A Single Detector Hyperspectral Imager

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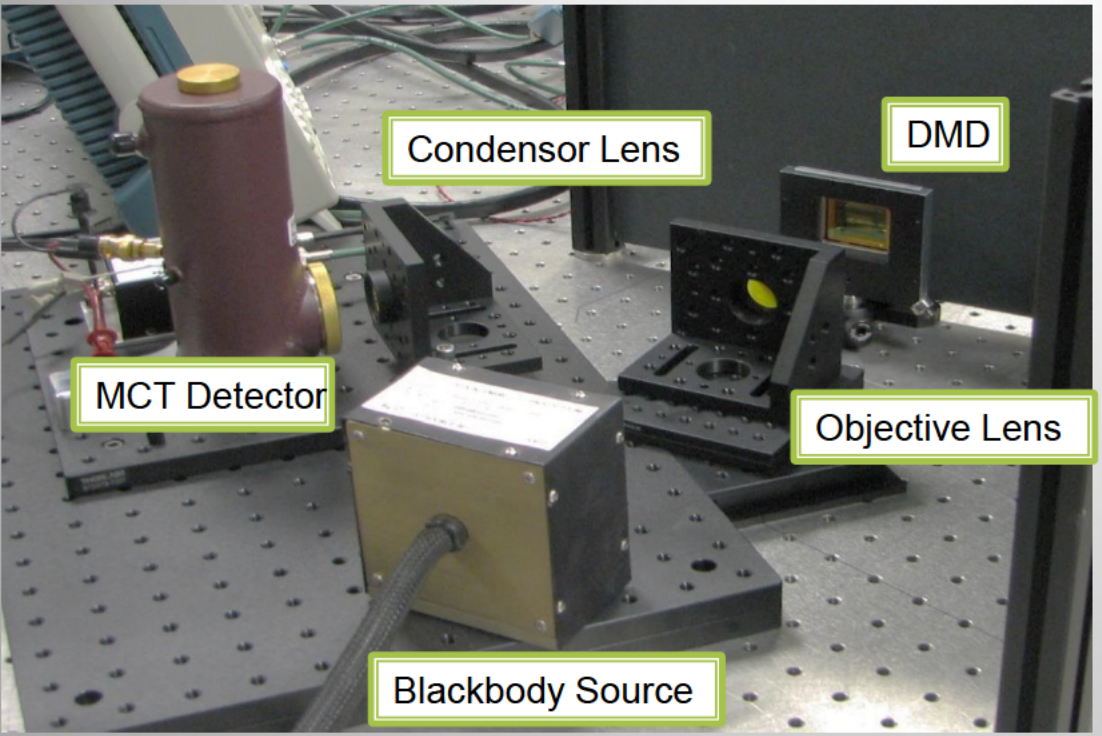
Outline

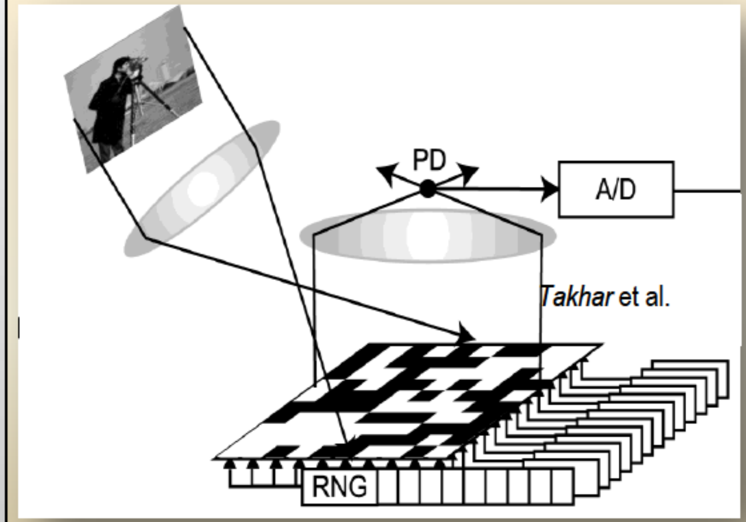
- Development funded by DOE   Enabling Capabilities.
- Defining the Real Time Optimized Spatial Spectral Scale (RTOSS) HSI Sensor Paradigm
  - *What's it good for?*
  - *Isn't this compressive sensing (CS)?*
- Problem:
  - *Detect/ID small (pixel sized) low spectral contrast targets with a single detector sensor having comparable coverage rates to FPA based sensors*
- Value of RTOSS single detector imager?
  - *Only viable single detector solution for defined problem*
  - *High data compression using active management of measurement resources*
  - *Low Cost compared to FPA based sensors*

