A large-scale passive laser gyroscope based on ultra-stable lasers

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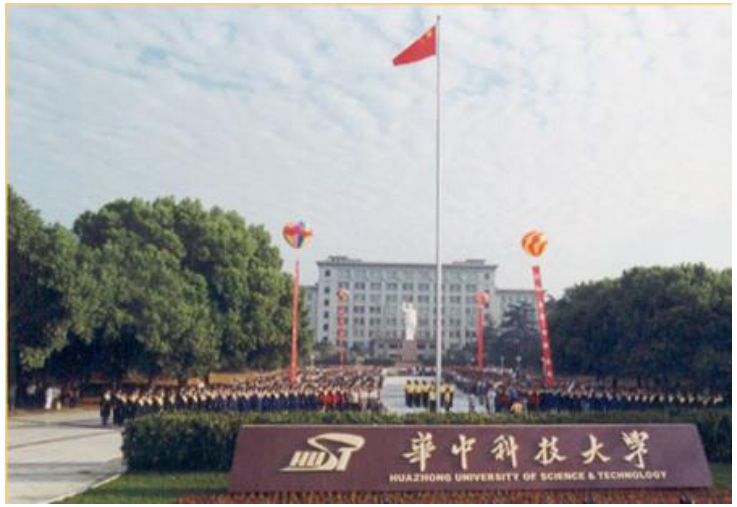
2016.6.21 @ Meeting of IWGoRS

Huazhong University of Science and Technology



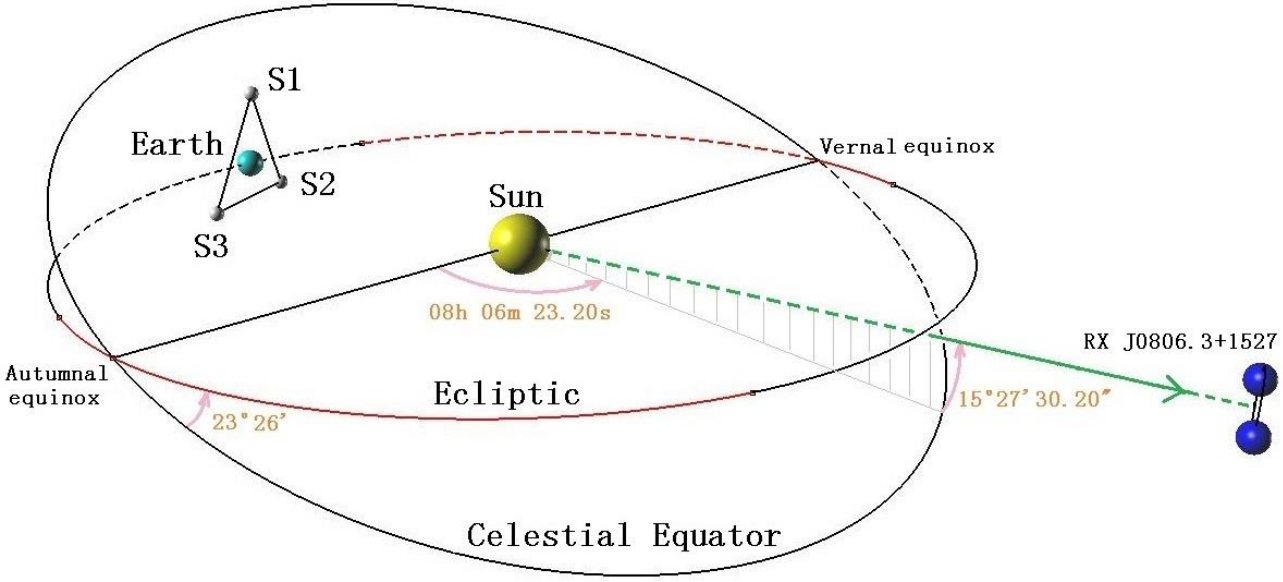
Outline

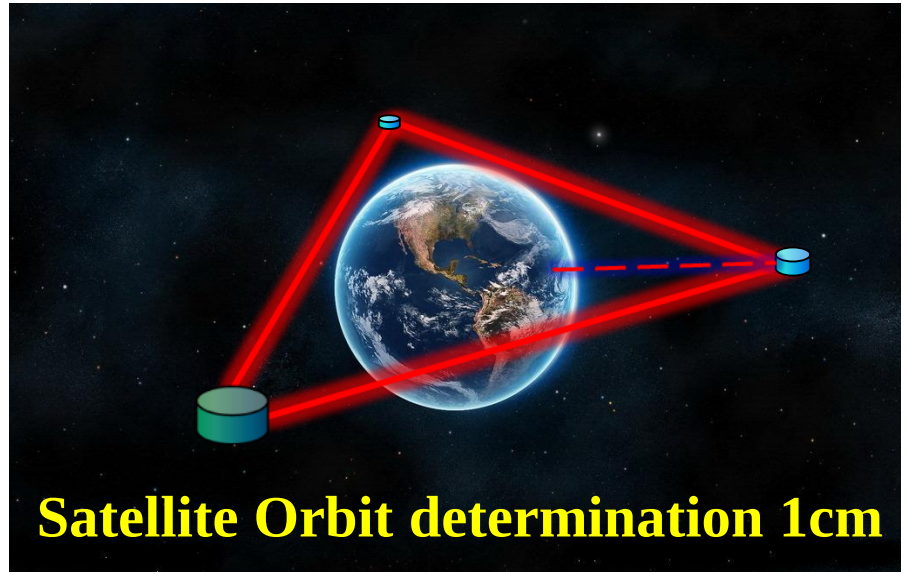
1. Motivation
2. Recent Progress
3. Summary

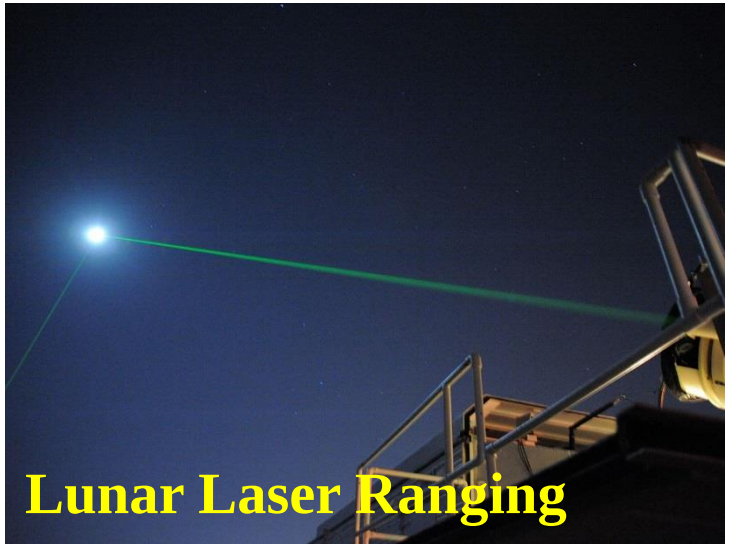
Motivation

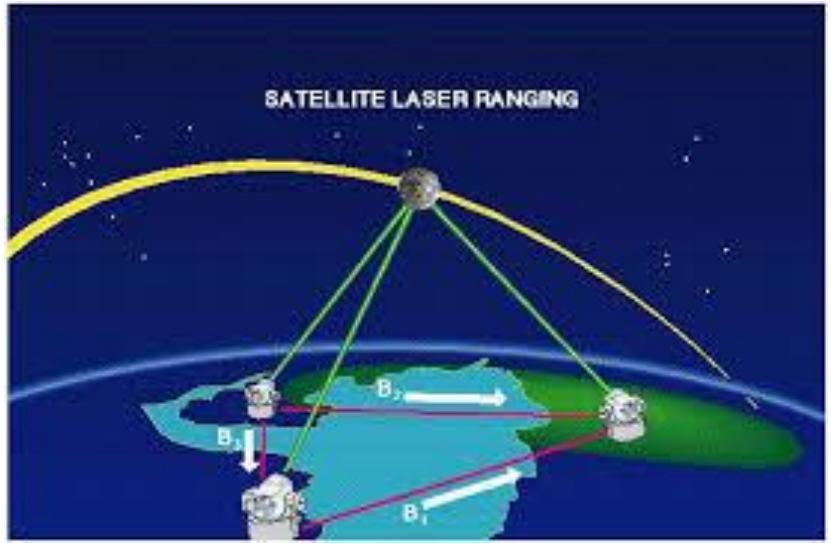
TianQin mission (a space-borne gravitational wave detector)

