Space Communications

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RUAG Space AB (Sweden)

4 May 2020

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RUAG Group at A Glance

- Innovation driven international technology company group
- Sites in:
  CH, DE, AT, SE, FI, HU, US, AU
- Sales 2018:
  2000 M€
- 9100 employees
- Joint stock company under private law since 1999
- Shareholder:
  The Swiss Confederation
- Headquarters:
  Berne (CH)

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RUAG Space in A Nutshell

Leading independent European supplier of space products

50 years of heritage in space

Headquarter in Zurich, Switzerland

326 M€ revenues in 2018

1300 employees

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RUAG Space
Product Portfolio Areas

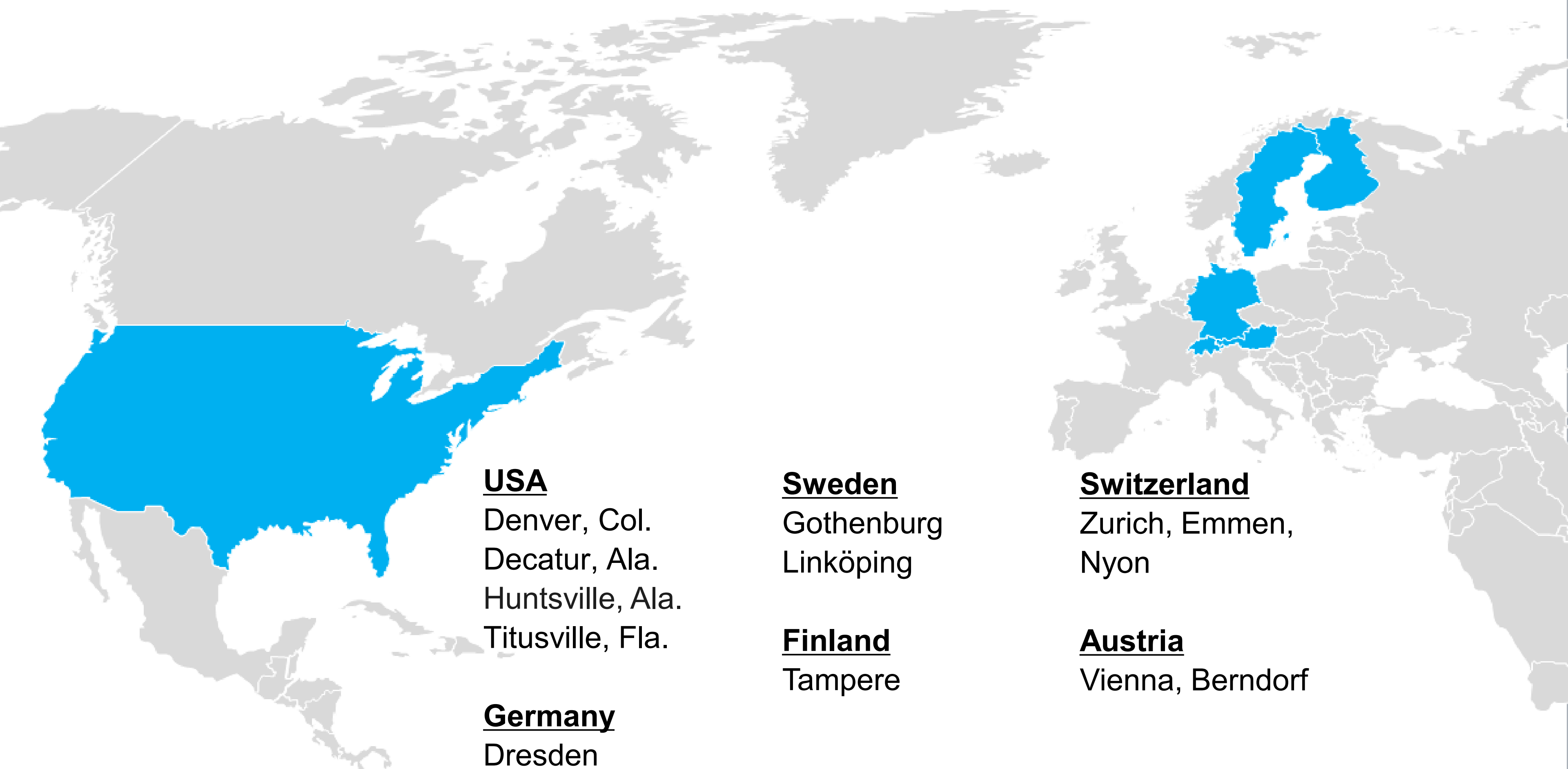
Digital Electronics for Satellites and Launchers

Satellite Structures, Mechanisms & Mechanical Equipment

Launcher Structures & Separation Systems

Satellite Communication Equipment

RUAG Space
14 Sites Worldwide



USA
Denver, Col.
Decatur, Ala.
Huntsville, Ala.
Titusville, Fla.

Germany
Dresden

Sweden
Gothenburg
Linköping

Finland
Tampere

Switzerland
Zurich, Emmen,
Nyon

Austria
Vienna, Berndorf

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RUAG Space AB (Sweden)

Gothenburg
Headquarters and Center for Computer Systems, Antennas and Microwave Electronics

RUAG Space AB (Sweden):

Sales (2016):	1029 MSEK (~109 M€)
Employees:	490 (Gothenburg 350, Linköping 100, Tampere 40)

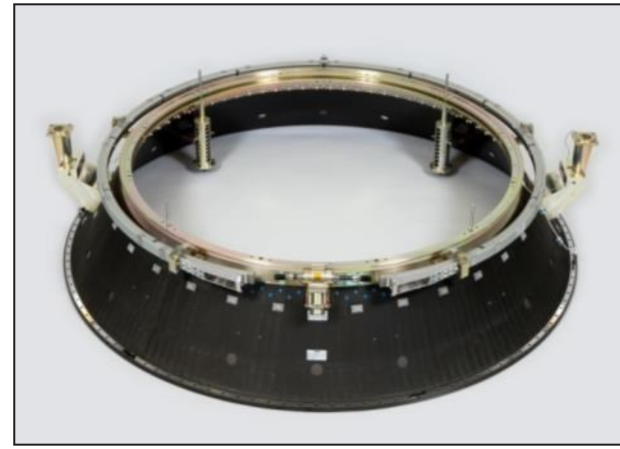
Tampere
Space Electronics

Linköping
Mechanical Systems

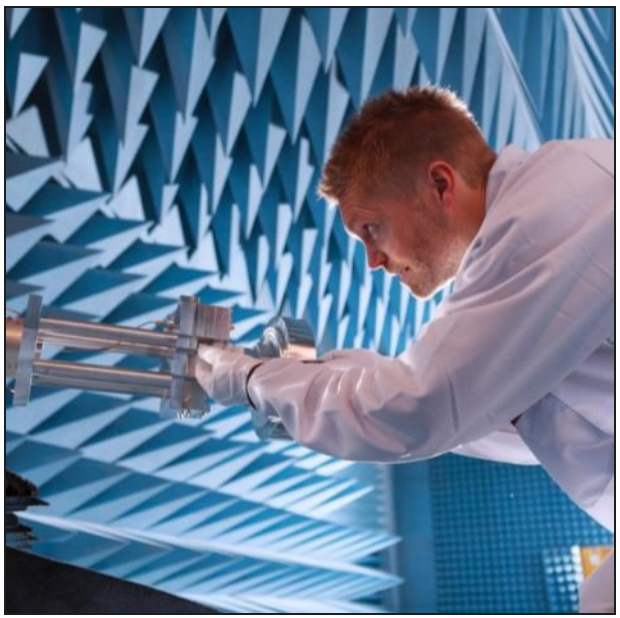
RUAG Space AB; Product Areas

Computer Systems (Gbg)

Microwave Electronics (Gbg)



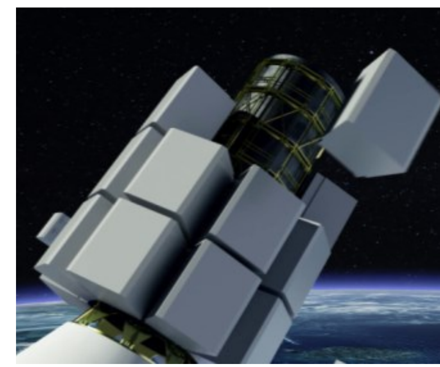
Adapters and Separation Systems (Lkp)



Antennas (Gbg)

Guidance Systems (Lkp)

Satellite structures (Lkp)



Dispensers (Lkp)

Space Communications

- All spacecraft would be essentially useless without space communications over radio!

- Enormous data sets are generated
  - Earth observation satellites (optical, radar)
  - Scientific satellites

- Large bandwidths
  - Direct broadcast TV satellites
  - Broadband
  - Misc. communication satellites

Basics of Space Communications

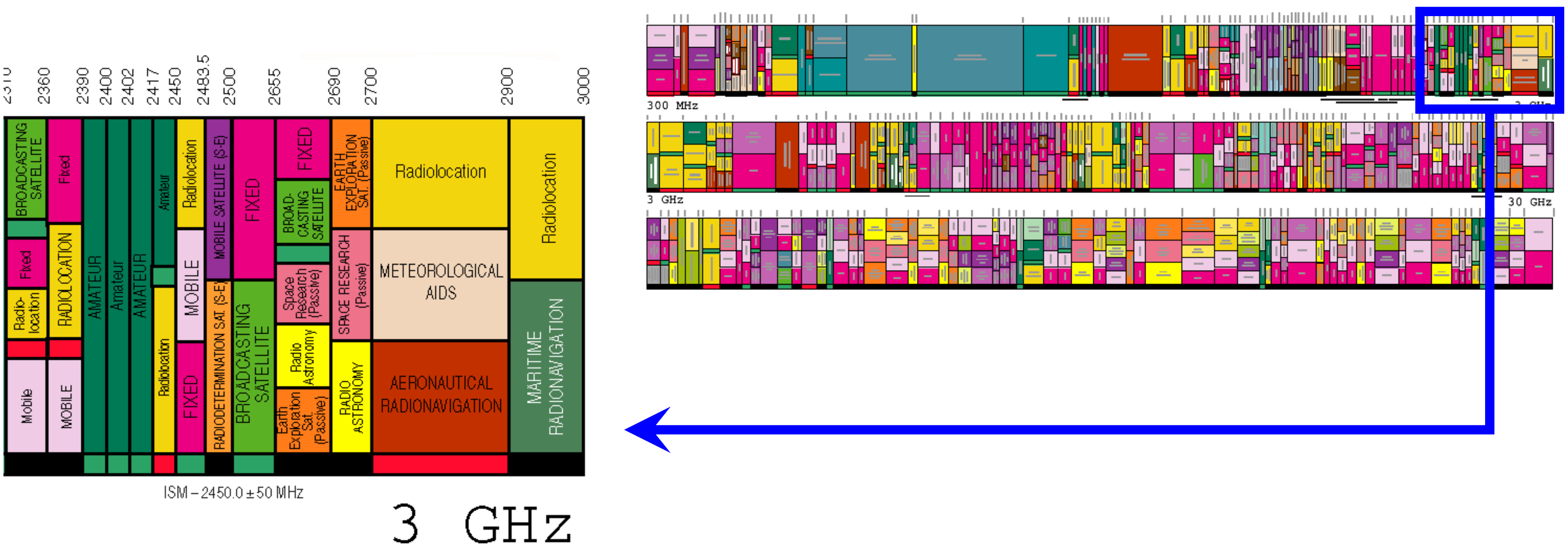
- What is the difference between space based communications and ground based ditto?
  - Only “line-of-sight”
    - $1/R^2$
    - No fading (but sensitive to rain at high frequencies)
  - Long distances
    - Delay / latency
    - High “free space loss”
  - Global coverage possible
    - Multiple access not as easy through frequency re-use
    - Legislative aspects
    - Frequency allocations

Basics of Space Communications
Contd.

- What is the difference between space based communications and ground based ditto?
  - Difficult to generate RF power in space
    - Reliability
  - Cost!

Frequency Allocations

- International treaties regulate which frequency bands the different “services” are allowed to use
  - The spectrum is a finite natural resource!



