WGCV-51

Progress on Chinese Space-based Radiometric Benchmark Project

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Agenda Item 3.5

WGCV-51, Tokyo, Japan

3rd - 6th October 2022

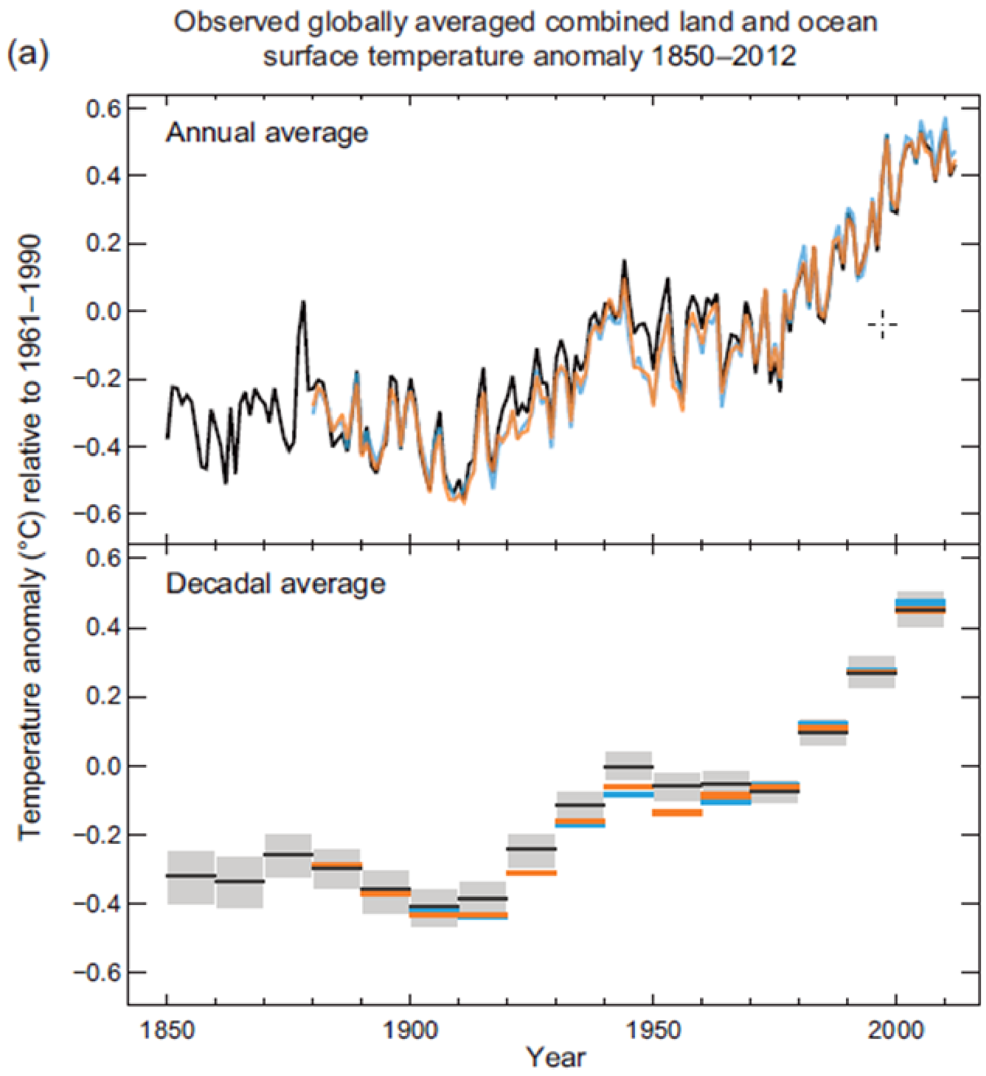
Committee on
Earth Observation Satellites

Outline

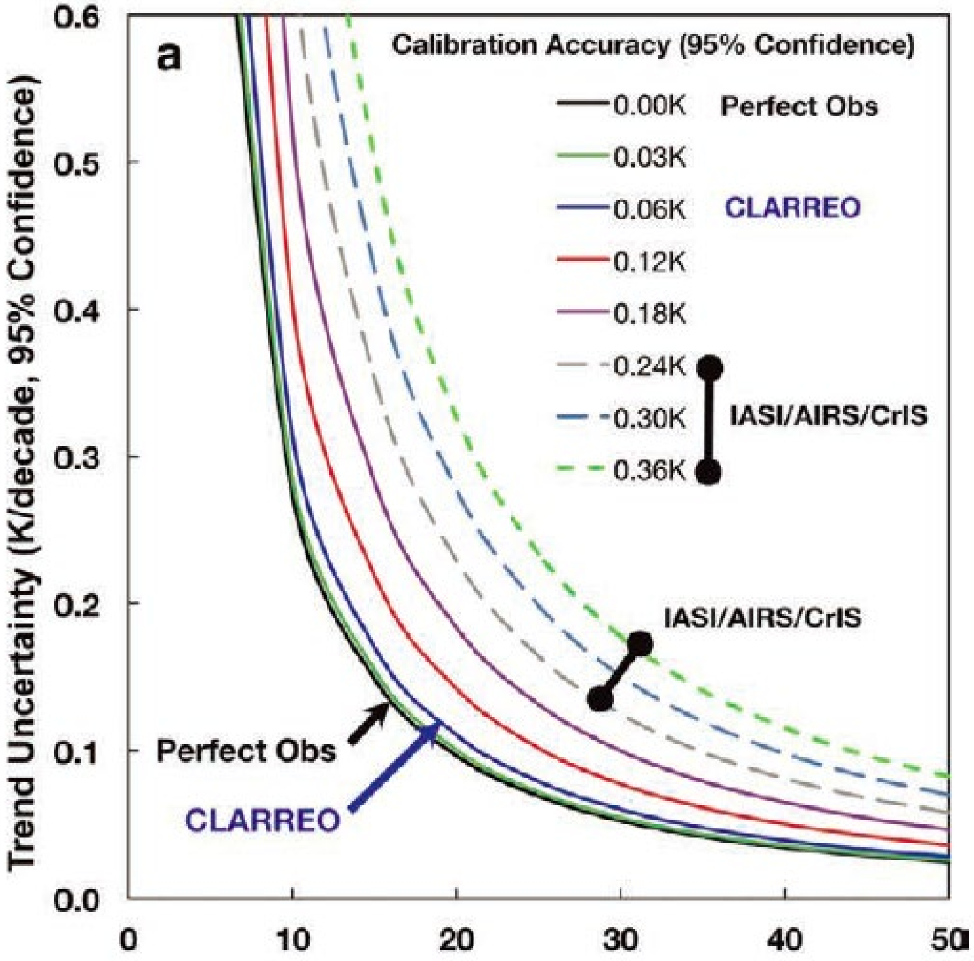
- Background
- Project Introduction
- Prototype Model Progress
- On-orbit Mode to Support Intercalibration
- Summary

1. Background

IPCC Assessment Report 5, 2013

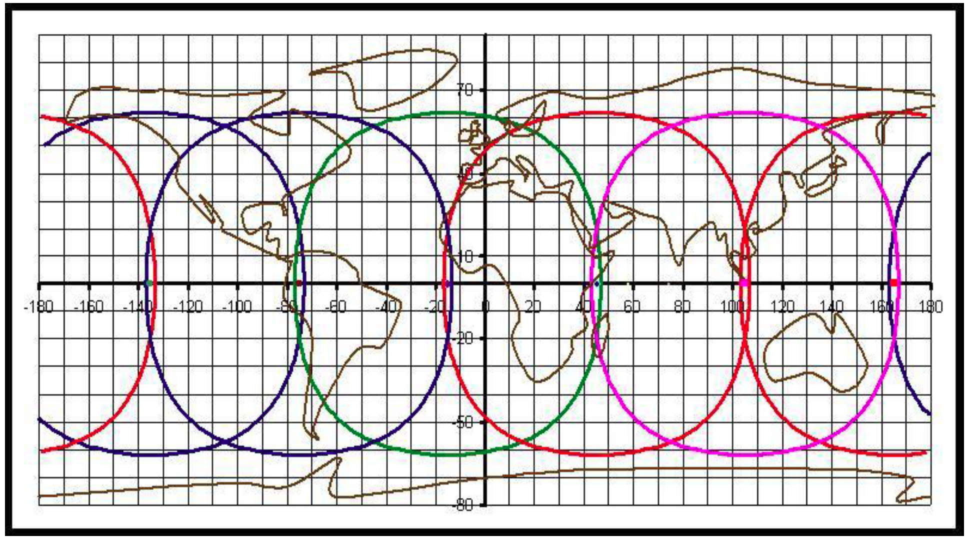


Bruce A. Wielicki, et al, 2013: Achieving Climate Change Absolute Accuracy in Orbit. BAMS



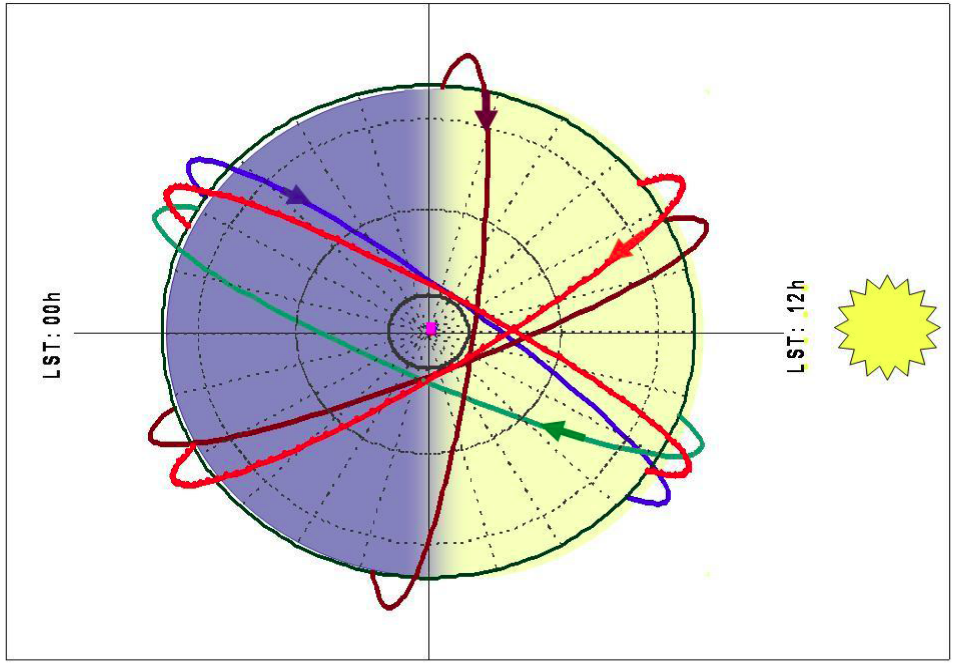
Vision for WMO Integrated Global Observing System in 2040

To harmonize the radiometric measurement from the all kinds of platform in operation



GSICS
Global Space-based Inter-Calibration System

CEOS
Working Group on Calibration and Validation



Tier 1 **Backbone system with specified orbital configuration and measurement approaches**

- Basis for Members' commitments, should respond to the vital data needs;
- Building on the current CGMS baseline, but with fully deployed (global) coverage, and with addition of newly maturing capabilities.

Tier 2 **Backbone system with open orbit configuration and flexibility to optimize the implementation**

- Basis for open contributions of WMO Members, responding to target data goals.

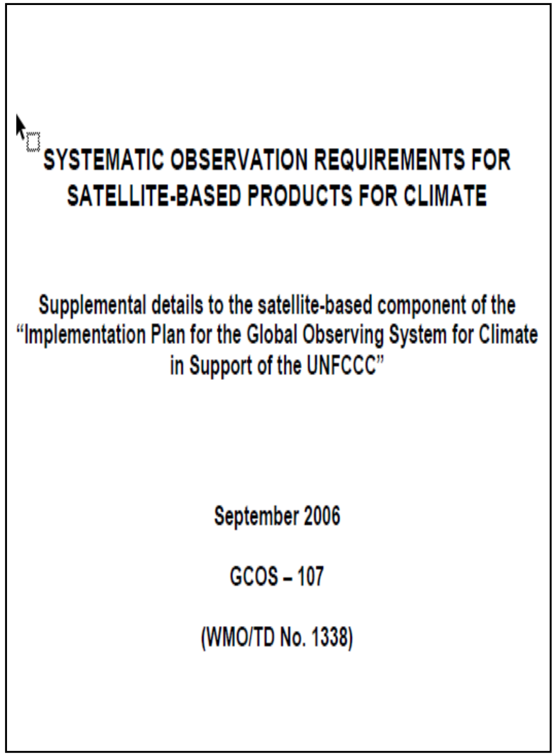
Tier 3 **Operational pathfinders, and technology and science demonstrators**

- Responding to R&D needs.

