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


General Conference
38 C

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

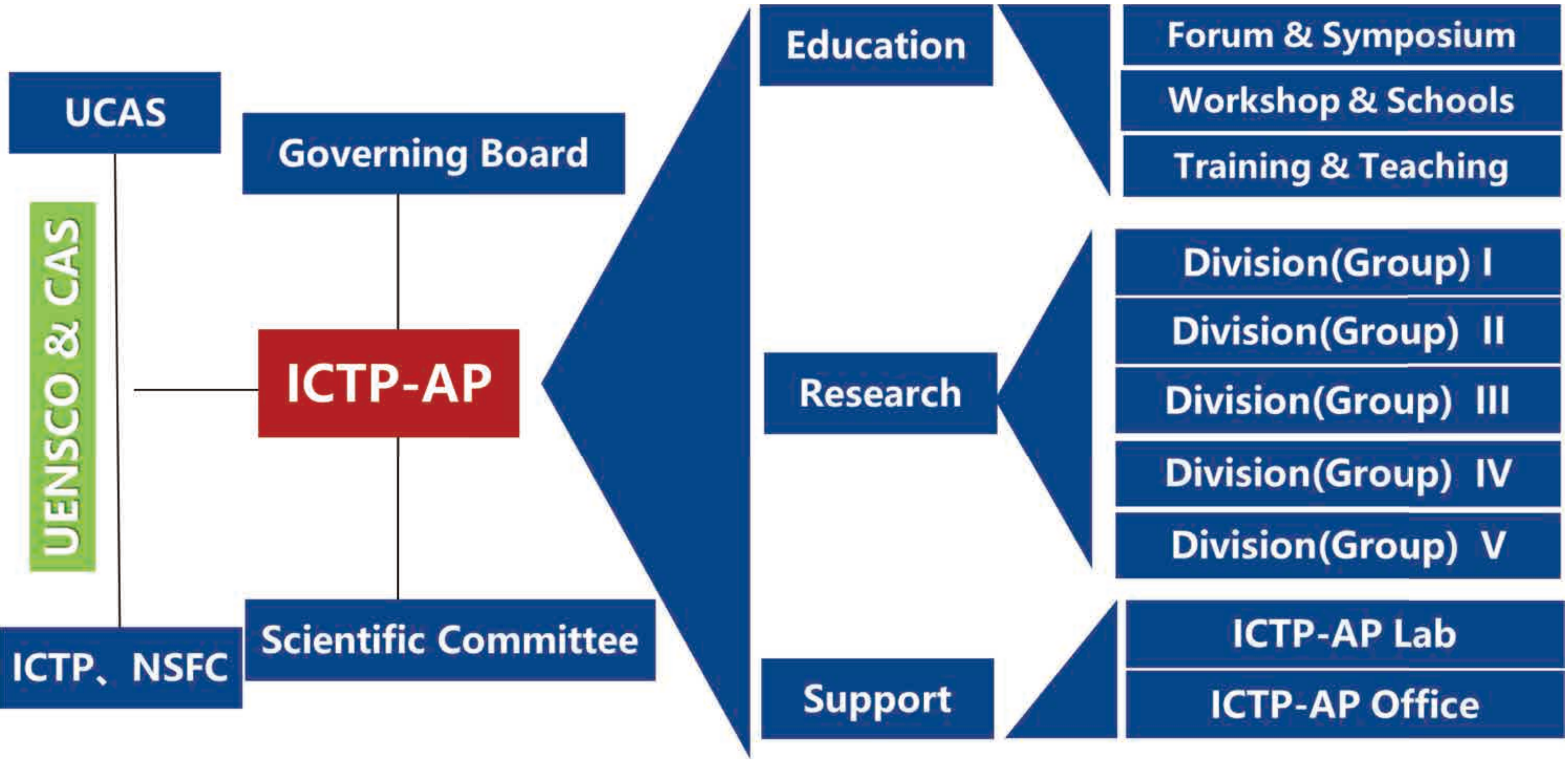
Timeline: Unveiling Ceremony

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

2016

Academic Actives in Preparatory Period

Conferring Ceremony for Honorary Doctors of UCAS

To David Gross & Edward Witten

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

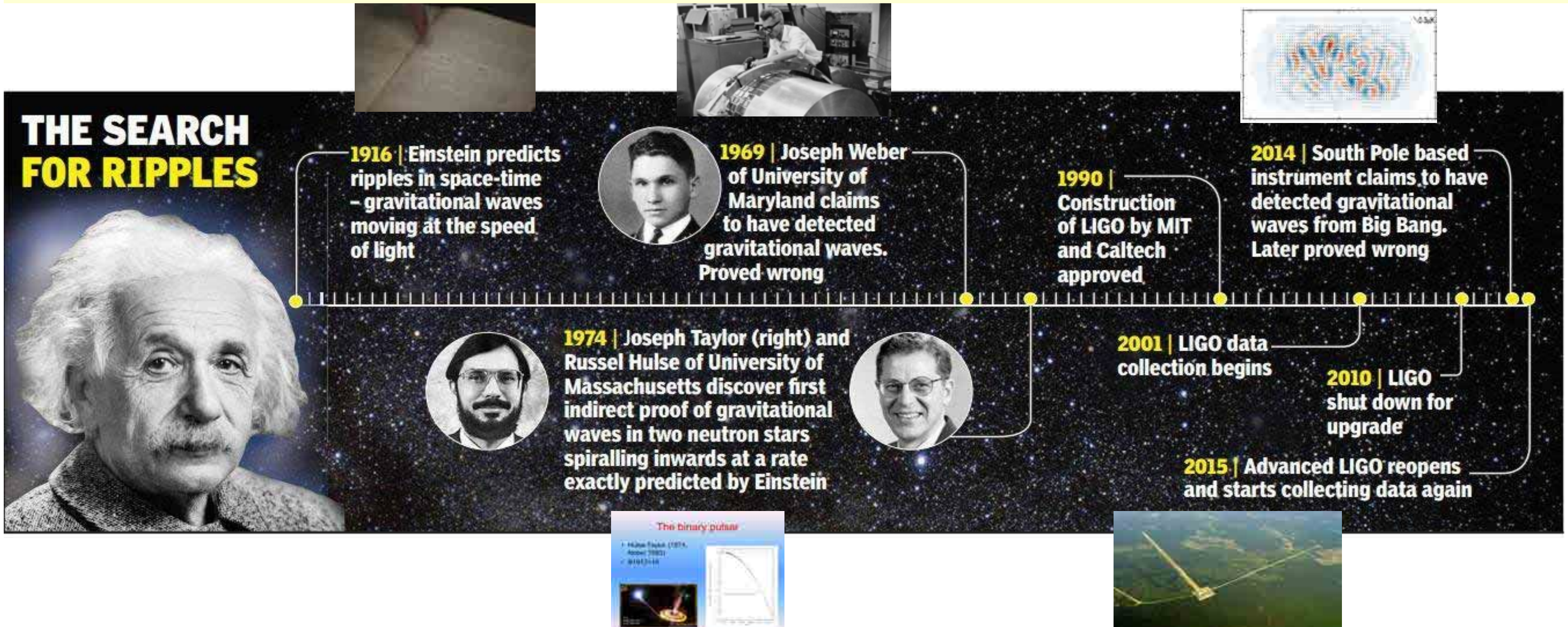
649th session of Xiangshan Science Conferences on Chinese Space Gravitational Wave Detection Mission and International Alliance for Collaboration

2019

Academic Actives

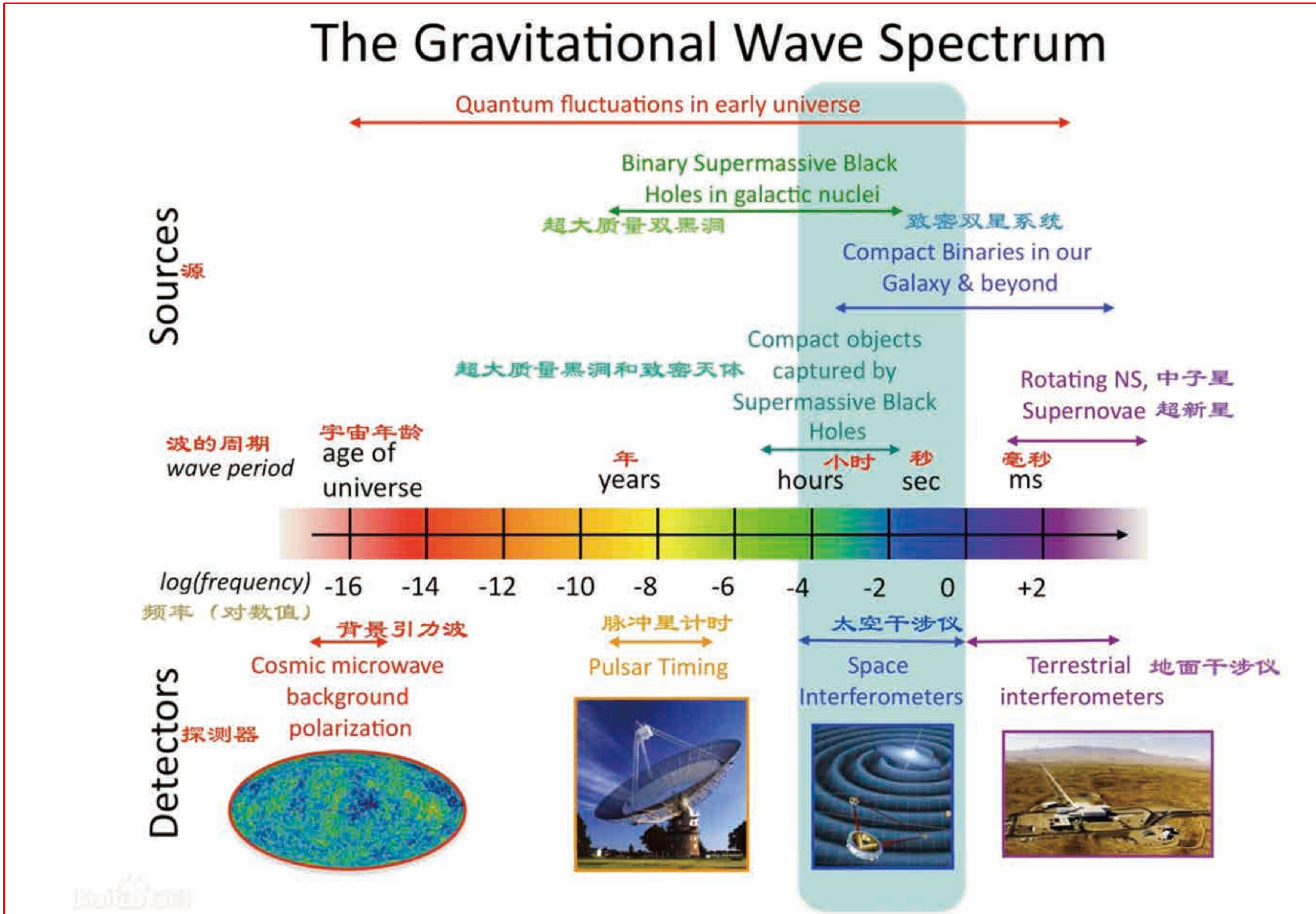
July 8-12，UCAS Gravitational Waves Summer School

The Observations of Gravitational Waves



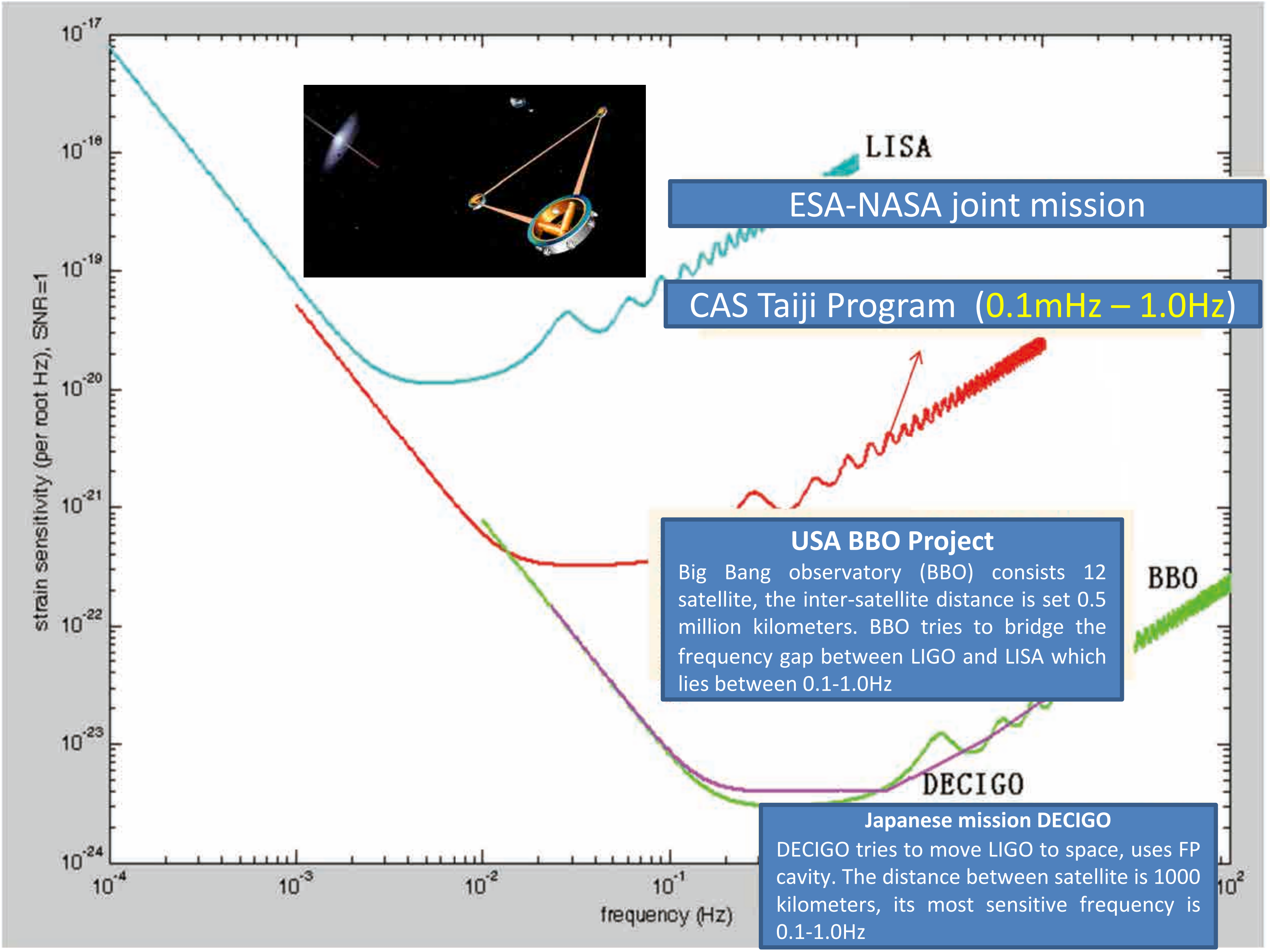
Feb. 11, 2016, LIGO announced the first direct observation of GW

