The 6th KAGRA International Workshop

June 21-23, 2019

Wuhan, China

Conference Booklet

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Introduction

It is a great pleasure to hold the 6th KAGRA International Workshop (KIW6) at Wuhan from the 21st to the 23rd of June, 2019.

Wuhan is the capital of Hubei Province, which has a population of 10 million. Located in the middle of China, Wuhan can be reached by speedy train in 4 hours from Shanghai, 4.5 hours from Beijing, 4 hours from Xi'an, and 4/4.5 hours from Guangzhou/Hong Kong/Sheng Zheng.

The KIW6 workshop will be organized by Wuhan Institute of Physics and Mathematics (WIPM), Chinese Academy of Sciences. WIPM has a history of over 60 years. WIPM conducts frontier and interdisciplinary research that focuses on magnetic resonance in life sciences, atomic, molecular and optical (AMO) physics, atomic frequency standards, and precision measurement physics. During her history, WIPM has been honored with nearly 300 scientific and technological awards.

The Yellow Crane Tower in Wuhan

WIPM now has about 300 students, 300 scientists and 100 staff members. The international cooperation and academic exchange between WIPM and the peer institutes around the world are routine, and long-term cooperative relationship has been developed between WIPM and institutes from over 20 countries and regions.

The group of cold atom physics (GCAP) led by Prof. Mingsheng Zhan is one of the earliest research groups that carry out cold atom physics study in China. This group has realized the first cold atom interferometer in China in 2007, built the biggest atom interferometer around the world in 2012, and achieved a precision test of the equivalence principle with atoms in 2015. In recent years, the group is working on quantum manipulation of single atoms, precision measurement with atom interferometers, application research of atom interferometer in gravity measurement, gravity gradient measurement, rotation measurement and general relativistic test. A project named as ZAIGA (Zhaoshan long-baseline Atom Interferometer Gravitation Antenna [arXiv1903.09288]) is proposed by GCAP. ZAIGA is a new type of underground laser-linked interferometer facility, be equipped with long-baseline atom interferometers, high-precision atom clocks, and large-scale gyros. The ZAIGA facility will be used for experimental research on gravitation and related problems including gravitational wave detection, high-precision test of the equivalence principle of micro-particles, clock based gravitational red-shift measurement, rotation measurement and gravito-magnetic effect.

In the face-to-face meeting on May 18-20, 2018, WIPM joined the KAGRA Collaboration. At present, Panwei Huang (D3), Mingsheng Zhan (Prof.) and Wei-Tou Ni (Prof.) are collaborating on the VIS subsystem; Guiguo Ge (D1), Jing Wang (Prof.) and WT Ni are collaborating on the IOO subsystem, and Dongfeng Gao (Associate Prof.), Wei Zhao (D1), Min Liu (Associate Prof.) and WT Ni are collaborating on the fundamental physics part of Data Analysis.

Welcome to KIW6! Welcome to Wuhan!

Min Liu, Wei-Tou Ni, Jing Wang and Mingsheng Zhan

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Mingsheng Zhan | Wei-Tou Ni

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Invited Speakers

Masaki Ando (Physics, U Tokyo)
Jo Van Den Brand (NIKHEF)
Jenne Driggers (LIGO Hanford, Caltech)
Lijun Gou (NAOC)
Gerhard Heinzel (AEI, Hanover)
Youjun Lu (NAOC)
Jun Luo (Sun Yat-Sen U)
Nozomu Tominaga (Konan U)
Yueliang Wu (ITP, CAS)
Guido Zavattini (INFN Ferrara)

Timetable

The 6th KAGRA International Workshop - June 21-23, 2019

June 21 (Friday)，M Building，WIPM			
Time	**Name**	**Title of presentation**	**Chair**
08:30-09:00	Registration		
Wang T. C. Lecture, M-428，WIPM			
09:00-09:15	Xiaojun Liu (WIPM)	Welcome Address	Mingsheng Zhan
09:15 - 09:20	Chaohui Ye (WIPM)	Remembrance of T. C. Wang	
09:20 - 10:00	Takaaki Kajita (ICRR)	KAGRA and Gravitational Wave Astronomy	
10:00 - 10:15	Coffee Break		
M-425, WIPM			
KAGRA Present Status			
10:15 - 10:25	Hisaaki Shinkai (Osaka Inst. Tech.)	Report from KAGRA Scientific Congress	Yuta Michimura
10:25 - 11:00	Takaaki Yokozawa (ICRR)	Status of the KAGRA (including the status of commissioning)	

