Tech Brief:
Imagery vs SAR for Military Applications

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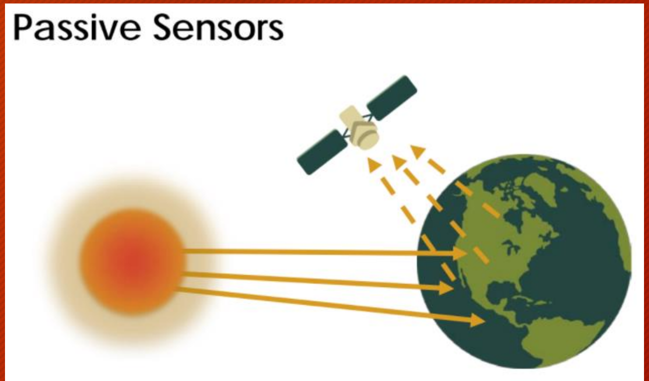
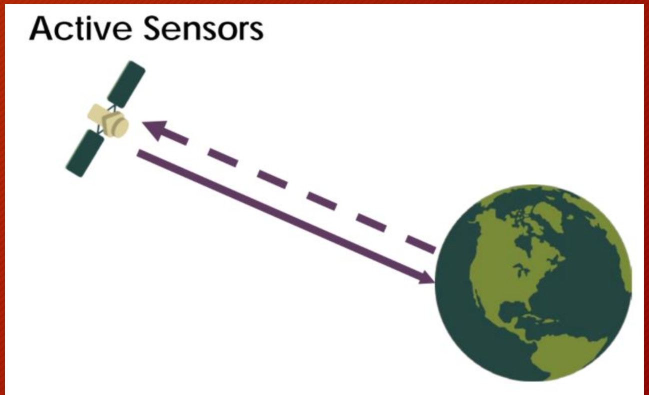
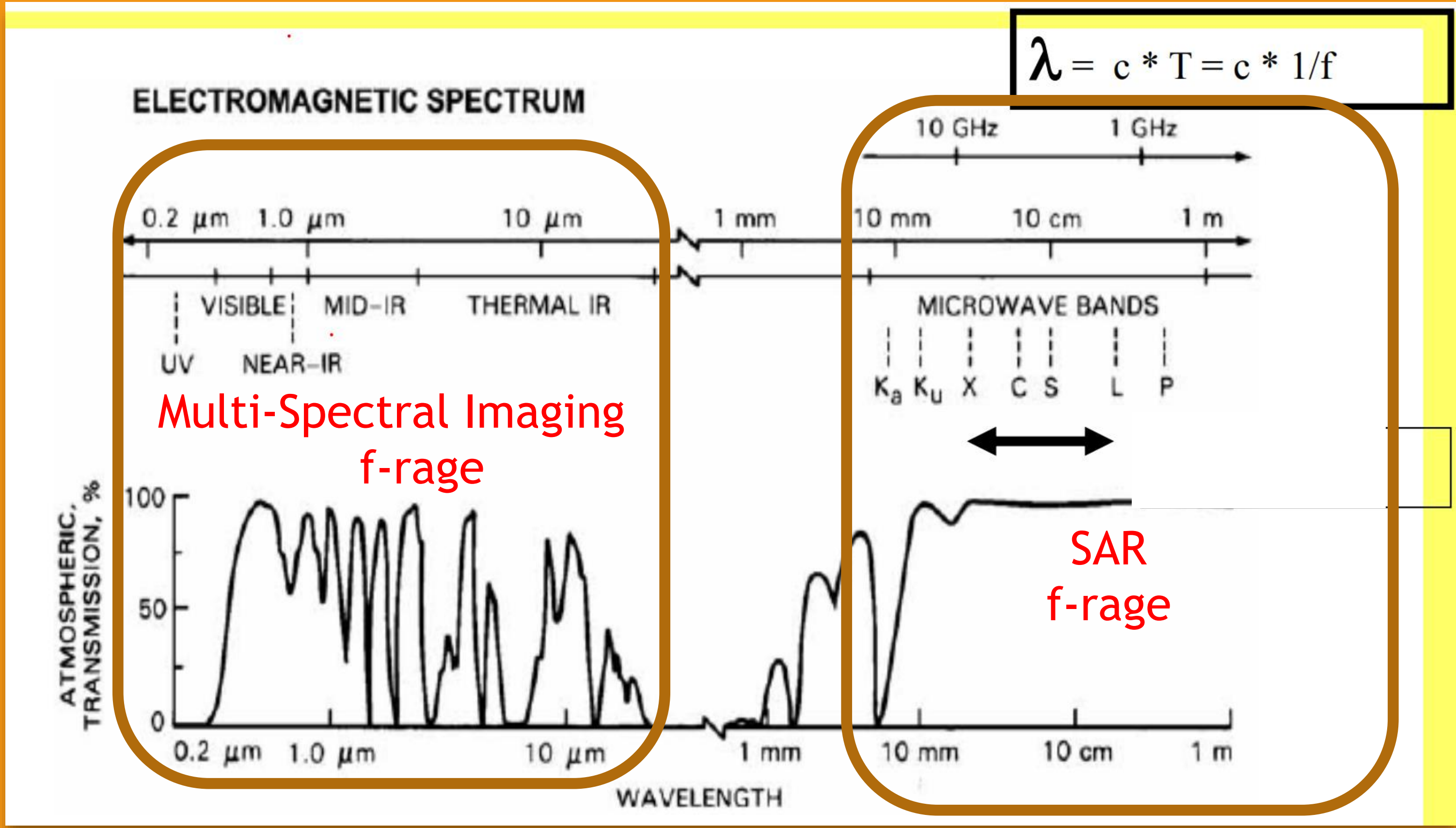
Synthetic Aperture Radar vs Imagery: An Introduction

