Course Remote Sensing and Climate

Summer 2026
University of Frankfurt

2. Day (R. Hollmann)

- ➔ Content and Structure of Course
- ➔ Motivation and background
- ➔ A short introduction in Physics
- ➔ Radiative Transport and retrieval basics
- ➔ **Satellite orbits and instruments**
- ➔ Climatologies based on satellite instrument and usage

Notes to PDF-Version

This PDF is based on the presentation given in the summer term 2025 of University Frankfurt as part of the course „remote sensing and climate“.

It is meant to recall the content the content of the lecture and is for the personal use of the participants of the course and <u>not</u> for a wider audience.

Parts in this document have been taken from other lectures, books, publications, the internet or other sources. These parts are not always have a correct acknowledgment or a proper citation.

Thus, please contact me (rainer.hollmann@dwd.de) in case you would like to cite from this pdf.

Satellite orbits and instruments

Content

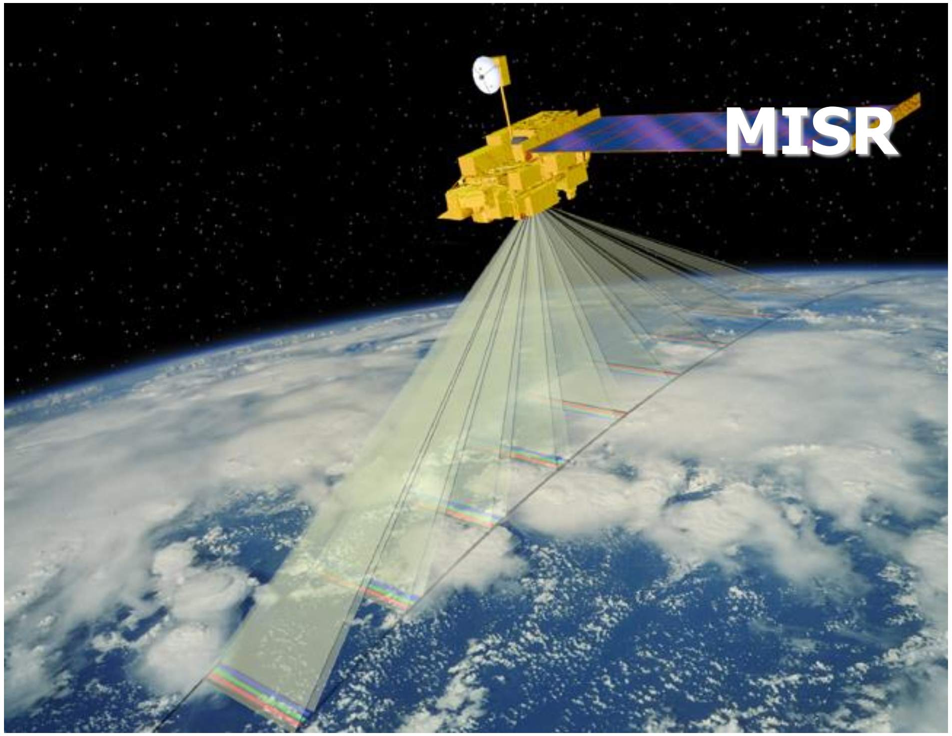
- Basics
  - What are the differences?
  - Which Orbits are mainly used?
  - Example of Orbits / Satellites
  - Observation geometry

- Satellite instruments
  - Where to find information about nearly all Satellite instruments?
  - Overview of a few often used satellite mission and instruments

Satellite orbits

Orbit:

- Controls the area on the Earth which is observable from a satellite
- Determines the projection and orientation of a satellite pixel, i.e. without knowledge about the orbit it is not possible to geolocate a pixel on the Earth‛s surface



MISR = Multi-Angle Imaging Spectro-Radiometer
Simultaneous Measurement of the reflected sunlight with 9 cameras (blue, green, red, near Infrared).
Suitable for measurements of Aerosols, type and height of clouds and vegetation type.

Abb.: MISR on Terra.

(NASA JPL MISR (2016): Mission http://misr.jpl.nasa.gov/Mission/ (Access: 2016-04-13).)

Circular Satellite orbit

Gravitational force: $F_g = -\frac{\gamma M m}{r^2}$ γ = gravitational constant = 6.673 x 10^{-11} Nm^2/kg^2

Centrifugal force: $F_c = -m\tilde{\omega}^2 = \frac{mv^2}{r}$

Equalizing the forces yield to ….

Angle velocity : $\tilde{\omega}^2 = \frac{\gamma M}{r^3}$

Orbit- or tangential velocity: $v = \sqrt{\frac{\gamma M}{r}}$

Revolution, period: $T = \frac{2\pi}{r} = 2\pi\sqrt{\frac{r^3}{\gamma M}}$

} Both depend only the height and not mass of satellite

Orbitalparameter – Definitions

- Apogee - point furthest from the earth
- Perigee - closest point to the earth
- Eccentricity - deviation from a circular orbit -> velocity almost const. (Link)
- Distance of a satellite from the centre of the earth:

Satellite orbits are elliptical!

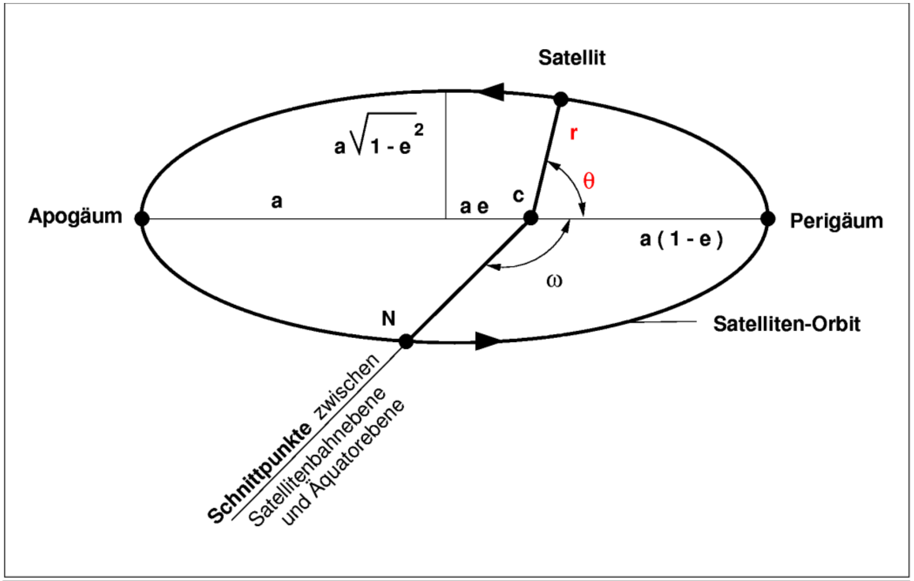
$$r = \frac{a(1-e^2)}{1+e\cos\theta}$$

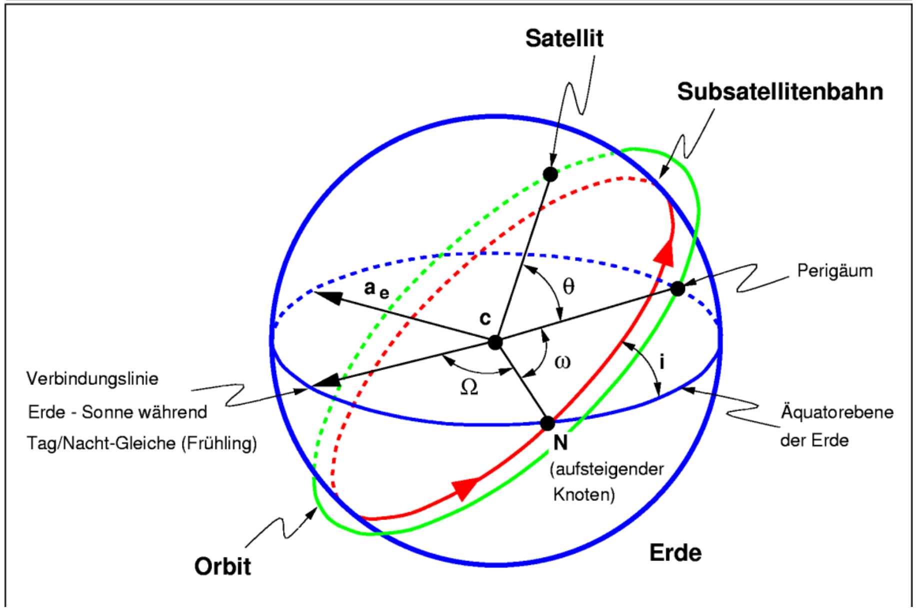
The position of the satellite on its orbit is determined by (θ, a, e)
The orbital plane is determined by 3 further parameters with regard to an inertial system:

- i: Inclination – the angle that the orbit has with the equator. It also determines the highest achievable latitude;
- Ω: Right ascension, angle between the x-axis (line connecting the earth and the sun at equinox) and the intersection of the ascending branch of the orbit with the equatorial plane
- ω: Angle between the ascending node and the perigee. (Link)

The position of a satellite is therefore given by 6 parameters!

Orbital parameter – Definitions





Orbital parameter – Environmental satellites

Most orbits of environmental satellite are almost circular orbits.

A few potential disruption:

- Aspheric gravitational potential (the Earth is not a sphere) -> important: That's the reason for precession.
- Gravitation from other bodies (Sun, moon,…)
- Radiation pressure (the Vikingsonde to Mars would have failed by 15.000 km without a corresponding correction).
- Collision with galactical particles (sun wind)
- air friction, important for orbits below 850 km
- Atmospheric buoyancy
- Electro-magnetic forces

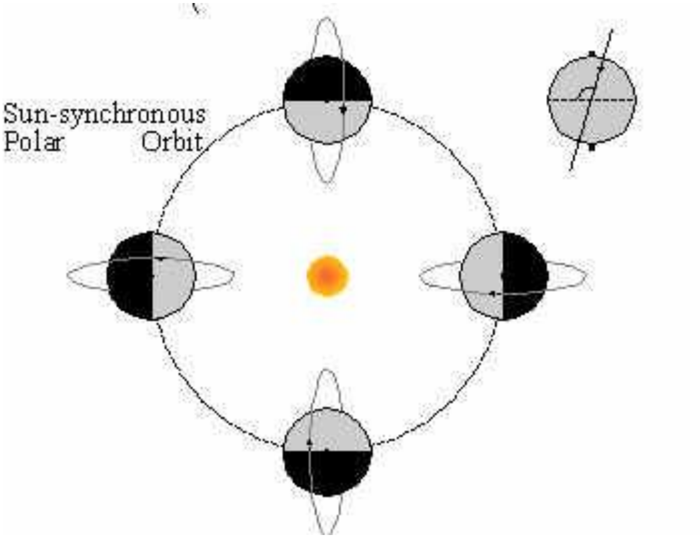
Usually the above disruptions are controlled by an adjustment of the orbit.

Sunsynchronous, polar Orbit (I)

The orbital perturbation caused by the non-spherical gravitational field can be used to advantage by selecting the inclination and orbital altitude so that the orbit is as precise as the Earth rotates around the sun.

A sun-synchronous orbit is therefore an orbit for which the orbital plane always remains the same in relation to the sun and the satellite flies over the equator at the same local time every day.

The orbit is not fixed, but must move at 1° per day to compensate for the Earth's rotation around the sun.



for 12.00 LT

for z ~ 1000 km,
i ~ 98 degrees
(90 degrees = North Pole)

Sunsynchronous, polar Orbit (II)

Local Time: $$LT \equiv UT + \frac{\Psi}{15°}$$

with: UT= universal time, GMT (Greenwich Meridian Time)
Ψ = geographic length (Grad)

equator crossing time (ECT): $$ECT = UT + \frac{\Psi_N}{15°}$$

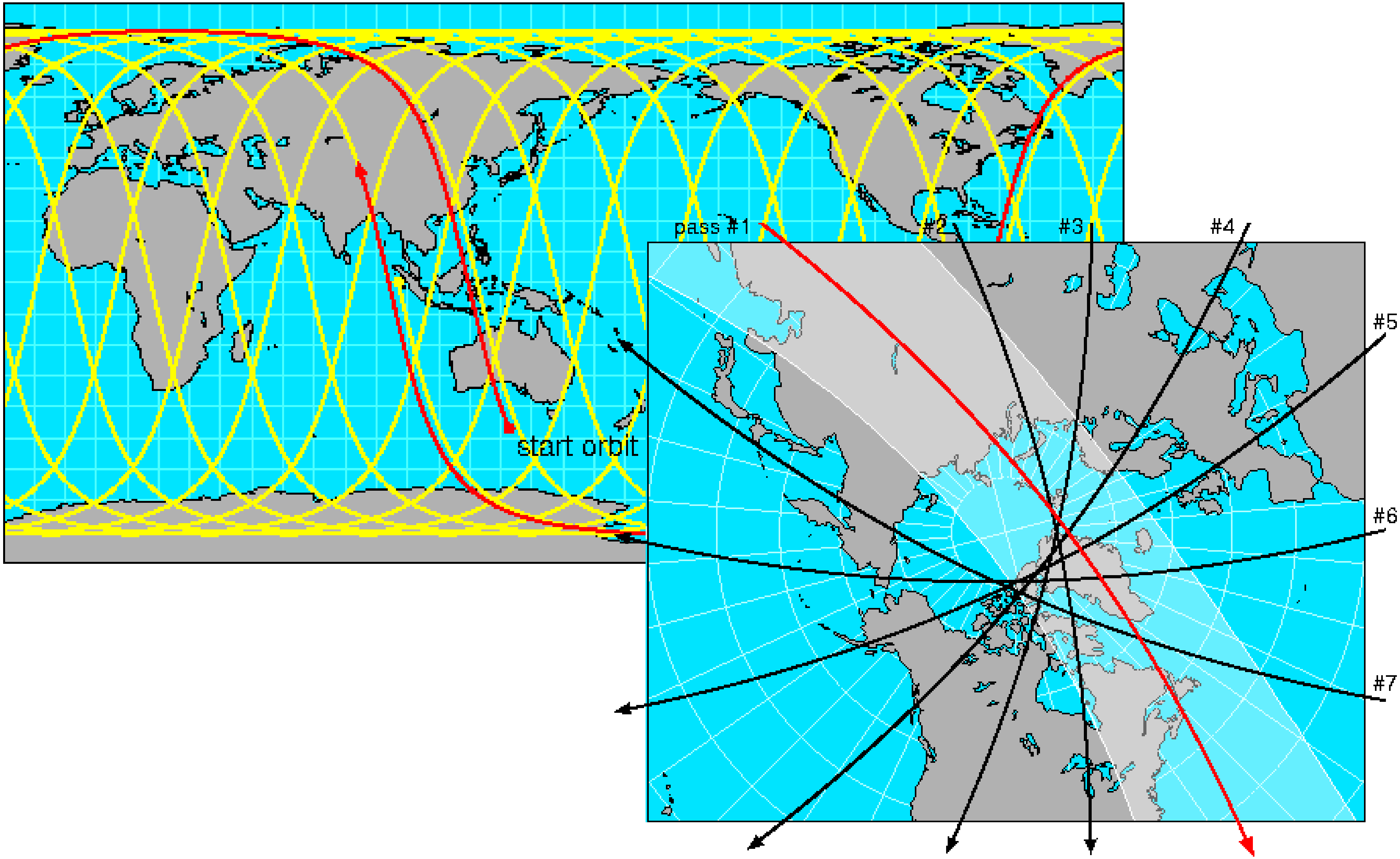
with: Ψ_N = Length of ascending or descending overpass

Length of sun : $\Psi_{Sonne} = -15°(UT - 12)$ with $\Delta\Psi = \Psi_N - \Psi_{Sonne}$

thus: $$ECT = 12 + \frac{\Delta\Psi}{15°}$$

$\Delta\Psi$ = const. for sunsynchronous Orbits, i.e. each satellite belongs to an ETC (Morning-, Noon-, Afternoon satellite)

Sunsynchronous, polar Orbit (III)



Geostationary Orbit

Subsatellite point (SSP) constantly at Equator

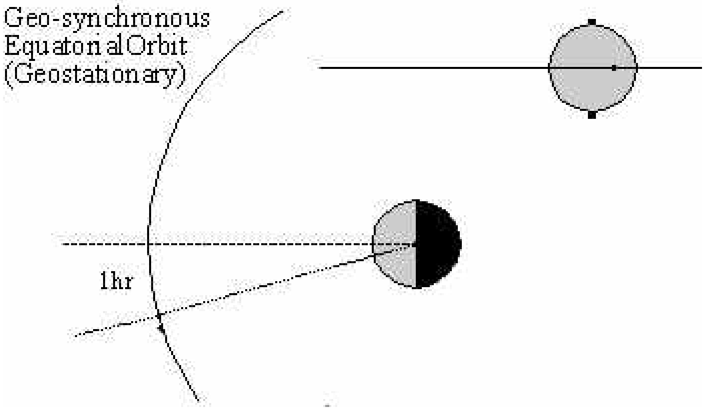
-> velocity of satellite is equal to rotation speed of Earth, Keplers 3. law:

$$T^2 = \frac{4\pi^2}{\gamma M (r+z)^3}$$

T = Period
γ = Gravitation constant
M = Mass of Earth
r = Radius of Earth
z = Height of satellite

Solution for z at a given T = 24 h

z = 35800 km



Satellitencomponent of Global Observing System (GOS)

