



**SI-Traceable Space-based Climate Observing System
– a CEOS and GSICS Workshop**



Stratospheric high-altitude-balloon-based Demonstration System for Chinese Space-based Benchmark Sensor

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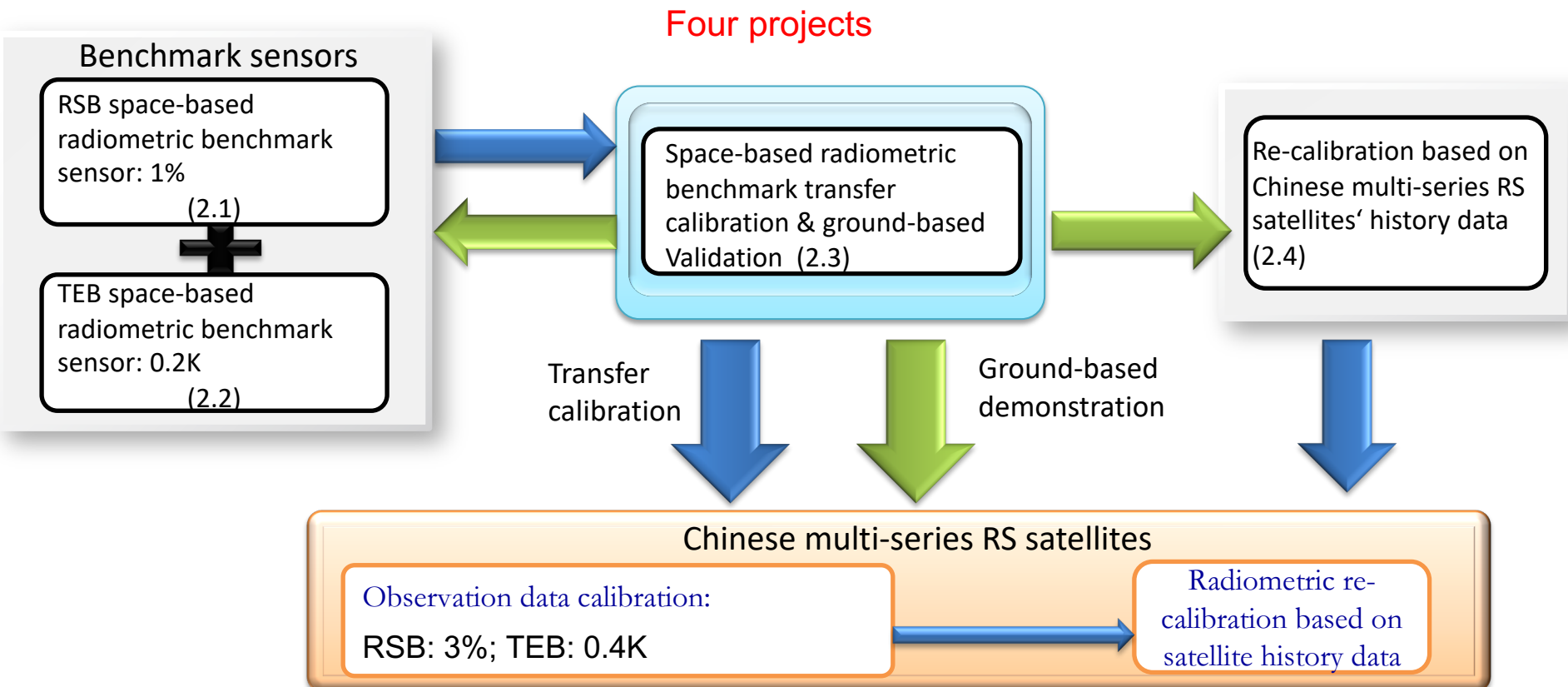
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1. Background



To improve the accuracy of Chinese satellites' radiometric calibration and consistency of RS products, MOST (Ministry of Science and Technology) of China had granted the National Key R&D Program "Space-based radiometric measurement benchmark sensors and transfer calibration" since 2018.

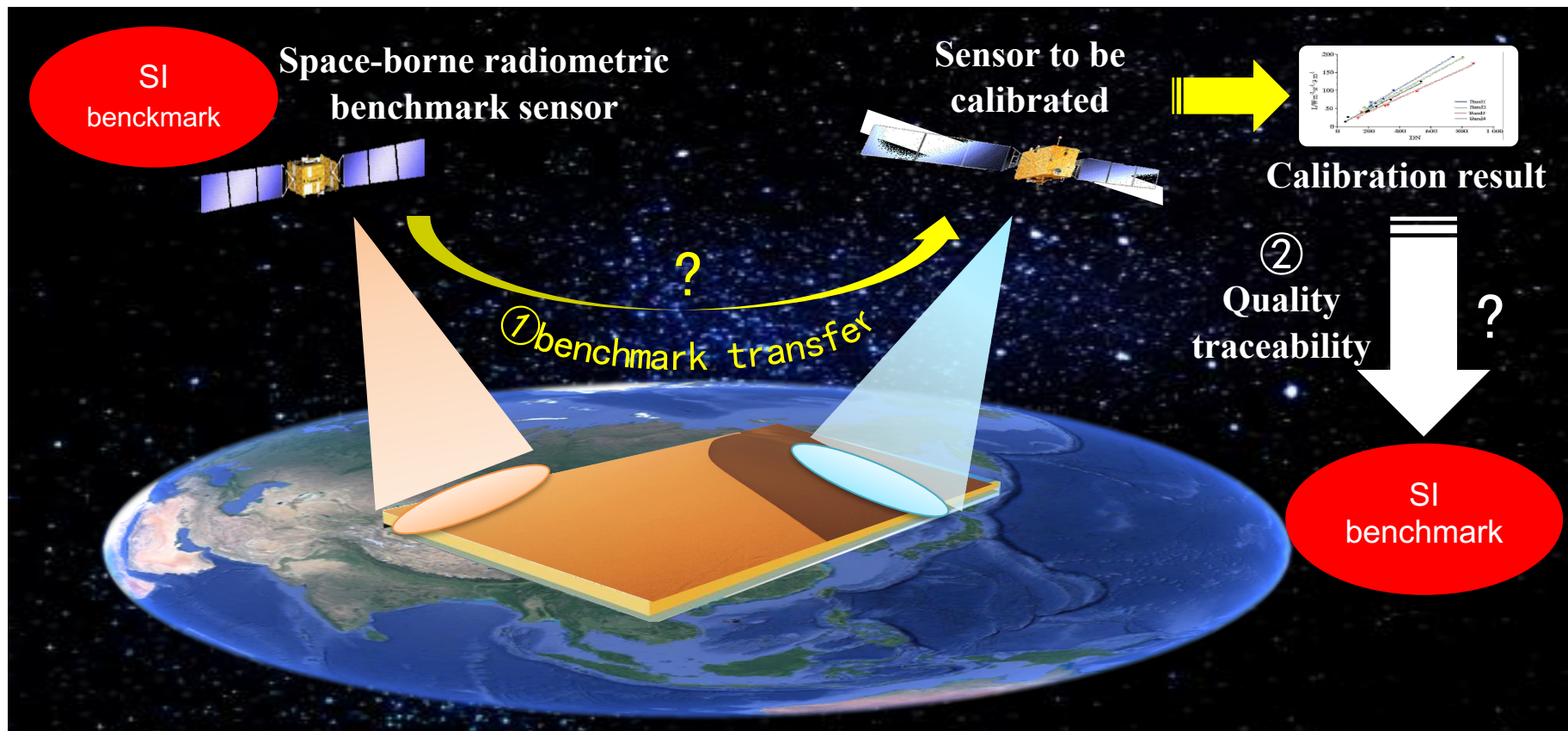


1. Background



- **Space-based radiometric benchmark transfer calibration & ground-based Validation**

Scientific objectives: **accurately transferring of spaceborne radiometric benchmark**, **and consistently tracing of the data radiometric quality**, achieving the **transfer uncertainty** (from the space-borne radiometric benchmark sensor to the sensor to be calibrated) of **2%** in reflective solar bands, and **0.2K** in the thermal emissive bands.