Tier 4 **Additional capabilities**

- Contributed by WMO Members and third parties including governmental and non-governmental actors (including from the academic and commercial sectors).

Documents to Support the SI-Traceable Space-based Climate Observing System / Radiometric Benchmark System



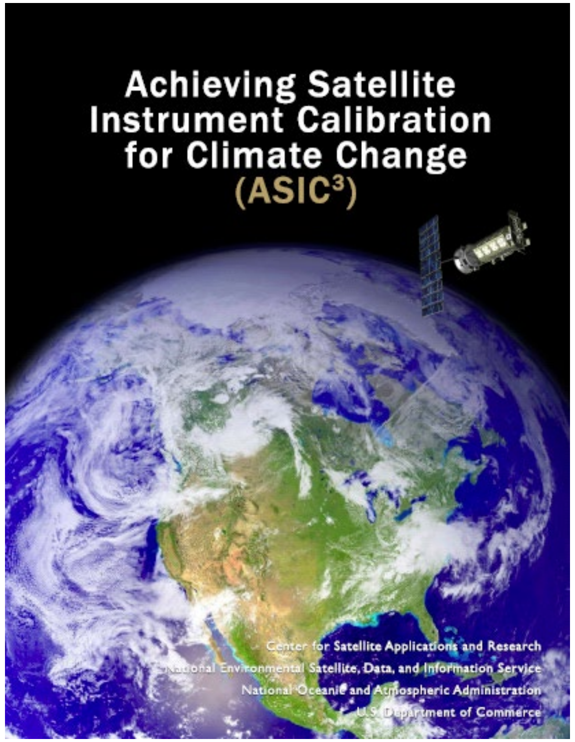
SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED PRODUCTS FOR CLIMATE

Supplemental details to the satellite-based component of the “Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC”

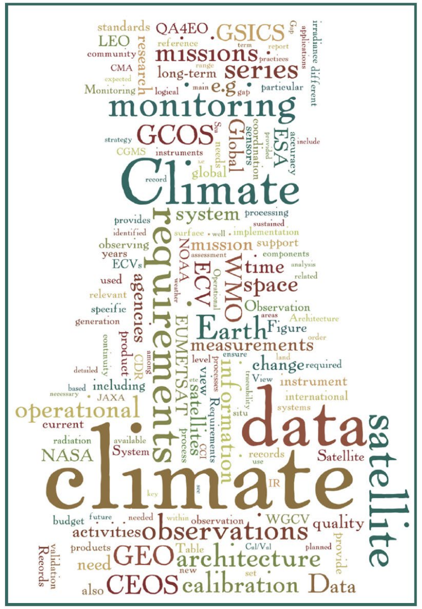
September 2006

GCOS – 107

(WMO/TD No. 1338)



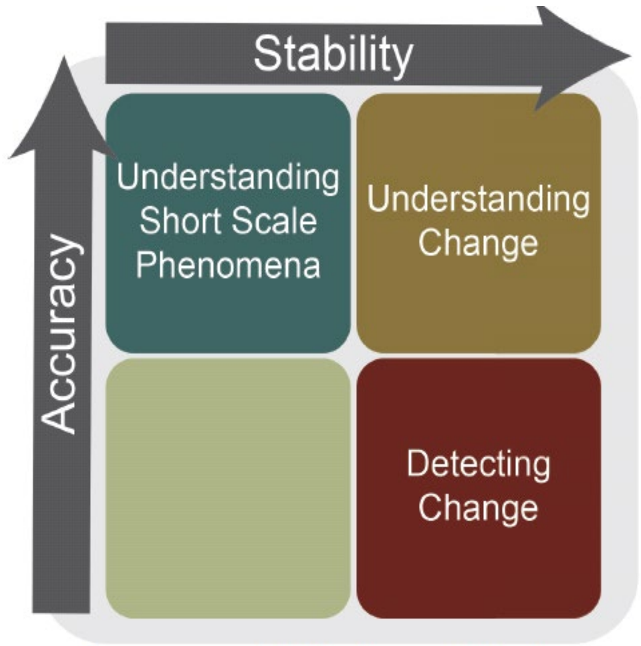
Strategy Towards an Architecture for Climate Monitoring from Space



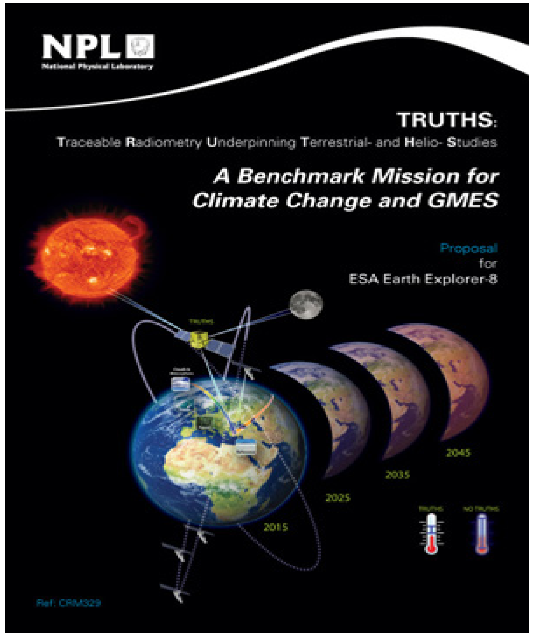
Space Agency Response to GCOS Implementation Plan

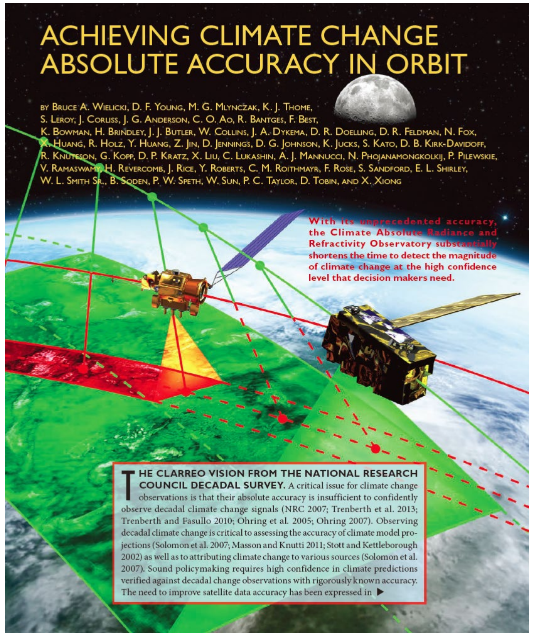
- WMO GCOS, 2006: Systematic observation requirements for satellite-based products for climate
- G. Ohringi, et al, 2007: Achieving satellite instrument calibration for climate change
- M. Dowell, et al, 2013: Strategy towards an architecture for climate monitoring from space
- CEOS/CGMS WGCliate, 2018: Space agency response to GCOS implementation plan

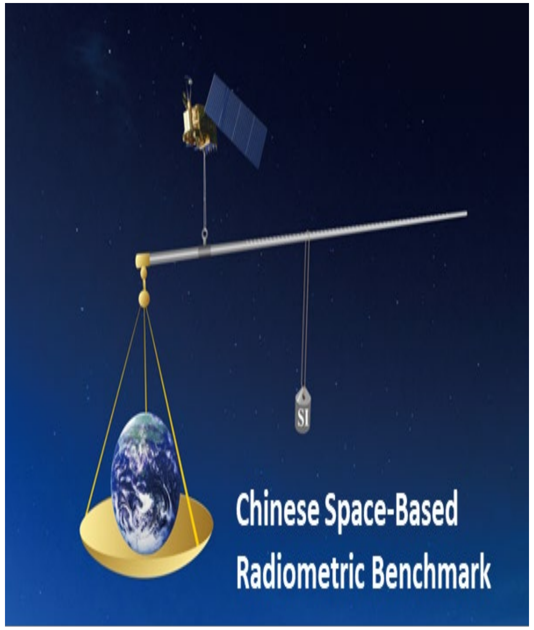
SI-Traceable Space-based Climate Observing System / Radiometric Benchmark System



Accuracy vs. stability diagram following Ohring et al. (2004)







- Weather Satellite to Climate Satellite
- CEOS, CGMS response to GCOS
- Multiple On-orbit Instruments
- Historical Satellite Data Records

Projects on Space-based Radiometric Benchmark

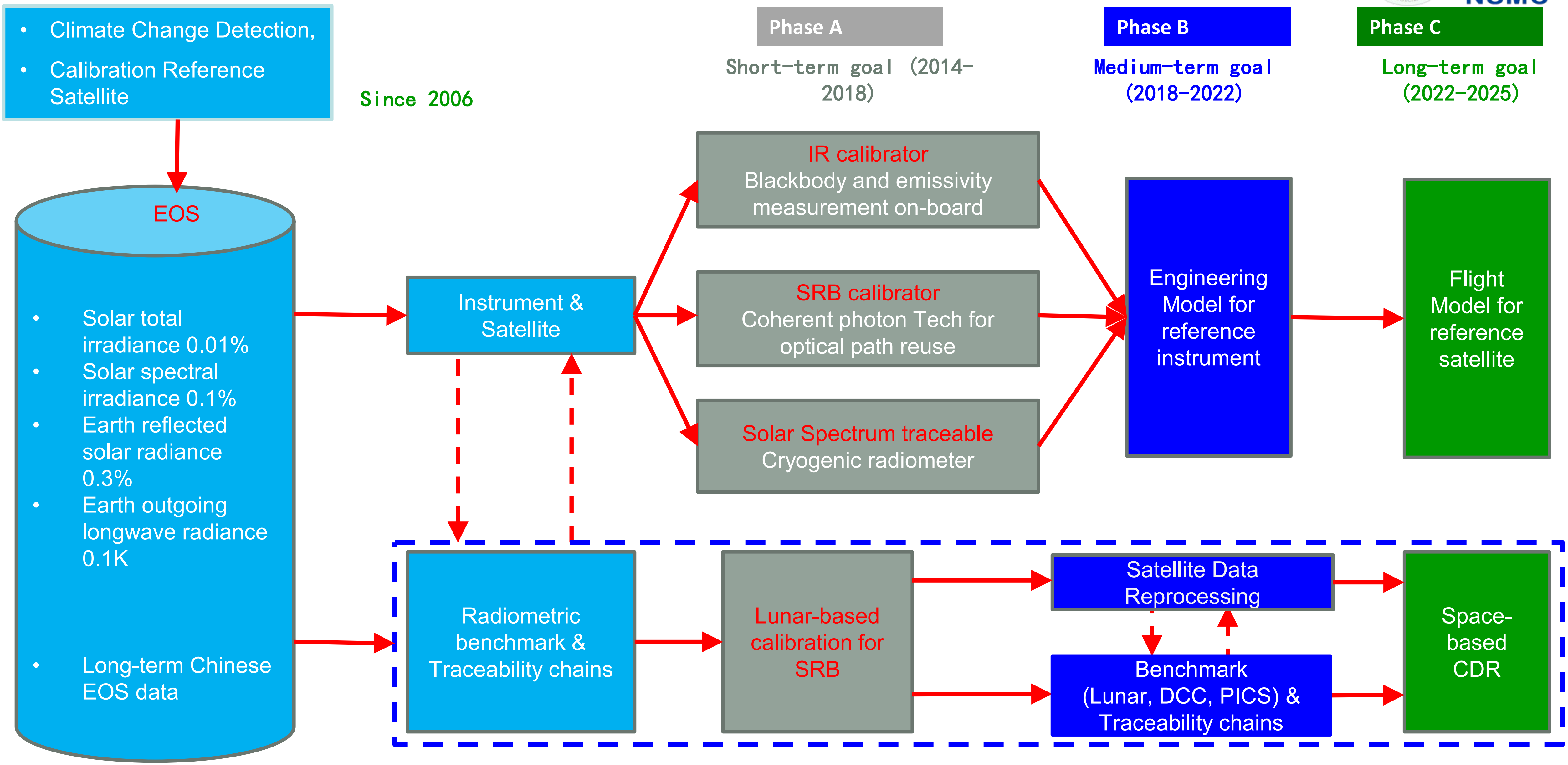
中华人民共和国科学技术部
Ministry of Science and Technology (MoST)

Realizing the importance of reference-type missions for improving climate science and for harmonizing global satellite observations, an expert team on Earth observation and navigation of Ministry of Science and Technology (MOST) proposed the concept of the Chinese Space-based Radiometric Benchmark (CSRB) in 2006. The CSRB project was approved and initially funded by MOST in 2014.

