AOMSUC-15 FYSUC-2025

FIFTEENTH ASIA-OCEANIA METEOROLOGICAL SATELLITE USERS' CONFERENCE

THE JOINT 2025 FENGYUN SATELLITE USER CONFERENCE

From the Sun to the Atmosphere - Research and Application of Fengyun Satellite Optical Payloads at CIOMP

He LingPing

Space Optics Research Department I

Changchun Institute of Optics, Fine Mechanics and Physics

Presentation Outline

- Introduction(Institute & Department)
- CIOMP Fengyun Satellite Optical Payload R&D:
  - Solar Radiation Monitoring Payload
  - Space Weather Payload
  - Atmospheric Sensing Payload
- Recommendations for Future Payloads

Introduction to CIOMP

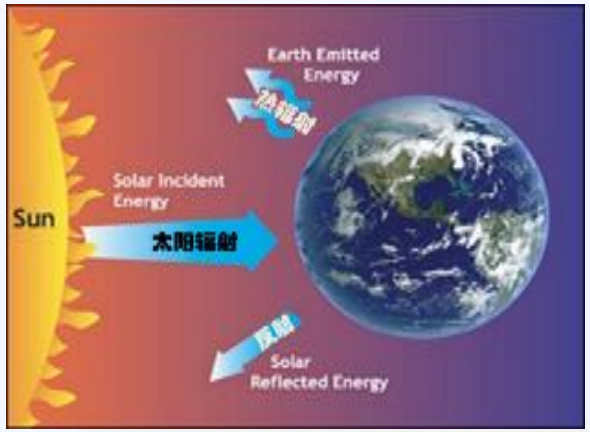
- **Cradle of Chinese optics**
- **115 National Science & Technology Awards**
- **International forefront in space optics, large-aperture mirror manufacturing, and optical engineering.**

Four Research Directions

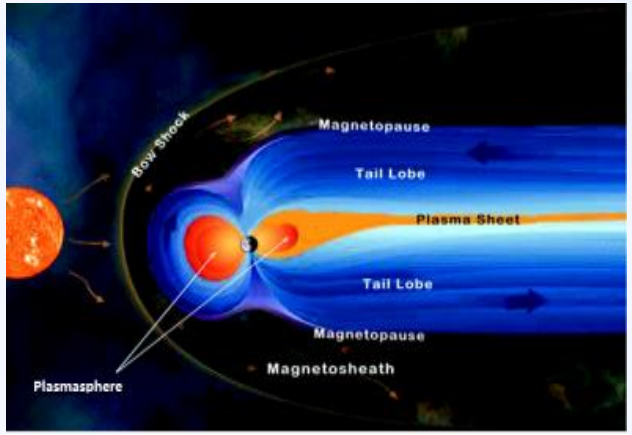
- Luminescence
- Applied Optics
- Optical Engineering
- Precision Machinery and Instruments

Space Optics Department-I Introduction

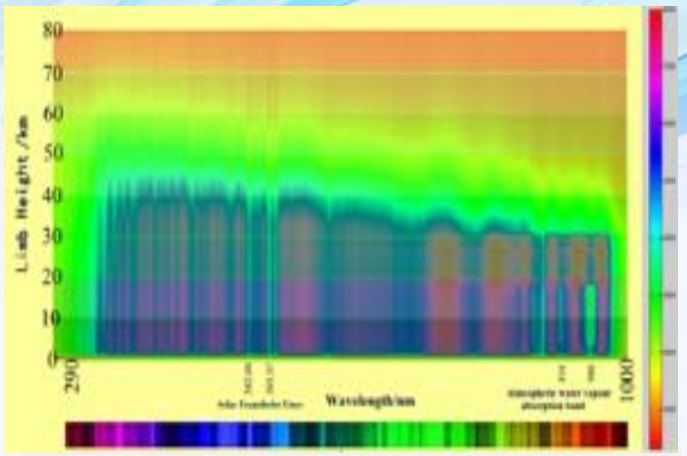
- Primarily engaged in research on space remote sensing technology, Focus on Atmosphere, Meteorology, Space Weather and other fields.
- Research directions : radiation measurement, sun-earth space detection, gravitational waves, atmospheric remote sensing, rendezvous and docking, and deep space exploration.



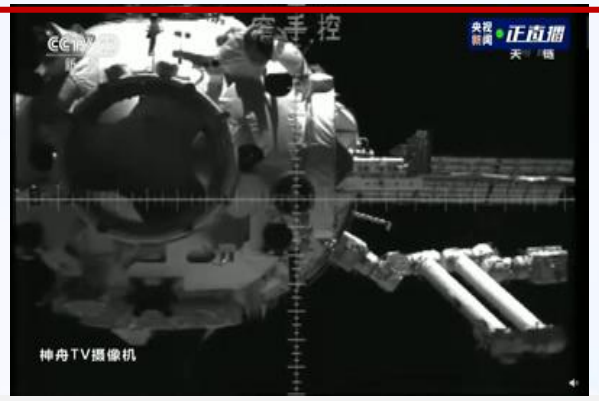
Radiation Measurement



Sun-Earth Space weather

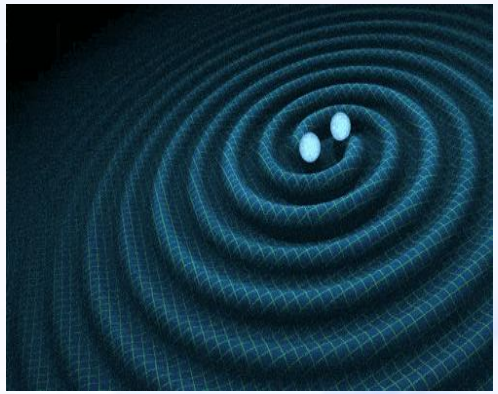


Atmospheric Remote Sensing



Rendezvous and Docking Imaging

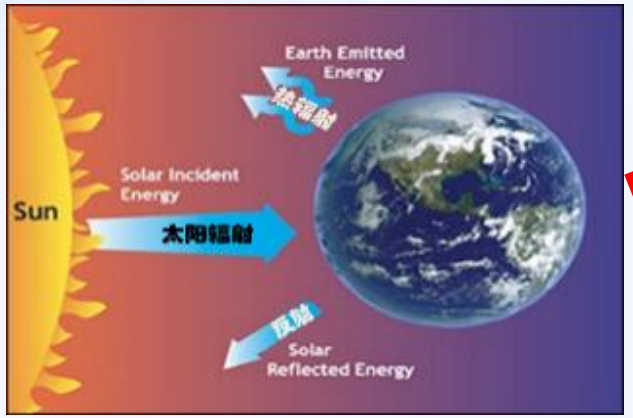
Deep Space Exploration



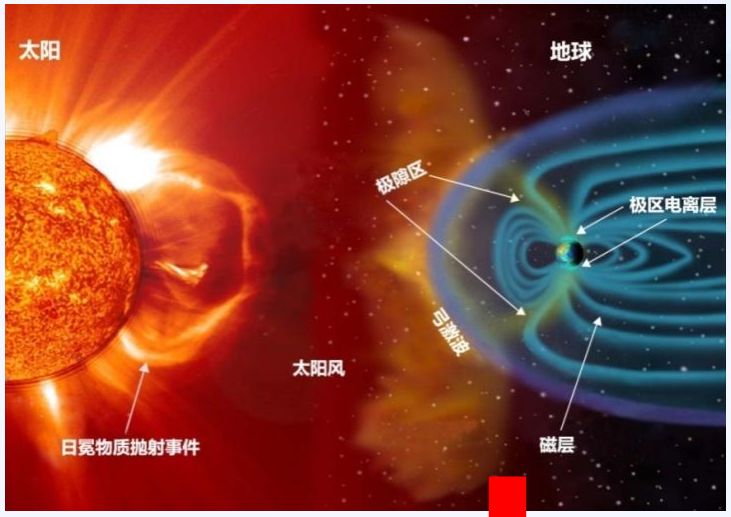
Gravitational Wave Detection

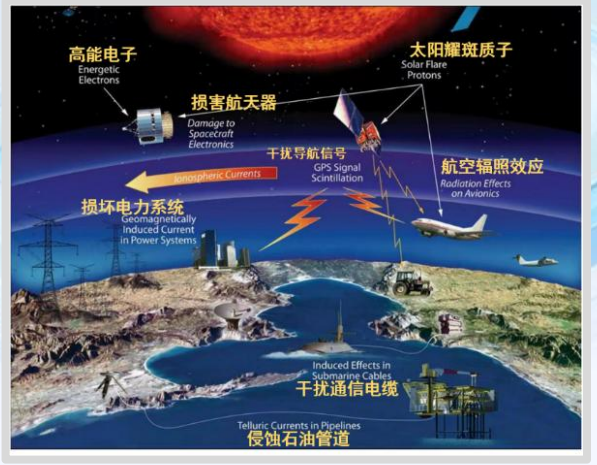
From the Sun to the Atmosphere, why?

A full-chain, three-dimensional monitoring network from "external input" to "internal response" is a strategic requirement for addressing climate change, space security, and environmental challenges.

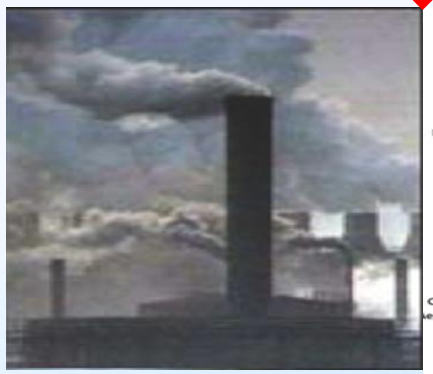


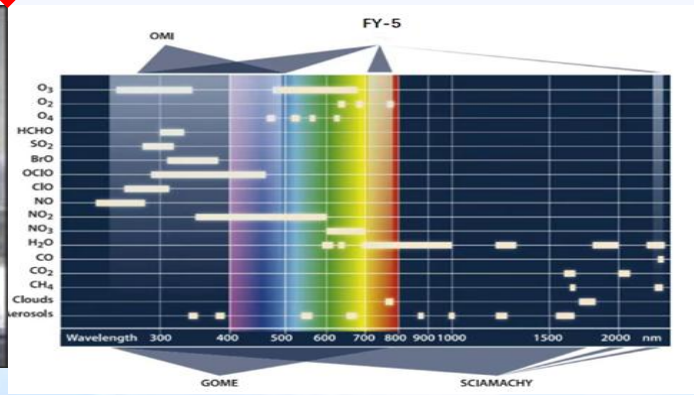
- **Fundamental energy input for climate models**
- **Baseline data for Earth's energy budget**





- **Protects communication, navigation, and space assets**
- **"Space-based early warning"**



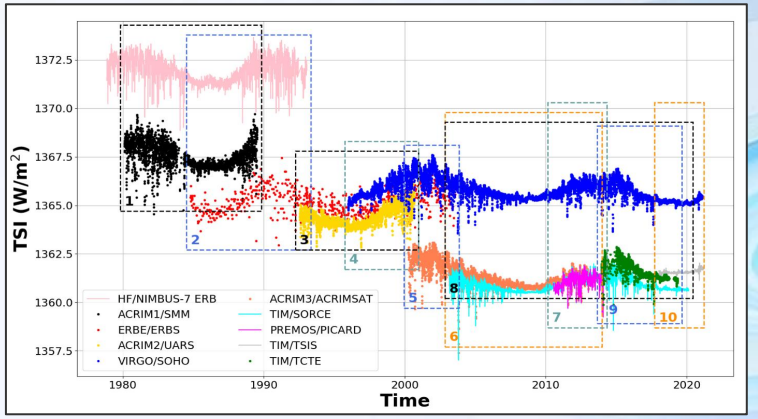


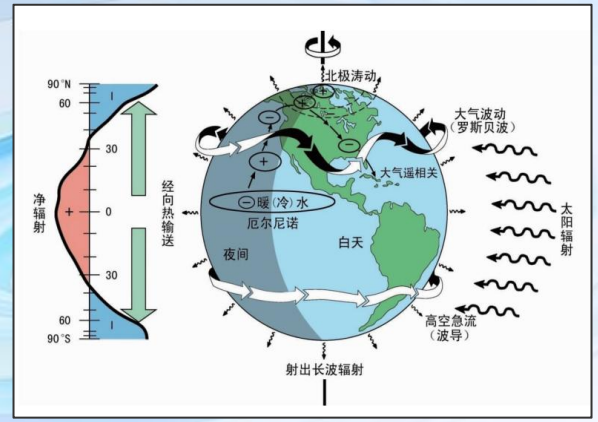
- **Supports "carbon neutrality" goals**
- **Reveals solar-climate chain effect**

