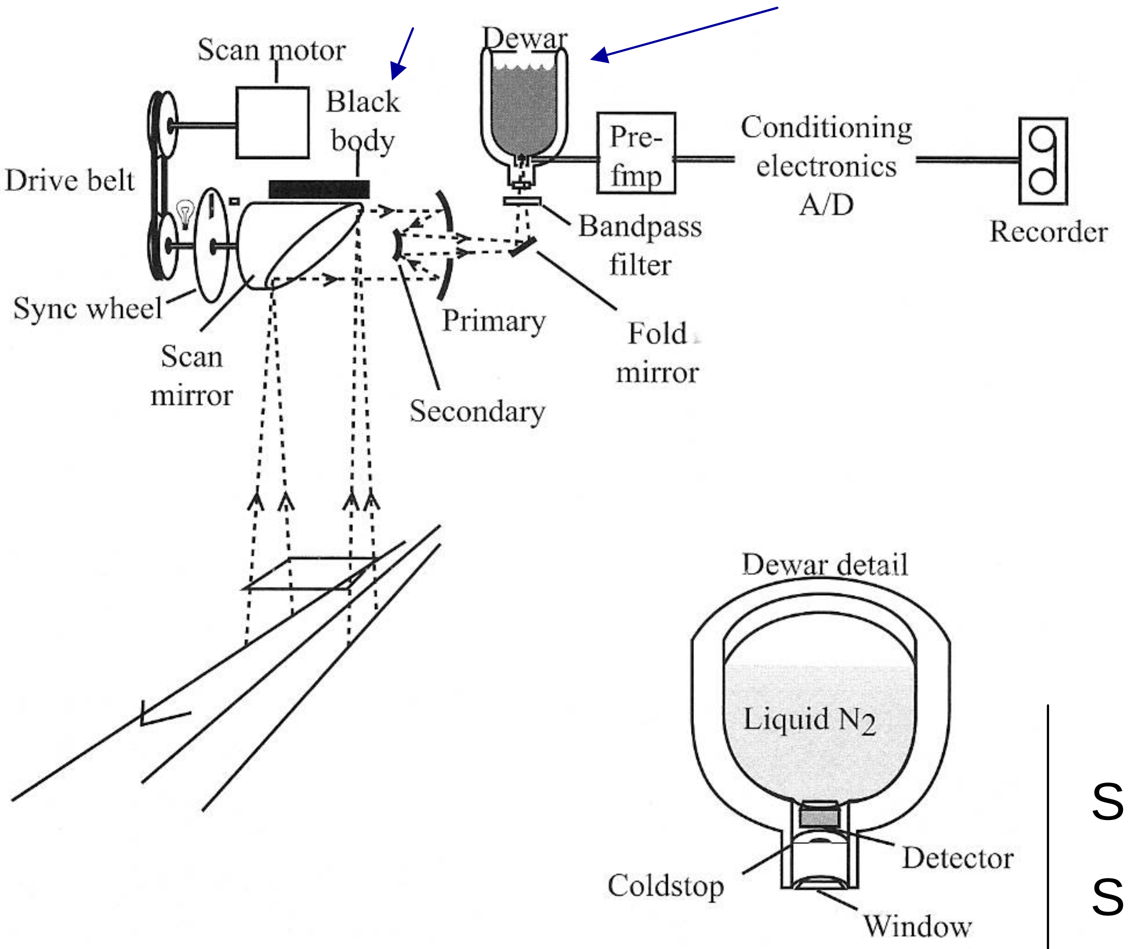
Optical Remote Sensing - Passive

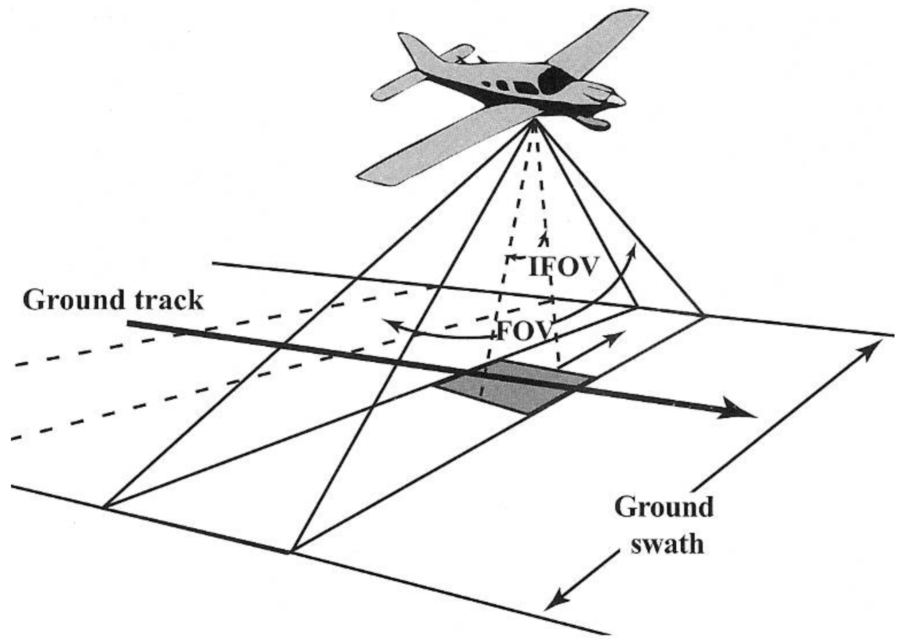
Chap. 7. Imaging Systems

F. Rocadenbosch
Dept. de Teoria del Senyal i Comunicacions
Universitat Politècnica de Catalunya

7.1 From line scanners to multi-spectral sensors

Line Scanners: Architecture and collection scheme





Single detector

Simple optics

Dead-time used for calibration

Line Scanners: Architecture and collection scheme

IFOV (Instantaneous Field Of View): *ANGULAR RESOLUTION* of the sensor,

$$IFOV = \frac{r_d}{f}$$

GFOV (Ground IFOV): Projection of the detector onto the ground,

$$GIFOV = H \cdot IFOV$$

where H is the flying height.

FOV: Angular extent [rad] of the image across-track (from which the *ground swath* can be computed).

Integration time (or "sampling" time or "dwell" time): Time it takes the mirror to sweep out one IFOV,

