

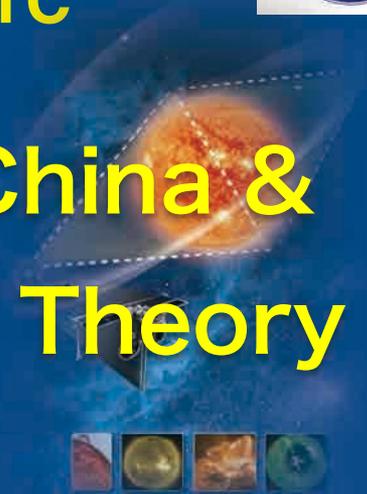


ICTP-AP
International Center
for Theoretical Physics Asia-Pacific
国际理论物理中心-亚太地区

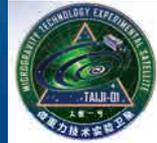
Gravitational Wave Astrophysics Conference 2021@USTC



The Taiji Project for GWD in China & The Exploration of Unification Theory



Yue-Liang Wu



1. Taiji Laboratory for Gravitational Universe, University of Chinese Academy of Sciences(UCAS)
2. International Centre for Theoretical Physics Asia-Pacific (ICTP-AP)
3. Institute of Theoretical Physics, CAS (ITP-CAS)
4. Hangzhou Institute for Advanced Study, UCAS



International Centre for Theoretical Physics

Asia-Pacific



**ICTP-AP:
ICTP's Newest
Partner Institute**

Timeline: Applying



2015
Formally submit the application



2015
Approved by 38th General Conference of UNESCO



2016.05
Assistant Director-General Flavia Schlegel visit UCAS



2016.09.12
State Council officially approved the establishment of the Centre.

Timeline: Signing Ceremony



2017.05.13

Signing Ceremony of ICTP-AP was held in Beijing Diaoyutai State Guesthouse

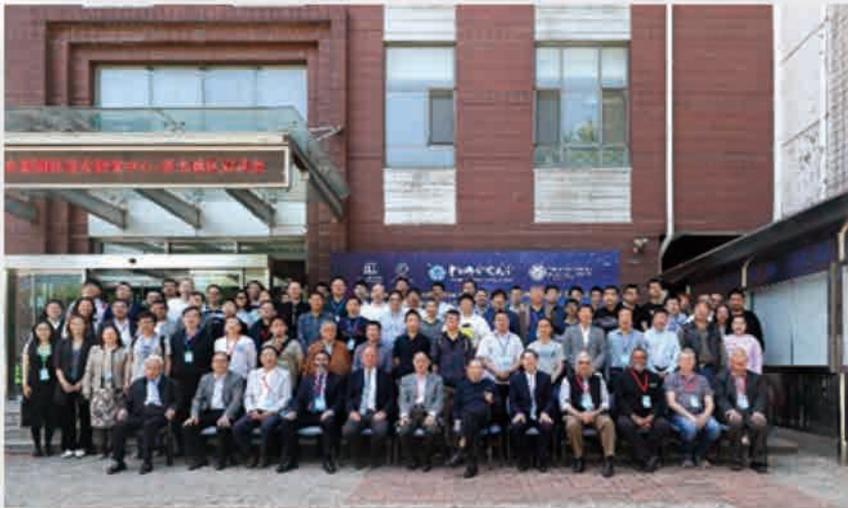
Timeline: Unveiling Ceremony



2018.11.04

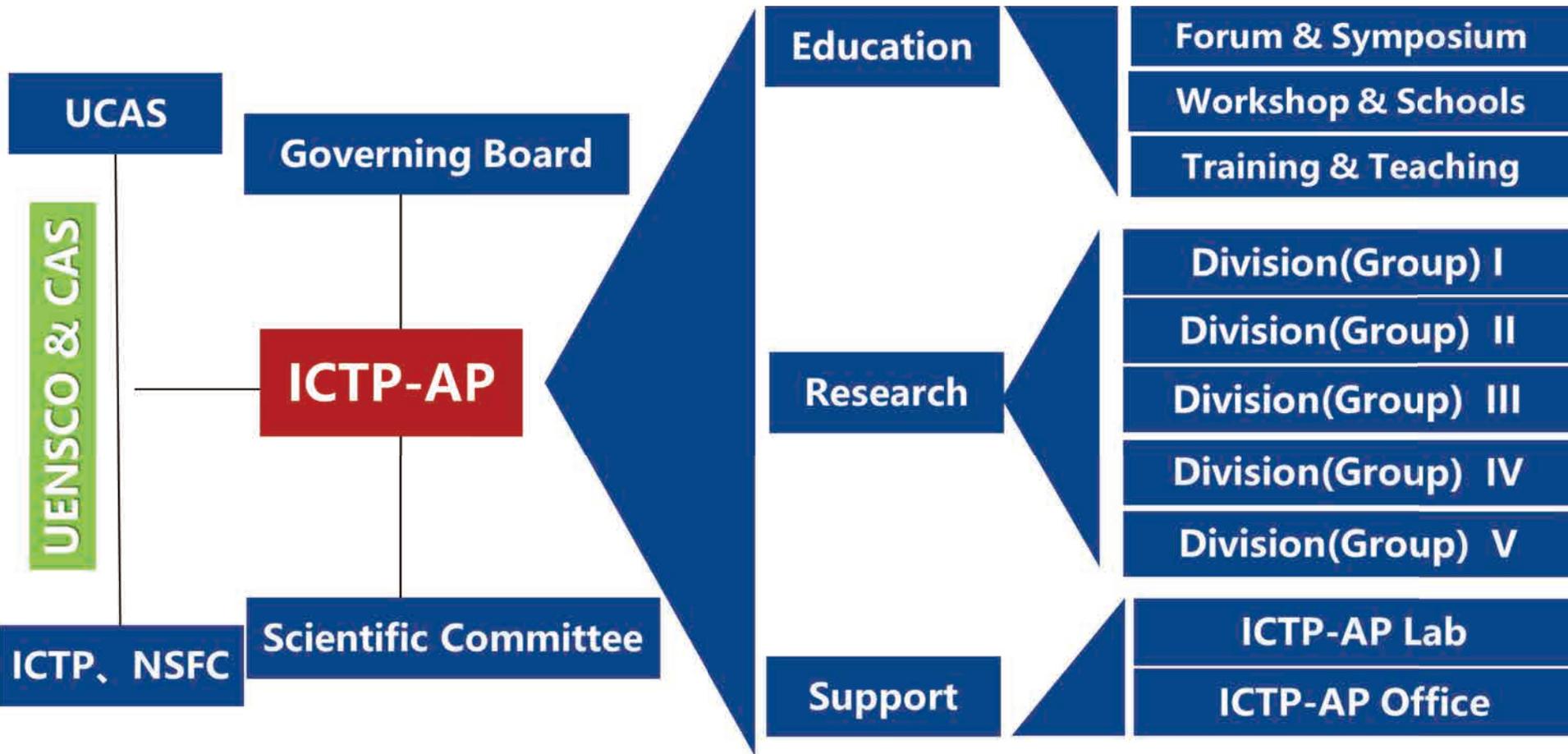
Unveiling Ceremony of ICTP-AP was held in Beijing.

Timeline: Kick-off



2019.05.13 ICTP-AP Kick-off Meeting.

Organizational Structure



2015

Academic Actives in Preparatory Period



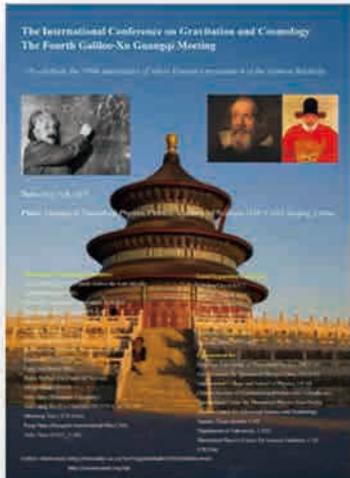
Jonathan Ellis



Chen-Ning Yang



Remo Ruffini

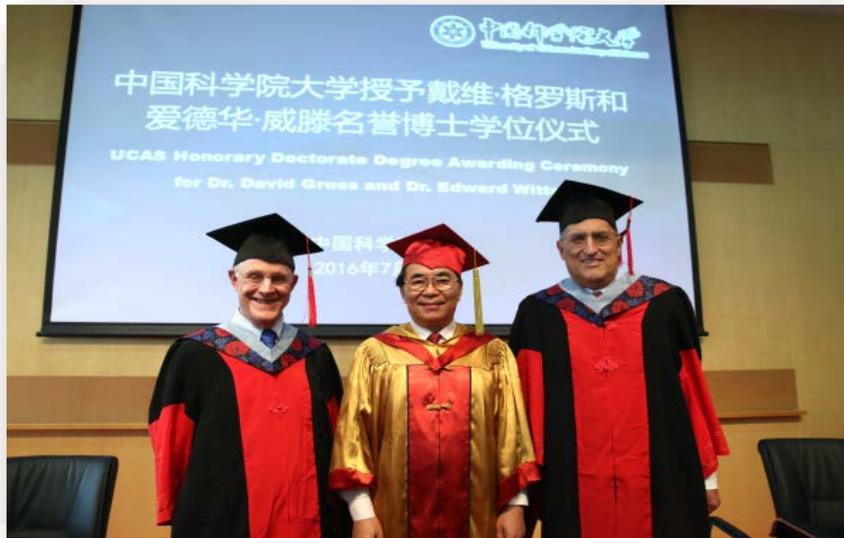


**100 years : Einstein' s
General Relativity
International Conference on
Gravity and Cosmology and
the Fourth Galileo-Xu Guangqi
Conference**

Academic Actives in Preparatory Period

Conferring Ceremony for Honorary Doctors of UCAS

To David Gross & Edward Witten



“量子宇宙物理前沿科学论坛”国际会议
International Conference on Frontiers of Science on
“Quantum Cosmophysics”

时间：2016年7月29-31日
地点：7月29日：中国科学院大学中关村校区S101报告厅
7月30-31日：中国科学院卡弗里理论物理研究所6620会议室

会议内容：暗物质、暗能量、黑格斯、黑洞、引力波、量子引力等前沿研究方向，将围绕物质属性、暗能量本质、黑格斯和对称破缺机制、黑洞特性、引力波宇宙、引力量子理论等展开广泛深入的探讨，进一步促进对物质起源、宇宙起源、引力本质等的理解和认识。

会议开幕式将举行荣誉博士学位授予典礼（7月29日上午9:00），由中国科学院院长白春礼院士为David Gross和Edward Witten教授颁发中国科学院大学荣誉博士学位证书，两位教授将发表公众演讲。

Ceremony of awarding UCAS Honorary Doctorate Degrees to Dr. David Gross and Dr. Edward Witten will be held on 9:00 July 29, 2016.

Public lecture speakers: David Gross, Edward Witten

Invited speakers:

Rong-Geng Cai (ITP)	Xuelei Chen (NAOC)
Bin Chen (PKU)	Jing Chang (PMO)
Song He (ITP)	Tao Han (Pittsburgh U/Tsinghua U)
Elias Kiritsis (Crete U)	Bum-Hoon Lee (Sogang U and APCTP)
Hong Liu (MIT)	Kimyeong Lee (KIAS)
Fernando Quevedo (ICTP)	Soo-Jong Rey (SNU)
Misao Sasaki (Kyoto U)	Andrew Strominger (Harvard U)
Gary Shiu (Wisconsin U/UCAS)	Jing Shu (ITP)
Heny Tye (HKUST)	Qian Yue (Tsinghua U)
Yue-Liang Wu (UCAS/ITP)	Yi Wang (HKUST)
Yu-Feng Zhou (ITP)	

主办单位：中国科学院理论物理研究所/中国科学院卡弗里理论物理研究所(ITP/KITPC)、中国科学院大学、亚太国际理论物理中心(UCAS/ICTP-AP)

协办单位：中科院高能物理研究所(IHEP)、清华大学(Tsinghua U)、南开大学(Nankai U)、浙江大学(Zhejiang U)、中国亚太理论物理中心(APCTP)

Academic Actives in Preparatory Period



International Symposium on Gravitational Waves (ISGW2017) was held from May 25 to 29, 2017 on the Yanqi campus of the University of Chinese Academy of Sciences (UCAS), Beijing, China.

The aim of the symposium is to bring together leading experts in gravitational wave physics and gravitational wave detection to present the latest research advances and to discuss possible collaborations on gravitational wave detection.

2017

Academic Actives in Preparatory Period



Prof. Kip S. Thorne

Conferring Ceremony for Honorary Professorship of UCAS

2019

Academic Actives



Karsten Danzmann



Stefano Vitale

649th session of Xiangshan Science Conferences on Chinese Space Gravitational Wave Detection Mission and International Alliance for Collaboration

2019

Academic Actives



July 8-12 , UCAS Gravitational Waves Summer School

The Observations of Gravitational Waves

THE SEARCH FOR RIPPLES

1916 | Einstein predicts ripples in space-time – gravitational waves moving at the speed of light

1969 | Joseph Weber of University of Maryland claims to have detected gravitational waves. Proved wrong

1974 | Joseph Taylor (right) and Russel Hulse of University of Massachusetts discover first indirect proof of gravitational waves in two neutron stars spiralling inwards at a rate exactly predicted by Einstein

1990 | Construction of LIGO by MIT and Caltech approved

2001 | LIGO data collection begins

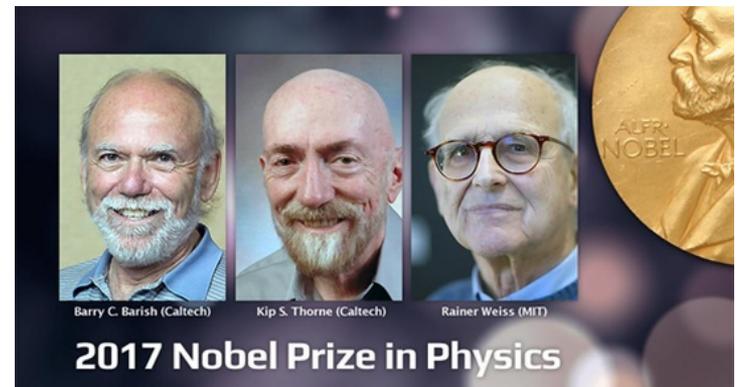
2010 | LIGO shut down for upgrade

2014 | South Pole based instrument claims to have detected gravitational waves from Big Bang. Later proved wrong

2015 | Advanced LIGO reopens and starts collecting data again

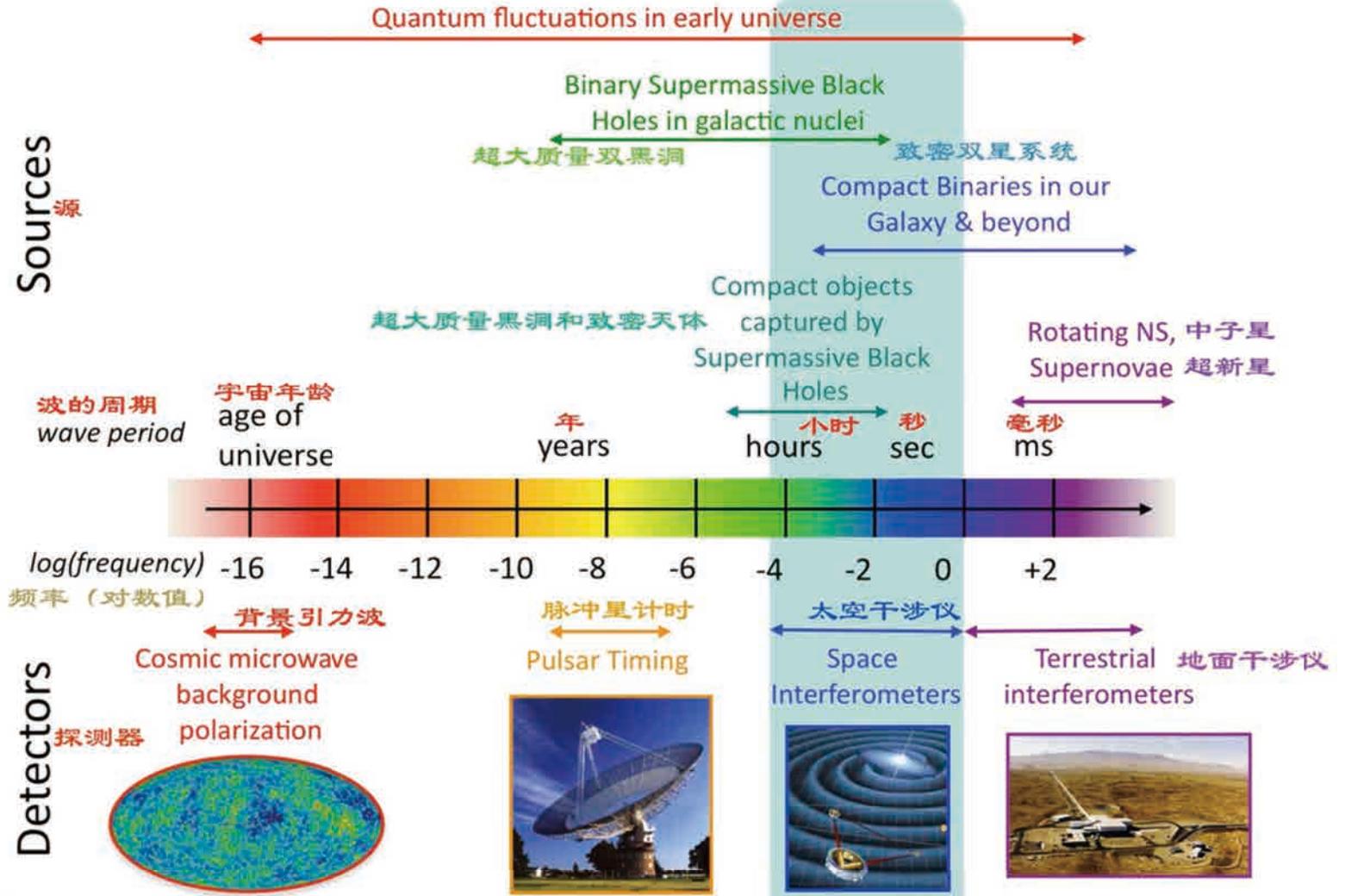


Feb. 11, 2016, LIGO announced the first direct observation of GW



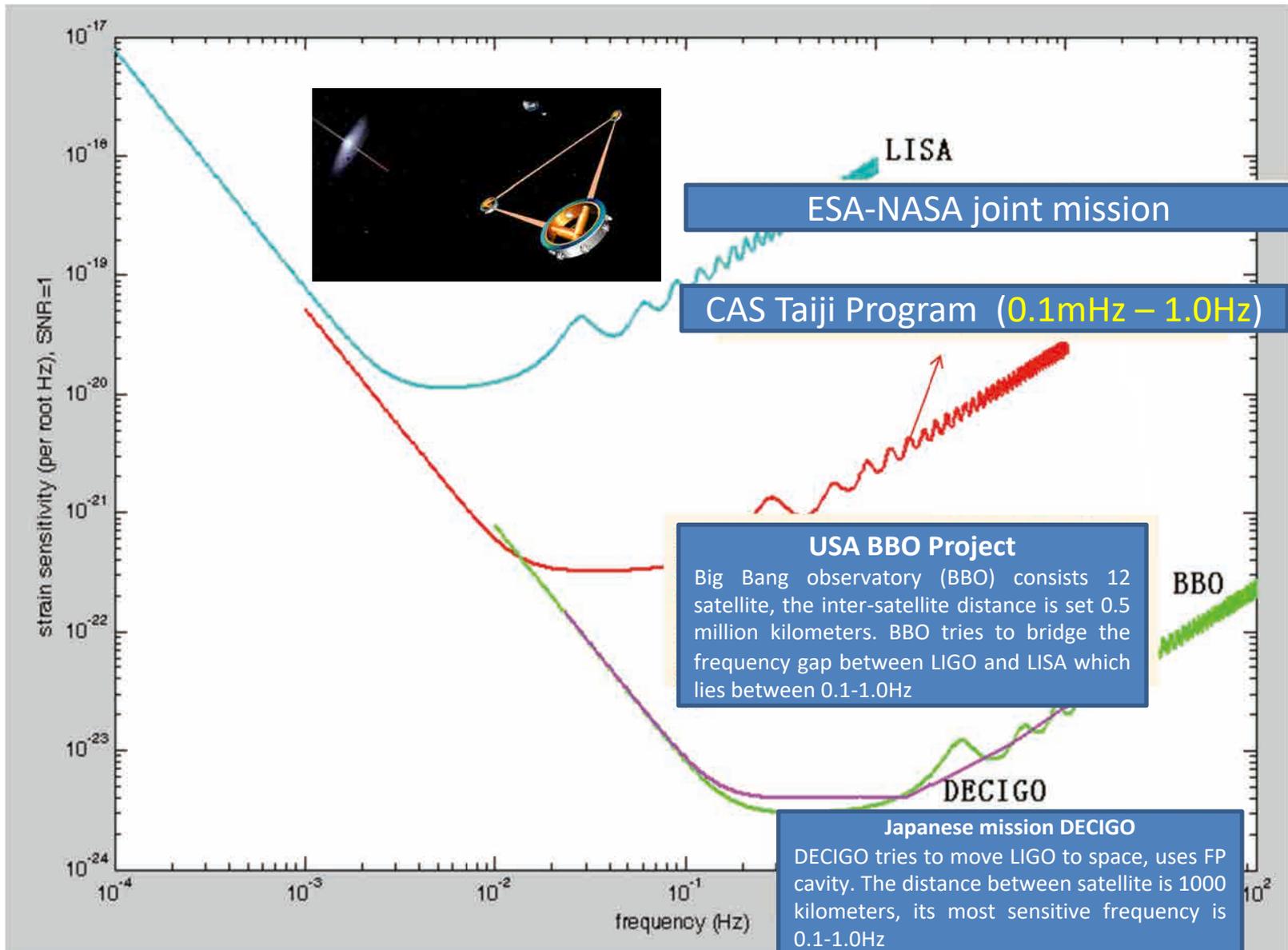
It not only provides a direct test for the Einstein GR, but also leads us to study deeply the nature of gravity