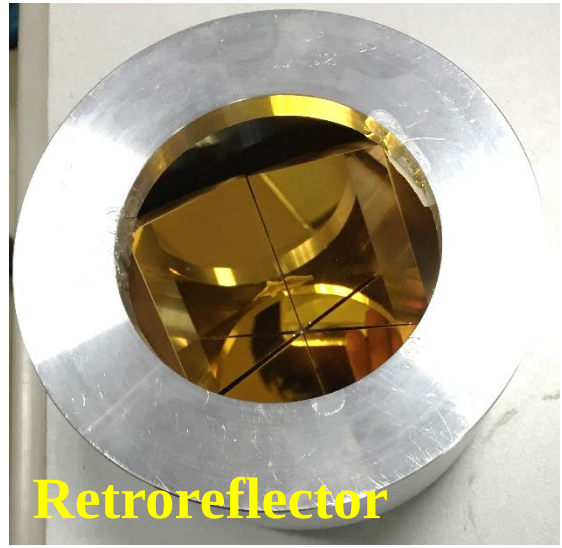
Satellite orbit determination to cm level





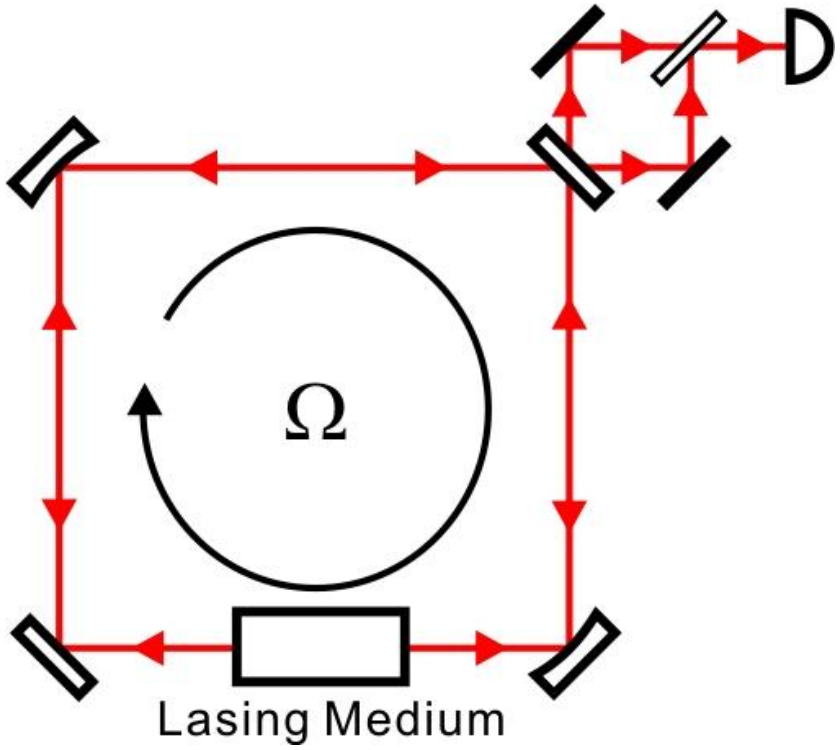




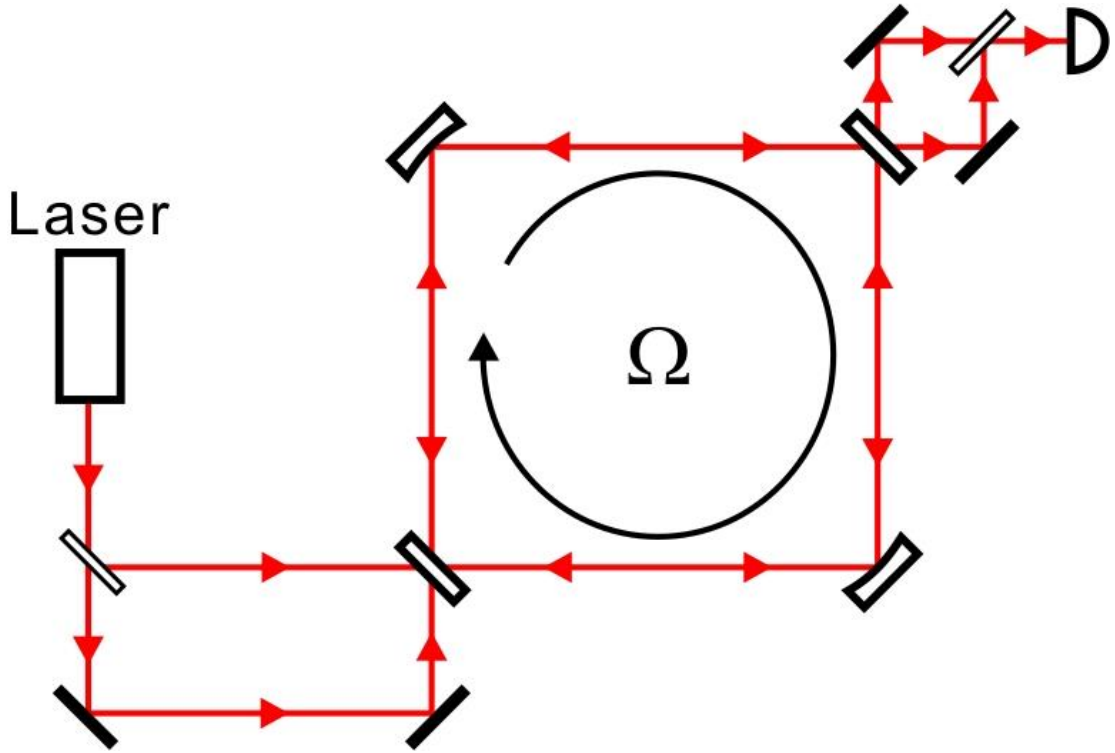


Active/Passive Laser Gyroscope

Active Laser Gyro



Passive Laser Gyro



"Comparison between active- and passive-cavity interferometers."
A. Abramovici and Z. Vager, Phys. Rev. A 33, 3181 (1986).

"Passive versus active interferometers: Why cavity losses make them equivalent." J. Gea-Banacloche, Phys. Rev. A 35, 2518 (1987).

