Remote Sensing: Fundamentals and Applications

HYDAP Kick-Off Meeting
Part Two

esf evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Sensor Capabilities - 1

- Multi-purpose VIS/IR imagery
- IR temperature/humidity sounding
- MW temperature/humidity sounding
- Multi-purpose MW imagery
- Low-frequency MW imagery
- Radio occultation sounding
- Earth radiation budget
- Sea-surface wind by active and passive MW
- Radar altimetry
- Ocean colour imagery
- Lightning imagery
- Cloud and precipitation profiling by radar

Sensor Capabilities - 2

- Lidar observation of atmosphere (for wind, for cloud/aerosol, for trace gases)
- Lidar observation of surface (for altimetry, biomass assessments)
- Cross-nadir SW/IR spectrometry (for chemistry)
- Limb-sounding spectrometry
- High-resolution imagery for land observation
- Synthetic Aperture Radar
- Gravity field measuring
- Space Weather: solar activity, solar wind and deep space monitoring
- Space Weather: ionosphere and magnetosphere monitoring

Remote Sensing - Resolutions

- 4 main resolutions
  - **Spatial resolution**
  - Spectral resolution
  - Temporal resolution
  - Radiometric resolution

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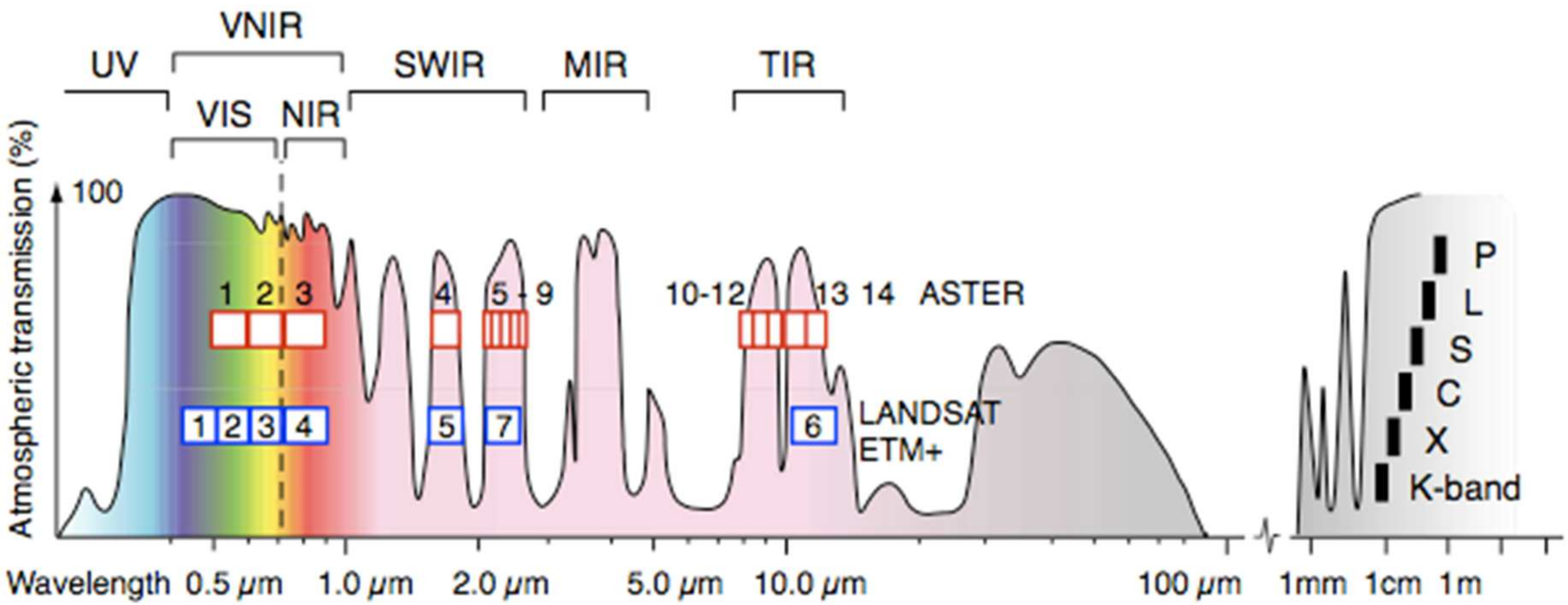

Fig. 5-1 Atmospheric transmission, sections of the optical and microwave spectrum, and spectral range of Landsat ETM+ and ASTER bands. UV: ultraviolet; VIS: visible; NIR: near infrared; SWIR: short-wave infrared; MIR: middle infrared; TIR: thermal infrared.

Remote Sensing - Resolutions

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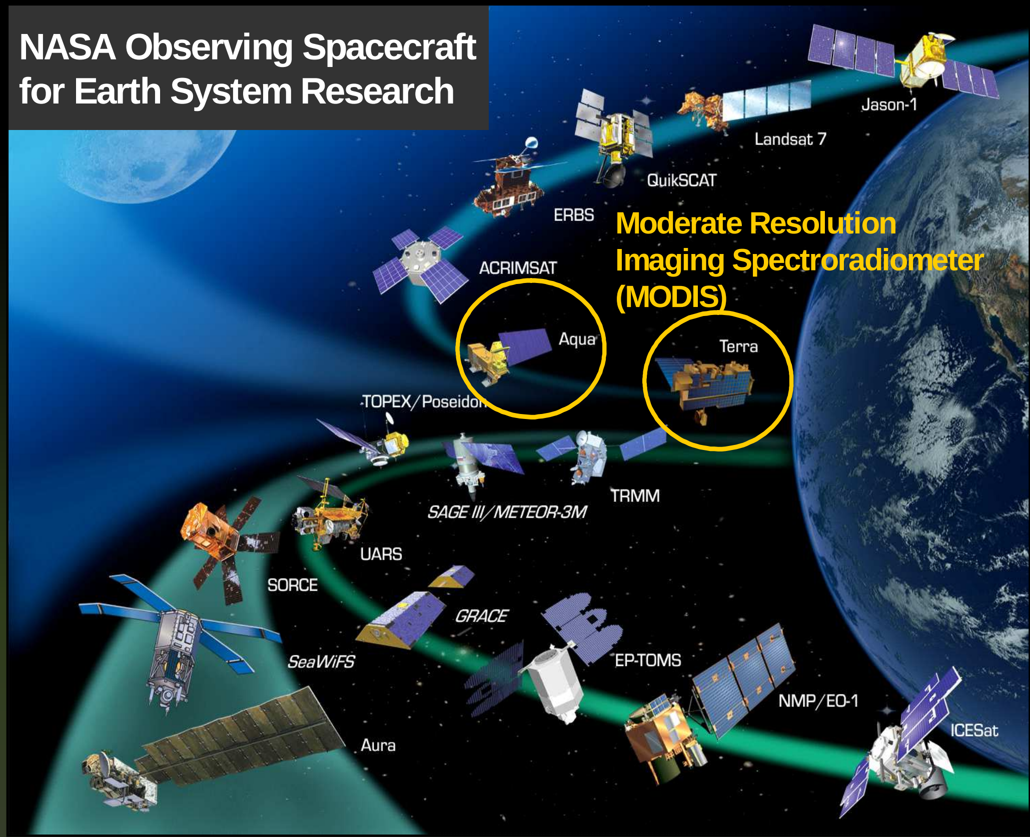
  - **Radiometric resolution**

Airborne remote sensing laboratory

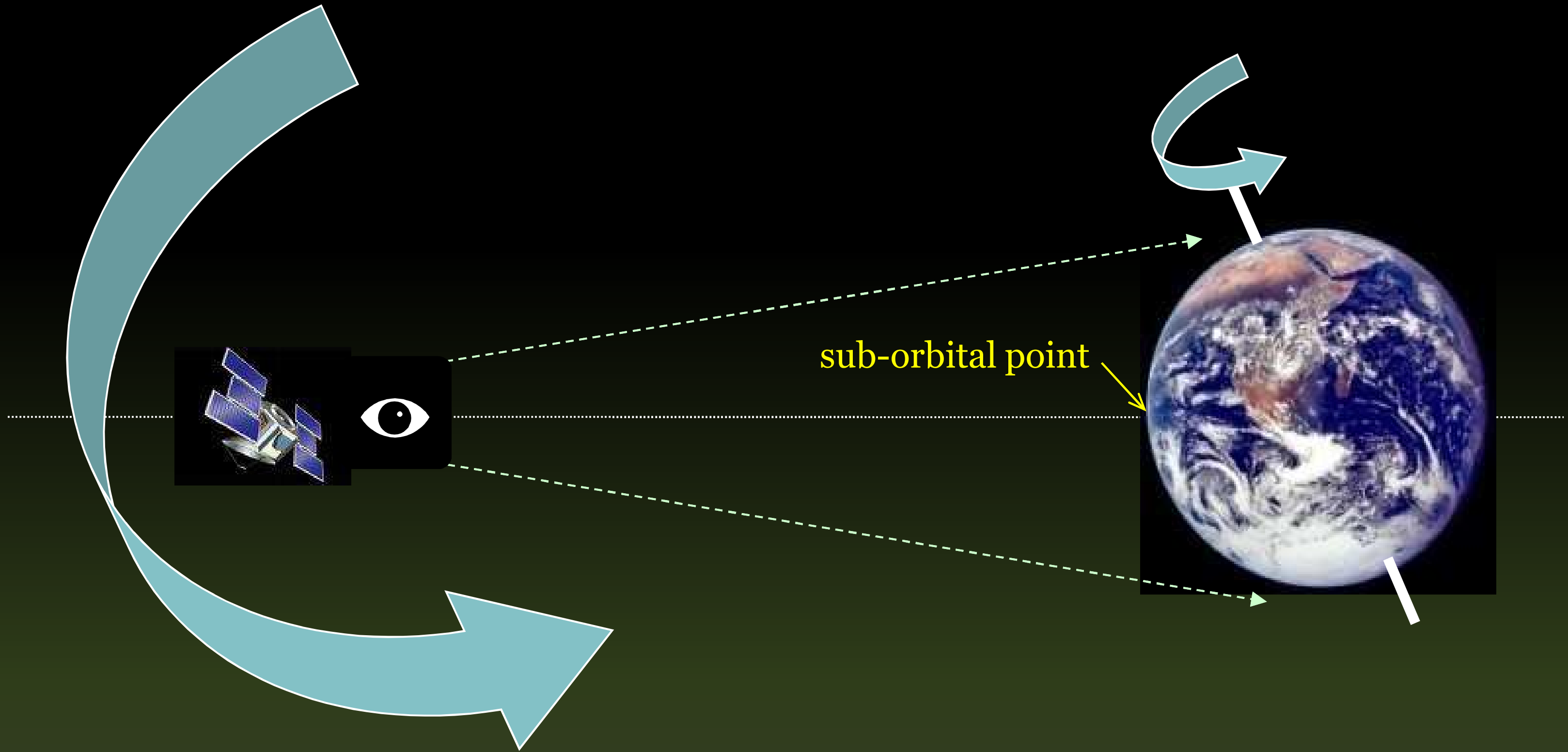
Platform for hyperspectral, TIR and LIDAR sensors

Why Satellite Remote Sensing?

- Advantages: Repeated reliable measurements
- Disadvantages: Expensive and need expertise to convert measurements to geophysical values such as temperature.
- Data from the numerous different satellites can be combined

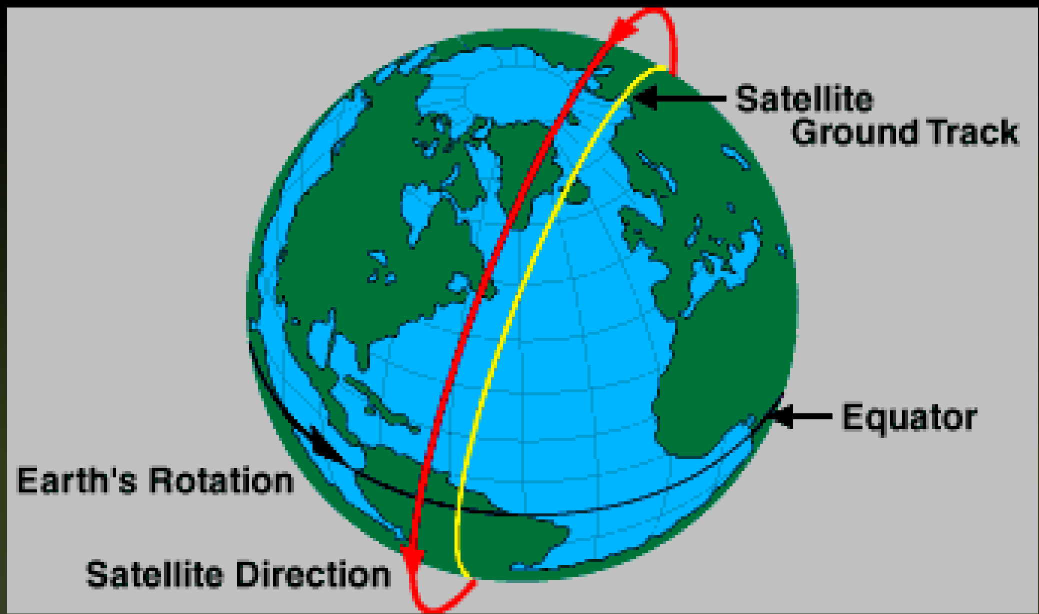


Geostationary Field-of-View (FOV)



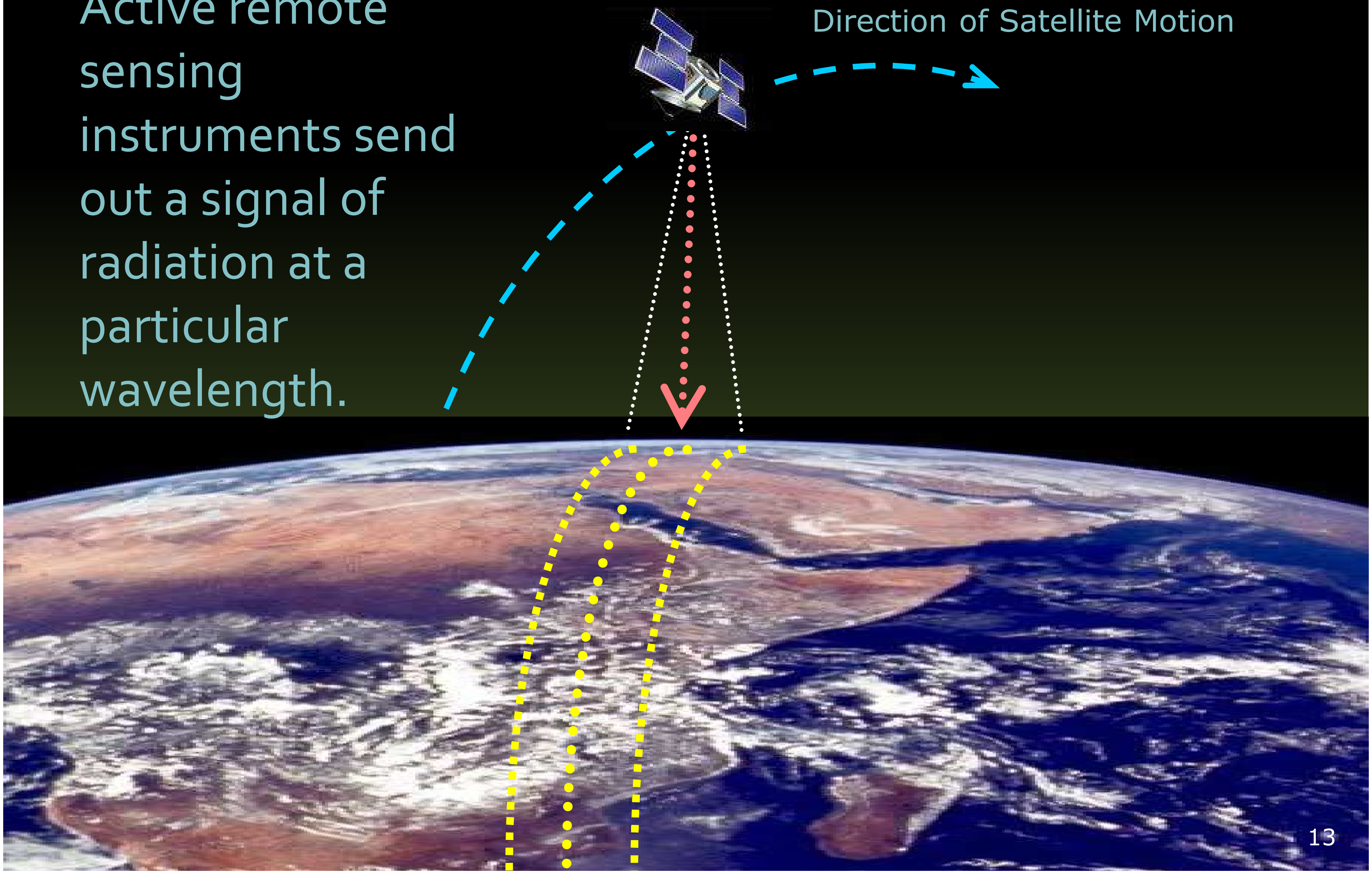
The field-of-view (FOV) of a Geostationary satellite (*i.e.*, what it can "see" from its vantage point in space) remains the same over time, and is at most ½ of the Earth's surface (±90° longitude one either side of the sub-orbital point on the equator).

Sun-Synchronous Orbits



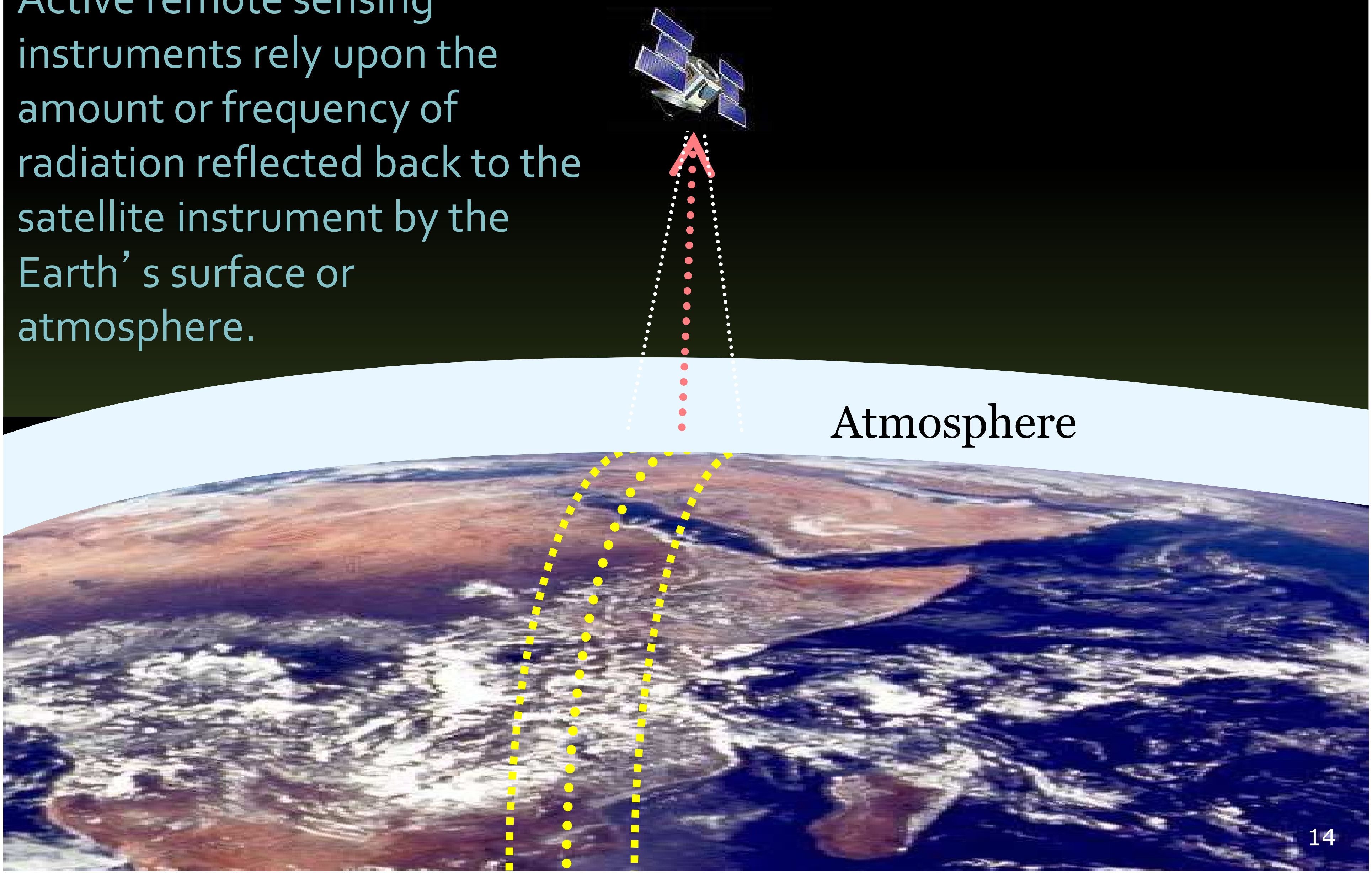
Active Remote Sensing

Active remote sensing instruments send out a signal of radiation at a particular wavelength.



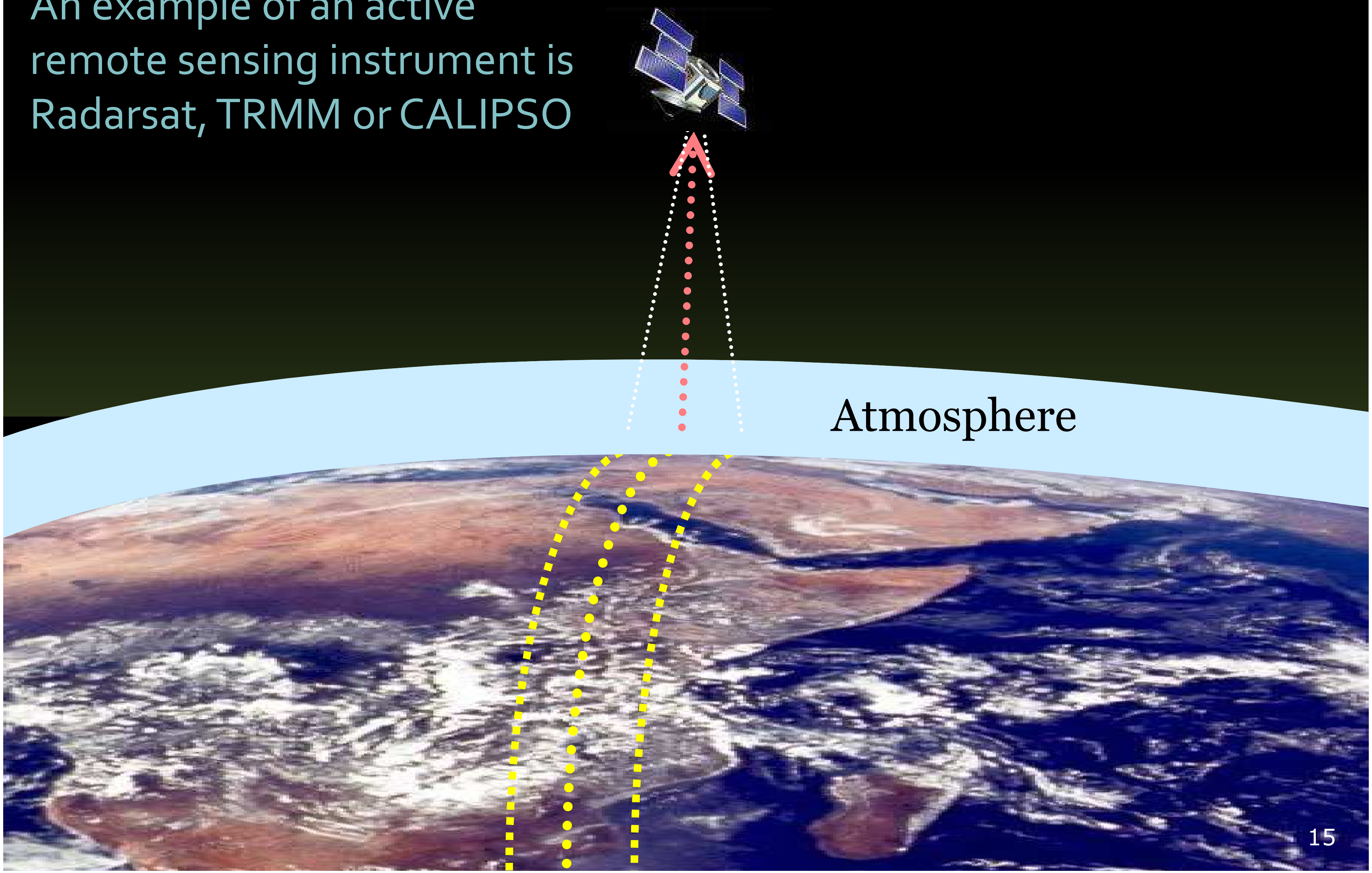
Active Remote Sensing

Active remote sensing instruments rely upon the amount or frequency of radiation reflected back to the satellite instrument by the Earth's surface or atmosphere.



