Satellite Communication Systems: A Vision for Beyond 2030

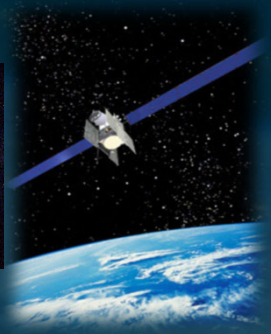
Alberto Ginesi
Head of the Telecom System Section
ESA/ESTEC
The Netherlands

ASMS/SPSC 2025 Conference, Sitges, 27/02/2025

ESA UNCLASSIFIED – For ESA Official Use Only

Looking back in history: the early days

SPACEWAY 1- 2005



1500 elements Ka band phased array

Olympus 1989

First satellite with Ka band

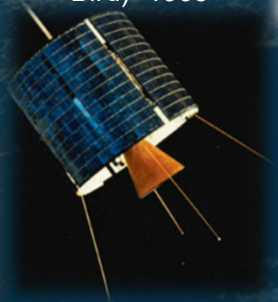
INTELSAT 4A- 1975

First use of multi-beam and frequency re-use

RCA SATCOM - 1975

First operational body-stabilized telecom satellite

INTELSAT I (Early Bird) -1965



First commercial geosynchronous telecom satellite

TELSTAR -1962

First active SATCOM satellite

ECHO 1A - 1960

First SATCOM relay link

Looking back in history: the HTS era - GEO

ANNIK F2- 2004

First HTS satellite(s)

IPSTAR -2005

First HTS satellite(s)

Wildblue-2006

5-10 Gbps

VIASAT 1- 2011

100-150 Gbps

KONNECT VHTS - 2020

450-550 Gbps

JUPITER 3 (ECHOSTAR XIV) - 2023

450-550 Gbps

VIASAT 3 –F2 (2025?)

1 Tbps

~ 600kg/Gbps

~ 1000W/Gbps

~ 6 Kg/Gbps

~ 30 W/Gbps

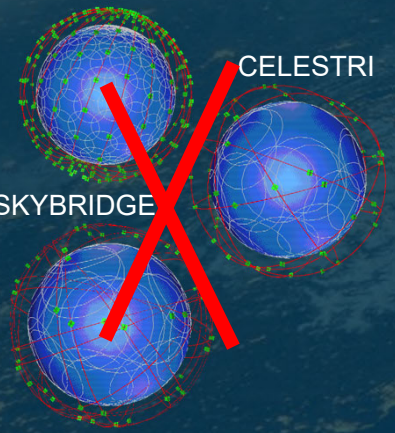
The HTS era - NGSO

1995-2000

TELEDESIC

CELESTRI

SKYBRIDGE



O3B MEO
FIRST OPERATIONAL
SATELLITE IN 2014

https://www.satellitetoday.com/

ONEWEB GEN1
FIRST OPERATIONAL
SATELLITE IN 2020

KUIPER
FIRST OPERATIONAL
SATELLITE IN 2025

https://dailygalaxy.com/

IRIS2
FIRST OPERATIONAL
SATELLITE IN 2030

https://spacenews.com/

STARLINK
FIRST OPERATIONAL
SATELLITE IN 2019

SPACESAIL
FIRST OPERATIONAL
SATELLITE IN 2024

https://www.leonarddavid.com/com

LIGHTSPEED
FIRST OPERATIONAL
SATELLITE IN 2026

https://www.satellitetoday.com/

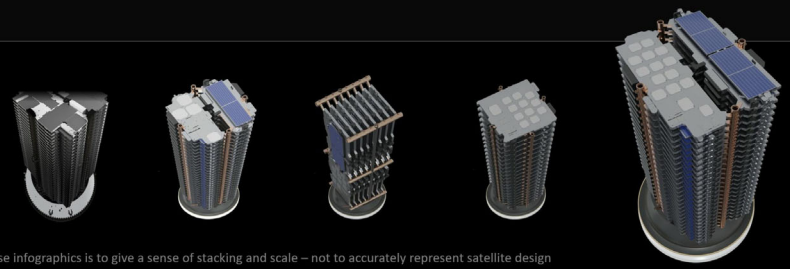
LEO HTS SATELLITES

https://www.nextbigfuture.com/2023/03/spacex-starlink-v2-mini-and-the-future-of-tesla-internet.html

Assumptions table

	Telesat Lightspeed	Amazon Kuiper	OneWeb	Starlink v2.0 Starship
Mass kg	800	600	150	2000
Gbps / sat	50	30	7	170
Launch	30 per New Glenn	61 per New Glenn	40 per Falcon 9	50 units per Starship
Tbps / launch	1.5	1.8	0.3	8.5
m$ / launch	Sats 13 + launch 55 = 68m$	Sats 27 + launch 35 = 62m$	Sats 40 + launch 60 = 100m$	Sats 60 + launch 15 = 75m$
$ / Mbps	46	34	347	9
Direct-to-mobile?	No	No	No	Yes

This is not investment advice (just some assumptions)

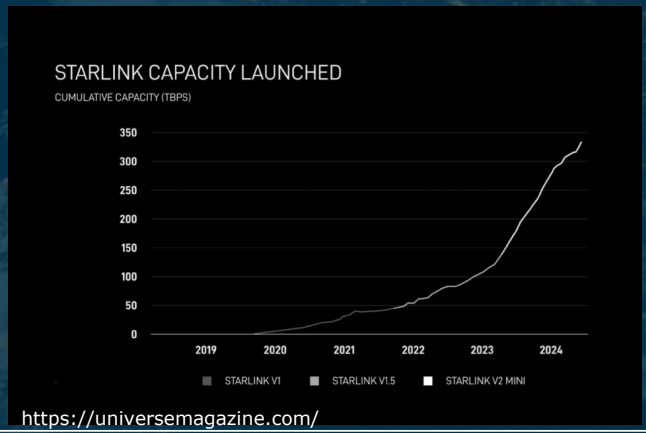


The goal of these infographics is to give a sense of stacking and scale – not to accurately represent satellite design