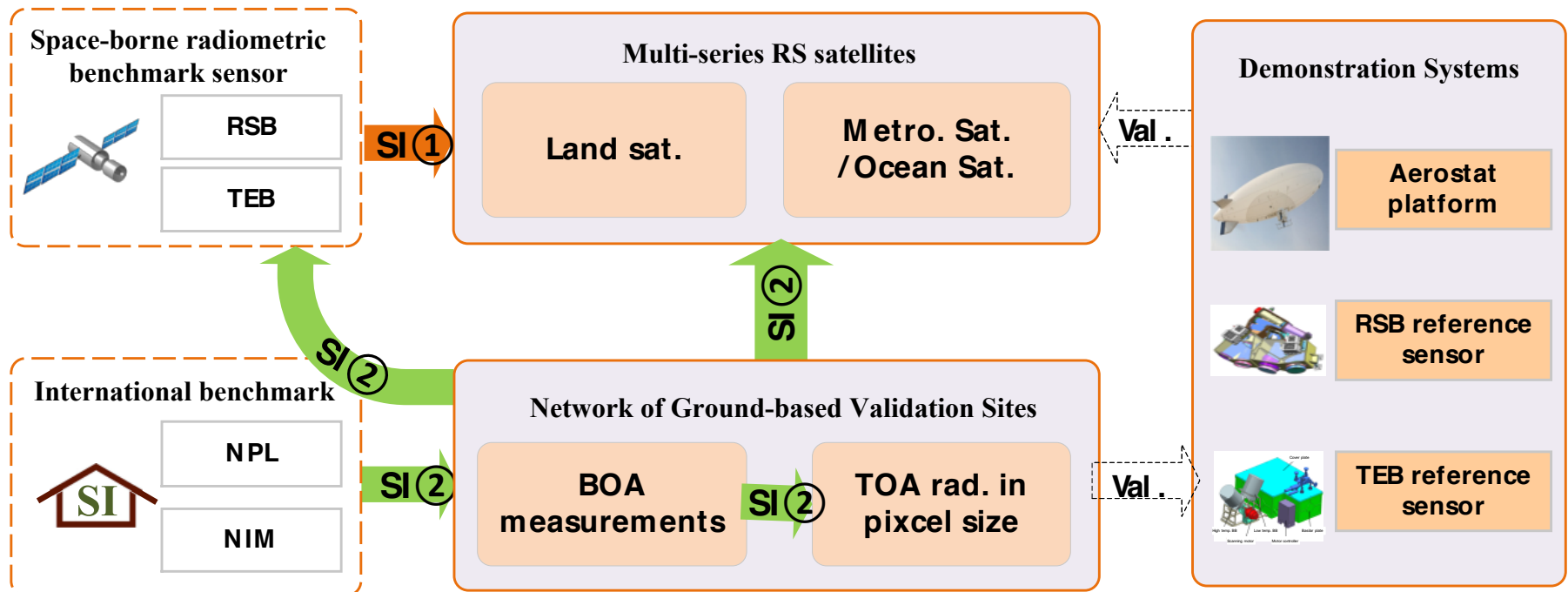


1. Background



Scientific problems:

- ① How to precisely transfer radiometric benchmark from the spaceborne standard calibration system to other operational RS satellites?
- ② How to guarantee consistent radiometric quality of RS products derived by different satellites which have discrepant radiometric/spectral/geometric characteristics?
- ③ How to validate full chain of the spaceborne radiometric benchmark transfer?



1. Background

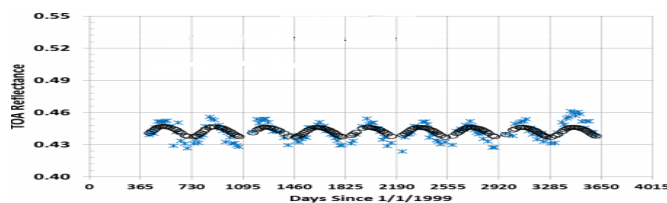


Problems 1&2:

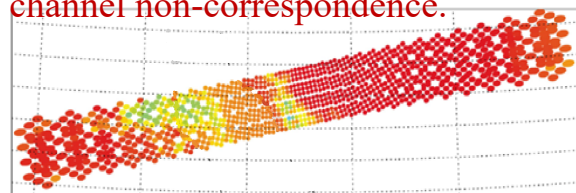
Cross-calibration on medium-high resolution land satellites: develop multi-element matching & conversion methods, mainly settle problems such as small swath and few cross-points.

Parameterized model for multi-element (Tempo, Spatial, Spectral, Angular) matching & conversion:

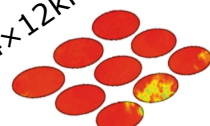
$$\Delta\rho_{ref-cal}^{TOA} = T(\theta_s, \theta_v, \varphi; \lambda_{ref}, \lambda_{cal}; \tau, w; BRDF, \rho_{target}^{BOA})$$



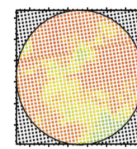
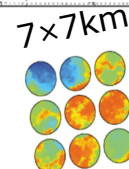
Cross-calibration on low resolution meteorological or oceanic satellites: develop high accuracy spatial/spectral compensation methods based on SNO, mainly settle problems such as pixel response discrepancy and partial channel non-correspondence.



24x12km

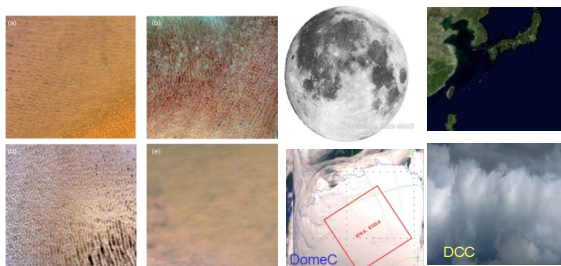


Q1: pixel deformation due to large swath scanning

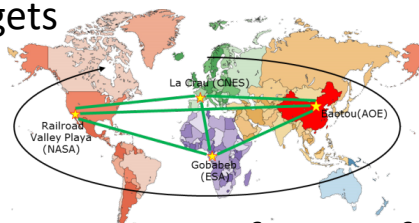


Q2: Surface non-uniformity inside low-res. pixel

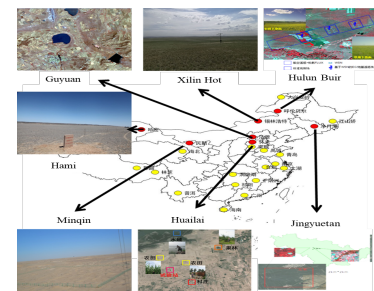
- **Wide-dynamic stable targets:** PICS sites, Moon, Seas, Ice sheet, DCCs, etc. Develop high accuracy TOA reflectance model



- **RadCalNet sites:** Establish three more Chinese automatic instrument sites; assure the consistency of different sites so as to act as calibration transfer targets



- **Product Validation sites:** grassland, desert, gobi, water, etc.



