National Institute of Information and Communications Technology

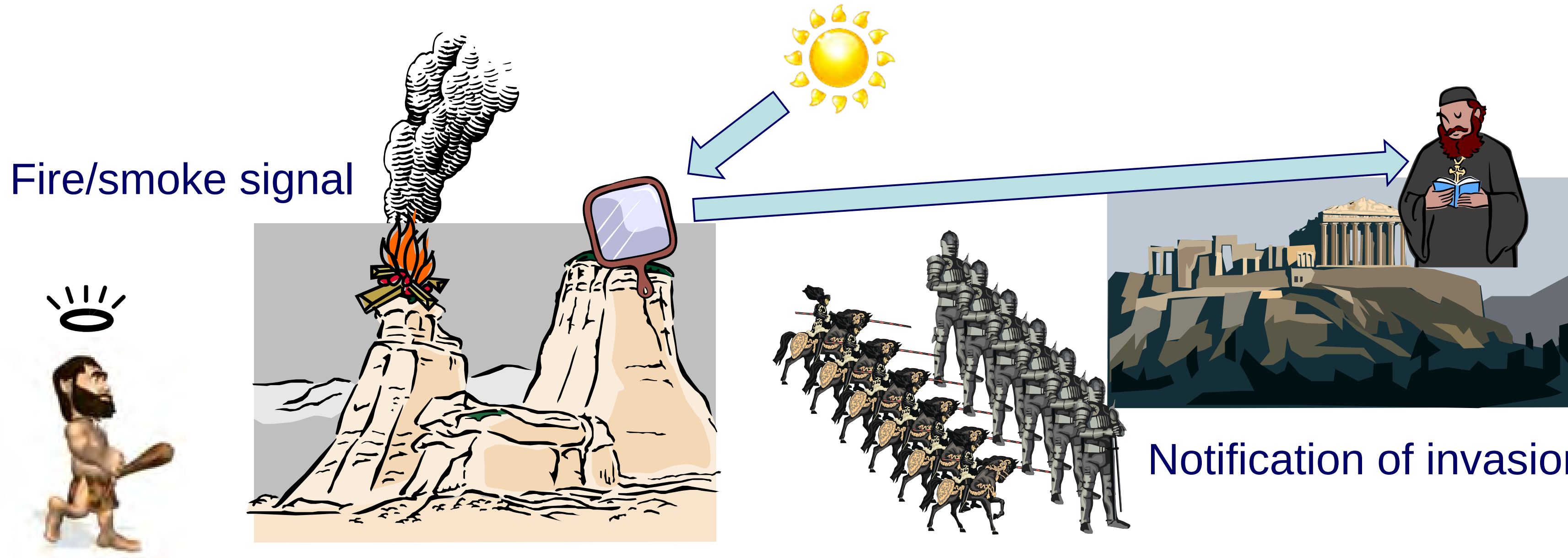
NICT's optical communication projects and ground station development

Morio Toyoshima and Alberto Carrasco-Casado

Space Communications Laboratory
Wireless Networks Research Center
National Institute of Information and Communications Technology (NICT)
Mail: morio@nict.go.jp

Transition of optical communications

Fire/smoke signal



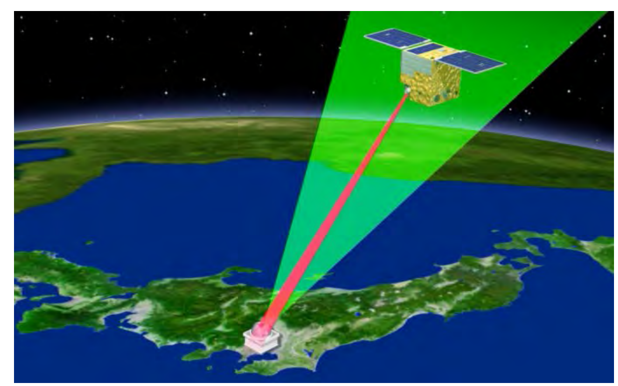
Notification of invasion

~year 700 AD

http://www.amazon.co.jp/古代の光通信-横地-勲/dp/4901346547

Canobeam

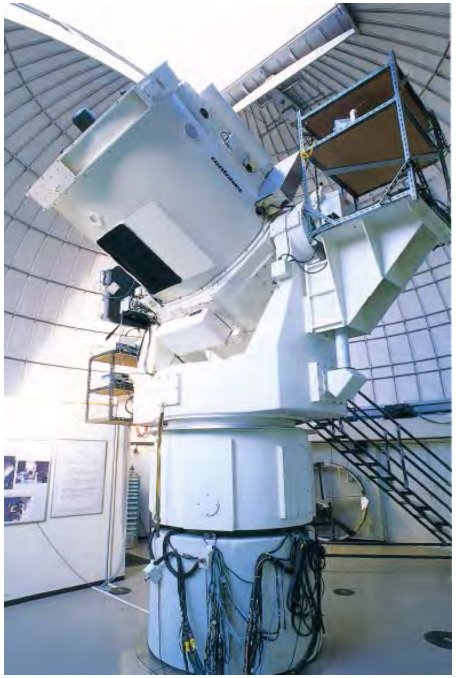
http://cweb.canon.jp/indtech/canobeam/



Satellite lasercomm

Outline

- Introduction
- NICT's activities for space laser communications
  - Engineering Test Satellite VI (ETS-VI)/ Laser Communications Equipment (LCE)
  - Optical Inter-orbit Communication Engineering Test Satellite (OICETS)
  - Space Optical Communications Research Advanced TEchnology Satellite (SOCRATES)/ Small Optical TrAnsponder (SOTA)
  - Very small SOTA (VSOTA)
- Concluding remarks

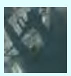


Advantages of space based-lasercom

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

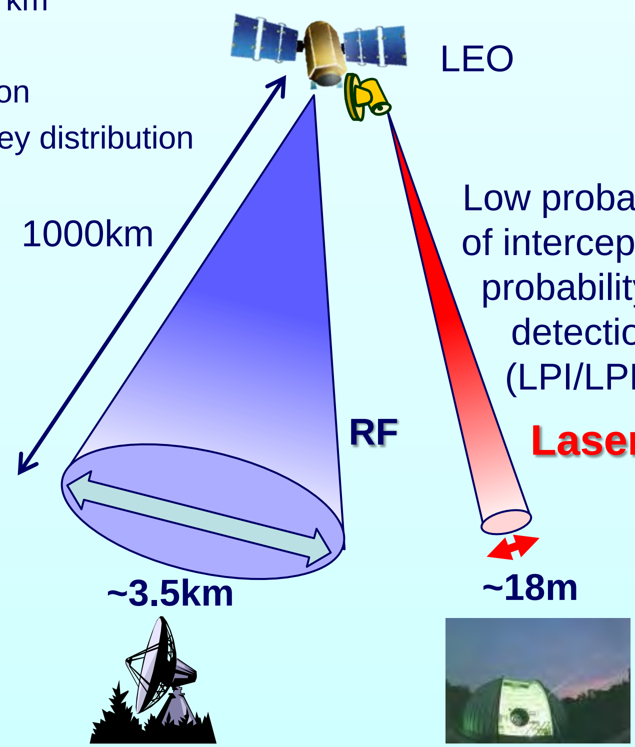
Beam divergence angle:
- -Optical: ~0.001 degrees
- -RF: ~0.2 degrees

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

LPI/LPD

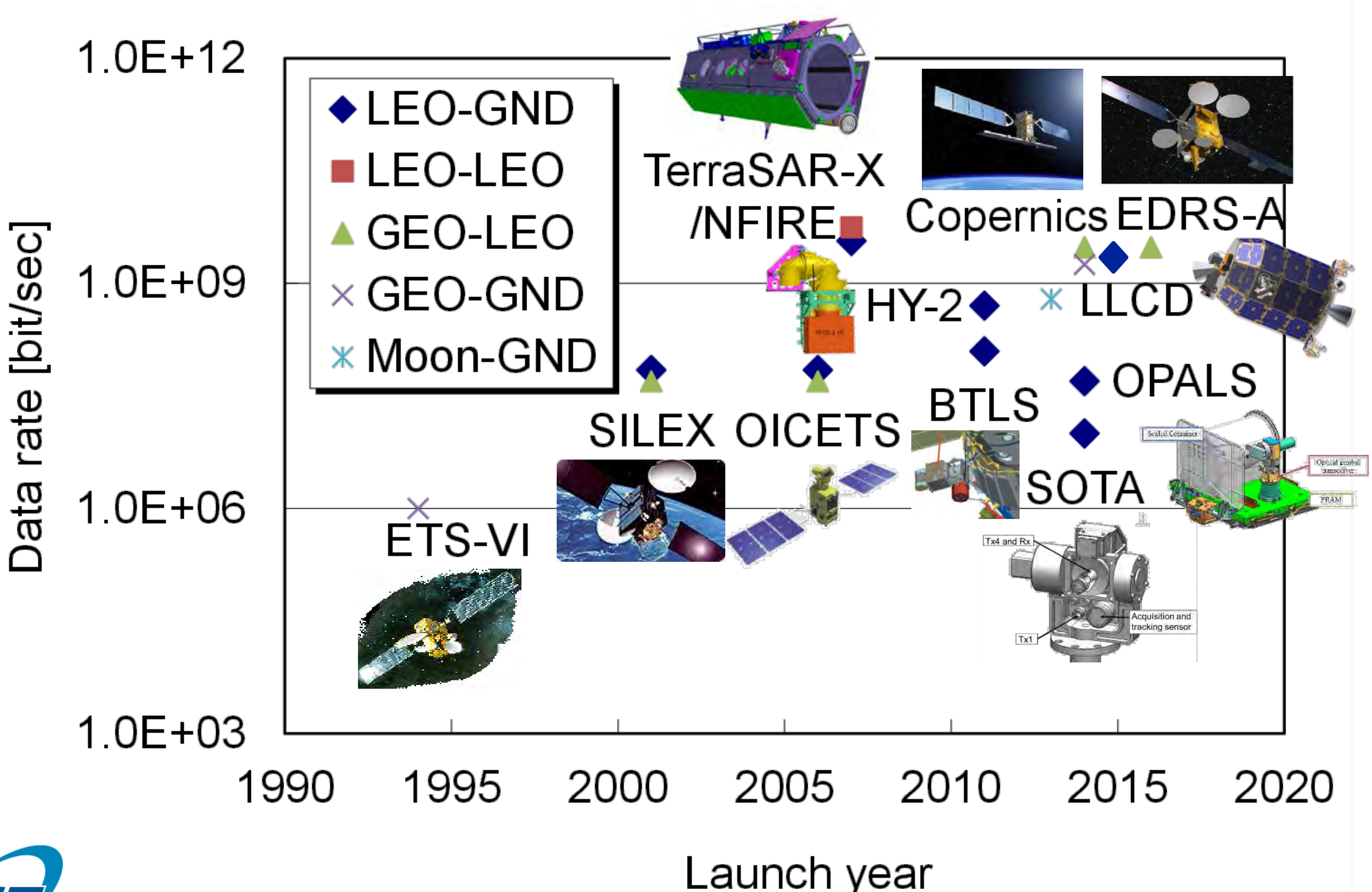
No regulation

Quantum key distribution

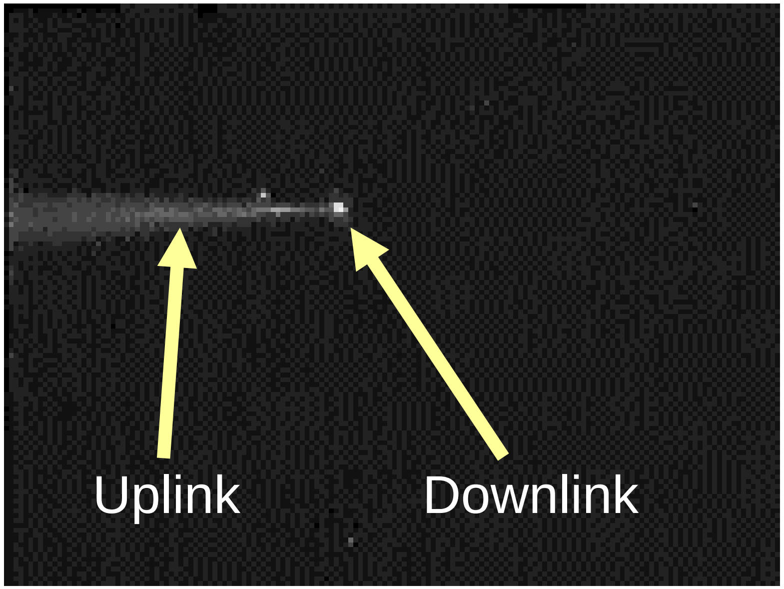


Low probability of intercept/low probability of detection (LPI/LPD)

