Introduction to space based remote sensing

Dipl.- Ing. Walter Ballheimer

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Remote Sensing

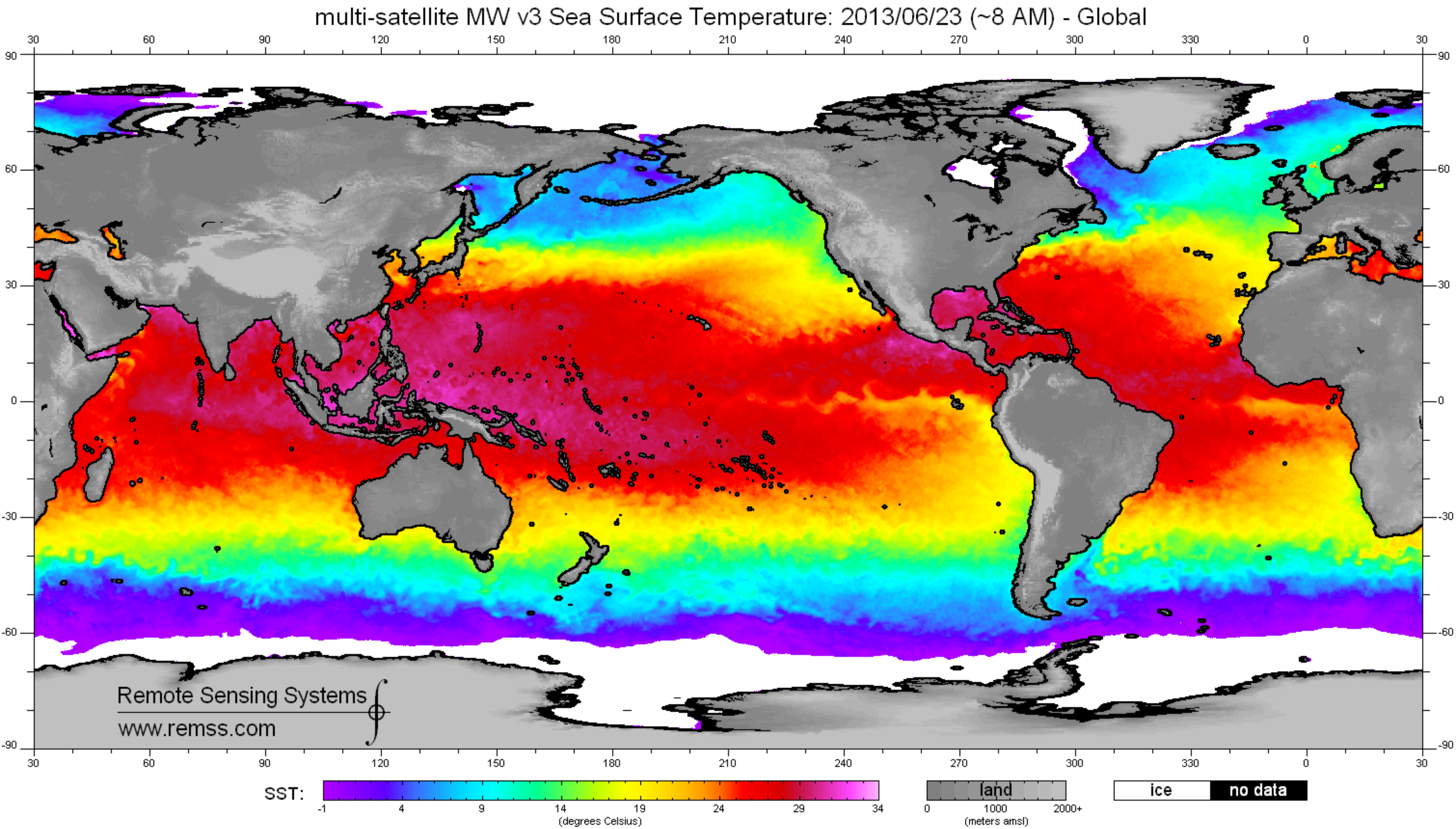
Remote sensing is the science of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. [1]

Дистанционное Зондирование

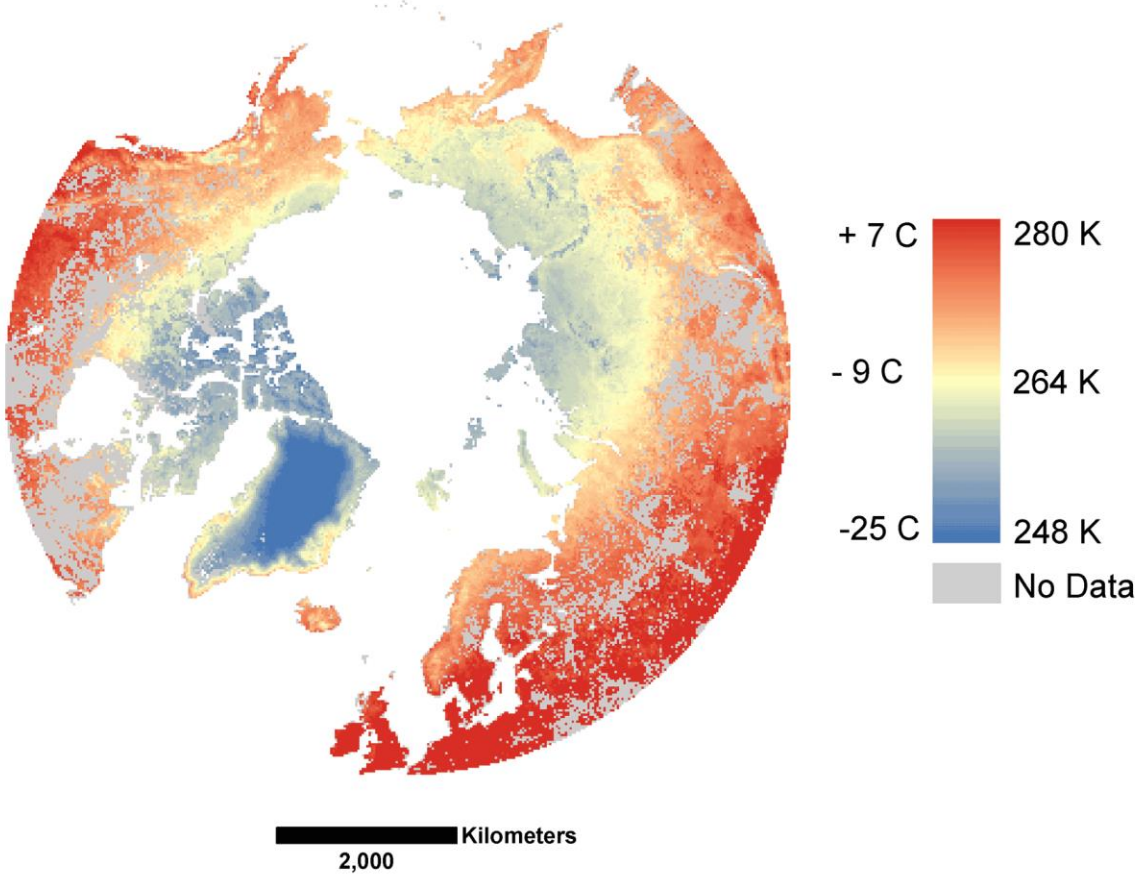
Дистанционное зондирование это наука о получении информации о состоянии поверхности земли, без прямого контакта с ней. Зондирование осуществляется с помощью детектирования отраженного или эмитированного электромагнитного излучения а также записи, обработки и анализа полученных данных.

Examples of Remote Sensing Products and Sensors

- Sea Surface Temperatures (SST)
- Earth Surface Temperatures (EST) Monitoring: e.g. permafrost soils (MODIS)
- Altimetry (CryoSat)
- Precise optical information (e.g. SPOT)


multi-satellite MW v3 Sea Surface Temperature: 2013/06/23 (~8 AM) - Global
Remote Sensing Systems
www.remss.com
SST:
(degrees Celsius)
land
(meters amsl)
ice
no data

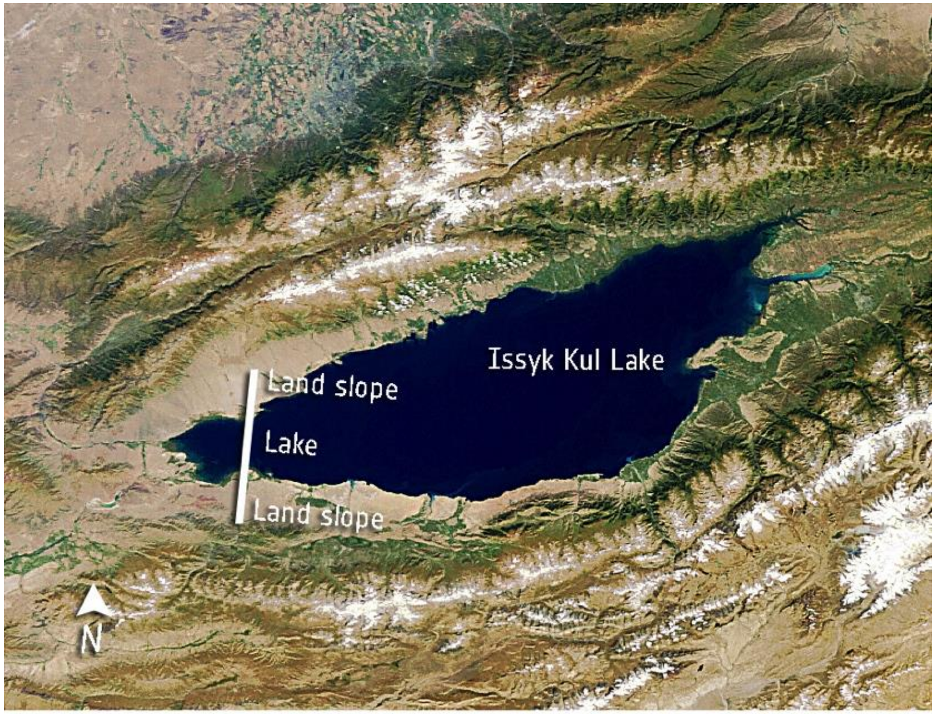
Mean Annual Surface Temperature of AATSR (Year 2005)

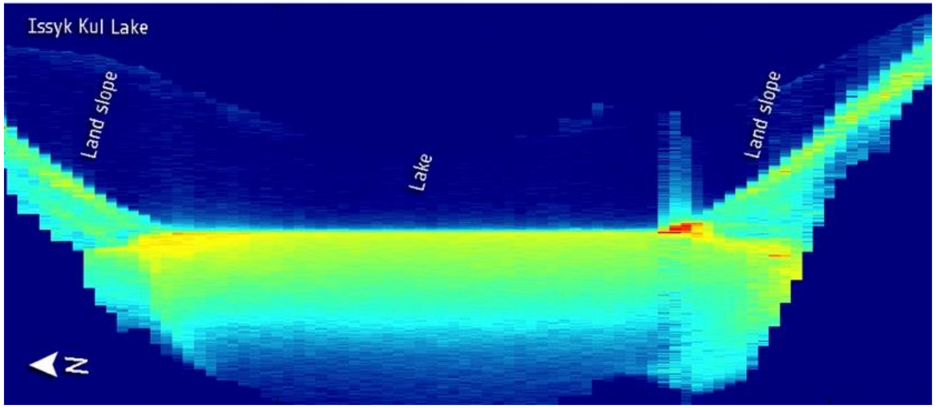


mean annual surface temperature is calculated with a minimum of 10 months.

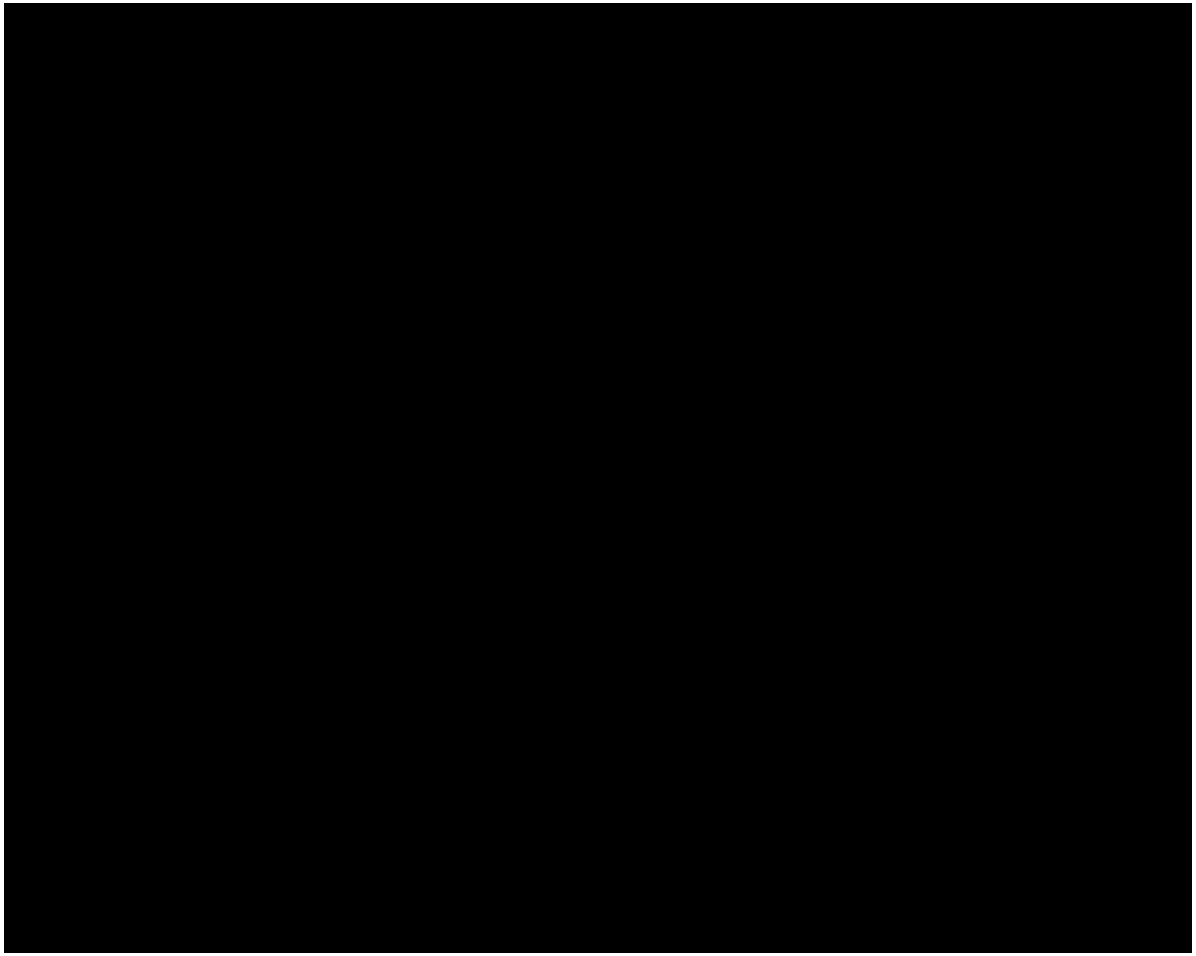
CryoSat Altimeter

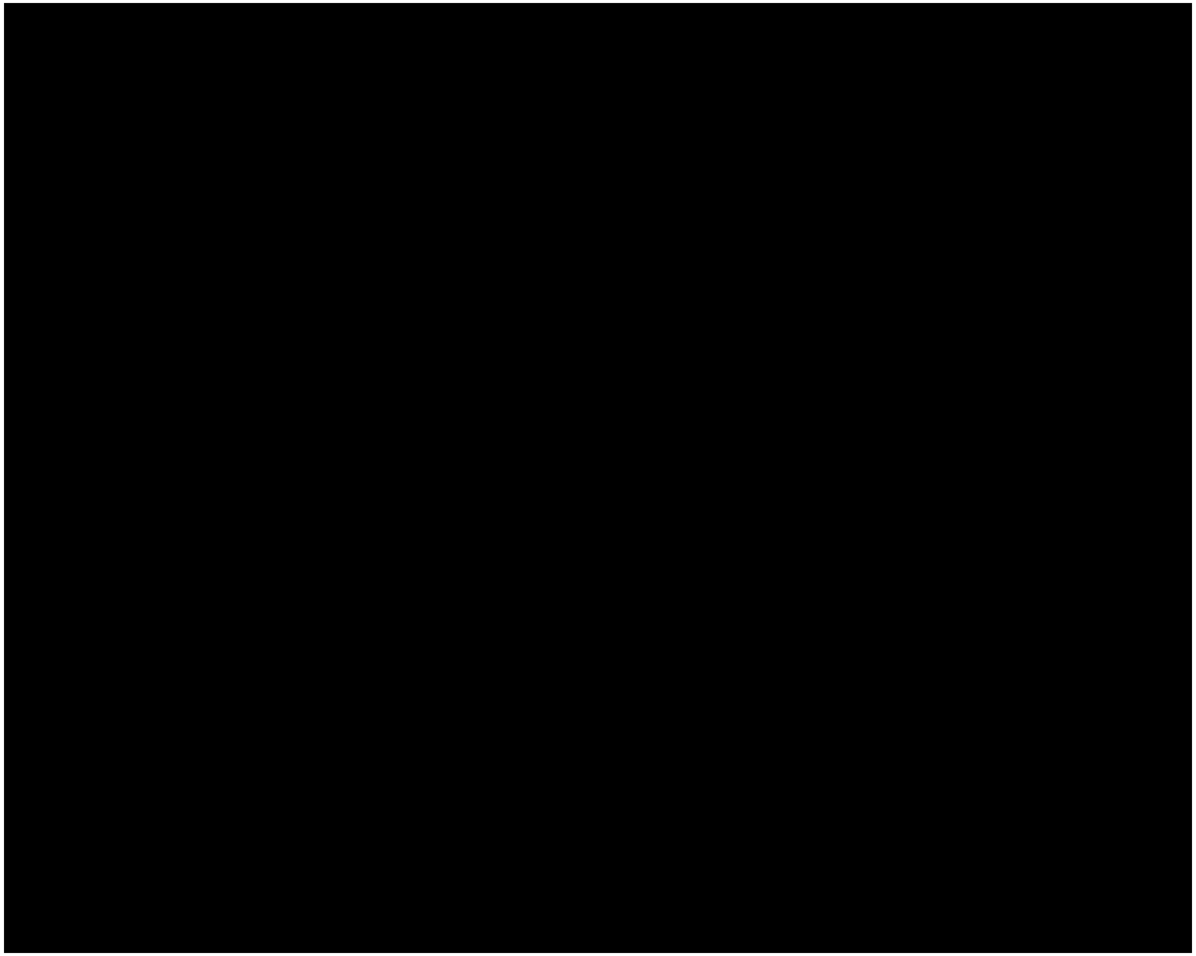
- Radar altimeter SIRAL
- Vertical resolution of 3 cm
- Horizontal res. 300 m
- Signal-rate 50 µs
- Different operating modes for different surfaces