The Gravitational Wave Spectrum



Different frequency Different sources Different science

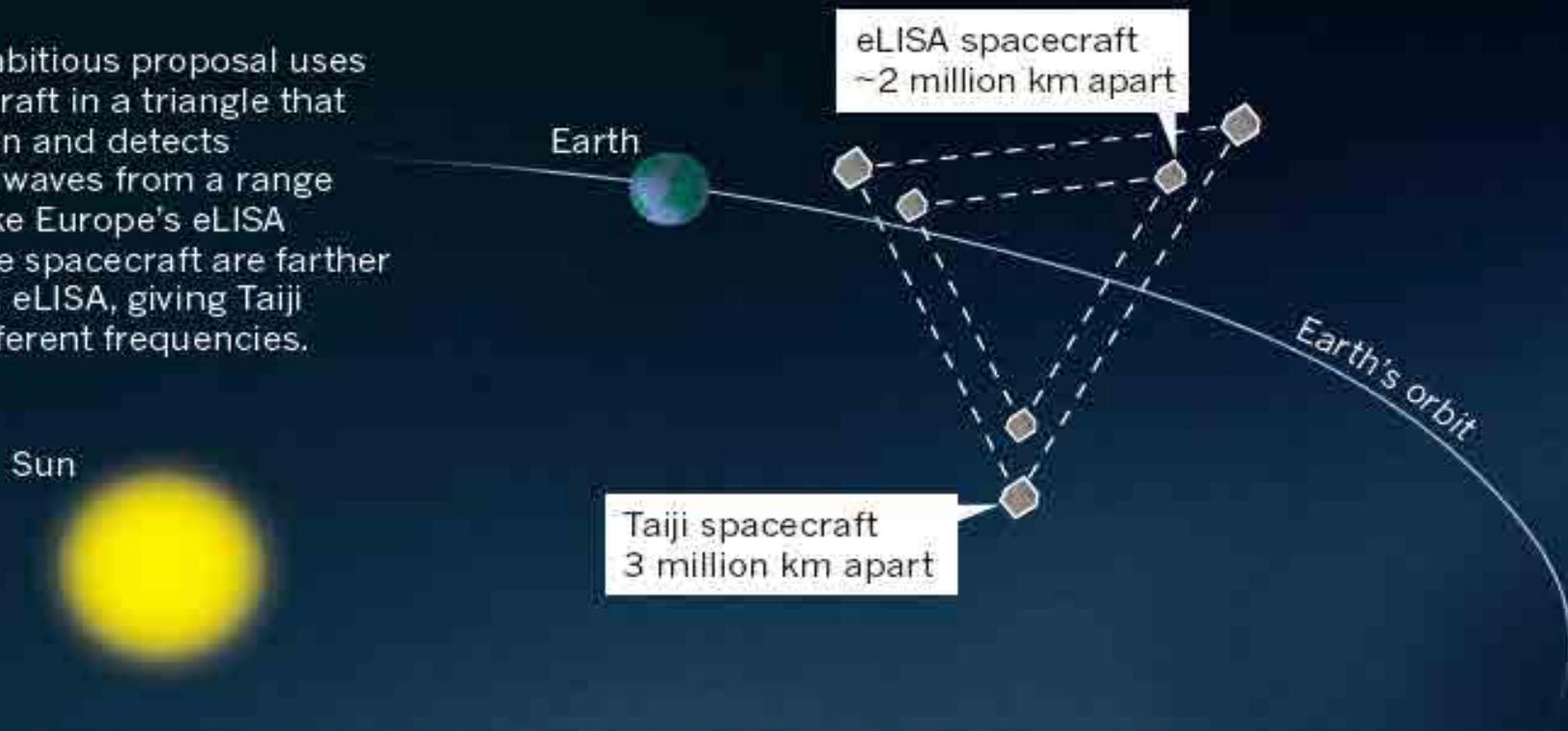
World-wide GW Detection in Space



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

TAIJI

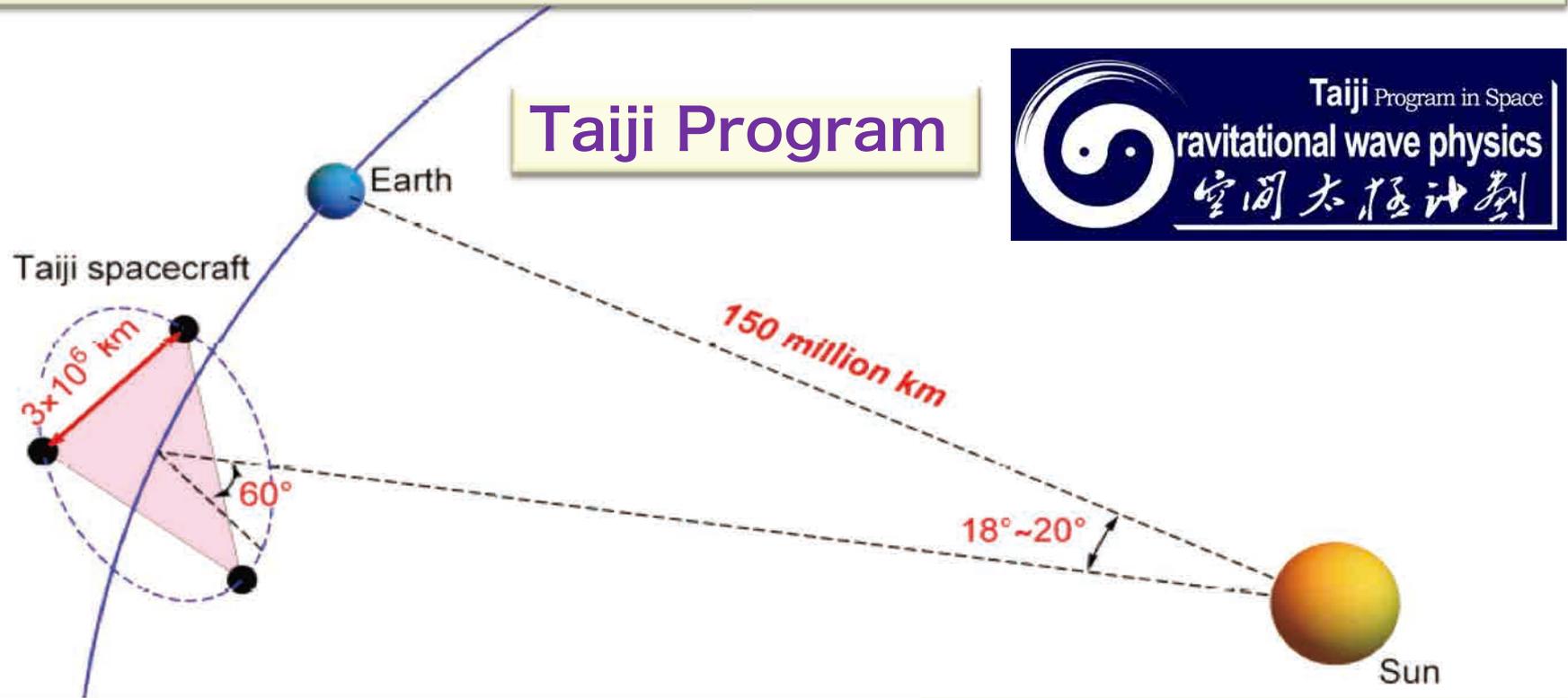
The most ambitious proposal uses three spacecraft in a triangle that orbits the Sun and detects gravitational waves from a range of objects, like Europe's eLISA proposal. The spacecraft are farther apart than in eLISA, giving Taiji access to different frequencies.



Compared with LIGO & other earth-based detectors

- ✓ The orbit around the Sun can effectively avoid noises and signal pollutions from the earth
- ✓ Meet the high thermo-mechanical stability
- ✓ Obtain more accurate gravitational wave with wider low and medium frequencies

Taiji program with 6 laser beams which are sent both ways between each pair of spacecraft. The differences in the phase changes between the transmitted and received laser beams at each spacecraft are measured.



- ❖ The signals between any two of the three satellites can be used to detect gravitational wave
- ❖ It could provide a cross check for GW signals and allows us to measure the polarization of GWs.

Taiji Program in Space VS Others

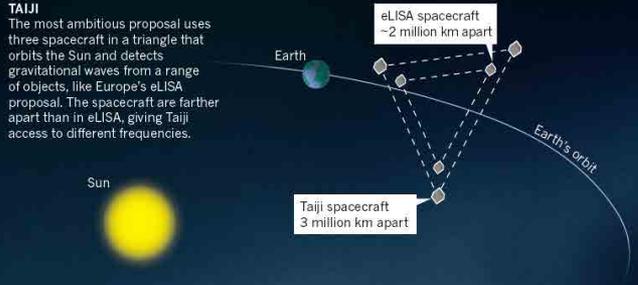
	Position noise 测距指标	Accelerate noise 加速度残差	Orbit 轨道	Armlength (10000km) 臂长 (万公里)	Frequency 频段	Launch 发射时间
Taiji 太极	8pm/Hz ^{1/2}	3×10 ⁻¹⁵ ms ⁻² /Hz ^{1/2}	Sun 太阳	300 (2012)	0.1mHz-1Hz	2030~2033
LISA	12pm/Hz ^{1/2}	3×10 ⁻¹⁵ ms ⁻² /Hz ^{1/2}	Sun Helio-center	500 (1995) 100 (2011) 250 (2017)	0.1mHz-1Hz	2030~2034

CHINA'S CHOICES

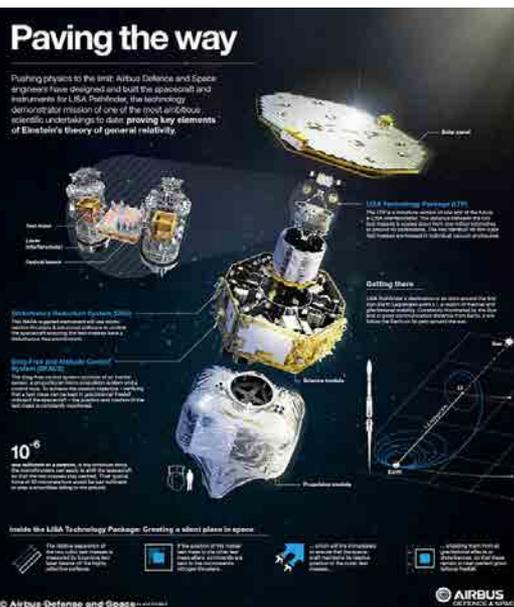
Chinese researchers have proposed several ways to detect gravitational waves in space.

TAIJI

The most ambitious proposal uses three spacecraft in a triangle that orbits the Sun and detects gravitational waves from a range of objects, like Europe's eLISA proposal. The spacecraft are farther apart than in eLISA, giving Taiji access to different frequencies.



1990s→2011→2017 : 5.0 →1.0→2.5 Million km



Model of LISA Pathfinder spacecraft

Mission duration	576 days
Dimensions	2.9 m × 2.1 m
BOL mass	480 kg (1,060 lb)
Dry mass	810 kg (1,790 lb)
Payload mass	125 kg (276 lb)

LISA Pathfinder launched on Dec. 3, 2015. It is successful in testing drag free, gravitational reference sensor, laser interference, 无拖曳航天+惯性传感器, 激光干涉仪

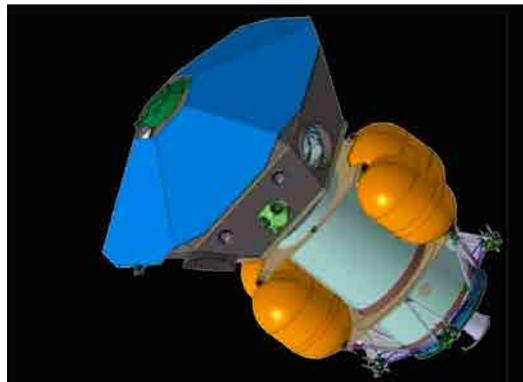
Space Gravitational Wave Detection in China

Yue-Liang Wu

University of Chinese Academy of Sciences (UCAS)

Kavli Institute for Theoretical Physics China (KITPC/ITP-CAS)

On behalf of Working Group on Space GWD/CAS

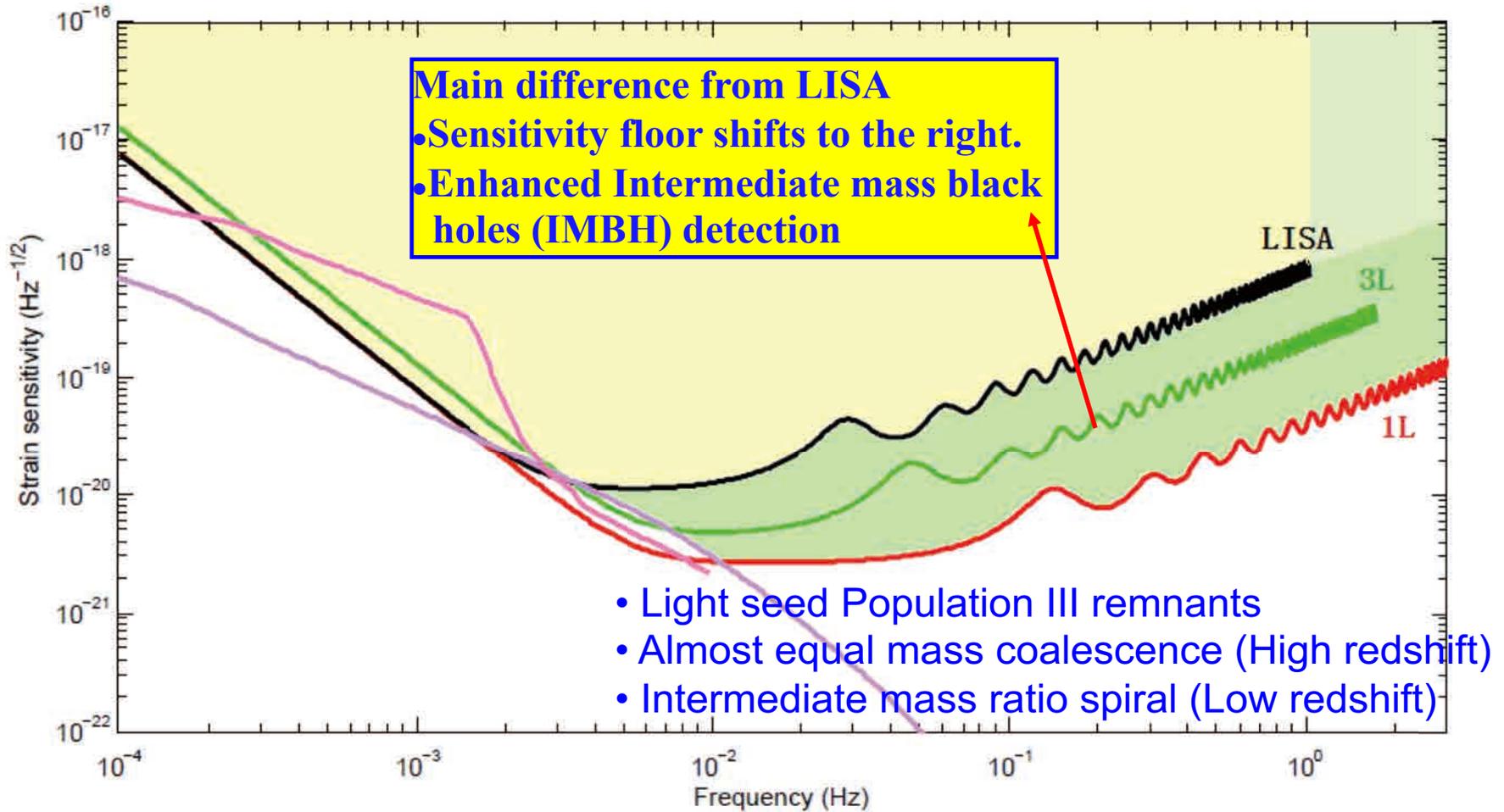


First eLISA Consortium Meeting
APC-Paris, France, Oct. 22-23, 2012

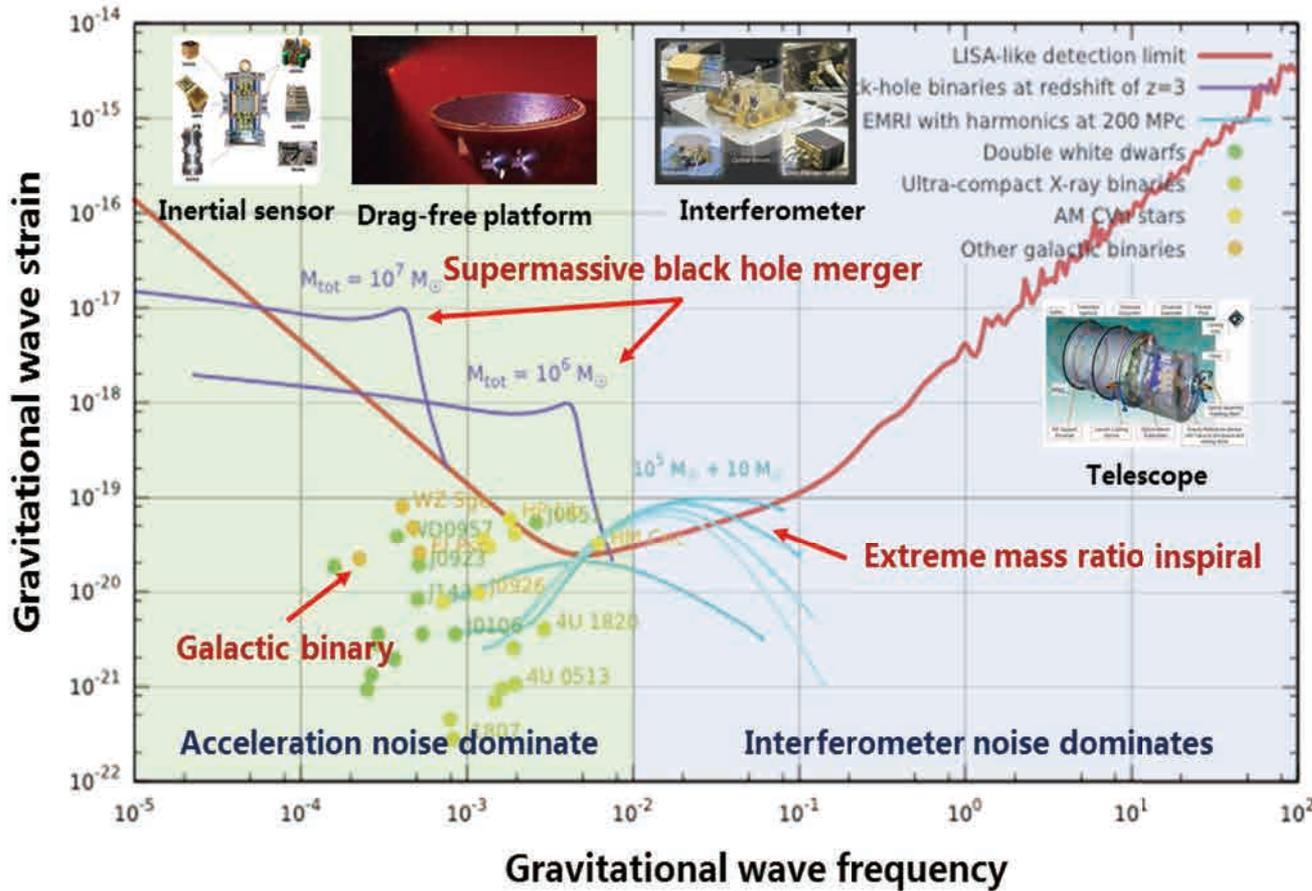
Taiji Program Baseline Design Parameters (preliminary mission proposal in 2012)

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

Better IMBH Detection – Extra Sciences on offer



Science Mission of Taiji Program



- MBHB/IMBH merger**
- Pop III恒星死亡
 - 黑洞形成和成长
 - 星系形成和成长
 - 标准烛光
 - 大尺度结构形成

- EMRI/IMRI**
- 强场扫描
 - 无毛定理
 - (银河)星系核动力学

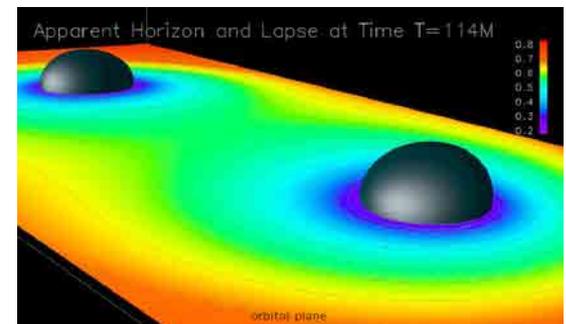
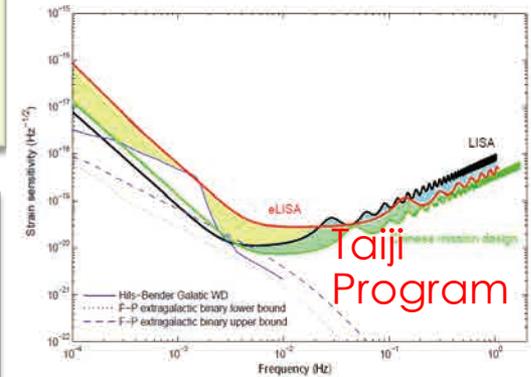
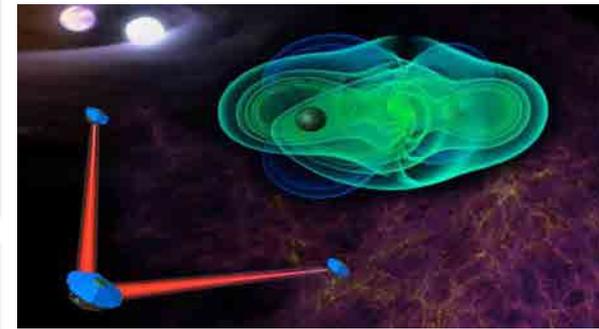
- Galactic Binary**
河内双星
- 河内恒星演化
 - 银河系演化

