Hyperspectral Imaging or Imaging Spectroscopy: An Overview

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Information in Remote Sensing of the Earth

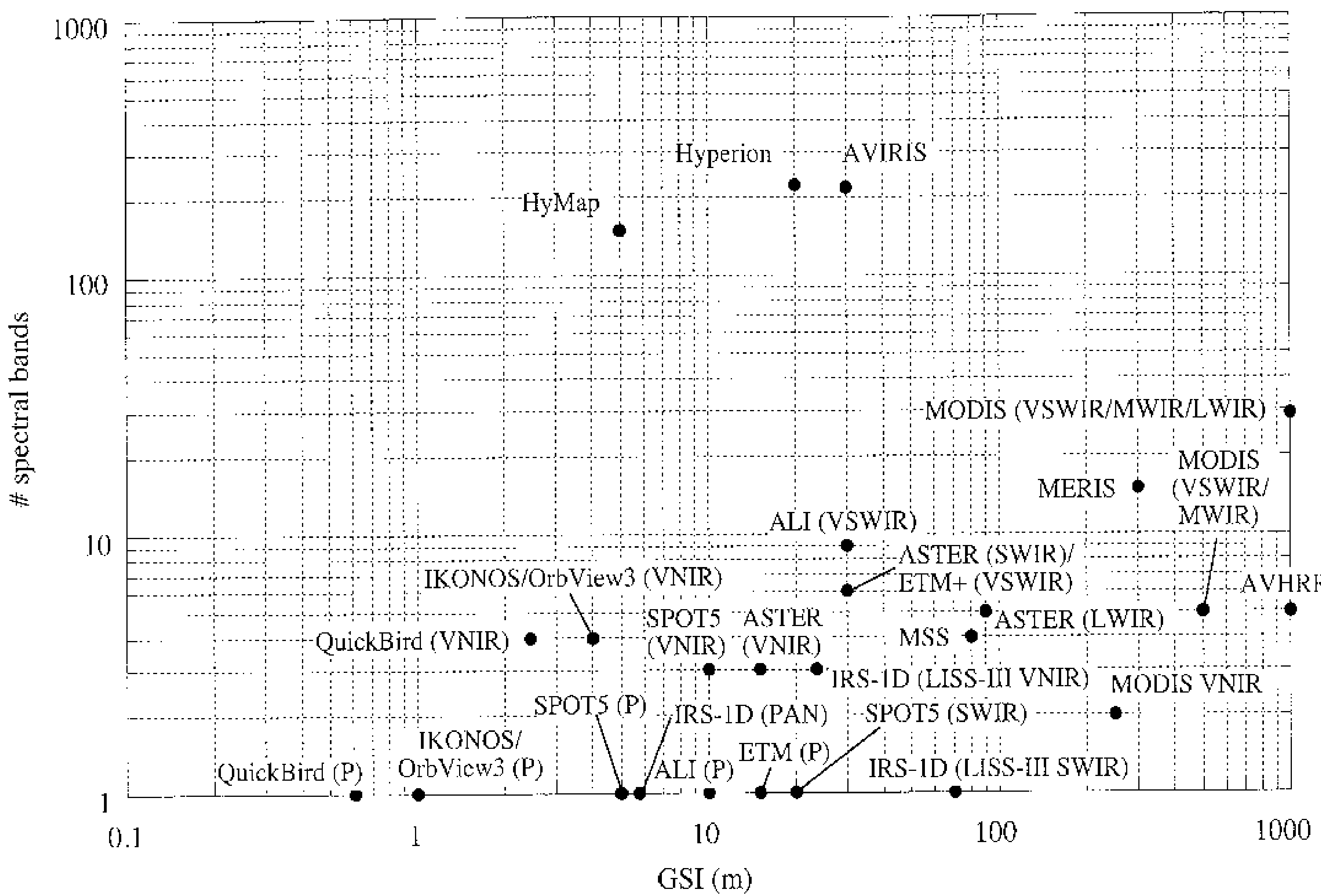
- Information about the earth can be derived from
  - Electromagnetic fields
    - Spatial
    - Spectral
    - Temporal
  - Gravitational fields
- To extract the information of interest one must
  - Measure variations of those fields → Sensors
  - Relate them to the desired information → Modeling

Apollo 17, 1972

Key Concepts

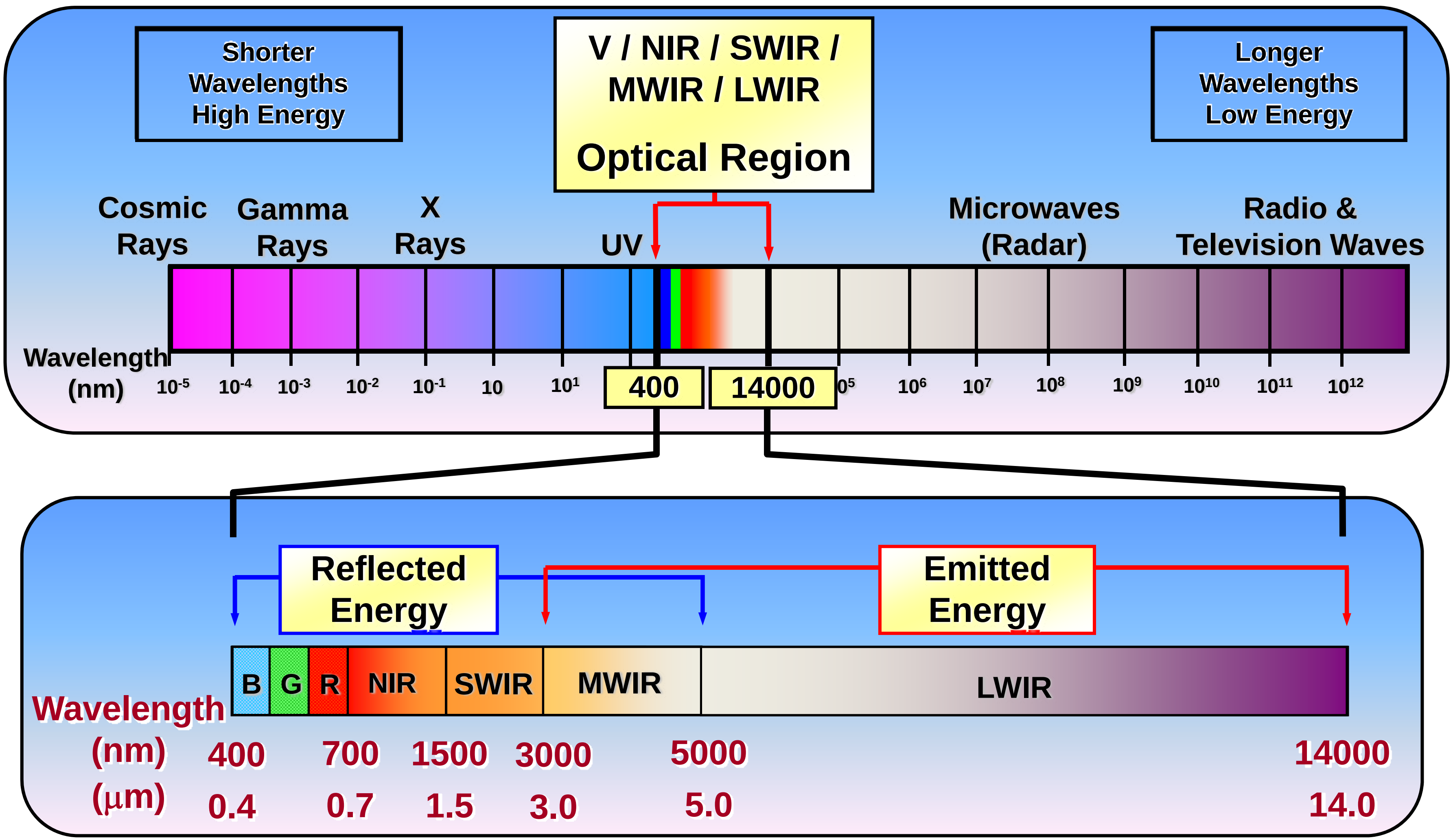
- SPATIAL DIFFERENTIATION - Every sensor is limited in respect to the size of the smallest area that can be separately recorded as an entity on an image. Object shapes and spatial relations are
- SPECTRAL DIFFERENTIATION - Remote sensing depends upon observed differences in the energy reflected or emitted from features of interest.
- RADIOMETRIC DIFFERENTIATION – Examination of any image acquired by remote sensing ultimately depends upon detection of differences in the brightness of objects and the features.