- Earth Observation is conducted using Active and/or Passive Sensors
  - <u>Passive Sensors:</u> Based on solar reflection in visible, infrared, thermal infrared, and uwave bands of EM spectrum.
    - Cloud coverage and night side of the earth can limit operation
    - **IMAGERY is based on Passive Earth Observation**
  - <u>Active Sensors:</u> Based on satellite emitting and receiving reflected energy
    - Generally all-weather operation
    - <u>**SAR is an Active Earth Observation Sensor**</u>
- Key Systems Parameters for EO satellite
  - <u>**Spatial Resolution:**</u> size of object/features being measured
  - <u>**Spectral Extent:**</u> breadth of electromagnetic spectrum sensed
  - <u>**Radiometric Resolution**</u>: number of digital levels expressed in the data collected
  - <u>**Temporal Resolution**</u>: intervals between imagery acquisition





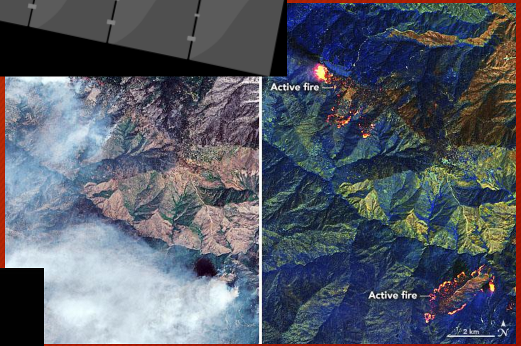
Electromagnetic Spectrum
SAR and Imagery capture two distinct reflected spectral components



Earth Observation a brief history

- 1951- Carl Wiley (Goodyear Aerospace) develops then patents the SAR concept
- 1960 Tiros-1 weather satellite
  - 2 visible spectrum cameras – 10 satellites launched
- 1964 – Nimbus-1 to 1978 Nimbus 7
  - introduced multi-spectral scan (MSS) w/uwave for water vapor detection
- 1974 – Landsat 1 to 2013 Landsat 8
  - MSS progressed from 3 bands to 11 bands
- 1974 - GEOS series – 1st Geostationary orbit EO satellites
  - GEOS-17 launched 2018 –<u>**program on going**</u>
- 1978 SAR introduced on NASA SEASAT
- 1986 SPOT program – commercial earth observations
- 1990 -2010 sensor types expand
  - 10 countries/regions (EU) operate EO/meteorological satellites
- 2010's – Nano/cube Sats – miniaturization w/full capabilities