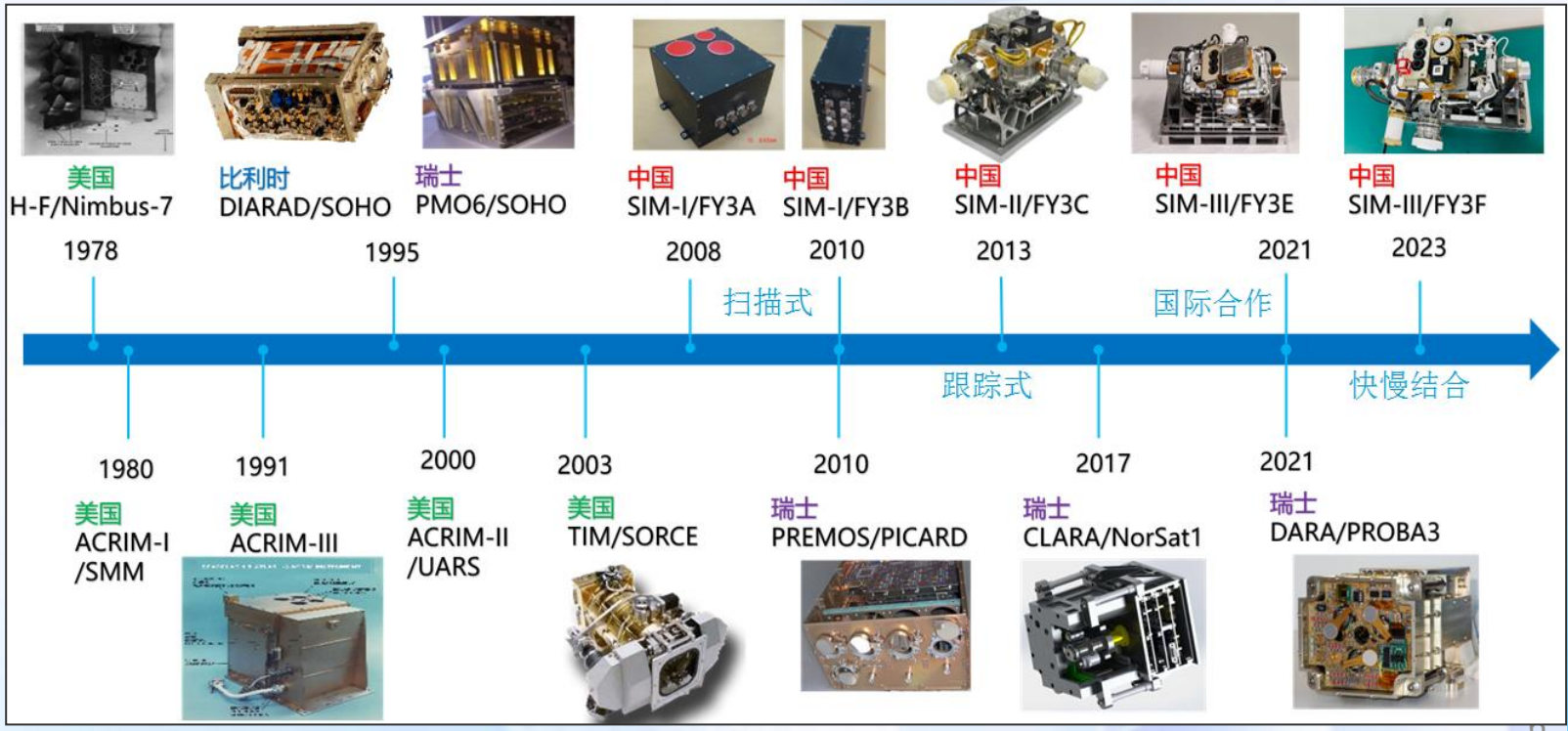
Fengyun Satellite Optical Payload Development:
Solar Radiation Monitoring Payloads

Our Evolution Path:

- FY-3A/B: Wide-field Scanning
- FY-3C: Active Tracking
- FY-3E: International Cooperation
- FY-3F: Sun-Earth Synchronous
- FY-3J: 80K Cryogenic Observation



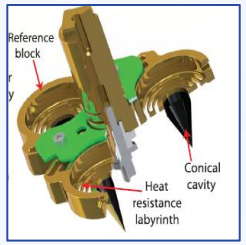


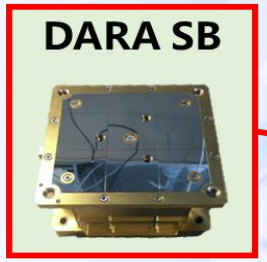


Fengyun-3E Satellite - Solar Radiation Monitor

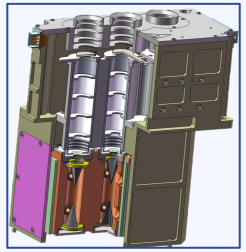
SIM/FY-3E was launched in 2021, jointly developed with PMOD/WRC of Switzerland, adding the Swiss DARA radiometer. For the first time, it achieved co-platform, synchronous monitoring of total solar irradiance changes with different types of radiometers from two countries.

- **I. Main Instrument Composition:**
- Three-channel SIAR absolute radiometer
- Three-channel DARA absolute radiometer
- 2-axis pointing gimbal
- Digital sun sensor
- Electronics control box

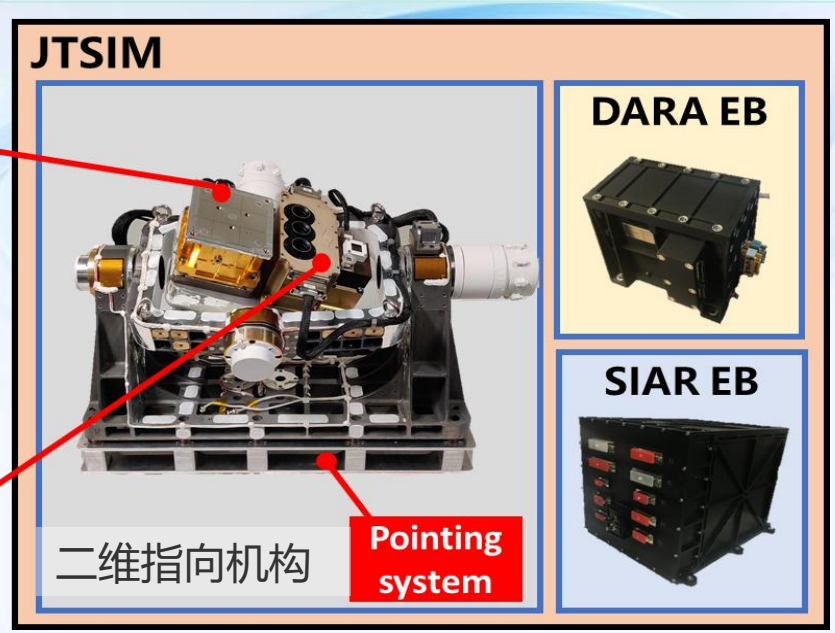




Swiss DARA Radiometer



SIAR Radiometer



- **II. Main Performance :**
- Spectral range: 0.2~20μm
- Measurement sensitivity: ≤0.05W/m^{-2}
- On-orbit stability: ≤0.01%/year
- Total solar irradiance calibration accuracy: ≤0.1%
- Sun tracking accuracy: <0.1°

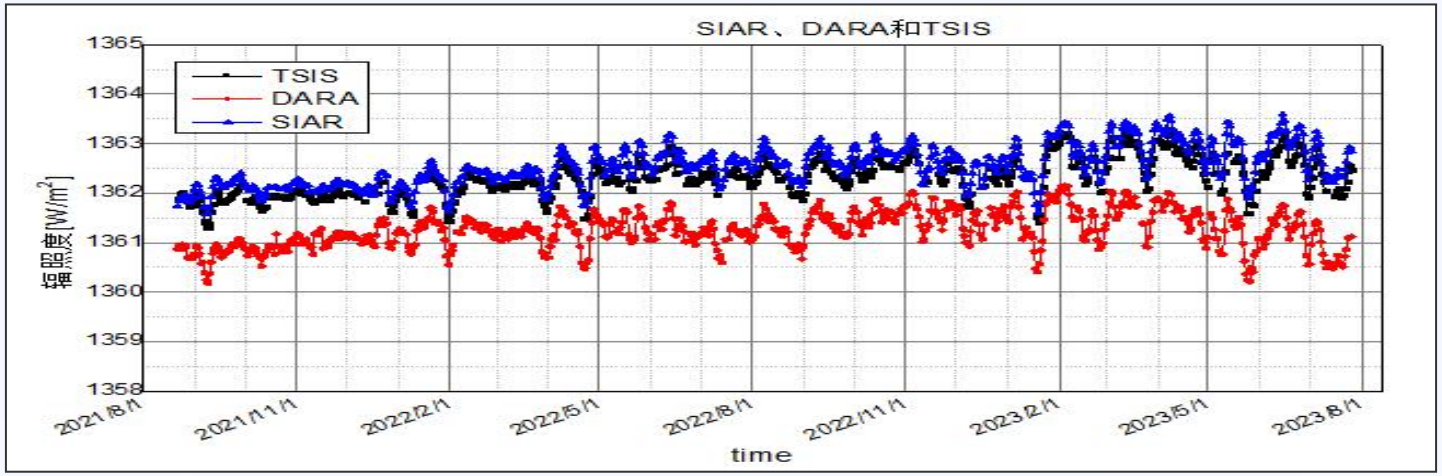
- **III. Key Breakthrough :**
- Three-channel integrated absolute radiation detector design
- Fast measurement algorithm, single observation time significantly shortened from 8 min to 2 min, achieving synchronous measurement with DARA
- On-orbit channel degradation auto-correction technology, reducing the impact of degradation by 50%

Fengyun-3E Satellite - Solar Radiation Monitor

- Calibration model traceable to SI units, established in cooperation with Switzerland

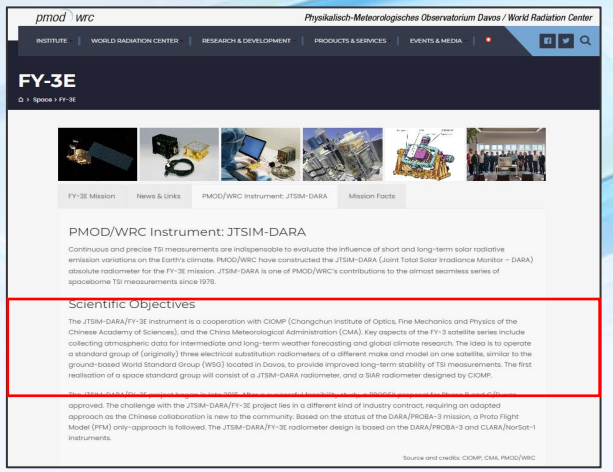
$$\mathbf{TSI} = (\mathbf{E} - \mathbf{E_b}) \cdot \mathbf{f}_{AU} \cdot \mathbf{f}_{\mathbf{pointing}} \cdot \mathbf{f}_{WRR} \cdot \mathbf{f}_{DA} \cdot \mathbf{f}_{\mathbf{T}} \cdot \mathbf{f}_{\mathbf{de}} \cdot \mathbf{f}_{\mathbf{dopp}} \cdot \mathbf{f}_{WRR-SI}$$

- On-orbit Performance

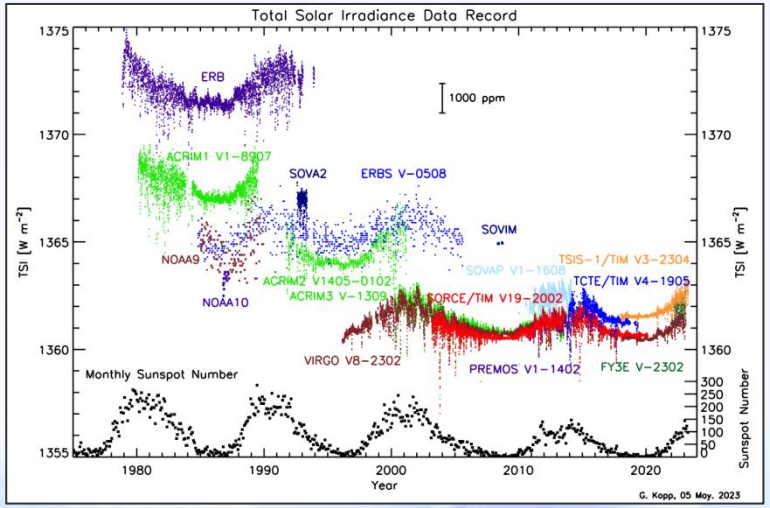


- SIAR calibration accuracy 0.018%, on-orbit stability 0.005%
- DARA calibration accuracy 0.07%, on-orbit stability 0.008%
- Consistency of relative variation with USA's TSIS is better than 0.01%

- PMOD/WRC: Established the first space-based reference group, significantly improving the long-term measurement stability of TSI.