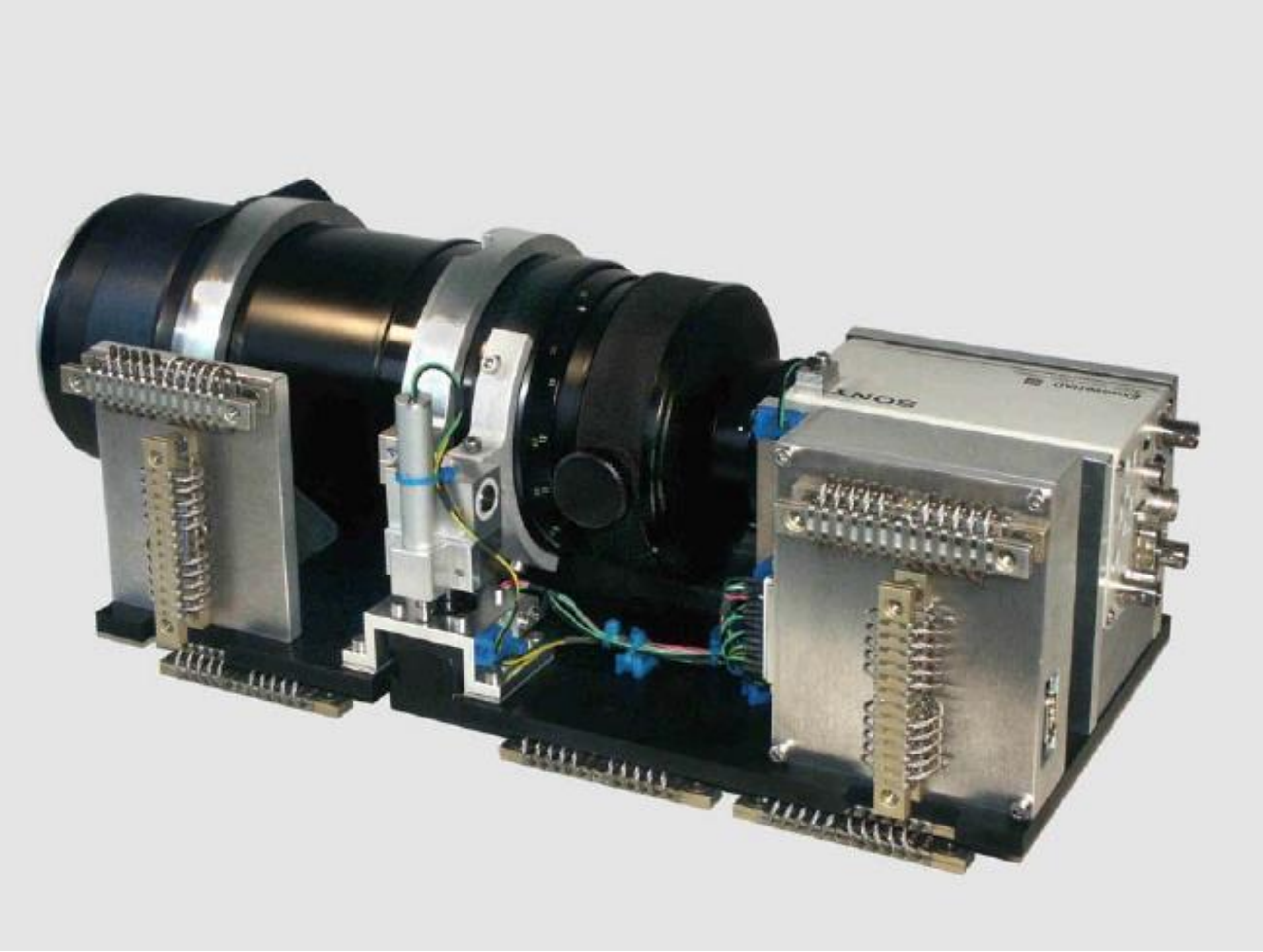


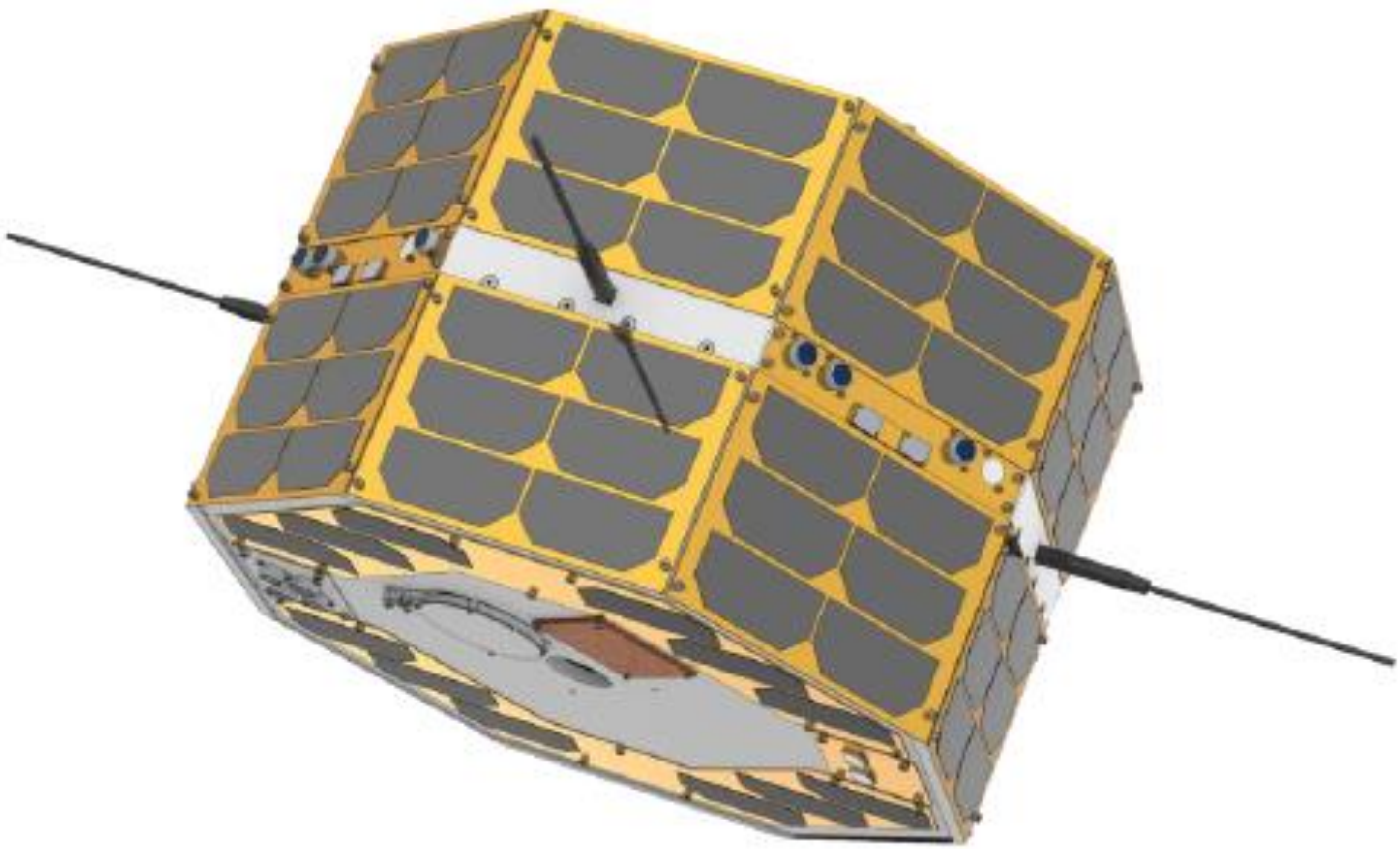


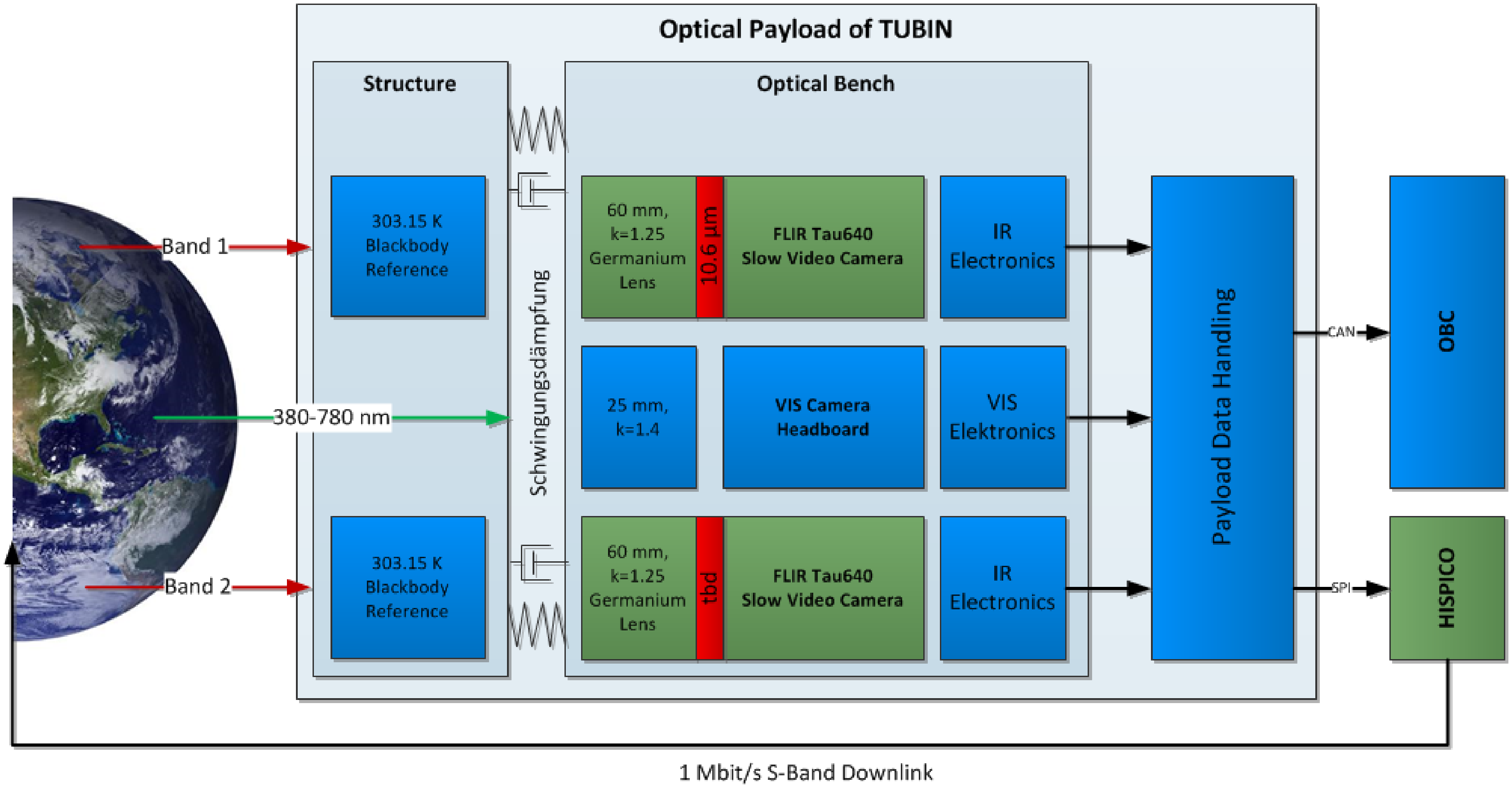

Îles Fidji
AIRBUS

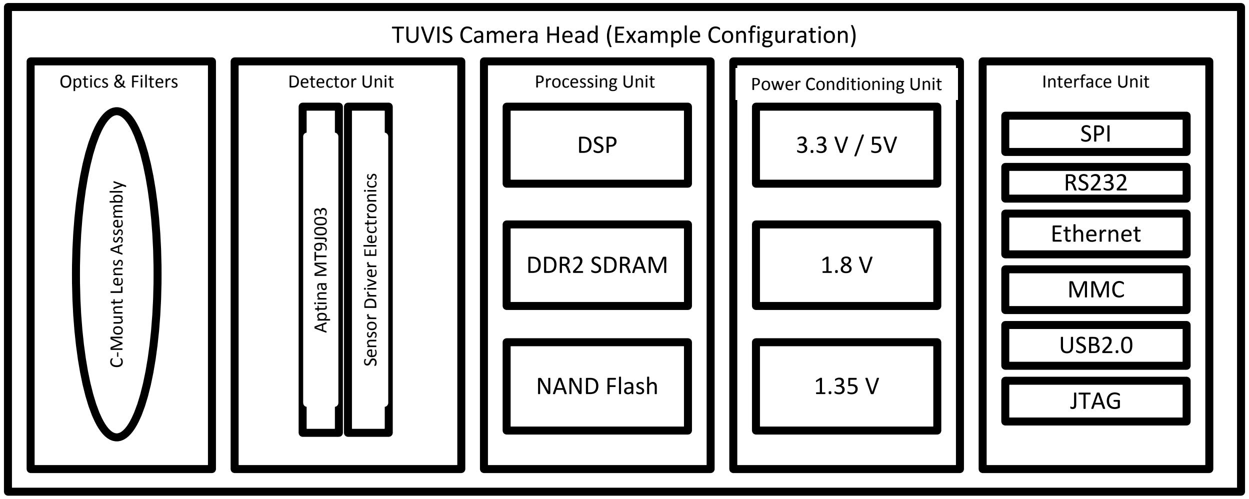


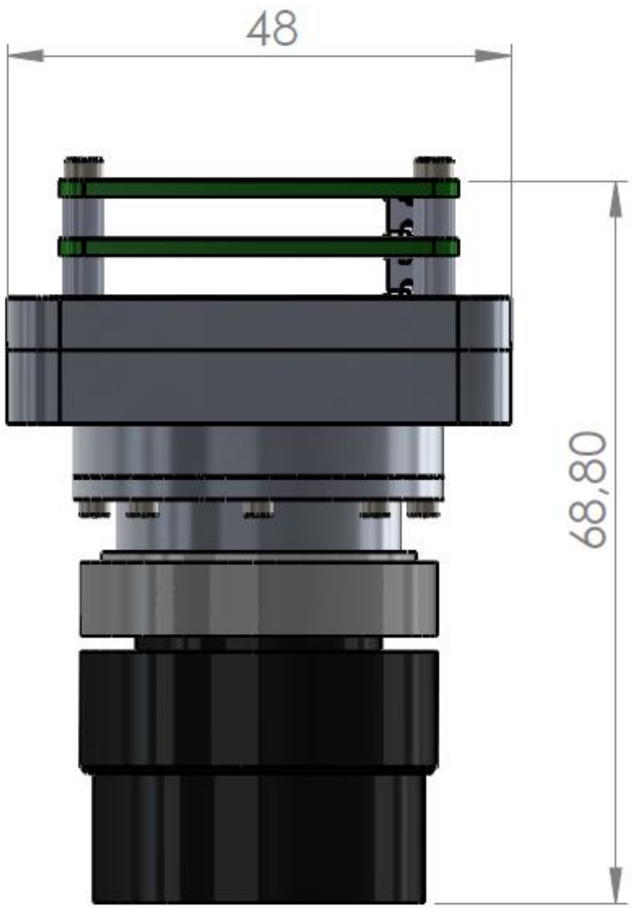


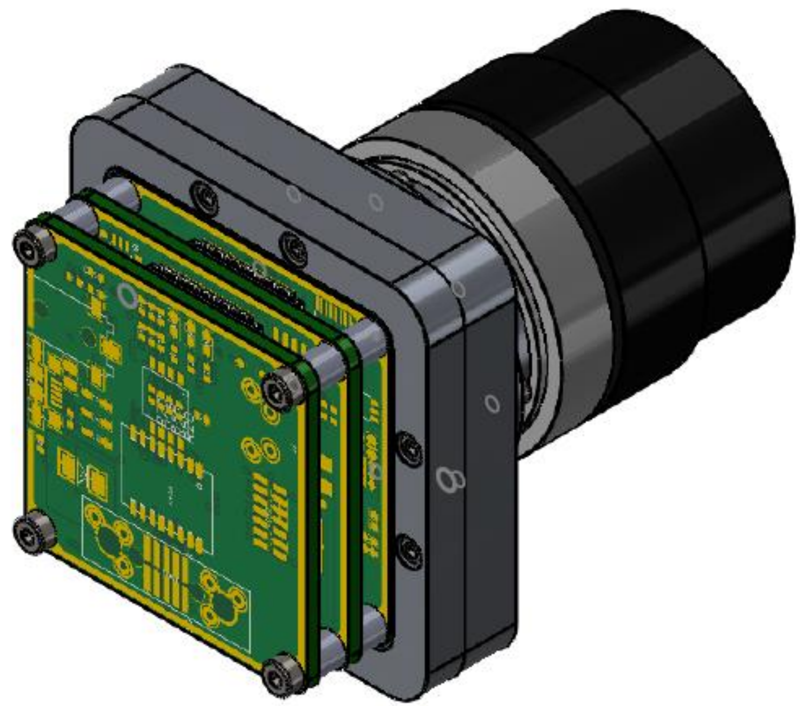




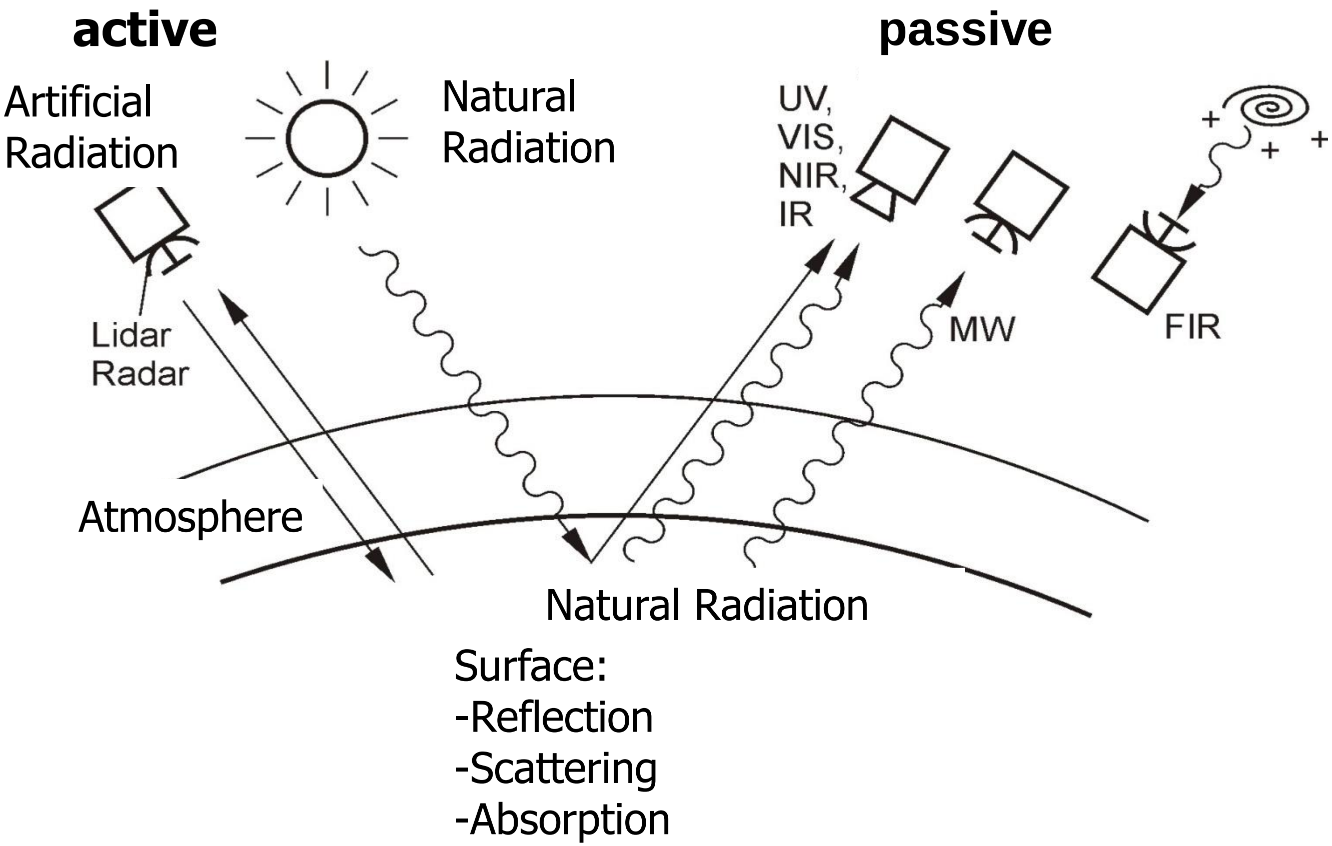

Optical Payload of TUBIN
Structure
Optical Bench
Band 1
303.15 K Blackbody Reference
60 mm, k=1.25 Germanium Lens
10.6 µm
FLIR Tau640 Slow Video Camera
IR Electronics
380-780 nm
Schwingungsdämpfung
25 mm, k=1.4
VIS Camera Headboard
VIS Elektronics
Payload Data Handling
CAN
OBC
Band 2
303.15 K Blackbody Reference
60 mm, k=1.25 Germanium Lens
tbd
FLIR Tau640 Slow Video Camera
IR Electronics
SPI
HISPICO
1 Mbit/s S-Band Downlink


