# Introduction of Climate and Atmospheric Composition Exploring Satellites (CACES) Mission

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**Thanks to all further colleagues at LSEE (RO Group) and IAP, CAS (CACES group) valuable discussions and advice!**

# Outlines

NSSC

Outline

- ◆1. Radio Occultation Group, NSSC
- ◆2. From GRO to LEO-LEO Occultation
- ◆3. CACES Mission
- ◆4. LMO Research in NSSC for CACES
- ◆5.Summary and Conclusion

# Radio occultation group, NSSC

## ➢Research domains:

- GNSS radio occultation (GNSS RO)
- GNSS reflectometry (GNSS-R)
- LEO-LEO microwave occultation (LMO)

## ➢Research Goals:

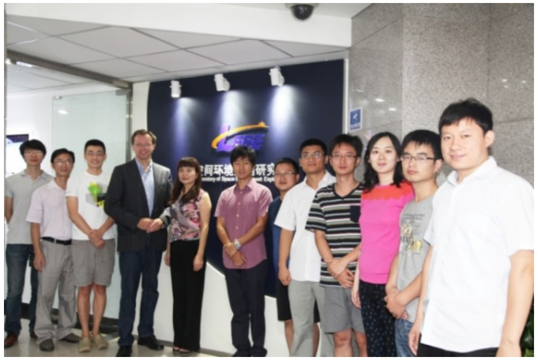
- To develop occultation and GNSS-R instruments
- To apply the GNSS remote sensing data

## ➢Research partners:

- China Meteorological Administration (CMA)
- Institute of Atmosphere Physics (IAP), CAS
- Wegener Center for Climate and Global Change (WEGC)
- Geo Forschungs Zentrum (GFZ)
- DMI, EUMETSAT ROM SAF
- Institut d’Estudis Espacials de Catalunya (IEEC)

ISSI BJ Forum Group photo

Prof Kirchengast and IAP colleagues



GNSS RS Group and Prof Gottfried Kirchengast

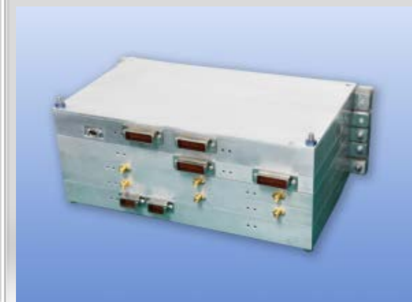
# Instrument products

## GNSS RO Receivers

**GPS RO receivers**

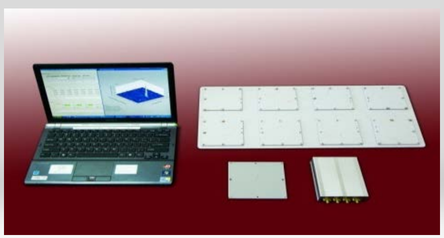
**FY-3C/-3D GPS/BDS compatible flight models**


FY-3E GNOS II



## GNSS Reflection Receivers

**GPS-R software receiver**

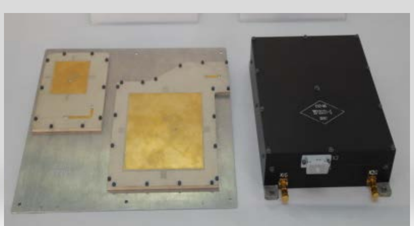


**FPGA+DSP GPS/BDS/GALILEO compatible ocean reflection receiver**

**LMO research fields:**
- **Satellite-to-Satellite occultation for Mars**
- **LEO-LEO occultation for Earth**

## LMO Transmitters and Receivers

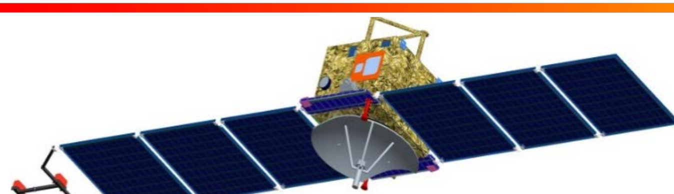
**YH-1 RO receiver flight model for Mars**



