Space Communications

Dr. Joakim Johansson, Retired Chief Engineer Antennas
Beyond Gravity Sweden AB


beyond gravity
1
The first start-up
with 40 years of experience.
100% mission success.

Key facts

beyond gravity

100 %
mission success

1800
employees across 14 sites

Products on **1000** payloads delivered to space

40+
years of experience

1000
successful separations

R&D spending equals **10 %** of total sales

CHF 383M
net sales in 2023

Our global footprint in Europe & the US

Sweden

beyond gravity

350 employees at two sites:
Gothenburg & Linköping.

- Competence center for high-reliability electronic products (digital electronics, microwave and antennas) and mechatronics in Gothenburg.
- World leader in engineering and production of dispensers and separation systems for all major launch vehicles worldwide with new production facilities opened in Linköping in 2017 & 2024.
- Strong industrial and academic environments with great opportunities for technology and operational excellence cooperation.

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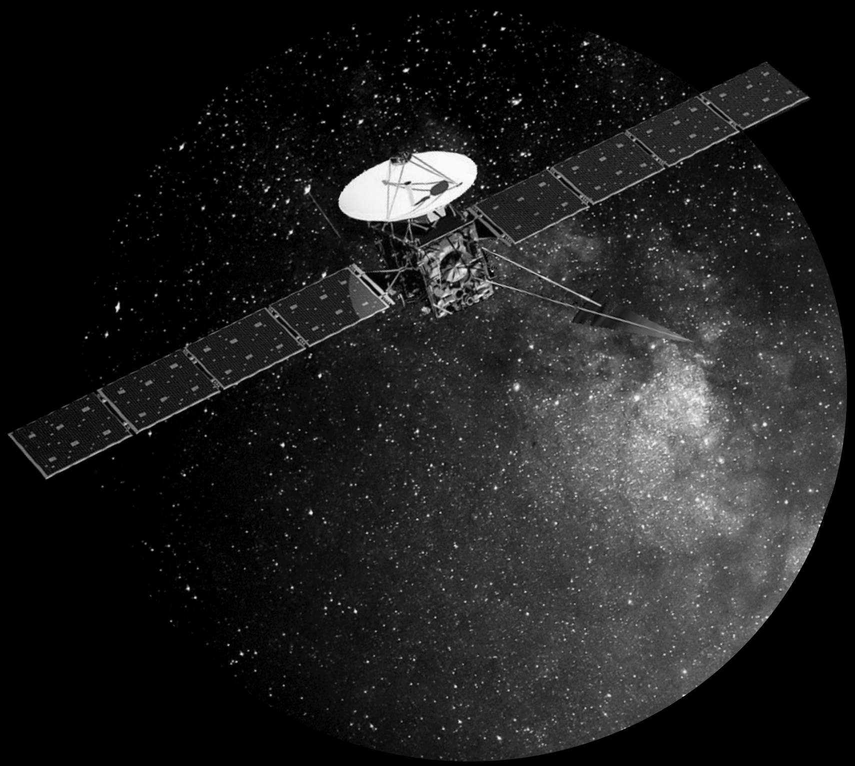
Our product portfolio

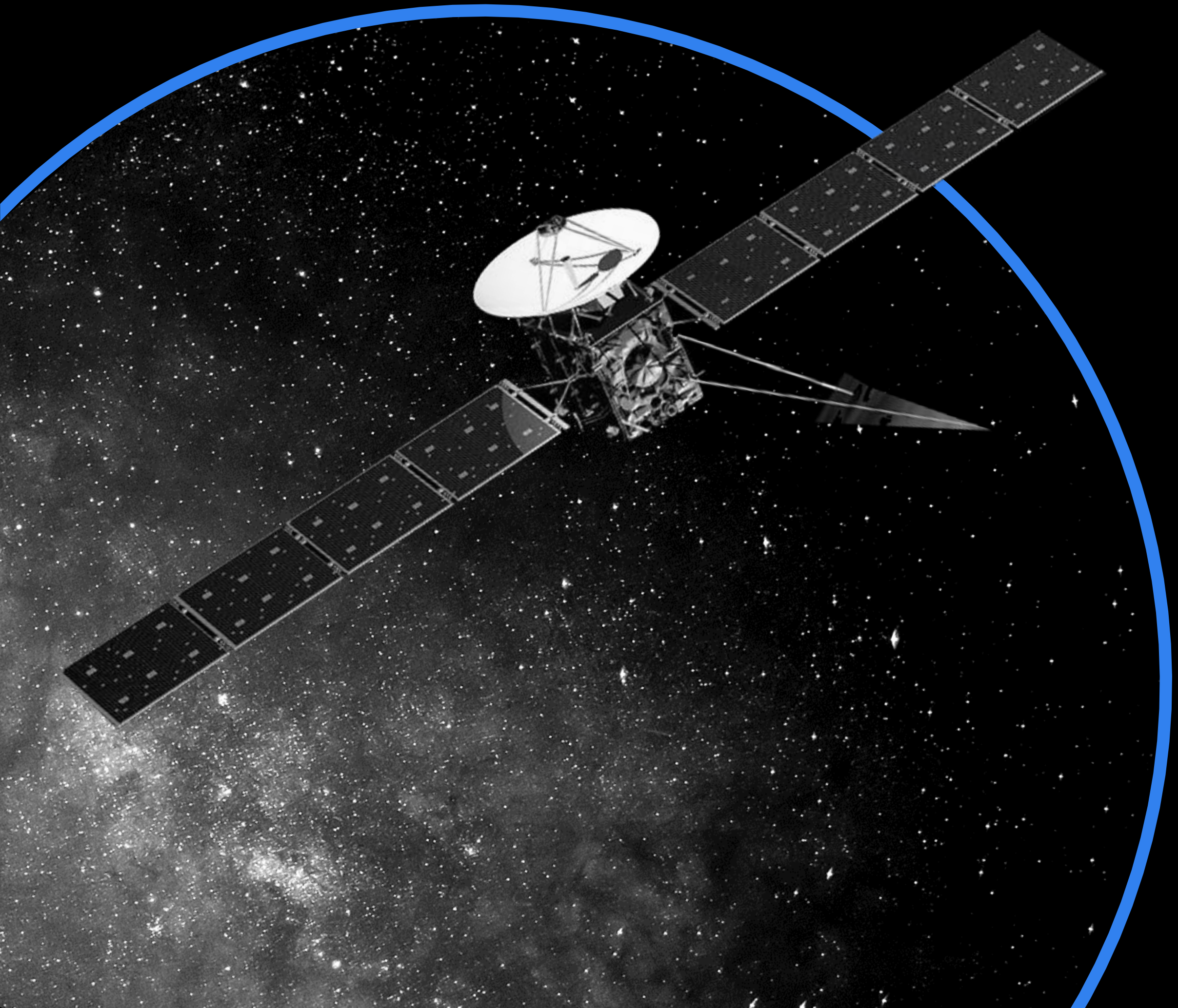


Satellites.

Launchers.

Satellites

beyond gravity



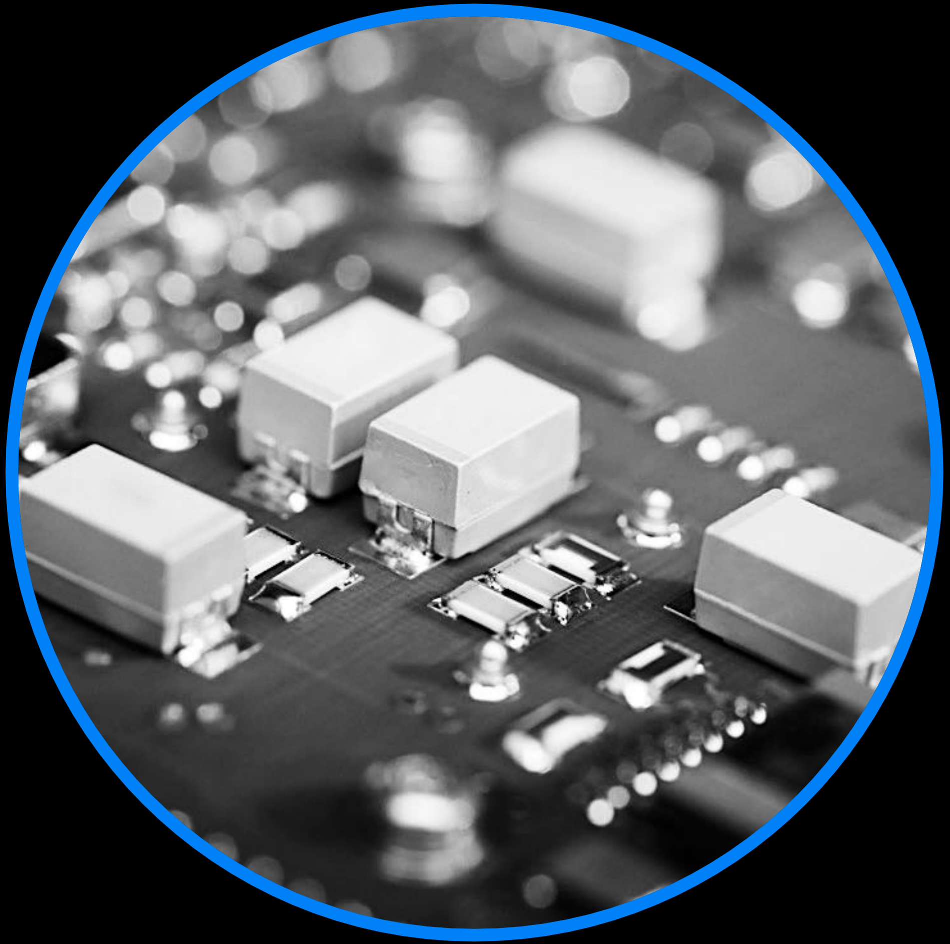
High performance in space.
Precise engineering on earth.

1 **Platform mechatronics**

2 **Platform electronics**

3 **Payloads**

2_Platform electronics



Competitive, radiation-hardened and reliable electronic components and subsystems to keep your platform running seamlessly – year after year.

Computer & data handling systems

Navigation receivers

Navigation including sensor & actuator integration

On-board data networks

3_Payloads

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State-of-the-art, reliable and cost-effective payload solutions for commercial and institutional customers alike.

Antennas

Microwave

Radio occultation

Positioning, navigation & timing

Data processing

Launchers

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Over four decades –
100% mission success.

1 **Launcher structures**

2 **Separation systems**

3 **Sounding rocket guidance systems**

Space Communications

Introduction

Space Communications

beyond gravity

- 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
  - Miscellaneous communication satellites

Basics of Space Communications

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- 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
  - Difficult to generate RF power in space
    - Reliability
  - Cost!

Different Orbits

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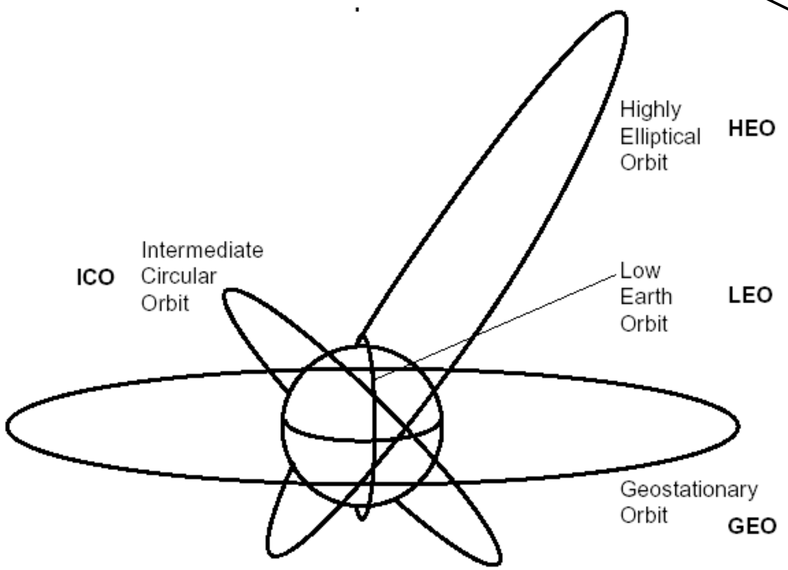
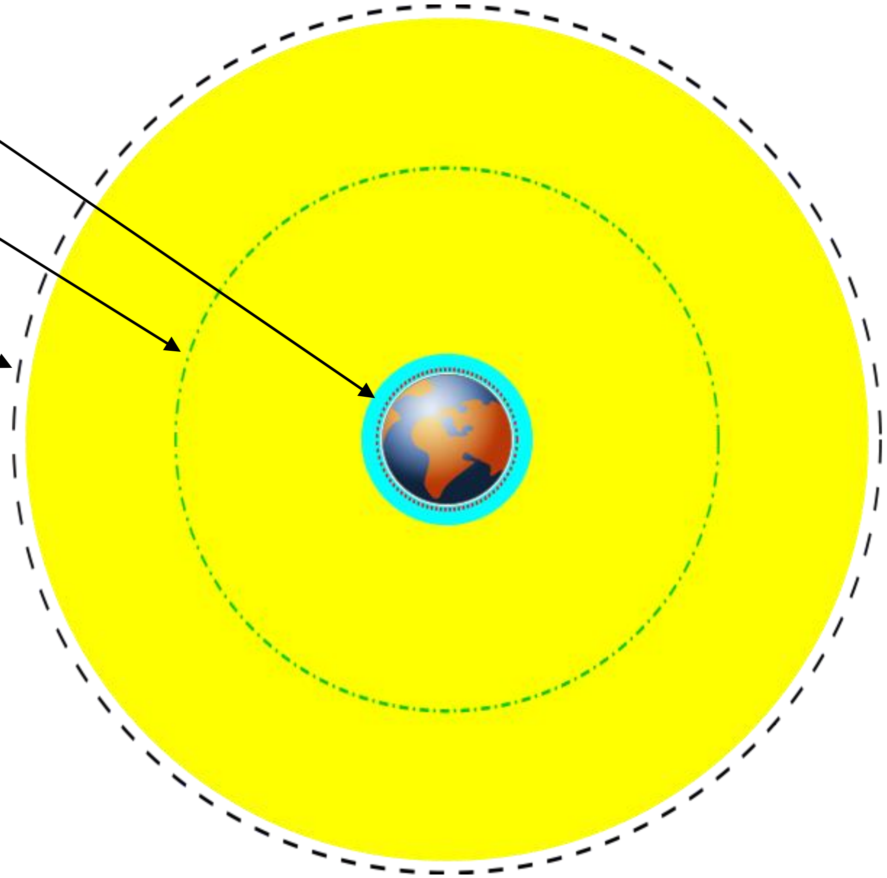
- LEO (typically 500 – 1500 km)
- MEO (typically 20000 km)
- GEO (36000 km)





Global Coverage

- Gothenburg as seen from:
  - 500 km orbit
  - 1000 km orbit
  - 10000 km orbit
  - 36000 km orbit (GEO)

Crowded Geostationary Orbit?

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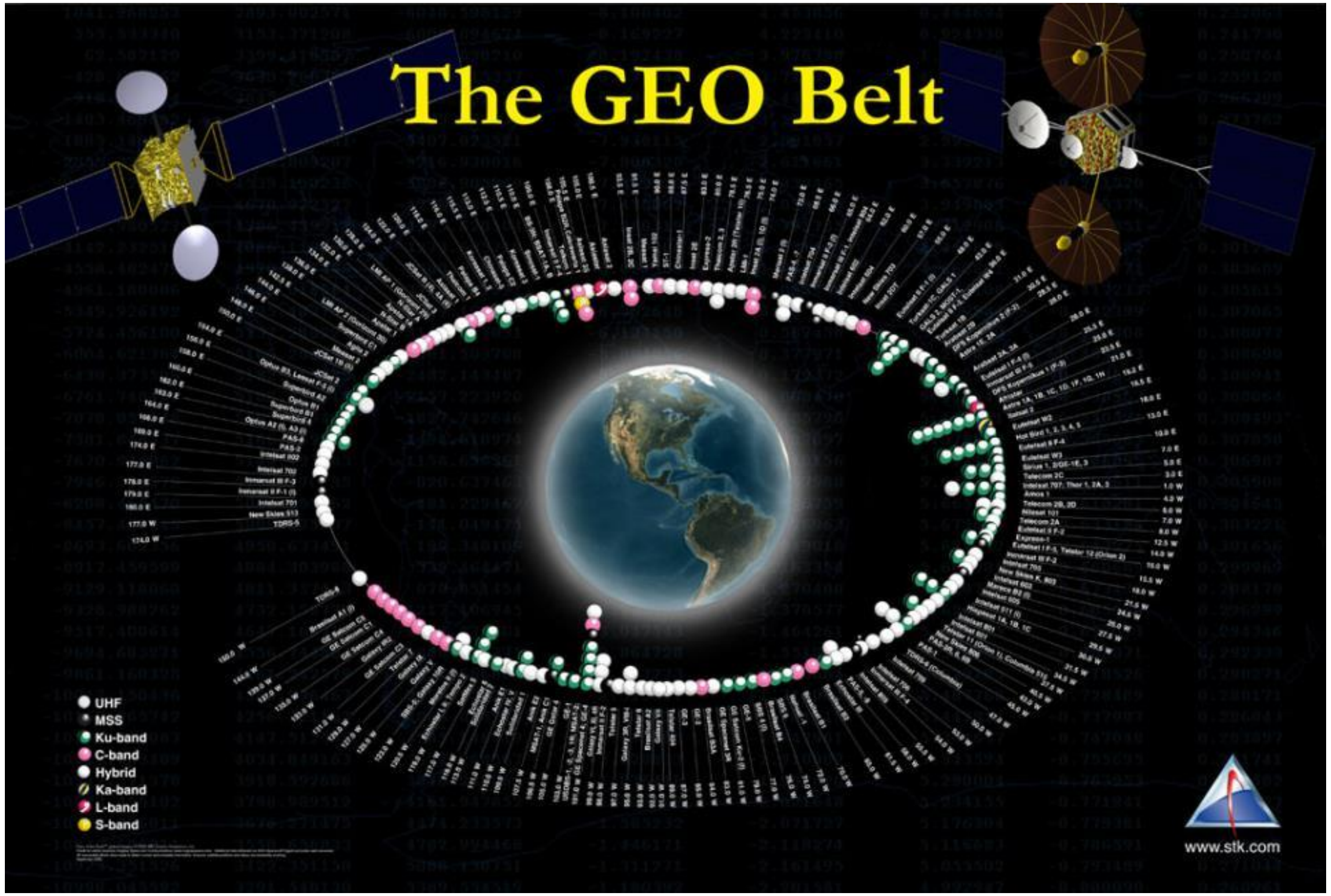
- Crowded in terms of frequency allocations – not in terms of distance!



