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

Gang JIN
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
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.

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

<table>
<thead>
<tr>
<th>Armlength (m)</th>
<th>Telescope diameter (m)</th>
<th>Laser power (W)</th>
<th>1-way position noise (pm/√Hz)</th>
<th>Acceleration noise (m/s²/√Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3 \times 10^9$ (Chinese mission option)</td>
<td>0.46</td>
<td>2</td>
<td>8</td>
<td>$3 \times 10^{-15} (&gt; 0.1 \text{mHz})$</td>
</tr>
<tr>
<td>$1 \times 10^9$ (eLISA)</td>
<td>0.2</td>
<td>2</td>
<td>11</td>
<td>$5 \times 10^{-15} (&gt; 0.1 \text{mHz})$</td>
</tr>
<tr>
<td>$5 \times 10^9$ (LISA)</td>
<td>0.4</td>
<td>2</td>
<td>18</td>
<td>$3 \times 10^{-15} (&gt; 0.1 \text{mHz})$</td>
</tr>
</tbody>
</table>

[Diagram showing strain sensitivity vs frequency for different missions including Chinese mission design.]
Enhanced detection performance on IMBH

Main difference from LISA
- Sensitivity floor shifts to the right.
- Enhanced Intermediate mass black holes (IMBH) detection

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.
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: $30 \text{ Hz/}\sqrt{\text{Hz}}$ (10mHz-100mHz),
  - Frequency drift: $<10 \text{ kHz/hour}$

Phase lock of two Nd:YAG lasers

- **Analog PLL (Phase Lock Loop) experiments**
  - Projected phase noise: $1 \times 10^{-4} \text{ rad/}\sqrt{\text{Hz}}$ (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

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

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

Tertiary Mirror subsystem, designed by CIOMP and aperture is $3m \times 2.5m$.

High resolution telescope of Mars 2020
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

Mode 1: sunlight enter the telescope, temperature of M1
Difference between M1 and M2: 1°C

Mode 2: no sunlight enter the telescope, temperature of M1
Difference between M1 and M2: 2°C
Radio frequency ion thruster (µRIT) for micropropulsion and satellite gravity In I.Mech

- 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

<table>
<thead>
<tr>
<th>Thruster Type</th>
<th>μRIT-2</th>
<th>μRIT-2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimated Thrust (μN)</strong></td>
<td>100-500</td>
<td>63-565</td>
</tr>
<tr>
<td><strong>Gas Flow Rate (μg/s)</strong></td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td><strong>Specific Impulse (s)</strong></td>
<td>416-2190</td>
<td>450-3600</td>
</tr>
<tr>
<td><strong>Specific Power (W/mN)</strong></td>
<td>&gt;60</td>
<td>&gt;55</td>
</tr>
<tr>
<td><strong>Propellant Utilization (%)</strong></td>
<td>9-47</td>
<td>10-80</td>
</tr>
<tr>
<td><strong>Energy Efficiency (%)</strong></td>
<td>30-38.6</td>
<td>12-42</td>
</tr>
</tbody>
</table>

![Graphs showing estimated thrust and specific impulse for μRIT-2 and μRIT-2.5 thrusters.](image-url)
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!