GNR607
Principles of Satellite Image Processing

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Slot 2

Lecture 4 Advanced Sensors for Remote Sensing

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Contents of the Lecture

- **Active Remote Sensing Techniques**
  - **Synthetic Aperture Radar (SAR)**
  - **Light Detection and Ranging (LiDAR)**
- **Hyperspectral Sensors**

Active Remote Sensing

What is Active Remote Sensing?

- In normal course the sensor does not provide its own source of radiation.
- The energy reflected by the objects illuminated by sunlight or emitted due to thermal energy is collected by the sensor in a process known as passive remote sensing.
- When the sensor employs its own source of radiation, it is known as active remote sensing.

Advantages of Active Remote Sensing

- Active sensors do not depend on sun illumination, therefore can operate at any time of day or night
- Illumination conditions can be controlled by adjusting transmitted signal power, look angle, wavelength/frequency etc.

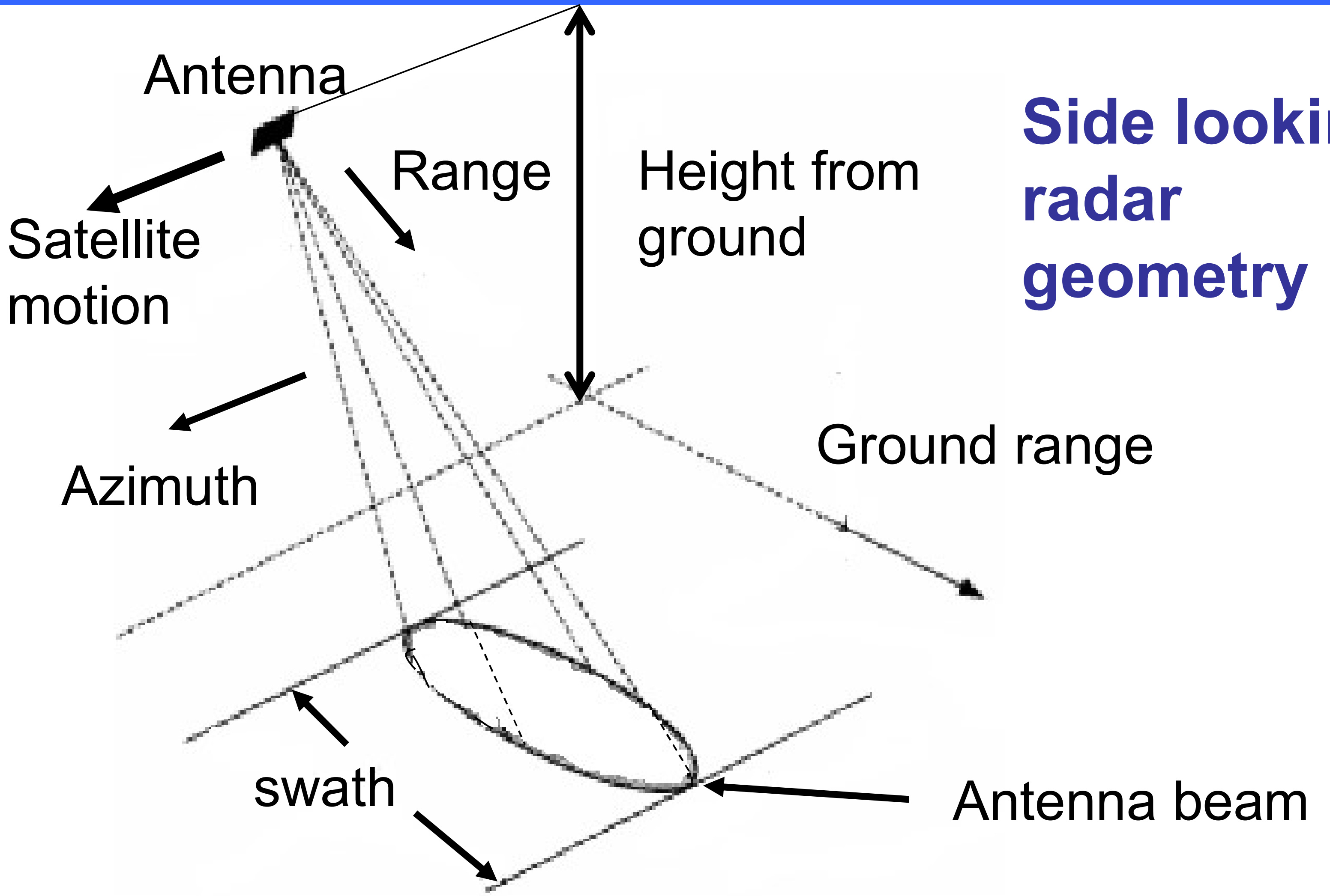
Active Remote Sensors

- Two technologies are in use today for active remote sensing
  - Radar remote sensing, operating in microwave region
  - Laser remote sensing, operating in near infrared wavelengths
  - More complex compared to passive systems

Active Microwave Remote Sensing

- Include a microwave signal generator, with a pre-defined frequency
  - **L band**: 1-2 GHz
  - **C band**: 4-8 GHz
  - **X band**: 8-12 GHz
- L band radar 1.3 GHz onboard Japanese (ALOS) satellite
- C band radar 5.3 GHz onboard Canadian Radarsat satellite
- C band radar 5.3 GHz onboard European Space Agency (ESA) ERS series of satellites
- ESA Tandem-X and TerraSAR-X missions operating in X-band
- https://www.dlr.de/dlr/en/Portaldata/1/Resources/documents/TSX_brosch.pdf

