Satellites and Sensors: How they work

18 April 2003

Outline

- Satellite and their orbits
- Sensor types
  - whiskbroom scanners
  - pushbroom scanners
- Example of pixel size calculation

How Satellites Work

- Launch -- how do they get up there?
- To put a satellite into a stable orbit, need to overcome gravitational attraction and the resistance of the lower atmosphere

A rocket of initial mass, M_i, burning a mass of fuel M_f will increase its velocity, ΔV, by

$$\Delta V = U \ln\left(M_i / \left(M_i - M_f \right) \right)$$

where U is the velocity of the exhaust gases with respect to the rocket.

$U = 2.4\ \mathrm{kms^{-1}}$

orbital velocity of a satellite is about $7\mathrm{kms^{-1}}$

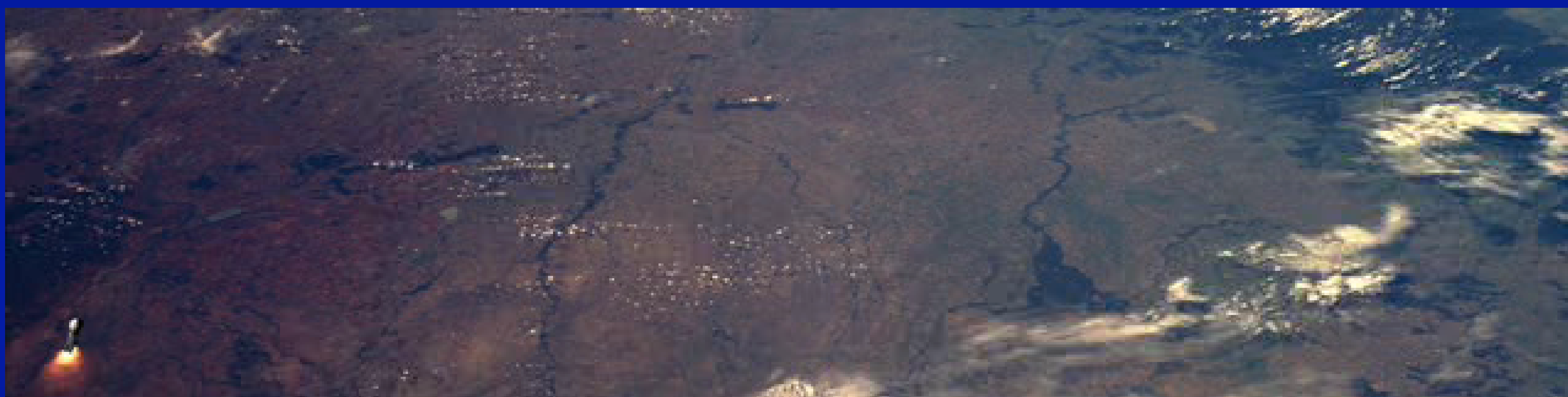
Rocket must be about 97% fuel

Payload can only be about 3% of rocket mass

Terra launch

Vandenberg AFB

18 December 1999



Description Satellite Orbits

- Determined by Kepler's Laws
  - perturbed by gravititational irregularities, friction, solar pressure, etc.
  - ranging and repositioning is required for satellites to maintain their orbit
- The orbital period is the time it takes for the satellite to circle the earth
- Easy to compute if assume the earth is a sphere but earth is an oblate ellipsoid
  - creates an orbit that precesses (it rotates around the polar axis)

Special Orbits

Orbital parameters can be tuned to produce particular, useful orbits

- Geostationary
- Geosynchronous
- Sun synchronous
- Altimetric

Geostationary Orbits

- Orbit is stationary with respect to a location on the earth
- Circular orbit around the equator (orbital inclination = zero)
- The orbital period is equal to the earth's rotation (for a sidereal day, rotation with respect to the Sun)
- Orbital altitude must be about 36,000 km above the equator

Uses of Geostationary Orbits

- Weather satellites (GOES, METEOSAT)
- Telephone and television relay satellites

