Investigation on Space Radiation Standard of Solar Reflection Spectrum

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Sep. 10nd ,2019

Brief Introduction of CIOMP

- Changchun institute of optics, fine mechanics and physics （CIOMP）was the first optics institute of China， founded in 1952

Research Areas:

- Luminescence
- Applied Optics
- Optical Engineering
- Precision Mechanics & Instruments

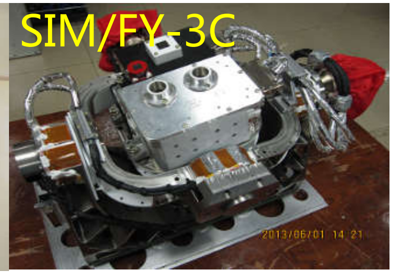
- CIOMP has created many "China Firsts"

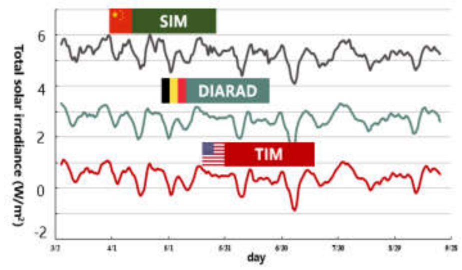
- ✓ Electron microscopy
- ✓ High temperature microscopy
- ✓ Universal tool microscopy
- ✓ Multiple projectors
- ✓ Lager spectrometer

Brief Introduction of CIOMP

Electrical substitution absolute radiometers

- SIARs: Since the 1980s, CIOMP developed a series of solar irradiance absolute radiometers on ground
- SIM: space-born total solar irradiance monitor, payload of FY-3

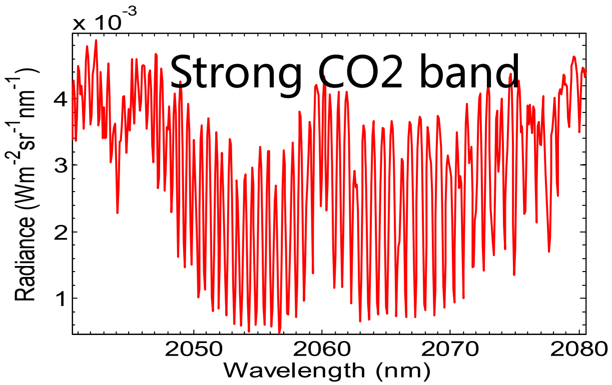




Results comparison

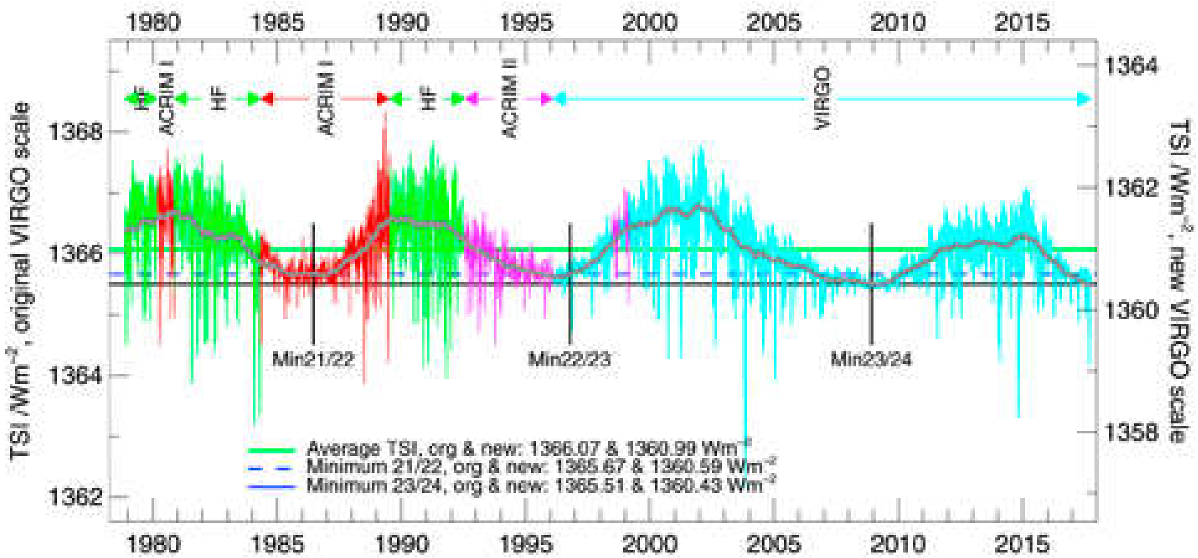
Hyperspectral imaging payloads

- 863-2: Maximum spectral and ground resolution
- Tansat: detect high resolution absorption spectra of atmospheric CO_2 on a global scale.



Climate research

The sun is the only external energy of the earth and the power source of the climate system. Since 1978, a number of global solar irradiance monitoring instruments have been launched and 40 years of continuous observation data have been accumulated.



With the development of absolute measurement and calibration technology, the uncertainty of total solar irradiance measurement is gradually increasing. At present, the world recognized solar irradiance is 1361 W/m2.

Climate research

- However, in the field of climate research, the establishment of climate models needs high accurate data of solar reflected spectrum. Space spectral instruments for observing these weak changes must have high accuracy and long-term stability.
- At present, the space remote sensors are difficult to trace to SI on orbit, and can not fully meet the requirements of climate research.

- **Direct Observation of Total Solar irradiance** ：0.01%
- **Observation of Reflected Solar Band** ：0.3%

Space remote sensing is facing new challenges!

Space Radiometric Calibration

- Radiometric calibration is important in the development of space optical remote sensing payload and a prerequisite for obtaining high-quality remote sensing data to the ground.

Space radiometric calibration has problems:

1) The calibration values of different remote sensors are not uniform and the data are not comparable.

- The attenuation of calibration sources such as lamp and solar diffuse reflector
- Influenced by launching process, space environment and model modification,etc, the traceability chain is broken

2) Radiometric calibration has low accuracy on-orbit and can not meet the needs of remote sensing applications.

- Absolute calibration accuracy of optical remote sensing Instruments ：2%~5%

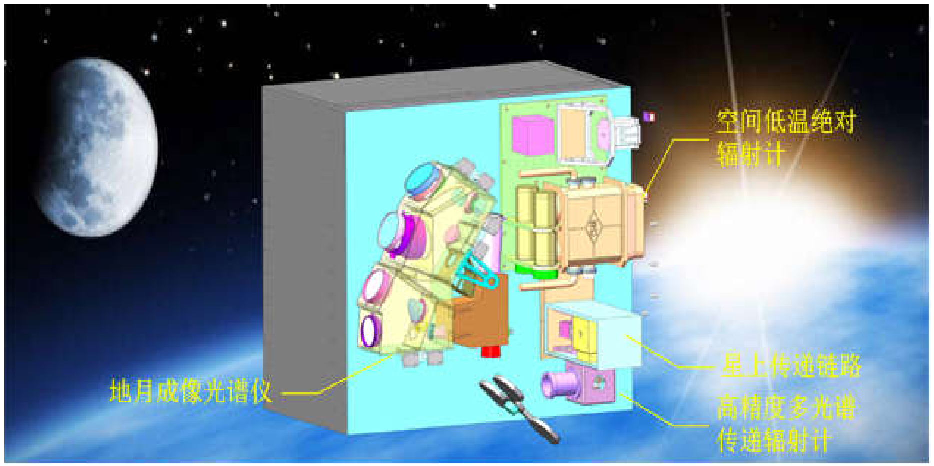
Limited by the problem of radiometric calibration of space remote sensing, space optical remote sensing payload is difficult to meet the urgent need of quantitative remote sensing with long time span and high precision.

Space absolute radiometric observation technology

- In order to realize on-orbit traceability, and improve the space absolute measurement accuracy and long-term stability, the absolute radiometric calibration technology is researched.

Research objectives:

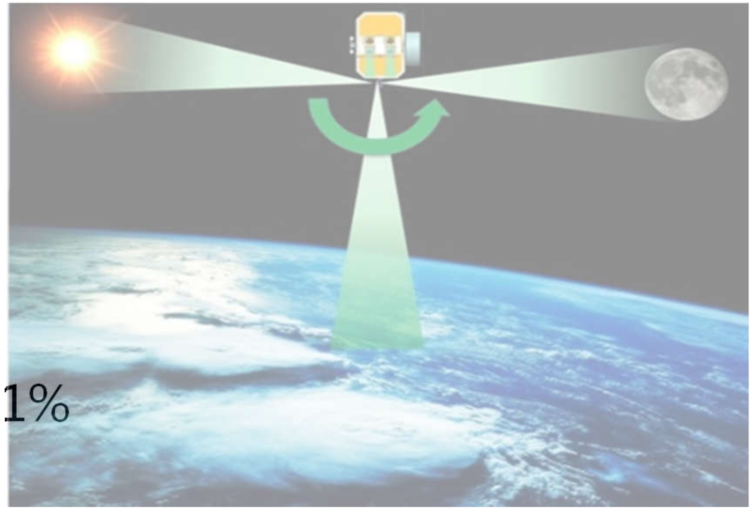
- Achieving space high precision absolute measurement and establishing on-orbit traceable radiation datum of solar reflection spectrum
- Overcoming on-board benchmark transfer technology to improve the absolute measurement accuracy and long-term stability of total solar irradiance, Earth spectral radiance
- Through cross-calibration to unify the on-orbit radiation scale



Propose new space absolute radiation observation technology

High Precision Observing Instrument for Sun, Earth and Moon in Solar Reflection Spectrum

Based on the breakthrough of space absolute radiation observation technology, a high-precision observation instrument for solar reflection spectrum will be developed in the future.



Sun

- Total solar irradiance uncertainty 0.02%
- Long-term stability 0.002%/10years

Earth

- Radiance measurement uncertainty 0.3%-1%
- Spatial resolution 100m-500m
- Spectral range 380nm -2350nm
- Spectral calibration Accuracy 0.5nm

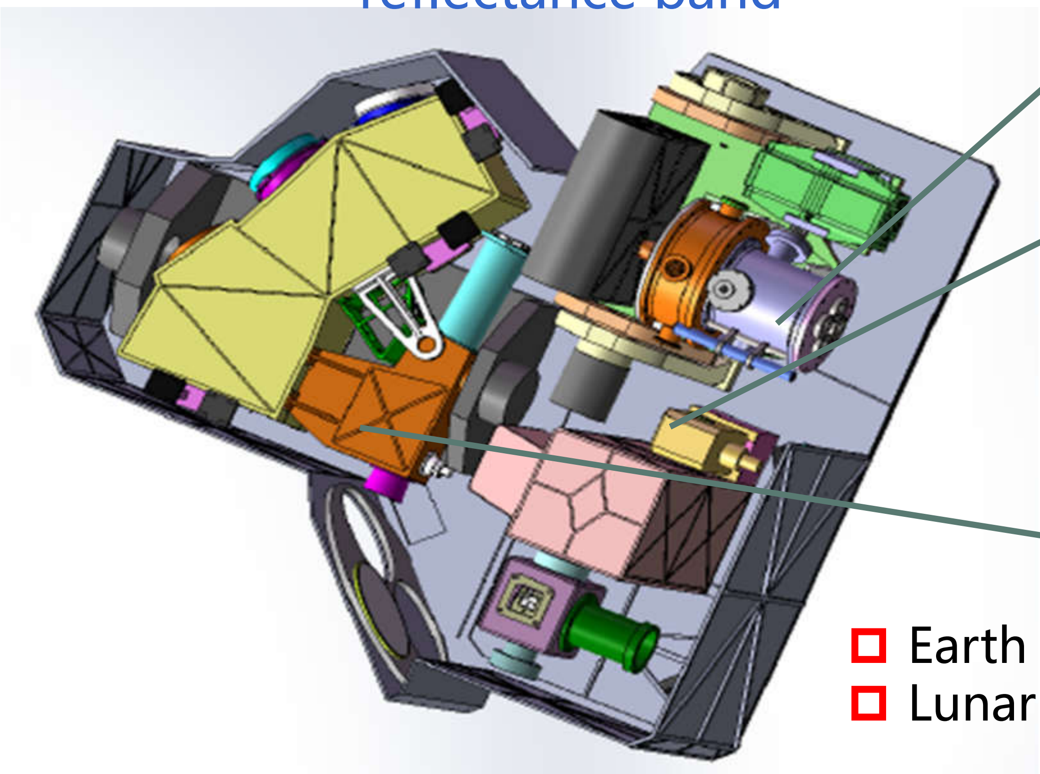
Moon

- Irradiance measurement uncertainty 2%

High Accurate Observing Instrument for Sun, Earth and Moon in Solar Reflection Spectrum

- High-accurate observation instrument in solar reflected band includes space cryogenic radiometer, earth-moon imaging spectrometer and benchmark transfer chain.

