

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



(0) Research field

CPR Subcommittee: 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, and yet very little are known about their explosion mechanisms. These astrophysical big bangs continue to 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 violent explosions and provide the-state-of-the-art physical interpretations for current, cutting-edge observations as well as useful predictions for future observations by the next-generation astronomical observatories. We are more than passionate to co-operate with researchers in RIKEN as well as 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 (FY2020) and plan (until Mar. 2025)

One of the most outstanding research achievements of ABBL in FY2020 is that we succeeded to perform numerical simulations on the evolution from supernovae to supernova remnants (paper [1], [2] in section 4). Currently, these theoretical studies can be done only by our group in the world. Using lots of time, we have developed a strong, international collaboration team with our collaborators in Italy, Germany, etc. Our achievement has been done thanks to these international collaborations. Thanks to our theoretical achievement, it is now possible to explore the legacy of supernova explosions in supernova remnants that are observed in detail in X-rays etc (we did it actually, and our paper has been accepted for publication in Nature in April 2021). Dr. Masaomi Ono has been contributing to these excellent achievements, and he won the RIKEN Baihou (梅峰) Prize in March 2021.

ABBL started in FY2013 at RIKEN, and has been leading the world for the sciences in SNe & GRBs. Nowadays, ABBL is one of the most famous laboratories in the world, and each paper from ABBL is highly recognized in the community of SNe & GRBs. Until the end of FY2020 (8yr from the start), 21 of researchers, special researchers, SPDR/FPR belonged to ABBL in total, and 14 people got next positions successfully. Among 14, 7 got permanent positions. About 1 ABBL member is getting a permanent position per year in average. 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 key words. ABBL has been studying SNe & GRBs that are gravitational wave sources. ABBL is going to cover NSs & BHs more. There is a tight relation between SNe/GRBs and NSs/BHs since the former is mother of the latter. As a good example, we are going to study neutron star mergers that will emit gravitational waves, forming a BH. The dynamics depends on equation-of-state (EOS) of neutron star matter. The neutron star mergers can be observed as kilo-novae that are brighten by the decays of r-process elements. Studies of neutron star mergers require huge computational resources. ABBL believes that the gravitational wave astrophysics fits very well with the sciences that RIKEN is leading.

(3) Members

as of March, 2020

PI, Chief Scientist: Shigehiro Nagataki

Researchers: Akira Mizuta (Tenured), Hirotaka Ito, Gilles Ferrand, Masaomi Ono, Eiji Kido, Hajime Sotani, Nobuya Nishimura

JRA: Yuki Takei

Secretary: Tamaki Shibasaki

(4) Representative research achievements

1. “The fully developed remnant of a neutrino-driven supernova: Evolution of ejecta structure and asymmetries in SNR Cassiopeia A”, Orlando, S.; Wongwathanarat, A.; Janka, H.-T.; Miceli, M.; Ono, M.; Nagataki, S.; Bocchino, F.; Peres, G., **Astronomy & Astrophysics** Vol. 645, A66 (32 pp.) (2021).
2. “From Supernova to Supernova Remnant: comparison of thermonuclear explosion models” Ferrand, Gilles; Warren, Donald C.; Ono, Masaomi; Nagataki, Shigehiro; Röpke, Friedrich K.; Seitenzahl, Ivo R.; Lach, Florian; Iwasaki, Hiroyoshi; Sato, Toshiki, **The Astrophysical Journal**, 906, id.93, 26 pp. (2021).
3. “The Maximum Energy of Shock-accelerated Electrons in a Microturbulent Magnetic Field”, Warren, Donald C.; Beauchemin, Catherine A. A.; Barkov, Maxim V.; Nagataki, Shigehiro, **The Astrophysical Journal** Volume 906, Issue 1, id.33, 10 pp. (2021).
4. “Monte Carlo simulations of fast Newtonian and mildly relativistic shock breakout from a stellar wind”, Hirotaka Ito; Amir Levinson; Ehud Nakar, **Monthly Notices of the Royal Astronomical Society** Volume 499, Issue 4, p.4961-4971, (2020).
5. “The X-Ray Fundamental Plane of the Platinum Sample, the Kilonovae, and the SNe Ib/c Associated with GRBs” Dainotti, M. G; Lenart, A. L.; Sarracino, G.; Nagataki, S.; Capozziello, S.; Fraija, N. **The Astrophysical Journal** Volume 904, Issue 2, id.97, 13 pp. (2020).

