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Optics in Japan's Space Missions: Mainly for Earth Observation

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Optics in Japan's Space Missions -Mainly for Earth Observation-

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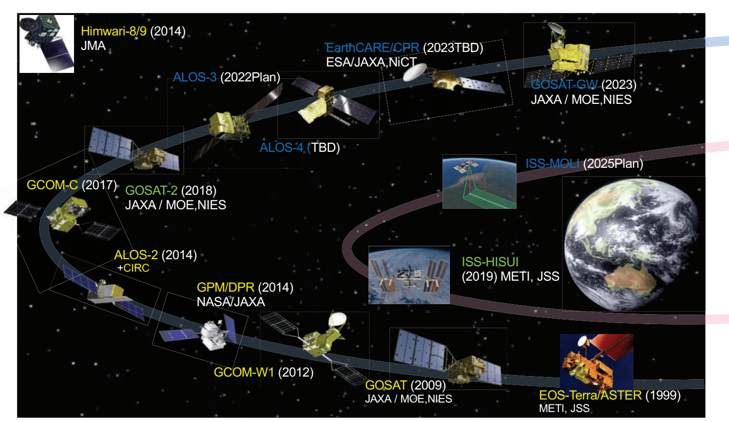
Research and Development Directorate
Japan Aerospace Exploration Agency (JAXA)

Contents

Major Japanese Earth Observation Satellites



JAXA Earth Observation program status

Current mid-term plan from 2018-2024 (7 years)

①Disaster Monitoring and Mitigation

High resolution Series

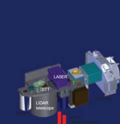
- ALOS-2(Daichi2)
- ALOS-3
- ALOS-4

②Climate Change

Global Environment Observation series

- GPM/DPR
- GCOM-W(Shizuku)
- GOSAT(ibuki)
- GCOM-C(Shikisai)
- GOSAT-2 (Ibuki2)
- EarthCARE/CPR
- GOSAT-GW

③ New technology development



- Laser Altimeter: ISS/MOLI

Candidates

- *Geostationary Optical Telescope Satellite (GOTS)*
- *Wind LIDAR*
- *Geostationary Imaging FTS*

- in operation
- under development
- *Under study*

Next mid term plan is under discussion with newly organized consortium in Japan

Optics in Japanese Space missions

Earth Observation

- ➢Passive
  - ✓Multiband imaging radiometer: GCOM-C/SGLI, GOSAT/TANSO-CAI, Himawari/AHI [JMA]*
  - ✓High-resolution multiband Imager: ALOS-3/WISH, EOS-Terra/ASTER [JSS]*
  - ✓Mid-resolution multiband video Imager: Geostationary Optical Telescope Satellite (GOTS)**
  - ✓Hyperspectral imager: HISUI on ISS [JSS]*, GOSAT-GW
  - ✓Fourier-Transform-Spectrometer: GOSAT/TANSO-FTS
  - ✓Compact IR imager: CIRC (IR)
- ➢Active
  - ✓Lidar (Mie-scattering/altimeter): MOLI on ISS

Communication

- ➢JDRS-Optical Communication System

[JSS] for Japan Space Systems, [JMA] for Japanese Meteorological Agency

- : not included in this presentation

** : Study phase

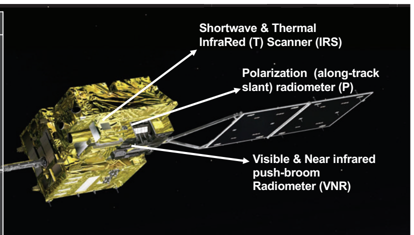
Earth Observation / Optical missions

Global Change Observation Mission- Climate（GCOM-C)

Launch Date: December 23, 2017 (JST)

Main Objectives
- Improving our understanding of climate change mechanisms through long-term monitoring of aerosols and clouds, as well as vegetation and temperatures, in the land and ocean regions.
- Contributing to enhancing the prediction accuracy of future environmental changes.

Major Characteristics
- Altitude: Approx. 800 km
- Local sun time at descending node: 10:30
- Mission Instrument:
  - ✓ Second-generation Global Imager (SGLI)



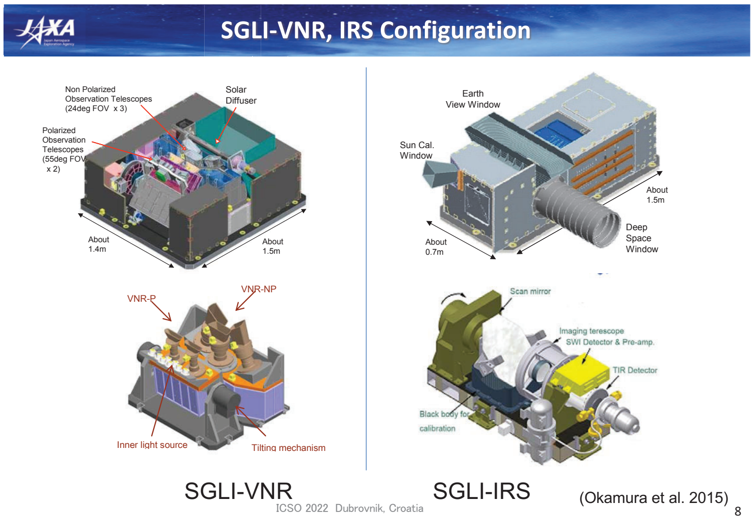
	SGLI-VNR (push-broom)	SGLI-IRS (whisk-broom)
Channels	Non-polarization channel : 11ch Polarization channel: 2ch	Shortwave infrared（SWI）: 4ch Thermal infrared（TIR）: 2ch
Spatial Resolution	Non-polarization: 250 m Polarization: 1000 m	SWI: 250 m / 1 km TIR: 250 m
Swath Width	1150 km	1400 km

