Abstract (Plenary)

July 3 (Mon) 09:15-12:30

Pl3-1

Quantum Clones in the Interior of a Black Hole

Gerard 't Hooft
Utrecht University

Black holes are more than just odd-looking curiosities in gravity theory. They uniquely intertwine the basic principles of General Relativity with those of quantum theory. Just by demanding that they nevertheless obey acceptable laws of dynamics, just like stars and planets, we hit upon strange structures that must play key roles in the quantum effects that we expect in the gravitational force at ultrashort distance scales.

Pl3-2

Quantum Improved Black Holes in Asymptotically Safe Gravity

Chiang-Mei Chen
National Central University, Taiwan

In this talk, I will discuss the quantum improvement of black hole solutions in the context of asymptotic safety. The Newton coupling in this formulation depends on an energy scale, which must be identified with some length scale in order to study physical consequences to black holes. We propose that the consistency of the first law of thermodynamics is the principle that should determine physically sensible scale identification, at least close to the horizon. I will discuss some interesting physical consequences, such as the phase structure of the quantum improved black holes.

Pl3-3

Cosmological Implications of James Webb

Wendy Freedman
U Chicago

The question of whether there is new physics beyond our current standard model, Lambda Cold Dark Matter (LCDM), is a crucial unresolved issue in cosmology today. Recent measurements of the Hubble constant (Ho) using Cepheids and Type Ia supernovae (SNe) appear to differ significantly (5-sigma) from values inferred from the cosmic microwave background (CMB) fluctuations. This discrepancy, if real, could indicate new physics beyond the standard model. In this talk, I will review results using data from the Hubble Space Telescope using Cepheids as well as the Tip of the Red Giant Branch (TRGB). A comparison of these results indicates that there remain systematic uncertainties in the local calibration of Ho. I will describe a new program using the James Webb Space Telescope (JWST) aimed at reducing uncertainties in extragalactic distances and the measurement of Ho, and present some new, preliminary results. JWST has four times the resolution and ten times the sensitivity of HST in the near infrared, and will be critical for ascertaining whether new physics is required beyond the standard model of cosmology.

PL3-4

Present and Future Terrestrial GW Detectors

David Shoemaker
MIT

The present network of terrestrial laser interferometric gravitational-wave detectors have demonstrated the initial possibilities for GW observational science, both stand-alone and multi-messenger. The network of LIGO, Virgo, and KAGRA has recently started its O4 observing run with higher sensitivity. Activities are underway for refinements of the current detectors to reach design sensitivity in an O5 run in the late 2020's. More aggressive rework is in planning for a final upgrade of the instruments to be operational in the early 2030's.. Then, on the longer timescale, Cosmic Explorer and Einstein Telescope are US and European proposals to build new infrastructures with longer baselines, offering a factor of 10 improvement over the current instruments. These new observatories could be on line by mid-2030.

July 4 (Tue) 09:00-12:30

Pl4-1

QCD critical Point and Induced Gravitational Wave by Black Hole Physic

Rong-Gen Cai
ITP-CAS

We build a holographic model of QCD matter at finite baryon chemical potential and finite temperature. Fixing all model parameters by use of the state-of-the-art lattice QCD data at zero chemical potential, the predicted equations of state and QCD trace anomaly relation are in quantitative agreement with the latest lattice results. We then give the exact location of the critical endpoint as well as the first-order transition line, which is within the coverage of many upcoming experimental measurements. Moreover, using the data from our model at finite baryon chemical potential, we calculate the spectrum of the stochastic gravitational wave background associated with the first-order QCD transition in the early universe, which could be observable via pulsar timing array in the future

Pl4-2

Quantum effects outside and inside black holes

Elizabeth Winstanley
University of Sheffield

We review some recent developments in quantum field theory on black hole space-times, both outside and inside the event horizon. The renormalized expectation value of the stress energy tensor (RSET) is an object of central importance as it governs the backreaction of the quantum field on the space-time geometry, but calculating the RSET on black hole space-times is far from trivial. The original methodology was developed in the 1980s and 1990s and successfully applied to a range of quantum fields on four-dimensional Schwarzschild black holes. The subject has enjoyed a renaissance in recent years with the development of novel approaches to computing the RSET and renormalized vacuum polarization (VP). These advances have enabled calculations on a wider range of black hole space-times to be performed and new physics questions to be addressed. In this talk we will discuss some recent results for the RSET and VP on a range of black hole backgrounds to give a flavour of the insights to be gained into the quantum properties of black holes both outside and inside the event horizon.

Pl4-3

Hamiltonian reduction of Einstein's theory without isometry

Jong Hyuk Yoon
Konkuk University

A mathematical prescription of a complete Hamiltonian reduction using (2+2) Hamiltonian formalism of Einstein's gravity without isometry is presented. The area of a cross-section of an out-going null hypersurface is chosen as the privileged time coordinate, and the privileged spatial coordinates are chosen as the coordinates of (and on) equipotential surfaces of a certain function on the gravational phase space. In the privileged coordinates, all the constraints are solved completely, and gravitational Hamiltonian and momentum densities are expressed as local functions of physical degrees of freedom. The logarithm of the 4 volume element of spacetime metric in the privileged coordinates turns out to be a superpotential, whose gradient is the energy-momentum 4 vector of physical Hamiltonian and momentum densities. The Hamilton's equations of motion obtained through Hamiltonian reduction agree with Einstein's equations in the privileged coordinates. This work is a generalization of Hamitonian reduction of Einstein's theory with two Killing vector fields by K. Kuchar to spacetimes without isometry.

PL4-4

The black hole astrophysics in the era of multi-messenger astronomy

Chunglee Kim
Ewha Womans University

The 21C has been a golden era of black hole astrophysics. Existence of stellar-mass black hole binaries were confirmed by gravitational-wave observations. The images of supermassive black holes at the center of galaxies were taken by the frontier technique of radio interferometry. Recent observations play a crucial role to improve our understanding of black holes. With upgrades of existing facilities and R&D to establish better, powerful instruments, more discoveries and surprises are expected. In this plenary talk, I will give an overview on the recent progress in black hole astrophysics mainly based on observations. I will also discuss some of the big questions to be answered in the context of black hole astrophysics.

Pl4-5

Cosmic expansion versus motion: Probing the difference

David Wiltshire

U Canterbury

General inhomogeneous cosmologies give rise to differential cosmic expansion which differs from that of Friedmann-Lemaitre-Robertson-Walker (FLRW) models. Even models with an average isotropic homogeneous isotropic expansion law on > 100/h Mpc scales will generically have expansion laws which differ from FLRW plus local Lorentz boosts. That is, they differ from the conventional "kinematic interpretation". Strong evidence (~ 5.1 sigma) against the kinematic interpretation has been provided by Secrest et al (2022), combining the Ellis-Baldwin test on 1.36 million distant quasars with similar studies of radio galaxies. There is a correlation with CMB anomalies. Such signatures are a generic expectation in models which differ from FLRW, exhibiting backreaction, including the timescape cosmology. The particular features of nonkinematic differential expansion, regardless of the backreaction scheme, can be isolated by constructing toy Lambda-Szekeres models which asymptote to FLRW/Lamda CDM on > 100/h Mpc scales but exhibit nonkinematic differential expansion on smaller scales. In this talk I will discuss ongoing work with the goal of constraining such toy models by local peculiar velocity data, and then using such models to probe the Ellis-Baldwin test, which in itself challenges the standard cosmology

July 5 (Wed) 09:00-12:30

Pl5-1

From the solar system to the first galaxies: how JWST is revolutionizing our view of the Universe

Elena Sabbi
STScI

Since the beginning of science operation just one year ago, the James Webb Space Telescope (JWST) has ushered in a new era in astronomy. In this talk, I will provide an overview of the remarkable journey that has brought us to this point, highlighting the telescope's design, instrument capabilities, launch, and commissioning process. I will then delve into the astonishing results already achieved by JWST and explore their implications for our understanding of the Universe in the years to come. With its unparalleled capabilities, JWST promises to revolutionize our view of the cosmos, shaping the course of astronomy in the decades to come. JWST's advanced technologies and innovative design allow it to capture stunningly sharp images and gather exquisite spectra from solar system planets to embedded star-forming regions to the first galaxies across a wide range of wavelengths. I will discuss how JWST's preliminary results are revolutionizing our understanding of the formation and evolution of stars and planets and challenging our view of the Universe's evolution.

Pl5-2

Numerical Relativity in Multi-messenger Era

Kenta Kiuchi
AEI Potsdam

Since the first observation of GW170817, AT2017gfo, and GRB170817A, there is no doubt that the binary neutron stars will continue playing a leading role in the multimessenger astronomy era. A precise numerical relativity simulation implementing the effects of all the fundamental interactions is the chosen way to theoretically predict and interpret binary neutron star mergers. In this talk, I will discuss the current status of our understanding of binary neutron star mergers and introduce a cutting-edge simulation result.

Pl5-3

Beyond Einstein's General Relativity: Hybrid metric-Palatini gravity and curvature-matter couplings

Francisco S.N.Lobo
Institute of Astrophysics and Space Sciences, University of Lisbon

Einstein's General Relativity (GR) is possibly one of the greatest intellectual achievements ever conceived by the human mind. In fact, over the last century, GR has proven to be an extremely successful theory, with a well established experimental footing. However, the discovery of the late-time cosmic acceleration, which represents a new imbalance in the governing gravitational field equations, has forced theorists and experimentalists to question whether GR is the correct relativistic theory of gravitation, and has spurred much research in modified gravity, where extensions of the Hilbert-Einstein action describe the gravitational field. In this talk, we perform a detailed theoretical and phenomenological analysis of two largely explored extensions of f(R) gravity, namely: (i) the hybrid metric-Palatini theory; (ii) and modified gravity with curvature-matter couplings. Relative to the former, it has been established that both metric and Palatini versions of f(R) gravity possess interesting features but also manifest severe drawbacks. A hybrid combination, containing elements from both of these formalisms, turns out to be very successful in accounting for the observed phenomenology and avoids some drawbacks of the original approaches. Relative to the curvature-matter coupling theories, these offer interesting extensions of f(R) gravity, where the explicit nonminimal couplings between an arbitrary function of the scalar curvature R and the Lagrangian density of matter, induces a non-vanishing covariant derivative of the energy-momentum tensor. We explore both theories in a plethora of applications, namely, the weak-field limit, cosmology, and the irreversible matter creation processes of a specific curvature-matter coupling theory.

Pl5-4

Pioneering science with the Laser Interferometer Space Antenna

Elena Rossi
Leiden U

In this talk, I will present the ESA mission LISA (Laser Interferometer Space Antenna, with launch in mid 2030s), and the revolutionary science allowed by its unprecedented data. LISA is a laser interferometer in space that will allow us to detect gravitational waves (GWs) in the milliHz frequency band: this is expected to be the richest band in terms of variety of sources. The most common sources will be white dwarf binaries, while the loudest will be mergers of supermassive black holes. In addition, we expect signals from stellar mass compact objects falling into supermassive black holes in galactic nuclei, and a stochastic background from primordial gravitational wave signals from the infancy of the Universe. I will walk through the richness of science cases --from astrophysics, to fundamental science to cosmology-- that can be pursued with LISA detections of these sources.

Pl5-5

Generating Peaks and Troughs in Primordial Perturbation Spectra

Alexei Starobinsky
Landau Inst Moscow

At the present state-of-the-art, the simplest inflationary models, based either on scalar fields in General Relativity or on modified f(R) gravity, which produce the best fit to all existing observational data, require only one dimensionless parameter to be taken from observations. These models include the pioneer $R+R^2$ (Starobinsky) one, the Higgs model, and the mixed R^2-Higgs model which has been shown to be effectively one-parameter, too. They predict scale-free and close to scale-invariant power spectra of primordial scalar perturbations and gravitational waves generated during inflation. Their target prediction for the tensor-to-scalar ratio is r=3(1-n_s)^2 = 0.004, that is still about one order of magnitude less than the present upper bound. Still future observations, in particular the discovery of primordial black holes, may prove that the primordial scalar power spectrum has additional local peaks and troughs what requires at least two new phenomenological parameters. I discuss mechanisms to produce such features including the recently proposed one which arise in many-field inflation with a large non-minimal kinetic term of an inflaton field leaving inflation before its end. In this case, in addition to PBHs, large peaks in the primordial tensor perturbation spectrum at small scales are generated in the second order of scalar perturbations. As for local non-scale-free features at cosmological scales suggested by features in the CMB temperature anisotropy for l = 2 and in the range l = 20-30, the existing CMB data including CMB polarization do not favor them, but are not able to exclude them completely.

July 6 (Thu) 09:00-12:30

Pl6-1

7-Dimensional Telescope for Multi-Messenger Astronomy

Myungshin Im
Seoul National University

The 2017 detection of the binary neutron star (BNS) merger event in both gravitational wave (GW) and electromagnetic wave (EM), GW170817, has shown the great potential for multi-messenger astronomy, allowing us to understand the link between neutron star mergers and gamma-ray bursts, physical mechanisms and environments of the EM counterpart, kilonova (KN), and cosmology with GW sources. Yet, GW170817 is still the only GW event for which MMA was possible. With the start of the LVK O4 run in May 2023, the situation is now changing. The forecast is about 10 BNS merger event detections during O4, with many of them having a GW localization accuracy on par with GW170817. To capitalize on the anticipated GW source discoveries, we have prepared an optical EM follow-up network of telescopes named the Gravitational-wave EM Counterpart Korean Observatory (GECKO). In particular, we are now constructing a new facility, the 7-Dimensional Telescope (7DT) in Chile for multi-messenger astronomy. 7DT is a multiple-telescope system that can perform spectral mapping over a wide field of view (> 1 deg2) and will be efficient in catching KNe associated with future GW events. A partial system of 7DT started operation. In this talk, we will outline the current challenges of optical/NIR counterpart observations for the KNe discovery and outline our past GW optical follow-up activities. Then we will introduce 7DT and our observing strategy as well as early results using the telescope.

Pl6-2

Concordance model and cosmic tensions: The gravity of the situation

Leonardo Giani
The University of Queensland

The LCDM model, despite providing the most successful description for the evolution of the Universe over the past 13 Gyr, has recently been under siege by a quartet of statistical tensions on the values inferred by different probes of a few critical Cosmological parameters. These are the rate of expansion of the Universe today H_0, the linear growth rate of structures at the pivotal scale of 8 Mpc σ_8, the energy density of the spatial curvature Ω_k and the direction and amplitude of the kinematic dipole v_{CMB} induced by our peculiar motion with respect to the Cosmological rest frame.
Whilst these tensions might be individually attributed to unaccounted experimental systematics, it is unavoidable (and tempting) to consider the possibility that they collectively hint towards new physics beyond LCDM. In this talk, I will briefly review the evidence for a physical interpretation of these tensions and explore their possible interplay. I will also provide a bird-eye view of the most studied strategies to solve or alleviate (some of) these tensions. Finally, I will speculate on these tensions' impact on our current understanding of the Universe and the gravitational interaction.

Pl6-3

TianQin: the Chinese mission to detect gravitational waves in space

Jun Luo
TianQin Center, Sun Yat-sen University

TianQin is a space-based gravitational wave (GW) detector expected to launch around 2035. It will detect GWs in the frequency band 0.1 mHz~1 Hz, offering the chance to detect GWs from a large variety of sources, such as massive black holes, stellar mass black holes, Galactic compact binaries, and so on. The mission was officially proposed in 2014 and has passed a couple of its main milestones. In this talk, I will introduce the mission and the main progress that has been made.

Pl6-4

Cosmological Implication of Electroweak Monopole

Yongmin Cho
Seoul National University

We discuss the physical implications, in particular the cosmological im[plications, of the electroweak monopole. As the only stable heavy particle in the early universe, it could become the seed of the primordial blackholes, the large scale structure of the universe, and source of the intergalactic magnetic field. Moreover, there are enough remnant monopoles in the present universe which can be detected. Most importantly, it generates the magnetic current, and becomes the topological avatar of the new physics.

Pl6-5

Blue Sky Physics with Dedicated Detectors at the LHC

James Lewis Pinfold
University of Alberta

The MoEDAL experiment , the first dedicated search experiment at the LHC, took data at LHC's Run-1/2. It was focussed on the quest for highly ionizing avatars of new physics. At LHC's' Run-3. the upgraded MoEDAL-MAPP experiment has an enhanced reach for physics beyond the Standard Model that includes sensitvity to highly ionizing, feebly ionizing, and, very long-lived particle messengers of new physics. MoEDAL-MAPP has now been joined at Run-3 by the FASER and MILLIQAN. experiments. Concentrating on MoEDAL-MAPP we will discuss all of these new dedicated search experiments and their physics horizons, in arenas that have cosmological implications., such as the search for dark matter.

Pl6-6

Anisotropic Horndeski Cosmology

Sergey Sushkov
Kazan Federal University

In this talk we will discuss the most general scalar-tensor theories of gravity which contain the only single scalar degree of freedom. These theories, known as Degenerate Higher-Order ScalarTensor (DHOST) theories, include Horndeski and Beyond Horndeski theories. More details, we will focus on the particular subclass of models, known as the theory of gravity with non-minimal derivative coupling, and consider isotropic and anisotropic cosmological models in such the theory. As well, we will shortly discuss compact astrophysical objects (black holes, wormholes, neutron stars) in the theory of gravity with non-minimal derivative coupling.

July 7 (Fri) 09:00-12:30

Pl7-1

GRB220101A the most powerful GRB with seven BdHN Episodes observed

Remo Ruffini
ICRANet

A long GRB that occurred at 2022-01-01 05:11:13 (UT), was triggered by multiple satellites, including Swift (Tohuvavohu et al. 2022), Fermi (Arimoto et al. 2022), AGILE (Ursi et al. 2022), and Konus-Wind (Tsvetkova et al. 2022). The optical observation by Xinglong-2. 16m telescope (Fu et al. 2022) revealed a broad absorption feature in the spectrum indicating the presence of Lyman alpha absorption, as well as from the absorption lines, the redshift was determined to be z=4.61, which was confirmed by the Liverpool tlescope (Perley 2022) and NOT (Fynbo et al. 2022). The burst exhibited a bright, complex multi-peaked time profile within the first ~ 150s. An estimated isotropic equivalent energy is of $L_{iso} \sim 4 \times 10^{54}$ erg, and a peak luminosity is of $L_p \sim 9 \times 10^{53}$erg s^{-1}, making GRB 220101A as one of the most luminous GRBs ever observed. The fact that it occurs at z=4.6 gives a great opportunity to exploit new perspectives of observations as presented in Bianco et al. 2023. The discovery of a radio source with a mean frequency of 6.0 GHz was reported in Laskar (2022a). This finding aligns with the X-ray position noted in Osborne et al. (2022), as well as the optical positions reported by Tohuvavohu et al. (2022) and Hentunen et al. (2022), along with the mm-band position mentioned in Laskar (2022b). All seven episodes characterizing a BdHN I, as predicted in Ruffini et al. (2022a,b), have been identified, details are presented in Ruffini et al., (submitted). Our attention in this article is to identify the earliest XRT observations meade possible by the use of the cosmological redshift of z = 4.61 and to obtain an unprecedented accurate description of the rising part and the power-law decay part of the X-ray emission evidencing the transition from a Jacobi ellipsoid into a Mac Laurin spheroid in the description of the newNS originating the afterglow.

Pl7-2

Cosmology of Primordial Black Holes and Gravitational Waves

Misao Sasaki
Kavli IPMU, University of Tokyo

After briefly reviewing what primordial black holes are and how they may have formed in the early universe, some recent topics will be discussed in particular in the context of gravitational wave cosmology.

Pl7-3

Imaging Black Holes with EHT

Mariafelicia De Laurentis
U Napoli

The Event Horizon Telescope has presented the first images of the shadows of the black holes in the Milky Way and in the M87 galaxy. The observed radiation has originated in two of the strongest gravitational fields found in the Universe, encoding during their travel to the Earth the properties of the black-hole spacetimes. In this talk, I'll give a rundown of the scientific process, imaging analysis, and theoretical explanation that led to the release of the first EHT images of supermassive black holes.

Pl7-4

Towards the detection of nonclassical primordial gravitational waves

Sugumi Kanno
Kyushu University

One of the cornerstones of inflationary cosmology is that the large scale structure of the Universe has a quantum mechanical origin. This invites the question of whether compelling observational evidence for the quantum nature of the origin can be found. Primordial gravitational waves are generated directly from quantum fluctuations during inflation. Since they interact with matter very weakly, travel through the Universe virtually unimpeded, it is expected that they keep their nonclassicality until today. In this talk, I will present some methods to clarify whether the universe has a quantum mechanical origin by detecting the nonclassical primordial gravitational waves.

