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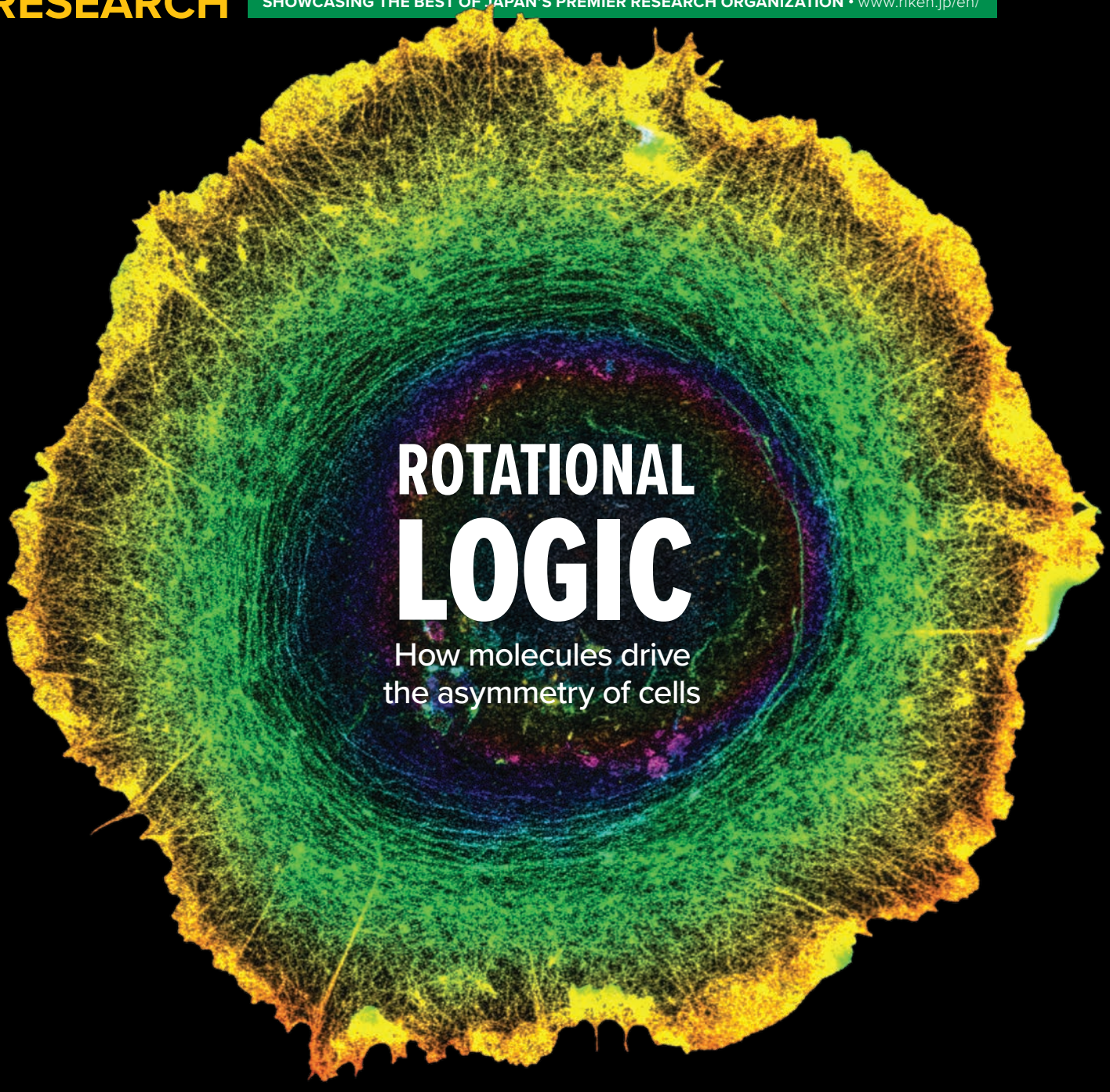


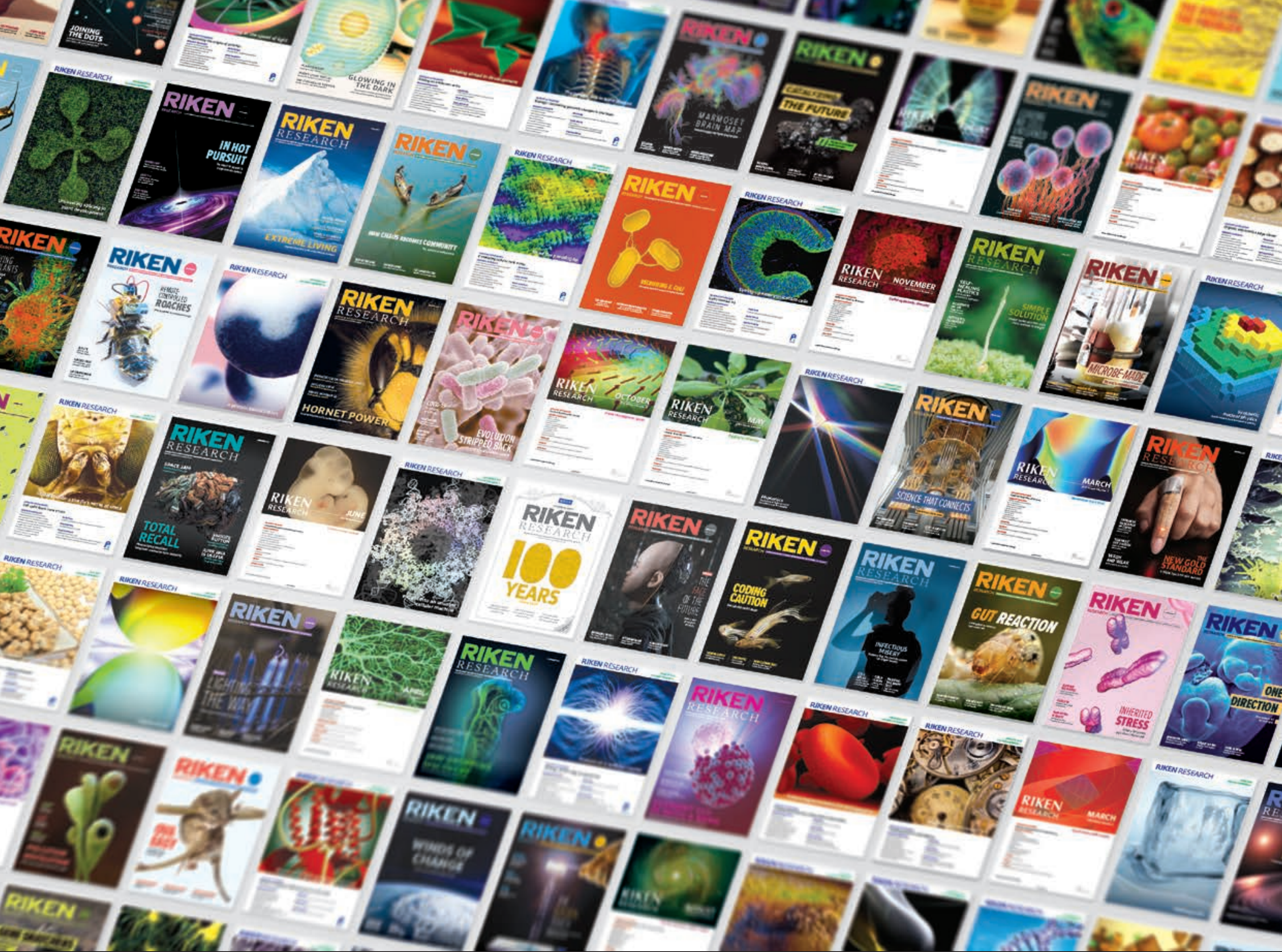
ROTATIONAL LOGIC

How molecules drive the asymmetry of cells

IRON SNATCHERS
Stopping parasites in their tracks

SMART YARN
High-tech fabric tracks muscle activity

GALACTIC EVOLUTION
AI supercharges astrophysics simulations



▲ **THE END OF AN ERA**
After 20 years of *RIKEN Research* magazines, this will be the last issue. Articles will continue to appear online (see page 3).

ABOUT RIKEN

RIKEN is Japan's only comprehensive research institute for the natural sciences. It conducts advanced research across a wide range of fields, including physics, engineering, chemistry, mathematical and information sciences, computational science, biology, and medical science.

Founded in 1917 as a private foundation, RIKEN has undergone several transformations throughout its history. After operating as a company and later as a public corporation, it was re-established in October 2003 as an Independent Administrative Agency under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). In April 2015, it became a National Research and Development Agency.

To ensure that the results of its research benefit society, RIKEN actively engages in joint and commissioned research with universities and private companies. It also promotes the transfer of intellectual property and technologies to industry.

RIKEN Research is an online and print publication that highlights the best research published by RIKEN in collaboration with Nature Custom Media, a part of Springer Nature.

For further information on the research in this publication or to arrange an interview with a researcher, please contact:

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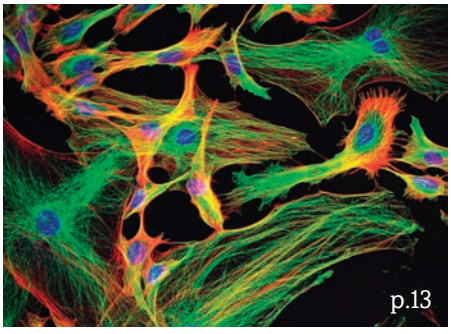
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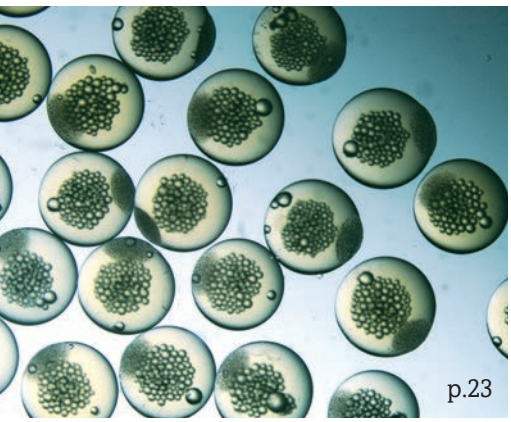

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To our readers

Makoto Gonokami
President, RIKEN

I would like to greet our readers with an important announcement: partly in consideration of the movement toward a paperless society, we have decided to discontinue *RIKEN Research* as a publication following 20 years of publication. We will continue to publicize our activities in other forms, and sincerely appreciate your continued support. Past issues will remain available on our website, and we will continue to deliver engaging and high-quality content online.

So in closing this publication's history, I would like to offer a look toward the future. RIKEN entered our Fifth Mid- to Long-Term Plan in April 2025 with the aim of redefining the role of science amid escalating global challenges such as climate change, energy crises and social divisions. The plan emphasizes a dual mission: advancing world-class basic science and sharing scientific knowledge to contribute to a sustainable and inclusive future for humanity.

To maximize RIKEN's interdisciplinary strength, we have identified five core research domains, and established a research-first management system led by internationally recognized scientists. Central to this effort is the TRIP initiative, which promotes data-driven, cross-disciplinary research under the concept of "Science that Connects."

We are also investing heavily in next-generation research infrastructure, including renovations of our bioresource facility, a new tech center on the Wako campus, the FugakuNEXT supercomputer, and SPring-8-II, designed to dramatically enhance synchrotron radiation brilliance.

The plan is framed within a rapidly changing global context. COP30, the UN climate-change conference in 2025, marked a shift in discussions from emissions reduction toward adaptation, highlighting the urgent need for scientific knowledge to assess risks, guide policy, and support resilience. Similarly, the rapid expansion of generative AI presents profound societal challenges.

Through programs such as AI for Science, international collaborations and strengthened partnerships with leading universities, RIKEN is seeking to reinforce Japan's global scientific presence. Looking ahead to 2026, we aim to drive breakthroughs in quantum technology, supercomputing, and AI, advancing basic science to help build a better future for humanity.

COVER STORY:
Colored microscopy image showing the concentric pattern of F-actin, which gives rise to the clockwise rotation of the nucleus cytoplasm. *Page 15*

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Boosting a plant's cold shock resilience

Bruno Pok Man Ngou
Special Postdoctoral Researcher,
Plant Immunity Research Group,
RIKEN Center for Sustainable Resource Science

Please describe your research.
My research focuses on cell-surface receptors in plants, which act like sensors. These receptors detect signals from the environment and transmit them into the cell, triggering responses. I study how these receptors have evolved in different plant species. By understanding their diversity and function, we can uncover new roles and potentially apply this knowledge to develop disease-resistant crops.

Our 2025 paper published in *Science* describes the discovery of the immune receptor, SCORE, which detects cold shock proteins. These proteins help organisms survive sudden temperature drops by stabilizing RNA, aiding transcription and translation and preventing other harmful secondary effects. Cold shock proteins are found in more than 85% of bacteria, fungi and insects, and they ensure cellular processes continue under cold stress. We also developed a technique to enhance SCORE's ability to recognize cold shock proteins by modifying a small portion of its amino acid sequence. This will enable stronger and faster immune signaling against pathogens.

How did you become interested in this?
My interest began during my undergraduate studies at Imperial College London. During my PhD at the University of East Anglia in the United Kingdom, I studied plant–microbe interactions at the Sainsbury Laboratory, a research institute looking to reduce crop losses. That experience led me to focus on plant immunity. I first joined the Plant Immunity Research Group at RIKEN as an intern for three months in 2018. In 2021, I returned to the group as a Special Postdoctoral Researcher, with funding to do independent research.

My research is important for society…
Because plants face multiple stresses, such as cold, drought, salinity and disease, especially under climate change. To survive, they need to accurately sense their surroundings. By uncovering how plants detect pathogens and environmental signals, we can help secure stable food supplies and restore ecosystems affected by climate change.

Our findings also open doors to practical applications, such as engineering crops with enhanced resistance to pathogens, reducing reliance on chemical pesticides.

What do you find most exciting about your research?
Each plant species has a unique set of receptors. We are characterizing these across a wide range of species and we don't know what we'll find. That sense of discovery and knowing something new is out there is what excites me most.

What do you enjoy about working at RIKEN?
RIKEN offers cutting-edge facilities and abundant resources, but what truly stands out is the people. Researchers, technicians and staff create a supportive environment where ideas flow freely. This openness fosters creativity and makes collaboration easy.

Do you have a message for those considering RIKEN?
RIKEN is a great place to do science. If you're interested in a research group or mentor, don't hesitate to reach out. ■

How plants deal with stress

Amelie Ducloy
Special Postdoctoral Researcher, Plant Symbiosis Research Team, RIKEN Center for Sustainable Resource Science

Describe your role at RIKEN.
I study the stress response of the plant endoplasmic reticulum (ER), a network of membranes involved in protein synthesis and lipid metabolism. When plants are exposed to heat stress, errors occur during protein synthesis, folding and maturation, leading to the accumulation of toxic misfolded proteins in the ER. Misfolded protein accumulation induces ER stress, which can threaten the plant's survival. This activates mechanisms to eliminate abnormal proteins and increase ER protein folding capacity, thereby alleviating the stress.