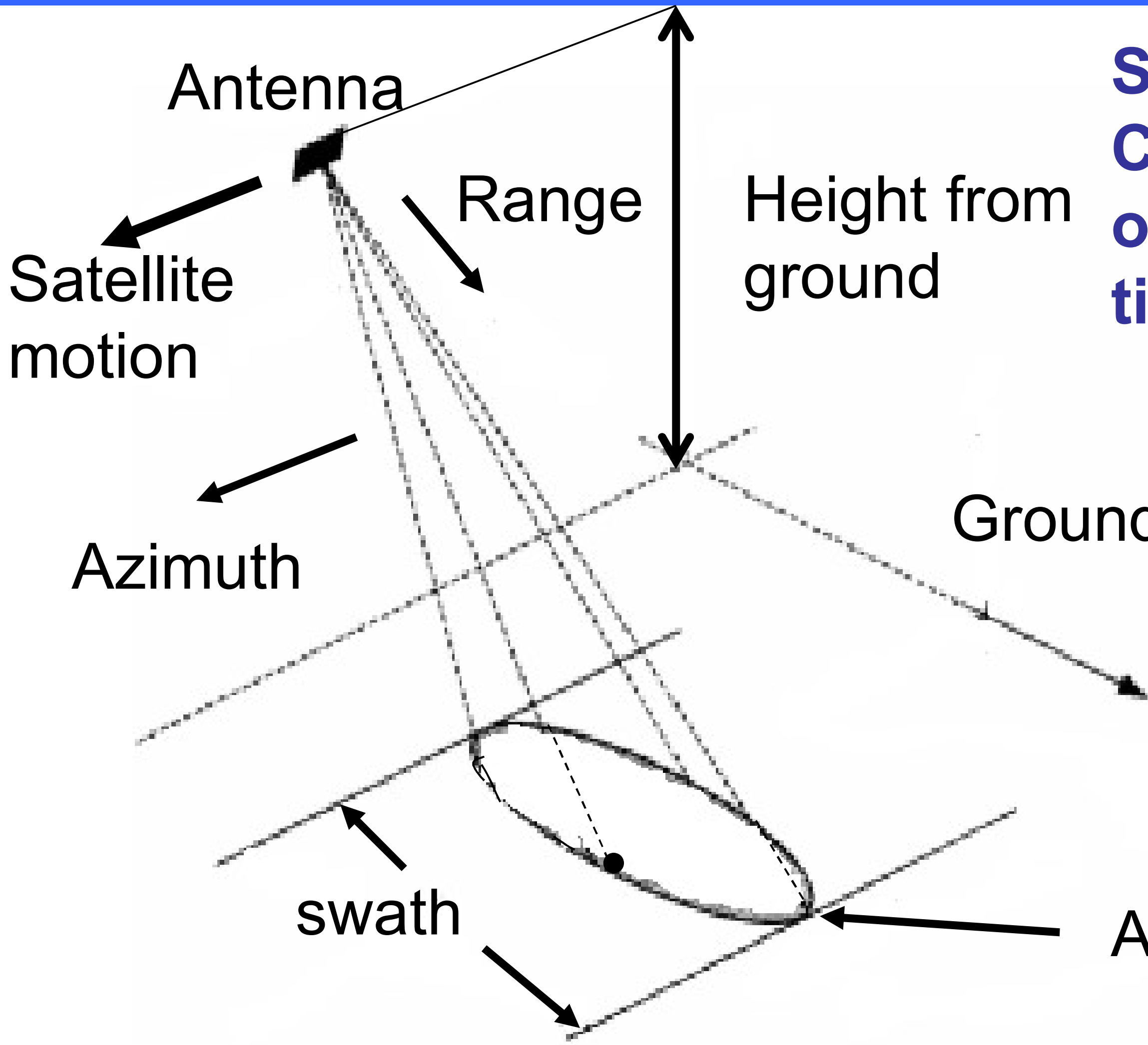
Side looking radar geometry



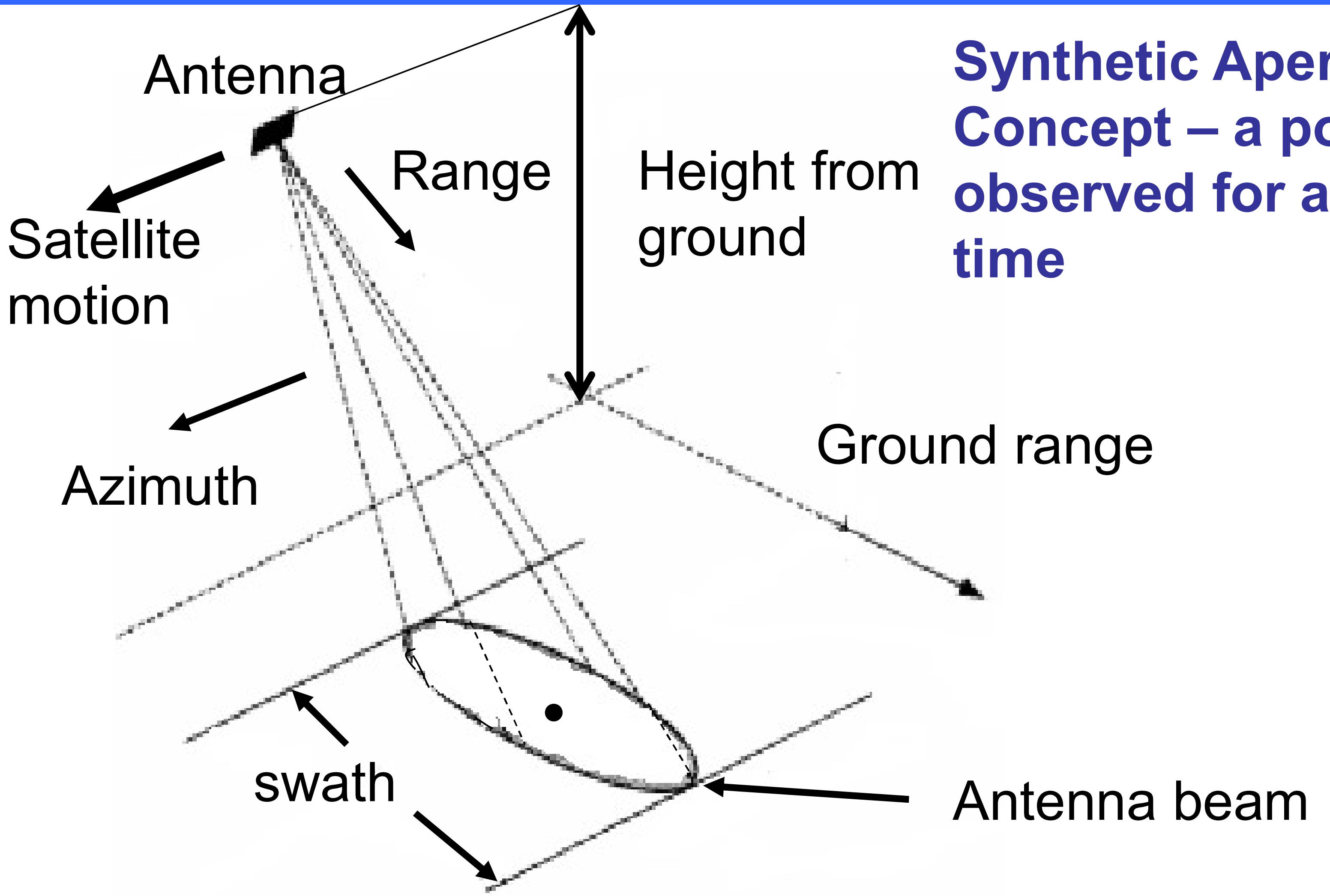
Active Microwave Imaging

- Complex process
- Radar antenna transmits a microwave beam to ground and receives the back scattered energy in phase
- Wavelength centimetres long, considered wave
- Most common technique synthetic aperture radar (SAR) based imaging
- Along-track (azimuth) resolution is dependent on the size of antenna
- Across-track (range) resolution depends on bandwidth of the transmitted radiation

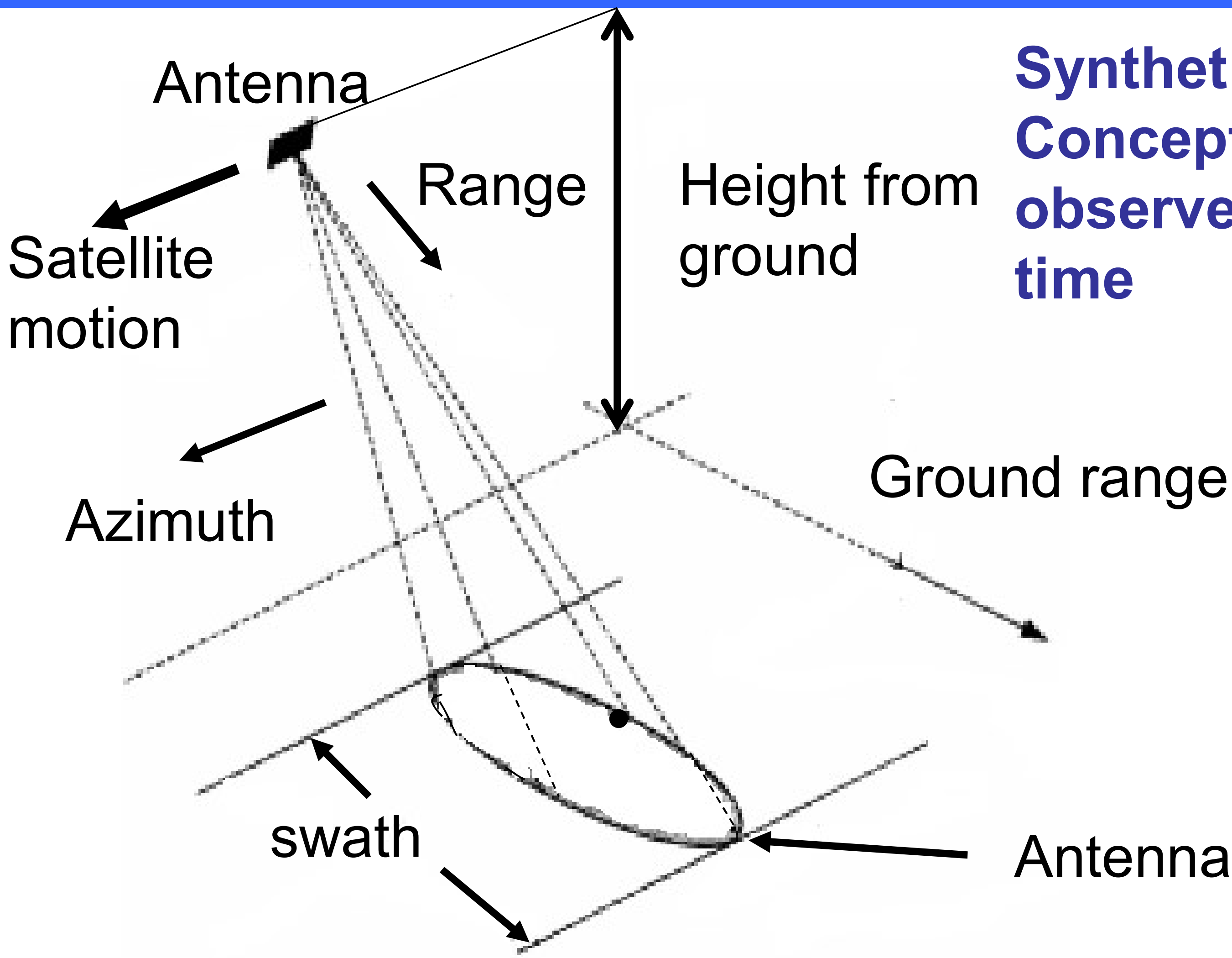
Synthetic Aperture Concept – a point is observed for a long time



Synthetic Aperture Concept – a point is observed for a long time



Synthetic Aperture Concept – a point is observed for a long time



SAR Imaging

- High resolution achieved using *synthetic aperture radar*
- Time history of any point in the field of view from entry in beam to exit
- Large virtual antenna synthesized resulting in effect of fine beam
- By pulse compression techniques across track resolution is improved
- Point characterized by range from antenna, and Doppler shift in frequency due to satellite motion
- Range-Doppler values are translated into row-column positions through signal processing techniques

Advantages of SAR Imaging

- Large wavelengths compared to size of particles in atmosphere – no effect of clouds, dust, gases
- Only very heavy rain can disturb the quality of the data collected
- All weather capability - advantage in tropical and polar regions
- Side-looking viewing geometry reacts to topography
- Requires additional corrections in hilly terrain
- Microwave radiation reacts to soil moisture and surface roughness
- Appearance of images slightly different from optical images

