Program in detection of gravitational wave in space in Chinese Academy of Sciences

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On behalf of Space Gravitational Wave Detection Working Group in Chinese Academy of Sciences

11th LISA Symposium
Zurich, Sept.5-9, 2016

Outline

- Roadmap of gravitational wave detection in Space in Chinese Academy of Sciences
- Primary science drivers
- Preliminary mission design
- Technological developments
- Some international activities

Progress of Space gravitational wave detection in China

2008 — Investigation group in CAS for Space GW Detection

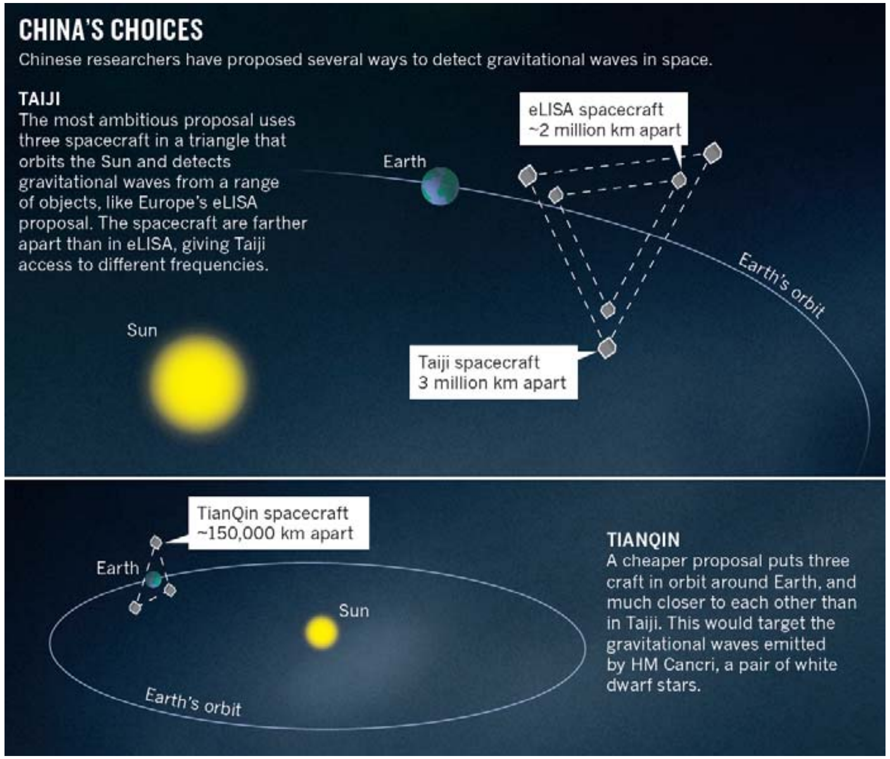
2009 — Space GW Detection listed in 2050 Development Project of CAS

2012 — Working Group for Space GW Detection of CAS

2015 — Proposal of Taiji

Taiji proposed and supported in 2016 by Chinese Academy of Sciences, uses three Spacecraft in a triangle that orbits the Sun.

Tianqin proposed by Zhongshan Univ. and supported by local government, orbits the Earth.



David Cyranoski. *Nature*, 2016, 531, 150.

Taiji gravitational physics consortium in CAS

Coordinators:

Wenrui Hu, Gang Jin (National Microgravity Laboratory, Institute of Mechanics)

Yueliang Wu (University of Chinese Academy of Sciences)

- **Member Institutes** participating in the group:

- Academy of Mathematics and Systems Science,
- Changchun Institute of Fine Optics and Engineering,
- Institute of Applied Physics, Lanzhou, CAST,
- Institute of high Energy Physics,
- Institute of Mechanics,
- Institute of Physics,
- Institute of Theoretical Physics,
- Nanjing Institute of Astronomy and Optics,
- National Astronomical Observatory,
- Shanghai Small Satellite Company,
- University of Chinese Academy of Sciences,
- University of Science and Technology of China, Hefei,
- Wuhan Institute of Physics and Mathematics,
- Wuhan institute of Geodesy and Geophysics.

Roadmap of GWD in Space in CAS

- 2016-2020:

Technique Prototype developments and ground testing.

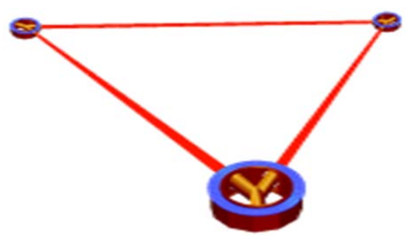
- 2021-2025:

Technological developments and a pathfinder mission

Two options (or both) to be considered (gravity satellite and a long interferometry arm in deep space)

- 2026-2035:

Chinese mission for gravitational wave detection in Space and launching



Chinese Pathfinder in planning

- Deep space (likely to be L_1 or L_2)
- 10^5 km apart
- Apart from inertial sensor, also test single arm optical interferometry (telescope, pointing, metrology, ...etc)

Dual tracks of development in GW mission

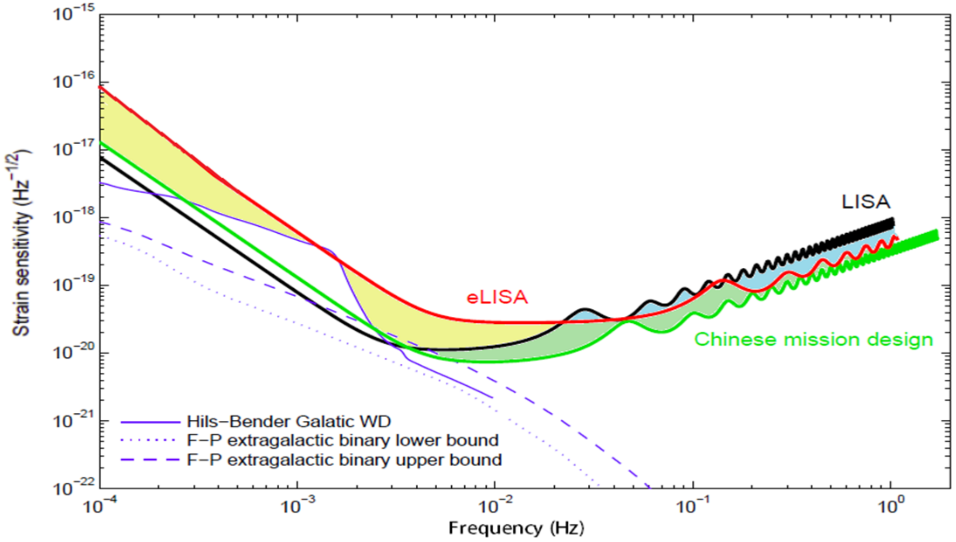
Develop a Chinese Mission with international collaboration