Active or Passive

Active laser gyro：

- Spontaneous emission
- Gain medium fluctuation
- Backscattering
- Geometrical stabilization

Passive laser gyro：

- Shot noise limit
- No gain medium (high vacuum)
- Backscattering
- Geometrical stabilization
- Injection laser
- Feedback locking

An ultrastable laser as injection laser source

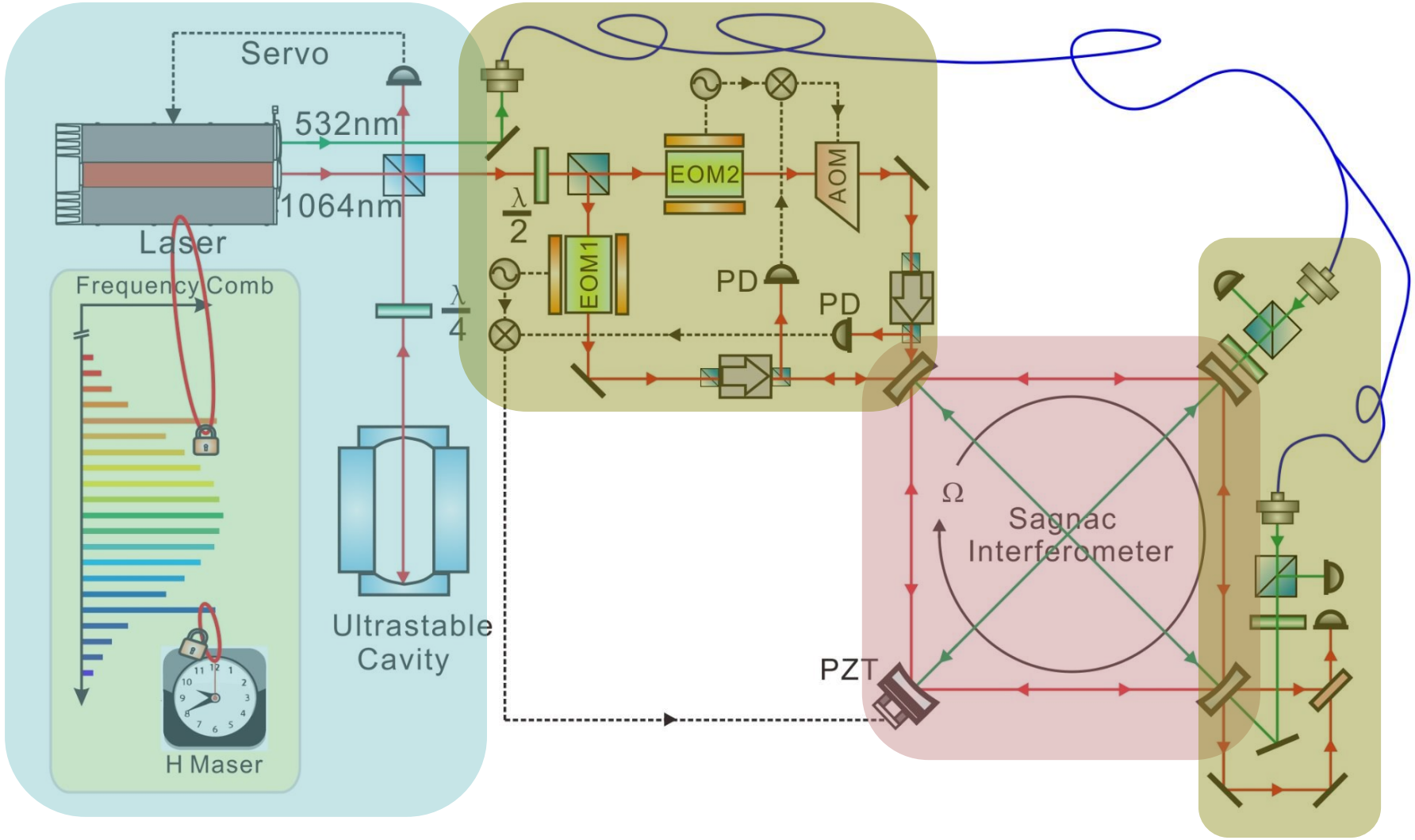
A large scale passive laser gyroscope: challenge but deserve to try.

Major theoretical parameters

$$\delta\Omega = \frac{cP}{4AQ}\sqrt{\frac{hf}{WT}}$$

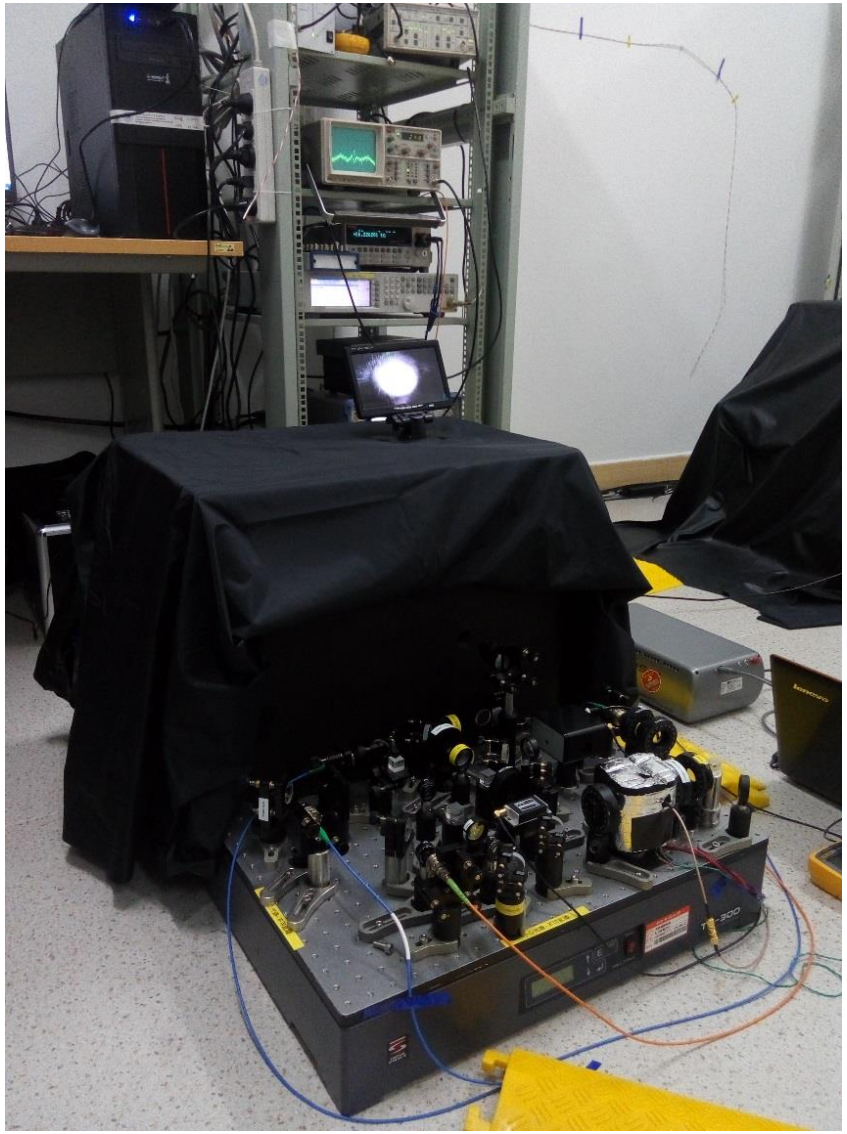
N30.52° E114.41°	1 m Gyroscope	10 m Gyroscope (Final Goal)
Square cavity	1 m×1 m	10 m×10 m
Perimeter/Area	4 m/1 m^2	40 m/100 m^2
Scale factor stability	10^{-9}	10^{-11}
Reflectivity	99.999%	99.999%
Finesse	157000	157000
FSR	74.9 MHz	7.49 MHz
Q factor	5.9×10^{11}	5.9×10^{12}
Sagnac frequency	34.7 Hz	347 Hz
Laser performance	Stability<10^{-14}@1s, Stability<10^{-13}@1000s	
Power	100 μW	
Sensitivity@1000s	$8\times10^{-9}\,\Omega_E$	$8\times10^{-11}\,\Omega_E$

