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研究課題名（英文）Time-resolved diagnostics of relativistic plasma singularities

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研究成果の概要（和文）：レーザー駆動による相対論的プラズマ特異点からのX線放射（我々が発見したBISER現象）である、空間的・時間的にコヒーレントで高輝度なアト秒keV X線源（光子数 >1e12）を開発中である [基課題：基盤(A)19H00669]。以前は、時間積分されたX線放射によってのみ特異点の情報を得ていた。特異点を時間分解で可視化することで、線源の輝度と安定性を高め、基課題を後押しすることを提案し、追加圧縮パルスによる光プローブとフェムト秒ゲートイメージングを開発した。これらの先進的な診断法は、すでに英国での実験でBISERの100倍以上の輝度増加につながり、R5年度の基課題実験でも使用される予定である。

研究成果の学術的意義や社会的意義
Unlike too-long-pulse XFEL or too-weak@keV atomic harmonics, our new x-ray source can image nanostructures and macromolecules before electrons escape. This will enable revolutionary Attosecond Lensless Quantum Imaging, show true molecule structure, and may clarify a debatable quantum nature of life.

研究成果の概要（英文）：We are developing a spatially and temporally coherent bright attosecond keV x-ray source (>1e12 photons, ~1e-17 s) [Root Project: Kiban(A)19H00669], where laser-driven relativistic plasma singularities emit x-rays (Burst Intensification by Singularity Emitting Radiation, BISER phenomenon discovered by us [Pirozhkov, Esirkepov, et al., Sci. Rep. 7, 17968 (2017)]). Earlier, we deduced singularities only by their time-integrated x-ray emission. We proposed to boost our Root Project by direct time-resolved visualization of singularities necessary to increase the photon number and source stability.

We developed two diagnostics: (1) optical probing with probe pulse post compression and (2) femtosecond-Kerr-gated imaging. The advanced diagnostics already led to >100x BISER brightness increase in our experiment in the UK. These diagnostics will be used for singularity visualization simultaneously with measuring coherent BISER x-rays in the FY2023 Root Project experiment.

研究分野：Physics

キーワード：Plasma singularities　Coherent x-ray source　BISER　Relativistic plasma　New imaging paradigm

１．研究開始当初の背景 Background at the beginning of the study

We were developing a *spatially* and *temporally* coherent bright attosecond keV x-ray source (>10^{12} photons, 10 attosecond pulse) [Root Project: Kakenhi Kiban (A) 19H00669], where laser-driven *relativistic plasma singularities* emit x-rays (Burst Intensification by Singularity Emitting Radiation (BISER) phenomenon discovered by us [Pirozhkov, Esirkepov, *et al*., *Sci. Rep*. **7**, 17968 (2017)]). Unlike too-long-pulse X-ray Free Electron Lasers (XFELs) and too-weak-at-keV atomic harmonics, our new source can image nanostructures and macromolecules before *electrons* escape from atoms. This enables revolutionary Attosecond Lensless Quantum Imaging which may elucidate a debatable quantum nature of life [Al-Khalili, McFadden, "Life on the Edge" (2014)]. By the beginning of this Project, we deduced singularities only by their *time-integrated x-ray emission*.

２．研究の目的 Purpose of the study

We proposed to boost our Root Project by direct *time-resolved* visualization of singularities with (1) a few-femtosecond optical probe and (2) femtosecond-Kerr-gated imaging, performed simultaneously with measuring coherent BISER x-rays. This would bring insight into the challenging problems of increasing the photon number and enhancing the stability, which are necessary for practical x-ray source.

３．研究の方法 Research methods

Burst Intensification by Singularity Emitting Radiation (BISER)

BISER is an ultrabright, *spatially* and *temporally* coherent attosecond x-ray source. The x-rays are emitted by multistream plasma flow singularities driven by multi-TW femtosecond laser propagating through underdense plasma. These bright x-rays were discovered [Pirozhkov *et al*., *PRL* **108**, 135004 (2012)], Fig. 1, and the BISER mechanism was validated [Pirozhkov, Esirkepov, *et al*., *Sci. Rep*. **7**, 17968 (2017)]], Fig. 2, by us.

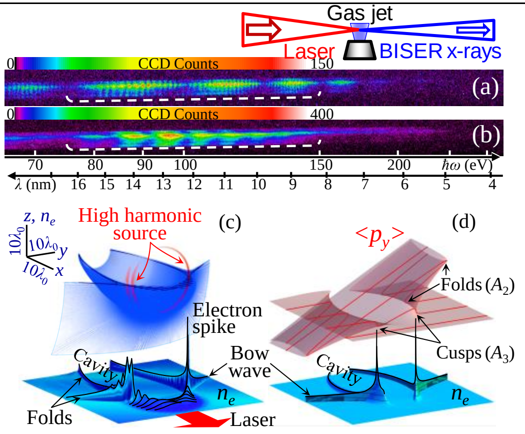


Fig. 1. **Discovery of singularity-based bright coherent x-ray source [Pirozhkov *et al*., *PRL* 108, 135004 (2012)].** Top: experimental setup. (a,b) Representative experimental spectra. (c,d) 3D PIC simulation and catastrophe-theory-based model.