RTOSS Hardware Similar To CS Imager Designs



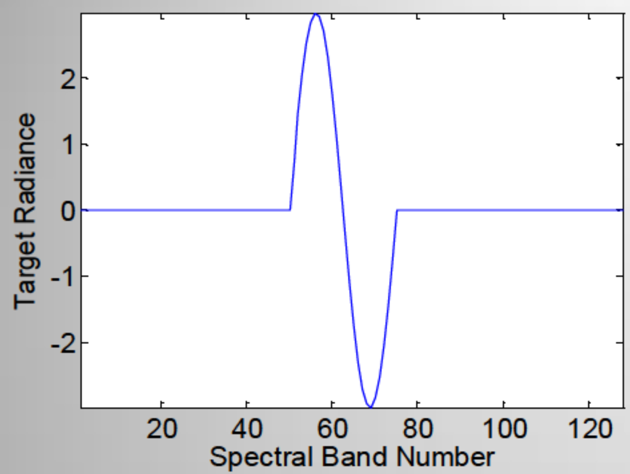
RTOSS Design

Example: Single-Pixel Compressive Imager

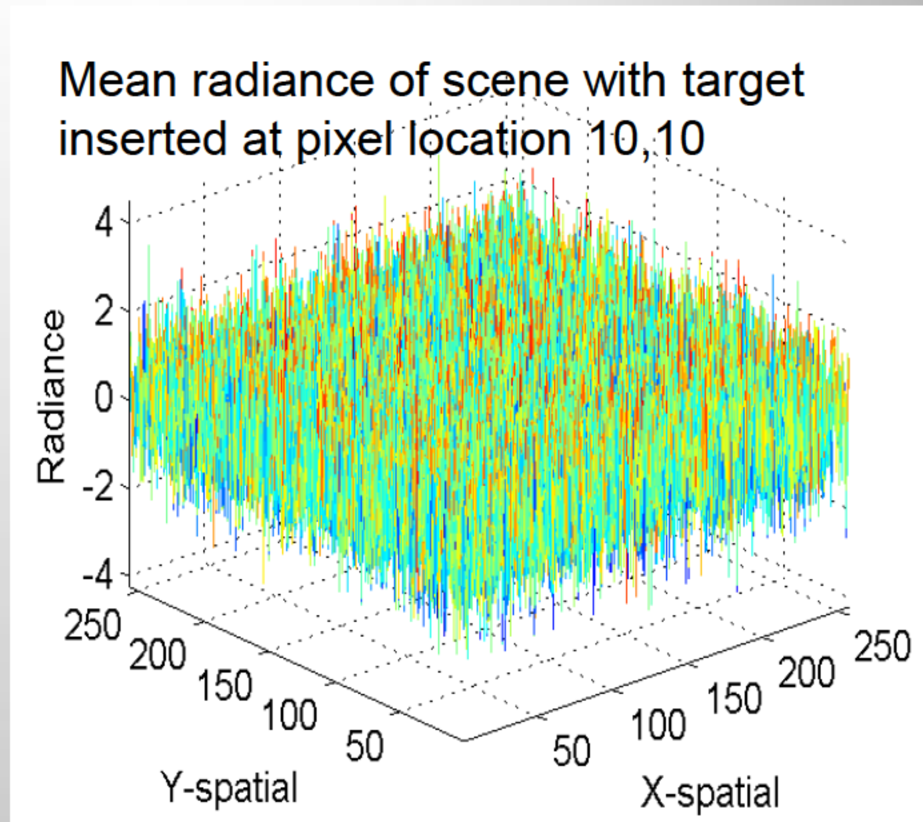


- **Unique RTOSS features:**
  - No slit
  - Independent control of spectral-spatial scale/resolution using dual DMD's
  - Actively managed measurement resources using real time algorithm