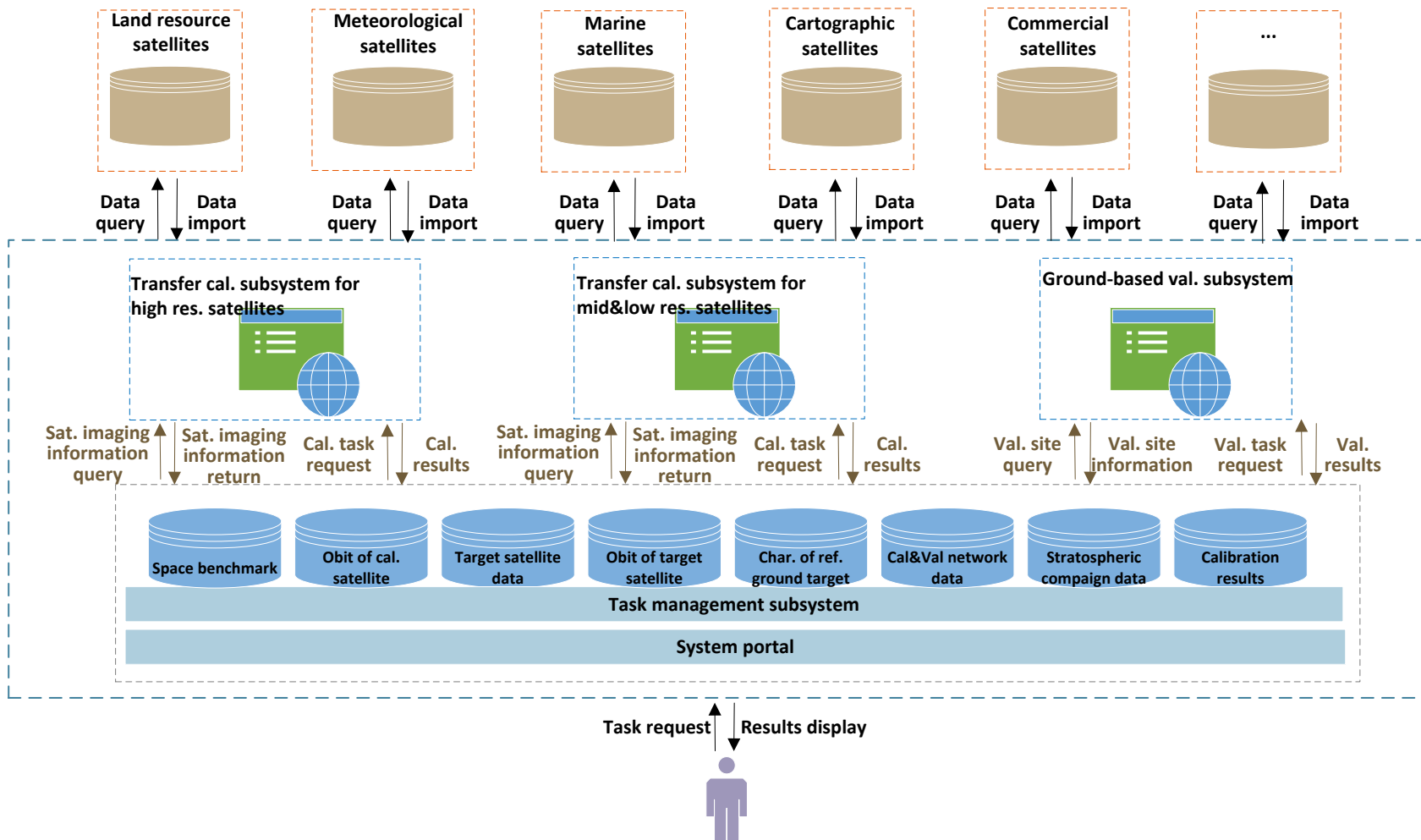
Multi-type validation site network: provide reference targets for transfer calibration and validation

1. Background



Problems 1&2:

The data processing & traceability analysis software will be developed for Chinese multi-series satellites.



1. Background



Problem 3: Initiatives of aerostat-based demonstration system to validate benchmark transfer chain



➤ The **flight altitude** of the aerostat can reach at least 18 km easily, where most of the atmosphere that contributes to the radiative transfer process is beneath this altitude.



provide **environment condition** closer to radiometric benchmark satellite.

➤ There is a **quasi-zero wind** speed layer at the height range of 18-25 km in middle-latitude area over China at the end of spring and in summer.



much easier to slow down the aerostat so as to **observe the land more stably**.

➤ The onboard sensors can be **recovered** after test flight, so that high accuracy calibration of the sensor are feasible both before and after the flight.



ensure **reliability of performance validation** for benchmark sensor.

2. Design of the Demonstration System



● System Composition



- Considering state-of-the-art of aerostats, the high-altitude-balloon was chosen as the demonstration platform, to provide heavy load capacity.

Platform subsystem

- Balloon
- Power
- Flying control
- Measurement and control
- Balloon-control equipment pod
- Launching and recovery

Cabin subsystem

- VNIR & SWIR imager/radiometer cabin
- MIR & TIR interferometer cabin

Scientific instrument subsystem

- VNIR & SWIR hyperspectral imager
- VNIR & SWIR hyperspectral radiometer
- MIR & TIR hyperspectral interferometer
- Position and Orientation System

Data proc. & ana. subsystem

- Scientific data processing
- Transfer calibration model

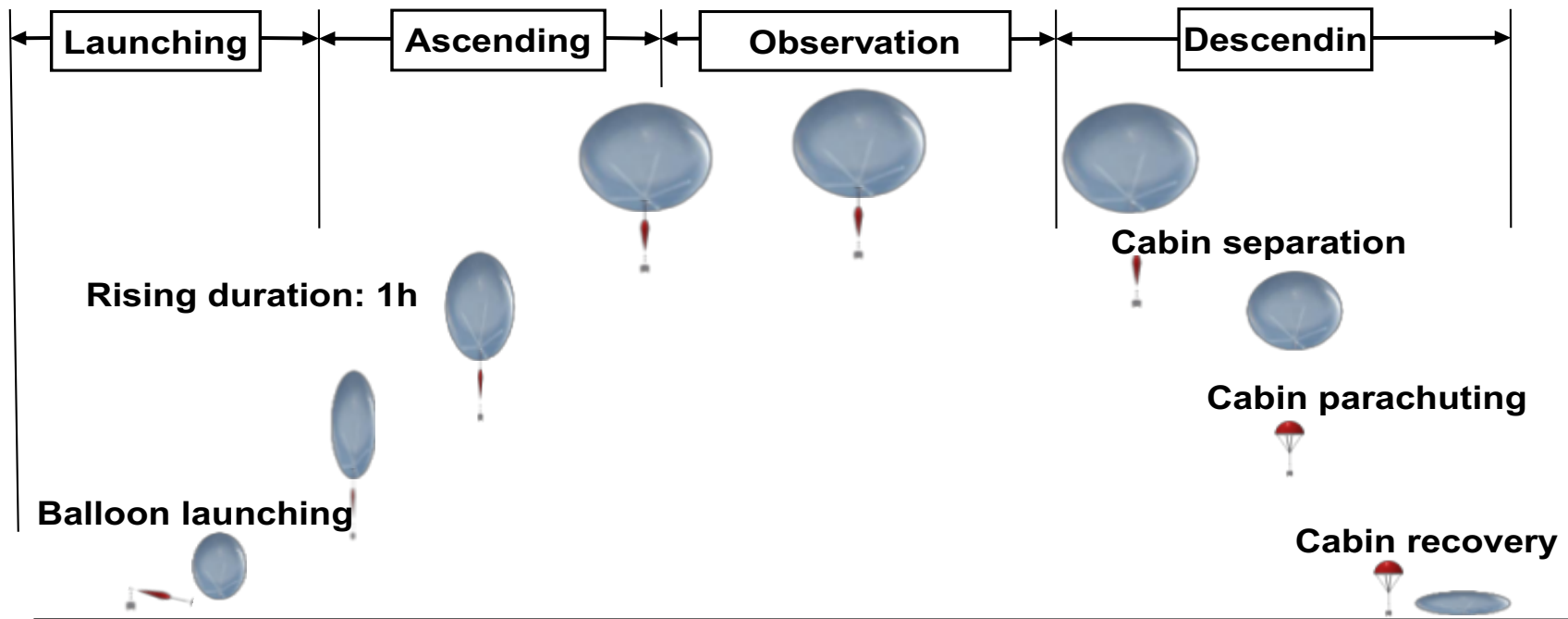
2. Design of the Demonstration System



- Control designs for observing specific target when using heavy load aerostat

Technical challenges

- **Environment of stratosphere** at 18 km altitude is still complex relative to satellite altitude, which affects high accuracy radiometric detection.
- **The motion of aerostat** is forced by atmospheric condition, which affects observation element matching between aerostat and satellite.