Observation band

GCOM-C SGLI characteristics	
Orbit	Sun-synchronous (descending local time: 10:30) Altitude 798km, Inclination 98.6deg
Mission Life	5 years
Scan	Push-broom electric scan (VNR) Wisk-broom mechanical scan (IRS)
Scan width	1150km cross track (VNR: VN & P) 1400km cross track (IRS: SW & T)
Digitalization	12bit
Polarization	3 polarization angles for P
Along track direction	Nadir for VN, SW and T, +45 deg and -45 deg for P
On-board calibration	VN: Solar diffuser, LED, Lunar cal maneuvers, and dark current by masked pixels and nighttime obs. SW: Solar diffuser, LED, Lunar, and dark current by deep space window T: Black body and dark current by deep space window

SGLI channels						
CH	λ	Δλ	L_{std}	L_{max}	SNR at Lstd	IFOV
	VN, P, SW: nm T: μm		VN, P: W/m²/sr/μm T: Kelvin		VN, P, SW: SNR T: NEΔT	m
VN1	380	10	60	210	250	250
VN2	412	10	75	250	400	250
VN3	443	10	64	400	300	250
VN4	490	10	53	120	400	250
VN5	530	20	41	350	250	250
VN6	565	20	33	90	400	250
VN7	673.5	20	23	62	400	250
VN8	673.5	20	25	210	250	250
VN9	763	12	40	350	1200	250/1000
VN10	868.5	20	8	30	400	250
VN11	868.5	20	30	300	200	250
P1	673.5	20	25	250	250	1000
P2	868.5	20	30	300	250	1000
SW1	1050	20	57	248	500	1000
SW2	1380	20	8	103	150	1000
SW3	1630	200	3	50	57	250
SW4	2210	50	1.9	20	211	1000
T1	10.8	0.7	300	340	0.2	250/1000
T2	12.0	0.7	300	340	0.2	250/1000

VNIR 9 bands (11 channels) + Polarimetry/bi-direc. 2 bands + SWIR 4 bands + TIR 2 bands = Total 17 bands (19 channels)


SGLI-VNR, IRS Configuration
Non Polarized Observation Telescopes (24deg FOV x 3)
Solar Diffuser
Polarized Observation Telescopes (55deg FOV x 2)
About 1.4m
About 1.5m
Earth View Window
Sun Cal. Window
About 1.5m
About 0.7m
Deep Space Window
VNR-P
VNR-NP
Inner light source
Tilting mechanism
Scan mirror
Imaging terescope SWI Detector & Pre-amp.
TIR Detector
Black body for calibration
SGLI-VNR
SGLI-IRS
(Okamura et al. 2015)
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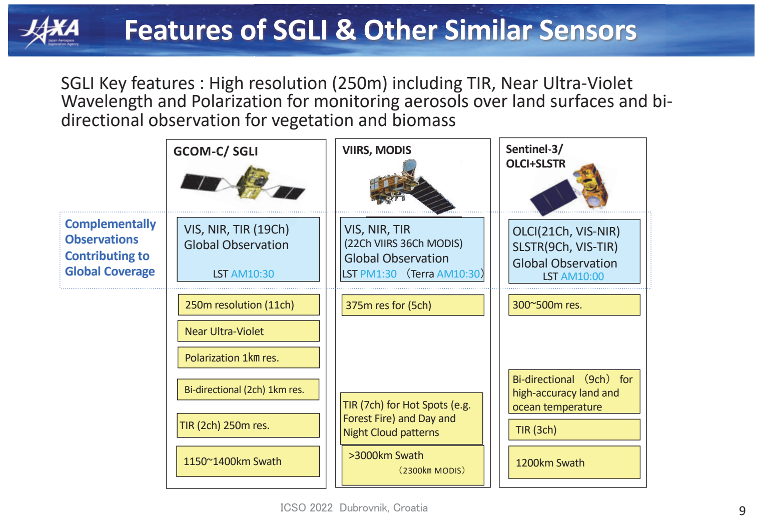
8