Problem Definition: Simple Detect/ID Example

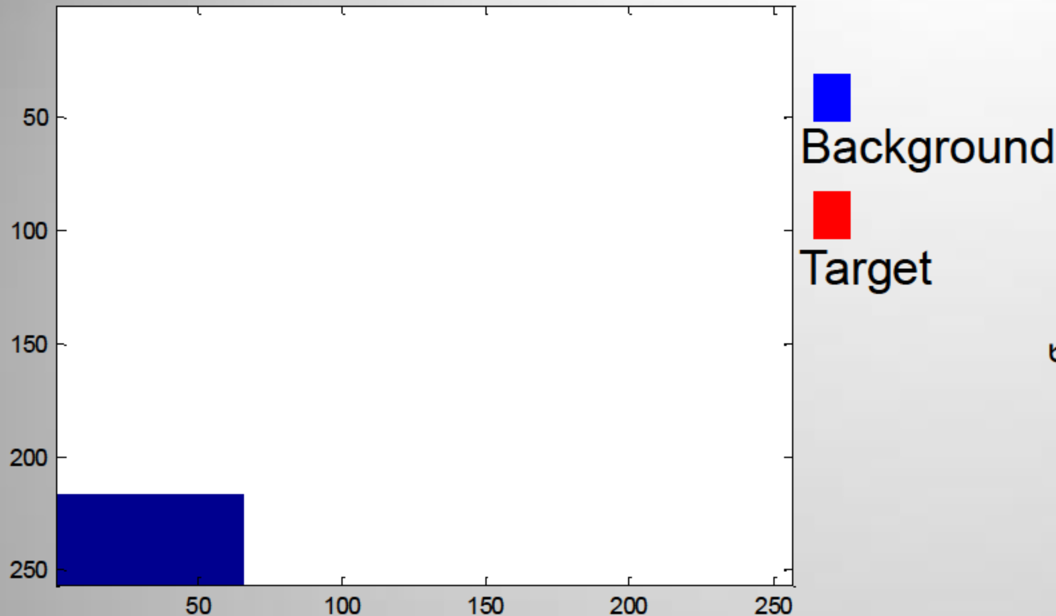


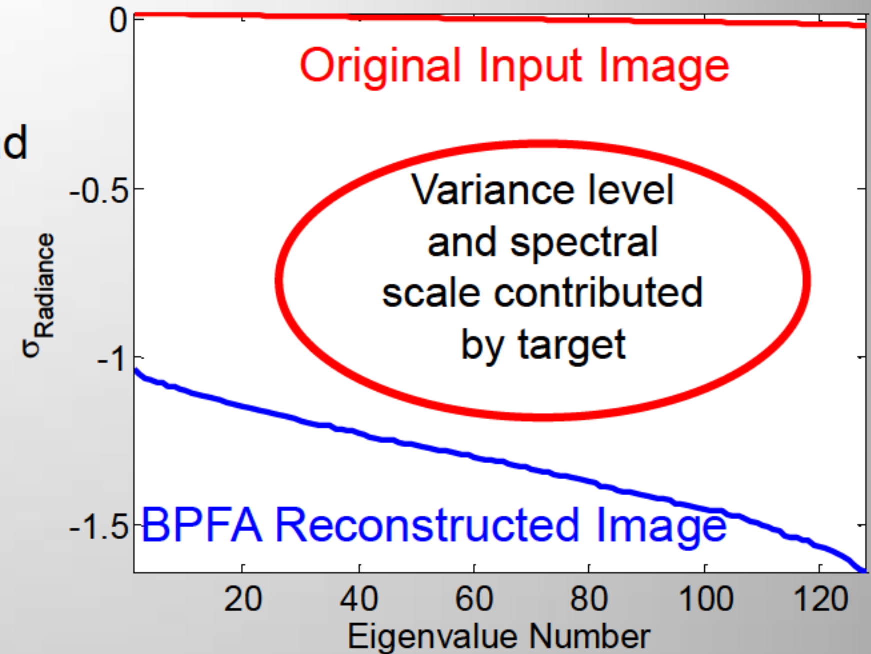
Mean Centered Target Spectrum



- 256 x 256 Spatial Scene x 128 spectral bands
- Single pixel target placed at pixel location 10,10 in Gaussian noise background of 1 unit radiance.
