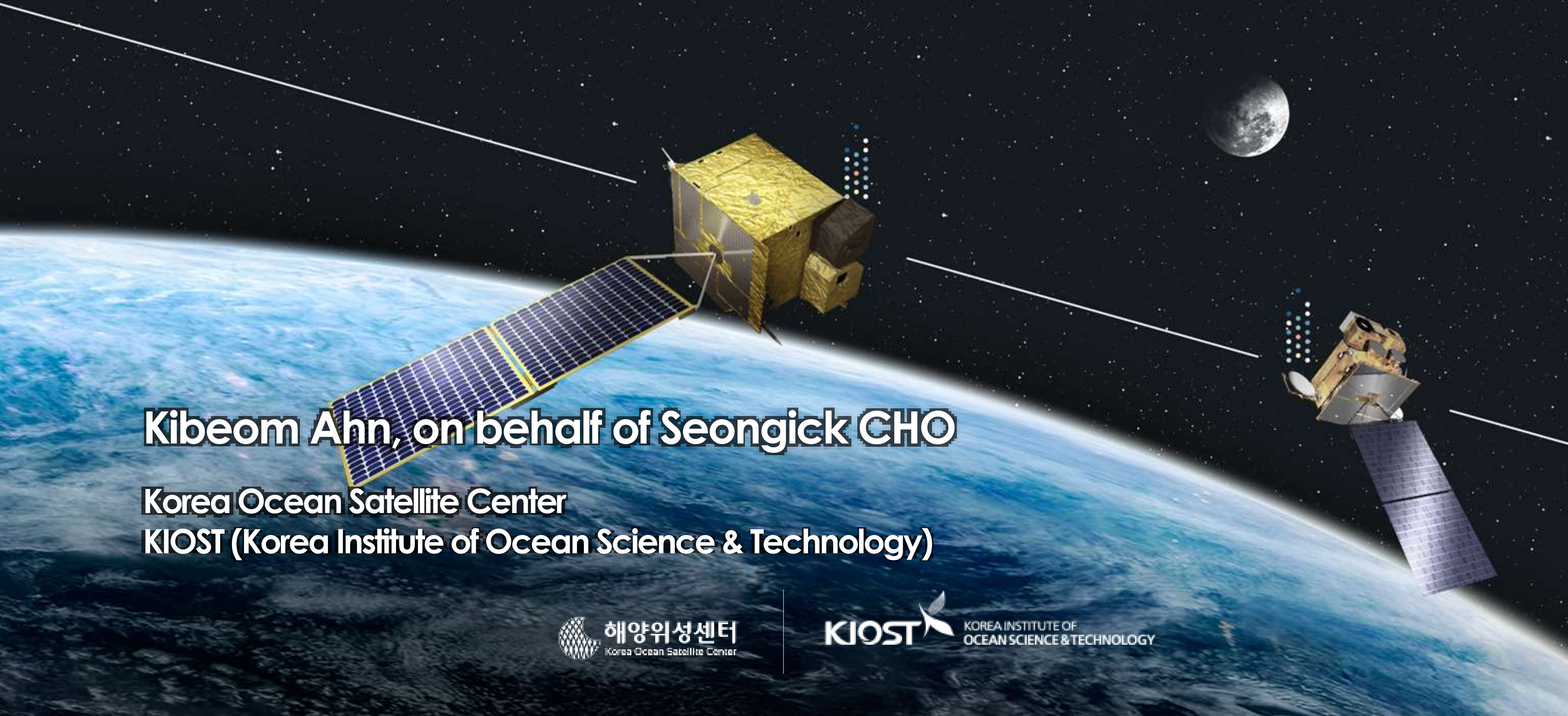
GOCI-II Lunar Calibration and MTF Measurement Plan



Kibeom Ahn, on behalf of Seongick CHO

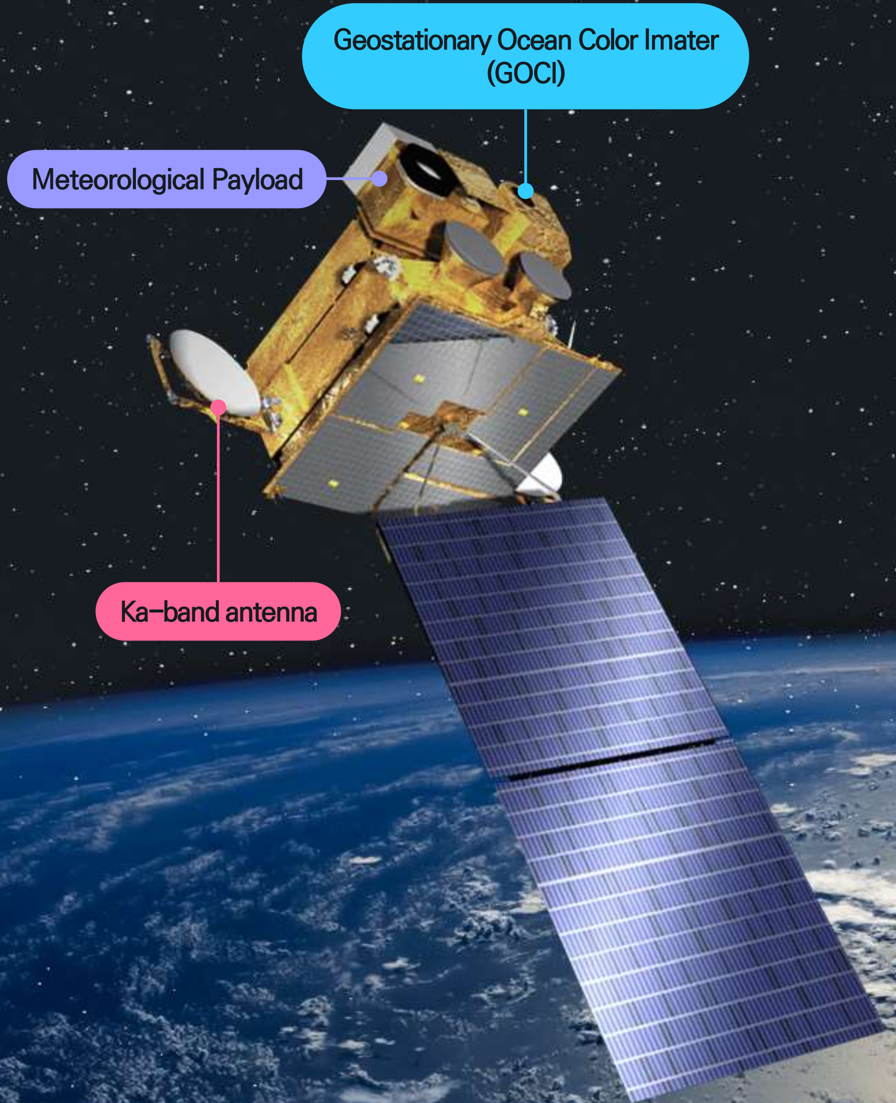
Korea Ocean Satellite Center
KIOST (Korea Institute of Ocean Science & Technology)

해양위성센터 Korea Ocean Satellite Center
KIOST KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