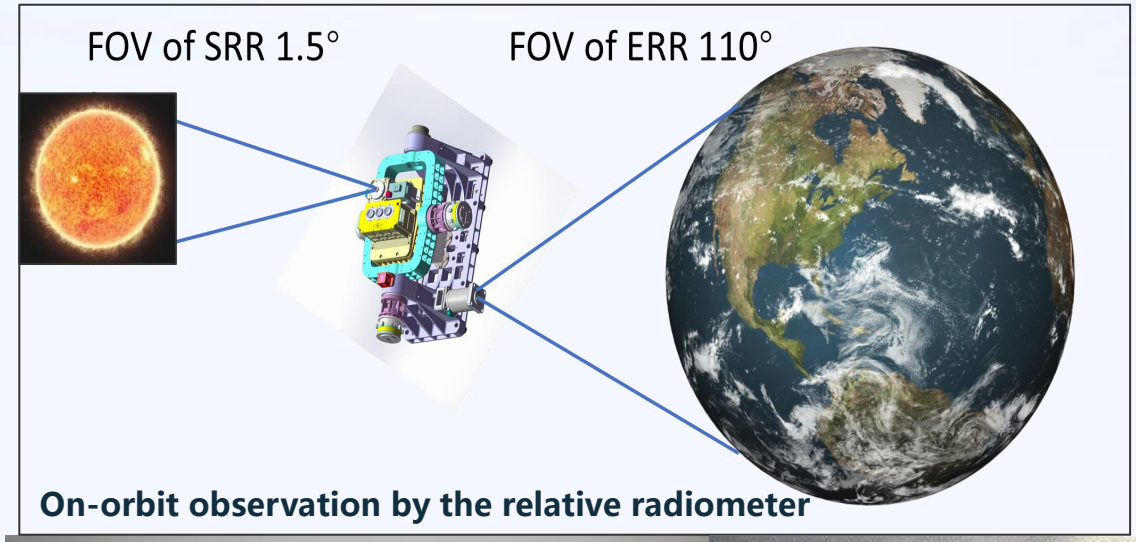


- FY-3E data has been included in the world's TSI observation series



Fengyun-3F Satellite - Solar Radiation Monitor

SIM/FY-3F was launched in 2023, adding a new planar-type relative radiometer. It is equipped for synchronous observation with a Solar Relative Radiometer (SRR) channel and an Earth Relative Radiometer (ERR) channel, providing support for research on Earth's radiation budget balance.



On-orbit observation by the relative radiometer

Main Performance :

- **Spectral range: 0.2~20μm**
- **Measurement sensitivity: ≤0.05W/m^{-2}**
- **On-orbit stability: ≤0.01%/year**
- **Total solar irradiance calibration accuracy: ≤0.1%**
- **Sun tracking accuracy: <0.1°**

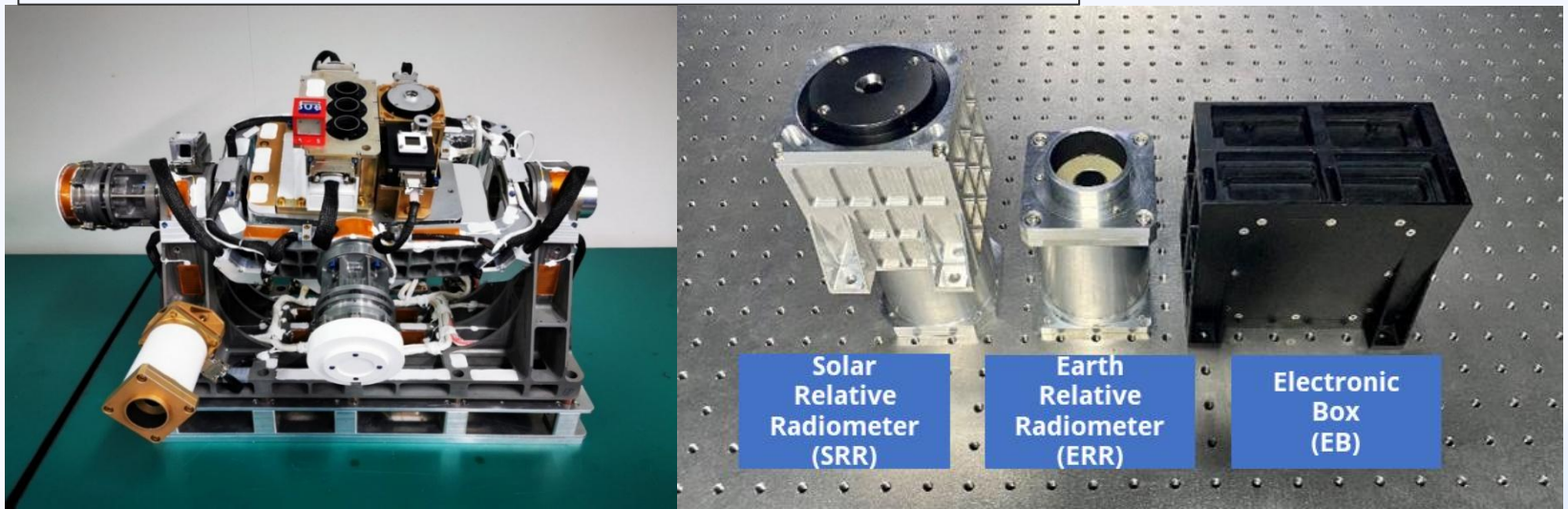


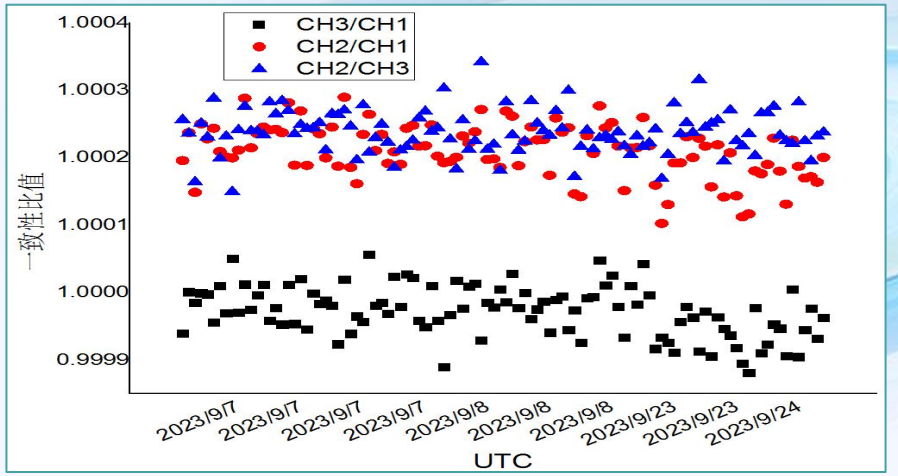
Photo of the relative radiometer

Fengyun-3F Satellite - Solar Radiation Monitor

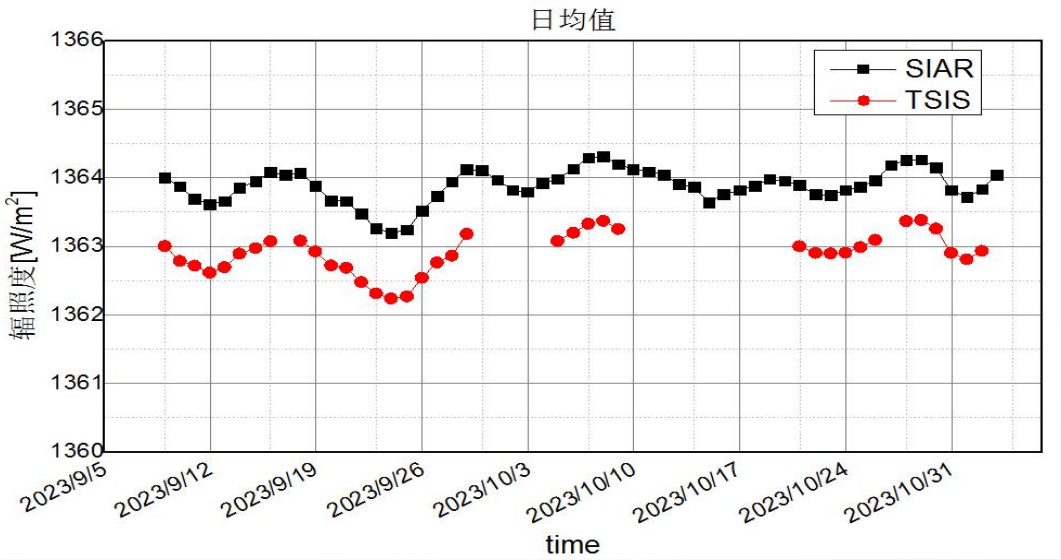
- **On-orbit Self-Traceable Calibration**

$$TSI = (E - E_b) \cdot f_{AU} \cdot f_{pointing} \cdot f_{di} \cdot f_{DA} \cdot f_T \cdot f_{de} \cdot f_{dopp} \cdot f_{CH}$$

- **High-Precision Channel Consistency: the consistency between channels reached 99.95%.**

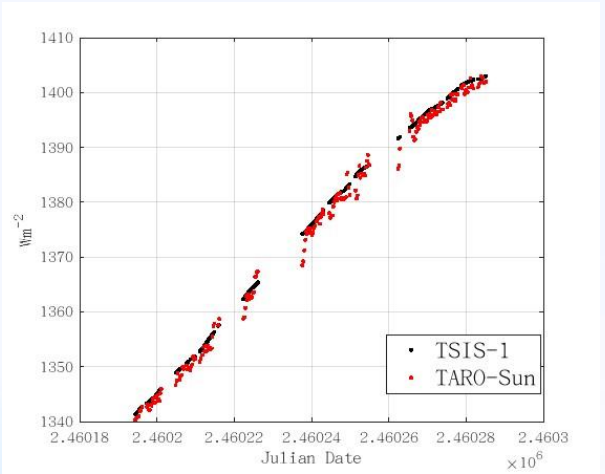


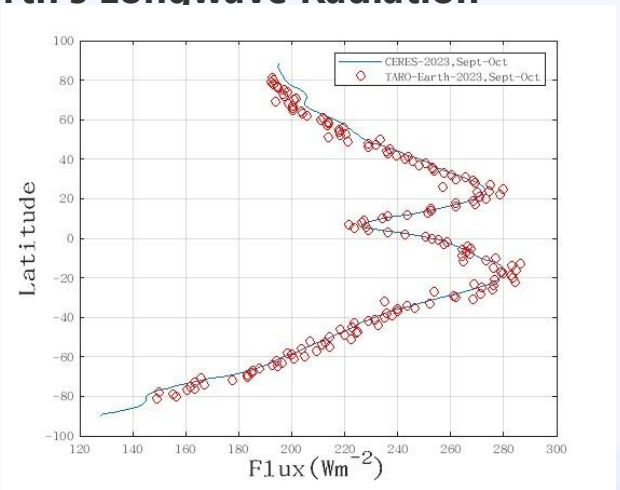
- **On-orbit Comparison (1): Total Solar Irradiance**