Features of SGLI & Other Similar Sensors
SGLI Key features : High resolution (250m) including TIR, Near Ultra-Violet Wavelength and Polarization for monitoring aerosols over land surfaces and bi-directional observation for vegetation and biomass
GCOM-C/ SGLI
VIIRS, MODIS
Sentinel-3/ OLCI+SLSTR
Complementally Observations Contributing to Global Coverage
VIS, NIR, TIR (19Ch) Global Observation LST AM10:30
VIS, NIR, TIR (22Ch VIIRS 36Ch MODIS) Global Observation LST PM1:30 (Terra AM10:30)
OLCI(21Ch, VIS-NIR) SLSTR(9Ch, VIS-TIR) Global Observation LST AM10:00
250m resolution (11ch)
375m res for (5ch)
300~500m res.
Near Ultra-Violet
Polarization 1㎞ res.
Bi-directional (2ch) 1km res.
Bi-directional (9ch) for high-accuracy land and ocean temperature
TIR (7ch) for Hot Spots (e.g. Forest Fire) and Day and Night Cloud patterns
TIR (2ch) 250m res.
TIR (3ch)
1150~1400km Swath
>3000km Swath (2300㎞ MODIS)
1200km Swath
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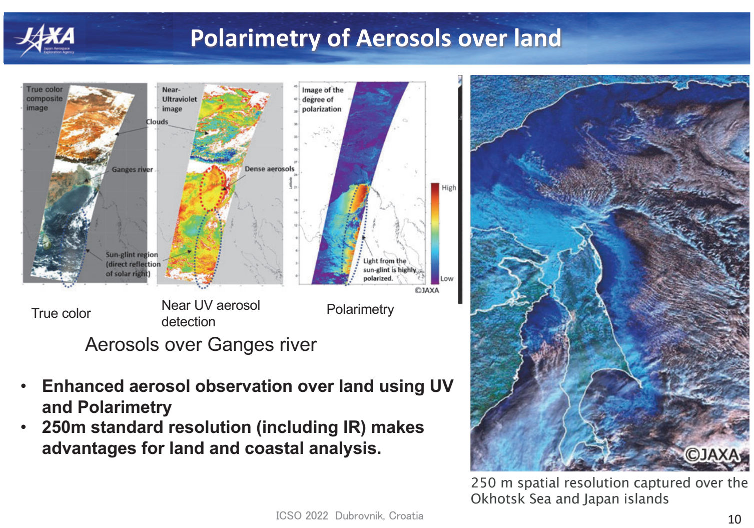
9


Polarimetry of Aerosols over land
True color composite image
Near-Ultraviolet image
Image of the degree of polarization
Clouds
Ganges river
Dense aerosols
Sun-glint region (direct reflection of solar right)
Light from the sun-glint is highly polarized.
High
Low
©JAXA
True color
Near UV aerosol detection
Polarimetry
Aerosols over Ganges river
• Enhanced aerosol observation over land using UV and Polarimetry
• 250m standard resolution (including IR) makes advantages for land and coastal analysis.
©JAXA
250 m spatial resolution captured over the Okhotsk Sea and Japan islands
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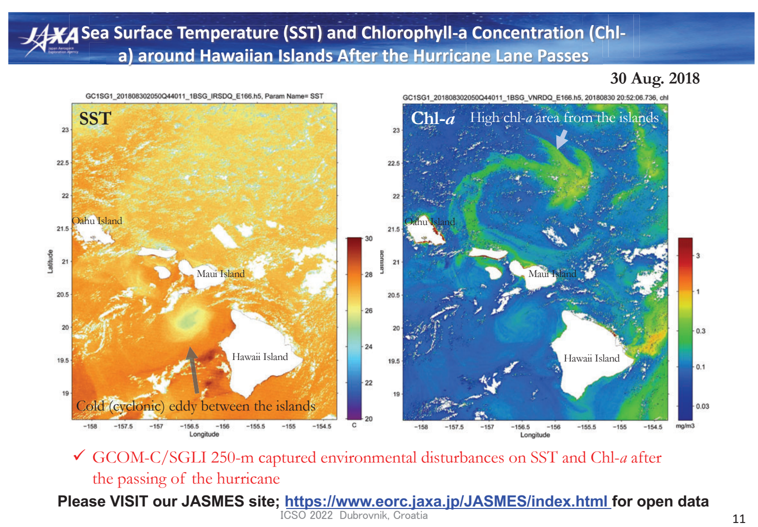
10