Trends of data rate for space laser comm.

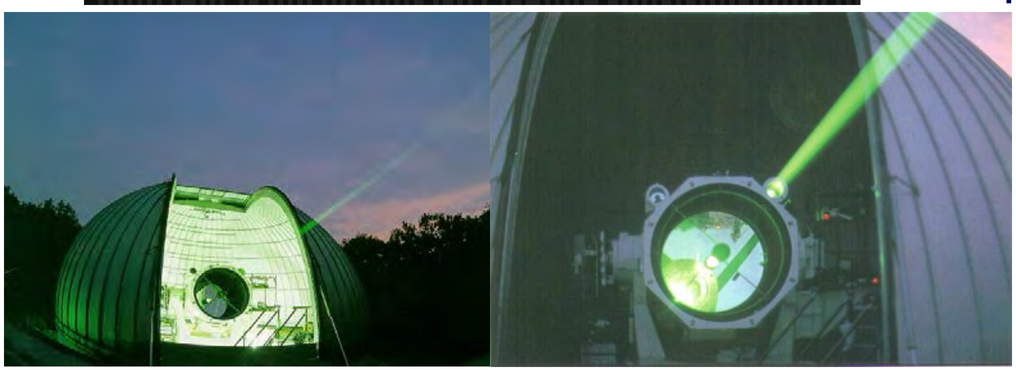


Engineering Test Satellite VI (ETS-VI) Experiments (Dec. 1994 - July 1996)



Laser Communication Equipment (LCE)

ETS-VI (GEO)



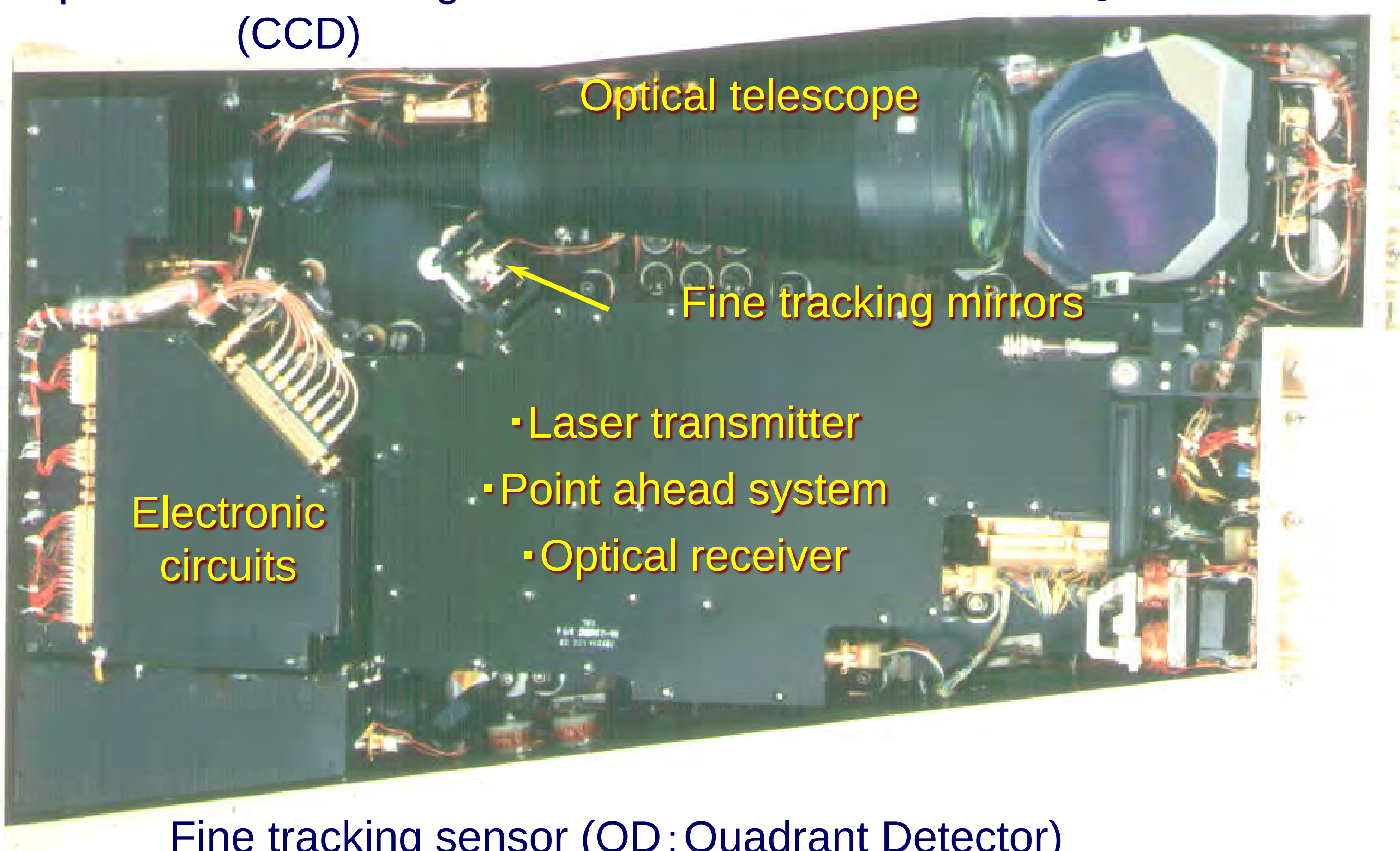
NICT optical ground station

- 1 Mbps bi-directional optical link experiment
- 22 kg, 60 W onboard equipment verification

Internal optics of LCE

Acquisition and tracking sensor (CCD)

Two-axis gimbal mirror

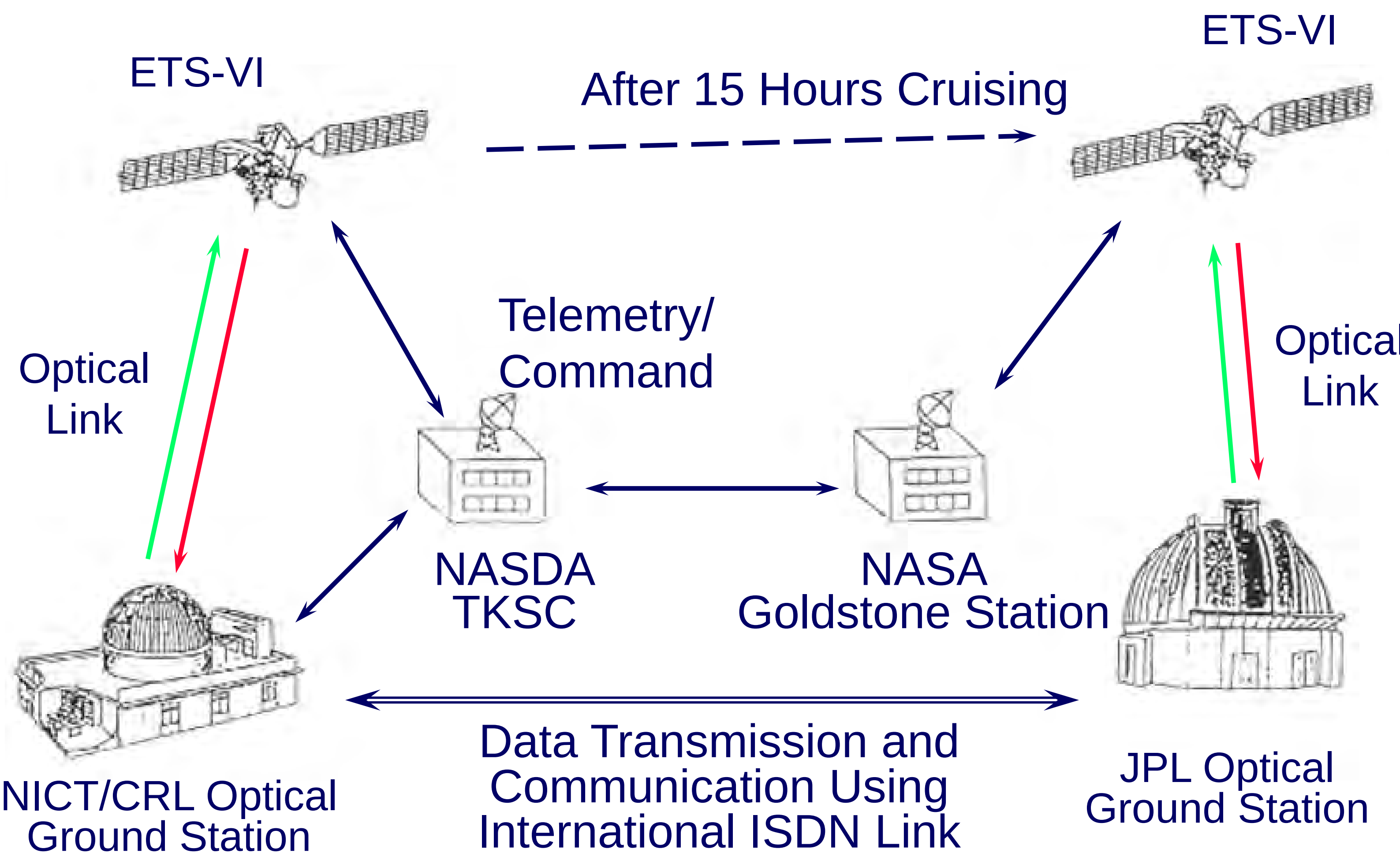


Fine tracking sensor (QD：Quadrant Detector)