0.04% consistency with USA's TSIS data

- **On-orbit Comparison (2): Earth's Longwave Radiation**





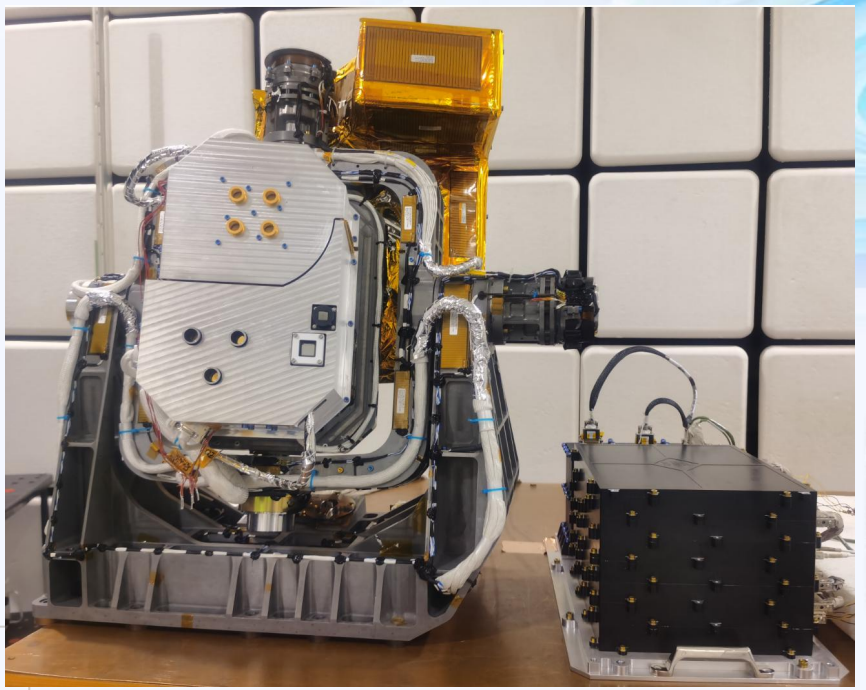
0.2% consistency with USA's CERES data

Fengyun-3 J Satellite： Solar Radiation Monitor (Under Development)

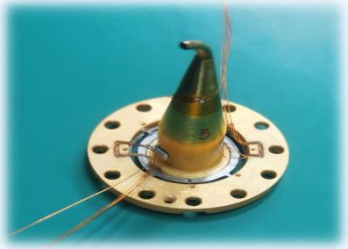
- A new 80K cryogenic radiometer is added to reduce measurement thermal noise, improve measurement accuracy, and capture the true variations in Total Solar Irradiance.
- The development of the qualification model is complete. Scheduled for launch in 2026, it will become the world's first space-based cryogenic radiometer.

I. Instrument Composition

- Three-channel SIAR ambient-temperature radiometer
- Four-channel CAR cryogenic radiometer
- Pulse tube cryocooler



Cryogenic Radiometer and Cryocooler



Cryogenic Detector

II. Main Performance

- Measurement Accuracy: ≤0.1%
- Three-channel Consistency: ≤0.1%
- Cryogenic Temperature Range: 80K - 93K
- On-orbit Long-term Stability: ≤0.01%/year

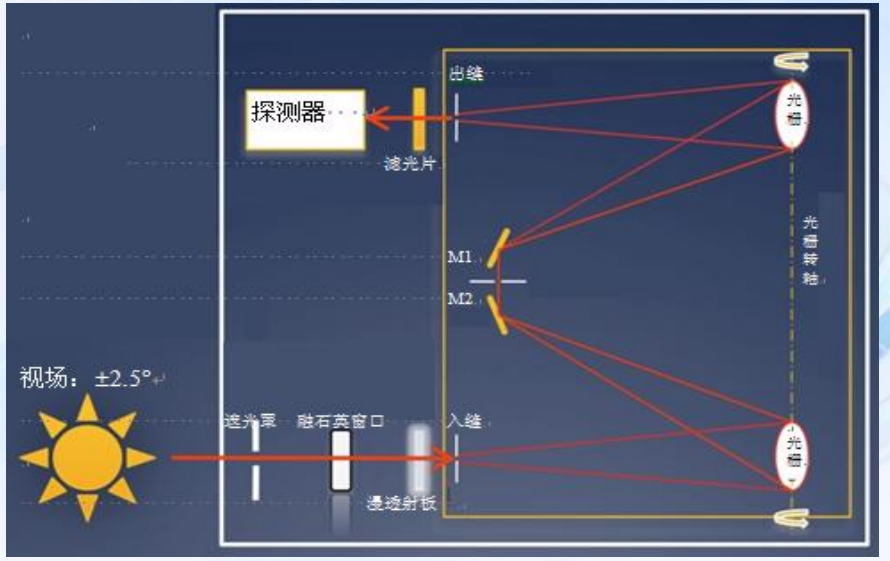
III. Key Breakthrough

- High-absorptance 80K cryogenic detectors
- High-efficiency space pulse tube cryocooler.

Fengyun-3E Satellite： Solar Irradiance Spectrometer

Mission: Measure Solar Spectral Irradiance (SSI)

- the Sun's energy distribution by wavelength.

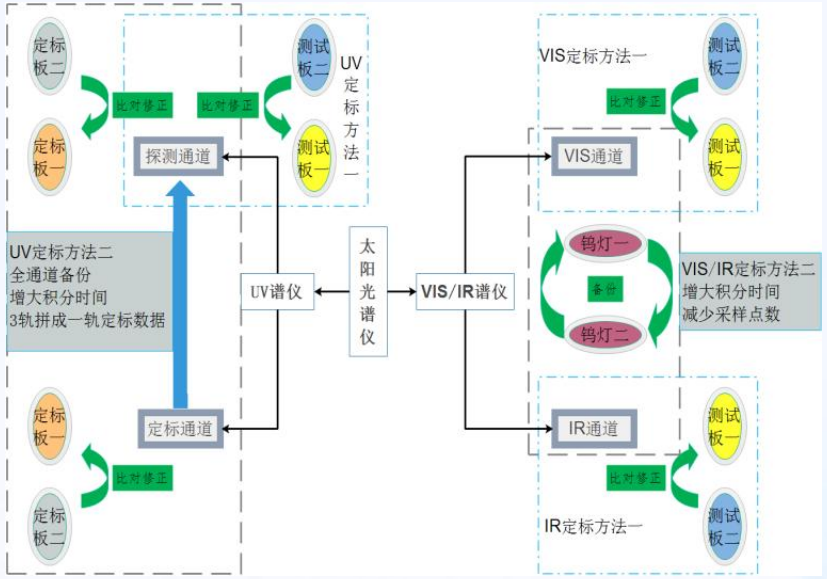


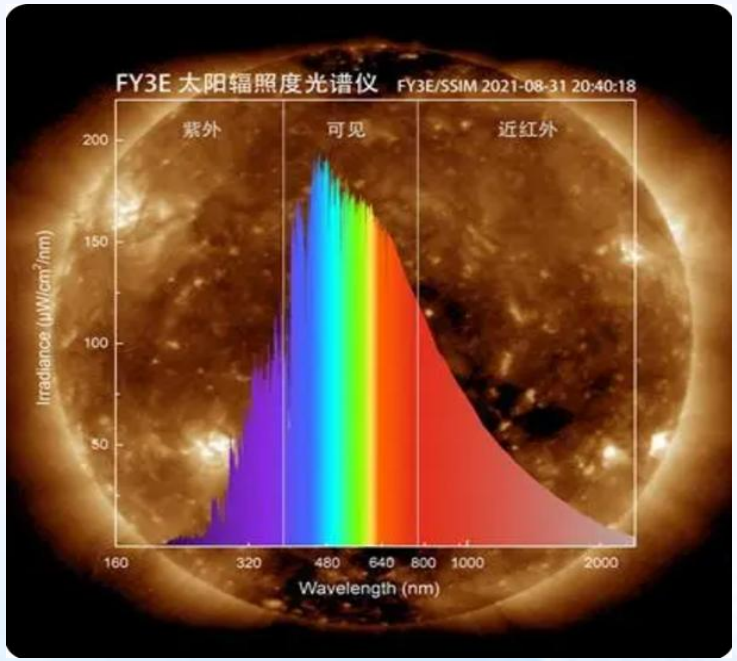
Key Technologies

(1) Compact tandem spectrometer design and assembly technology;

(2) High-precision, wide-dynamic-range spectral detection technology;

(3) High-stability on-orbit radiometric calibration technology;





Key Indicators:

- **Spectral Range:** 165 nm – 2400 nm
- **Absolute Calibration Accuracy: ≤ 2% ~ 3%**
- **Stability:** ≤0.2%/year
- **Dynamic Range:** 10^5

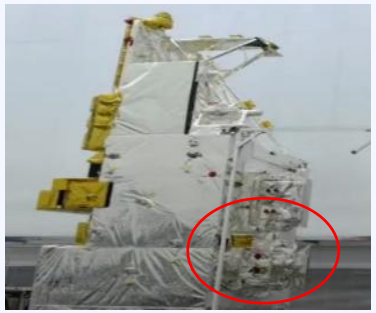
Space Weather Payloads

To meet the demands for operational space weather monitoring, Solar X-ray and Extreme Ultraviolet (X-EUV) and Wide-field Auroral Imager (WAI) detection technologies have been independently developed. Starting with the Fengyun-3D satellite, continuous observation of space environment elements such as solar activity, geomagnetic storms, and ionospheric weather has been achieved, providing crucial data support for China's space weather forecasting and warning systems.