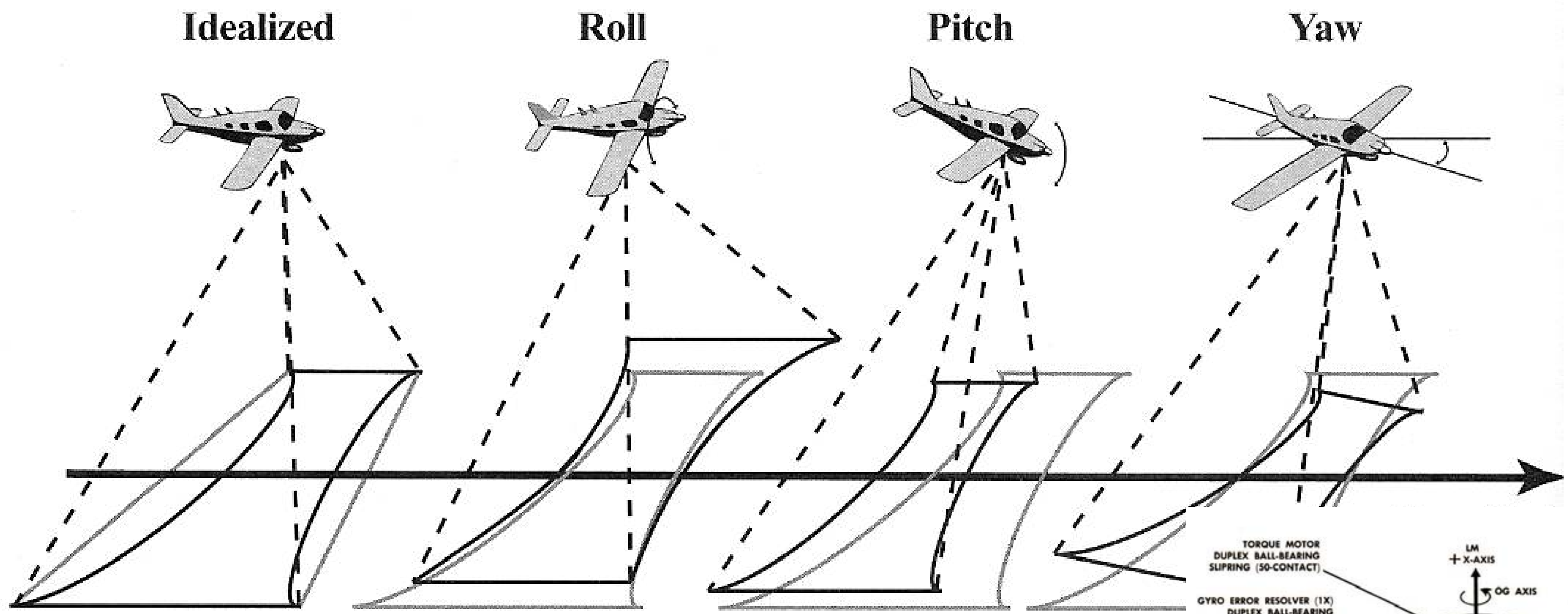
$$t_S = \frac{IFOV}{2\pi f_{scan}}$$

where f_{scan} is the mirror scanning frequency.

By sampling the signal from the detector the across-track image lines can be formed.

During the rotation of the mirror, the sensor platform advances 1 GIFOV so that consecutive rotations of the mirror sweep out consecutive lines on the ground.

Line Scanners: Geometric distortions (I)



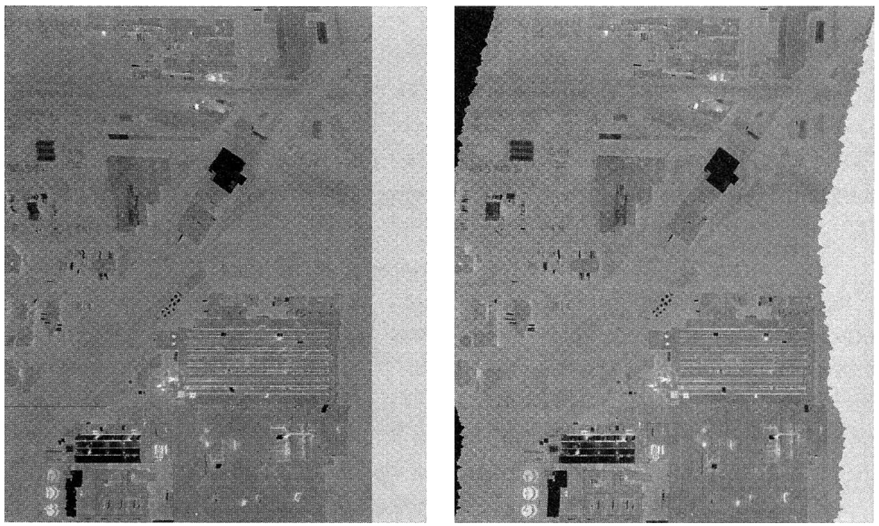


FIG. LEFT:

8-14 μm image: before (left) and after (right) roll correction

FIG. RIGHT: Gyroscope

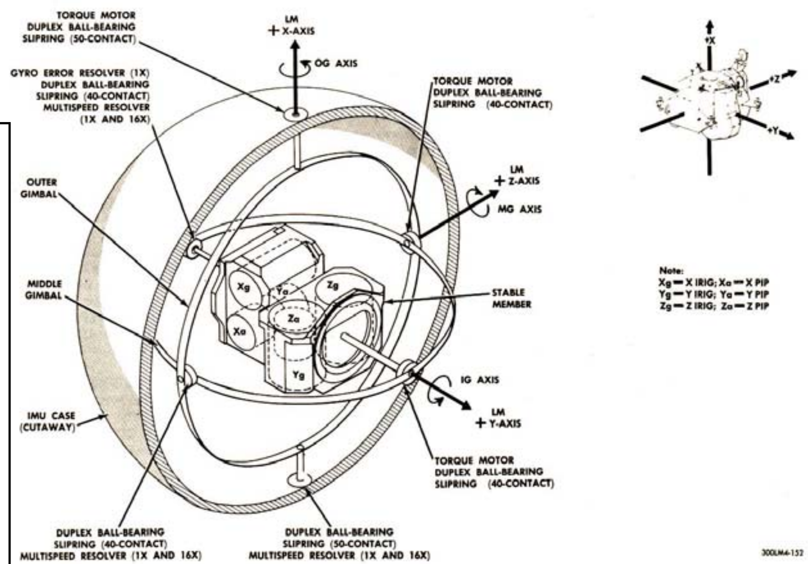
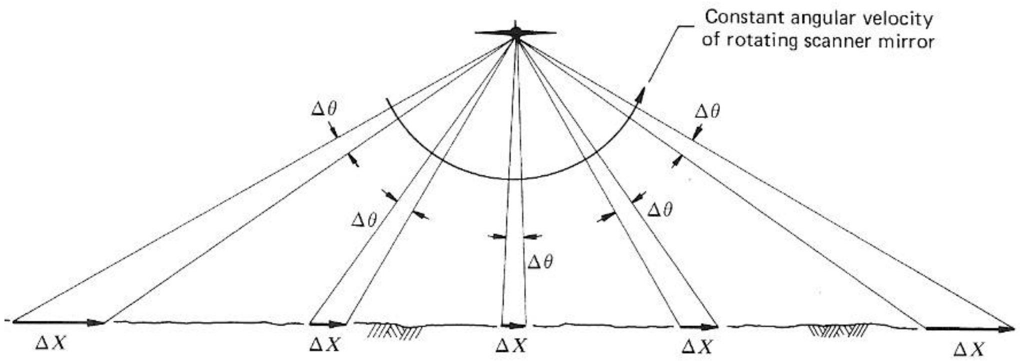
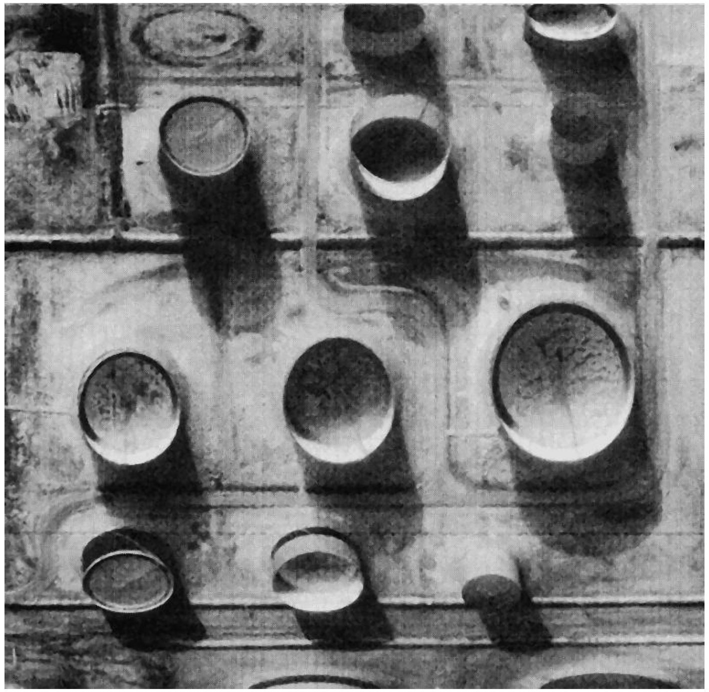