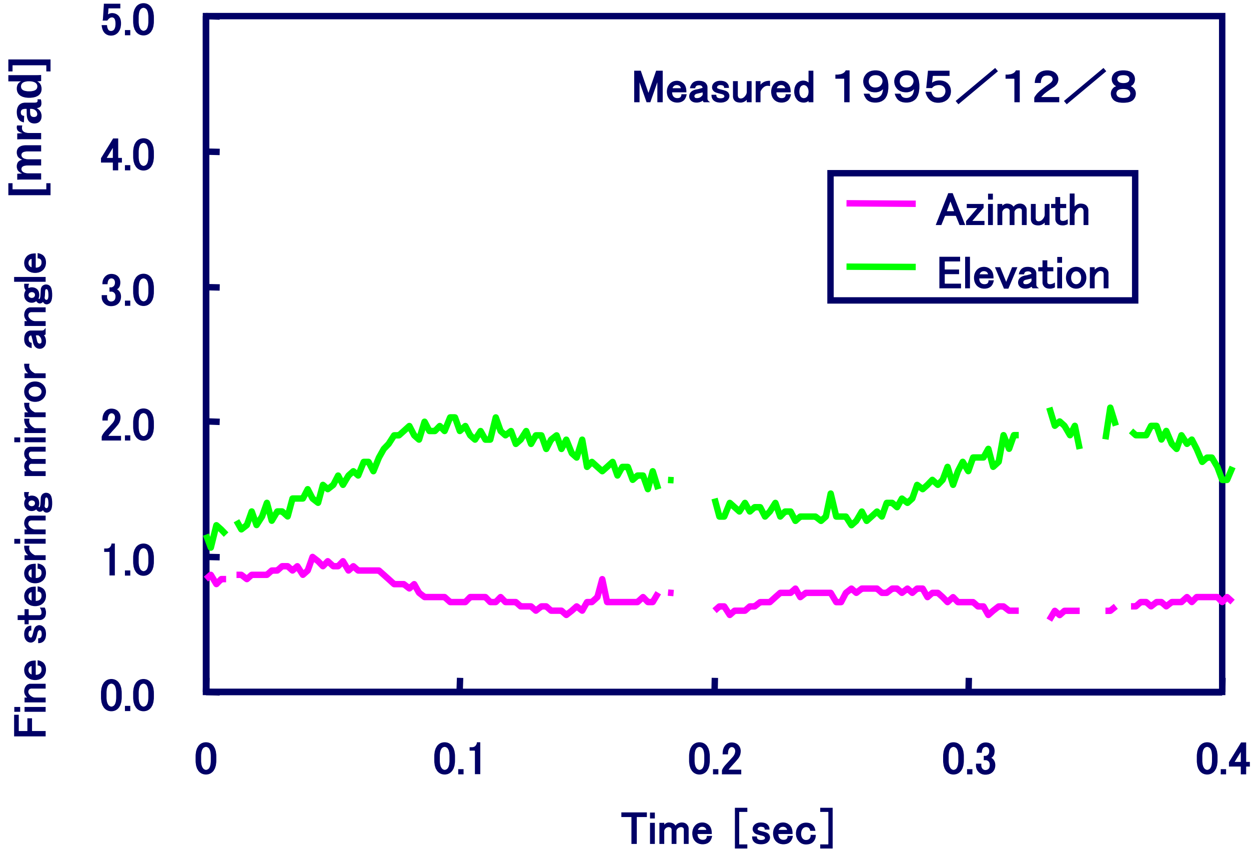
NASA GOLD (1995)

- ETS-VI
- International collaboration between CRL and JPL
- JPL Table mountain facility

Experimental configuration with JPL

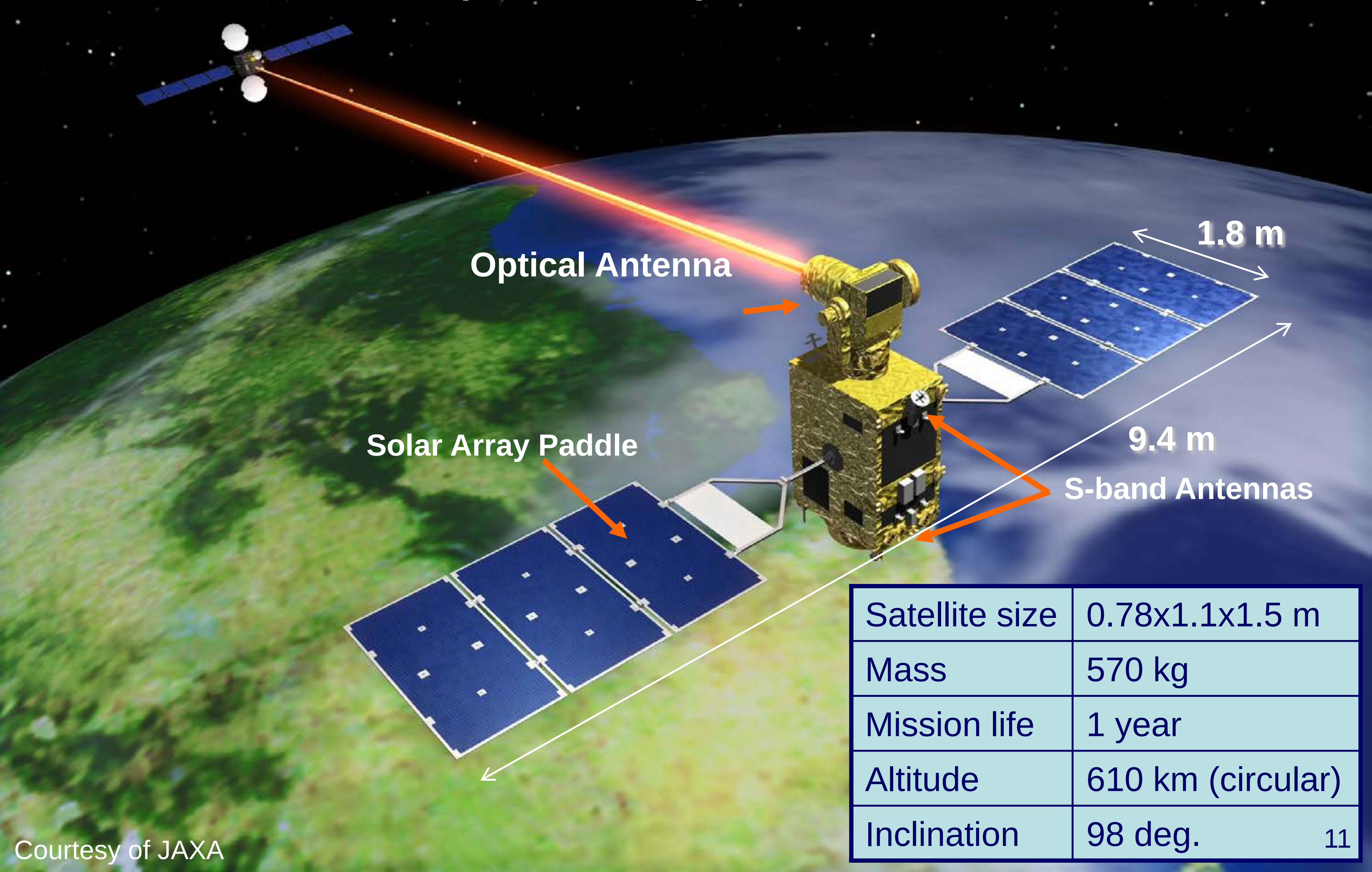


World first transmitted telemetry data via optical communication link with 1 Mbps



Sampling freq. 500Hz

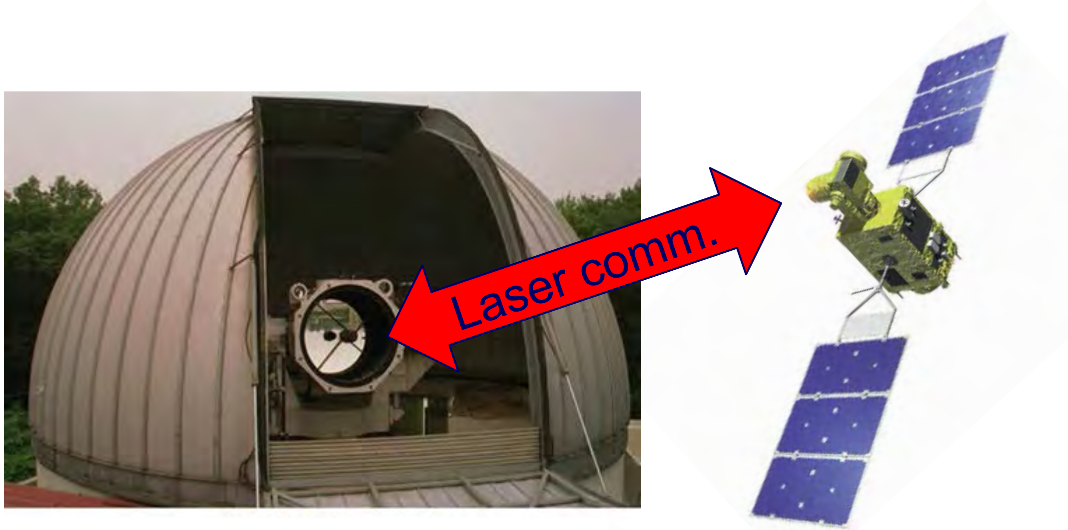
Optical Inter-orbit Communication Engineering Test Satellite (OICETS) (August 2005 – Sept. 2009)



Satellite size	0.78x1.1x1.5 m
Mass	570 kg
Mission life	1 year
Altitude	610 km (circular)
Inclination	98 deg.