Sea Surface Temperature (SST) and Chlorophyll-a Concentration (Chl-a) around Hawaiian Islands After the Hurricane Lane Passes
30 Aug. 2018
SST
Chl-a
High chl-a area from the islands
Oahu Island
Maui Island
Hawaii Island
Cold (cyclonic) eddy between the islands
Latitude
Longitude
✓ GCOM-C/SGLI 250-m captured environmental disturbances on SST and Chl-a after the passing of the hurricane
Please VISIT our JASMES site; https://www.eorc.jaxa.jp/JASMES/index.html for open data
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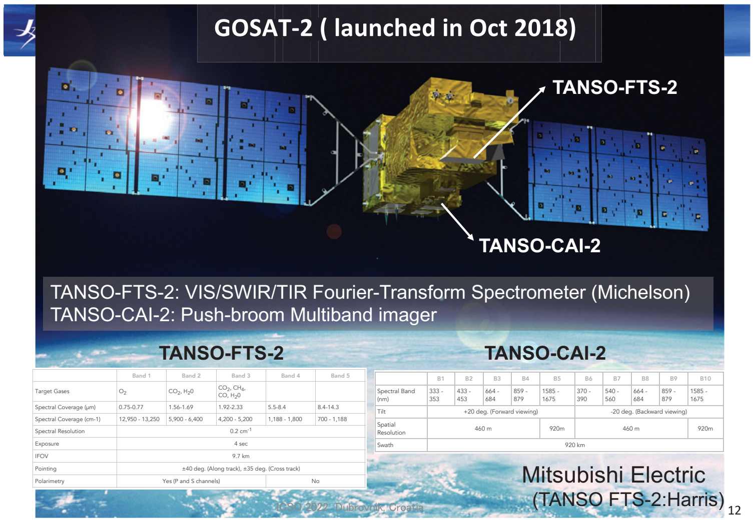
11

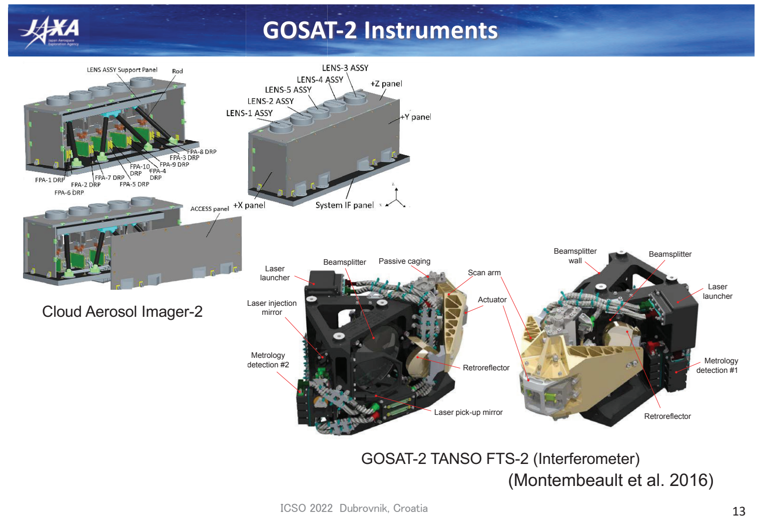


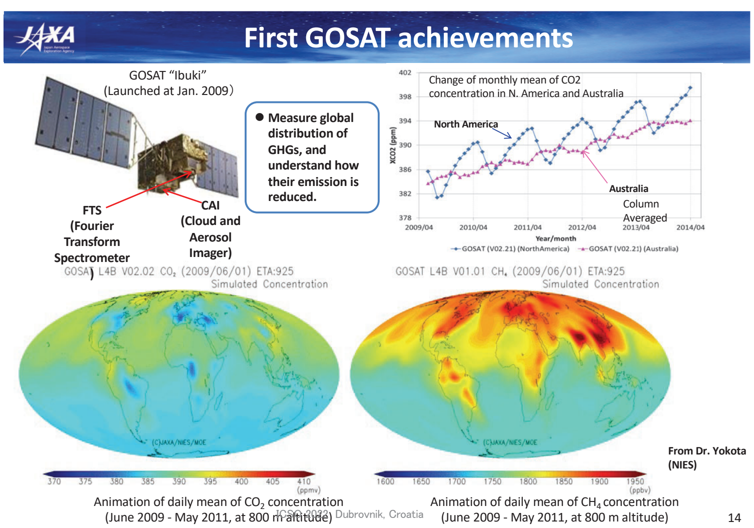
TANSO-FTS-2

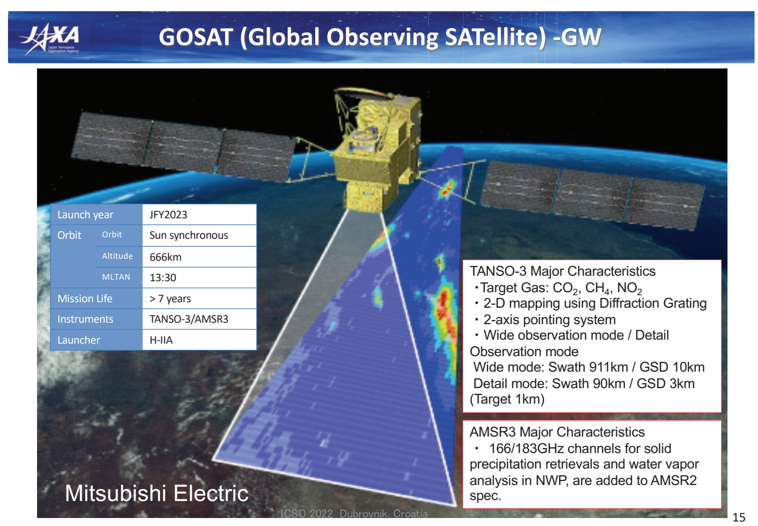
	Band 1	Band 2	Band 3	Band 4	Band 5
Target Gases	O_2	CO_2, H_2O	CO_2, CH_4, CO, H_2O		
Spectral Coverage (μm)	0.75-0.77	1.56-1.69	1.92-2.33	5.5-8.4	8.4-14.3
Spectral Coverage (cm-1)	12,950 - 13,250	5,900 - 6,400	4,200 - 5,200	1,188 - 1,800	700 - 1,188
Spectral Resolution	$0.2\ cm^{-1}$				
Exposure	4 sec				
IFOV	9.7 km				
Pointing	±40 deg. (Along track), ±35 deg. (Cross track)				
Polarimetry	Yes (P and S channels)			No	