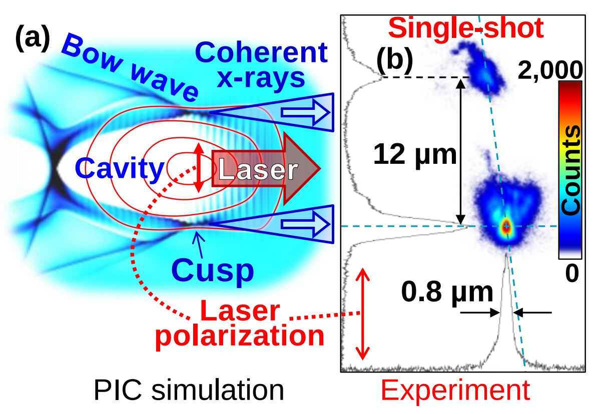


Fig. 2. **BISER mechanism validation [Pirozhkov, Esirkepov, *et al*., *Sci. Rep*. 7, 17968 (2017)].** (a) PIC simulation showing double x-ray source driven by a linearly polarized laser pulse. (b) Single-shot image of the BISER source in the 60-100 eV spectral range (experiment).

(1) A few-femtosecond optical probing of relativistic plasma singularities

We proposed to visualize plasma singularities by an ultrafast (femtosecond) transverse optical probe. Plasma optical probing is often employed in experiments [Sävert *et al*., *PRL* **115**, 055002 (2015)], however, the relativistic singularities emitting bright x-rays have not been studied by this method till now.

(2) Femtosecond-Kerr-gated imaging

We also proposed to visualize plasma singularities using time-gated imaging [Symes *et al*., *APL* **96**, 011109 (2010)] of their self-emission, the technique is somewhat similar to Polarization-Gated Frequency-Resolved Optical Gating (PG FROG). In contrast to PG FROG, where the spectrum is polarization-gated, in Kerr-gated imaging the image itself is polarization-gated, which provides femtosecond "shutter speed".

The main challenges for all singularity visualization methods are:

- (i) the nano-scale size of the singularities,
- (ii) their micro-scale separation (typically ~ 5 µm), and
- (iii) their relativistic speed.

Thus, both of the proposed methods required significant modifications and improvements.

４．研究成果 Research results

COVID-19 made a significant impact on the Project. All international experiments were delayed and some even cancelled; the Team Leader of our Counterpart Research Institution, Professor David Neely sadly passed away in 2020, which was a hard blow to the entire international research community. Nevertheless, we achieved significant research results.

Simulations of optical probing of singularities. The optical probing cannot resolve a few-nm singularities size. However, very important information, necessary for the x-ray source development, includes positions of the singularities in the mm-scale plasma, and their geometry – that is, relative positions and distances. These properties can be extracted by optical probing provided that the spatial resolution *and* motion blur are both smaller than inter-singularity separations, i.e. typically ~5 μm. The spatial resolution of ~1 μm is possible with a good microscope objective; however, the 5 μm motion blur requires optical probe duration of shorter than (5 μm/c) ≈ 17 fs; here c is the speed of light. Ideally, the probe should have duration of ~10 fs or shorter. We developed the theory and performed Particle-In-Cell (PIC) simulations of optical probing of relativistic plasma singularities and published these results in [1], Fig. 3.

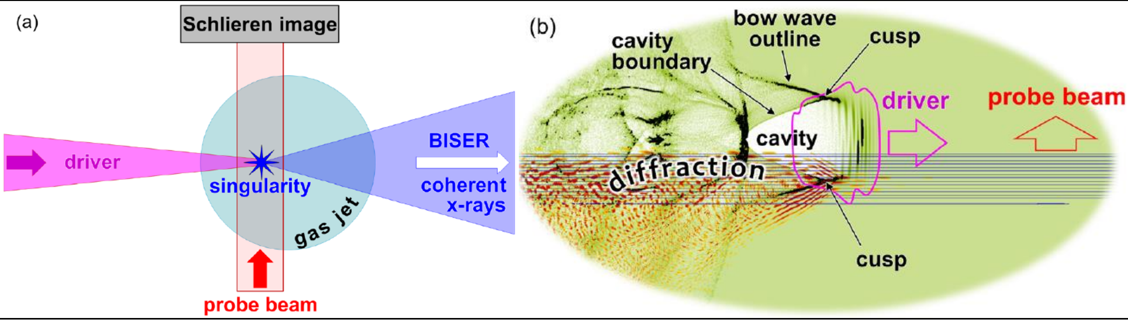


Fig. 3. **Optical probing of relativistic plasma singularities [1].** (a) Schematic. (b) PIC simulation.

Optical probing of singularities: practical considerations. After that, we considered practical implementation of the proposed scheme. In experiments we are using lasers with ~50 fs typical durations. Thus, a part of the laser pulse used for optical probing must be shortened several times. A method suitable for large-scale (100 TW and above) facilities and short experimental campaigns is Compression after Compressor Approach, CafCA [Khazanov, Mironov, and Mourou, *Phys.-Usp*. **62**, 1096 (2019)]. Unlike typically used fiber post-compression, in CafCA the nonlinear spectral broadening (Self-Phase Modulation, SPM) is achieved in thin glass plates, and the entire setup can be implemented in vacuum. After SPM, the broadband pulse is compressed with chirped (negative-dispersion) mirrors, similar to the fiber post-compression. We simulated the pulses compressed with CafCA, starting from the experimental SPM spectra obtained in our experiment with the J-KAREN-P laser; it turned out that even best-compressed pulses exhibit satellite pre- and post-pulses. To check how this affects probing of singularities, we performed PIC simulations using realistic probe pulses. We showed that for expected CafCA-compressed probe pulses, the probing of singularities is possible. We published these findings in [6], Fig. 4, Fig. 5.