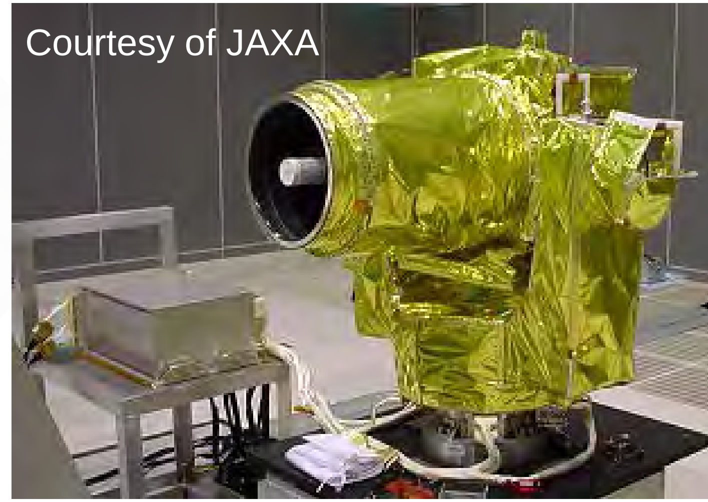
Courtesy of JAXA

Laser communications experiment using the OICETS satellite (Mar. 2006 – Sep. 2009)



NICT optical ground station

OICETS (LEO)



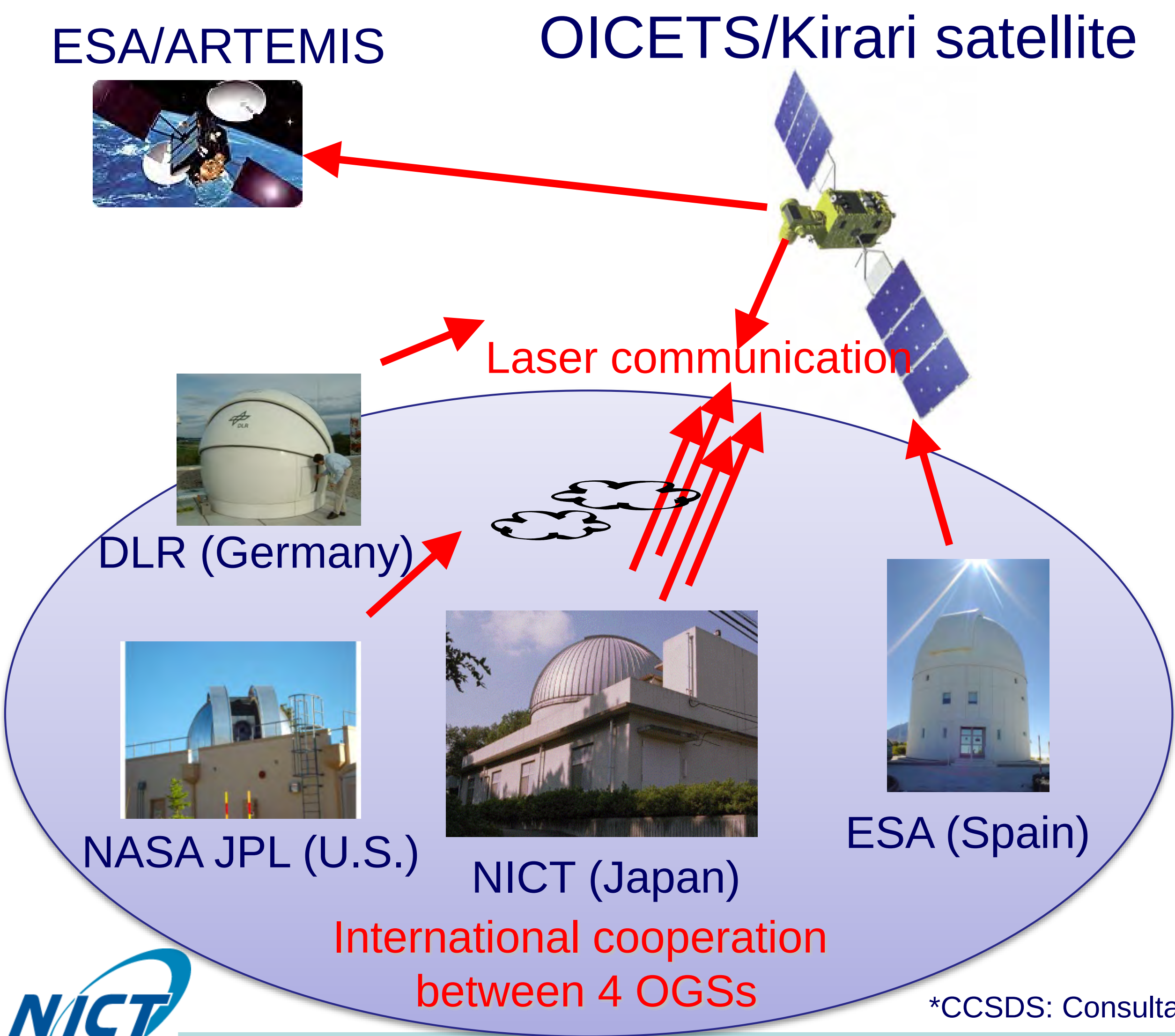
Laser Utilizing Communication Equipment (LUCE)

- Major specifications
  - Wavelength: 0.8 μm
  - Data rate: downlink: 50 Mbps, uplink: 2Mbps
  - Successful tracking through all the paths
  - Footprint of the laser beam: only ~6 m (from 1000 km)

Acquisition and tracking

Wide FOV CCD	CCD at Tx bench
Guide Telescope	CCD at Rx bench

International laser communications experiment



Data acquisition of laser beam propagation and link establishment at different sites

↓

Modeling the atmospheric propagation channels and learning site diversity effect

↓

Examining optimum error correcting codes and the best combination of OGSs

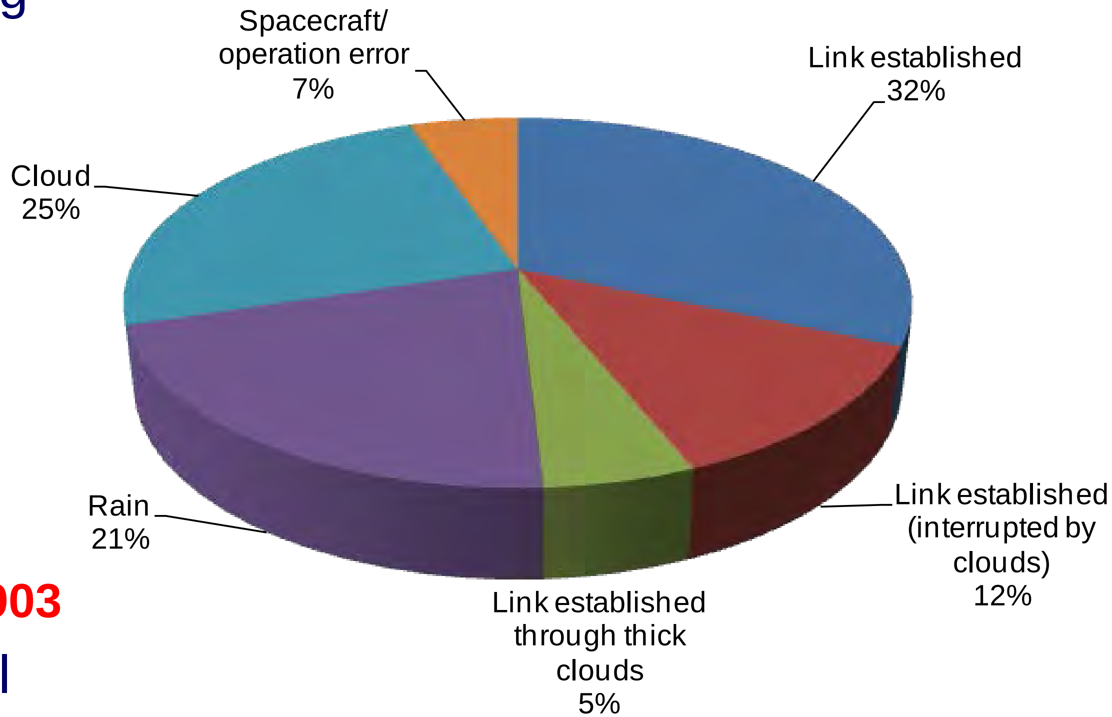
↓

Contribution to the standardization in ITU-R and CCSDS*.

*CCSDS: Consultative Committee for Space Data Systems

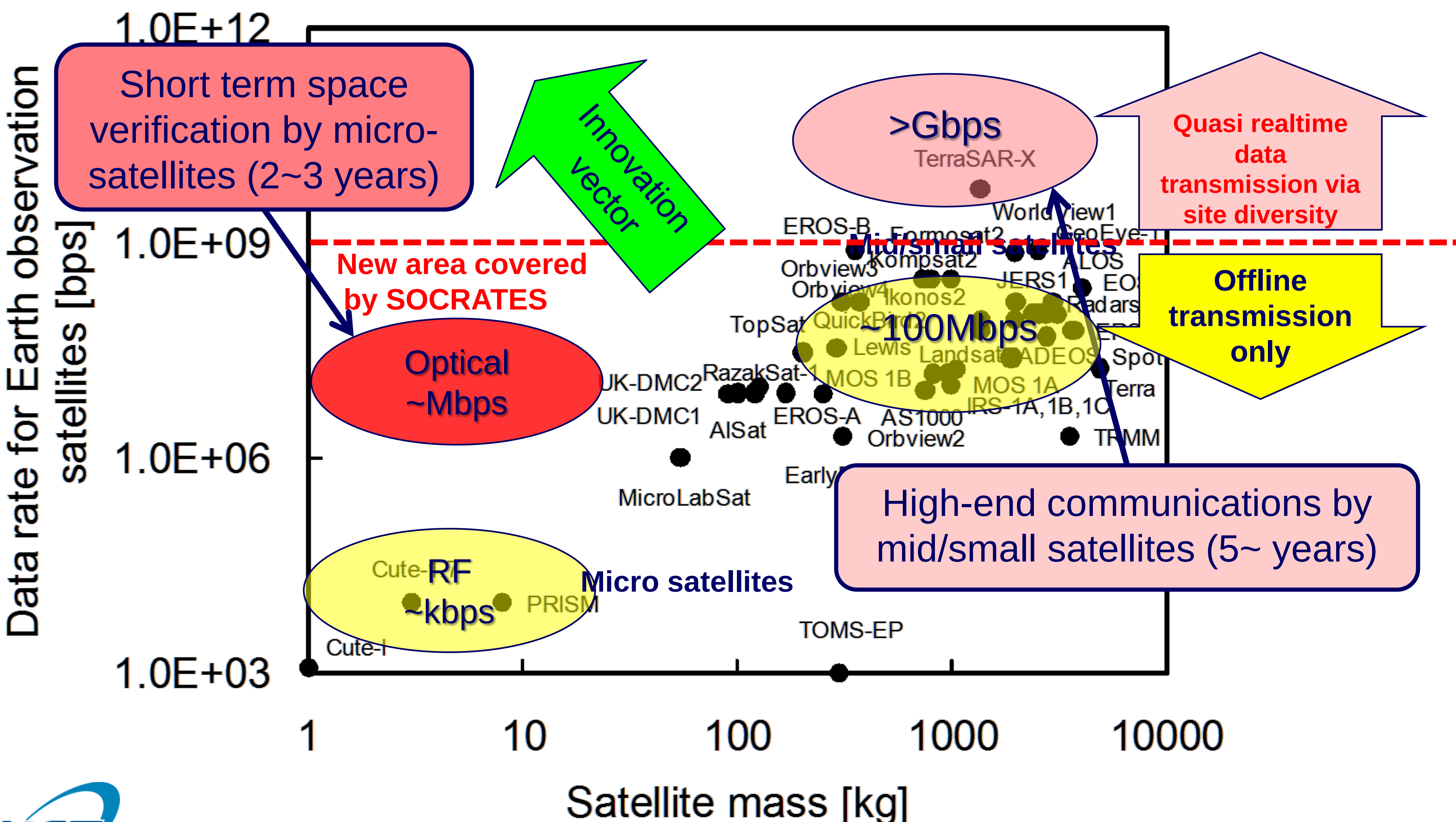
Statistics of link establishment

- Probability of success during all the experiments
  - NICT: 49.1 %
  - NASA JPL: 57.1 %
  - DLR: 60.0 %
  - ESA: 88.9 %
- Total probability of success between Earth and space:
  - 1-[(1-0.491)x(1-0.571) x(1-0.60)x(1-0.889)] = **0.9903**
- Four OSGs combination will help to download massive data from space with the probability of 99%.