Assumptions

Designation	Starlink V1.5	Starlink V2 F9-1	Starlink V2 F9-2	Starlink V2 mini	Starlink V2 Starship
Status	Launched	FCC filing – may not realize	FCC filing – may not realize	Launched	FCC filing
Mass kg	306	303	800	800	2000
Gbps / sat	15	18	70	60	170
Launch	60 units per Falcon 9	60 units per Falcon 9	16 units per Falcon 9	21 units per Falcon 9	50 units per Starship
Tbps / launch	0.9	1.1	1.1	1.3	8.5
m$ / launch	Sats 18 + launch 30 = 48m$	Sats 18 + launch 30 = 48m$	Sats 11 + launch 30 = 41m$	Sats 15 + launch 30 = 45m$	Sats 60 + launch 15 = 75m$
$ / Mbps	53	45	37	35	9
Direct-to-mobile?	No	No?	Yes	Yes?	Yes

This is not investment advice (just some assumptions)



https://universemagazine.com/

Now V3 with 1 Tbps downlink and 160 Gbps uplink !

LEO HTS SATELLITE EVOLUTION

F. Alby, M. Danvel, C. Hourtolle, E. Frayssinhes,
Debris assessment for Skybridge constellation,
Acta Astronautica, Volume 53, Issue 3,2003

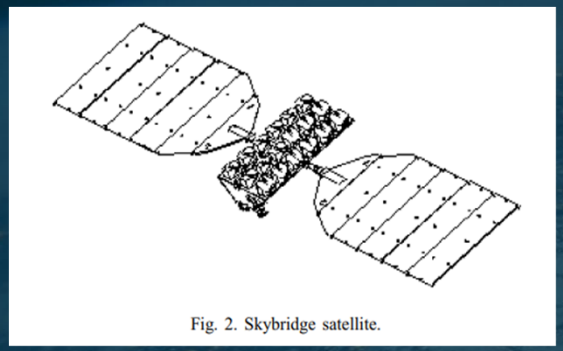
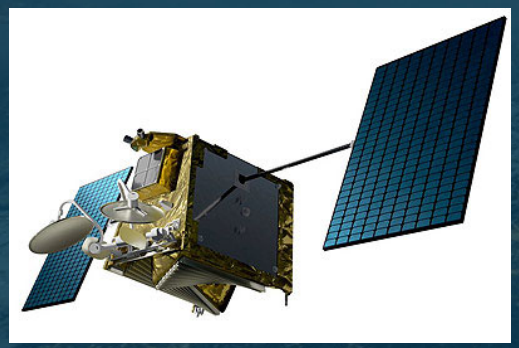


Fig. 2. Skybridge satellite.



https://lieber.westpoint.edu/

STARLINK V3
??

SKYBRIDGE: LATE 90's
- 2 Gbps per satellite
- Power consumption 1.8 kW
- 1400 Kg mass

ONEWEB: 2020
- 5-7 Gbps per satellite
- Power consumption ~250 W
- 150 Kg mass

STARLINK V1: 2019
- 10-15 Gbps per satellite
- Power consumption ~1000 W
- 250 Kg mass

STARLINK V3: 2025
- ~ 1Tbps per satellite
- DC power – 15-20 kW??
- 2000 Kg mass ??

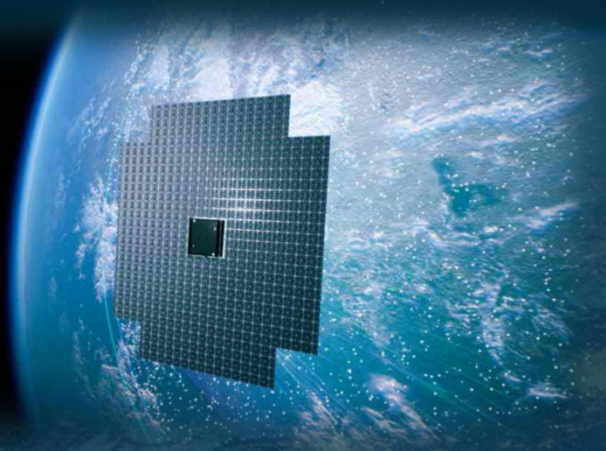
~ 700kg/Gbps | ~ 25kg/Gbps | ~ 25 Kg/Gbps | ~ 2 Kg/Gbps

~ 1000W/Gbps | ~ 50W/Gbps | ~ 70 W/Gbps | ~ 15-20 W/Gbps

Other recent breakthrough endeavours- direct to handhelds

AST SpaceMobile

Globe



5 operational BlueBird satellites just launched (1 prototype already in orbit)

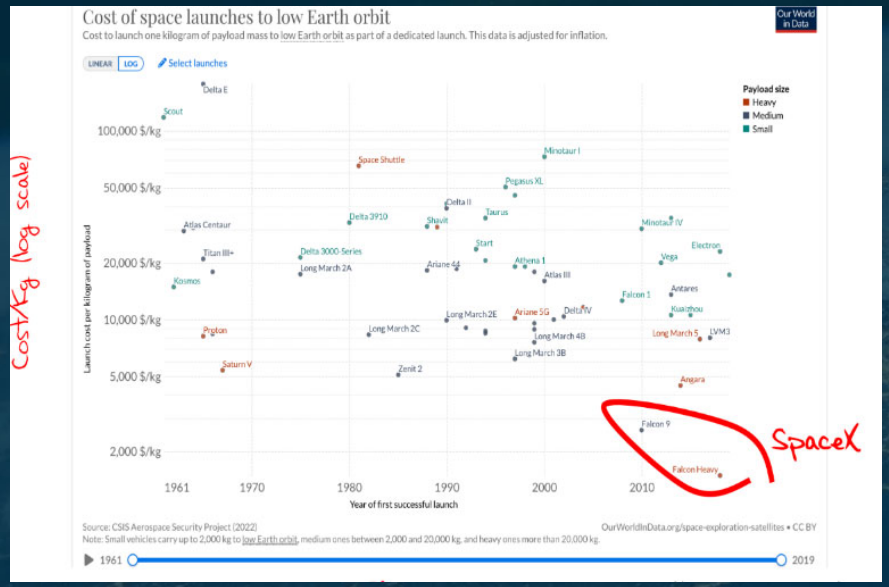
~ 10 Mbps data rate to unmodified smartphone

