The Preliminary Results of Laser Time Transfer (LTT) Experiment

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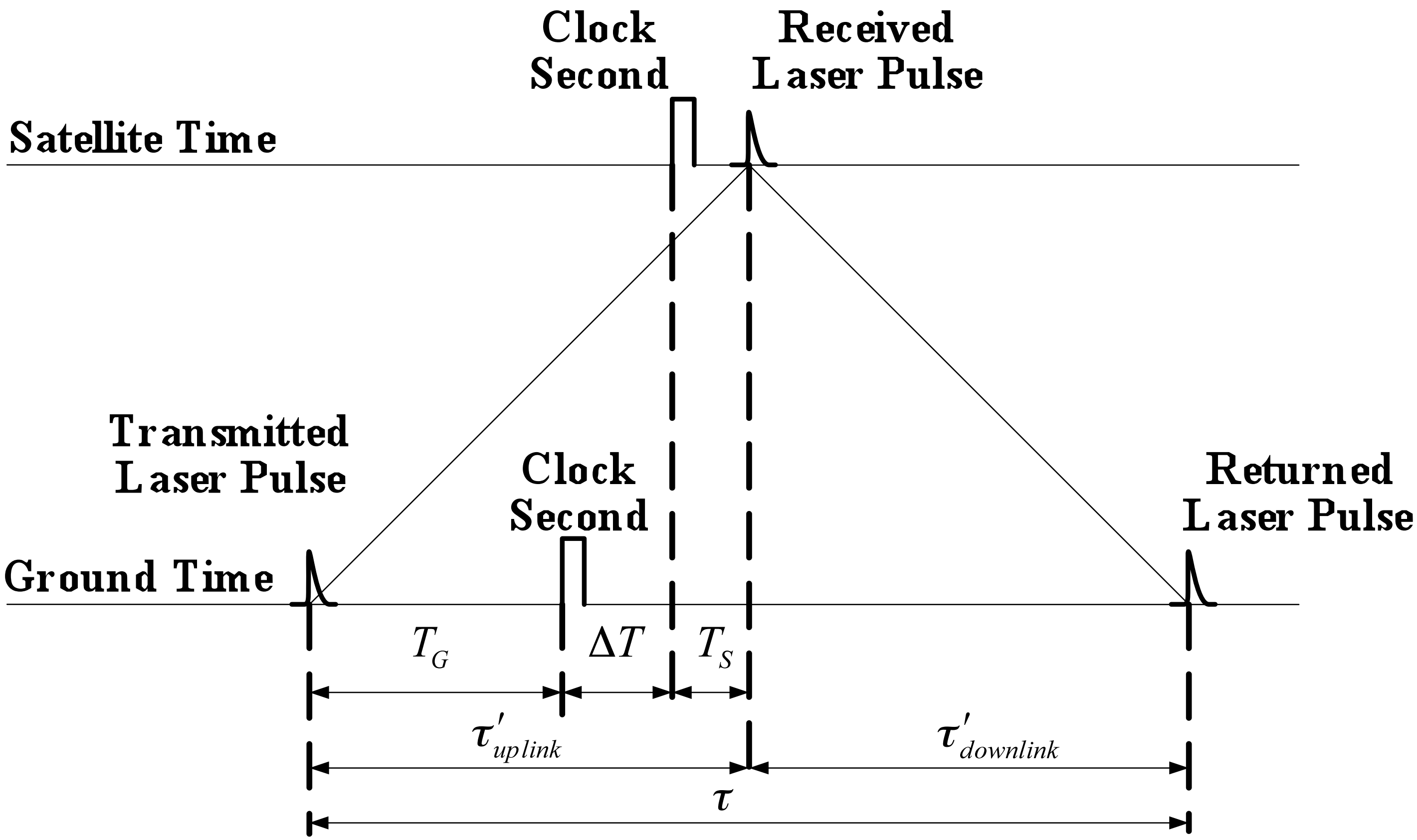
Goals

- Evaluate the performance of the space rubidium clocks with respective to the ground hydrogen maser, dedicated for the Compass system
- Testing of the Relativity theory

Time Table of LTT Project

- **1999-2000** **Proposal of LTT**
- **2002-2004** **Phase A study, Principle module finished**
- **2004-2005** **Phase B study, Engineering module finished**
- **2005-2006** **Flight module finished**
- **April 13, 2007** **The first LTT payload onboard the COMPASS-M1 into space, and LTT experiment started**
- **Mid-2009** **The second LTT payload will be onboard COMPASS-IGSO 1**
- **End of 2009** **The third LTT payload will be onboard COMPASS-IGSO 3**

Principle of Laser Time Transfer (LTT)