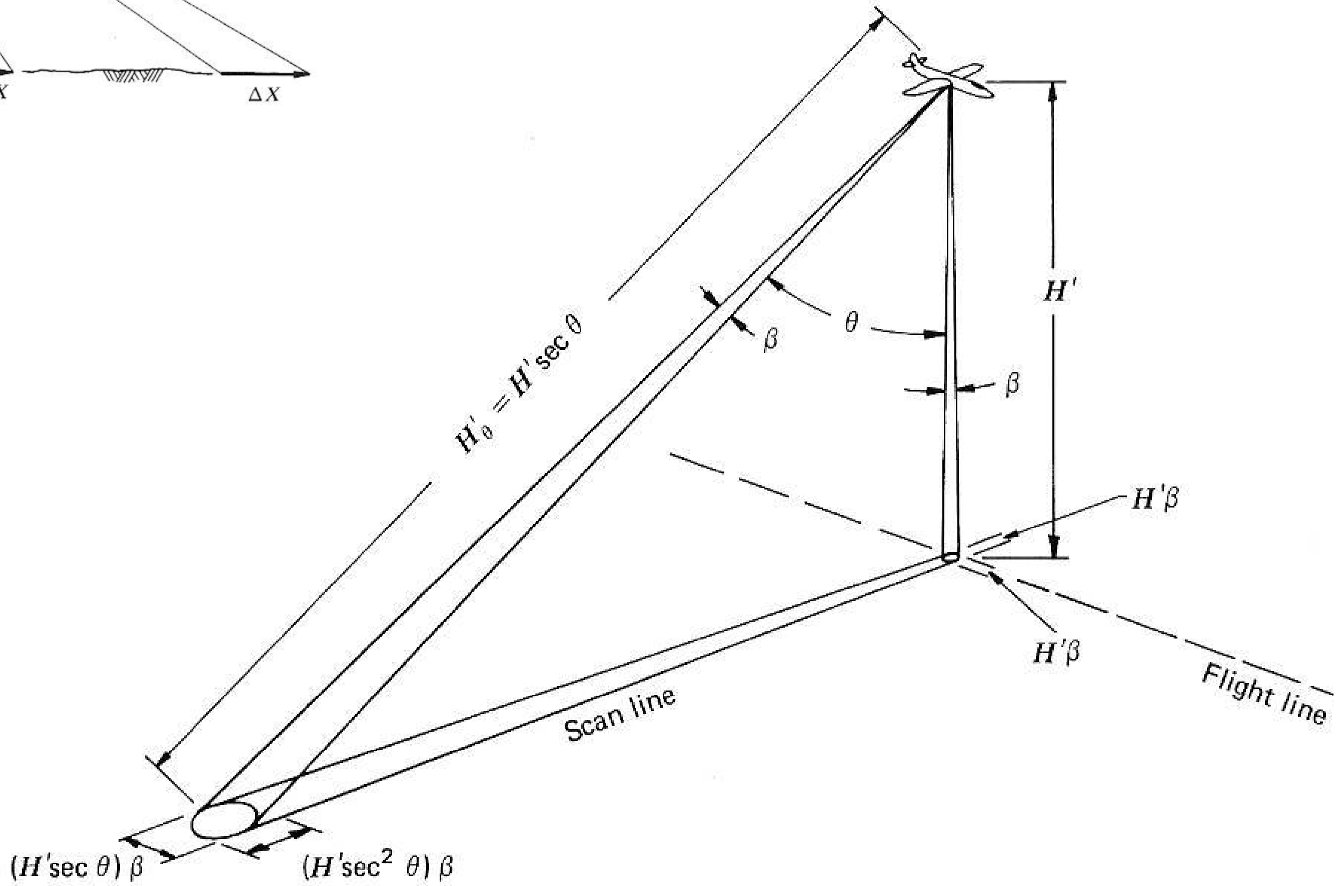
Figure 2.1-24. IMU Gimbal Assembly

Line Scanners: Geometric distortions (II) – Tangent distortion



Data is typically sampled at every IFOV. Each sample represents a larger projected area on the ground as we progress off axis.





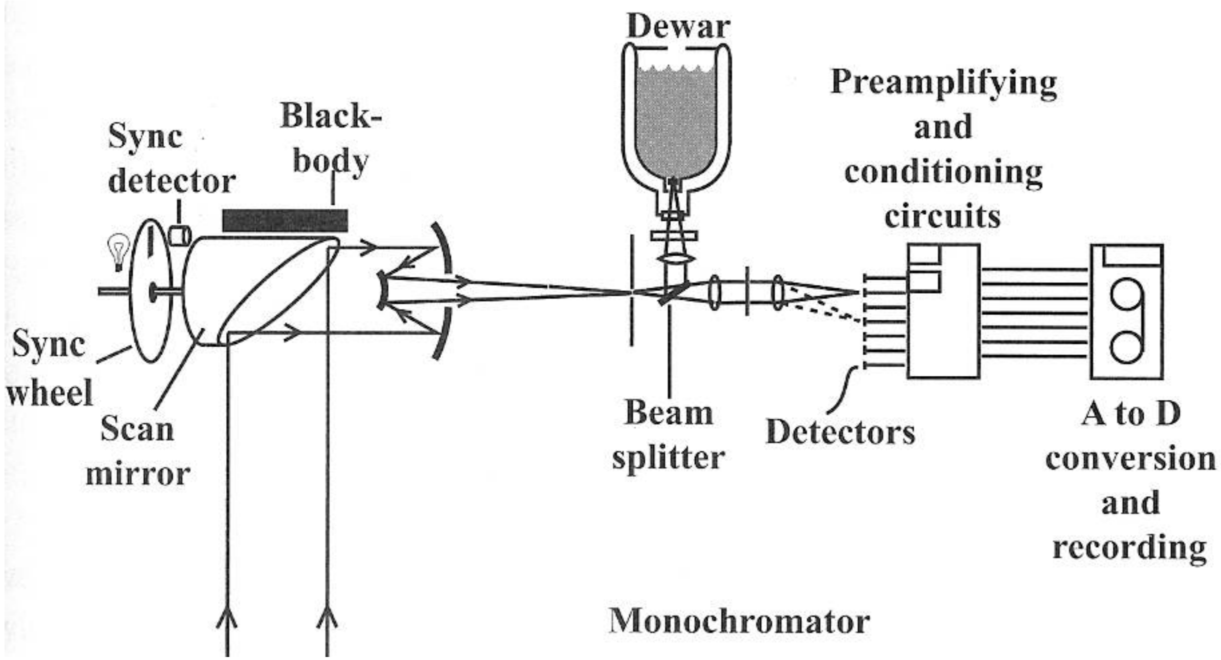
Line Scanners: Geometric distortion correction (III)

1) *Roll correction*: Requires recording the amount of roll using a gyroscope. Advance or delay each line of data by the number of IFOVs of roll.
2) *Pitch&yaw* correction: Requires a 3-axis system. Today GPS-INS record the (x,y,z) location and (roll, pitch, yaw) orientation of the platform. Combination with DEMs to project data onto an ortho-rectified space.
3) *V/A* (velocity over altitude): The aircraft does not advance exactly one GIFOV between scan lines.
4) *Tangent distortion* correction: This type of systematic error can be removed by geometric re-sampling of the image.
5) *Resolution loss* due to the larger GIFOV off axis (tangent distortion): Cannot be restored.

Line Scanners: Multi-spectral

The entrance aperture of a monochromator (e.g, *grating, prism*) is placed at the focal plane of the optical system.

- Detector width defines the spectral bandwidth of each channel
- Spectral sampling performed with discrete detectors or a linear array.



1-10 channels: *Multispectral*

10s-100s of channels: *Hyperspectral*

- AVHRR (Advanced Very High Resolution Radiometer), http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
- GOES (Geosyn. Operation Environ. Sat.) “spinning scanning satellite” http://www.oso.noaa.gov/goes/

Whisk-broom and Bow-Tie Imagers (I)

Goal: Increase the "dwell time" of the line-scanner sensor design.