Contents

Introduction of GOCI & GOCI-II

Introduction of GOCI



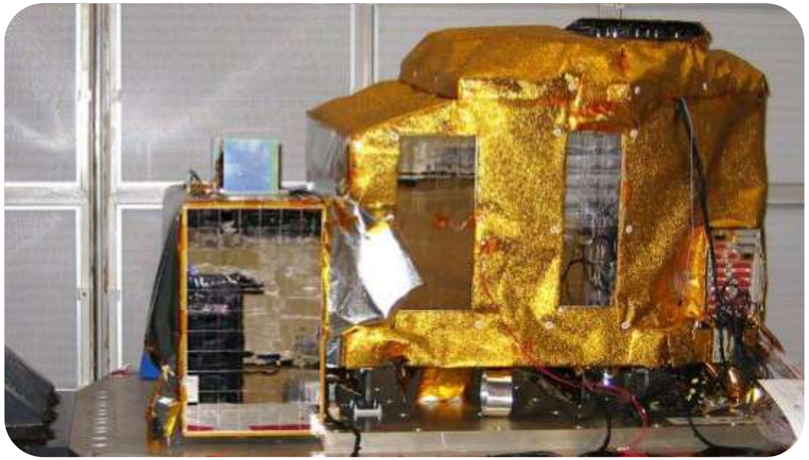
Chollian Satellite

COMS Communication, Ocean & Meteorological Satellite

- Developments of COMS(H/W) and GDPS(S/W) : 2003
- Establishment of KOSC (Ground System) : 2005
- The first Korean Geostationary multipurpose Satellite
- Launch date : June 27 2010
- Lifetime : 7 years
- Payloads (3 Missions)

  - Geostationary Ocean Color Imager (GOCI)
  - Meteorological Imager
  - Ka-band Communication

Introduction of GOCI



Geostationary Ocean Color Imager

- GSD(Ground Sampling Distance) : 500m * 500m
- Target Area : 2,500km * 2,500km (Center : 130˚E 36˚N)
- Included Nations : Korea, E. China, Japan, Taiwan, Russia, etc.
- Temporal Resolution : 1hour (8 times / day)

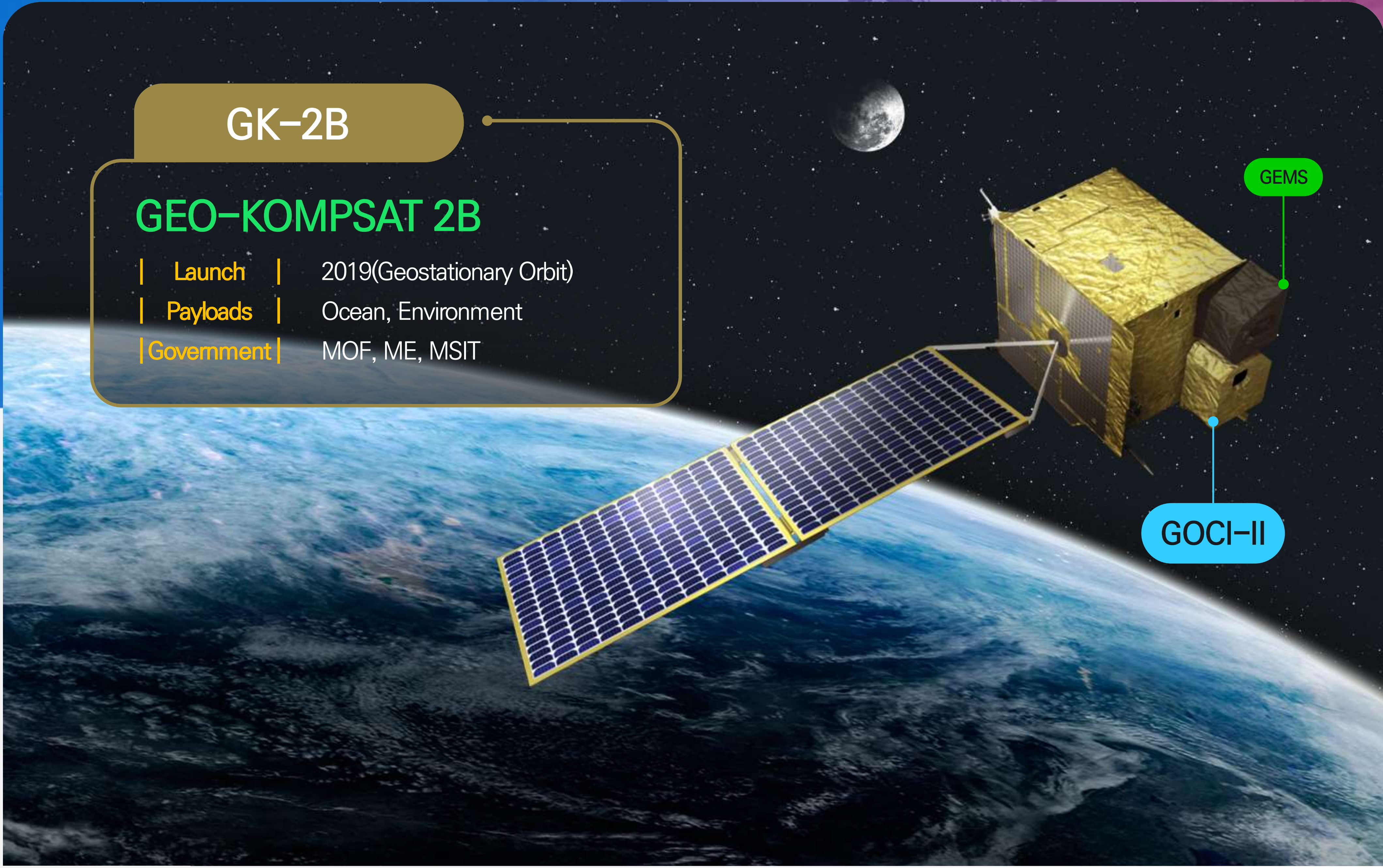
Band	Central wavelengths	Band Width	SNR	Primary Application
B1	412nm	20nm	1,070	Yellow substance and turbidity
B2	443nm	20nm	1,190	Chlorophyll absorption maximum
B3	490nm	20nm	1,170	Chlorophyll and other pigments
B4	555nm	20nm	1,070	Turbidity, suspended sediment
B5	660nm	20nm	1,010	Baseline of fluorescence signal, Chlorophyll, suspended sediment
B6	680nm	10nm	870	Atmospheric correction and fluorescence signal
B7	745nm	20nm	860	Atmospheric correction and baseline of fluorescence signal
B8	865nm	40nm	750	Aerosol optical thickness, vegetation, water vapor reference over the ocean