Spectral vs Spatial Resolution

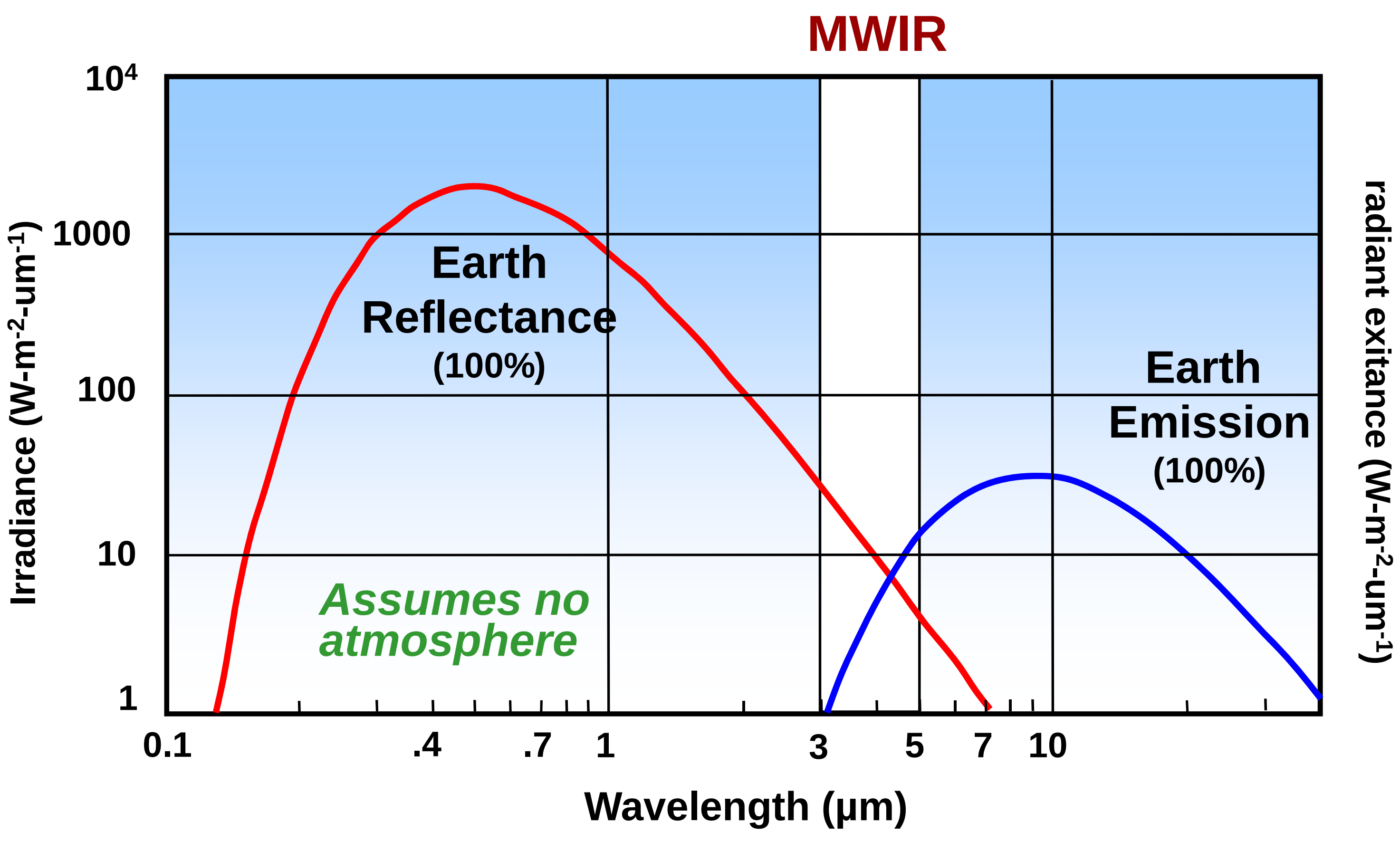


Electromagnetic Energy

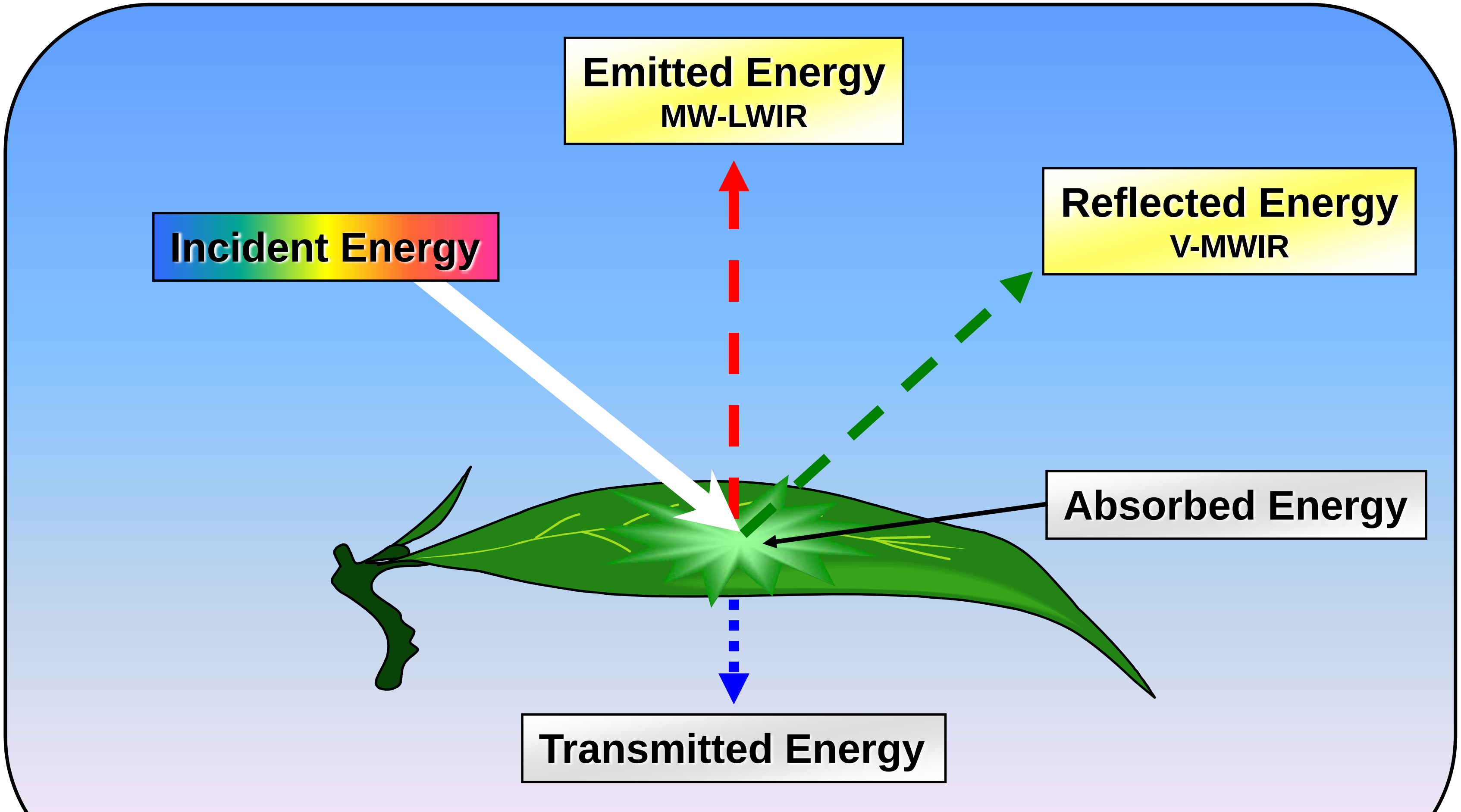
Electromagnetic Spectrum



Reflected vs. Emitted Energy

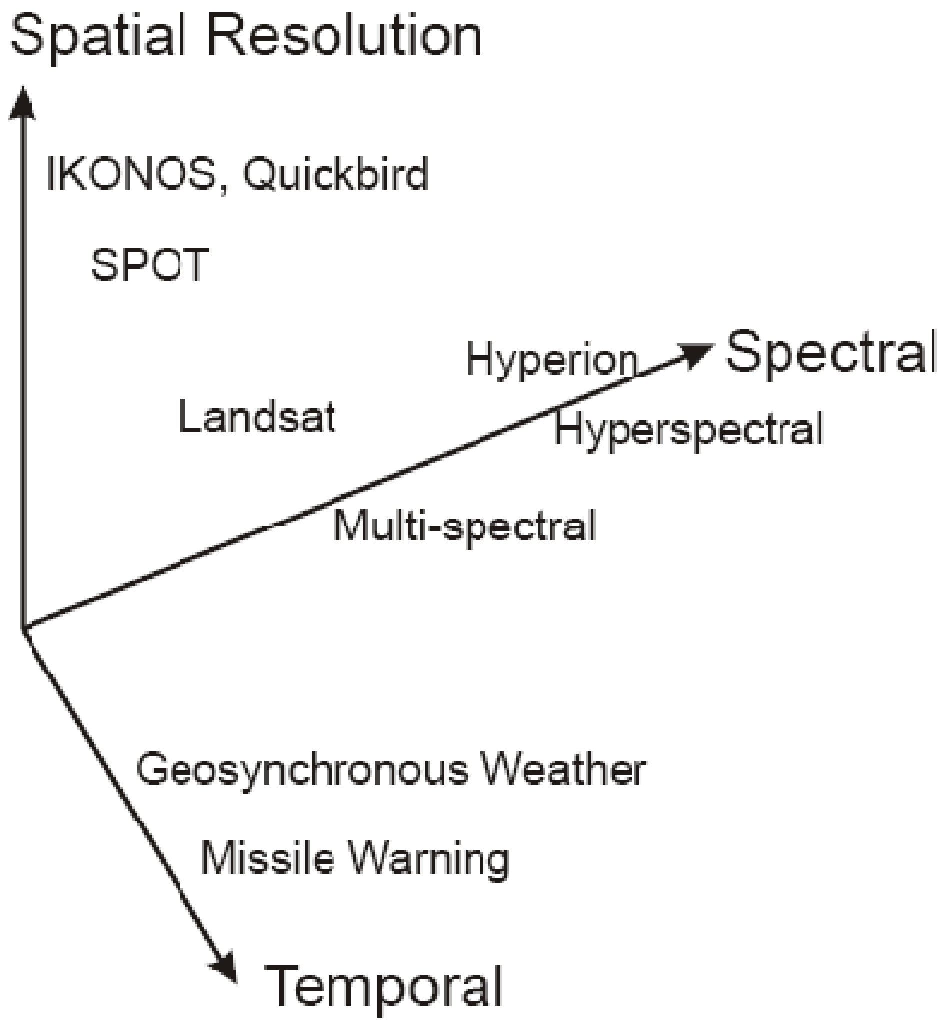


Interaction of energy and objects

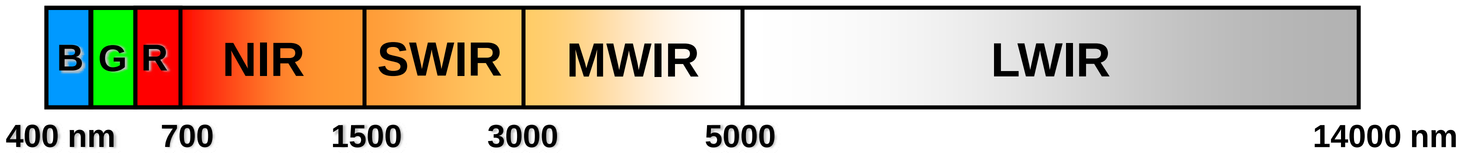


Energy Balance Equation: $E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$

Three Dimensions for RS

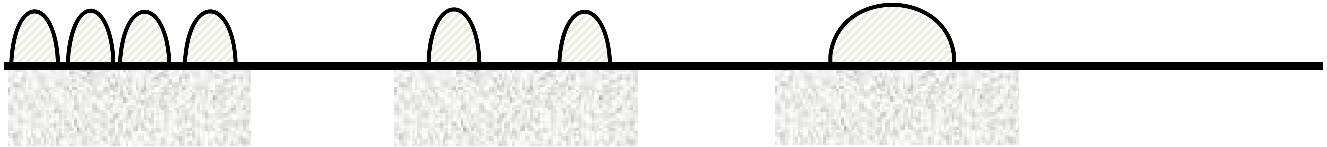


Sampling the Spectrum

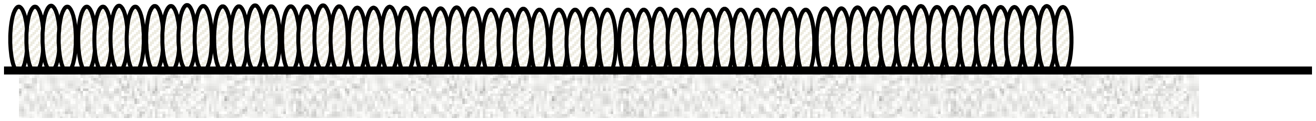


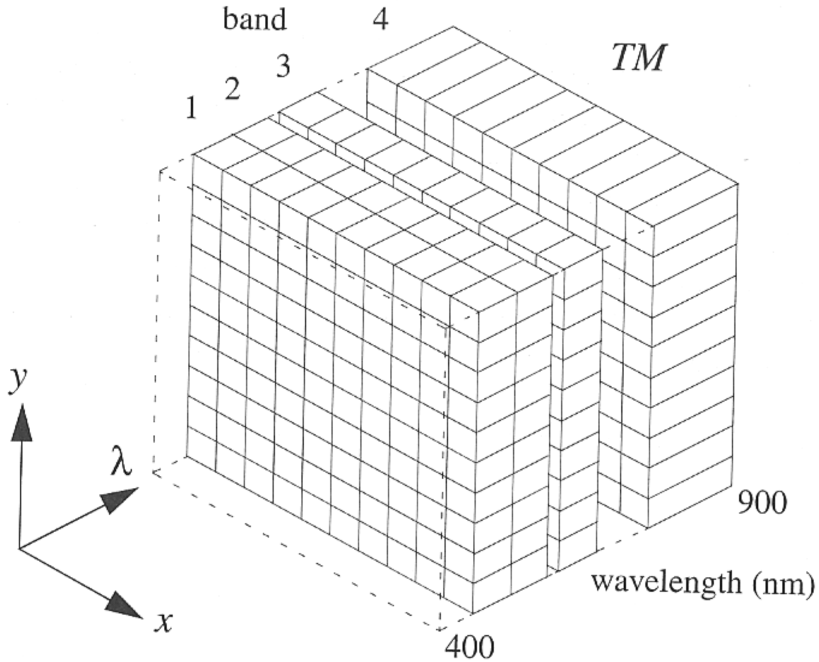
LOW **Panchromatic: one very wide band**

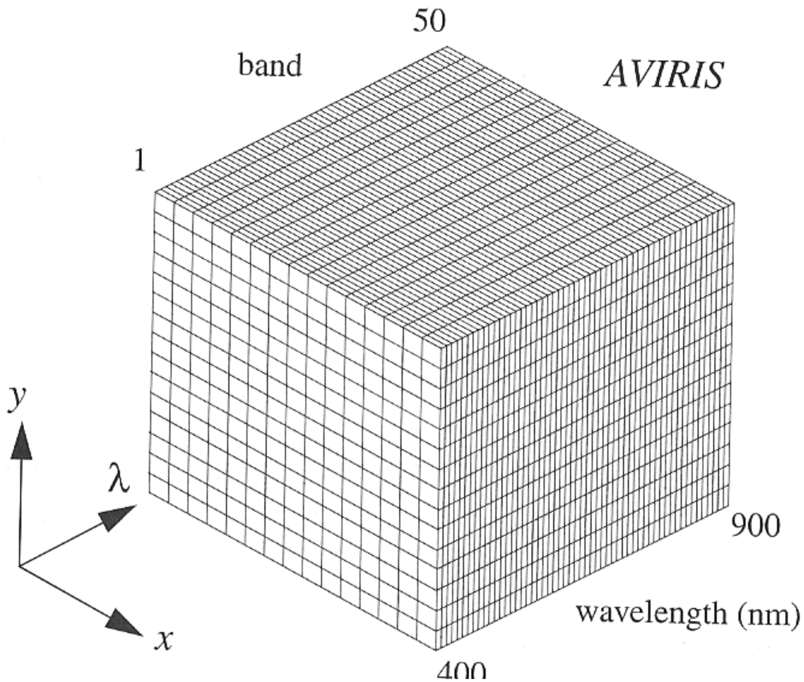
MED **Multispectral: several to tens of bands**



