Spectral Target Detection at Twilight

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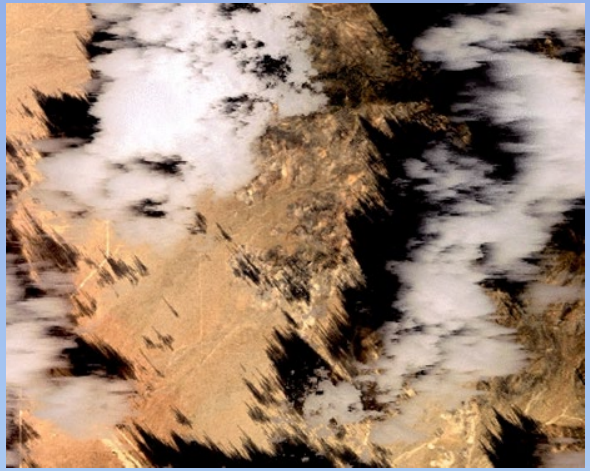
Presenter's Resume

- Dr. Robert L. Sundberg
- Experience at Spectral Sciences, Inc.
  - President Emeritus (2022-Present)
  - President (2011-2021)
  - Vice President of Technology (2002-2011)
  - Group Leader of Detection/Discrimination Group (1998-2002)
  - Principal Scientist (1988-1998)
- Education
  - Post Doctorial Position, Massachusetts Institute of Technology (1983-1985)
  - Ph.D. (Physical Chemistry), University of California, 1983
  - B.A. (Chemistry & Physics), Colby College, 1978

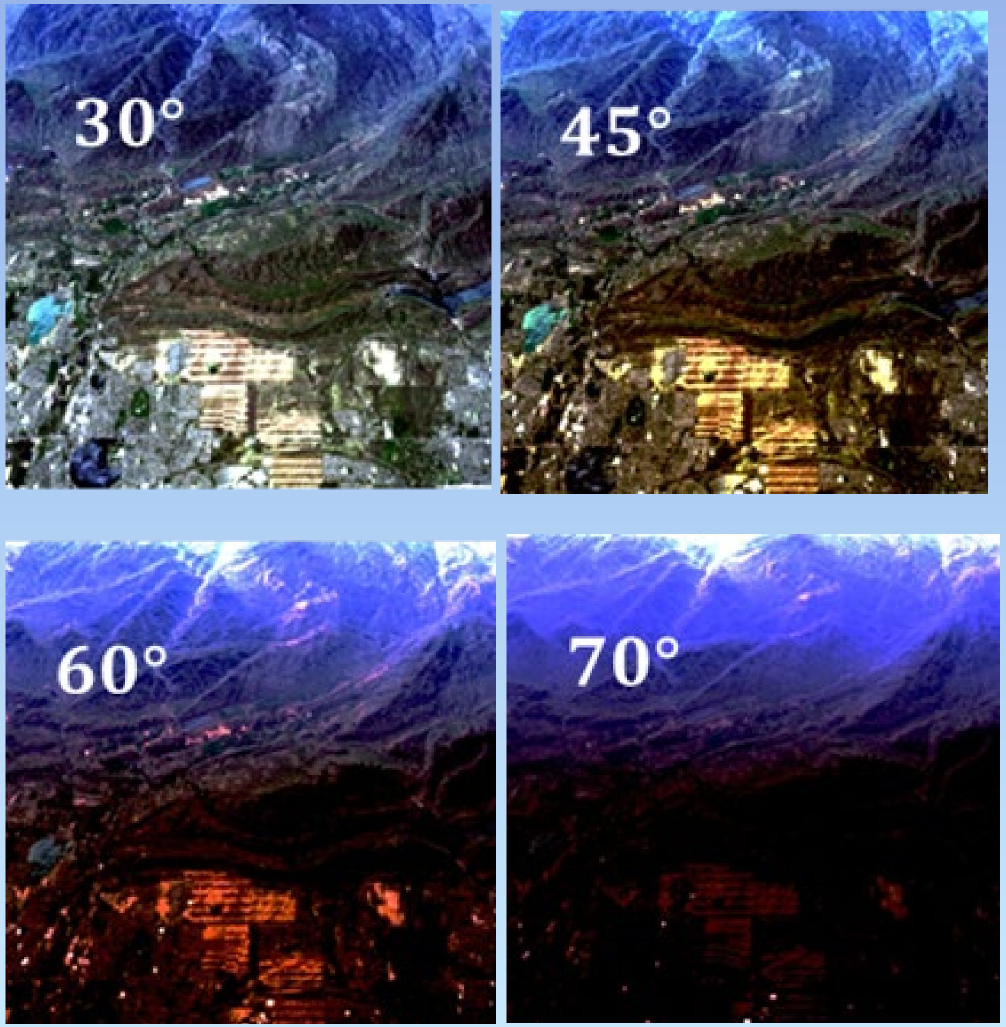
Research Interests

- Remote Sensing
  - Spectral Scene Simulation
    - High-fidelity 3D simulations
    - Real-time target simulations
  - Atmospheric Compensation of Spectral Data
    - Visible-SWIR
    - MWIR-LWIR
  - Target Detection Algorithm Development
- Rocket Plume Radiance Simulations
- Calibration of Spectral Sensors



