National Institute of Information and Communications Technology

NOAA Working Group on Space-Based Lidar Winds

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Feasibility Study for Space-borne Doppler Wind Lidar

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Outline

- Background and objectives
- Comparison of space-borne Doppler wind lidar
- Super-Low-Altitude-Satellite-borne Doppler wind lidar
  - Specifications
  - Geometry
- Development of laser system
  - Single-frequency pulse laser
  - Detector
- Summary

Background and Objective

Background

- WMO technical report 2012-1
  - Development of satellite-based wind profiling systems remains a priority for the future global observing system.
- ESA is planning to launch the first space-borne Doppler Wind Lidar (DWL) ADM-Aeolus for obtaining LOS wind profiles.
- Japanese working group is studying a space-borne coherent DW for vector wind measurement.
  - NICT has developed key technologies of 2-μm coherent lidar for CO_2 and wind measurements.
  - ISS-borne CDWL (2001-2005)
  - Ground-Based 2-μm Coherent Lidar (2006-2010)
  - Ground-based and airborne system (Ongoing)

Objective

For a future space-borne DWL mission, motivations is to develop and demonstrate key technologies: 2-μm single-frequency pulse laser and a high-speed detector.

Comparison of space-borne DWL for WMO requirement

	Wind profile	Application	Horizontal resolution (km)			Vertical resolution (km)			Observing Cycle (h)			Accuracy (m/s)		
			Goal	B/T	T/H	Goal	B/T	T/H	Goal	B/T	T/H	Goal	B/T	T/H
WMO requirement	U,V (LT)	Global NWP	15	100	500	0.5	1	3	1	6	12	1	3	5
	U,V (HT)	Global NWP	15	100	500	0.5	1	3	1	6	12	1	3	8
	U,V (LS)	Global NWP	15	100	500	0.5	1	3	1	6	12	1	3	5
Japan	0-2 km	Global NWP		100			0.5						1	
	2km	Global NWP		100			0.5						1	
	5km	Global NWP		100			1						2	
	10km	Global NWP		100			2						4	
ESA ADM	0-2 km	Global NWP		100			0.5						≤1-2 (Bias: ≤0.5)	
	2-16 km	Global NWP		100			1						≤2 (Bias: ≤0.5)	
	16-20 (30) km	Global NWP		100			2						≤3 (Bias: ≤0.5)	
NASA	0-2 km	Global NWP		80-350			1						≤2 (Bias: ≤0.5)	
	2-12 km	Global NWP		80-350			2						≤2 (Bias: ≤0.5)	
	16-25 km	Global NWP		80-350			4						≤3 (Bias: ≤0.5)	

Coherent
2 LOS wind spd

Direct
1 LOS wind spd

Direct
2 LOS wind spd

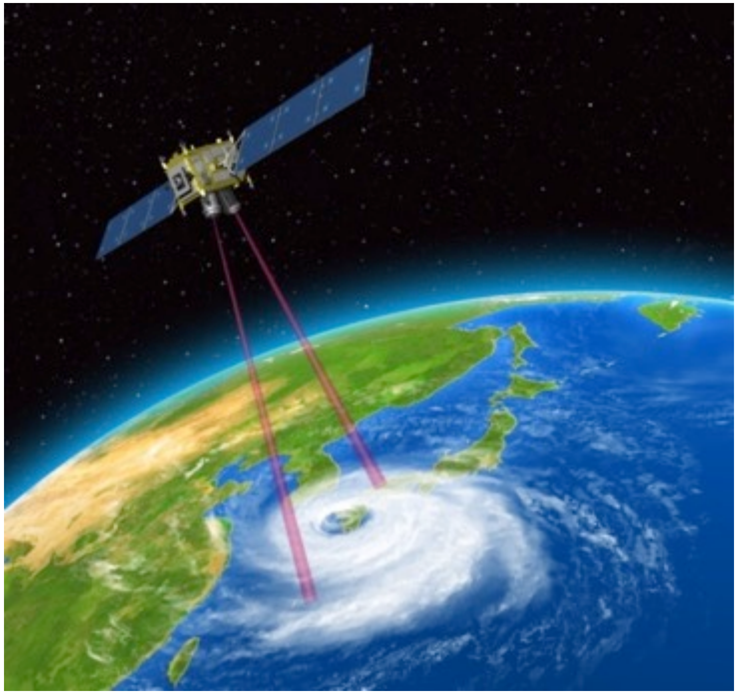
Depends on orbit and number of satellite

B/T: Breakthrough, T/H: Threshold
www.wmo-sat.info/oscar/variables/view/179

WMO requirement: horizontal wind vector
ESA ADM-Aeolus: 1 LOS wind measurement, no wind vector.
Japan and NASA: 2 LOS wind measurement, wind vector.