HIGH **Hyperspectral: hundreds of narrow bands**



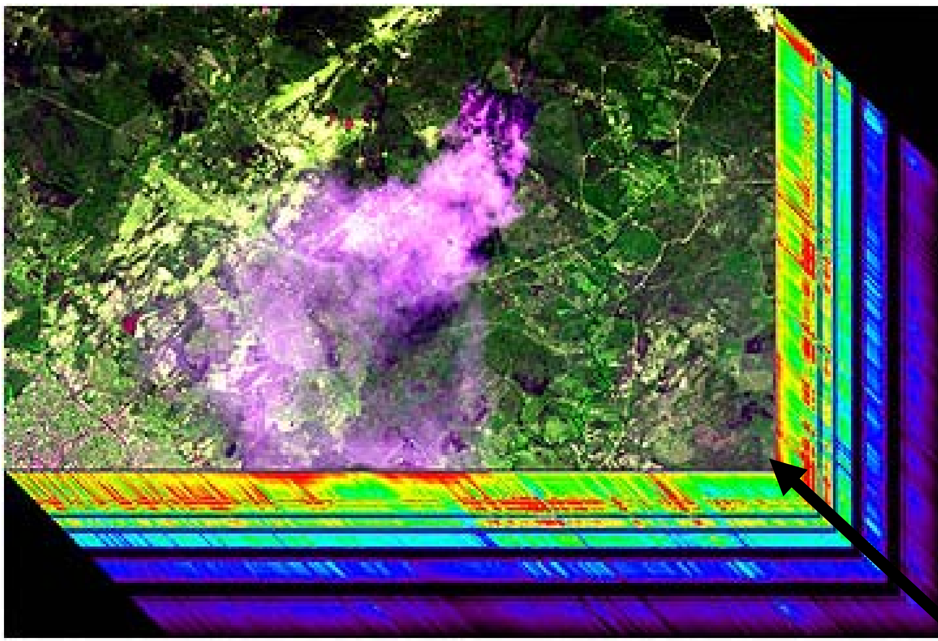




The Spectral Cube

The Spectral Image Cube

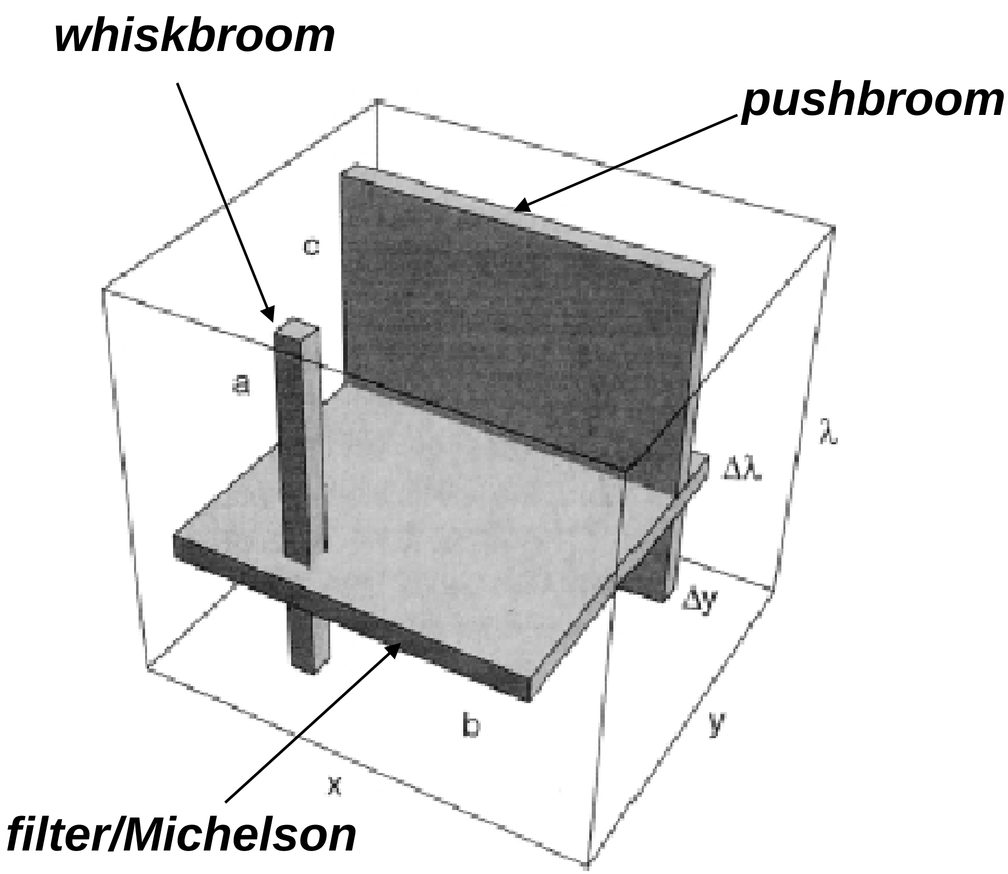
The image cube is a 3-dimensional data set. We have two spatial dimensions and a third spectral dimension that is usually put vertical



It is important to remember that the spectral dimension is fundamentally different, and the 3-D spatial analogy can only go so far…

How do the various sensors assemble this image cube?

Building up the Image Cube

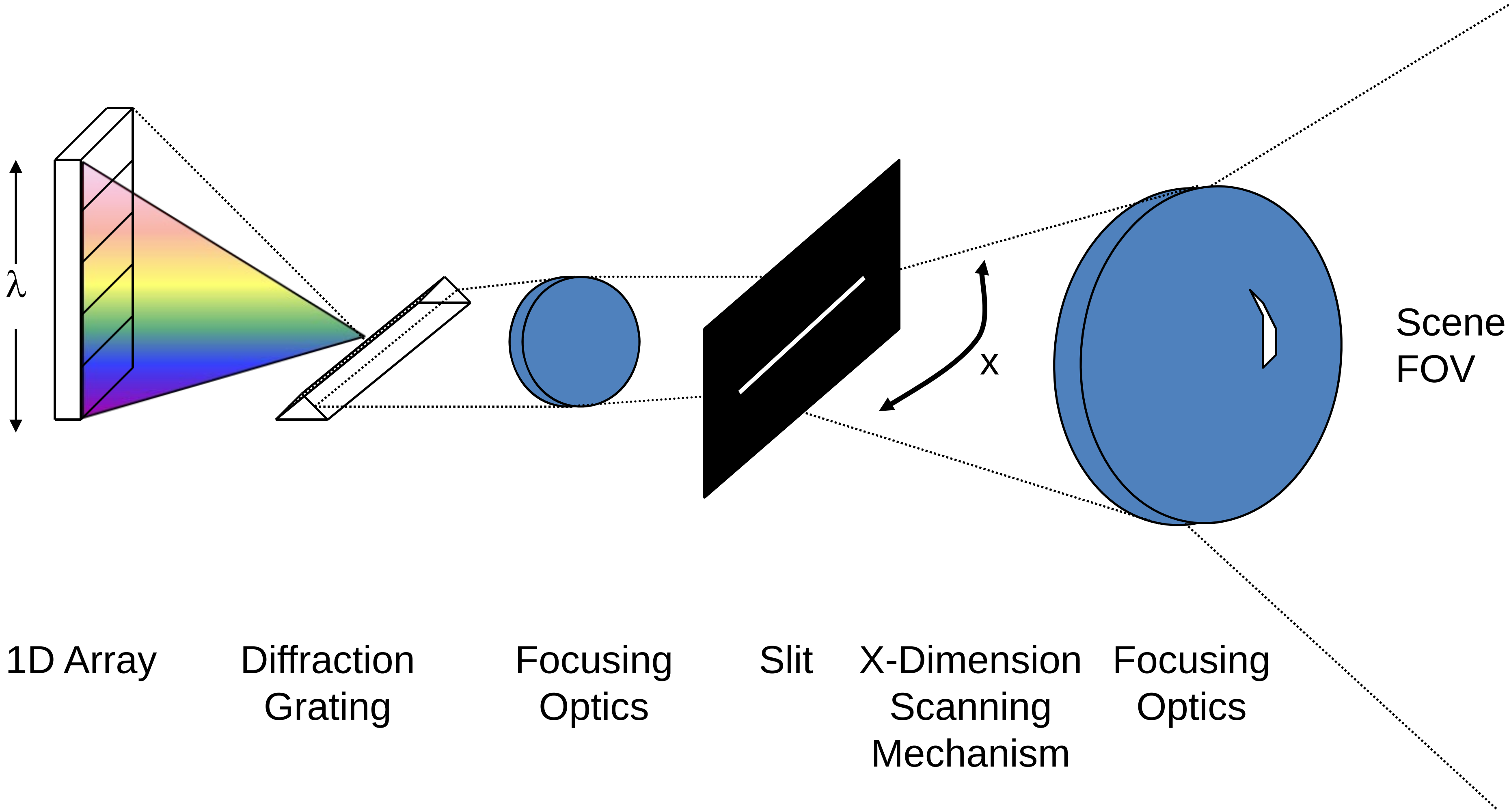


*Descour, et al., Applied Optics **34** 1995*

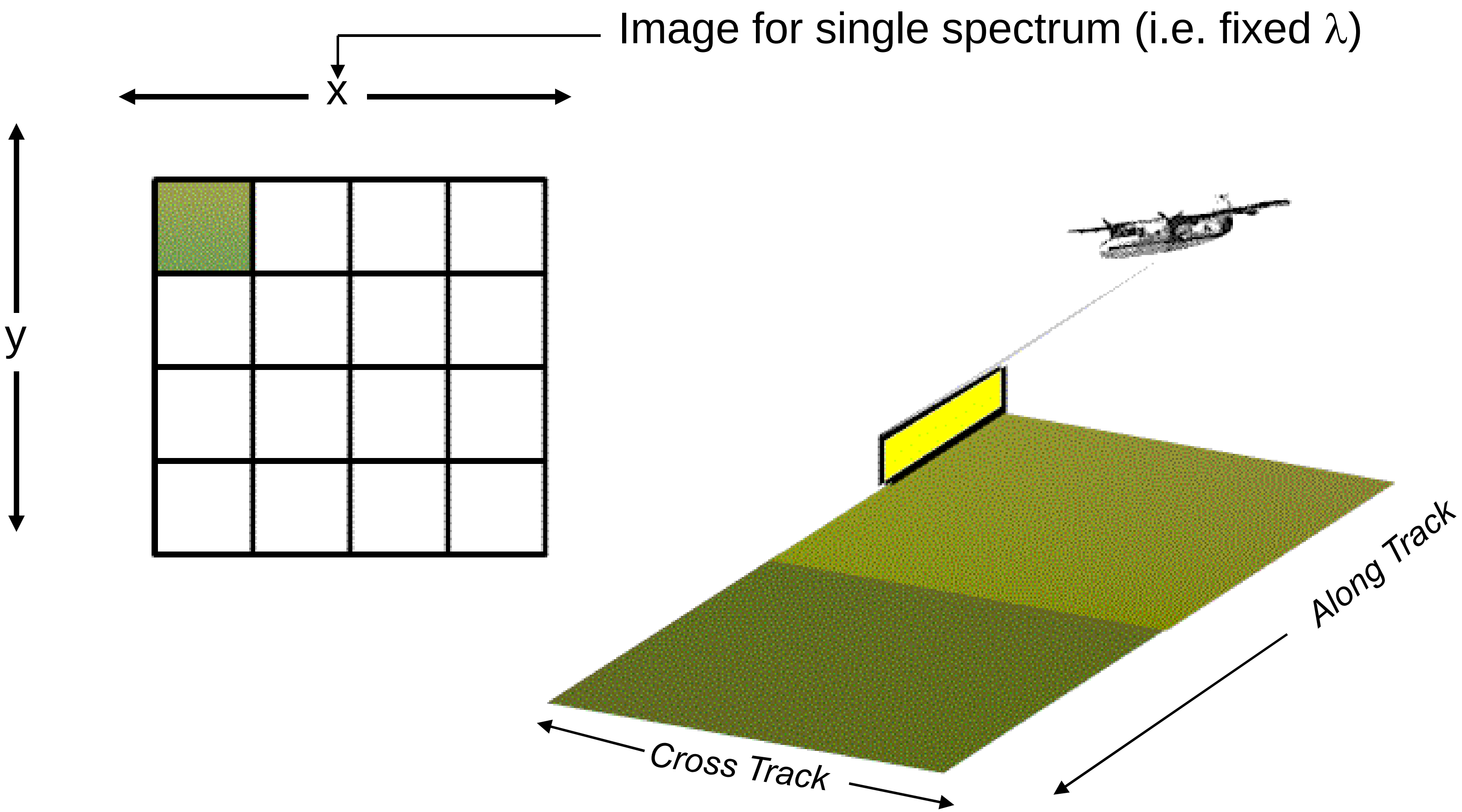
Most spectral imagers build up the image cube by scanning through it. The conventional methods are whiskbroom (a), filter/Fourier transform (b), pushbroom (c)*

**We will also discuss the CTIS snapshot hyperspectral imager*

1D Array Usage in Imaging Spectrometer



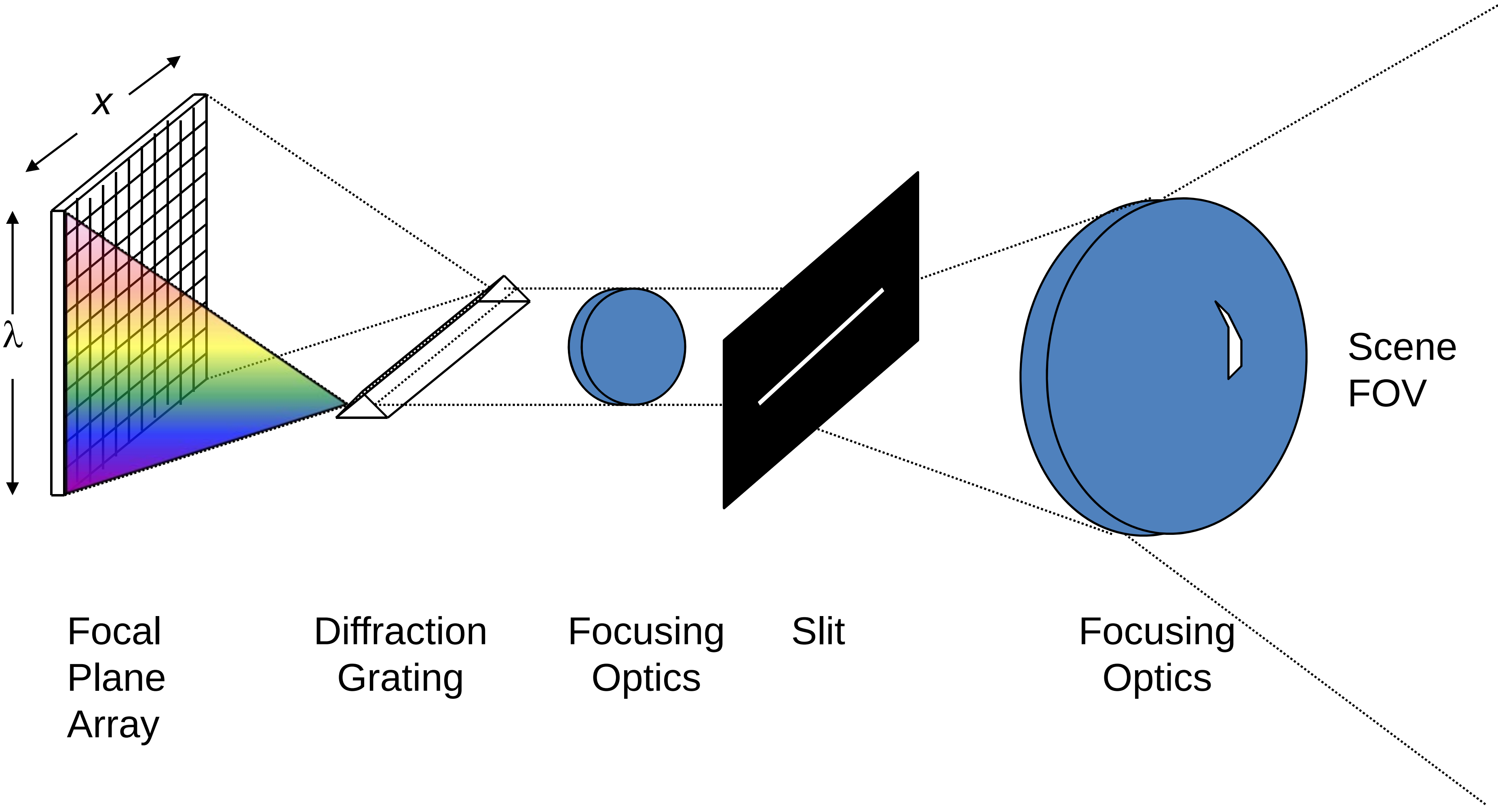
Whiskbroom Sensor Accumulation
(AVIRIS, AVHRR/MODIS, LANDSAT)