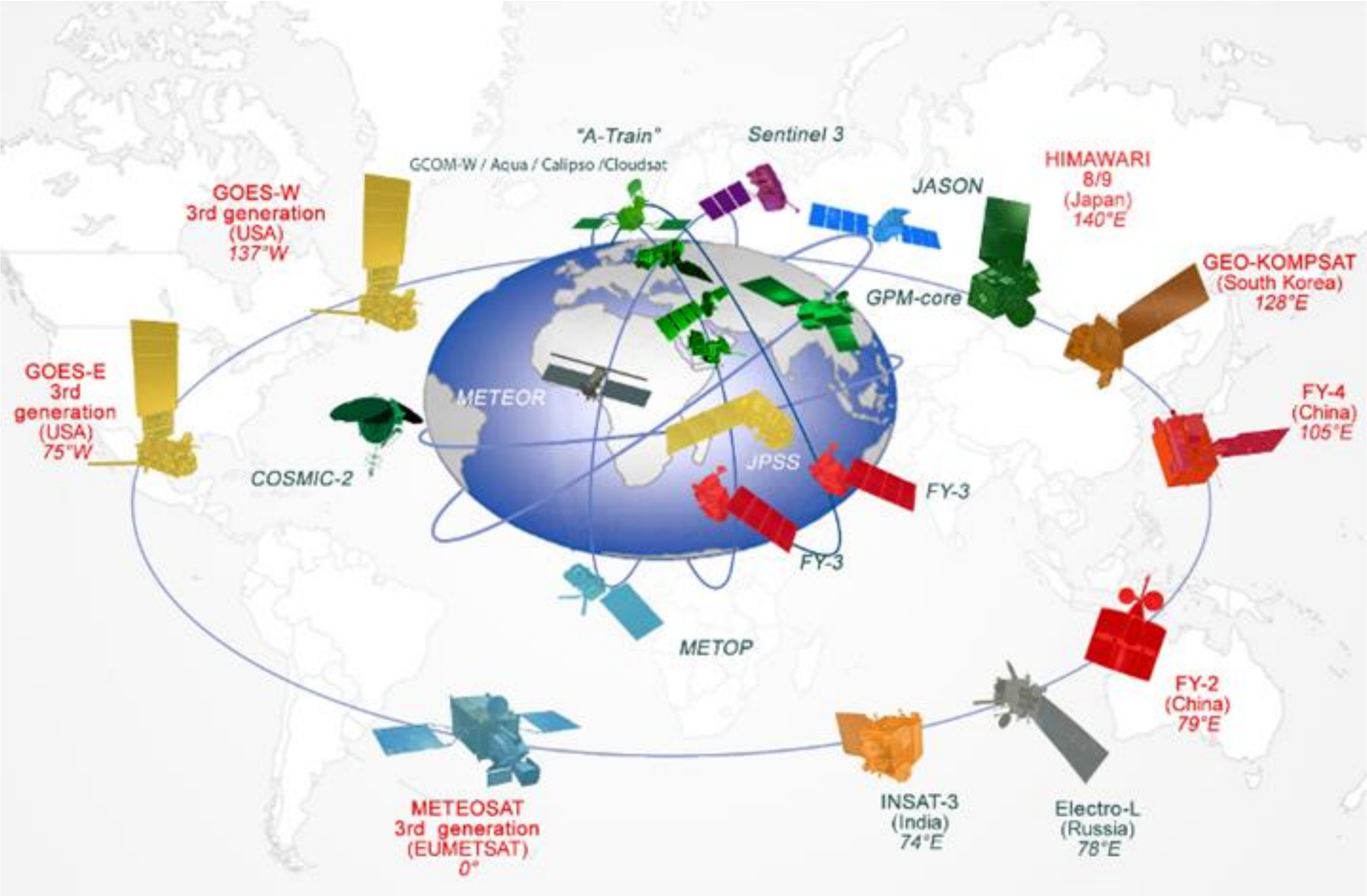
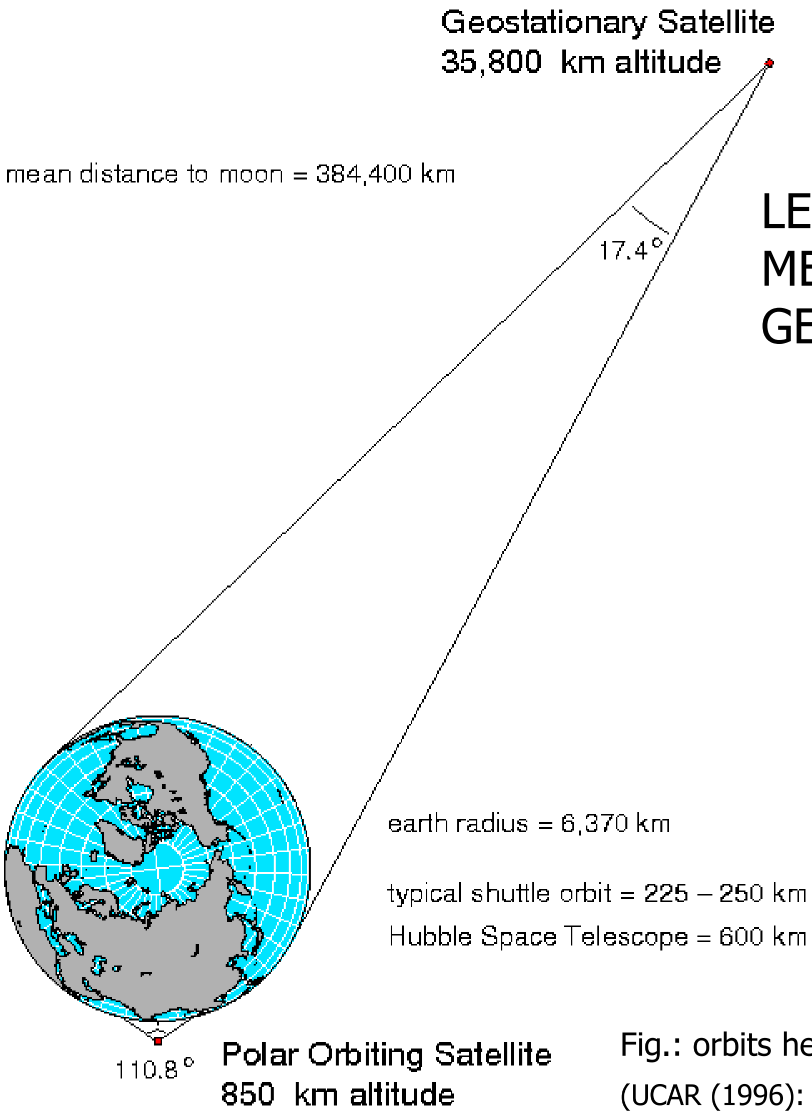


Fig.: Satellite component GOS.

(WMO (2025): Programmes. Space. Space-based GOS. Global Planning.
<https://wmo.int/activities/global-observing-system-gos/global-observing-system-gos>
(last access: 2025-04-12).)

Meteorological Orbits - Summary



LEO = Low Earth Orbit 300-1500 km
MEO= Medium Earth Orbit 8000-20000 km
GEO = Geostationary Orbit ~36000 km

Polar Orbits
the lower the orbital altitude:

- Shorter the period
- Less coverage of the surface
- Stronger signal
- Better spatial resolution
- Higher friction and shorter the lifetime

Fig.: orbits heights GEO and LEO.

(UCAR (1996): Satellite Coverages and Orbits. <http://www.rap.ucar.edu/~djohnson/satellite/coverage.html> (last access: 2016-04-13).)

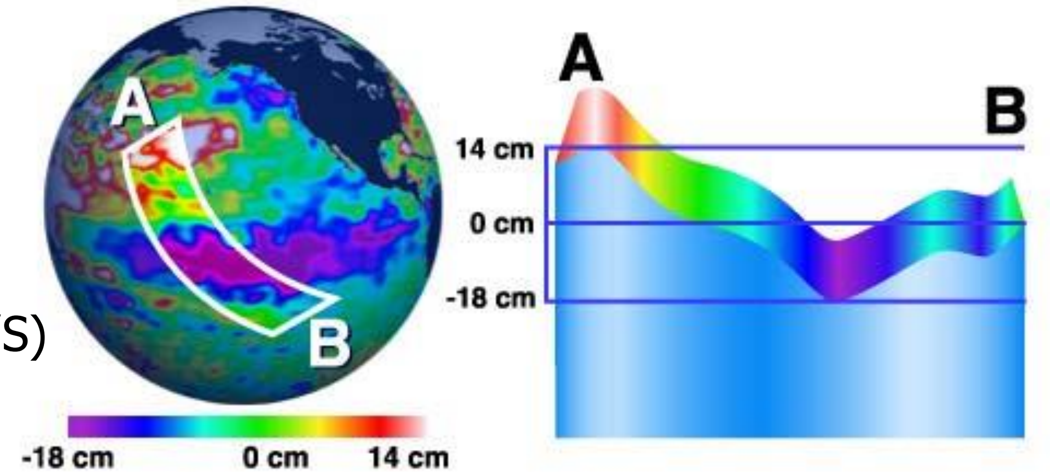
Special Orbits (I)

Example: TOPEX/POSEIDON (USA, France, 1992)

- Surface height (changes e.g. due to tide) with 13 cm accuracy
- Drift by the sun, i.e. always the same measurement with sun-synchronised orbit
- Objectives:
  - Equidistant grid of overflights
  - Angle of 45° between the overflights to measure the surface inclination in east-west and north-south -> no polar or tropical orbits
  - coverage of high latitudes

- Result:
  - Height 1334 km
  - Inclination 66°

  -> 45° intersection angle (30° N/S)



special orbits (II)

Example GRACE (Gravity Recovery and Climate Experiment): Measurement of the earth's gravitational field

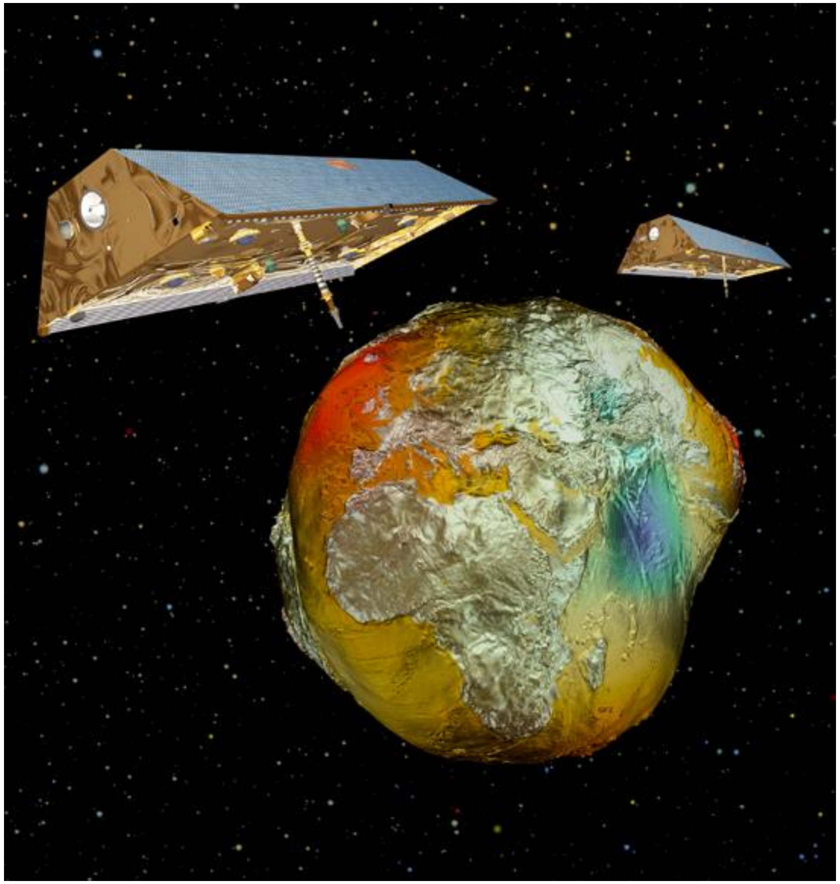


Fig.: The GRACE satellite twins with the Earth's gravitational field (in greatly exaggerated form).

(GFZ (2012): Schwerkraft ist Klima. <http://www.gfz-potsdam.de/pressemitteilungen/article/schwerkraft-ist-klima/> (last access: 2016-04-13).)

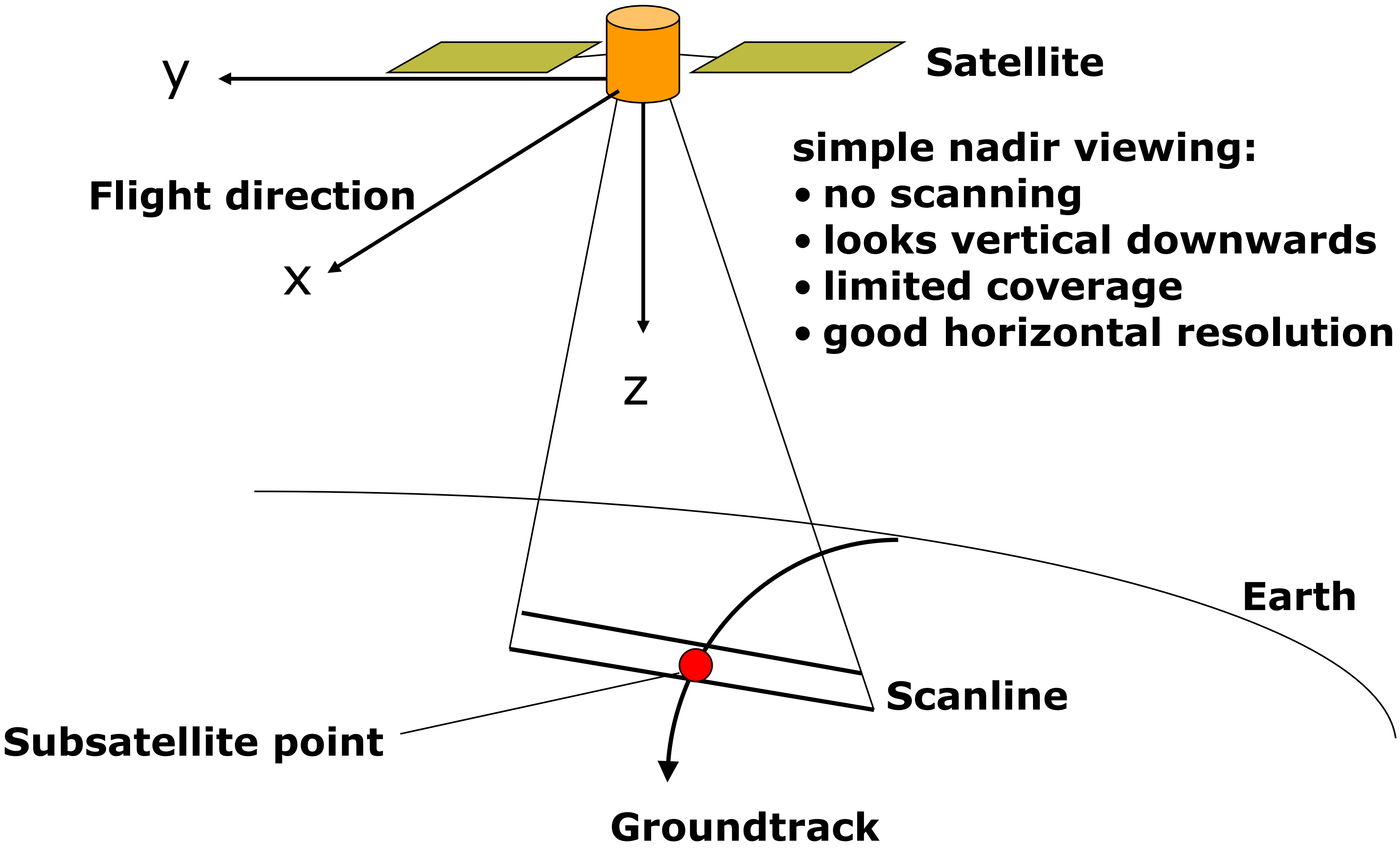
- Dependence of the gravitational field exclusively on the internal structure

  -> no sun-synchronous orbit necessary
- Detection of small changes in the gravitational field

  -> lowest possible orbit

- **Optimum orbit:**
  - height: ~160 km (Burning up at even lower altitudes)
  - Inclination: 90°

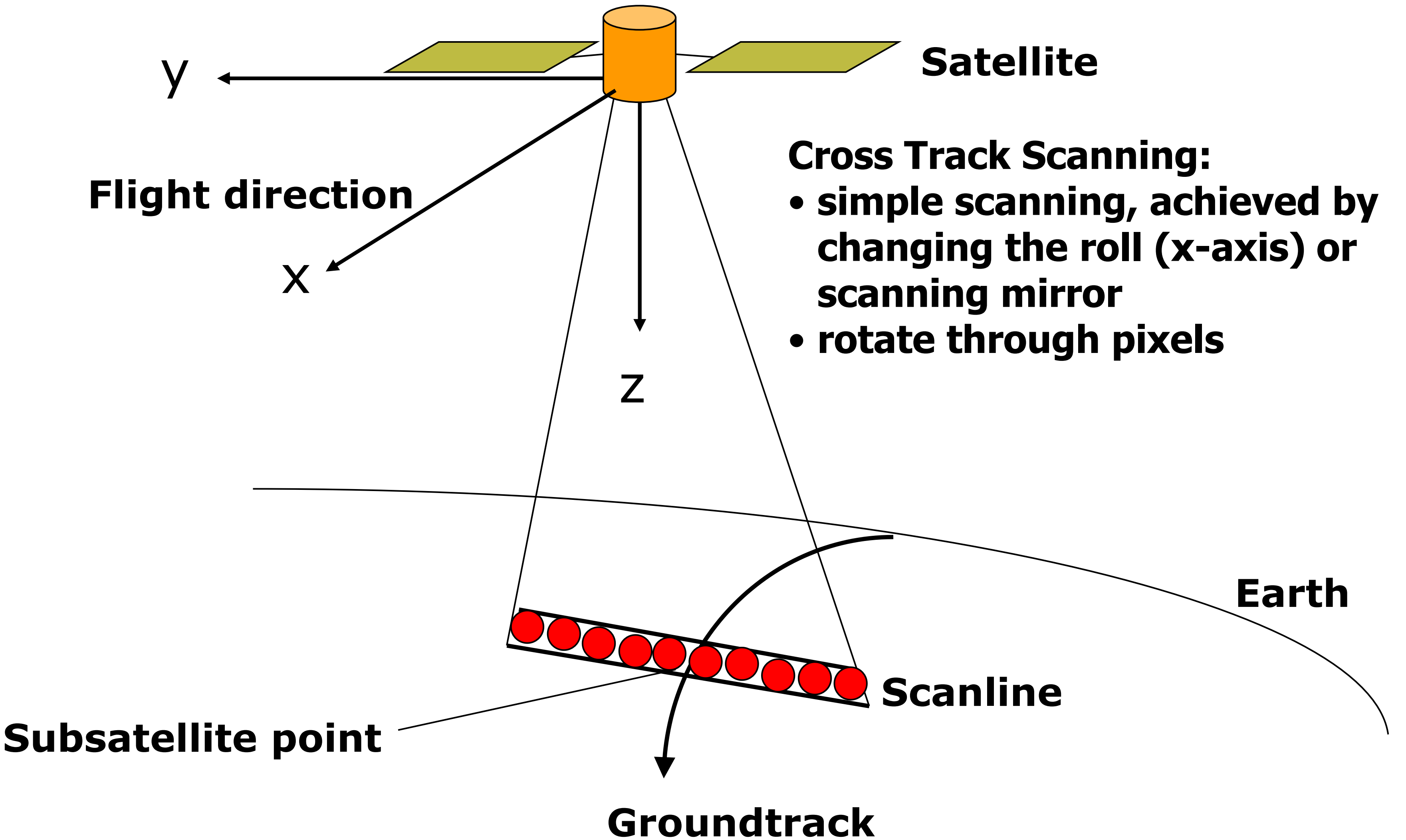
Observation geometry



simple nadir viewing:

- no scanning
- looks vertical downwards
- limited coverage
- good horizontal resolution