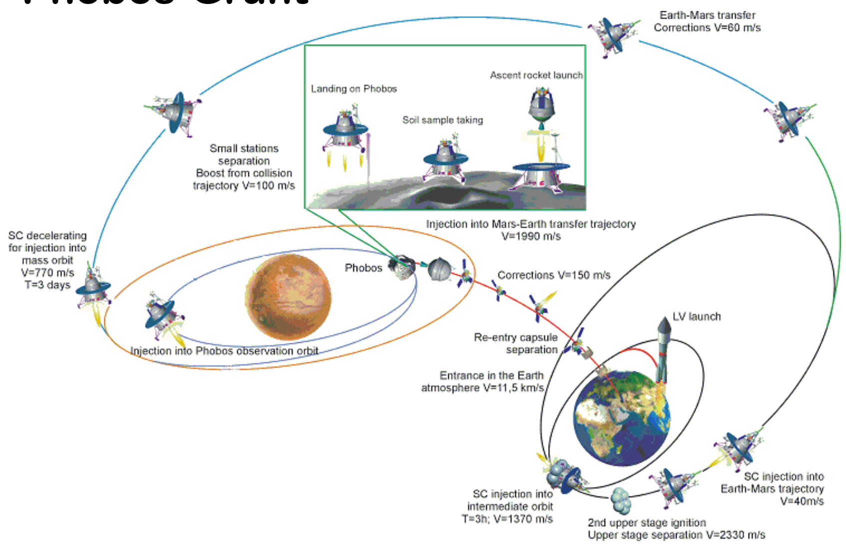
**LMO transmitter receiver for Earth**


# YingHuo-1 mission

Phobos-Grunt



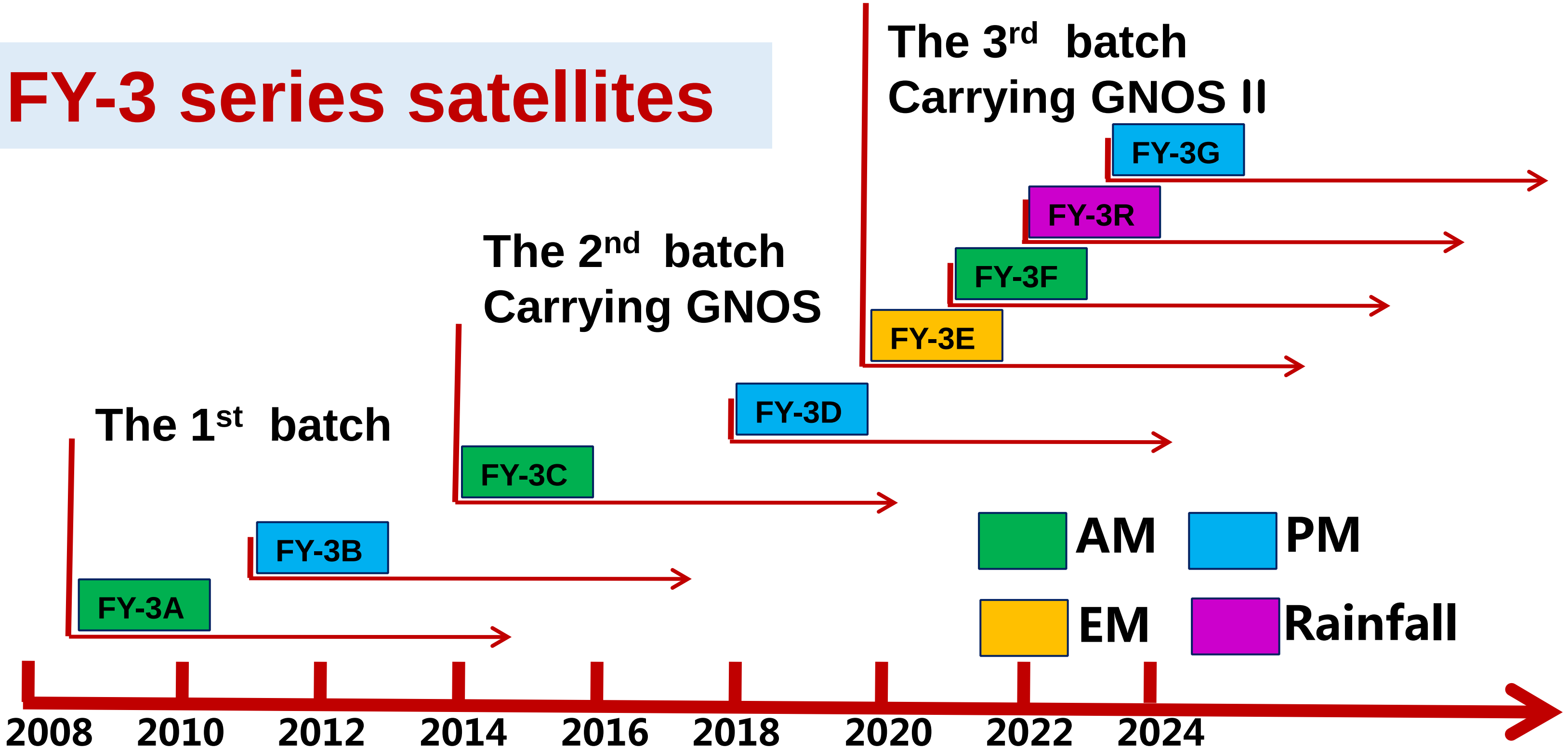
HY-1 micro-satellite structure




- One of the major scientific objectives of YH-1 mission is **to investigate the ionosphere of the Mars by using Sat-Sat occultation.** (The 2 frequencies signals are ~415.5 and ~833 MHz. )
- The indoor testing of the Tx and Rx showed that both of them were working well.
- However, they were not successfully launched into the Martian orbit in 2011
- And this is the start point of RO research group in NSSC.

