The 2024 Chengdu Symposium on Particle Physics and Cosmology: Phase Transitions, Dark Matter and Experimental Probes (CPCS 2024)

Friday, 27 September 2024 - Monday, 30 September 2024

Book of Abstracts

Contents

1

Cosmological implications of radiative electroweak symmetry breaking theories

Author: Ke-Pan Xie[1]

[1] *Beihang University*

Corresponding Author: kpxie@buaa.edu.cn

Radiative symmetry breaking (classically conformal) theories are plausible solution to the hierarchy problem. Such a paradigm also induces very rich cosmological implications via first-order phase transitions in the early Universe. This talk will discuss those effects.

2

Intertwining Axion and gravitational waves, generations and detection.

Author: Sichun Sun[1]

[1] *Beijing Institute of Technology*

Corresponding Author: sichunssun@gmail.com

Firstly, we discuss how the beyond the Standard Model hypothetical particle, the axion, can produce gravitational waves through several different mechanisms either in the astrophysical setting or the early universe. Then we present our recent new detection proposals for axions/gravitational waves using cryogenic quantum transport technology. The electric signal is enhanced by the high-quality factor of a resonant LC circuit and then amplified and detected by the cryogenic measurement technique. We demonstrate that this setup has promising sensitivity for axions with mass from kHz to GHz, and a similar device can also be used for high-frequency gravitational wave detection with the same frequency range.

3

The exploration into U(1) hidden sectors using gravitational waves

Author: Wan-Zhe Feng[1]

[1] *Tianjin University*

Corresponding Author: vicf@tju.edu.cn

Abstract: A variety of supergravity and string-based models feature hidden sectors with U(1) gauge groups, playing significant roles in particle physics and cosmology. As constraints on dark matter tighten, exploration into these hidden sectors intensifies. These hidden sectors can engage in feeble interactions with the visible sector and vary between feeble and normal strength with each other. In scenarios where all hidden sector particles are produced via the freeze-in mechanism, they do not reach thermal equilibrium with standard model particles in the thermal bath. Consequently, the hidden sector sustains a distinct temperature from the visible universe, posing challenges in calculating the evolution of these particles. We have devised a general method to compute the complete evolution of hidden sector particles in this model class. My discussion will cover the U(1) extension of the standard model, focusing on various dark matter candidates. The detection of gravitational waves

offer an alternative way to explore the details of hidden sectors. Gravitational wave originated from a weakly coupled U(1) hidden sector will be discussed.

Collider and Dark Matter / 4

Recent progress of Dark SHINE R&D

Author: Kang Liu[1]

Co-author: Shu Li [2]

[1] *TDLI,. SJTU*

[2] *TDLI, SJTU*

Corresponding Authors: lucker@sjtu.edu.cn, shuli@sjtu.edu.cn

Sci. China-Phys. Mech. Astron., 66(1): 211062 (2023)
arXiv:2310.13926
arXiv:2401.15477
arXiv:2311.01780
arXiv:2407.17800
arXiv:2407.20723
DOI:10.5281/zenodo.8373963
DOI:10.1016/j.nuclphysbps.2024.06.019
DOI:10.1016/j.nuclphysbps.2024.07.008
DOI:10.1016/j.nuclphysbps.2024.06.014

Dark SHINE is a fixed-target experiment initiative to search for light Dark Matter and mediators at SHINE (Shanghai high repetition rate XFEL and extreme light facility, being the 1st hard X-ray FEL in China) under construction targeting completion in 2026. Dark SHINE aims to search for the new mediator, Dark Photon, bridging the Dark sector and the ordinary matter. In this work and presentation, we present the idea of this new project and 1st prospective study in search for Dark Photon decaying into light dark matter. It also provides the opportunity to incorporate broader scope of BSM search ideas such as ALP, utilizing the fixed-target experiment of this type.

Collider and Dark Matter / 5

Recent ATLAS results of Dark Matter and Dark Photon combinations, and Dark Higgs searches

Author: Ngoc Khanh Vu[1]

Co-author: Shu Li [2]

[1] *Tsung-Dao Lee Institute, Shanghai Jiao Tong University*

[2] *TDLI, SJTU*

Corresponding Authors: nkvu@sjtu.edu.cn, shuli@sjtu.edu.cn

Ref: https://arxiv.org/abs/2306.00641
Science Bulletin (doi:10.1016/j.scib.2024.06.003)
Results from a wide range of searches targeting different experimental signatures with and without missing transverse momentum () are used to constrain a Two-Higgs-Doublet Model (2HDM) with an additional pseudo-scalar mediating the interaction between ordinary and dark matter (2HDM+a). The analyses use up to 139 fb^{-1} of proton-proton collision data at a centre-of-mass energy $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector at the Large Hadron Collider between 2015-2018. The

results from three of the most sensitive searches are combined statistically. These searches target signatures with large EmissT and a leptonically decaying Z boson; large □□□□□ and a Higgs boson decaying to bottom quarks; and production of charged Higgs bosons in final states with top and bottom quarks, respectively. Constraints are derived for several common as well as new benchmark scenarios within the 2HDM+a.

Ref. https://arxiv.org/abs/2406.01656
JHEP 08 (2024) 153
A combination of searches for Higgs boson decaying into a visible photon and a massless dark photon (H$\longrightarrow_{d}$) is presented using 139 fb^{-1} of proton–proton collision data at a centre-of-mass energy of √s = 13 TeV recorded by the ATLAS detector at the Large Hadron Collider. The observed (expected) 95% confidence level upper limit on the Standard Model Higgs boson decay branching ratio is determined to be Br(H$\longrightarrow_{d}$) < 1.3% (1.5%). The search is also sensitive to higher-mass Higgs bosons decaying into the same final state. The observed (expected) 95% CL limit on the cross section times branching ratio ranges from 16 fb (26 fb) for m_H = 400 GeV to 1.0 fb (1.5 fb) for m_H = 3 TeV. Results are also interpreted in the context of a minimal simplified model.

Ref. https://arxiv.org/abs/2407.10549 & ATLAS-CONF-2024-004
A first dedicated search is performed for dark matter particles produced in association with a resonantly produced pair of b-quarks with m(bb) < 150 GeV using 140 fb^{-1} of proton-proton collisions recorded by the ATLAS detector at a center-of-mass energy of 13 TeV. This signature is expected in extensions of the Standard Model predicting the production of dark matter particles, in particular those containing dark Higgs bosons. This search uses a novel experimental method to extend the experimental reach to lower bb-pair invariant masses, considers a wider range of dark Higgs boson interpretations and excludes new regions of parameter space for this model. For dark Higgs boson masses between 30 and 150 GeV, Z′ mediator masses up to 3.4 TeV and 4.8 TeV are excluded for benchmark scenarios.