- Background GW**
随机引力波背景
- 大爆炸引力波遗迹
 - 原初黑洞双星
 - 致密双星随机引力波背景

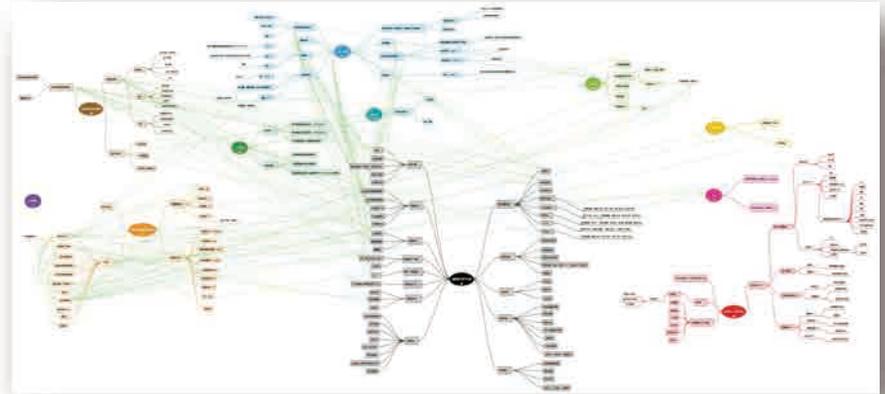
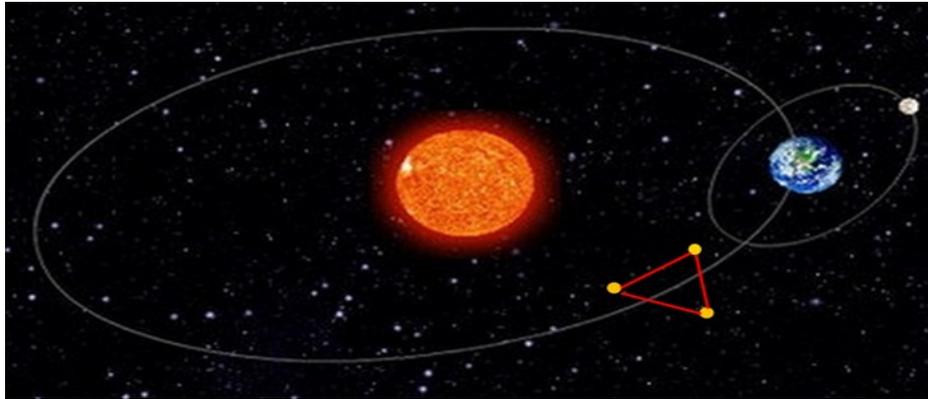
- Early GWs for LIGO.**
早期波源
- Unknown GWs**
可能的未知波源

Sciences Mission of Taiji Program

- Taiji Program is proposed to detect GWs with frequency covering over range similar to LISA (0.1mHz-1.0Hz)
- Focus on the intermediate BH binaries (mass range $10^2 \sim 10^4 M_{\odot}$) with more sensitivity around (0.01-1Hz) (in comparison eLISA)
- How does the intermediate mass seed BH formed in early universe
- Whether DM could form the BH
- How the seed BH grows into the large or extreme-large BH
- Probe the polarization of GWs and understand the nature of gravity



The peculiarity of space GW mission



1. Ultra precise & key techniques

- ✓ Pico-meter measurement within millions of kilometers
- ✓ sub-femto g drag-free technology

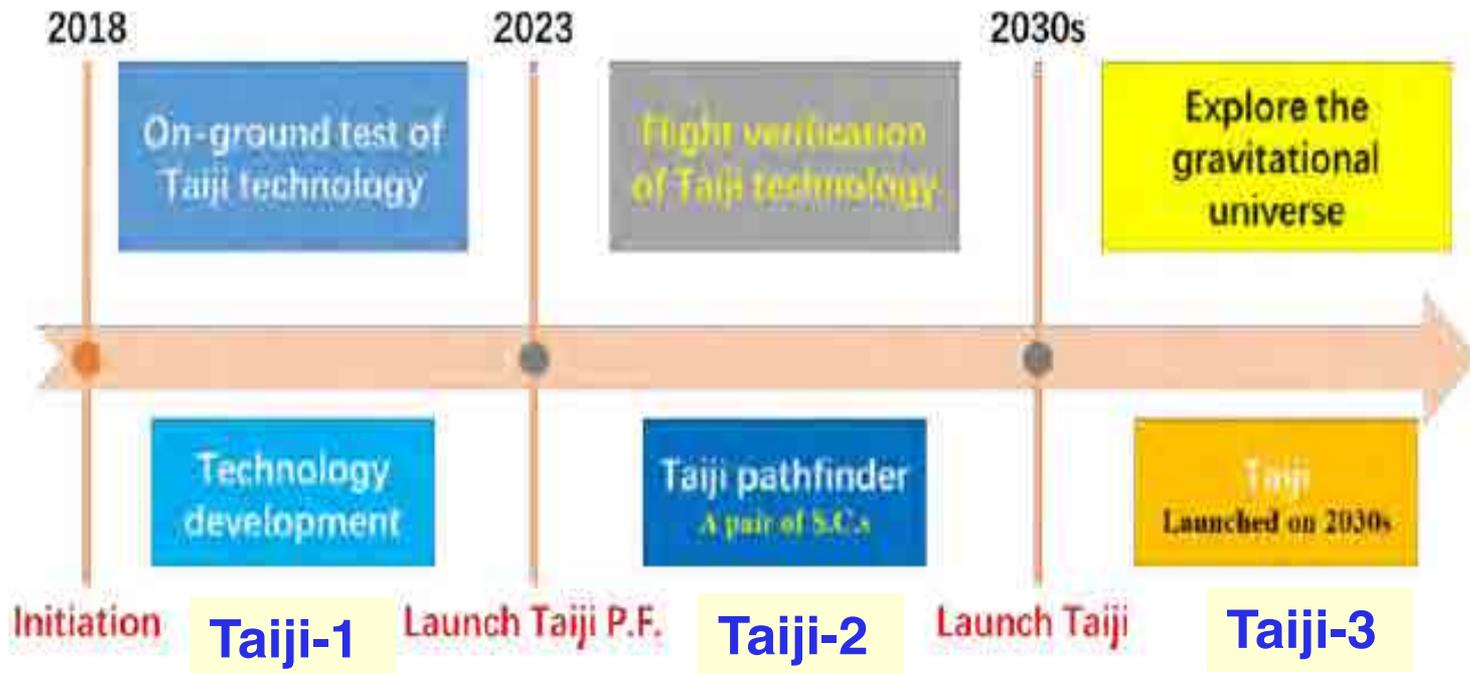
- Laser interferometric ranging system
- Gravitational reference sensor
- Drag-free control and micro-thruster
- Ultra stable satellite platform

2. Ultra complex & key techniques

- ✓ Strong confusion of G.W. signals
- ✓ strong couplings of subsystems
- Parameters of sources & templates bank development
- Optimization of constellation & sensitivity curves
- Optimization and simulation of satellite design
- TDI and data analysis

Science Mission and Road Map of Taiji Program

The Roadmap of Taiji with 3 Stages



Taiji-1 launched successfully in 2019

The CAS Strategic Priority Research Program A in 2018

Taiji-1 launched August 31, 2019

2019年8月31号

07:41发射

08:08:49星箭分离

30秒后转对日定向

TC 00:03:07:20

太极一号 V3



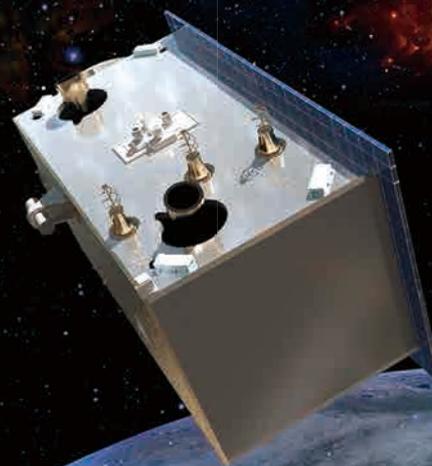
Taiji-1--the first step of China's efforts

- **Approved on 30 Aug. 2018 & set to fly on 31 Aug. 2019**
- **Taiji-1, a 180 kg satellite with 600 km orbit altitude , was a successful and quick mission.**
- **Two major technology units have been tested on Taiji-1**
 - 1. The optical metrology system,**
 - 2. The drag-free control system**

**All of the payloads were tested !
All results fulfilled the mission requirement !**

“太极一号”卫星 首批科学成果发布

国科大为“太极一号”用户和科学应用系统承担单位



Bo-Quan Li⁷, Dong-Jing Li¹², Fan Li⁷, Hao-Si Li², Hua-Wang Li⁸, Liu-Feng Li¹⁰, Wei Li¹², Xiao-Kang Li^{1,2},
Ying-Min Li¹, Yong-Gui Li¹, Yun-Peng Li¹⁵, Yu-Peng Li^{1,12}, Zhe Li¹², Zhi-Yong Lin¹, Chang Liu^{1,3},
Dong-Bin Liu¹², He-Shan Liu^{2,5}, Hong Liu⁸, Peng Liu¹¹, Yu-Rong Liu⁷, Zong-Yu Lu¹⁰, Hong-Wei Luo⁹, Fu-Li Ma⁷,
Long-Fei Ma¹², Xiao-Dong Ma¹², Jia Shen^{1,2}, Wen-Ze Tang¹², Shao-Xin Wang⁷, Li-Ming Wu¹, Peng-Zhan Wu¹⁶, Zhi-Hua Wu⁸, Dong-Xue Xi¹⁵, Yi-Fang Xie⁷, Guo-Feng Xin⁹, Lu-Xiang Xu^{1,5,17},
Peng Xu^{1,16}, Shu-Yan Xu^{5,17}, Yu Xu⁸, Sen-Wen Xue^{1,2}, Zhang-Bin Xue⁷, Chao Yang^{1,2}, Ran Yang^{1,2}, Shi-Jia Yang¹⁵,
Shuang Yang⁷, Yong Yang⁸, Zhong-Guo Yang⁹, Yong-Li Yin¹⁸, Jin-Pei Yu⁸, Tao Yu¹², Ai-Bing Zhang⁷,
Chu Zhang^{1,2}, Min Zhang^{1,4,5}, Xue-Quan Zhang⁷, Yuan-Zhong Zhang³, Jian Zhao⁹, Wei-Wei Zhao⁸, Ya Zhao^{1,12},
Jian-Hua Zheng⁷, Cui-Yun Zhou⁹, Zhen-Cai Zhu⁸, Xiao-Bo Zou¹⁶ & Zi-Ming Zou⁷

COMMUNICATIONS PHYSICS | (2021) 4:34 |
<https://doi.org/10.1038/s42005-021-00529-z>
www.nature.com/commsphys

¹Taiji Laboratory for Gravitational Wave Universe (Beijing/Hangzhou), University of Chinese Academy of Sciences (UCAS), Beijing, China. ²National Microgravity Laboratory, Center for Gravitational Wave Experiment, Institute of Mechanics, Chinese Academy of Sciences (CAS), Beijing, China. ³Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, China. ⁴International Centre for Theoretical Physics Asia-Pacific (ICTP-AP) (Beijing/Hangzhou), UCAS, Beijing, China. ⁵Hangzhou Institute for Advanced Study, UCAS, Hangzhou, China. ⁶Shanghai Institute of Technical Physics, CAS, Shanghai, China. ⁷National Space Science Center, CAS, Beijing, China. ⁸Innovation Academy for Microsatellites, CAS, Shanghai, China. ⁹Space Laser Engineering Technology Laboratory, Shanghai Institute of Optics and Fine Mechanics, CAS, Shanghai, China. ¹⁰Innovation Academy for Precision Measurement Science and Technology, CAS, Wuhan, China. ¹¹Tsinghua University, Beijing, China. ¹²Changchun Institute of Optics, Fine Mechanics and Physics, CAS, Changchun, China. ¹³Aerospace Information Research Institute, CAS, Beijing, China. ¹⁴Nation Astronomical Observatory, CAS, Beijing, China. ¹⁵Lanzhou Institute of Physics, Lanzhou, China. ¹⁶Lanzhou University, Lanzhou, China. ¹⁷Nanyang Technological University, Singapore, Singapore. ¹⁸China Astronaut Research and Training Center, Beijing, China. [✉]email: ylwu@mail.itp.ac.cn; luozhen@mech.ac.cn; jzwang@mail.sitp.ac.cn

SPECIAL ISSUE

Special Issue on Taiji Program in Space for Gravitational Universe
 with the First Run Key Technologies Test in Taiji-1
 Guest Editors: Yue-Liang Wu and Wen-Rui Hu

CONTENTS

The idea of Taiji program: From the ground to Taiji-2	0100001
Taiji program as space for gravitational universe with the first run key technologies test in Taiji-1	0100002
Scientific objectives of ground tests in Taiji-1 based laser interferometer	0100003
W. Shao, G. Peng and Y. Nie	
Experiment of the coupling between mass and acceleration in EMG	0100004
J. Wang, H. Wang and Y. Nie	
Frequency modulation analysis of the temperature fluctuation effect on Taiji-1 laser interferometer	0100005
A. Deng, B. Hong and Y. Nie	
Ground performance of the laser interferometer of Taiji-1 experimental satellite	0100006
H.-S. Liu, C. B. Dai and W. Shao	
The principles of Taiji-1 experimental satellite	0100007
J. Wu, J. Ye and H. Shao	
Taiji stability laser system for Taiji-1 satellite	0100008
Ji. M., Pan, D., H. Chen, G. F. Xu, J. C. Ma, C. Ye and W. H. Chen	
A systematic procedure to find optimal alignment parallel lines with rectangular ring for laser configuration	0100009
G. Peng, L. D and H. Chen	
Development of an optical line of Taiji-1 inertial reference	0100010
Z. Wang and H. H. Liu	

Continued

International Journal of Modern Physics A

April 2021, 11 & 12 (April 2021)

International Journal of Modern Physics A

PARTICLES AND FIELDS • GRAVITATION • COSMOLOGY

Volume 36 • Numbers 11 & 12 • 30 April 2021 www.worldscientific.com/ijmpa/

**Special Issue on Taiji Program in Space for
 Gravitational Universe with the First Run Key
 Technologies Test in Taiji-1**

Guest Editors:
Yue-Liang Wu and Wen-Rui Hu



Taiji program in space for gravitational universe with the first run key technologies test in Taiji-1

The Taiji Scientific Collaboration

Received 15 September 2020

Accepted 30 October 2020

Published 17 May 2021

Yue-Liang Wu^{1-5,32}, Zi-Ren Luo^{1,2,4,5,33}, Jian-Yu Wang^{1,5,6,34}, Meng Bai⁷, Wei Bian^{1,5,7}, Hai-Wen Cai^{8,9,25}, Rong-Gen Cai^{1,3,5}, Zhi-Ming Cai^{8,23}, Jin Cao⁸, Bin Chen⁷, Di-Jun Chen^{5,9}, Guang-Feng Chen¹⁵, Kun Chen⁸, Ling Chen⁷, Li-Sheng Chen^{10,26,27,28}, Ming-Wei Chen^{1,2}, Wei-Biao Chen^{5,9,25}, Yan Chen²¹, Ze-Yi Chen⁹, Yi-Xing Chi, Lin-Xiao Cong¹, Jian-Feng Deng⁸, Xiao-Qin Deng^{1,5,12}, Xiao-Long Dong⁷, Li Duan^{1,2}, Da Fan¹⁹, Sen-Quan Fan⁸, Shou-Shan Fan¹¹, Chao Fang¹², Yuan Fang⁸, Ke Feng¹³, Jian-Chao Feng⁸, Pan Feng⁹, Zhun Feng⁷, Chen Gao⁷, Rui-Hong Gao^{1,2}, Run-Lian Gao⁷, Bin Guo²⁰, Tong Guo⁸, Xiao-Liang Guo²², Xu Guo^{5,12}, Zong-Kuan Guo^{1,3,5}, Jian-Wu He^{1,2}, Ji-Bo He¹, Xia Hou⁹, Liang Hu², Wen-Rui Hu^{1,2}, Zhi-Qiang Hu⁸, Min-Jie Huang⁹, Jian-Jun Jia^{1,5,6}, Kai-Li Jiang¹¹, Gang Jin^{2,5}, Hong-Bo Jin^{14,30}, Bao-Peng Kang⁸, Qi Kang^{1,2}, Feng-Lian Kong¹⁵, Jun-Gang Lei^{5,15}, Bo-Quan Li⁷, Cun-Hui Li¹⁵, Dong-Jing Li¹², Fan Li⁷, Hao-Si Li^{2,31}, Hua-Dong Li¹², Hua-Wang Li⁸, Jiang Li²⁴, Liu-Feng Li^{10,27,28}, Wei Li¹², Xiao-Kang Li^{1,2}, Ying-Min Li¹, Yong-Gui Li¹, Yun-Peng Li¹⁵, Yu-Peng Li^{1,12}, Zhao Li⁸, Zhe Li¹², Hong Liang⁸, Huang Lin²², Zhi-Yong Lin^{1,31}, Chang Liu^{1,3}, Dong-Bin Liu¹², He-Shan Liu^{1,2,5}, Hong Liu⁸, Peng Liu¹¹, Yu-Rong Liu⁷, Zong-Yu Lu¹⁰, Hong-Wei Luo⁹, Jun Luo², Fu-Li Ma⁷, Long-Fei Ma^{1,2}, Xiao-Shan Ma⁷, Xin Ma⁷, Yi-Chuan Man⁷, Jun-Cheng Mao¹⁵, Jian Min¹⁵, Yu Niu^{1,2}, Jian-Kang Peng^{10,26}, Xiao-Dong Peng^{4,5,7}, Ke-Qi Qi¹², Li-É Qiang⁷, Cong-Feng Qiao¹, Ye-Xi Qu⁹, Wen-Hong Ruan^{1,3}, Wei Sha¹², Jia Shen^{1,2}, Xing-Jian Shi⁸, Rong Shu⁶, Ju Su⁷, Peng Su²⁴, Yan-Lin Sui¹², Guang-Wei Sun^{9,25}, He-Ping Tan²⁰, Wen-Lin Tang⁷, Hong-Jiang Tao¹², Wen-Ze Tao¹⁵, Zheng Tian⁷, Ling-Feng Wan¹⁰, Chen-Yu Wang^{1,2}, Jia Wang², Juan Wang^{1,2}, Jun-Biao Wang², Lin-Lin Wang⁷, Peng-Cheng Wang⁸, Shao-Xin Wang¹², Xiao-Peng Wang¹², Yan-Feng Wang⁸, Yu-Kun Wang¹², Zhi Wang^{1,5,12}, Zuo-Lei Wang^{15,29}, Yong-Qiang Wei¹⁵, Yu-Xiao Wei¹, Di Wu², Li-Ming Wu^{1,31}, Peng-Zhan Wu¹⁶, Zhi-Hua Wu⁸, Dong-Xue Xi¹⁵, Yi-Fang Xie⁷, Guo-Feng Xin⁹, Heng-Tong Xu¹⁵, Lu-Xiang Xu^{1,5,17}, Peng Xu^{1,5,16}, Shu-Yan Xu^{5,17}, Yu Xu⁸, Bing Xue²⁴, Da-Tong Xue¹⁵, Sen-Wen Xue^{1,2}, Zhang-Bin Xue⁷, Chao Yang^{1,2}, Ran Yang^{1,2}, Shi-Jia Yang¹⁵, Shuang Yang⁷, Yong Yang⁸, Zhong-Guo Yang⁹, Yong-Li Yin¹⁸, Du-Li Yu²², Jin-Pei Yu⁸, Tao Yu¹², Ai-Bing Zhang⁷, Bing Zhang²⁴, Chu Zhang^{1,2}, Min Zhang^{1,4,5}, Jing Zhang⁸, Rui-Jun Zhang¹⁵, Xiao-Feng Zhang^{8,20}, Xiao-Qing Zhang¹⁵, Xue-Quan Zhang⁷, Yong-He Zhang⁸, Yu-Zhu Zhang⁷, Yuan-Zhong Zhang³, Meng-Yuan Zhao⁷, Jian Zhao⁹, Wei-Wei Zhao⁸, Ya Zhao^{1,12}, Jian-Hua Zheng⁷, Cui-Yun Zhou⁹, Ying Zhou¹⁵, Ren Zhu⁹, Xiao-Cheng Zhu^{8,20}, Xiao-Yi Zhu²⁴, Zhen-Cai Zhu⁸, Xiao-Bo Zou¹⁶ and Zi-Ming Zou⁷

¹Taiji Laboratory for Gravitational Wave Universe (Beijing/Hangzhou), University of Chinese Academy Sciences (UCAS), Beijing 100049, China

²Center for Gravitational Wave Experiment, National Microgravity Laboratory, Institute of Mechanics, Chinese Academy of Sciences (CAS), Beijing 100190, China

³Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China

⁴International Centre for Theoretical Physics Asia-Pacific (ICTP-AP) (Beijing/ Hangzhou), UCAS, Beijing 100190, China

⁵Hangzhou Institute for Advanced Study, UCAS, Hangzhou 310024, China

⁶Shanghai Institute of Technical Physics, CAS, Shanghai 200083, China

⁷National Space Science Center, CAS, Beijing 100190, China

⁸Innovation Academy for Microsatellites, CAS, Shanghai 201800, China

⁹Laboratory of Space Laser Engineering and Technology Shanghai Institute of Optics and Fine Mechanics, CAS, Shanghai 201800, China