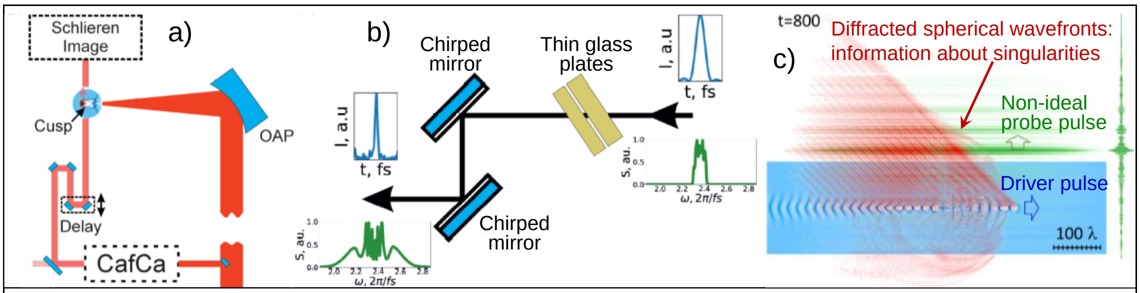


Fig. 4. **Optical probing of relativistic plasma singularities, practical considerations [6].** (a) Setup. (b) CafCA pulse compression stage schematic. (c) PIC simulation with realistic probe pulse containing satellite pre- and post-pulses.

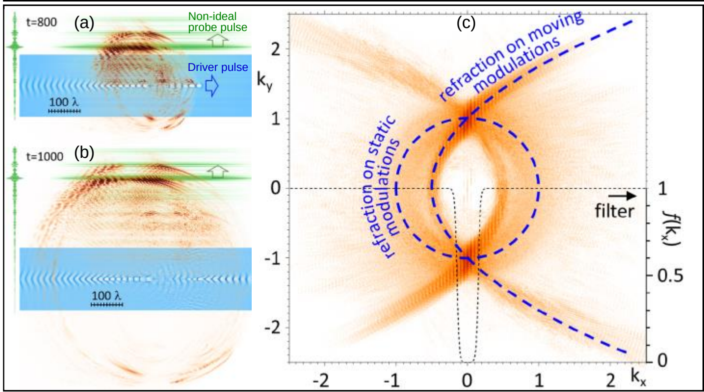


Fig. 5. **Optical probing of relativistic plasma singularities, practical considerations [6].** (a,b) PIC simulations: the spherical wavefronts (information about singularities) after filtering representing model of the Schlieren method. (c) Spatial Fourier transform of the probe field in PIC simulation. The black dotted line shows the Schlieren filter $f(k_x)$. The blue dashed lines show refraction on static modulations (circle) and relativistic singularities (ellipse).

Time-resolved imaging of singularities. We designed a Kerr-gate imaging setup with ~µm optical resolution, all-reflective microscope objective to preserve high temporal resolution, and 50 fs gate pulse. For higher optical resolution and higher rejection ratio of the gate beam, we selected imaging of singularities self-emission at 400 nm, while keeping the gate beam at original laser wavelength of 800 nm, Fig. 6.

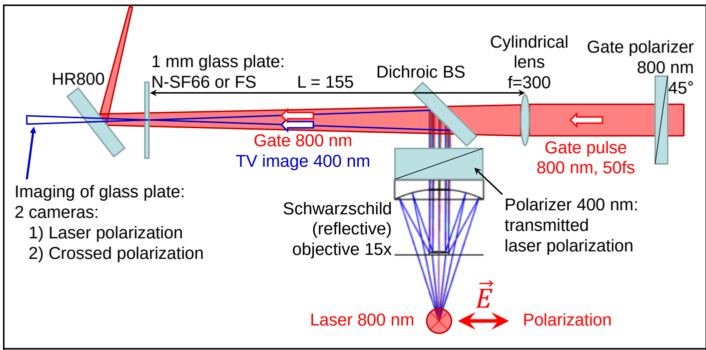


Fig. 6. **Kerr-gate Top View imaging setup**.

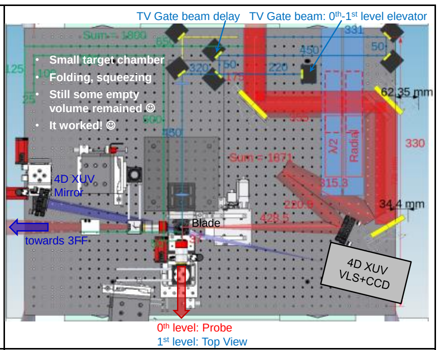


Fig. 7. **Astra experiment schematic.**

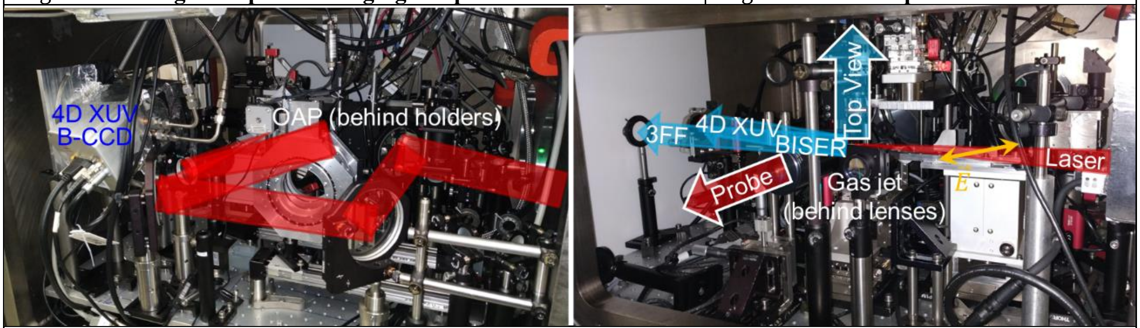
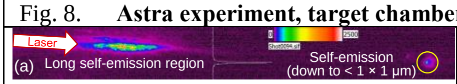


Fig. 8. **Astra experiment, target chamber photos**.