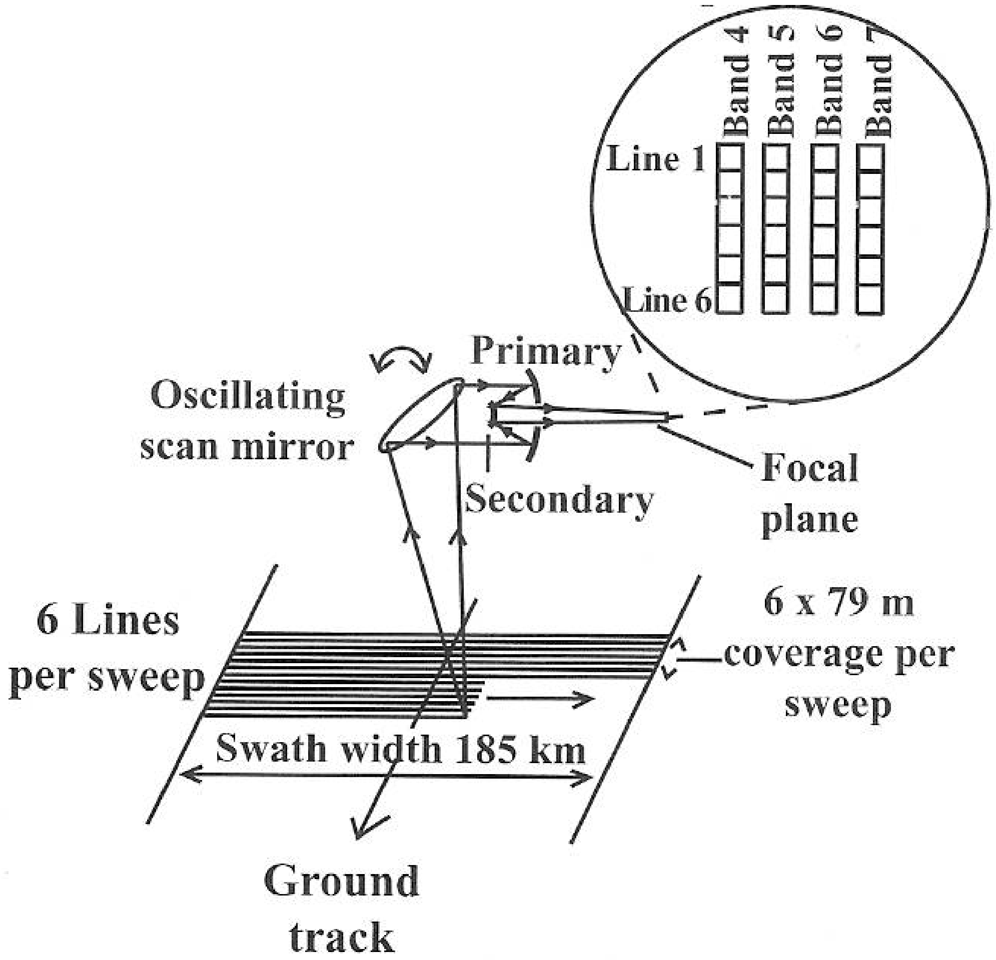
Take N data lines simultaneously

Higher SNR, spatial and spectral resol.

WHISK-BROOM

The scan mirror oscillates but only in *one* direction.

- The next mirror sweep is timed so that the next N lines are immediately adjacent to the last (continuous ground coverage)
- Wastes approx 50% of the useful scan time



MSS (Multi-Spectral Scanner) on LANDSAT1-5 (first on 1972)

http://landsat.gsfc.nasa.gov/about/

Whisk-broom and Bow-Tie Imagers (II)

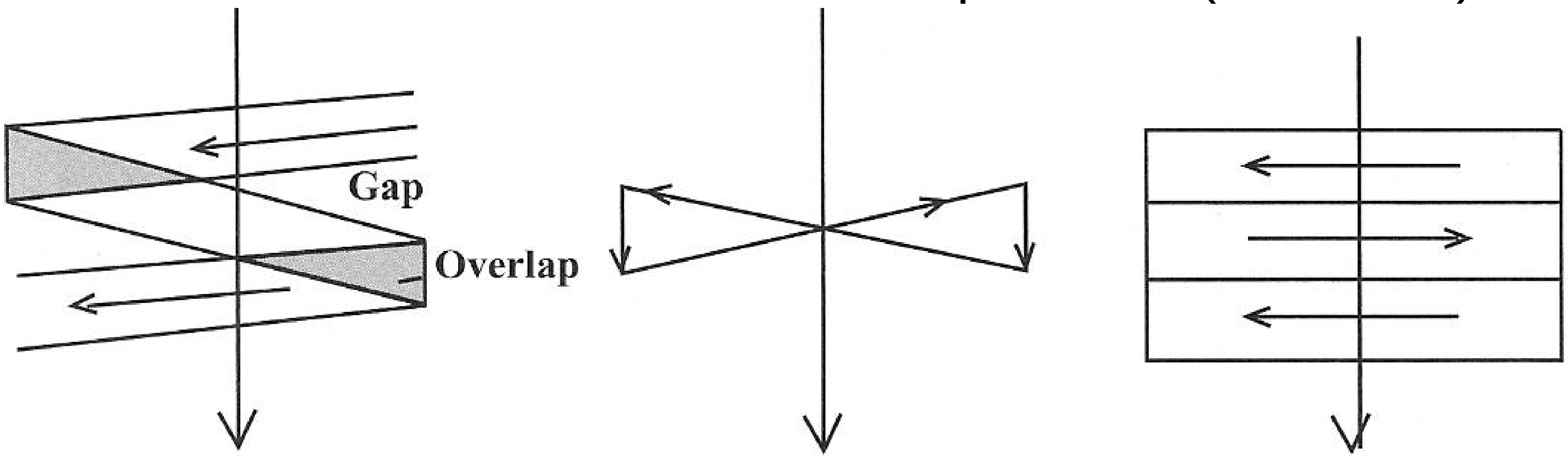
BOW-TIE

Mirror scans in *both* directions.

- Gaps and overlaps regions in the ground coverage occur.
- LANDSAT TM and ETM+ (Enhanced Thematic Mapper)

Whisk-Broom & Bow-Tie

- Signals transmitted to ground must be corrected for staggered effects, spectral offsets, rotation
- Largely used in space because of the difficulties in correcting for geometric errors in unstable platforms (GPS+INS)



Satellite ground track
(a) Uncorrected scan

(b) Image projection through scanline correction with no satellite motion

(c) Corrected scan

Historical outline (LANDSAT ETM 4&5)

Optics	40.6 cm Ritchy-Chretien F/6
Scan Method	Osc. Mirror (bidir.) 7 Hz, 85 % scan efficien.
IFOV	43.0 μrad for B1-5, B7; 170.0 for B6
FOV	14.9 deg
Swath	185 km
Orbit	Sun synchronous, 16 days (Desc. equatorial crossing 0945AM, 705 km)

BAND NO.	WAVEL	DETECTOR	GIFOV
1	0.45-0.52 μm	Si PD	30 m
2	0.52-0.60 μm	Si PD	30 m
3	0.63-0.69 μm	Si PD	30 m
4	0.76-0.90 μm	Si PD	30 m
5	1.55-1.75 μm	Si PD	30 m
6	10.4-12.5 μm	MCT	120 m
7	2.08-2.35 μm	InSb PD	30 m