64 sqm DRA antenna

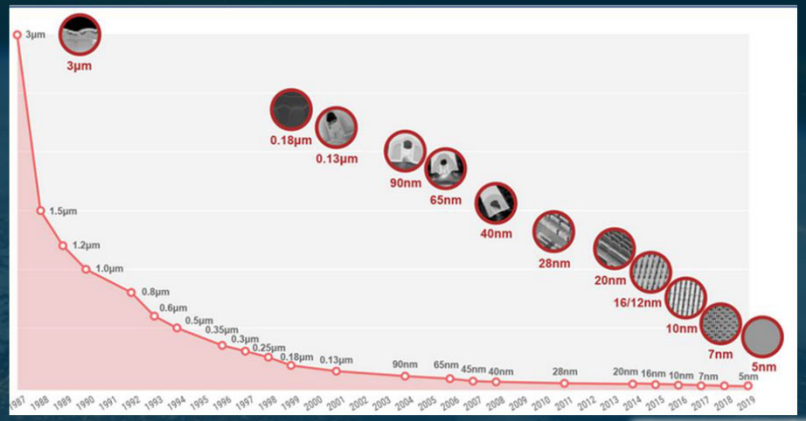
~ 100 V2 mini STARLINK satellites embark 1-2 GHz direct to hand-held connectivity
Further data rate improvements expected when V3 SATs will be launched

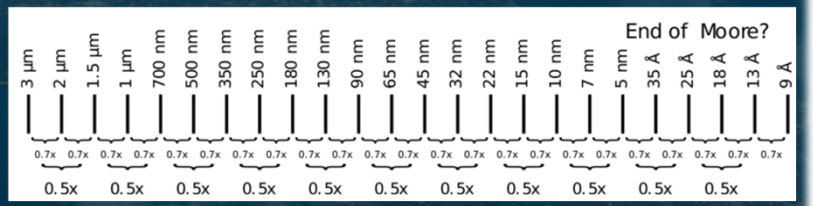
Key performance trends (1)

LAUNCH COST



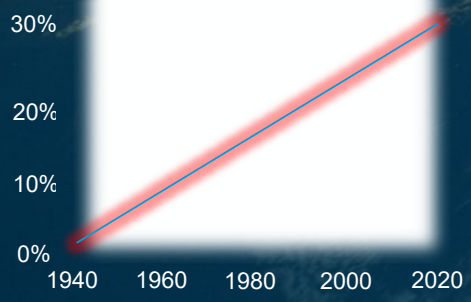
DEEP SUB-MICRON TECHNOLOGY





Generally, between two successive process nodes: speed improves by 30%, power shrinks by 50% (for the same processing speed).

SPACECRAFT SOLAR PANEL EFFICIENCY



MASS AND POWER THROGHPUT EFFICIENCY

Mass/Gbps: 10 times reduction in ~10 years
Power/Gbps: 5 times reduction in ~10 years

SATELLITE TOTAL COST PER KG

Large HTS GEOs of the past: ~ 50K$ - 100K$ per Kg now reduced by a factor 2-3
Now at X $ per kg (LEO)

Key performance trends (2)

- Large HTS (5-6 tons) GEO manufacturing time around 30 months in 2010
- More recent (2023) medium size GEOs ~18 months
- Manufacturing of smaller LEO satellites enjoying new integrated and modular satellite architectures
    - STARLINK production rate: 120 v1 satellites per month
- Typical car assembly line production rate: 30K cars per month

Prediction of key performance trends in 2035

Launcher: cost well below 1000$/Kg (Starship +) and more than 250 t launch mass-> more than 500 small LEO sats<->100 large LEOs

Satellite throughput increase for same mass/power: ~5->10 times
- Electronics integration (Satellite on-chip concept) - Lighter materials
- Higher satellite EIRP/G/T- lower orbits- larger BWs – better solar panel efficiency – better HPA's efficiency