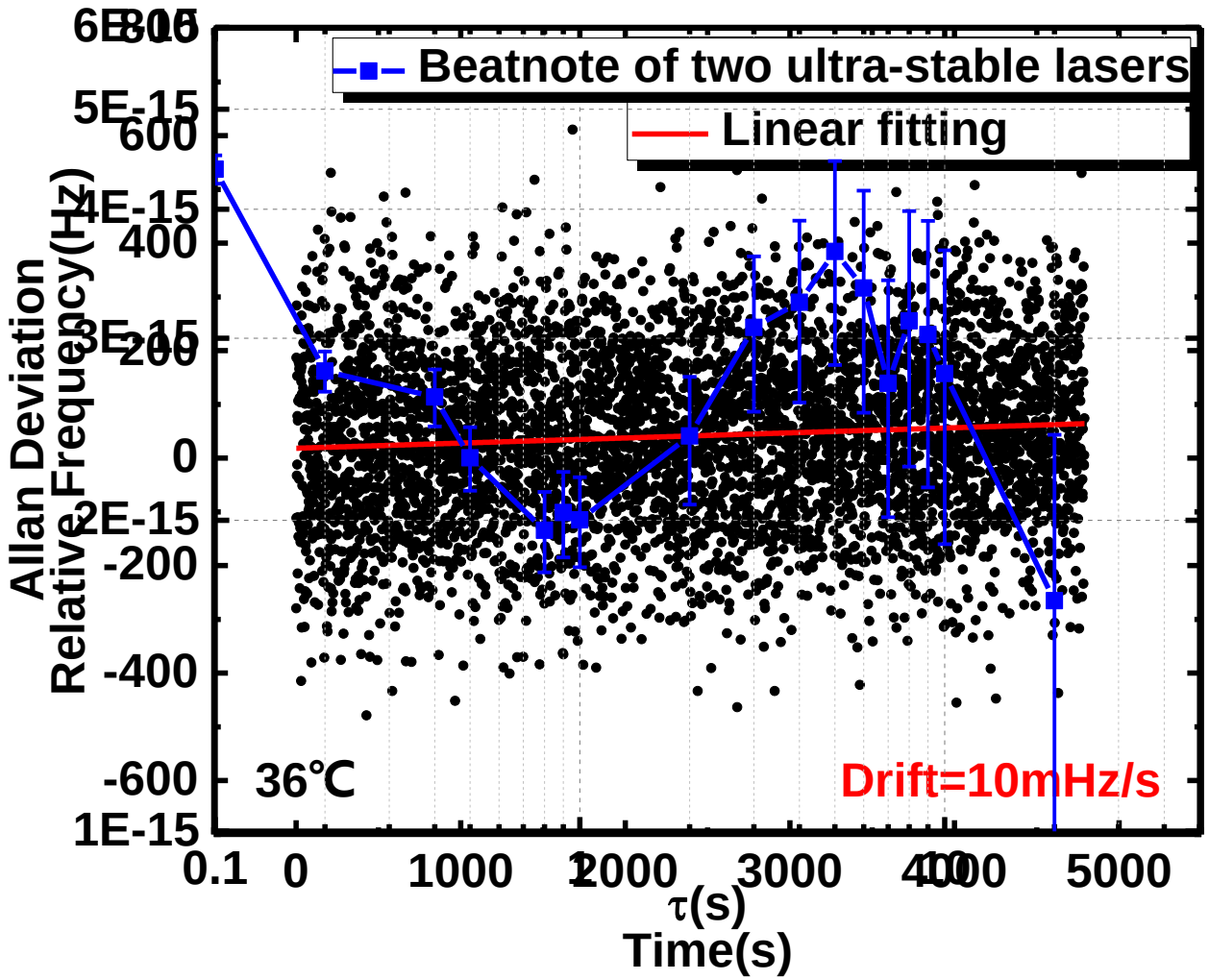
Optical Setup



The ring cavity is locked to one injection beam, and the other beam is locked to the ring cavity, monitoring diagonal lengths.