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



Different frequency Different sources Different science

World-wide GW Detection in Space



ESA-NASA joint mission

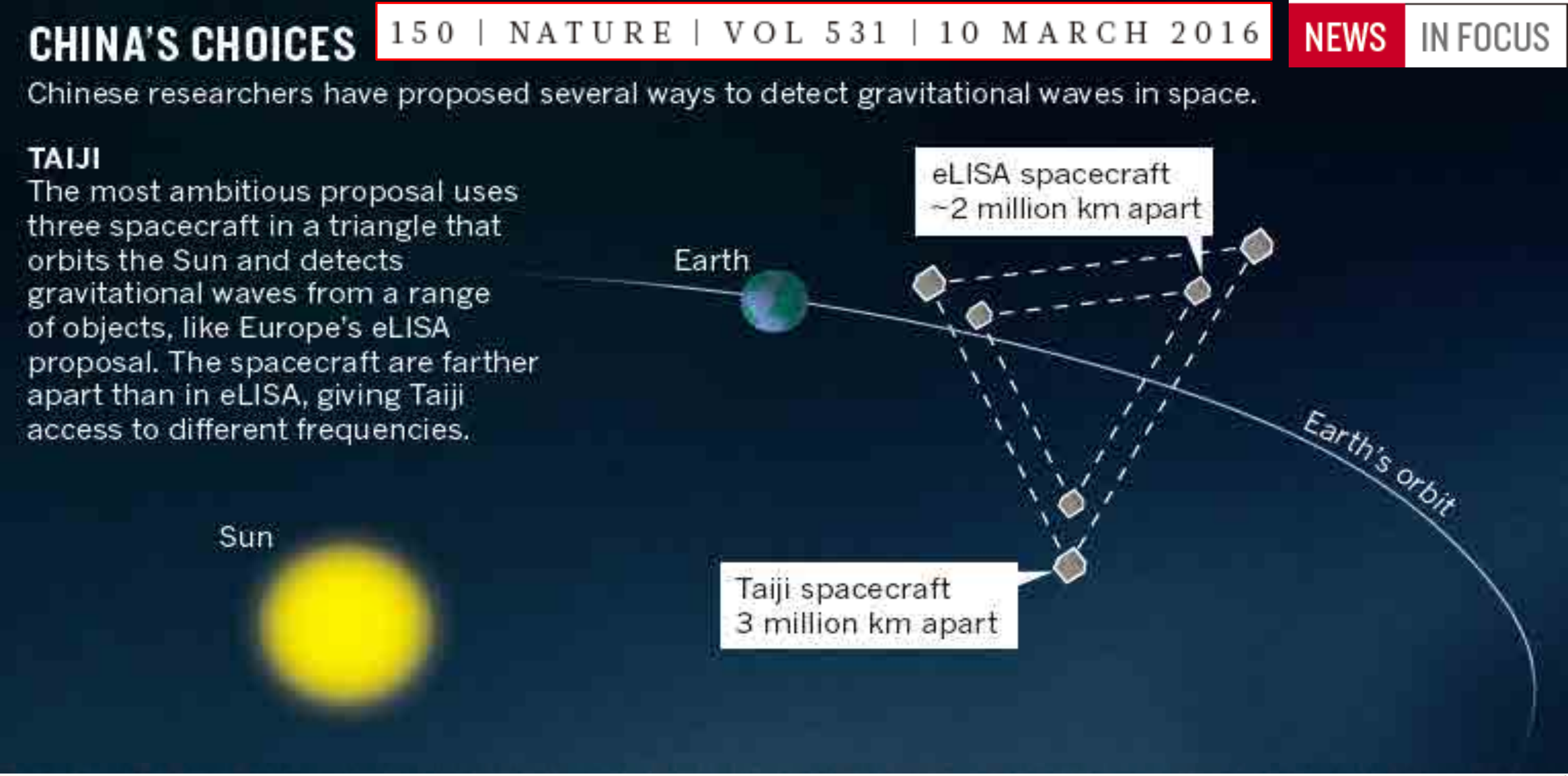
CAS Taiji Program (0.1mHz – 1.0Hz)

USA BBO Project

Big Bang observatory (BBO) consists 12 satellite, the inter-satellite distance is set 0.5 million kilometers. BBO tries to bridge the frequency gap between LIGO and LISA which lies between 0.1-1.0Hz

Japanese mission DECIGO

DECIGO tries to move LIGO to space, uses FP cavity. The distance between satellite is 1000 kilometers, its most sensitive frequency is 0.1-1.0Hz



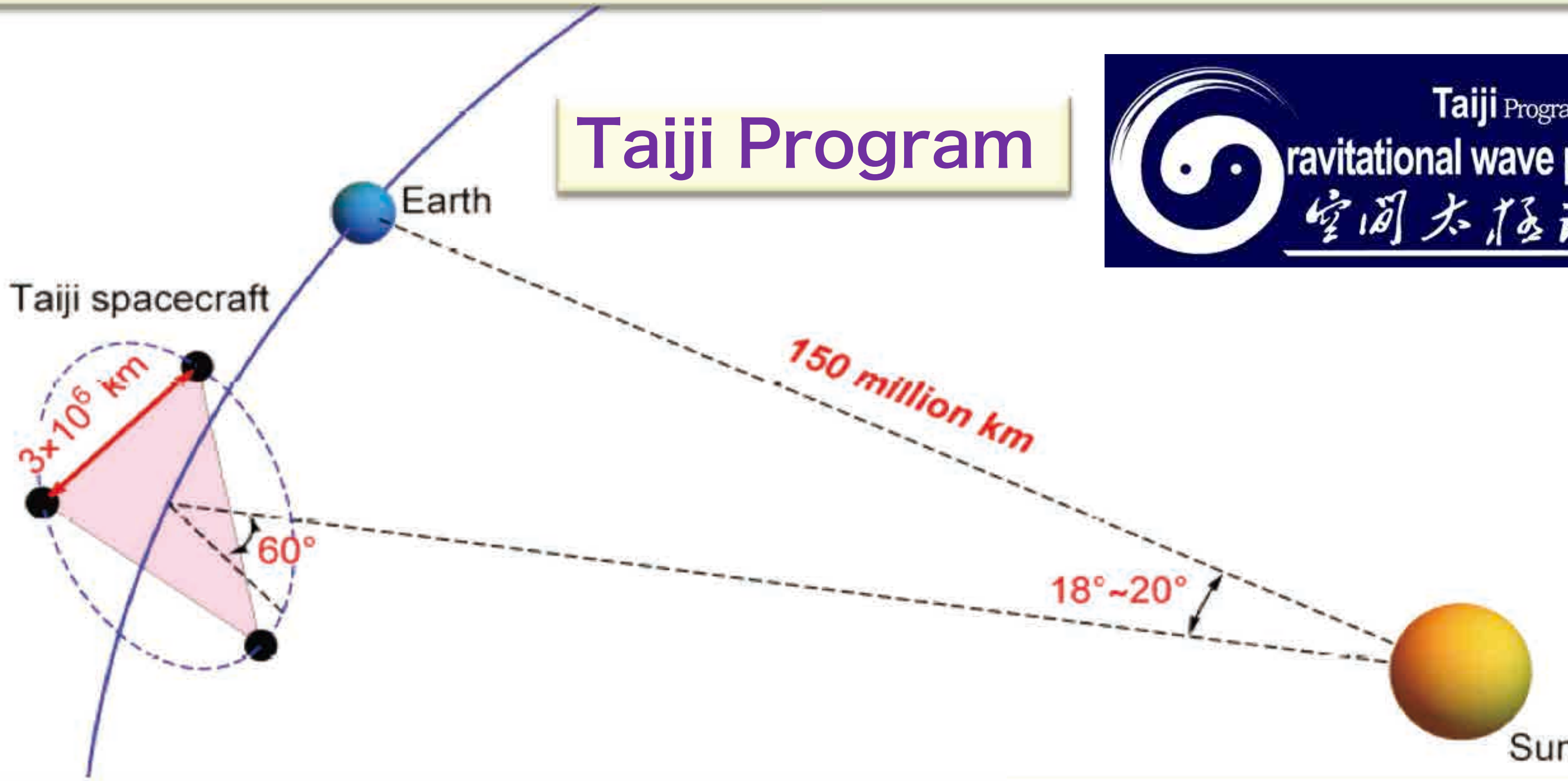
Compared with LIGO & other earth-based detectors

- ✓ 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.

Taiji Program

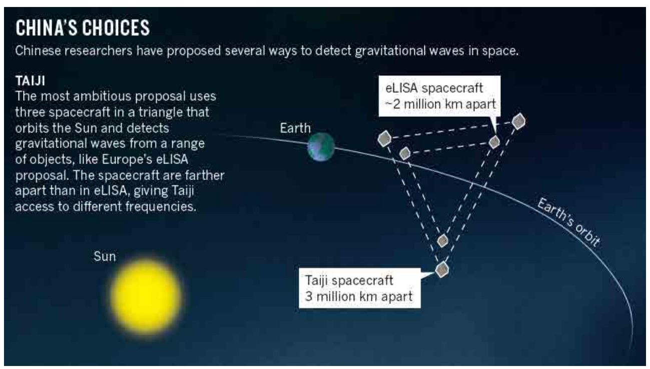
Taiji Program in Space
ravitational wave physics
空间太极计划



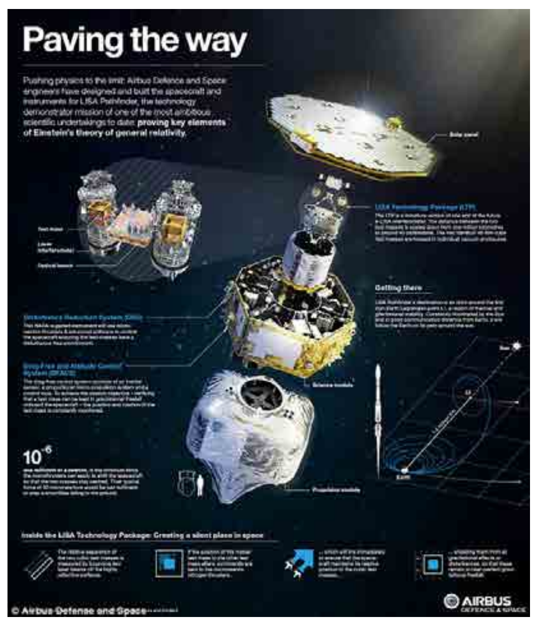
- ❖ The signals between any two of the three satellites can be used to detect gravitational wave
- ❖ It could provide a cross check for GW signals and allows us to measure the polarization of GWs.

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	$8pm/Hz^{1/2}$	$3\times10^{-15}ms^{-2}/Hz^{1/2}$	Sun 太阳	300 (2012)	0.1mHz-1Hz	2030~2033
LISA	$12pm/Hz^{1/2}$	$3\times10^{-15}ms^{-2}/Hz^{1/2}$	Sun Helio-center	500 (1995) 100 (2011) 250 (2017)	0.1mHz-1Hz	2030~2034