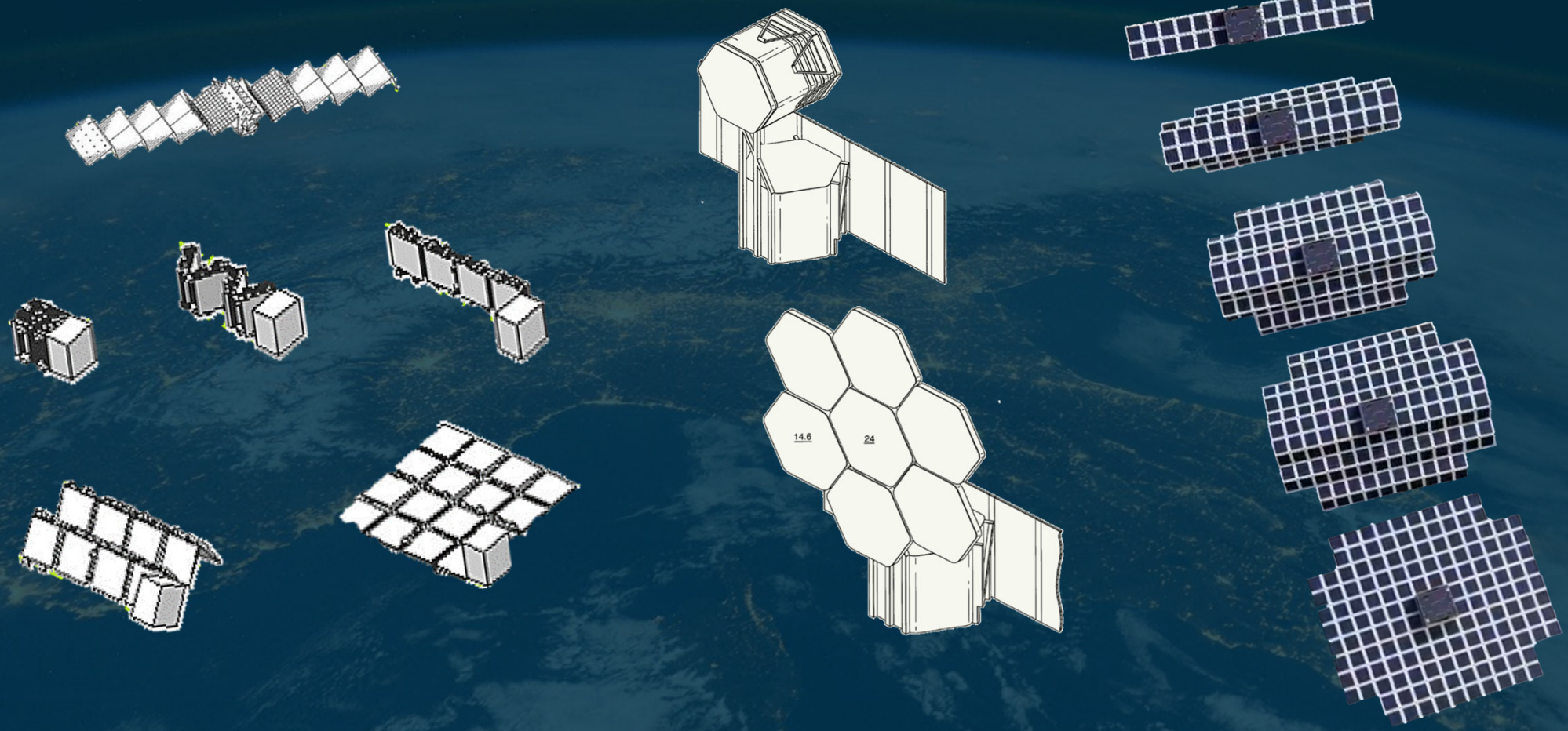
DSP capability: 1.4 nm technology to increase processed bandwidth by a factor of 3 w.r.t 7nm for the same power consumption

Increase Manufacturing rate: thousands of satellites could be manufactured in a few months

Reduce satellite cost: below 1000$/kg
- AI-assisted development
- Larger volumes
- More efficient production lines
- Lower cost materials

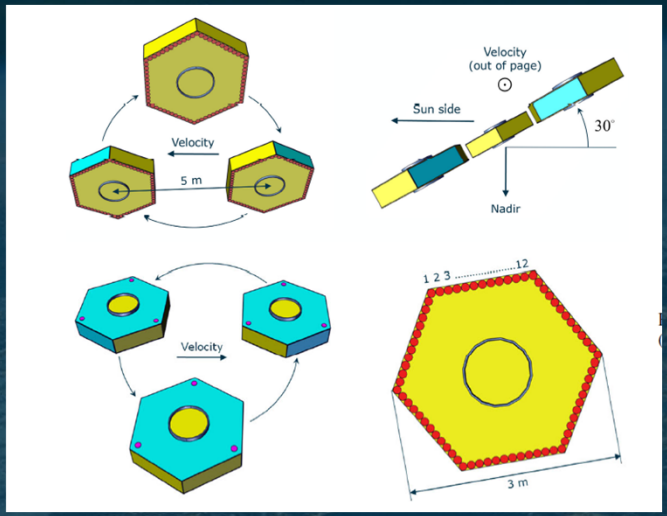
https://aiworldschool.com/research/artificial-intelligence-in-manufacturing-how-does-ai-impact-the-indust

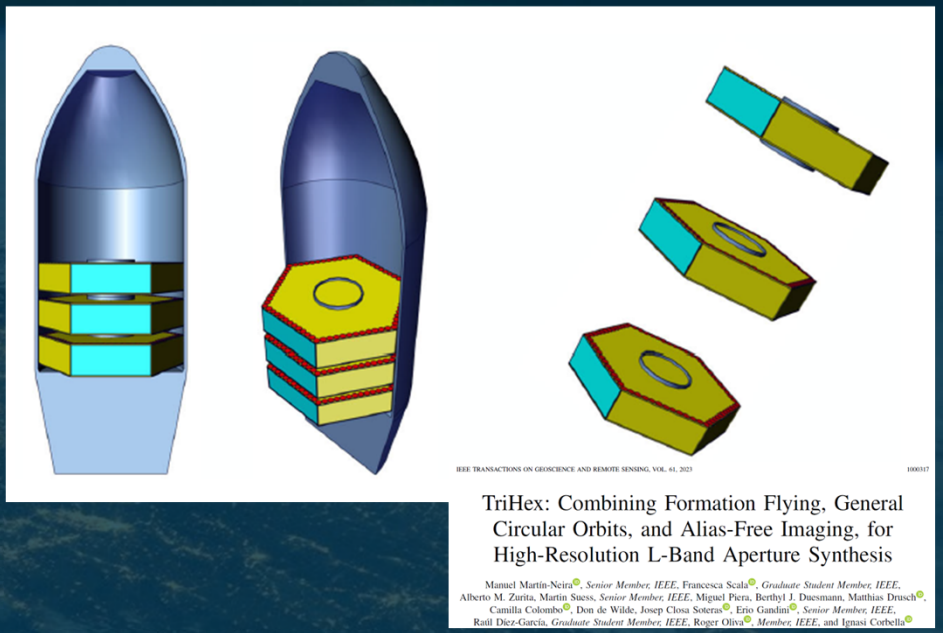
Game changers: very large deployable arrays