6

The impact of chiral effects on lepton flavor asymmetry in the early Universe

Author: Kohei Kamada[1]

[1] *HIAS UCAS*

Corresponding Author: kohei.kamada@ucas.ac.cn

Anomalous transport phenomena, such as the chiral magnetic effect, arise from the chiral anomaly in gauge theories and have recently gained attention in hadron and condensed matter physics. These effects can also lead to intriguing phenomena in the early Universe, where chirality is well-conserved at temperatures above 100 TeV. One example is the chiral plasma instability, in which helical hypermagnetic fields are amplified due to chiral asymmetry, ultimately contributing to baryon asymmetry through the decay of hypermagnetic helicity.
In particular, we highlight that a large lepton flavor asymmetry, possibly present before electroweak symmetry breaking and consistent with a vanishing total B-L, generally corresponds to a significant chiral asymmetry. This asymmetry induces the amplification of strong helical magnetic fields, leading to baryon overproduction. Our findings suggest that this mechanism imposes a stricter constraint on lepton flavor asymmetry than those derived from Big Bang Nucleosynthesis (BBN). Similar to how large lepton asymmetry before electroweak symmetry breaking is constrained by the SU(2) chiral anomaly through electroweak sphalerons to prevent baryon overproduction, we conclude that large lepton flavor asymmetry is also constrained by the U(1) hypergauge chiral anomaly.

Collider and Dark Matter / **7**

Exploring Dark Matter Microphysics Through Neutron Star Col-

lapse

Author: Arvind Kumar Mishra[1]

Co-authors: Chih-Ting Lu [1]; Lei Wu [1]; Ning Liu [1]

[1] *Nanjing Normal University, China*

Corresponding Authors: ctlu@njnu.edu.cn, leiwu@njnu.edu.cn, arvindkh2015@gmail.com, liuning@njnu.edu.cn

Neutron stars (NS) situated in dark matter (DM)-rich environments can capture DM particles. The captured DM particles can thermalize, form a gravitationally bound core, and eventually form a black hole inside the NS. After accreting the surrounding material, the black hole can destroy the NS. In light of this, we constrain DM microphysics from the survival of the neutron star. In this talk, we will discuss the constraints on fermionic and bosonic dark matter particles utilizing existing neutron star data.

8

Can Supercooled Phase Transitions Explain the Gravitational Wave Background Observed by Pulsar Timing Arrays?

Authors: Andrew Fowlie[None]; Chih-Ting Lu[1]; Lei Wu[2]; Peter Athron[1]; Yongcheng Wu[1]

[1] *Nanjing Normal University*

[2] *Nanjing Normal Univeristy*

Corresponding Authors: ycwu0830@gmail.com, andrew.fowlie@xjtlu.edu.cn, leiwu@njnu.edu.cn, peter.athron@njnu.edu.cn, ctlu@njnu.edu.cn

Several pulsar timing array collaborations recently reported evidence of a stochastic gravitational wave background (SGWB) at nHz frequencies. While the SGWB could originate from the merger of supermassive black holes, it could be a signature of new physics near the 100 MeV scale. Supercooled first-order phase transitions (FOPTs) that end at the 100 MeV scale are intriguing explanations, because they could connect the nHz signal to new physics at the electroweak scale or beyond. Here, however, we provide a clear demonstration that it is not simple to create a nHz signal from a supercooled phase transition, due to two crucial issues that could rule out many proposed supercooled explanations and should be checked. As an example, we use a model based on nonlinearly realized electroweak symmetry that has been cited as evidence for a supercooled explanation. First, we show that a FOPT cannot complete for the required transition temperature of around 100 MeV. Such supercooling implies a period of vacuum domination that hinders bubble percolation and transition completion. Second, we show that even if completion is not required or if this constraint is evaded, the Universe typically reheats to the scale of any physics driving the FOPT. The hierarchy between the transition and reheating temperature makes it challenging to compute the spectrum of the SGWB.

9

Degeneracy Enhancement of Neutron-Antineutron Oscillation in Neutron Star

Author: Shao-Feng Ge[1]

[1] *TDLI-SJTU*

Corresponding Author: gesf@sjtu.edu.cn

We explore the fermion oscillation in a degenerate environment. The direct consequence is introducing a Pauli blocking factor 1−fi, where fi is the phase space distribution function, for each intermediate mass eigenstate during propagation. It is then much easier for a state with larger existing fraction or density to oscillate into other states with less degeneracy while the reversed process is not enhanced. This can significantly modify the oscillation behaviors. We apply this degenerate fermion oscillation to a concrete scenario of neutron-antineutron oscillation in neutron star. It turns out antineutrons receive a standing fraction to annihilate with the environmental neutrons. The subsequent neutron star heating can put an extremely stringent bound on the baryon number violating cross mass term between neutron and antineutron.

10

Status of the CEPC Project

Author: Haijun Yang[1]

[1] *Shanghai Jiao Tong University (CN) and TDLI*

Corresponding Author: haijun.yang@sjtu.edu.cn

The discovery of the Higgs boson marked the beginning of a new era in HEP. Precision measurement of the Higgs boson properties and exploring new physics beyond the Standard Model using Higgs as a tool become a natural next step beyond the LHC and HL-LHC. Among the proposed Higgs factories worldwide, the Circular Electron Positron Collider (CEPC) with 100km circumference was proposed by the Chinese HEP community in 2012. CEPC is an e+e- Higgs factory to produce Higgs/W/Z bosons and top quarks which aims to measure Higgs, EW, flavor physics and QCD with unprecedented precision and to probe new physics beyond the SM. With the official release of CEPC Accelerator Technical Design Report (TDR) in December, 2023, we are intensively preparing accelerator Engineering Design Report (EDR) and reference detector TDR. The purpose is to submit CEPC proposal to Chinese government for approval and start construction within the "15th five-year plan (2026-2030)" . In this talk, the overview and global aspects of the CEPC project, highlights of CEPC physics, accelerator and detector R&D will be presented.

11

Cosmic gauge strings and superstrings in the Early Universe

Author: Ye-Ling Zhou[1]

[1] *HIAS-UCAS*

Corresponding Author: zhouyeling@ucas.ac.cn

Cosmic string is a well-known topological defect widely predicted in field theories. It is regarded as one of the main sources of gravitational wave (GW) background that might be observed in the coming future. Most relevant studies have focused on cosmic strings in gauge field theory, which we call cosmic gauge strings. On the other hand, superstring theories also predict this defect, and it is called cosmic superstring. More than what we know about cosmic gauge strings, cosmic superstrings provide different types of cosmic strings and predict different inter-commutating probabilities among them, making the phenomenological consequences distinguishable from gauge strings. In this talk, I will compare the evolution between cosmic gauge strings and superstrings. The consequent GW signals and experimental hints will also be discussed.