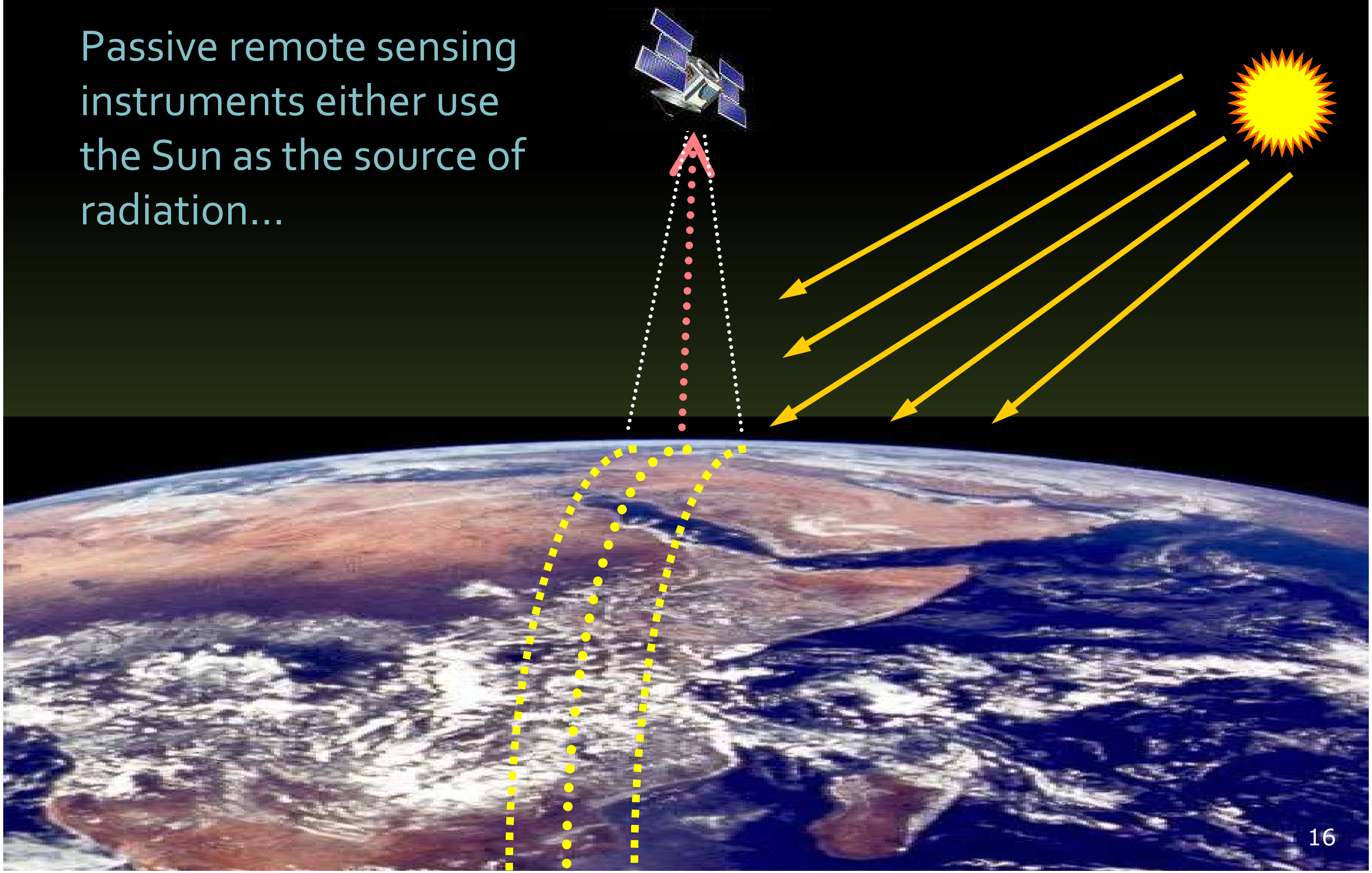
Active Remote Sensing

An example of an active remote sensing instrument is Radarsat, TRMM or CALIPSO



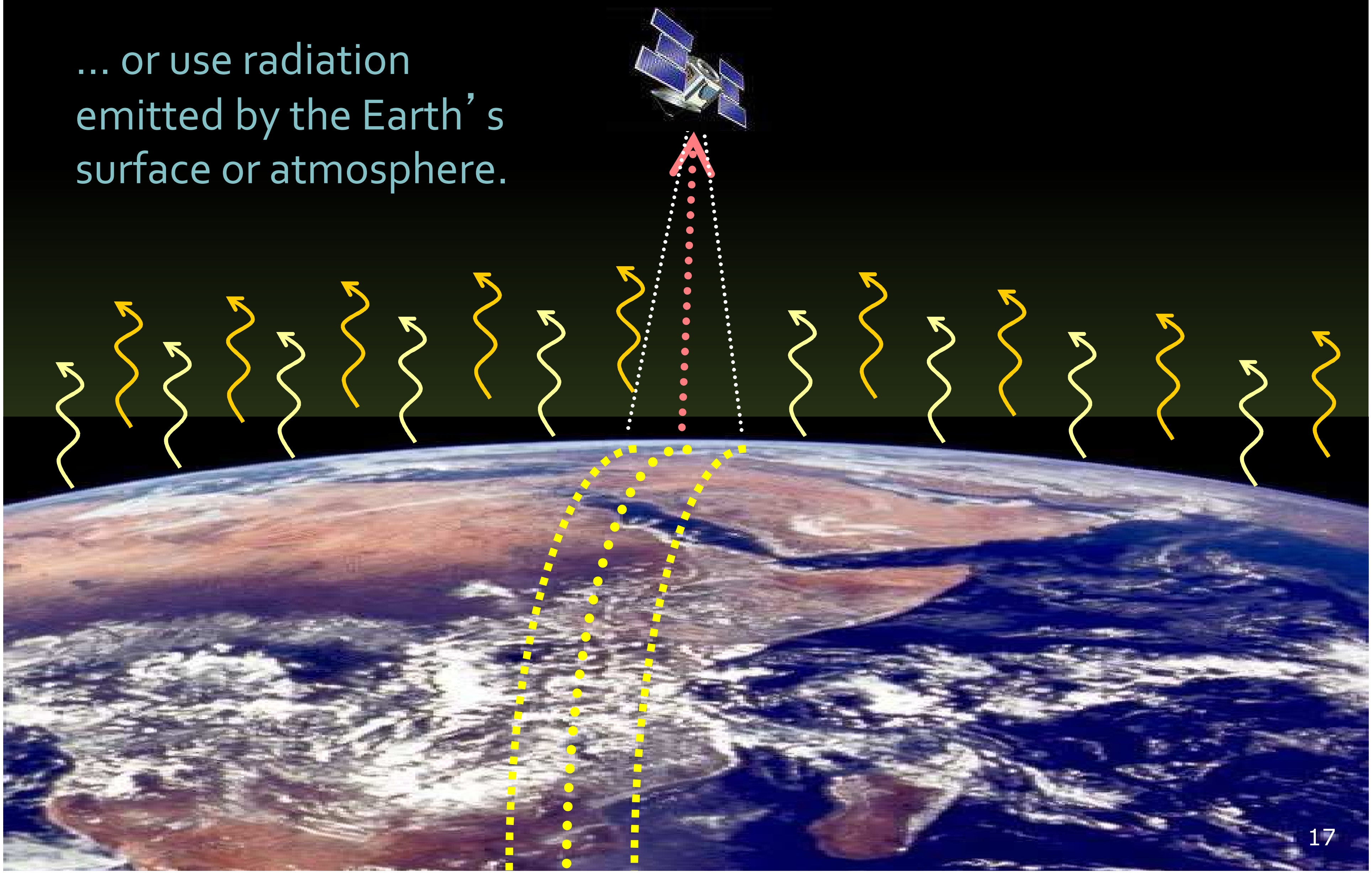
Passive Remote Sensing

Passive remote sensing instruments either use the Sun as the source of radiation…



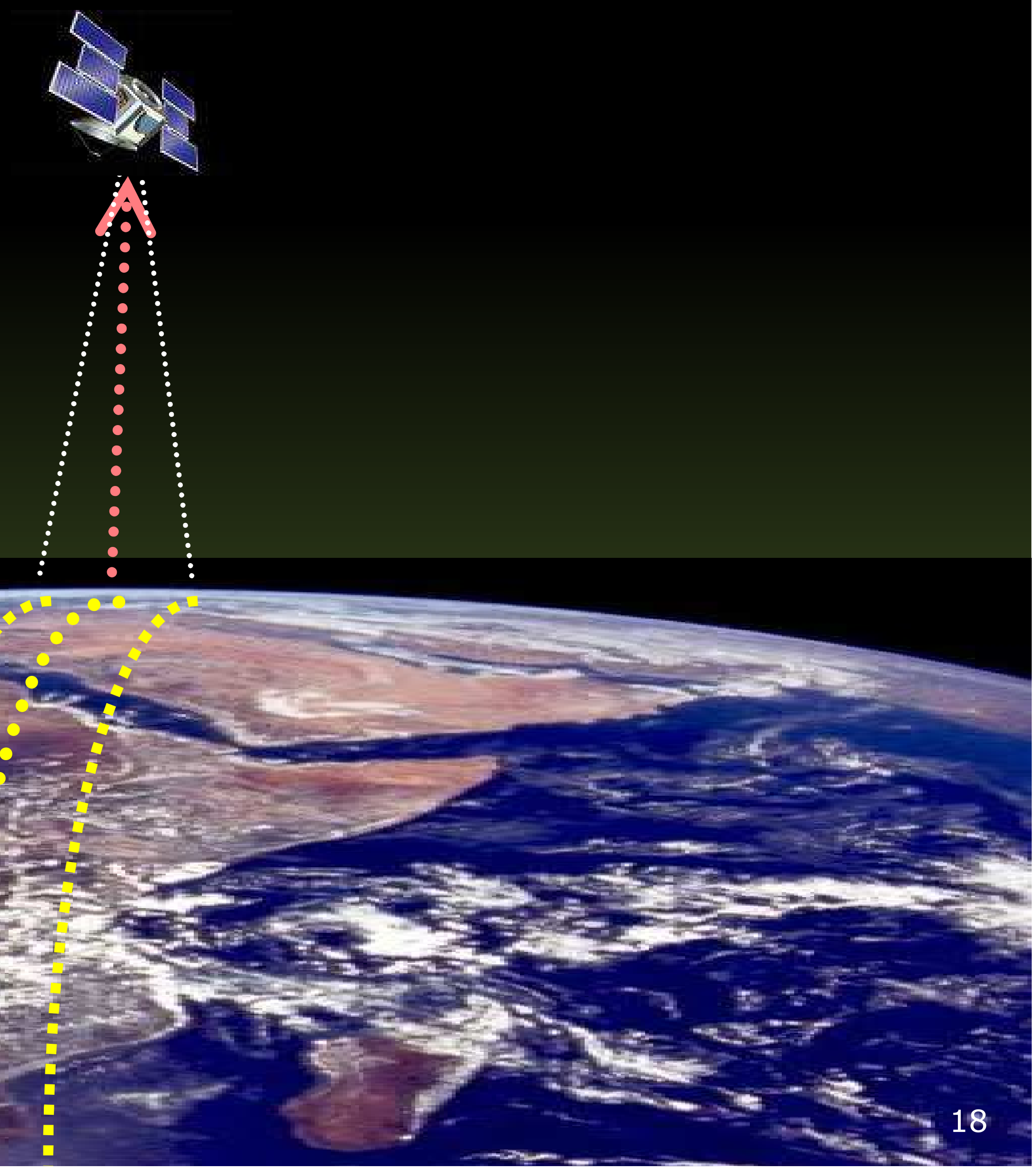
Passive Remote Sensing

… or use radiation emitted by the Earth’s surface or atmosphere.



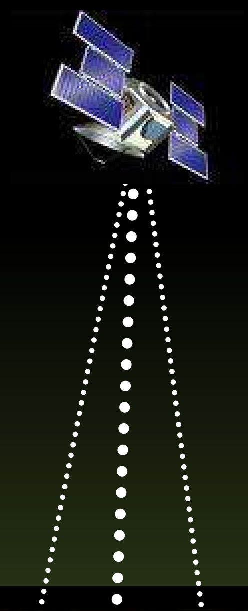
Passive Remote Sensing

Passive remote sensing instruments rely upon the amount or frequency of radiation *received by* the satellite instrument from the Earth's surface or atmosphere.

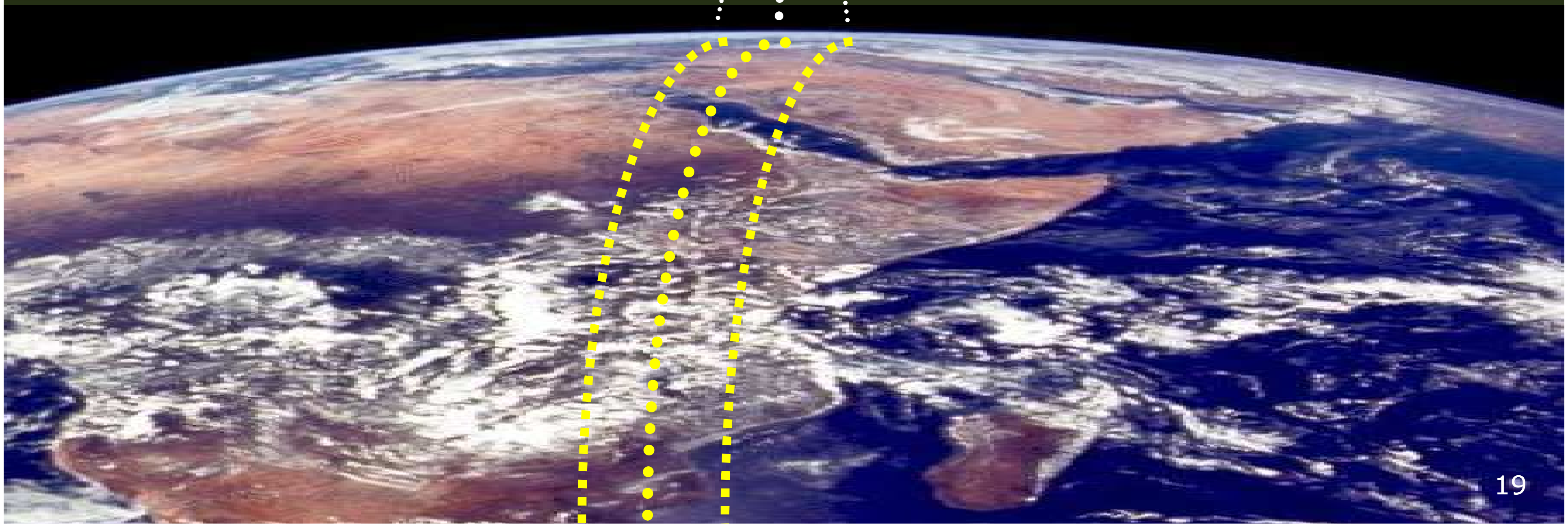


Low Earth Orbit (LEO) FOV

Satellites in Low Earth Orbit have only a *limited* Field-of-View (FOV) compared to Geostationary satellites, because they are comparatively closer to the Earth's surface.

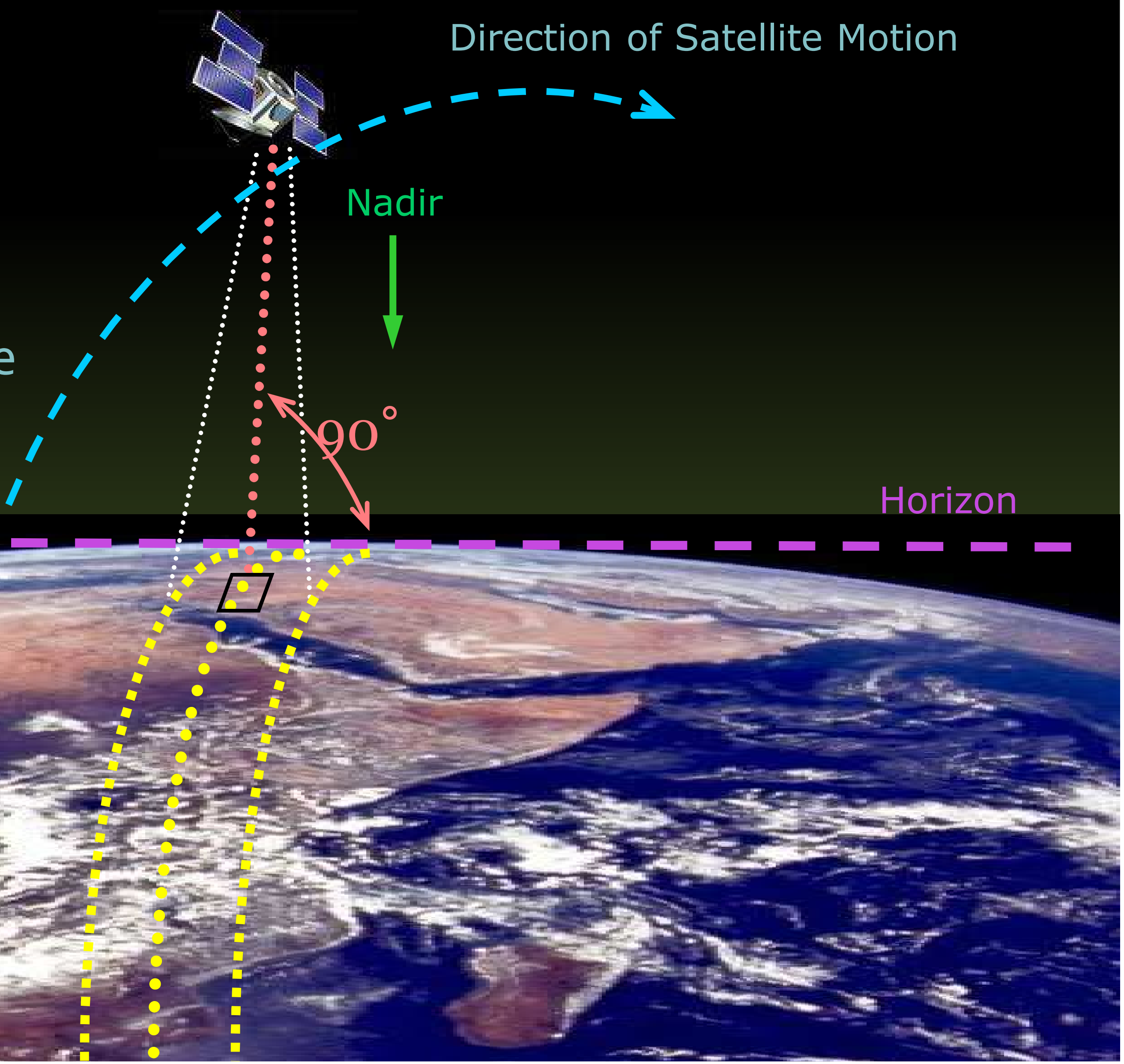


Therefore, they use a variety of techniques to expand their coverage of the planet's surface.



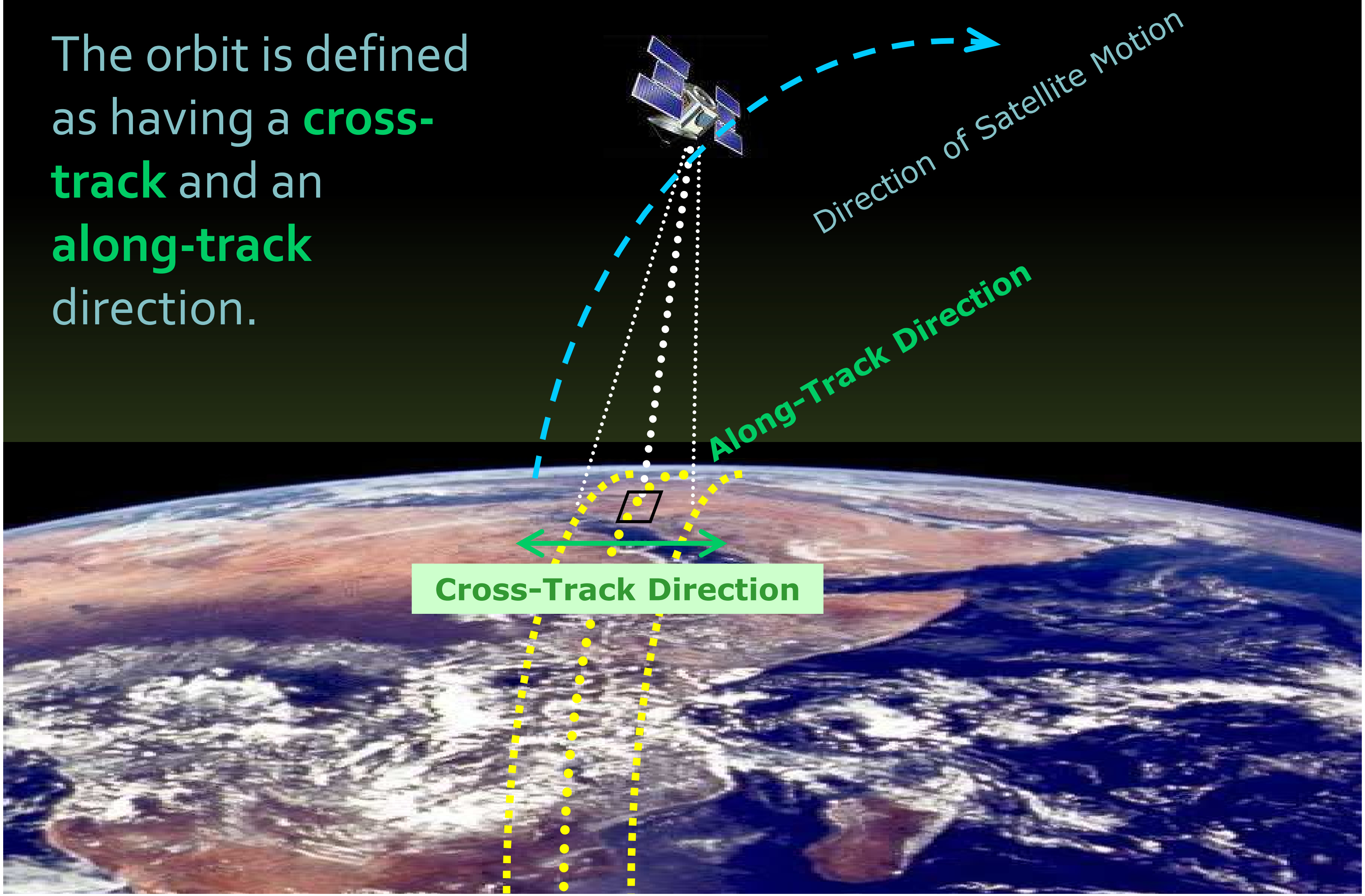
Low Earth Orbit (LEO) FOV

The nadir FOV is defined as directly beneath the satellite track, when the satellite is overhead (90° elevation angle from the horizon).