# Operational and future missions

## FY-3 series satellites

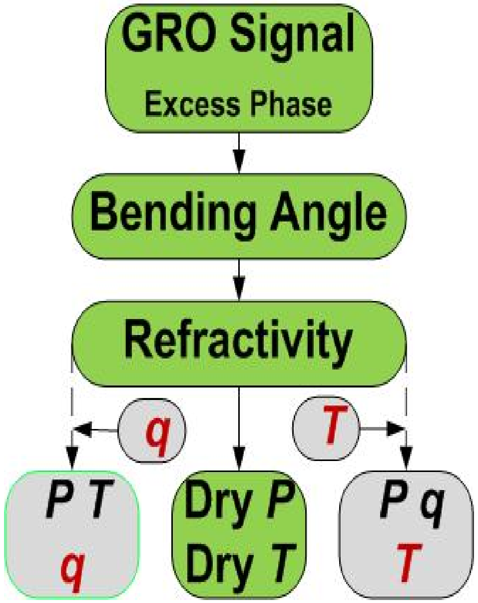


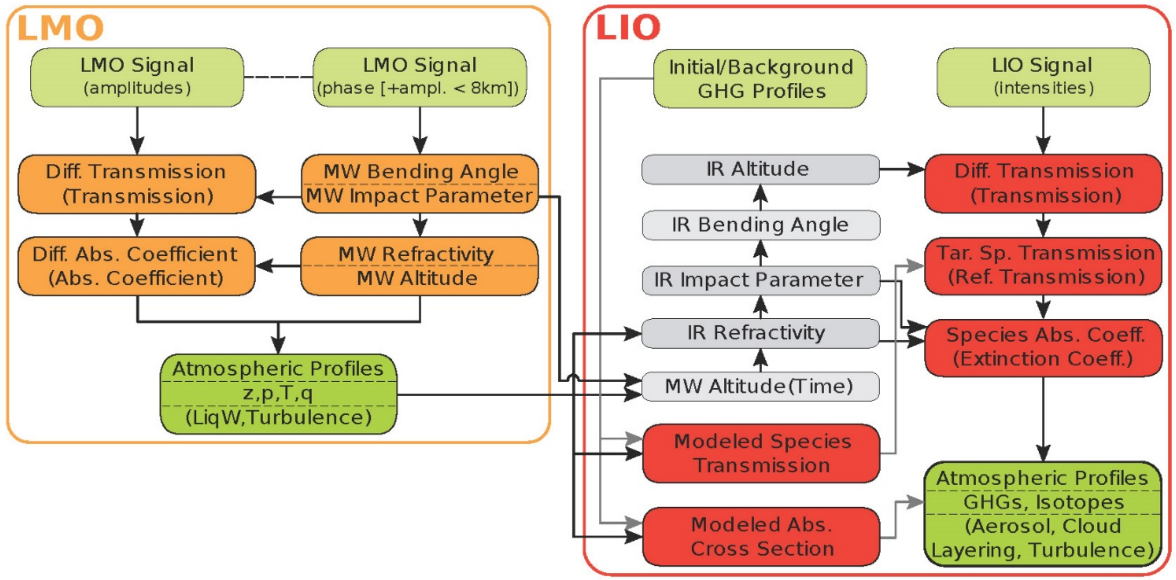
Timeline of FengYun 3 series satellites

- **FY-3C GNOS was launched in September 2013**
- **FY-3D GNOS was launched in November 2017**
- **FY-3E GNOS II plan to be launched in 2020**
- **The following FY-3 satellites will carry GNOS II as a key payload…**

# From GRO to LEO-LEO occultation

## Retrieval processing of GRO, LMO and LIO (LMIO) :




[V. Proschek, G. Kirchengast, and S. Schweitzer, AMT, 4, 2035–2058, 2011]

GRO has been established by various **missions (COSMIC , MetOP, FY-3 GNOS…)**

Widely used for **NWP**, **climate monitoring and space weather.**

**Temperature-humidity ambiguity,** **which means the temperature and humidity in the troposphere can only be retrieved separately from refractivity by co-using a priori humidity or temperature information**

GRO cannot realize the atmosphere GHGs monitoring

# LMO principle

The complex refractive index is given by:

$$n = n' + i \cdot n''$$

The optical path is given by:

$$L = \int_{Tx}^{Rx} n' ds$$

Excess phase

Bending angle

Abel transform to refractivity real part:

$$n'(a) = \exp\left[\frac{1}{\pi}\int_a^{\infty} \frac{\alpha(a')}{\sqrt{a'^2 - a^2}} da'\right]$$

The optical depth is given by:

$$\tau = \int_{Tx}^{Rx} k ds$$

Amplitude

$$T = I/I_0 = \zeta \exp(-\tau)$$

Abel transform to absorption coefficient :

$$\Delta k(a) = -\frac{1}{\pi}\frac{da}{dr}\int_a^{\infty} \frac{d\Delta\tau/dx}{\sqrt{x^2 - a^2}} dx$$

Constraining the atmosphere to be in hydrostatic balance to obtain a set of equations:

$$\Delta k = F_1(p, T, p_w)$$

$$n' = F_2(p, T, p_w)$$

$$\mathrm{d}p/\mathrm{d}z = F_2(p, T, p_w)$$

# LMIO principle

The optical depth is given by:

$$\tau = \int_{Tx}^{Rx} k ds \xrightarrow[T = I/I_0 = \zeta \exp(-\tau)]{\text{Amplitude}}$$

**Abel transform** to absorption coefficient :

$$k(z_j) = \frac{1}{\pi} \frac{\mathrm{da}}{\mathrm{dr}}\bigg|_{a=a_j} \int_{a_i}^{a_{top}} \frac{d \ln T(a)}{da} \frac{1}{\sqrt{a^2 - a_j^2}} \mathrm{da}$$

The **Volume Mixing Ratio (VMR in ppmv)** profiles for species can retrieved by:

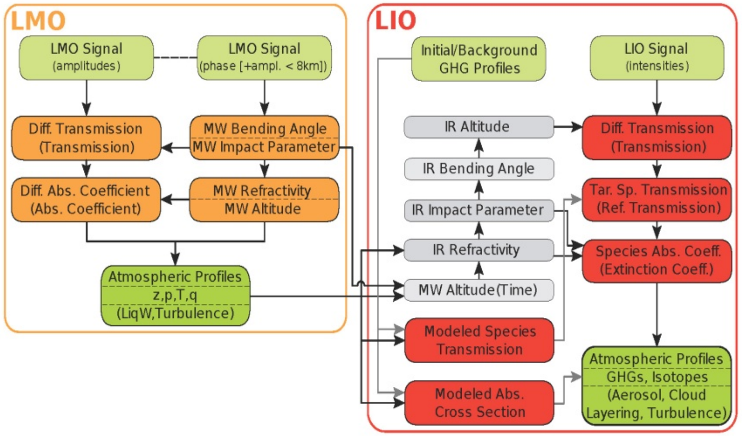
$$\chi(z_i) = 10^6 R \frac{k(z_i)}{\varepsilon(z_i)} \frac{T(z_i)}{p(z_i)}$$

**Doppler effected** optical depth difference is give by:

$$\Delta\tau = \int_{Tx}^{Rx} \Delta k_0 ds - \frac{1}{c} \int_{Tx}^{Rx} \Delta\chi_0 v_{\|} ds$$