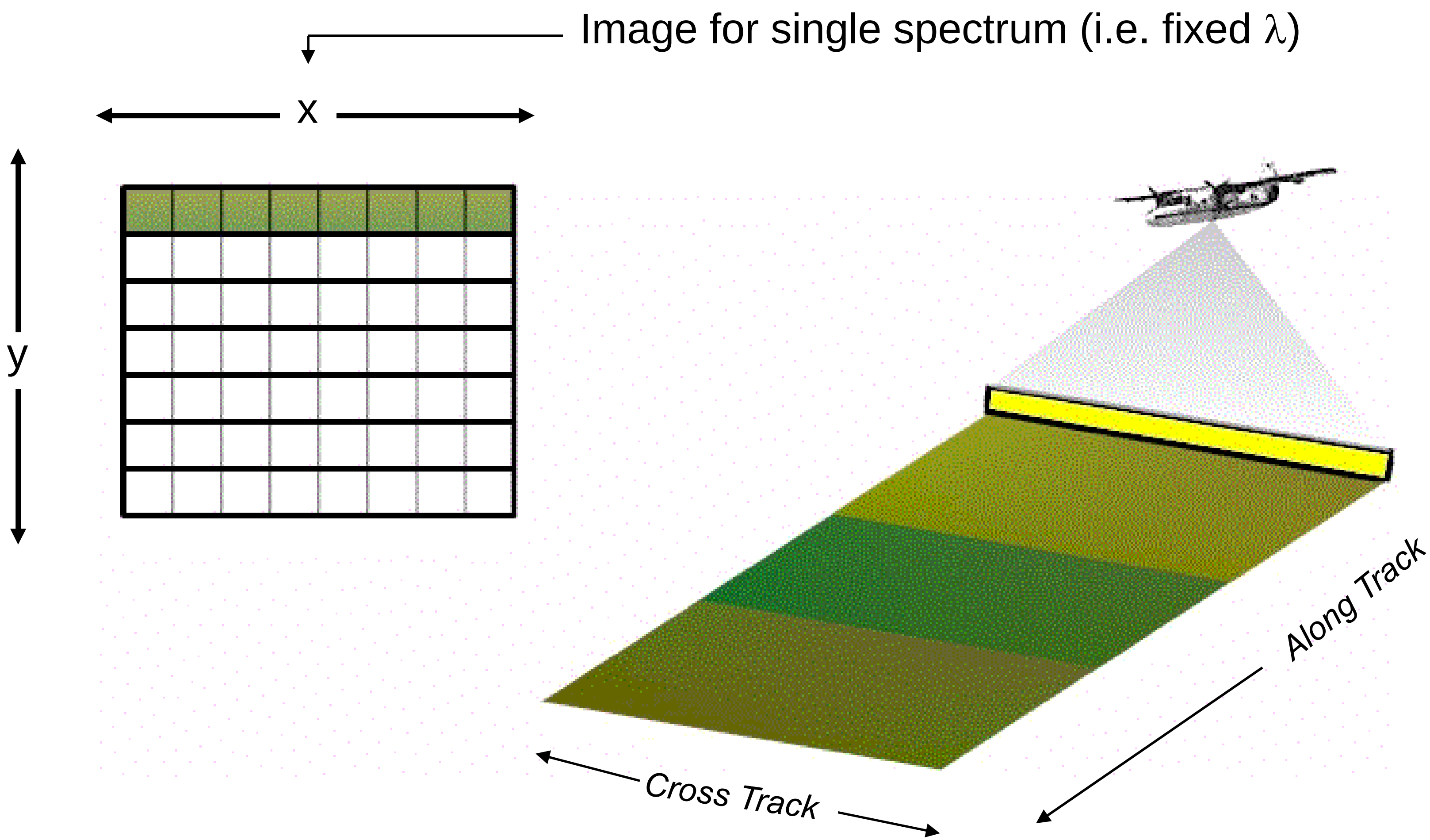
x, the first spatial dimension is obtained by scanning orthogonal to the direction of sensor motion.

y, the second spatial dimension, is obtained in time as sensor is moved across the scene.

2D Array Usage in Imaging Spectrometer



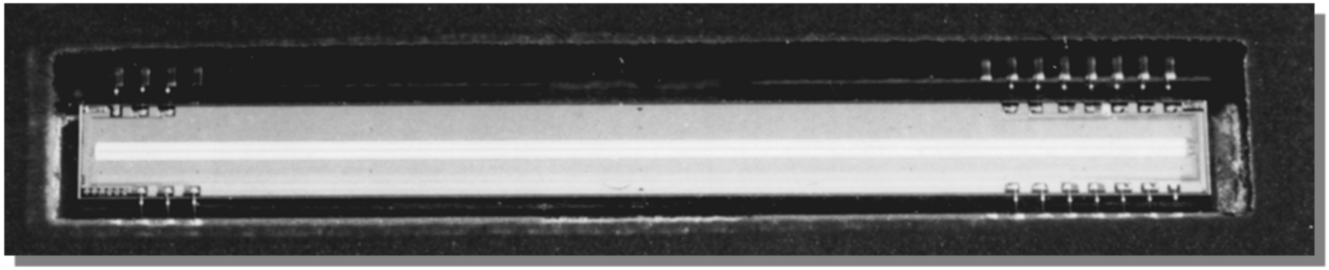
Push-broom Sensor Accumulation
(HYDICE, NVIS, Hyperion)



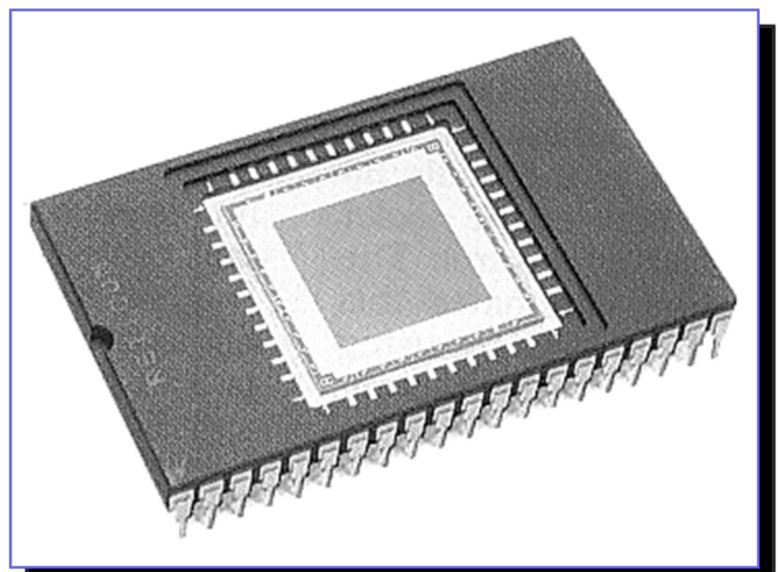
y, the second spatial dimension, is obtained in time as sensor is moved across the scene.

Sensor can also acquire data using a whiskbroom scan procedure to increase FOV.

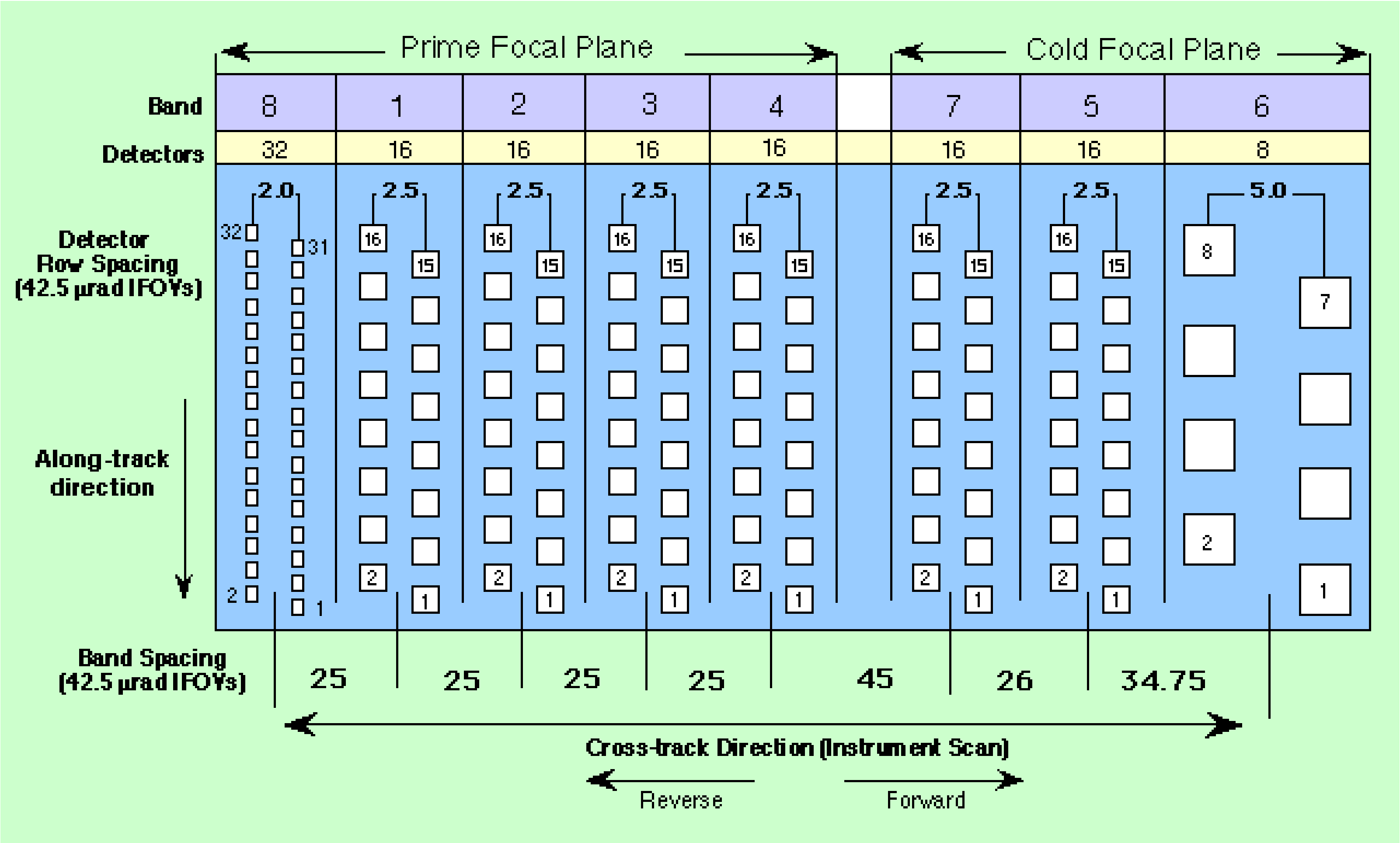
Linear Array CCD



Area Array CCD



Landsat ETM Focal Plane Array



Landsat Sensors

Thematic Mapper (TM)

Spectral bands (micro meters)		IFOV (m)
1.	.45-.52 (blue)	30x30
2.	.52-.60 (green)	30x30
3.	.63-.69 (red)	30x30
4.	.76-.90 (near IR)	30x30
5.	1.55-1.75 (mid IR)	30x30
7.	2.08-2.35 (mid IR)	30x30
6.	10.4-12.5 (thermal)	120x120