Landsat-1

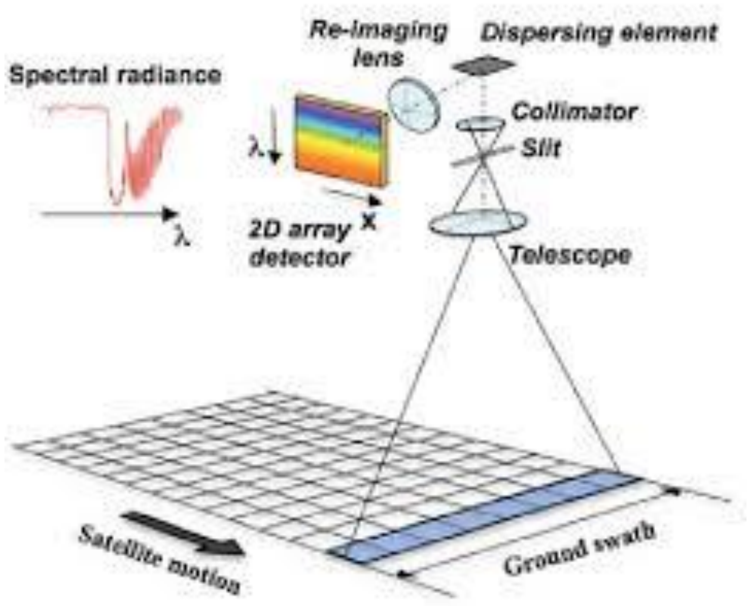


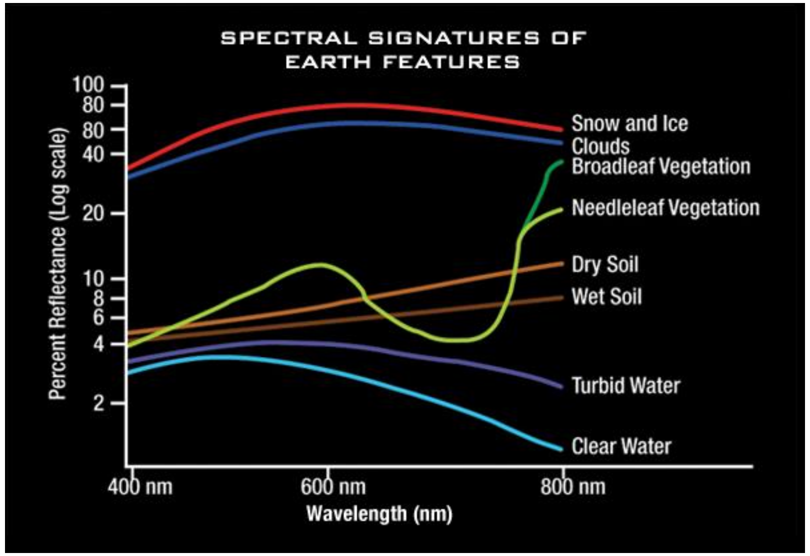
SEASAT

Imagery Overview

Imagery – Visible, Infrared, and beyond

- Imaging Sensors
  - **<u>Imaging Radiometer:</u>** two-dimensional array of sensors scanned electrically or mechanically
  - **<u>Spectrometer:</u>** uses a prism or grating for spectral discrimination
- Earth Features and materials reflect specific spectral components
  - "Spectral Signatures"





