# Wuhan SLR station progress and time synchronization for multi-station ranging

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# 1. SLR system

## 1.1 Basic information

We began the research of laser ranging and related technologies from 1970s at Wuhan SLR station, and the first SLR system (7231) is a 60cm aperture telescope, and then a new 1m aperture telescope (7396) was built in 2018, and this SLR system obtained the first ranging data at September 28, 2018.

# 1. SLR system

## 1.2 key parameters

- **Fork mount**

  Track accuracy: <1″

  Pointing accuracy: <3″

- **Telescope**

  1010mm aperture

  10 arcminute receiving view

- **Laser**

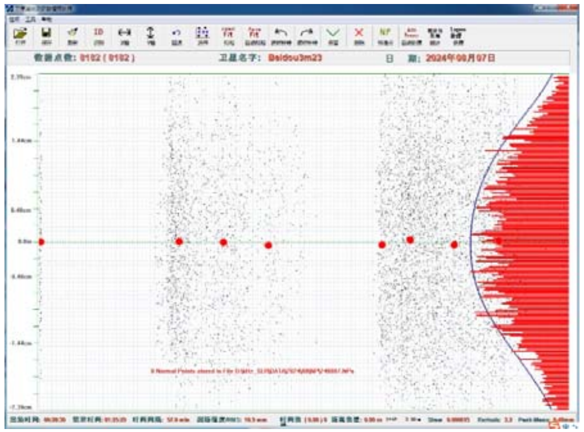
  2kHz repetition rate

  2.5mJ per pulse (Maximum)

- **Ranging ability**

  Daytime Ranging (difficult for GNSS satellites)

  2kHz ranging



| Items | 2021 | 2022 | 2023 |
|---|---|---|---|
| Calibration RMS | 5.2 mm | 5.3 mm | 4.6 mm |
| Starlette RMS | 8.0 mm | 7.5 mm | 6.6 mm |
| LAGEOS RMS | 6.6 mm | 6.8 mm | 6.6 mm |
| Total Passes | 5689 | 5534 | 3738 |

# 1. SLR system

## 1.3 Equipment Update

Laser, clock and coaxial-cables for transmit and echo signals had renewed.

