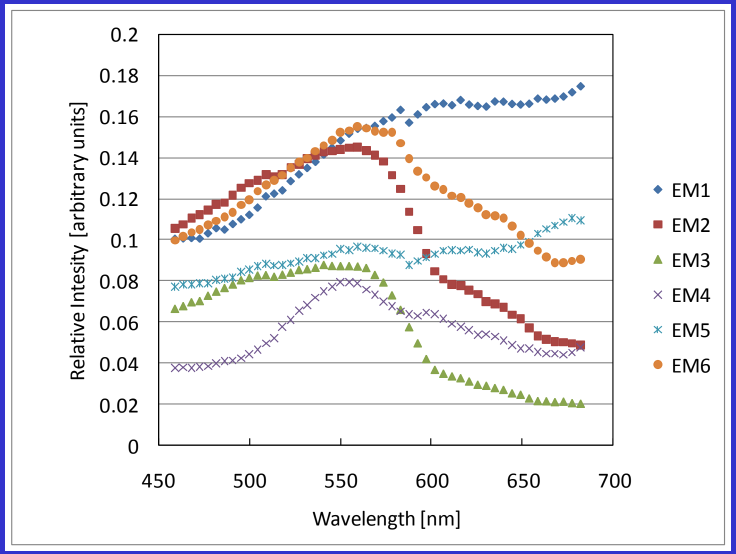
Enrique Reef, Puerto Rico

James Goodman, University of Puerto Rico
David Allen, NIST

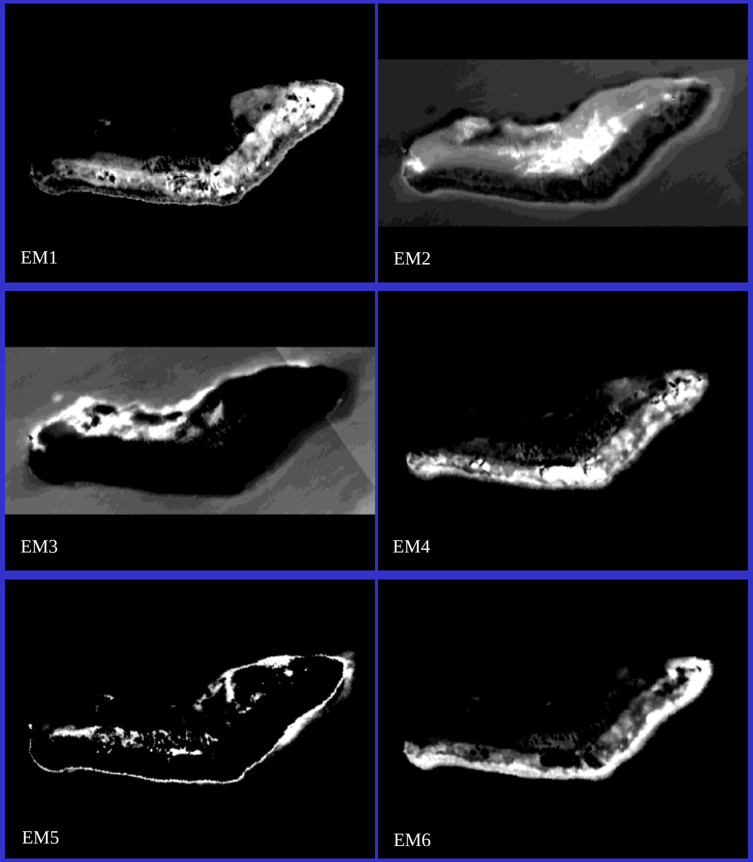


Enrique Reef Decomposition

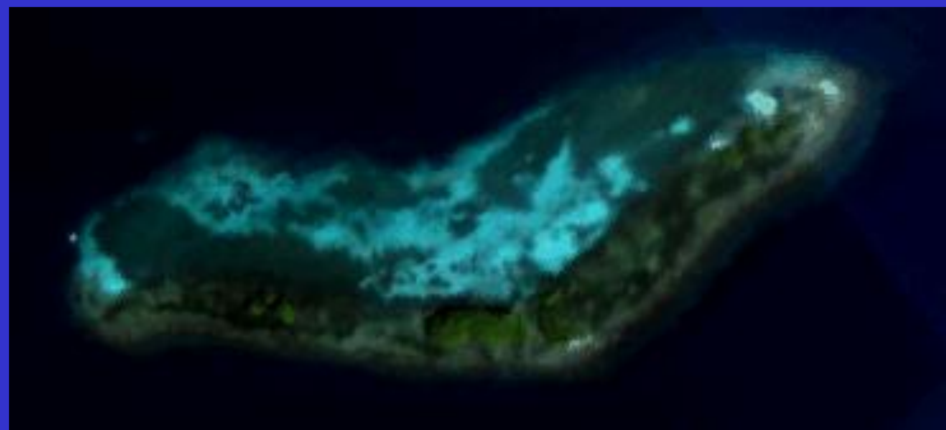