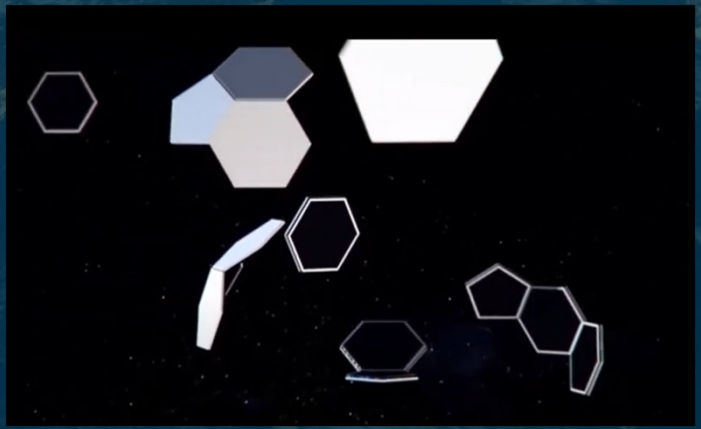
Game changers: very large in-orbit assembled arrays

Formation Flying





In orbit Assembly



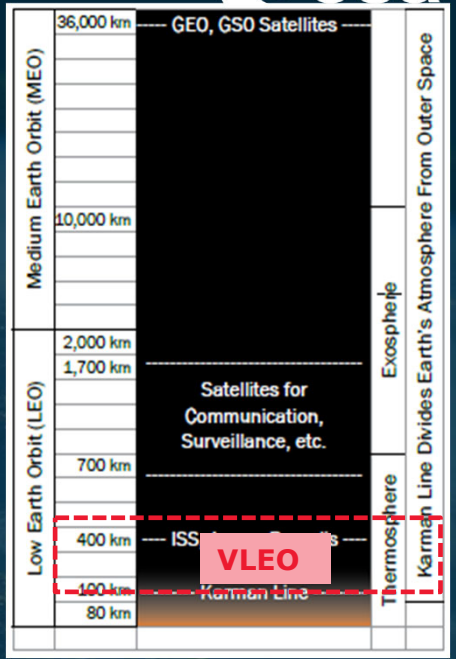
Very large apertures > 100 m diameter combining antenna arrays and solar panels->

- 200 kw DC power generation –
- Few km beam size on ground

Game changer: Very Low Earth Orbit (VLEO)

https://dsiac.org/

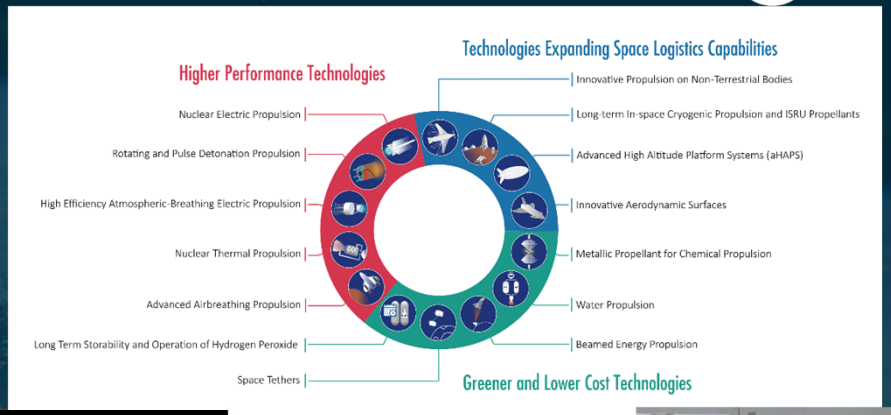
Pros	Cons
Improved signal-to-noise ratios, smaller beams	Higher atmosphere drag
Lower latency (comparable to terrestrial)	Atomic oxygen erosion
No need for de-orbiting manoeuvres	Higher satellite speed, lower ground coverage
Less expensive launches	Spacecraft may get electrically charged
Reduced probability of collision with space debris	Need to have body-fixed solar arrays or low drag
Lower level of radiation	Higher probability of terrestrial impact events from debris

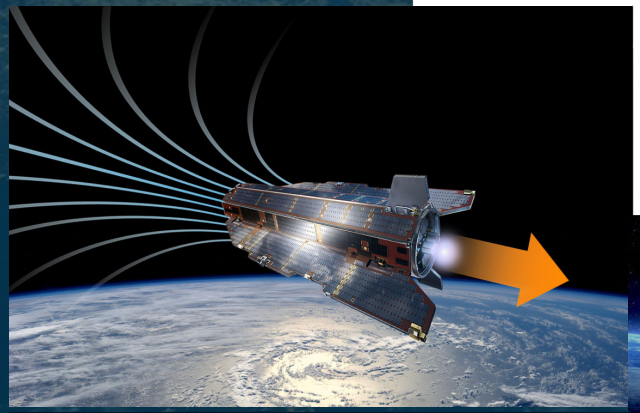


- Higher atmosphere drag -> Efficient propulsion system (i.e. air breathing thruster) and aerodynamic efficient platforms
- Materials resistant to oxygen erosion
- Platform allowing large solar arrays with low drag
- Optimized payload

Game changers: innovative propulsions

- The ability to manoeuvre and travel through space is a fundamental one for numerous space missions. ESA's innovative propulsion initiative has the main goal of boosting breakthrough technologies to harness significant benefits in terms of mass, performance, cost and flexibility.