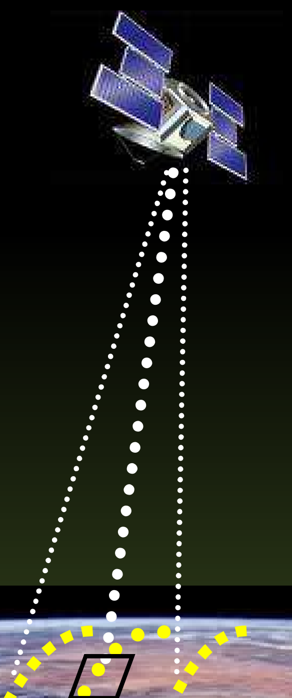
Low Earth Orbit (LEO) FOV

The orbit is defined as having a **cross-track** and an **along-track** direction.

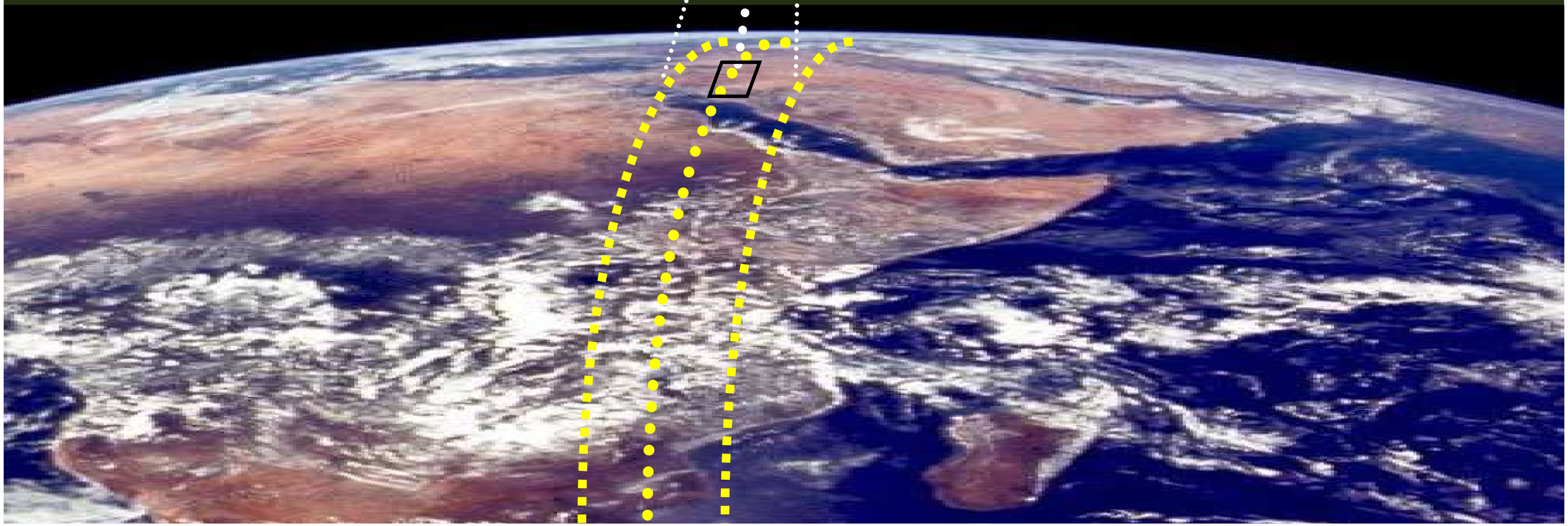


Instantaneous Field-of-View (IFOV)

Satellites in Low Earth Orbit have only an **instantaneous Field-of-View (IFOV)–** what can be observed in a single pixel or view by the sensor looking in the nadir-

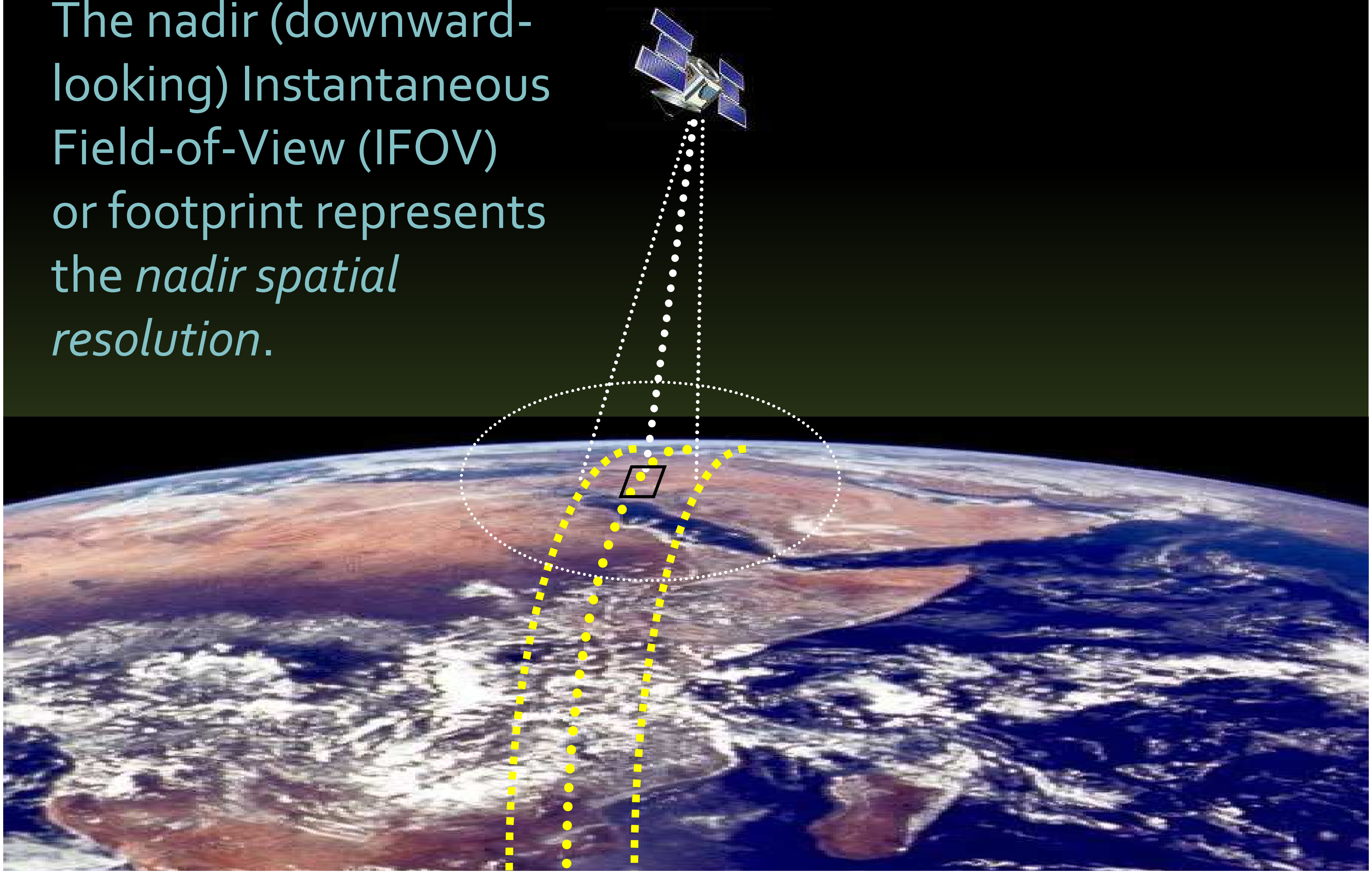


measured either as a solid viewing angle or as a geometric shape or *footprint* on the surface of the Earth (*i.e.*, 10×14 km^2 or $0.25° \times 0.5°$ lat/lon).



Instantaneous Field-of-View (IFOV)

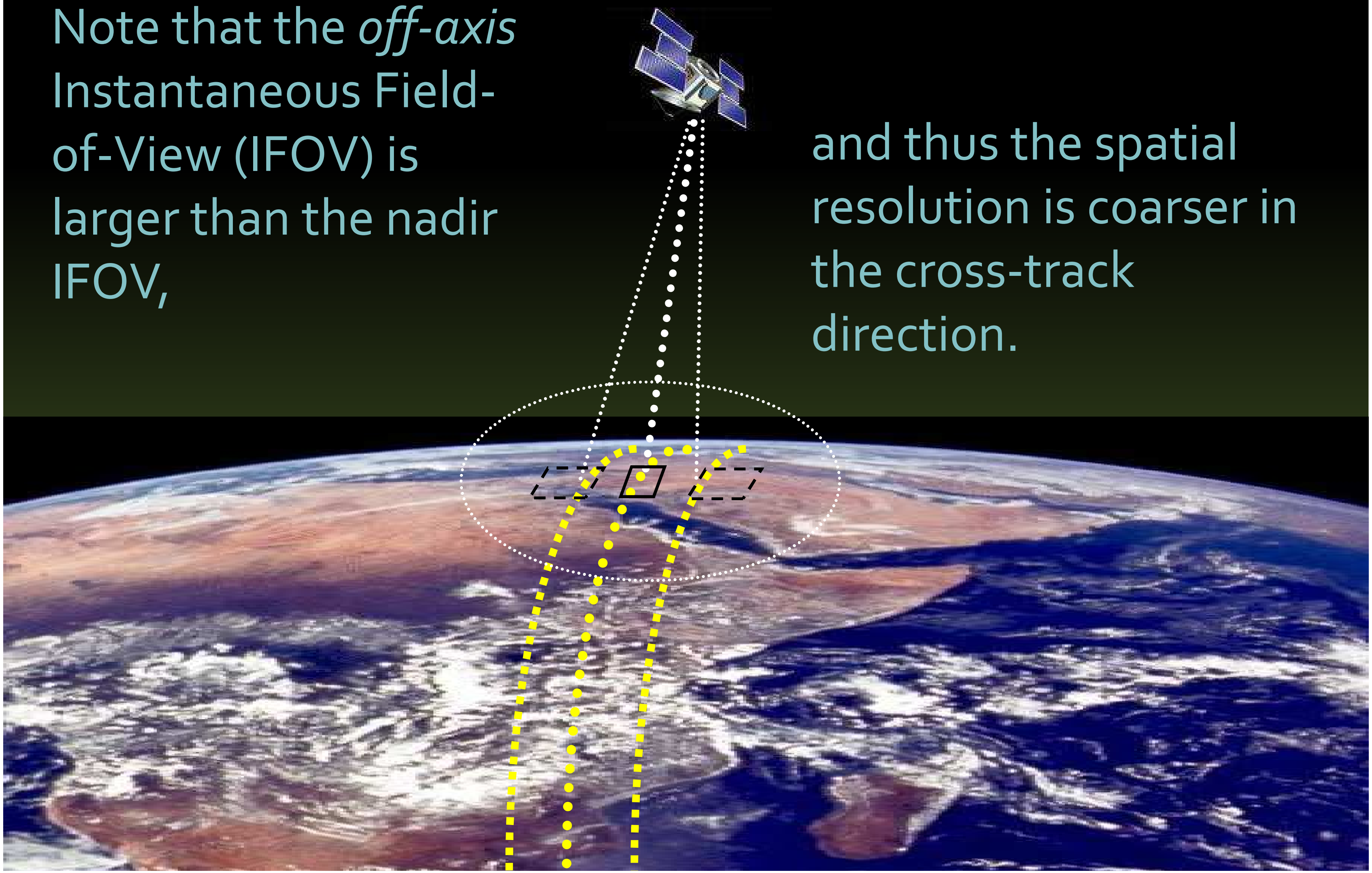
The nadir (downward-looking) Instantaneous Field-of-View (IFOV) or footprint represents the *nadir spatial resolution*.



Instantaneous Field-of-View (IFOV)

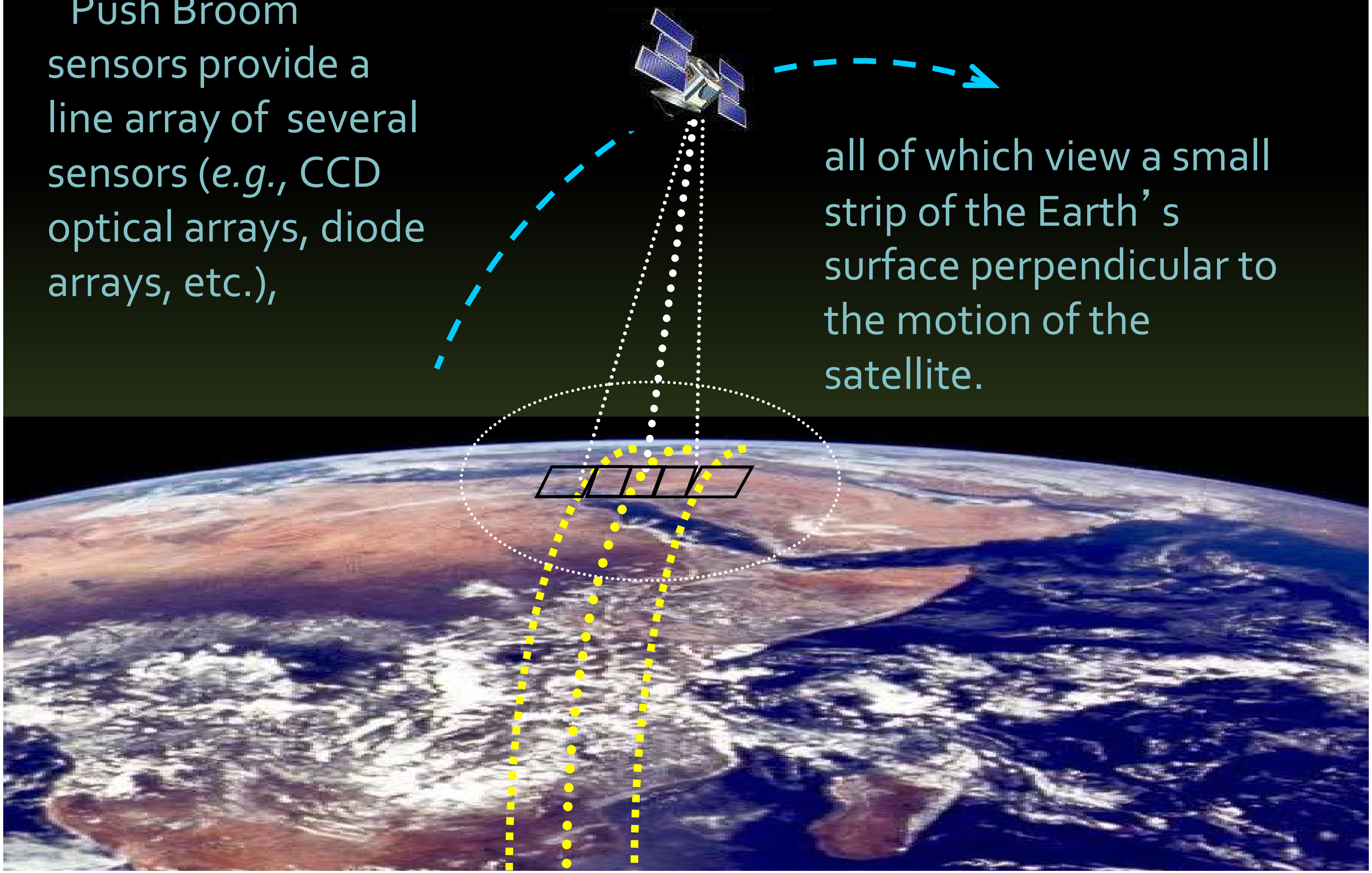
Note that the *off-axis* Instantaneous Field-of-View (IFOV) is larger than the nadir IFOV,

and thus the spatial resolution is coarser in the cross-track direction.



Push-Broom Sensors

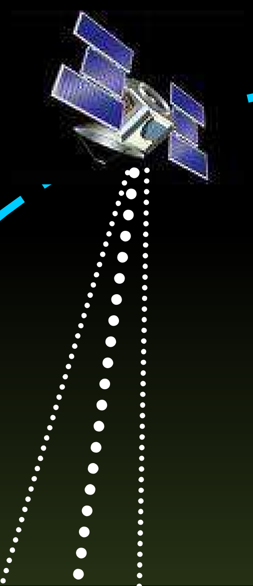
"Push Broom" sensors provide a line array of several sensors (*e.g.*, CCD optical arrays, diode arrays, etc.),

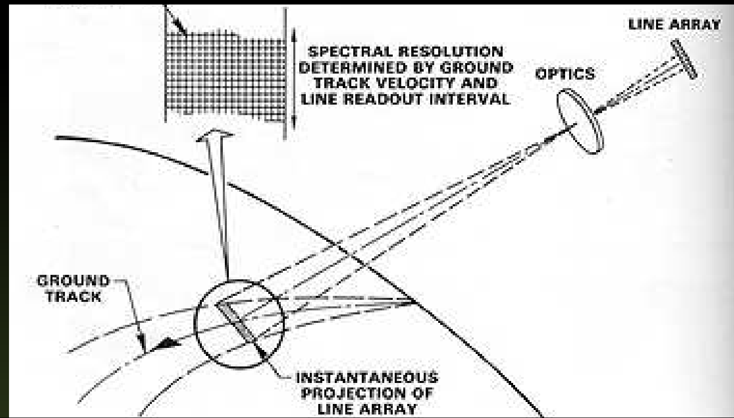


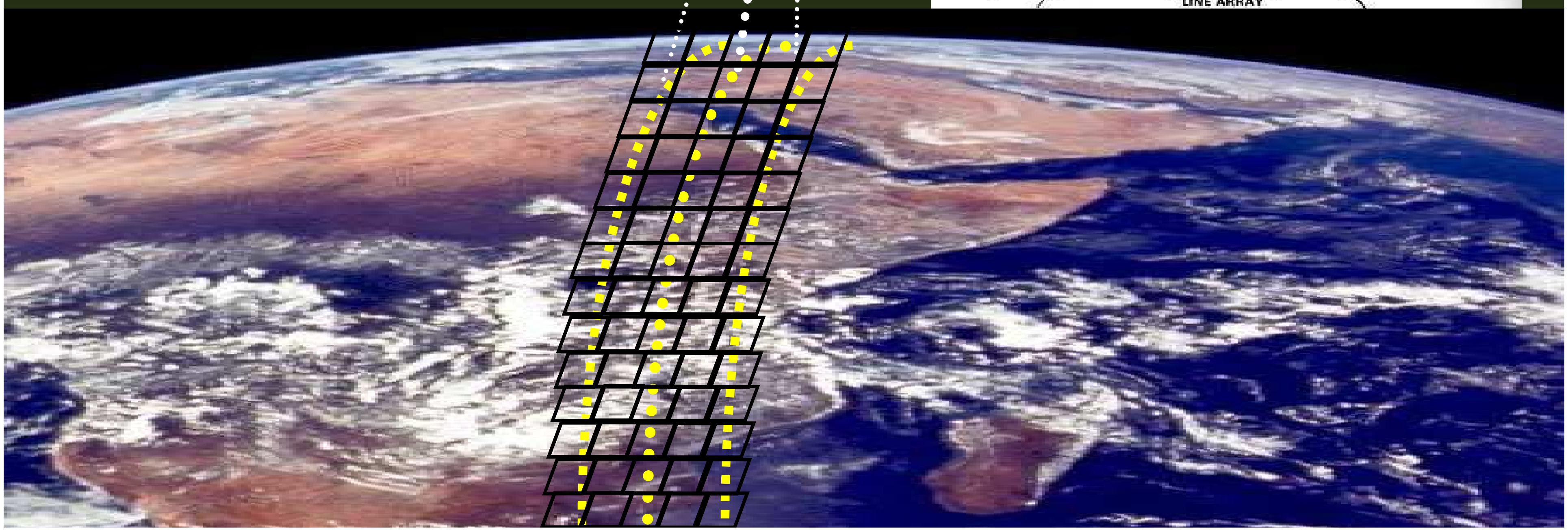
all of which view a small strip of the Earth's surface perpendicular to the motion of the satellite.

Push-Broom Sensors

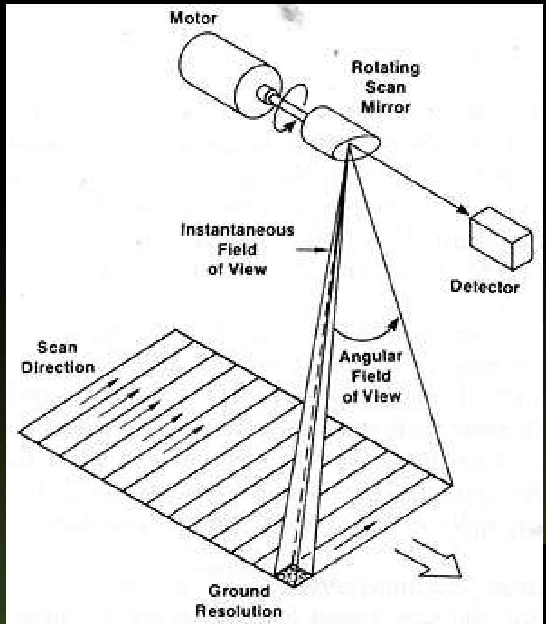
By stitching together a continuous series of push broom images, a contiguous swath or ribbon of data encircling the Earth can be achieved.