High-Accurate observation instrument in solar reflectance band



Space cryogenic ESR

- On-orbit benchmark detector

Benchmark Transfer Chain

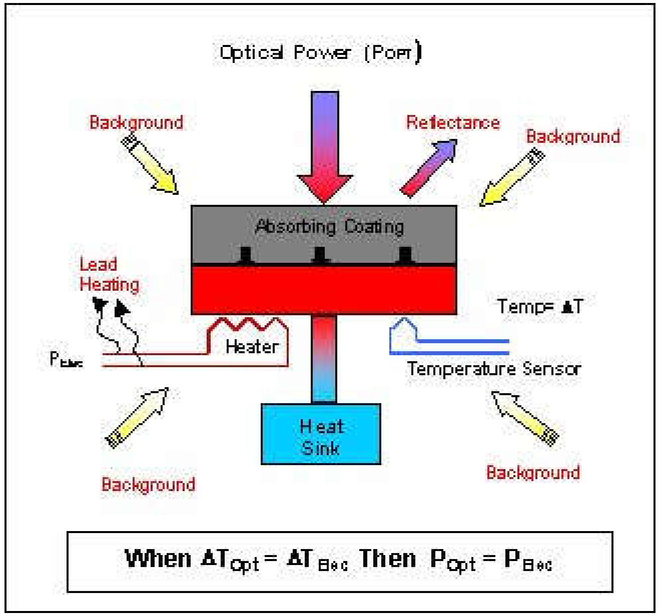
- Multispectral calibration
- Radiance calibration
- Linearity calibration

Earth-moon imaging spectrometer

- Earth Spectral Radiation Observation
- Lunar Spectral Radiation Observation

Space cryogenic radiometer

- Space cryogenic radiometer is the key to realize absolute measurement in space
- The principle of electrical substitution measurement adopted by space cryogenic radiometer is the main way to realize absolute measurement of light radiation.
- The core detector of the electrical substitution measurement is a blackbody cavity with ultra-high absorption ratio of light.



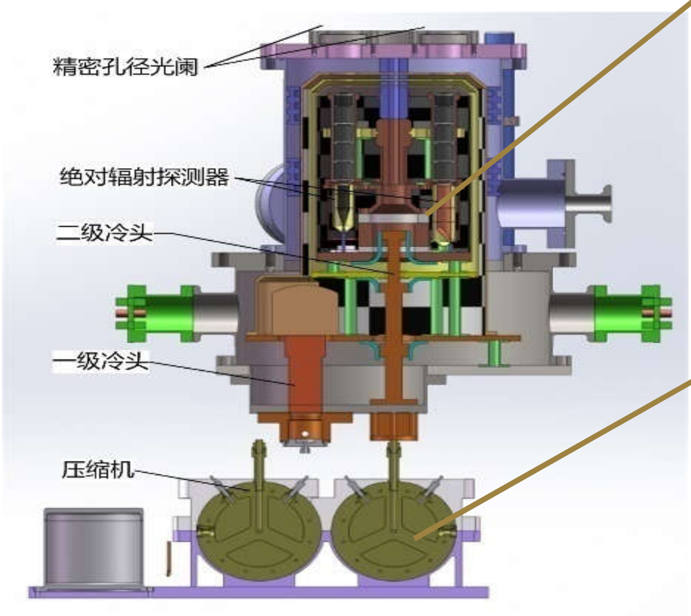
The process of electrical substitution measurement consists of two stages:

① incident light observation
② Electrical Calibration

High Accuracy Measurement of Optical Power by Photoelectric Equivalence

Space cryogenic radiometer(SCR)

- High-accurate absolute measurement on satellite will be realized by using space cryogenic radiometer. The uncertainty is better than 0.02%. The benchmark detector of on-satellite can be established.
  - ✓ Uncertainty 0.02%
  - ✓ Spectral range 0.2 μm-35μm
  - ✓ working temperature 20 K
  - ✓ dynamic range 10μW -30mW



Space cryogenic absolute detector

- High precision absolute radiation observation in space
- On-orbit radiation benchmark

Space cooler

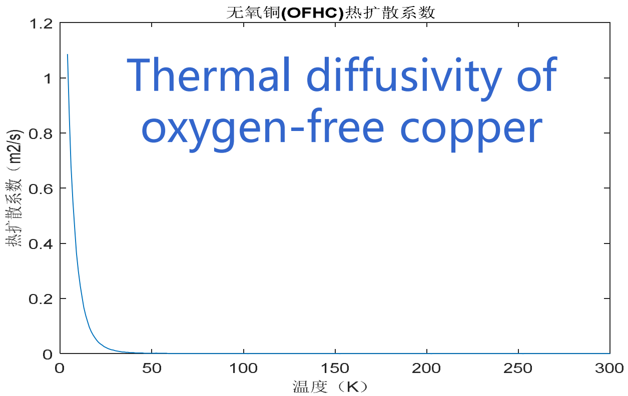
- Provide 20K Cold Source for Space cryogenic detector

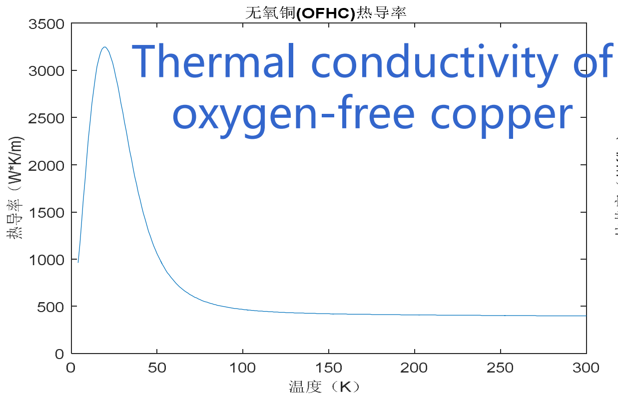
Cryogenic material properties improvement

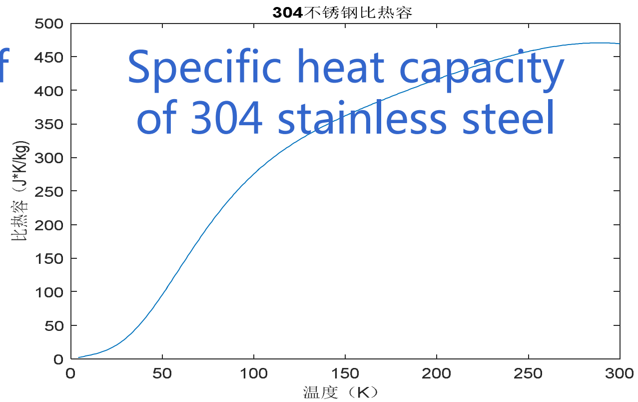
- The working temperature of space cryogenic radiometer is 20K

- The thermal diffusivity of OFHC cavity is increased by about four orders of magnitude ， The thermal conductivity is increased by one order of magnitude.
- The specific heat capacity of stainless steel thermal connection is reduced by two orders of magnitude

- The absorption of blackbody cavity is better than 0.9999;
- Uniform temperature distribution;
- equivalent incident light heating and electric heating



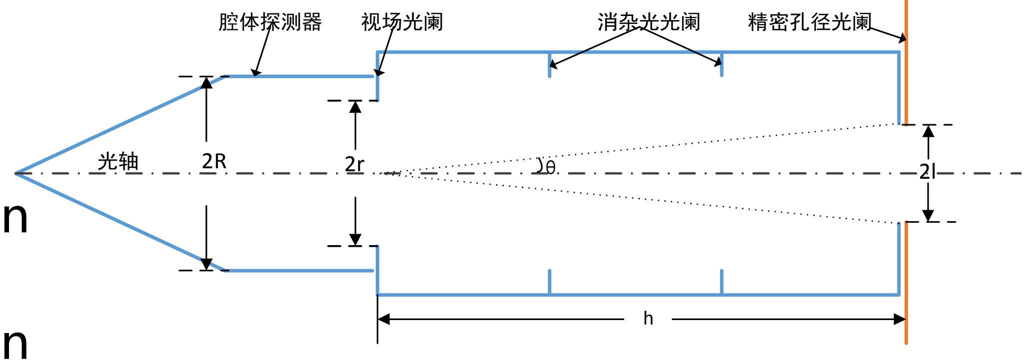


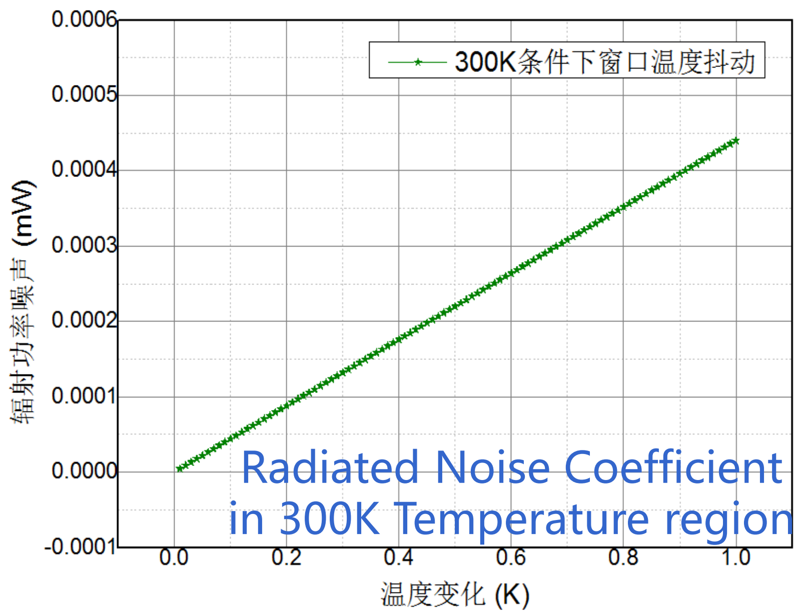


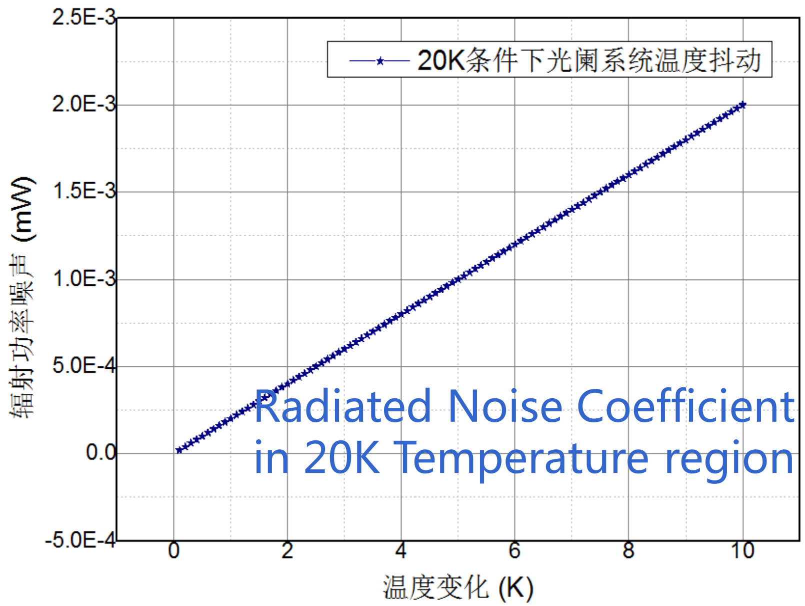
Background radiated noise analysis

- According to the design of diaphragm assembly, the radiated noise model is established.
- Analysis of background Noise in 300K Temperature Zone
- Analysis of background Noise in 20K Temperature Zone

Design of diaphragm assembly



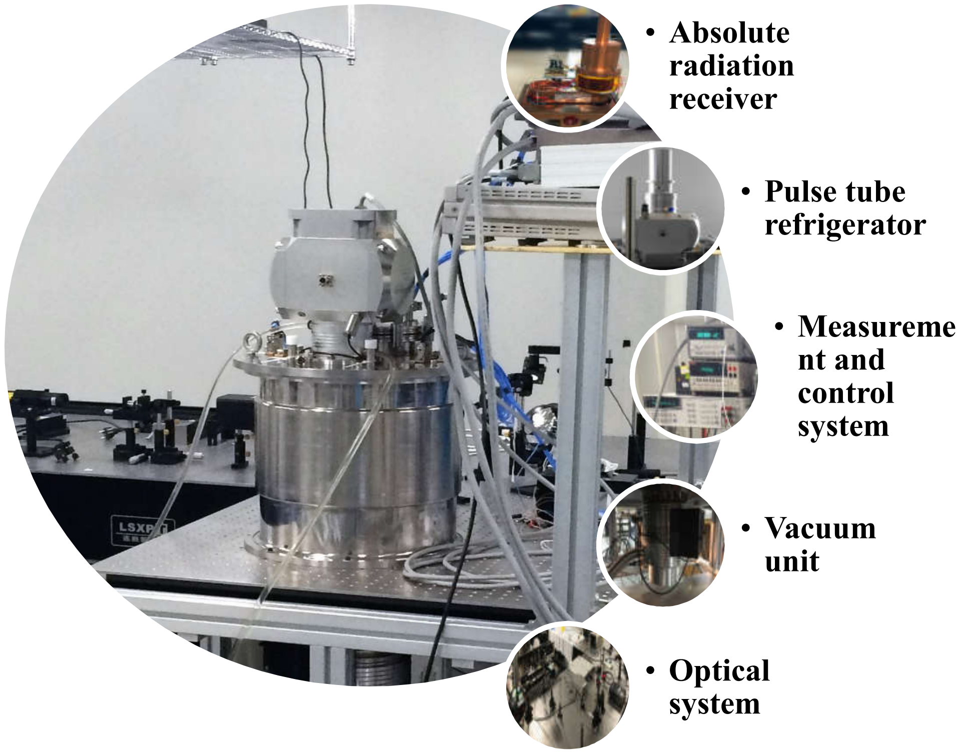




Key Technologies of cryogenic radiometer

- Supported by the National Natural Science Foundation of China and the National High-tech Research and Development Program (863 Program), a prototype of space cryogenic radiometer is developed, including cryogenic detector, pulse tube cooler, measurement and control system, etc.