Collider and Dark Matter / 12

Baryogenesis, Dark Matter, and PTA signal from a Dark Conformal Phase Transition

Author: Sudhakantha Girmohanta[1]

Co-authors: KOHEI FUJIKURA [2]; Yuichiro Nakai ; Zhihao Zhang [3]

[1] *Tsung-Dao Lee Institute and Shanghai Jiao Tong University*

[2] *U. Tokyo*

[3] *Tsung-Dao Lee Institute*

Corresponding Authors: zhangzhh@sjtu.edu.cn, sudhakantha.girmohanta@alumni.stonybrook.edu, supersaiyajinkohei@gmail.com, ynakai@sjtu.edu.cn

We consider the intriguing possibility that the recently reported nano-Hz gravitational wave signal by Pulsar Timing Array (PTA) experiments is sourced by a strong first-order phase transition from a nearly conformal dark sector. The phase transition has to be strongly supercooled to explain the signal amplitude, while the critical temperature has to be in the $calO(GeV)$ range, as dictated by the peak frequency of the gravitational wave spectrum. However, the resulting strong supercooling exponentially dilutes away any pre-existing baryon asymmetry and dark matter, calling for a new paradigm of their productions. We then develop a mechanism of cold darkogenesis that generates a dark asymmetry during the phase transition from the textured dark $SU(2)_{\mathrm{D}}$ Higgs field. This dark asymmetry is transferred to the visible sector via neutron portal interactions, resulting in the observed baryon asymmetry. Furthermore, the mechanism naturally leads to the correct abundance of asymmetric dark matter, with self-interaction of the scale that is of the right order to solve the diversity problem in galactic rotation curves. Collider searches for mono-jets and dark matter direct detection experiments can dictate the viability of the model.

13

Primordial black hole formation from an aborted phase transition

Author: Wen-Yuan Ai[1]

[1] *King's College London*

Corresponding Author: wenyuan.ai@kcl.ac.uk

Primordial black holes may be produced from cosmological first-order phase transitions. I will discuss a new mechanism for PBH formation based on an aborted heating phase transition during reheating. Here "heating" means that the phase transition occurs as the temperature increases during the earlier stage of reheating (when the Universe is still matter-dominated). "Aborted" means that there are bubble nucleations but the nucleation rate is so low such that there is no coalescence for these nucleated bubbles. The particular evolution of the effective potential during reheating makes the bubble expand first, then shrink, and finally disappear. However, such disappeared bubbles generate perturbed spherical regions with over-density in energy, which would accrete the surrounding matter (reheaton) and collapse into black holes.

14

Searching for heavy millicharged particles from the atmosphere

Author: Ningqiang Song[1]

[1] *Institute of Theoretical Physics, Chinese Academy of Sciences*

Corresponding Author: songnq@itp.ac.cn

If millicharged particles (MCPs) exist they can be created in the atmosphere when high energy cosmic rays collide with nuclei and could subsequently be detected at neutrino experiments. We extend previous work, which considered MCPs from decays of light mesons and proton bremsstrahlung, by including production from Υ meson decays and the Drell-Yan process. MCPs with masses below a GeV primarily arise from proton bremsstrahlung, while heavier MCPs predominantly originate from heavy meson decays and Drell-Yan. We analyse the resulting single scatter and multiple scatter signals at SuperK and JUNO. Searches for low energy coincident signals at JUNO will be sensitive to MCPs with milli-charges up to an order of magnitude beyond current constraints for MCP masses between 2 GeV and 10 GeV.

15

Low-Energy Supernova Constraints on Millicharged Particles

Author: Zuowei LiuNone

Corresponding Author: zuoweiliu@nju.edu.cn

The hot and dense environment of the supernova core serves as an extraordinary factory for new feebly-interacting particles. Low-energy supernovae, a class of supernovae with low explosion energy, are particularly intriguing due to their stringent constraints on the energy transfer caused by new particles from the supernova core to the mantle. We investigate low-energy supernova constraints on millicharged particles by considering three production channels in the core: plasmon decay, proton bremsstrahlung, and electron-positron annihilation processes. We find that the electron-positron annihilation process, previously omitted in supernova studies on millicharged particles, is the dominant production channel in the high-mass region. By studying the energy deposition due to Coulomb scatterings with protons in the supernova mantle, we find that low-energy supernovae impose the most stringent constraints on millicharged particles in the mass range of ~(10–200) MeV, surpassing the energy loss limit from SN1987A by nearly one order of magnitude.

16

Constraining dark matter properties by astronomical observations

Author: 效军毕 [1]

[1] 中科院高能所

Corresponding Author: bixj@ihep.ac.cn

Recently observed ultra diffuse dwarf galaxies or dark matter deficit dwarf galaxies may have important implications on the properties of dark matter particles. In the talk I will give explanations of the observations based on numerical simulation. It shows that the standard cold dark matter seems difficult to give a satisfied explanation to data.

17

Phenomenology with ALP and Dark Matter

Author: Xiaoping Wang[1]

[1] *Beihang University*

Corresponding Author: hcwangxiaoping@163.com

The strong CP problem and dark matter candidates are two significant challenges for the Standard Model. QCD axions are regarded as the most natural solution to the strong CP problem, making the development of a UV-complete model and the precision testing of their theoretical framework critical. As potential dark matter candidates, axion-like particles (ALPs) have garnered significant attention in both particle physics and cosmology. In particular, axion dark matter with a mass below the eV scale, due to its long-wavelength nature, offers an effective solution to the small-scale structure problems in the universe. Furthermore, to account for the relic abundance of dark matter, the high particle number density of such axions exhibits the characteristics of a classical wave field. How to explore the theory and phenomenology of various axions and axion dark matter is very interesting.

18

Dark matter formed through a cosmological first-order phase transition and its associated gravitational wave signals

Author: Fa Peng Huang[1]

[1] *Sun Yat-sen University*

Corresponding Author: huangfp8@sysu.edu.cn

We systematically discuss the new dark matter formation mechanism from a cosmological first-order phase transition and its associated gravitational wave signals.

