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Trends in satellite communications and the role of free-space optical communications

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Outline

- Introduction
- Activities on Space Laser Communications in Japan
- Space Laser Communications for Mega-Constellation Programs
- Future Vision on Space Communications toward 5G/Beyond 5G
- Concluding Remarks

情報通信研究機構
National Institute of Information and Communications Technology

National Institute of Information and Communications Technology (NICT)

Delivery of Japan Standard Time (JST)
Address: Koganei, Tokyo
Railroad station:
15 min from JR Chuo line, Kokubunji-station

- Employees: 1,204
- Researchers: 483
- Ph.D. holders: 471

*As of April 2021

http://www.nict.go.jp/index.html

NICT: National Institute of Information and Communications Technology

~ Only one public research organization specialized for ICT in Japan ~

Advanced Electromagnetic Technology

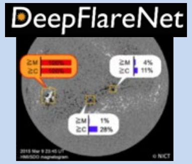
Remote sensing

Early detection of guerrilla torrential rains

Smartphone application

Space Environment and Space-Time Standards

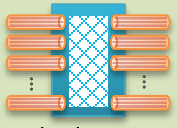
Space weather forecast, generation and distribution of highly accurate reference times



Innovative Networks

Photonic network

Realizing a high-capacity optical network for Beyond 5G


Ultra-high capacity optical exchange node

Next-generation wireless and space communications

Beyond 5G, Ultra-high-speed power-saving, expandable-space wireless network

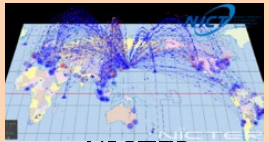
Cross-sectoral R&D and other operations

- Promoting Beyond 5G
- Create Open Innovation
- Research Support and Business Promotion

Cybersecurity

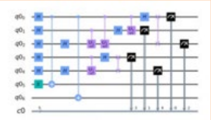
Cybersecurity

Responding to Diversifying Cyberattacks


NICTER

Cryptography

Cryptographic technologies used in the future, such as post-quantum computer cryptography


Cryptanalysis using quantum computers

Public services based on the Organization Act

- Emission of standard radio waves, standard time notification
- Space Weather Forecast
- Testing and calibration of equipment in radio installations

Universal communication

Automatic simultaneous interpretation

Practical automatic simultaneous interpretation


N:N simultaneous interpretation

Social knowledge communication

The user's interests and background, Contextual dialogue


Interactive Robot

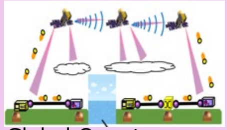
Other matters related to business operations

- Agile and flexible resource allocation
- Securing diverse and excellent and young human resources
- Disseminate information to the news media, etc.

Frontier science

Quantum Secure network

Long-term safety without the risk of eavesdropping or decryption


Global Quantum Cryptography Network

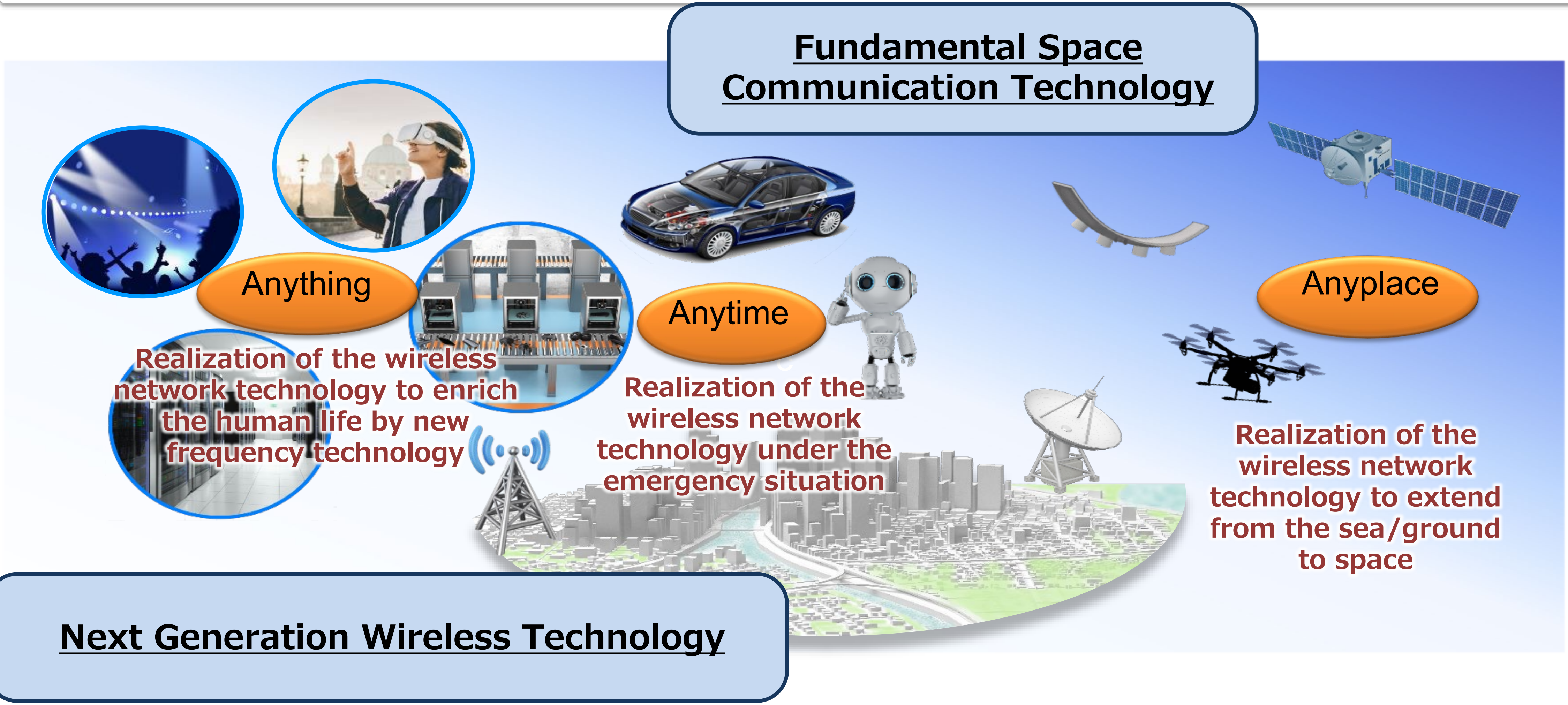
Advanced ICT Devices and Brain Information Communication

Expansion of human functions by brain information communication


Deep UV Light Devices

Overview of Wireless Networks Research Center

Looking ahead to the Beyond 5G era, NICT conduct R&D and disseminate results thereof, targeting wireless network technology in all circumstances and environments.



Location of Wireless Networks Research Center

Laboratory

- Wireless Systems Laboratory (Yokosuka Research Park)
- Space Communication Systems Laboratory (Koganei, Kashima)

Planning Section (Yokosuka, Koganei, Kashima)

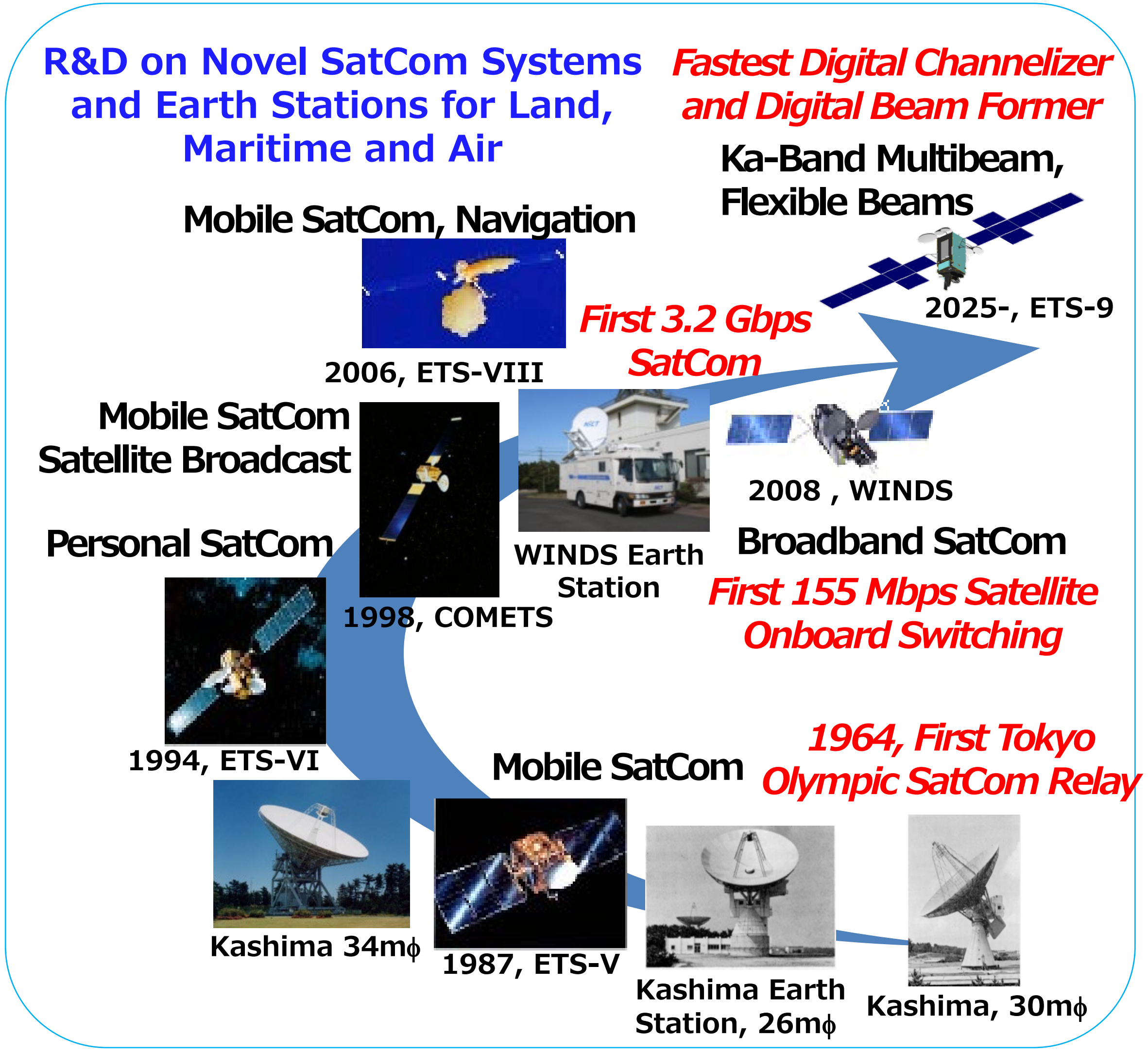
Number of Staffs (April 1st, 20224)

Staff: 84 (including limited term staffs)
(Including 45 Researchers)
Yokosuka: 33
Koganei: 35
Kashima: 15
Other: 1

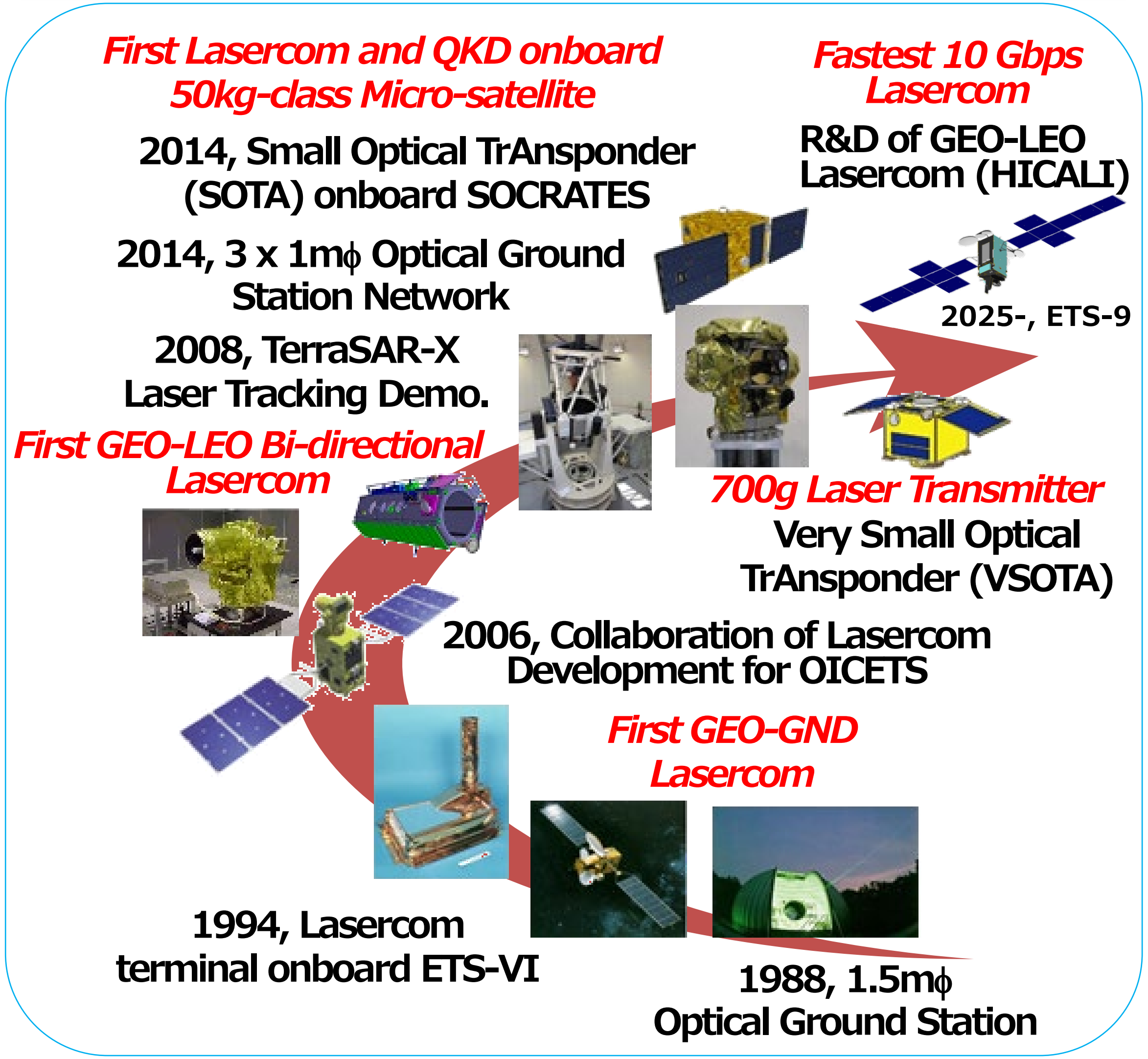
Location

R&D on SatCom Technologies in NICT

R&D on SatCom Systems in NICT



Pioneering R&D for Lasercom in NICT



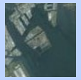
Space Laser Communications

Advantages of space based-lasercom

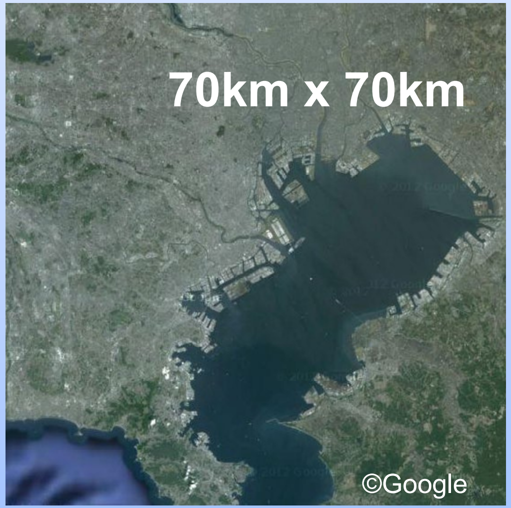
Large communication capacity

80Gbytes data transmission:
- -Optical: 16 seconds
- -RF: 13 minutes

Amount of data:
- 50 times wider area can be observed.



10km x 10km



Low vibrational disturbance

Example: antenna diameter:
- -Optical: ~10 cm
- -RF: ~1.3 m

Laser

RF

Size comparison

Highly secure wireless communication

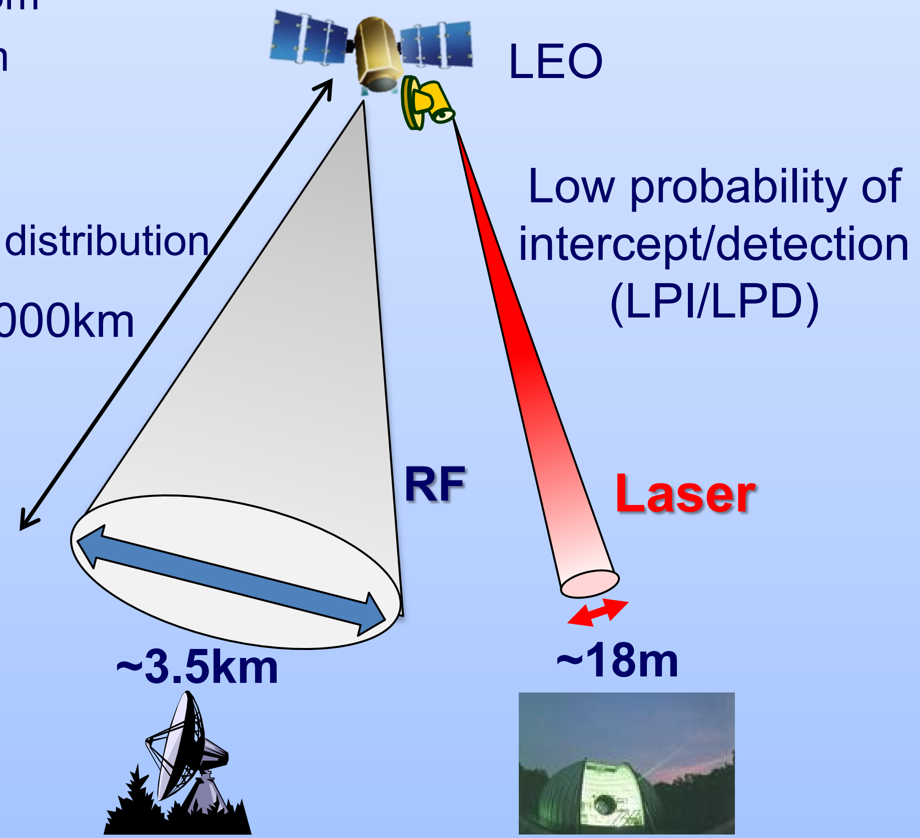
Beam divergence angle:
- -Optical: ~0.001 degrees
- -RF: ~0.2 degrees

Footprint of the beams (LEO case):
- -Optical: ~18m
- -RF: ~3.5 km

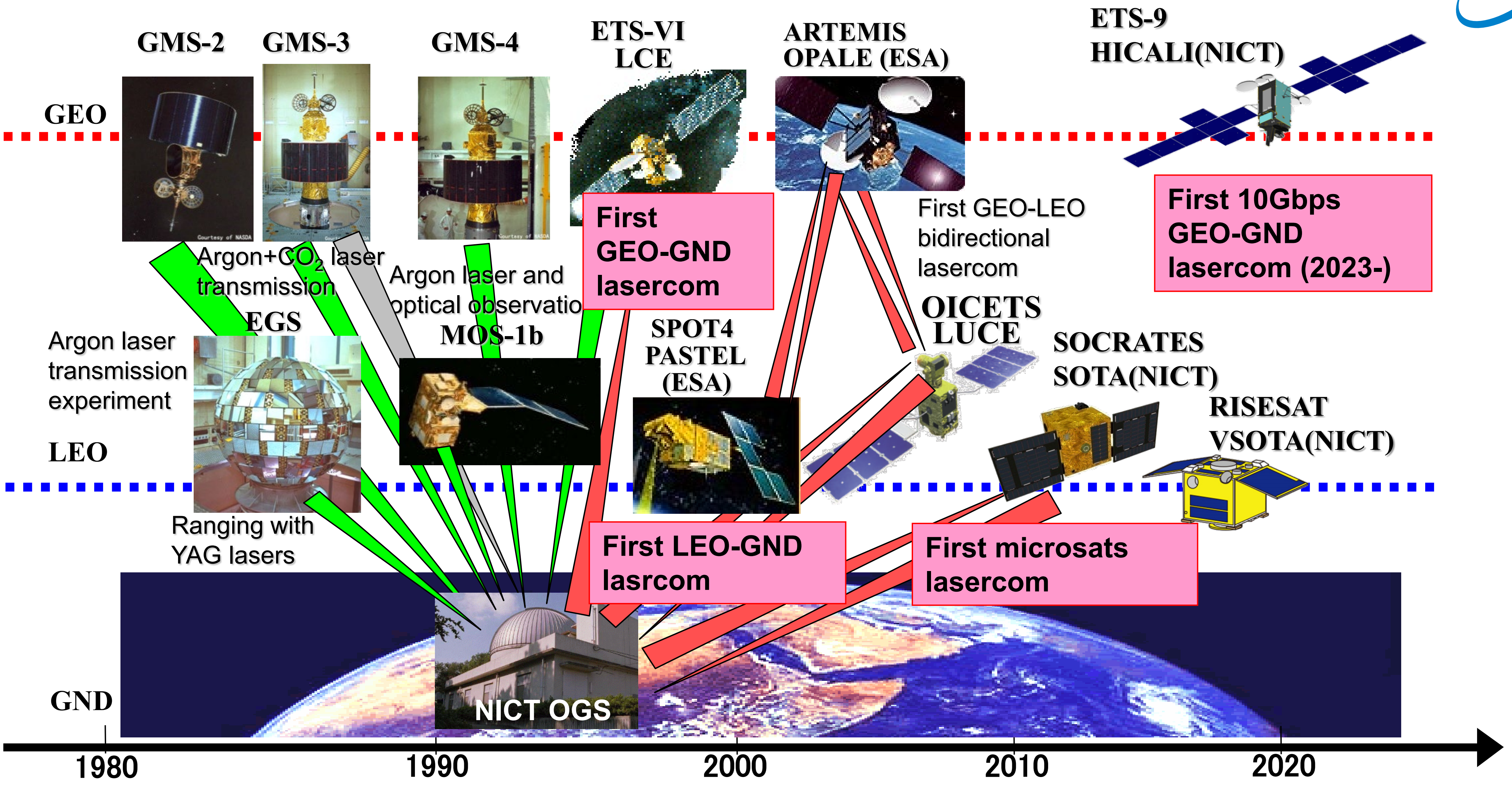
LPI/LPD

No regulation

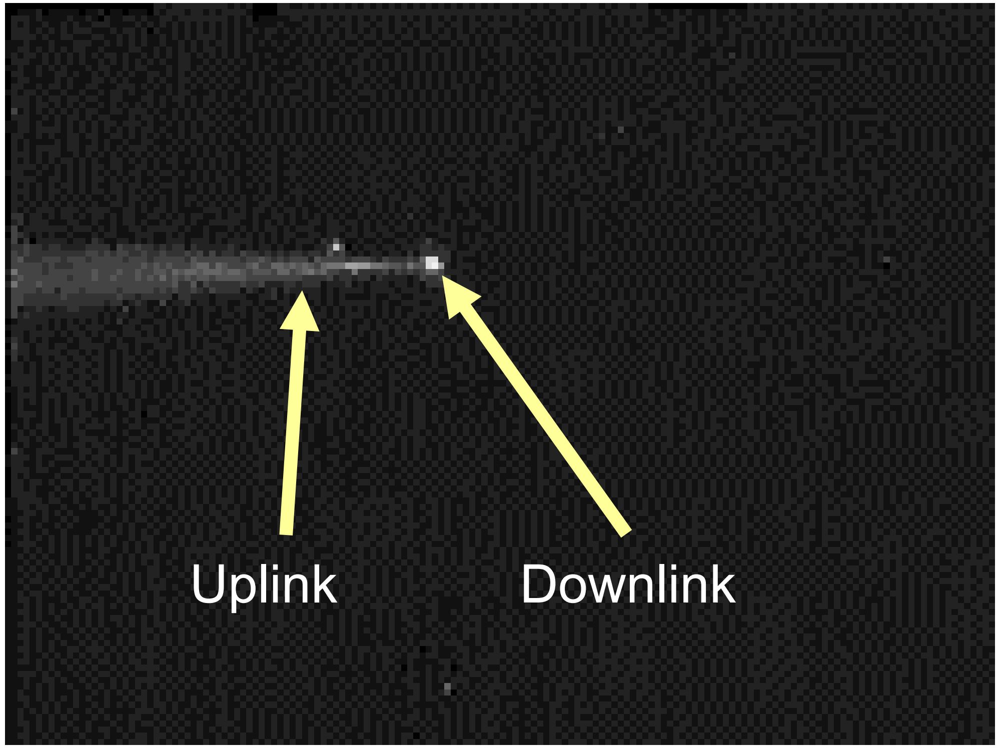
Quantum key distribution



R&Ds on Space Laser Communications in NICT

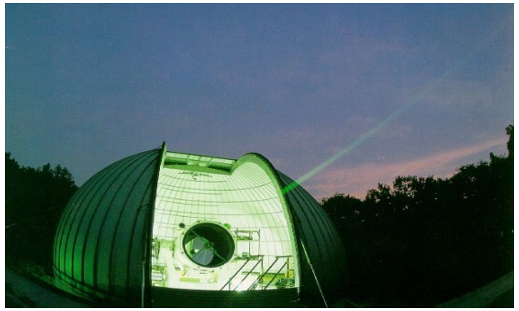


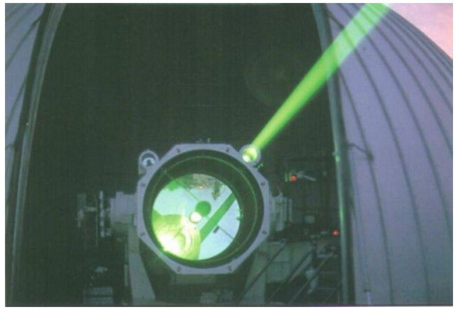
Engineering Test Satellite VI (ETS-VI)
Laser Communication Experiments (Dec. 1994 - July 1996)



Laser Communication Equipment (LCE)

ETS-VI (GEO)





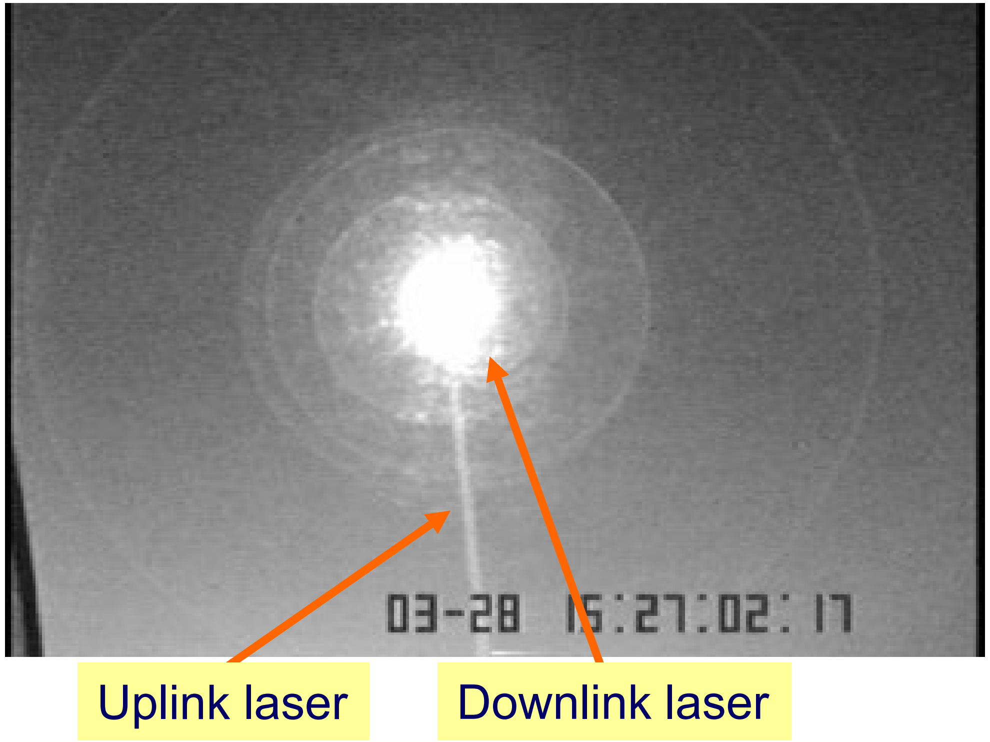
NICT optical ground station

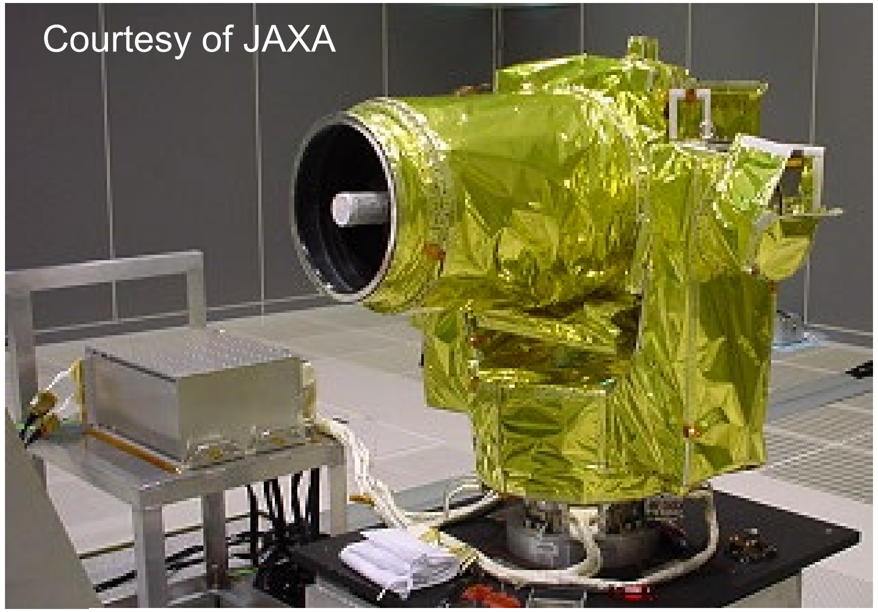
- 1 Mbps bi-directional optical link experiment
- Modulation: OOK
- Mass: 22 kg
- Power: 60 W