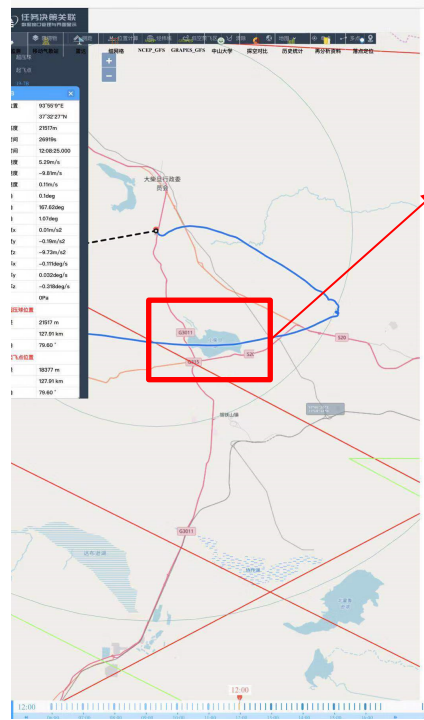
2. Design of the Demonstration System



- Control designs for observing specific target when using heavy load aerostat
 - Flight path prediction of high-altitude-balloon by flight control system (FCS) :
 - ✓ Before the flight mission, historical wind field data & past two days' radiosonde data will be collected to preview balloon flight path, in order to **choose proper flight time window and plan optimized flight path**.
 - ✓ During the flight mission, through real-time wind field calculation, FCS can obtain instant flight path, precisely **forecast short-term trajectory and fall point of the payload cabin**.



Flight control system



In the high-altitude-balloon test flight carried out in Qaidam basin of Qinghai province of China in August 2019, the balloon precisely overpassed the predetermined lake area.



2. Design of the Demonstration System

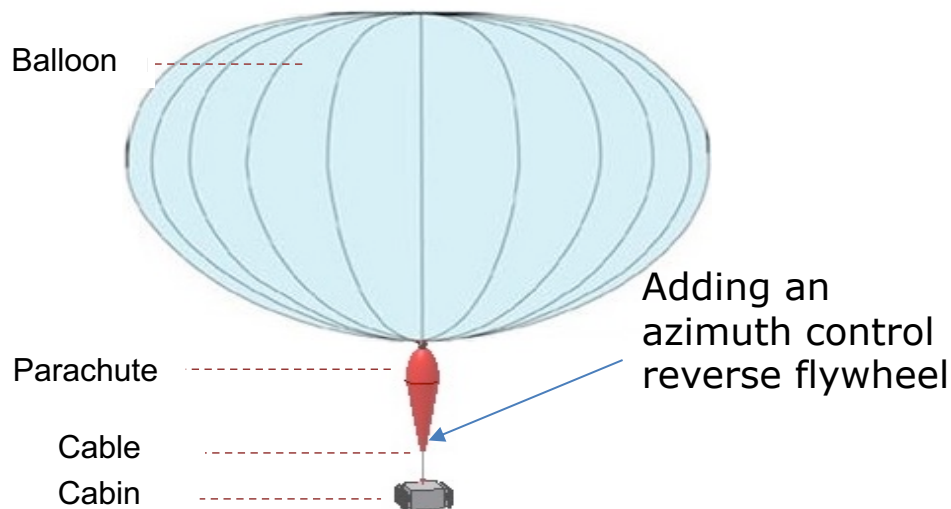


- Control designs for observing specific target when using heavy load aerostat

- Flight attitude control of high-altitude-balloon

During horizontal flying stage, rotational inertia will be generated due to atmospheric friction which make the payload cabin rotate around the linkage cable.

- ✓ **Azimuth control reverse flywheel** will be applied to alleviate the impact from balloon rotation.
- ✓ Precise calculation of sensor position & attitude will be realized through the **onboard high accuracy POS**.



Structure of high-altitude balloon



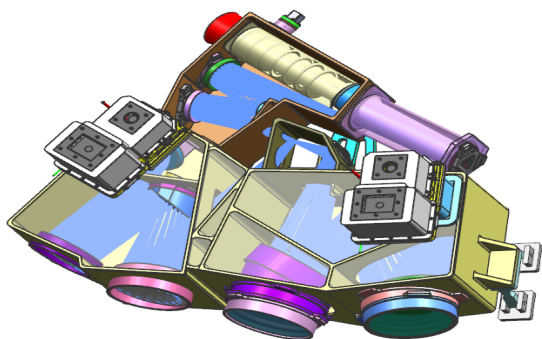
High-altitude POS

2. Design of the Demonstration System

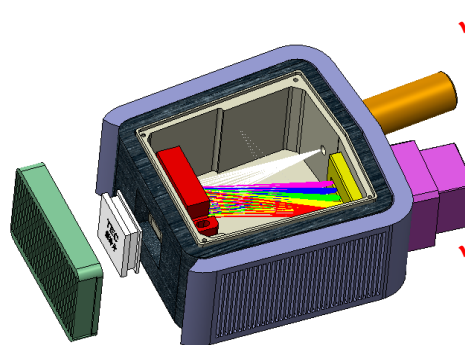


● Radiometric reference sensors to be developed: RSB sensors

Earth-Lunar Hyperspectral Imager (ELHI, by CIOMP): a prototype of the space-based radiometric benchmark sensor covering a spectral range of 380nm-2350nm.



Reference spectroradiometer (by AIOFM): non-imaging, totally covering a spectral range of 380-2380 nm.



- ✓ No collimating beam path, no moving component, all-solid-state instrument. Assuring structural reliability and wavelength measurement stability.
- ✓ Constant temperature environment is maintained for the sensor with temperature control accuracy better than 0.1°C.