Contribute to eLISA or LISA likely to be > 20%

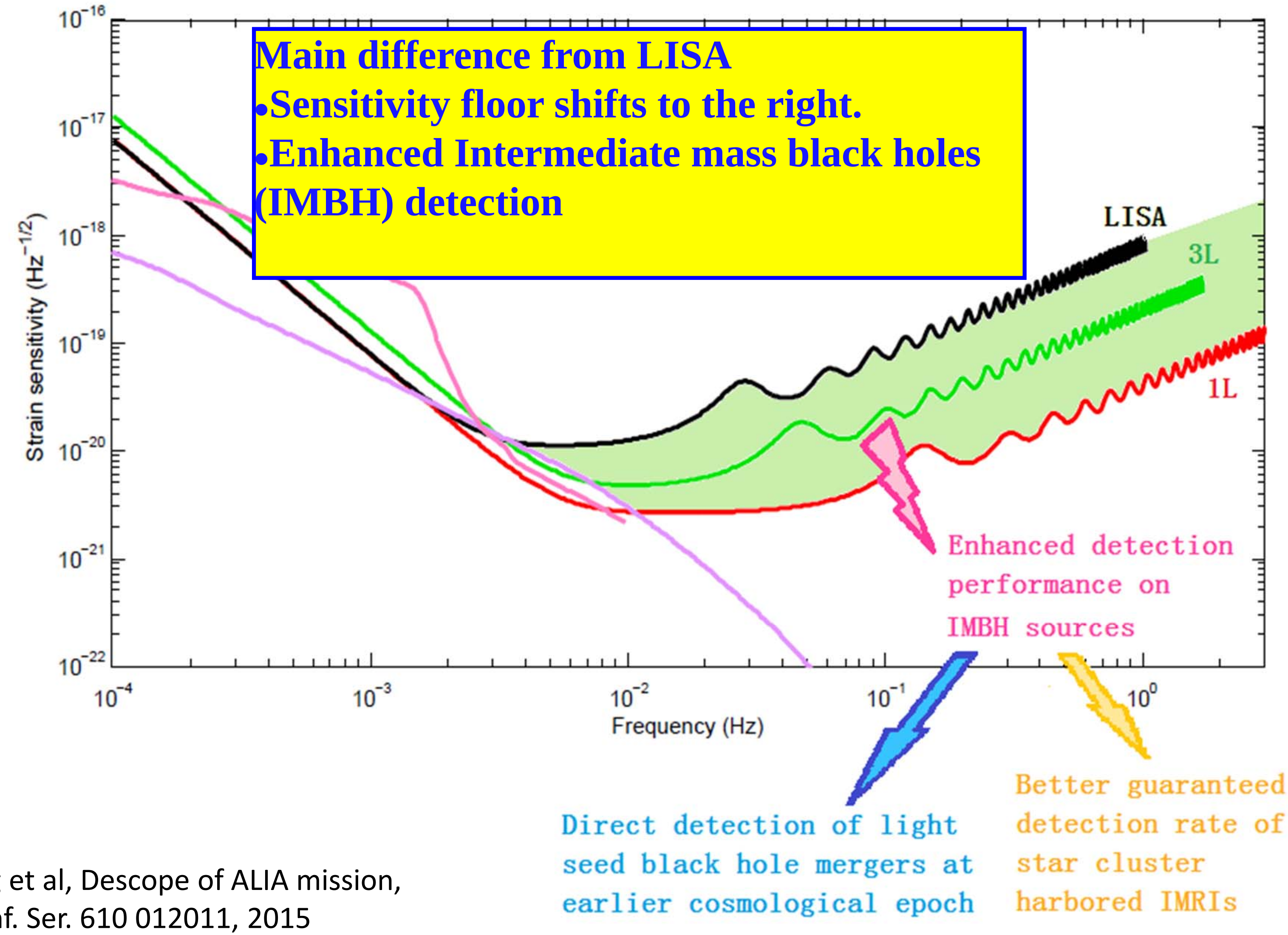
- Micro-Thruster
- Telescope,
- Laser,
- Launcher,
- others ...

Chinese GWD in Space Mission design

Armlength (m)	Telescope diameter (m)	Laser power (W)	1-way position noise ($\frac{\text{pm}}{\sqrt{\text{Hz}}}$)	Acceleration noise ($\frac{\text{m s}^{-2}}{\sqrt{\text{Hz}}}$)
3×10^9 (Chinese mission option)	0.46	2	8	$3 \times 10^{-15}(> 0.1\text{mHz})$
1×10^9 (eLISA)	0.2	2	11	$5 \times 10^{-15}(> 0.1\text{mHz})$
5×10^9 (LISA)	0.4	2	18	$3 \times 10^{-15}(> 0.1\text{mHz})$



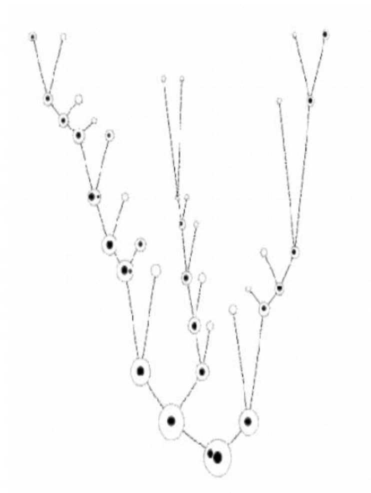
Enhanced detection performance on IMBH

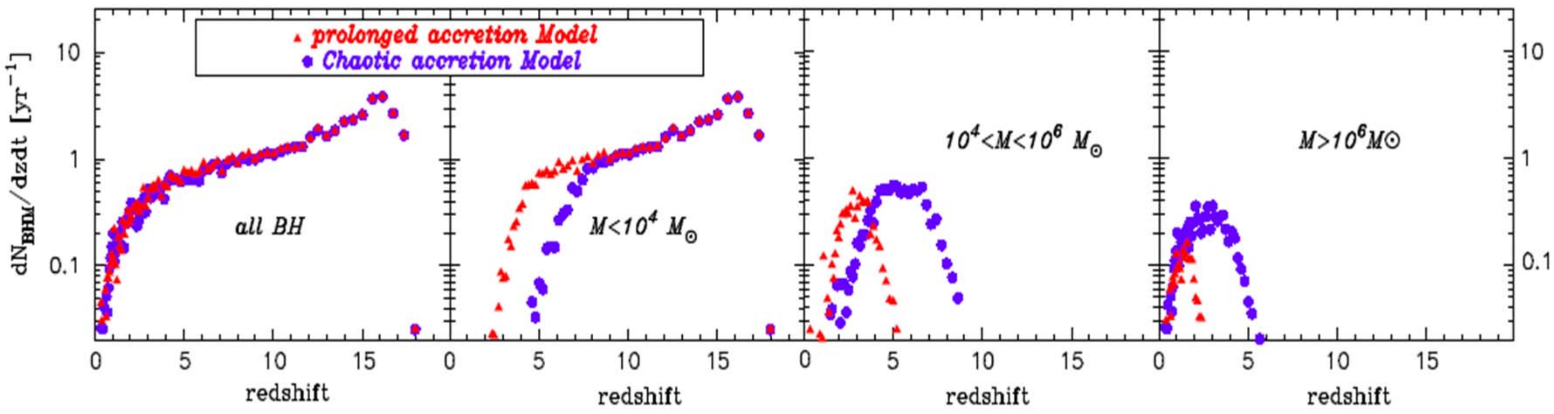


Xuefei Gong et al, Descope of ALIA mission,
J. Phys.: Conf. Ser. 610 012011, 2015