Briefly describe your research.
In a 2022 study in France, I induced misfolded protein accumulation in the ER of plants using a specific antibiotic instead of heat stress and analyzed which genes were expressed. I discovered that ER stress affects the lipid composition not only of the ER membrane, but also others such as the plasma membrane.

How did you become interested in this field?
My passion for living organisms began in childhood. In high school science class, I learned about DNA and was particularly struck by restriction enzymes—proteins that recognize and cut specific DNA sequences. I was amazed. How could enzymes do something so precise? That moment inspired me to become a biological researcher.

Plants cannot move in the same way as animals, which is why they've evolved sophisticated defense mechanisms against environmental stress. That's what makes them so fascinating to me.

When did you join RIKEN?
While conducting research in France, I learned that Japan is a global leader in ER stress response research. A colleague who worked at RIKEN introduced me to its outstanding research environment and high academic standards. This motivated me to apply for a job.

In December 2022, my husband—who majored in physics—and I moved to Japan after he also secured a research position.

How do you balance family life with your work at RIKEN?
My husband and I are extremely happy with our life in Japan, and we both hope to continue working here. I enjoy exploring traditional crafts in Kanazawa, such as gold leaf and *Kaga Mizuhiki* (tying decorative knots with paper cords) and *temari* (making embroidered balls) and visiting workshops for kimono dyeing. In Tokyo, I love Ueno for its pond, museums and art galleries. I'm also a big fan of Japanese cuisine and enjoy cooking it myself. A recent find has been a duck-and-green-onion ramen shop in Ueno, Tokyo. On my days off, I try not to think about research but rather I try to appreciate beauty as I find it without thinking too much about it.

My research is important for society because…
France is a leading European agricultural producer and Japan is at the forefront of ER stress research. I hope my work can help address food security challenges in both countries. ■

Learn more about careers at RIKEN

RIKEN and AMD sign an agreement to collaborate on science and technology

RIKEN and Advanced Micro Devices (AMD), an American semiconductor company, have signed a memorandum of understanding for collaboration aimed at advancing science and technology. Under this agreement, researchers at both organizations will work on collaborative projects, and come together to host lectures, joint seminars and symposiums on relevant topics.

AMD has driven innovation for more than 55 years in the area of high-performance computing, graphics and visualization technologies. RIKEN is expanding its research efforts in the realm of computer science through supercomputers, quantum computers, AI and mathematics, while advancing essential technologies for next-generation semiconductors. Through conducting collaborative work leveraging both organizations' strengths, RIKEN and AMD aim to contribute to the advancement of science and technology and the benefit of the international community.

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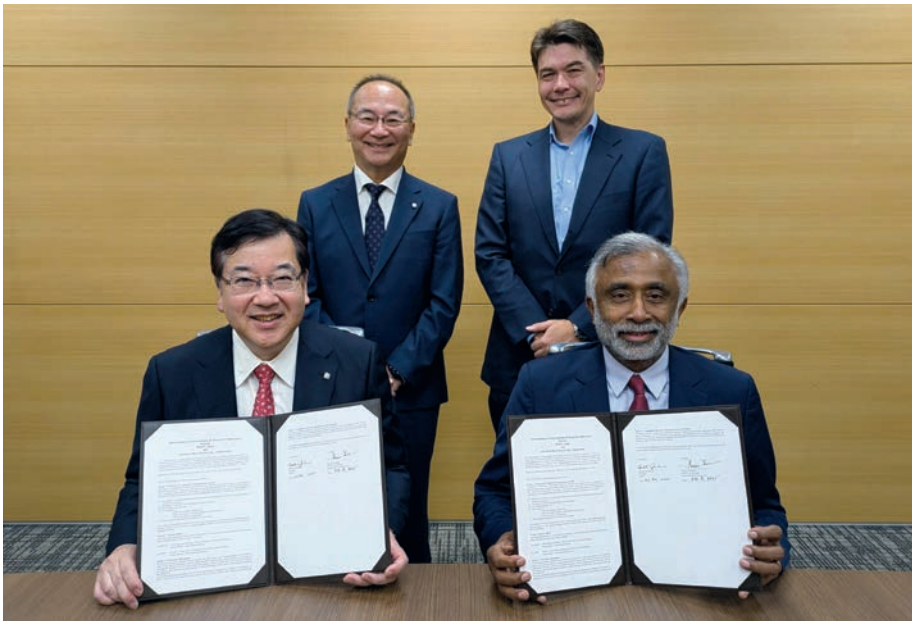

Front row, left to right: RIKEN President Makoto Gonokami, AMD Senior Vice President Thomas Zacharia. Back row, left to right: RIKEN Executive Vice President Masashi Kawasaki; AMD Japan President and CEO Jon Robottom.

Collaborative agreement with NVIDIA

RIKEN and the US tech company NVIDIA Corp. have signed a memorandum of understanding on collaboration and cooperation. It covers exchanges of researchers and other personnel; exchanges of scientific and technological data, including the organization of lectures, joint seminars and symposiums; planning of joint research projects; and other related projects and activities.

Since its founding in 1993, NVIDIA has tackled challenges in accelerated computing. The company's efforts in AI computing are impacting society through transforming some of the world's largest industries. RIKEN is working to expand the realm of computable science through the use of supercomputers, quantum computers, AI and mathematics. The aim is to accelerate the research cycle while advancing the development of essential technologies required for next-generation semiconductors. Collaborative research that leverages both parties' strengths will help to advance science and technology in this area.

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RIKEN President Makoto Gonokami (left) and NVIDIA Founder and CEO Jensen Huang.

RIKEN's highly cited researchers for 2025

Fifteen RIKEN researchers appeared in Clarivate's Highly Cited Researchers for 2025. More than 6,800 researchers from 60 nations and regions were recognized in Clarivate's annual list, which selects researchers based on their publications over the past decade or more. Researchers from RIKEN were recognized for their contributions in cross-field studies; immunology; physics; plant and animal science; neuroscience and behavior; and geoscience.

www.riken.jp/en/news_pubs/news/2025/20251126_1

CROSS-FIELD

- **Ryotaro Arita**
  Team Director, First-Principles Materials Science Research Team, RIKEN Center for Emergent Matter Science
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- **Takaomi Saido**
  Senior Visiting Scientist, RIKEN Center for Brain Science

- **Wataru Suda**
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- **Takao Someya**
  Chief Scientist, Thin-Film Device Lab, RIKEN Pioneering Research Institute
  Team Director, Emergent Soft System Research Team, RIKEN Center for Emergent Matter Science
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- **Susumu Tonegawa**
  RIKEN Fellow

PHYSICS

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  Group Director, Strong Correlation Physics Research Group, RIKEN Center for Emergent Matter Science
  Team Director, Strong Correlation Quantum Transport Research Team, RIKEN Center for Emergent Matter Science

- **Naoto Nagaosa**
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- **Franco Nori**
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- **Lam-Son Phan Tran**
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  Professor, Texas Tech University

GEOSCIENCE

- **Naoto Yokoya**
  Team Director, Geoinformatics Team, Goal-Oriented Technology Research Group, RIKEN Center for Advanced Intelligence Project

Ambassadors of Cuba and Jordan visit RIKEN

The Ambassador of the Republic of Cuba to Japan, H. E. Gisela García, visited the RIKEN Tokyo Campus on December 5, 2025. The visit commenced with an address from President Makoto Gonokami and an introduction to RIKEN by the Global Strategy Division. Discussions were then held regarding the potential for future research collaboration between RIKEN and the Republic of Cuba. Three days later, on December 8, 2025, the Ambassador of the Hashemite Kingdom of Jordan to Japan, H. E. Nasser Shraideh, accompanied by Deputy Chief of Mission, Ali Al-Arabiyat, visited the RIKEN Tokyo Campus. Gonokami first gave some welcoming remarks and then the Global Strategy Division presented an overview of RIKEN. The participants then engaged in discussions on potential avenues for pursuing collaborative research together.

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An electron hovering over a surface of liquid helium could be used as a qubit in future quantum computers.

QUANTUM SYSTEMS

Reading qubits in an ultraclean environment

Microwaves should be able to probe qubits made from single electrons floating above liquid helium

One intriguing method that could be used to form the qubits needed for quantum computers involves electrons hovering above liquid helium. But it wasn't clear how data in this form can be read easily—now RIKEN researchers may have found a solution[1].

Conventional computers work by performing operations on bits encoded in silicon. But no one is really sure how qubits will be encoded in the quantum computers of the future. Half a dozen or so platforms are currently being pursued, including superconductors, silicon, light and trapped ions.

One of the most intriguing ideas for qubits is electrons that float above the surface of liquid helium at a temperature of about four degrees Celsius above absolute zero.

The great advantage of such a system is that it provides a very clean environment, with minimum interference from spins of nearby particles. This will allow qubits to maintain their quantum state for much longer than in noisier environments.

"For an electron floating in a vacuum above helium, the only thing close to it is helium atoms, which are highly inert," explains Asher Jennings of the RIKEN Center for Quantum Computation (RQC) and RIKEN Center for Advanced Photonics. "That means the electron is very well protected, making it an excellent system for storing quantum information."

But for such qubits to be used in quantum computers, the data they store needs to be readable. The small magnetic moment of an electron above helium makes direct readout of its spin infeasible. And so, scientists are exploring indirect schemes for reading out the electron spin.

A promising way to do that is to detect the transition of the electron from its lowest energy state to a higher one, known as the Rydberg state.

Now, scientists including Jennings and Erika Kawakami, also of RQC, have demonstrated it should be possible to detect the Rydberg transition of a single electron by measuring the change in capacitance.

They did this by using 10 million electrons floating above liquid helium, thereby creating a system that acts as a capacitor. The team were able to detect the change in the quantum capacitance that occurred when the electrons were promoted to the Rydberg state through changes in the microwave frequency.

While the system needs to be scaled down by a factor of 10,000 times, it demonstrates that such a scaled-down device should be able to detect the signal from a single qubit.

"Our measurements of the capacitance change in a large system indicate that it should be easily measurable for a single electron in a single-electron device," says Jennings.

The team is now working on performing the same measurement in a one-electron system.

Reference

1. Jennings, A., Grytsenko, I., Tian, Y. Rybalko, O., Wang, J., Barabash, I. J. & Kawakami, E. Probing the quantum capacitance of Rydberg transitions of surface electrons on liquid helium via microwave frequency modulation. *Physical Review Letters* **135,** 087001 (2025).

SUPERCONDUCTING THIN FILMS

Surprising way to create thin films that superconduct

A 'misaligned' thin film is found to be superconducting at low temperatures

RIKEN researchers have discovered an unexpected way to make a high-quality superconducting thin film from a material that isn't usually superconducting[1]. This new superconducting thin film is promising for use in quantum chips.

Certain types of quantum computers use superconducting thin films to encode qubits. However, such thin films often contain impurities or other defects that destabilize the qubits, which reduces the accuracy of quantum operations.

Iron telluride has few impurities and would thus be a good substance for quantum thin films, except that it isn't normally superconducting.

Thin films are grown on top of another layer, or substrate, in a process called epitaxy. Each substrate has a repeating atomic pattern that forms a grid-like lattice.

When a thin film grows, its atomic structure aligns itself to this grid as best it can. When developing new thin films, the goal is usually to use a substrate that gives the best lattice match—atom-to-atom alignment—with the thin film.

The twist in this study is that, despite using a substrate that did not align well, Yuki Sato and colleagues at the RIKEN Center for Emergent Matter Science created a high-quality thin film.

"Although we used a substrate that should not allow good lattice matching, the film quality somehow improved," says Sato.

They sprayed two tiny beams of iron and telluride atoms onto a layer of cadmium telluride.

Molecular beam epitaxy systems, such as this one, are used to form highly precise thin films with multiple layers. Usually, the lattices of adjacent layers should be very similar to each to obtain high-quality films, but RIKEN researchers have found an exception to this rule.

The iron and telluride then self-assembled into crystal layers as expected, but alignment to the underlying atomic grid was off by about 20%.

Such a large misalignment would usually render the thin film unusable. However, the iron telluride thin film turned out to be superconducting, making it suitable for studying quantum phenomena and possibly for use in quantum computer chips.

Analysis revealed higher-order alignment to the atomic grid in cadmium telluride, which stabilized the crystal structure. This alignment was of a higher order than the atom-to-atom alignment that is usually desired. Instead, it involved alignment of groups of atoms.

Further analysis showed that this structural change reduced lattice distortion normally present in bulk iron telluride. This distortion prevents superconductivity at the low temperatures needed for quantum computing. Without the distortion, the new iron telluride film became superconducting at temperatures below –263 degrees Celsius (10 degrees Kelvin).

The researchers used the same process to grow iron telluride thin films on strontium titanate, which has very high lattice matching in terms of atom-to-atom alignment. The resulting thin film was not superconducting, supporting the idea that higher-order epitaxy was the key for realizing superconductivity.

"Our findings indicate that intentionally creating higher-order epitaxial matching could be the future of thin-film research," says Sato. ●

Reference

1. Sato, Y., Nagahama, S., Kitou, S., Sagayama, H., Belopolski, I., Yoshimi, R., Kawamura, M., Tsukazaki, A., Kanazawa, N., Nomoto, T. *et al.* Superconductivity and suppressed monoclinic distortion in FeTe films enabled by higher-order epitaxy. *Nature Communications* **16,** 10913 (2025).

SCHISTOSOMIASIS

Iron-snatching compounds effective against parasitic flatworm

Taking iron from the larvae of a pathogenic parasite is shown to reduce their survival rate, potentially pointing at new treatments

A series of compounds that deprive iron essential for a parasitic worm could provide effective new agents for blocking parasite growth, a RIKEN researcher has found[1]. This finding could give a much-needed new strategy for fighting the parasite.

Parasitic flatworms of the genus *Schistosoma* cause the neglected tropical disease schistosomiasis, which leads to acute symptoms such as diarrhea, fever and bloody urine. Chronic infections can damage the liver, intestine, bladder and kidney. Globally, there are estimated to be about 250 million sufferers, of which about half are children of school age.

Praziquantel was developed as a drug for treating schistosomiasis about five decades ago, but there are concerns that the parasites could develop resistance. It is thus important to develop new drugs that employ different strategies for combating schistosomiasis. Since praziquantel specifically attacks adult worms, it is highly desirable to develop new alternative drugs that can kill their larval forms, schistosomula and cercariae (see image).

That is what Akira Wada of the RIKEN Center for Integrative Medical Sciences wanted to do. "To help improve the current situation with schistosomiasis, we aimed to discover untapped compounds that have the potential to be new antischistosomal drugs," says Wada.

His group had recently shown that snatching iron from malaria and amebic parasites using metal-binding compounds curtailed their growth. He wondered if the same strategy could be effective against *Schistosoma* species.