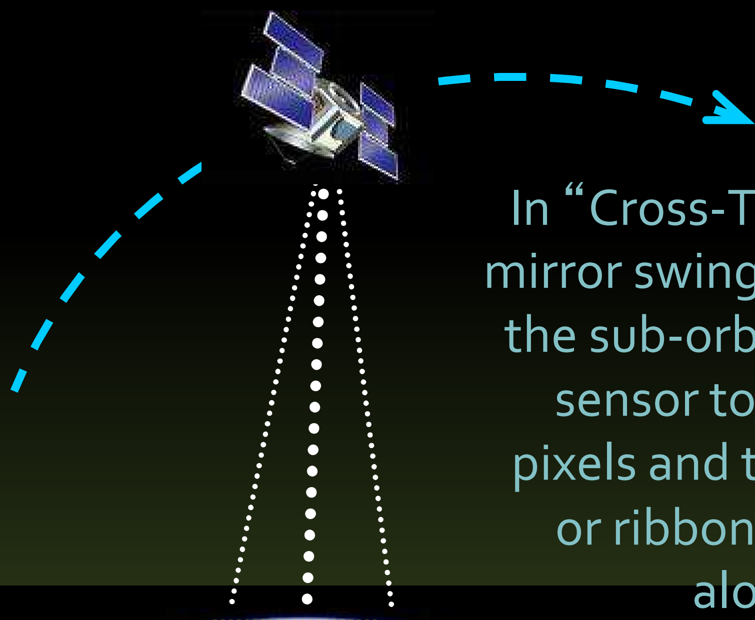


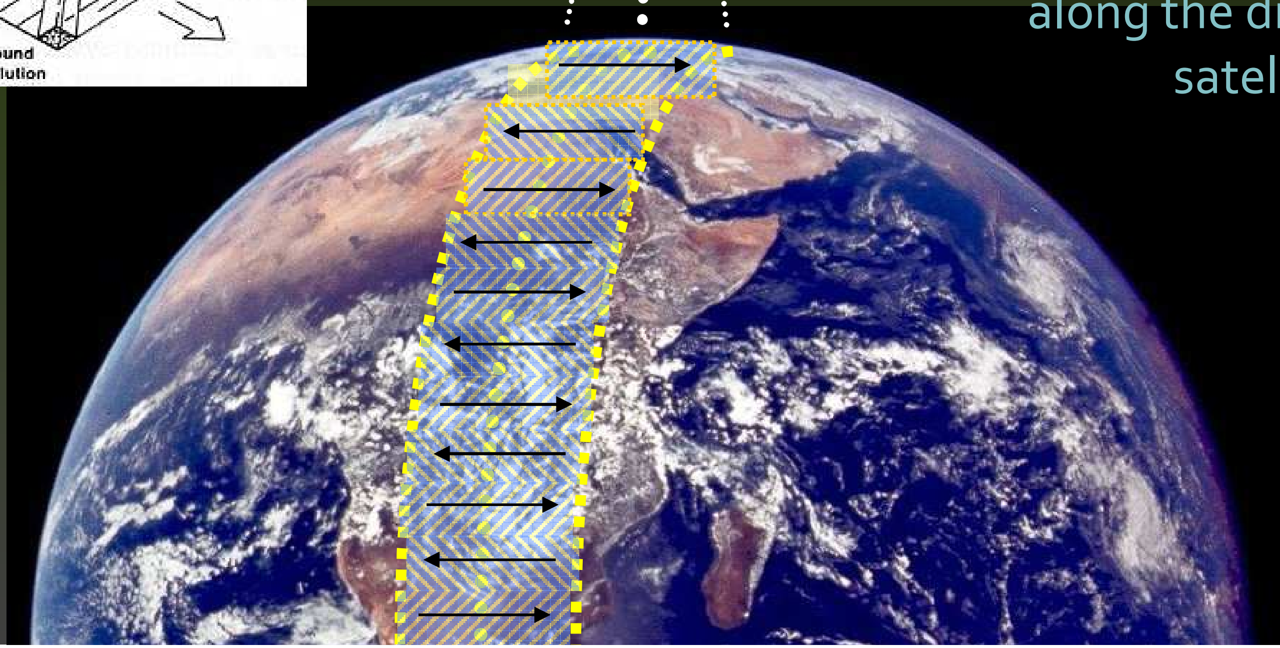




Cross-Track Scanning Sensors

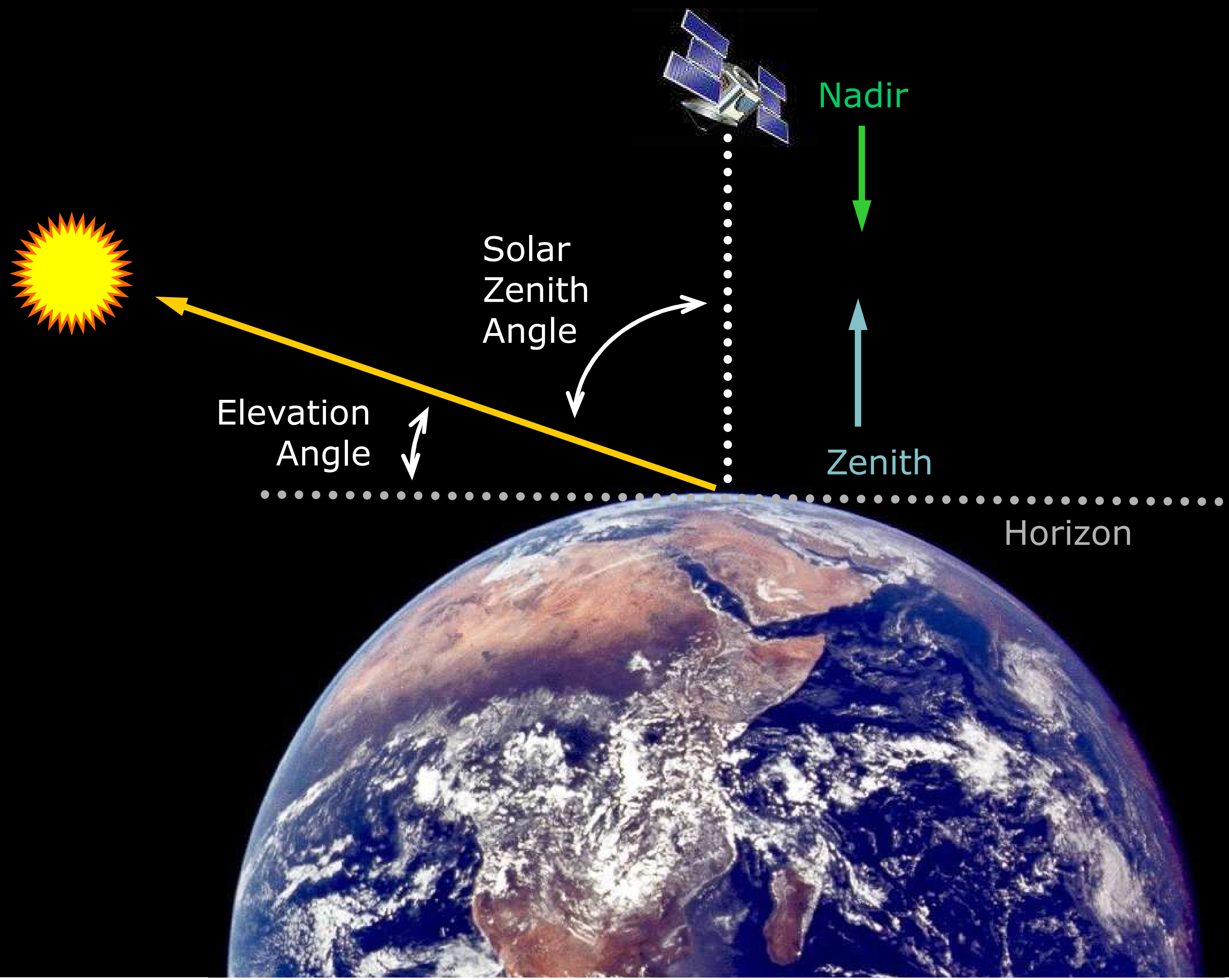




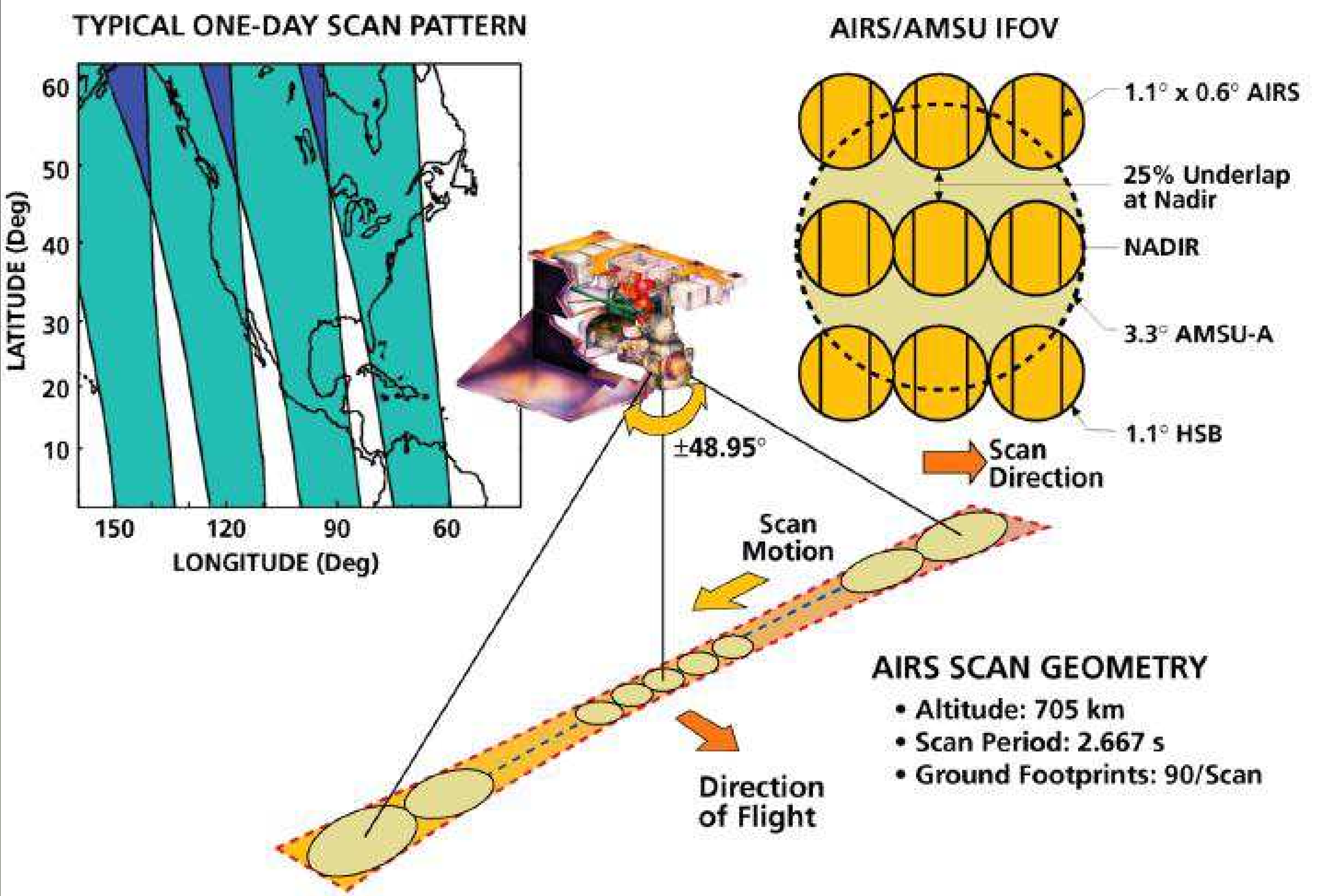


In "Cross-Track Scanning," a scan mirror swings back and forth along the sub-orbital track, allowing the sensor to sequentially observed pixels and trace out a small swath or ribbon of the Earth's surface along the direction of the satellite's motion.

Orbital Geometry

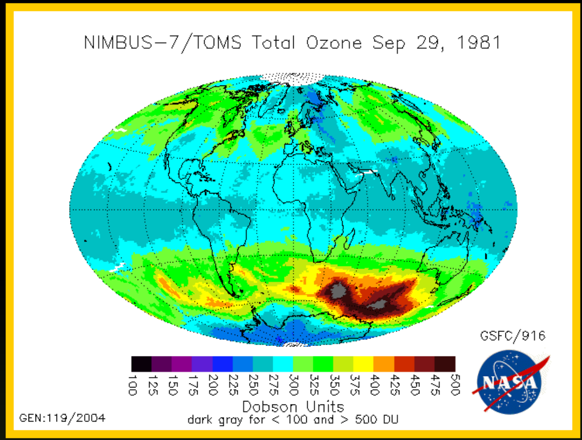


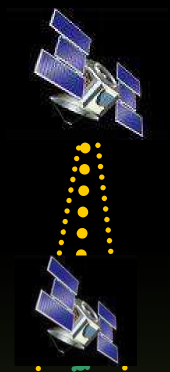
Cross-Track Scanning Sensors



Cross-track scanning results in individual observations ("pixels") of varying size, and can leave gaps between successive orbits if the scan angle is not wide enough.

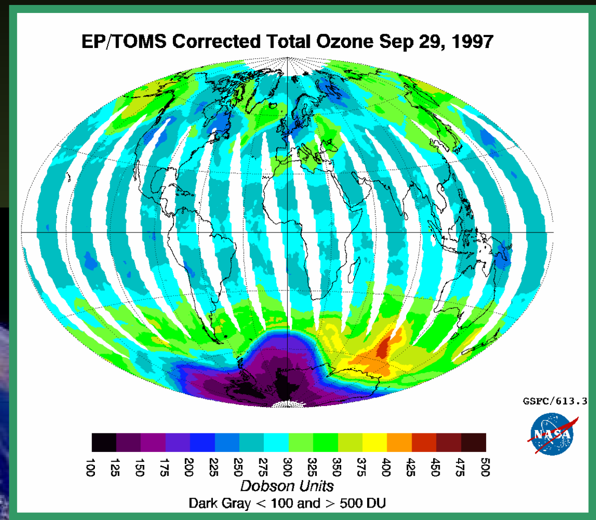
Spatial Coverage



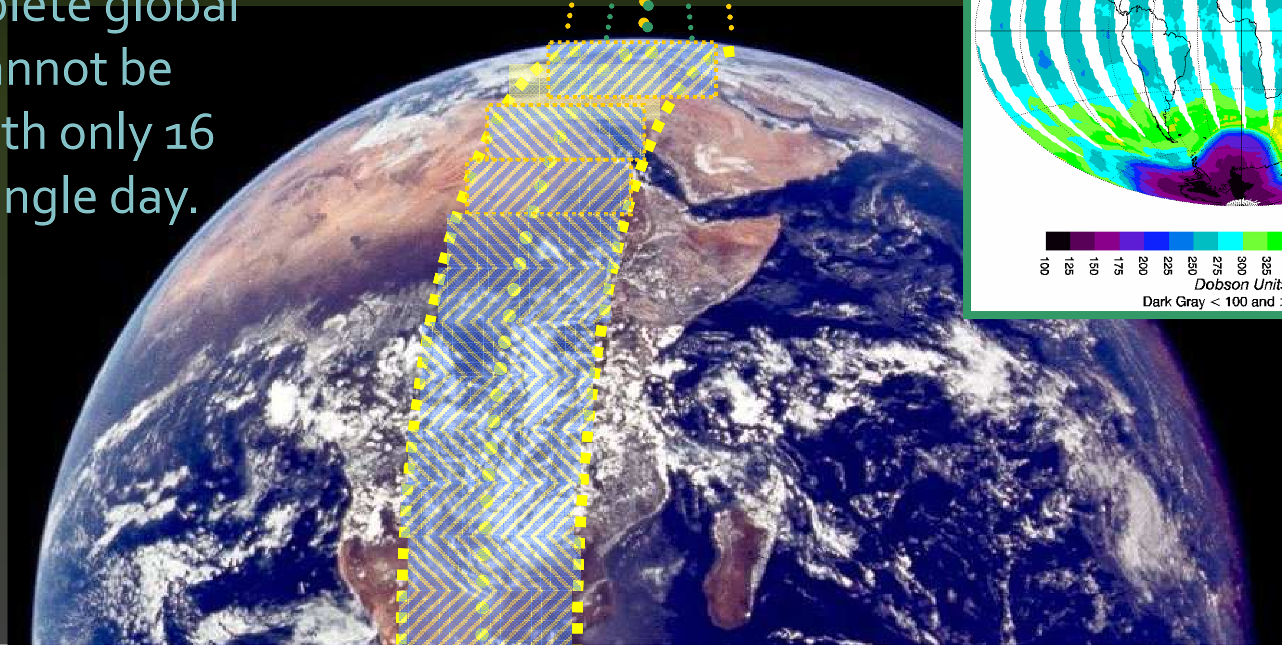


Nimbus-7 TOMS Orbital Altitude: 955 km

EarthProbe TOMS (original) Orbital Altitude: 500 km



If the orbit is too low and/or the FOV is too small, complete global coverage cannot be obtained with only 16 orbits in a single day.

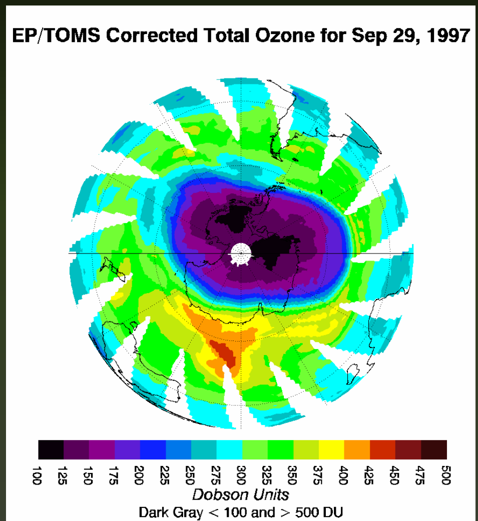


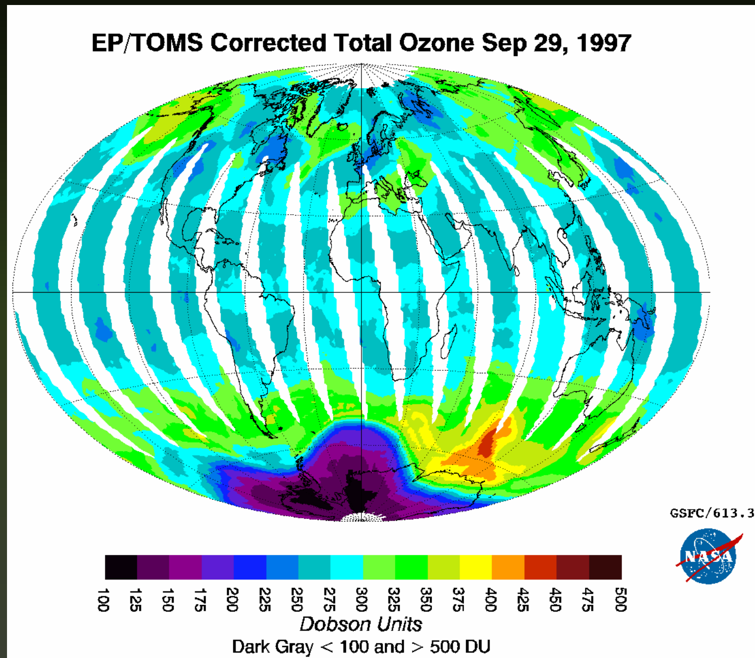
Incomplete Global Coverage

Incomplete daily global coverages results in daily global maps composed of ribbons of data with data gaps between the swaths in the equatorial regions. Note that for high inclination satellites, there is still significant overlap at the poles even when equatorial coverage is incomplete.

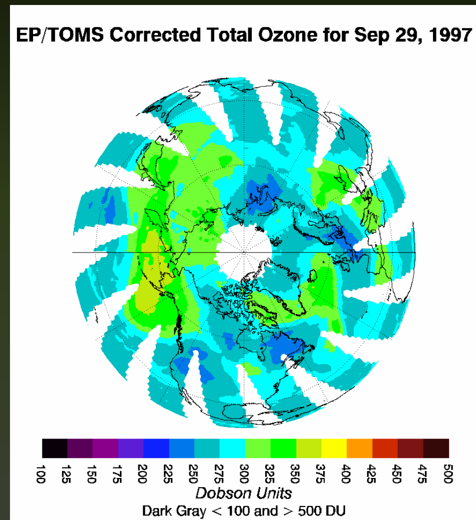
Global View

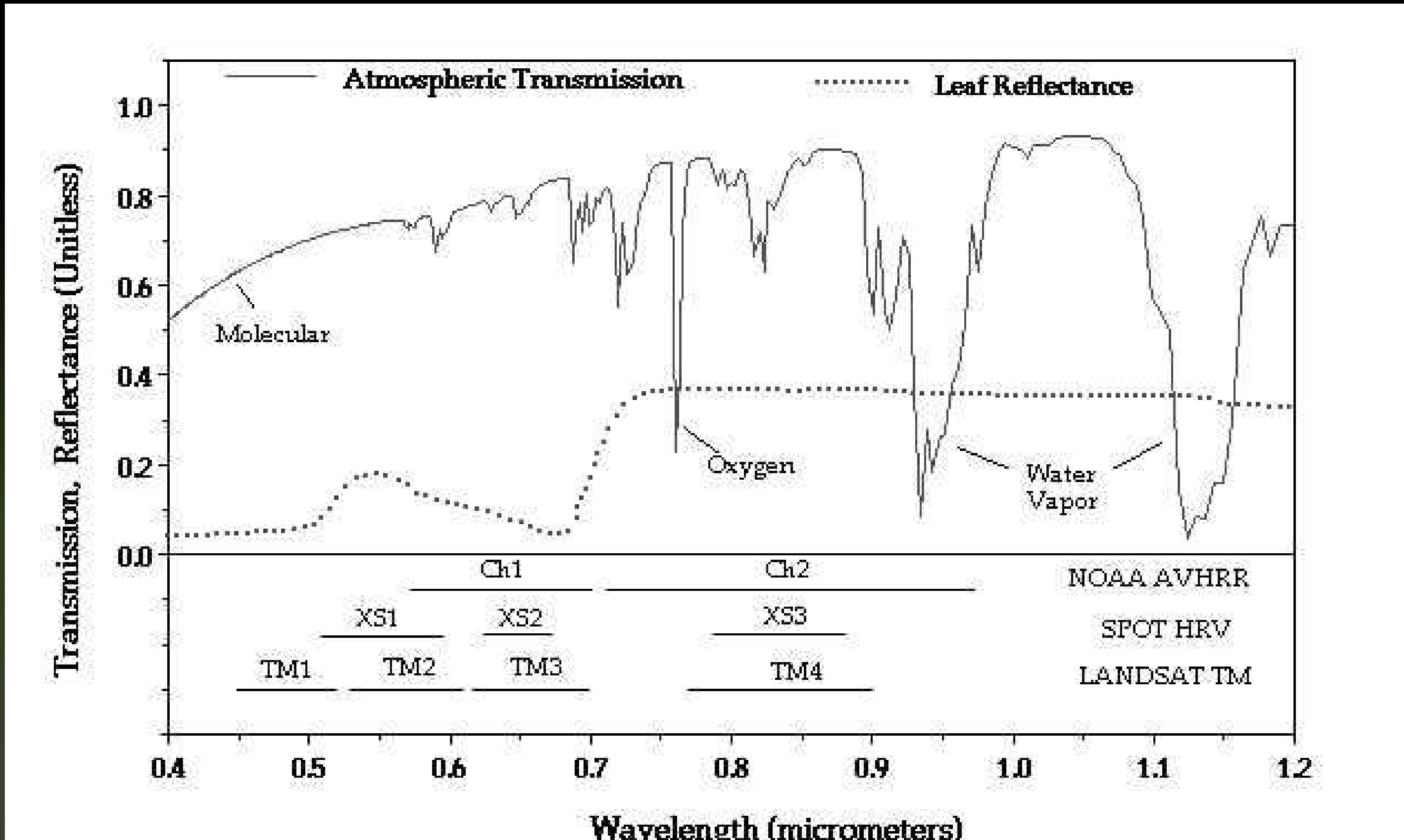
South Polar View





North Polar View





Atmospheric Transmission
Leaf Reflectance
Transmission, Reflectance (Unitless)
1.0
0.8
0.6
0.4
0.2
0.0
Molecular
Oxygen
Water Vapor
Ch1
Ch2
NOAA AVHRR
XS1
XS2
XS3
SPOT HRV
TM1
TM2
TM3
TM4
LANDSAT TM
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Wavelength (micrometers)

Meteorological Satellites

- Meteorological satellites provided some of the earliest view of Earth from Space
- They are still a vital resource for weather prediction
- Operated by the US, EU, Brazil, India and China (and others)
- Exist in both LEO and GEO orbits
- Include imagers and sounders
- US DMSP - long time series of MW and OLS

Sample Application

- The normalized difference vegetation index (NDVI) was first derived using NOAA AVHRR
  - Uses the difference in broadband VIS (red) and NIR, normalized by their sum
  - Sensitive to the combined effects of chlorophyll concentration, leaf area and canopy architecture

Landsat

- Operated continuously since 1972
- MSS, TM, ETM+
- 30 – 90 m resolution (ETM+ has 15 m panchromatic band)
- 183 km x 170 km scene area
- L7 degraded, SLC-off, in 2003
- Entire archive released in 2008
- LCDM will launch in 2013

ASTER

- Japanese instrument on NASA's Terra platform
- 14 spectral bands in 3 subsystems
  - 3 VIS/NIR (NIR both nadir and back-looking)
  - 6 SWIR (subsystem failed in 2011)
  - 5 TIR
- Smaller scene area (60 km x 60 km) than Landsat
- 15 m (VIS/NIR), 60 m (SWIR), 90 m (TIR) resolutions