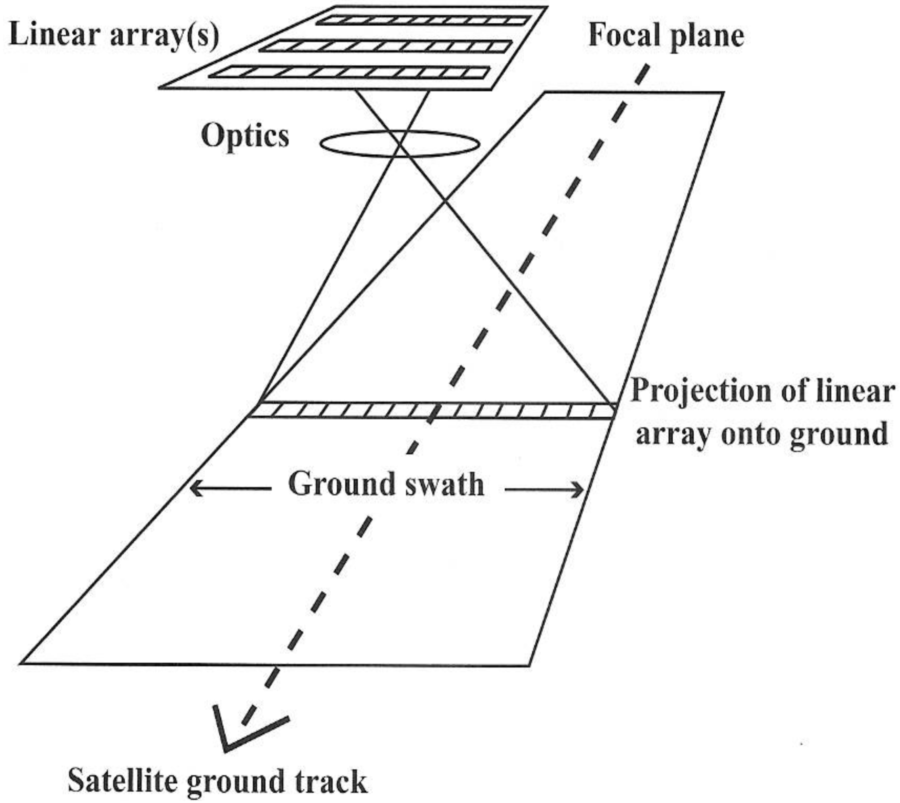
Etna eruption captured by LANDSAT-5

Adapted from Joseph, G., “Imaging Sensors for Remote Sensing”, Rem. Sens. Rev., (13), 257-342 (1996).

Push-Broom Imagers

Further steps toward increasing the dwell time by using a linear array (LA)

1. (+)Collect entire lines of data simultaneously
2. (+)Multiple spectral bands with multiple LAs filtered for the bands of interest.
3. (+)An individual detector element only needs to sample at one across-track location → increased integration time
4. (-)Very long LAs necessary to achieve a large ground swath
5. (+)No movable parts
6. (-)Difficult to cool large focal planes



7. (+)Higher spatial/spectral resol.
8. (+)Time Delay & Integration allowed

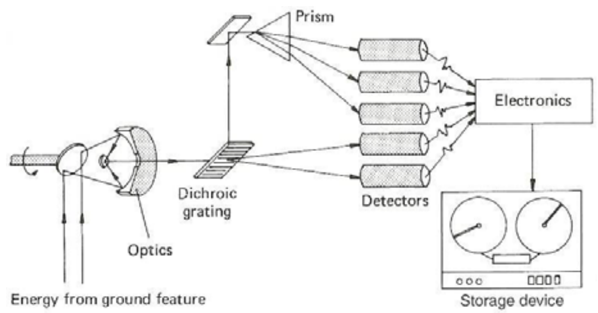
SPOT (1986), http://www.spotimage.com/web/es/311-informacion-tecnica.php

7.2 Imaging Spectrometers (I)

GOAL: Collect spectral and spatial characteristics of the imaged scene.

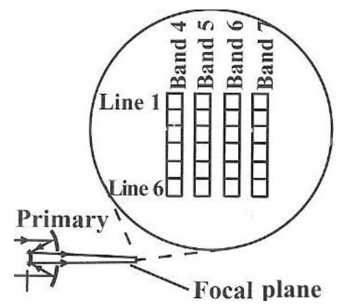
LINE-SCANNER Spectrometer [Line-scanner + monochr. (Prob.1)]. ▷

- E.g., NASA's AVIRIS "image cube".



PUSH-BROOM Spectrometer ▷

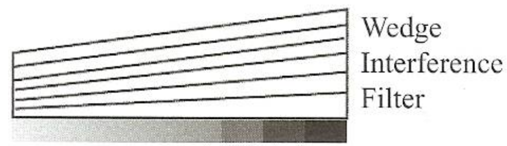
- An entire line of sight is imaged onto the FPlane (push-broom philosophy)
- (Slit+grating) The beam is dispersed perpendicularly to the long axis of the slit and imaged onto a 2D array. E.g., NASA's AIS (Airborne Imaging Spect.)



2D arrays ▷

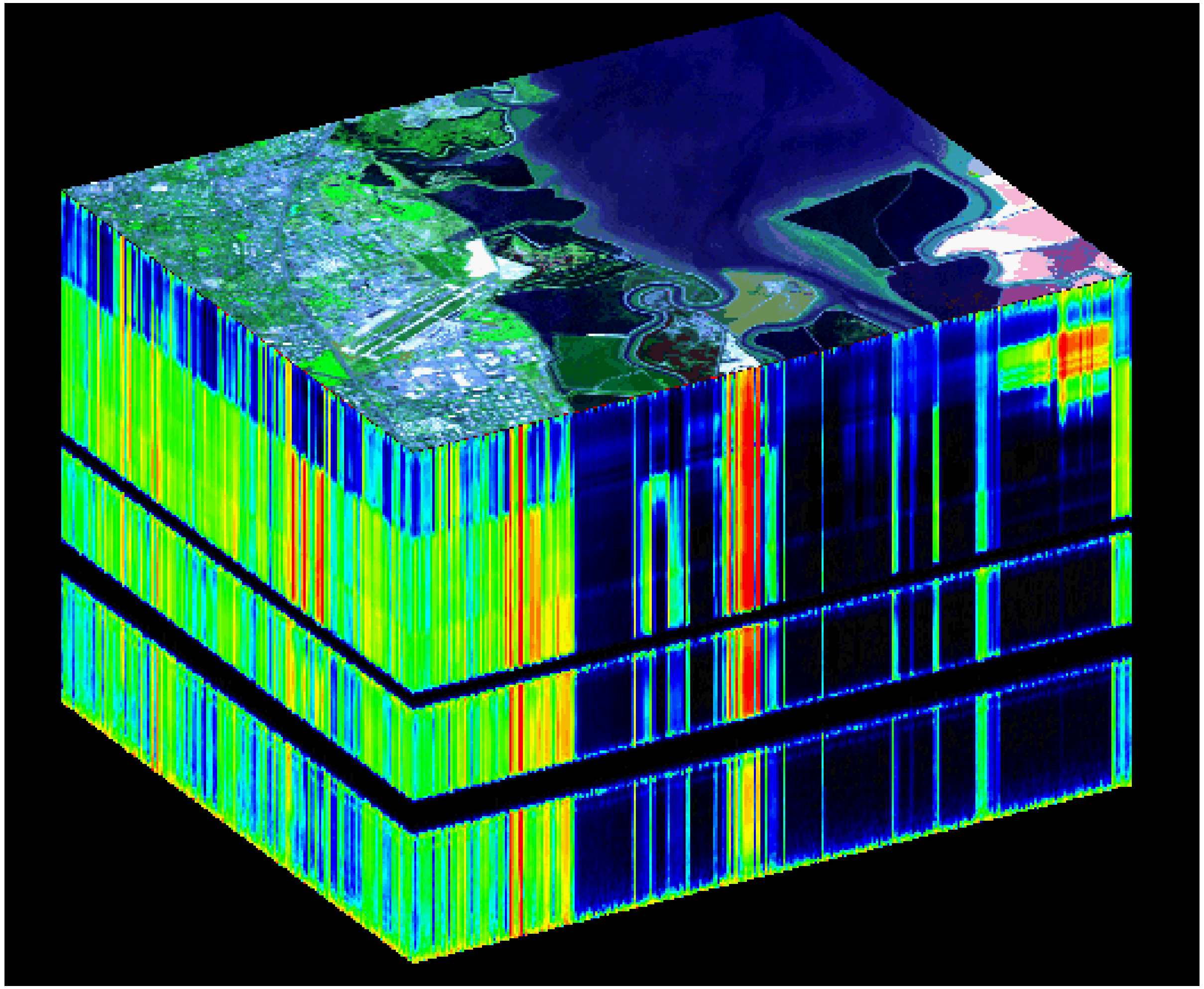
LVE (Linearly Variable Etalon or "wedge filter")

- By changing the spacing between interference layers ("wedge" concept) the center wavelength of the interference filter ("wedge" concept) is shifted.
- Each row of the array sees different spectral band.