Disadvantages of Coherent Imaging

- SAR images have a problem of a particular type of noise, known as *speckle noise*
- Speckle effect is as a result of coherent addition of echoes from all the sub-pixel scatterers at the receiving antenna
- In-phase addition of such echoes results in strong signal
- Out-of-phase addition of the echoes results in weak signal
- Irrespective of terrain condition, some pixels can be unusually brighter and some pixels darker than their background
- Speckle noise removal has many known tools, and it is also a topic of research around the world

From NASA Remote Sensing Tutorial

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Image of California Bay area, taken by NASA Shuttle Imaging Radar Mission (SIR-C) in 1994

From NASA Remote Sensing Tutorial

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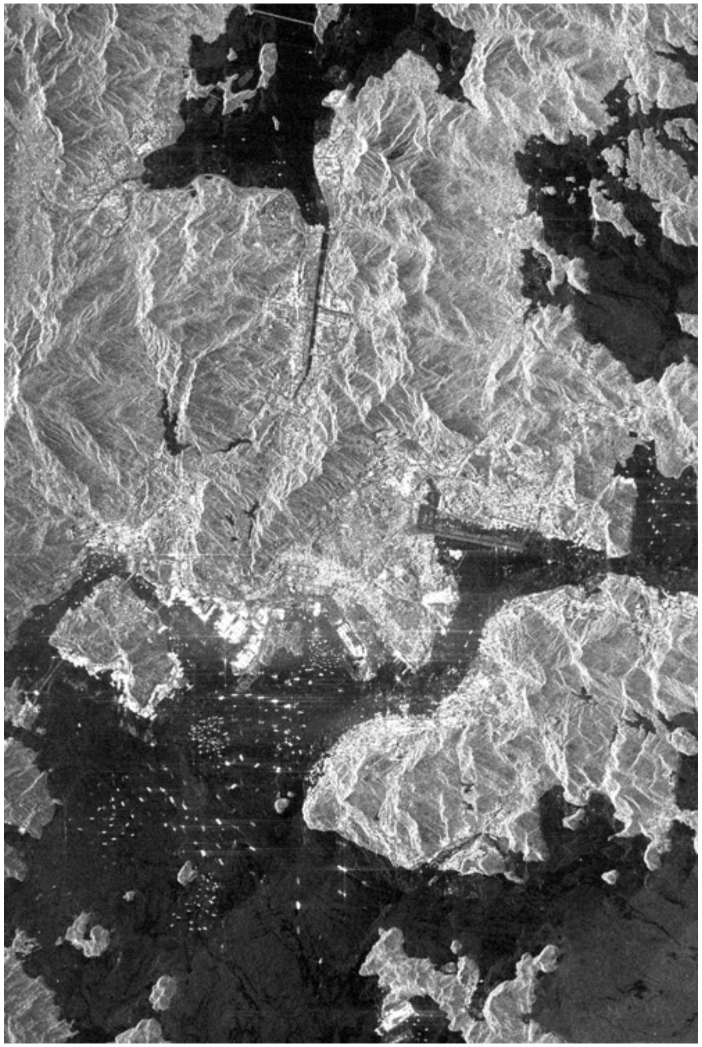


X-Band SAR image of Hong Kong and nearby mountains, ships in the coast; image taken by NASA Shuttle Imaging Radar Mission (SIR-C) in 1994

Points to ponder…

- Why is an active remote sensing system more complex and expensive to build?
- Why is that microwaves can penetrate through clouds easily, while optical radiation is blocked by clouds?