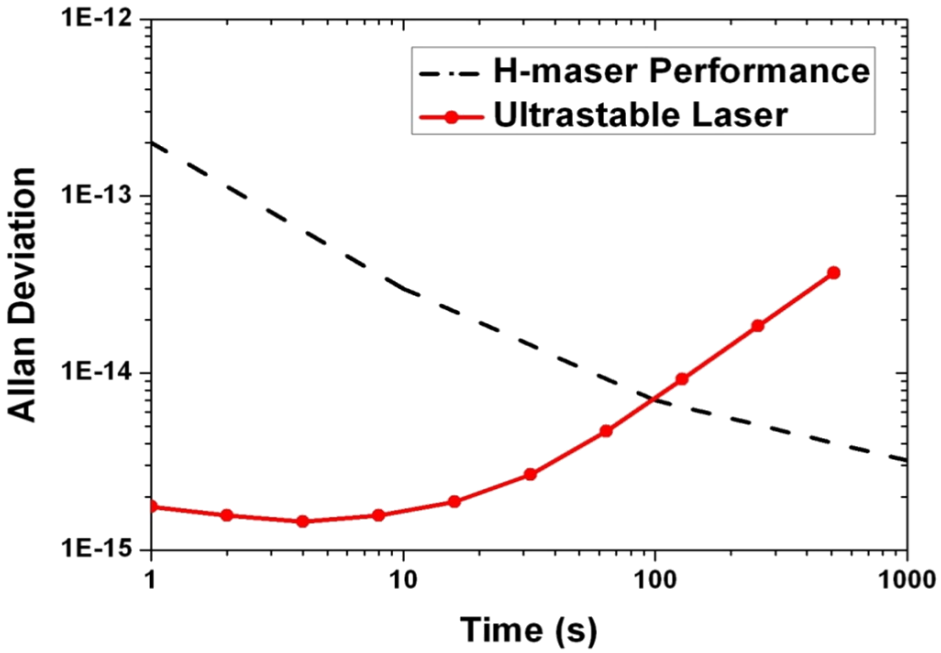
Laser Development: Short-term Stability

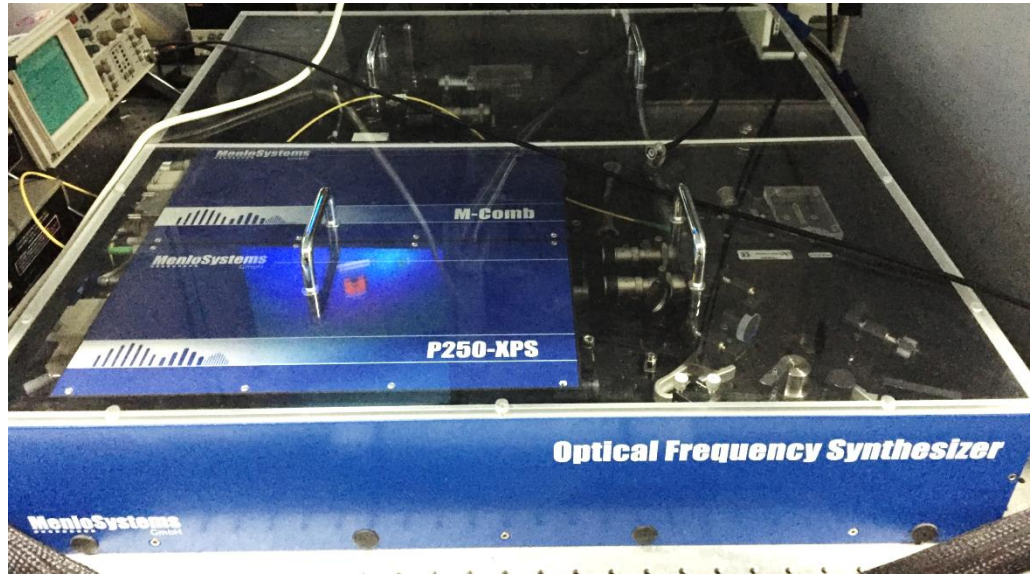


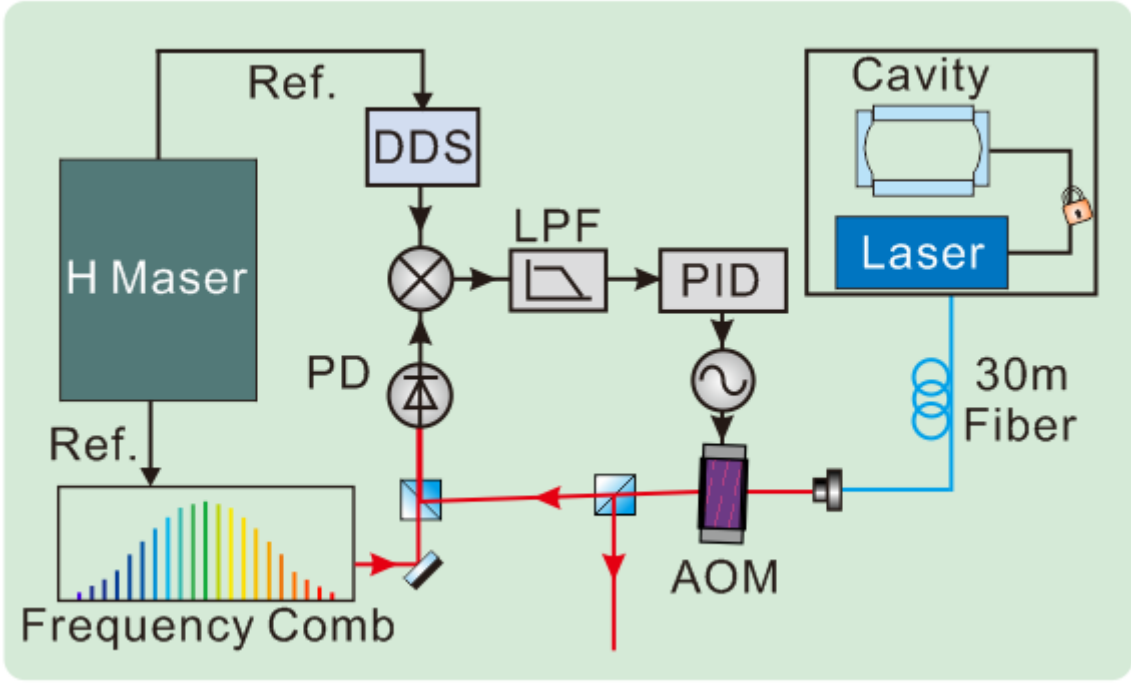


A diode laser is locked to a 10 cm-long ULE ultra-stable cavity.