TUVIS Camera Head (Example Configuration)
Optics & Filters
C-Mount Lens Assembly
Detector Unit
Aptina MT9J003
Sensor Driver Electronics
Processing Unit
DSP
DDR2 SDRAM
NAND Flash
Power Conditioning Unit
3.3 V / 5V
1.8 V
1.35 V
Interface Unit
SPI
RS232
Ethernet
MMC
USB2.0
JTAG


48
68,80



Active and passive remote sensing systems

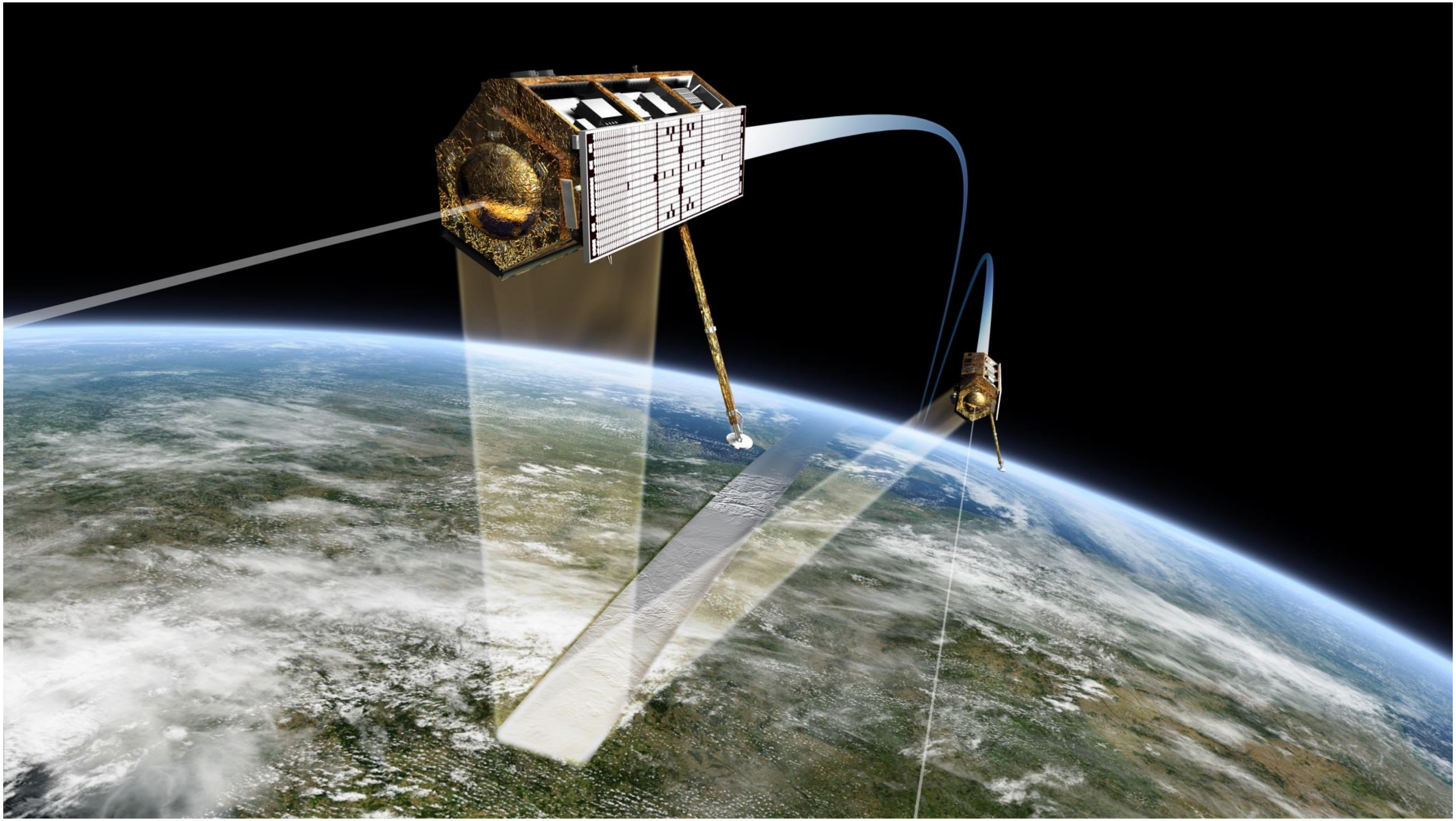


Passive Systems

- Can only detect and measure radiation parameters
- Examples: cameras, spectrometer, radiometer, polarimeter, microwave receiver

Active Systems

- detect and measure self generated electromagnetic radiation, reflected by the target
- Examples: LIDAR – **Li**ght **D**etection **a**nd **R**anging, SAR – **S**ynthetic **A**perture **R**adar



4 Parts of the Remote Sensing Problem

1. Radiation Source
2. Atmosphere (clouds, aerosols, humidity, temperature)
3. Object of measurement (Transmission, Absorption, Reflection, Emission)
4. Instrument, Sensor

Depending on the scenario, one has to distinguish between the **direct** and the **inverse** remote sensing problem.

Direct and Inverse Remote Sensing Problem

To predict sensor output, caused by a certain parameter of a target, a precise knowlege of the transmission pass is mandotory. This problem is refered to as the direct remote sensing problem.

To determine accurate parameters of a distant surface only relying on sensor data, complex calculations are needed. Here we talk about the inverse remote sensing problem.

Direct Remote Sensing Problem

Numerical calculation of sensor signal
$U_S = \boldsymbol{f}\,[L_S(h,\theta)]$

Calculation of in-orbit Radiance $\boldsymbol{L_S}$ with FOV θ
$L_S(h,\theta)=\boldsymbol{f}\,[L(0)]$

Calculation of Radiance $\boldsymbol{L}$ of the surface in height $h=0$ →
$L(0)=\boldsymbol{f}\,(a_1,a_2)$
a_2 – *Imaging Parameters*

Determination of surface parameter, here a_1

Inverse Remote Sensing Problem

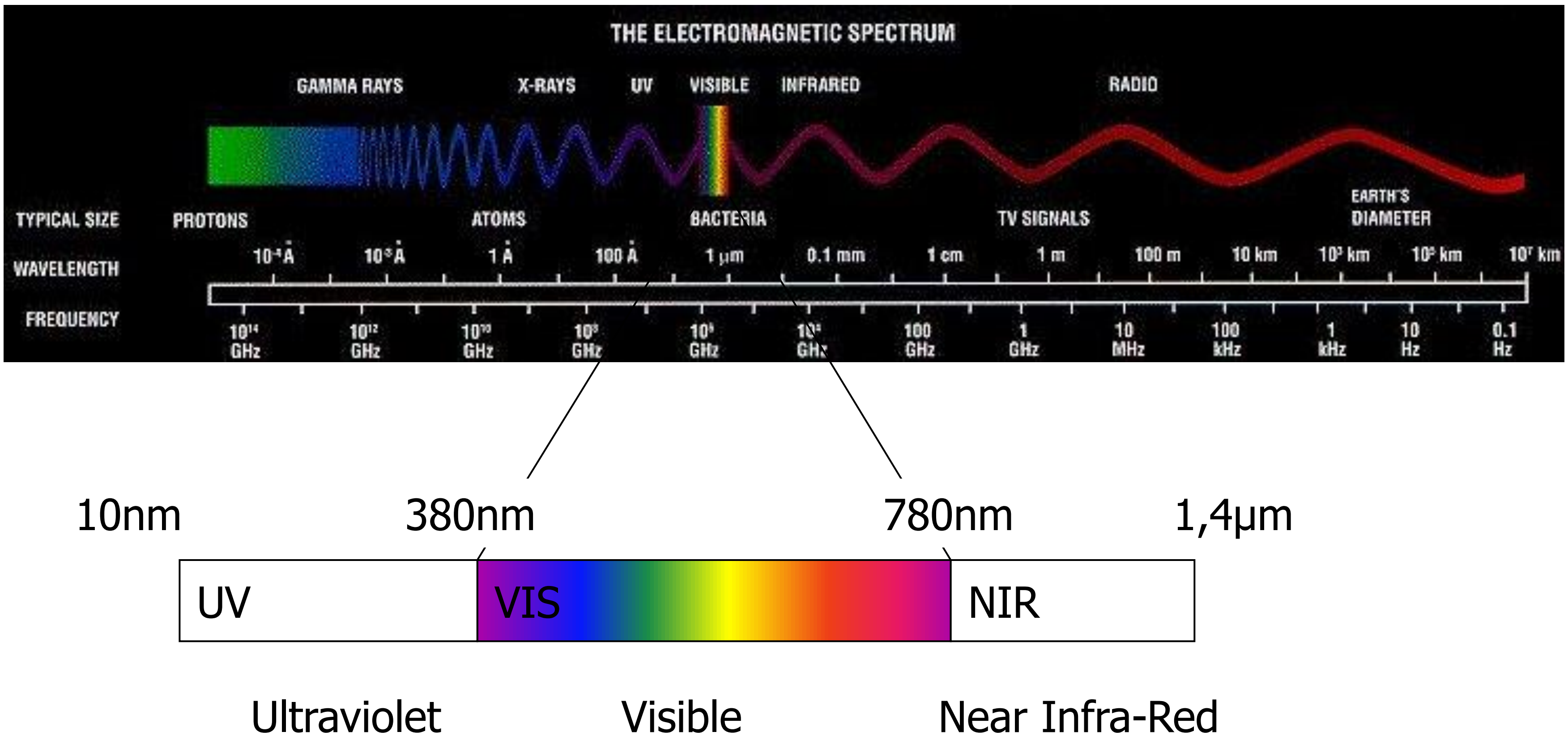
Calibration of the sensor Signal
$L_S(h,\theta)]=\boldsymbol{g}\,(U_S)$

Atmospherical correction and determination of on-surface radiance
$L(0)=\boldsymbol{g}\,[L_S(h,\theta)]$

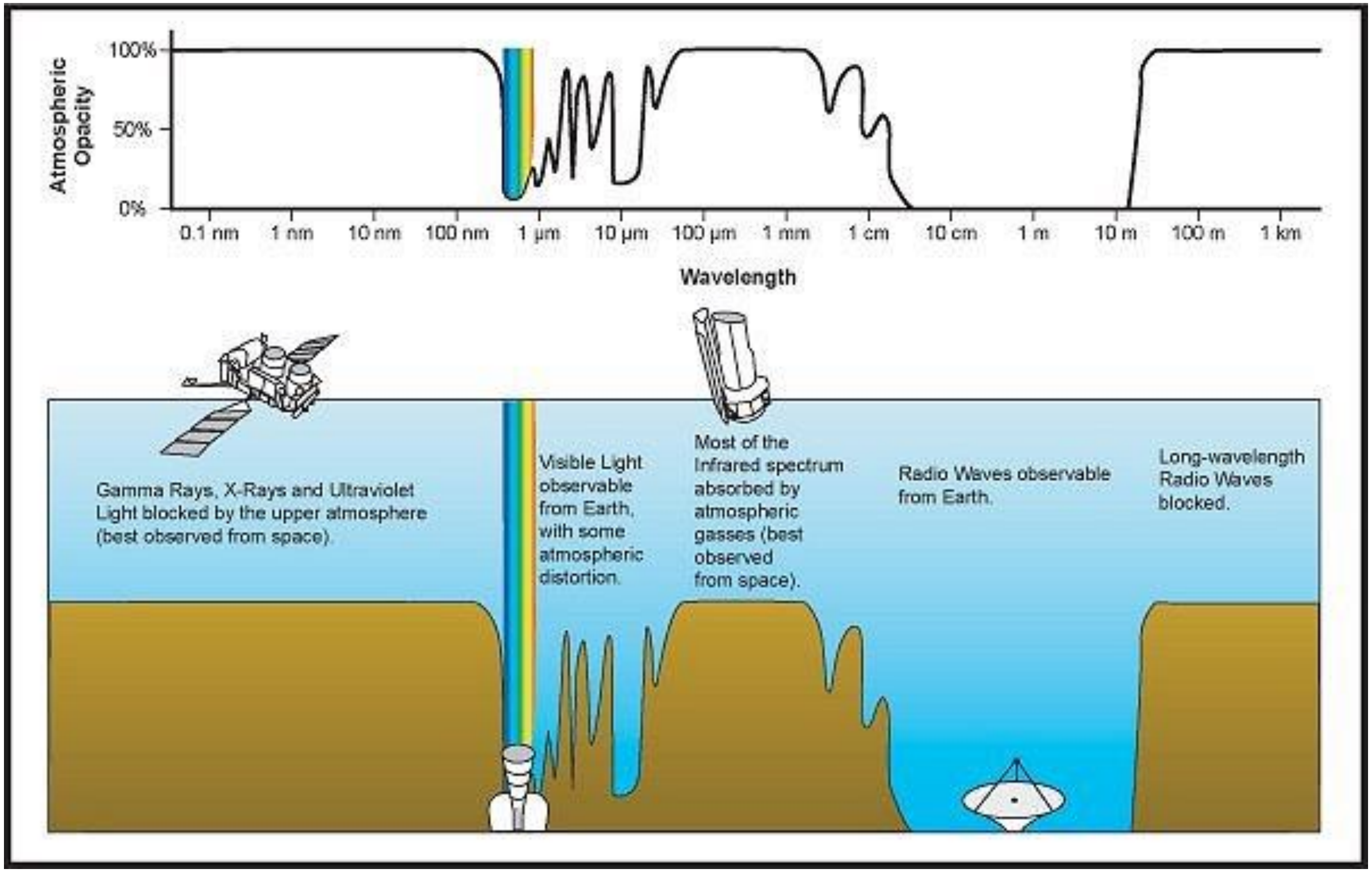
Radiometrical exclusion of the radiation source
$r=\boldsymbol{g}\,[L(0)]$
= *radiative surface parameter*

Calculation of the characteristic surface parameter $a_1=\boldsymbol{g}\,(r,a_2)$

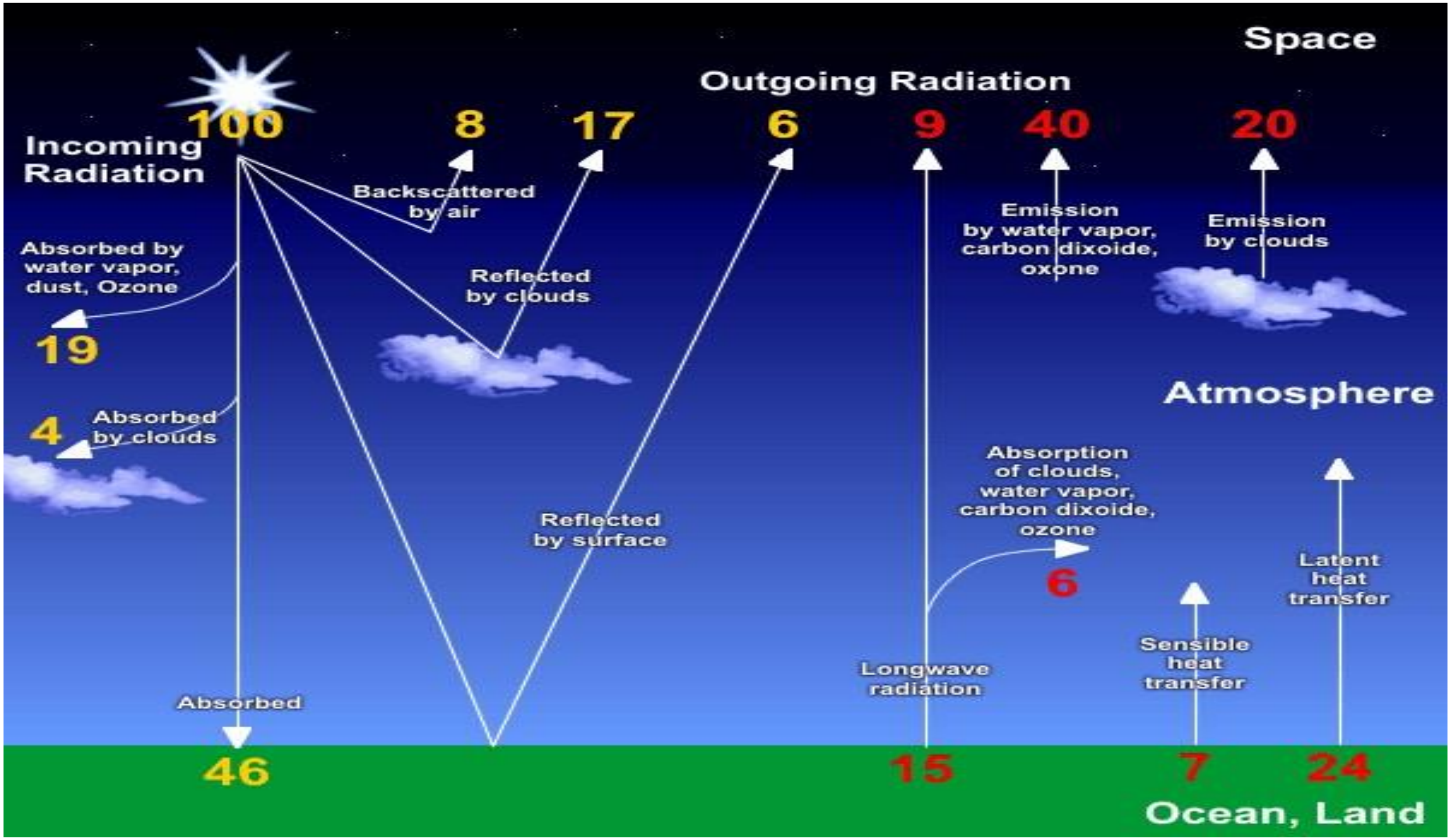
The Electromagnetic Spectrum



Atmospheric Windows



Modelling the Atmosphere



Fundamentals of remote sensing: Radiometric Terms

Radiant Flux *Φ*

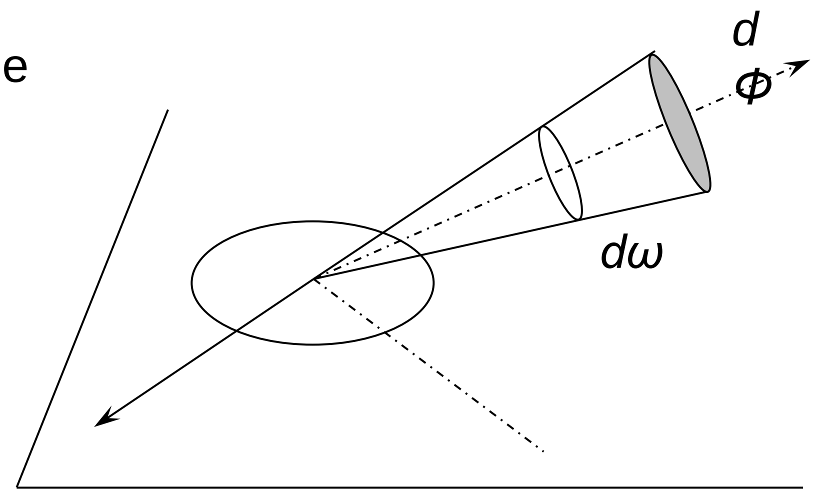
Φ = radiated energy flux through an area per time unit with Q = radiated energy

$$\Phi = \frac{dQ}{dt}\left[W\right] \qquad Q = \int_{T_{\text{int}}} \Phi dt \left[J, Ws\right]$$