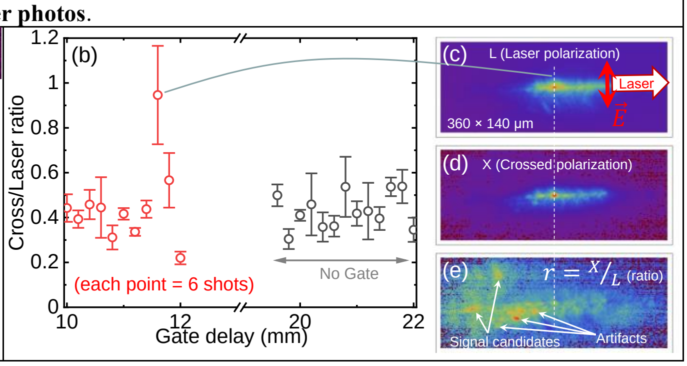


Fig. 9. **Top View (TV) image and gate delay scan in the Astra experiment.** (a) Representative TV image example. (b) Ratio of cross-polarized to laser-polarized intensities vs. gate delay. (c) Laser polarized and (d) cross-polarized images in the same shot, and (e) their ratio. The white arrows in (e) show identified artifacts and gated signal candidates.

Astra experiment (UK). The first joint international experiment was performed with the Astra laser in CLF RAL, UK (0.35 J, 50 fs, 7 TW). Due to the high quality of our science case and complexity of diagnostics, we were given 13 weeks of the beam time. That allowed to implement the complex setup, including few-µm-resolution optical probe, Kerr-gated Top View (TV) imaging, 3-channel on-axis spectrograph 3FF (17-34 nm), and 4D off-axis XUV spectrograph (12.4-20 nm), for simultaneous diagnostics of BISER x-rays and singularities, Fig. 7, Fig. 8. Due to the COVID-19 restrictions before and at the beginning of the experiment, the probe pulse was not shortened to 10 fs (50 fs was used).

The Kerr-gated Top View achieved ~1 µm resolution, Fig. 9a. The gate timing was scanned and the signal candidates found, Fig. 9b-e. However, the noise level was quite high, and several artifacts in the gated images were identified (caused by secondary reflections, crossed polarizers leakage, and different band-pass filters in the two channels). The analysis is now on-going to clarify the origin of all signal candidates.

We implemented for the first time a 4D XUV spectrograph based on aperiodic broadband multilayer mirror (our design based on [Pirozhkov and Ragozin, *Phys. – Usp.* **58**, 1095 (2015)]) and large-gradient Varied Line Space (VLS) grating (our design based on [Koike *et al.*, *JESRP* **101–103**, 913 (1999)]). The spectrograph provided a spatially-resolved spectrum (spatial resolution up to 8 µm, spectral resolving power up to 300) in its 1st spectral order *and* 2D angular distribution in its 0th order. Important data on BISER source properties were obtained with this new instrument. A paper with the results is now in preparation.

Taking advantage of our advanced diagnostics, we managed to increase the BISER brightness ~100 times compared to the earlier experiments with similar laser powers (~10-20 TW). This significant result is now in preparation for publication; it was reported at 2023 Annual Meetings of JPS and JSAP, and at OPIC-2023 and (invited talk) at SPIE OOE-2023 International Conferences.

J-KAREN-P experiment (Japan). The second joint international experiment was performed with the J-KAREN-P laser [Pirozhkov *et al.*, *Opt. Express* **25**, 20486 (2017); Kiriyama *et al.*, *HPLSE* **9**, e62 (2021)] in KPSI QST, Japan. We implemented a compact in-vacuum CafCA setup for probe compression, Fig.10ab, and within a short experimental campaign managed to compress the probe from 50 down to minimum of 18 fs, which amounts to ~5.4 μm motion blur, Fig.10cd. The results are submitted to *Optics Express* [10]. Modification of this setup with 10 fs probe capability will be used in the next experimental campaign of our Root Project in FY2023.

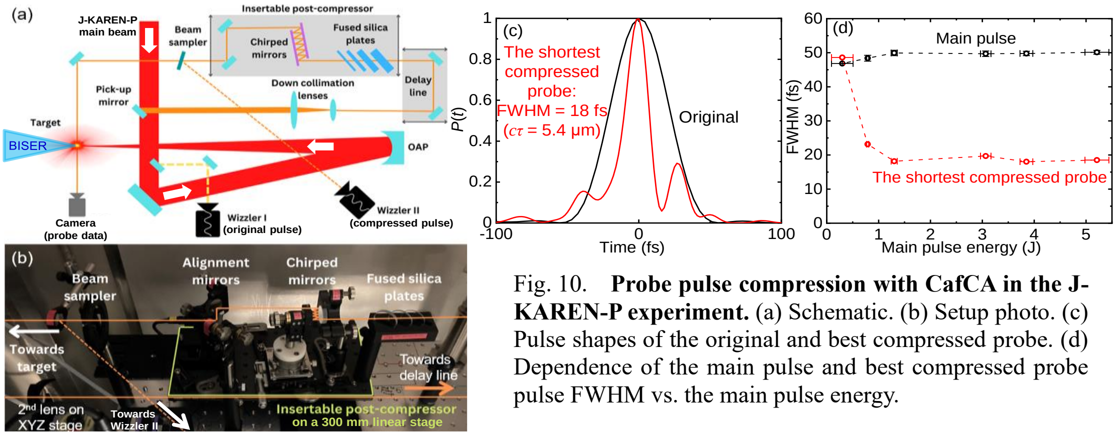


Fig. 10. **Probe pulse compression with CafCA in the J-KAREN-P experiment.** (a) Schematic. (b) Setup photo. (c) Pulse shapes of the original and best compressed probe. (d) Dependence of the main pulse and best compressed probe pulse FWHM vs. the main pulse energy.