Laser communications experiment using OICETS

(Mar. 2006 – Sep. 2009) (OICETS: Optical Inter-orbit Communications Engineering Test Satellite)

NICT optical ground station **OICETS (LEO)**

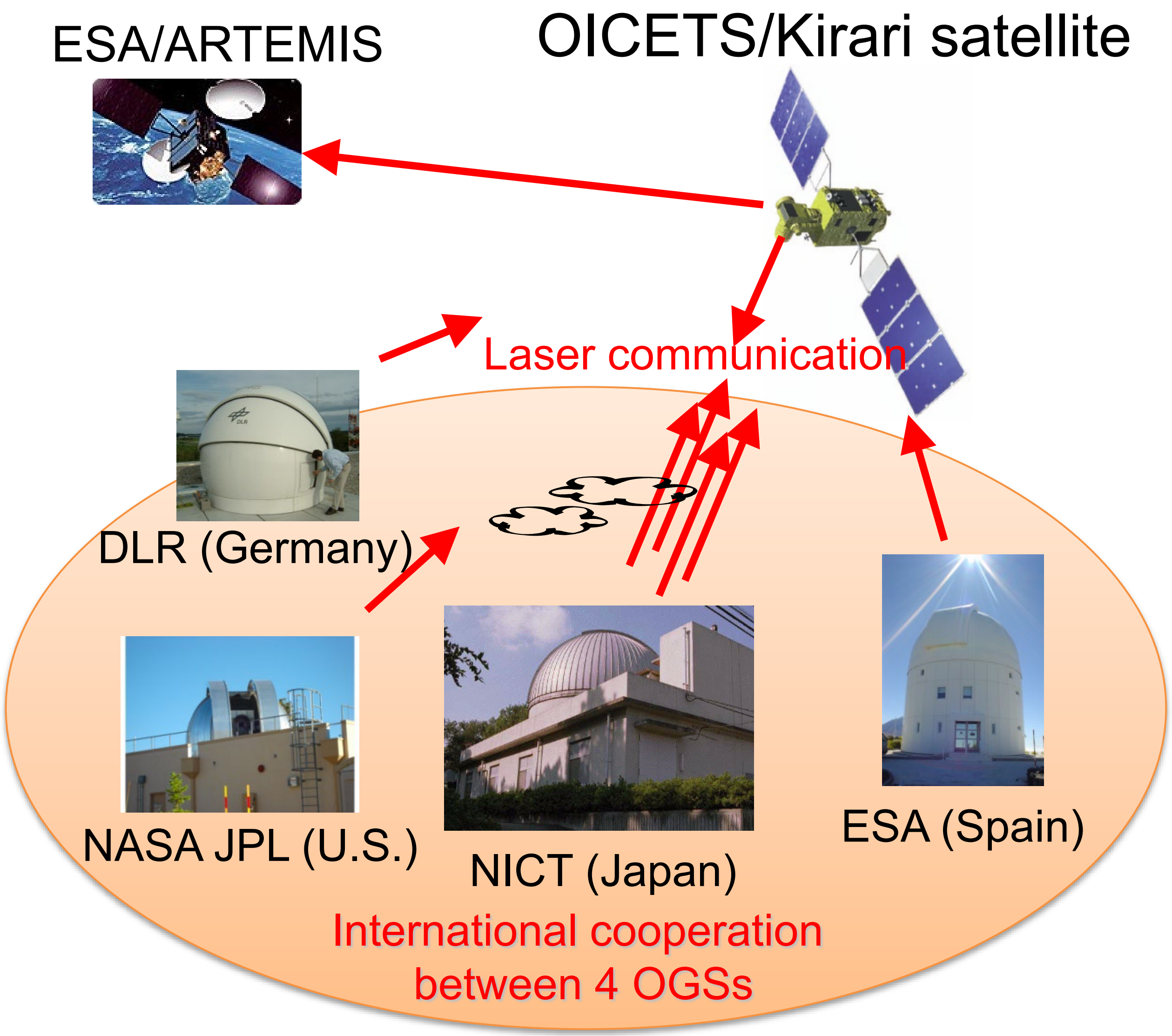


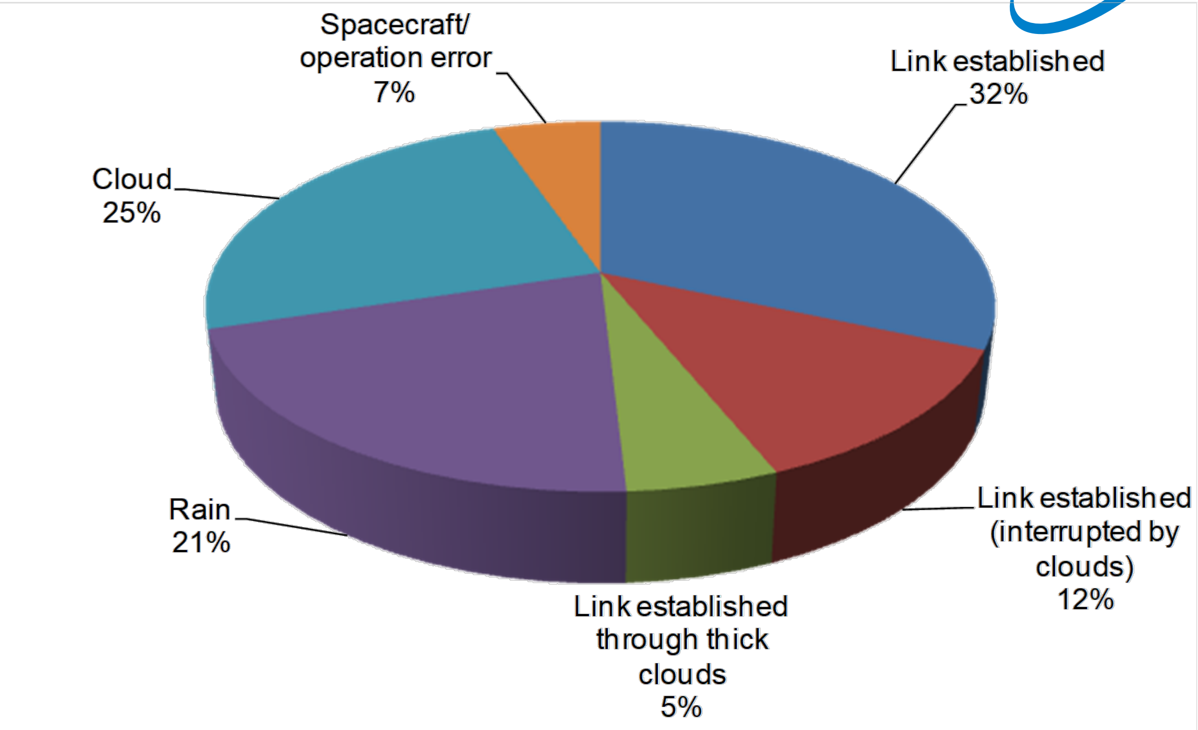


Laser Utilizing Communication Equipment (LUCE)

- Data rate (down/up): 50/2 Mbps
- Modulation: OOK
- Format: NRZ/2PPM
- Wavelength: 0.8 μm
- Mass: 150 kg
- Power: 220 W

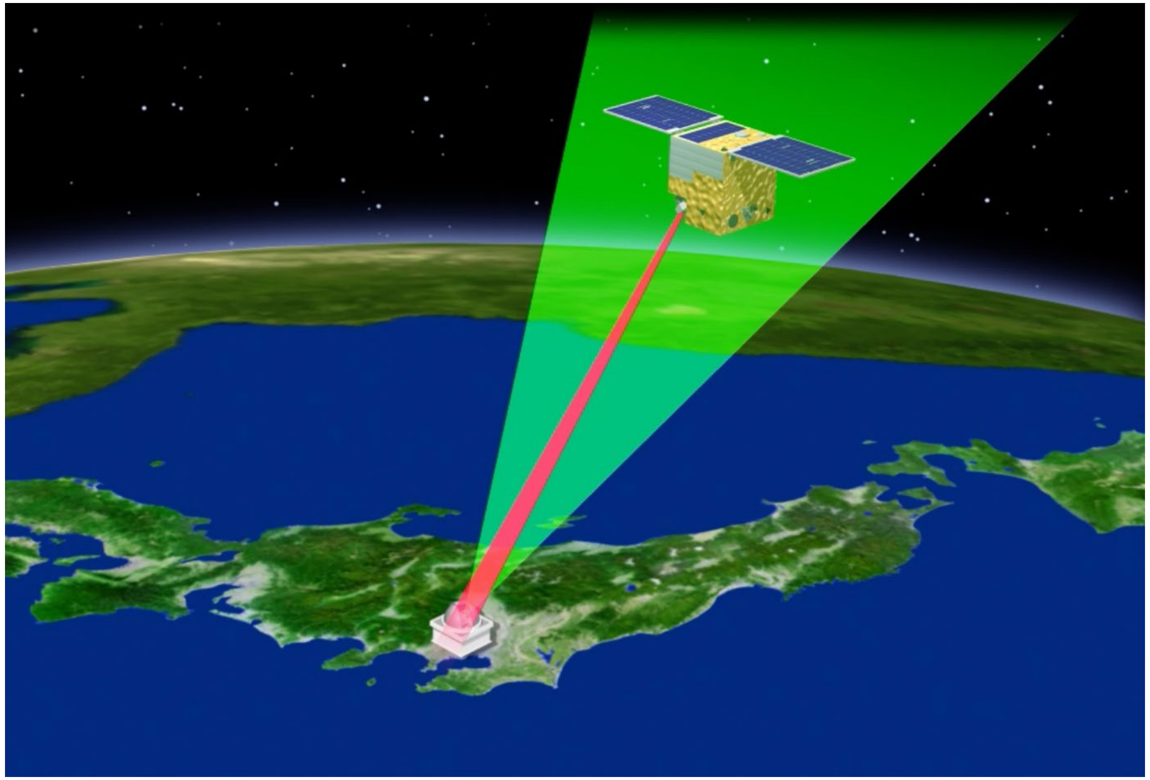
International site diversity experiments

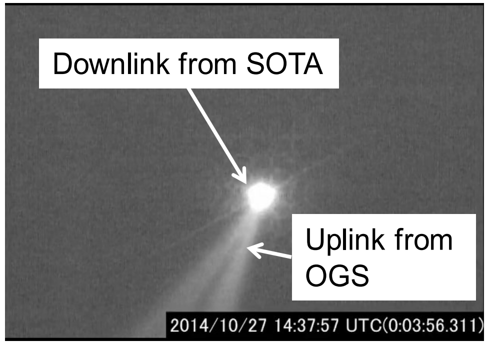


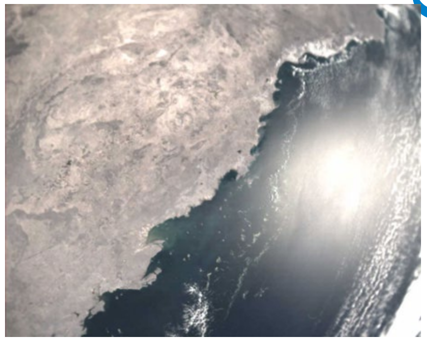


- **Probability of success during all the experiments**
  - **NICT: 49.1 %**
  - **NASA JPL: 57.1 %**
  - **DLR: 60.0 %**
  - **ESA: 88.9 %**
- **Total probability of success:**
  - **1-[(1-0.491)x(1-0.571)x(1-0.60)x(1-0.889)] = 0.9903**

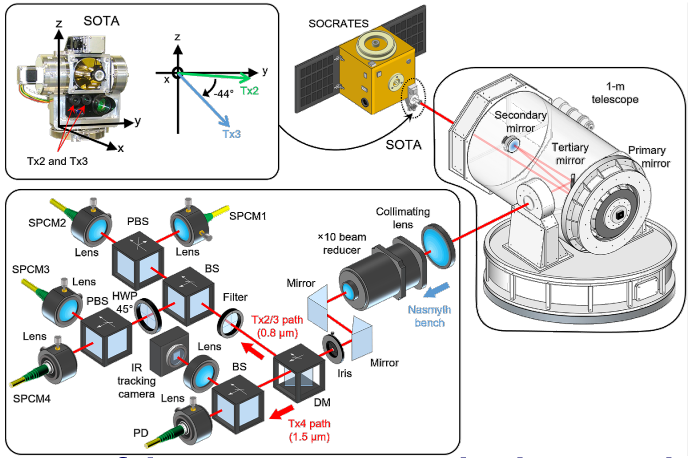
Space Optical Communications Research Advanced TEchnology Satellite (SOCRATES)/Small Optical TrAnsponder (SOTA)
(July, 2014-Nov., 2016)





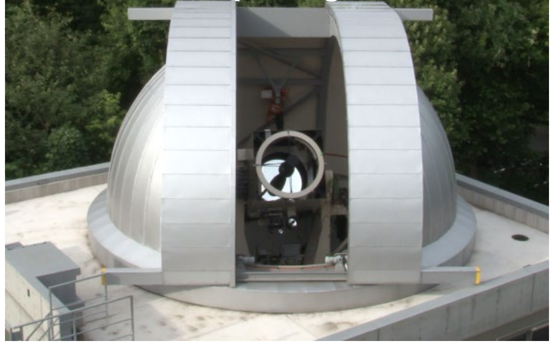


Onboard camera image via laser communication links

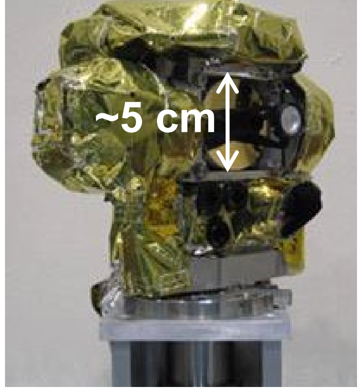


Successful quantum communication experiments

Nature Photonics 11, 502–508 (2017)


Overview of optical ground station

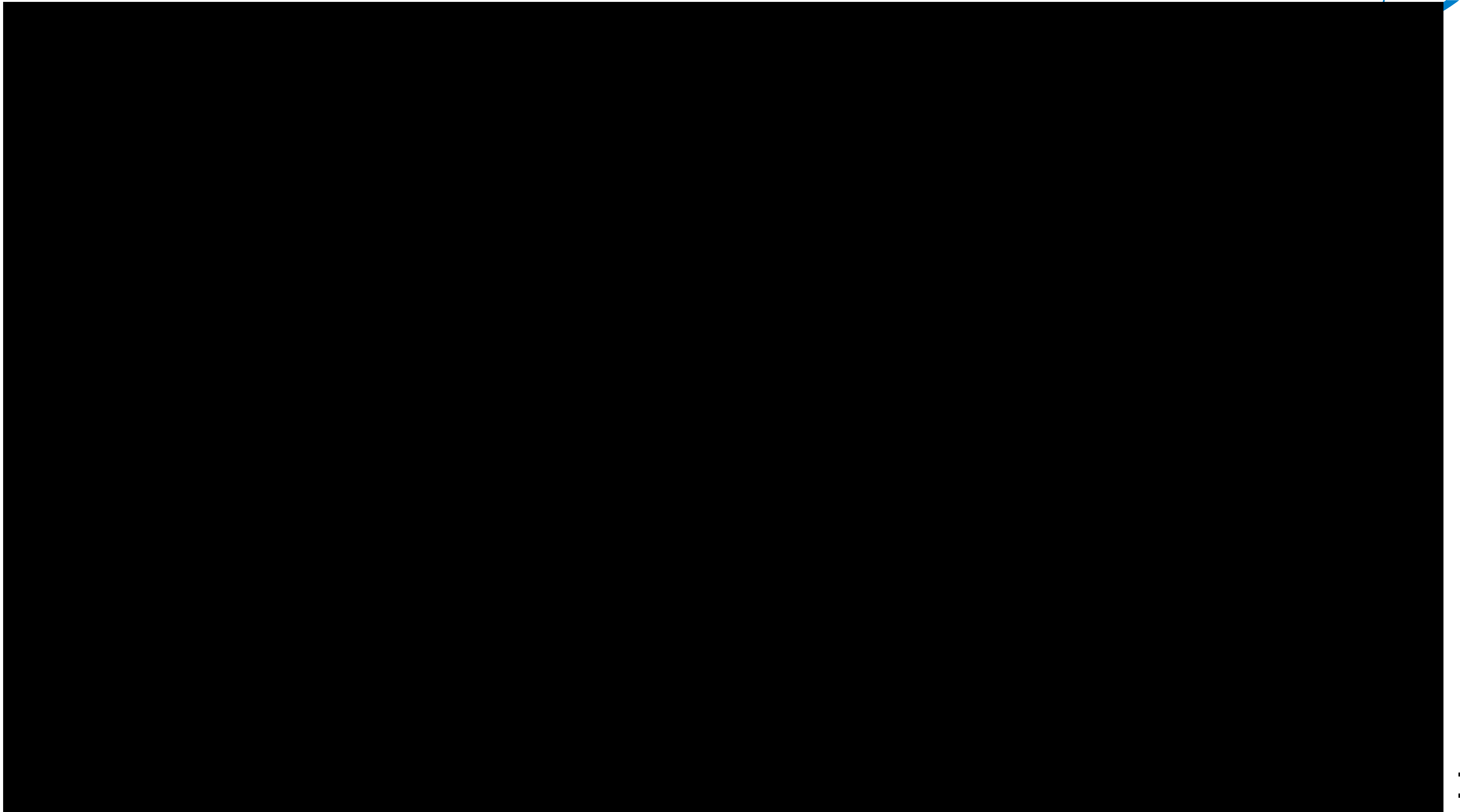
Optical part



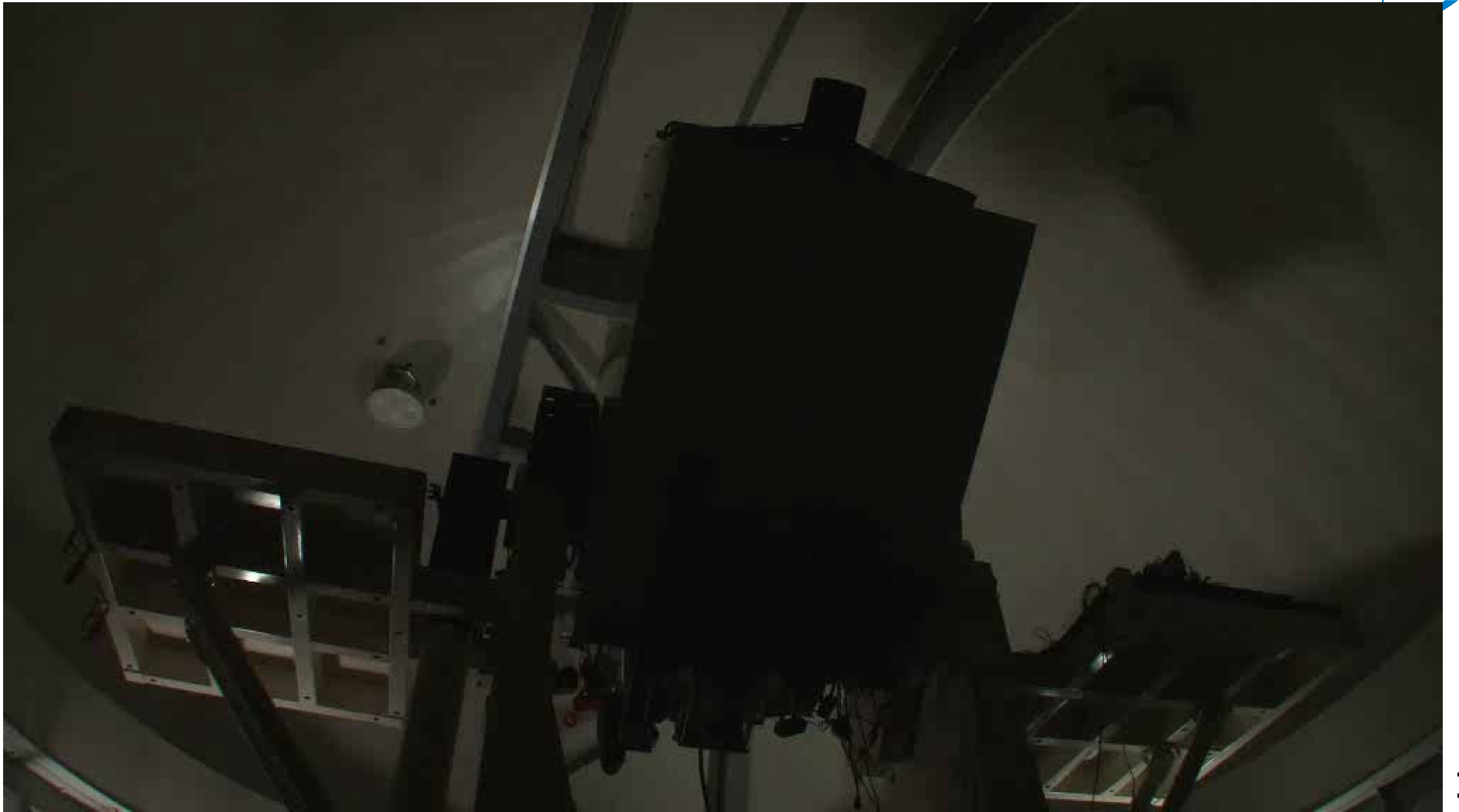
Electrical part

- Data rate: 10 Mbps
- Wavelength: 1.55 μm
- Modulation format: IMDD
- Mass: 5.9 kg
- Power: 15.7 W

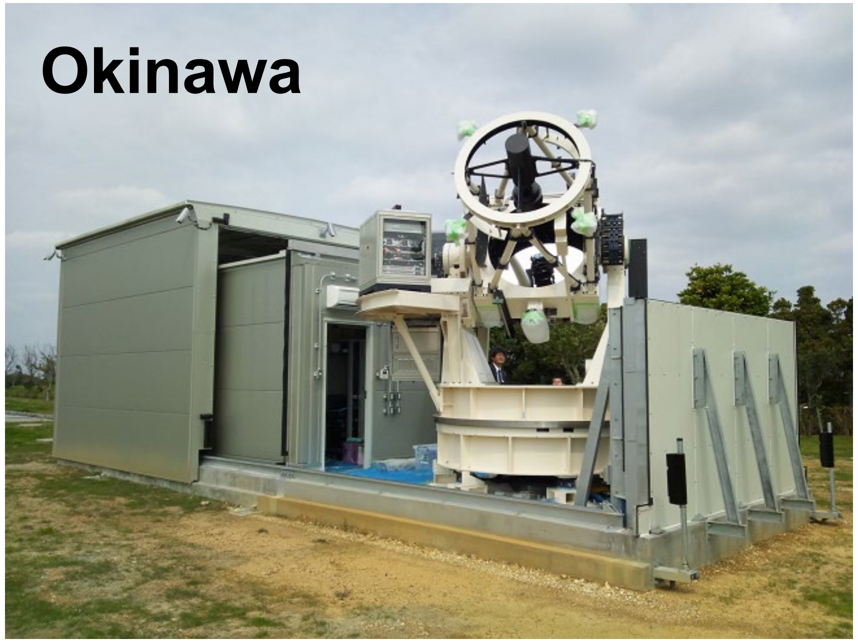
Scenario for SOCRATES/SOTA

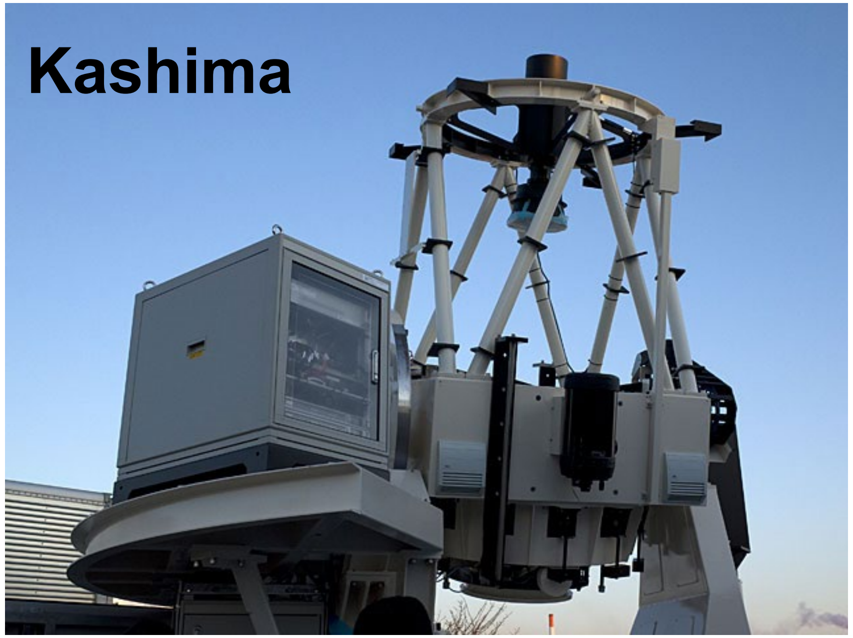


Laser communication experiments with a 50 kg-microsat



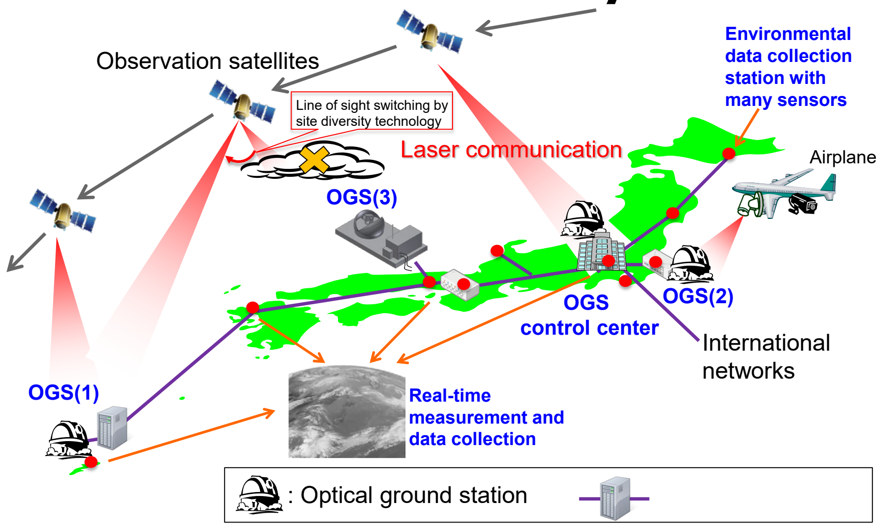
Optical ground stations (1-m diameter)