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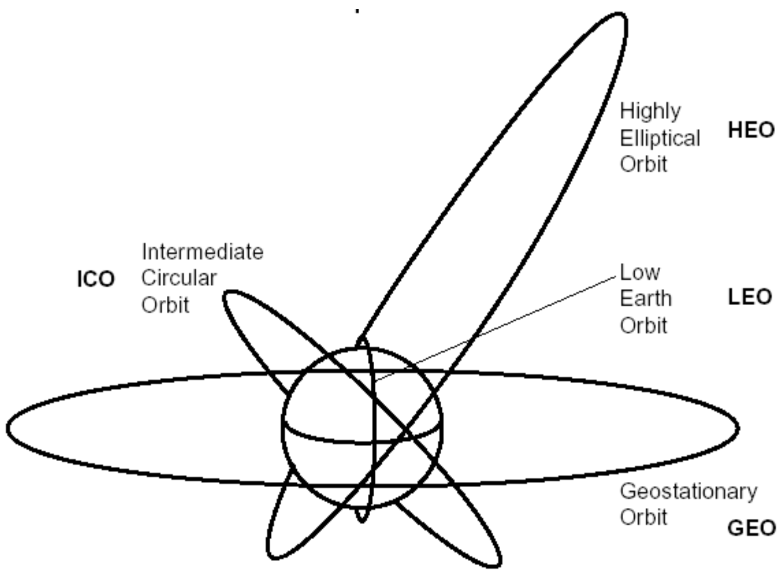
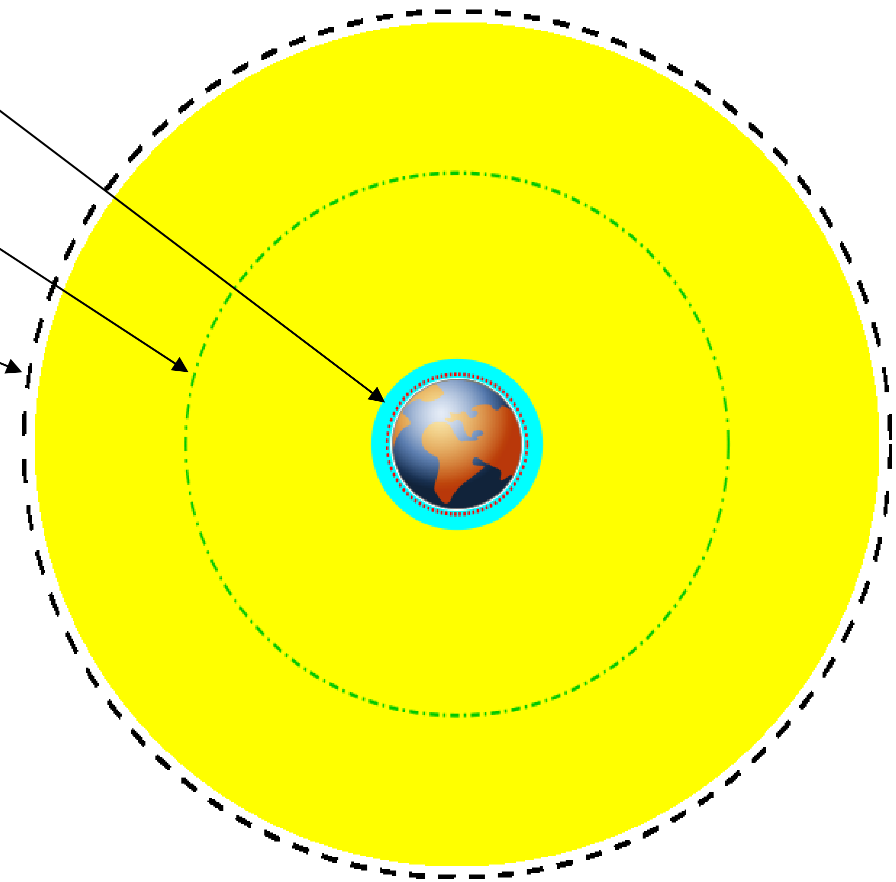
Different Orbits

- LEO (typically 500 – 1500 km)
- MEO (typically 20000 km)
- GEO (36000 km)





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Direct Broadcast Satellites

- Very large (and expensive) satellites
- 10 – 15 years lifetime
- Geostationary orbit
  - 36000 km altitude
  - Over the equator
  - 24 hour orbit

History of TV Satellites

- Telstar 1
  - Launched 1962
  - First TV satellite
  - Could relay TV signals 20 minutes now and then…
- In 1964 came satellites in geostationary orbit
  - Continuous coverage
- ”Telstar” with The Tornados was No. 1 on the hit lists…

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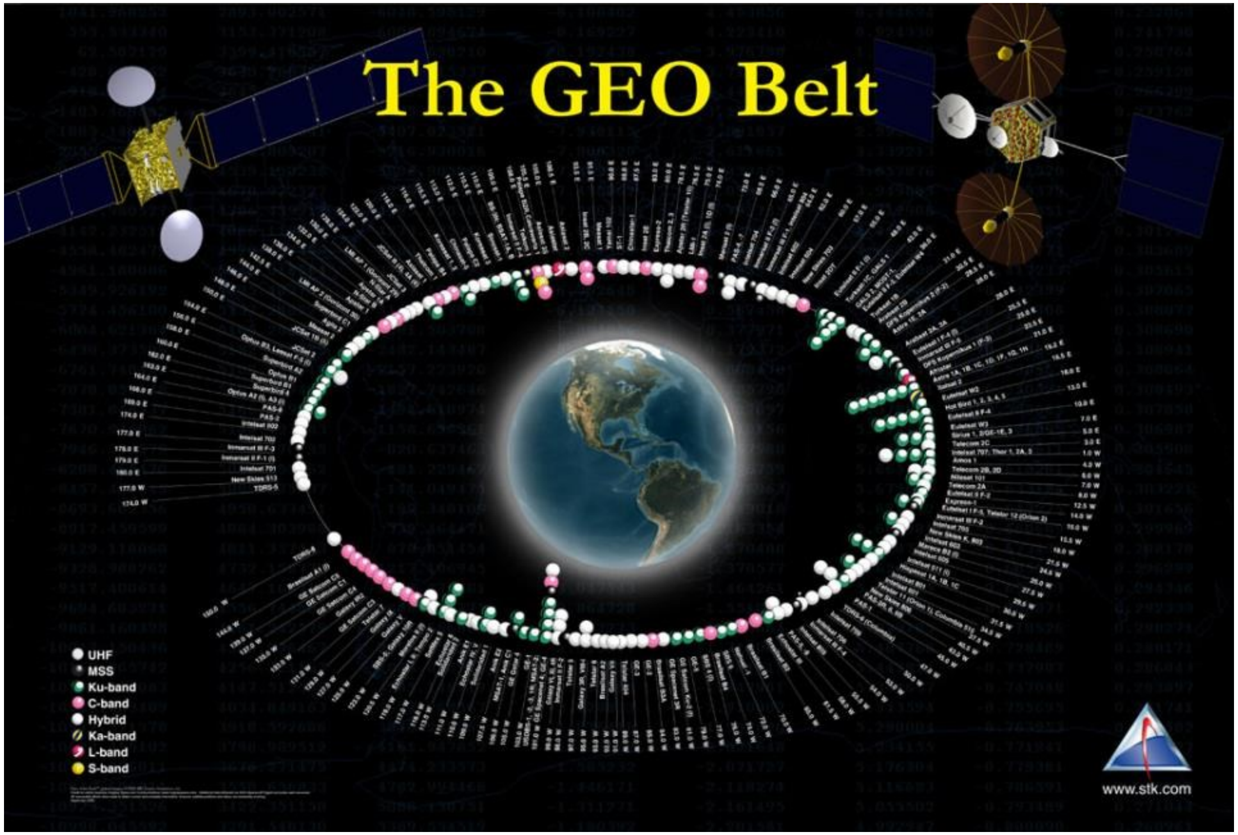
Crowded Geostationary Orbit?

- Crowded in terms of frequency allocations – not in terms of distance!



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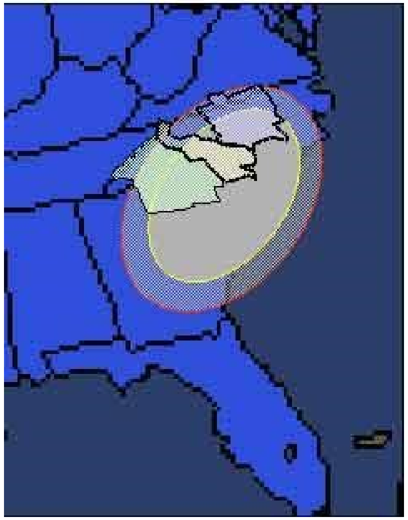
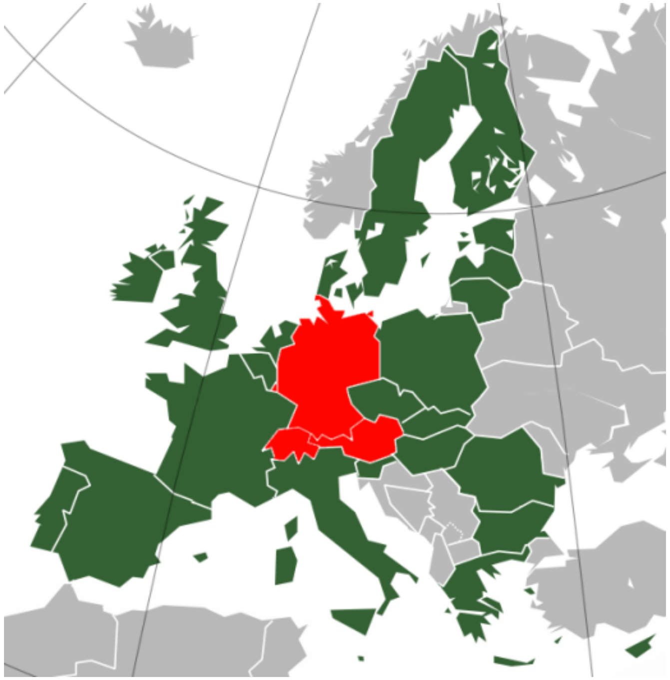
Communication
TV Satellites

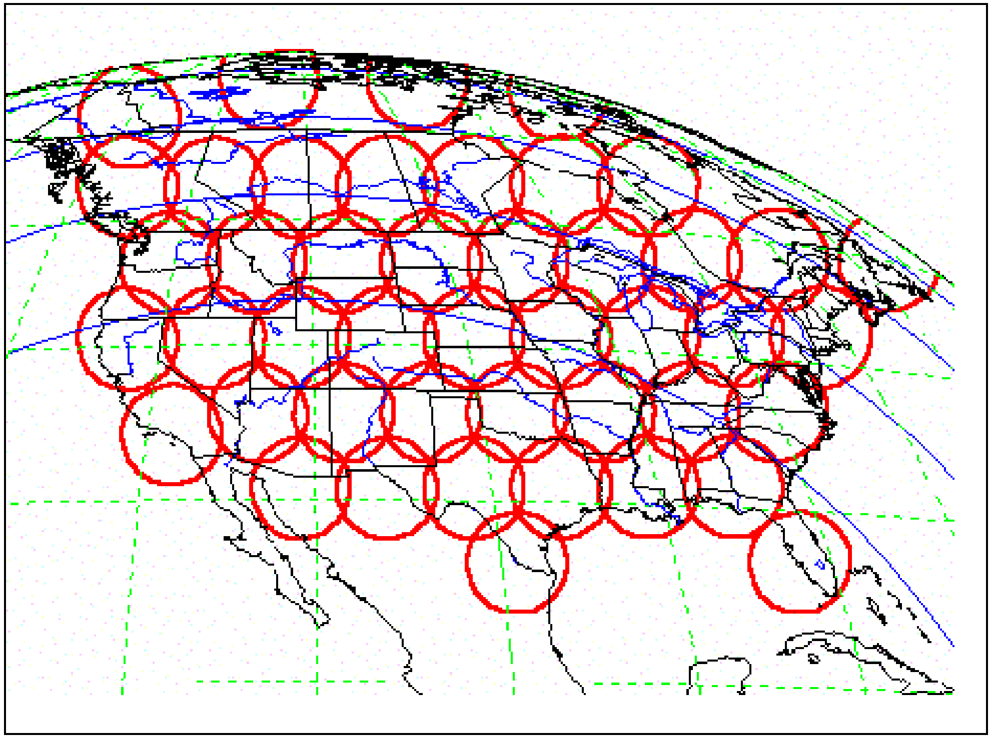
- Beam types:
  - “Spot”
  - Continental
  - Political
  - National
    - ”CONUS”
    - EU
  - Linguistic