Additional research results. In addition to the results and achievements which were planned, our international team actively performed broad-scope research on relativistic plasma, singularities, and their bright x-ray emission. We showed by PIC simulations that singularities emitting BISER can efficiently reflect a counter-propagating pulse, generating laser harmonics with Doppler-boosted frequency [2]. We performed fundamental research on relativistic flying mirror singularities, including simulations of their reflection [5], prospects for ultra-high-field science [7], and Analog Black Hole Evaporation via Lasers [8]. We developed x-ray instruments for relativistic plasma diagnostics, including broadband Mo/Be normal-incidence multilayer mirrors [3] and hard x-ray linear absorption spectrometer and its data deconvolution method [4]. We demonstrated experimentally several methods of precise on-target ultra-relativistic intensity maximization (submitted to *Optics Express*, preprint [9]). Finally, our research on singularities allowed us to discover a new phenomenon, *alloharmonics* (submitted to *Nature Physics*, preprint [11]).

Selected papers containing results of this Project (chronological order):

1. T. Zh. Esirkepov<他 7 人>D. Neely<他 2 人>A.S. Pirozhkov, "Optical probing of relativistic plasma singularities," *Physics of Plasmas* **27**, 052103 (2020) DOI: 10.1063/5.0004525.
2. J. Mu<他 4 人>A. S. Pirozhkov<他 4 人>"Relativistic flying forcibly oscillating reflective diffraction grating," *Physical Review E* **102** (5), 053202 (2020). DOI: 10.1103/PhysRevE.102.053202.
3. M. M. Barysheva<他 2 人>A. S. Pirozhkov<他 6 人>"Broadband normal-incidence mirrors for a range of 111-138 Å based on an a-periodic Mo/Be multilayer structure," *Optical Materials Express* **11**, 3038 (2021). DOI: 10.1364/OME.434506.
4. C. D. Armstrong, D. Neely, D. Kumar, P. McKenna, R. J. Gray, and A. S. Pirozhkov, "Deconvolution of multi-Boltzmann x-ray distribution from linear absorption spectrometer via analytical parameter reduction," *Review of Scientific Instruments* **92**, 113102 (2021). DOI: 10.1063/5.0057486.
5. T. M. Jeong<他 5 人>A. S. Pirozhkov<他 2 人>"Relativistic flying laser focus by a laser-produced parabolic plasma mirror," *Physical Review A* **104**, 053533 (2021). DOI: 10.1103/PhysRevA.104.053533.
6. A. V. Kotov<他 10 人>A. S. Pirozhkov, "Enhanced diagnostics of radiating relativistic singularities and BISER by nonlinear post-compression of optical probe pulse," *Journal of Instrumentation* **17**, P07035 (26-Jul 2022). DOI: 10.1088/1748-0221/17/07/p07035.
7. M. Kando, A. S. Pirozhkov, J. K. Koga, T. Zh. Esirkepov, S. V. Bulanov, "Prospects of relativistic flying mirrors for ultra-high-field science," *Photonics* **9**, 862 (2022). DOI: 10.3390/photonics9110862.
8. P. Chen<他 12 人>A. Pirozhkov<他 6 人>"AnaBHEL (Analog Black Hole Evaporation via Lasers) Experiment: Concept, Design, and Status," *Photonics* **9**, 1003 (2022). DOI: 10.3390/photonics9121003.
9. E. Vishnyakov<他 39 人>A. Pirozhkov, "Diagnostics for precise target positioning in ~10^{22} W/cm^2 laser-plasma experiments," submitted to *Opt. Express* (preprint *Optica Open* 107143). DOI: 10.1364/opticaopen.23310221.
10. S. Lorenz<他 18 人>A. Pirozhkov, "In-vacuum post-compression of low-fluence femtosecond probe laser pulses," submitted to *Opt. Express*.
11. M. S. Pirozhkova<他 18 人>D. Neely, and A. S. Pirozhkov, "High-order alloharmonics produced by nonperiodic drivers," submitted to *Nature Physics* (*arXiv*:2306.01018).

５．主な発表論文等

〔雑誌論文〕　計8件（うち査読付論文　7件／うち国際共著　8件／うちオープンアクセス　6件）

１．著者名 C. D. Armstrong; D. Neely; D. Kumar; P. McKenna; R. J. Gray; and A. S. Pirozhkov	４．巻 92
２．論文標題 Deconvolution of multi-Boltzmann x-ray distribution from linear absorption spectrometer via analytical parameter reduction	５．発行年 2021年
３．雑誌名 Review of Scientific Instruments	６．最初と最後の頁 113102
掲載論文のDOI（デジタルオブジェクト識別子） 10.1063/5.0057486	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 M. M. Barysheva; S. A. Garakhin; A. O. Kolesnikov; A. S. Pirozhkov; V. N. Polkovnikov; E. N. Ragozin; A. N. Shatokhin; R. M. Smertin; M. V. Svechnikov; and E. A. Vishnyakov	４．巻 11
２．論文標題 Broadband normal-incidence mirrors for a range of 111-138 A based on an a-periodic Mo/Be multilayer structure	５．発行年 2021年
３．雑誌名 Optical Materials Express	６．最初と最後の頁 3038
掲載論文のDOI（デジタルオブジェクト識別子） 10.1364/OME.434506	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Tae Moon Jeong; Sergei V. Bulanov; Petr Valenta; Georg Korn; Timur Zh Esirkepov; James K. Koga; Alexander S. Pirozhkov; Masaki Kando; and Stepan S. Bulanov	４．巻 104
２．論文標題 Relativistic flying laser focus by a laser-produced parabolic plasma mirror	５．発行年 2021年
３．雑誌名 Physical Review A	６．最初と最後の頁 053533-16
掲載論文のDOI（デジタルオブジェクト識別子） 10.1103/PhysRevA.104.053533	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Esirkepov Timur Zh.、Mu Jie、Gu Yanjun、Jeong Tae Moon、Valenta Petr、Klimo Ondrej、Koga James K.、Kando Masaki、Neely David、Korn Georg、Bulanov Sergei V.、Pirozhkov Alexander S.	４．巻 27
２．論文標題 Optical probing of relativistic plasma singularities	５．発行年 2020年
３．雑誌名 Physics of Plasmas	６．最初と最後の頁 052103-9
掲載論文のDOI（デジタルオブジェクト識別子） 10.1063/5.0004525	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