KAGRA Technologies			
11:00-11:20	Takayuki Tomaru (NAOJ)	Status Report of KAGRA Cryogenics	Yoichi Aso
11:20-11:35	Masayuki Nakano (U Toyama)	Status of the input and output optics	
11:35-11:50	Ryosuke Sugimoto (U Toyama)	Current status of Arm Length Stabilization system in KAGRA	
11:50-12:05	Guiguo Ge (WIPM)	Mach-Zehnder modulation system	
12:05-12:15	Group Photo		
12:15-14:00	Lunch Break		
14:00-14:15	Satoshi Tanioka (Sokendai)	Alignment signals of a triangular optical cavity and its performance	Yoichi Aso
14:15-14:30	Tatsuki Washimi (NAOJ)	PEM Status of KAGRA Physical Environmental Monitors toward the O3	
14:30-14:45	Kiichi Kaihotsu (U Toyama)	Investigation of the magnetic and sound field environments in KAGRA site	
KAGRA DetChar, Science Targets, R&D, and Future Plans			
14:45-15:05	Takahiro Yamamoto (ICRR, U Tokyo)	Detector Characterization for joining O3 observation	Keiko Kokeyama
15:05-15:20	Yuhang Zhao (NAOJ)	Status of the frequency dependent squeezing experiment at TAMA	
15:20-15:40	Atsushi Nishizawa (RESCEU, U Tokyo)	KAGRA scientific contribution to the global detector network	
15:40-16:20	Sadakazu Haino (Academia Sinica)	KAGRA Upgrade plans and current status of white paper (20 min + 20 min for discussion)	
16:20-16:50	Coffee Break		
Scalar-tensor Gravity Model and Cavity Simulation			
16:50-17:10	Lijing Shao (Peking U)	A reduced-order model for the scalar-tensor gravity	Dongfeng Gao
17:10 - 17:30	Haoyu Wang (USST)	Finesse simulation of near-unstable cavities with mirror maps	
17:30-19:10	Dinner Break		
Public Lecture, M-428，WIPM			
19:10-20:40	Jenne Driggers	Advanced LIGO and	Xiaojun Liu

	(LIGOHanford,Caltech)	Gravitational Waves	

June 22 (Saturday)，　M-425，WIPM

Time	Name	Title of presentation	*Chair*
LIGO/Virgo Status, Vacuum Birefringence			
09:00-09:35	Jenne Driggers (LIGO Hanford, Caltech)	The Status of LIGO	Takaaki Yokozawa
09:35-10:05	Jo Van Den Brand (NIKHEF)	The Status of Virgo	
10:05-10:35	Guido Zavattini (INFN Ferrara)	Present Status of Vacuum Birefringence Experiments	
10:35-11:00	Coffee Break		
Science, Sources and Underground Technology			
11:00-11:30	Nozomu Tominaga (Konan U)	Japanese Collaboration for Gravitational-Wave Electro-Magnetic Follow-up	Hisaaki Shinkai
11:30-12:00	Lijun Gou (NAOC)	Review to the BH spin measurement in the GW era	
12:00-13:30	Lunch Break		
13:30-14:00	Youjun Lu (NAOC)	Host Galaxy Properties of Gravitational Wave Sources Detected by aLIGO and VIRGO	Hisaaki Shinkai
14:00-14:20	Hideyuki Tagoshi (ICRR)	Status of KAGRA Data Analysis Working Group	
14:20-14:40	Chunglee Kim (Ewha Womans U)	Galactic neutron stars in the era of multi-messenger astronomy	
14:40-15:00	Shinji Miyoki (ICRR, U Tokyo)	Experiences with the underground facility for KAGRA Site	
15:00-18:30	**Diversity Gathering**		Keiko Kokeyama
18:30-21:00	**Social Dinner**		

June 23 (Sunday)，M-425，WIPM

Time	Name	Title of presentation	Chair
ZAIGA Project Design			
09:00-09:30	Mingsheng Zhan (WIPM)	ZAIGA – Zhaoshan Long-baseline Atom	Jenne Driggers

		Interferometer Gravitation Antenna	
09:30-09:50	Dongfeng Gao (WIPM)	ZAIGA-GW (Gravitational Wave detection)	
09:50-10:10	Lin Zhou (WIPM)	ZAIGA-EP (Equivalence Principle test)	
10:10-10:30	Lingxiang He (WIPM)	ZAIGA-CE (Clock-based Experiment)	
10:30-10:50	Runbing Li (WIPM)	ZAIGA-RM (Rotation Measurement)	
10:50-11:10	Coffee Break		
DECIGO and Neutron Interferometry			
11:10-11:40	Masaki Ando (Physics, U Tokyo)	B-DECIGO and DECIGO	Jin Wang
11:40-12:00	Toshifumi Futamase (Kyoto Sangyo U)	Hamiltonian of a free neutron in curved spacetime on the Earth and application to neutron interferometer	
12:00-13:30	Lunch Break		
GW Space Missions (1)			
13:30-14:20	Gerhard Heinzel (AEI, Hanover)	LISA	Mingsheng Zhan
14:20-15:00	Jun Luo (Sun Yat-Sen U)	TIANQIN	
15:00-15:20	Yurong Liang (WIPM)	Digital phasemeter and weak-light phase locking for space-borne GW detection missions	
15:20-15:40	Coffee Break		
GW Space Missions (2)			
15:40-16:20	Yue-Liang Wu (ITP, CAS)	TAIJI	Gerhard Heinzel
16:20-16:45	AD Group	Study of a Joint LISA-TAIJI Observation Scenario – Orbit Design, Sensitivity & Angular resolution Improvement, and Deployment	
16:45-17:05	Lisheng Chen (WIPM)	Laser Frequency Study for TAIJI	
17:05-17:25	Li'e Qiang (Chang'an U)	Simulations of Post processed Time Delay Interferometry for TAIJI mission	
Concluding Remarks and Next KIW (KIW7) Announcement			
17:25 - 18:00	Concluding remarks KIW7 announcement Closing		Hisaaki Shinkai Yuki Inoue Jin Wang

Abstracts of Talks

Wang T. C. Lecture

KAGRA and Gravitational Wave Astronomy – Takaaki Kajita (ICRR)

A completely new astronomy, gravitational wave astronomy, has born a few years ago. With gravitational waves, we would like to unveil the secrets of the Universe such as black holes and neutron stars. In this lecture, I would like to discuss the gravitational wave detector, KAGRA, and the science to be carried out by the global network of gravitational wave detectors.

