Ando Group Seminar

Masaki Ando's Travels in these Two Weeks
Chinese Space GW Mission and VIRGO

Masaki Ando (Univ. of Tokyo / NAOJ)

Ando's Travel Schedule

May	20	(Travel)	
	21	↑	KIW3: 3rd KAGRA int. workshop (Taipei, Taiwan)
	22	↓	
	23	↕	AIW2: 2nd ASTROD int. workshop (Shinchu, Taiwan)
	24		Visit to NSPO (Hsinchu)
	25	(Travel) ↑	ISGW2017: International Symposium on Gravitational Waves (Beijing, China)
	26	(Travel) ↓	
	27		U-Tokyo Guidance
	28	(Travel)	
	29		
	30	↑	VIRGO STAC (Scientific and Technical Advisory Committee) (Pisa, Italy)
	31	↓	
June	1	(Travel)	
	2		
	3		U-Tokyo Open Public lecture

Chinese Space GW Mission

Chinese GW Mission

Nature 531, 150 (March 2016)

- Just after the LIGO's announcement of the first discovery in Feb. 2016, China decided to launch space GW mission.

NEWS IN FOCUS

ASTROPHYSICS

Chinese gravitational-wave hunt hits crunch time

The pressure is on to choose between several proposals for space-based detectors.

BY DAVID CYRANOSKI

In the wake of last month's historic detection of gravitational waves by a US-led collaboration, a range of Chinese proposals to take studies of these ripples in space-time to the next level are attracting fresh attention.

The suggestions, from two separate teams, are for space-based observatories that would pick up a wider range of gravitational radiation than ground-based observatories can. The most ambitious plan could give China an edge over the leading European proposal to detect gravitational waves from space, but whether a single country can achieve that on its own is unclear. Also under consideration are a possible collaboration between Chinese researchers and the European effort, and a cheaper Chinese plan.

Although an Earth-based detector — the US Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) — was the first to confirm a prediction made by Albert Einstein a century ago, launching the field of gravitational-wave astronomy, such detectors can pick up only limited frequencies. Advanced LIGO compares laser light beamed along two perpendicular detector arms to reveal whether one beam has been compressed or stretched by gravitational waves.

Each LIGO arm measures 4 kilometres, but picking up the frequencies that are richest in gravitational waves requires distances of hundreds of thousands of kilometres or more. This can be achieved only in space, where spacecraft equipped with lasers can be positioned at these distances. Space-based detectors also avoid fluctuations in Earth's gravitational field, which can obscure signals.

> ***"If China decides to have a space gravitational mission, there should be an integrated one."***

With such considerations in mind, the European Space Agency (ESA) is pursuing a space-based gravitational-wave detector. One of the Chinese proposals, Taiji, meaning 'supreme ultimate', is to create a more ambitious version of the leading proposal for the European project, which is called eLISA (Evolved Laser Interferometer Space Antenna).

Like eLISA, Taiji would consist of a triangle of three spacecraft in orbit around the Sun, which bounce lasers between each other (see 'China's choices'). The distance between eLISA's components is still under discussion, but current plans suggest it could be 2 million kilometres, says eLISA member Karsten Danzmann of the Max Planck Institute for Gravitational Physics in Hanover, Germany. Taiji's spacecraft would be separated by 3 million kilometres, giving the detector access to different frequencies. Taiji would launch in 2033, slipping in a year ahead of eLISA's current schedule. "If Taiji produces a Chinese version of eLISA, then it will bring China to the frontier," says Yanbei Chen, a gravitational-wave physicist at the California Institute of Technology in Pasadena, who works on LIGO.

Gerhard Heinzel, an eLISA physicist also at the Max Planck Institute in Hanover, cautions against a single country going it alone on such a large project. It "is definitely too big — mainly in terms of cost but also resources in terms of scientists and experts in the presence of competing science projects", he says.

Taiji project leader Wu Yue-Liang, a particle physicist at the Chinese Academy of Sciences' Institute of Theoretical Physics in Beijing, estimates that the project will cost 14 billion yuan (US$2 billion), roughly twice as much as ESA is budgeting for its gravitational-wave detector.

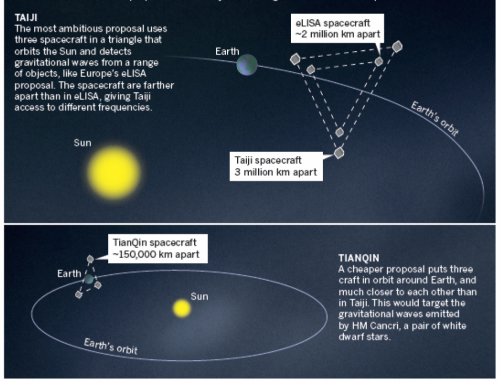
SECOND STRING

A second Chinese proposal, led by Luo Jun, a physicist at the Sun Yat-Sen University campus in Zhuhai, would lower the bar in terms of cost and resources. Called TianQin, a name that refers to the metaphor of nature playing a stringed instrument (a zither) in space, the project has three satellites that orbit Earth at a distance of about 150,000 kilometres from each other. It would cost 2 billion yuan, says Luo.

TianQin would be more limited than Taiji in terms of what it could detect: rather than acting as an observatory for the waves emitted by myriad objects including black holes and neutron stars, it would mainly target a particular pair of orbiting white dwarf stars, called HM Cancri. TianQin's simplicity makes it cheaper and

CHINA'S CHOICES

Chinese researchers have proposed several ways to detect gravitational waves in space.