- Cryogenic absolute radiation detector with high sensitivity and absorption
- Establishment of ultra-high stability cryogenic thermal environment
- Cryogenic electrical substitution precision measurement technology

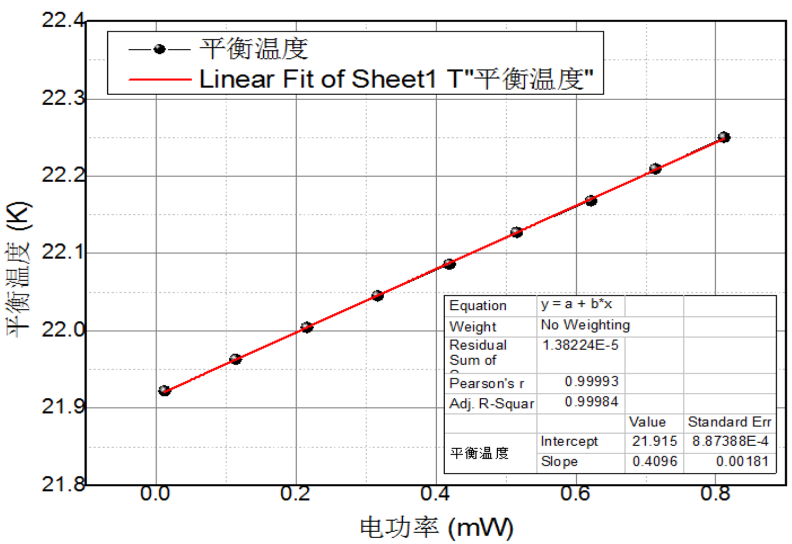


Cryogenic detector with high sensitivity and absorption

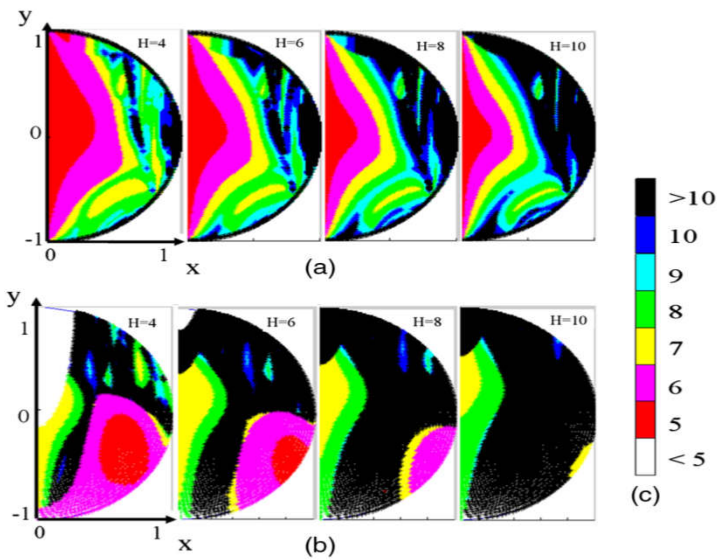
- The multi-layer structure is used to realize high sensitivity cryogenic detector.

  sensitivity: 0.4K/mW
- The absorption of blackbody cavity is better than 0.999 by optimizing cavity design and improving blackening process through simulation analysis.

Blackbody Cavity Sensitivity



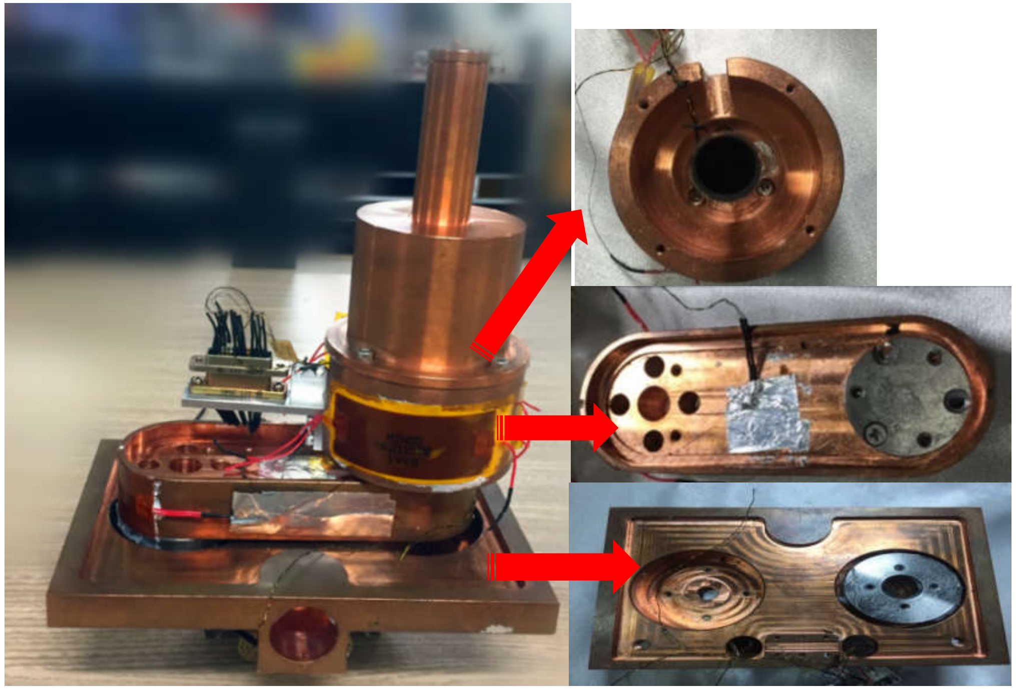
Absorption Simulation

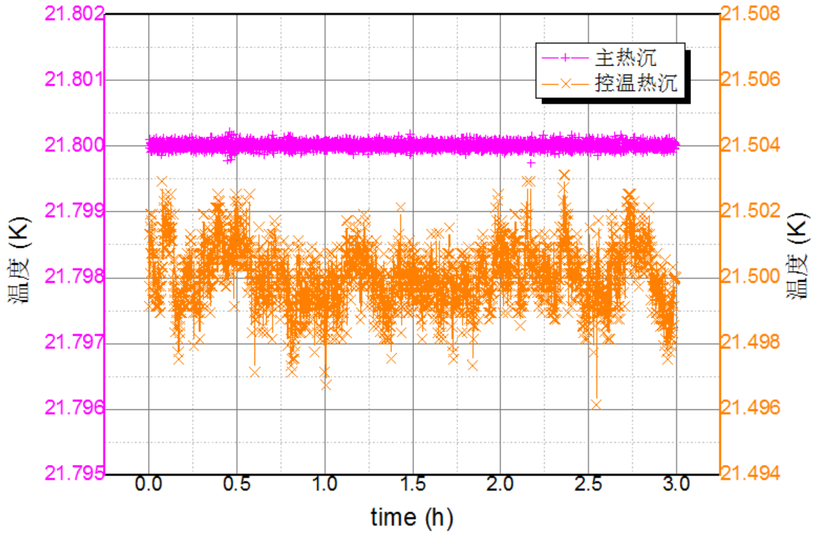


Establishment of Ultra-high Stability Cryogenic Thermal Environment

- A three-stage heat transfer structure of main heat sink, temperature-controlled heat sink and cryogenic platform is designed. A high stability working environment of 0.2mK suitable for cryogenic detector is successfully established in 20K temperature region by using digital closed-loop control.

Three-stage heat transfer structure



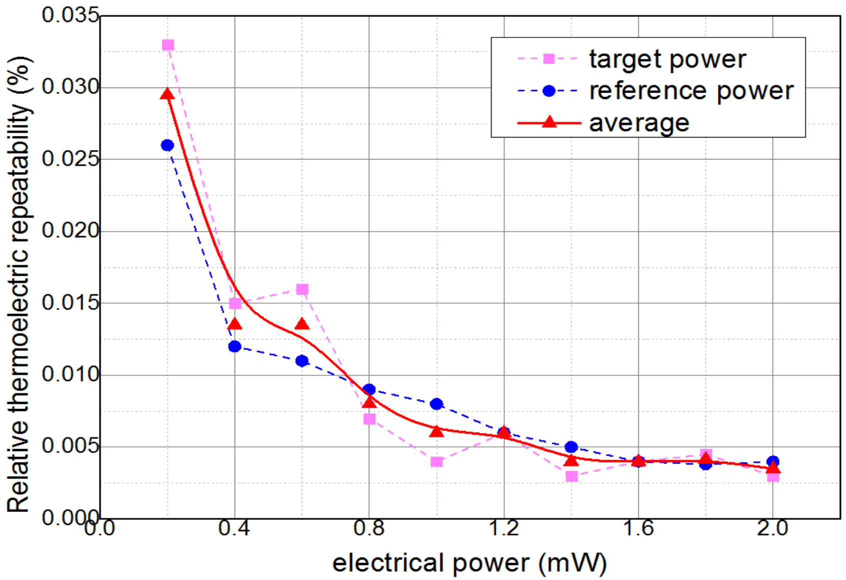


- Temperature-controlled heat sink stability is 6 mK
- Stability of main heat sink is 0.2mK

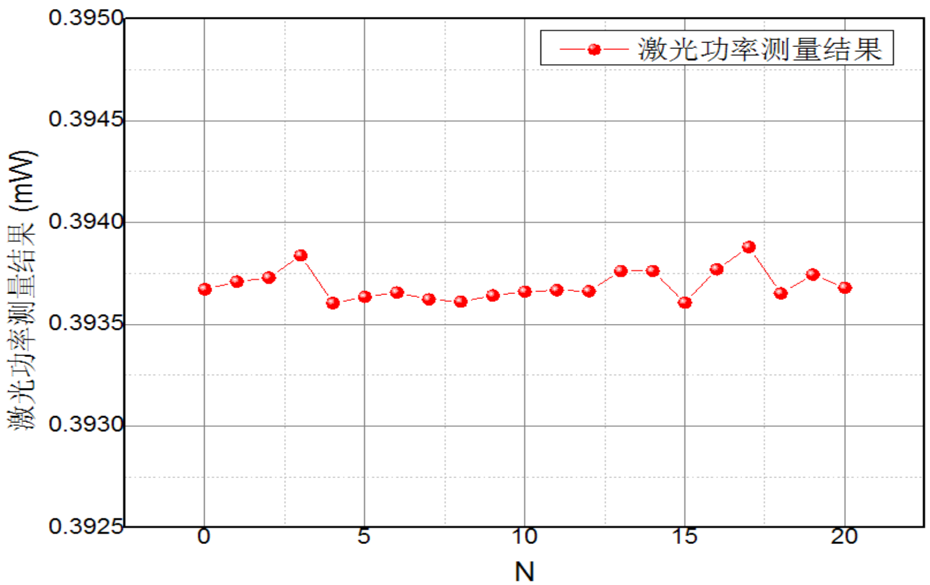
Cryogenic electrical substitution precision measurement technology

- The thermoelectric repeatability of cryogenic radiometer is better than 0.005% based on the establishment of ultra-high stability cryogenic thermal environment.
- The repeatability of optical power measurement is better than 0.02% by correcting the sensitivity nonlinearity error by two electrical calibrations.

Thermoelectric Repeatability Measurement of Blackbody Cavity



Measurement results of 0.4mW laser power

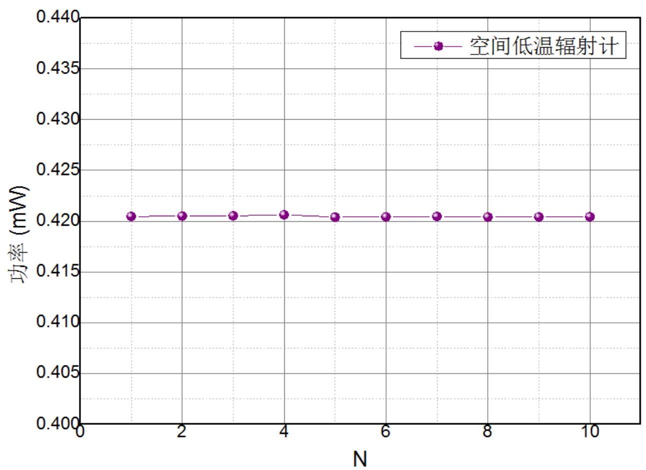


Uncertainty evaluation

- The uncertainty of type A and B laser power measurement is evaluated, and the uncertainty of 0.4 mW laser power measurement is 0.029%, which meets the requirement of space absolute radiation measurement.