2017年

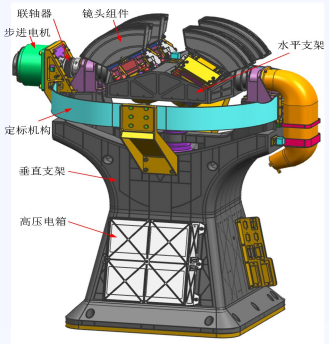
FY-3D WAI

2021年



FY-3E XEUV

2025年



FY-3H WAI

2025年

FY-4C EUVI

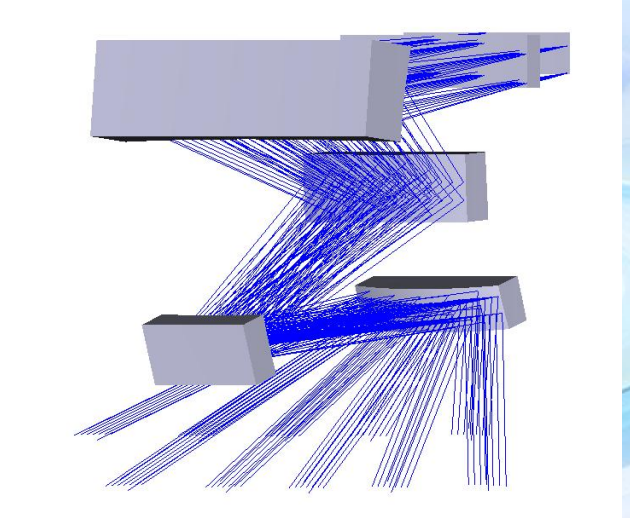
2026年

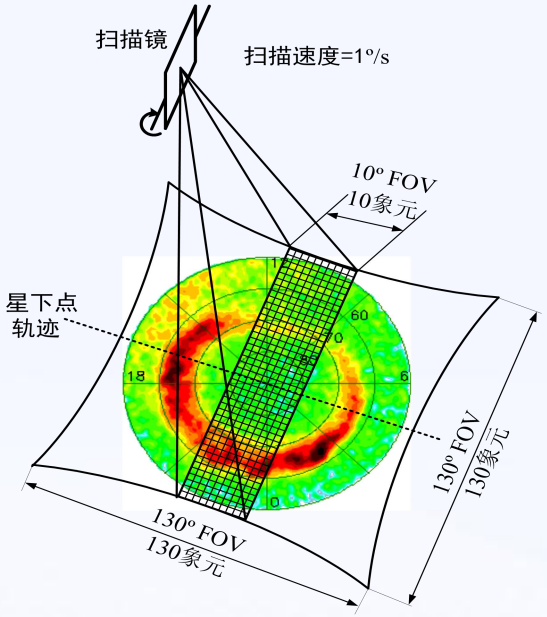
FY-4D EUVI

Fengyun-3D Satellite : Wide-Field Auroral Imager

Instrument Features:

- **Key Method: Dual-lens stitching achieves a combined FOV, which is then extended by one-dimensional scanning.**
- **Operating Wavelength: 140 nm to 180 nm (FUV band)**



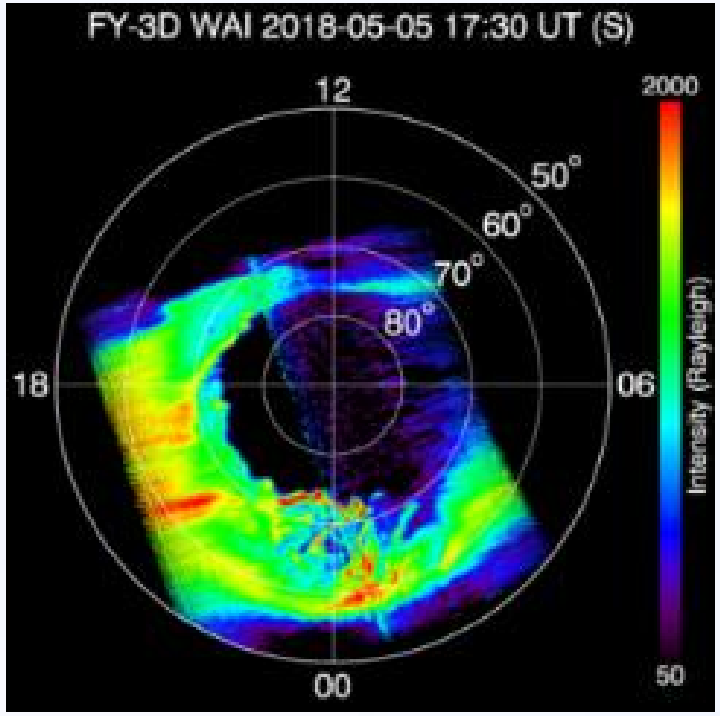


Key Specifications:

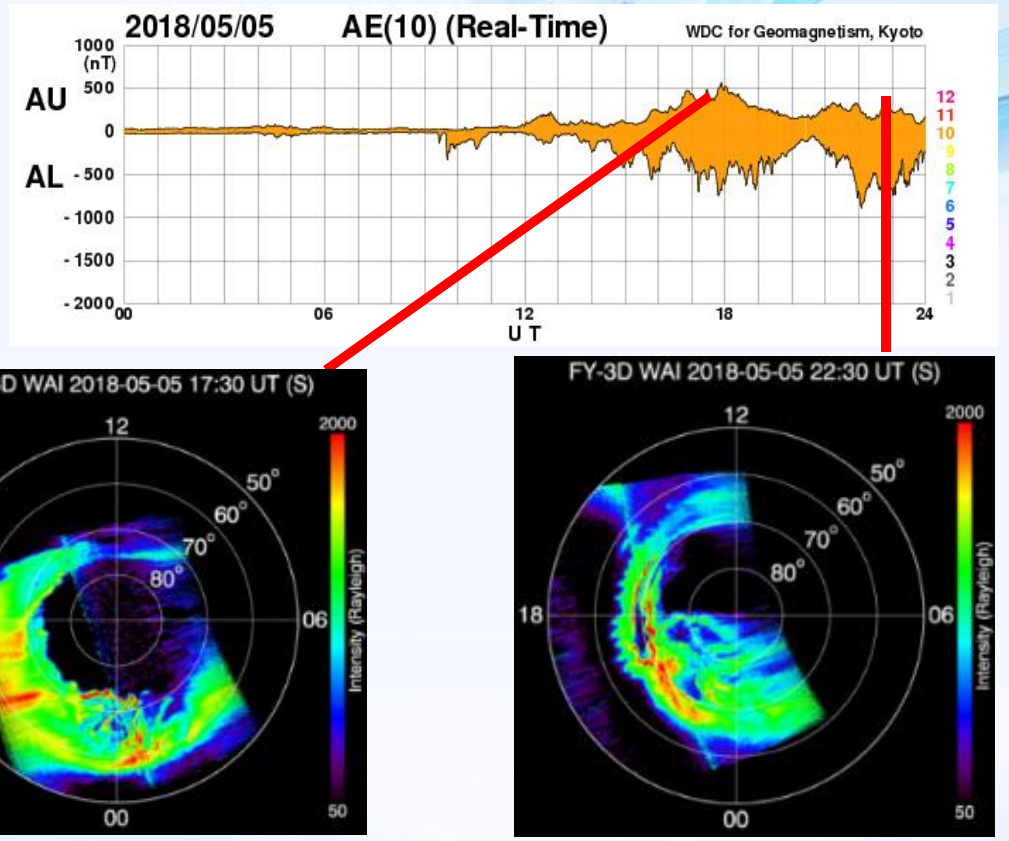
- **Observation Type:** 140nm-180nm scanning imaging observation
- **Detection Intensity Range:** 10R ~ 10^4R (Rayleigh)
- **Detection Sensitivity:** 0.007 cps/R (counts per second per Rayleigh)
- **Out-of-band Rejection Ratio:** 1000
- **Field of View (FOV):** 130° × 130° (Scanning)
- **Sub-satellite Point Resolution:** 10 km
- **Frame Rate:** 2 min

Fengyun-3D Satellite : Wide-angle Auroral Imager

The Wide-angle Auroral Imager acquires image data of the Earth's auroral oval while in orbit. Based on the auroral oval's radiation intensity distribution and an algorithm for extracting the auroral oval's boundary position, it performs geomagnetic substorm forecasting by analyzing the trends in auroral intensity and boundary changes from continuous observation data.



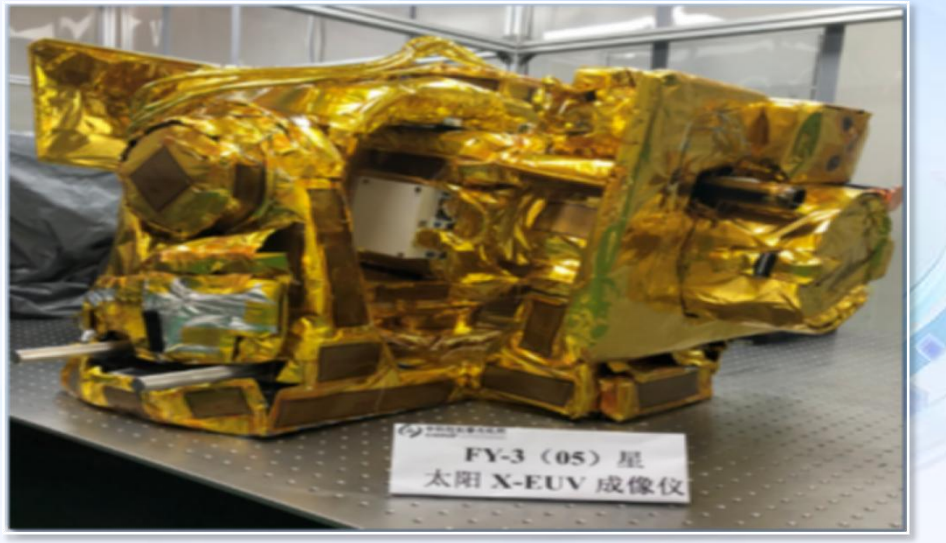
Observed Auroral Oval Image

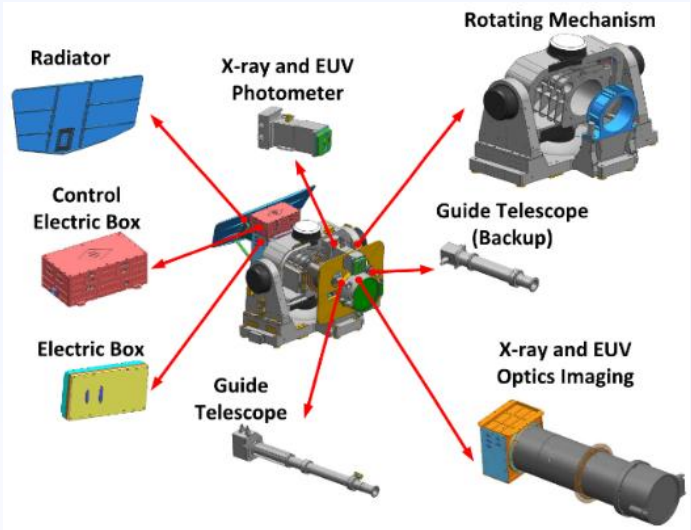


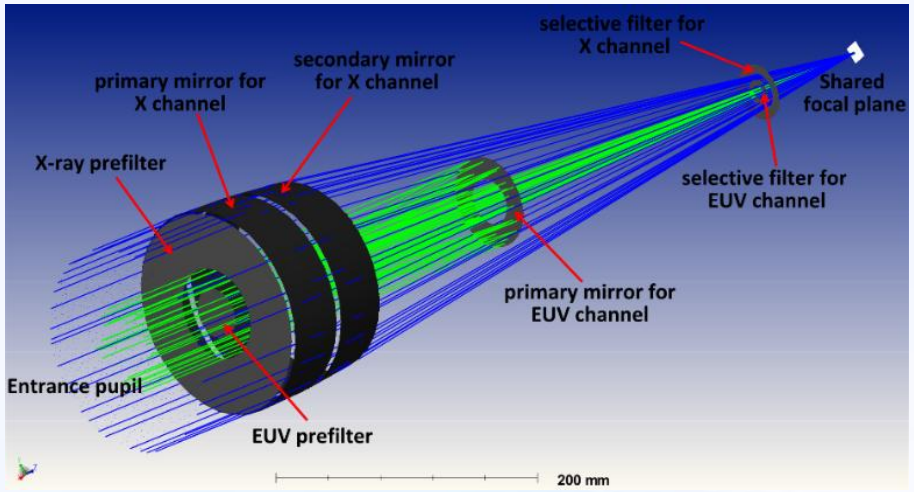
Comparison of Auroral Oval Images with International Geomagnetic Indices

Fengyun-3E Satellite: Solar X-EUV Imager

- Key Tech 1: Dual-band compound optical system
- Key Tech 2: High-precision sun-tracking mount
- Key Tech 3： High-Precision Solar Image Stabilization