Radiant Intensity I

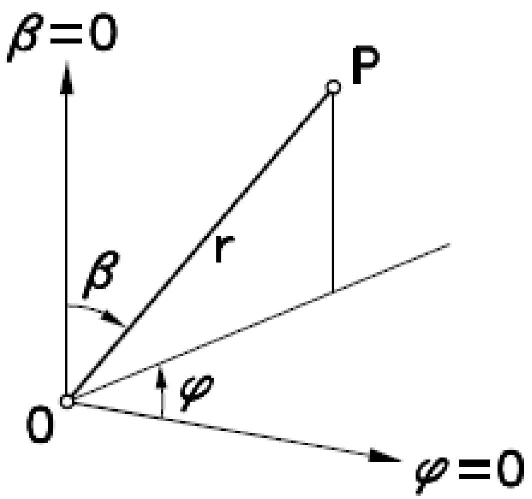
I = Radiant flux emitted per unit solid angle

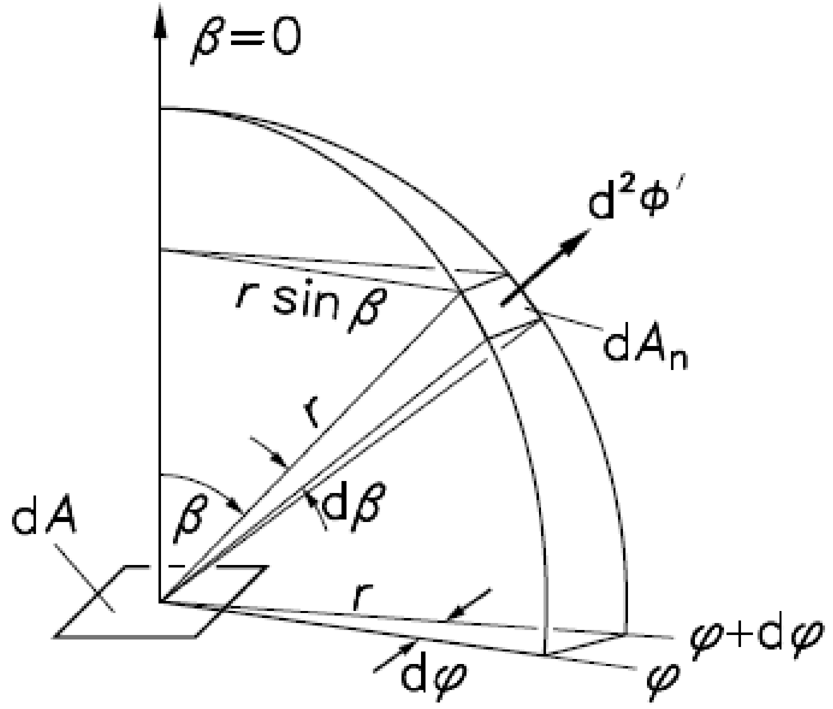
$$I = \frac{d\Phi}{d\omega}\left[\frac{W}{sr}\right] \qquad \Phi = \int_{\omega} I \, d\omega \left[W\right]$$



Area of a sphere = 4πr²
Solid angle of a complete sphere = 4π

Solid angle





- *Radiant Emmitance* ***M(T)***
    - Hemispherical term
    - Sums up all emitted energy by a unit area
    - SI-Unit: W/m^2

- *Spectral Radiant Exitance* $\boldsymbol{M_\lambda(\lambda,T)}$
  - Hemispherical spectral term
  - Describes the wavelength-dependence of the energy emitted into the hemisphere
  - SI-Unit: $\frac{W}{m^2\ \mu m}$

- *Radiance* ***L(β,φ,T)***
  - Directional term
  - Describes the distribution of radiated energy over the directions of the hemisphere
  - SI-Unit: $\frac{W}{m^2\ sr}$

- *Spectral Radiance* $\boldsymbol{L_\lambda(\lambda,\beta,\varphi,T)}$
  - Directional spectral term
  - Describes the distribution of the radiated flux over the spectrum of wavelengths and angles of the hemisphere
  - SI-Unit: $\frac{W}{m^2\ \mu m\ sr}$

The dependence of radiated energy from wavelength and direction has to be taken into account when solving radiation exchange problems

To simplify calculation, additional radiometric terms are introduced for emitter and reciever. There are four types of terms.

- *Directional spectral terms*
- *Hemispherical spectral terms*
- *Directional terms*
- *Hemispherical terms*

- *Directional spectral terms*
  - Describe the distribution of radiated energy in dependence of direction and wavelength
  - Of fundamental importance, but difficult to calculate or to measure

- *Hemispherical spectral terms*
  - Sum up the radiated energy of all directions of a hemisphere over a unit area
  - Only depending on wavelength

- *Directional terms*
    - Sum up the radiated energy over all wavelengths
    - Only depending on direction

- *Hemispherical terms*
    - Sum up the radiated energy over all directions and wavelengths
    - Enough to solve simple problems

The terms introduced above are connected to eachother by means of integration. Every type can be calculated from the fundamental directional spectral term.

$$L_\lambda(\lambda, \beta, \varphi, T)$$

spectral radiance

$$M_\lambda(\lambda, T) = \int_{\frown} L_\lambda(\lambda, \beta, \varphi, T) \cos\beta \, \mathrm{d}\omega$$

Spectral radiant exitance

$$L(\beta, \varphi, T) = \int_0^\infty L_\lambda(\lambda, \beta, \varphi, T) \, \mathrm{d}\lambda$$

Radiance

$$M(T) = \int_0^\infty M_\lambda(\lambda, T) \, \mathrm{d}\lambda$$

Radiant exitance

$$M(T) = \int_{\frown} L(\beta, \varphi, T) \cos\beta \, \mathrm{d}\omega$$

Radiant exitance

If there is no medium between the radiation source and the receiver, which absorbs, scatters or emits radiation, the spectral radiance of the source remains unchanged and is therefore equal to the spectral irradiance per unit angle at the receiving surface

$$L_\lambda(\lambda, \beta, \varphi, T) = K_\lambda(\lambda, \beta', \varphi')$$

- *In complete analogy to the emitter side of the problem, the terms on the receiver side can be defined as follows*
  - Spectral Irradiance per Unit Angle *(directional spectral term)*
  - Spectral Irradiance *(hemispherical spectral term)*
  - Irradiance per Unit Angle *(directional term)*
  - Irradiance*(hemispherical term)*

$$K_\lambda(\lambda, \beta, \varphi)$$

Spectral Irradiance per Unit Angle

$$E_\lambda(\lambda) = \int_{\frown} K_\lambda(\lambda, \beta, \varphi) \cos\beta \,\mathrm{d}\omega$$

Spectral Irradiance

$$K(\beta, \varphi) = \int_0^\infty K_\lambda(\lambda, \beta, \varphi) \,\mathrm{d}\lambda$$

Irradiance per Unit Angle

$$E = \int_0^\infty E_\lambda(\lambda) \,\mathrm{d}\lambda$$

Irradiance

$$E = \int_{\frown} K(\beta, \varphi) \cos\beta \,\mathrm{d}\omega$$

Irradiance

Exersise 1

Calculate the solar constant (incident radiant flux density) above the atmosphere

- *Temperature of the sun:* *T = 5777 K*
- *Distance:* *r = 1AU = 149597870691 m*
- *Radius of the sun:* *r = 696000 km*

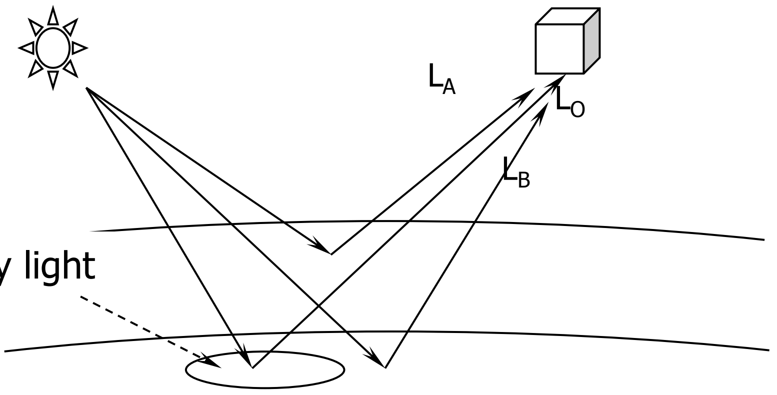
…первые фотоснимки поверхности земли были сделаны французским фотографом по имени Гаспар Феликс Турнашон, больше известного под прозвищем Надар, в 1858 году. Фотография не сохранилась.

Старейшим сохранившемся фотоснимком считается фотография американского города Бостон, датируемая 1860 годом. Фотограф Джеймс Уоллес Блейк.

…первая фотография из космоса снята с борта немецкой ракеты V2, в 1946 году. Ракету запустили американцы. На снимке видно Мексику.

The Basic Equation of Space Remote Sensing

$$\boxed{E_S = L_O + L_A + L_B}$$



E_S irradiance at space sensor

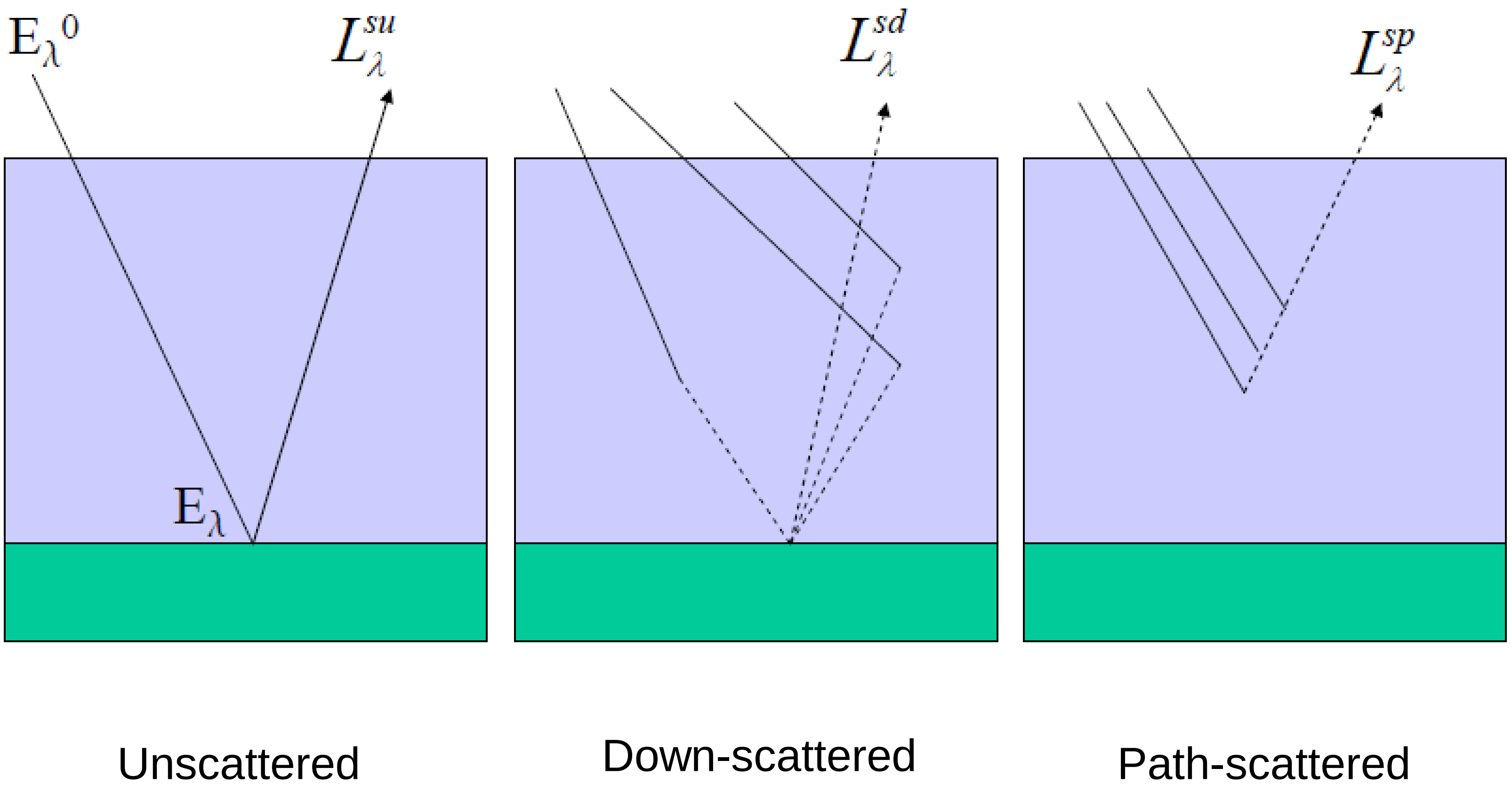
L_O radiance of the target object (surface reflection of direct sunlight and diffuse sky radiation)

L_A atmosperic scattering

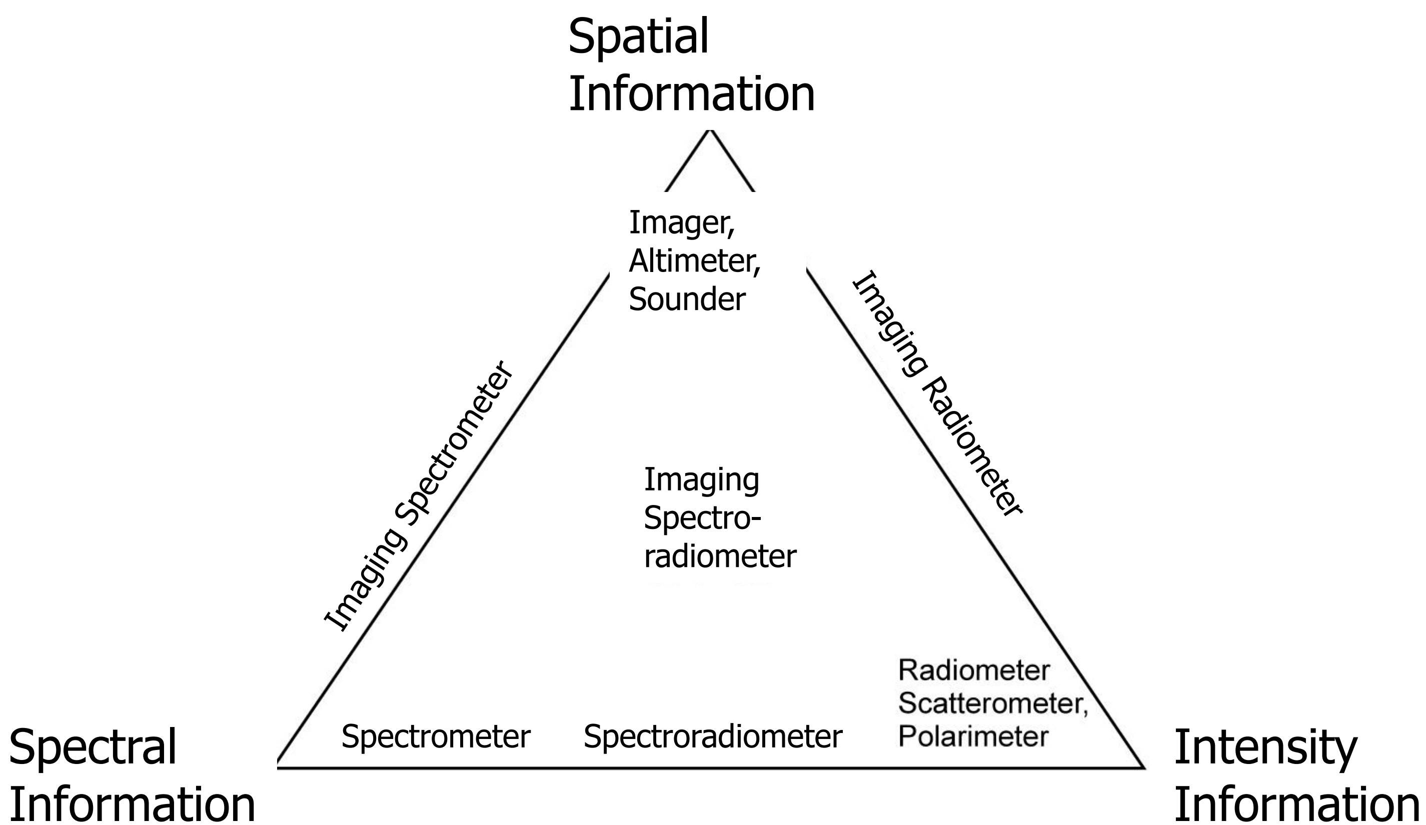
L_B background radiance

$L_A + L_B = L_{path}$

$L_A + L_B =$ path radiance

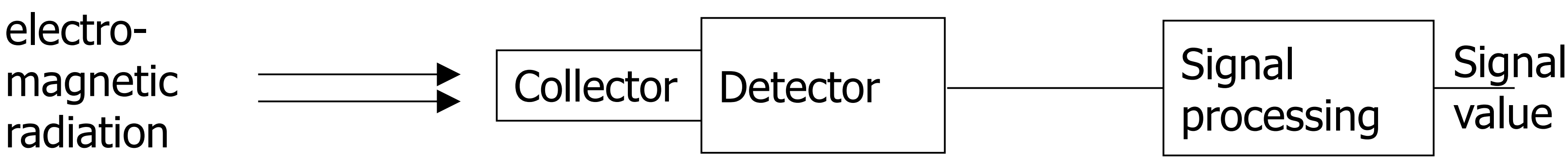

$E_\lambda{}^0$
L_λ^{su}
L_λ^{sd}
L_λ^{sp}
E_λ
Unscattered
Down-scattered
Path-scattered