- Use adaptive cosine estimator (ACE) as detect/ID algorithm for RTOSS and an exemplar compressive sensing algorithm

Exemplar Compressive Sensing Algorithm



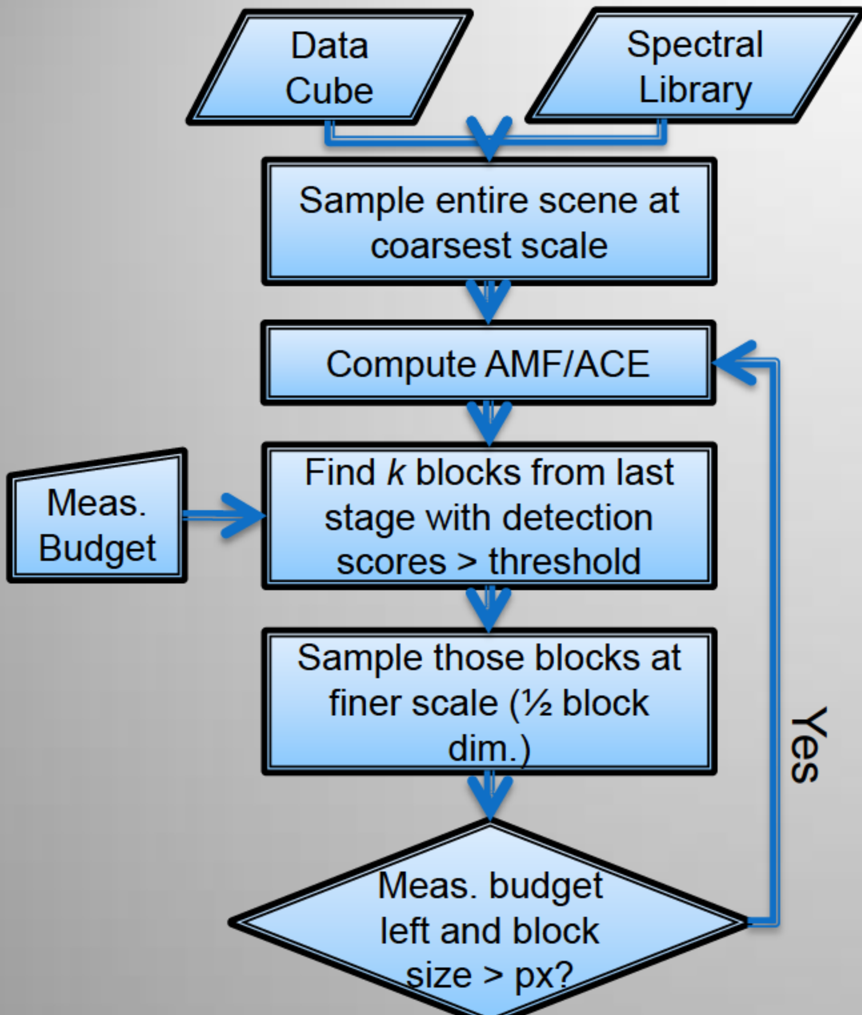


Beta-Process Factor Analysis Algorithm (BPFA) used to reconstruct image from 10% random sample and ACE to exploit target from reconstructed image.