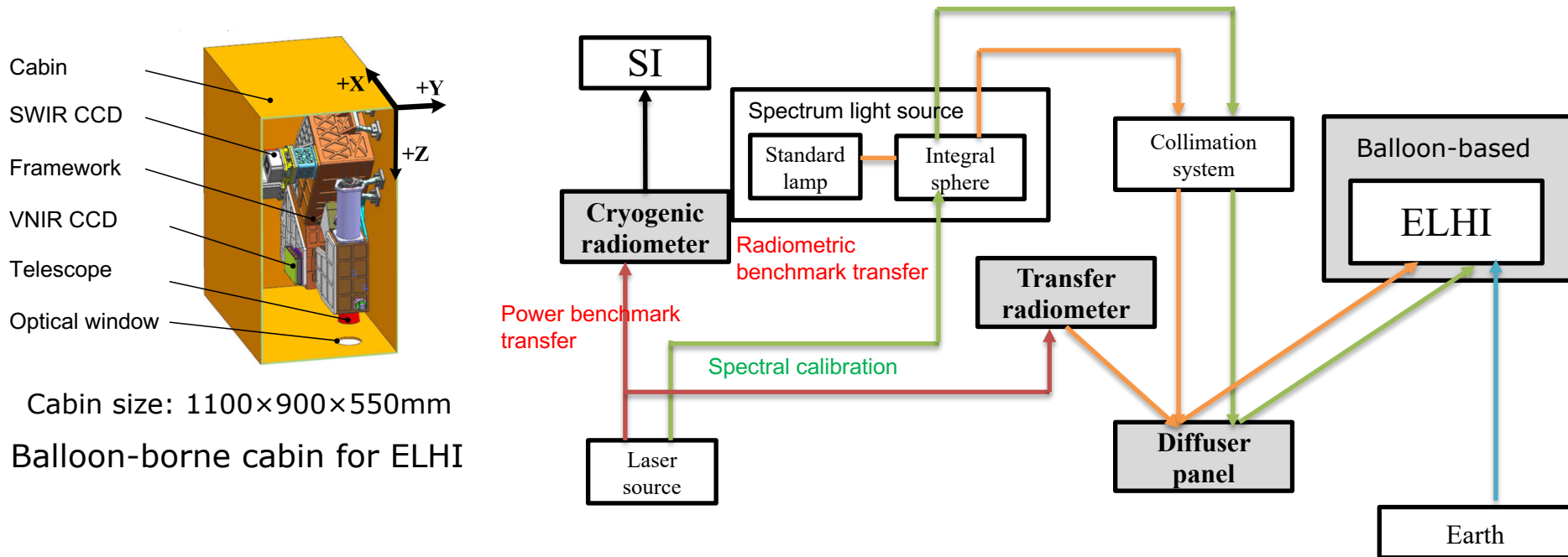
Parameter	ELHI	Reference spectroradiometer
Spectral range	380 nm-2350 nm	380 nm~950 nm, 900 nm~1650 nm, 1600 nm~2380 nm
Spectral resolution	≤ 10 nm	4 nm@(380 nm~950 nm), 10 nm@(900 nm~2380 nm)
Spatial resolution	0.33 m@20km	3°, 5°, 10° optional
Swath	1.68 km@20km	Max FOV 10°
Radiometric calibration accuracy	$\leq 1\%$	$\leq 1\%$

2. Design of the Demonstration System



● Radiometric reference sensors to be developed: ELHI

- A **payload cabin** with temperature control capability will be developed to provide 20°C working temperature for ELHI in flight. Full cabin temperature control accuracy is approximately $\pm 2\text{K}$.
- Before and after test flight, **transfer radiometer** will be used to implement ELHI's radiometric calibration and traceability.



In laboratory calibration, the transfer radiometer is traceable to the cryogenic radiometer, and then it will observe the diffuser panel just like the ELHI does, to give a radiometric reference value.

2. Design of the Demonstration System



● Radiometric reference sensors to be developed: ELHI

Estimated uncertainties budget

Sources of uncertainty		Uncertainty components	Estimated values
Laboratory calibration	Monochromatic light source	Laser power uncertainty	≤0.1%
		Power measure repeatability	≤0.1%
	Transfer radiometer	Power-radiance conversion uncertainty	≤0.08%
		Intensity measure repeatability	≤0.1%
		Uncertainty due to detector	≤0.14%
	Full-spectrum light source	Spectral power uncertainty	≤0.2%
		Hyperspectral curve restoration uncertainty	≤0.3%
	Diffuser panel	Uncertainty due to non-Lambertian surface	≤0.2%
Uncertainty due to stray light		≤0.2%	
Observation environment	Observation SNR	Uncertainty due to SNR	≤0.35%
	Working temperature	Uncertainty due to temperature fluctuation	VNIR : ≤0.2% SWIR : ≤0.7%
Total uncertainty:			VNIR : 0.66% SWIR : 0.94%

- In actual observation when flight, besides the laboratory calibration accuracy (total uncertainty $\leq 0.52\%$), observation result will also be influenced by full-chain noise and payload cabin temperature fluctuation, which bring about dark background drifting.
- Total uncertainty of balloon-borne ELHI observation is estimated to be no more than 1%.

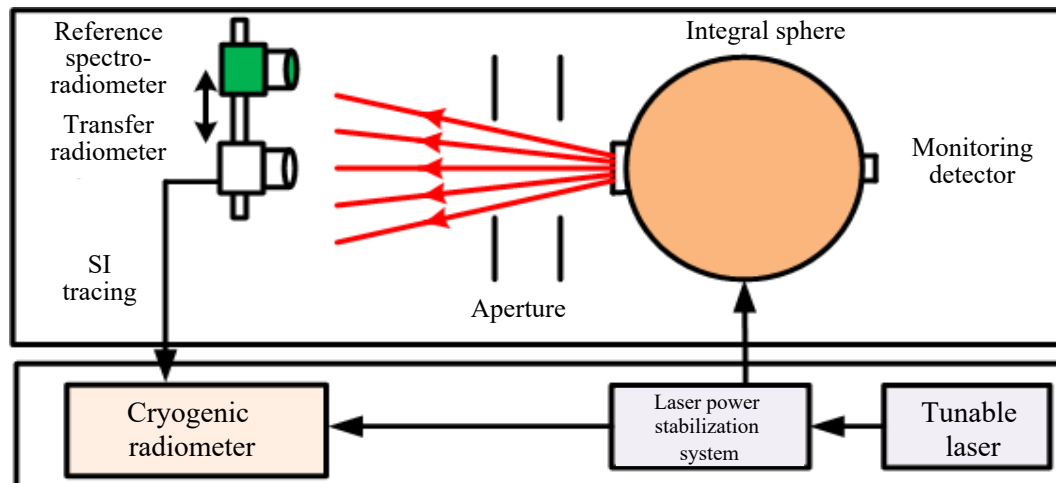
2. Design of the Demonstration System



● Radiometric reference sensors to be developed: Reference spectroradiometer

Cryogenic radiometer -> Transfer radiometer -> Reference spectroradiometer

- ✓ In balloon-borne test flight, the reference spectroradiometer will be loaded in a payload cabin which hangs below the balloon.



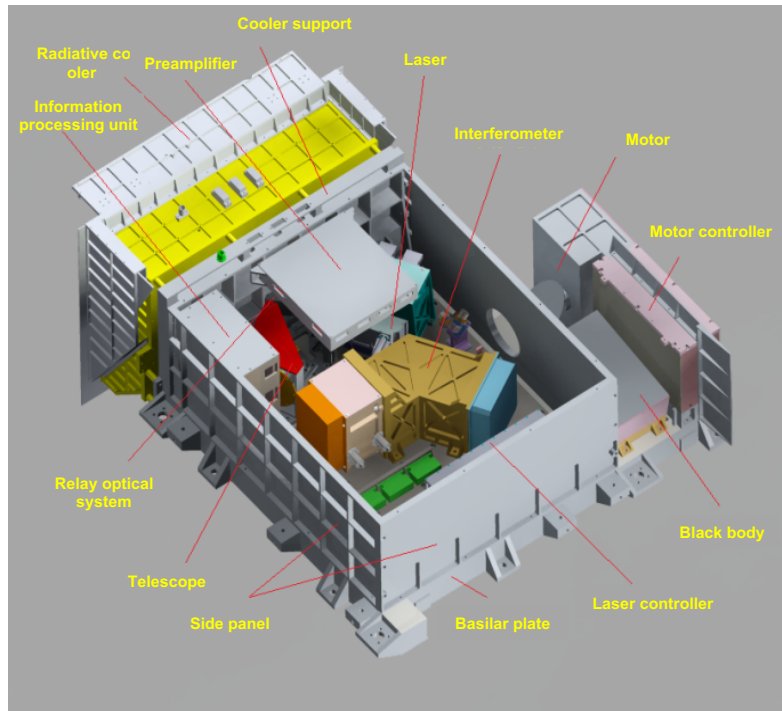
- ✓ Temperature control accuracy during sensor operation is expected to be better than 0.1K, which introduced uncertainty is nearly negligible.