$$\Delta T = \tau'_{uplink} - T_G - T_S$$

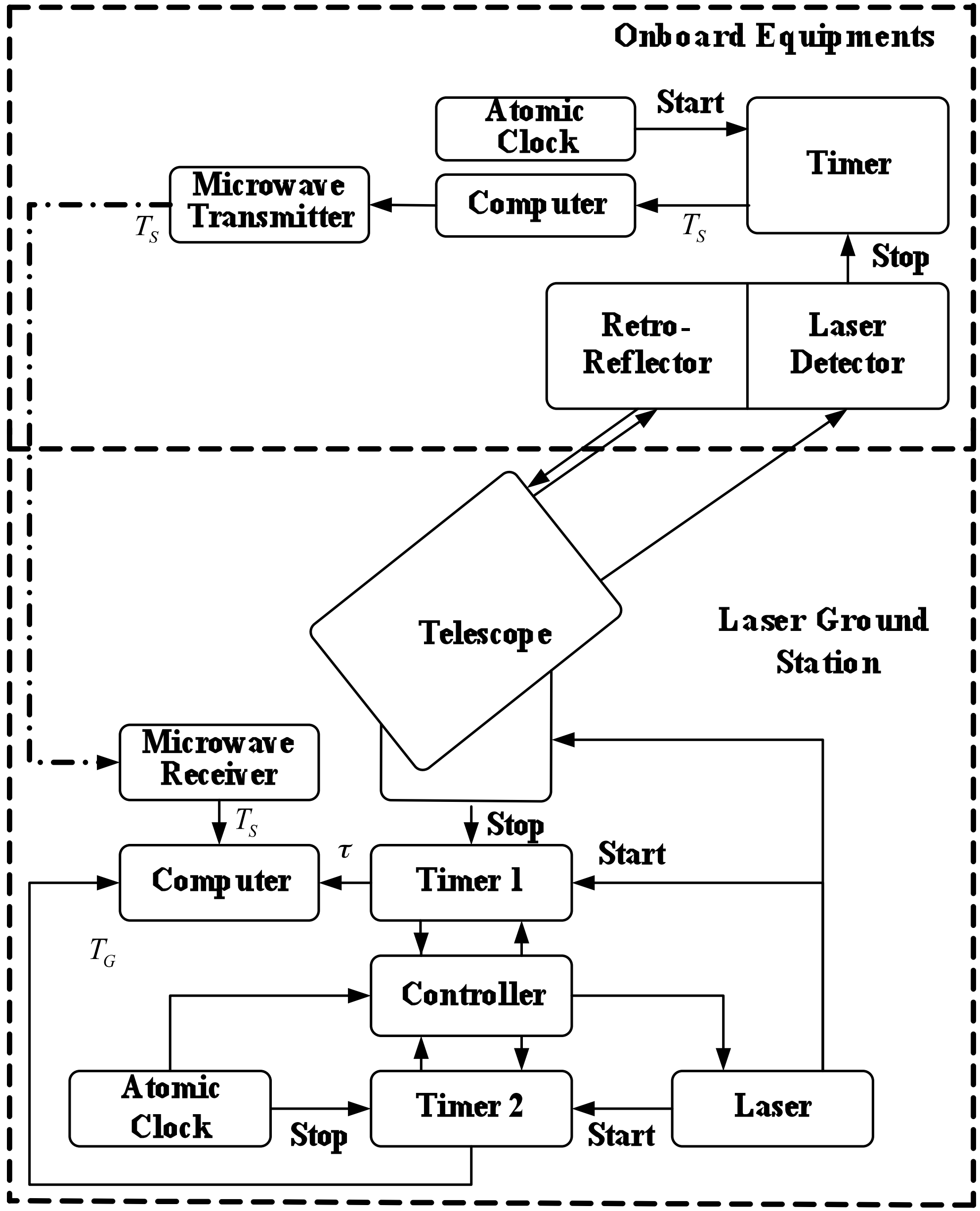
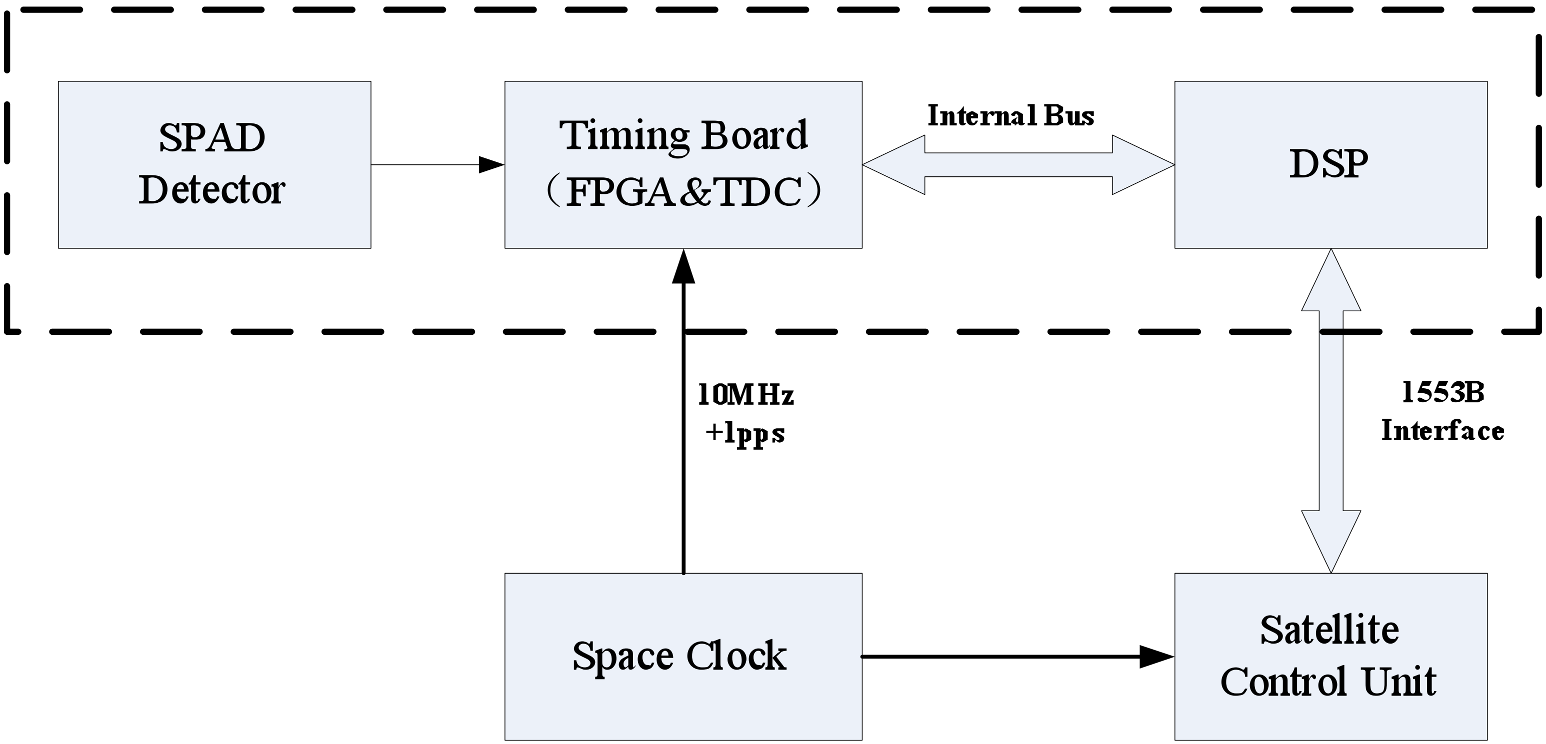