LANDSAT TM Simulator, Añasco/Mayaguez, PR

Band 1

Band 2

Band 3

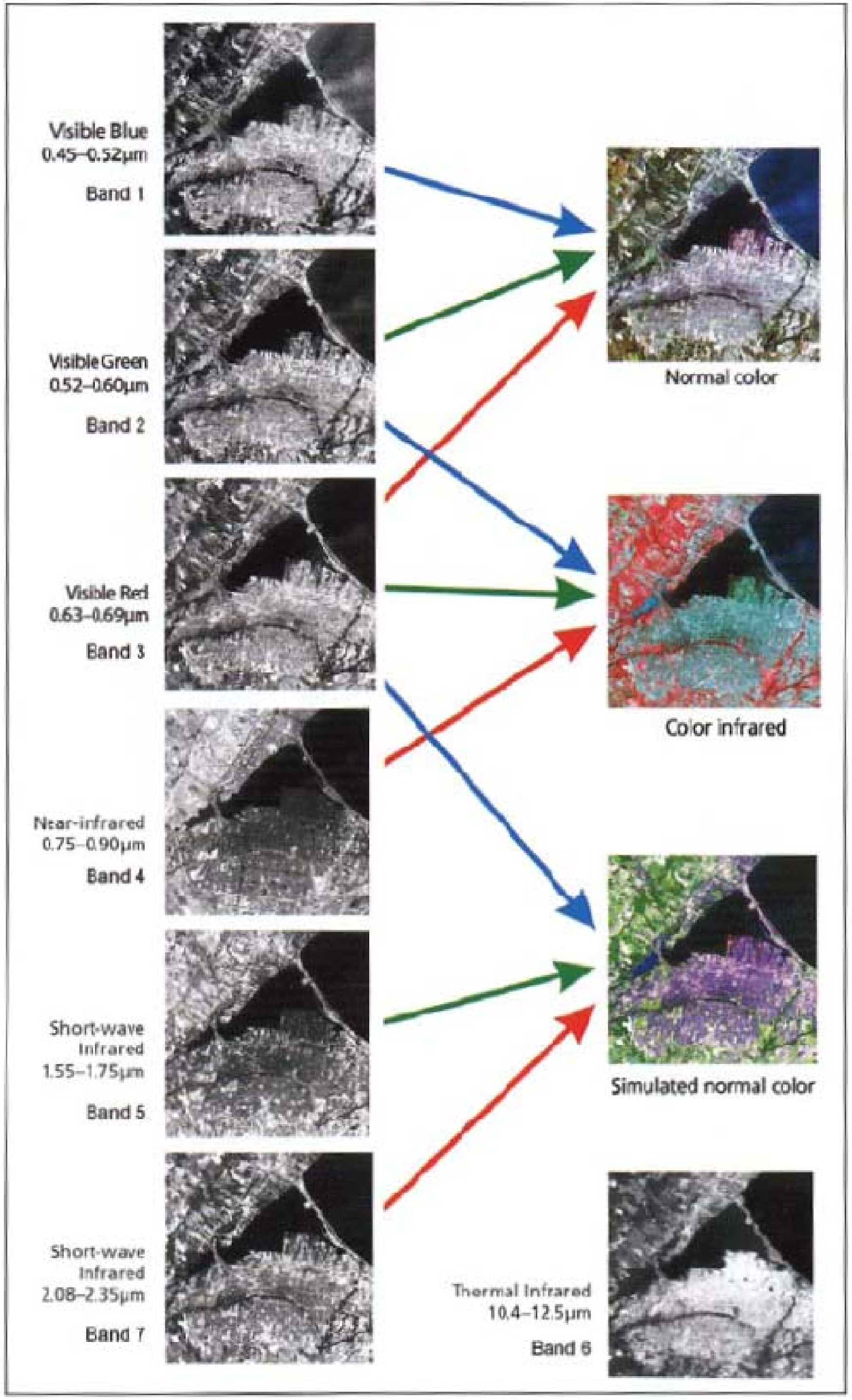
Band 4

Band 5

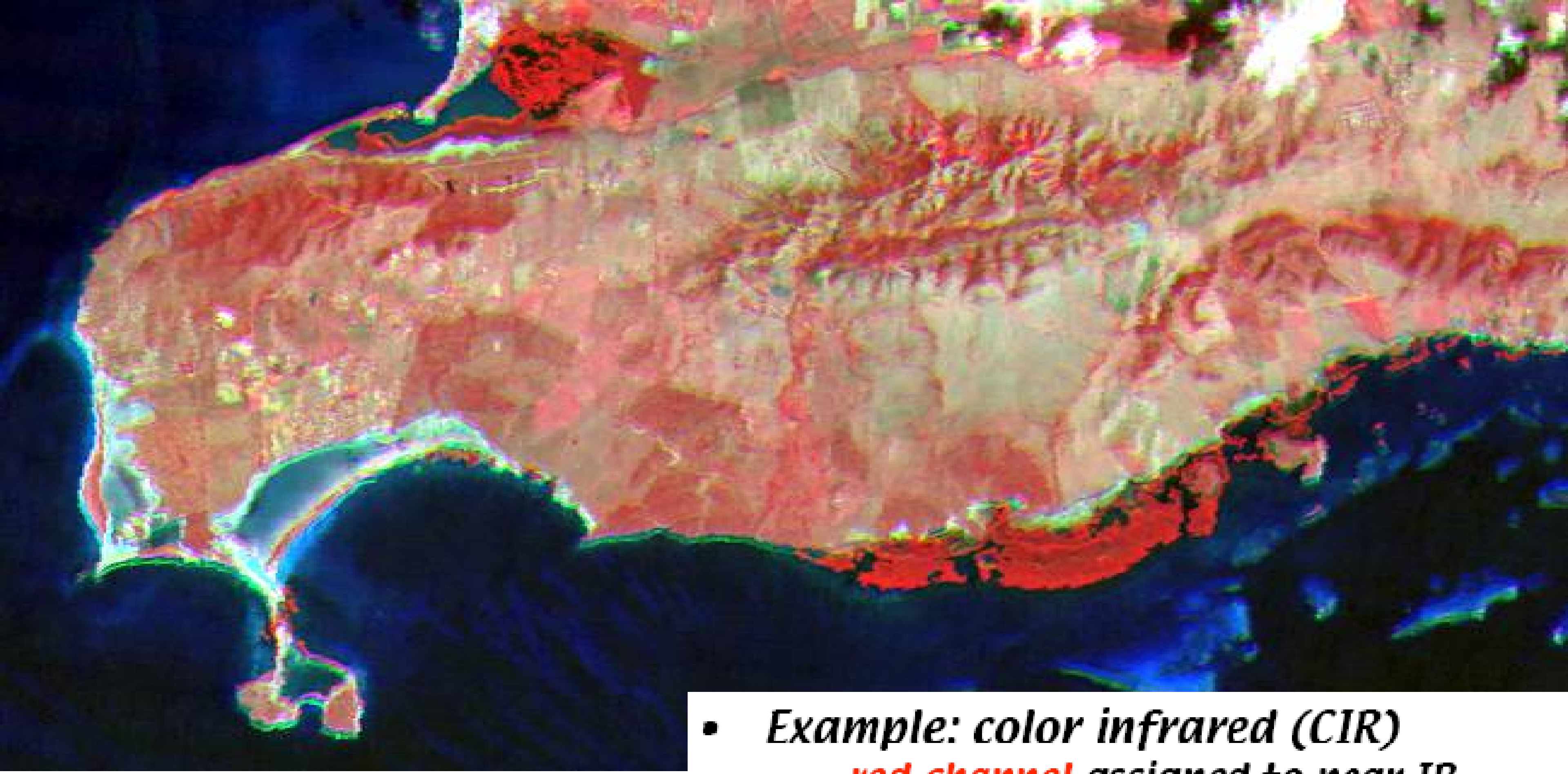
Band 6

Band 7

Landsat TM Color Composites



Landsat TM SW Puerto Rico



Landsat: Color IR image from SW Puerto Rico

- *Example: color infrared (CIR)*
  - *red channel assigned to near IR sensor band*
  - *green channel assigned to red sensor band*
  - *blue channel assigned to green sensor band*
- *vegetation appears red, soil appears yellow - grey, water appears blue - black*

Landsat Simulated Normal Color of PR

IKONOS PAN Sharpened
Old San Juan Bay

Hyperspectral Imagery

or Imaging Spectroscopy

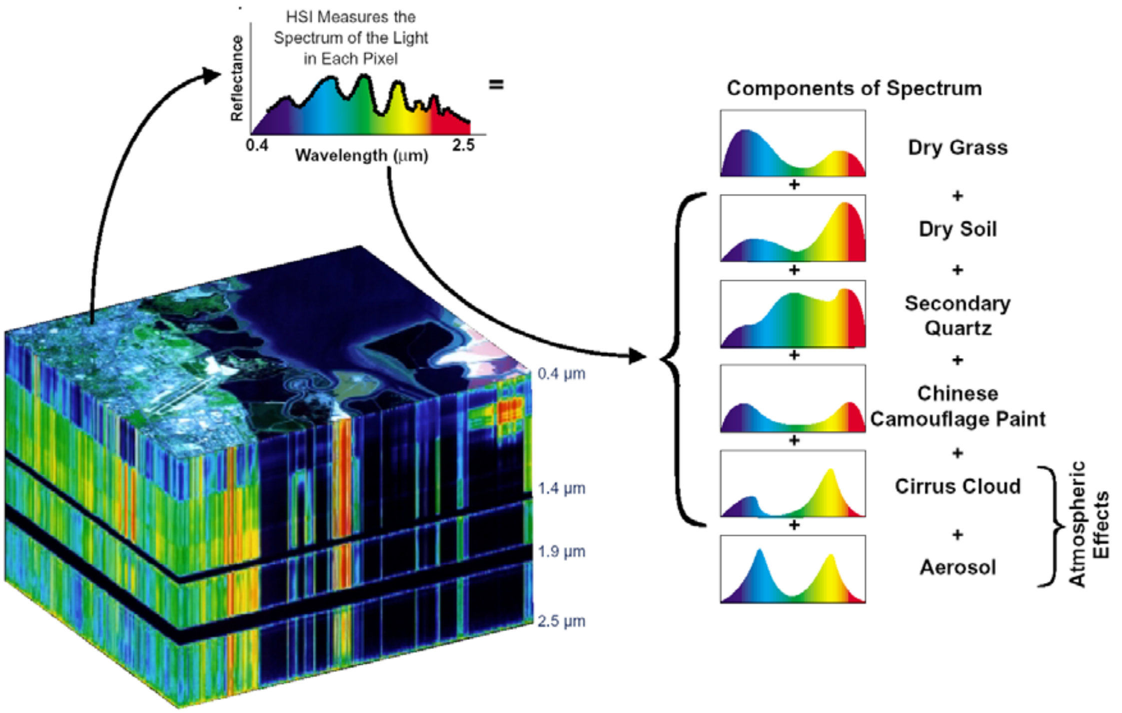
Hyperspectral Imaging, also referred to as *Imaging Spectrometry, combines:*

(i) conventional imaging,

(ii) spectroscopy, and

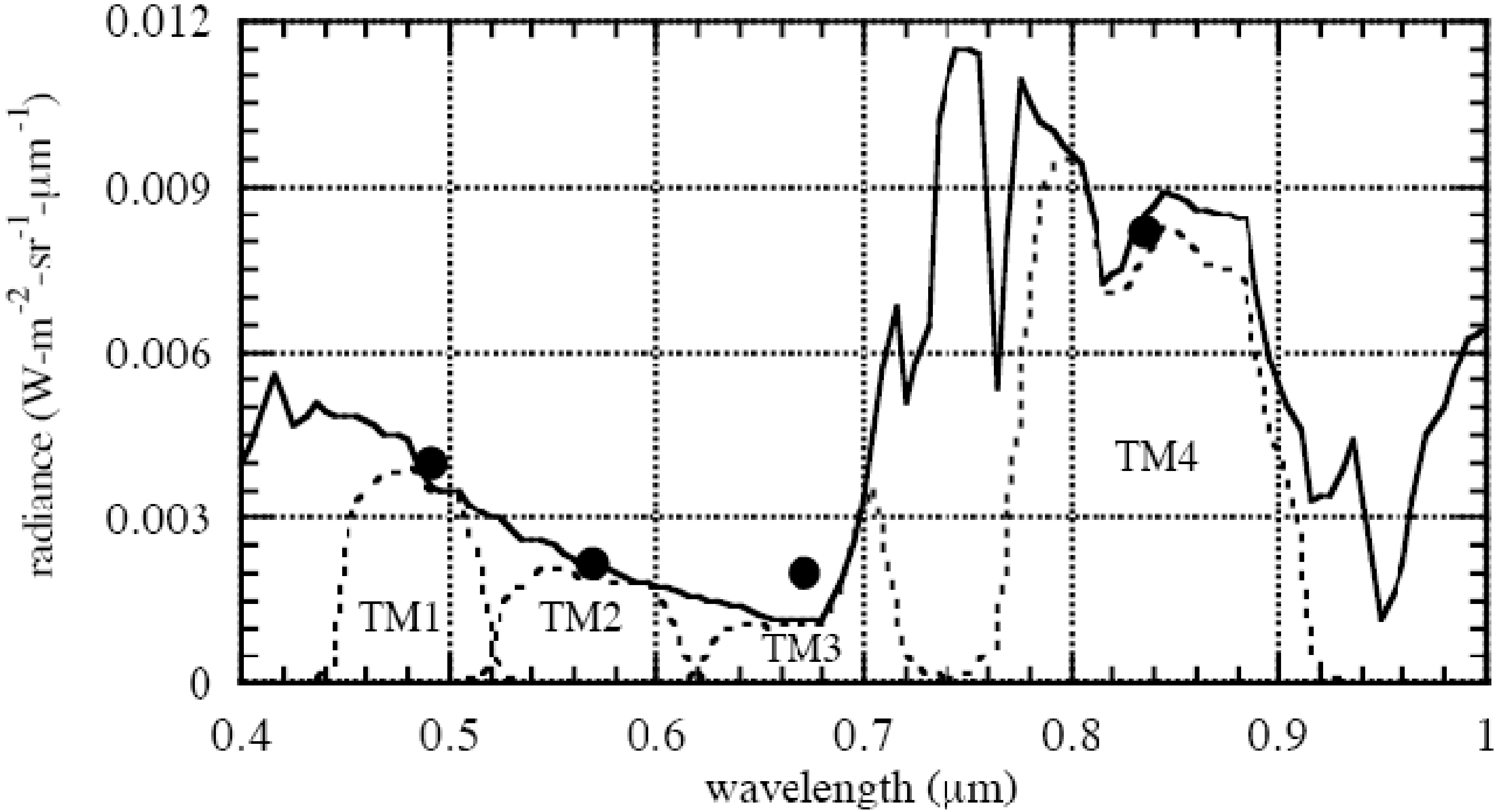
(iii) radiometry

to produce images for which a spectral signature is associated with each spatial resolution element (pixel).