Constant contact w/ground stations

Limited spatial coverage

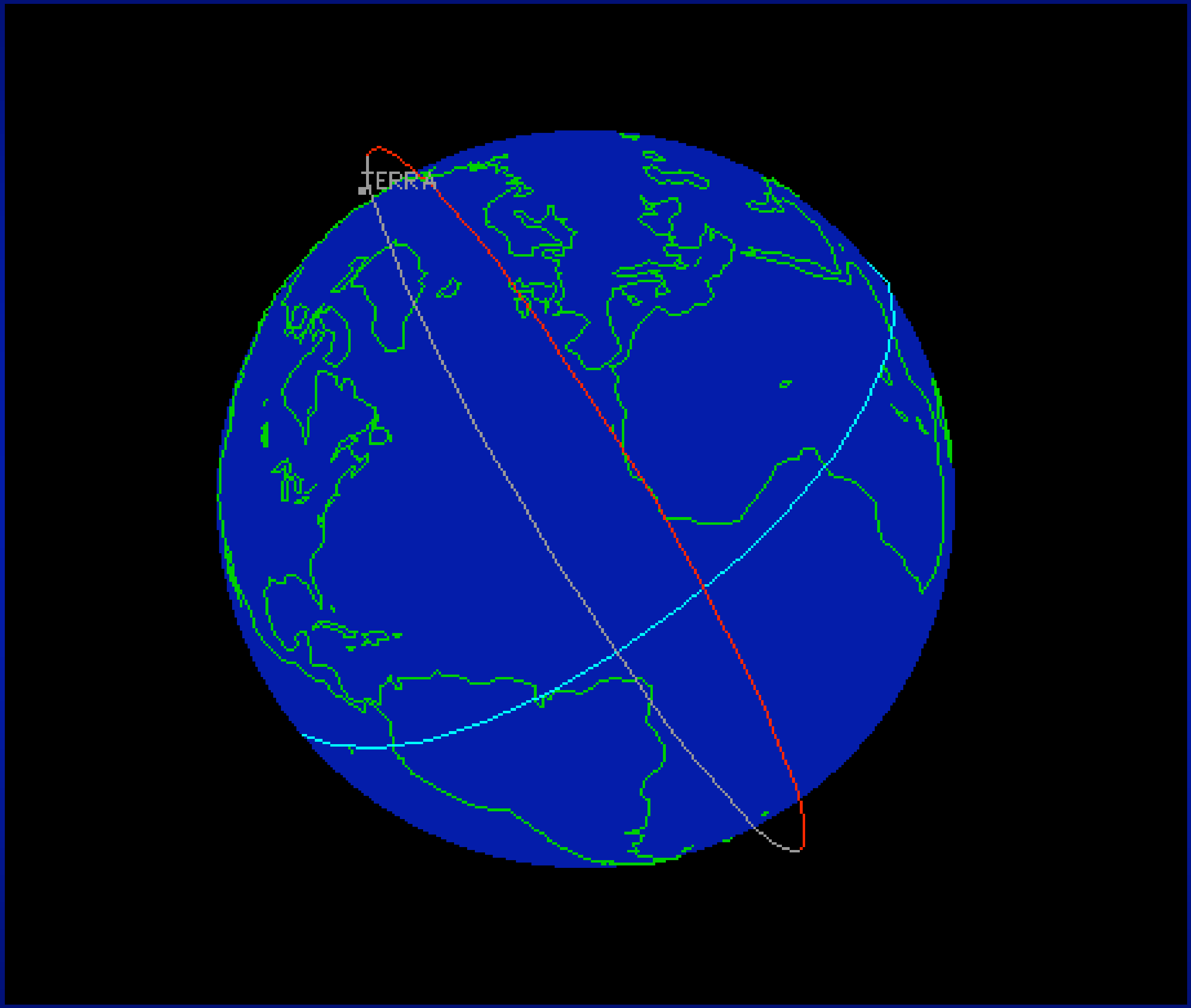
- each satellite can only cover about 25-30% of the earth's surface
- coverage extends only to the mid-latitudes, no more than about 55^o

Geosynchronous Orbits

- Orbital period = earth's rotation
- Orbital inclination $\neq$ zero
  - traces a figure eight
  - half the time, the orbit is above(below) where it needs to be
  - highly eccentric versions of this sort of orbit are possible but not widely used

Sun-synchronous Orbit

- Precession of the satellite orbit is the same as the angular speed of rotation of the sun
- Satellite will cross the equator at the same time each day
- Orbital inclination is retrograde (typically ~98^{o})


TERRA

Uses of Sun-Synchronous Orbits

- Equatorial crossing time depends on nature of application (low sun angle vs. high sun angle needs)
- Earth monitoring -- global coverage
- Orbital altitude typically between 600 and 1000km -- good spatial resolution