The next satellite, GOCI-II

GK-2B

GEO-KOMPSAT 2B

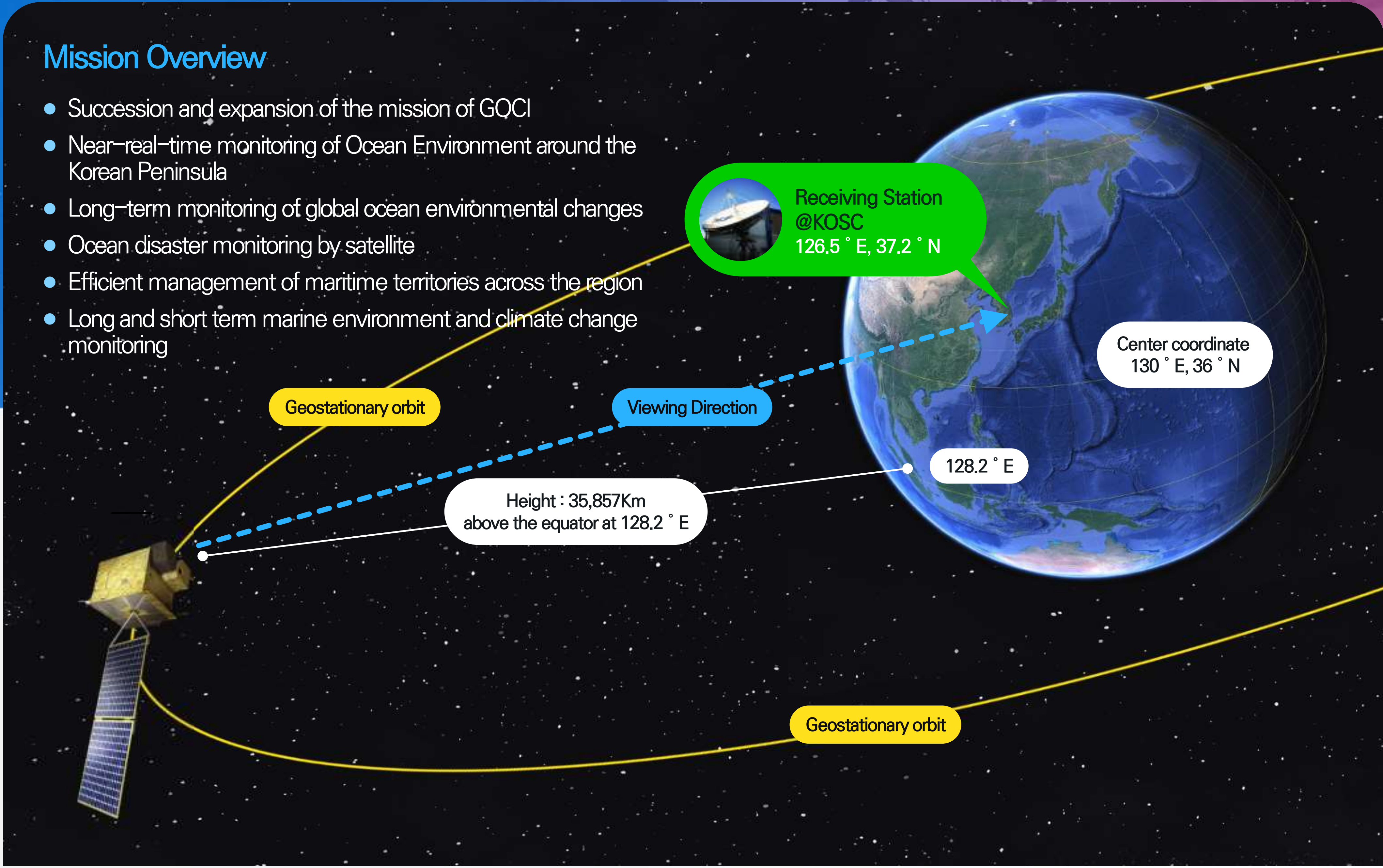
Launch	2019(Geostationary Orbit)
Payloads	Ocean, Environment
Government	MOF, ME, MSIT



Missions of GOCI-II

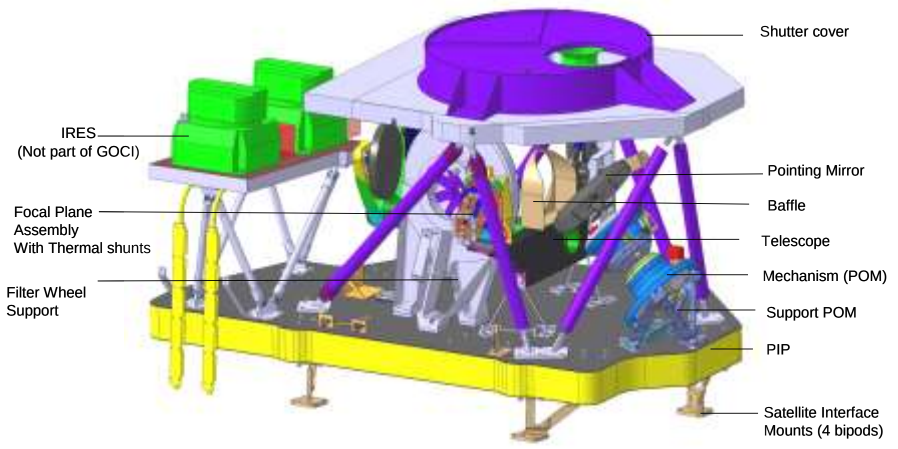
Mission Overview

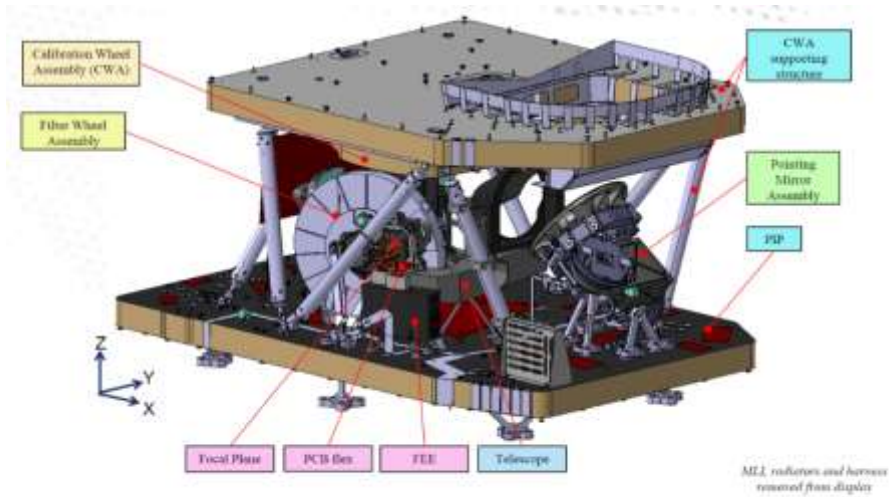
- Succession and expansion of the mission of GOCI
- Near-real-time monitoring of Ocean Environment around the Korean Peninsula
- Long-term monitoring of global ocean environmental changes
- Ocean disaster monitoring by satellite
- Efficient management of maritime territories across the region
- Long and short term marine environment and climate change monitoring



GOCI & GOCI-II

GOCI	GOCI-II





Dimension is **similar** to **GOCI except the width**
- Width : ~ 50 % increase

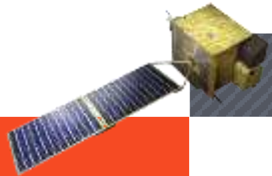
Mass is almost **two times**

	GOCI	GOCI-II
Dimension	1015 x 888 x 854 mm2	1,520 x 1,000 x 891 mm2
Main Unit mass	78.5 Kg	140 Kg
Overall mass	83.3 Kg	150 Kg

CWA	Calibration Wheel Assembly
FEE	Front End Electronics
PIP	Payload Interface Plate
POM	POinting Mechanism
STA	Star Trackers Assembly