KAGRA present status

Report from KAGRA Scientific Congress - Hisaaki Shinkai (Osaka Inst. Tech.)

Brief announcement from KSC (KAGRA Scientific Congress); How we organize scientific activities, how to join KAGRA collaboration, etc.

Status of the KAGRA – Takaaki Yokozawa (ICRR)

KAGRA is the 2nd generation large gravitational wave detector which is placed in Japan. We successfully installed almost all of the planned items. We will report the schedule and prospect toward joining the international network observation, which is called O3 run, at this year. Also, we will report the status of the detector commissioning toward operating the Dual Recycled Fabry-Perot Michelson with better sensitivity.

Status Report of KAGRA Cryogenics - Takayuki Tomaru (NAOJ)

Cryogenic mirror suspension system (Cryo-Payload) and its cooling technologies are one of the most feature in KAGRA. We successfully completed all of Cryo-Payload in to cryostats and started cooling down. And we have already succeeded cryogenic operation of the Y-arm Fabry-Perot cavity at cryogenic condition. We report about the status of cryogenic subsystem activities.

Status of the input and output optics - Masayuki Nakano (U Toyama)

The input optics is one of the subsystems to provide a stable laser light into the main interferometer. On the other hand, the output optics is the subsystem for the extract the gravitational signal from the output laser beam. In this talk, we will describe the status of the input and output optics.

Current status of Arm Length Stabilization system in KAGRA - Ryosuke Sugimoto (U Toyama)

Gravitational wave telescope KAGRA is a complex system composed of multiple cavities and interferometers. They should be controlled at the same time. For this purpose, KAGRA adopts green lasers with which the arm cavities are stabilized independently of the main infrared laser. This system with green laser is called Arm Length Stabilization (ALS) system. We were already installed ALS system and successfully stabilized one arm cavity and then the cavity smoothly get resonant with the main laser hand-over from ALS to main laser. I report the latest status of the ALS system.

Mach-Zehnder modulation system – Guiguo Ge (WIPM)

One technology named the Detuned Resonant Sideband Extraction (RSE) can improves the quantum noise beyond Standard Quantum Limit. The Detuned RSE potentially introduces the excess noise. But such noise can be reduced by a laser modulation system we propose which has two Mach-Zehnder interferometers in series. We call this system Mach-Zehnder Modulator (MZM). In this talk, we will report the basic idea of MZM and the results of our proof-of-principle experiment.

Alignment signals of a triangular optical cavity and its performance - Satoshi Tanioka (Sokendai)

Optical cavities are widely used in precise measurement, such as in gravitational wave detectors. In gravitational wave detectors, input mode cleaner (IMC) is used to stabilize the laser frequency and reduce the jitter of the beam injected to main interferometer. IMC is an isosceles triangular cavity with the much longer lengths two sides than the third, consisting of a curved mirror placed at the end to yield a waist halfway between the two at mirrors. Each mirror in IMC is suspended to reduce the seismic motion, however, suspended mirrors are subjected to angular fluctuations which leads to misalignment of cavity. In order to reduce angular misalignment, alignment sensing control (ASC) is adopted to IMC using wave front sensing (WFS) technique. WFS is a spatial sensing technique which is sensitive to small tilts of mirrors, and WFS signals are obtained by quadrant photodiodes (QPDs). Since the WFS signals have Gouy phase dependence, one have to precisely estimate its behavior and choose QPD position carefully in order to discriminate which mirror causes misalignments in either pitch or yaw. Therefore, one cannot formulate them and give an interpretation.

Here, I will treat the IMC triangular cavity as a block diagram, and compute WFS signals from first principle. Then, I present an analytical formalism which can be used to calculate WFS signals of triangular cavity. Finally, I will compare the performance of KAGRA-like geometry IMC and aLIGO-like one, and discuss desirable IMC geometry for next generation gravitational wave detectors.

Status of KAGRA Physical Environmental Monitors toward the O3 – Tatsuki Washimi (NAOJ)

Physical Environmental Monitors (PEM) play an important role of the noise identification/hunting for GW detectors. Especially, the environmental information of KAGRA will be important for the future GW detectors, because KAGRA is a underground and cryogenic experiment. We have installed the seismometers, accelerometers, microphones and magnetometers to KAGRA site and are monitoring their behavior during the commissioning term. In this talk, we will report the current progress and future prospect of the PEM in KAGRA toward our joining the O3.

Investigation of the magnetic and sound field environments in KAGRA site – Kiichi Kaihotsu (U Toyama)

We will report the results of the sound fields and the magnetic fields environments in the center aria of KAGRA. We placed various physical environmental monitors (PEMs), and for this measurement, we used a microphone and a magnetometer. KAGRA has unique features, one is that the interferometer is located in the underground and another is the four mirrors are cooled down to the cryogenic temperature. In order to join the O3, it is necessary to grasp the environmental noise of this KAGRA environment, so we measured the sound fields and the magnetic fields in December. We measured the environments with 36 locations, and investigated the environmental noise propagation to some chambers and the correlation between the sound and the magnetic fields.