Altimetric Orbits

- Ascending and descending orbits should cross at 90°
  - Designed so that orthogonal components of surface slope will have equal accuracy
- Orbital inclination depends on location of altimetric needs

Getting the Data to the Ground

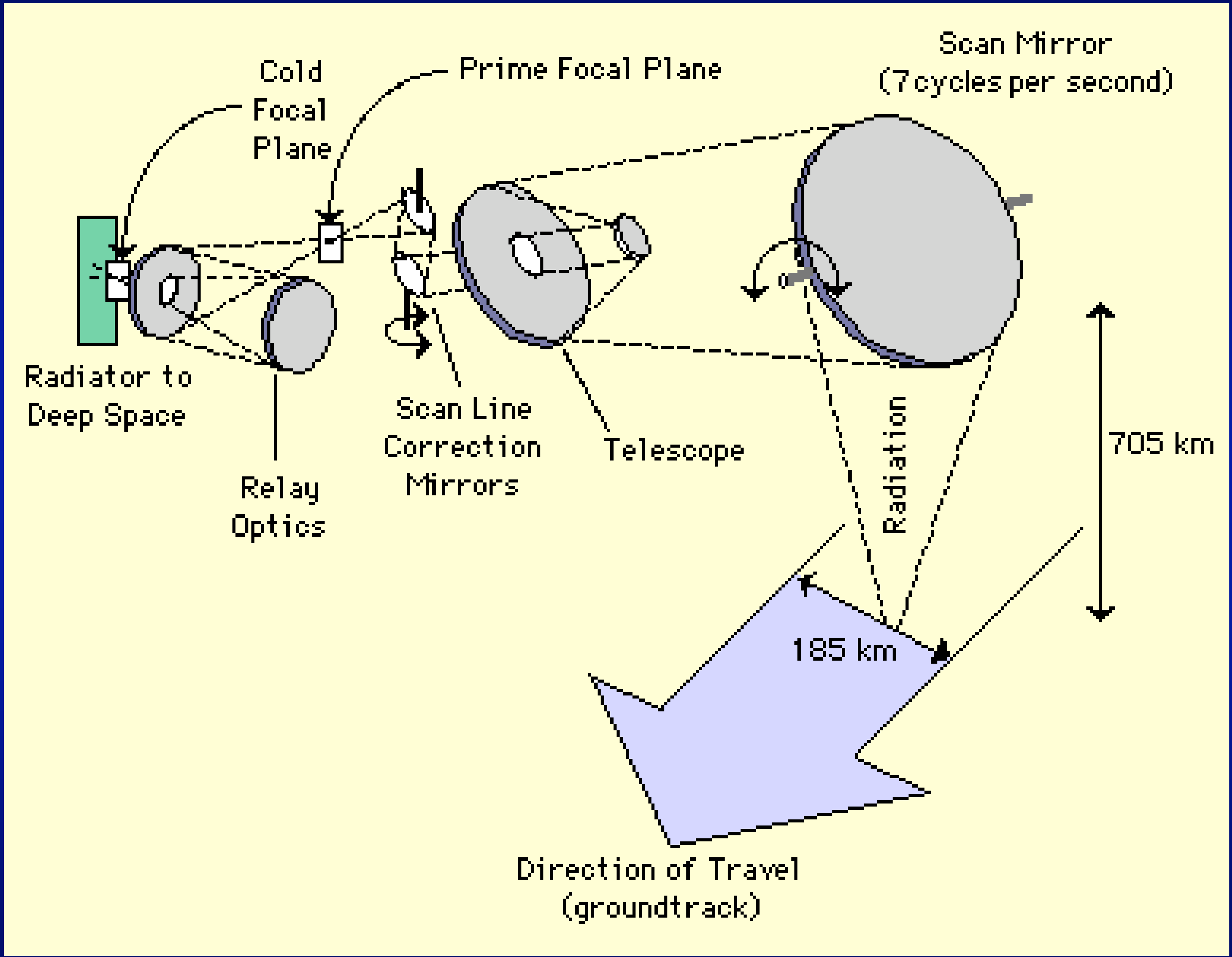
- On-board recording and pre-processing
- Direct telemetry to ground stations
  - receive data transmissions from satellites
  - transmit commands to satellites (pointing, turning maneuvers, software updating
- Indirect transmission through Tracking and Data Relay Satellites (TDRS)