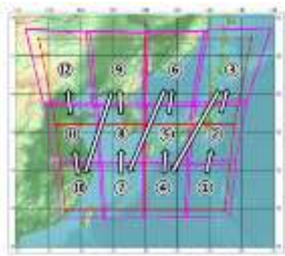
Development of GOCI-II

Performance Comparison

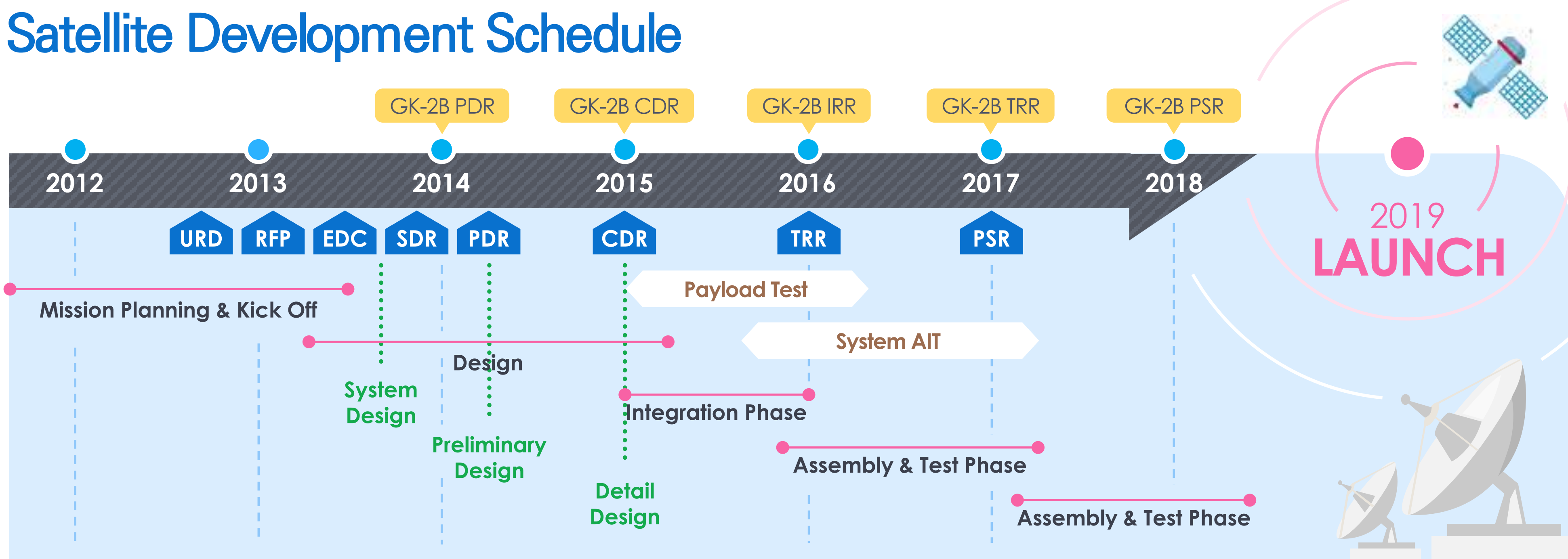


Items	GOCI	GOCI-II
Spectral Resolution	8 bands	13 bands
Spatial resolution	500m	250m (equator)
Number of observations	8 times/day	10 times/day
Target Area	Local	Local & Global

Observation Mode

Local	Full Disk
	
(User-definable)	(Red line)

Satellite Development Schedule



GOCI-II Spectral Bands

Radiance : W/m²/μm/sr

GOCI Band	GOCI-II Band	Band center	Bandwidth	Nominal Radiance	Maximum Ocean radiance	Threshold Radiance	Maximum Cloud Radiance	NEdL	SNR @ Nominal radiance
-	**1**	380 nm	20 nm	93	139.5	143.1	634.4	0.093	998
1	**2**	412 nm	20 nm	100	150	152	601.6	0.095	1050
2	**3**	443 nm	20 nm	92.5	145.8	148	679.1	0.081	1145
3	**4**	490 nm	20 nm	72.2	115.5	116	682.1	0.059	1128
-	**5**	510 nm	20 nm	64.9	108.5	122	665.3	0.055	1180
4	**6**	555 nm	20 nm	55.3	85.2	87	649.7	0.049	1124
-	**7**	620 nm	20 nm	53.3	64.1	65.5	629.5	0.048	1102
5	**8**	660 nm	20 nm	32	58.3	61	589	0.03	1060
6	**9**	680 nm	10 nm	27.1	46.2	47	549.3	0.03	914
-	**10**	709 nm	10 nm	27.7	50.6	51.5	450	0.03	914
7	**11**	745 nm	20 nm	17.7	33	33	429.8	0.02	903
8	**12**	865 nm	40 nm	12	23.4	24	343.8	0.015	788
-	**13**	643.5 nm	483 nm	-	-	-	-	-	-

Field of Regard

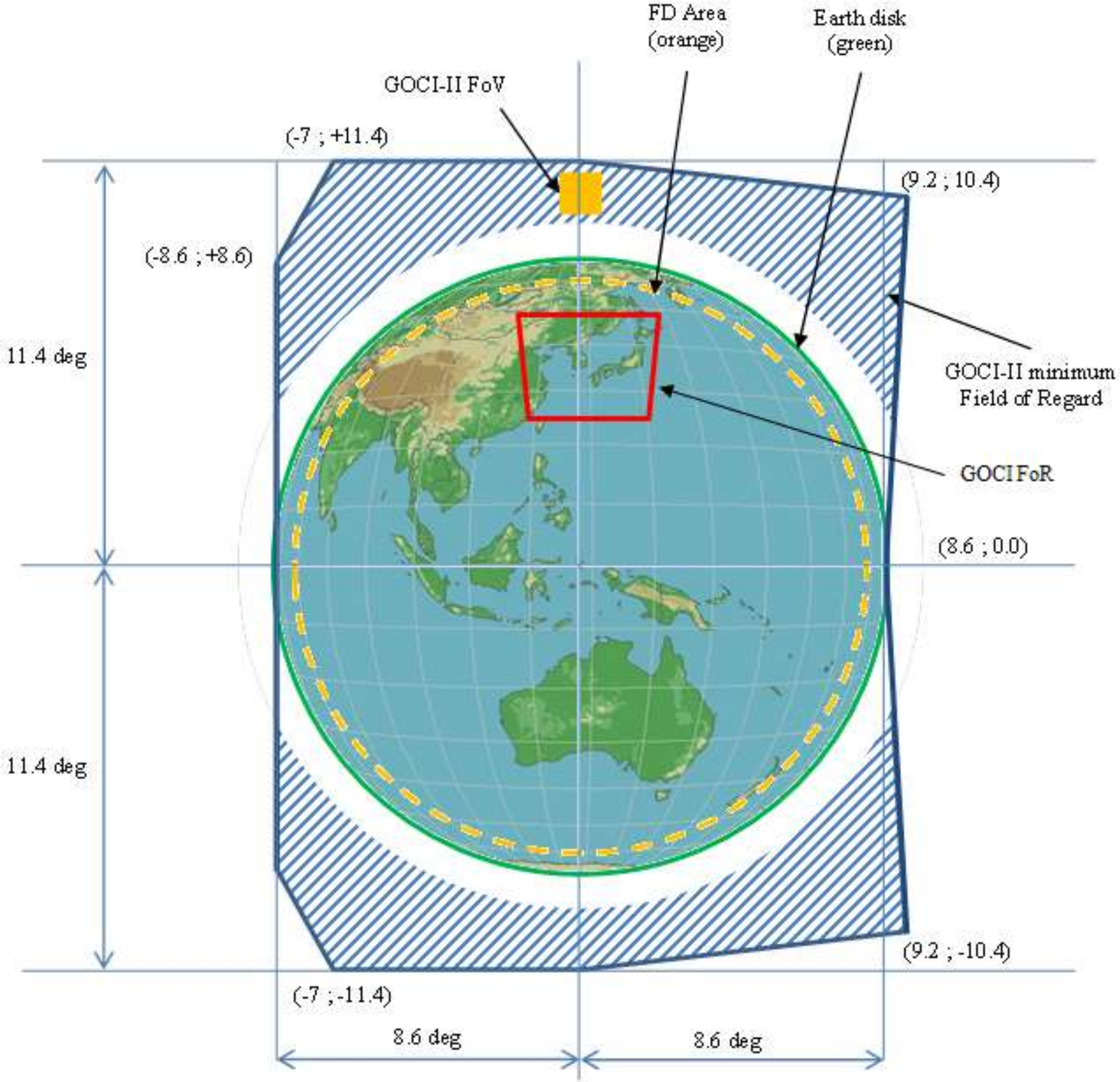
◆ Targeted Field of Regard

◆ SN FoR (±11.4 deg)