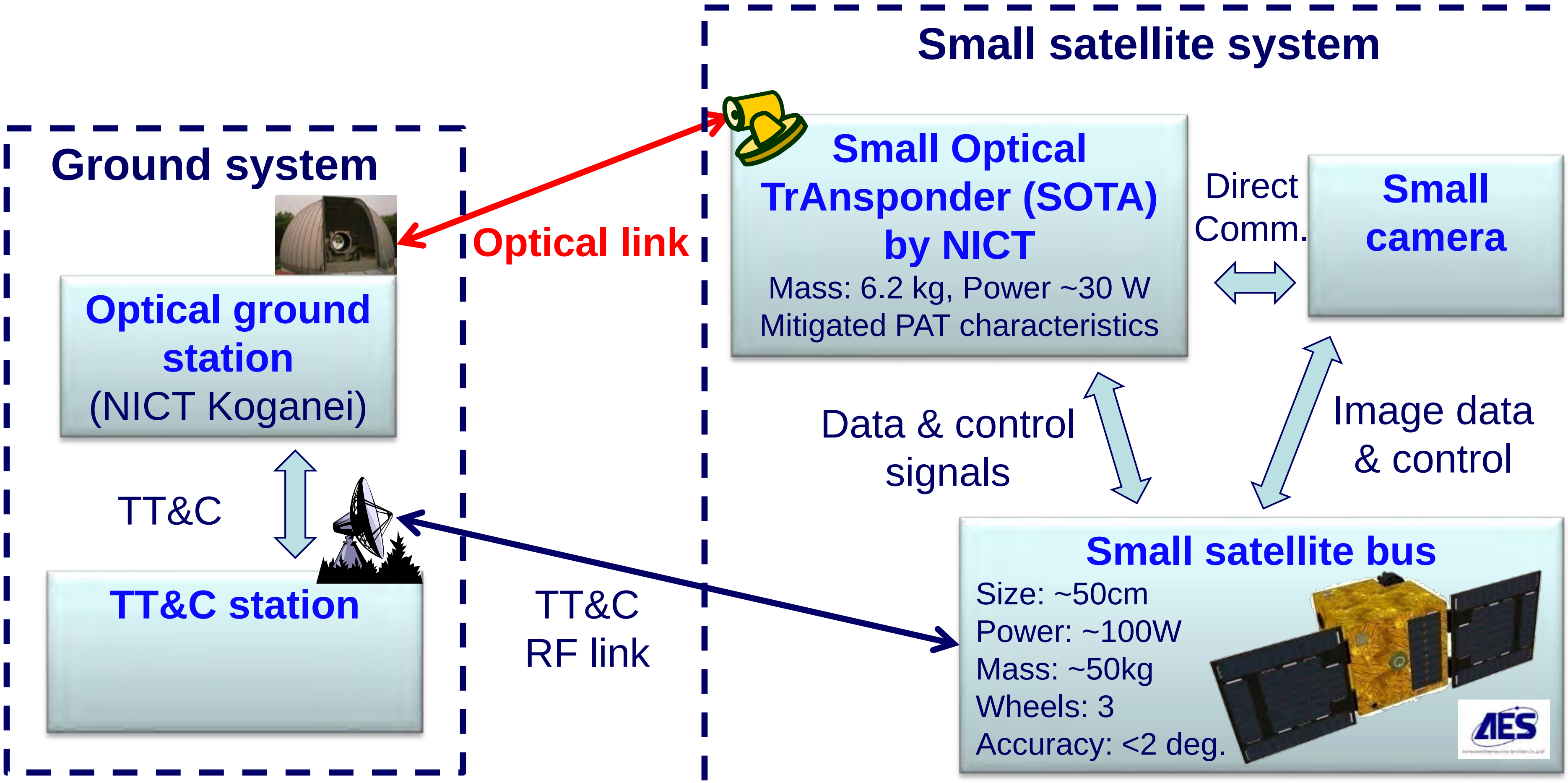


Statistics of link establishment at NICT

Laser communication infrastructure for micro-satellites



Space Optical Communications Research Advanced TEchnology Satellite (SOCRATES) (1/2)



*TT&C: Tracking, Telemetry and Control

Space Optical Communications Research Advanced TEchnology Satellite (SOCRATES) (2/2)

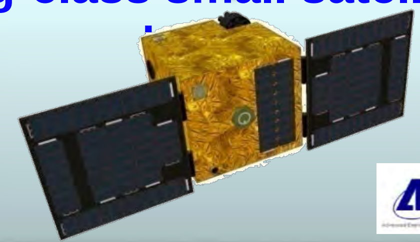
Main objectives:

- In-orbit verification of acquisition, tracking and pointing performances
- Data acquisition of laser beam propagation at various wavelengths
- Laser communication experiments with coding
- Basic experiments for satellite QKD
- Experiments with international Optical Ground Stations (OGSs)

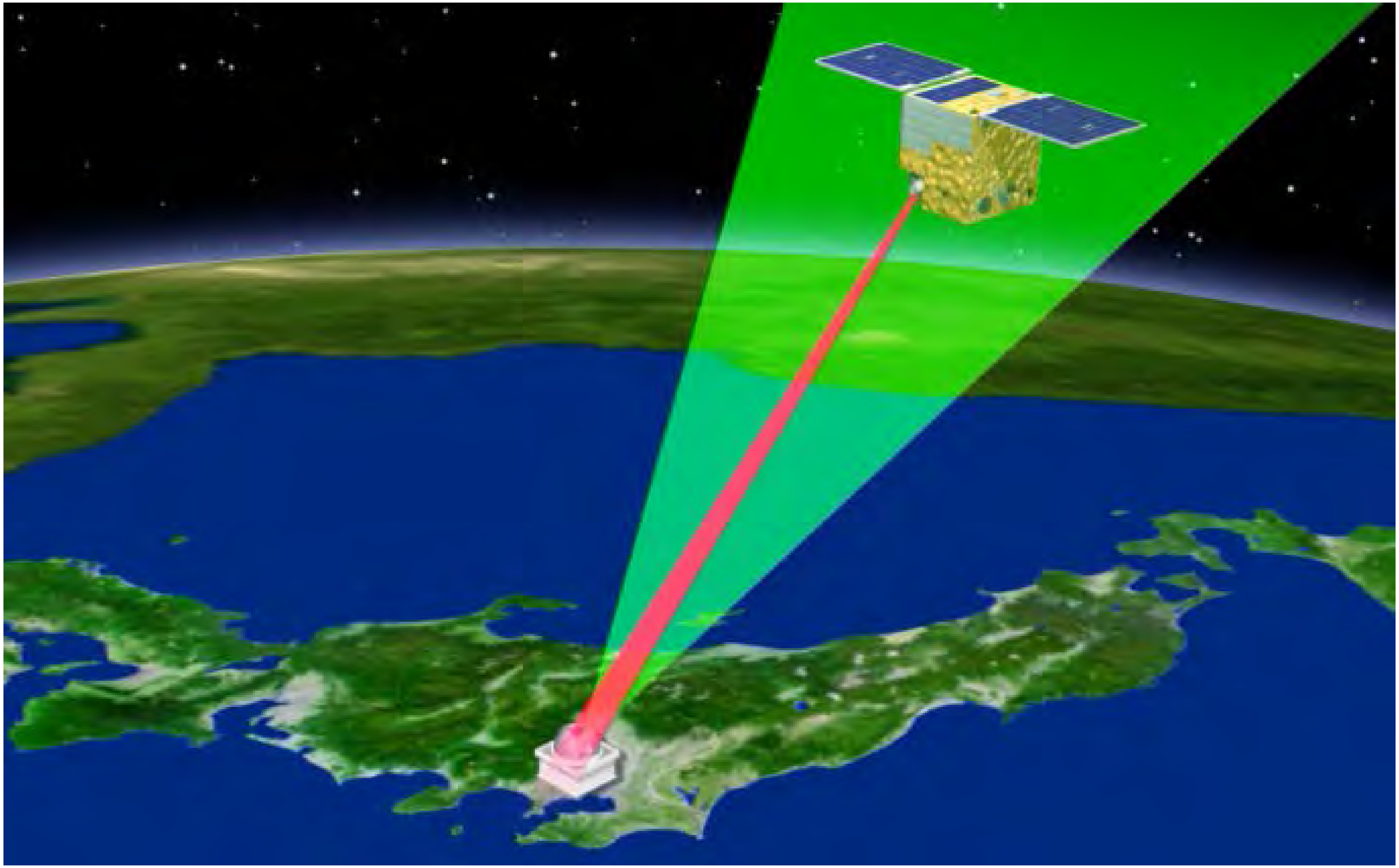
Major design parameters of the PFM				
Mass	6.2 kg			
Power	Tx1	Tx1+Rx	Tx2,3,4	Tx2,3,4+Rx
	28.1W	39.5W	32.5W	37.3W
Acquisition/Tracking	Az: >±50deg, El: >±50deg			
Link range	1000km			
Wavelength	TX 1: 975nm			
	TX 2 & 3 : 800nm-band			
	TX 4 : 1543nm			
	RX: 1064nm			
Data Rate	10Mbps			

Small Optical TrAnsponder (SOTA) by NICT

50-kg-class small satellite



Scenario for SOCRATES/SOTA

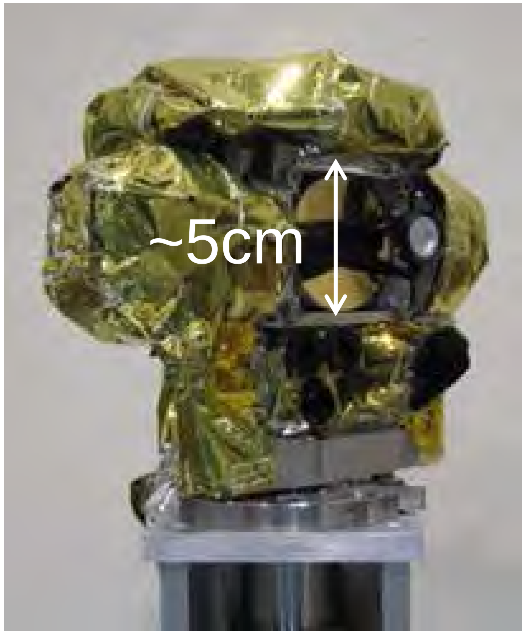


How small is SOTA?