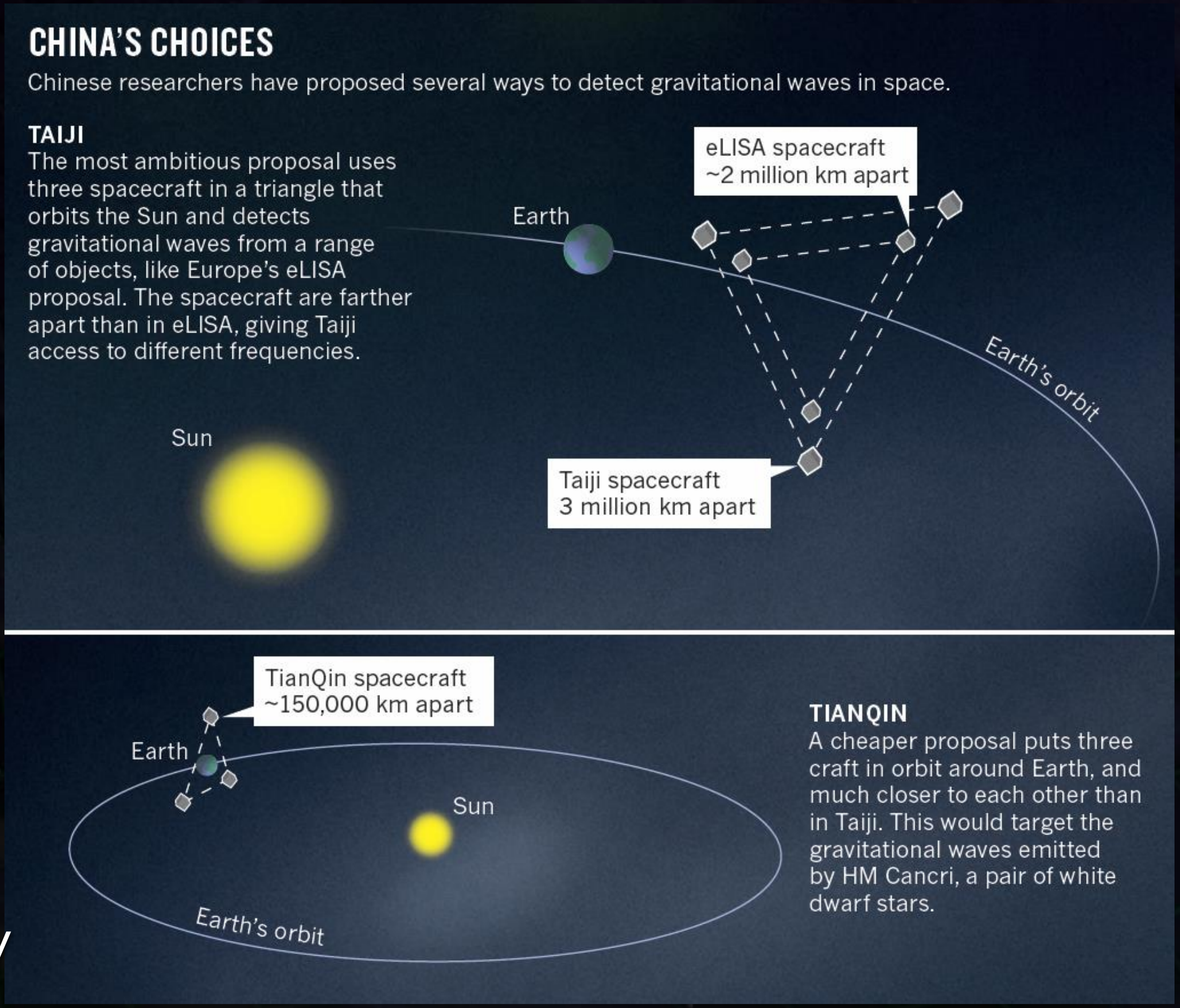


SOURCES: ELISA/WU YUE-LIANG/LUO JUN

Chinese GW Missions

- Taiji (太極)
  - * Slightly longer than LISA
  - * Heliocentric orbit
  - * Proposed by Chinese Academy of Science

- TianQin (天琴)
  - * ~10 times shorter
  - * Geocentric orbit
  - * Proposed by Sun Yat-Sen University



KIW3 and AIW2

KIW3 and AIW2

<u>ASTROD Int. Workshop</u>
at Hsinchu (National Tsing Hua Univ.)
* 1 day, ~20 participants
* LPF/LISA, DECIGO, TianQin, ASTROD
* Visit to NSPO in the next day

<u>KAGRA Int. Workshop</u> at Taipei
(NTU: National Taiwan Univ.)
* Two days
* KAGRA reports, Status reports (LIGO, VIRGO, KAGRA), KAGRA future plans, and space missions (LPF/LISA, DECIGO, TianQin, ASTROD)

by Google Map

AIW2: The 2nd ASTROD Int. Workshop

第二屆雷射天文動力學專題討論會

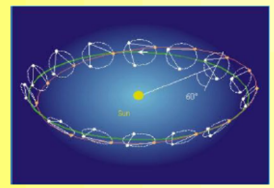
2nd ASTROD International Workshop (AIW2)

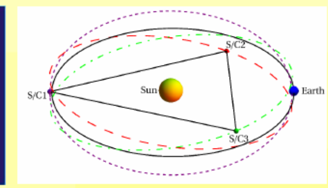
620 Phys. Bldg., National Tsing Hua Univ., Hsinchu • May 23, 2017

Topic: Gravitational Wave (GW) Detection in Space

All the present active space GW proposals – New LISA, DECIGO, TAIJI, TIANQIN and ASTROD-GW will be discussed

Open to all the scientists of various fields





Talks and Lecturers

- *Martin Hewitson* (Max Planck I.) LISA Pathfinder: Experiment results
  LISA: A GW Observatory in Space
- *Hsien-Chi Yeh* (Sun Yat-sen U.) TIANQIN GW mission and key technologies
- *Masaki Ando* (Tokyo U.) Science and Design of DECIGO and B-DECIGO
- *Wei-Tou Ni* (NTHU) ASTROD-GW
- *An-Ming Wu* (NSPO) Deployment for Various Gravitational Wave Missions
- *Gang Wang* (INFN) Orbit design and TDI simulation for LISA, TAIJI and others

Organizing Committee Ling-Wei Luo (National Tsing Hua Univ.), Wei-Tou Ni (National Tsing Hua Univ.), Sheau-shi Pan (Industrial Technology Research Institute), An-Ming Wu (National Space Organization), Hwei-Jang Yo (National Cheng-Kung Univ.)

- http://www.phys.nthu.edu.tw/~gravity/gws2017/
- **Deadline: 10 May 2017 (registration)**
- **Contact: Ling-Wei Luo** lwluo@mx.nthu.edu.tw

GSROC

中華民國重力學會

Sponsors: National Tsing Hua Univ./Physics Department
The Gravitational Society of the Republic of China

Photos at Hsinchu (新竹市)

Physics Building of
National Tsing Hua Univ.

LISA

Folks temple (新竹城隍廟)

Photos at Hsinchu

NSPO
(National Space Organization, 国家天空中心)
Three floors in a office building (Office, Meeting rooms, Operation rooms), and One dedicated building (Clean building with Satellite assembly and Full-scale tests) in a industrial park.