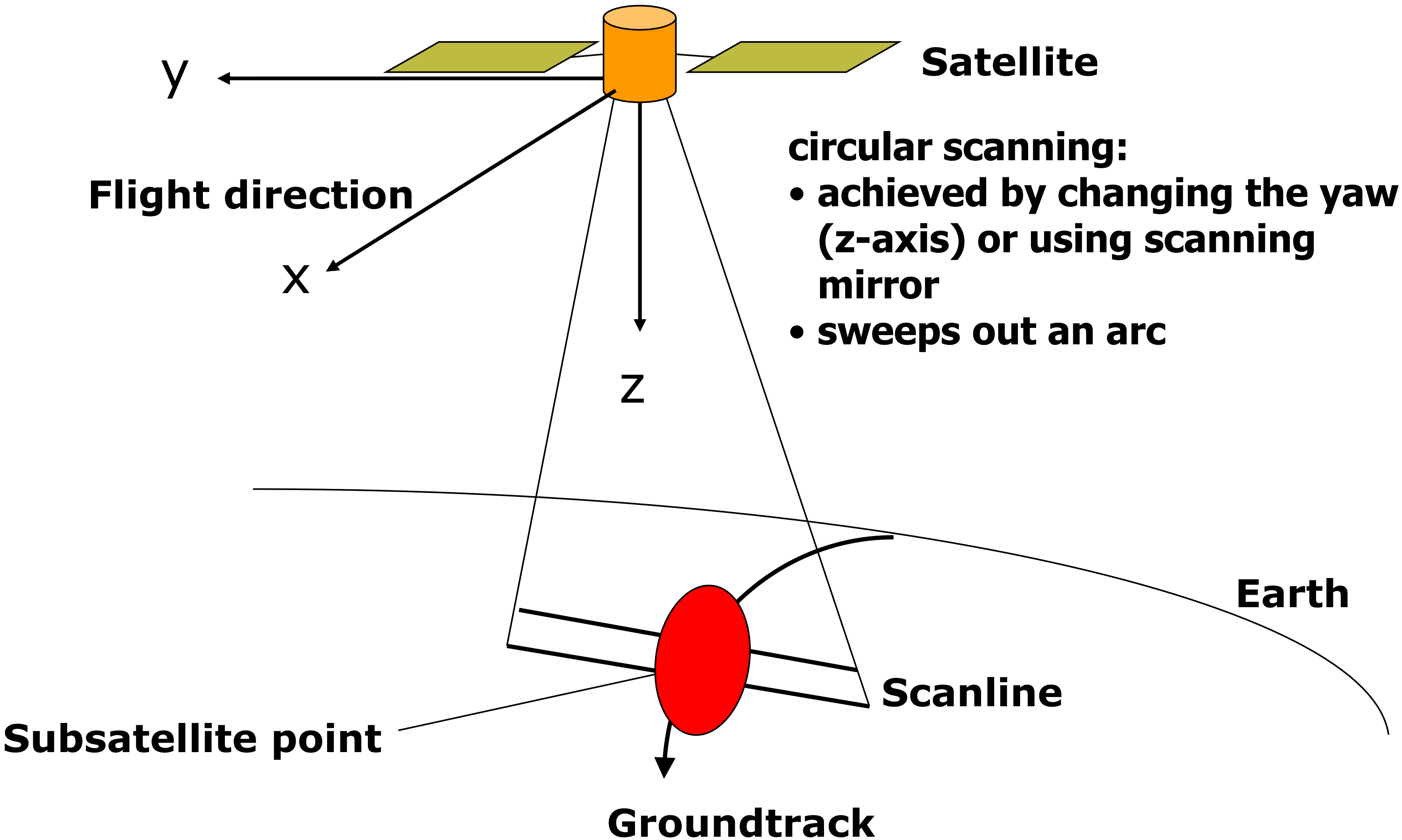
Observation geometry



Cross Track Scanning:

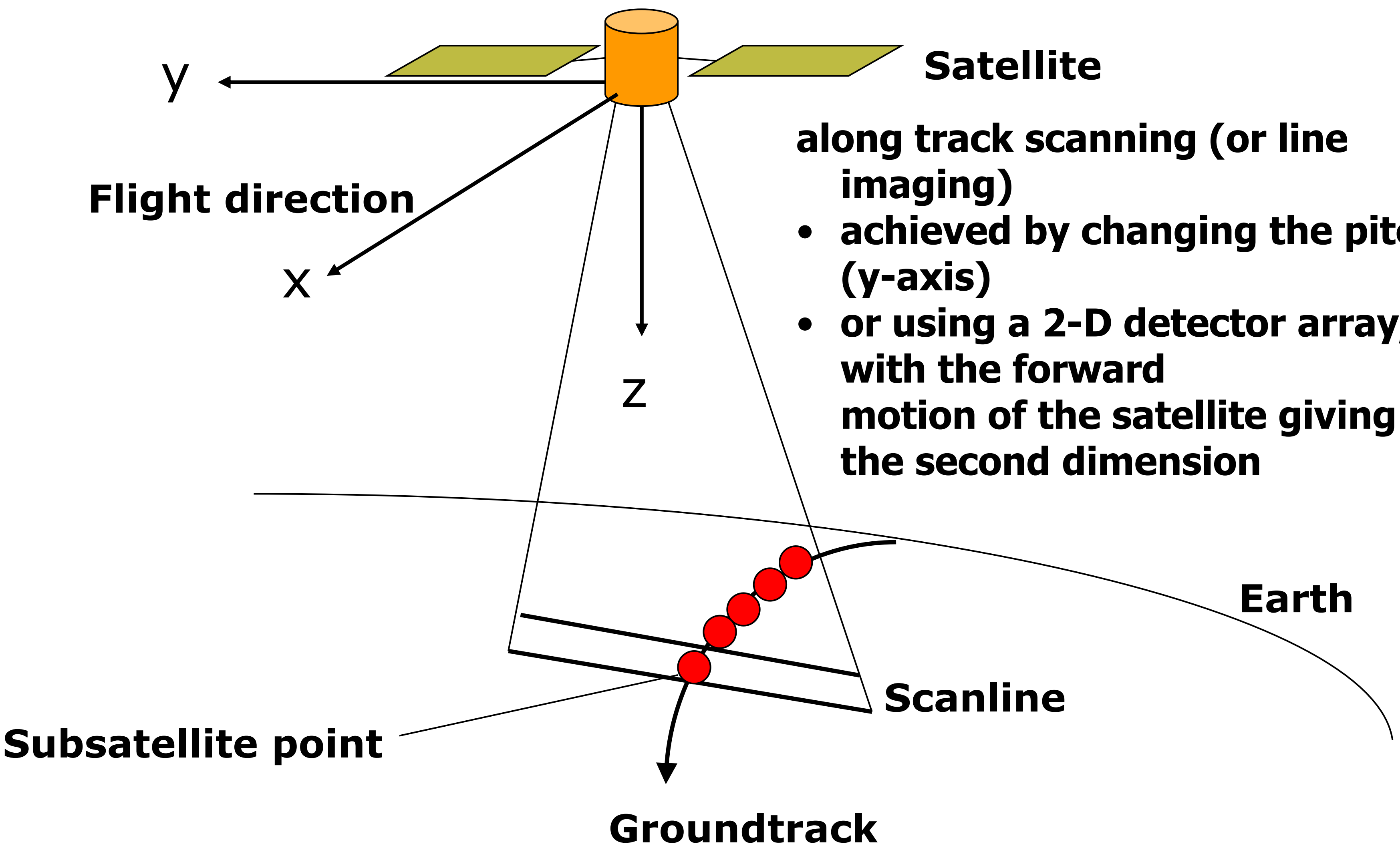
- **simple scanning, achieved by changing the roll (x-axis) or scanning mirror**
- **rotate through pixels**

Observation geometry



circular scanning:
- **achieved by changing the yaw (z-axis) or using scanning mirror**
- **sweeps out an arc**

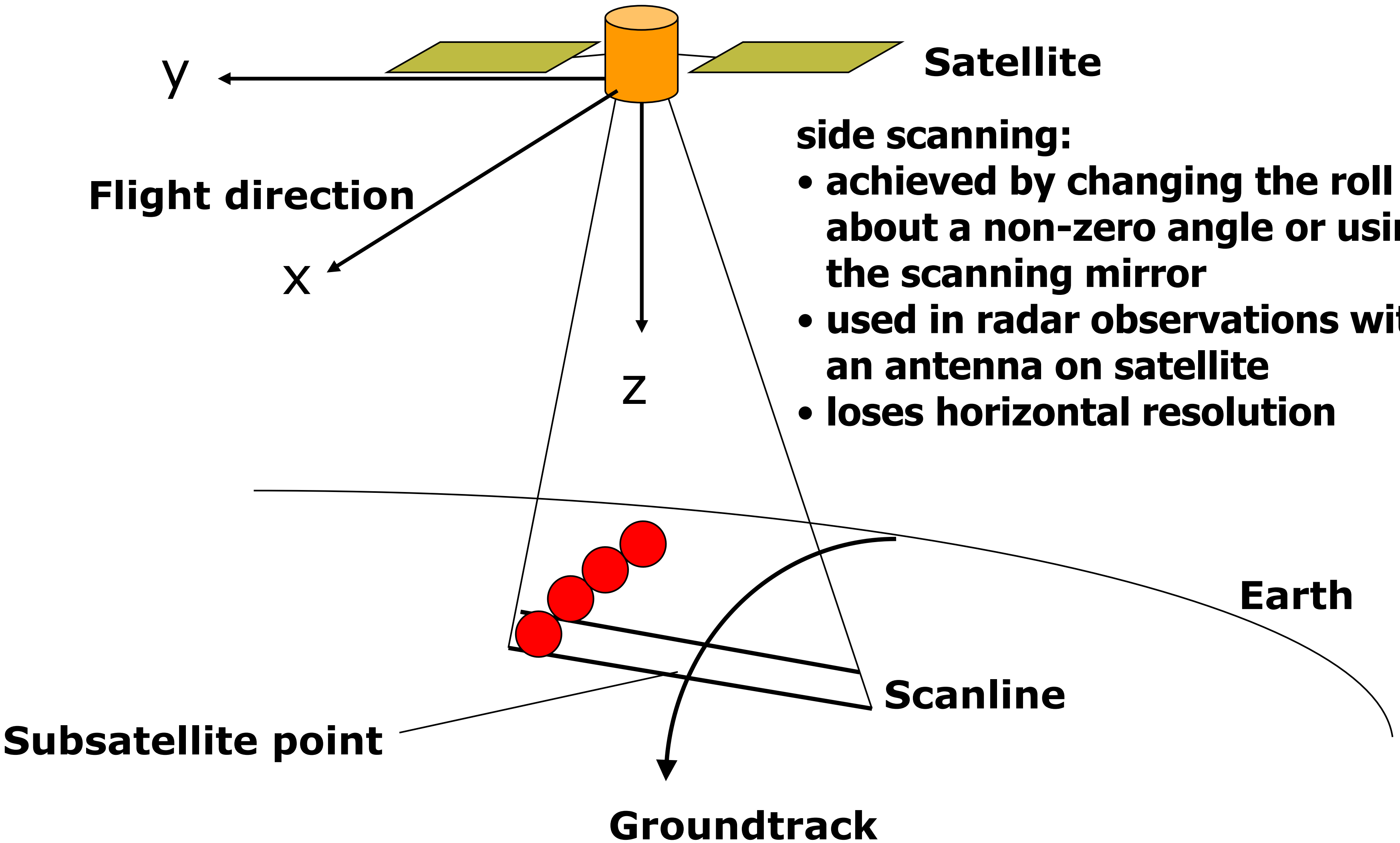
Observation geometry



along track scanning (or line imaging)

- **achieved by changing the pitch (y-axis)**
- **or using a 2-D detector array, with the forward motion of the satellite giving the second dimension**

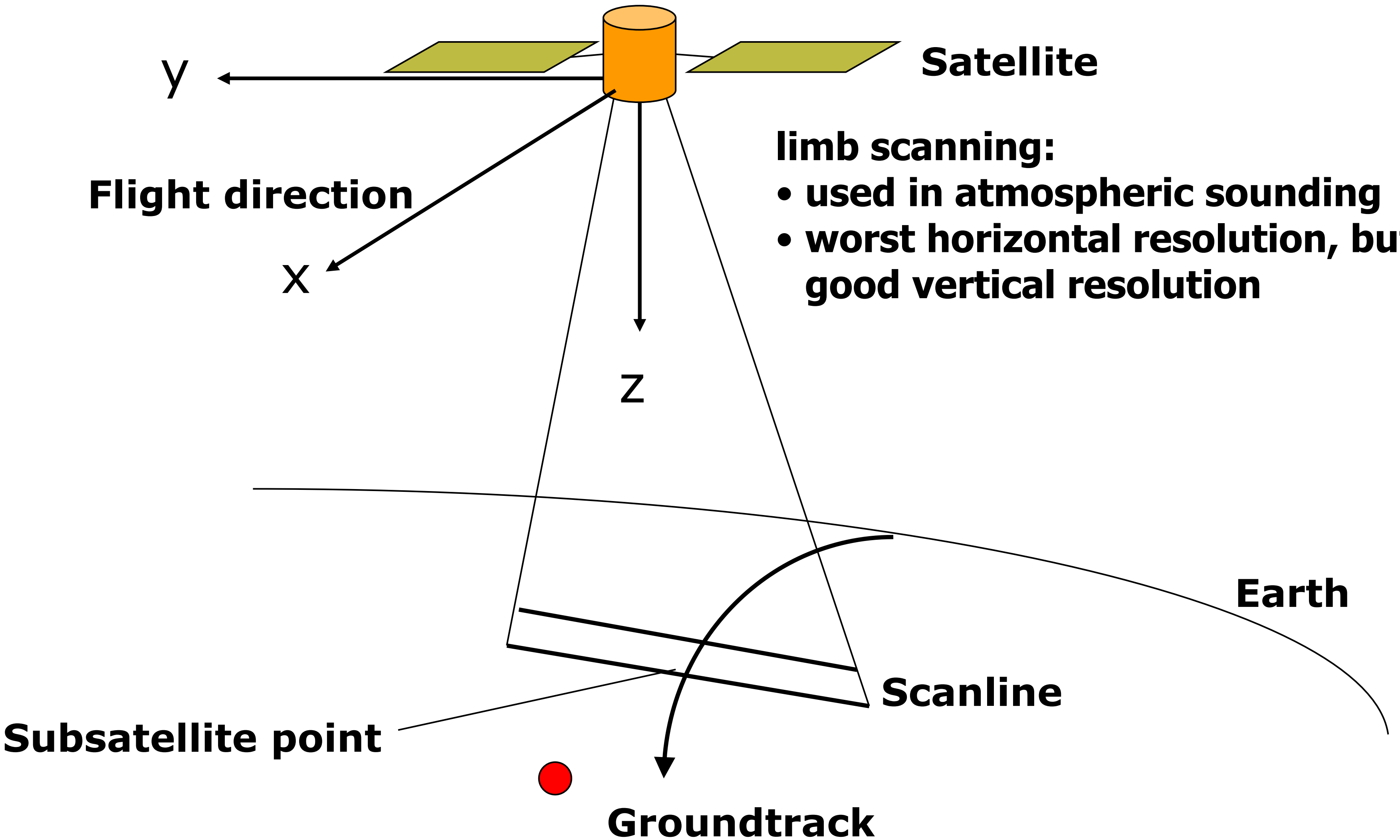
Observation geometry



side scanning:

- **achieved by changing the roll about a non-zero angle or using the scanning mirror**
- **used in radar observations with an antenna on satellite**
- **loses horizontal resolution**

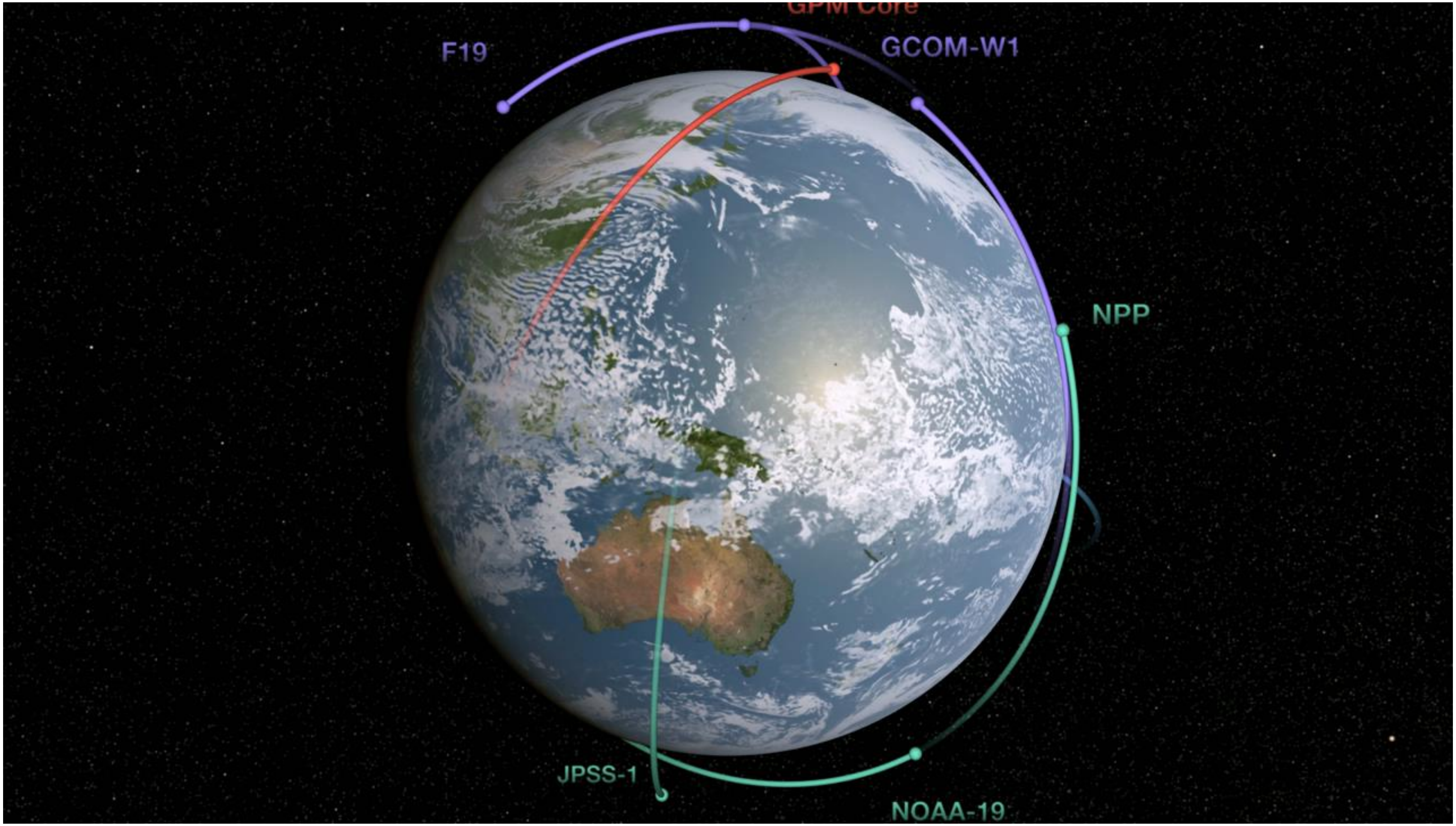
Observation geometry



limb scanning:
- **used in atmospheric sounding**
- **worst horizontal resolution, but good vertical resolution**

Interplay of several missions on different orbits

Source NASA



Satellite combination

Example for in sequence flying satellites:

American A-Train, consists of AQUA, CALIPSO, CloudSat, AURA

Satellite orbits and instruments

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WMO OSCAR

https://www.wmo-sat.info/oscar/

➔ Observing Systems Capability Analysis and Review Tool

- ➔ Main pillar of Rolling Review Requirements (RRR) Process (Comparison of requirements with actual and planned capacities)
- ➔ Support to the WIGOS (WMO Global Observing System)
- ➔ Information to support applications, studies and for global co-ordination for earth observation

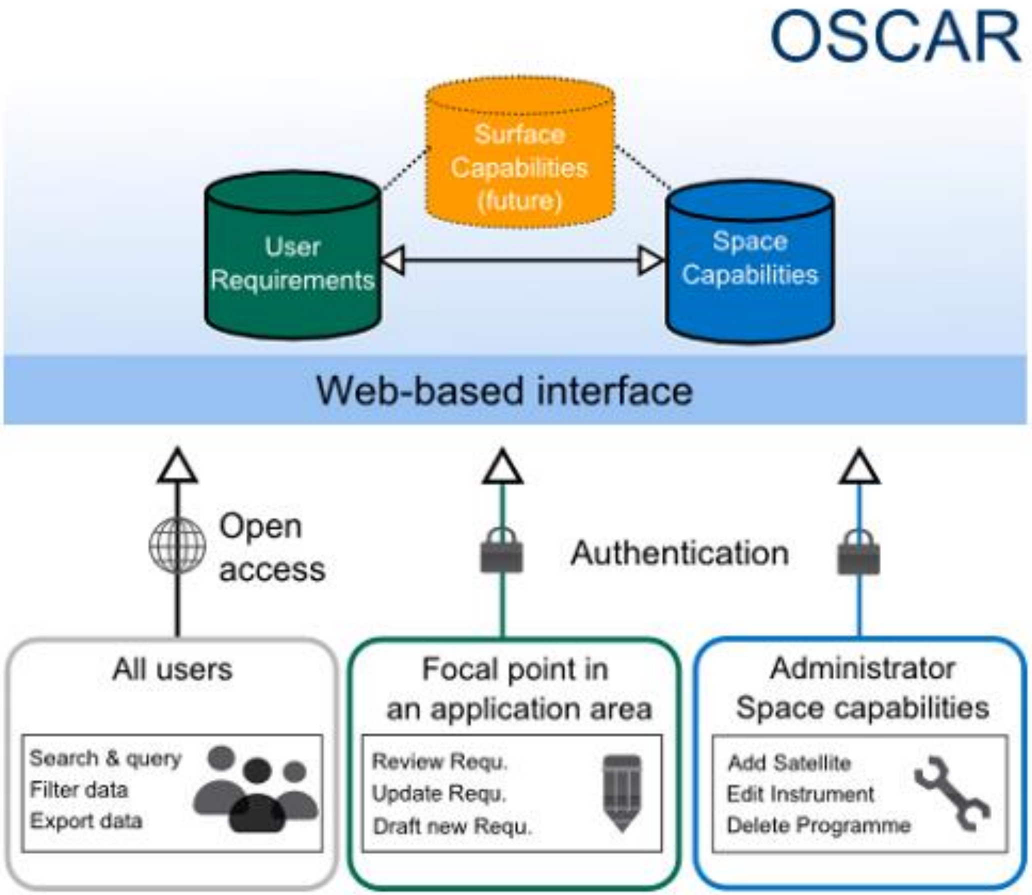

Abb.: Concept of WMO OSCAR.
(WMO (2016): OSCAR. http://www.wmo-sat.info/oscar/ (access: 2016-04-08).)