The parasite needs iron in both the larval and egg-laying stages.

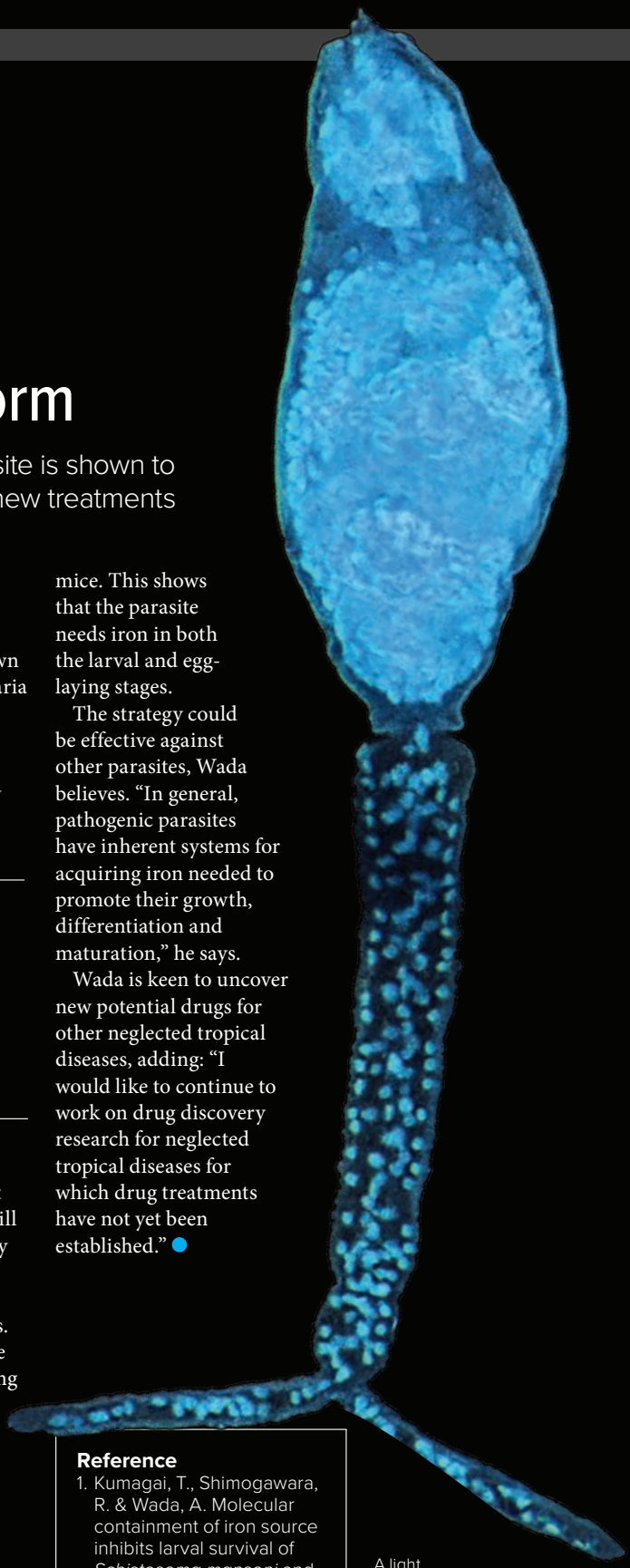
Now, Wada and his collaborators have shown that such compounds are able to kill schistosomula more efficiently than the first-line drug for the disease, making them a promising basis for new drugs.

"Our results suggest that the unique approach for containing the iron source essential for *Schistosoma* parasites could provide valuable insights for developing a next-generation antischistosomal drug," says Wada.

As an added bonus, one of the compounds also interfered with the egg-laying behavior of female adult worms, significantly suppressing the production of parasite eggs in mice. This shows that the parasite needs iron in both the larval and egg-laying stages.

The strategy could be effective against other parasites, Wada believes. "In general, pathogenic parasites have inherent systems for acquiring iron needed to promote their growth, differentiation and maturation," he says.

Wada is keen to uncover new potential drugs for other neglected tropical diseases, adding: "I would like to continue to work on drug discovery research for neglected tropical diseases for which drug treatments have not yet been established." ●



A light micrograph of a larva of the parasitic flatworm that causes the disease schistosomiasis. A RIKEN researcher has discovered the basis of a new drug for treating the disease caused by the parasite.

Reference

1. Kumagai, T., Shimogawara, R. & Wada, A. Molecular containment of iron source inhibits larval survival of *Schistosoma mansoni* and egg-laying behavior of the female adult worms via ovarian atrophy. *Tropical Medicine and Health* **53,** 121 (2025).

QUANTUM LIGHT SOURCES

Fabricating single-photon light sources from carbon nanotubes

Atomically precise quantum light sources have been created on carbon nanotubes

Tiny tubes of carbon that emit single photons from just one point along their length have been made in a deterministic manner by RIKEN researchers[1]. Such carbon nanotubes could form the basis of future quantum technologies based on light.

Light is currently used to freight data over long distances via optical fibers. But harnessing its quantum nature could offer several benefits including unprecedented security since any interception by a third party can be detected.

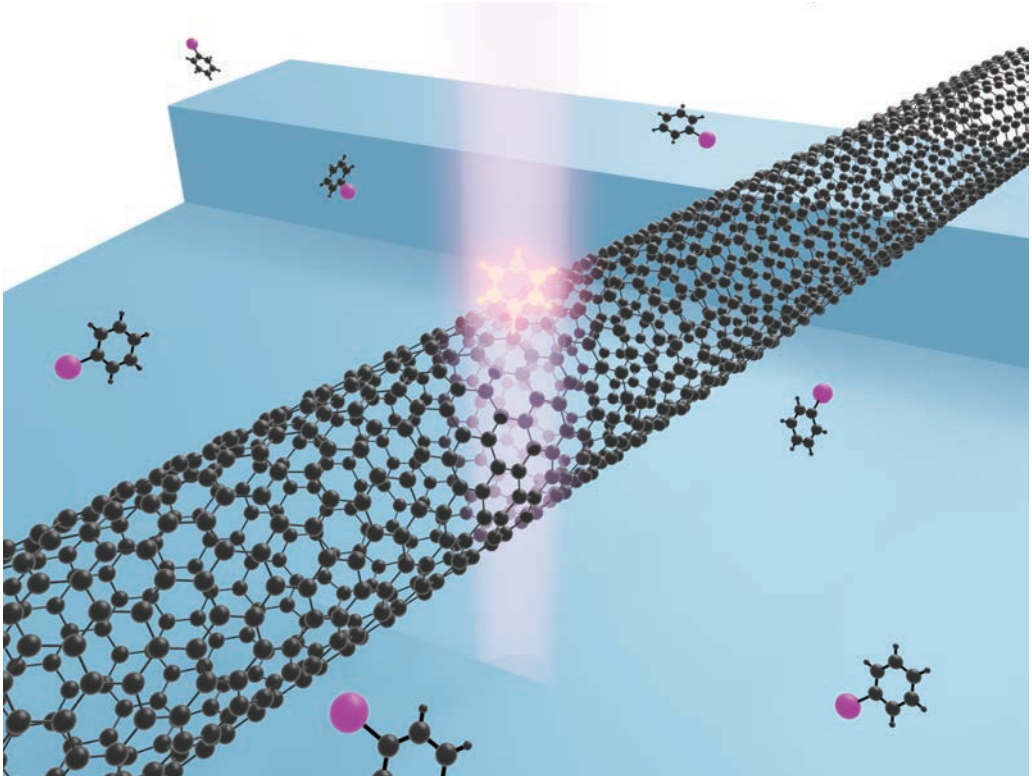
Such quantum communication technology requires light sources that emit one photon at a time. Several systems are capable of realizing that, but of them carbon nanotubes are the most promising.

"Carbon nanotubes are the only quantum emitters that can emit single photons at room temperature and also at wavelengths used for telecommunications," explains Yuichiro Kato of the RIKEN Center for Advanced Photonics. "That makes them very attractive for real-world applications."

However, one problem with nanotubes is that it has been difficult to control the number of points along their length that emit single photons. It has also been challenging to determine the position of light-emitting points along a nanotube.

Now, Kato and co-workers have overcome both issues and produced nanotubes that emit single photons from one point whose position can be controlled.

This demonstration takes fabrication precision to the next level, Kato notes. "We're already going beyond nanotechnology," he says. "This is entering the world of atomically defined technology—that's pretty exciting to me."



A 'color center' being created in a carbon nanotube through a photochemical reaction induced by an ultraviolet laser and a molecule of iodobenzene.

The team realized this by suspending a carbon nanotube across a trench just micrometers wide and exposing it to iodobenzene vapor. They then focused an ultraviolet laser beam on one point on the carbon nanotube. The combination of ultraviolet and iodobenzene generates defects known as color centers on carbon nanotubes (see image).

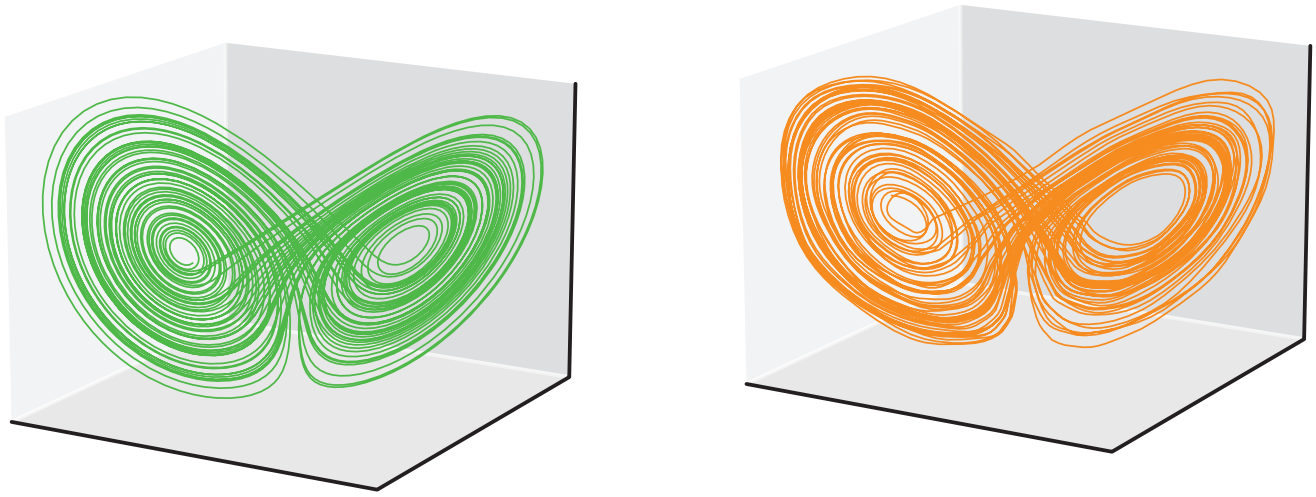
To ensure they produced only one color center on the nanotube, the team continuously monitored the light emitted. They immediately stopped the reaction as soon as they noticed a change in the light that indicated the formation of a color center.

The team was able to control the position of the color center to within a micrometer through the position of the focused laser beam on the carbon nanotube.

Kato's ultimate goal is to create devices that contain single-photon-emitting nanotubes. "We want to integrate them into photonic circuits on chips," says Kato. "And then once we have a chip, we can probably start talking to photonics manufacturers about real-world applications."

Reference

1. Kozawa, D., Shiota, Y., Wang, M. & Kato, Y. K. Deterministic formation of single organic color centers in single-walled carbon nanotubes. *Nano Letters* **25,** 13103–13109 (2025).



The Lorenz attractor (left: target; right: actual output) is an example of complex dynamical systems. Two neuroscientists have discovered a way to learn complex dynamics in a biologically plausible way.

NEURAL NETWORKS

Taming chaos in neural networks

A biologically plausible way to control chaos in artificial neural networks could provide insights into how the brain works

A new framework that causes artificial neural networks to mimic how real neural networks operate in the brain has been developed by a RIKEN neuroscientist and his collaborator[1].

As well as shedding light on how the brain works, this development could help inspire new AI systems that learn in a brain-like way.

Humans and animals have remarkable capacities to learn and perform complex tasks thanks to their brains. That's due to the brain's amazing ability to take in sensory information and produce complex outputs.

Toshitake Asabuki of the RIKEN Center for Brain Science is fascinated by the brain and wants to discover how it works.

"My team investigates how the brain learns efficiently and robustly," he says. "We aim to identify learning rules that could, in principle, be implemented by real neural circuits in the brain."

A promising way to mimic real neural circuits in the brain is to use artificial ones known as recurrent neural networks. The neurons in these networks influence each other in loops.

"We were surprised by how efficiently the network stabilized itself. It was both simple and powerful."

"Unlike simple feedforward models, recurrent networks can store traces of past activity, enabling them to represent time, memory and context," explains Asabuki. "That's why they're often seen as the closest mathematical analog to real brain circuits."

Recurrent neural networks often generate chaotic output that can vary dramatically with just a small change in the input. This is both a good and bad thing.

"Chaos gives the system rich dynamics that can support flexible learning and generalization," says Asabuki. "But it also makes the system unstable and difficult to train. So there's a trade-off between richness and control."

So far, harnessing such complexity has been the main challenge. Several learning rules have been proposed, but they are implausible from a biological perspective.

Now, Asabuki and Claudia Clopath of Imperial College London, UK, have found a way to do it in a biologically plausible way.

"Our study shows that a neural network can stabilize its chaotic activity through a biologically plausible mechanism, without relying on unrealistic computations," says Asabuki.

The pair started from a simple question: if the brain is constantly predicting the future, could prediction itself be used as a stabilizing force?

"We designed a learning rule that allows each neuron to predict the future output of the network," says Asabuki. "By aligning these predictions with the actual feedback signals, the network gradually learns to suppress its chaotic dynamics."

Through simulation, they found that this rule led to remarkably smooth transitions. "We were surprised by how efficiently the network stabilized itself," says Asabuki. "It was both simple and powerful." ●

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ASTROCYTES

Astrocytes burn experiences into our memories

Surprisingly, astrocytes rather than neurons are responsible for stabilizing long-term memories

The brain cells responsible for consolidating memories aren't neurons but astrocytes, a type of glial cell that plays a role in learning and memory, RIKEN neuroscientists have found[1]. This discovery could shed light on post-traumatic stress disorder (PTSD) and related conditions.

Jun Nagai of the RIKEN Center for Brain Science and his coworkers wanted to discover why we are able to recall only some of our past experiences.

When it became clear that engrams—the actual memory traces that exist in neurons—cannot solely account for stabilized, long-term memories, Nagai wondered if astrocytes, which have been thought to play a supporting role in the brain, might be involved.