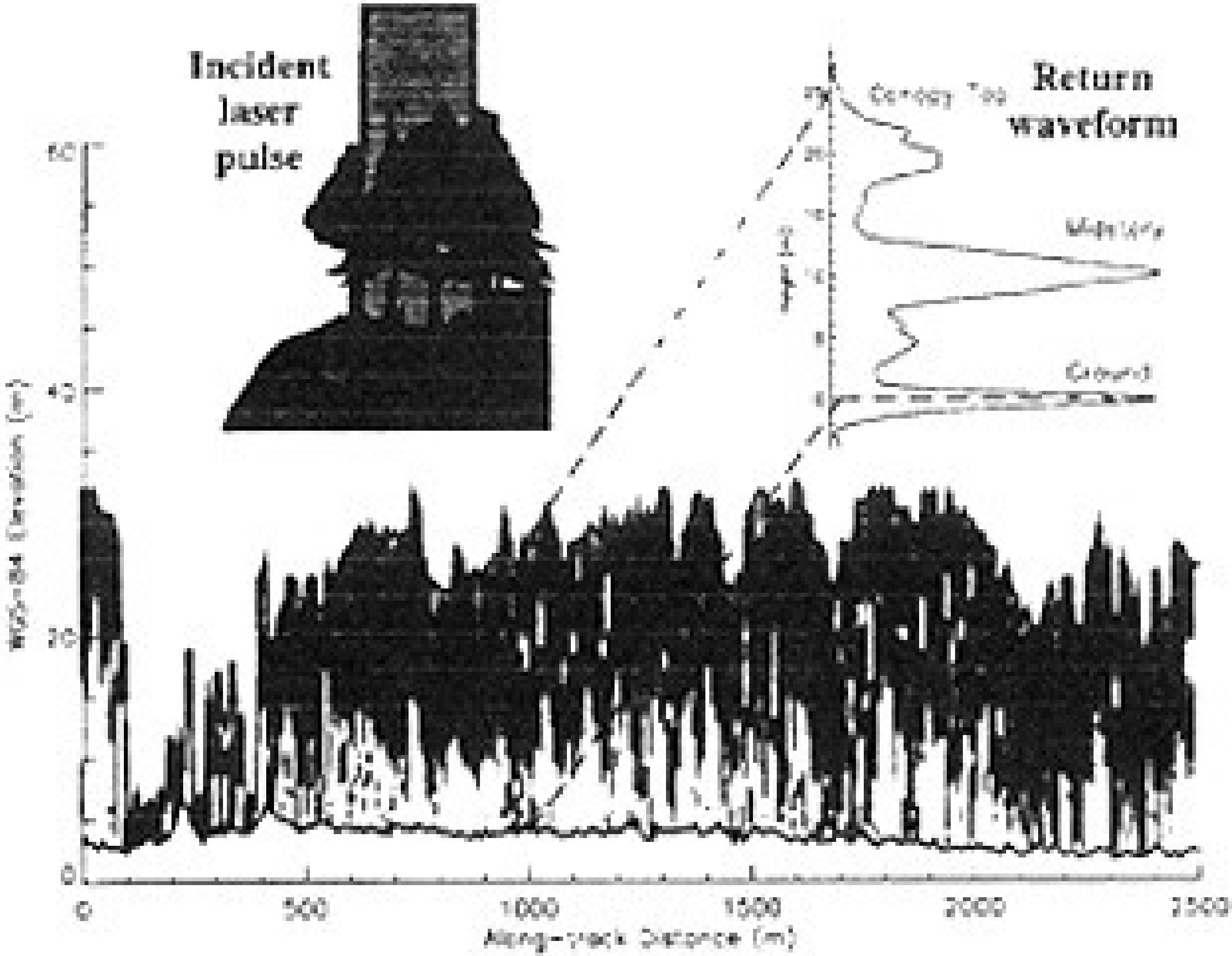
LiDAR

- LiDAR – Light Detection And Ranging
- Wavelength commonly used - Near Infrared (1 micron)
- Developed in 1960's; entered market in 1990's
- Major applications
  - Measurement of Elevation or Range
  - Atmospheric sounding
- Currently available on aircraft platform for terrain studies
- Satellite based sensors are used for atmospheric studies
- Height accuracy in terrain modeling can be up to 10-15 cms

LiDAR

- Principle
  - As the plane flies over a surface a concentrated light beam in a very narrow wavelength band is emitted from the sensor to the ground
  - Elevations can be calculated based on the time taken for the echo of the beam received from the target
- Data (point clouds)
  - LiDAR data is comprised of 4 attributes
  - X, Y, range, Intensity

LiDAR Operation



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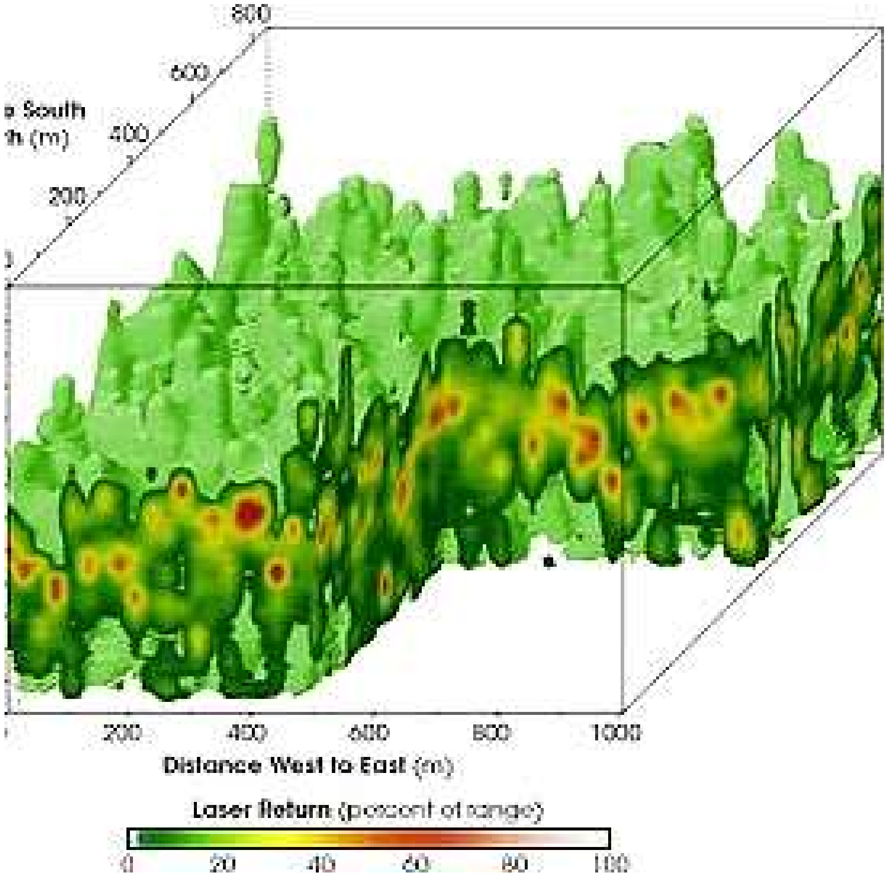
Output from LiDAR