Optical Space Sensor Systems



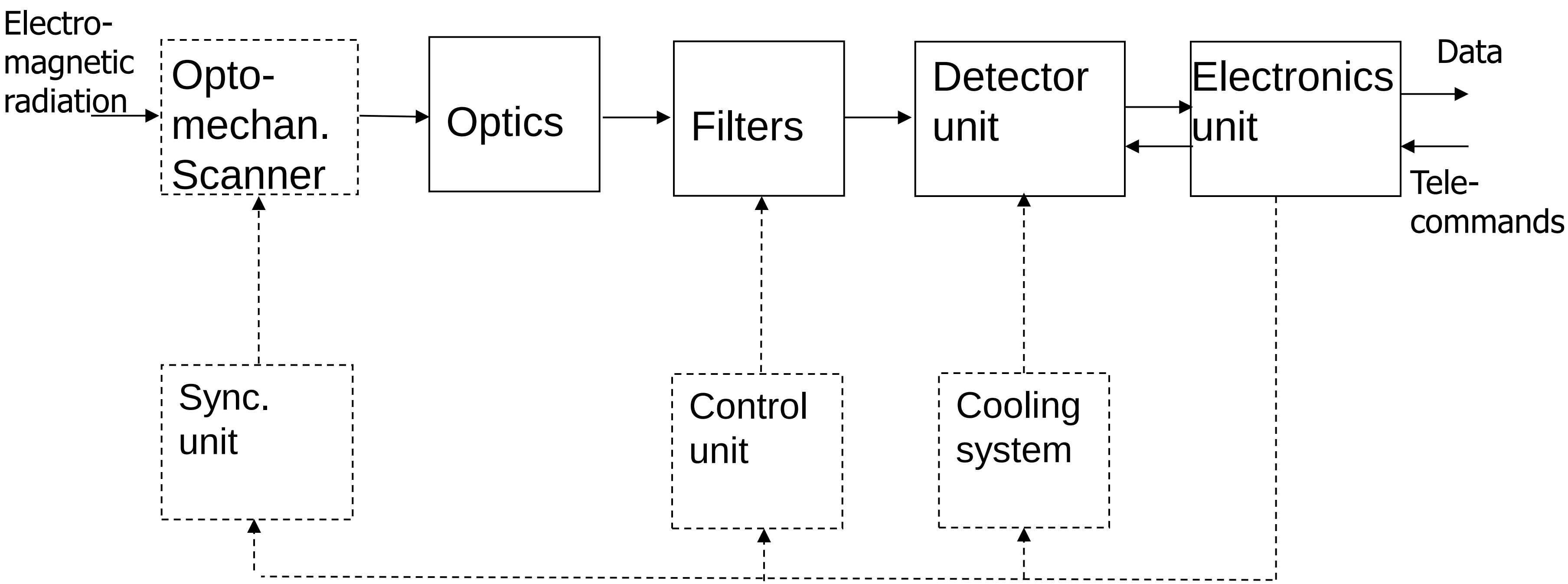
Reference: Elachi, Charles: Introduction to the physics and techniques of remote sensing. - New York [a.o.] : Wiley, 2006, 552 p.

The General Remote Sensor System



Wave length	Collector	Detector	Measurement value
γ-rays X-rays	Detector is the collection aperture Particles interchange with the detector material, Ionisation $\rightarrow$ light emission or charges are generated emitted light or generated current is an equivalent for the energy flux		Incident energy flux or photon number
UV, VIS, IR	**Optics, reflecting surfaces (mirrors)**	**Conversion of EM-Energy in heat, current or state changes**	**Energy of the field on one point as function of wave length (Spectrometer) or total radiation flux (Radiometer) or Polarisation**
Micro wave	Antenna	EM detector antenna	Amplitude, Polarisation, Frequency, Phase

System Components of a Passive Optical Sensor System



Performance Parameter of an Optical Instrument

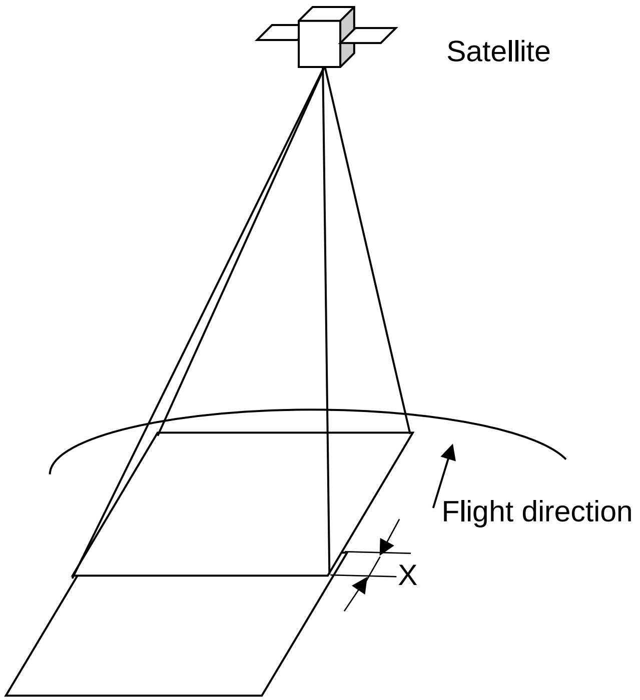
- overall sensitivity
- dynamic range and linearity
- spectral response and out of band rejection
- radiometric resolution (expressed through detectivity, NEP)
- spectral resolution (expressed through equivalent bandwidth)
- time resolution (e.g. acquisition time frame)
- polarization measurement accuracy and instrumental polarization
- straylight rejection
- preflight and In flight calibration
- radiation damage and radiation induced transients

Passive Sensor System Concepts

- Optical Sensor System Concepts
  - Film camera
  - Whiskbroom
  - Pushbroom
  - Staring Array
  - Time Delay and Integration (TDI)

Film Camera

image reconstruction:



$$\tau_{shutter} = \frac{X}{V_{gt}}$$

Advantages:
- Large image format
- high information density
- Cartographic precision
- analogue data

Drawbacks:
- expensive Digitalisation
- Transportation of the film
- Image smearing

Whiskbroom Scanner

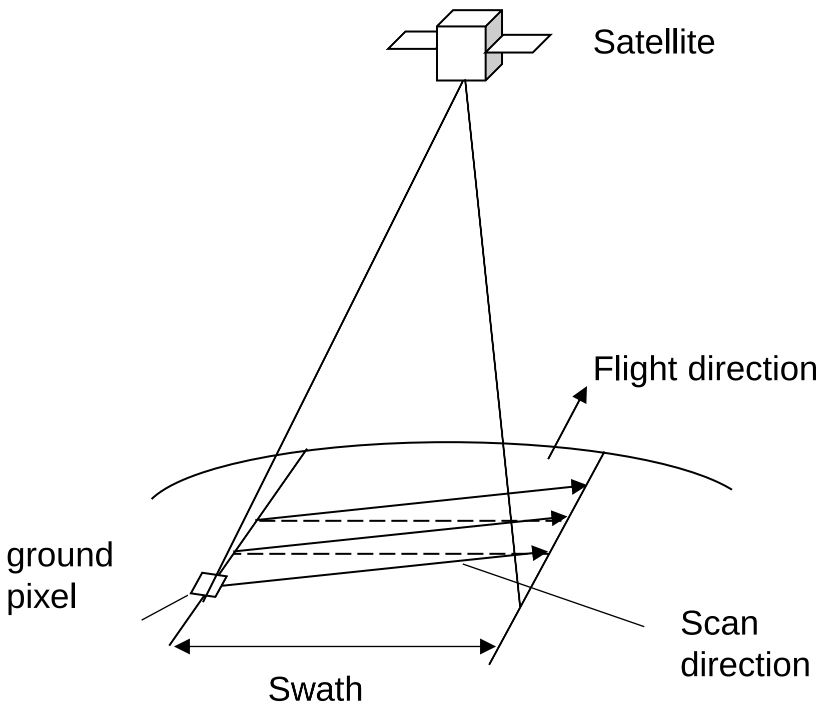
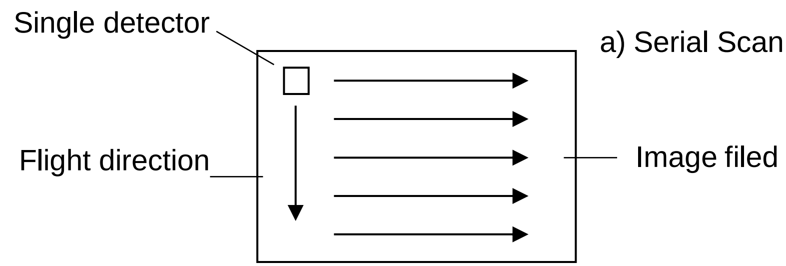


image reconstruction:



Dwell-time of the single scanner

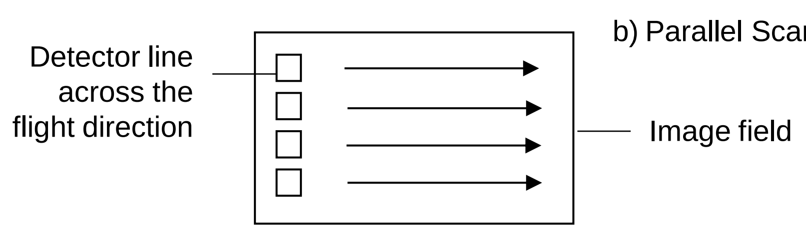
$$\tau_{dwell} = \frac{x}{v_{gt} \cdot n_{pix}} \cdot \eta_{scan}$$

with x = ground pixel size

v_{gt} = ground track velocity

n_{pix} = Pixel number per Swath = swath width/x

h_{scan} = Scan efficiency



Whiskbroom Scanner

Advantages:
- simple detectors
- Optics with small Field of View
- large swath width
- several spectral channels are feasible

Drawbacks:
- very short detector dwell time (low signal)
- movable mechanical parts
- expensive geometric image correction

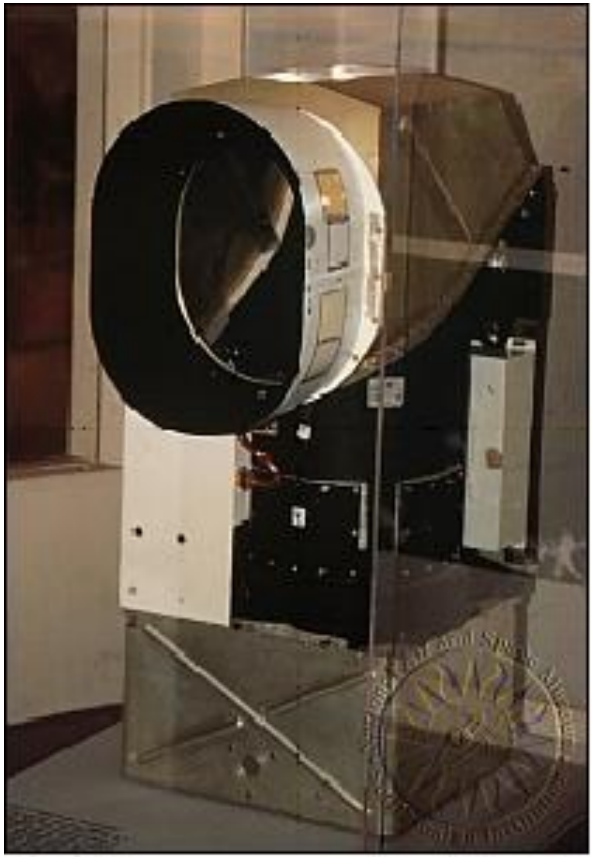
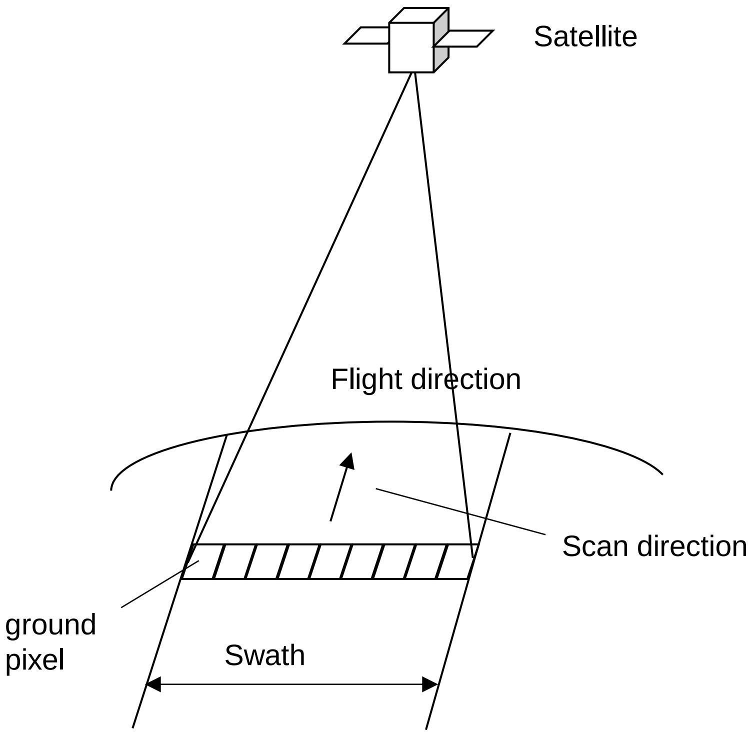
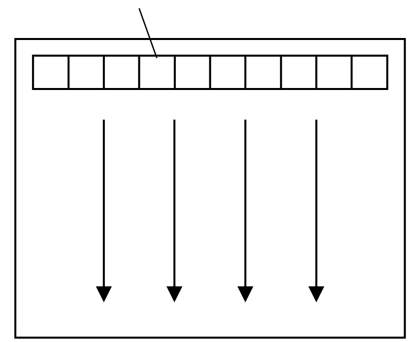


Photo of the MSS Instrument (image credit: NASA)

Pushbroom Scanner

image reconstruction:
detector line across the flight direction





dwell time: $$\tau_{dwell} = \frac{x}{v_{gt}}$$

Pushbroom Scanner

Advantages:

- large swath width and high resolution feasible (depending on pixel number)
- relatively „long“ dwell time for each pixel
- high geometric accuracy across the flight direction
- No movable parts

Drawbacks:

- Optics with a large Field of View necessary
- Expensive geometrical image correction due to flight attitude necessary (line by line)

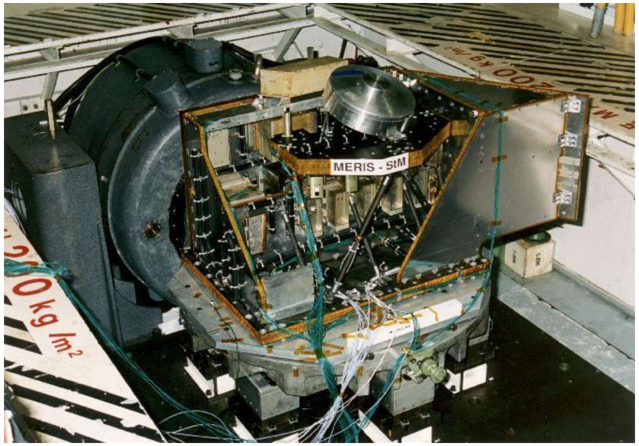
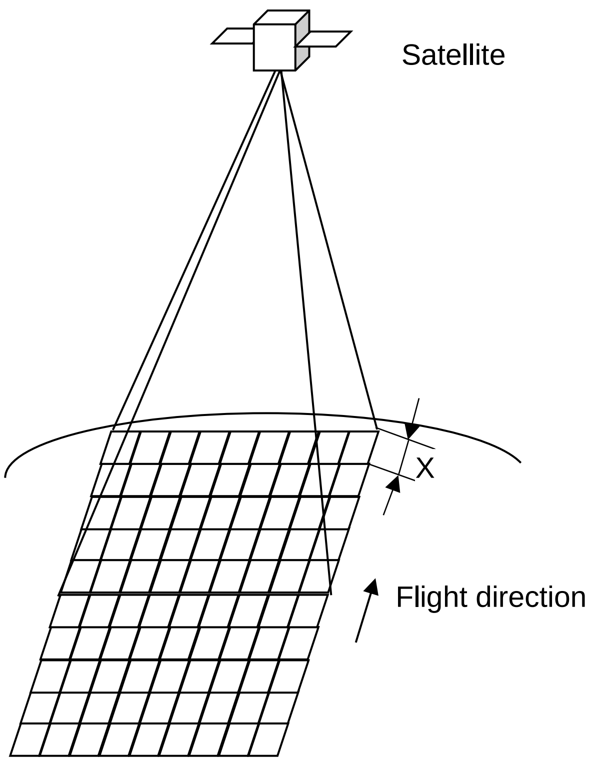


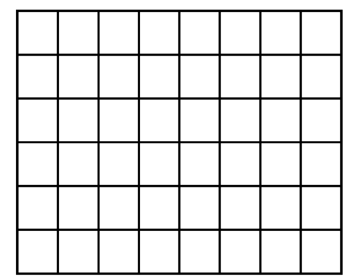
Photo of the MERIS STM (image credit: ESA)

Staring Array



Staring imaging principle

image reconstruction:
2D-image within the dwell time



Dwell time $$\tau_{dwell} = \frac{X}{v_{gt}}$$

Staring Array

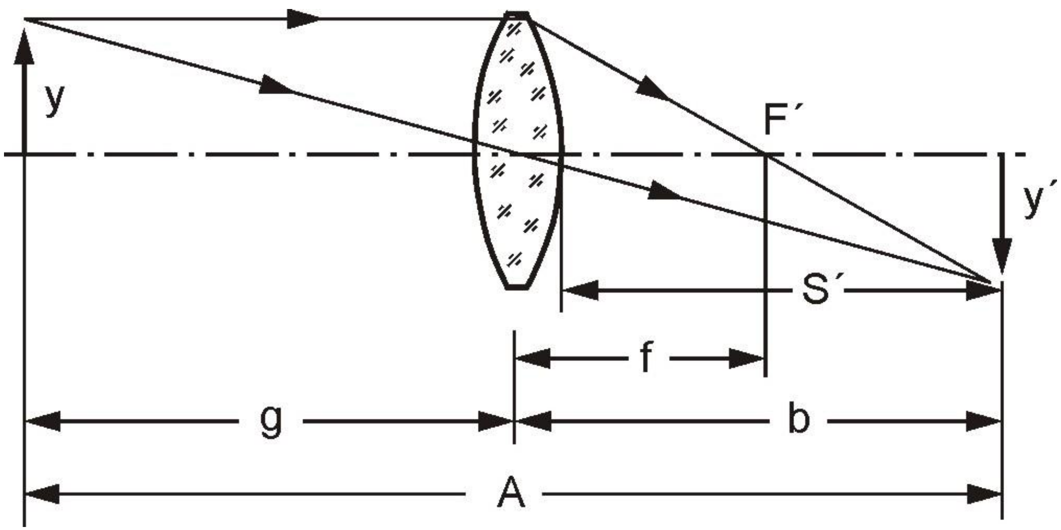
Advantages :