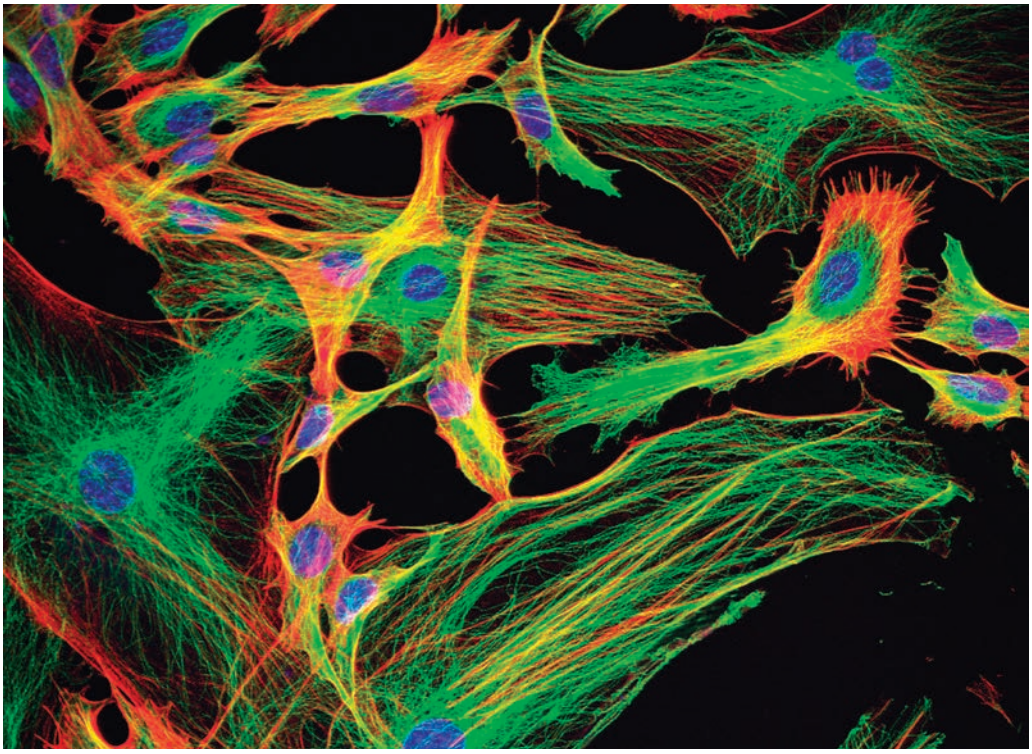
When activated, neurons produce a protein called Fos. Experiences can also trigger Fos production in some astrocytes.

To monitor how astrocytes across the whole brain respond during learning and recall, the researchers developed a system that fluorescently labels astrocytes but not neurons with active Fos.

They then taught mice to associate a certain cage with an unpleasant experience. When mice were returned to the cage several days later, their reaction showed whether they remembered the past event.

The key finding was that unlike in neurons, the researchers observed strong Fos activity in astrocytes only during recall, but not during the initial learning.

Further experiments showed that Fos activity in these astrocytes requires input from the neurons in the amygdala that form the fear-memory engram in question, as well as simultaneous input from neurons that use the compound noradrenaline as a transmitter.



A confocal light micrograph of astrocytes from the brain of a mouse. RIKEN researchers have found that astrocytes are responsible for consolidating memories.

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But engram activity and noradrenergic input happen during both learning and recall. So why does the Fos activity in astrocytes only happen during recall?

Single-cell RNA sequencing of the astrocytes revealed that in the days following the emotional experience, the astrocytes began to produce alpha1A and beta1 adrenoreceptors, which are activated by noradrenaline. The extra adrenoreceptors can be thought of as a tag that identifies which astrocytes should be activated and produce Fos the next time the animal recalls the experience and the neural engram is activated.

To test this, the researchers blocked Fos^+ astrocyte signaling during recall. They observed that mice had unstable memories and did not react as if they remembered anything during the recall test.

Conversely, when the team forced the astrocytes to activate, animals were able to recall mildly unpleasant experiences. If the experiences were very unpleasant, the mice would even generalize their recalled experiences to other cages where no unpleasant incident had occurred.

"These findings could lead to new therapeutic approaches that target the astrocytic memory switch, leading to therapies that gently dampen traumatic memories while sparing others," says Nagai.

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OXYGEN EVOLUTION REACTION

Manganese's resilience is key to its use as a catalyst

Researchers have discovered why manganese is an effective catalyst for a key reaction in photosynthesis

It's rather curious that manganese is the key catalyst in one of nature's crucial chemical reactions rather than similar, more plentiful elements such as iron. RIKEN researchers may have discovered the reason why[1]. This finding could have implications for generating renewable energy.

The oxygen evolution reaction is crucial for life on Earth since it lies at the heart of photosynthesis. It uses energy to liberate protons and electrons from water—freeing oxygen in the process, which we and other life forms breathe.

Manganese, in the form of oxide-like manganese clusters, is the main catalyst in this reaction. The manganese in this cluster can exist in various oxidation states.

When solar or electrical energy fluctuates, manganese's oxidation state changes, allowing it to drive the reaction repeatedly. The cyclic nature of this process is a key feature for sustainable reactions, as it allows catalysts to be used over and over.

For an ideal catalyst, this process could be repeated indefinitely. However, real catalysts deactivate over time, due to processes such as the dissolution of manganese ions. This is usually a one-way path, and the lost ions do not return to the catalyst.

Now, a team led by Ryuhei Nakamura of the RIKEN Center for Sustainable Resource Science has incorporated the Guyard reaction—in which the oxidation state of the manganese ion changes from seven to three.

RIKEN researchers have discovered why plants use the metal manganese as a catalyst for the oxygen-evolution reaction in photosynthesis.

When the Guyard reaction was incorporated, the catalyst decomposed as expected when the voltage became too high, but it was regenerated when the excess voltage was removed. This highlights the importance of pathway design for sustainable energy conversion from intermittent renewable sources.

"We have shown it is possible to develop materials resistant to fluctuating voltages."

This regeneration is unique to manganese, since similar chemical elements in the 3d block of the periodic table, such as cobalt, iron and nickel, cannot regenerate under the same experimental conditions. The researchers believe this is a major reason why manganese is the key catalyst in photosynthesis.

"We have shown it is possible to develop materials resistant to fluctuating voltages, with the potential to eventually develop materials that can be used in water electrolyzers—devices that convert water into oxygen and hydrogen—connected directly to renewable energy sources," says Nakamura. This is because renewable energy sources, such as solar and wind power, fluctuate on time scales of seconds to hours.

"This is important work, but in order to create industrial applications for this, we would need to be able to extend the lifespan by at least an order of magnitude," says Nakamura. "We're tackling this issue now." ●

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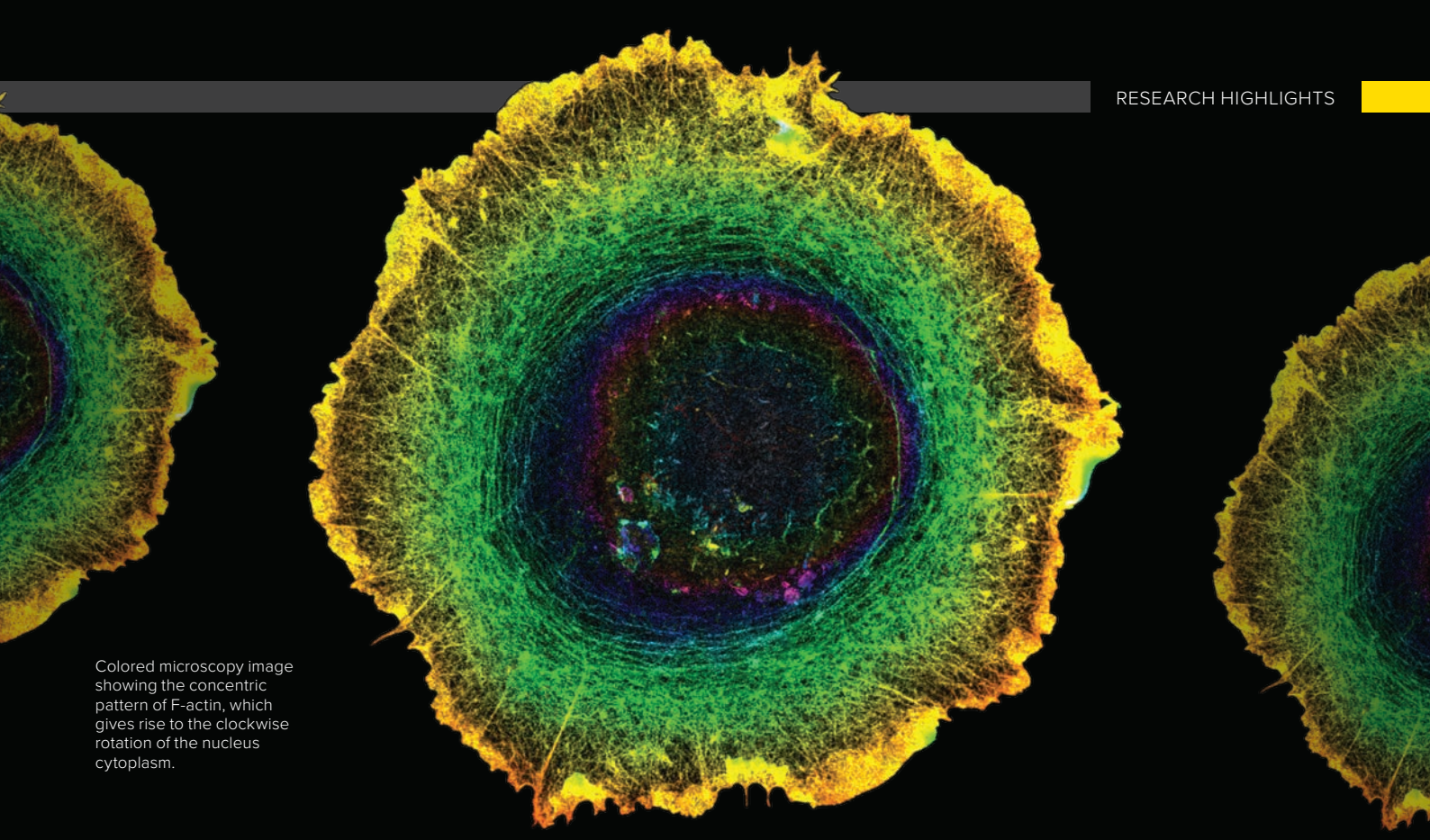

Colored microscopy image showing the concentric pattern of F-actin, which gives rise to the clockwise rotation of the nucleus cytoplasm.

CELL CHIRALITY

How molecules impart cells with chirality

A cell's molecular scaffolding is found to be responsible for the clockwise movement of its contents

RIKEN researchers have discovered how right-handed molecules in our cells can give rise to cells that are not symmetrical about their central axes[1]. This discovery is a key step toward determining why most of our organs lack left–right symmetry.

It's conceivable that if some molecules that make up our cells were twisted in the opposite direction, our hearts would be on the right side of our bodies rather than on the left.

That's because the difference between the left and right sides of our organs may originate from the 'handedness', or chirality, of cells, which in turn comes from the chirality of molecules in cells.

However, the link between the chirality of molecules and cellular chirality is largely unknown. Many molecules in cells are chiral, including DNA and some amino acids and proteins, but it's not clear which ones convey their chirality to cells.

The team lead by Tatsuo Shibata of the RIKEN Center for Biosystems Dynamics Research first became interested in this question while studying genital discs in fly larvae, which always rotate in a clockwise direction. They wanted to trace this phenomenon back to its molecule-level source.

"Through our work with flies, we became interested in working out how tissue-level chirality emerges from the chirality of individual cells, and how the chirality of individual cells emerges from the molecular-level chirality."

Now, by studying the chiral behaviors of individual cells, Shibata and co-workers have found that the cells' scaffolding, or cytoskeleton, gives rise to the cell's chirality.

When single cells were placed on a substrate, their nuclei and surrounding cytoplasm rotated in a clockwise direction when viewed from above. This rotational motion is driven by the concentric pattern of the actomyosin filaments that make up the cytoskeleton.

This finding implies that the cell nucleus can rotate even when there is no chiral orientation of the cytoskeleton on a cellular level.

To confirm whether this mechanism was driving the rotation, the team created a 3D theoretical model of a cell and evaluated the effect of the molecular chirality of actin and myosin on it. The results revealed that the molecular scale torque generated by individual components of the cytoskeleton can generate rotation, even when cell-level chiral structures were absent.

These results help fill in a critical link in the chain from molecules to organs and bodies, the researchers say.

"Our findings provide new insights into how molecular chirality gives rise to cellular chirality," says Shibata. "They thus represent an important step toward understanding left–right symmetry breaking in tissues and organs."

Reference

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NUCLEAR PHYSICS

AI helps scientists find new atomic nucleus

AI helps to track down an exotic nucleus lurking undetected in old, unanalyzed data

RIKEN researchers have identified an exotic nucleus by allowing deep learning to trawl through vast amounts of unexamined data[1]. The finding provides new insights into the composition of cores of neutron stars—one of the most extreme environments in the Universe.

The atoms of ordinary matter consist of protons and neutrons, which are, in turn, made of quarks. The strong nuclear force binds particles such as protons and neutrons together. Understanding the origin of this force is crucial for explaining how matter and the Universe formed.

To probe the strong force more deeply, scientists study hypernuclei—atomic nuclei that contain hyperons, which are particles that include a strange quark.

"We believe that this approach can deepen our understanding of the nuclear force and the structure of matter in the Universe."

In extremely rare cases, two hyperons can be bound within the same nucleus, forming a double-Lambda hypernucleus.

These systems allow researchers to explore how the strong nuclear force behaves when strange quarks are involved. They can also better understand the properties of matter under the extreme densities found in neutron stars, where hyperons are expected to exist.

Detecting double-Lambda hypernuclei has been a major challenge because they are produced very rarely and exhibit complex decay structures.

In the J-PARC E07 experiment, nuclear emulsion plates recorded the tracks of particles resulting from hypernuclear formation and decay. However, only a tiny fraction of the emulsion data has been analyzed because conventional methods are time- and labor- consuming. Consequently, a vast amount of valuable information remains unexplored.

To process this enormous dataset, the RIKEN-led team developed a deep-learning–based analysis framework. By training neural networks to recognize the subtle signatures of double-strangeness events, the researchers could automatically extract candidate images indicating the potential formation and decay of double-Lambda hypernuclei.

When these candidates were examined under a microscope, one event was confirmed to be the production of a double-Lambda hypernucleus of boron-13, in which two Lambda particles are bound to a boron-11 nucleus.

This identification is only the second unambiguous observation of a double-Lambda hypernucleus in history; the first one was made nearly 25 years ago.

An illustration of a neutron star. By analyzing previously acquired data from a proton accelerator, RIKEN researchers have identified an exotic nucleus that may exist in neutron stars.