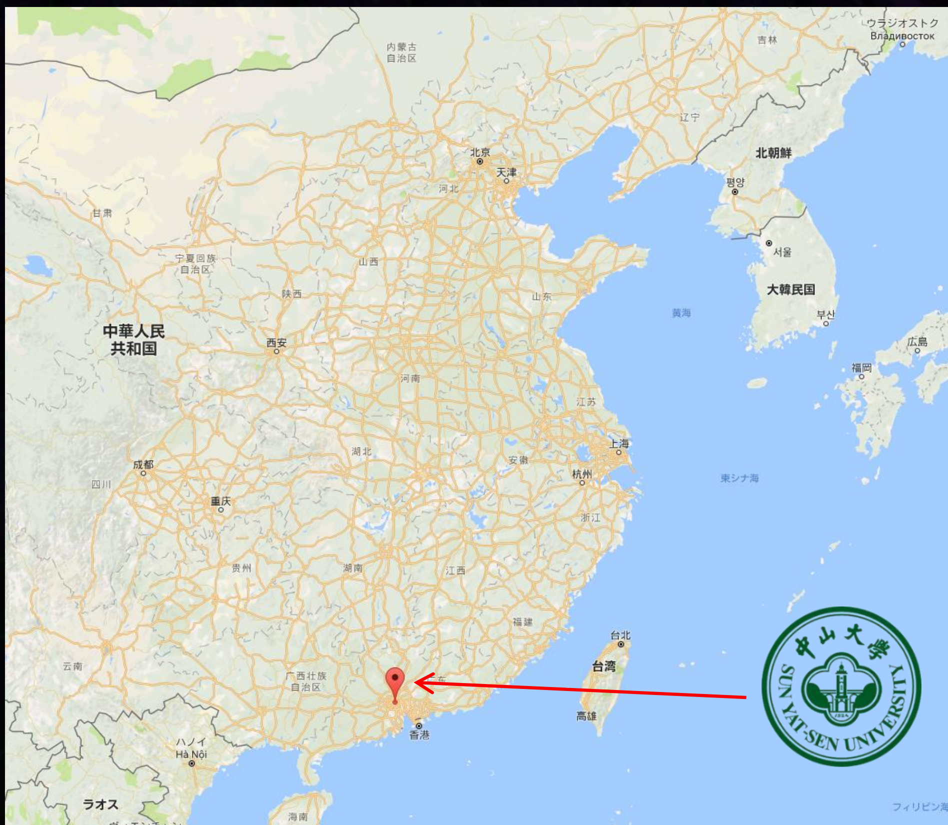
Sea food restaurant

TianQin (天琴) Mission

from Presentations at KIW3 and AIW2 by Prof. Hsien-Chi Yeh (Tianqin Research Center for Gravitational Physics, Sun Yat-Sen Univ.)

KIW3: http://grqc.ncts.ncku.edu.tw/KAGRA2017/program.html
AIW2: http://www.phys.nthu.edu.tw/~gravity/gws2017/prog.php

Sun Yat-Sen Univ (中山大学)



by Google Map

Sun Yat-sen University
(孫逸仙大学, 中山大学)
* At Guangdong (広東省)
* Founded in 1924

TianQin Mission

TianQin Mission Concept

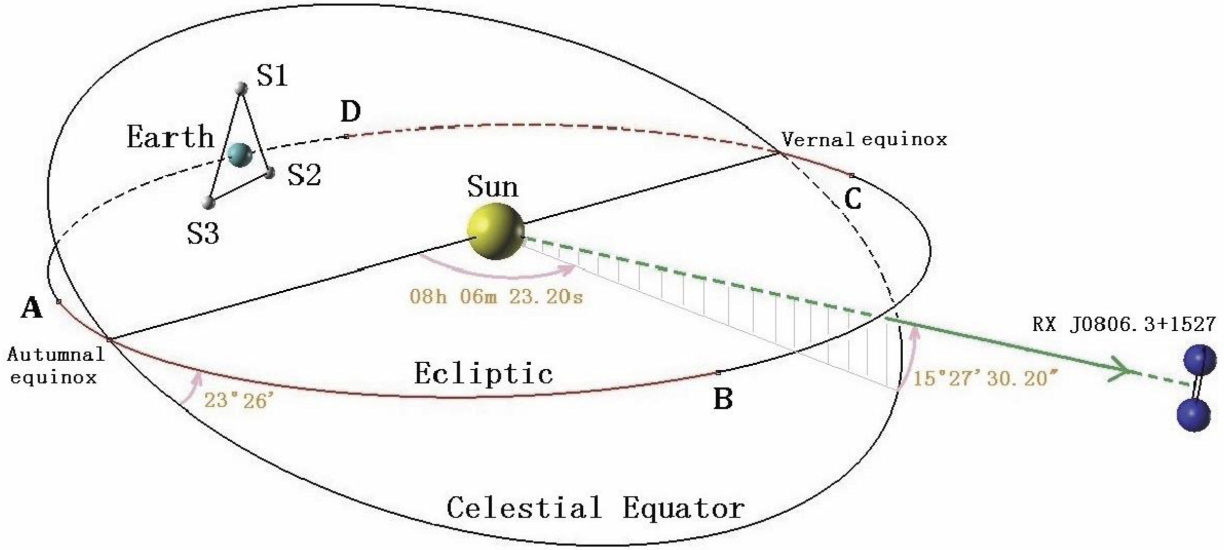
Guidelines :

- **Geocentric orbit, shorter arm-length, higher feasibility;**
- **Target a well-known GW source (location and GW frequency) first, as the "calibrated source";**

TianQin Mission

TianQin GW Antenna

- **Orbit:** geocentric orbit with altitude of 100,000km;
- **Configuration:** 3-satellite triangular constellation, nearly vertical to the Ecliptic;
- **"Calibrated" source:** J0806.3+1527, close to the ecliptic;
- **Detection time window:** 3 months;



TianQin Mission

Sensitivity goal

Gravitational wave from RX J0806.3+1527

- Masses (0.5, 0.27) Msun
- Period 321.5s (distance between stars 66000km)
- Distance (0.05 ~ 5) kpc
- Strain

G.H.A.Roelofs et al, ApJ, 711, L138 (2010)
T.E.Strohmayer, ApJ, 627,920(2005)
Simbad data base

$$h_0 \sim h_+ \sim h_\times \sim \frac{2G_N^2 M_1 M_2}{r_0 a}$$

$$\approx 6.4 \times 10^{-23} \left(\frac{M_1}{0.55 M_\odot}\right)\left(\frac{M_2}{0.27 M_\odot}\right)\left(\frac{5kpc}{r_0}\right)\left(\frac{66000km}{a}\right)$$

- Integrated strength (90days)

$$h_f = h_0 \sqrt{90\text{days}} \approx 1.8 \times 10^{-19}/\text{Hz}^{1/2} \left(\frac{M_1}{0.55 M_\odot}\right)\left(\frac{M_2}{0.27 M_\odot}\right)\left(\frac{5kpc}{r_0}\right)\left(\frac{66000km}{a}\right)$$

- Relation to noise (SNR=10)

$$\frac{h_f}{10} \geq \frac{2}{\sqrt{R_0}}\left[\frac{S_x}{L_0^2} + \frac{S_a}{(2\pi f)^4 L_0^2}\left(1 + \frac{10^{-4}\text{Hz}}{f}\right)\right]^{1/2}, \quad R_0 \approx 2.0$$