TANSO-CAI-2

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Spectral Band (nm)	333 - 353	433 - 453	664 - 684	859 - 879	1585 - 1675	370 - 390	540 - 560	664 - 684	859 - 879	1585 - 1675
Tilt	+20 deg. (Forward viewing)					-20 deg. (Backward viewing)				
Spatial Resolution	460 m				920m	460 m				920m
Swath	920 km									







Improvement of GOSAT series

Specifications of GOSAT, GOSAT-2, and GOSAT-GW

	GOSAT	GOSAT-2	GOSAT-GW
Launch / lifetime	2009 / 5 years	2018 / 5 years	FY2023 / 7 years
Satellite mass / power	1.75 t / 3770 W	1.8 t / 5000 W	2.9 t / 5200 W
Orbit	666 km, 3 days, 13:00, descending	613 km, 6 days, 13:00, descending	666 km, 3 days, 13:30, ascending
Spectrometer	FTS	FTS-2	**TANSO-3** (Grating)
Major targets	CO_2, CH_4	CO_2, CH_4, CO	**CO_2, CH_4, NO_2**
Spectral bands	0.7 / 1.6 / 2 μm + TIR	0.7 / 1.6 / 2 μm + TIR	0.45 / 0.7 / 1.6 μm
Spectral Resolution (Sampling interval)	0.2 cm^{-1}, (≈ 0.01 nm @ 0.7 μm, ≈ 0.05 nm @ 1.6 μm)		< 0.5 nm @ 0.45 μm, <0.05 nm @ 0.7 μm, < 0.2 nm @ 1.6 μm
Swath	Discrete, 1 – 9 points	Discrete, 5 points	Selectable, 911 km (**Wide Mode**) or 90 km (Focus Mode)
Footprint size, nadir	10.5 km	9.7 km	Selectable, 10 km (Wide Mode) or 1 – 3 km (**Focus Mode**)
Pointing	±20 /±35 deg	±40 /±35 deg (AT/CT) Intelligent pointing	± 40 /± 34.4 deg (AT/CT) for Focus Mode
Other instruments	CAI (Cloud and Aerosol Imager)	CAI-2 (Cloud and Aerosol Imager 2)	AMSR3 (Advanced Microwave Scanning Radiometer 3)

NIES SOC 衛星観測センター Satellite Observation Center

SPIE SENSORS+IMAGING (Berlin, September 5-7 2022)
Tsuneo Matsunaga (matsunag@nies.go.jp), National Institute for Environmental Studies (NIES)

(Matsunaga et al. 2022)

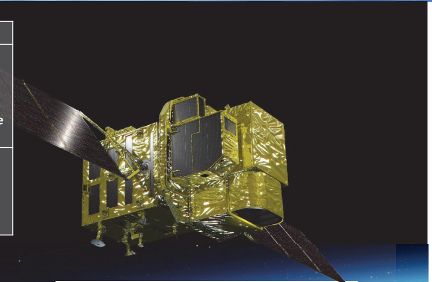
ICSO 2022 Dubrovnik, Croatia 16

Advanced Land Observing Satellite-3 (ALOS-3) (Optical)

Launch Date: JFY2022 (Plan)

Main Objectives
- Contributing to security and disaster management activities.
- Promoting data utilization in various fields such as maintenance and updates of precise geographical information

Major Characteristics
- Altitude: Approx. 669km
- Local sun time at descending node: 10:30
- Mission Instrument: Wide-swath and high-resolution optical imager



Wide-swath and high-resolution optical imager	
Band	Panchromatic band: 1 band Multi-band (color): 6 bands
Spatial Resolution	Panchromatic band: 0.8 m Multi-band: 3.2 m
Swath Width	70 km

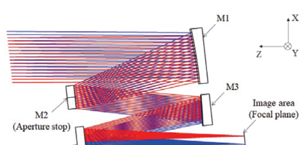
ICSO 2022 Dubrovnik, Croatia 17

WISH (Wide Swath and High Resolution Imager)