Abstract (Parallel)

July 3 (Mon) 14:00-16:00

A4. Modified gravity

Pa1-a1

Scalar-Tensor Gravity at the First Loop

Boris Latosh
Center for Theoretical Physics of the Universe, Institute for Basic Science

In this talk, I will review the recent progress made in the implementation of perturbative quantum gravity for scalar-tensor gravity models. The perturbative approach views gravity as a quantum theory of small metric perturbations propagating around flat spacetime. I will briefly discuss the renormalization issues that arise from this theory, and despite it being non-renormalizable, it allows us to analyze both the UV and IR limits of the theory. Furthermore, I discuss the usage of the effective action technique which is a powerful tool that enables us to draw meaningful conclusions about the impact of quantum gravitational effects on the early Universe. I will base our discussion on recent papers, including arXiv:2003.02462, 2004.00927, 2102.08025, 2109.09797, and 2201.06812.

Pa1-a2

Symmetric teleparallel theory of gravity and its extensions

Avik De
Universiti Tunku Abdul Rahman

The standard theory of gravity, governed by Einstein's general relativity (GR) is formulated based on the curvature of the spacetime. Whereas there are two other geometric entities which can demonstrate gravity, torsion and non-metricity. In the present talk, a flat and torsion-free affine connection is used to formulate an equivalent theory of GR from its non-metricity tensor. The most important formulations in such theory and its extension in the form of f (Q), f (Q, T) and f (Q, C) are discussed. The cosmological and astrophysical implications and finally the possible limitations of such theories are described.

Pa1-a3

The reheating constraints to natural inflation in Horndeski gravity

Gansukh Tumurtushaa
Jeju National University

For the subclass of Horndeski theory of gravity, we investigate the effects of reheating on the predictions of natural inflation. In the presence of derivative self-interaction of a scalar field and its kinetic coupling to the Einstein tensor, the gravitational friction to inflaton dynamics is enhanced. As a result, the tensor-to-scalar ratio is suppressed. We place the observational constraints on a natural inflation model and show that the model is now consistent with the observational data, mainly due to the suppressed tensor-to-scalar ratio. To be consistent with the CMB data at the 1σ (68% confidence) level, a slightly longer inflation is preferred. Consequently, we imposed the effects of reheating to the inflationary predictions to put further constraints. The results show that the duration of inflation is affected by considerations of reheating. If reheating occurs instantaneously, the duration of inflation is estimated to be N~57 e-folds. The duration of inflation is longer (or shorter) than N~57 e-folds for the equation of state larger (or smaller) than 1/3. The maximum temperature at the end of reheating is 3×10^{15}GeV, which corresponds to the instantaneous reheating. The low reheating temperature, as low as a few MeV, is also possible when the equation of state is closer to 1/3.

Pa1-a4

A comprehensive phase space analysis of the Hu-Sawicki $f(R)$ model

Saikat Chakraborty
The Institute for Fundamental Study "The Tah Poe Academia Institute", Naresuan University

One of the popular late-time $f(R)$ models is the Hu-Sawicki model. I will present a comprehensive compact phase space analysis of FLRW cosmologies in the Hu-Sawicki $f(R)$ model for the parameter choice $\{n, C_1\} = \{1,1\}$. I will outline how, given an $f(R)$ model, one can determine the coordinate of the phase space point that corresponds to the present-day Universe and the equation of a surface in the phase space that represents the ΛCDM evolution history. Then I will discuss what results it gives when we apply the above procedures to the Hu-Sawicki model under consideration. Lastly, I will present a numerical analysis comparing the ΛCDM evolution and Hu-Sawicki evolution. My talk will be based on our recent work 2208.15002.

Pa1-a5

WIMPs in Dilatonic Einstein Gauss-Bonnet Cosmology

Arpan Kar
Center for Quantum Spacetime (CQUeST), Sogang University

In this talk I will discuss how the Weakly Interacting Massive Particle (WIMP) thermal decoupling scenario can be used to probe Cosmologies in dilatonic Einstein Gauss-Bonnet (dEGB) gravity, where the Gauss–Bonnet term is non–minimally coupled to a scalar field with vanishing potential. Constraints on the model parameters can be obtained when the ensuing modified cosmological scenario drives the thermal WIMP annihilation cross-section beyond the present bounds from dark matter indirect detection searches. In the presentation I will assume WIMPs that annihilate to Standard Model particles through an s-wave process. I will also show that the bounds from WIMP indirect detection are nicely complementary to late-time constraints from compact binary mergers. This suggests that it could be interesting to use other Early Cosmology processes to probe the dEGB scenario.

D1. Dark Energy

Pa1-c1

Evidence for strong progenitor age bias in supernova cosmology

Young-Wook Lee
Yonsei University

Supernova (SN) cosmology is based on the assumption that the width-luminosity relation (WLR) in the type Ia SN luminosity standardization would not show a luminosity offset with progenitor age. Unlike this expectation, recent age datings of stellar populations in host galaxies have shown significant correlations between progenitor age and Hubble residual (HR). Here we show that this correlation originates from a strong progenitor age dependence of the zero-point of the WLR, in the sense that SNe from younger progenitors are fainter each at given light-curve parameters x1 and c. This 4.6 sigma result is reminiscent of Baade's discovery of the zero-point variation of the Cepheid period-luminosity relation with population age, and, as such, causes a serious systematic bias with redshift in SN cosmology. When this progenitor age bias is properly taken into account, there is little evidence left for an accelerating universe, urging follow-up investigations with larger samples at different redshift bins.

Pa1-c2

Is H_0 a constant?

Eoin O Colgain
Atlantic Technological University

If Lambda-CDM tensions are physical and not due to systematics, they imply a breakdown in the model. For physicists, this necessitates evolution of constant fitting parameters within the LCDM model. I will highlight observations supporting redshift evolution of cosmological parameters in LCDM cosmology. These observations tie together H0 and S8 tensions, and imply that either dark energy is not the cosmological constant or matter is not pressure-less.

Pa1-c3

Dark energy from quantum entanglement

Jaeweon Lee
Jungwon univ.

We reconsider the idea that the vacuum entanglement energy, which is associated with the entanglement entropy of the horizon of the universe, is the source of holographic dark energy. By examining the properties of entanglement energy, we can explain the observed behavior of dark energy without resorting to modifications of gravity or exotic matter. We also explore the potential of this model to address the Hubble tension.

Pa1-c4

Dynamics of Interacting Dark Matter Dark Energy

Md Saddam Hussain
Indian Institute of Technology Kanpur, India

The most successful model to probe the cosmic dynamics of the universe is assumed to be the LambdaCDM model, which is composed of constant energy density as Lambda and CDM stands for pressureless cold dark matter. Dark energy is responsible for the universe's cosmic acceleration, which has been observationally verified. Since then, people have proposed many models to study dark energy's characteristics. But the further enhancement of the cosmological data raises a discrepancy in measuring the local Hubble parameter, which is now referred to as

Hubble tension. Several solutions are proposed to tackle this problem namely Early Dark Energy, Decaying Dark Matter, Interacting Dark Sector, etc. Recently it has been shown that interacting Dark sector can lower the Hubble Tension. However, this interaction is introduced in the continuity equation by hand, which raises a number of problems defining physical quantities and perturbations. In this talk, we will focus on the Lagrangian approach to construct the kinetically coupled Dark Sectors, where the Dark Matter is assumed to be a pressureless perfect fluid given by relativistic fluid action and the Dark Energy is a non-canonical scalar field. Because of this, the Friedmann and Field equations are modified and will analyze this complex system using the Dynamical System Technique.

Pa1-c5

The Halo Occupation Distribution of HI Galaxies

Fei Qin

Korea Astronomy and Space Science Institute

The next generation of galaxy surveys will provide more precise measurements of galaxy clustering than have previously been possible. The 21-cm radio signals that are emitted from neutral atomic hydrogen (HI) gas will be detected by large-area radio surveys such as WALLABY and the SKA, and deliver galaxy positions and velocities that can be used to measure galaxy clustering statistics. But, to harness this information to improve our cosmological understanding, and learn about the physics of dark matter and dark energy, we need to accurately model the manner in which galaxies detected in HI trace the underlying matter distribution of the Universe. For this purpose, we develop a new HI-based Halo Occupation Distribution (HOD) model, which makes predictions for the number of galaxies present in dark matter halos conditional on their HI mass. The parameterised HOD model is fit and validated using the Dark Sage semi-analytic model, where we show that the HOD parameters can be modelled by simple linear and quadratic functions of HI mass. However, we also find that the clustering predicted by the HOD depends sensitively on the radial distributions of the HI galaxies within their host dark matter halos, which does not follow the NFW profile in the Dark Sage simulation. As such, this work enables -- for the first time -- a simple prescription for placing galaxies of different HI mass within dark matter halos in a way that is able to reproduce the HI mass-dependent galaxy clustering and HI mass function simultaneously and without requiring knowledge of the optical properties of the galaxies. Further efforts are required to demonstrate that this model can be used to produce large ensembles of mock galaxy catalogues for upcoming surveys.

A1. General relativity: Theory and Mathematical developments

Pa1-d1

Steady heat conduction in general relativity

Hyeong-Chan Kim

Korea National University of Transportation

We investigate the steady state of heat conduction in general relativity using a variational approach for two-fluid dynamics. We adopt a Landau-Lifschitz frame of reference instead of the commonly used Eckart frame due to the time-dependence of the geometry in the latter. We show that the established stability condition of a thermal equilibrium state comes from the fact that heat flows not faster than light. Then, we formulate the equations for steady heat conduction and highlight the physicality condition that requires the Tolman temperature gradient along the perpendicular directions to the heat. As an example, we consider radial heat conductions in a spherically symmetric spacetime. We find that the total diffusion over a spherical surface, $J(r)$, satisfies a red-shifted form, $J(r)\sqrt{-g_{tt}} =$ constant. We also discuss the behavior of local temperature around an event horizon and specify the condition that the local temperature is finite there.

Pa1-d2

Energy (non-)conservation and a conserved charge in general relativity

Sinya Aoki

Yukawa Institute for Theoretical Physics, Kyoto University

We first argue that conservations of both Einstein's energy from the pseudo-tensor and quasi-local energies are related to each other through identities implied by Noether's 2nd theorem associated with general coordinate transformation, and their conservations hold without using equations of motions. Although these non-dynamical conservations are still useful as constraints of dynamics, their charge may not be suitable to be regarded as the energy of the system. We then propose to use a matter energy to define the total energy in a curved spacetime, which is a natural generalization of energy in a flat spacetime but is conserved only for special spacetimes such as one with a Killing vector or one generated by matters without pressure. We then modify the non-conserved matter energy by introducing a some scalar function, in order to define an alternative charge which is always conserved in curved spacetime by construction. By applying this definition to the FLRW Universe, we argue that this conserved charge may be identified as an "entropy" of the system as well as the scalar function may be an local inverse temperature in the spacetime.

Pa1-d3

On Uniqueness of electro-vacuum static spacetime

Xiaoning Wu
Academy of Mathematics and System Science, CAS

Black hole uniqueness is the cornerstone of black hole physics. In past decade, the development of gravitational detection technique makes it possible to measure the geometry surrounding us. Traditional uniqueness theorem requires the information of the horizon which is unmeasurable. In this talk, I will introduce our new result on the uniqueness of electro-vacuum static black hole based on data near null infinity.

Pa1-d4

Analytic topological hairy dyonic black holes and thermodynamics

Supragyan Priyadarshinee
NIT Rourkela, Sundergarh, Odisha, India

We present and discuss a new family of topological hairy dyonic black hole solutions in asymptotically anti-de Sitter (AdS) space. The coupled Einstein-Maxwell-Scalar gravity system, that carries both the electric and magnetic charges is solved, and exact hairy dyonic black hole solutions are obtained analytically. The scalar field profiles that give rise to such black hole solutions are regular everywhere. The hairy solutions for planar, spherical, and hyperbolic horizon topologies are obtained. In addition, analytic expressions of regularized action, stress tensor, conserved charges, and free energies are obtained. We further comment on different prescriptions for computing the black hole mass with hairy backgrounds. We analyse the thermodynamics of these hairy dyonic black holes in canonical and grand canonical ensembles, and we find that both electric and magnetic charges have a constructive effect on the stability of the hairy solution. For the case of planar and hyperbolic horizons, we find thermodynamically stable hairy black holes favoured at low temperatures compared to the non-hairy counterparts. We further find that, for a spherical hairy dyonic black hole, the thermodynamic phase diagram resembles to that of a Van der Waals fluid not only in canonical but also in the grand canonical ensemble.

Pa1-d5

Dimming of light in general relativity: On the possible emergence of dark energy effects in space-times with ordinary matter

Asta Heinesen
ENS de Lyon

Can modern cosmological observations be reconciled with a general-relativistic Universe without an anti-gravitating energy source? Usually, the answer to this question by cosmologists is in the negative, and it is commonly believed that the observed excess dimming of supernovae relative to that in the Milne model is evidence for dark energy. This intuition can be shown to be correct within Friedman-Lemaitre-Robertson-Walker space-times. In this talk I will illustrate that there is no fundamental result in general relativity that prevents the excess dimming of light in space-times satisfying the strong energy condition, once the Friedman-Lemaitre-Robertson-Walker symmetries are broken. This opens up an avenue of research into general-relativistic space-time solutions without dark energy that may be competitive cosmological models. I will discuss the geometrical constraints that such space-times must satisfy in order to conform with cosmological observations.

Pa1-d6

Birefringence of wave packets with angular momentum in gravity

Dan-Dan Lian
Sun Yat-sen University

The dynamics of spinning test objects have been studied in the form of Mathisson-Papapetrou-Dixon (MPD) equations. However, it is impossible to find a unique trajectory by the MPD equations unless we artificially add a constraint to the angular momentum. The artificial constraints would also lead to some non-physical effects. So in this talk, we propose another method, using the energy-momentum tensor, to analyze the motion of objects in gravity. Then, we calculate the evolution of spin-polarized electromagnetic wave packets in gravitational fields and find that the wave packets with opposite helicity are separated in the direction perpendicular to spin and gravity. This behavior is thus a kind of gravitational birefringence. Furthermore, we find that the trajectories defined by different components and expressions of the energy-momentum tensor are also different. This difference suggests that the trajectory of spin-polarized wave packets in gravity, and its confrontation with the weak equivalence principle, depend not only on the gravitational interaction but also strongly on how the wave packets are measured and analyzed.

Pa1-d7

Photon sphere and shadow evolution in a dynamical black hole spacetime

Yasutaka Koga
Nagoya University

A photon sphere is a characteristic spherical surface surrounding a black hole, on which photons take circular orbits. It is known as the important geometrical structure that shapes black hole shadow. The mechanism of shadow formation is well understood for static or stationary black hole spacetimes. However, for dynamical spacetimes, even the notion of photon sphere is unclear although possible definitions have been discussed so far. In this talk, we investigate black hole shadow of a dynamical spacetime and discuss what we should regard as the photon sphere with specific models. We consider specific cases of Vaidya spacetime and explicitly specify the photon sphere. I also mention cases where the black holes are dynamically formed by gravitational collapse.

A2. Exact solutions

Pa1-e1

Cosmological Solutions in Extended Theory of Gravity

Muhammad Sharif
The University of Lahore

In this paper, we consider a non-static spherical geometry and formulate its extension for the case of anisotropic matter configuration through minimal gravitational decoupling in curvature-matter coupled gravity. We apply a particular transformation only on the radial metric function that divides the modified field equations into two distinct sectors corresponding to their parent (original and additional) sources. The unknowns in the first (isotropic) set are reduced by taking the Friedmann-Lemaitre-Robertson-Walker cosmic model. We then obtain the isotropic solution by employing a linear equation of state and power-law form of the scale factor. The other set involves the decoupling function and components of an extra source, therefore we adopt a density-like constraint to close it. Finally, we analyze the role of this modified gravity and the decoupling parameter on three different eras of the cosmos by graphically observing the developed extended solution. It is concluded that the resulting solutions fulfill all the physical requirements only for the matter and radiation-dominated eras.

Pa1-e2

Trouble with the Penrose diagram in spacetimes connected via a spacelike thin shell

Wei-Chen Lin
Pusan National University

In this talk, I'll talk about the issue of the first junction condition in the Penrose diagram constructed by cutting and pasting analytically known metrics by a static spacelike thin shell. This issue is demonstrated by using two examples - the generalized black-to-white hole bounce with mass difference and the Schwarzschild-to-de Sitter transition. The goal is to construct the corresponding Penrose diagrams without any explicit or implicit illness at the thin shell. This talk is based on two recent articles, arXiv:2302.04923 and 2304.01654.

Pa1-e3

Ernst equation in a complete Hamiltonian reduction and exact solutions

Yeongji Kim
Konkuk University

The Ernst equation is a single complex equation equivalent to Einstein's field equations with two isometry assumptions. Using the Einstein's equations previously obtained from the general (2+2) Hamiltonian reduction in the privileged coordinates and then imposing two isometry conditions, we obtain a new form of the Ernst equation in the privileged coordinates, which is expressed in two physical degrees of freedom of gravitational fields only. In this talk, we will find a number of solutions to the new form of the Ernst equation and physically identify some of them. They are plane symmetric solutions of Taub, general Kasner solutions, the Gowdy T^3 solutions, and others. In addition, we will discuss a number of families of new solutions with one or two parameters whose physical meanings are yet unclear.

D2. Status of Standard cosmology and alternatives

Pa1-e4

On the uniqueness of ΛCDM-like evolution for homogeneous and isotropic cosmology in General Relativity

Daniele Gregoris
Jiangsu University of Science and Technology

The Lambda-ColdDarkMatter model, despite being in well agreement with many observational datasets at the background level, exhibits a growth of perturbations troubled by some inconsistencies: the H0 and sigma8 tensions. Adopting a theoretical perspective, this opens the question on the possibility of having a cosmological model, based on other degrees of freedom than a cosmological constant and a pressureless dark matter, whose background cosmic history is as in LCDM. Tuning the novel degrees of freedom can potentially resolve the issues arising at the perturbation level. Therefore, in my talk I will discuss some models with cosmographic jerk parameter j=1 all along their evolution (as from the statefinder diagnostic, this is enough for reproducing the LCDM at the background level, but for very specific models with deceleration parameter q=1/2). Our class of models will involve interactions in the dark sector in which dark energy is accounted for either by a non-ideal fluid or a canonical scalar field, while we maintain the assumptions of general relativity as the gravitational theory, and of homogeneity and isotropy as in the usual Friedmann scenario. By applying dynamical system techniques, we will show that coupled fluid-fluid models with non-phantom fluids or coupled quintessence models with power law and exponential potential can never reproduce a cosmological evolution similar to that of the LCDM. Hence, assuming those tensions to be a genuine manifestation of some cosmological effects, we may need to resolve them by invoking some different extensions of the current standard model. My talk will be based on 2208.04596 [gr-qc].

Pa1-e5

Late time acceleration with varying speed of light model

Seokcheon Lee
Sungkyunkwan University

The Robertson-Walker (RW) metric allows us to apply general relativity to model the behavior of the Universe as a whole (i.e., cosmology). Recently, it has been known that one can obtain the so-called minimally extended varying speed-of-light (meVSL) model which is theoretically consistent with all known local physics laws. Thus, the validity of this model needs to be determined by observations. We investigate the results of this model in various late-time cosmological observations to investigate their effects on dark energy.

Pa1-e6

Satellite Galaxy Populations In A Cosmological Simulation

Minyong Jung
Seoul National University

We analyze and compare the satellite halo populations at z~2 in the high-resolution cosmological zoom-in simulations of a $10^{12}M_{sun}$ target halo (z=0 mass) carried out on seven widely-used astrophysical simulation codes (Art-I, Enzo, Ramses, Changa, Gadget-3, Gear, and Gizmo) for the AGORA High-resolution Galaxy Simulations Comparison Project. We use slightly different redshift epochs near z=2 for each code (hereafter "z~2") at which the seven simulations are in the same stage in the target halo's merger history. We also study the dark matter-only (DMO) simulations with the same cosmological initial condition to isolate the effect of baryonic physics. We find that the number of satellite halos at z ~ 2 in all participating AGORA hydrodynamic simulations (CosmoRun) is fewer than its counterpart in the DMO runs. When we consider only the halos containing stellar particles at z~2, the number of satellite galaxies is significantly fewer than that of dark matter halos in all participating AGORA simulations, and is comparable to the number of present-day satellites near the Milky Way or M31. This difference between the hydrodynamic simulations and the DMO simulations can be attributed to various baryonic effects. After identifying the matched pairs of halos between the CosmoRun simulations and the DMO simulations, we discover that each CosmoRun halo tends to be less massive than its DMO counterpart. The so-called "missing satellite problem" is fully resolved across all participating codes simply by implementing the common baryonic physics adopted in AGORA and the stellar feedback prescription commonly used in each code, with sufficient numerical resolution (< 100 proper pc at z=2). This marks the first time that different codes have converged on a common conclusion for this issue. We also find reasonable inter-code agreement in other properties of satellite galaxies such as the stellar mass-halo mass relation and the mass-metallicity relation.