Event rate estimates of MBH mergers at earlier cosmological epoch

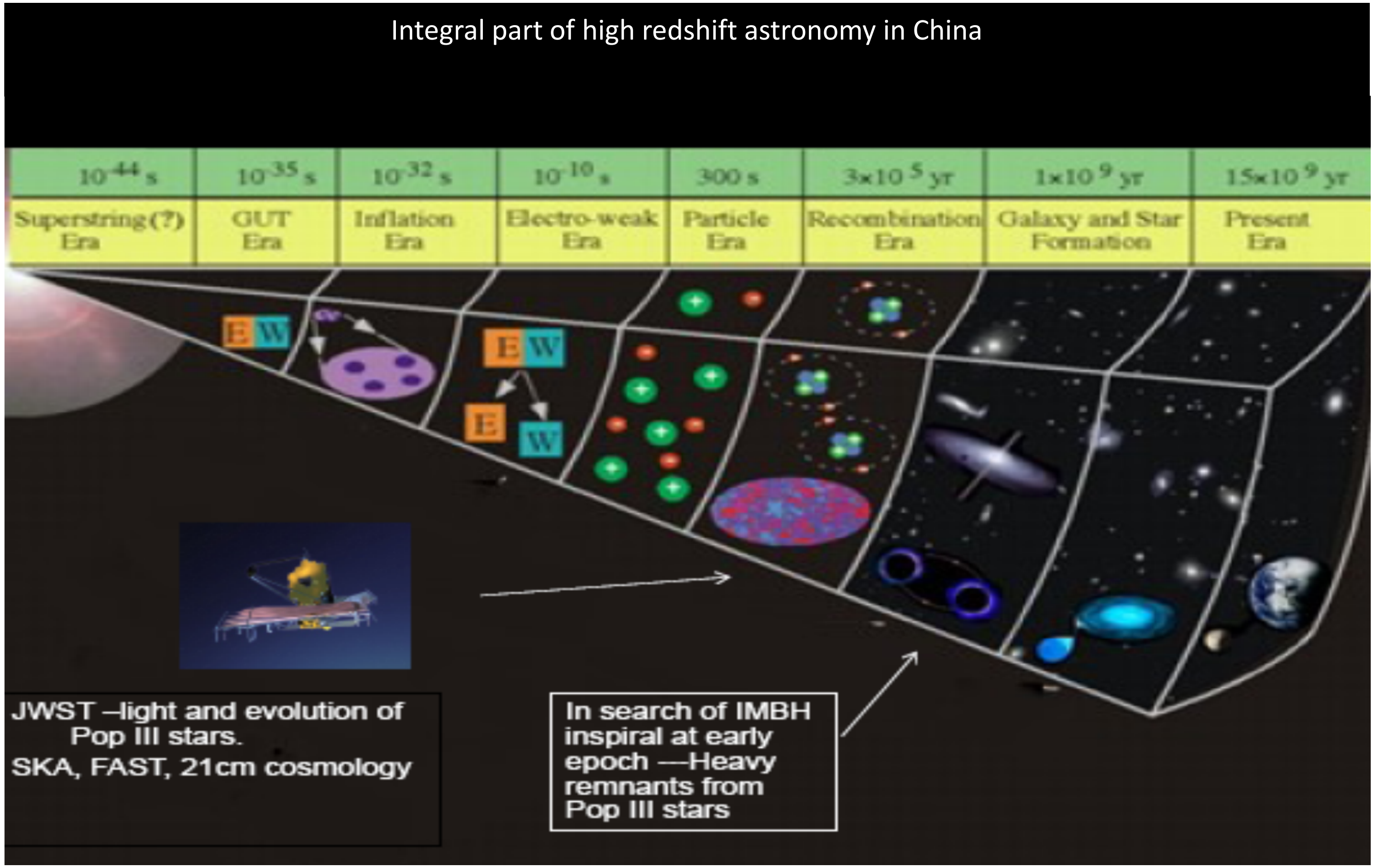
Cosmological MBH merger simulation based on
- Monte Carlo realization of EPS formalism
- Equal mass light seed black hole (PopIII remnants) seeding
- Semi-analytical dynamics ——
  prolonged and chaotic accretion models
  coalescence spin and recoil determination: numerical relativity fitting formula





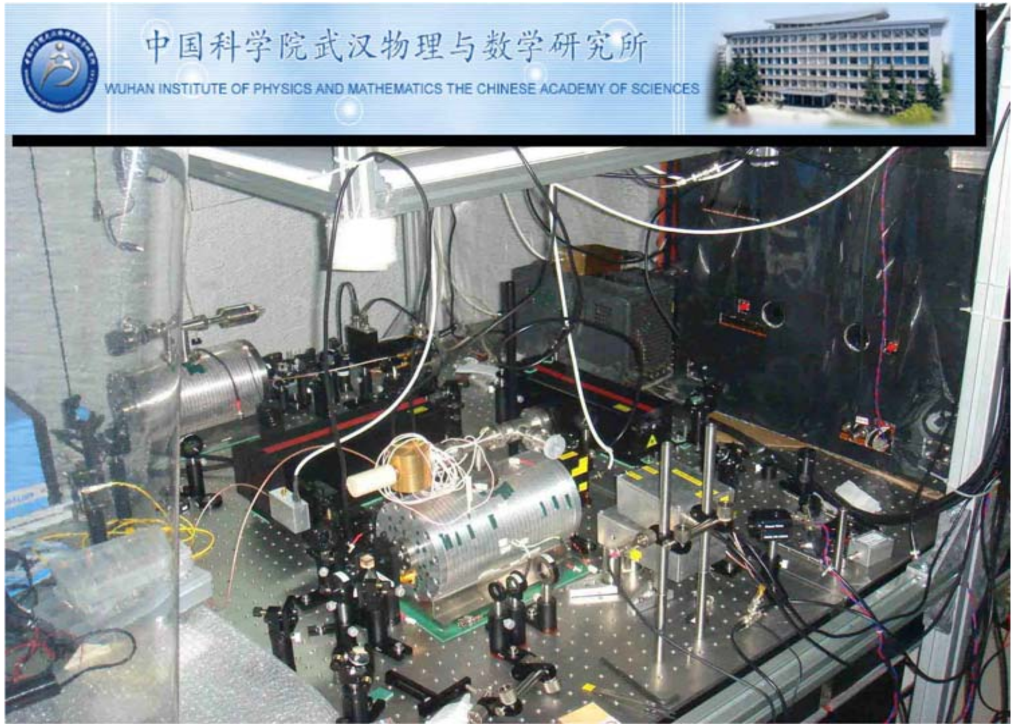
Coalescence rate predicted by the realized simulations.

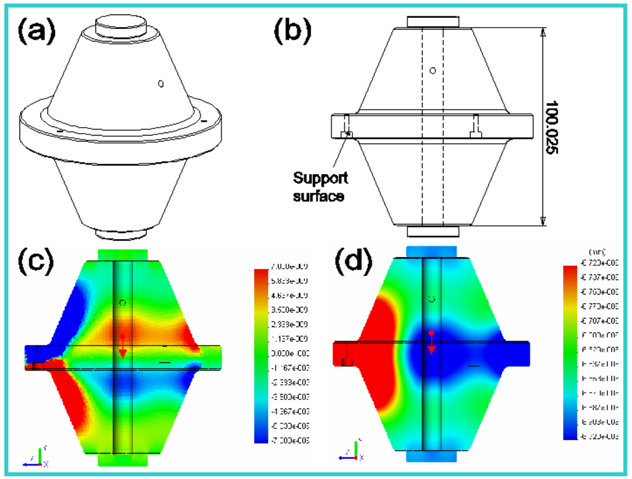
Astronomy application



Taiji mission is going to be an integral part of high redshift astronomy in China, complementary to the Infrared and radio astronomy.