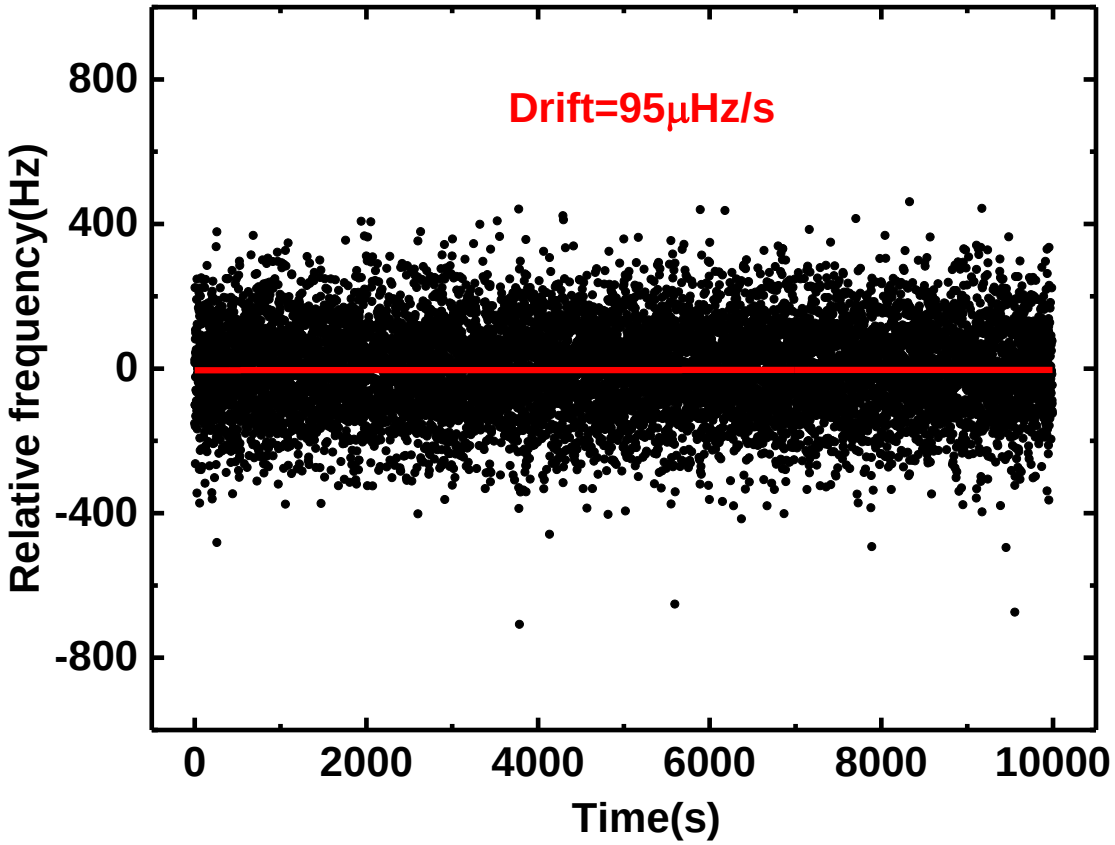
Laser Development: Long-term Stability

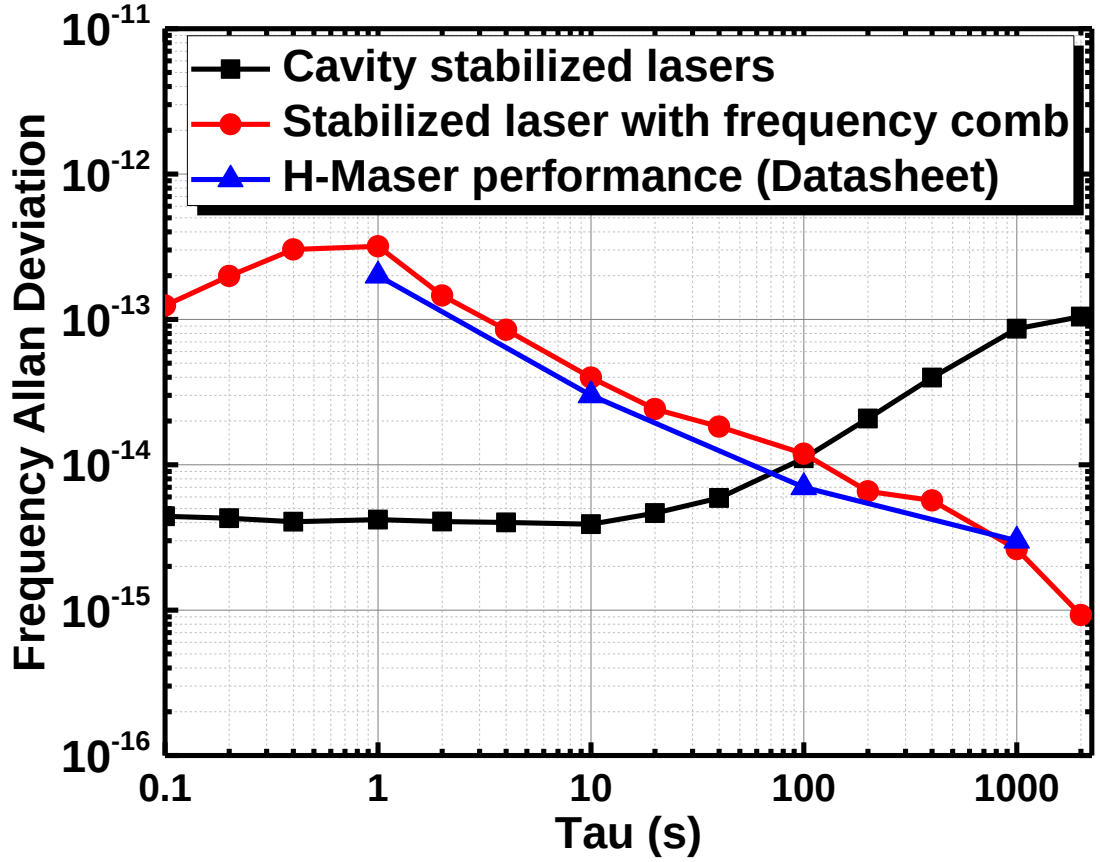






Laser Development: Long-term Stability

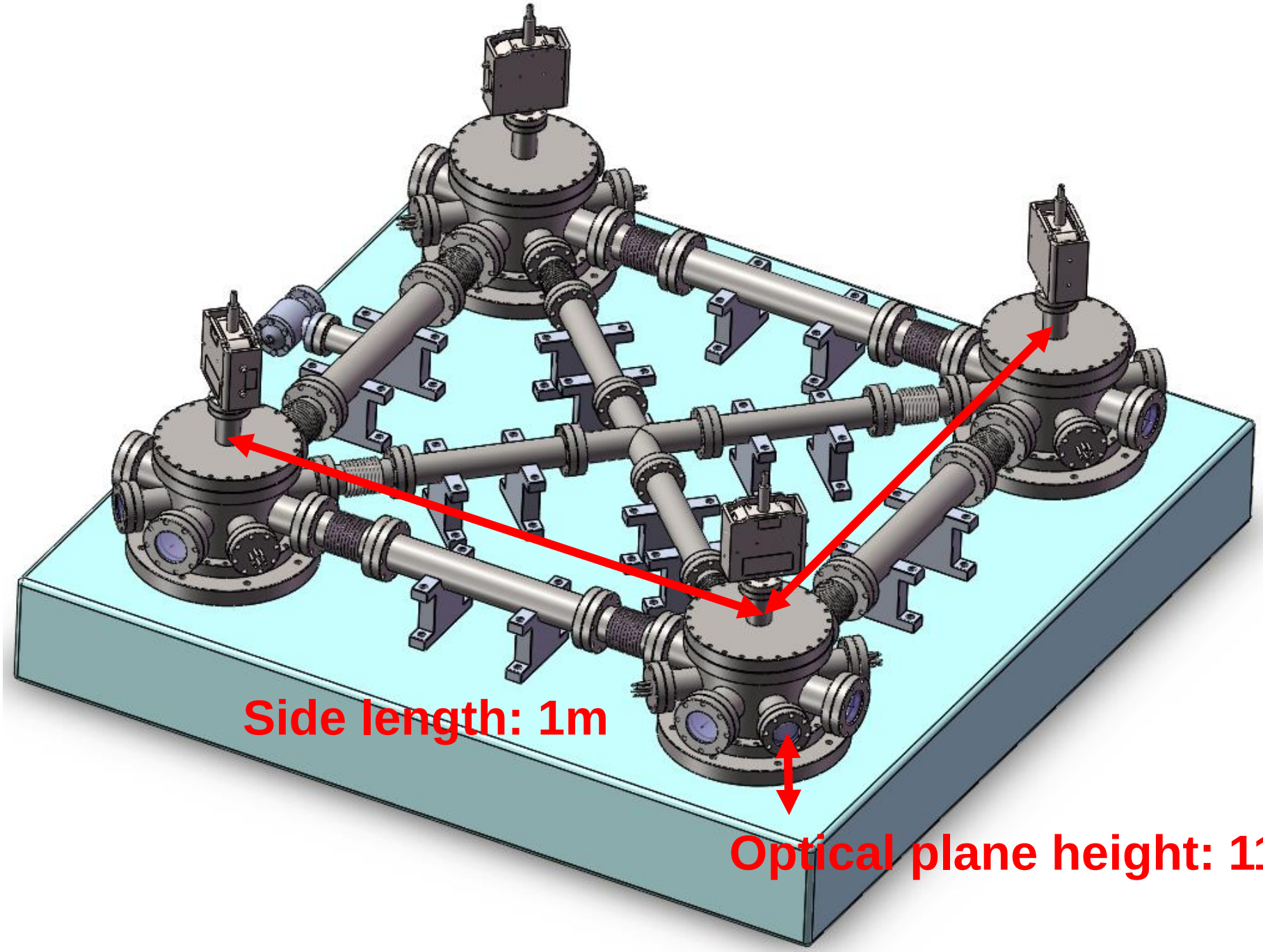




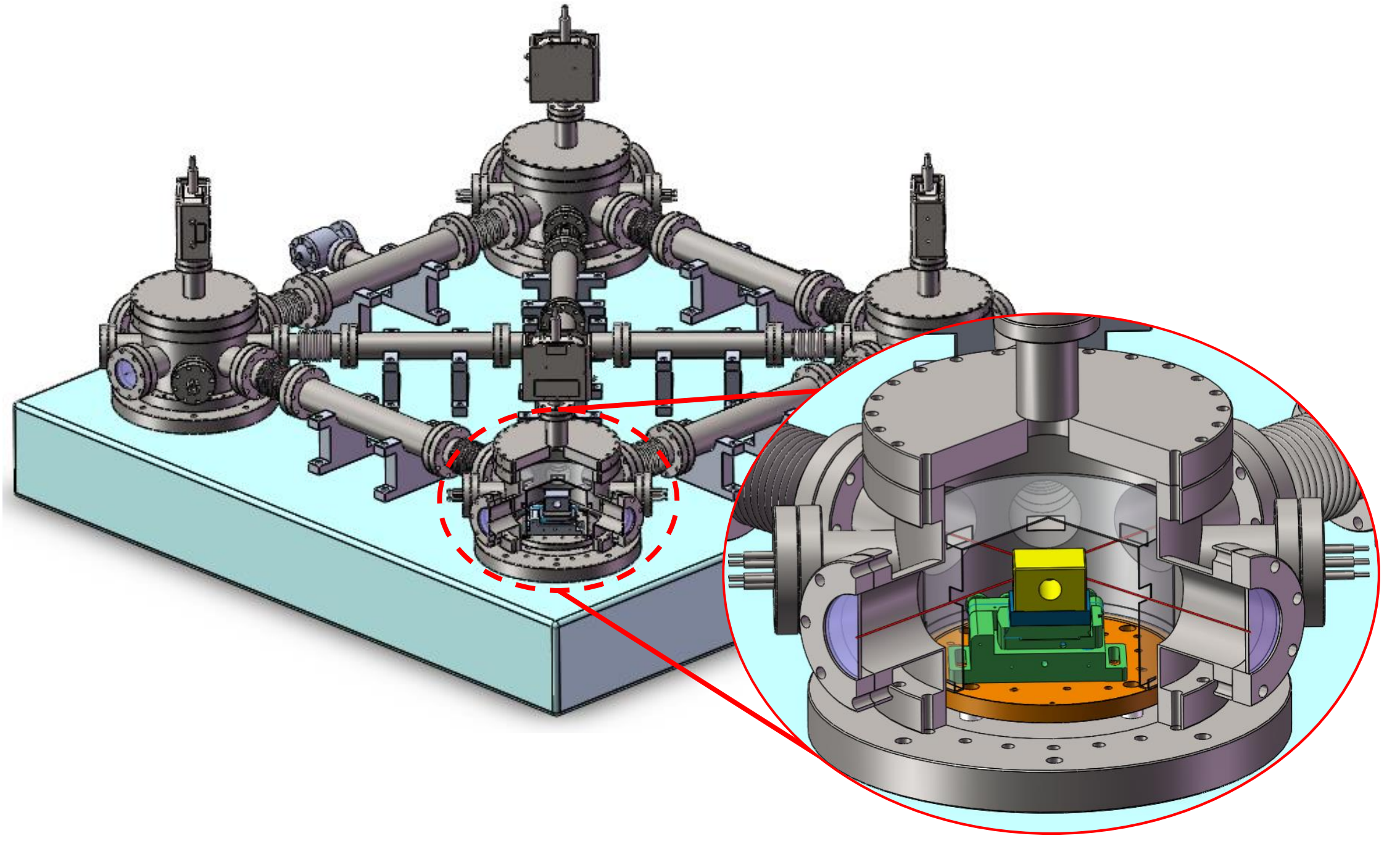
Next step:

- Digital PID locking for better short-term performance

Vacuum System Design



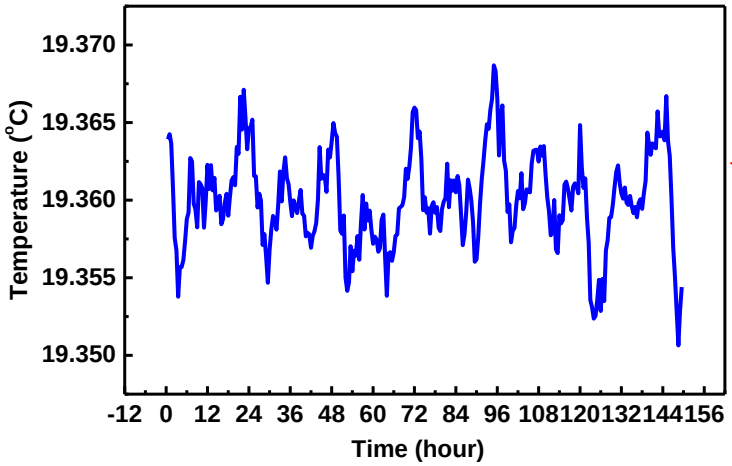
Vacuum System Design



Cave Lab

Lab Space: 7000 m² (cave lab: 4000 m², machine shop: 600 m²)

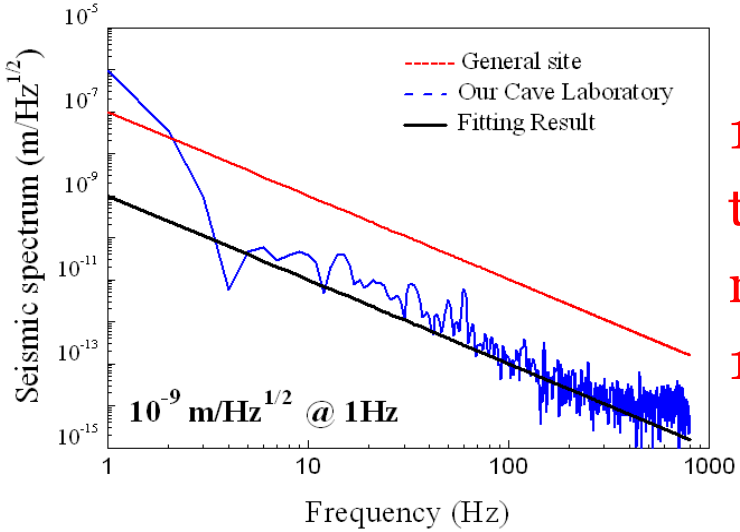
Temperature variation inside cave laboratory