C1. Relativistic Astrophysics

Pa1-f1

Application of GBT theorem for Gravitational deflection of light by Compact Objects

Nurzada Beissen
al Farabi Kazakh national university

In this study, we employ the material medium approach to determine the refractive index associated with the gravitational field of a compact object with a quadrupole moment. Our research presents a method for calculating the gravitational deflection angle for compact objects by utilizing the refractive index and the GBT theorem for an isotropic metric. This method is particularly important because it allows for the calculation of the deflection angle for both light and relativistic particles. The material medium approach enables us to consider the compact object's gravitational field as a medium with a refractive index. By applying this approach, we establish a relationship between the refractive index and the quadrupole moment of the compact object. We then utilize this relationship to calculate the deflection angle of light and relativistic particles.

Pa1-f2

Nonlinear Vacuum Electrodynamic effects on magnetars

Medeu Abishev
Al Farabi Kazakh National university

Considered the birefringence and generation of the electromagnetic radiation, caused by a plane gravitational wave propagating in a magnetic dipole and quadrupole fields of magnetar. It is shown that a radiated electromagnetic wave has the frequency of the gravitational wave, and its amplitude is proportional to the square of that frequency. Polarization of the arising electromagnetic wave coincides with the polarization of the gravitational wave. Based on an example of how a gravitational wave propagates in a magnetar's magnetic dipole field, an evaluation of a conversion coefficient of gravitational waves into electromagnetic waves has been made: the required amplitude of a gravitational wave for on-Earth detection of electromagnetic radiation has been calculated as well. Also effect of the magnetic dipole and quadrupole fields on the propagation of electromagnetic waves in the eikonal approximation of the parametrized post-Maxwell electrodynamics of the vacuum is calculated. Equations of motion for electromagnetic pulses transmitted in a strong magnetic field of a pulsar by two normal modes with mutually orthogonal polarization are constructed. The difference Δt in propagation times of normal waves from the common source of electromagnetic radiation to the receiver is calculated.

Pa1-f3

Crustal magnetic fields do not lead to large magnetic-field amplifications in binary neutron-star mergers

Michail Chabanov
Goethe University Frankfurt

The amplification of magnetic fields plays an important role in explaining numerous astrophysical phenomena associated with binary neutron-star mergers, such as mass ejection and the powering of short gamma-ray bursts. At the same time, magnetic fields in isolated neutron stars are often assumed to be confined to a small region near the stellar surface, while they are normally taken to fill the whole stars in the numerical modelling of binary mergers. In this talk I will present results from high-resolution, global, and high-order general-relativistic magnetohydrodynamic simulations which investigate the impact of a purely crustal magnetic field. In particular, I will show how these configurations are very effective in generating strong magnetic fields during the Kelvin-Helmholtz-instability stage but also fail to achieve the same level of magnetic-field amplification of the full-star configurations.

Pa1-f4

Accelerated protons produced by magnetic Penrose process in Sgr A*

Myeonghwan Oh
Kyungpook National University

The Penrose process (PP) and the Blandford-Znajek process are considered to be the key processes for extracting energy from a rotating black hole. Among them, PP has a special constraint. However, the constraint may be removed by combining the PP with the electromagnetic effect (magnetic Penrose process, MPP). Furthermore, the MPP has very high efficiency when neutral particles decay to charged particles near a black hole. We, in this study, apply the MPP with the neutron decay to the Sagittarius A* (Sgr A*) which is the supermassive black hole at the center of the Galaxy. We assume that nuclear reactions within the advection-dominated accretion flow in the vicinity of the Sgr A* are the source of neutrons. We find that the peak of the energy spectrum of accelerated protons is Q_MPP(E_p=2.1x10^15 eV)=1.4x10^18 eV^-1 s^-1 when B_0=100 G and a=0.5, where B_0 and a are the uniform magnetic field strength in the vicinity of the Sgr A* and the black hole spin parameter, respectively. Also, we compare the flux of gamma rays from the accelerated protons and the flux of accelerated proton cosmic rays at the earth with observed data.

July 3 (Mon): 16:30-18:30

A4. Modified gravity

Pa2-a1

Cosmology in Double Field Theory

Hocheol Lee
Sogang University

The closed-string massless sector forms a multiplet of O(D, D) symmetry. This suggestions yield a specific modification to General Relativity. We explore 4-dimensional Friedmann equations and evolution of the universe in double field theory.

Pa2-a2

Dual descriptions of late-time cosmology: Bouncing and collapsing Jordan frames

Dipayan Mukherjee
Indian Institute of Science Education and Research Mohali

Scalar-tensor theories of gravity can be recast as Einstein's gravity with a scalar field using conformal transformations. Though mathematically equivalent, the Jordan and Einstein frame representations of the theory may describe drastically different universes. We explore the conformal duality between scalar-tensor theories and Einstein's gravity in the context of late-time cosmology. The Einstein frame is modeled to produce the standard late-time cosmological evolution of the universe, driven by dark energy and non-relativistic matter. In the Jordan frame, we choose the Brans-Dicke model as an example of scalar-tensor theories. We show that an Einstein frame universe, mimicking the cosmological evolution of the ΛCDM model, is always dual to a bouncing Jordan frame governed by a Brans-Dicke model. On the other hand, quintessence models of dark energy are found to be always dual to a Brans-Dicke Jordan frame with a turn-around, that is, a bounce or a collapse. The equation of state of the quintessence field determines whether the Jordan frame turn-around is a bounce or a collapse. The point of the Jordan frame turn-around for all these models can be tuned anywhere in the Einstein frame by choosing an appropriate Brans-Dicke parameter. This allows for alternative descriptions of the standard late-time physical universe, undergoing an accelerated phase of expansion, in terms of bouncing and collapsing universes. We further explore the effect of linear perturbations on the conformal map. Such conformally dual universes may have interesting implications; for example, one may study the present accelerating phase of the universe through a spacetime collapsing towards a quantum regime. It may also provide new insights into the physical equivalence between Einstein and Jordan frames. This abstract is based on the articles "Bouncing and collapsing universes dual to late-time cosmological models" (https://arxiv.org/abs/2207.02835) and "f(R) Dual Theories of Quintessence : Expansion-Collapse Duality" (https://doi.org/10.1088/1475-7516/2021/12/016)

Pa2-a3

Revisiting TOV Problems in F(R) Gravity

Kota Numajiri
Nagoya University

F(R) gravity is one of the hopeful modified gravity theories, and it has additional scalar d.o.f. for the gravitational field. We will revisit the effect of this scalar component in an isolated spherical star system explicitly. Especially we will focus on the scalar profile inside the star and the asymptotic region, which have not been discussed carefully in the literature.

Pa2-a4

Non-relativistic stellar structure in generic linear massive gravity

Tomoya Tachinami
Hirosaki University

We study the non-relativistic stellar structure in linear massive gravity (MG), including but not limited to the Fierz-Pauli (FP) theory avoiding the ghost scalar graviton. We first formulate the governing equation for the polytropic stellar profile, an extended version of the Lane-Emden (LE) equation known in Newtonian gravity. The equation is fourth or sixth order in derivatives depending on whether the theory is FP or not. Then, we establish the boundary conditions. Finally, we find exact solutions to the modified LE equations and use them to discuss observational constraints on the graviton masses. We also show that the vDVZ discontinuity is resolved in the non-FP theories thanks to the repulsive potential produced by the scalar ghost.

Pa2-a5

Thermodynamic phase transitions of the Schwarzschild AdS black hole with the modified Tolman temperature

Sojeong Jung
Sogang University

We study the stability and thermodynamic phase transitions of the Schwarzschild AdS black hole in an isothermal surface of a cavity. In this work, we apply a modified Tolman temperature satisfying the Hartle-Hawking vacuum condition which states that the ingoing and outgoing fluxes vanish at the horizon so that the local temperature is naturally zero there. We find a critical AdS curvature radius that allows a stable black hole. If the AdS curvature radius is smaller than the critical one, a medium-sized black hole is stable; otherwise, no stable black hole exists. Furthermore, we clarify several critical temperatures related to thermodynamic phase transitions between black holes and thermal AdS. Interestingly, we reveal a certain critical temperature related to the zeroth-order phase transition between the medium-sized black hole and thermal AdS. Thus, we find that the medium-sized black hole undergoes both the Hawking-Page phase transition and the zeroth-order phase transition.

Pa2-a6

Relativity in motion: long version

Frederic Lassiaille
FL research

In General Relativity (GR), the motion of quarks is assumed to be entirely taken into account when converting their energy of motion into their corresponding macroscopic energy at rest using $E=mc^2$ equation. This is correct locally, but this motion generates also microscopic gravitational waves which propagate their space-time deformations everywhere. Therefore globally this motion yields immediatly a retardation of the gravitational force. This is the first effect of this motion. The other consequences of this motion should be calculated in GR, but those calculations are cumbersome. Hopefully they can be approximated using a new and discrete equation. This equation shows that another effect arises, which is that the gravitational force must be divided by the energy of the surroundings of the location where the force is exerted, after multiplication by an appropriate factor. This effect was studied in a previous work [1] and was called "surrounding". The main result of this study is that the motion of the quarks generate a surrounding effect in gravitation which might give an explanation to the gravitational issues of today. [1] F. Lassiaille, EPJ Web of Conf. 182 (2018) 03006.

Pa2-a7

Cartan modified gravity and reheating of universe.

Naoki Yoshioka
Hiroshima University

Inflation is a standard theory for solving the cosmological problems of an expanding universe. Various models of inflation have been proposed, including the reheating of the universe. One of the interesting models is constructed by modifying the Einstein-Hilbert action in Cartan geometry. It has been shown that Cartan F(R) gravity is represented by an equivalent scalar-tensor type theory without a conformal transformation. The induced scalar mode can play a role of the inflaton. In this talk, I consider a generalized fermionic matter with non-minimal coupling in the Cartan F(R) gravity. Interaction terms between the fermionic matter field and the inflaton are obtained in the scalar-tensor type theory from the spin connection. I calculate the decay rate from the inflaton to the fermions and evaluate the reheating process. The value of non-minimal coupling contributes to the reheating process. I found a possible parameter region in the presence of reheating.

A3. Alternative theory of gravity

Pa2-c1

Resonant Kaluza-Klein modes and quasinormal modes on brane

Yu-Xiao Liu
Lanzhou University

Usually, massive Kaluza-Klein modes in a five-dimensional braneworld model with an infinite extra dimension are not localized on the brane. In this talk, we discuss resonant Kaluza-Klein modes quasilocalized on the brane and quasinormal modes in thick brane models. We also discuss evolution of these resonances and their relation with quasinormal modes.

Pa2-c2

Gravitational wave memory effects in modified theories of gravity

Shaoqi Hou
Wuhan University

When gravitational waves pass by two adjacent test particles, their relative distance oscillates constantly. After the gravitational wave disappears, the distance may not return to its original value. This is the gravitational memory effect. In this talk, the memory effect in modified theories of gravity (mainly, Brans-Dicke theory and dynamical Chern-Simons theory) will be presented. Working in the Bondi-Sachs formalism, one starts with the asymptotically flat spacetime in modified theories of gravity, discusses the asymptotic symmetry, and determines the associated conservation laws. The memory effect could also be identified in this formalism and related to the asymptotic symmetry. The conservation laws can be applied to calculate the memory effect, which enables the use of memory effects to probe the nature of gravity.

Pa2-c3

DeWitt boundary condition requires Ho\v{r}ava-Lifshitz quantum gravity

Hiroki Matsui
Yukawa Institute for Theoretical Physics, Kyoto University

In quantum cosmology the DeWitt boundary condition is a proposal to set the wave function of the universe to vanish at the classical big-bang singularity. We show that in many gravitational theories including general relativity, the DeWitt wave function does not take a desired form once tensor perturbations around a homogeneous and isotropic closed universe are taken into account: anisotropies and inhomogeneities due to the perturbations are not suppressed near the classical singularity. We then show that Ho\v{r}ava-Lifshitz gravity provides a satisfactory DeWitt wave function. In particular, in the limit of $z=3$ anisotropic scaling, we find an exact analytic expression for the DeWitt wave function of the universe with scale-invariant perturbations. In general cases with relevant deformations, we demonstrate that the DeWitt wave function can be systematically expanded around the classical big-bang singularity with perturbations under control.

Pa2-c4

Spinor Walls in Five-Dimensional Warped Spacetime

Zheng-Quan Cui
Sun Yat-Sen University

We will talk about domain wall solutions of a real spinor field coupled with gravitation in five dimensions. We find that the nonlinear spinor field supports a class of soliton configurations which can be viewed as a wall embedded in five dimensions. We present three sets of solutions of the spinor field with nonconstant curvature bulk spacetimes. We show that some of these solutions, under certain conditions, have the energy density distributions of domain walls for the spinor field, where the scalar curvature is regular everywhere. Therefore, the configurations of these walls can be interpreted as spinor walls, which are interesting spinor field realisations of domain walls. To study the stability of these spinor configurations, the linear perturbations are considered. The localisation of the zero mode of the tensor perturbation is also discussed.

Pa2-c5

Cosmological Constant, Inflaton, and Dark Matter Occurred Naturally from the Duplex Higgs Mechanism for Poincare Gauge Gravity

Hongchao Zhang
Zhejiang University of Technology

We propose a cosmological model in the framework of Poincare gauge gravity, where cosmological constant, inflaton, and dark matter candidate occur naturally from the duplex Higgs mechanism. The spontaneous breakdown of the Poincare group to the Lorentz group, in terms of the nonlinear representations, is parameterized by the coset fields. In this case, the Higgs field is a pure gauge, with a vanishing groundstate and parameterized around the groundstate by the coset fields, i.e. the Nambu-Goldstone bosons. A vanishing potential is the unique possible choice for the Higgs field, while its kinetic term introduces a cosmological constant to the Lagrangian. The second Higgs mechanism occurs when we consider a cosmologically homogeneous and isotropic reduction. Under the reduction, the Lorentz connection remains a scalar mode and a pseudo-scalar mode, while the tetrad remains a scale factor. In this case, the Higgs field is also a pure gauge, with a vanishing groundstate and parameterized by the scale factor. We construct a minimum Einstein-Hilbert-Yang-Mills type Lagrangian, which is ghost- and tachyon-free, and has no extra modes up to linear order. We find that in this model the scalar and the pseudo-scalar modes obtain masses. The scalar mode triggers slow-rolling inflation with enough e-folds, then spontaneously decays to the pseudo-scalar mode. The pseudo-scalar mode behaves as dark matter.

Pa2-c6

Quantum Yang-Mills Gravity, Feynman-Dyson Rules and Tests

Jongping Hsu
University of Massachusetts Dartmouth

Yang-Mills gravity is a quantum theory of gravity with translational gauge symmetry that is based on a flat space-time. It is a new theory, consistent with experiments, that bring gravity back to the arena of gauge field theory. The universal coupling of all quantum fields to quantum Yang-Mills gravity is based on the replacement of $\p_\mu$ by the translational gauge covariant derivative $(\p_\mu +g\phi_\mu^\nu \p_\nu)$ in the Lagrangians of non-gravitational fields. The space-time translational gauge covariant derivative (acting on quantum wave functions) gives a simple explanation as to why the gravitational force is always attractive, in comparison with the electromagnetic forces. The Feynman-Dyson rules for gravitons and ghosts are obtained in inertial frames. All internal gauge symmetries are violated by the presence of Yang-Mills gravity. For Josephson effects, near the surface of the Earth, Yang-Mills gravity causes the phase gradient $\p_k \th$ and the time derivative $\p_t \th$ to be altered respectively by $h_1 \p_k \th$ and $h_0 \p_t \th$, where $h_1\approx 1/h_0 \approx (1- g\phi_0^0)\approx 1-7\times 10^{-10}$. The voltage across a Josephson junction is affected by the presence of quantum Yang-Mills gravity. Suppose one compares the voltage across a Josephson junction in a laboratory at rest on Earth with that across a junction in free fall (e.g., in the International Space Station). Quantum Yang-Mills gravity predicts a difference on the order of 1 part in 10^{9}, which should be detectable as the precision of the Josephson junction voltage standard is on the order of a few parts in 10^{10}.

C2. Neutron stars & compact objects

Pa2-d1

Systematic analysis of the impacts of symmetry energy parameters on neutron star properties

Naresh Kumar Patra
BITS Pilani K K Birla Goa Campus, NH-B, South Goa, Goa, Pin-757040

The impacts of various symmetry energy parameters on the properties of neutron stars (NSs) have been recently investigated, and the outcomes are at variance, as summarized in Table III of Phys. Rev. D 106, 063005 (2022). We have systematically analyzed the correlations of slope and curvature parameters of symmetry energy at the saturation density ($\rho_0=0.16 \text{fm}^{-3}$) with the tidal deformability and stellar radius of non-spinning neutron stars in the mass range of $1.2 - 1.6 M_\odot$ using a large set of minimally constrained equations of state (EoSs). The EoSs at low densities correspond to the nucleonic matter and are constrained by empirical ranges of a few low-order nuclear matter parameters from the finite nuclei data and the pure neutron matter EoS from chiral effective field theory. The EoSs at high densities ($\rho > 1.5 - 2\rho_0$) are obtained by a parametric form for the speed of sound that satisfies the causality condition. Several factors affecting the correlations between the NS properties and the individual symmetry energy parameters usually encountered in the literature are considered. These correlations are quite sensitive to the choice of the distributions of symmetry energy parameters and their interdependence. But, variations of NS properties with the pressure of $\beta -$ equilibrated matter at twice the saturation density remain quite robust which maybe due to the fact that the pressure depends on the combination of multiple nuclear matter parameters that describe the symmetric nuclear matter as well as the density dependence of the symmetry energy. Our results are practically insensitive to the behavior of EoS at high densities.

Pa2-d2

Ultracompact stars in the light of minimal geometric deformation

Muhammad Zubair
COMSATS University Islamabad, Lahore Campus, Lahore Pakistan

Adopting gravitational decoupling through minimal geometric deformation (MGD) procedure, we develop an analytical version of gravastar model with non-uniform and anisotropic features, in the framework of modified gravity theory. This new non-uniform model describes an ultracompact stellar structure of Schwarzschild radius, whose interior solution smoothly joins a conformally deformed Schwarzschild exterior solution, and it is matched to the standard Schwarzschild exterior solution under certain conditions. The constructed solution presents a family of stellar models satisfying some of the fundamental properties of a stable configuration, including a positive energy density everywhere with monotonically decreasing behavior from the center to surface. Besides, a non uniform pressure is observed with monotonic behaviour. The behaviour of energy conditions is analyzed inside the stellar configurations.

Pa2-d3

Analyzing the speed of sound in neutron stars with machine learning

Sagnik Chatterjee
Indian Institute of Science Education and Research Bhopal

The matter at Neutron star (NS) cores are at highly compressed state and due to gravity, the density can be built up to a few times the nuclear saturation density. They are very compact and have been observationally identified with pulsars with their mass being in the range from 0.7 - 3 solar masses and a radius between 10-15 km. They are therefore one of the best laboratories to test the theory of strong interaction at high-density low temperature regimes. The information about the structure of an NS can be given by their equation of states (EoSs). At high densities, the first principle pQCD calculations are consistent and at lower densities field theory calculations are consistent. The central density of the NS lies somewhere between these two densities and in this regime the lattice QCD calculations fail. Hence, we need to resort to model-based or agnostic approaches to construct EoSs. In this talk, I will present how we can effectively create several new EoSs from the information on the speed of sound. Using the created EoSs, we create several datasets to train our neural network. I will also talk about the neural network model using which we can effectively predict a new EoS. Using these we study the variation in the speed of sound inside the NS.

Pa2-d4

Quark matter in neutron stars

Márcio Ferreira
University of Coimbra

We explore several multi-quark interaction channels within a NJL-type model to describe quark matter in the interior of neutron stars. The hybrid star scenario - hadronic and quark matter - for neutron stars is tested using all known observational constraints. The effect of the different quark interactions on several hybrid stars properties is investigated. We show that the hybrid stars with a large strangeness content and large quark cores are compatible with the present observational constraints.