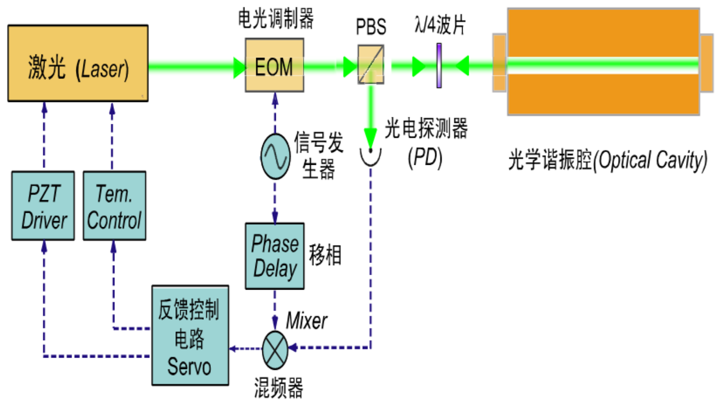
Experiments on frequency locking of Nd:YAG lasers





Ongoing experiments in the Wuhan Institute of Physics and Maths, CAS

Frequency locking of Nd:YAG lasers

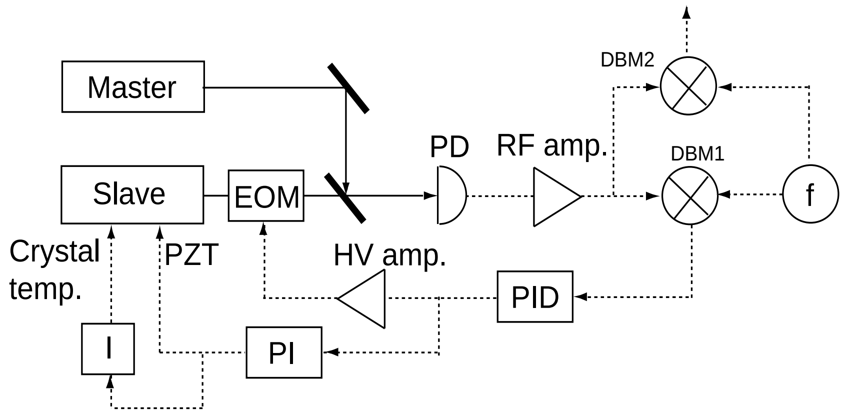


▪Projected system performance:

▪Frequency noise: 30 Hz/√Hz (10mHz-100mHz),

▪Frequency drift: <10 kHz/hour

Phase lock of two Nd:YAG lasers



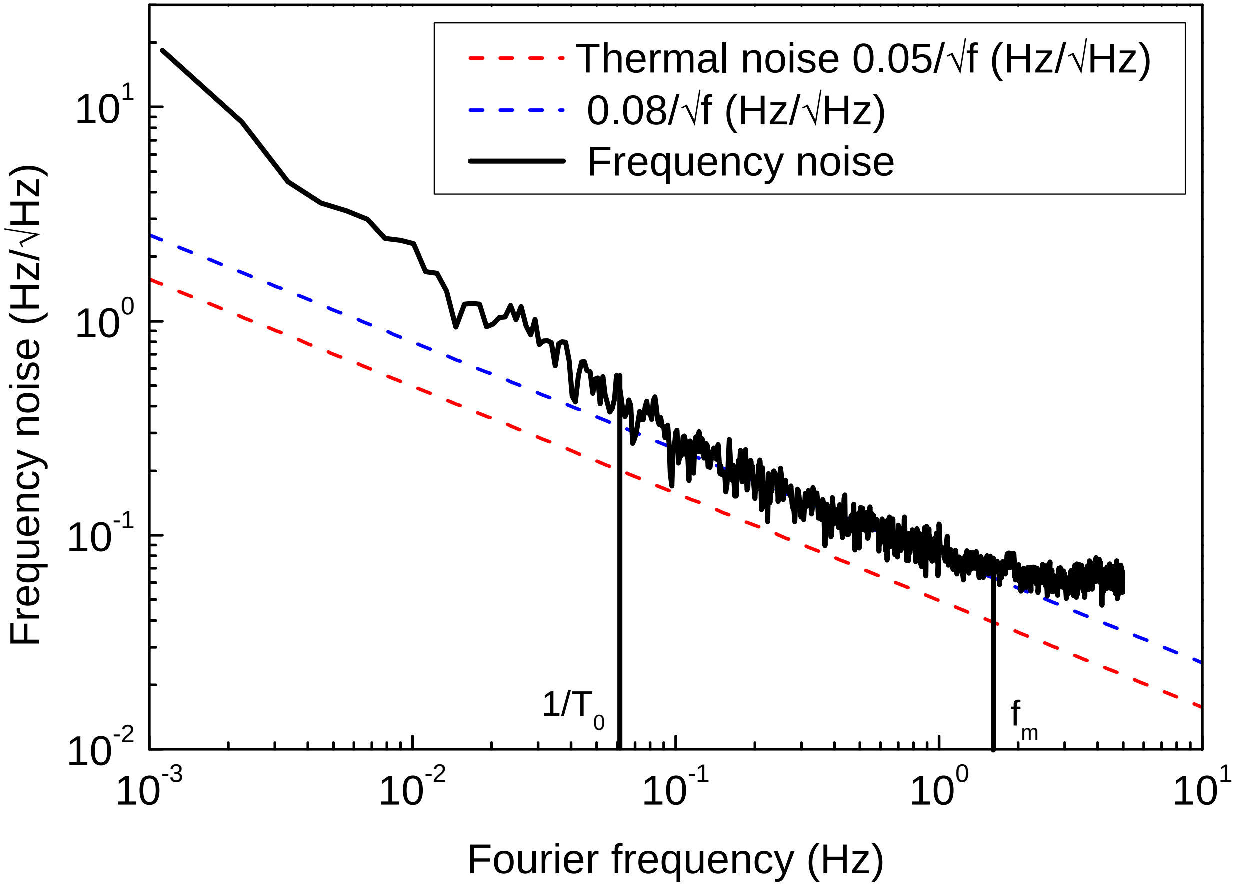
- Analog PLL(Phase Lock Loop) experiments

  Projected phase noise: 1×10^{-4} rad/√Hz (10 - 100 mHz)
- Digital PLL – design and experiments

  a.digital phase detector

  b.analysis of phase noise
- Our goal: Increase the gain at low frequencies (1 mHz-1 Hz) while extend the unit-gain frequency up to several MHz.

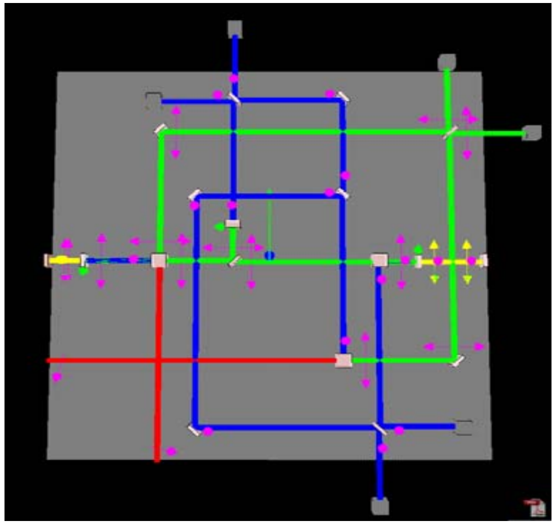
Frequency noise of two beating Nd:YAG lasers independently referenced to 20 cm cavities



Laser linewidth deduced from frequency noise:
0.11 Hz (FWHM) (assuming a measurement time of T_0=16 s)

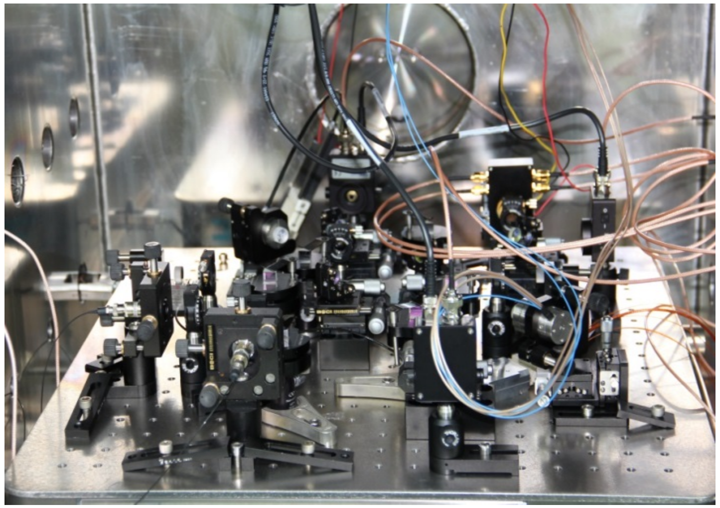
Notice that the above result is achieved in a ground-based system. One should bear in mind that the effort to reach the same stability for a spaceborne laser are challenged by many new technical difficulties.