WMO OSCAR

- 3 Modules: with search function and thematic overview tables to filter and export detailed information
- Modul 1: Observation / User Requirements
  - Quantitative user defined requirements on physical variables for the WMO application areas (related to Weather, Climate, Water)
  - Overview tables: Variables, Requirements, vertical layers, application areas, specific themes
- Modul 2: Satellite / Space based Capabilities
  - Information earth observing satellites & instruments
  - Analyse tools: Capability Review, Gap Analysis by Variable
- Modul 3: Surface based Capabilities (not available)

WMO OSCAR

https://www.wmo-sat.info/oscar/

A short exercise

➔ I Which instruments are onboard the Envisat satellite?

➔ II Which instruments can be used to measure total solar irradiance?

➔ III What is the ABI instrument and on which satellite?

WMO OSCAR

https://www.wmo-sat.info/oscar/

A short exercise (solution)

→ I Which instruments are onboard the Envisat satellite?

Satellite Payload

All known Instruments flying on Envisat

Acronym	Full name
AATSR	Advanced Along-Track Scanning Radiometer
ASAR	Advanced Synthetic Aperture Radar
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
GOMOS	Global Ozone Monitoring by Occultation of Stars
LRR	Laser Retro-Reflector
MERIS	Medium Resolution Imaging Spectrometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MWR	Micro-Wave Radiometer
RA-2	Radar Altimeter - 2
SCIAMACHY-limb	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (limb-scanning component)
SCIAMACHY-nadir	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (nadir-scanning component)

WMO OSCAR

https://www.wmo-sat.info/oscar/

A short exercise (solution II)

→ II Which instruments can be used to measure total solar irradiance?

Search for	Agency	Instrument types	Spectral domain	Expert search	Orbit	Years of operation
total solar irradiance		Select	First select instrument type	First select instrument type	Select	Select

Acronym	Full Name	Providing agency	Instrument type	Flying on satellites	Usage from	Usage to
ACRIM-I	Active Cavity Radiometer Irradiance Monitoring - I	NASA	Solar irradiance monitor	SMM	1980	1989
ACRIM-II	Active Cavity Radiometer Irradiance Monitoring - II	NASA	Solar irradiance monitor	UARS	1991	2005
ACRIM-III	Active Cavity Radiometer Irradiance Monitoring - III	NASA	Solar irradiance monitor	ACRIMSat	2000	2013
BUV	Backscatter Ultraviolet Spectrometer	NASA	Cross-nadir scanning SW sounder	Nimbus-4	1970	1980
CERES	Clouds and the Earth's Radiant Energy System	NASA	Broad band radiometer	Aqua NOAA-20 SNPP TRMM Terra	1998	2031
CSAR	Cryogenic Solar Absolute Radiometer	ESA	Solar irradiance monitor	TRUTHS	2031	2041
CTIM-FD	Compact Total Irradiance Monitor-Flight Demonstration	NASA	Solar irradiance monitor	CTIM-FD	2022	2024
DIFOS	Solar Flux Optical Photometer	Roscosmos	Solar irradiance monitor	Coronas-F Coronas-I	1994	2005
ERB	Earth Radiation Budget	NASA	Broad band radiometer	Nimbus-6 Nimbus-7	1975	1994

WMO OSCAR

https://www.wmo-sat.info/oscar/

A short exercise (solution III)

→ What is the ABI instrument and on which satellite(s)?

ABI	Advanced Baseline Imager	NOAA	Moderate-resolution optical imager	GOES-16 GOES-17 GOES-18 GOES-19	2017	2040

Instrument details

Acronym	ABI				
Full name	Advanced Baseline Imager				
Purpose	Multi-purpose VIS/IR imagery and wind derivation by tracking clouds and water vapour features				
Short description	16 channels, balanced VIS, NIR, SWIR, MWIR and TIR [see detailed characteristics below]				
Background	Replacing IMAGER flown on GOES 8 to 15				
Scanning Technique	Mechanical, 3-axis stabilised satellite, E-W continuous, S-N stepping				
Resolution	Changing with channel (see table)				
Coverage / Cycle	Full disk every 15 min, 3000 x 5000 km2 ("CONUS", Continental U.S.) in 5 min, 1000 x 1000 km2 in 30 s				
Mass	338 kg	**Power**	450 W	**Data Rate**	66 Mbps

Satellite orbits and instruments

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Details of a few often used satellite instruments

- → AVHRR
- → SCIAMACHY
- → SEVIRI – MVIRI
- → (OLCI – MERIS)
- → SLSTR – (A)ATSR
- → MODIS
- → CALIOP / Cloudsat
- → SSM/I + SSMIS
- → ATOVS / TOVS / HIRS
- → GOME – SCIA – OMI
- → (POLDER)

AVHRR (Advanced Very High Resolution Radiometer)

Sensor	AVHRR/1	AVHRR/2	AVHRR/3
Years	1978–2001	1981–2007	1998–2024
Satellite	NOAA-6, 8, 10 TIROS-N	NOAA-7, 9, 11, 12, 13, 14	NOAA-15, 16, 17, 18, 19, Metop-A, B, C
Satellite type	LEO		
Sensor type	Moderate Resolution Imager		
Pixel	1.1 km IFOV (SSP)		
Coverage	Global, 2/Day IR, 1/Day VIS		
Spectral coverage	5 Channels (VIS, IR)		
Channel #	λ [μm]	λ [μm]	λ [μm]
1	0.58–0.68	0.58–0.68	0.58–0.68
2	0.725–1.10	0.725–1.00	0.725–1.00
3A	-	-	1.58–1.64
3B	3.55–3.93	3.55–3.93	3.55–3.93
4	10.50–11.50	10.30–11.30	10.30–11.30
5	Ch 4 repeated	11.50–12.50	11.50–12.50
Application area	Cloud remote sensing, Radiation, Composites e.g. VIS, IR		
Important for	Sea-ice cover, aerosol volcanic ash, cloud cover, …		

AVHRR (Advanced Very High Resolution Radiometer)

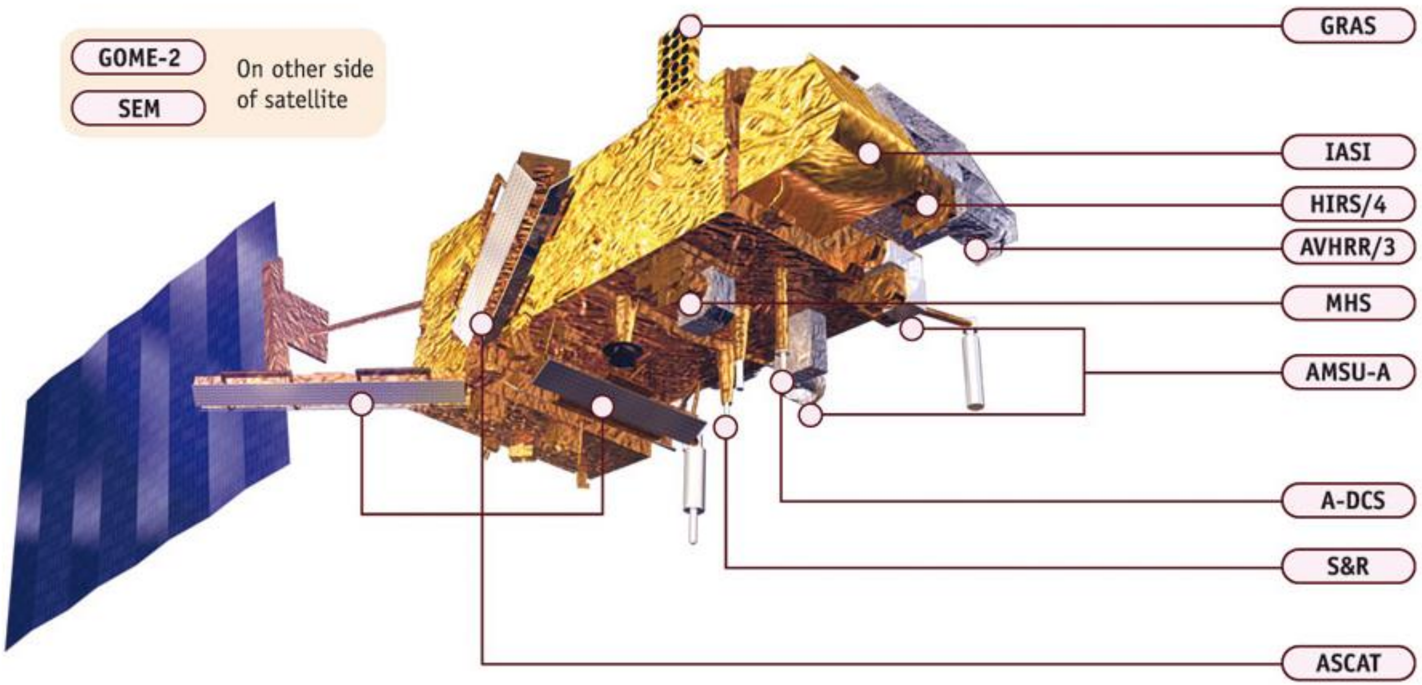


Abb.: Metop with Instruments.

(EUMETSAT (2016): METOP DESIGN.<http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/index.html> (Access: 2016-04-11).)

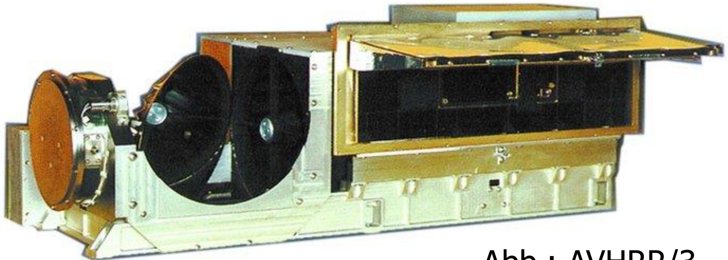


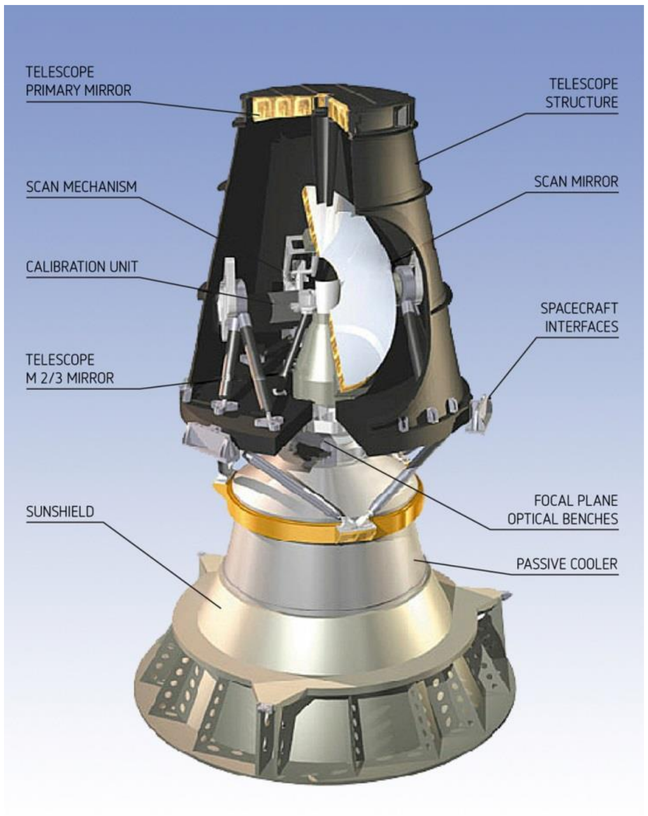
Abb.: AVHRR/3.

(NASA PO.DAAC (2016): AVHRR-Pathfinder. AVHRR Instrument. <http://podaac.jpl.nasa.gov/sites/default/files/ocean-story/images/AVHRR_instrument_node_full_image_2.jpg> (Access: 2016-04-11).)

SEVIRI (Spinning Enhanced Visible Infra-Red Imager)
MVIRI (Meteosat Visible Infra-Red Imager)

Sensor	SEVIRI	MVIRI
Years	2004–2022+	1978–2017+
Satellite	Meteosat-8, 9, 10, 11	Meteosat-1, 2, 3, 3 (ADC), 3 (X-ADC), 4, 5, 5 (IODC), 6, 6 (IODC), 7, 7 (IODC)
Satellite type	GEO	
Sensor type	Moderate-resolution optical imager	
Pixel	4.8 km IFOV (3 km sampling), broadband 1.6 km IFOV (1 km sampling)	5.0 km IFOV IR, 2.5 km IFOV VIS
Coverage	Meteosat Disc, every 15 Min.	Meteosat Disc, every 30 Min.
Spectral coverage	11 channel (VIS, IR; 0.635 ± 0.075 µm – 13.4 ± 1 µm) + broadband 0.6–0.9 µm	3 channel (VIS, TIR): 0,70 ± 0.1 µm, 6.4 ± 0.7 µm, 11.5 ± 1.0 µm
Application area	Nowcasting, atmospheric motion vectors, composites Mulit-image composites (VIS, IR)	
Important for	Aerosol volcanic ash, soil moisture at surface, cloud proerties, + lot more	

SEVIRI (Spinning Enhanced Visible Infra-Red Imager)
MVIRI (Meteosat Visible Infra-Red Imager)



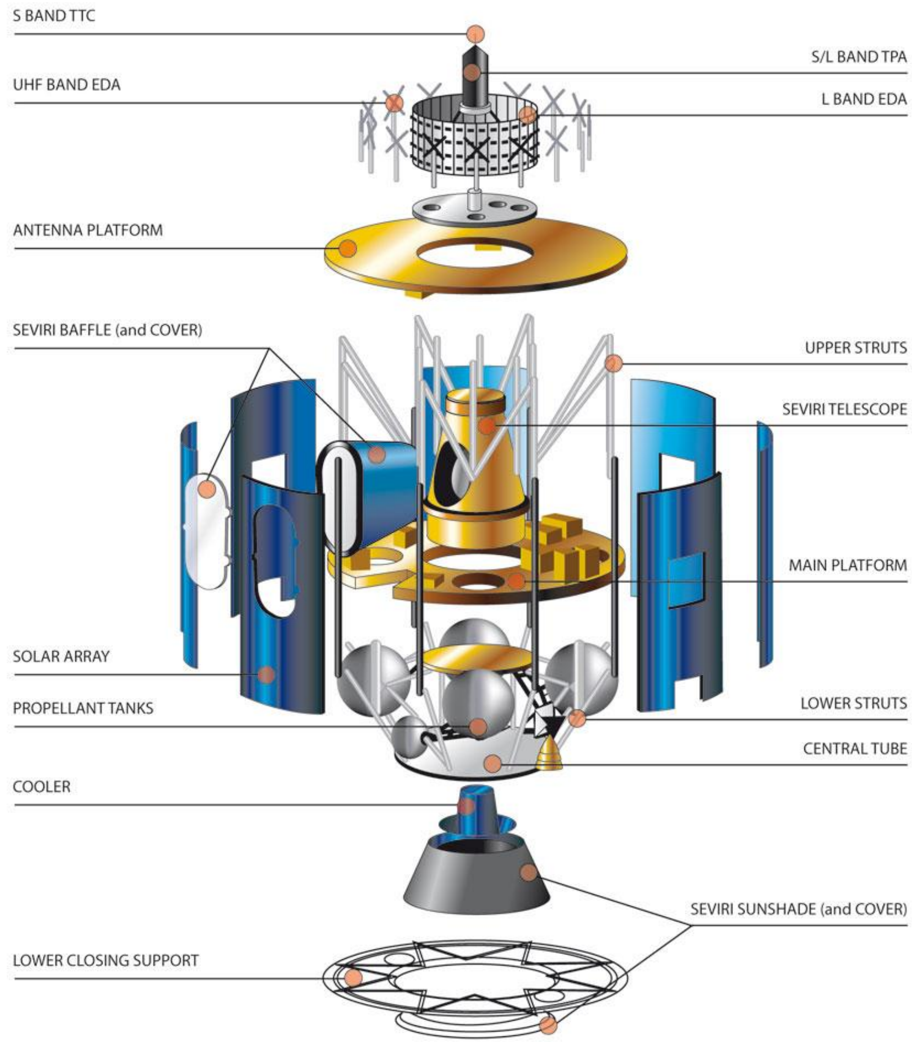
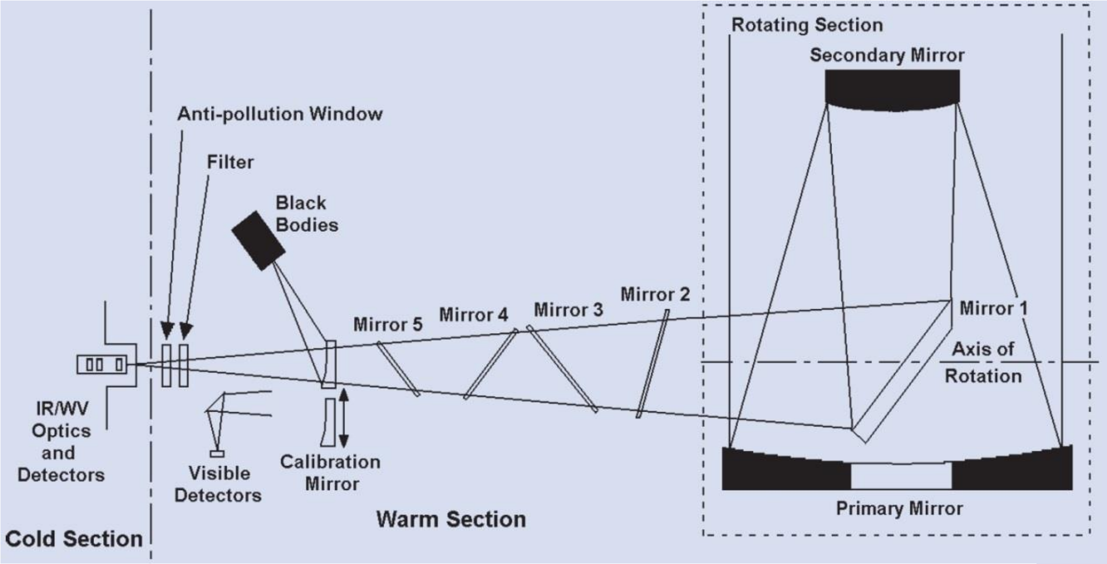


Abb.: SEVIRI (l.) and Meteosat design (r.).