Frequency Allocations

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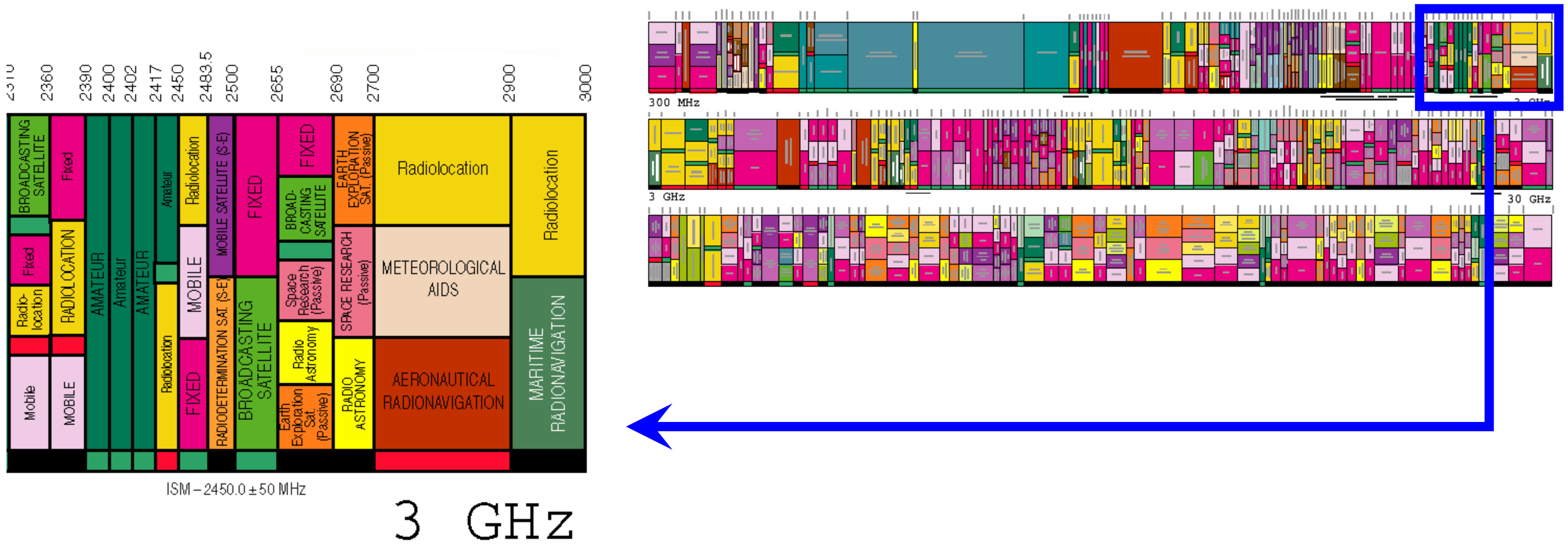
- International treaties regulate which frequency bands the different “services” are allowed to use
  - The spectrum is a finite natural resource!



Crowded Low-Earth Orbit?

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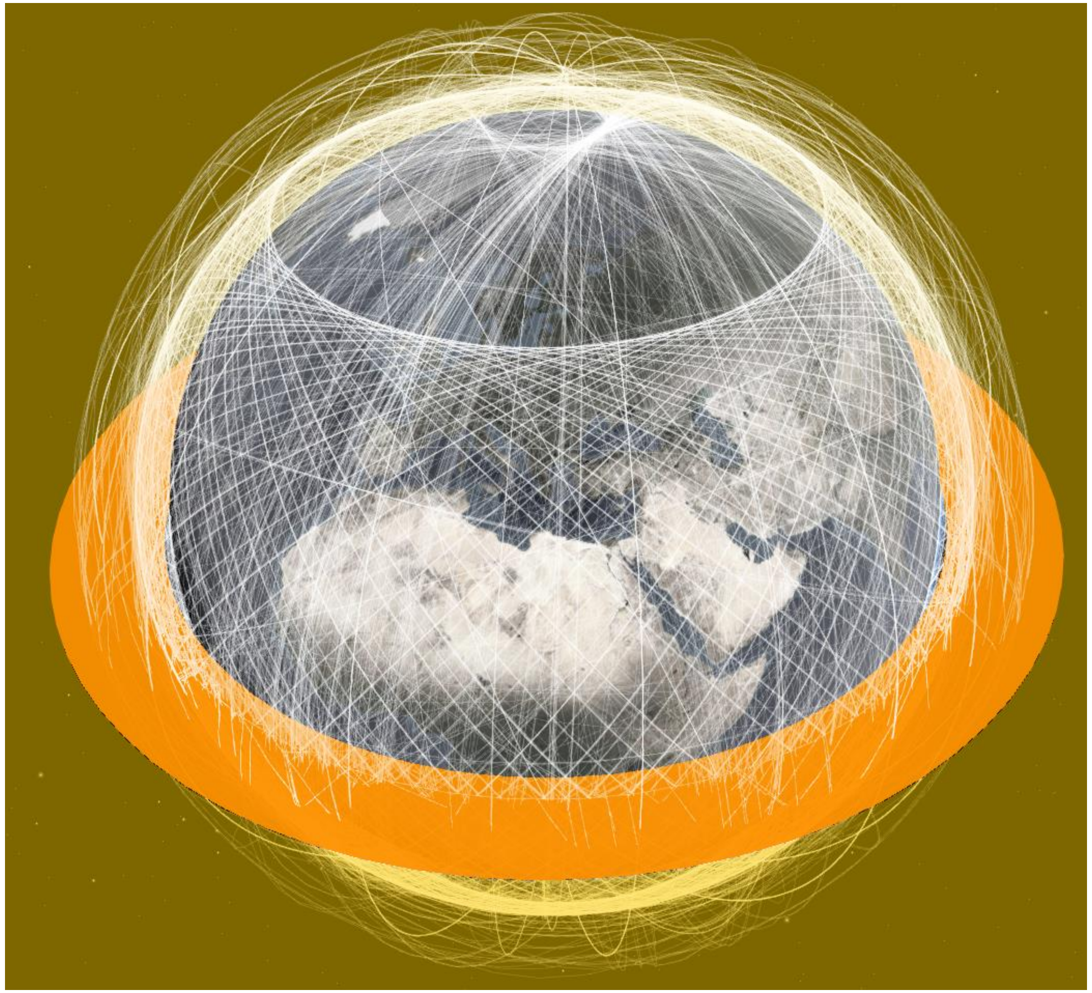
- **Yes!**



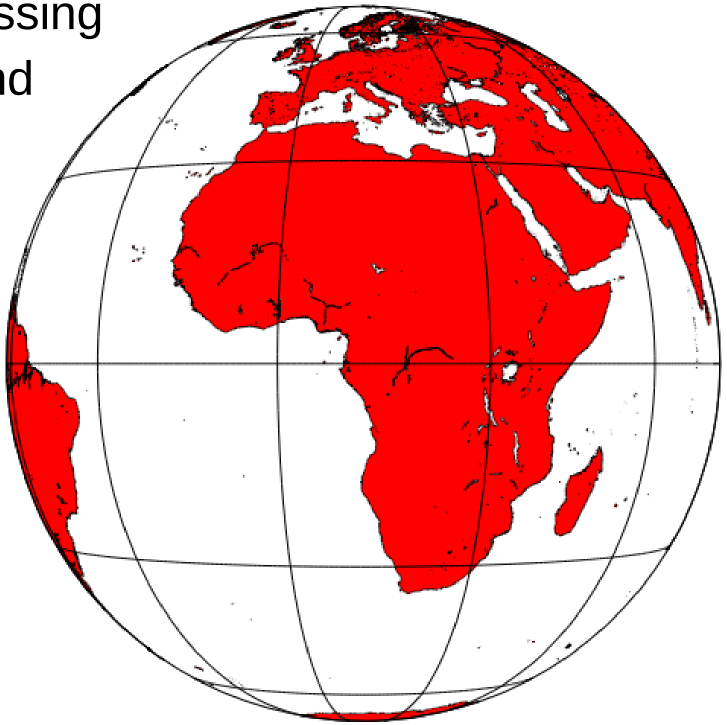
- https://geoxc-apps.bd.esri.com/space/satellite-explorer/

“Old Space”
Geostationary Satellites

- Very large (and expensive) satellites

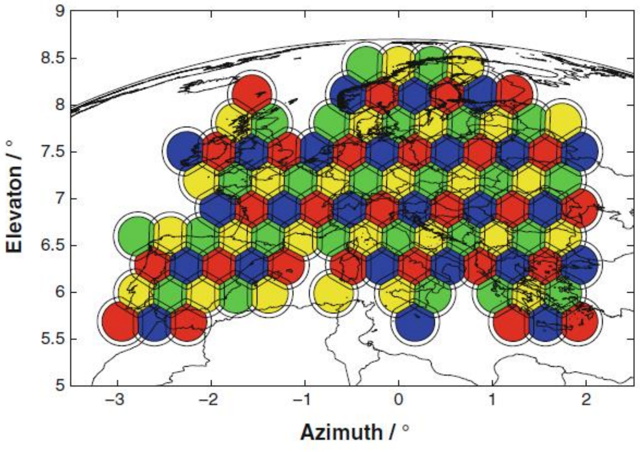
- 10 – 15 years lifetime
- Multi-kW available
- “Bent pipe” → payload processing
- Direct broadcast → broadband

- Geostationary orbit
  - 36000 km altitude
  - Over the equator
  - 23 h 56 m orbit



"New Old Space"

- Hundreds or thousands of beams
- Terabits per second in total!
  - High Throughput Satellites (HTS)
  - Very High Throughput Satellites (VHTS)



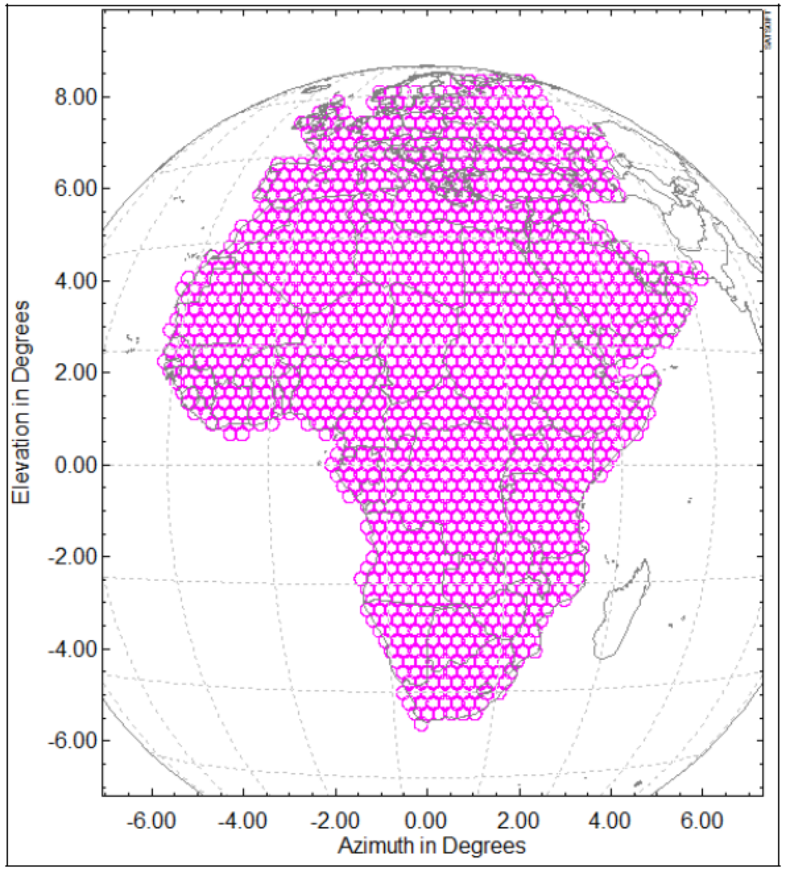
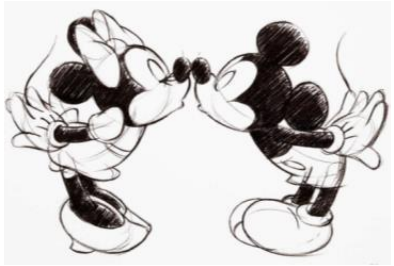


Fig. 1. VHTS coverage of 1587 beams of 0.3° diameter

TAS/Eutelsat Spacebus Neo HTS spacecraft



History of TV Satellites

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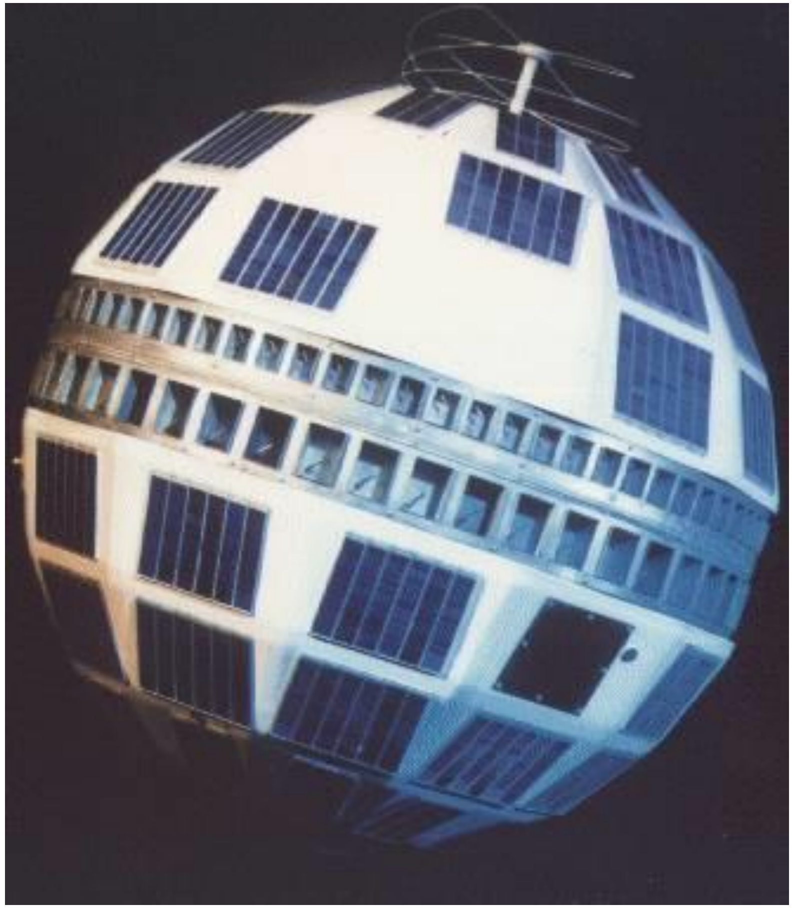
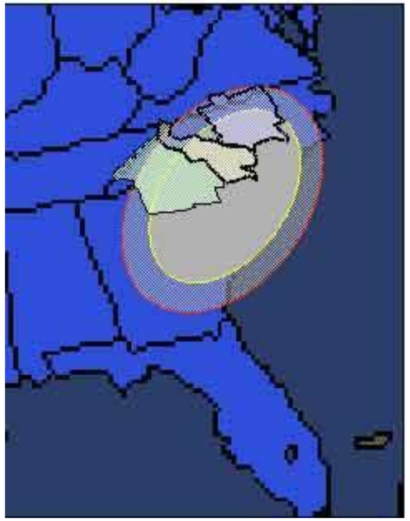
- Telstar 1
  - Launched 1962
  - First TV satellite
  - Could relay TV signals 20 minutes now and then…
- In 1964 came satellites in geostationary orbit
  - Continuous coverage