- fix geometry of the complete 2D-image
- high geometric accuracy
- Large spectral range feasible

Drawbacks:

- Pixel number across the flight direction less then pixel number of a line sensor (lower swath width)
- High read-out velocity necessary
- Additional smearing effects during read-out possible

Basic Parameters of an Optical System



Focal Length f

= distance of the focal point to the main plane

$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

$$\text{imaging scale:}$$

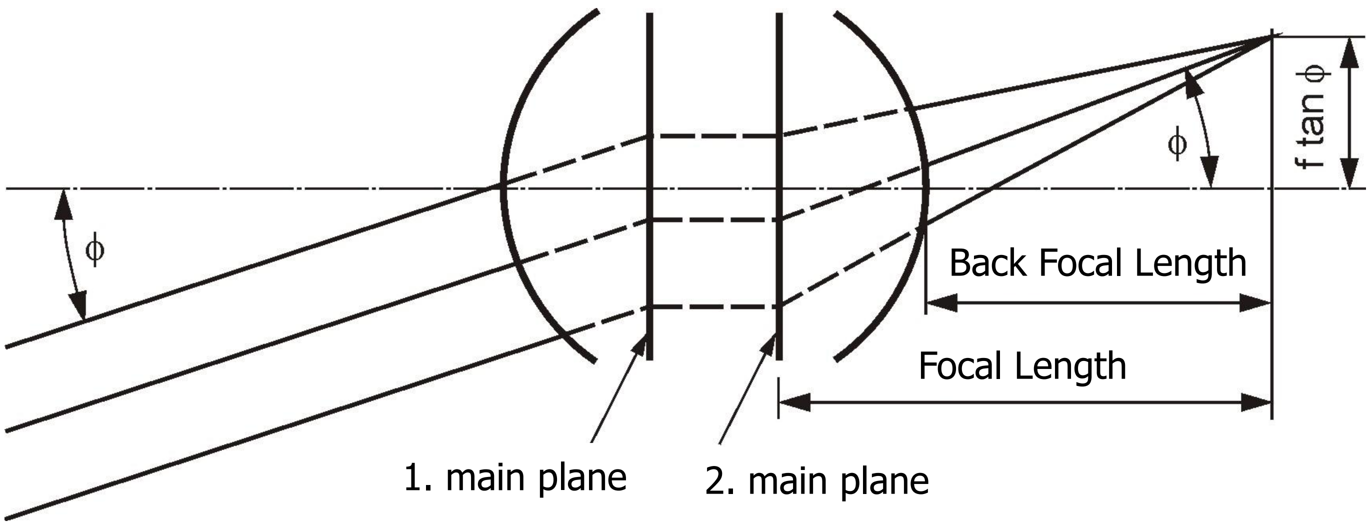
$$m' = \frac{b}{g} = \frac{b}{f} - 1$$

f = focal length
g = object distance
b = image distance
y = object size
y‘ = image size
m‘= imaging scale
F‘ = focal point

Back Focal Length (BFL)

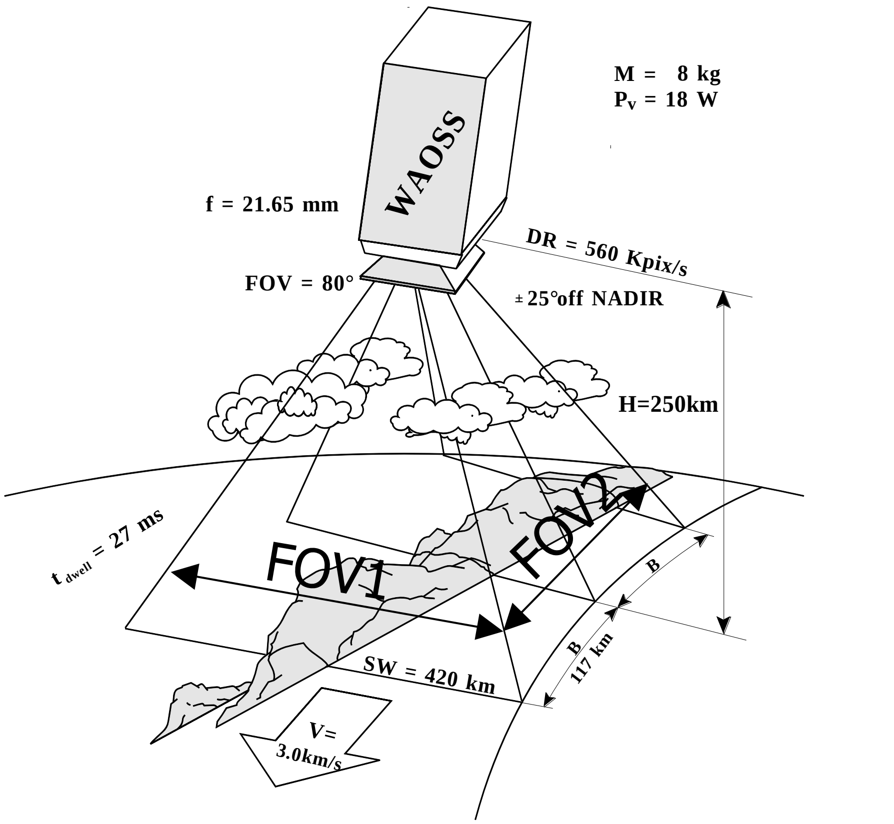
= distance of the last lens to the image plane

- Can be measured directly (in contrast to the focal length)
- Important parameter for the opto-mechanical system design

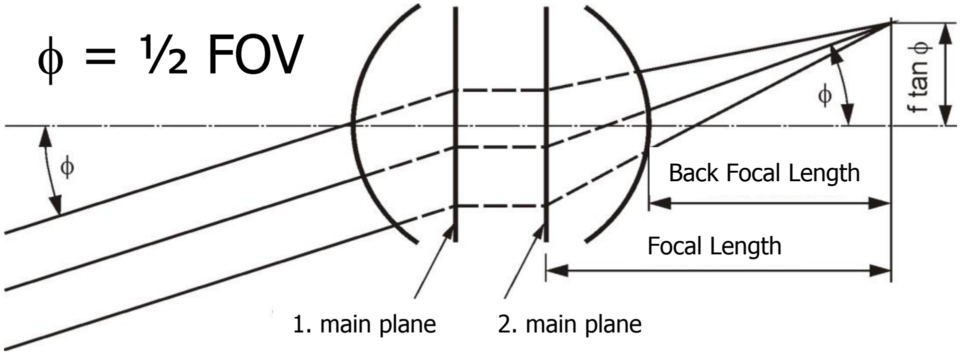


Field of View (FOV)

- Maximum view angle of an optical system
- Maximum image field angle
- Can be rotational symmetric (Total Field of View) or be different in 2 directions (FOV1, FOV2)



ϕ = ½ FOV



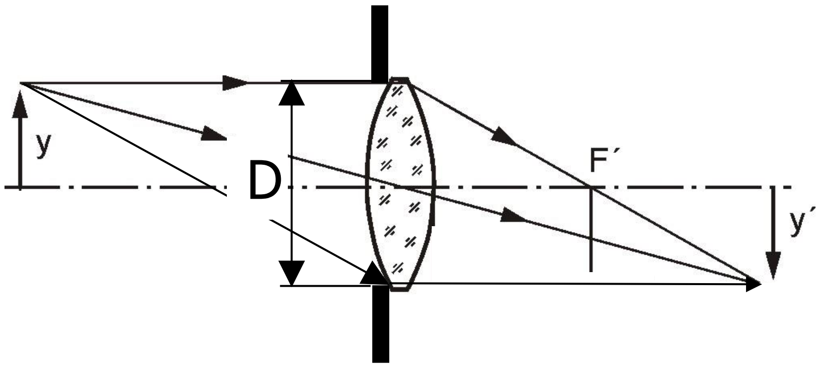
$$FOV = \pm \arctan\left(\frac{\text{image field}}{2 \cdot f}\right)$$

Exersise 2

Calculate the ground sampling distance of a given spacebased sensor. Calculate the dwell time, and the data amount generated if the dyty cycle is assumed to be 25%.

Aperture D

- Maximum entrance aperture limits the rays on the border
- Determines the light quantum on the focal plane



F/number, F/# or k

- Reciprocity of the entrance aperture
- F/number sequence: factor √2

Entrance Aperture number
D = Diameter of the entrance

k= 0,7; 1; 1,4; 2,8; 4; 5,6; 8; 11; 16; 22; ...

$$k = \frac{f}{D}$$

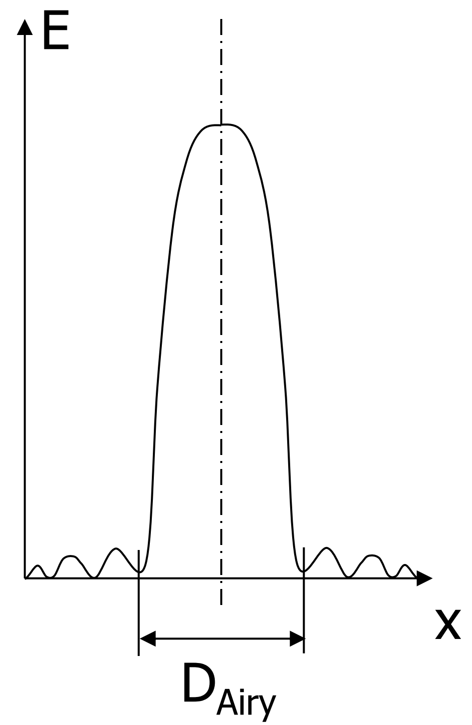
Limits of Optical Resolution

Effect:

An ideal point light source is depicted in the image plane as an blurred or smeared circle. The energy is distributed over an area.

2 reasons:

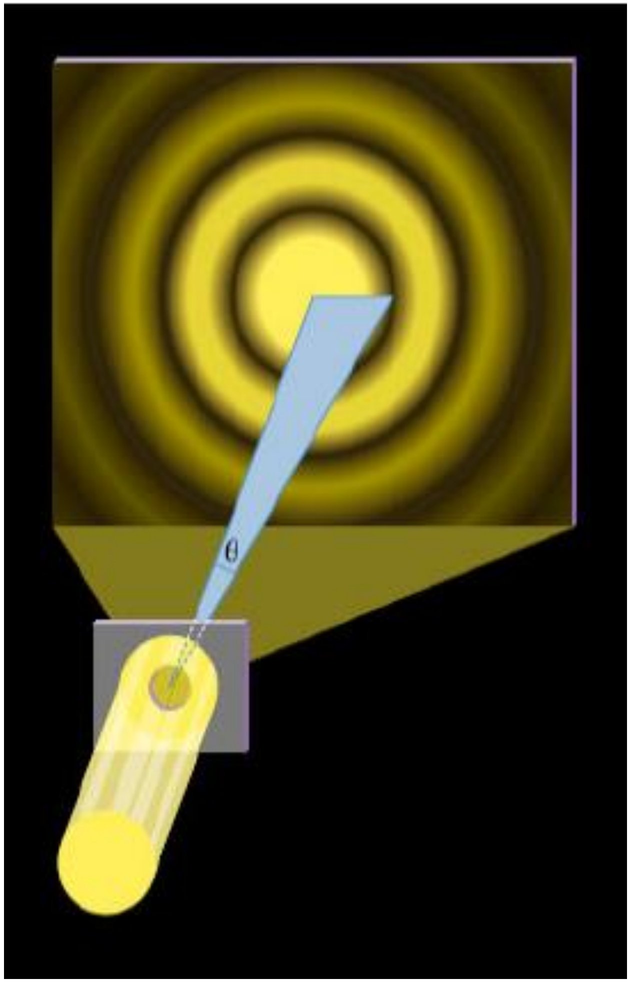
- Diffraction (of the light ray at the entrance pupil) and
- Aberrations, i.e. imaging failures of the optics



Point Spread Function PSF

- The spatial distribution of an ideal point light source in the image plane is called Point Spread Function. It represents the performance of sharpness of the image.

Diffraction Limitation of Optical Systems

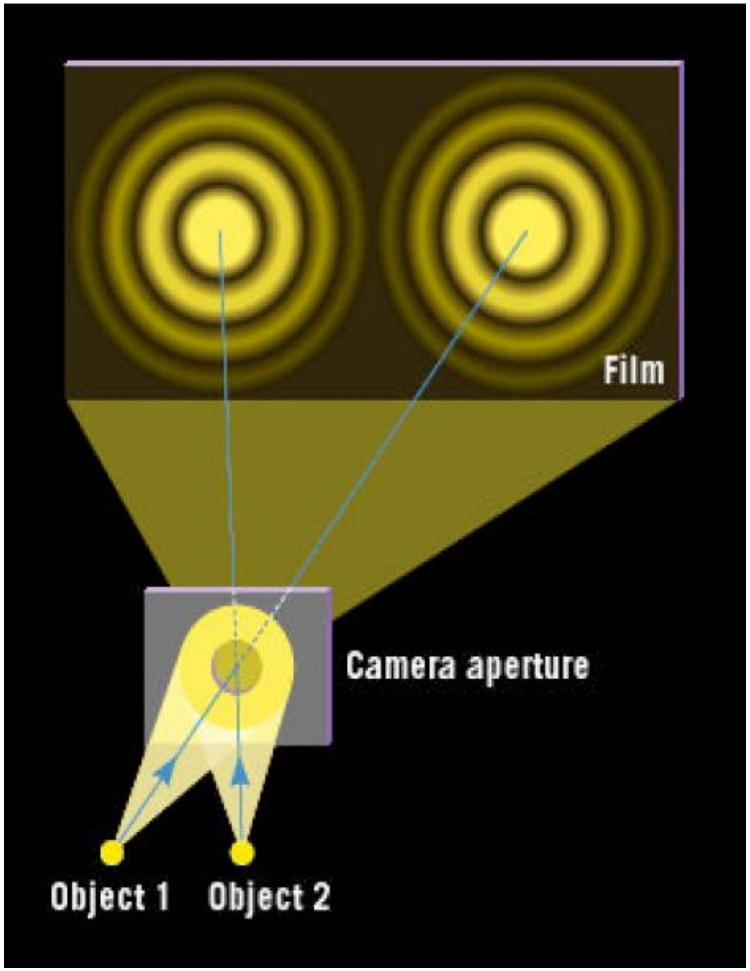


- Light, which passes an aperture is diffracted.

- The system images a perfect ray bundle as a circular diffraction pattern in the image plane. The angle θ describes the angular distance from the center of the pattern to the first dark ring.

- Rayleigh Criterion:

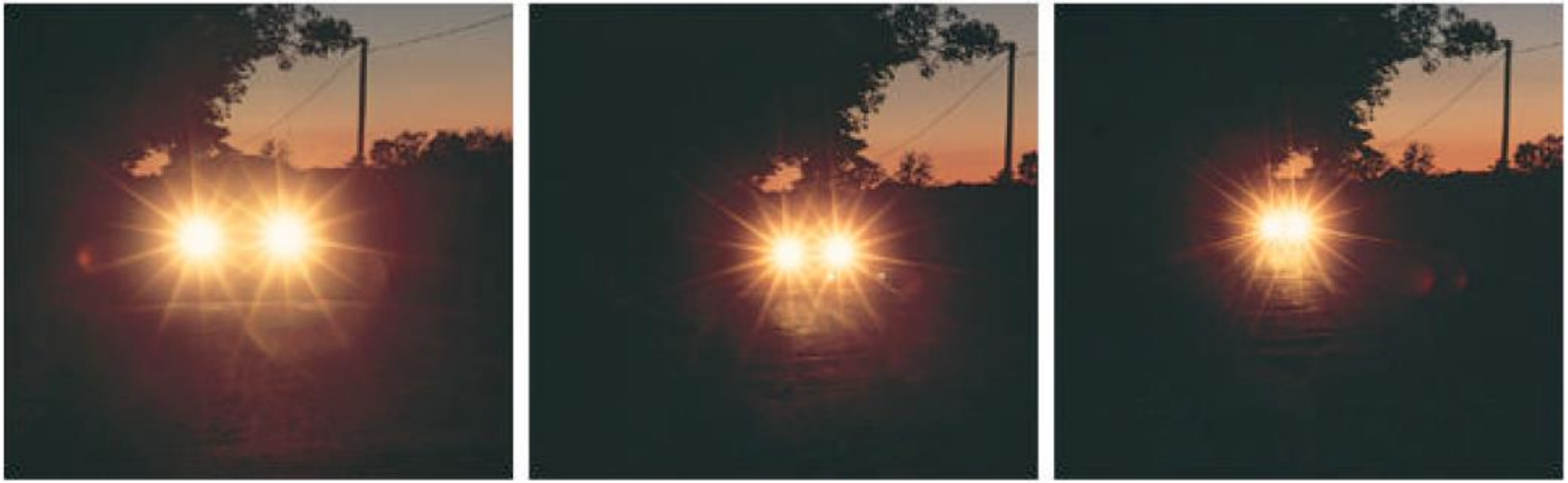
$$\Delta\theta = \frac{1.22\lambda}{D}$$



- Light from two different, perfect light sources creates two diffraction patterns in the image plane. If the angular distance between the light sources is big enough, they can be easily distinguishes on the image.

- Otherwise, their images are superimposed.

Diffraction Limitation of Optical Systems



- The angular distance between the headlights of this car increases with decreasing distance. The human eye is a diffraction limited system..

- Every optical system is limited by diffraction effects. Even if all aberrations are removed completely, this limitation is the theoretical border of the systems geometrical resolution.

Aberrations

The light, which is assumed to be a wave, interacts with the aperture stop, the lens geometry and the lens materials. This can dramatically change the form of the wave front. This undesirable changes are referred to as aberrations. They influence the point spread function of the system and have direct effect on the spatial resolution.

Monochromatic	Chromatic
Spherical	Longitudinal Chromatic
Coma	Transverse Chromatic
Astigmatism	
Field Curvature	
Distortion	

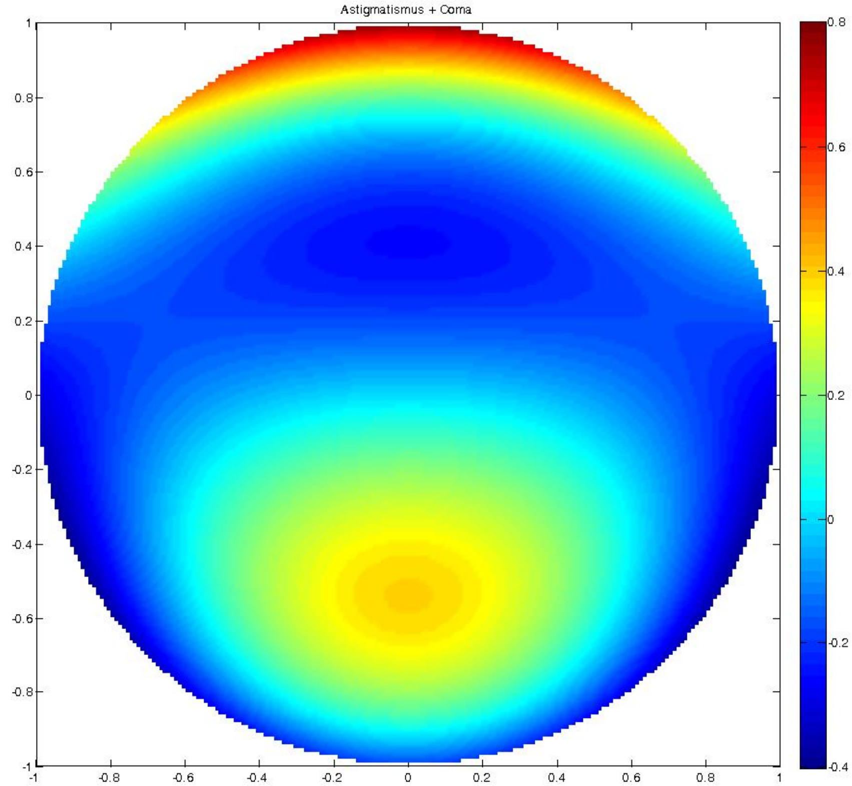
Can only be corrected in this order!