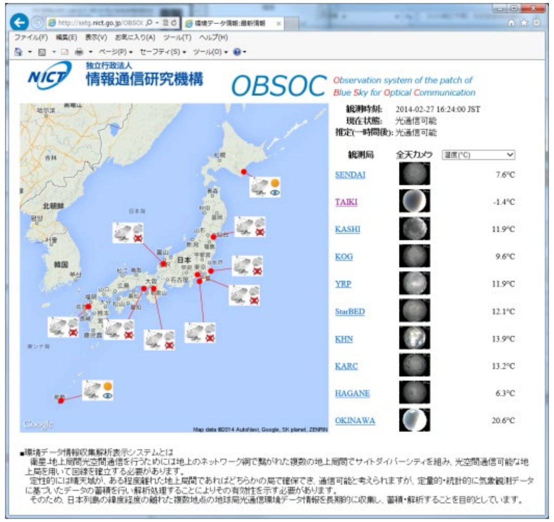




Site diversity study in Japan

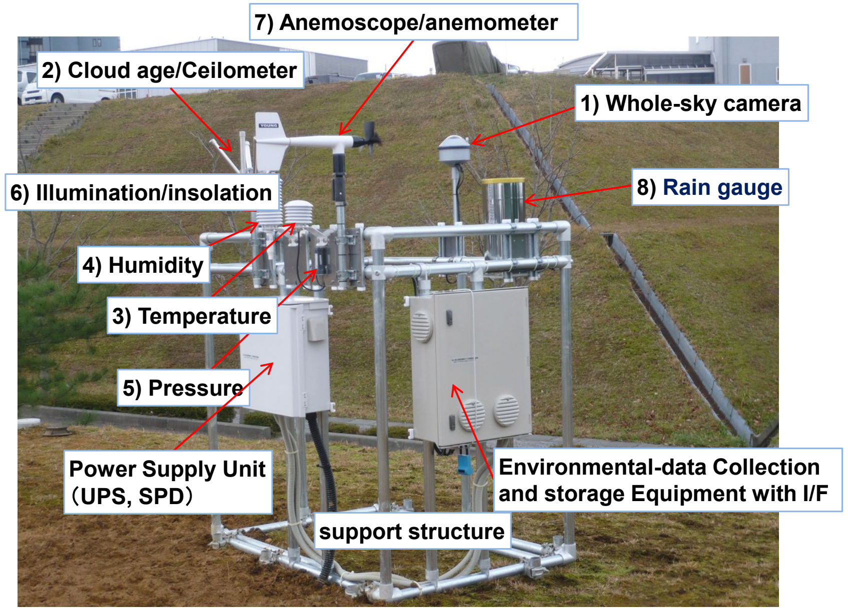
Data collection system



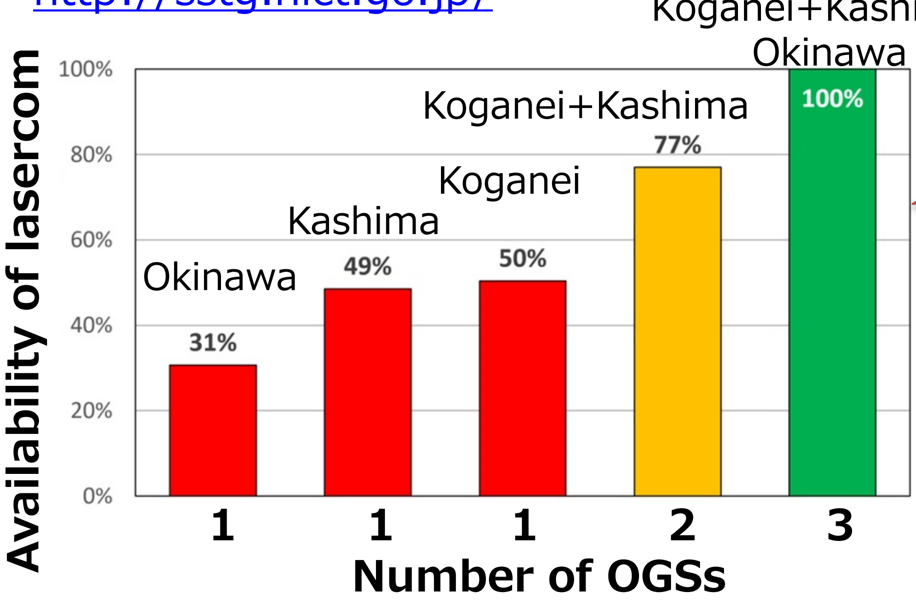


Realtime data available:
http://sstg.nict.go.jp/

Visible pass analysis



Sensor station

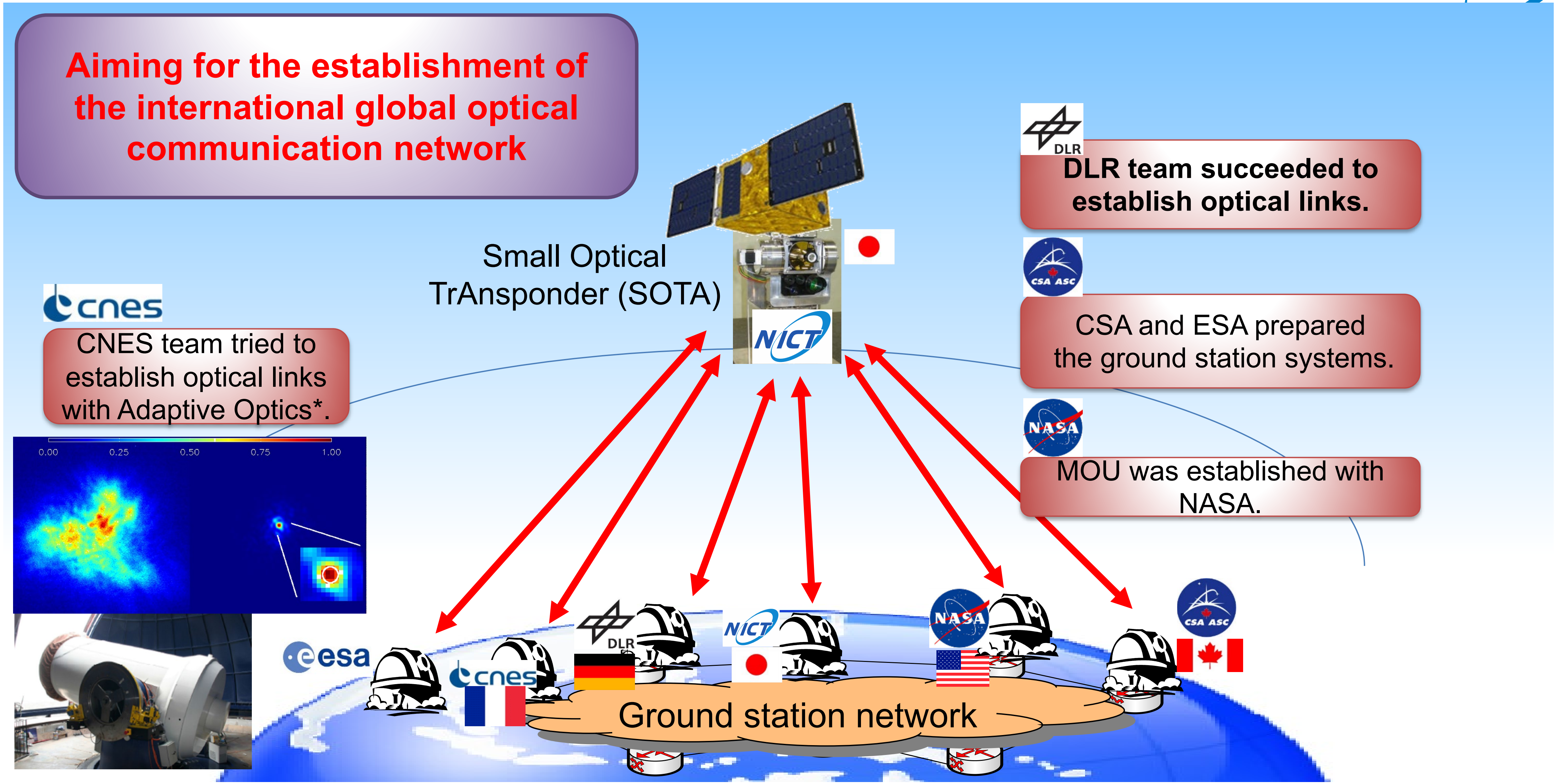


Contribution to Standards
(Consultative Committee for Space Data System (CCSDS))

Even if it was the rainy season in 2016, the availability was ~100 % between the Earth and the space!

Site-diversity effect (June 5-July 18, 2016)

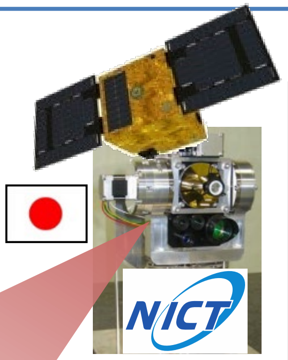
International experiment campaign with SOTA



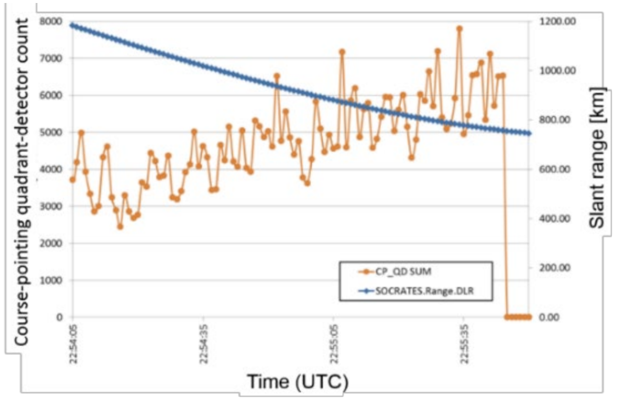
*Cyril Petit, et. al., Optical Engineering, 55(11), 111611 (2016)

Successful experiment between SOTA payload (NICT) and optical ground station at DLR

- To demonstrate a global lasercom network for future site-diversity implementations
- To enhance the understanding of atmospheric propagation at different sites
- To attract attention to satellite lasercom technology
- Successful experiment in May, 2016

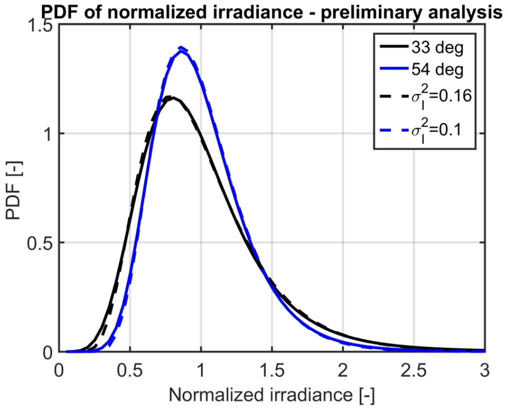


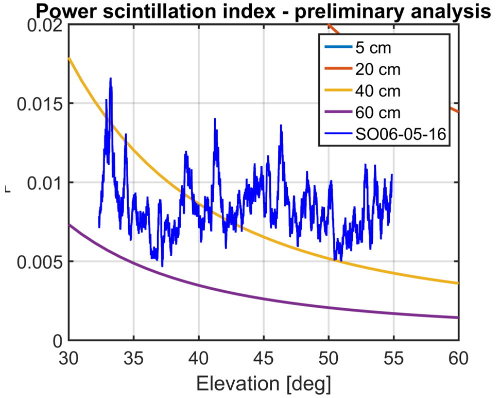
SOTA



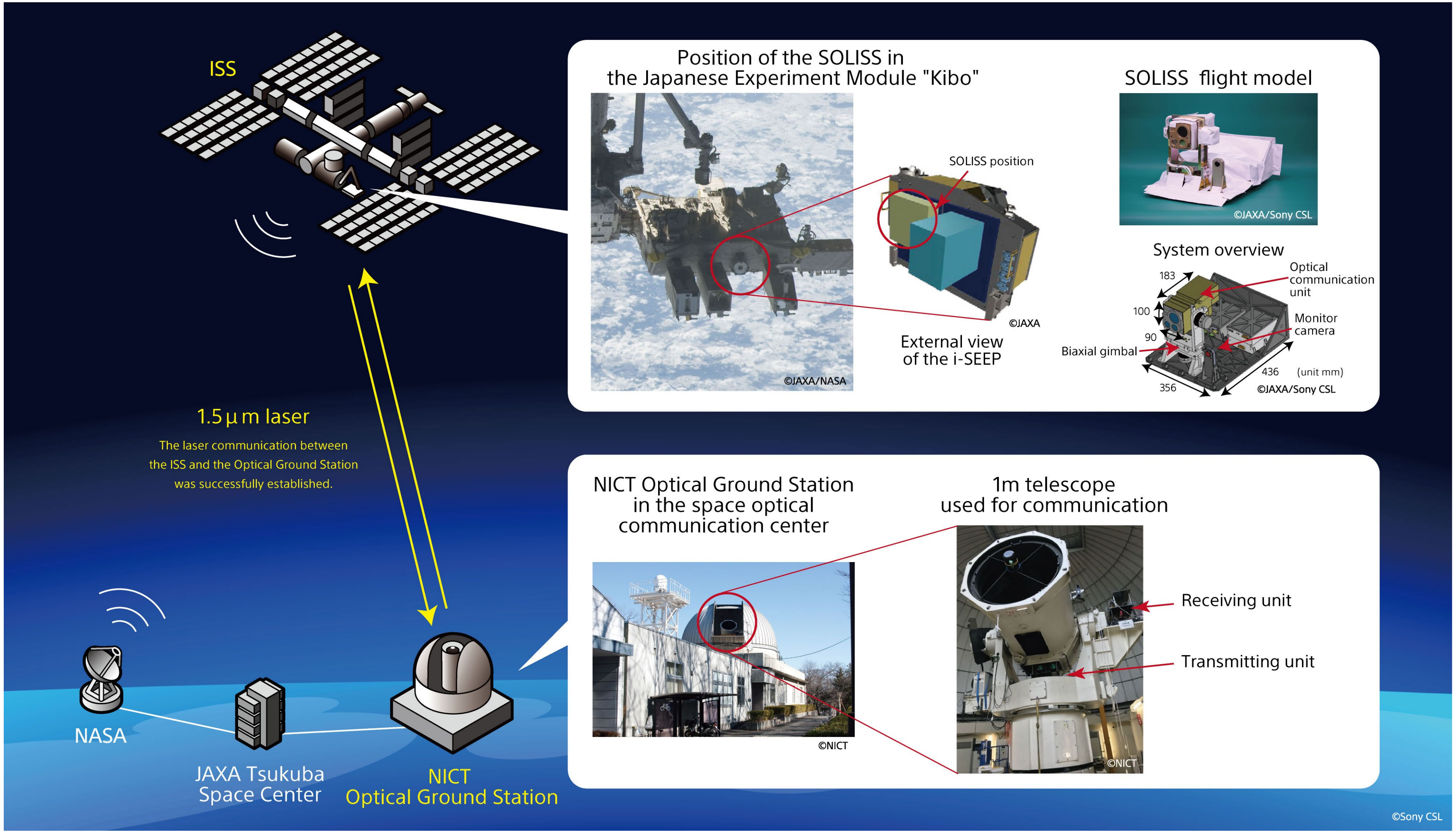
- DLR side collected data from several satellite missions
- NICT collected data between SOTA and different ground stations
- DLR/NICT joint standardization efforts for fading vector generators and FEC codes

Oberpfaffenhofen





Small Optical Link for International Space Station (SOLISS) (April 23, 2020)



SOLISS Succeeds in Bidirectional Laser Communication Between Space and Ground Station

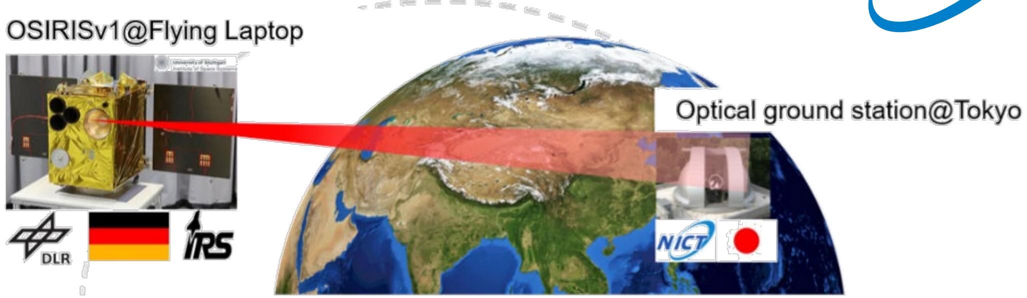
https://www.sonycsl.co.jp/press/prs20200423/

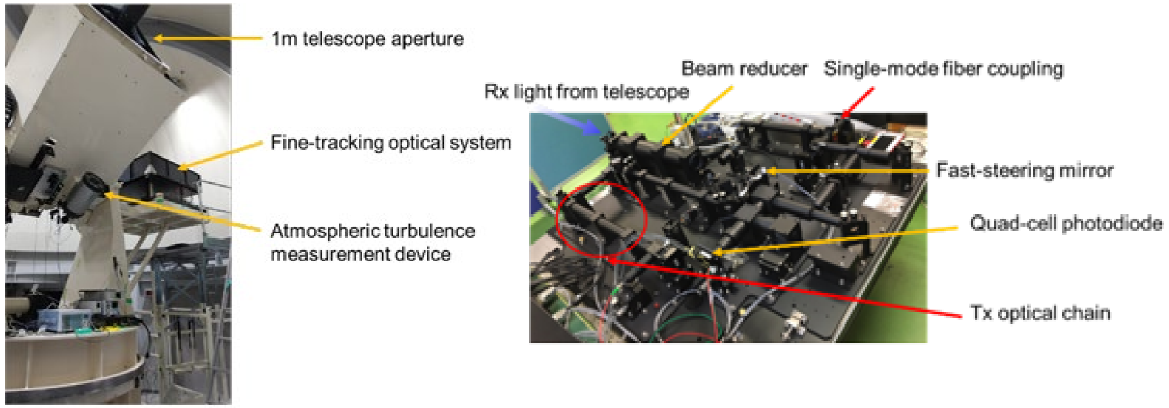
Joint experiments between OSIRISv1 payloads (DLR) and NICT-prepared optical ground station

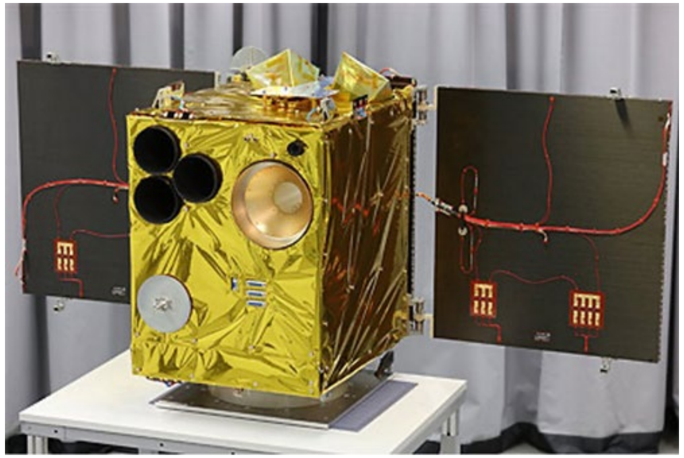
Press released on March 25, 2021

Successful International Joint Experiment Between Japan and Germany in the Field of Space Optical Communication Using a Small Satellite

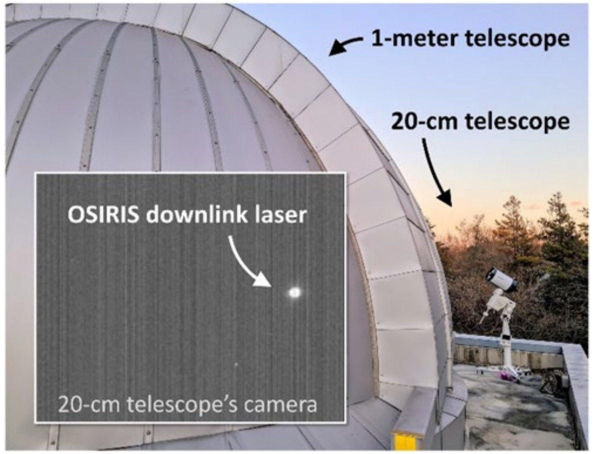
- Successful experiment to receive downlink light at NICT optical ground station from DLR optical terminal mounted on Univ. of Stuttgart's Flying Laptop satellite
- Succeeded in the initial experiment of the newly developed atmospheric turbulence measuring device and simple optical ground station for future optical ground station technology enhancement
- Acquired valuable data to contribute to the research and development of future space optical communication technology







OSIRISv1 Flying Laptop
(Univ. of Stuttgart/DLR)

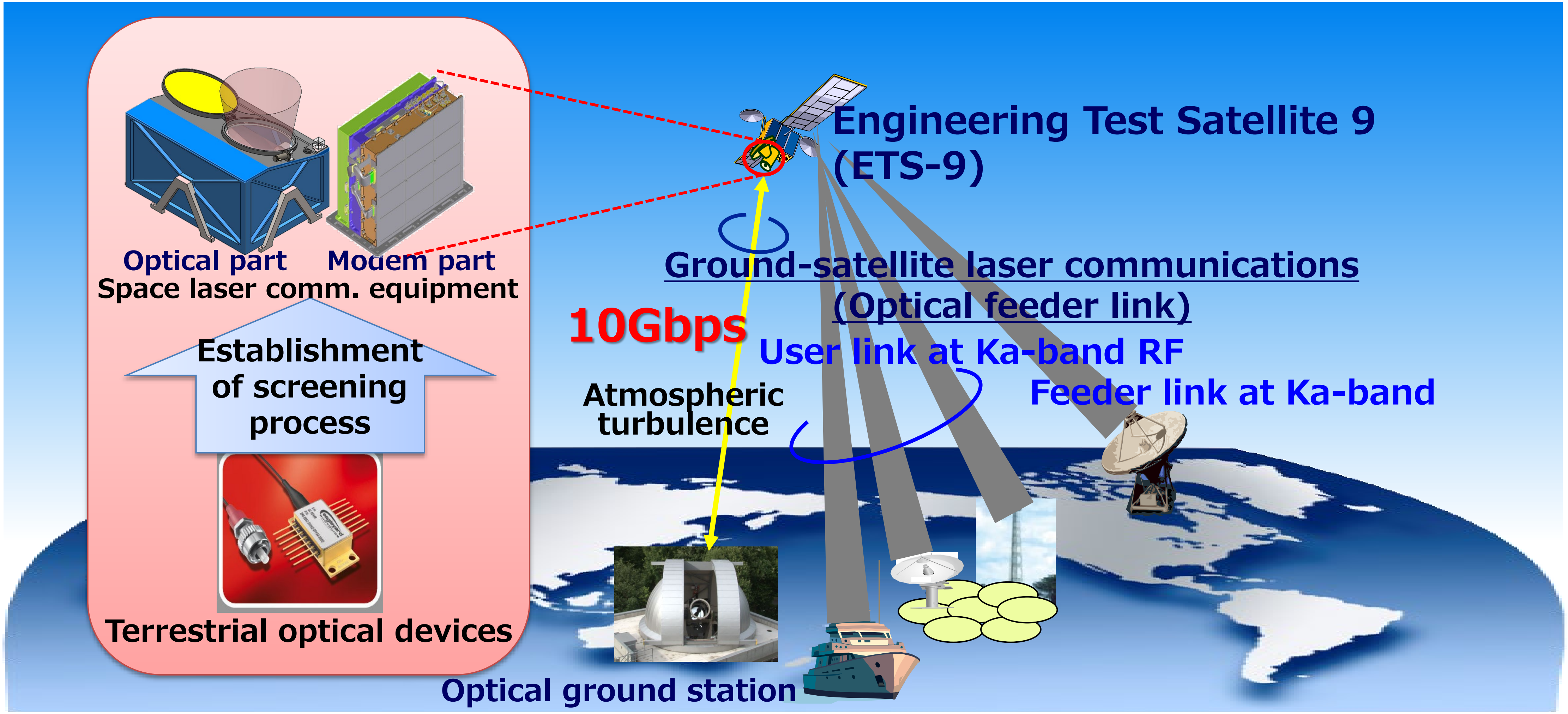


Optical ground station
(NICT)

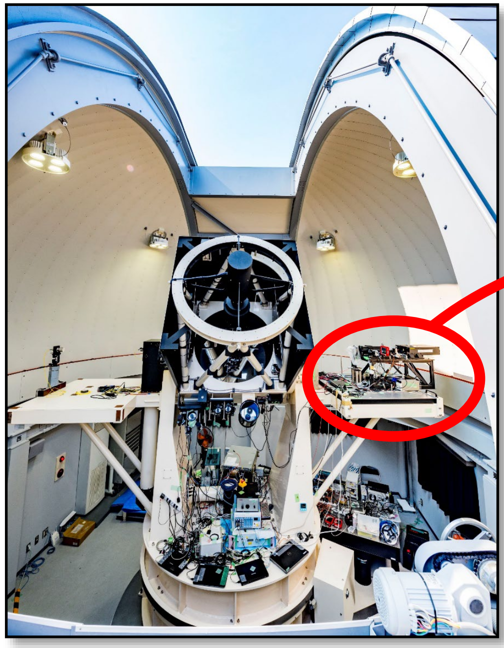
Research and development for optical feeder links ~10-Gbps laser communication terminal (HICALI)~

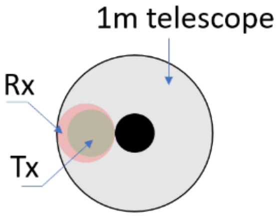
HICALI: **HI**gh speed **C**ommunication with **A**dvanced **L**aser **I**nstrument

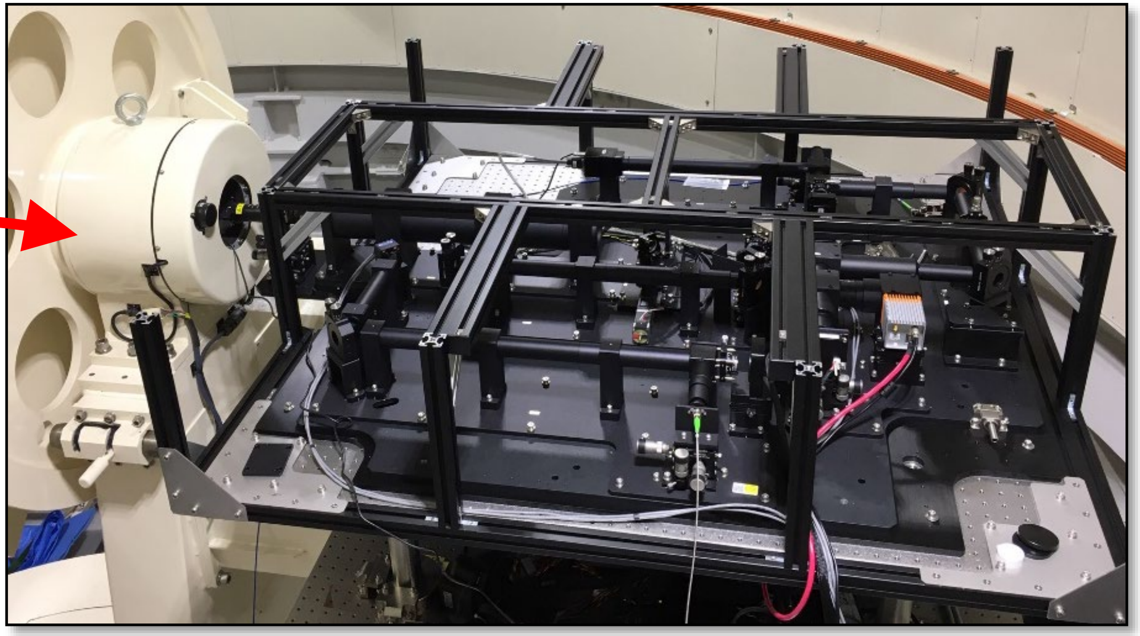
NICT conducts the R&D for 10-Gbps ground-to-GEO laser communication technology and aims for the in-orbit verification of the basic optical feeder link technology onboard the Engineering Test Satellite 9 (ETS-9). Advanced major optical communication devices are evaluated through the screening process to ensure the space environmental tolerance and reliability.