(EUMETSAT (2016): Meteosat Design. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/MeteosatDesign/index.html> (access: 2016-04-11).)

SEVIRI (Spinning Enhanced Visible Infra-Red Imager)

MVIRI (Meteosat Visible Infra-Red Imager)



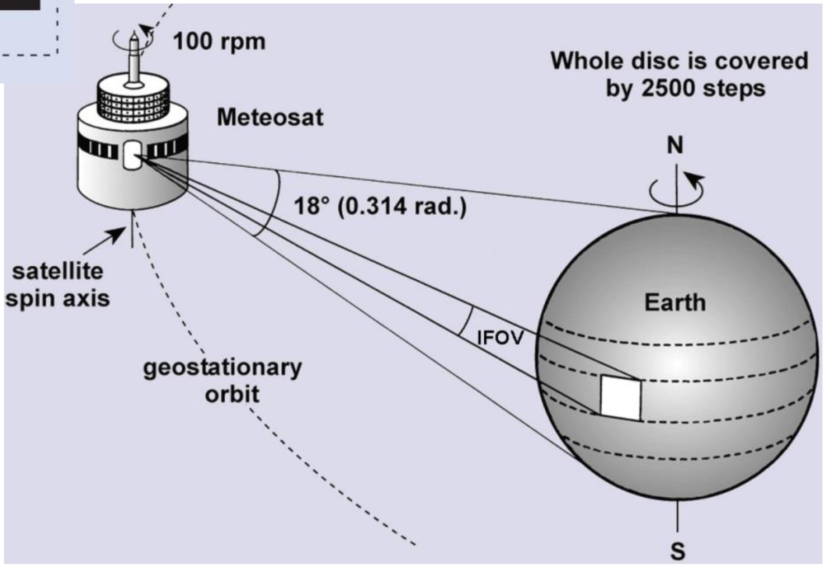


Abb.: MVIRI. Schema (l.o.), scan pattern (r.u.)

(EUMETSAT (1998): The Meteosat System. Satellites, Ground Segment, Missions, Global Coordination. EUM TD 05. Darmstadt: EUMETSAT.)

OLCI (Ocean and Land Colour Imager)
MERIS (MEdium Resolution Imaging Spectrometer)

Sensor	OLCI	MERIS
Years	2016–2024+	2002–2012
Satellite	Sentinel-3A, 3B	Envisat
Satellite type	LEO	
Sensor type	Moderate-resolution optical imager	
Pixel	300 m	Basis-IFOV 300 m (1200 m)
Coverage	Global in 2 days, daylight only	Global in 3 days, daylight only
Spectral coverage	21 channel (VIS, NIR): 400 ± 7.5 nm – 1020 ± 20 nm	15 channel (VIS,NIR): 412.5 ± 5 nm – 900 ±5 nm
Application Areas	Cloud properties	Atmospheric properties
	Ocean colour, Aerosols, Vegetation, composites e.g. VIS, IR	
Important for	Ocean Diffuse Attenuation Coefficient (DAC), Colour Dissolved Organic Matter (CDOM), ocean chlorophyll concentration, NDVI, …	

OLCI (Ocean and Land Colour Imager)

MERIS (MEdium Resolution Imaging Spectrometer)

Abb.: OLCI.

(ESA (2016): Missions. Sentinel-3. Instrument Payload. OLCI. <https://sentinel.esa.int/web/sentinel/missions/sentinel-3/instrument-payload/olci> (access: 2016-04-11).)

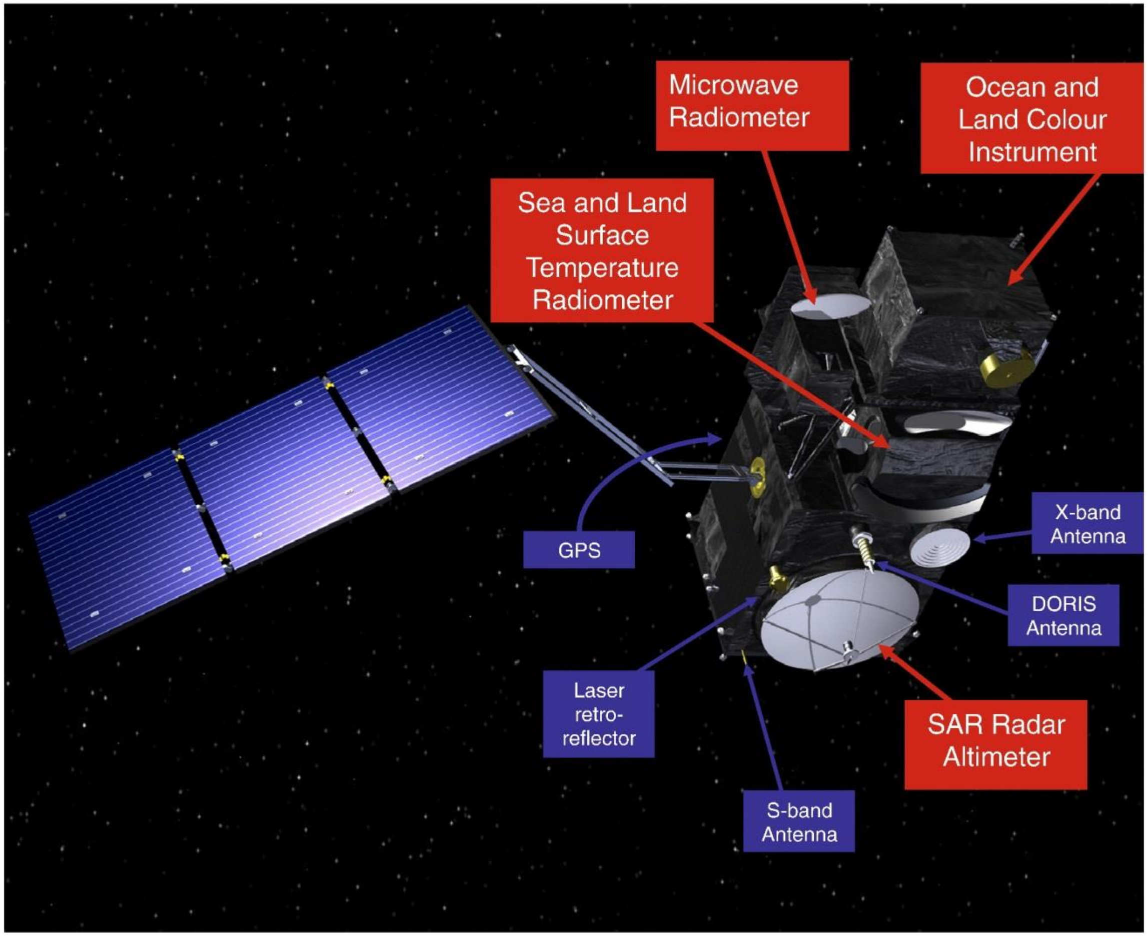


Abb.: Sentinel-3.

(ESA (2016): Missions. Sentinel-3. Instrument Payload. <https://sentinel.esa.int/web/sentinel/missions/sentinel-3/instrument-payload> (access: 2016-04-11).)

OLCI (Ocean and Land Colour Imager)

MERIS (MEdium Resolution Imaging Spectrometer)

Abb.: Envisat

(ESA (2002): Envisat, Artist's Impression. ESA/Denmann production. <http://www.esa.int/spaceinimages/Images/2002/02/Envisat_satellite_artist_s_impression> (access 2016-04-12).)

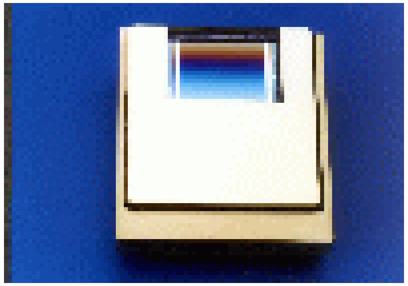


Abb.: MERIS CCD detectors.

(ESA (2016): Missions. ESA EO Missions. Envisat. MERIS. Design Hardware. Image courtesy of Alcatel. <https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/meris/design#_56_INSTANCE_X9zC_matmp> (access: 2016-04-12).)

SLSTR (Sea and Land Surface Temperature Radiometer)
(A)ATSR((Advanced) Along-Track Scanning Radiometer)

Sensor	SLSTR	AATSR	ATSR-2	ATSR
Years	2016–2024+	2002–2012	1995–2008	1991 – 2000
Satellite	Sentinel-3A, 3B	Envisat	ERS-2	ERS-1
Satellite type	LEO			
Sensor type	Moderate resolution imager (dual viewing)			
Pixel	0.5 km IFOV SW, 1.0 km IFOV TIR	1 km IFOV		1 km (SSP)
Coverage	Global, 24 h–4 d	Global, 3 d IR, 6 d VIS		Global, 3 d TIR, 6 d SWIR
Spectral coverage	9 channel (VIS, IR): 0.555 ± 0.01 – 12.0 ± 1.00 µm	7 channel (VIS, IR): 0.555 ± 0.01 – 12.0 ± 0.50 µm		4 channel (SWIR, TIR): 1.61 ± 0.15 – 12.0 ± 0.50 µm, 2 channel MW-Sounding: 23.8 & 36.5 ± 0.2 GHz
Application area	Multi image composites (VIS, IR), Clouds, SST, climate and weather forecasting			
Important for	SST, sea-ice cover, fire temperature/radiative power, cloud characteristics, …			

SLSTR (Sea and Land Surface Temperature Radiometer)

(A)ATSR((Advanced) Along-Track Scanning Radiometer)

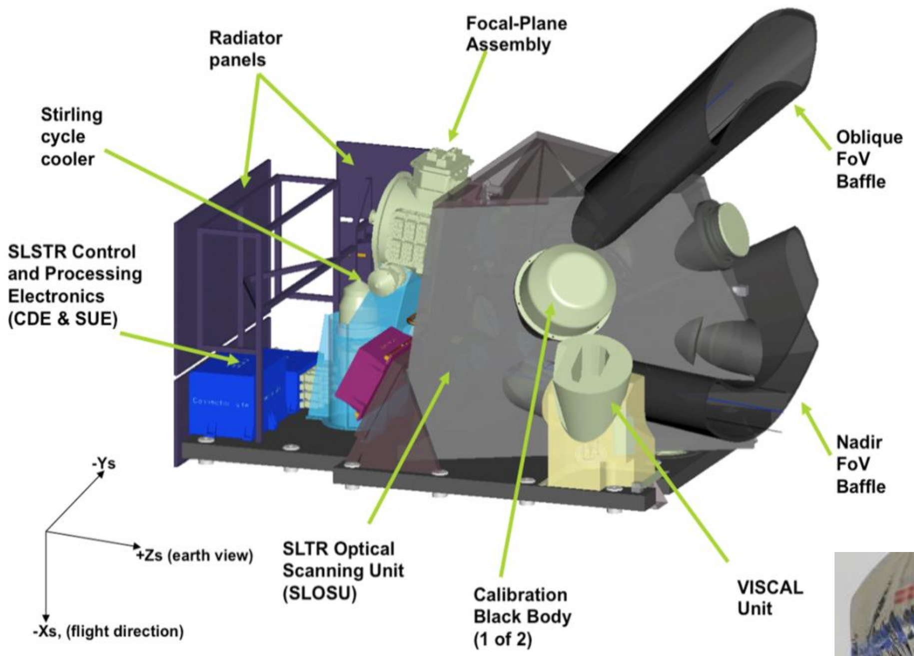


Abb.: SLSTR instrument.

(ESA (2016): Technical Guides. Sentinel-3 SLSTR. Instrument. <https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-slstr/instrument> (access: 2016-04-11).)

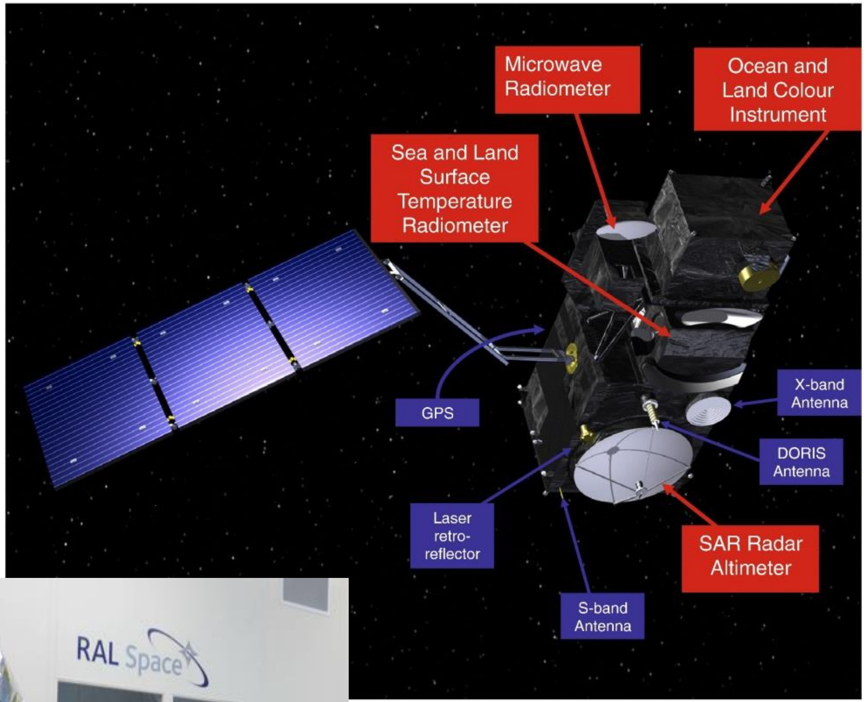


Abb.: Sentinel-3.

(ESA (2016): Missions. Sentinel-3. Instrument Payload. <https://sentinel.esa.int/web/sentinel/missions/sentinel-3/instrument-payload> (access: 2016-04-11).)

Abb.: SLSTR.

(ATSR Exploitation Board (2016): The Four ATSR Sensors (1991-2020). <http://www.atsrsensors.org/> (access: 2016-04-12).)

SLSTR (Sea and Land Surface Temperature Radiometer)

(A)ATSR((Advanced) Along-Track Scanning Radiometer)

Abb.: ATSR-1, 2, AATSR.

(ATSR Exploitation Board (2016): The Four ATSR Sensors (1991-2020). <http://www.atsrsensors.org/> (access: 2016-04-12).)

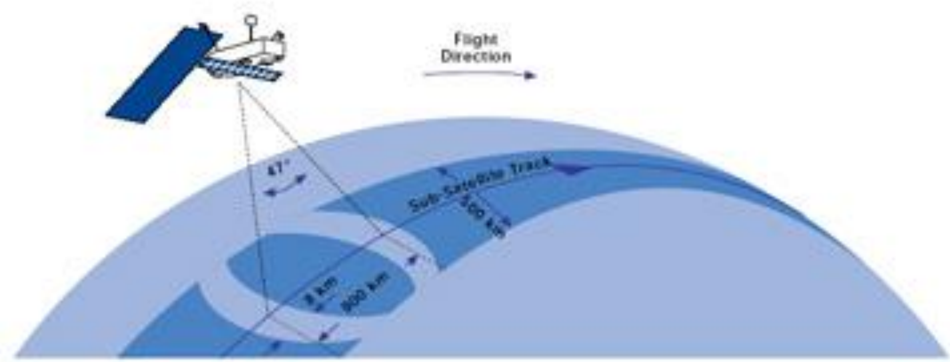


Abb.: AATSR. Scanning.
(ESA (2016): Missions. Envisat. Instruments. AATSR. Design. <https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/aatsr/design> (access: 2016-04-11).)

Abb.: Envisat

(ESA (2002): Envisat, Artist's Impression. ESA/Denmann production. <http://www.esa.int/spaceinimages/Images/2002/02/Envisat_artist_s_impression> (access 2016-04-12).)

MODIS (MODerate-resolution Imaging Spectro-radiometer)

Sensor	Modis
Years	2000–2016+
Satellite	Terra, Aqua
Satellite type	LEO
Sensor type	Moderate-resolution optical imager
Pixel	IFOV: 0.25 km, 0.5 km, 1.0 km
Coverage	Global, fast 2/d LW, 1/d SW
Spectral coverage	36 channel (VIS, IR): 645± 25 nm – 14.235 ± 0.150 µm
Application area	Ocean colour, Multi-imager composites (VIS, IR)
Important for	Ocean colour, vegetation, clouds, radiation, fire, aerosols

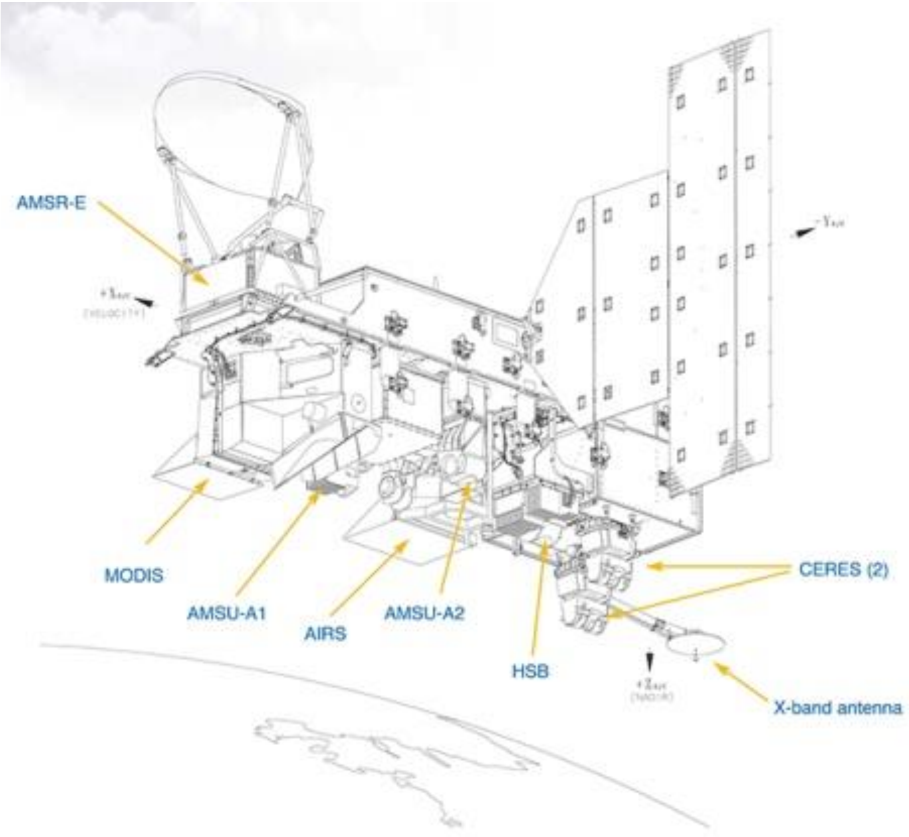


Abb.: Aqua. Instruments.

(NASA (2016): Aqua Project Science. About Aqua. Instruments. <http://aqua.nasa.gov/content/instruments> (access 2016-04-12).)