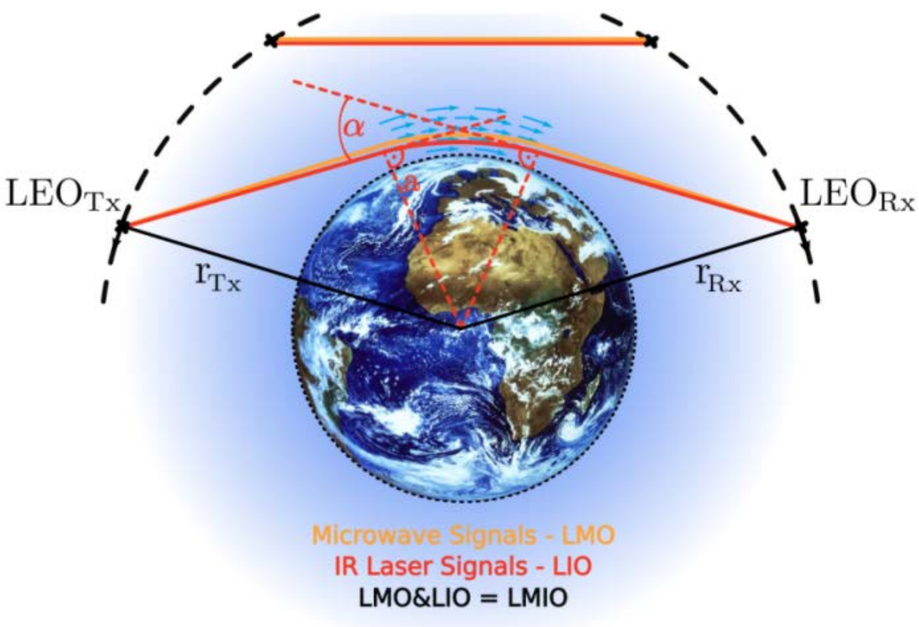
Abel transform to wind velocity :

$$v(a) \approx \frac{c}{\Delta\chi_0(a)} \left[ \frac{1}{\pi} \frac{d}{dr} \int_a^{\infty} \frac{\Delta\tau(x) dx}{\sqrt{x^2 - a^2}} + \Delta k_0(a) \right]$$



# CACES concept mission

**Climate and Atmospheric Composition Exploring Satellites (CACES) accepted by Strategic Priority Research Program of Chinese Academy of Sciences (SPRPCAS)**



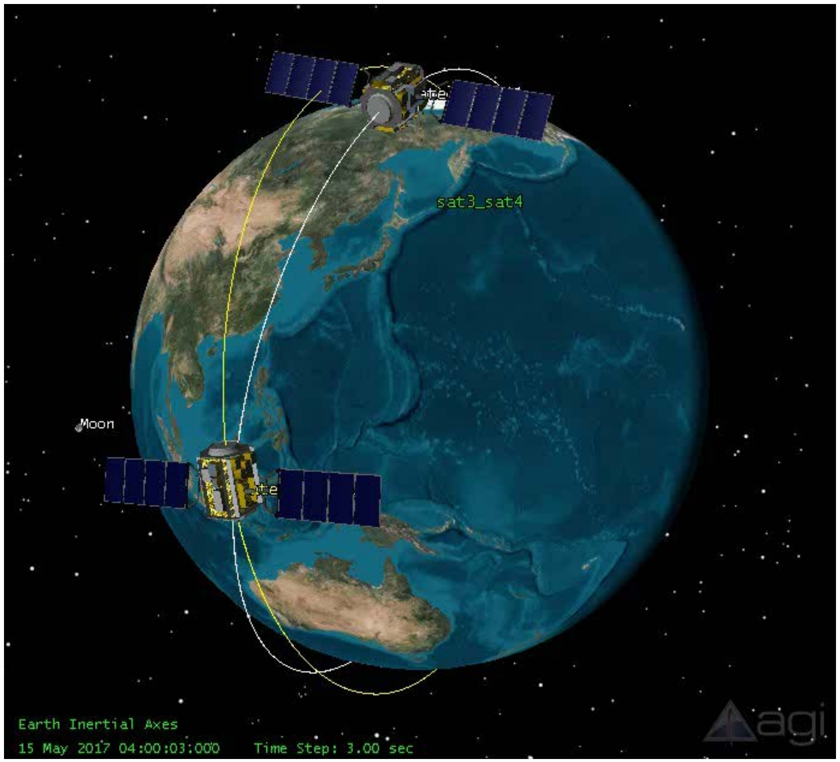

- 4 LEO Satellites
- Combining microwave and infrared laser occultation and clouds & water vapor VIR dual-channels imaging
- LMO and LIO limb sounding for vertical profiles of T, P, WV, $CO_2$, $CH_4$ (etc.) at high vertical resolution
- CWAVI camera for down-looking multi-angle images over occ. event regions

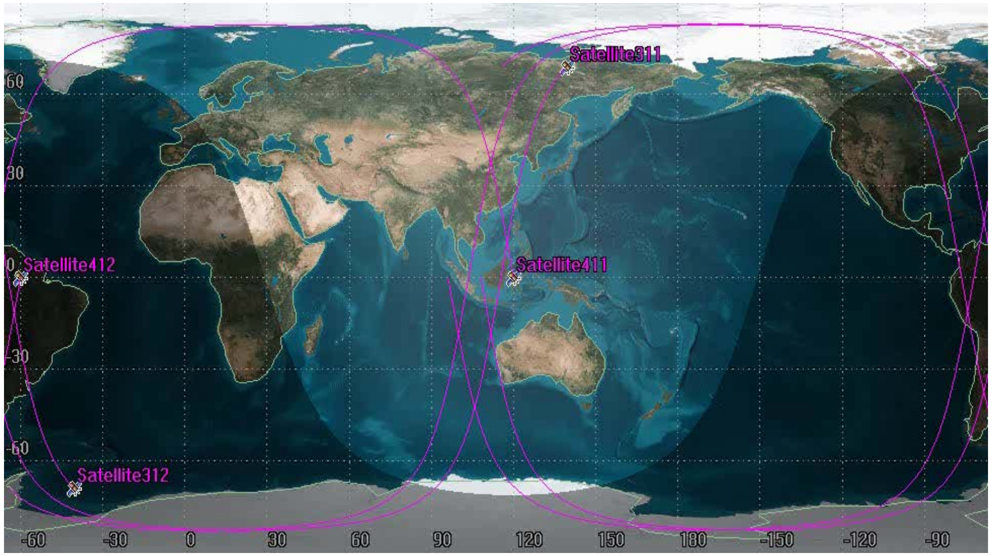
# Scientific objectives of CACES

- To monitor the multiple parameters simultaneously in high accuracy, high vertical resolution, to provide a new understanding of spatial-temporal distribution and variation.
- To know the transport and exchange of atmospheric water vapor, liquid water, maybe including ice crystals, in clouds under strong convections.
- To reveal the physical and chemical processes of different atmospheric composition at the key interface between troposphere and stratosphere, and to study their impacts and feedbacks on global climate change.
- To study the impact of atmospheric composition change on the Earth's ecosystem and the interaction mechanisms