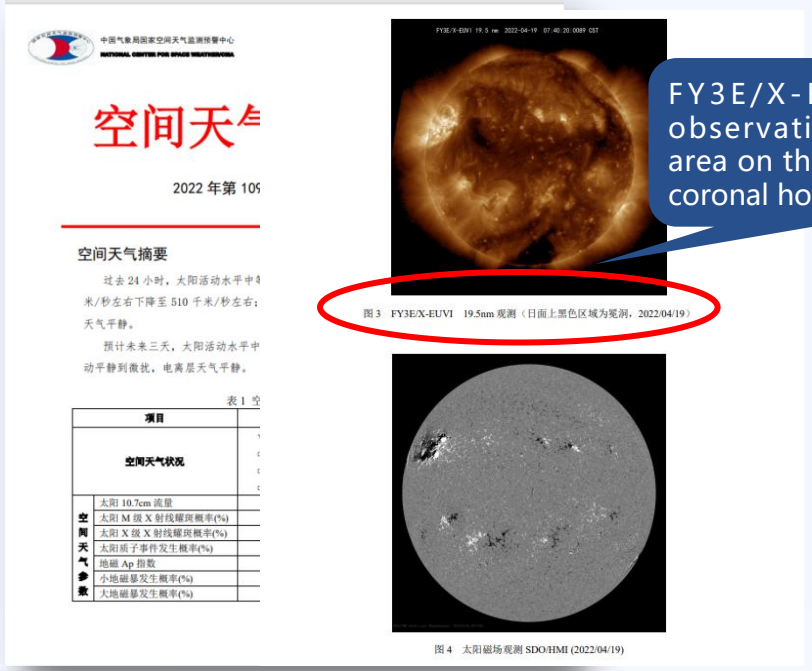
Instrument Composition

Main Specifications:

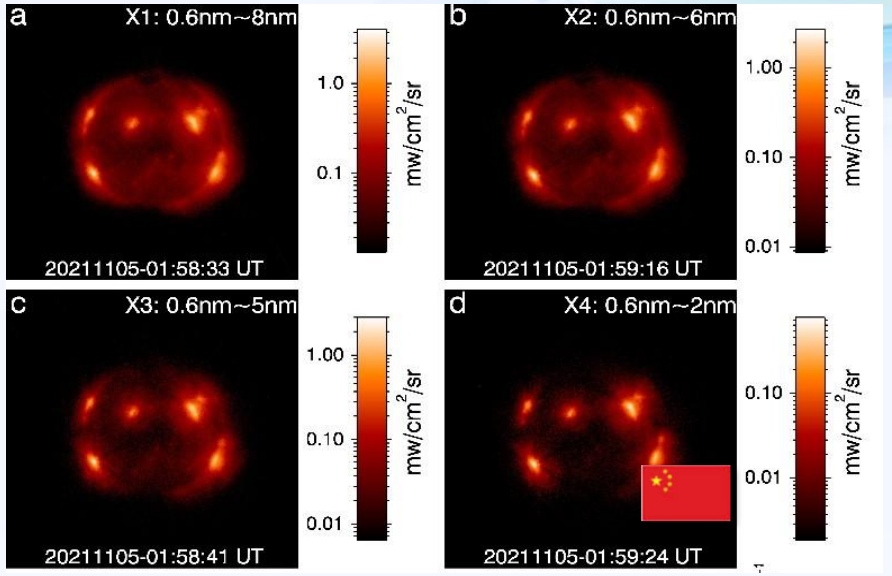
- Imaging channels: 6 X-ray channels, 1 EUV channel
- Spatial resolution: 2.5" (arcseconds)
- Spectral bandwidth: 1.0nm
- Field of View: 42' (arcminutes)

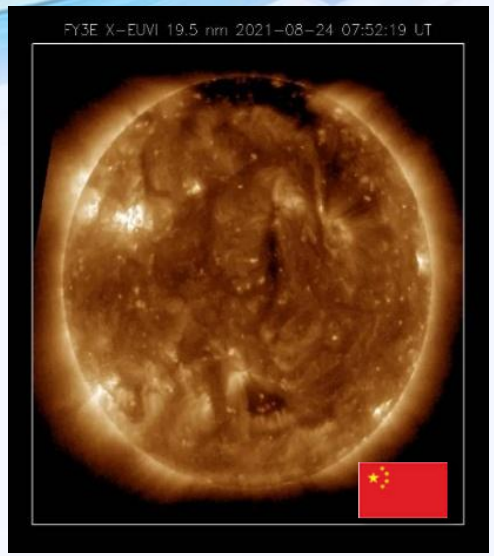
Fengyun-3E Satellite: Solar X-EUV Imager

- Conducts long-term, continuous, high-temporal-resolution imaging observations of the full solar disk and low corona in the X-ray and extreme ultraviolet (EUV) bands.
- Integrated into the operational system of the National Space Weather Monitoring and Warning Center to forecast space weather.



National Space Weather Monitoring and Warning Space Weather Analysis Report

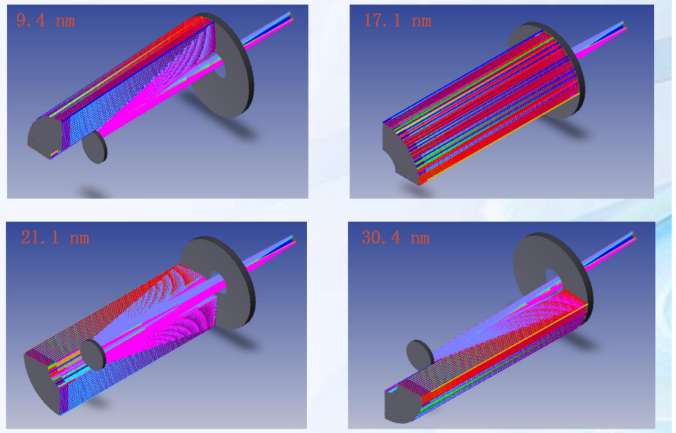


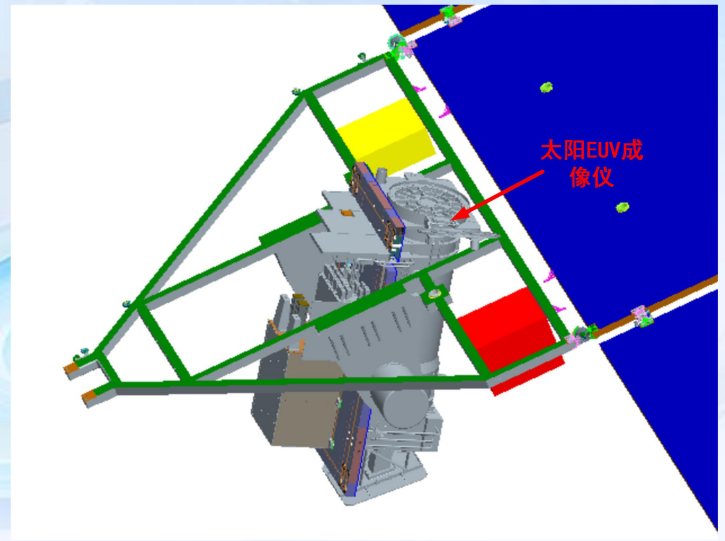


X-ray images and extreme ultraviolet images

Fengyun-4C/D Satellite: Solar EUV Imager

- **Platform:** FY-4C/D Geostationary Satellite
- **Key Method: One optical system, one detector** with **Four-band partitioned mirror coating**.
- **Wavebands: 9.4nm, 17.1nm, 21.1nm, and 30.4nm**.
- **Advantage: Continuous, high-temporal-resolution** imaging of the Sun
- Launch: C 2025, D 2026





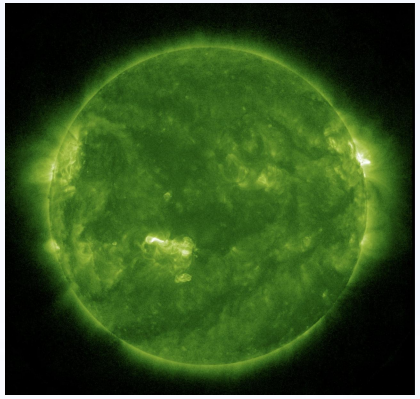
Specification	Value
Wavelength Bands	Fe XVIII 9.4nm 、Fe IX 17.1nm 、Fe XIV 21.1nm、He II 30.4nm
Reflecting Mirror	Multilayer film - microcrystalline substrate
Field of View	42×42 arcminutes
Resolution	3.5 arcseconds
CMOS Detector	2048×2048
Temporal Resolution	5s

Solar Extreme Ultraviolet Imager

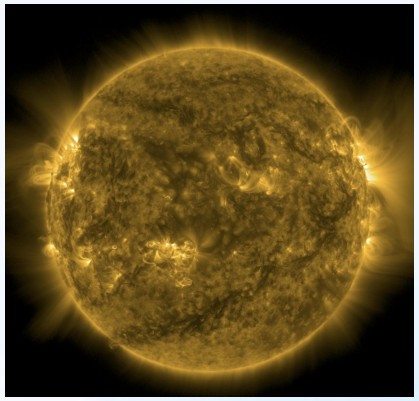
Fengyun-4C/D Satellite: Solar EUV Imager

Key Application: Multi-layer monitoring for hazardous space weather warnings

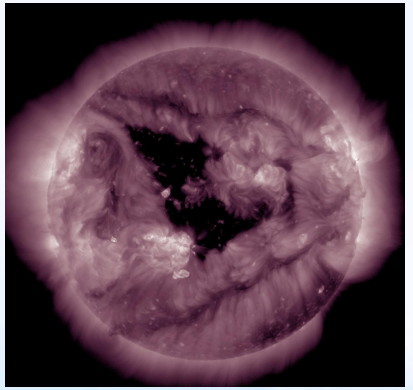
Wavelength Band	Response Temperature	Observation Area
9.4nm/10.8nm	Approx. 6.7 million degrees	1. Core regions of active areas, plasma heated during flare processes; 2. CME current sheets, high-temperature magnetic ropes, and other high-temperature structures.
17.1nm/17.4nm	Approx. 1 million degrees and partial transition region temperatures	1. Coronal structures with relatively lower temperatures such as coronal holes and active regions; 2. Monitoring activities like filaments/prominences, jets, etc.
21.1nm	Approx. 1.8 million degrees	1. Typical coronal structures such as coronal holes, active regions, etc.; 2. Flare loops, coronal dimming caused by CMEs, and EUV waves, etc.
30.4nm	Approx. 50,000 degrees	1. Structures like spicules, network structures, filaments/prominences, etc.; 2. Jets, flare ribbons, flare loops, and CMEs.



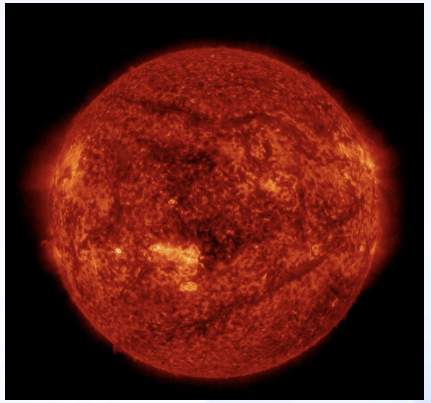
9.4nm



17.1nm



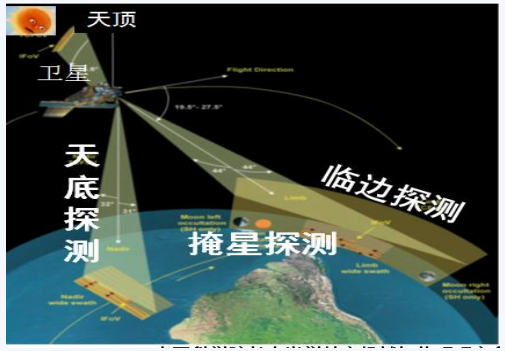
21.1nm



30.4nm

Atmospheric Sensing Payloads

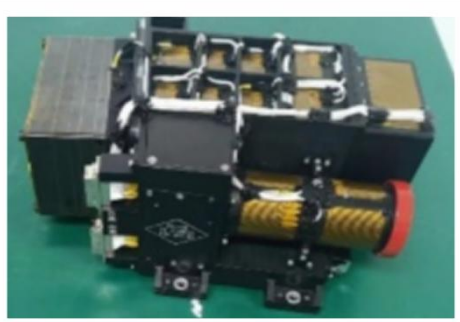
- **Our "Traditional Advantage": 40-year history of development (since 1985)**
- **Provided a wealth of data for atmospheric dynamics research in the upper troposphere and stratosphere**
- **Major Payloads Include: Tiangong-2 Ultraviolet Limb Imaging Spectrometer 、 Fengyun-3 Ultraviolet Limb Ozone Profile Sounder**



