High Energy Theory Group
Status and Plan 2023

Kin-Wang Ng (吳建宏)

Research Fellow
Institute of Physics, Academia Sinica
&
Joint Research Fellow
Institute of Astronomy and Astrophysics, Academia Sinica

On behalf of the Medium and High Energy Group (Theory)

Man Power in Theory Group

- **Research Faculty (6, 3/6 will retire within 4 years at age 65)**

(1) Hsiang-nan Li (李湘楠) – Distinguished
(2) Tzu-Chiang Yuan (阮自強) – World's Top 2% Scientists (by Stanford data)
(3) Kin-Wang Ng (吳建宏) – Joint faculty at ASIAA
(4) Meng-Ru Wu (吳孟儒) – Joint faculty at ASIAA
(5) Di-Lun Yang (楊迪倫)
(6) Anatoli Fedynitch (安納托里)

- **Postdocs (10+1 going+2 coming)**

Reginald Christian Bernardo (貝納多)→ APCTP, Soumya Bhattacharyya (秀明帕塔亞), Madhurima Chakraborty, Shu-Lin Cheng (鄭書麟), Geraint Evans, Avdhesh Kumar (庫馬), Yen-Hsun Lin (林彥勳), Manu George (曼魯喬治), Anton Prosekin (普羅安東), Dmitry Prokhorov (普羅迪瑪), Van Que Tran, Yi-Peng Wu (吳亦鵬), Dave Yeeles (易戴夫)
Former (5 since 2021): Che-Yu Chen (陳哲佑)→ RIKEN, Patrick Copinger (波都陸.朝.河品雅)→ Univ. of Plymouth, Raymundo Ramos (雷蒙拉莫斯)→ Seoultech , Hiroyuki Umeeda (梅枝宏之) → Beijing, IHEP, Herlik Wilbowo (吳智立)→ Univ. of York

- **Master and PhD students from universities**
- **Funding support from NSTC, AS, IoP**

Main Research Areas of Theory Group

- Particle Physics Phenomenology
  - Flavor and hadron physics (Hsiang-nan Li)
  - Perturbative and non-perturbative QCD (Hsiang-nan Li)
  - QCD in dense matter, heavy ion collisions (Di-Lun Yang)
  - Beyond Standard Model particle physics, dark matter (Tzu-Chiang Yuan)
- Particle and Nuclear Astrophysics and Cosmology
  - Inflation, CMB B-mode polarization, gravitational waves (Kin-Wang Ng)
  - Neutrinos, nucleosynthesis, and bSM physics in astrophysics and their multi-messenger observables (Meng-Ru Wu)
  - Ultra high energy cosmic rays, IceCube neutrinos, multi-messengers, modeling of hadronic and nuclear interactions (Anatoli Fedynitch)

Group activities (hybrid): Friday seminars, Wednesday journal club,
Monday noon chat on arXiv papers

2021 AAC and External Review Recommendations

- hire a well-established mid-career researcher to lead HETG
- ASGC to play a more critical and important role as a local high performance computing center to support selected research projects within AS
- keep this goal of synergy between experiment and theory in mind in its next round of hires
- a hire in the area of general relativity and gravitational-wave astronomy/cosmology
- a hire in the area of QCD and top quark physics, in collider physics