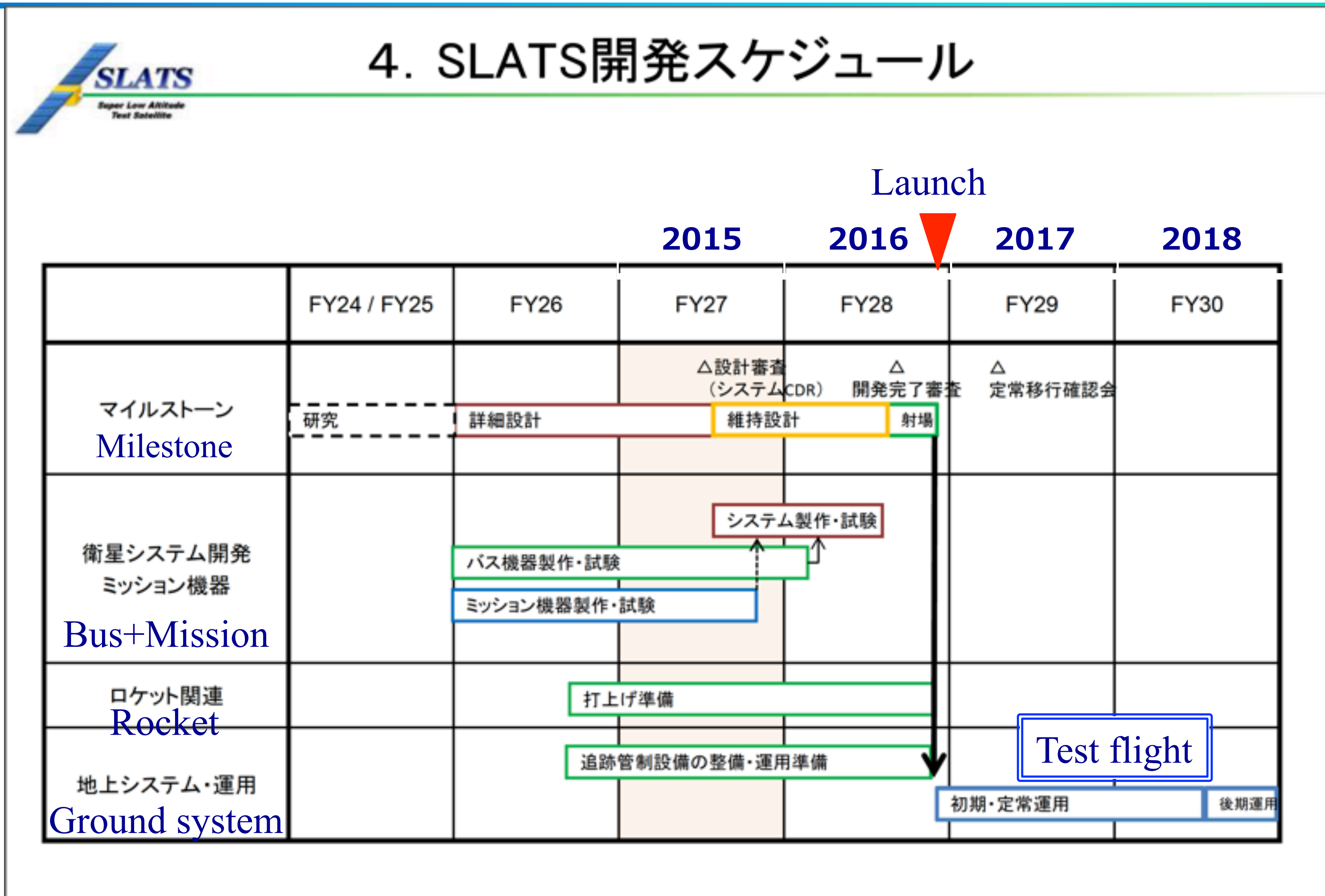
Specifications of Super-Low-Altitude-Satellite-borne DWL

	Super Low Altitude space-borne Coherent Doppler Wind Lidar
Orbital altitude Inclination	220km TBD
Instrument volume	1.5 × 1 × 1 m^3
Mass	600 kg (bus + Instrument)
Power	1600 W(bus + Instrument)
Laser power	3.75 W (125 mJ/pulse × 30 Hz) @2µm
	3.75 W (10 mJ/pulse × 2500 Hz) @1.6µm
Telescope	0.4 m (primary mirror) x 2
Horizontal resolution	<100 km
Vertical resolution	Altitude 0.5-3 km: 0.5 km Altitude 3-8 km: 1 km Altitude 8-20 km: 2 km
Nadir angle	~35 degree
Looking angle	45 and 135 degrees along direction of travel



Super Low Altitude Test Satellite
Launch: 2016

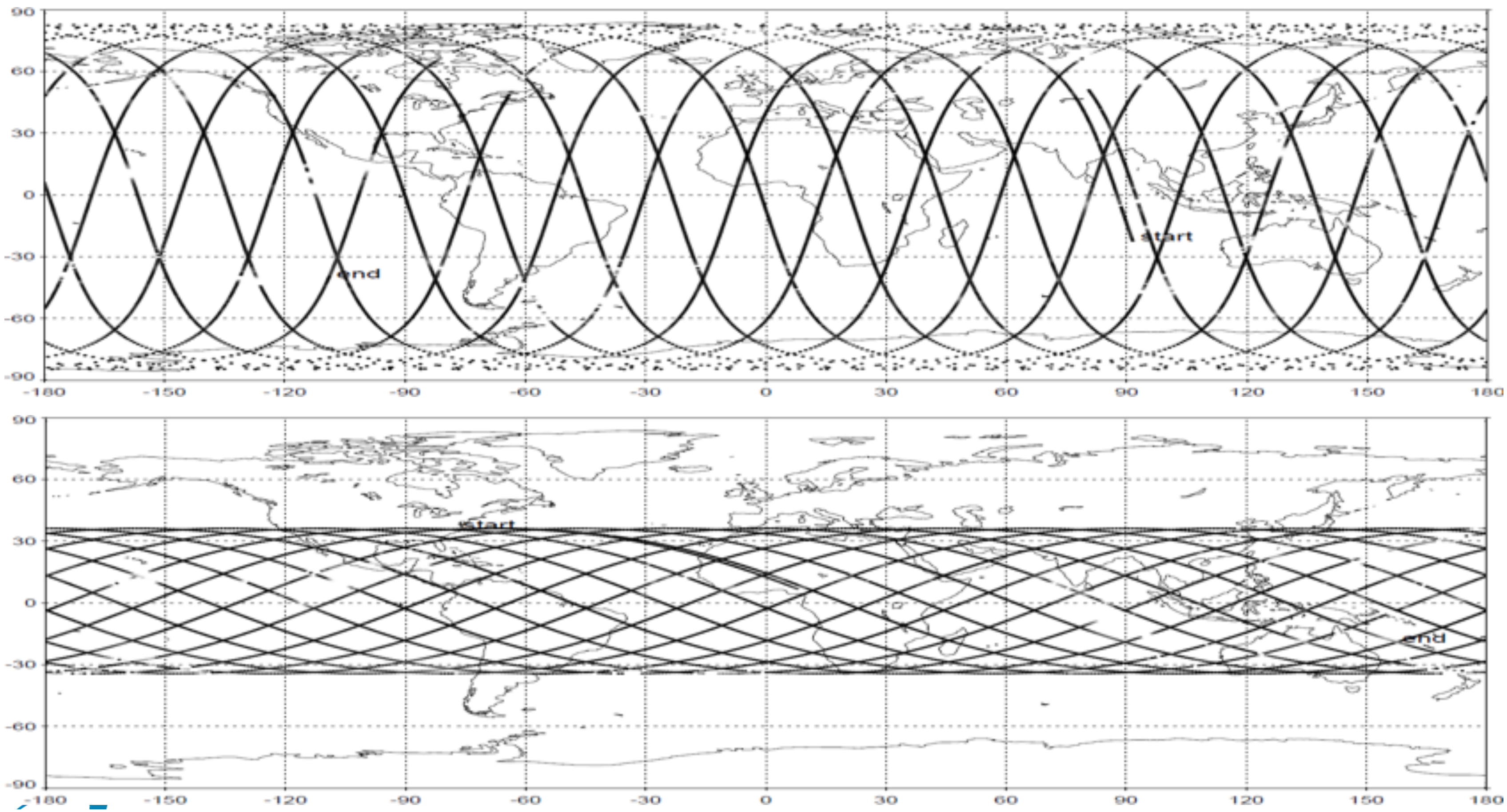
Super Low Altitude Test Satellite: Schedule