- ”Telstar” with
  The Tornados was
  No. 1 on the hit lists…



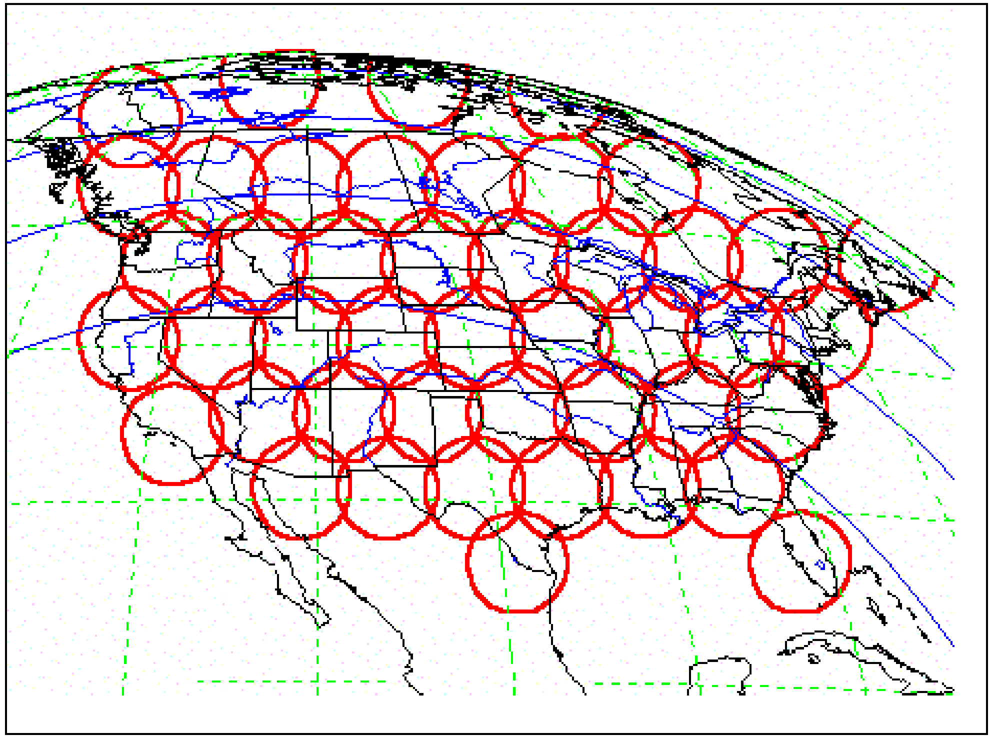
Communication

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



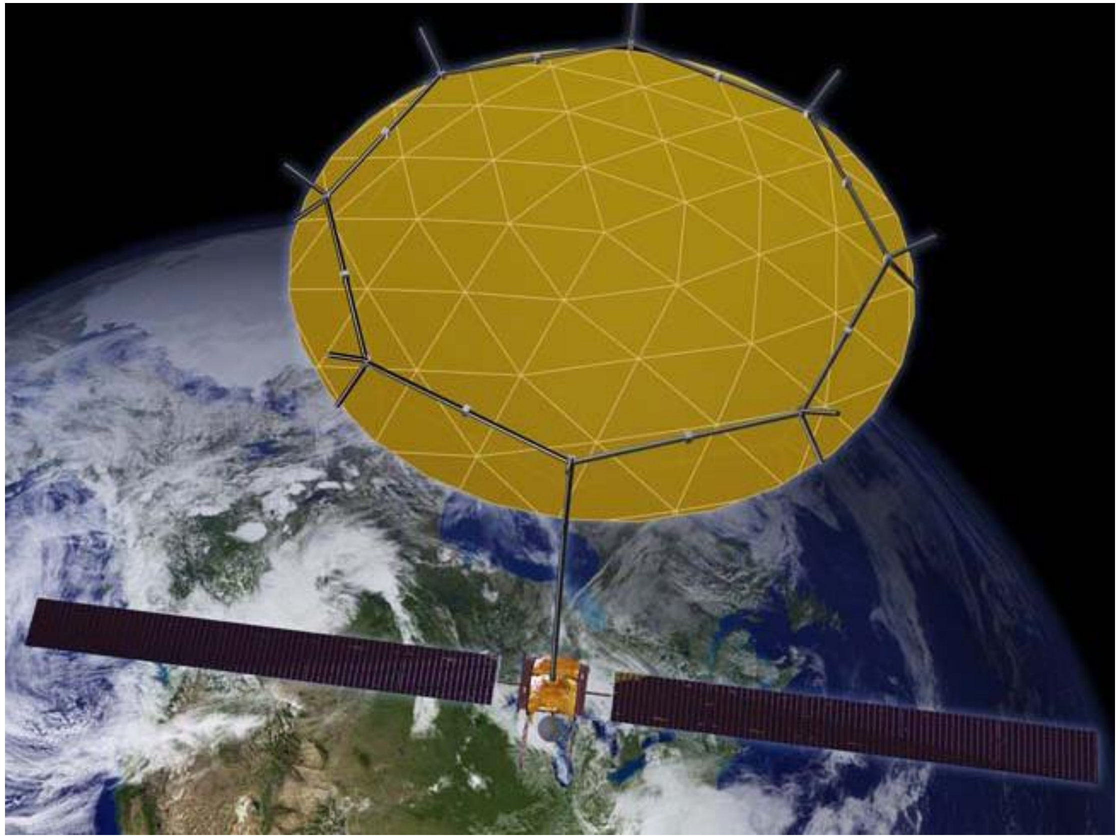
Mobile Communication

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



Mobile Communication

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



New Space

- New kids on the block!
- New money

- Rapidly decreasing launch costs
- Vertical integration
- Short design cycle
- Small(er) satellites
- COTSification
- Constellations (large to mega)

- “However, unfortunately”:
  – Limited spectrum
  – Legislation/Regulation
  – Laws of physics apply

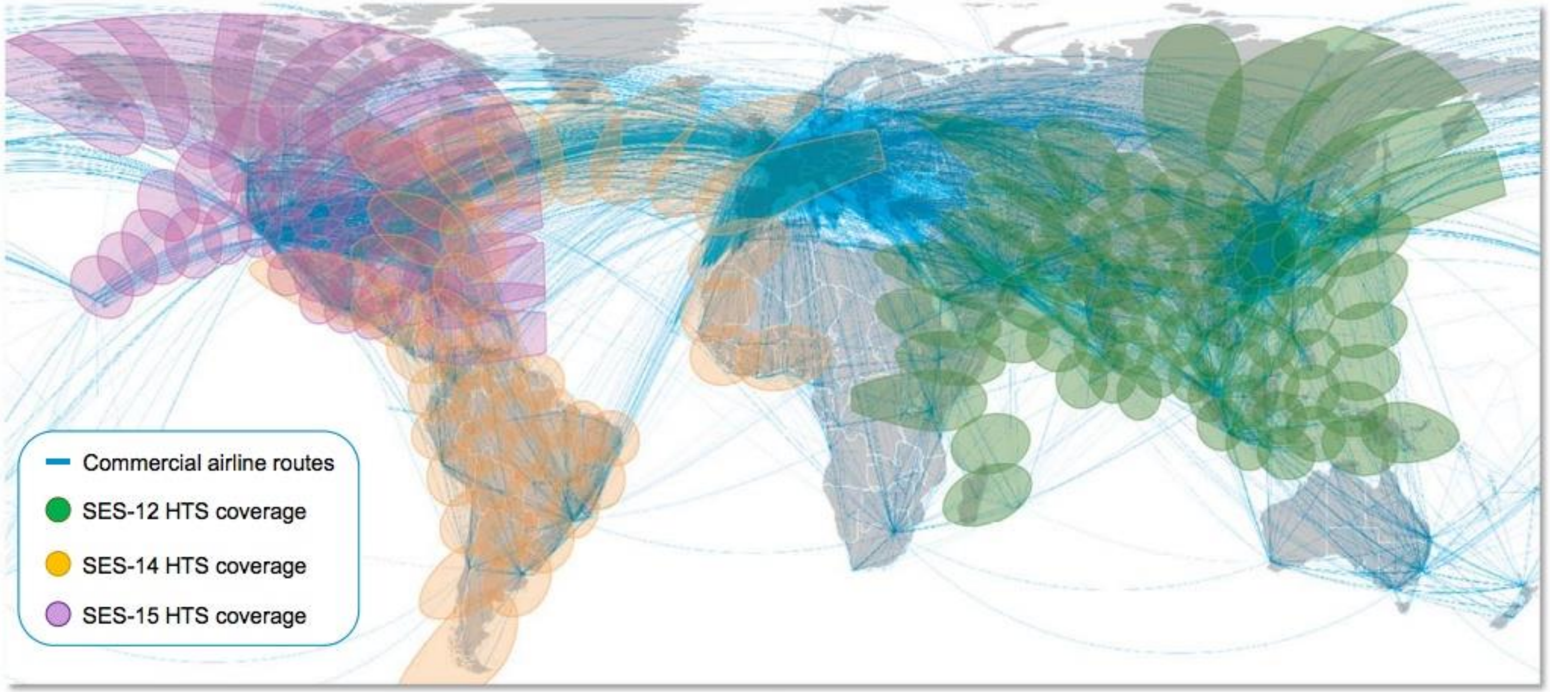
“New Space”

beyond gravity

- OneWeb

New Space
Rationales

- Ubiquitous broadband

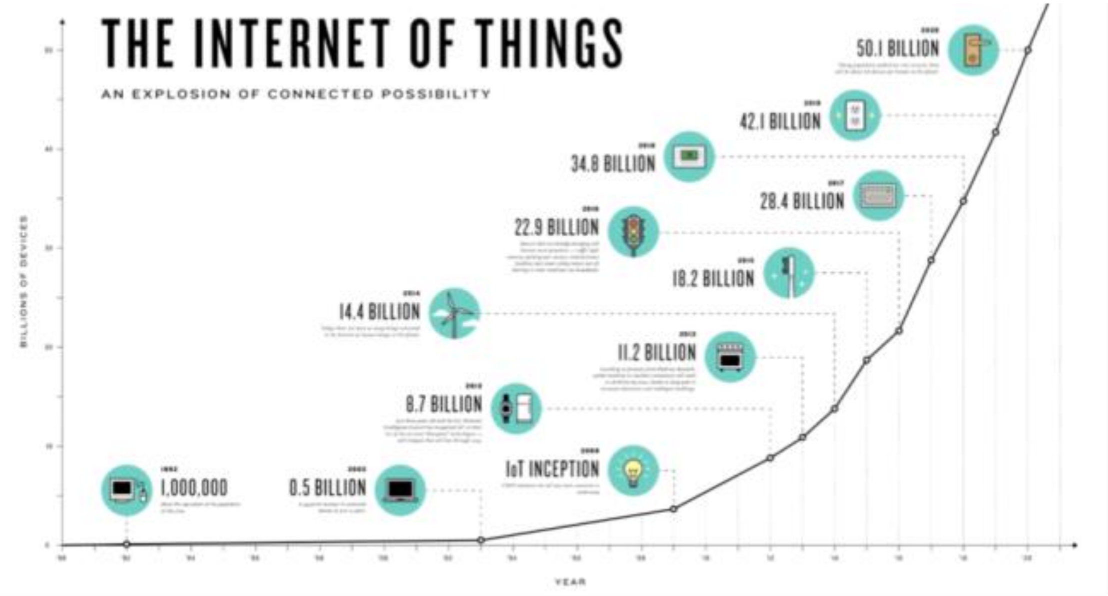


▲ Complementing SES's global wide beam GEO network, along with O3b's unique MEO HTS

New Space
Rationales

- Mobile users
  - Aeronautical
  - Maritime

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



New Space
Rationales

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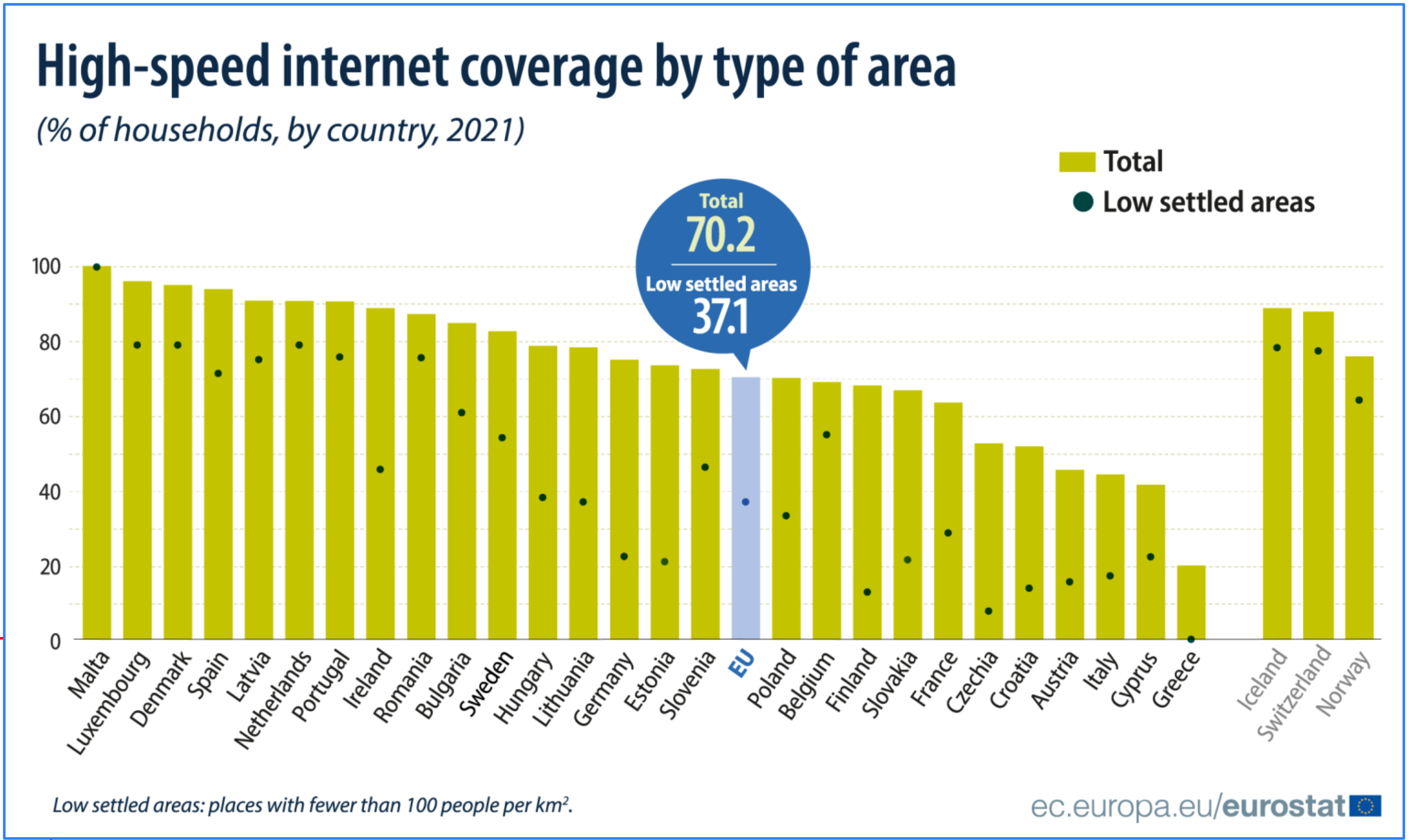
- Fixed terminals
  – "The Digital Divide"

- 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
Unexpected Things Happen…

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

New Space
Unexpected Things Happen…

- Corona fall-out in 2020, with 74 out of planned >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

The Hype Cycle

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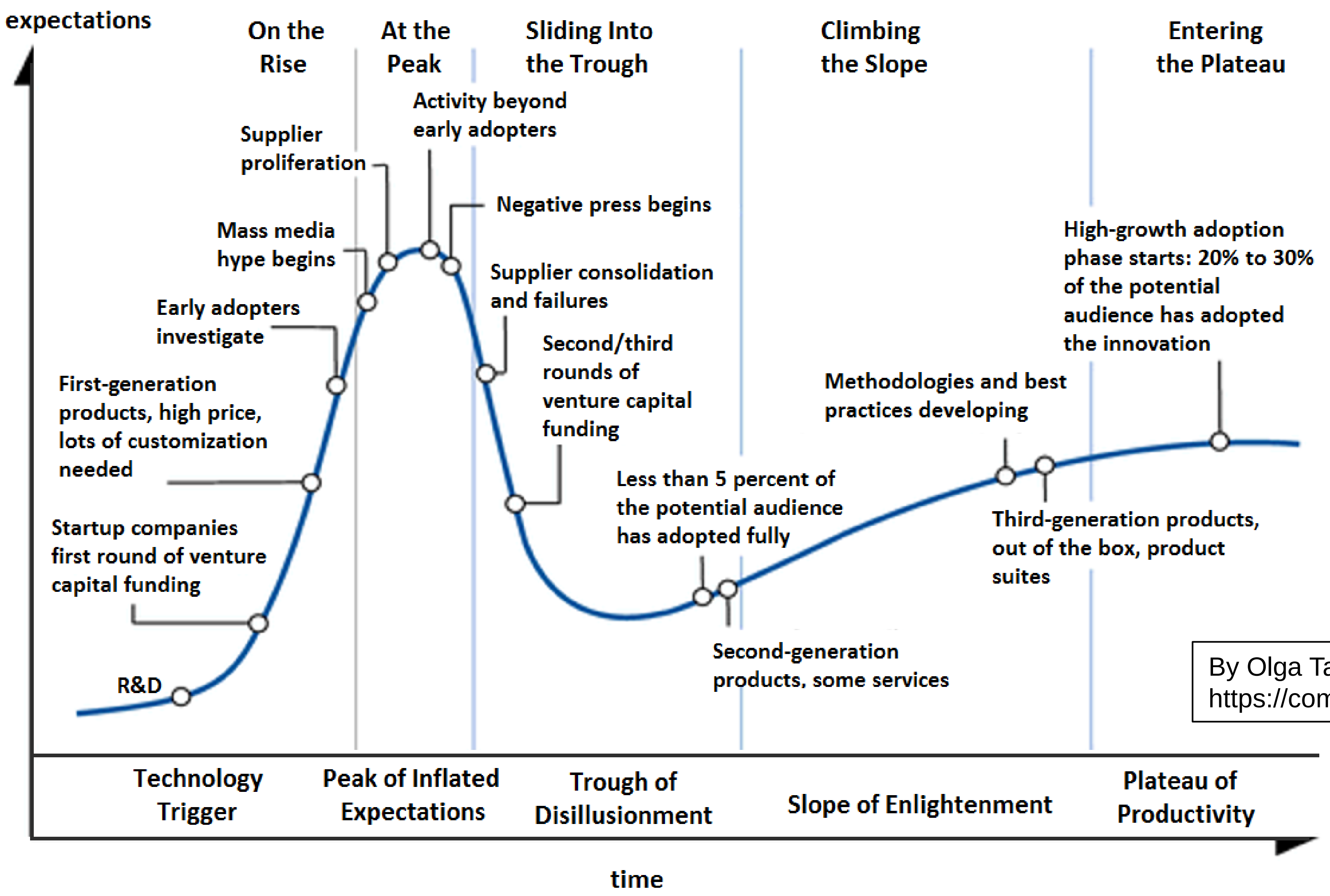
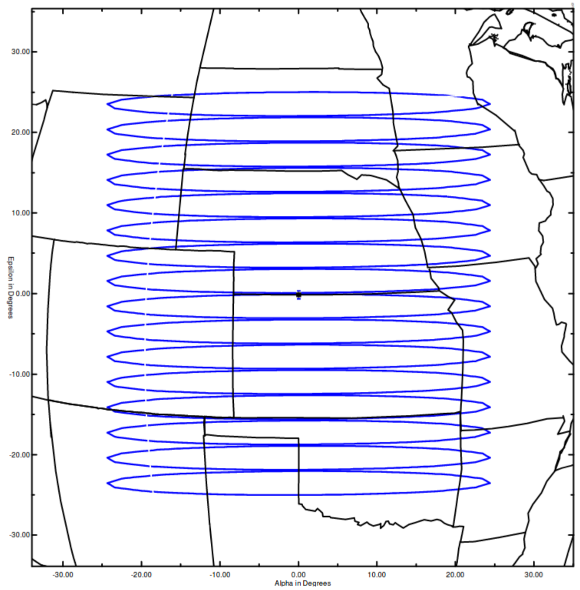


New Space
OneWeb



- Dispenser (made in Linköping!) with 4x8+3 satellites
- 626 operational by April 2024
- Many launches with Soyuz/Fregat