Commercial High-Res

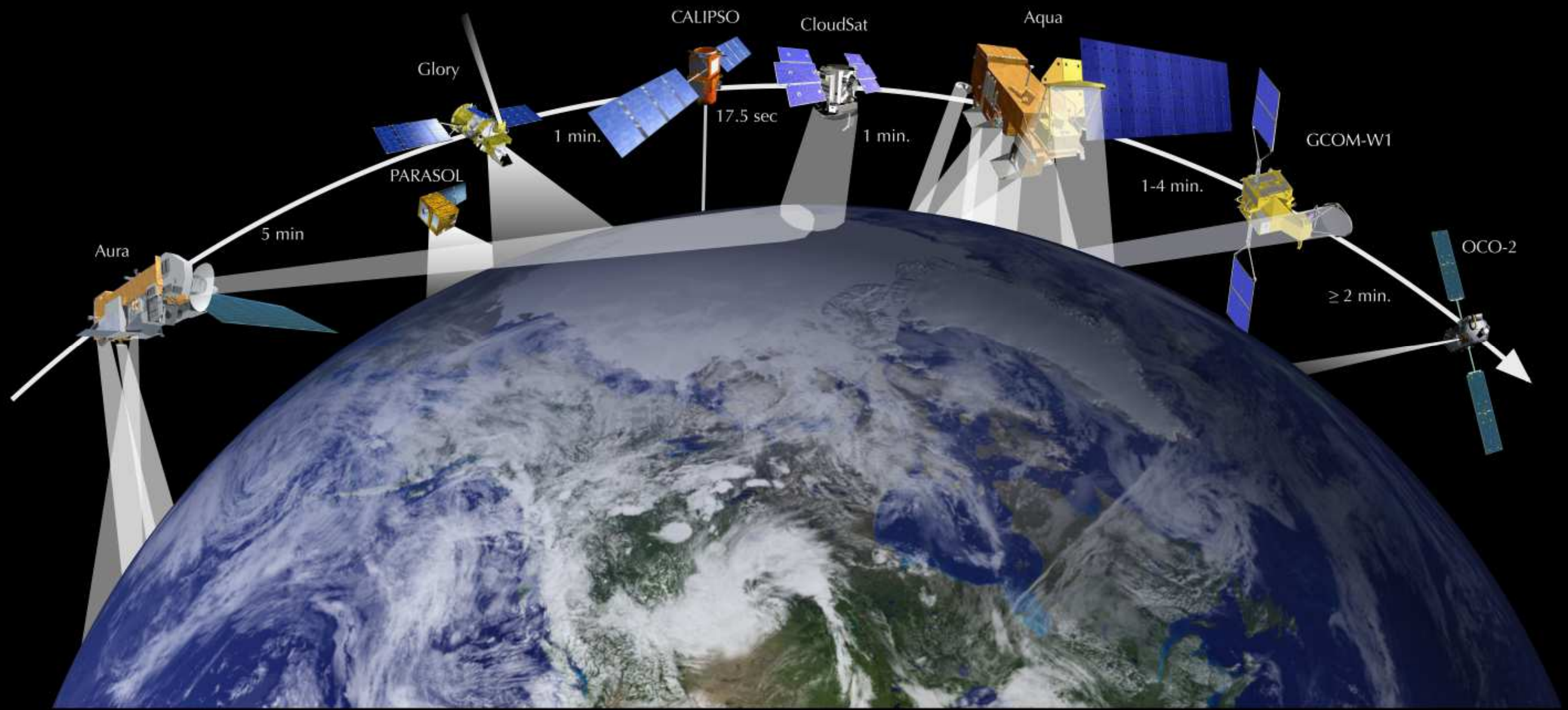
- SPOT-Image pioneered commercial RS
- This was followed by US ventures such as Digital Globe
- Ikonos, QuickBird, WorldView, GeoEye
- Offer sub-meter resolution mutlispectral imagery, with stereo capabilities.

Formation Flying

- Also called a constellation
- NASA's "A-Train" pioneered
  - CloudSat, NASA
  - CALIPSO, NASA/CNES
  - OCO-2, NASA
  - Aqua, NASA
  - Aura, NASA
  - PARASOL, CNES
  - GCOM-W, JAXA

National Aeronautics and Space Administration

The Afternoon Constellation "A-Train"



04/06/10

The Afternoon Constellation consists of eight U.S. and international Earth Science satellites that fly within approximately ten minutes of each other to enable concurrent science. The joint measurements provide an unprecedented sensor system for Earth Observations.

United States | Brazil | Canada | Finland | France | Japan | Netherlands | United Kingdom

www.nasa.gov

Hyperspectral Imaging Sensors

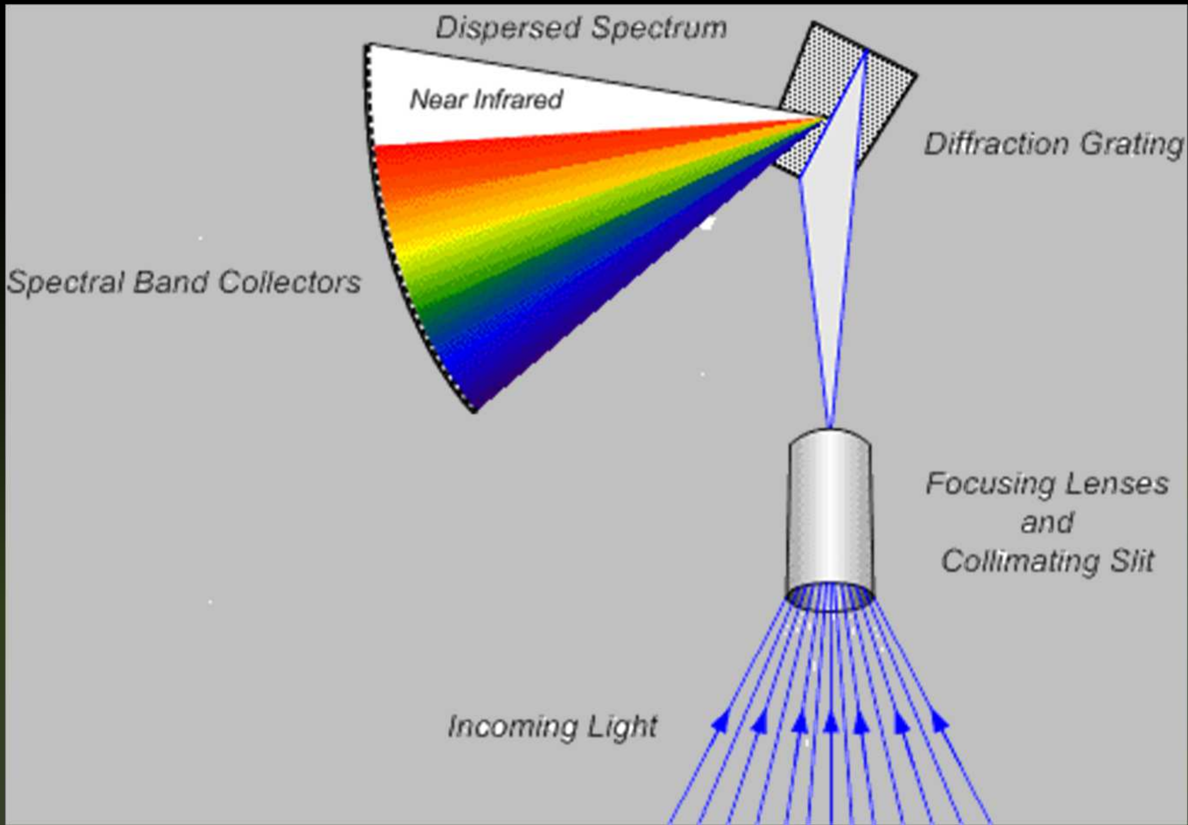


Diagram courtesy of Space Computer Corp.

Hyperspectral imaging instruments make simultaneous observations of 2-D images at a large number of wavelengths.

Hyperspectral Imaging Sensors

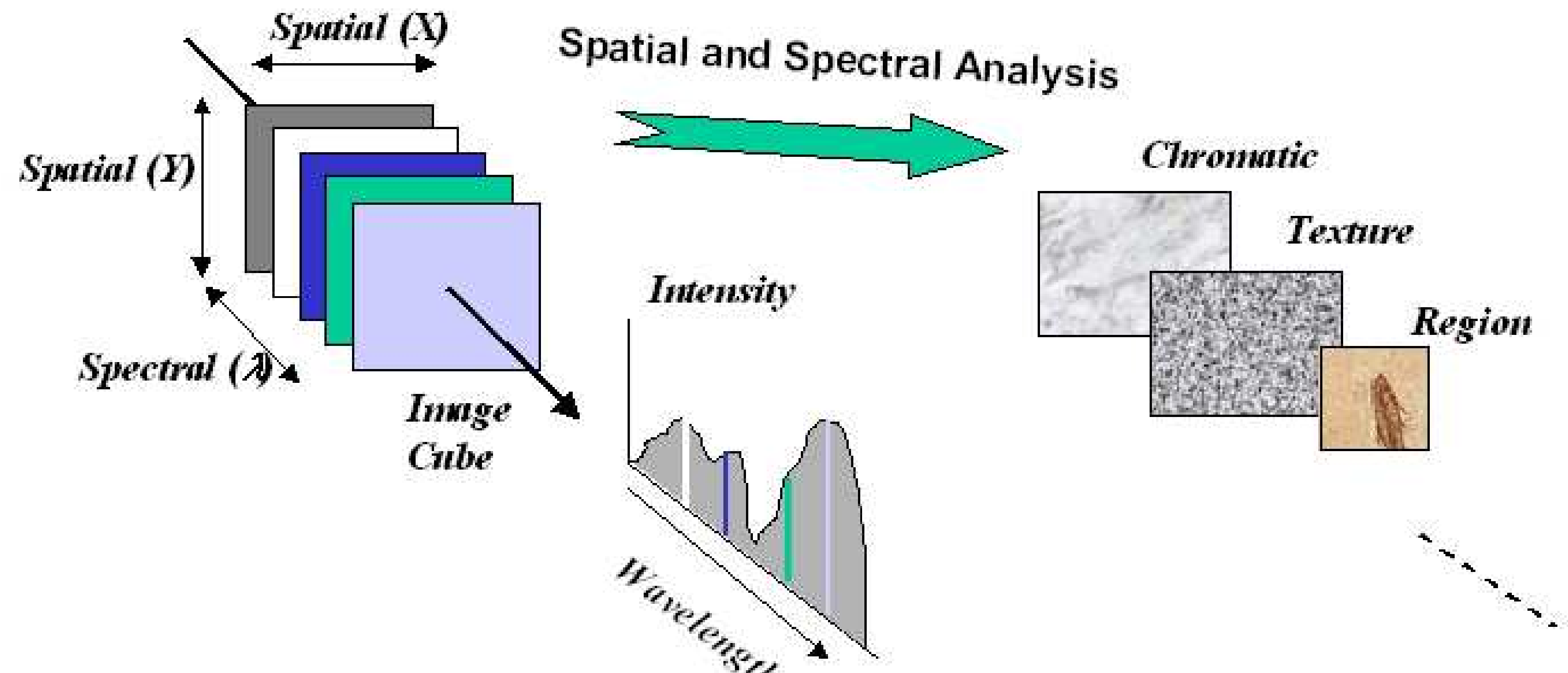
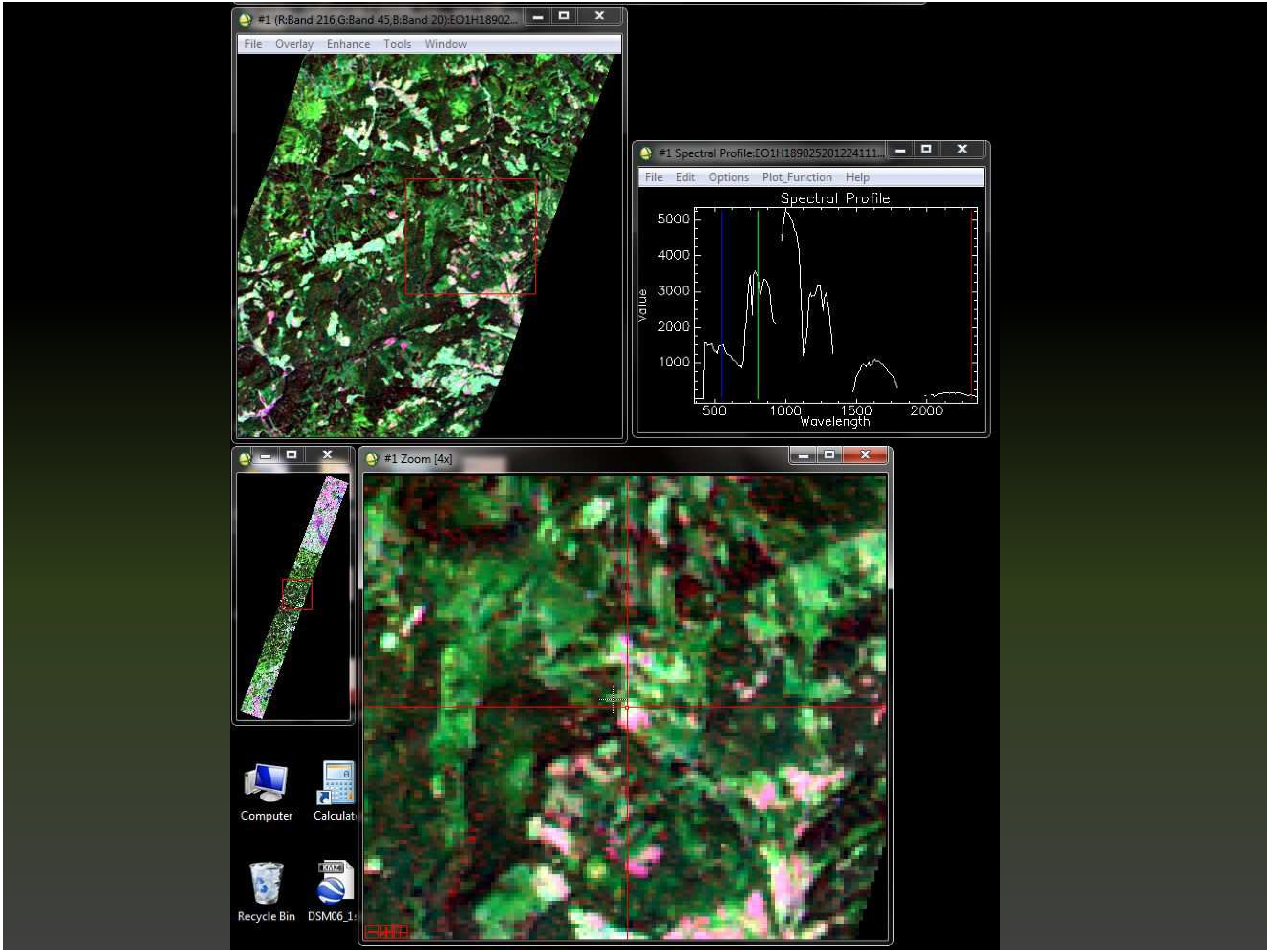


Diagram and caption courtesy of Georgia Tech.

Multiple images in different spectral bands form an image cube for the same spatial image. Spatial and spectral analyses are performed on the image cube to obtain chromatic, textural, and regional information.


#1 (R:Band 216,G:Band 45,B:Band 20):EO1H18902...
File Overlay Enhance Tools Window
#1 Spectral Profile:EO1H189025201224111...
File Edit Options Plot_Function Help
Spectral Profile
5000
4000
3000
2000
1000
Value
500 1000 1500 2000
Wavelength
#1 Zoom [4x]
Computer
Recycle Bin
KMZ

Microwave Remote Sensing

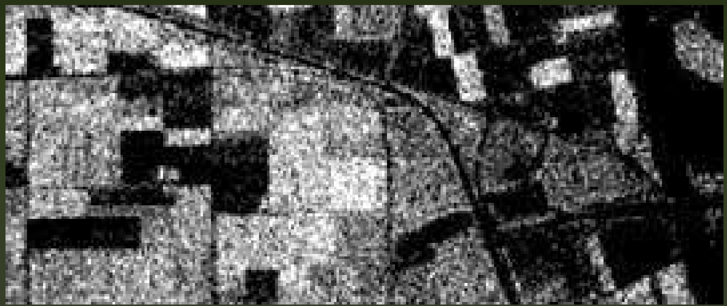
- Includes both active (radar) and passive (radiometry) sensing
- Wavelengths 1 cm to 1 m, so can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall
- Because the source of energy is either the Earth's surface or the instrument, data can be acquired day or night

Passive MW Radiometry

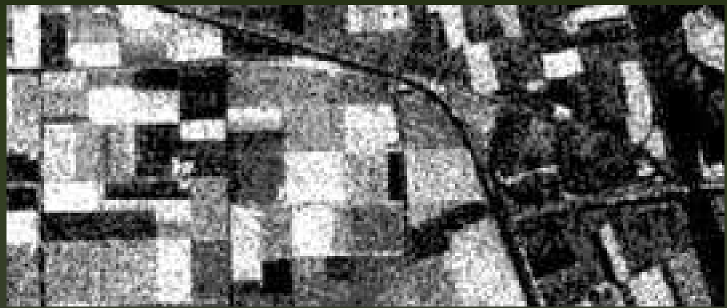
- Uses naturally emitted energy, collected with an antenna
  - Amplitude of the energy is small
  - AMSR-E has a 2 m diameter antenna
  - IFOVs are relatively large (typically 10's of km)
- Emissivity determined by diaelectric constant of surface, so is useful to detecting soil moisture
  - Longer wavelengths receive energy from deeper in the soil

Active MW Sensors

- Supplies radiation to illuminate the target
- Radar transmits a microwave (radio) signal and measures the backscattered signal
  - Strength (and polarization) used to characterize target and time delay yields range



C-Band



L-Band

- Non-imaging microwave sensors include altimeters and scatterometers

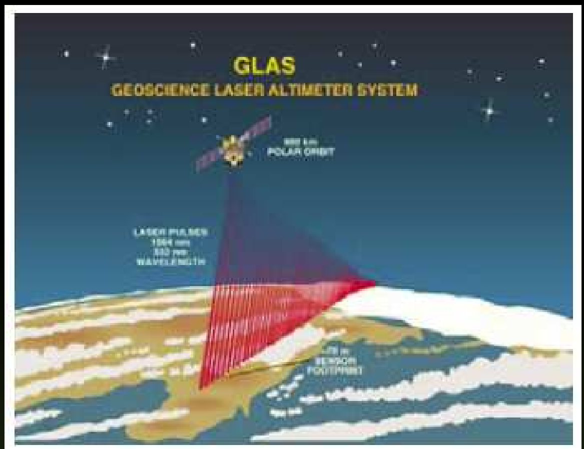
SAR and inSAR

- Synthetic Aperture Radar (SAR) uses the motion of the sensor (aircraft or satellite) to create a large virtual (synthetic) antenna
  - Allows for creation of high-resolution (1-3 m) images
- Interferometry between two SAR images can be used to detect horizontal and vertical displacements down to cm's

Soil Moisture

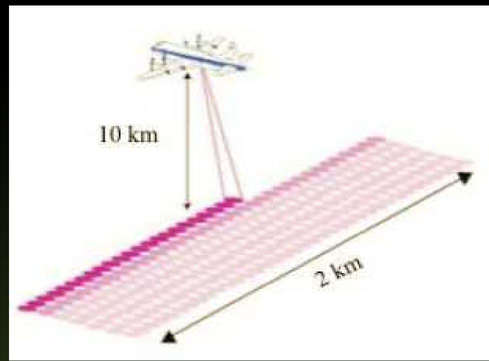
- SMAP – Soil Moisture Active/Passive
  - NASA/JPL
  - L-band radar and radiometer, sharing a common antenna
- SMOS – Soil Moisture Ocean Salinity
  - ESA/CNES
  - L-band using an interferometric radiometer

LiDAR Data Platforms



Satellite - Icesat

~500 thousand points/day
600 km altitude
70 m footprint



High Altitude Airborne Land Vegetation and Ice Sensor (LVIS)

5 million points/day
10 km altitude
10 m footprint

Low Altitude Airborne Laser Scanning

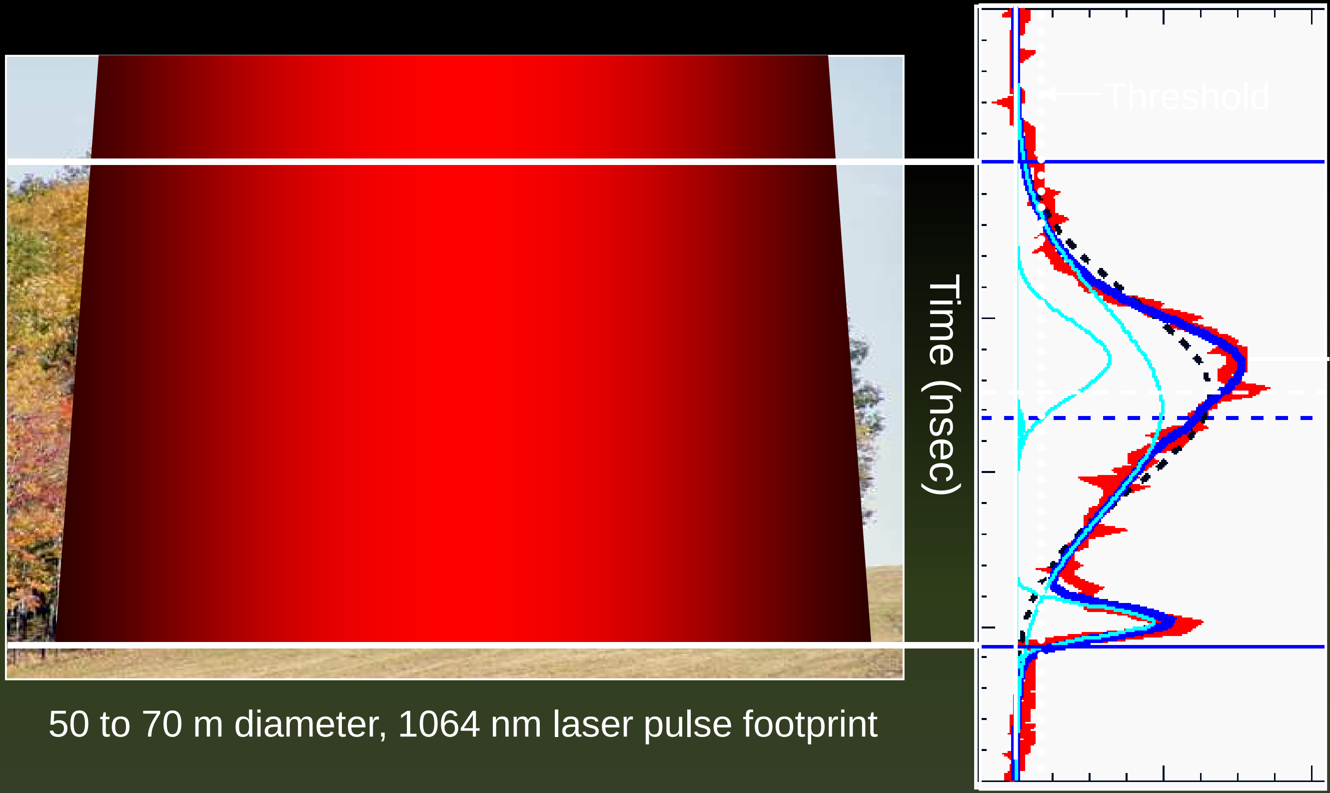
500 million-1 billion/day
0.5 km altitude
20 cm footprint

Terrestrial LiDAR Scanning

100-500 million points/day
tripod
1 cm footprint

ICESat Elevation Data Products

There are 4 primary elevation parameters:



50 to 70 m diameter, 1064 nm laser pulse footprint

(highest detected surface)

Standard Gaussian Fit
Alternate Centroid
(mean illuminated surfaces)

Alternate End
(lowest detected surface)

Plus elevations for up to 6 Gaussian fits (cyan) for land and up to 2 for ice sheets, sea ice and ocean.