http://ictfss.nict.go.jp/ictfss-2015/dl/lecture2_sasaki.pdf

Super-Low-Altitude-Satellite-borne DWL: Orbit

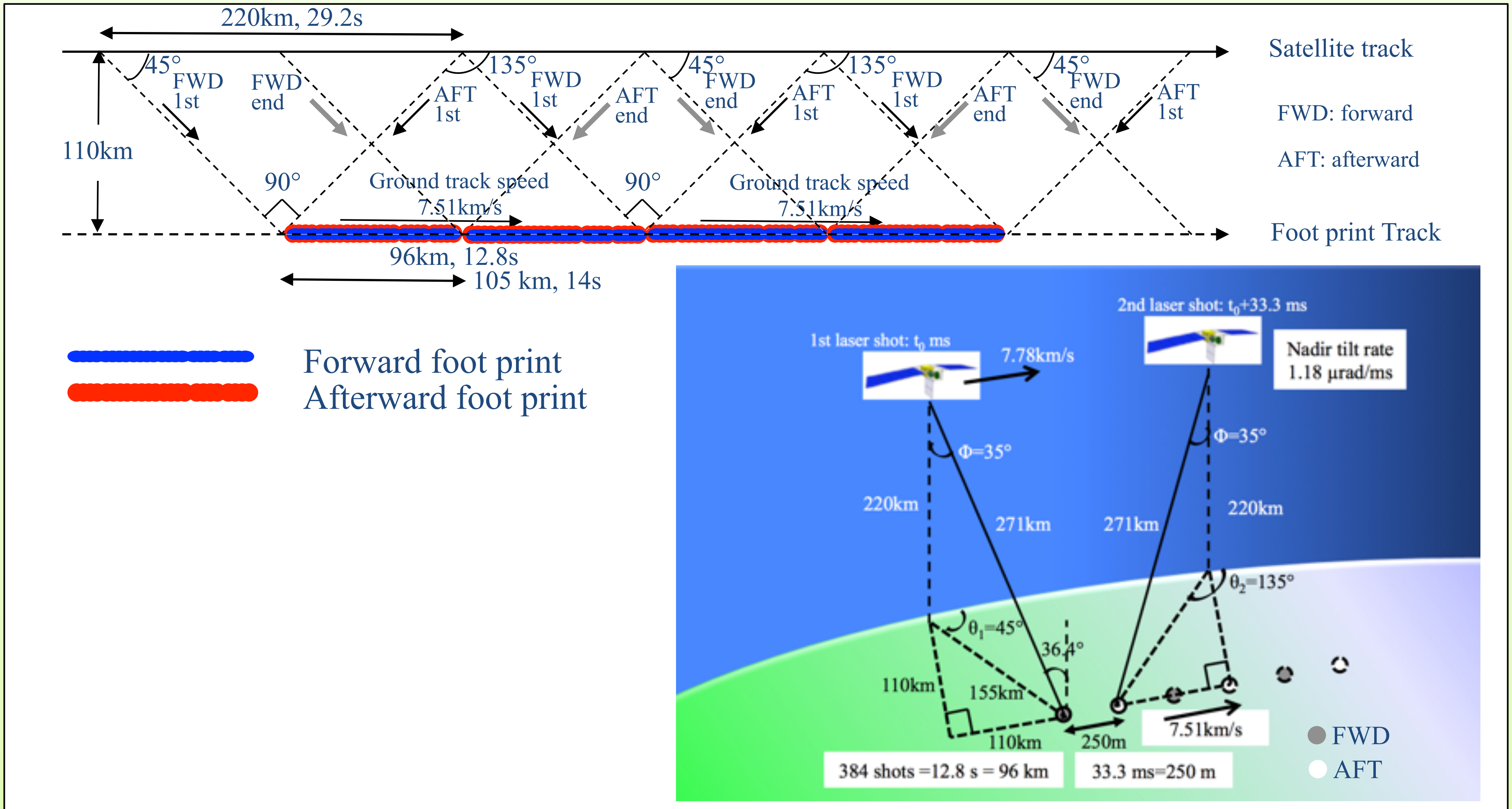
We are discussing candidate orbits, sun-synchronous polar orbit (LST18) and low inclination orbit like TRMM (0-20, 20-45).