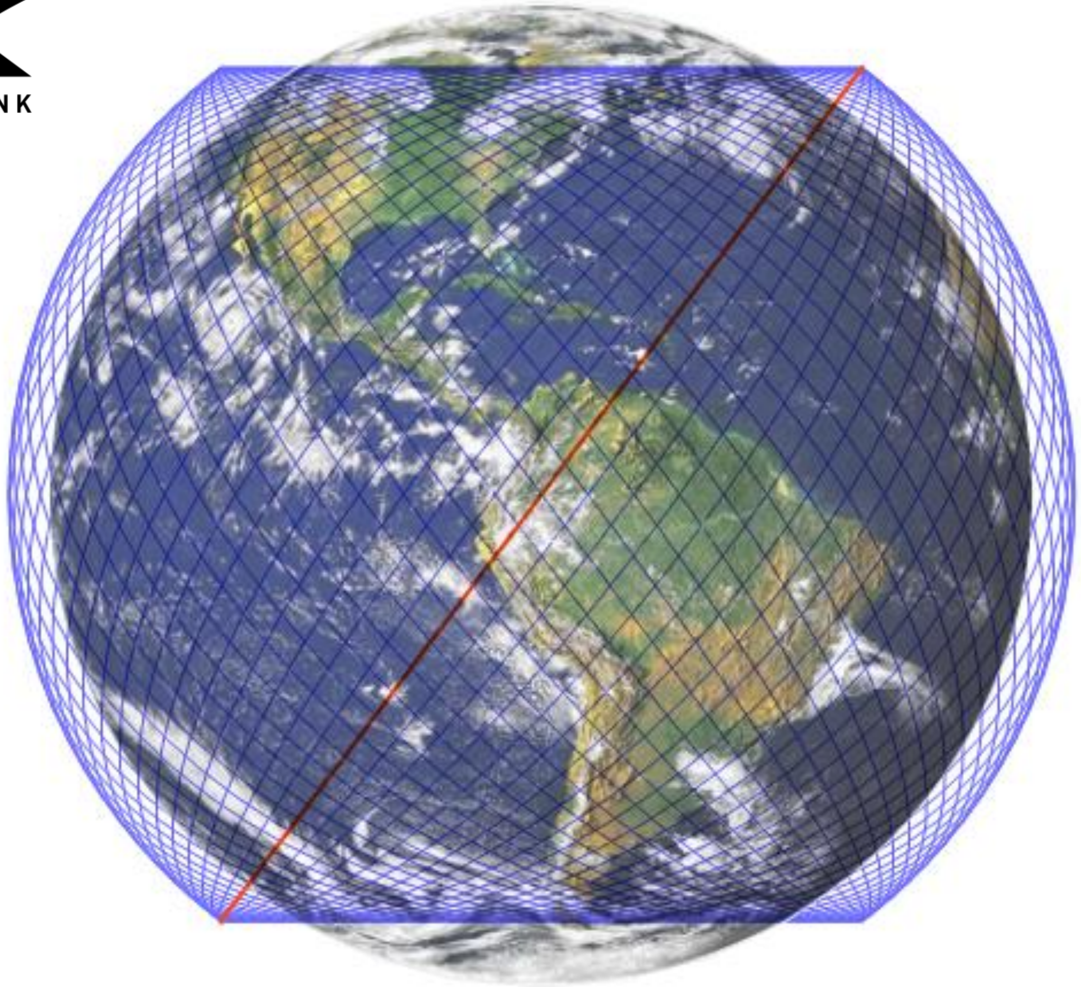
- Ku-band
  - 16 elliptical user beams
- Ka-band
  - Gateway antennas

- 1200 km polar orbit
  - C. 30 dB advantage to GEO

New Space
SpaceX StarLink

- Around 5228 satellites working in April 2024
  - 60 satellites per launch
  - 550 km orbit (72 orbital planes with > 20 each)
  - 2.7 M subscribers in April 2024
- Plans for 12000 + 30000 satellites!
- Flat packs

STARLINK



Starlink

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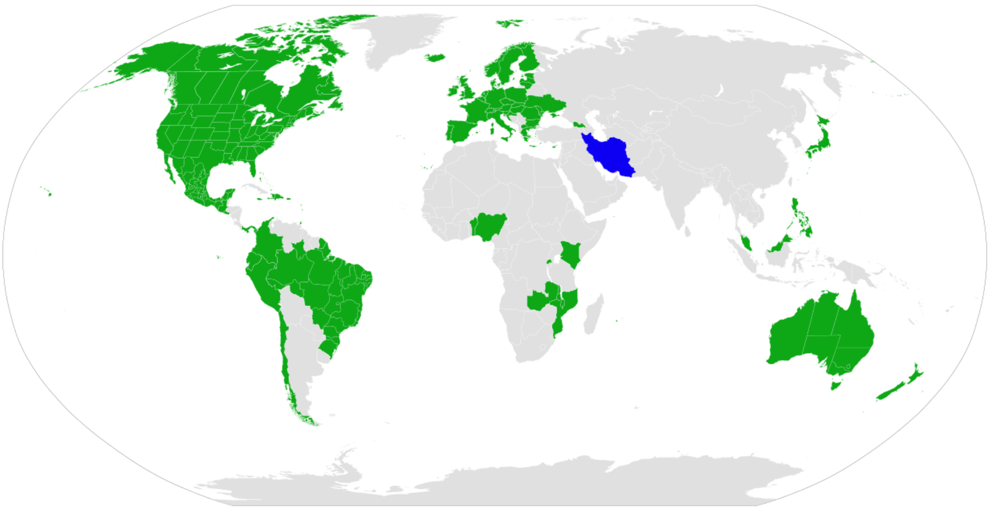
- Ukraine war 2022
  - 5000 terminals
- Geo-fencing



Starlink

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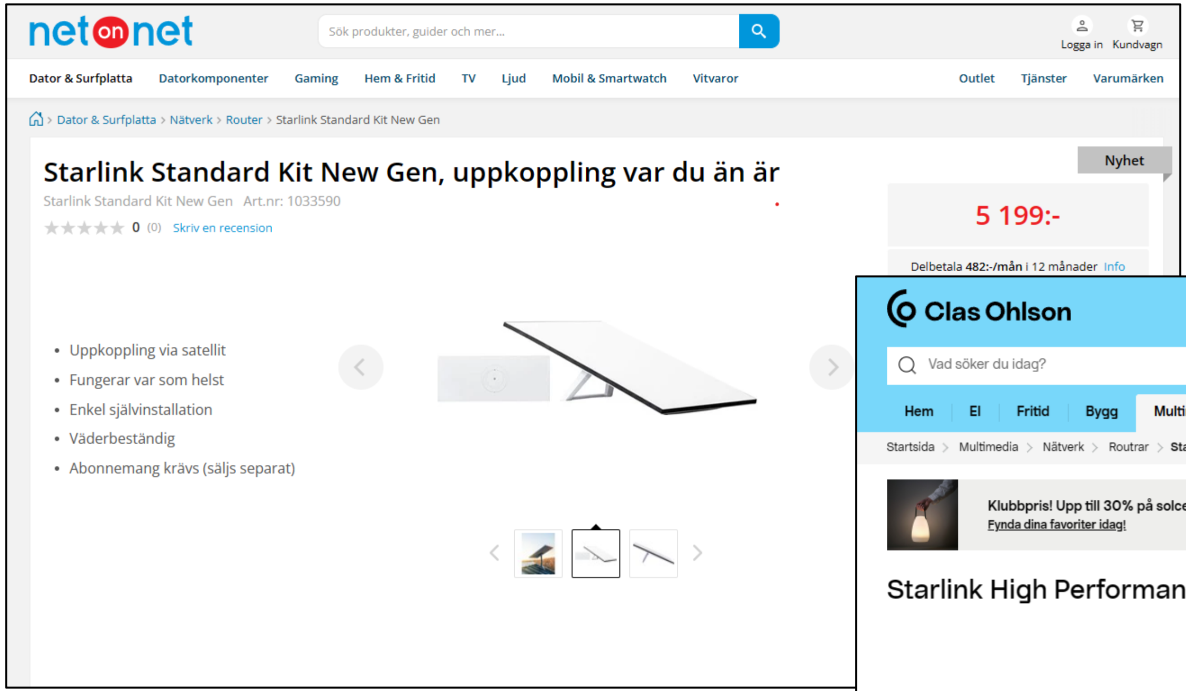
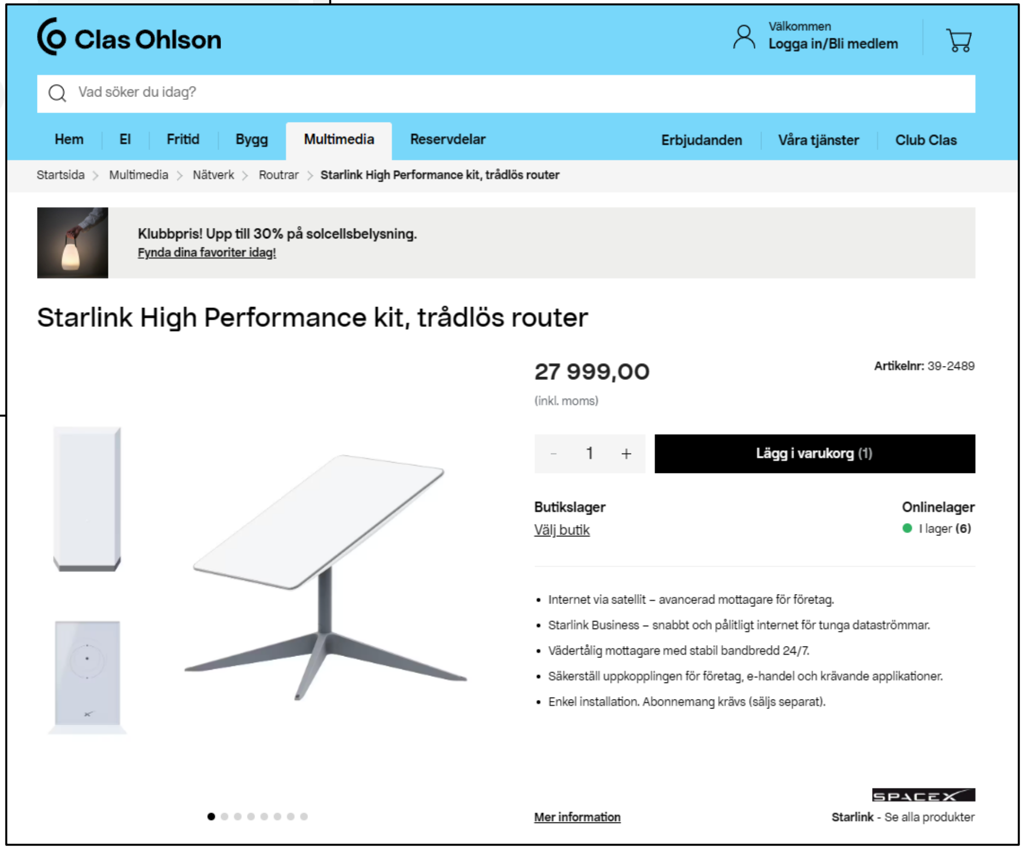
- Now a consumer product…





“New Old Space” Earth Observation Satellites

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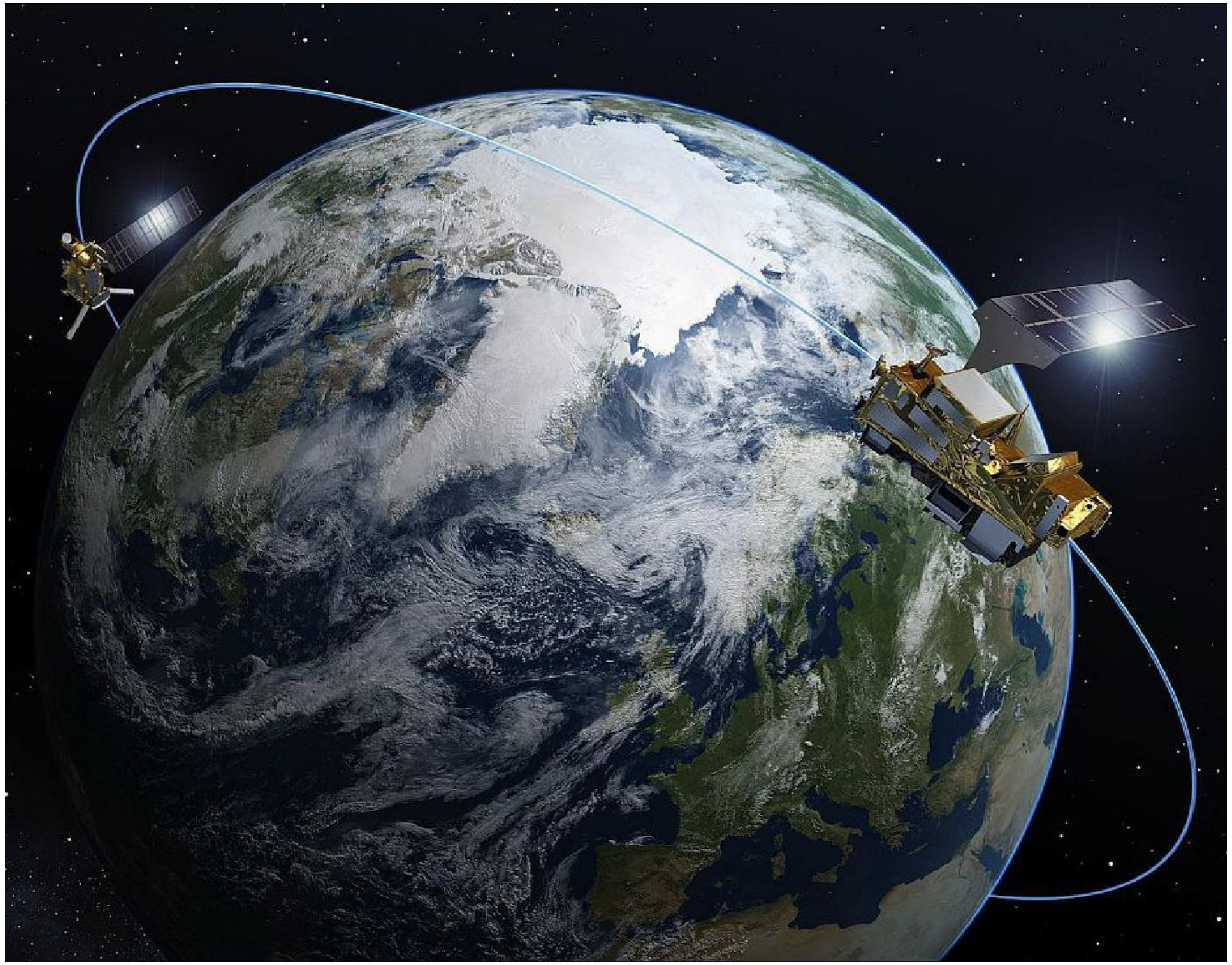
- Often very large (and expensive) satellites

- Polar orbit
  - C. 800 km altitude
  - Sun-synchronous
  - C. 100 min orbit

- Generated data:
  - 500 Gbit/orbit
- Data downlink data rate:
  - 781 Mbit/s @ K-band



“New Old Space” Science

- Extremely large (and extremely expensive) satellites/spacecraft

- L2 orbit
  - 1500000 km altitude
  - 1 year orbit

- Generated data:
  - 250 Gbit/day
- Data downlink data rate:
  - 28 Mbit/s @ K-band
  - 40 kbit/s @ S-band

Mega-Constellations

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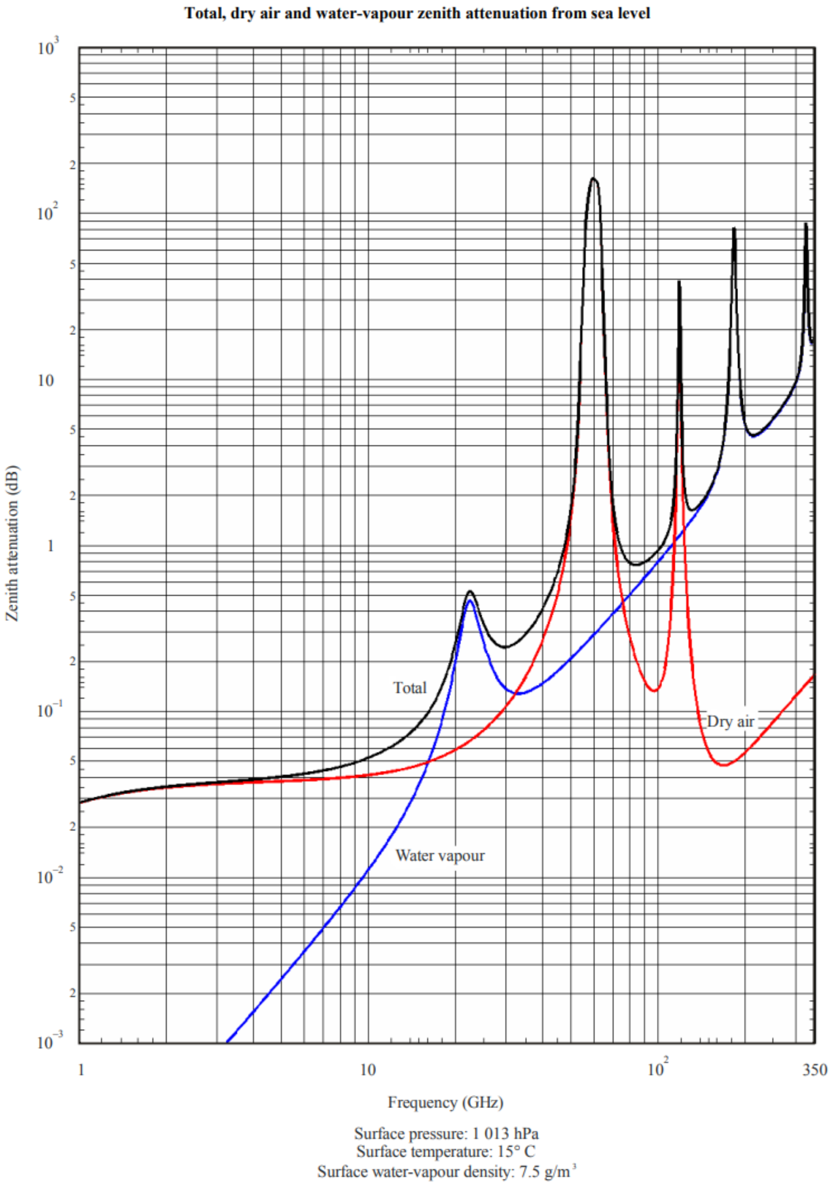
- Source: Jonathan McDowell https://planet4589.org
  - As per 2024-04-30

Constellation	Country	Altitude	Planned	Operational
OneWeb P1	**UK**	**c. 1200 km**	**716**	**626**
OneWeb P2	UK	c. 1200 km	6372	0
Kuiper	US	590 – 630 km	3232	0
Starlink SG1	**US**	**540 – 570 km**	**4408**	**3437**
Starlink SG2 P1	**US**	**525 – 560 km**	**7500**	**1791**
Starlink SG2 P2	US	340 – 614 km	22488	0
Yinhe / Galaxy Space	CN	511 km	1000	7
Xingwang	CN	860 – 1150 km	966	9
Guangwang	CN	508 – 1145 km	12992	0
Hanwha	KR	500 km	2000	0
Astra	US	380 – 700 km	13620	0
Lynk	US	500 km	2000	6
Globalstar	DE	485 – 700 km	3080	0
E-Space Semaphore-C	FR	415 – 600 km	116400	0
E-Space Cinnamon-937	RW	550 – 638 km	337323	3

Constraints

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
  – 0.5 dB @ zenith
- Oxygen line around 60 GHz
  – 150 dB @ zenith



Frequency Bands

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Band	Radar/IEEE	Space	Waveguide
• ”UHF”	–	c. 400 & 460 MHz	
• L-band	1 – 2 GHz	1 – 2 GHz	
• S-band	2 – 4 GHz	c. 2 – 3,4 GHz	
• C-band	4 – 8 GHz	c. 3,4 – 7,0 GHz	
• X-band	8 – 12 GHz	c. 7,2 – 11,7 GHz	
• K_u-band	12 – 18 GHz	c. 11,7 – 18 GHz	
• K-band	18 – 27 GHz	c. 25 – 27 GHz	
• K_a-band	27 – 40 GHz	18 – 40 GHz	
• Q			33 – 50 GHz
• U			40 – 60 GHz
• E			60 – 90 GHz
• V	40 – 75 GHz		50 – 75 GHz
• W	75 – 110 GHz		75 – 110 GHz

Distance and Time...