# Orbit of CACES

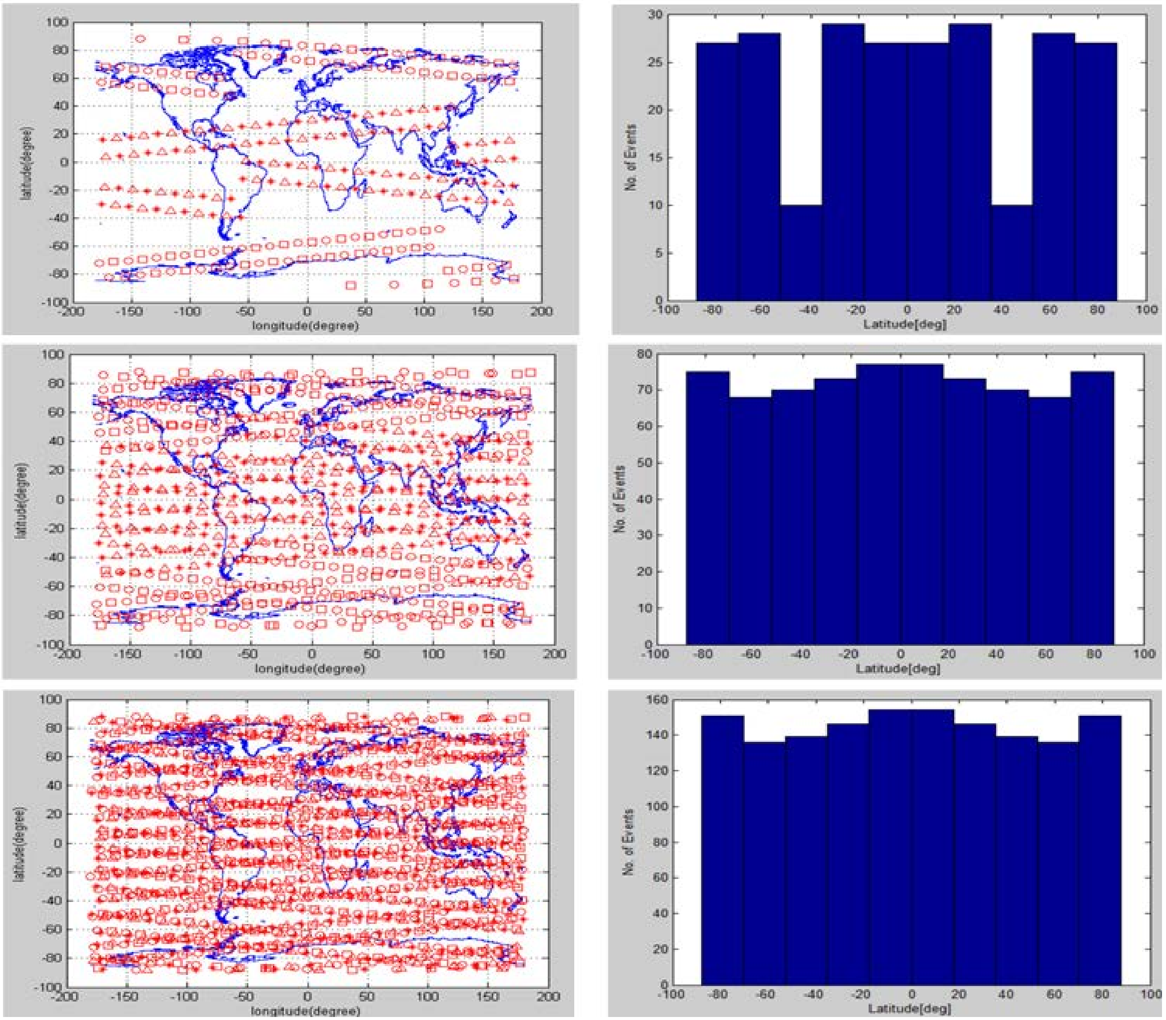
## Constellation Design




- Sun synchronous/near polar counter-rotating orbits of Tx and Rx
- 550/500 km
- 2 Satellites/orbit,
  4 Satellites in total

# LEO-LEO occultation analysis




| Orbits | 2 Rx Sat | 2 Tx Sat |
|---|---|---|
| **Height** | 500km | 550km |
| **Eccentricity** | 0 | 0 |
| **Inclination** | 97.41° | 97.60° |
| **Time** | 12:00 | 0:00 |
| **Period** | 5676.98 sec | 5738.99 sec |

**Global distribution of the LEO-LEO events for 24/72/144 hours**

# Parameters of CACES system

| System | | Mass (Kg) | Avg. P (W) | Peak P (W) |
|---|---|---|---|---|
| **Platform** | Att. | 30.00 | 40.00 | 76.0 |
| | Energy | 28.00 | 10.00 | 10.0 |
| | Task | 8.00 | 12.00 | 12.0 |
| | M&C | 6.00 | 23.00 | 23.0 |
| | Data Tr. | 8.00 | 6.00 | 60.0 |
| | Struc. | 80.00 | 0.00 | 0.0 |
| | Thermal | 7.00 | 30.00 | 40.0 |
| | Line | 9.00 | / | / |
| | Orbit | 15.00 | / | / |
| | Propel | 15.00 | / | 10.0 |
| **Payloads** | LIO (Tx/Rx) | 60/40 | 5/4 | 100/30 |
| | LMO (Tx/Rx) | 40/30 | 5/4 | 50/30 |
| **Mass in total ( Tx/Rx )** | | 306/276 | | |
| **Power in total ( Tx/Rx )** | | | 131/129 | 381/291 |

# Observations of CACES

- Vertical range: Earth surface – 40 to 80 km
- Vertical Resolution: better than 500 m
- T, P, WV, $CO_2$, $CH_4$, (etc.)

