

Astrophysical Big Bang Laboratory
Chief Scientist: Shigehiro Nagataki (Ph.D.)



(0) Research field : Astrophysics Physics

Keywords: Supernovae (SNe), Gamma-Ray Bursts (GRBs),
Black Holes (BHs), Neutron Stars (NSs), Cosmic Rays (CRs)

(1) Long-term goal of laboratory and research background

Our laboratory, Astrophysical Big Bang Laboratory (ABBL), was established on 1st Apr. 2013. Our group focuses on unveiling lots of mysteries surrounding astrophysical explosive phenomena such as supernovae (SNe) and gamma-ray bursts (GRBs). SNe and GRBs are the most powerful explosions in the universe, yet very little is known about their explosion mechanisms. These astrophysical big bangs fascinate us with their unknown physics and puzzling astronomical phenomena such as gravitational waves, r-process nucleosynthesis, particle acceleration, high-energy gamma-rays/neutrinos, ultra-high-energy cosmic rays. Through our theoretical and computational approaches, we strive to reveal the complete pictures of these explosions and provide the-state-of-the-art physical interpretations for current, cutting-edge observations and useful predictions for future observations by the next-generation astronomical observatories. We are more than passionate about co-operating with researchers in RIKEN and all other interested groups in Japan and the world, and together we would like to establish a Utopia in RIKEN for scientists.

(2) Current research activities (FY2021) and plan (until Mar. 2025)

One of the significant achievements of ABBL in 2021 is the discovery of legacies of the supernova explosion mechanism in the young supernova remnant Cassiopeia A (Paper [1] in section (4), published in Nature). First, from detailed X-ray observations, we found that the iron clump at the rim of Cassiopeia A contained a small amount of titanium and chromium. Then, from the comparison with the nucleosynthesis calculations of a supernova explosion, we found that the iron clump was formed at the neutron star's surface and blown off by the neutrino wind. This result was press-released and widely reported in newspapers. We also have theoretical studies on black hole accretion disks that are deeply related to GRB formation (paper [2] in section (4)), the radiation mechanism of short GRB, based on photospheric models (paper [3]). Furthermore, we promoted theoretical research on GRB afterglow models (paper [4]) and theoretical research on X-ray bursts on neutron stars (paper [5]).

ABBL started in FY2013 at RIKEN and has led the world for the sciences in SNe & GRBs. Nowadays, ABBL is one of the most famous laboratories globally, and each paper from ABBL is highly recognized in the community of SNe & GRBs. Until the end of FY2021 (9yr from the start), 22 researchers, postdoctoral researchers, and SPDR/FPR belonged to ABBL, and 14 people got the next positions successfully. Among 14, 7 got permanent positions. ABBL is developing further and further, keeping high research quality. Our goal is that each ABBL member will get a permanent position in the world, and each member will organize her/his research group that will collaborate with ABBL tightly.

For the mid-term (until FY2025) goal of ABBL, Gravitational Wave is one of the keywords. ABBL has been studying SNe & GRBs, which are gravitational wave sources. ABBL is going to cover NSs & BHs more. There is a close relation between SNe/GRBs and NSs/BHs since the former is the mother of the latter. As a good example, we will study neutron star mergers that will emit gravitational waves, forming a BH. The dynamics depends on the equation-of-state (EOS) of neutron star matter. The neutron star mergers can be observed as kilo-novae brightened by the decays of r-process elements. Studies of neutron star mergers require substantial computational resources. ABBL believes that gravitational wave astrophysics fits very well with the sciences that RIKEN is leading.

(3) Members

as of March, 2021

PI, Chief Scientist: Shigehiro Nagataki

Researchers: Akira Mizuta (Tenured), Hiroataka Ito, Gilles Ferrand, Masaomi Ono, Eiji Kido, Hajime Sotani, Nobuya Nishimura, Yuta Sekino, Donald Warren (Concurrent)