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

Orbit	Distance	Delay (1-way)	Data Rate
Low Earth (LEO)	500 – 1500 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!

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- 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

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- 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

Ground Stations 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

Ground Stations
ESA 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

Ground Stations SSC

- Commercial network

Polar Orbits

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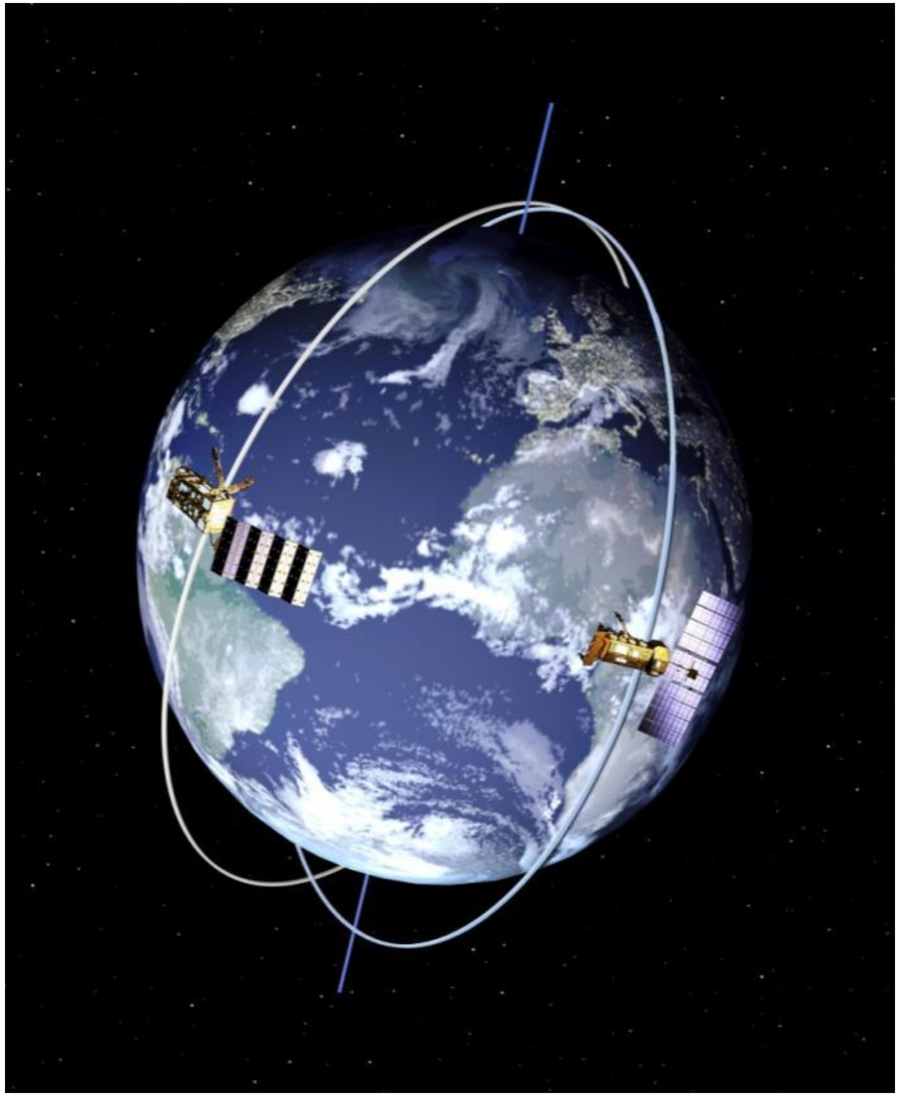
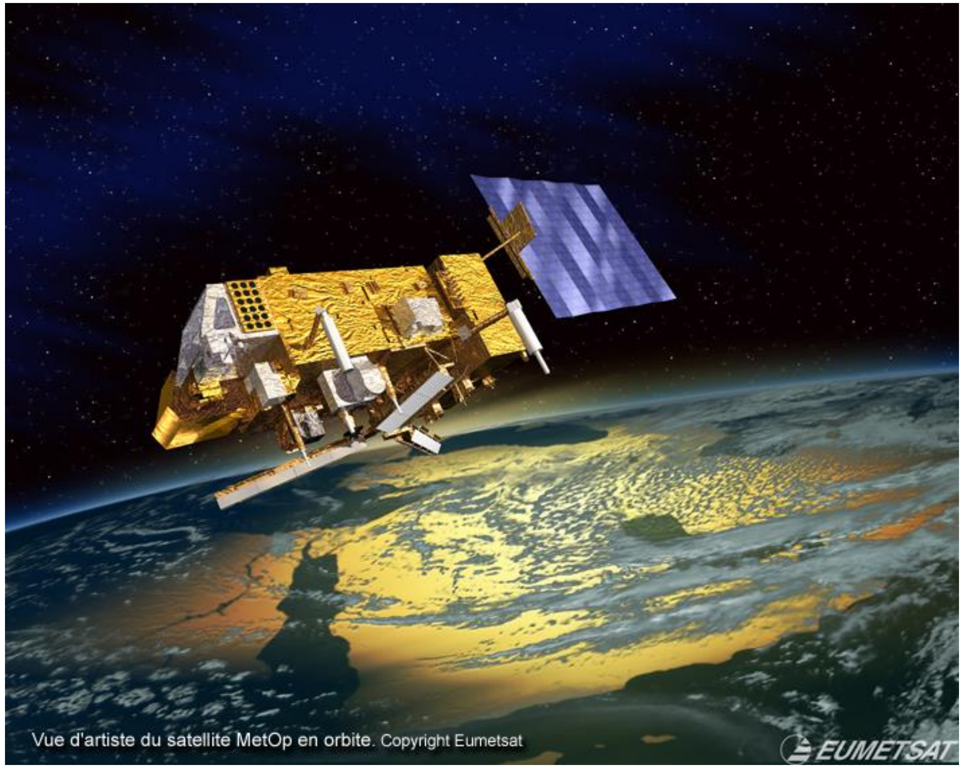
- Satellites for Earth observation often have an orbit that passes over the poles
- So-called sun synchronous orbits pass over the equator at the same <u>local</u> time each orbit
  – MetOp 09:30

- Big advantage to have ground stations at high latitudes!



Polar Orbits

- 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



Polar Orbits

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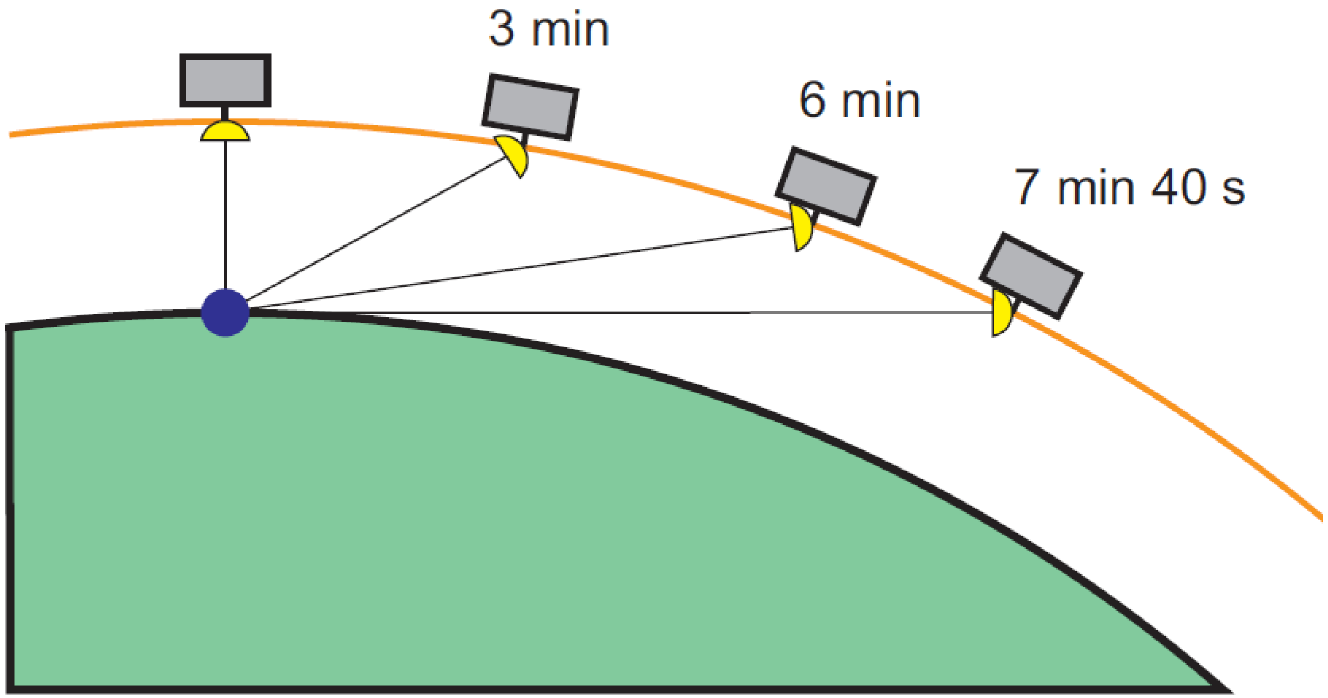
- Reflector high gain antenna on antenna pointing mechanism
  - A maximum of 10 – 15 minutes of link



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Case Study

James Webb Space Telescope (JWST)

Case Study:

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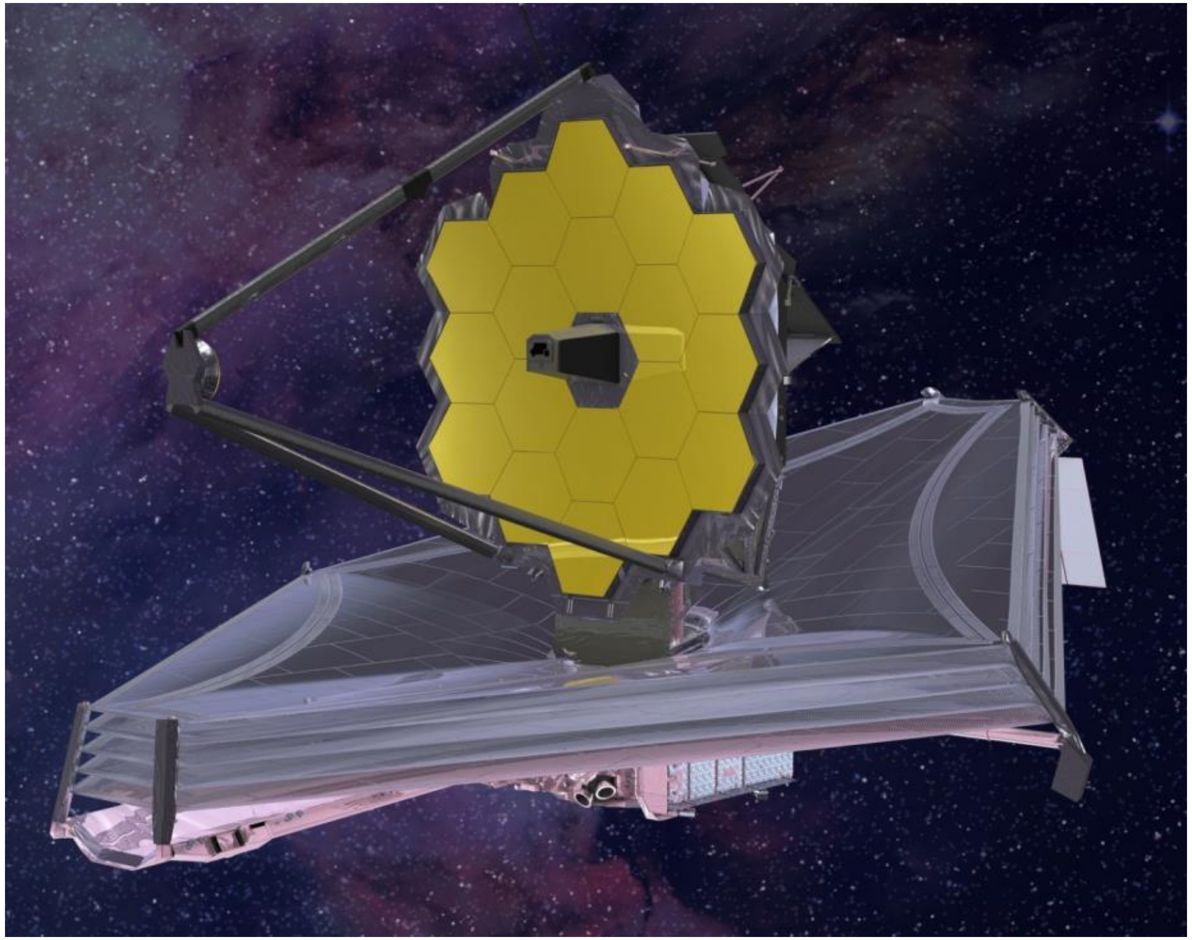
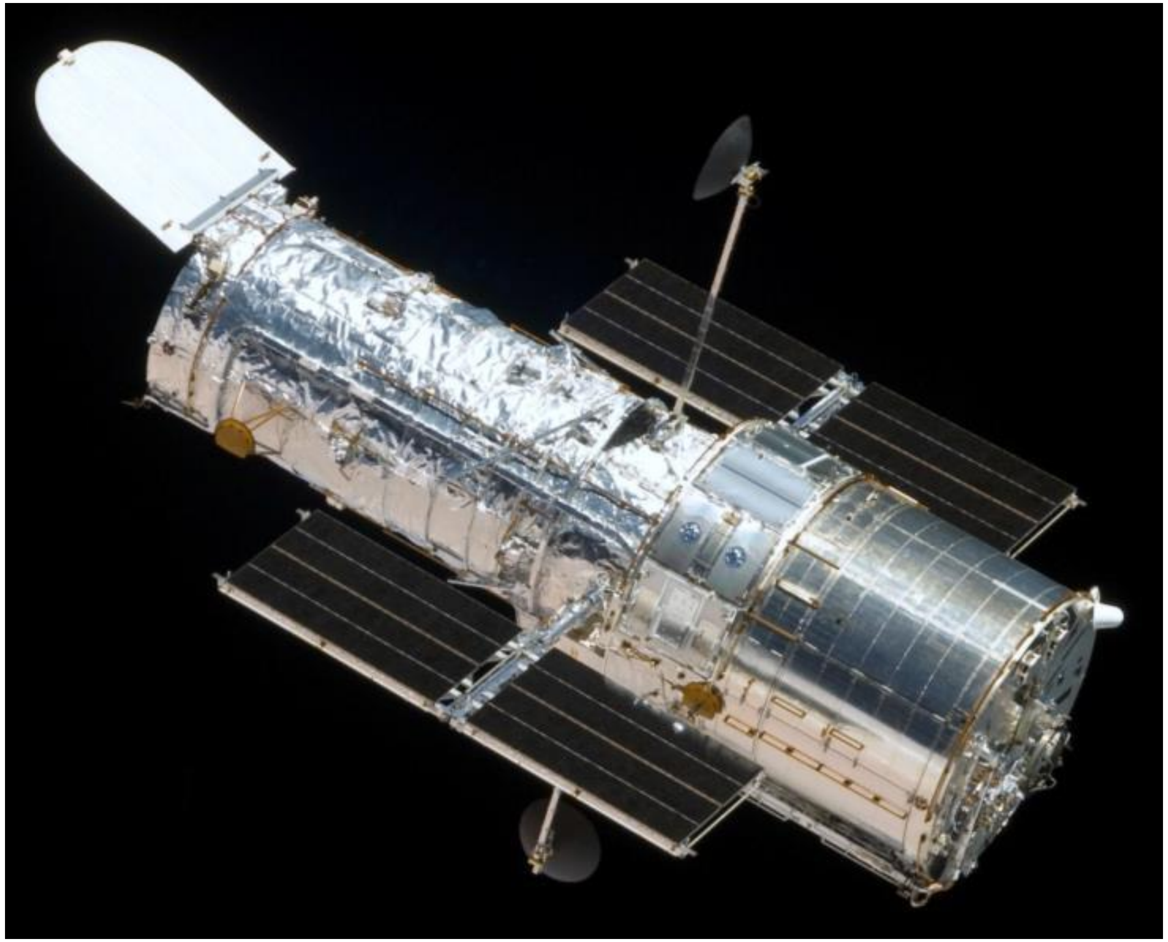
- Next generation space telescope
- NASA & ESA
- Named after the NASA administrator 1961 – 68