KAGRA DetChar, Science Targets, R&D, and future plans

Detector Characterization for joining O3 observation - Takahiro Yamamoto (ICRR)

In the end of 2019, KAGRA will join the O3 observation. Our urgent tasks are to reach the target sensitivity as soon as possible and to perform stable operation. Detector Characterization (DetChar) group aims to contribute these tasks by evaluating detector noise, and identifying noise sources. Providing data quality (DQ) flags is also crucial task for DetChar in order to conduct the joint GW searches with LIGO and Virgo. I will report the recent detector characterization activities.

Status of the frequency dependent squeezing experiment at TAMA - Yuhang Zhao (NAOJ)

Co-authors:Koji Arai, Naoki Aritomi, MatteoBarsuglia, EleonoraCapocasa, Marc Eisenmann, YuefanGuo, MatteoTacca, MatteoLeonardi, Henning Vahlbruch, Manuel Marchio, Laurent Pinard, EleonoraPolini, Pierre Prat, Roman Schnabel, KentaroSomiya, Ryutaro Takahashi, Chienming Wu, Aso Yoichi, RaffaeleFlaminio

In the current and future generation of gravitational wave detectors, quantum noise will be one of the main limiting noise. Frequency dependent squeezing was proposed to achieve broadband quantum noise reduction. It can be realized by the combination of frequency independent squeezing and detuned Fabry-Perot cavity, usually addressed as filter cavity. A cavity length of 300m was proven to be optimal in terms of round trip loss per meter and detector's sensitivity improvement.

At NAOJ, we are testing the production of frequency dependent squeezing, by using one 300m arm of former TAMA detector as a filter cavity. We have already integrated and locked the cavity and we set up a frequency independent squeezing source in the central area of TAMA. Up to now, we have achieved 4.4dB of squeezing and 15dB of anti-squeezing above 40 kHz. We are currently working to improve the frequency independent squeezing performance and preparing the injection of the squeezing into the filter cavity.

KAGRA scientific contribution to the global detector network - Atsushi Nishizawa (U Tokyo)

KAGRA is planning to join the global detector network from the middle stage of O3 observation. In this talk, I would like to review sciences that can be contributed by KAGRA and show how much KAGRA improves the sensitivity of the detector network to the sciences in O3 and future observations.

KAGRA Upgrade plans and current status of white paper – Sadakazu Haino (Academia Sinica)

Scalar-tensor Gravity Model and Cavity Simulation

A reduced-order model for the scalar-tensor gravity - Lijing Shao (Peking U)

I will talk about testing the scalar-tensor gravity with binary pulsars and gravitational waves using a newly built reduced-order surrogate model.

Finesse simulation of near-unstable cavities with mirror maps - Haoyu Wang (USST)

Near-unstable cavities have been proposed as an enabling technology for future gravitational wave detectors, as their compact structure and large beam spot can reduce the thermal noise floor of the interferometer. These cavities operate close to the edge of geometrical stability, and may be driven into instability via small cavity length perturbations or mirror surface distortions. They are at risk of suffering from problems such as high optical scattering loss and Gaussian mode degeneracy. The well-defined Gaussian beams can also be distorted through their interaction with the small imperfections of the mirror surfaces. These issues have an adverse impact on the detector sensitivity and controllability. We will report the latest simulation study of influences of mirror defects to modes in a near-unstable cavity with realistic mirror maps, compared with the tabletop experiment carried out in Birmingham.

Public Lecture

Advanced LIGO and Gravitational Waves - Jenne Driggers (LIGO Hanford, Caltech)

The Advanced LIGO and Advanced Virgo detectors revolutionized the field of gravitational wave astronomy with the direct detection of gravitational waves from the mergers of compact stellar remnants, almost 100 years after Einstein predicted their existence. During the first two observation runs, the interferometers detected 10 black hole binary mergers, as well as the first coalescence of a binary neutron star which was followed up by electromagnetic telescopes around the world. The third observation run of the advanced gravitational wave network began in April 2019, and has already produced several interesting gravitational wave candidates, all of which were announced publicly within a short time of being seen by the detectors. In this talk I will discuss several of our gravitational wave detections and the science that we have learned from them. I will also discuss the status of the LIGO instruments and conclude with an outlook on upgrades that are currently being prepared to further improve our ability to detect gravitational waves.

LIGO/Virgo Status, Vacuum Birefringence

The Status of LIGO - Jenne Driggers (LIGO Hanford, Caltech)

LIGO, along with Virgo, is in the middle of our third advanced interferometer observation run, and we already have many exciting gravitational wave candidate events. In this talk I will discuss the current status of the LIGO interferometers, some challenges that we have overcome, as well as an outlook for future detector upgrades.

The Status of Virgo - Jo Van Den Brand (NIKHEF)

Present Status of Vacuum Birefringence Experiments - Guido Zavattini (INFN Ferrara)

Vacuum magnetic birefringence is a non-linear electrodynamic effect predicted as a consequence of the formulation of the Euler-Kockel-Heisenberg effective Lagrangian, first proposed in 1935, which takes into account electron-positron fluctuations. A direct laboratory observation of vacuum magnetic birefringence is still lacking today due to its minute value: Δn = 4x10e-24 @ B = 1T.

A brief status in the research field will be given followed by the description of a new initiative: VMB@CERN.