World-first firing of air-breathing electric thruster

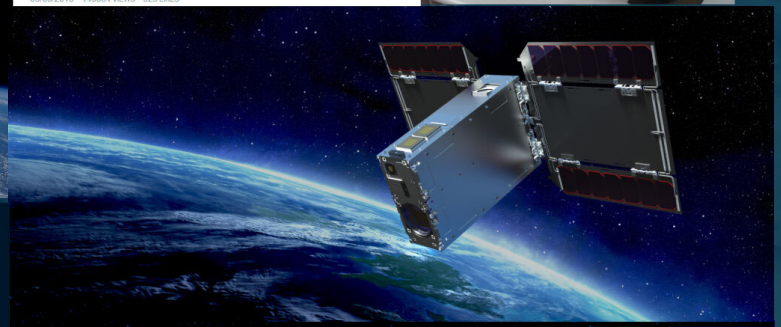
05/03/2018 145384 VIEWS 925 LIKES

Water Propulsion for hydrazine replacement on LEO satellites

Atmosphere-Breathing Propulsion to enable operation in extremely low orbits

arianeGROUP

WATER: THE PROPELLANT OF THE FUTURE

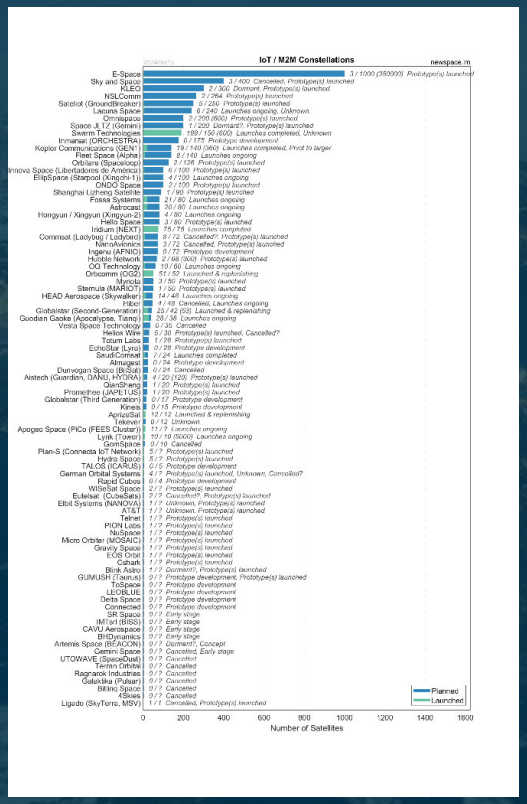


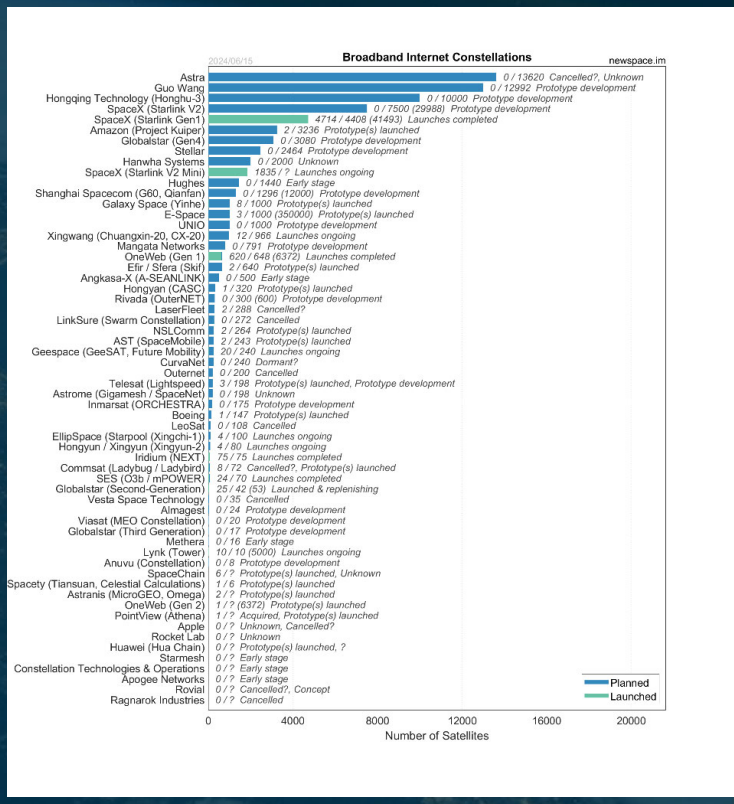
Pale Blue successfully operates its water-based propulsion system in orbit

https://pale-blue.co.jp/news/314/

Other game changers: higher frequency bands

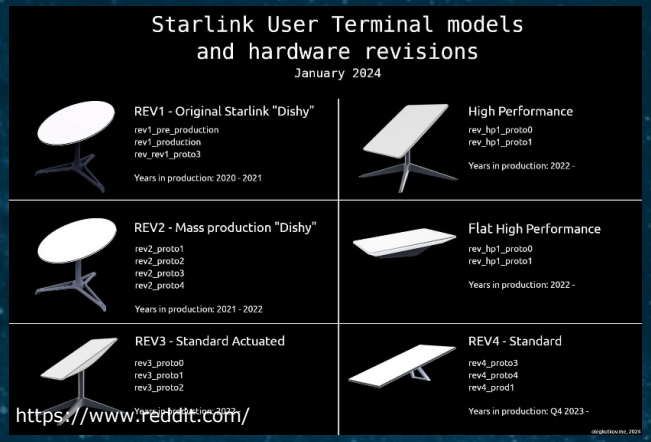
- Traditional frequency bands are getting crowded across different services from IoT to HTS
- Re-use of terrestrial bands from space helps on the D2D side
- Migrating services to higher frequency and underutilized bands seems to be a must
  - Q/V band, W band (E-band), D band
  - Pros: more bandwidth available
  - Cons: 1) technology tends to be more expensive 2) higher impact of rain fading