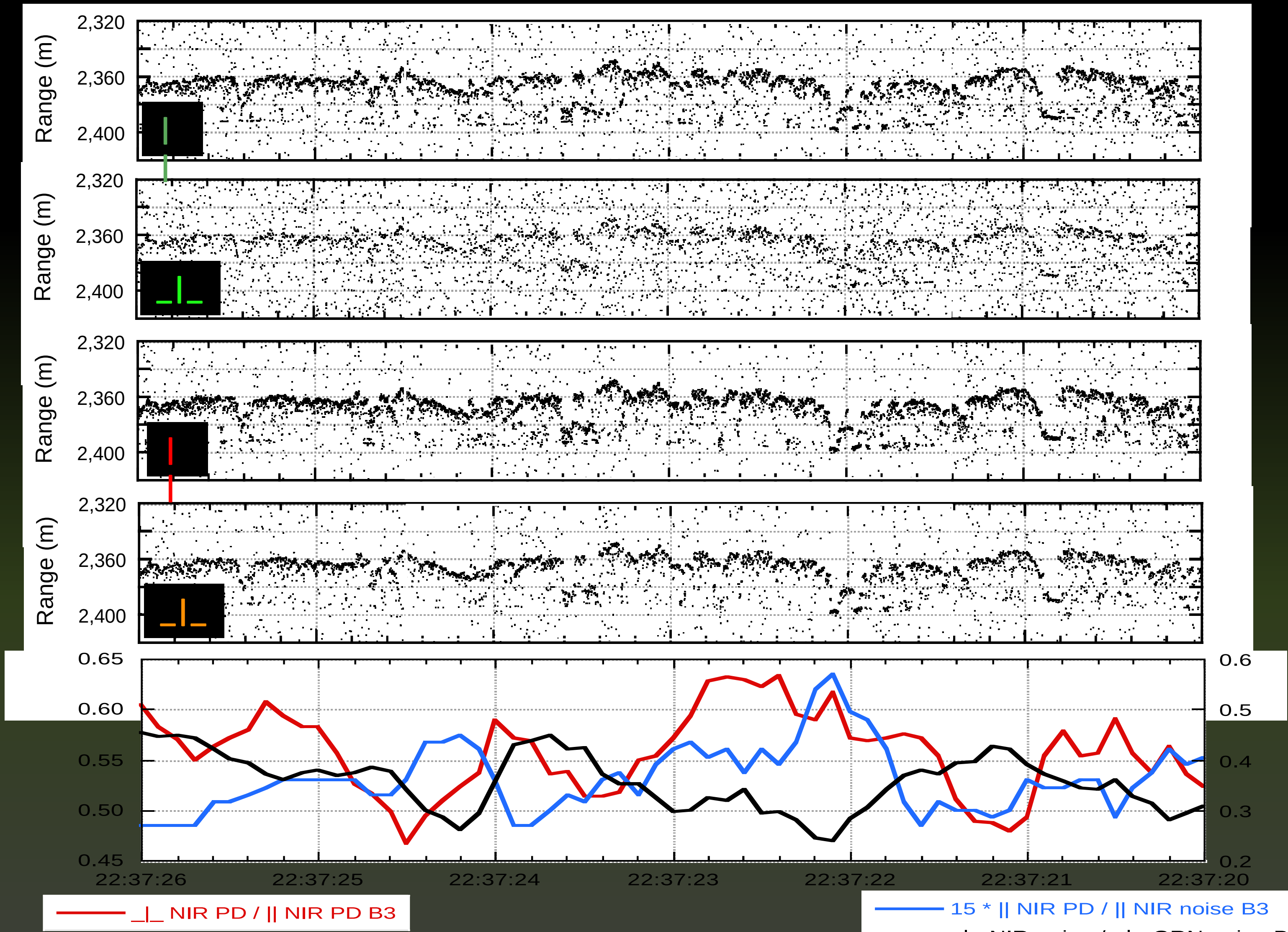
D. Harding, C. Carabajal, NASA ACCESS NLAS Meeting, Boulder, CO

FLIGHT Micropulse Photon Counting Instrument Model Parameterization

Parameter	ATLAS	MABEL	SIMPL
Operational altitude	496 km	20 km	2.5 km
Telescope diameter	0.8 m	0.15 m	0.20 m
Wavelength	532 nm	532 and 1064 nm	532 and 1064 nm
Laser pulse repetition rate	10 kHz	variable 5 – 25 kHz	11.6 kHz
Laser pulse energy	strong and weak beams 164 and 41 µJ	532: ? µJ 1064: ? µJ	532: 0.13 µJ 1064: 0.3 to 0.8 µJ
Laser beam divergence ($1/e^2$)	20 µrad 10 m footprint	100 µrad 2 m footprint	76 µrad 0.2 m footprint
Laser pulse polarization	?	?	plane polarised
Filter width	532: 30 pm	532: ~30 pm 1064: ~400 pm	532: ~170 pm 1064: ~900 pm
Detector field of view	83 µrad 40 m diameter	210 µrad 4.2 m diameter	233 µrad 0.6 m diameter
Detector quantum efficiency	532: 15%	532: 10-15% 1064: 1-2%	532: 60% 1064: 2%
Receiver dead time	~ 3 nsec	~ 3 nsec	~ 50 nsec; PD <10% to minimize 1st photon bias
Receiver throughput	?	TBD	TBD
Receiver timing precision	?	?	0.1 nsec
Receiver impulse response laser pulse shape convolved with receiver bandwidth	?	?	1 ns FWHM main pulse ~10% energy after-pulse: 2.7 ns FWHM offset 8 ns
Receiver polarization	n.a.	n.a.	parallel & perpendicular to transmit beam
Polarization purity	n.a.	n.a.	> 100:1
Number of beams	6 at 532 nm	16 at 532 nm 8 at 1064 nm	4 with co-aligned 532 and 1064 nm
Beam pattern	3 sets of strong & weak 6.6 mrad btw strong cross-track 5 mrad btw strong & weak along-track rotated for 90 m cross-track btw strong & weak	cross-track selectable divergences	cross-track 2.2 mrad btw beams
Cross-track beam spread	constant 13.2 mrad 6.5 km	maximum 100 mrad 2 km	constant 6.6 mrad 16 m

SIMPL 4 Channel Data across SIGEO Stem Map at SERC, MD

Line 2 Beam 3, 532 nm and 1064 nm, parallel and perpendicular polarizations

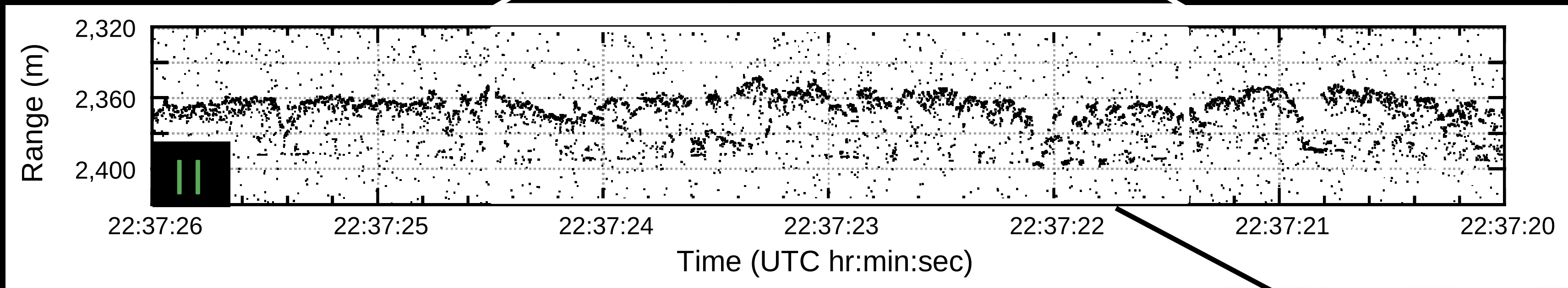


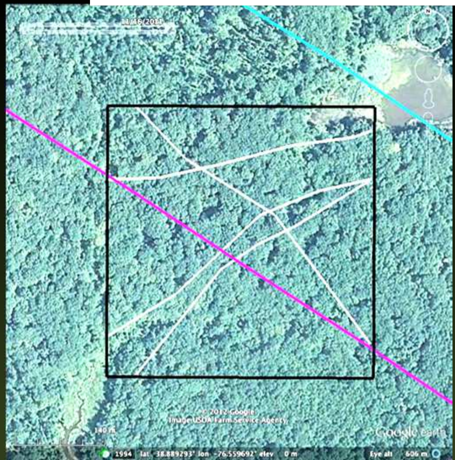
1064 nm laser depolarization insensitive to shadows

1064 vs 532 nm solar reflectance **1064 nm laser backscatter vs solar reflectance** sensitive to shadows and anti-correlated

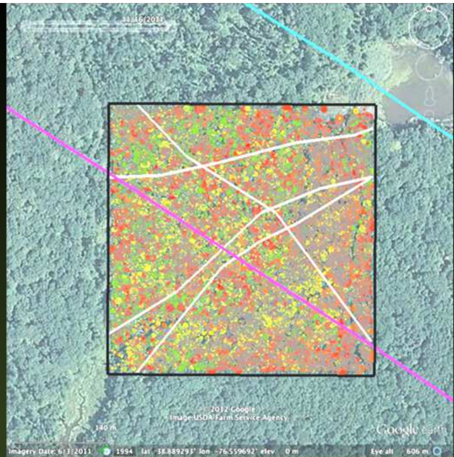
Airborne Lidar Data Sets across SIGEO Stem Map at SERC, MD

~ 20 photons per meter per beam per || channel (~5x veg strong beam design cases)

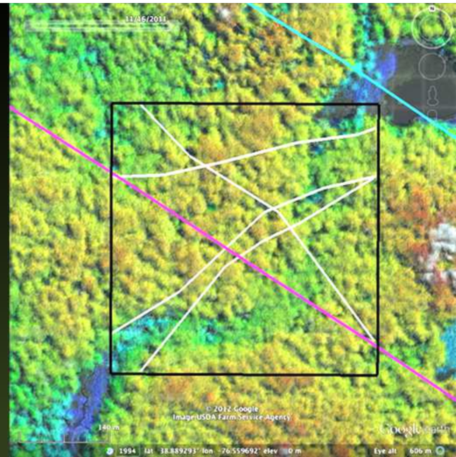




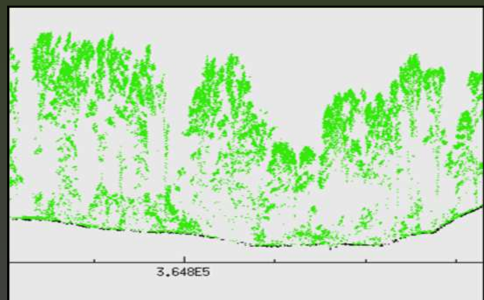
August, 2010 image
SIMPL ground tracks: white
06/26/10 5 to 6 pm
MABEL 09/15/12 6 pm: cyan
MABEL 09/21/12 8:30 pm: pink



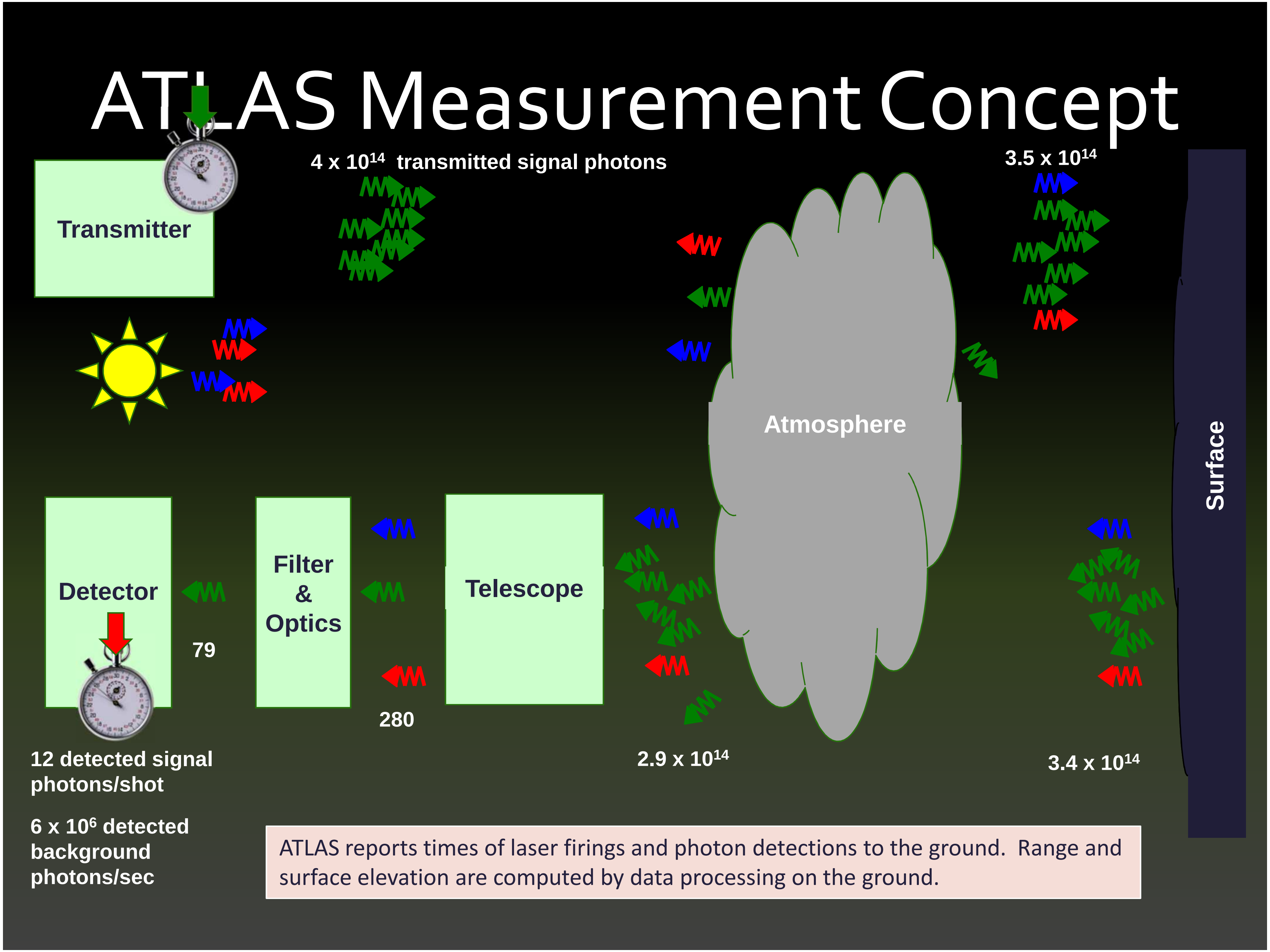
SIGEO Stem Map
all stems ≥ 1 cm DBH
33,430 stems
81 species
crown shape via allometry
(height, depth, width)
reflectance properties from
field and lab measurements
(leaf, stem, ground)



G-LiHT airborne lidar
classified discrete return points
high resolution DSM and DTM



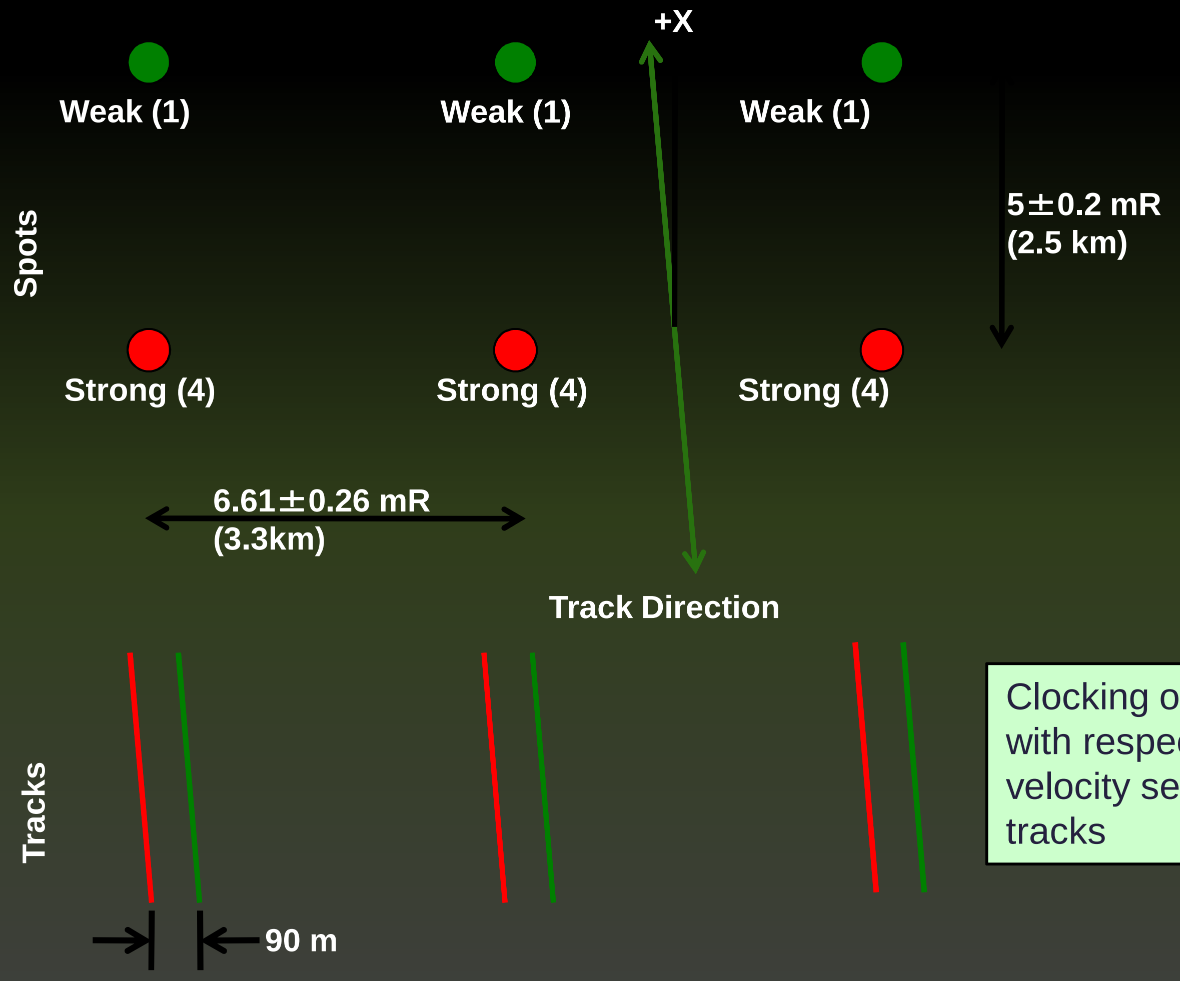
SIMPL Video
Line 2 5:30 pm
Solar Azimuth 280°
Solar Elevation 19°
Zenith Cosine 0.33


ATLAS Measurement Concept
4 x 10^14 transmitted signal photons
3.5 x 10^14
Transmitter
Atmosphere
Surface
Detector
Filter & Optics
Telescope
79
280
2.9 x 10^14
3.4 x 10^14
12 detected signal photons/shot
6 x 10^6 detected background photons/sec
ATLAS reports times of laser firings and photon detections to the ground. Range and surface elevation are computed by data processing on the ground.

Transmit Pattern

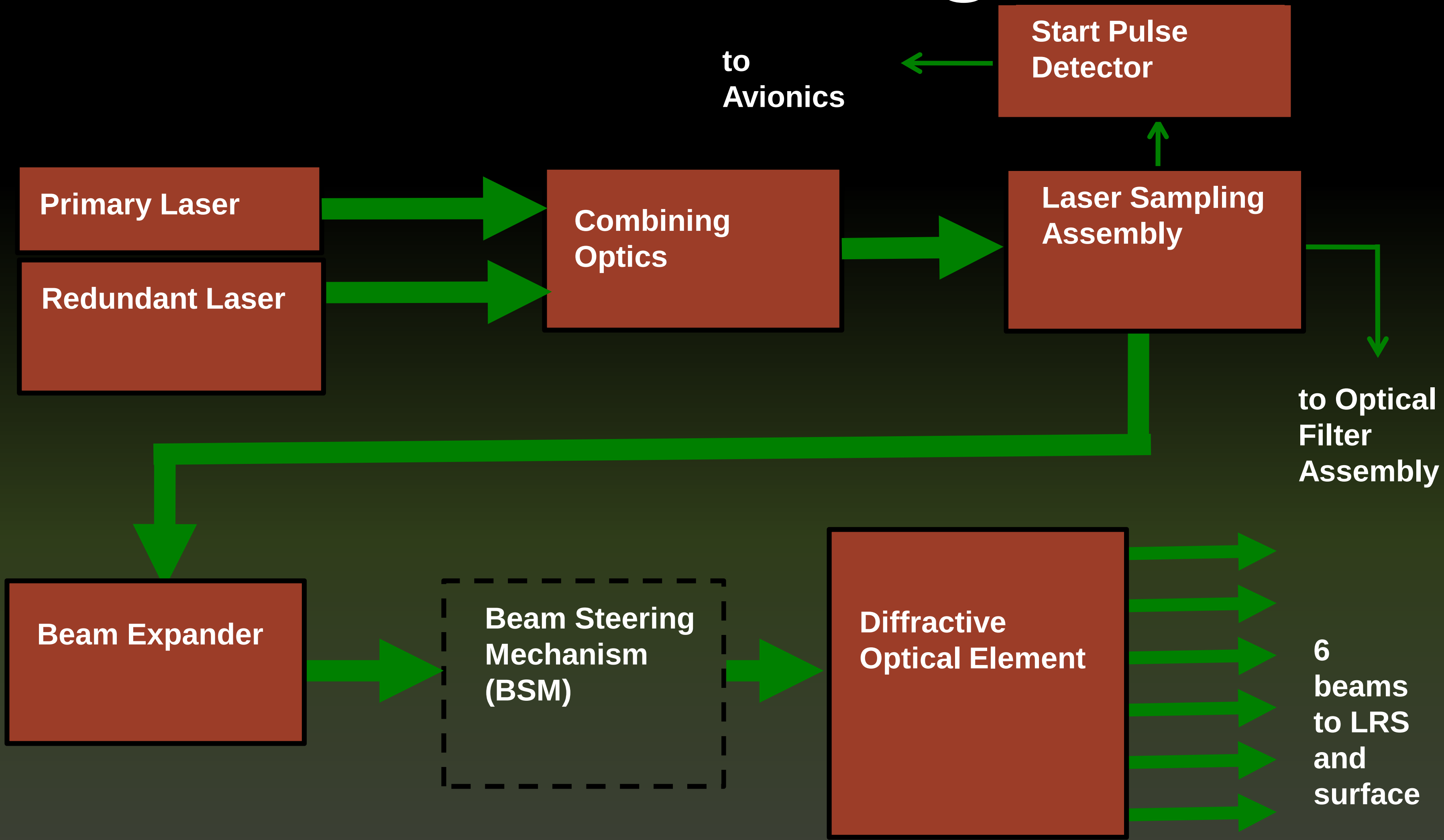
Illuminated Spots
<25 µR (12.4 m) diameter (85% EE)
Nominal 20 µR (10 m)