OICETS optical terminal (2006)
Mass: ~140kg

T. Jono, et al., AIAA ICSSC (2006).

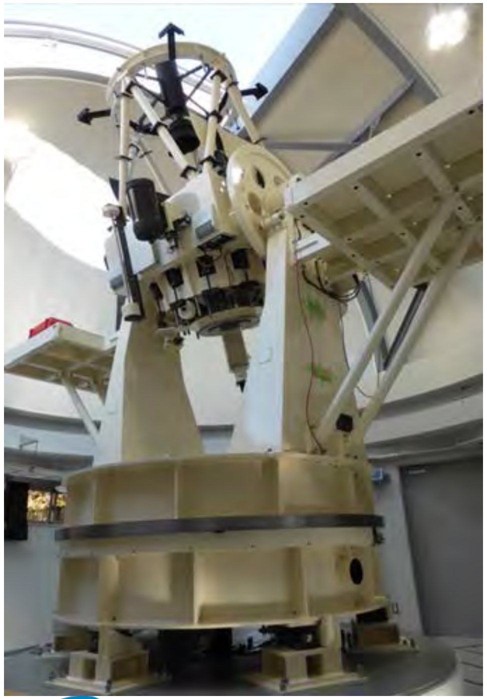
SOTA optical terminal (2014)
Mass: ~6kg

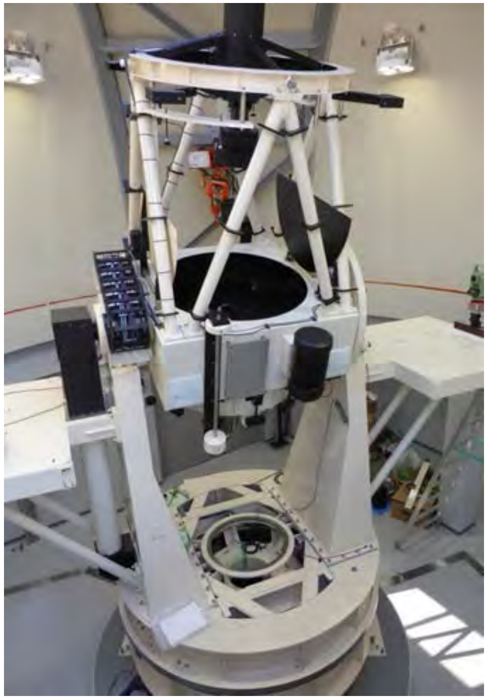


Optical ground station in Koganei (1-m diameter)

- 1-m diameter reflective telescope
- Improved tracking ability for LEO satellites
- Focus availability: 5 ports (Cassegrain, Nasmyth, Coude

Koganei





Major specification

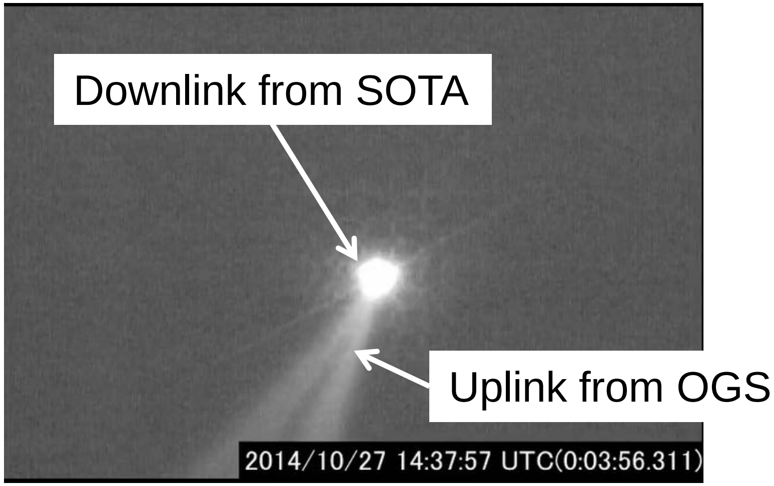
Mount	Altazimuth
Focus	Classical Cassegrain
Diameter	ϕ1000 mm
D/f	F12
Tracking accuracy	
LEOs	< 10 arcsec
Stars	< 0.4 arcsec (EL > 30 deg.)
Stars	< 1 arcsec (EL=15~30 deg.)
Angle coverage	Azimuth ±270 deg. Elevation 15~88 deg.
Total mass	7.5 t
Tube mass	1.3 t
Nasmyth payload mass	1 t (max)

Launch of SOCRATES satellite

National Institute of Information and Communications Technology (NICT) concludes an research agreement with Advanced Engineering Services Co., Ltd. (AES).
NICT is aiming at demonstration experiments of LEO-to-Ground laser communication. AES is encouraged to show demonstration of the small satellite standard bus and provision of environment to demonstrate advanced missions and element technologies in orbit.

Launch Vehicle: H-IIA No.24
Date: May 24th,2014.
Location: Tanegashima Space Center of JAXA

Image transmission experiments via an optical link



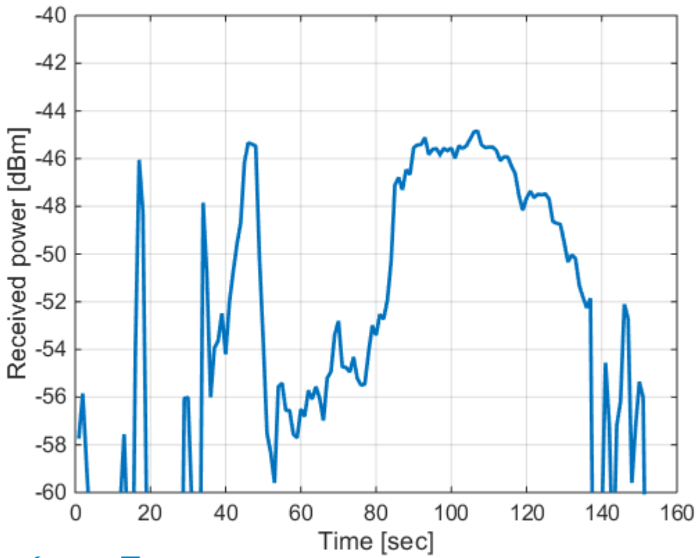
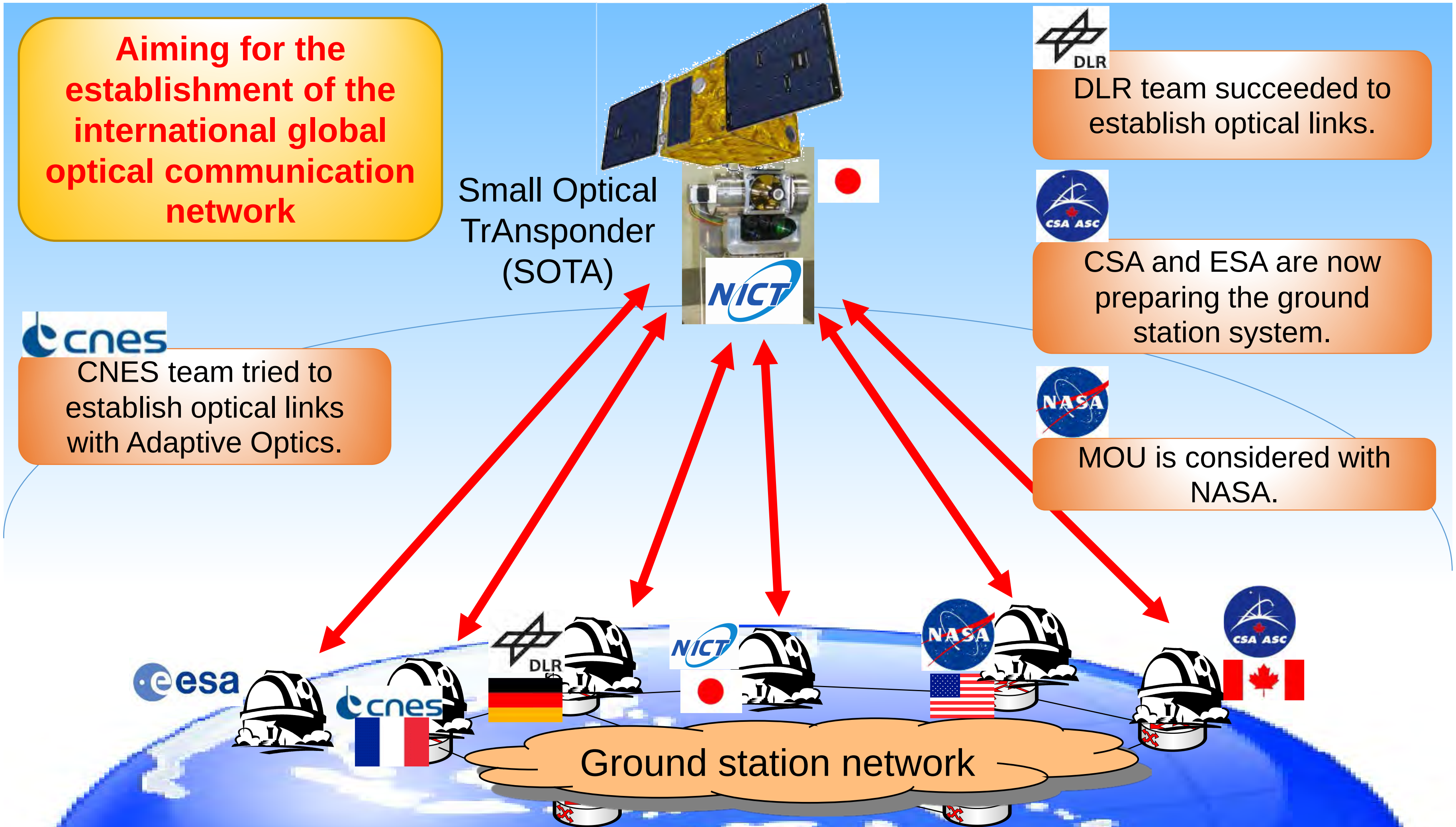


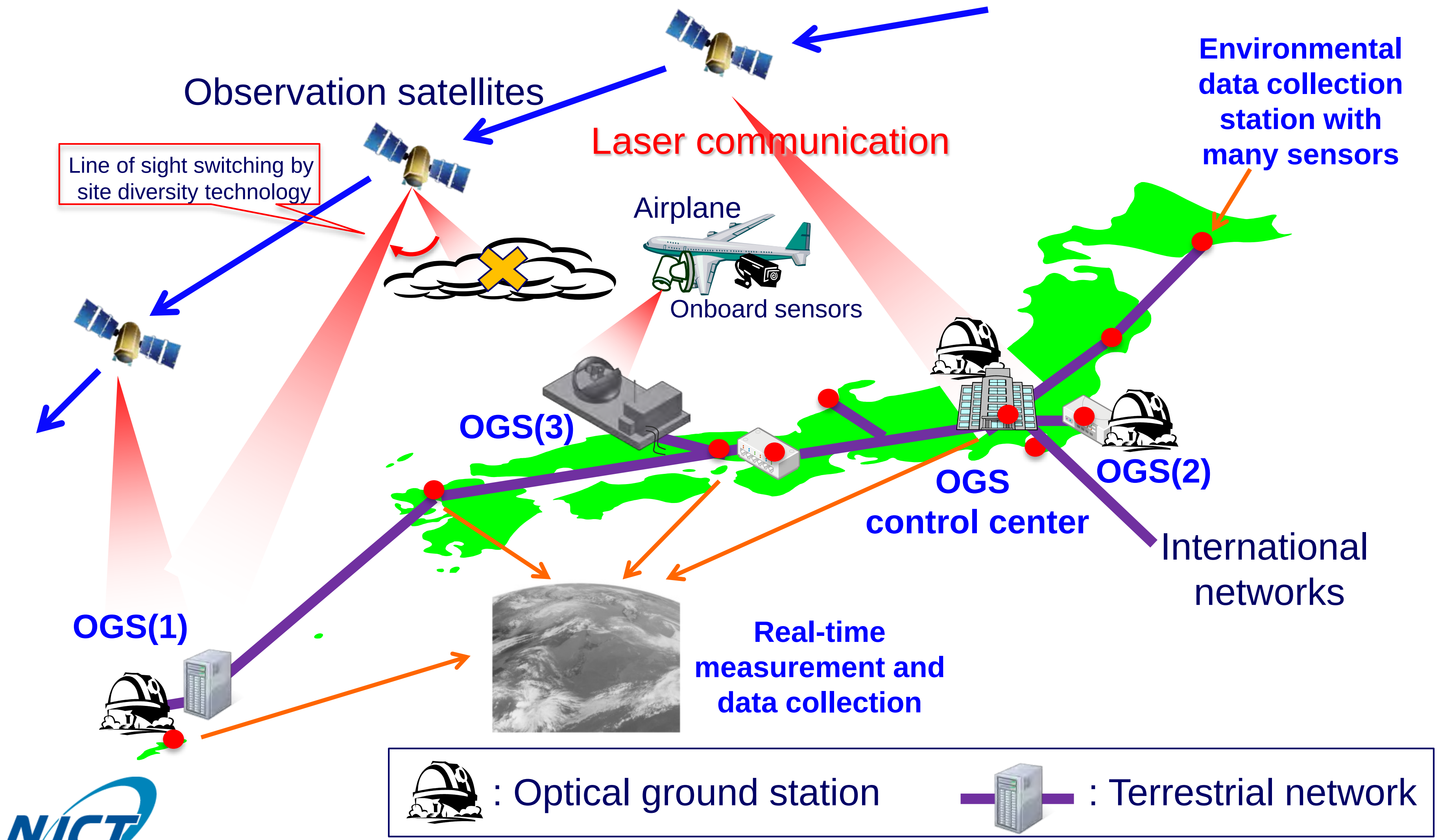
Image transmitted via an optical link (Press released on 3 June, 2015)