FOURIER TRANSFORM (FT) Spectroscopy

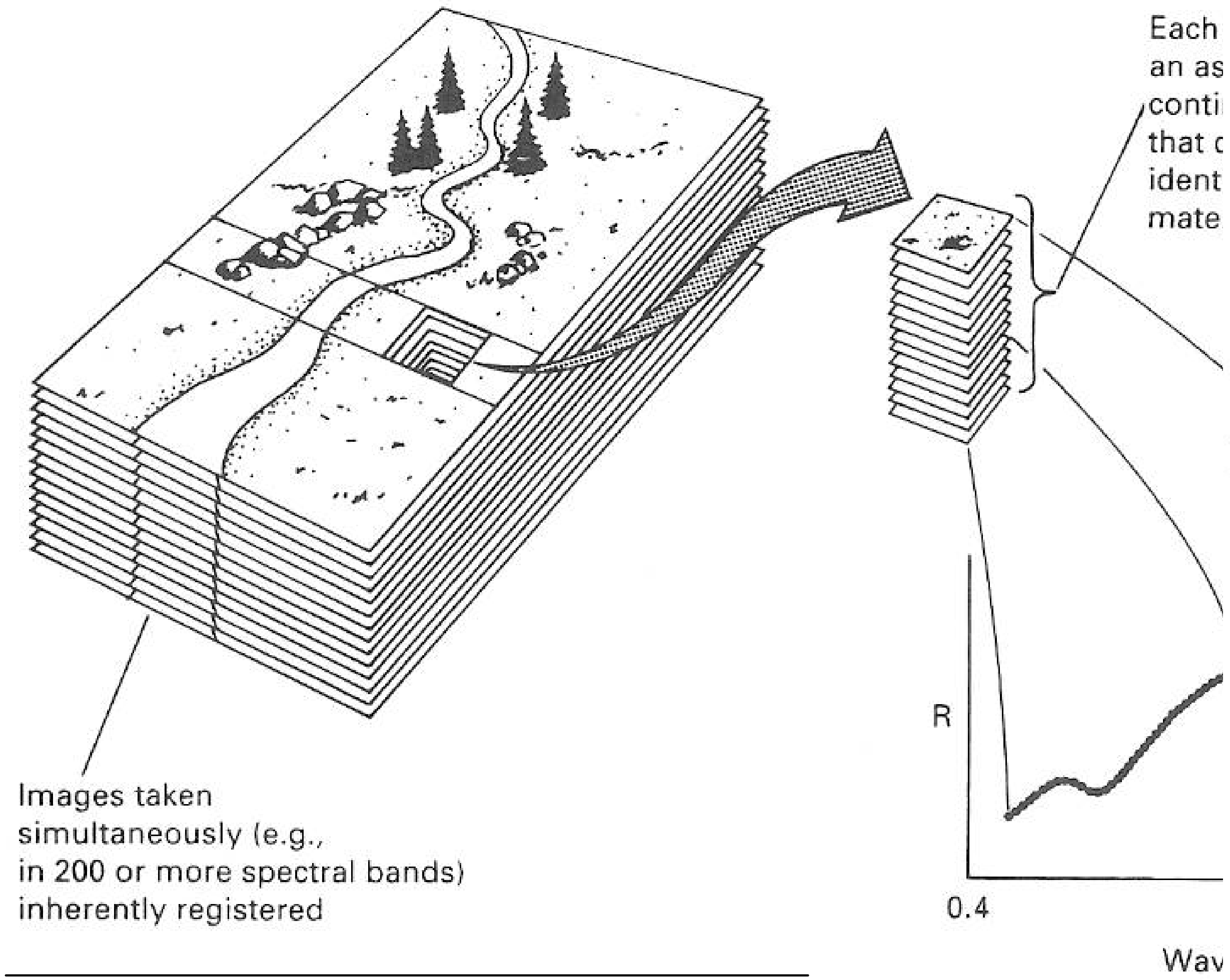
Imaging Spectrometers (II): AVIRIS line scanner (Hyperspectral)

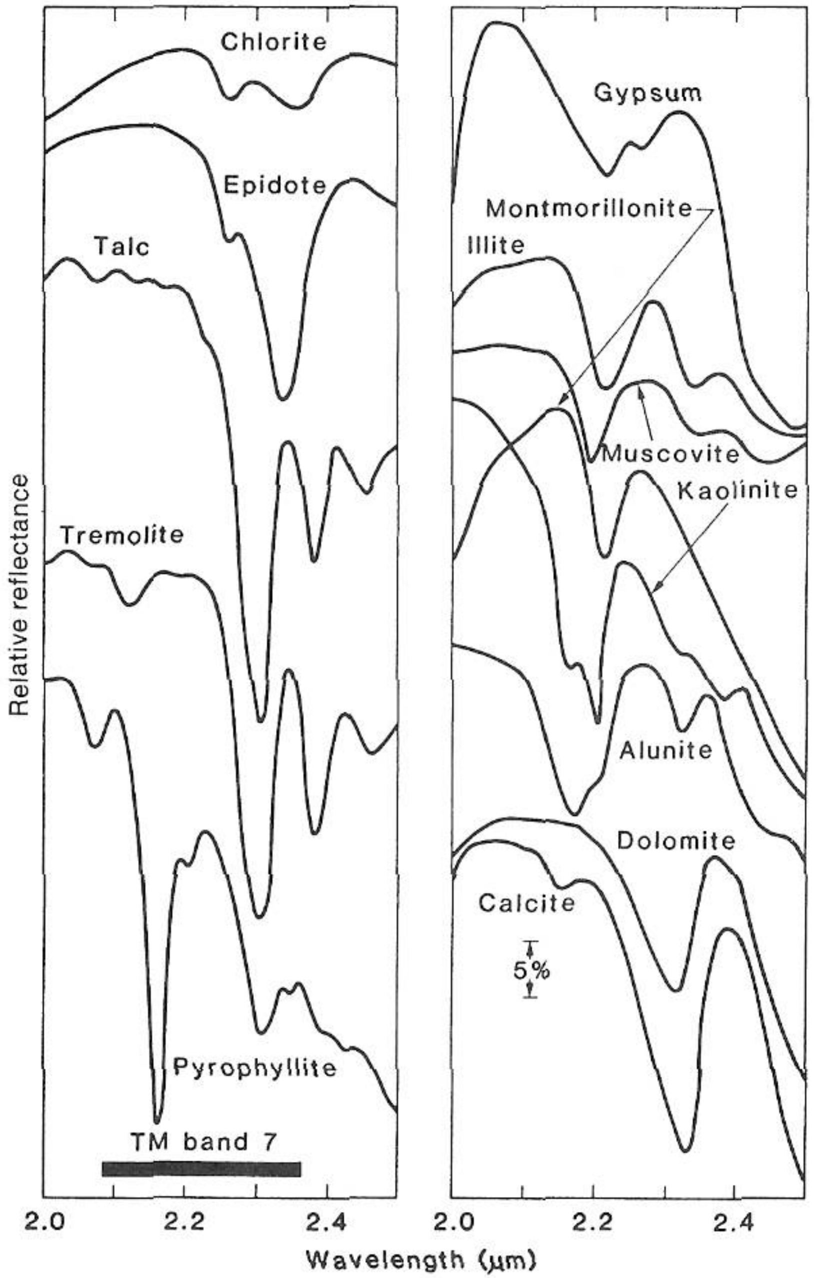


Advanced Visible and IR imaging spectrometer (NASA's AVIRIS)

- Function: Airborne test bed for satellite-based imaging spectrometers.
- 224 channels, 0.4-2.5μm, 10 nm spectral resolution
- 4 spectrometers using fiber optics to carry the flux
- 1 mrad IFOV (20 m pixels when flown at 20.000 m)
- "Black bands": 1.4 and 1.9 atmospheric absorption bands

