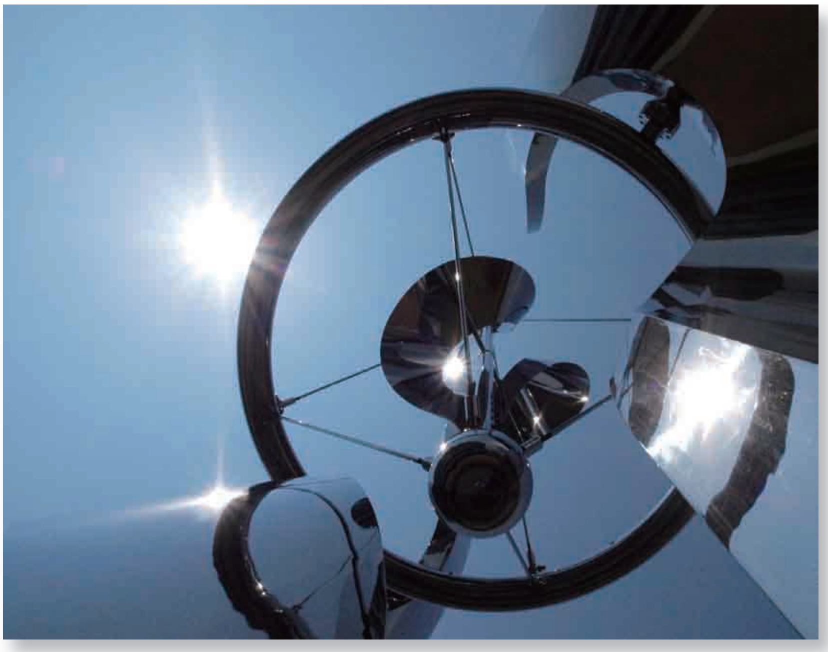
A Place in the "X-ray" Sun



2011 Breakthrough of the Year

In the "best of 2011" list of "*Science*" Magazine, two breakthroughs related to SPring-8 were compiled [1]. One is about the dust sample of the asteroid Itokawa, which was probed by Japan's Hayabusa after a long voyage full of misfortunes and troubles. Investigation of samples via SPring-8 helped to settle the mystery about asteroids and the earth. The other is the crystal structure determination of Photosystem II after many years of research using SPring-8. The finding shall provide a range of insights into photosynthesis to produce energy.

Other path-breaking stories, which are the development of energy saving vehicle tires via an advanced industry application and the first challenge application of nonlinear X-ray optics, were unveiled.

[1] Breakthrough of the Year: Science **334** (2011) 1630.

Synchrotron Radiation SkyGazers

Akira Tsuchiyama, professor of Kyoto University, has carried out years of investigation about "Pebble in the Universe" at SPring-8 in collaboration with JAXA (Japan Aerospace Exploration Agency) and NASA (National Aeronautics and Space Administration). In 2006, NASA Stardust spacecraft safely returned to Earth with cometary dust from Comet Wild2 captured in silica aerogel collectors [2]. The particles and impact tracks left in the aerogel have been analyzed by scientists all over the world. Via SR at Diamond Light Source, UK scientists found minerals, such as chondrule-like and CAI-like particles, in dust and proved the existence of an unexpected high-temperature, chemical process in the comet formation region. Tsuchiyama has further investigated various 3D structures and elemental distributions of impact tracks by microtomography and XRF and determined the quantitative proportion of high-temperature crystalline particles as approximately 6 vol.% with Tomoki Nakamura, a professor of Tohoku University [3]. Their research results provided fundamental parameters to model closely a scenario comet formation and evolving process.

Asteroid 25143 Itokawa became their next research target in order to uncover the real features of asteroids as well as the solar system formation by the Hayabusa mission of JAXA [4]. The story about the long return trip of Hayabusa after overcoming various technical troubles is all too famous to describe the incredible voyage (Fig. 1). In the returned sample box, only