Pa2-d5

Crustal deformation and fracture by Hall evolution of magnetic field in strongly magnetized stars

Yasufumi Kojima

Hiroshima University

We discuss the deformation of the neutron star crust as a result of the magnetic field evolution on a secular timescale. Evolutionary change of the Lorentz force owing to the Hall drift of the field, which is an important process in strongly magnetized neutron stars, magnetars, leads to the elastic deformation. Accordingly, elastic energy is accumulated, and the crust is eventually fractured beyond a particular threshold. We show the breakup time of the crust and the maximum elastic energy.

Pa2-d6

Nonlinear electrodynamical lensing of electromagnetic waves on the dipole magnetic field of the magnetar.

Tursynbek Izmukhanovich Yernazarov
al-Farabi Kazakh National University

In this work, we study the gravitational lensing of light rays by a magnetar. We consider the strong dipole magnetic and gravitational fields of the magnetar within the framework of nonlinear electrodynamics. We focus on the lensing of the leading edge of light passing through the magnetar, and calculate the influence of such a field on the lensing of the leading edge of light using numerical methods based on effective geodesics in curved spacetime. We analyze the results and note that in the limiting case they agree with previous analytical studies, but we emphasize that the calculations performed here aim to determine the deflection angle of the leading edge of light in the case where $eta_1 = eta_2$ and it exits the equatorial plane. We also define the value of the effect of the magnetic field on the deflection of light.

Pa2-d7

Oscillations and tidal deformations of crystallized white dwarfs

Yat To Tang
The Chinese University of Hong Kong

Long predicted more than fifty years ago, strong evidence for the existence of crystalline cores inside white dwarfs has recently been obtained by the Gaia space telescope. It is thus important to investigate how a crystalline core may affect the properties and dynamics of white dwarfs. In this paper, we first study the dependence of the frequencies of the fundamental (f), interfacial (i), and shear (s) oscillation modes on the size of the crystalline core. We find that the frequencies of the i- and s-modes depend sensitively on the size of the core, while the frequency of the f-mode is affected only slightly by at most a few percent for our chosen white dwarf models. We next consider the tidal deformability of crystallized white dwarfs and find that the effect of crystallization becomes significant only when the radius of the core is larger than about 70% of the stellar radius. The tidal deformability can change by a few to about 10 percent when a white dwarf becomes fully crystallized. We also show that there exist approximate equation-of-state insensitive relations connecting the mass, moment of inertia, tidal deformability, and f-mode frequency for pure fluid white dwarfs. Depending on the stellar mass and composition, however, these relations can be affected by a few percent when the white dwarf is crystallized. These changes could leave an imprint on the gravitational waves emitted from the late inspiral or merger of white dwarf binaries, which may be detectable by future space-borne gravitational wave detectors.

Pa2-d8

Light bending by charged black hole and magnetar in the generalized Born-Infeld nonlinear electrodynamics

Jin Young Kim
Kunsan National University

We study the bending of light by strong electric and magnetic field in the generalized Born-Infeld electrodynamics. We compute the bending angle of light by an Einstein-Born-Infeld black hole using the geodesic equation of the effective metric. In the limit where the classical Born-Infeld parameter is infinite, the bending angle agrees with the one computed from Euler-Heisenberg Lagrangian. We also consider the bending of light when the light is passing on the equator of the magnetic dipole. We compute the bending angle using the geodesic equation of the effective metric induced by a massive object with magnetic dipole. We apply the result to magnetar to estimate the order of magnitude for bending angles.

E2. EHT (Event Horizon Telescope)

Pa2-e1

AGN studies with the EHT and synergies with GR/theory

Georgios Filippos Paraschos
Max Planck Institute

Black holes are among the most fascinating objects in the universe. In 2017, the Event Horizon Telescope (EHT) finally enabled us to observe for the first time the shadow of black holes at the centre of M 87 and our Milky Way galaxy, Sgr A*, demonstrating that it is now possible to directly study the closest vicinity of supermassive black holes (SMBHs) via electromagnetic radiation. The interplay between the tremendous gravitational pull of such SMBHs and the accompanying electromagnetic effects can launch relativistic jets of particles that travel across vast distances in the universe. Despite the great number of observational and theoretical work on jets, a number of questions about how they are launched, stay collimated, and accelerate remain open to this day. The EHT, offering high resolution, high sensitivity observations in the optically thin regime, is essential in answering these questions. Besides M 87 and Sgr A*, the EHT has also observed and resolved the fine structure in the vicinity of the central SMBHs in a number of AGN targets.
In this talk, I will present the multi-faceted work of the EHT collaboration, which enables us to test the newest theoretical models predicting the generation of black-hole shadow emission and jet formation, as well as to investigate the origin of the high-energy emission and jet morphology over a wide range of physical scales.

Pa2-e2

EHT Simulations: A Preview of the Next Decade

Dongjin Kim
MIT

The Event Horizon Telescope (EHT) is a global facility that has revolutionized our understanding of black holes. In 2019, the EHT Collaboration (EHTC) released the first image of a black hole. Since then, the EHT has continued to grow in terms of imaging capability and fidelity. The EHTC envisions future development of the array to obtain a more detailed view of the vicinity of supermassive black holes with improved uv-coverage, sensitivity, and frequency coverage. Substantial simulation and evaluation work is needed to design an array configuration that is optimized for the scientific goals. This talk will present the on-going developments of the EHT and introduce new observing capabilities that will be achievable in the next decade. These capabilities will allow the EHT to study black holes in unprecedented detail and to answer some of the most fundamental questions about the universe.

Pa2-e3

Insights From the First Polarized Images of the Supermassive Black Hole M87*

Benjamin Scott Prather
Los Alamos National Laboratory

The Event Horizon Telescope has now published the first horizon-scale polarized images of the supermassive black hole at the center of the galaxy M87. The polarization of its synchrotron emission gives us the most direct data yet on the magnetic field structure around the black hole, but turning that data into insights about the source itself is challenging, due to the warped lines of sight and complex field structure near the event horizon. I will present the results of EHT Theory Working Group efforts to understand everything we can about the black hole environment from these exciting measurements.

Pa2-e4

Imaging the Black Hole Shadow from the EHT observations

Ilje Cho
IAA-CSIC, Spain

Black holes have long been studied as fascinating astronomical objects that provide insights into physics under extreme gravitational conditions. Theoretical predictions suggest that black holes are ubiquitous, with supermassive black holes residing at the centers of most galaxies. To unravel the properties of these enigmatic objects, extensive observational efforts have been made, especially with very long baseline interferometry (VLBI) observations at radio wavelengths that play a crucial role in resolving their innermost structures with unprecedented angular resolution, reaching (sub-) milli-arcseconds. Of particular significance, the Event Horizon Telescope (EHT) has achieved a major breakthrough by capturing the first-ever image of a black hole shadow from the center of the M87 (M87*) and our Galaxy (Sagittarius A*).

In this presentation, I will discuss the imaging algorithms and procedures employed to obtain these black hole shadow images from the EHT data. In principle, the sparse coverage of the VLBI measurements in Fourier domain results in an ill-posed inverse problem that prevents the recovery of a unique image. Therefore, recovering the underlying image requires sophisticated imaging algorithms that impose additional constraints and/or assumptions. In this regard, we have employed various approaches and verified the robustness of the results. In addition, for Sagittarius A*, specific considerations have been further taken to address interstellar scattering and fast variability effects. To this end, the EHT results toward M87* and Sagittarius A* prove that general relativity is valid under the strong gravitational field of supermassive black holes spanning a mass range of 10^(6-9) solar masses.

F1. Education on Astrophysics and Relativity

Pa2-f1

Teaching relativity theory to foster scientific literacy

Jongwon Park
Chonnam National University

The theory of relativity is already over 100 years old, and in the modern world, it is connected to many aspects of students' everyday lives. Therefore, teaching relativity is necessary for all students to develop scientific literacy, not just those who plan to enter college of science. This means that teaching relativity is needed not only for students preparing for science and engineering colleges, but also for middle school and even elementary school students. In this presentation, I will briefly review the basic characteristics of scientific literacy and discuss how relativity can be taught in this context. According to a model of scientific literacy (Park, 2016), scientific literacy requires a balanced consideration of the following six factors in three dimensions: Relevance (personal-public), Scope (inward science-outward science), Competency (cognition/mind-performance/execution). [Model of Scientific Literacy] Dimension 1: Scope (Inward science-outward science) Inward science: science ideas, concepts, laws, principles, … Outward science: everyday life, technology/engineering, history/philosophy of science, … Dimension 2: Relevance (Personal-Public) Personal: individual development, curiosity, needs, interests, … Public: nation's development, public security, nature/energy conservation, … Dimension 3: Competency (Cognition/Mind-Performance/execution) Cognition/Mind: understanding, application, recognition, belief, attitude, … Performance/execution: performing scientific inquiry, communication, argumentation, decision-making, … For example, some students accept time dilation as mathematical and logical, but do not believe that it is true. In this case, for the 'belief' factor in the 'cognition/mind' of the 'competency' dimension, we need to invent ways to help them believe in relativity as a natural and plausible phenomenon, rather than a bizarre and mysterious one. To do this, the change in shadow length of a bar in three-dimensional space can be used as an analogy to teach time dilation in four-dimensional space-time. And a demonstration to directly observe the gravitational lens effect in the classroom is also helpful for the 'performing scientific inquiry' factor in the 'performance/execution' of the 'competency' dimension. Likewise, this presentation will introduce teaching approaches to relativity by considering six factors.

Pa2-f2

Making the relativity curriculum: Recent curriculum reforms in Korea and competing views about physics knowledge

Wonyong Park
University of Southampton

This study uses the recent history of physics curriculum revisions in Korea as a canvas to elucidate how different views about the science curriculum are expressed and negotiated in the process of curriculum making. Our particular focus is on the decision to teach special and general relativity in the high school curriculum, which was made during the national curriculum revision in 2009. This decision came about in the context of the growing international call to teach young people about twentieth-century physics that represents our best understanding of the universe. Yet, some stakeholders considered relativity theory to be too theoretical and difficult for students and therefore against the national drive to reduce study load. This study sets out to illuminate such different views espoused on the relationship of physics as a scientific discipline and as a school subject. We then analyse how the curriculum designers positioned knowledge of relativity in the physics curriculum not only as core disciplinary knowledge of physics but also as a servant of 'Science for All', using Basil Bernstein's concept of 'recontextualisation', through which disciplinary knowledge undergoes to become knowledge in the curriculum and then knowledge taught in the science classroom. The analysis illustrates the competing views about knowledge in physics, and the factors influencing the views at different levels: the broad context of education (e.g., study load, standardised testing), the science curriculum (e.g., subject choice), and the physics community (e.g., secondary-university transition) that were negotiated in determining the value of relativity in the physics curriculum. The findings provide insights into the various views, values and interests involved in deciding what science knowledge is worth learning.

Pa2-f3

Re-visiting Einstein's original derivation of E =mc2

Ajay Sharma
Fundamental Physics Society

Einstein derived $\Delta L= \Delta mc$ 2 (inter-conversion of light energy -mass) in Sep. 1905 paper (2.5 pages) in a speculative way. In the thought experiment, Einstein considered two systems i.e. system at rest (SR), where the luminous body (emanating light energy L) , and another system (SV) moving with uniform velocity v. The corresponding change in mass and energy of the body is measured in SV. Thus equation $\Delta L= \Delta mc$ 2 is derived. $\Delta L= \Delta mc$ 2 is speculated as true for all possible energies (heat, chemical, invisible, cosmological, co-existing in many forms, etc.) as $\Delta E = \Delta mc$ 2. It is never justified The luminous body emanates only two light waves, of equal magnitude of energy (L/2), in the opposite direction (angle , 180°). The choice of the equation for variation in light energy is in relativistic form and interpretation in classical form (Binomial theorem, v< Δmc 2 (or equivalently for $\Delta E= \Delta mc$ 2). Thus derivation is full of speculations and arbitrariness, thus the equation needs to be derived by a different method. The general equation is $\Delta L = A\ \Delta mc$ 2 or $\Delta E = A\ \Delta mc$ 2 . The plenty of abandoned experimental data may justify the same. The data of atom bomb "Little Boy" was declassified in 1965, which implies that energy emitted is only 2% . The 98% energy lost can be explained with $\Delta E = A\ \Delta mc2$ (A

Pa2-f4

Analysis of pre-service physics teachers' conceptual understanding on special relativity theory

Sungmin Im
Daegu University

The purpose of this study is to investigate the understanding of the basic concepts of special relativity theory for preservice physical teachers and analyze the results to derive implications for teaching and learning of relativity theory in the context of physical teacher education. To this end, the Relativity Concept Inventory was applied and the responses of 51 preservice physics teachers majoring in physics at the College of Education were analyzed. Based on the response data, the following contents were analyzed. (1) the distribution of the preservice physics teachers' conceptual understanding of special relativity theory by topic. (2) the relationship between preservice physics teachers' conceptual understanding and confidence for the special relativity theory. (3) the relationship between preservice physics teachers' conceptual understanding and individual variables of respondents such as gender, grade, and prior knowledge. The results of this study provide implications for teaching and learning relativity theory in the context of physical teacher education and secondary school science education.

Pa2-f5

A heuristic approach to compute the bending of light

Dong-han Yeom
Pusan National University

The bending of light is very important historical evidence of general relativity. However, in order to really compute the bending angle, we need very detailed skills in general relativity. In this presentation, we show that there might be a heuristic way to compute the exact bending angle, which can be applied to undergraduate-level students or even advanced high school-level students.

Pa2-f6

The convergence of astrophysics and modern art after World War II

Jin Young Kim
KARTS

In the early 20th century, several artworks of Cubism and Surrealism expressed themselves in the physical concepts such as the relativity of simultaneity, time dilation, length contraction, through the way of time deconstruction. This was the typical example of the convergence of science and art in the first half of the 20th century. However since then new research and interpretation have been continuously emerging in the scientific community, and there also have been changes in the form and style of the art due to the development of new media. Currently, therefore another physical concepts and term of astrophysics are used as linguistic appropriation in the field of culture, and some artistic practice also adopt these physical terminology. Indeed the singularity of a black hole is used as a term to predict the direction of media art, Shannon's information concept is directly or indirectly applied to media art, the concept of entropy is adopted in land art and process art. Thus, this study aims to show physical concepts or terms that have been applied to directly or indirectly influencing modern and contemporary art since the World War II and interpretations thereof. In this study, I would like to analyze the above convergence cases in the field of physics and art to deepen the understanding of art works related to science, and do various discussions on the relationship between science and art.

July 4 (Tue): 14:00-16:00

C3. Black hole

Pa3-a1

Probing the structure inside the black hole event horizon

Li Li
Institute of Theoretical Physics, Chinese Academy of Sciences

The existence of black holes has been confirmed by experiments and observations. While the exterior physics of black holes has been extensively investigated in the literature, the interior structure of spacetime behind the event horizon has not been well understood. In this talk, I will introduce our recent progress toward understanding the interior of black holes.

Pa3-a2

Metrics with irreducible mass leading to a correct parameter dependence of gravitational effects around charged and rotating compact objects

Zahid Zakir
Centre for Theoretical Physics and Astrophysics

The standard metrics outside of charged and rotating sources (Kerr-Newman in general, Reissner-Nordström and Kerr in particular) contain the total mass at infinity, which includes both the mass of a neutral non-rotating body and the mass equivalents of rotational and electric field energies. Therefore, the total mass is related with other parameters of the metric - angular momentum and charge. However, at studying the dependence of gravitational effects on parameters, this relationship was ignored, assuming total mass to be constant at varying angular momentum and charge. This error led to physically absurd predictions about the weakening of gravity and its effects with increasing the rotational and electric field energies. To eliminate such errors, the total mass must be expressed in terms of independent parameters - the mass of the neutral non-rotating matter of the source, charge and angular momentum. Recently this has been done using as an independent parameter the mass determined from the gravitational radius at the pole when the charge is only on the surface (Zakir, 2022). In the present paper it is used “irreducible mass”, earlier defined heuristically as the remainder of total mass after the removal of angular momentum and charge. Earlier, the mass formulas expressing total mass in terms of irreducible mass were proposed by Florides (1960) (improved by the author (2022)) for charged bodies and then by Christodolou (1970) for rotating and Christodolou-Ruffini (1971) for charged rotating sources. In the paper, the standard metrics are transformed to metrics with independent parameters by substituting the expression for the total mass according to these mass formulas. It is shown that the metrics in this form lead to a physically correct dependence of the effects of gravity on the parameters, in particular, the growth of the rotation and electric field energies strengthens gravity and its effects, such as time dilation and redshifts, increases radii of orbits and the area of shadow (see Z.Zakir 2023 doi: 10.9751/QGPH.4-022.8074).

Pa3-a3

General mass formula for charged Kerr-AdS black holes

Sijie Gao
Beijing Normal University

It is well-known that the mass of a non-asymptotically flat spacetime cannot be uniquely defined. A reasonable definition of mass for the Kerr-AdS black hole has been found and widely used in studying black hole thermodynamics. However, the derivation usually needs a background subtraction to eliminate the divergence. It is also unknown whether this formula can be extended to a more general form. In this paper, we provide a more straightforward derivation for the mass formula, only demanding that the first law of black hole thermodynamics and Smarr formula are satisfied. We first make use of the Iyer-Wald formalism to derive a first law of charged Kerr-AdS black hole in the extended phase space. However, this mass is obviously not integrable. We then modify the coefficients of the first law to make the mass integrable. Finally, by applying the scaling argument to the modified first law, we obtain the Smarr formula, i.e., the explicit form of the mass. Remarkably, our mass formula contains a free parameter and when it is set to zero, we recover the familiar mass M/Xi^2 in the literature. Moreover, by making use of the gauge freedom of the Killing vector field $\ppa{t}{a}$, we find a favorite parameter t' which just gives the first law and makes the mass integrable. The mass also satisfies the Smarr formula and takes the form $M/Xi^{3/2}$. This mass formula has not been widely concerned, and could have important applications in future studies.

Pa3-a4

New black hole solutions with a dynamical traceless nonmetricity tensor in Metric-Affine Gravity

Jorge G. Valcarcel
Tokyo Institute of Technology

July 4 (Tue)

In the framework of Metric-Affine Gravity, the existing correspondence between the Einstein tensor and the energy-momentum tensor of matter provided by General Relativity is extended towards a post-Riemannian description in terms of the torsion and nonmetricity fields, which are sourced by the spin, dilation and shear currents of matter. In this talk, we discuss the dynamical role of the traceless part of the nonmetricity tensor and its intrinsic connection with shears, defining a model which encloses a new black hole solution endowed with shear charges. We show that the extension in the presence of dynamical torsion and Weyl vector leads to the broadest family of static and spherically symmetric black hole solutions with spin, dilation and shear charges in Metric-Affine Gravity so far.

Pa3-a5

Thermodynamics from conformal Killing vector in the charged Vaidya metric

Abbas Mohamed Sherif
Jeju National University

We consider thermodynamic properties of horizons generated by conformal Killing vectors in the Vaidya metric with a time dependent charge.

E5. Gravitational wave detection

Pa3-c1

Science of TianQin

Jianwei Mei
TianQin Center, Sun Yat-sen University

TianQin is a space-based gravitational wave (GW) detector expected to launch around 2035. It will detect GWs in the frequency band 0.1 mHz~1 Hz, offering the chance to study mysterious objects including massive black holes using GWs. In this talk, I report the progress made concerning the detection and discovery potential of TianQin.

Pa3-c2

Progress of high-precision inertial sensor for TianQin

Yanzheng Bai
Huazhong University of Science&Technology

High-precision inertial sensor is one of the key technologies for gravitational space detection missions. This talk presents the progress of the inertial sensor developed at Huazhong University of Science and Technology (HUST) for the TianQin mission, including the basic principle, noise model, main technique, ground and space testing of the inertial sensor

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Pa3-c3

Constraining Kaluza-Klein extra dimensions with Taiji

Minghui Du
Institute of Mechanics, Chinese Academy of Science

The precise inspection of gravitational waveforms offers a new way to test the modified theories of gravity. The Kaluza-Klein (K-K) theory is one of the most inspiring and promising theory among them, since it's capability of unifying gravity and other gauge interactions with the introduction of compact extra spacetime dimensions. The modulation of K-K extra dimensions to the inspiral stage of gravitational wave (GW) can be expressed in terms of a single parameter $\chi \equiv n / (2 + n)$, regardless of its specific topology. This deviation from general relativity can be evident for strong sources like supermassive black hole binares (SMBHBs), hence will be very hopefully captured by the future space-based GW detectors such as Taiji. In this paper, we estimate the effect of compact extra dimensions on the time delay interferometry (TDI) output of Taiji , and then use this relationship to forecast the constraint on the number of extra dimensions with simulated SMBHB sources. To make our estimation realistic, we adopt the numerical orbits of Taiji satellites, and simulate the SMBHB population according to the theoretical merger rate. Our analysis shows that, with 4 years of Taiji's observation, χ can be constrained to $\sigma_\chi = 0.0029$ among the fiducial value $\chi = 0$.