- 8.7 deg Earth Disk
- 1.1 deg Instrument FoV
  set as margin
- 1.1 deg useful FoV
  for moon and star
- 0.5 deg margin
  for pointing bias

◆ EW FoR (±8.6 deg)

- 8.06 deg FD area
- 0.5 deg margin
  for pointing bias



GOCI-II Lunar Calibration Plan

GOCI-II Lunar Calibration Plan

Moon Imaging Feasibility Assessment (1/2)

- 5 Moon imaging criteria with hierarchical priority

(Priority 1) **Moon in GOCI-II FoR (Field of Regard)**
- GOCI-II FoR (Field of Regard): ±8.7 deg in EW direction, ±11.0 deg in SN direction
- Earth disk size corresponds to ±8.7 deg
- No spacecraft maneuver (esp. roll maneuver) is planned

(Priority 2) **GOCI-II Nominal Operation Duration**
- 05:15 ~ 19:45 (KST)

(Priority 3) **Moon phase: more than 50% of illuminated area (100% in Full Moon)**
- First quarter → Waxing gibbous → Full Moon → Waning gibbous → Last quarter

(Priority 4) **Moon imaging time shall not be fully overlapped with the operation time of another payload on GK2B**
- Allocated GOCI-II operation timeline is 15 to 45 min in every hour

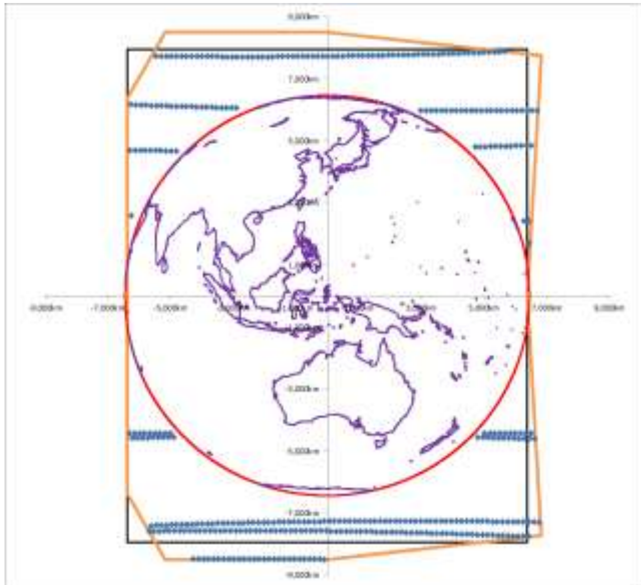
(Priority 5) **Continuous single observable duration shall be equal to or longer than 10 min(TBD) per day**

- Additional criteria regarding image quality of the Moon

(Priority 6) **Rejection of Earth straylight Area**
- Moon image can be affected by Earth straylight
- Potential Earth straylight region : 1 deg from Earth disk

(Priority 7) **Optimum Moon phase angle range for DAMD* monitoring**
- Relative uncertainty of ROLO model w.r.t. phase angle : ~1%
- Required determination of optimal phase angle range

(*DAMD : Diffuser Ageing Monitoring Device)



Monthly lunar intrusion in GOCI-II FOR (Jan. 2019)

GOCI-II Lunar Calibration Plan

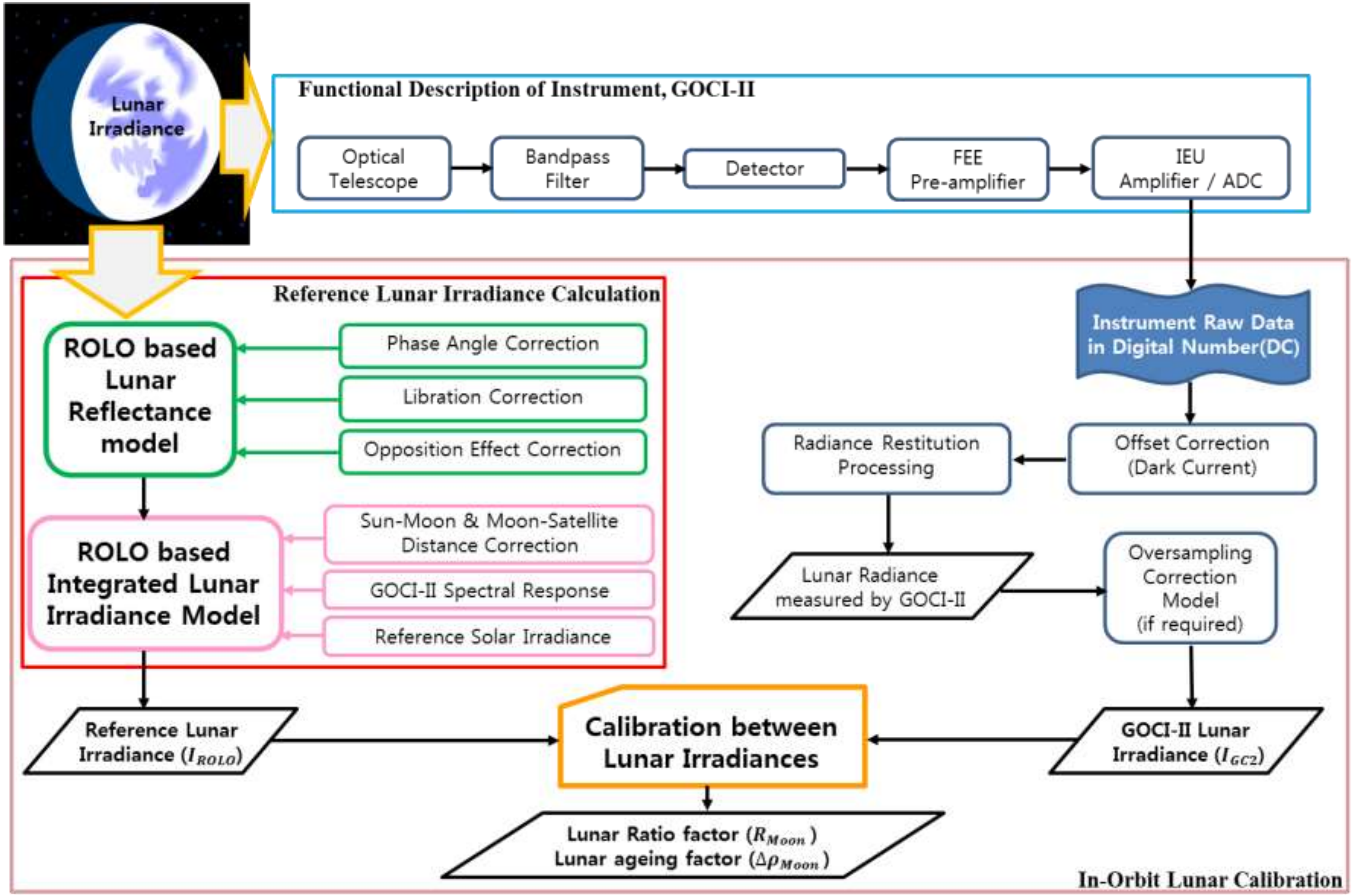
Moon Imaging Feasibility Assessment (2/2)