Supplementary



ABBL Members in FY2020 (including visiting researchers (Maxim Barkov, Yohei Kawazura, Oliver Just, Haoning He, Susumu Inoue, Noemie Globus))

Laboratory Homepage

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

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

(5) 業績データ

(A) プレスリリース等

RIKEN & KIPAC Press Release on “The longest “rulers” in the universe -- Gamma-Ray Bursts associated with Kilonovae are the new standard candles” by Maria Dainotti, Shigehiro Nagataki, et al. 19 Nov. 2020.
https://www.riken.jp/press/2020/20201119_3/index.html

Delving Back Deeper: Towards GRBs as Standard Candles | Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) (stanford.edu)

NASA & INAF Press Release on “Indication of a Pulsar Wind Nebula in the hard X-ray emission from SN 1987A” by Emanuele Greco et al. (including Shigehiro Nagataki, Masaomi Ono), 23 Feb. 2021.
https://www.nasa.gov/mission_pages/chandra/images/reclusive-neutron-star-may-have-been-found-in-famous-supernova.html

小野勝臣、「超新星1987Aにおける非対称爆発がもたらす元素合成と物質混合の研究」、2020年度理研梅峰賞、2020年3月18日

Gilles Ferrand “Supernova simulations reveal how stellar explosions shape debris clouds”RIKEN Research Highlight, 26th Mar. 2021.

(B) 授業・本

長瀧重博「巨大星の爆発と中性子星・ブラックホール」奈良女子大学 理学部共通科目 連続講義「現代科学の最前線 ー 数学・宇宙・物質・生命・情報のフロンティア ー」(Zoom)、奈良女子大学、奈良、日本、23 & 30 October 2020.

(C) 論文 (査読あり)

Orlando, S.; Ono, M.; Nagataki, S.; Miceli, M.; Umeda, H.; Ferrand, G.; Bocchino, F.; Petruk, O.; Peres, G.; Takahashi, K.; Yoshida, T. “Hydrodynamic simulations unravel the progenitor-supernova-remnant connection in SN1987A” *Astronomy & Astrophysics* Vol. 636, A22 (19 pp.) 2020/4/8.

Sato, Toshiki; Yoshida, Takashi; Umeda, Hideyuki; Nagataki, Shigehiro; Ono, Masaomi; Maeda, Keiichi; Hirai, Ryosuke; Hughes, John P.; Williams, Brian J.; Maeda, Yoshitomo “A Subsolar Metallicity Progenitor for Cassiopeia A, the Remnant of a Type IIb Supernova” *The Astrophysical Journal* Vol. 893, 49 (9 pp.) 2020/4/10.

Sotani, H; Takiwaki, T. “Dimension dependence of numerical simulations on gravitational waves from protoneutron stars” *Physical Review D* Vol.102, No.2, P.023028, 2020/7/22.

Telescope Array Collaboration (including Hirotaka Ito, Eiji Kido, Shigehiro Nagataki, Masaomi Ono) “Search

for Large-scale Anisotropy on Arrival Directions of Ultra-high-energy Cosmic Rays Observed with the Telescope Array Experiment” *Astrophysical Journal Letters*, Vol 898, L28, 2020/07/27.

Yuki Takei, Toshikazu Shigeyama “A numerical light curve model for interaction-powered supernovae” *Publications of the Astronomical Society of Japan*, Vol. 72, No. 4, pp. 67-76, 2021/8.

Sotani, H.; Takiwaki, T. “Avoided crossing in gravitational wave spectra from protoneutron star” *Monthly Notices of the Royal Astronomical Society*, Vol.498, No.3, P.3503, 2020/8/27.