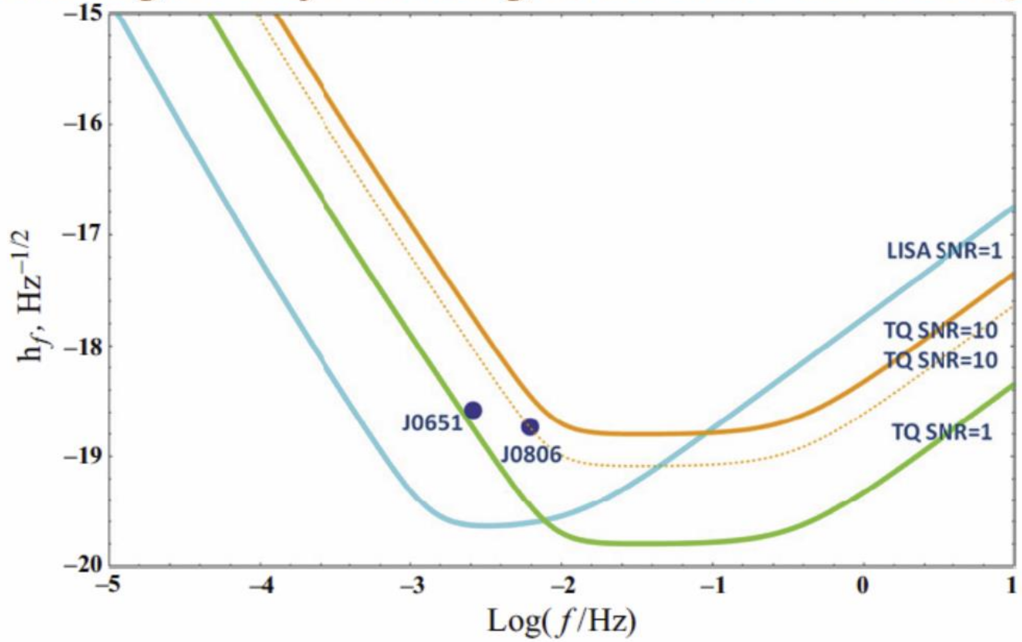
: Transfer function

S_x Noise in distance measurement; S_a Noise in acceleration

TianQin Mission

Sensitivity Curve of TianQin

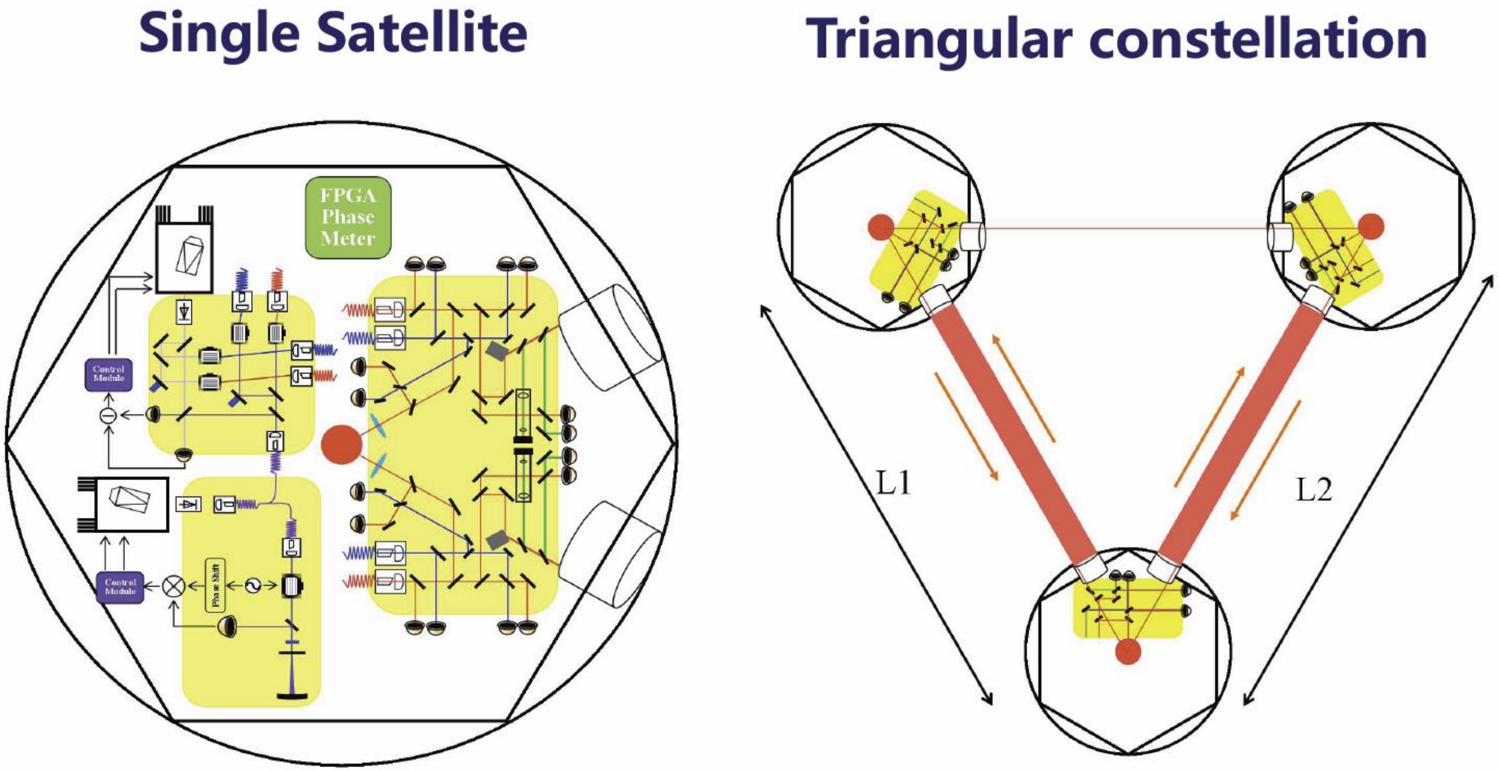
Assuming 90 days of integration time for TIANQIN



Para.	eLISA	TianQin
Arm Len.	10^6 km	$1.7*10^5$ km
$Sa^{1/2}$	$7*10^{-15}$ $m/s^2/Hz^{1/2}$	$3*10^{-15}$ $m/s^2/Hz^{1/2}$
$Sx^{1/2}$	10 $pm/Hz^{1/2}$	1 $pm/Hz^{1/2}$