Sorted eigenvalues using PCA indicates BPFA reconstruction reduces image noise level

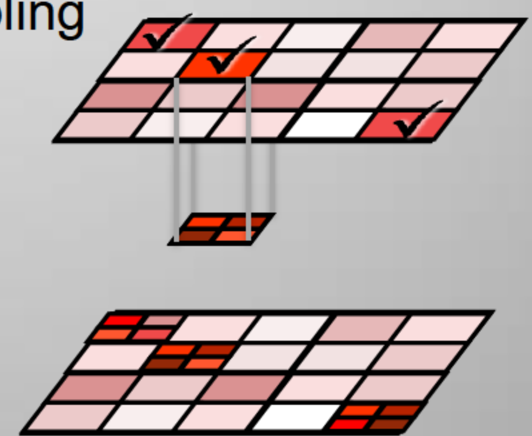
No detect/ID of small low contrast target spectra for BPFA algorithm – similar performance for broadband imager

RTOSS: Spatial Scale Sampling Strategy



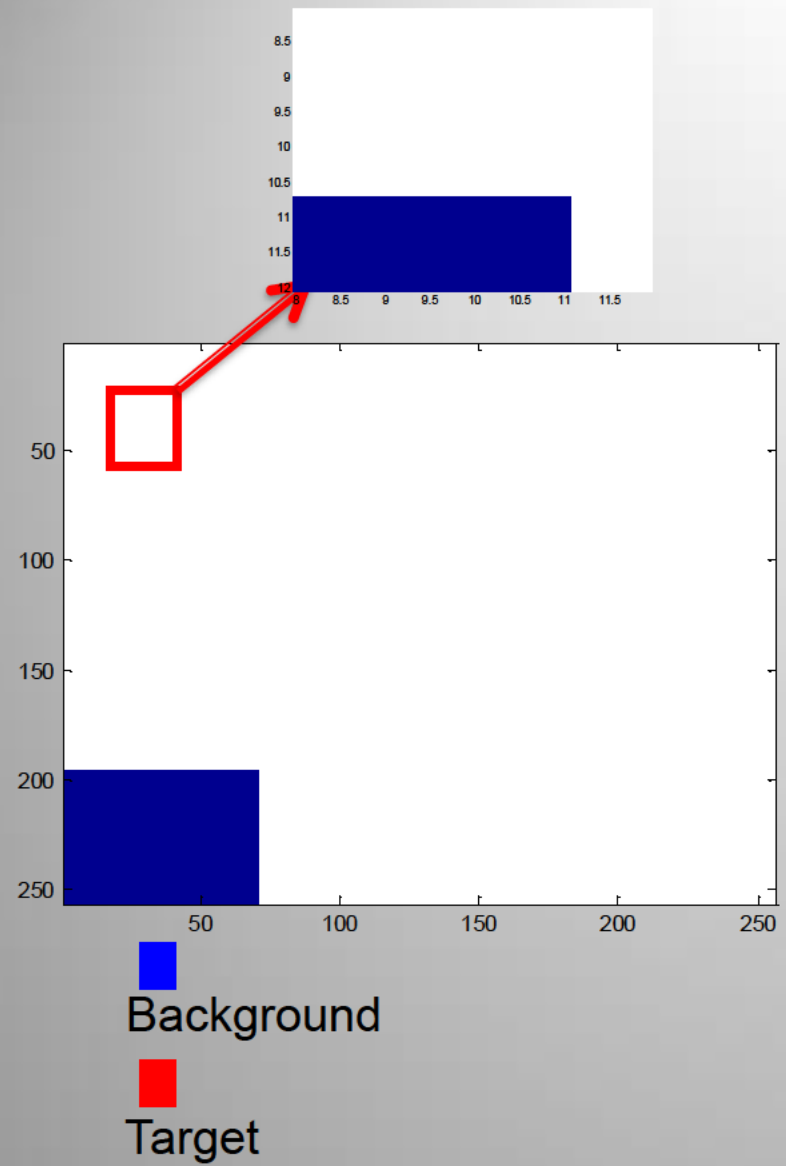
Recursive Dyadic Partition

- Goal of measurements at coarse spatial scales is not to detect/ID but to reduce search area
- An adaptive compressive sensing approach
- Group testing through directed sampling