19

Pulsar Polarization Arrays

Author: Jing Ren[1]

[1] *Institute of High Energy Physics*

Corresponding Author: renjing@ihep.ac.cn

As one of the major dark matter candidates, the ultralight Axion-Like Dark Matter (ALDM) exhibits a pronounced wave nature on astronomical scales and offers a promising solution to small-scale structure issues within local galaxies. While the linearly polarized pulsar light travels through the ALDM galactic halo, its position angle (PA) can be subject to an oscillation induced by the ALDM Chern-Simons coupling with electromagnetic field. The Pulsar Polarization Array (PPA) is thus especially suited for the detection of the ultralight ALDM, by correlating polarization data across the arrayed pulsars. We conduct the first-ever PPA analysis to detect the ultralight ALDM, using the polarization data of 22 millisecond pulsars from the third data release of Parkes Pulsar Timing Array. To accomplish this task, we develop a Bayesian framework dedicated to analyzing the time series of PA residuals of these pulsars. We find that the PPA provides the most stringent constraints on the ALDM Chern-Simons coupling so far for the relevant mass range. We also demonstrate the crucial role of cross-correlation analysis in recognizing the nature of the derived limits.

20

Towards the precise calculation of acoustic gravitational waves

sourced from first-order phase transitions —— a new hydrodynamic-simulation-based framework

Author: Xiao Wang[1]

Co-authors: Chi Tian [2]; Csaba Balazs [1]

[1] *Monash University*

[2] *Anhui University*

Corresponding Author: xiao.wang1@monash.edu

Phase transition gravitational waves could be a novel probe for fundamental physics in the near future. Hence, precise calculation of phase transition gravitational waves is essential for detecting the sign of new physics. I will discuss a framework that could allow us to omit some unnecessary approximations and give a relatively more accurate calculation of gravitational waves generated by the sound wave mechanism. With some benchmark models, I will demonstrate the procedures of this framework and show the corresponding results.

21

New perspective of QCD cosmology with Beyond the Standard Model

Author: Shinya Matsuzaki[1]

[1] *Jilin University*

Corresponding Author: synya@jlu.edu.cn

This talk plans to introduce a couple of recent new phenomenologies and cosmology related to the QCD phase transition epoch, coupled to Beyond the Standard Model, in the thermal history of the universe. Baryogenesis with a QCD-induced dynamical chemical potential (a la Higgs relaxation mechanism), strong CP problem, and gravitational wave predictions will be covered in scenarios of this class, which can also be embedded into the scalegenesis to address the dynamical origin of mass based on the classical scale invariance. Typical new physics accessible at the upcoming collider experiments are to be a dark eta-prime with mass of sub GeV and leptoquarks with mass of sub GeV, or sub TeV, which depends on the type of baryogenesis. Possible issues left necessary to persist in the future will also be addressed.

Gravitational Wave / **22**

Gravitational waves induced by first-order QCD phase transitions

Authors: Jingdong Shao[1]; Mei Huang[2]

[1] *University of Chinese Academy of Sciences*

[2] *University of Chinese Academy of Sciences(UCAS)*

Corresponding Authors: huangmei@ucas.ac.cn, shaojingdong19@mails.ucas.ac.cn

We calculated the gravitational waves induced by different QCD phase transitions including in a chirality imbalanced system, in pure gluon system, in PQM, QM, and Friedberg-Lee model, and the gravitational waves can be detected by LISA, Taiji and DECIGO. We find that the values of inverse duration β/H of these QCD phase transitions are of order

10^4 or 10^5, which means the phase transitions complete in an extreme short time. We also find that with larger chemical potential, the values of inverse duration increase with lower nucleation temperatures.

23

Bubble wall velocity from local equilibrium: A new approach

Authors: Zi-Yan Yuwen[1]; Jun-Chen Wang[2]; Shao-Jiang Wang[1]

[1] *Institute of Theoretical Physics, Chinese Academy of Sciences*

[2] *Peking University*

Corresponding Authors: yuwenziyan@itp.ac.cn, schwang@itp.ac.cn, junchenwang@stu.pku.edu.cn

Cosmological first-order phase transitions (FOPTs) serve as comprehensive probes into our early Universe with associated generations of stochastic gravitational waves and superhorizon curvature perturbations or even primordial black holes. In characterizing the FOPT, phenomenological parameters like transition temperatures, strength factors, bubble separations, and energy budgets can be reliably extracted from the macroscopic features of the underlying particle physics models except for the terminal velocity of the bubble wall expansion, making it the last key parameter to be determined most difficultly due to the non-equilibrium nature of the microscopic transition model. In this talk, I will introduce a new approach to determine the bubble wall velocity model-independently assuming local equilibrium.

24

Sphaleron in the Higgs Triplet Model

Author: Shun Zhou[1]

Co-authors: Bingrong Yu [2]; Jiahang Hu [3]

[1] *IHEP*

[2] *Institute of High Energy Physics (Beijing)*

[3] *ICTP-AP, Beijing*

Corresponding Author: zhoush@ihep.ac.cn

We study the vacuum structure of the gauge and Higgs fields and calculate the saddle-point sphaleron configuration in the Higgs Triplet Model (HTM). The coupled nonlinear equations of motion of the sphaleron are solved using the spectral method. We find the inclusion of the triplet scalar could in principle significantly change the sphaleron energy compared with the Standard Model (SM).

Gravitational Wave / 25

Impact of an early matter-dominated era on the cosmic string gravitational waves

Authors: 世祺凌 N[one]; 钊焕余 [1]

[1] 中山大学

Corresponding Authors: lingshq3@mail2.sysu.edu.cn, yuzhaoh5@mail.sysu.edu.cn

We study the stochastic gravitational wave background from cosmic strings modified by an early matter-dominated era caused by the dark matter dilution mechanism, which is commonly considered as a way to dilute the overproduced dark matter in particular scenarios. The dilutor in such a mechanism could lead to a matter-dominated era inside the conventional radiation-dominated era, affecting the expansion process of the universe. This would modify the shape of the spectrum of cosmic string gravitational waves. We show how the dilutor mass and other parameters influence the gravitational wave spectrum.

Gravitational Wave / **26**

Cosmic superstrings, metastable strings and ultralight primordial black holes: from NANOGrav to LIGO

Author: Satyabrata Datta[1]

Co-author: Rome Samanta [2]

[1] *Nanjing Normal University*

[2] *INFN- Sezione di Napoli, SSM, Naples*

Corresponding Authors: amisatyabrata703@gmail.com, samanta@na.infn.it

Recent observations of nHz stochastic gravitational waves (GW) by Pulsar Timing Arrays (PTA), such as NANOGrav, have disfavored the existence of topologically stable cosmic strings. However, cosmic metastable strings and superstrings remain viable candidates. Gravitational waves from all classes of strings generally span a wide range of frequencies, which conflicts with LIGO's non-observation of stochastic gravitational waves at the ~ 10 Hz band for a substantial string-parameter space favored by PTA data. The existence of ultralight primordial black holes ($M_{\mathrm{BH}} < 10^9$ g) in the early universe could mitigate this conflict by reducing the amplitude of GWs at higher frequencies through an early matter-dominated phase. This would alleviate the tension between LIGO observations and PTA data. We demonstrate that recent PTA data, complemented by future LIGO-Virgo-Kagra (LVK) runs and detectors such as LISA and ET, could elucidate the properties and search strategies for these ultralight primordial black holes, which are otherwise elusive due to their early evaporation via Hawking radiation.