Diagram of LTT between Space and Ground clocks

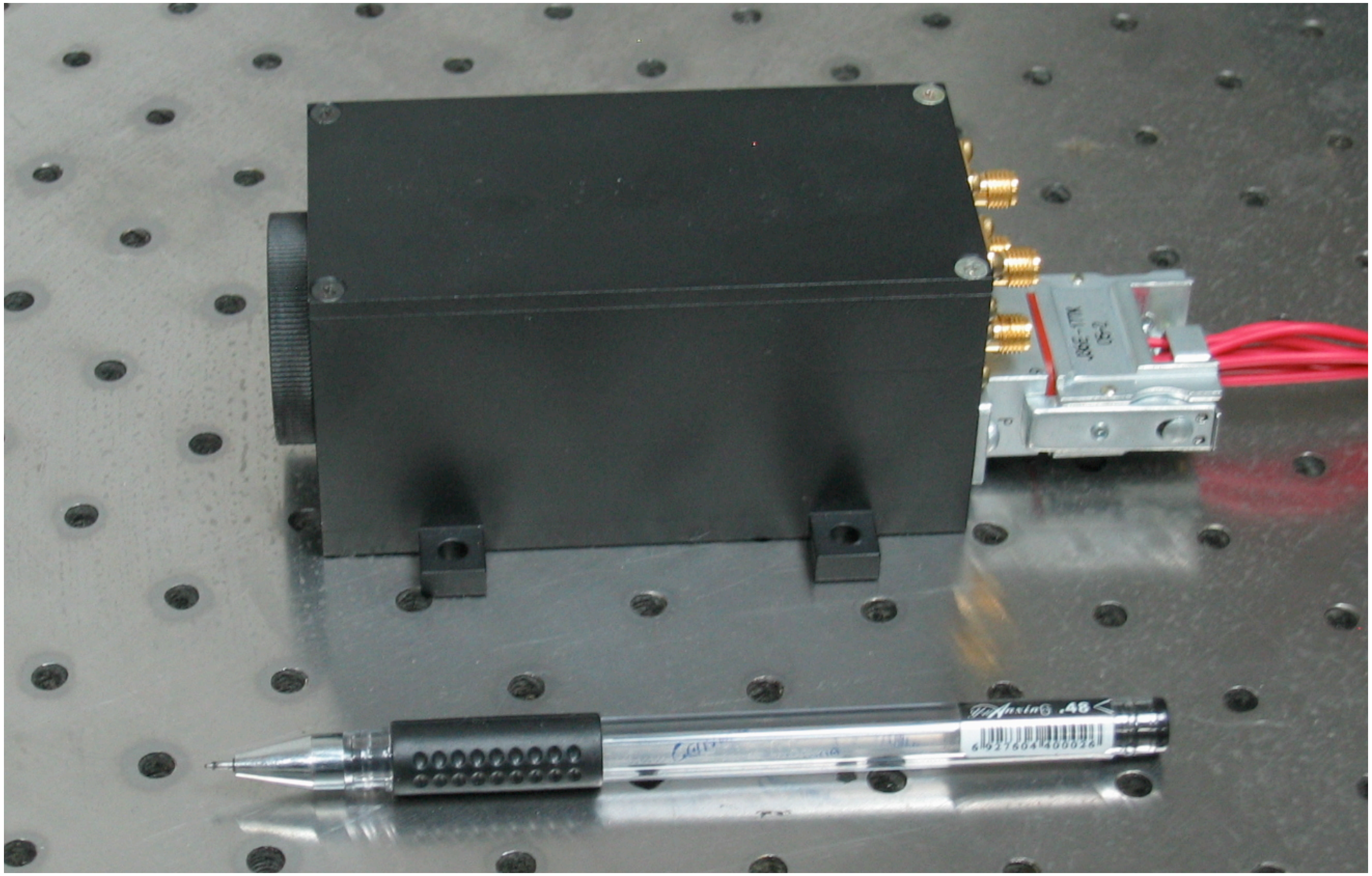


Block Diagram of LTT Module

Specifications of the Detector

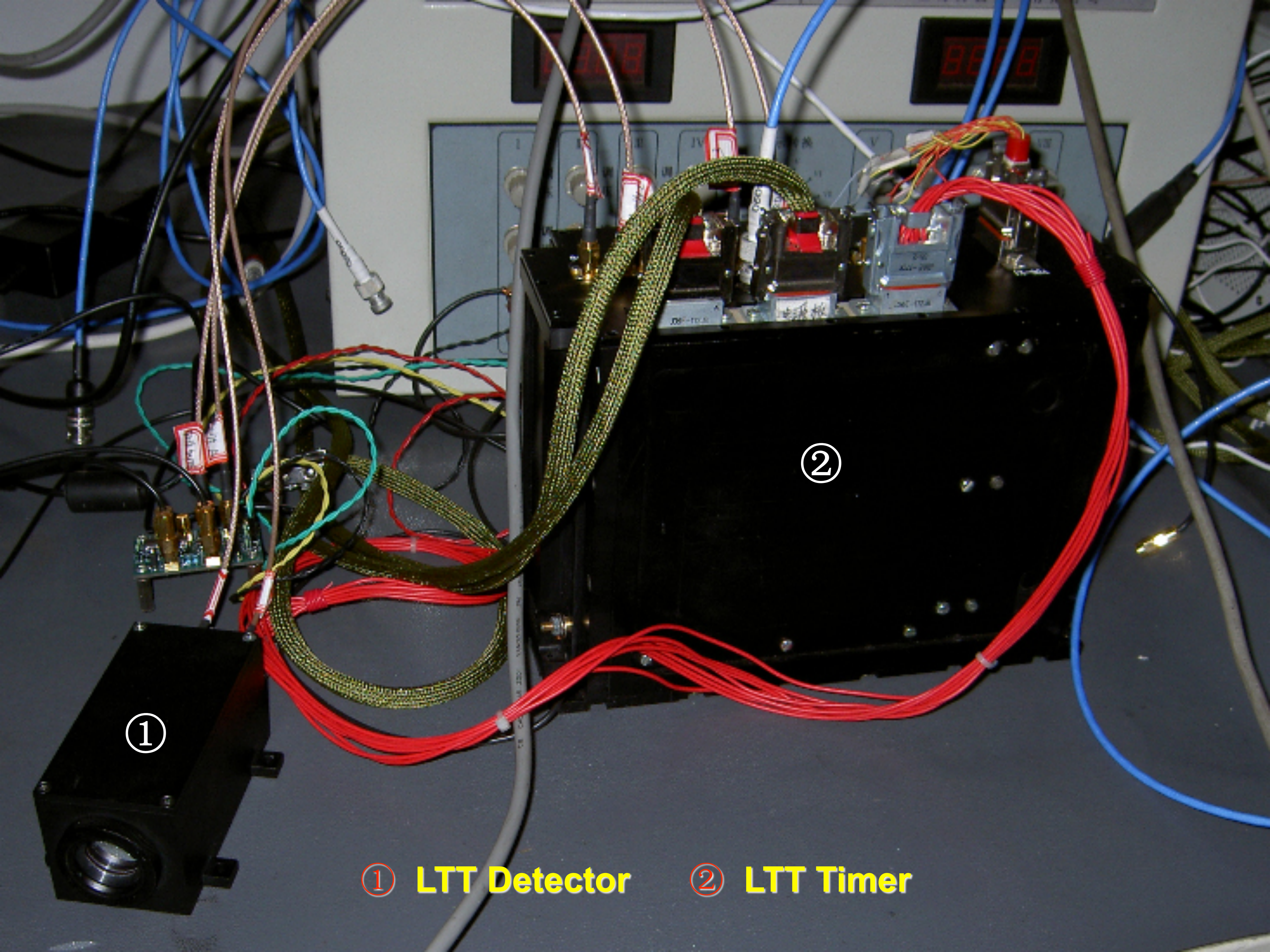
- Active area — circular 25 um diameter
- Timing resolution — < 100 psec
- Configuration — dual photon counting detector based on Silicon K14 SPAD
- Operating temp. — -30 … +60°C no cooling, no stabilisation
- Power consumption — < 400 mW
- Optical damage th. — full Solar flux 100 nm BW, > 8 hr
- Lifetime in space — > 5 years

LTT Detector



Dual-SPAD detector, 300g, <1W, 105×70×50mm

Field of View: 28°, 8.8nm bandwidth filter


①
②
① LTT Detector
② LTT Timer

Estimate of the Received Photons by the Onboard Detector

The number of photons (N_P) received by the onboard detector can be estimated by:

$$N_P = \frac{4 \cdot E \cdot S \cdot A_P \cdot K_t \cdot K_r \cdot T \cdot \alpha}{\pi \cdot R^2 \cdot \theta_t^2}$$

Where

E: Laser pulse energy, 100mJ(532nm)

S: Number of photons per joule (532nm), 2.7×1018

A_P: 40μm SPAD without any lenses, diameter of active area, 0.025mm

K_t: Eff. of transmitting optics, 0.60

K_r: Eff. of receiving optics, 0.60

T: Atmospheric transmission (one way), 0.55

R: Range of satellite, for MEO orbit at elevation 30°, 22600Km

θ_t: Divergency of laser beam from telescope, 10 arcsec

α: Attenuation factor, 0.3

We have,

$$N_p=8.4 \text{ (Photons)}$$

It can be detected by the 40 μm SPAD detector.

Laser Firing Control

- No gating on the 40um SPAD detector onboard.
- To reduce the effect of the noises produced by the albedo of the Earth, the ground station must control the laser firing epoch strictly according to the flight time from ground station to satellite, and let the laser pulse arrive at the detector just after the second pulse of the clock onboard about 50 ns or so. So it is equal to have a gate onboard.
- To meet the timing requirement, the laser on the ground station should be actively switched, and the passive switch (or active-passive) can not be used.
- The firing jitter of the new laser at Changchun now is 10ns.

Situation of the LTT project (1/3)

- Flight module for LTT experiment was completed in September 2006
- The parameters of the payload of the LTT including dual-detector and dual-timer are:
  - Mass 4.6Kg
  - Power consumption 18W
  - Dimensions:
    - 240×100×167mm (dual-timer, interfaces and power supply)
    - 105×70×50mm (dual-detector)
- The indoor testing showed the uncertainty of measurement for the relative frequency differences by laser link for two rubidium clocks was:
  - 4.0×10^{-13} in 200 seconds
  - 5×10^{-14} in 1000 seconds

Situation of the LTT project (2/3)

- The LTT payload onboard the Chinese experimental navigation satellite <Compass-M1> was launched on April 13, 2007. The orbital altitude of Compass-M1 is 21500km.
- The LTT experiment between the ground and the LTT payload has been done at the Changchun SLR station since August 2007.

Situation of the LTT project (3/3)