International experiment campaign with SOTA



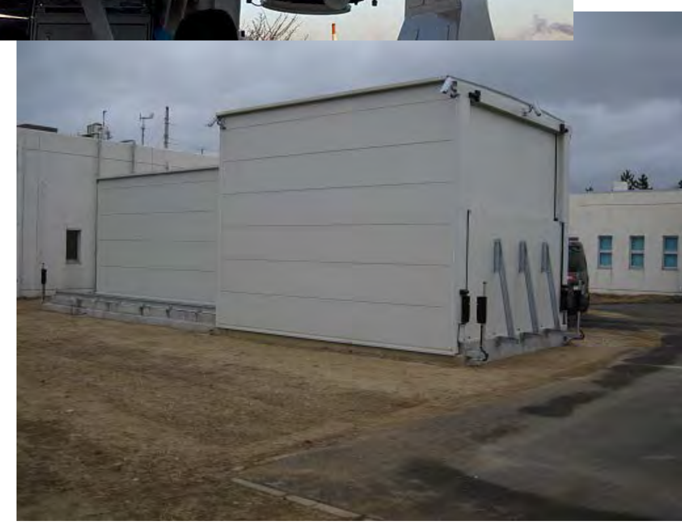
Overview of Terrestrial Free-Space Optical Communications Network, INNOVA

(IN-orbit and Networked Optical ground stations experimental Verification Advanced testbed)



Site diversity experiments with 1-m diameter optical ground stations in Okinawa and Kashima

Extra success level



Okinawa station

Kashima station

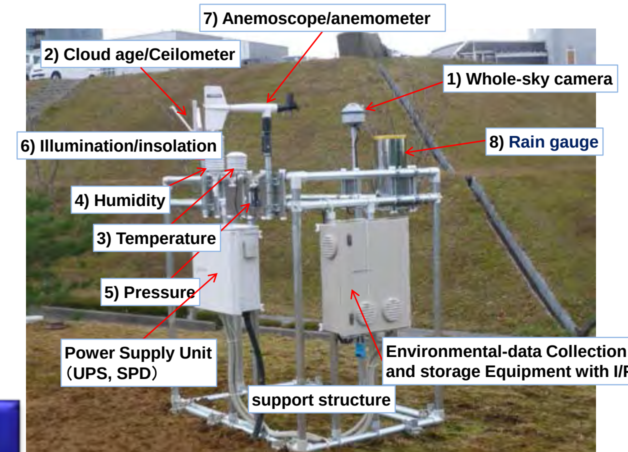
Environmental data collection system contributing to site diversity

Real time weather monitoring

Data collection and analysis for link availability

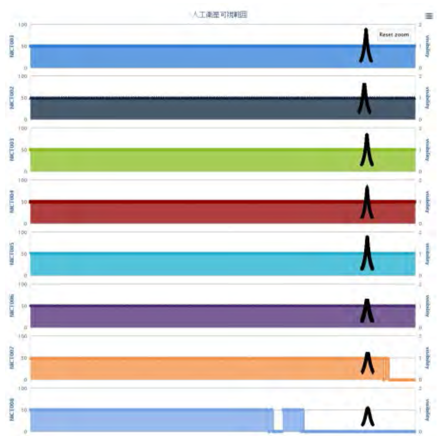
Common data I/F and world first verification model

Contribution to CCSDS and linked international OGSs

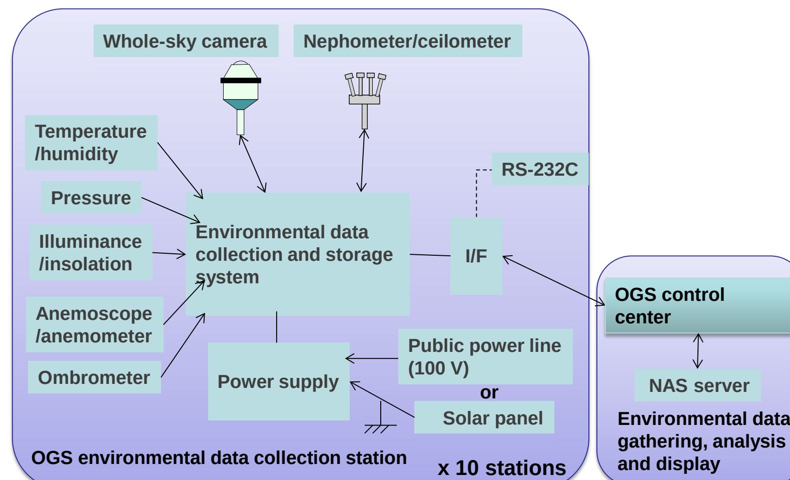


Sensor station in NICT Hokuriku StarBED

Top page for Website



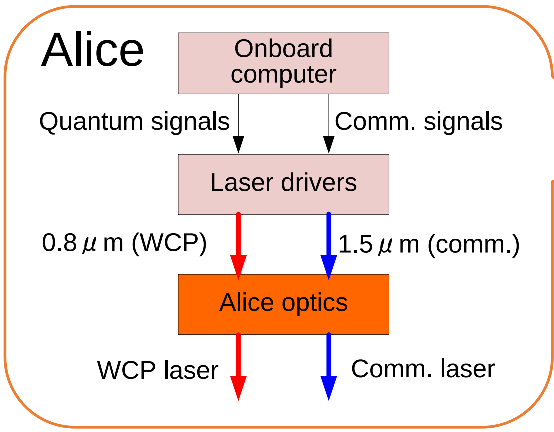
Visible pass analysis

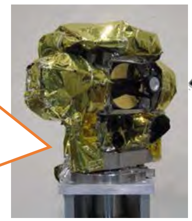


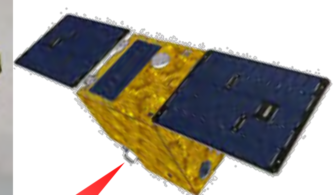
Configuration of data collection system

Block diagram of basic QKD experiments

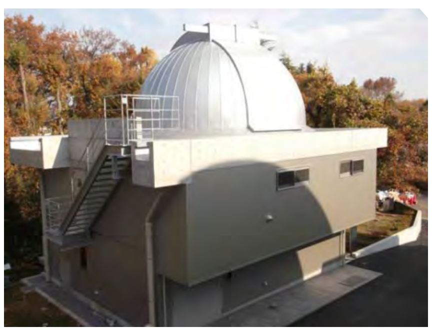
Extra success level



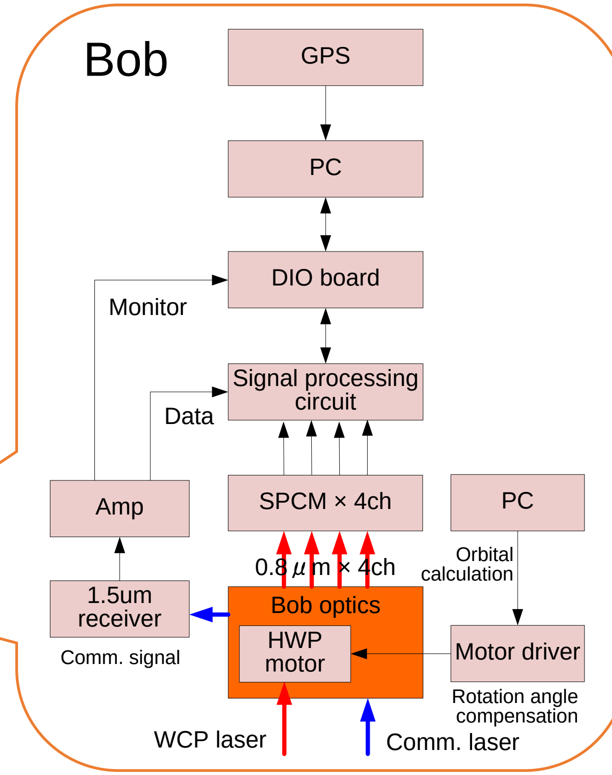




SOTA (Alice)



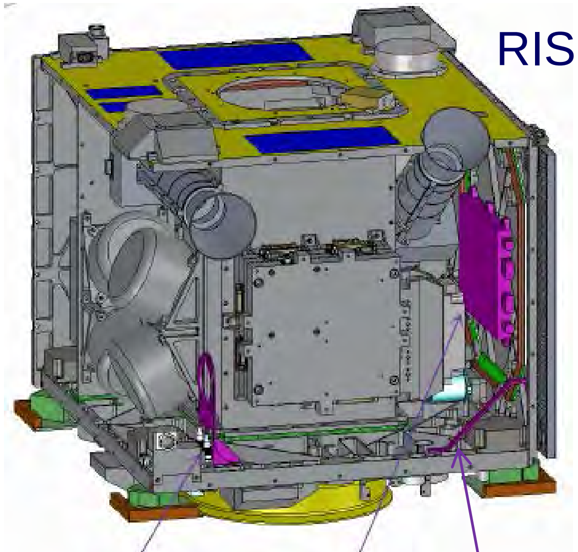
Bob optics in OGS

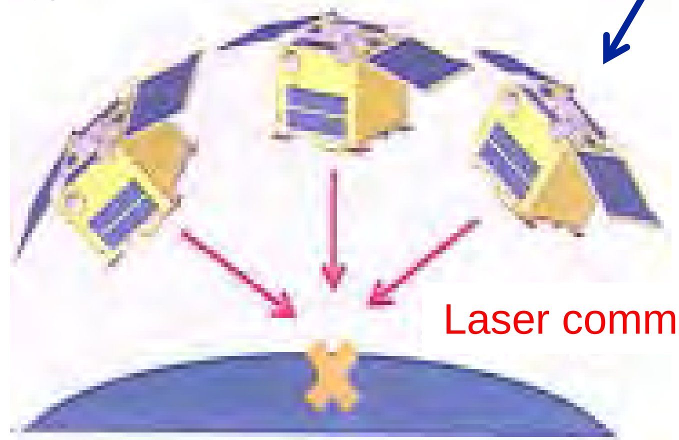


Laser communication mission onboard RISESAT, VSOTA (Very Small Optical TrAnsmitter for component validation)