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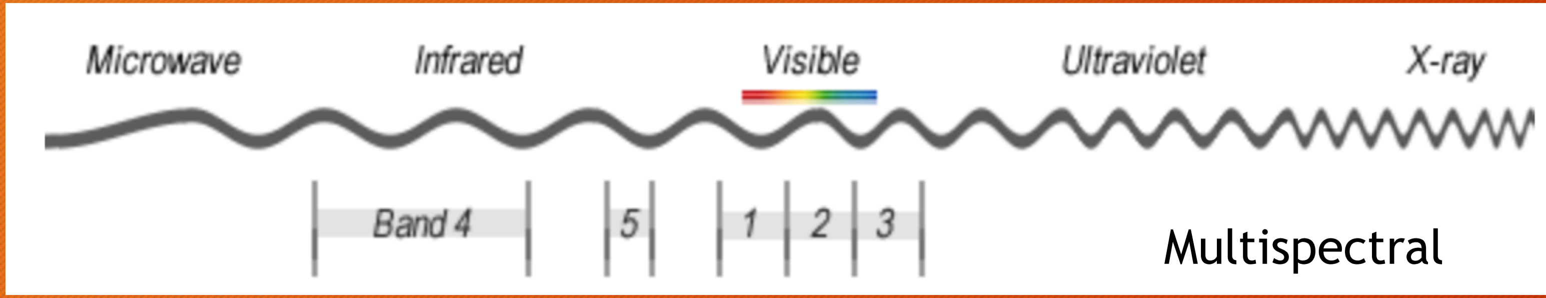
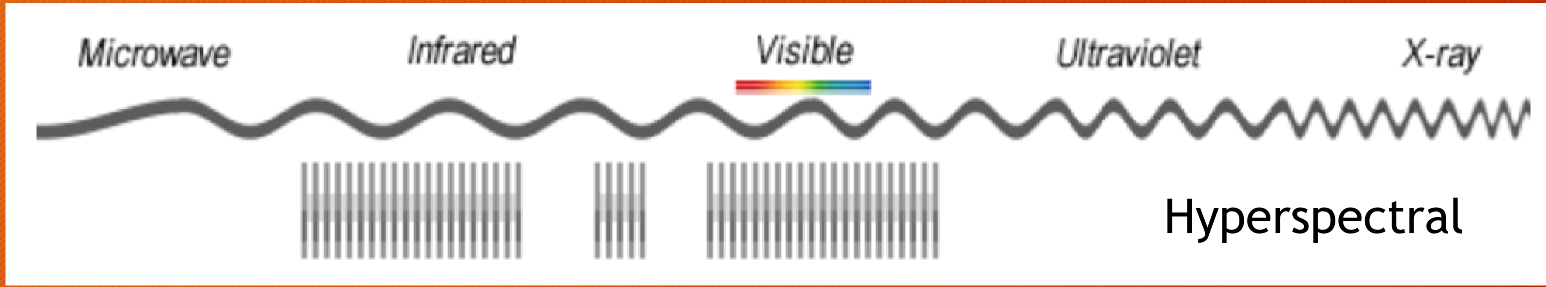
Imaging Technology Evolution: Multispectral to Hyperspectral



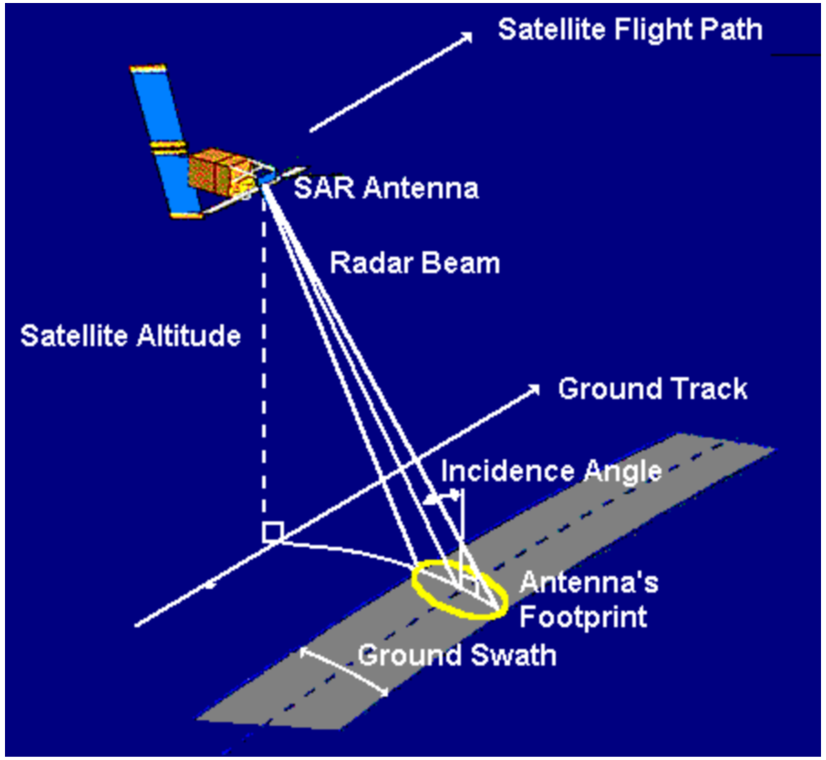


- Multispectral: typically 3-10 frequency bands – relatively wide bands
- Hyperspectral: Hundreds of narrow bands
- Evolution through a multiple decades of technology advances
- Advantages of Hyperspectral:
  - Capture all data at one time
  - More accurate segmentation and classification of the image
- Disadvantages of Hyperspectral:
  - Cost and Complexity