- Moon imaging timeline in year of 2019

Month in '2019	Observable days for monthly Moon imaging (day)	Observable times for recommended monthly Moon imaging	Start time of recommended monthly Moon imaging (yyyy-mmm-dd hh:mm, KST)	End time of recommended Moon imaging (yyyy-mmm-dd hh:mm, KST)	Observable time for selected Monthly Moon imaging (min, approx.)
Jan.	2	1	2019-Jan-15 07:15	2019-Jan-15 07:45	30
Feb.	3	1	2019-Feb-20 13:15	2019-Feb-20 13:45	30
Mar.	1	2	2019-Mar-20 11:15 2019-Mar-20 12:15	2019-Mar-20 11:36 2019-Mar-20 12:32	38
Apr.	1	2	2019-Apr-20 12:29 2019-Apr-20 13:15	2019-Apr-20 12:45 2019-Apr-20 13:45	46
May	1	1	2019-May-18 11:16	2019-May-18 11:45	29
Jun.	2	1	2019-Jun-14 09:15	2019-Jun-14 09:45	30
Jul.	2	2	2019-Jul-21 15:15 2019-Jul-21 16:15	2019-Jul-21 15:39 2019-Jul-21 16:30	39
Aug.	2	2	2019-Aug-17 13:15 2019-Aug-17 14:15	2019-Aug-17 13:45 2019-Aug-17 14:28	43
Sep.	1	1	2019-Sep-18 15:15	2019-Sep-18 15:45	30
Oct.	2	1	2019-Oct-11 10:34	2019-Oct-11 10:45	11
Nov.	4	1	2019-Nov-11 10:32	2019-Nov-11 10:44	12
Dec.	3	2	2019-Dec-09 09:15 2019-Dec-09 10:15	2019-Dec-09 09:45 2019-Dec-09 10:29	44

ROLO model implementation for GOCI-II

GOCI-II lunar calibration procedure



Reference Lunar Irradiance

Lunar reflectance (A_k) provided by ROLO model

$$\ln A_k = \sum_{i=0}^{3} a_{ik} g^i + \sum_{j=0}^{3} b_{jk} \Phi^{2j-1} + c_1\theta + c_2\phi + c_3\Phi\theta + c_4\Phi\phi + d_{1k} e^{-\frac{g}{p_1}} + d_{2k} e^{-\frac{g}{p_2}} + d_{3k} \cos\left[\frac{(g-p_3)}{p_4}\right]$$

where:

A_k	: disk-equivalent reflectance for each band k
g	: absolute phase angle
θ	: selenographic latitude of GOCI-II
ϕ	: selenographic longitude of GOCI-II
Φ	: selenographic longitude of the Sun

- Calculated ROLO model(version 311g) coefficients for GOCI-II

Band	Band Center (nm)	a0	a1 (rad^{-1})	a2 (rad^{-2})	a3 (rad^{-3})	b1 (rad^{-1})	b2 (rad^{-3})	b3 (rad^{-5})	d1	d2	d3
B1	380	-2.53875	-1.73218	0.424342	-0.22212	0.034985	0.010926	-0.00362	0.345536	-0.01098	-0.00502
B2	412	-2.34249	-1.74246	0.420812	-0.21495	0.03156	0.013508	-0.00467	0.365353	-0.05816	0.000765
B3	443	-2.32145	-1.71791	0.375473	-0.19491	0.037671	0.015208	-0.00552	0.376755	-0.09156	0.008859
B4	490	-2.22836	-1.68141	0.371029	-0.1969	0.038784	0.015455	-0.00546	0.366226	-0.09036	0.007187
B5	510	-2.19513	-1.65353	0.336892	-0.18481	0.038616	0.014135	-0.00488	0.368327	-0.09626	0.009814
B6	555	-2.1225	-1.65885	0.383235	-0.20625	0.040559	0.010087	-0.00388	0.372053	-0.10775	0.003567
B7	620	-1.98473	-1.61287	0.336911	-0.19021	0.042679	0.009935	-0.00389	0.371673	-0.12392	0.008829
B8	660	-1.89995	-1.58457	0.308405	-0.18034	0.043984	0.009842	-0.00389	0.37144	-0.13387	0.012067
B9	680	-1.89178	-1.58316	0.292015	-0.1712	0.044225	0.009463	-0.00369	0.381883	-0.15395	0.015173
B10	709	-1.91429	-1.59811	0.365081	-0.20418	0.044258	0.010299	-0.00396	0.371204	-0.14098	0.004827
B11	745	-1.86933	-1.57541	0.337351	-0.19423	0.039708	0.013156	-0.00463	0.368899	-0.14822	0.009541
B12	865	-1.7458	-1.58485	0.350134	-0.19572	0.041439	0.016106	-0.0055	0.391924	-0.18828	0.009775

Reference Lunar Irradiance

Integrated Lunar Irradiance based on ROLO model

✓ The integrated lunar reference spectral irradiance, $I_{ROLO\_Ref}(B,t)$, is calculated by the actual solar spectral response of GOCI-II, reference solar spectral irradiance, reference lunar reflectance, and reference distance value for Sun-Earth and Moon-Satellite(GOCI-II) as follows:

$$I_{ROLO\_Ref}(B,t) = \frac{\Omega_M}{\pi} \frac{\int_{\lambda_1}^{\lambda_2} E_{SUN} \cdot R_\lambda(B) \cdot A(B,t)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} R_\lambda(B)\, d\lambda} \quad [W \cdot m^{-2} \cdot \mu m^{-1}]$$

where:
IROLO_Ref(B,t) : Integrated lunar reference spectral irradiance
ESUN : Reference solar spectral irradiance
Rλ(B) : Spectral response of GOCI-II for each spectral band B
A(B, t) : Disk-equivalent lunar reflectance for each band B
ΩM : 6.4177 × 10-5 sr

Measured lunar spectral irradiance at GOCI-II, $I_{ROLO}(\mathrm{B}, t)$

$$I_{ROLO}(B,t) = I_{ROLO\_Ref}(B,t) \cdot C_{DIS}(t) \quad [W \cdot m^{-2} \cdot \mu m^{-1}]$$

where:
I_{ROLO}(B,t) : Distance corrected measured integrated lunar spectral irradiance
I_{ROLO_Ref}(B,t) : Integrated lunar reference spectral irradiance
C_{DIS}(t) : Distance correction factor of Sun-Moon and Moon-Satellite (GOCI-II)

GOCI-II Lunar Irradiance

Oversampling Correction

- ✓ Due to the step and stare imaging mechanism of GOCI-II with 2D CMOS detector, **scan rate correction is not required**.
- ✓ **Spatial oversampling correction may be required** for GOCI-II due to ***the motion of the Moon and satellite*** during the integration time.
- ✓ Expected integration time of GOCI-II for Moon imaging is less than 4.5sec for HG image acquisition, and the mean orbit angular velocity of GOCI-II is about 72.9 μrad/sec.
  - ➢ Moon will moves about 10 pixels (FOV of one pixel is about 7 μrad for GOCI-II) in the integration time with 1 sec (the worst case is about 50 pixels at 4.5 sec integration time).
- ✓ **The oversampling correction** based on the comparison ***between actual size of the Moon and the acquired image*** can be expressed in ROLO model (Eplee et al, 2004) as:

$$C_{SAM}(t) = \frac{arctan\left(\frac{3476.4\ [km]}{D_{MSat}(t)}\right)}{Y_{Moon}(t)}$$

where:

YMoon(t)	: Angular size of the Moon in the GOCI-II lunar image
DMSat(t)	: Distance between the Moon and Satellite (GOCI-II)
3476.4 km	: Diameter of the Moon

- ✓ If oversampling correction is understood to be required, detailed oversampling correction model regarding the motion of the Moon and the satellite, GOCI-II, and satellite level pointing stability will be done in a next step.