Upgrading of Changchun SLR

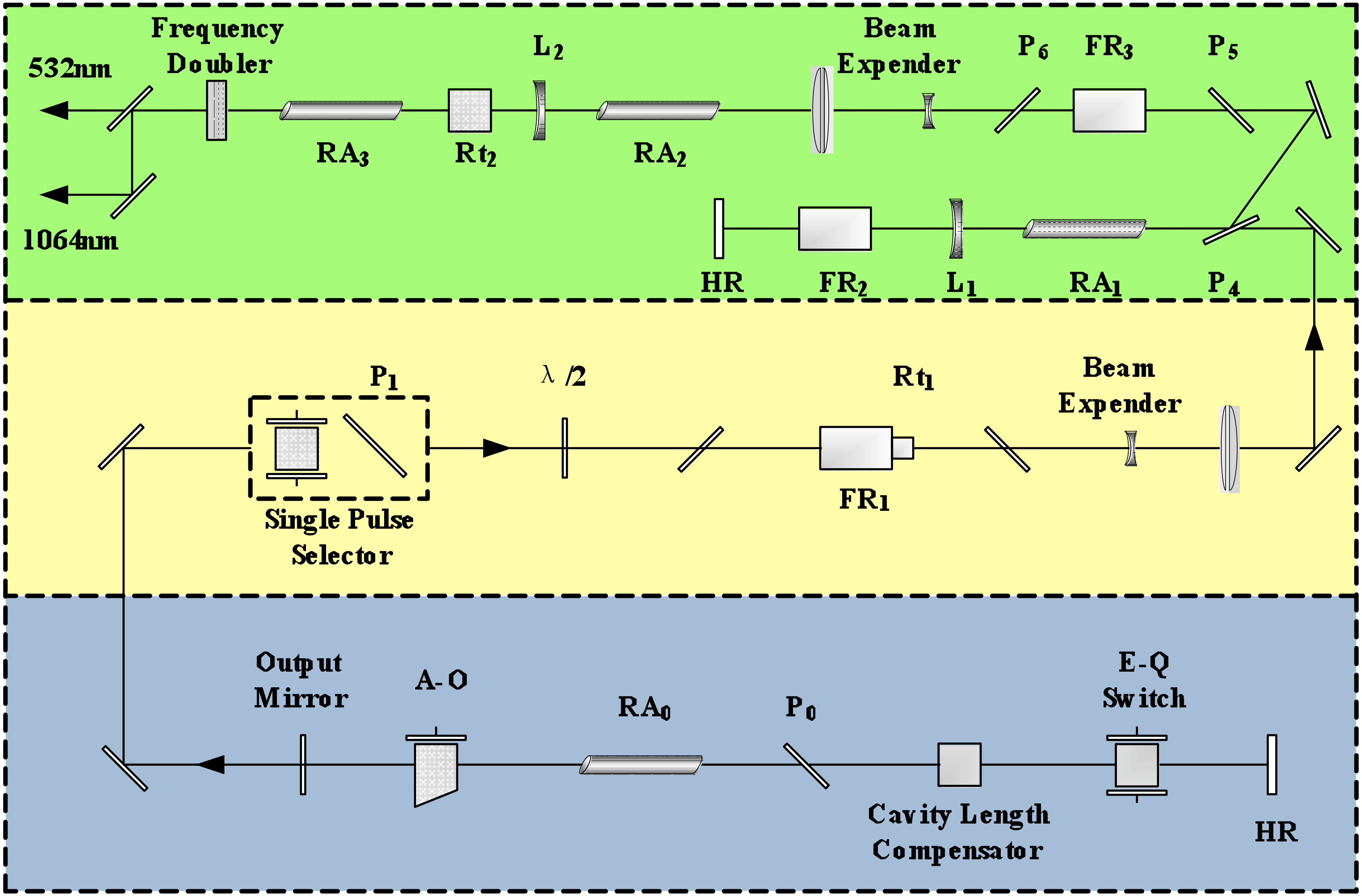
- New laser: (a loan from the NCRIEO in Beijing)
  Active-active mode-locked Nd:YAG laser
  100-150mJ in 532nm, 250ps, 20Hz
- New Coude mirrors
- 210mm diameter transmitting telescope
  10 aresec laser beam divergency
- 2 sets of event timer (Riga Univ.)
- 1 set of hydrogen maser (Shanghai Obs.)
- LTT software: laser firing control, LTT data analysis