Hubble; The Predecessor

- Launch: 25 April 1990
  with the Space Shuttle
- Life length: 34 years already…
  - A number of repairs
    during the years
  - De-orbiting or service mission?
- Orbit: LEO 559 km
- Mass: 11100 kg
- Telescope diameter: 2.4 m
- Size: 13.2 m (length)
- Wavelength range:
  Visible light, UV, NIR



Hubble

- Galaxies, galaxies, galaxies…

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

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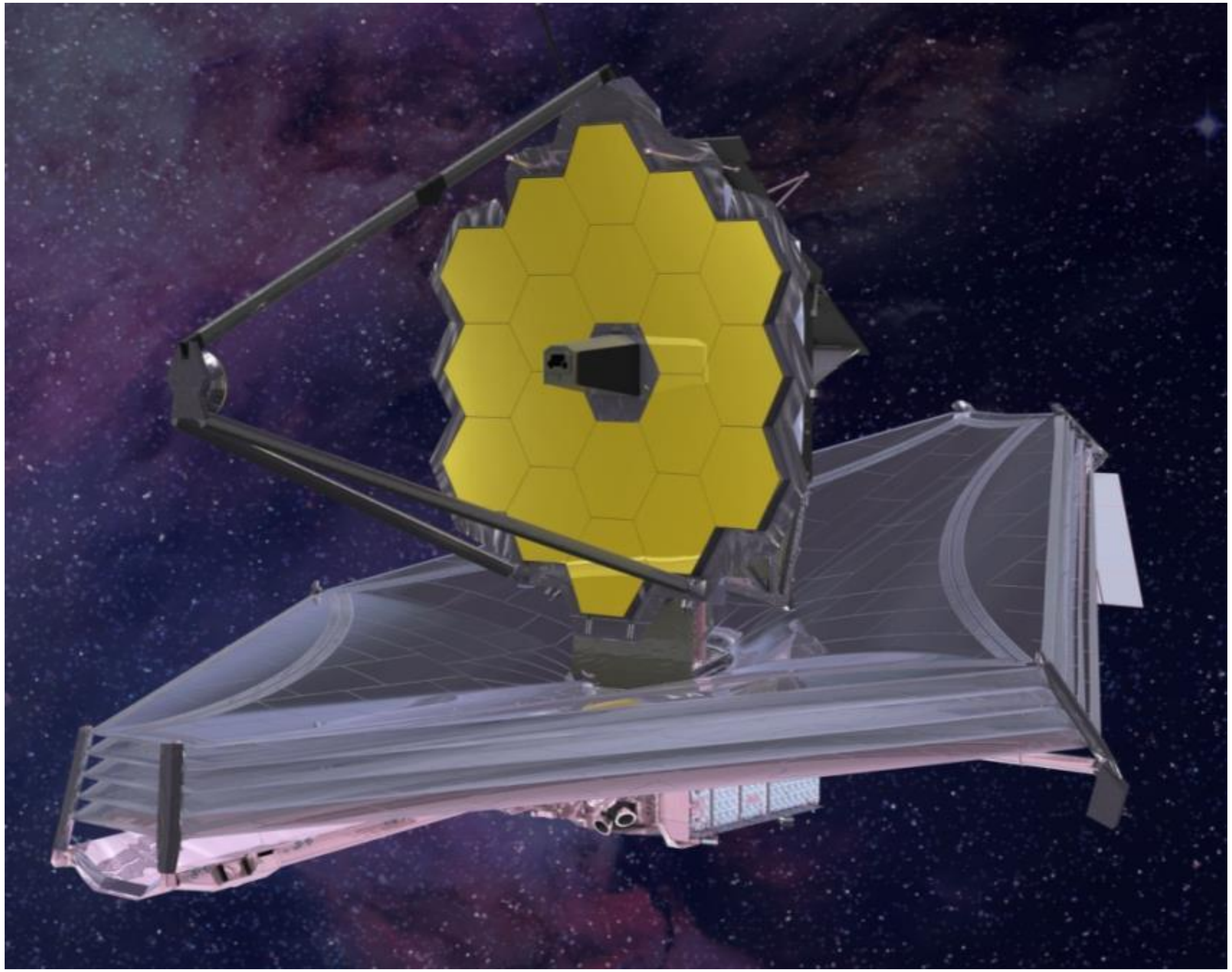
- Launch: Dec. 25, 2022 with Ariane 5 from Kourou
- Budget: 9.7 billion USD
- Life length: 5 – 10 years
- Orbit: L2 halo (1 year)
- Mass: 6200 kg
- Telescope diameter: 6.5 m
- Wavelength range:
  0.6 µm (orange) – 28.5 µm (IR)



“Kinder Egg Engineering”

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

JWST K-band Antenna from Beyond Gravity (RUAG Space)

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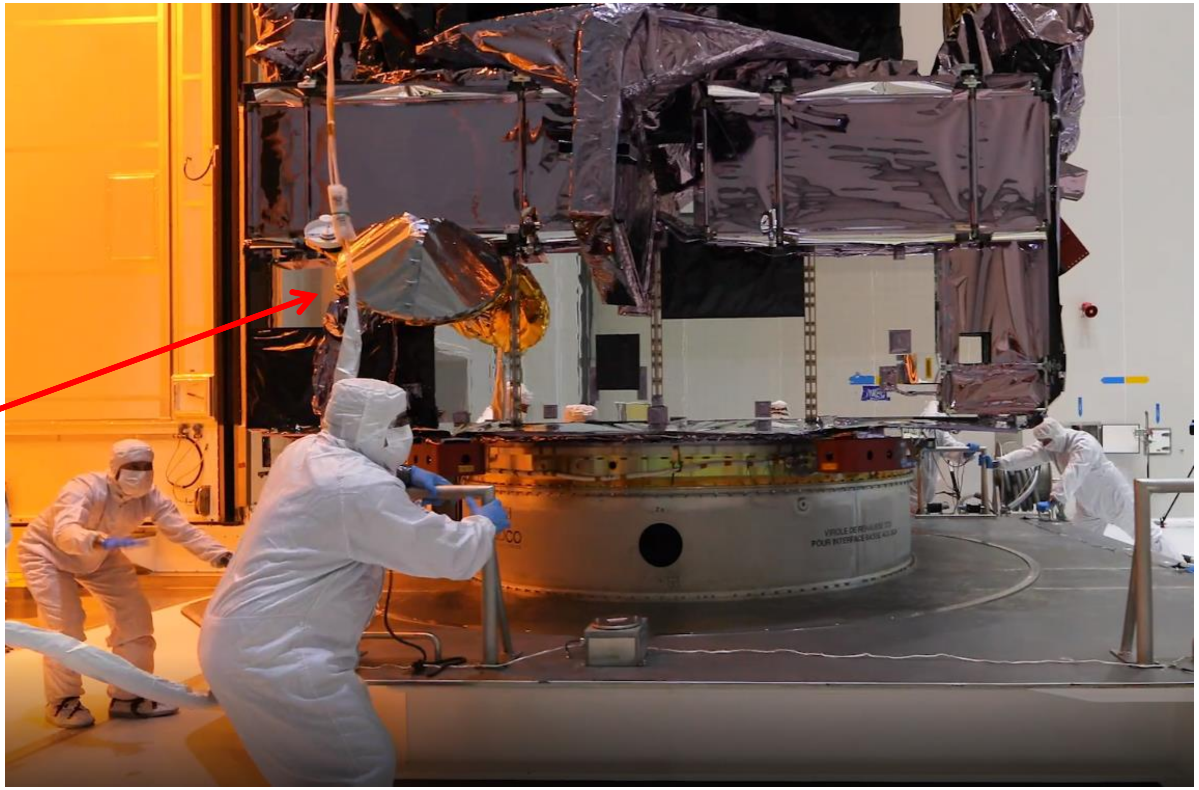
- Reflector antenna in carbon fiber reinforced plastic (CFRP)
  - 26 GHz



The JWST Orbit

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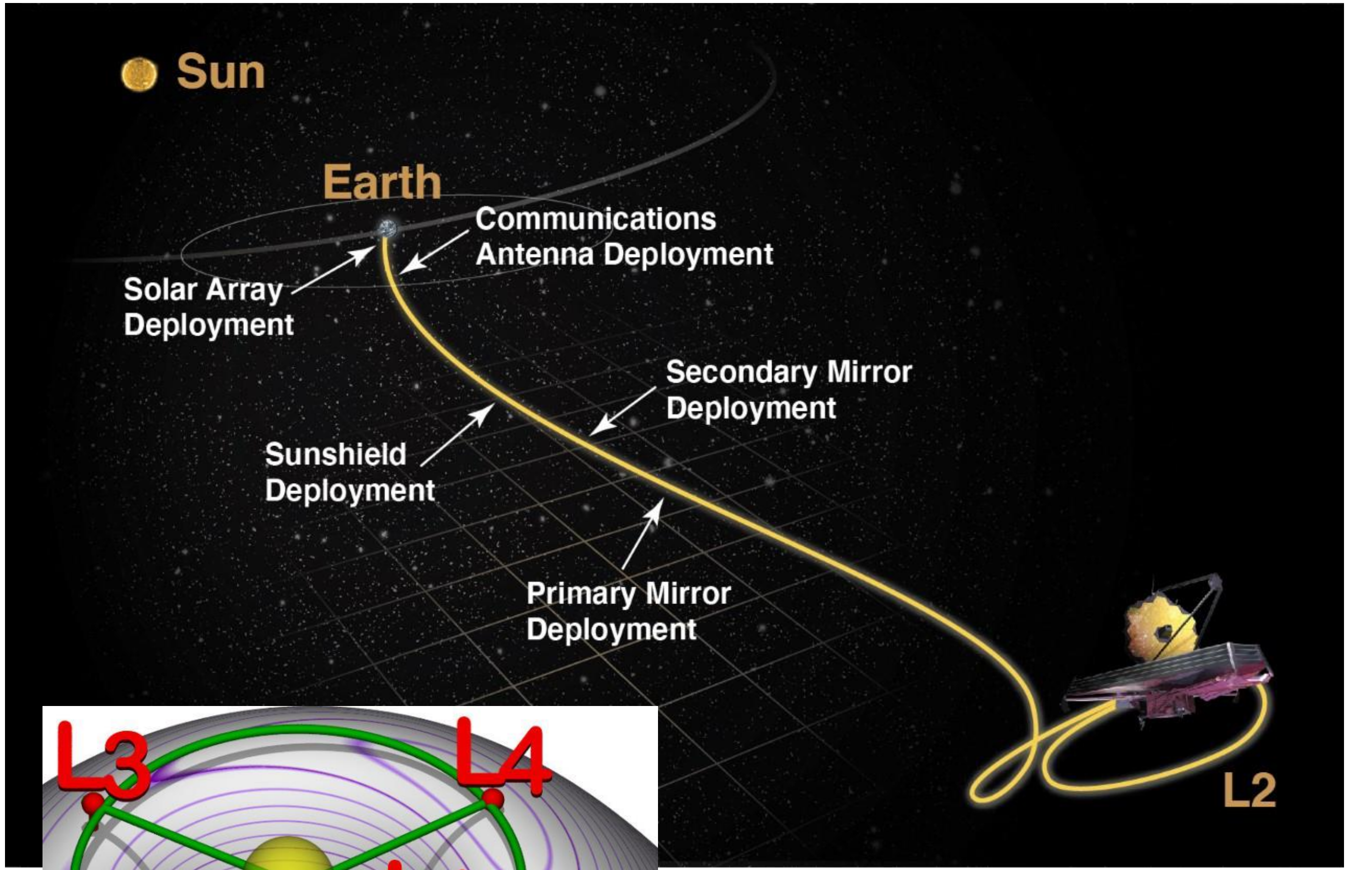
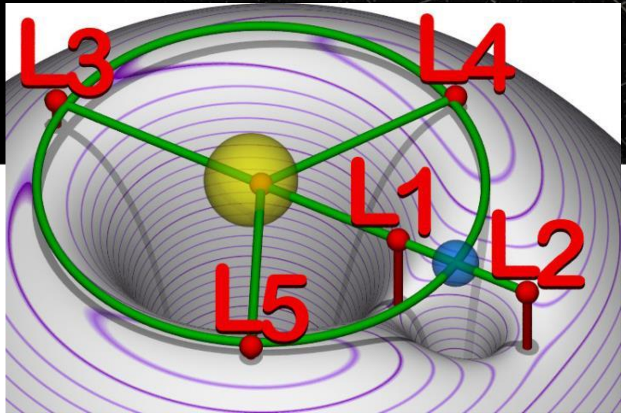
- JWST: quasiperiodic halo orbit (Lissajou) around L2 (second Lagrange point)
  - 1.5 million km from Earth
  - Earth shadow: 1.4 miljoner km
- Lagrange points:
  - “Balance” between centripetal acceleration and gravitation from the Earth and the Sun
  - Five “points”
  - Co-rotate with the Earth-Sun system
    - 1 year orbit
- The solar telescope SOHO is at L1





