Impact Objectives

- Utilise advanced technology to explore the origins of the solar system, the Earth and life, and open up a new world of knowledge for humankind
- Accumulate various experiments and theoretical research relating to planet evolution
- Use the techniques to explore different aspects of a planet, including what kind of material it is made of, the presence of organic matter and whether there are any traces of life

The search for the origins of planetary systems

***Professor Takafumi Matsui** is one of the pioneers of planetary origin research and the proposer of famous theoretical models on planetary formation. Here he talks about the value this research adds to the knowledge base on the evolution of planets*

What is at the core of your research focus?

Hypervelocity impacts on planetary bodies are among one of the most basic processes throughout the history of our solar system. Ancient craters on the moon tell us that an early phase of planetary evolution would be driven by frequent impact bombardments. Shock vaporisation, and the subsequent chemical reactions during hypervelocity impacts, are particularly interesting to us because they are thought to lead to unique chemical reactions never seen under a mean field on planets due to the injection of foreign objects with enormous kinetic energy. An intense and impulsive perturbation due to hypervelocity impacts might cause the release of a large amount of free energy for chemical evolution into a prebiotic field, and produce unique geochemical features through the recovery processes from the disastrous event.

If we can predict impact outcomes quantitatively, we would accurately know how the surface environments on planets grow during the impact bombardments. Since the recovery processes are expected to depend on the surface environments, the impact bombardments may increase the diversity observed in the planets in our solar system. We have been conducting experimental research to understand the impact-driven physical/chemical processes after each impact event. We have also studied post-impact chemistry progressing in impact-induced plumes by developing novel techniques and by using several experimental apparatuses.

Do you have any state-of-the-art technologies that you are using for these studies?

We have two advanced technologies: a measuring system for hypervelocity impact phenomena and the Mars environmental simulation chamber. State-of-the-art technologies have enabled the researchers to develop a novel experimental technique allowing, for the first time, quantitative measurements of shock-generated gas after unbounded release, without any contaminations from the gun. This method meant they could resolve a long-standing inconsistency between experimental results and theoretical predictions, which Matsui says has occurred since the 1970s: 'The main problem in the previous experimental work is that containers were used to collect the shock-generated gases. This situation is referred to as closed system; however it is very different from natural impact events, which occur in an open system.' He notes that this means they have now been able to extend the technique to quantitative measurements, which includes 'chemical composition analyses of shock-generated gases from analogues of meteorites and comets, enabling investigations of post-impact chemistry'.

Can you tell us a little about your studies using high power lasers and two-stage light gas guns?

We can simulate extreme shock compression (>100 GPa, >10,000 K) produced by greater than 10 km/s impacts using the high power laser at Osaka University. This laser allows us to investigate thermodynamic responses of silicate minerals and to examine the final chemical composition after the Cretaceous-Paleogene (K-Pg) extinction event. Based on the experimental results, we have proposed a new mechanism to account for the extinction pattern at the K-Pg boundary. The experiments using the gas gun at the Planetary Exploration Research Centre (PERC) allow us to investigate the impact-driven chemical processes with a much higher accuracy. We have developed a novel technique to measure the final chemical composition of the impact-generated vapour using a two-stage light gas gun. Although the maximum impact velocity in the case of the gun experiments is not enough to vaporise geologic materials, we can address the controlling processes of shock vaporisation and post-impact chemistry with a high accuracy if we use analogue materials with a low vaporisation threshold.

Discovering the origin stories of planets

*Through their research into planetary exploration, **Professor Takafumi Matsui** and his team have been developing instruments and processes that enable the measurement of hypervelocity impacts on planets, ultimately increasing our understanding of the evolution of solar systems*

Professor Takafumi Matsui is the Director of the Planetary Exploration Research Centre (PERC) at Japan's Chiba Institute of Technology and has been involved in planetary exploration and research into the formation of planets since the 1970s. He has proposed various theoretical models about these processes and published many papers explaining this thinking. His work today involves addressing the gaps in theory that existed due to lack of experimental data to construct reliable theoretical models in the past.

As Matsui's career has progressed, his earlier hypotheses on planetary evolution have largely been supported by his later experiments. 'The results from our work published in 1984 on the brittle behaviour of iron-like planetesimals in the low-temperature asteroid zone were consistent with our hypothesis developed in 1977 that this process prevents growth into full-sized planets,' Matsui explains. Of particular importance is his work in collaboration with Associate Professor Y Abe on the evolution of an impact-induced atmosphere and magma ocean on the accreting Earth, which was published in *Nature* in 1986. This work, explains Matsui, presented a quantitative study into the process of 'early rapid formation of the atmosphere and hydrosphere during accretion by planetesimal impacts'. Matsui and Abe were able to show that 'an impact-induced H_2O atmosphere increases the surface temperature of the Earth to a stage where a magma ocean is possible'.

Matsui led a Japanese-Cuban joint research group in 2000. They discovered a 180 metre thick layer in Cuba, which is evidence of the generation of impact-induced tsunamis after the Cretaceous–Paleogene (K–Pg) extinction event. 'Following, my collaborators and I numerically simulated the propagation of impact-generated tsunamis within the Gulf of Mexico to access the magnitude, the duration and the repetition frequency of impact-generated tsunamis,' says Matsui. Later, he joined an international research team, which summarised a number of studies on the global stratigraphy across the K-Pg boundary. 'We concluded that a single asteroid impact, i.e. the K-Pg impact, triggered the mass extinction at the boundary.'