Other game changers: Flat Panel User-Terminal Antennas

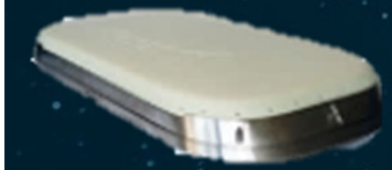
FIXED



https://www.reddit.com/

Next challenges

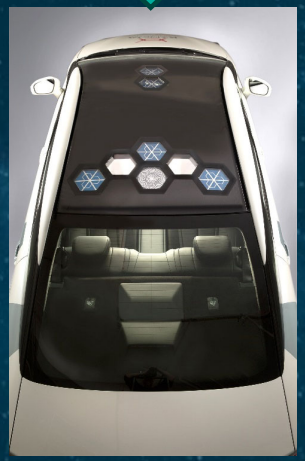
- Full duplex operations in single aperture
- Generic Broadband
  - GEO/NGSO
  - Multi-Frequency (Ku+Ka)



AUTOMOTIVE

https://www.cnbc.com/

https://www.geekwire.com/



Challenges:

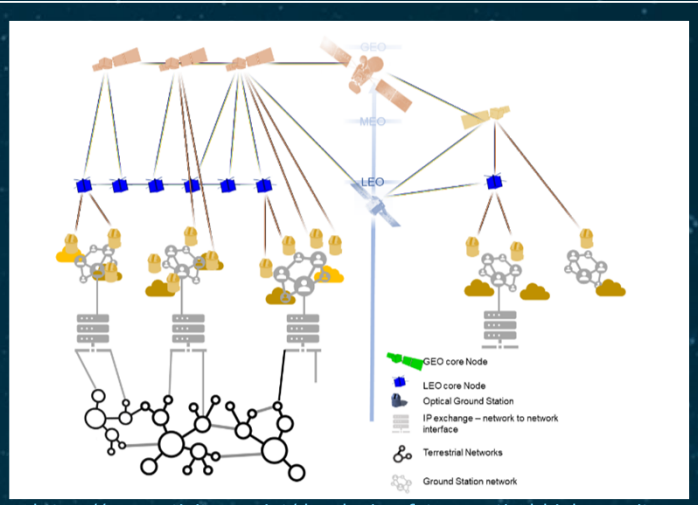
1) Integration into the car roof
2) Good performance with max 15cm size footprint
3) Low(er) cost

https://www.wired.com

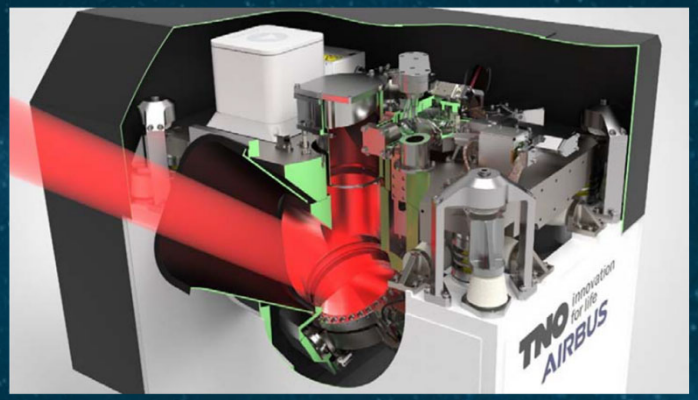
Game changer: Optical comms

- Terabit/s all optical networks (space-space and space-ground) by multiplexing several optical channels (Example application: interconnecting data centers between continents from space.). See ESA's High Throughput Optical Network Demo System – HydRON-DS

- Provide point-to-multipoint optical communications via Optical Phased Array Antenna and Multi-beam Position Acquisition and Tracking sensor (Example application: Providing Gbps broadband to airplanes via satellite)