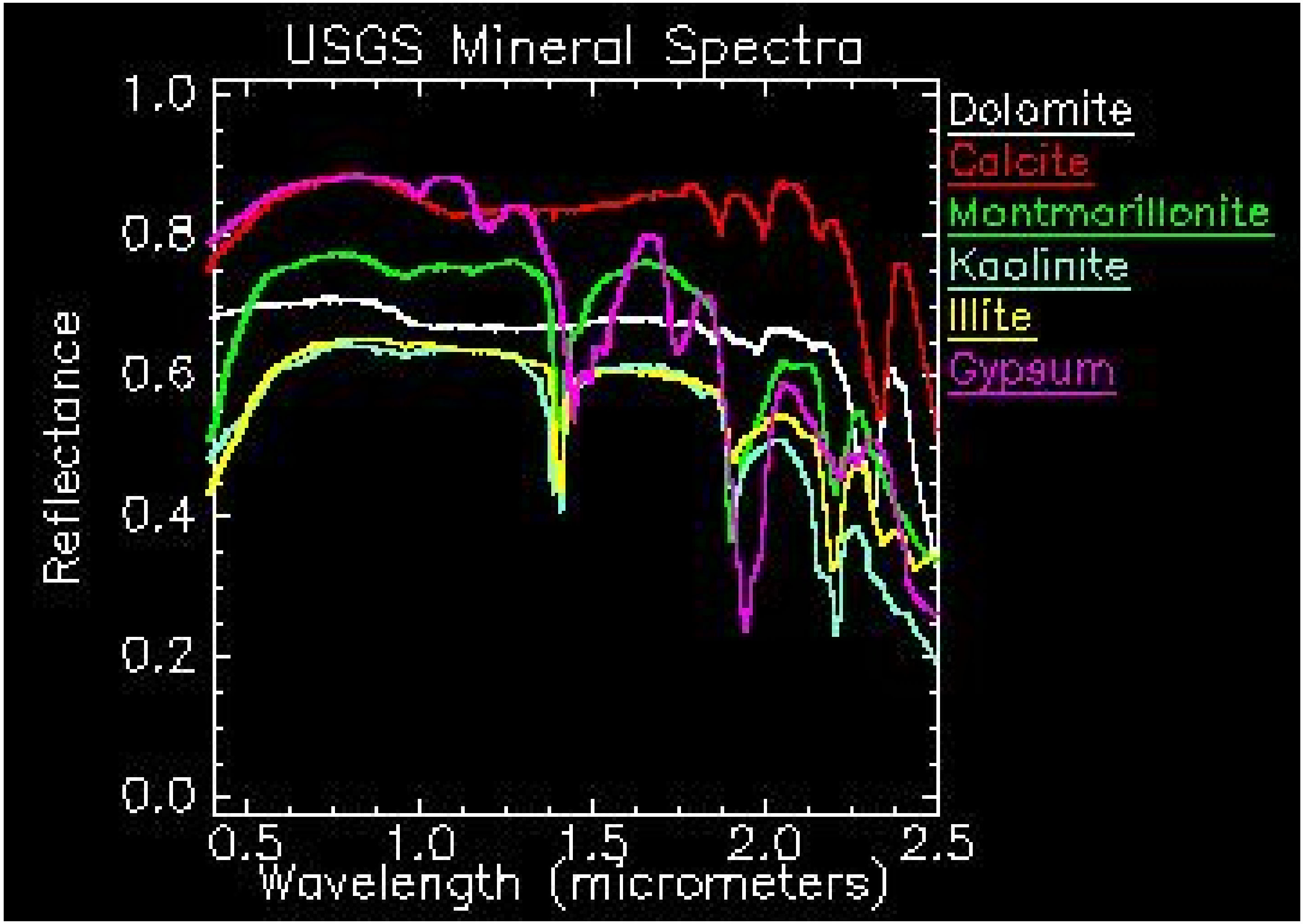


Information Extraction Algorithms for HSI should take advantage of spatial, spatial and temporal variability in the data.

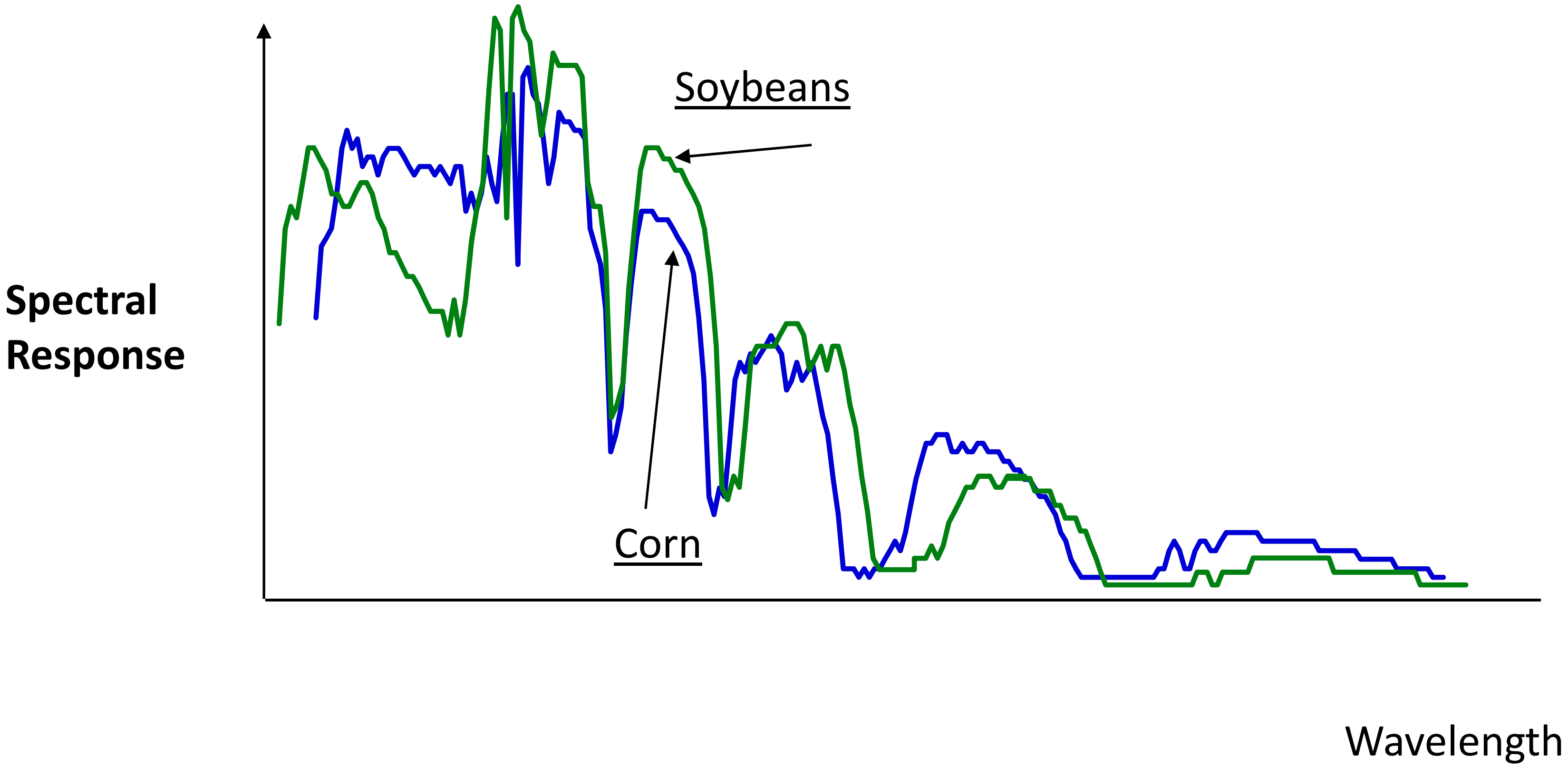
Hyperspectral versus Multispectral



The Spectrum is the Fundamental Datum of HSI RS



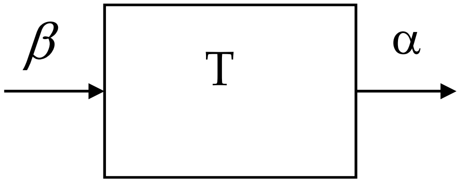
Higher Discriminability



Goals of Spectral Sensing & Imaging Estimation, Detection, Classification, or Understanding

- Estimate: probed spectral signature $\{\alpha(x,y,\lambda)\}$

  physical parameter to be estimated $\{\beta(x,y,\lambda)\}$



Examples of β	Land cover type Crop health Chemical composition, pH, CO_2 Metabolic information Ion concentration Physiological changes (e.g., oxygenation) Extrinsic markers (dyes, chemical tags)

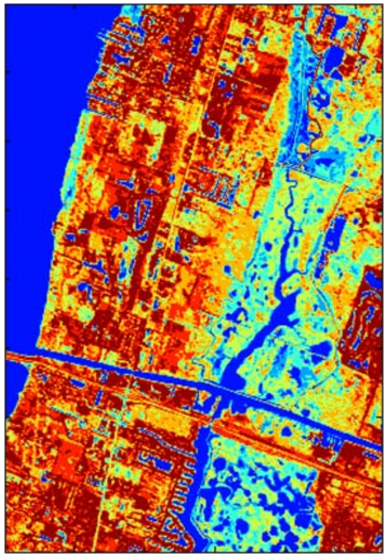
- Detect: presence of a target characterized by its spectral features α or β

- Classify: objects based on features exhibited in α or β.

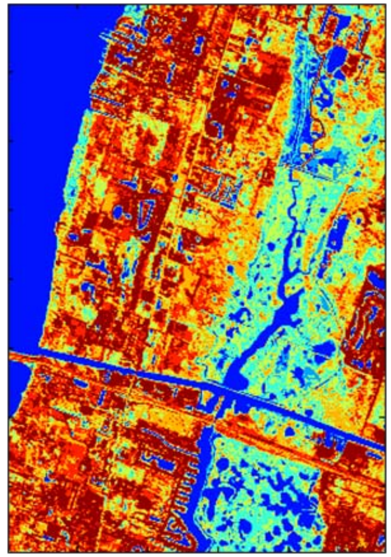
- Or Understand: object information, e.g., spectral signature, shape or other features based on α or β.

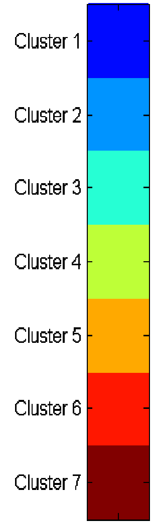
Examples of Classification Maps Derived from Different Feature Sets