¹⁰Innovation Academy for Precision Measurement Science and Technology, CAS, Wuhan 430071, China

¹¹Tsinghua University, Beijing 100084, China

¹²Changchun Institute of Optics, Fine Mechanics and Physics, CAS, Changchun 130033, China

¹³Aerospace Information Research Institute, CAS, Beijing 100094, China

¹⁴Nation Astronomical Observatory, CAS, Beijing 100101, China

¹⁵National Key Laboratory of Science and Technology on Vacuum Technology and Physics, Lanzhou Institute of Physics, Lanzhou 730000, China

¹⁶Lanzhou University, Lanzhou 730000, China

¹⁷Nanyang Technological University, Singapore 637616, Singapore

¹⁸China Astronaut Research and Training Center, Beijing 100094, China

¹⁹Qian Xuesen Laboratory of Space Technology, Beijing 100094, China

²⁰Harbin Institute of Technology, Harbin 150001, China

²¹University of Science and Technology Beijing, Beijing 100083, China

²²Beijing University of Chemical Technology, Beijing 100029, China

²³Zhejiang University, Hangzhou 310058, China

²⁴Institute of Earthquake Forecasting, China Earthquake Administration, Beijing 100036, China

²⁵School of Optoelectronics, University of Chinese Academy of Sciences, Beijing 100049, China

²⁶University of Chinese Academy of Sciences, Beijing 100049, China

²⁷State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan 430071, China

²⁸Laboratory of Atomic Frequency Standards, Chinese Academy of Sciences, Wuhan 430071, China

²⁹Lanzhou Institute of Space Technology Physics, Lanzhou, China

³⁰CAS Key Laboratory of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, P. R. China

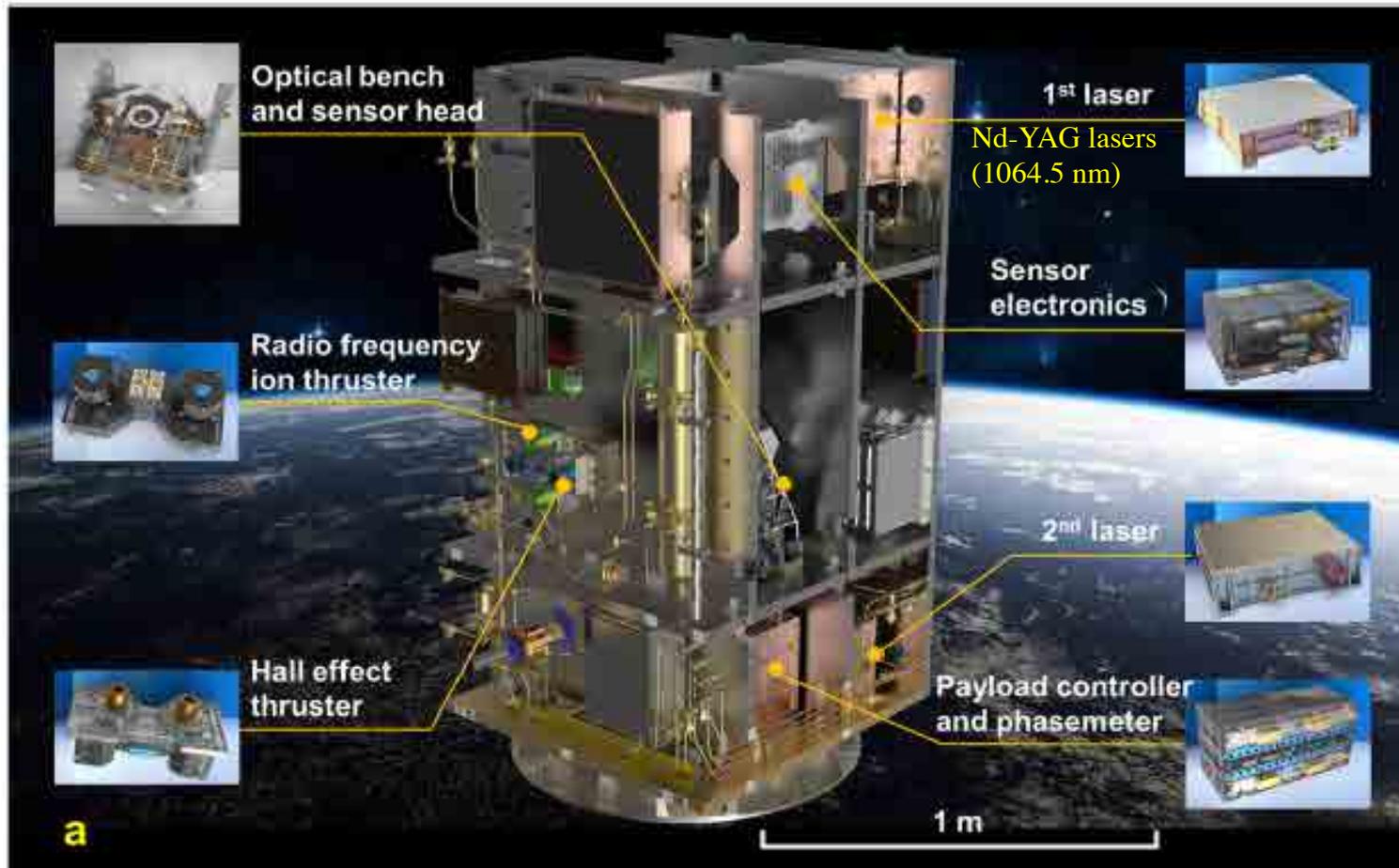
³¹Chang'an University, Xi'an 710054, China

³²ylwu@mail.itp.ac.cn

³³luoziren@imech.ac.cn

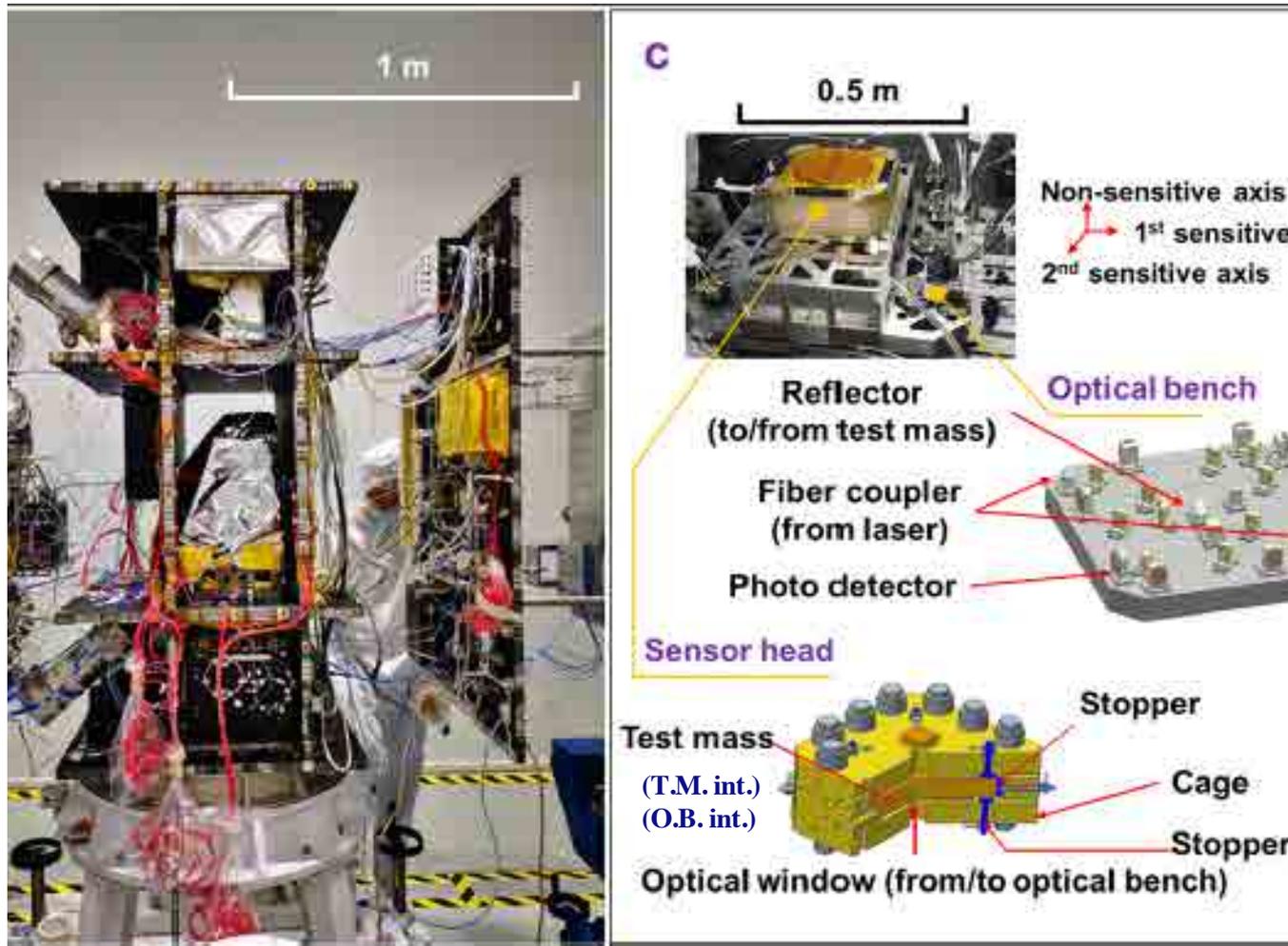
³⁴jiwang@mail.sitp.ac.cn

Distribution of the payloads in Taiji-1



The optical bench and the sensor head are integrated in order to ensure the laser beam to get accurate access to the test mass. The difference between the nominal geometric center of the test mass and the mass center of the satellite is smaller than 0.15mm after the balancing is achieved with a 0.1mm measurement accuracy.

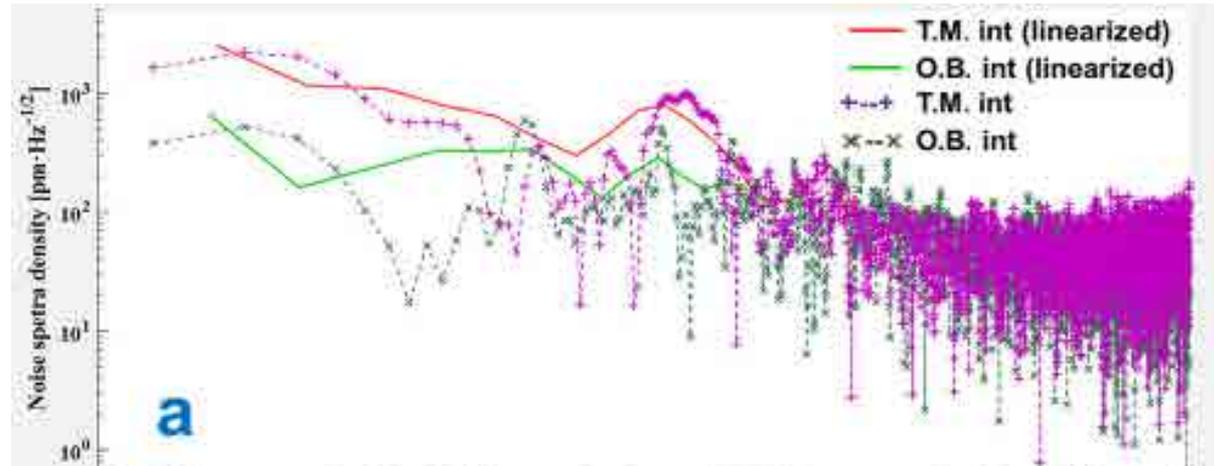
Taiji-1 satellite before assembling & Core measurement unit



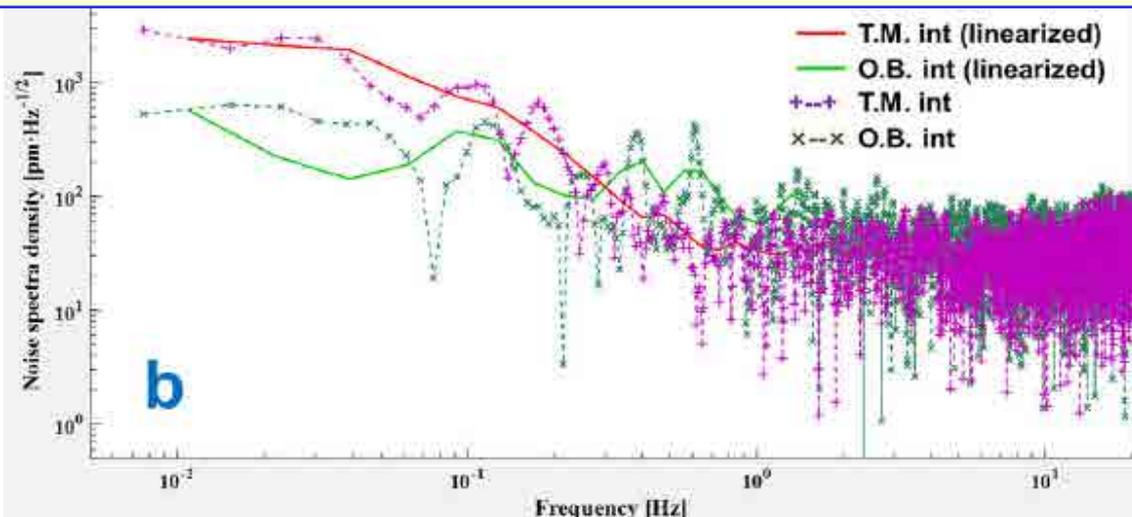
The plate of the optical bench is made of invar steel; the mirrors: fused silica; The cage of the sensor head: the low thermal expansion glass ceramics coated with gold. The test mass: titanium alloy coated with gold . The stoppers are used to prevent the test mass from contacting the inner surface of the cage during launch.

On-orbit test results of Taiji-1 payload

Precision of optical bench interferometer (O.B. int) and test mass interferometer (T.M. int) by using the first laser

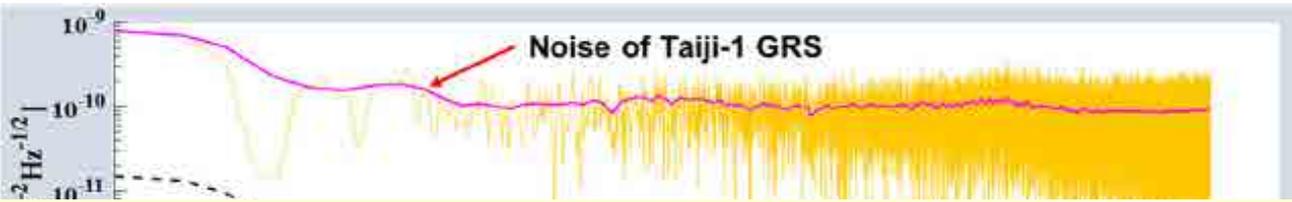


- ❖ The distance measurement noise amplitude spectra density of O.B. interferometer : $\sim 100 \text{ pm Hz}^{-1/2}$ (10 mHz–1.0Hz).
- ❖ The best precision can reach $25 \text{ pm Hz}^{-1/2}$ in a high frequency bin



The precision of the two primary interferometers by the second laser

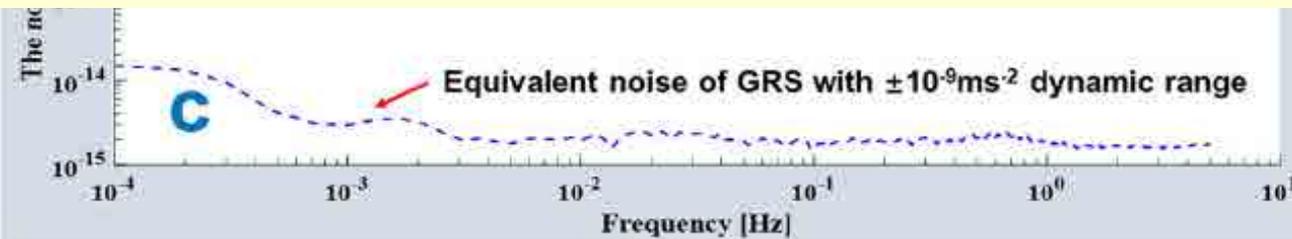
On-orbit test results of Taiji-1 payload



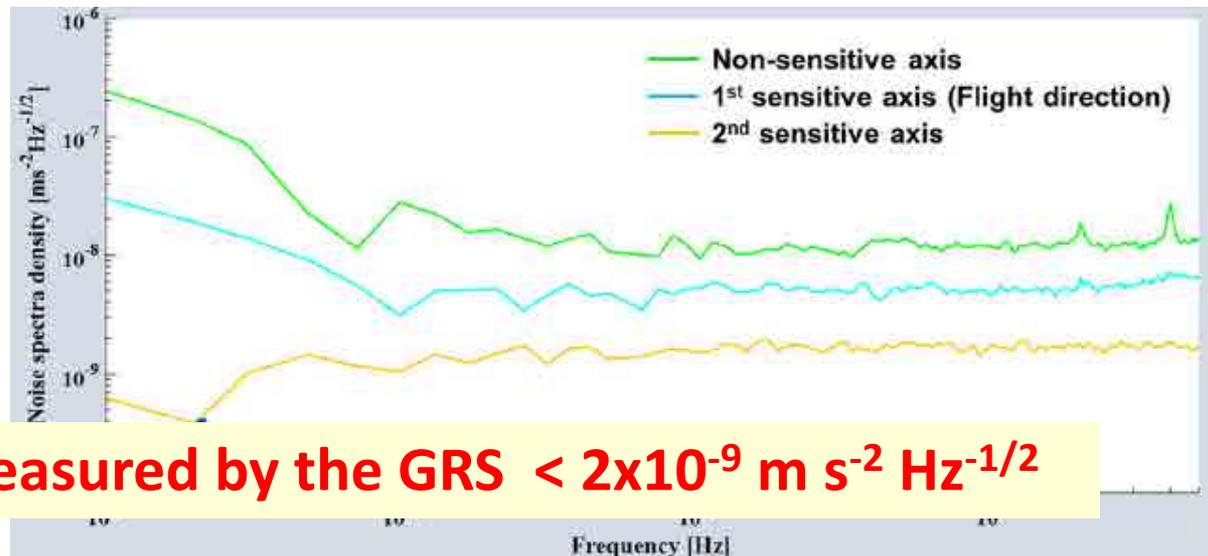
Acceleration noise measured by the readout voltage fluctuation = $10^{-10} \text{ m s}^{-2} \text{ Hz}^{-1/2}$

The noise of Taiji-1's gravitational reference sensor (GRS)

Equivalent noise of GRS corresponding to smaller dynamic ranges

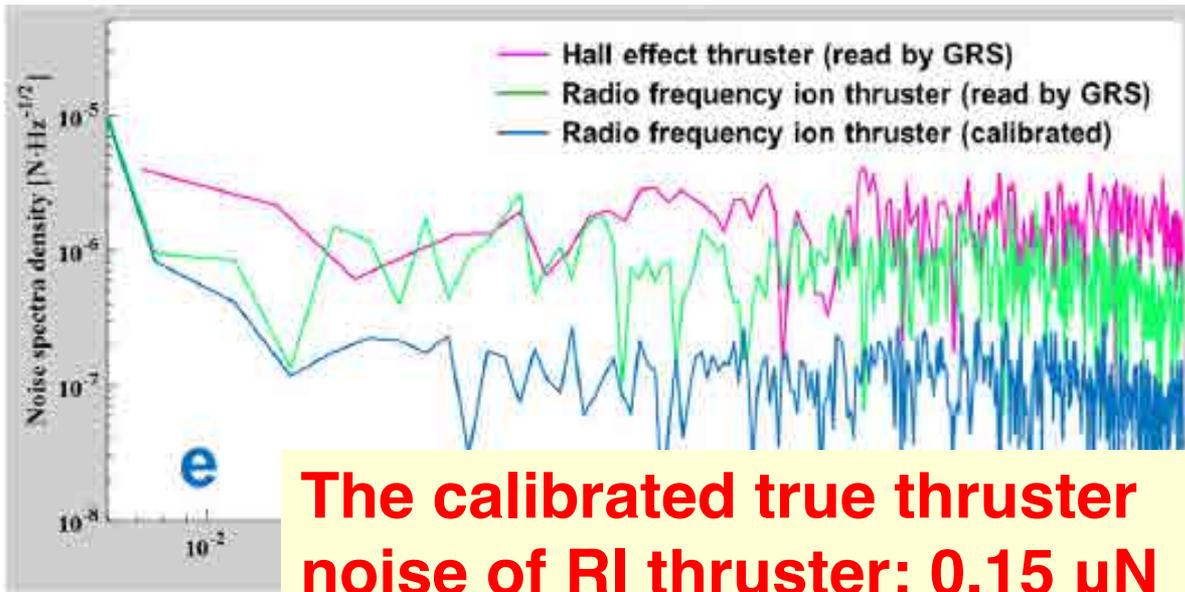


The acceleration of the Taiji-1 satellite in three axes readout by GRS



Acceleration measured by the GRS $< 2 \times 10^{-9} \text{ m s}^{-2} \text{ Hz}^{-1/2}$

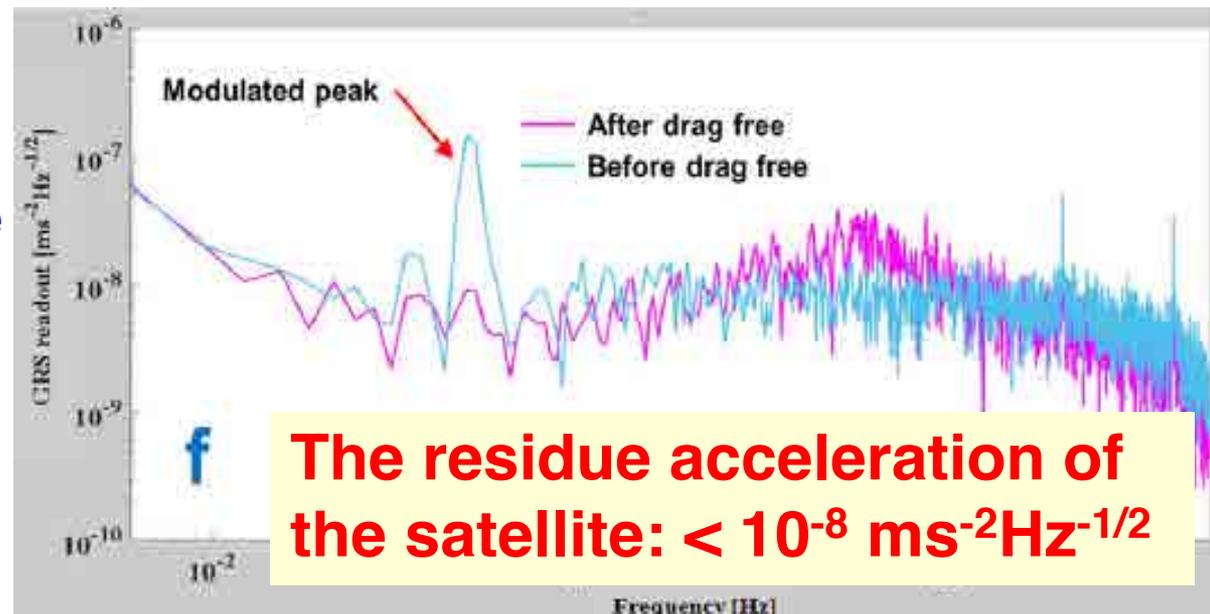
On-orbit test results of Taiji-1 payload



The noise from the two types of thrusters readout by the GRS

The calibrated noise of RI thruster by ion acceleration voltage, gas pressure at supply valve, temperature around the thruster.