JWST Commissioning Phase

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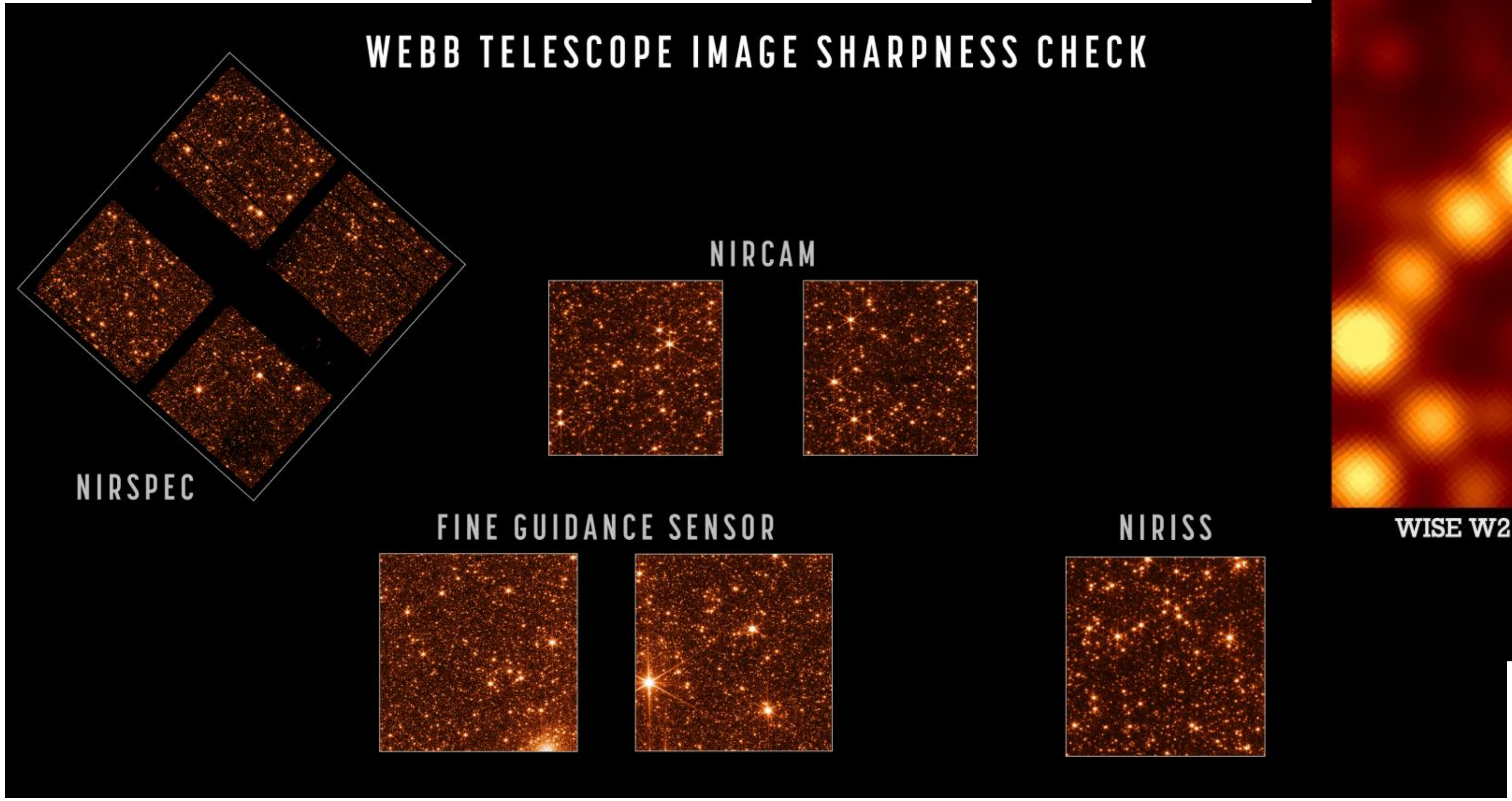
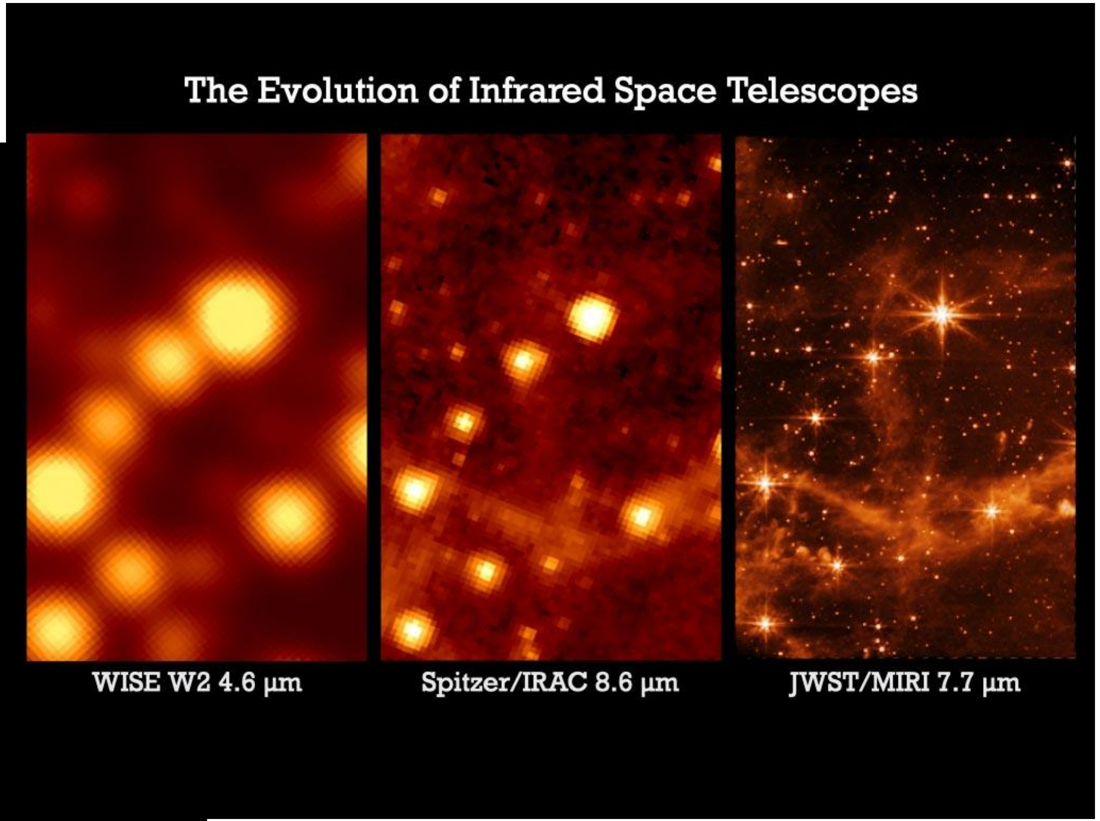
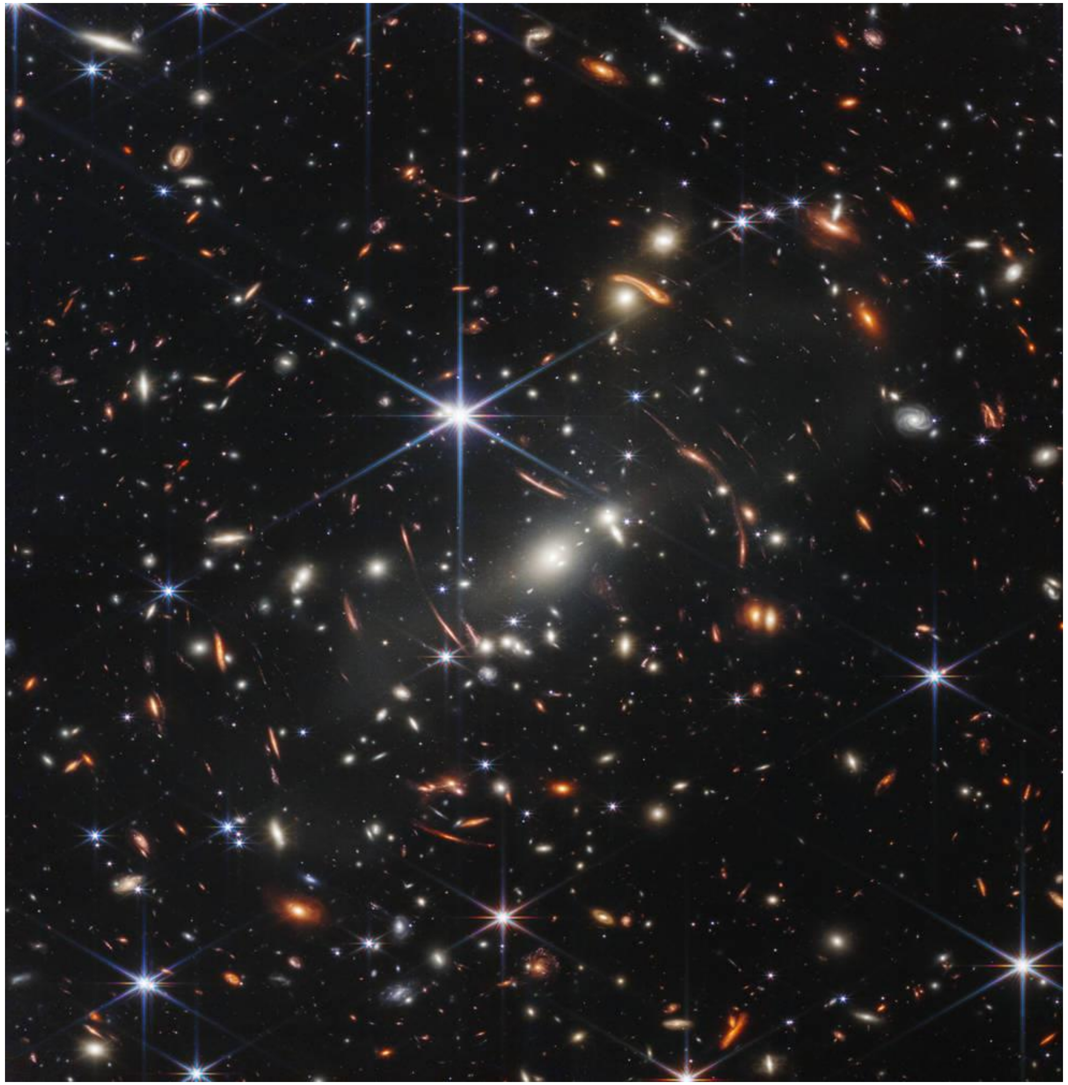
- The commissioning phase ended in June 2022





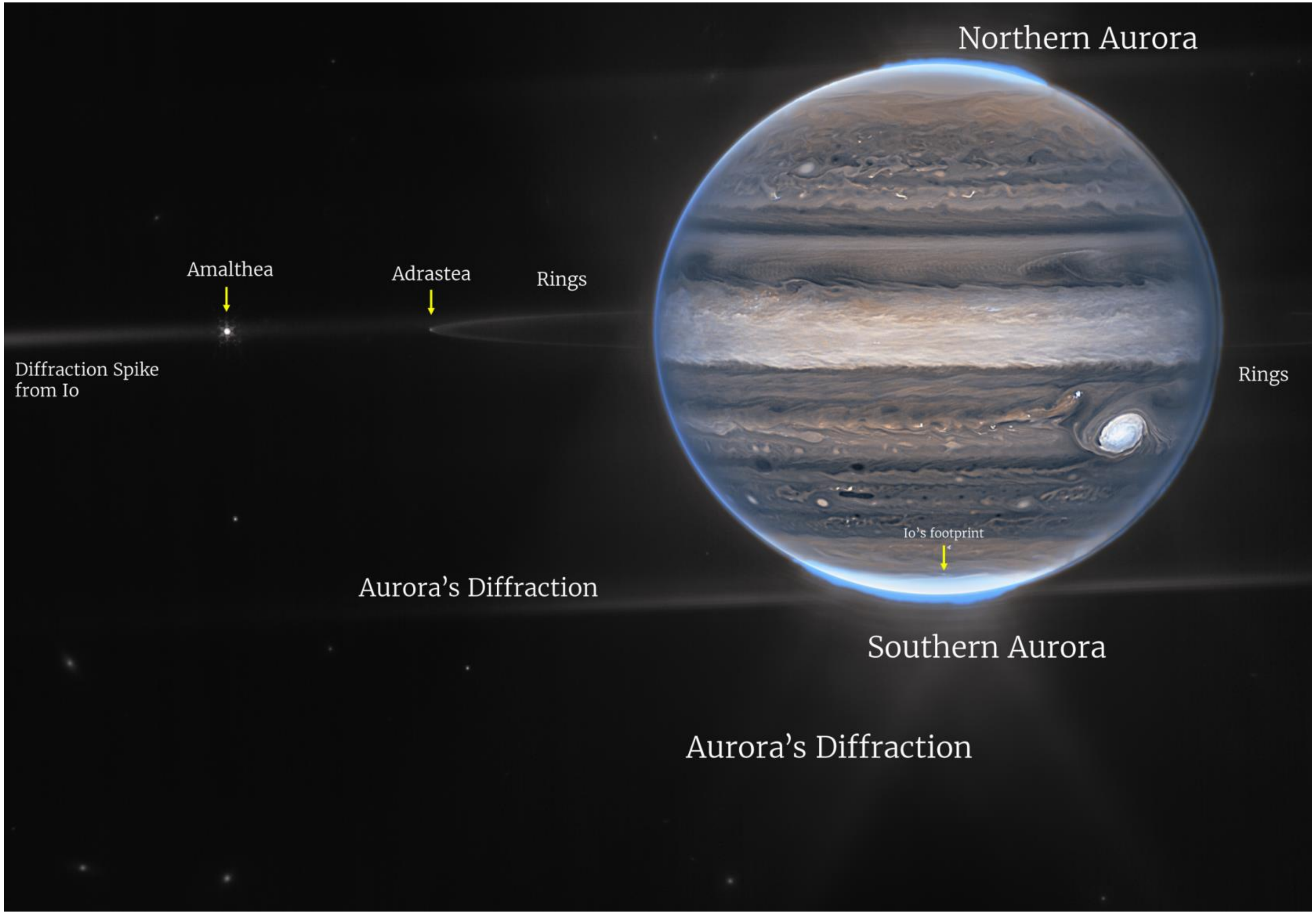
JWST Science Phase – Stephan's Quintet

JWST Science Phase – SMACS 0723



JWST Science Phase – Rho Ophiuchi

JWST Science Phase – Jupiter



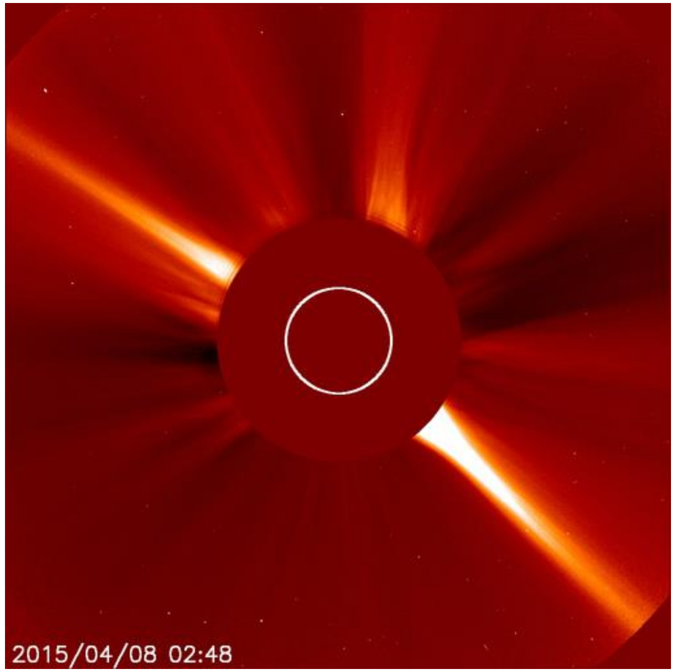
Case Study

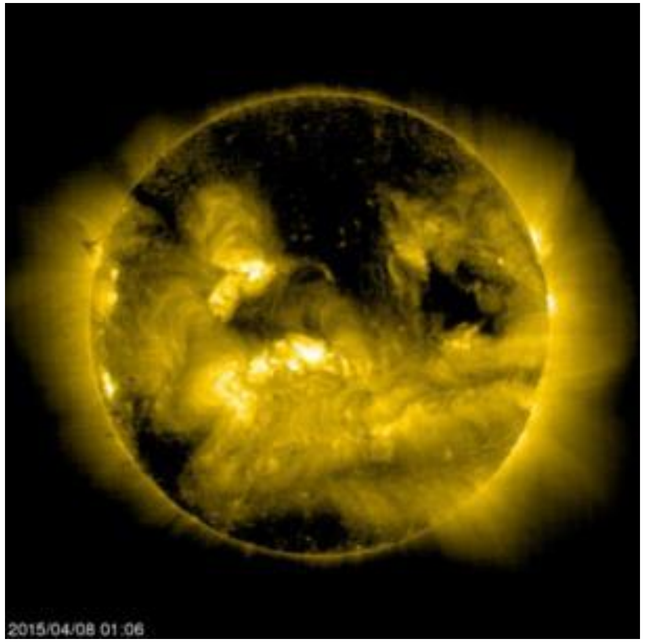
SOHO & Rosetta

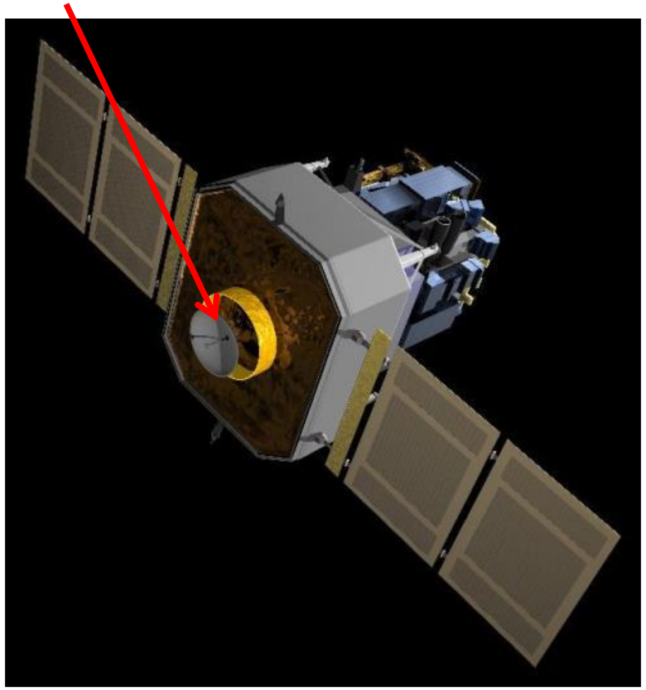
An Angry Sun!