Laser interferometer prototype in I.Mech

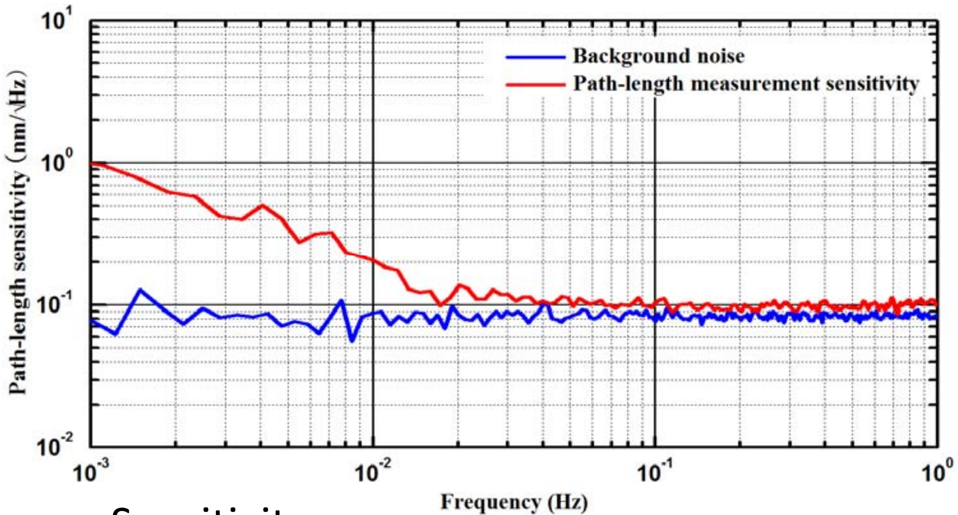


Simulation of optical path

Experimental setup



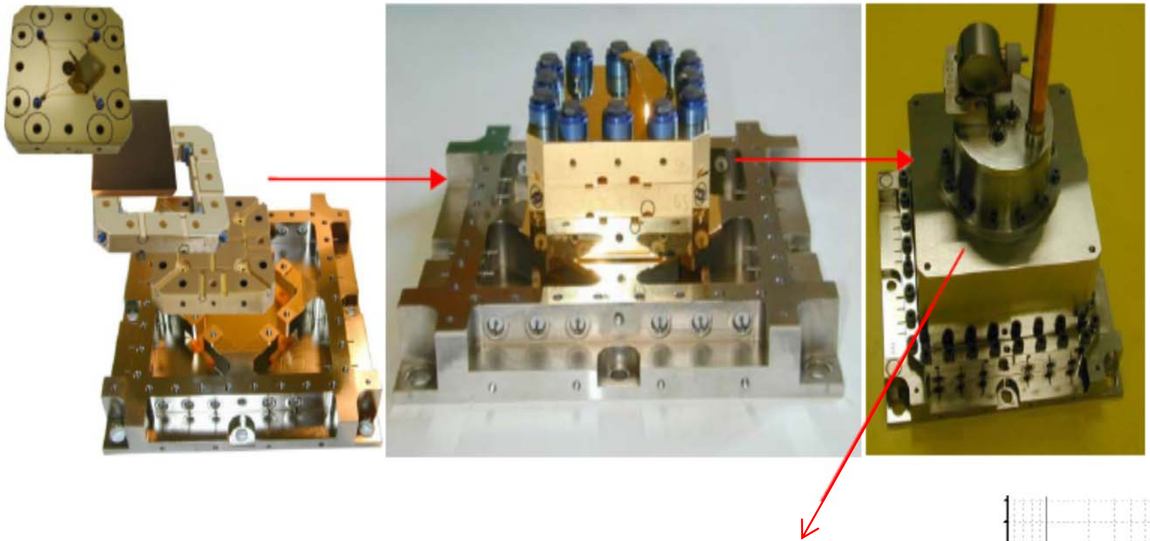
Interferometer

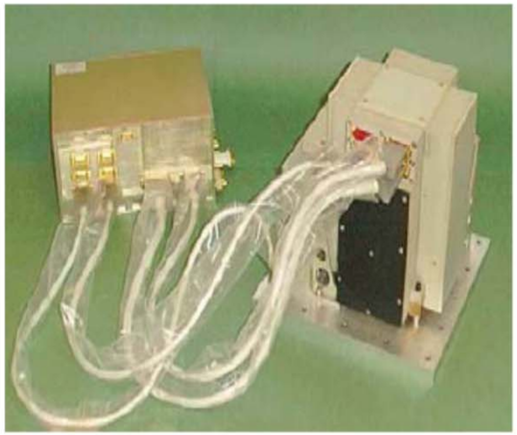


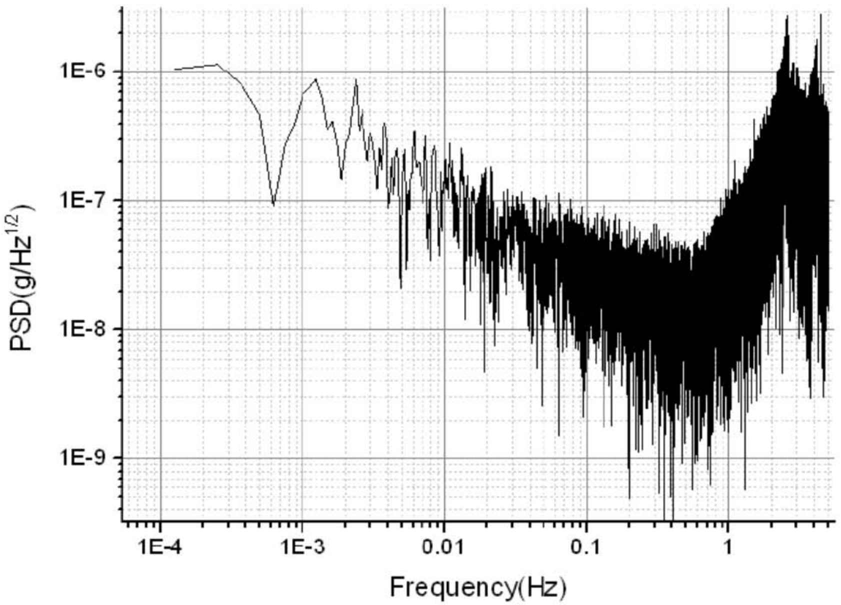
Sensitivity

Y. Q. Li, et al. *Appl. Phys. B: Lasers and Optics*, 118, 2015.

Accelerometer in Lanzhou Institute of Physics, CAST

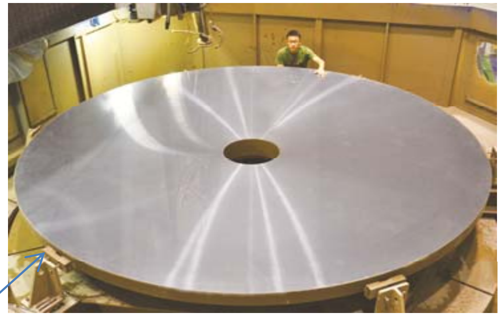




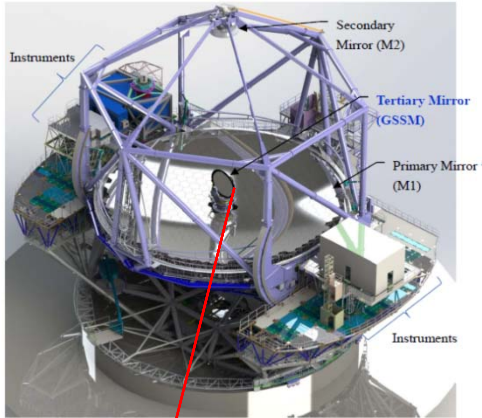