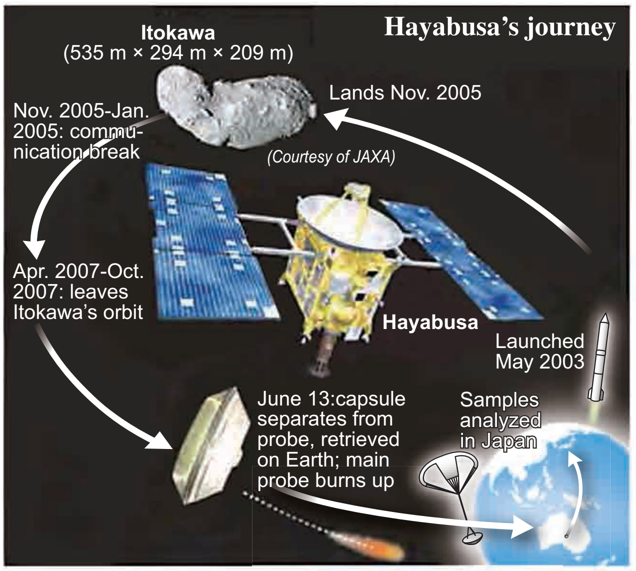


Fig. 1. Hayabusa's journey.

Fig. 3. Tsuchiyama and Nakamura with Hayabusa box.

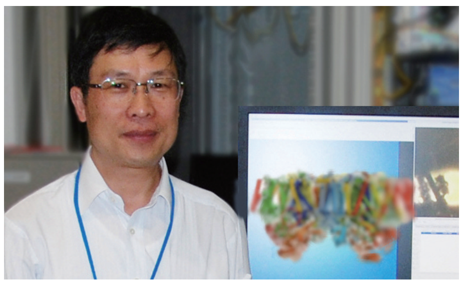
micron-size particles were observed. The first question was whether those particles were really collected from Itokawa or not. Consequently, X-ray microbeam analysis using Synchrotron Radiation conclusively identified the samples as LL chondrite from Itokawa (Fig. 2). Tsuchiyama and Nakamura (Fig. 3) have further challenged an investigation of mineral and element abundances, size distribution, 3D shape distribution as well as textures related to asteroid crash impact. The obtained results allow an improvement in the prediction of the Asteroid Itokawa formation. Their findings from "Pebble in the Universe" at SPring-8 shall draw up a scenario of the solar system history and evolution in the future.

[2] D. Brownlee *et al*.: Science **314** (2006) 1711.
[3] T. Nakamua *et al*.: Science **321** (2008) 1664.
[4] T. Nakamua *et al*.: Science **333** (2011) 1113;
A. Tsuchiyama *et al*.: Science **333** (2011) 1125.

Fig. 2 . Sample from Itokawa at SPring-8.

Unravel the Mystery in the Heart of Plant Life

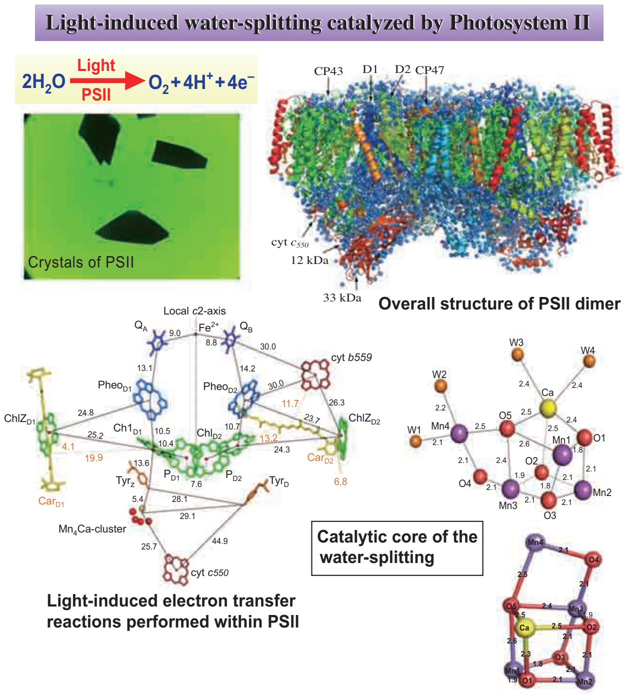
Jian-Ren Shen, a professor of Okayama University, has long wanted to unravel the mystery lying in the heart of plant life, which is the structure and function of photosystem II (PSII). PSII is a protein complex performing the initial reaction of photosynthesis by using sunlight to split water into molecular oxygen that we breathe. This reaction leads to the conversion of light energy into biologically useful chemical energy that sustains almost all life on the earth. The light-induced water-splitting reaction is also important in terms of efficient harvesting and utilization of sunlight to produce virtually unlimited clean energy, in order to overcome the increasing energy and environmental problems that we face. Thus, studies to unravel the mystery of the natural water-splitting reaction of PSII has been competitive over the last several decades. However, since PSII is a membrane-protein complex consisting of 19-20 different subunits with a total molecular weight of 350 kDa, it has been a major challenge to obtain crystals of PSII that diffract to an atomic resolution.