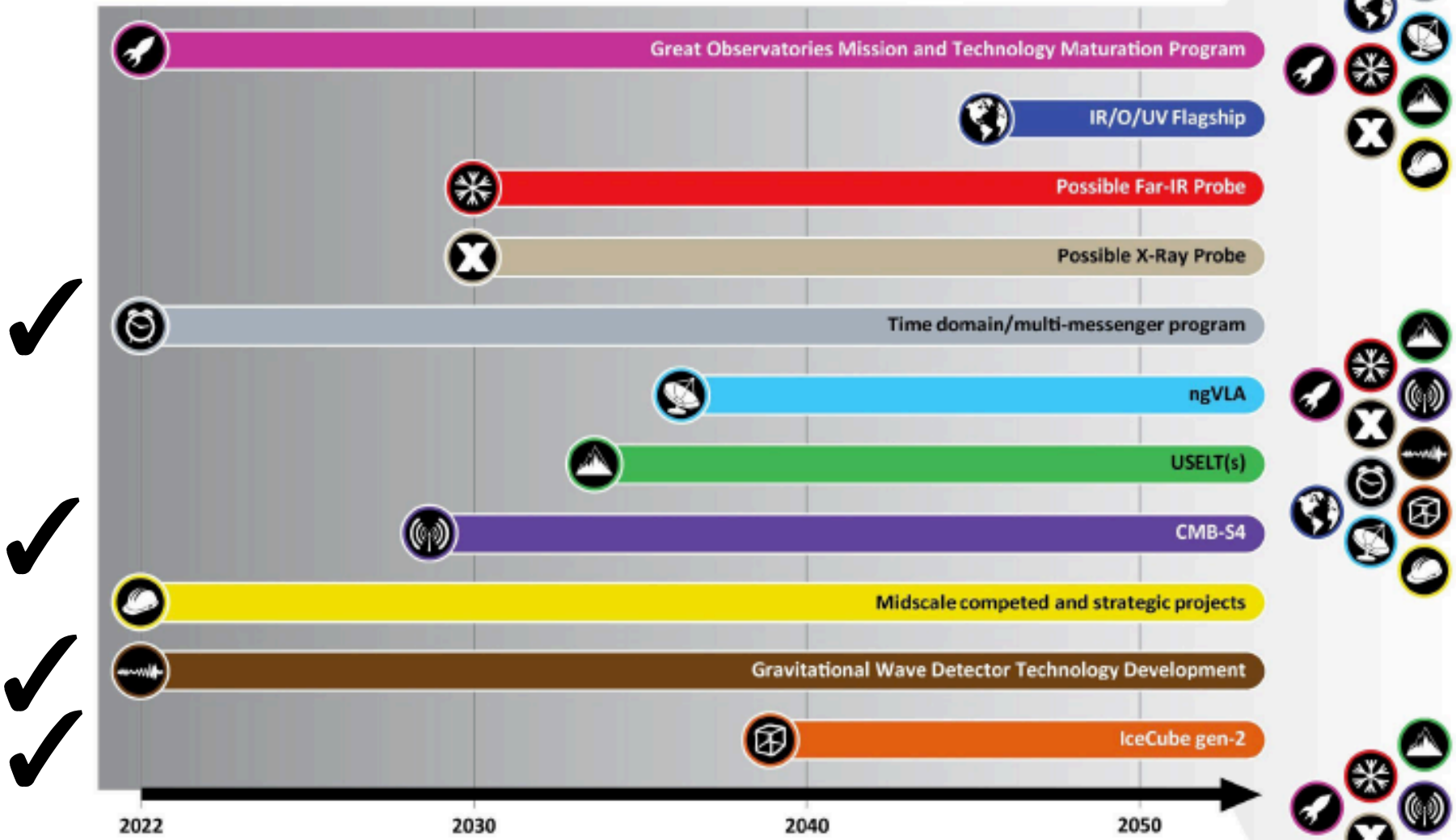
Our Responses and Future Directions

- Computation Frontiers – newly established Computational Lab
- Theory Frontiers – meet with current and future experiments
- New recruitments

Newly Established Project-oriented Computational Lab for Fundamentals/Astrophysics/Gravity/Cosmology - supported by IOP & Academia Sinica Grid-computing Centre (ASGC)

- Computational Lab @ ASGC supports HPC to
  - IoP high-energy experiments, KAGRA, LIGO, and IceCube
  - Lattice QCD (Ting-Wai Chiu, adjunct professor at IOP, GPU expert)
  - Quantum transport of neutrinos (Meng-Ru Wu)
  - Integrating computing facilities such as ASIAA, ASIoC into ASGC
- IOP-supported HETG postdoc fellowships (Bernardo, Y.-P. Wu, Yeeles)
  We run a postdoc program to recruit outstanding junior postdoc fellows with competitive offer packages including international-level salary plus research and travel supports
- IOP-supported long-term (3-12 months) professorships to lead topical research and nurture junior fellows (Bei-Lok Hu, Univ. of Maryland, Dec 2023-Apr 2024)
- Counterparts - Center for Theory and Computation (前沿理論及計算研究中心) at NTHU, Astrophysics and Cosmology Simulation Group at NTU

