NEWSLETTER

of the International Consortium "Development of High-Power Terahertz Science & Technology"

June 2022 № 21

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EDITORIAL: HOW TO CONTRIBUTE TO THE NEWSLETTER

Dear Reader,
We are inviting contributions to the following rubrics:
- Research highlights (annotations) presenting the projects pursued by the members of the Consortium.
- Short regular and invited papers.
- Proposals for collaborative research work.
- News from the participating institutions.
- Information about conferences, symposia, workshops, seminars.
- Programs and frameworks for an exchange of visits and mobility of researchers. Job opportunities (especially for young researchers, e.g. postdoctoral positions, specializations, internships).
- Annotations of books, conference proceedings, software and internet resources. Additions to the list of the recent scientific publications and conference reports at the website of the Consortium (http://fir.ufukui.ac.jp/Website_Consortium/publist.html).
- Information and announcements about awards and nominations.
- Short presentations of laboratories and research groups belonging to the participating institutions.

Please submit your contributions to the Newsletter as well as requests for information to:

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INVITED PAPER

Influence of reflections on mode-competition processes in a high-power multimode gyrotron

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Gyrotrons provide highest power in sub-THz and THz frequency bands. However, one of the most problems is ensuring of high-stable single-mode generation. Modern gyrotrons mostly operate at very high-order transverse modes, for which the mode spectrum is very dense and self-excitation conditions are fulfilled simultaneously for several modes with close frequencies. Thus, mode competition processes may strongly affect the gyrotron operation.

The effect of partial reflection from a remote load on gyrotron power and oscillation frequency has been studied in many works since 1990-ies and possibilities of control of the gyrotron radiation by reflection are now a subject of active studies. The delayed reflection can increase frequency stability and expand frequency tuning range due to excitation of high-order axial modes.

In this study, we consider interaction of several modes with neighboring azimuthal indexes, equal radial indexes, and equidistant spectrum of eigenfrequencies. We use the nonlinear time-domain theory with fixed profile of the RF field [0]. The fixed field profile approximation is known to be valid when the diffractive Q-factor of the cavity is much higher than its minimum value $Q_{\min} = 4\pi\left(L/\lambda\right)^2$ (L and λ are the cavity length and the wavelength, respectively) and the cavity filling time for each interacting mode Q_s/ω_s (Q_s and ω_s are Q-factor and the eigenfrequency of s-th mode, respectively) is much longer than the electron transit time.

In modern high-power gyrotrons self-excitation conditions can be fulfilled simultaneously for several modes with neighboring azimuthal indexes m_s, $s = 0, \pm 1, \pm 2, \ldots$, and their frequency spectrum is nearly equidistant. Hereinafter $s = 0$ corresponds to the operating mode. Since the frequencies ω_s and azimuthal indexes m_s satisfy the resonance conditions [0]

$$\begin{gathered} \omega_{+s} + \omega_{-s} - 2\omega_0 << \omega_0/Q_0, \\ 2m_0 = m_{+s} + m_{-s}, \end{gathered}, \qquad (1)$$

a parametric coupling of the spurious sideband modes may occur and cause the instability of the operating mode.

We use the equations of electrons' motion with the standard initial conditions. Since we consider the competition of modes with high azimuthal indexes, we can assume the axial structure $f_s(\zeta)$ of different modes approximately the same.

Let us choose the Gaussian profile of the RF field. We study the mode competition scenarios in a multimode gyrotron without the reflection. Consider the high-power 170-GHz fusion gyrotron with $TE_{28.12}$ operating mode developed in IAP RAS [0].

In Fig. 1 we plot the oscillation zones in the case of zero reflections. We simulate nonlinear multimode dynamics in the cases of three and five competing modes and plot the stability domain of the operating mode. Outside the stability domain, these perturbations start to grow, and we observe spurious excitation of the sidebands. Note that in the domain of hard excitation, $|A_0|$ should be large enough to ensure oscillation build-up.