Sources of uncertainty		Contribution/%
Integrating sphere intensity	Stability	0.63
	Non-uniformity	0.120
Transfer radiometer	Power responsibility	0.450
	Diaphragm area	0.036
	I-V gain	0.136
	Measurement stability	0.361
	Calibration distance	0.120
Reference spectroradiometer	ISRF	0.07
	Measurement stability	0.223
	I-V gain	0.180
	Calibration	0.121
Composite uncertainty		0.890

2. Design of the Demonstration System



● Radiometric reference sensors to be developed: TEB reference sensor



Band	Spectral range (cm ⁻¹)	Chan nels	Spectral resol. (cm ⁻¹)	Radiometri c resol. (NEΔT@28 0K)	Spectral calibration accuracy (ppm)
LWIR	650 ~ 1136 (15.38 μm~8.8 μm)	778	0.625	0.15~0.4 K	10 ppm 5 ppm expected
MWIR1	1210 ~ 1750 (8.26 μm~5.71 μm)	433	1.25	0.1~0.7 K	
MWIR2	2155 ~ 2550 (4.64 μm~3.92 μm)	159	2.5	0.3~1.2 K	

Composition of FY-3D/HIRAS

The engineering prototype of the FY-3D/HIRAS (by SITP) is selected to be the TEB reference sensor onboard the balloon-based demonstration system, which covers the same spectral range and has similar spectral resolution as the future spaceborne MIR-TIR benchmark sensor.

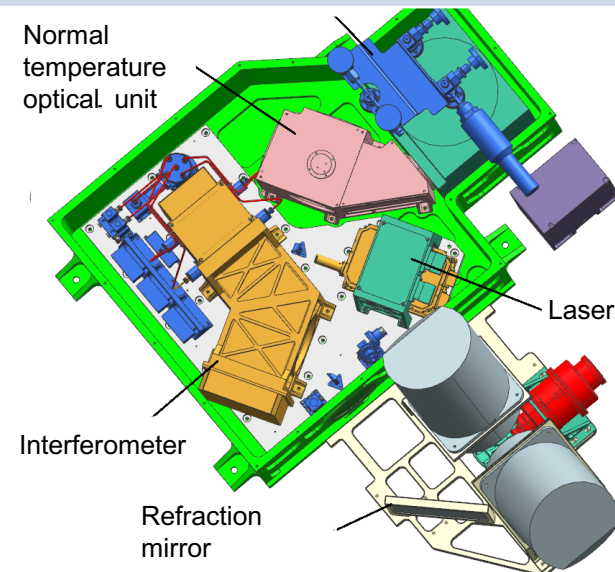
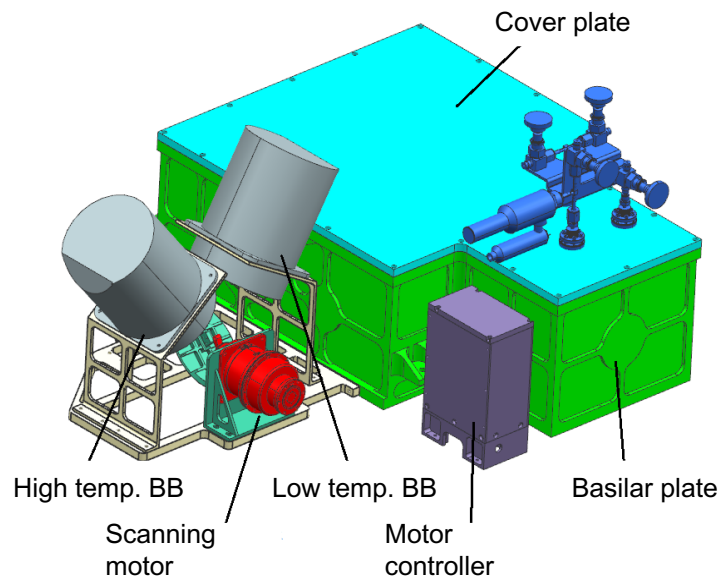
2. Design of the Demonstration System



- **Radiometric reference sensors to be developed: TEB reference sensor**

Taking balloon-borne conditions into consideration, some components need to be renovated:

	Original scheme	New scheme
Calibration	Blackbody + cold space	Cold space cannot be accessible during balloon fight, so two blackbodies (high-temperature BB + low-temperature BB) are used to perform onboard calibration.
Detector refrigeration	Radiation refrigeration	The liquid nitrogen refrigerator is adopted, in view of relatively high temperature of the stratospheric atmosphere.
Observation scan way	Interferometer was installed vertically, facing to the ground	Interferometer is installed horizontally, with an extra scanning mirror to capture ground info. This way can alleviate influence of the gravity.

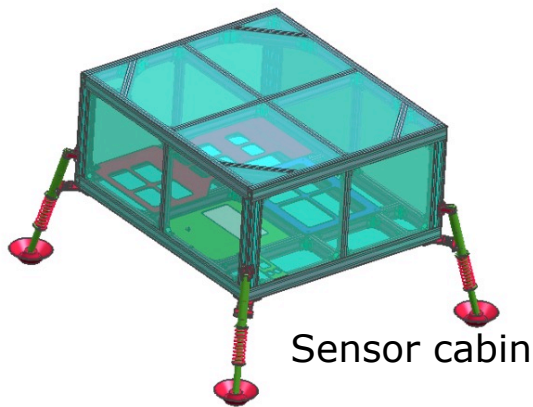


2. Design of the Demonstration System

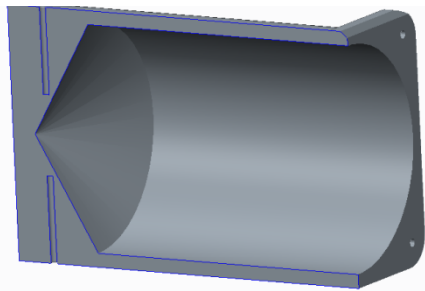


● Radiometric reference sensors to be developed: TEB reference sensor

- The reference sensor is installed in an independently designed sensor cabin, which has **strong shock resistance ability** and adopts active temperature control to maintain 20°C.
- In flight it is calibrated by a high temperature blackbody and a low temperature blackbody, which temperature is set to 30°C and 10°C, respectively. The eventual infrared observation uncertainty is estimated to be about 0.446 K.



Sensor cabin



Blackbody

Blackbody parameters:

- 1) Emissivity: ≥ 0.996
- 2) Temp. control stability: 30 mK;
- 3) Temp. uniformity: 50 mK;
- 4) Material of BB: LD2;
- 5) Temp. measuring points at BB cavity: 6 points