Changchun Satellite Observatory

Changchun SLR Telescope

Active-active mode-locked Nd:YAG laser

100-150mJ (532nm), 250ps, 20Hz



RA_0: Oscillator Rod

RA_1-RA_3: Amplifier Rod

P_1-P_6: Polarizer

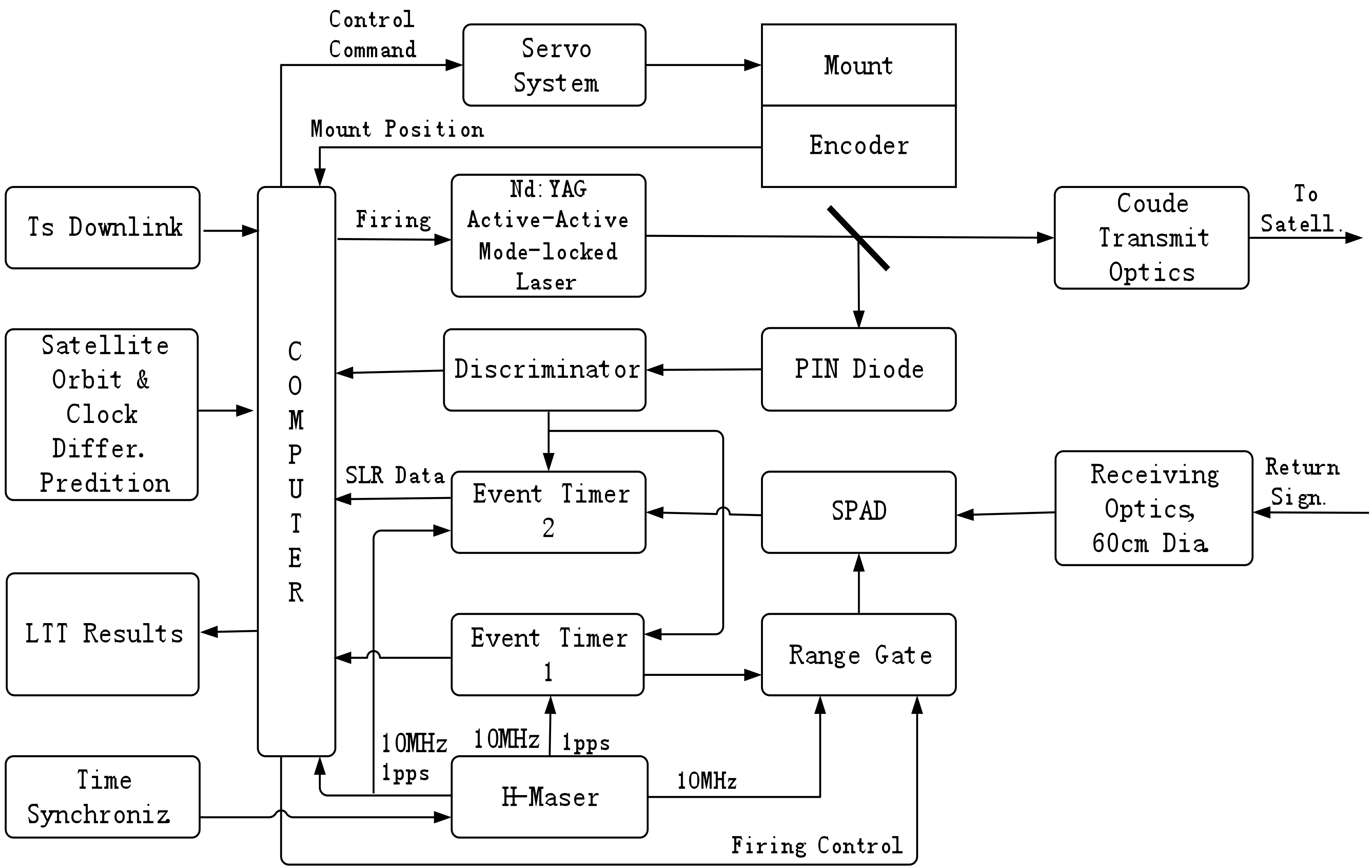
FR_1-FR_3: Faraday Isolator

Rt_1-Rt_2: Rotator

L_1-L_2: Negative Lens

Diagram of Active-active mode-locked laser for LTT

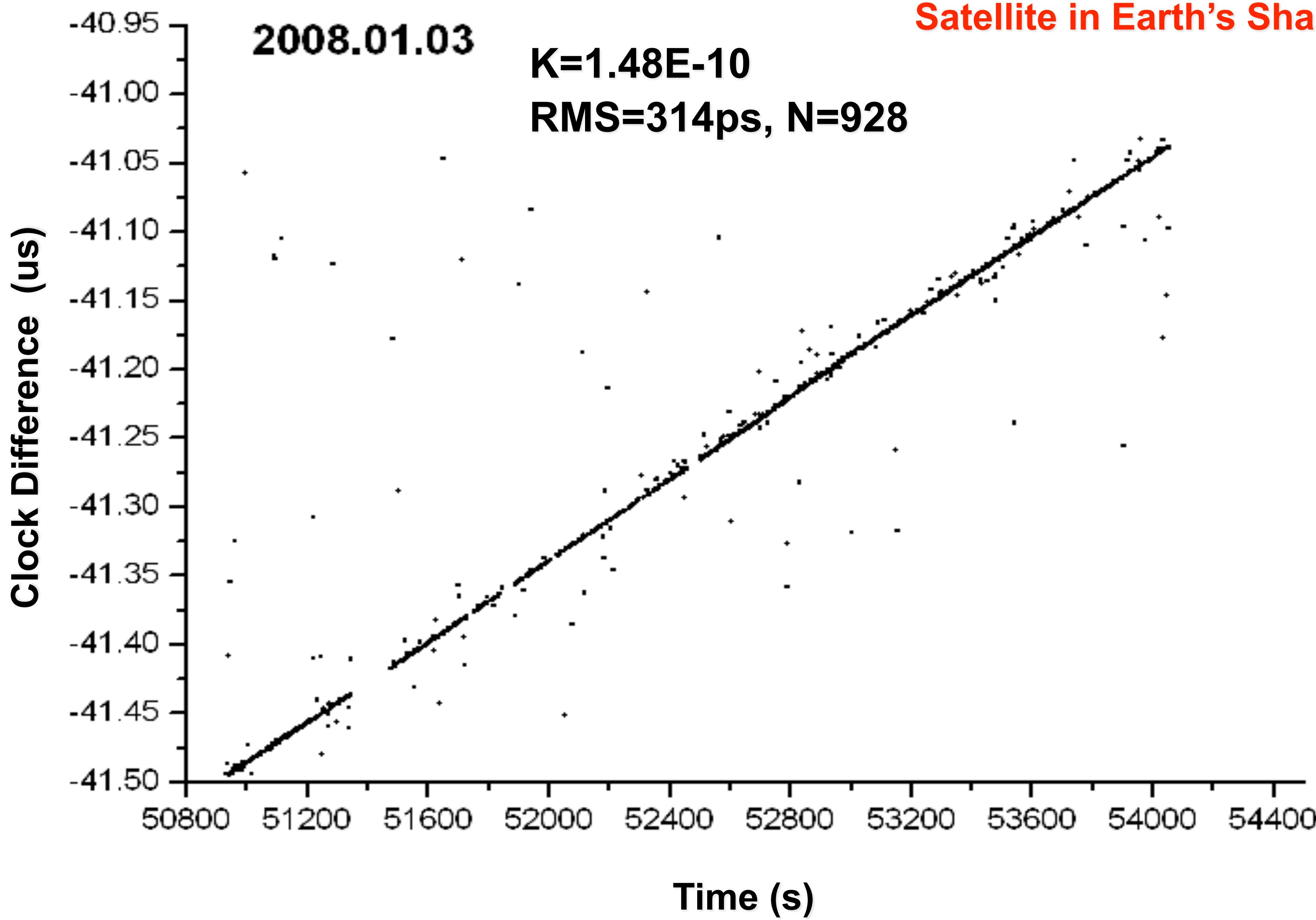

Timing Electronics
Laser & Tracking Control
Event Timer (2)
Compass Receiver
Hydrogen Maser
2007/06/14 09:17
Changchun SLR & LTT Control Room



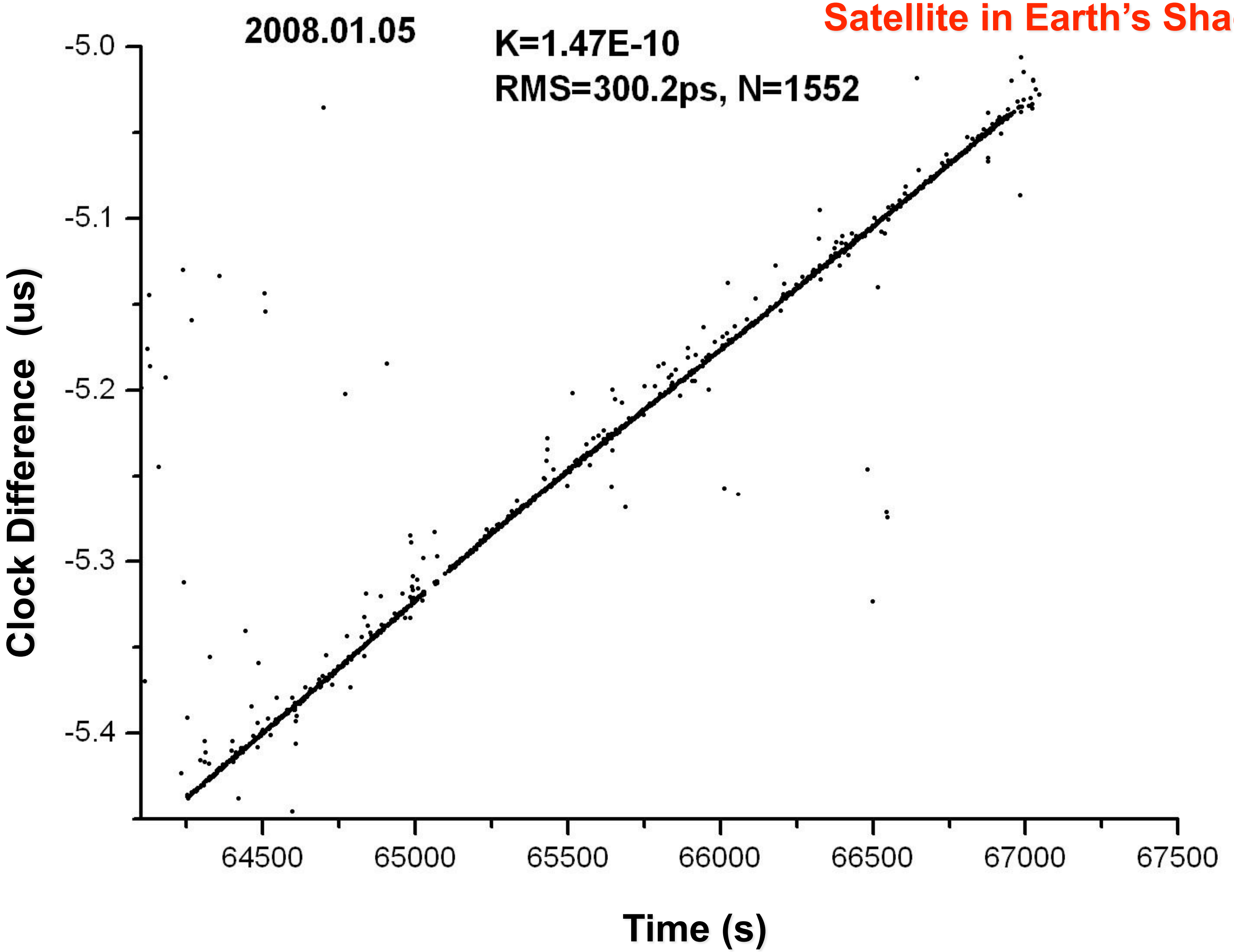
Block Diagram of Ground Station for LTT Experiment