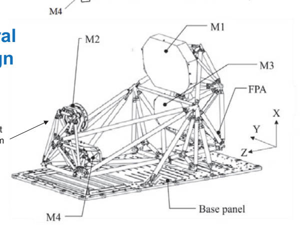
WISH Specification

Parameter	Specification
Telescope type	Four Mirror Anastigmat
FOV	> 6.0 deg (>70 km at nadir)
Aperture	> 0.54 m
Focal length	6.86 m
Bands	Pan: 520 – 760 nm Mu: 400 – 450 nm (Coastal), 450 – 500 nm (Blue), 520 – 600 nm (Green), 610 – 690 nm (Red), 690 – 740 nm (RedEdge), 760 – 890 nm (NIR)
Detectors	Pan: 8 μm pitch-8192 pixels with 128 stages TDI × 12 CCDs Mu: 32 μm pitch-2048 pixels with 32 stages TDI ×6 bands × 12 CCDs
Instantaneous FOV	Pan: <0.247 arcsec (80cm at nadir) Mu: <0.987 arcsec (3.2m at nadir)
MTF @ Nf	Pan: >0.1, Mu: >0.2
SNR	Pan: >200, Mu: >200

Optical design



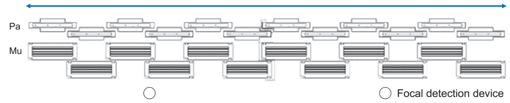
Structural design



(Hayato et al. 2022)

ICSO 2022 Dubrovnik, Croatia 18

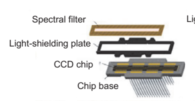
Focal plane of WISH/ALOS-3

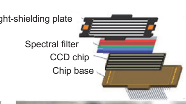


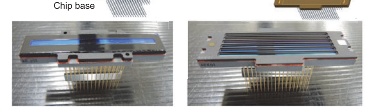
MITSUBISHI ELECTRIC

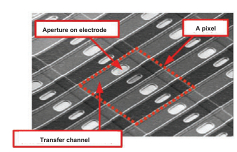
Parameter	Pa	Mu
Pitch	8 μm	32 um
# of pixels / CCD	8192	2048
# of CCDs	12	12
MAX TDI stages	128	32
# of bands	N/A	6

CCD configuration









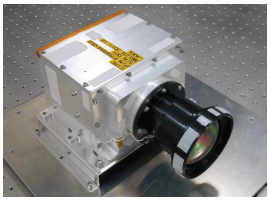
(Hayato et al. 2022)

ICSO 2022 Dubrovnik, Croatia 19

Compact Infrared Camera (CIRC)

CIRC is a technology demonstration instrument equipped with an uncooled infrared array detector (microbolometer) for space application.

CIRC PFM onboard ALOS-2



- Microbolometer without heavy cooler
- Athermal optics for wider operating temp.
- Shutter-less system without mechanical parts

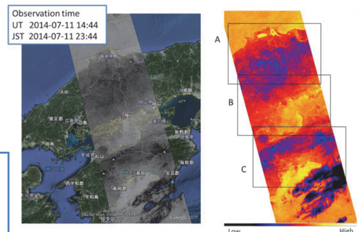
◆ Small size (~200 mm³), Light weight (~3 kg), Low power consumption (<20 W)
◆ High-resolution (ALOS-2:<200m, JEM/CALET:<130m)
◆ 2nd Generation CIRC is under study
◆ Over 7 years life using COTS

Mission of the CIRC

- Wildfire, Volcanoes, Heat island

Two CIRCs on orbit

- On ALOS-2 (SSO, alt. 600km) 2014〜
- On JEM/CALET(ISS, alt.400km) 2015〜2020

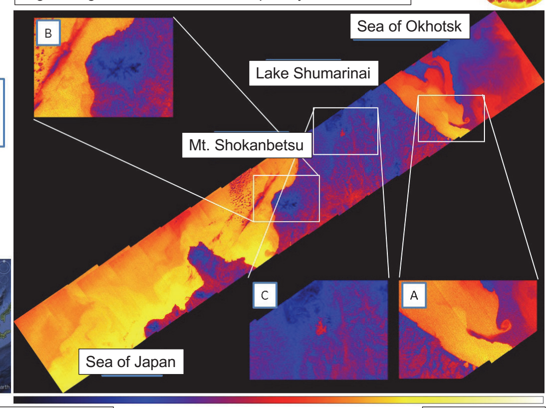


Night image in Japan

CALET/CIRC First image

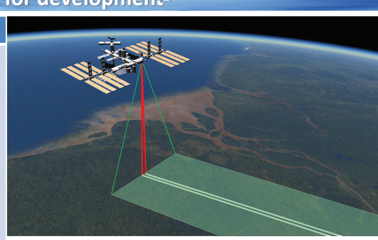
Night Image of Hokkaido Island, Japan by CALET/CIRC

観測時刻
UT 2015-10-06 09:25
JST 2015-10-06 18:25

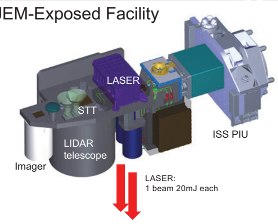


Multi-footprint Observation Lidar and Imager (MOLI) - preparation for development-