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

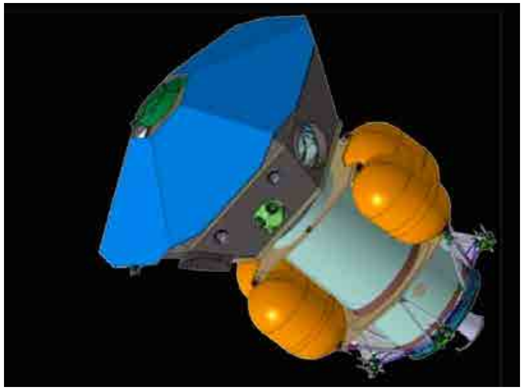
中国科学院
CHINESE ACADEMY OF SCIENCES

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

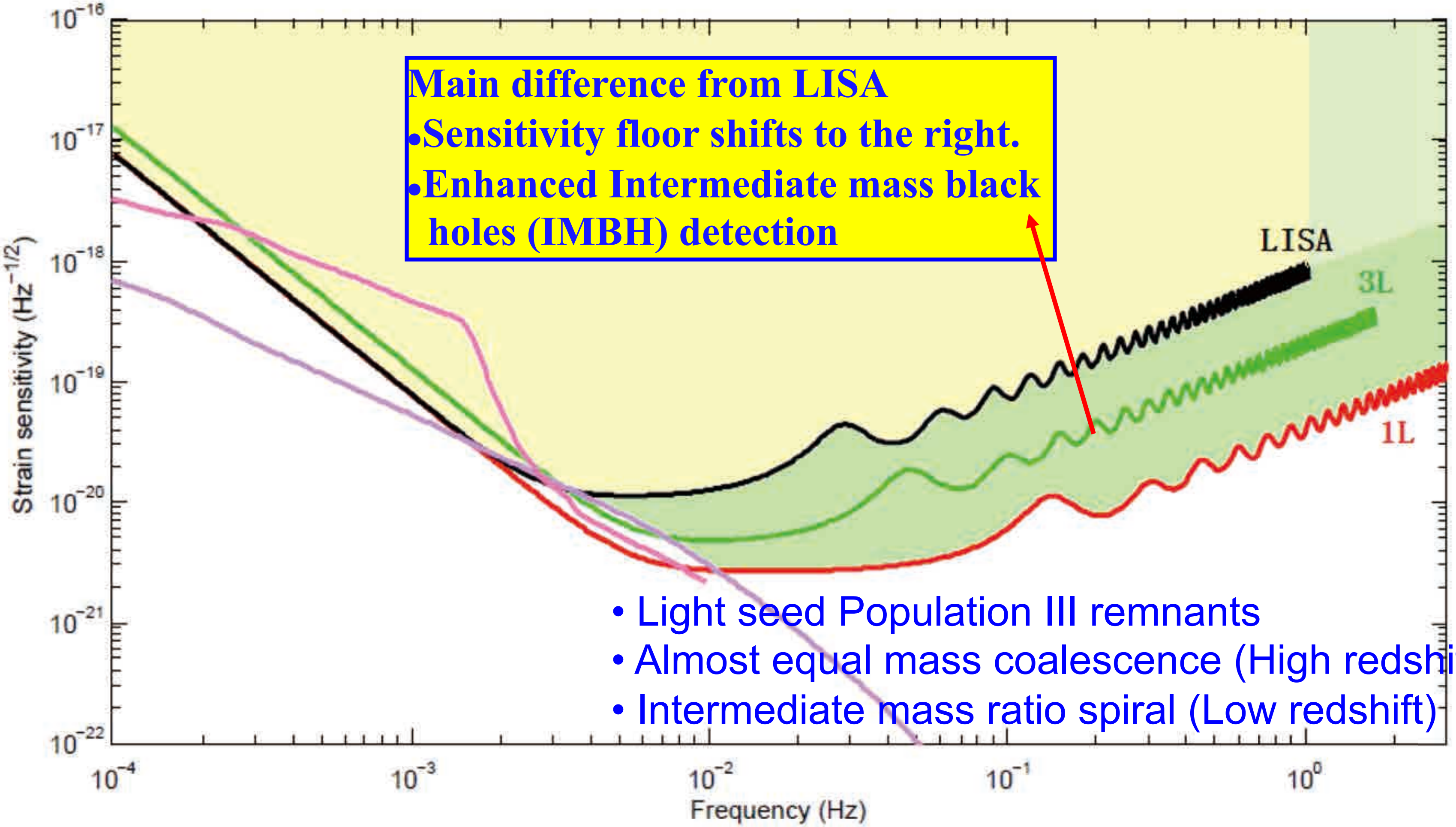


First eLISA Consortium Meeting
APC-Paris, France, Oct. 22-23, 2012

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

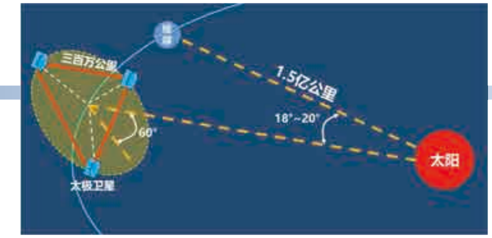
	Taiji Program preliminary mission proposal	LISA	eLISA
Arm length	$3\times10^{9}m$	$5\times10^{9}m$	$1\times10^{9}m$
1-way position noise budget	$5\sim10\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$	$18\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$	$11\ \mathrm{pm\ Hz}^{-\frac{1}{2}}$
Laser power	2W	2W	2W
Telescope diameter	~50cm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

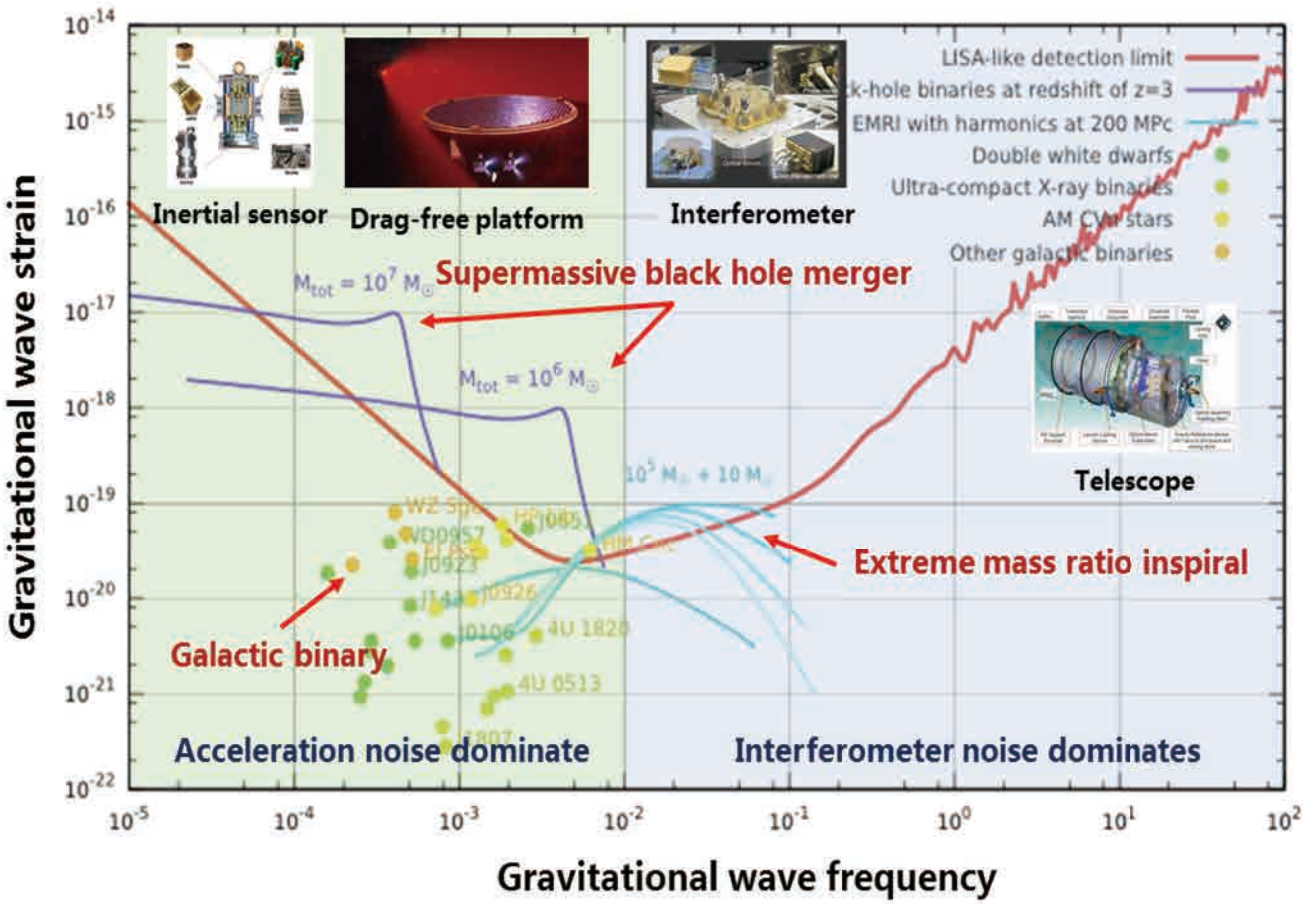
Better IMBH Detection – Extra Sciences on offer



• Light seed Population III remnants
• Almost equal mass coalescence (High redshift)
• Intermediate mass ratio spiral (Low redshift)

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

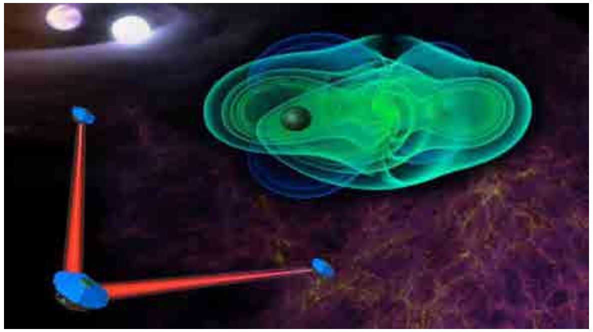
Early GWs for LIGO.
早期波源

Unknown GWs
可能的未知波源

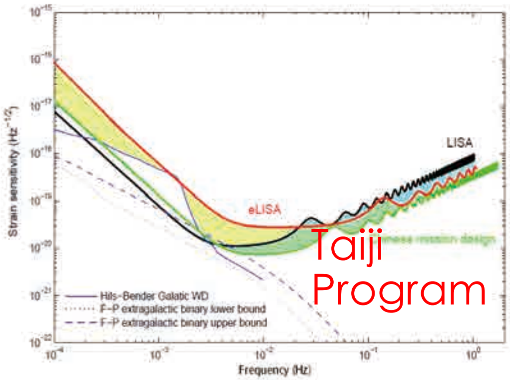
Taiji Program in Space
Gravitational wave physics
空间太极计划

Sciences Mission of Taiji Program

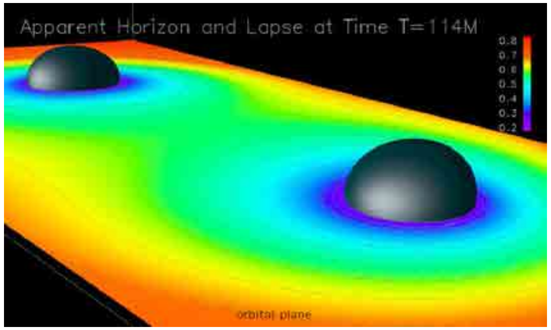
- Taiji Program is proposed to detect GWs with frequency covering over range similar to LISA (0.1mHz-1.0Hz)



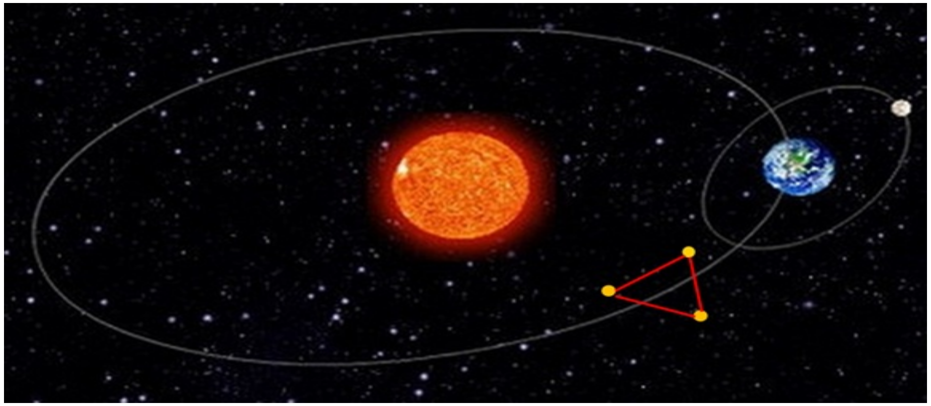
- Focus on the intermediate BH binaries (mass range10^2~10^4 M_o) with more sensitivity around (0.01-1Hz) (in comparison eLISA)

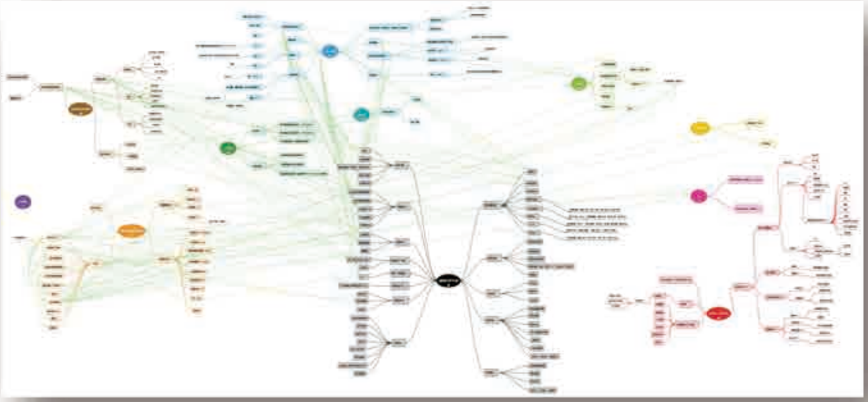


- How does the intermediate mass seed BH formed in early universe
- Whether DM could form the BH
- How the seed BH grows into the large or extreme-large BH
- Probe the polarization of GWs and understand the nature of gravity



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

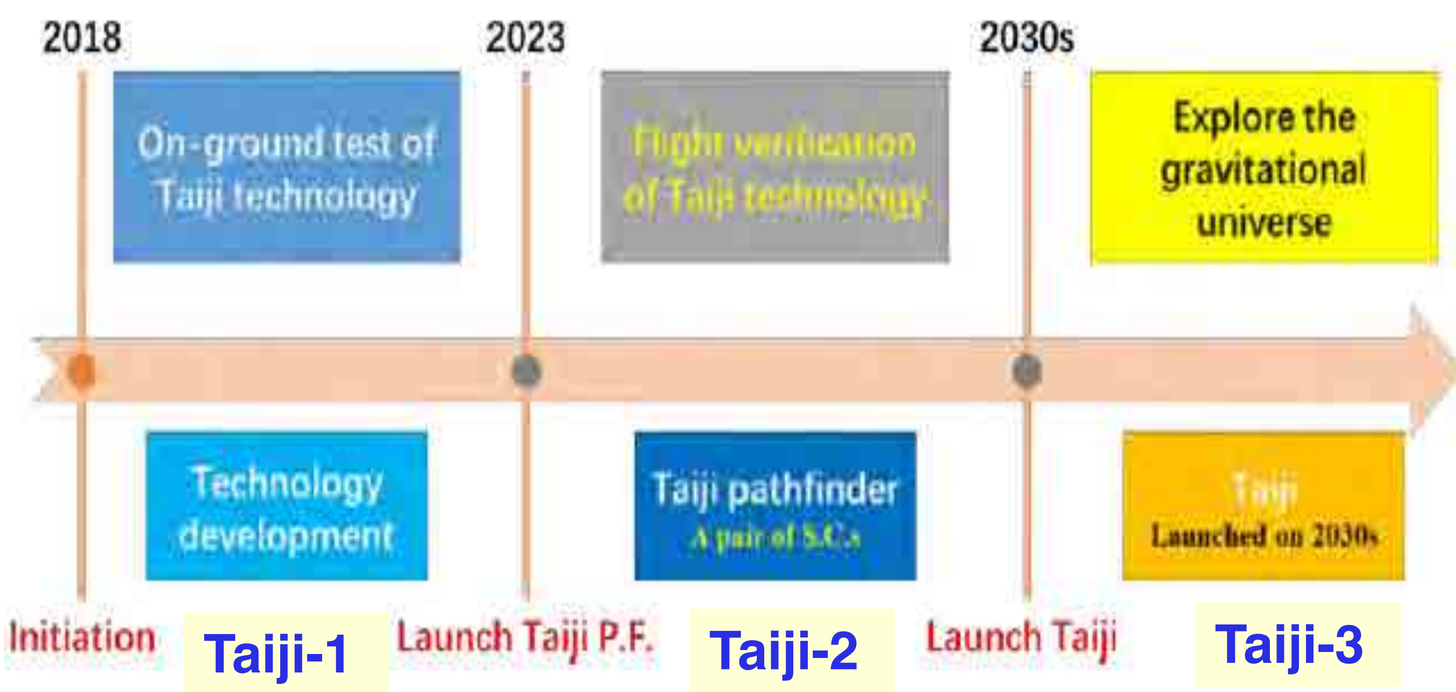
2. Ultra complex & key techniques

- ✓ 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

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 !