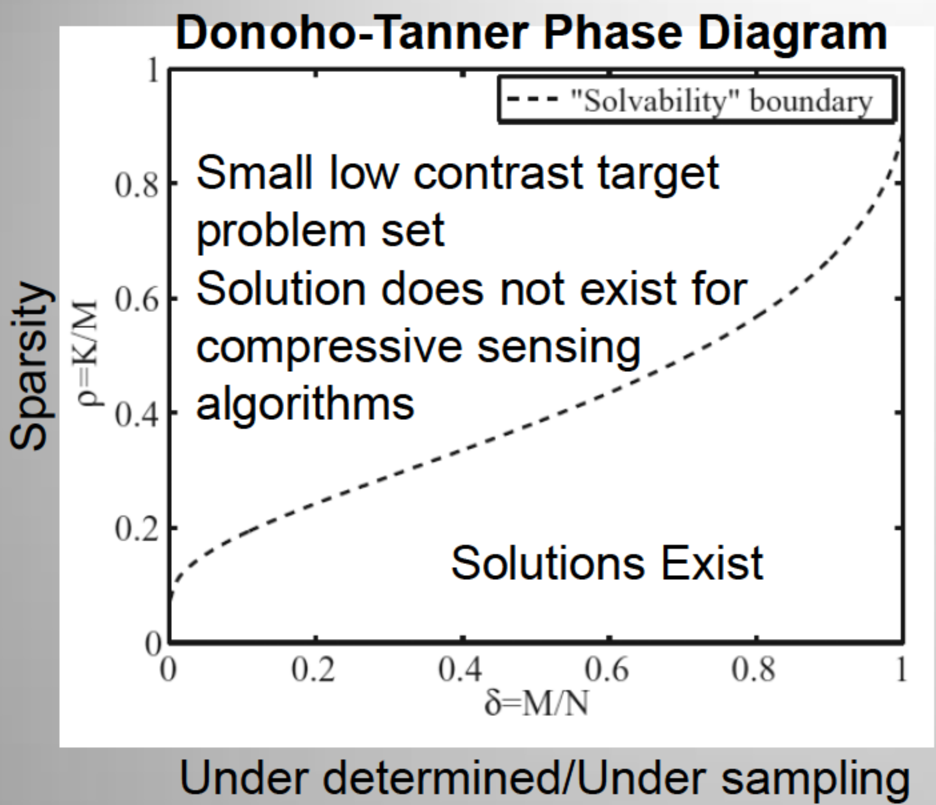
A sampling strategy is required to achieve detect/ID performance