Imaging Systems

- Cross-track scanner
- Whiskbroom scanner
- Pushbroom sensor

Cross-track Scanner

- “back and forth” motion of the foreoptics
- scans each ground resolution cell one-by-one
- Instantaneous Field of View (IFOV) of instrument determines pixel size
- Image is built up by movement of satellite along the orbital track and scanning across-track



Cold
Focal
Plane
Prime Focal Plane
Scan Mirror
(7 cycles per second)
Radiator to
Deep Space
Relay
Optics
Scan Line
Correction
Mirrors
Telescope
Radiation
705 km
185 km
Direction of Travel
(groundtrack)

Dwell Time

- the amount of time a scanner has to collect photons from a ground resolution cell:

(scan time per line)/(#cells per line)

depends on:

  - satellite speed
  - width of scan line
  - time per scan line
  - time per pixel

Dwell time example

$$\text{dwell time} = \frac{(\text{down track pixel size / orbital velocity})}{(\text{cross-track line width / cross-track pixel size})}$$

dwell time =

[(30m / 7500 m/s)/(185000m / 30m)]

$=6.5 \times 10^{-7}$ seconds/pixel

This is a very short time per pixel -- low SNR

Along-track scanner ("Pushbroom)

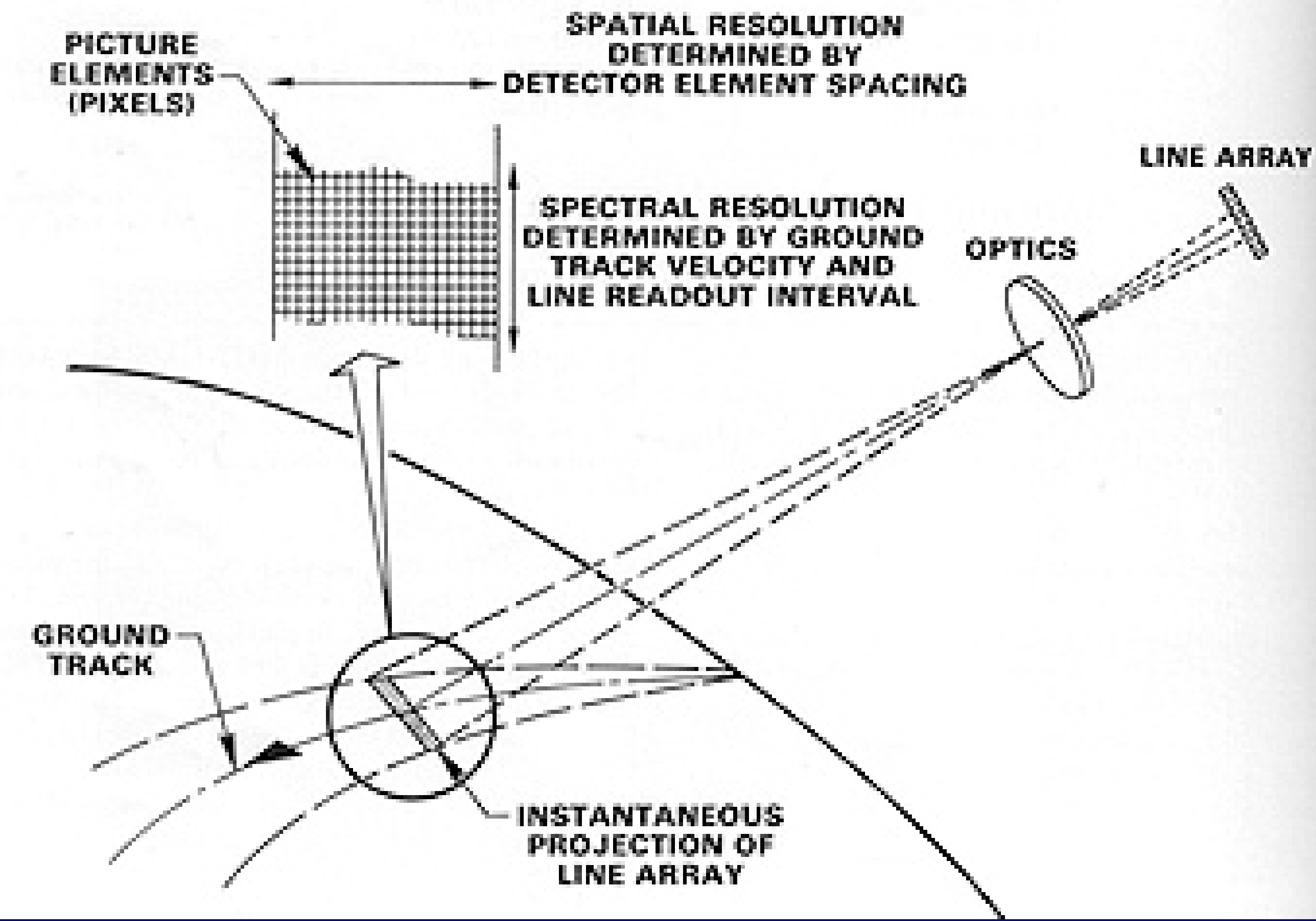
- Linear array of detectors (aligned cross-track)
  - reflected radiance passes through a lens and onto a line of detectors
- Image is built up by movement of the satellite along its orbital track (no scanning mirror)
- Area array can also be used for multi-spectral remote sensing
  - dispersion used to split light into narrow spectral bands and individual detectors