After the initial phase of his research career, Matsui proceeded to organise an experimental research group at the University of Tokyo with Professor Seiji Sugita and Professor Toshihiko Kadono. Their main focus was the study of physical and chemical processes progressed in impact-generated vapour plumes. 'By studying the intense and impulsive unconformities that result in a planet's surface environment, we are able to gain a deeper understanding of the solar system's development,' says Matsui.

HIGH POWERED LASER EXPERIMENTS

An area of focus for Matsui's team has been undertaking experimental work using a high powered laser. Their progress in this field since 2002 has been significant. The early work involved using mass spectroscopic observations of sulphur chemistry in laser-simulated impact vapour clouds, as well as studying whether laser ablation vapour simulates impact vapour. The learnings from this work enabled the researchers to use an experimental method to discover more about vapour clouds in 2005. 'We proposed an experimental method to estimate the chemical reaction rate in vapour clouds and we also applied it to the redox reactions of sulphur oxides,' explains Matsui. They also used laser-induced vapour clouds to investigate the oxidation of carbon compounds by silicon dioxide-derived oxygen within those clouds.

This experimental work was further built on in 2007 through ablation experiments on hydrogen cyanide production in a neutral atmosphere, as well as studies into cyanide production as a result of chemical reactions that occur after an oblique impact between the impact material and an ambient atmosphere. The team's work on hydrogen cyanide production and oblique impacts was continued since 2007 using both a laser and a two-stage light gas gun. The correspondence relation between laser-induced and impact-generated vapors was also addressed. 'The following year we conducted laser ablation experiments in redox-neutral gas mixtures using graphite to assess the fate of cyanide radicals produced by the oblique impacts,' Matsui says.

Alongside experts in this field Matsui has previously explored the origin of Saturn's moon Titan's thick N_2 atmosphere. To study the origin of Titan's thick N_2 atmosphere the team used a laser gun with a much lower energy than that used at Osaka University. They looked at the way that atmospheric N_2 was replaced and formed on undifferentiated Titan. With expert collaborators Associate Professors Yasuhito Seikine and Hidenori Genda and Professors Seiji Sugita and Toshihiko Kadono, this work has been published in *Nature Geoscience*. 'For this work we proposed that Titan's nitrogen atmosphere formed after accretion, by the conversion from ammonia that was already present on Titan', Matsui says. 'Our laser-gun experiments showed that ammonia ice converts to N_2 very efficiently during impacts.'

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DELVING INTO EARTH'S BIOSPHERE

Matsui's latest work involves exploring a hypothesis connected to the Panspermia and how this relates to the origin of life on Earth. His approach is to investigate the material flux across the Earth's atmosphere and to study recovered samples from the upper atmosphere in great detail. To achieve this he has started a number of focused research projects. Whilst these all have their individual goals, the projects are linked by their exploration of the material flux from space to the Earth's atmosphere and from the Earth's surface to space. In the Biopause project the researchers are exploring the upper boundary of the biosphere of the Earth (biopause) to determine the biological flux. To achieve this they employed the Japan Aerospace Exploration Agency (JAXA)'s scientific balloon so they could collect aerosol particles in the stratosphere.

Dr Sohsuke Ohno, Principal Investigator of the Biopause project, says that their work helps them to understand whether microorganisms and viruses are coming from the universe to Earth or the other way around. To explore these areas of the atmosphere the team have used balloon experiments to test the microorganisms present. Ohno explains that contamination of terrestrial microorganisms was a concern for their research: 'In our balloon experiment conducted in 2016, microorganisms floating in the stratosphere were collected using a collecting device with a low possibility of incorporation of newly developed terrestrial microorganisms, and directly analysed using a microscope instead of the culture method.'

REMOTE CONTROL DATA GATHERING

Matsui has been working closely with his colleague Dr Kosuke Kurosawa to build a better picture of the material exchanges between two planetary bodies, which is known as 'Litho-panspermia'. To achieve this they have been using gas gun and hydrocode calculations. In 2013 a new simulator was installed for the purpose of investigating the physical and chemical processes that occur during mutual collisions between planetary bodies. Kurosawa explains: 'A two-stage hydrogen gas gun allows us to accelerate projectiles up to 4.6 mm in diameter at a velocity up to ~9 km/s. A high speed digital video camera, a streaked spectrometer and a quadrupole mass spectrometer are equipped in the experimental system. These allow us to investigate the ejection velocities of the surface materials accurately.'

The team's work is making an important contribution to processing and analysing planetary exploration data through demonstration. 'We can verify the past, present and future events in our solar system with the ground truth, including recovered samples and remote sensing data obtained by planetary explorations. Data analyses or interpretations based on our scientific knowledge are necessary to extract useful information about such events from the samples and data,' Matsui concludes.

Project Insights

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Professor Takafumi Matsui completed his undergraduate education at the University of Tokyo and received his PhD from the same institution. He has been a NASA researcher, Invited Scientist at the Massachusetts Institute of Technology, Visiting Professor at the Max Planck Institute of Chemistry and a Professor in the Graduate School of Frontier Sciences, University of Tokyo. Since April 2009 he has been the Director of PERC at the Chiba Institute of Technology. He is also Professor Emeritus of the University of Tokyo.