**Laser (2023.2)**


**Clock**


2.5mj@2kHz@532nm

FWHM ≤50ps

M2＜1.3@532nm

Timing: <0.9ns （ UTC(NIM) or UTC(NTSC) ）

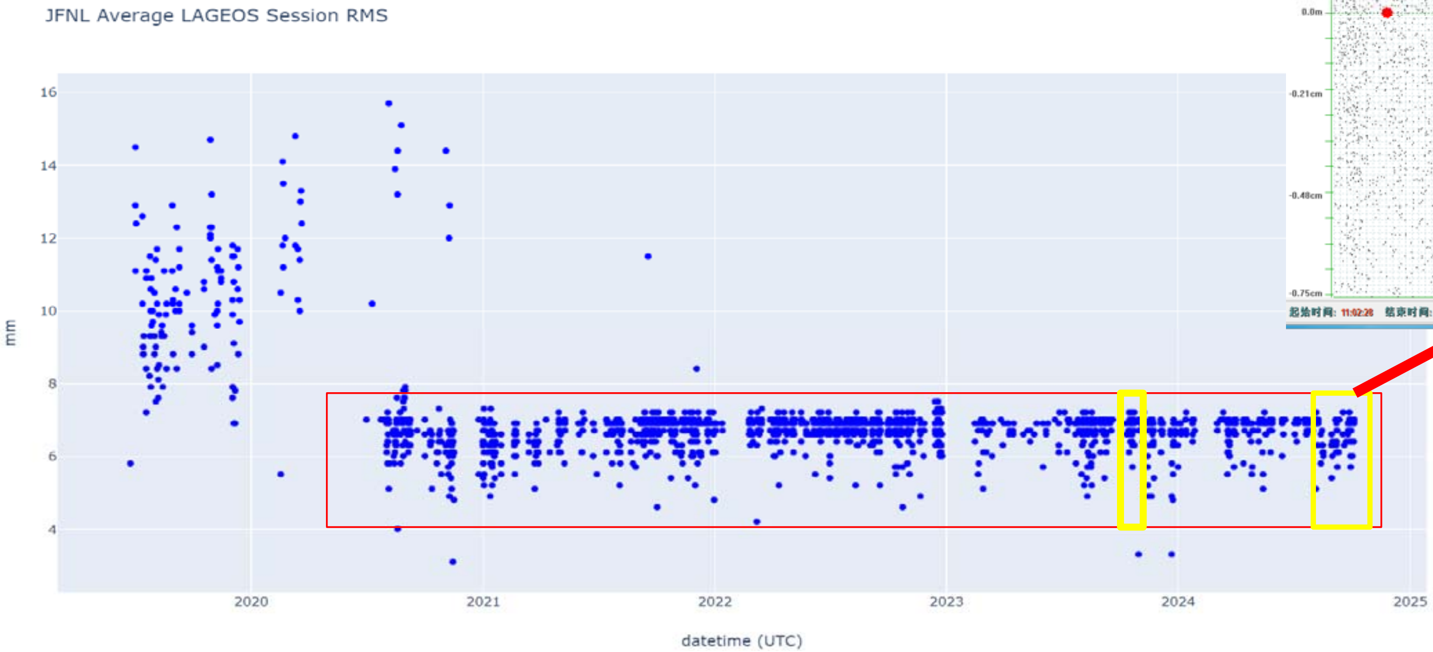
Frequency deviation: <2E-13@day

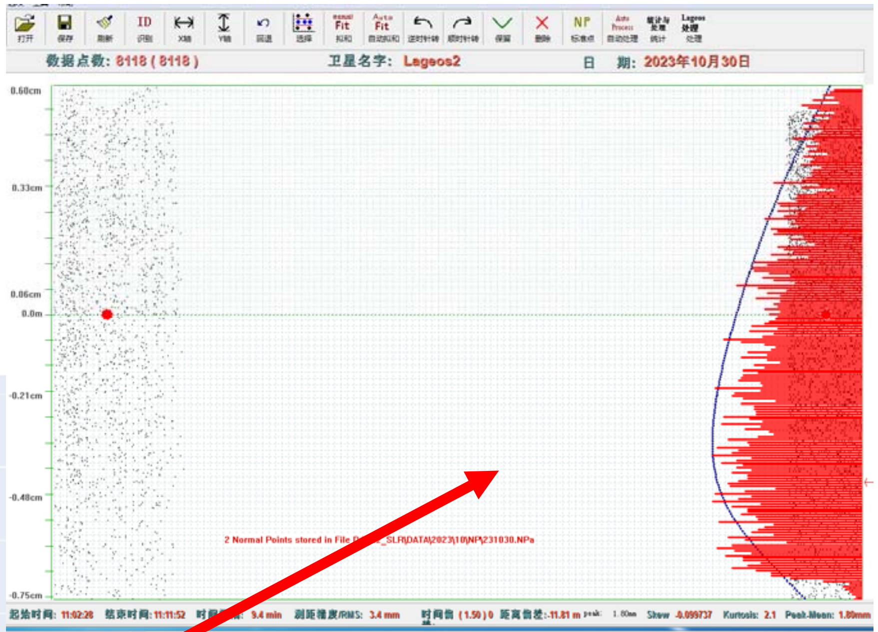
VCH1008: using for laser time transfer