SAR Overview

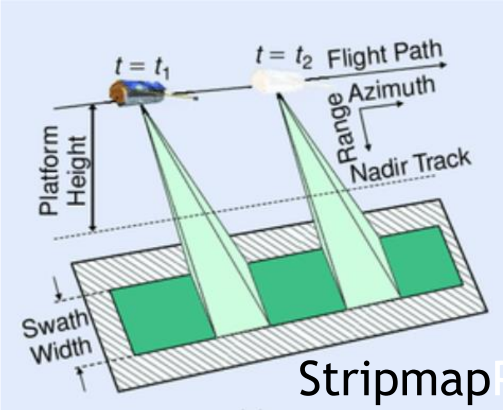
What is SAR?

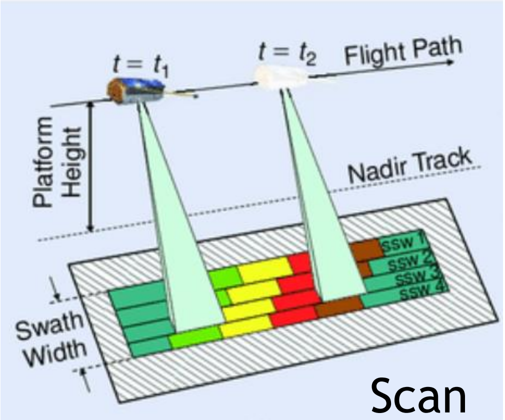
- <u>Synthetic-aperture radar (SAR)</u> is a form of radar that is used to create two-dimensional images or three-dimensional reconstructions of objects, such as landscapes
- The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates the <u>large synthetic antenna aperture</u>
  - A 450 Km orbit LEO SAR Sat has synthetic aperture **<u>~0.9 km</u>**
- SAR can create high-resolution images with relatively small physical antennas - ***<u>PERFECT for LEO CubeSats</u>***
- LEO X-Band SAR can achieve resolutions < **50 cm**
- Interferometric (InSAR) and differential Interferometric (D-InSAR) processing can approach GPS in accuracy

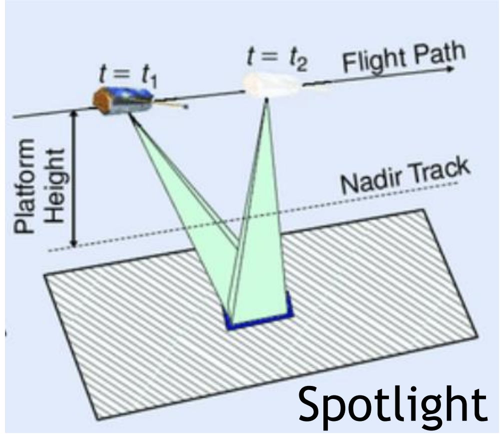


Types of SAR Systems

- <u>Stripmap mode</u>
  - Antenna remains fixed relative to the orbit path
  - Terrain is illuminated with a pulse repetition radar signal
  - Backscatter of radar pulses cumulatively added on a pixel-by-pixel basis to attain the fine azimuth resolution desired in radar imagery
- <u>Scan mode:</u>
  - Antenna beam sweeps periodically and thus cover much larger area than the spotlight and stripmap modes
  - Resolution is reduced but a far greater area is scanned
- <u>Spotlight mode:</u>
  - Radar is steered at a fixed terrestrial point
  - Radar dwell period is extended resulting high azimuth resolution