Decadal Survey on Astronomy and Astrophysics 2020 (US NAS)



nap.edu/astro2020

www.nap.edu/26141

Interaction with experiments

- Electron-Ion Collider (EIC) and Heavy-Ion Collisions (HIC) to study QCD in nuclear matter
  PI: Hsiang-nan Li, Di-Lun Yang (talk to condensed matter group)
  Expt: Wen-Chen Chang
- sub-GeV, MeV, ultra-light dark matter phenomenology
  PI: Tzu-Chiang Yuan, Kin-Wang Ng, Meng-Ru Wu
  Expt: Tsz-King Wong (sub-GeV dark matter), Yuan-Hann Chang (AMS, axion)
- Gravitational wave background and cosmology
  PI: Kin-Wang Ng, Tzu-Chiang Yuan
  Expt: Sadakazu Haino (KAGRA), Yuki Inoue+Tsz-King Wong (LIGO)
- Hot and dense matter in astrophysics and multi-messengers (cosmic rays, neutrinos, EM signals, gravitational waves)
  PI: Meng-Ru Wu, Di-Lun Yang, Anatoli Fedynitch (lead to join Icecube and Telescope Array)
- Quantum computing and AI: Quantum algorithms and applications of quantum computing in scientific research; AI and machine learning
  PI: Sai-Ping Li
  Expt: Chii-Dong Chen (superconducting qubits)

New Faculty Recruitments

- In Nov 2021, verbal offers were made to two outstanding junior candidates, in gravitational-wave and Standard-Model precision calculations. Recruitment was stopped due to lack of quota from AS. One becomes a faculty at NTU and one stays in Europe as a senior scientist.
- In Apr 2022, we talked to Daniel Baumann (a renowned cosmologist) and recommended IOP and IAA to push his case at AS level. He becomes the new LeCosPA/NTU director?
- In Nov 2022, we interviewed five outstanding junior candidates. Yuji Hirono is the top candidate. He has common interests between HETG, CMP, and PABS. IOP has just approved his case as our first inter-disciplinary faculty.

HETG Research Highlights

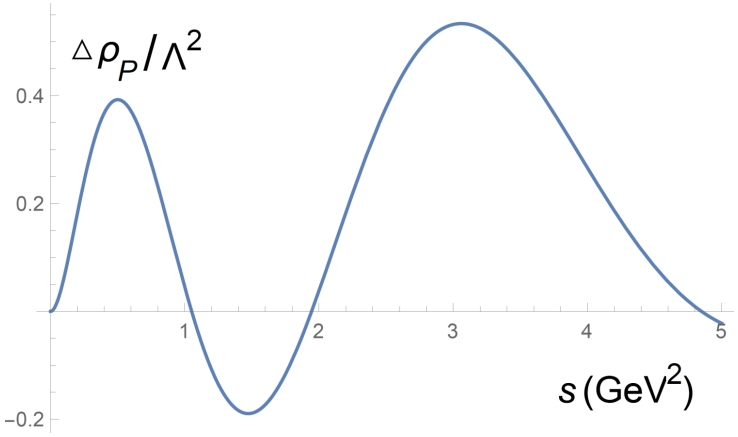


FIG. 1 ：Pseudoscalar glueball spectral density, where peak locations correspond to possible glueball masses.