Items	Specifications
Mission instruments	◯ Dual Beam LIDAR Laser wavelength/ 1064nm Number of beam / 2 beam Beam power/ 40mJ (20mJx2) Pulse width / less than 7ns Footprint radius / Φ25m ◯ Imager Band / Green; 550-630nm Red; 630-740nm NIR; 740-880nm Spatial resolution / 5m Swath / 1km
Size	1605 × 640 × 830 [mm]
Mass	About 300 kg
Power	Less than 400W
Operation	Over 1year
Operational orbit	ISS orbit(Inclination : 51.6 deg) Non-synchronous at an altitude of 400km



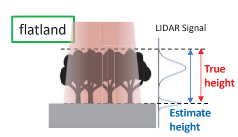
On ISS/JEM-Exposed Facility



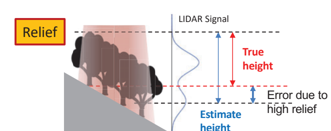
Multi -footprint Laser Altimeter with Imager on ISS for Biomass measurement and Digital Terrain Model (3-D map)
Possible cooperation with GEDI mission for continuity

Biomass evaluation at high relief situation

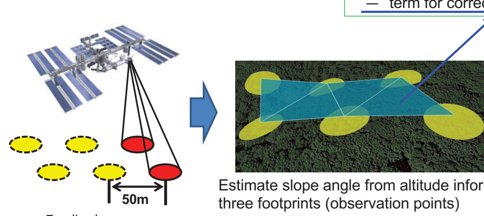
Calibrate Terrain relief using multi-footprint measurement



Canopy height
= Distance between Signal start and last pulse

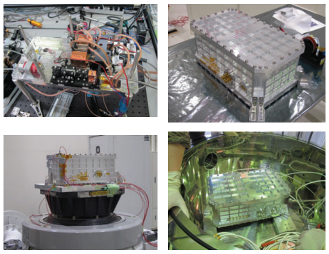


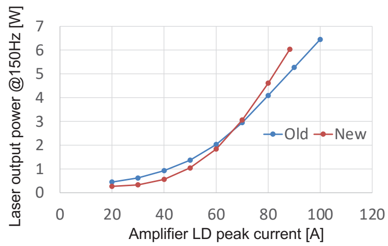
Canopy height
= Distance between Signal start and last pulse
— term for correcting error by relief



Estimate slope angle from altitude information of three footprints (observation points)

Laser Transmitter status





- MOLI Laser design employs MOPA architecture, which consists of a low energy end-pumped Q-sw Nd:YAG ceramics laser, 2-stage amplifier chain.
- The pre- and power- amplifier is also equipped Nd:YAG ceramics composite.
- Laser output over 40mJ with a repetition rate of 150 Hz, and pulse width is less than 6ns.
- Vibrational test is passed in JFY2020.
- Laser amplifier output of 40mJ is improved at current peak of ~90 A from previous operation of 100 A

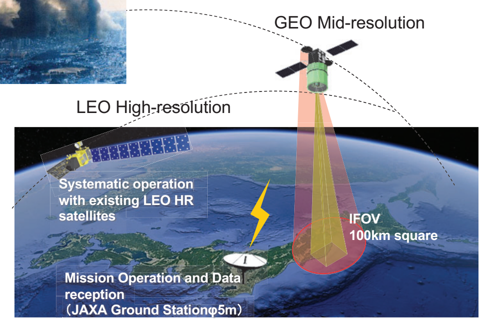
(Sakaizawa et al. 2022 in Japanese)

ICSO 2022 Dubrovnik, Croatia 24

Geostationary Optical Telescope Satellite (GOTS)

Under study

Large scale and sudden disasters need *instantaneous observation* to protect people



Integrated system of GEO Mid-resolution and LEO High-resolution observation will fill gaps of timing and ground resolution.

Also, video observation will help recognition of object with its movement.

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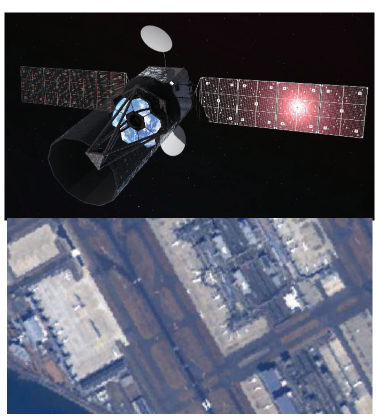
Major system specifications (Tentative)

- Φ3.6m Segmented Telescope (6 seg)
  - Ceramic Light Weight Mirror
  - Active optics
  - Wave front control system
- Multi band (Visible~IR)
- Video mode (1 fps)
- Fast data deliver latency (<30min)

Item	Spec. (TBD)
Orbit	Geostationary
Sensor	Area Imager (Still/Movie, VNIR+IR)
Spectral Bands	Pan, 6ch-Multi, IR
FOV	100km sq.
Observation Area	Full Disk
Latency	Under 30min. (Emergency)
Satellite Mass	About 4,600kg
Mission Life	Over 10 years
Launcher	H-3

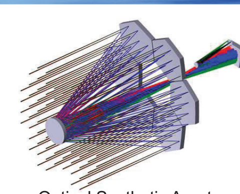


Haneda Airport (10m res. by ALOS)

