Studying the Auroras and What Makes Them Shine

Dr Toshi Nishimura
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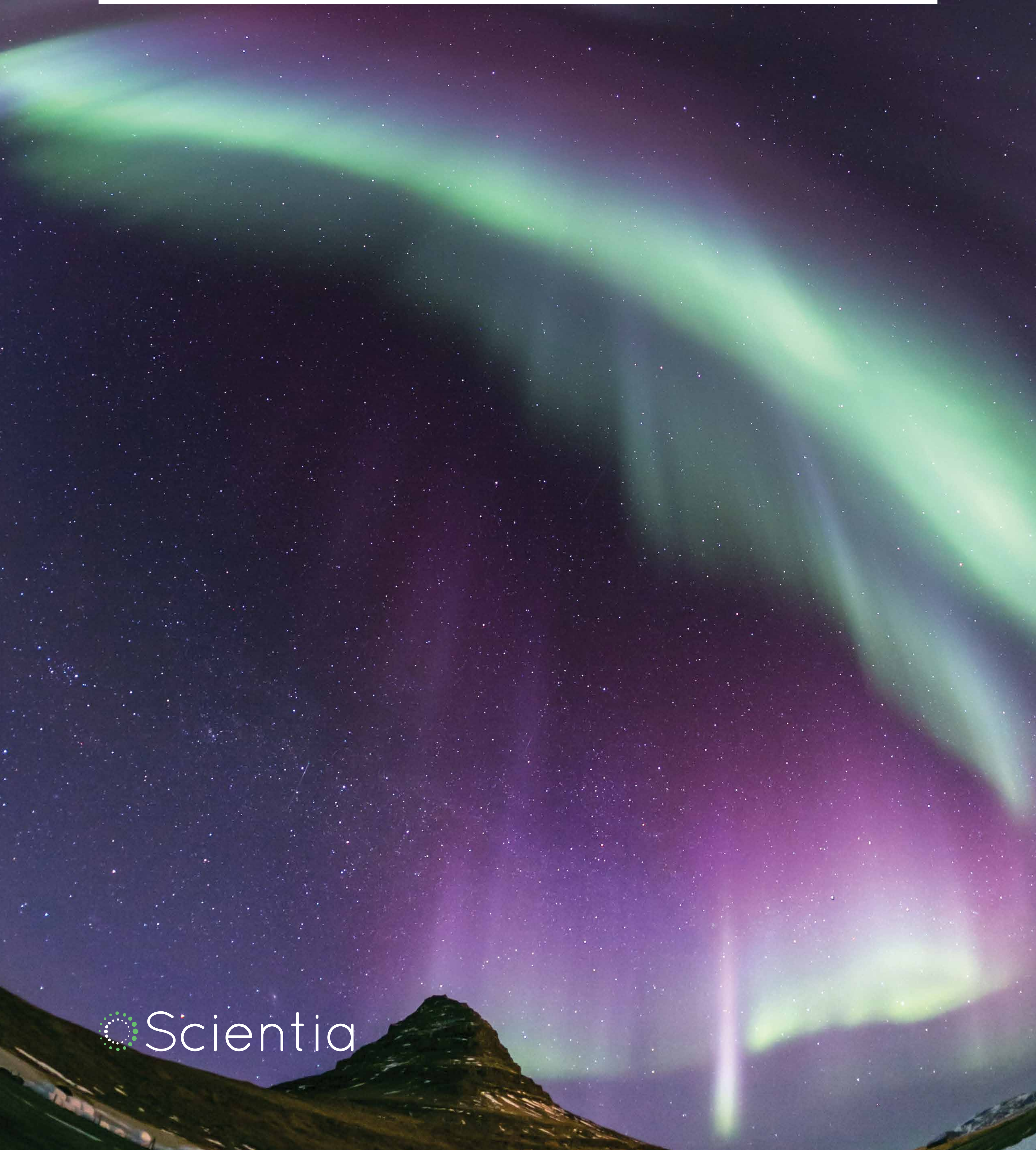

Scientia

STUDYING THE AURORAS AND WHAT MAKES THEM SHINE

Space physicists **Dr Yukitoshi (Toshi) Nishimura** and **Dr Ying Zou,** along with their colleagues at Boston University and at UCLA, study the interactions between Earth's atmosphere and energy that flows from the solar wind to determine how the Northern Lights – and the Southern Lights – get their beauty.