| | | MO | | | | IO | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature | | Sp. Humidity | | Trace Species | | l.o.s. Wind | | |
| Requirement | | Target | Thres | Target | Thres | Target | Thres | Target | Thres | Units |
| Vertical domain | | S-80 | S-40 | S-15 | S-10 | 5-40 | 5-30 | 5-40 | 5-30 | [km] |
| Vertical samp-ling | LT | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | [km] |
| | UT | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | [km] |
| | LS | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 | [km] |
| | US | 1 | 2 | - | - | 1 | 2 | 1 | 2 | [km] |
| RMS accu-racy | LT | best-effort basis | | | | | | | | Temp [K] Humi [%] Species [%] Wind [m/s] |
| | UT-bottom | 1 | 2 | 10 | 20 | TBD | | | | |
| | UT-≥10km | 0.5 | 1 | 10 | 20 | | | | | |
| | LS | 0.5 | 1 | 10 | - | | | | | |
| | US | 1.5 | 3 | - | - | | | | | |

# LMO research status in NSSC

To propose a LMO mission in China, NSSC has conducted a pre-study in four aspects:

- Orbit design and GRO&LMO events analysis
- Frequencies selection and error analysis
- Transmitter and receiver design&development
- Preparing an outdoor demonstration experiment

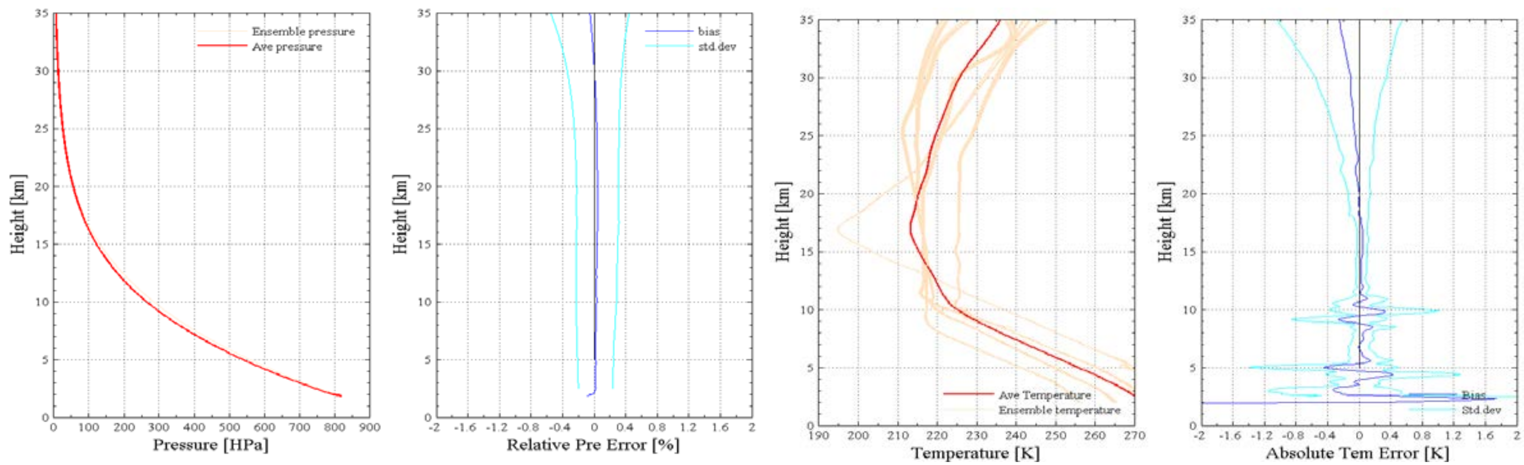
(The simulation work was conducted by using EGOPS (WEGC))

# LMO payloads design

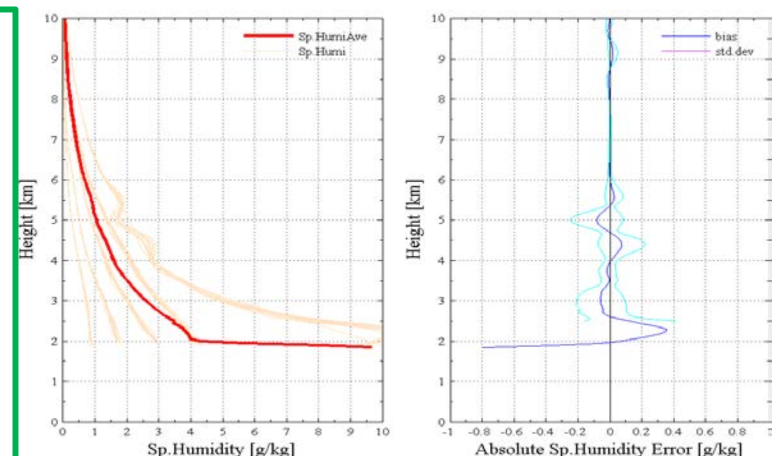

| Frequencies | ~9.4GHz | ~14.6GHz | ~17.4GHz | ~22.6GHz |
|---|---|---|---|---|
| Antenna Gain | ≥26dB | ≥27.5dB | ≥28.5dB | ≥30dB |
| Transmit Power | ≥2W | ≥2W | ≥2W | ≥2W |
| Amplitude Measurement Accuracy | Less than 0.022dB ( 0.5% ) RMS ( within 15 seconds ) | | | |
| Phase Measurement Accuracy | Better than 1% cycle | | | |
| Clock Short-term Frequency Stability | Better than 1e-12/ second | | | |
| Sampling Rate | ≥500Hz | | | |
| Weight | 30kg (T & R) | | | |
| Power consumption | 60W (T) 40W (R) | | | |
| Size | Antenna: X/Ku : φ270*920mm<br>Ku/K: φ200* 900mm | | | |