Dwell Time Example

$$\frac{\text{(down track pixel size / orbital velocity)}}{\text{(cross-track line width / cross-track pixel size)}}$$

- denominator = 1.0
- dwell time = 4.0×10^{-3} seconds/pixel
- but different response sensitivities in each detector can cause striping in the image

Pushbroom Imager



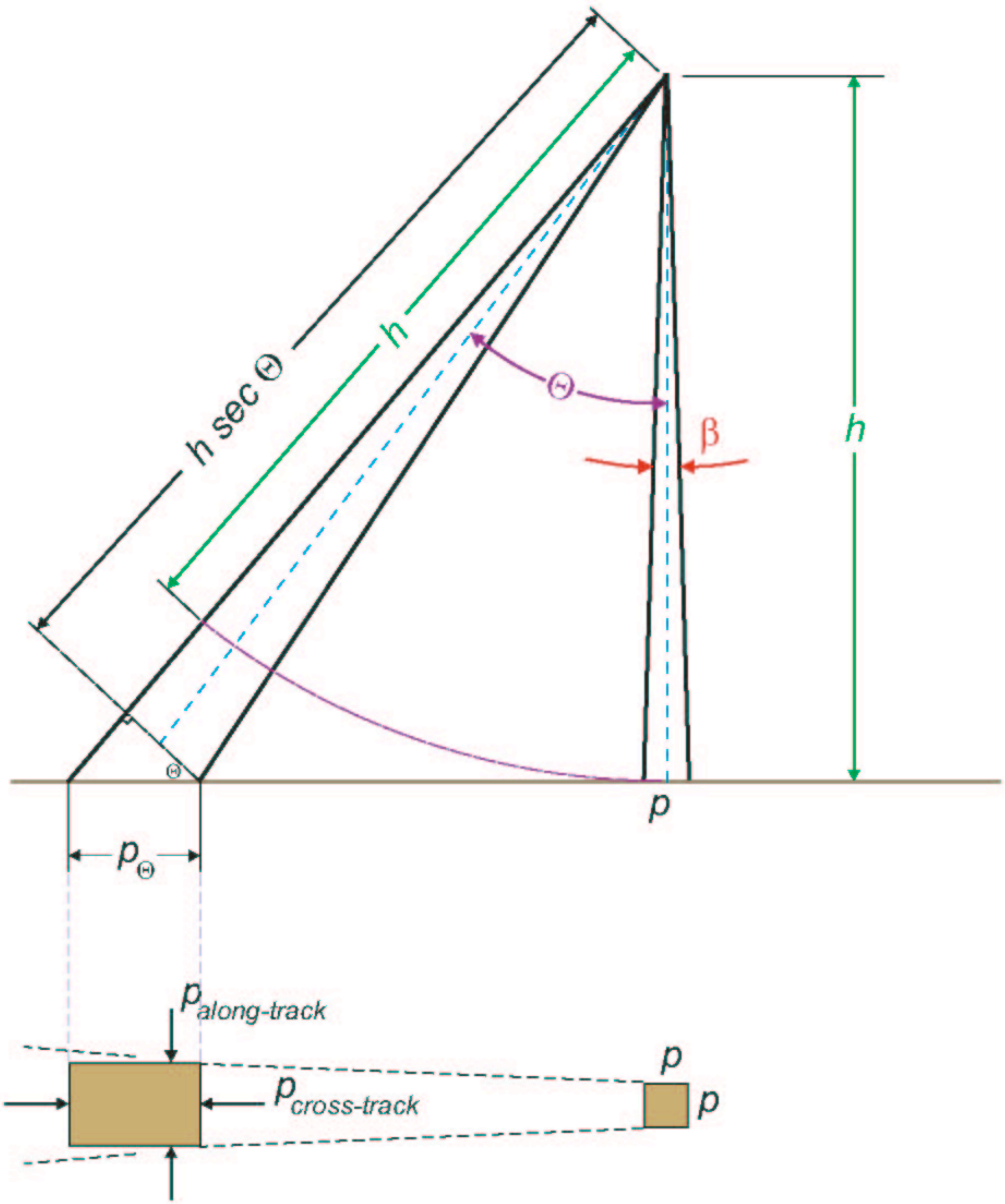
Whiskbroom Sensor

- Linear or area array of detectors
- Image is built up by movement of satellite along its orbital track and by cross-track scanning using a mirror
  - wide field of view (FOV)
  - pixel resolution varies with scan angle

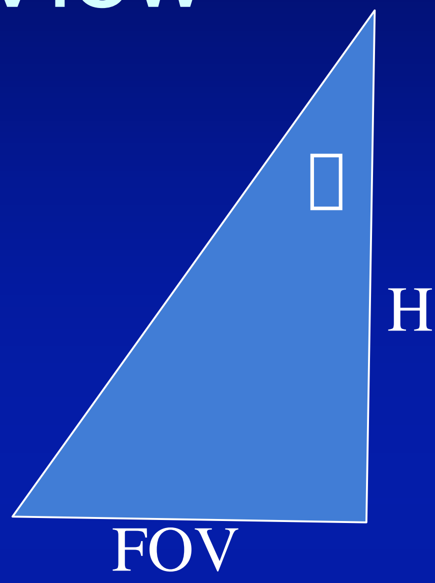
Whiskbroom vs. Pushbroom

- Wide swath width
- Complex mechanical system
- Simple optical system
- Filters and sensors
- Shorter dwell time
- Pixel distortion

- Narrow swath width