Bo-Quan Li[7], Dong-Jing Li[12], Fan Li[7], Hao-Si Li[2], Hua-Wang Li[8], Liu-Feng Li[10], Wei Li[12], Xiao-Kang Li[1,2],
Ying-Min Li[1], Yong-Gui Li[1], Yun-Peng Li[15], Yu-Peng Li[1,12], Zhe Li[12], Zhi-Yong Lin[1], Chang Liu[1,3],
Dong-Bin Liu[12], He-Shan Liu[2,5], Hong Liu[8], Peng Liu[11], Yu-Rong Liu[7], Zong-Yu Lu[10], Hong-Wei Luo[9], Fu-Li Ma[7],
Long-Fei M
Xiao-Dong ... ei Sha[12],
Jia Shen[1,2], ... ang Tao[12],
Wen-Ze T... Wang[7],
Shao-Xin ... , Di Wu[2],
Li-Ming Wu[1], Peng-Zhan Wu[16], Zhi-Hua Wu[8], Dong-Xue Xi[15], Yi-Fang Xie[7], Guo-Feng Xin[9], Lu-Xiang Xu[1,5,17],
Peng Xu[1,16], Shu-Yan Xu[5,17], Yu Xu[8], Sen-Wen Xue[1,2], Zhang-Bin Xue[7], Chao Yang[1,2], Ran Yang[1,2], Shi-Jia Yang[15],
Shuang Yang[7], Yong Yang[8], Zhong-Guo Yang[9], Yong-Li Yin[18], Jin-Pei Yu[8], Tao Yu[12], Ài-Bing Zhang[7],
Chu Zhang[1,2], Min Zhang[1,4,5], Xue-Quan Zhang[7], Yuan-Zhong Zhang[3], Jian Zhao[9], Wei-Wei Zhao[8], Ya Zhao[1,12],
Jian-Hua Zheng[7], Cui-Yun Zhou[9], Zhen-Cai Zhu[8], Xiao-Bo Zou[16] & Zi-Ming Zou[7]

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

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

INTERNATIONAL JOURNAL OF MODERN PHYSICS A
Vol. 36, Nos. 11 & 12 (30 April 2021)

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

Continued

ISSN: 0217-751X

MCI (P) No: 004/03/2021

International Journal of Modern Physics A
Vol. 36, Nos. 11 & 12 (30 April 2021)

International Journal of
Modern Physics A

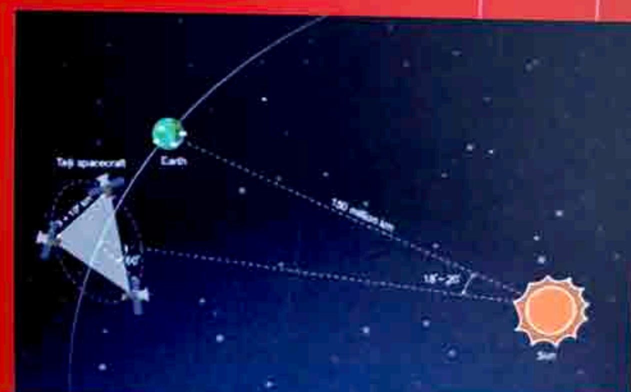
PARTICLES AND FIELDS ▪ GRAVITATION ▪ COSMOLOGY

www.worldscientific.com/ijmpa/

Volume 36 • Numbers 11 & 12 • 30 April 2021

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**



World Scientific

International Journal of Modern Physics A
Vol. 36, Nos. 11 & 12 (2021) 2102002 (2 pages)

DOI: 10.1142/S0217751X21020024

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

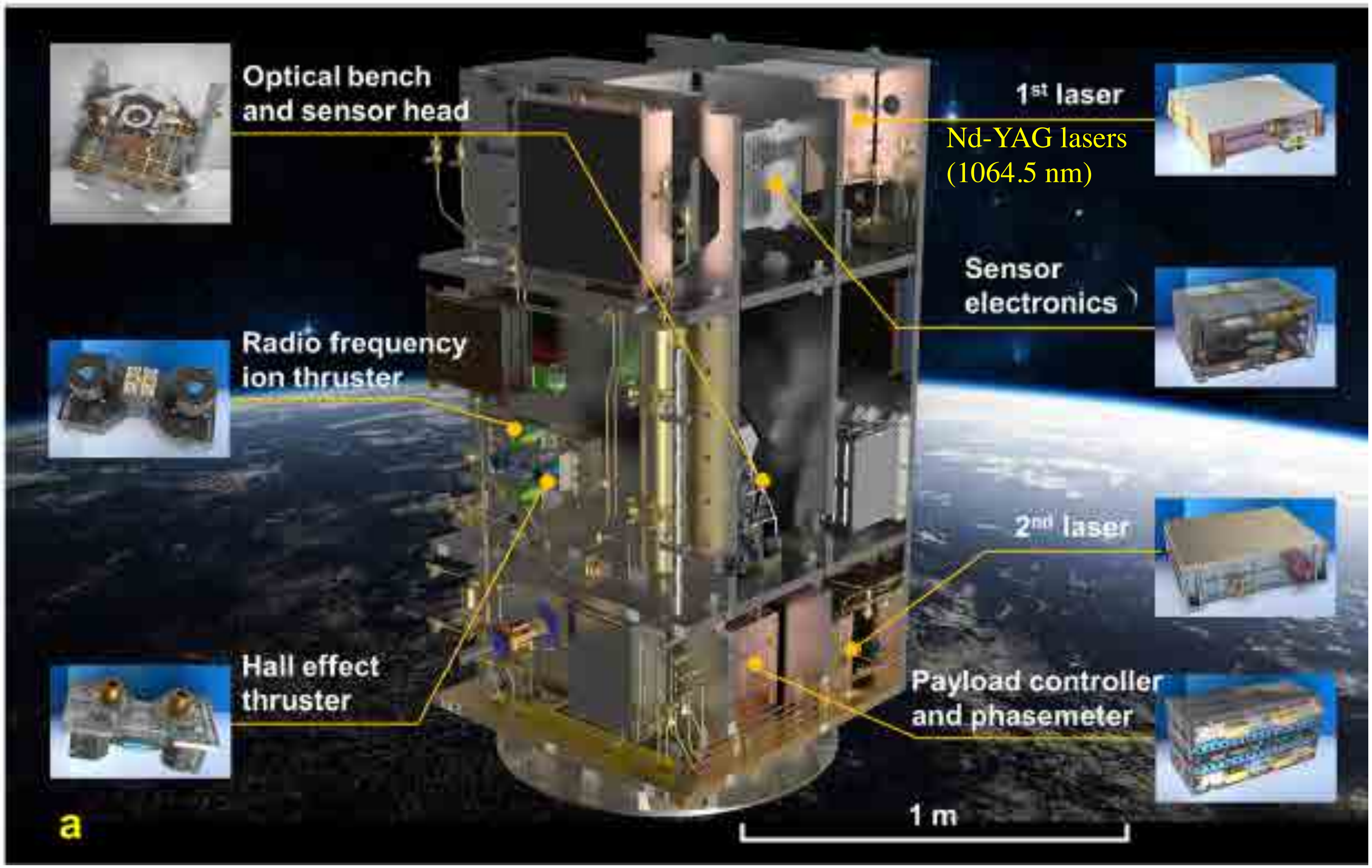
The Taiji Scientific Collaboration

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 Bai[7], Wei Bian[1,5,7], Hai-Wen Cai[8,9,25], Rong-Gen Cai[1,3,5], Zhi-Ming Cai[8,23], Jin Cao[8], Bin Chen[7], Di-Jun Chen[5,9], Guang-Feng Chen[15], Kun Chen[8], Ling Chen[7], Li-Sheng Chen[10,26,27,28], Ming-Wei Chen[1,2], Wei-Biao Chen[5,9,25], Yan Chen[21], Ze-Yi Chen[9], Yi-Xing Chi, Lin-Xiao Cong[1], Jian-Feng Deng[8], Xiao-Qin Deng[1,5,12], Xiao-Long Dong[7], Li Duan[1,2], Da Fan[19], Sen-Quan Fan[8], Shou-Shan Fan[11], Chao Fang[12], Yuan Fang[8], Ke Feng[13], Jian-Chao Feng[8], Pan Feng[9], Zhun Feng[7], Chen Gao[7], Rui-Hong Gao[1,2] Run-Lian Gao[7], Bin Guo[20], Tong Guo[8], Xiao-Liang Guo[22], Xu Guo[5,12], Zong-Kuan Guo[1,3,5], Jian-Wu He[1,2], Ji-Bo He[1], Xia Hou[9], Liang Hu[2], Wen-Rui Hu[1,2], Zhi-Qiang Hu[8], Min-Jie Huang[9], Jian-Jun Jia[1,5,6], Kai-Li Jiang[11], Gang Jin[2,5], Hong-Bo Jin[14,30], Bao-Peng Kang[8], Qi Kang[1,2], Feng-Lian Kong[15], Jun-Gang Lei[5,15], Bo-Quan Li[7], Cun-Hui Li[15], Dong-Jing Li[12], Fan Li[7], Hao-Si Li[2,31], Hua-Dong Li[12], Hua-Wang Li[8], Jiang Li[24], Liu-Feng Li[10,27,28], Wei Li[12], Xiao-Kang Li[1,2], Ying-Min Li[1], Yong-Gui Li[1], Yun-Peng Li[15], Yu-Peng Li[1,12], Zhao Li[8], Zhe Li[12], Hong Liang[8], Huang Lin[22], Zhi-Yong Lin[1,31], Chang Liu[1,3], Dong-Bin Liu[12], He-Shan Liu[1,2,5], Hong Liu[8], Peng Liu[11], Yu-Rong Liu[7], Zong-Yu Lu[10], Hong-Wei Luo[9], Jun Luo[2], Fu-Li Ma[7], Long-Fei Ma[1,2], Xiao-Shan Ma[7], Xin Ma[7], Yi-Chuan Man[7], Jun-Cheng Mao[15], Jian Min[15], Yu Niu[1,2], Jian-Kang Peng[10,26], Xiao-Dong Peng[4,5,7], Ke-Qi Qi[12], Li-É Qiang[7], Cong-Feng Qiao[1], Ye-Xi Qu[9], Wen-Hong Ruan[1,3], Wei Sha[12], Jia Shen[1,2], Xing-Jian Shi[8], Rong Shu[6], Ju Su[7], Peng Su[24], Yan-Lin Sui[12], Guang-Wei Sun[9,25], He-Ping Tan[20], Wen-Lin Tang[7], Hong-Jiang Tao[12], Wen-Ze Tao[15], Zheng Tian[7], Ling-Feng Wan[10], Chen-Yu Wang[1,2], Jia Wang[2], Juan Wang[1,2], Jun-Biao Wang[2], Lin-Lin Wang[7], Peng-Cheng Wang[8], Shao-Xin Wang[12], Xiao-Peng Wang[12], Yan-Feng Wang[8], Yu-Kun Wang[12], Zhi Wang[1,5,12], Zuo-Lei Wang[15,29], Yong-Qiang Wei[15], Yu-Xiao Wei[1], Di Wu[2], Li-Ming Wu[1,31], Peng-Zhan Wu[16], Zhi-Hua Wu[8], Dong-Xue Xi[15], Yi-Fang Xie[7], Guo-Feng Xin[9], Heng-Tong Xu[15], Lu-Xiang Xu[1,5,17], Peng Xu[1,5,16], Shu-Yan Xu[5,17], Yu Xu[8], Bing Xue[24], Da-Tong Xue[15], Sen-Wen Xue[1,2], Zhang-Bin Xue[7], Chao Yang[1,2], Ran Yang[1,2], Shi-Jia Yang[15], Shuang Yang[7], Yong Yang[8], Zhong-Guo Yang[9], Yong-Li Yin[18], Du-Li Yu[22], Jin-Pei Yu[8], Tao Yu[12], Ài-Bing Zhang[7], Bing Zhang[24], Chu Zhang[1,2], Min Zhang[1,4,5], Jing Zhang[8], Rui-Jun Zhang[15], Xiao-Feng Zhang[8,20], Xiao-Qing Zhang[15], Xue-Quan Zhang[7], Yong-He Zhang[8], Yu-Zhu Zhang[7], Yuan-Zhong Zhang[3], Meng-Yuan Zhao[7], Jian Zhao[9], Wei-Wei Zhao[8], Ya Zhao[1,12], Jian-Hua Zheng[7], Cui-Yun Zhou[9], Ying Zhou[15], Ren Zhu[9], Xiao-Cheng Zhu[8,20], Xiao-Yi Zhu[24], Zhen-Cai Zhu[8], Xiao-Bo Zou[16] and Zi-Ming Zou[7]