Eigenspectra



Abundance Images



Original Image



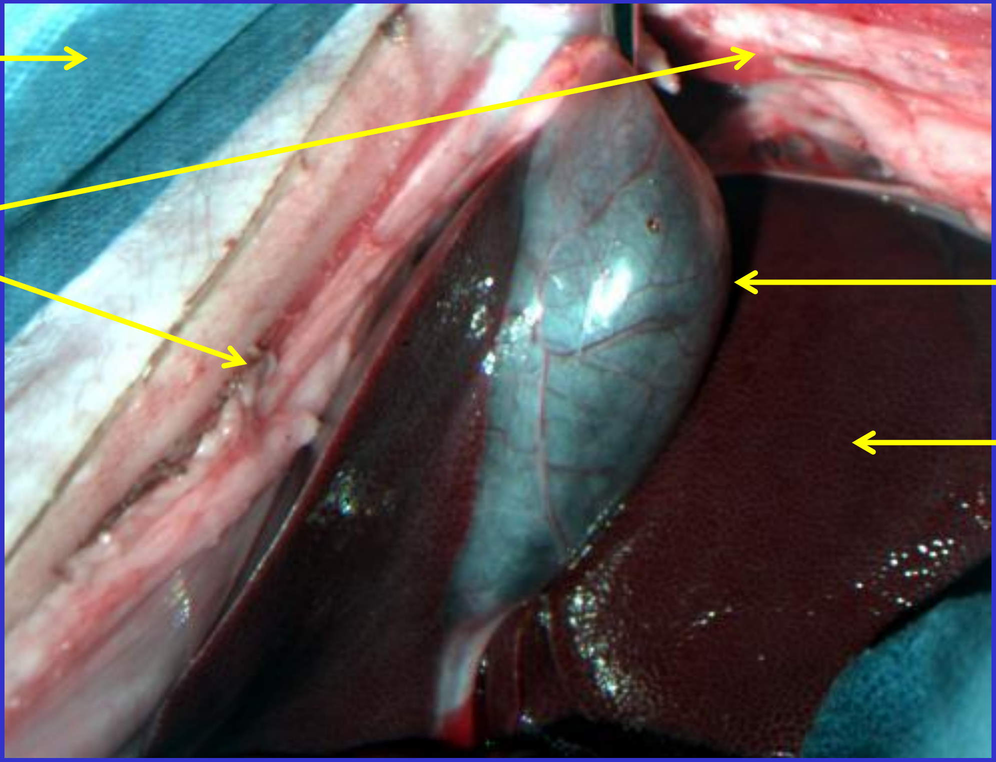
Re-created Image

Gall Bladder, Liver, Skin Image

Drs. Edward Livingston & Karel Zuzak
University of Texas Southwestern Medical Center
Maritoni Litorja, NIST