Pa3-c4

Constraining the acceleration of moving binary black holes using gravitational wave

Xinmiao Zhao
Peking University

Binary black holes (BBHs) are one of the most important types of gravitational wave (GW) sources. Recent studies show that BBHs may form and merge in the vicinity of a supermassive black hole (SMBH), which results in overestimated masses of black holes due to gravitational and Doppler redshift. One of the distinctive features of these GW sources is that they are accelerating around the SMBH, and we can search for them by constraining their acceleration using GW signals. In this work, we treat the GW sources which give deviated results from general relativity in the inspiral-merger-ringdown (IMR) consistency test as candidates for potentially accelerating ones. We use the Bondi-Metzner-Sachs (BMS) transformation to construct the GW waveform of accelerating BBHs and use the Bayesian inference method to estimate these candidates' acceleration.

B2. Stringy gravity and AdS/CFT

Pa3-d1

The TsT/TTbar correspondence

Wei Song
Tsinghua University

I will describe a class of toy models of holographic duality beyond the AdS/CFT correspondence. The starting point is IIB string theory on AdS3 with NS-NS three form flux, which is holographically dual to a two dimensional CFT. Performing TsT transformations (T-duality, shift, and T-duality) in the bulk, we can obtain black black solutions which interpolate BTZ black holes in the IR and linear dilaton background in the UV. The holographic dual is conjectured to be a single trace TTbar deformed CFT. As supporting evidence, we find a matching of the deformed spectrum, the thermodynamics of black holes, and the correlation functions.

Pa3-d2

A Geodesic Network in Classical AdS_3 Gravity from the Entanglement Wedge Cross Section

Jie-qiang Wu
Institute of Theoretical Physics, Chinese Academy of Sciences

In this work, we study a geodesic network in AdS_3 gravity, in the context of the entanglement wedge cross section. By measuring the length of each geodesic segment of the network, we construct a set of diffeomorphism invariant observables: the entanglement wedge cross section and four extra half geodesics' lengths. We try to study the properties of these observables in Hamiltonian formalism, including their Hamiltonian flows and the brackets between them. We study these problems by the brackets of the Brown-York tensor's components in the covariant phase space formalism. We find that the entanglement wedge cross section generates a novel behavior in the Hamiltonian flow, which includes a split at the HRT surface. We compute all of the brackets between the observables that we construct, and the only non-zero ones are the brackets of the entanglement wedge cross section with the half geodesics. Inspired from this set-up, we also construct a slightly different geodesic network where all geodesics' lengths commute with each other. As a cross check, we also reproduce some of these results by the canonical formalism of gravity.

Pa3-d3

Spacetime covariant disordered field theories

Cheng Peng
UCAS, KITS

In this talk I will review recent development in spacetime covariant SYK-like disordered models. I will discuss the motivations of this program, provide examples in 1+1d and 2+1d, and comments on relations with other theories.

Pa3-d4

Defect Localized Entropy and Holography

Yang Zhou
Fudan U.

How to construct a defect C-function is a longstanding problem. We consider p-dimensional defects in D-dimensional conformal field theories (CFTs) and construct defect localized entropy by performing Casini-Huerta-Myers transformation for the system with defect. The defect localized entropy is a measure of entanglement be- tween the degrees of freedom localized on the defect. We show that at the fixed point of defect renormalization group (RG) flow, defect localized entropy is equal to minus defect free energy for universal part. We construct defect C-functions from the defect localized entropy for surface defects and volume defects, and show that they coincide with the known results at defect fixed points. We discuss the discrepancy between C-function defined on flat defect and that on spherical defect, therefore explains why the latter candidate of C-function is not monotonically decreasing (non-perturbatively). We also study the holographic dual of defect localized entropy and find that it is given by the minimal surface located at string or brane worldvolume embedded in the holographic bulk.

Pa3-d5

On holographic time-like entanglement entropy

Run-Qiu Yang
Tianjin University

In order to study the pseudo entropy of timelike subregions holographically, the previous smooth space-like extremal surface was recently generalized to mix space-like and time-like segments and the area becomes complex value. Our recent paper finds that, if one tries to use such kind of piecewise smooth extremal surfaces to compute timelike entanglement entropy holographically, the complex area is not unique in general. We then generalize the original holographic proposal of spacelike entanglement entropy to pick up a unique area from all allowed ``space-like+time-like" piecewise smooth extremal surfaces for a timelike subregion. We give some concrete examples to show the correctness of our proposal.

Pa3-d6

Holographic two-point functions in a disorder system

Chanyong Park
GIST

We study the holographic dual of two-point correlation functions for nonconformal field theories. We first take into account a Lifshitz geometry as the dual of a Lifshitz field theory which may appear at a critical or IR fixed point. We explicitly show the holographic relation between a Lifshitz geometry and a Lifshitz field theory by calculating two-point correlators and equation of state parameter on both sides. We also investigate a disorder deformation, which allows a UV conformal field theory to flow into a new IR Lifshitz field theory. In this deformed theory, we investigate an anomalous dimension representing the change of an operator's scaling dimension along the RG flow.

Pa3-d7

Breaking rotations without violating the KSS viscosity bound

Hao-Tian Sun
Institute of Theoretical Physics, Chinese Academy of Sciences

We revisit the computation of the shear viscosity to entropy ratio in a holographic p-wave superfluid model, focusing on the role of rotational symmetry breaking. We study the interplay between explicit and spontaneous symmetry breaking and derive a simple horizon formula for η/s, which is valid also in the presence of explicit breaking of rotations and is in perfect agreement with the numerical data. We observe that a source which explicitly breaks rotational invariance suppresses the value of η/s in the broken phase, competing against the effects of spontaneous symmetry breaking. However, η/s always reaches a constant value in the limit of zero temperature, which is never smaller than the Kovtun-Son-Starinets (KSS) bound, $1/4\pi$. This behavior appears to be in contrast with previous holographic anisotropic models which found a power-law vanishing of η/s at small temperature. This difference is shown to arise from the properties of the near-horizon geometry in the extremal limit. Thus, our construction shows that the breaking of rotations itself does not necessarily imply a violation of the KSS bound.

Pa3-d8

Dynamical Instability of Holographic Two-component Superfluids Interface

Yuping An
Institute of Theoretical Physics, Chinese Academy of Sciences

E4. Multi-Messenger Astrophysics

Pa3-e1

Electromagnetic follow-up of GW

Elahe Khalouei
Seoul National University

I will talk about the Electromagnetic Follow Up of gravitational wave with Korean facilities.

Pa3-e2

Rapid Generation of Kilonova Light Curves Using Conditional Variational Autoencoder

Surojit Saha

Institute of Astronomy, National Tsing Hua University, Taiwan

The discovery of the optical counterpart, along with the gravitational waves from GW170817, of the first binary neutron star (BNS) merger, opened up a new era for multi-messenger astrophysics. The optical counterpart, designated as a kilonova (KNe), has immense potential to reveal the nature of compact binary merging systems. Ejecta properties from the merging system provide important information about the total binary mass, the mass ratio, system geometry, and the equation of state of the merging system. In this work, we adopt KNe data to prepare a training, test, and validation data set to be fed into a conditional variational autoencoder (CVAE) to regenerate the KNe light curves for the required values of physical parameters. The KNe data are the light curves in different filter bands. For different KNe models, the physical parameters governing the light curves are different based on the pre-merger or post-merger properties of the BNS merger event. We train the CVAE on the KNe light curve data from one chosen model by conditioning the light curves on the physical parameters, with a training time of ~20 minutes, and rapidly generate light curves for the desired values of the physical parameters across the whole parameter space. Once the CVAE is trained and conditioned on the physical parameters, it takes ~1 milli-second to generate the light curves with a root mean square value of ~0.02 (AB mag) between the true and generated light curves, thus speeding up the process by ~1000 times as compared to the existing method. We have separately trained, generated, and verified the CVAE approach on two different KNe models, where one model is based on pre-merger while the other is on post-merger properties of BNS, and have obtained satisfactorily accurate results, with training time and light curves generating time of ~20 minutes and ~1 millisecond respectively while achieving a root mean square value of ~0.02 and 0.015 AB mag between the original and generated light curves for each model. This technique has the ability to provide an alternative to the time-consuming and resource-draining simulations. Using the CVAE, we can look into the extremum detection limit associated with a KN model. The merit of this approach lies in its rapid generation of light curves based on desired parameters and at the same time encompasses all the possible light curves related to KN.

Pa3-e3

Pulsar timing residual induced by wideband ultralight dark matter

Yun-Long Zhang
National Astronomical Observatories, Chinese Academy of Sciences

The coherent oscillation of ultralight dark matter induces changes in gravitational potential with the frequency in the nanohertz range. This effect is known to produce a monochromatic signal in the pulsar timing residuals. Here we discuss a multifield scenario that produces a wide spectrum of frequencies, such that the ultralight particle oscillation can mimic the pulsar timing signal of stochastic common spectrum process. We discuss how ultralight dark matter with various spins produces such a wide band spectrum on pulsar timing residuals and perform the Bayesian analysis to constrain the parameters. It turns out that the stochastic background detected by NANOGrav can be associated with a wideband ultralight dark matter. (arXiv: 2112.15593)

Pa3-e4

New ideas for dark matter search in dwarf galaxies through direct gamma-ray detection exploiting the acceleration of electromagnetic shower development in oriented crystals

Alexei Sytov
INFN Ferrara Division; Korea Institute of Science and Technology Information (KISTI)

Dr Bandiera, Laura (INFN Ferrara Division); Prof. Gaitskell, Richard (Center for the Fundamental Physics of the Universe, Brown University); Prof. Koushiappas, Savvas M. (Department of Physics, Brown University); Dr. Sytov, Alexei (INFN Ferrara Division; Korea Institute of Science and Technology Information (KISTI)), Prof. Cho, Kihyeon (Korea Institute of Science and Technology Information (KISTI)); Mr. Haurilavets, Viktar (Institute for Nuclear Problems, Belarusian State University); Dr Paterno, Gianfranco (INFN Ferrara Division; University of Ferrara); Mr. Soldani, Mattia (INFN; University of Ferrara); Prof. Tikhomirov, Victor (Institute for Nuclear Problems, Belarusian State University). Dwarf spheroidal galaxies are dark matter dominated systems without known sources of astrophysical emission which makes these objects extremely promising for dark matter annihilation searches. Moreover, Fermi LAT observations show a strong evidence for a gamma-ray anomalous signal in the dwarf galaxy Reticulum II at the energies from few GeV up to 20 GeV [1]. At the same time the angular resolution of the gamma direction measurement by the existing gamma-ray space telescopes is well above the angular size of this dwarf galaxy which makes signal-background discrimination extremely difficult. Furthermore, such kind of missions are very expensive and technically complicated. We propose various probable setups of a nowel gamma-ray space telescope exploiting the acceleration of electromagnetic shower development in oriented crystals [2]. This effect is activated in a narrow angular range ~1 mrad vs the direction of a crystalline atomic string. Such angle is comparable with the desired angular resolution for gamma-ray signal observation from Reticulum II, which can resolve the problem of signal-background discrimination. Moreover this effect allows one to hold an electromagnetic shower in a several times shorter oriented crystal than in an amorphous material or in a randomly directed crystal. This effect can be potentially used both for a gamma-e± converter and a calorimeter and will help to considerably reduce the weight, the complexity and, therefore, the cost of the space mission. In addition, it opens wide prospects for gamma-ray astronomy at ultra-high energies including the TeV scale. Furthermore, we carry out the first simulations of the setups proposed using Geant4 simulation toolkit [3] and our simulation models of electromagnetic effects in oriented crystals [2,4]. [1] A. Geringer-Sameth, S.M. Koushiappas et al. arXiv:1807.08740v1 [2] L. Bandiera et al. Phys. Rev. Lett. 121, 021603 (2018) [3] J.Allison et al., NIM A 835, 186-225 (2016). [4] A. Sytov et al. arXiv: 2303.04385 Accepted for publication in the Journal of Korean Physical Society. A. Sytov is supported by the European Commission (TRILLION, GA. 101032975). We acknowledge partial support of the INFN through the MC-INFN and the INFN OREO project. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support. This work is also supported by the National Supercomputing Center with supercomputing resources including technical support (KSC-2022-CHA-0003).

E1. Test of gravity

Pa3-e5

Testing black hole eikonal correspondence

Che-Yu Chen
iTHEMS, RIKEN

Adopting geometric-optics approximations in black hole spacetimes enables the construction of a mapping between black hole images and eikonal black hole quasinormal modes (QNMs). More explicitly, the real part and imaginary part of the QNM frequencies correspond to the ring size and the detailed ring structure of the image, respectively. This correspondence may be violated when going beyond general relativity. In this talk, I'll discuss the possibility of testing this mapping using real black hole observations. We propose a novel method to test the eikonal correspondence via the comparison of two sets of observables from a nonrotating black hole, one extracted from QNM spectra and the other from the lensed photon rings on the image plane. In particular, I'll demonstrate that the photon ring observables robustly capture the information of the black hole spacetime itself regardless of the surrounding emission models. Therefore, the proposed test of eikonal correspondence can be validated in quite broad scenarios.

Pa3-e6

Testing Gravitational Violation of Electromagnetic U_1 Symmetry: Light Deflection by the Sun and Josephson Effects in Quantum Yang-Mills Gravity

Yun Hao
University of Massachusetts Dartmouth

We discuss the possibility of testing the gravitational violation of electromagnetic U_1 symmetry by measuring the angle of deflection of light by the sun. First, we derived the modified eikonal equation of Maxwell's equation in the presence of Yang-Mills gravity to calculate a theoretical prediction. Then, we simplify the modified Maxwell's equation and derive the Einstein-Grossmann (EG) equations by taking the geometric-optic limit. Next, we obtain two different effective metric tensors $G^{\mu\nu}$ and $G_L^{\mu\nu}$: (A) without using $\partial_\mu A^\mu=0$: $ G^{\mu\nu} \partial_\mu \Psi \partial_\nu \Psi = 0, \ \ \ \ \ \ G^{\alpha\sigma} = J_{\lambda}^\alpha J^{\lambda\sigma}, \ \ \ \ $ (B) using $\partial_\mu A^\mu=0$: $ G_L^{\mu\nu} \partial_\mu \Psi \partial_\nu \Psi = 0, \ \ \ \ G_L^{\mu\nu} = G^{\mu\nu} - \frac{g}{4}\phi_{\lambda}^\mu J^{\lambda\nu}. $ The deflection angle of light due to the sun is calculated using two different effective metric tensors. Without using the $\partial_\mu A^\mu=0$ condition, the angle is $\Delta \phi \approx 1.75^{\prime \prime}$. With the $\partial_\mu A^\mu=0$ condition, the angle is $\Delta \phi \approx 1.53^{\prime \prime}$. The two different results indicate that electrodynamics is not gauge invariant in the presence of Yang-Mills gravity. It is demonstrated that quantum Yang-Mills gravity implies that the electric charge of the electron by itself is not absolutely conserved in the presence of gravity. However, the modification of the electron charge conservation in QED due to the presence of Yang-Mills gravity is small and difficult to detect by experiments. One can also test the violation of U_1 gauge symmetry by quantum Yang-Mills gravity by using Josephson effects. The voltage across a Josephson junction is affected by the presence of quantum Yang-Mills gravity and is now given by $V_{g21}\approx Q \int_1^2 [- \mbox{\boldmath$ {\bf \nabla}$} A_0 - h_0^{2}{\p {\bf A}}/{\p t}]\cdot d{\bf s}$. The modified voltage V_{g21} is not U_1 gauge invariant. Suppose one compares the voltage across a Josephson junction in a laboratory at rest on Earth with that across a junction in free fall (e.g., in the International Space Station). Quantum Yang-Mills gravity predicts a difference on the order of 1 part in 10^{9}, which should be detectable as the precision of the Josephson junction voltage standard is on the order of a few parts in 10^{10}. Measurements of the two terms in V_{g21} can test (i) the gravitational effect on the Josephson voltage-phase relation, and (ii) the violation of U_1 gauge symmetry in superconductors by quantum Yang-Mills gravity.

A6. Gravitational waves-Theory

Pa3-f1

Gravitational wave observables from subleading soft factors

Karan Fernandes
National Taiwan Normal University

The soft factorization in scattering amplitudes of gravitationally interacting point particles can be systematically derived in the eikonal approximation. The leading term is the Weinberg soft graviton factor, while the next-to-eikonal O(G^2) contribution is due to a double soft graviton emission. This subleading soft factor is applicable in the eikonal approach to binary black hole scattering processes and contains information about the early inspiral phase. We accordingly use the subleading soft factor to compute the order G^2 memory, radiated momentum and angular momentum from double soft graviton emissions in binary black hole events.

Pa3-f2

Chaotic Orbits in Effective One Body Formulation

Avani Vikrambhai Patel
National Taiwan Normal University

In this talk, I will discuss our work about the chaotic signatures of the geodesic dynamics of a non-spinning test particle in the effective-one-body (EOB) formalism for the inspiral process of spinning binary black holes. We first show that the second order post-Newtonian (2PN) EOB dynamics is non-integrable by demonstrating that the EOB metric does not satisfy the criterion for the existence of Carter constant. We then employ the numerical study to find the plateaus of the rotation curve, which are associated with the existence of Birkhoff islands in the Poincaré surface of section, signifying the chaotic dynamics in the system. Our results show the signatures of chaos for the EOB dynamics, especially in the regime of interest for which the Kerr bounds of the component black holes hold. We also find that chaotic behavior is more obvious as the spin parameter a of the deformed EOB background metric increases. Our results can help to uncover the implications of dynamical chaos in gravitational wave astronomy. Finally, we also present some preliminary results due to corrections at 3PN order.

Pa3-f3

Conformal gravitational waves and their symmetries

Qiliang Zhao
Sun Yat-sen University

The Weyl tensor can be used to find all conformally at space-times and to derive the conformally redefined time transformation proposed by Gibbons. Such transformations can be used to study the conformal relations of gravitational waves and to deduce their symmetries by interchanging the conformal structure of the respective space-times. The procedure allows us to derive the Carroll symmetry and O(2,1) symmetry of two conformally related gravitational waves as illustrated by the time-dependent linearly polarized plane gravitational waves, the Lukash gravitational wave and a special gravitational wave.

Pa3-f4

Hydrodynamic sound shell model

Zi-Yan Yuwen
Institute of Theoretical Physics，Chinese Academy of Sciences

For a cosmological first-order phase transition in the early Universe, the associated stochastic gravitational wave background is usually dominated by the sound waves from plasma fluid motions, which have been analytically modeled as a random superposition of freely propagating sound shells but with the force by the scalar field that produces the self-similar profile removed. In this Letter, we complete the previous analytic sound shell model by including the forced propagating contribution from the initial collision stage of sound shells with their self-similar profiles still maintained by the moving bubble walls. Besides the causal k^3-scaling in the infrared regime, we have identified additional $k^{-3/2}$ and $k^{-5/2}$ scalings in the ultraviolet regime for the forced propagating contributions from the single and double sound shells, respectively. New numerical fitting templates are also provided for the gravitational-wave energy density power spectrum from the sound waves.

Pa3-f5

Hydrodynamic perspective of cosmological first-order phase transitions

Shao-Jiang Wang
Institute of Theoretical Physics, Chinese Academy of Sciences

The stochastic gravitational-wave backgrounds from cosmological first-order phase transitions are indispensable probes for new physics beyond the standard model of particle physics. In this talk, I will provide a hydrodynamic perspective for the cosmological first-order phase transition, including an effective picture of bubble expansion, a hydrodynamic evaluation of backreaction force, an energy budget beyond constant sound velocity model, a hydrodynamic evaluation of the bubble wall velocity from strongly coupled first-order phase transition, and a new hydrodynamic sound shell model for the sound waves as a dominated source of stochastic gravitational-wave backgrounds.

Pa3-f6

Double-inflection-point inflation and gravitational waves

Tie-Jun Gao
Xidian University

We will talk about a kind of inflationary models with double-inflection-point. Such double-inflection-point can be generated from polynomial potential or from the supergravity theory with a single chiral superfield. In such models, the inflection point at large scales leads to a nearly scale-invariant spectrum, which is consistent with current CMB constraints. Another inflection point leads to a large peak in the scalar power spectrum at small scales, which will induce GWs.