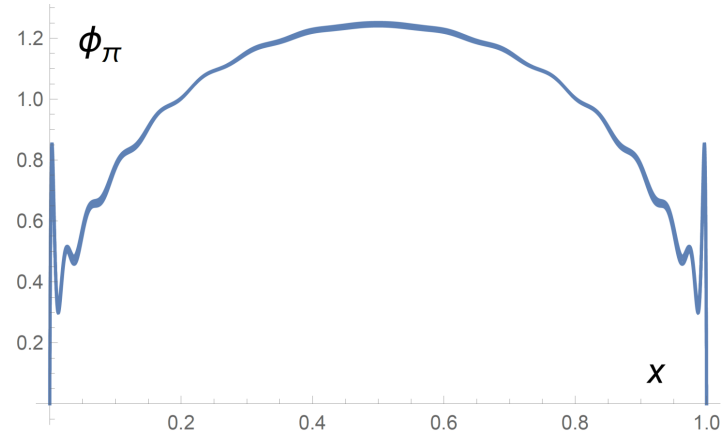


FIG. 2 ：leading-twist pion distribution.

Hsiang-nan Li

Dispersion-relation-based nonperturbative approach

Study of nonperturbative dynamics has had a long history. We developed a dispersion-relation-based approach to investigations of nonperturbative quantum chromodynamics (QCD) in a series of works recently. Given a quantity defined as a correlation function, we solved the dispersion relation obeyed by the correlation function directly from its standard operator-product-expansion inputs at high energy, and obtain nonperturbative behaviors of this quantity at low energy. Compared to the known QCD-sum-rule method, which has been adopted for several decades, our approach is free of theoretical uncertainties from resonance modeling and the quark-hadron duality assumption, has much higher predictive power, and can be improved systematically in precision. Applying this method, we have reproduced ρ meson (including excited states) properties, predicted glueball masses, and acquired the leading-twist pion distribution amplitude in the entire momentum-fraction space.

Physical Review D 106, 034015 (2022).

Gauged Two-Higgs Doublet Model – a gauge dark matter model

Tze-Chiang Yuan

[1] W.C. Huang, Y. L. S. Tsai and T. C. Yuan,
"G2HDM : Gauged Two Higgs Doublet Model,"
JHEP **04**, 019 (2016) doi:10.1007/JHEP04(2016)019 [arXiv:1512.00229 [hep-ph]].

[2] R. Ramos, V. Tran and T. C. Yuan,
"A Sub-GeV Low Mass Hidden Dark Sector of $SU(2)_H \times U(1)_X$,"
JHEP **11**, 112 (2021) doi:10.1007/JHEP11(2021)112 [arXiv:2109.03185 [hep-ph]].

[3] V. Tran and T. C. Yuan,
"Charged lepton flavor violating radiative decays $l_i \to l_j + \gamma$ in G2HDM,"
JHEP **02**, 117 (2023) doi:10.1007/JHEP02(2023)117 [arXiv:2212.02333 [hep-ph]].