Temperature Controlled Calibration Panels

Motivation for Study



Setting Sun Over Fort Collins, CO, USA

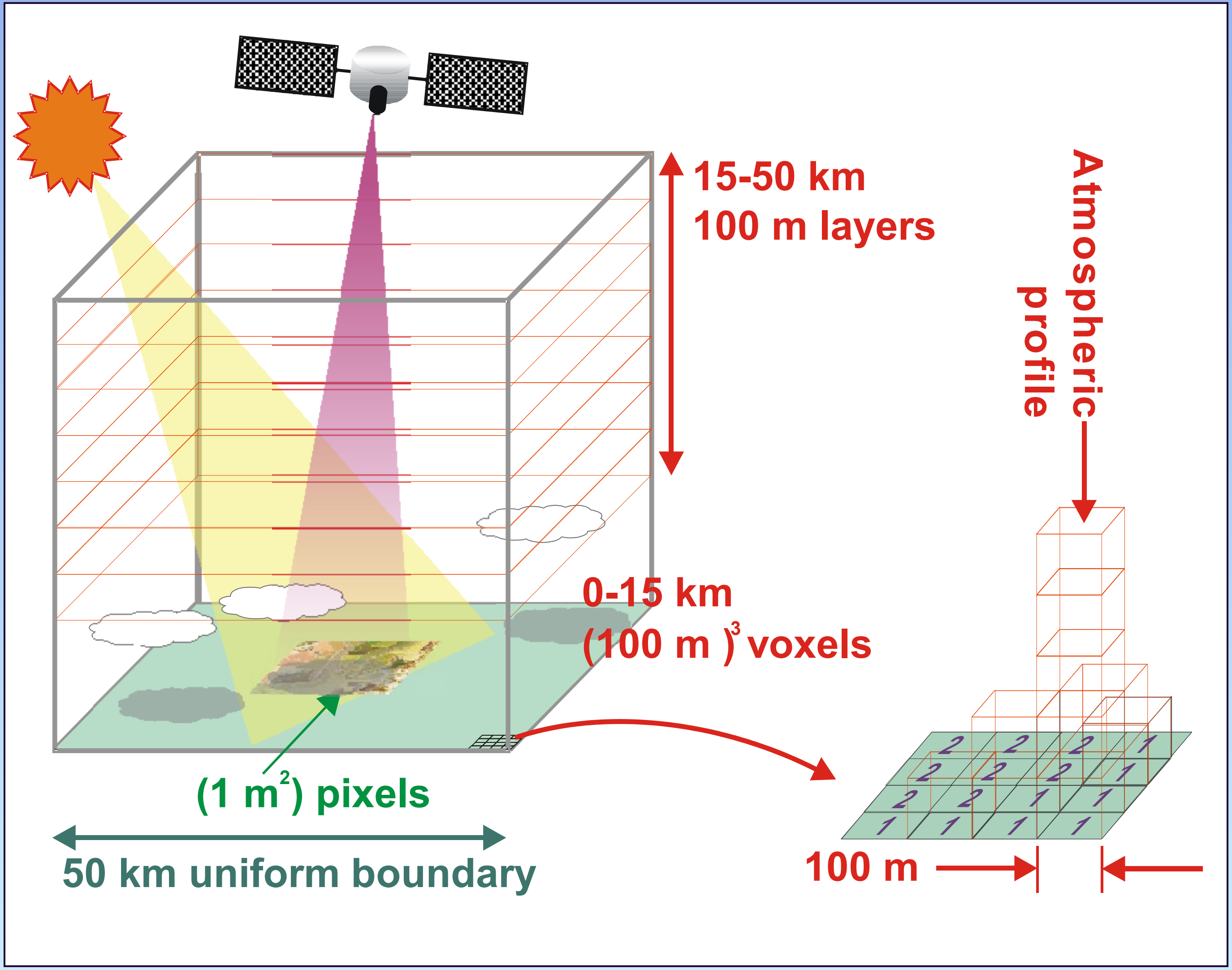
- Improvements in Spectral Imager Technology is Allowing Data to be Acquired Under Twilight Illumination Conditions
- MCScene Spectral Scene Simulation Tool can Simulate Scenes with the Sun Below the Horizon
  - Photons reaching the sensor from the ground must scatter in the atmosphere
- Investigate Target Detection Under Twilight Lighting Conditions

Presentation Outline

- Motivation
- **Overview of the MCScene Simulation Tool**
- Examine Target Detection Under Twilight Illumination
- Summary

MCScene Simulation Tool

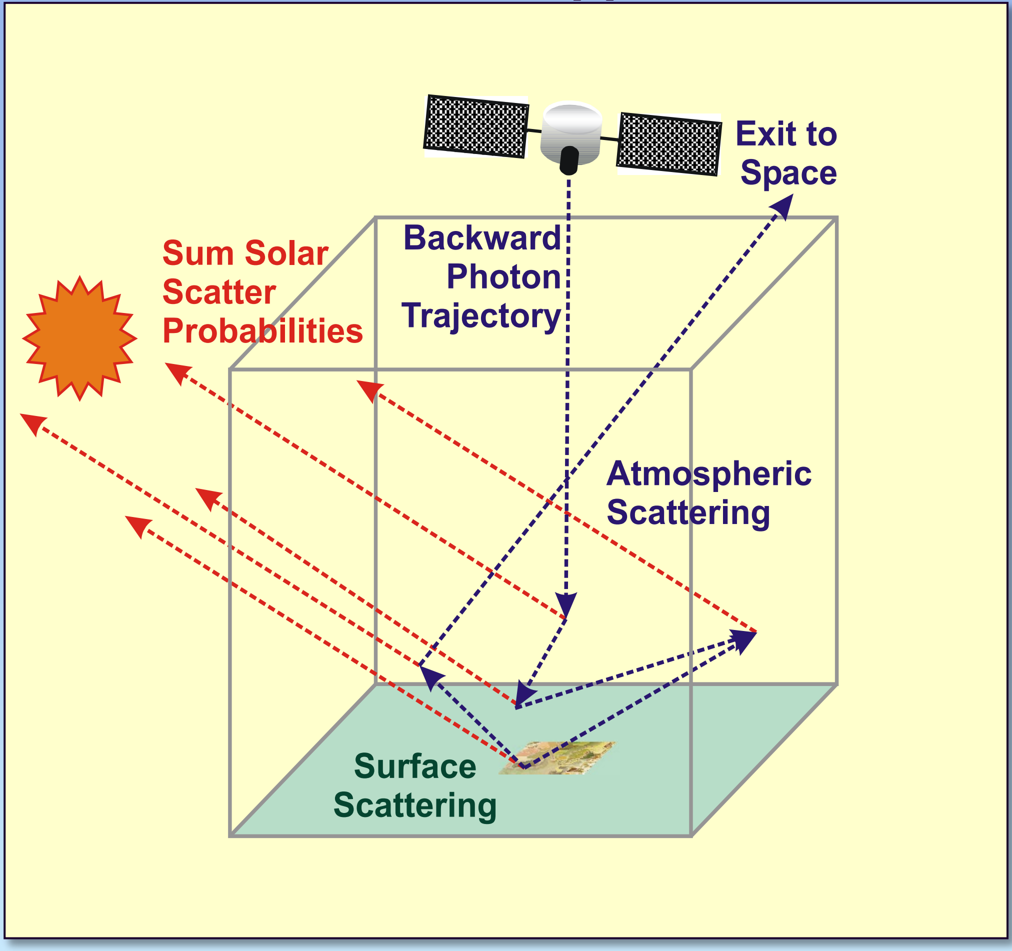
- UV through LWIR 3D radiative transport
- 3D atmospheres with clouds, 3D surfaces and object insertion
- Molecular absorption, Rayleigh scattering, aerosol absorption and scattering, multiple scattering and adjacency effects
- **MODTRAN®** optical properties, profiles, and spectroscopy
- Land and water surfaces, 3D terrain and objects, scattering by and transmission through clouds