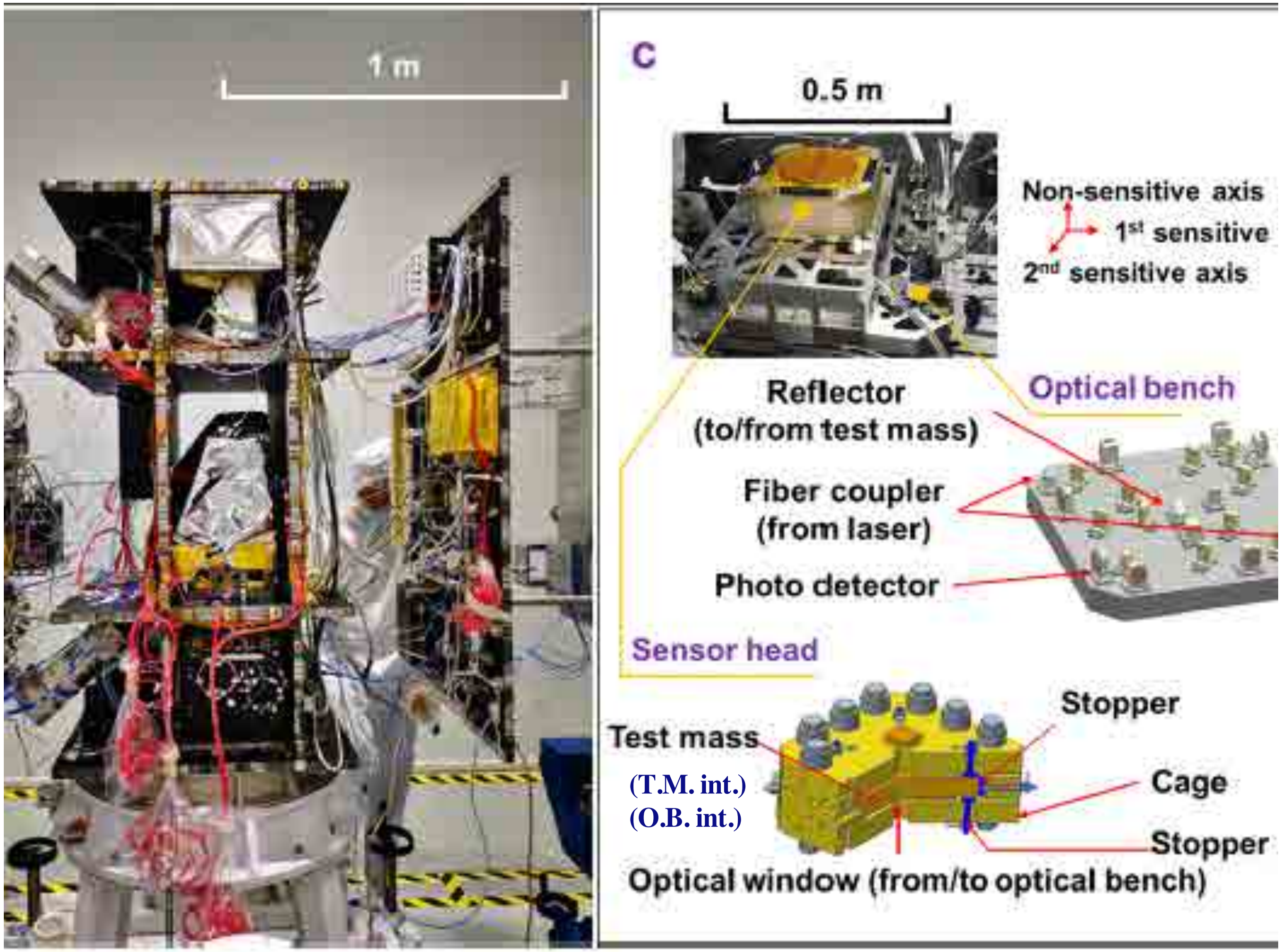
[1]Taiji Laboratory for Gravitational Wave Universe (Beijing/Hangzhou), University of Chinese Academy Sciences (UCAS), Beijing 100049, China
[2]Center for Gravitational Wave Experiment, National Microgravity Laboratory, Institute of Mechanics, Chir Academy of Sciences (CAS), Beijing 100190, China
[3]Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China
[4]International Centre for Theoretical Physics Asia-Pacific (ICTP-AP) (Beijing/ Hangzhou), UCAS, Bei 100190, China
[5]Hangzhou Institute for Advanced Study, UCAS, Hangzhou 310024, China
[6]Shanghai Institute of Technical Physics, CAS, Shanghai 200083, China
[7]National Space Science Center, CAS, Beijing 100190, China
[8]Innovation Academy for Microsatellites, CAS, Shanghai 201800, China
[9]Laboratory of Space Laser Engineering and Technology Shanghai Institute of Optics and Fine Mechar CAS, Shanghai 201800, China
[10]Innovation Academy for Precision Measurement Science and Technology, CAS, Wuhan 430071, China
[11]Tsinghua University, Beijing 100084, China
[12]Changchun Institute of Optics, Fine Mechanics and Physics, CAS, Changchun 130033, China
[13]Aerospace Information Research Institute, CAS, Beijing 100094, China
[14]Nation Astronomical Observatory, CAS, Beijing 100101, China
[15]National Key Laboratory of Science and Technology on Vacuum Technology and Physics, Lanzhou Insti of Physics, Lanzhou 730000, China
[16]Lanzhou University, Lanzhou 730000, China
[17]Nanyang Technological University, Singapore 637616, Singapore
[18]China Astronaut Research and Training Center, Beijing 100094, China
[19]Qian Xuesen Laboratory of Space Technology, Beijing 100094, China
[20]Harbin Institute of Technology, Harbin 150001, China
[21]University of Science and Technology Beijing, Beijing 100083, China
[22]Beijing University of Chemical Technology, Beijing 100029, China
[23]Zhejiang University, Hangzhou 310058, China
[24]Institute of Earthquake Forecasting, China Earthquake Administration, Beijing 100036, China
[25]School of Optoelectronics, University of Chinese Academy of Sciences, Beijing 100049, China
[26]University of Chinese Academy of Sciences, Beijing 100049, China
[27]State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan 430071, China
[28]Laboratory of Atomic Frequency Standards, Chinese Academy of Sciences, Wuhan 430071, China
[29]Lanzhou Institute of Space Technology Physics, Lanzhou, China
[30]CAS Key Laboratory of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, P. R. China
[31]Chang'an University, Xi'an 710054, China
[32]ylwu@mail.itp.ac.cn
[33]luoziren@imech.ac.cn
[34]jywang@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.

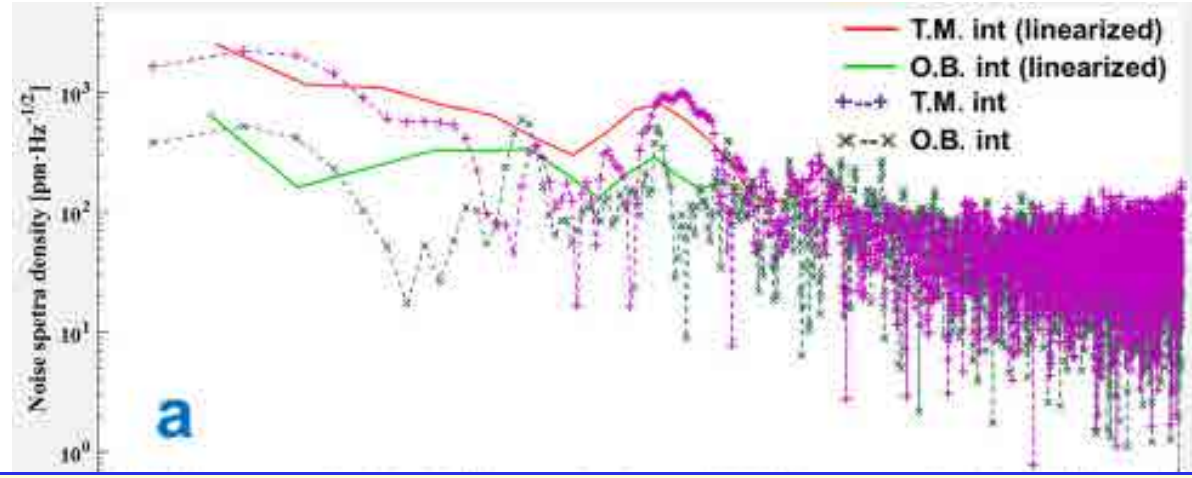
Taiji-1 satellite before assembling & Core measurement unit



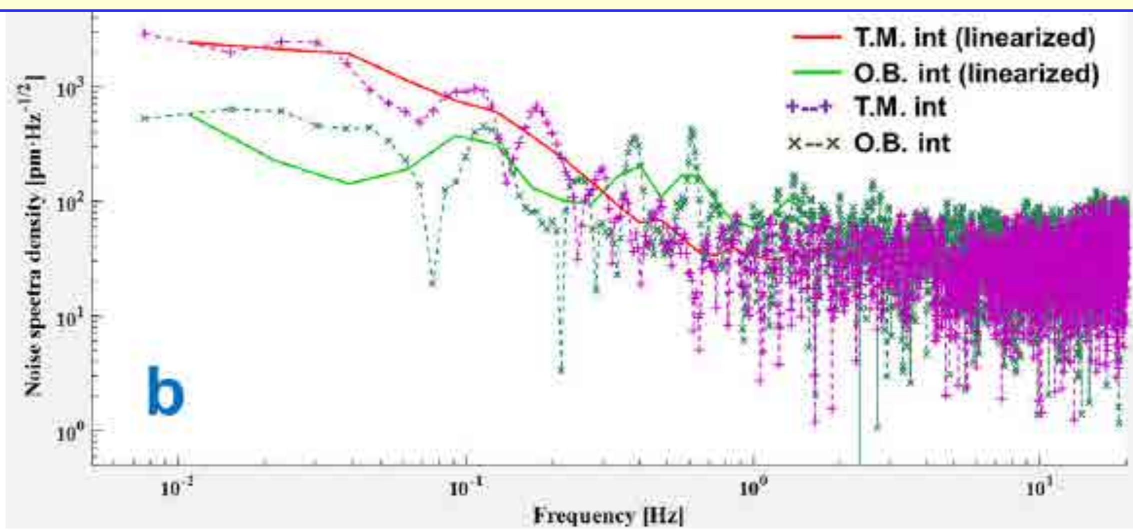
The plate of the optical bench is made of invar steel; the mirrors: fused silica; The cage of the sensor head: the low thermal expansion glass ceramics coated with gold. The test mass: titanium alloy coated with gold . The stoppers are used to prevent the test mass from contacting the inner surface of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

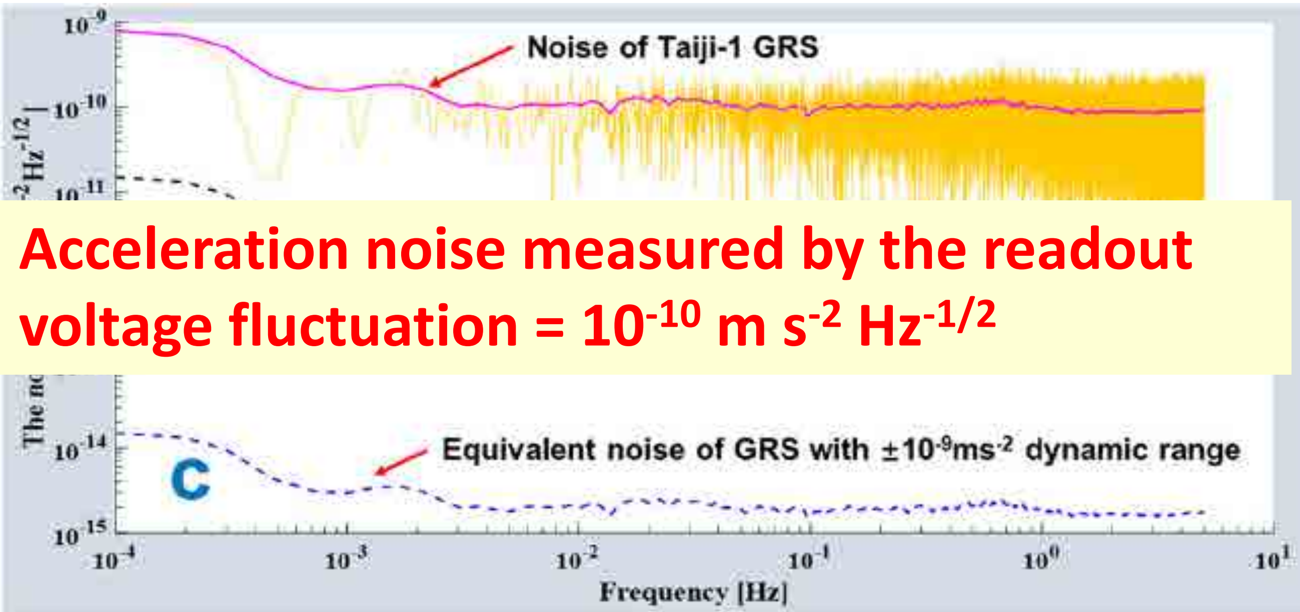


- ❖ The distance measurement noise amplitude spectra density of O.B. interferometer : ~100 pm $Hz^{-1/2}$ (10 mHz–1.0Hz).
- ❖ The best precision can reach 25 pm $Hz^{-1/2}$ in a high frequency bin



The precision of the two primary interferometers by the second laser

On-orbit test results of Taiji-1 payload

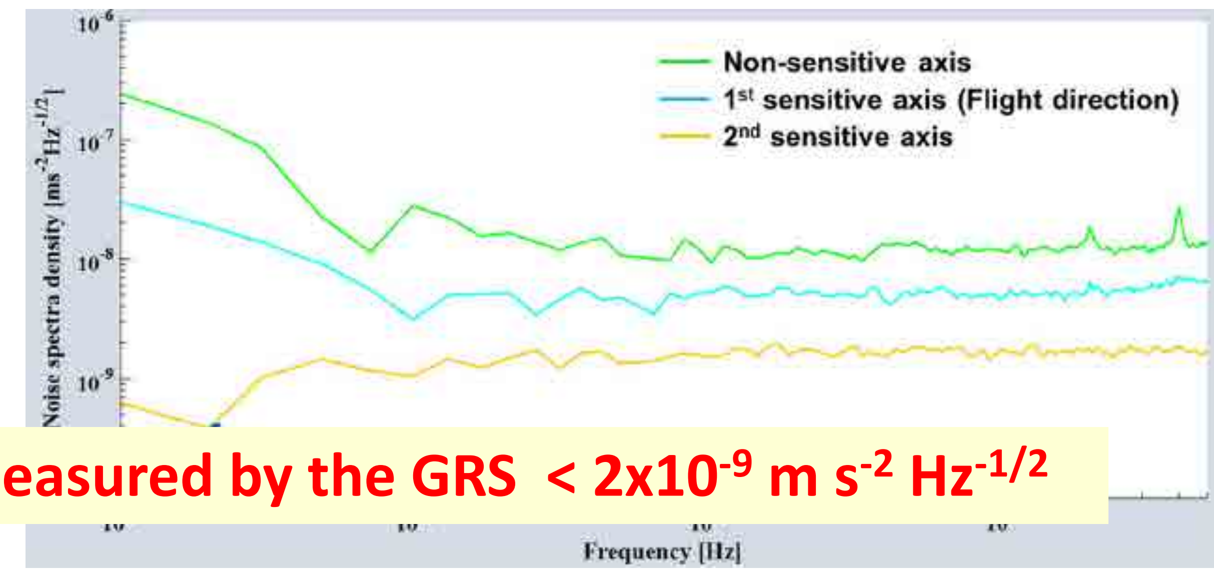


Acceleration noise measured by the readout voltage fluctuation = 10^{-10} m s^{-2} $Hz^{-1/2}$