(Upper panel) sun-synchronous orbit (98 degree) and (lower panel) low inclination angle orbit (35 degree)

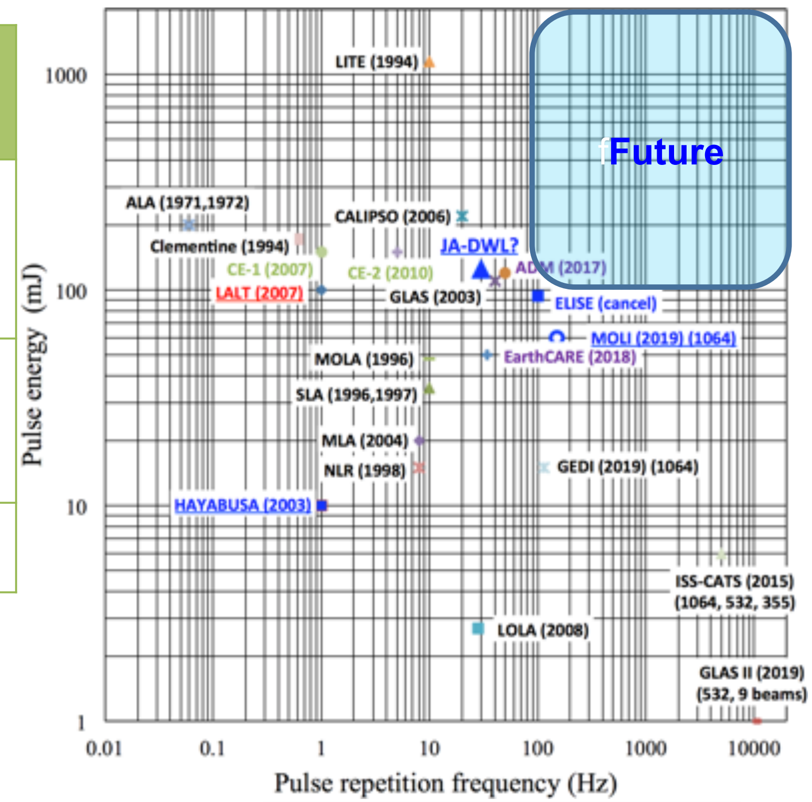
Super-Low-Altitude-Satellite-borne DWL: Geometry

- Orbital period of Satellite: 88.9 minutes
- Gap between orbits: 1922 km =2032 km – 110 km



Technologies required for space-borne DWL

Technologies required for space-borne CDWL		Task
Single-frequency 2-µm pulse laser	Single-frequency 2-µm CW laser for seeding technique	●High power ●High stability ●Narrow line width ●Price/Availability
	High pulse-energy laser	●High power ●High stability ● High efficiency
Detector		● High-speed response ● Low NEP



Target: **125mJ at -40 ºC**

- Current Tm,Ho:YLF laser system: 80mJ × 30Hz at –80 ºC.
- Power consumption of the cooling system is more than 2 times higher than that of the laser. (Laser:84W, Cooling system:199W)
- Current InGaAs detetor developed for 2-µm optical communication experiment: 1GHz, NEP≅0.2pw/√Hz

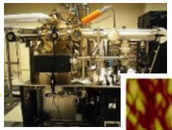
Target:
cut-off frequency: **>4 GHz**
NEP : **<10 fw/√Hz**

NICT

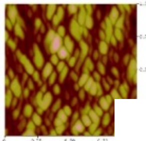
Single-frequency high power laser

2µm Quantum-dot laser

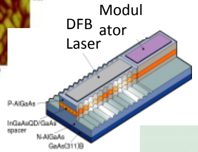
NICT



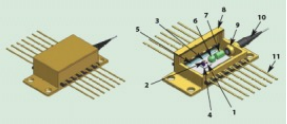
PDLに設置されている分子線
エピタキシー装置



分子線エピタキシー装置を用いて
作成された量子ダッシュ構造



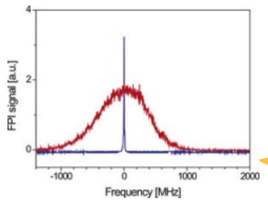
量子ドットレーザ試作



2µm Quantum-dot laser
(pigtail, Future)

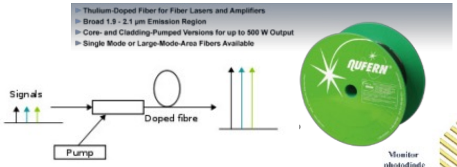
2µm semiconductor laser

narrow line width,
high power, high
stability



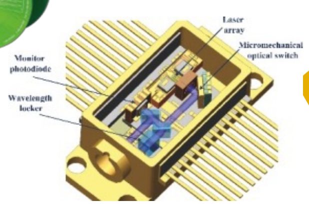
2µm optical fiber amplifier

2µm optical fiber amplifier



A doped fiber amplifier

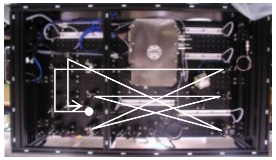
NICT



2µm Quantum-dot laser + AMP
(pigtail, Future)

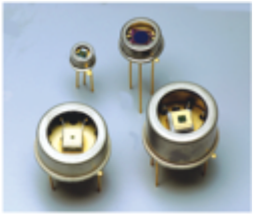
Single-frequency high pulse energy 2µm laser