MODIS (MODerate-resolution Imaging Spectro-radiometer)

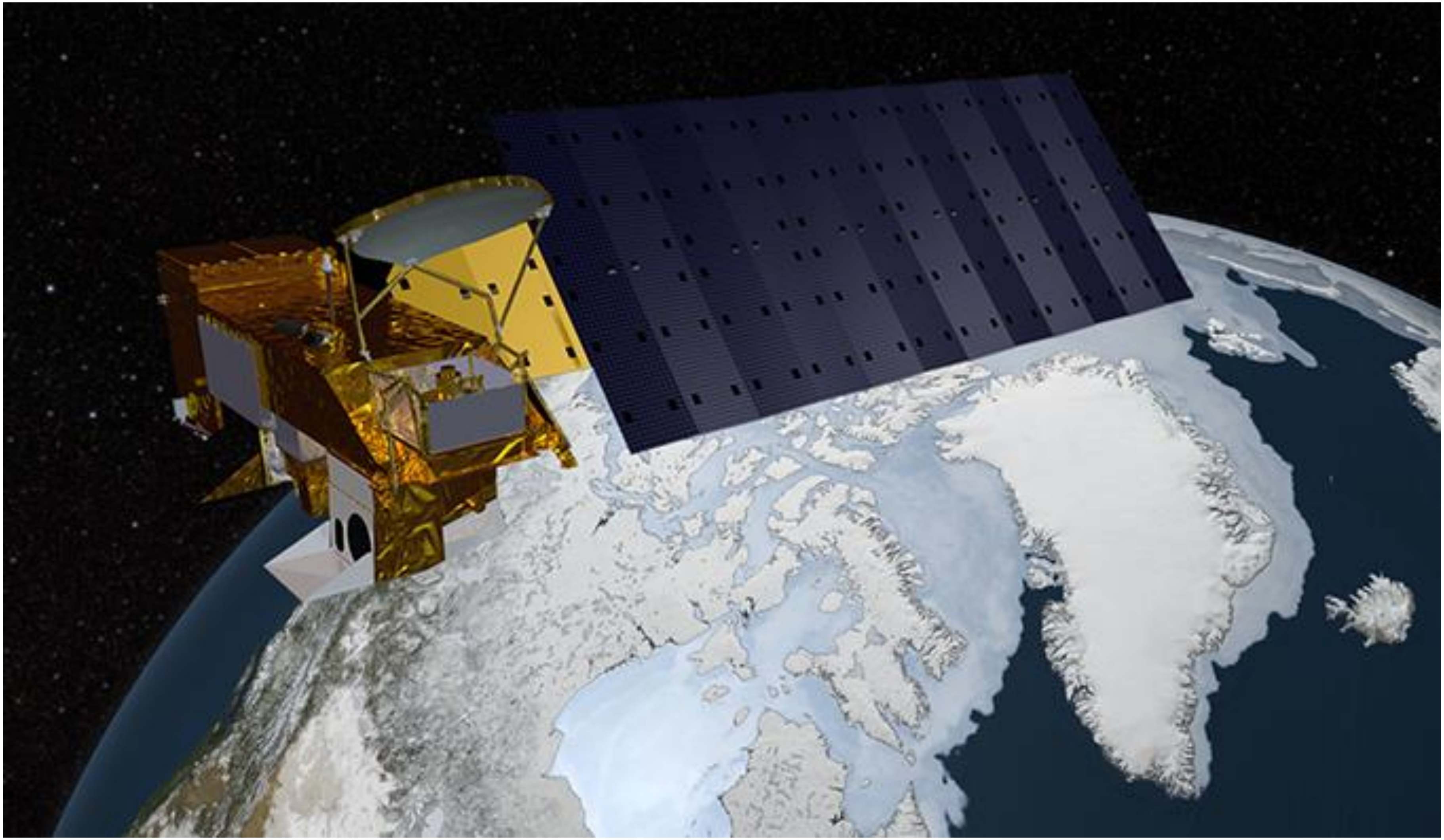


Abb.: Aqua.

(NASA (2016): Aqua Project Science. About Aqua. Spacecraft. <http://aqua.nasa.gov/content/about-aqua> (access 2016-04-12).)

CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation)
CPR (Cloud Profiling Radar for CloudSat)

Sensor	CALIOP	CPR
Years	2006–2016+	2006–2028+
Satellite	CALIPSO	ACE, CloudSat
Satellite type	LEO	LEO
Sensor type	Space lidar	Cloud and precipitation radar
Pixel	70 m IFOV (sampling 33 m), vertical 30 m	1.4 km x 3.5 km, vertical 500 m
Coverage	Global, 1/16 d	
Spectral coverage	532 nm and 1064 nm, 2 orthogonal Polarisation	Frequence 94.95 GHz
Application area	Aerosol profiles, cloud top height Lidar observations for Wind, Clouds, Aerosols, trace gases, Altimetry	Vertical profiles cloud water (liquid and solid), Cloud and precipitation profiles with Radar
Important for	Aerosol properties, cloud properties, height of the tropopause, height of the planetary boundary layer	Cloud properties

CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation)
CPR (Cloud Profiling Radar for CloudSat)

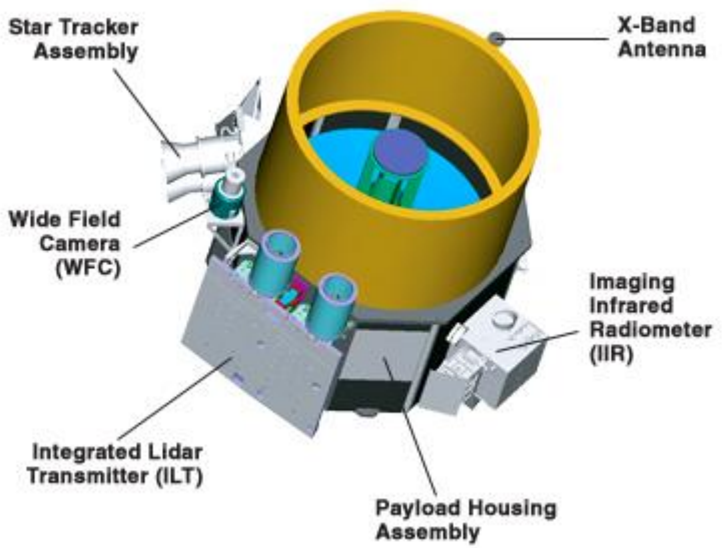


Abb.: CALIPSO. Instrument

(NASA (2016): About CALIPSO. CALIPSO Payload. <http://www-calipso.larc.nasa.gov/about/payload.php> (access: 2016-04-12).)

Abb.: CALIPSO.

(CNES (2009): CALIPSO switches to back-up laser. Illustration P. Carril. <https://cnes.fr/en/web/CNES-en/7655-calipso-switches-to-back-up-laser.php> (access: 2016-04-12).)

CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation)

CPR (Cloud Profiling Radar for CloudSat)

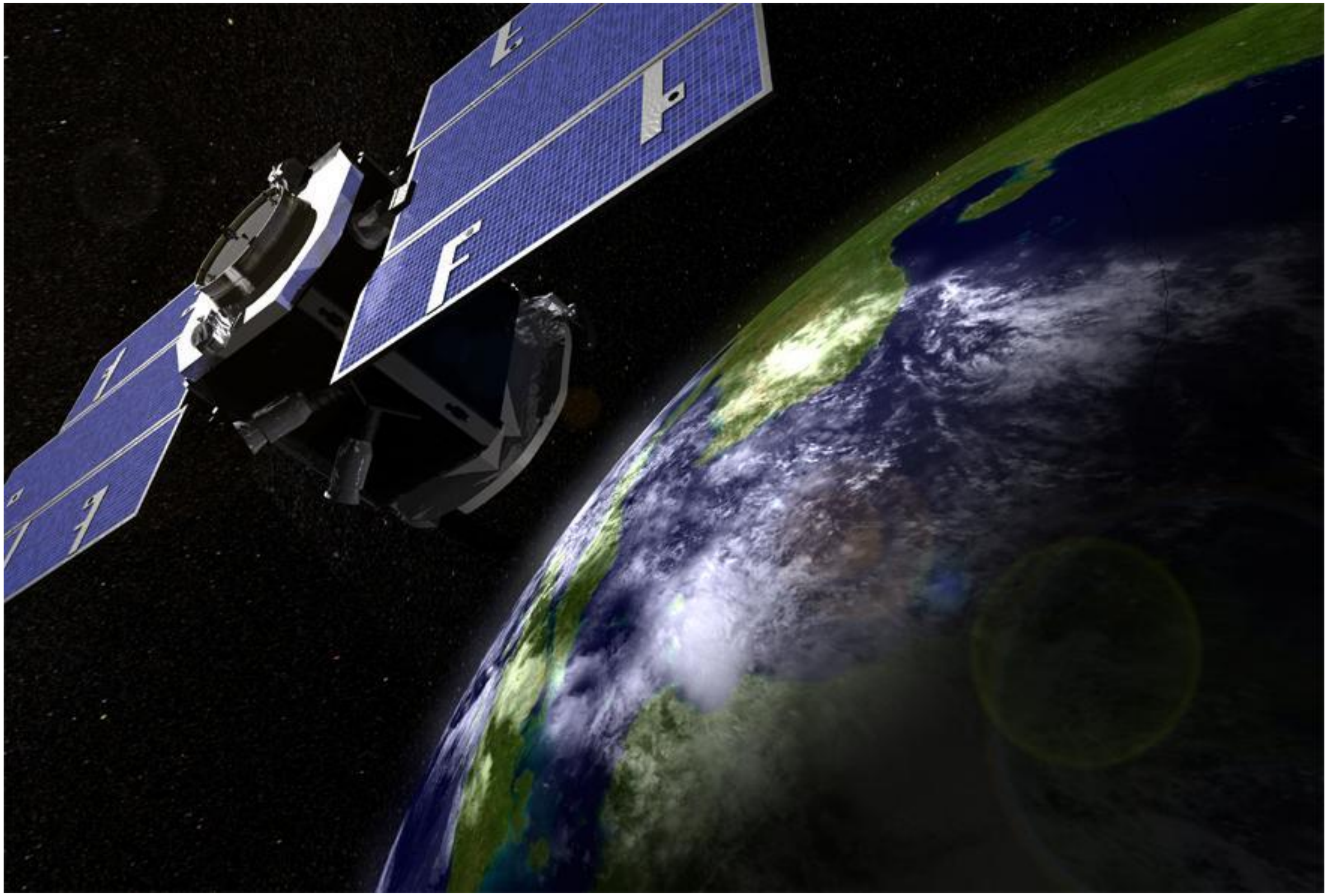


Abb.: CloudSat.

(NASA JPL (2005): Above Earth 2 (Artist's Concept). <http://photojournal.jpl.nasa.gov/catalog/PIA03012> (access: 2016-04-12).)

SSM/I (Special Sensor Microwave - Imager)
SSMIS (Special Sensor Microwave - Imager/Sounder)

Sensor	SSM/I	SSMIS
Years	1987–2016+	2003–2025+
Satellite	DMSP-F08, 09, 10, 11, 12, 13, 14, 15	DMSP-F16, 17, 18, 19, 20
Satellite type	LEO	
Sensor type	MW imaging radiometer, conical scanning	MW imaging/sounding radiometer, conical scanning
Pixel	Frequency dependent: 12.5 km x 12.5 km, 25.0 km x 12.5 km	Frequency dependent: 12.5 km x 12.5 km, 25.0 km x 12.5 km, 37.5 km x 12.5 km, 75.0 km x 12.5 km
Coverage	Global, 1/Tag	
Spectral coverage	4 channel (MW) 19.35 ± 0.2 – 85.5 ± 1.5 GHz, 7 channel	21 channel (MW) 19.35 ± 0.178–183.31 ± 1.0 ± 1.026 GHz, 25 channel
Application area	Multi channels composites (MW)	Multi channels composites (MW) with humidity and temperature sounding channels for precipitation
Important for	Precipiation intensity at surface (liquid or solid), snow cover	Cloud liquid water total column, snow cover, cloud liquid water, cloud ice

SSM/I (Special Sensor Microwave - Imager)

SSMIS (Special Sensor Microwave - Imager/Sounder)

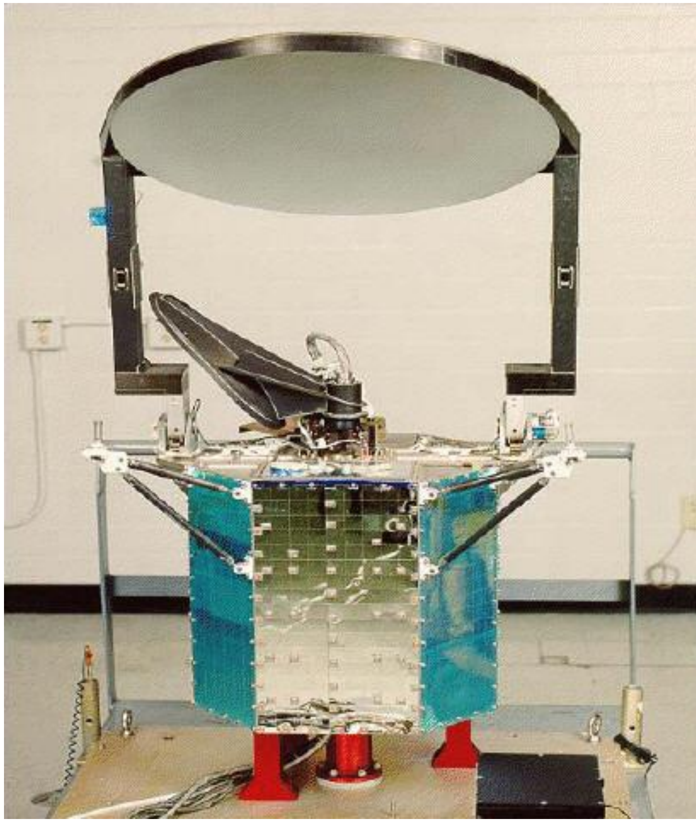


Abb.: SSMIS.

(NSIDC (2010): Special Sensor Microwave Imager/sounder (SSMIS). The SSMIS Instrument. Image courtesy of Colorado State University. <http://nsidc.org/data/docs/daac/ssmis_instrument/> (access: 2016-04-12).)

Abb.: DMSP-F19 bzw. DMSP-Satellites.

(DMSP Legacy (2016): The Satellites. <http://www.dmsplegacy.com/the-program/> (access: 2016-04-12).)

HIRS (High-Resolution Infra-Red Sounder)

Sensor	HIRS	HIRS/2	HIRS/3	HIRS/4
Years	1975–1983	1979–2007	1998–2014	2005–2018+
Satellite	Nimbus-6	TIROS-N, NOAA-6, 7, 8, 9, 10, 11, 12, 13, 14	NOAA-15, 16, 17	NOAA-18, 19, Metop-A, B
Satellite type	LEO			
Sensor type	Cross-nadir scanning IR sounder (0, 1, 2: Filter radiometer)			
Pixel	25 km (SSP)	20.4 km (SSP)	18 km (SSP)	10 km (SSP)
Coverage	almost global, 2/d			
Spectral coverage	17 channel (VIS 0.69 µm, IR 3.71–15.0 µm)	20 channel (VIS 0.69 µm, IR 3.76–14.95 µm)		
Application area	Temperature-/humidity profiles (IR)			
Important for	Humidity, cloud properties, temperature			

HIRS (High-Resolution Infra-Red Sounder)

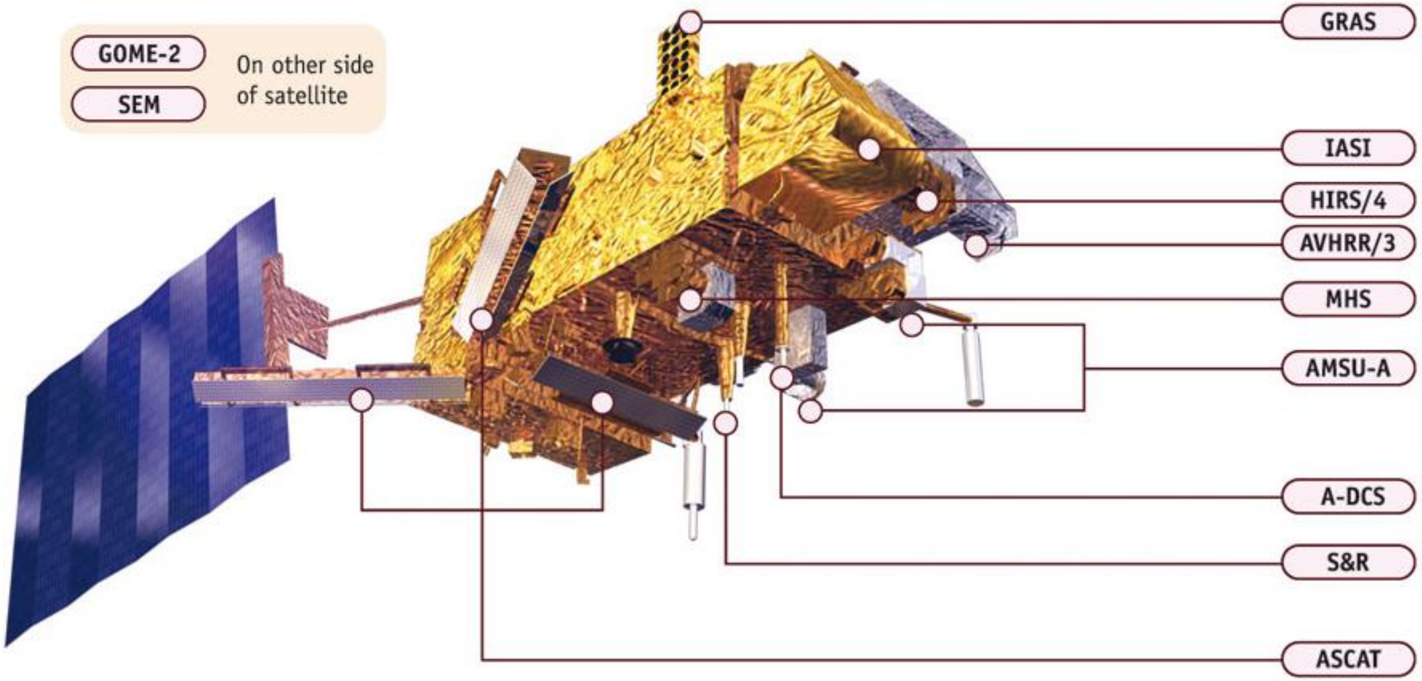


Abb.: Metop Instruments

(EUMETSAT (2016): METOP DESIGN. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/index.html> (access: 2016-04-11).)

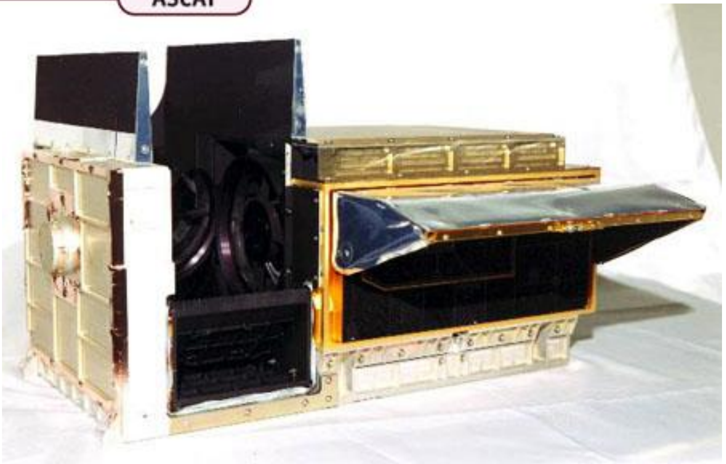


Abb.: HIRS/4.