Key ingredients of a polarimeter for detecting such a small birefringence are a long optical path within an intense magnetic field and a time-dependent effect. To lengthen the optical path a Fabry-Perot cavity is generally used. Interestingly, there is a difficulty in reaching the predicted shot noise limit of such polarimeters: the cavity mirrors generate a birefringence-dominated noise whose ellipticity is amplified by the cavity itself limiting the maximum finesse capable of increasing the SNR.

The VMB@CERN collaboration proposes an experiment which overcomes this difficulty by using an

LHC superconducting magnet together with a novel polarization modulation scheme for the polarimeter.

Science, Sources and Underground technology

Japanese Collaboration for Gravitational-Wave Electro-Magnetic Follow-up – Nozomu Tominaga (Konan U)

Japanese Collaboration for Gravitational-Wave Electro-Magnetic Follow-up (J-GEM) is the collaboration of optical to radio telescopes for the follow-up observation of gravitational wave sources. It consists of Subaru 8m telescope and several 0.5-2m telescopes, located at various longitude and north and south hemispheres. We constructed a system that effectively coordinates observations with these telescopes. In this talk, I summarize the activity of J-GEM in the LVC O3 run.

Review to the BH spin measurement in the GW era - Lijun Gou (NAOC)

BHs are one of the most exotic objects in the universe, and usually they are characterized by two parameters: mass and spin. Compared to the mass, the spin is much harder to be constrained. In this talk, I will review the different methods of measuring the BH spin in the traditional EM method. Finally, I will give an prospect on the spin measurement in the GW era.

Host Galaxy Properties of Gravitational Wave Sources Detected by aLIGO and VIRGO - Youjun Lu (NAOC)

Ground-based Laser Interferometer Gravitational Wave (GW) Observatories are expected to detect numerous mergers of stellar mass binary black holes and double neutron stars and provide statistics on the physical parameter distributions of these compact binaries. Combining the multi-messenger signals from both GW and electromagnetic observations, one may obtain the environmental information of those GW sources, which can be used to further constrain the formation and evolution of those compact binaries. In this talk, I will first introduce a simple frame work on the formation of stellar mass binary black holes and double neutron stars in cosmological galaxy formation and evolution model, and then talk about their host galaxy properties and its distribution across cosmic time. I will also talk about the gravitational wave background from those cosmic compact binaries and its detectability by LIGO/VIRGO/KAGRA and LISA.

Status of KAGRA Data Analysis Working Group - Hideyuki Tagoshi（ICRR）

KAGRA data analysis group is preparing KAGRA's observation run which is planned in late 2019. The observation is done while LIGO and Virgo are performing the 3rd observation run (O3). I will present the status of our efforts to perform the data analysis for this observation.

Galactic neutron stars in the era of multi-messenger astronomy - Chunglee Kim (Ewha Womans U.)

Neutron stars are one of the best targets for multi-messenger astronomy (MMA). GW170817 was the first extragalactic double neutron star system and was discovered by gravitational waves (GWs). In this talk, I will focus on the Galactic neutron star population in the context of MMA. As the first topic of the talk, I will summarize our understanding of neutron stars in the center of our Galaxy and discuss prospects GW observations targeting Galactic center. As a second topic, I will introduce Korean effort to observe bright pulsars/magnetars using the Korean VLBI network (KVN). With better sensitivities of future detectors and telescope, we expect we can compare underlying properties of pulsar binaries (mainly observable by electromagnetic waves; most likely to be galactic) and double neutron star systems (observable only by GWs; mostly extragalactic) in the future and understand better their formation and evolution.

Experiences with the underground facility for KAGRA Site - Shinji Miyoki (ICRR, U. Tokyo)

KAGRA is a unique gravitational wave telescope that is constructed underground in Mt. Ikenoyama, Kamioka, Japan, among km-scale gravitational wave telescopes (GWTs) such as advanced-LIGO and advanced-Virgo. Underground environment has some merits, those are low seismic noise and low Newtonian noise for low frequency range, compared with the surface. Actually, underground is regarded as one of a suitable location for the 3rd generation (3G) gravitational wave telescopes such as Einstein Telescope (ET) in Europe. To utilize these underground merits for GWTs, we demonstrated displacement sensitivity enhancement and stable operation of proto-type laser interferometers, LISM and CLIO at the KAGRA site, then we anticipated underground environment for KAGRA. In addition to these, we also accumulated a lot of knowledge about ground motion, gravity changes and so on by using a laser strain meter, a superconductive gravimeter, an absolute gravity meter and pore water pressure meter. In our talk, we will review some results of proto-type interferometers and show specific features of Kamioka underground site.

ZAIGA Project Design

ZAIGA – Zhaoshan Long-baseline Atom Interferometer Gravitation Antenna - Mingsheng Zhan (WIPM)

Long baseline interferometers with electromagnetic waves, such as VLBI, SKA, LIGO, VIRGO, and KAGRA have been developed and widely used in astronomy and gravitational wave detection. On the other hand, large scale atom interferometers (AIs) with matter waves of cold atoms have also been proposed and built in several places, including our 10 m AI in Wuhan [1]. The AI was successfully used to test the Equivalence Principle at 10^{-8} level [2]. Now with these AIs we suggest to build a long-baseline AI, the ZAIGA, for gravitation study. ZAIGA is an underground facility located at Zhaoshan, a mountain in outskirts of Wuhan city. It consists of a vertical tunnel of 300 m high and a horizontal equilateral triangle cave with sides 1 km long (3 km extendable). It will be a home for large scale AIs, laser or atomic gyros, and optical atomic clocks. It serves as a platform for high precision experiments, e.g. quantum test of the weak equivalence principle with entangled atoms [3], local position invariance test by gravitational red-shift, measurement of the Lense-Thirring effects, and mid-band gravitational wave detection.