Gravitational wave readout in spectrum density before & after the drag-free control. The sinusoidal force (peak) was well suppressed by using drag-free control,



The stability of the temperature control was $\sim \pm 2.6$ mK.



CONCLUSIONS

The first on-orbit scientific run of Taiji-1 showed that the space-borne interferometers could work properly.

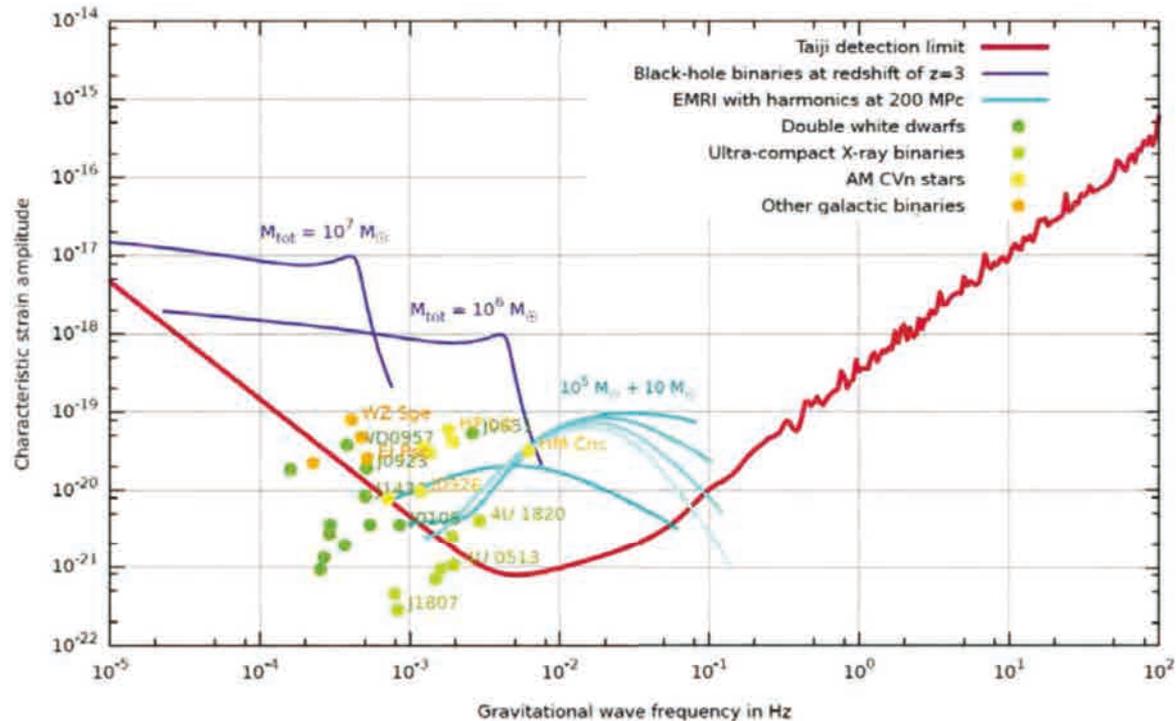
The on-orbit performance of Taiji-1 demonstrated the feasibility of the payloads.

The design, the manufacturing, the assembling, and the adjusting of payloads were effectively verified.

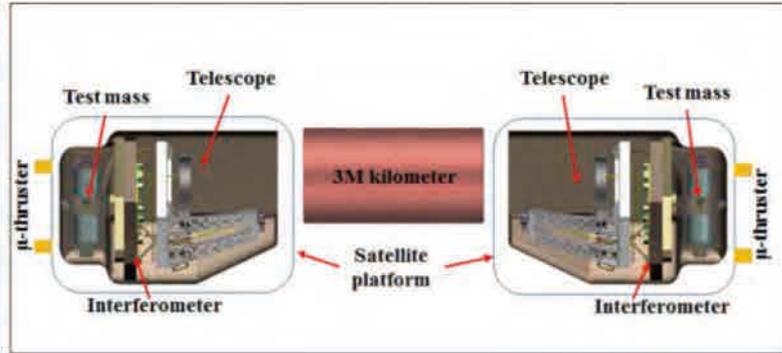
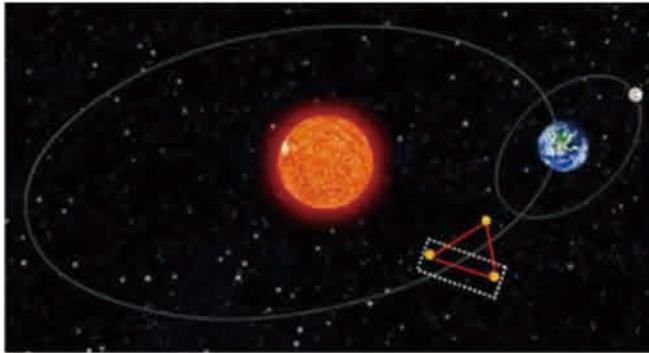
Taiji Project



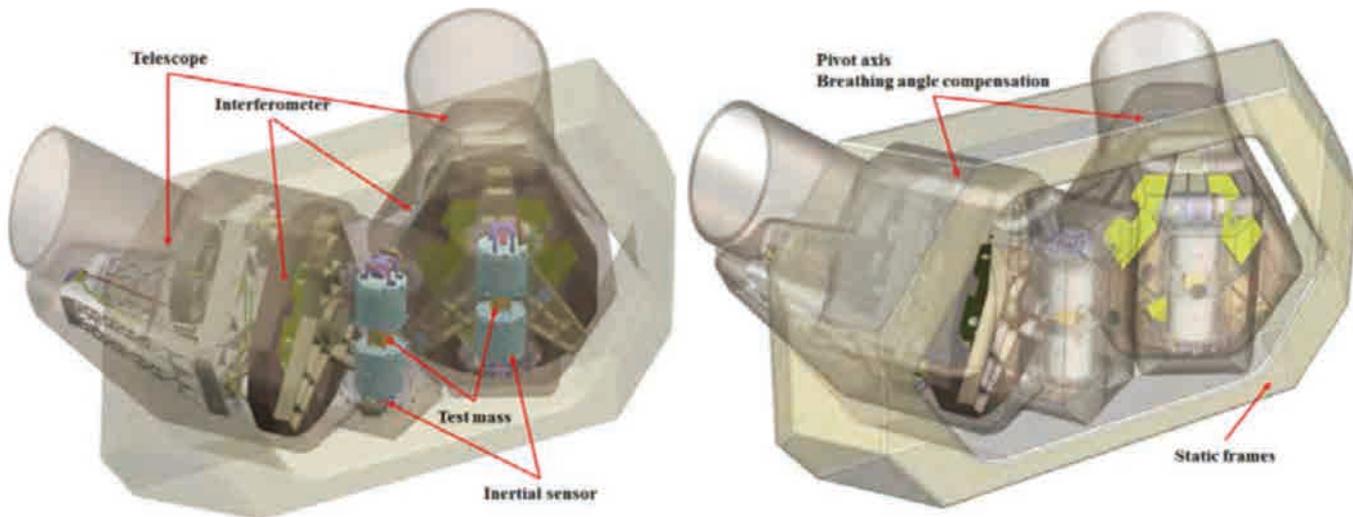
The sensitivity curve of Taiji (with mass ratio 1:1 for black hole binaries)



- ❖ Hu, W. R. & Wu, Y. L. The Taiji Program in Space for gravitational wave physics and the nature of gravity. *Natl Sci. Rev.* 4, 685–686 (2017).
- ❖ Luo, Z. R., Guo, Z. K., Jin, G., Wu, Y. L. & Hu, W. R. A brief analysis to Taiji: science and technology. *Results Phys.* 16, 102918 (2020).
- ❖ Luo, Z. R., Jin, G., Wu, Y. L. & Hu, W. R. The Taiji program: a concise overview. *Progr. Theor. Exp. Phys.*
<https://doi.org/10.1093/ptep/ptaa083> (2020).



Inter-satellite laser interferometry for Taiji. The Taiji constellation (Left); A schematic diagram of the inter-satellite laser link (Right).



Preliminary payload design for Taiji. The telescope, interferometer, test mass, and inertial sensor are shown on the left; the pivot axis of the breathing angle compensation structure and static frames are shown on the right.

Preliminary payload requirement

Laser	Wavelength: 1064 nm Frequency stability: 30 Hz Hz ^{-1/2} Relative intensity stability: 10 ⁻⁴ Hz ^{-1/2}
Telescope	Angular jitter (deliver to optical bench): 1 μrad Hz ^{-1/2} Optical path-length stability: 1 pm Hz ^{-1/2} Angular jitter (outgoing beam): 1 nrad Hz ^{-1/2} Field of view (acquisition): 400 μrad Field of view (in plane): ±4.2 μrad Field of view (out of plane): ±7 μrad
Interferometer	Optical path-length noise: 1 pm Hz ^{-1/2} Differential wavefront sensing: 1 nrad Hz ^{-1/2} Stray light noise: 1 pm Hz ^{-1/2} Tilt to length noise: 1 pm Hz ^{-1/2} Fiber and electronics noise: 1 pm Hz ^{-1/2} ; Unknown noise (seen in experiments but not identified): 1~3 pm Hz ^{-1/2} Auxiliary functionality: Reference interferometer, acquisition sensing, pointing ahead angle mechanism, inter-satellite ranging, clock noise transferring, clock synchronization, arm-locking (Opt.), inter-satellite communication

Phasemeter	Phase readout noise: 1 pm Hz ^{-1/2} Beat frequency range: 2–20 MHz; Frequency sweeping: 1–3 Hz s ⁻¹
Inertial sensor	Test mass residual noise: 3 × 10 ⁻¹⁵ ms ⁻² Hz ^{-1/2} Capacitive sensing (sensitive axis): 1.8 nm Hz ^{-1/2} Capacitive sensing (non-sensitive axis): 3 nm Hz ^{-1/2} Voltage stability: 10 ⁻⁶ V Hz ^{-1/2} Vacuum: 10 ⁻⁶ Pa Charge management: <10 ⁻⁷ C
μN thruster	Average force: >10 μN Resolution: 0.1 μN Noise: 0.1 μN Hz ^{-1/2} Response time: <0.33 s
Drag-free controller Platform	Residual displacement noise (spacecraft, sensitive axis): 2 nm Hz ^{-1/2} Temperature stability (core payload): 10 ⁻⁶ K Hz ^{-1/2} Residual magnetic field (core payload): 10 ⁻⁶ T Magnetic field stability (core payload): 10 ⁻⁷ T Hz ^{-1/2} Gravity gradient (between two test masses): 10 ⁻⁹ ms ⁻² Hz ^{-1/2}

ISGW2017

International Symposium on Gravitational Waves

May 25-29, 2017, University of Chinese Academy of Sciences, Beijing, China

Topics

Gravitational Wave Physics

Missions, Strategies and Plans of Gravitational Wave Detection

Frontiers of Science and Technology in Gravitational Wave Detection

International Collaboration in Gravitational Wave Detection



2017.5.26-28 , more than 140 scientists from 66 Institutions participated in the conference with 65 invited talks. It is expected to have two sets of space-based GWD around the sun



Register link: <http://isgw2017.csp.escience.cn/>
Visit the symposium website for more information.

Deadline for abstract submission: 5 April, 2017
Second announcement release for details: 25 April, 2017



中国科学院大学
University of Chinese Academy of Sciences

UCAST Yan Qi Lake Campus
Photo by Zhang Qi

第649次香山科学会议

The Xiangshan Science Conferences (XSSC)

2019. 4. 17-18

中国空间引力波探测及国际协作联盟学术讨论会



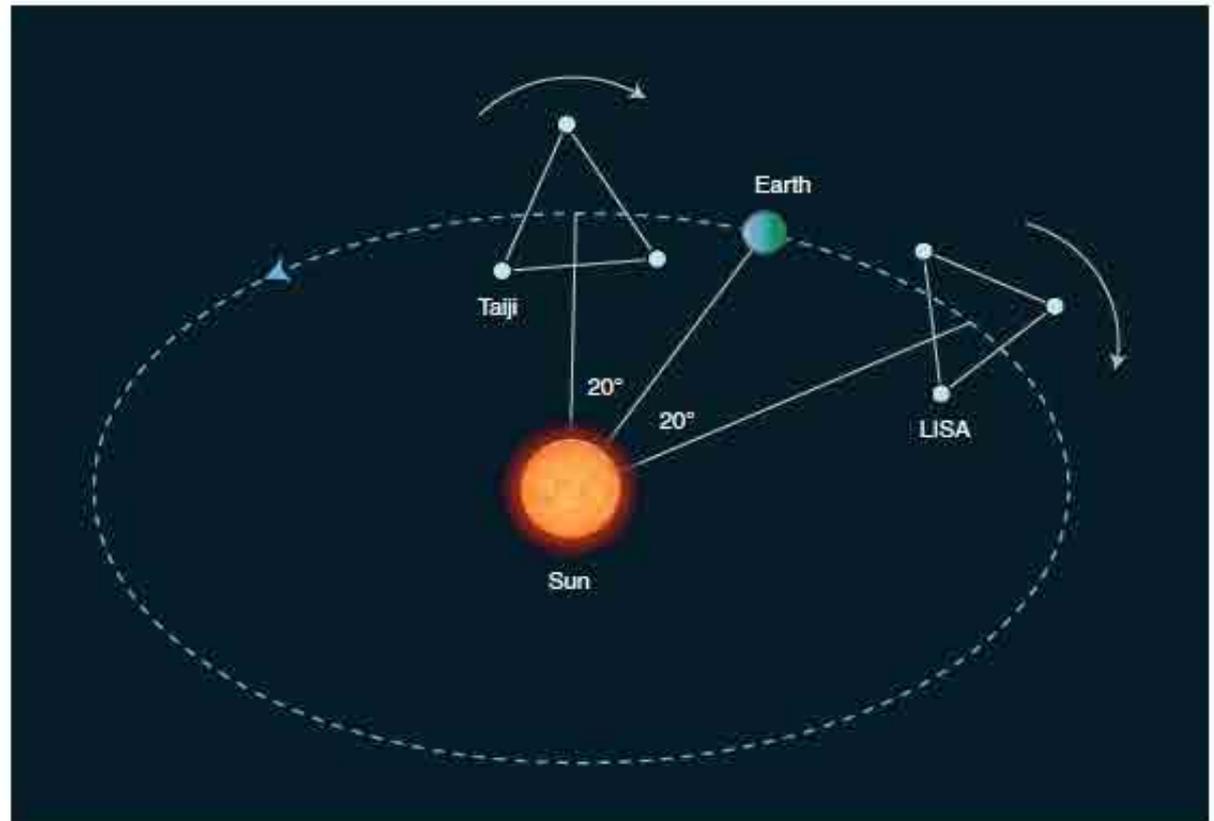
Discussions on the mission of spaced-based GWD in China and the potential international collaboration

The LISA-Taiji network

NATURE ASTRONOMY | www.nature.com/natureastronomy

To the Editor — The Laser Interferometer Space Antenna (LISA), a space-based gravitational-wave observatory, was proposed in the 1990s to detect gravitational waves with a frequency band from 10^{-4} Hz to 10^{-1} Hz (ref. ¹). LISA consists of a triangle of three identical spacecraft with a separation distance of 2.5 million kilometres in orbit around the Sun, which will bounce lasers between each other with a displacement noise of about $10 \text{ pm Hz}^{-1/2}$ in a one-way measurement. The constellation will follow the Earth by about 20° (Fig. 1). It is expected to launch between 2030 and 2035, with a mission lifetime of 4 years, extendable to 10 years. Recently, some technologies have been successfully tested in the LISA pathfinder mission².

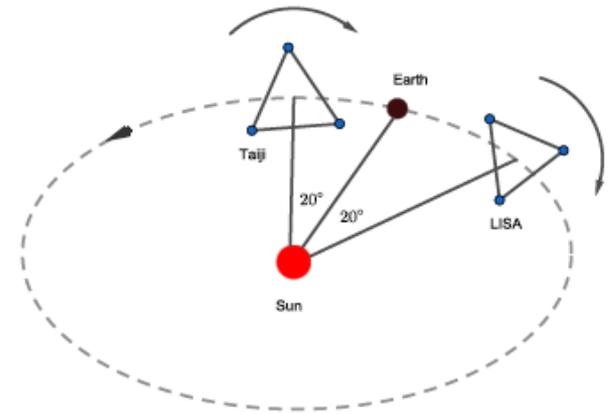
Taiji is a gravitational-wave space facility proposed by the Chinese Academy of Sciences³. The University of the Chinese Academy of Sciences and other institutes of the Chinese Academy of Sciences are involved in building it. Like LISA, Taiji is



Ruan, W., Liu, C., Guo, Z., Wu, Y. & Cai, R. The LISA-Taiji network. *Nat. Astron.* 4, 108 (2020).

LISA-Taiji network in space can fast and accurately localize the gravitational-wave sources, and may achieve about several orders of magnitude improvement on the event localization region compared to an individual detector.

LISA–Taiji Network



It is an optimistic expectation that LISA and Taiji will be both orbiting the sun to detect a standard siren from a massive binary black hole merger. With the LISA–Taiji network, it is highly possible that the Hubble constant can be determined with an uncertainty $< 0.5\%$.

The data of LISA–Taiji network can be used to study the cosmology in a more precise manner. The searching for GW signals with space-borne detectors network enable us to understand not only the nature of gravity but also the expanding history of our universe

As the early universe is filled with elementary particles at a very high energy and temperature, so that quantum gravity must play a role !!!



Picture of universe: Inflation ⊕ DE ⊕ DM ⊕ Atomic Matter



Frontiers on Quanta-to-Cosmos Physics in 21st Century

- Understand the nature of gravity & origin of universe
- Explain the puzzles of dark energy & dark matter
- Explore intrinsic laws in relating the very small elementary particles and extremely large universe
- Establish unified field theory for all basic forces

QUESTION & CHALLENGE



Basic issue: can we describe the gravitational interactions within the framework of QFTs ?

Can we establish a theory of gravity not based on the Einstein's postulate of the general covariance under the coordinate transformations ?

It is necessary to go beyond the Einstein's postulate on the General Theory of Relativity !

PHYSICAL REVIEW D 93, 024012 (2016)

**Quantum field theory of gravity with spin and scaling gauge invariance
and spacetime dynamics with quantum inflation**

Yue-Liang Wu*

State Key Laboratory of Theoretical Physics (SKLTP), Kavli Institute for Theoretical Physics China (KITPC), Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China, and International Centre for Theoretical Physics Asia-Pacific (ICTP-AP), University of Chinese Academy of Sciences (UCAS), Beijing 100049, China
(Received 17 June 2015; published 11 January 2016)

物理评论 D93, 024012 (2016)

**自旋和标度规范不变的引力量子场论
& 量子暴胀宇宙时空动力学**

吴岳良

I. Introduction	3
II. Gauge Symmetries and Gravitational Fields in QFT	6
III. Gravifield Spacetime and Gauge Theory of Gravity	10
A. Gravifield spacetime	11
B. Gauge theory of gravity	12
IV. Field Equations and Dynamics in the QFT of Gravity	14
V. Conservation Laws and Equation of Motion for Gravifield	17
A. Conservation law for internal gauge invariance	17
B. Conservation laws for spin and scaling gauge invariances	17
C. Energy-momentum conservation in the QFT of gravity	18
D. Conservation laws under the global Lorentz and scaling transformations	20
E. Equation of motion and conservation law for gravifield tensor	21
VI. Gravitational Gauge Symmetry Breaking and Dynamics of background Fields	22
A. Gravitational gauge symmetry breaking	22
B. Equations of motion and dynamics for the background fields	23
VII. Geometry of Gravifield spacetime and Evolution of Early Universe With Conformal Inflation and Deflation	25
A. Line element of gravifield spacetime and scalinon field	26
B. Background gravifield spacetime and cosmological horizon	27
C. Evolution of Early Universe with conformal inflation and deflation	28

VIII. Quantization of Gravitational Interactions in Unitary Basis and Quantum Inflation of Early Universe	29
A. Quantization of gravitational interactions in unitary basis	30
<u>B. Physical degrees of freedom with massless graviton and massive spinon</u>	32
<u>C. Gauge-fixing contributions to quantization of gravity theory</u>	33
<u>D. Perturbative expansion and renormalizability of quantized gravity theory</u>	36
E. Quantum inflation of early Universe	38
IX. Spacetime Gauge Field and Quantum Dynamics with Goldstone-like Gravifield and Gravimetric Field	41
A. Spacetime gauge field with Goldstone-like gravifield & gravimetric field	41
B. Quantum dynamics of spacetime in the hidden gauge formalism	43
X. <u>Gravity Equation Beyond and Extension to Einstein's Equation and Hidden General Coordinate Invariance</u>	45
XI. Conclusions and Remarks	50
References	52

Principles & Postulates of GQFT Beyond Einstein

Basic considerations:

- ✓ Quantum field theory of gravity is constructed within the framework of QFT in a globally flat Minkowski space-time
- ✓ Treat the gravitational force on the same footing as the other three basic forces

➤ A concept of biframe spacetime is introduced for GQFT

One frame is a globally flat coordinate Minkowski spacetime, which acts as an **inertial** reference frame for characterizing the motions of basic fields. The other is a locally flat non-coordinate gravigauge spacetime, which functions as an intrinsic **interaction** frame for characterizing the dynamics of basic fields.