(EUMETSAT (2016): METOP DESIGN. HIRS. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/HIRS/index.html> (access: 2016-04-11).

TOVS (TIROS Operational Vertical Sounder)
= MSU (Microwave Sounding Unit)
+ SSU (Stratospheric Sounding Unit)
+ HIRS/2

Sensor	MSU	SSU
Years	1979–2007	
Satellite	TIROS-N, NOAA-6, 7, 8, 9, 10, 11, 12, 13, 14	
Satellite type	LEO	
Sensor type	MW sounding radiometer, cross-track scanning	Cross-nadir scanning IR sounder
Pixel	110 km (SSP)	150 km (SSP)
Coverage	Global, 2/d	Global, daily
Spectral coverage	4 channel MW: 50.30 ± 0.1 – 57.95 ± 0.1 GHz	3 channel IR: 14.92, 14.93, 14.94 µm
Application area	Atmospheric Temperature profiles, Temperature-/ humidity sounding (MW)	Stratospheric tem-perature sounding, Temperature-/ humidity sounding (IR)
Important for	Cloud liquid water (total column), …	marginal

TOVS (TIROS Operational Vertical Sounder)

= MSU (Microwave Sounding Unit)

+ SSU (Stratospheric Sounding Unit)

+ HIRS/2

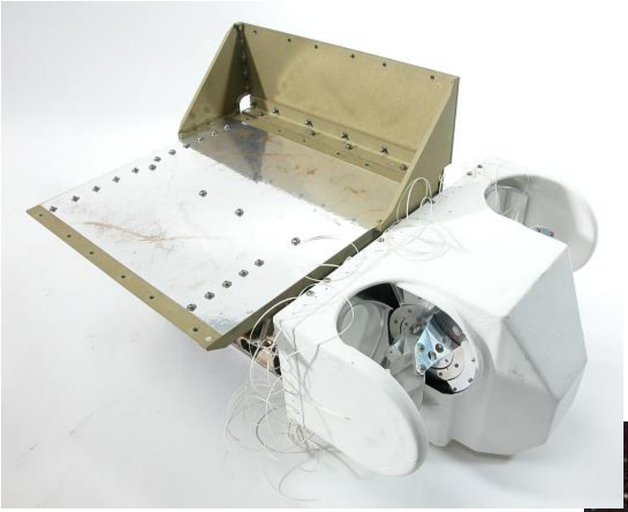


Abb.: MSU

(Smithsonian National Air and Space Museum (2016): MSU. <http://airandspace.si.edu/collections/artifact.cfm?object=nasm_A20040176000> (access: 2016-04-13).

Abb.: TIROS-N.

(NOAA Photo Library (2015): Graphic of TIROS-N satellite in orbit. <http://www.photolib.noaa.gov/htmls/ spac0173.htm> (access: 2016-04-13).)

Abb.: NOAA-14.

(NOAA STAR (2016): STAR / SMCD / SPB Solar Backscatter Ultraviolet (SBUV/2) Project - Data Products. NOAA-14 (1996-2004). <http://www.star.nesdis.noaa.gov/smcd/spb/ozone/NOAA 14.php> (access: 2016-04-12).)

ATOVS (Advanced TIROS Operational Vertical Sounder)

= AMSU-A (Advanced Microwave Sounding Unit - A)
+ AMSU-B (Advanced Microwave Sounding Unit - B)
bzw. MHS (Microwave Humidity Sounding)
+ HIRS/3 bzw. HIRS/4

Sensor	AMSU-A	AMSU-B	MHS
Years	1998–2024+	1998–2014	2005–2024+
Satellite	(Aqua,) Metop-A, B, C, NOAA-15, 16, 17, 18, 19	NOAA-15, 16, 17	Metop-A, B, C, NOAA-18, 19
Satellite type	LEO		
Sensor type	MW sounding radiometer, cross-track scanning		
Pixel	48 km IFOV	16 km IFOV	
Coverage	almost global, 2/d		
Spectral coverage	15 channel (MW): 23.800 ± 0.135 – 89.000 ± 3.000 GHz	5 channel (MW): 89.0 ± 1.0 – 183.31 ± 1.0 ± 0.5 GHz	5 channel (MW): 89.0 ± 1.0 – 190.311 ± 1.0 GHz
Application area	Temperature sounding all weather	Humidity sounding all weather precipitation rate	
Important for	Cloud liquid water, atm. T, …	Specific humidity, integrated water vapour, …	

ATOVS (Advanced TIROS Operational Vertical Sounder)

= AMSU-A (Advanced Microwave Sounding Unit - A)

+ AMSU-B (Advanced Microwave Sounding Unit - B)

bzw. MHS (Microwave Humidity Sounding)

+ HIRS/3 bzw. HIRS/4

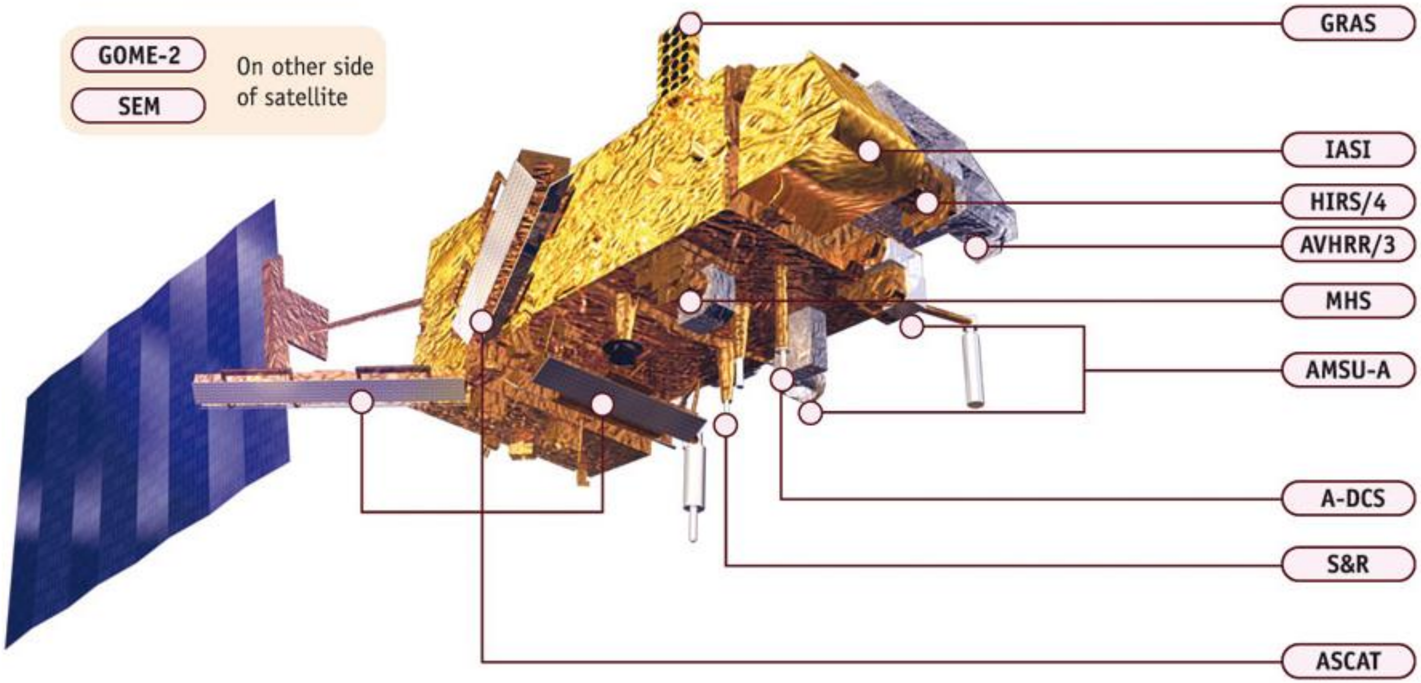


Abb.: Metop with Instruments

(EUMETSAT (2016): METOP DESIGN. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/index.html> (access : 2016-04-11).)

ATOVS (Advanced TIROS Operational Vertical Sounder)

= AMSU-A (Advanced Microwave Sounding Unit - A)

+ AMSU-B (Advanced Microwave Sounding Unit - B)

bzw. MHS (Microwave Humidity Sounding)

+ HIRS/3 bzw. HIRS/4

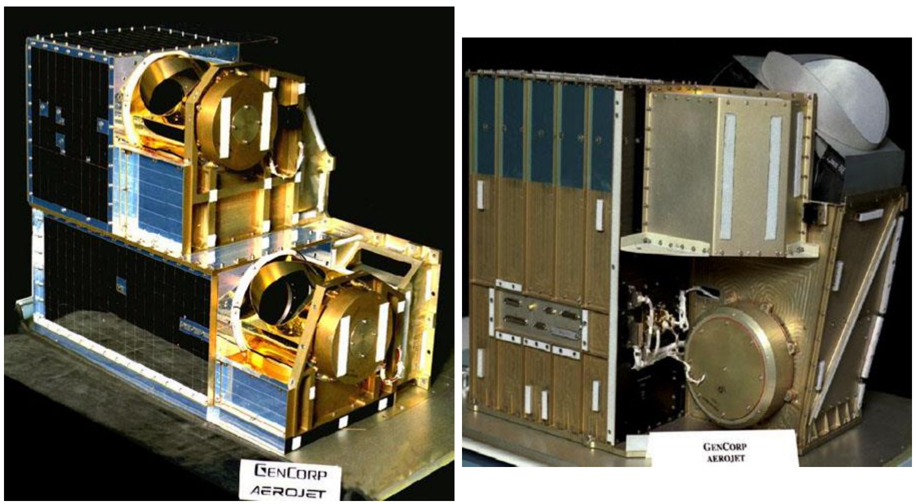


Abb.: AMSU-A units

(EUMETSAT (2016): METOP DESIGN. AMSU-A. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/AMSUA/index.html> (access : 2016-04-13).)

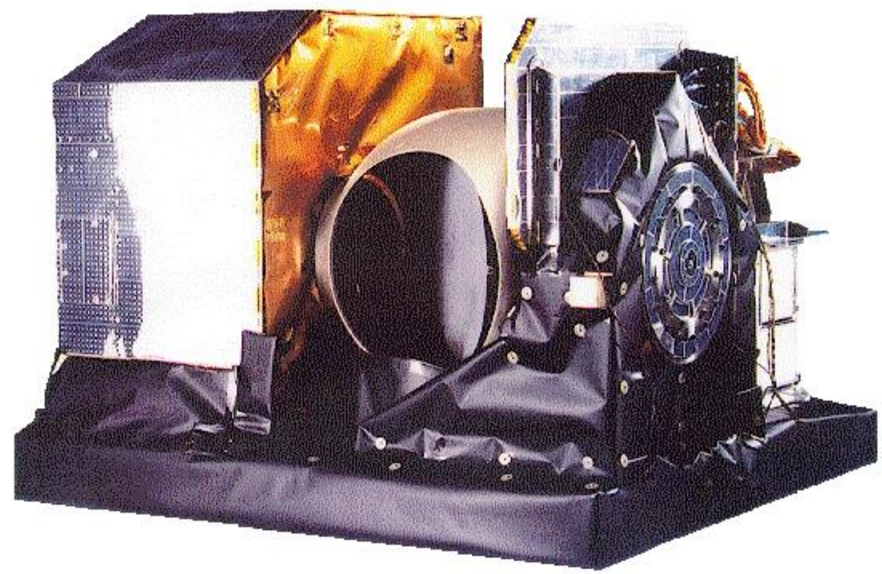


Abb.: MHS.

(EUMETSAT (2016): METOP DESIGN. MHS. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/MHS/index.html> (access: 2016-04-13).)

GOME (Global Ozone Monitoring Experiment)

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY)

(griechisch σκιαμαχή, sinngemäß: gegen Schatten kämpfen)

OMI (Ozone Monitoring Instrument)

Sensor	GOME	GOME-2	SCIAMACHY-limb/-nadir	OMI
Years	1995–2011	2007–2024+	2002–2012	2004–2016+
Satellite	ERS-2	Metop-A, B, C	ENVISAT	Aura
Satellite type	LEO			
Sensor type	Cross-nadir scanning SW sounder (SCIAMACHY limb: limb sounder)			
Pixel	40 x 40 km (120 km swath)	40 km x 40 km (960 km swath)	30 km x 240 km	13 km x 24 km (2600 km sw.)
Coverage	Global, 3–24 days, daylight only	Global, 1,5–3 days, daylight only	Global, up to 3 days, daylight only	Global, daily, daylight only
Spectral coverage	4 x 1024 channel (240–792 nm), 3 Polarisation channel (292–790 nm) (UV, VIS)	4 x 1024 channel (240–790 nm), 200 Polarisation channel (312–792 nm) (UV, VIS, NIR)	8 x 1024 channel (214–2386 nm), 7 Polarisation channel (310–2380 nm) (UV, VIS, NIR, SWIR)	2 x 390, 1 x 780 channel (270–500 nm) (UV, VIS)
Application area	Atmospheric chemistry, Ozon profiles			
Important for	O3 (!), trace gases (+ cloud cover, albedo, aerosols)			

GOME-2 (Global Ozone Monitoring Experiment - 2)

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY)

OMI (Ozone Monitoring Instrument)

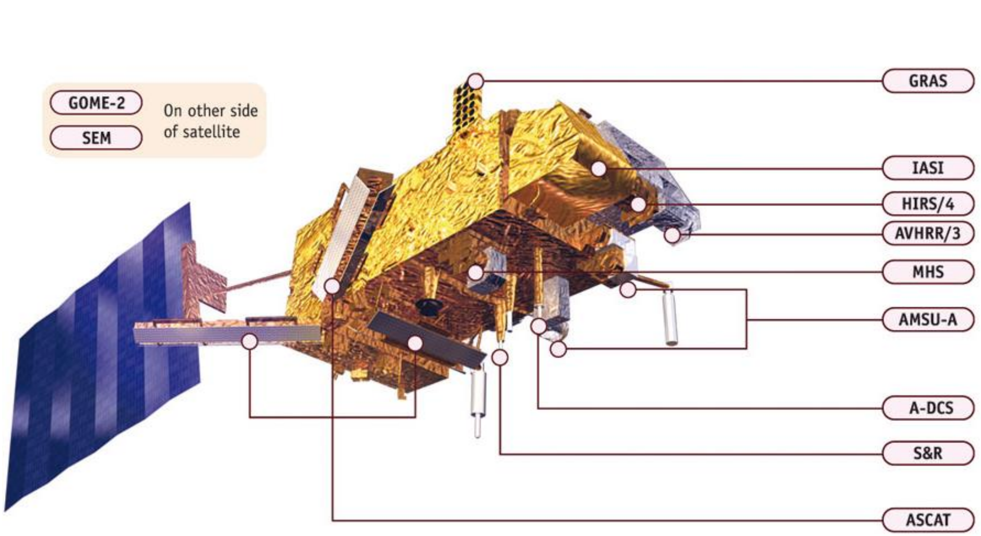


Abb.: Metop with Instruments.

(EUMETSAT (2016): METOP DESIGN. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/index.html> (access : 2016-04-11).)

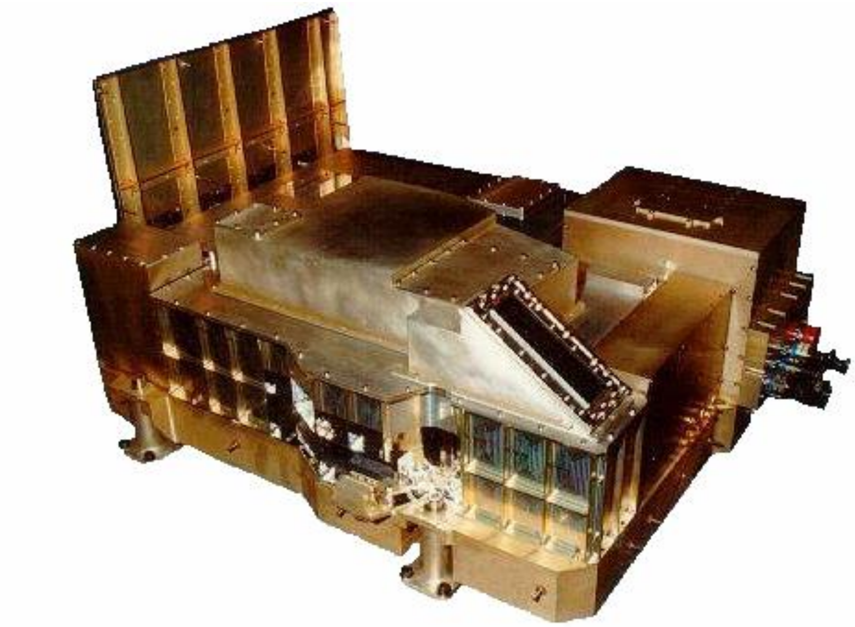


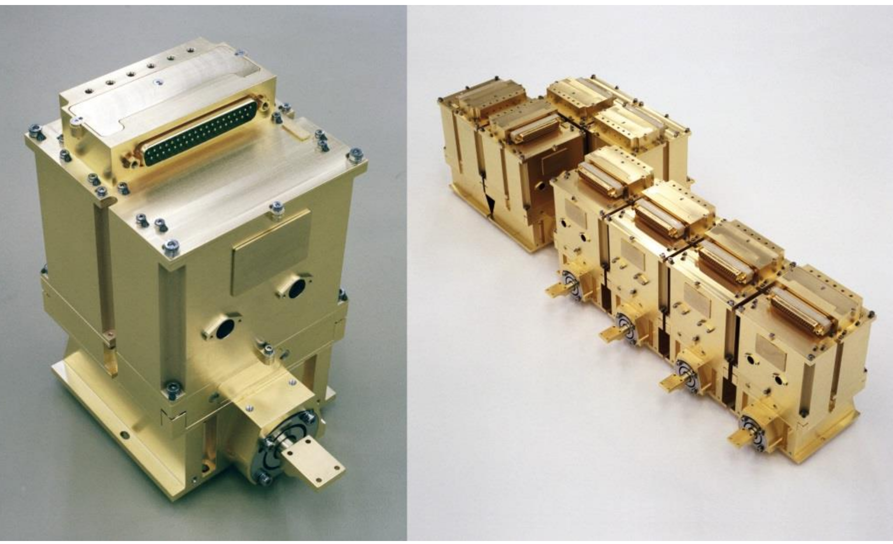
Abb.: GOME-2.

(EUMETSAT (2016): METOP DESIGN. GOME-2. <http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/GOME2/index.html> (access : 2016-04-11).)