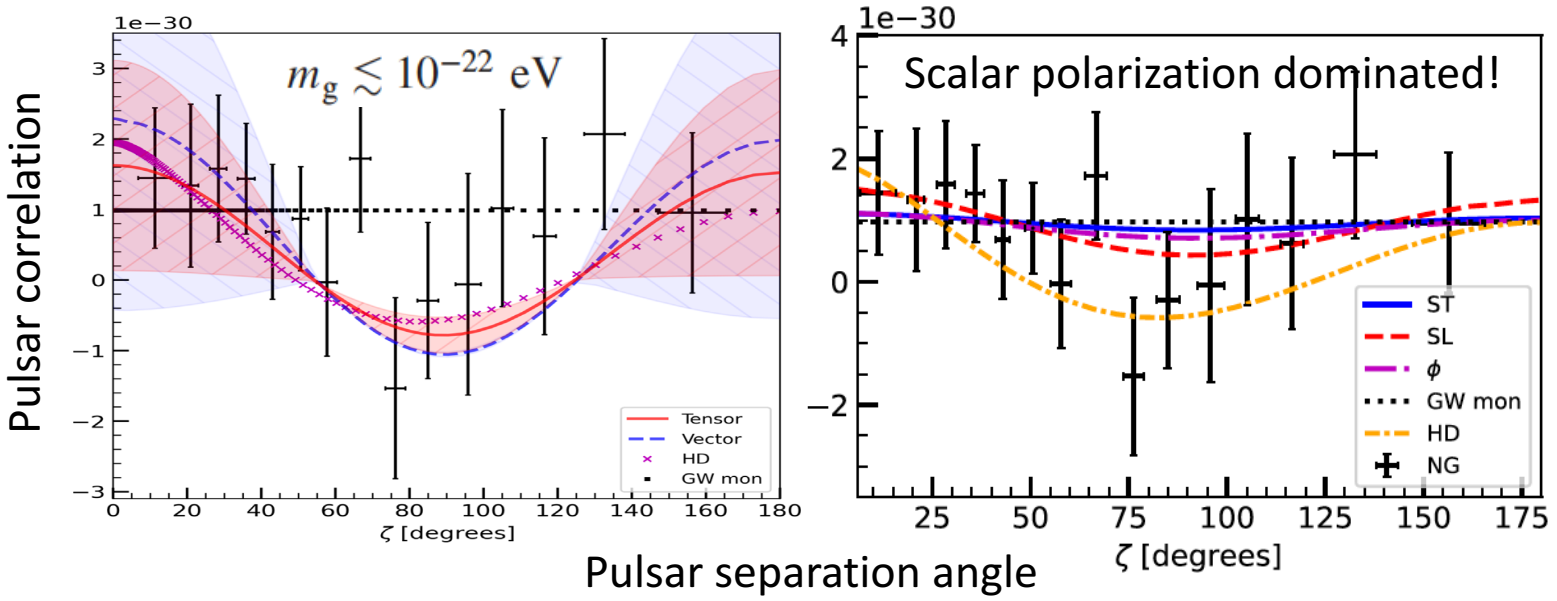
[4] V. Tran, T. T. Q. Nguyen and T. C. Yuan,
"Scrutinizing a hidden SM-like gauge model with corrections to oblique parameters," Eur. Phys. J. C **83**, no.4, 346 (2023)
doi:10.1140/epjc/s10052-023-11495-x [arXiv:2208.10971 [hep-ph]].

[5] L. Chen, T.-W. Chan, T. W. Kepart, W.-Y. Keung and T. C. Yuan,
"GUT origins of general electroweak multiplets and their oblique parameters,"
doi.org/10.48550/arXiv.2306.10973 [arXiv:2306.10972 [hep-ph]].

- Birefringence B-mode in cosmic microwave background polarization (+Guo-Chin Liu, Seokcheon Lee) to search for axionic dark energy and axionic dark matter

Kin-Wang Ng

- Inflation – primordial density fluctuations and gravitational waves, primordial black holes (+Shu-Lin Cheng, Dashin Lee, Wolung Lee, Yi-Peng Wu) to perform state-of-the-art numerical calculations incorporating backreactions
- Stochastic gravitational wave background – overlap reduction functions in LIGO-Virgo-KAGRA, Einstein Telescope-Cosmic Explorer, LISA-Taiji, and pulsar timing arrays (PTA) (+Reggie Bernardo, Guo-Chin Liu, Yu-Kuang Chu) to invent new methods with public codes to accelerate data analysis and test gravity since 2021 - 5 PRD, 2 JCAP, 1 PLB, 1 PRDL, 1 arXiv



+ NG : NANOGrav 12.5-yrs data on nanohertz gravitational-wave search, Dec 2020

On June 29 2023, NANOGrav 15-yrs + EPTA-InPTA + PPTA + CPTA confirmed the detection of a nanohertz stochastic GW background through pulsar correlation !

please stay tuned to our new works

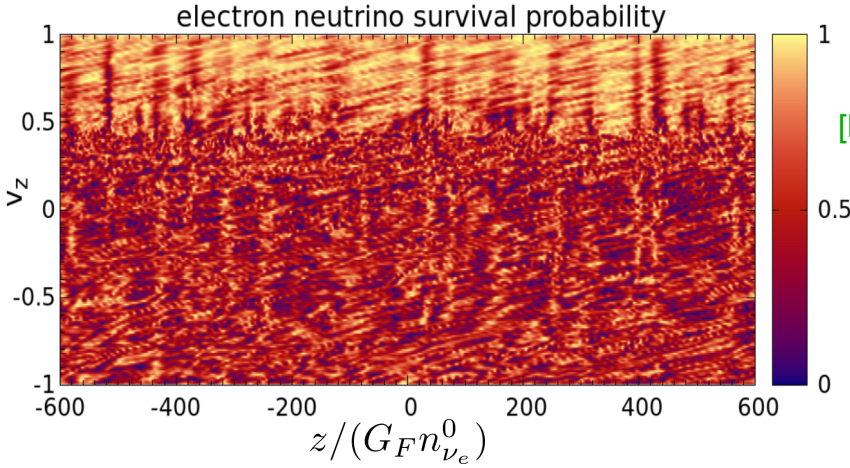
Neutrinos and Dark Sector in astrophysics