Remarkably, this breakthrough was achieved by analyzing just 0.2% of the total emulsion data from the J-PARC E07 experiment. Based on this detection rate, the researchers estimate that the full dataset could contain more than 2,000 double-strangeness events awaiting discovery.

"This achievement demonstrates how AI can uncover extremely rare phenomena hidden within massive experimental datasets, revealing events that would be nearly impossible to find by human inspection alone," says Takehiko Saito of the RIKEN High Energy Nuclear Physics Laboratory. "We believe that this approach can deepen our understanding of the nuclear force and the structure of matter in the Universe." ●

Reference

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SPERMATOGENESIS

Key proteins in sperm tails could be involved in male infertility

Interruptions to key critical proteins in germ cells result in sperm that are unable to swim

A key structure in the germ cells of male mice that, when disturbed, leads to deformations in sperm flagella—tails that allow sperm to swim—has been discovered by RIKEN researchers[1]. This could explain some forms of male infertility.

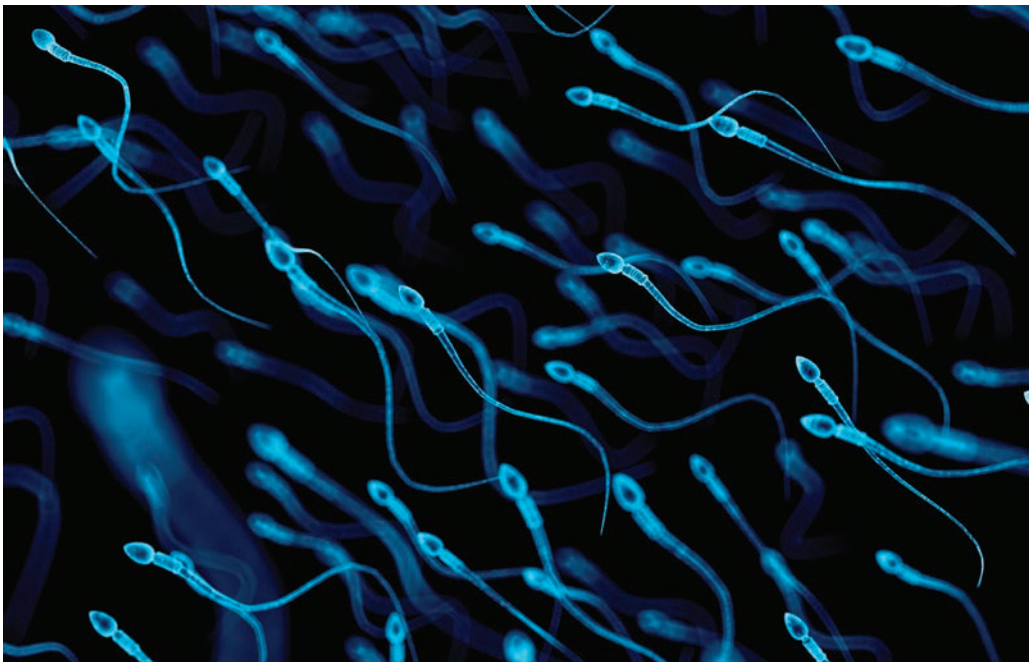
When conception fails, it is often due to abnormalities in egg or sperm cells that occur during their development. In males, this process is called spermatogenesis and continues throughout life after puberty. Scientists have yet to map everything that happens at the subcellular level of this process.

"While the causes of female infertility have been studied extensively, the mechanisms underlying male infertility—which are known to account for about half of all infertility cases—remain poorly understood," says Hiroki Shibuya at the RIKEN Center for Biosystems Dynamics Research.

Shibuya's team tackled this problem by adapting ultrastructure expansion microscopy, a relatively new technique that can overcome limitations of conventional techniques such as electron microscopy and fluorescence microscopy.

Cells of interest are placed on a gel, which is then expanded many times its original size. Standard immunofluorescence labeling combined with a fluorescence microscope can be used to look at the giant specimen and specific ultrastructures can be imaged at high resolution.

The researchers adapted this technique for male mouse germ cells by gently fixing and drying the cells onto coverslips before putting them in the gel. This prevented the cells from moving around, which is a problem for male germ cells.



An illustration of human sperm. RIKEN researchers have identified a key structure in the germ cells of male mice that, when disturbed, results in sperm with deformed tails.

The team focused on the centriole, a tiny cylindrical structure that undergoes major changes during spermatogenesis that allow the flagellum to form. A correctly formed flagellum is critical because without it, sperm cannot reach an egg cell to fertilize it.

Using their modified protocol, the researchers were able to visualize both the proximal and distal centriole throughout the entire transformation from germ cell to sperm.

They found that the inner scaffold within the distal centriole becomes stronger after the germ cells divide and the daughter cells contain only one copy of each gene.

Fluorescent labeling of key proteins that make up the distal centriole inner scaffold showed an increase in centrin–POC5 protein complexes.

The results highlighted the importance of these proteins for fertility. Knocking out *Poc5* produced normal male mice with no viable sperm. Analysis revealed that while centriole function in regular cells was unaffected, the lack of POC5 caused malformed flagella that disintegrated, explaining why the mice were completely infertile.

"Our modified expansion microscopy protocol can be extended to other analyses, including human sperm," says Shibuya. "In the long-term, this could lead to novel diagnostic and therapeutic approaches in reproductive medicine." ●

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A new approach to simulations combines numerical simulations and AI. It can greatly accelerate the simulation of how a galaxy evolves.

ASTROPHYSICS

Simulating a galaxy of stars for a million years

A new approach to simulations can accelerate the replication of galaxy evolution at a single-star level

The world's first simulation of the Milky Way at an individual star level across a simulated span of 10,000 years has been performed by RIKEN astrophysicists[1]. Combining AI with numerical simulations, the simulation represented 100 times more individual stars than previous state-of-the-art models and was performed more than 100 times faster.

Astrophysicists want to simulate the Milky Way down to the individual star level since they could then test theories of galactic formation and stellar evolution against real observations. But scientists had been unable to model large galaxies like the Milky Way while also maintaining a star-level resolution.

The upper mass limit of current state-of-the-art simulations is about a billion stars, while the Milky Way has more than 100 times that number. Consequently, these simulations can only replicate large-scale events accurately.

Rapid changes at the level of individual stars, like the evolution of supernovae, can only be observed by making the time between each snapshot of the galaxy short enough. But processing smaller time steps takes more time and computational resources.

If the best conventional physical simulation to date were to simulate the Milky Way down to individual stars, it would take roughly 36 years to simulate one billion years of galaxy evolution.

Adding more supercomputer cores is not a viable solution as they will not necessarily accelerate the process due to reductions in efficiency, as well as consume an incredible amount of energy.

Now, a new approach that combines a deep learning surrogate model with physical simulations has been developed by a team led by Keiya Hirashima of the RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS).

The surrogate model was trained on high-resolution simulations of a supernova and learned to predict how the surrounding gas expands in the 100,000 years after a supernova explosion, without using resources from the rest of the model. This AI shortcut enabled the simulation to model both the overall dynamics of the galaxy and fine-scale phenomena such as supernova explosions.

To verify the simulation's performance, the team compared its output with large-scale tests using supercomputers.

The method allowed individual star resolution in large galaxies with more than 100 billion stars. It also took only 2.8 hours to simulate a million years. Thus, the desired billion years could be simulated in a mere 115 days, rather than 36 years.

Beyond astrophysics, this approach could transform other multiscale simulations—such as those in weather, ocean and climate science—in which simulations need to link both small-scale and large-scale processes.

"I believe that integrating AI with high-performance computing marks a fundamental shift in how we tackle multiscale, multi-physics problems across the computational sciences," says Hirashima. ●

Reference

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SLEEP

How deep sleep purges the mind

Deep sleep is found to be important for clearing the brain of fluid buildup

RIKEN researchers have uncovered a link between deep sleep and cerebrospinal fluid—the clear liquid that surrounds and supports the brain and spinal cord[1]. This finding offers a clue as to why stable sleep is important for normal brain function.

Sleep is important for consolidating memories and removing waste products from the brain. In particular, it is thought to control the flow of cerebrospinal fluid and could be important for clearing this waste.

But how it does this and which of the sleep stages—light sleep, rapid eye movement (REM) sleep, and deep, non-REM sleep—is important for this clearance had been unclear.

Determining the role of deep sleep in controlling cerebrospinal-fluid dynamics has been challenging. That's partly because the usual method for observing the signals coming from the fluid—a functional magnetic resonance imaging (fMRI) scan—is extremely loud. The noise makes it difficult for subjects to attain deep sleep and remain there long enough to collect meaningful data.

To overcome this problem, a team led by Masako Tamaki of the RIKEN Center for Brain Science used sparse fMRI, which performs scans roughly every 3 seconds rather than continuously. The silences between the scans allowed the human subjects to reach deep sleep.

While subjects slept in the fMRI scanner, their brain waves were also recorded because slow waves are thought to be important for controlling cerebrospinal fluid.

RIKEN researchers have found that deep sleep affects cerebrospinal fluid signals differently from the other phases of sleep.

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The researchers found clear differences in how fMRI signals from fluid-filled regions of the brain changed during the three different sleep stages.

Slow brain waves and other events during deep, non-REM sleep triggered frequent, medium-sized signal increases within 8 seconds. The pattern was quite different during light sleep and arousal, with slow waves triggering a sharp increase in the signal, which was slower and less frequent. REM sleep also affected the signal, but the changes were very small and took almost 30 seconds.

The sleep stages were also associated with activity in different brain networks. Memory-related brain regions, such as the hippocampus and frontal cortex, were more active during slow-wave sleep than light sleep.

These results indicate that when the memory network is active during deep sleep, the slow brain waves have a specific effect on the cerebrospinal-fluid signal that does not occur during other sleep stages when different brain regions are more active.

"Our findings indicate that deep sleep affects cerebrospinal fluid signals differently than do light sleep, REM sleep or arousal," says Tamaki. "The rapid, yet moderate increases in the signal might relate to a process that is necessary for removing the particular kinds of waste that tend to accumulate within the learning and memory brain network during the day." ●

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CHIRAL MAGNETS

Why a chiral magnet is a direction-dependent street for electrons

Two different mechanisms are found to be responsible for the direction-dependent flow of electrons in chiral magnets

RIKEN physicists have discovered for the first time why the magnitude of the electron flow depends on direction in a special kind of magnet[1]. This find could help realize future low-energy devices.

In a normal magnet, all the spins of electrons point in the same direction. In a special class of magnets known as chiral magnets, the electron spins resemble a spiral staircase, having a helical organization.

This structure imparts chiral magnets with special magnetic and electronic properties. For example, electrons can preferably flow along them in one direction but not another. This effect is akin to what occurs in diodes, except it occurs within a single material rather than in a junction between two semiconductors.

"If we can determine the mechanism, it would give us more control of the system."

Chiral magnetics could have practical applications since they can host tiny magnetic whirlpools known as skyrmions, which are promising for realizing memory devices that have low energy consumption.

Several mechanisms have been proposed for the direction-dependent flow of electrons in chiral magnets, but no previous study had successfully separated and assigned multiple mechanisms in a single material.

Understanding what causes the effect has been important, as it would help physicists to exploit it better. "If we can determine the mechanism, it would give us more control of the system," explains Daisuke Nakamura of the RIKEN Center for Emergent Matter Science.

Now, Nakamura and co-workers have found that two separate effects can account for the direction-dependent flow of electrons in a chiral magnet.

Which effect dominates depends on the temperature and the magnetic field. In some cases, electrons traveling in one direction are scattered more frequently by magnetic quasiparticles with chirality, whereas those traveling in the other direction are not scattered so much.

The other mechanism occurs when mobile electrons couple with the helical spins of static electrons. The latter contribute to the symmetry-breaking energy map of mobile electrons in the chiral magnet.

Measurements alone were not enough to determine the mechanisms—theoretical calculations were also required. "Clarifying the mechanism is very challenging," says Nakamura. "We had to enlist the help of theoretical physicists that are based at RIKEN and collaborative research groups."

For the investigation, the team chose a chiral magnet made of the three metals cobalt, zinc and manganese. Unlike many chiral magnets, this type can show a helical spin arrangement at a wide range of temperatures, including room temperature.

However, the researchers anticipate that their findings will apply to other systems and materials, opening the door to new discoveries in the one-way conduction of electricity.

They now intend to investigate what happens when they vary the makeup of the chiral magnet by tweaking the ratio of the three metals. ●

The arrangement of electron spins in a chiral magnet resembles a spiral staircase. RIKEN researchers have determined why electrons flow in only one direction in a chiral magnet.

Reference

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PLANT GENETICS

Iron supplement helps stressed wheat grow big and strong

Counteracting an iron deficiency in wheat caused by extreme heat can produce healthier plants

Wheat crops subjected to extended periods of stress such as excessive heat exhibit iron deficiency that stunts their growth, RIKEN researchers have found[1]. But they also showed that a synthetic organic compound can reduce the iron deficiency, resulting in better growth and healthier plants.

A major threat of climate change is that extended hot periods could disrupt food production. Even moderate warming could reduce the yield of cool-season cereal crops such as wheat.

Most research into how plants adapt to heat stress has focused on acute stress—very high temperatures over a few days. However, Keiichi Mochida of the RIKEN Center for Sustainable Resource Science views extended periods of moderately high temperatures as a greater threat.

Mochida's team found that, after two weeks of moderate heat stress, wheat plants photosynthesized less than those grown at normal temperatures. Also, leaves from the heat-stressed plants contained less than half the normal amount of iron, suggesting that iron deficiency stunts growth.

Because wheat is genetically complex, the researchers used a genetically simpler grass that is a model plant for cereal crops. In experiments, the model grass responded to heat stress similarly to wheat. But the degree to which the grass was affected varied between samples, as did the iron deficiency.

For example, grass sample Bd21 had extremely low biomass, very yellow leaves and 91% less iron than plants grown in normal temperatures, whereas sample Bd21-3 had somewhat milder symptoms and only 61% iron deficiency.

The simpler genome of the grass allowed the researchers to track down the gene responsible for this difference—*BdTOM1*.

Plants cannot directly extract iron from the soil. Instead, they make organic compounds called mugineic acids, which bind to iron in the soil and plants take them up through their roots.

The gene *BdTOM1* is responsible for making mugineic acids. After two weeks of heat stress, grass sample Bd21-3 had much more deoxymugineic acid in its roots than Bd21. This explains why Bd21 had greater iron deficiency, and suggests that variations in *BdTOM1* are likely responsible for variations in heat-stress susceptibility.

The researchers wondered if they could alleviate iron deficiency and improve growth by giving heat-sensitive plants more deoxymugineic acid. When they gave PDMA, a synthetic deoxymugineic acid, to the model grass and wheat under heat stress, the team observed that both photosynthesis and biomass improved, provided the PDMA concentration wasn't too high.

Mochida is optimistic about testing these findings in the field. "In the short term, this research proposes a new approach to enhancing crop heat stress tolerance," he says. "In the long term, breeding efforts targeting the genes involved could contribute to food security and sustainable agriculture."