2µm pulse laser



NICT, TIT

2µm detector
(Future)

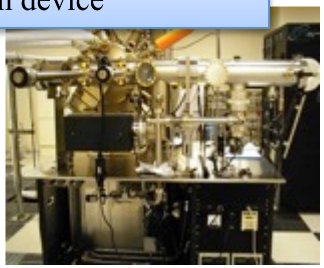


Commercial detector (non space -qualification

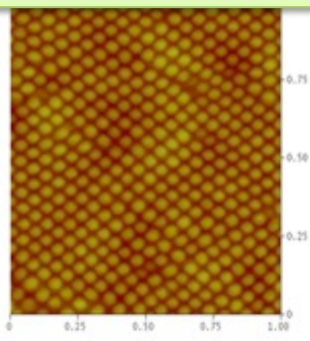
NICT

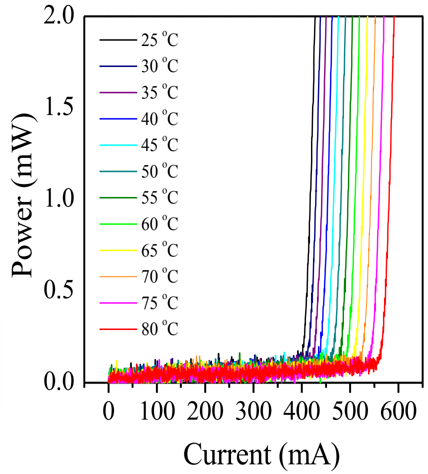
Single-frequency 2-µm CW laser：semiconductor laser

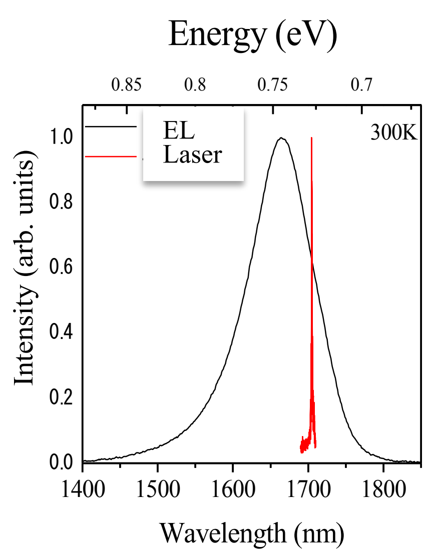
Molecular beam epitaxial growth device



Highly-stacked InAs quantum dot layer for 1.55-µm laser

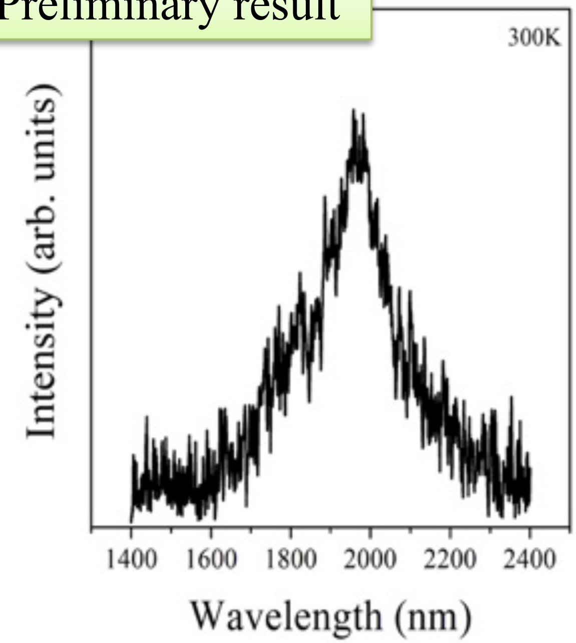






Development of gain medium for 2-µm laser

Preliminary result



- Highly-stacked InAs quantum dot layer for 2-µm laser
- Demonstration at 2-µm
- Next step
  - High output power
  - Narrow linewidth

Highly-stacked quantum dot laser fabricated by a strain compensation technique at NICT

Single-frequency 2-μm CW laser: Optical fiber amplifier

- Requirement for optical output power
  Wavelength: 2051nm
  Gaing: 13dB (input optical power:~1mW)
  Output: 20mW
- Other requirements
  - Long-term mechanical stability (vibration and shocks)
  - Maintenance-free
  - Compact and high efficiency (E-O conversion, removal heat)
  - Space-qualification