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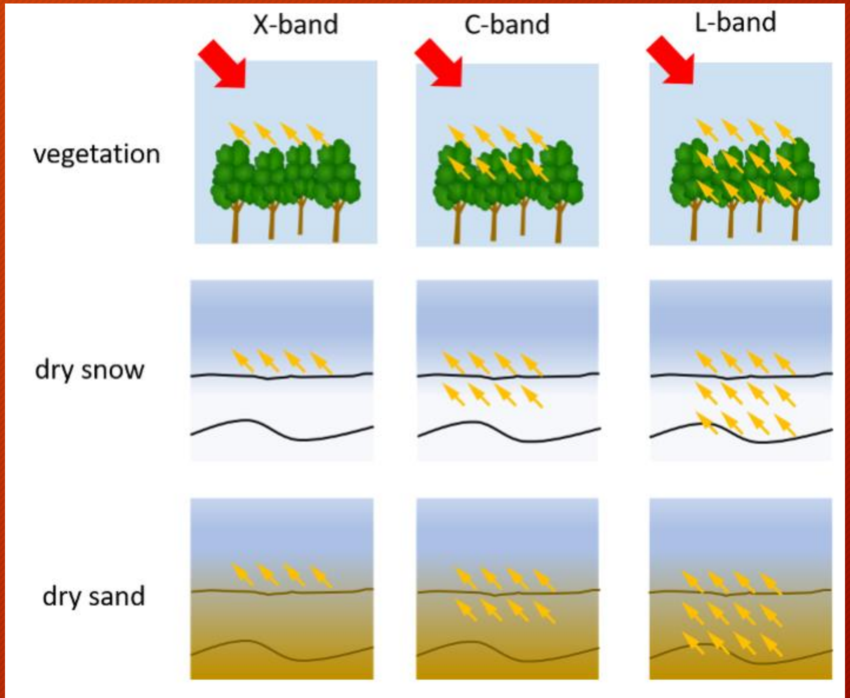
SAR Frequency bands of operation

Band	Frequency	Wavelength	Typical Application
Ka	27 – 40 GHz	1.1 – 0.8 cm	Rarely used for SAR (airport surveillance)
K	18 – 27 GHz	1.7 – 1.1 cm	rarely used (H_2O absorption)
Ku	12 – 18 GHz	2.4 – 1.7 cm	rarely used for SAR (satellite altimetry)
X	8 – 12 GHz	3.8 – 2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8 GHz	7.5 – 3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2 – 4 GHz	15 – 7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1 – 2 GHz	30 – 15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3 – 1 GHz	100 – 30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.



Penetration Capability by Frequency Band

Commercialization of Imagery and SAR Intelligence

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NRO, DARPA, & the War in Ukraine: Drivers of LEO commercial satellite intelligence

- NRO granted study contracts to five commercial SAR satellite companies:
  - Airbus's US arm
  - Capella Space –California startup
  - Finnish firm ICEYE's US branch
  - Florida startup PredaSAR
  - California-based Umbra
- Equivalent DARPA program is enabling Imagery Sat companies
- Ukraine provided real time imagery by MAXAR and others

PredaSAR
planned 96 satellite constellation

Commercial LEO SAR satellite constellations

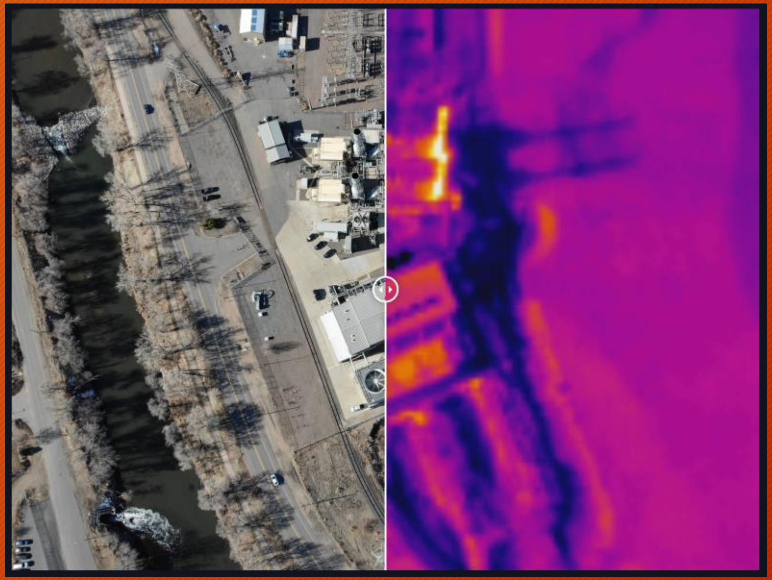
Constellation: 21 Sats
Frequency Band: X-Band
Bandwidth: 30 to 300 Mz
Resolution: 0.25 m

Port of Rotterdam (ICE EYE)

Constellation: 30 Sats planed
Frequency Band: X-Band
Bandwidth: 0 to 500 MHz
Resolution: < 0.5 m

Commercial LEO Imagery satellite constellations

Constellation: TBD Sats
Optical Res: 30 cm
Infrared Res ~2 m



RGB & Infrared Imaging
(Albedo)

Constellation: 6+ Sats
Optical Res: 15 – 30 cm
Multispectral 0.15 – 2 m

Thank You

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