# 1. SLR system

## 1.4 Ranging performance

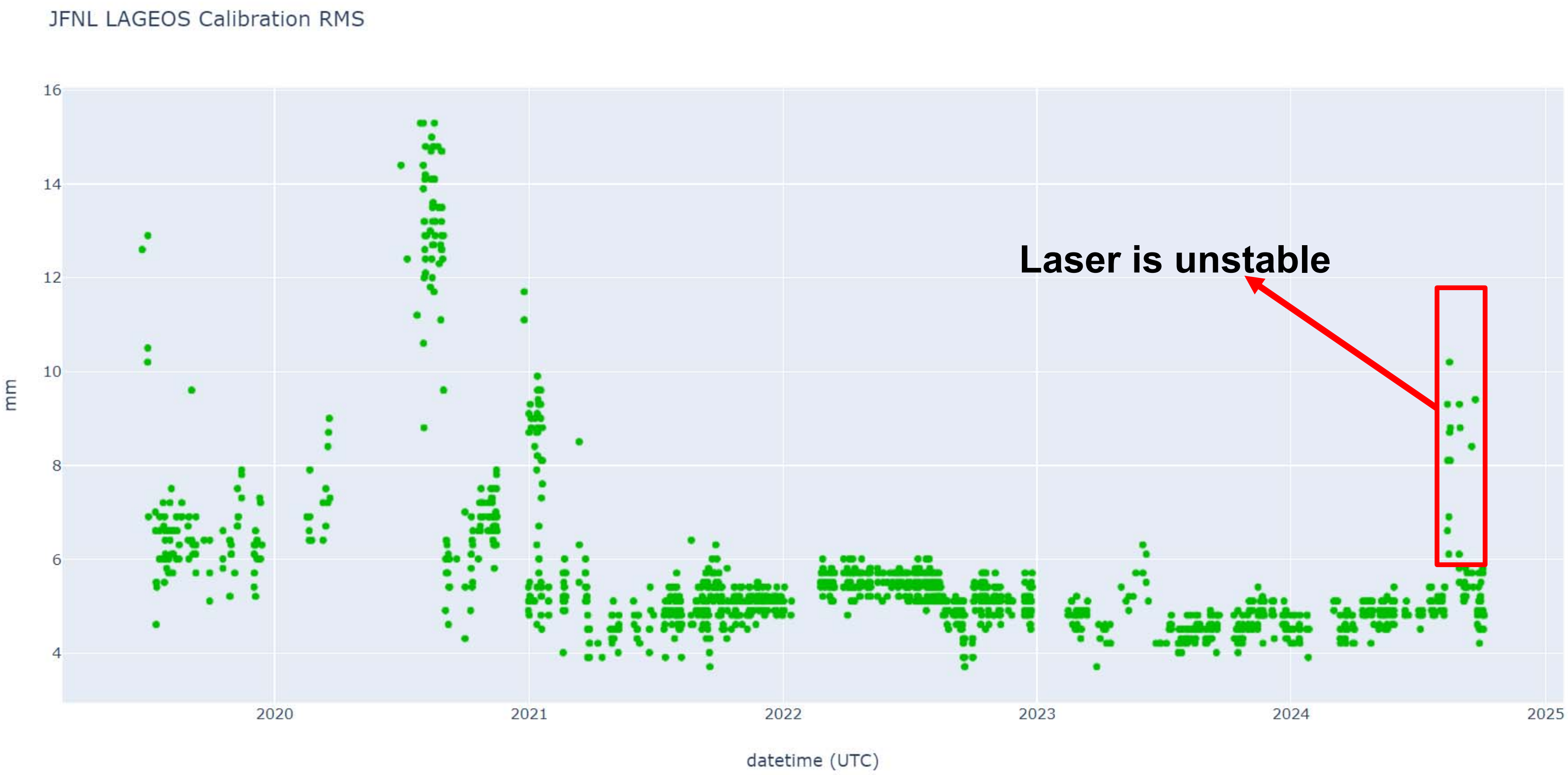
The RMS values of Lageos satellites are less than 8mm，but we find that the waveforms of the valid data statistics charts of 1kHz and 2kHz are different