TianQin Mission

Configuration of Space GW Antenna



TianQin Mission

Requirements

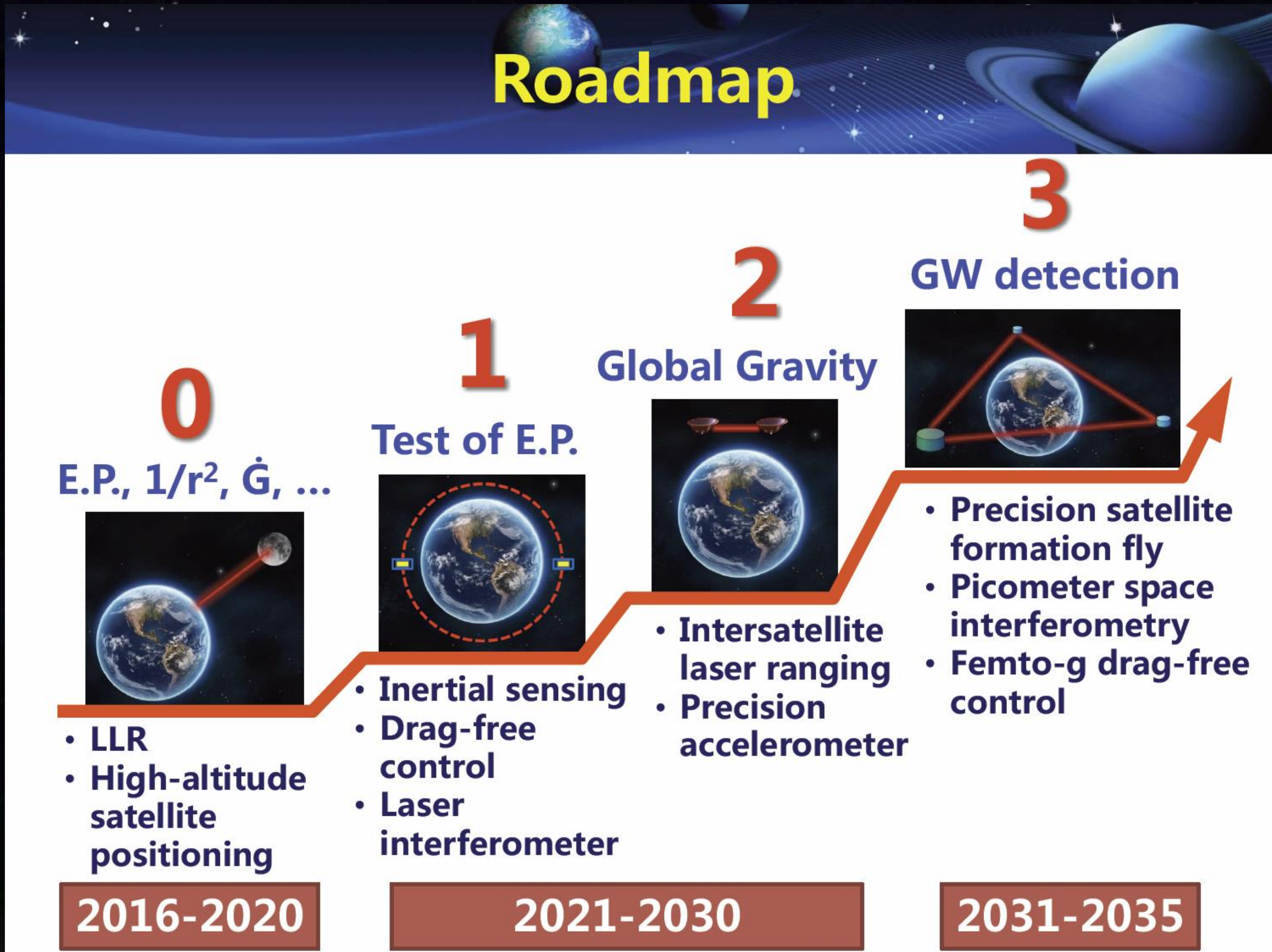
Key Technologies		Specifications
Inertial sensing & Drag-free control 10^{-15} m/s^2/Hz$^{1/2}$	Proof mass	magnetic susceptibility 10^{-5} Residual charge $1.7*10^{-13}$C Contact potential 100uV/Hz$^{1/2}$ @ 10mV
	Cap. Sensor	$1.7*10^{-6}$pF/Hz$^{1/2}$（3nm/Hz$^{1/2}$） @ 5mm
	Temp. stability	5uK/Hz$^{1/2}$
	Residual magnetic field	$2*10^{-7}$T/Hz$^{1/2}$ Satellite remanence 1Am^2@0.8m
	uN-thruster	100 uN (max); 0.1 uN/Hz$^{1/2}$
Space Interferometry 1pm/Hz$^{1/2}$	Nd:YAG Laser	Power 4 W, Freq. noise 0.1 mHz/Hz$^{1/2}$
	Telescope	Diameter 20 cm
	Phasemeter	Resolution 10^{-6} rad
	Pointing control	Offset & jitter 10^{-8} rad/Hz$^{1/2}$
	Wavefront distortion	λ/10
	thermal drift of OB	5nm/K

TianQin Mission

Key Technologies

- **Femto-g Drag-free control:**
  - Ultraprecision inertial sensing: ACC, proof mass
  - uN-thruster: continuously adjustable, 5-year lifetime
  - Charge management (UV discharge)
- **Picometer laser interferometry:**
  - Laser freq. stab.: PDH scheme + TDI
  - Ultra-stable OB: thermal drift 1nm/K
  - Phase meas. & weal-light OPLL: 10^{-6}rad , 1nW
  - Pointing control: 10^{-8}rad@10^{6}km
- **Ultrastable satellite platform:**
  - Stable constellation: min. velocity and breathing angle
  - Environment control: temperature, magnetic field, gravity and gravity gradient
  - Satellite orbiting: position(100m), velocity(0.1mm/s) (VLBI+SLR)

TianQin Mission



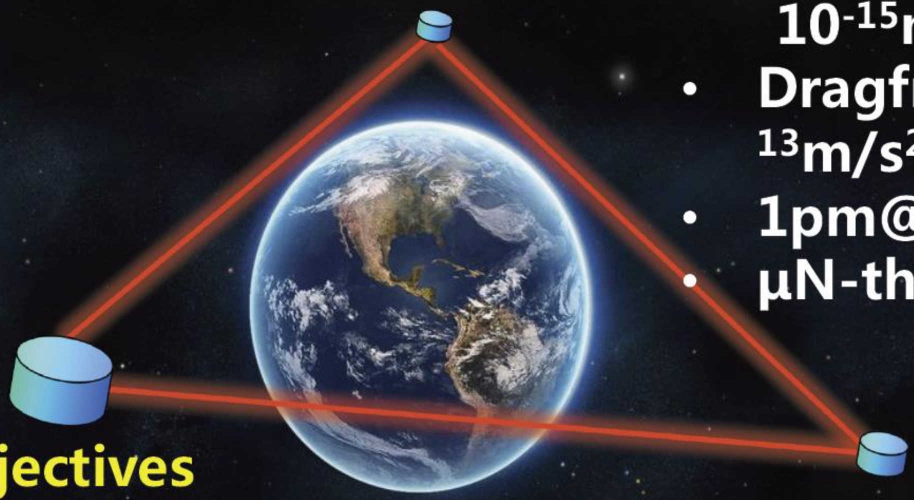
TianQin Mission

Four Steps to GWD

Step-3:
TianQin
2016-2035

Technology objectives

- Inertial sensor $10^{-15} m/s^2$
- Dragfree $10^{-13} m/s^2$
- $1pm@10^7m$
- μN-thruster



Science objectives

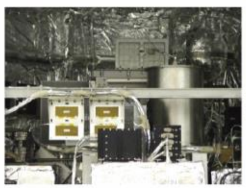
- General Relativity
- GW astronomy

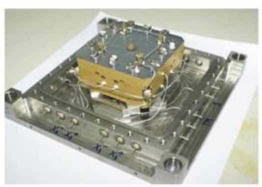
Class. Quantum Grav. 33, 035010 (2016)

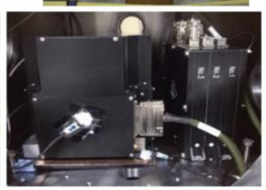
TianQin Mission

Precision Inertial Sensing

1996-2000: develop flexure-type ACC
2001-2005: space test of flexure-type ACC
— launched in 2006
2006-2010: develop electrostatic ACC
2011-2015: space test of electrostatic ACC
— launched in 2013



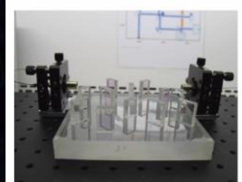


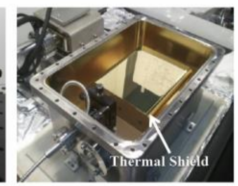


Space Laser Interferometry

2006-2010: (10m) nm laser interferometer
2011-2015: (200km) inter-satellite laser ranging system

- Picometer laser interferometer
- nW weak light OPLL
- nrad pointing angle measurement
- 10Hz space-qualified laser freq. stab.