A type

- Repeatability



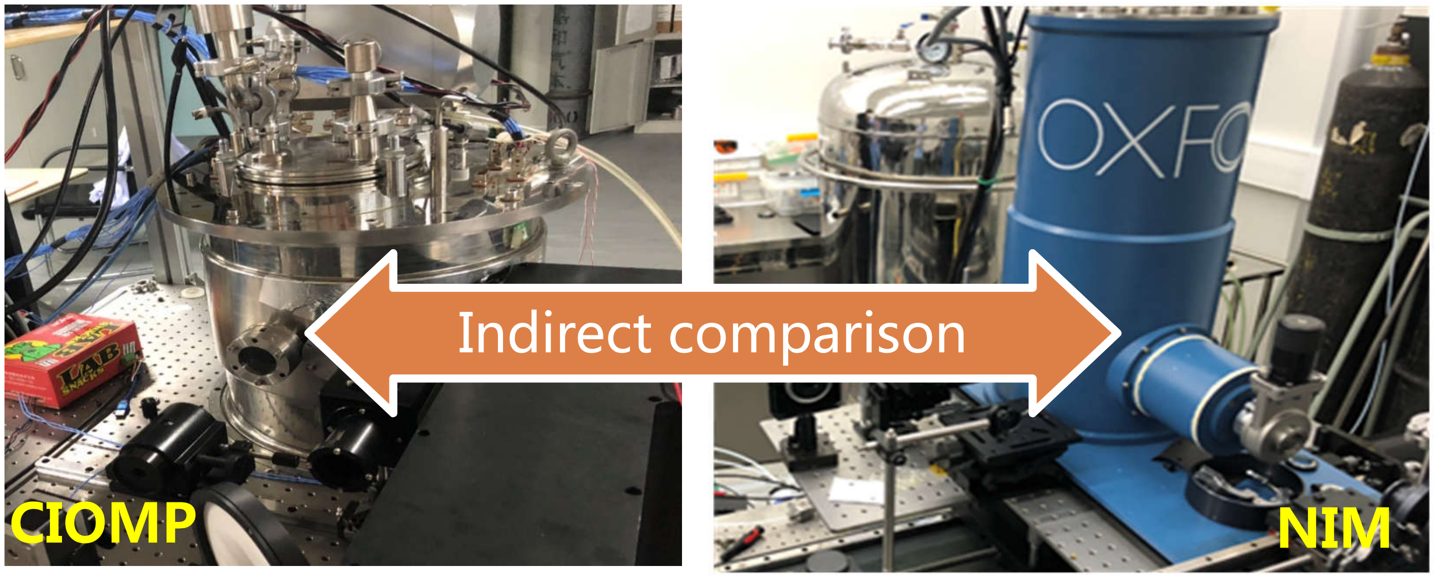
B type

- Stray light power
- Absorption
- Standard resistance voltage
- Heating voltage
- Standard resistance
- Equilibrium cavity temperature
- Sensitivity

Indirect comparison

- Indirect comparison is an international universal method for testing absolute measurement accuracy of radiometers. The results of indirect comparison with the benchmark cryogenic radiometer of the National Institute of Metrology are as follows: Normalized deviation |En|=0.4 < 1 , The validity of 0.029% uncertainty evaluation results is verified.

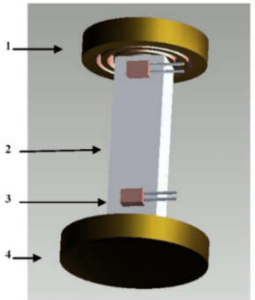
Normalized deviation: $E_n = \frac{Y_1 - Y_2}{ku}$



Space cooler

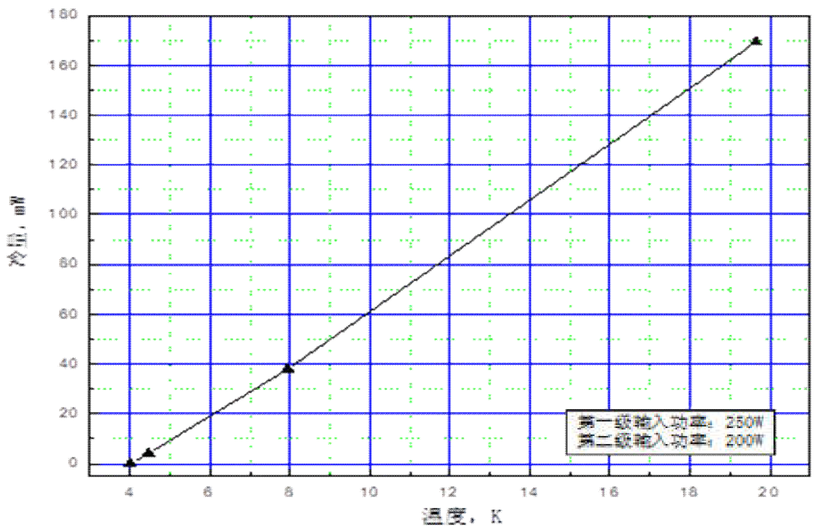
- Space cooler Provides 20K Working Temperature for Space Cryogenic Absolute Radiometer
- At present, the cooling capacity of internal cryogenic refrigerator can reach 160 mW in 20K temperature region.

Refrigerator developed by Institute of Physical and Chemical Technology, Chinese Academy of Sciences



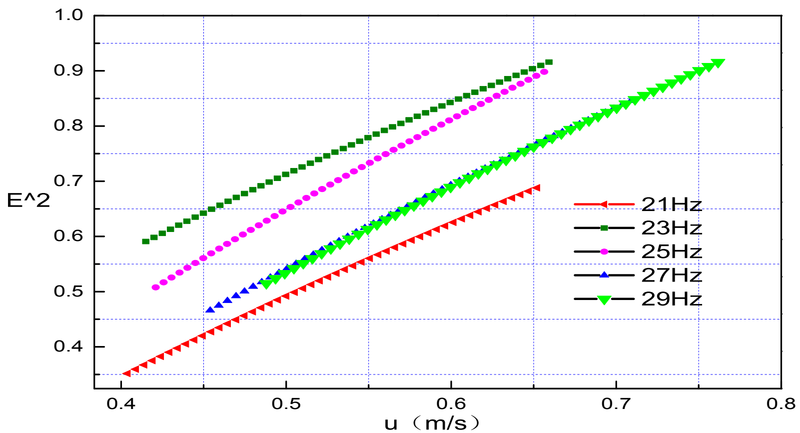
1— 电加热器； 2— 样品； 3— Cernox 电阻温度计； 4— 热沉； 5— 制冷机二级冷头；
6—制冷机一级冷头

Refrigerator cooling capacity

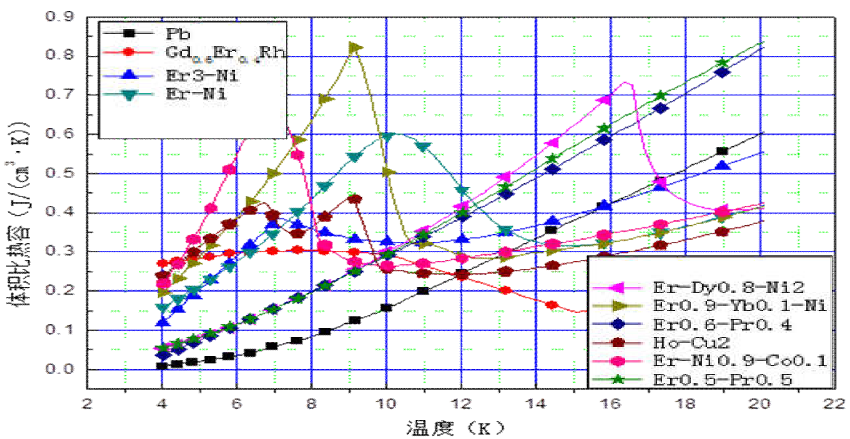


Space cooler

- To overcome the key technology of pulse tube cooler with large cooling capacity in space and achieve 350mW@20K cooling capacity
  - High Efficiency Heat Exchange Technology of Magnetic Regenerative Material for the coolerb
  - The influence of characteristic size of regenerator on the performance of refrigerator
  - High Efficiency and Large Displacement Compressor Technology under Low Operating Pressure



Research on Compressor Efficiency Improvement



Study on magnetic regenerative materials

中国科学院长春光学精密机械与物理研究所

Earth-Moon Imaging Spectrometer

- The earth-moon imaging spectrometer is used to measure reflected solar radiance or irrdiance, including the earth and moon
- The earth-moon imaging spectrometer consists of VNIR and SWIR spectrometers, spectral range coverage 380nm-2350nm

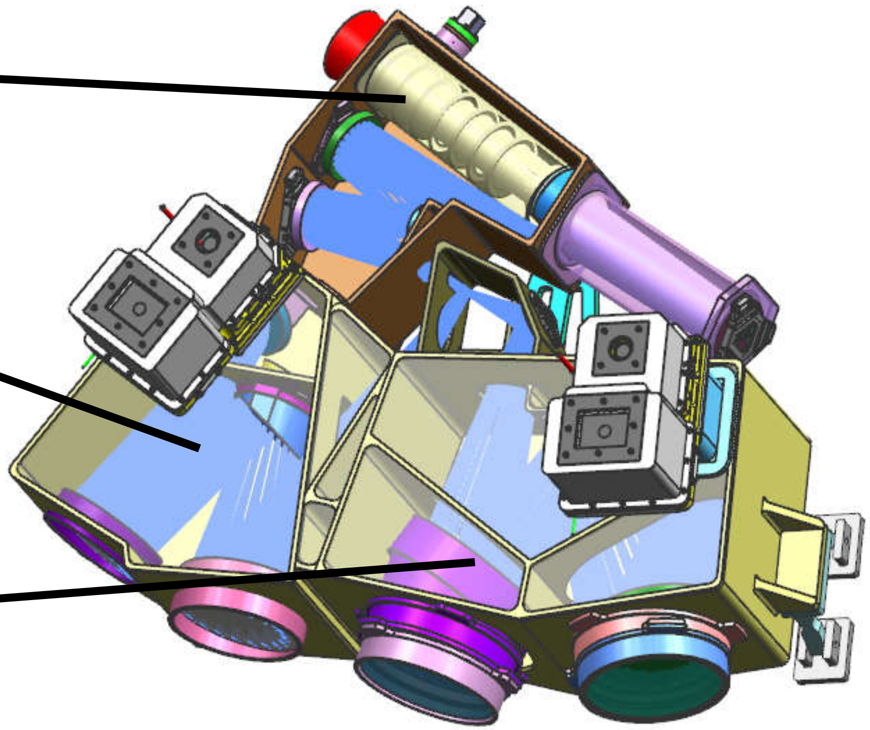
Telescope system

VNIR spectrometer

◆380nm-920nm

SWIR spectrometer

◆870nm-2350nm

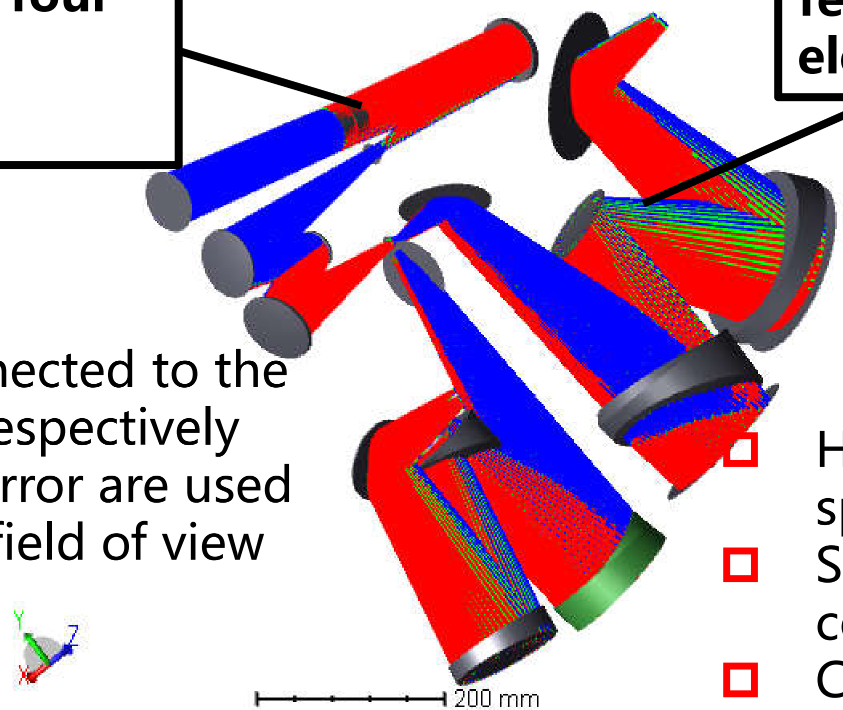


Earth-Moon Imaging Spectrometer

- The two spectrometers share a common telescope system, adopt offner structure, use fery prism as dispersion element

Common off-axis four-mirror telescope system

Offner structure fery prism dispersion element



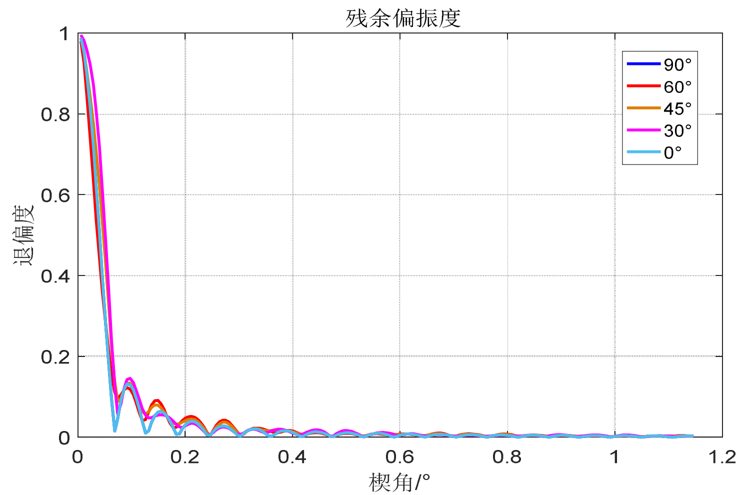
- Two slits are connected to the spectrometer respectively
- The edge and mirror are used to separate the field of view

- High transmittance in full spectrum band
- Spectral line bending and color distortion
- Combination prism correction to improve dispersion uniformity

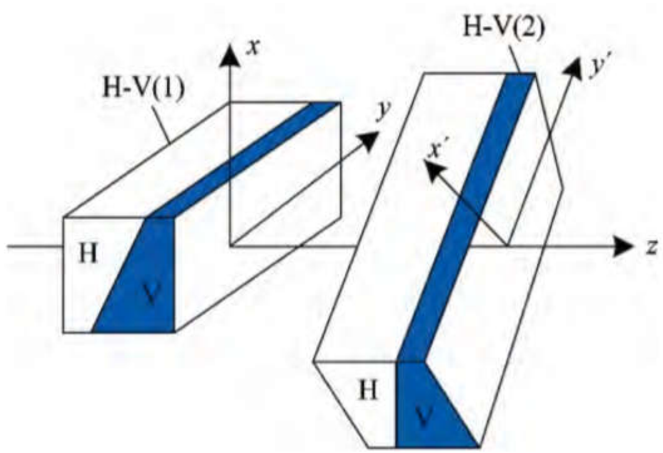
Depolarizer

❖ The dual Babinet depolarizer reduces polarization sensitivity of the optical system, ensures the measurement accuracy.