Founded by

- **National High Technology R&D Program of China before 2018**
- **National Key R&D Program of China after 2018**

Road Map of Chinese Space-based Benchmark Project



Phase A for SI-Traceable Standard （20 million RMB）

- National High Technology Research & Development Program of China (863 program)

Standard for Emitted Earth Spectrum Blackbody and emissivity measurement on-board	Shanghai Institute of Technical Physics (SITP), CAS
Standard for Incident Solar Spectrum Coherent photon Tech for optical path reuse	Anhui Institute of Optics and Fine Mechanics (AIOFM), CAS
Standard for Reflected Solar Spectrum Cryogenic radiometer	Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), CAS
Lunar Radiometric Model and Lunar-based Calibration	National Satellite Meteorological Center (NSMC), CMA

Phase B for Prototype Instrument

- National Key R&D Program of China（300 million RMB）
- Chinese FY Satellite Program
- Chinese HY Satellite Program
- Chinese ZY Satellite Program

Prototype Model for Benchmark Instrument

Historic Satellite Data Re-Calibration

Radiometric Reference (Lunar, DCC, PICS) & Traceability Chains

Shanghai Institute of Technical Physics (SITP), CAS

Anhui Institute of Optics and Fine Mechanics (AIOFM), CAS

Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP), CAS

National Satellite Meteorological Center (NSMC), CMA

Academy of OPTO-Electronics (AOE), CAS

Specification of the Prototype Instrument

Table 1. Detailed payloads specifications of the LIBRA prototype model.

Instrument Name	Payload Requirements	Key Technology
IRS	Spectral range: 600–2700 cm^{-1} Spectral resolution: 0.5 cm^{-1} IFOV: 24 mrad Sensitivity: 0.1 K@270 K Emissivity of BB: ≥0.999 Measurement uncertainty: 0.15 K (k = 2)	Miniature fixed-temperature phase-change cells
EMIS	Spectral range: 380–2350 nm, Spectral resolution: 10 nm, Spectral precision: 0.5 nm, Spatial resolution: 100 m, Coverage: 50 km, Measurement uncertainty: 1% (k = 2)	Space Cryogenic Absolute Radiometer
TSI	Spectral range: 0.2–35 μm, Measurement uncertainty: 0.05% (k = 2) Long-term stability:0.005%	Space Cryogenic Absolute Radiometer
SITQ	Spectral range: 380–2500 nm, Spectral resolution: 3 nm (380–1000 nm), 8 nm (1000–2500 nm) Spectral precision: 0.1–0.3 nm, Self-calibration uncertainty: 0.2%, Measurement uncertainty: 0.35% (k = 2)	Spontaneous Parametric Down-Conversion

Infrared Spectrometer (IRS)

Earth-Moon Imaging Spectrometer (EMIS)

Total Solar Irradiance (TSI)

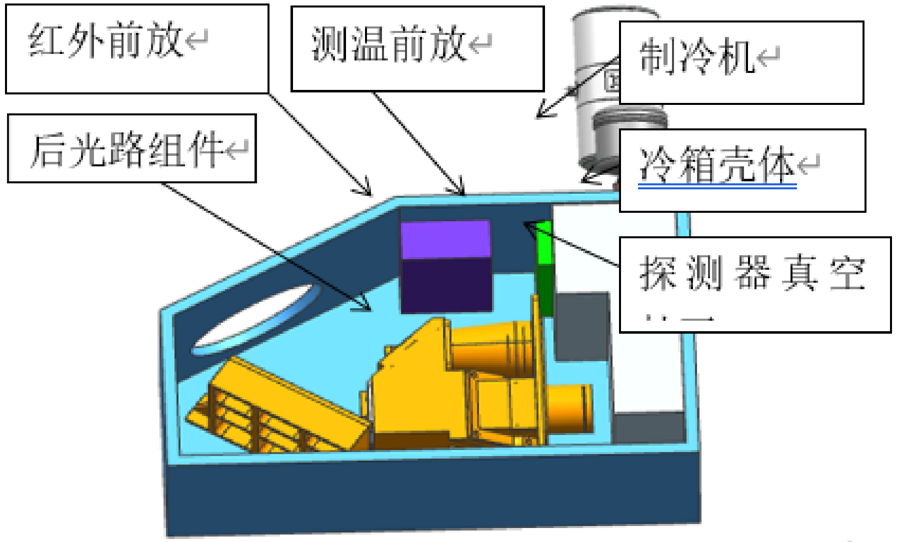
Solar spectral Irradiance monitoring instrument Traceable to Quantum benchmark (SITQ)

P. Zhang et al., 2020: Development of the Chinese Space-Based Radiometric Benchmark Mission LIBRA. Remote Sensing

3. Prototype Model Progress

IRS: System Scheme and performance

- Infrared interferometer
  - Response spectrum: **600 cm^{-1}~2700cm^{-1}**
  - Spectral resolution: **0.5cm^{-1}**



Broadband, large field of view infrared interferometer

Broadband, large size & small array infrared sensors

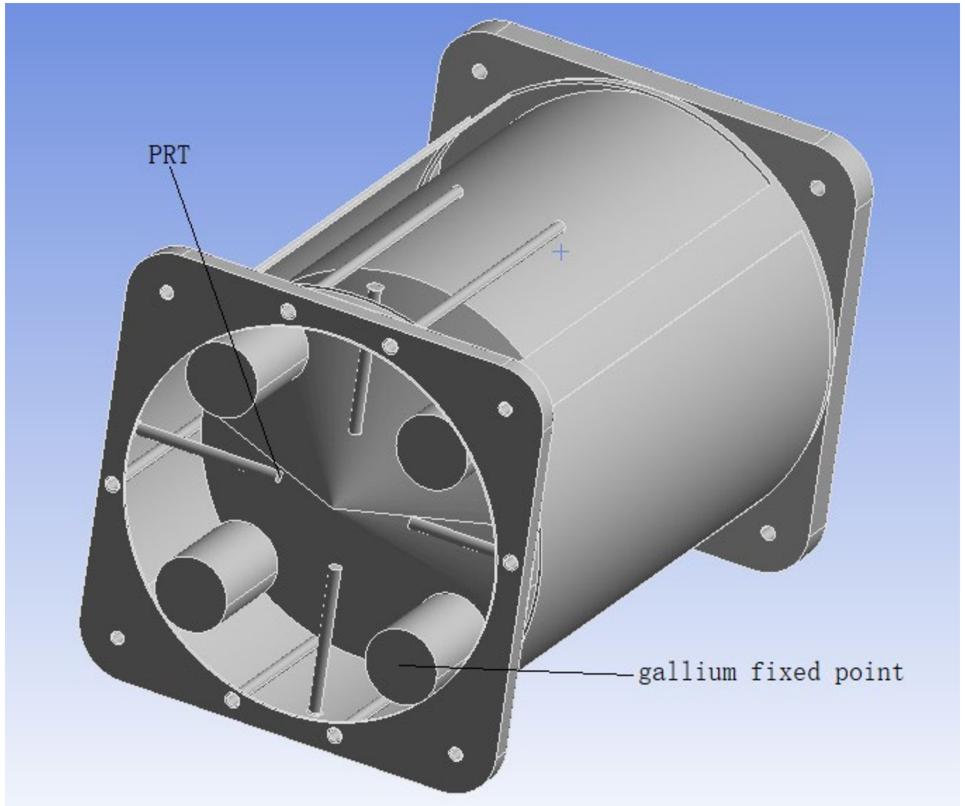
Multi-temperature zone infrared cryogenic optics technology

Efficient refrigeration for 50K temperature technology

IRS: fixed point cells

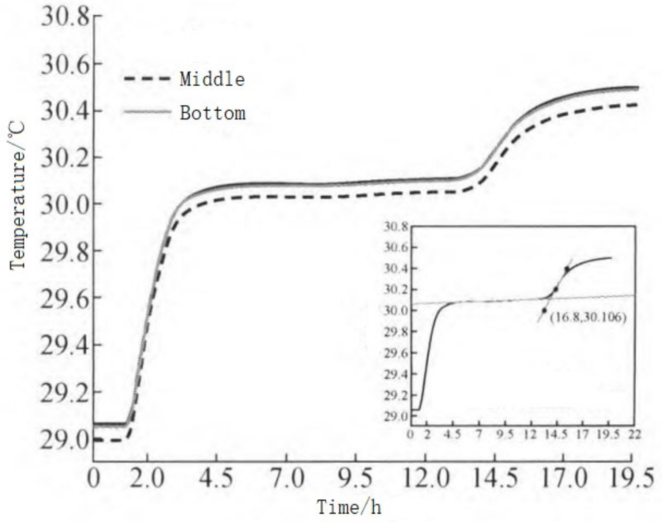
on-orbit accurate temperature scale established by using fixed-point-cells (miniature phase change cells)

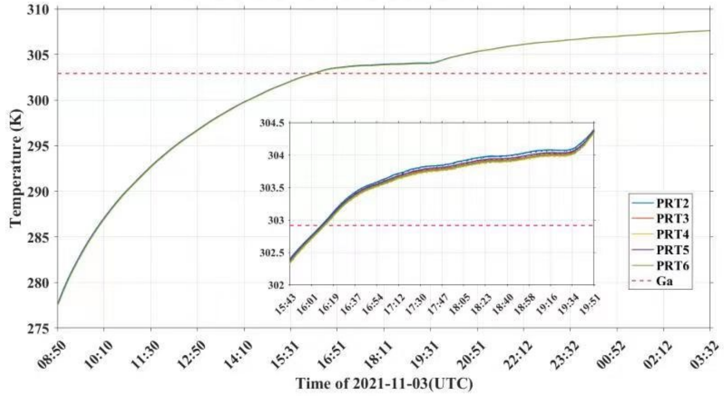
- System of miniature gallium fixed point onboard blackbody radiation source was added on HIRAS of FY-3E satellite as the prototype
- 4 crucibles filled with gallium and fixed on the bottom of the blackbody
- Heating circuit used to provide stable heat flow into the blackbody
- The temperature of gallium is very stable during the phase change process



Fixed point cells: Data colletced in experiment and on FY-3E

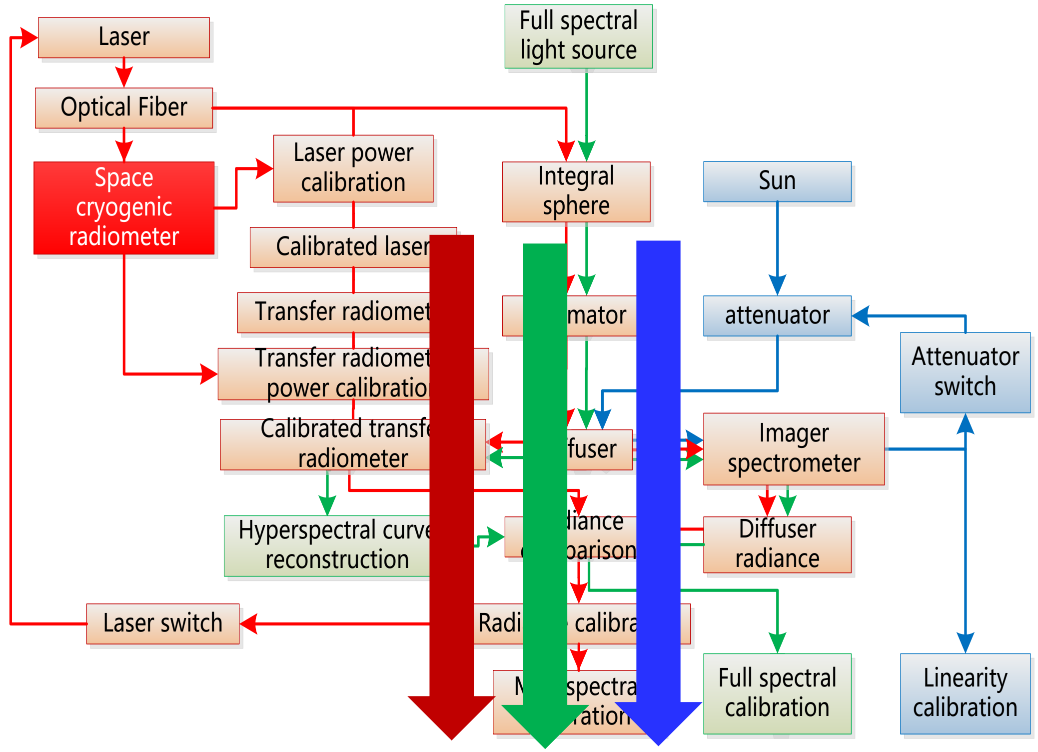
- Inflection point : the momentary temperature when the phase change is finished
- Inflection point has a relationship with the heating power
- In the experiment with the blackbody only, the reproducibility of the inflection point is better than 0.03K.
- In the on-orbit measurement, inflection point can be observed clearly. When the heating power is 4.11W, the inflection point is 304.1K.
- The relationship between the heating power and the inflection point is being analyzed with modeling.