- Simple mechanical system
- Complex optical system
- Dispersion grating and CCDs
- Longer dwell time
- No pixel distortion


h sec Θ
h
Θ
β
h
Θ
p
p_Θ
$p_{along\text{-}track}$
$p_{cross\text{-}track}$
p
p

Calculating the Field of View (FOV)



FOV = 2 H tan(scan angle + □/2)

H = satellite altitude

Example:

SeaWIFS satellite altitude = 705 km

Scan angle = 58.3^{o}

FOV = 1410 x tan(58.3^{o}) = 2282 km

Computing pixel size

tan(angle)= opposite/adjacent

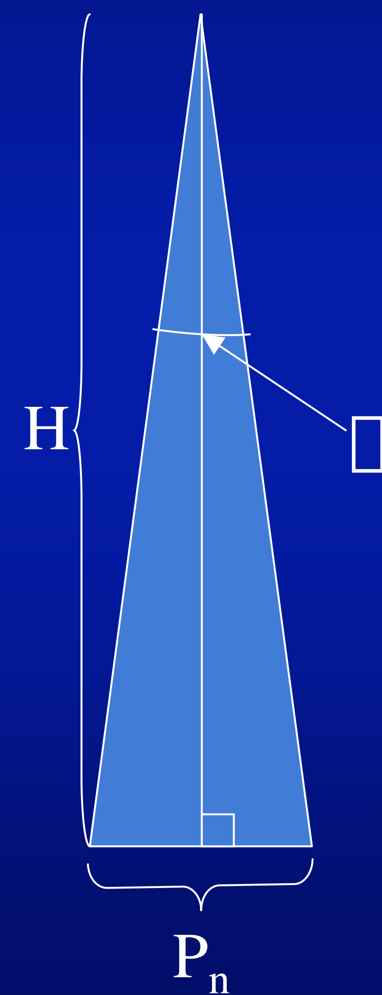
□ = IFOV

P_n = pixel size at nadir

H = altitude of satellite

tan(□/2) = (P_n/2) / H

P_n= 2 H tan(□/2)



Cross-track pixel size

$x = H \tan(\square + \square/2)$

$x_2 = H \tan(\square\ \square\ \square/2)$

$x_1 = x - x_2$

$P_c = H \tan(\square + \square/2) - H \tan(\square\ \square\ \square/2)$