GOCI-II Lunar Irradiance

Integrated Lunar Irradiance of GOCI-II

$$I_{GC2}(B,t) = \sum_{i=1}^{N} L_{MOON}\,(B,t,i)\cdot\Omega(i) \qquad [W\cdot m^{-2}\cdot \mu m^{-1}]$$

where:

N	: Number of pixels on lunar disk in GOCI-II lunar image
$I_{GC2}(B,t)$	: Lunar irradiance determined from GOCI-II lunar image at given time, t
L_{MOON}	: Observed lunar radiance from GOCI-II after oversampling correction
$\Omega(i)$	: Solid angle subtended by i^{th} pixel in lunar disk
B	: Spectral band of GOCI-II
t	: Time of the Moon imaging in lunar calibration timeline series

Solid angle subtended by pixel of GOCI-II

$$\Omega(i) = \frac{GSD^2}{(35786\ [km])^2} \qquad [steradian]$$

where:

GSD	: Ground Sampling Distance of GOCI-II at Nadir, less than 250m
35786 [km]	: The Spacecraft altitude (H) assigned in the chapter 4

- ✓ If required, solid angle subtended by pixel can be calculated for each pixel.
- ✓ In a next step, analytical formulae for GOCI-II lunar irradiance will be established.

GOCI-II Lunar Calibration

- ✓ The Moon is widely used for the monitoring of in-orbit calibration stability.
- ✓ In this purpose, lunar ratio factor between the reference lunar irradiance based on the ROLO model (I_{ROLO}) and GOCI-II lunar irradiance (I_{GC2}) retrieved from the GOCI-II lunar image is defined as follows:

$$R_{Moon} = \frac{I_{GC2}}{I_{ROLO}}$$

- ✓ Where R_{Moon} is named as the lunar irradiance ratio factor, shortly ratio factor.

- ✓ Because lunar disk observed in single GOCI-II lunar image is only a portion of all detector pixels, and ROLO model can provide the integrated lunar irradiance only, absolute in-orbit calibration to update radiometric gain for each pixel is normally not suitable to lunar calibration.
- ✓ With this technical limitation, lunar ageing factor ($\Delta\rho_{Moon}$) to compensate the degradation of the radiometric performance defined by the lunar calibration can be defined as follows:

$$\Delta\rho_{Moon} = \frac{I_{ROLO}}{I_{GC2}}$$

- ✓ With lunar aging factor and PRNU (Pixel Response Non-Uniformity), variation of the radiometric performance for each pixel can be assessed.

Technical Issue

Earth Shine Straylight

- ✓ For the effective lunar calibration, leakage of the Earth shine (i.e. Earth straylight) at Moon imaging of GOCI-II is expected to be analyzed as part of GOCI-II straylight analysis.
- ✓ In a next step, minimum distance between the Earth and the Moon to avoid the Earth straylight on the Moon will be provided based on the result of the straylight analysis.

Lunar Radiance Model for each pixel

- ✓ Because the ROLO model can only provide the integrated lunar irradiance at this moment, lunar radiance for each pixel can't be retrieved.
- ✓ In order to overcome this technical limitation, it is known that a lunar radiance model for each pixel is under development by USGS (IOCCG Report No. 14).
- ✓ The expected accuracy of the lunar radiance model is about 0.5% for long-term monitoring and about 5% for single lunar image.

G2GS Lunar Calibration Module

GOCI-II Lunar Calibration Module

Algorithm

- Lunar Irradiance Calculation
  - Based on ROLO Model

- Moon Pixel Selection
  - ROI Selection + DN Threshold
    - ROI Selection for Earth Contamination
    - DN Threshold for Extraction of Moon Pixel only

- Interpolation for spacecraft position determination
  - Linear interpolation at Lunar Observation Time

Verification

- Using MI/COMS Moon images (provided by KMA)

GOCI-II Lunar Calibration Module - Verification

Input Image

- MI/ COMS Moon Image (L1A)
  - W_KR-KMA-NMSC,VISNIR+SUBSET+MOON, COMS1+Imager_C_RKSL_20130420225822_01.nc
    - Bands > dc_obs_imgt
  - Image size : 699 X 699 (Unsigned Integer)

GOCI-II Lunar Calibration Module - Verification

Calculation of ROLO Irradiance

Contents	Reference	Lunar Calibration Module	P / F
Abs Phase Angle	1.092966255e+00	1.092966255e+00	Pass
ROLO Irradiance	9.644399507e-04	9.644399509e-04	Pass
Reference Irradiance	7.558361117e-04	7.558361120e-04	Pass

Calculation of Lunar Image Irradiance

Contents	Reference	Lunar Calibration Module	P / F
Moon Irradiance	6.897984906e-04	6.897984907e-04	Pass

Slope Factor

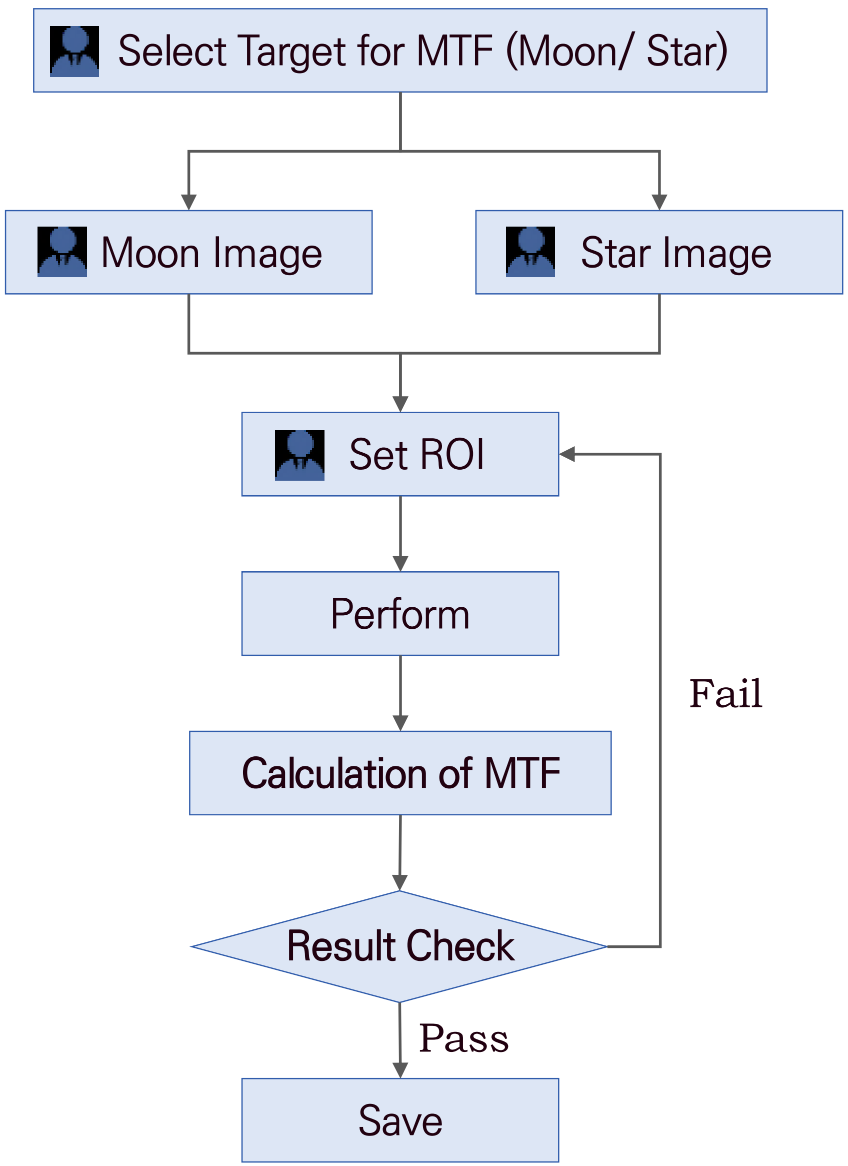
Contents	Reference	Lunar Calibration Module	P / F
Slope Factor	9.126297083e-01	9.126297087e-01	Pass