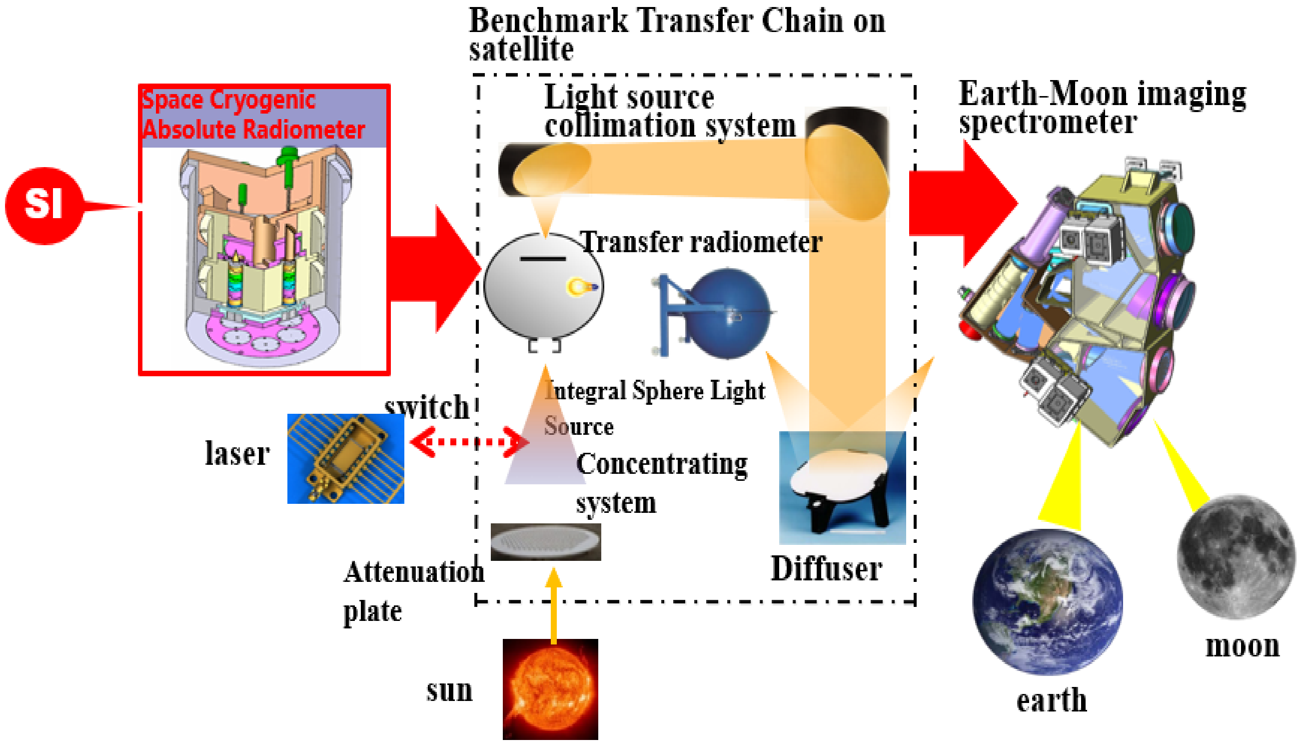




EMIS: System Scheme and performance

The radiometric benchmark is established by space cryogenic absolute radiometer, and transferred to the Earth-Moon imaging spectrometer by benchmark transfer chain, in order to improve the long-term accuracy.





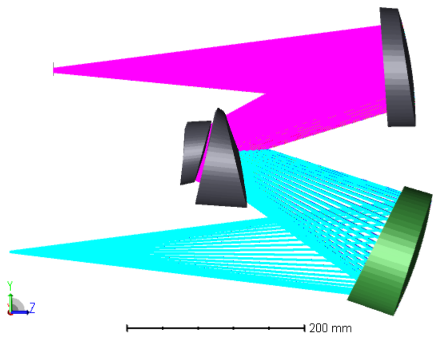
A Multispectral Calibration

B Full spectrum Calibration

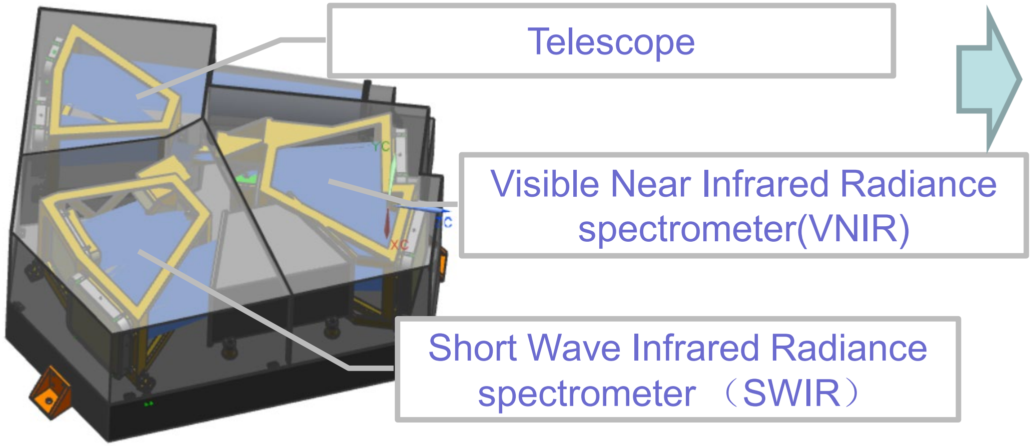
C Linearity Calibration

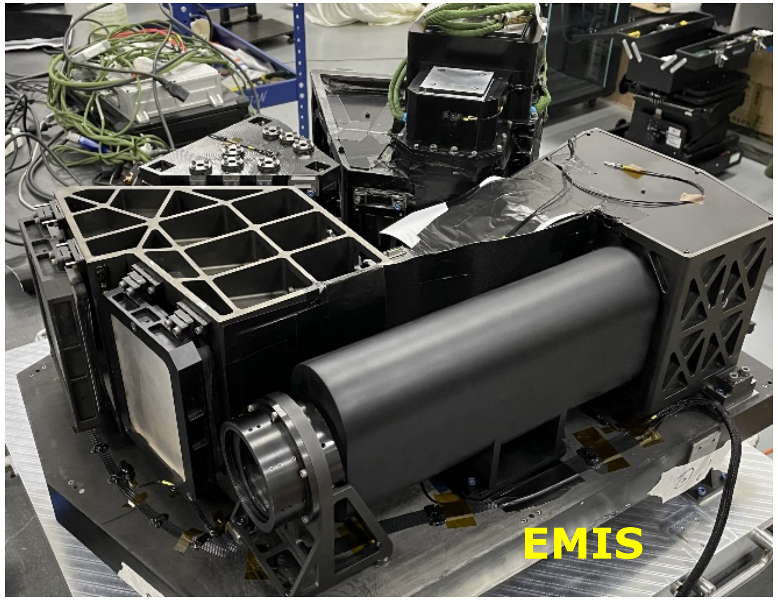
Earth–Moon Imaging Spectrometer（EMIS）

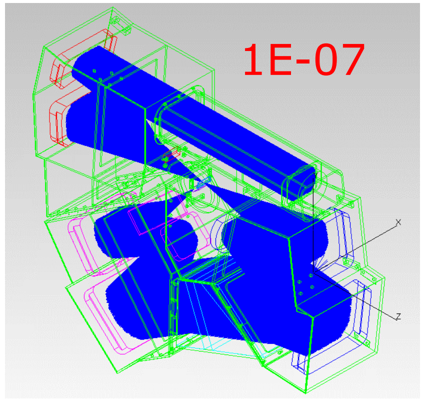
EMIS has completed the whole machine integration, detected the spectral radiation characteristics, and carried out the flight calibration experiment



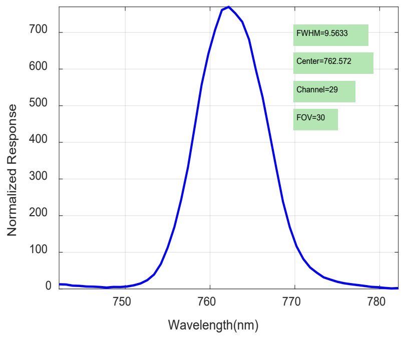
EMIS adopts off axis three mirror optical design



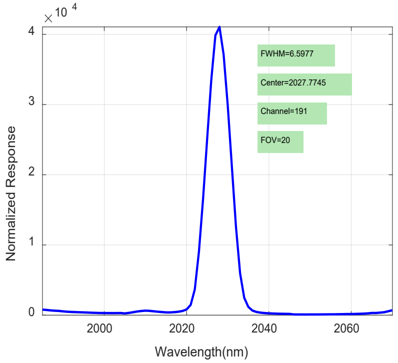




Stray light analysis



9.56nm



6.59nm

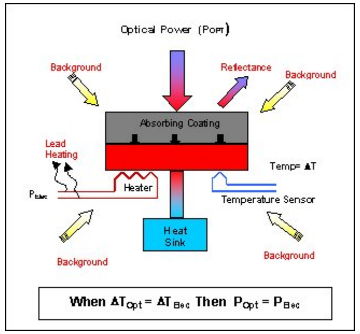
The average spectral resolution is better than 10nm

Local images of ground objects taken in flight calibration experiment

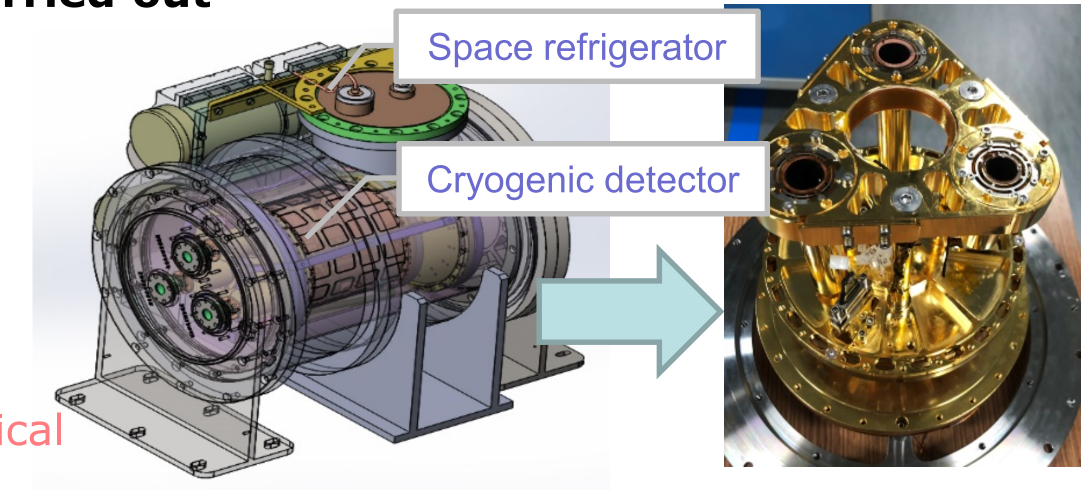
Space Cryogenic Absolute Radiometer (SCAR)