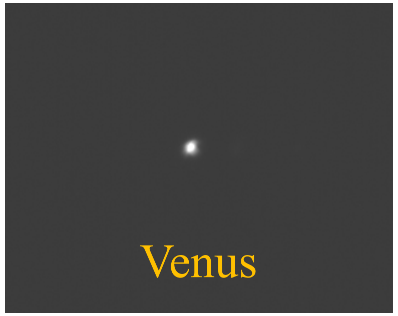
Tracking performance of Optical Ground Station

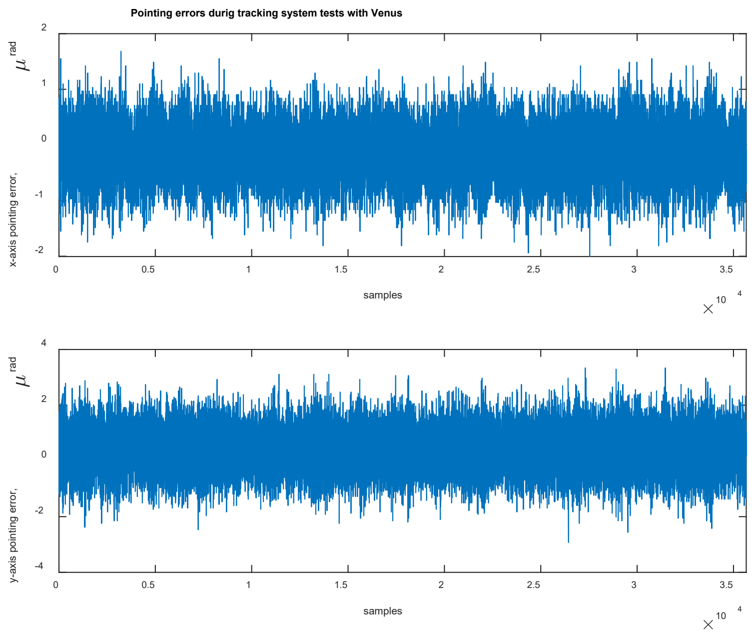


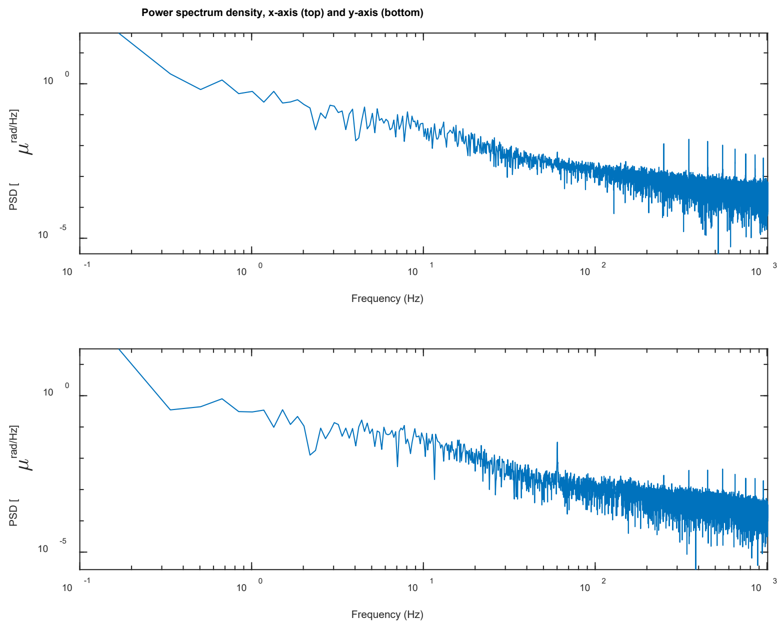




- Optical bench
- 40-cm receiver aperture, tracking function
- Atmospheric turbulence measurement (DIMM)

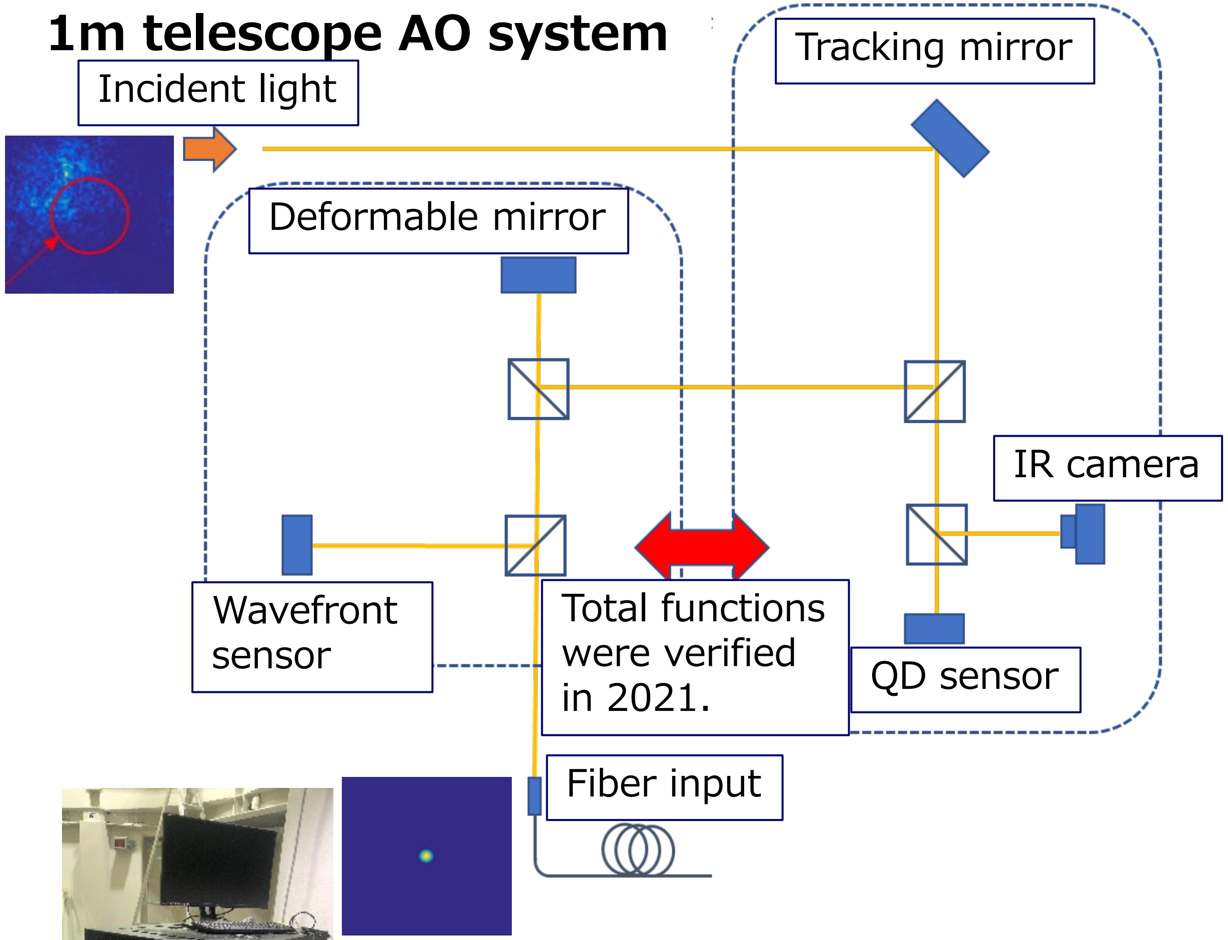


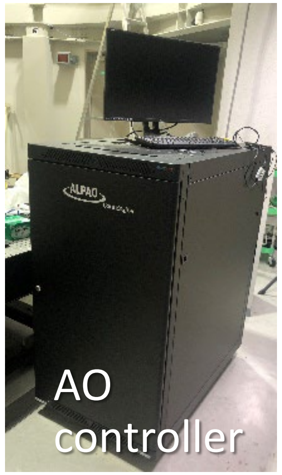




Adaptive Optics (AO) and performance evaluation

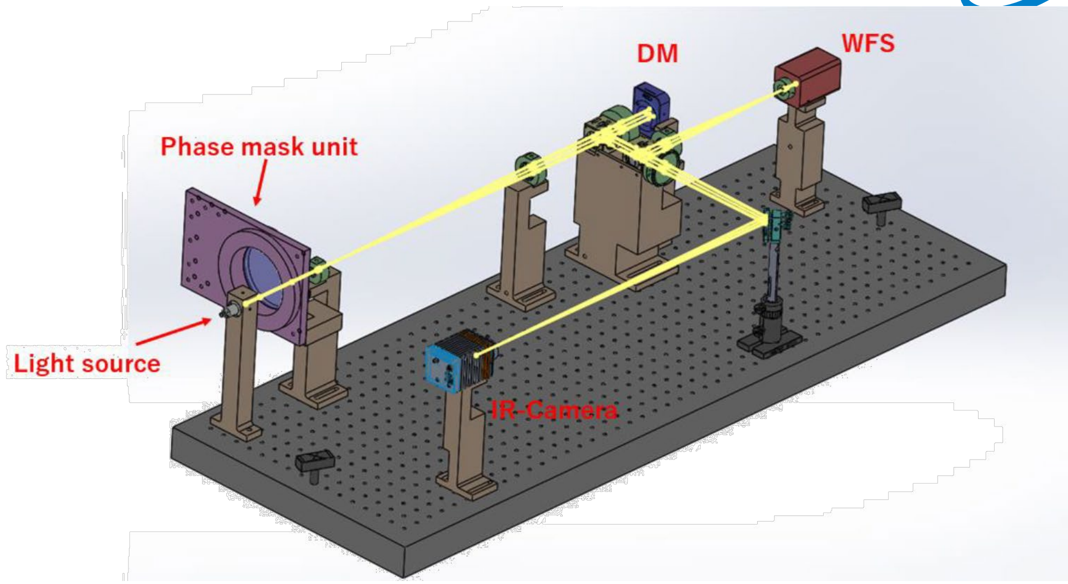
1m telescope AO system



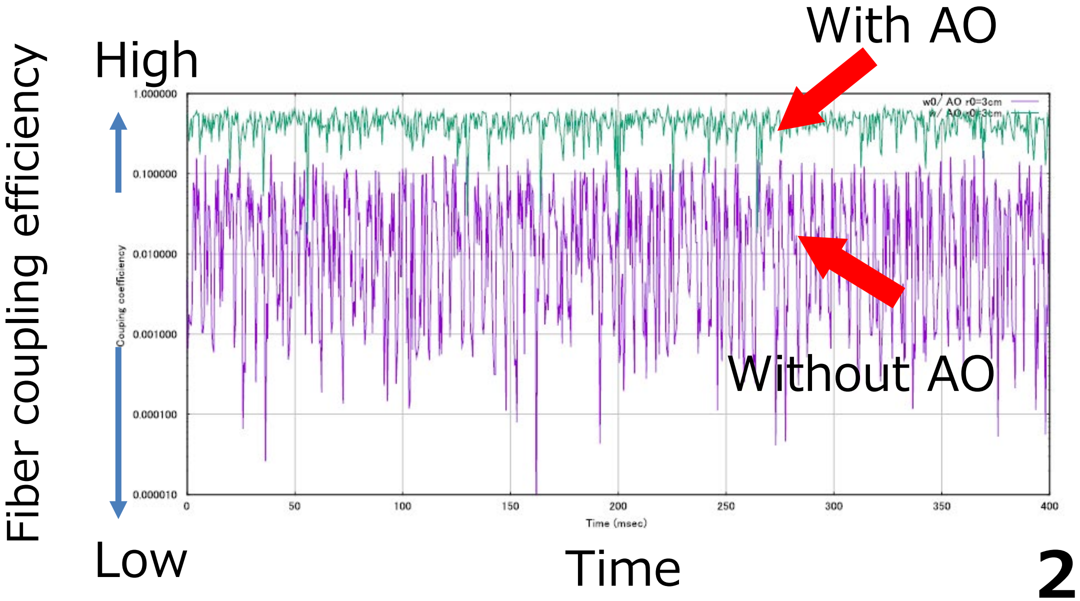


Evaluated result (right figure)

- ☐ Fried parameter: 3 cm
- ☐ Wind velocity: 20 m/s
- ☐ Fiber coupling with AO: ~x 100
- ☐ Average improvement: ~x 3



Evaluation system using a light source



Broadband satellite communication trends

Satellite development trends and capacity prospects

Conventional GEO satellites

Cost base = ~$350/Mbps/Month
(Capex* & effective lifetime included)
*Capex: Capital expenditure

GEO HTS*

Cost base < $40/Mbps/Month
*HTS: High Throughput Satellite

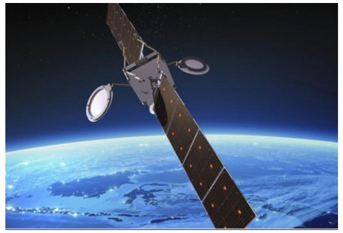
GEO VHTS

Konnect VHTS - EUR
Jupiter 3 - USA
Viasat 3 - Global

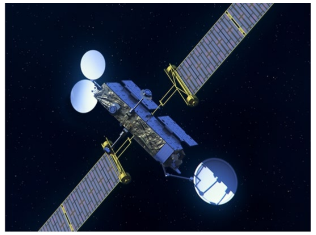
Cost base = ~$5/Mbps/Month

GEO Small Flex HTS
(3 t-class, 100-200 Gbps)

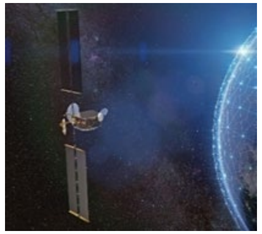
Including 3 technologies:
- Phased array antenna
- Beam hopping
- Mitigation of interference & multiple access



©Boeing
Boeing 702X



©Thales Alenia Space
TAS Space Inspire



©Airbus
Airbus OneSat

©JAXA
Melco ETS-9
(Hybrid HTS)

Low latency

Non-GEO Constellation

O3b(SES), Telesat LEO
SpaceX Starlink
Amazon Kuiper

Cost base = ~$5/Mbps/Month

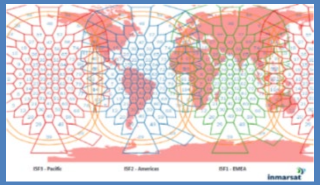
- Total capacity: from 2.9 Tbps (2019) to 26.5 Tbps (2026)
- It depends on HTS GEO (Viasat-3: 1 Tbps, Konnect VHTS: 500 Gbps) and NGSO constellation (O3b, Telesat LEO, and Starlink).
- These might cause the excess supply in capacity and the competition.

Trends on High Throughput Satellite (HTS)

- **Space laser communications is attractive all over the world.**
- **Satcom is aiming for high capacity with lower cost/bit. (Ku -> Ka band)**
- **Needs for airborne and ocean usages are increasing.**
- **High speed/large capacity HTS satcom needs tens of Gbps, which can not be transmitted via RF wireless communications.**

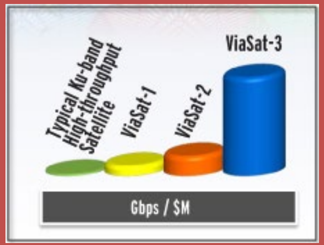
Current

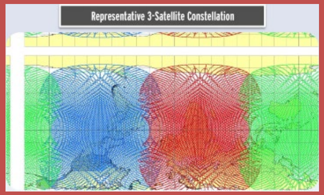
Inmarsat-5
Ka,80-100 beams
Capacity: ~10Gbps



2023~

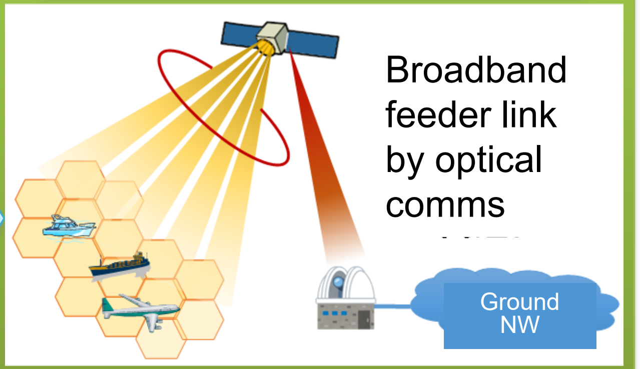
Viasat-3
Ka,1000 beams
Capacity: ~1Tbps



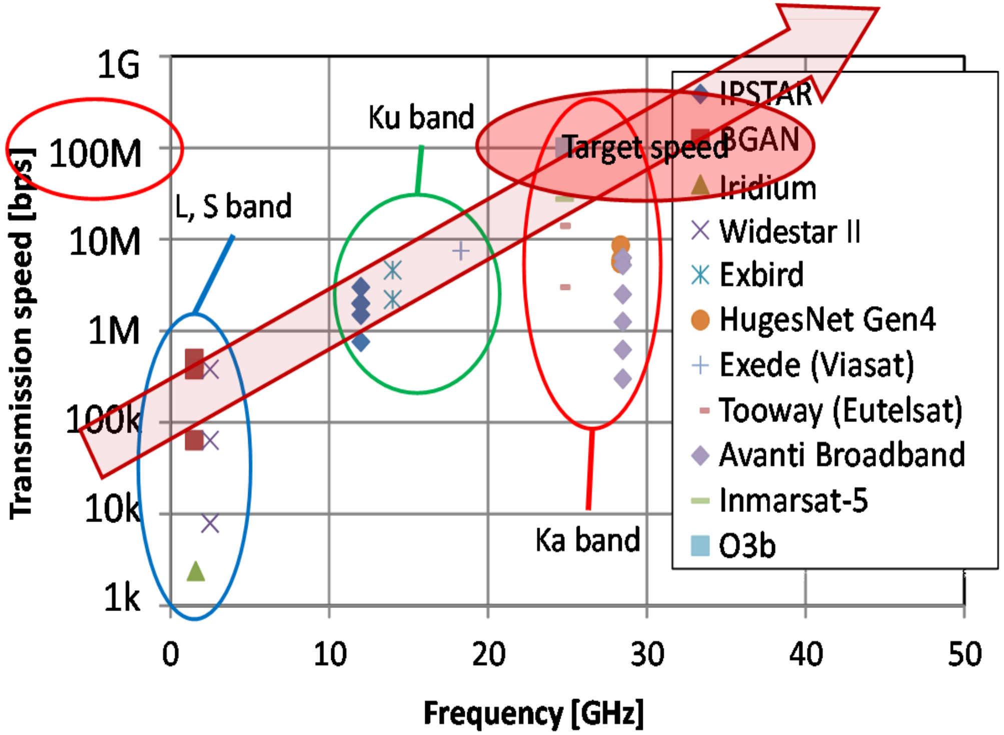


~2030

Hybrid HTS
Ka + optical feeder link

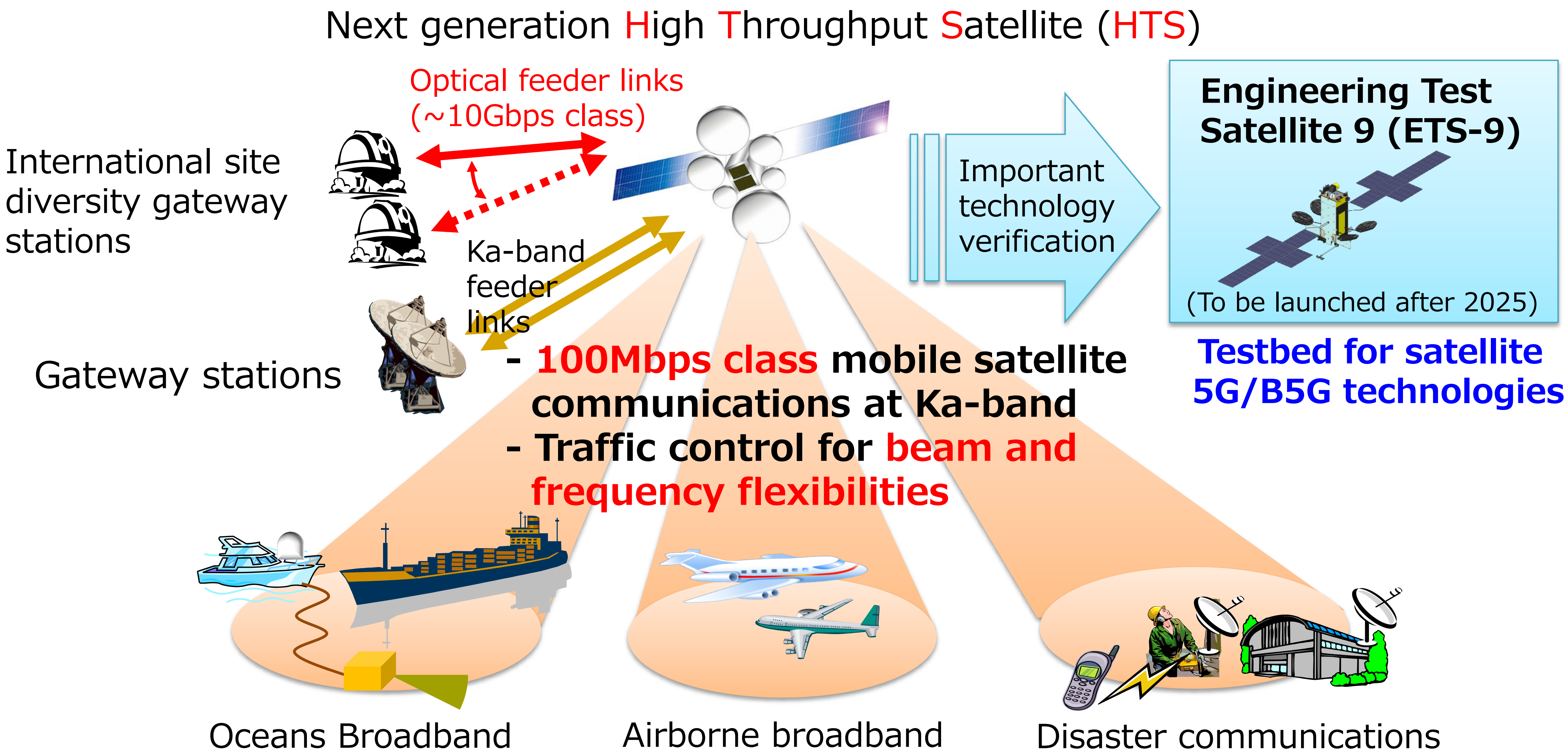


- Worldwide satellite operators are interested in the optical feeder link.
- Acquisition of the competitive technology can be possible in the future HTS field.

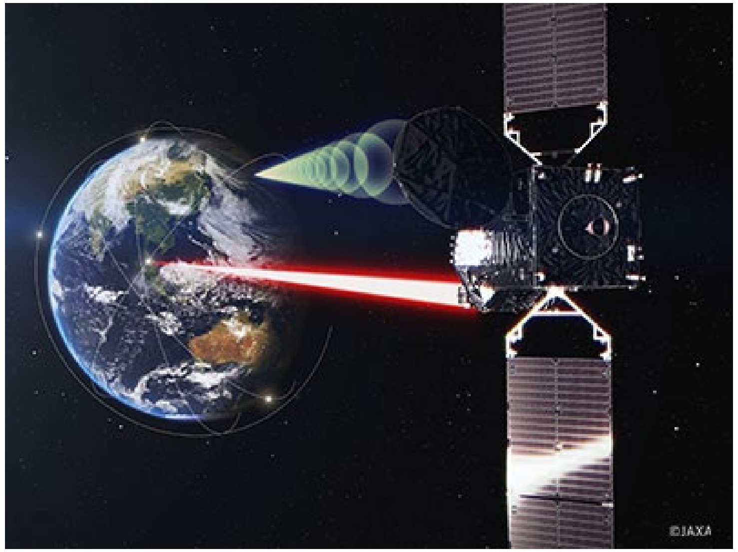


Reference: from each website

Next-generation hybrid HTS communication system



Laser Utilizing Communication System (LUCAS)/ Japan Aerospace eXploration Agency (JAXA) (2020~)



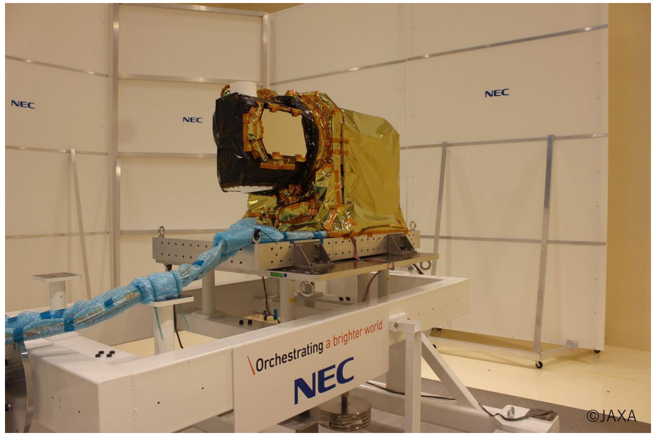
Launched on Nov. 29, 2020

- Laser Utilizing Communication System (LUCAS) onboard the GEO optical data relay satellite
- High speed data transmission between Earth observation LEO satellites and GEO
- Checkout conducted from Jan. 27 to Feb. 20, 2021

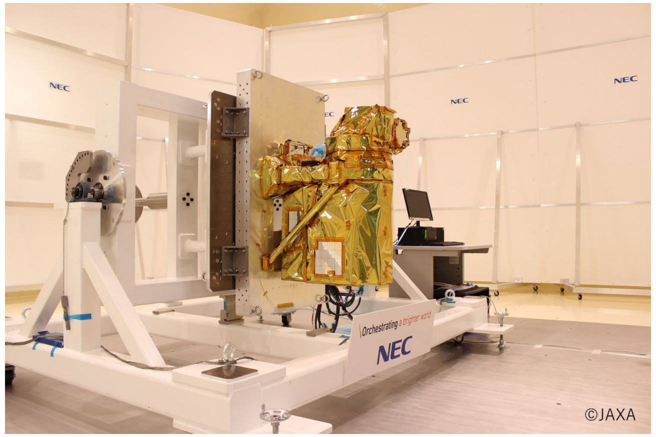
GEO Optical data relay satellite

Okinawa NICT OGS

- Checkout
- Periodic calibration
- Atmospheric turbulence measurements



GEO Laser Terminal

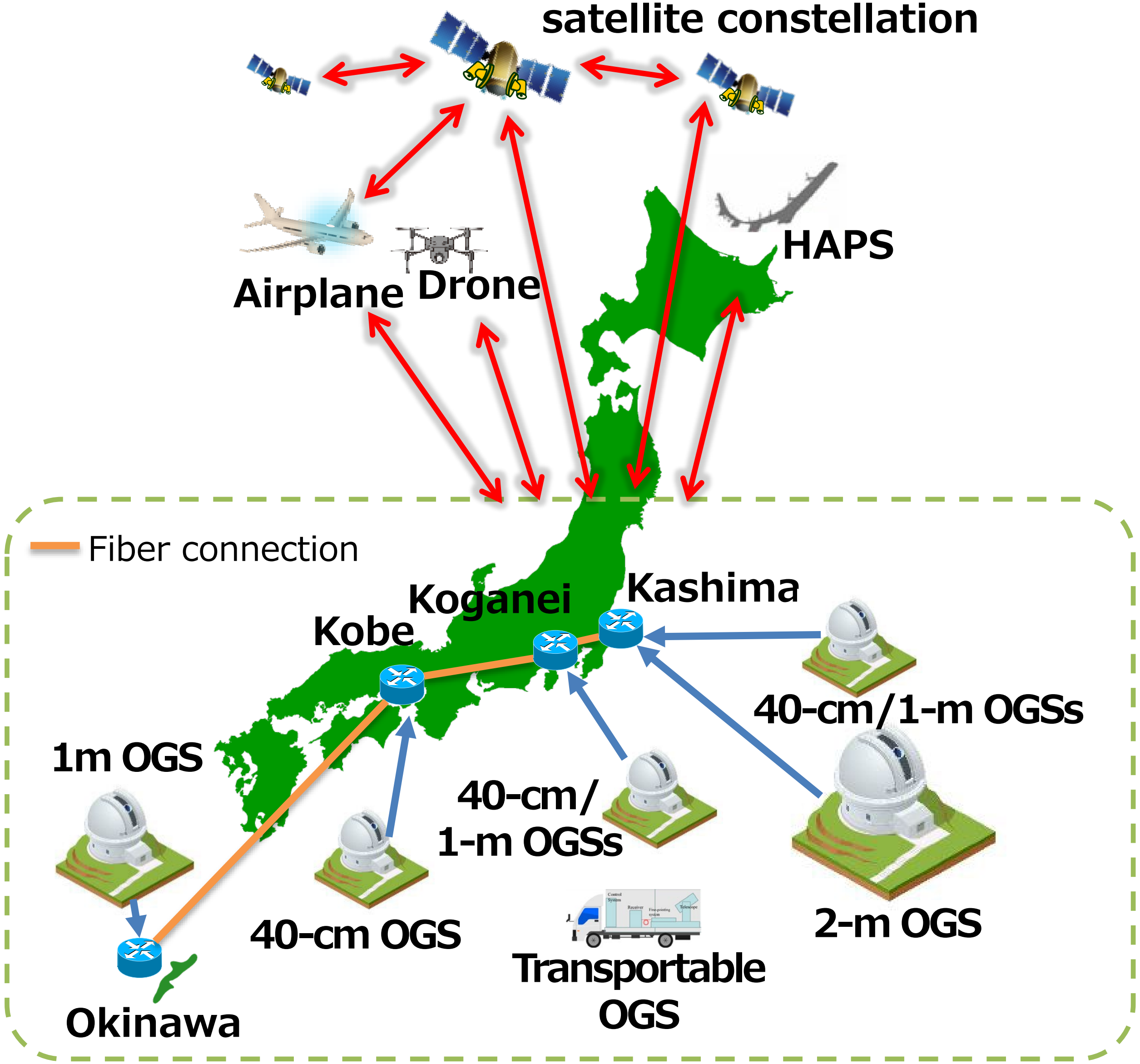


LEO Laser Terminal

- Data rate:
  Return: 1.8Gbps
  Forward: 50Mbps
- Wavelength: 1.55μm
- Modulation:
  Return: RZ-DPSK-DD
  Forward: IM-DD