Erbium-Doped Fiber AMP:EDFA

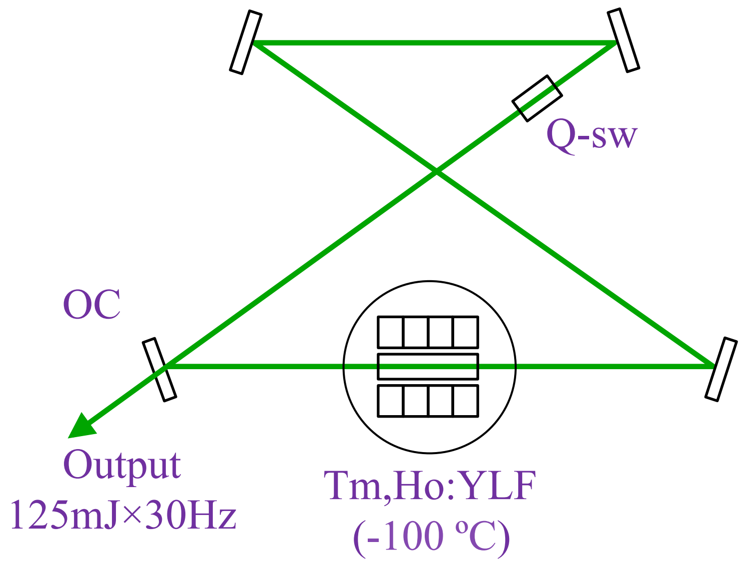
Thulium-Doped Fiber AMP:TDFA

- Previous TDFA research
  - Small signal gain: 16 dB at 2050 nm
  - Output power: >100mW @1.9μm (420mW pumped@1550nm)
  - All optical fiber
  - Low E-O efficiencty: ~10% (w/o TEC E.P.)
    Z.Li *et al*., Opt. Express, **21**, 9282 (2013)
    Z.Li *et al*., Opt. Express, **21**, 26450 (2013)
  - High E-O efficiency in the free space pumped at 793nm
    Y. Jung *et al*., Opt.Express, **22**, 10544 (2014)
  - Photobrightening (793 nm) recovering from photodarkening due to cosmic radiation exposure
    Y. Xing *et al*., Opt. Lett, **40**, 681 (2015)

Concept of TDFA for space application
- Double-crad Tm optical fiber
- 793nm multi-mode LD pump
- All optical fiber