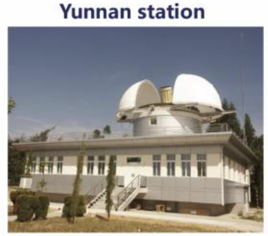




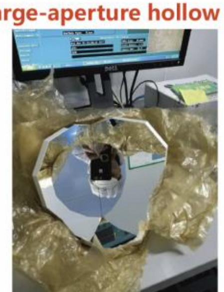
Large-aperture CCR & SLR

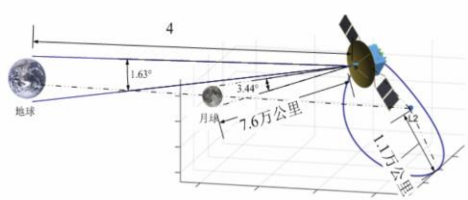
Laser Ranging for CE 4 relay satellite
- Manufacturing next-generation laser ranging CCR
- Upgrading ground stations

Yunnan station



Large-aperture hollow CCR





Basic Infrastructure at Zhuhai (2016-2019)

TianQin Mission

Conclusions

1. Tianqin will develop all key technologies required for space-based GW detection step by step in the following 15 years.
2. Aiming at frequency range of 1mHz-1Hz, Tianqin can provide joint observations with LIGO, KAGRA and LISA.
3. Collaboration with DESIGO should be considered seriously, including studying science cases and developing key technologies required for both missions.

ISGW2017

University of Chinese Academy of Science

by Google Map

UCAS : University of Chinese Academy of Science (中国科学院大学)

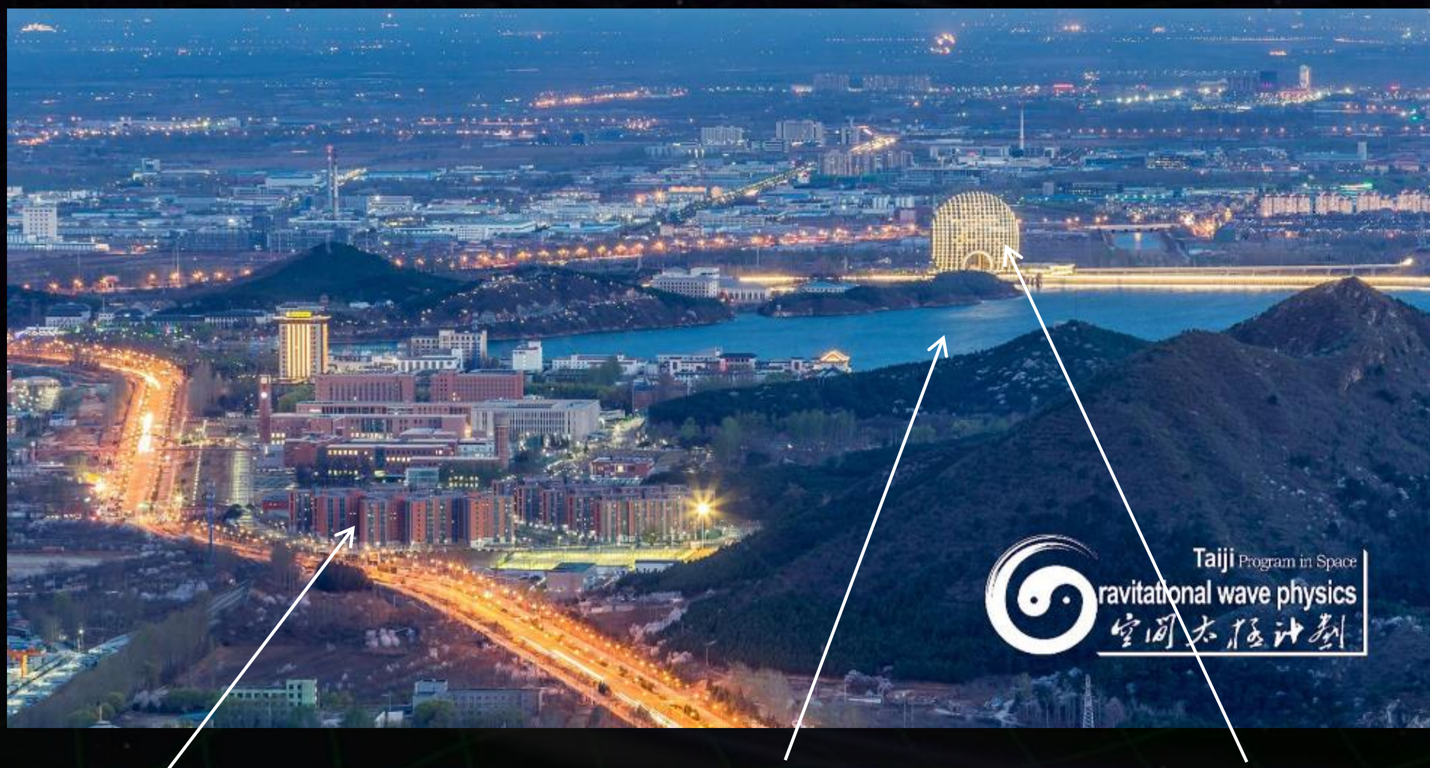
* Several campuses at Beijing
* Founded in 1978
* World's #1 university in Nature Publishing Index (NPI): Ranking of number of papers published in Nature and related scientific magazines (2016).

ISGW2017

* Held at International Conference Center (ICC) in the Yanqi campus of the University of Chinese Academy of Sciences (UCAS), Beijing, China.
* 3-day Scientific Workshop (1st day was for forum)
* 12 invited speakers

Venue

* Yanqi campus of UCAS
  50km North from Beijing city area (~1hour drive).
* The conference center has nice accommodations.
* APEC (Asia-Pacific Economic Cooperation, アジア太平洋経済協力) was held at this area in 2014.