1．著者名	4．巻
Chen Pisin、Mourou Gerard、Besancon Marc、Fukuda Yuji、Glicenstein Jean-Francois、Nam Jiwoo、Lin Ching-En、Lin Kuan-Nan、Liu Shu-Xiao、Liu Yung-Kun、Kando Masaki、Kondo Kotaro、Paganis Stathes、Pirozhkov Alexander、Takabe Hideaki、Tuchming Boris、Wang Wei-Po、Watamura Naoki、Wheeler Jonathan、Wu Hsin-Yeh	9
2．論文標題	5．発行年
AnaBHEL (Analog Black Hole Evaporation via Lasers) Experiment: Concept, Design, and Status	2022年
3．雑誌名	6．最初と最後の頁
Photonics	1003
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.3390/photonics9121003	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名	4．巻
Kando Masaki、Pirozhkov Alexander S.、Koga James K.、Esirkepov Timur Zh.、Bulanov Sergei V.	9
2．論文標題	5．発行年
Prospects of Relativistic Flying Mirrors for Ultra-High-Field Science	2022年
3．雑誌名	6．最初と最後の頁
Photonics	862
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.3390/photonics9110862	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名	4．巻
Kotov A.V.、Esirkepov T.Zh.、Soloviev A.A.、Sagisaka A.、Ogura K.、Bierwage A.、Kando M.、Kiriyama H.、Starodubtsev M.V.、Khazanov E.A.、Mironov S.Yu.、Pirozhkov A.S.	17
2．論文標題	5．発行年
Enhanced diagnostics of radiating relativistic singularities and BISER by nonlinear post-compression of optical probe pulse	2022年
3．雑誌名	6．最初と最後の頁
Journal of Instrumentation	P07035
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.1088/1748-0221/17/07/p07035	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名	4．巻
Vishnyakov,Sagisaka,Ogura,Pikuz,Armstrong,Pikuz,Gonzalez-Izquierdo,Esirkepov,Yan,Jeong,Singh,Hadjisolomou,Finke,Grittani,Nevrkla,Lazzarini,Velyhan,Hayakawa,Fukuda,Koga,Ishino,Kondo,Miyasaka,Kon,Nishikino,Nosach,Khikhlukha,Tsygvintsev,Kumar,Nejdl,Margarone,Sasorov,Kando,Kiriyama,Korn,Kondo,Bulanov,Kawachi,Pirozhkov	12582
2．論文標題	5．発行年
Instruments for best target position determination in the high-intensity laser-solid interaction experiment	2023年
3．雑誌名	6．最初と最後の頁
Proc. SPIE	125820E
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.1117/12.2665527	無
オープンアクセス	国際共著
オープンアクセスではない、又はオープンアクセスが困難	該当する

〔学会発表〕　計12件（うち招待講演　3件／うち国際学会　8件）

1．発表者名 A.S.Pirozhkov; A.Sagisaka; K.Ogura; T.Zh.Esirkepov; B.Gonzalez Izquierdo; A.N.Shatokhin; E.A.Vishnyakov; C.Armstrong; T.A.Pikuz; M.A.Alkhimova; S.A.Pikuz; W.Yan; T.M.Jeong; S.Singh; P.Hadjisolomou; O.Finke; G.Grittani; M.Nevrkla; C.Lazzarini; A.Velyhan; T.Hayakawa; Y.Fukuda; J.K.Koga; M.Ishino; Ko.Kondo; et al.
2．発表標題 Multiple diagnostics in laser-plasma experiment at ~10^22 W/cm^2
3．学会等名 The Optics & Photonics International Congress 2021 - International Conference on High-Energy Density Sciences 2021（国際学会）
4．発表年 2021年

1．発表者名 A.S.Pirozhkov; A.Sagisaka; K.Ogura; T.Zh.Esirkepov; B.Gonzalez Izquierdo; A.N.Shatokhin; E.A.Vishnyakov; C.Armstrong; T.A.Pikuz; M.A.Alkhimova; S.A.Pikuz; W.Yan; T.M.Jeong; S.Singh; P.Hadjisolomou; O.Finke; G.Grittani; M.Nevrkla; C.Lazzarini; A.Velyhan; T.Hayakawa; Y.Fukuda; J.K.Koga; M.Ishino; Ko.Kondo; et al.
2．発表標題 Generation of hard x-rays at intensities approaching ~10^22 W/cm^2
3．学会等名 3rd International Conference on Nuclear Photonics 2020 (NP2020)（国際学会）
4．発表年 2021年