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

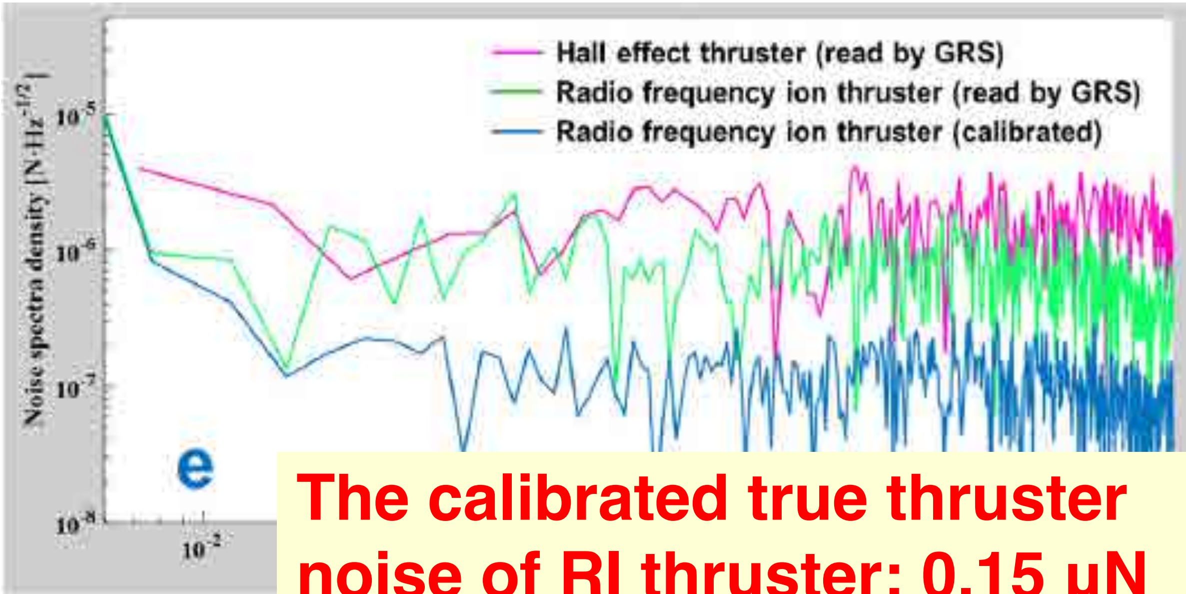
Equivalent noise of GRS corresponding to smaller dynamic ranges

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



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

On-orbit test results of Taiji-1 payload

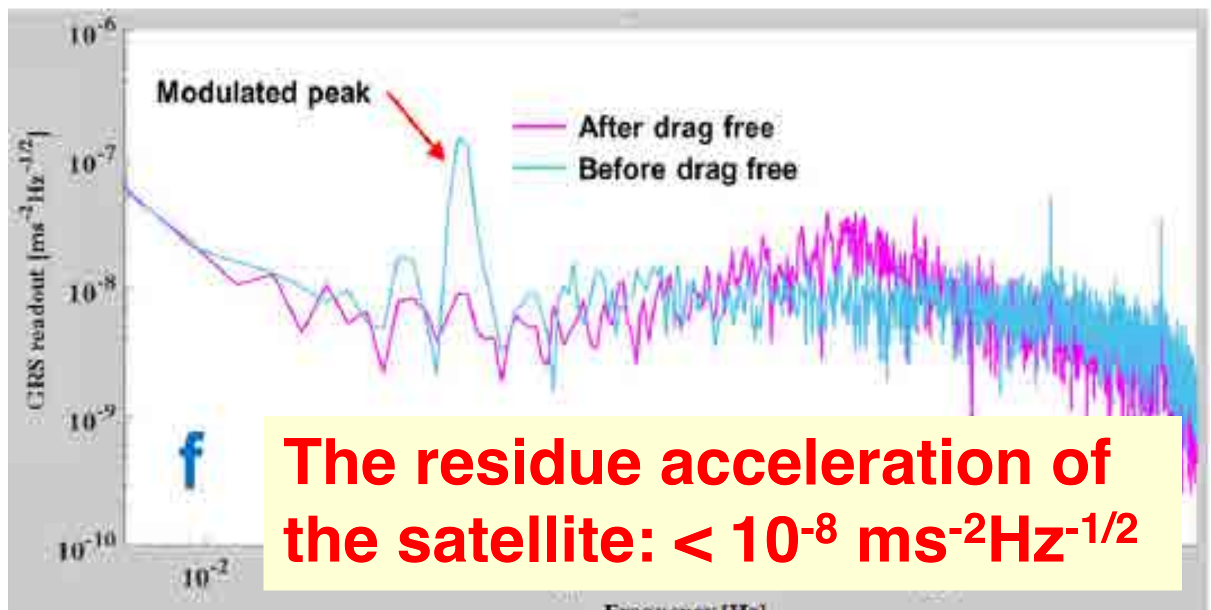


The calibrated true thruster noise of RI thruster: 0.15 μN

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 residue acceleration of the satellite: < 10^{-8} ms^{-2}Hz$^{-1/2}$

The stability of the temperature control was ~ ±2.6 mK.

CONCLUSIONS

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

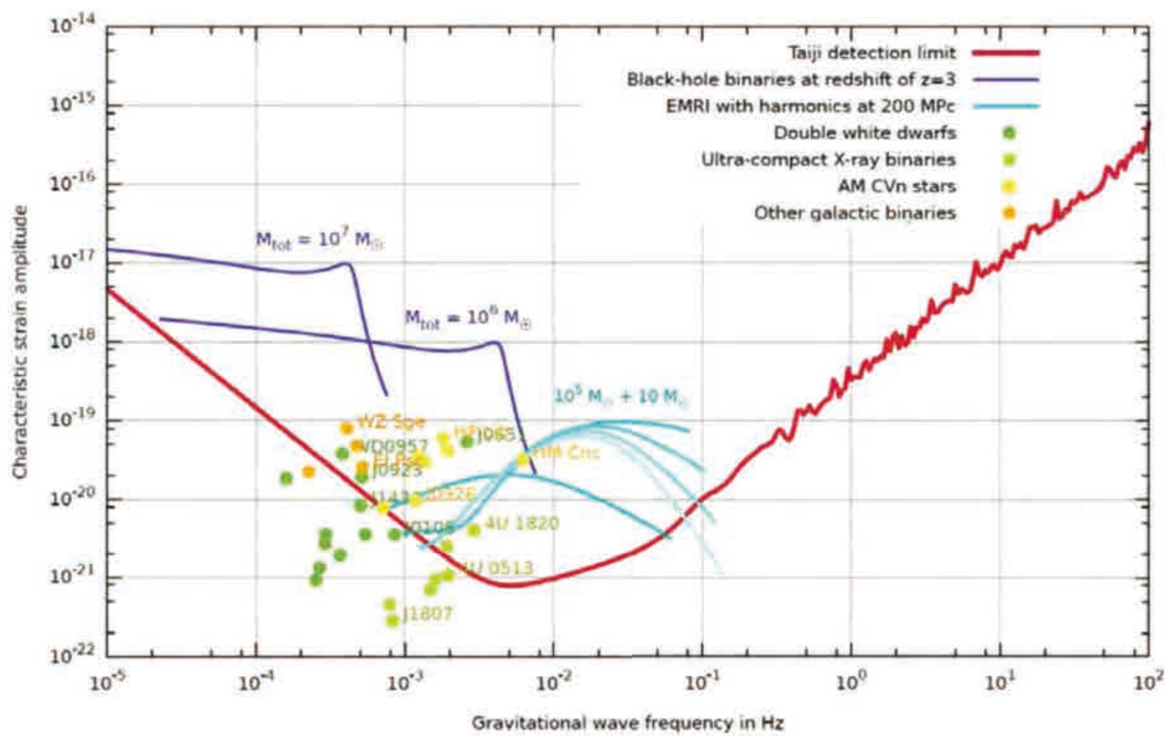
The on-orbit performance of Taiji-1 demonstrated the feasibility of the payloads.

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

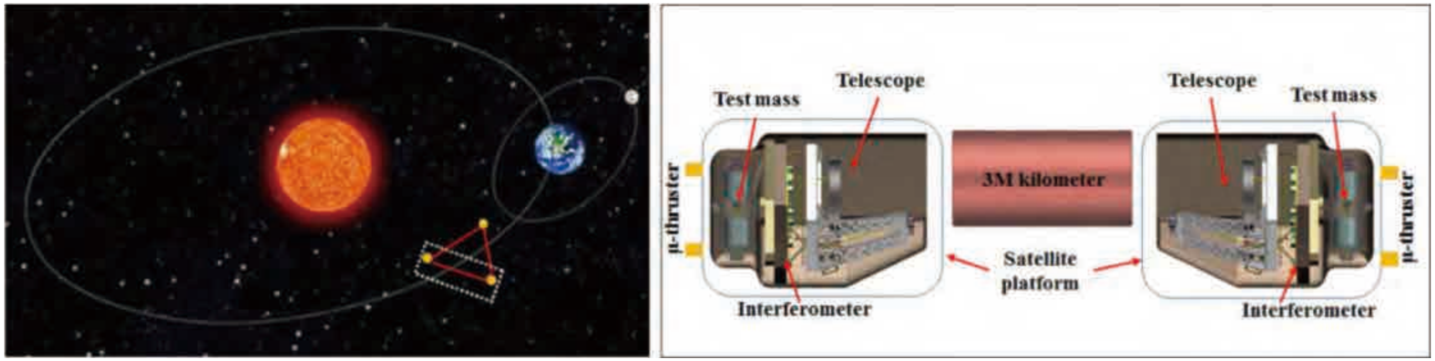
Taiji Project

The sensitivity curve of Taiji

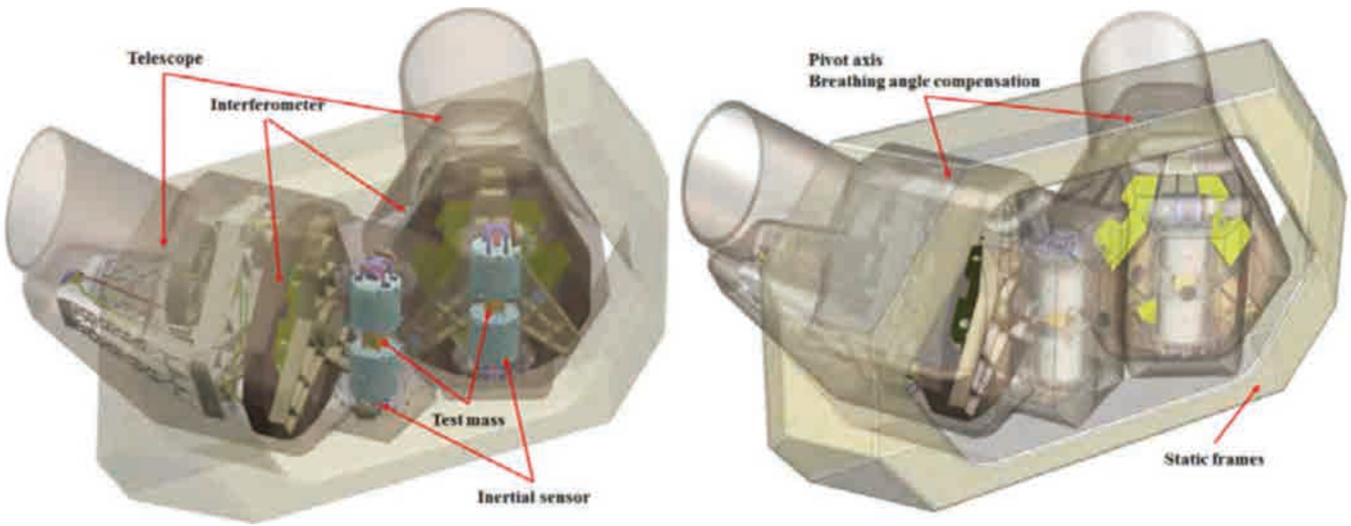
(with mass ratio 1:1 for black hole binaries)



- 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} $Hz^{-1/2}$
	Angular jitter (deliver to optical bench): 1 μrad $Hz^{-1/2}$
Telescope	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	Residual displacement noise (spacecraft, sensitive axis): 2 nm $Hz^{-1/2}$
Platform	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

UCAS Yan Qi Lake Campus
Photo by Zhang Qi

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

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

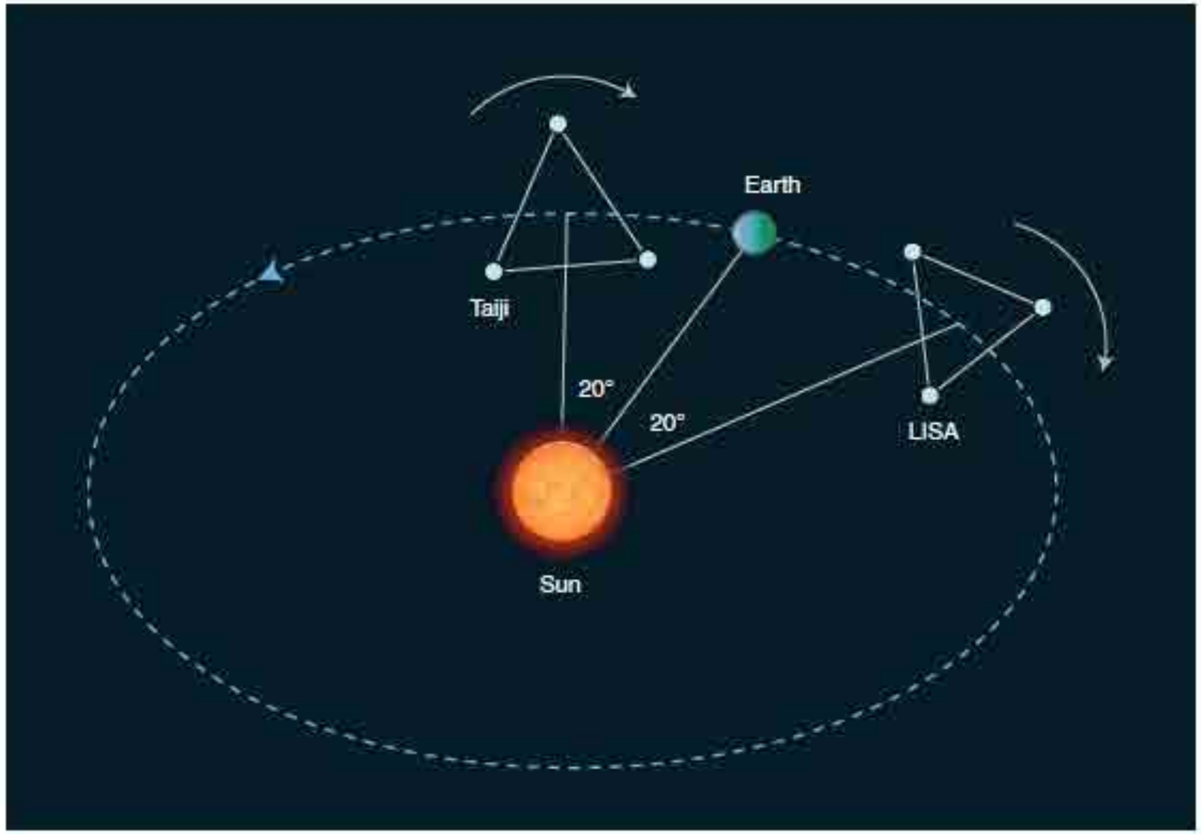
Discussions on the mission of spaced-based GWD in China and the potential international collaboration

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 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 mission[2].

