Universität Hamburg
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MIN-Fakultät
Fachbereich Informatik
Arbeitsbereich SAV/BV (KOGS)

IP2: Image Processing in Remote Sensing

6. Sensors I: Types of Sensors and Optical Systems

Summer Semester 2014

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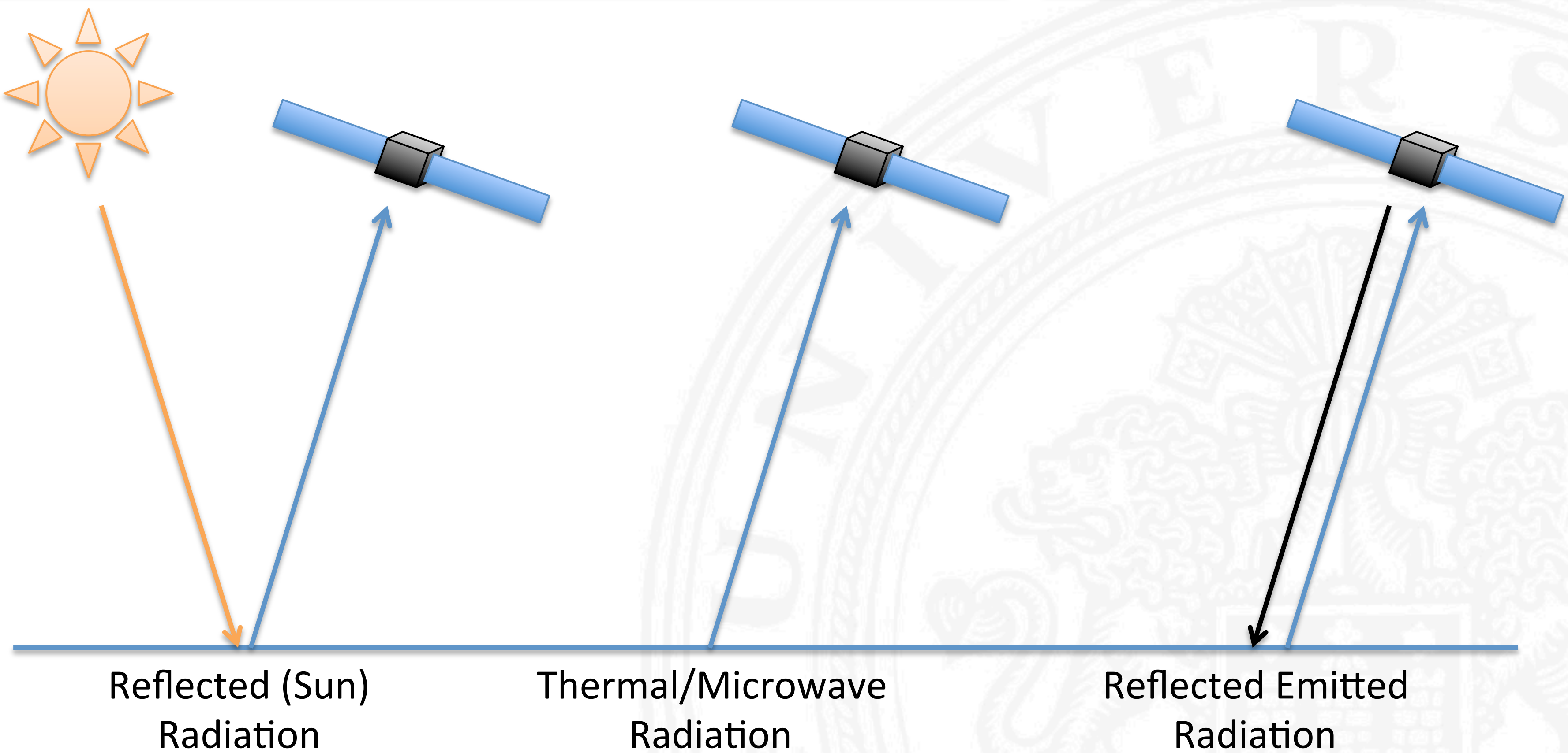
Agenda

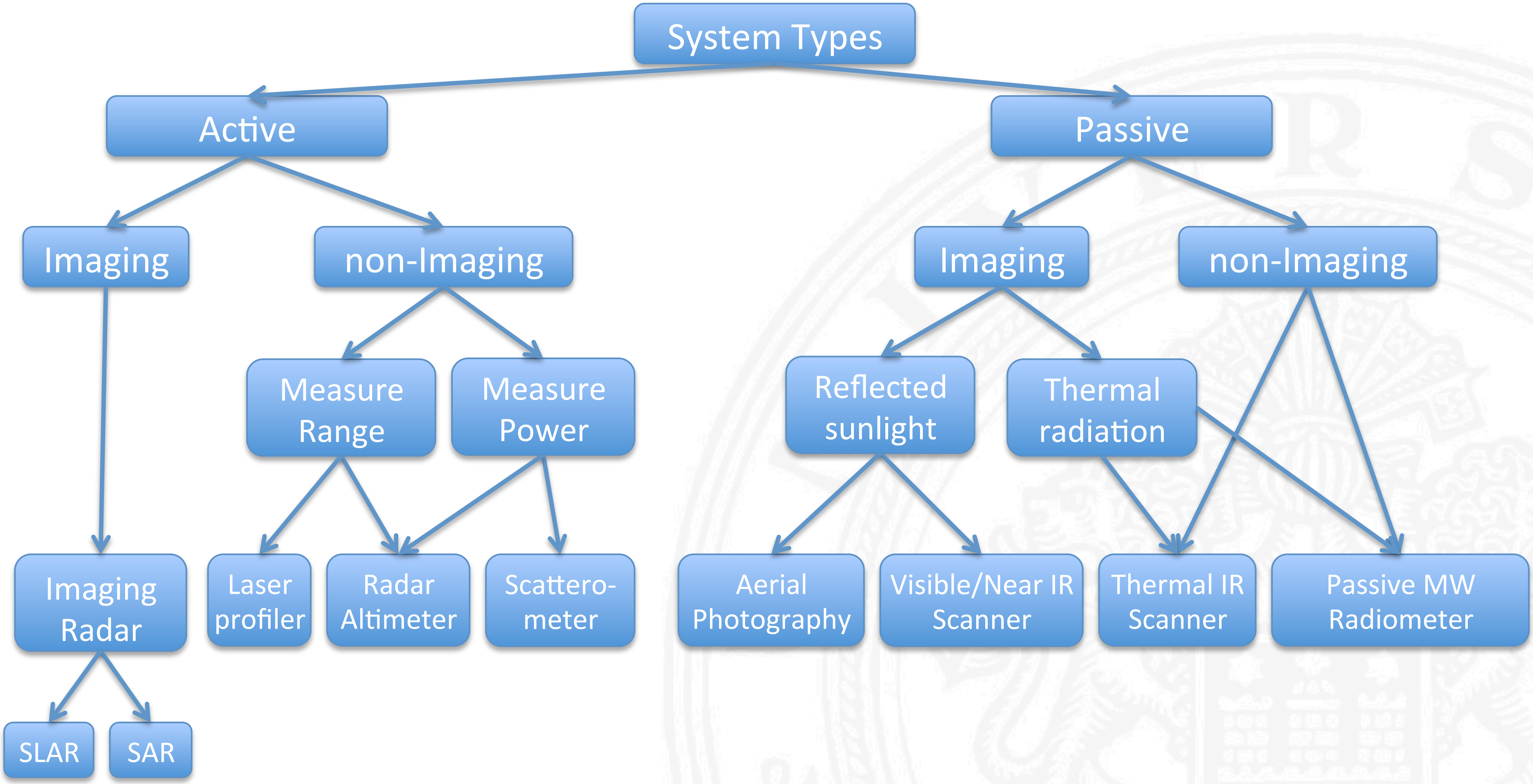
- Overview of Sensor Types
  - Spectral Range
  - Acquisition methods
- Optical Sensors
  - Photographic film vs. electro optic systems
  - Construction
  - Multi- and Hyper spectral Sensors
  - High-Resolution Systems
  - Challenges for Image Processing