The basic gravitational field is no longer the metric field, but a gauge-type bicovariant vector field in biframe spacetime

Metric field $g_{\mu\nu}$ \longrightarrow χ_{μ}^a Gauge-type bicovariant vector field

Generalized Dirac equation in Gravitational Quantum Field Theory (GQFT)

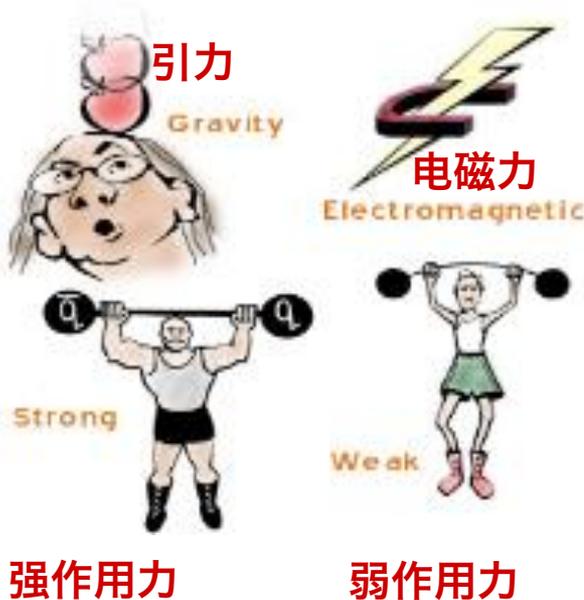
$$\gamma^\mu i \partial_\mu \Psi - m \Psi = 0$$



$$\gamma^a \hat{\chi}_a^\mu i (\nabla_\mu + V_\mu) \psi = 0$$

$$\nabla_\mu = \partial_\mu + \Omega_\mu$$

$$V_\mu(x) \equiv \frac{1}{2} \hat{\chi}_\mu^c \nabla_\rho (\chi \hat{\chi}^{\rho})$$



GQFT

- ◆ Provide a new possible way for combining general theory of relativity with quantum mechanics
- ◆ Provide a new theoretical framework for describing four basic forces of nature in a unified way

Postulate for GQFT

The laws of nature obey the gauge invariance and should be independent of the choice of coordinates



Regular Article - Theoretical Physics

Hyperunified field theory and gravitational gauge–geometry duality

Yue-Liang Wu^{1,2,3,a}

¹ International Centre for Theoretical Physics Asia-Pacific (ICTP-AP), Beijing, China

超统一场论和引力规范-几何对偶
吴岳良

Received: 2 October 2017 / Accepted: 22 December 2017

© The Author(s) 2018. This article is an open access publication

Abstract A hyperunified field theory is built in detail based on the postulates of gauge invariance and coordinate independence along with the conformal scaling symmetry. All elementary particles are merged into a single hyper-spinor field and all basic forces are unified into a fundamental interaction governed by the hyper-spin gauge symmetry $SP(1, D_h - 1)$. The dimension D_h of hyper-spacetime is conjectured to have a physical origin in correlation with the hyper-spin charge of elementary particles. The hyper-gravifield fiber bundle structure of biframe hyper-spacetime appears naturally with the globally flat Minkowski hyper-spacetime as a base spacetime and the locally flat hyper-gravifield spacetime as a fiber that is viewed as a dynamically emerged hyper-spacetime characterized by a non-commutative geometry. The gravitational origin of gauge symmetry is revealed with the hyper-gravifield that plays an essential role as a Goldstone-like field. The gauge-gravity and gravity-geometry correspondences bring about the gravitational gauge-geometry duality. The basic properties of hyperunified field theory and the issue on the fundamental scale are analyzed within the framework of quantum field theory, which allows us to describe the laws of nature in deriving the gauge gravitational equation with the conserved current and the geometric gravitational equations of Einstein-like type and beyond.

Contents

1	Introduction	.....
2	Unification of elementary particles and maximal symmetry in hyper-spacetime	.....
2.1	Unity of hyper-spin charges for each family of quarks and leptons	.....

2.2	Discrete symmetries (CPT) and hyper-spinor structure in hyper-spacetime	.....
2.3	Family and mirror hyper-spin charges with additional dimensions	.....
2.4	Unification of all quarks and leptons as elementary particles in hyper-spacetime with minimal dimension and maximal symmetry	.....
3	Unification of basic forces with hyper-spin gauge symmetry and dynamics of the hyper-spinor field	.....
3.1	Unification of basic forces with hyper-spin gauge symmetry	.....
3.2	Equation of motion of the hyper-spinor field in a general gravitational relativistic quantum theory with a conformal scaling symmetry	.....
4	Fiber bundle structure of hyper-spacetime and hyperunified field theory in hyper-gravifield spacetime	.....
4.1	Hyper-gravifield fiber bundle structure	.....
4.2	Hyperunified field theory with postulates of gauge invariance and coordinate independence	.....
5	Hyperunified field theory within the framework of QFT and dynamics of basic fields with conserved currents	.....
5.1	Hyperunified field theory within the framework of QFT	.....
5.2	Equations of motion of basic fields in hyper-spacetime	.....
5.3	Conserved currents in hyperunified field theory	.....
6	Conservation laws and dynamics of hyper-gravifield in hyperunified field theory	.....
6.1	Conservation law of translational invariance in hyperunified field theory	.....
6.2	Conservation laws of global Lorentz and conformal scaling invariances	.....
6.3	Dynamics of hyper-gravifield with conserved hyper-stress energy-momentum tensor	.....

^a e-mails: ylwu@itp.ac.cn; ylwu@ucas.ac.cn

7	Gravitational origin of gauge symmetry and hyper-unified field theory in hidden gauge formalism with emergent general linear group symmetry $GL(D_h, R)$
7.1	Hyper-spin gravigauge field and gravitational origin of gauge symmetry
7.2	Hyper-spacetime gauge field and Goldstone-like hyper-gravifield
7.3	Field strength of hyper-spacetime gauge field in hidden gauge formalism
7.4	General covariance and Riemannian geometry of hyper-spacetime
7.5	Hyperunified field theory in hidden gauge formalism and emergent general linear group symmetry $GL(D_h, R)$
8	Hyperunified field theory with general conformal scaling gauge invariance and Einstein–Hilbert-type action with essential gauge massless condition and gravity–geometry correspondence
8.1	Hyperunified field theory with general conformal scaling gauge invariance and essential gauge massless condition
8.2	Einstein–Hilbert-type action with gravity–geometry correspondence in hyper-spacetime and symmetric Goldstone-like hyper-gravifield with unitary gauge
9	Hyperunified field theory in hidden coordinate formalism and gauge–gravity correspondence
9.1	Hyper-spin gauge field and field strength in a hidden coordinate formalism
9.2	Riemann-like and Ricci-like tensors in locally flat hyper-gravifield spacetime and symmetry properties of field strengths
9.3	Hyperunified field theory in locally flat hyper-gravifield spacetime and gauge–gravity correspondence
10	Gravitational gauge–geometry duality and hyper-unified field theory with non-commutative geometry in locally flat hyper-gravifield spacetime
10.1	Gravitational gauge–geometry duality with flowing unitary gauge
10.2	Hyperunified field theory with non-commutative geometry in locally flat hyper-gravifield spacetime
11	Basic properties of hyperunified field theory and gravitational equations of Einstein-like and beyond with fundamental mass scale
11.1	Basic properties of hyperunified field theory within the framework of QFT
11.2	Fundamental mass scale in hyperunified field theory with scaling gauge fixing

11.3	Gauge gravitational equations with conserved hyper-gravifield current and hyper-stress energy-momentum tensor in hyperunified field theory
11.4	Geometric gravitational equations of Einstein-like and beyond in hyper-spacetime
12	Conclusions and remarks
	References

1 Introduction

Since Einstein established the general theory of relativity (GR) [1] in 1915, it has become a great challenge for many physicists and mathematicians to unify the then-known basic forces. Historically, the idea of unification was put forward because of the dynamical theory of the electromagnetic field formulated in 1864 by Maxwell, who combined electricity and magnetism into a unifying theory of electromagnetism, which is considered as the first successful classical unified field theory. The constancy of the speed of light in Maxwell's theory led Einstein to unify the space and time into a four-dimensional spacetime characterized by the global Lorentz symmetry $SO(1,3)$, which has laid the foundation for the special theory of relativity (SR) [2]. Such a globally flat four-dimensional Minkowski spacetime holding for SR was

Reviewer Report: “I find this article original and rigorously developed. Some novel ideas about unification have been proposed and, although their validity as guiding principles for the construction of unified theories remains to be investigated, they are interesting in their own right.”

Unification of all Elementary Particles into a Single Hyperspinor Field

Treat all spin-like charges of elementary particles on the same footing as a **hyperspin charge** (boost spin, helicity spin, chirality spin, isotopic spin, color spin, family spin)

Express the degrees of freedom of all elementary particles into a single column vector in a spinor representation of a **high-dimensional hyper-spacetime**

Establish a **coherent relation** between the **hyperspinor structure** of the elementary particles and the **dimension** of a hyper-spacetime

Lead to a globally flat **Minkowski hyper-spacetime** with the dimension $D_h = 19$

A minimal hyper-unified spinor field is a **Majorana-type hyperspinor field** in an irreducible spinor representation of a hyperspin group $SP(1,18) \cong SO(1,18)$

Hyperunified Field Theory in Two Equivalent Formalisms

$$\begin{aligned}
 I_H \equiv & \int [d\hat{x}] \chi \left\{ \frac{1}{2} \bar{\Psi} \Gamma^A \hat{\chi}_A^M (i\partial_M + g_h \mathcal{A}_M) \Psi \right. \\
 & + \phi^{D_h-4} \left[-\frac{1}{4} (\tilde{\chi}_{ABA'B'}^{MNM'N'} \mathcal{F}_{MN}^{AB} \mathcal{F}_{M'N'}^{A'B'} + \mathcal{W}_{MN} \mathcal{W}^{MN}) \right. \\
 & \left. \left. + \alpha_E \phi^2 \frac{1}{4} \tilde{\chi}_{AA'}^{MNM'N'} \mathbf{G}_{MN}^A \mathbf{G}_{M'N'}^{A'} + \frac{1}{2} \hat{\chi}^{MN} d_M \phi d_N \phi \right. \right. \\
 & \left. \left. - \beta_E \phi^4 \right] \right\} + 2\alpha_E g_h \partial_M (\chi \phi^{D_h-2} \mathcal{A}_N^{NM}),
 \end{aligned}$$

Gauge fixing $SP(1, D_h - 1)$ to a unitary gauge

$$\chi_{MA} = \chi_{AM}$$

$$\chi_{MN} = (\chi_{MA})^2$$

Gravitational Gauge-Geometry Duality

$$\begin{aligned}
 I_H = & \int [d\hat{x}] \chi \left\{ \frac{1}{2} \bar{\Psi} \Gamma^M [i\partial_M + (\Xi_M^{PQ} + g_h \mathbf{A}_M^{PQ}) \frac{1}{2} \Sigma_{PQ}] \Psi \right. \\
 & + \phi^{D_h-4} \left\{ -\frac{1}{4} (\chi_{MNP'Q'}^{MNM'N'} \mathbf{F}_{MN}^{PQ} \mathbf{F}_{M'N'}^{P'Q'} + \mathcal{W}_{MN} \mathcal{W}^{MN}) \right. \\
 & \left. \left. + \alpha_E [\phi^2 \mathcal{R} - (D_h - 1)(D_h - 2) \partial_M \phi \partial^M \phi] - \beta_E \phi^4 \right. \right. \\
 & \left. \left. + \frac{1}{2} \hat{\chi}^{MN} d_M \phi d_N \phi \right\} \right\} + 2\alpha_E g_h \partial_M (\chi \phi^{D_h-2} \mathbf{A}_N^{NM}),
 \end{aligned}$$

Equivalence of actions

Bimaximal Global and Local Symmetries in HUFT

$$G_S = PO(1, D_h - 1) \times S(1) \rtimes SP(1, D_h - 1) \times SG(1)$$

The foundation of the hyperunified field theory I - fundamental building block and symmetry

Yue-Liang Wu*

¹*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*

²*International Centre for Theoretical Physics Asia-Pacific (ICTP-AP),
(Beijing/Hangzhou), UCAS, Beijing 100190, China*

³*Taiji Laboratory for Gravitational Wave Universe (Beijing/Hangzhou),
University of Chinese Academy of Sciences, Beijing 100049, China*

⁴*School of Fundamental Physics and Mathematical Sciences,
Hangzhou Institute for Advanced Study, UCAS, Hangzhou 310024, China*

Abstract

Starting from motional property of functional field based on the action principle of path integral formulation with proposing maximum coherence motion principle and maximum entangled qubit-spinor principle as guiding principles, we show that such a functional field as fundamental building block is an entangled qubit-spinor field represented as locally entangled state of qubits.

**超统一场论的基础 I
——自然界基本构造块与对称性**

吴岳良

arXiv2104.05404 (138 pages)

I. Introduction	5
II. Appearance of spinor field with canonical anticommutation relation and the emergence of Minkowski spacetime and basic symmetry with proposing maximum coherence motion principle as guiding principle	10
A. Anti-commuting field operator as the spinor field based on the simplest motion postulate	11
B. Appearance of temporal and spatial dimensions with quadratic free motion postulate and the free motion of single real spinor field in two-dimensional spacetime	12
C. Existence of real column vector field as the spinor field in Hilbert space through introduction of motion-correlation \mathcal{M}_c -matrices and motion-irrelevance \mathcal{Q}_c -matrices with proposing maximum coherence motion principle as guiding principle	13
D. Presence of high dimensional Minkowski spacetime with single temporal dimension and the action of spinor field with scalar coupling associated to intrinsic \mathcal{Q}_c -matrices	18
E. Appearance of canonical anticommutation relation and Pauli exclusion principle with maximum coherence motion principle as guiding principle	20
F. Emergence of \mathcal{M}_c -spin and \mathcal{Q}_c -spin symmetries in Hilbert space in association with Poincaré-type symmetry and scaling symmetry in Minkowski spacetime	22
III. Spinor field in 2D Hilbert space as local coherent state of qubit and basic properties of uniqubit-spinor field with appearance of 3D Minkowski spacetime	26
A. Spinor field in 2D Hilbert space as local coherent state of qubit and the appearance of 3D Minkowski spacetime for uniqubit-spinor field	26
B. Properties of uniqubit-spinor field and three-dimensional Minkowski spacetime under intrinsic discrete symmetries	29
C. Presence of spatial dimensions in correspondence to rotational \mathcal{M}_c -spin group symmetry	31
D. Presence of temporal dimension in correspondence to non-homogeneous scaling symmetry	32
E. Maximal coherent symmetry of uniqubit-spinor field and the equation of motion with dynamic \mathcal{Q}_c -spin scalar field in three-dimensional Minkowski spacetime	34
IV. Qubit-spinor postulate and the nature of biqubit-spinor field and triqubit-spinor field as Majorana and Dirac fermions with appearance of 4D and 6D Minkowski spacetimes	36
A. Local coherent state of qubits as basic spinor field and qubit-spinor postulate	36
B. Local coherent states of 2-qubit and 3-qubit in 4D and 8D Hilbert spaces and the appearance of 4D and 6D Minkowski spacetimes for biqubit-spinor and triqubit-spinor fields	37
C. Dynamics of \mathcal{Q}_c -spin bi-scalar field and intrinsic discrete symmetries of biqubit-spinor and triqubit-spinor fields	40
D. Maximal coherent symmetries of biqubit-spinor and triqubit-spinor fields	42

E.	Local coherent states of 2-qubit and 3-qubit as basic constituents of matter and Majorana and Dirac fermions as biqubit-spinor and triqubit-spinor fields	44
F.	Intrinsic properties of complex uniqubit-spinor and complex biqubit-spinor fields with $SL(2,\mathbb{C})$ and $SL(2,\mathbb{Q})$ group symmetries in 4D and 6D Minkowski spacetimes	49
G.	Massless Dirac fermion with W-charge conjugation in 6D Minkowski spacetime and self-conjugated triqubit-spinor field with intrinsic Q_c -spin symmetry $SU(2)$	52
H.	Equivalent description of Dirac- & Majorana- & Weyl-type fermions as qubit-spinor fields with the same M_c -spin and Q_c -spin charges in corresponding to complex & self-conjugated & chiral representations	54
V.	Local coherent state of 4-qubit as hyperqubit-spinor field with hyperspin symmetry $SP(1,9)\cong SL(2,\mathbb{O})$ in 10D Minkowski hyper-spacetime and the periodic feature of Q_c-spin charge	56
A.	Local coherent state of 4-qubit in 16D Hilbert space with zero Q_c -spin charge $C_{Q_c}=0$ as tetraqubit-spinor field in 10D Minkowski hyper-spacetime	56
B.	Hyperspin symmetry $SP(1,9)\cong SL(2,\mathbb{O})$ and intrinsic discrete symmetries of hyperqubit-spinor field in 10D Minkowski hyper-spacetime	58
C.	Self-conjugated chiral uniqubit-spinor field in 2D Minkowski spacetime as zeroqubit-spinor field or bit-spinor field with zero Q_c -spin charge $C_{Q_c} = Q_N = 0$	60
D.	Periodic behavior of Q_c -spin charge for qubit-spinor fields with Q_c -spin charges $C_{Q_c}=0,1,2,3,0$ in corresponding to Hilbert space with dimensions $D_H=1,2,4,8,16$ and Minkowski spacetime with dimensions $D_h=2,3,4,6,10$	63
VI.	Categorization of hyperqubit-spinor fields and hyper-spacetimes with periodic Q_c-spin charges and the genesis of hyper-spacetime dimension from categoric qubit number	64
A.	Local coherent state of five qubits with Q_c -spin charge $C_{Q_c}=1$ and the action of pentaqubit-spinor field as hyperqubit-spinor field in 11D hyper-spacetime	64
B.	Local coherent state of six qubits with Q_c -spin charge $C_{Q_c}=2$ and the action of hexaqubit-spinor field as hyperqubit-spinor field in 12D hyper-spacetime	66
C.	Local coherent state of seven qubits with Q_c -spin charge $C_{Q_c}=3$ and the action of heptaqubit-spinor field as hyperqubit-spinor field in 14D hyper-spacetime	68
D.	Local coherent state of eight qubits and the action of octoqubit-spinor field as hyperqubit-spinor field in 18D hyper-spacetime in analogous to tetraqubit-spinor field in 10D hyper-spacetime and zeroqubit-spinor field in 2D spacetime	70
E.	Classifications of arbitrary qubit number and spacetime dimension with four categories of Q_c -spin charge and the genesis of spacetime dimension from categoric qubit number	73
F.	Categorization of hyperqubit-spinor field and hyper-spacetime with four categories of Q_c -spin charge and the action of hyperqubit-spinor field in category- q_c with hyperspin symmetry	74
VII.	String-like qubit-spinor field with free motion in two-dimensional spacetime and the self-conjugated chiral qubit-spinor field with full anti-commuting Γ-matrices	78
A.	Self-conjugated chiral-like spinor structure and string-like qubit-spinor field	78

B.	Self-conjugated chiral hyperqubit-spinor field and full anti-commuting Γ -matrices in an extended Hilbert space	81
C.	Massless Dirac fermion as self-conjugated chiral tetraqubit-spinor field in category-3 with full anti-commuting \mathcal{M}_c -matrices and \mathcal{Q}_c -matrices in 6D spacetime	85
VIII.	Entangled hyperqubit-spinor field from local entanglement postulate and inhomogeneous hyperspin symmetry as basic symmetry of lepton-quark states	87
A.	Entangled state in quantum theory and local entanglement postulate	88
B.	Majorana-Weyl type fermions as entangled qubit-spinor fields in category-2 & category-3 and the inhomogeneous \mathcal{M}_c -spin symmetries associating with inhomogeneous Lorentz group symmetries in four- and six-dimensional Minkowski spacetimes	91
C.	Entangled pentaqubit-spinor field as entangled hyperqubit-spinor field in category-0 and inhomogeneous hyperspin symmetry WS(1,9) as unified spin-color symmetry of chiral lepton-quark state in 10D hyper-spacetime	95
D.	Entangled hexaqubit-spinor field in Category-1 as entangled hyperqubit-spinor field and inhomogeneous hyperspin symmetry as unified spin-color symmetry of lepton-quark state in 11D hyper-spacetime	98
E.	Entangled Heptaqubit-spinor field in Category-2 as entangled hyperqubit-spinor field and inhomogeneous hyperspin symmetry as unified spin-color-flavor symmetry of lepton-quark states in 12D hyper-spacetime	101
IX.	Entangled octoqubit-spinor field as ultra-grand unified qubit-spinor field in 14D hyper-spacetime with inhomogeneous hyperspin symmetry as ultra-grand unified symmetry and the comprehension on lepton-quark state with one more family and the observed universe with 4D spacetime	104
A.	Entangled octoqubit-spinor field in 14D hyper-spacetime with inhomogeneous hyperspin and \mathcal{Q}_c -spin symmetries in producing basic symmetries of leptons and quarks in SM and comprehension on lepton-quark state beyond one family in nature	104
B.	Ultra-grand unified qubit-spinor field in 14D hyper-spacetime with inhomogeneous hyperspin symmetry as ultra-grand unified symmetry and comprehension on the observed universe with only 4-dimensional spacetime	109
X.	Hyperunified qubit-spinor field as fundamental building block and inhomogeneous hyperspin symmetry as hyperunified symmetry from maximum entangled qubit-spinor principle	115
A.	Least \mathcal{Q}_c -spin postulate and maximum entangled qubit-spinor principle	115
B.	Entangled enneaqubit-spinor field with zero \mathcal{Q}_c -spin charge as minimal hyperunified qubit-spinor field and inhomogeneous hyperspin symmetry as minimal hyperunified symmetry in 18D hyper-spacetime	116
C.	Entangled decaqubit-spinor field in 19D hyper-spacetime as hyperunified qubit-spinor field for fundamental building block and inhomogeneous hyperspin symmetry WS(1,18) as hyperunified fundamental symmetry	122
D.	Conservation of H-parity and U-parity in hyperunified field theory with vector-like lepton-quark state and comprehension on P-parity violation in SM	128

I.
o
e
g
t
ti

The HUFT has taken the first step towards unifying all the elementary particles and basic forces. In order to clarify more profound problems raised in particle physics and QFT, we should think of more fundamental concepts and carry out a more systematic analysis along with the line of HUFT.

us to make the unified description on four basic forces within the framework of quantum field

The well-known long-standing open questions which have been answered in the part I of “The Foundation of the Hyperunified Field Theory I” are as follows:

- what is made to be the fundamental building block of nature?
- What brings about the fundamental symmetry of nature?
- Which symmetry governs the gravitational interaction?
- What is the basic structure of spacetime?
- How many dimensions does spacetime have?
- What makes time difference from space?
- Why is there only one temporal dimension?
- Why do we live in a universe with only 4D spacetime?
- Why are there leptons and quarks more than one family?
- Why are the existed leptons and quarks the chiral fermions with maximum parity violation?