# Frequencies and analysis

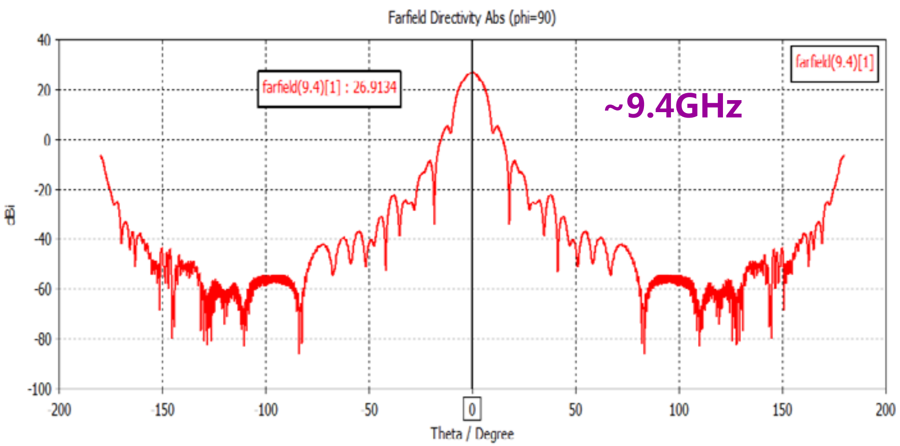
| | | | | |
|---|---|---|---|---|
| **Frequencies** | **~9.7GHz** | **~13.5GHz** | **~17.25GHz** | **~22.6GHz** |
| **Gain** | **≥26dB** | **≥27.5dB** | **≥28.5dB** | **≥30dB** |
| **Power** | **≥2W** | **≥2W** | **≥2W** | **≥2W** |
| **Sampling** | **≥500Hz** | | | |

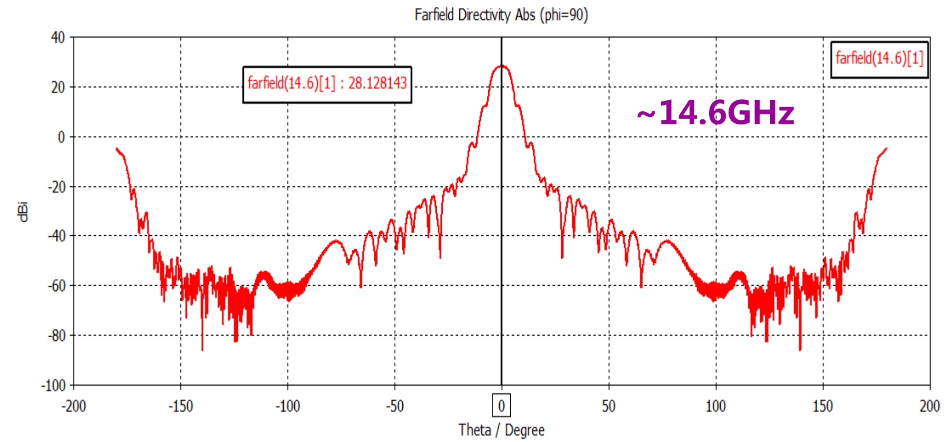


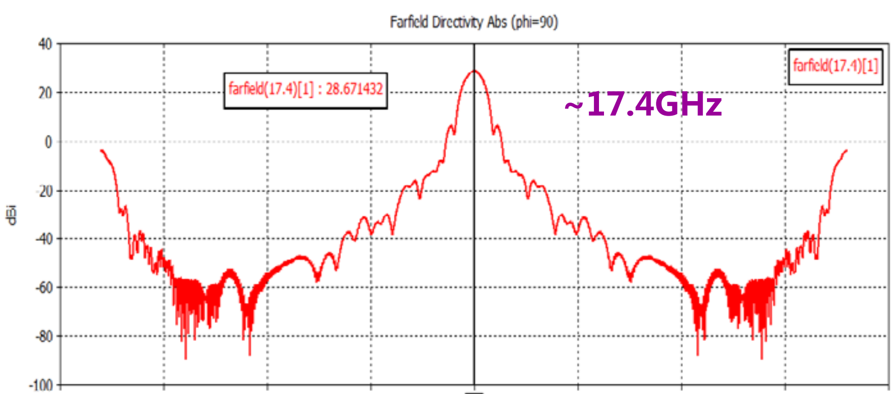

In order to probe the lower troposphere using differential measurements, four frequency channels (see the table) were selected for the Tx and Rx design. Using these four frequencies, an error effects analysis has been conducted using End-to-End simulation (EGOPS).
Each error (e.g. POD uncertainty, thermal noise, gain drift, clock bias… ) effect has been analyzed, individually. Then the total errors' effect on the LMO retrievals was performed. Here we show the total errors' effects on pressure, temperature and humidity, by RO profiles.

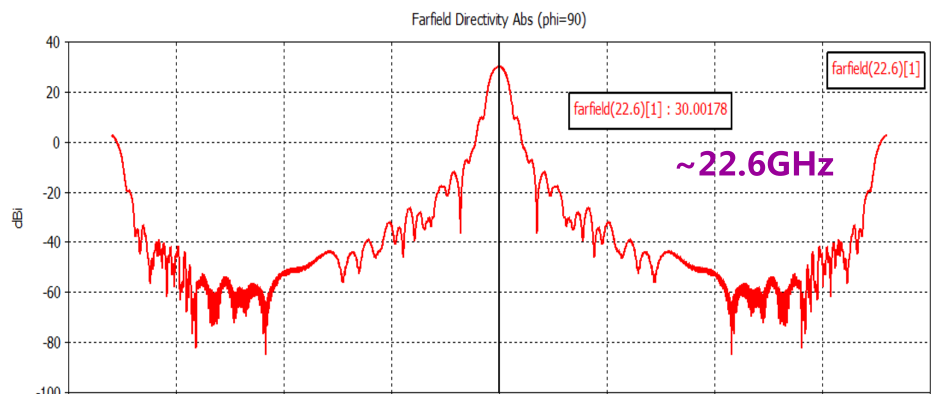


# Antenna amplitude stability control



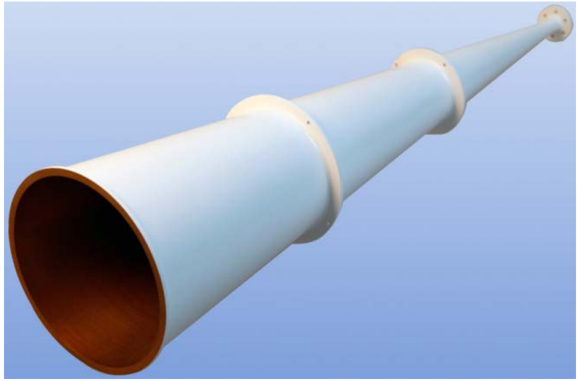




| Working Frequency | ~9.4GHz | ~14.6GHz | ~17.4GHz | ~22.6GHz |
|---|---|---|---|---|
| Gain Requirement | ≥26dB | ≥27.5dB | ≥28.5dB | ≥30dB |
| Simulation Results | 26.9 dB | 28.1 dB | 28.7 dB | 30 dB |