Passive vs. Active Systems

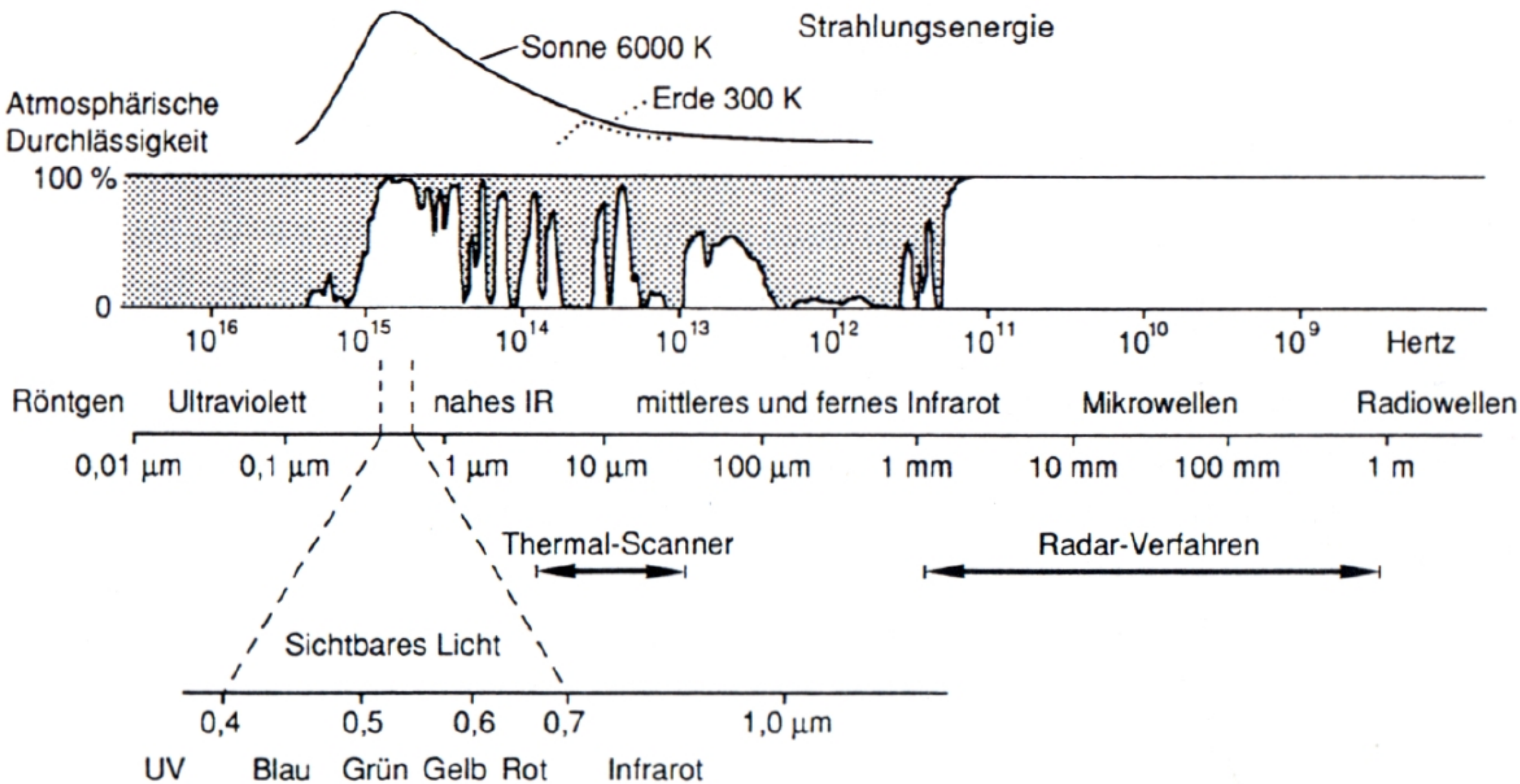
Passive Systems | **Active Systems**



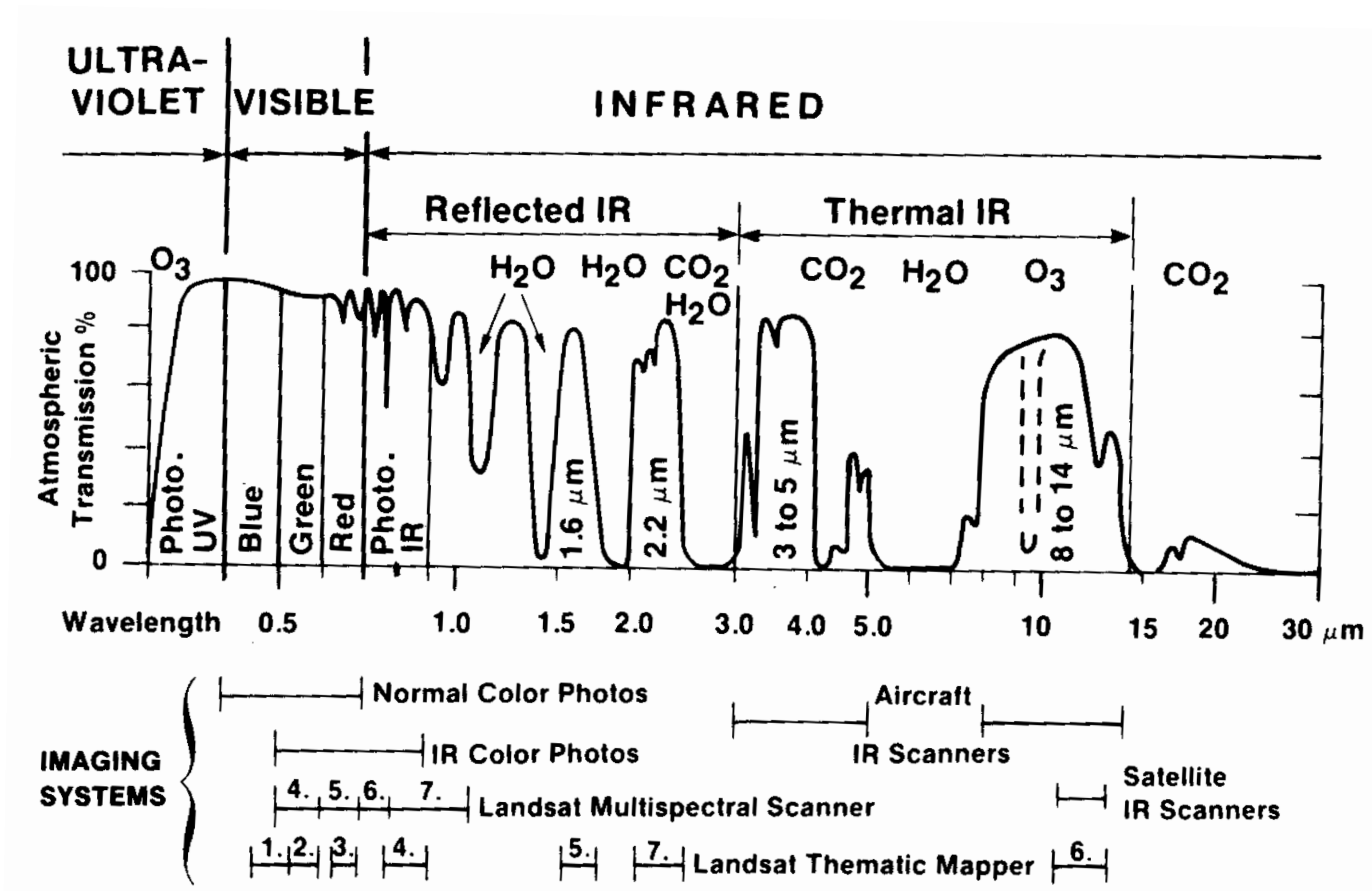
Categories of Remote Sensing Systems



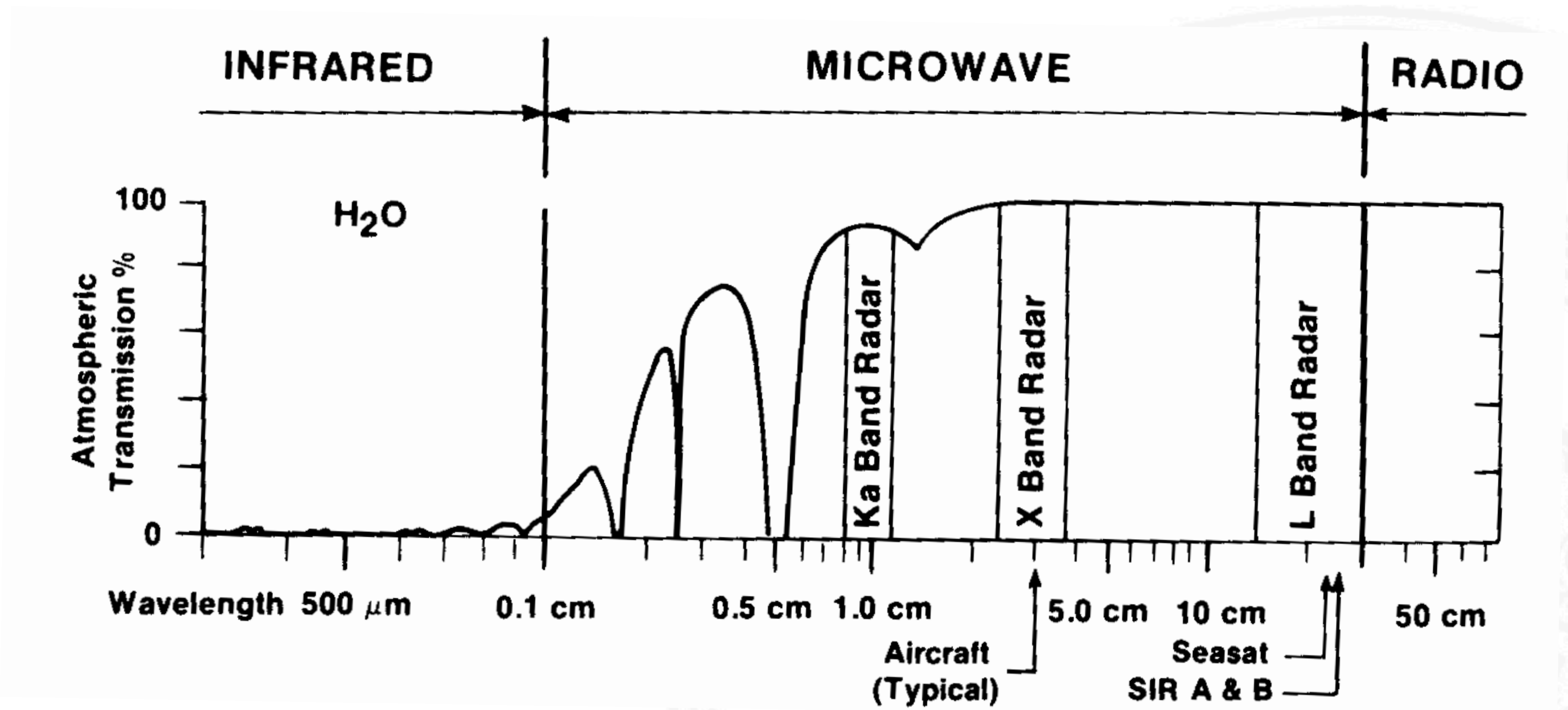
EM Spectrum and the Atmosphere



Bands for Optical (Multispectral) Sensors



Bands for Microwave Sensors



Typical Satellite Sensor Requirements

- Robustness
  - Huge (!) accelerations
  - (Low) Temperature
  - Cosmic radiation/particles, Sun winds
- Maintenance-free
  - Nearly impossible in orbit
  - Example: Hubble Space Telescope
- Low Energy consumption
  - Solar panels
  - Onboard batteries

⇨ The more requirements met, the higher the lifetime of a satellite sensor!

Today: Optical Sensors

- Passive acquisition of EM-Radiation at ~ 400 – 700 nm
- Two major system designs
  1. Framing Systems
     Photographische Systeme
     Measure all pixels of an image synoptically (at same time)
     Examples:
     - Photographic films
     - CCD Cameras (e.g. Digital SLR at ISS)
  2. Scanning Systems
     Abtastende Systeme
     Measure (all) pixels of an image sequentially
- Attention: Different System designs yield to different image properties!

Framing Systems

Photographische Systeme

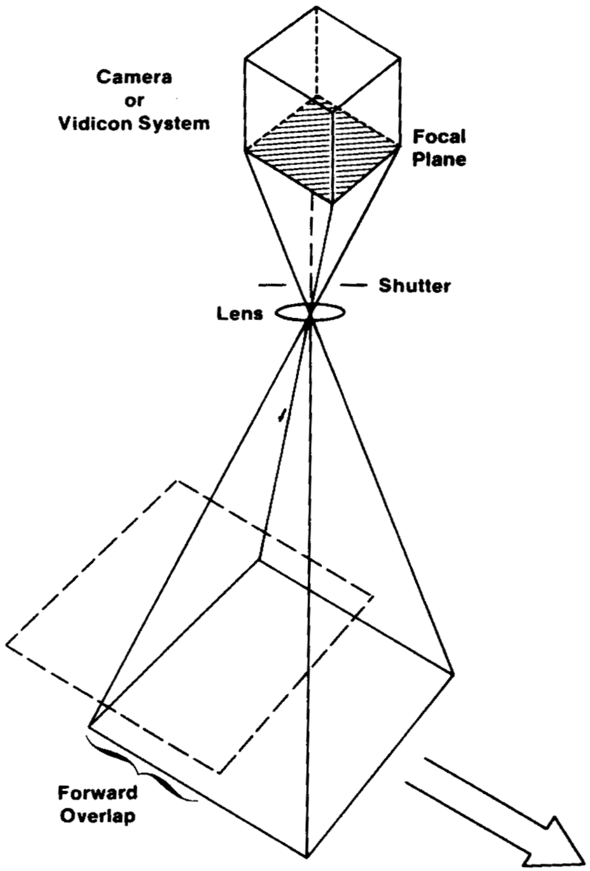


FIGURE 1.11 Framing system for acquiring remote sensing images.

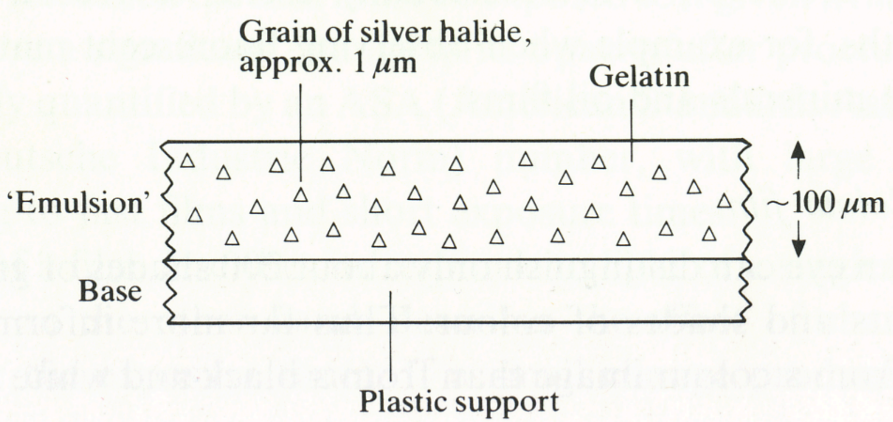
- Acquisition through an objective (here: lens)
- Shutter to control exposure time of light on:
  - Photographic film
  - Luminous surface (which is sampled by a Return Beam Vidicon (RBV) scanner)
  - CCD-Array
- Sensor size proportional to image size

Photographic Process

- Many photographic films are based on the photo sensitiveness of silver ions (e.g. silver iodide)
- Silver sensitized paper: gelatin emulsion of 100 μm thickness with embedded silver layer of 10 μm.
- Exposed material changes crystal aggregation of film (even for very short expositions):

  $Ag^{+} Br^{-} \rightarrow Ag + ½ Br^{2}$
- A developer (chem.) resolves the exposed silver crystals to metallic (black) grains

Fig. 4.1. Schematic diagram showing the construction of a typical photographic film.