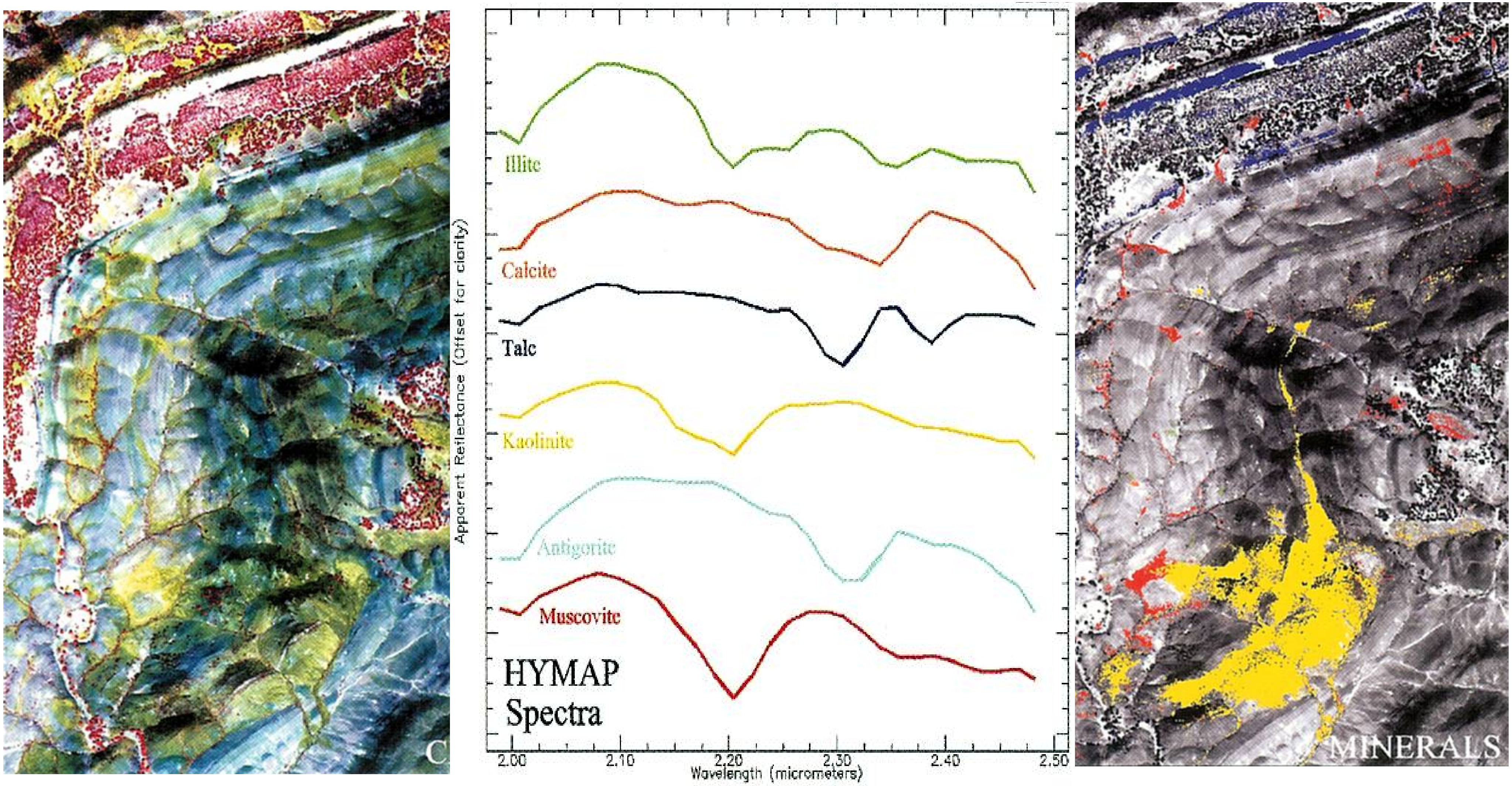
Imaging Spectrometers (II): AVIRIS line scanner (Hyperspectral)





(Left) Source: Vane, G., Sensors, Vol.2, pp. 11-20, (1985).
(Right) Source: AAAS, NASA JPL.

Imaging Spectrometers (II): HYMAP (Hyperspectral)



HYMAP (Hyperspectral Mapping) airborne sensor. Image-derived spectral reflectance vs. laboratory models. 2.6 x 4.0 km Mt. Fitton, Australia.128 channels, 0.4-2.5 microns, 5 m/pixel. (left) Color IR composite using 0.557 (displayed as blue), 0.665 (green) and 0.863 um (red) bands. (right) Color composite corresponding to the lab. Model used in Fig. (center).

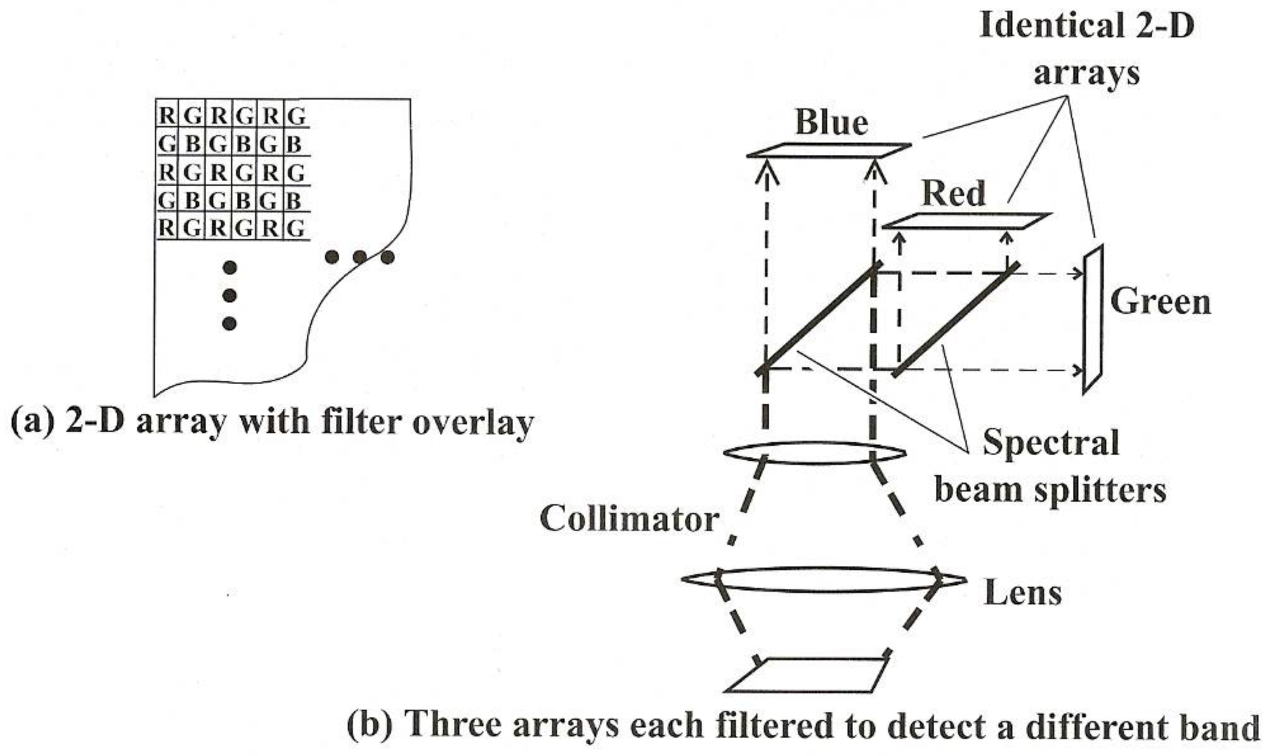
Imaging Spectrometers (III): 2D arrays

Essentially an "electronic" camera

Forward motion will blur the image

- → exposure time < time it takes the sensor to move 1 GIFOV
- No inherent gain in SNR. The advantage is in "geometric fidelity".