Laser Utilizing Communication System (LUCAS)
http://www.satnavi.jaxa.jp/project/lucas/

Development of Optical Ground Station Testbed



NICT's Optical Ground Station (OGS) Testbed

Overview:

2-m Optical Ground Station (Kashima) :
- 2-m telescope with adaptive optics
- Available for deep space communication
- 100 Gbps class laser communication with satellites

1-m Optical Ground Station (Koganei, Kashima, Okinawa):
- Replaceable FPS or receiver for user

40-cm Optical Ground Station (Koganei, Kashima, Kobe):
- Replaceable FPS or receiver for user

Transportable Optical Ground Station (Koganei):
- 40-cm telescope with FPS
- Deployment flexibility as a ground station
- 2 trucks with telescope and its control system

High speed fiber networks among OGSs with VPN
- Site diversity verification
- Virtual Private Network (VPN)

Use case:

- Testbed for communication with various flying objects
- Demonstration of QKD between satellites and ground stations
- Demonstration for social use of LEO constellation
- Verification test of new device
- Demonstration of site diversity

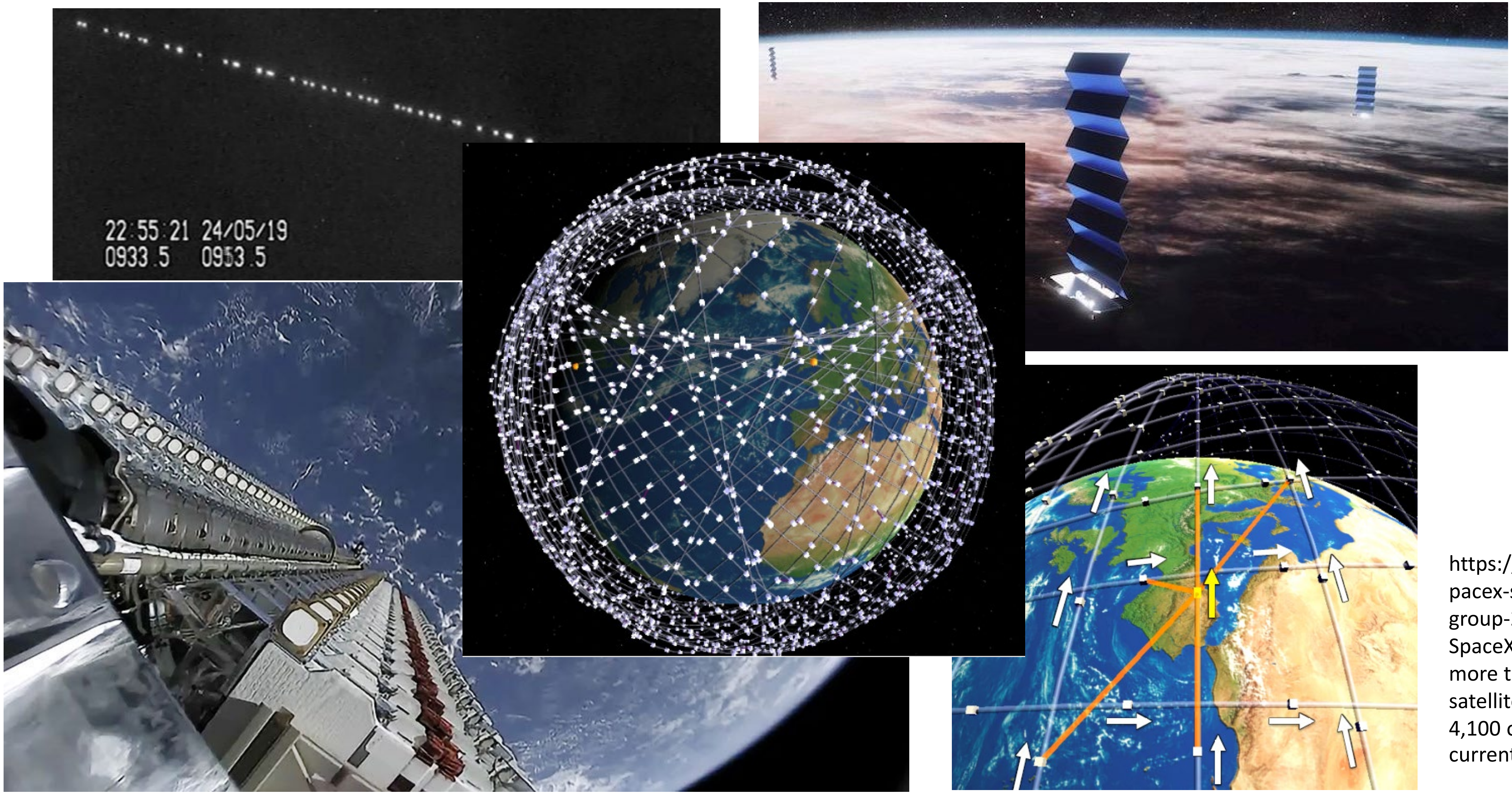
Available to all the users worldwide next year

情報通信研究機構
National Institute of Information and Communications Technology

Space Laser Communications for Mega-Constellation Programs

Starlink has 4,100 operational satellites in orbit

Space laser communications will be used for the 2nd generation system.



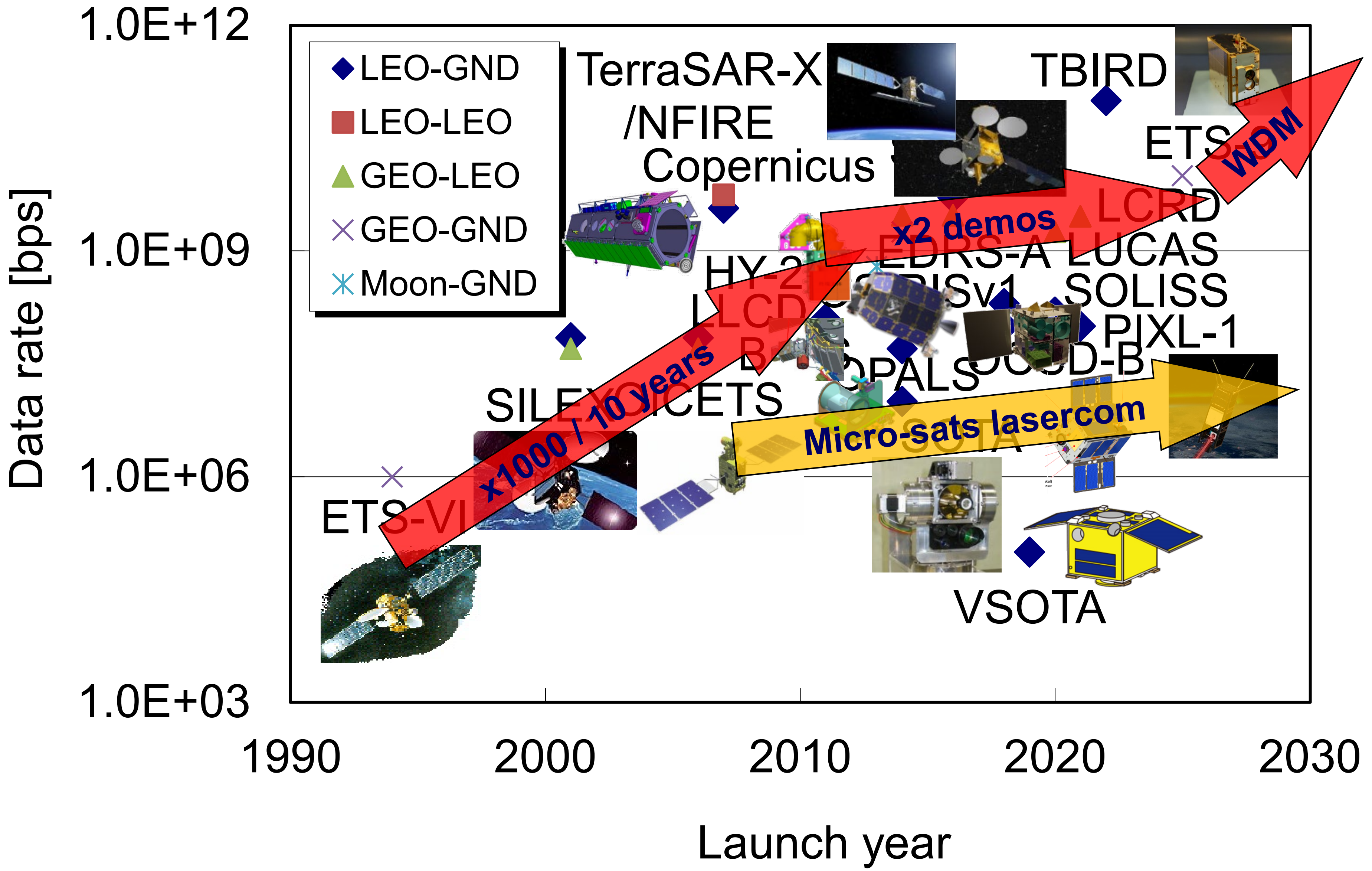
https://www.space.com/spacex-starlink-launch-group-2-10
SpaceX has now launched more than 4,500 Starlink satellites, more than 4,100 of which are currently active

Refs: https://www.space.com/spacex-starlink-launch-rocket-landing-january-2022
https://www.space.com/spacex-starlink-satellites-phone-home-dimming.html
https://spaceflightnow.com/2019/05/24/spacexs-first-60-starlink-broadband-satellites-deployed-in-orbit/
https://www.newsweekjapan.jp/stories/world/2019/06/post-12259.php
http://nrg.cs.ucl.ac.uk/mjh/starlink-draft.pdf

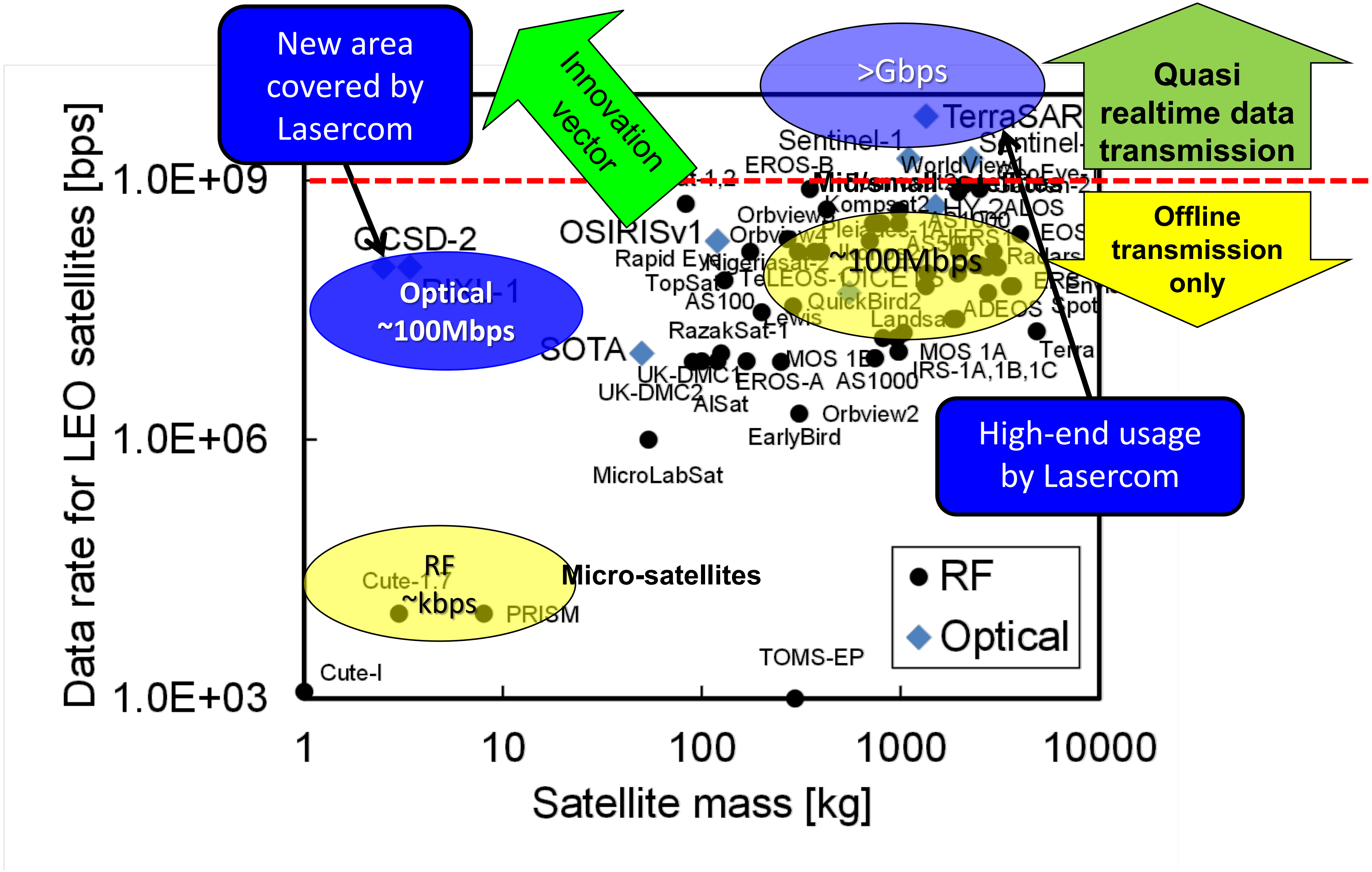
Space-based laser communication programs

	Asia	USA	Europe
Past	- 1994: **ETS-VI** (NICT), GEO-GND, 0.8μm/0.5μm, IMDD, 1Mbps - 2006: **OICETS** (JAXA/NICT), LEO-GEO,LEO-GND, 0.8μm, IMDD, 50Mbps - 2011: **HY-2** (China), LEO-GND, 1.5μm, IMDD, 504 Mbps - 2014: **SOCRATES/ SOTA** (NICT), LEO-GND, 0.98/1.5μm, IMDD, 10Mbps - 2016: **Micius** (China), BB84, 0.85/0.532/0.671μm - 2019: **RISESAT/ VSOTA** (NICT), LEO-GND, 0.98/1.5μm, IMDD, ~1kbps - 2019: **ISS/ SOLISS** (SONY), IMDD - 2020: **ODRS** (JAXA), GEO-GND, 1.5μm, DPSK, 1.8Gbps - 2022: **ALOS-3** (JAXA), LEO-GEO, 1.5μm, DPSK, 1.8Gbps, Failure	- 1995: **GOLD** (NASA JPL), GEO-GND, 0.8/0.5μm, IMDD, 1Mbps - 2000: **STRV-2** (BMDO), LEO-GND, Failure, 0.8μm, IMDD, 1.2Gbps - 2001: **GeoLITE** (NRO), GEO-GND - 2008: **NFIRE** (MDA), LEO-LEO, 1.06μm, BPSK, 5.6Gbps - 2013: **LLCD** (NASA GSFC), Lunar-GND, 1.5μm, PPM, 622Mbps - 2014: **OPALS** (NASA JPL), ISS-GND, 1.5μm, IMDD, 30~50Mbps - 2015: **OCSD-A** (Aero. Corp.), LEO(1.5U)-GND, Failure, 1.06μm, IMDD, 5-50Mbps - 2018: **OCSD-B/ AeroCube-7B** (Aero. Corp.), LEO-GND, 1.06μm, IMDD, 50/100Mbps - 2018, 2019: **AC-11/15** (Aero. Corp.), LEO-GND, 1.06μm, IMDD, 200Mbps - 2021: **LINCS** (General Atomics), LEO-GND, 1.06/1.5μm, IMDD, 5Gbps - 2021: **LCRD** (NASA GSFC), GEO-LEO, GEO-GND, 1.5μm, DPSK/PPM, 2.8G/622Mbps - 2022: **Flashlight** (Aero. Corp.), LEO-GND, 1.06μm, IMDD, 200Mbps - 2022: **TBIRD** (MIT LL), LEO-GND, 1.55μm, DP QPSK, 200Gbps - 2023: **DSOC** (NASA JPL), Deep space-GND, PPM, 264Mbps(max)	- 2001: **SILEX** (ESA), GEO-LEO, GEO-GND, GEO-Air, 0.8μm, IMDD, 50Mbps - 2008: **TerraSAR-X** (DLR), LEO-LEO/GND, 1.06μm, BPSK, 5.6Gbps - 2011: **BTLS** (Russia), ISS-GND, 1.55μm/0.85μm, IMDD, 125Mbps - 2013-2016: **EDRS/ Copernics** (ESA), GEO-LEO, GEO-GND, 1.06μm, BPSK, ~1.8Gbps, Including **AlphaSat, Sentinel-1A, EDRS-A, Sentinal-1B** - 2016-2017: **OSIRISv1-2** (DLR), LEO-GND, 1.5μm, IMDD, 20M-100Mbps - 2019: **EDRS-C** (ESA), GEO-LEO, 1.06μm, BPSK, ~1.8Gbps - 2019: **OPS-SAT** (TU Graz), LEO-GND, PPM, 2kbps (uplink) - 2021: **PIXL-1** (DLR), LEO-GND, 1.5μm, IMDD, 100Mbps - 2023: **CubeCat** (TNO), LEO-GND, 1.5μm, IMDD, 1Gbps
Future plan	- 2023: **BBM** (DST/Australia), LEO-GND, 1.06μm, IMDD, ~200Mbps - 2025: **ETS-9/HICALI** (NICT) , 1.5μm, DPSK, 10Gbps	- 2024: **ARTEMIS O2O** (NASA GSFC), Moon-Earth, PPM, 311Mbps	- 2024: **ScyLight #1**（ESA） - 2025: **Hydron**（ESA）, 100Gbps, WDM - **SAGA**（ESA）, QKD

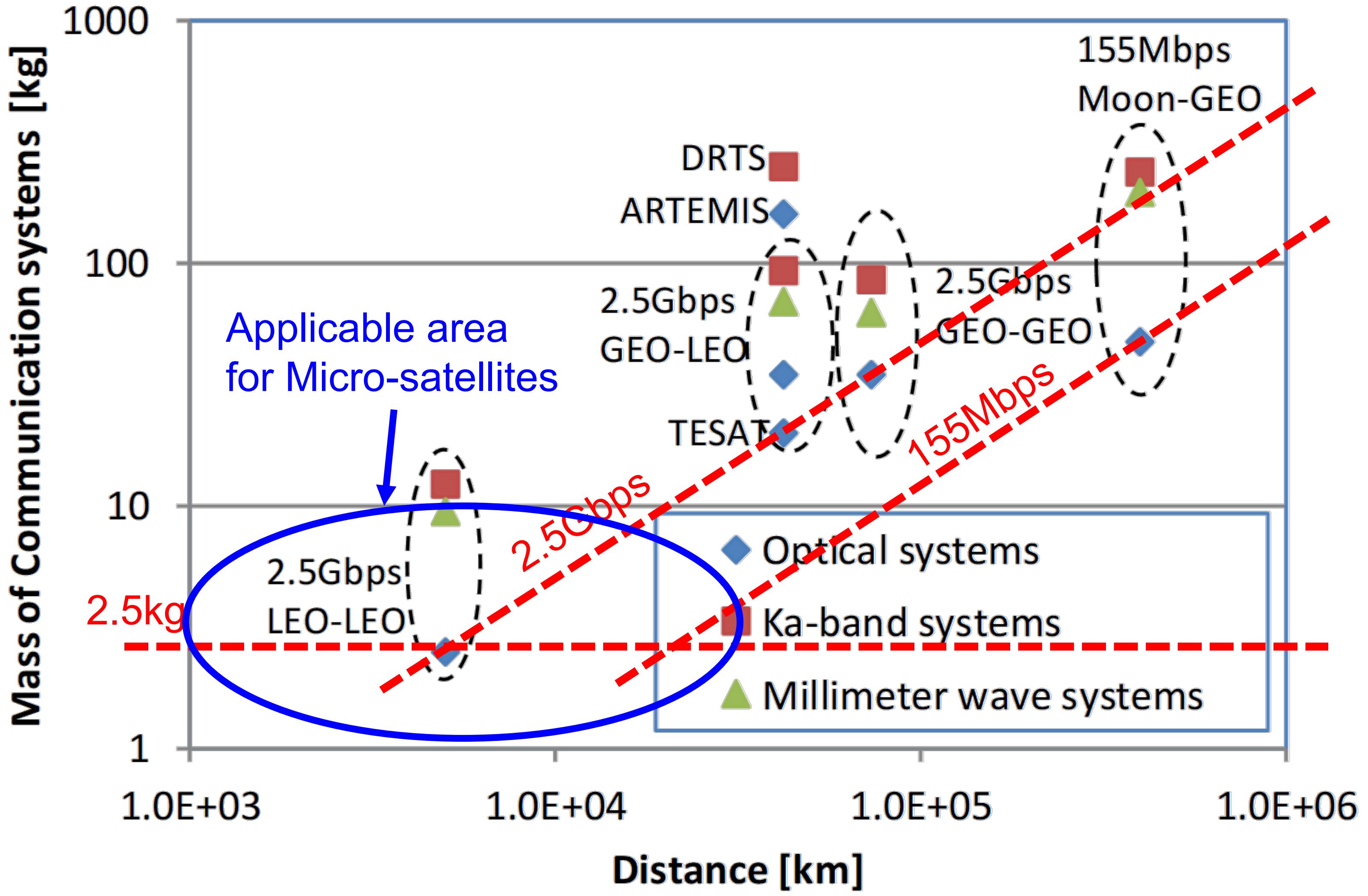
Trends of data rate for space laser comm.



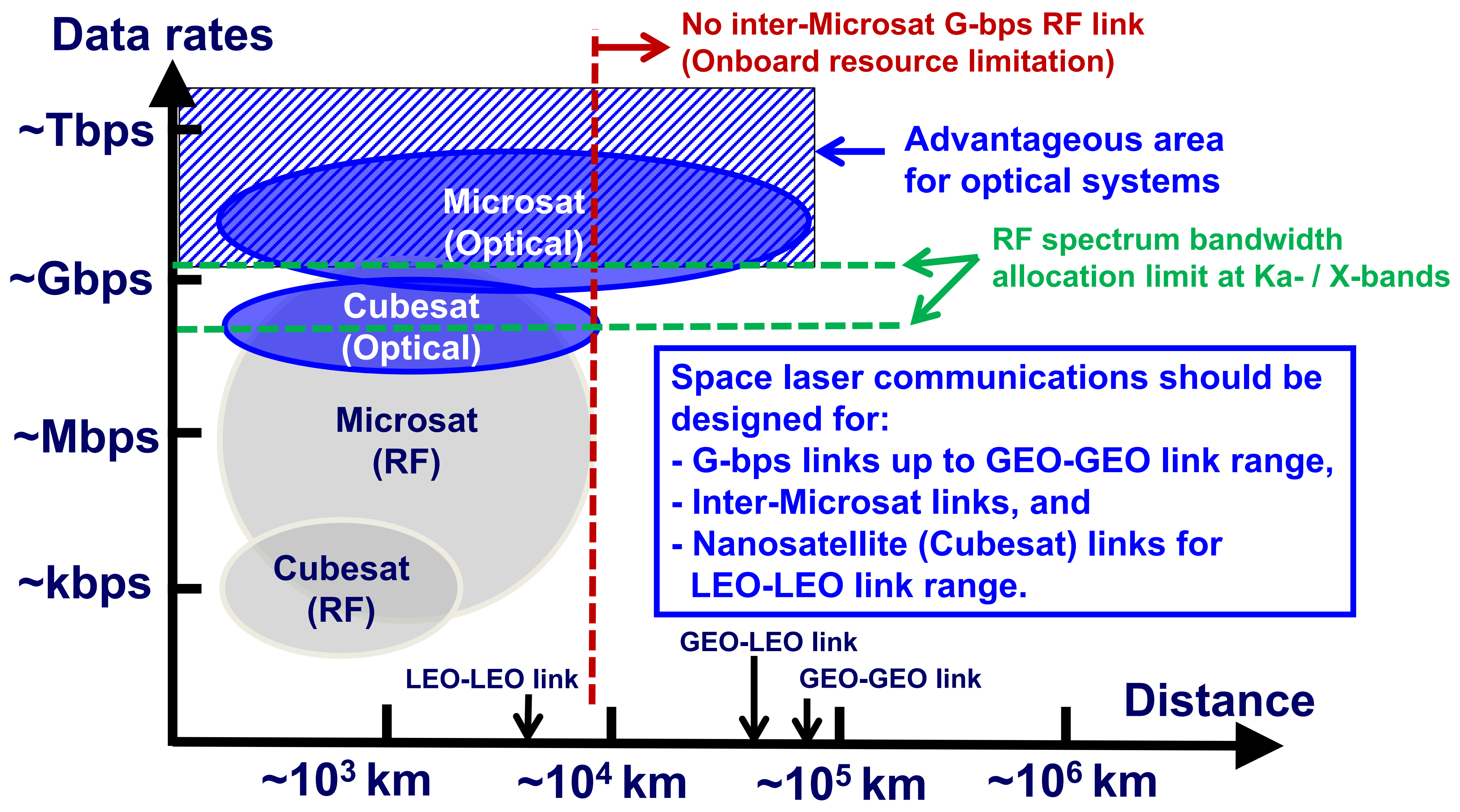
Lasercom infrastructure for Micro-satellites



Applicable area with mass and distance



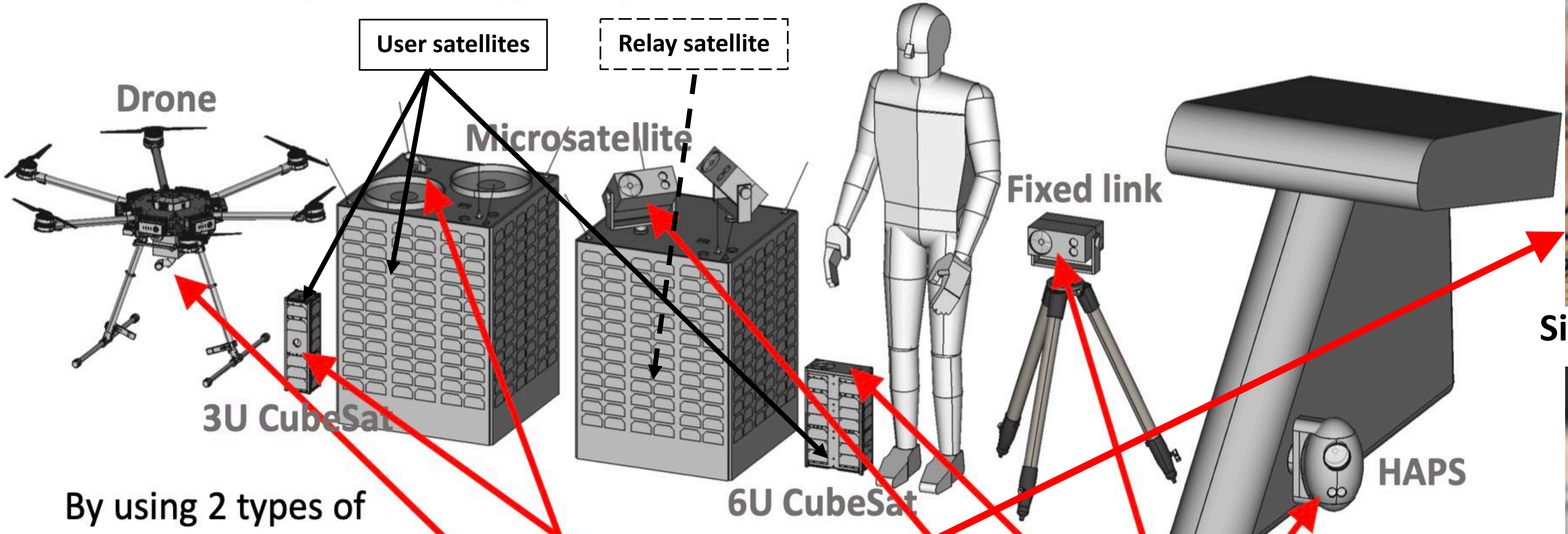
Applicable area of Gbps-laser links for Micro-satellites