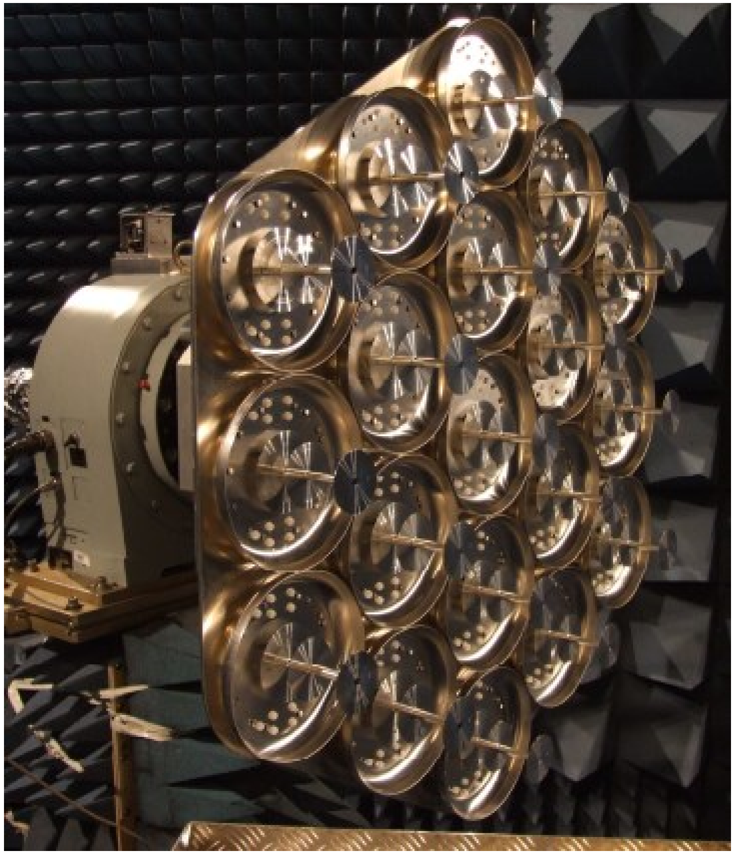
Mobile Communication
Cellular Systems

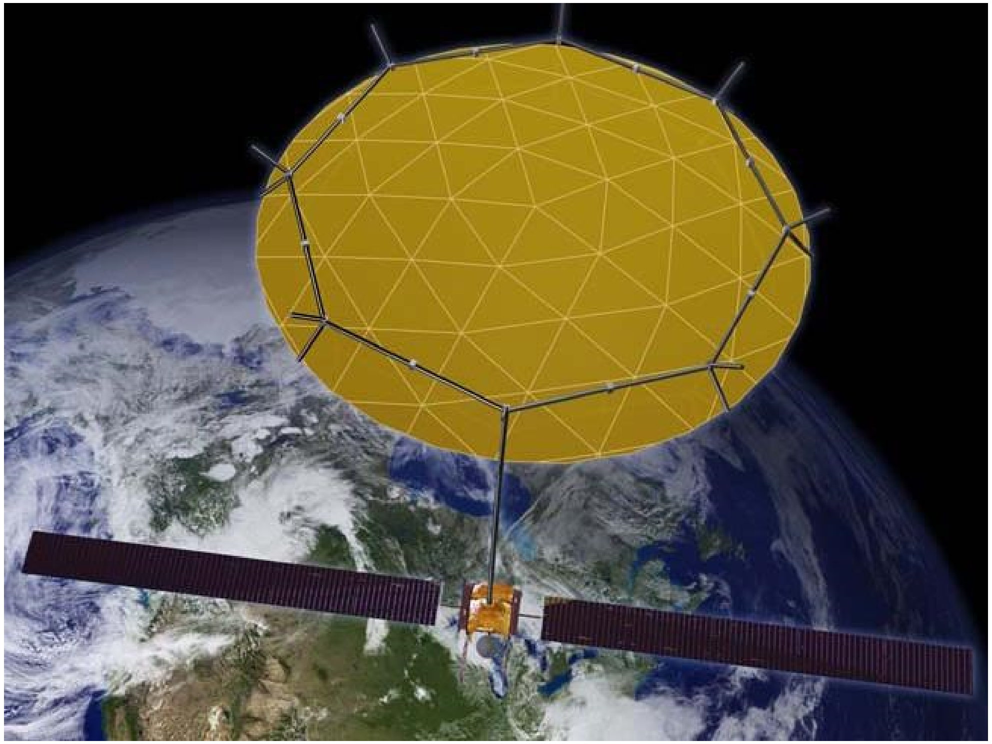
- For mobile communications you want a regular cell pattern on Earth
  - Small cells + low frequency = large reflectors



Mobile Communication
Cellular Systems

- Huge deployable reflectors (30 m) with many feeds in the focal plane





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“New Space”
Constellation Systems

- OneWeb (c. 900 satellites)

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"New Space"
Constellation Systems

- Corona fall-out in 2020, with 74 out of > 648 satellites in orbit…

OneWeb files for Chapter 11 bankruptcy

by **Caleb Henry** — March 27, 2020

Softbank, having already invested $2 billion in OneWeb, declined to invest more. Credit: OneWeb

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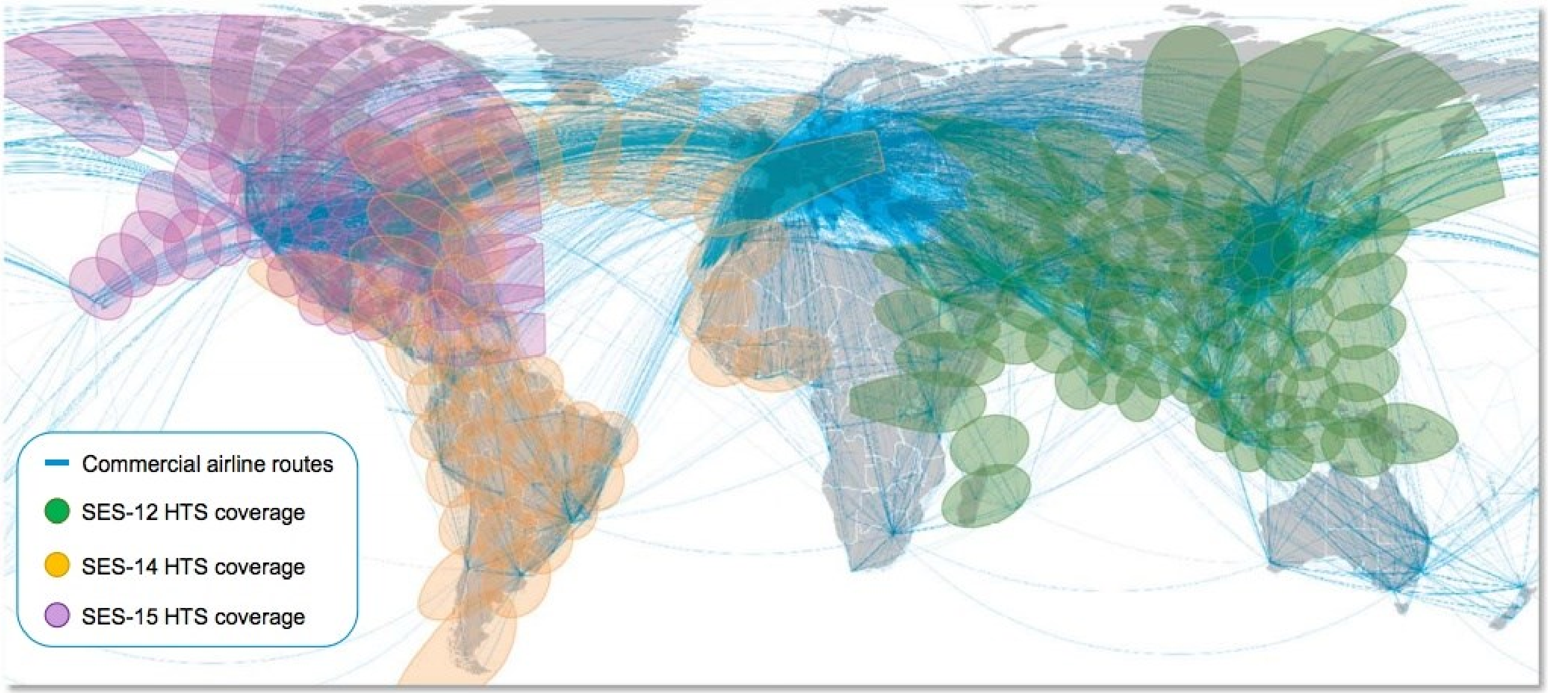
“New Space”
High Throughput Satellites

- Ubiquitous broadband



▲ Complementing SES’s global wide beam GEO network, along with O3b’s unique MEO HTS

"New Space"
High Throughput Satellites

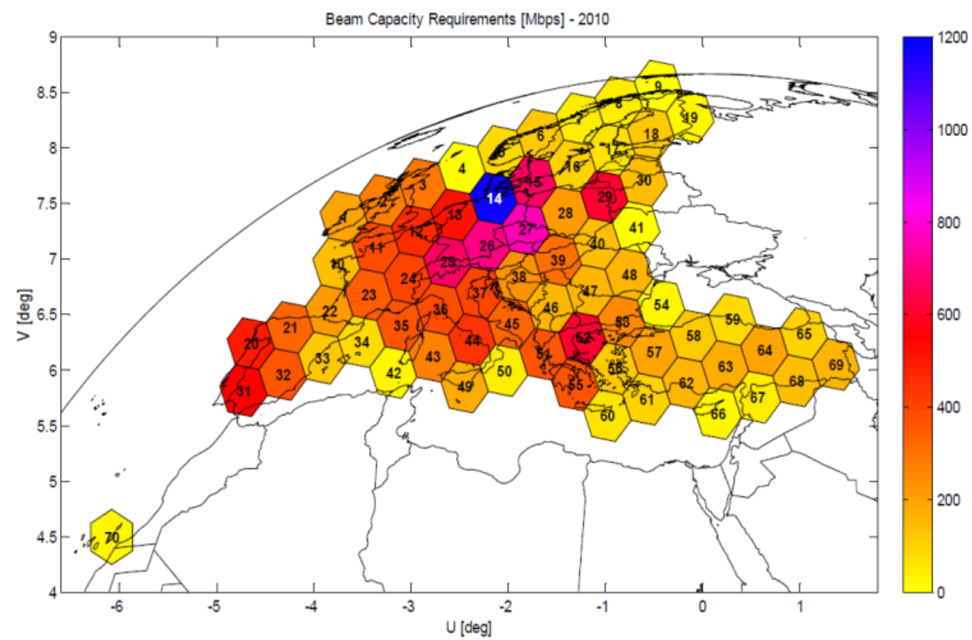
- Corona fall-out: 7 March vs. 27 April 2020

“New Space”
Why Broadband over Satellite?

- Fixed terminals
  - “The Digital Divide”

distribution across the coverage area was used. The model, corresponding to predicted demands for 2010 was taken directly from the original ESA DDSO (Digital Divide Satellite Offer) study [6] is shown in Fig. 3. It shows the predicted capacity per beam in Mbits/sec for the coverage presented in Fig. 1.

- Non-space competition:
  - Fiber
  - 3G/4G/5G



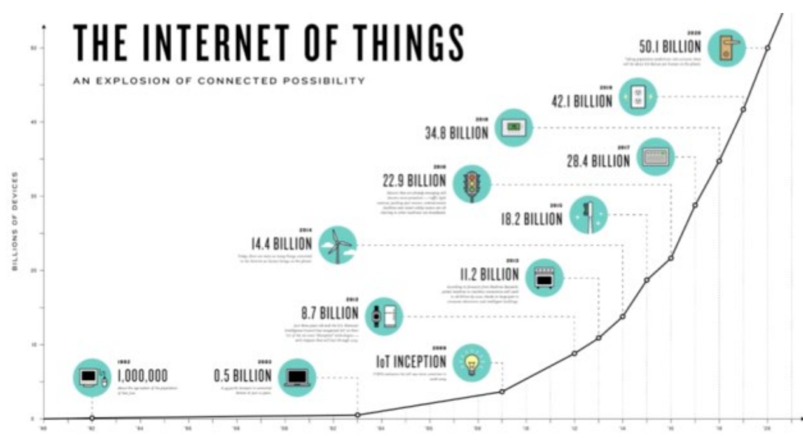
År 2025 bör hela Sverige ha tillgång till snabbt bredband

- *98 procent av alla hushåll och företag bör ha tillgång till 1 Gbit/s*
- *1,9 procent av alla hushåll och företag bör ha tillgång till 100 Mbit/s*
- *0,1 procent av alla hushåll och företag bör ha tillgång till 30 Mbit/s*

“New Space”
Why Broadband?

- Mobile users
  - Aeronautical
  - Maritime

- On board entertainment
- Work on board
- “Fleet management”
- “TT&C”
- “Internet of Things” (IoT)



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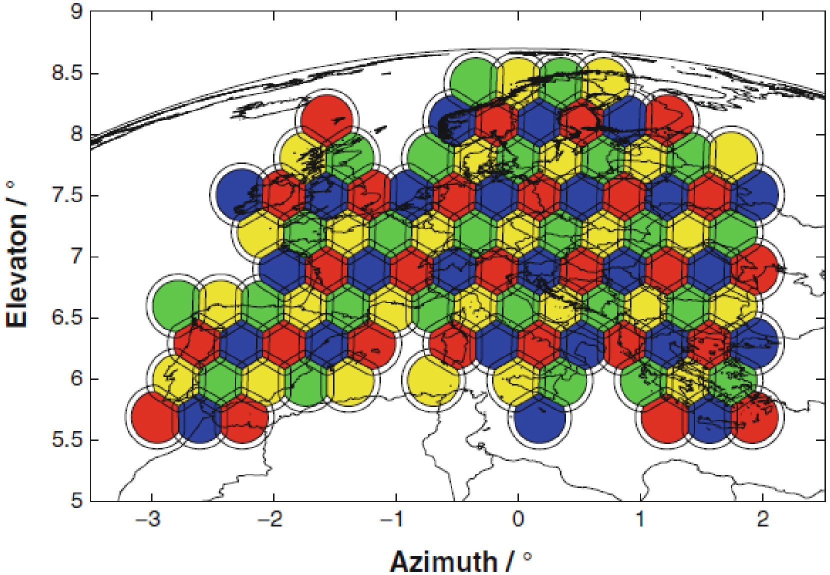
"New Space"
High Throughput Systems (HTS)

- Hundreds or thousands of beams
- Terabits per second in total!

- How to accomplish this within a limited spectrum allocation?