# Tx, Rx and their indoor test



**Antenna performance**

| Parameters | Gain ( dBi ) | Targets ( dBi ) |
|---|---|---|
| 9.4G-v | 27.03 | ≥26 |
| 14.6G-v | 29.11 | ≥27.5 |
| 17.4G-v | 28.61 | ≥28.5 |
| 22.6G-v | 30.90 | ≥30 |
| 9.4G-vf | 26.95 | ≥26 |
| 14.6G-vf | 29.39 | ≥27.5 |
| 17.4G-vf | 28.71 | ≥28.5 |
| 22.6G-vf | 30.85 | ≥30 |
| 9.4G-h | 26.49 | ≥26 |
| 14.6G-h | 29.08 | ≥27.5 |
| 17.4G-h | 28.73 | ≥28.5 |
| 22.6G-h | 30.75 | ≥30 |
| 9.4G-hf | 26.52 | ≥26 |
| 14.6G-hf | 29.16 | ≥27.5 |
| 17.4G-hf | 28.83 | ≥28.5 |
| 22.6G-hf | 30.79 | ≥30 |

**Transmitter performance**

| Frequencies | | 9.4GHz | 14.6GHz | 17.4GHz | 22.6GHz |
|---|---|---|---|---|---|
| Powers | Targets | ≥2W | ≥2W | ≥2W | ≥2W |
| | Test values | 2.29W | 2.63W | 2.45W | 2.63W |

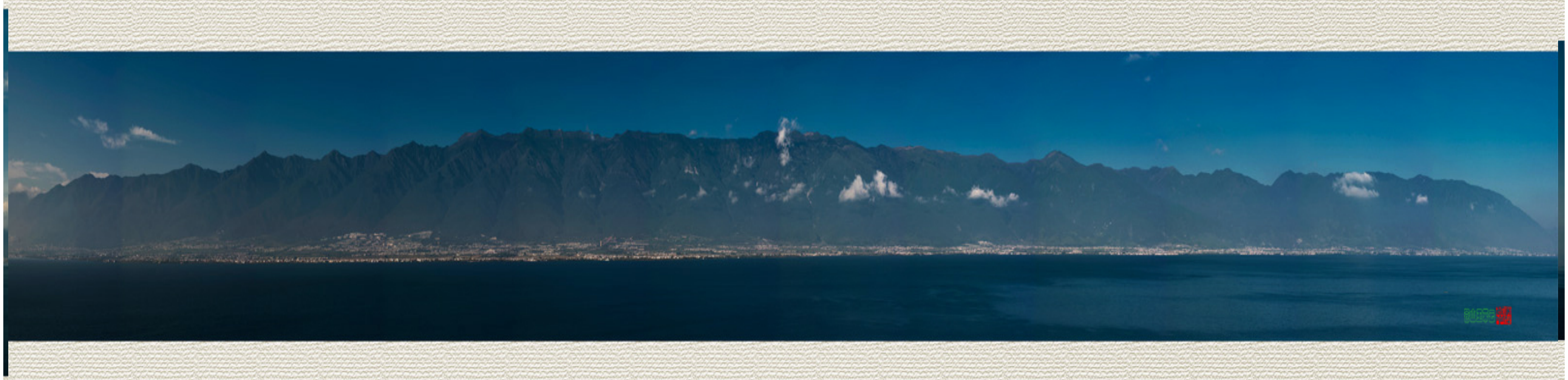
| Frequencies | | 9.4GHz | 14.6GHz | 17.4GHz | 22.6GHz |
|---|---|---|---|---|---|
| Amplitude Stability | Targets | ≤0.01dB | ≤0.01dB | ≤0.01dB | ≤0.01dB |
| | Test values | 0. 0025dB | 0. 0027dB | 0. 0053dB | 0. 0025dB |

**Receiver performance**

| Frequencies | | 9.4GHz | 14.6GHz | 17.4GHz | 22.6GHz |
|---|---|---|---|---|---|
| Gain Stability | Targets | ≤0.01dB | ≤0.01dB | ≤0.01dB | ≤0.01dB |
| | Test values | 0.0027dB | 0.0025dB | 0.0033dB | 0.0032dB |

# Tx, Rx and their outdoor test plan

## Dali, Yunnan province



# Summery and Conclusion

**In China:**

●A flight model Sat-Sat occultation receiver has been developed for Mars

●An Earth observation mission named Climate and Atmospheric Composition Exploring Satellites (CACES) using LEO-LEO occultation and clouds & water vapor imaging has been accepted by the Strategic Priority Research Program of Chinese Academy of Sciences (SPRPCAS) as a concept study.

●The study of Earth LMO has been conducted in four aspects:

- Orbit design and GRO&LMO events analysis;
- Frequencies selection and error analysis;
- Transmitter and receiver design&development;
- Preparing an outdoor demonstration experiment.

●Preliminary studies of LIO have been started as well.

**Look forwards your cooperation…**

**Thank you!**

# Conferences announcement:

Conference: IEEE GNSS+R 2021
Country: China
City: Beijing
Start Date: 10th May 2021
End Date: 12th May 2021

We would like to provide conference venues, service and another contributions to the following on IROWG workshops as well.

Conference: IGL-2 2021
Country: China
City: Beijing
Start Date: 13th May 2021
End Date: 14th May 2021

Welcome to Beijing!

*or other weeks in May (TBC)*