- Two H-V depolarizers with relative rotation of optical axes
- Uniaxial crystal wedge with equal thickness and equal inclination angle
- The optical axis of one wedge is horizontal and the other is vertical.
- the sensitivity to polarization is 2%@920nm



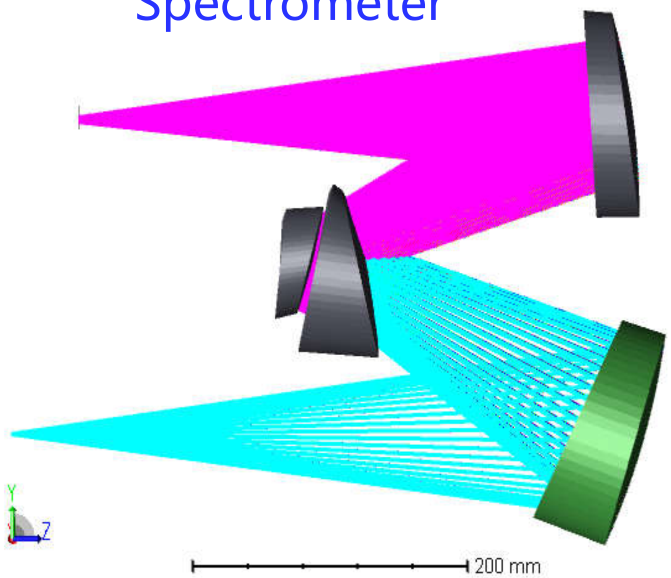
At 920nm wavelength , the trend of depolarizer residual polarization degree with inclination angle



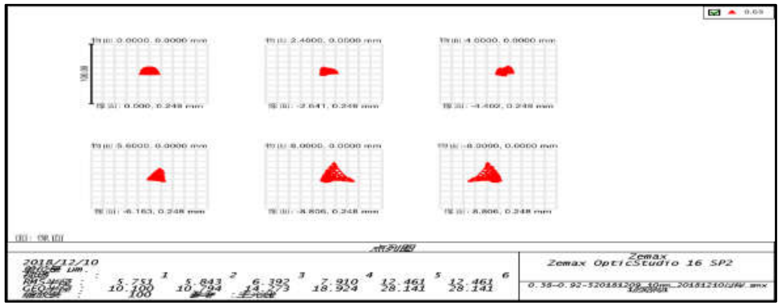
Earth-Moon Imaging Spectrometer

- The V-NIR spectrometer is composed of four Fery prisms with object telecentric structure.
- The spectral range is 0.38μm~0.92μm, and the spectral resolution is better than 5 nm.

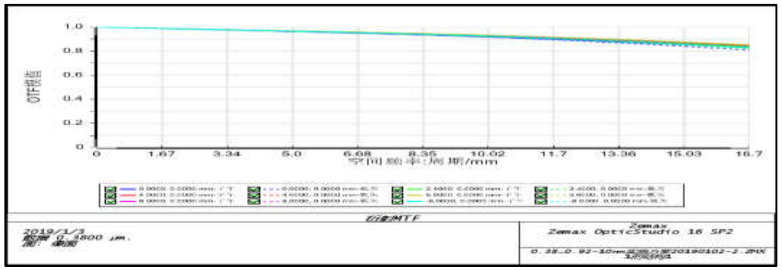
Optical Design of VNIR Spectrometer



Point diagram of optical system



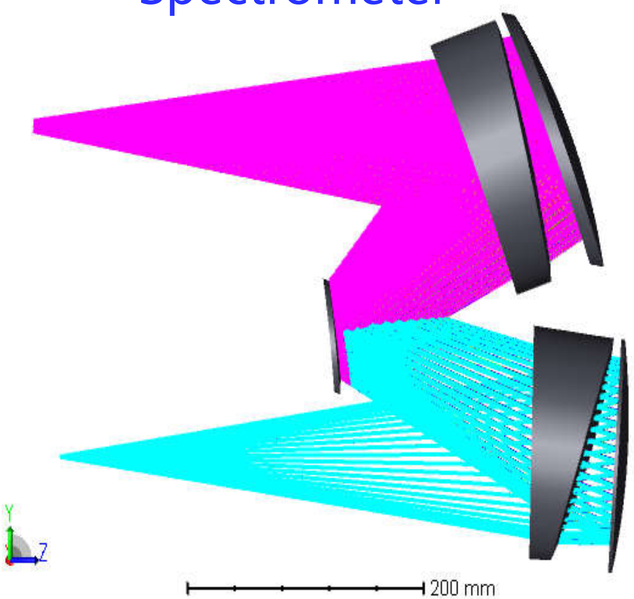
MTF of VNIR Band Spectrometer



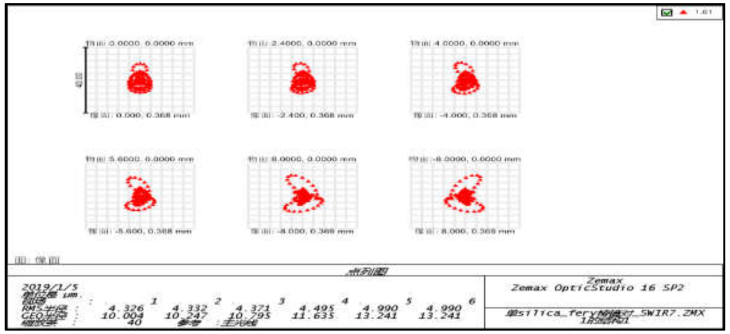
Earth-Moon Imaging Spectrometer

- The SWIR spectrometer is also composed of four Fery prisms, two of which are placed on the two arms of the spectrometer, and the object telecentric structure is adopted.
- The range of band is 0.87μm ~2.35μm. and the spectral resolution is better than 10 nm.

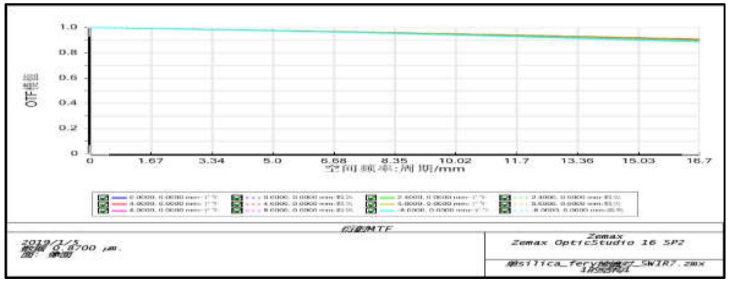
Optical Design of SWIR Spectrometer



Point diagram of optical system



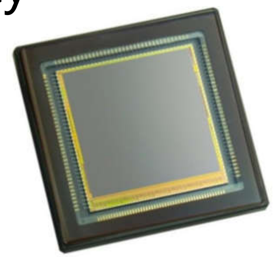
MTF of SWIR Spectrometer



Detector

- VNIR detector selects GSENSE400 CMOS array detector

  - Large format
  - Broadband response
  - High quantum efficiency
  - Low noise
  - Large dynamic range



GSENSE400 adopts the shutter mode of rolling shutter, and the starting time of integral time of each line is delayed in turn.

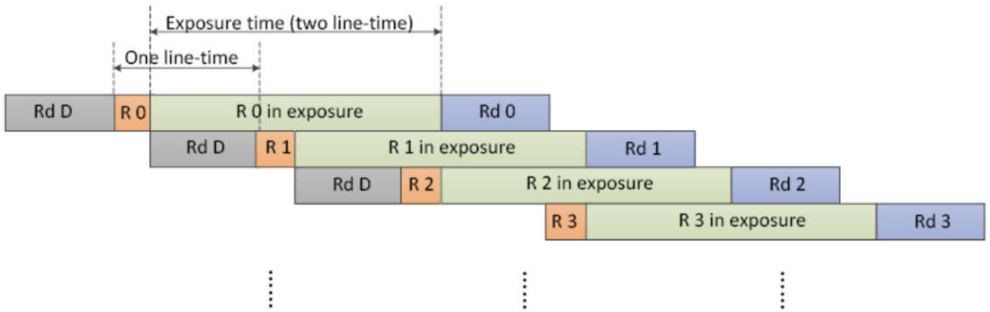
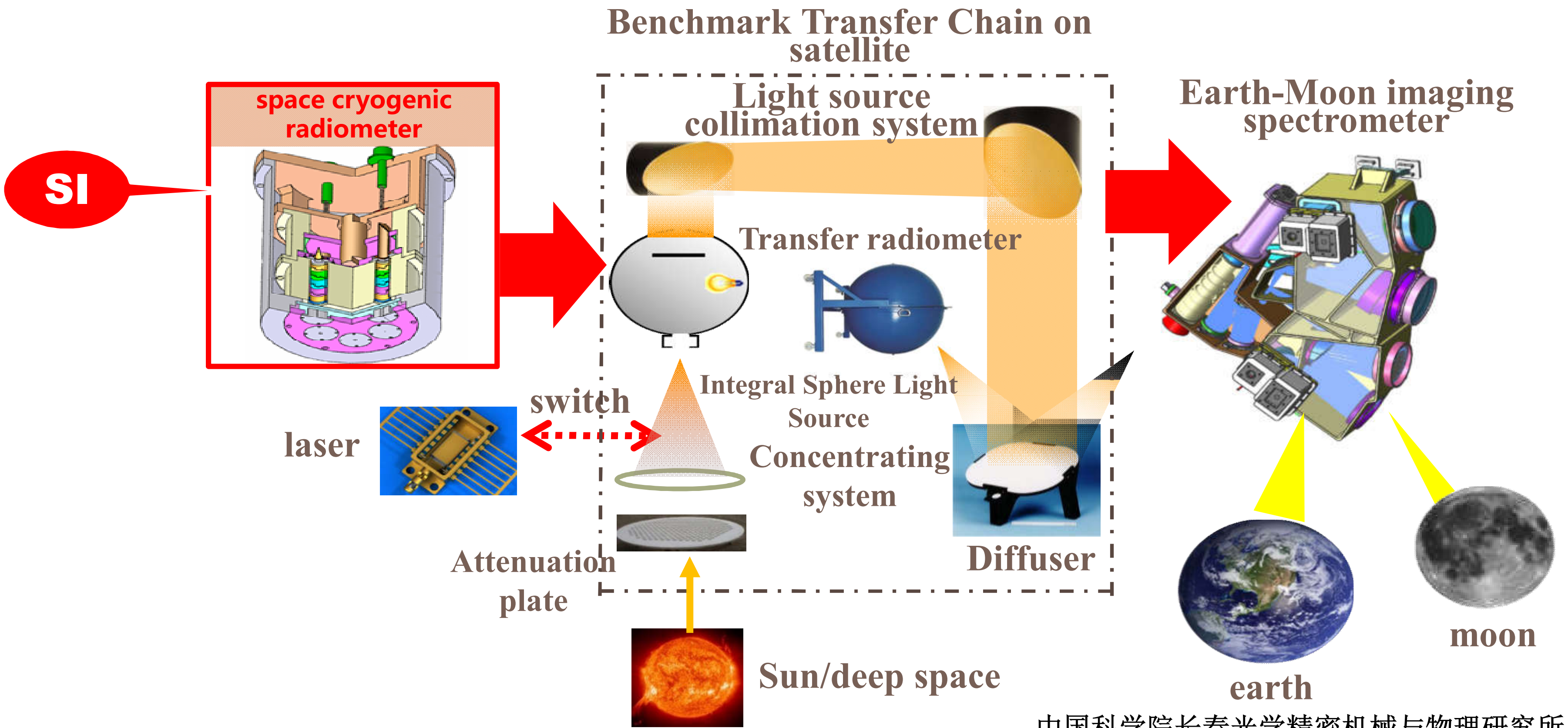


Image Size	22.528mm×22.528mm
pixel size	11μm×11μm
Pixel number	2048(H)×2048(V)
Shutter mode	Rolling shutter
FWC	90ke-
Dark noise	< 1.6 e-
Output modes	8路
frame rate	24 fps @ HDR mode 48 fps @ STD mode
dynamic range	>93dB (HDR mode)
data rate	2.4Gbps

Benchmark Transfer Chain

- Using space cryogenic radiometer as benchmark, the transfer chain on satellite should be established, the solar irradiance monitor and the Earth-Moon imaging spectrometer are calibrated on orbit, and the absolute observation of the solar reflected band can be realized.