[1] L. Zhou, Z. Y. Xiong, W. Yang, B. Tang, W. C. Peng, K. Hao, R. B. Li, M. Liu, J. Wang, and M. S. Zhan, Development of an atom gravimeter and status of the 10-meter atom interferometer for precision gravity measurement, *Gen. Relativ. Gravit.* **43**, 1931 (2011).
[2] L. Zhou, S.T. Long, B. Tang, X. Chen, F. Gao, W.C. Peng, W.T. Duan, J.Q. Zhong, Z.Y. Xiong, J. Wang, Y.Z. Zhang, and M.S. Zhan. Test of equivalence principle at 10^{-8} level by a dual-species double-diffraction Raman atom interferometer, *Phys. Rev. Lett.* **115**, 013004(2015).
[3] Y. Zeng, P. Xu, X.D. He, Y.Y. Liu, M. Liu, J. Wang, D.J. Papoular, G.V. Shlyapnikov, and M.S. Zhan, Entangling two individual atoms of different isotopes via Rydberg blockade, *Phys. Rev. Lett.* **117**, 123201(2017).

ZAIGA-GW (Gravitational Wave detection) - Dongfeng Gao (WIPM)

The ZAIGA-GW is a proposed underground GW detector in an equilateral triangle configuration. To minimize the effect of the seismic noise, the whole detector is about 200-meter-on-average below a mountain. With two 3-km-apart laser-linked AIs, each arm can detect the GW independently. In other words, the ZAIGA-GW actually consists of three co-located GW detectors in a closed triangle. It has several advantages: the generation of null data stream, a full detection of GW polarizations, and 100% on duty. The ZAIGA-GW can fill in the detection gap between the ground-based laser interferometer GW detectors (such as LIGO) and the future space-based GW detectors (such as LISA) [1].

[1] Ming-Sheng Zhan *et al.*, ZAIGA: Zhaoshan Long-baseline Atom Interferometer Gravitation Antenna, *Int. J. Mod. Phys. D* **28** (2019), 19400054; arXiv:1903.09288.

ZAIGA-EP (Equivalence Principle test) – Lin Zhou (WIPM)

The ZAIGA-EP apparatus will locate at the 300-meter-vertical tunnel, where two10-meter atom fountains[1] mounted on both top and bottom of the tunnel. The primary goal of ZAIGA-EP is to test the weak equivalence principle (WEP) using atom interferometers (AIs). The secondary goal is 300-meter-vertical prototype antenna for mid-frequency gravitational waves. In this talk, we will present recent progress on WEP test using ^{85}Rb and ^{87}Rb atoms [2,3]. In addition, the overall structure of ZAIGA-EP, main technical parameters and key techniques for ZAIGA-EP will be briefly introduced.

Keywords: Weak Equivalence Principle test, Atom Interferometry,

References:

[1] L. Zhou, Z.Y. Xiong, W. Yang *et al*, Gen. Relativ. Gravit. **43**, 1931 (2011).

[2] L. Zhou, S. T. Long, B. Tang, *et al.*,Phys. Rev. Lett.**115**,013004(2015).

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ZAIGA-CE (Clock-based Experiment) - Lingxiang He (WIPM)

Gravitational redshift is predicted by Einstein general relativity as a classical phenomenon. Observing the gravitational redshift in the solar system is one of the classical tests of general relativity. In a gravitational field, clock swill ticks slower from a viewpoint of a distant observer. We will describe the lattice clock-based gravitational redshift measurement in the ZAIGA project. It's a good opportunity to verify the local position invariance (LPI) experiment with two lattice optical clocks. By comparing the frequency ratios of the two clocks, we can demonstrate the extent of LPI violation at 100-meter height. So violation of LPI can be tested on the same order of magnitude or even better than GP-A experiment on the ground 40 years later.

ZAIGA-RM (Rotation Measurement) - Runbing Li (WIPM)

Since the atom interferometer was realized in 1991 [1], its application has been found in rotation measurements [2-6]. The sensitivity of an atom gyroscope can be improved by suppressing the phase noise and enlarging the atomic interference area.

In this talk, we will firstly present the experimental progress of the atom gyroscope in WIPM. The dual atom interferometers were used to build the atom gyroscope, and the dynamic rotation was measured by modulating the platform [7]. Due to the fact that the symmetry and overlapping of atomic trajectories becomes important as the area of the atom-interferometer loop is increased, we developed a method for calibrating atomic trajectories in the large-area dual-atom-interferometer gyroscope. The performance of the dual-atom-interferometer gyroscope was evaluated, and its long-term stability is 8×10^{-9} rad/s @ 5000 s. The Earth's rotation rate was precisely measured with our dual-atom-interferometer gyroscope [8]. Then, we will introduce a large-scale dual-atom-interferometer gyroscope which may be developed in WIPM for precisely measuring the Lens-Thirring effect in the future.