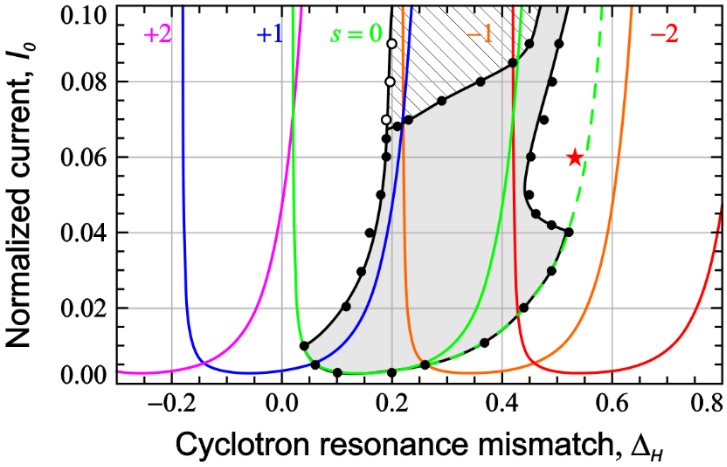

FIG. 1. Domain of stability of the operating mode on the $\Delta_H - I_0$ plane (shaded) in the case of zero reflections. The stability boundaries calculated for three and five competing modes are shown with light and dark circles, respectively. Start-oscillation currents for the modes with $s = +2$ (magenta), +1 (blue), 0 (green), –1 (orange), and–2 (red) are also shown. The green dashed line shows the boundary of the hard excitation of the operating mode. The red star shows the point of maximal efficiency.

The simulations reveal different mechanisms of instability and a complicated shape of the stability domain. The point of maximal efficiency is marked by the red star in Fig. 1. It is located in the domain of hard excitation of the operating mode and soft-excitation of the $s = -1$ and $s = -2$ sideband modes. The simulation shows that the five-mode oscillation regime establishes where the amplitude of the operating mode is much larger than that of the sidebands. In this regime, the efficiency is $\eta \approx 0.55$. This regime remains stable until the hard transition to single-mode oscillation of the $s = -1$ mode takes place. The efficiency drops to $\eta \approx 0.3$ in that case. Thus, the operating mode oscillation regime at the point of maximal efficiency is unstable.

Let us investigate the influence of the reflected signal on the mode competition scenarios. To suppress the spurious modes, the reflection should decrease the Q-factors of the sideband modes and, accordingly, increase their starting currents. This takes place when the phases of the reflected signals are $\psi_{\pm 1,2} \approx (2n+1)\pi$ [0]. These phases are determined by the location of the reflector. Assuming that the frequencies of the modes are $f_s = f_0 + s\Delta f$ with $\Delta f \approx 3$ GHz, this condition is satisfied, for instance, when the reflected signal passes the distance of $l \approx 0.292$ m. The corresponding value of the normalized delay time is $\tau_d = 0.5$.

In Fig. 2, the domain of stability of the operating mode is presented for zero reflections on the operating mode ($\Gamma_0 = 0$) and for strong reflections on the neighboring modes ($\Gamma_{\pm 1} \approx 0.55$ and $\Gamma_{\pm 2} \approx 0.8$, respectively). Compared with the case of zero reflections (dotted line), it expands significantly towards the large values of Δ_H and encloses the point of maximal efficiency. In the domain of high currents, the left-hand stability boundary has a complicated shape, which requires an additional study. However, that domain is not of particular interest due to the rather low efficiency, $\eta \sim 0.3$.

One can see the loops appearing on the $I_r(\Delta_H)$ curves, which indicate the multistability emerging due to the "long-line" effect (see [0] for details).

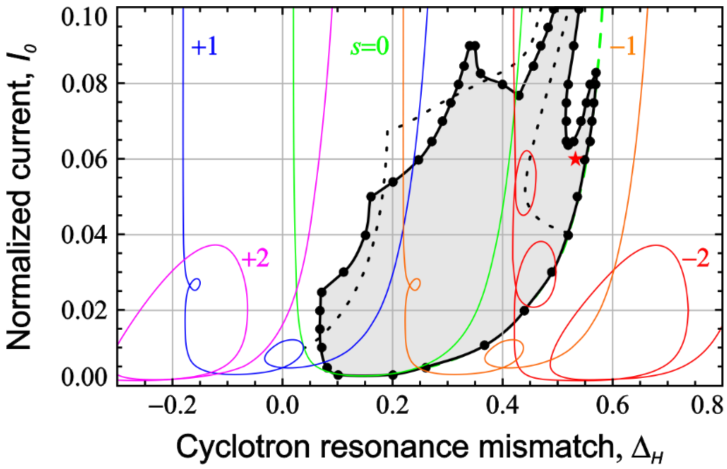

FIG. 2. Domain of stability of the operating mode on the $\Delta_H - I_0$ plane (shaded area) in the case of in the case of strong reflections at the parasitic modes: $\Gamma_{\pm1} = 0.55$, $\Gamma_{\pm2} = 0.80$, $\tau_d = 0.5$, $\psi_{\pm1,2} = \pi$. Start-oscillation currents for the modes with $s = +2$ (magenta), +1 (blue), 0 (green), –1 (orange), and –2 (red) are also shown. The green dashed line shows the boundary of the hard excitation of the operating mode. The red star shows the point of maximal efficiency. The domain of stability without the reflections is shown with the dotted line.