Jian-Ren Shen

Through a long-term and extensive search for the right conditions of crystallization, Shen and his colleagues eventually succeeded in analyzing the dimeric structure of the 19-subunit PSII complex at 1.9 Å resolution, using the beamlines BL41XU, BL44XU, and BL38B1 at SPring-8 [5]. They revealed for the first time the clear structure of the catalytic center of the water-splitting reaction, which is a Mn_4CaO_5 core organized in a distorted chair form, harbored by a number of amino acid residues and water molecules in a specific environment within PSII. The structure determination of the largest membrane-protein complex PSII provides a blueprint for the design of artificial catalysts capable of utilizing visible light to split water into oxygen and hydrogen, that is, a key technology that may lead to an unlimited source of clean energy.

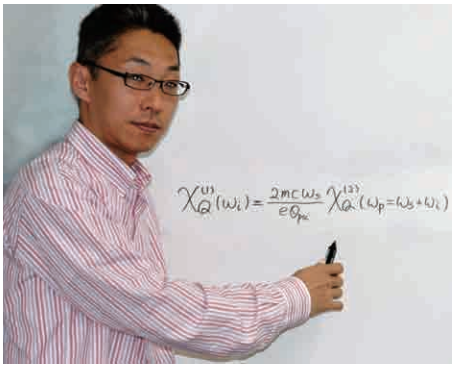
[5] Crystal structure of oxygen-evolving photosystem II at a resolution of 1.9 Å: Nature **473** (2011) 55.



Light-induced water-splitting catalyzed by Photosystem II.

Vanguard of the X-ray Nonlinear Optics

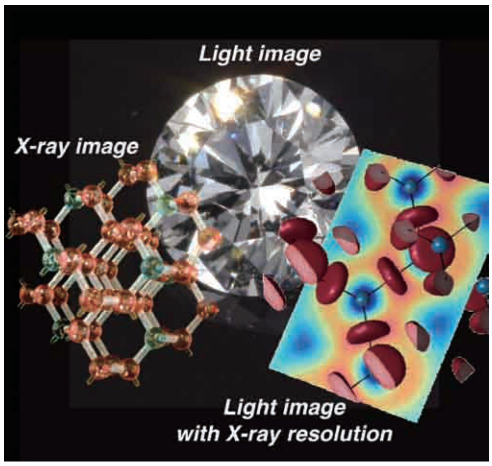
The most exciting developments of photon science will sit at the intersection between the Synchrotron Radiation of SPring-8 and the X-ray Free-Electron Laser of SACLA. It is an intersection that shall break the novel research ground of X-ray science application. Kenji Tamasaku of RIKEN Harima and his research group succeeded in visualizing how the electrons in



Kenji Tamasaku

diamonds respond to the light (λ=203 Å) with an unprecedented resolving power of λ/380 (0.54-Å resolution) far beyond the wavelength limit [6] using an X-ray nonlinear optical phenomenon, which *detaches the resolution from the probing wavelength*. No one has imagined that she or he can see the scene of electrons responding to the light in the material. This is the angstrom version of the saying "A picture is worth a thousand words". Tamasaku stated that his microscopic optical probe with X-ray resolution crosses the bonds of the research on the optical response of materials and the related charge dynamics, opening a new window into the optical properties of solids. Now, scientists can see which part of the unit cell is responsible for the optical response of interest and use the knowledge for the better understanding of the optical property and to enhance the optical functions of materials.

Using SPring-8, he has been creating a firm vision for the essence of X-ray nonlinear optics (XNLO). Needless to say, nonlinear optics is one of the most important fields in modern science. In spite of extensive research over half a century, the X-ray region is still not explored and remains as a frontier. Tamasaku emphasized that XNLO is not a simple X-ray analogue of nonlinear optics, and that XNLO is important as it is, because the nonlinear interaction



Visualized image via each light probe.

between radiation and electrons is completely different from those in the optical region. His article highlights one side of this unique feature and builds a bridgehead to explore other sides, which should open up novel applications in multidisciplinary scientific fields, such as laser physics, chemistry, solid-state physics, and material science.