Keywords: Atom interferometry, Atom gyroscope, Earth's rotation rate, Precision measurement

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DECIGO and Neutron Interferometry

B-DECIGO and DECIGO - Masaki Ando (Physics, U Tokyo)

Hamiltonian of a free neutron in curved spacetime on the Earth and application to neutron interferometer – Toshifumi Futamase (Kyoto Sangyo U)

We derived full expression of Hamiltonian of a free neutron moving on the curved spacetime produced by gravitational field of the Earth from the covariant Dirac equation in the Kerr spacetime used as the first principle including general relativistic effects up to the first post-Newtonian order. The observability of these effects by neutron interferometer is discussed.

GW Space Missions

LISA - Gerhard Heinzel (AEI, Hanover)

The gravitational detector LISA has been selected as large mission by ESA, for a launch around 2034. It is now in Phase A, with the target of defining a baseline mission later this year. I will summarize the expected science from LISA, the results from LISA Pathfinder and GRACE Follow-On and the ongoing design work.

TIANQIN - Jun Luo (Sun Yet-Sen U)

Digital phasemeter and weak-light phase locking for space-borne GW detect missions - Yurong Liang (WIPM)

Pico-meter level laser interferometer is an important equipment in the future space-borne GW detectors like LISA, TIANQIN and Taiji. The ultra-low noise laser interferometer requires high precision phasemeter to extract the phase or frequency of the beatnote. One other challenge is that the received light is as weak as pico-Watt level because of the long arm-length and the finite aperture of the telescope. An optical phase-locked loop must be equipped to transfer the phase information of the incoming light back to the interferometer on the remote spacecraft. On the basis of the research on the digital phasemeter, digital control algorithm has been implemented on weak-light phase locked loop for auto-locking. In this talk, I will introduce the development of digital phasemeter and the preliminary experiment results of weak-light phase locked loop.

TAIJI - Yueliang Wu (ITP, CAS)

Study of a Joint LISA-TAIJI Observation Scenario – Orbit Design, Sensitivity & Angular resolution Improvement, and Deployment – AD group

In the Xiang Shan meeting on GW (Gravitational Wave) detection in space (April 17-18, 2019), a discussion between LISA team and TAIJI team focussed on the joint observation of LISA and TAIJI to observe more sensitively on the GW background and to improve the angular resolution of GW sources for quicker identification of sources for multi-messenger observations. Here we study orbit design and angular resolution for this joint observation. We find an optimized LISA science formation drifting 18-22° behind the Earth's solar orbit for 6 years according to LISA requirement with nominal arm length 2.5 Gm. Simultaneous with the LISA formation, we find a set of optimized TAIJI science formation drifting18-22° in front of the Earth's solar orbit for 6 years according to TAIJI requirement with nominal arm length 3 Gm. With joint LISA and TAIJI observation of GWs, the distance span of 2 formations reached 100 Gm. The angular resolution in a short period of time (e.g. bursts) improved by 30 times. The sensitivity for GW background is improved by 2 orders of magnitude.

Laser Frequency Study for TAIJI - Lisheng Chen (WIPM)

Ultra-stable laser is one of the key elements in a space-based long-baseline laser interferometer. The primary solution to the laser source is an on-satellite frequency and intensity stabilized Nd:YAG laser. The system consists a NPRO (non-planer ring oscillator) based Nd:YAG seed and a fiber optic gain stage, being capable of delivering more than 2 W optical power at 1064 nm. The frequency noise of the pre-stabilized laser will be on the order of 30 Hz/ÖHz at Fourier frequency of 1 mHz. The talk concentrates on the frequency stabilization of the Nd:YAG laser. Several candidate stabilization schemes will be discussed, and the development of a portable system based on an ultra-stable optical reference cavity will be introduced.

Simulations of Postprocessed Time Delay Interferometry for TAIJI mission – Li'e Qiang (Chang'an U)

The Taiji mission is a future planned laser interferometer gravitational wave (GW) antenna that initiated by Chinese Academy of Sciences since 2008. Being a LISA-like mission, Taiji will have three almost identical space-crafts that form a triangle constellation (with armlength about 3 million kilometers) following heliocentric orbits. The incoming GWs will modulate the frequencies of the laser light propagating in-between the space-crafts, which are then supposed to be isolated in the inter-satellites heterodyne interferometry readouts. However, the measurement laser links will be plagued by many noise sources, especially the laser frequency and clock instabilities whose affects will be several orders of magnitudes larger compared to the magnitudes of the expected GW signals. Therefore a key technology of data processing called the time-delay interferometry (TDI) was developed in the literature to sufficiently remove or compress the dominate noises and as the same time maintain the GW signals in the inter-satellites measured data. In this work, based on the optimized orbits, we applied the 2nd TDI algorithm to Taiji and set up the first stage simulator for Taiji's TDI data flow. We tried to verify the efficiency of the main noises compression such as the ones from laser carrying frequency instability, clock instability, optical bench jitters and etc. Corrections from the Doppler shifts due to the relative orbital motions between space-crafts are included in the frequency plan and therefore are included in the clock noise removal algorithm. This work is supported by the by the Strategic Priority Research Program of CAS and also the MPG-CAS collaboration.