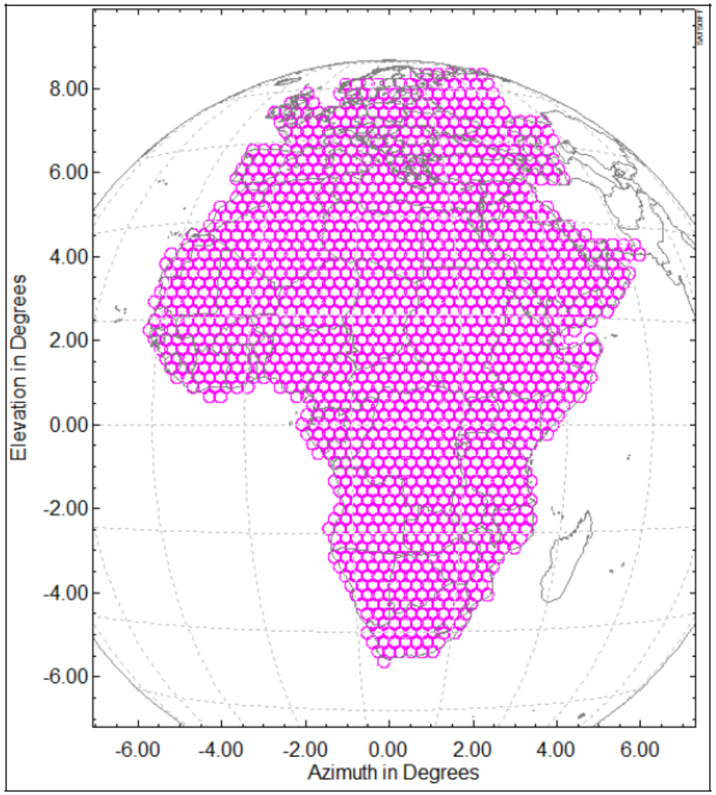


Fig. 1. VHTS coverage of 1587 beams of 0.3° diameter

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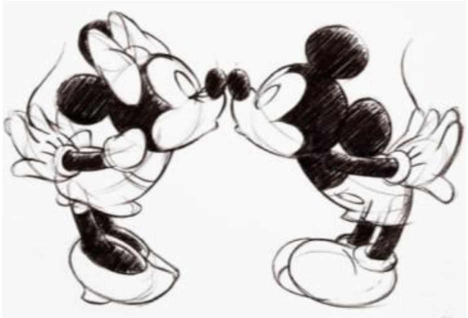
Multiple Beams
HTS

- Four large reflectors



TAS/Eutelsat Spacebus Neo HTS spacecraft

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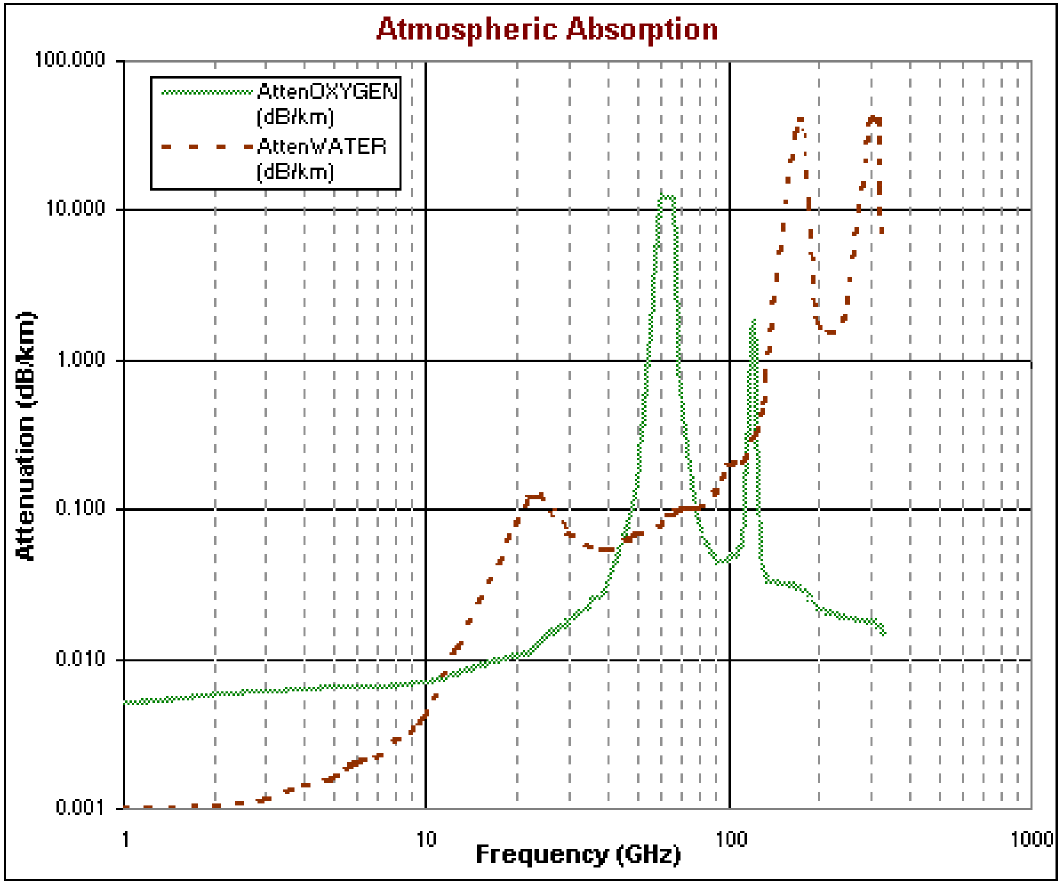
Atmospheric Attenuation

- The frequency range up to 20 GHz has low attenuation and is well suited for communication between the ground stations and the satellite
- Resonance for water vapor around 24 GHz
- Oxygen line around 60 GHz



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Distance and Time…
A Comparison

- Enormous range of distances…
  - The signal strength decays with the square of the distance

Orbit	Distance	Delay	Data Rate
Low Earth (LEO)	500 – 800 km	ms	Gbps
Geostationary (GEO)	36000 km	0.12 s	Gbps - Tbps
Moon	384000 km	1.3 s	
L1/L2	1.5 million km	5 s	Mbps
Rosetta (comet)	500 million km	28 m	28 kbps
Cassini (Titan)	1.5 billion km	1.4 h	14 kbps
New Horizons (Pluto)	4.9 billion km	4.5 h	1 kbps

Different Requirements!

- Earth observation satellites in low earth orbit
  - 500 – 800 km
  - Large data quantities / high data rate
  - High angular rate for ground station
  - Small coverage area / short connection time
  - Small / medium size ground station antenna
- “Deep space”
  - > 2 million km
  - Medium data quantities / low data rate
  - Low angular rate for ground station
  - Large coverage area / long connection time
  - Large ground station antennas

Frequency Bands for Data Downlinks

- Frequency band
  - 2 GHz (S-band)
  - 8 GHz (X-band)
  - 26 GHz (K-band)
  - 32 GHz (Ka-band) ”Deep Space”

Low frequency	High frequency
Small attenuation	Large attenuation
Large antennas	Small antennas
High transmitter power possible	Difficult to generate high power
Low receiver noise	Somewhat higher receiver noise
Narrow bands	Wide bands

NASA DSN

- NASA Deep Space Network (DSN)
  - Under Jet Propulsion Laboratory (JPL)
- Ground stations in
  - Goldstone, Cal., US
  - Madrid, ES
  - Canberra, AU
- Arid areas…
- Reflector antennas
  - 70 m
  - 34 m

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ESTRACK

- European Space Tracking (ESTRACK)
- Ground stations:
  - Maspalomas, Gran Canaria, ES
  - Kourou, Guayana, FR
  - New Norcia, AU
  - Perth, AU
  - Redu, BE
  - Cebreros, ES
  - Villafranca, ES
  - Kiruna, SE
  - Santa Maria, Azores, PT
  - Malargüe, AR

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SSC

- Commercial network

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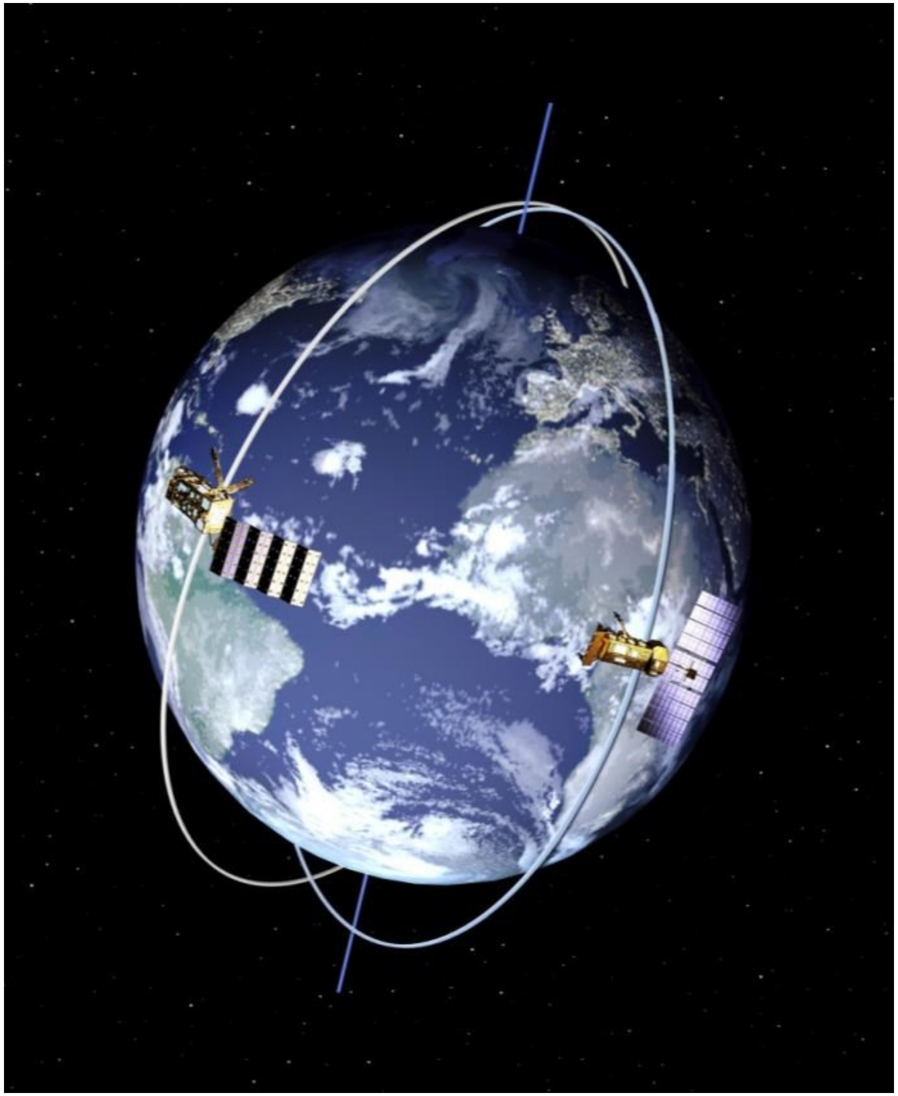
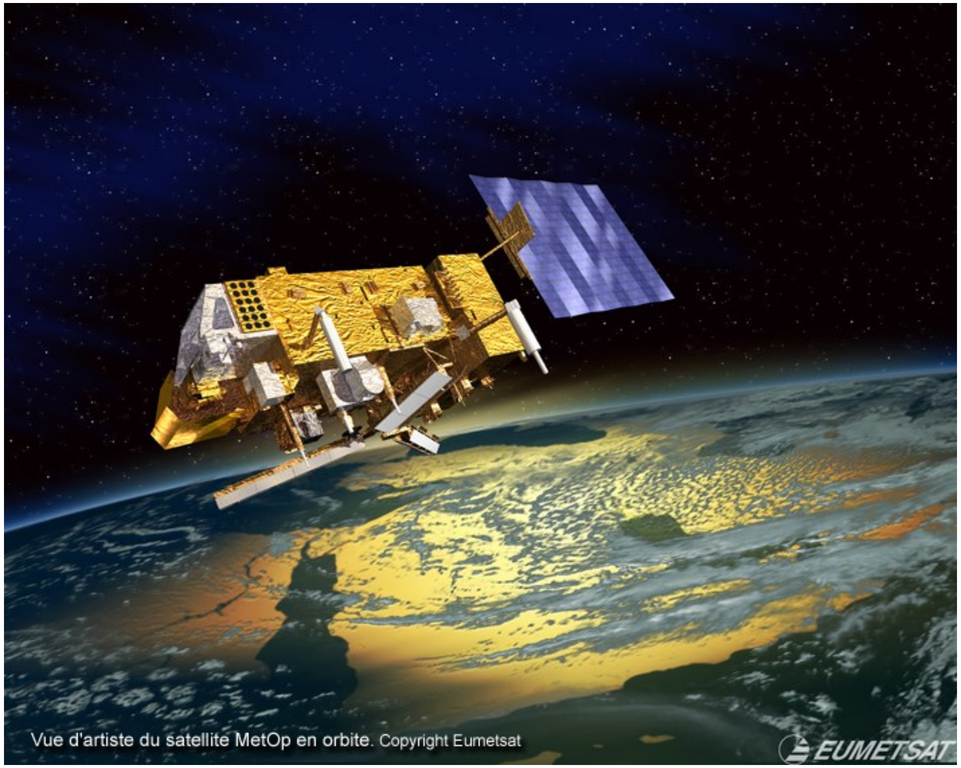
Polar Orbits
Sun Synchronous Orbits

- Satellites for Earth observation often have an orbit that passes over the poles
- So-called sun synchronous orbits pass over the equator at the same <u>local</u> time each orbit
  - MetOp 09:30
- Big advantage to have ground stations at high latitudes!