Beauty is in the Eye of the Beholder . . . Especially at Night

From earliest childhood, most of us have been struck by the wonders of Nature that surround us. The blue seas, the verdant forests, the colourful birds and fascinating animals – all of these have at one time or another awed us with their beauty and fascination. But one special sight that has drawn human attention from the dawn of history is the twinkling, always moving but somehow unchanging, night sky. The stars, the planets, the romance of the Universe – it appears to be moving around us just outside our reach. It was this very sight that inspired Dr Toshi Nishimura to make space physics his life's work. 'I was a kid who liked to watch stars and think about undiscovered worlds in the universe,' he tells Scientia. 'One day my parents bought me a small telescope and I was excited by watching Saturn's rings, the Jovian satellites, lunar craters and comets.' This became his passion. So when Dr Nishimura went to the college, he took lectures of space science and electromagnetism, and soaked up his professors' enthusiasm about space. That energy simply whet his curiosity even more, so he decided to study the science of space.

But there is one particular phenomenon of the night sky, one that people in many parts of the world never see, that is perhaps the most stunning of all the night's visions – the auroras, those hypnotic shows of dancing lights that fill the skies, especially near or after dark in the higher latitudes. In the northern hemisphere, it is called the aurora borealis or Northern Lights, while south of the equator, it is the aurora australis or Southern Lights. Often highlighted in movies and television programmes set in extreme northern locations, auroras are usually depicted as pale green or pink. However, auroras have been seen in shades of red, yellow, green, blue, and violet.

Auroral displays can appear as patches or clouds of light, or they can be seen as arcs, rippling curtains or shooting rays, eerily lighting up the sky. These wondrous light shows are glorious to watch and are high on many people's 'bucket list.' In fact, Dr Ying Zou thinks that auroras don't only serve as Nature's works of art. According to her: 'Auroras not only entertain us, but they also communicate with us, telling us what is happening in near Earth space – we just have to learn how to interpret their language. Studying auroras is truly the most romantic profession I can think of.' And that is exactly the research she and Dr Nishimura have been working on, finding out what is happening in space that makes it possible for us on Earth to see the beauty of the auroras. This approach has the great advantage of grasping the state of space through imaging and radar remote sensing techniques.

Everyone Talks About the Weather – But Space Weather?

The dynamic flowing and ebbing of energies in the space around the Earth – space weather – has significant effects on our life here on Earth. 'Space weather phenomena have large impacts on human life through disturbances of radio communication and spacecraft operation,' explains Dr Nishimura. High-energy plasma particles shot to Earth by the Sun can bombard delicate electronic instruments and even cause energy fluctuations in the electrical grid, causing massive power outages.

For example, in 1989 a massive solar storm struck the Earth, knocking out power in Québec, Canada, for hours, interrupting transmission from NASA and other satellites, and even interfering with communications vital to an on-going UN-Australian military peace keeping operation on the African continent. The Northern Lights caused by this storm were seen as far south as Texas and Florida in the United States. This space weather and these types of potentially disastrous effects are caused by the effects of those high-energy particles that make up the plasma stream from the Sun called solar wind and their interaction with the Earth's magnetic field, the magnetosphere. The plasma particles are charged and therefore can be affected by the Earth's magnetic field, causing massive energy flows and shifts that essentially produce near-Earth space weather conditions.