Optical Density
Schwärzung

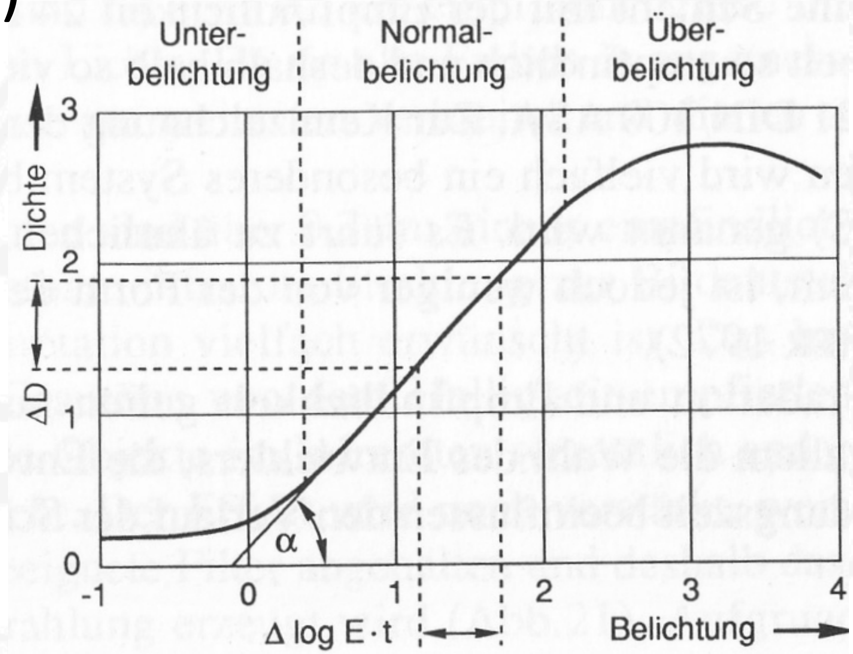
- The dependency between exposure and the resulting optical density is given by the density curve
- A measure of the optical density is given by the ratio of the incoming light flux ϕ_0 and the transmitted flux ϕ:

$$D = \log\left(\frac{\phi_0}{\phi}\right)$$

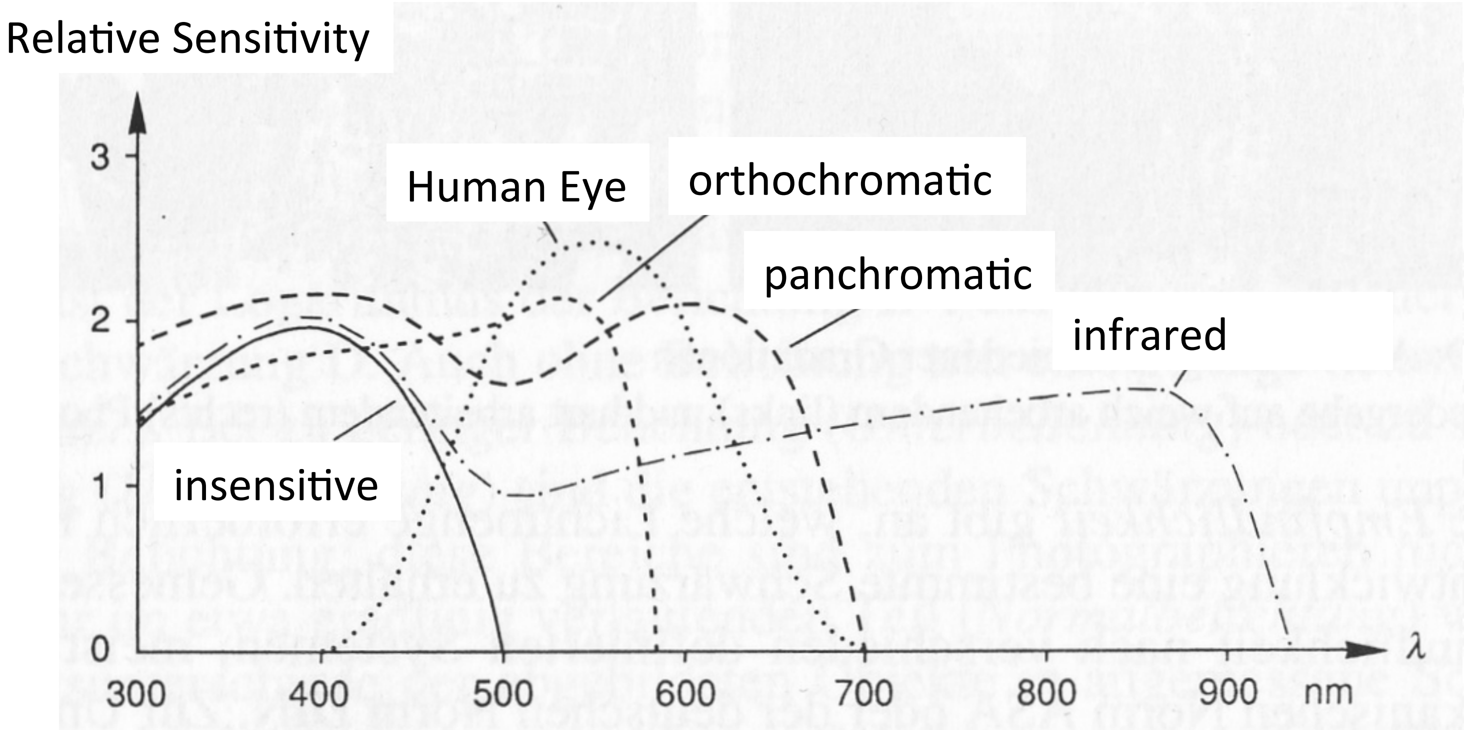
- D is dimensionless and of logarithmic scale:
  - $D=1$ if 10% of the incoming light flux is transmitted
  - $D=2$ if 1% of the incoming light flux is transmitted
- A small D is (always) present, even without exposure!
- D may not be proportional to the exposure at low and high exposures!
- Linear part of the density:
  - Derivative: Gradation
  - Location: Sensitivity

Gradation

- Gradation: Assignment of large or small density differences to object contrasts
- Measure: γ, the gradient of the linear part of the density curve ($\gamma = tan(\alpha)$)
- Distinguish between:
  - soft ranges ($\gamma < 1$):
    low contrast images
  - standard ranges($\gamma \approx 1$):
    “standard” contrast
  - hard ranges ($\gamma > 1$):
    high contrast images



Relative Sensitivity of Monochrome Photographic Films



Note (for the human eye): Even without any filter, wavelengths < 400 nm are absorbed at the vitreous!

Glaskörper

Example: Panchromatic and IR-Photography

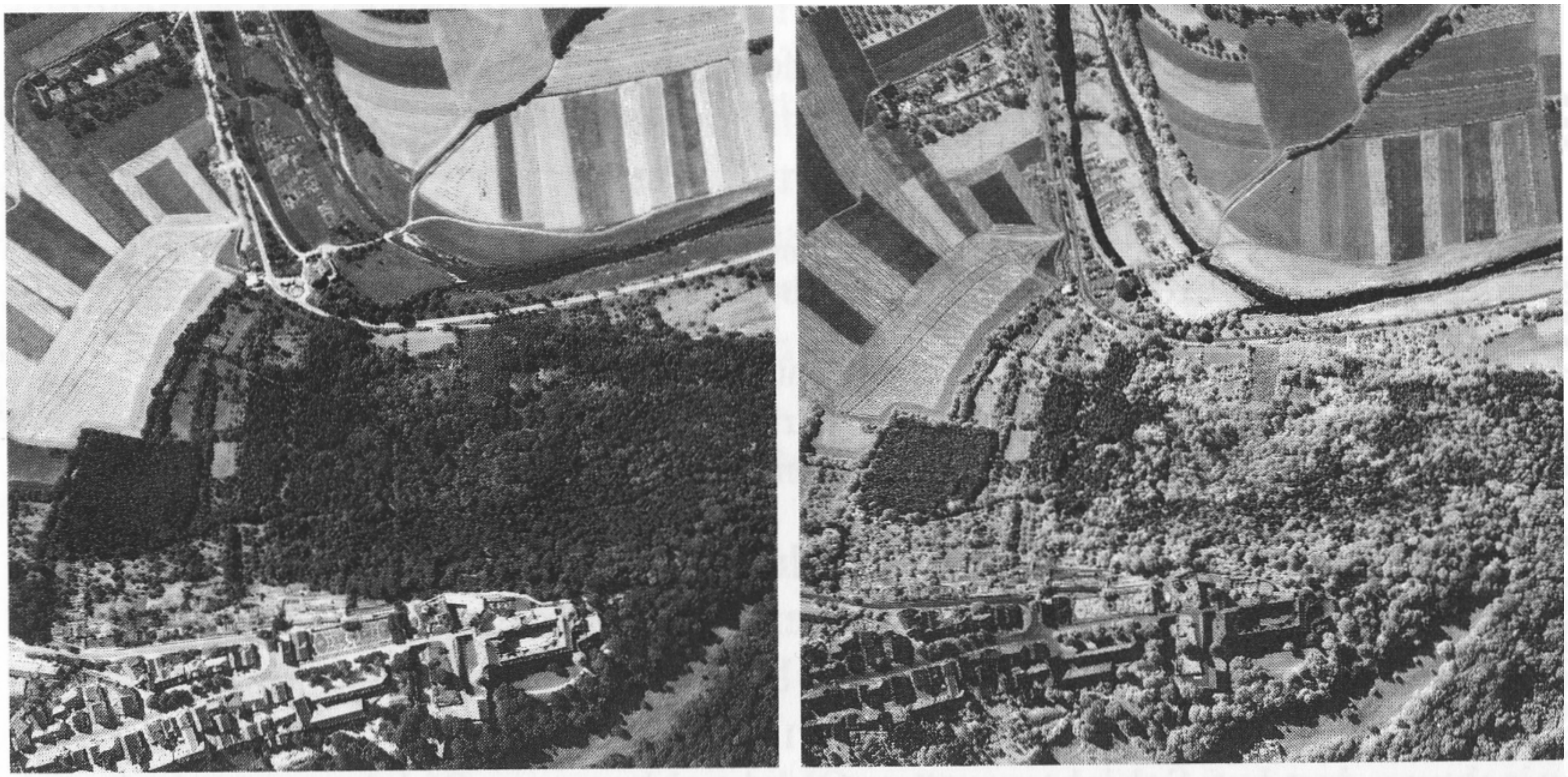


Abb. 21: Panchromatisches und Infrarot-Luftbild: Langenburg (Württemberg)
Links: Panchromatisches Bild (mit einem Gelbfilter aufgenommen). Rechts: Infrarot-Bild (mit einem Orangefilter aufgenommen). (Photo: CARL ZEISS, Oberkochen)

Conclusions: Film-based Photography

Advantages:

- exposed material is also storage medium
- Synoptical acquisition and storage on comp. small space and at low costs
- Pictures are easy to understand (for humans)
- Formerly: Highest possible resolutions

Disadvantages:

- Radiometric Calibration hard (depends on film)
- Photographic spectral range is restricted
- Unnecessary and inappropriate intermediate step for image processing
- Who gets/exchanges the films in orbit?

Electro Optic Systems: Return Beam Vidicon (RBV)

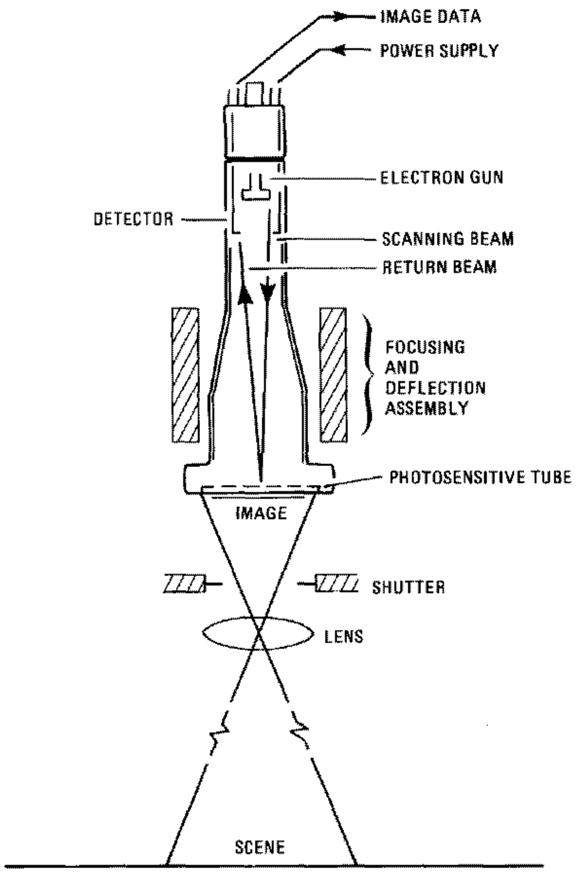


FIGURE 4.10 Return-beam vidicon system.