Maximum Coherence Motion Principle & Comprehension on Fundamental Questions

Maximum coherence motion principle:

The Hermitian action of real column vector field $\Psi(x)$ as basic matter field in path integral formulation is built to bring on a free and continuous motion that concerns only the first order derivative on $\Psi(x)$ with respect to variables X_μ and possesses maximally correlated motion with involving solely the bilinear form of $\Psi(x)$. Meanwhile, each component of $\Psi(x)$ obeys independent quadratic free motion.

The maximum coherence motion principle as guiding principle actually contains three postulates:

- The simplest motion postulate,
- The maximum correlation motion postulate,
- The quadratic free motion postulate.

Explain on the presence of spinor field with automatic appearance of canonical anticommutation relation & Pauli exclusion principle

$$\mathcal{S}_\Psi = \int [dx] \frac{1}{4} \{ \lambda_C \delta_a^\mu \Psi^\dagger(x) \Upsilon^a \partial_\mu \Psi(x) + \tilde{\lambda}_C \delta_p^\alpha \Psi^\dagger(x) \Upsilon^p \partial_\alpha \Psi(x) + H.c. \}$$

$$\{ \psi_i(x), \psi_j(x') \} = \lambda_d \delta_{ij} \Delta(x - x'),$$

$$\Delta(x - x') = \int \frac{d^{D_h} p}{(2\pi)^{D_h-1}} \delta(p_0^2 - p^2) (p_0 + p_k \Upsilon^k) e^{-ip \cdot (x-x')}.$$

$$\Delta(x^k - x'^k) = \lambda_d \delta(x^k - x'^k)$$

Lead to natural comprehension on the basic questions:

- why there exists only one temporal dimension in high dimensional Minkowski spacetime
- why the temporal dimension is not geometrically visible though it is physically measurable.

$$\square \Psi(x) \equiv (\partial_0^2 - \partial_k^2) \Psi(x) \equiv \eta^{\mu\nu} \partial_\mu \partial_\nu \Psi(x) = 0$$

$$\eta^{\mu\nu} = \text{diag.}(1, -1, \dots, -1), \quad \mu, \nu = 0, 1, \dots$$

$$\Upsilon^a \hat{\Upsilon}^b + \Upsilon^b \hat{\Upsilon}^a = 2\eta^{ab}; \quad \hat{\Upsilon}^{a,b} = (\Upsilon^0, -\Upsilon^{k,l}),$$

$$\eta^{ab} = \text{diag.}(1, -1, \dots, -1), \quad a, b = 0, 1, \dots,$$

- The presence of spatial dimensions in correspondence to the rotational M_c -spin group symmetry
- The presence of temporal dimension in correspondence to the non-homogeneous scaling symmetry
- The appearance of M_c -spin and Q_c -spin symmetries in Hilbert space in association with Poincare-type symmetry and scaling symmetry in Minkowski spacetime

Brings on the emergence of associated symmetry for the action

$$\mathcal{S}_\Psi = \int [dx] \left\{ \frac{1}{2} \Psi^\dagger(x) \delta_a^\mu \Upsilon^a i \partial_\mu \Psi(x) - \frac{1}{2} \phi_p(x) \Psi^\dagger(x) \tilde{\Upsilon}^p \Psi(x) \right\}$$

$$G = SC(1) \ltimes P^{1,D_h-1} \ltimes SO(1, D_h - 1) \tilde{\bowtie} SP(1, D_h - 1) \rtimes SG(1) \times SP(q_c) \\ \equiv SC(1) \ltimes PO(1, D_h - 1) \tilde{\bowtie} SP(1, D_h - 1) \rtimes SG(1) \times SP(q_c),$$

$$PO(1, D_h - 1) \equiv P^{1,D_h-1} \ltimes SO(1, D_h - 1)$$

$$SP(1, D_h - 1)$$

$$SP(q_c)$$

Poincare-type group symmetry
(inhomogeneous Lorentz-type group symmetry)

M_c -spin symmetry/hyperspin symmetry

Q_c -spin symmetry

Starting from motional property of a functional column vector field based on the action principle of path integral formulation with proposing maximum coherence motion principle and maximum locally entangled qubit motion principle as guiding principles, we have shown that:

Such a functional column vector field as fundamental building block is an entangled qubit-spinor field represented as locally entangled state of qubits.

Its motion brings about the appearance of Minkowski spacetime with dimension determined by the motion-correlation M_c -spin charge and the emergence of M_c -spin or hyperspin symmetry as fundamental symmetry.

Intrinsic Q_c -spin charge displays a periodic feature as the mod 4 qubit number, which enables us to classify all entangled qubit-spinor fields and spacetime dimensions into four categories corresponding four Q_c -spin charges $C_Q = 0, 1, 2, 3$.

An entangled decaqubit-spinor field in 19-dimensional hyper-spacetime is found to be a hyperunified qubit-spinor field which unifies all discovered leptons and quarks and brings on the existence of mirror lepton-quark states.

The inhomogeneous hyperspin symmetry $WS(1,18)$ as hyperunified symmetry in association with inhomogeneous Lorentz-type symmetry $PO(1,18)$ and global scaling symmetry provides a unified fundamental symmetry.

The motion nature of locally entangled state of qubits with obeying two guiding principles is shown to lay the main part of the foundation of hyperunified field theory, which enables us to comprehend the mentioned longstanding questions raised in particle physics and quantum field theory.

Local coherent state of qubits as hyperqubit-spinor field

Categorization of hyperqubit-spinor fields and hyper-spacetimes with periodic Qc-spin charges and the genesis of hyper-spacetime dimension from categoric qubit number

TABLE I: The properties of qubit-spinor fields and spacetime dimensions

Qubits Q_N	0	1	2	3	4
Qubit-spinor field	ψ_{Q^0}	ψ_{Q^1}	ψ_{Q^2}	ψ_{Q^3}	ψ_{Q^4}
Qubit-spinor	bit-spinor	uniqubit-spinor	biquubit-spinor	triquubit-spinor	tetraqubit-spinor
Hilbert space \mathcal{D}_H	$2^0 = 1$	$2^1 = 2$	$2^2 = 4$	$2^3 = 8$	$2^4 = 16$
Q_c -spin charge \mathcal{C}_{Q_c}	0	1	2	3	$0 = 4 - 4$
Q_c -spin sym.	SP(0)	SP(1) \cong O(1)	SP(2) \cong U(1)	SP(3) \cong SU(2)	SP(0)
Spacetime D_h	2	$3 = 2 + 2^0$	$4 = 2 + 2^1$	$6 = 2 + 2^2$	$10 = 2 + 2^3$
Trans. Dim. $D_h - 2$	0	1	2	4	8
Spinor structure	$\psi_{Q_T \pm}$	$\psi_{Q_S^1}$	$\psi_{Q_S^2}, \psi_{Q_C^1}$	$\psi_{Q_S^3}, \psi_{Q_C^2}$	$\psi_{Q_S^4}$
\mathcal{M}_c -spin sym.	SP(1,1)	SP(1,2)	SP(1,3)	SP(1,5)	SP(1,9)
Isomorphic group		\cong SL(2, \mathbb{R})	\cong SL(2, \mathbb{C})	\cong SL(2, \mathbb{Q})	\cong SL(2, \mathbb{O})
Lorentz-type sym.	SO(1,1)	SO(1,2)	SO(1,3)	SO(1,5)	SO(1,9)
Poincaré-type sym.	PO(1,1)	PO(1,2)	PO(1,3)	PO(1,5)	PO(1,9)

**Local coherent state of qubits
as hyperqubit-spinor field**

$$Q_N^{(q_c, k)} \equiv q_c + 4k,$$

$$q_c = 0, 1, 2, 3, \quad k = 0, 1, 2, \dots,$$

TABLE II: The properties of local coherent state of qubits as hyperqubit-spinor field

Qubits Q_N	4	5	6	7	8
Hyperqubit-spinor	Ψ_{Q^4}	Ψ_{Q^5}	Ψ_{Q^6}	Ψ_{Q^7}	Ψ_{Q^8}
Qubit-spinor	tetraqubit-	pentaqubit-	hexaqubit-	heptaqubit-	octoqubit-
Hilbert space \mathcal{D}_H	$16 = 2^4$	$32 = 2^5$	$64 = 2^6$	$128 = 2^7$	$256 = 2^8$
Q_c -spin charge \mathcal{C}_{Q_c}	$Q_N - 4 = 0$	$Q_N - 4 = 1$	$Q_N - 4 = 2$	$Q_N - 4 = 3$	$Q_N - 4 \times 2 = 0$
Q_c -spin sym.	SP(0)	SP(1) \cong O(1)	SP(2) \cong U(1)	SP(3) \cong SU(2)	SP(0)

- ❖ **Classifications of qubit number and spacetime dimension with four categories of Q_c -spin charge**
- ❖ **The genesis of spacetime dimension from categoric qubit number**

$$\mathcal{C}_{Q_c} = q_c = 0, 1, 2, 3 = Q_N \pmod{4}$$

$$\mathcal{C}_{Q_c} \equiv \mathcal{C}_{Q_c}^{(q_c, k)} = \mathcal{C}_{Q_c}^{(q_c)} = q_c,$$

$$q_c = 0, 1, 2, 3, \quad k = 0, 1, 2, \dots$$

$$D_h^{(q_c, k)} \equiv D_{q_c} + 8k, \quad k = 0, 1, 2, \dots$$

$$D_{q_c} = 2, 3, 4, 6, \quad q_c = 0, 1, 2, 3,$$

$$D_{q_c} = 2 + 2^{q_c - 1} \theta(q_c - 1)$$

The foundation of the hyperunified field theory II - fundamental interaction and evolving universe

Yue-Liang Wu*

¹*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China*

²*International Centre for Theoretical Physics Asia-Pacific (ICTP-AP)
(Beijing/Hangzhou), UCAS, Beijing 100190, China*

³*Taiji Laboratory for Gravitational Wave Universe (Beijing/Hangzhou),
University of Chinese Academy of Sciences, Beijing 100049, China*

⁴*School of Fundamental Physics and Mathematical Sciences,
Hangzhou Institute for Advanced Study, UCAS, Hangzhou 310024, China*

Abstract

In the part I of the foundation of the hyperunified field theory, we have shown the presence of entangled hyperqubit-spinor field as fundamental building block with appearance of Minkowski hyper-spacetime as free-motion spacetime and emergence of inhomogeneous hyperspin symmetry

超统一场论的基础 II ——自然界基本相互作用和演化宇宙

吴岳良

arXiv:2104.11078(117 pages)

I. Introduction	4
II. Inhomogeneous hyperspin and \mathcal{Q}_c -spin gauge symmetries and gravitational relativistic quantum theory with scaling gauge symmetry based on gauge invariance principle	8
A. Inhomogeneous hyperspin and \mathcal{Q}_c -spin gauge symmetries with introduction of bicovariant vector field and gauge field by making gauge invariance principle	8
B. Scaling gauge symmetry based on gauge invariance principle and the gauge covariant equation of motion of entangled hyperqubit-spinor field as gravitational relativistic quantum theory	12
III. Hyper-fiber bundle structure of biframe hyper-spacetime with gravitational origin of gauge symmetry and \mathcal{W}_e -spin invariant-gauge field as genesis of hyper-gravigauge field with graviscalar and gravivector fields	16
A. Locally flat gravigauge hyper-spacetime with emergence of non-commutative geometry and biframe hyper-spacetime with hyper-fiber bundle structure	16
B. Gravitational origin of gauge symmetry and the hyperspin gravigauge and covariant-gauge fields with gauge covariant field strengths	18
C. \mathcal{W}_e -spin invariant-gauge field as genesis of hyper-gravigauge field in the presence of graviscalar field	20
D. Biframe displacement correspondence in biframe hyper-spacetime and the hyper-gravicoordinate displacement and derivative with respect to hyper-gravivector field in locally flat gravigauge hyper-spacetime	21
IV. Hyperunified field theory for fundamental building block and fundamental interaction based on gauge invariance principle and scaling invariance hypothesis	23
A. Hyperunified qubit-spinor structure of entangled decaqubit-spinor field as fundamental building block and the inhomogeneous hyperspin symmetry $WS(1,18)$ as hyperunified symmetry in gravigauge hyper-spacetime	23
B. Scaling properties of biframe hyper-spacetime and fundamental fields with scaling gauge invariant hyperspin gravigauge field and field strength	26
C. Hyperunified field theory for fundamental building block and fundamental interaction based on gauge invariance principle and scaling invariance hypothesis	28
V. Hyperunified field theory in hidden scaling gauge formalism with gauge-gravity correspondence and the dynamics of fundamental fields with conserved currents	30
A. Hyperunified field theory in hidden scaling gauge formalism with gauge-gravity correspondence and the kinetic motion of fundamental fields as the source of gravitational interaction	30
B. Equations of motion and dynamics of fundamental fields	33
C. Conserved currents in correspondence to gauge symmetries in hyperunified field theory	35
VI. Conservation law and dynamic evolution equation from global symmetry	

of Minkowski hyper-spacetime in hyperunified field theory	37
A. Conservation law of hyper-stress energy-momentum tensor from translation group symmetry of Minkowski hyper-spacetime in hyperunified field theory	37
B. Dynamic evolution equations of hyper-rotation angular momentum tensor from Lorentz-type group symmetry and hyper-conformal scaling momentum tensor from conformal scaling symmetry in hyperunified field theory	38
C. Dynamic evolution equation for the total bicovariant hyper-angular momentum tensor in hyperunified field theory	40
VII. Hyperunified field theory in hidden gauge formalism with gravity-geometry correspondence and Einstein-Hilbert type action with appearance of Riemann geometry and emergent group symmetry $GL(D_h, \mathbf{R})$ as generalization of gauge invariance principle under flowing unitary gauge	42
A. Hyper-gravigauge field as Goldstone-like boson and the hyper-spacetime gauge field with gauge covariant field strength in hidden gauge formalism	42
B. Hyperunified field theory in hidden gauge formalism and Einstein-Hilbert type action on gravitational interaction of hyper-spacetime gravimetric-gauge field	44
C. Hyperunified field theory in hidden gauge formalism with emergent general linear group symmetry $GL(D_h, \mathbf{R})$ as generalization of gauge invariance principle and the appearance of Riemann geometry in curved hyper-spacetime	45
D. Flowing unitary gauge with symmetric Goldstone-like hyper-gravigauge field and the gravity-geometry correspondence in hyper-spacetime	49
VIII. Hyperunified field theory in hidden coordinate formalism with geometry-gauge correspondence and dynamics of fundamental fields with hyper-gravigauge field as auxiliary field and emergent structure factor of non-commutative geometry in locally flat gravigauge hyper-spacetime	52
A. Hyperspin gauge field and field strength in hidden coordinate formalism with zero global and local scaling charges	53
B. Hyperunified field theory in hidden coordinate formalism with geometry-gauge correspondence and the hyperspin gravigauge field as auxiliary field in locally flat gravigauge hyper-spacetime	55
C. Emergence of non-commutative geometry with non-Abelian Lie algebra structure and constraint equation of the hyper-gravigauge field as auxiliary field in locally flat gravigauge hyper-spacetime	56
D. Dynamics of fundamental fields in hyperunified field theory with emergent gravitational interaction in locally flat gravigauge hyper-spacetime	58
IX. Hyperunified field theory in framework of GQFT with fundamental symmetry under entirety unitary gauge and the dynamics of electromagnetic-like gravitational field with gauge-type and Einstein-type gravitational equations and first order gravitational differential equation based the gauge-geometry duality	61
A. Hyperunified field theory within framework of GQFT and gauge-geometry duality with respect to hyper-gravigauge field and hyper-gravimetric gauge field	62
B. Hyperunified field theory with maximal joint symmetry and the entirety unitary gauge in gravitational quantum field theory with fundamental symmetry of	

nature	65
C. Gauge-type and geometric Einstein-type gravitational equations and beyond for the dynamics of gravitational field	68
D. The first order gravitational differential equation of hyper-gravigauge field from the constraint equation of hyperspin gravigauge field as auxiliary field in locally flat gravigauge hyper-spacetime	70
E. Dynamic equation of hyper-gravimetric gauge field as geometric gauge-type gravitational equation and the electric-like and magnetic-like gravitational interactions based on gauge-geometry duality	71
X. Conformally flat gravigauge hyper-spacetime with evolving graviscalar field as nonsingularity background for evolution of early universe and scaling gauge field and Q_c-spin scaling field as basic constituents of dark universe and quantum cosmic matter in hyperunified field theory	75
A. Hyperunified field theory under entirety unitary gauge with scaling gauge fixing and conformally flat gravigauge hyper-spacetime under background basis with fundamental mass scale	75
B. Geometry of gravigauge hyper-spacetime and the dynamics of graviscalar and Q_c -spin scalar fields with conformally flat gravigauge hyper-spacetime as background spacetime	79
C. Evolution of early universe with evolving graviscalar and Q_c -spin scalar field in conformally flat gravigauge hyper-spacetime as nonsingularity background spacetime	84
D. Evolution of early universe with inflationary expansion governed by the potential energy of Q_c -spin scalar field	88
E. Evolving universe with scaling gauge field as dark matter candidate and Q_c -spin scalar field as quantum cosmic matter and dark energy candidate	91
XI. Symmetry structure and symmetry breaking mechanism in hyperunified field theory and comprehensions on presence of Higgs boson and three families of leptons and quarks	97
A. Hyperunified field theory with inhomogeneous hyperspin gauge symmetry $WS(1,18)$ as hyperunified symmetry in gravigauge hyper-spacetime	97
B. Hyperspin gauge fields beyond four-dimensional gravigauge spacetime as the Higgs-like scalar fields and presence of Higgs-like bosons in hyperunified field theory	99
C. Appearance of three families of chiral type leptons and quarks and property of fourth family of lepton-quark state with the chirality-correlation discrete symmetry of bulk space	106
XII. Conclusions and discussions	111
References	116

I. INTRODUCTION

In the previous paper as the part I of the foundation of the hyperunified field theory[1], starting from the motional property of functional field by proposing the maximum coherence motion principle and maximum entangled qubit-spinor principle as two guiding principles,

we have provided a detailed analysis and systematic investigation on the existence of entangled hyperqubit-spinor field and Q_c -spin scalar field as fundamental building blocks of

In this paper as the part II of the foundation of the hyperunified field theory, we have studied the basic properties of entangled hyperqubit-spinor field and Q_c -spin scalar field as fundamental building blocks and also the essential features of inhomogeneous hyperspin symmetry and scaling symmetry as fundamental symmetries. More fundamental questions which have been answered are as follows:

arrive at an associated symmetry in which inhomogeneous hyperspin symmetry group and global scaling symmetry group in Hilbert space as internal space of basic fields are in as-

- ❖ what is acted as the fundamental interaction of nature?
- ❖ how does the fundamental symmetry govern basic forces?
- ❖ what is the nature of gravity?
- ❖ what is the basic structure of spacetime?
- ❖ how does early universe get inflationary expansion?
- ❖ what is a dark matter candidate?
- ❖ what is the nature of dark energy?
- ❖ what is the nature of Higgs boson?
- ❖ how can we understand three families of chiral type leptons and quarks discovered by current experiments?

gauge invariance principle as guiding principle, which brings global symmetry in Hilbert space into local symmetry with the introduction of gauge field [7, 8] as basic field for charac-

In the part II, we demonstrate by following along gauge invariance principle and scaling invariance hypothesis that the inhomogeneous hyperspin gauge symmetry and scaling gauge symmetry govern fundamental interactions and reveal the nature of gravity and spacetime.