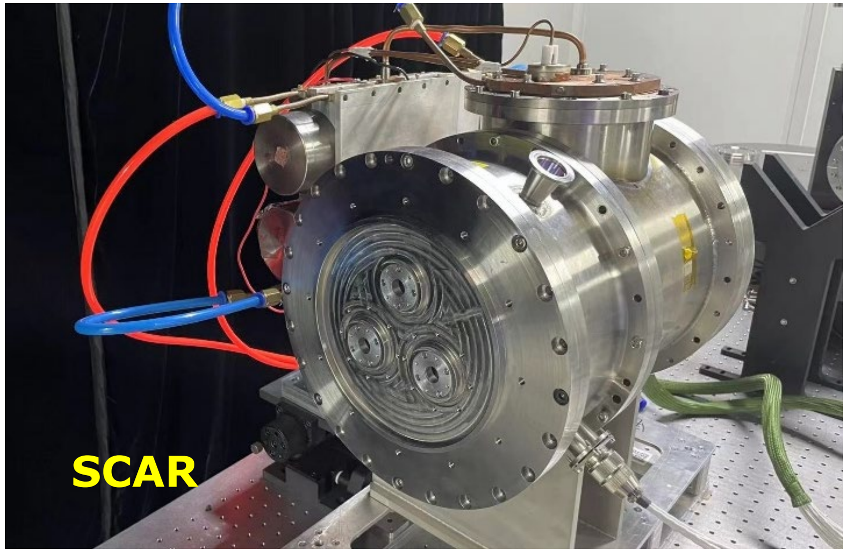
NSMC

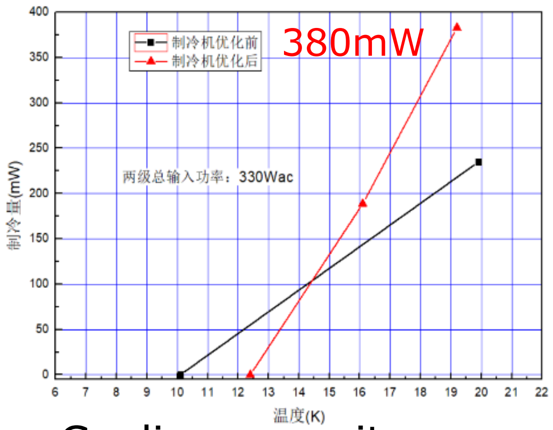
The cryogenic detector and space refrigerator of the SCAR are integrated, and relevant tests and optimization are carried out



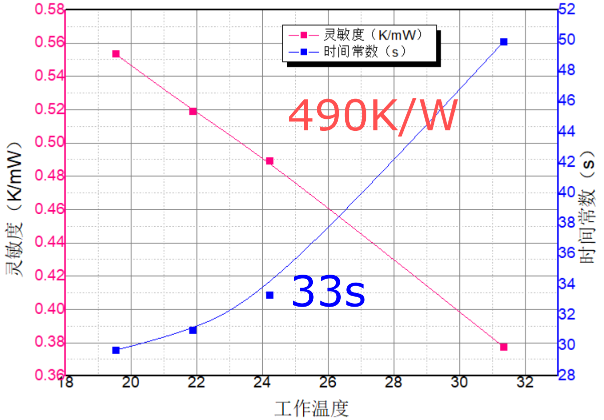
SCAR is based on electrical substitution principle



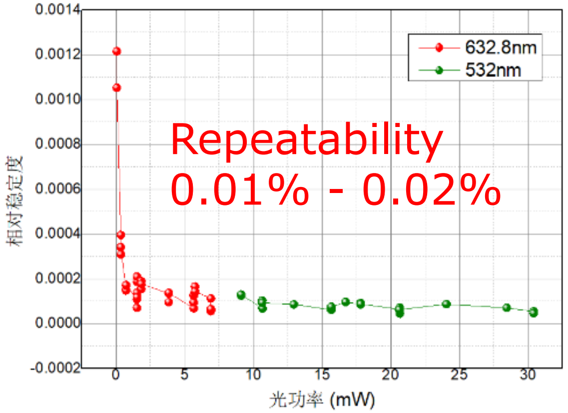




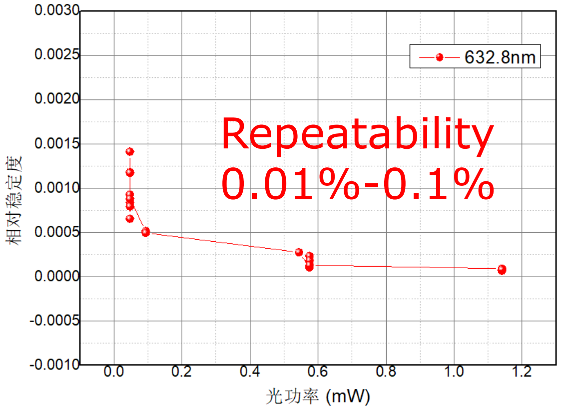
Cooling capacity was optimized to 380mW



Sensitivity is 490K/W@25K
Time constant is 33s@25K



High power channel (1-30mW)



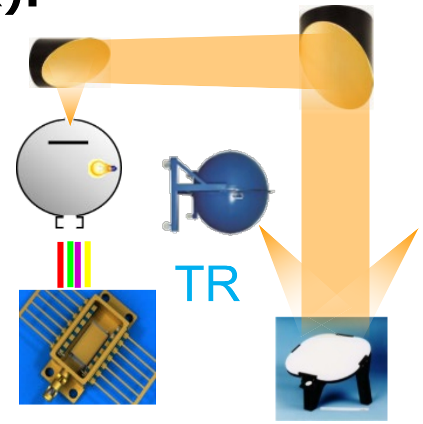
Low power channel (0.01-2mW)

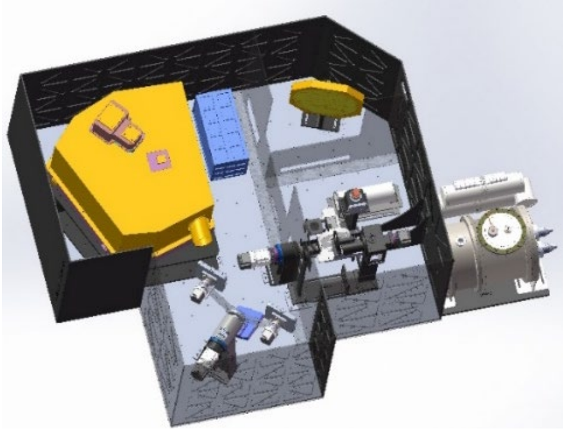
Optical power measurement

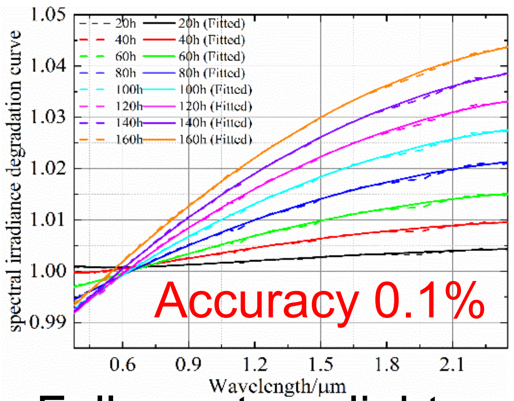
Benchmark Transfer Chain(BTC)

The BTC has completed layout, and researched the full spectrum light source, multi-spectrum monochromatic light source, free-form surface reflector and Transfer Radiometer (TR).

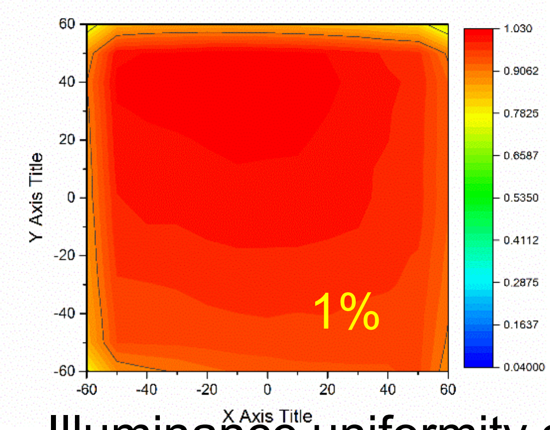
Benchmark is transferred by the calibrated TR