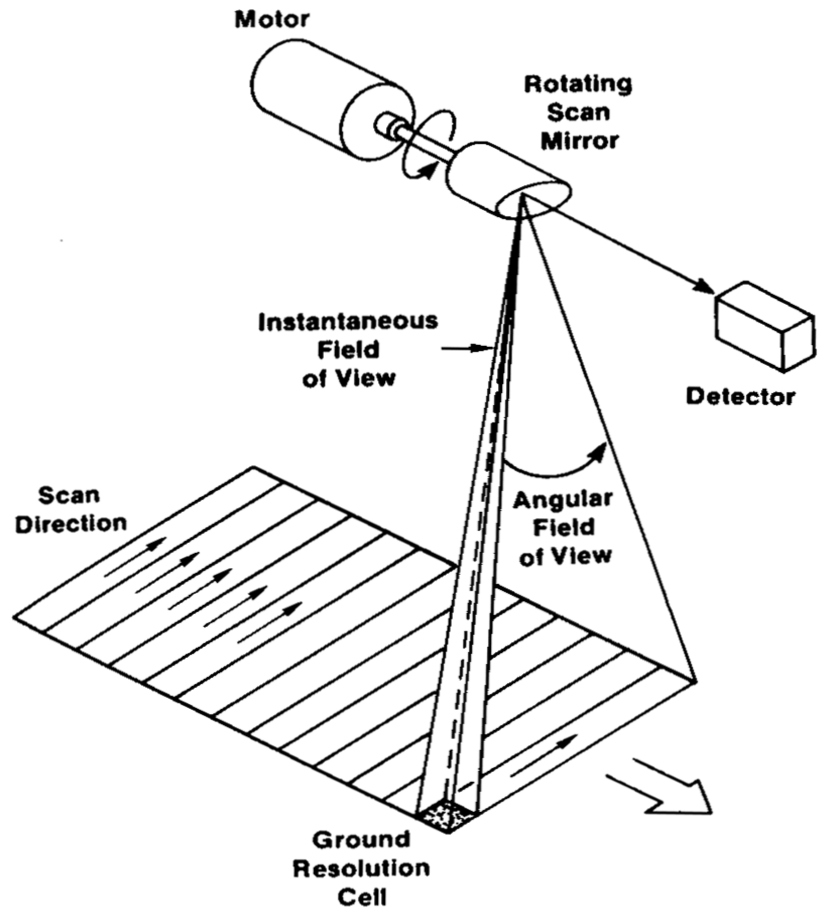
- Framing System:
  - Resolution at ground: 40 m
  - EM-Spectrum: 500 – 750 nm
- Imaging like inverse Television:
  1. Lens projects light on sensitive layer
  2. Electronic ray samples the layer(line wise). Intensity is proportional to the charge.
  3. Charges of layer are reset for next acquisition.
- **Formerly** better resolution than scanning systems
- Worse geometric and photometric properties

Acquisition using Scanning Systems

- In contrast to photographic acquisitions, only a small terrain element in monitored (scanned) w.r.t. the emitted radiation.
- To monitor a large area, many sub-measurements need to be combined
- Distinguish between technical setup:
  - Optomechanic scanners
  - Optoelectronic scanners
- Distinguish between spectral range
  - "single band" acquisition
  - multi spectral acquisition

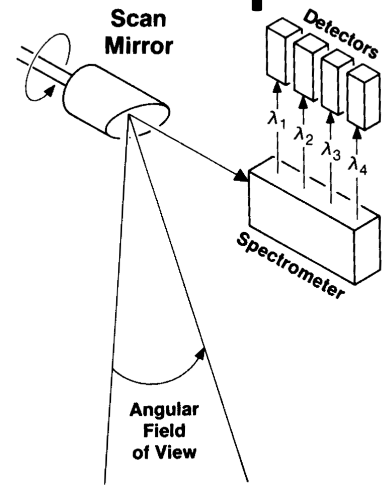
Optomechanic
Cross Track- or Whiskbroom Scanner

- Passive scanning System
- Used for visible and IR ranges (using filters)
- Rotating Mirror reflects light to the Sensor
- Image is composed of single "scan lines"
- Rectangular images
- Non-uniform pixel size



Optomechanic
Cross Track Scanner – Multispectral Setup

- Radiation is divided into band-specific (single) signals. E.g.:
  - Filter
  - Prisms
  - Lattices
- One detector for each band
- Result: 3-dimensional image of size $w \times h \times c$, with:
  - width w, height h, and
  - channel/band count c
- Usually at least 1 band at infrared



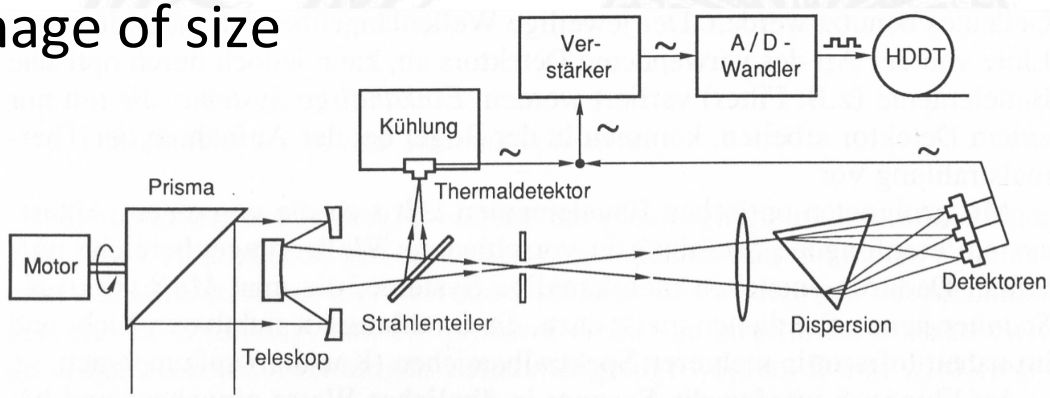
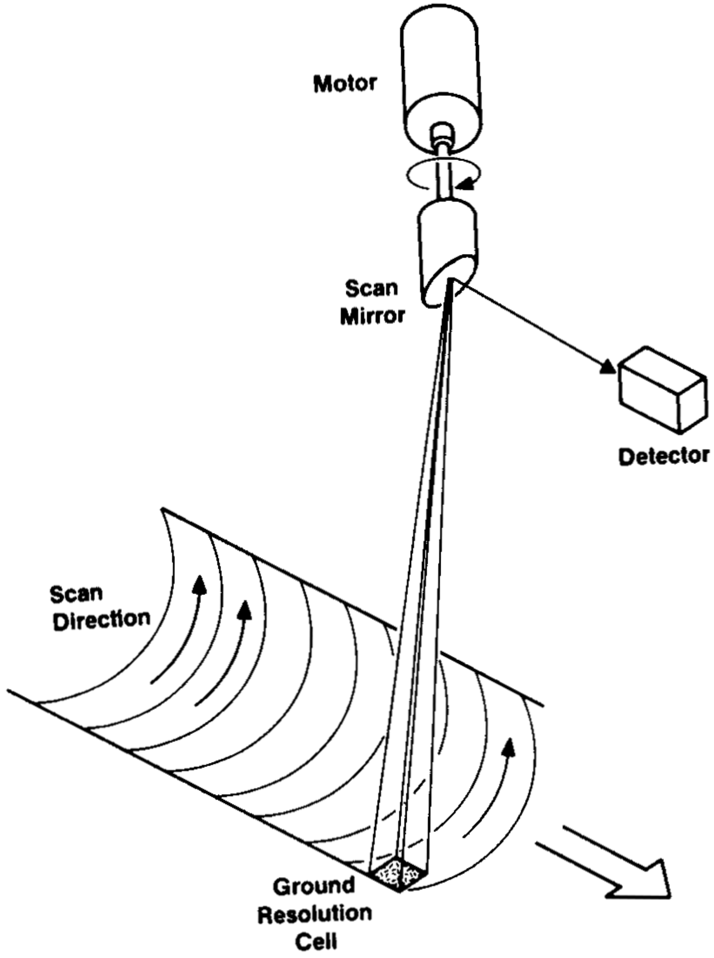


Abb. 34: Zerlegung der empfangenen Strahlung in einzelne Spektralbereiche (Nach KRAUS & SCHNEIDER 1988)

Optomechanic
Circular Scanning System

- Passive scanning System
- Used for visible and IR ranges (using filters)
- Rotating Mirror reflects light to the Sensor
- Image is composed of single “scan lines”
- Non-rectangular images
- uniform pixel size



Seamless Image Creation for *Optomechanical* Scanning Systems

To ensure that the samples rows can be composed to an image without overlapping, the following must hold:

$$\Delta\alpha \cdot h \cdot f = v \quad \Rightarrow \quad \frac{v}{h} = \Delta\alpha \cdot f$$

with:

- $\Delta\alpha$ angle of aperture of the scanner (IFOV)
- h (flight) altitude
- v platform velocity
- f scanning frequency

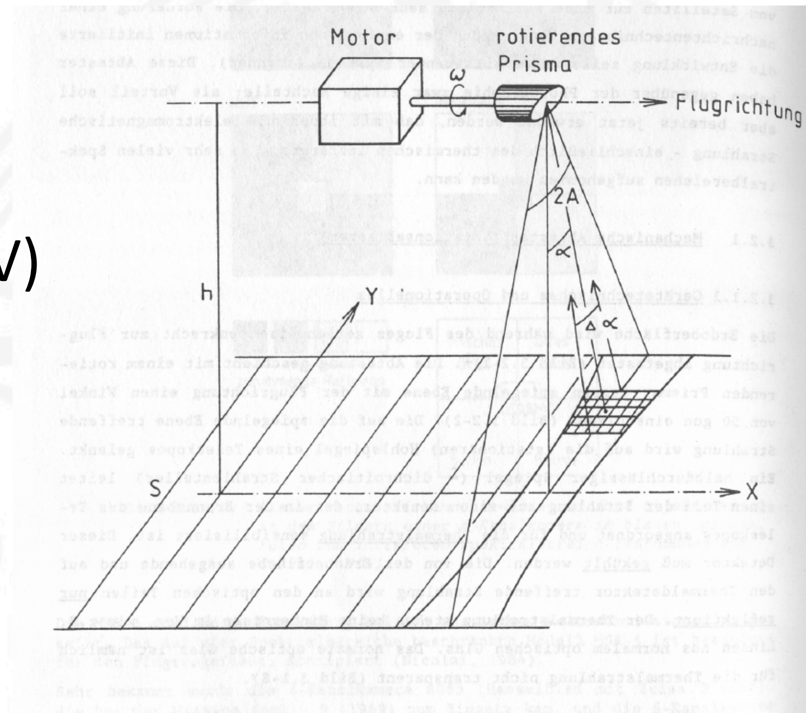


Bild 3.2-1: Zeilenweise Abtastung senkrecht zur Flugrichtung

IFOV: Instantaneous Field of View

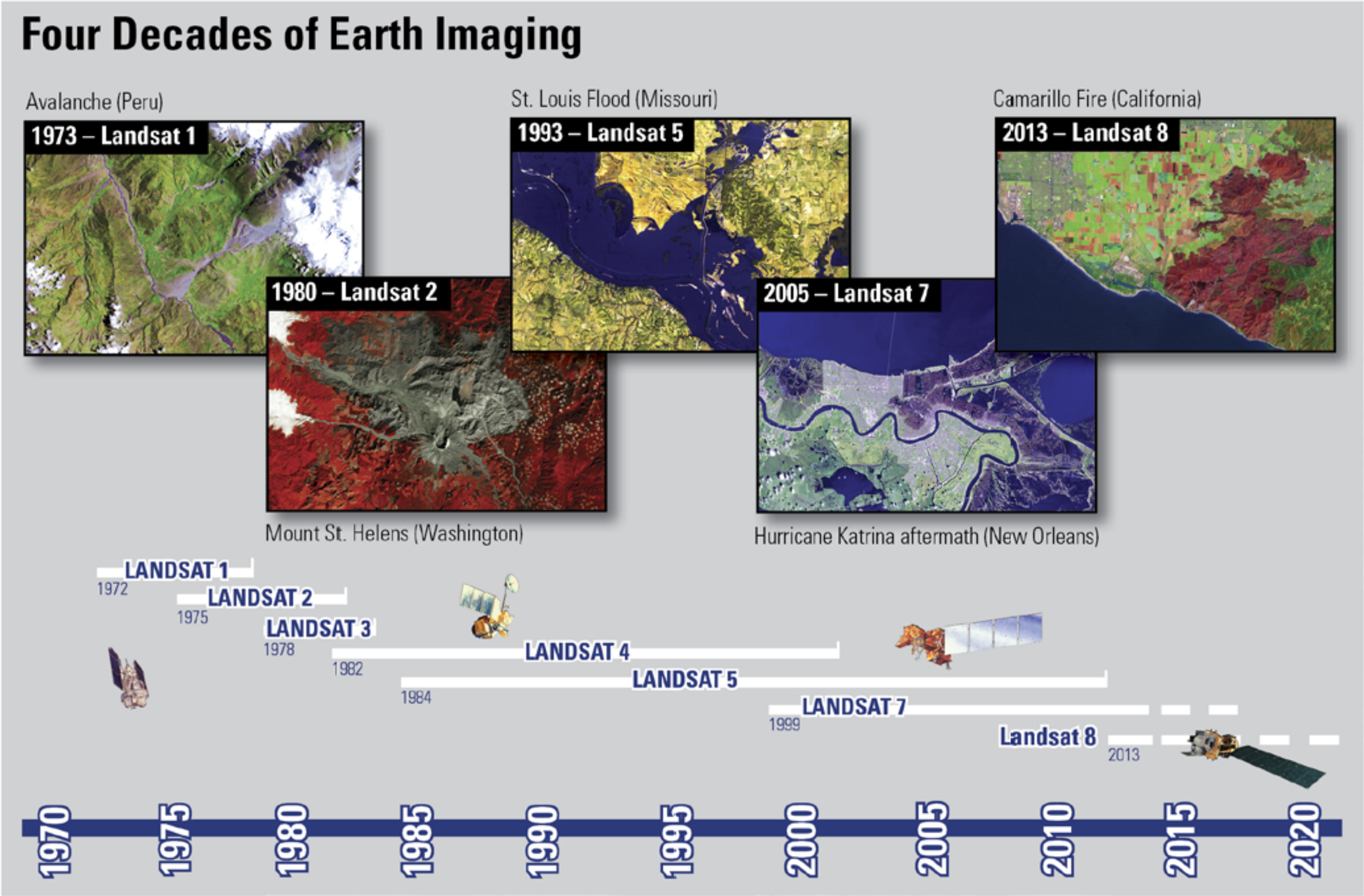
Example for Scanning Systems: The Landsat Program

- Origin: Earth Resources Technology Satellites Program (ERTS), Renamed to Landsat in 1974
- First Satellite carried first multi spectral scanners (RBV, 1969)
- Formerly commercial, nowadays: many images are freely available at the Landsat Archive: http://landsat.usgs.gov/
- 8 satellites launched 2 still operational
- Aim: Consistent long-term database
- Open Skies Policy
- Major efforts in promoting the Remote Sensing discipline

Table 1. Landsat mission dates.