Fig. 3 displays the mode dynamics at the point of the maximum efficiency. Without the reflections, the operating mode is unstable and is suppressed by the –1-th mode during the mode-competition process. Accordingly, the efficiency drops from $\eta \approx 0.7$ to $\eta \approx 0.3$ (Fig. 3(b)). However, the reflections stabilize the operating mode oscillation with high efficiency and all the sidebands are totally suppressed as is shown in Fig. 3(a). In this figure, the initial values of the sideband amplitudes are increased substantially to clearly illustrate their decay.

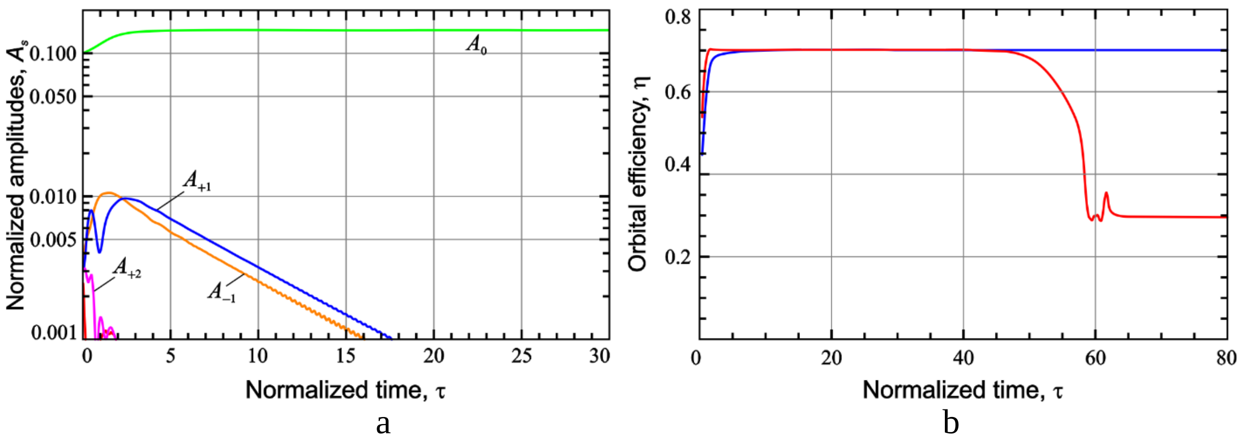

FIG. 3. (a) Mode-competition scenario at the point of the maximum efficiency ($I_s = 0.06$, $\Delta_H = 0.53$, $\Gamma_{\pm1} = 0.55$, $\Gamma_{\pm2} = 0.8$, $\psi_{\pm1,2} = \pi$, $\tau_d = 0.5$). (b) Orbital efficiency versus time with (blue) and without (red) the reflections.

The injection of the reflected signal leads to expansion of the domain of stability of the operating mode. When the reflection of the sideband modes is strong enough, it completely suppresses the spurious modes and provides stable single frequency oscillation with maximal efficiency.

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For more detail, please see the original paper:

M.M. Melnikova and N.M. Ryskin, "Influence of reflections on mode-competition processes in a high-power multimode gyrotron", Physics of Plasmas, vol. 29 (2022) 013104. https://doi.org/10.1063/5.0071210

INTERNATIONAL COLLABORATIVE RESEARCH PROGRAM 2022

Announcement of International Collaborative Research Program 2022

The Research Center for Development of Far-Infrared Region, University of Fukui (FIR UF), has started the International Collaborative Research Program from FY2017. This program aims to support the development of the far-infrared region research through the international personnel exchanges and studies, being conducted at the FIR UF in a wide array of fields, including the development of light sources, applied research, and research and development of new technologies. FIR UF are now accepting proposals for the FY 2022 (August 2022 – March 2023).

How to apply

Please send an application form (Form 1) through the members of the FIR UF faculty after setting a research theme and organizing a research team. The deadline for applications is June 17, 2022.

Procedures

Term: Within one year (from the date of the acceptance notice to March 31, 2023). In principle, collaborative research shall be performed approximately for two weeks at the FIR UF.