Polar Orbits
Remote Sensing

- EUMETSAT's weather satellite MetOp
- No accurate weather forecasts possible without these satellites
- Many optical and microwave instruments to measure various meteorological parameters
- 817 km altitude



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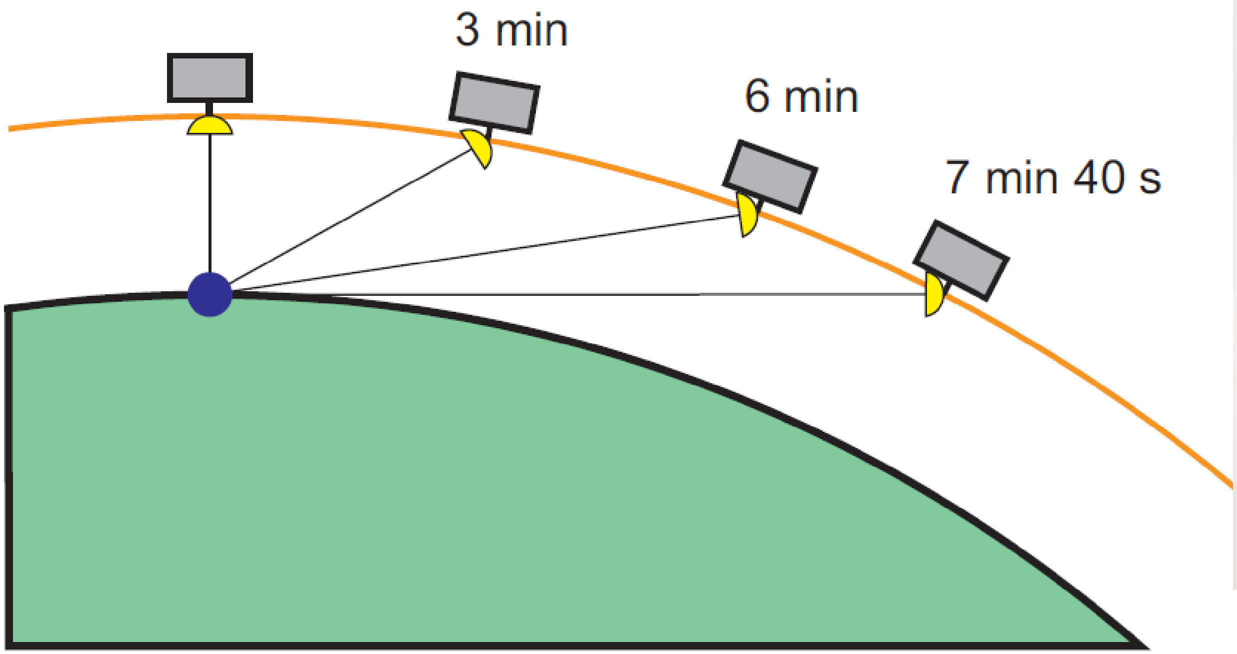
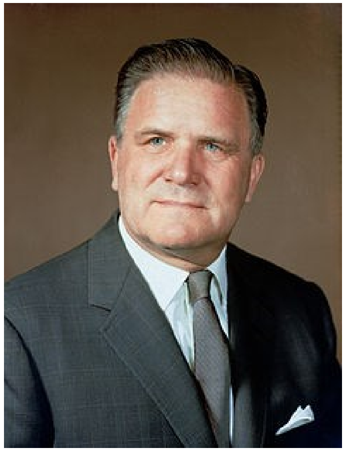
Polar Orbits
Data Downlink

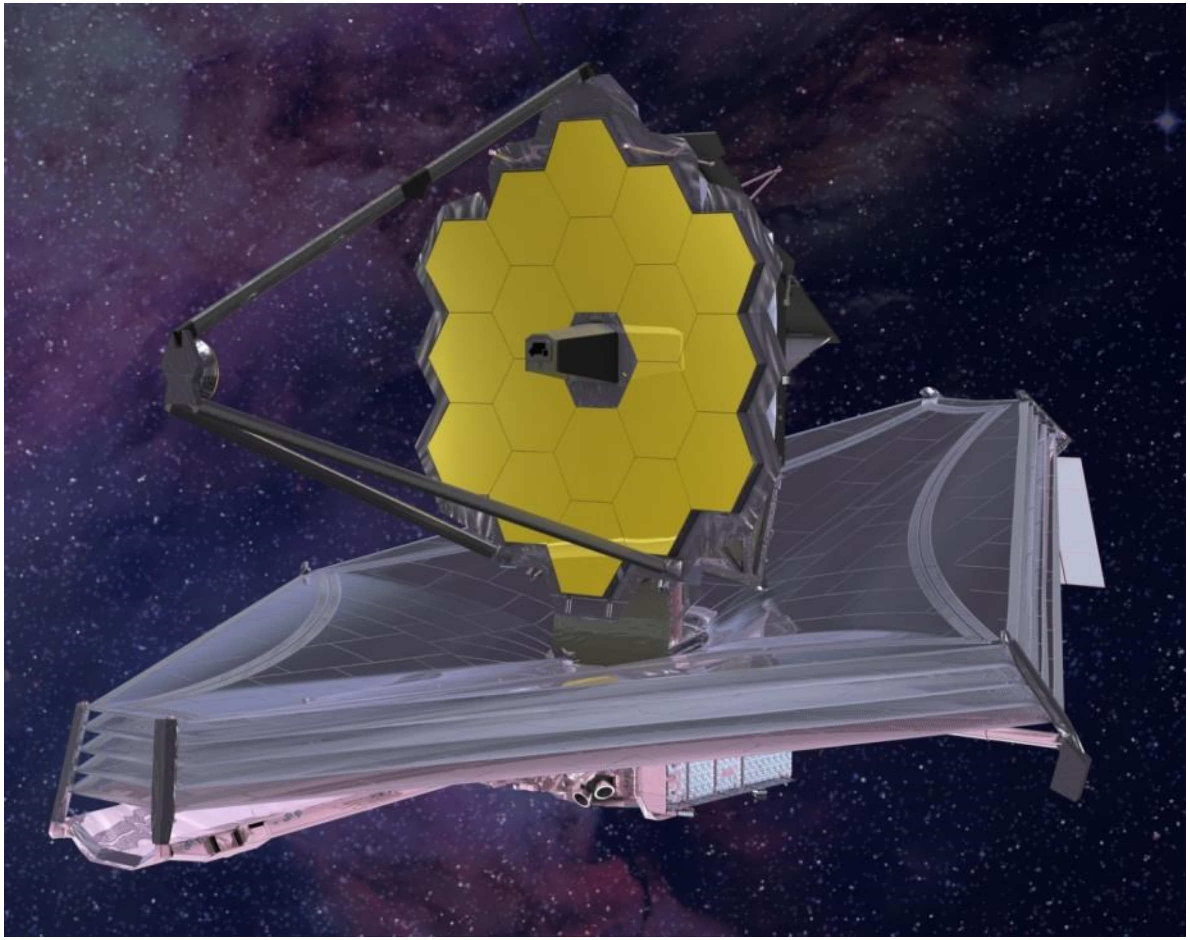
- Reflector high gain antenna on antenna pointing mechanism
  – A maximum of 10 – 15 minutes of link



Case Study:
James Webb Space Telescope (JWST)

- Next generation space telescope
- NASA & ESA
- Named after the NASA administrator 1961 – 68





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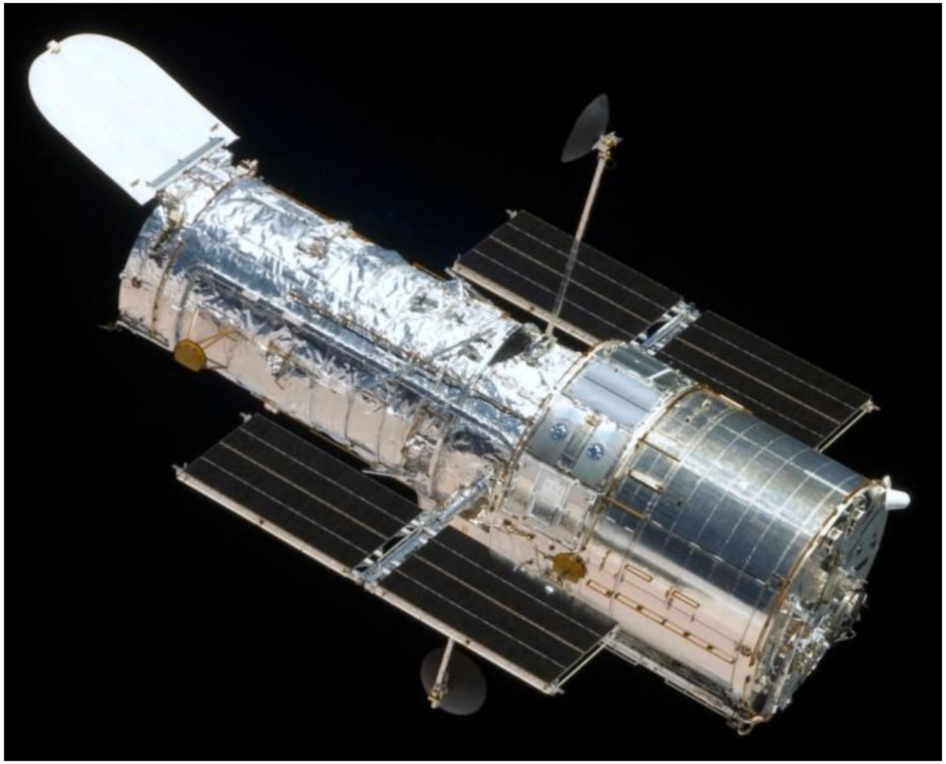
The Predecessor:
Hubble Space Telescope

- Launch: 25 April 1990
  with the Space Shuttle
- Life length: 28 years already…
  - A number of repairs
    during the years
  - De-orbiting > 2020?
- Orbit: LEO 559 km
- Mass: 11100 kg
- Telescope diameter: 2.4 m
- Size: 13.2 m (length)
- Wavelength range:
  Visible light, UV, NIR



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Hubble
Ultra Deep Field

- Galaxies, galaxies, galaxies…

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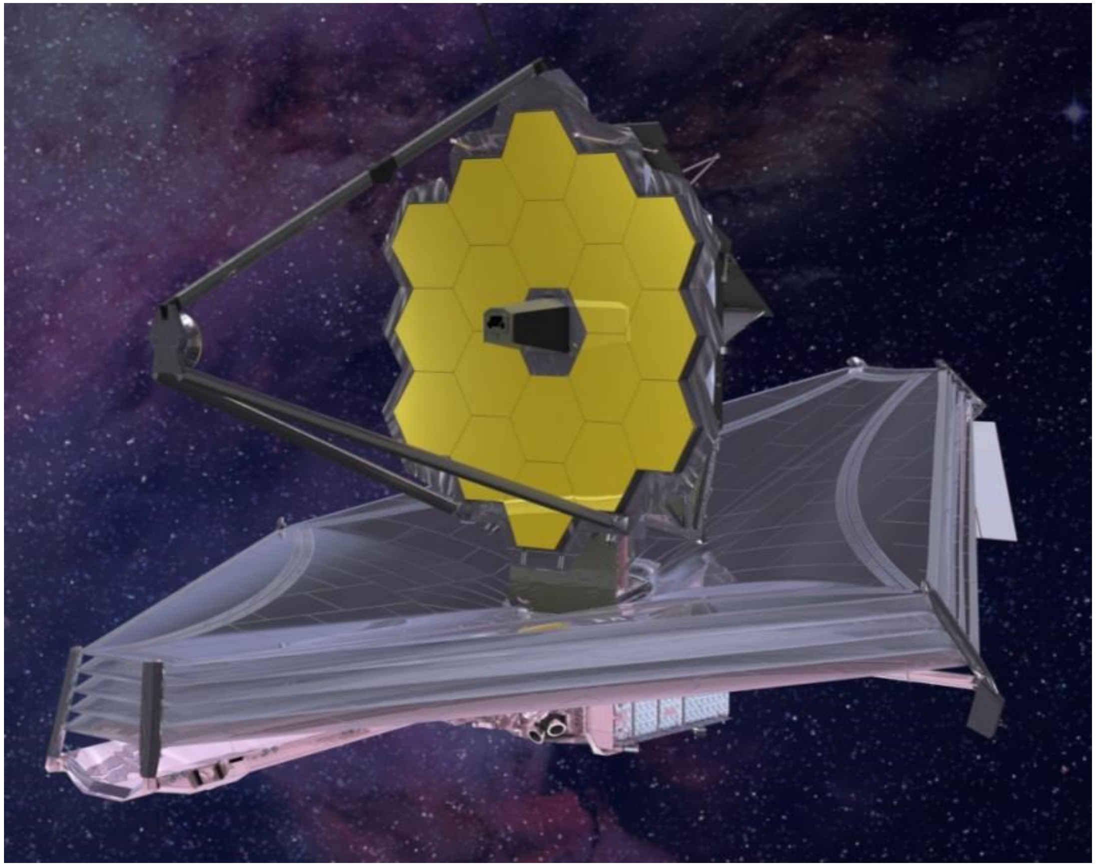
Hubble vs. JWST

- Unlike Hubble, the JWST will mainly cover the infra-red range, and can thereby look deeper into dust and gas clouds.
- What one wants to get insight into is the genesis of the first stars and galaxies in the young universe, as well as star and planet formation in dust clouds.