Meng-Ru Wu

– recent achievement and highlights from Meng-Ru Wu

- Development of multidimensional quantum kinetic transport code for collective neutrino flavor oscillations + understanding

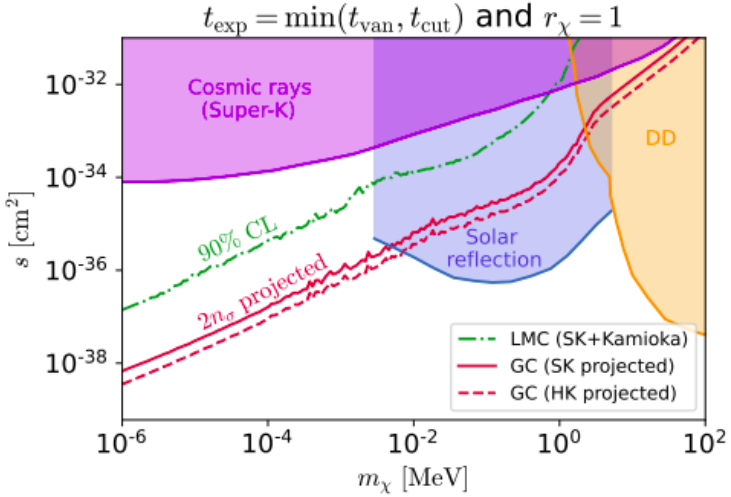
  MRW, George, Lin, Xiong, PRD 104 (2021) 103003
  Just, Abbar, **MRW**, et. al., PRD 105 (2022) 083024
  Richers, Duan, **MRW**, et. al., PRD 106 (2022) 043011
  Xiong, **MRW**, Martinez-Pinedo, et. al., PRD 107 (2023) 083016
  George, Lin, **MRW**, Liu, Xiong, CPC 283 (2023) 108588
  Xiong, Johns, **MRW**, Duan, arXiv:2212.03750
  Xiong, **MRW**, Qian, arXiv:2303.05906 (to appear in PRD)
  Xiong, **MRW**, Abbar et. al., arXiv:2307.11129



[MRW+ PRD 2021]

- Probing dark matter / sterile neutrinos with supernovae and neutron star mergers

  Sung, Guo, **MRW**, PRD 103 (2021) 103005
  Sigurdarson, Tamborra, **MRW**, PRD 106 (2022) 123030
  Lin, Wu, **MRW**, Wong, PRL 106 (2023) 111002
  Bauswein, Guo, Lien, Lin, **MRW**, PRD 107 (2023) 083002
  Lin, Tsai, Lin, Wong, **MRW**, arXiv:2307.03522



[Lin+ PRL 2023]

- others (HE neutrinos and nucleosynthesis)

  Banerjee, **MRW**, Jeena SK, MNRAS 512 (2022) 4948
  Guo, Qian, **MRW**, PRD 108 (2023) L021303
  An, **MRW**, Guo, et. al., arXiv:2306.07659

Chiral transport phenomena in astrophysics

- "Chiral effects in astrophysics and cosmology" (review), Kohei Kamada, Naoki Yamamoto, Di-Lun Yang, Prog. Part. Nucl. Phys. 129, 104016 (2023).

  We review how chiral effects could affect supernova explosions, magnetic-field generation in magnetars, and pulsar kicks.

- "Effective chiral magnetic effect from neutrino radiation", Naoki Yamamoto, Di-Lun Yang, PRL 131, 012701 (2023).