Reference

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RIKEN researchers have found that a synthetic organic compound could be useful for treating iron deficiency in wheat (pictured) caused by extended periods of stress, such as excessive heat.

BIODEGRADABLE POLYMERS

A plant-based polymer that is fully degradable in saltwater

A cellulose-based polymer that biodegrades within hours in seawater could help tackle the problem of microplastics

RIKEN researchers have created a strong, flexible plastic that decomposes rapidly in natural environments from plant cellulose—the world's most abundant organic compound[1]. This plastic could help address the global problem of microplastics.

Microplastics are a ubiquitous contaminant. They have even been found in human tissue and blood, where they are likely to have adverse effects.

Most 'biodegradable' plastics do not degrade in marine environments or they take a very long time, creating microplastics in the meantime.

In 2024, Takuzo Aida of the RIKEN Center for Emergent Matter Science and his team developed a plastic that could degrade in salt water within several hours, without leaving any microplastics behind.

That plastic was made from two monomers held together by reversible interactions called salt bridges. These salt bridges broke in the presence of salt water, causing the plastic to decompose. However, this plastic still faced challenges in terms of practical applications.

The new plastic is similar, except that one of the two monomers is a commercially available, biodegradable derivative of wood pulp.

The team found a compatible second monomer: a safe cross-linking agent made from positively charged polyethylene-imine guanidinium monomer. When the cellulose and guanidinium ions were mixed in water at room temperature, the negatively and positively charged molecules attracted each other, forming the critical cross-linked network that makes this kind of plastic strong.

The salt bridges holding the network together broke in the presence of salt water. But the new plastic was too brittle because of the cellulose, having a fragile, glass-like quality. The team needed a good plasticizer—a small molecule they could add to make the plastic more flexible, yet hard.

They discovered that the organic salt choline chloride worked wonders. By adding varying amounts of it to the plastic, the researchers could fine-tune the flexibility of the plastic.

The improvements on the original design are non-trivial. "While our initial study focused mostly on the conceptual, this study shows that our work is now at a more practical stage," explains Aida.

Microplastics such as those shown here pose a major environmental problem. RIKEN chemists have developed a strong and flexible plastic that decomposes in marine environments.

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The new plastic is as strong as conventional petroleum-based plastics. In addition, its mechanical properties can be adjusted as needed, without spoiling the intrinsic transparency, processability, seawater dissociability or closed-loop recyclability.

The plastic should be able to move quickly to practical applications since it uses common and inexpensive biodegradable ingredients.

"Nature produces about one trillion tons of cellulose every year," notes Aida. "From this abundant natural substance, we have created a flexible yet tough plastic material that safely decomposes in the ocean. This technology will help protect the Earth from plastic pollution." ●

Reference

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EMBRYO DEVELOPMENT

How embryos first regulate their genes

Scientists have uncovered how genes are regulated in fish embryos when they first use their own DNA

A RIKEN researcher and his colleague have identified how genes are expressed in embryos of two fish species when they first start using their own genetic material[1]. If the same mechanisms apply to humans, the finding could shed light on developmental problems.

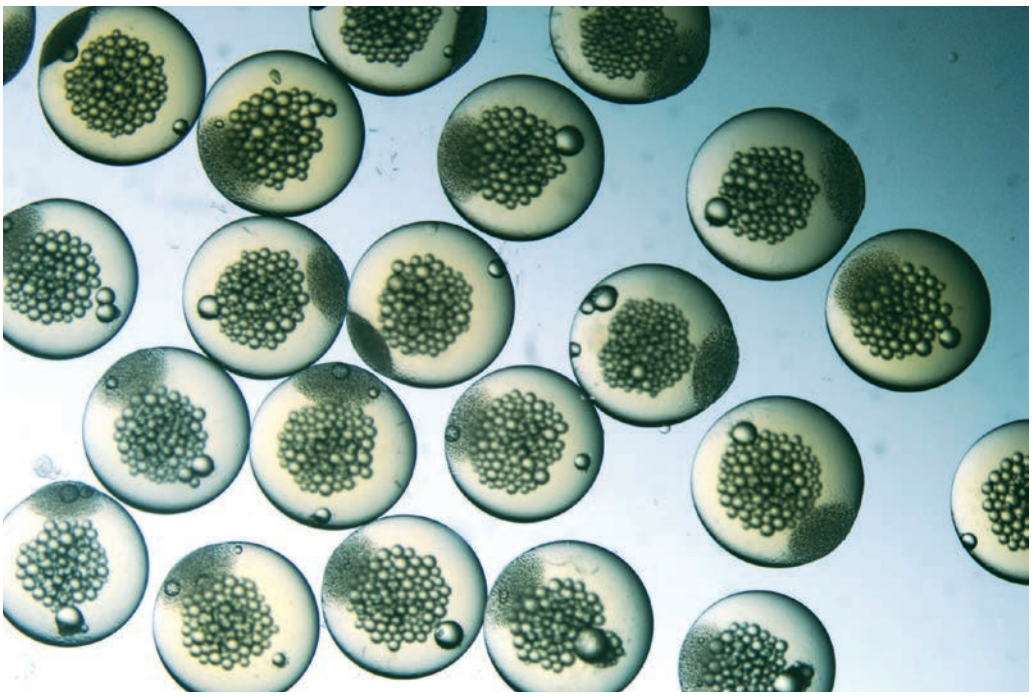
After an egg is fertilized by a sperm, the fertilized egg initially relies on proteins and RNA it received from its mother. But after several cell divisions, it undergoes a critical transition and switches to using its own genome to guide development.

Known as zygotic genome activation (ZGA), this transition is accompanied by a flurry of genetic activity.

"Unlike normal transcription of DNA in typical cells, more than 1,000 genes are simultaneously activated in only a few hours during ZGA in non-mammalian species," explains Hiroto Fukushima of the RIKEN Center for Integrative Medical Sciences. "This implies that transcription during ZGA proceeds in a unique manner, but the regulations that govern it have yet to be identified."

One way the genome in embryos is modified during ZGA is through chemical changes to the four different proteins that make up histones—the spools around which DNA is wrapped. Such histone modifications can turn the expression of certain genes on or off. However, their roles in ZGA hadn't been fully clarified until now.

Fukushima first became interested in this question serendipitously. "While teaching an undergraduate student about an unrelated topic, I was very surprised when I found that the active histone modification H3K27ac is strongly accumulated specifically during ZGA," he recalls. "I first thought it was an artifact, but it proved to be reproducible."



Fish embryos 34 hours after fertilization during zygotic genome activation. A RIKEN researcher and his colleague have determined the mechanism of gene expression during this stage.

Previously, the only other observation of such strong enrichment of histone modification was during sperm production. That led Fukushima to wonder whether the exceptional accumulation of H3K27ac was important for the unique nature of transcription during ZGA.

Fukushima and Hiroyuki Takeda of Kyoto Sangyo University have now comprehensively examined the roles of histone modifications in zebrafish and Japanese rice fish embryos (see image).

The pair discovered that H3K27ac and another histone modification, H3.3S31ph, activate developmental genes during ZGA by modulating RNA polymerase activity.

"The function of H3.3S31ph during ZGA is particularly significant," says Fukushima. "It's known to be involved in regulating the cell cycle, and the cycle slows dramatically after ZGA in non-mammalian species."

The researchers found that at least six histone modifications coordinate to regulate ZGA. They also discovered that developmental genes—those that control the growth, differentiation, and organization of cells during development—and housekeeping genes, which are needed for normal cellular functions, are activated by different active histone modifications.

The findings confirm the special nature of ZGA. "As we expected, our data indicates that gene activation during ZGA occurs in a unique manner," says Fukushima. ●

Reference

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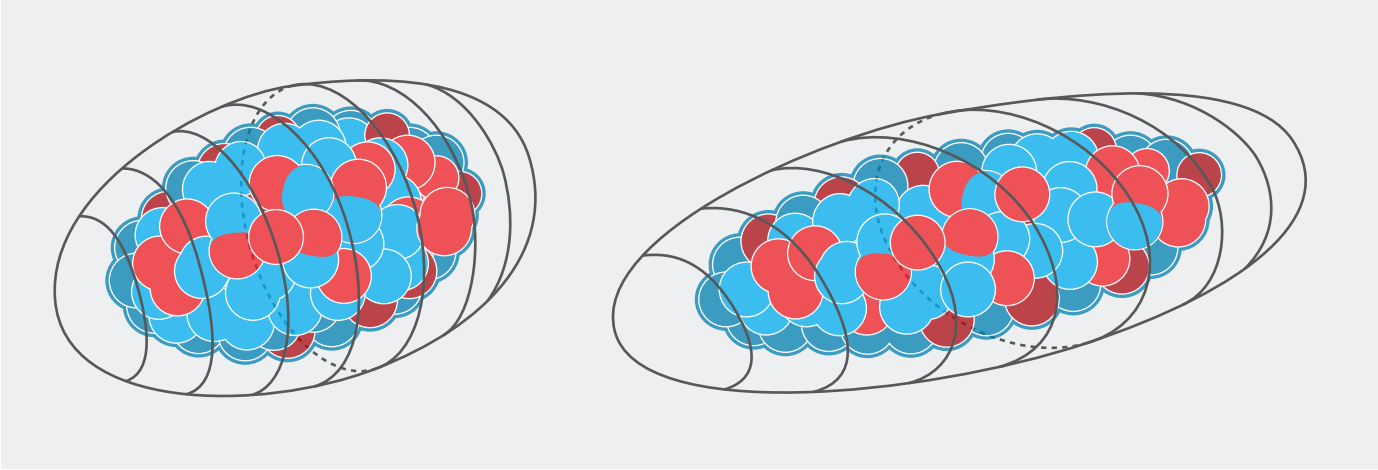


Until now, physicists thought that all heavy nuclei deformed from spheres are elongated in one direction like rugby balls (left), but RIKEN researchers have shown that virtually all of such nuclei have triaxial symmetry with oval cross-sections like almonds (right).

NUCLEAR SHAPES

Heavy atomic nuclei are not as symmetric as previously thought

Big atomic nuclei are closer to almonds than rugby balls in shape, RIKEN nuclear physicists find

Many heavy atomic nuclei are shaped more or less like squashed rugby balls than fully inflated ones, a theoretical study by RIKEN nuclear physicists has found[1]. This unexpected finding overturns the consensus held for more than half a century.

Illustrations of atoms often depict the nucleus as a round blob made up of neutrons and protons. Physicists initially assumed that nuclei were spherical like soccer balls.

But in the 1950s, Aage Bohr and Ben Mottelson developed a theory that predicted that many heavy nuclei are elongated in one direction, being shaped like a rugby ball.

Following in the footsteps of his father Niels Bohr, who was awarded the 1922 Nobel prize in physics for his model of the structure of atoms, Aage Bohr shared the 1975 Nobel prize for physics for this discovery.

But Takaharu Otsuka, a visiting scientist at the RIKEN Nishina Center for Accelerator-Based Science, always had niggling doubts about this.

"This work represents a major shift in the fundamental description of nuclear structure."

In particular, he wondered why heavy nuclei should be shaped like rugby balls, which are round in cross section, and not have a more general, almond-like shape that is oval in cross section. It struck him that the lower symmetry shape would be more natural for nuclei to adopt (see image).

"When Aage Bohr's model was proposed it produced some simple calculations, but they appeared overly simplistic to me," he recalls. "And there was no convincing general argument why the nucleus should be deformed in such a symmetric way."

Over the decades, this doubt nagged at the back of Otsuka's mind, and he increasingly began to question whether most large nuclei were actually rugby-ball shaped. But when he started proposing at conferences that nuclei with almond-like shapes are common, he experienced a lot of scepticism and even opposition from other nuclear physicists.

Now, Otsuka has been vindicated, showing in a theoretical study with co-workers that virtually all heavy ellipsoidally deformed nuclei actually have triaxial shapes resembling almonds rather than biaxial shapes like rugby balls.

"This work represents a major shift in the fundamental description of nuclear structure that was entrenched for nearly 70 years," says Otsuka.

One thing that was indispensable for Otsuka's team was having access to one of the most powerful supercomputers in the world, the Fugaku computer.

This finding about the shape of nuclei affects how nuclei rotate since it means they can rotate about two axes instead of just one. It also has implications for the search for new superheavy nuclei that are heavier than currently known nuclei. ●

Reference

1. Otsuka, T., Tsunoda, Y., Shimizu, N., Utsuno, Y., Abe, T. & Ueno, H. Prevailing triaxial shapes in atomic nuclei and a quantum theory of rotation of composite objects. *The European Physical Journal A* **61,** 126 (2025).

CONTEXTUAL BEHAVIOR

Modeling how the brain factors in context

A simple model goes a long way to explaining how context-dependent behavior occurs

How animals may modify their behavior depending on their context has been modeled mathematically by two RIKEN neuroscientists[1]. Their simple but biologically plausible model could shed light on nondevelopmental conditions such as autism and schizophrenia.

Animals, including humans, commonly behave differently depending on the situation they are in. For example, hearing the word "Fire!" could cause someone to evacuate a building or to pull the trigger of a gun depending on the context.

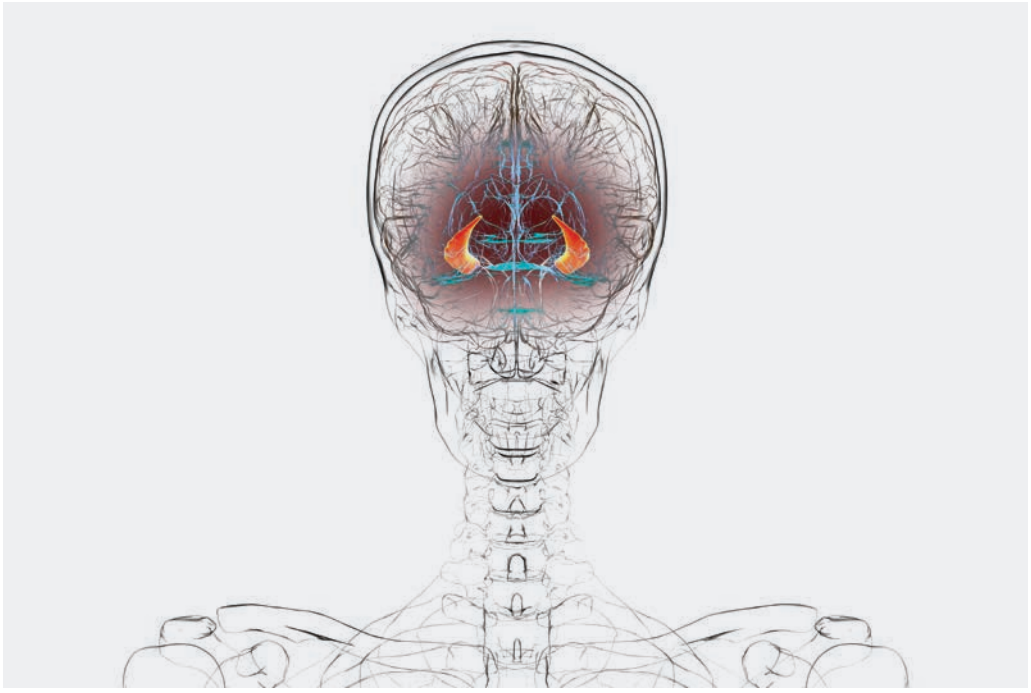
That implies that the brain must combine sensory input and context when deciding how to react.