Weak and strong spots maximize the penetration of a given total laser energy



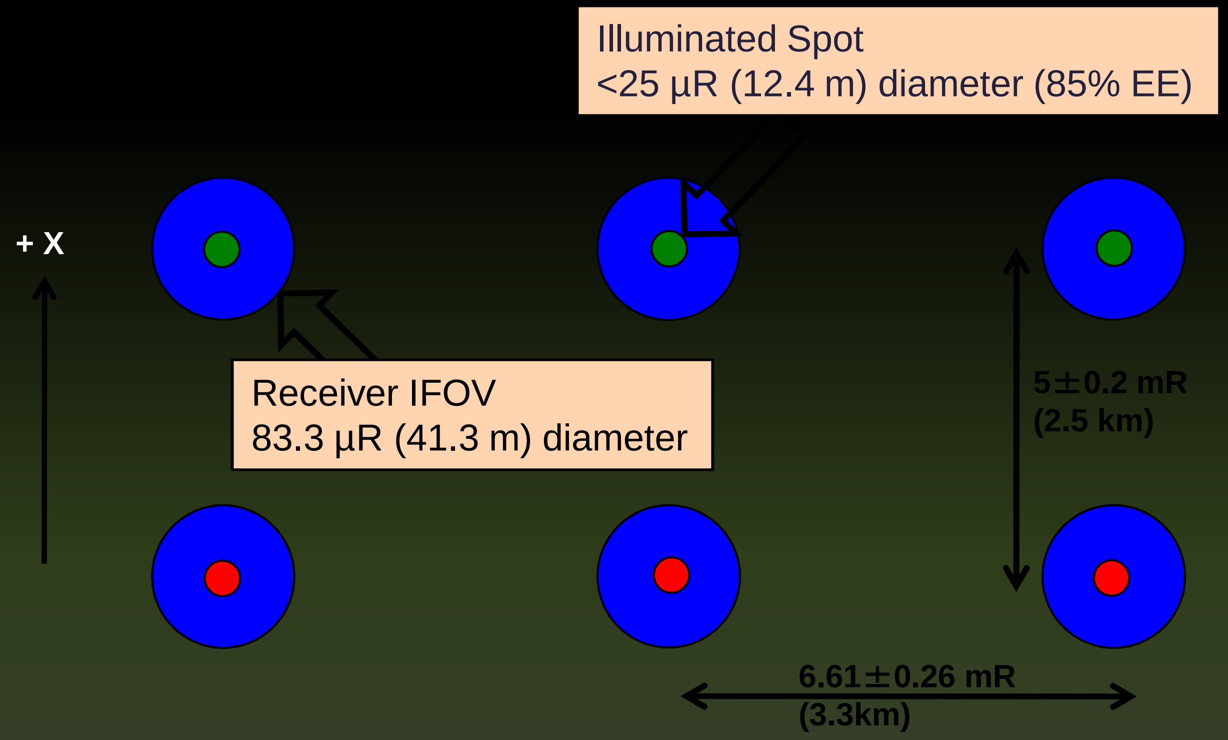
Clocking of pattern with respect to velocity separates tracks

Transmitter Diagram



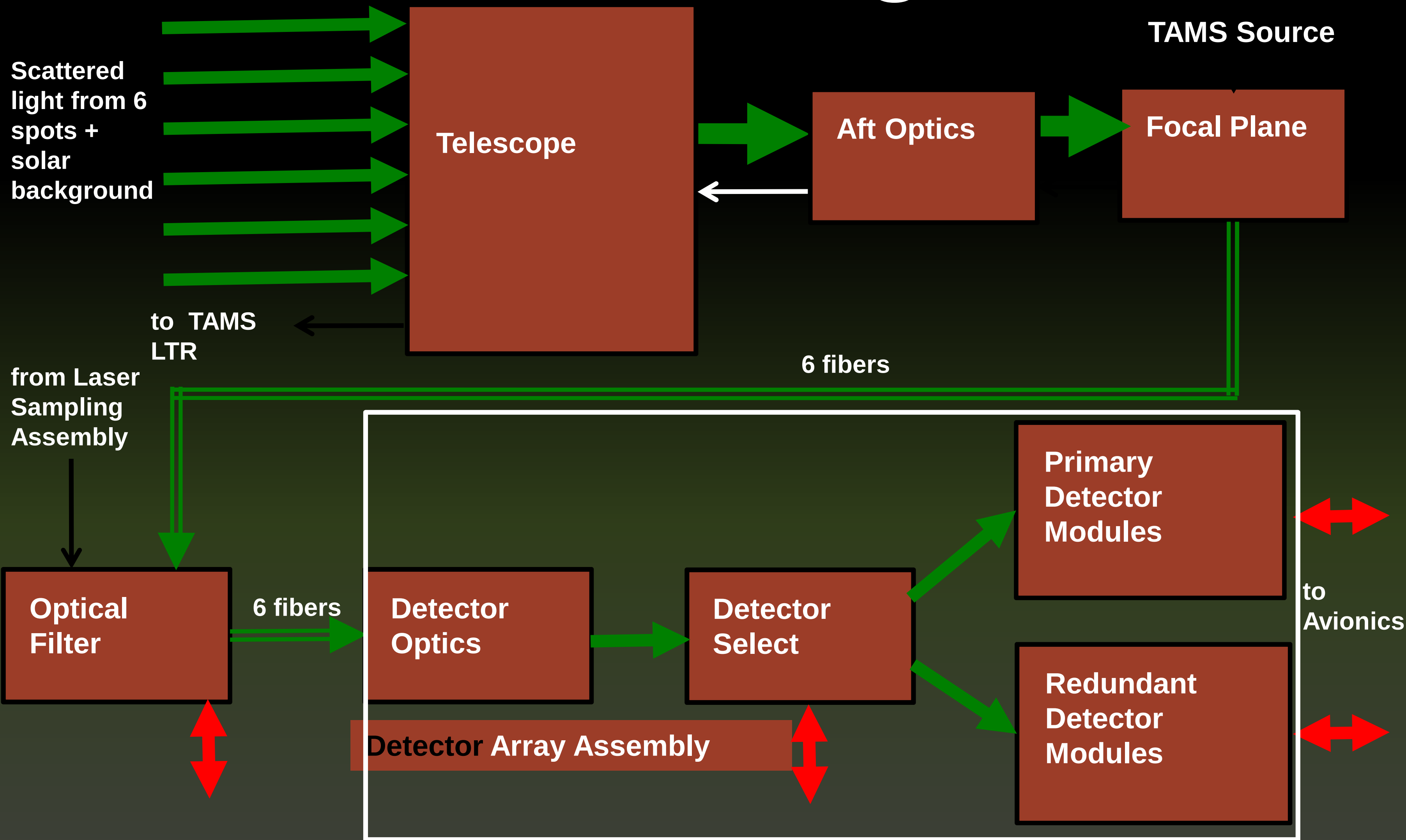
The transmitter generates 6 pulsed laser beams, samples them for use within ATLAS, and projects them toward the target.

Receiver Fields of View



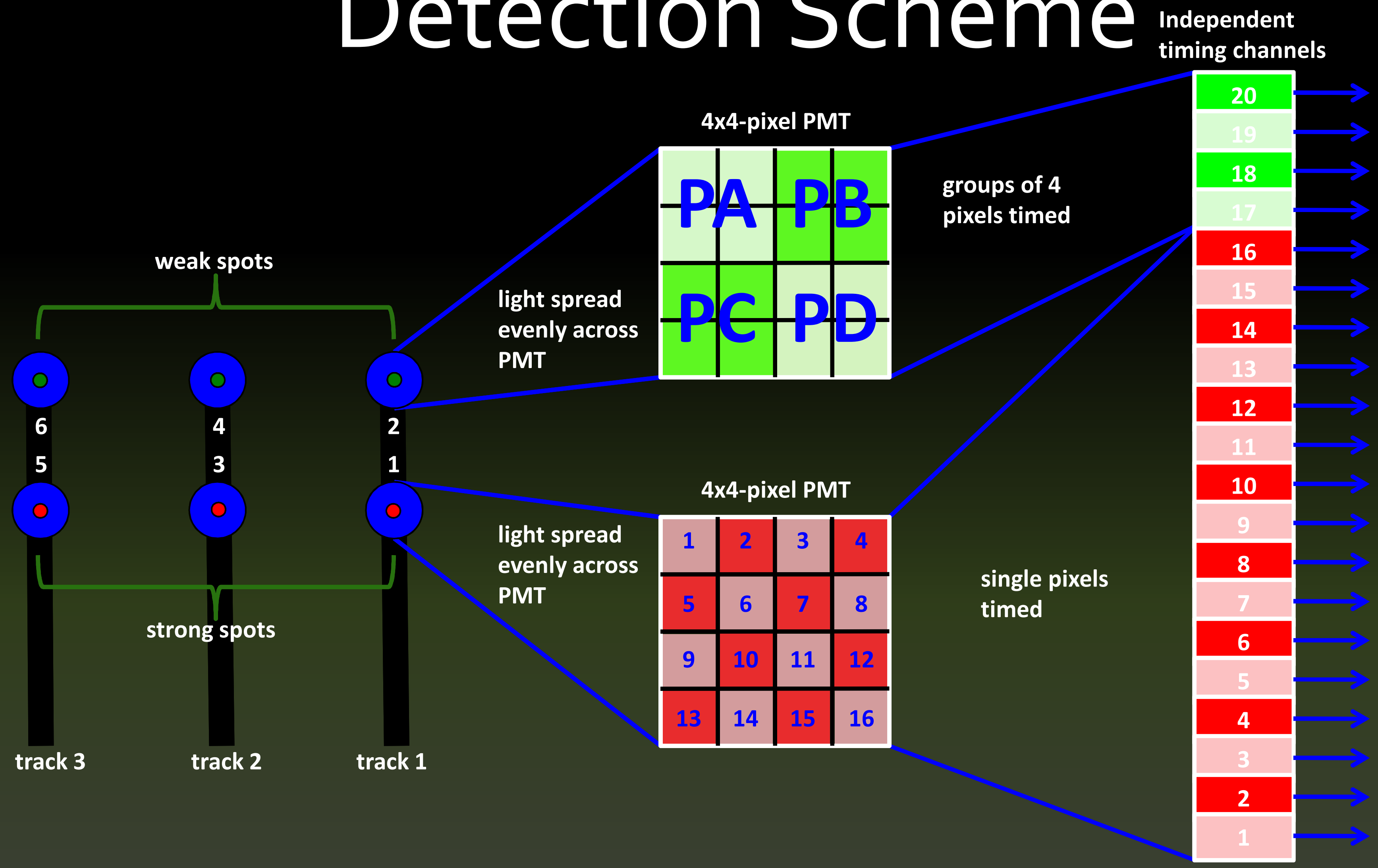
The ATLAS receiver has 6 individual fields of view – one around each laser spot.

Receiver Diagram



The Receiver collects light from the target, filters out most of the solar background, and generates electrical signals corresponding to the arrival of individual photons in each of the 6 spots.

Detection Scheme

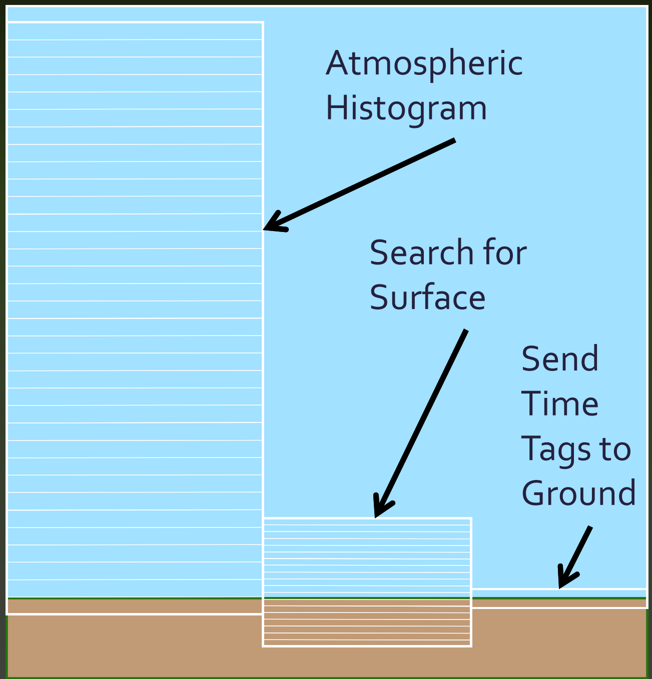


Light from each spot illuminates its own detector. Light illuminating each detector is divided among multiple independent timing channels to reduce the effects of dead time.

ATLAS Data Products: Returns

Atmospheric Histogram

- Used to evaluate validity and bias in altimetry data
- 500-shot integration
- One histogram per track
- 30 meter vertical bins
- Nominal range -1 to +13 km



Altimetry Time Tags

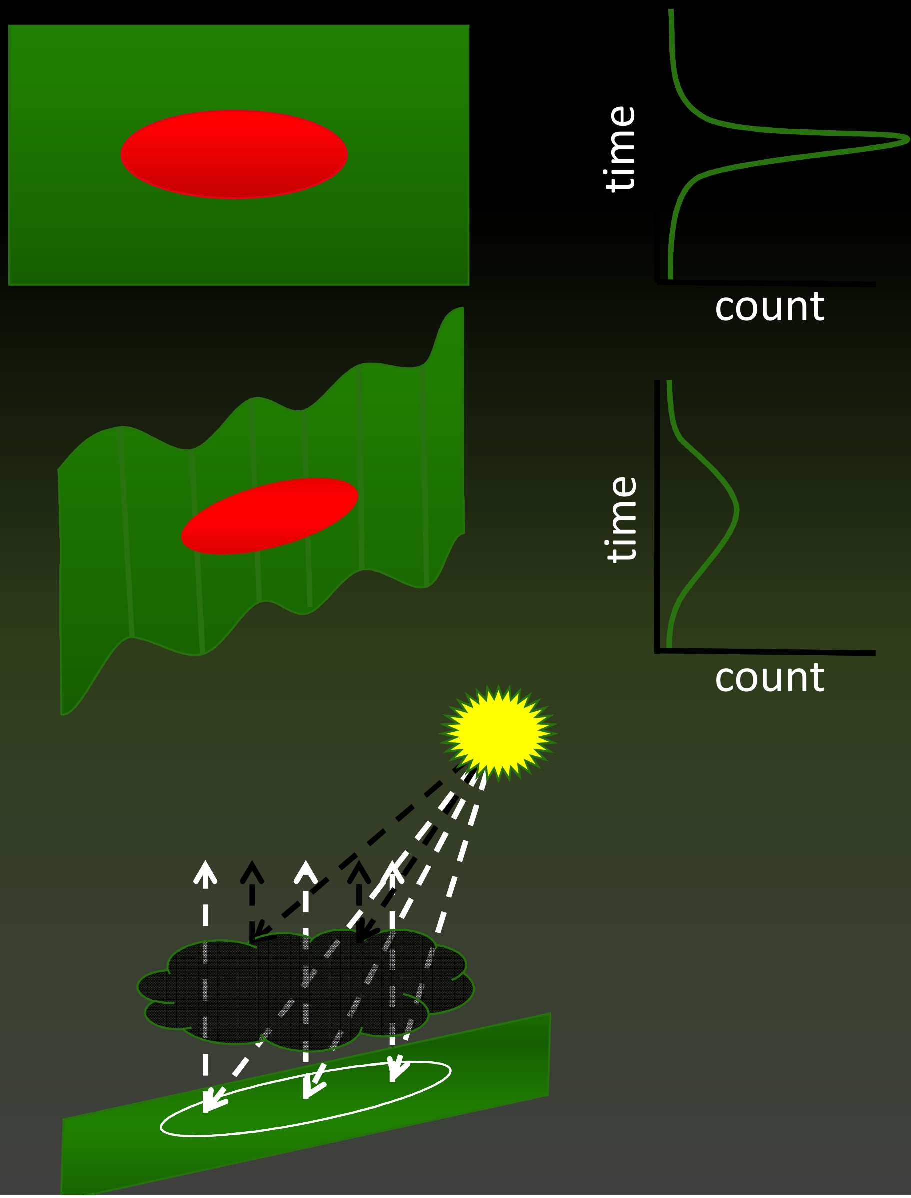
- Use spacecraft position and pointing information along with onboard Earth Height Map to select a period of time after the laser start pulse (called Range Window) to search for surface signal.
- Histogram receive events and perform signal processing to select a range value with the highest probability of containing the surface return.
- Use onboard Earth Relief Map to determine width of band about the selected signal to telemeter to ground.
- Selection rules governed by ground commands.
  - Telemetry band size
  - Number and identity of spots to be telemetered
  - Maps: elevation, relief, terrain type
  - Data validity criteria

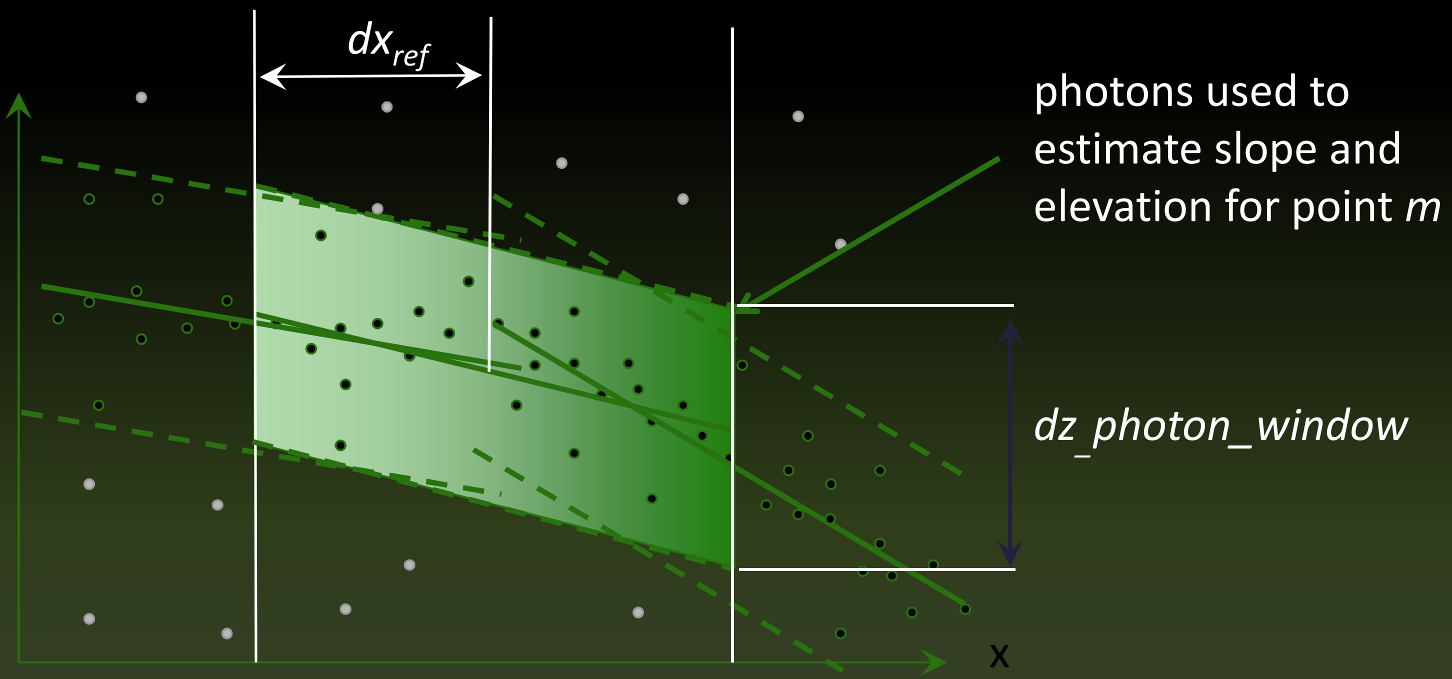
Telemetering time tags for all events would result in an unacceptably high data volume. An on-board algorithm defines a band about the surface and selects for telemetry only the time tags within the band.

Photon distributions

- Signal-Photon time distribution is driven by
  - Transmit-pulse shape
  - Surface slope
  - Surface roughness
  - Cloud conditions

- Background rates are driven by surface aspect, reflectance, solar illumination, and cloud conditions



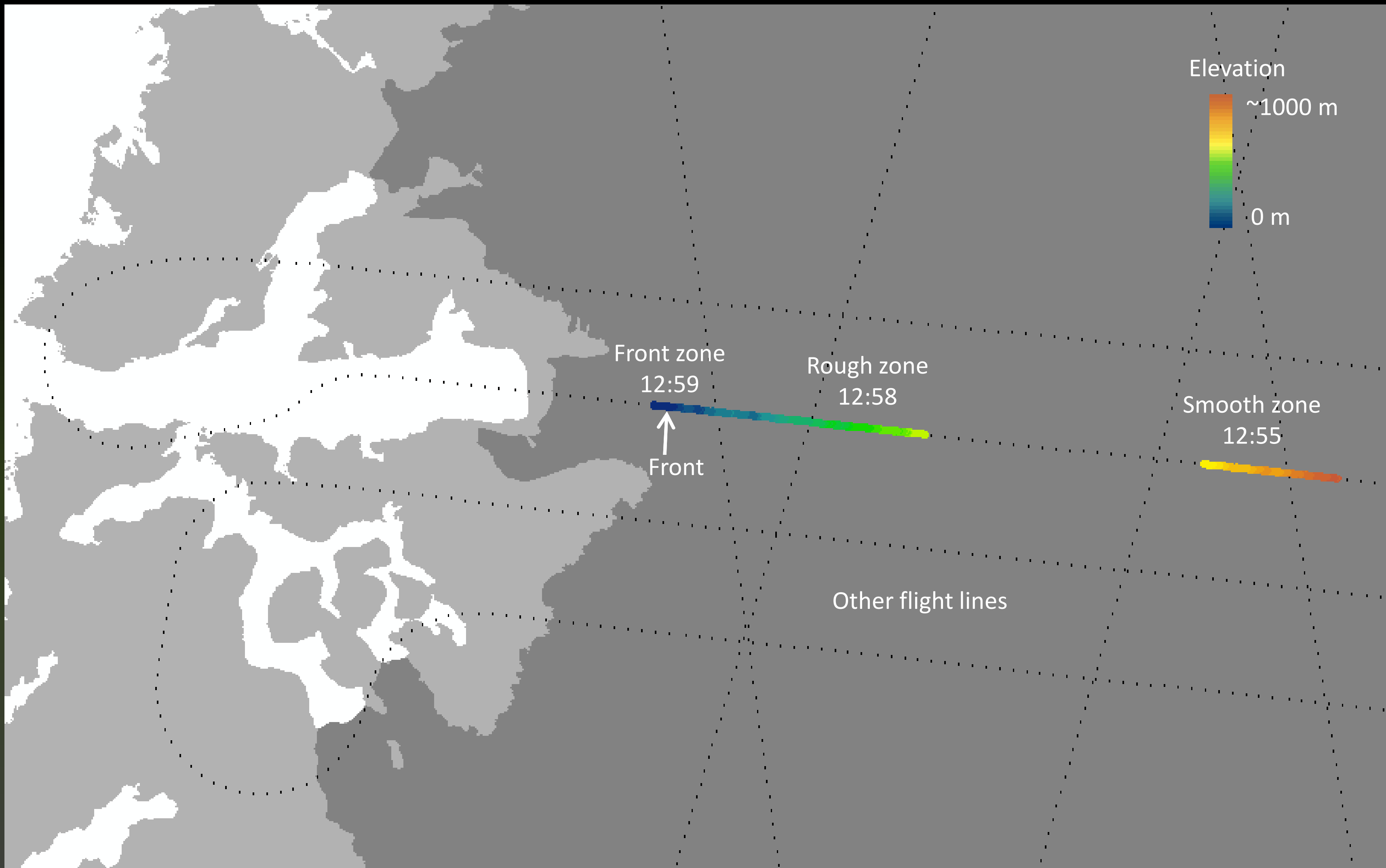


-The point cloud contains signal and noise photons, with signal photons clustered around the ground