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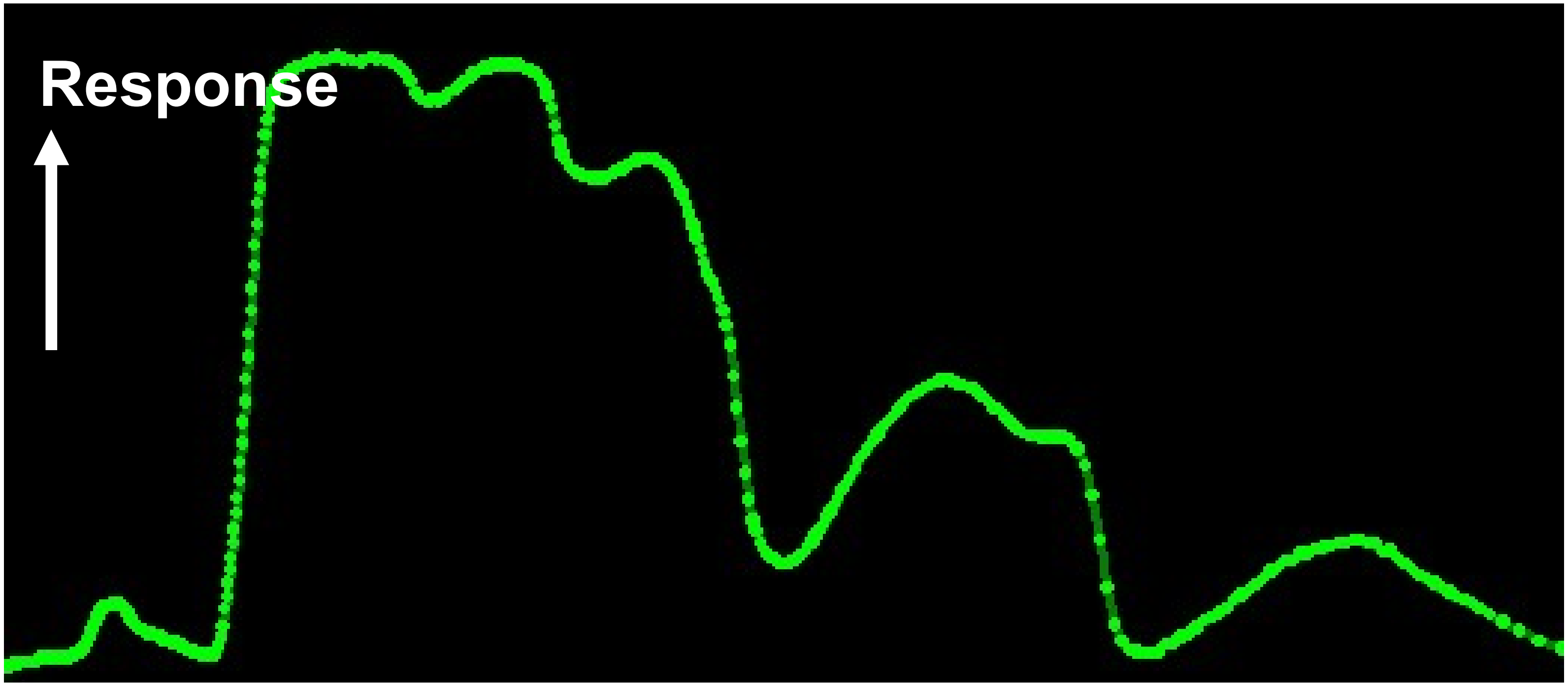
Forest tree canopy model

Hyperspectral Sensors

Hyperspectral Image Analysis

- Hyperspectral images are very high dimensional data sets
- Number of bands in a typical hyperspectral image > 200
- Narrow bandwidth and contiguous
- A new perspective on image analysis
- New sensor technology
- Spatial resolution relatively coarse