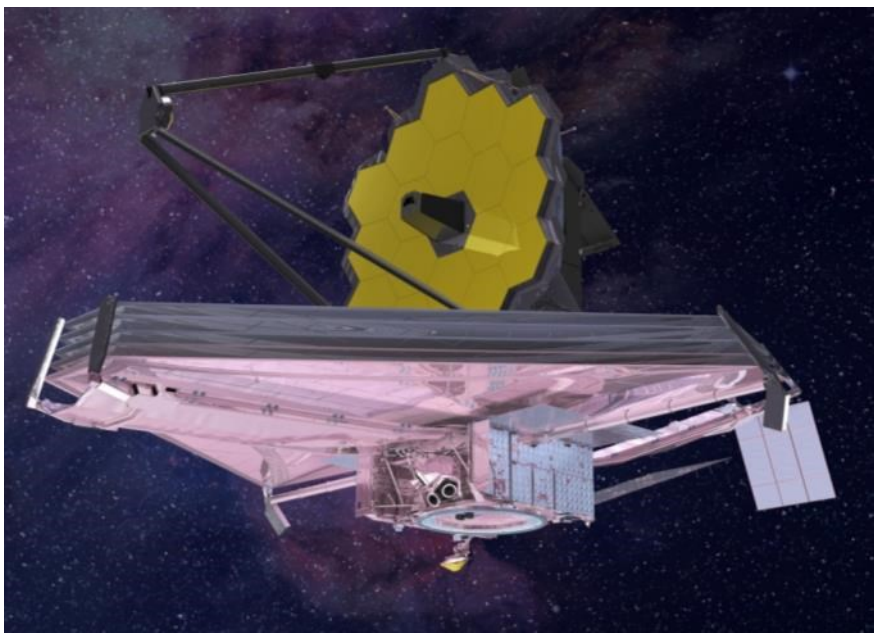
Data for JWST

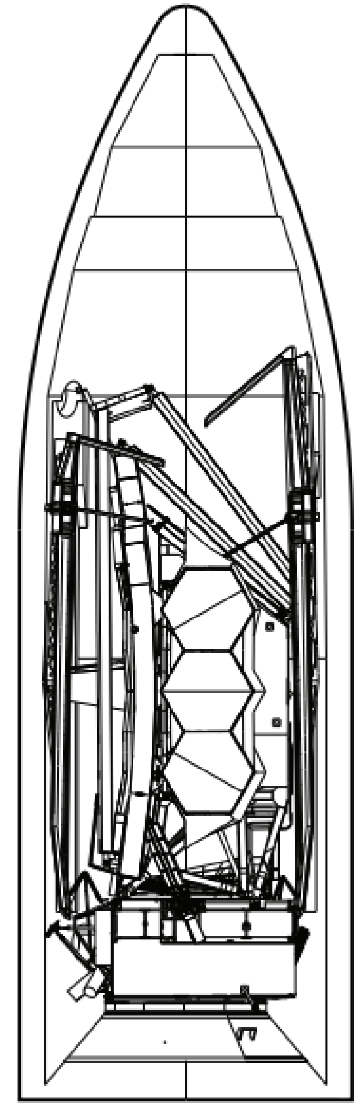
- Launch: > 2021 with Ariane 5 from Kourou
- Budget: 9 billion USD
- Life length: 5 – 10 years
- Orbit: L2 halo (1 year)
- Mass: 6200 kg
- Telescope diameter: 6.5 m
- Wavelength range: 0.6 – 28.5 µm



“Kinder Egg Engineering”

- A 24 m x 12 m x 12 m telescope shall be packed into a 4.6 m diameter fairing!



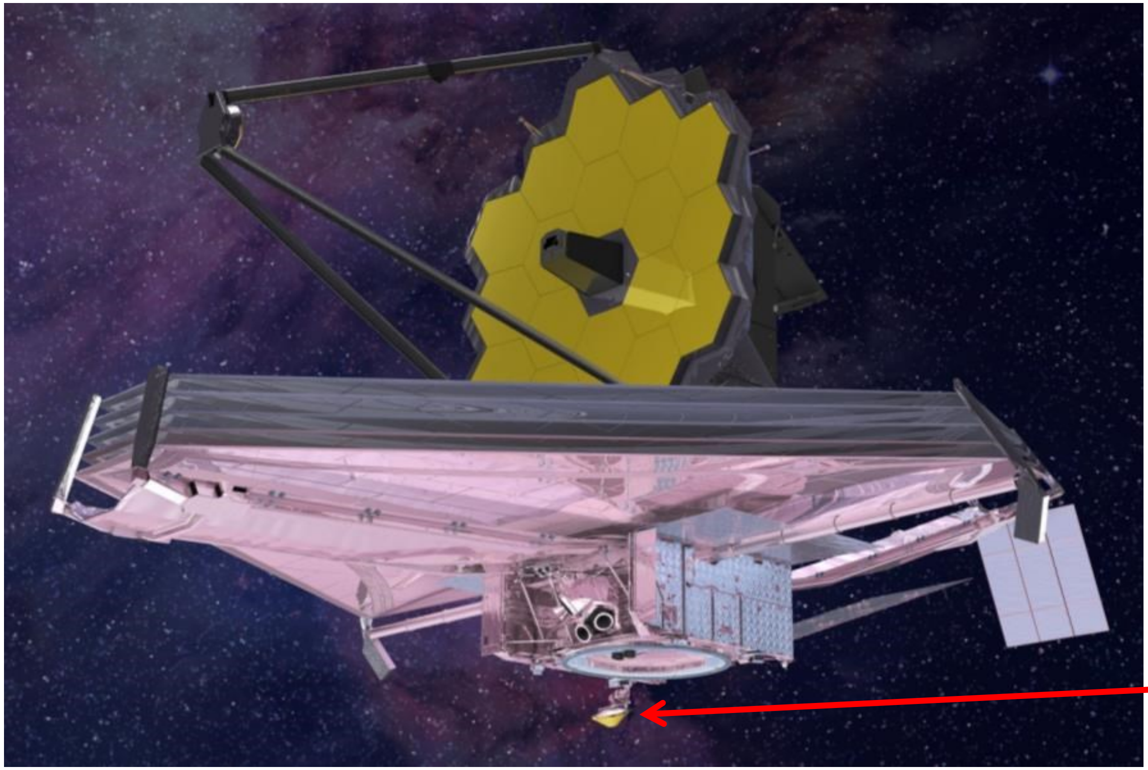


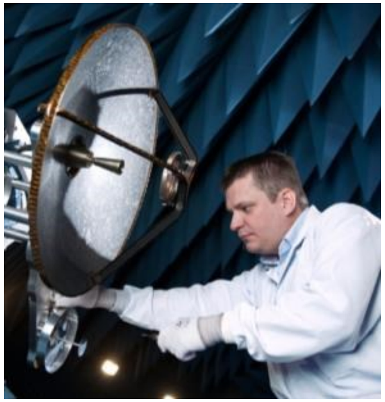
JWST K-band Antenna from RUAG

- Reflector antenna in carbon fiber reinforced plastic (CFRP)
  – 26 GHz

JWST K-band Antenna from RUAG

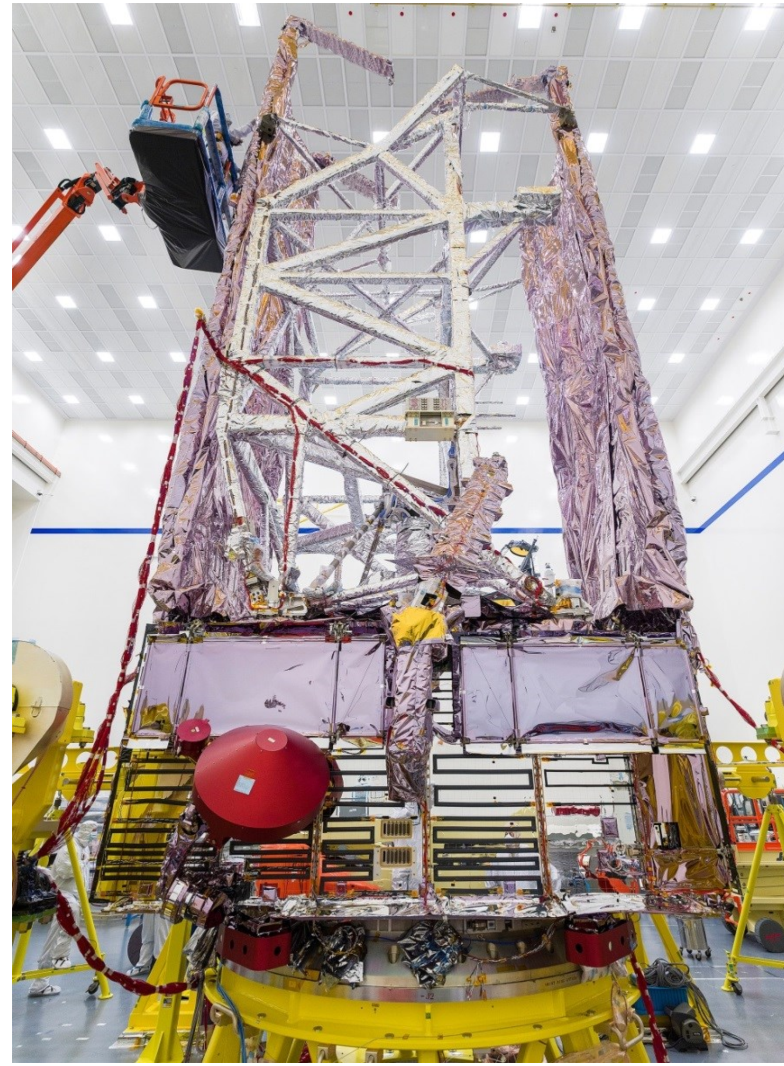
- Interesting size comparison…





JWST in Reality Now
Integration in Redondo Beach

- NASA administrator Bridenstine on a visit 9 October 2019:



  – Your lecturer visits on 10 October…
    – Unfortunately no selfies allowed ☹

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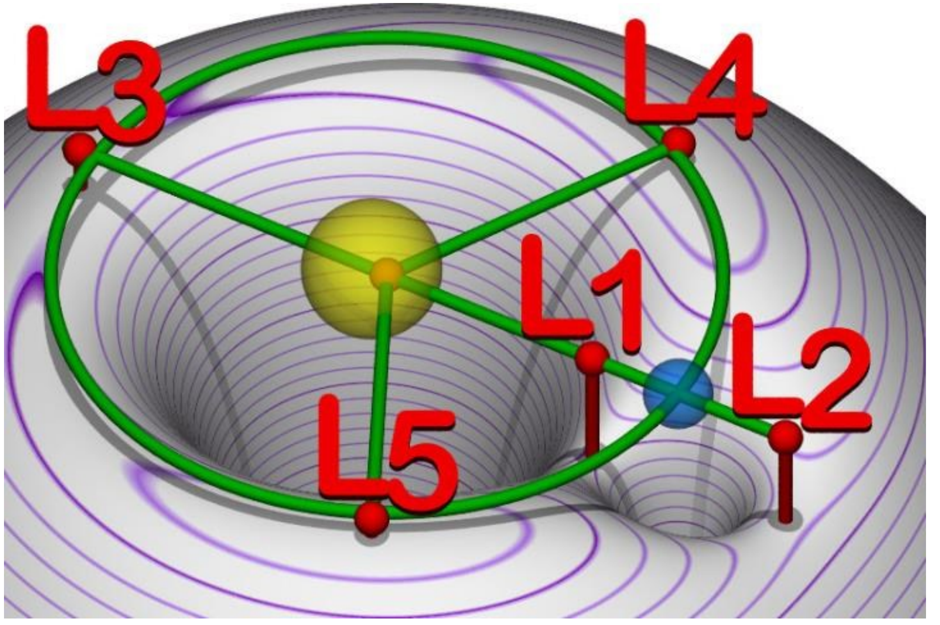
The JWST Orbit

- L2 = Second Lagrange point
  - 1.5 million km from Earth
- Lagrange points:
  - “Balance” between centripetal acceleration and gravitation from the Earth and the Sun
  - Five “points”
  - Co-rotate with the Earth-Sun system
    - 1 year orbit
- The solar telescope SOHO is at L1



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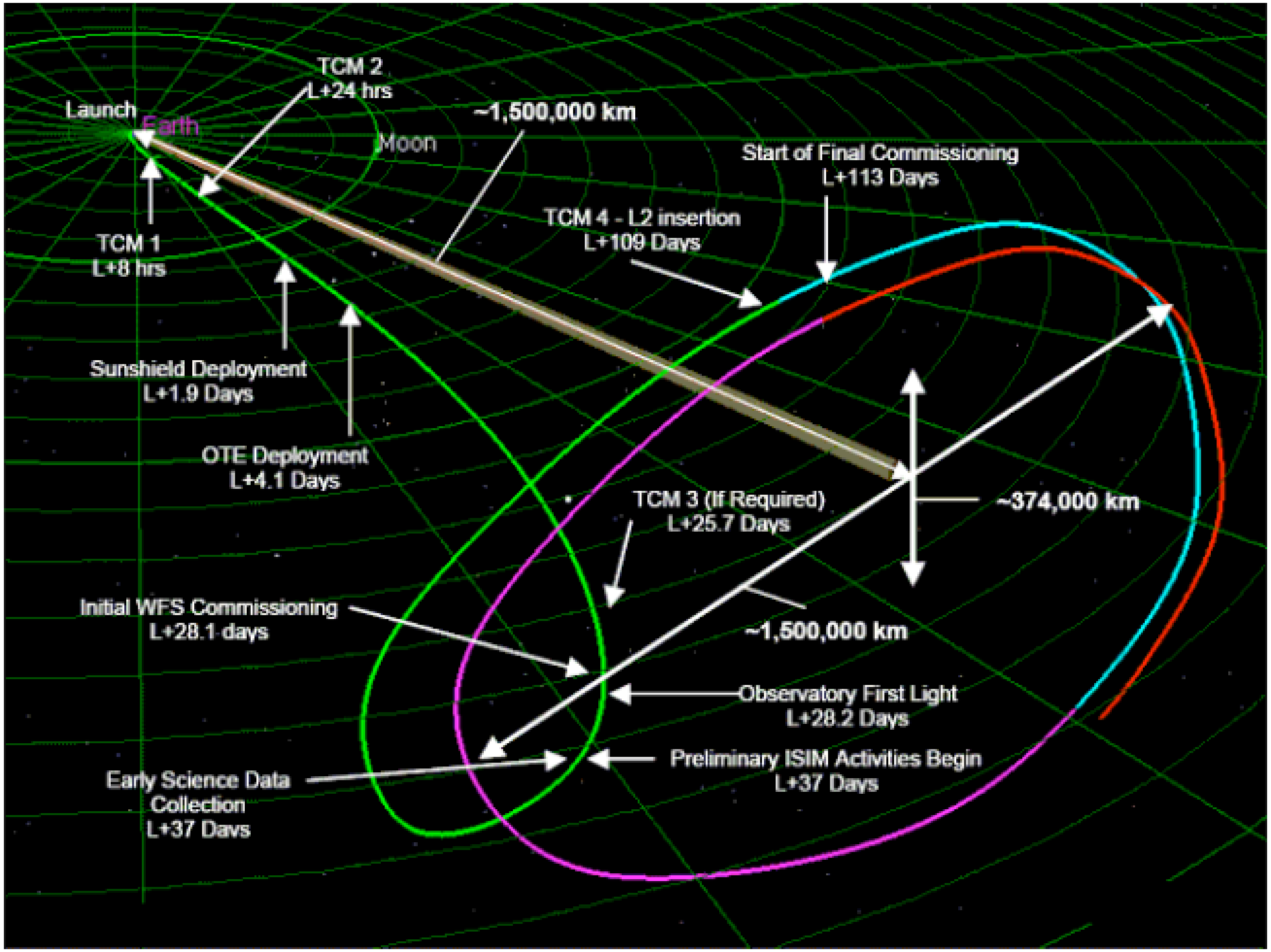
The JWST Orbit