  As opposed to the traditional CME, electric and energy currents triggered by magnetic fields without an axial chemical potential through weak interaction are derived.

Quantum kinetic theories and spin transport in relativistic heavy ion collisions

- "Foundations and applications of quantum kinetic theory", (review), Yoshimasa Hidaka, Shi Pu, Qun Wang, Di-Lun Yang, Prog. Part. Nucl. Phys. 127 (2022), 103989.

  We review recent developments of the quantum kinetic theories widely studied in high-energy nuclear physics.

- "Spin alignment of vector mesons by glasma fields", Avdhesh Kumar, Berndt Müller, Di-Lun Yang, PRD 108, 016020 (2023).

  Spin correlation from the color glass condensate is proposed to explain large spin alignment measured in LHC.

- "Quantum kinetic theory for spin transport of quarks with background chromo-electromagnetic fields", Di-Lun Yang, JHEP 06, 140 (2022).

  A novel kinetic theory tracking spin dynamics for relativistic quarks with color degrees of freedom is constructed.

Anatoli Fedynitch

Model building & phenomenology

Data-driven hadronic interaction model for atmospheric lepton flux calculations

Anatoli Fedynitch and Matthias Huber
Phys. Rev. D **106**, 083018 – Published 24 October 2022

22 pages, basis for new `daemonflux` atmospheric neutrino flux model

Data-driven muon-calibrated neutrino flux

Juan Pablo Yañez and Anatoli Fedynitch
Phys. Rev. D **107**, 123037 – Published 30 June 2023

21 pages, new generation atmospheric neutrino flux model; uncertainties reduced by up to factor 10. New baseline in IceCube; → KM3NeT, →P-ONE, → Baikal GVD

"Creative papers" with N. Globus & R. Blandford:

1. "Treasure maps"; science goal for future observatory, ApJ 945, 2023
2. Cosmic ray origin of bilogical homocirality; ApJ 910, 2021

IceCube Neutrino Observatory

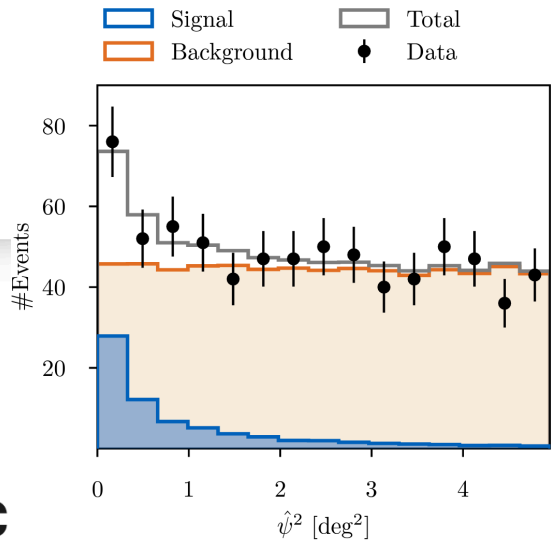
Science

BACK TO VOL. 378, NO. 6619

2022

RESEARCH ARTICLE | NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068



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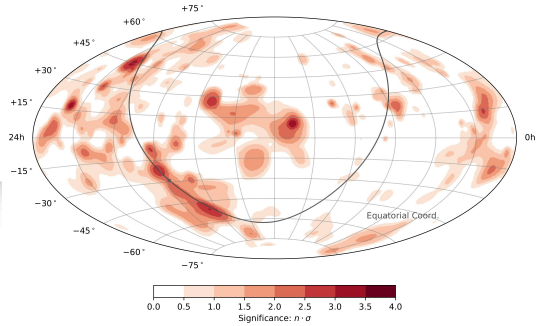
Science

2023

BACK TO VOL. 380, NO. 6652

RESEARCH ARTICLE | NEUTRINO ASTROPHYSICS

Observation of high-energy neutrinos from the Galactic plane



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Roles: ICB (exec board), Publication committee, Diffuse WG, "soft approved" as next group leader from Oct. 2023

Thank you for your attention!