# 1. SLR system

## 1.4 Ranging performance



# 1. SLR system

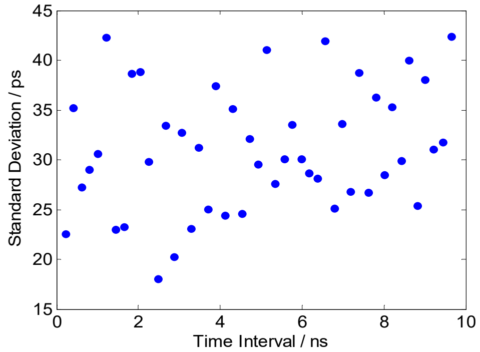
## 1.5 Technology research

### 1) SLR orbit determination and determination of coordinates of SLR station

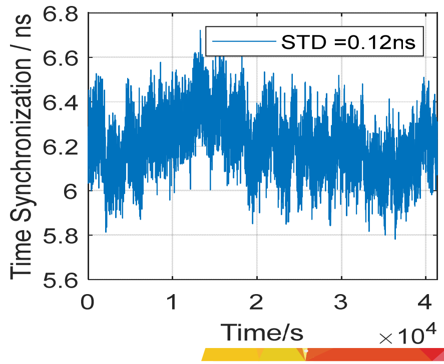
| | LAGEOS1 | | LAGEOS2 | |
|---|---|---|---|---|
| | Mean | RMS | Mean | RMS |
| **Radial** | 0.289 | 0.605 | -0.039 | 0.613 |
| **Tangential** | -0.063 | 2.615 | -0.249 | 2.667 |
| **Normal** | -0.067 | 2.522 | 0.011 | 2.512 |
| **3DRMS** | 3.683 | | 3.714 | |

### 2) Time measurement and time synchronization

TDC realized on 130nm FPGA, the resolution is less than 10ps



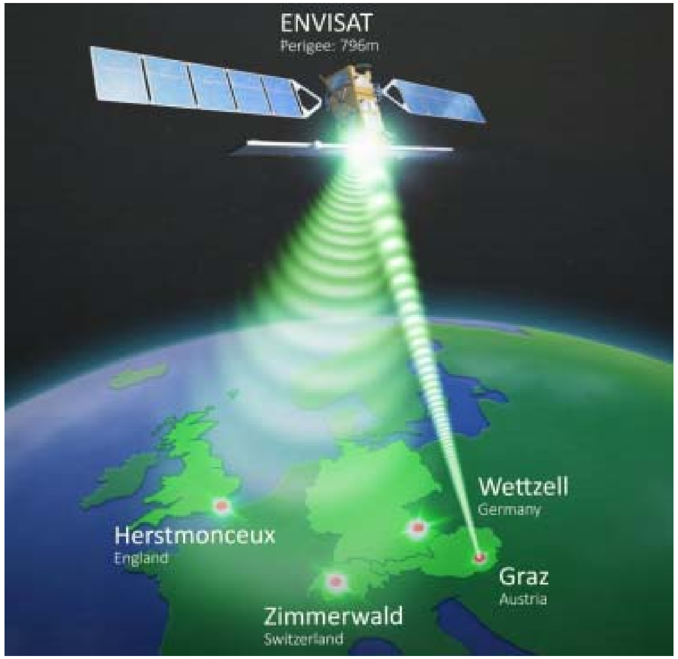

High precision time comparison based on GNSS PPP, real-time time synchronization is less than 0.2ns