High Spectral Resolution

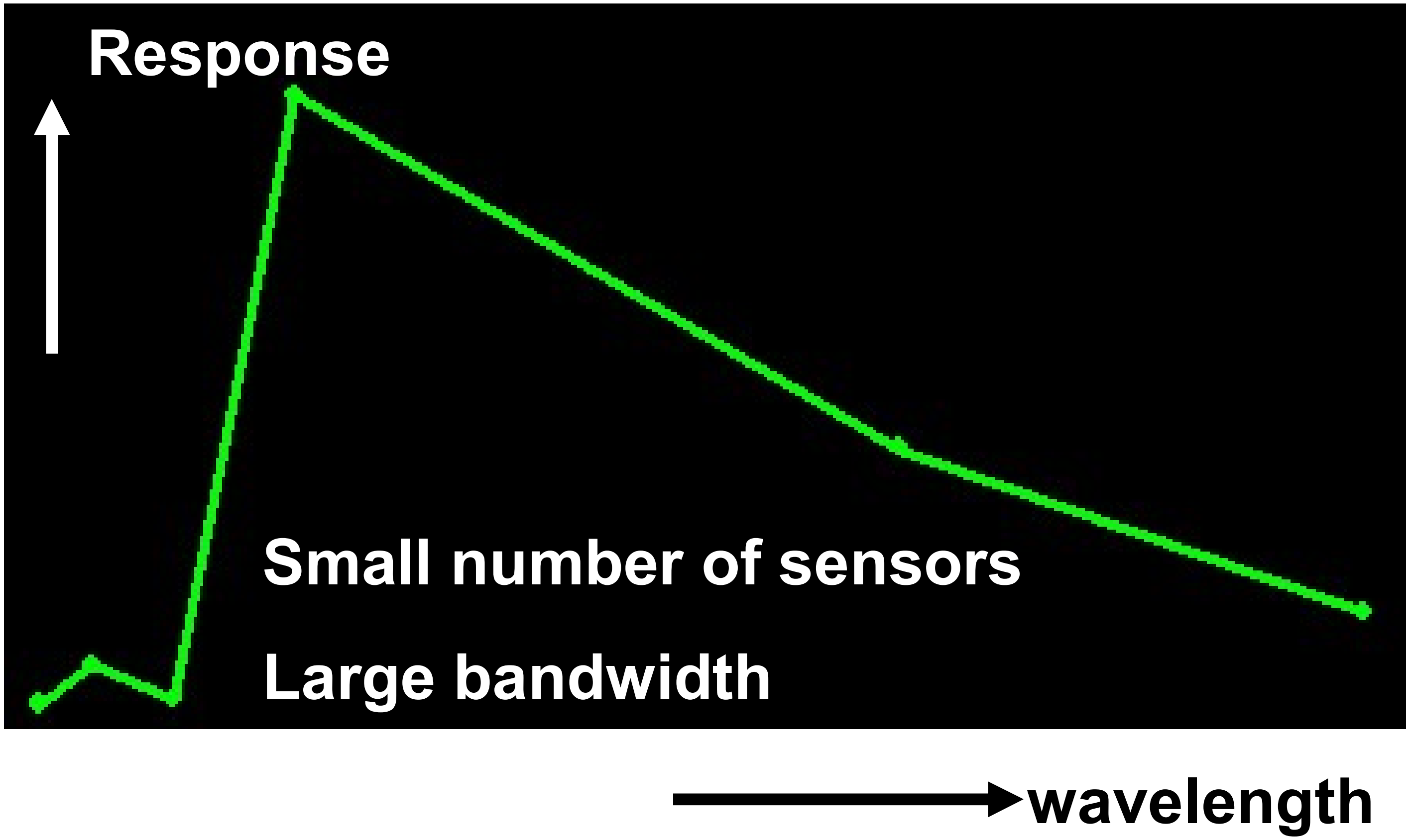


Large number of contiguous sensors

wavelength

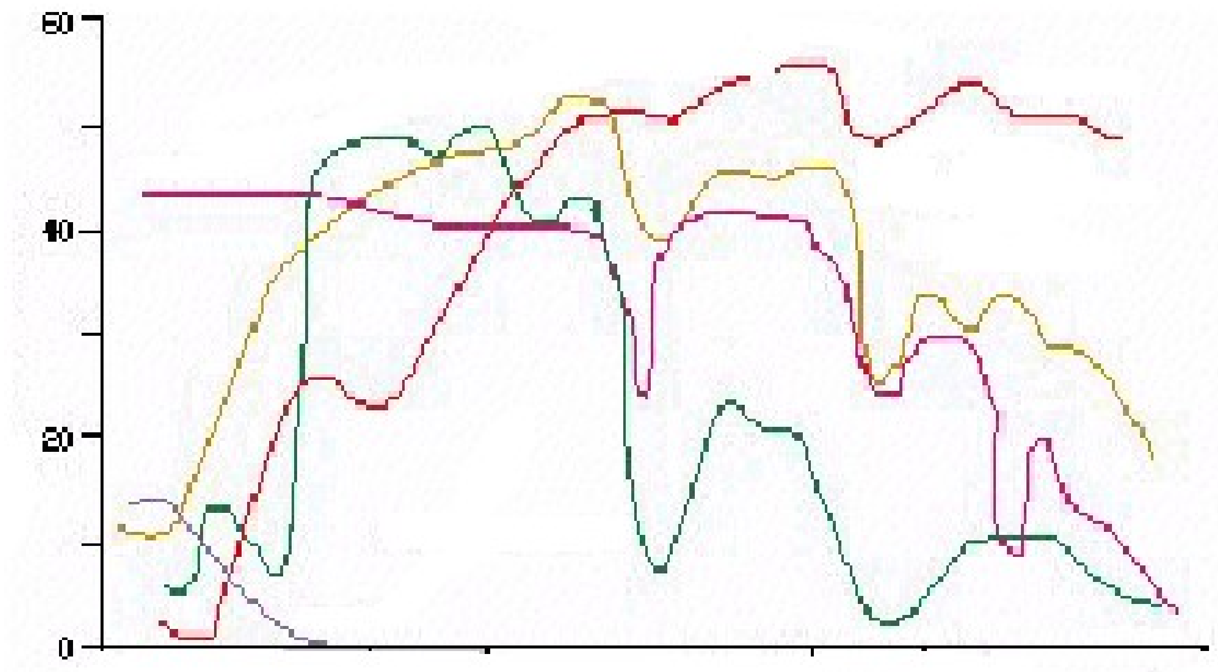
Narrow bandwidth

Coarse Spectral Resolution



Reflectance Spectra