Satellite	Launch	Decommissioned	Sensors
Landsat 1	July 23, 1972	January 6, 1978	MSS/RBV
Landsat 2	January 22, 1975	July 27, 1983	MSS/RBV
Landsat 3	March 5, 1978	September 7, 1983	MSS/RBV
Landsat 4	July 16, 1982	June 15, 2001	MSS/TM
Landsat 5	March 1, 1984	2013	MSS/TM
Landsat 6	October 5, 1993	Did not achieve orbit	ETM
Landsat 7	April 15, 1999	Operational	ETM+
Landsat 8	February 11, 2013	Operational	OLI/TIRS

The Landsat Program



Landsat 1 – 3 Setup

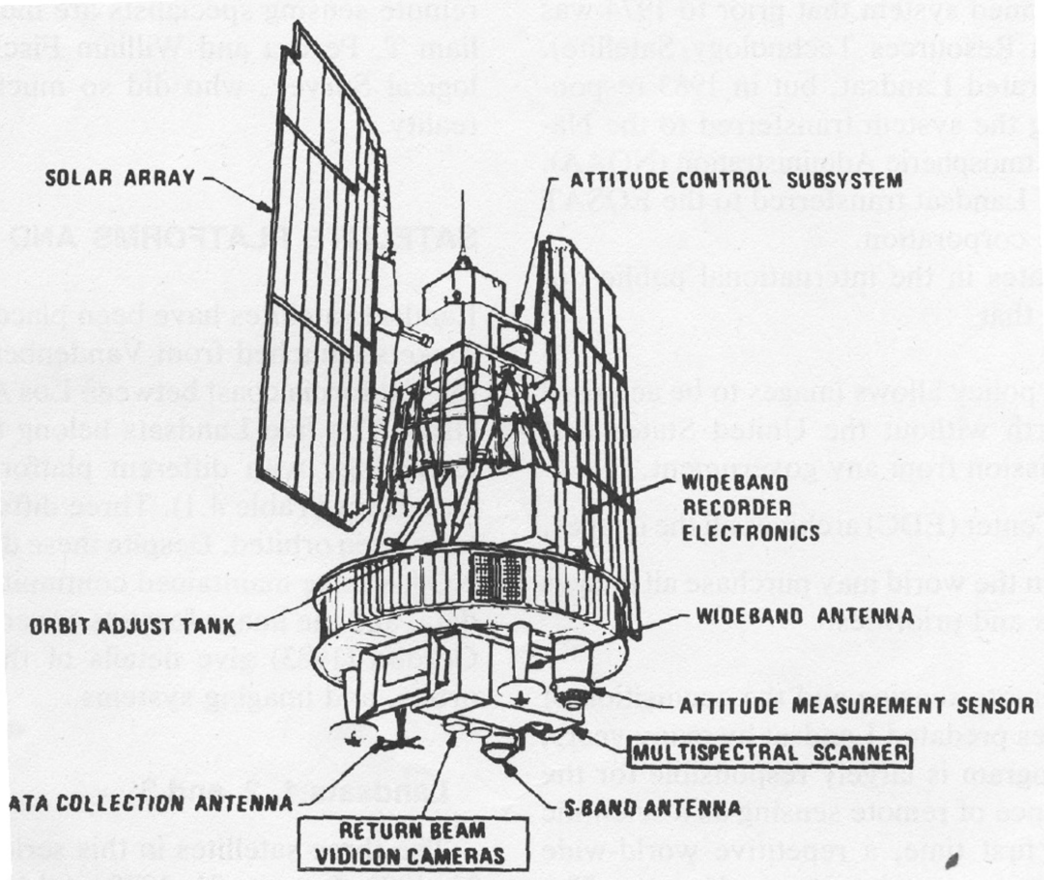


FIGURE 4.1 Satellite platform of Landsats 1, 2, and 3 showing location of multispectral scanner (MSS) and return-beam vidicon (RBV) systems.

Landsat 4 – 5 Setup

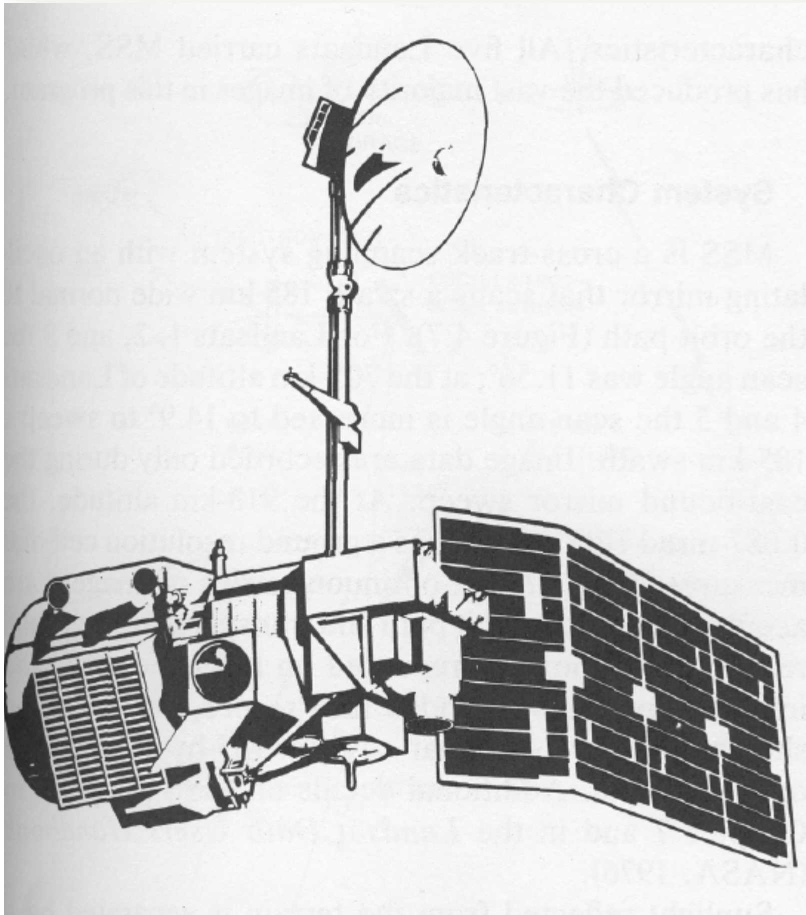


FIGURE 4.4 Satellite platform of Landsats 4 and 5.

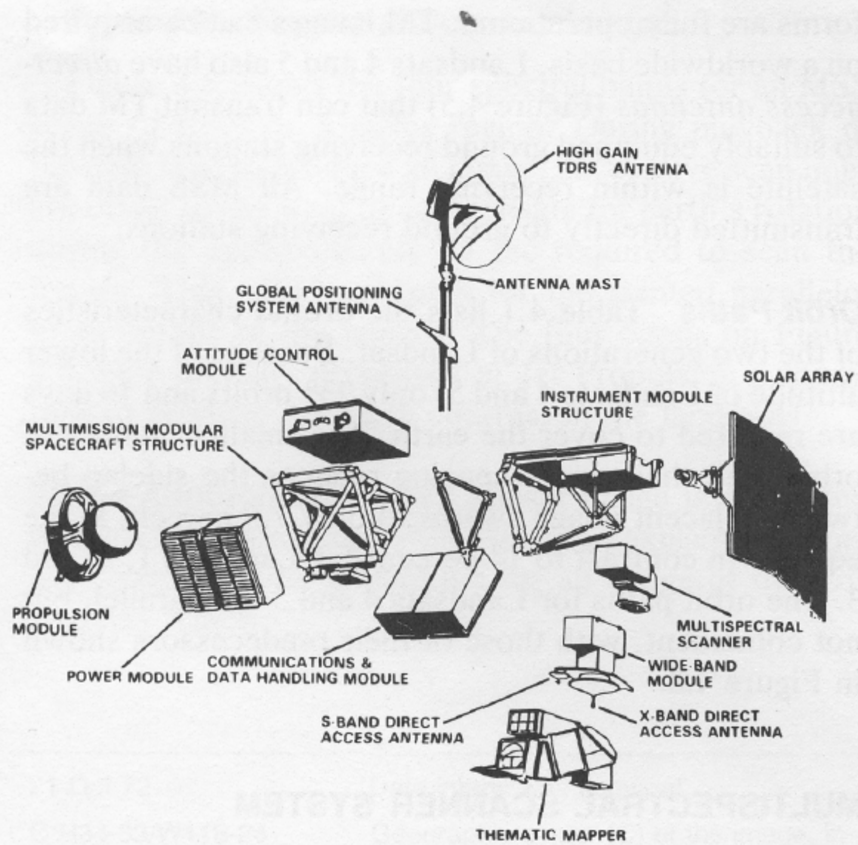


FIGURE 4.5 Components of the platform of Landsats 4 and 5.

Landsat Spectral Sensor Characteristics

TABLE 4.2 Characteristics of Landsat imaging systems

	Multispectral scanner (MSS)	Return-beam vidicon (RBV)	Thematic mapper (TM)
Spectral region			
Visible and reflected IR	0.5 to 1.1 μm	0.50 to 0.75 μm	0.45 to 2.35 μm
Thermal IR (TM band 6)	—	—	10.5 to 12.5 μm
Spectral bands	4	1	7
Terrain coverage			
East-west direction	185 km	99 km	185 km
North-south direction	185 km	99 km	170 km
Instantaneous field of view			
Visible and reflected IR	0.087 mrad	0.043 mrad	0.043 mrad
Thermal IR (TM band 6)	—	—	0.17 mrad
Ground resolution cell			
Visible and reflected IR	79 by 79 m	40 by 40 m	30 by 30 m
Thermal IR (TM band 6)	—	—	120 by 120 m
Number of picture elements			
Single band	7.6×10^6	6.1×10^6	39×10^6
All bands	30.4×10^6	6.1×10^6	273×10^6

Landsat Thematic Mapper (TM)

TABLE 4.4 Thematic-mapper spectral bands

Band	Wavelength, μm	Characteristics
1	0.45 to 0.52	Blue-green—no MSS equivalent. Maximum penetration of water, which is useful for bathymetric mapping in shallow water. Useful for distinguishing soil from vegetation and deciduous from coniferous plants.
2	0.52 to 0.60	Green—coincident with MSS band 4. Matches green reflectance peak of vegetation, which is useful for assessing plant vigor.
3	0.63 to 0.69	Red—coincident with MSS band 5. Matches a chlorophyll absorption band that is important for discriminating vegetation types.
4	0.76 to 0.90	Reflected IR—coincident with portions of MSS bands 6 and 7. Useful for determining biomass content and for mapping shorelines.
5	1.55 to 1.75	Reflected IR. Indicates moisture content of soil and vegetation. Penetrates thin clouds. Good contrast between vegetation types.
6	10.40 to 12.50	Thermal IR. Nighttime images are useful for thermal mapping and for estimating soil moisture.
7	2.08 to 2.35	Reflected IR. Coincides with an absorption band caused by hydroxyl ions in minerals. Ratios of bands 5 and 7 are potentially useful for mapping hydrothermally altered rocks associated with mineral deposits.

NASA | Landsat 8 Onion Skin [HD]

http://www.youtube.com/watch?v=CqRyhun96Po

Conclusions for Rotational Scanners

Have been proven to work reliably at first generation of EO satellites!