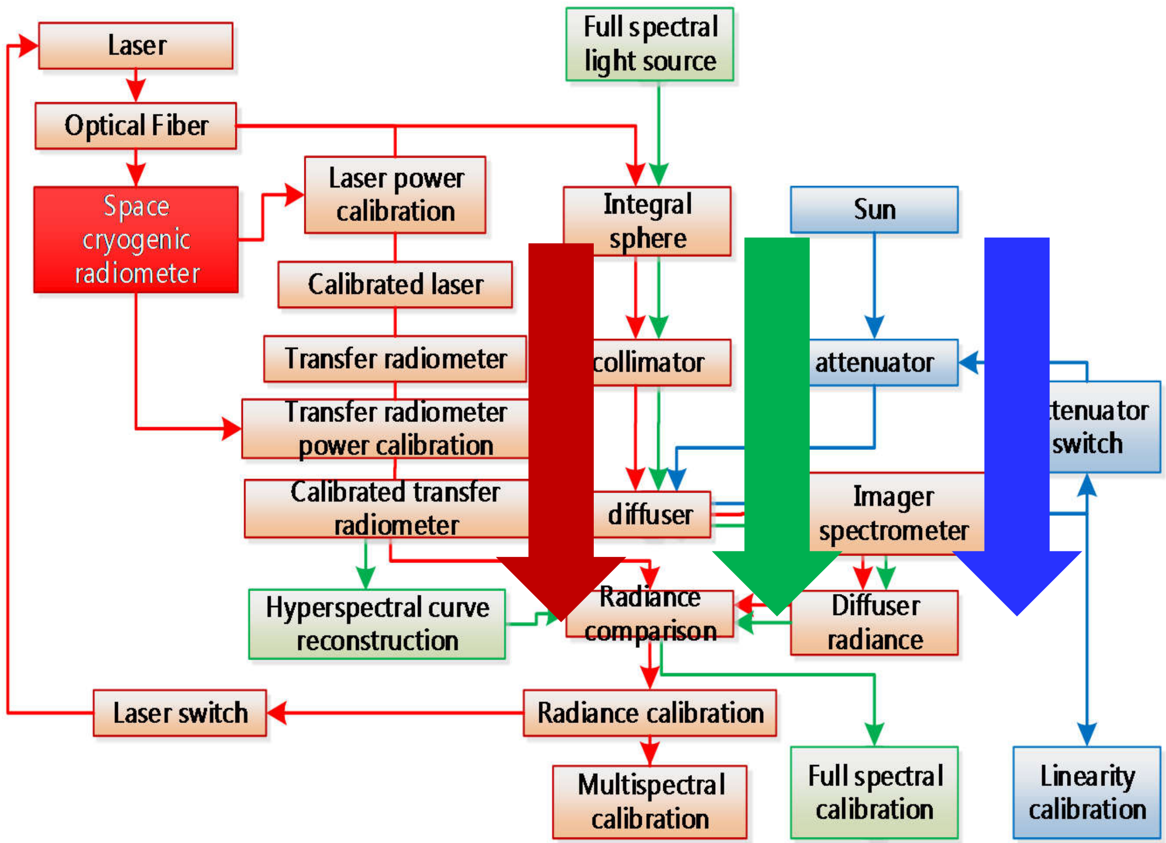
Benchmark Transfer Chain

- The benchmark Transfer Chain includes optical components such as laser, lamp, integrating sphere, transfer radiometer, diffuser, attenuator and so on.

A Multispectral Calibration

B Full spectrum calibration

C linearity calibration

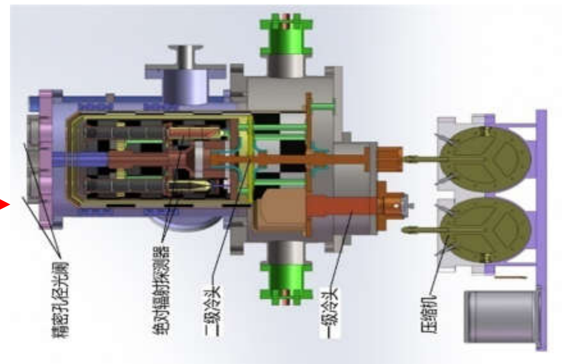


Multispectral power calibration Chain

- Multispectral power calibration of transfer radiometer is realized by the lasers and cryogenic radiometer

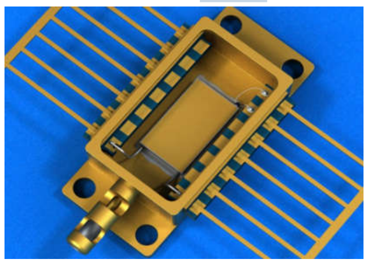
laser diodes are coupled by optical fibers

单模光纤耦合 → 多光纤捆绑封装 → 多光纤再准直



cryogenic radiometer

transfer radiometer

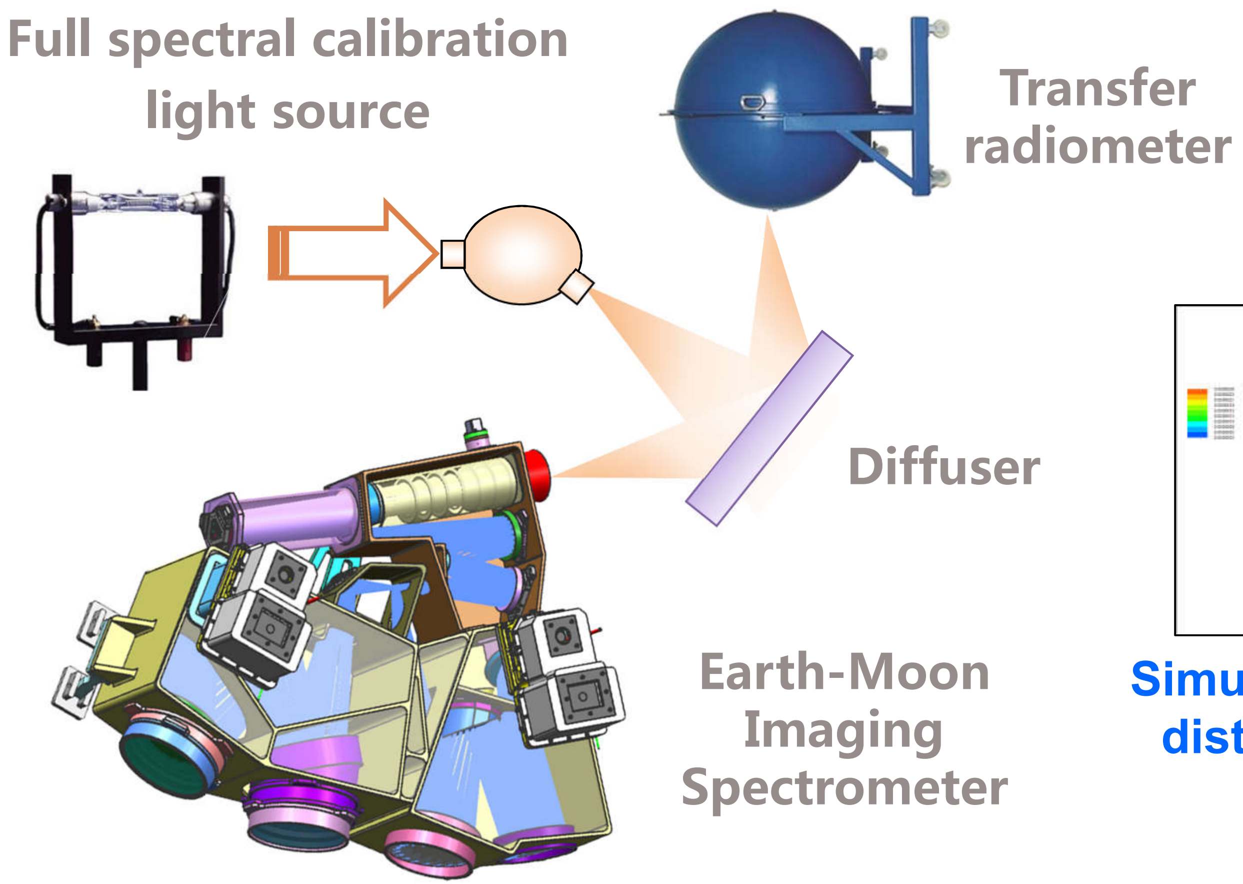


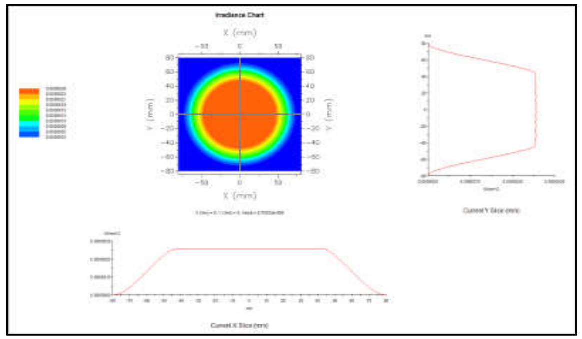
laser diode

- Power stability≤0.1%
- Wavelength stability≤0.2nm
- Spectral bandwidth ≤0.5nm

Full spectral calibration chain

- The full spectral calibration is established by the hyperspectral curve reconstruction, then the earth-moon imaging spectrometer can be calibrated on full spectral band