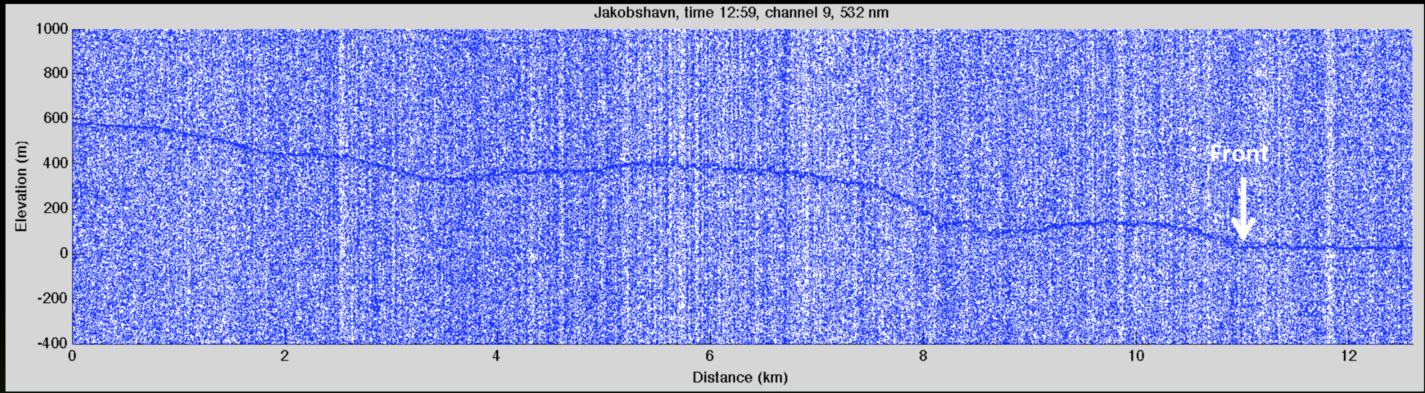
-The ATL03 algorithm finds ground photons for overlapping bins of width 2 *dx_ref*

-The ATL03 output gives an initial slope and elevation for each bin, and selects a bin height

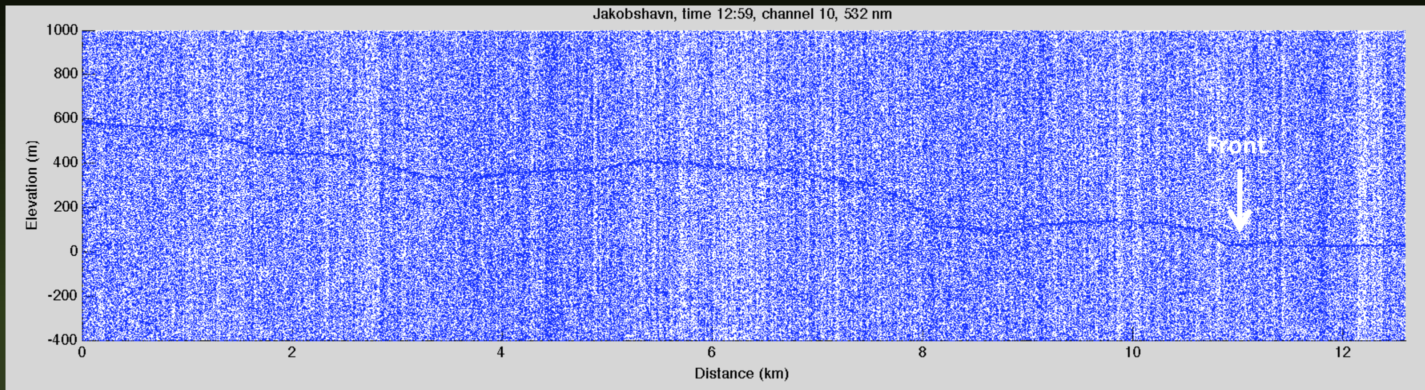
Jakobshavn Isbræ



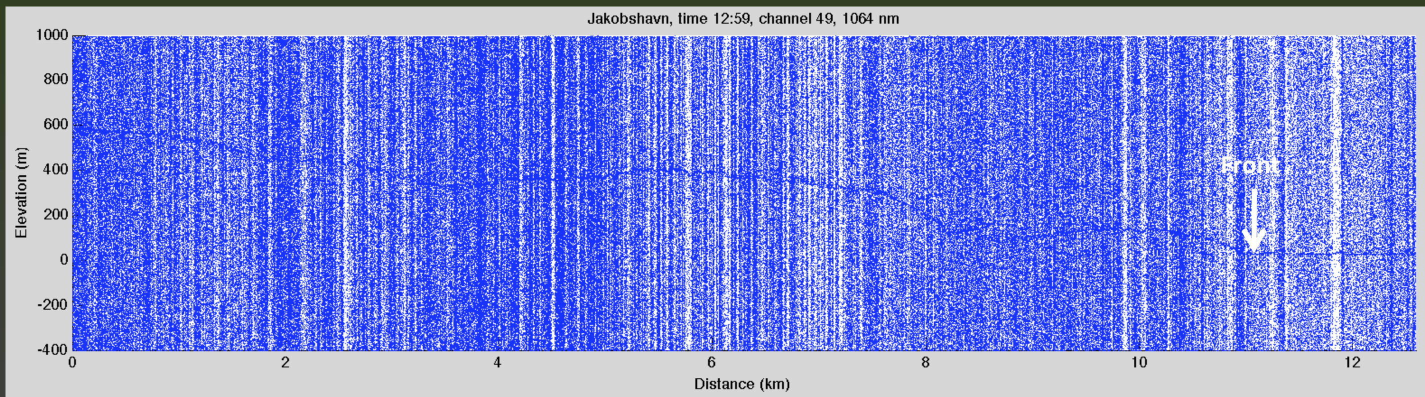
Jakobshavn front, 3 channels, example



Channel 9
Strong signal

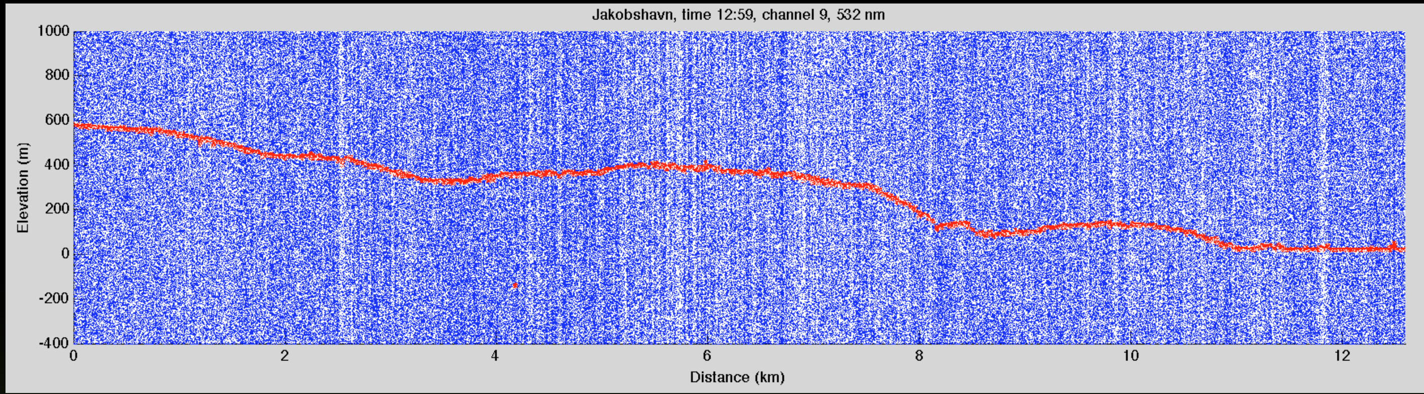


Channel 10
Medium signal



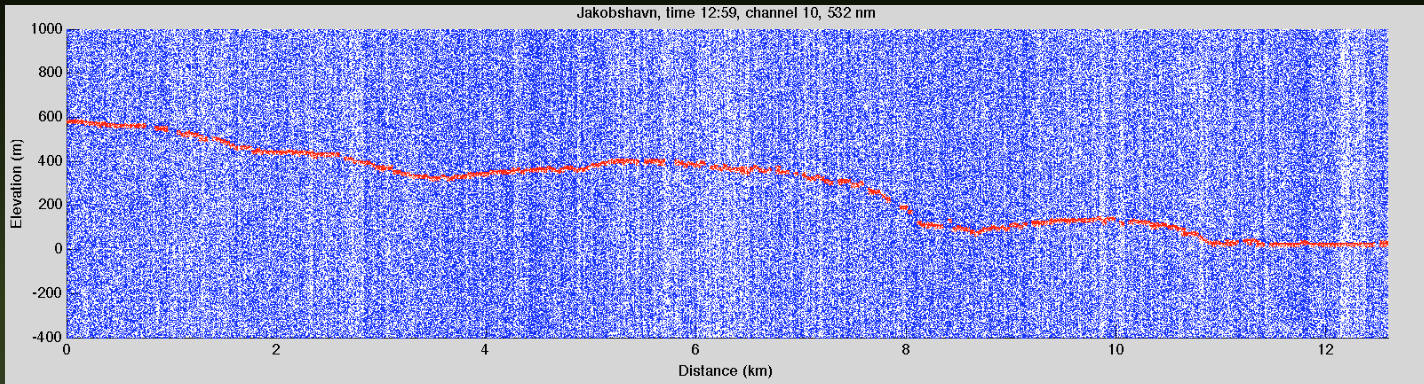
Channel 49
High background

Jakobshavn front, classified photons - Anita



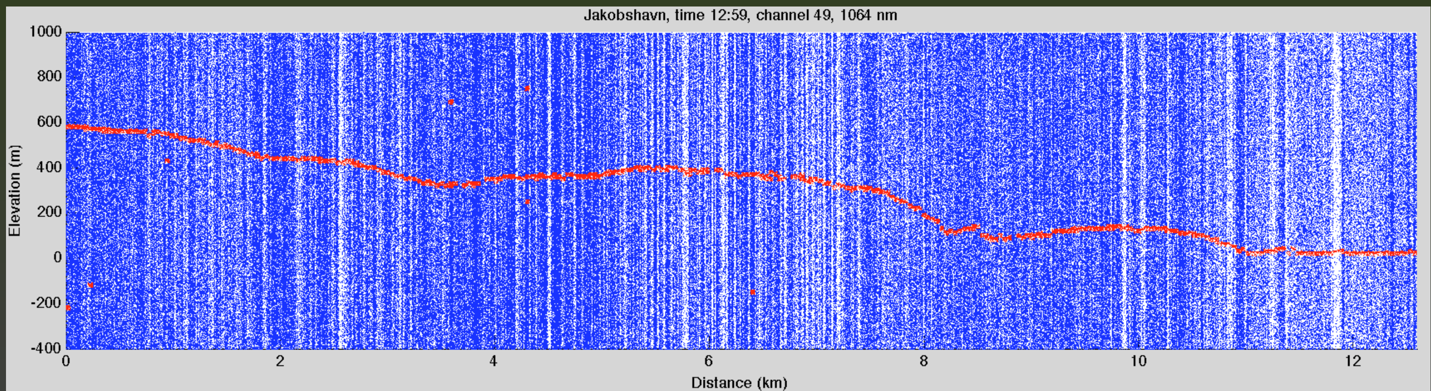
Channel 9
Strong signal

100% surface detection



Channel 10
Medium signal

91% surface detection



Channel 49
High background

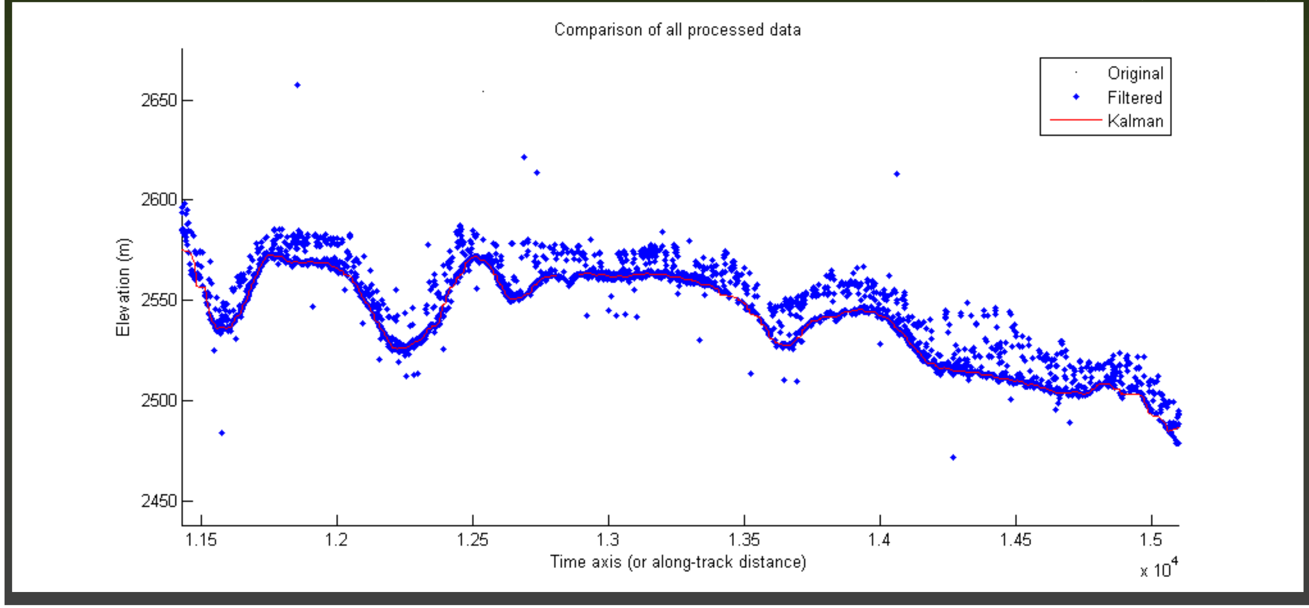
98% surface detection

Level-3 Along-Track Products

- ASSUMPTIONS: A terrain surface has been estimated by some method (TBD) to classify the point cloud.
- The point cloud data have been classified into land/vegetation/noise photons (noise -above the canopy and below the surface)
- Beam-pair products for vegetation are meaningless. Thus, we will defer to methodology used for ICE to compute segment facet slopes, etc of open terrain.

Level-3 Along-Track Products

- ASSUMPTIONS:
  - Ground photons lie within 2 m (TBD) of estimated ground surface
  - Canopy Photons are all other photons above the ground and not considered noise
  - Noise Photons have been successfully filtered away via some method (TBD)



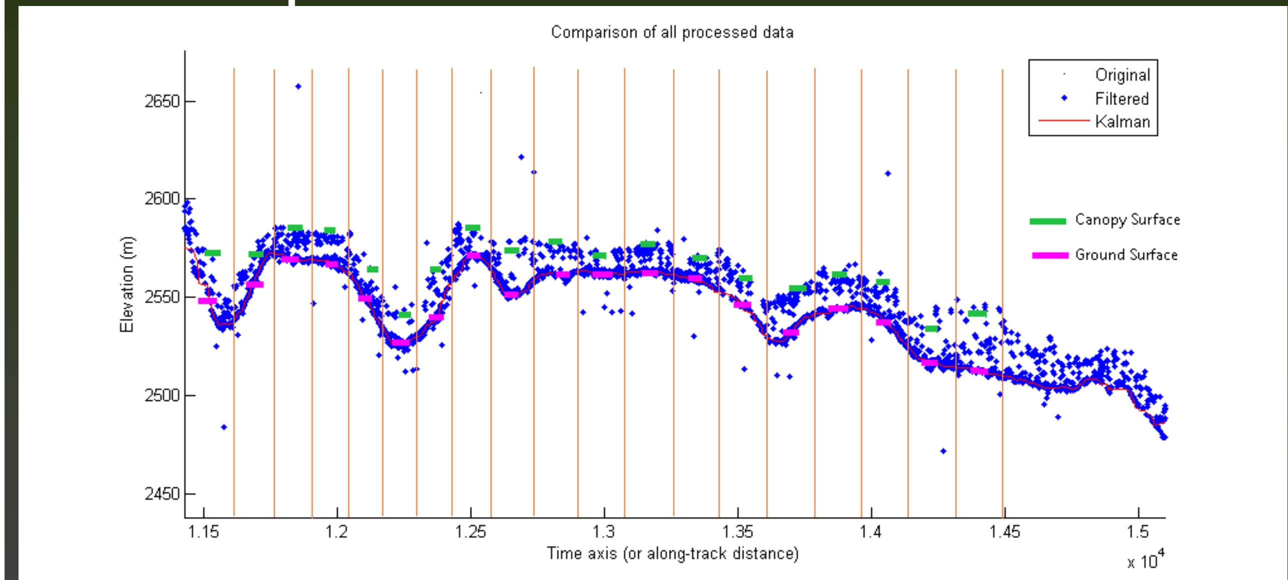
Level-3 Along-Track Products

single

- SEGMENT CANOPY SURFACE

Upper canopy surface is defined as the 95% height of canopy photons above the terrain surface.

Mean 95% canopy elevation each segment.

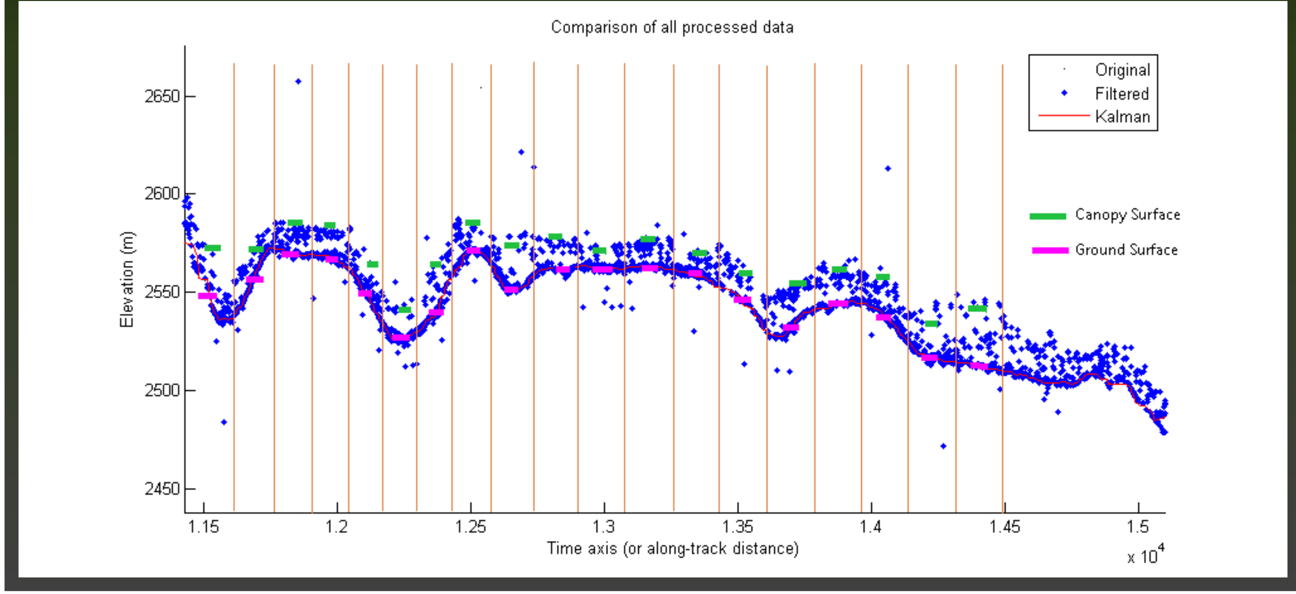


Level-3
Along-Track
Products

Single beam

- SEGMENT CANOPY HEIGHT

Difference between the segment canopy surface and segment terrain elevation



Level-4 Gridded Products

Anticipated Gridded Products
Produced Annually

Global Terrain Model and associated accuracy (500 m posting)
Method - TBD

Global Canopy Height and associated accuracy (500 m posting)
Method - TBD

Global Canopy Cover and associated accuracy (500 m posting)
Method - TBD

Copan Ruinas, Honduras

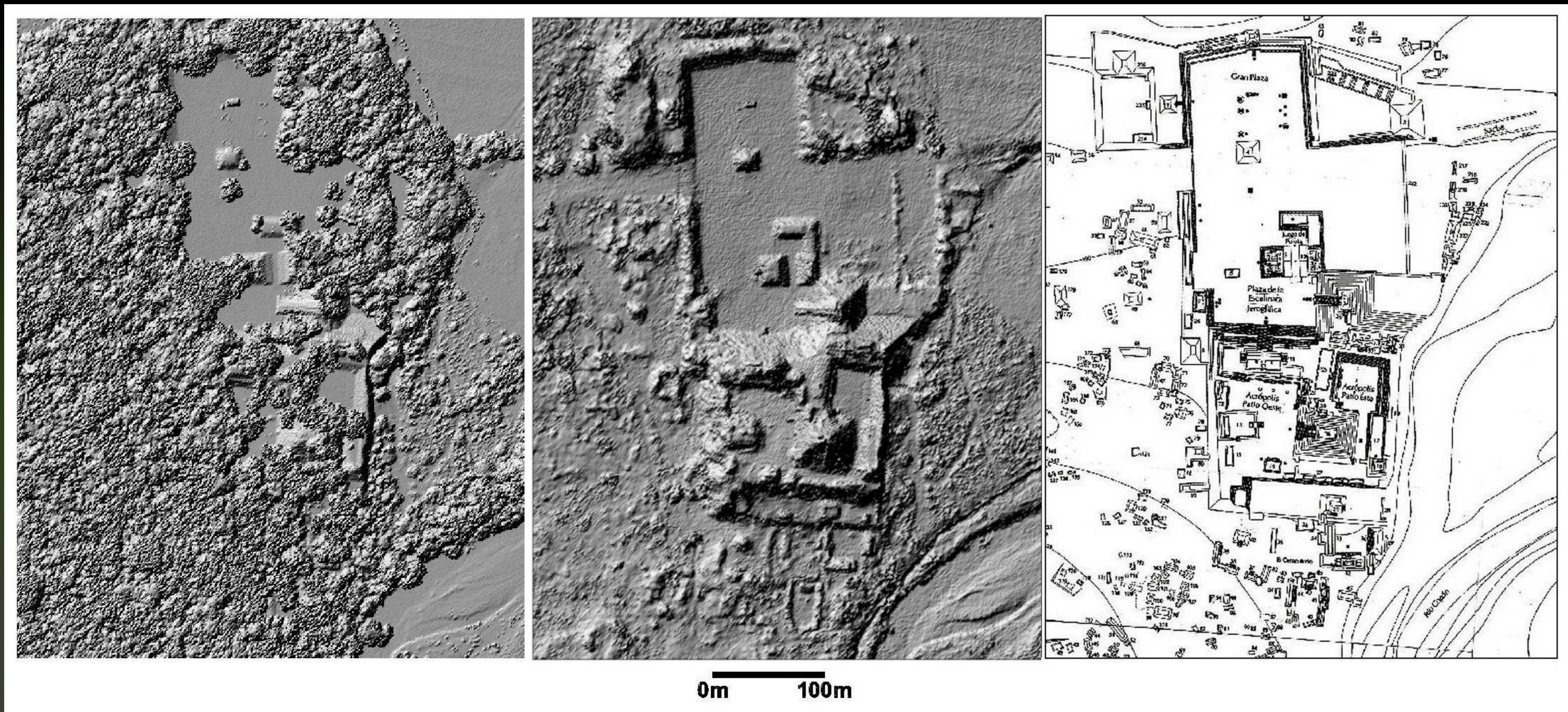
- **Archaeological Park includes Mayan ruins, open park-like areas, and dense tree cover**

- **Above: A significant amount of the LIDAR energy can penetrate the forest canopy just like sunlight**

UT CSR Data Classification

Copan Ruinas, Honduras

all points DEM **buildings and ground DEM** **Havard total station survey**



- Can distinguish between ground, vegetation, and buildings

Other Sensors

- TanDEM-X, TerraSAR-X (DLR)
- ICESat, ICESat-2 (NASA)
- EO-1 (ALI, Hyperion, taskable)
- Formosat (taskable)
- China Brazil Earth Resources Satellite (CBERS)
- China FY meteorological satellites