Transportation

Date (June)	Departure Time	Gathering place	Destination	Note
21st	8:25	Hotel	WIPM	The bus arranged is only available at **East Lake Hotel** and **Hongshan Hotel**
	20:50	WIPM	Hotel	
22nd	8:25	Hotel	WIPM	
	21:10	Hu Jin Restaurant	Hotel	
23rd	8:25	Hotel	WIPM	
	18:10	WIPM	Hotel	

Contact person

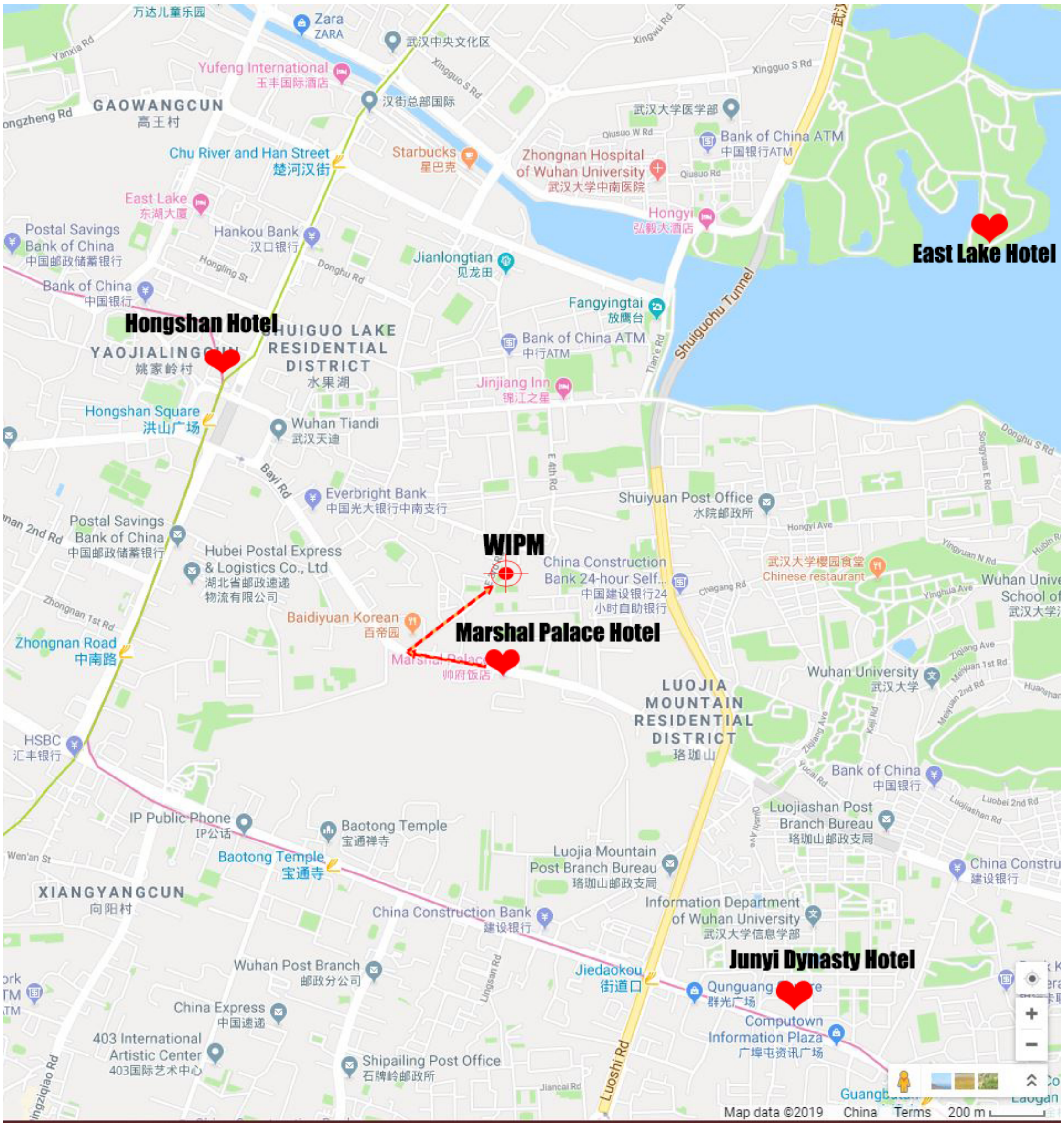
Hotel	Contact person	Cell	E-mail
East Lake Hotel	Panwei Huang	+86 18771036941	huangpanwei@wipm.ac.cn
Hongshan Hotel	Ruijun Guo	+86 18207161496	1115733235@qq.com
Marshal Palace Hotel	Xiao Li	+86 13237180067	lixiao@wipm.ac.cn
Junyi Dynasty Hotel	Guiguo Ge	+86 18020287061	geguiguo@wipm.ac.cn

Schedule for Meals

Date(June)	Lunch	Dinner
21st	Buffet (Canteen of Wuhan Institute of Physics and Mathematics)	Box Lunch （(Meeting Room on the 4thFloor)
22nd	Buffet (Canteen of Wuhan Institute of Physics and Mathematics)	Table (Hu Jin RestaurantRoom No. 418)
23rd	Buffet (Canteen of Wuhan Institute of Physics and Mathematics)	

Hu Jin Restaurant: 湖锦酒楼

Address: Wuchang district, Ba Yi Road No.105 .武昌八一路 105 号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Hongshan Hotel
WIPM
Marshal Palace Hotel
Junyi Dynasty Hotel
GAOWANGCUN
YAOJIALING
LUOJIA MOUNTAIN RESIDENTIAL DISTRICT
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