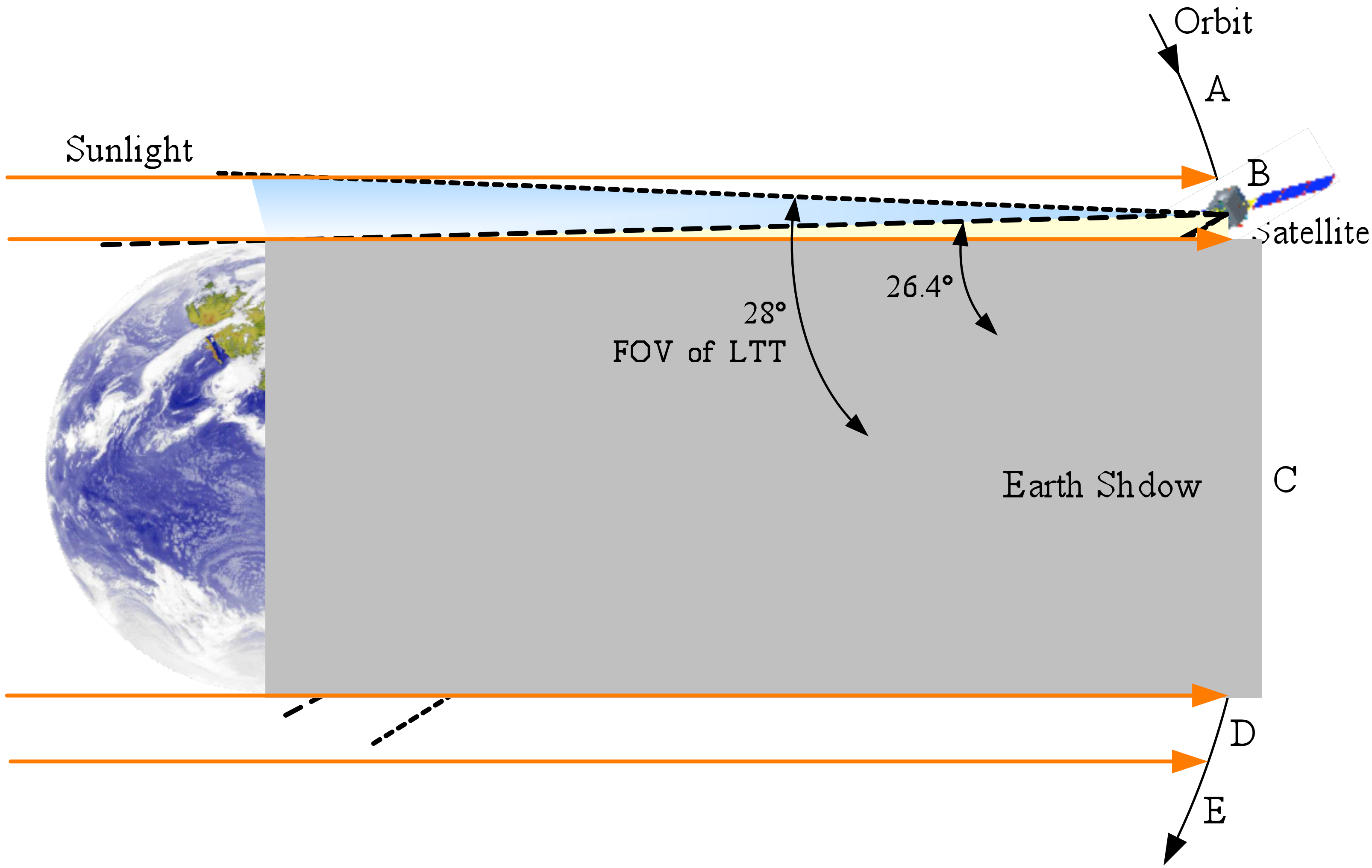
Some results of LTT experiment on clock differences between space and ground clocks

