

► solar panels flew off into space. A JAXA investigation blamed faulty project-management techniques for not catching the error.

The failure has reverberated at every level of JAXA's Institute of Space and Astronautical Science (ISAS) in Sagami-hara, which managed Hitomi. JAXA president Naoki Okumura was one of three leading officials who took a 10% pay cut for four months "to express our regret and caution ourselves", he said in a June press conference. He has also ordered a systems review of the institute's next big project: a mission to study Earth's radiation belts that is slated to launch in the coming months.

Before Hitomi, JAXA's lowest point was perhaps the loss of its Nozomi mission to Mars, which sailed past the red planet in 2003 without entering orbit as it was supposed to. The same year, a new JAXA rocket design failed during a test launch, prompting a review of all agency projects.

#### TRY, TRY AGAIN

Some have questioned whether JAXA is trying to do too much with too little. It often assigns one person to cover a number of tasks that NASA would spread among multiple project engineers, says Lorenz, who collaborates on the Akatsuki Venus probe.

Okumura has acknowledged as much, saying that ISAS will generally develop a mission using a small in-house team, along with the

spacecraft manufacturer. By contrast, Hitomi involved a larger number of complex systems. There were simply not enough safeguards built into the process to catch the software error. "The previously conventional ISAS methods were not necessarily suited for the production

**"It's important to note how resourceful JAXA has been at recovering from failures."**

of modern satellites and spacecraft," Okumura said. JAXA has released an extraordinary level of technical detail about the failure. Agency officials have said that because Hitomi was meant as a community mission to serve X-ray astronomers across the globe, they feel obligated to explain what happened so that nobody makes the same mistake.

Because of this determination and openness, "I think Hitomi's successor is in safe hands with JAXA," says Elizabeth Tasker, an astrophysicist at Hokkaido University in Sapporo, Japan.

But such projects may be a hard sell to politicians. "High-profile setbacks like Nozomi and Hitomi make it difficult for JAXA to justify big-ticket science missions in today's political atmosphere," says Saadia Pekkanen, an expert in Japanese space policy at the University of Washington in Seattle.

JAXA has not yet decided whether a Hitomi

successor would fly or which instruments it would carry, says ISAS spokeswoman Chisato Ikuta. But Hitomi's premier scientific instrument was the spectrometer provided by NASA; data that it collected before the spacecraft died revealed secrets about gas flows in the Perseus galaxy cluster.

The spectrometer seems to be thrice cursed; two earlier versions on different satellites were lost to a launch failure and a coolant leakage. Even so, a NASA advisory group reported on 5 July that launching a copy of the instrument no later than 2023 "would fulfill the immense scientific promise of the Hitomi" spectrometer. The cost to rebuild would be roughly US\$70 million to \$90 million.

Paul Hertz, NASA's astrophysics director, will meet with JAXA representatives to discuss the options. "Certainly we would not be overseeing JAXA," he told a NASA advisory committee on 20 July. "We can discuss practices that NASA implements to prevent us from making avoidable mistakes."

Other international missions in the works from JAXA include a magnetospheric orbiter, which is scheduled to launch next year on the European Space Agency's BepiColumbo mission to Mercury.

"The Olympics of engineering is when things go wrong," says Lorenz. "Maybe the best time to fly is right after a failure." ■

#### MATHEMATICS

# Grand proof fazes theorists

Conference on Shinichi Mochizuki's 'revolutionary' work inspires cautious optimism.

BY DAVIDE CASTELVECCHI

Nearly four years after Shinichi Mochizuki unveiled an imposing set of papers that could revolutionize the theory of numbers, other mathematicians have yet to understand his work — although they have made modest progress.

Some four dozen mathematicians converged in Japan last week for a rare opportunity to hear Mochizuki present his monumental proof of the 31-year-old *abc* conjecture, which sits at the heart of number theory. The conference took place on his home turf, at Kyoto University's Research Institute for Mathematical Sciences (RIMS).

Mochizuki is "less isolated than he was before the process got started", says Kiran Kedlaya, a number theorist at the University of California, San Diego. At first, Mochizuki's proof, which stretches over more than 500 pages (available at [go.nature.com/2amidei](http://go.nature.com/2amidei)), seemed like an

impenetrable jungle of formulae. But experts have slowly discerned a strategy, and have zeroed in on particular passages that seem crucial, Kedlaya says.

And Jeffrey Lagarias, a number theorist at the University of Michigan in Ann Arbor, says that he got far enough to see that Mochizuki's work is worth the effort. "It has some revolutionary new ideas," he says.

Still, Kedlaya says that the more he delves into the proof, the longer he thinks it will take to reach a consensus on whether it is correct. He used to think that the issue would be resolved perhaps by 2017. "Now I'm thinking at least three years from now."