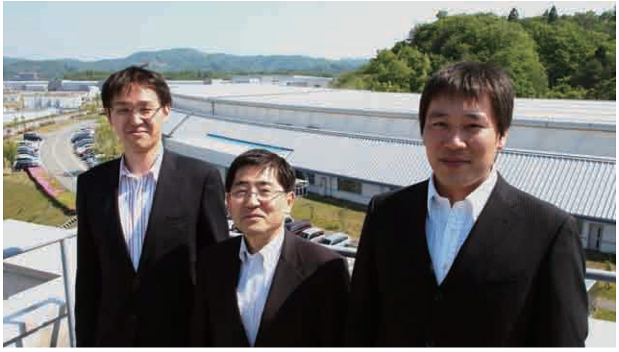
The present achievement is an unprecedented application of the X-ray nonlinear optical processes. Remembering the successful history of nonlinear optics in the visible region from the invention of lasers in 1961, his success stimulated many scientists in various fields related to the nonlinear optics. He is now challenging XNLO using an X-ray free electron laser at SACLA.

[6] Tamasaku *et al*.: Nature Physics **7** (2011) 705.

Industrial Innovations from SPring-8

Industry Application of SPring-8 has been one of the most valued activities from the viewpoints of social demands. Testing of various materials and product assurance were successfully carried out as a result of appropriate promotion based on marketing of attainment targets since early years. However, according to the progress in the performance of industry utilization, further demand for SR application has increased and enhanced the new firm collaborative relationship with academy. Such movements lead to the new beamline constructions based on the strategic project, such as the Catalytic Reaction Dynamics for Fuel Cells beamline BL36XU, Advanced Basic Science for Battery Innovation beamline BL28XU and Advanced Soft-material Beamline BL03XU.

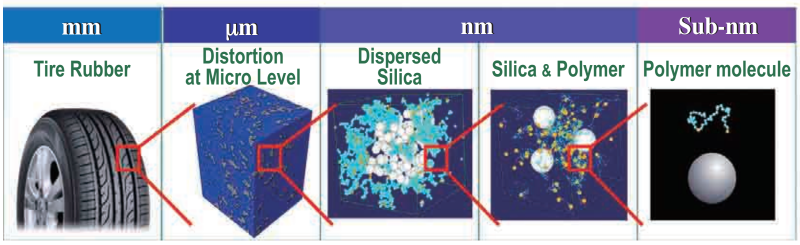
Sumitomo Rubber Industries, Ltd. has developed a new material development technology named 4D NANO DESIGN using the SR application of SPring-8 and the supercomputer Earth Simulator, and successfully created high-performance tires to meet both environment protection and safety requirements in collaboration with Yoshiyuki Amemiya and Yuya Shinohara, professors of the University of Tokyo and National Institute of Advanced Industrial Science and Technology (AIST).



Yuya Shinohara and Yoshiyuki Amemiya (the University of Tokyo) with Hiroyuki Kishimoto (Sumitomo Rubber Industries, Ltd.)

The key for the material design of rubber materials has been to mix-and-match the molecular structure and the compound characteristics to confer excellent performance to tires. The 4D NANO DESIGN allows us to enhance tire performance and control tire materials at the nano level by combining 4 separate technologies focusing on (1) the investigation, (2) estimation, (3) Producing, and (4) drawing of characteristics. Among them, the investigation conducted by Hiroyuki Kishimoto of Sumitomo Rubber Industries, Ltd. minutely visualized the nanoparticle construction inside rubber, which has a major impact on tire performance, by 2D-USAXS experiment at SPring-8 and Reverse Monte Carlo (RMC) simulation analysis using Earth Simulator. It allows us to simulate the characteristics of rubber materials more accurately at the molecular level. Their research is described in detail in their report. The results were applied to the simulation and molecular design by multi scale simulation in the estimation. Then, the optimization of a material process in order to draw such performance out of materials at maximum was achieved by drawing the characteristics, resulting in the drawing of the potential performance out of tire rubber materials. ENASAVE PREMIUM, which will be sold beginning February 2012, achieved a 6% improvement in fuel efficiency and is the first innovative product that adopts the 4D NANO DESIGN.

Various advanced approaches for product development are now emerging from the industry-academy utilization at SPring-8 and shall drive technological innovations.



Multi-scale materials design of tire.

by Masaki Takata