With the fiber bundle structure of biframe hyper-spacetime and emergence of non-commutative geometry, we explore methodically the gauge-geometry duality and genesis of gravitational interaction in locally flat gravigauge hyper-spacetime.

A whole hyperunified field theory in 19-dimensional hyper-spacetime is established to unify not only all discovered leptons and quarks into hyperunified qubit-spinor field but also all known basic forces into hyperunified interaction governed by inhomogeneous hyperspin gauge symmetry.

Present a systematic investigate on the hyperunified field theory with:

Deriving the dynamics of fundamental fields as basic laws of nature and conservation laws relative to basic symmetries,

Showing the existence of Higgs-like bosons and three families of lepton-quark states.

Provide a detailed analysis about:

The evolving graviscalar field characterizes inflationary early universe,

The scaling gauge field as dark matter candidate;

Q_c -spin scalar field as source of dark energy.

$$\begin{aligned}
S_{\text{HU}} \equiv & \int [d^{D_h}x] \chi(x) \{ \bar{\Psi}_{\text{QH}} \Sigma_-^A \hat{\chi}_A^M \hat{D}_M \Psi_{\text{QH}} - \phi_1 \bar{\Psi}_{\text{QH}} \Sigma_- \Psi_{\text{QH}} \\
& + \phi^{D_h-4} [-\hat{\chi}_C^M \hat{\chi}_D^N \hat{\chi}_{C'}^{M'} \hat{\chi}_{D'}^{N'} (\hat{\eta}_{ABA'B'}^{CDC'D'} g_H^{-2} \frac{1}{4} \mathcal{F}_{MN}^{\text{AB}} \mathcal{F}_{M'N'}^{\text{A'B'}} \\
& + \hat{\eta}_{AA'}^{CDC'D'} g_H^{-2} \frac{1}{4} F_{MN}^{\text{A}} F_{M'N'}^{\text{A'}} - \hat{\eta}^{CDC'D'} g_W^{-2} \frac{1}{4} F_{MN} F_{M'N'}) \\
& + \frac{1}{2} \hat{\chi}_C^M \hat{\chi}_D^N \eta^{\text{CD}} g_H^{-2} \beta_G^2 \phi_1^2 (\mathcal{A}_M^{\text{AB}} - \Omega_M^{\text{AB}}) (\mathcal{A}_{\text{NAB}} - \Omega_{\text{NAB}}) \\
& - \lambda_D^2 \phi_1^4 F (\frac{\phi_1}{\phi})] \}
\end{aligned}$$

The gauge-gravity correspondence

$$G_S = \text{SC}(1) \times \text{PO}(1, D_h-1) \times \text{WS}(1, D_h-1) \times \text{SG}(1)$$

$$\begin{aligned}
S_{\text{HU}} \equiv & \dots \\
= & \dots \\
= & \dots \\
= & \dots
\end{aligned}$$

- ❖ The scaling gauge field becomes naturally as Dark Matter candidate
- ❖ The Q_c -spin scaling field is the sources for both inflation of early universe & dark energy of current universe

✓ Gauge invariance
✓ Scaling invariance

✓ Gauge invariance
✓ Hidden Scaling gauge invariance

1. Y. Tang and Y. L. Wu, Phys. Lett. B803, 135320 (2020), arXiv:1904.04493 [hep-ph].
2. Y. Tang and Y. L. Wu, JCAP 2003, 067 (2020), arXiv:1912.07610 [hep-ph].
3. Y. Tang and Y. L. Wu, Phys. Lett. B 809, 135716(2020), arXiv:2006.02811 [hep-ph].

$S_{\text{HU}} \equiv$ Gravity-geometry correspondence

Hidden Gauge Formalism

Emergent hidden symmetry

GL(1,D-1,R)

In coordinate hyper-spacetime

$$\begin{aligned}
 & \cdot \{ \bar{\Psi}_{Q_H} \hat{\Sigma}_-^M i \mathcal{D}_M \Psi_{Q_H} - \beta_Q \sinh \chi_s \bar{\Psi}_{Q_H} \hat{\Sigma}_- \Psi_{Q_H} \\
 & + \hat{H}^{MM'} \hat{H}^{NN'} \frac{1}{4} g_H^{-2} \mathcal{F}_{MNQ}^P \mathcal{F}_{M'N'P}^Q + g_H^{-2} \mathcal{R} \\
 & - \frac{1}{2} g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \hat{H}^{MM'} (\mathcal{A}_{MQ}^P - \Gamma_{MQ}^P) (\mathcal{A}_{M'P}^Q - \Gamma_{M'P}^Q) \\
 & - \hat{H}^{MM'} \hat{H}^{NN'} \frac{1}{4} g_W^{-2} F_{MN} F_{M'N'} + \frac{1}{2} \lambda_S^2 (1 + \sinh^2 \chi_s) \hat{H}^{MM'} W_M W_{M'} \}
 \end{aligned}$$

$$\frac{1}{4} \mathfrak{A} \hat{H}_{AA'}^{MM'NN'} F_{MN}^A F_{M'N'}^{A'} + 2 \partial_M (\mathfrak{A} \hat{H}^{MP} \hat{A}_A^Q F_{PQ}^A) = \mathfrak{A} \mathcal{R}$$

$$i \mathcal{D}_M \equiv i \partial_M + (\Omega_{[MPQ]} + \mathcal{A}_{[MPQ]}) \frac{1}{2} \hat{\Sigma}^{PQ}$$

$S_{\text{HU}} \equiv$ Geometry-gauge correspondence

Hidden coordinate Formalism

Emergent gravitational interaction In locally flat gravigauge hyper-spacetime

$$\begin{aligned}
 & \cdot \{ \bar{\Psi}_{Q_H} \hat{\Sigma}_-^C i \mathcal{D}_C \Psi_{Q_H} - \beta_Q \sinh \chi_s \bar{\Psi}_{Q_H} \hat{\Sigma}_- \Psi_{Q_H} \\
 & - \frac{1}{4} g_H^{-2} \mathcal{F}_{CDAB} \mathcal{F}^{CDAB} + g_H^{-2} \eta^{CD} \mathcal{R}_{CD} \\
 & + \mathfrak{A} \mathcal{R} \equiv \mathfrak{A} \hat{H}^{MQ} \mathcal{R}_{MQ} = \mathfrak{A} \hat{H}^{MQ} \mathcal{R}_{MNPQ} \hat{H}^{NP} \\
 & \quad \equiv \mathfrak{A} \eta^{CB} \mathcal{R}_{CB} = \mathfrak{A} \eta^{CB} \mathcal{R}_{CDAB} \eta^{DA}, \\
 & - \mathfrak{A} \Omega_{CAB} \Omega^{ABC} - \mathfrak{A} \Omega_{CA}^C \Omega_D^{DA} + 2 \partial_M (\mathfrak{A} \hat{A}_A^M \Omega_C^{CA}) \\
 & + \frac{1}{2} \lambda_S^2 \hat{\partial}_C \chi_s \hat{\partial}^C \chi_s - \lambda_D^2 \mathcal{F}(\chi_s) \}
 \end{aligned}$$

$$\begin{aligned}
 i \mathcal{D}_C & \equiv i \hat{\partial}_C + \mathcal{A}_{CAB} \frac{1}{2} \Sigma^{AB} \equiv \hat{A}_C^M i \mathcal{D}_M, \\
 [\delta^{Dh} \mathcal{X}] & \equiv [d^{Dh} x] \mathfrak{A}(x), \quad \delta \mathcal{X}^A(x) = \mathbf{A}_M^A dx^M
 \end{aligned}$$

$$\begin{aligned}
\mathcal{S}_{\text{HU}} \equiv & \int [d^{D_h} x] \mathfrak{A}(x) \{ \hat{H}^{\text{MN}} \bar{\Psi}_{\text{QH}} A_{\text{MC}} \Sigma_-^{\text{C}} i \mathcal{D}_{\text{N}} \Psi_{\text{QH}} \\
& - \beta_{\text{Q}} \sinh \chi_s \bar{\Psi}_{\text{QH}} \hat{\Sigma}_- \Psi_{\text{QH}} - \hat{H}^{\text{MM}'} \hat{H}^{\text{NN}'} g_{\text{H}}^{-2} \frac{1}{4} \mathcal{F}_{\text{MNAB}} \mathcal{F}_{\text{M}'\text{N}'}^{\text{AB}} \\
& + \frac{1}{2} g_{\text{H}}^{-2} \beta_{\text{G}}^2 \beta_{\text{Q}}^2 \sinh^2 \chi_s \hat{H}^{\text{MM}'} (\mathcal{A}_{\text{MAB}} - \Omega_{\text{MAB}}) (\mathcal{A}_{\text{M}'\text{N}'}^{\text{AB}} - \Omega_{\text{M}'\text{N}'}^{\text{AB}}) \\
& + \frac{1}{8} \hat{H}^{\text{MM}'} \hat{H}^{\text{NN}'} \hat{H}_{\text{PP}'} g_{\text{H}}^{-2} F_{\text{MN}}^{\text{P}} F_{\text{M}'\text{N}'}^{\text{P}'} \\
& - \frac{1}{4} g_{\text{H}}^{-2} \mathfrak{A} \hat{H}^{\text{NP}} \hat{\partial}^{\text{M}} \partial_{\text{N}} (\mathfrak{A} H_{\text{MP}}) - \frac{1}{4} g_{\text{H}}^{-2} \hat{\partial}^{\text{N}} (\ln \mathfrak{A}) \partial_{\text{N}} (\ln \mathfrak{A}) \\
& + \frac{1}{4} g_{\text{H}}^{-2} \hat{H}_{\text{PQ}} \mathfrak{A}^2 \hat{\partial}^{\text{M}} (\mathfrak{A} H_{\text{M}}^{\text{P}}) \hat{\partial}^{\text{N}} (\mathfrak{A} H_{\text{N}}^{\text{Q}}) + \frac{1}{2} g_{\text{H}}^{-2} \mathfrak{A} \hat{\partial}^{\text{Q}} (\ln \mathfrak{A}) \hat{\partial}^{\text{N}} (\mathfrak{A} H_{\text{N}}^{\text{Q}}) \\
& - \hat{H}^{\text{MM}'} \hat{H}^{\text{NN}'} \frac{1}{4} g_{\text{W}}^{-2} F_{\text{MN}} F_{\text{M}'\text{N}'} + \frac{1}{2} \lambda_{\text{S}}^2 (1 + \sinh^2 \chi_s) \hat{H}^{\text{MN}} W_{\text{M}} W_{\text{N}} \\
& + \frac{1}{2} \hat{H}^{\text{MN}} \lambda_{\text{S}}^2 \partial_{\text{M}} \chi_s \partial_{\text{N}} \chi_s - \lambda_{\text{D}}^2 \mathcal{F}(\chi_s) \},
\end{aligned}$$

Gauge-geometric Duality in Framework of Gravitational Quantum Field Theory

$$F_{\text{MN}}^{\text{P}} = \partial_{\text{M}} H_{\text{N}}^{\text{P}} - \partial_{\text{N}} H_{\text{M}}^{\text{P}}$$

$$H_{\text{MN}} = (\bar{\mathbf{A}})_{\text{MN}}^2$$

$$\begin{aligned}
& \frac{1}{4} \mathfrak{A} \hat{H}_{\text{AA}'}^{\text{MNM}'\text{N}'} F_{\text{MN}}^{\text{A}} F_{\text{M}'\text{N}'}^{\text{A}'} \equiv \mathfrak{A} \frac{1}{8} \hat{H}^{\text{MM}'} \hat{H}^{\text{NN}'} \hat{H}_{\text{PP}'} F_{\text{MN}}^{\text{P}} F_{\text{M}'\text{N}'}^{\text{P}'} \\
& - \mathfrak{A} \frac{1}{4} \hat{H}^{\text{MN}} \partial_{\text{M}} (\ln \mathfrak{A}) \partial_{\text{N}} (\ln \mathfrak{A}) + \mathfrak{A} \frac{1}{4} \hat{H}_{\text{PQ}} \mathfrak{A}^2 \hat{\partial}^{\text{M}} (\mathfrak{A} H_{\text{M}}^{\text{P}}) \hat{\partial}^{\text{N}} (\mathfrak{A} H_{\text{N}}^{\text{Q}}) \\
& + \frac{1}{2} \mathfrak{A}^2 \hat{H}_{\text{Q}}^{\text{M}} \partial_{\text{M}} (\ln \mathfrak{A}) \hat{\partial}^{\text{N}} (\mathfrak{A} H_{\text{N}}^{\text{Q}}) - \frac{1}{4} \mathfrak{A}^2 \hat{H}^{\text{NP}} \hat{\partial}^{\text{M}} \partial_{\text{N}} (\mathfrak{A} H_{\text{MP}}) \\
& - \frac{1}{4} \partial_{\text{M}} \left(\mathfrak{A} H_{\text{PQ}} \partial_{\text{N}} (\mathfrak{A} \hat{H}^{\text{MP}} \mathfrak{A} \hat{H}^{\text{NQ}}) - \partial_{\text{N}} (\mathfrak{A} H_{\text{PQ}}) \mathfrak{A} \hat{H}^{\text{MP}} \mathfrak{A} \hat{H}^{\text{NQ}} \right) \\
& + \partial_{\text{M}} \left(\mathfrak{A} \hat{H}^{\text{MN}} \partial_{\text{N}} \ln \mathfrak{A} \right) - 2 \partial_{\text{M}} \left(\mathfrak{A} \hat{\mathbf{A}}_{\text{A}}^{\text{M}} \partial_{\text{N}} \hat{\mathbf{A}}^{\text{AN}} \right) + \frac{3}{2} \partial_{\text{M}} \partial_{\text{N}} \left(\mathfrak{A} \hat{H}^{\text{MN}} \right)
\end{aligned}$$

Gauge-type gravitational equation in HUFT

$$\partial_N \hat{F}_A^{MN} = \hat{J}_A^M$$

Hyper-gravigauge field

$$\hat{F}_A^{MN} \equiv \hat{H}_{AA'}^{[MN]M'N'} F_{M'N'}^{A'} = -\hat{F}_A^{NM}$$

$$F_{M'N'}^{A'} = \partial_{M'} A_{N'}^{A'} - \partial_{M'} A_{N'}^{A'}$$

$$\hat{J}_A^M \equiv \mathfrak{Q} J_A^M - \hat{F}_A^{MN} \partial_N \ln \mathfrak{Q} \equiv G_A^M + g_H^2 T_A^M$$

$$\partial_N \hat{F}_P^{MN} = \hat{J}_P^M$$

Hyper-gravimetric gauge field

$$H_{MN} = (\bar{A})_{MN}^2$$

$$\hat{F}_P^{MN} \equiv \hat{H}^{MM'} \hat{H}^{NN'} \hat{H}_{PP'} F_{M'N'}^{P'}$$

$$F_{MN}^P = \partial_M H_N^P - \partial_N H_M^P$$

$$\hat{J}_P^M \equiv 2\hat{G}_P^M + 2g_H^2 \hat{T}_P^M$$

$$\hat{T}_P^M \equiv \hat{H}_P^Q T_{QN} \hat{H}^{NM} = \hat{A}_P^A T_A^M$$

Equivalent geometric gravitational equation of hyper-gravimetric field in HUFT

Generalized Einstein equation in Hyper-spacetime

$$R_{MN} - \frac{1}{2}H_{MN}R = -\frac{1}{2}g_H^2 T_{MN}$$

推广的爱因斯坦方程

Extra gravitational equation

$$g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \hat{\nabla}_P \hat{A}^P_{MN} = T_{[MN]}$$

Generalized Einstein tensor in Hyper-spacetime

$$\begin{aligned} T_{MN} &\equiv \hat{\nabla}_M \hat{A}^A_{NP} \hat{A}^P_{MQ} \\ &= \frac{1}{2} (\bar{\Psi}_{Q_H} \Sigma_-^C A_{MCi} \mathcal{D}_N \Psi_{Q_H} + \bar{\Psi}_{Q_H} \Sigma_-^C A_{NCi} \mathcal{D}_M \Psi_{Q_H}) \\ &\quad - g_H^{-2} \left(\mathcal{F}_{MP}^{AB} \mathcal{F}_{NQAB} - H_{MN} \frac{1}{4} \hat{H}^{M'N'} \mathcal{F}_{M'P}^{AB} \mathcal{F}_{N'Q}^{AB} \right) \hat{H}^{PQ} \\ &\quad + g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \left(\hat{A}_M^{PQ} A_{NPQ} - H_{MN} \frac{1}{2} \hat{H}^{M'N'} \hat{A}_{M'}^{PQ} A_{N'PQ} \right) \\ &\quad + \frac{1}{2} g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \left(\hat{A}^{(PQ)}_M A_{(PQ)N} - \hat{A}^{[PQ]}_M A_{[PQ]N} \right) \\ &\quad + \frac{1}{2} g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \left(\hat{A}_M^{PQ} A_{[PQ]N} + \hat{A}_N^{PQ} A_{[PQ]M} + 2 \hat{\nabla}_P \hat{A}^P_{(MN)} \right) \\ &\quad - g_W^{-2} \left(F_{MP} F_{NQ} - H_{MN} \frac{1}{4} \hat{H}^{M'N'} F_{M'P} F_{N'Q} \right) \hat{H}^{PQ} \\ &\quad + \left(W_M W_N - H_{MN} \frac{1}{2} \hat{H}^{PQ} W_P W_Q \right) \\ &\quad + \lambda_S^2 \left(\partial_M \chi_s \partial_N \chi_s - H_{MN} \frac{1}{2} \hat{H}^{PQ} \partial_P \chi_s \partial_Q \chi_s \right) \\ &\quad + \left(\beta_Q \sinh \chi_s \bar{\Psi}_{Q_H} \tilde{\Sigma}_- \Psi_{Q_H} + \lambda_D^2 \mathcal{F}(\chi_s) \right) H_{MN}, \end{aligned}$$

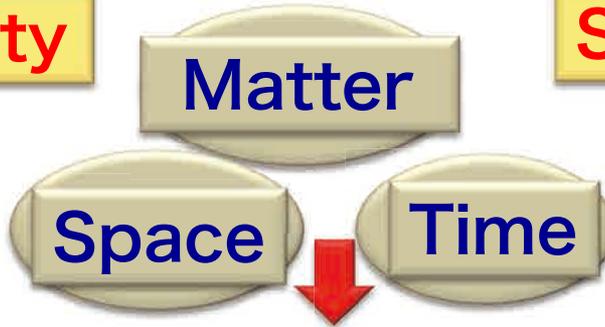
Antisymmetric tensor

$$T_{[MN]} \equiv \bar{\Psi}_{Q_H} \Sigma_-^C A_{MCi} \mathcal{D}_N \Psi_{Q_H} - \bar{\Psi}_{Q_H} \Sigma_-^C A_{NCi} \mathcal{D}_M \Psi_{Q_H}$$

Nature of Gravity

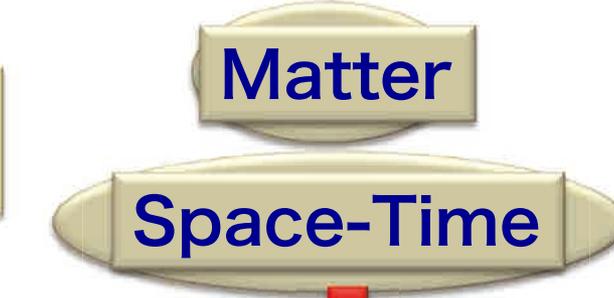
Spacetime Structure

Newton theory

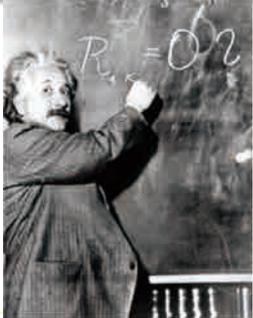


Matter, Space, Time are all independent

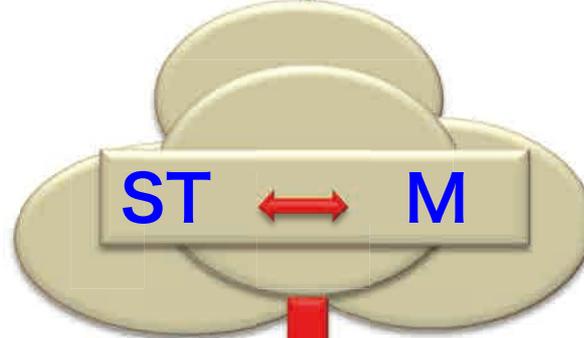
Einstein Special Relativity



Space & time related as a 4D spacetime → a globally flat Minkowski

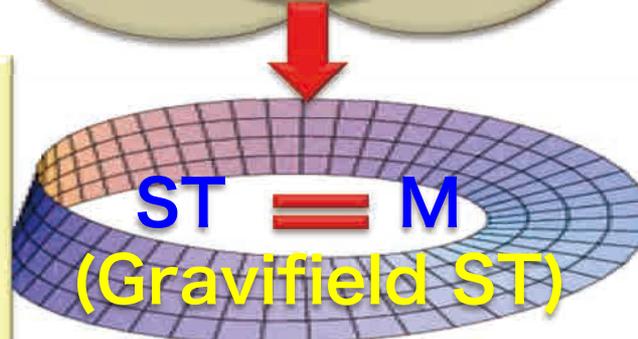


Einstein General Relativity



Matter & spacetime related → dynamics of Riemannian spacetime

Gravitational Quantum field theory (GQFT)
 Hyperunified field theory in hyper-spacetime (HST)
 (HUFT 超统一场论)



Spacetime itself is the matter → hyper-gravigauge spacetime
 → Biframe spacetime
 Fiber bundle $E \sim V^D \times G^D$



ICTP-AP
International Center
for Theoretical Physics Asia-Pacific
国际理论物理中心-亚太地区



THANKS



Taiji Program in Space

gravitational wave physics

空间太极计划

谢谢