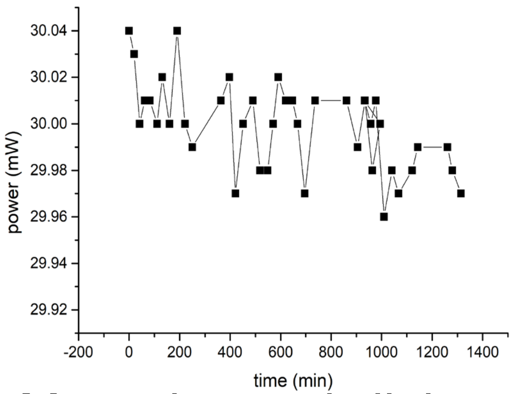




Full spectrum light source reconstruction



Illuminance uniformity of free-form surface reflector is 1%

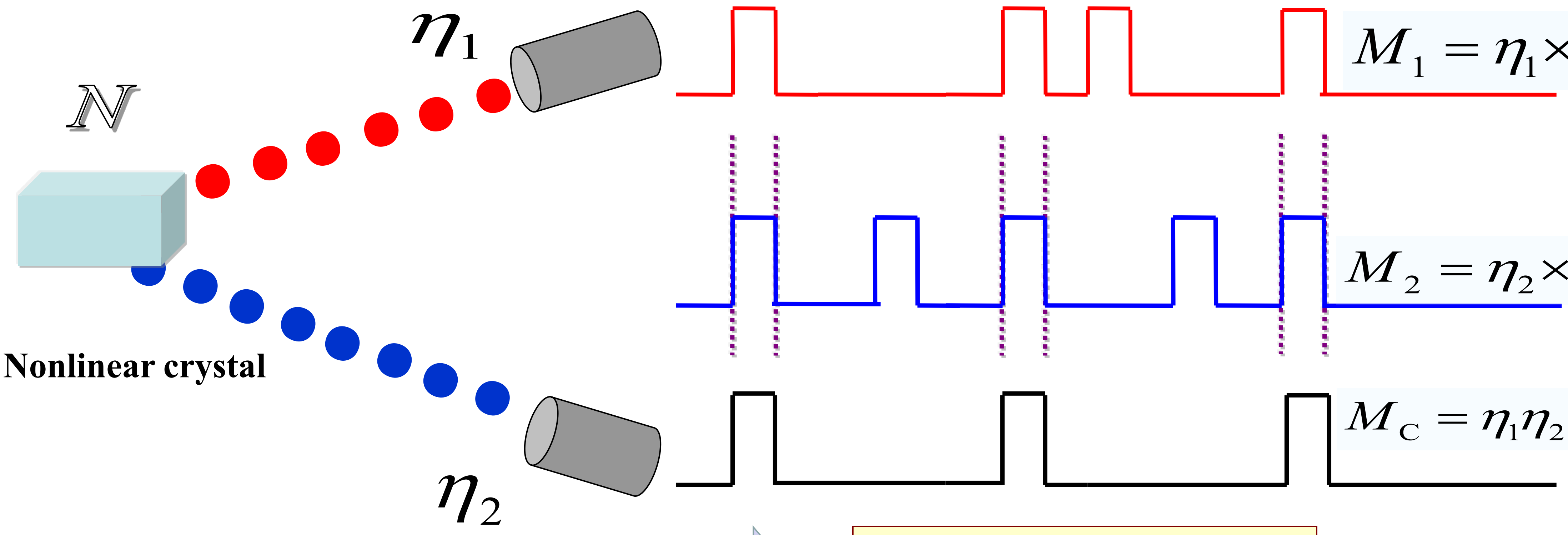


Monochromatic light source stability is 0.1% （P-P）@781nm

Radiance comparison with National Institute of Metrology

SITQ: System Scheme and performance

Spontaneous Parametric Down-Conversion with Correlated Photos



$$M_1 = \eta_1 \times < N_1 >$$

$$M_2 = \eta_2 \times < N_2 >$$

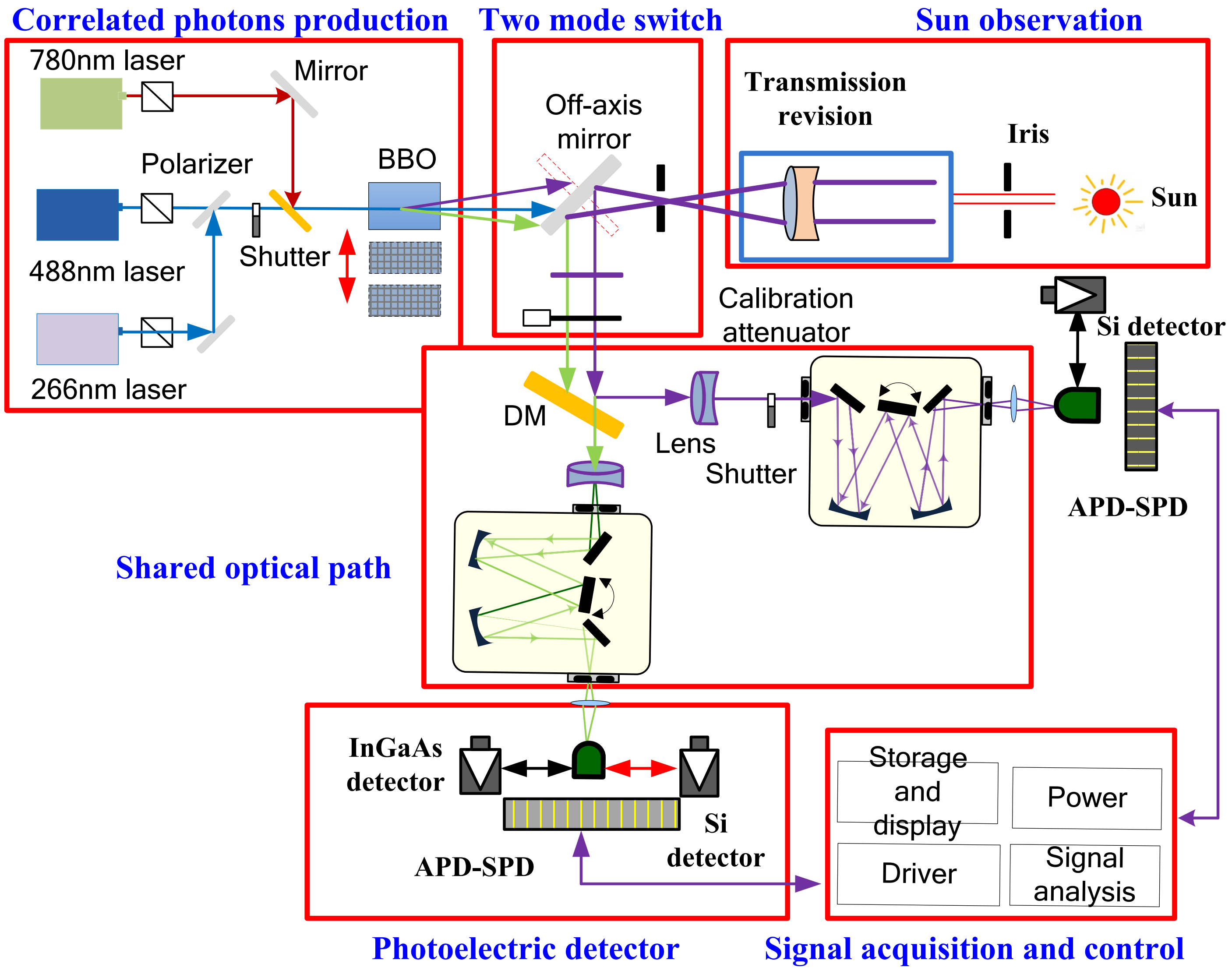
$$M_C = \eta_1 \eta_2 \times < N_c >$$

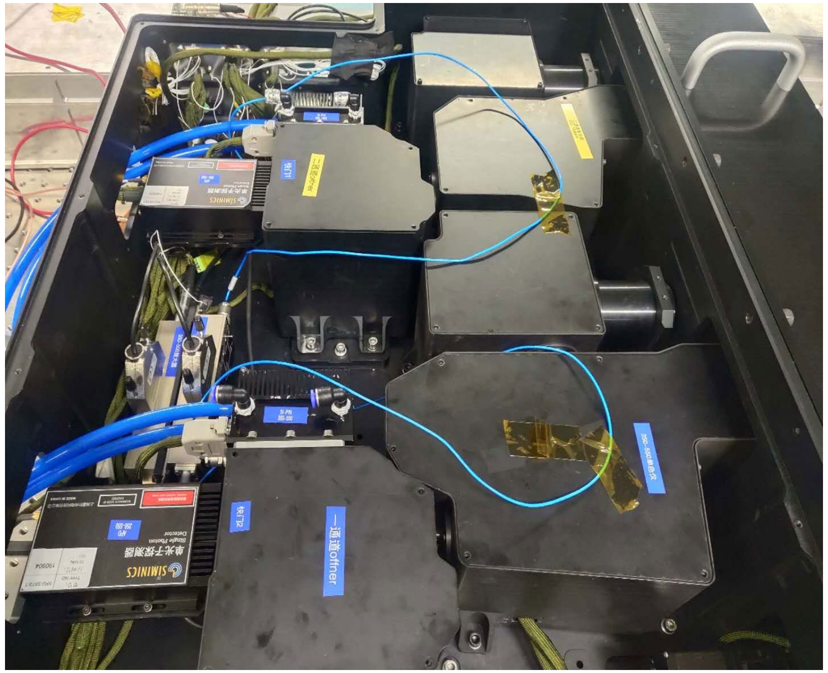
Twin photons of strict correlation in crystal → $< N_1 > = < N_2 > = < N_C >$

Absolute quantum efficiency of detectors → $\eta_1 = M_c / M_2$, $\eta_2 = M_c / M_1$

Independent on primary standard and standard transfer train, the method is intrinsically absolute

Space-borne solar spectral irradiance radiometry with absolute calibration by correlated photons

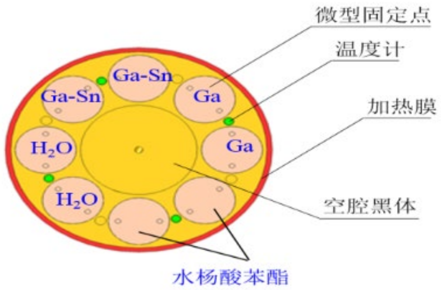


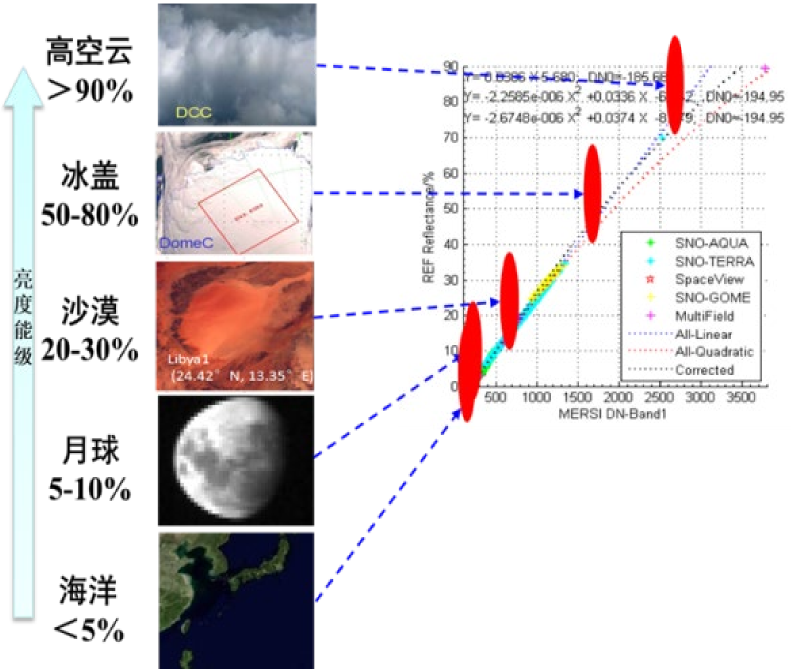


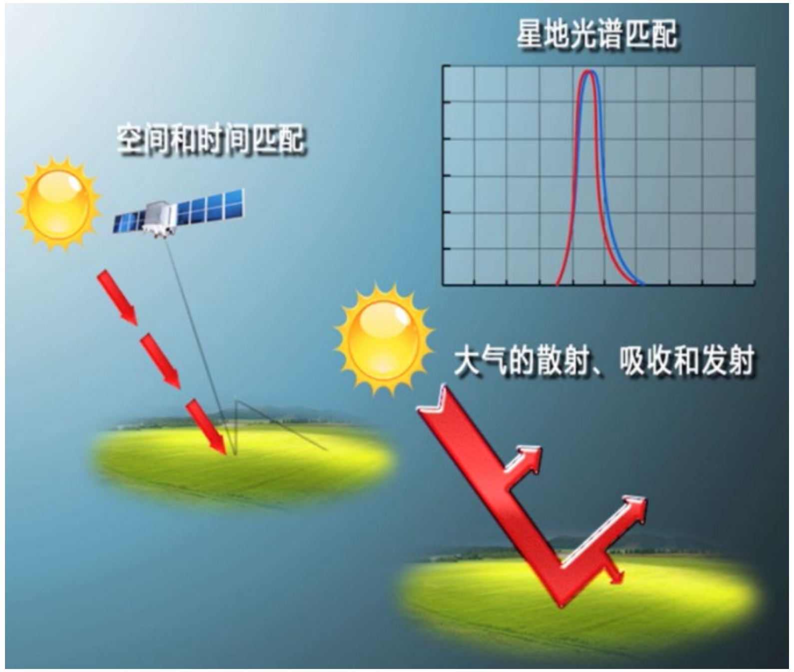
- Spectral range:380 nm - 1000 nm
- Spectral resolution: 3 nm
- Absolute solar spectral irradiance accuracy: 0.3%
- Spectral expanded to 2500 nm by 2022.