Gravitational Wave / **27**

Bubble wall velocity and gravitational wave in the minimal left-right symmetric model

Authors: Mei Huang[1]; Qi-Shu Yan[2]; 典为王 [3]

[1] *University of Chinese Academy of Sciences*

[2] *University of Chinese Academy of Sciences, Beijing*

[3] 中国科学院大学

Corresponding Authors: wangdianwei19@mails.ucas.ac.cn, yanqishu@ucas.ac.cn, huangmei@ucas.ac.cn

The bubble wall velocity in the first order phase transition plays an important role in determining both the amplitude and the pivot frequency of stochastic gravitational wave background. In the framework of the minimal left-right symmetric model, we study the wall velocity when the first order phase transition can occur. The wall velocity can be determined by matching the distribution functions in the free particle approximation and the local thermal equilibrium approximation. It is found that the wall velocity can be determined in the range $0.2 < v_w < 0.5$ for the parameter space with the first order phase transition. It is also found that for the case when the wall velocity is close to the speed of sound, the peak amplitude of gravitational wave spectrum can be larger than that in the runaway case. Moreover, It is also found that there exists an approximate power law between the wall velocity and pressure difference between broken and symmetry phases, and the power index is equal to 0.41 or so.

Collider and Dark Matter / 28

Phenomenological aspects of dark QCD at QCD scale inspired by strong CP problem

Authors: Bin Wang[1]; Ishida Hiroyuki[2]; Shinya Matsuzaki[3]

[1] *Jilin University*

[2] *Center for Liberal Arts and Sciences, Toyama Prefectural University*

[3] *Cnter of theoretical physics, Jilin.U, China*

Corresponding Authors: 1296029386@qq.com, ishidah@pu-toyama.ac.jp, synya@mails.jlu.edu.cn

We discuss a QCD-scale composite axion model arising from dark QCD coupled to QCD. The presently proposed scenario not only solves the strong CP problem, but also is compatible with the preheating setup for the QCD baryogenesis. The composite axion is phenomenologically required to mimic the QCD pion, but can generically be flavorful, which could be testable via the induced flavor changing processes at experiments. Another axionlike particle (ALP) is predicted to achieve the axion relaxation mechanism, which can phenomenologically act as the conventional QCD axion. This ALP can be ultralight, having the mass less than 1 eV, to be a dark matter candidate. The QCD \times dark QCD symmetry structure constrains dark QCD meson spectra, so that the dark \eta'-like meson would only be accessible at the collider experiments. Still, the Belle II experiment can have a high enough sensitivity to probe the dark \eta-like meson decaying to diphoton, which dominantly arises from the mixing with the QCD \eta' and the pionic composite axion. We also briefly address nontrivial cosmological aspects, such as those related to the dark-chiral phase transition, the dark matter production, and an ultraviolet completion related to the ultralight ALP.

29

暗色区相变动力学

Author: kang zhaofeng[1]

[1] 华中科技大学 *(HUST)*

Corresponding Author: zhfkang@outlook.com

暗色区是新物理模型构造中常见的一个对象，其早期的相变可能是一级相变，从而产生随机引力波信号。但研究的非微扰性是一个困难，本报告将简要介绍其相关方面及其进展。

30

Domain walls beyond the minimal scenario

Author: Bowen Fu[1]

[1] *Northeastern University, Shenyang*

Corresponding Author: fubowen@mail.neu.edu.cn

Domain wall is one of the topological defects that can be created during phase transitions. The minimal and most well-studied domain wall is from Z_2 symmetry breaking. In this talk, we will go beyond this minimal case in two ways: embedding the Z_2 symmetry into a $U(1)$ and generalising the abelian discrete symmetry to non-abelian ones. On the one hand, the Z_2 symmetry can result from a $U(1)$ symmetry at a higher scale. In such a breaking chain, the domain walls from Z_2 symmetry breaking form hybrid defects with the cosmic strings from $U(1)$ symmetry breaking. On the other hand, the breaking of non-abelian discrete symmetries also generates domain walls. Adopting S_4 as an example, we will see these non-abelian domain walls have a richer structure and thus can lead to many interesting phenomena.

31

Probing dark matter halos with extreme mass ratio inspirals

Author: Yungui Gong[1]

[1] *Huazhong University of Science and Technology*

Corresponding Author: yggong@hust.edu.cn

Using the static and spherically symmetric metric for a black hole immersed in dark matter (DM) halos with Hernquist, Burkert, and Navarro-Frenk-White density distributions, we study the possibility of the detection of DM halos and the distinction between different DM halos with the extreme mass ratio inspiral systems (EMRIs). We also consider gravitational waves from the EMRIs consisting of primordial black holes inspiralling inside neutron stars within the Galaxy to probe the internal structure of neutron stars.

32

Wess-Zumino-Witten Interactions of Axions

Corresponding Author: jialiu@pku.edu.cn

We present a consistent derivation of the complete Wess-Zumino-Witten interactions of axions, including the counter-term necessary to guarantee the gauge invariance of the Standard Model. By treating the derivative of the axion field as a background gauge field and incorporating auxiliary chiral rotation phases, we ensure consistency in the axion-interaction Lagrangian. This approach allows us to derive basis-independent physical interactions of axions with gauge bosons and vector mesons. As an example, we explore the interaction of a-ω-γ to illustrate the potential for searching for axion-like particles at colliders.

33

Detecting Axion-like Particles with Gravitational Waves

Corresponding Author: hyangdoa@tsinghua.edu.cn

In this talk I will review the progress of using LIGO events to probe/constrain the parameter space of Axion-like particles (ALPs), which may be generated through the super-radiant process around rotating black holes, and/or coupling with nuclear matter around neutron stars. I will also discuss current efforts trying to understand dynamical effects induced by ALP clouds in a compact object binary system and observational signatures in future GW/EM detections.