Sarira Sahu; López Fortín, Carlos E.; Nagataki, Shigehiro “Photohadronic Model for the Neutrino and Gamma-Ray Emission from TXS 0506+056” *The Astrophysical Journal* Volume 898, Issue 2, id.103, August 2020

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Telescope Array Collaboration (including Hirotaka Ito, Eiji Kido, Shigehiro Nagataki, Masaomi Ono) “Measurement of the proton-air cross section with Telescope Array’s Black Rock Mesa and Long Ridge fluorescence detectors, and surface array in hybrid mode” *Physical Review D*, Vol 102, 062004, 2020/09/15.

Telescope Array Collaboration (including Hirotaka Ito, Eiji Kido, Shigehiro Nagataki, Masaomi Ono) “Search for Ultra-High-Energy Neutrinos with the Telescope Array Surface Detector” *Journal of Experimental and Theoretical Physics* Vol 131, Page 255-264, 2020/09/22.

Sotani, H. “Gravitational wave asteroseismology for low-mass neutron stars” *Physical Review D* Vol.102, No.6, P.063023, 2020/9/24.

Sotani, H.; Takiwaki, T. “Accuracy of the relativistic Cowling approximation in protoneutron star asteroseismology” *Physical Review D*, Vol.102, No.6, P.063025, 2020/9/25.

Tutone, Antonio; Orlando, Salvatore; Miceli, Marco; Ustamujic, Sabina; Ono, Masaomi; Nagataki, Shigehiro; Ferrand, Gilles; Greco, Emanuele; Peres, Giovanni; Warren, Donald C.; Bocchino, Fabrizio “3D modeling from the onset of the SN to the full-fledged SNR. Role of an initial ejecta anisotropy on matter mixing”, *Astronomy & Astrophysics* 642, id.A67, 15 pp. October 2020.

Sarira Sahu; López Fortín, Carlos E.; Castañeda Hernández, Luis H.; Nagataki, Shigehiro; Rajpoot, Subhash “A Two-zone Photohadronic Scenario for EHBL-like Behavior of Mrk 501” *The Astrophysical Journal* Volume 901, Issue 2, id.132, 7 pp. October 2020.

Srinivasaragavan, G. P.; Dainotti, M. G.; Fraija, N.; Hernandez, X.; Nagataki, S.; Lenart, A.; Bowden, L.; Wagner, R. “On the Investigation of the Closure Relations for Gamma-Ray Bursts Observed by Swift in the Post-plateau Phase and the GRB Fundamental Plane” *The Astrophysical Journal* Volume 903, Issue 1, id.18, 15 pp. November 2020.

Sotani, H. “Estimating the nuclear saturation parameter via low-mass neutron star asteroseismology” *Physical Review D*, Vol.102, No.10, P.103021, 2020/11/18.

Hirota Ito; Amir Levinson; Ehud Nakar “Monte Carlo simulations of fast Newtonian and mildly relativistic shock breakout from a stellar wind” *Monthly Notices of the Royal Astronomical Society* Volume 499, Issue 4, p.4961-4971, December 2020.

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Orlando, S.; Wongwathanarat, A.; Janka, H.-T.; Miceli, M.; Ono, M.; Nagataki, S.; Bocchino, F.; Peres, G. “The fully developed remnant of a neutrino-driven supernova: Evolution of ejecta structure and asymmetries in SNR Cassiopeia A” *Astronomy & Astrophysics* Vol. 645, A66 (32 pp.) 2021/1/14.

Ferrand, Gilles; Warren, Donald C.; Ono, Masaomi; Nagataki, Shigehiro; Röpke, Friedrich K.; Seitzzahl, Ivo R.; Lach, Florian; Iwasaki, Hiroyoshi; Sato, Toshiki “From Supernova to Supernova Remnant: comparison of thermonuclear explosion models” *The Astrophysical Journal*, 906, id.93, 26 pp. January 2021.

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Morokuma, Tomoki (37 authors including Shigehiro Nagataki) “Follow-up observations for IceCube-170922A: Detection of rapid near-infrared variability and intensive monitoring of TXS 0506+056” *Publications of the Astronomical Society of Japan* Volume 73, Issue 1, pp.25-43, February 2021.