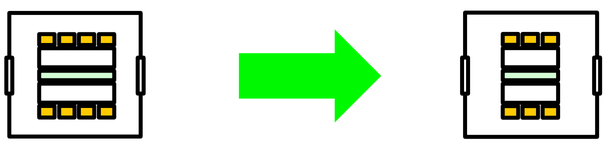
2µm laser block diagram

1 Oscillator



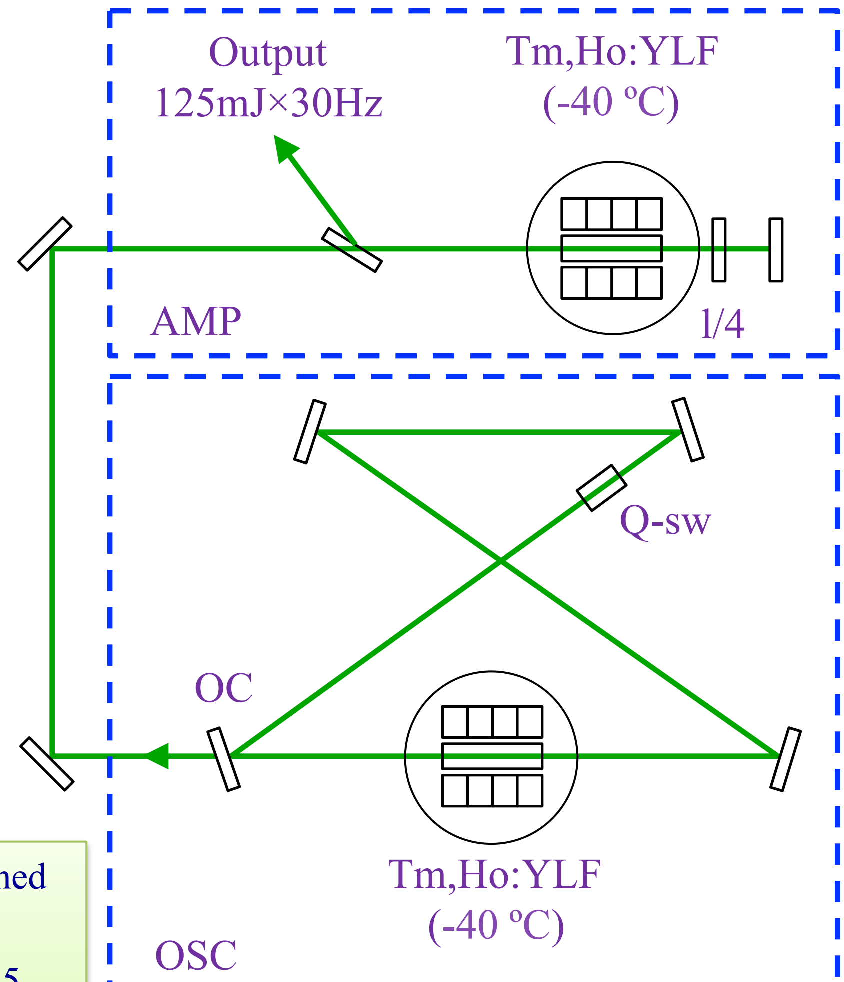
Laser rod=44mm

Laser rod=33mm



High-density excitation

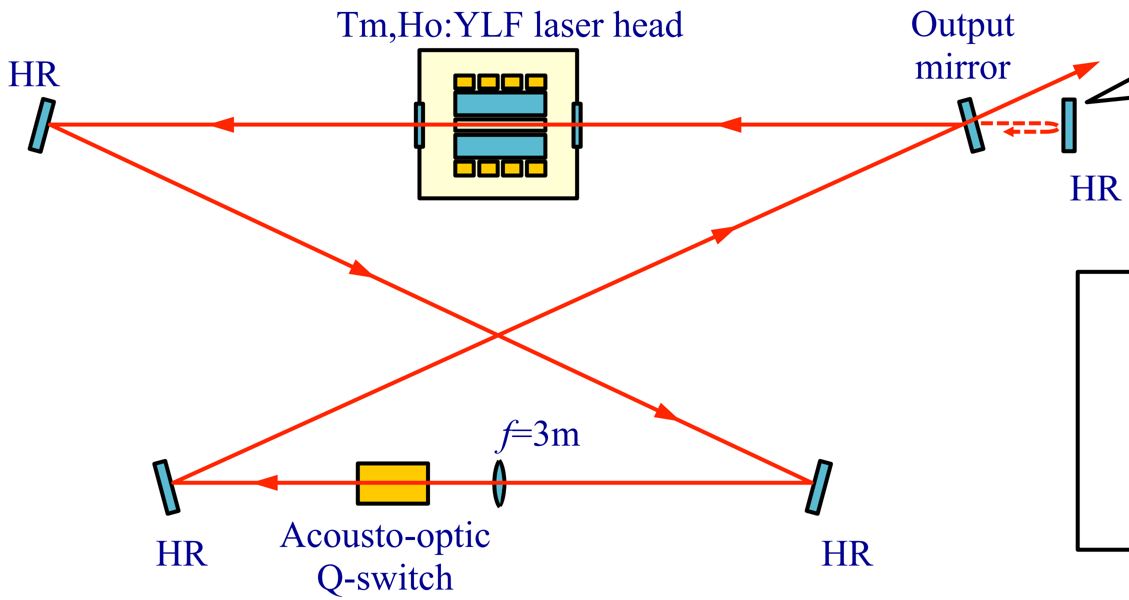
1 Oscillator+ 1 Power amplifier



OC: Output Coupler

- Understanding of temperature dependence of the Q-switched Tm,Ho:YLF laser at temperatures lower than -20 ºC.
- Investigations of parameters needed for the design of a 125-mJ laser transmitter operating around -40 ºC.

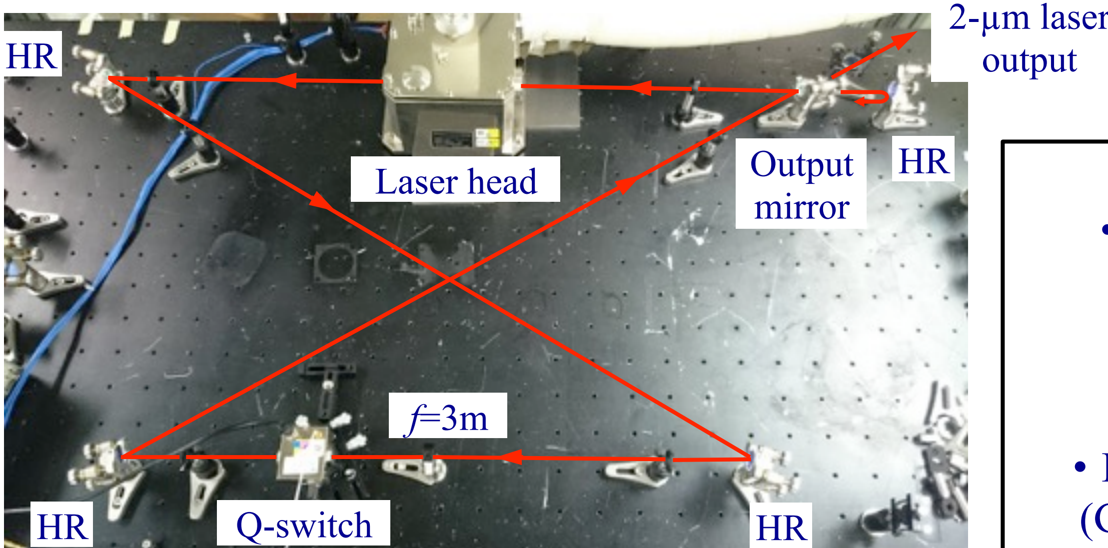
Setup for 2-μm laser experiment



This mirror was used to achieve unidirectional lasing in the ring resonator.

<u>Operating conditions</u>

- Pulse repetition frequency: 30 Hz
- Pump pulse length: 1 ms
- Q-sw trigger time: 1.6 ms
- Resonator length: 3.86 m