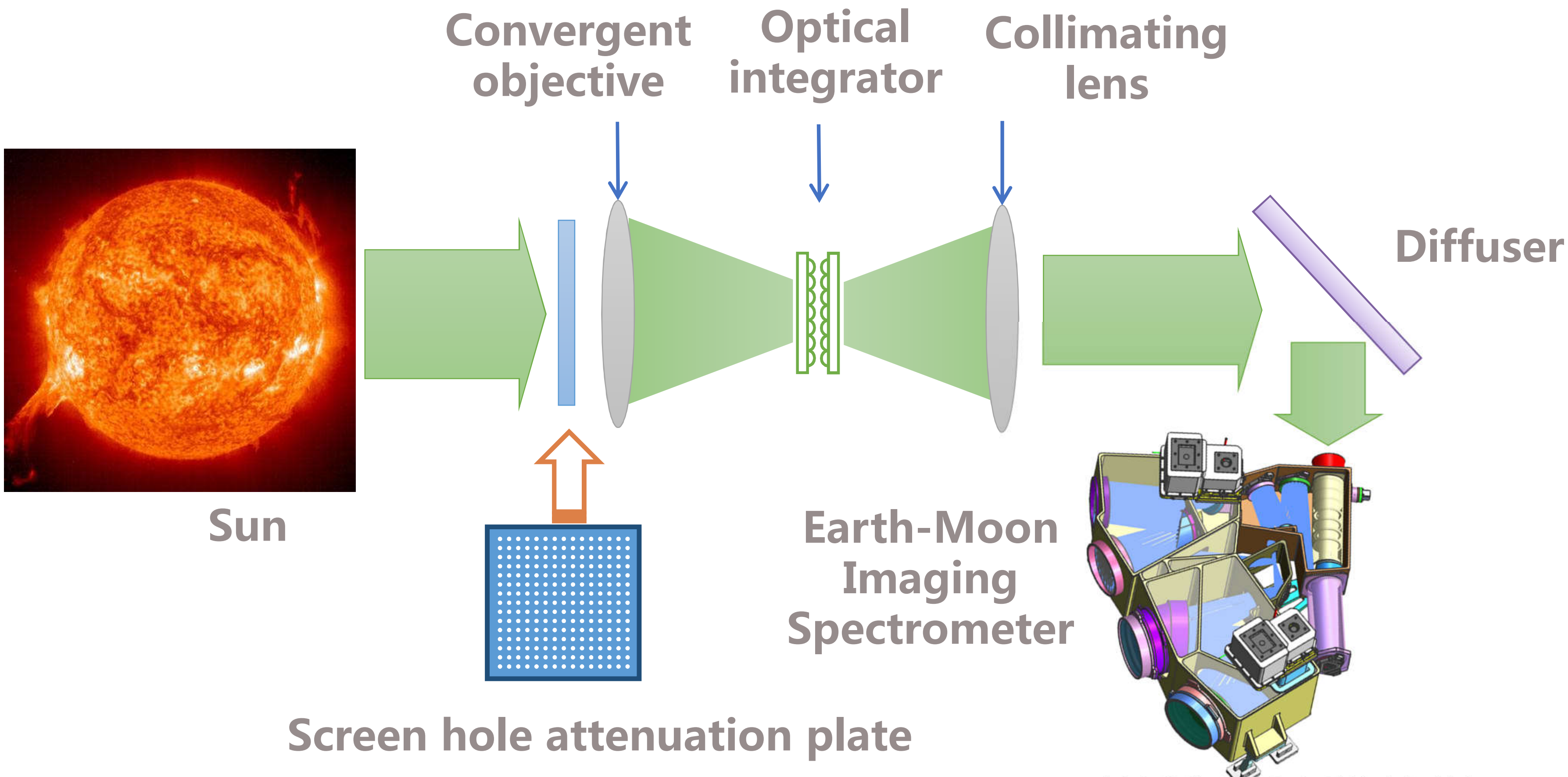




Simulation of illumination distribution on diffuser

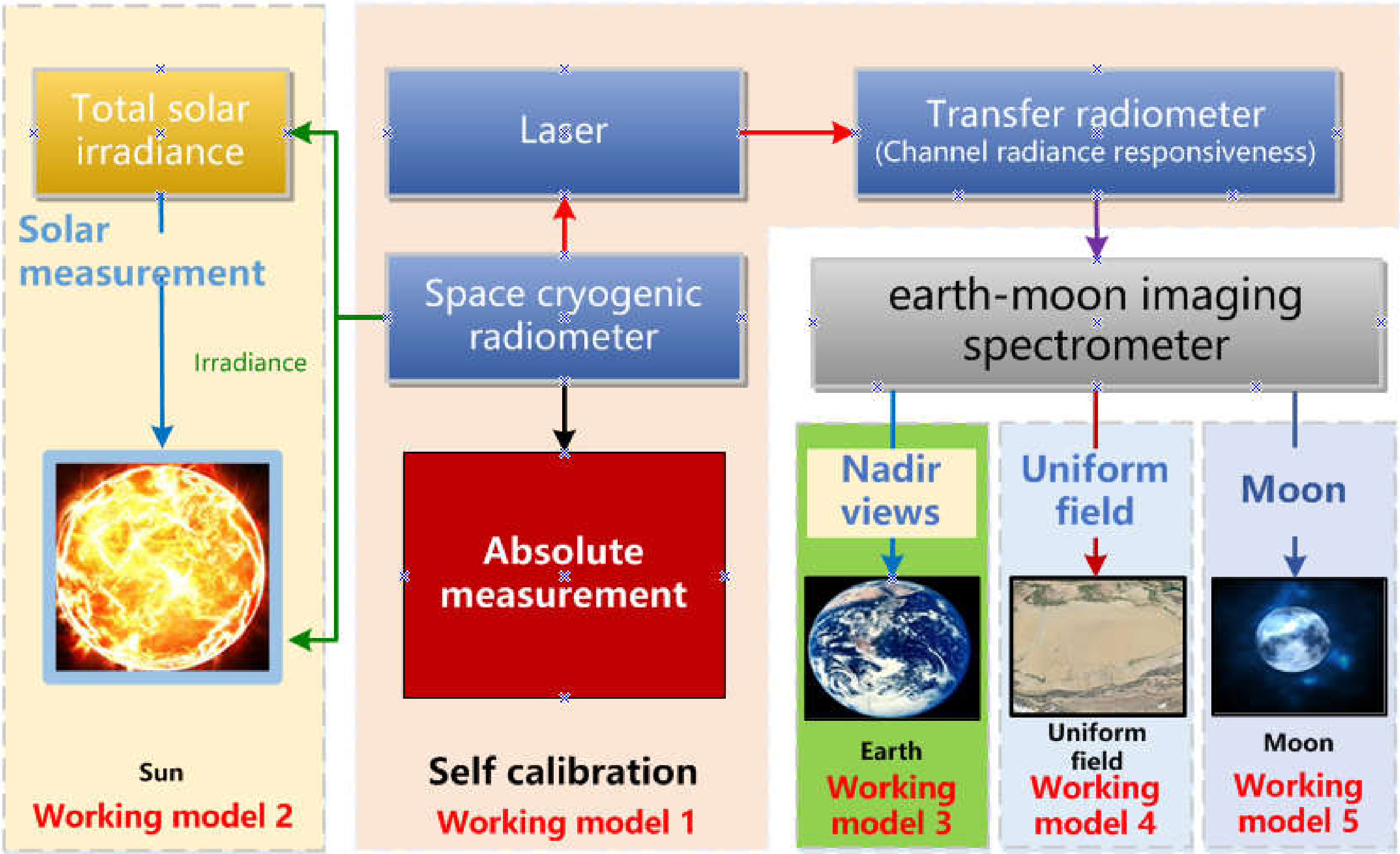
Linearity Calibration Chain

- Screen-hole attenuation plates with different transmittances are placed in the solar parallel light path, the linearity of earth-moon imaging spectrometer can be calibrated



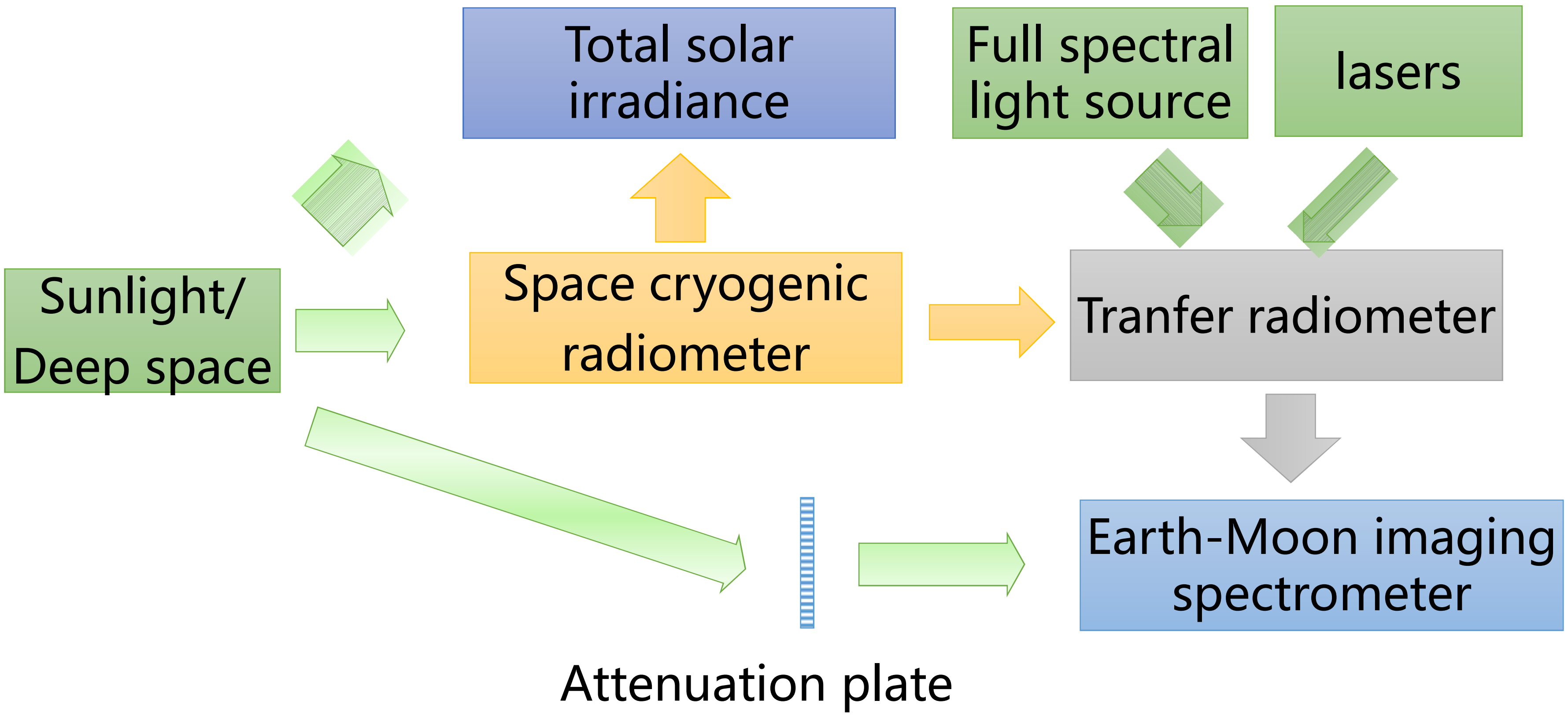
Working mode

- Five working modes are designed to realize on-orbit self-calibration and solar, Nadir views, uniform field observation and lunar observation.



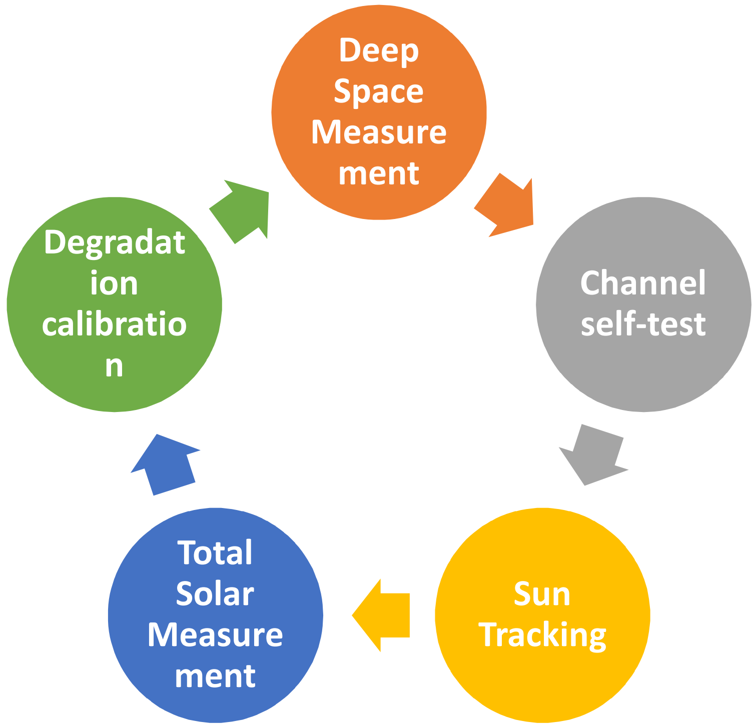
Self calibration

- On-orbit calibration of Earth-Moon imaging spectrometer based on space cryogenic radiometer



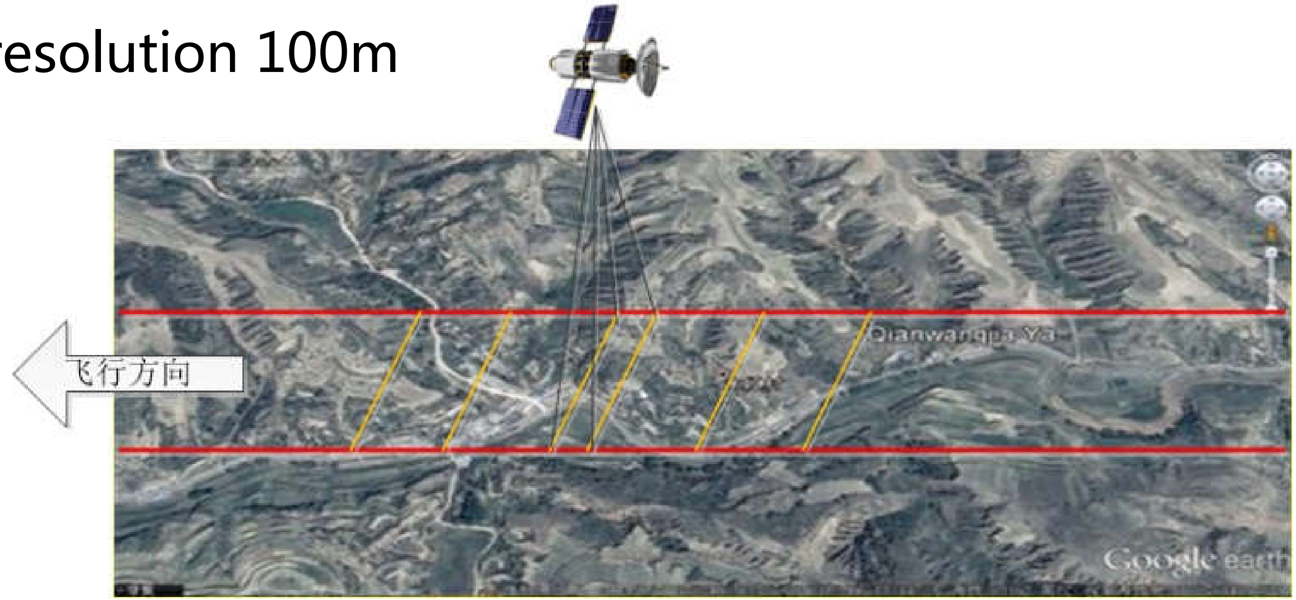
Solar Observation Mode

- After launched, the sun tracker points the sun and the total solar irradiance is measured on-orbit..



Nadir views observation mode

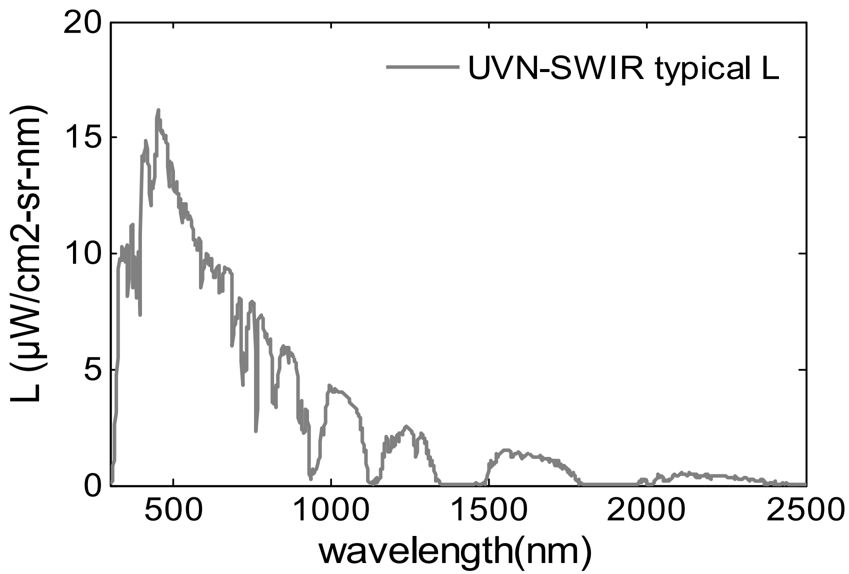
- Nadir views observation mode is conventional observation mode
- swath is 50km
- spatial resolution 100m



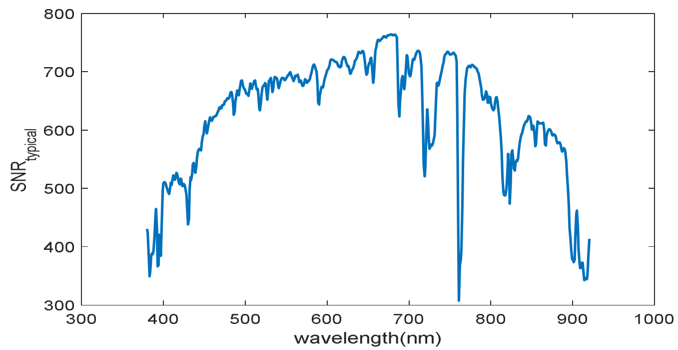
Under this mode, the satellite runs in the prescribed orbit and ensures that the optical axis of the Earth-Moon Spectrometer points to the ground, and obtains the atlas information of the ground objects by pushing along the orbit.