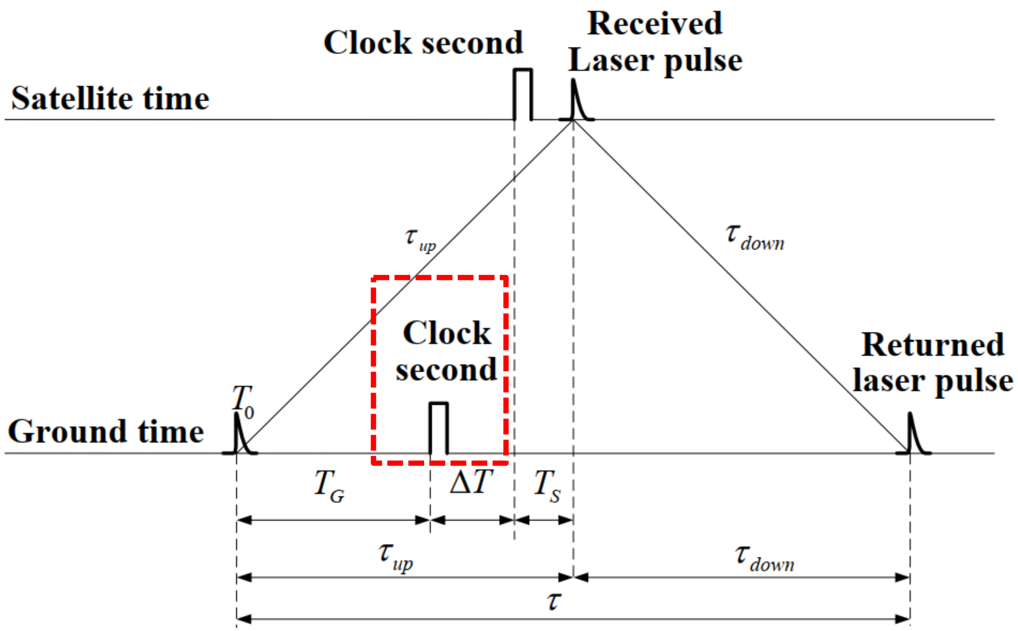


# 2. Time synchronization

## 2.1 Background

**Multi-telescope (debris) laser ranging and laser time transfer**




$$R = c * (t_{receive} - t_{send} + \Delta t)/2 + \varepsilon$$

# 2. Time synchronization

## 2.2 Principle of GNSS PPP Time Transfer

**The PPP time transfer technology is based on dual-frequency pseudorange and carrier phase observations using the GNSS satellite high-precision orbit and clock products and the extended Kalman filter parameter estimation.**

$$P_{r,j}^{S,i} = u_r^s * x + c d\bar{t} + M_r^{S,i} \cdot Z_r + \varepsilon_{r,IFij}^s$$

$$L_{r,j}^{S,i} = u_r^s * x + c d\bar{t} + M_r^{S,i} \cdot Z_r + N_{r,IFij}^s + \xi_{r,IFij}^s$$

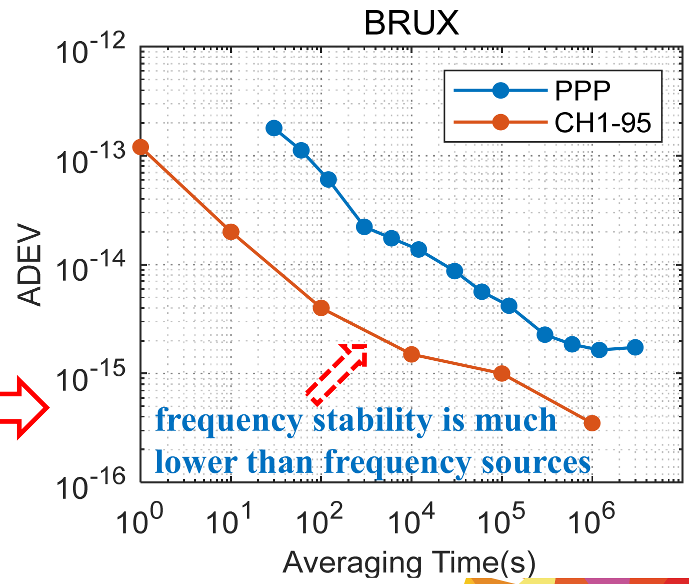
- **White noise clocks model**
  - **state equation:** $\hat{x}(t_{k+1}) = x(t_k)_{SPP}$
  - **process noise** $Q_W$**:** $\boldsymbol{Q}_w = \infty$

➕

- **Unmodeled Error**
  - **Zenith Wet Tropospheric**
  - **Elevation**

⇩ **high-precision atomic clocks model**

⇩ **Common-view difference**



# 2. Time synchronization

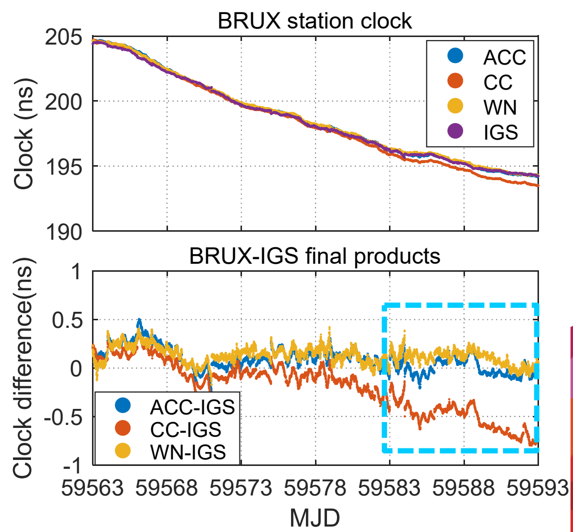
## 2.3 Adaptive clock constraint (ACC) model