Satellite in Earth's Shadow

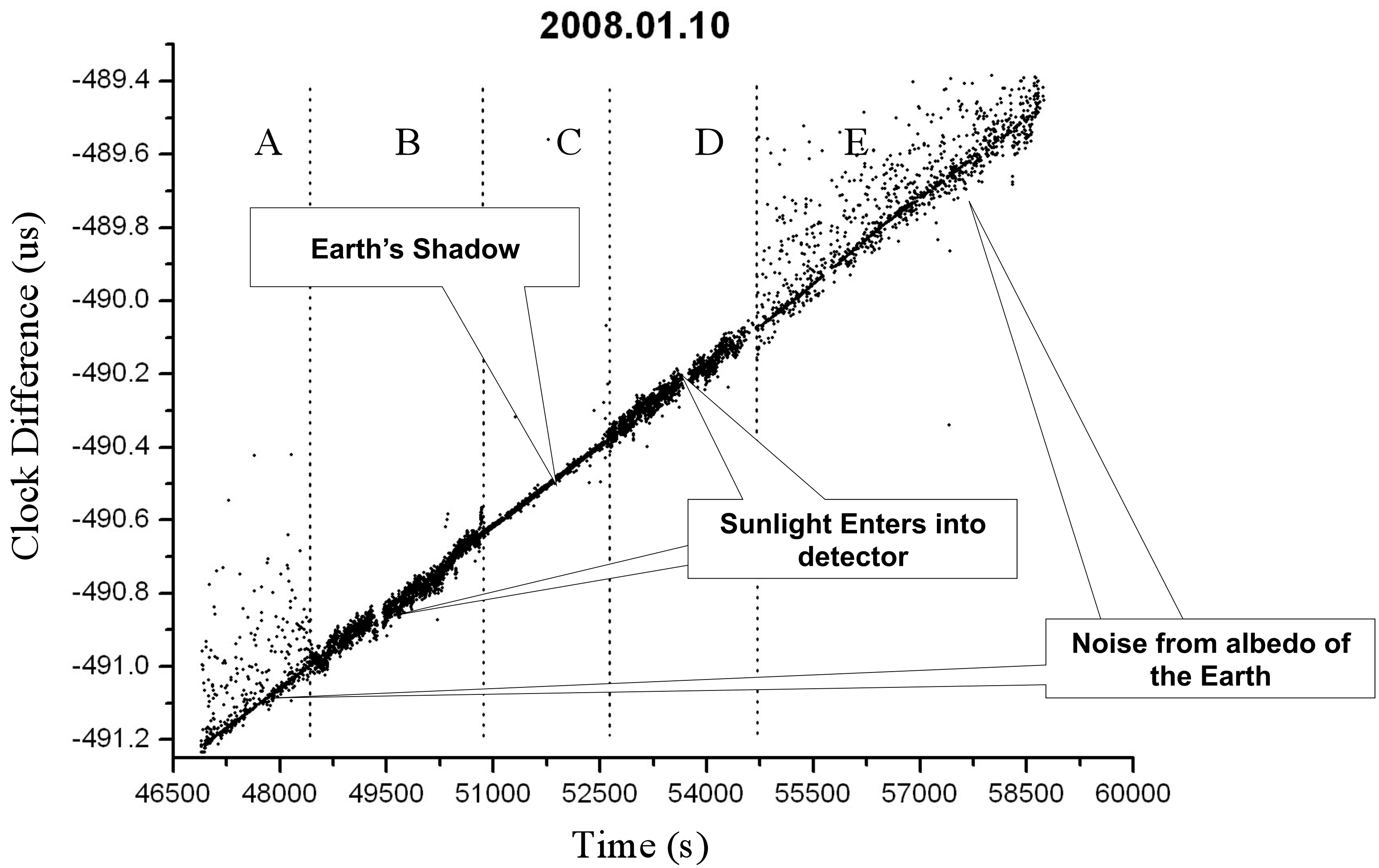


Satellite in Earth's Shadow





Sunlight can enter the FOV of detector nearby the Earth's shadow



A: Noises from the albedo of the Earth

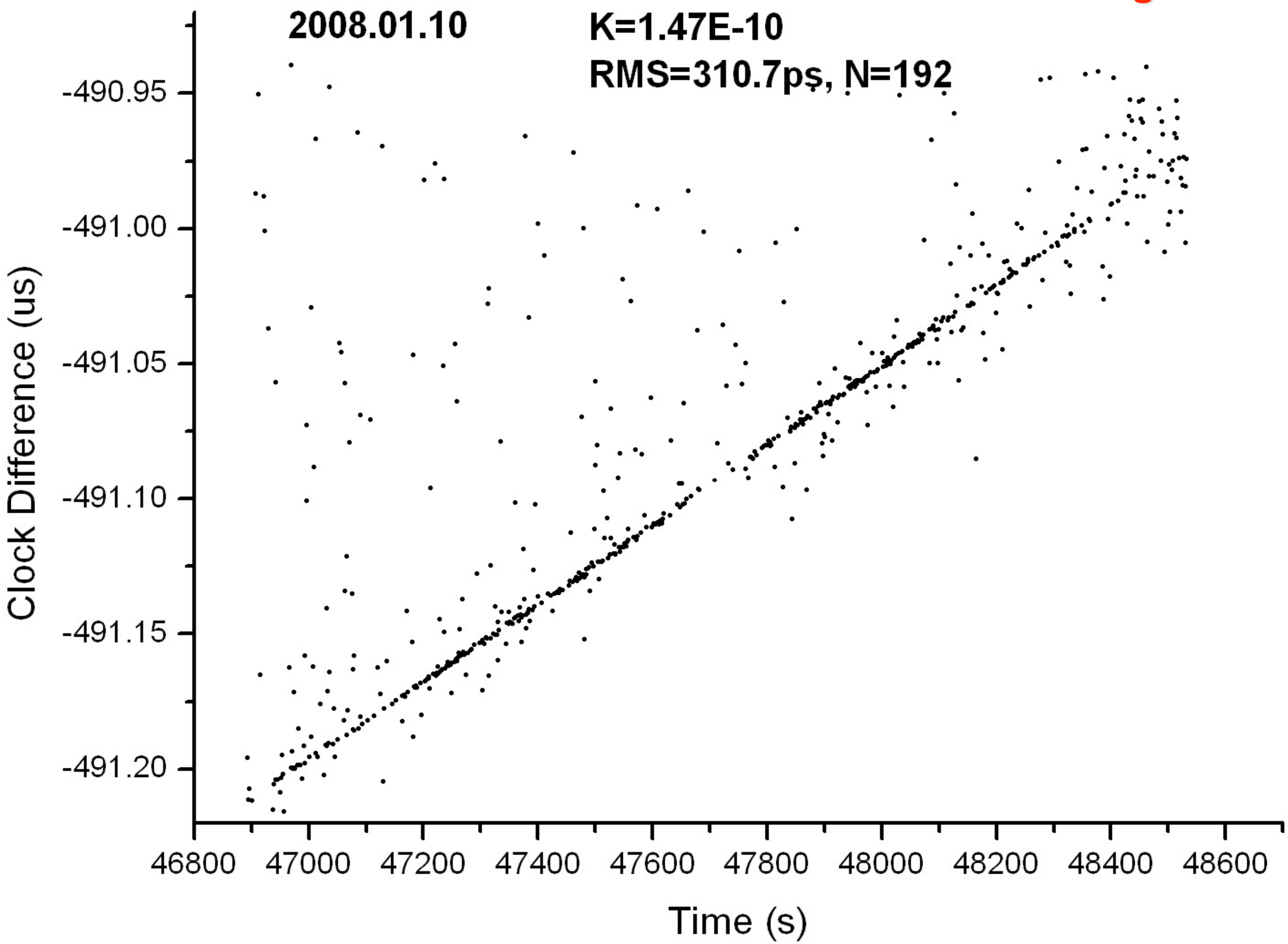
B: Sunlight entered the FOV of detector, extremely strong noises

C: Satellite in the shadow

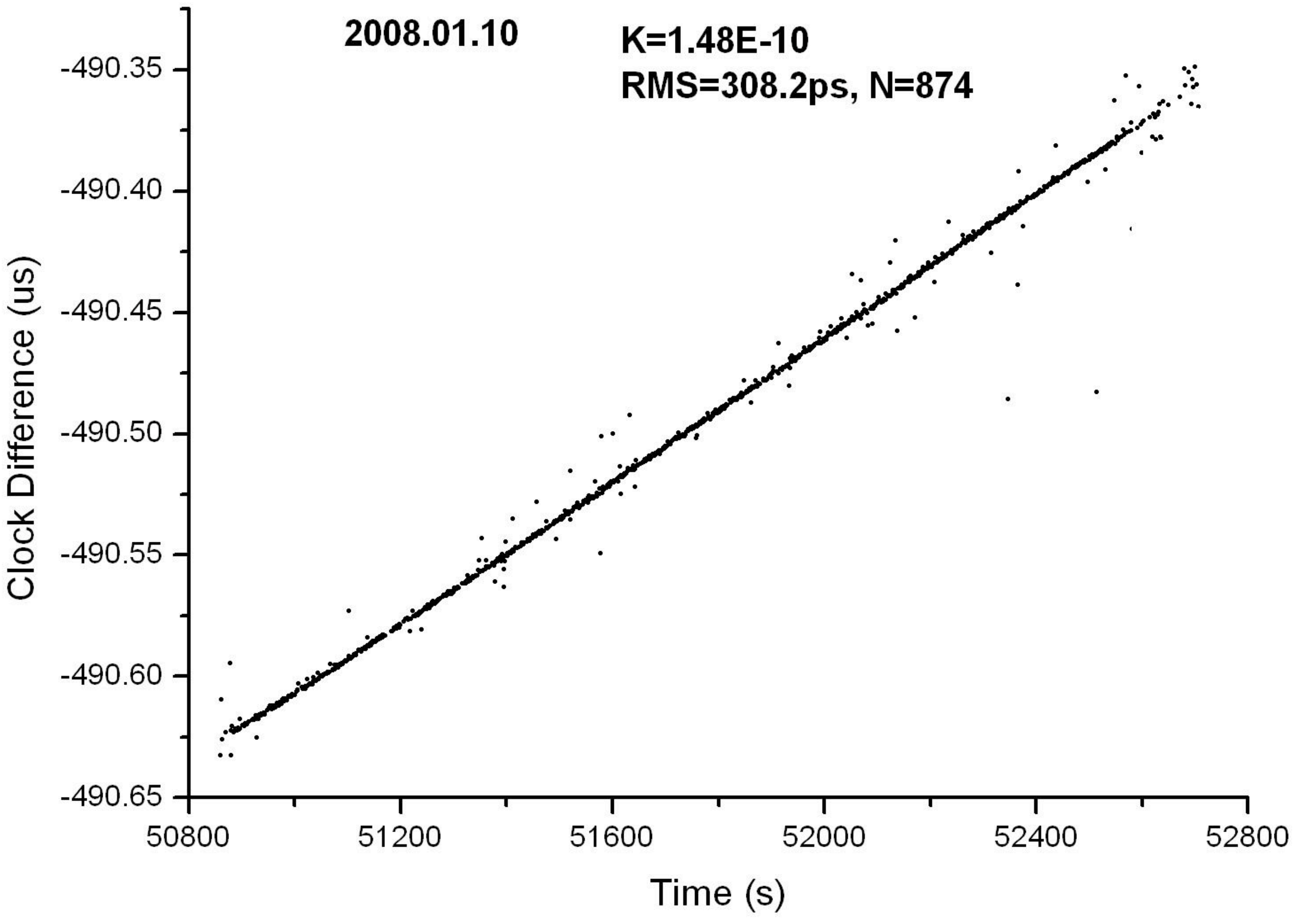
D: Out of the shadow, and sunlight entered the FOV of detector again