Nadir views observation mode

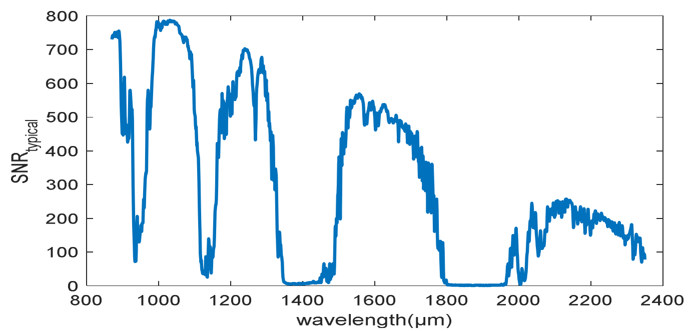
- In nadir views observation mode, the signal-to-noise ratio in non-absorption region is greater than 300(VNIR),SWIR(100) .



VNIR spectrometer



SWIR spectrometer

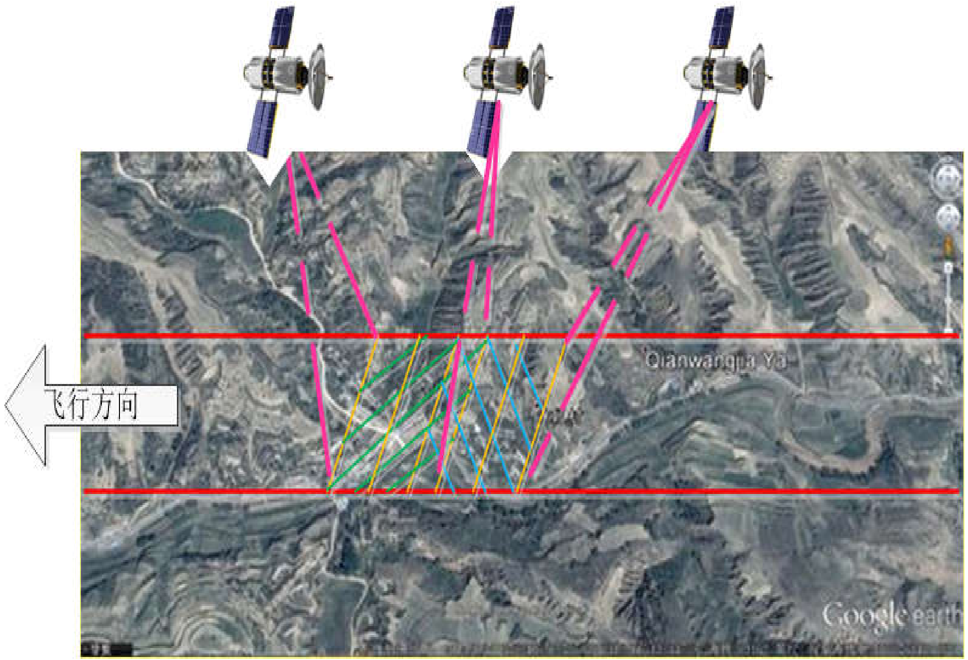


parameter ：

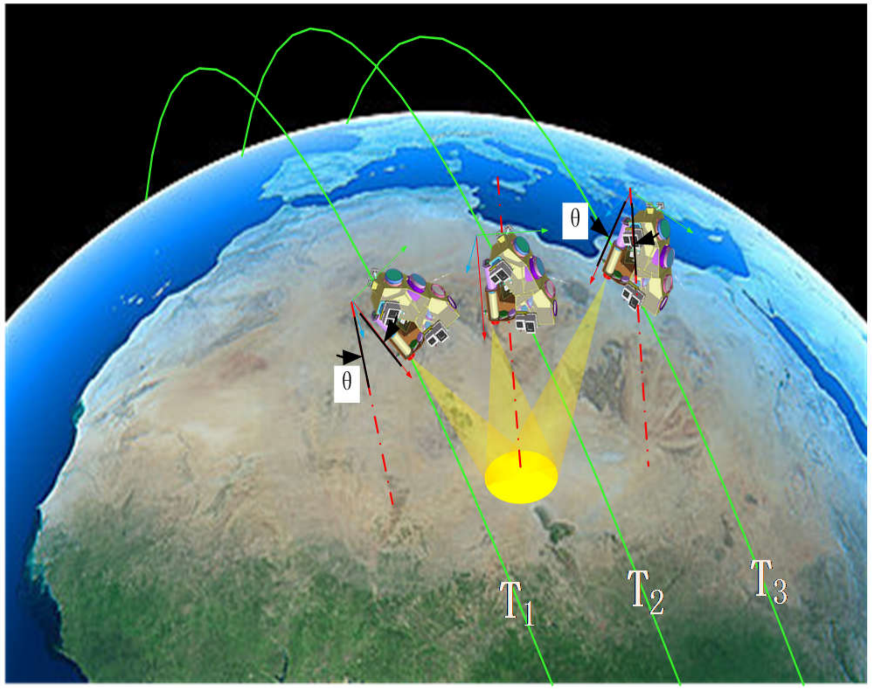
- **Solar zenith angle ：60°**
- **Ground albedo ：0.3**
- **Integral mode ： 3-divide frequency**

Uniform field observation mode

- The integral time is improved by motion compensation and across track measurement



Motion compensation



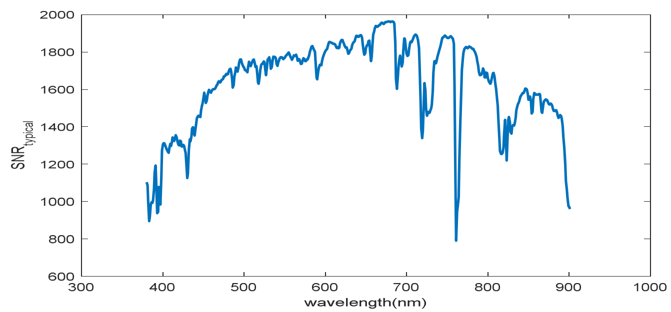
Across track

Uniform field observation mode

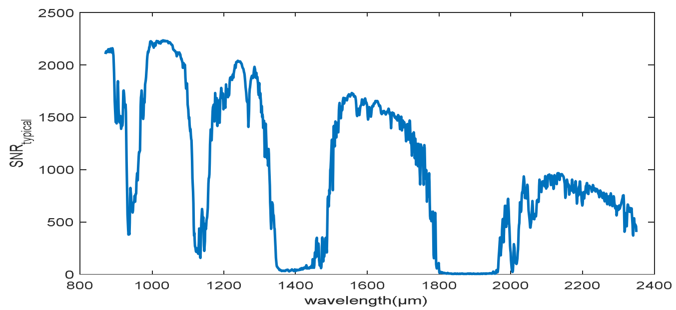
- Uniform field observation model has the capability of 8 times integral time

Observation time and maximum observation distance			
number	Integral multiple	time （s）	distance （km）
1	2	92.99	341.47
2	3	68.73	168.20
3	4	60.80	111.59
4	5	56.87	83.49
5	6	54.52	66.70
6	7	52.95	55.53
7	8	51.84	47.56

VNIR spectrometer



SWIR spectrometer



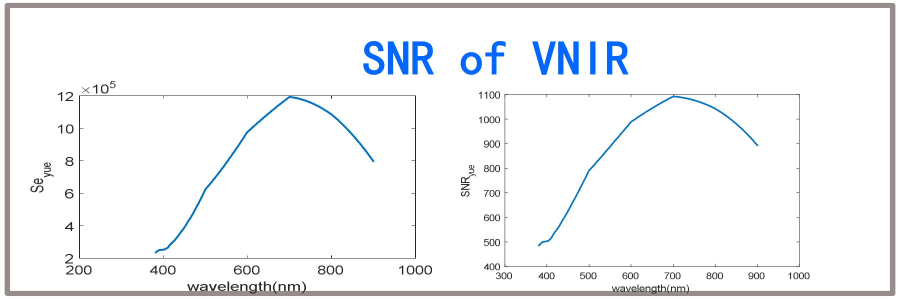
At 6 times integral time, signal-to-noise ratio is greater than 300

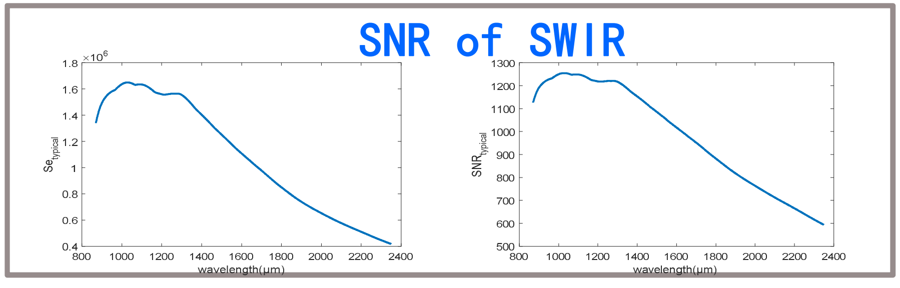
Lunar Observation Mode

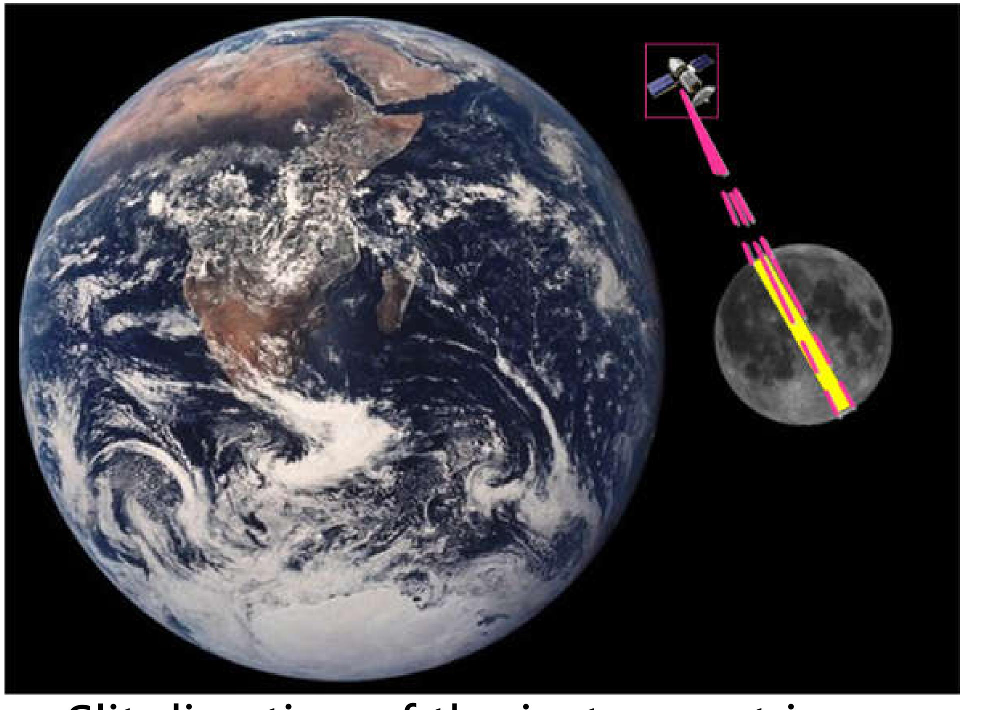
- In lunar observation mode, periodic observation of the moon by adjusting the attitude of the remote sensor, earth-moon imaging spectrometer scans the lunar surface

Parameters

- Scanning time: 8s
- spatial resolution : 64km
- Coverage width : 3500km
- Covering Pixel Number : 55pixel



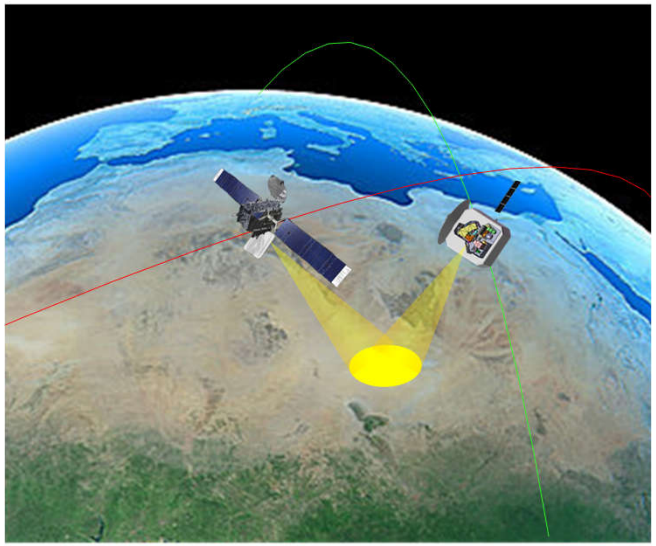




Slit direction of the instrument is perpendicular to the motion direction of the moon

Conclusion

- Establishing on-board absolute radiometric benchmark, improving absolute measurement accuracy and long-term stability of space optical remote sensing instrument, and providing key data basis for the research of Earth climate change
- Using the uniform fields such as the calibrate site and the moon, and through cross-calibration, the on-orbit radiometric scale can be unified.



Thank you for attention！

Changchun institute of optics, fine mechanics and physics, Chinese academy of science.