But, there are some disadvantages:

- Mechanics (motor) needed
- Maintenance needed (critical on unmanned platforms)
- Worse signal to noise ratio (SNR) compared to photographic acquisitions

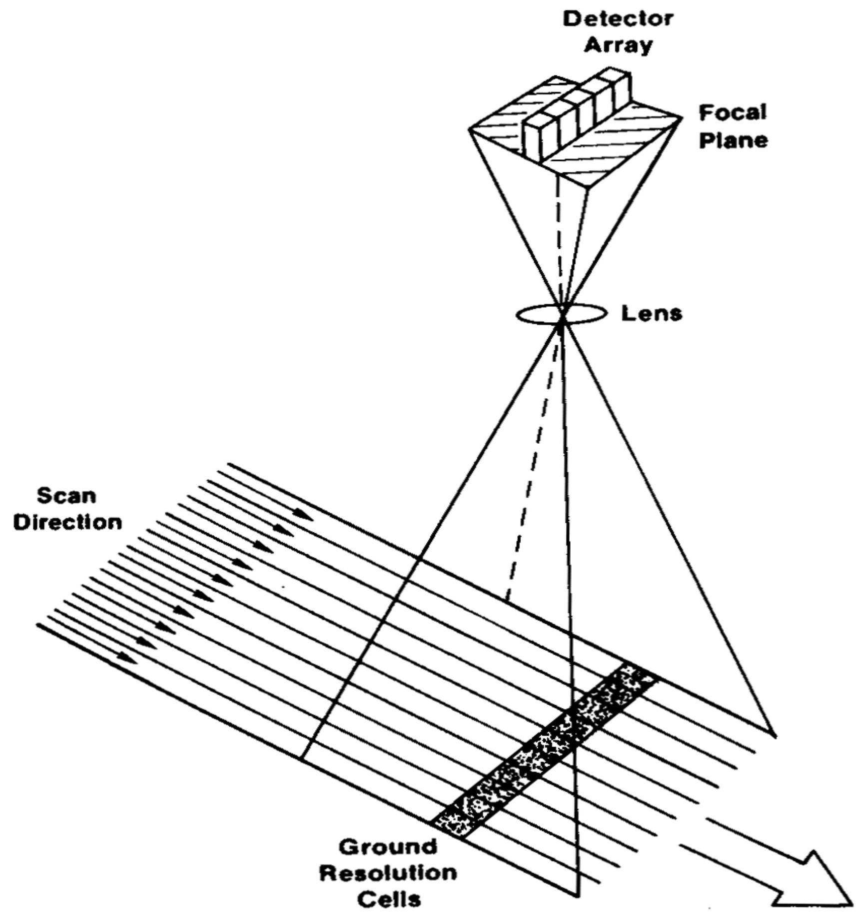
Next development step:

Line-Array Cameras

Zeilenkameras

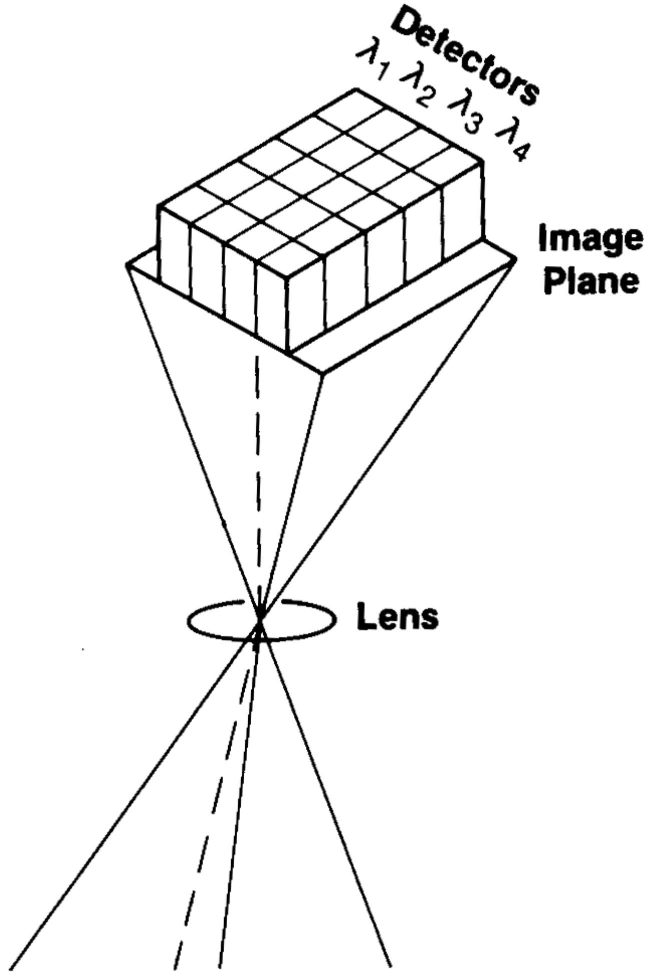
Optoelectronic
Along Track- or Push broom Scanner

- The detector/sensor-array scans a complete line at once
- Sensors mostly: CCD
- Used in current satellites
  - SPOT
  - Ikonos
  - SeaWiFS
  - Aqua & Terra
  - …
- No mechanical parts needed!



Optoelectronic
Along Track Scanner – Multispectral Setup

- The detector/sensor-array scans a complete line for each selected bandwidth
- Array of line arrays needed!
- Still: No mechanical parts needed!
- Similar properties than single channel along track scanners



Optoelectronic
Along Track Scanner – Imaging Resolution

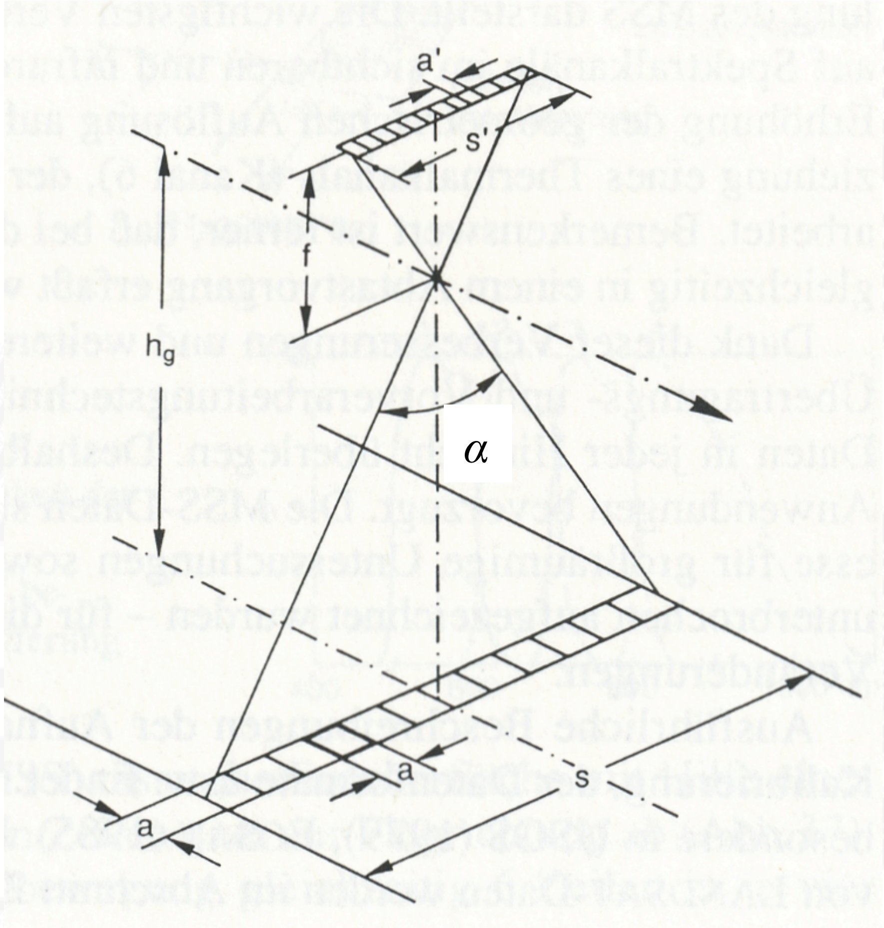
The resolution at ground can be set by the imaging optic:

- f focal length
- h_g (flight) altitude
- α aperture angle

The sensor array remains the same.