Venue: Research Center for Development of Far-Infrared Region, University of Fukui (FIR-UF).

Financial Support: Expenses will be available until the end of January 2023.

Report: Recipients are expected to submit a one-page research report in A4 sheet on or before the set deadline (March 31, 2023).

The number of recipients is limited. Notice of the selection will be by the end of July, 2022.

Application to be sent to:
International Collaboration Office, FIR UF
e-mail: int-office@fir.u-fukui.ac.jp

Masahiko Tani
Director
FIR-UF,
University of Fukui

The list of the previous recipients in the period 2017-2020 is available here.

IN MEMORIAM

Professor Toshitaka Idehara
(1940-2022)

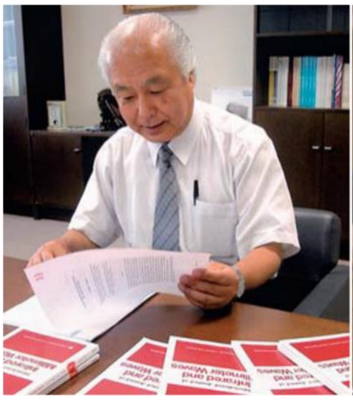
Professor Toshitaka Idehara, the founder and first director of the FIR Research Center, Professor emeritus at the University of Fukui, Editor-in-chief of the Journal of Infrared, Millimeter, and Terahertz Waves passed away on 18 March 2022 at the age of 81.

Professor Toshitaka Idehara was born in Ibara Japan, on April 15, 1940. He received the B.S. degree in mathematics and the M.S. and D.S. degrees in physics from Kyoto University, Kyoto, Japan, in 1963, 1965, and 1968, respectively. After graduating from Kyoto University, he joined the University of Fukui, Fukui, Japan, and was a Lecturer from 1968 to 1970 and an Associate Professor from 1970 to 1990. During this term, he worked on fundamental plasma physics. After 1979, his interest was directed toward the development of high-frequency gyrotrons. From 1990 to 1999, he was a Professor in the Applied Physics Department, Fukui University, and from 1992 to 1999, he was the Head of the Laboratory for Application of Superconducting Magnet, Fukui University. Since 1999, he was a Professor and a founding Director of the Research Center for Development of Far-Infrared Region, University of Fukui (FIR UF). Since 2007 he was also a Supervisor of the research at FIR UF. From June 2004 to December 2010 he was an Editor in Chief of the International Journal of Infrared and Millimeter Waves and later Journal of Infrared, Millimeter, and Terahertz Waves. In 2009, he won the Prize for Science and Technology, The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology of Japan, for Study on High Power THz Radiation Sources High Harmonic Gyrotrons. In 2011, he was awarded the Prize for Science and Technology from Fukui Prefectural Governor for Development of high power THz radiation sources Gyrotrons, and application to THz technologies. In 2016 he was awarded the Kenneth J. Button Prize for outstanding contributions to the development of high power THz radiation sources (harmonic gyrotrons) and their applications to high power THz spectroscopy. His current research interests include development of frequency tunable, sub-THz and THz gyrotrons and their applications to high-power THz technologies, novel spectroscopic techniques (NMR-DNP, ESR), and advanced technologies.

Professor Idehara was an organizer and facilitator of the first International Consortium for Development of High-Power Terahertz Science and Technology established in 2015. He has an active international collaboration with a great number of institutions and researchers around the world. Professor Idehara is recognized worldwide as a brilliant scientist, devoted teacher, and leader in the field of development and applications of gyrotrons. His remarkable achievements in advancing the operation of gyrotrons towards the THz region is an epochal contribution, which is an inspiration for the new generation of younger researchers as well as for all his colleagues and collaborators.

We pray that the soul of our beloved teacher, colleague, and friend Professor Idehara may rest in peace.

We will always keep nice memory of him as a great scientist and a man of vision who bequeath us to continuing his great mission.



LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium and published after February 2022, i.e. after issuing the previous Newsletter #20. This cumulative list is in chronological order as collected from various bibliographical and alert services

A. Publications by authors from the institutions participating in the International Consortium

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NEW BOOKS

Mikhail Glyavin (Ed.) "Design, Technologies and Applications of High Power Vacuum Electronic Devices from Microwave to THz Band," (MPDI Books, 2021). ISBN 978-3-0365-2242-5 (Hbk); ISBN 978-3-0365-2241-8 (PDF). DOI:10.3390/books978-3-0365-2241-8. (Open Access) https://www.mdpi.com/books/pdfview/book/4790

NEWS FROM THE NET (OUR BROADER HORIZONS)

Researchers have discovered a new effect in two-dimensional conductive systems that promises improved performance of terahertz detectors

A post published in in PHYSORG on 23 May 2022 reports that researchers at the Cavendish Laboratory, together with colleagues at the Universities of Augsburg (Germany) and Lancaster have found that a new type of THz detector that they were developing is demonstrating better performance since it provides stronger signal than should be theoretically expected. This motivated them to seek for a new explanation. Furthermore, they found a new physical effect when two-dimensional electron systems are exposed to terahertz waves. The quantitative theory of the effect was developed by a researcher from the University of Augsburg, Germany, and the international team of researchers published their findings in the journal Science Advances.

For more detail, please seem the original publication:

"An in-plane photoelectric effect in two-dimensional electron systems for terahertz detection" by Wladislaw Michailow, Peter Spencer, Nikita W. Almond, Stephen J. Kindness, Robert Wallis, Thomas A. Mitchell, Riccardo Degl'Innocenti, Sergey A. Mikhailov, Harvey E. Beere and David A. Ritchie, 15 April 2022, Science Advances. DOI: 10.1126/sciadv.abi8398.

Kyoto Fusioneering closed 150M JPY loan granted by Japan Finance Corporation

According to the news, released by Kyoto Fusioneering Ltd (KF) on 12 April 2022, (KF), this fusion technology company, based in Japan, closed a long-term loan agreement with the Japan Finance Corporation for a total of JPY 150 million, for a period of 10 years aiming to develop further advanced technologies for fusion reactors. Kyoto Fusioneering, a spin-off of Kyoto University, **is pioneering in advancement of gyrotron systems, tritium fuel cycle technologies, and breeding blankets for tritium production and power generation**.

The fund supports KF´s work towards establishing a supply chain of key technologies for the deployment of fusion energy. In addition, it enables the company to accelerate its recruitment effort and its go-to-market team.

In 2021, Kyoto Fusioneering was awarded a contract by the UK Atomic Energy Authority to provide **dual frequency microwave heating sources (gyrotrons) for MAST Upgrade (Mega Amp Spherical Tokamak)**, based at Culham, near Oxford, UK. Use of these gyrotrons on MAST Upgrade is also relevant to UKAEA's STEP (Spherical Tokamak for Energy Production) initiative – the UK's flagship programme to design and build a prototype fusion power plant. Furthermore, the company is working with several private developers, in the U.S. and Europe, to solve reactor engineering challenges for more novel routes to fusion energy.

This support reflects progress during the years and a recognition of the role of Kyoto Fusioneering in driving a new energy industry and building a neutral carbon society.

For more detail about KF Ltd please visit their site and follow them on Twitter. The Newsletter of KF is available at the following link.

ITER maintains neutrality and continues the continuation of the planned tasks

Russia takes part in the development and production of 25 diagnostic, vacuum, electromagnetic and other systems. Some of them are indispensable for launching the reactor. "Russia will continue to fulfill all of its obligations. We have already shipped some of the critical systems and components. Other essential shipments are scheduled for later this year, and we keep working on the systems we have undertaken to produce," said Alexander Petrov, the press secretary of ITER Center (Russian office of the ITER project). ITER firmly maintains political neutrality and, despite political and economic headwinds, does not refuse to cooperate with Russia. "There are no marked changes in the team's attitude. ITER has long been positioning itself as a fundamentally neutral project. In early March, we received a confirmation of this principle and assurances that any signs of disrespect in the team, particularly those related to the crisis, would be addressed immediately. The objectives of ITER cannot be achieved without Russia's contribution, and everyone understands it. According to the information I have, Director-General of the ITER Organization Bernard Bigot has repeatedly assured that he will do his best to tackle any problems with contracts, customs clearance, bank payments, etc.," Vitaly Krasilnikov, a supervisor of Neutron Diagnostics at the ITER Organization (France), shares his opinion.

By the end of 2022 Q2, Russia will ship a poloidal field coil PF1 to France, where ITER is constructed. It will be placed outside the ITER toroidal magnet system and generate a poloidal magnetic field to produce plasma, control its position and shape and maintain electric current in it. There will be six poloidal field coils. One of them will be supplied by China; another four are made right on the site – so big they are – the Russian-produced coil is 9 meters in diameter and weighs 200 tons.