reflectance



Unique spectra of objects

wavelength

Scanning Mechanism

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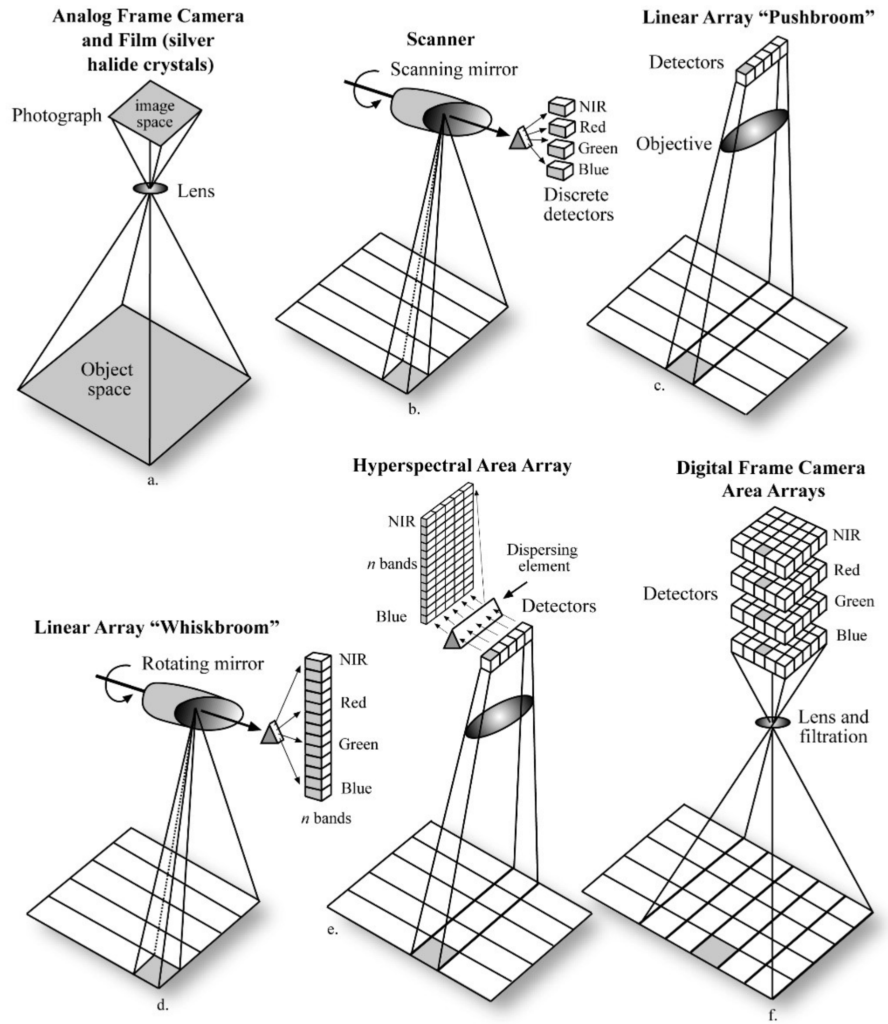
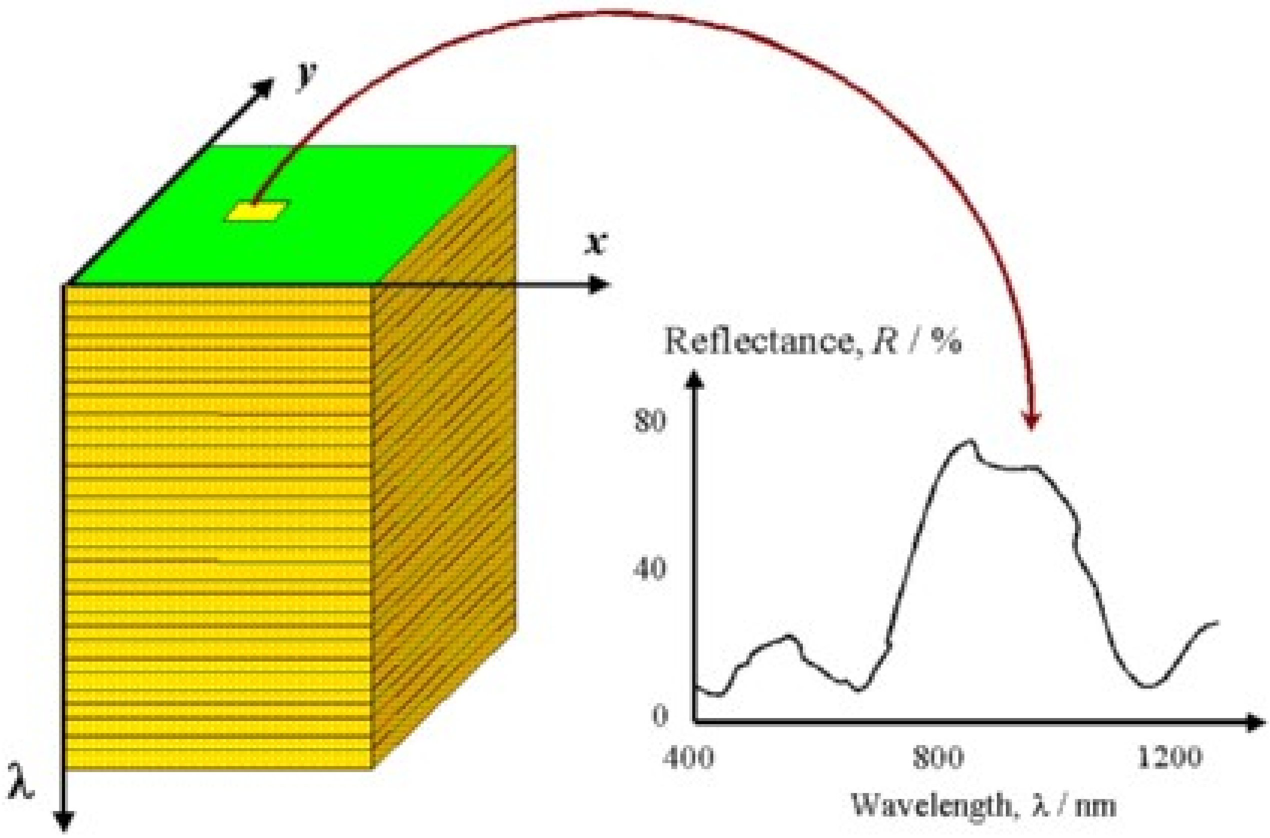