Space laser communications should be designed for:
- **G-bps links up to GEO-GEO link range,**
- **Inter-Microsat links, and**
- **Nanosatellite (Cubesat) links for LEO-LEO link range.**

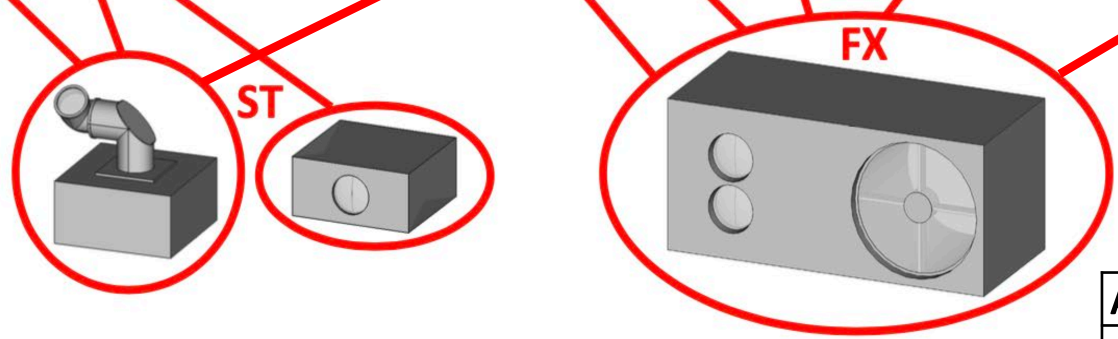
Prototype Developments of Lasercom Terminals

Main goal:
To fit into many different types of platforms:

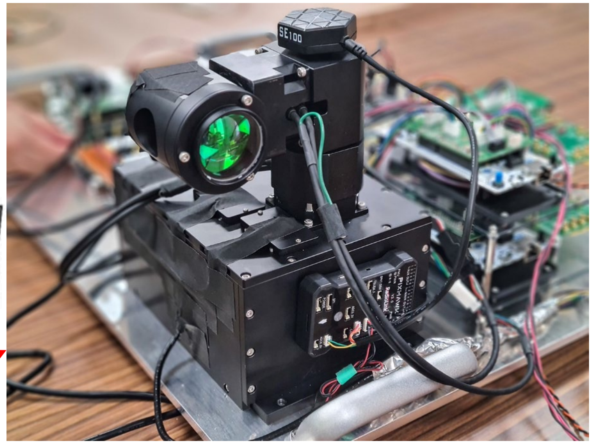


By using 2 types of lasercom terminals:
- Simple transmitter (ST)
- Full transceiver (FX)

and 2 types of modems:
- 10-Gbps class
- 100-Gbps class



FY2021's prototypes:



Simple-transmitter (ST) terminal

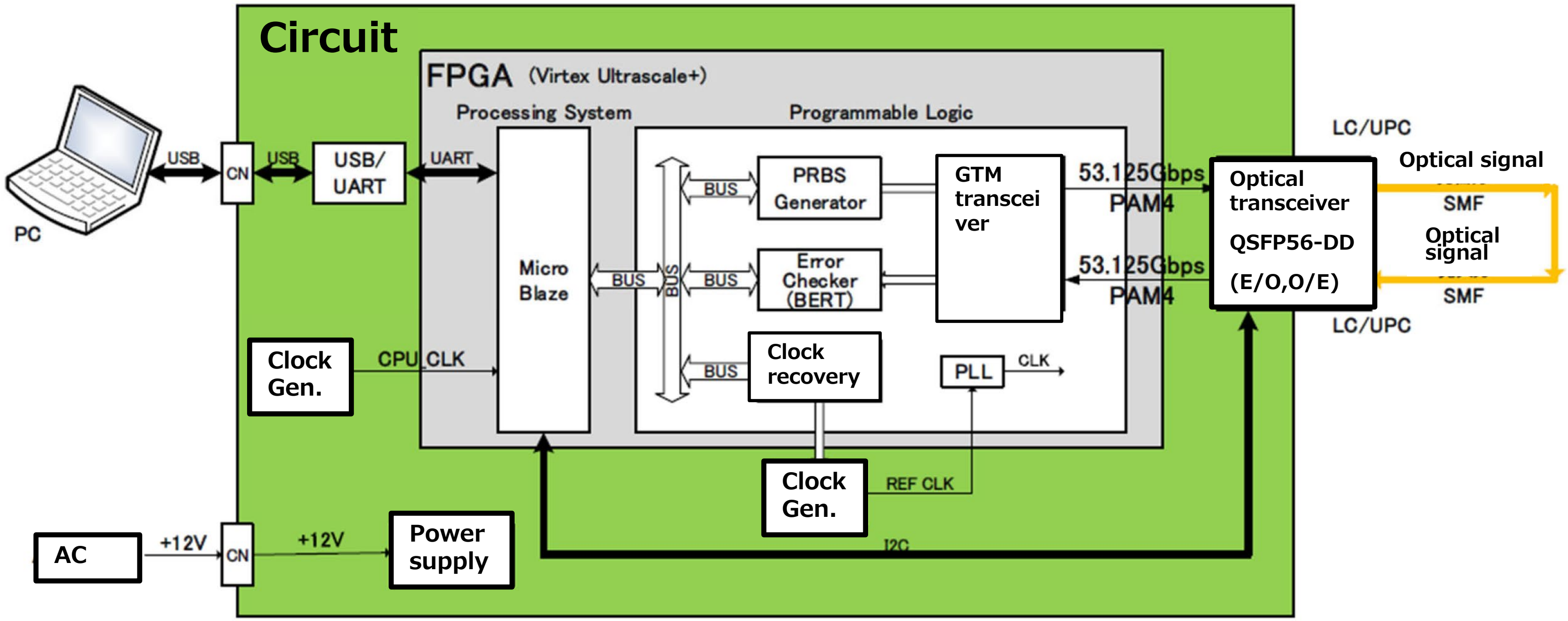
Full-transceiver (FX) terminal

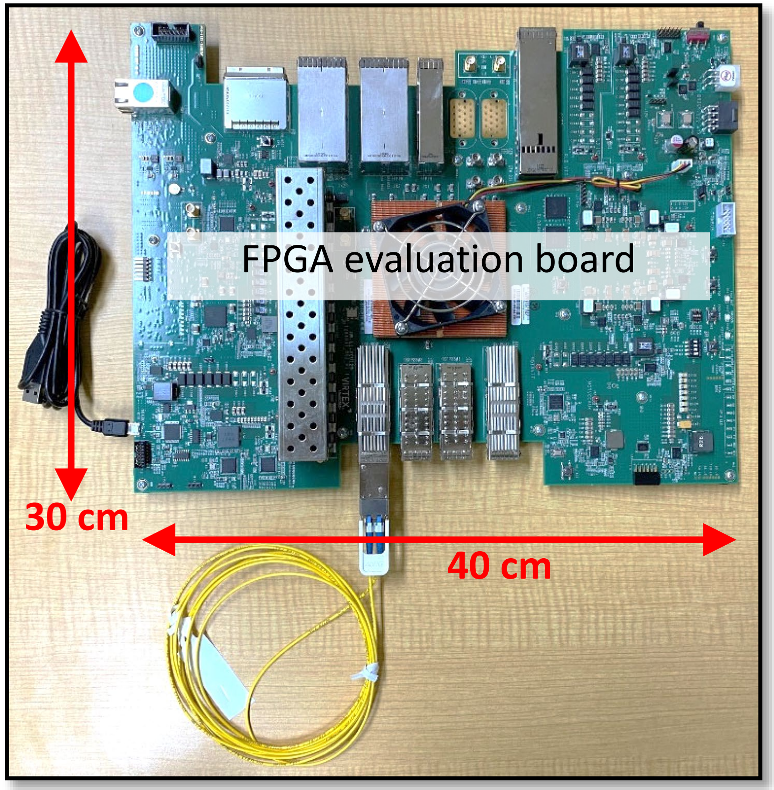
	FX terminal	ST terminal
Aperture size	9 cm	3 cm
Mass	~8 kg	~4 kg

Development of Optical 400-Gbps Modem

A prototype developed in FY2021

Block diagram:





Characteristics:

- **Bitrate:** 400 Gbit/s (including FEC)
- **Wavelength:** C-band (single tunable channel)
- **Communication format:** Digital coherent DP-16QAM
- **Modem functions:** PRBS generator / BER tester

Development of Optical 2-Tbps modem

A prototype developed in FY2022

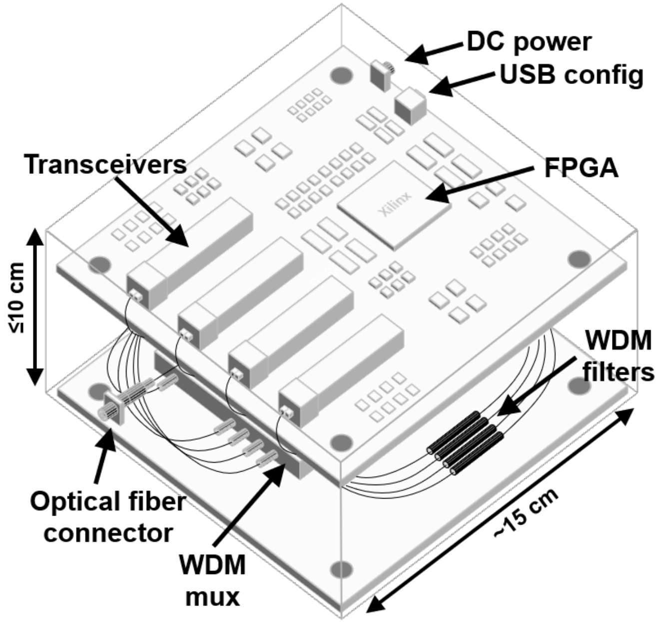
Goals:

- **Miniaturization:**
  Custom electronic boards
  Compact device for field experiments
- **Performance enhancement:**
  Increase data rate to 2 Tbit/s
  Adaptable to channel conditions

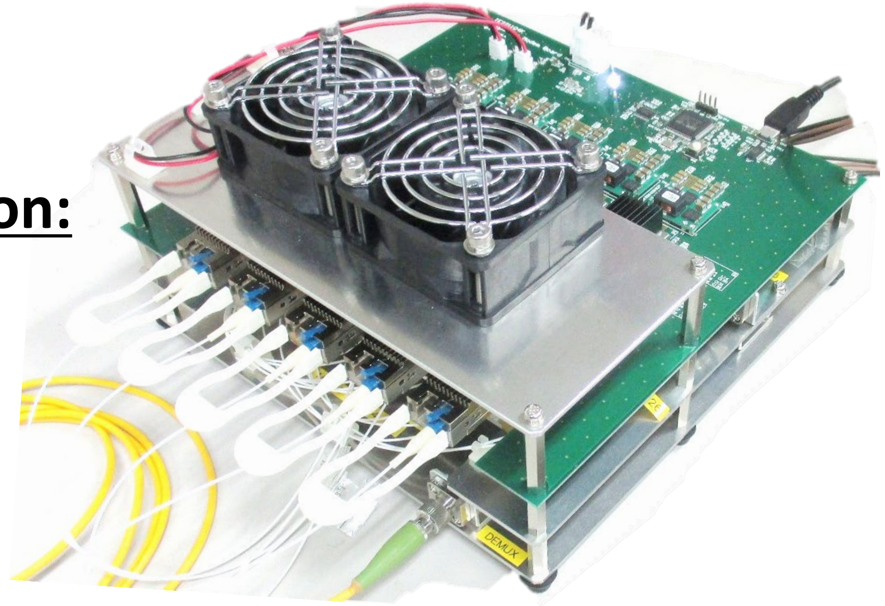
Characteristics:

- **Bitrate:** 2 Tbit/s (5×400 Gbit/s)
- **Wavelength:** C-band (5×WDM)
- **Communication format:**
  Digital coherent DP-16QAM/8QAM/QPSK
- **Modem functions:**
  - PRBS generator
  - BER tester
  - Variable data rate

Original design:



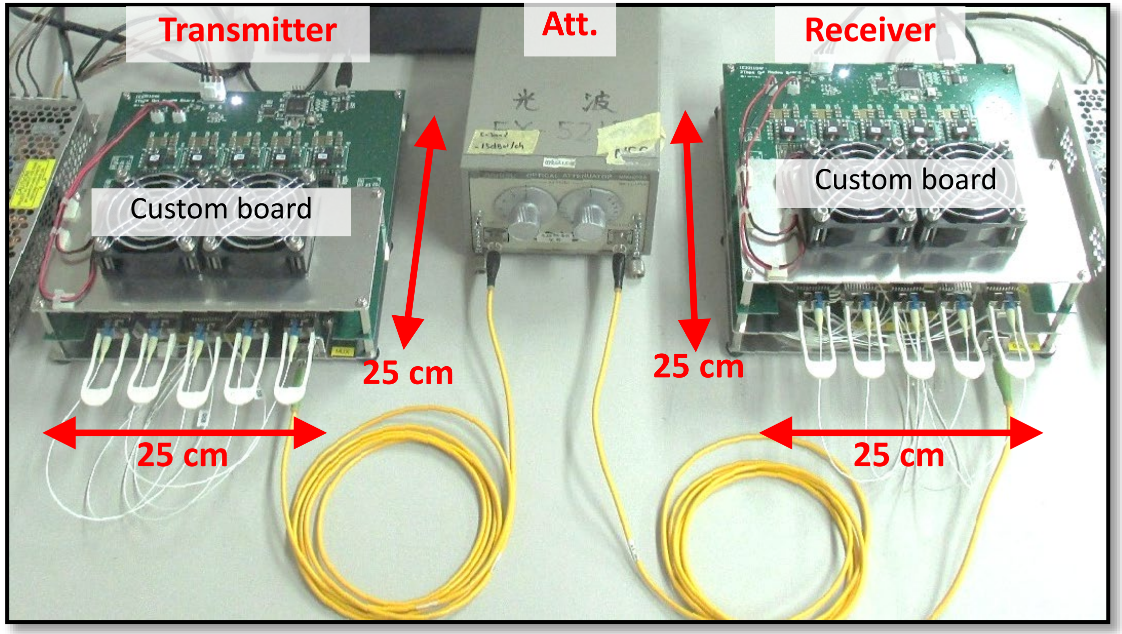
Implementation:



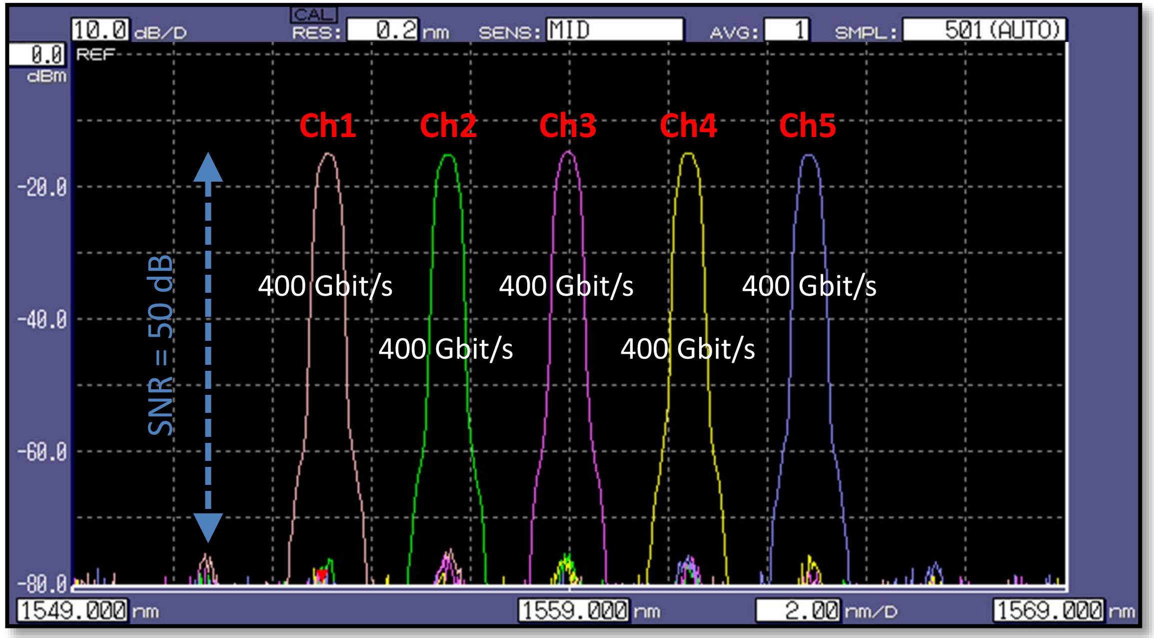
Optical 2-Tbps modem experiments

Evaluation experiments in FY2023

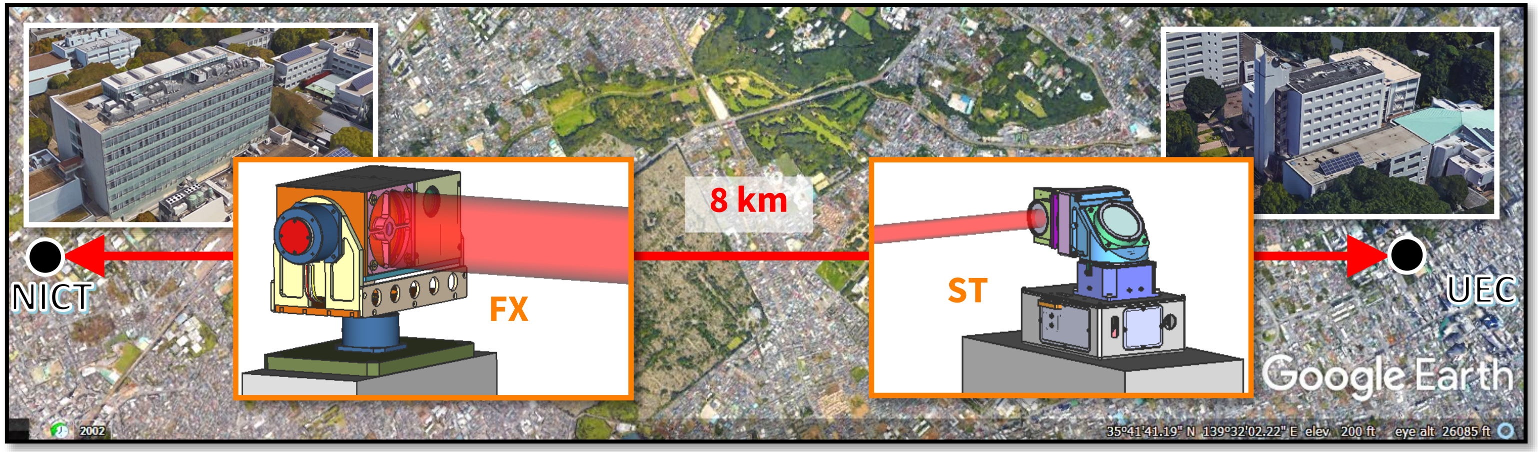
Laboratory experiment



Spectral analysis

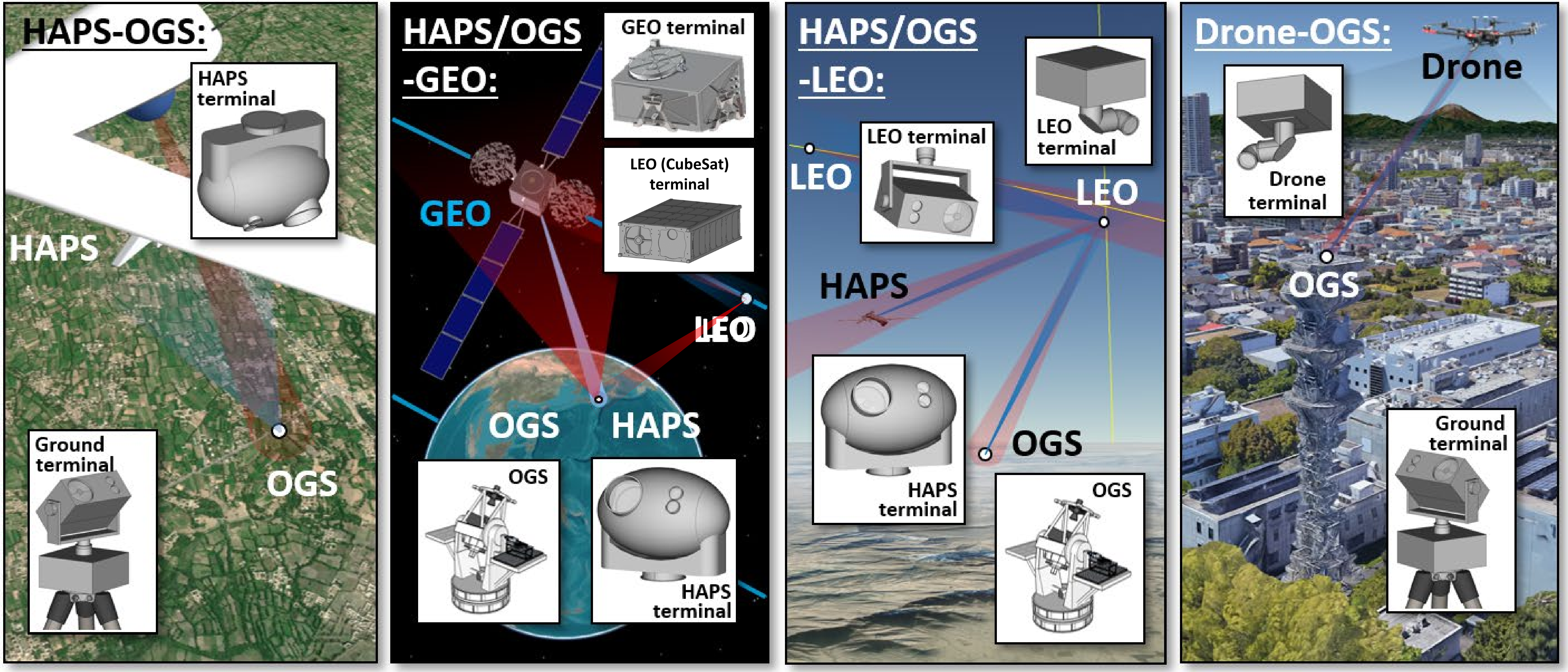


Field experiment



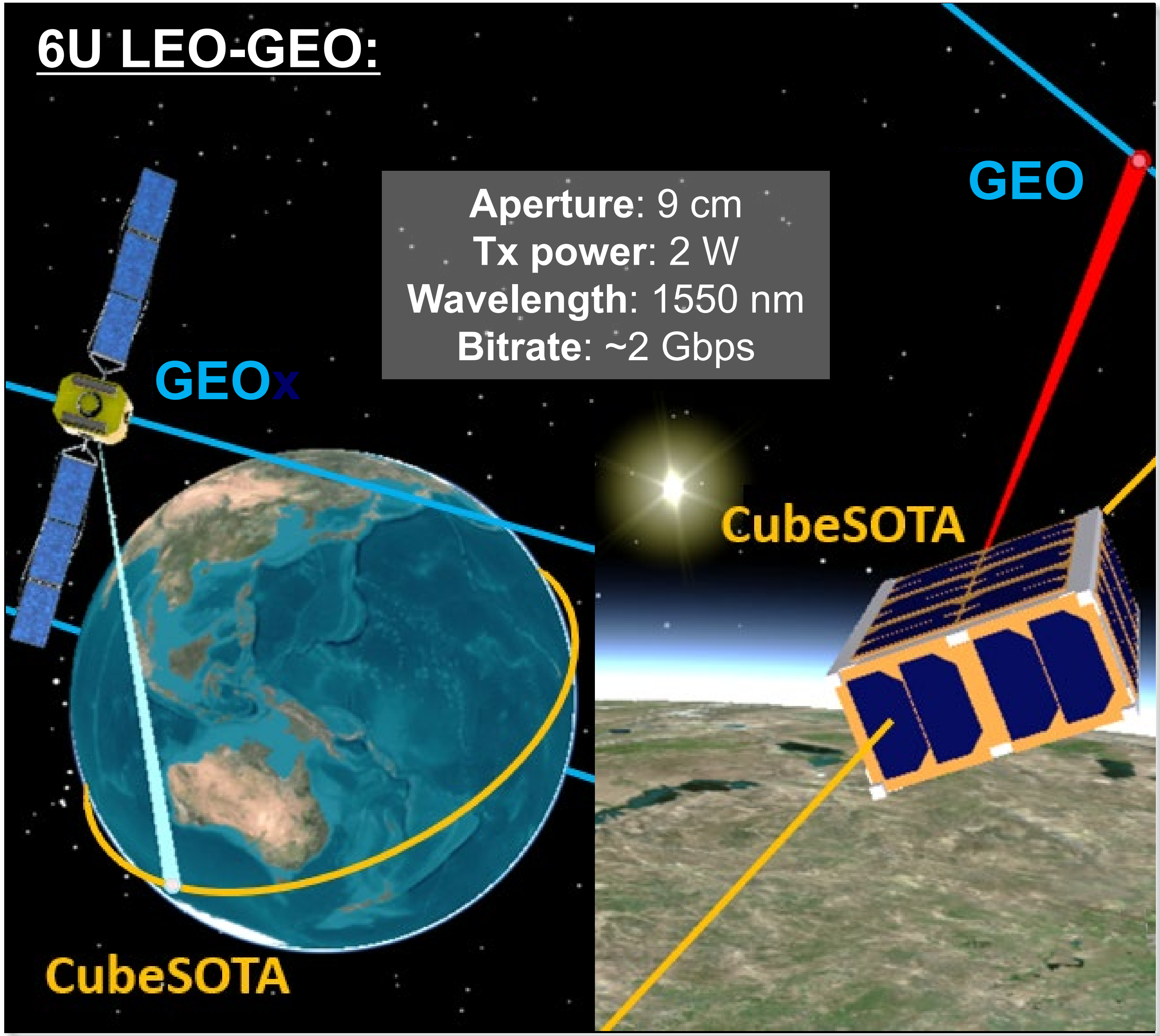
Development of Lasercom Terminals

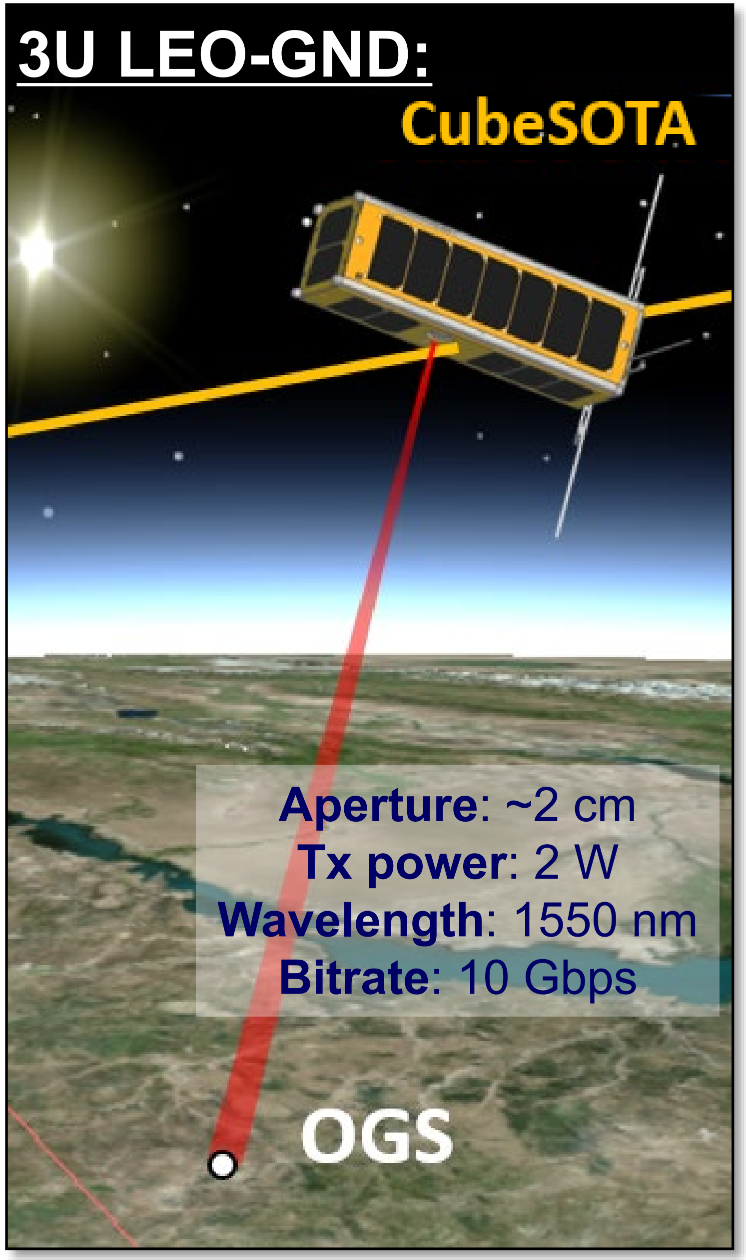
NICT's lasercom terminals for small platforms:



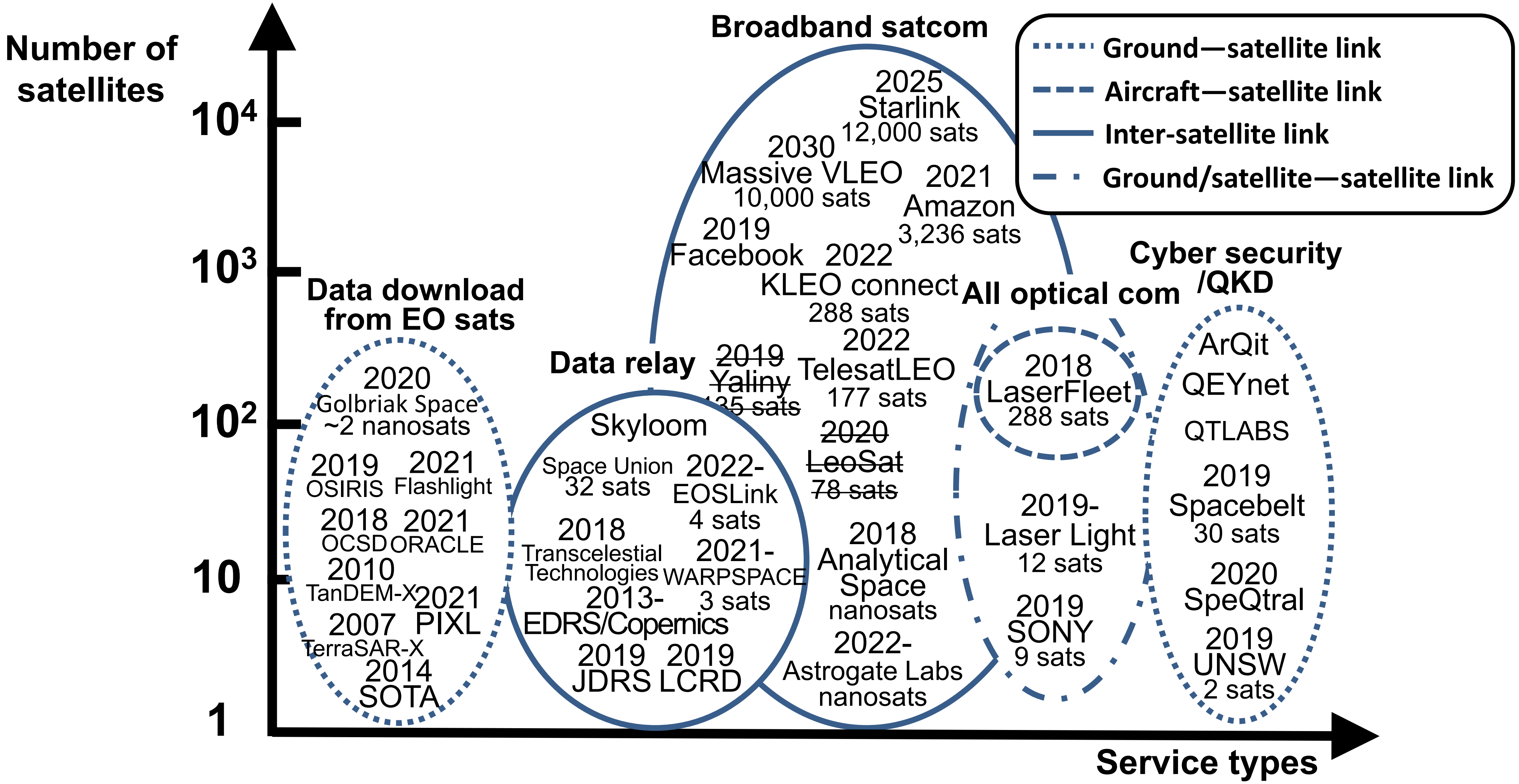
LEO Cubesat (CubeSOTA) – GEO Intersatellite laser communication demonstration plan (2023~)

NICT

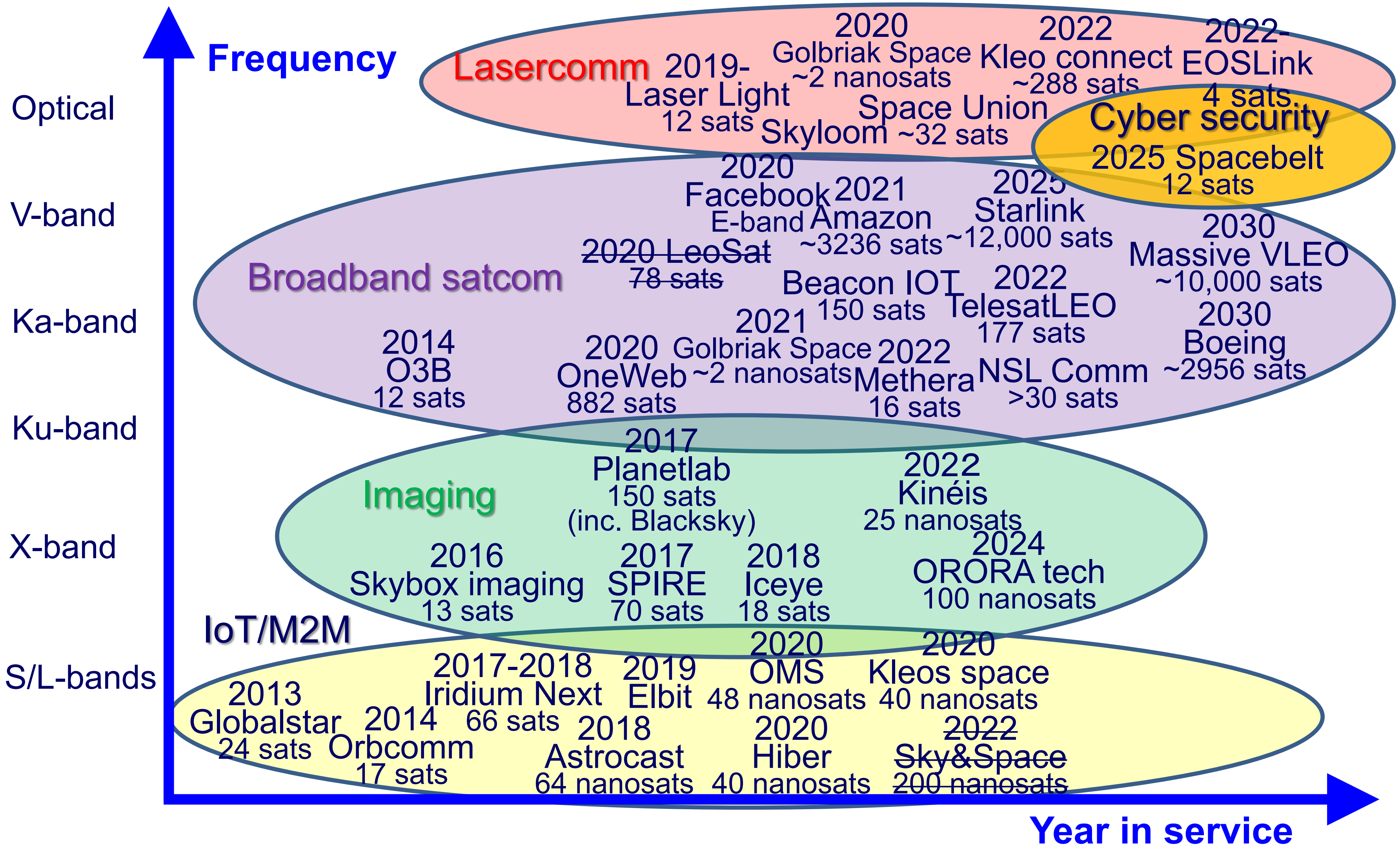




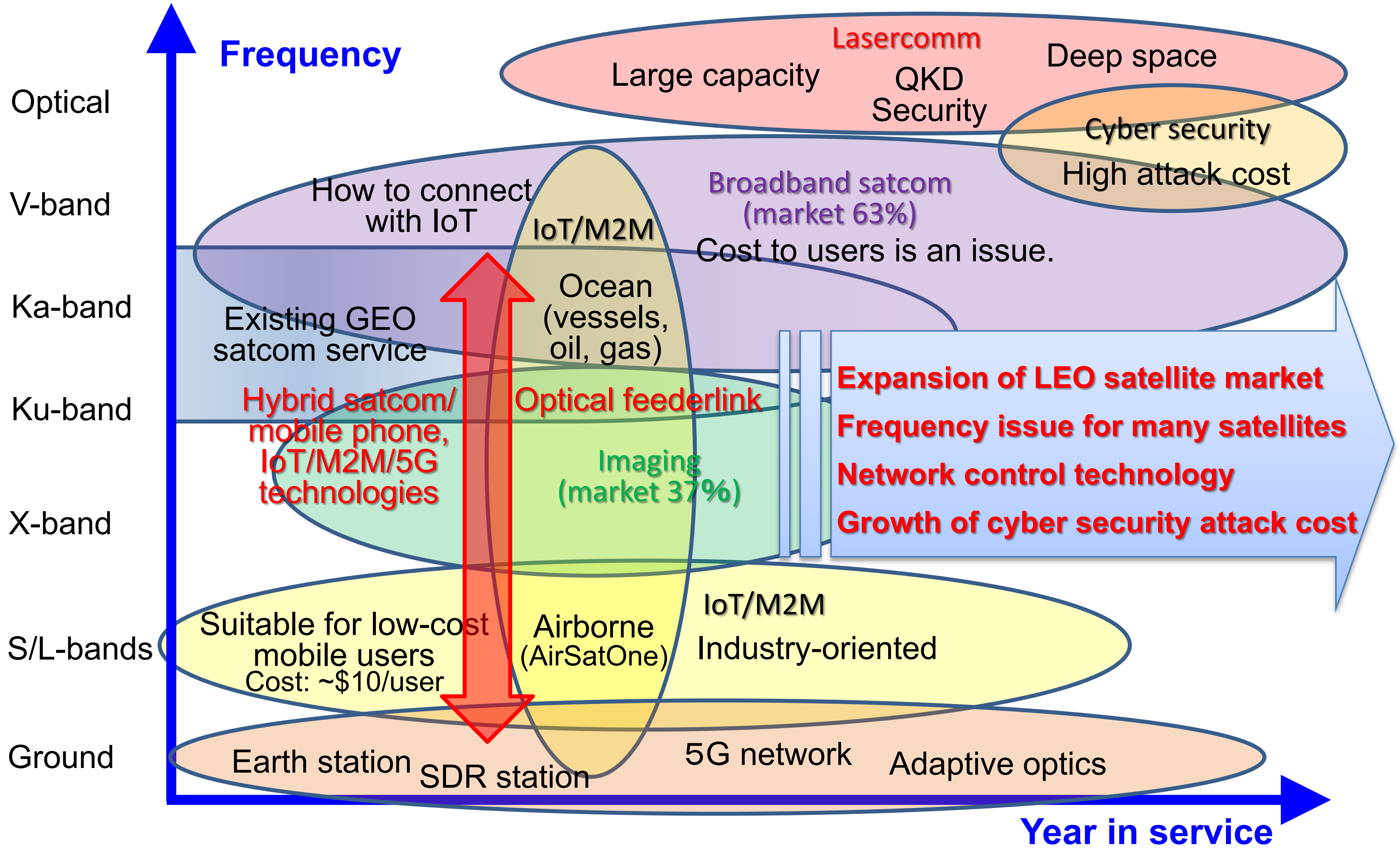
Applications and link scenarios of space laser communications for Mega-constellations



Frequency map for Mega-constellations programs



Frequency map for Mega-constellations technologies



R&D of space laser communication terminals for LEO constellations for Beyond 5G (2021-)

R&D of flexible laser communication terminals for LEO constellations has been started by “Beyond 5G R&D promotion fund” in NICT.

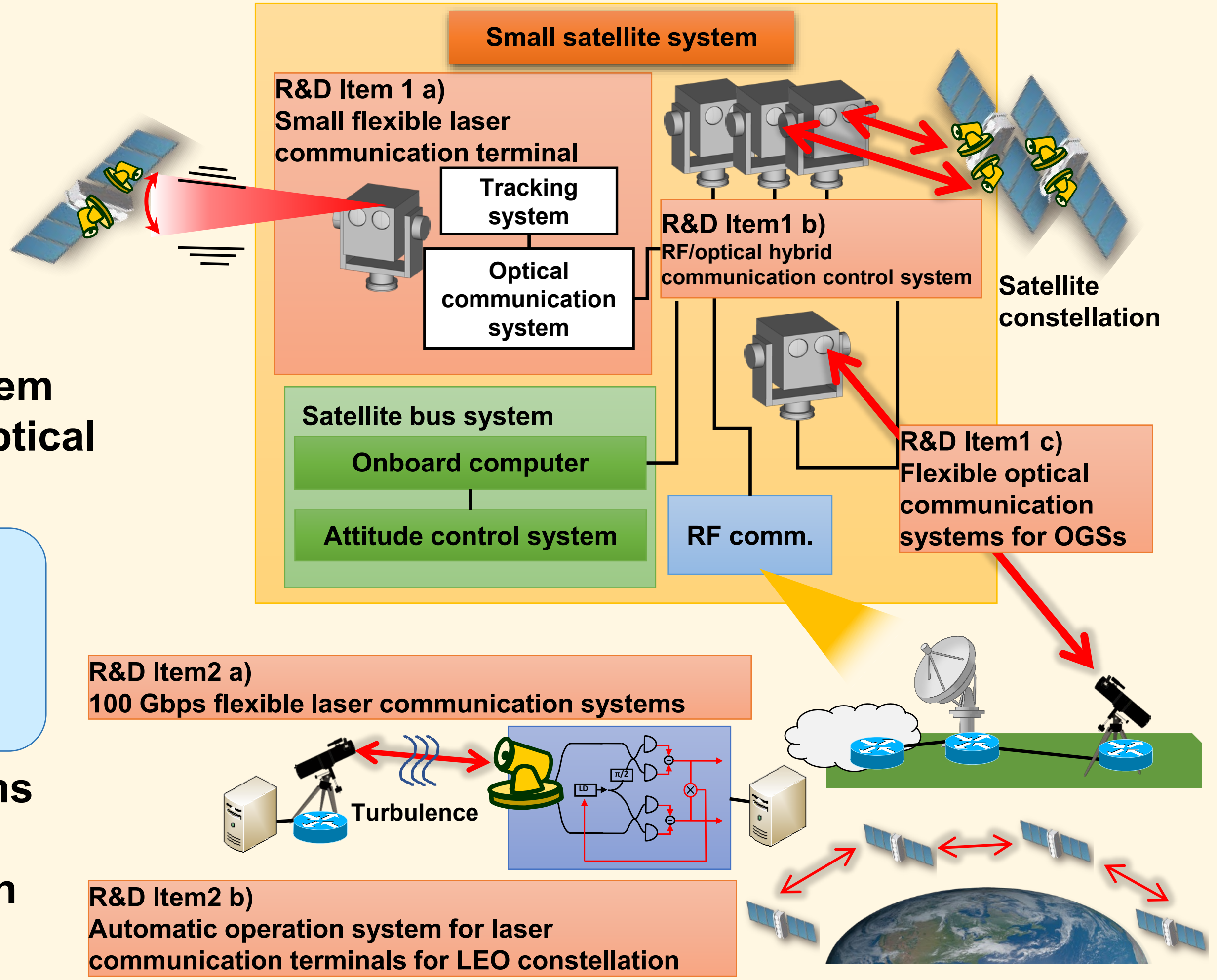
Overview

R&D Item 1:
Laser communication terminals for LEO constellations and RF/optical hybrid communication technology

a) Small flexible laser communication terminal
b) RF/optical hybrid communication control system
c) Flexible optical communication systems for optical ground stations (OGSs)

R&D Item 2:
Fundamental technologies for ultra-broadband optical communication systems

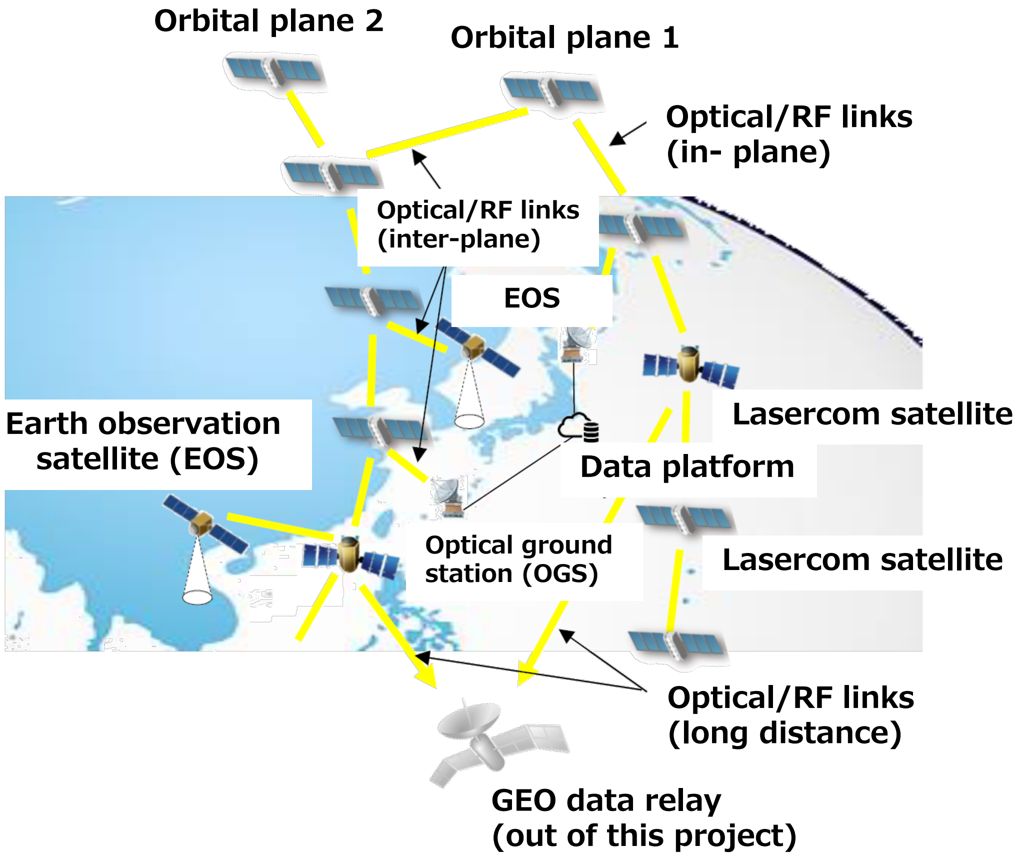
a) 100 Gbps flexible laser communication systems
b) Automatic operation system for laser communication terminals for LEO constellation

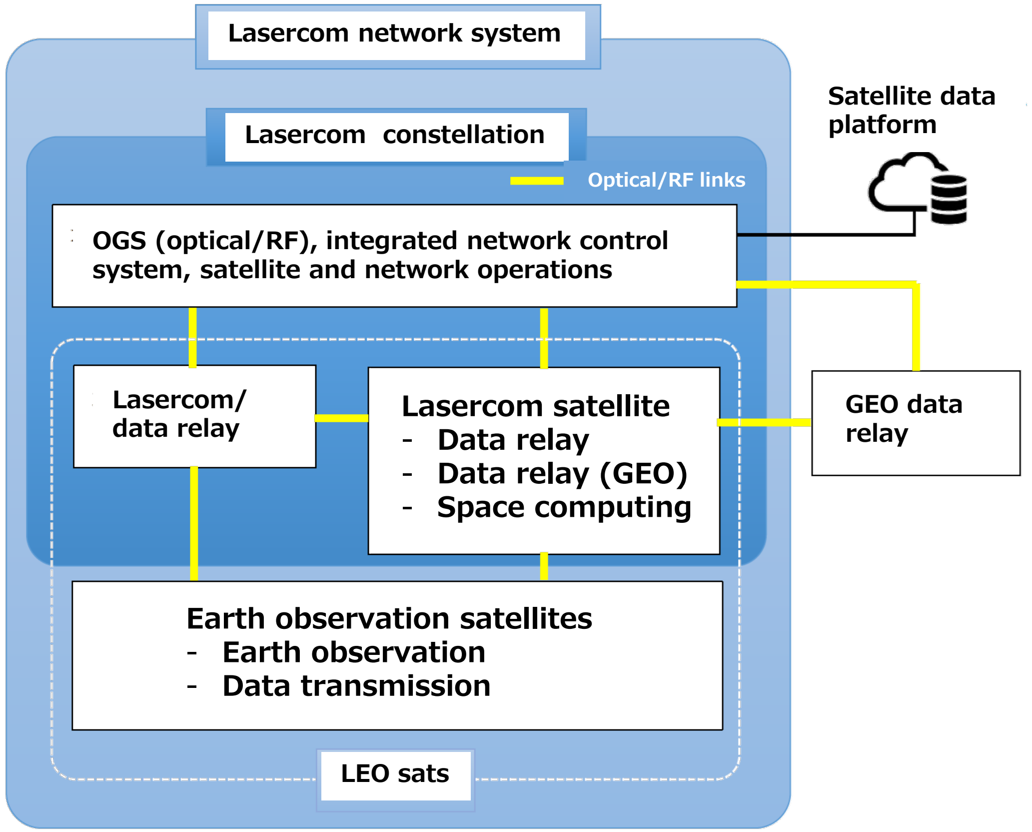


https://www.nict.go.jp/collabo/commission/B5Gsokushin/B5G_kobo/20210716kobo.html

Development and demonstration of fundamental technologies on space laser communications for LEO constellations (2023-)

In-orbit demonstration project by the Cabinet Office and the Ministry of Economy, Trade and Industry has been started since March 27, 2023. Multiple laser communication satellites are deployed, including earth observation satellites, and a space laser communication network on multiple orbital planes is established.





https://www8.cao.go.jp/cstp/anzen_anshin/20221021_meti_1.pdf
https://www.nedo.go.jp/news/press/AA5_101622.html

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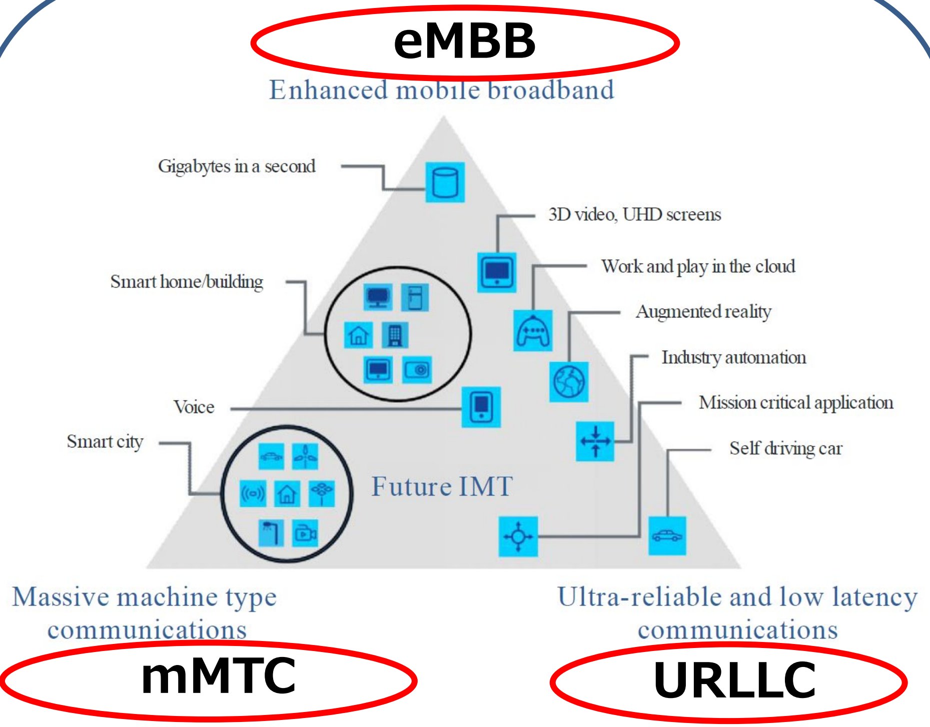
National Institute of Information and Communications Technology

Future Vision on Space Communications toward 5G/Beyond 5G

Role of satellite communications in 5G era



Expected important elements in 5G

Expected role of satellite-5G integration

- Extension and supplement of the service area with seamless connections between terrestrial 5G and satellites
- Realization of 5G scalability by high-capacity data transmission in global multicast/broadcast
- Broadband service for mobile platforms like vessels and aircraft
- Extension of 5G service for M2M/IoT and unmanned driving controls

Ref： NetWorld2020's - SatCom WG The role of satellite in 5G

3D extension of B5G/6G global networks towards space

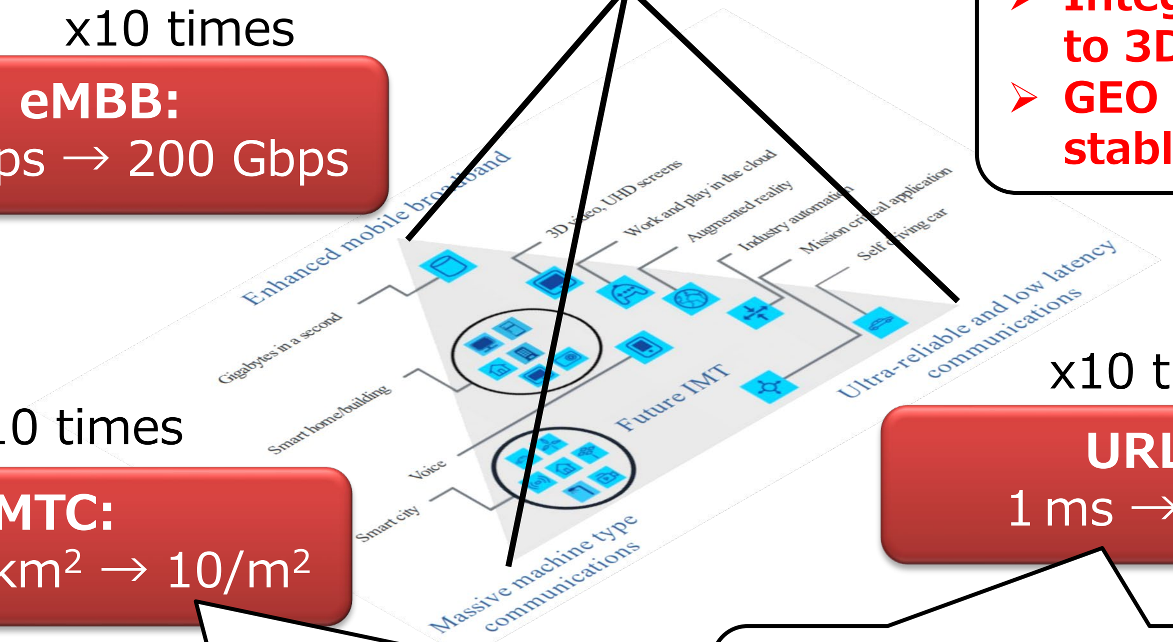
3D Expansion:
Ultra-global coverage for NTN
2D level (m^2) → 3D level (m^3)