At present, methods of atomic clock models mainly include three-dimensional kalman (TK) model, clock constraint (CC) model and random wander (RW) model. However, the external atomic clock has high short-term stability and time-variant characteristic. We use a sliding window to update covariance and frequency characteristics parameters in real-time, the state equation is expressed as :

$$\hat{x}(t_{k+1}) = x(t_k) + \left(\tilde{a}_1 + \frac{1}{2}\tilde{a}_2 \cdot (t_{k+1} + t_k - 2t_0)\right) \cdot \tau$$

$$\tilde{Q}_{w-ACC} = \tilde{Q}_{clock} + \tilde{Q}_{pre} \longrightarrow RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(\dot{x}_i - x_i)^2}$$

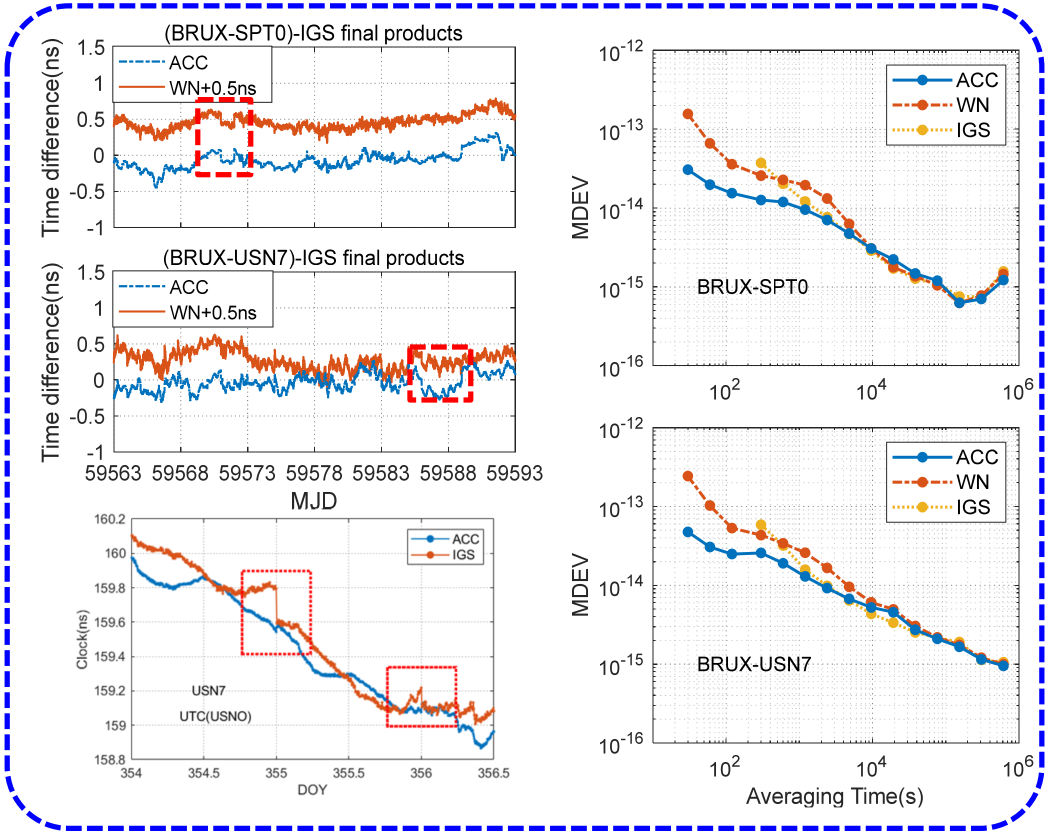
$$\tilde{Q}_{clock} = (H_{MDEV}(\tau) \cdot c)^2 \cdot \tau$$