Very attractive for AIRCRAFT

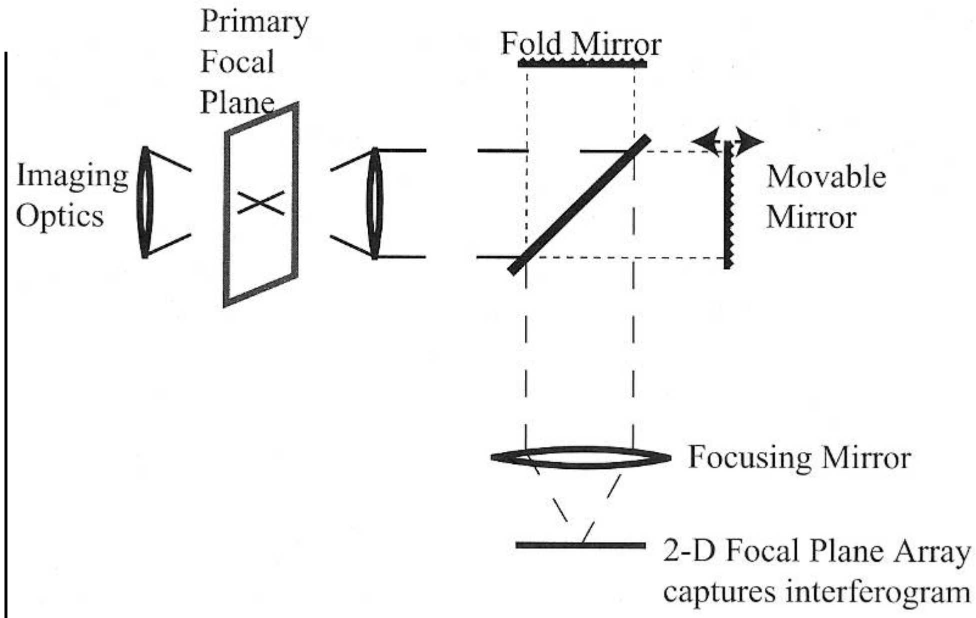


Multispectral data (two approaches):

- Filter mask
- Dichroic beam splitters

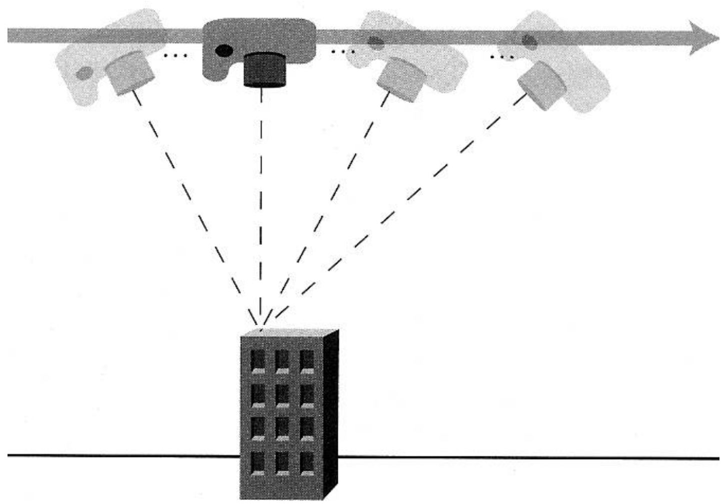
Imaging Spectrometers (IV): Interferometric (Fourier-Transform Spectroscopy)

Principle (Michelson Interf): The combined beams interfere due to the wavelengths of energy present and *path difference* between the two paths.

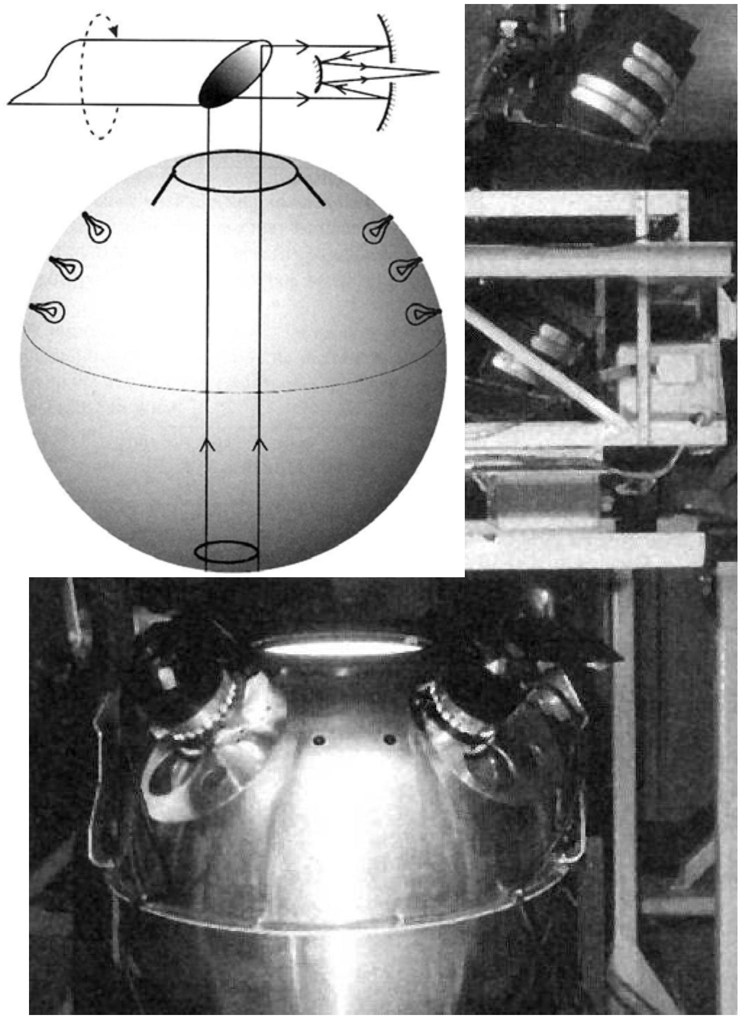


Imagine a 2D-ARRAY SENSOR:

- Each pixel will form over time an interferogram of a signal from a different location.
- Stack these time samples to form an interferogram cube (with *Z the time dimension*) and take the 1-D FT in the Z direction (i.e., for the signal acquired by a single detector element):
  - the result is the image SPECTRUM.
  - resolution controlled by the number of path differences.



7.3 Radiometric calibration of EO sensors



KEY: Convert any digital count to a known radiance level

ABSOLUTE CAL.: Fill the entire entrance aperture of the sensor with know radiance from an integrating sphere.

$$DC = gL + b; \quad g\left[\frac{counts}{\frac{W}{m^2 sr}}\right], b\left[counts\right]$$

- Reflective region: Source-based standard (tungsten halogen lamp) + detector standards
- Self-emissive region: Change blackbody T (thermistors). G# must be known.

In practice:

- (Aircraft sensors) Recalibrated after each flight
- (NOAA AVHRR) Desert regions as stable targets and natural calibration sources (Moon)
- On-board calibration
- Sensor intercomparison (TOA irradiance)

ACKNOWLEDGEMENTS

Schott, J.R., “Remote Sensing. The Image Chain Approach”, 2nd. Ed., Oxford Univ. Press (2007).

Lillesand, T.M.; Kiefer, R.W.; Chipman, J.W., “Remote Sensing and Image Interpretation”, 6th Ed., John Wiley&Sons (2008).

Campbell, J.M., “Introduction to Remote Sensing”, 4th Ed., Gilford Press (2008).

Hamamatsu Photonics Application Notes:

- “Characteristics and use of Si APD”, SD-28, Hamamatsu AN (2004).
- “Characteristics and use of infrared detectors”, SD12, Hamamatsu AN (2004).
- “Characteristics and use of FFT-CCD area image sensor”, SD-25 Hamamatsu AN (2003)
- “Characteristics and use of Charge amplifier”, SD-37, Hamamatsu AN (2001).
- “Photon Counting using Photomultiplier Tubes”, Hamamatsu AN (1998).

UDT sensors, Advanced Photonics

Judson Technologies LLC