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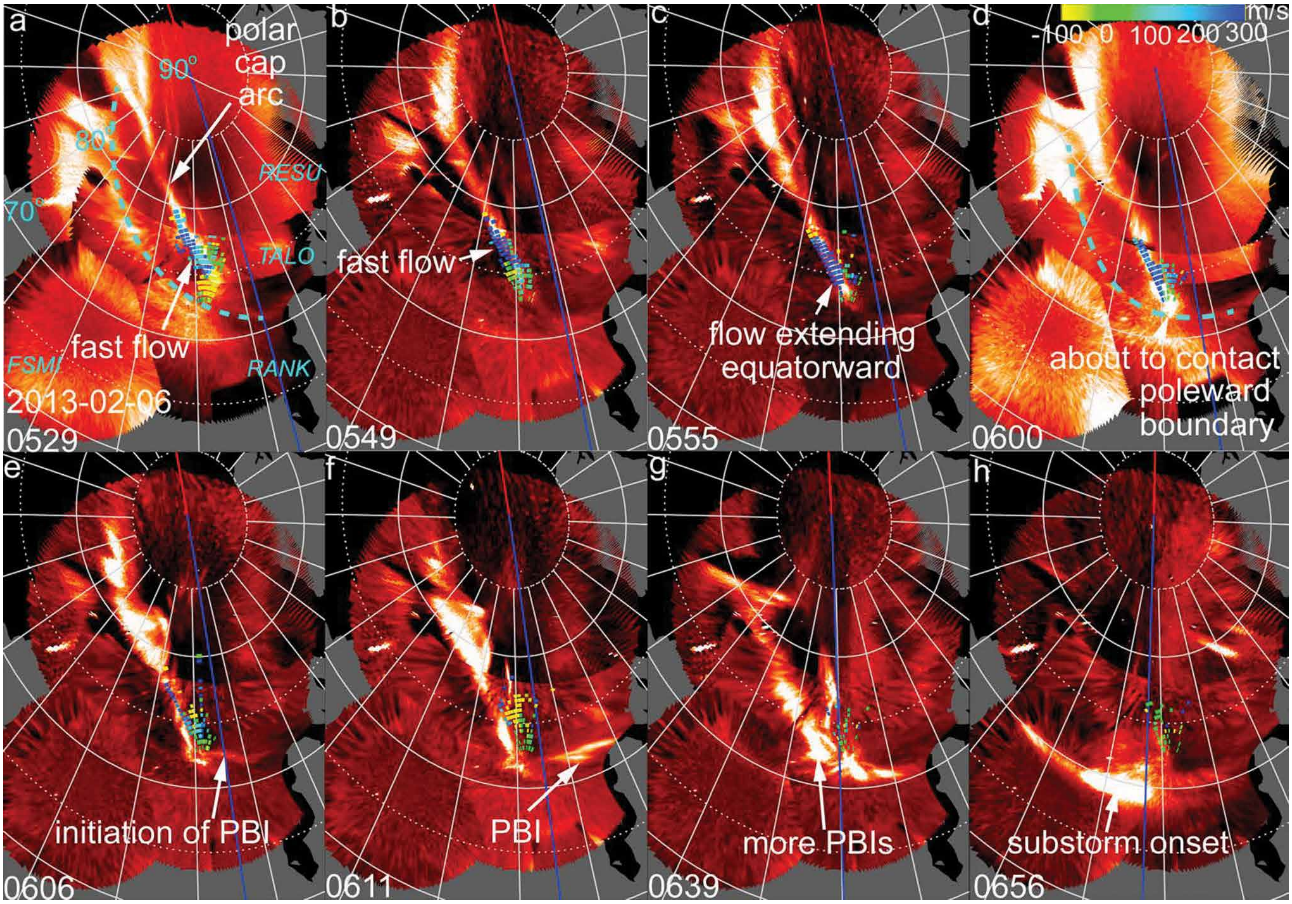

Snapshots (630.0 nm) showing the association of a polar cap arc to poleward boundary intensification activity within a thick auroral oval on 6 February 2013. Y Zou, Y Nishimura, LR Lyons, EF Donovan, K Shiokawa, JM Ruohoniemi, KA McWilliams, and N Nishitani, J. Geophys. Res. Space Physics, 2015, 120, 10698–10711.

The scientific community has made tremendous progress on understanding and forecasting this space weather in recent years. However, Dr Nishimura says one big challenge right now is the capability to predict sudden energy releases and particle acceleration processes. These often start in a localised area in space, but it has been very difficult to pin down their energetics. More specifically, it is hard to figure out how the solar wind coming to Earth on the dayside – the side where energy from the Sun first reaches – transfers its energy to the night-side of the Earth – away from the Sun – and then releases a large amount of energy to the Earth's atmosphere. Some of this energy can be seen – as the auroras. Dr Zou adds: ‘Although the location and activity of the global-scale auroral activity has been correlated well with solar wind driving, when and where individual auroral arcs, for example, intensifications along the poleward boundary of night-side aurora oval, brighten is not well explained.’ In other words, why do the auroras pop out in particular areas and not in others?