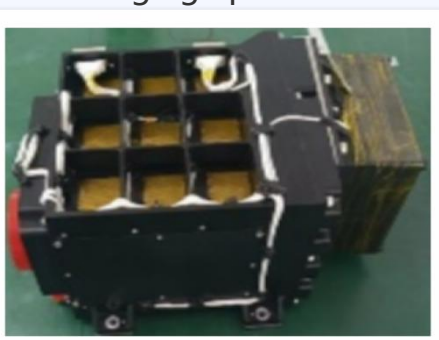
Tiangong-2 Ultraviolet Limb Imaging Spectrometer

Tiangong-2 Ultraviolet Annular Imaging Spectrometer

Ultraviolet Hyperspectral Ozone Sounder (Limb)



Limb XX Payload1

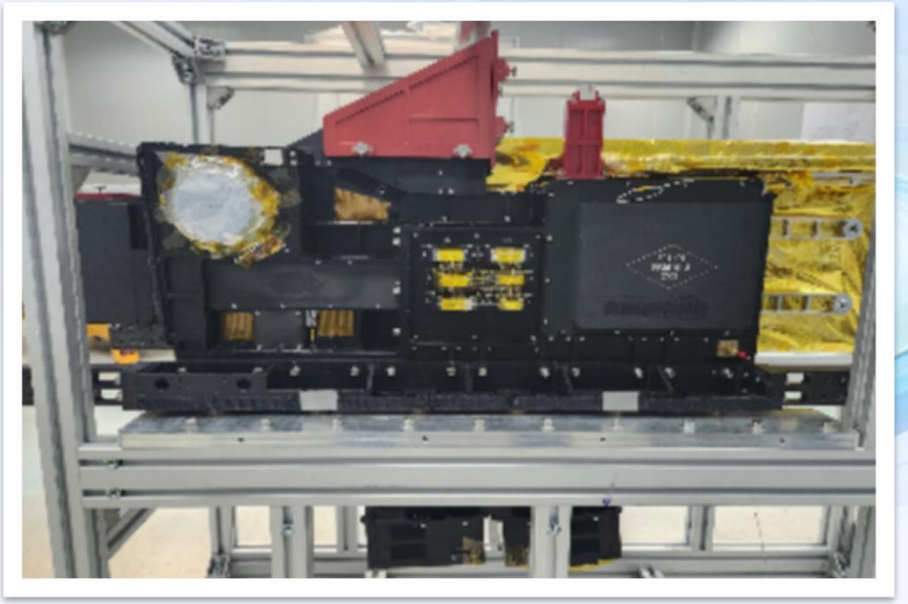


Limb XX Payload2

Fengyun-3F Satellite: Ultraviolet Hyperspectral Limb Imager

Major Breakthrough: China's FIRST Operational UV Hyperspectral Limb Imager

- **Mission: Detect trace gases O_3 , CO, SO_2 , NO_2 , CH_4 , and CO_2**
- **Application: Monitoring pollution and climate change**

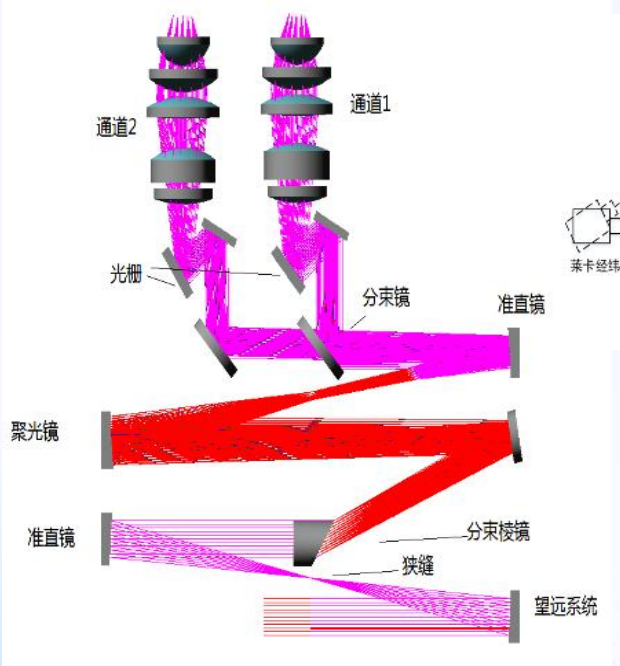


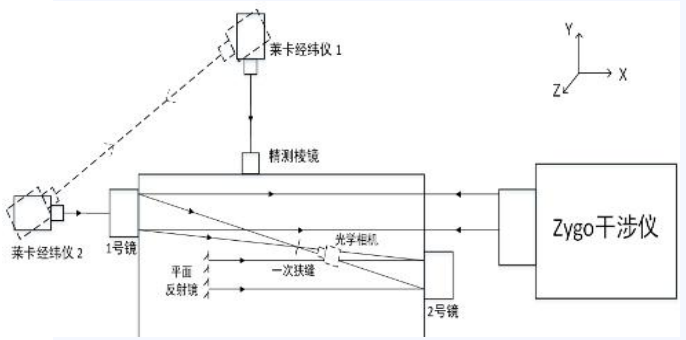
Key Technologies

1.Design and integration of a low F-number aspheric hyperspectral system.

2.Wide dynamic range detection and high-precision pointing.

3.High-precision spectral calibration and on-orbit polarization correction.

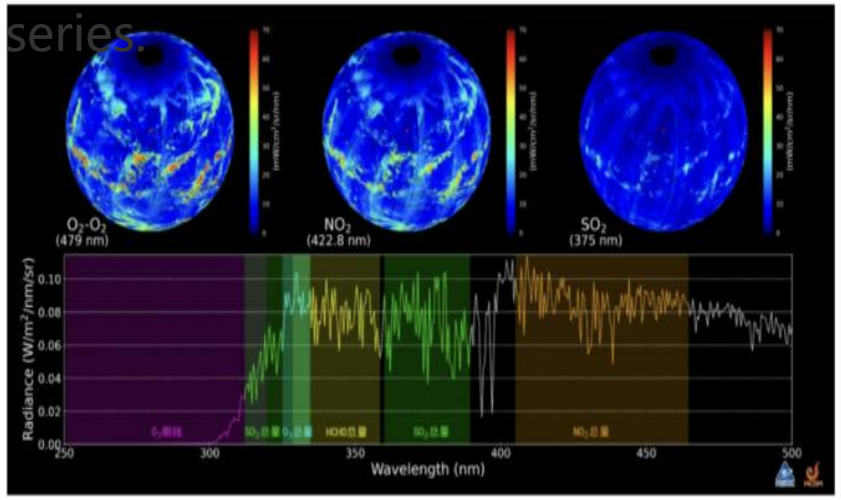




FY-3(06 Satellite) Ultraviolet Hyperspectral Limb Sounder

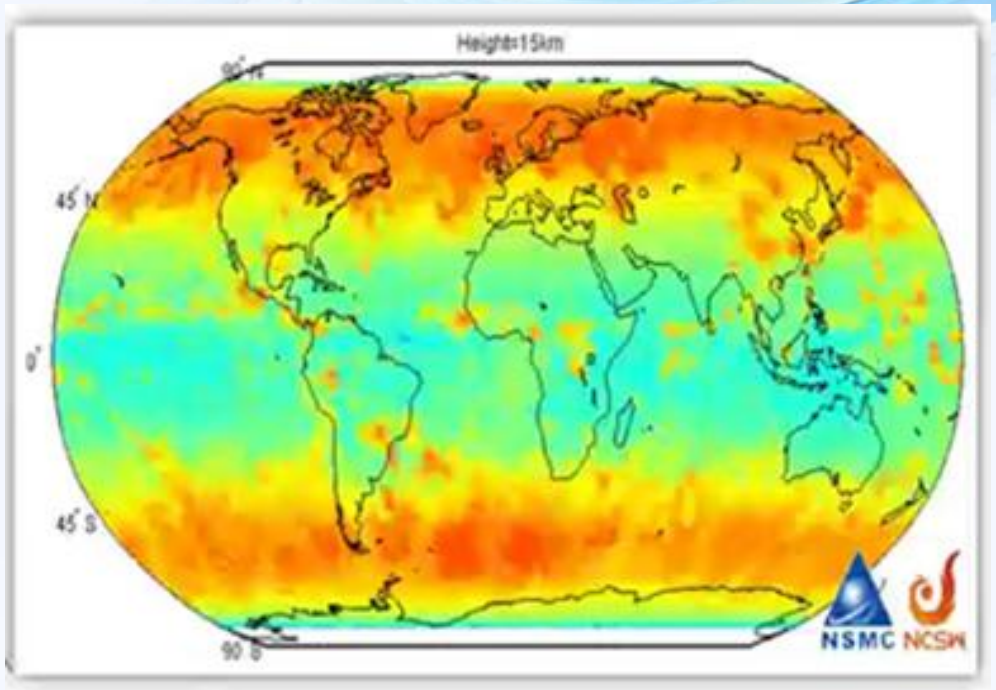
On-orbit Situation:

- **Successfully launched:** August 3, 2023.
- **On-orbit Test Score: 99 points**, a complete success.
- **Reached advanced international level**.
- **Filled a critical gap** for China's Fengyun satellite series.



风云三号F星紫外高光谱大气成分探测 图片来源：国家卫星气象中心

Clearly demonstrates layered detection of atmospheric composition in the stratosphere



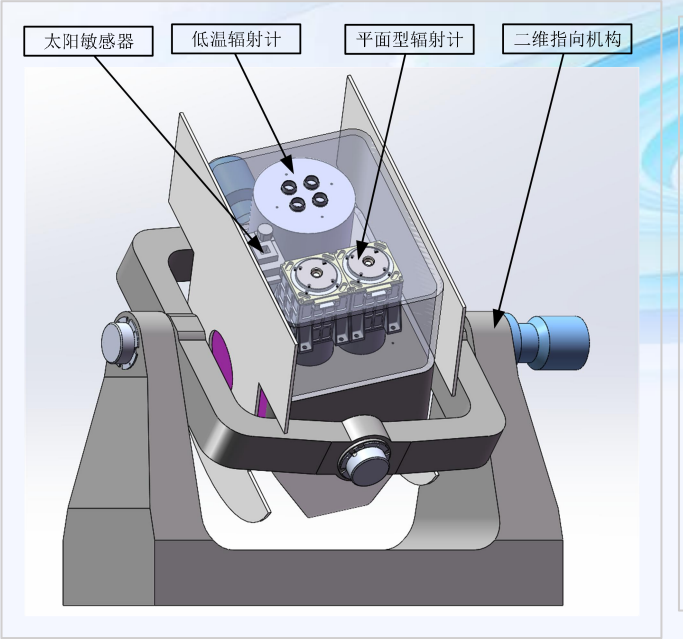
Retrieves the **global vertical distribution** of trace gases, filling a key gap.