Each of 16 coil cables is made of niobium-titanium (NbTi) superconductors manufactured at the production facilities of Rosatom's fuel division and the Russian Research Institute for the Cable Industry. Their superconducting properties manifest themselves at the temperature of about 4ºK. The work on the coil started in 2014. Technology and equipment were developed at Rosatom, while manufacturing takes place at Sredne-Nevsky Shipbuilding Plant in Saint Petersburg.

In September, ITER expects to receive **gyrotrons** – vacuum devices generating high-power, high-frequency radiation that overheat electrons in plasma – made in Russia. More important is that they cause breakdown and plasma initiation. Output power of each gyrotron is 1 MW and radiation frequency is 170 GHz. ITER needs 24 gyrotrons in total, and Russia will supply eight of them. Six devices are ready; five of them have already passed acceptance tests.

The gyrotrons will be placed in a detached building since they are susceptible to external electromagnetic fields that are present in abundance in the tokamak, ITER's core functional component. The engineering process is supervised by the Institute of Applied Physics of the Russian Academy of Sciences; manufacturing takes place at Gycom in Nizhny Novgorod.

Shipment of pedestals for blanket module connectors is scheduled for November–December 2022. The pedestals will be mounted by welding on the reactor's vacuum chamber. They are designed to hold electrical connectors that complete a path for currents induced in the blanket modules at the time of plasma disruption. The connectors were manufactured at the Research and Development Institute of Power Engineering (NIKIET, part of Rosatom). The manufacturing process took about three years and a half. The pedestals are made of two materials, a chromium zirconium copper alloy and stainless steel.

By the end of 2022, Russian companies will produce port plugs and test stands for them. Port plugs are modules that enable the installation of plasma diagnostic systems inside the reactor. They protect the systems against neutron flux and mitigate the effects of ionizing radiation in the areas accessible by personnel. There will be a total of 40 port plugs installed along the perimeter of the tokamak vacuum chamber, and four of them will be made in Russia. It will also supply four stands for pre-operational vacuum, thermal and functional testing of the port plugs. The test stands will be pre-assembled at the factory and then assembled on the site in a Lego-like manner. Each port plug will be tested for about five months, this is why several stands are needed. If there were a single test stand, it would take more than 16 years to test all the devices. The first shipment of the stands is scheduled for next year. The last stand will be delivered in 2026. The port plugs will be manufactured at the Institute of Nuclear Physics of the Russian Academy of Sciences Siberian Branch, and test stands at GKMP Research and Production Company in Bryansk.

The above information has been abridged from the following post. Please access the original for more detail.

Fusion reactors could generate more power thanks to a reworking of Greenwald's Law.

In a report by Tom Metcalfe, published at Space.com, it has been announced that physicists just rewrote a foundational rule for nuclear fusion reactors that could unleash twice the power. As a result, the future fusion reactions inside tokamaks could produce much more energy than previously thought, thanks to groundbreaking new research that found a foundational law for such reactors was wrong. The nuclear fusion research, led by physicists from the Swiss Plasma Center at École Polytechnique Fédérale de Lausanne (EFPL), has determined that the maximum hydrogen fuel density is about twice the "Greenwald Limit" — an estimate derived from experiments more than 30 years ago. The discovery that fusion reactors can actually work with hydrogen plasma densities that are much higher than the Greenwald Limit they are built for will influence the operation of the massive ITER tokamak being built in southern France, and greatly affect the designs of ITER's successors, called the Demonstration power plant (DEMO) fusion reactors, said physicist Paolo Ricci at the Swiss Plasma Center. "The exact value depends on the power," Ricci told Live Science. "But as a rough estimate, the increase is on the order of a factor of two in ITER."

The original research paper by Giacomin et al. demonstrates that a first-principles scaling law, based on turbulent transport considerations, and a multimachine database of density limit discharges from the ASDEX Upgrade, JET, and TCV tokamaks, show that the increase of the boundary turbulent transport with the plasma collisionality sets the maximum density achievable in tokamaks. This scaling law shows a strong dependence on the heating power, therefore predicting for ITER a significantly larger safety margin than the Greenwald empirical scaling [Greenwald et al., Nucl. Fusion, 28, 2199 (1988)] in case of unintentional high-to-low confinement transition.

Journal reference:

M. Giacomin et al. First-Principles Density Limit Scaling in Tokamaks Based on Edge Turbulent Transport and Implications for ITER. Physical Review Letters 128, 185003. DOI:10.1103/PhysRevLett.128.185003.