Dr Nishimura, Dr Zou and their colleagues are hot on the trail of the mechanism by which these energy flows somehow trigger auroras. They have some promising data showing how the energy flows across the regions around the Earth's poles called polar caps, giving them an idea of how the system works.

Predicting Night-side Auroras

To actually understand how the energy flows through the magnetosphere and causes the auroras, these displays must be observed from different locations across the globe to determine how the energy gets from here to there. Drs Zou and Nishimura's group is using a network of imagers and radars to follow the energy and map out how it flows from the solar wind, from dayside to night-side, where the auroras shimmer and shine.

In a paper published in the journal Geophysical Research Letters, Dr Nishimura, Dr Zou and their colleagues reported on data derived from their observations of the dayside, polar cap, and night-side auroras using three all-sky imagers (from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission, Optical Mesosphere Thermosphere Imagers (OMTI), and University of Oslo), two Super Dual Auroral Radar Network (SuperDARN) radars, and Defence Meteorological Satellite Program (DMSP) satellite. They found that a dayside aurora moving toward the pole evolved into a diffuse glow called polar cap patch that then propagated across the polar cap and then activated a large, bright, night-side aurora along the poleward boundary of the night-side auroral oval. The SuperDARN observations showed fast flows away from the Sun associated with the dayside bright aurora, and the DMSP satellite measured

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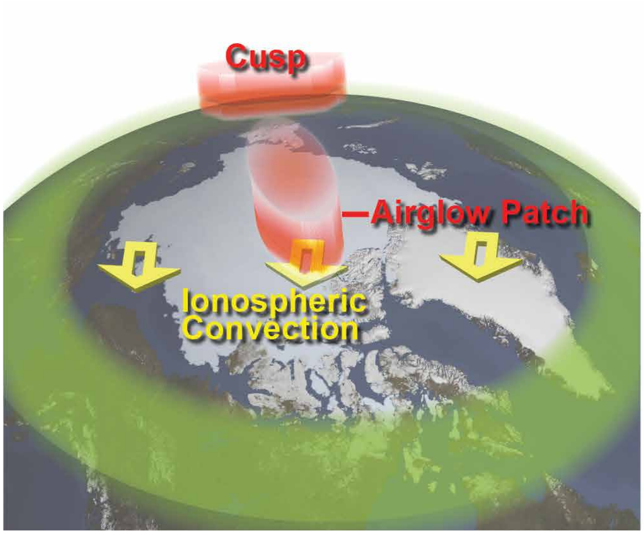

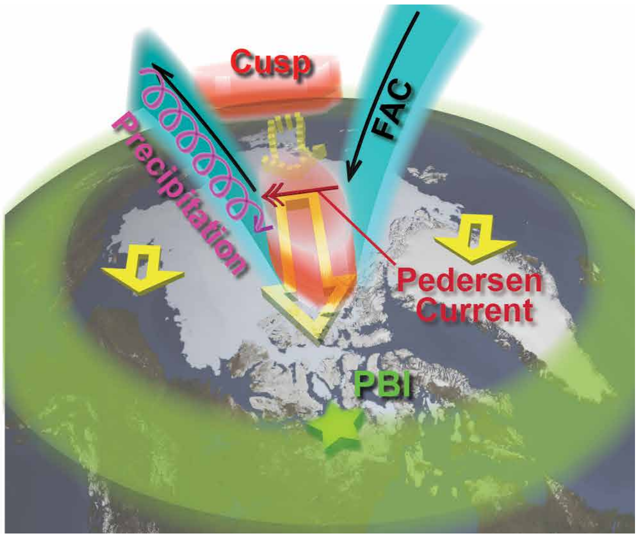

increased precipitation of energetic particles and enhanced plasma density with a strong flow burst moving away from the Sun.

The polar cap patch coincided with a narrow flow channel away from the Sun as well. The propagation across the polar cap and the subsequent night-side auroral flares told the group that the channel of energy flow originated from dayside and then reached the night-side, triggering a localised energy release in the night-side magnetosphere. Dr Nishimura explains this: ‘We discovered a new mode of energy transport from dayside to night-side, and its importance to triggering night-side energy release processes that create auroras. This finding opens up a possibility of predicting night-side aurora brightening by tracing localised transient energy flow from dayside to night-side.’