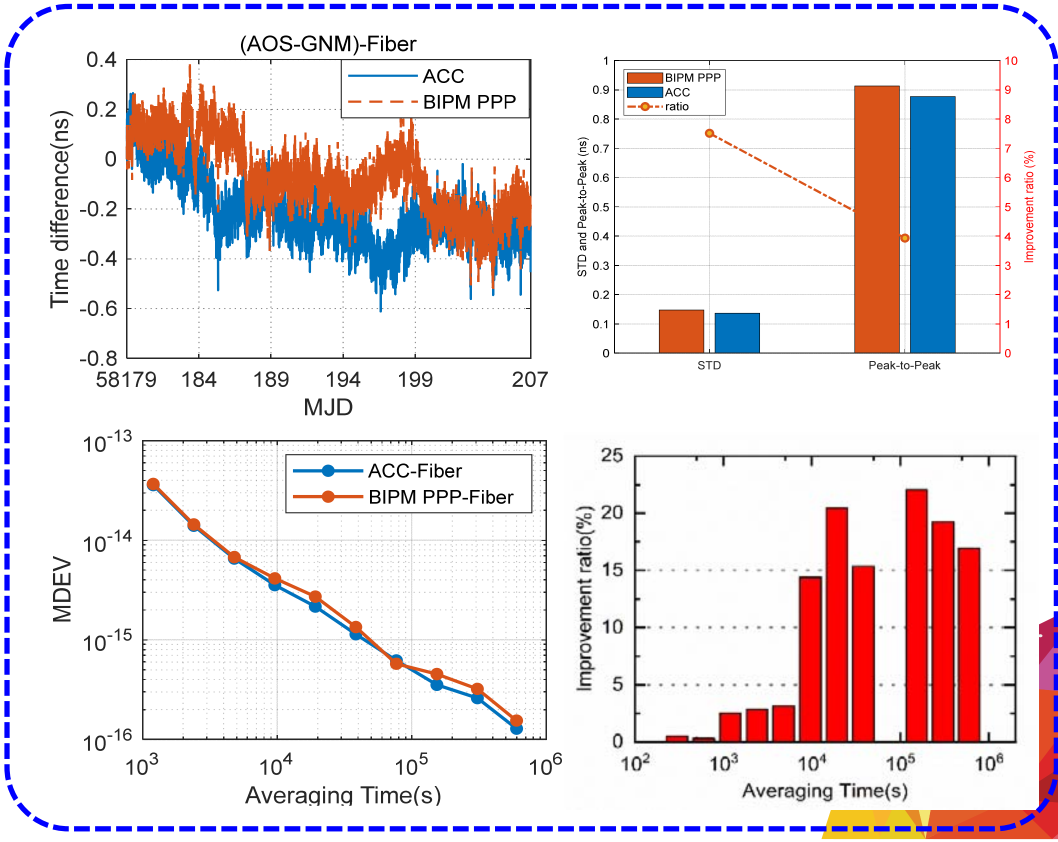
# 2. Time synchronization

## 2.3 Adaptive clock constraint (ACC) model

### 1) long baseline time transfer



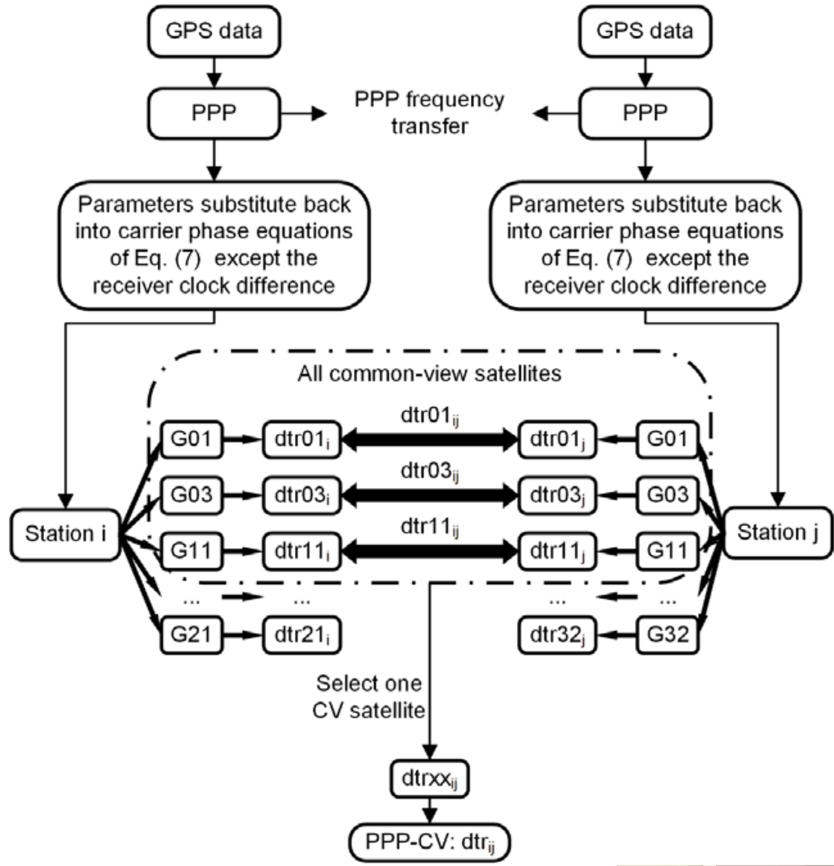

### 2) Using optical fiber (84.5km) results as reference



# 2. Time synchronization

## 2.4 Common-view difference time transfer based on PPP-derived parameters

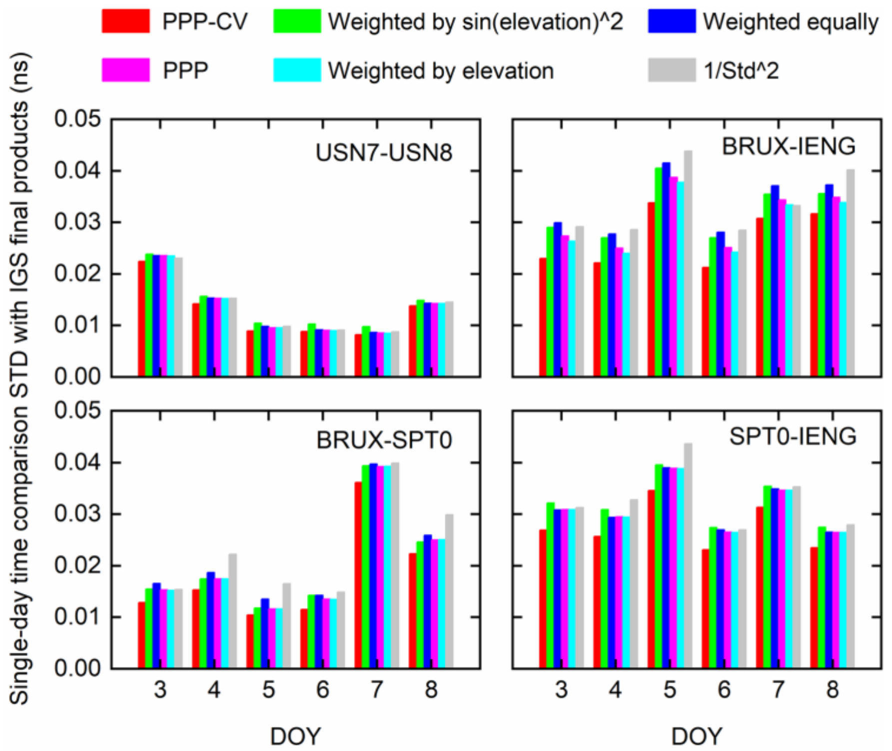
1) Calculating unknown parameters based on PPP method.
2) All solution parameters except the receiver clock difference are substituted back into the carrier phase combined observation equations, and obtained the clock difference of the receiver relative to every satellite.
3) Select the common-view satellite based on the minimum STD of the time comparison result for every fixed time interval (e.g. One hour)
4) choose the clock difference between the two stations with respect to the CV satellite as the transfer result.