MCScene Reflective Domain Approach

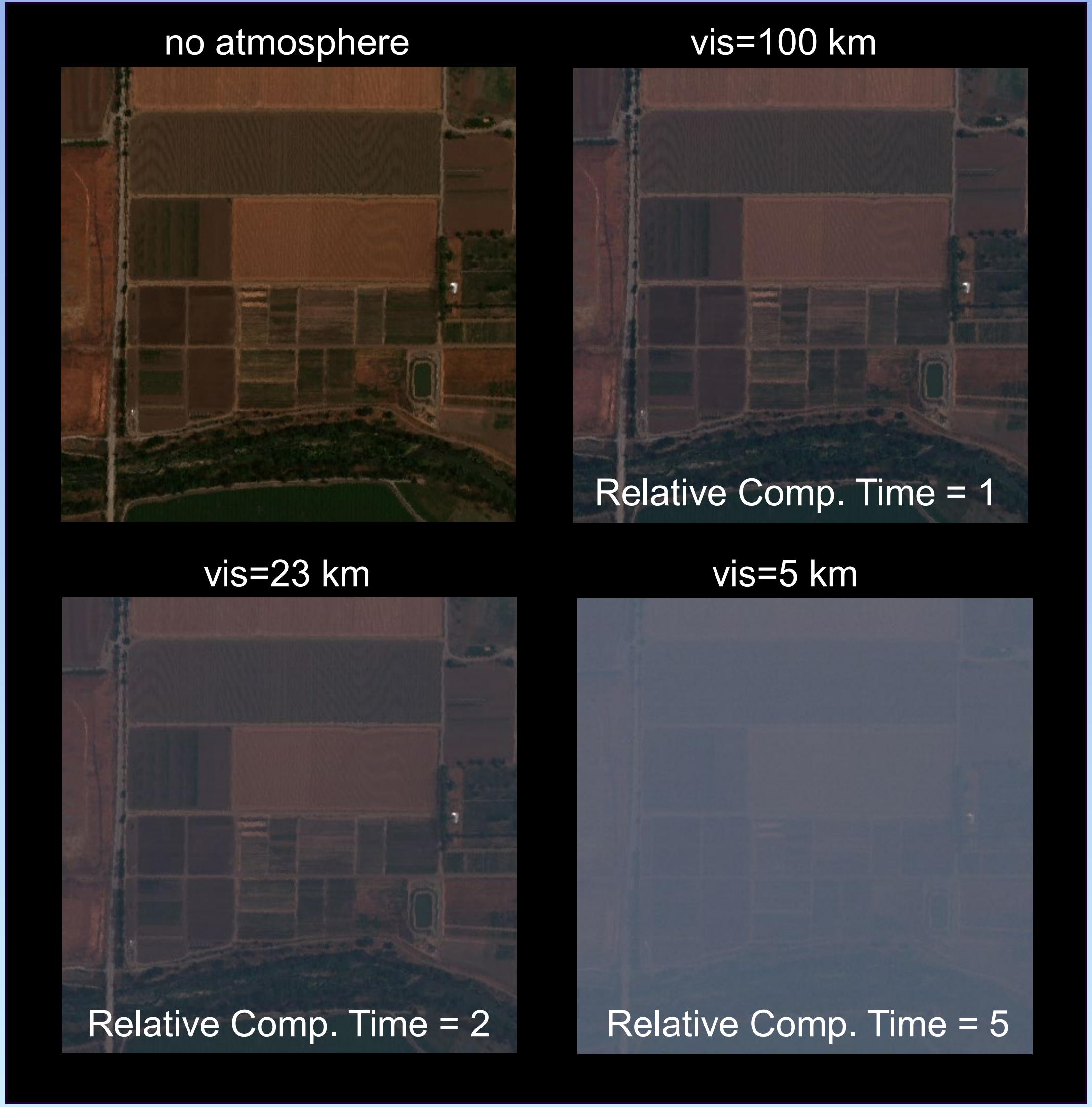
- Direct sun-ground-sensor term calculated explicitly
- Backward simulation ensures all photons hit the sensor
- Integrate thru 3D world in small steps
- Sample probability distributions for distance traveled and atmospheric and surface scattering directions
- Generates hyperspectral imagery

Monte Carlo Approach



Example Simulation of Visibility

- Davis CA scene
  - Reflectance from HYMAP data
  - 121 spectral bands
  - 2.75 m GSD
- Sensor altitude
  - 50 km
  - nadir view
- 45 deg solar zenith angle
- Uniform atmosphere
  - Mid-latitude summer
  - Rural aerosol
- Reflectance outside of scene is assigned the in-band average