E: Noises from the albedo of the Earth

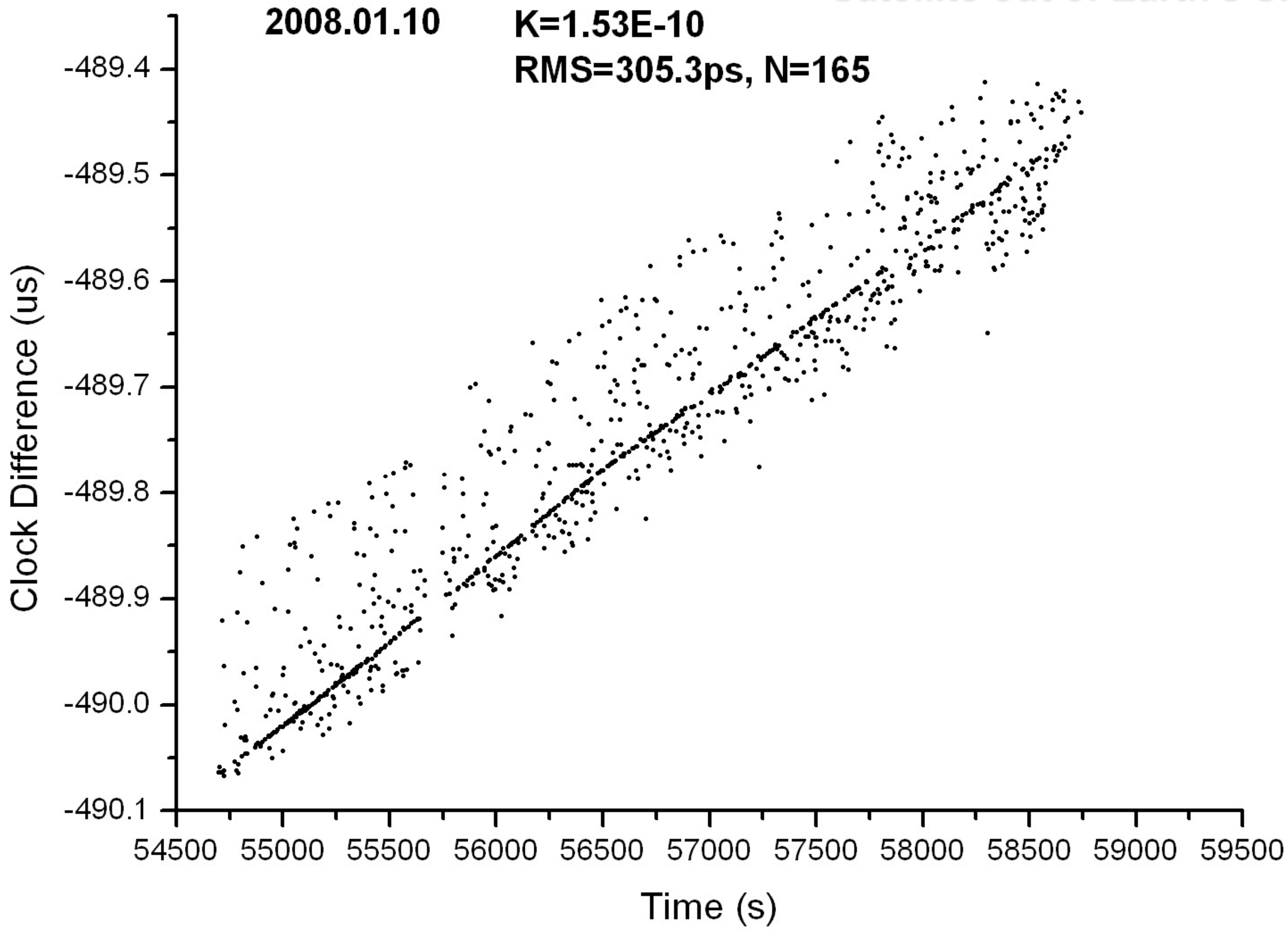
Before entering Earth's Shadow



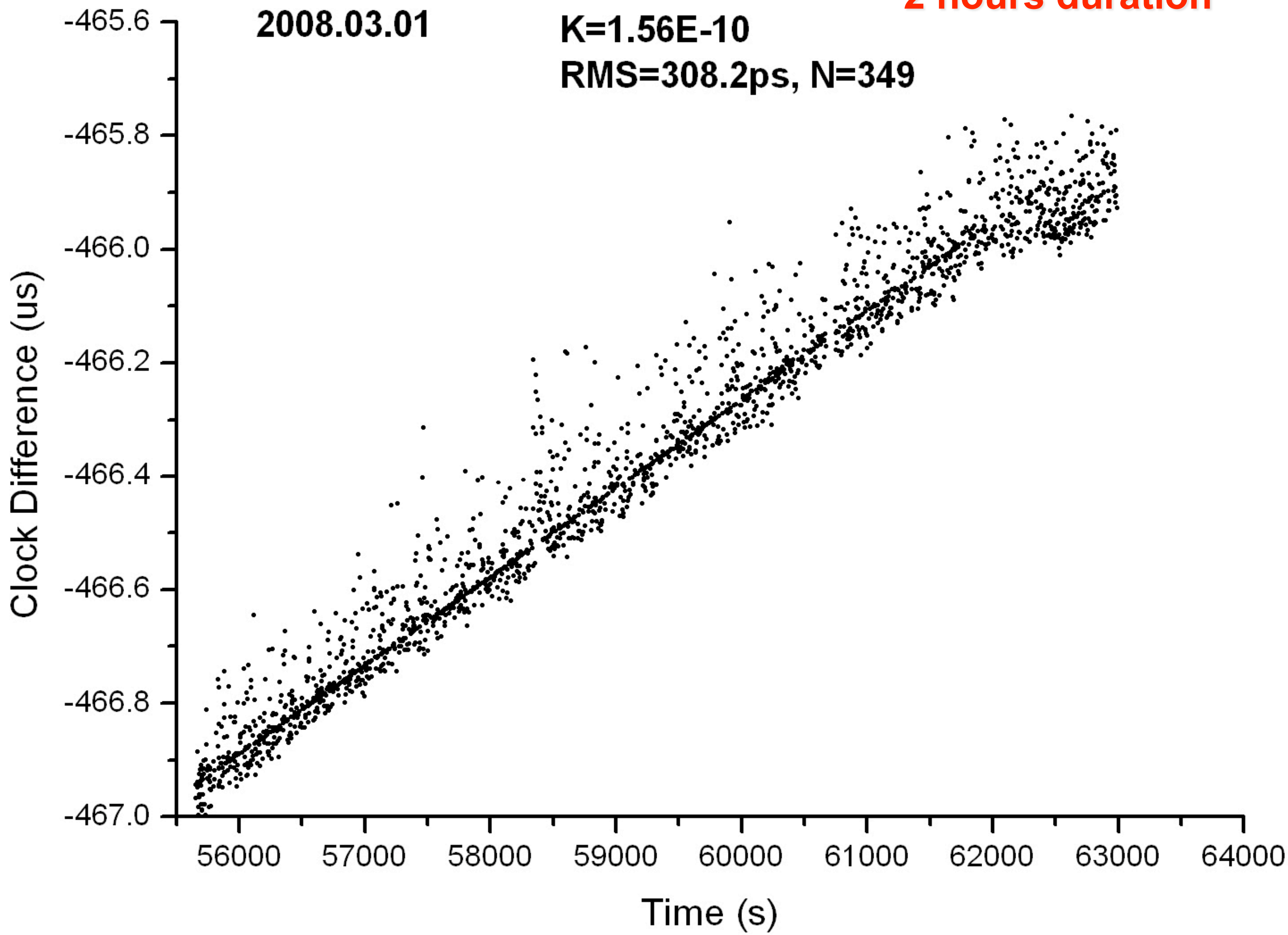
Satellite in Earth's Shadow



Satellite out of Earth's Shadow



Not in the Earth's Shadow
2 hours duration



The uncertainty of the relative frequency differences is about 1.1E-14 in 7200 seconds

Plans for Next Missions

- 2 new LTT payloads for the next Compass missions, IGSO orbit (24 hr period, with 55°inclination), one mission will be in orbit by mid-2009, another will be by the end of 2009.
- Some upgrading of the new LTT payloads:
  - Add gating circuit in the payload for reducing the effect of the dead time of SPAD. It is of importance when the noises are strong. (See Ivan Prochazka's presentation in this Workshop)
  - Reducing the FOV and adopting two FOV for two detectors respectively: one is bigger for nighttime experiment, another is smaller for daylight experiment (but to be restricted to ranging for higher elevation passes). The FOV will be carefully adjusted in the lab.

- 20 Hz onboard timing data will be downloaded in stead of 1 Hz before. Last mission(Compass-M1), only 1Hz timing data were downloaded in spite of 20Hz laser firing at the ground station, so a lot of useful data were lost.
- Narrowing the bandwidth of the interferometric filter from 8.8nm to 4nm due to smaller FOV for IGSO orbit.

Summary

- The LTT payload onboard the Compass-M1 was in space on 13 April 2007.
- The LTT experiment has been carried on since August 2007. Until now, the performance of the LTT module has been fine (shown by the telemetric data).
- Preliminary results of the LTT experiment has been obtained. The experiment can be done in the nighttime only.

✓ The clock differences between the space rubidium clocks and ground hydrogen maser have been measured with a precision of 300ps (single measurement).

✓ The frequency drift (1.47E-10) and stability (10E-13) of the China-made space rubidium clocks have been obtained.

✓ The uncertainty of the relative frequency differences is about 3E-14 in 2000 seconds.

Thank you