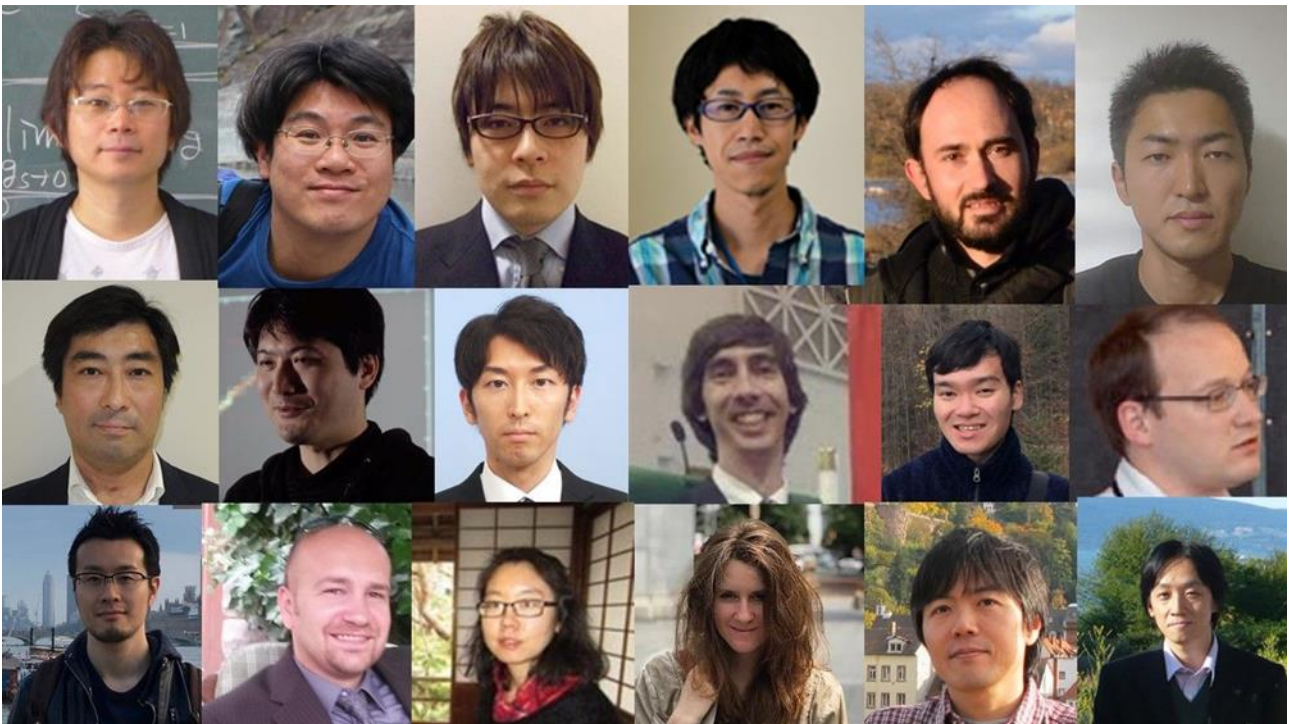
Trainee: Yuki Takei

Secretary: Tamaki Shibasaki

(4) Representative research achievements

1. “High-entropy ejecta plumes in Cassiopeia A from neutrino-driven convection”, Sato, T.; Maeda, K.; Nagataki, S.; Yoshida, T.; Grefenstette, B.; Williams, B. J.; Umeda, H.; Ono, M.; Hughes, J. P., Nature, Volume 592, Issue 7855, p.537-540 (2021).
2. “Neutrino absorption and other physics dependencies in neutrino-cooled black hole accretion discs”, Just, O.; Goriely, S.; Janka, H. -Th; Nagataki, S.; Bauswein, A., Monthly Notices of the Royal Astronomical Society, Volume 509, Issue 1, pp.1377-1412 (2022).
3. “A Global Numerical Model of the Prompt Emission in Short Gamma-ray Bursts”, Ito, H.; Just, O.; Takei, Y.; Nagataki, S., The Astrophysical Journal, Volume 918, Issue 2, id.59, 12 pp. (2021).
4. “A Semianalytic Afterglow with Thermal Electrons and Synchrotron Self-Compton Emission”, Warren, D. C.; Dainotti, M.; Barkov, M. V.; Ahlgren, B.; Ito, H.; Nagataki, S., The Astrophysical Journal, Volume 924, Issue 1, id.40, 16 pp. (2022).
5. “Effects of the Nuclear Equation of State on Type I X-Ray Bursts: Interpretation of the X-Ray Bursts from GS 1826-24”, Dohi, A.; Nishimura, N.; Hashimoto, M.; Matsuo, Y.; Noda, T.; Nagataki, S., The Astrophysical Journal, Volume 923, Issue 1, id.64, 16 pp. (2021).