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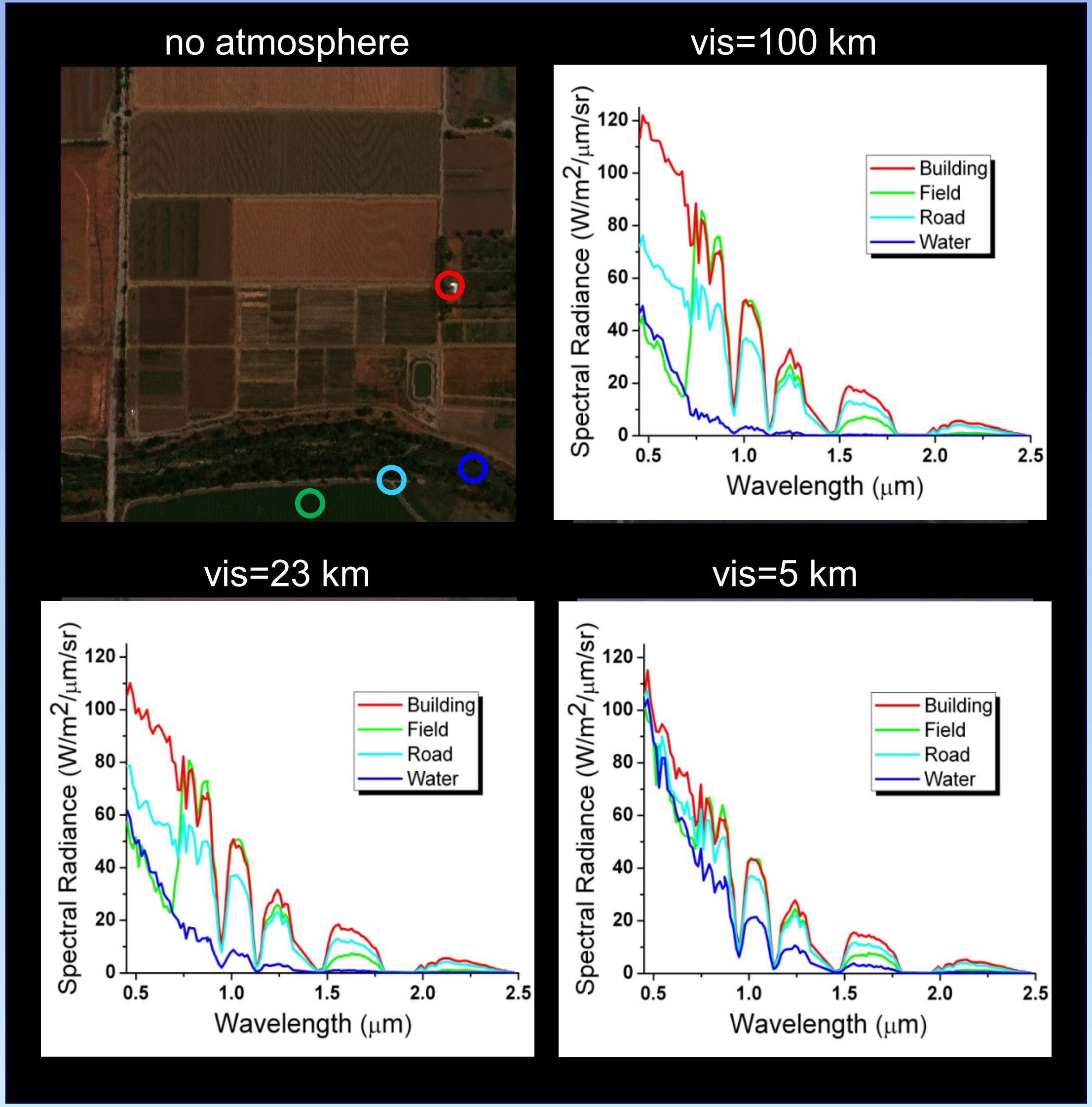
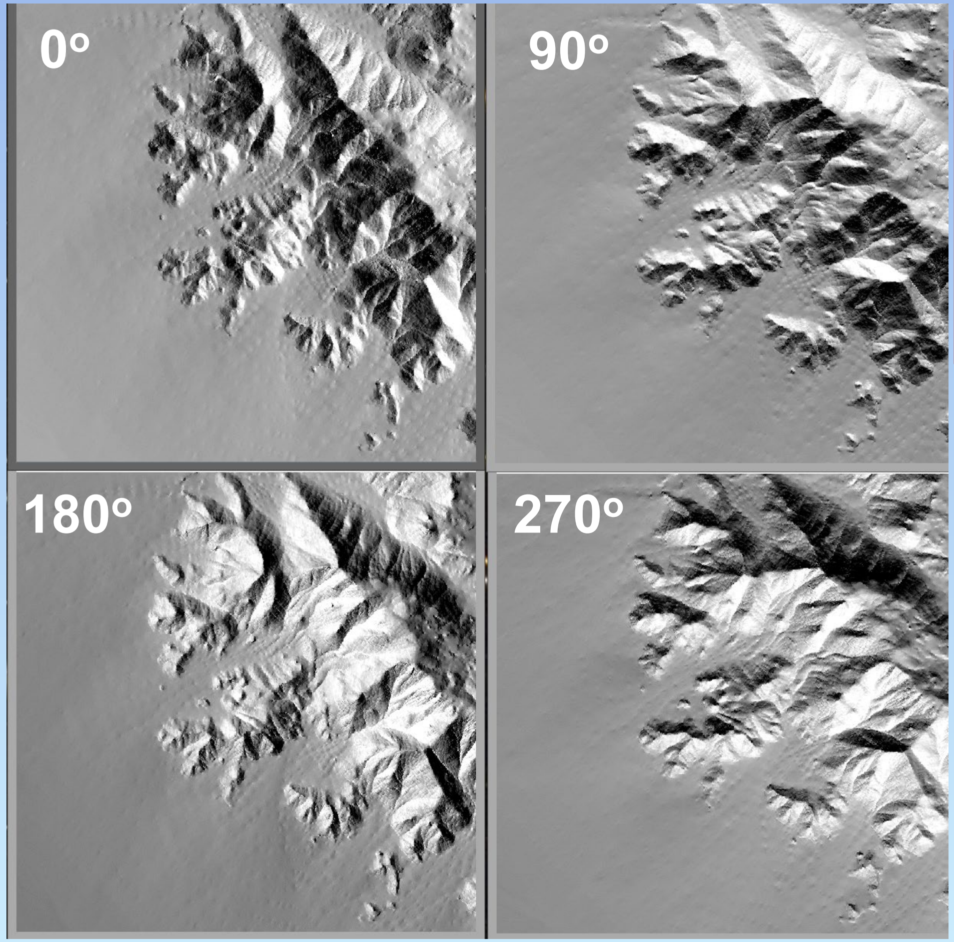