Telescope in Changchun Institute of Optics, Fine Mechanics and Engineering, CAS

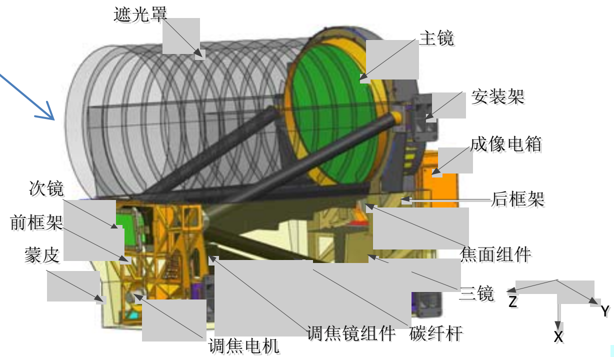
Expertise in off axis triple mirror assembly



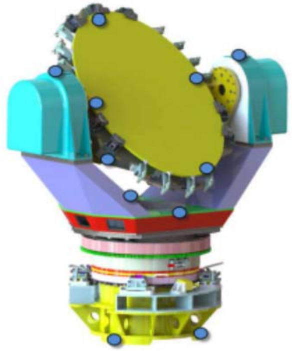
SiC mirror of 4 m aperture



Thirty Meter Telescope (TMT), USA

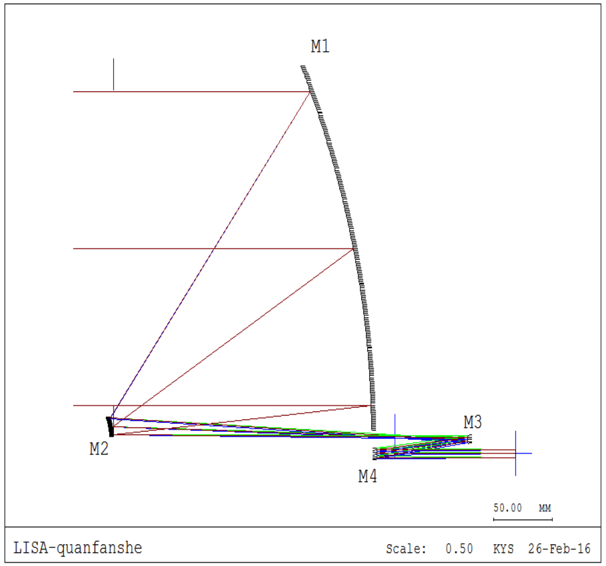


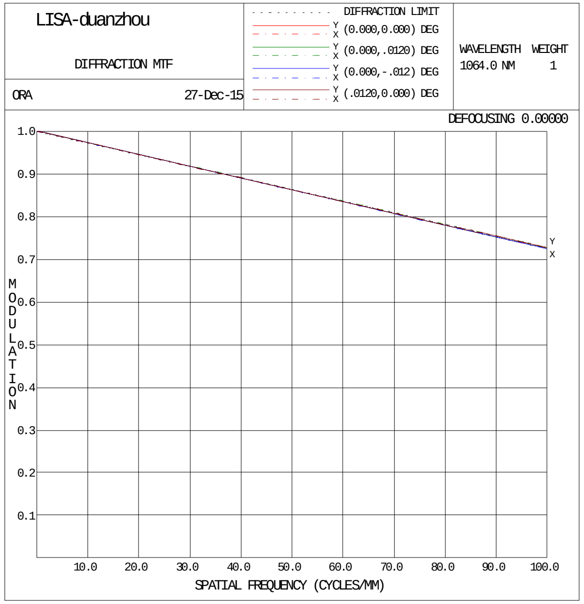
High resolution telescope of Mars 2020

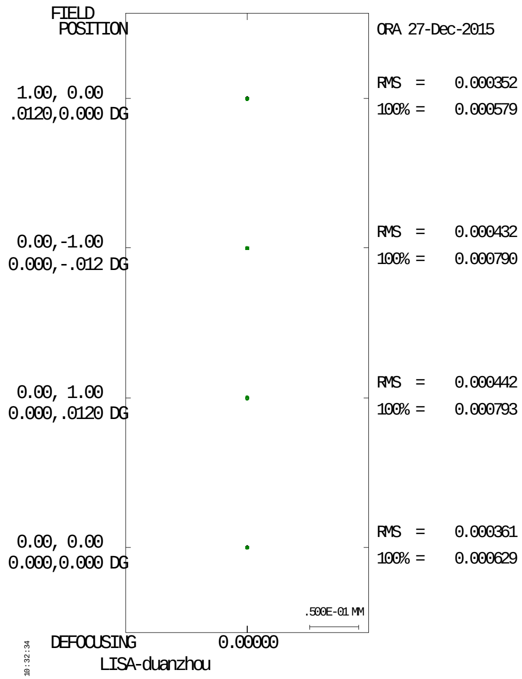


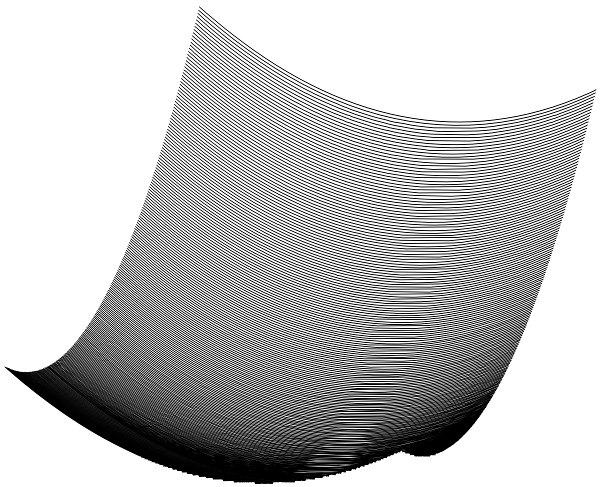
Tertiary Mirror subsystem, designed by CIOMP and aperture is 3m×2.5m。