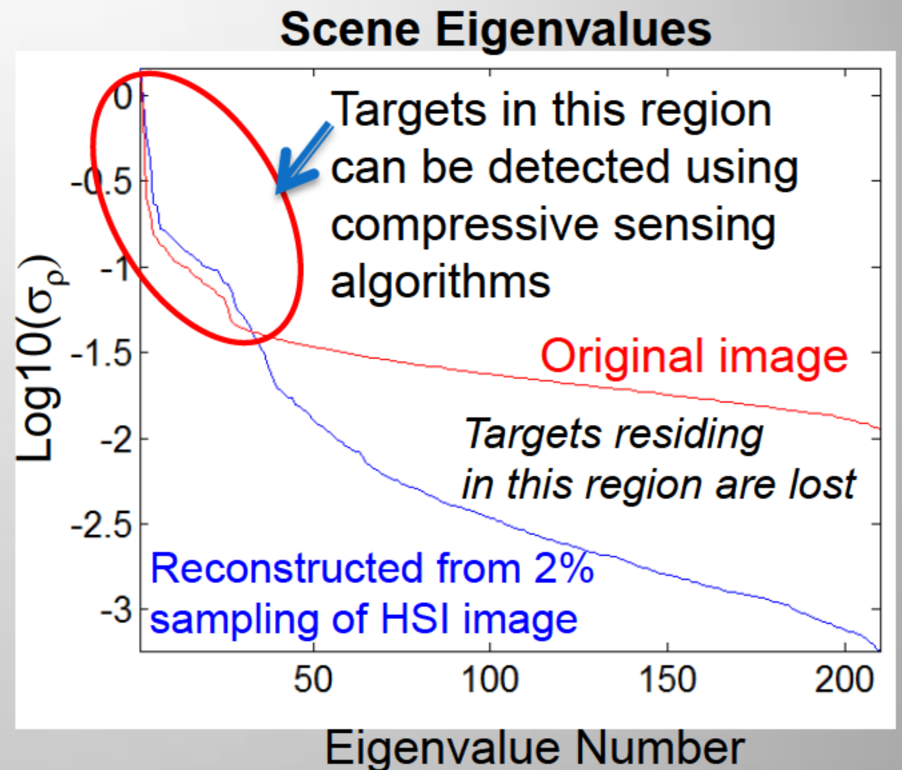
RTOSS: Foveated Detect/ID Image Product



- ACE thresholds optimized for 4 dyadic spatial scales
- Detect/ID @ 2% spatial sampling compared to FPA
- 2X reduction of spectral measurements using Hadamard transform
- Detect/ID of spectral target for 99.6% of simulated images
- Definition: Foveated Image - Processing technique where the image resolution, or amount of detail varies across the image according to the target detect/ID

Solution Space Of RTOSS Versus CS





RTOSS provides detect/ID independent of target sparsity using algorithms that exploit below the sensor noise floor

FPA versus A Photovoltaic Detector

- Shot noise from MCT CCD and PV detector is limiting factor given proper design:

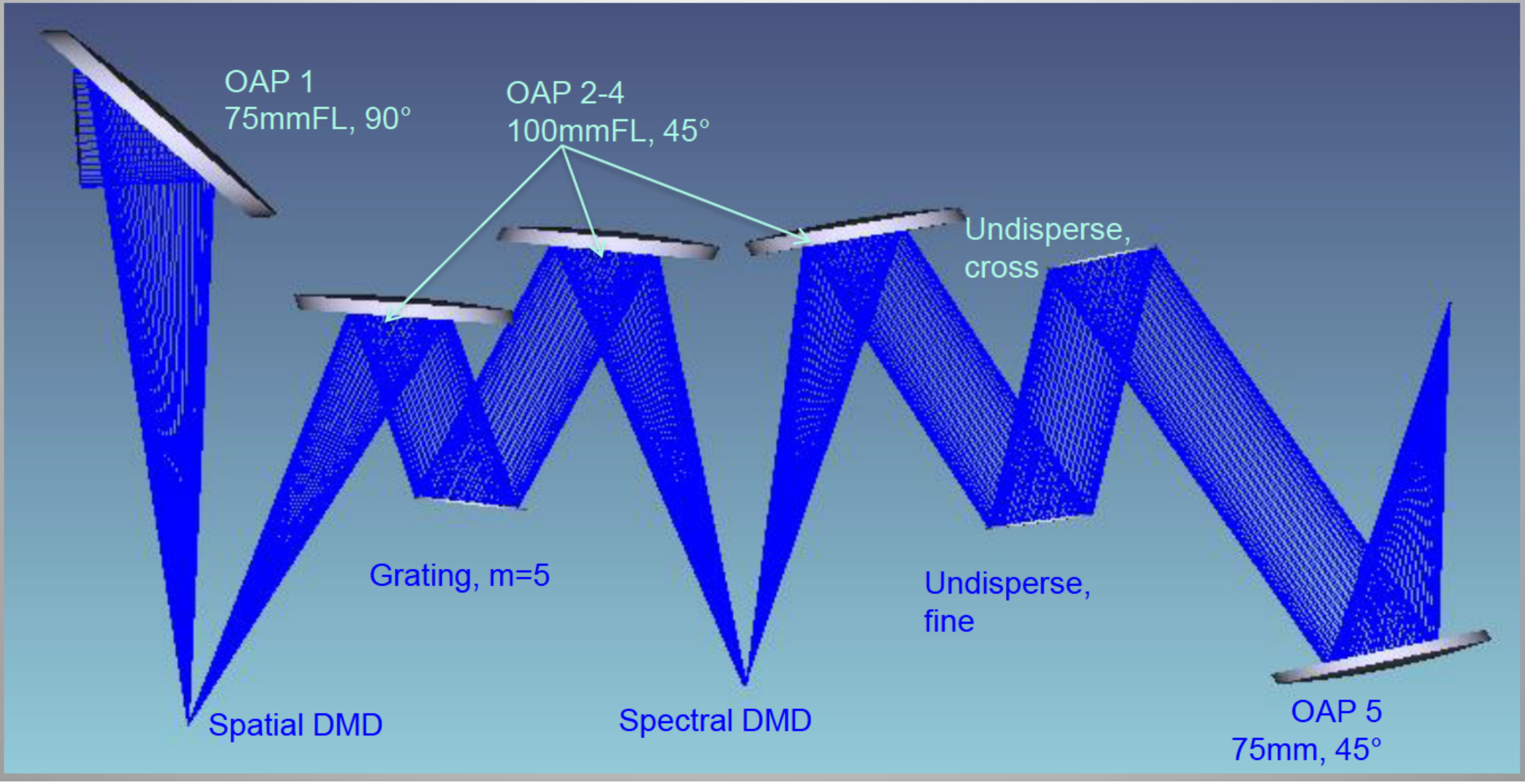
$$i_{PV-SN} = \sqrt{2\, q^2 \eta\, E_p A_d \Delta f} \qquad e_{CCD-SN} = \sqrt{2\, \eta\, E_p A_d \Delta f}$$

  - Performance difference is in sampling frequency
  - Where:
    - — $i_{PV\text{-}SN}$ is the shot noise current from a PV detector
    - — $e_{CCD\text{-}SN}$ is the CCD shot noise in electrons from a detector
    - — q is the electron charge
    - — η the quantum efficiency (QE)
    - — E_p the photon flux (ph/s m^2)
    - — A_d the detector area
    - — Δf the frequency of operation

- **FPA operates at 150Hz versus 15KHz – a factor of 10 lower in noise**
- **Single detector sensor gains are from no slit and a sampling strategy**

All Reflective Optical Design

- Compact optimized size, weight and power
- Potential to swap gratings to cover multiple spectral regions (VNIR-LWIR)
- Work in progress to clean up optical aberrations



RTOSS Paradigm Attributes

- Potential wide spectral coverage (VNIR/SWIR/MWIR/LWIR) in a single **sensor**
- Digital micro mirror devices control spatial-spectral scale/resolution and serve the purpose of a spectrometer entrance slit
- Dyadic target search based strategy
- Exploitation occurs in real time
  - Uses HSI gas/solids spectral libraries
  - Uses below the noise floor exploitation algorithms
  - Produces foveated image of target
- Real-time optimized spectral-spatial measurement scale
- Independent control of spectral and spatial resolution
- Control of area coverage rate and spectral range
- Apply measurement resources to the target not the entire scene
- Paradigm results in ability to dwell over targets to improve detect/ID performance

Summary

- Single detector spectrometer operates at 77K
- Compared to FPA based systems
  - Lower in-scene NESR compared to MCT FPA sensors
  - Design leads to better size, weight and power (SWAP)
  - Broader spectral range
  - Equivalent area coverage rates