RISESAT satellite

東北大学 TOHOKU UNIVERSITY





Onboard components

Laser driver (Flight model)

Major specification

Mass:
- Satellite bus total: 55kg, VSOTA: 700g

Orbit:
- 500-900km (Nominal 700km), Sun synchronous (inclination 98 degree) (TBD)

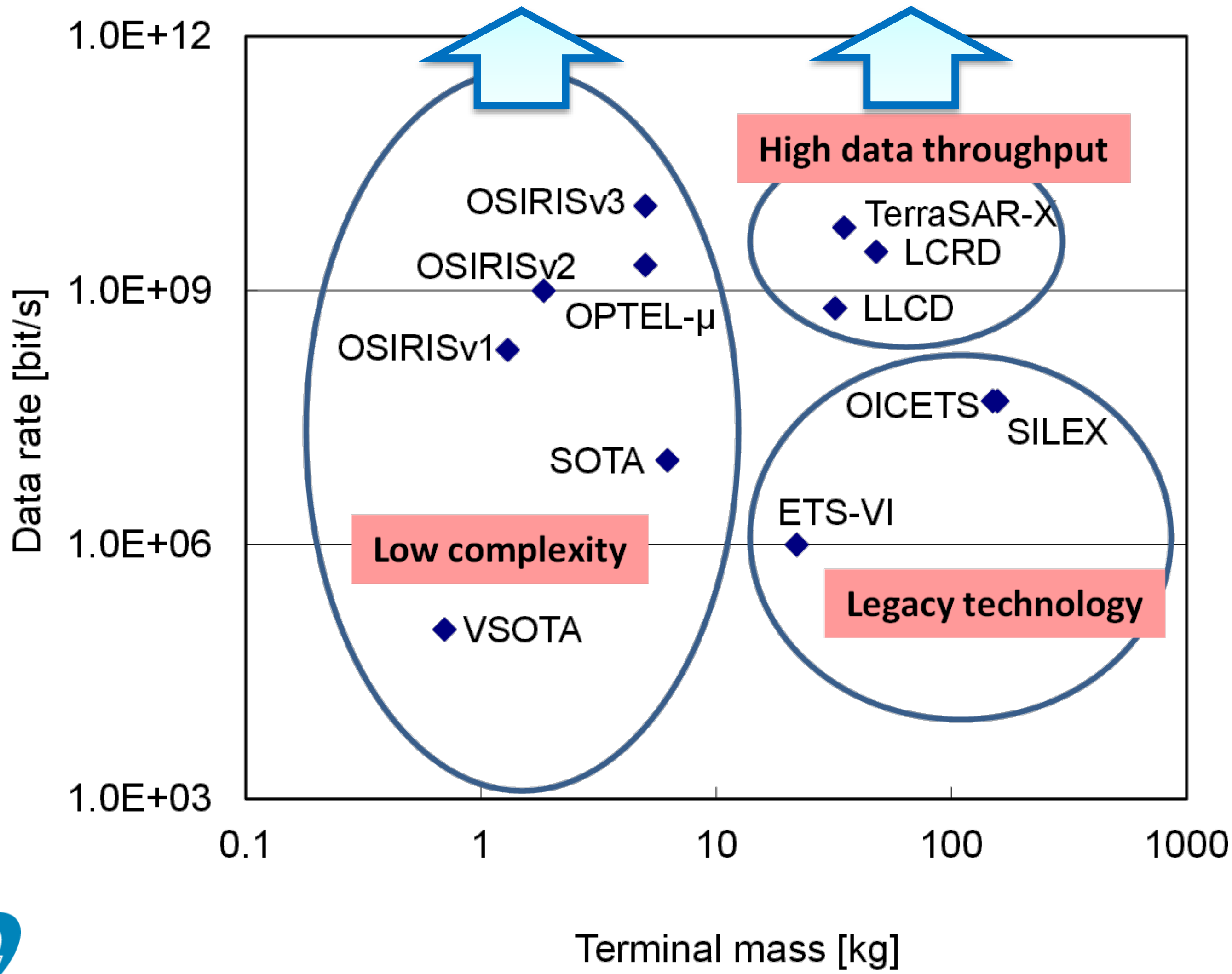
Power consumption:
- 3.5W (10 minutes)

Attitude control accuracy:
- Requirement: 0.1degree or 1.7mrad (3σ)
- Target: 0.04 degree or 0.7mrad（3σ）

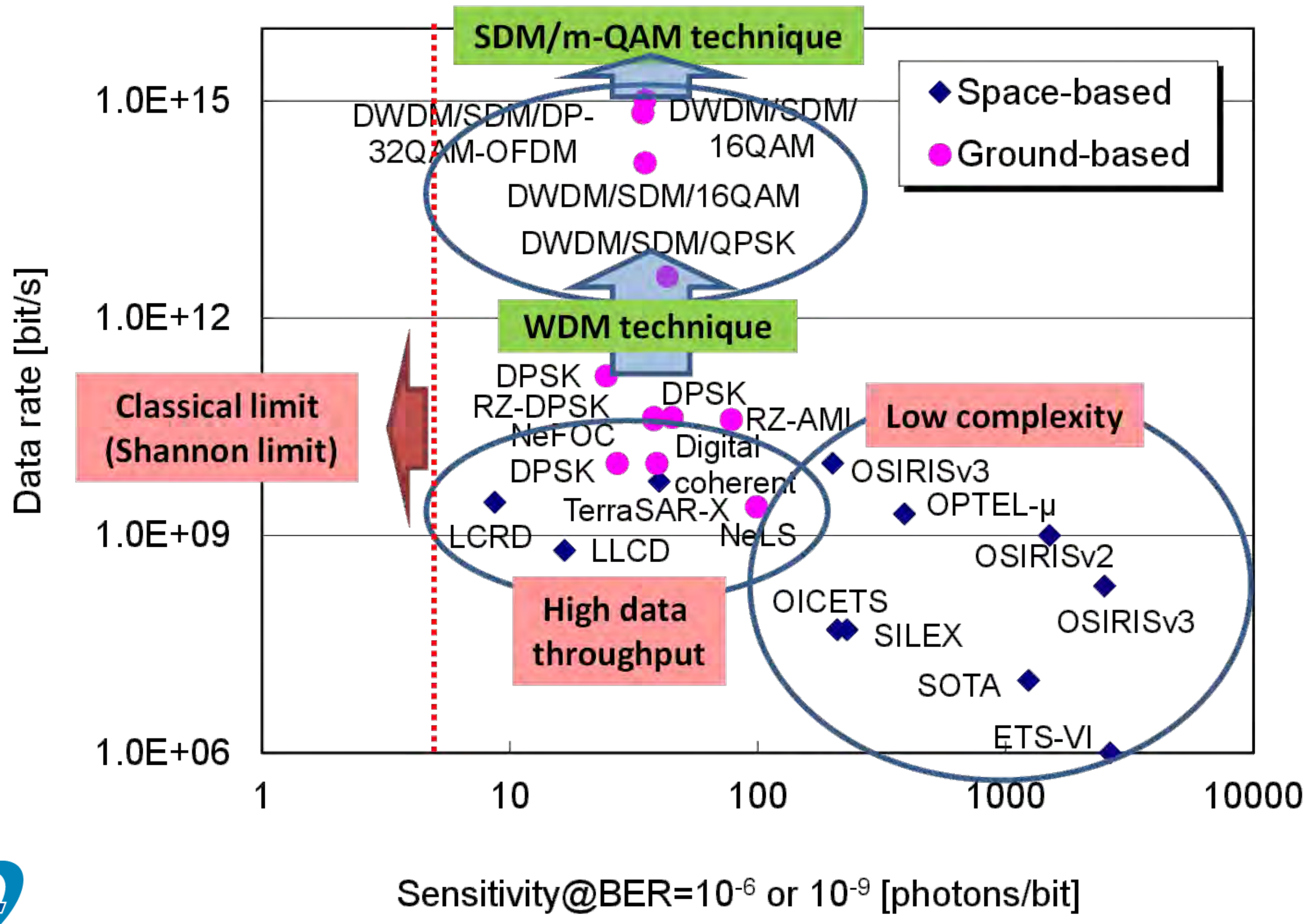
Space-based laser communication programs

	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	- 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, homodyne 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, 1.5μm, IMDD, 5-50Mbps	- 2001: **SILEX** (ESA), GEO-LEO, GEO-GND, GEO-Air, 0.8μm, IMDD, 50Mbps - 2008: **TerraSAR-X** (DLR), LEO-LEO, LEO-GND, 1.06μm, homodyne 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, homodyne BPSK, ~1.8Gbps, Including **AlphaSat, Sentinel-1A, EDRS-A, Sentinal-1B**
Future plan	- 2016: **QKD satellite** (China), BB84, 0.85/0.532/0.671μm - 2017: **RISESAT/ VSOTA** (NICT), LEO-GND, 0.98/1.5μm, IMDD, ~1kbps - 2019: **JDRS** (JAXA), GEO-GND, 1.5μm, DPSK, 1.8Gbps - 2021: **HICALI** (NICT) , 1.5μm, 10-40Gbps	- 2016: **OCSD-B&C** (Aero. Corp.), LEO-LEO, LEO-GND, 1.5μm, IMDD, 5-200Mbps - 2018: **LCRD** (NASA GSFC), GEO-LEO, GEO-GND, 1.5μm, DPSK/PPM, 2.8G/622Mbps - **DSOC** (NASA JPL), Deep space-GND	- 2016~: **OSIRISv1-3** (DLR), LEO-GND, 1.5μm, IMDD, 20M-10Gbps - 2017: **EDRS-C** (ESA), GEO-LEO, 1.06μm, homodyne BPSK, ~1.8Gbps - 2020: **OPTEL-D** (ESA), Deep space-GND

Trends of data rate vs. terminal mass



Trends of data rate vs. receiver sensitivity



Concluding remarks

- Recent trends of space laser communications were introduced.
- History of space laser communications was mentioned with the achievements including the ETS-VI/LCE and OICETS missions.
- NICT's laser communication mission called SOCRATES/SOTA was shown, SOTA experiment was successfully performed with the full success level.
- For future experiments,
  - International experiment campaign has been started and will be conducted with more international space agencies,
  - Site diversity experiments in Japan will be performed and,
  - Basic measurements for satellite QKD will be conducted.
- International collaboration is necessary for establishing the world wide site diversity system.