PCA

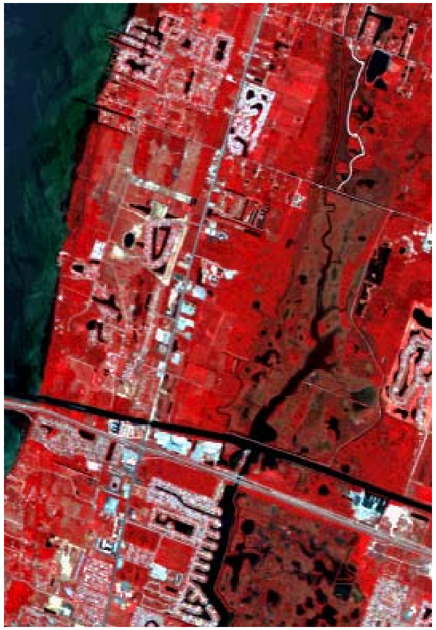


SVDSS

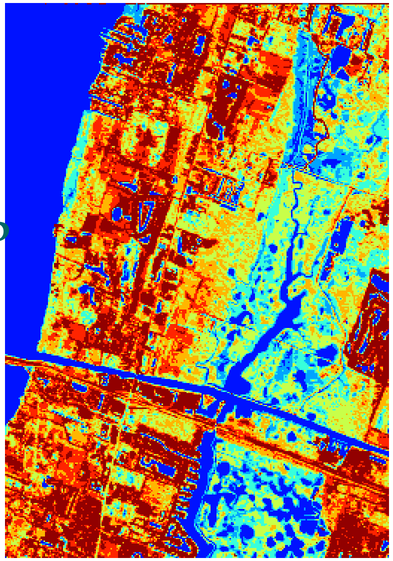




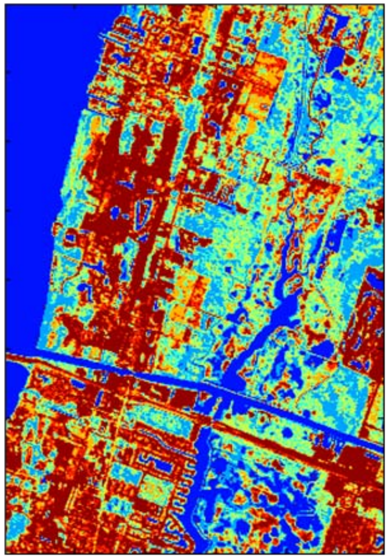
AVIRIS KSC Image



OIDPP



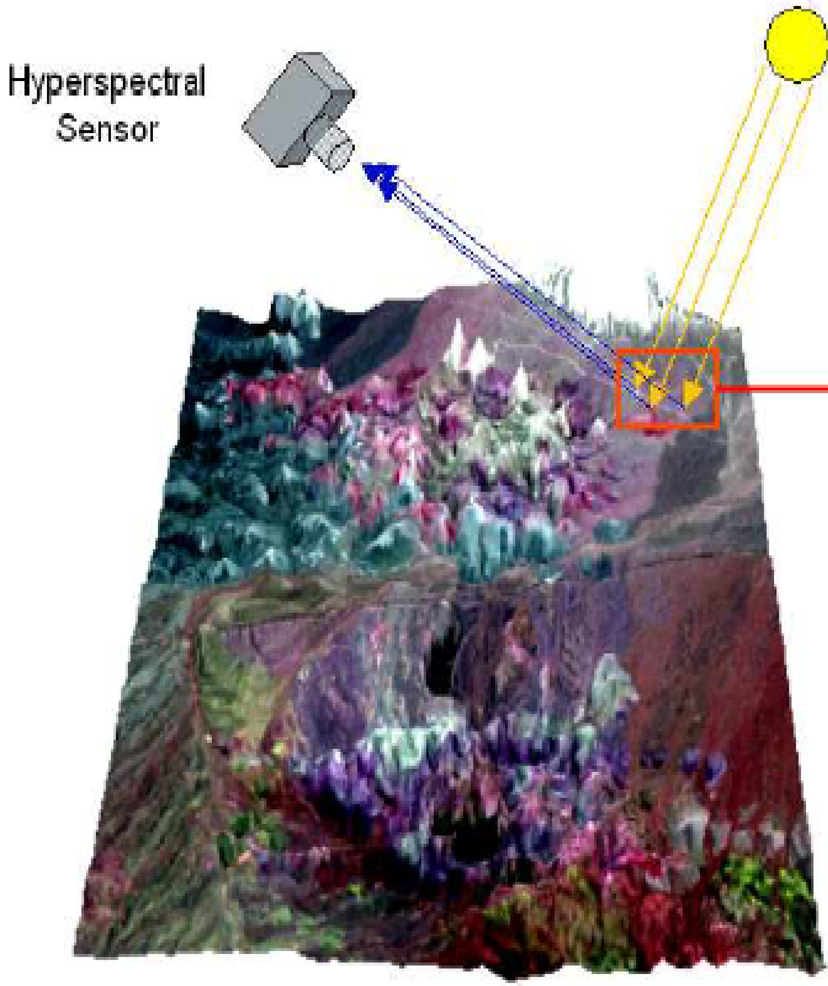
IDSS

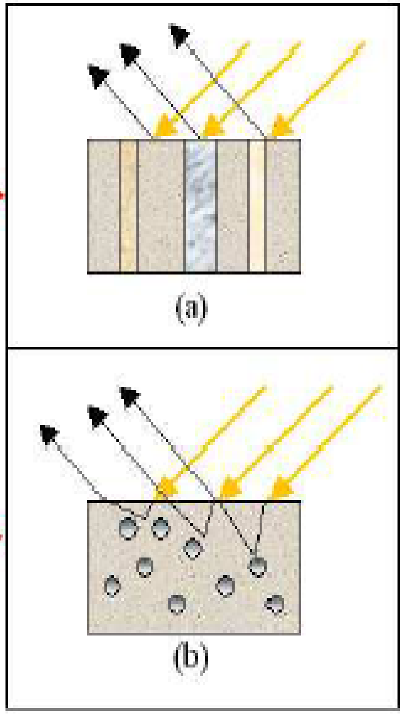


Method	Minimum Bhattacharyya Distance
PCA	0.85
OIDPP	1.56
SVDSS	0.44
IDSS	0.10

C-means with covariance <u>Unsupervised</u> Classification 2 features 7 clusters

Spectral Mixing

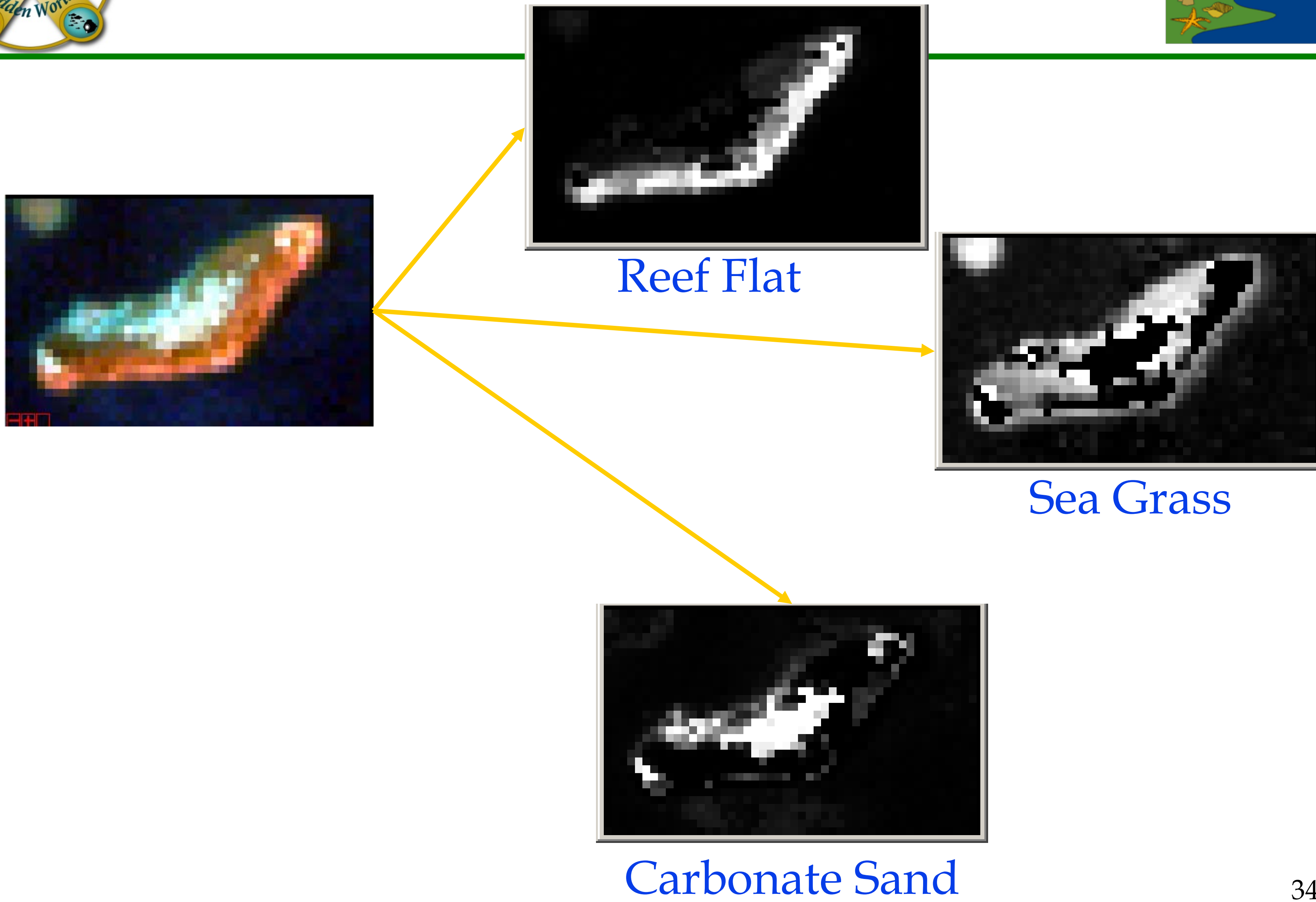




Linear

Nonlinear

HSI Abundance Estimation



Benthic Habitat Monitoring and Mapping

Driving Application in Spectral Sensing

Estimate:

{ α, β }

- Atmospheric constituents
- Aquatic optical properties
- Aquatic constituents
- Benthic composition
- Bathymetry (water depth)

Detect:

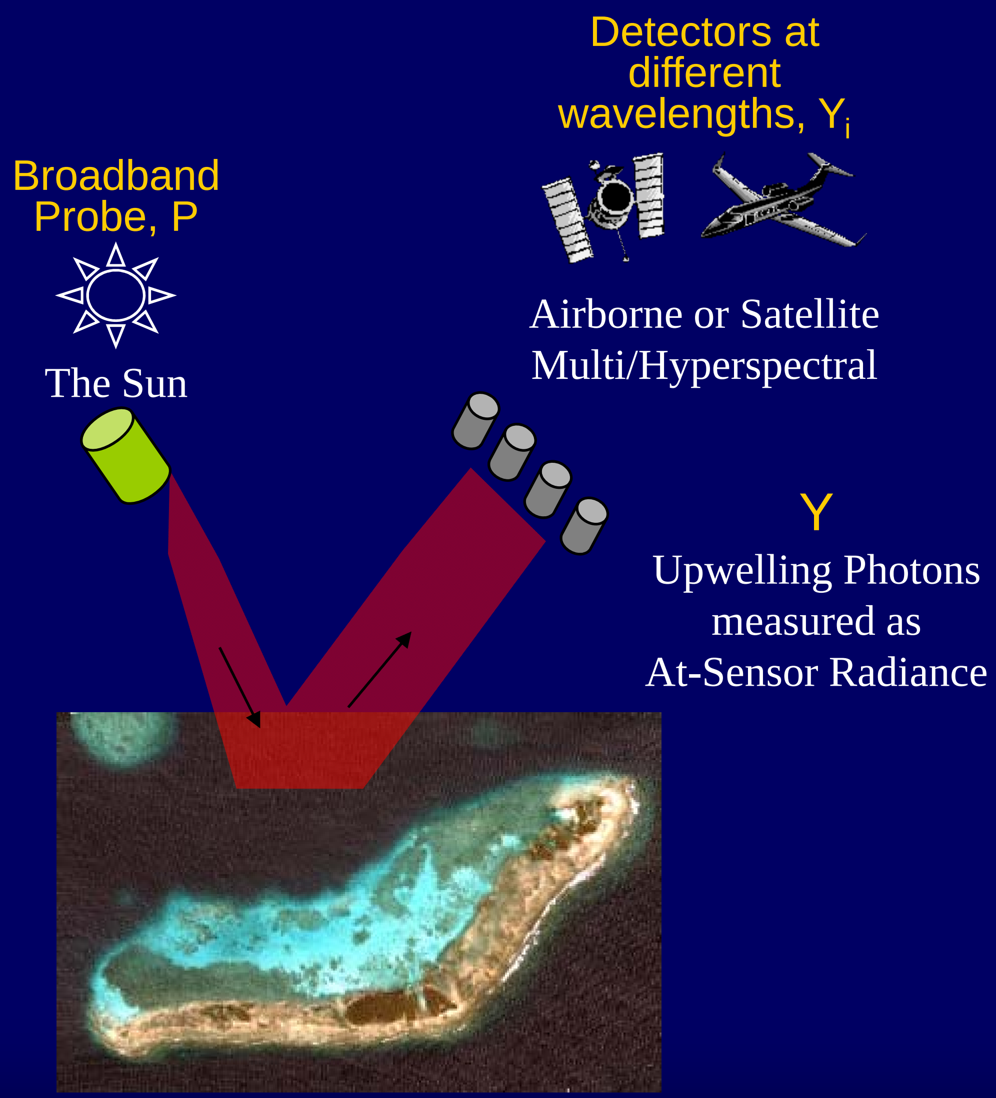
- Healthy/unhealthy coral
- Unexploded ordinance
- Human induced changes

Classify:

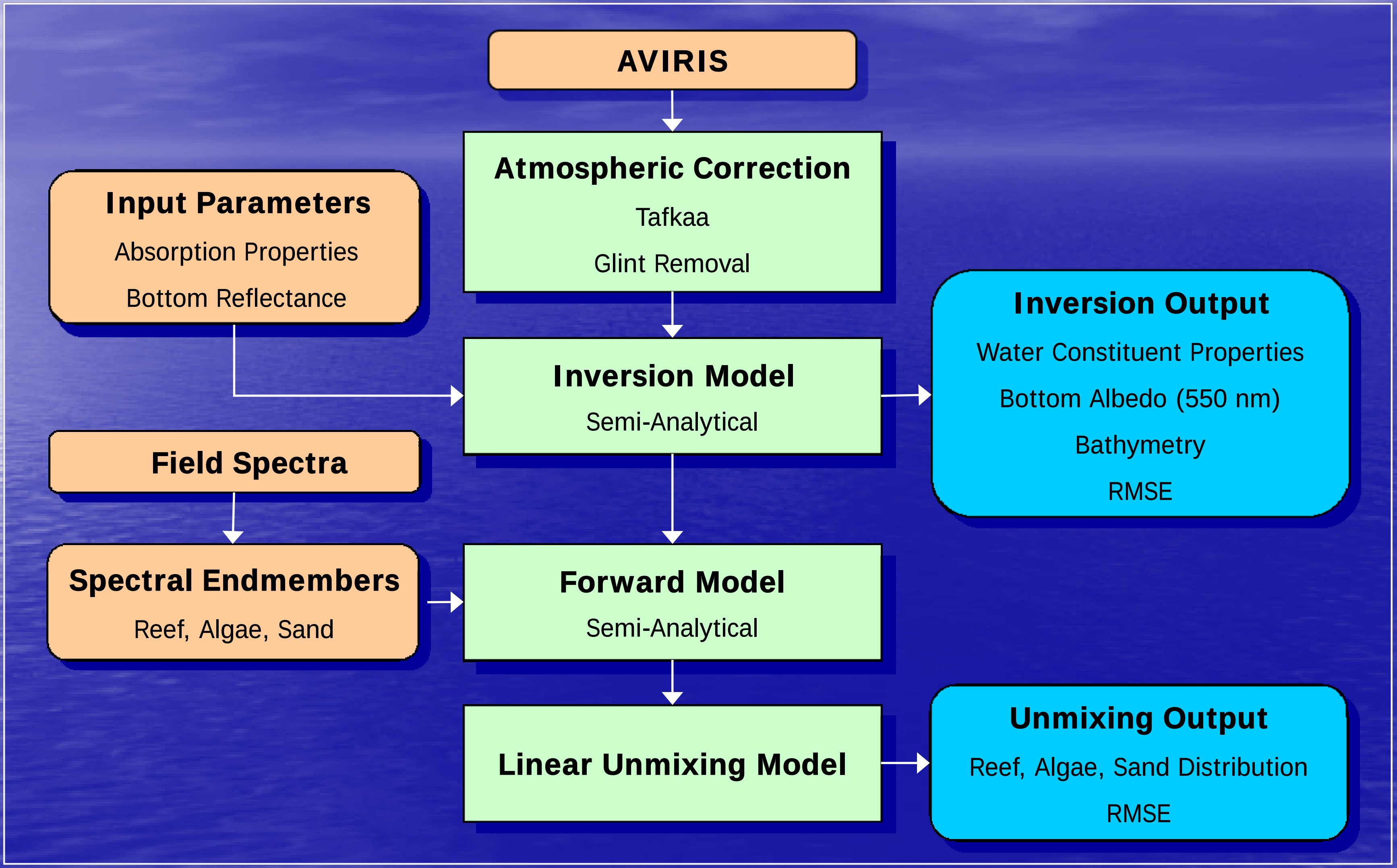
- Coral distribution
- Seagrass density
- Benthic habitat maps

