Aurora mysteries unlocked with NASA's THEMIS mission

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Auroral beads seen from the International Space Station, Sept. 17, 2011 (Frame ID: ISS029-E-6012). Credit: NASA

A special type of aurora, draped east-west across the night sky like a glowing pearl necklace, is helping scientists better understand the science of auroras and their powerful drivers out in space. Known as auroral beads, these lights often show up just before large auroral displays, which are caused by electrical storms in space called substorms. Previously, scientists weren't sure if auroral beads are somehow connected to other auroral displays as a phenomenon in space that precedes substorms, or if they are caused by disturbances closer to Earth's atmosphere.

But powerful new computer models combined with observations from NASA's Time History of Events and Macroscale Interactions during Substorms—THEMIS—mission have provided the first strong evidence of the events in space that lead to the appearance of these beads, and demonstrated the important role they play in our near space environment.

"Now we know for certain that the formation of these beads is part of a process that precedes the triggering of a substorm in space," said Vassilis Angelopoulos, principal investigator of THEMIS at the University of California, Los Angeles. "This is an important new piece of the puzzle."

By providing a broader picture than can be seen with the three THEMIS spacecraft or ground observations alone, the new models have shown that auroral beads are caused by turbulence in the plasma—a fourth state of matter, made up of gaseous and highly conductive charged particles—surrounding Earth. The results, recently published in the journals *Geophysical Research Letters* and *Journal of Geophysical Research: Space Physics*, will ultimately help scientists better understand the full range of swirling structures seen in the auroras.

"THEMIS observations have now revealed turbulences in space that cause flows seen lighting up the sky as of single pearls in the glowing auroral necklace," said Evgeny Panov, lead author on one of the new papers and THEMIS scientist at the Space Research Institute of the

Austrian Academy of Sciences. "These turbulences in space are initially caused by lighter and more agile electrons, moving with the weight of particles 2000 times heavier, and which theoretically may develop to full-scale auroral substorms."

Mysteries of Auroral Beads Formation

Auroras are created when charged particles from the Sun are trapped in Earth's magnetic environment—the magnetosphere—and are funneled into Earth's upper atmosphere, where collisions cause hydrogen, oxygen, and nitrogen atoms and molecules to glow. By modelling the near-Earth environment on scales from tens of miles to 1.2 million miles, the THEMIS scientists were able to show the details of how auroral beads form.

As streaming clouds of plasma belched by the Sun pass Earth, their interaction with the Earth's magnetic field creates buoyant bubbles of plasma behind Earth. Like a lava lamp, imbalances in the buoyancy between the bubbles and heavier plasma in the magnetosphere creates fingers of plasma 2,500 miles wide that stretch down towards Earth. Signatures of these fingers create the distinct bead-shaped structure in the aurora.

"There's been a realization that, all summed up, these relatively little transient events that happen around the magnetosphere are somehow important," said David Sibeck, THEMIS project scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "We have only recently gotten to the point where computing power is good enough to capture the basic physics in these systems."

Now that scientists understand the auroral beads precede substorms, they want to figure out how, why and when the beads might trigger full-blown substorm. At least in theory, the fingers may tangle magnetic field lines and cause an explosive event known as magnetic reconnection, which is well known to create full-scale substorms and auroras that fill the nightside sky.

New Models Open New Doors

Since its launch in 2007, THEMIS has been taking detailed measurements as it passes through the magnetosphere in order to understand the causes of the substorms that lead to auroras. In its prime mission, THEMIS was able to show that magnetic reconnection is a primary driver of substorms. The new results highlight the importance of structures and phenomenon on smaller scales—those hundreds and thousands of miles across as compared to ones spanning millions of miles.

"In order to understand these features in the aurora, you really need to resolve both global and smaller, local scales. That's why it was so challenging up to now," said Slava Merkin, co-author on one of the new papers and scientist at NASA's Center for Geospace Storms headquartered at Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. "It requires very sophisticated algorithms and very big supercomputers."

The new computer simulations almost perfectly match THEMIS and ground observations. After the initial success of the new computer models, THEMIS scientists are eager to apply them to other unexplained auroral phenomena. Particularly in explaining small-scale structures, computer models are essential as they can help interpret what happens in between the spaces where the three THEMIS spacecraft pass.

"There's lots of very dynamic, very small-scale structures that people see in the auroras which are hard to connect to the larger picture in space since they happen very quickly and on very small scales," said Kareem

Sorathia, lead author on one of the new papers and scientist at NASA's Center for Geospace Storms headquartered at Johns Hopkins Applied Physics Laboratory. "Now that we can use global models to characterize and investigate them, that opens up a lot of new doors."

More information: K. A. Sorathia et al, Ballooning-Interchange Instability in the Near-Earth Plasma Sheet and Auroral Beads: Global Magnetospheric Modeling at the Limit of the MHD Approximation, *Geophysical Research Letters* (2020). DOI: 10.1029/2020GL088227

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