Others are even less optimistic. "The constructions are generally clear, and many of the arguments could be followed to some extent, but the overarching strategy remains totally elusive for me," says mathematician Vesselin Dimitrov of Yale University in New Haven, Connecticut. "Add to this the heavy,

unprecedentedly indigestible notation: these papers are unlike anything that has ever appeared in the mathematical literature."

#### THE ABC PROOF

The *abc* conjecture relates to prime numbers — whole numbers that cannot be evenly divided by any smaller number except 1. The conjecture comes in a number of different forms, and explains how the primes that divide two numbers, *a* and *b*, are related to those that divide their sum, *c*.

If Mochizuki's proof is correct, it would have repercussions across the entire field, says Dimitrov. "When you work in number theory, you cannot ignore the *abc* conjecture," he says. "This is why all number theorists eagerly wanted to know about Mochizuki's approach." For example, Dimitrov showed in January how, assuming the correctness of Mochizuki's proof, one might be able to derive many other results, including an independent proof

of the celebrated Fermat's last theorem (V. Dimitrov. Preprint available at <http://arxiv.org/abs/1601.03572>; 2016).

The purported proof, which Mochizuki first posted on his webpage in August 2012, builds on more than a decade of previous work, in which he developed a novel and extremely abstract branch of mathematics in virtual isolation.

#### MOCHIZUKI IN THE ROOM

The Kyoto workshop followed on the heels of one held last December in Oxford, UK. Mochizuki did not attend that first meeting, although he answered questions over a video link. This time, having him in the room — and hearing him present some of the materials himself — was helpful, says Taylor Dupuy, a mathematician at the Hebrew University of Jerusalem.

Around ten mathematicians are now putting substantial effort into digesting the material — up from three before the Oxford workshop, says Ivan Fesenko, a mathematician at the University of Nottingham, UK, who co-organized both workshops.

Mochizuki did not take part in the customary mingling and social activities at the Kyoto meeting. And although he was unfailingly forthcoming in answering questions, it was unclear what he thought of the proceedings. "Mochizuki does not give a lot away," Kedlaya says. "He's an excellent poker player."

Mathematicians have criticized Mochizuki for his refusal to travel: after he posted his papers, he turned down multiple offers to go abroad. He spent much of his youth in the United States, but is now said to rarely leave the Kyoto area. (Mochizuki does not respond to interview requests, and the workshop's website noted: "Activities aimed at interviewing or media coverage of any sort within the facilities of RIMS, Kyoto University, will not be accepted.")

"He is very level-headed," says another workshop participant who did not want to be named. "The only thing that frustrates him is people making rash judgemental comments without understanding any details." Still, Dupuy says, "I think he does take a lot of the criticism about him really personally. I'm sure he's sick of this whole thing, too." ■



MATTHEW CHATTLE/REX/SHUTTERSTOCK

David Davis leads the UK government's Department for Exiting the European Union.

#### POLITICS

# UK scientists seek Brexit influence

*They hope for active role in negotiations to exit EU.*

BY ELIZABETH GIBNEY

British science's largest lobbying campaign in years is under way. After the shock of the United Kingdom's vote to leave the European Union, anxious researchers are doing all they can to ensure that their interests are represented in Brexit negotiations. One big unanswered question is what role science will have in the new 'Brexit ministry' — the Department for Exiting the European Union (DEEU) — that has been expressly formed to take the country out of the EU.

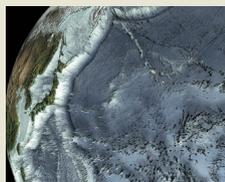
Worried at the prospect of losing access to EU funding and collaborations, scientific societies have fired off numerous letters asking the government to keep their country in the EU's research system, and warning of damage already caused by Brexit. An advocacy group, Scientists for EU, says it has gathered (in confidence) 25 cases of foreign scientists withdrawing job applications or being refused a UK

post as a result of Brexit, 7 cases of someone in UK science leaving the country, and 33 of disruption to funding for the EU's Horizon 2020 research-grants programme.

The government has indicated that it is listening to scientists — but seems reluctant to say so too loudly. On 18 July, Prime Minister Theresa May sent a letter to Paul Nurse, the director of London's Francis Crick Institute, telling him that the government was committed to "ensuring a positive outcome for UK science" as the country exited the EU. But the letter — effectively May's first statement on science — did not become public knowledge until science minister Jo Johnson referred to it in passing in a 25 July speech at the EuroScience Open Forum in Manchester, prompting journalists to press for a copy. Venkatraman Ramakrishnan, the president of London's Royal Society, said he welcomed the comments and was looking forward to working with May and her colleagues "to turn these words into action." ▶



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