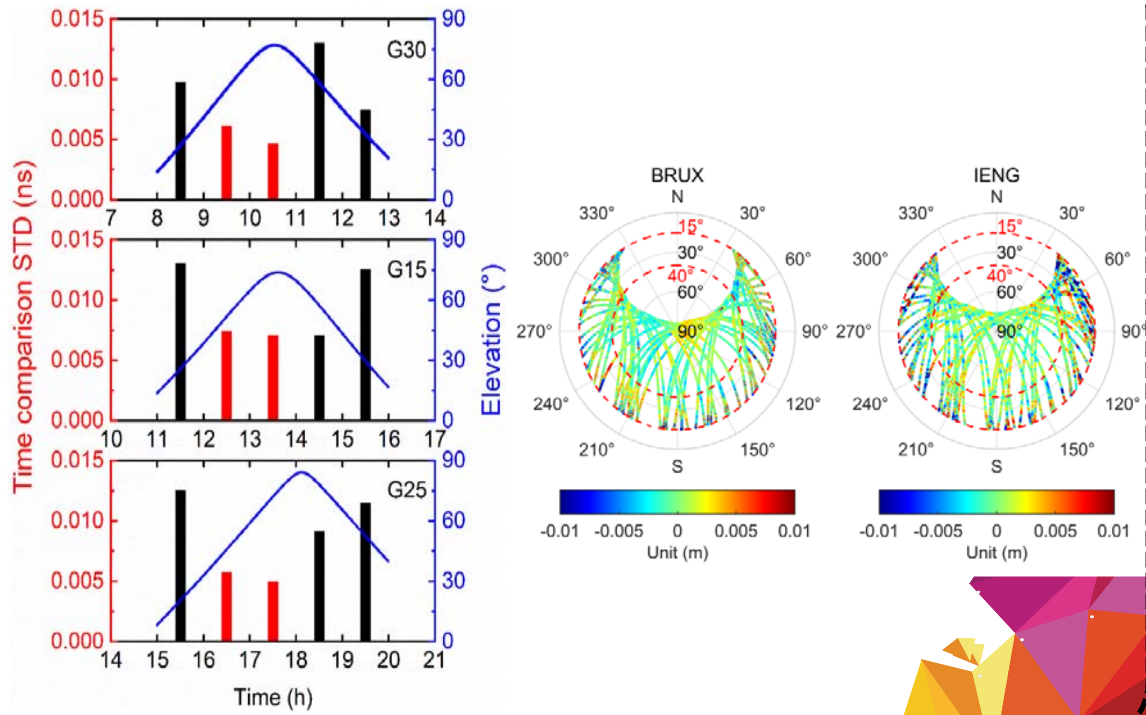
# 2. Time synchronization

## 2.4 Common-view difference time transfer based on PPP-derived parameters

### 1) Selection strategy of CV satellite



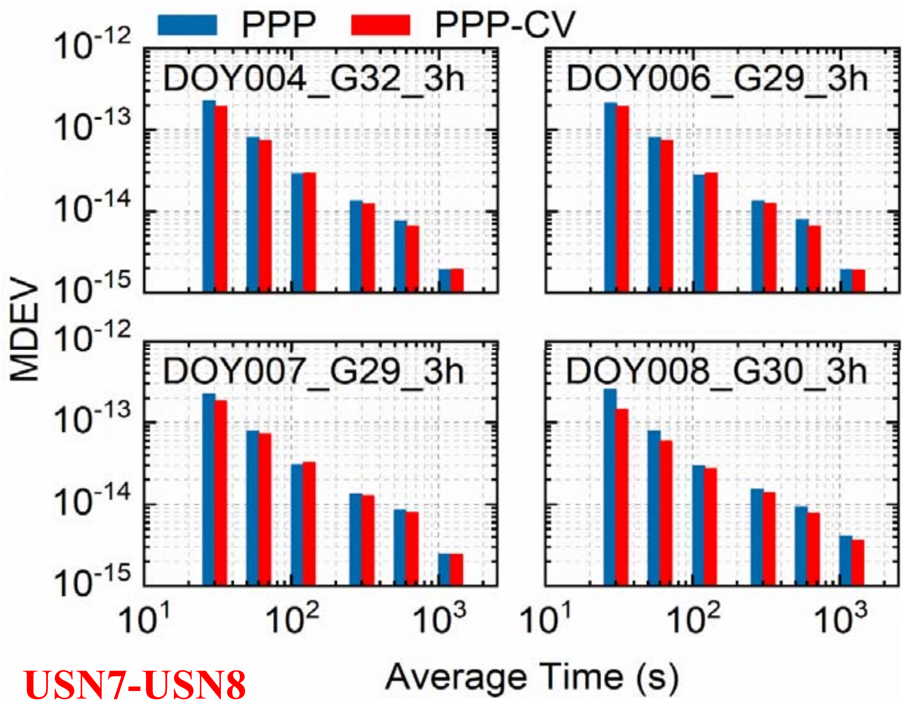

### 2) CV difference reducing symmetric atmosphere error



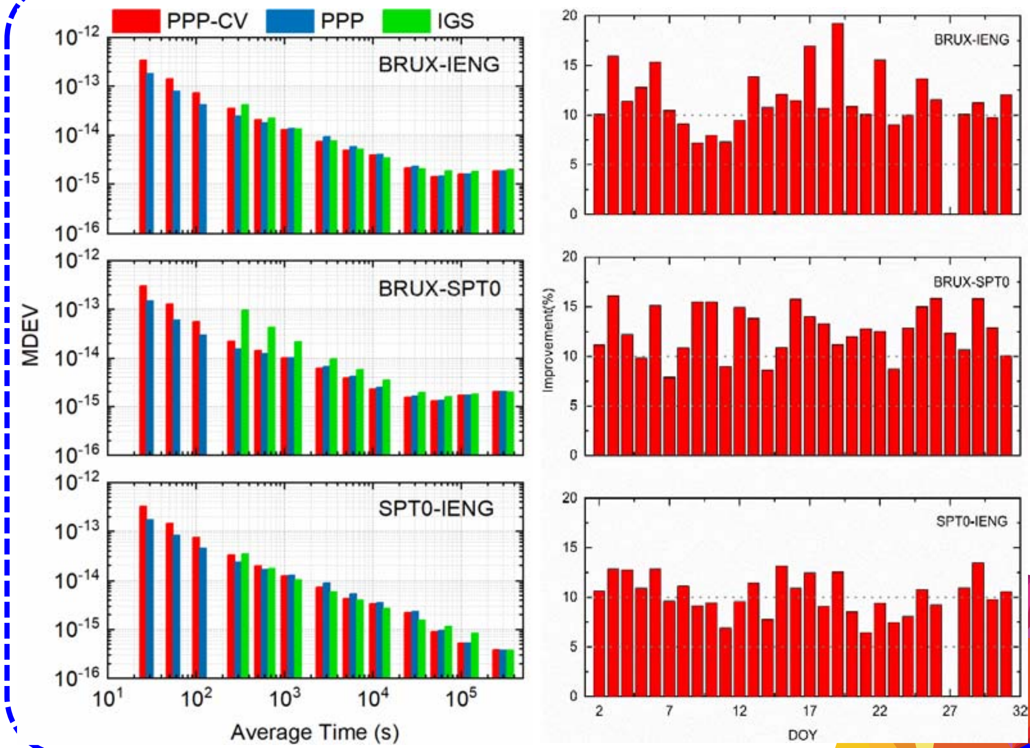
# 2. Time synchronization

## 2.4 Common-view difference time transfer based on PPP-derived parameters

**3) Short-term performance for only one satellite**




**4) long baseline time transfer**



# 3. Conclusion and Outlook

**Conclusion**

1) Wuhan SLR updated some key equipment, realized daytime ranging and 2kHz ranging, and the ranging precision is improving year by year.
2) Determined lageos orbit using ranging data, and the error is less than 4cm for three-dimensional.
3) Researched GNSS PPP time transfer method, proposed the ACC model of receiver clock and common-view difference time transfer based on PPP-derived parameters.
4) ACC model has better time transfer precision and frequency stability than the WN model. Time transfer precision is about 0.13 ns and the frequency stability is up to $5.6*10^{-16}$ /day.
5) CV based on PPP-derived parameters can reducing part of symmetric atmosphere error, and the performance of this method is better than PPP.

# 3. Conclusion and Outlook

Outlook

1) Method of suppressing noise light, make it easy for daytime ranging
2) Modifying the data processing for 2kHz ranging to improve the ranging precision
3) Developing the debris laser ranging technology.

# Thank you

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