The Cherenkov Telescope Array (CTA) Consortium (including Gilles Ferrand, Shigehiro Nagataki) “Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation” *Journal of Cosmology and Astroparticle Physics*, Issue 02, article id. 048 February 2021.

(D) 国内会議口頭発表 (招待・基調講演) 木戸英治「TA実験の最新結果」CRCタウンミーティング (オンライン会議)、2020/9/18.

長瀧重博「UHECRs from Nuclear & Astro Physical Points of Views」JEM-EUSO-Japan 会合 (Zoom), Tokyo, Japan, 06 October 2020.

小野勝臣「重力崩壊型超新星爆発と超新星爆発-超新星残骸進化における元素合成から分子形成まで」第3回 理研-九大ワークショップ ～数理で繋ぐマイクロとマクロ: 素粒子・原子核・宇宙～ (オンライン開催) 2020/12/21.

(E) 国際会議口頭発表 Akira Mizuta “Astrophysical plasma jet” Workshop on Laboratory Astrophysics: Novel Development in Nonlinear Plasma Physics with Lasers, Osaka Univ. (online), Osaka, Japan, 2020/Sep/02.

Hajime Sotani “Gravitational waves from supernova and protoneutron star asteroseismology” 7th KAGRA International Workshop, National Central University, Taiwan (online), 2020年12月19日

(F) 国内会議口頭発表 武井勇樹「A two-temperature radiative transfer simulation for interaction-powered supernovae」Planet2/RESCEU Summer School, 東京大学 (オンライン開催) 2020/8/18.

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年会（オンライン開催）2020/9/8.

木戸英治「TA実験340：TAx4実験全体報告7」日本物理学会2020年秋季大会（オンライン開催）2020/9/14.

祖谷元「原始中性子星からの重力波振動数における擬交差と固有振動の振る舞い」日本物理学会2020年秋季大会（オンライン開催）2020/9/14.

木戸英治「超高エネルギー宇宙線の伝搬と光核反応」日本物理学会2020年秋季大会（オンライン開催）2020/9/17

西村信哉「超新星rプロセス残骸？」初代星初代銀河研究会2020（オンライン開催）、東北大学、日本、2020/11/16.

伊藤裕貴「相対論的輻射媒介衝撃波の第一原理計算」高エネルギー宇宙物理学研究会2020、東京大学宇宙線研究所（オンライン）、2020年12月17日

木戸英治「光核反応の超高エネルギー宇宙線伝播への影響」日本物理学会第76回年次大会（オンライン）、2021/3/12.

祖谷元「低質量中性子星震学を用いた原子核飽和パラメータの推定」日本物理学会第76回年次大会（オンライン）、2021/3/15.

伊藤裕貴「ショートガンマ線バーストジェットからの光球面放射の輻射輸送計算」日本天文学会春季年会（オンライン）、2021年3月17日

西村信哉「中性子過剰ウラン同位体の核分裂がrプロセス元素合成に与える影響」日本天文学会春季年会（オンライン）、2021年3月18日

水田晃「ブラックホール降着流シミュレーションのためのGRMHDコードの開発」ブラックホール磁気圏研究会2021、名古屋大学（オンライン）2021年3月26日

(G) 国内セミナー発表

Shigehiro Nagataki “Why Massive Stars Explode?” OIST seminar (Zoom), OIST, OKINAWA, Japan (zoom), 30 July 2020.

Shigehiro Nagataki “Introduction to The Nobel Prize in Physics 2020” iTHEMS Seminar (Zoom), Saitama, Japan, 09 October 2020.

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(H) 国際会議ポスター発表

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Ferrand Gilles, Warren, Donald, Nagataki, Shigehiro “Engaging the public with supernova and supernova remnant research using virtual reality” CASCA 2020 Annual General Meeting, York Univ. Canada (online), 2020/05/25.

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(I) 国内会議ポスター発表

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小野勝臣「3次元流体計算に基づく超新星1987Aの超新星爆発から超新星残骸までの進化と分子形成」第33回理論懇シンポジウム（オンライン研究会）、2020年12月23-25日

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(J) アウトリーチ

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速ジェットが噴き出す？」 JSOL seminar (Zoom),
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