Surgical Dressing

Skin

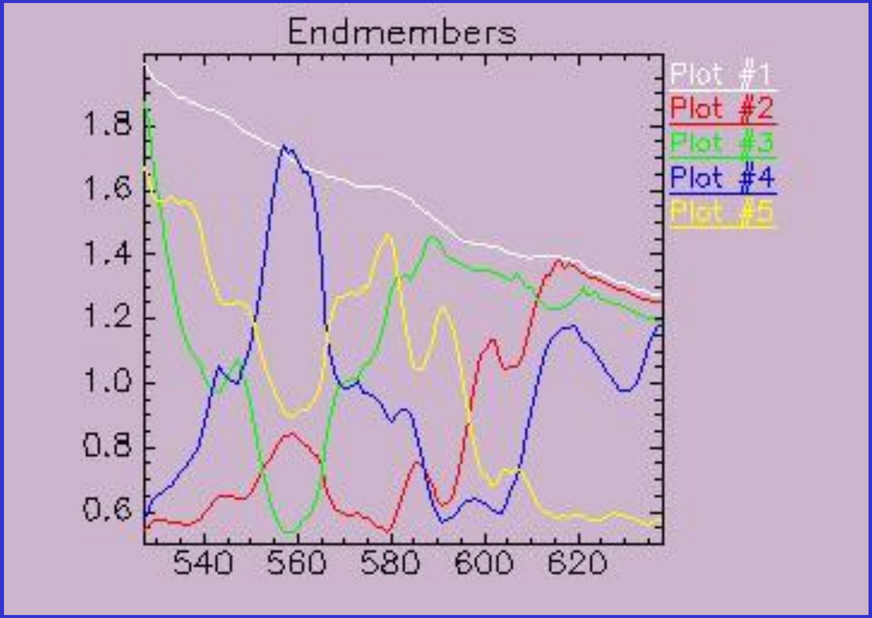


Gall Bladder

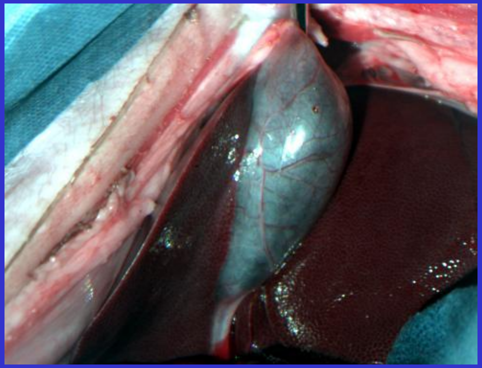
Liver

Image Decomposition

Into Endmember Spectra and Abundance Images

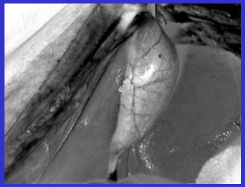


Original RGB image

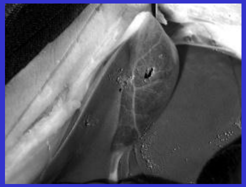


Abundance Images

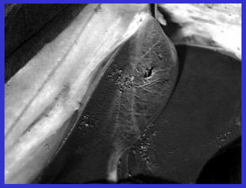
Spectrum 1



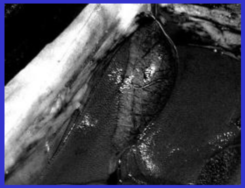
Spectrum 2



Spectrum 3



Spectrum 4

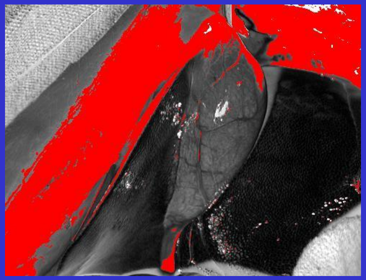


Spectrum 5

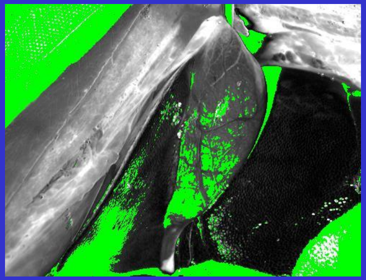
Image Decomposition - Visible

Classification according to components spectra

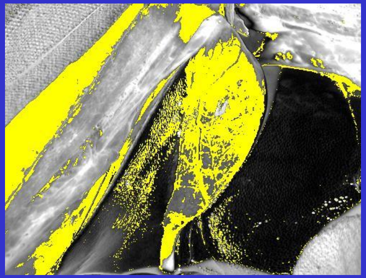
Skin (bloody)