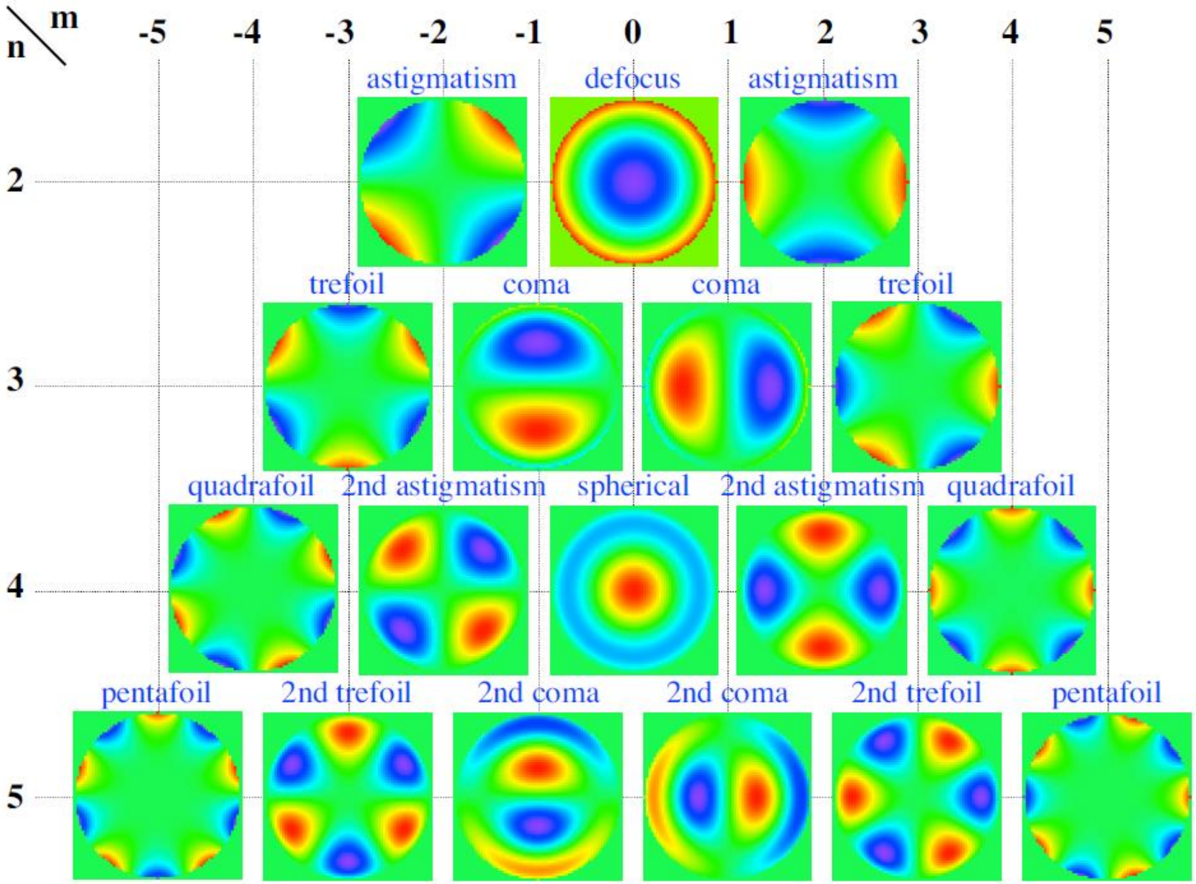
Aberrations are described with so-called Zernike-Polynomials:

$$W(\rho, \theta) = \sum C_n{}^m Z_n{}^m(\rho, \theta)$$

E.g. Astigmatism can be described as follows (m =2, n = 2):

$$Z_2{}^2(\rho, \theta) = \rho^2 \cos(2\theta)$$


Astigmatismus + Coma
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4


m
n
-5
-4
-3
-2
-1
0
1
2
3
4
5
2
3
4
5
astigmatism
defocus
astigmatism
trefoil
coma
coma
trefoil
quadrafoil
2nd astigmatism
spherical
2nd astigmatism
quadrafoil
pentafoil
2nd trefoil
2nd coma
2nd coma
2nd trefoil
pentafoil

Optical Concepts

- Refractive Optics
  - optical system consists of lenses only

- Katadioptical System
  - optical system consists of lenses and mirrors

- Reflective Optics
  - optical system consists of mirrors only

Refractive Optics

When

- the focal length less then 500 mm
- the Filed of View is large (90° or more)
- the spectral bands are wide (200 nm or more)

Examples:

- Symmetric lenses for different applications
- Wide angle lens systems
- Telescopes and Zoom lenses

Advantages:

- Low costs because of spherical lens surfaces
- High image quality and strong light signal possible, because of no obscuration by mechanical elements
- Inexpensive optic adjustment by circular lenses and axial locations
- Diversity of optical lens materials allows spectral corrections in a wide range of applications
- Stray light suppression by simple baffle arrangements possible

Drawbacks:

- No long focal length with high aperture numbers possible
- Chromatic aberrations at high spectral band with (> 200nm) have to be corrected

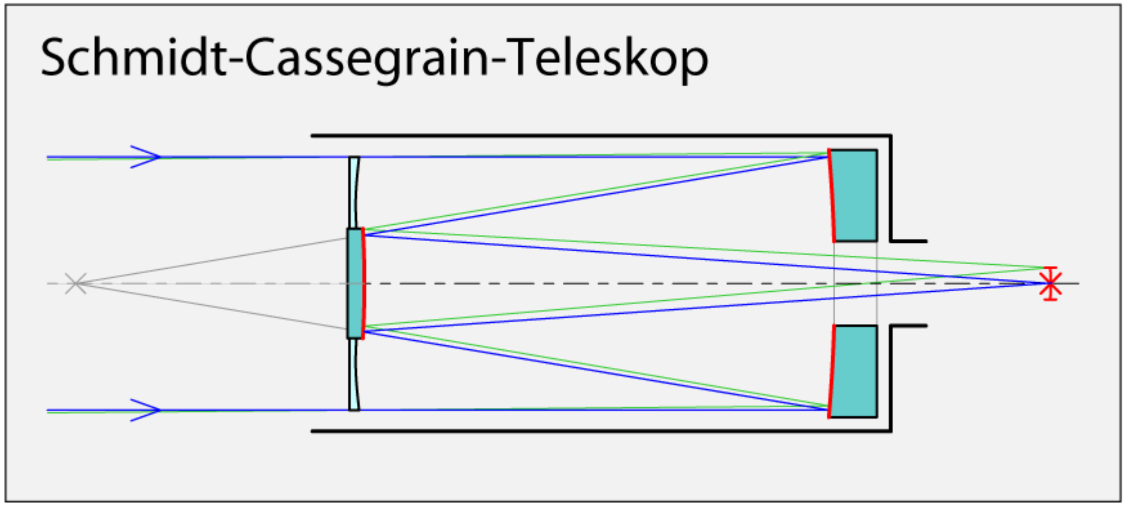
Katadioptical System

When

- The focal length is larger then 500mm
- The Filed of View is large

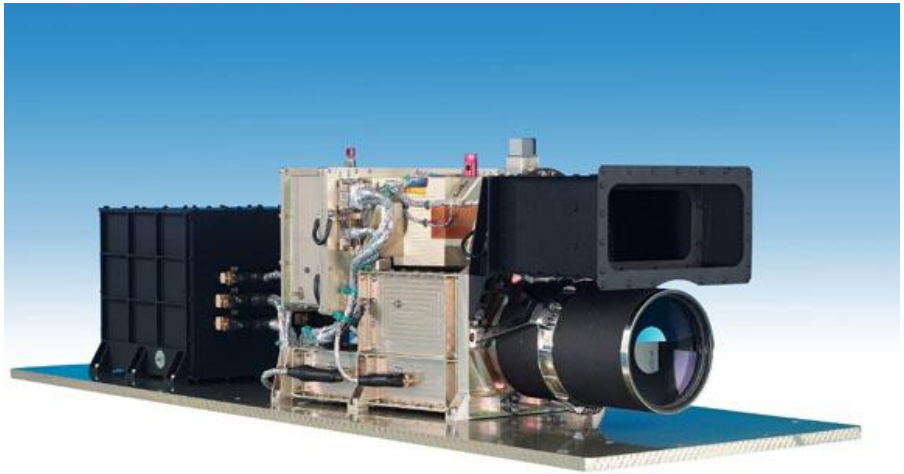
Examples:

Schmidt-Camera, Schmidt-Cassegrain-Telescope, Maksutov-Telescope



Katadioptical System Example: Maksutov-Telescope at the German Mars Camera

- The Super Resolution Channel is a separate 1024 x 1024 framing camera with a Maksutov-Cassegrain telescope (f= 974,5mm)
- Ground pixel size: 2.3 m/pix at pericenter of Mars Orbit
- Pericenter altitude = 250 km

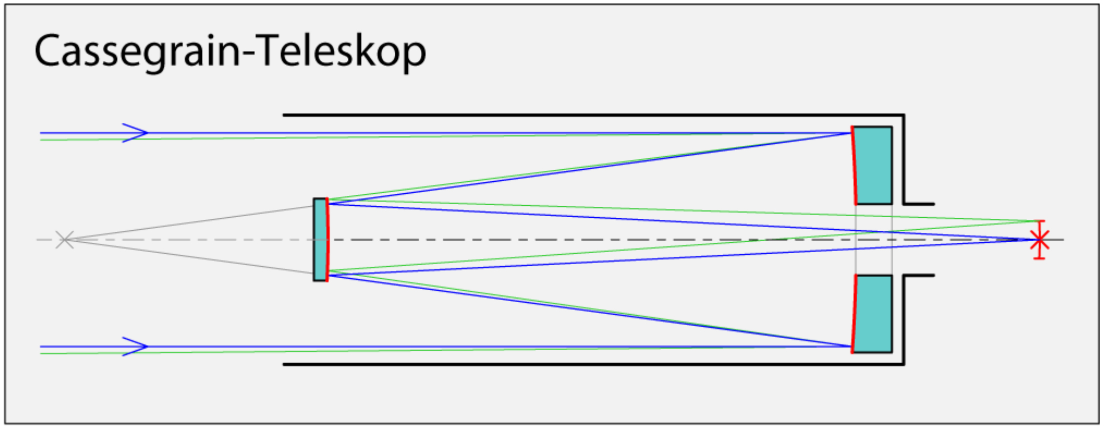


High Resolution Stereo Camera of DLR for the Mars Express Mission. The lower optical system is the Maksutov-Cassegrain telescope of Super Resolution Channel (Photo: DLR)

Reflective Optics

- Consists of 2 or 3 mirrors (primary mirror, secondary mirror(s) and supporting elements
- No lenses
- All telescopes with an diameter > 1m are reflective telescopes

Examples: Newton-telescope, Cassegrain-telescope, Richey-Chrétien-telescope, Three Mirror Anastigmat)



Advantages:

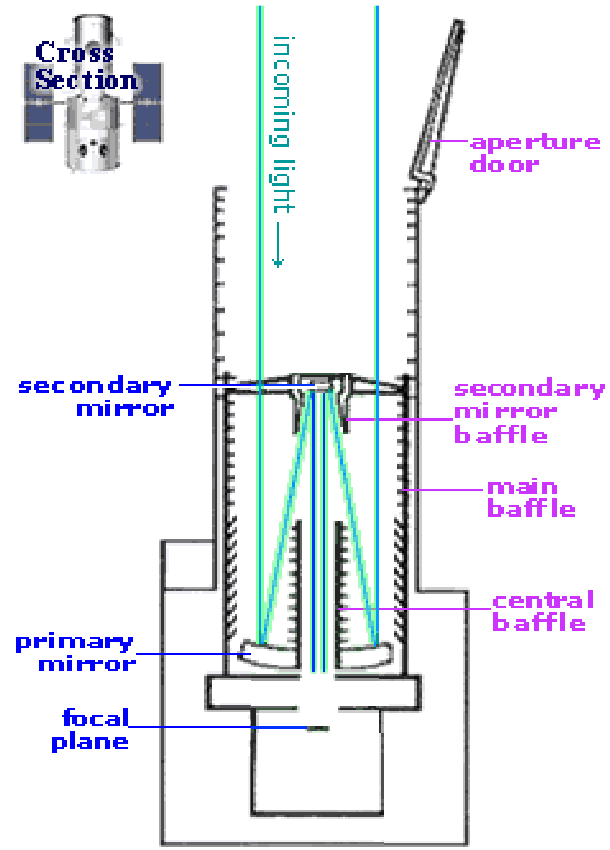
- Only one surface of an optical element has to be manufactured with high precision (the mirror)
- The backside can be lightweight
- High numerical aperture feasible
- distortions and optical performance are not dependent from the wavelength
- Many different materials are suitable for a mirror (optical glasses, metals, Zerodur, SiC, etc.)

Drawbacks (in comparison to refractive systems):

- For small Field of Views only
- More expensive in manufacturing, assembly and integration (higher precision)
- Obscuration due to supporting elements for secondary mirror
- Higher mass and volume
- More stray light

Reflective Optics Example:
Richey-Chrétien-Cassegrain-Telescope of HST

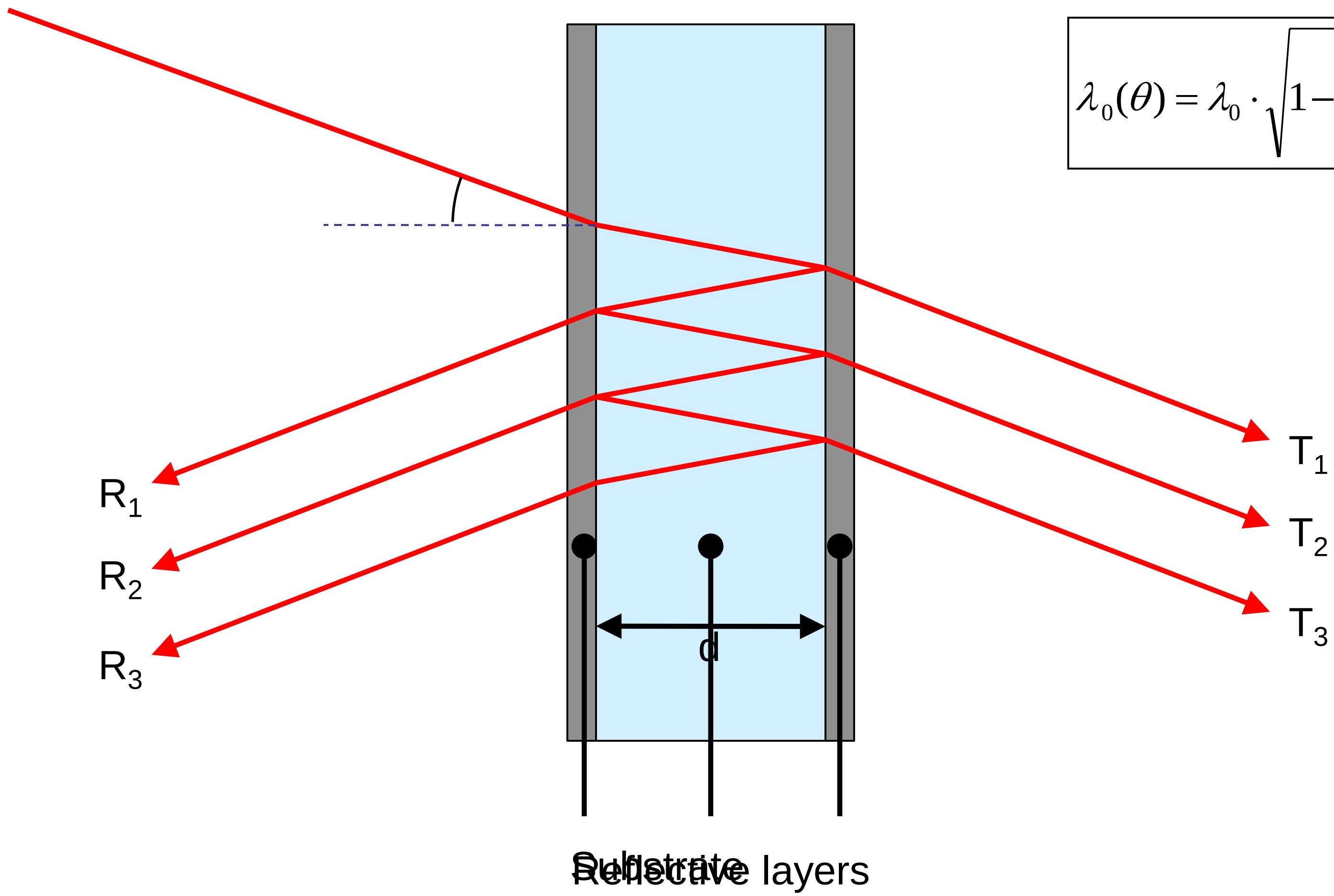
- main telescope of the Hubble-Space-Telescope HST
- Diameter of the primary mirror = 2,4 m
- Diameter of the secondary mirror = 0,30m
- Baffle for stray light suppression at secondary mirror and at centre hole of primary mirror



Filters

Advantages	Disadvantages
GLASS FILTERS	
low impact of inclined entrance ray	limited filter assortments
robustness and long-term stability	very limited band-pass characteristics feasible
high transmission within a large bandwidth	fine tuning not possible
INTERFERENCE FILTERS	
any narrow bandwidth feasible	near parallel incidence of light required
spectral fine tuning feasible	sensitive against environmental impacts
steep edges in the spectral characteristics feasible	additional glass blocking filters necessary

Interference Filters



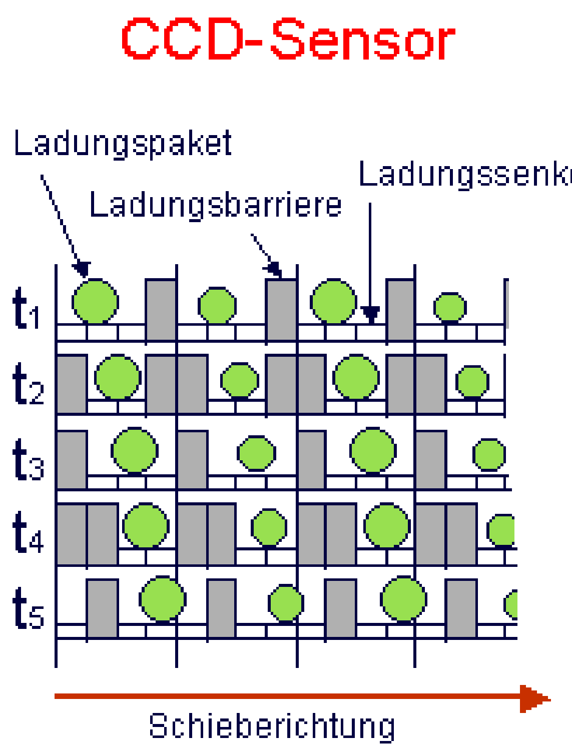
$$\lambda_0(\theta) = \lambda_0 \cdot \sqrt{1-\left(\frac{n_U}{n_F}\right)^2 \sin^2(\theta)}$$