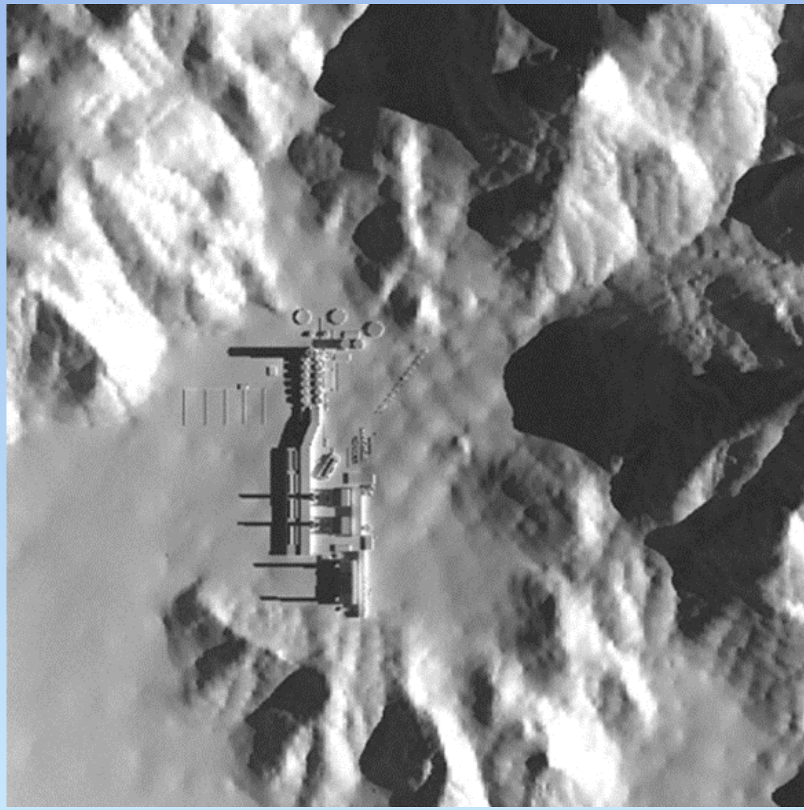
Topological Shadows
Shadows Cast by Scene DEM

Varying Solar Azimuth Angle



- Virgin Mts. USGS 10 m DEM
- Uniform Unit Reflectance
- 30 deg solar zenith angle
- 20 km sensor altitude

Embedded Power Plant



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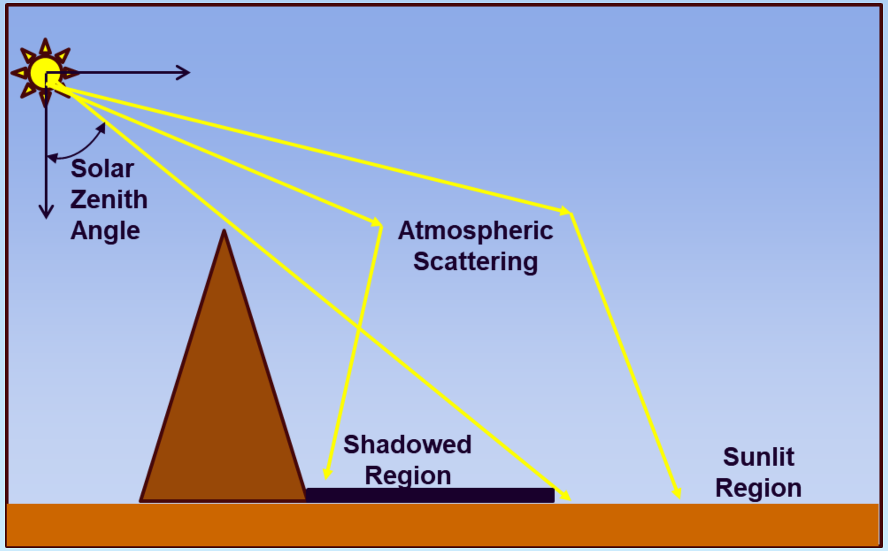
Topographic Shadows