An important brain area for this context-dependent behavior is the region known as the hippocampus. In particular, neurons in the hippocampus—especially place cells that register location—undergo reorganization in different contexts. This process is known as hippocampal remapping.

But it's not known how context-dependent behavior sequences arise in the hippocampus. Researchers have developed various theoretical models to explain context-dependent behavior, but they suffer from shortcomings such as not being realistic from a biological standpoint.

"The main thing we want to try to understand is how the brain can achieve flexible behavior without resorting to highly sophisticated learning rules," says Taro Toyoizumi of the RIKEN Center for Brain Science (CBS).

Now, Toyoizumi and Yoshiki Ito, also of CBS, have modeled flexible behavior in animals using a simple reinforcement learning model that makes sense biologically.



A human brain with the hippocampus highlighted in red. RIKEN researchers have developed a model that may explain how context-dependent behavior arises in the hippocampus.

Despite its simplicity, the model can reproduce various observations in both mice and people.

"It's surprising that this concept hadn't been proposed before," says Toyoizumi. "It uses the well-known associative memory model to retrieve an appropriate context, defined as the combined activity pattern of the sensory-encoding and context-encoding neurons."

The model consists of two network modules: a context selector that stores possible contexts as attractors, and a sequence composer that learns to create context-dependent sequences. These sequences inform courses of actions and predictions about future outcomes via reward-based learning. When the prediction differs from what actually occurs, the context selector triggers remapping in the sequence composer.

Despite being a very basic model, it could offer valuable insights into mental disorders, the researchers think. Patients with schizophrenia or autism often have problems with processing sensory input and flexibility in behavior, but the underlying causes of these symptoms are unknown. A possible explanation is that the balance between the numbers of sensory-encoding and context-encoding neurons could be skewed in these conditions.

"A good balance between the two is crucial for performance," says Toyoizumi. "We conjecture that if one of them is too big, it may give rise to these mental disorders."

"Restoring the balance of neural representations in the brain may help improve psychiatric symptoms," Ito adds. ●

Reference

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SPRING-8-II WILL TRANSFORM THE WAY WE DO SCIENCE

RIKEN's synchrotron is getting a major upgrade, enabling it to deliver 100 times more brilliant X-rays, reveal structures below one nanometer and halve its energy use.

The large-scale synchrotron radiation facility SPring-8 (Super Photon ring–8 GeV), located in the town of Sayo, Hyogo Prefecture, Japan, enables scientists to observe a universe of atoms and molecules using some of the world's most intense and brilliant X-rays. As a shared-use facility, it has produced outstanding research achievements across a wide range of scientific fields. Nearly 30 years after its launch, a major upgrade project is now underway to create SPring-8-II, involving a boost in the brightness of its synchrotron radiation to more than 100 times its current levels.

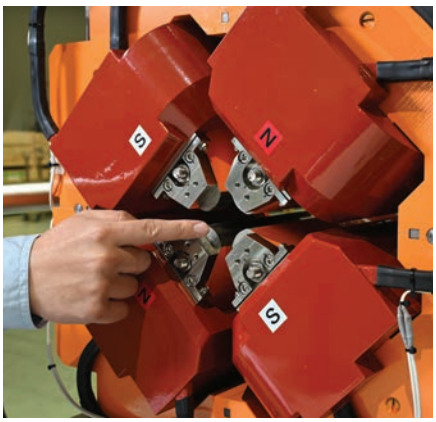
According to Tetsuya Ishikawa, director of the RIKEN SPring-8 Center, the goal of the upgrade is to "pursue cutting-edge research that allows us to see what was previously invisible and expand applications into fields that have not yet sought to see things at this level." With this next-generation, world-class analytical capability, the question is: How will it change science itself?

TOOLS OF DISCOVERY

Across the centuries, humanity has invented tools such as microscopes and telescopes, revealing that living organisms are made of cells and that the Earth is not the center of the universe. Each new 'tool' has opened a new door for science.

Since its launch as a shared-use facility in 1997, SPring-8 has been one of the world's most powerful instruments for probing the microscopic world with X-rays. It has contributed to solving challenges across a wide range of fields—from materials and life sciences to archaeology—by enabling a range of advances. These have included semiconductor structure analysis, elucidation of photosynthetic reactions, the development and evaluation of porous materials, the analysis of asteroid Ryugu samples and even the study of ancient bronze mirrors from Japan's Kofun period.

Having access to a world-class synchrotron facility within Japan is of particular importance to industry.



The four poles of magnets that guide electrons used to produce X-rays in SPring-8-II

One example of industrial applications is the analysis of the internal structure of rubber to support the development of fuel-efficient tires. Because this cutting-edge research could be conducted domestically, companies were able to safeguard their data and proprietary technologies. "This development was possible because SPring-8 existed," says Ishikawa.

However, nearly 30 years have passed since SPring-8 first began operation. The facility has aged and many overseas institutes have already moved toward constructing, or upgrading existing, facilities to next-generation synchrotron facilities. In response, Japan decided to undertake a major upgrade to dramatically enhance SPring-8's performance.

HOW SPRING-8 WORKS

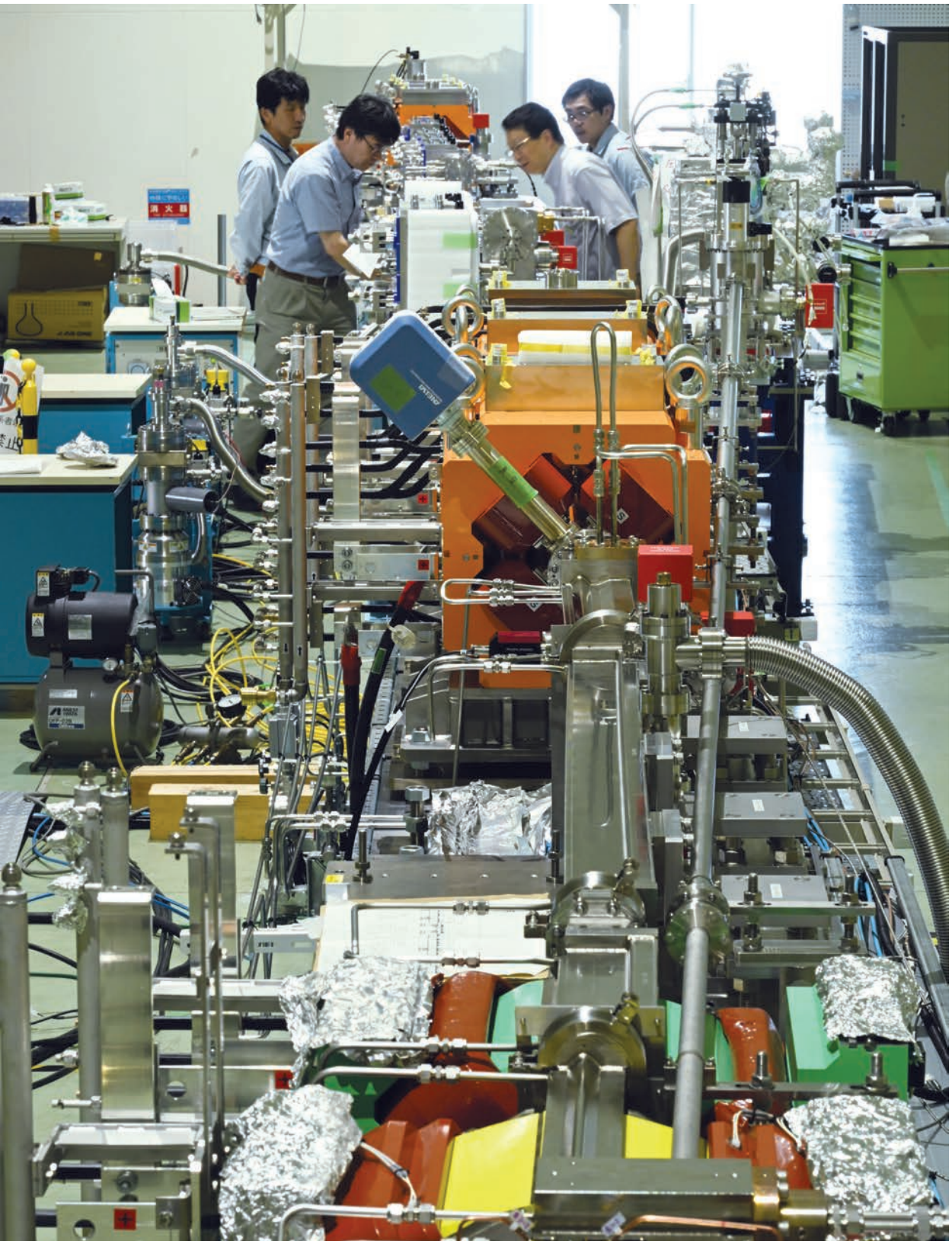
SPring-8 generates highly intense and brilliant X-rays, known as synchrotron radiation, by using magnetic fields to deflect the trajectory of electrons accelerated to nearly the speed of light. The resulting photon flux density exceeds that of conventional X-ray sources by more than seven orders of magnitude, enabling the observation and analysis of nanoscale structures that cannot be resolved with optical microscopy. The facility comprises an injector system that produces and accelerates electrons, and a storage ring approximately 1.5 kilometers in circumference in which the electrons circulate. There are around 60 beamlines installed along the storage ring, each providing experimental stations where synchrotron radiation can be used for a wide range of advanced scientific and industrial applications.

BELOW ONE NANOMETER

So, what will set SPring-8-II apart from the current facility?

The biggest difference is that the brightness (brilliance) of its synchrotron radiation will be increased 100-fold. This leap will be achieved by using cutting-edge technology to focus the electron beam circulating in the storage ring into a pinpoint—just as a magnifying glass focuses sunlight to a single spot.

"The brighter the light, the more finely we can see," explains Ishikawa. The spatial resolution—a measure of how small a world can be observed—is expected to improve dramatically from the current



A prototype of SPring-8-II, which is scheduled to come online in 2029.

TETSUYA ISHIKAWA
Director, RIKEN SPring-8 Center

Tetsuya Ishikawa has been the director of the SPring-8 Center at RIKEN since 2006. After graduating from the University of Tokyo and receiving his doctoral degree in 1982, he joined the Photon Factory at the High Energy Accelerator Research Organization (KEK), as a research associate, overseeing precision X-ray optics. After working at the University of Tokyo, in 1995 RIKEN appointed him chief scientist in charge of beamline development for SPring-8. Under the nation's Third Science and Technology Basic Plan (2006–2010), he spearheaded the development of a compact X-ray Free Electron Laser (XFEL), which culminated in the realization of the SPring-8 Angstrom Compact Free-electron Laser (SACLA). He is now proceeding with the upgrade of the SPring-8.

50 nanometers to below 1 nanometer.

This will enable non-destructive observation of the intricate three-dimensional structures of next-generation semiconductors with line widths as small as several nanometers. Real-time monitoring of chemical reactions inside operating fuel cells, down to the level of individual atoms, will also be possible.

HALVING ENERGY USE

Another major feature of SPring-8-II is its energy efficiency: despite its increased enhanced performance, power consumption will be cut nearly in half.

Thanks to improved beam focusing, the energy needed to circulate electrons in the storage ring will be reduced from 8 to 6 giga-electronvolts. Additional energy savings will come from upgrading the injector system and replacing the electromagnets that bend electron paths with permanent magnets.

Given that SPring-8-II will tackle research critical to building a sustainable society—such as energy and environmental studies—its own sustainability is essential. "A facility that consumes excessive energy would undermine the credibility of its 'green' research," Ishikawa notes. "That's why the facility itself must be green."

DATA-DRIVEN DISCOVERY

SPring-8 will suspend operations in the summer of 2027 and replacing some of its equipment will take about a year. The upgraded SPring-8-II is scheduled to begin shared use in fiscal year 2029.

The enhanced facility is expected to further contribute to fields where SPring-8 has already achieved remarkable success. It has improved infrastructure maintenance by analyzing asphalt degradation and contributed to agricultural research through developing rice varieties resilient to global warming.

But the impact will not end there. "SPring-8-II will not only let us see things previously invisible. It will also expand applications into fields that have not yet used synchrotron radiation," says Ishikawa.

With brighter light comes vastly more data in the same measurement time, meaning experiments can be completed far faster. As a result, synchrotron applications will spread into areas that were once impractical or unimaginable for such techniques—although these are yet to be revealed.

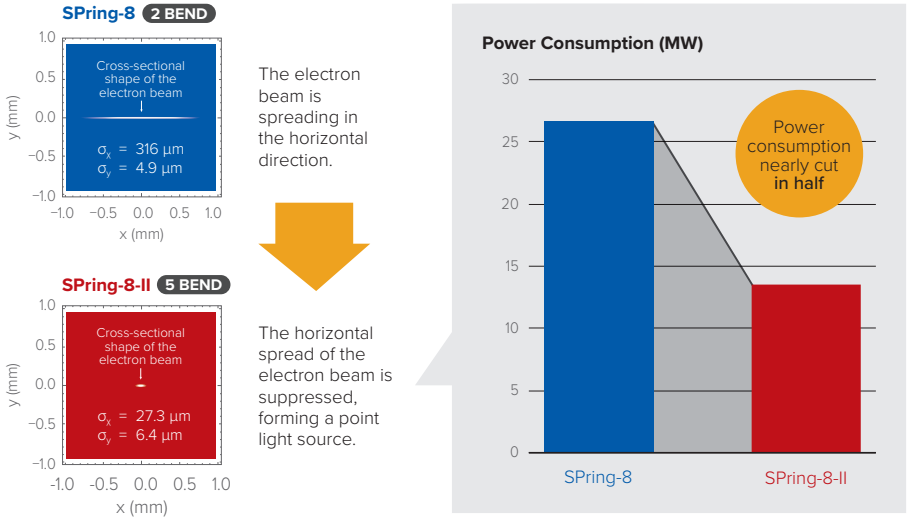
Moreover, SPring-8-II holds the potential to transform the very nature of scientific inquiry. Traditional science has followed the model of forming a hypothesis and designing experiments to test it. In the age of SPring-8-II, a new paradigm—data-driven science—will emerge, where researchers collect massive amounts of data first and then discover patterns and principles from it.

Having worked with SPring-8 since its earliest development more than three decades ago, Ishikawa says: "Synchrotron facilities used to be things that were nice to have. Thanks to SPring-8, they've become indispensable. And SPring-8-II will be even more essential than ever before."