Supplementary



ABBL Members in FY2021 (including visiting researchers (Maxim Barkov, Yohei Kawazura, Oliver Just, Haoning He, Noemie Globus, Susumu Inoue, Atsushi Tamii))

Laboratory Homepage

https://www.riken.jp/en/research/labs/chief/astro_big_bang/index.html

http://nagataki-lab.riken.jp/index_en.html

(5) Research Records

(A) 受賞・プレスリリース等

長瀧重博、小野勝臣等、「大質量星の超新星エンジンをX線観測で解明」。責任著者は佐藤寿紀（立教大学）。2021年4月22日。

プレスリリース（理研、立教大学、東京大学）

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NASA Press Release

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https://www.nasa.gov/mission_pages/chandra/images/bubbles-with-titanium-trigger-titanic-explosions.html

Gilles Ferrand, “RIKEN Research: Supernova simulations reveal how stellar explosions shape debris clouds”

<https://ithems.riken.jp/ja/news/riken-research-supernova-simulations-reveal-how-stellar-explosions-shape-debris-clouds>

Oliver Just, Shigehiro Nagataki “Where does gold come from? — New insights into element synthesis in the universe” GSI Press Release, 15th Nov. 2021.

<https://www.gsi.de/en/start/news/details/2021/11/15/elementsynthese-schwarze-loecher>

Hirota Ito “A Global Numerical Model of the Prompt Emission in Short Gamma-ray Bursts”, AAS Journal Author Series: Hirota Ito on

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西村信哉（翻訳者として貢献）「2022年カレンダー「宇宙核物理を築いた女性研究者たち」出版について」、2022年1月27日。

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(B) 授業・本

長瀧重博、「一般相対性理論で宇宙はどこまで分かるのか」2021年度S Semester 学術フロンティア講義、東大駒場（オンライン）、2021年4月14日、21日

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西村信哉, “Stellar Alchemy: in the era of astronomical observations and nuclear measurements”, Nobuya Nishimura, GPPU Seminar (国際大学院教育

プログラムの授業の一環), 24 Mar. 2022, 東北大学

(C) 論文（査読あり）

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Hajime Sotani and Kohsuke Sumiyoshi, "Stability of the protoneutron stars toward black hole formation", *Mon. Not. R. Astron. Soc.* 507(2), 2766–2776 (10/2021).

Dohi, A.; Nishimura, N.; Hashimoto, M.; Matsuo, Y.; Noda, T.; Nagataki, S., “Effects of the Nuclear Equation of State on Type I X-Ray Bursts: Interpretation of the X-Ray Bursts from GS 1826-24”,

The Astrophysical Journal, Volume 923, Issue 1, id.64, 16 pp. December 2021

Hajime Sotani, Tomoya Takiwaki, and Hajime Togashi, "Universal relation for supernova gravitational waves", Phys. Rev. D 104(12), 123009 (12/2021) (10 pages).

Hajime Sotani and Bharat Kumar, "Universal relations between the quasinormal modes of neutron star and tidal deformability", Phys. Rev. D 104(12), 123002 (12/2021) (7 pages).

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Hiroyuki Tajima, Yuta Sekino, and Shun Uchino, "Optical spin transport theory of spin-1/2 topological Fermi superfluids", Phys. Rev. B 105, 064508 (2022).

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Li, Wei-Jian; Xue, Rui; Long, Guang-Bo; Wang, Ze-Rui; Nagataki, Shigehiro; Yan, Da-Hai; Wang, Jian-Cheng, "Can the one-zone hadronuclear model explain the hard-TeV spectrum of BL Lac objects?", Astronomy & Astrophysics, Volume 659, id.A184, 6 pp. , March 2022

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(D) 国際会議口頭発表 (招待・基調講演)

Masaomi Ono, "Three-dimensional hydrodynamical simulations unravel the evolution of SN 1987A from the explosion to the supernova remnant", IReNA Seminar, Online, April 9 (JST)/April 8 (ET), 2021.

E. Kido, "Status and results of the TA experiment and TAx4 experiment", GCOS workshop, Online, May 2021.

Hirotaka Ito, "Numerical Simulations of Photospheric Emission in GRBs", The Sixteenth Marcel Grossmann Meeting, オンライン国際会議, 2021年7月6日

Hirotaka Ito, "The photospheric origin of Ep-Lp and Ep-Eiso correlations in GRBs", The Sixteenth Marcel Grossmann Meeting, オンライン国際会議, 2021年7月9日

Hajime Sotani, "Gravitational wave asteroseismology and universal relations", (invited) Workshop on "Probe into core-collapse SuperNovae via Gravitational-Wave and neutrino signals (SNeGWv2021)", online, 2021年12月1日-2日.