Pa3-f7

Growth of curvature perturbations in non-minimal curvaton scenario

Chao Chen
HKUST

We reexamine the growth of curvature perturbations in non-minimal curvaton scenario. We find that the dynamics of curvaton perturbation during inflation is not merely determined by the depth of the dip, but also strongly affected by its shape.

July 4 (Tue): 16:30-18:30

C3. Black hole

Pa4-a1

Scalar Hairy Black Holes with Asymmetric Potential

Xiao Yan Chew
Jiangsu University of Science and Technology

In this talk I will present my latest paper (arxiv:2210.01313) in which I studied the properties of hairy black holes in Einstein gravity when it is minimally coupled to a scalar field with an asymmetric potential constructed in Phys. Rev. D 73 (2006) 084002 a few decades ago. This potential has been applied in cosmology to describe the quantum tunneling process from false vacuum to the true vacuum and contains a local maximum, a local minimum (false vacuum) and a global minimum (true vacuum). A branch of hairy black hole solutions emerged from the Schwarzschild black hole, and we studied the domain of existence of such configurations. They tend to a particle-like solution in the small horizon limit, i.e., the scalarons. We also studied the stability of hairy black holes and they are unstable under the radial perturbation.

Pa4-a2

Properties of the charged rotating black hole with an anisotropic matter field

Wonwoo Lee
CQUeST, Sogang University

We present a family of new rotating black hole solutions that generalizes the Kerr-Newman spacetime to include an anisotropic matter. The geometry is obtained by employing the Newman-Janis algorithm. We discuss the properties of the black hole are analyzed in detail including the electromagnetic field and shadow cast.

Pa4-a3

Spins of primordial black holes from fluids with soft equation of state parameters

Daiki Saito
Nagoya University

In recent years, primordial black holes (PBHs), which are black holes (BHs) could have formed in the early universe, have been attracting attention as candidates for a substantial part of dark matter and possible origins of BH binaries, which can be sources of gravitational waves. The observational constraints on their abundance can provide us with information about inhomogeneity in the early universe. In this talk, I will discuss the estimation of the spins of the PBHs formed from perfect fluids with 0<w

Pa4-f4

Diverse External Magnetic Field Configurations Surrounding a Black Hole

Saken Toktarbay
Al farabi kazakh national university

In this work, we present a review of the motion of charged particles around a black hole under the influence of external magnetic fields. The dynamics of charged particles can be described by equations that incorporate the specific magnetic field configuration. We analyze various magnetic field configurations surrounding a static black hole, including uniform, dipole, and parabolic magnetic fields, as well as possible combinations of magnetic fields. Our analysis aims to provide insights into the properties and behaviors of the surrounding environment, including the interactions between the magnetic field and other astrophysical phenomena such as accretion disks, jets, and outflows.

E5. Gravitational wave detection

Pa4-c1

SOGRO in Tetrahedral Configuration for Mid-Frequency Gravitational Waves

Ho Jung Paik
Department of Physics, University of Maryland, College Park, MD

Ho Jung Paik, Christopher J. Collins, Ronald S. Norton, and Peter S. Shawhan Department of Physics, University of Maryland, College Park, MD 20742, U.S.A. A mid-frequency terrestrial full-tensor gravitational wave (GW) detector, called SOGRO (Superconducting Omnidirectional Gravitational Radiation Observatory), has been proposed to detect GWs from intermediate-mass black hole (IMBH) binaries and white dwarf binaries, as well as inspiraling stellar mass BH binaries, in the frequency band of 0.1 to 10 Hz. The originally proposed concept of SOGRO was to combine the relative displacements of 6 three-axis superconducting test masses (TMs) in an octahedral configuration levitated from a 3D cross-shaped cryogenic platform. Since then, we discovered that SOGRO can also be realized by combining signals from 4 three-axis TMs in a tetrahedral configuration. Here we propose a double tetrahedral SOGRO, i.e., two collocated tetrahedral SOGROs, formed by 8 TMs located at all 8 vertices of a cuboid. This will allow us to maximally utilize the platform which has a four-fold symmetry about the vertical axis, with a sensitivity enhancement by a factor of $\sqrt{2}$ in amplitude. We also propose some major design changes to significantly reduce the technical challenge and the cost of the construction and operation of SOGRO. The two most significant proposed changes are: (1) to replace the superconducting levitation of the TMs with a mechanical pendulum suspension, and (2) to only cool essential parts of the instrument, rather than the whole platform. Even without the superconducting levitation, the TMs need to be cooled to 4.2 K to reduce their thermal noise to below the sensor noise in the decihertz range. Nevertheless, suspending the TMs as long pendula would eliminate the major technical challenge of magnetically levitating multi-ton TMs against gravity. Each TM will now respond only to forces in two horizontal directions. Without measuring the vertical motion of the TMs, the detector would no longer directly measure the 6 common-mode (CM) accelerations and 5 gravity gradient components. The full strain tensor h_{ij} could, however, still be recovered if the platform is sufficiently well isolated from ground tilt. By suspending the entire platform also as a pendulum, we decouple it from the angular motions of the ground. In the absence of the CM angular motions of the platform, one can measure h_{xz} and h_{yz} by combining horizontal displacements of the TMs separated along the vertical direction alone. These measurements would be degenerate with tilt motion of the platform, but if its resonance frequency is low enough, the tilt motion can be suppressed to below the sensor noise over the signal frequency band. Thus, one can construct an omnidirectional full-tensor detector by combining the horizontal displacements of the 4 TMs alone. To lighten the cryogenic requirement for SOGRO significantly, we also propose to cool down only the TMs, their housings, transmission lines, and SQUIDs to a cryogenic temperature, while keeping the massive platform at the ambient temperature exposed to the air, although it will be a major challenge to design the platform with high enough resonance frequencies and low enough thermal noise contributions at ambient temperature and pressure. The entire detector will be constructed underground to reduce the seismic and the Newtonian noise. The underground tunnel will also provide a stable temperature and quiet acoustic environment. We will present a design concept of the detector and the platform, aimed at achieving a strain sensitivity of $10^{-19} - 10^{-20} Hz^{-1/2}$ at 0.1-10 Hz.

Pa4-c2

Development of Superconducting Weak Force Sensors for Gravitational Wave Detection

Xing Bian
Institute of Mechanics, Chinese Academy of Sciences

Weak force sensing based on the Meissner effect, flux quantization, and superconducting quantum interference devices is considered one of the most sensitive technologies to detect weak forces and displacements. The sensitivity can be as high as 10^(-18) m Hz^(-1/2) or even better, making it a good candidate to detect the very weak signals produced by gravitational waves. Several gravitational wave detectors based on this technology have been proposed, such as the Superconducting Omni-directional Gravitational Radiation Observatory (SOGRO), which directly measures the relative displacement between separated test masses caused by the tidal force of gravitational waves with superconducting sensing, and the Lunar Gravitational Waves Antenna (LGWA), which detects the vibration of the moon excited by gravitational waves with seismometers of superconducting and optical displacement readouts. In the past five years, we have been developing two superconducting weak force sensors, part of the purpose is to demonstrate the technologies for these gravitational wave detectors. One of our sensors has magnetically levitated test masses and is a downscaled prototype of the vertical axis of SOGRO. The other has mechanically suspended test masses and is a prototype of the seismometers of LGWA. Both sensors are designed to have a low resonance frequency to increase sensitivity and lower the detection frequency band to the deci-Hertz region. In this talk, we will present our progress in the development of the sensors.

Pa4-c3

Detection of gravitational waves by electromagnetic cavity: a review

Chan Park
IBS

Gravitational wave (GW) detection using electromagnetic (EM) cavities has garnered significant attention in recent years. With ongoing experiments on axion detection using highly sensitive electromagnetic cavity, there is potential to apply these existing facilities to GW detection, opening up a new channel of GW observation. In this review, we comprehensively examine the principles of GW detection using EM cavities within the framework of general relativity. We expect that it not only provides analysis of existing EM cavity experiments and but also offers insights for the design of new ones.

B2. Stringy gravity and AdS/CFT

Pa4-d1

On higher-dimensional Carrollian field theory

Bin Chen
Peking University

Carrollian conformal symmetry (CCS) appears as the asymptotic symmetry group of Einstein gravity at null infinity. It could play an indispensable role in studying the flat space holography, as shown in 3D flat holography. The higher dimensional CCS presents novel features. In this talk, I will introduce our recent work on higher dimensional Carrollian conformal field theory, including the representations of the algebra, the determination of 2-point correlators and the explicit construction of the Carrollian field theory through null reduction.

Pa4-d2

Pseudo-entropy in 2d CFTs

Song He
Jilin University

We study the late-time properties of pseudo-(Rényi) entropy of locally excited states in rational conformal field theories (RCFTs). The two non-orthogonal locally excited states used to construct the transition matrix are generated by acting different descendant operators on the vacuum. We prove that for the cases where two descendant operators are generated by a single Virasoro generator respectively acting on a primary operator, the late-time excess of pseudo-entropy and pseudo-Rényi entropy always coincides with the logarithmic of the quantum dimension of the corresponding primary operator. Furthermore, we consider two linear combination operators generated by the generic summation of Virasoro generators. We find their pseudo-Rényi entropy and pseudo-entropy may get additional contributions, as the mixing of holomorphic and anti-holomorphic parts of the correlation function enhances the entanglement. Finally, we assert the pseudo-Rényi entropy and pseudo-entropy are still the logarithmic quantum dimension of the primary operator when the correlation function of linear combination operators can be divided into the product of its holomorphic part and anti-holomorphic part. We offer some examples to illustrate the phenomenon.

Pa4-d3

Boundary theory in asymptotically flat spacetime

Jiang Long
Huazhong University of Science and Technology

We present a method to reduce field theory in asymptotically flat spacetime to its future/past null infinity. We will discuss various properties of the boundary theory, including the solution space, symplectic strucuture, operators and correlation functions. We will construct the flux operators which could encode the information of the radiation fluxes in the bulk theory. By working out the commutators of the flux operators, we could extend the Carrollian diffeomorphism in a consistent way. Our method may shed new light on flat holography and could be used to find more physically interesting Carrollian field theories.

Pa4-d4

Matching partition functions of deformed JT gravity and cSYK model

XianHui Ge
Department of Physics, Shanghai University

Motivated by recent analogies between the large-q cSYK model and charged black holes, we aim to find a concrete gravitation theory with matching partition function. Our main focus is to match the thermodynamics of the (0 + 1)-dimensional SYK model, with that of a (1 + 1)-dimensional gravitational model. We focus on a model of deformed JT gravity, characterized by some unknown dilaton potential function and unknown dilaton-to-Maxwell field coupling. By finding the general solutions, we are able to find the Lagrangian which produces the same partition function and equation of state as that of the considered SYK model. We also study the pole-skipping phenomenon of the boundary SYK model dual to Jackiw-Teitelboim(JT) gravity with a minimally coupled massive scalar field. We find that there is a one-to-one correspondence of the pole skipping points between the JT gravity and the SYK model.

Pa4-d5

Temperatures in quantum black holes

Wontae Kim
Sogang University

We calculate the temperature of an evaporating black hole that is initially formed by a shock wave, taking into account the quantum backreaction. Based on the holographic principle, along with the assumption of a boundary equation of motion, we show that the black hole energy is maintained for a while during the early stage of evaporation. The Stefan-Boltzmann law tells us that the black hole temperature, defined by the emission rate of the black hole energy, starts from zero temperature and reaches a maximum value at a critical time, and finally vanishes. It is also shown that the maximum temperature of the evaporating black hole never exceeds the Hawking temperature of the eternal AdS_2 black hole.

Pa4-d6

Soft Theorems in AdS spacetime

Arpita Mitra
POSTECH

At the classical level, the soft factor can be obtained from radiative profiles arising from the gravitational and electromagnetic bremmstrahlung in the vanishing frequency limit. We have studied scattering of a probe particle by a four dimensional AdS black hole background at large impact factor with the small negative cosmological constant. Our analysis is consistent perturbatively to leading order in the AdS radius and black hole mass parameter. We define a "soft limit" of the radiation and extract out the "soft factor" from it. We find the correction to the well known flat space soft factors due to the presence of a small negative cosmological constant. The leading soft factor can be expected to be universal and holds beyond tree level. This allows us to derive a correction to the Ward identity, following the known equivalence between large gauge Ward identities and soft photon theorems in asymptotically flat spacetimes. We have also recovered this corrected large gauge Ward identity from the CFT ward identity defined at the boundary in the large AdS radius limit.

Pa4-d7

Quantum Critical Magnetocaloric Effect in Holography

Jun-Kun Zhao
ITP, CAS

The magnetocaloric effect (MCE) refers to the phenomenon of temperature changes that occur when a magnetic field is applied to or removed from certain materials. When a quantum critical point is approached, the various quantum many-body interactions can result in a diverging Gruneisen parameter, leading to a significant MCE and serving as a direct indicator of quantum criticality. Using holographic methods, we investigate the MCE in a class of strongly coupled systems with the chiral anomaly that is dual to Einstein-Maxwell-Chern-Simons theory. Our findings indicate that the sign change of the Gruneisen parameter near quantum critical points is absent, and the temperature scaling of the Gruneisen parameter predicted from mean field theory is violated.

D3. Cosmological dynamics and Fundamental Constants

Pa4-e1

Singularities of Magnetic Monopoles in the Universe

Kenmoku Masakatsu
Nara Women's Universiry

The magnetic monopole is one of the important problems in the early stage of universe as well as the observations and the experiments on the earth. We study the existence or non-existence of magnetic monopoles using the pre-potential method focusing on their singularities.

Pa4-e2

Numerical Investigation of Two-Dimensional Fokker-Planck Equation in Inflationary Models: Importance of Slow-Roll Conditions

Jie Jiang
Pusan National University

We generalize the Fokker-Planck equation to two-dimensional cases, with the aim of analyzing the probability distribution in inflationary models. We employ the spectral method for spatial derivatives and the Crank-Nicolson method for the time evolution to solve the equation numerically.

Our findings reveal that the slow-roll conditions must be satisfied throughout the entire field space, while a violation in any region can lead to the pollution of the other healthy areas. We conclude that the Fokker-Planck equation has some limitations in analyzing the probability distribution in inflationary scenarios and emphasize the importance of satisfying the slow-roll conditions of the entire domain for accurate results.

D4. Cosmology beyond FLRW-theory and Obs

Pa4-e3

Thermodynamic equation of state and phase transitions for the spacetime of Friedmann-Robertson-Walker universe

Ya-Peng Hu
Nanjing University of Aeronautics and Astronautics

It is well-known that the spacetime of Friedmann-Robertson-Walker (FRW) universe is a thermodynamic system, where it has temperature, entropy and satisfies the first law of thermodynamics. We recently make a further significant step that we construct the thermodynamic equation of state for the FRW spacetime for the first time, i.e. P=P (V,T) where the gravitational pressure P is directly derived from the unified first law, in fact the gravitational field equation in spherically symmetric spacetime through a first principle study. Furthermore, by using the thermodynamic equation of state, we have discovered three kinds of thermodynamic phase transitions in the FRW spacetime. We also make some investigations on insights into the potential astronomic observations of these phase transitions.

Pa4-e4

A DEEP LATENT VARIABLE MODEL FOR RECOVERING CMB ANISOTROPY MAP OVER LARGE ANGULAR SCALES OF THE SKY

Vipin Sudevan
LeCosPA, NTU, Taiwan

Rapid advancements in the field of observing Cosmic Microwave Background (CMB) radiation have made it possible to map the primordial signal over the entire sky with increasingly higher resolution. Accurate measurement of the fluctuations in the temperature and polarization fields of CMB provides us with a wealth of knowledge regarding the geometry, composition, and renders stringent constraints on cosmological parameters. However, the emissions in the microwave spectrum from various astrophysical sources present within and outside our galaxy contaminate the CMB observed by satellite and ground-based missions. Hence, an important task in the CMB science is to recover the underlying true CMB signal in the CMB observations by properly minimizing the so-called foreground emissions. We have developed a convolutional neural network that integrates Bayesian statistics and variational methods to solve the problem of minimizing foreground contamination present in the observed CMB maps. We have applied this architecture to minimize the foregrounds present in Planck CMB observations. The model which is trained using simulated foreground-contaminated maps generated by the Python Sky Model (PySM) also incorporates both the model and statistical uncertainties due to its Bayesian optimization. A cleaned CMB map is obtained by taking the mean of several samples of cleaned CMB maps generated by the trained neural network, and the standard deviation of these maps gives the per-pixel error estimates. In this talk, I will discuss in detail the architecture of our Bayesian convolutional neural network and the training procedure using simulated foreground-contaminated CMB maps. I will show the results from the training and testing phases and finally the cleaned CMB map and its corresponding angular power spectrum obtained after using the observed CMB maps by the Planck satellite mission. I will also compare our results with the cleaned CMB maps and angular power spectra provided by the Planck science team after implementing various analytical foreground removal algorithms.

Pa4-e5

Discordance of dipole asymmetries seen in large radio surveys (VLASS & RACS) with the Cosmological Principle

Ashok Kumar Singal
Physical Research Laboratory, Ahmedabad

In recent years, large radio surveys of Active Galactic Nuclei (AGNs), comprising millions of sources, have become available where one could investigate dipole asymmetries, assumedly arising due to peculiar motion of the Solar system. Such dipoles in AGNs have turned out to be of much larger amplitude (a factor of ~2 to 20) than the one seen in the cosmic microwave background (CMB), though their directions have turned out to be largely within statistical uncertainties with respect to the CMB dipole. Here we investigate dipoles asymmetries in two recent large radio surveys, Very Large Array Sky Survey (VLASS) at 3 GHz, carried out at Karl G. Jansky Very Large Array (VLA), covering the sky north of -40 deg declination containing 1.9 million sources, and the Rapid ASKAP Continuum Survey (RACS), covering the sky south of +30 deg declination at 887.5 MHz, carried out using the Australian Square Kilometre Array Pathfinder (ASKAP), containg 2.1 million sources. We find these two radio source dipole amplitudes to be significantly larger (about 4 and 7 times) than the CMB dipole. Directions of the VLASS and RACS dipoles, along with a number of dipoles determined from other previous catalogs, e.g. NVSS, TGSS, DR12Q, WISE, Supernovae Ia, all appear to be pointing in a narrow region about the CMB dipole, which has a joint probability less than one part in ten million to occur by a random chance. However, their discordant amplitudes seem in contravention of what would be expected from the Cosmological Principle (CP).

B1. Quantum physics in curved spacetime

Pa4-f1

Yang-Mills black holes and end of black hole evaporation

Dong-han Yeom
Pusan National University

We discuss Yang-Mills black holes and regular Yang-Mills instantons. These solutions consistently contribute to black hole evaporation. We discuss the possibility that these instantons can be the end point of black hole evaporation. We connect this scenario to the context of the information loss paradox.

Pa4-f2

Relativistic particle wavepacket in quantum electromagnetic fields: Quantum coherence and the Unruh effect

Shih-Yuin Lin
National Changhua University of Education

We have developed a linearized effective theory with Gaussian wavepackets of a charged relativistic particle coupled to quantum electromagnetic fields at a scale well below the Schwinger limit. Using this effective theory, we address the issues of decoherence of electron beams, and the Unruh effect on electrons.

G: After-deadline

Pa4-f3

The periapsis shift of a quasi-circular orbit in a static spherically symmetric spacetime and the active gravitational mass density

Tomohiro Harada
Rikkyo University

We study the periapsis shift of a quasi-circular orbit in a general static spherically symmetric spacetime. We derive two formulae in full order with respect to the gravitational field, one in terms of the gravitational mass mm and the Einstein tensor and the other in terms of the orbital angular velocity and the Einstein tensor. These formulae reproduce the well-known ones for the prograde shift in the Schwarzschild spacetime. In a general case, the shift deviates from that in the vacuum spacetime due to a particular combination of the components of the Einstein tensor at the radius r of the orbit. The formulae give a retrograde shift due to the extended-mass effect in Newtonian gravity. In general relativity, in the weak-field regime near a massive object, the active gravitational mass density plays an important role. We show that a retrograde shift requires the active gravitational mass density to be beyond a critical value \rho_{c}\simeq 2.8\times 10^{-15} \mbox{g}/\mbox{cm}^{3} (m/M_{\odot})^{2}(r/\mbox{au})^{-4}, while a prograde shift greater than that in the vacuum spacetime instead implies that it is negative, i.e., the violation of the strong energy condition, and thereby provides evidence for dark energy.