34

Collective excitations from boosted dark matter

Author: 斌祝 None

Corresponding Author: zhubin@mail.nankai.edu.cn

Plasmon, a collective mode of electronic excitation in solid-state detectors, provides a novel way to detect light dark matter (DM). In this work, we present the conditions of DM to produce plasmon resonance, requiring relativistic velocities for light DM, and generalize the collective excitation framework to account for relativistic DM. As a demonstration, we consider the cosmic ray boosted DM (CRDM) and find that the plasmon resonance can be significantly enhanced in the scenario with a light mediator. Utilizing the first data from SENSEI experiment with the skipper-CCDs at SNOLAB, we obtain a new strong limit on the sub-MeV DM-electron scattering cross section.

35

QCD Phase Structure under a Rotation

Author: Guojun Huang[1]

Co-author: Pengfei Zhuang [1]

[1] *Tsinghua University*

Corresponding Author: zhuangpf@mail.tsinghua.edu.cn

The rotation effect on the QCD phase structure is still an open question: Lattice simulations favor confinement but model calculations favor deconfinement. We discuss this problem in the frame of resumed QCD.

36

SRF Cavity Searches for DP

Author: JING SHU[1]

[1] *PKU*

Corresponding Author: jshu@pku.edu.cn

Dark photons have emerged as promising candidates for dark matter, and their search is a toppriority in particle physics, astrophysics, and cosmology. We report the first use of a tunable niobiumsuperconducting radio-frequency cavity for a scan search of dark photon dark matter with innovativedata analysis techniques. We mechanically adjusted the resonant frequency of a cavity submergedin liquid helium at a temperature of 2 K, and scanned the dark photon mass over a frequency rangeof 1.37 MHz centered at 1.3 GHz. Our study leveraged the superconducting radio-frequency cavity' sremarkably high quality factors of approximately 1010, resulting in the most stringent constraintsto date on a substantial portion of the exclusion parameter space on the kinetic mixing coefficientϵ between dark photons and electromagnetic photons, yielding a value of ϵ<2.2×10ˆ(-16).

37

Nano-hertz gravitational waves and cosmic phase transition

Corresponding Author: jmyang@itp.ac.cn

Will talk about cosmic phase transition and nano-hertz gravitational waves is given. Two examples of new physics models are illustrated, which respectively predict a supercool first-order electroweak phase transition and a first-order phase transition in the dark sector at MeV scale. Both models are shown to be able to explain the reported evidences of nano-hertz gravitational waves.

Collider and Dark Matter / **39**

Bubbles kick off primordial black holes to form more binaries

Authors: Zi-Yan Yuwen[1]; Cristian Joana[1]; Shao-Jiang Wang[1]; Rong-Gen Cai[1]

[1] *Institute of Theoretical Physics, Chinese Academy of Sciences*

Corresponding Authors: yuwenziyan@itp.ac.cn, schwang@itp.ac.cn

Primordial black holes (PBHs) may form before cosmological first-order phase transitions, leading to inevitable collisions between PBHs and bubble walls. In this Letter, we have simulated for the first time the co-evolution of an expanding scalar wall passing through a black hole with full numerical relativity. This black hole-bubble wall collision yields multiple far-reaching phenomena including the PBH mass growth, gravitational wave radiations, and momentum recoil that endows PBHs with additional velocities, approximately doubling the formation rate for PBH binaries and hence strengthening the observational constraints on the PBH abundances.

Gravitational Wave / **40**

The bubble wall velocity: from the local Boltzmann equations to the non-local Kadanoff-Baym equations

Author: Jiang Zhu[1]

Co-author: Michael J. Ramsey-Musolf [2]

[1] *TDLi institution*

[2] *TDLi institude*

Corresponding Author: jackpotzhujiang@gmail.com

There are two common methods to compute the bubble wall velocity for the cosmological phase transitions: the fluid method, which analyzes the macroscopic fluid system, and the local Boltzmann equations; the microscopic method, which studies the force acting on the bubble wall by the particle interactions. However, those two methods are not consistent with each other. In this study, we present a comprehensive analysis of the friction force and velocity for the bubble wall in the early universe cosmological phase transitions. We offer a systematic framework to solve that inconsistency between two common methods by rederiving the Boltzmann equation from the quantum field theory in the background field. Furthermore, to show the self-consistency of this framework, we derive this framework from the first-principle non-local Kadanoff-Baym equations. We apply this framework to compute the new friction force from the $2 \to 2$ scattering process in light to heavy and its inverse process in $\phi^2\Phi^2$ theory and find a γ-linearly related friction force that eliminates the run-aways bubble configurations in two-step phase transitions.

Gravitational Wave / **41**

Estimating the uncertainty of cosmological first order phase transitions with numerical simulations of bubble nucleation

Author: Yang Xiao[1]

Co-authors: Huai-ke Guo [2]; Jin min Yang [1]; Song Li [3]; Yang Zhang [4]

[1] *nstitute of Theoretical Physics, Chinese Academy of Scienc*

[2] *International Centre for Theoretical Physics Asia-Pacific, University of Chinese Academy of Sciences*

[3] *Henan Normal University*

[4] *Zhengzhou University*

Corresponding Authors: guohuaike@ucas.ac.cn, zhangyangphy@zzu.edu.cn, xiaoyang@itp.ac.cn, lisong@itp.ac.cn, jmyang@itp.ac.cn

In order to study the validity of analytical formulas used in the calculation of characteristic physical quantities related to vacuum bubbles, we conduct several numerical simulations of bubble kinematics in the context of cosmological first-order phase transitions to determine potentially existing systematic uncertainties. By comparing with the analytical results, we obtain the following observations: (1) The simulated false vacuum fraction will approach the theoretical one with increasing simulated volume. When the side length of the cubic simulation volume becomes larger than 14.5 β_{th}^{-1}, the simulated results do not change significantly; (2) The theoretical expected total number of bubbles do not agree with the simulated ones, which may be caused by the inconsistent use of the false vacuum fraction formula; (3) The different nucleation rate prefactors do not affect the bubble kinetics much; (4) The lifetime distribution in the sound shell model does not obey an exponential distribution, in such a way as to cause a suppression in the gravitational wave spectra.

Inflation / **42**

Constrain Primordial Black Hole via CMB distortion

Authors: Junyue YangN[one]; Xiaoding WangN[one]; Xiao-Han MaN[one]; Dongdong ZhangN[one]; Shengfeng Yan[1]; Amara IlyasN[one]; Yi-Fu Cai[2]

[1] *UESTC*

[2] *University of Science and Technology of China*

Corresponding Authors: i.newton.f@outlook.com, yifucai@ustc.edu.cn

Primordial black holes (PBHs) are considered viable candidates for dark matter and the seeds of supermassive black holes (SMBHs), with their fruitful physical influences providing significant insights into the conditions of the early Universe. Cosmic microwave background (CMB) μ distortion tightly constrain the abundance of PBHs in the mass range of $10^4 \sim 10^{11} M_\odot$ recently, limiting their potential to serve as seeds for the SMBHs observed. Given that μ distortion directly constrain the primordial power spectrum, it is crucial to employ more precise methods in computing PBH abundance to strengthen the reliability of these constraints. By a Press-Schechter (PS) type method utilizing the compaction function, we find that the abundance of PBHs could be higher than previously estimated constraints from μ distortion observations. Furthermore, our analysis shows that variations in the shape of the power spectrum have a negligible impact on our conclusions within the mass ranges under consideration. This conclusion provides us a perspective for further research on the constrain of PBH by μ distortion.