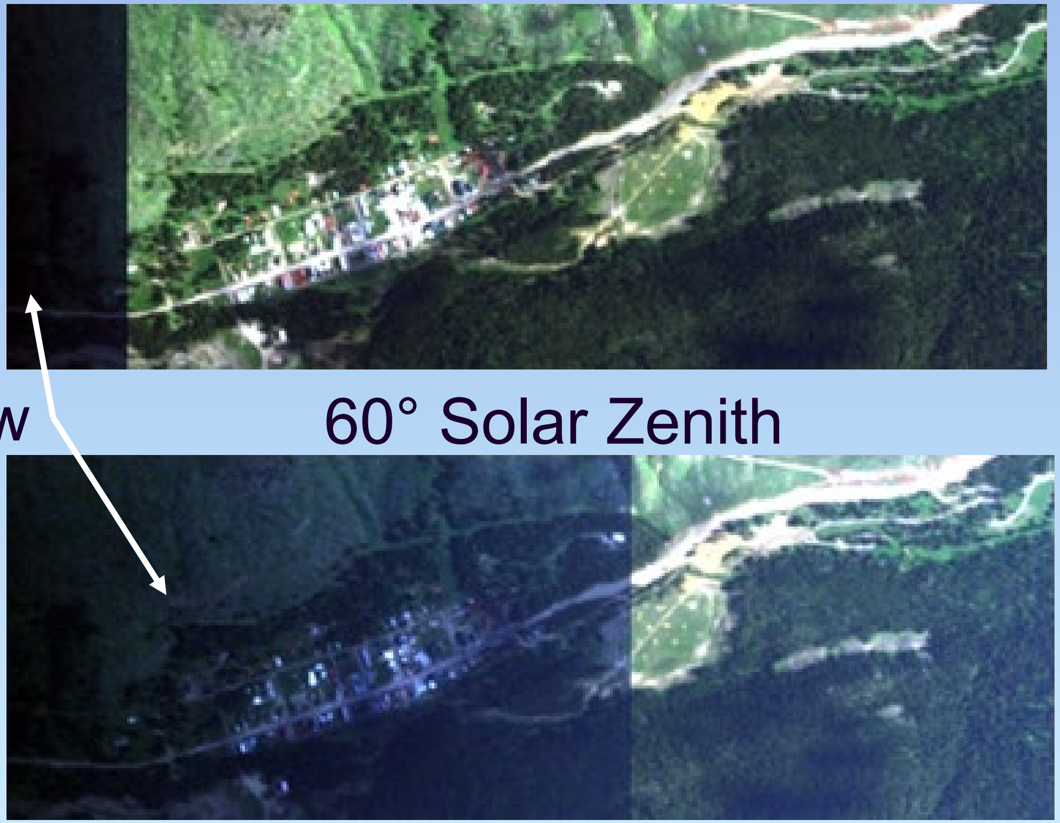
- Simplified Topographic Simulation Scenario
  - Tall mountain placed to the west of RIT Blind-Test data
  - Vary solar zenith angle
    - Overhead to 90° (twilight)
    - Scene fully shadowed by 75°



30° Solar Zenith

Shadow

60° Solar Zenith



Linear Stretch on RGB Images

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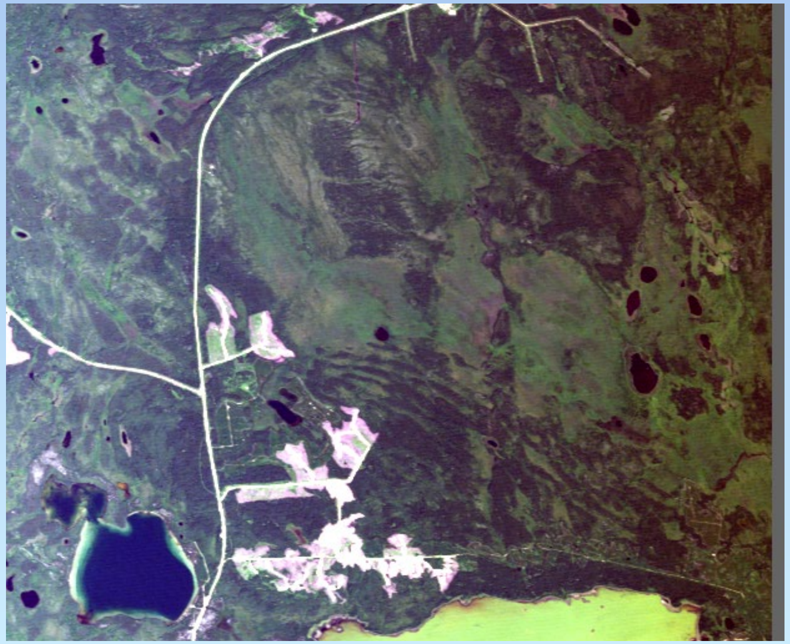
Data Used In Study

- RIT Target Detection Blind Test
  - Cooke City, MT
  - Collected on July 4, 2006
  - 3 m GSD
  - HyMap 128 bands
  - Visible to SWIR

True Color Image

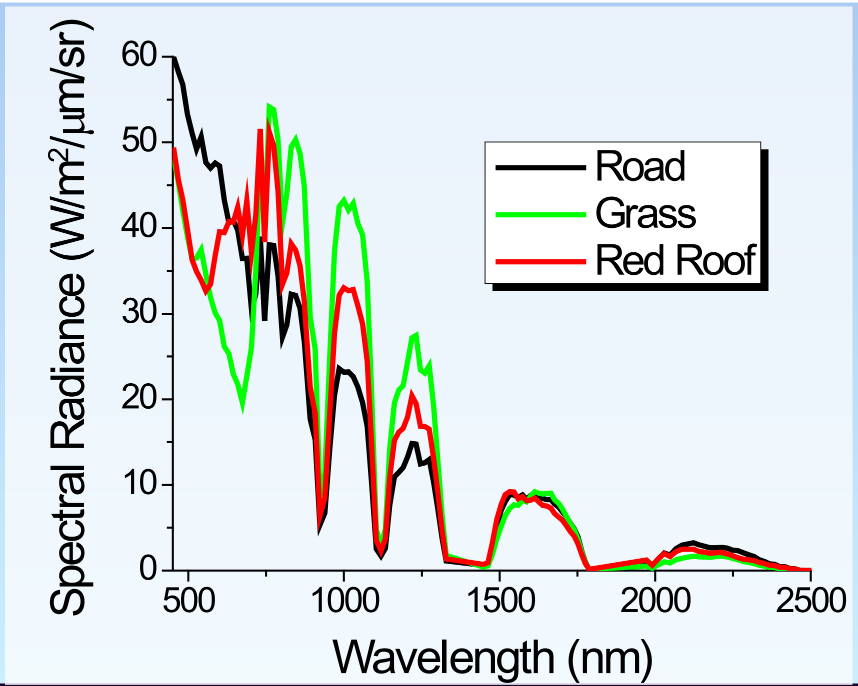
E. Ientilucci & S. Adler-Golden,
IEEE Geosci. Remote Sens. Mag., vol. 7, no. 2, pp. 31-50, 2019