Nobuya Nishimura, "Future perspectives of r-process studies from observations and measurements", Nobuya Nishimura, JSPS/NRF/NSFC A3 Foresight Program "Nuclear Physics in the 21st Century" Joint Annual Meeting, 17-18 Feb. 2022, Online

(E) 国内会議口頭発表 (招待・基調講演)

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西村信哉, 「宇宙における元素の起源と進化: rプロセスを中心に」, 研究会「高エネルギー現象で探る宇宙の多様性I」, 東大宇宙線研, 2021年10月.

長瀧重博, "Overview of the Nucleus Subgroup", r-EMU Workshop 2021 (Online), Presentation Date: 2021/10/18.

(F) 国際会議口頭発表

Gilles Ferrand, "From the (thermonuclear) supernova to the supernova remnant", Annual general meeting of the Canadian astronomical society – CASCA (online), 10 May 2021.

E. Kido, "Status of the Telescope Array detectors", TIPP2021, Online, May 2021.

Hajime Sotani, "Gravitational wave asteroseismology on proton-neutron stars", KAGRA data analysis meeting, zoom, Jun. 16, 2021.

E. Kido on behalf of the Telescope Array Collaboration, "Current status and prospects of surface detector of the TAx4 experiment", ICRC2021, Online, Jul. 2021.

Hajime Sotani, "Stability of collapsing protoneutron stars and gravitational waves", YITP-OzGrav WS "Nuclear burning in massive stars" - towards formation of black-hole binaries-, YITP/Monash Univ./zoom, July. 26-30, 2021.

E. Kido, T. Inakura, M. Kimura, S. Nagataki, N. Shimizu and A. Tamii, "Simulations of propagation of UHECR nuclei using photonuclear reaction models", 2nd PANDORA workshop, Online, Sep. 9-10, 2021.

N. Nishimura, "Jet-induced core-collapse supernovae with the production of r-process elements", XVI symposium on "Nuclei in the Cosmos", 中国+オンライン, 2021年9月

Hajime Sotani, "Gravitational wave asteroseismology in protoneutron stars", NEB-19 Recent Developments in Gravity, Athens (Online), Sep. 20-23, 2021.

N. Nishimura, "Possible observational properties of r-process nucleosynthesis in magneto-rotational core-collapse supernovae", INT Program, シアトル (アメリカ) +オンライン, 2021年10月

(G) 国内会議口頭発表

西村 信哉, 「中性子星を考慮したバーストモデルに基づいたrpプロセスの再検討」, 研究会「中性子星の観測と理論」, オンライン, 2021年8月.

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西村 信哉, 「ジェット状超新星におけるrプロセス元素の生成と放出」, 日本天文学会秋季年会, オンライン, 2021年9月.

西村 信哉, 「超ウラン元素の核分裂とrプロセス元素合成」, 日本物理学会秋季大会, オンライン, 2021年9月.

伊藤裕貴, "Relativistic radiation mediated shocks in photon starved regime", 一般講演, 日本天文学会秋季年会, 2021年9月15日, オンライン研究会

木戸英治, 他Telescope Array Collaboration "TA 実験364: TAx4 実験全体報告9", 日本物理学会, オンライン開催, 2021年9月

木戸英治, 宇都野穰, 木村真明, 清水則孝, 民井淳, 長瀧重博, "光核反応の超高エネルギー宇宙線伝播への影響 II", 日本物理学会, オンライン開催, 2021年9月

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関野裕太, 西田祐介, 「2体および3対相互作用する1次元スピンレスフェルミ系とボース・フェルミ対応の拡張」, 日本物理学会2021年秋季大会(オンライン), 2021年9月20日

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Masaomi Ono, "Molecule formation in core-collapse supernova ejecta: The case of SN 1987A", r-EMU Workshop 2021, オンライン開催, 2021年10月19日

木戸英治, "Simulations of propagation of ultra-high energy cosmic ray nuclei using photo-nuclear reaction models", r-EMU workshop 2021, オンライン, 2021年10月

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関野裕太, 田島裕之, 内野瞬「冷却原子気体における光学スピン輸送II」日本物理学会第77回年次大会(2022年), 2022年3月15日, オンライン

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小野勝臣, "Evolution of SN 1987A based on 3D hydrodynamic simulations: properties of the NS and molecule formation in the ejecta", SNR Workshop 2022, オンライン開催, 2022年3月28日

(H) 国際会議ポスター発表

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(I) 国内会議ポスター発表

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(J) 国際セミナー発表

Gilles Ferrand, "From the thermonuclear supernova to the supernova remnant", Colloquium of the Dept. of Physics and Astronomy, U. of Manitoba (Canada), 21 April 2021.

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(K) 国内セミナー発表

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(L) アウトリーチ・研究会主催

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