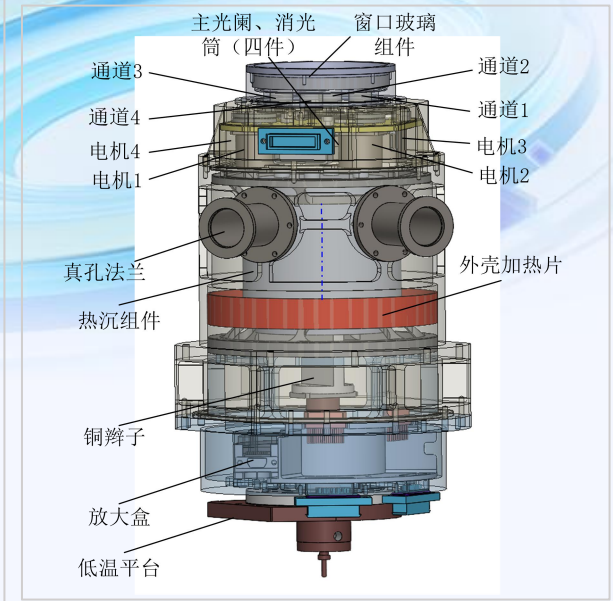
Future Recommended Payload: Fengyun-5 - Total Solar Irradiance Monitor

- **For the first time: A 60K cryogenic radiometer will be used for operational observations.**
- **Goal: Comprehensively enhance measurement accuracy and stability by another order of magnitude.**

I. Performance Indicator Enhancements

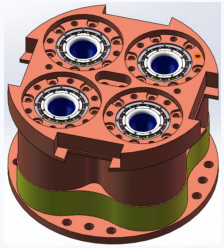
- **Measurement Accuracy:** Improved from ≤0.1% to **≤0.05%**.
- **Long-term Stability:** Improved from ≤0.01%/year to **≤0.005%/year**.
- **Measurement Sensitivity:** Improved from ≤0.05 Wm^{-2} to **≤0.03 Wm^{-2}**.
- **Cryogenic Temperature Range:** Changed from 80K-93K to **60K-69KMaximum**



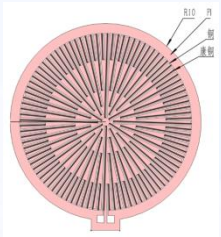


II. Breakthrough Key Technologies

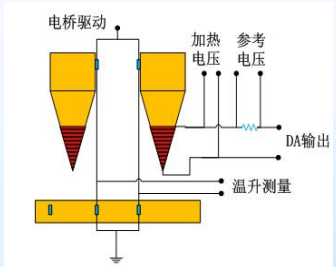
✓ Development of a 60K Deep Cryogenic High-Performance Radiometer



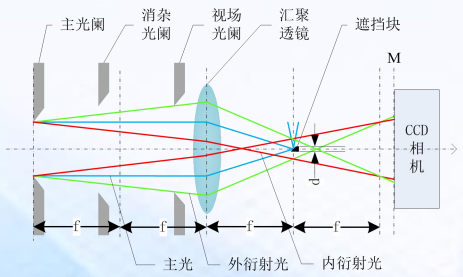
✓ Development of a Fast-Response Planar Detector



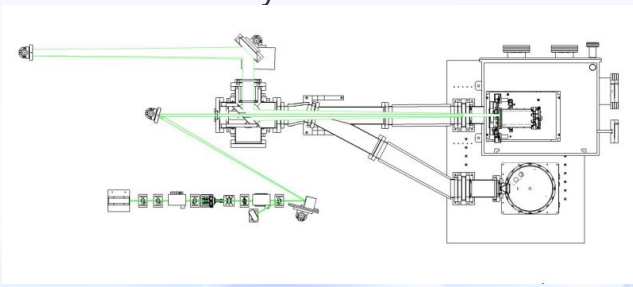
✓ Space-Grade Precision Measurement Electronics



✓ Self-Traceability for Cryogenic Measurement



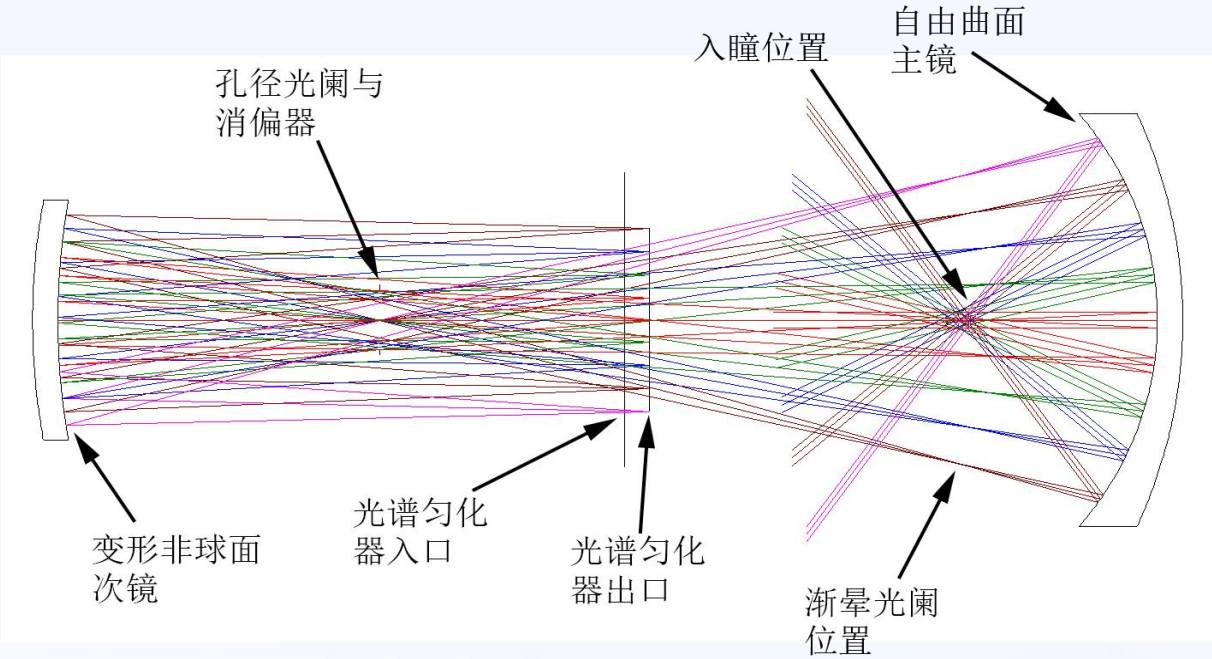
✓ Irradiance Comparison for Traceability to SI Units



Future Recommended: Fengyun-5 Atmospheric Payload

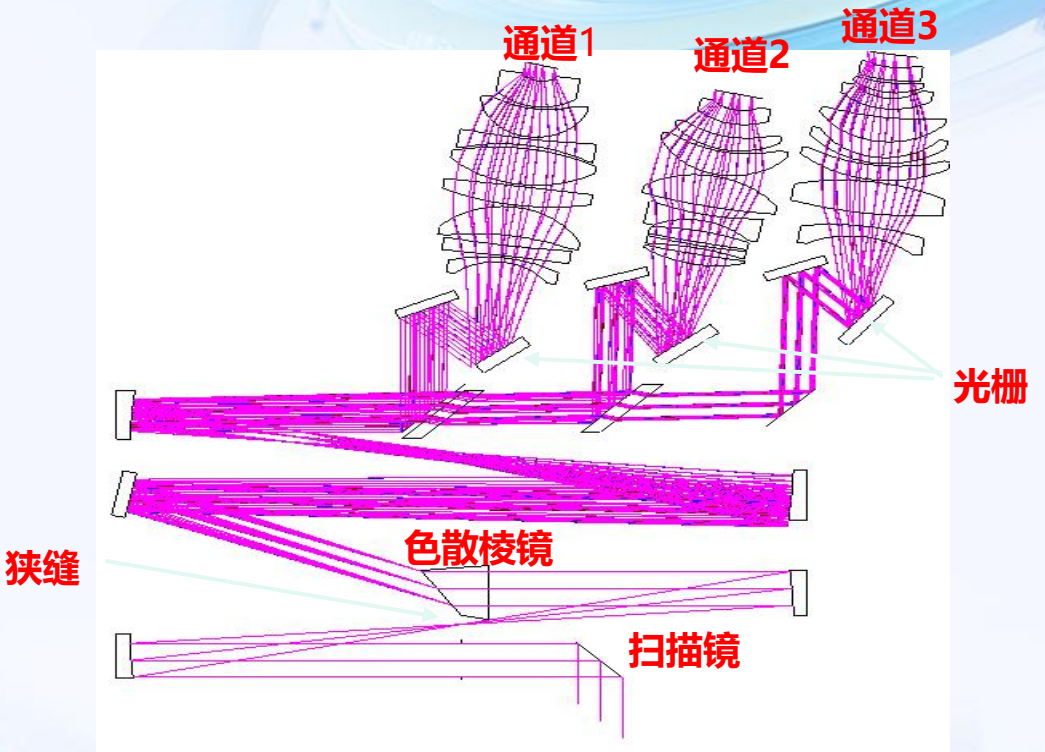
- **A Major Leap: Combining Nadir (Wide Coverage) + Limb (Vertical Detail) for more complete and sensitive atmospheric monitoring**

1. Nadir Payload: Wide Swath Coverage



Nadir Telescope System

2. Lim Payload: High Vertical Resolution



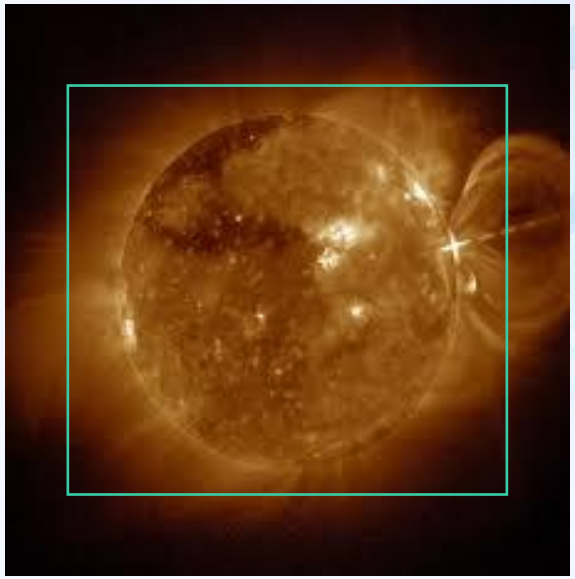
Limb System Structure

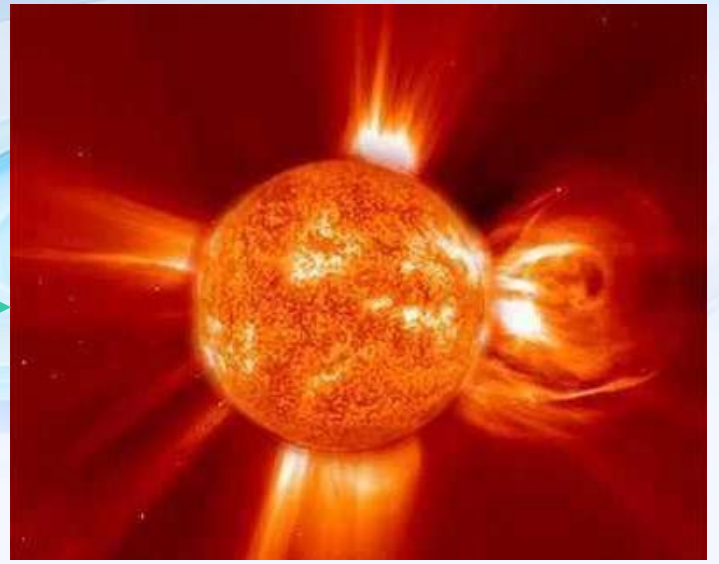
Future Recommended Payload: Fengyun 6 - Large Field-of-View Extreme Ultraviolet Solar Disk and Corona Imager

Identified Deficiencies in Current Instruments

1. Field of View (FOV) Bottleneck: Cannot see the full initial phase of a CME

- **Current (FY-4): 42' FOV** (see green box)
  Problem: CME quickly travels **outside this limited view**
- **Result:** Cannot observe crucial **early development**





- GOES-R SUVI :53′
- FY-3/FY/4： 42′

Cover the near-solar corona out to 2.5 solar radii

2. Lack of Key Wavelengths: Cannot see the source of the eruption clearly.

- **Missing 121.6 nm:** To capture the **initial eruption** of solar flares
- **Missing 28.4 nm:** To track **coronal hole boundaries** (solar wind source)

Technical Indicator	This Project's Payload (Proposed for FY-6)	FY4-03 Satellite	GOES-19 SUVI (USA)
Field of View	> 80 arcminutes	~42 arcminutes	~53.3 arcminutes
Spatial Resolution	≤ 2.5 arcseconds	~3.5 arcseconds	5 arcseconds
Wavelength Configuration (nm)	9.4, 17.1, 28.4, 121.6	9.4, 17.1, 21.1, 30.4	9.4, 13.1, 17.1, 19.5, 28.4, 30.4

Thanks for your attention!