Photos

International Conference Center

Accommodation

UCAS School Visit (I could not join)

Tour to the Great wall (I could not join)

Group Photo

Group Photo (Zoom Up)

*Somewhere: Yanbei Chen
*Not arrived yet :
Stefano Vitale, William Joseph Weber, Misao Sasaki

Gary Shiu
Masaki Ando
Gerhard Heinzel
Daniel Shaddock
David Blair
Lee

Wei-Tou Ni
Bernard F. Schutz
Karsten Danzmann
Wen-Rui Hu (?)
Yue-Liang Wu
Stefan Danilishin
Bangalore Sathyaprakash

Taiji Mission (空間太極計画)

from Presentations at ISGW2017 by

Prof. Yue-Liang Wu

(UCAS：University of Chinese Academy of Science)

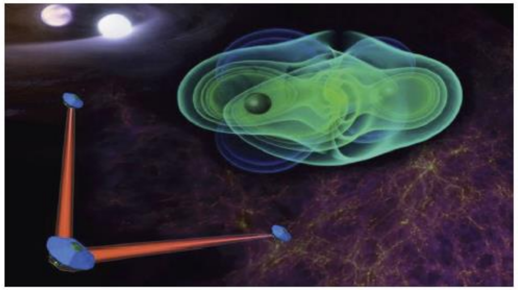
ISGW2017: http://isgw2017.csp.escience.cn/dct/page/15

Taiji Mission

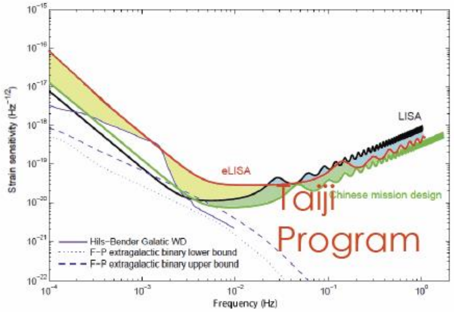
Taiji Program in Space
ravitational wave physics
空间太极计划

Taiji Program in Space

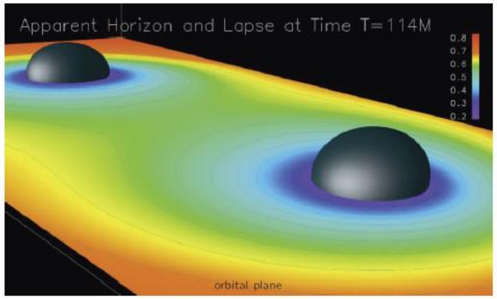
- Taiji Program is proposed to detect GW with frequency covering over the range of eLISA (0.1mHz-1.0Hz).



- Focus on the intermediate BH binaries (10^2~10^4 M_sun)
- With more sensitivity around (0.01-1Hz) (in comparison eLISA)



- How did the intermediate mass seed BH formed in early universe
- Whether DM could form BH
- How the seed BH grows into large or extreme-large BH
- Probe the polarization of GW and understand the nature of gravity

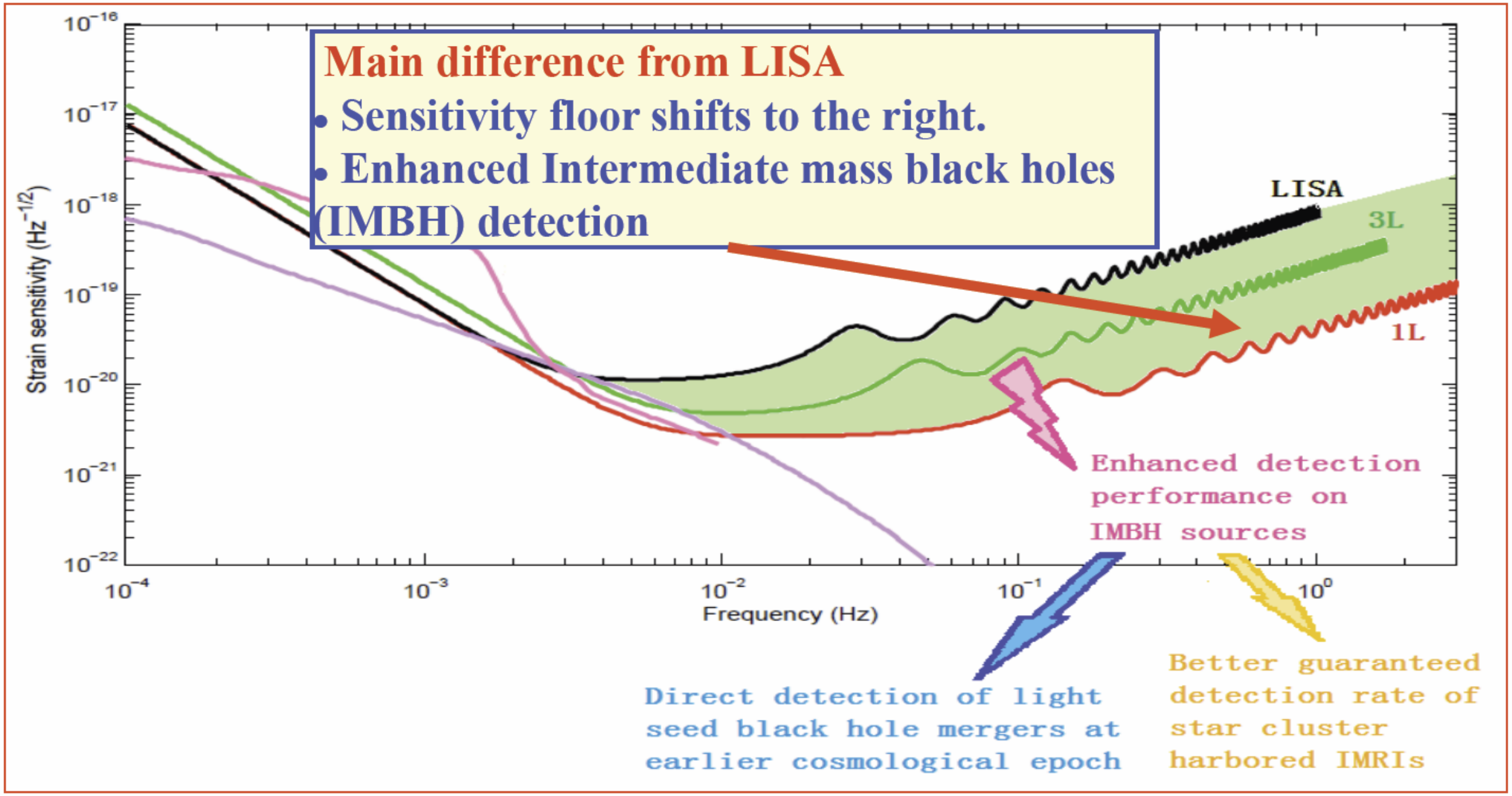


Taiji Mission

Taiji Program Baseline Design Parameters (preliminary mission proposal)

	Taiji Program preliminary mission proposal	LISA	eLISA
Arm length	$3\times10^9 m$	$5\times10^9 m$	$1\times10^9 m$
1-way position noise budget	$5\sim10\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$	$18\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$	$11\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$
Laser power	2W	2W	2W
Telescope diameter	~50cm	40cm	20cm
Acceleration noise budget	$3\times 10^{-15} ms^{-2}Hz^{-1/2}$	$3\times 10^{-15} ms^{-2}Hz^{-1/2}$	$3\times 10^{-15} ms^{-2}Hz^{-1/2}$

Taiji Mission



Better Guaranteed Detection Rate on Cluster Harbored IMRIs

Chinese mission option	Optimistic confusion	Pessimistic confusion
	$(\times \frac{f_{tot}}{0.1} \frac{\nu_0}{10^{-10}\mathrm{yr}^{-1}} \frac{10 M_{\odot}}{\mu}\ \mathrm{yr}^{-1})$	
Chinese mission option	~ 26	~ 32
LISA	~ 3	

Taiji Mission

Road Map of Taiji Program in Space

Phase I: 2016-2020 Pre-study on EP. & TH.