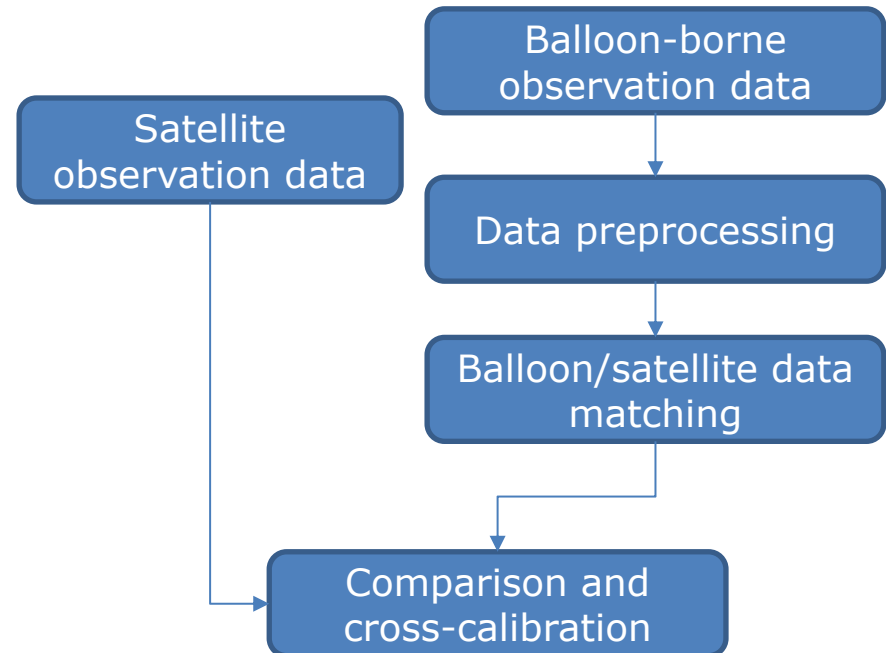
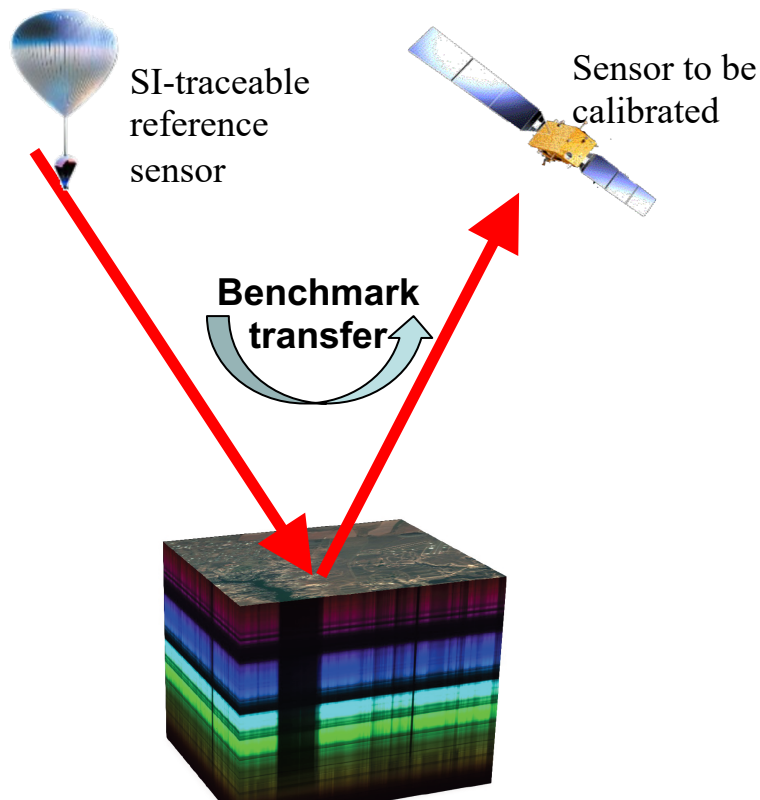
Sources of uncertainty		Contribution/K
Calibration blackbody	Effective emissivity	0.22
	Temperature measurement	0.049
	Temperature non-uniformity	0.18
Background thermal radiation		0.0206
Detector temperature fluctuation		0.34
Composite uncertainty		0.446

2. Design of the Demonstration System



● Data processing of the demonstration system

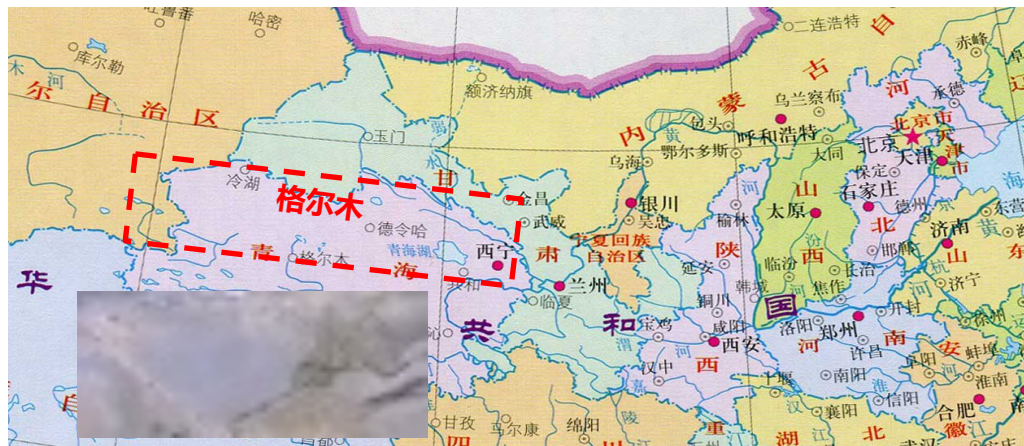
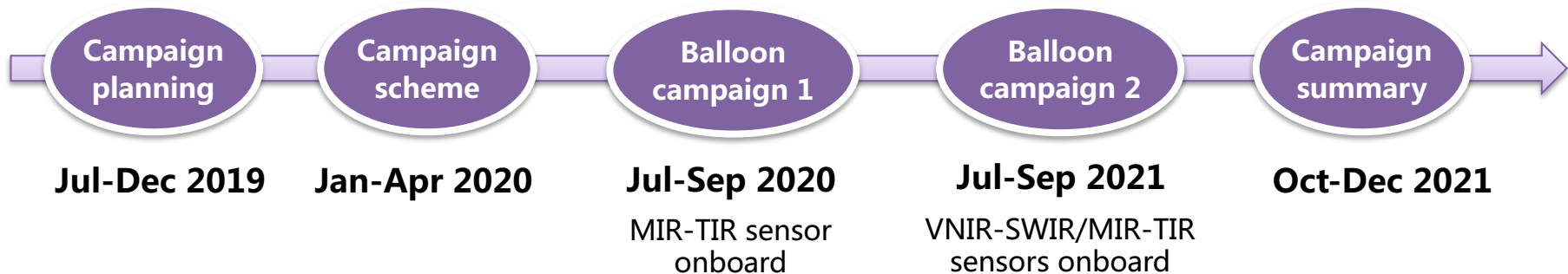
- ✓ Considering the narrow swath of balloon-based reference sensor and controlling efforts of the balloon for observing uniform targets (water, gobi, desert, etc), observation difference between balloon-borne sensor and satellite sensor will be inevitable.
- ✓ Besides data preprocessing of the balloon-borne reference sensor, some important processing (temporal matching, spatial matching, angular conversion) between balloon data and satellite data are key steps so that benchmark transfer (from reference sensor to target sensor) can be realized through spectral convolution.



3. Flight Campaign Plan



- Several stratospheric balloon-based test flights will be performed **in next two years**. Reference sensors will be onboard the balloon to realize radiometric benchmark transfer calibration upon some typical satellite sensors.
- Synchronous ground measurements will also be conducted, to validate the benchmark transfer calibration results and estimate a set of relevant technical indices.