- **Large capacity laser communications** to solve the frequency allocation issue
- **Site diversity technology**

x10 times

eMBB:
20 Gbps → 200 Gbps

- **Integrated system from 2D to 3D broadband network**
- **GEO should be used for the stable secure links**



x10 times

mMTC:
1 Millions/km^2 → 10/m^2

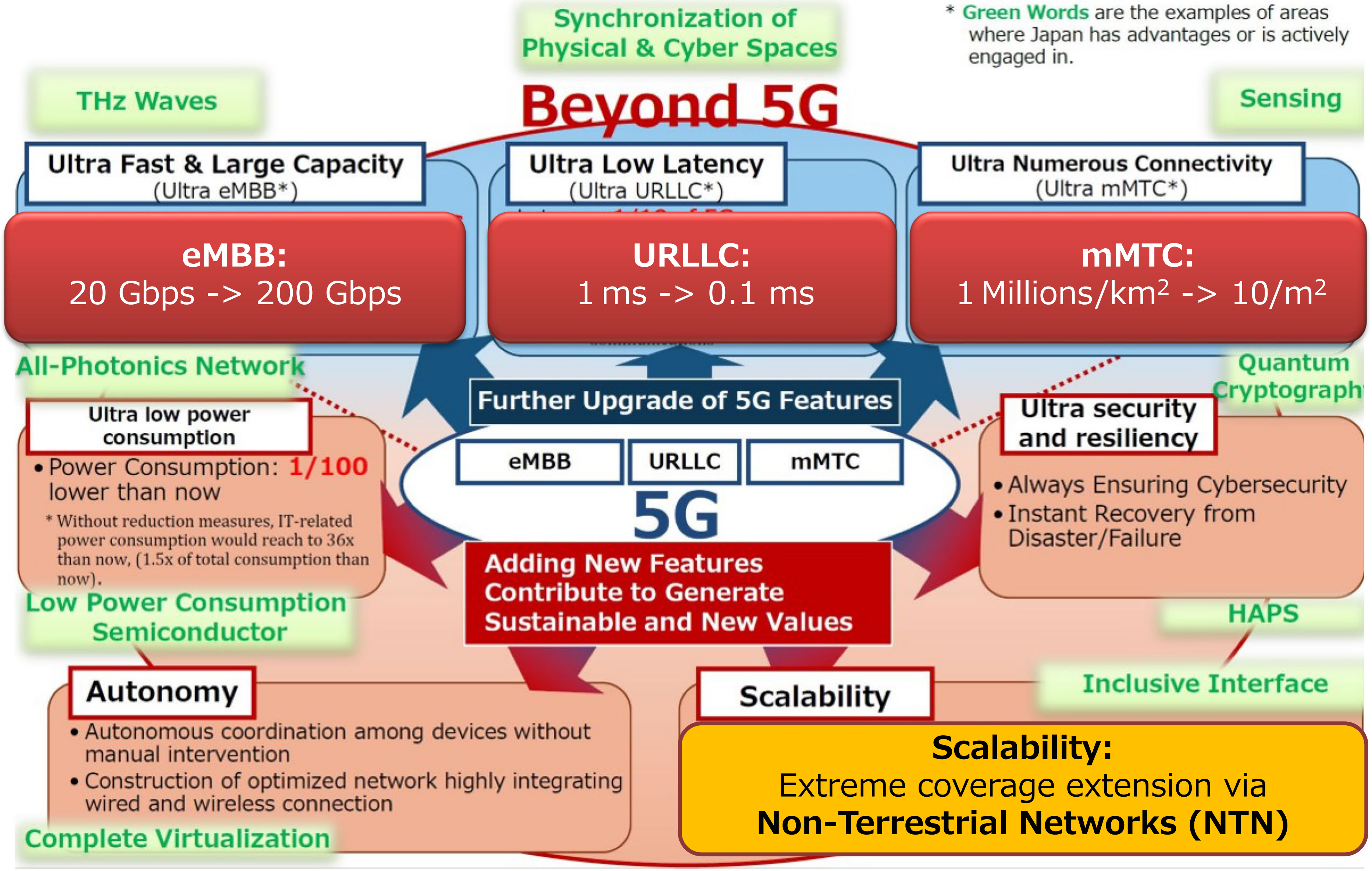
x10 times

URLLC:
1 ms → 0.1 ms

- Global coverage with UAVs, HAPS and Mega-constellations
- **High capacity using RF Multi-beam and digital beam former (DBF) technologies**

- **1 ms level achieved by LEO satellites**
- **0.1 ms level realized by UAVs and HAPS**
- Multi-layered networks

Requirements for Beyond 5G

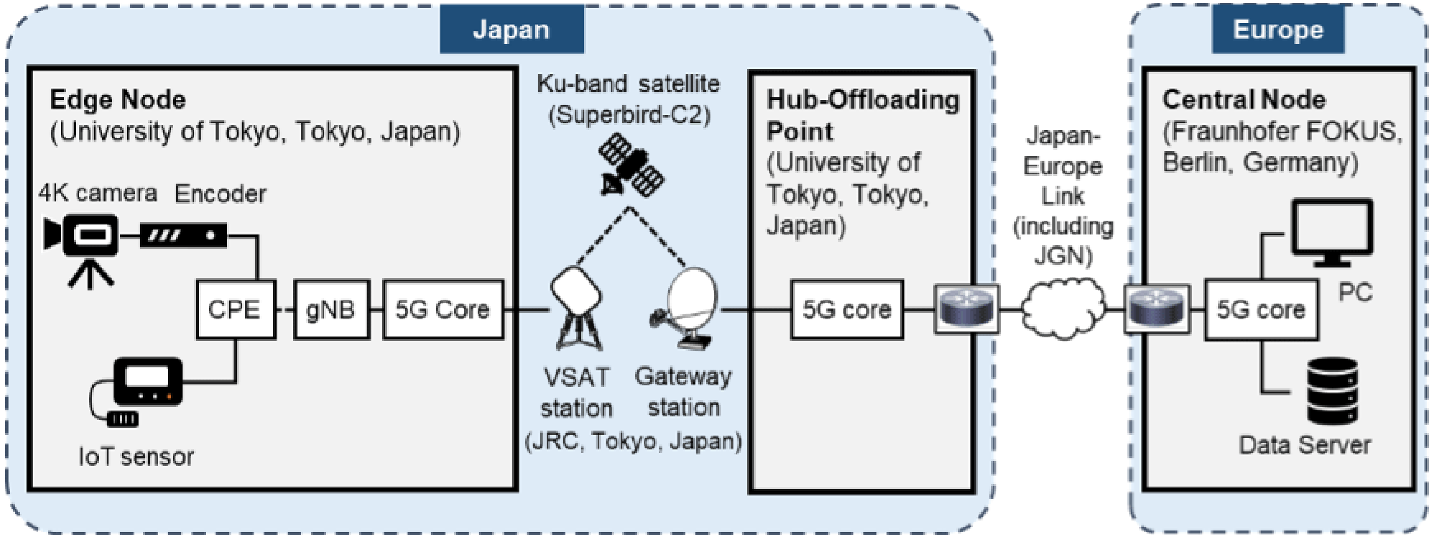


https://www.soumu.go.jp/main_content/000702111.pdf

Successful Japan-Europe Joint Experiment on Integration of Satellite Links in Japan-Europe Long Distance 5G Network

Press released on June 8, 2022

- Successful data transmission between Japan and Europe via international 5G communication links including satellite links in a Japan-Europe joint experiment.
- We demonstrated that satellite links can be utilized in 5G networks over very long distances with high latency.
- Progress toward realization of Beyond 5G to seamlessly connect between space and terrestrial networks.

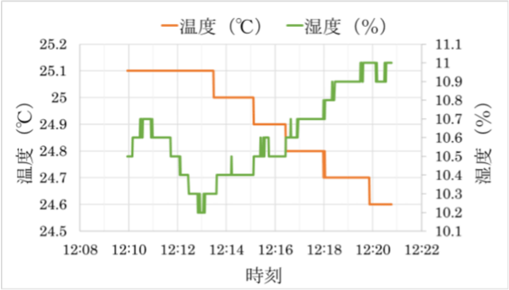


System configuration of the testbed in the Japan-Europe joint experiment

Gateway station and VSAT station

gNB (5G base station)

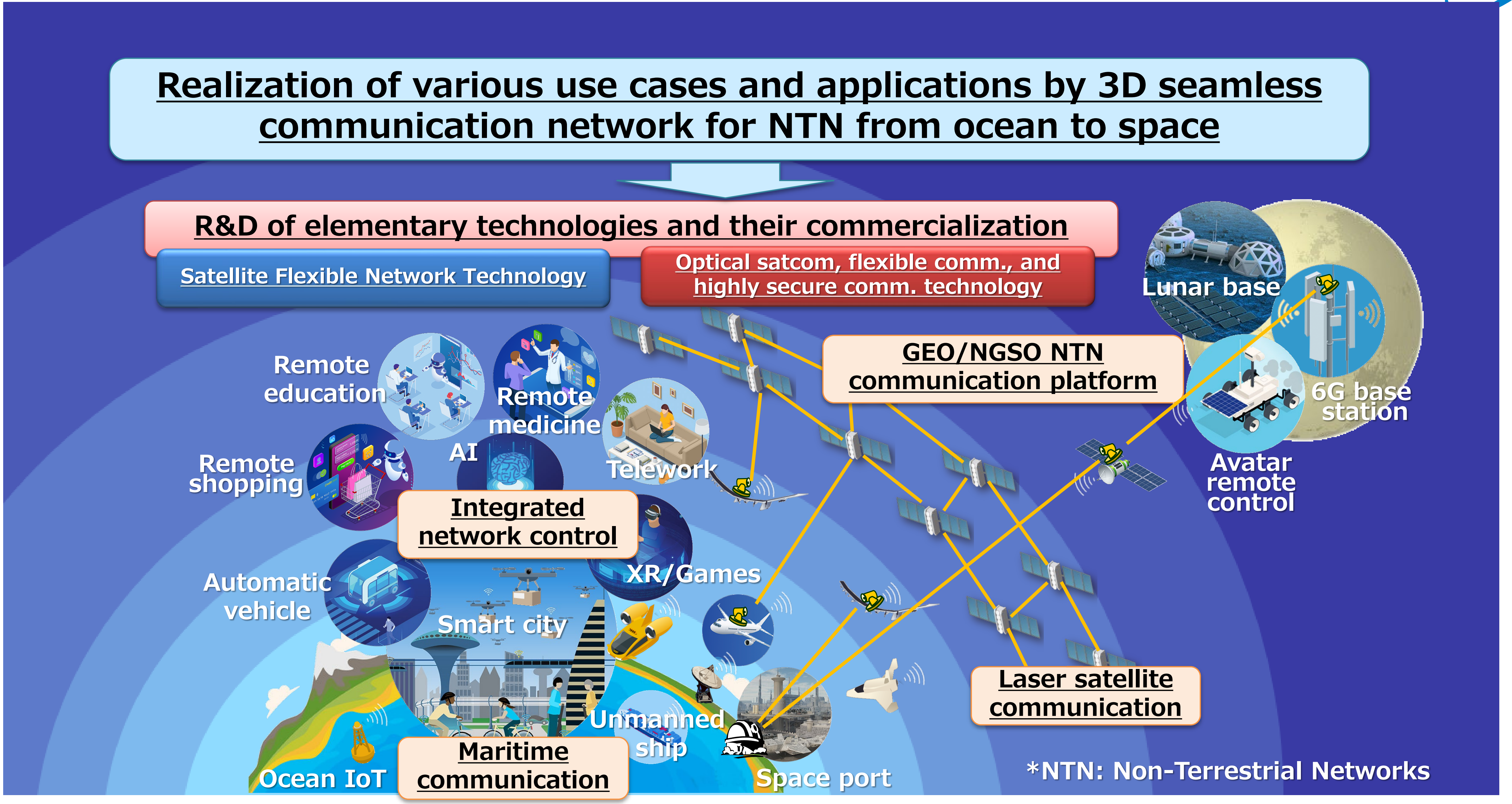
Transmitted 4K video



Transmitted IoT data

https://www.nict.go.jp/press/2022/06/08-1.html

3D seamless communication network for NTN* toward Beyond 5G/6G



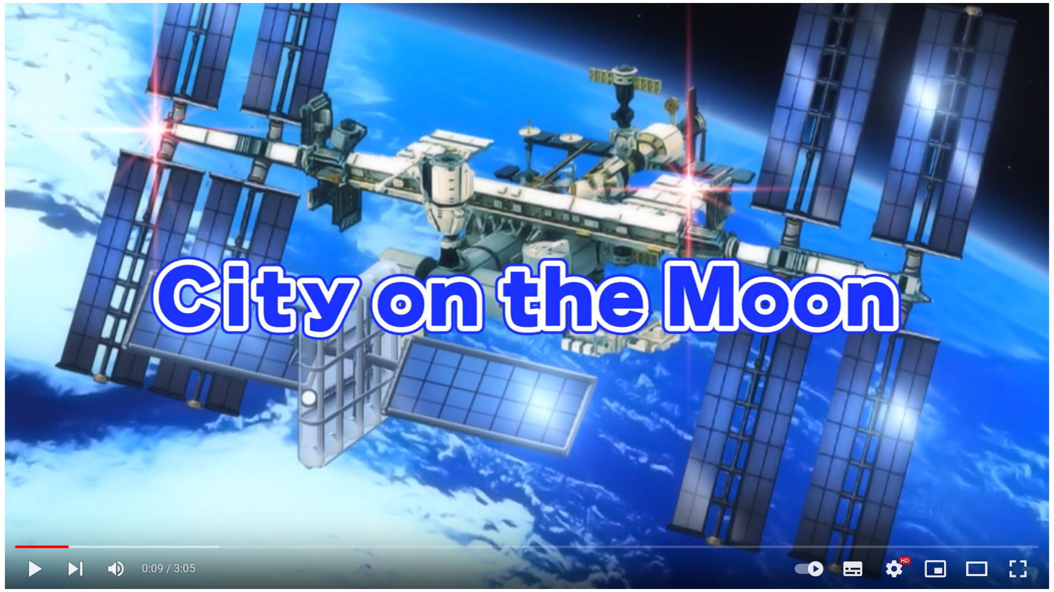
*NTN: Non-Terrestrial Networks

Publication of white paper for Beyond 5G/6G

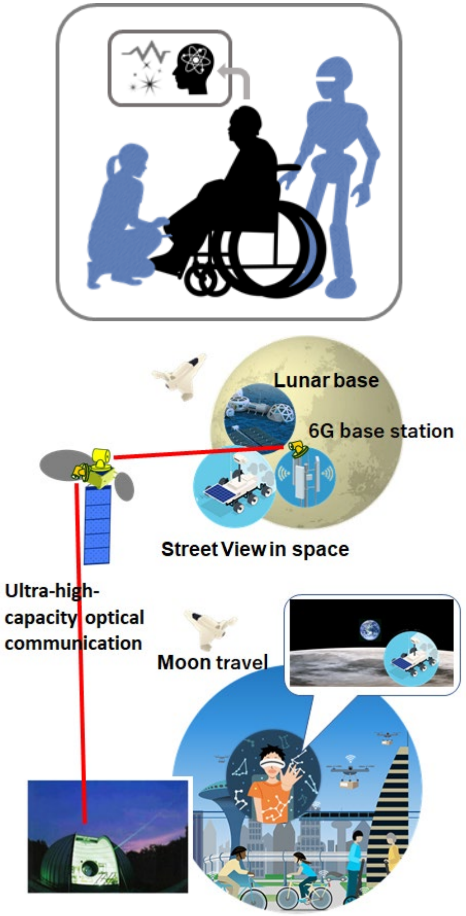
Press released on April 1st, 2021
Version 2: March 31, 2022
Version 3: March 31, 2023

In several countries, R&D on the next-generation information and communications infrastructure, "Beyond 5G/6G", which is expected to be the foundation of all industries and societies in the 2030s, is becoming active. It is important to establish Beyond 5G/6G key technologies as soon as possible. NICT has been conducting R&D on wired and wireless network technologies of Beyond 5G.

Download site URL:
https://www2.nict.go.jp/idi/en/#whitepaper
Version 2: https://beyond5g.nict.go.jp/download/index.html
Version 3: https://beyond5g.nict.go.jp/news/20230331.html



What is the future life of the Beyond 5G era?
~Scenario 2: City on the Moon:
https://www.youtube.com/watch?v=DekDHTdJwjI

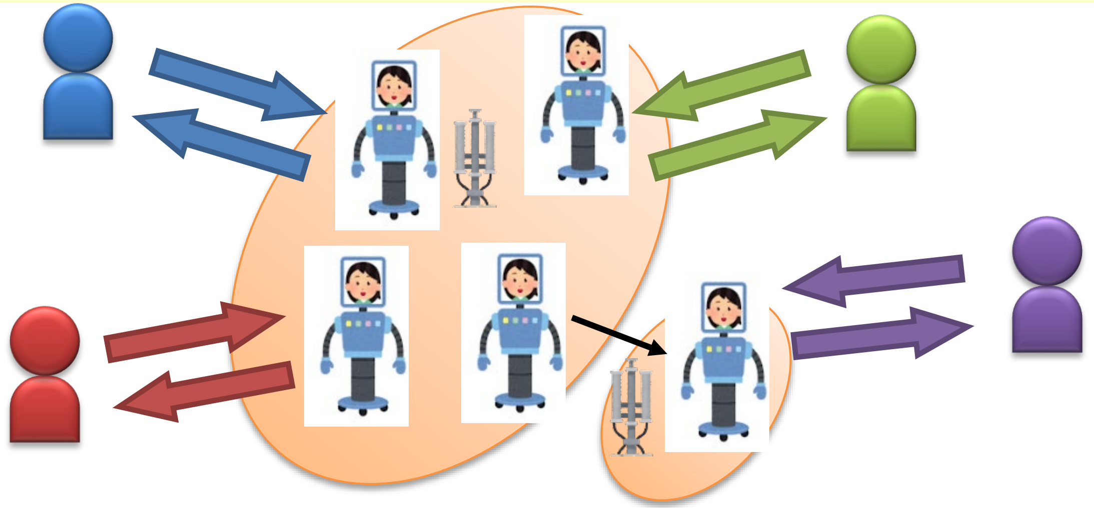


Cabinet Office Moonshot adopted PM

Press released on July 28, 2022 by Science technology and innovation office

Moonshot objective 1 “Realization of the society that human beings will be released from body, brain, space and time by 2050”

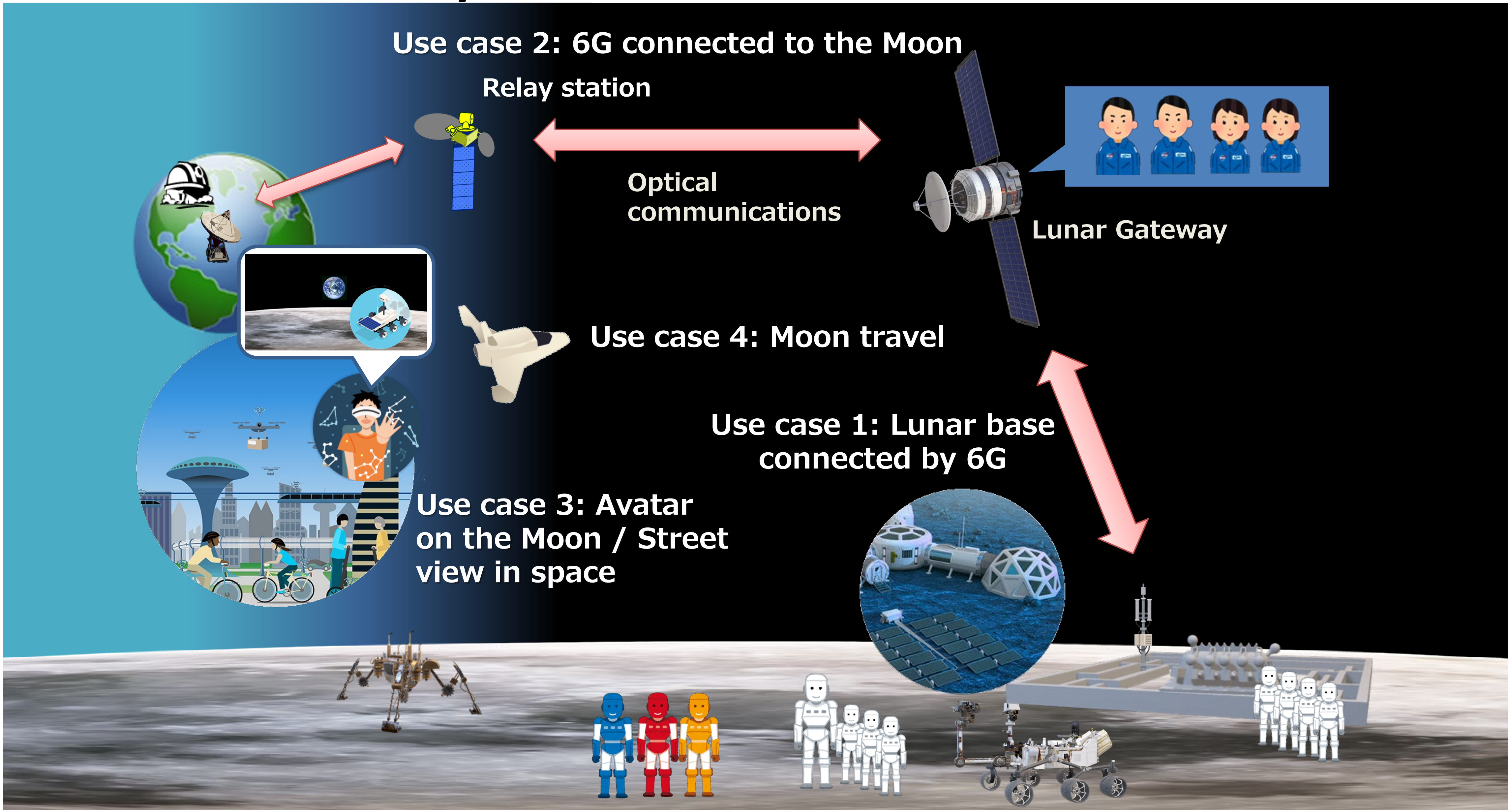
- **Dr. Matsumura (Director of Wireless Systems Laboratory) was adopted as Project Manager (PM)**
- **Project name:**
  “Trustable remote-control technology for cybernetic avatars”



https://www8.cao.go.jp/cstp/stmain/20220728ms.html https://www8.cao.go.jp/cstp/moonshot/sub1.html

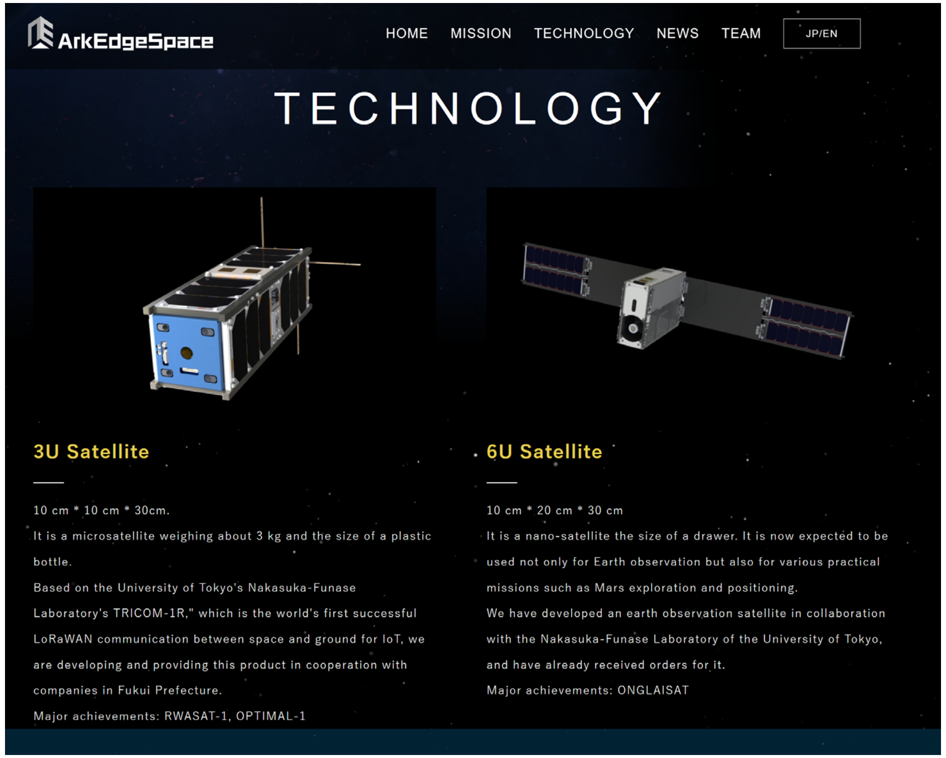
City on the Moon

Vicinity of the Moon around 2030-2035



Navigation and Communication Technology Development for Lunar Surface Activities

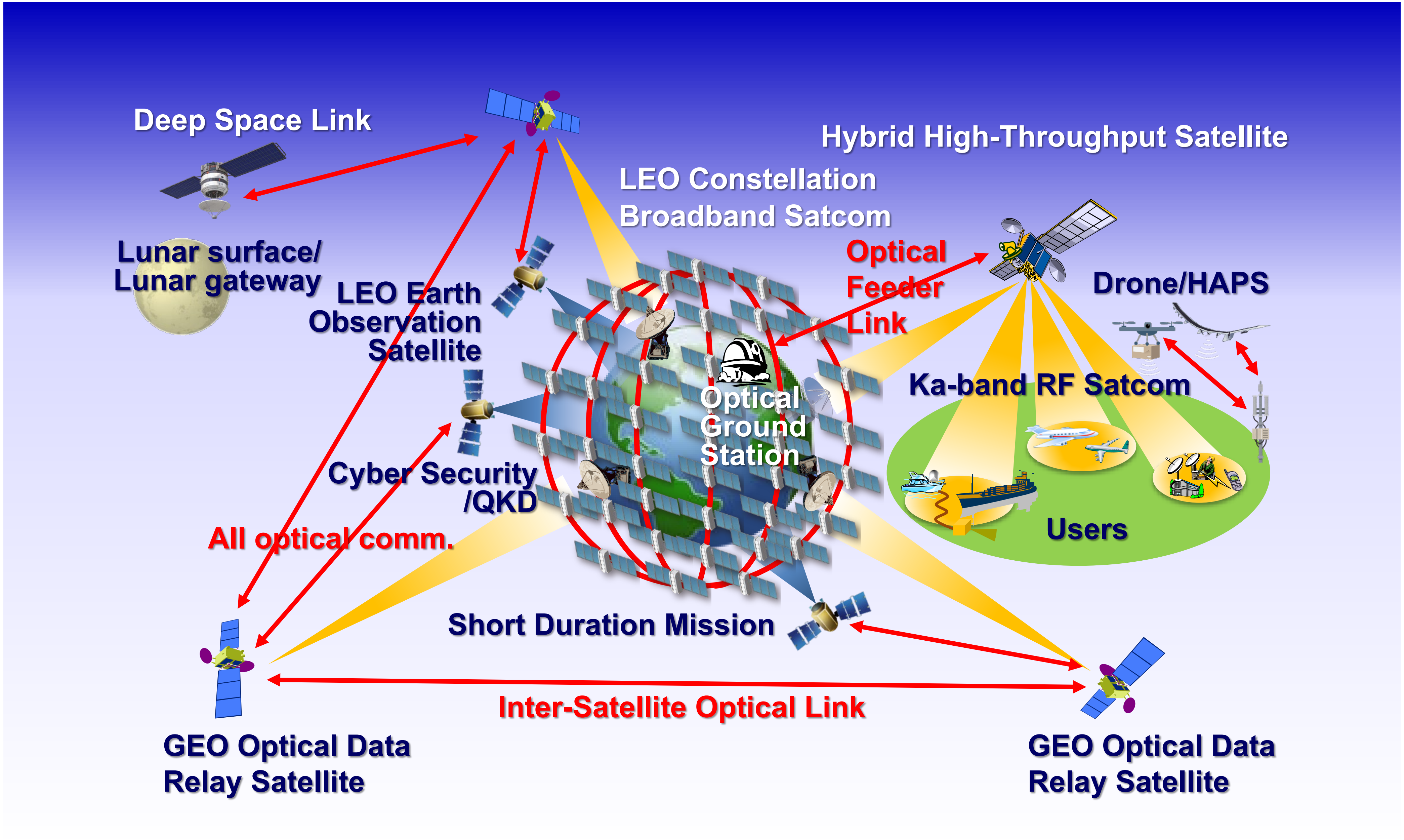
- **JAXA selects a consortium to study "Navigation and Communication Technology Development for Lunar Surface Activities".**
- **December 22, 2021:**
  ArkEdge Space Inc. has been awarded as a contract by JAXA for this study.
- Consortium:
  ArkEdge Space Inc.
  AAI - GNSS Consulting Office
  Kiyohara Optics Inc.
  KDDI Corporation
  KDDI Research, Inc.
  Mitsubishi Precision Co., Ltd.



https://arkedgespace.com/

https://www.kddi-research.jp/english/newsrelease/2022/011101.htm
https://arkedgespace.com/news/2022-01-11_jaxa_moon

Major applications for space laser communications



Concluding remarks

- Recent activities on space laser communications were introduced.
- Due to the difficulty of the RF bandwidth allocation under many constellations, space laser communications will be a promising solution to achieve the higher data rate.
- Space laser communications should be designed for the following applications:
  - Spectrum band limited applications (HTS, Data relay service),
  - Resource limited applications (Micro- / Nano-satellites, and Inter-microsatellite links), and
  - Radio Regulation (RR) free usages.
- Role of space laser communications for NTN should be further discussed for Beyond 5G/6G.