Optical system design and analysis of LISA telescope

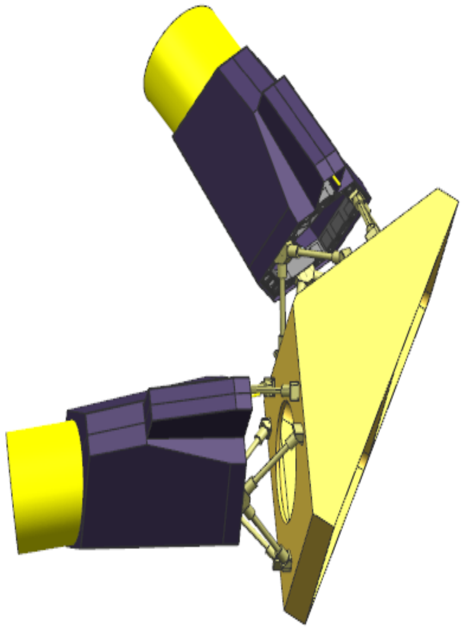


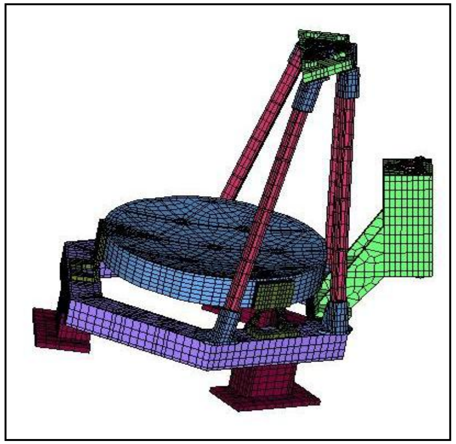




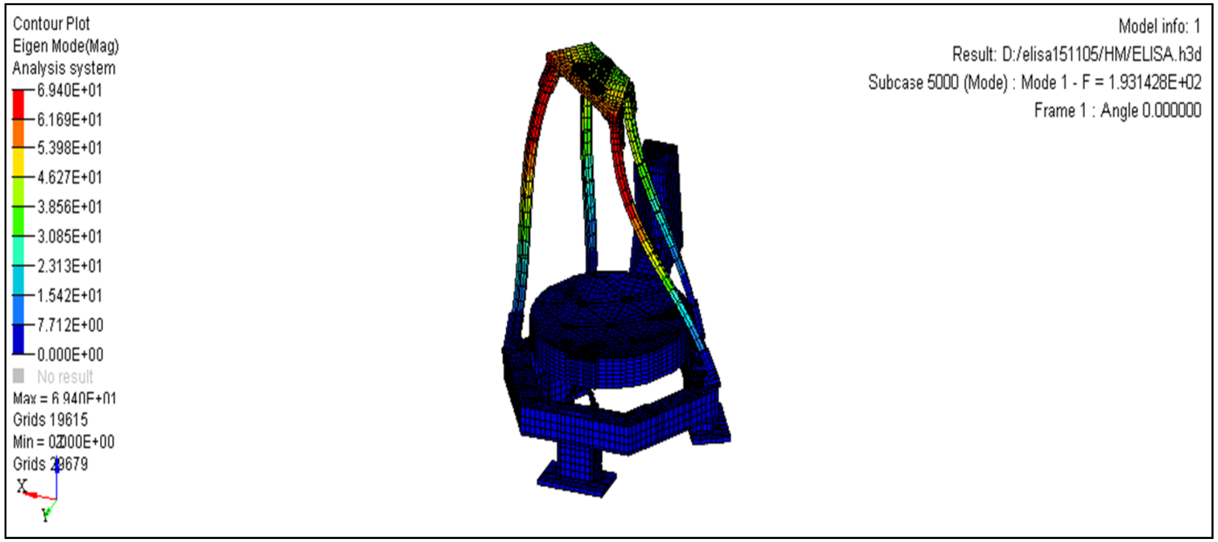


Structure design and analysis of eLISA telescope

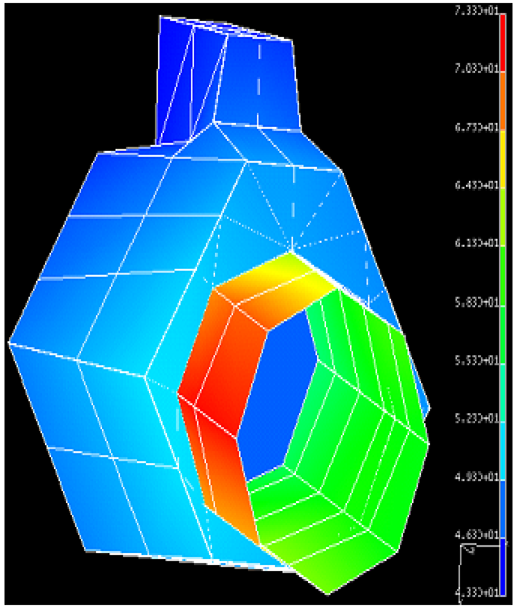


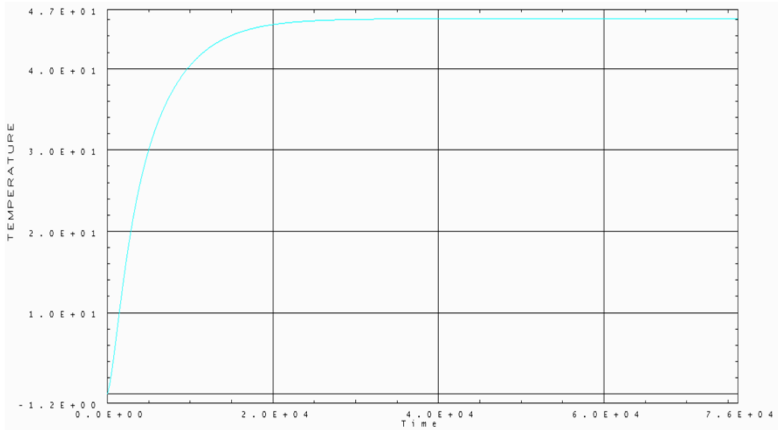


First-order modal:193Hz
Second-order modal:301Hz
Third-order modal:376Hz



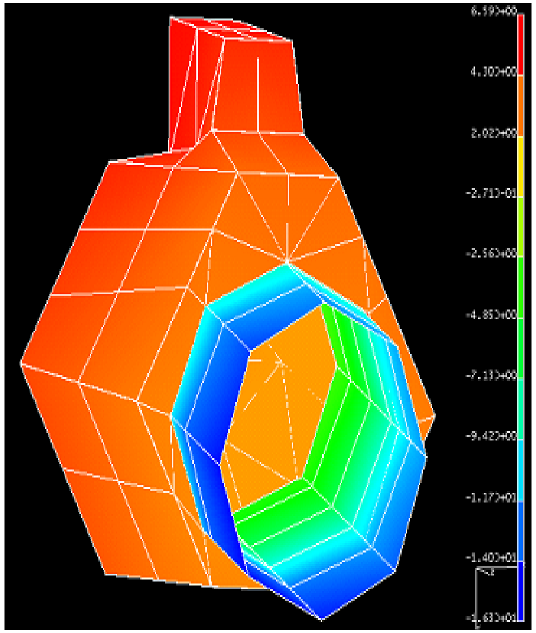
Preliminary thermal analysis of telescope