ICSO 2022 Dubrovnik, Croatia 26

Telescope

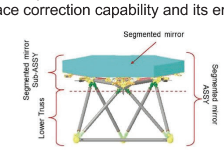
Item	Specification
Type	*Segmented-Aperture Telescope (6 Hexagonal segments)*
Telescope design	Korsch type Reflected optics
Aperture	*3.6m approx.*
Focal Length	*30m approx.*(tentative)
Field of View (FOV)	0.2 × 0.2deg
Dimension	φ4×7m (tentative)
Adjustment Mechanism (candidate)	·6-axes adjustment mechanism on PM ·Curvature adjustment mechanism on PM ·Adjustment mechanism on SM ·Deformable mirror on FM

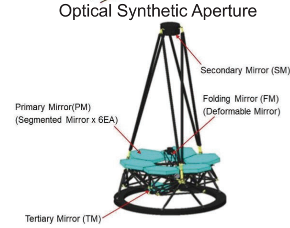


Optical Synthetic Aperture

<u>BBM production and test study(~2022)</u>

Manufacture one full size segment mirror with structure Φ1.3m Ceramic mirror production. Ultra accurate actuator system was installed and under test for surface correction capability and its error.

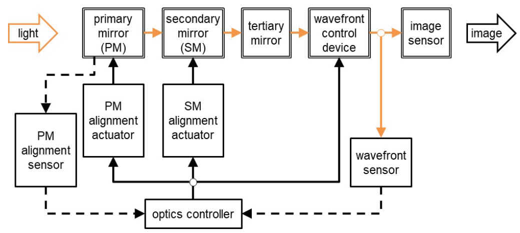




(Fujii et al. 2021)

ICSO 2022 Dubrovnik, Croatia 27

Telescope control system



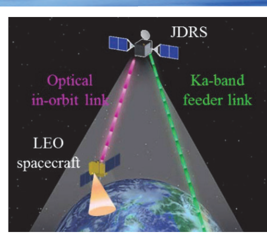
Segmented Primary mirror control to align mirrors
Secondary mirror control to adjust PM~SM length and LOS
Wave front Control Device (Deformable Mirror) to final wave control
Each control needs a few 10 nm level accuracy. It does not assume high frequency control for atmospheric disturbance, just to correct surface deformation by low-gravity and thermal distribution change

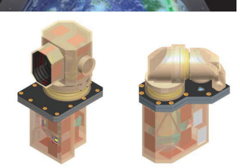
Telecommunication satellite

Optical communication on JDRS

Item	Specifications
JDRS	
Launch vehicle	H-IIA
Launch year	2020 in Japanese fiscal year
Position	90.75E longitude (same as KODAMA)
Mission period	10 years
Data relay system	
User data rate	Return link: 1.8 Gbps Forward link: 50 Mbps
Bit error rate*	Return link: 1e-5 Forward link: 1e-6
Target LEO spacecraft	Altitude of 200-1000km
Optical link	
Wave length	Forward: 1540 nm Return: 1560nm
Modulation/Demodulation	Return link: RZ-DPSK-DD Forward link: IM-DD
Acquisition time	< 60s (beacon-less)
Terminal's optical antenna diameter	GEO: 15cm, LEO: 10cm
Feeder link	
frequency	Ka-band
Modulation/Demodulation	Return link: 16QAM Forward link: QPSK
Division multiplexing method	frequency or polarization (return link)

* Total bit error rate of optical link and feeder link





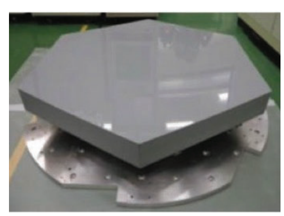
(a) GEO component (b) LEO component

LEO components are already installed in ALOS-3,4 and will be launched soon. Then GEO-LEO test campaign will start

(Chishiki et al. 2016)

Materials and Devices

Light weight Ceramic Mirror



Φ1.3mCA Ceramic mirror (Cordierite)
surface accuracy: < 63nm rms
Surface roughness: < 2nm rms

- **Approx. 70% weight of glass mirror with its high specific stiffness**
- **CTE is very low around ambient temp.**

Melco/Nikon (Fujii et al. 2021)

Type II Superlattice IR detector array

640x512 MTIR JAXA

Major specifications
- Format : 640x512
- Cut-off :15 micron
- D*: >10E11

Now 1Kx1K format is under test

Sumitomo Electric. Industry (Sakai et al. 2017)

Summary

- Japanese optical missions in Earth Observation Program, and key technology studies are introduced.
- Passive sensors in Japan is already demonstrated with enhancement of various ability, such as Polarimetry, Bi-directional, Expansion of Swath. Recent trend is to organize integrated LEO / GEO satellites system, to improve high temporal resolution keeping high spatial resolution. On the other hand, small and light optical sensors are being studied for small satellites for new technological demonstration or formation flight by commercial activities.
- Active optical sensor in japan is just started with ISS/MOLI, and will expand to Wind Lidar and DIAL. Also, optical data-link geostationary satellite was launched in 2020. After launch of LEO satellites with Optical link, the LEO GEO data-link demonstration will start soon.

Thank you !