- In reality a so-called halo orbit…



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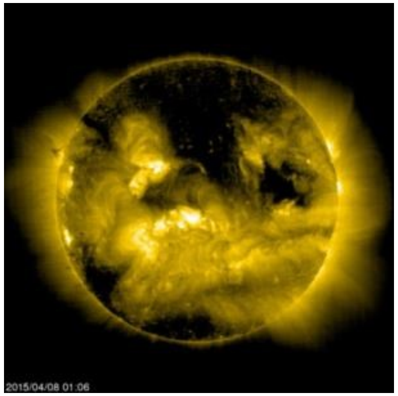
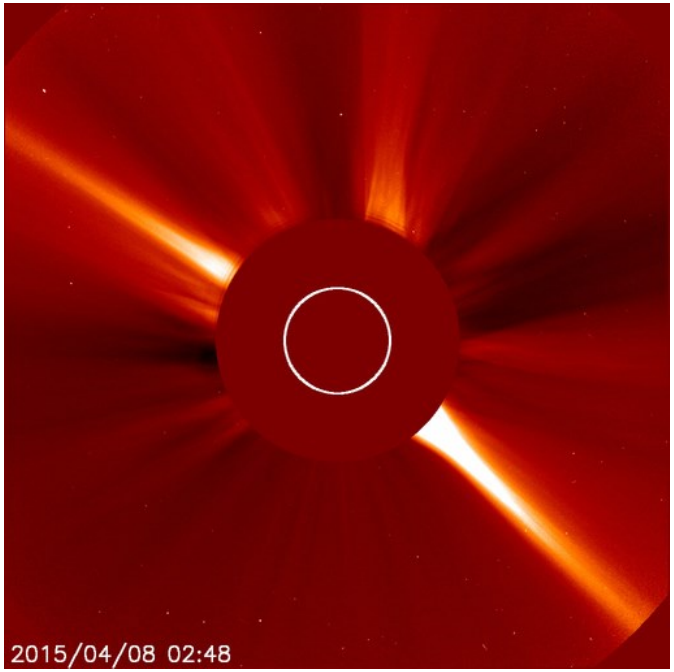
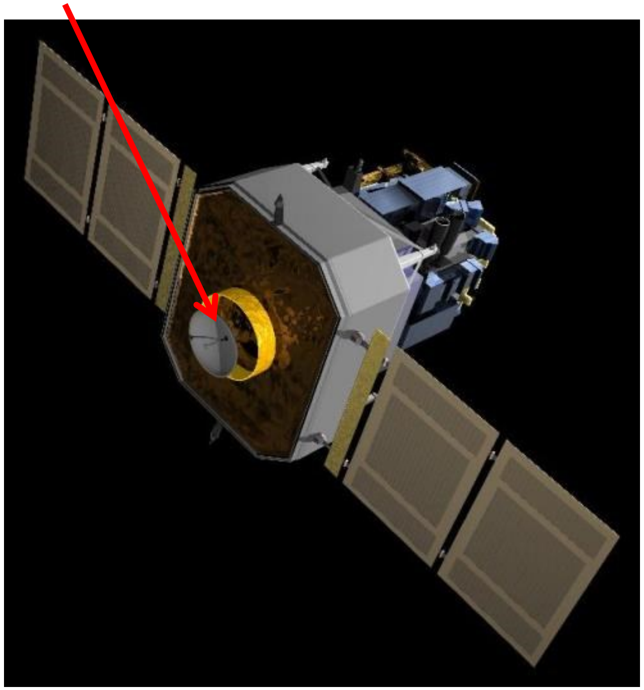
An Angry Sun!



- SOHO gives real time warnings about solar storms
  - Placed in L1
- S-band down-link (reflector antenna) from RUAG





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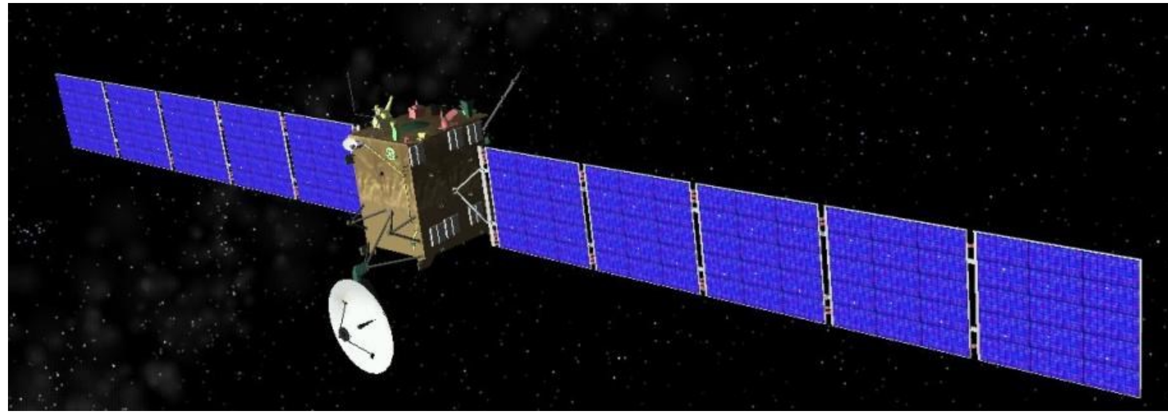
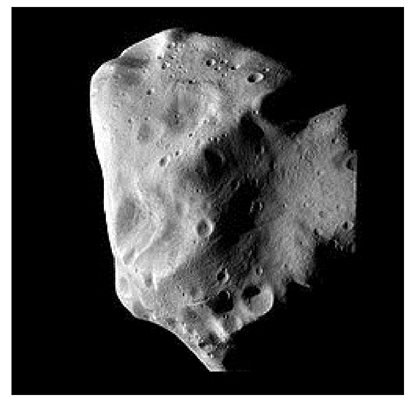
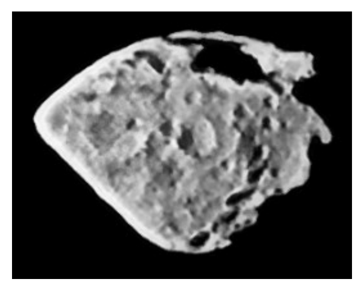
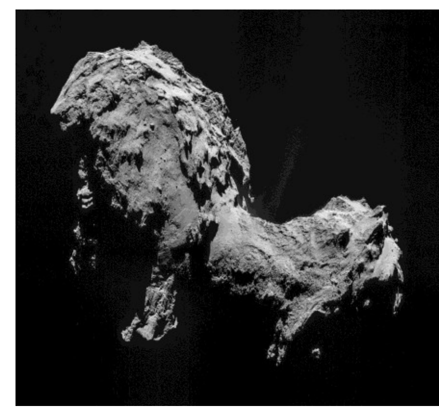
Rosetta



- Launched 2004
- Ariane 5
- Kourou, Guyana
- “Slingshot” around Mars and Earth
- Scared the astronomers…
  – NEO 2007 VN84
- Fly-by of asteroids:
  2867 Šteins (2008)
  21 Lutetia (2010)
- Rendezvous in August 2014 with comet 67P / Churyumov-Gerasimenko







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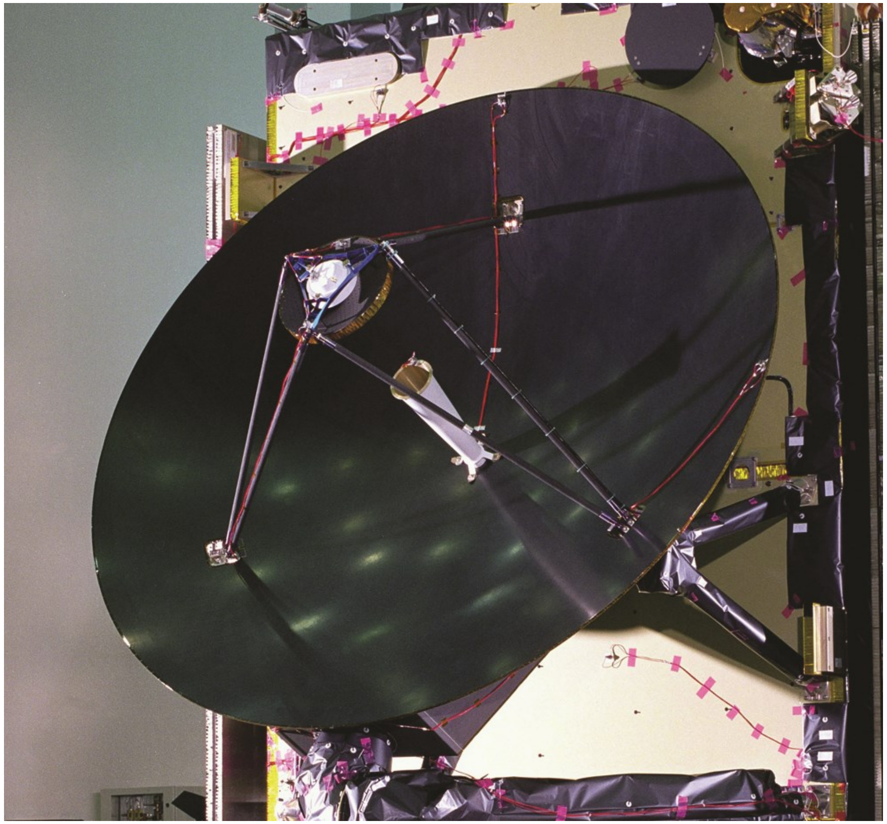
Rosetta HGA

- RUAG (Saab Ericsson Space) were responsible for the high gain antenna (HGA)

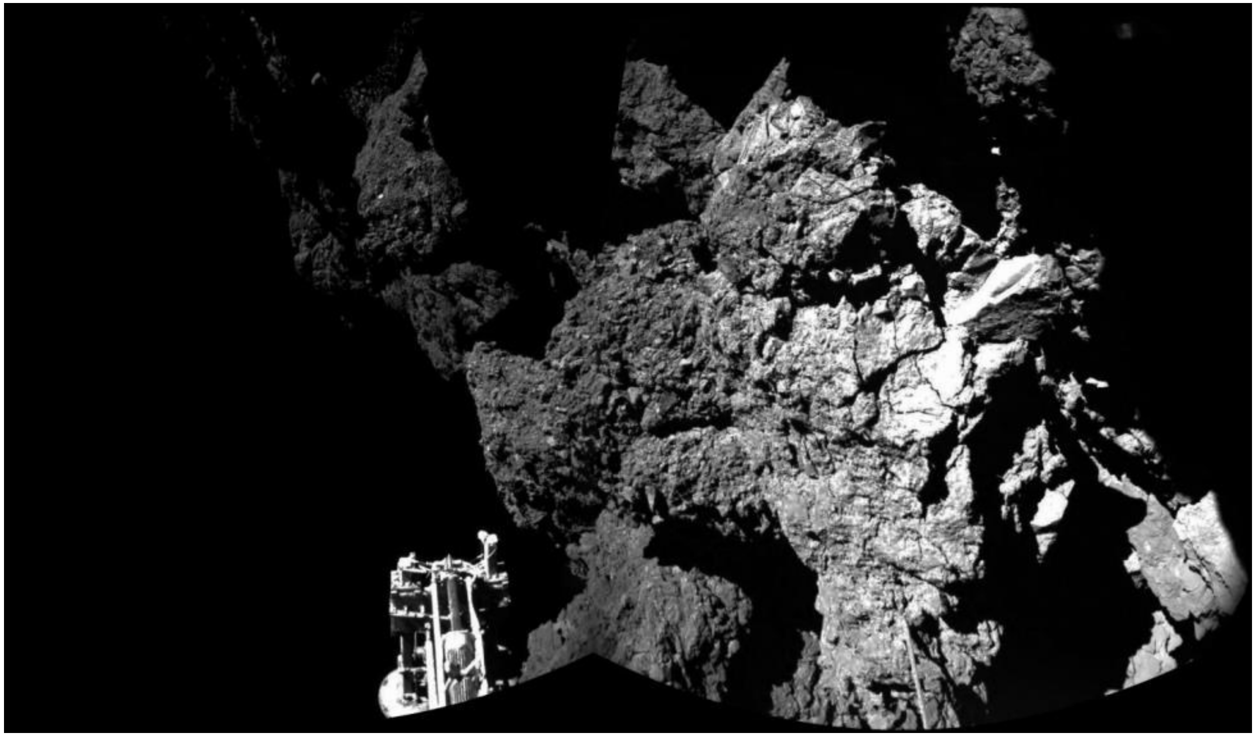
- CFRP reflector
  – 2.2 m diameter

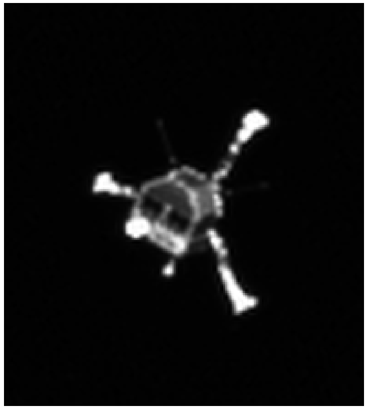
- X- & S-band



Rosetta

- The lander ”Philae” was stuck in a crevice on the comet
  - There were some hopes that the batteries would recharge later…