GOME (Global Ozone Monitoring Experiment)

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY)

OMI



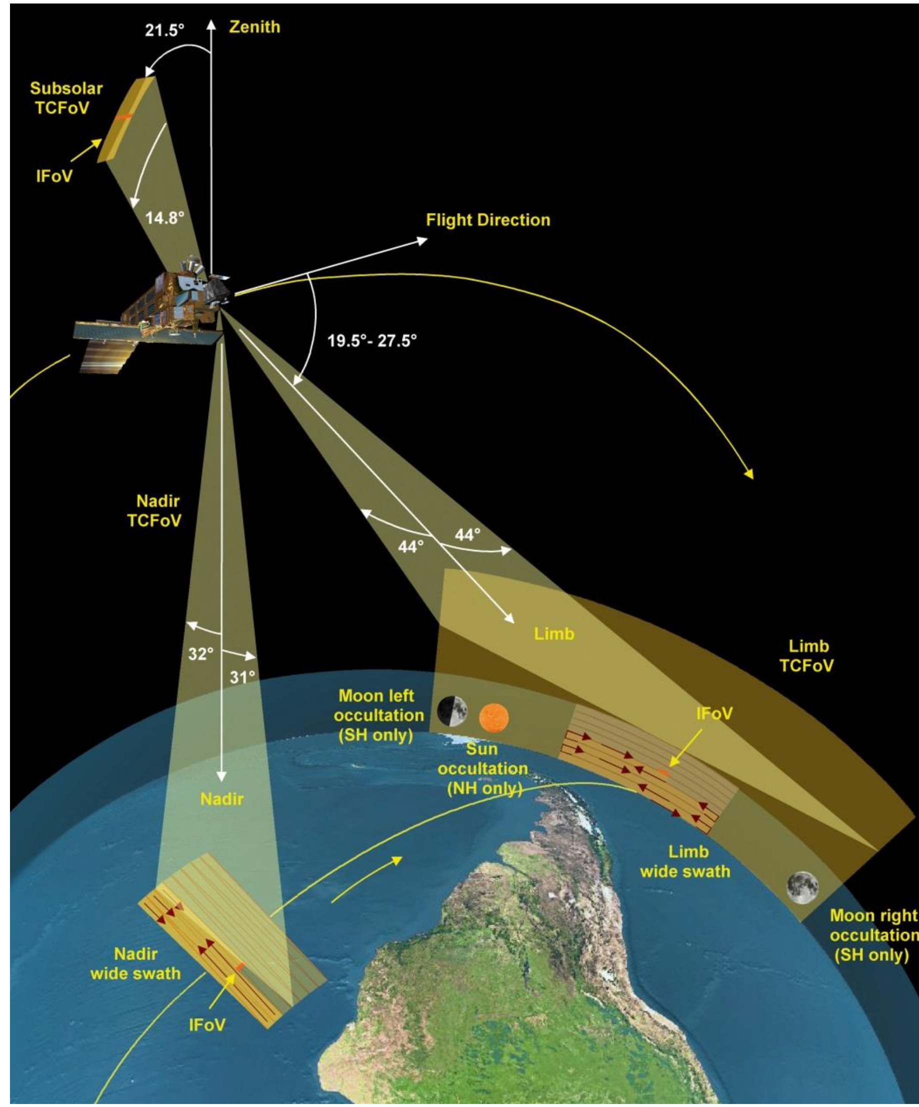


Abb.: SCIAMACHY. Detector modules (l.), observation geometry (r.)

(Gottwald et al. (2006): SCIAMACHY. Monitoring the Changing Earth's Atmosphere. Köln: DLR.)

GOME (Global Ozone Monitoring Experiment)

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY)

OMI (Ozone Monitoring Instrument)

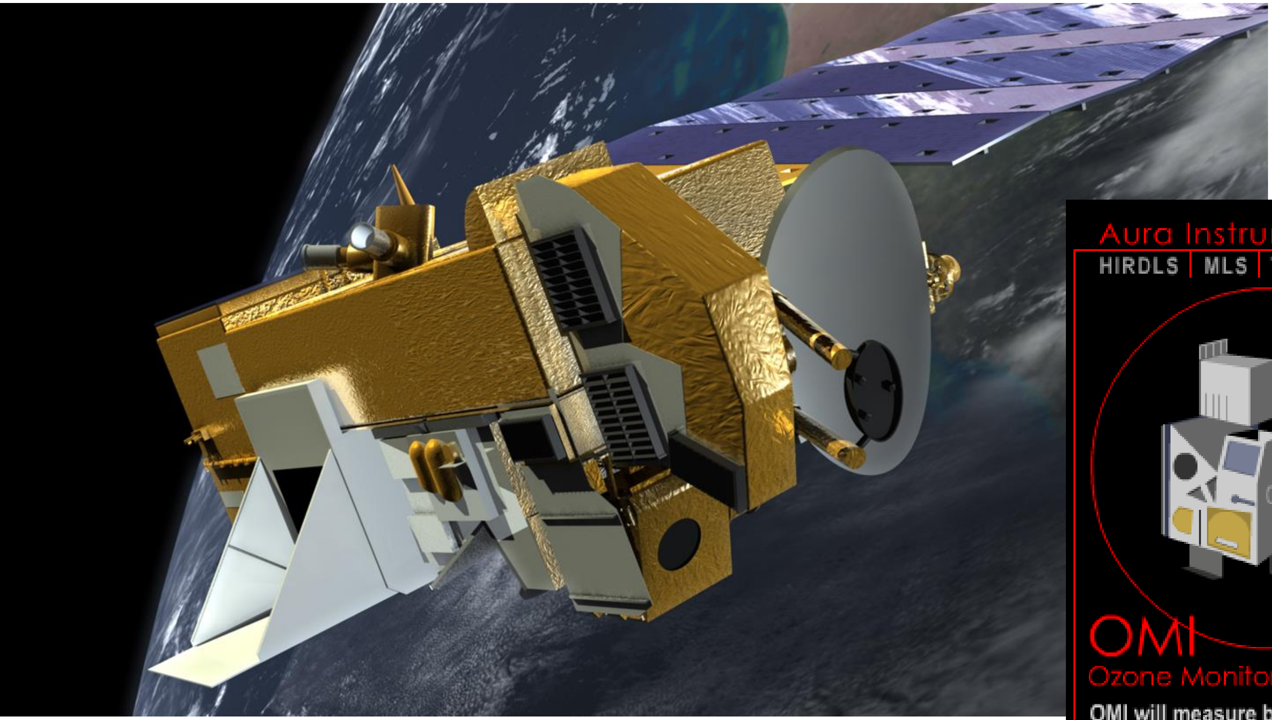


Abb.: Aura.

(NASA GSFC (2016): Aura. The Aura Mission. <http://aura.gsfc.nasa.gov/about.html> (access : 2016-04-12).)

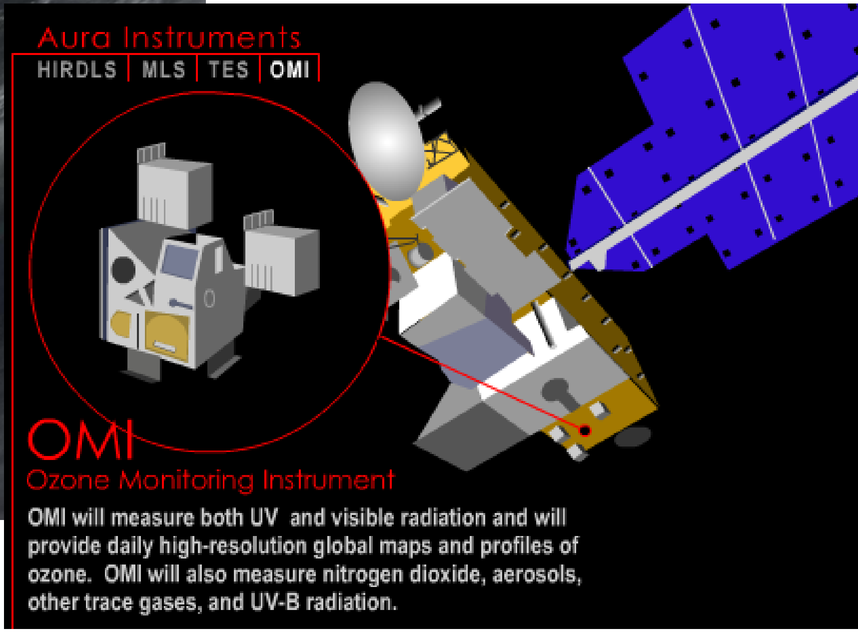


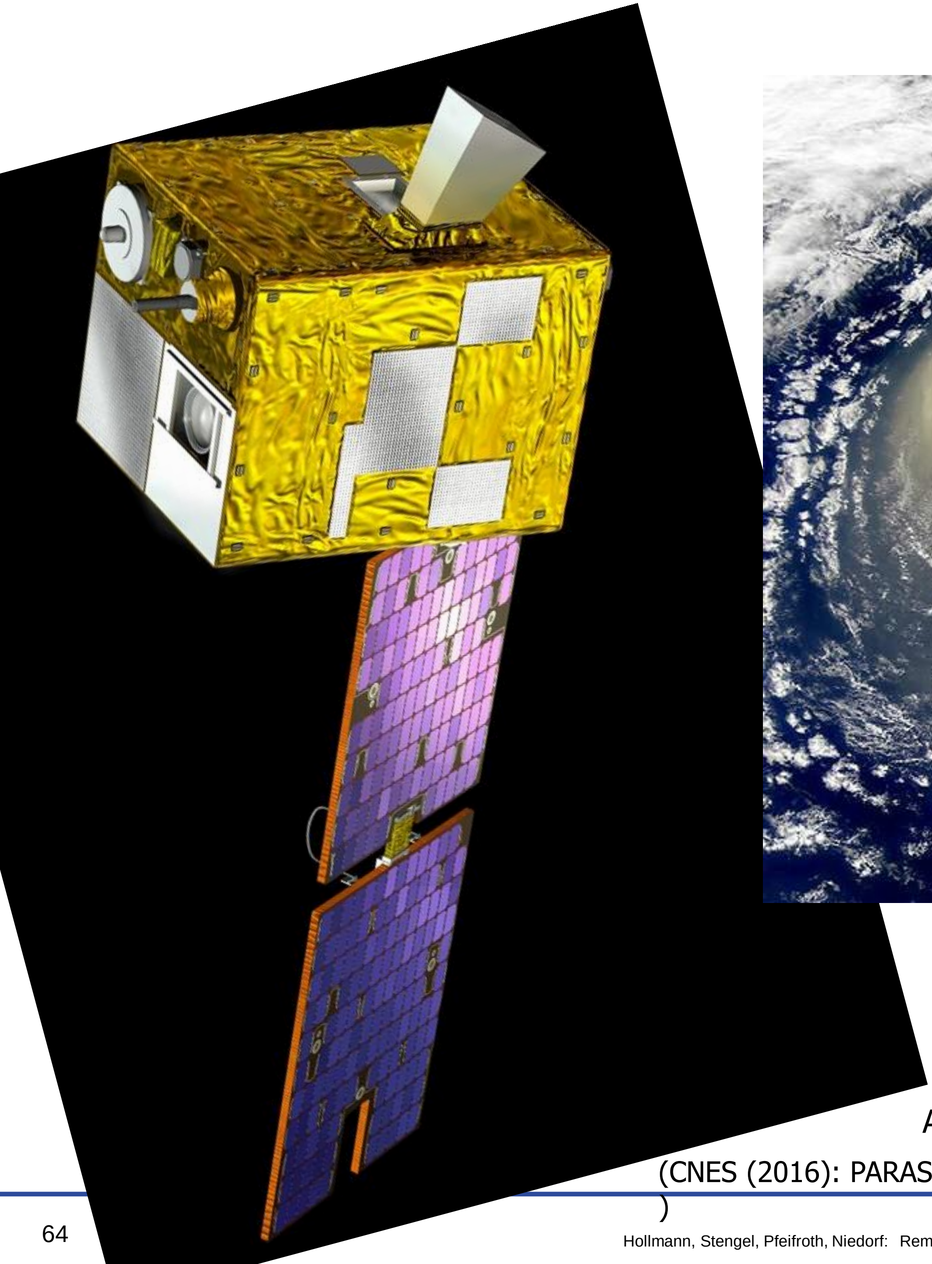
Abb.: Aura OMI

(NASA GSFC (2016): Aura. The Aura Mission. Spacecraft and Instruments. <http://aura.gsfc. nasa.gov/scinst/index.html> (access : 2016-04-12).)

POLDER (POLarization and Directionality of the Earth's Reflectances)

Sensor	POLDER
Years	1996–2013
Satellite	ADEOS, ADEOS-2, PARASOL
Satellite type	LEO
Sensor type	Moderate resolution optical imager
Pixel	6.5 km
Coverage	Quasi-global, daily, daylight only
Spectral coverage	15 channels (9 Bands, 3 with 3 Polarisations; 443.5 ± 6.7 – 1019.6 ± 8.55 nm) (VIS, NIR)
Application area	Aerosol, Ocean colour, Vegetation, Bidirectional Reflectance Distribution Function (BRDF), composites e.g. VIS, IR
Important for	Aerosol & cloud properties, radiation, NDVI

POLDER (POLarization and Directionality of the Earth’s Reflectances)



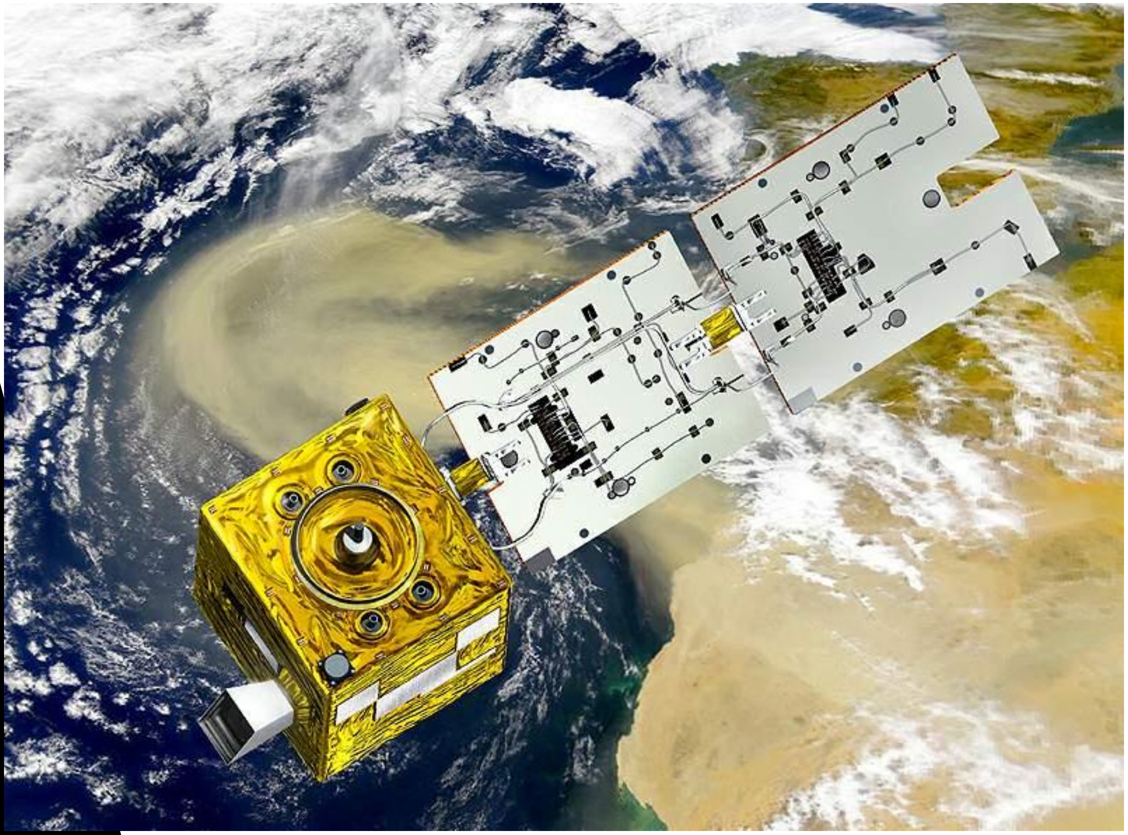


Abb.: Parasol.

(CNES (2011): PARASOL Satellite mission could be extended. <https://cnes.fr/en/web/CNES-en/9047-gp-parasol-satellite-mission-could-be-extended.php> (access : 2016-04-12).)

Abb.: Parasol.

(CNES (2016): PARASOL. <https://parasol.cnes.fr/en/PARASOL/index.htm> (access : 2016-04-12).)

A-Train

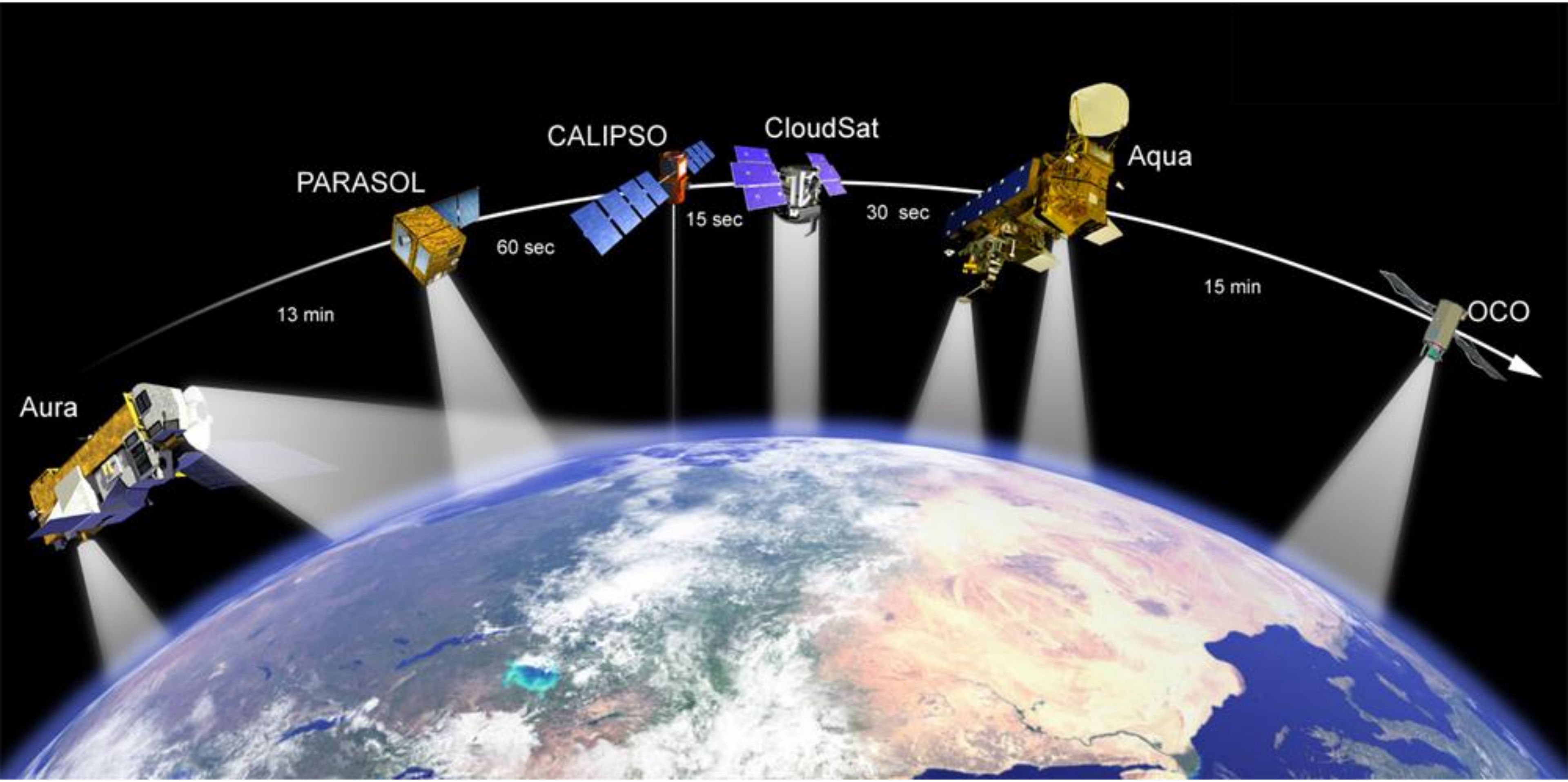


Abb.: A-Train.

(CNES (2009): PARASOL moves off the A-train's track. Picture credits NASA. <https://cnes.fr/en/web/CNES-en/8230-gp-parasol-moves-off-the-a-train-s-track.php> (access: 2016-04-12).)