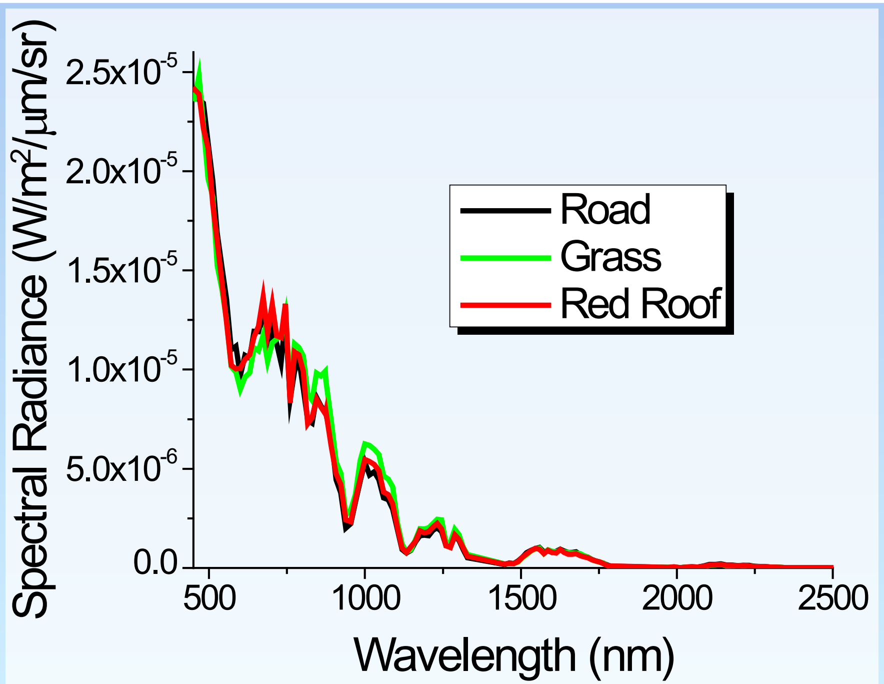
- AVIRIS Boreal region in Saskatchewan, Canada
  - Collected 1994
  - 20 m GSD
  - 256 bands resampled to 128 bands
  - Visible to SWIR



Simulated RIT Blind-Test Scenes

Sensor at 20 km Altitude



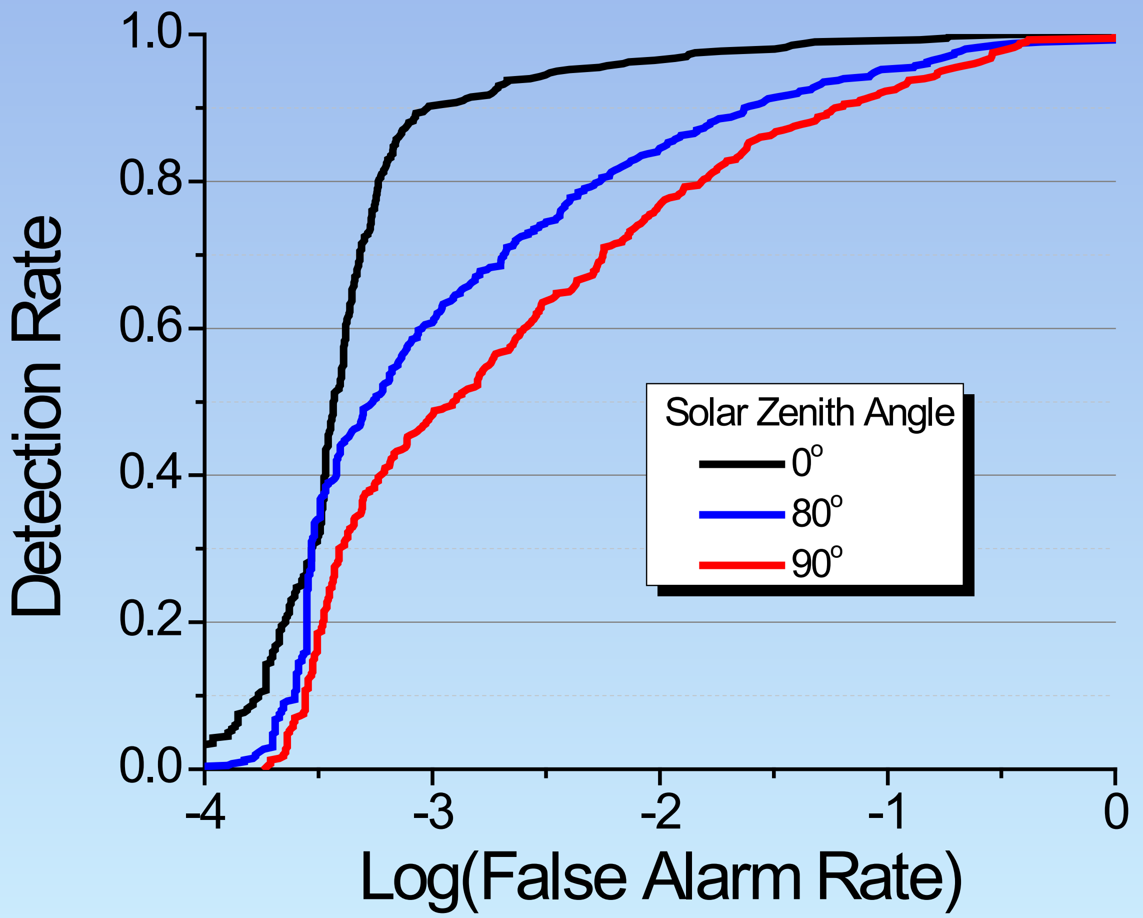


Target Detection Approach

- Randomly Embedded Target Pixels in Reflectance Scene as Subpixel Targets
  - Blue roof target in RIT scene
  - 400 targets
  - 2% to 10% fill factor
    - Such low fill factors because the target is so spectrally different than most of scene
- Use MCScene to Produce Radiance Scene
  - Move sun from overhead to twilight (below the horizon)
- Atmospheric Compensation from Radiance to Reflectance with QUAC
  - In-scene atmospheric compensation
  - Determines average scene radiance based on automatically selected scene endmembers
- Target Detection Adaptive Covariance Estimator (ACE)
  - Compares whitened target spectrum with each whitened pixel spectrum