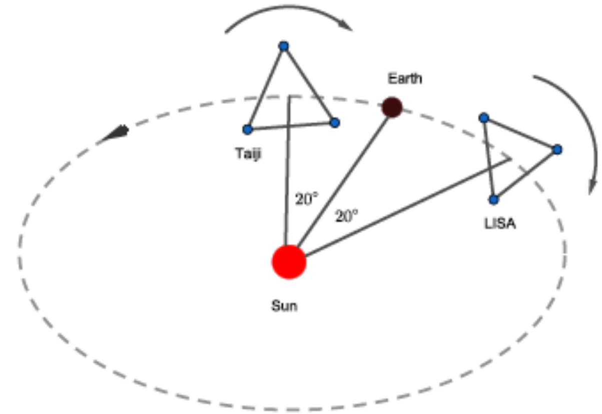
Taiji is a gravitational-wave space facility proposed by the Chinese Academy of Sciences[3]. The University of the Chinese Academy of Sciences and other institutes of the Chinese Academy of Sciences are involved in building it. Like LISA, Taiji is



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

Contents

Contents

ICTP-AP

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.

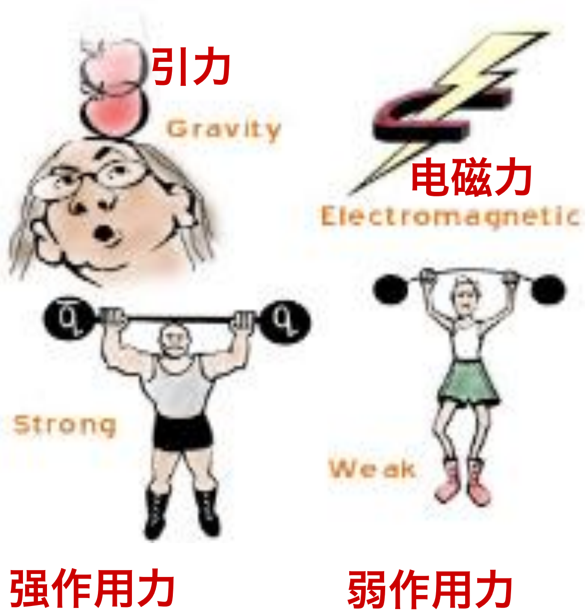
The basic gravitational field is no longer the metric field, but a gauge-type bicovariant vector field in biframe spacetime

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

Generalized Dirac equation in Gravitational Quantum Field Theory (GQFT)

$$\gamma^\mu i\partial_\mu \Psi - m\Psi = 0 \;\Rightarrow\; \boxed{\gamma^a \hat{\chi}_a{}^\mu i(\nabla_\mu + V_\mu)\psi = 0}$$

$$\nabla_\mu = \partial_\mu + \Omega_\mu \qquad V_\mu(x) \equiv \frac{1}{2}\hat{\chi}\chi_\mu{}^c \nabla_\rho(\chi\hat{\chi}_c{}^\rho)$$



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

Eur. Phys. J. C (2018) 78:28
https://doi.org/10.1140/epjc/s10052-017-5504-3

THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

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

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

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

Published online: 13 January 2018

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

$$I_H \equiv \int [d\hat{x}]\chi \{ \frac{1}{2}\bar{\Psi}\Gamma^{\mathbf{A}}\hat{\chi}_{\mathbf{A}}^{\ \mathbf{M}}(i\partial_{\mathbf{M}} + g_h \mathcal{A}_{\mathbf{M}})\Psi$$
$$+\phi^{D_h-4}[-\frac{1}{4}(\tilde{\chi}^{\mathbf{MNM'N'}}_{\mathbf{ABA'B'}}\mathcal{F}^{\mathbf{AB}}_{\mathbf{MN}}\mathcal{F}^{\mathbf{A'B'}}_{\mathbf{M'N'}} + \mathcal{W}_{\mathbf{MN}}\mathcal{W}^{\mathbf{MN}})$$
$$+\alpha_E\phi^2\frac{1}{4}\tilde{\chi}^{\mathbf{MNM'N'}}_{\mathbf{AA'}}\mathbf{G}^{\mathbf{A}}_{\mathbf{MN}}\mathbf{G}^{\mathbf{A'}}_{\mathbf{M'N'}} + \frac{1}{2}\hat{\chi}^{\mathbf{MN}}d_{\mathbf{M}}\phi d_{\mathbf{N}}\phi$$
$$-\beta_E\phi^4]\} + 2\alpha_E g_h \partial_{\mathbf{M}}(\chi\phi^{D_h-2}\mathcal{A}^{\mathbf{NM}}_{\mathbf{N}}),$$

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

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

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

Gravitational Gauge-Geometry Duality

$$I_H = \int [d\hat{x}]\chi\{\frac{1}{2}\bar{\Psi}\Gamma^{\mathbf{M}}[i\partial_{\mathbf{M}} + (\Xi^{\mathbf{PQ}}_{\mathbf{M}} + g_h\mathbf{A}^{\mathbf{PQ}}_{\mathbf{M}})\frac{1}{2}\Sigma_{\mathbf{PQ}}]\Psi$$
$$+\phi^{D_h-4}\{-\frac{1}{4}(\chi^{\mathbf{MNM'N'}}_{\mathbf{PQP'Q'}}\mathbf{F}^{\mathbf{PQ}}_{\mathbf{MN}}\mathbf{F}^{\mathbf{P'Q'}}_{\mathbf{M'N'}} + \mathcal{W}_{\mathbf{MN}}\mathcal{W}^{\mathbf{MN}})$$
$$+\alpha_E[\phi^2\mathcal{R} - (D_h-1)(D_h-2)\partial_{\mathbf{M}}\phi\partial^{\mathbf{M}}\phi] - \beta_E\phi^4$$
$$+\frac{1}{2}\hat{\chi}^{\mathbf{MN}}d_{\mathbf{M}}\phi d_{\mathbf{N}}\phi\}\} + 2\alpha_E g_h\partial_{\mathbf{M}}(\chi\phi^{D_h-2}\mathbf{A}^{\mathbf{NM}}_{\mathbf{N}}),$$

Equivalence of actions

Bimaximal Global and Local Symmetries in HUFT

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

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)

Contents

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 Ψ (x) with respect to variables $X\mu$ 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

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

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

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

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

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.**

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

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

$$\Upsilon^a \hat{\Upsilon}^b + \Upsilon^b \hat{\Upsilon}^a = 2\eta^{ab}; \quad \hat{\Upsilon}^{a,b} = (\Upsilon^0, -\Upsilon^{k,l}),$$
$$\eta^{ab} = \mathrm{diag}.(1, -1, \cdots, -1), \quad a, b = 0, 1, \cdots,$$

- **The presence of spatial dimensions in correspondence to the rotational Mc-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

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

$$\begin{aligned} G &= SC(1) \ltimes P^{1,D_h-1} \ltimes SO(1,D_h-1) \,\widetilde{\Join}\, SP(1,D_h-1) \rtimes SG(1) \times SP(q_c) \\ &\equiv SC(1) \ltimes PO(1,D_h-1) \,\widetilde{\Join}\, SP(1,D_h-1) \rtimes SG(1) \times SP(q_c), \end{aligned}$$

$PO(1,D_h-1) \equiv P^{1,D_h-1} \ltimes SO(1,D_h-1)$ — **Poincare-type group symmetry (inhomogeneous Lorentz-type group symmetry)**

$SP(1,D_h-1)$ — **M_c-spin symmetry/hyperspin symmetry**

$SP(q_c)$ — **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	biqubit-spinor	triqubit-spinor	tetraqubit-spinor
Hilbert space 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)≅O(1)	SP(2)≅U(1)	SP(3)≅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	$\psi_{Q_{T\pm}}$	$\psi_{Q^1_S}$	$\psi_{Q^2_S}, \psi_{Q^1_C}$	$\psi_{Q^3_S}, \psi_{Q^2_C}$	$\psi_{Q^4_S}$
$\mathcal{M}_c$-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

$$Q_N^{(q_c,k)} \equiv q_c + 4k,\quad q_c = 0,1,2,3,\quad k = 0,1,2,\cdots,$$

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 D_H	$16=2^4$	$32=2^5$	$64=2^6$	$128=2^7$	$256=2^8$
Q_c-spin charge C_{Q_c}	Q_N-4=0	Q_N-4=1	Q_N-4=2	Q_N-4=3	Q_N-4×2=0
Q_c-spin sym.	SP(0)	SP(1)≅O(1)	SP(2)≅U(1)	SP(3)≅SU(2)	SP(0)

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

$$C_{Q_c} = q_c = 0,1,2,3 = Q_N \ (\mathrm{mod}\ 4),$$

$$C_{Q_c} \equiv C_{Q_c}^{(q_c,k)} = C_{Q_c}^{(q_c)} = q_c,\quad q_c = 0,1,2,3,\quad k = 0,1,2,\cdots$$

$$D_h^{(q_c,k)} \equiv D_{q_c} + 8k,\quad k = 0,1,2,\cdots$$
$$D_{q_c} = 2,3,4,6,\quad q_c = 0,1,2,3,$$

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

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)

Contents

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 Qc-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.

$$
\begin{aligned}
S_{\mathrm{HU}} \equiv \int [d^{D_h}x]\,\chi(x)\,\{\, & \bar{\Psi}_{\mathrm{Q_H}}\Sigma_-^{\mathrm{A}}\hat{\chi}_{\mathrm{A}}^{\ \mathrm{M}} iD_{\mathrm{M}}\Psi_{\mathrm{Q_H}} - \phi_1\bar{\Psi}_{\mathrm{Q_H}}\tilde{\Sigma}_-\Psi_{\mathrm{Q_H}} \\
& + \phi^{D_h-4}[-\hat{\chi}_{\mathrm{C}}^{\ \mathrm{M}}\hat{\chi}_{\mathrm{D}}^{\ \mathrm{N}}\hat{\chi}_{\mathrm{C'}}^{\ \mathrm{M'}}\hat{\chi}_{\mathrm{D'}}^{\ \mathrm{N'}}(\hat{\eta}_{\mathrm{ABA'B'}}^{\mathrm{CDC'D'}} g_H^{-2}\frac{1}{4}\mathcal{F}_{\mathrm{MN}}^{\mathrm{AB}}\mathcal{F}_{\mathrm{M'N'}}^{\mathrm{A'B'}} \\
& + \tilde{\eta}_{\mathrm{AA'}}^{\mathrm{CDC'D'}} g_H^{-2}\frac{1}{4}\mathrm{F}_{\mathrm{MN}}^{\mathrm{A}}\mathrm{F}_{\mathrm{M'N'}}^{\mathrm{A'}} - \hat{\eta}^{\mathrm{CDC'D'}} g_W^{-2}\frac{1}{4}\mathrm{F}_{\mathrm{MN}}\mathrm{F}_{\mathrm{M'N'}}) \\
& + \frac{1}{2}\hat{\chi}_{\mathrm{C}}^{\ \mathrm{M}}\hat{\chi}_{\mathrm{D}}^{\ \mathrm{N}}\eta^{\mathrm{CD}} g_H^{-2}\beta_G^2\phi_1^2(\mathcal{A}_{\mathrm{M}}^{\mathrm{AB}}-\Omega_{\mathrm{M}}^{\mathrm{AB}})(\mathcal{A}_{\mathrm{NAB}}-\Omega_{\mathrm{NAB}}) \\
& \cdots - \lambda_D^2\phi_1^4\mathrm{F}(\frac{\phi_1}{\phi})]\,\}
\end{aligned}
$$

- ✓ Gauge invariance
- ✓ Scaling invariance

The gauge-gravity correspondence

$$\boxed{G_S = \mathrm{SC}(1) \ltimes \mathrm{PO}(1, D_h\text{-}1) \bowtie \mathrm{WS}(1, D_h\text{-}1) \rtimes \mathrm{SG}(1)}$$

$S_{\mathrm{HU}} \equiv \cdots \partial_{\mathrm{M}}\ln(\lambda_S^2\phi^2 + \lambda_Q^2\phi_1^2)$

$= \cdots \Psi_{\mathrm{Q_H}}\tilde{\Sigma}_-\Psi_{\mathrm{Q_H}}$

$- \cdots g_H^{-2}\mathrm{F}_{\mathrm{MN}}^{\mathrm{A}}\mathrm{F}_{\mathrm{M'N'}}^{\mathrm{A'}}$

$- \cdots \mathrm{F}_{\mathrm{M'N'}}]$

- ✓ Gauge invariance
- ✓ Hidden Scaling gauge invariance

- ❖ **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**

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].