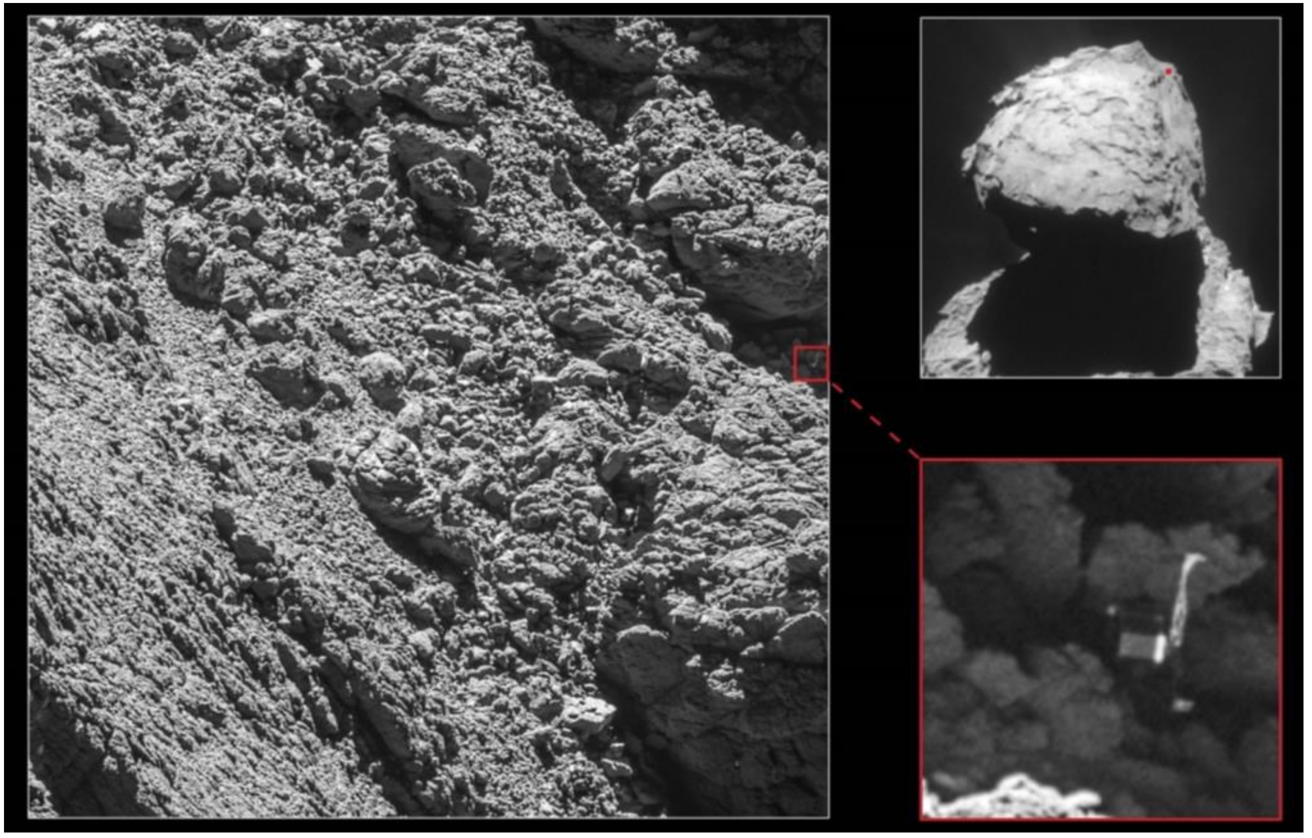




Together ahead. RUAG

Rosetta

- Philae was found again 2 September 2016!



RUAG Space
Antennas – Strength Areas

- Wide Coverage Antennas for
  - Telemetry and telecommand, GPS receivers, beacons, and data downlinks

- Array Antennas for
  - SAR, scatterometers, and mobile communication applications

- Reflector Antennas for
  - Satellite data links, deep space probes, DBS applications, radio astronomy, and earth observation

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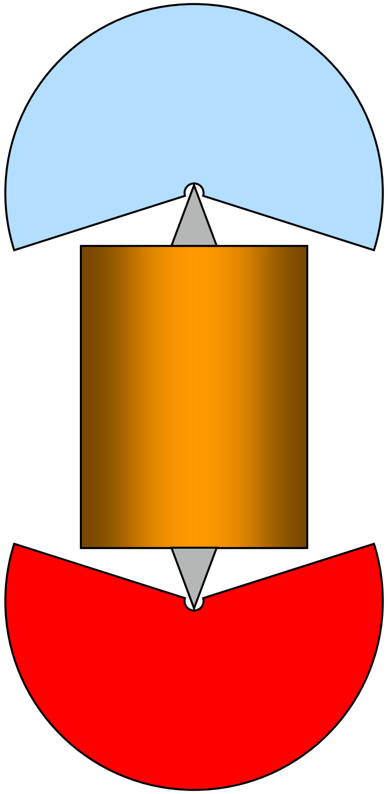
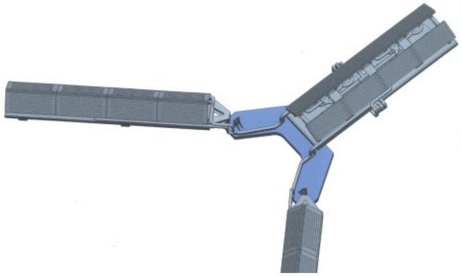
TT&C Antennas

- Telemetry (TX)
- Tracking (RX/TX)
- Command (RX)

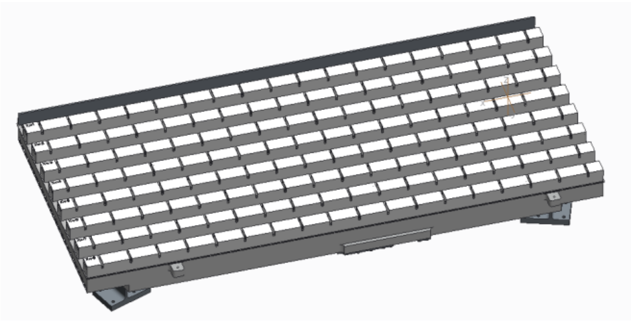
- Omni-directional antenna patterns desired
- Typically two hemi-spherical coverage antennas
- Typically S-band (2 GHz)

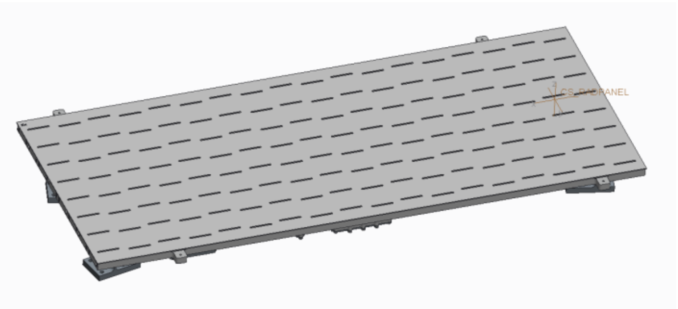


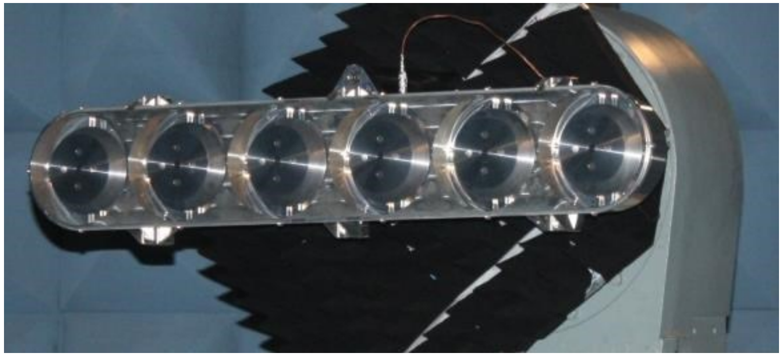
Array Antennas
Instrument Arrays for Earth Observation



- MetOp SG
  - Single and Dual Polarization Slotted Waveguide Arrays
  - Radio Occultation Array







Space Antennas – How Difficult Can It Be?

Magnetic Field
Magnetic Moment

Vacuum
Outgassing
Venting

Solar Radiation & Albedo
Thermo-Mechanical Fatigue
Thermal Distortion
Heat Flux

Shock
Acoustical Noise
Quasi-Static Load
Random & Sine Vibrations
Structural Damage
Deformation

Thermal Engineering

Structural Engineering

Materials Science

Electromagnetics
Microwave Engineering
Computational Electromagnetics (CEM)

Surface Physics

Chemistry

Plasma Physics

Micrometeoroids & Debris
Reliability
Abrasion

UV
Charged Particles (e^-, p^+)
Electrostatic Discharge (ESD)
Radiation Damage

Atomic Oxygen (ATOX)
Corrosion

External RF Radiation
Passive Intermodulation (PIM)

RF Power
RF Losses (Heating)
Multipactor, Corona, & Arcing

Together ahead. RUAG

The Launch
– A Shaking Experience

- The antennas will be placed in such positions that they will encounter extreme vibrations from the launch
  - Whine from turbo pumps (“sine”)
  - Aerodynamic turbulence (“random”)
  - Noise from the rocket engine (“random”)
  - Shock from pyrotechnical devices

- Vibrations can be transmitted either acoustically or by the suspension

Radiation

- Solar irradiation
  - UV
  - Heat, c. 1400 W/m^2
- Charged particles
  - Electrons & protons in the Van Allen belts
  - High energetic particles
  - Destroy electronics and charge plastic materials

Vacuum

- Tribology
  - Metals cold weld together
  - Lubrication difficult
- Microwave breakdown
  - Multipactor
- No convection
  - Heat transfer only through conduction or radiation
- Out-gassing
  - Many forbidden materials…

Where/What?	Pressure [Pa]
Earth's surface	100000
High vacuum	10^{-1} to10^{-7}
Ultra high vacuum	10^{-7} to10^{-10}
Outer space	10^{-4} to 10^{-15}

Hot and Cold

- The side facing the Sun can become very warm
  - +150 ° C
- The side facing deep space can become very cold
  - –150 ° C

- Temperature gradients in the antennas can cause deformations
  - Insulation needed sometimes

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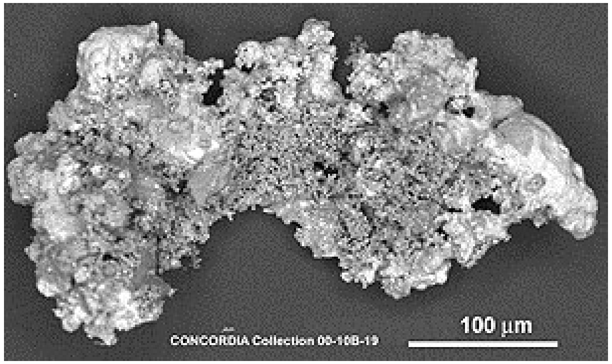
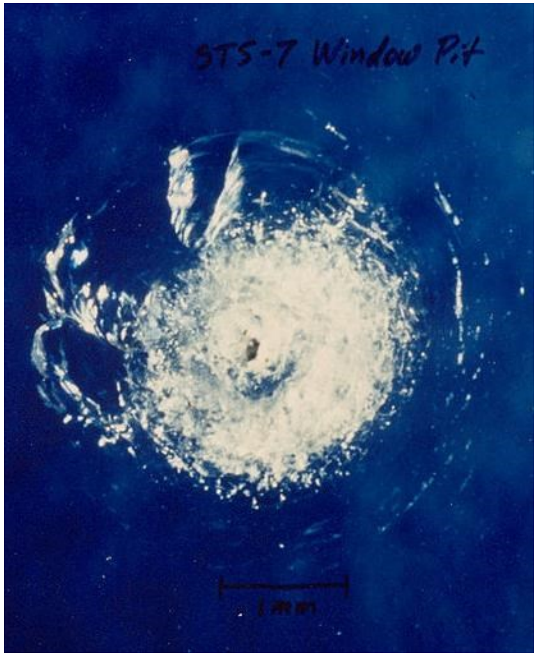
Dust & Debris

- Micrometeoroids
  - Dust & sand
  - 40 tons a day towards Earth
  - Up to 71 km/s!
  - Punch holes in the antennas

- Space debris
  - 600000 objects larger than 1 cm!
  - > 5000 tons in total in orbit
  - Up to c. 15 km/s





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A Bad Day at Work…

- NOAA-N “mishap”, 2003