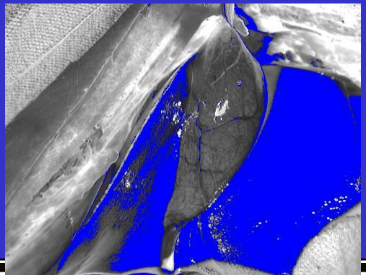
Gall bladder

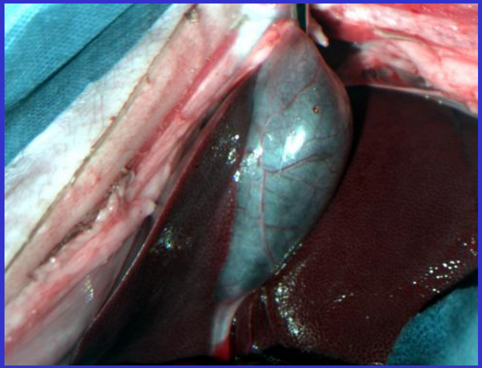


Cystic duct



Liver





Original RGB image

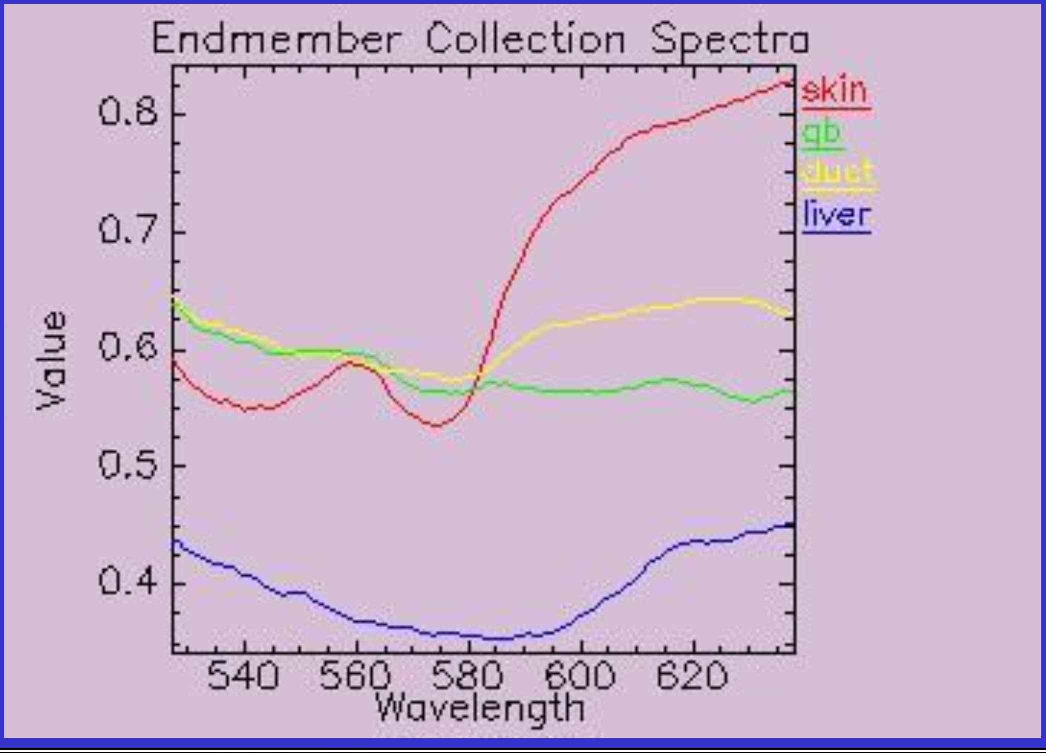
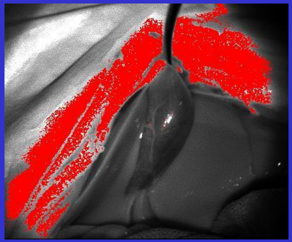