Gravity-geometry correspondence

Hidden Gauge Formalism

Emergent hidden symmetry GL(1,D-1,R) In coordinate hyper-spacetime

$$\mathcal{S}_{HU} \equiv$$

$$\cdot \{ \bar{\Psi}_{Q_H} \Sigma_-^{M} i\mathcal{D}_M \Psi_{Q_H} - \beta_Q \sinh\chi_s \, \bar{\Psi}_{Q_H} \tilde{\Sigma}_- \Psi_{Q_H}$$

$$+ \hat{H}^{MM'}\hat{H}^{NN'} \frac{1}{4} g_H^{-2} \mathcal{F}^{P}_{MNQ} \mathcal{F}^{Q}_{M'N'P} + g_H^{-2} R$$

$$- \frac{1}{2} g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2\chi_s \, \hat{H}^{MM'} (\mathcal{A}^{P}_{MQ} - \Gamma^{P}_{MQ})(\mathcal{A}^{Q}_{M'P} - \Gamma^{Q}_{M'P})$$

$$- \hat{H}^{MM'}\hat{H}^{NN'} \frac{1}{4} g_W^{-2} F_{MN} F_{M'N'} + \frac{1}{2}\lambda_S^2 (1 + \sinh^2\chi_s) \hat{H}^{MM'} W_M W_{M'}$$

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

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

Geometry-gauge correspondence

Hidden coordinate Formalism

Emergent gravitational interaction In locally flat gravigauge hyper-spacetime

$$\mathcal{S}_{HU} \equiv$$

$$\cdot \{ \bar{\Psi}_{Q_H} \Sigma_-^{C} i\mathcal{D}_C \Psi_{Q_H} - \beta_Q \sinh\chi_s \, \bar{\Psi}_{Q_H} \tilde{\Sigma}_- \Psi_{Q_H}$$

$$- \frac{1}{4} g_H^{-2} \mathcal{F}_{CDAB} \mathcal{F}^{CDAB} + g_H^{-2} \eta^{CD} R_{CD}$$

$$+ \quad \Omega^{CAB})$$

$$-$$

$$\mathfrak{A}\, R \equiv \mathfrak{A}\, \hat{H}^{MQ} R_{MQ} = \mathfrak{A}\, \hat{H}^{MQ} R_{MNPQ} \hat{H}^{NP}$$

$$\equiv \mathfrak{A}\, \eta^{CB} R_{CB} = \mathfrak{A}\, \eta^{CB} R_{CDAB} \eta^{DA},$$

$$\equiv -\mathfrak{A}\, \Omega_{CAB} \Omega^{ABC} - \mathfrak{A}\, \Omega^{C}_{CA} \Omega^{DA}_{D} + 2\partial_M (\mathfrak{A}\, \hat{A}_A^{\ M} \Omega^{CA}_{C})$$

$$+ \frac{1}{2}\lambda_S^2 \hat{\partial}_C \chi_s \hat{\partial}^C \chi_s - \lambda_D^2 \mathcal{F}(\chi_s) \}$$

$$i\mathcal{D}_C \equiv i\hat{\partial}_C + \mathcal{A}_{CAB} \frac{1}{2} \Sigma^{AB} \equiv \hat{A}_C^{\ M} i\mathcal{D}_M,$$

$$[\delta^{D_h} \varkappa] \equiv [d^{D_h} x]\, \mathfrak{A}(x), \quad \delta\varkappa^A(x) = A_M^{\ A} dx^M$$

$$
\begin{aligned}
\mathcal{S}_{\mathrm{HU}} \equiv & \int [d^{D_h}x]\, \mathfrak{A}(x) \{ \hat{\mathrm{H}}^{\mathrm{MN}} \bar{\Psi}_{\mathrm{Q_H}} \mathrm{A_{MC}} \Sigma_-^{\mathrm{C}} i \mathcal{D}_{\mathrm{N}} \Psi_{\mathrm{Q_H}} \\
& - \beta_Q \sinh \chi_s \, \bar{\Psi}_{\mathrm{Q_H}} \tilde{\Sigma}_- \Psi_{\mathrm{Q_H}} - \hat{\mathrm{H}}^{\mathrm{MM'}} \hat{\mathrm{H}}^{\mathrm{NN'}} g_H^{-2} \frac{1}{4} \mathcal{F}_{\mathrm{MNAB}} \mathcal{F}^{\mathrm{AB}}_{\mathrm{M'N'}} \\
& + \frac{1}{2} g_H^{-2} \beta_G^2 \beta_Q^2 \sinh^2 \chi_s \, \hat{\mathrm{H}}^{\mathrm{MM'}} (\mathcal{A}_{\mathrm{MAB}} - \Omega_{\mathrm{MAB}})(\mathcal{A}^{\mathrm{AB}}_{\mathrm{M'}} - \Omega^{\mathrm{AB}}_{\mathrm{M'}}) \\
& + \frac{1}{8} \hat{\mathrm{H}}^{\mathrm{MM'}} \hat{\mathrm{H}}^{\mathrm{NN'}} \hat{\mathrm{H}}_{\mathrm{PP'}} g_H^{-2} \mathrm{F}^{\mathrm{P}}_{\mathrm{MN}} \mathrm{F}^{\mathrm{P'}}_{\mathrm{M'N'}} \\
& - \frac{1}{4} g_H^{-2} \mathfrak{A} \hat{\mathrm{H}}^{\mathrm{NP}} \hat{\partial}^{\mathrm{M}} \partial_{\mathrm{N}} (\hat{\mathfrak{A}} \mathrm{H_{MP}}) - \frac{1}{4} g_H^{-2} \hat{\partial}^{\mathrm{N}} (\ln \mathfrak{A}) \partial_{\mathrm{N}} (\ln \mathfrak{A}) \\
& + \frac{1}{4} g_H^{-2} \hat{\mathrm{H}}_{\mathrm{PQ}} \mathfrak{A}^2 \hat{\partial}^{\mathrm{M}} (\hat{\mathfrak{A}} \mathrm{H}^{\mathrm{P}}_{\mathrm{M}}) \hat{\partial}^{\mathrm{N}} (\hat{\mathfrak{A}} \mathrm{H}^{\mathrm{Q}}_{\mathrm{N}}) + \frac{1}{2} g_H^{-2} \mathfrak{A} \hat{\partial}_{\mathrm{Q}} (\ln \mathfrak{A}) \hat{\partial}^{\mathrm{N}} (\hat{\mathfrak{A}} \mathrm{H}^{\mathrm{Q}}_{\mathrm{N}}) \\
& - \hat{\mathrm{H}}^{\mathrm{MM'}} \hat{\mathrm{H}}^{\mathrm{NN'}} \frac{1}{4} g_W^{-2} \mathrm{F_{MN}} \mathrm{F_{M'N'}} + \frac{1}{2} \lambda_S^2 (1 + \sinh^2 \chi_s) \hat{\mathrm{H}}^{\mathrm{MN}} \mathrm{W_M} \mathrm{W_N} \\
& + \frac{1}{2} \hat{\mathrm{H}}^{\mathrm{MN}} \lambda_S^2 \partial_{\mathrm{M}} \chi_s \partial_{\mathrm{N}} \chi_s - \lambda_D^2 \mathcal{F}(\chi_s) \},
\end{aligned}
$$

Gauge-geometric Duality in Framework of Gravitational Quantum Field Theory

$$
\mathrm{F}^{\mathrm{P}}_{\mathrm{MN}} = \partial_{\mathrm{M}} \mathrm{H}^{\mathrm{P}}_{\mathrm{N}} - \partial_{\mathrm{N}} \mathrm{H}^{\mathrm{P}}_{\mathrm{M}}
$$

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

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

Gauge-type gravitational equation in HUFT

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

Hyper-gravigauge field

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

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

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

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

Hyper-gravimetric gauge field

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

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

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

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

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

Equivalent geometric gravitational equation of hyper-gravimetric field in HUFT

Generalized Einstein equation in Hyper-spacetime

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

推广的爱因斯坦方程

Extra gravitational equation

$$g_H^{-2}\beta_G^2\beta_Q^2\sinh^2\chi_s\,\hat{\nabla}_{\mathrm{P}}\hat{\mathrm{A}}^{\mathrm{P}}{}_{\mathrm{MN}} = \mathrm{T_{[MN]}}$$

Generalized Einstein tensor in Hyper-spacetime

$$\begin{aligned}
{}_{\mathrm{N}} &\equiv \hat{\mathfrak{A}}\mathrm{A_M{}^A T_A{}^P H_{PN}} \\
&= \frac{1}{2}\left(\bar{\Psi}_{\mathrm{Q_H}}\Sigma_-^{\mathrm{C}}\mathrm{A_{MC}}i\mathcal{D}_{\mathrm{N}}\Psi_{\mathrm{Q_H}} + \bar{\Psi}_{\mathrm{Q_H}}\Sigma_-^{\mathrm{C}}\mathrm{A_{NC}}i\mathcal{D}_{\mathrm{M}}\Psi_{\mathrm{Q_H}}\right) \\
&- g_H^{-2}\left(\mathcal{F}_{\mathrm{MP}}^{\mathrm{AB}}\mathcal{F}_{\mathrm{NQAB}} - \mathrm{H_{MN}}\frac{1}{4}\hat{\mathrm{H}}^{\mathrm{M'N'}}\mathcal{F}_{\mathrm{M'P}}^{\mathrm{AB}}\mathcal{F}_{\mathrm{N'Q}}^{\mathrm{AB}}\right)\hat{\mathrm{H}}^{\mathrm{PQ}} \\
&+ g_H^{-2}\beta_G^2\beta_Q^2\sinh^2\chi_s\left(\hat{\mathrm{A}}_{\mathrm{M}}^{\mathrm{PQ}}\mathrm{A_{NPQ}} - \mathrm{H_{MN}}\frac{1}{2}\hat{\mathrm{H}}^{\mathrm{M'N'}}\hat{\mathrm{A}}_{\mathrm{M'}}^{\mathrm{PQ}}\mathrm{A_{N'PQ}}\right) \\
&+ \frac{1}{2}g_H^{-2}\beta_G^2\beta_Q^2\sinh^2\chi_s\left(\hat{\mathrm{A}}^{\mathrm{(PQ)}}{}_{\mathrm{M}}\mathrm{A_{(PQ)N}} - \hat{\mathrm{A}}^{\mathrm{[PQ]}}{}_{\mathrm{M}}\mathrm{A_{[PQ]N}}\right) \\
&+ \frac{1}{2}g_H^{-2}\beta_G^2\beta_Q^2\sinh^2\chi_s\left(\hat{\mathrm{A}}_{\mathrm{M}}^{\mathrm{PQ}}\mathrm{A_{[PQ]N}} + \hat{\mathrm{A}}_{\mathrm{N}}^{\mathrm{PQ}}\mathrm{A_{[PQ]M}} + 2\hat{\nabla}_{\mathrm{P}}\mathrm{A}_{\mathrm{(MN)}}^{\mathrm{P}}\right) \\
&- g_W^{-2}\left(\mathrm{F_{MP}F_{NQ}} - \mathrm{H_{MN}}\frac{1}{4}\hat{\mathrm{H}}^{\mathrm{M'N'}}\mathrm{F_{M'P}F_{N'Q}}\right)\hat{\mathrm{H}}^{\mathrm{PQ}} \\
&+ \left(W_{\mathrm{M}}W_{\mathrm{N}} - \mathrm{H_{MN}}\frac{1}{2}\hat{\mathrm{H}}^{\mathrm{PQ}}W_{\mathrm{P}}W_{\mathrm{Q}}\right) \\
&+ \lambda_S^2\left(\partial_{\mathrm{M}}\chi_s\partial_{\mathrm{N}}\chi_s - \mathrm{H_{MN}}\frac{1}{2}\hat{\mathrm{H}}^{\mathrm{PQ}}\partial_{\mathrm{P}}\chi_s\partial_{\mathrm{Q}}\chi_s\right) \\
&+ \left(\beta_Q\sinh\chi_s\,\bar{\Psi}_{\mathrm{Q_H}}\tilde{\Sigma}_-\Psi_{\mathrm{Q_H}} + \lambda_D^2\mathcal{F}(\chi_s)\right)\mathrm{H_{MN}},
\end{aligned}$$

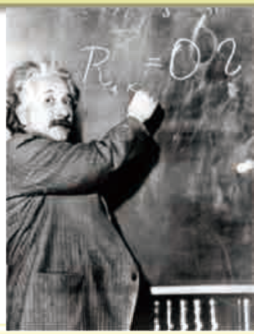
Antisymmetric tensor

$$\mathrm{T_{[MN]}} \equiv \bar{\Psi}_{\mathrm{Q_H}}\Sigma_-^{\mathrm{C}}\mathrm{A_{MC}}i\mathcal{D}_{\mathrm{N}}\Psi_{\mathrm{Q_H}} - \bar{\Psi}_{\mathrm{Q_H}}\Sigma_-^{\mathrm{C}}\mathrm{A_{NC}}i\mathcal{D}_{\mathrm{M}}\Psi_{\mathrm{Q_H}}$$

Nature of Gravity

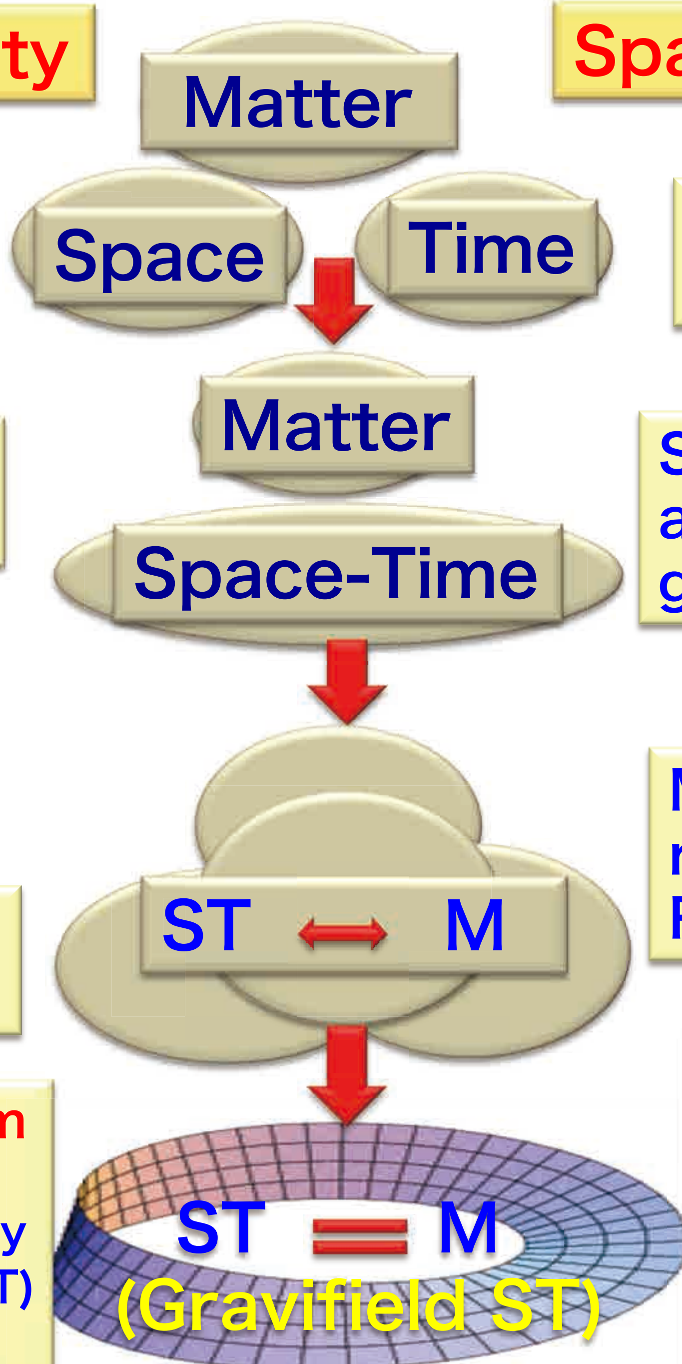
Newton theory

Einstein
Special Relativity



Einstein
General Relativity

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



Spacetime Structure

Matter, Space, Time are all independent

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

Matter & spacetime related→dynamics of Riemannian spacetime

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

ICTP-AP

UNESCO

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