Experiment area consideration:

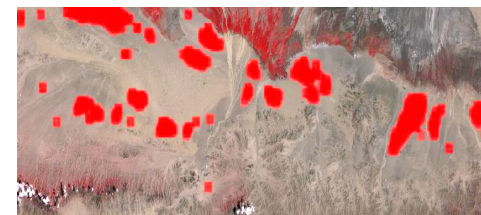
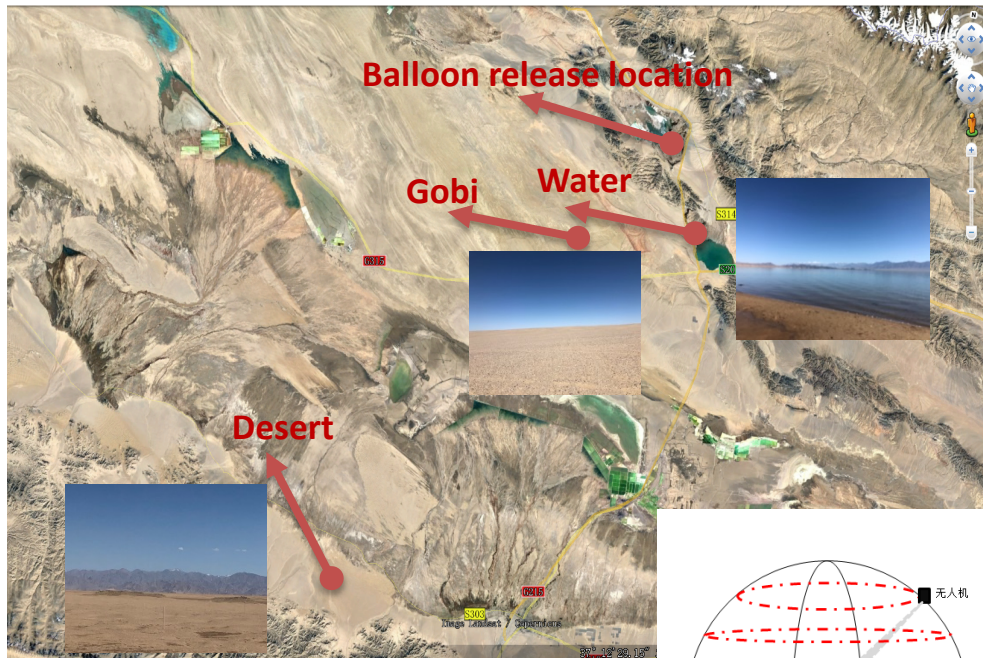
- Golmud: Large area gobi, desert and water
- Qinghai Lake: large area water

3. Flight Campaign Plan

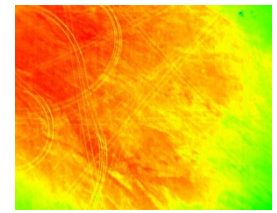


● Experiment area investigation

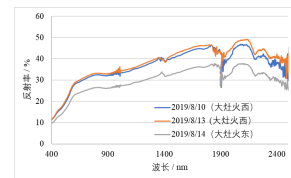
- ✓ **Golmud area:** good condition to release & recover the balloon; uniform landcover (like gobi, desert, water) is often accessible in this area.
- ✓ Site uniformity was analyzed through high resolution satellite images, and further in-situ data collection of surface spectral feature and angular feature has been carried out during August 2019.



Chosen uniform area suitable for calibration (GF1/WFV, 3%)



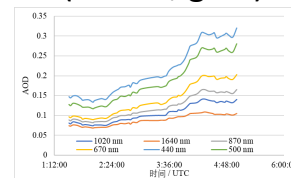
L8 bright temperature uniformity



Reflectance (desert, gobi)



Snapshot



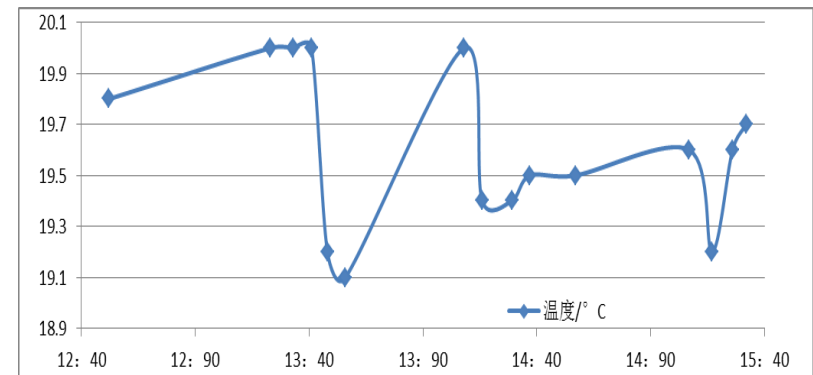
AOD

3. Flight Campaign Plan

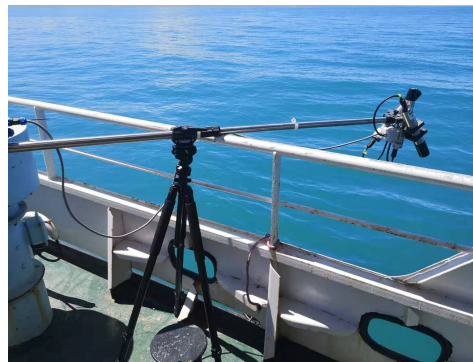


● Experiment area investigation

- ✓ **Qinghai Lake area:** possible balloon release places were investigated nearby the lake, however details need to be confirmed in next step.
- ✓ In August 2019, in-situ measurements were performed over the lake, including: water spectrum, infrared angular feature, transparency, water quality parameters, back-scattering coefficient, etc.



Measured time variation of water temperature



3. Flight Campaign Plan



● Expected involved Chinese satellites

More than twenty Chinese satellites

No.	Satellite	Type of sensor	Resolution	Spectral range	bands	Product
1	GF-1	PMS	2m/8m	0.45-0.90μm	5	L1 radiance
2	GF-2	PMS	1m/4m	0.45-0.90μm	5	L1 radiance
3	GF-5	VNIR-SWIR hyperspectral	30m	0.4-2.5μm	330	L1 radiance
4	GF-6	PMS	2m/8m	0.45-0.90μm	5	L1 radiance
5	ZY3-01	MUX	6m	0.45-0.89μm	4	L1 radiance; Reflectance
6	ZY3-02	MUX	5.8m	0.45-0.89μm	4	L1 radiance; Reflectance
7	SV-1 01/02/03/04	MUX	2m	0.45-0.89μm	4	L1 radiance
8	TH-01/02/03	MUX	10m	0.43-0.90μm	4	L1 radiance
9	FY-3D	VNIR~TIR hyperspectral	250m/1km	0.43-12.5μm	10	L1 radiance
10	FY-3C	MUX	1.1 km	0.4-12.5μm	25	L1 radiance
11	HY-1C	MUX	1100m	0.4-12.5μm	8	L1 radiance; Sea water color

3. Flight Campaign Plan



● Expected involved international satellites

Anticipated international satellites

No.	Sensor/Satellite	Resolution	Spectral range	Bands	Swath	Revisit period	Orbit type
1	MODIS/Aqua MODIS/Terra	250m/500m/1km (at-nadir)	0.4-14.4μm	36	2330km	1d	Polar orb.
2	OLI/Landsat-8	15m/30m	0.43-2.3μm	9	185km	16d	Polar orb.
3	Sentinel-2A	10m/20m/60m	0.4-2.4μm	13	290km	10d	Polar orb.
4	NPP/VIIRS	375m/750m (at-nadir)	0.3-14μm	22	3000km	1d	Polar orb.
5	AIRS/Aqua	13km (at-nadir)	3.7-15.4μm	2378	1650km	1d	Polar orb.
6	IASI/MetOp	12km (at-nadir)	3.62-15.5μm	8741	2052km	1d	Polar orb.
...							

4. Conclusions and Future Plan



- The implementing scheme of stratospheric high-altitude-balloon-based radiometric benchmark transfer calibration demonstration system has been drawn out, and related studies on benchmark transfer calibration and ground-based validation were also continuously in progress.
- In the next two years, reference sensor will be carried on the high-altitude balloon to perform demonstration experiments. It is expected to accumulate experiences to make further improvement on space-based radiometric benchmark sensors and transfer calibration technology.
- In future, with the development of dwelling airship technology, near space radiometric benchmark sensors with attributes of light weight, low energy consumption and highly stable performance will be designed based on long-term fixed-point airship platform, a so-called practical "Near space radiometric metrology station" might be promising.

Thanks !