44

Lattice simulation of SU(2) dark glueball

Author: Wei WangN[one]

Corresponding Author: wei.wang@sjtu.edu.cn

The presence of dark matter, a fundamental cosmic constituent constituting a significant portion of the universe' s mass-energy content, has captivated the scientific community for decades. Recently, there has been a growing fascination with strongly interacting dark matter. We will focus on the intrinsic appeal of SU(2) glueballs as potential dark matter candidates and their implications for particle physics. A detailed exposition of mass, wave function analyses, and interaction potential offers fresh insights into the nature of SU(2) glueballs and their potential role in elucidating the mysteries of dark matter.

45

Consequencies of phase transitions happened during inflation

Author: Haipeng An[1]

[1] *Tsinghua University*

Corresponding Author: anhp@mail.tsinghua.edu.cn

I will discuss the phenomenological consequencies of phase transitions happened during inflation.

Inflation / 46

Walking-dilaton hybrid inflation with B - L Higgs embedded in dynamical scalegenesis

Authors: He-Xu Zhang[1]; Ishida Hiroyuki[2]; Jie Liu[None]; Shinya Matsuzaki[3]

[1] *University of Chinese Academy of Sciences*

[2] *Center for Liberal Arts and Sciences, Toyama Prefectural University*

[3] *Cnter of theoretical physics, Jilin.U, China*

Corresponding Authors: bruce.j.liu@outlook.com, zhanghexu@ucas.ac.cn, synya@mails.jlu.edu.cn, ishidah@pu-toyama.ac.jp

We propose a hybrid inflationary scenario based on eight-flavor hidden QCD with the hidden colored fermions being in part gauged under $U(1)_{B-L}$. This hidden QCD is almost scale-invariant, so-called walking, and predicts the light scalar meson (the walking dilaton) associated with the spontaneous scale breaking, which develops
the Coleman-Weinberg (CW) type potential as the consequence of the nonperturbative
scale anomaly, hence plays the role of an inflaton of the small-field inflation.
The $U(1)_{B-L}$ Higgs is coupled to the walking dilaton inflaton, which is dynamically induced from the so-called bosonic seesaw mechanism.
We explore the hybrid inflation system involving the walking dilaton inflaton and the $U(1)_{B-L}$ Higgs as a waterfall field.
We find that observed inflation parameters tightly constrain the $U(1)_{B-L}$ breaking
scale as well as the walking dynamical scale to be $\sim 10^9$ GeV and $\sim 10^{14}$ GeV, respectively, so as to make the waterfall mechanism worked.
The lightest walking pion mass is then predicted to be around 500 GeV. Phenomenological perspectives including embedding of the dynamical electroweak scalegenesis and
possible impacts on the thermal leptogenesis are also addressed.

Baryogenesis / 47

Baryogenesis via QCD preheating with nonadiabatic baryon chemical potential

Authors: Jimin Wang[1]; Shinya Matsuzaki[2]; Xin-Ru Wang[3]

[1] *Center for Theoretical Physics and College of Physics, Jilin University, Changchun, 130012, China.*

[2] *Cnter of theoretical physics, Jilin.U, China*

[3] *Jilin University*

Corresponding Authors: xrwang24@mails.jlu.edu.cn, synya@mails.jlu.edu.cn, 1048851758@qq.com

The chiral phase transition in QCD can be supercooled in the thermal history of the universe to be instantaneously out-of equilibrium, if QCD is coupled to a dark QCD sector exhibiting the dark chiral phase transition of the first order. In that case the QCD sigma meson field (as the chiral order parameter, or the light quark condensate) starts to roll in a nonadiabatic way down to the true QCD vacuum. Meanwhile a dynamic baryonic chemical potential can be generated solely within QCD, which is governed by the dynamic motion of the QCD sigma meson field, analogously to the spontaneous baryogenesis or the leptogenesis via the Higgs or axionlike relaxation scenario. When QCD is further allowed to communicate with a dark fermion with mass of order of 1 GeV and the baryon number violating coupling to neutron, the nonadiabatic QCD sigma motion along with the nonadiabatic baryon chemical potential can trigger the preheating and produce the baryon number asymmetry. We discuss this scenario in details to find that the QCD-induced dynamic baryon chemical potential plays a significant role for the QCD preheating and the baryogenesis, which yields the desired amount of the asymmetry today consistently with current astrophysical, cosmological, and terrestrial experimental constraints. Cosmological and phenomenological consequences characteristic to the present scenario are also addressed.

Gravitational Wave / 48

Impact of local CP-odd domain in hot QCD on axionic domain-wall interpretation for NANOGrav 15-year Data

Authors: Akio Tomiya[1]; He-Xu Zhang[2]; Hiroyuki Ishida[3]; Linlin Huang[2]; Mamiya Kawaguchi[4]; Shinya Matsuzaki[2]; Yuanyuan Wang[2]

[1] *Department of Information Technology, International Professional University of Technology in Osaka*

[2] *Jilin University*

[3] *Center for Liberal Arts and Sciences, Toyama Prefectural University*

[4] *School of Nuclear Science and Technology, University of Chinese Academy of Sciences*

Corresponding Authors: synya@jlu.edu.cn, yuanyuanw23@jlu.edu.cn, ishidah@pu-toyama.ac.jp, huangll22@jlu.edu.cn, hxzhang18@163.com, mamiya@ucas.ac.cn, akio@yukawa.kyoto-u.ac.jp

We argue that the axionic domain-wall with a QCD bias may be incompatible with the NANOGrav 15-year data on a stochastic gravitational wave (GW) background, when the domain wall network collapses in the hot-QCD induced local CP-odd domain. This is due to the drastic suppression of the QCD bias set by the QCD topological susceptibility in the presence of the CP-odd domain with nonzero θ parameter of order one which the QCD sphaleron could generate. We quantify the effect on the GW signals by working on a low-energy effective model of Nambu-Jona-Lasinio type in the mean field approximation. We find that only at $\theta = \pi$, the QCD bias tends to get significantly large enough due to the criticality of the thermal CP restoration, which would, however, give too big signal strengths to be consistent with the NANOGrav 15-year data and would also be subject to the strength of the phase transition at the criticality.