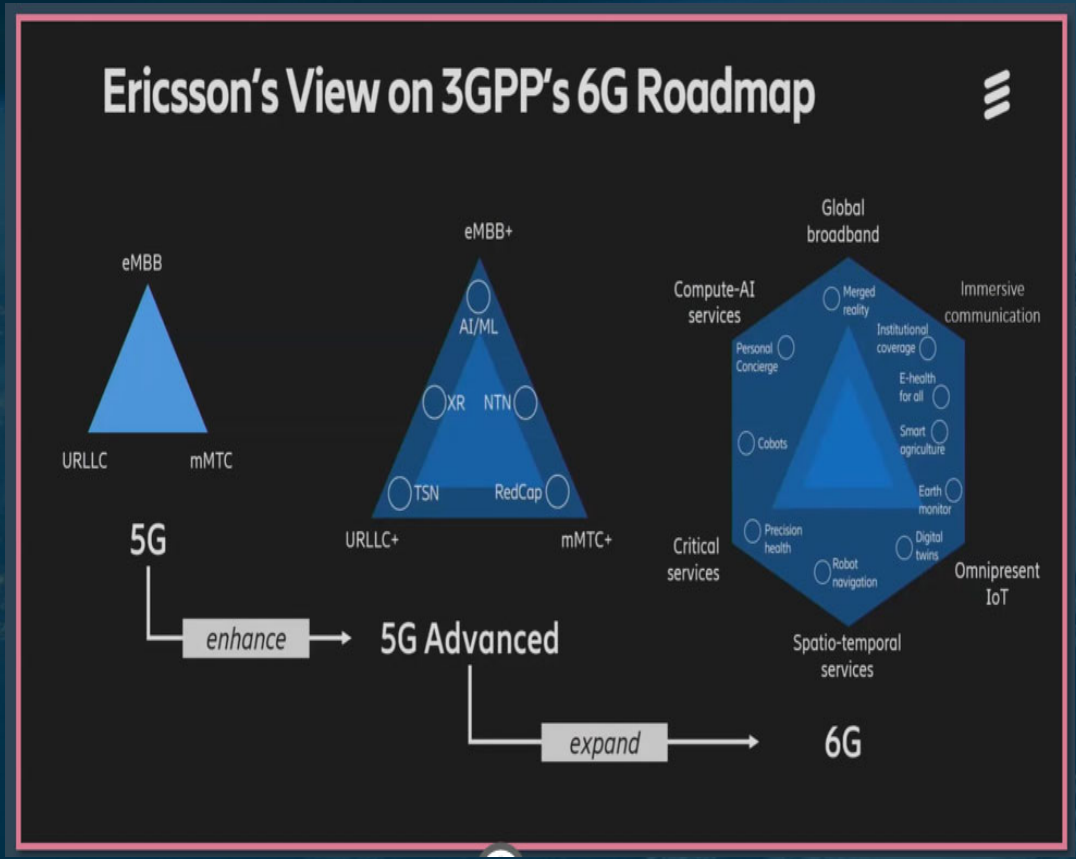


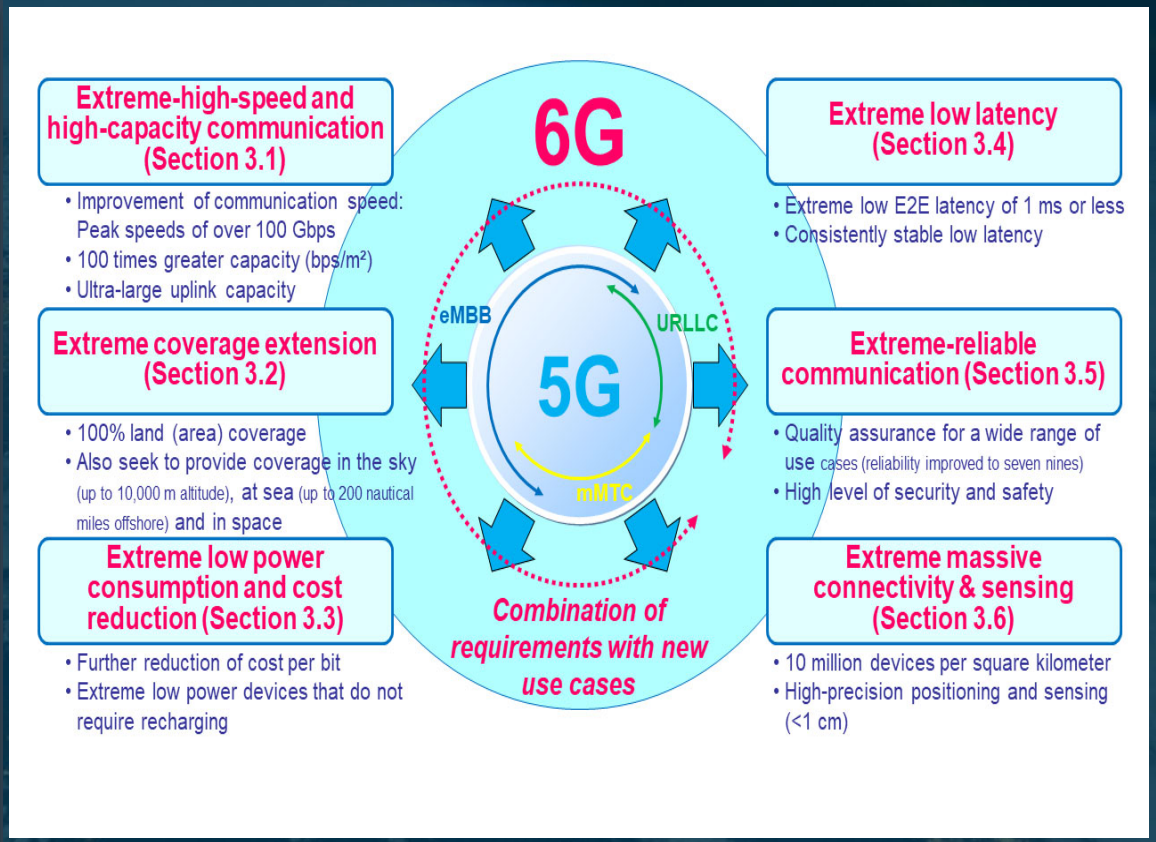
https://connectivity.esa.int/developing-future-optical-highcapacity-satellite



https://connectivity.esa.int/projects/ultraair

Game changers: 6G





Non-Technical Key Factors

- Increasing Safety/Security needs vs public investments
  - Geopolitical aspects
  - Partnerships between public and private entities as solutions to accelerate public space agendas while boosting commercial space economies
- HTS capacity demand growth: a never-ending story?
- Short-term vs. long term investor focus
- Upcoming new EU Space Law (sustainability, space debris, cybersecurity)
- Regulatory: Fighting for spectrum (terrestrial vs satellite)

IRIS²: the new EU Secure Satellite Constellation

Infrastructure for Resilience, Interconnectivity and Security by Satellite

High throughput satellites poised to become leading commercial growers in space infrastructure, with wholesale capacity revenues projected to top $100b by 2030

Published on March 23, 2022

The latest edition of Euroconsult's "High Throughput Satellites" report investigates the effects of recent constellation developments on HTS production and market, as well as the long-term impact on global communications.

EU Space law