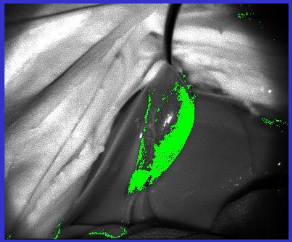
Image Decomposition - Near IR

Classification according to components spectra

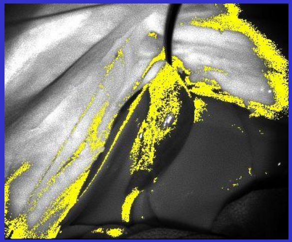
skin



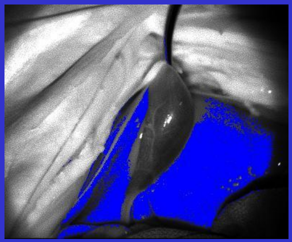
gall bladder

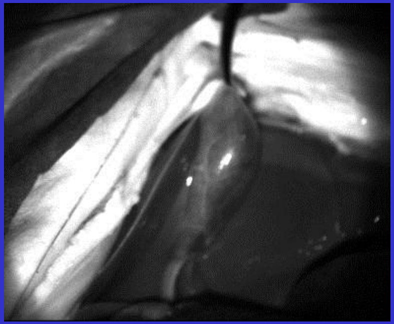


duct

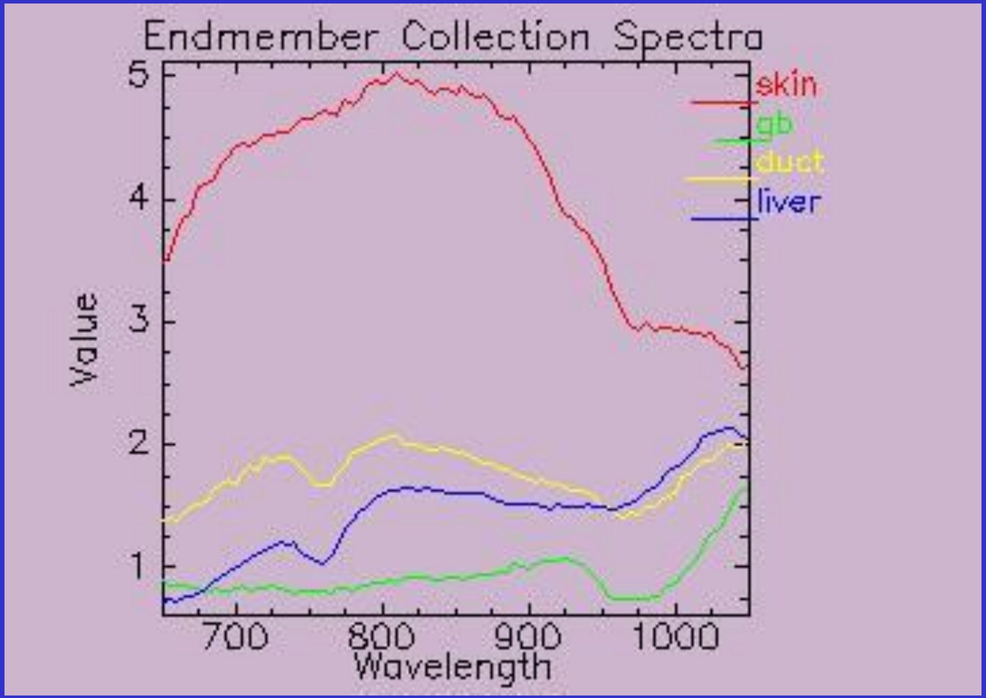


liver





Original NIR image at 800 nm



Future Directions

- Working with NOAA exploring Liquid Crystal on silicon (LCOS) array-based spectral light engines
- Working with NASA to include polarization
- Extending range into UV and further into the IR
  - Currently looking at the 3 to 5 um range
  - Plans to consider extending capabilities to the 8μm to 12 μm range

Summary

Hyperspectral Image Projector (HIP)

Being developed as a scene projector for testing spectral/imaging sensors

- Projects a 2D image with programmable spectra at each pixel
- Unique applications in testing sensors with realistic spectra and scenes
- Using a 4 W supercontinuum source, the HIP is capable of 2 nm spectral resolution over the VNIR and 5 nm over the SWIR, providing spectral, spatial, and radiometric fidelity for simulating solar-illuminated Earth scenes.

- Used for testing Laboratory for Atmospheric and Space Physics (LASP) HSI prototype in May 2011
- Currently being used for testing NASA Ocean Radiometer for Carbon Assessment (ORCA) prototype

For more information: Contact Joe Rice (joe.rice@nist.gov)

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by the NIST Office of Law Enforcement Standards, and
by the NIST Optical Medical Imaging IMS project