Target Detection Results

MCScene Results on Blue Roof Target



- Target Detection Performance Degrades with Lower Solar Illumination
- Scenes with Mixtures of Shadow and Sunlit Areas Generally have Poorer Detection Performance
  - Processing sunlit & shadowed regions separately can improve detection performance
- Twilight Scene can Still Produce Reasonable Detection Performance
  - Radiance signatures are 10^6 times smaller
  - Noise of sensor becomes dominant effect

Simulated Boreal Scenes

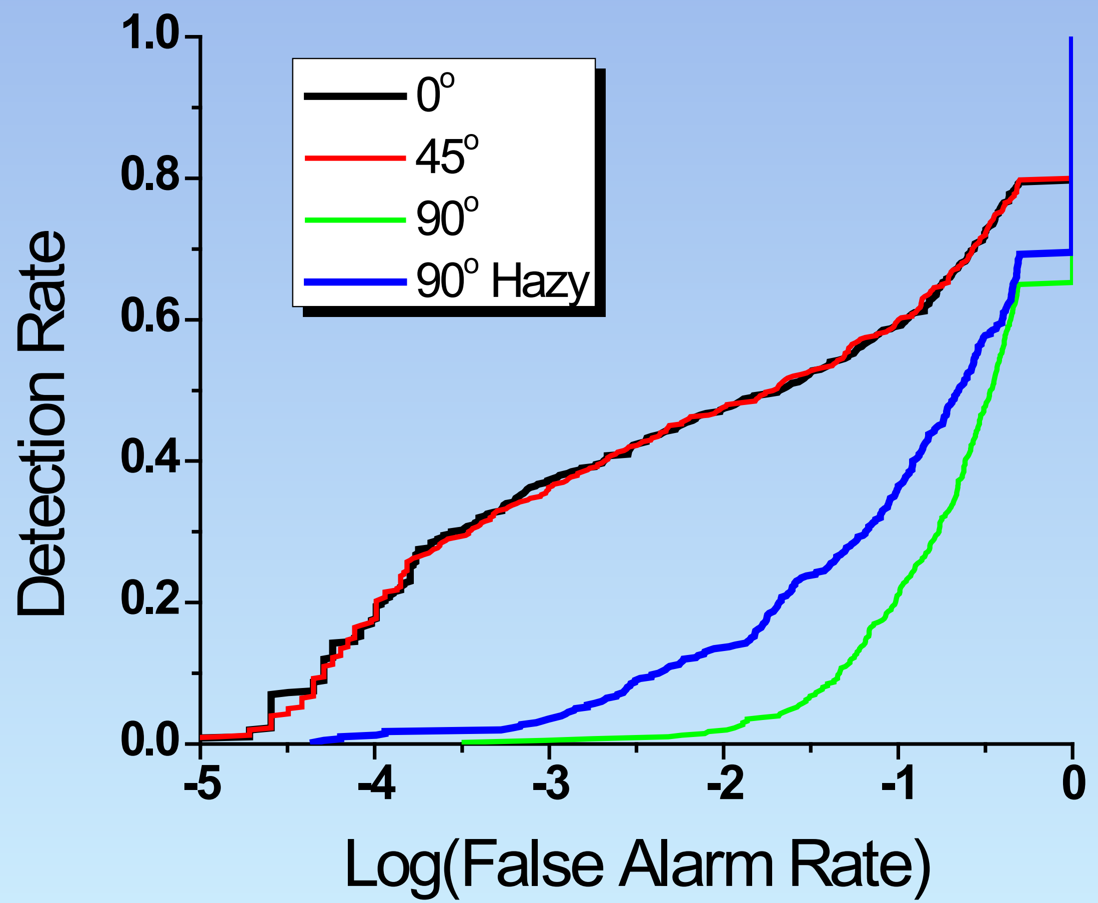
Sensor at 20 km Altitude

45° Solar Zenith

Twilight (90° Solar Zenith)

Target Detection Results

MCScene Results on Blue Roof Target



- Target Detection Performance Degrades with Lower Solar Illumination
- Twilight Scene can Still Produce Reasonable Detection Performance
- Scene with More Haze Produced Better Detection Performance
  - Additional scattering increased the number of photons reaching the ground
  - 23 km visibility in hazy scene

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Summary and Future Work

- MCScene Simulations of Twilight Illuminated Scenes
  - Sun can be placed below the horizon
  - Investigated the influence of illumination effects on target detection after atmospheric compensation
- Radiance Scene Converted to Reflectance using QUAC
  - Detection is done in reflectance space
- Detection Performance Generally Reduced with Reduced Illumination
- Surprisingly, Good Target Detection in Twilight Conditions
  - Sensor noise may limit the performance
- Improved Detection Results When Haze in the Atmosphere is Sufficient to Induce a Few Scattering Events
- Future Work
  - Investigate sensitivity of twilight illuminated target detection to target signatures

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Detection Algorithms

- Adaptive Coherence Estimator (ACE) Detector
  - Single spectrum for target
  - Can be used for tracking if spectral shape is nearly constant
  - ACE detector: $\mathbf{r} = [\, \mathbf{x}^T\mathbf{x} \,/\, (\mathbf{x}^T\mathbf{x} - \mathbf{x}^T\mathbf{s}(\mathbf{s}^T\mathbf{s})^{-1}\mathbf{s}^T\mathbf{x}) \,]^{1/2}$
    - Whitened target spectrum, **s**
    - Whitened pixel spectrum, **x**
    - **r** = csc(θ)
    - θ → angle between **s** & **x**
  - Generalized likelihood ratio statistic