Detectors

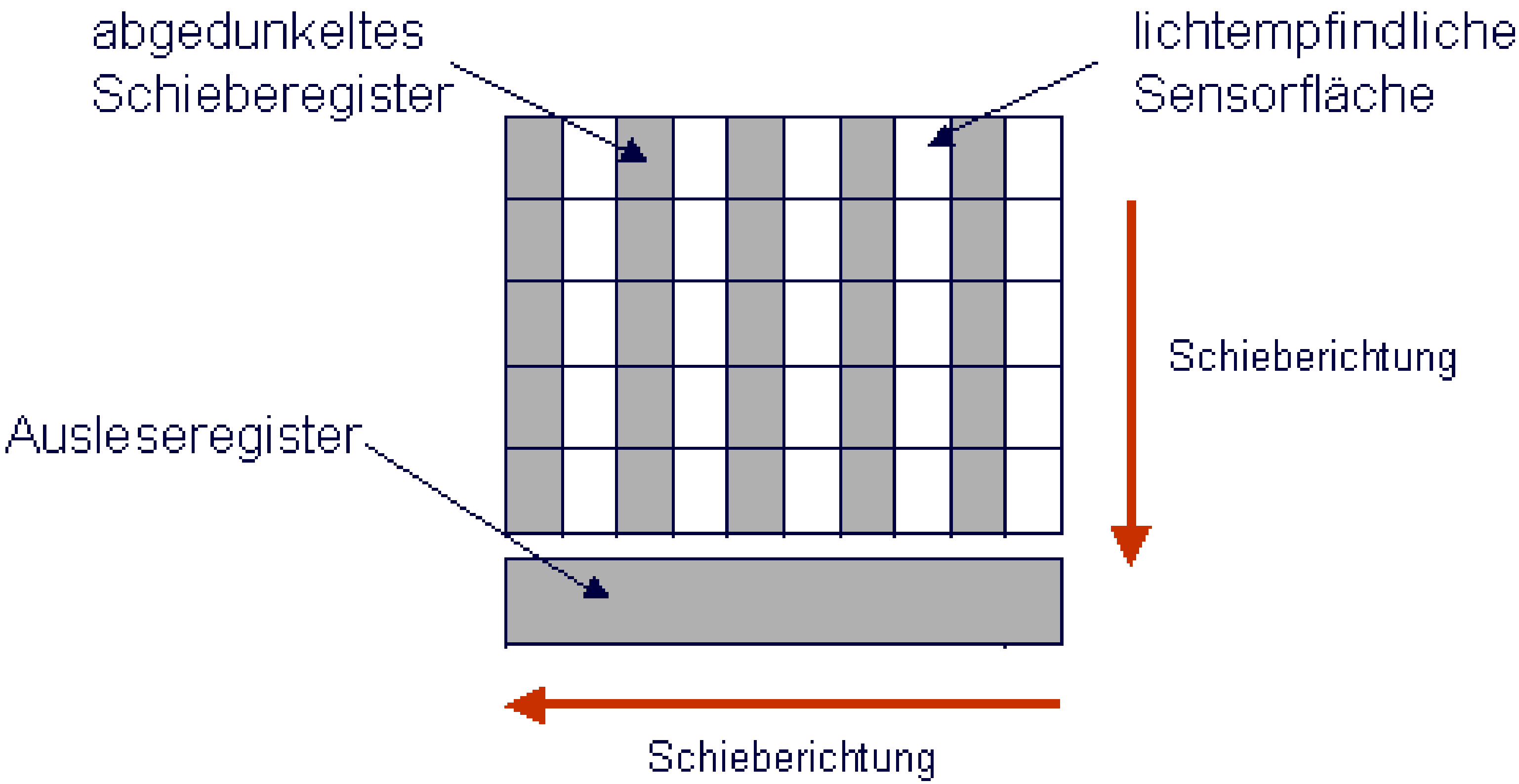
Type	Sensitivity (QE)	Remarks
Film	~0.01	Non-linear • Dyn. Range: 1/100 • Detector is memory • High capacity
Photo Multiplier Tube	0.1 ... 0.3	• Photocathode, SE - Multiplier (10^6 ... 10^7) • distortions
Micro Channel Plate	0.1 ... 0.2	• Photocathode, SE - Multiplier (10^6 ... 10^7) • no distortions
CCD	0.3 ... 0.9	• Dyn. Range to 1/1000, Limited by photon noise • Very sensitive • Linear system (200000 e-/ pixel) • High capacity

Charge Coupled Devices

- CCD = Charge Coupled Device
- CCD sensors consists of a one or two dimensional array of light sensitive and storage elements
- Two different types:
  - CCD-Lines
  - CCD-Matrices

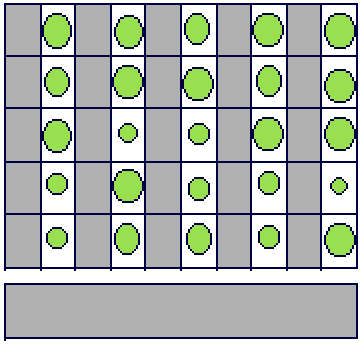


Charge Coupled Devices: Interline transfer matrix



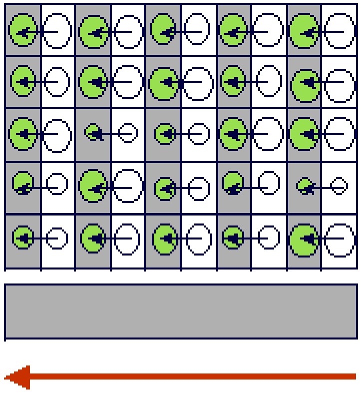
Charge Coupled Devices: Interline transfer matrix

1. Integration phase - photons generate charges (green dots) in the pixels



1.

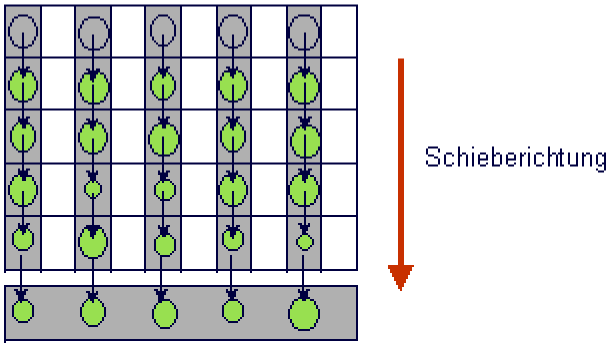
2. Parallel transfer of the charges in light protected shift registers



2.

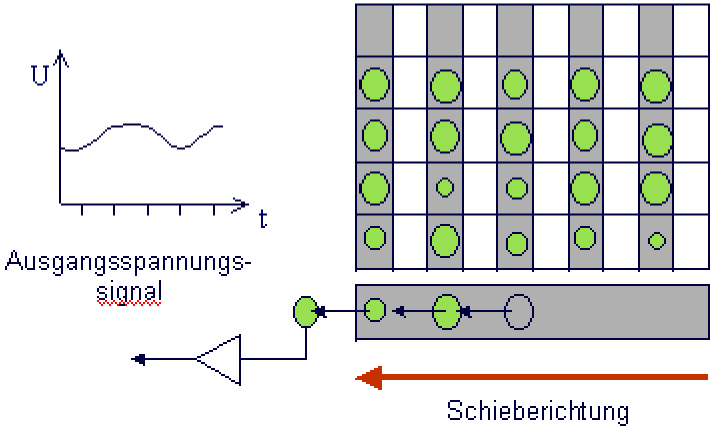
Charge Coupled Devices: Interline transfer matrix

3. Vertical shifting into the read-out register



3.

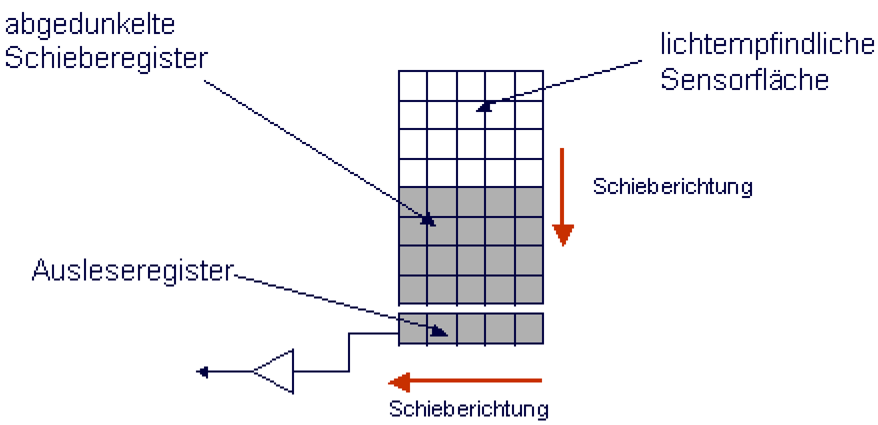
4. The read-out process is a serial process.



4.

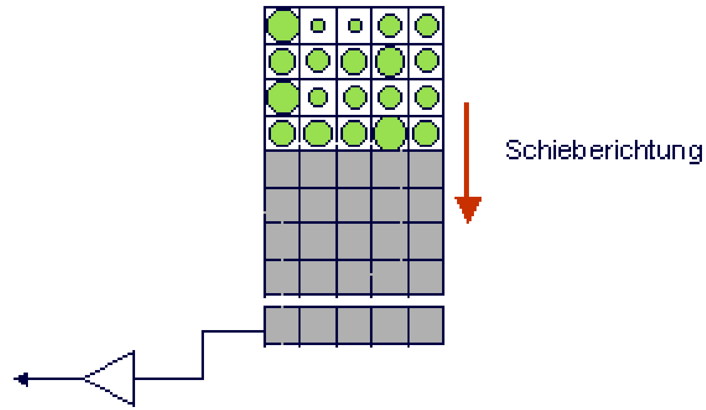
Charge Coupled Devices: Frame transfer matrix

- The complete image (frame) is transfered into a light-protected frame area.
- The light sensitive area is also the transfer register field.
- Actually there are two CCD matrices, one is sensitive and the other in a shadow area.
- They have a higher pixel density but they are more expensive (2 matrices).
- Smearing is an important impact.

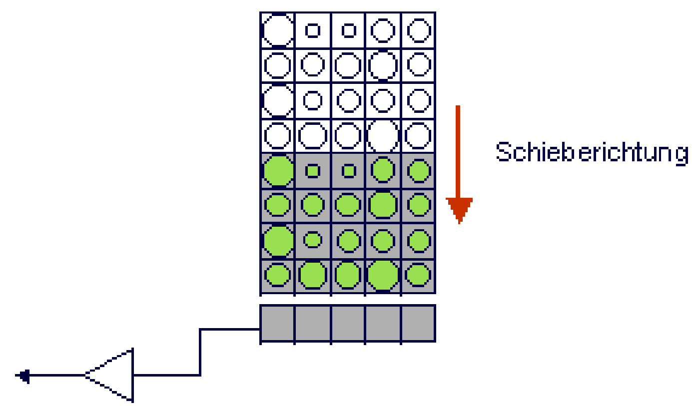


Charge Coupled Devices: Frame transfer matrix

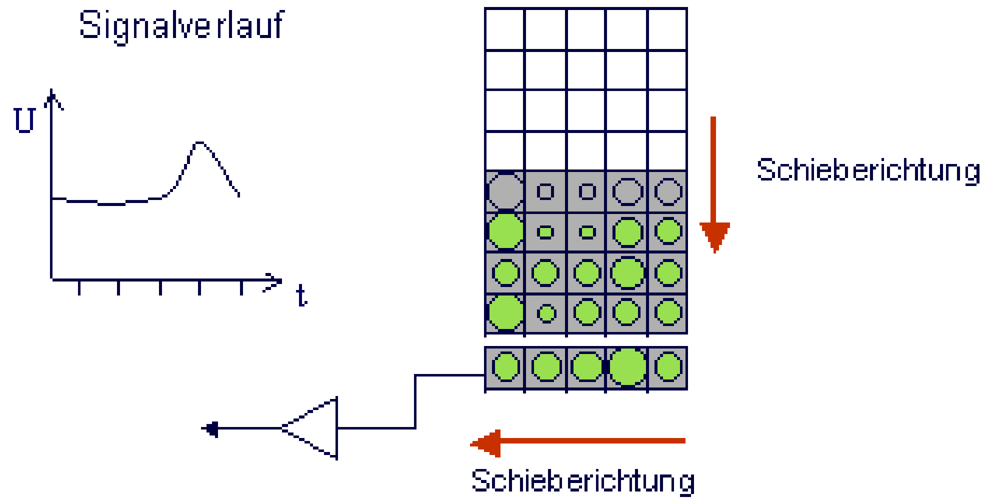
1. Integration phase



2. Transfer phase into the temporal memory

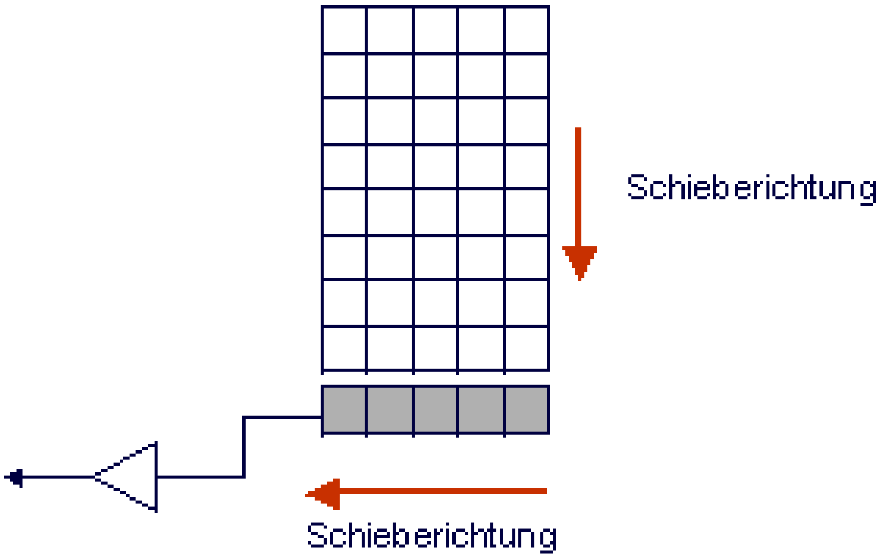


3. serial read-out of the temporal memory.



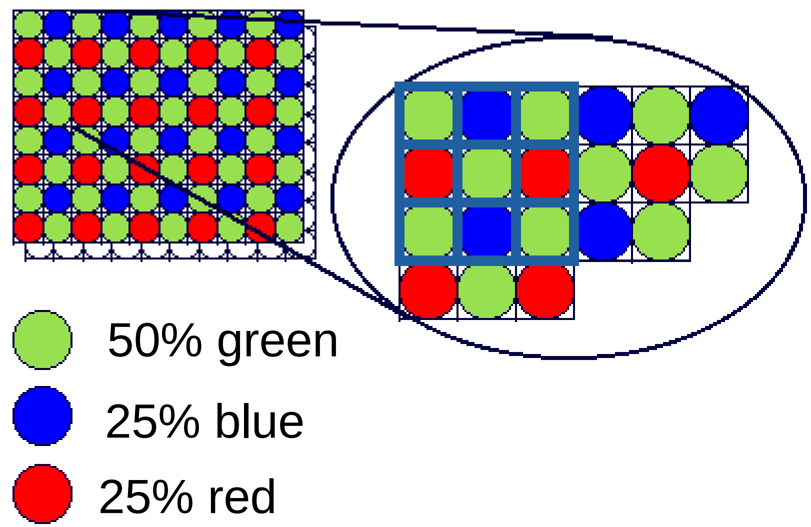
Charge Coupled Devices: Full Frame CCD

- No light-protected memory area.
- Integration time can not be controlled electronically.
- Mechanilcal shutter necessary.
- Maximum use of the light sensitive area.
- Application for high sensitivities and long integration times.



Charge Coupled Devices: 1-Chip-Colour CCD

- Color filter mosaic in front of the light sensitive sensor area
- Each pixel records only one colour, the object colour has to be interpolated from the surrounding pixels
- Interpolation algorithms are different from supplier to supplier



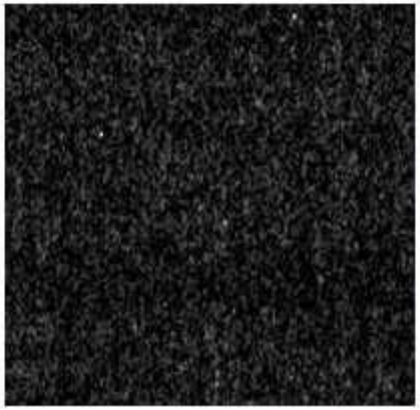
give an interpolated colour image

Charge Coupled Devices: Dark Current

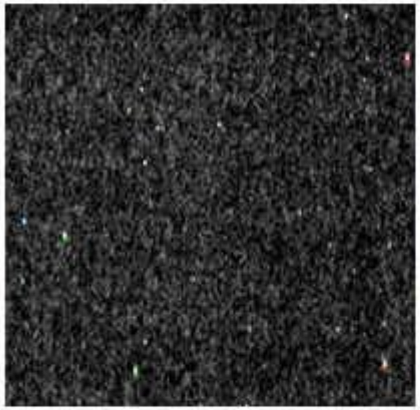
- In the semiconductor material charge carriers are generated in dependence from the temperature.

- The effect of generation and recombination of the carriers and electrons is called thermal noise or dark signal or dark current.

- For applications with a long integration time or high sensitivity the sensor has to be cooled or and the dark signal has to be corrected.



CCD image signal at 20°C



CCD image signal at 37°C

Charge Coupled Devices: Blooming Effect

- Blooming is the loss of contrast in high illuminated image regions.
- If the CCD pixel is saturated then the new generated electrons overflow to the neighbour pixels.
- The CCD manufacturer can build in a special potential wall to prevent the overflow effects. In this case the CCD is called "**with anti-blooming**".

Charge Coupled Devices: Smear Effect

- The Smear effect is a light vertical stripe in a CCD image across a very bright image region.
- Ther reasons are different but they are connected with light impact during transport mechanisms.
- **Interline Transfer CCD**: the smear effect is generated by photons, penetrating the darkening stripes on the vertical shift register (light transmission up to 0,1%).
- **Frame Transfer CCD:** the smear effect is generated by very bright light points during the fast transport of the image into the darkening region of the CCD.
- The instrument designer has to take into account the possibility of this effect and can build in a mechanical shutter as a countermeasure.

CCD smear effect

CCD smear protection by means of a shutter

Thank you for your attention!