<u>HR mirror</u>

- High reflection at 2051 nm, flat

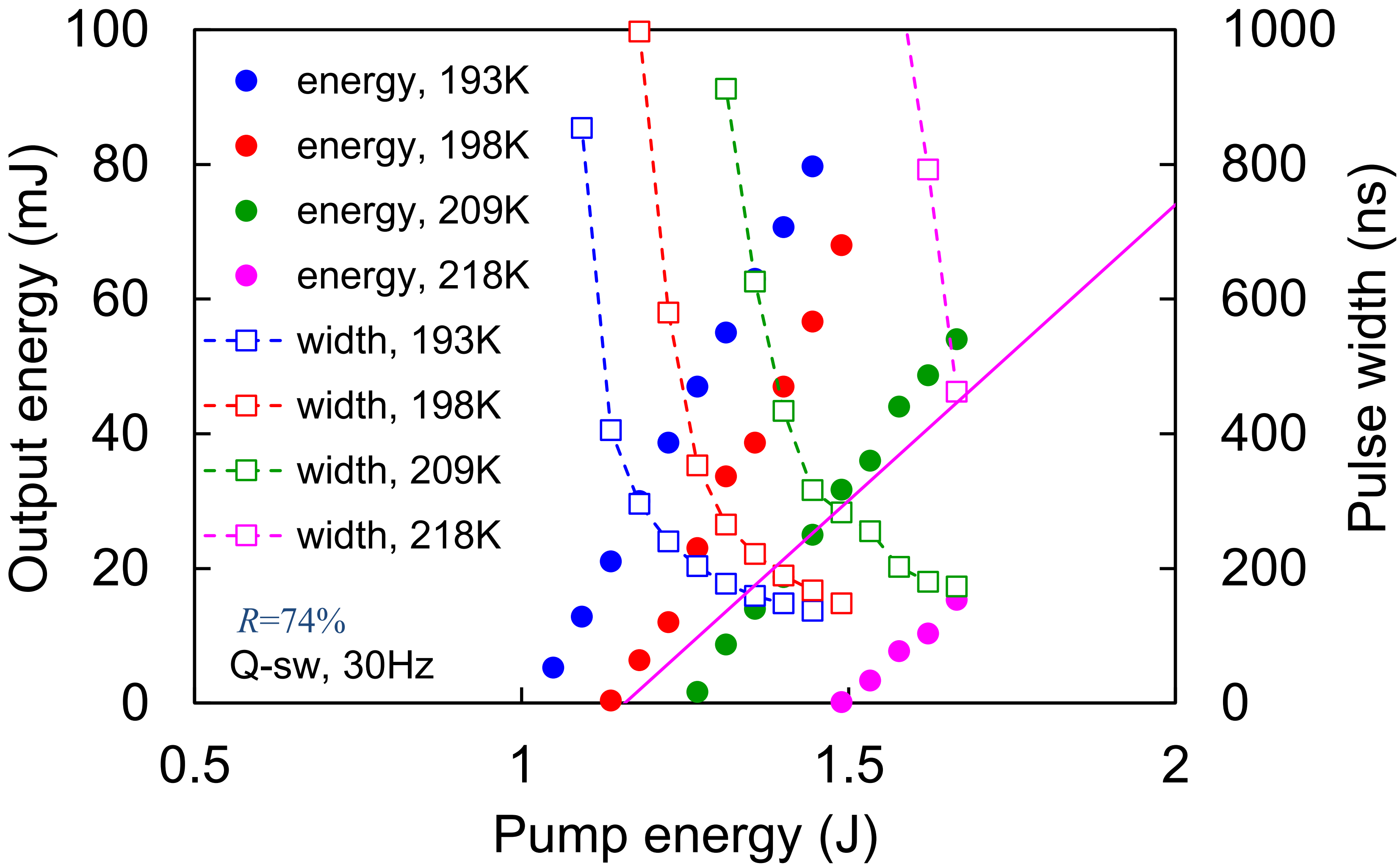
<u>Output mirror</u>

- R=61, 74, 81%, flat

<u>Q-switch</u>

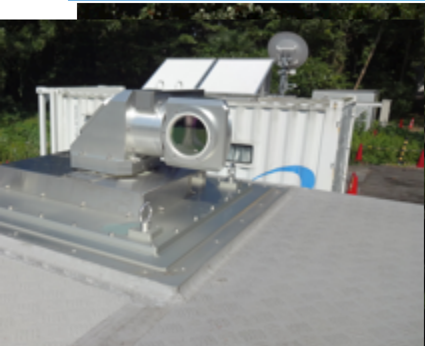
- Fused silica, RF signal: 27.12MHz (Gooch & Housego QS027-4M-0S5)

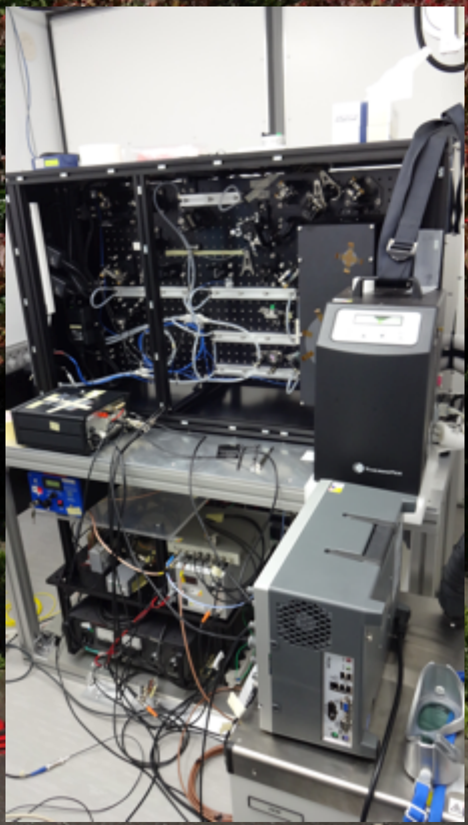
Experiments

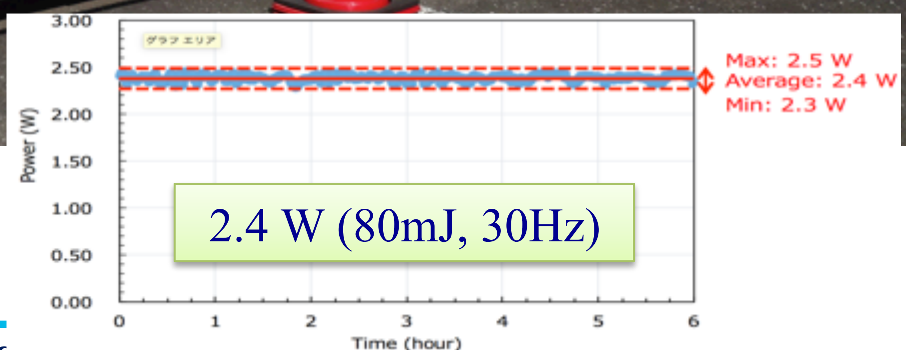


Sato et al., CLEO-PR 2015, Paper 25F3-3より

New ground-based 2-µm Doppler Wind lidar







Summary

A new super low altitude test satellite will be launched after 2016. NICT is developing key technologies required for a future super-low-altitude-borne DWL.

- Geometry
- Laser
  - 2-µm semiconductor CW laser
  - Tm optical fiber amplifier
  - High pulse-energy 2-µm laser
- 2-µm detector

- Future works:
  - Demonstration of single-frequency 2-µm CW laser
  - Demonstration of high pulse-energy 2-µm laser
  - Evaluation of high-speed 2-µm detector
  - Evaluation of impact on forecasts in one-month assimilation experiments (summer and winter)
  - Minor updating of ISOSIM-L (ongoing)
  - Improve data assimilation pre-processing including QC (ongoing)
  - Comparison SOSE-OSSE with different systematic parameter (lidar, spatiotemporal resolution, systematic geometry)
  - Comparison SOSE-OSSE with different OSSE (nature run / ensemble OSSE)

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