Annual variation: ~ 1K

Daily variation < 5mK

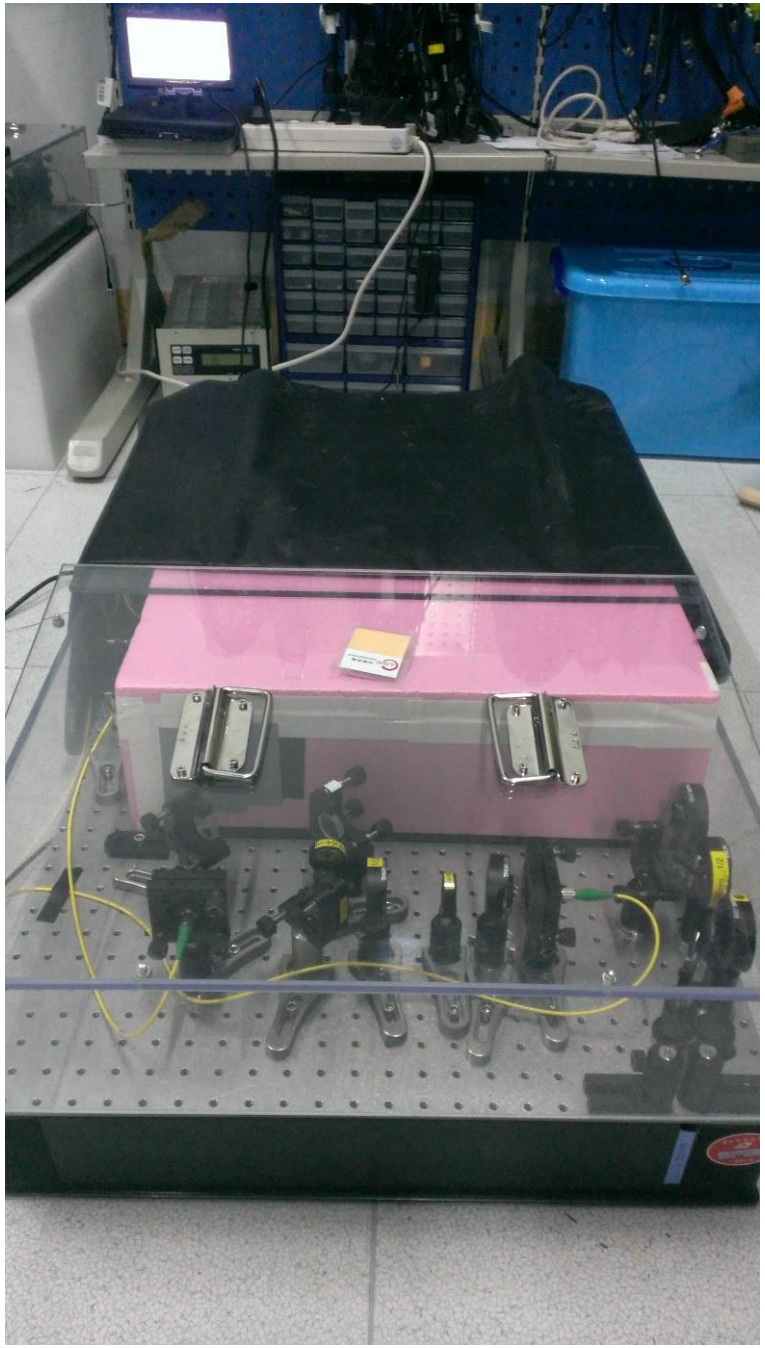
Seismic noise at cave laboratory

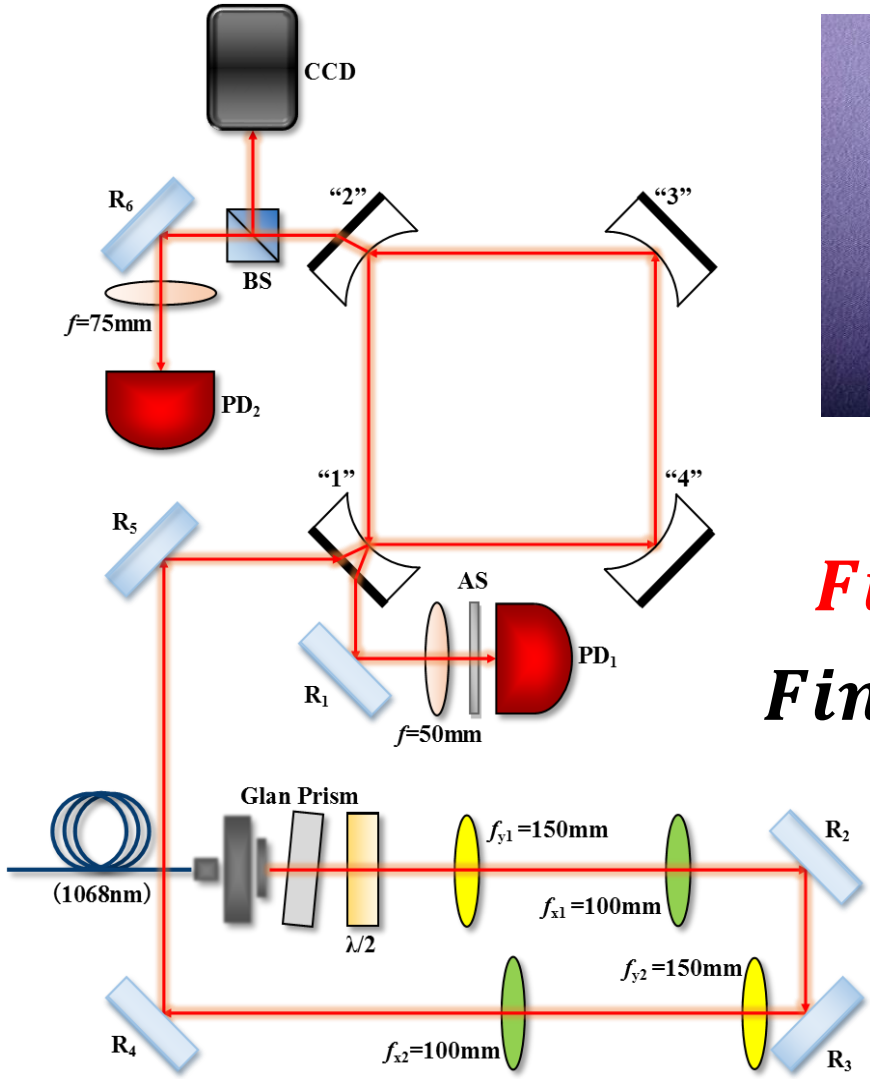


100 times lower than the seismic noise of a typical 1st-floor laboratory

Lab for 10m×10m Laser Gyroscope: 174m²

A Free Space 0.3 m × 0.3 m Ring Cavity





$\alpha = 20\%$

$Finesse = 329$

$Finesse_{th} = 1573$

S-polarization reflectivity : 99.9%

Summary

- A laser source is developed with a short-term stability of 1×10^{-13} at 0.1s. The long-term stability is 1×10^{-15} at 2000s;
- We have designed the Sagnac interferometer;
- Ring cavity alignment and mode matching is under test.

Future Plans:

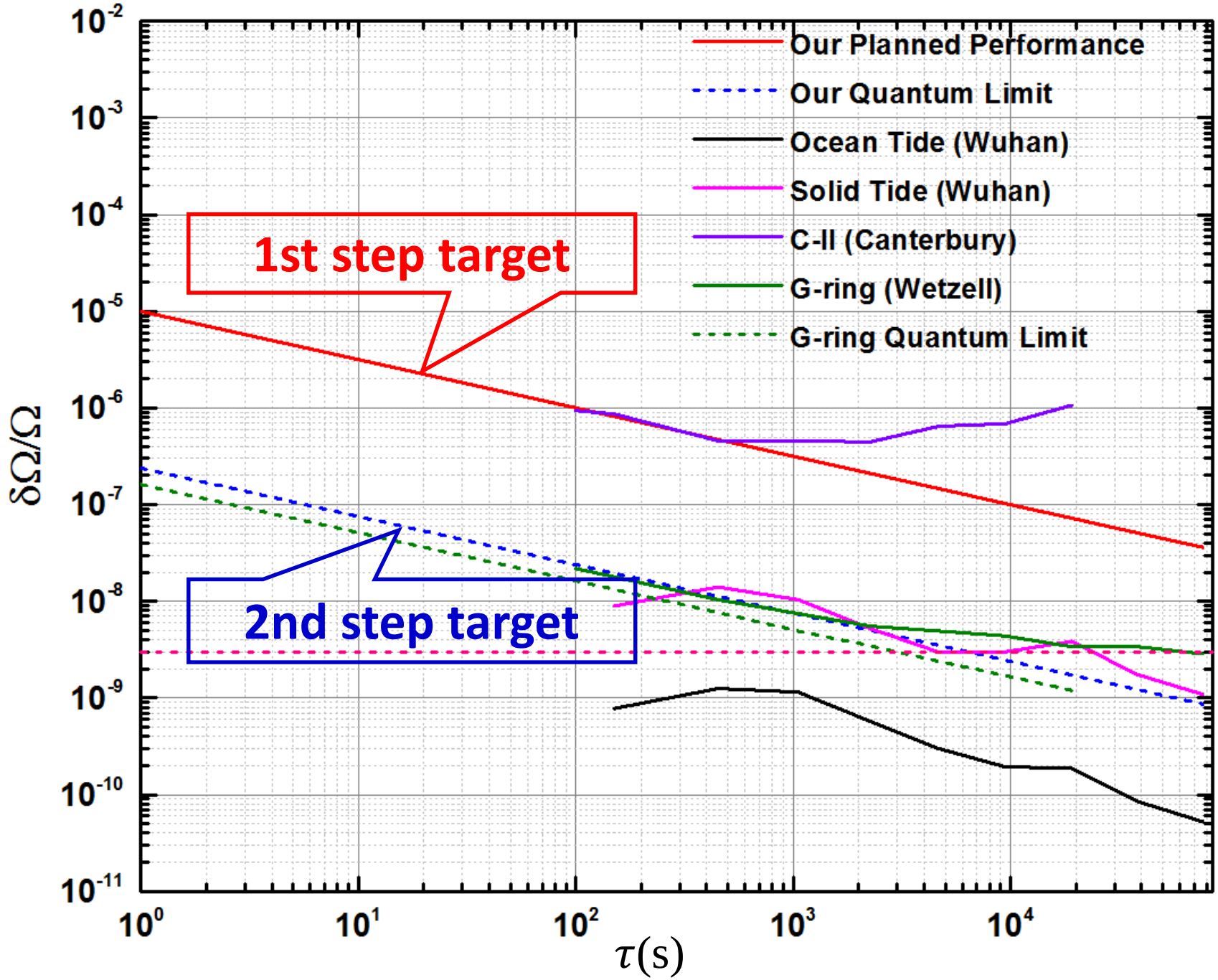
- For the 1m×1m gyroscope, a 1st step goal is to achieve a relative sensitivity of 3×10^{-7} at 1000s in 2017;
- a 2nd step goal is a relative sensitivity of 8×10^{-9} at 1000s;
- Design a 10m ×10m gyroscope.

National Facility (2017-2021)

Precision Gravity Measurement Facility (PGMF)

Thank you very much for your attention !

Research Goal for the 1m×1m Gyroscope



Digital Locking

- **Long-term running**
- **Self-locking**
- **Remote control**