Pa4-f4

Thermodynamics and weak cosmic censorship conjecture for a Kerr-Newman Taub-NUT black hole

Si-Jiang Yang
Lanzhou University

Stimulated by the recent researches of black hole thermodynamics for black hole with Newman-Unti-Tamburino (NUT) parameter, we investigate the thermodynamics and weak cosmic censorship conjecture for a Kerr-Newman Taub-NUT black hole. By defining the electric charge as a Komar integral over the event horizon, we construct a consistent first law of black hole thermodynamics for a Kerr-Newman Taub-NUT black hole through Euclidean action. Having the first law of black hole thermodynamics, we investigate the weak cosmic censorship conjecture for the black hole with a charged test particle and a complex scalar field. We find that an extremal black hole cannot be destroyed by a charged test particle and a complex scalar field. For a near-extremal black hole with small NUT parameter, it can be destroyed by a charged test particle but cannot be destroyed by a complex scalar field. Since there are many different viewpoints on thermodynamics for black holes with NUT parameter, the investigation of weak cosmic censorship conjecture might provide a preliminary selection for the thermodynamics for black holes with NUT parameter.

Pa4-f5

Black hole radiation phase space from 1d higher point of view

Mahdis Ghodrati
APCTP

After reviewing the JT gravity, we discuss the four saddles in the mixed correlation measures of black holes Hawking radiation in the setup of geometric evaporation of Verlinde and Verheijden. By looking from 1d1d higher point of view and partial dimensional reduction, we examine the phase structures and the universalities for these four saddles. We also discuss the behavior of quantum error correction codes for each of these four phases, reaching to consistent results. Then, instead of dimension reduction between Einstein gravity and JT, we comment on the connections between partition functions and saddles of 3d Chern-Simons and 2d BF theories, 2d Liouville and 2d Wess-Zumino-Witten models, and also the dimensionally reduced 1d Schwarzian and 1d particles on group. We comment on the connections between these theories in the setup of mixed correlations and Page curves.

Pa4-f6

Is there a Hubble-variation tension?

Shao-Jiang Wang
Institute of Theoretical Physics, Chinese Academy of Sciences

The variation in the measured Hubble constant with respect to our local density contrast can be made negligible below percentage level by choosing the Hubble-flow type Ia supernovae (SNe Ia) outside of our homogeneity scale. However, the Hubble-constant variation with respect to the local density contrast of SN-host galaxy has never been explored before. We have revealed both theoretically and observationally this Hubble-constant variation correlation, which becomes more and more positively correlated with the ambient density contrasts of SN-host galaxies estimated at larger and larger scales, on the contrary to but still marginally consistent with the theoretical expectation from the Λ-cold-dark-matter (LCDM) model. In particular, this Hubble-constant variation correlation admits nearly 3σ tension with LCDM prediction, leading to another Hubble-variation tension in addition to the Hubble tension and S8 tension.

July 6 (Thu): 14:00-16:00

C3. Black hole

Pa5-a1

Black hole shadow and inner shadow

Minyong Guo
Beijing Normal University

In this talk, I will focus on the shadow and inner shadow of black holes. These phenomena depend primarily on the properties of the black hole itself, rather than being influenced by the light source. As a result, by calculating the shadow and inner shadow of black holes, we can directly determine the parameters of the black hole and test the relevant gravitational theory.

Pa5-a2

Numerical Modeling of the Black Hole Shadow and Relativistic Jets on Horizon Scale

Yosuke Mizuno
Tsung-Dao Lee Institute, Shanghai Jiao Tong University

Recently the Event Horizon Telescope has presented a ring-like emission structure of M87 and our galactic center Sgr A* at 1.3mm with unprecedented angular resolutions. These images are consistent with the size and shape of the lensed photon orbit encircling the “shadow” of a supermassive black hole. In this talk, I would like to overview the theoretical interpretation of EHT results of M87, and present the recent progress of theoretical modeling by numerical simulations of magnetized accretion flows onto a black hole. I also discuss the numerical modeling of relativistic jets and comparison with the observations.

Pa5-a3

Gravitational Lensing in the NUT Spacetime: A Multimessenger Approach

Torben Christian Frost

Kavli Institute for Astronomy and Astrophysics at Peking University

The existence of a gravitomagnetic charge, the gravitational equivalent to a hypothetical magnetic charge in classical electrodynamics is a long-standing open question in physics. In the framework of general relativity the so-called NUT spacetime realises such a gravitomagnetic charge. It is an exact solution of Einstein's field equation and a generalisation of the Schwarzschild spacetime. However, it is rather exotic. It possesses conical singularities on the axes, the so-called Misner strings, and regions with closed timelike curves close to them. However, when we exclude these regions it can still serve as a good first approximation for an astrophysical black hole with gravitomagnetic charge. This talk has now two main objectives. The first objective is to demonstrate how we can observe the gravitomagnetic charge using gravitational lensing. The second objective is to demonstrate how a multimessenger approach combining gravitational lensing of light rays and massive particles in the geometric optics limit can be used to overcome potential degeneracies. For this purpose we will first analytically solve the equations of motion for lightlike and timelike geodesics in the NUT spacetime using elementary and Jacobi's elliptic functions and Legendre's elliptic integrals. For a stationary observer in the domain of outer communication we will then relate the constants of motion to latitude-longitude coordinates on the observer's celestial sphere. For lightlike and timelike geodesics we will derive the angular radius of the shadow and write down a lens equation. In addition, we will also calculate the travelled proper time for massive particles. We will compare the results and discuss how we can combine them into a multimessenger approach.

Pa5-a4

Relating photon orbit observable with quasinormal modes in generic axisymmetric stationary spacetime

Hsu-Wen Chiang
LeCosPA, NTU

We introduce the concept of phase space averaging to relate the geodesic observable to quasinormal mode observable. More precisely the averaged radius of the photon orbit is directly tied to the peak of the effective potential in a deformed Schwarzschild manifold. This reframing of the geometric optics approximation does not rely on any symmetry principle, thus opening a window to much more complicated geodesics existed only in less symmetric manifold.

Pa5-a5

Numerical simulation of type II primordial black hole formation

Koichiro Uehara
Nagoya University

A primordial black hole (PBH) is a black hole that formed in the early universe. According to the standard scenario, a primordial density fluctuation generated during the inflationary period is followed by gravitational collapse during the radiation-dominated period. Depending on the intensity distribution of primordial density fluctuations in the early universe, density fluctuations with amplitudes exceeding a certain threshold will contract due to self-gravity, causing gravitational collapse and forming a black hole. In the typical spherically symmetric situation of PBH formation, it is known that the area radius becomes a non-monotonic function with respect to the radial coordinate, especially when considering large-amplitude curvature fluctuations. Such fluctuations are called Type II fluctuations, which are distinguished from those given by monotonically increasing functions, referred to as Type I. In this presentation, we will present the results of simulations of PBH formation from Type II fluctuations using a numerical method different from those used in the past. And we suggest clarifying PBH formation by the space-time structure associated with it.

Pa5-a6

Numerical simulations of vacuum bubbles and their consequences on the PBH scenario

Albert Escrivà
Nagoya University

There are several mechanisms for producing PBHs apart from the collapse of adiabatic fluctuations, for instance, from false vacuum bubbles, which can be generated if the inflaton becomes trapped during inflation. These localized bubbles will eventually end up forming black holes, also called baby Universes. In this work, we have numerically simulated the formation of such vacuum bubbles in a specific inflationary model. In particular, we have studied its dynamics, quantified the thresholds needed for its formation and studied its size. Our preliminary results show that the abundance of such PBHs dominates over those coming from the collapse of adiabatic fluctuations in the case of large-non gaussianities, and the mass distribution of the two channels of PBH production (collapse of adiabatic fluctuations--false vacuum bubbles) is different, being the latter one much broader.

E6. LIGO theory and experiment

Pa5-c1

Overview of the KAGRA commissioning for O4

Shinji Miyoki
ICRR, The University of Tokyo

After O3GK gravitational wave observation with GEO600 in April 2020, KAGRA has been reconstructed for repairs and upgrades for O4 which is planned to start 24th May 2023. The target BNS sensitivity of KAGRA O4a is 1~3Mpc. In the seismic noise isolation systems, several kinds of malfunctions in all main test mass suspensions, the unstable performance of two of power recycling mirrors, the control of traversers for PRMs suspensions, and so on were repaired. Consequently, the “healthy” conditions of all suspensions were verified. In addition, the new low-noise LVDTs and thermal control systems were also installed. In the cryogenic system, all short-lifetime cryocoolers for the radiation duct shields were replaced with longer-lifetime ones. Then, over one-year stable continuous operation of these cryocoolers was demonstrated. The mirror frosting that happened during the O3 commissioning has not occurred owing to the well-designed cooling processes and the stricter vacuum leak requirement of 10^-10 [Pa m^3 sec]. Consequently, the finesse of the X-arm Fabry-Perot cavity whose mirrors are cooled at 80K and 250K individually was kept to be ~1450 for about one year. We also reduced the suspension control noises that used to dominate the KAGRA sensitivity in some frequency ranges below the target sensitivity of O4. Although the wide/narrow angle baffles for main mirrors were installed before O3GK, we also installed all mid-size baffles for mirrors in the Michelson part to mitigate the scattered/stray light noise. With new high-quality mirrors, the transmittance of OMC was also improved. The laser intensity noise reached the O4 requirement of 10^-8 with a newly reconstructed optical system. Finally, the power-recycled Fabry-Perot Michelson interferometer operation was recovered again in February 2023. Owing to the newly designed MICH/PRLC control noise mitigation filter, the displacement noise of KAGRA around 100Hz was improved. In addition, the mirror alignment control system that was missed in O3 was also newly applied to KAGRA. Finally, the BNS sensitivity of KAGRA was recovered to be 1Mpc as O3GK. The displacement noise between 40Hz to 100Hz was reduced by a factor of 10 at most.

Pa5-c2

Development of Gravitational Wave Detection Technology at KASI

Sungho Lee
Korea Astronomy and Space Science Institute (KASI)

We are developing technology for gravitational wave (GW) detectors with our main focus on quantum noise reduction technology which can enhance the sensitivity of a GW detector beyond its limit by classical physics. Squeezed vacuum state of light (SQZ) can be generated by a nonlinear process of light and injected into a Michelson interferometer type GW detector to reduce quantum uncertainty of light along the laser beam path at a specific light mode. Through this R&D, our ultimate goal is making contribution to international collaborations for upgrade of existing GW detectors and/or construction of next generation detectors. KASI is participating in the KAGRA collaboration, which is a part of the LIGO-Virgo-KAGRA (LVK) collaboration, and the Einstein Telescope (ET) collaboration, which is a 3rd generation GW detector project.

Pa5-c3

Lab-Scale Experiment for Laser Interferometer Gravitational Wave Detector

June Gyu Park
Yonsei University

The ground-based laser interferometer gravitational wave detector is a large-scale facility with a single arm length of 3-4 km. Due to its high precision in detecting objects smaller than protons, various advanced technologies are integrated. In this presentation, I would like to introduce various technologies used in gravitational wave detectors, as well as experiments that can be conducted on a laboratory scale. After that, I'll introduce some experiments related with optical birefringence measurement.

Pa5-c4

Development of a new control method for optical resonators under the influence of non-uniform birefringence

Daiki Haba
Tokyo Institute of Technology

KAGRA, a gravitational wave telescope built in Japan, uses a composite resonator that incorporates an optical resonator with a Michelson interferometer, which imposes stringent requirements on optical path length and mirror orientation. KAGRA is a low-temperature telescope where the temperature of the mirror is cooled to 20 K to reduce thermal noise. For this reason, the mirror is made of sapphire crystal, which has high thermal conductivity and low heat dissipation at low temperatures. On the other hand, non-uniform birefringence in the sapphire crystal reduces the linearity of the control signal, which interferes with attitude control. In this talk, we will introduce the current status of a solution to this problem using a multi-segmented photodetector and its table-top scale verification experiment.

Pa5-c5

Deep Learning for Gravitational Wave Detection and Its Analysis Using Grad-CAM

Seiya Sasaoka

Tokyo Institute of Technology

The field of gravitational wave astronomy has made remarkable progress in recent years, with 90 successful detections by Advanced LIGO and Advanced Virgo in the O1, O2, and O3 observing runs. The use of deep learning to analyze gravitational wave data is an active area of research with the potential to improve our ability to detect and study these signals. However, the inherent black-box nature of deep learning models poses challenges in interpreting their predictions. To address this, we used the gradient-weighted class activation mapping (Grad-CAM) technique to visualize our 4-class classification model trained on signals from binary black hole mergers, neutron star-black hole mergers, binary neutron star mergers, and noise. Grad-CAM allowed us to gain insight into which part of the strain were most influential in the model's predictions. Our visualizations provided insights into the model's decision-making process and revealed the physical features that contribute to its predictions.

A5. Numerical Relativity

Pa5-d1

Simulation of PBH formation

Chulmoon Yoo
Nagoya Univ.

(I was invited by Prof. Gungwon Kang as an invited speaker for the parallel session A5.) Brief review and currente status of simulation of PBH formation will be given. In the first part, I will review general settings for the standar PBH formation scenario. Then I will briefly introduce recent progress on Type II PBH formation with our numerical code for spherically symetric situations. Our recent work on PBH formation from iso-curvature perturbation will be also discussed. Finaly, I will report the current status of the simulation of non-spherical PBH formation.

Pa5-d2

Compact Binary object Coalescence along eccentric orbit---From Template to Science

Zhoujian Cao
Chinese Academy of Sciences

With the discovery of more and more novel and important gravitational wave events by ground-based gravitational wave detectors, the development of gravitationa-wave astronomy is in full swing. In addition, with the success of the space laser interference detector Pathfinder (LISA pathfinder), Taiji 1, and Tianqin 1, more and more countries and research teams are increasing their research investment in space gravitational wave detection. Currently, LISA in Europe and America, Taiji and Tianqin in China, and DECIGO in Japan are the four most promising space gravitational wave detection plans. Under the favorable development trend of cooperation and competition among these four projects, it is likely that space gravitational wave detectors will become a reality in 10 years. The gravitational waveform template is an important theoretical foundation for gravitational wave data processing. This talk will introduce the current status of gravitaitonal waveform template and data analysis, compare the requirements of the expected gravitational waveformtemplate for space gravitational wave detection, and introduce the current development of modeling for space gravitational wave detection. The CBC along elliptical orbit is a gravitational wave source that has attracted wide attention in recent years driven by space gravitational wave detection and GW190521 event. This talk will also introduce the profound scientific connotation of CBC along elliptical orbit.

Pa5-d3

Hyperbolic encounter of two black holes

Yeong-Bok Bae
Institute for Basic Science

To date, most gravitational wave observations have been limited to cases where the orbits of black holes are quasi-circular or have small eccentricities, and the orbits of black holes with eccentricities close to or greater than 1 are relatively poorly studied. In this talk, I will discuss the highly eccentric black hole binaries from various perspectives, including their formation process and gravitational waveforms.

Pa5-d4

Imprints of the Strong Gravity Regime in Black Hole Encounters: Insights from Numerical Simulations

Young-Hwan Hyun
KASI

This talk will explore the imprints of the strong gravity regime on gravitational waveforms during black hole encounters, using insights from numerical simulations. We will discuss the impact of strong gravity on the behavior of black hole encounters and the various stages of gravitational wave emission. Our simulations incorporate relativistic speeds of scattering black holes, going beyond the range of post-Newtonian and post-Minkowskian approximations, thus capturing the strong gravity effects in a more comprehensive manner. The presentation will conclude with a look at future research directions and the potential for uncovering new insights through increasingly sophisticated simulations.

Pa5-d5

3PM EOB Hamiltonian and its numerical test by scattering angles of encountering black holes

Gungwon Kang
Chung-Ang University

The 3rd order post-Minkowskian effective one body (EOB) Hamiltonian for encountering two black holes having an arbitrary eccentricity has been tested by comparing scattering angles with those obtained in numerical simulations for hyperbolic encounters.

E7. LISA theory and experiment

Pa5-e1

Space Gravitational-Wave Antenna B-DECIGO and DECIGO

Masaki Ando
University of Tokyo

DECIGO is a future gravitational wave antenna targeting at 0.1-10 Hz frequency band. It will bridge the observation gap between ground-based detectors and space missions such as LISA. The main target of DECIGO is stochastic background GWs from primordial universe. The precursor mission B-DECIGO is 10 times smaller than DECIGO. However, it still has a fruitful science with 100-km laser interferometer. It can detect compact binaries with ~10^5 events/year rate and identify the sky position and merger time before merger.

Pa5-e2

NASA's Contributions to LISA Science and Technology

John G Baker
NASA-GSFC

LISA is a planned mission led by the European Space Agency in partnership with NASA, to realize a space-based gravitational-wave instrument sensitive to millihertz band gravitational waves. While LISA is currently in the design stage, with plans for launch in the mid 2030s, much work is already underway in both Europe and the US. This talk will provide a brief overview and update of the current status of the mission and its science objectives. We will review the plans for NASAs hardware contributions to the mission and current planning for data processing in LISA's science ground segment.

Pa5-e3

The recent status of Taiji program

Ziren Luo
Chinese Academy of Sciences

Taiji program is a Chinese space-borne gravitational wave detection mission. It was planned to be launched around 2030s, slightly later than LISA, in order to perform a joint detection by LISA-Taiji network. It was believed that by using LISA-Taiji network it could maximize the scientific output. To catch up with the LISA's schedule, Taiji setup a 3-step plan. The first step was to launch Taiji-1, a single satellite to verify the basic principle of Taiji technology. The second step was to launch a pair of satellite called Taiji-2 to demonstrate all the Taiji technology in helio-centric orbit. The evaluation of phase-A of Taiji-2 was just finished. In this presentation the recent status of Taiji program will be introduced.

Pa5-e4

LISA Phase Measurement System Development and Testing

Yongho Lee
AEI Hannover

Laser Interferometer Space Antenna (LISA) will detect gravitational waves in the low frequency between 0.1 and 1Hz, which ground-based GW detectors cannot cover. Among many challenges in the LISA mission, the development of phasemeter should meet the stringent requirement with a sensitivity of micro cycle of the MHz beat-note up to about 25MHz, which is equivalent to picometer precision in length readout. The performance of the phasemeter should be evaluated on the ground prior to its flight. In this talk, we present optical testbeds to verify the performance of the phasemeter, which are experimental campaigns among our activities in the context of LISA.

Pa5-e5

The LISA Gravitational Reference Sensor: technology and challenges

Davide Dal Bosco
University of Trento and INFN/TIFPA

In this talk, we will present the Gravitational Reference Sensor (GRS) for LISA. The GRS is the LISA subsystem that hosts each test mass (TM). Its primary goal is to create an environment around the test mass compatible with LISA's acceleration noise requirement, which is critical for achieving the ambitious low-frequency science goals of the mission. Apart from protecting the purity of the free-fall of the LISA test masses, the GRS can provide capacitive sensing and actuation on the test mass in all degrees of freedom. Moreover, the GRS is equipped with a TM caging system for the launch and grabbing, positioning, and release mechanism (GPRM) that allows placing the TM into geodesic motion with minimal residual velocity. The ambitious science goals of LISA require the GRS acceleration noise performance to be better than inertial sensors used in previous space missions by orders of magnitude. For this reason, its design was validated on ground by torsion pendulum experiments and in space by the LISA Pathfinder mission, which successfully demonstrated that the current GRS design induces a force noise below the requirement in the whole LISA band. Tightly connected with the GRS is a contactless charge management system (CMS) based on photoemission, which aims to dissipate the excessive electric charge deposited on the TM by cosmic rays and energetic particles coming from the Sun. It is currently envisioned to employ UV-LEDs as light sources for the LISA CMS instead of the mercury lamps used in LISA Pathfinder. We will wrap up the talk by presenting the advantages of such a choice.

Pa5-e6

XMRI in the centre of our galaxy, formation mechanisms and the information we can extract from them.

Veronica Vazquez-Aceves
The Kavli Institute for Astronomy and Astrophysics, Pekin University

Extremely large mass-ratio inspirals (XMRIs) are among the most promising sources of GWs that will be detected by future space-based detectors such as the Laser Interferometer Space Antenna (LISA), TianQin, or Taiji. Understanding their formation channels and their orbital properties is key in determining their event rates and will also help in the development of accurate templates for their detection. In this talk, I introduce the physical processes that lead to the formation of an XMRI, the derivation of the event rates, and the number of XMRIs we can expect in our galactic centre. I will also show that by detecting a single XMRI, we can measure the mass and spin of SgrA*, the supermassive black hole at the centre of our galaxy, with very high accuracy.