Researchers around the world eagerly await the start of shared operations in 2029. ●

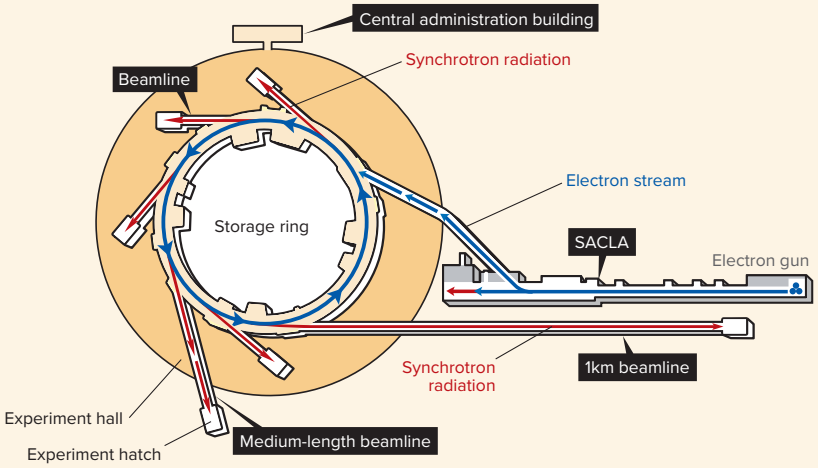
MINIMIZATION OF THE ELECTRON BEAM

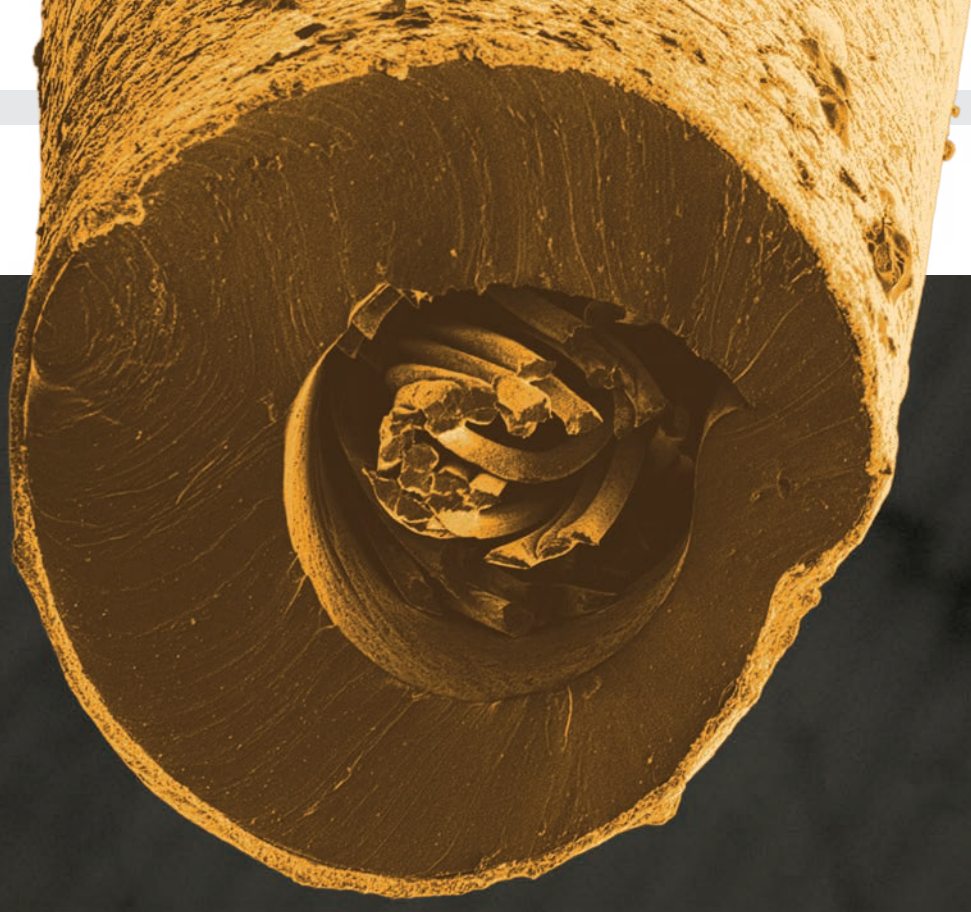
Despite boasting a 100-fold increase in brightness, SPring-8-II will consume half the power of SPring-8. This reduction is achieved by narrowing the electron beam to a very small spot.



X-RAYS FROM ELECTRONS IN SPRING-8-II

A scheme of SPring-8-II, showing how electrons are accelerated in SPring-8 Angstrom Compact Free-electron Laser (SACLA) and then used to generate synchrotron radiation for the beamlines in the storage ring.





SMART YARN THAT TRACKS MUSCLE ACTIVITY IN THE BODY

Created from noise-resistant, conductive threads, a high-tech new smart fabric could find uses in health monitoring, sports performance and rehabilitation.

Sunghoon Lee's job as a materials engineer at RIKEN allows him to combine his love of sports with his passion to pursue research. "Personally, I'm interested in baseball," says Lee, whose research team previously developed a fingertip sensor to monitor the pitching motion of baseball players.

Now the team has developed a thin, comfortable textile that is intended to help monitor health, analyze sports performance and inform rehabilitation[1].

Lee, who is based at the RIKEN Center for Emergent Matter Science, says the technology can monitor muscle activity across the body with high precision during dynamic movement. It has the potential for clinicians to better track recovery, athletes to optimize their movement and researchers to improve understanding of biomechanics.

The textile uses electromyography (EMG), which measures tiny electrical signals generated when muscles contract, revealing how they activate during movement.

However, since the signals from muscles are very weak—just a few millivolts—they are easily swamped by electrical noise. This problem has hindered EMG from being widely adopted.

NOISELESS MEASUREMENTS

Conventional EMG systems employ relatively bulky amplifiers or wireless modules placed

This feature looks at the work of **SUNGHOON LEE**

Sunghoon Lee is a research scientist at RIKEN and concurrently a special visiting associate professor in the Department of Electrical and Electronic Engineering at the University of Tokyo. He received his BSc degree from the Department of Applied Physics (University of Tokyo) in 2009 and his MSc and PhD degrees from the Department of Electrical and Electronic Engineering (University of Tokyo) in 2011 and 2017, respectively. From 2020 to 2023, he was a project assistant professor and lecturer at the University of Tokyo. His current research interests include organic electronics, soft electronics and flexible electronics.

A scanning electron micrograph showing a cross-section of the smart fabric (top of page).

close to muscles, which add weight and restrict movement. But the new flexible EMG textiles should make it much easier to acquire signals over the whole body, says Lee.

A critical component of flexible EMG textiles is an intrinsically stretchable electromagnetic conductor that senses the muscle signals, Lee explains. For the study, Lee's team used commercially available silver-plated nylon wrapped around a polyurethane core, but they are now developing their own stretchable wiring.

However, larger stretchable systems using these types of conductors suffer from electrical noise arising from physical contact, motion or electromagnetic fields from nearby electronics.

These factors can generate a surprising amount of noise, says Lee, "so we needed a good wiring shield system to suppress the noise."

To insulate the technology from outside interference, Lee's team fabricated a yarn with a triple-layered structure. A conductive fiber at the core carries the signal and is surrounded by a layer of polyurethane insulation.

The outer shielding layer is made by embedding silver flakes—tiny, highly conductive particles—inside a fluoroelastomer matrix, which is a rubber-like polymer. The elastomer provides flexibility, while the silver flakes maintain conductivity by forming an overlapping network that stays connected even when stretched. High conductivity allows the shield to absorb and redirect electromagnetic noise away from the signal wire.

This combination results in a continuous, protective layer that stretches without breaking, preserving electromagnetic shielding even when stretched to 120% of its original length.

KNITTED DEVICES

The researchers then integrated the yarn into a knitted textile that included electrodes and wireless EMG modules to interpret and relay the wearer's muscle signals. The modules are worn on the waist to avoid hindering limb movement.

In testing, the yarn stretched enough for most joint movements, while maintaining shielding integrity. It also exhibited good suppression of noise. "Even when someone pressed on the wiring, the signal stayed clean," Lee says.

In shoulder range-of-motion tests, the shielding was particularly critical to signal acquisition during passive movements assisted by another person, such as one might see in a rehabilitation facility. This was because without the shielding, electrical noise from the touch of the other person obscured the EMG signal.

Subsequent testing of muscles in the lower body demonstrated the system's capability during dynamic activities. Eight electrodes were used to effectively monitor four lower-body muscle groups during jumping, cycling and running.

The garment itself resembles thin sportswear. "It's a bit like a thin inner layer," Lee says. "So you actually feel quite comfortable."

Repeated wear tests showed no significant signal degradation, although washability remains a challenge.

"The textile's ability does not change after a few wears," Lee says. "However, if washed, this version could be easily damaged. So we need to find a way to further protect the shielding layer."

TAILORING THE GARMENT

Next steps for the researchers include personalizing the garment. A one-size-fits-all garment is not ideal for accurate EMG monitoring because muscle positions vary between individuals. Current prototypes work for average body shapes, but precision measurements for all body types will require tailoring.

"We're now interested in how to 100% personalize the textile for a specific person," Lee says.

He envisages 3D scanning each wearer's body and then digitally designing and printing electrode placement and wiring paths to match their anatomy. This would ensure electrodes align perfectly with target muscles, improving signal quality and comfort.

It's a step toward custom-fit smart garments, similar to bespoke athletic gear, but with embedded electronics.

The team also plans to improve sweat management and explore biodegradable elastomers and carbon-based conductors for sustainability, says Lee.

He believes that textiles are the ultimate platform for wearable electronics. Clothing naturally covers large areas, enabling full-body monitoring, he explains. Textiles also offer comfort, stretchability and seamless integration into everyday life.

"We believe textiles are a great platform and now we have tackled the noise issue, which was a key problem," Lee says. "This is a highly useful system that can be used to measure multiple activities."

One of the wireless electromyography modules (bottom left) that is used to transmit data collected from the wearer.

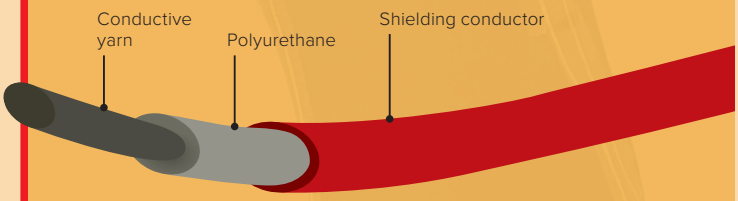
REFERENCE

1. Lee, S., Takano, K., Yukita, W., Tagawa, Y., Sun, L. *et al.* A body-scale textile-based electromyogram monitoring system with coaxially shielded conductive yarns. *Science Advances* **11,** eadx4518 (2025).

A DETAILED LOOK

TRIPLE-LAYERED TEXTILE

The textile is made up of three layers: a conductive yarn that transports the signal, a stretchable polymer layer, and a conductor that shields the signal from noise. This structure allows the textile to convey signals collected from the wearer to the wireless modules, without restricting movement.



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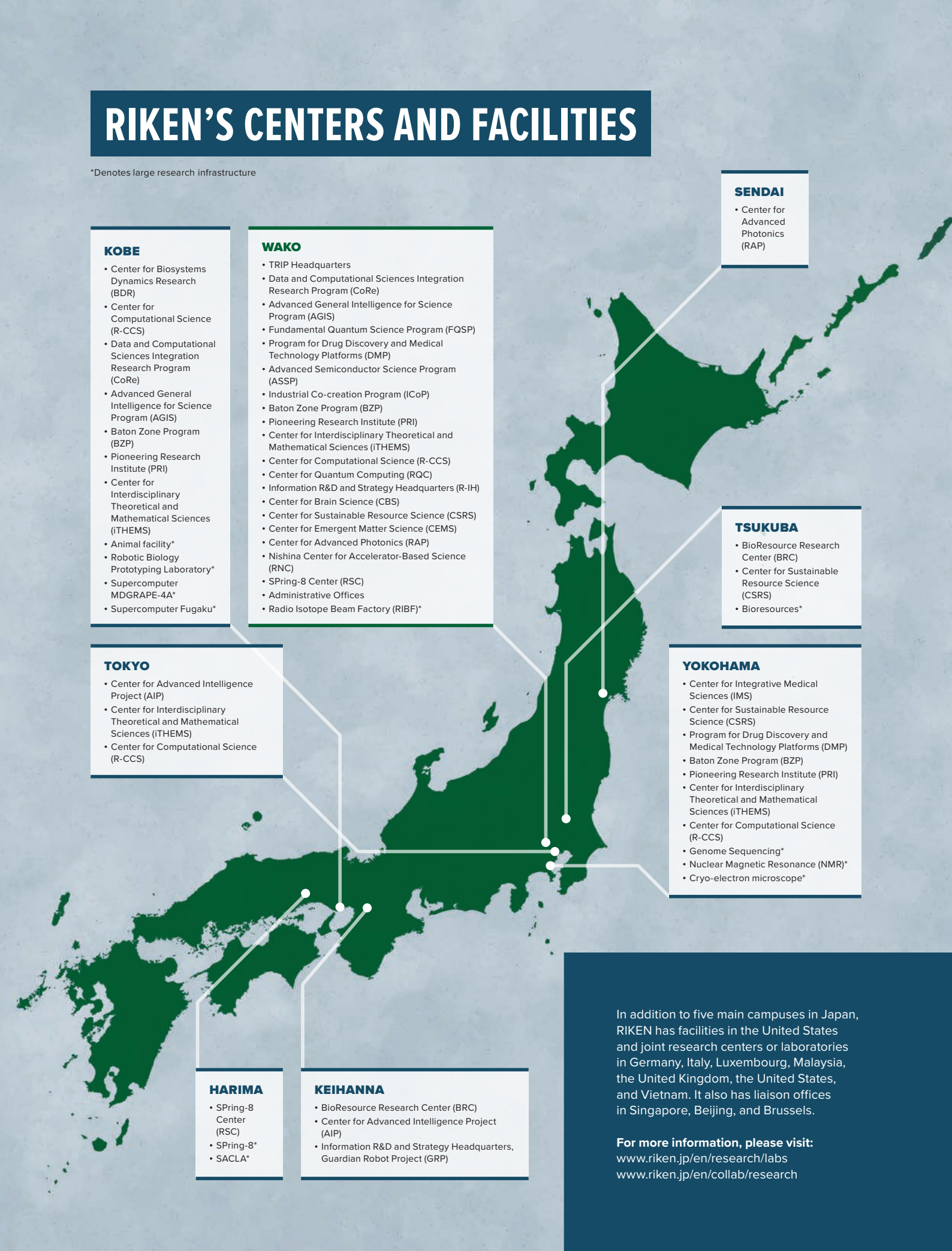

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