4. On-orbit Mode to Support Intercalibration

The integration of space and ground





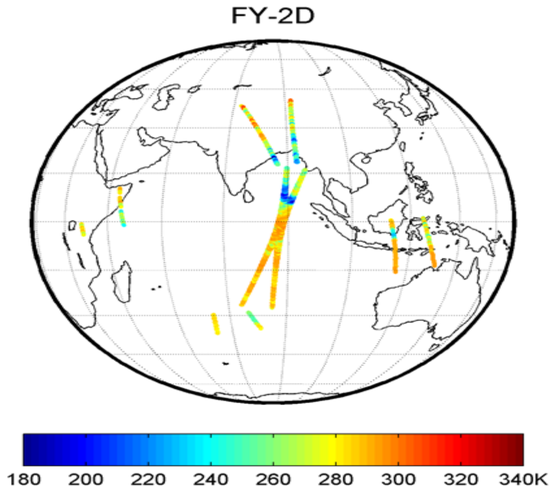


1. Making benchmark

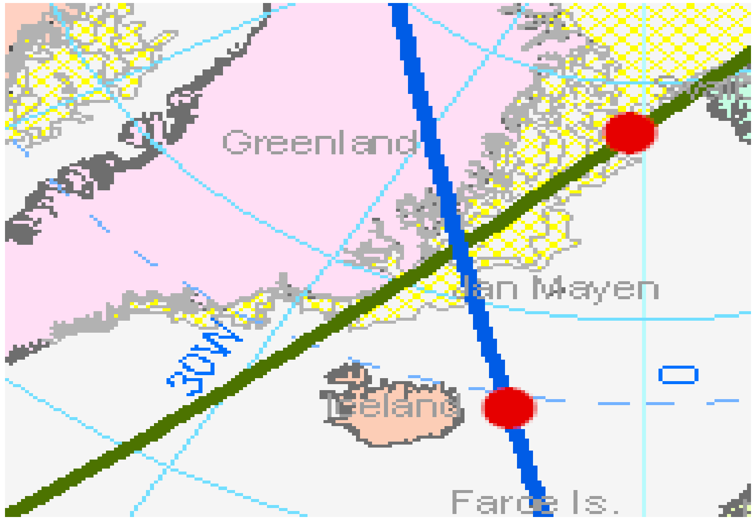
2. Finding benchmark

3. Radiometric transfer & SI traceability

Inter-calibration with reference sensors



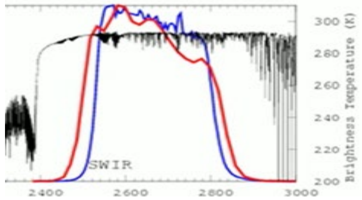
Geo-Leo

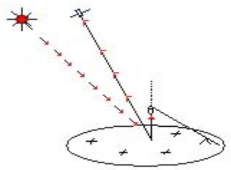


Leo-Leo

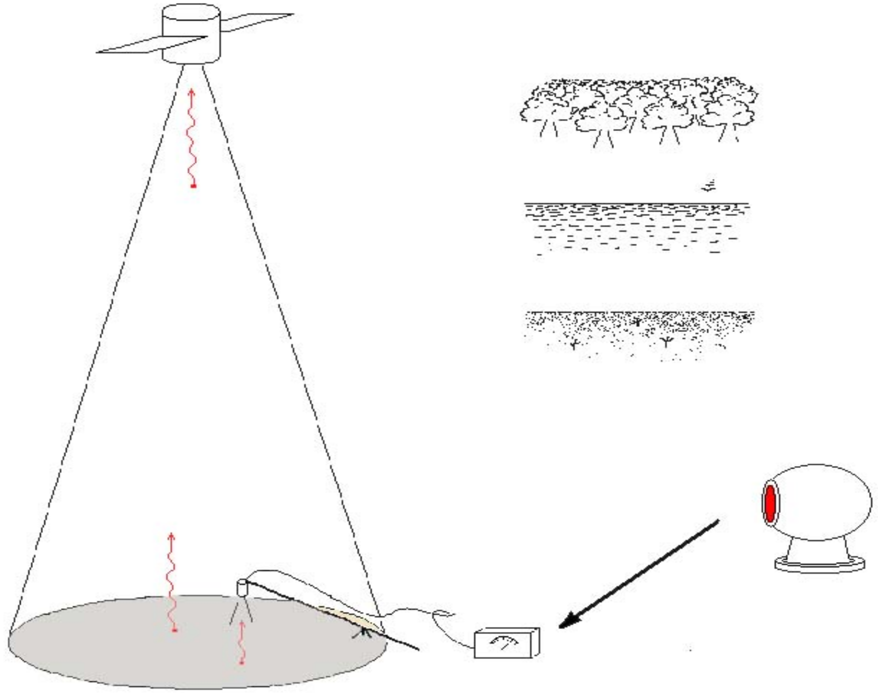
Direct Inter-calibration with global data matching

- Space
- Time
- Geometry
- Spectral

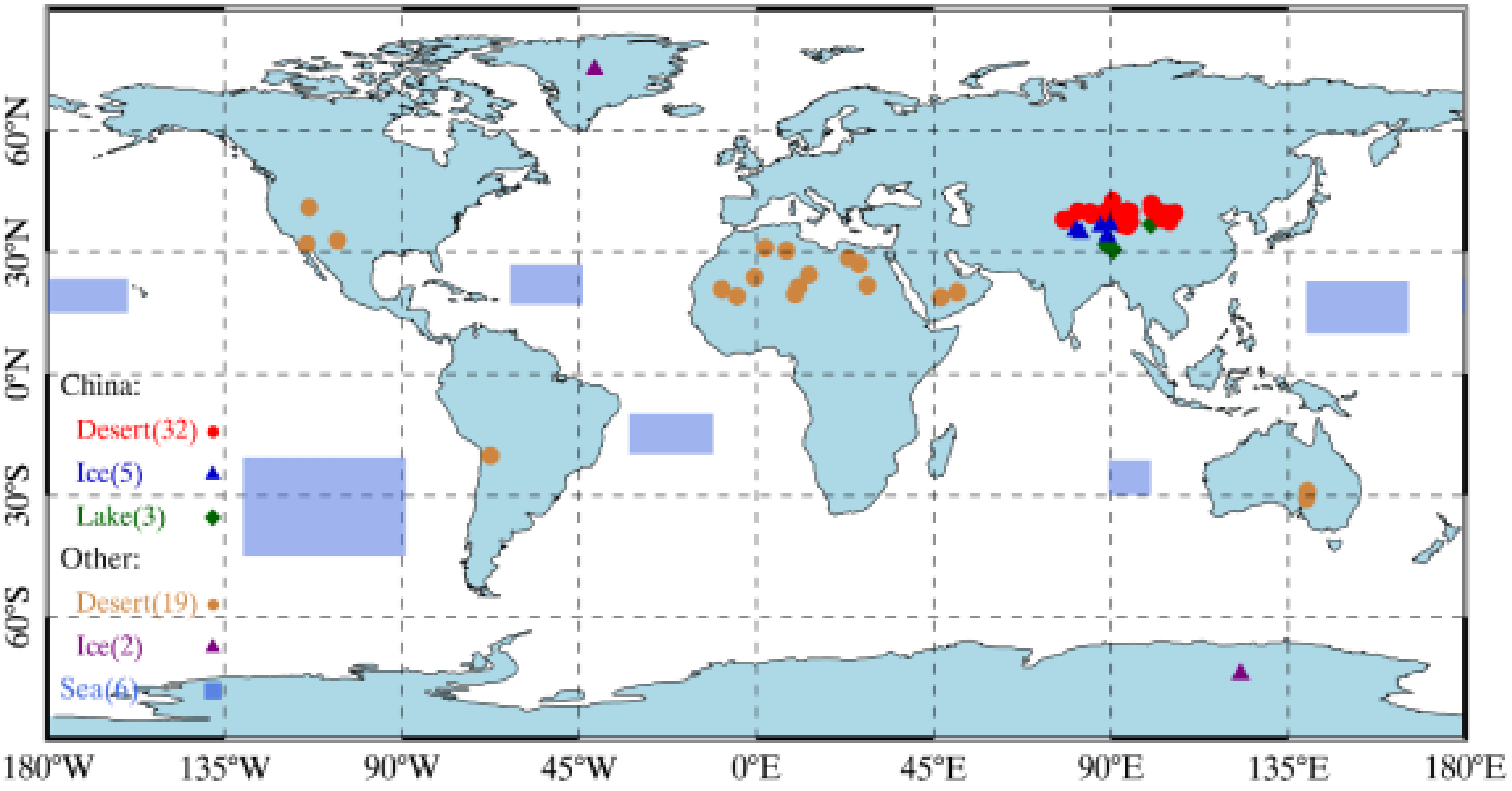




Indirect Inter-calibration with PICS

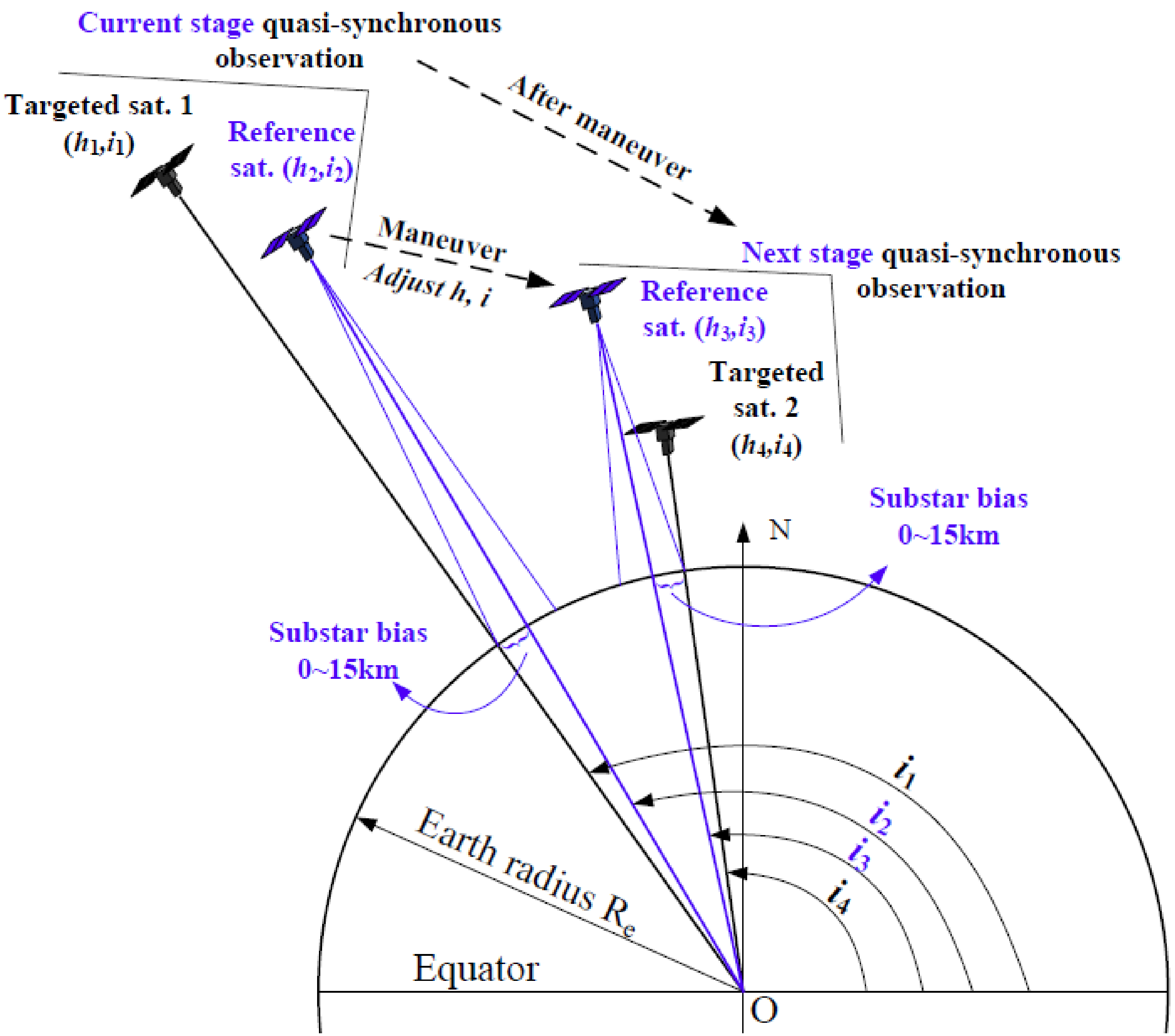


Pseudo-invariant sites（PICs)