GOCI-II MTF Measurement Plan

GOCI-II MTF Measurement Plan

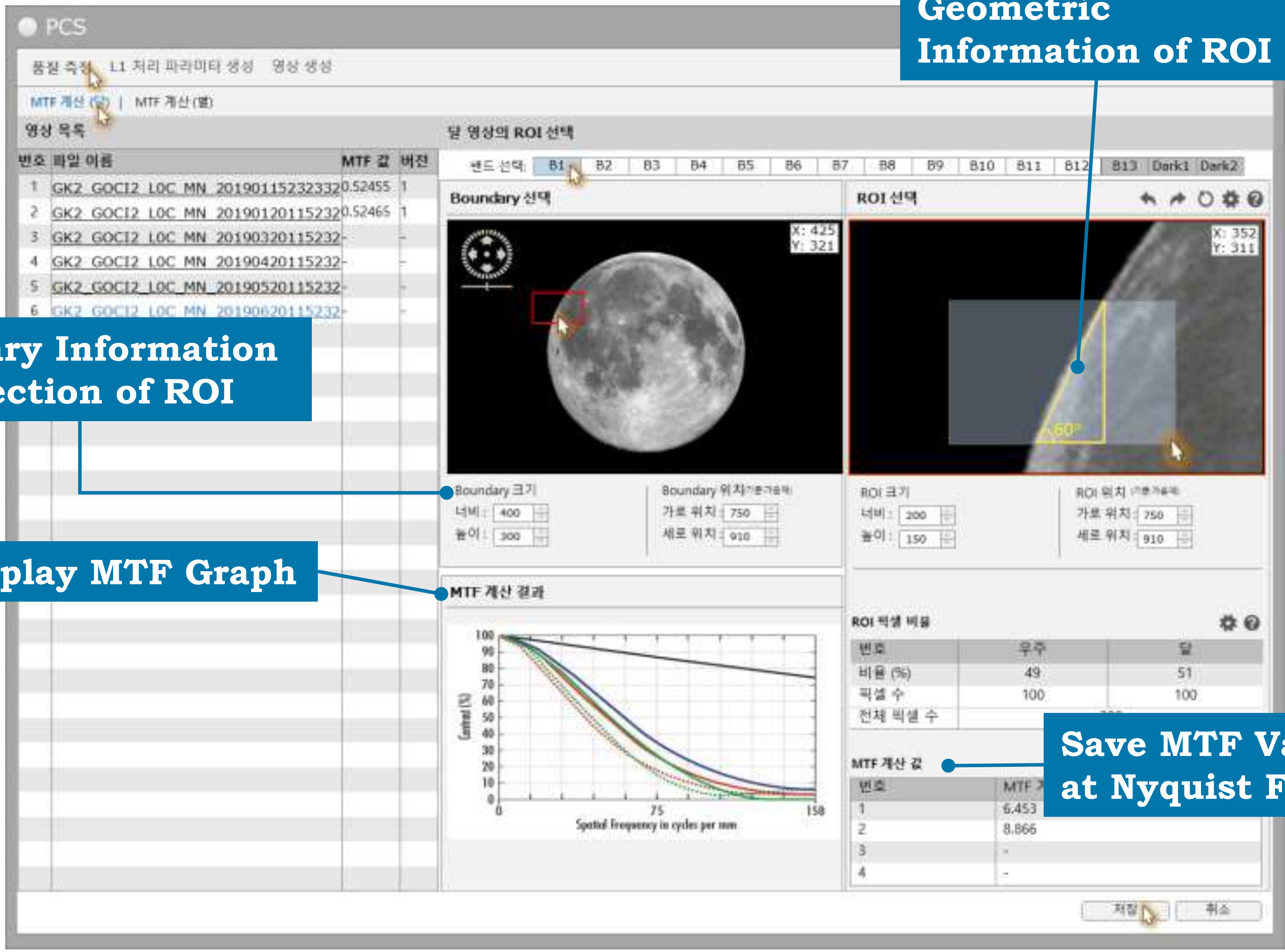
- **MTF Measurement from Moon Image**
  - Input – Moon Image (L0C)
  - Output – MTF of Moon Image
  - Using Lunar Edge as Slant-Edge Source
  - Algorithm
    - ① Set a ROI including Lunar Edge
    - ② Calculate ESF & LSF
    - ③ Calculate MTF

- **MTF Measurement from Star Image**
  - Input – Star Image (L0C)
  - Output – MTF of Star Image
  - Using Star Image as Point Source
  - Algorithm
    - ① Set a ROI including Star
    - ② Calculate PSF
    - ③ PSF Normalization
    - ④ Calculate MTF



GOCI-II MTF Measurement Plan

GUI for MTF Measurement



Conclusion

Conclusion

✓ Technical feasibility of the Moon observation was confirmed

✓ Theoretical adaptation of ROLO model is accomplished for GOCI-II

✓ Prototype implementation of ROLO model for GOCI-II
: Verification using MI/COMS Moon images (provided by KMA)

✓ In the next step, followings are planned to be completed with in-depth analysis:
- Recommendation of the Moon imaging time after the determination of reference phase angle
- Instrument oriented reference lunar irradiance model
- Oversampling correction to retrieve GOCI-II lunar irradiance
- Technical Feasibility to implement reference lunar radiance model for each pixel

Thank you for your attention.

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GOCI-II Ground Systems

GOCI-II Ground System Development (2015 ~ Present)

- **G2GS**
  - **OQMS** (Operation & Quality Management Subsystem)
  - **ODPS** (Ocean Data Processing Subsystem)
  - **DMS** (Data Management Subsystem)
  - **PCS** (Precision Correction Subsystem)
    - Dark Current Calibration
    - Gain Matrix Generation
    - Straylight Correction
    - ISRD Correction
    - SNR Measurement
    - BTDF Calibration
    - Solar Calibration
    - **Lunar Calibration**
    - **MTF Measurement**
    - .....