49

Panel Discussions

Corresponding Author: hexg@sjtu.edu.cn

50

拍照合影

51

晚宴

52

Glueballs on the lattice

Author: Ying Chen[1]

[1] *Institute of High Energy Physics, Chinese Academy of Sciences*

Corresponding Author: cheny@ihep.ac.cn

This talk will review the current status of the glueball relevant lattice QCD study.

53

Excustion with Informal Dinner at City Center

54

Opening Speech

55

Registeration

56

Was There an Electroweak Phase Transition

Determining the thermal history of electroweak symmetry breaking is a forefront challenge for particle physics and cosmology. The occurrence of a first order electroweak phase transition (EWPT) would have profound implications for explaining the origin of the cosmic baryon asymmetry and generation of primordial gravitational radiation. I discuss recent theoretical developments in assessing the possibility of an EWPT in beyond Standard Model theories and highlight the corresponding phenomenological implications.

57

Study the QCD Phase diagram with Beam Energy Scan at RHIC

Corresponding Author: xfluo@mail.ccnu.edu.cn

Understanding the properties of quark matter and its phase structure is crucial for advancing our knowledge of the universe's evolution and the composition of visible matter. Over the past two decades, numerous experimental observations have provided evidence for the existence of strongly interacting quark-gluon plasma (sQGP) in relativistic heavy-ion collisions. As a result, exploring the QCD phase structure at high baryon densities—such as mapping the first-order phase transition boundary and locating the QCD critical point—has become a primary objective in heavy-ion collision research. Between 2010 and 2021, the first and second phase of the Beam Energy Scan (BES-I) at RHIC wrere completed, with the STAR experiment collecting data from Au+Au collisions at energies ranging from 200 GeV to 3 GeV (Collider and Fixed-target mode). In this talk, I will present the latest experimental progress in exploring the QCD phase structure at RHIC, with a special emphasis on the search for the QCD critical point. I will also discuss new facilities designed for exploring the high baryon density region and outline future research plans.

58

Closing Speech

59

How robust are gravitational wave predictions from first order cosmological phase transitions?

Author: Peter Athron[1]

[1] *Nanjing Normal University*

Corresponding Author: peter.athron@njnu.edu.cn

The prospect of detecting Gravitational waves from first order phase transitions opens up a whole new way to test particle physics models. However in order to make use of this we need to have an understanding of the uncertainties involved involved in theoretical calculations and the reliability of commonly used approximations. I will discuss various subtle issues in the prediction of gravitational wave spectra from first order phase transitions that can significantly impact the predictions and discuss how robust the predictions are. In particular I will discuss criteria for determining if a phase transition completes, the dependence of gravitational wave predictions on the transition temperature and a variety of standard approximations.

Baryogenesis / 60

Nonperturbative study of the electroweak phase transition in the real scalar singlet extended Standard Model

Authors: GUO TAO XIANN[one]; Lauri NiemiN[one]; Michael Ramsey-Musolf[1]

[1] *TDLI-SJTU*

Corresponding Authors: xiagt-summer@sjtu.edu.cn, mjrm@physics.umass.edu

In this talk, we explore the electroweak phase transition in the real singlet scalar extension of the Standard Model through a nonperturbative lattice study. We examine both heavy and light singlet-like scalar scenarios, focusing on non-zero singlet-doublet mixing angles.

The presentation begins with an overview of the lattice methods relevant to phase transition analysis. We then analyze how thermodynamic properties depend on order parameters. In the heavy scalar regime, we find that the transition is a crossover for small mixing angles, despite an energy barrier in the potential, while it becomes first order for larger mixing angles.

We also discuss the strong agreement between two-loop perturbation theory and our lattice results for critical thermodynamic quantities when the transition is strongly first order. For the light scalar regime, pertinent to exotic Higgs decays, we update previous one-loop results using two-loop effective field theory and present lattice simulations at specific benchmark parameters. Our findings indicate that the transition shifts to a crossover with small Higgs-singlet portal couplings.

This work enhances our understanding of the electroweak phase transition and its implications in high-energy physics.

Baryogenesis / 61

Phase transitions, anomalous baryon number violation and electroweak multiplet dark matter

Authors: Yanda WuN[one]; Wenxing ZhangN[one]; Michael Ramsey-MusolfN[one]

Corresponding Author: yanda.wu7@sjtu.edu.cn

Our study presents a comprehensive analysis of baryon number violation during the electroweak phase transition (EWPT) within the framework of an extended scalar electroweak multiplet. We perform a topological classification of scalar multiplet's representation during the EWPT, identifying conditions under which monopole or sphaleron field solutions emerge, contingent upon whether their hypercharge is zero; which indicates that only monopole scalar multiplet can contribute to the dark matter relic density. We also conduct a systematic research of other formal aspects, like the construction of higher dimensional sphaleron matrix, computation of the sphaleron and monopole mass, and the analysis of boundary conditions for the field equation of motions. We then scrutinize the computation of sphaleron energy and monopole mass within the context of a multi-step EWPT, employing the SU(2) septuplet scalar extension to the Standard Model (SM) as a case of study. In the scenario of a single-step EWPT leading to a mixed phase, we find that the additional multiplet's contribution to the sphaleron energy is negligible, primarily due to the prevailing constraint imposed by the parameter. Conversely, in a two-step EWPT scenario, the monopole mass can achieve significantly high values during the initial phase, thereby markedly constraining the monopole density and preserving the baryon asymmetry if the universe undergoes a first-order phase transition. In the two-step case, we delineate the relationship between the monopole mass and the parameters relevant to dark matter phenomenology.

62

Simulations of Bosonic Dark Matter

Corresponding Author: chenjiajun@swu.edu.cn

This talk discusses simulations of bosonic dark matter, focusing on the condensation and evolution of halos and boson stars, as well as the polarization evolution of vector dark matter.

The background section highlights the nature of cold dark matter, its problems, and possible solutions like warm dark matter, self-interacting dark matter, and ultra-light axions. It introduces axion-like particles and the mathematical framework used to model their behavior.

The first part addresses the formation and evolution of halos and boson stars, with detailed discussion on condensation, growth rates, and the role of self-interaction in shaping these structures. The formation of multiple boson stars due to gravity and self-interactions is also explored.

The second part explores the polarization evolution of vector dark matter. It examines how different initial conditions affect the formation of Proca stars, and how spin and polarization evolve over time. The talk shows that the density of vector dark matter correlates closely with polarization density, and that Proca stars can form due to spin in one direction, leading to a spin reversal in the outer regions.