1．発表者名 A.S.Pirozhkov; A.Sagisaka; K.Ogura; T.Zh.Esirkepov; B.Gonzalez Izquierdo; A.N.Shatokhin; E.A.Vishnyakov; C.Armstrong; T.A.Pikuz; M.A.Alkhimova; S.A.Pikuz; W.Yan; T.M.Jeong; S.Singh; P.Hadjisolomou; O.Finke; G.Grittani; M.Nevrkla; C.Lazzarini; A.Velyhan; T.Hayakawa; Y.Fukuda; J.K.Koga; M.Ishino; Ko.Kondo; et al.
2．発表標題 Overview of the 10^22 Experiment with the J-KAREN-P laser
3．学会等名 OPTO-2021 Symposium on Photon and Beam Science
4．発表年 2021年

1．発表者名 A.S.Pirozhkov; A.Sagisaka; K.Ogura; T.Zh.Esirkepov; B.Gonzalez Izquierdo; A.N.Shatokhin; E.A.Vishnyakov; C.Armstrong; T.A.Pikuz; M.A.Alkhimova; S.A.Pikuz; W.Yan; T.M.Jeong; S.Singh; P.Hadjisolomou; O.Finke; G.Grittani; M.Nevrkla; C.Lazzarini; A.Velyhan; T.Hayakawa; Y.Fukuda; J.K.Koga; M.Ishino; Ko.Kondo; et al.
2．発表標題 Experiment towards the Gamma Flare regime
3．学会等名 The 5th Asia-Pacific Conference on Plasma Physics (AAPPS-DPP)（招待講演）（国際学会）
4．発表年 2021年

１．発表者名
Alexey Shatokhin; Alexander Kotov; Tae Moon Jeong; Gabriele Maria Grittani; Thomas Dzelzainis; Gregory Hull; Stephen Dann; Akito Sagisaka; Eugene Vishnyakov; Alexey Kolesnikov; Timur Esirkepov; Masaki Kando; Alexander Soloviev; Eugene Ragozin; Dan Symes; David Neely ; and Alexander Pirozhkov

２．発表標題
2021 Astra BISER experiment highlights

３．学会等名
Christmas High Power Laser Science Community Meeting（国際学会）

４．発表年
2021年

１．発表者名
A.N.Shatokhin; A.V.Kotov; T.M.Jeong; G.M.Grittani; T.Dzelzainis; G.Hull; S.Dann; A.Sagisaka; E.A.Vishnyakov; A.O.Kolesnikov; M.Koike; T.Zh.Esirkepov; M.Kando; K.Ogura; T.A.Pikuz; J.K.Koga; H.Kiriyama; A.A.Soloviev; E.N.Ragozin; S.V.Bulanov; K.Kondo; T.Kawachi; D.R.Symes; D.Neely; A.S.Pirozhkov

２．発表標題
BISER enhancement with Astra laser

３．学会等名
The 69th JSAP Spring Meeting 2022

４．発表年
2022年

１．発表者名
A.S.Pirozhkov, T.Zh.Esirkepov, B.Gonzalez-Izquierdo, A.Sagisaka, T.A.Pikuz, Z.E.Davidson, K.Ogura, A.Bierwage, K.Huang, N.Nakanii, J.K.Koga, A.Ya.Lopatin, Y.Fukuda, D.Neely, P.McKenna, E.N.Ragozin, S.A.Pikuz, N.I.Chkhalo, N.N.Salashchenko, S.Namba, H.Kiriyama, M.Koike, K.Kondo, T.Kawachi, M.Kando

２．発表標題
BISER coherent x-rays source

３．学会等名
XXV International Symposium “Nanophysics & Nanoelectronics”（招待講演）（国際学会）

４．発表年
2021年

１．発表者名
A.Pirozhkov,A.Shatokhin,A.Sagisaka,K.Ogura,T.Pikuz,A.Kotov,T.Dzelzainis,A.Bierwage,Ko.Kondo,H.Ohiro,S.Lorenz,Y.-K.Liu,G.Grittani,T.Jeong,N.Nakanii,K.Huang,A.Kon,Y.Miyasaka,G.Hull,S.Dann,E.Vishnyakov,A.Kolesnikov,M.Koike,P.Chen,T.Esirkepov,J.Koga,R.Gray,A.Soloviev,E.Ragozin,S.Bulanov,S.Namba,et al.

２．発表標題
Ultrabright laser-driven BISER coherent x-ray source

３．学会等名
SPIE Optics + Optoelectronics Symposium, Compact Radiation Sources from EUV to Gamma-rays: Development and Applications Conference（招待講演）（国際学会）

４．発表年
2023年

１．発表者名 A.Pirozhkov,A.Shatokhin,A.Sagisaka,K.Ogura,T.Pikuz,A.Kotov,T.Dzelzainis,A.Bierwage,Ko.Kondo,H.Ohiro,S.Lorenz,Y.-K.Liu,G.Grittani,T.Jeong,N.Nakanii,K.Huang,A.Kon,Y.Miyasaka,G.Hull,S.Dann,E.Vishnyakov,A.Kolesnikov,M.Koike,P.Chen,T.Esirkepov,J.Koga,R.Gray,A.Soloviev,E.Ragozin,S.Bulanov,S.Namba,et al.
２．発表標題 BISER and diagnostics of relativistic plasma singularities
３．学会等名 The Optics & Photonics International Congress OPIC-2023, The 12th Advanced Lasers and Photon Sources ALPS-2023（国際学会）
４．発表年 2023年