A Tedious but Rewarding Process On-going Still

Besides these first observations of energy transport from dayside to night-side and aurora triggering, which were done by simultaneous imaging operations in Europe and North America, the group has also made several other significant discoveries. They have carried out a statistical study of energy transport from dayside to night-side and its relation to the interplanetary magnetic field. Their findings, which were published in the Journal of Geophysical Research: Space Physics, indicate that the polar cap patches moved across the pole from dayside to night-side pretty much in unison with localised plasma flows across the pole. Essentially, if you watch how patches move, you can tag areas of the sky that carry a large amount of energy from the solar wind.

In the same journal, the team reported specific imaging of night-side auroral triggering, determining that the auroras were probably triggered by plasma flows over the pole, rather than simply coincidentally being in the same area. Further, they determined where the energy required to power auroras is stored. In a pair of papers looking at numerical simulations of day-night energy transport and night-side auroral triggering, they offer a better understanding of the processes involved in the flow of the energy that creates beautiful auroras.

Where Do They Go Next?

Now, according to Dr Zou: ‘We will examine the dayside source process of the intense night-side aurora triggering. This is where the solar wind interacts with the Earth’s magnetosphere transferring mass, momentum, and energy into the magnetosphere.’ She says this interaction often generates rapid anti-sunward directed flow bursts in the conjugate dayside ionosphere, some of which can propagate thousands of kilometres away over an hour-long period to the night-side auroral oval, triggering night-side auroras. They are interested in what solar wind conditions drive the formation of these flow bursts, what controls the flow shapes and sizes, and what determines how far the flows propagate towards night-side. This kind of information will be an essential component of their proposed day-to-night coupling system. They want to nail down every step involved in how the energy gets from the Sun to generating the aurora, and investigate why are they triggered the way they are.

‘We started this aurora research by looking at the night-side polar region, where the aurora is most commonly seen,’ Dr Nishimura tells Scientia. ‘But the ultimate energy source of the auroras is in the solar wind, on the dayside of the Earth, so our exploration has been to search and walk against the flow of energy.’ In other words, they are tracking the energy backward, against the flow, from the aurora to the solar wind (and therefore the Sun). So far, they have just reached the source of the flow on the dayside and found the path, so their research will further look at the behaviour of the energy flow from the solar wind to the dayside of the Earth. But auroras aren’t the only phenomena of interest. They aren’t the scientific end game.

Another important direction their research is heading – in fact, perhaps the most important direction – is using their newly acquired knowledge to better qualify and quantify Space Weather. There is still a long way to go before they can predict radio communication disruptions, satellite operation disruptions, or power grid failures, but that is the ultimate goal. Dr Nishimura, Dr Zou and their colleagues feel that we as a community should keep moving forward in our description and understanding of Space Weather phenomena, both to better understand the beauties of Nature, and also for our own self-defence.

Meet the researchers

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Dr Toshi Nishimura received his training in Geophysics from Tohoku University in Japan. Here, he achieved his PhD in 2009, for a thesis entitled 'Evolution of convection electric fields in the magnetosphere during geomagnetic storms and substorms.' Dr Nishimura went on to a JSPS Research Fellowship at Nagoya University and then moved to UCLA in California as a visiting scholar and then as a research scientist. He received a James B. Macelwane Medal from American Geophysical Union in 2016. He joined the faculty of Boston University in 2016, where he is currently Research Associate Professor in the Department of Electrical and Computer Engineering and a member of the Center for Space Physics, where he is actively engaged in studying a variety of topics in Space Science, particularly aurora and upper atmospheric phenomena.

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Dr Ying Zou received her baccalaureate in Space Physics from Peking University and then did her graduate work at UCLA, where she received her PhD in 2015. She received Jacob Bjerknes award from UCLA in 2015. From 2015 to 2017 she was a postdoctoral scholar at UCLA, and in 2017 she joined the staff at Boston University where she is currently a research scientist with the Center for Space Physics. She has been selected for a Jack Eddy postdoctoral fellow in 2017. Dr Zou's present research interest is the mechanism of the auroras, particularly those arising from currents flowing around the polar caps.

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