Hyperspectral Image Analysis

- Imaging Spectroscopy principle
  - Obtain reference spectra of materials of interest
  - Correct images
  - Match pixel spectra with reference spectra
  - Model mixing of classes
  - Generate map of proportion of each pure class with a pixel

Hyperspectral Remote Sensing



Selected Hyperspectral Sensors

HYDICE

- HYDICE: Hyperspectral Digital Imagery Collection Experiment
- It was one of the first (1994) airborne hyperspectral instruments to be operated from a relatively low altitude thereby achieving a high spatial resolution.
- Spectral range of 400 – 2500 nm with spectral channel bandwidth 3 – 15 nm
- It combined a high SNR and significantly good spatial and spectral resolution and radiometric accuracy

AVIRIS

- JPL developed the Airborne Visible/Infrared Imaging Spectrometer in 1983
- First imaging spectrometer to measure the solar reflected spectrum from 400 nm to 2500 nm
- 224 contiguous bands of 10 nm width
- Spatial resolution of 20m and size of one scene is 11 Km X 800 Km

AVIRIS-NG

- JPL developed the Airborne
- 2nd generation system
- Double spectral resolution (5nm)
- 5metre spatial resolution
- Several sites of India are covered by AVIRIS-NG during 2017-2019.

HyMAP

- HyMap Airborne Imaging Spectrometer is operated by HyVista Corporation
- It provides 126 bands across the wavelength region of 400 – 2500 nm except in atmospheric water vapour bands
- Bandwidths are between 11 – 21 nm
- Spatial configuration of Sensor is
  - IFOV 2.5 mrad along track, 2 mrad across track, FOV is 61.3 degrees (512 pixels)
  - Swath width = 2.56 km
- High SNR > 500:1

AIMS – ISRO's Imaging Spectrometer

- SAC, ISRO developed AIMS in 1997
- Specifications
  - IFOV (μrad) : 660, 2mX2m from 3km altitude
  - Swath width (degrees) : 14.5, 770m from 3 km
  - Spectral Range : 450 - 880 (nm)
  - Encoding bits/pixel : 10
  - Number of Spectral Bands : 143
  - Spectral Bandwidth : 3 nm

Hyperion Spaceborne Sensor

- First spaceborne sensor to acquire both VNIR and SWIR through two spectrometers and a single telescope
- 220 unique spectral channels collected with a complete spectrum covering from 355 nm to 2577 nm with 10 nm bandwidth
- 30 m spatial resolution
- Instrument can image 96 km by 7.5 km land area per image
- Radiometric resolution : 16 bit signed integer
- Hyperion VNIR sensor has 70 bands (355.589 – 851.92 nm) and the SWIR has 172 bands (1057.36 – 2577.07 nm)
- SNR varies from 190 to 40 as wavelengths increases

HySI – Hyperspectral Imager onboard Chandrayaan - 1

- On-board Chandrayaan-1, India's first mission to moon
- Specifications
  - Spectral range : 400 – 950 nm
  - Spectral resolution < 15 nm
  - Spatial resolution : 80 m
  - Swath width : 20 km

Points to ponder…

- What is the biggest hurdle in working with hyperspectral imagery?
- What is a limitation of hyperspectral images?

Contd…