１．発表者名 A.Pirozhkov,A.Shatokhin,A.Sagisaka,K.Ogura,T.Pikuz,A.Kotov,T.Dzelzainis,A.Bierwage,Ko.Kondo,H.Ohiro,S.Lorenz,Y.-K.Liu,G.Grittani,T.Jeong,N.Nakanii,K.Huang,A.Kon,Y.Miyasaka,G.Hull,S.Dann,E.Vishnyakov,A.Kolesnikov,M.Koike,P.Chen,T.Esirkepov,J.Koga,R.Gray,A.Soloviev,E.Ragozin,S.Bulanov,S.Namba,et al.
２．発表標題 Ultrabright BISER coherent x-ray source driven by the Astra and J-KAREN-P lasers
３．学会等名 Christmas Meeting of the High Power Laser User Community（国際学会）
４．発表年 2022年

１．発表者名 A.Pirozhkov,A.Shatokhin,A.Sagisaka,K.Ogura,T.Pikuz,A.Kotov,T.Dzelzainis,A.Bierwage,Ko.Kondo,H.Ohiro,S.Lorenz,Y.-K.Liu,G.Grittani,T.Jeong,N.Nakanii,K.Huang,A.Kon,Y.Miyasaka,G.Hull,S.Dann,E.Vishnyakov,A.Kolesnikov,M.Koike,P.Chen,T.Esirkepov,J.Koga,R.Gray,A.Soloviev,E.Ragozin,S.Bulanov,S.Namba,et al.
２．発表標題 Ultrabright BISER coherent x-ray source in experiments with the Astra and J-KAREN-P lasers
３．学会等名 JPS Spring Meeting 2023
４．発表年 2023年

１．発表者名 A.Pirozhkov,A.Shatokhin,A.Sagisaka,K.Ogura,T.Pikuz,A.Kotov,T.Dzelzainis,A.Bierwage,Ko.Kondo,H.Ohiro,S.Lorenz,Y.-K.Liu,G.Grittani,T.Jeong,N.Nakanii,K.Huang,A.Kon,Y.Miyasaka,G.Hull,S.Dann,E.Vishnyakov,A.Kolesnikov,M.Koike,P.Chen,T.Esirkepov,J.Koga,R.Gray,A.Soloviev,E.Ragozin,S.Bulanov,S.Namba,et al.
２．発表標題 BISER experiments with the Astra and J-KAREN-P lasers
３．学会等名 The 70th JSAP Spring Meeting 2023
４．発表年 2023年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
主たる渡航先の主たる海外共同研究者	Ｎｅｅｌｙ　Ｄａｖｉｄ (Neely David)	ＳＴＦＣ　Ｒｕｔｈｅｒｆｏｒｄ　Ａｐｐｌｅｔｏｎ　Ｌａｂｏｒａｔｏｒｙ・Central Laser Facility・STFC Fellow	Professor David Neely sadly passed away in 2020; he was a colleague, mentor, and friend to us
主たる渡航先の主たる海外共同研究者	Ｓｙｍｅｓ　Ｄａｎ (Symes Dan)	ＳＴＦＣ　Ｒｕｔｈｅｒｆｏｒｄ　Ａｐｐｌｅｔｏｎ　Ｌａｂｏｒａｔｏｒｙ・Central Laser Facility・Gemini Target Area section leader	

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
その他の研究協力者	ＭｃＫｅｎｎａ　Ｐａｕｌ (McKenna Paul)	Ｕｎｉｖｅｒｓｉｔｙ　ｏｆ　Ｓｔｒａｔｈｃｌｙｄｅ・Deputy Associate Principal	
その他の研究協力者	Ｌｏｒｅｎｚ　Ｓｅｂａｓｔｉａｎ (Lorenz Sebastian)	ＥＬＩ－ＥＲＩＣ・ELI-Beamlines・Researcher Assistant	

６．研究組織（つづき）

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
その他の研究協力者	Ｌｉｕ　Ｙｕｎｇ－Ｋｕｎ (Liu Yung-Kun)	Ｎａｔｉｏｎａｌ　Ｔａｉｗａｎ　Ｕｎｉｖｅｒｓｉｔｙ・Leung Center for Cosmology and Particle Astrophysics・Research Assistant	
その他の研究協力者	Ｇｒｉｔｔａｎｉ　Ｇａｂｒｉｅｌｅ (Grittani Gabriele)	ＥＬＩ－ＥＲＩＣ・ELI-Beamlines・Researcher Assistant	
その他の研究協力者	Ｊｅｏｎｇ　Ｔａｅ　Ｍｏｏｎ (Jeong Tae Moon)	ＥＬＩ－ＥＲＩＣ・ELI-Beamlines・Senior Researcher	
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その他の研究協力者	Ｐｉｋｕｚ　Ｔａｔｉａｎａ (Pikuz Tatiana) (20619978)	大阪大学・先導的学際研究機構・特任准教授（常勤） (14401)	
その他の研究協力者	難波　愼一 (Namba Shinichi) (00343294)	広島大学・先進理工系科学研究科（工）・教授 (15401)	
その他の研究協力者	Ｋｏｇａ　Ｊａｍｅｓ (Koga James) (70370393)	量子科学技術研究開発機構・関西光科学研究所・専門業務員 (82502)	

6．研究組織（つづき）

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
その他の研究協力者	桐山　博光 (Kiriyama Hiromitsu) (40354972)	量子科学技術研究開発機構・関西光科学研究所・グループリーダー (82502)	
その他の研究協力者	神門　正城 (Kando Masaki) (50343942)	量子科学技術研究開発機構・関西光科学研究所・次長 (82502)	
その他の研究協力者	Ｅｓｉｒｋｅｐｏｖ　Ｔｉｍｕｒ (Esirkepov Timur) (10370363)	量子科学技術研究開発機構・関西光科学研究所・上席研究員 (82502)	

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関			
英国	Central Laser Facility, STFC RAL	University of Strathclyde		
チェコ	ELI-Beamlines			
その他の国・地域 - Taiwan	National Taiwan University			