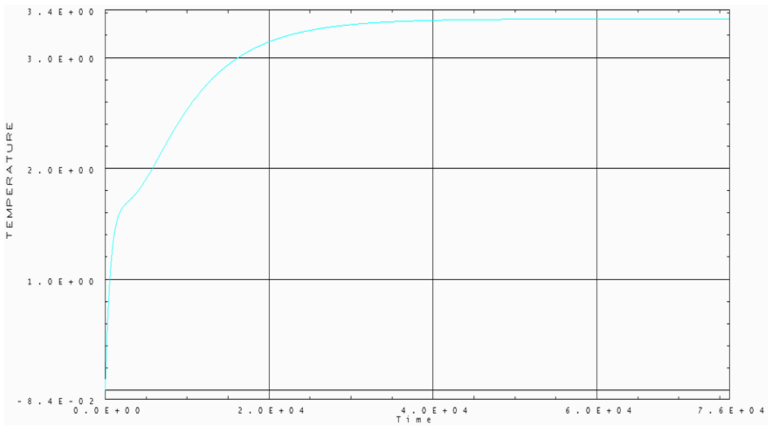




Mode1: sunlight enter the telescope, temperature of M1

Difference between M1 and M2: 1℃

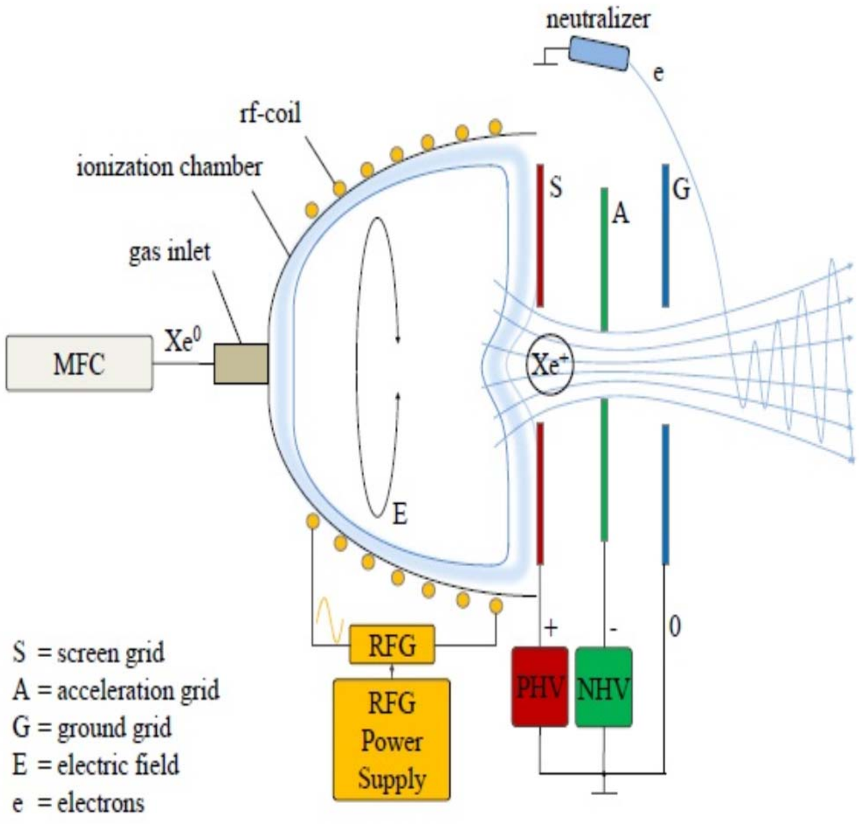




Mode2: no sunlight enter the telescope, temperature of M1

Difference between M1 and M2: 2℃

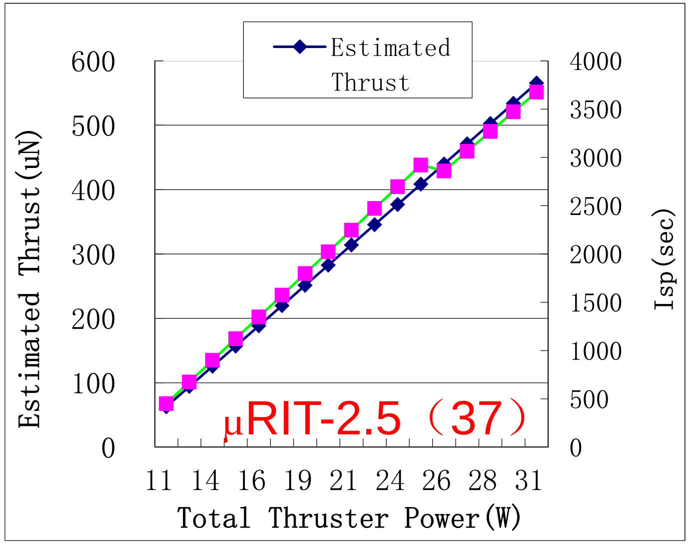
Radio frequency ion thruster (μRIT) for micropropulsion and satellite gravity In I.Mech

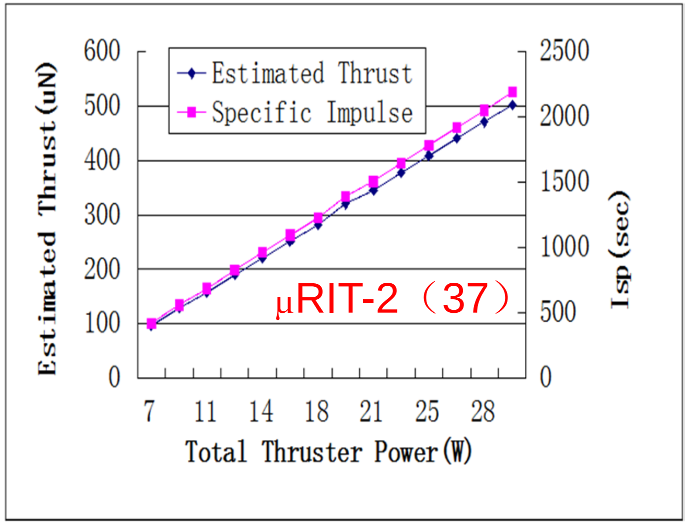


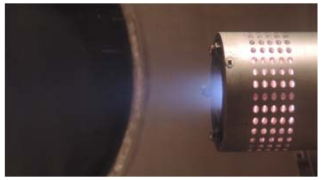
Function principle of a RIT

- **RIT's advantages**
  - **Cathodeless**
  - **No magnets and high voltage biased devices**
  - **No sputtered electrode**
  - **High resolution and Low noise**
  - **Fast response**
  - **High thrust regulability**

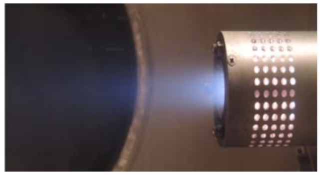
µRIT experimental results



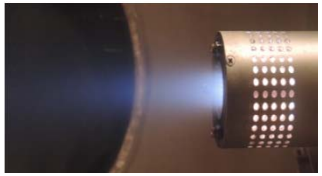




～200µN



～350µN



～500µN

µRIT-2(37)

Thruster Type	µRIT-2	µRIT-2.5
Thrust Range（µN）	100-500	63-565
Gas Flow Rate（µg/s）	21	16
Specific Impulse（s）	416-2190	450-3600
Specific Power（W/mN）	>60	>55
Propellant Utilization（%）	9-47	10-80
Energy Efficiency（%）	30-38.6	12-42

Launch Vehicle Technology

An escaped orbit launch service for the mission.

CZ-5 rocket will launch the main part of Chinese space station around 2020,
Load: 25 tons.

CZ-5 is able to launch 3 satellites orbiting the Sun
Load：5.7 tons

China Academy of Launch Vehicle Technology (CALT)

Mission for gravitational wave detection in Space in China

- Open for collaboration with international society, especially with ESA scientists;

- Develop and work with eLISA for collaboration and data comparison;

- Employ more technology in same models and types for high efficiency and low cost

International Scientific activities

- International conference on Gravitational Wave Detection in Space, Beijing, April or May, 2017

- Taiji Union for Gravitational Wave Detection in Space will be set up soon and all researchers and scientists all over the world are welcome.

- Joint Albert Einstein Institute for Radio Astronomy and Gravitational Physics between Max Planck Society and Chinese Academy of Sciences to be discussed in MPG-CAS Meeting to be held in Shanghai in November, 2016.

- Chinese pathfinder would be launched in 10 years to test key technology for GWD in Space or/and Grace II, International collaboration is welcome.

- Joint research proposal to be submitted to the DFG and National Science Foundation, China after the Sino-German meeting in 2015

Prospect

- Step I (2016-2020)

  Ground studies on theoretical analyses and key technology

- Step II (2021-2025)

  Space technology for Chinese pathfinder of key technology experiment

- Step III (2026 – 2035)

  Satellite of SGW mission


Thank You!
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CZ-2F