beyond gravity

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



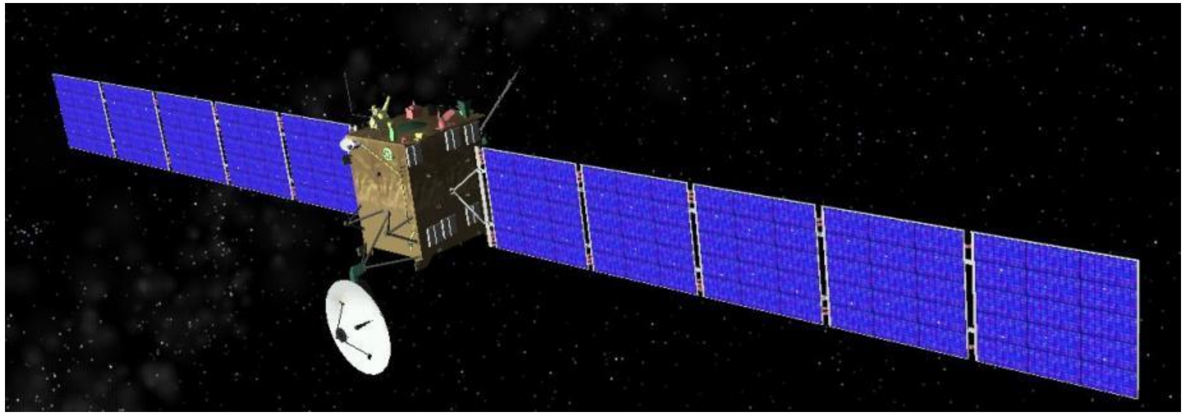


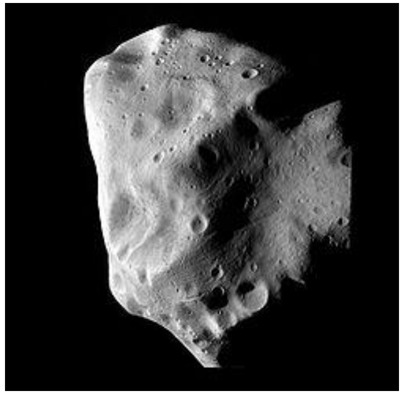


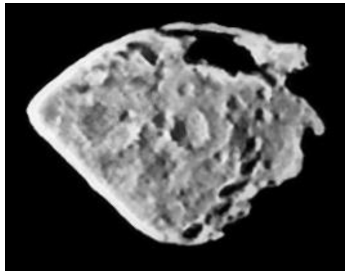
Rosetta

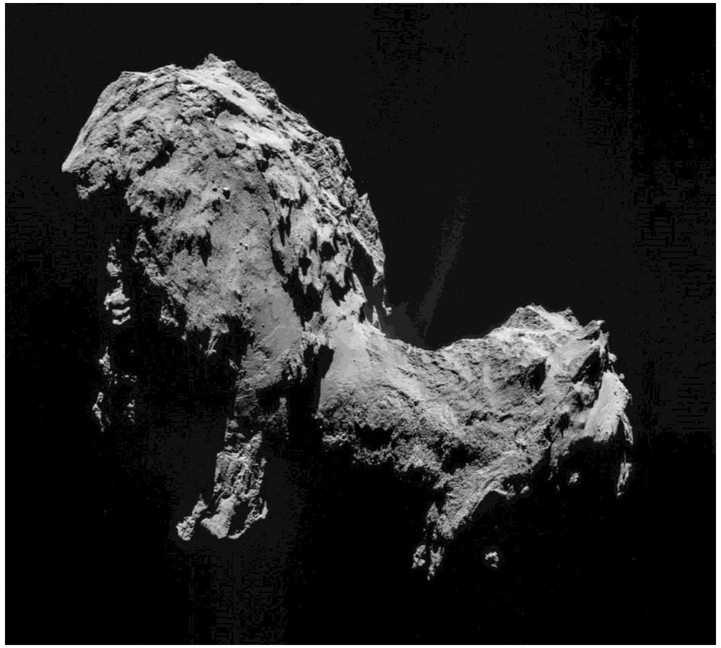
beyond gravity

- 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





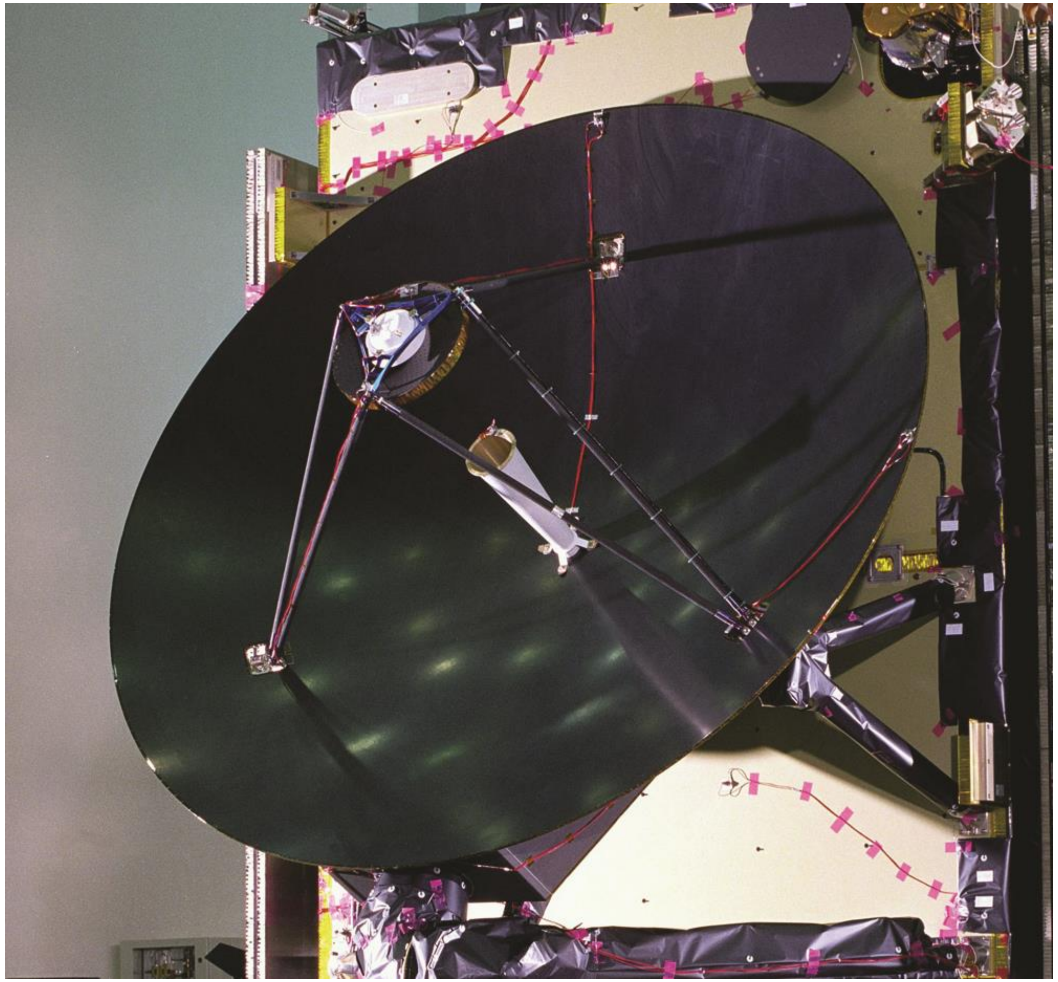




Rosetta HGA

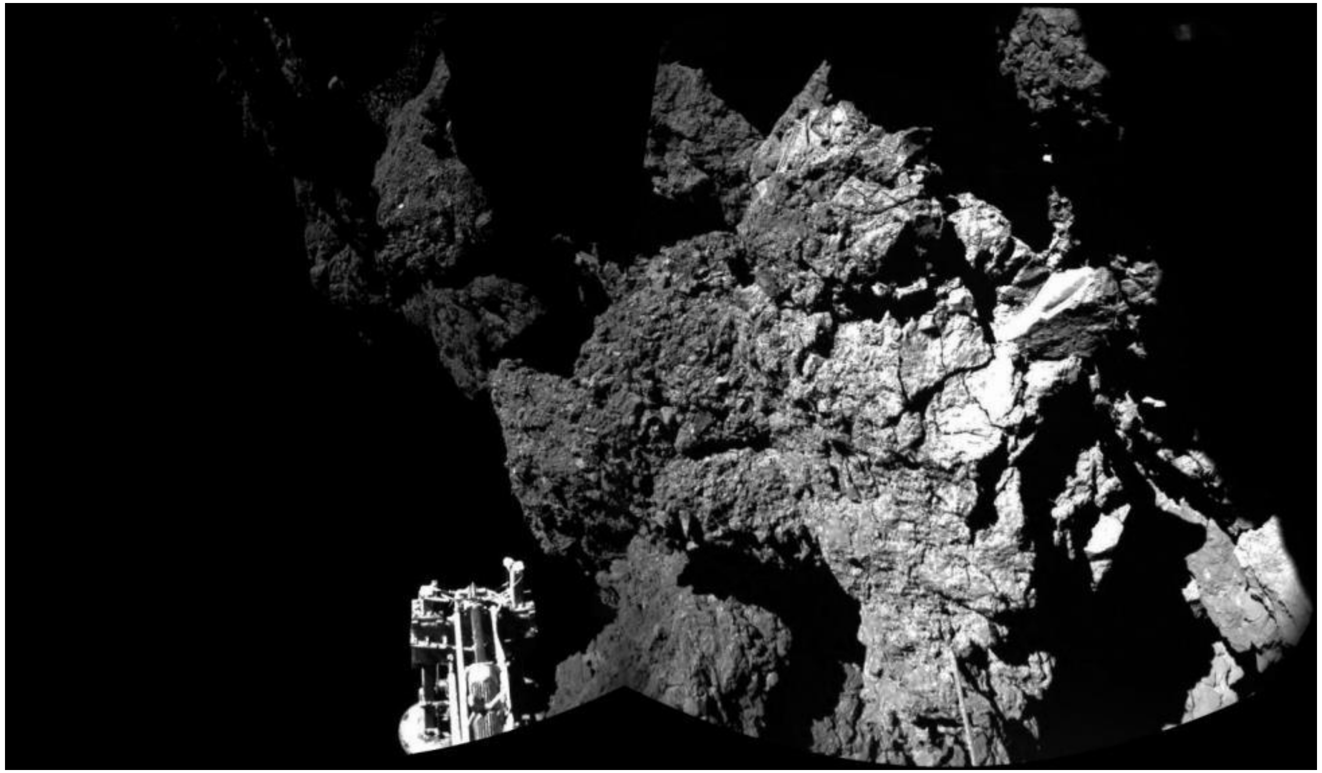
beyond gravity

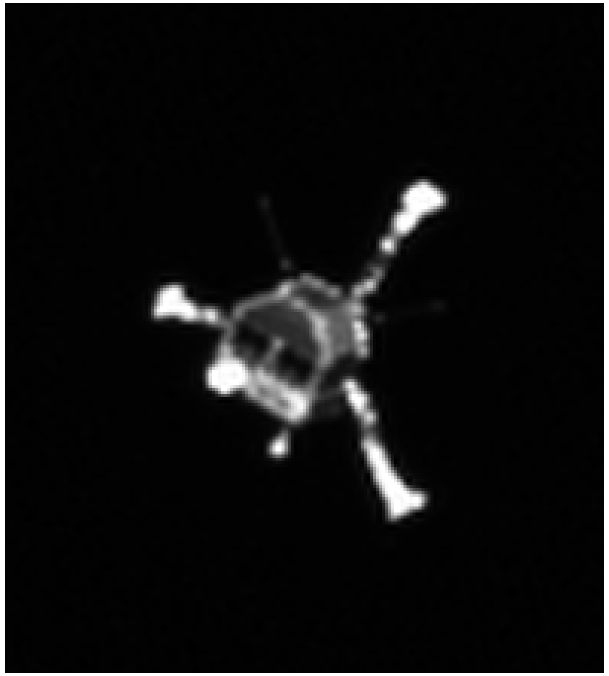
- RUAG (Saab Ericsson Space) were responsible for the high gain antenna (HGA)
- CFRP reflector
  – 2.2 m diameter
- X- & S-band



Rosetta

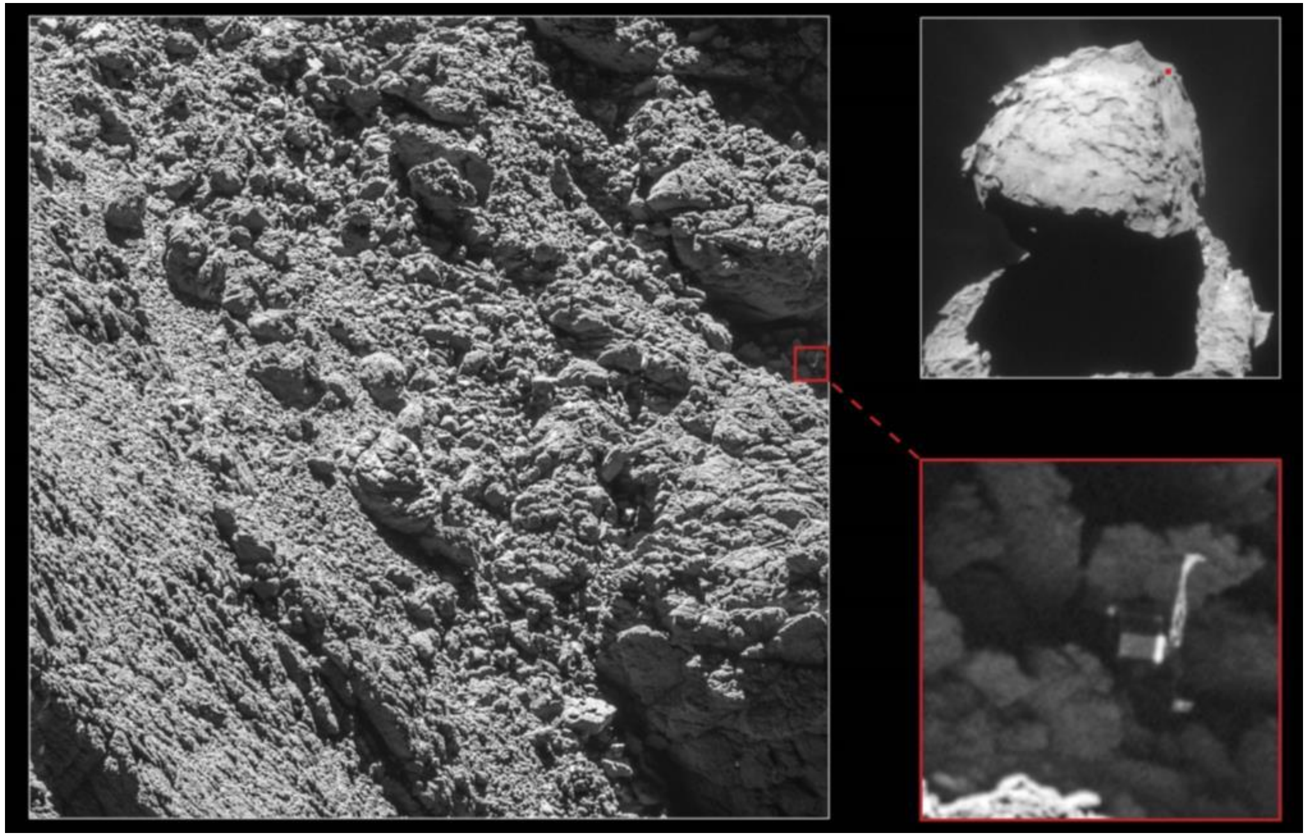
- The lander ”Philae” was stuck in a crevice on the comet
  - There were some hopes that the batteries would recharge later…





Rosetta

- Philae was found again 2 September 2016!



Antennas for Space

Beyond Gravity Antennas (RUAG Space)

beyond gravity

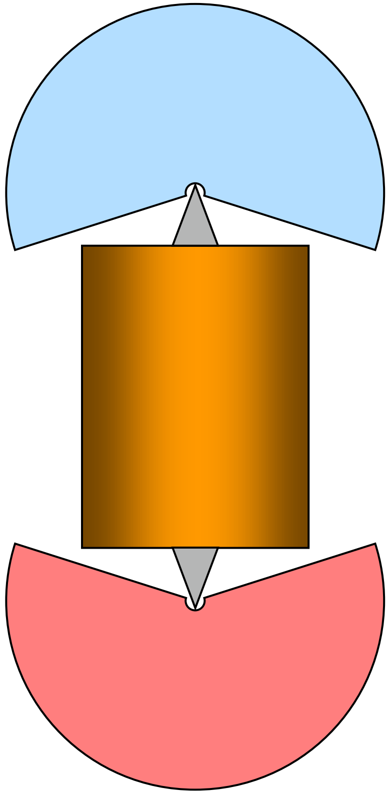
- Wide Coverage Antennas for
  - Telemetry and telecommand, GPS receivers, beacons, and data downlinks
- Array Antennas for
  - SAR, scatterometers, and mobile communication applications
- Reflector Antennas for
  - Satellite data links, deep space probes, DBS applications, radio astronomy, and earth observation

TT&C Antennas

beyond gravity

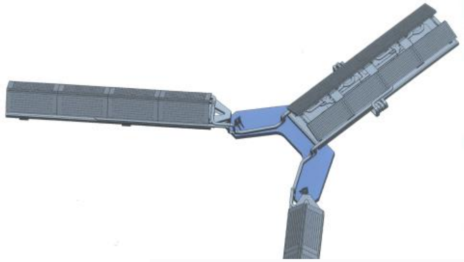
- Telemetry (TX)
- Tracking (RX/TX)
- Command (RX)

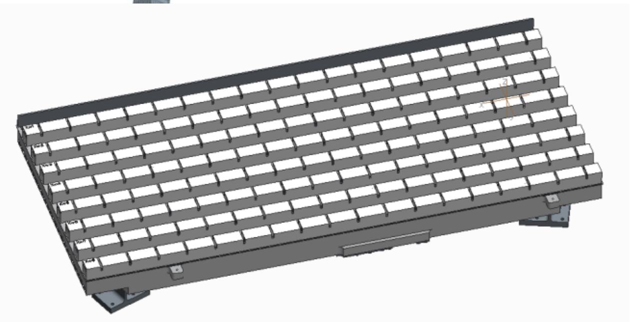
- Omni-directional antenna patterns desired
- Typically two hemi-spherical coverage antennas
- Typically S-band (2 GHz)

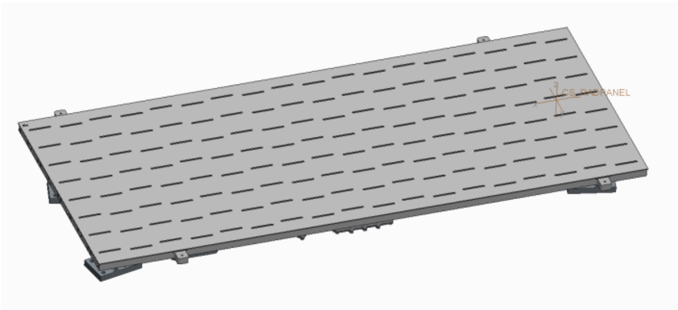


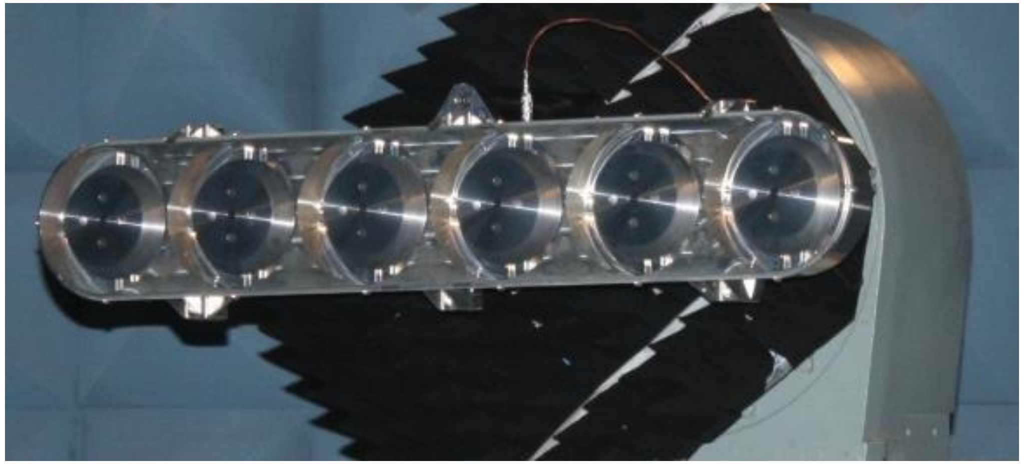
Array Antennas

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









Space Antennas – How Difficult Can It Be?

beyond gravity

- 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

The Launch

- 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

beyond gravity

- 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

beyond gravity

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

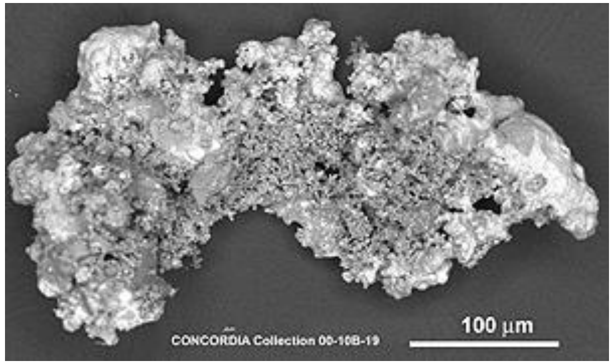
- Temperature gradients in the antennas can cause deformations
  – Insulation needed sometimes

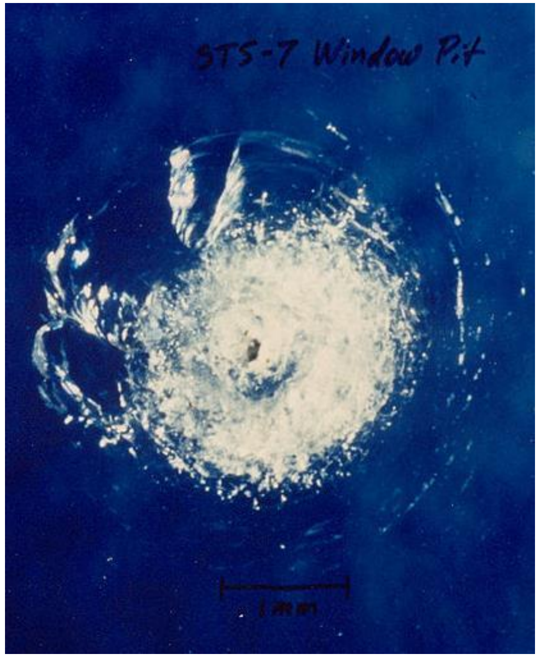
Dust & Debris

beyond gravity

- 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





A Bad Day at Work…

- NOAA-N “mishap”, 2003