Understand:

- Environmental stressors
- Seasonal/annual changes
- System productivity



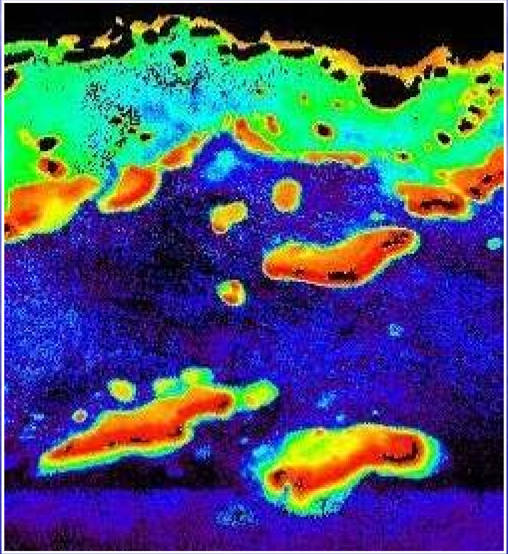
Analysis Procedure

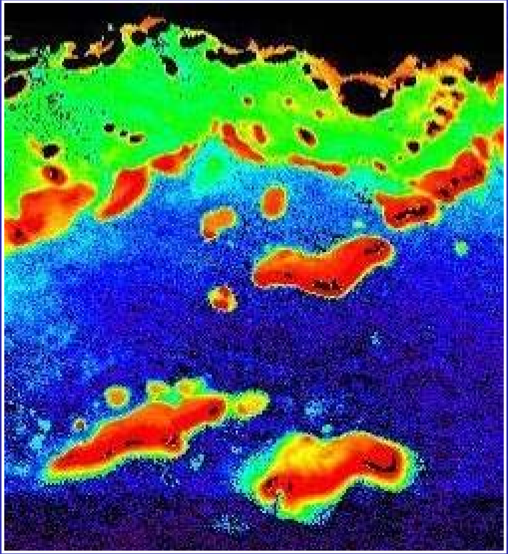


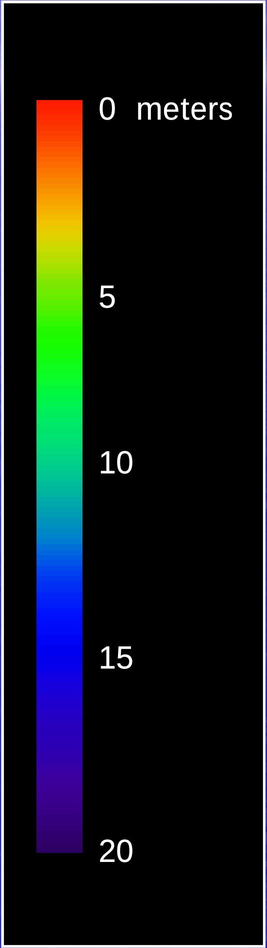
AVIRIS Derived Bathymetry

AVIRIS Color Composite

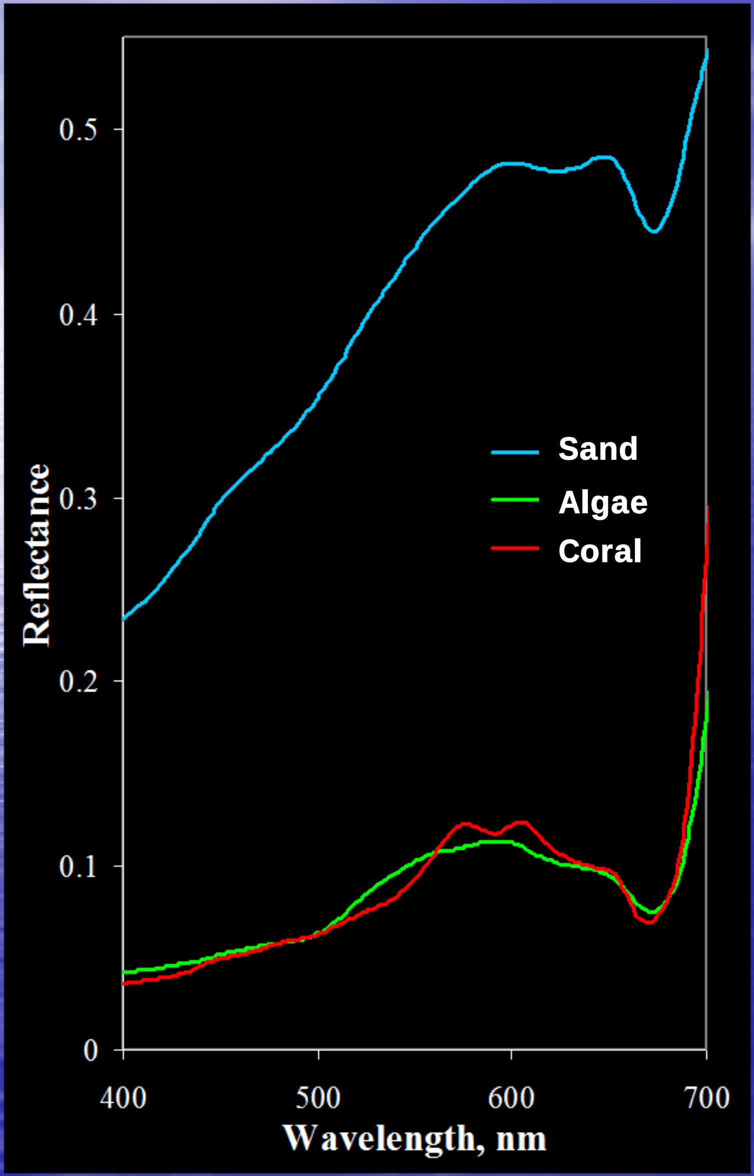
Bathymetry







Endmembers


Reflectance
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
Wavelength, nm
Sand
Algae
Coral


Sand

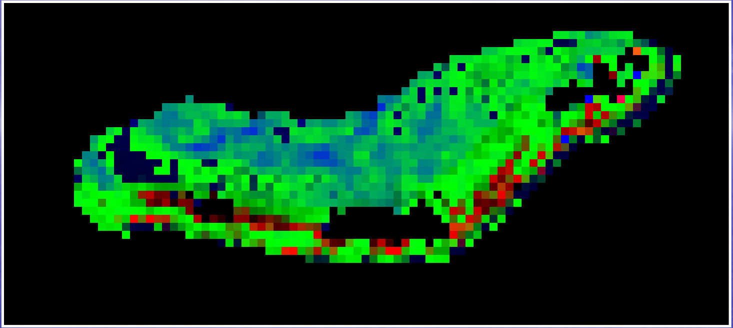

Algae

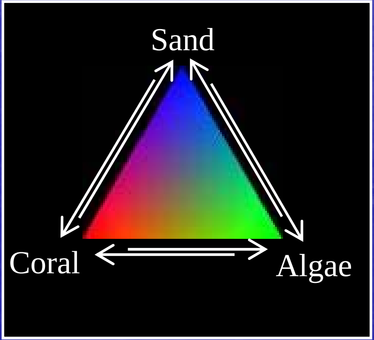

Coral

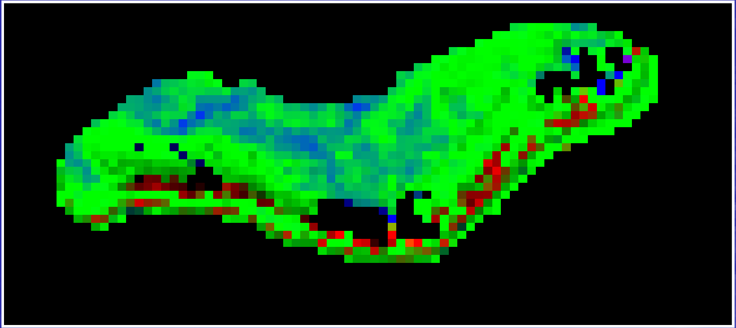
AVIRIS Linear Unmixing

AVIRIS Color Composite

Benthic Habitat Composition

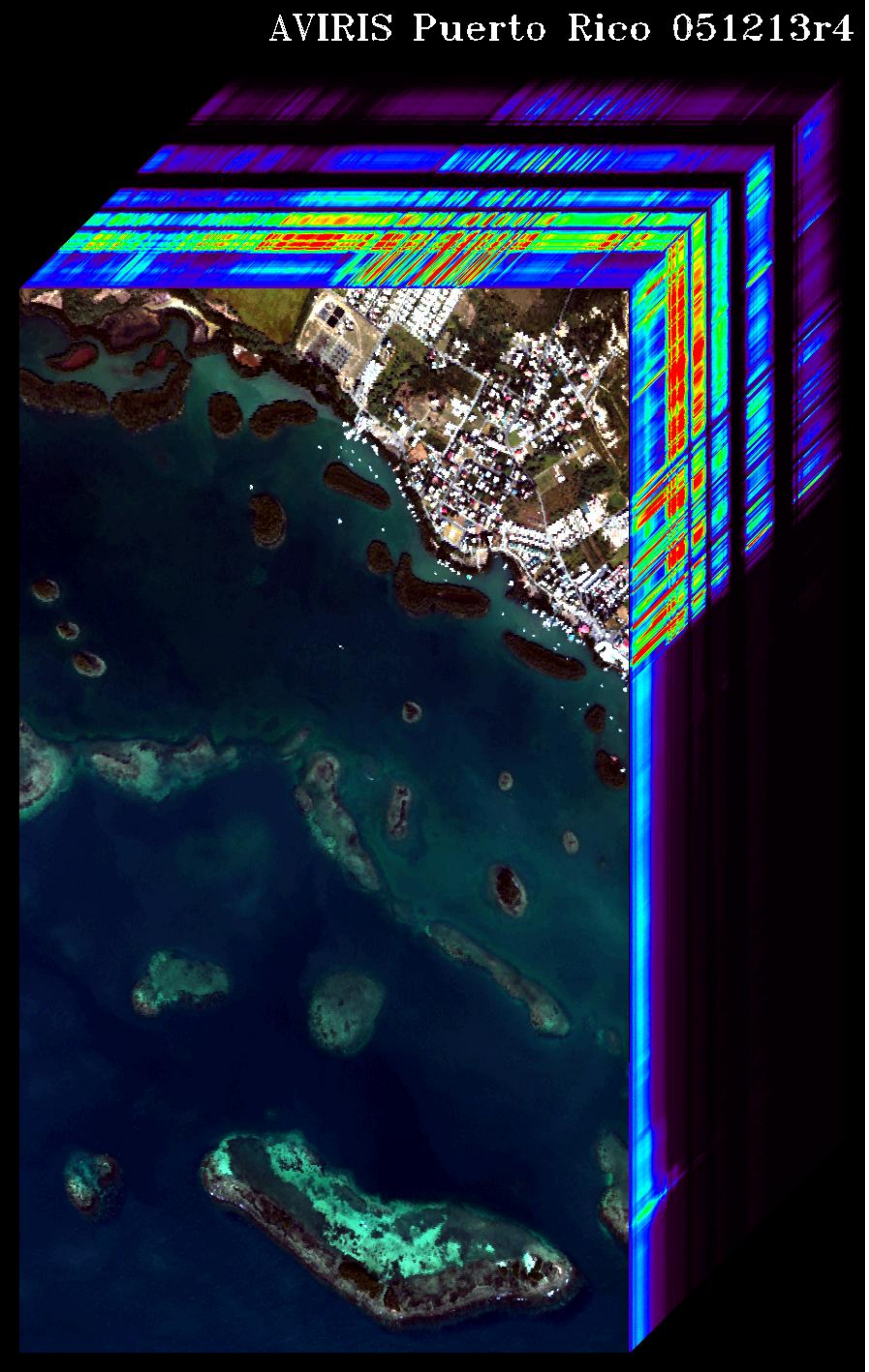






Final Remarks

- Hyperspectral remote sensing is a powerful technology for quantitative remote sensing.
- It is becoming more widely available
  - Commercial providers
    - ITRES, Galileo, etc
- Satelite platforms in plan
  - Hyperion – only avialble
  - ARTEMIS and others coming!



Any Questions