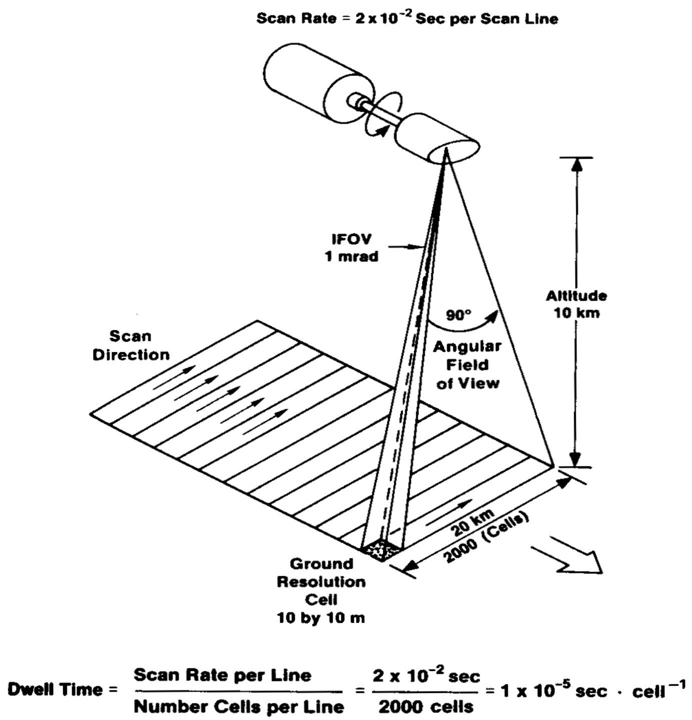
Lower resolutions
→ Larger coverage

Higher resolution
→ Smaller coverage

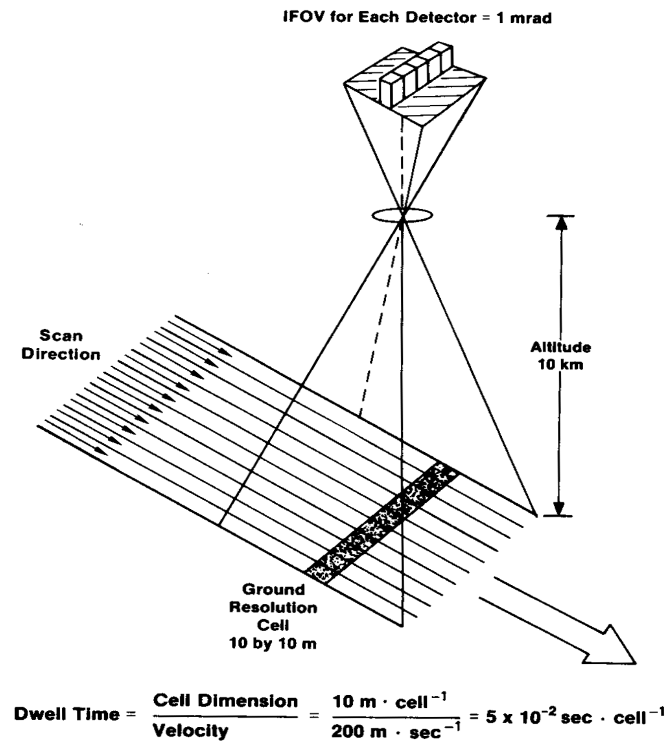


Dwell Time

Verweilzeit



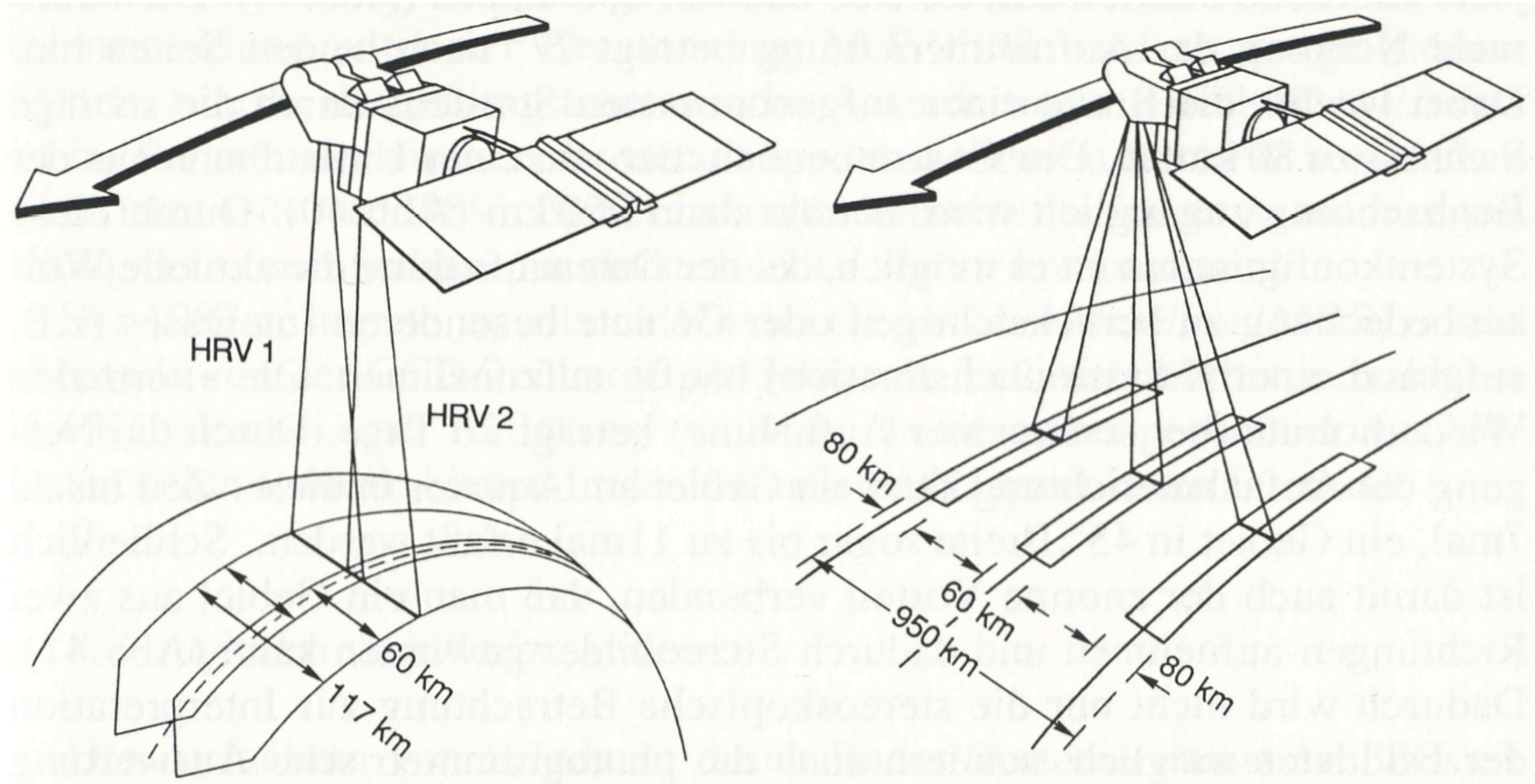
A. CROSS–TRACK SCANNER.



B. ALONG–TRACK SCANNER.

Important for imaging intensity!
An Along Track Scanner allows a larger dwell time at same travelling speed.

Example 1: SPOT – Nadir and Off-Nadir Mode



Example 1: SPOT – Imaging Modes

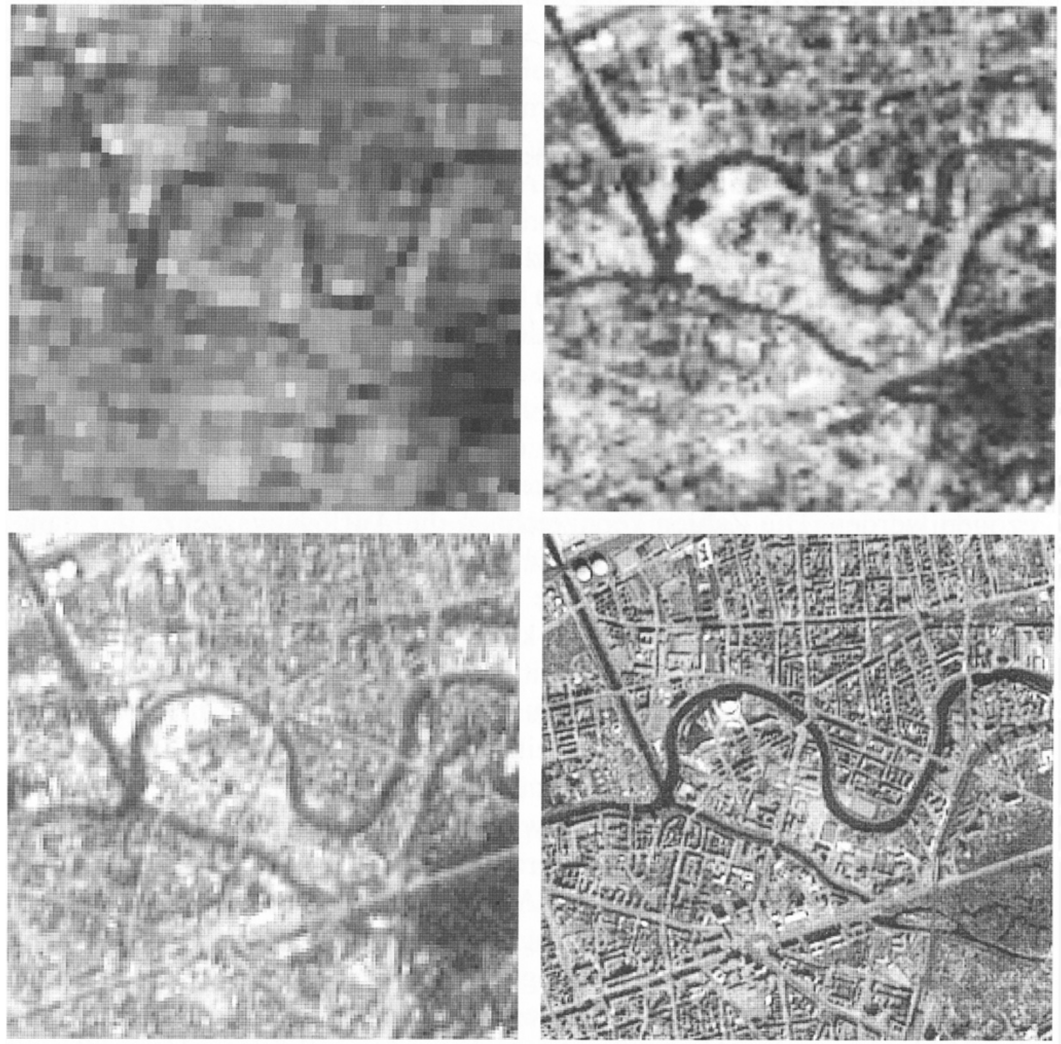
Tabelle 8: Technische Daten der SPOT-Sensoren

	SPOT - HRV (XS-Mode) multispektral	SPOT - HRV (P-Mode) panchromatisch
Betrieb	seit 1986	seit 1986
Flughöhe	832 km	832 km
Wiederholrate	26 Tage*	26 Tage*
Pixelgröße	20×20 m²	10×10 m²
Bildformat	60×60 km²	60×60 km²
Spektralkanäle	1 0,50 - 0,59 µm 2 0,61 - 0,69 µm 3 0,79 - 0,89 µm	0,51 - 0,73 µm

* Durch Neigung der Aufnahmerichtung kann ein bestimmtes Gebiet gezielt wesentlich häufiger aufgenommen werden

Stereo Imaging via large inclination angle and multiple visits!

Example 1: SPOT – Resolution Comparison (Berlin)



Landsat MSS
(80 m)

Landsat TM
(30 m)

SPOT multi spectral
(20 m)

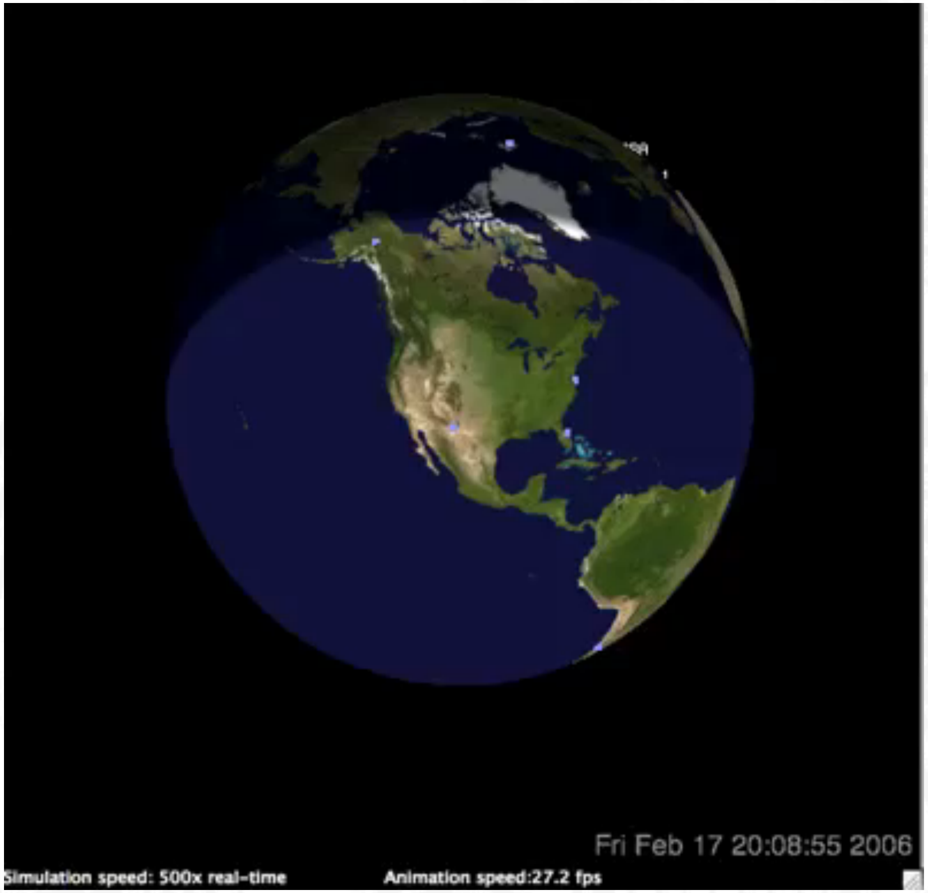
SPOT panchromatic
(10 m)

Example 2: Terra & Aqua

- After successful test with the experimental EO-1 satellite: Two Earth Observation satellites
- Orbit: Landsat-7 (temporal displaced!)
- Equator crossing:
  - Terra: 10:30 h
  - Aqua: 22:30 h
- Synonyms:

Terra: EOS am

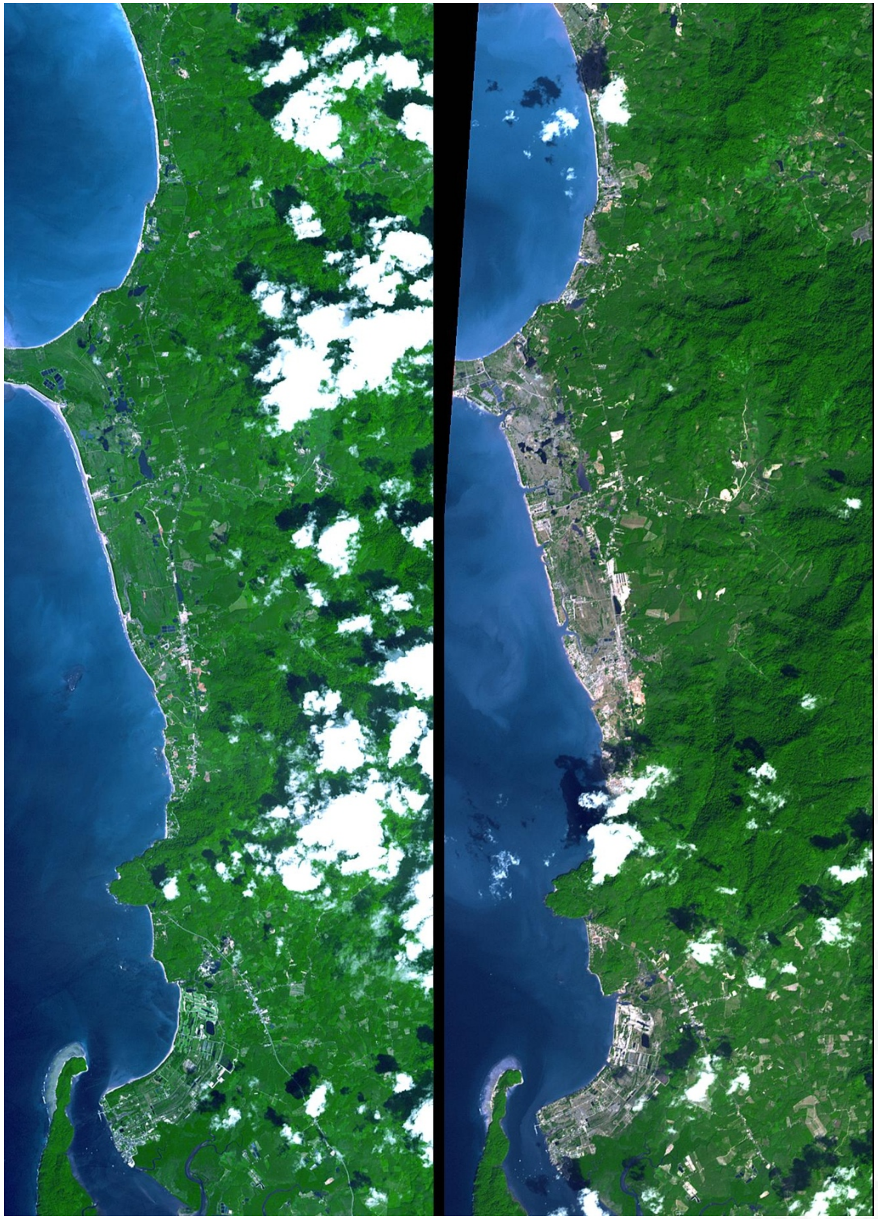
Aqua: EOS pm



Example 2: Terra & Aqua – Spectral Sensors

Table A.15. Aqua and Terra sensor characteristics

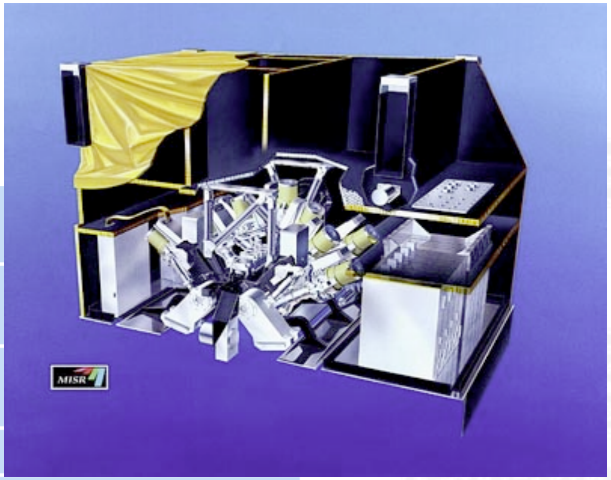
Instrument	Spectral Bands (µm)	IFOV (m)	Swath (km)	Dynamic Range (bits)
MODIS*	0.620–0.670	250 × 250	2330	12
	0.841–0.876	250 × 250	2330	12
	0.459–2.155 (5 bands)	500 × 500	2330	12
	0.405–14.385 (29 bands)	1000 × 1000	2330	12
ASTER	0.52–0.60	15 × 15	60	8
	0.63–0.69	15 × 15	60	8
	0.76–0.86	15 × 15	60	8
	0.76–0.86 (backward looking)	15 × 15	60	8
	1.600–1.700	30 × 30	60	8
	2.145–2.185	30 × 30	60	8
	2.185–2.225	30 × 30	60	8
	2.235–2.285	30 × 30	60	8
	2.295–2.365	30 × 30	60	8
	2.360–2.430	30 × 30	60	8
	8.125–8.475	90 × 90	60	12
	8.475–8.825	90 × 90	60	12
	8.925–9.275	90 × 90	60	12
	10.250–10.950	90 × 90	60	12
	10.950–11.650	90 × 90	60	12



Example 2: Terra ASTER at Phuket

- Images before and after the Tsunami 2004/12
  - 2002/11/15 (left)
  - 2004/12/31
- Data resolution: 15 m
- Image composed from ASTER bands
  - 3: Red
  - 2: Green
  - 1: Blue

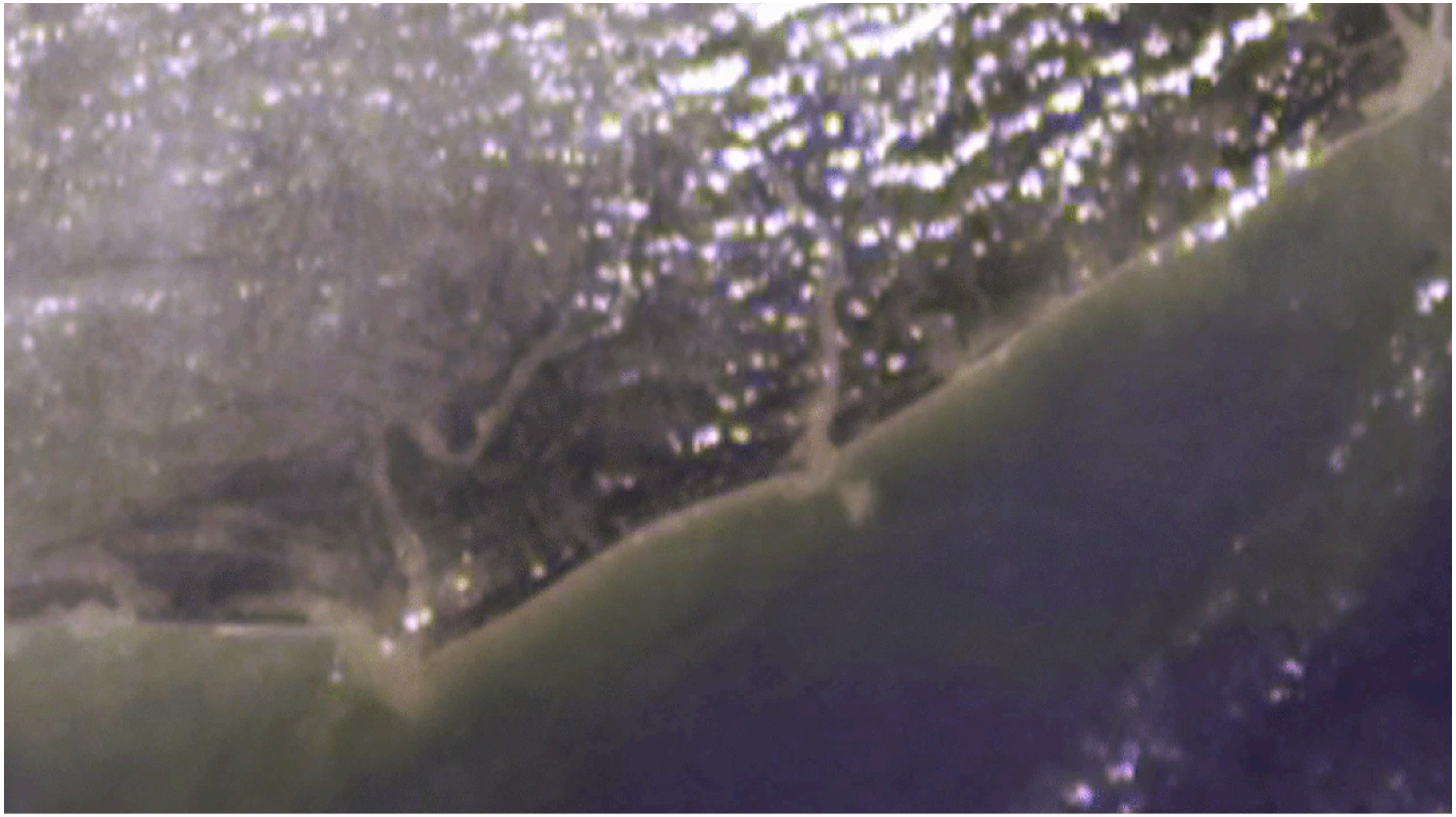
Example 2: Terra MISR Instrument



Mission life:	6 years
Instrument mass:	148 kg
Instrument power:	Approximately 117 W peak, 75 W average
Data rate:	3.3 Megabits/second average, 9.0 Megabits/second peak
Global coverage time:	Every 9 days, with repeat coverage between 2 and 9 days depending on latitude
Crosstrack swath width:	360 km common overlap of all 9 cameras
Nine pushbroom cameras:	Named An, Af, Aa, Bf, Ba, Cf, Ca, Df, and Da where fore, nadir, and aft viewing cameras have names ending with letters f, n, a respectively and four camera designs are named A, B, C, D with increasing viewing angle respectively
View angles:	0, 26.1, 45.6, 60.0, and 70.5 degrees
Spectral coverage:	4 bands (blue, green, red, and near-infrared)
Detectors:	Charge Coupled Devices (CCDs), each camera with 4 independent line arrays (one per filter), 1504 active pixels per line
Radiometric accuracy:	3% at maximum signal
Detector (focal plane) temperature:	-5 ±0.1 degrees C (cooled by thermo-electric cooler)
Temperature of main structure:	+5 degrees C
Builder:	Jet Propulsion Laboratory, Pasadena, California, U.S.A.

Source: http://www-misr.jpl.nasa.gov/Mission/misrInstrument/

Example 2: Terra MISR Demo



26 December 2004, Beach of Andhra Pradesh, close to the Godavari River Mouth
Cloud "motion" results from apparent displacements due to parallax associated with their height.

Current Optical Satellite Image Resolutions

Commercially available images (Source: http://mirgeospatial.com, 2014)

	GeoEye-1	WorldView-1	WorldView-2	Pleiades	QuickBird	IKONOS
Resolution	0.5m	0.5m	0.5m	0.5m [2]	0.6 m	1 m
Dynamic Range	8 or 16 bits	8 or 16 bits	8 or 16 bits	8 or 16 bits	8 or 16 bits	8 or 16 bits
Product Type	Panchromatic PanSharpened Multispectral Bundle	Panchromatic	Panchromatic PanSharpened Multispectral Bundle	Panchromatic PanSharpened Multispectral Bundle	Panchromatic PanSharpened Multispectral Bundle	Panchromatic PanSharpened Multispectral Bundle
Agility	Very/Stereo	Very/Stereo	Very/Stereo	Very/Stereo	Limited	Very/Stereo
	Multi-scan	Multi-scan	Multi-scan	Multi-scan	Single Scan	Multi-scan
Image Accuracy Specification [1]	5 m (CE90)	5 m (CE90)	5 m (CE90)	5 m (CE90)	23 m (CE90)	15 m (CE90)

[1] At nadir, exclusive of terrain distortions
[2] Commercial product is being interpolated and resampled to 50cm (Original Panchomatic: 70cm, Multispectral: 2 m)

Note that in general:

Res. Military < Res. Commercial < Res. Public avail. (e.g. Landsat)

Task-dependent Minimum Image Resolution

- Johnson's experiments distinguish between:
  1. Discover Object
  2. Classify Object
  3. Identify Object
- Example: Tank Detection

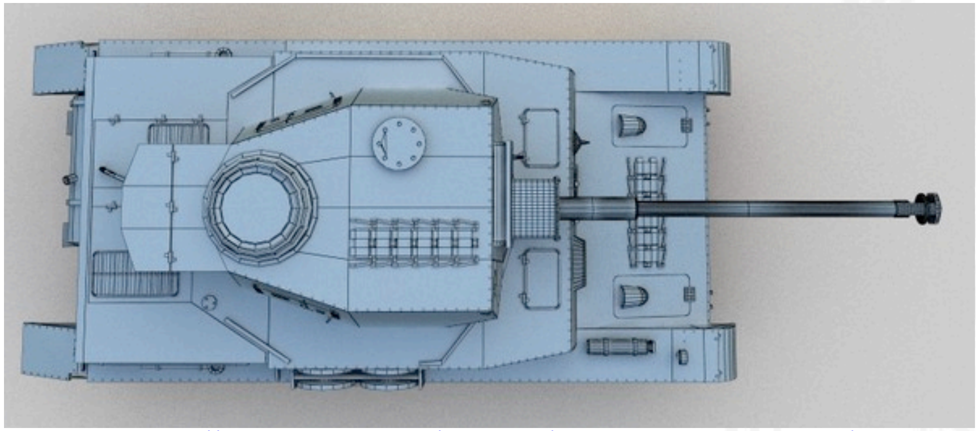
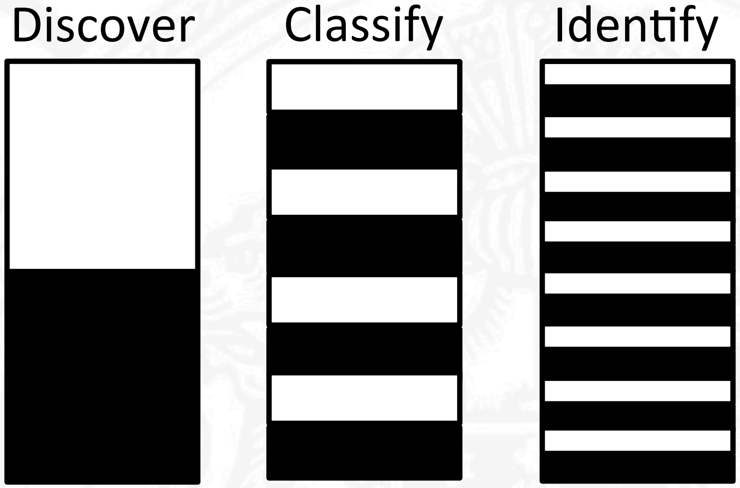


Image source: http://www.turbosquid.com/3d-models/german-2-tank-panzer-iv-max/716550



Photography vs. Scanning Imagery

- Aircrafts:
  - Photography still results in highest resolutions.
  - Analogue Cameras are replaced by CCD Cameras.
  - Aircrafts are replaced by unmanned “drones”.
- Satellites:
  - Scanning Systems are the systems of choice and are transmitted while or after acquisition.
  - Resolution of scanner images is comparable to photographic images.
  - Nowadays: Along-Track (Push broom) Scanner and special sensor setups (see Terra MISR).