Concept & Design

Taiji concept
- ✓ Design concept
- ✓ Measurement scheme
- ✓ Data Analysis

Mission Design
- ✓ Spacecraft design
- ✓ Mission Analysis

Scientific Research

- ✓ Gravitational waves
- ✓ Astrophysics BH
- ✓ Ultra-Compact Binaries
- ✓ Fundamental laws
- ✓ Extreme mass ratio inspirals
- ✓ Astrophysics of dense stellar sys.
- ✓ Test GR & Nature of gravity
- ✓ Cosmology

Key technologies & Payload

- ✓ Laser system
- ✓ Optical Sys.
- ✓ Phase measurement
- ✓ Telescope
- ✓ Micropropulsi on design

Taiji Mission

Road Map of Taiji Program in Space

Phase II: 2020-2025 Taiji Pathfinder mission

Launch Taiji-pathfinder
with two satellites
Test crucial technologies

Study on the EP.
Prototype of GW

Phase III: 2025-2035 Taiji GW detection

2025-2029:
Develop
Engineering
prototype

2029-2034:
Flight load
development

~2035:
Launch GW
spacecraft

Taiji Mission

More than 10 institutes in China, most of them from the Chinese Academy of Sciences (CAS) have jointly studied the space-based GWD, it dates back to 2008 pioneered by Hu et.al.

The institutions of working groups include:

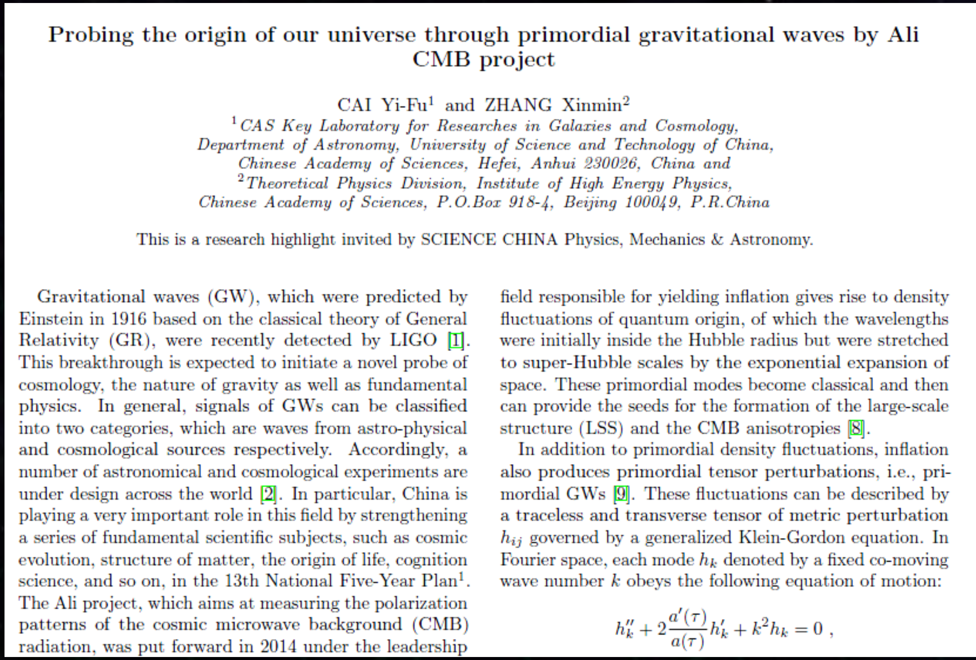
- ✧ Institute of Mechanics,
- ✧ University of Chinese Academy of Sciences (UCAS),
- ✧ Institute of Theoretical Physics,
- ✧ Academy of Mathematics and Systems Science,
- ✧ Institute of Physics,
- ✧ Institute of high Energy Physics,
- ✧ Nanjing Institute of Astronomy and Optics,
- ✧ National Astronomical Observatory,
- ✧ Wuhan Institute of Physics and Mathematics
- ✧ Changchun Institute of Optics,
- ✧ Fine Mechanics and Physics, CAS,
- ✧ Institute of Geodesy and Geophysics, Wuhan,
- ✧ Huazhong University of Science and Technology in Wuhan

We are going to organize the Taiji Alliance to make both national & international efforts on GW studies.

GWD covers physics, photonics, astronomy, cosmology, precision measurement, navigation technology and space engineering, etc. We shall work all together with our international colleagues to explore the unknown aspects.

Ali Project

Ali: Micro-wave telescope at Tibet for CMB Polarization Obs.



Probing the origin of our universe through primordial gravitational waves by Ali CMB project

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Gravitational waves (GW), which were predicted by Einstein in 1916 based on the classical theory of General Relativity (GR), were recently detected by LIGO [1]. This breakthrough is expected to initiate a novel probe of cosmology, the nature of gravity as well as fundamental physics. In general, signals of GWs can be classified into two categories, which are waves from astro-physical and cosmological sources respectively. Accordingly, a number of astronomical and cosmological experiments are under design across the world [2]. In particular, China is playing a very important role in this field by strengthening a series of fundamental scientific subjects, such as cosmic evolution, structure of matter, the origin of life, cognition science, and so on, in the 13th National Five-Year Plan[1]. The Ali project, which aims at measuring the polarization patterns of the cosmic microwave background (CMB) radiation, was put forward in 2014 under the leadership

field responsible for yielding inflation gives rise to density fluctuations of quantum origin, of which the wavelengths were initially inside the Hubble radius but were stretched to super-Hubble scales by the exponential expansion of space. These primordial modes become classical and then can provide the seeds for the formation of the large-scale structure (LSS) and the CMB anisotropies [8].

In addition to primordial density fluctuations, inflation also produces primordial tensor perturbations, i.e., primordial GWs [9]. These fluctuations can be described by a traceless and transverse tensor of metric perturbation h_{ij} governed by a generalized Klein-Gordon equation. In Fourier space, each mode h_k denoted by a fixed co-moving wave number k obeys the following equation of motion:

$$h_k'' + 2\frac{a'(\tau)}{a(\tau)}h_k' + k^2 h_k = 0 \ ,$$

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End