B3. Other topics on Quantum gravity

Pa5-f1

Carroll Symmetries for Particles, Strings and Gravity

Eric Bergshoeff
University of Groningen

For several reasons Carroll symmetries have been the focus of recent investigations in theoretical physics. In this talk I will review what Carroll symmetries are and what makes them interesting to study as a possible symmetry arising in special corners of physics. In particular, I will discuss how Carroll symmetries can be realized for particles, strings and gravity. They even can be used to study special solutions of general relativity.

Pa5-f2

Geometric actions in gravity

Glenn Barnich
Université libre de Bruxelles

After reviewing how geometric actions capture the dynamics of asymptotically anti-de Sitter and flat spacetimes in three dimensions, the construction is extended to four dimensions where it yields BMS4 invariant dual field theories. Based on arxiv: 1707.08887, 2103.11253, 2211.07592

Pa5-f3

Intrinsic Time Geometrodynamics

Hoi Lai Yu
Institute of Physics, Academia Sinica, Taiwan

Einstein's geometrodynamics is the dynamics of three-geometry, not four-geometry; quantum gravity spells the demise of the classical ideal of a four-dimensional space-time. Instead of a theory obfuscated by four-covariant paradigm, Schr\"odinger-Heisensberg quantum evolution and causal temporal ordering with respect to the cosmic clock of our expanding closed universe is well-defined in a theory of gravitation with just spatial diffeomorphism invariance. The paradigm shift prompts modifications of Einstein's theory to include a Cotton-York term for power-counting ultraviolet renormalizability, in addition to infrared convergence from spatial compactness. The physical contents of Einstein's General Relativity are captured at low frequencies and low curvatures; except in the very early Cotton-York dominated era, the time-dependent physical Hamiltonian ensures primacy of Einstein's theory and its observational consequences afterwards and at late times. An exact Chern-Simons Hartle-Hawking state is advocated as the initial state of the universe. At the level of expectation values, it is in accord with Penrose's Weyl Curvature Hypothesis, of a smooth Robertson-Walker, but also hot beginning due to Euclidean instanton tunneling; the gravitational arrow of time of increasing intrinsic volume concurs with the thermodynamic Second Law arrow of increasing entropy. The state also exhibits quantum gravity metric fluctuations, with, at the lowest approximation, scale-invariant two-point correlations as one of its defining characteristics.

Pa5-f4

Non-trivial effective null dynamics from extended Carroll symmetries

Loïc Marsot
Sun Yat-sen University

Carroll symmetries and dynamics has recently seen an increase in popularity as it was found to be an effective way to describe some null phenomena in General Relativity. In this talk, I will show that the usually trivial-looking Carroll symmetry group becomes richer in 2+1 dimensions, which are the relevant dimensions for physical applications. This richness manifests with two non-trivial central extensions appearing in this case, which then imply the possibility of non-trivial dynamics for Carroll particles. I will also discuss the Hall form of some Carrollian equations of motion, the potential physical implications of such effective particles, and give an example of Carroll motion on the horizon of Kerr-Newman black holes.

Pa5-f5

Sturm–Liouville equation and Carroll symmetry of plane gravitational wave

Pengming Zhang
Sun Yat-sen University

The well-known 5-parameter isometry group of plane gravitational waves in 4 dimensions is identified as Lévy-Leblond's Carroll group in 2 + 1 dimensions with no rotations. And in Brinkmann coordinates, the matrix Sturm–Liouville equation $$P\ddot = K P$ with given profile $K(U$) plays a central rôle to understand the Carroll symmetry. Furtheremore, the trajectories of particles can be obtained from trivial "Carrollian" ones by a suitable action of the (broken) Carrollian isometry group.

July 6 (Thu): 16:30-18:30

E6. LIGO theory and experiment

Pa6-c1

Defining Eccentricity for Gravitational Wave Astronomy

Md Arif Shaikh
Seoul National University

Eccentric compact binary mergers are significant scientific targets for current and future gravitational wave observatories. To detect and analyze eccentric signals, there is an increasing effort to develop waveform models, numerical relativity simulations, and parameter estimation frameworks for eccentric binaries. Unfortunately, current models and simulations adopt different internal parameterisations of eccentricity in the absence of a unique natural definition of eccentricity in general relativity, which can result in incompatible eccentricity measurements. In this work, we present a standard definition of eccentricity and mean anomaly based solely on waveform quantities. This definition is free of gauge ambiguities, has the correct Newtonian limit, and can be applied as a postprocessing step when comparing eccentricity measurements from different models. This standardization puts all models and simulations on the same footing and enables direct comparisons between eccentricity estimates from gravitational wave observations and astrophysical predictions. We demonstrate the applicability of our definition for waveforms of different origins, including post-Newtonian theory, effective one body, extreme mass ratio inspirals, and numerical relativity simulations. We focus on binaries without spin-precession in this work, but possible generalizations to spin-precessing binaries are discussed. We make our implementation publicly available through an easy-to-use Python package, gw_eccentricity.

Pa6-c2

Rapid parameter estimation of binary neutron star merger using reduced order quadrature

Soichiro Morisaki
Institute for Cosmic Ray Research, University of Tokyo

Parameter estimation of gravitational waves from binary neutron star coalescence is computationally costly, taking days to years depending on the analysis configuration. One of the techniques to speed up the parameter estimation, which has been applied for the production analysis of the LIGO-Virgo-KAGRA collaboration, is reduced order quadrature (ROQ). In this talk, I am going to talk about the application of ROQ to the analysis of binary neutron star signal. I am going to explain how we apply this technique with taking account precession effects and detector calibration uncertainties. I am also going to explain how useful this technique is for rapid sky localization and detailed parameter estimation taking into account tidal effects of colliding objects.

Pa6-c3

Effects of eccentricity and aligned spins in the parameter estimation of CBC inspirals

JeongCho Kim
Seoul National University

We performed Markov chain Monte Carlo parameter estimation (MCMC PE) using the TaylorF2 inspiral waveform with eccentricity corrections. In order to examine the effects of eccentricity in the existence of aligned spins, we considered two binary black holes (GW151226, GW170608) and one black hole - neutron star binary (GW200105) . Our work consists of two steps. The first step is to generate artificial gravitational-wave (GW) signals varying the spin magnitudes and relative directions (up and down) along with eccentricities while the mass values are fixed to be those adopted from the GW transient catalog papers for the selected sources. The second step is to find the set of parameters by MCMC PE considering the advanced LIGO-Virgo network sensitivity. Main results from MCMC PE are probability density distributions of astrophysical parameters relevant to CBCs such as masses, spins, and eccentricity. Our results show a clear advantage of having a long duration signal of the inspiral phase in parameter estimation. Also, larger spin magnitudes are helpful to constrain mass and eccentricity regardless of their relative directions. Effects of the spin directions are not as strong as the magnitudes.

A5. Numerical Relativity

Pa6-d1

Relativistic hydrodynamics and its application with AMR

Jinho Kim
Korea Astronomy and Space Science Institute

Adaptive mesh refinement (AMR) is essential software for numerical computations with large dynamical scales, such as numerical relativistic simulations. In this talk, I am going to introduce the cell-by-cell AMR software being developed by the Korean Numerical Relativity Group and present the results of its testing and application to neutron star simulations.

Pa6-d2

How Including New Physics Changes The Evolution of Massive Black Holes In Simulations: Perspectives in the Era of High-resolution Simulations

Ji-hoon Kim
Seoul National University

[I was invited to give a talk on my recent work in numerical simulations.] The community of numerical astrophysicists has benefited greatly from the ever-improving computing technology over the past decades. I will discuss the new possibilities in the upcoming era of high-resolution numerical studies to form stars, massive black holes and galaxies, all at the same time. In one early example, using a high-resolution cosmological simulation of a high-redshift quasar-host galaxy, I will describe how a new stellar feedback channel and a new black hole accretion channel may hold important clues for the growth of supermassive black holes.

Pa6-d3

General relativistic advection-dominant accretion disk model in tidal disruption events

MAGESHWARAN TAMILAN
Chungbuk National University, South Korea

Tidal disruption events (TDEs) provide a good probe for supermassive black holes (SMBHs) in the centers of inactive galaxies. A star is tidally disrupted by an SMBH when the star approaches the SMBH closely enough that the black hole's tidal force exceeds the stellar self-gravity. The SMBH's subsequent super-Eddington accretion of stellar debris produces characteristic flares lasting several months. We present a numerical model of steady-state, general relativistic (GR) super-Eddington accretion in an advection-dominated regime. Our model includes the radiation-driven angular momentum loss and the scale-height derivative in the basic equations of the GR slim disk. We studied and compared our model with the previous GR slim disk model for TDE ASAS-SN 14li. We find that the scale-height derivative decreases the surface density near the disk's inner edge, whereas it increases the disk temperature and scale height, brightening the disk spectrum in the soft X-ray waveband. An extremely high mass accretion rate significantly enhances the effect of the scale-height derivative. The radiation-driven angular momentum loss only slightly impacts the disk surface density and temperature and reduces the disk luminosity. However, its impact on the disk is insignificant for a high mass accretion rate. The scale-height derivative is crucial as it impacts the disk structure and its resultant spectrum, particularly in the soft X-ray waveband.

Pa6-d4

Generation of Ultra-High Energy Cosmic Rays at Radio Galaxy Jets

Jeongbhin Seo
UNIST

Radio galaxy jets are considered strong candidates for producing ultra-high energy cosmic rays (UHECRs). Using a newly developed relativistic hydrodynamic (RHD) code, we simulated the dynamic evolution of relativistic jets with various model parameters, covering both FR I and FR II radio galaxies. Our study confirms that the flow dynamics are mainly governed by jet power, while the jet-to-background density and pressure ratios play secondary roles. The simulations also revealed that jet-induced flows contain nonlinear structures, such as shocks, shear, and turbulence, which have the potential to accelerate particles to extremely high energies. By adopting the snapshot data from the simulations and physically motivated models for magnetic fields and particle scattering, we followed the transport and acceleration of cosmic rays in the jets through Monte Carlo simulations. For energy levels below ~10^{18} eV, diffusive shock acceleration (DSA) is the dominant acceleration mechanism, while relativistic shear acceleration (RSA) at the jet-backflow interface becomes more important for energy levels above ~10^{18} eV. Turbulence shear acceleration (TSA) plays a minor role. The energy spectrum of escaping particles shows a double-power law, with the break energy (E_{break}) primarily dependent on jet power and jet size. The talk will present our recent results, including particle acceleration at the FR I jet.

Pa6-d5

Spherical Einstein Field Equations on Hyperboloidal Slices

Shalabh Gautam
ICTS, Bengaluru

One of the challenges in numerical relativity is to include future null infinity in the computational domain with a well-posed formulation. Success will not only enable us to evolve any system of astrophysical interest, e.g. binary black holes and extracting the gravitational wave signal at future null infinity, with any desired accuracy, but also help in studying various phenomena of fundamental interest. One proposal is to use hyperboloidal slices. In this talk, I will present our ongoing efforts for obtaining a well-posed formulation of the Einstein Field Equations on hyperboloidal slices, all in spherical symmetry. The natural extension will be to generalize these methods to full 3d.

C5. Dark Matter

Pa6-e1

Observational phenomena on black hole with dark matter dress

Xing-Yu Yang
KIAS

The accretion of dark matter around the black hole could lead to the formation of surrounding halo. Such a dark matter dressed black hole can leave characteristic imprints in the observations including gamma-ray, gravitational lensing and gravitational waves. In this talk, I will talk several observational phenomena on the black hole with dark matter dress.

Pa6-e2

An analytic model for the core-halo mass relation in fuzzy dark matter halos

Hiroki Kawai
University of Tokyo

Fuzzy dark matter (FDM) is a promising alternative to cold dark matter (CDM). Due to the presence of the quantum pressure, the structures in FDM halos are different from those in the CDM halos. One of these differences is the soliton core that exists around the center of FDM halos. While the core-halo mass relations are widely studied in the literature, there are no consensus among them. We assume that the FDM density profile can be obtained by the redistribution of Navarro-Frenk-White (NFW) density profile due to the quantum nature of FDM, and construct an analytical model for the core-halo mass relation in FDM halos. We find that the radius where mass redistribution occurs is determined by the condition via relaxation time, and the dispersion of the core-halo mass relations in FDM halos might originate from the dispersion of concentration parameter in the NFW profile.

Pa6-e3

Gravitational microlensing by dressed primordial black holes

Tan Chen
Institute of Theoretical Physics, Chinese Academy of Sciences

The accretion of dark matter around the primordial black holes (PBHs) could lead to the formation of surrounding minihalos. The gravitational microlensing produced by such dressed PBHs could be quite different from that of the bare PBHs. In this talk, I will discuss the gravitational microlensing produced by dressed PBHs. We find that all the microlensing effects by dressed PBHs have asymptotic behavior depending on the minihalo size. Applying the stellar microlensing by dressed PBHs to the data of the Optical Gravitational Lensing Experiment and Subaru/HSC Andromeda observations, we obtain the improved constraints on the PBH abundance. It shows that the existence of dark matter minihalos surrounding PBHs can strengthen the constraints on the PBH abundance from stellar microlensing by several orders, and can shift the constraints to the well-known asteroid mass window where PBHs can constitute all the dark matter.

Pa6-e4

Imprints of ultralight axions on the gravitational wave and pulsar timing measurement

Ning Xie
Sun Yat-sen University

TBA

Pa6-e5

The evolution of domain wall network with inflationary fluctuations

Junseok Lee
Tohoku University

Domain wall networks can induce cosmological problems. Previous work has shown that networks with initial inflationary fluctuations are long-lived despite being under population bias. This is due to large scale correlations, which cannot be seen in white noise case. However, the fate of these networks under potential bias is not well-understood. In our research, we investigate the time evolution of such networks under the linear potential bias using 2 dimensional lattice simulations. We show that the networks have a finite lifespan and collapse when the pressure becomes comparable to the tension they experience. Specifically, we find the relation between the lifetime and the bias strength. This implies that the cosmic domain wall problem is avoidable in certain scenarios.

Pa6-e6

Cosmological production of dark photon dark matter

Naoya Kitajima
Tohoku University

In this talk, I will show several production mechanisms of dark photon dark matter in the early universe. It contains (i) resonant dark production from axion oscillation, (ii) dark photon emission form the collapse of cosmic string loops, (iii) misalignment production of coherently oscillating dark photons. Observational implications will also be discussed.

Pa6-e7

Directional detection of boosted dark matter from direction of the Galactic center

Keiko Nagao
Okayama University of Science

Dark matters with MeV- or keV-scale mass are difficult to detect with standard direct search detectors. However, they can be searched for by considering the up-scattering of kinetic energies by cosmic-rays. Since dark matter density is higher in the central region of the Galaxy, the up-scattered dark matter will arrive at Earth from the direction of the Galactic center. Once the dark matter is detected, we can expect to recognize this feature by directional direct detection experiments. In this study, we simulate the nuclear recoils of the boosted dark matter and quantitatively reveal that a large amount of this type of dark matter is arriving from the direction of the Galactic center.

Pa6-e8

Pulsar timing residual induced by wideband ultralight dark matter

Yun-Long Zhang
National Astronomical Observatories, Chinese Academy of Sciences

The coherent oscillation of ultralight dark matter induces changes in gravitational potential with the frequency in the nanohertz range. This effect is known to produce a monochromatic signal in the pulsar timing residuals. Here we discuss a multifield scenario that produces a wide spectrum of frequencies, such that the ultralight particle oscillation can mimic the pulsar timing signal of stochastic common spectrum process. We discuss how ultralight dark matter with various spins produces such a wide band spectrum on pulsar timing residuals and perform the Bayesian analysis to constrain the parameters. It turns out that the stochastic background detected by NANOGrav can be associated with a wideband ultralight dark matter. (arXiv: 2112.15593)

C4. Wormholes and other massive objects

Pa6-f1

Modified-gravity wormholes without exotic matter

Francisco S.N. Lobo
Institute of Astrophysics and Space Sciences, University of Lisbon

A fundamental ingredient in wormhole physics is the flaring-out condition at the throat which, in classical general relativity, entails the violation of the null energy condition. In this work, we present the most general conditions in the context of modified gravity, in which the matter threading the wormhole throat satisfies all of the energy conditions, and it is the higher order curvature terms, which may be interpreted as a gravitational fluid, that support these nonstandard wormhole geometries. Thus, we explicitly show that wormhole geometries can be theoretically constructed without the presence of exotic matter, but are sustained in the context of modified gravity.

Pa6-f2

Gravitational waves by a wormhole and wormhole binary system

Sung-Won Kim
Ewha Womans University

We consider the gravitational wave generation by a wormhole and binary wormhole system. For the case of single wormhole, perturbed precession of slowly rotating thin-shell wormhole is the source of the gravitational waves. In the case of binary system, the Newtonian approximation of traversable wormhole is adapted with the effective mass by high tension from flare-out condition. If two wormholes are far enough from each other, we can treat them as point particle with effective masses and the nature of gravitational waves by the system is very similar to those by binary compact stars. However, as they approach each other and the system is at the late inspiral state, the finite-size effects such as the tidal effects become very important.

Pa6-f3

A study on Casimir wormholes

Pradyumn Kumar Sahoo
BITS-Pilani, Hyderabad Campus

In recent years there has been a growing interest in the field of Casimir wormhole. In classical general relativity (GR), it is known that the null energy condition (NEC) has to be violated to have a wormhole to be stable. The Casimir effect is an experimentally verified effect that is caused due to the vacuum field fluctuations in quantum field theory. Since the Casimir effect provides the negative energy density, thus this act as an ideal candidate for the exotic matter needed for the stability of the wormhole. In this paper, we study the Casimir effect on the wormhole geometry in modified symmetric teleparallel gravity or \$f(Q)\$ gravity, where the non-metricity scalar \$Q\$ drives the gravitation interaction. We consider three systems of the Casimir effect such as (i) two parallel plates, (ii) two parallel cylindrical plates, and (iii) two-sphere separated by a large distance to make it more experimentally feasible.

Pa6-f4

Emergent Universe from Dynamical wormhole

Paul Bikash Chandra
University of North Bengal

A novel way is presented to obtain flat emergent universe using dynamical wormholes in Higher dimensions as well as in the usual four dimensions. It is proposed that the Emergent universe (EU) is free from initial singularity accommodating late accelerating universe. In EU model basic assumption is that the universe emerge from an initial Einstein static universe in infinite past. The Einstein Static universe phase corresponds to the throat of a dynamical wormhole. Considering a homogeneous Ricci scalar, a class of dynamical wormholes are identified with non-linear equation of state which permit EU model. The non-linear EoS parameter is equivalent to three different types of cosmic fluids. The space-time dimensions (D) determines the rate of change of a particular fluid with the scale factor of evolving universe for non-interacting fluids. A realistic scenario of EU is obtained considering interaction among the three fluids at a later epoch. In a higher dimensional universe it is found that near the throat null energy condition (NEC) is violated, but away from the throat NEC is found to obey admitting the observed universe with $D>3$. At a later epoch the EU model permits the observed universe with late accelerating phase. Thus a universe emerged from the wormhole throat that exists in the infinite past thereafter the evolving phases encompass the observed universe subsequently

Pa6-f5

General solution of 5 dimensional rotating wormhole

Keiya Uemichi
Nagoya University

For evaluating the feasibility of wormhole spacetimes in general situations, the effect of angular momentum would be considerable. As a first step, we construct stationary rotating wormhole solutions in 4+1 dimensional spacetimes with equal angular momenta extending the previous work [Dzhunushaliev et al. (2013)] to more general cases. Considering the cases of equal angular momenta, the spacetimes can have a cohomogeneity-1 symmetric structure. Then, under the same ansatz as in the previous work, the Einstein equations can be reduced to a set of ordinary differential equations for functions of the radial coordinate. We solve this set of equations imposing the asymptotically flat boundary condition at one of the asymptotic regions, while the reflection symmetry with respect to the wormhole throat has been assumed in the previous work. Then we discuss the effect of the finite angular momenta.

Pa6-f6

Light Ring behind Wormhole Throat

Hyat Huang
University of Oldenburg

The geodesics of the Ellis-Bronnikov wormhole with two parameters are studied. The asymmetric wormhole has only one light ring and one innermost stable circular orbit located on one side of the wormhole throat. Consequently, certain light rays can be reflected back by the wormhole. Additionally, the same wormhole can have different appearances on both sides of the throat. We present novel images of the wormhole with a light ring behind the throat in a scenario with an accretion disk as the light source and in a backlit wormhole scenario, which are distinct from the images of other compact objects and have the potential to be observed.

Pa6-f7

Stability of slowly rotating Ellis-Bronnikov wormholes

Fech Scen Khoo
University of Oldenburg

We consider Ellis-Bronnikov wormholes in slow rotation up to second order in rotation. We conjecture that the radial instability of the wormholes will disappear under sufficiently rapid rotation.