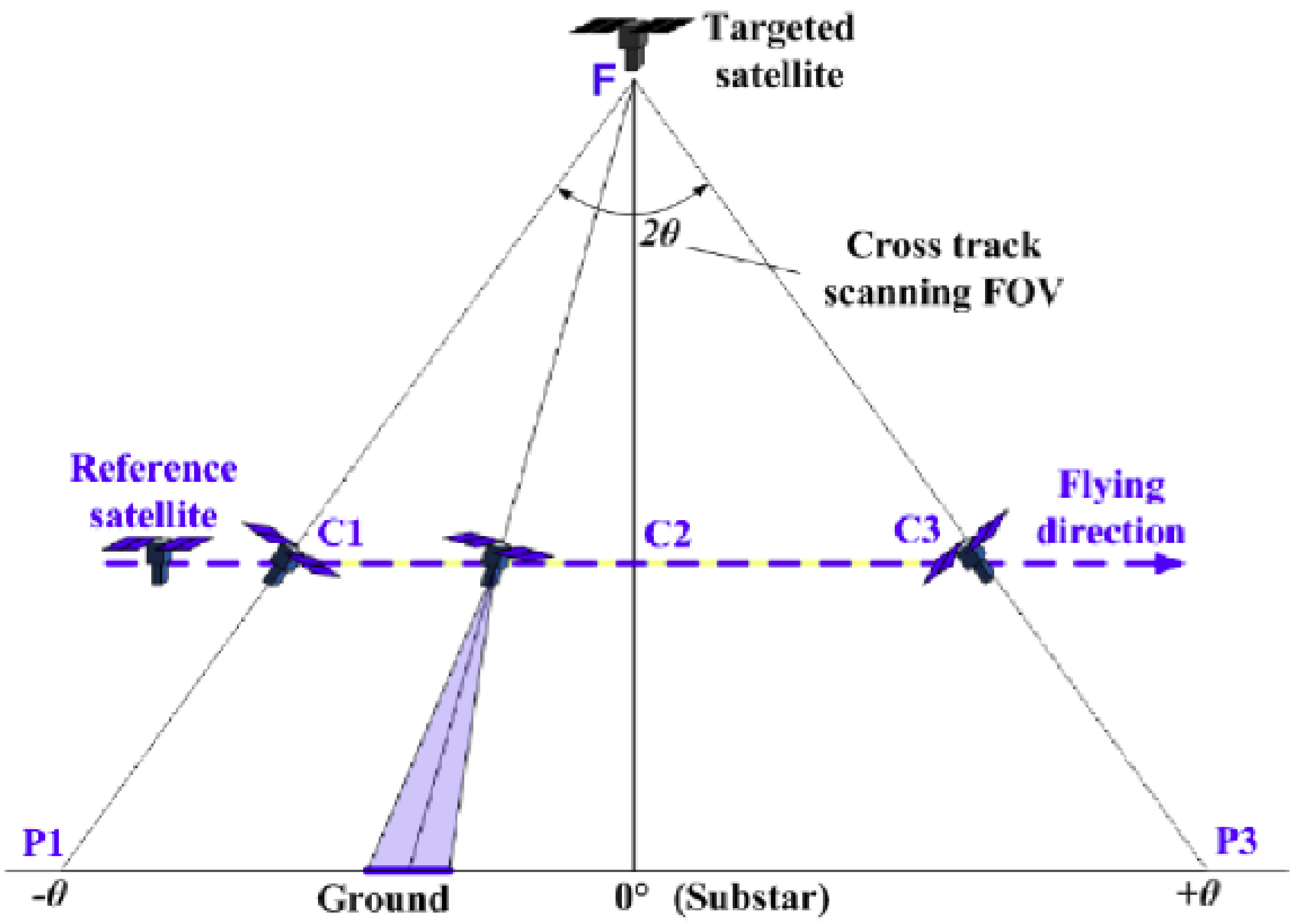
Xiuqing Hu, Ling Wang*, etal, Preliminary Selection and Characterization of Pseudo-Invariant Calibration Sites in Northwest China, Remote Sens. 2020, 12, 2517; doi:10.3390/rs12162517.

Quasi-Synchronous Intercalibration Transfer Mode by Orbital Maneuver



Active SNO mode

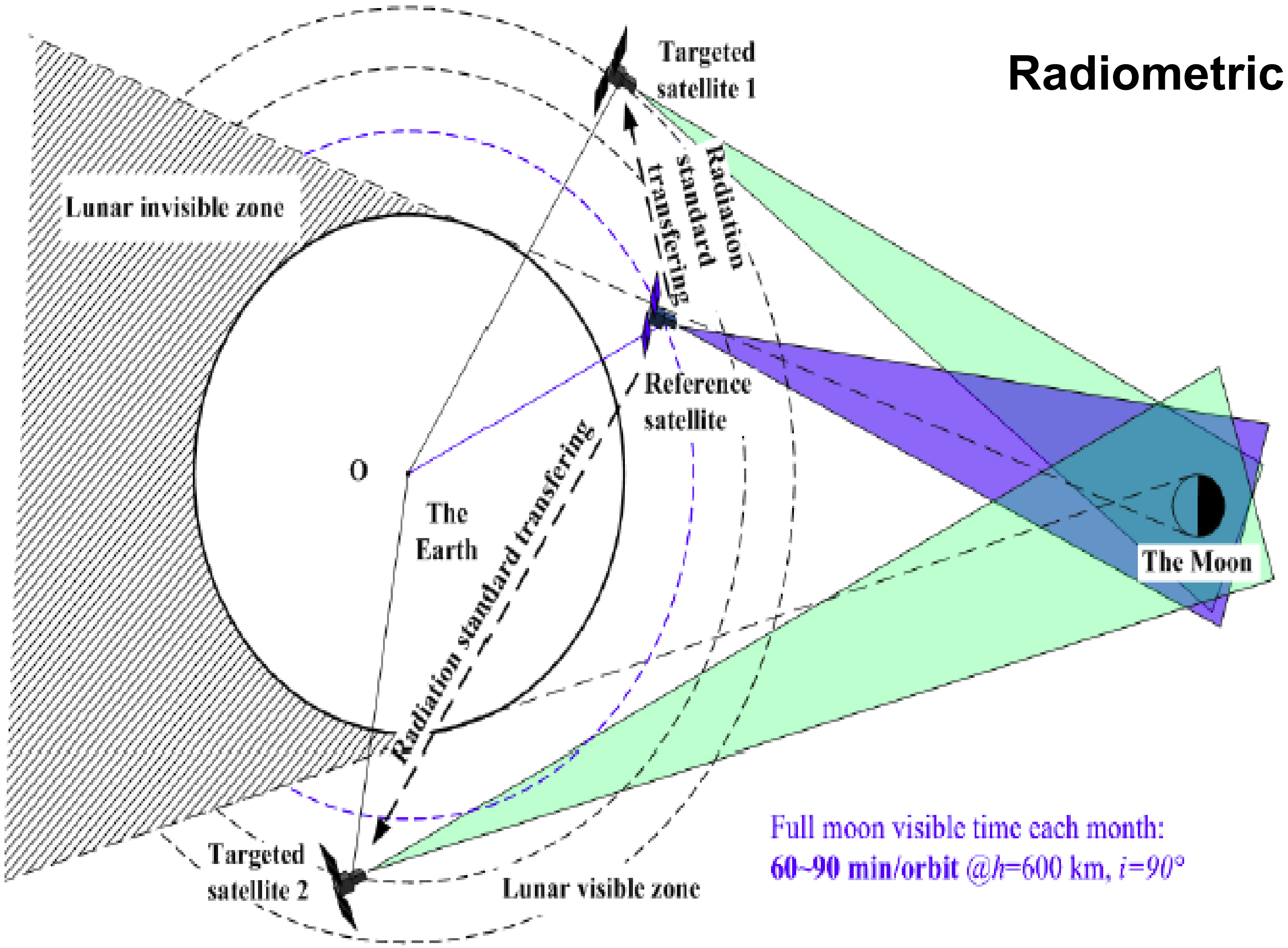
Simultaneous Nadir Overpass (SNO) Cross Intercalibration Transfer Mode (GEO-LEO or LEO-LEO)



Passive SNO mode

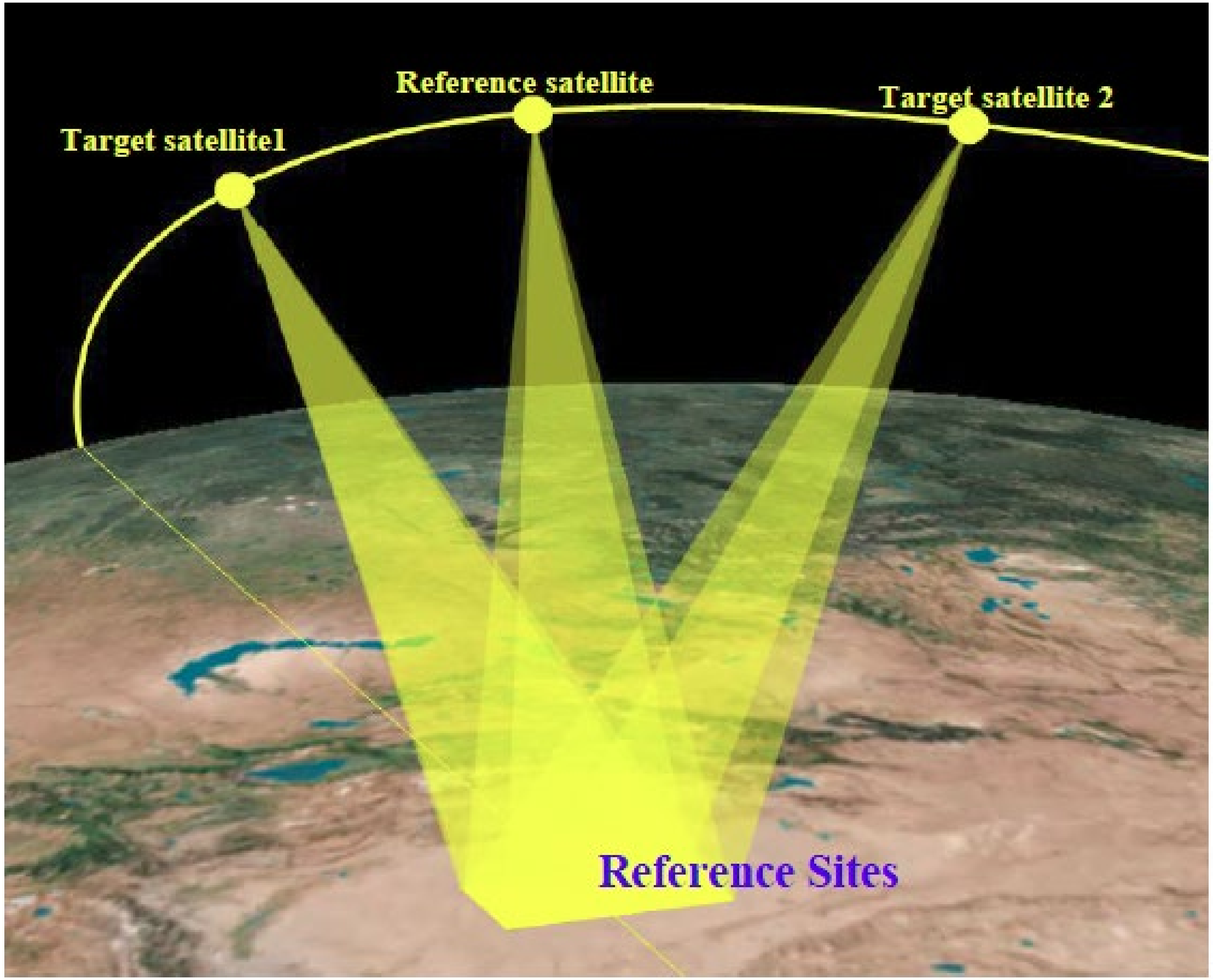
Using Lunar Observations for Intercalibration

Radiometric Transfer mode 1



Full moon visible time each month:
60~90 min/orbit @*h*=600 km, *i*=90°

Using Vicarious Reference Targets for Intercalibration



Radiometric Transfer mode 2

Products to support intercalibration with radiometric traceability

Calibration Metadata

Table 3. Products to support intercalibration with radiometric traceability.

Instruments	Products	Intercalibration Method	Example
IRS	Spectrally-resolved infrared radiance	Quasi-synchronous intercalibration	[16]
		LEO-LEO SNO	[30,31]
		GEO-LEO SNO	[32,33]
EMIS	Spectrally-resolved reflectance of solar radiation	Quasi-synchronous intercalibration	[34]
		LEO-LEO SNO	[35,36]
		GEO-LEO SNO	[37]
	Selected DCC reflectance	DCC	[38,39]
	Selected PICS reflectance	PICS	[40]
	Selected Lunar reflectance	Lunar	[41,42]

P. Zhang et al., 2020: Development of the Chinese Space-Based Radiometric Benchmark Mission LIBRA. Remote Sensing

5. Summary

1. CSRB project keeps going well. The engineering model of the reference instrument (IRS, EMIS, TSI and SITQ) will be completed this year. The 3rd phase CSRB will be funded by MOST since 2023.
2. The LIBRA mission hasn't been approved yet. However, the demonstration mission with IRS only is considered as the opportunity mission by CNSA.
3. IRS will be considered to mount on FY-5. The key technology of the EMIS, TSI and SITQ will be considered to use in the development of FY-5 in 2028.
4. Each satellite agency to consider sample and store the match-up data in the standard way by the recommended inter-calibration method as the satellite calibration metadata.

Make the data better and easier to use !