Pennsylvania State University
Graduate School Commencement
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Good evening, everyone.

It is a great privilege to be with you to witness the crowning moment of your graduate education – the receipt of your well-earned degrees. Your knowledge, talent, and energy are poised to accomplish great things.

My story today begins with energy, but of a different kind.

Three years ago, almost to the day, on May 15, 2005, a colossal burst of energy occurred. Something no one had ever witnessed before. Most likely, very few of you were even aware of it.

It was a coronal mass ejection — a spectacular explosion from the sun, which suddenly and violently released huge tongues of gas, charged particles, and magnetic fields. They streaked through space at several million miles per hour, and hit the Earth. They rippled all the way through the atmosphere surrounding our planet. It was classified as a G-5 geomagnetic storm — the highest level on the scale — and it sparked an unprecedented phenomenon in Earth's atmosphere: large intense auroral spirals – features that were repeated during this major active storm. Auroral displays were seen over the southern United States – with some hints of a great red aurora.

Have no fear – this is not going to be a lecture on particle physics and atmospheric dynamics. That's about all I'm going to say about this phenomenon, because what I really want to tell you about is the way we set about trying to figure it out.

We had something that no one had ever seen before, and that no one could explain. The spiral was an emergent feature that was telling us something about an unusual process between the sun and earth.

Scientists — like most human beings — get excited about solving mysteries. They also like to solve problems.

It turns out geomagnetic storms like this are not just fabulous curiosities of physics. They can have catastrophic societal impacts: they can cause energy surges that produce

blackouts - and complete collapses of power grid systems, and they can disrupt and damage satellites used for global navigation, communications, and military operations.

But it was hard to begin to comprehend this phenomenon, because it was really a series of interrelated phenomena. We weren't just dealing with the troposphere, that part of the atmosphere nearest the Earth's surface. We were also dealing with all the other layers of the atmosphere: the stratosphere, the ionosphere, and the magnetosphere – each its own dynamic system.

We had to look at the interplanetary medium between Earth and Sun — yet another dynamic system - all the way back to the huge, dynamic system that sparked the energy that rippled through all the rest of the systems — the sun and the heliosphere.

We were exploring the convoluted workings of a system of systems. It's fantastically hard to get a handle on such a system, a system in which each component is — itself — a complex system. Even if you did understand how each component worked, you still couldn't predict how they interacted with each other.

An event upstream could change the behavior of the entire system downstream. In such complex systems there are no simple cause and effects. Instead, what one system produces, will have impacts on how another system is working — which may, in turn, effect the first system. We call these linkages positive or negative feedbacks. "Interconnectedness" always produces surprises.

Through an international program that I was privileged to chair we came up with an unusual idea: to organize a virtual conference. We brought together:

> Scientists who studied all the different components of the system — the sun, the interplanetary medium, and Earth's atmosphere.
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> Scientists who specialized in plasmas, magnetics, optics, physics, chemistry, fluid dynamics.
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> Scientists who specialized in making observations,in analyzing data, in using computer models, in creating visualizations.

We colleted data from ground-based instruments throughout the world and from 20 different satellites, which, literally, could look at this spectacular event from different angles. And using cyber infrastructure we created a virtual observatory.

We put together a virtual conference, which lasted for a month, in which people — online and in real time — could share and compare all the various data.

We gathered 270 participants, from many different countries.

All these people, from diverse geographic settings, and diverse perspectives, could continually analyze and discuss the data, and bring up and refine questions. Then — on demand — modelers could test the observations and theories, creating simulations of the dynamics. I might add that the output from a single simulation reached terabyte-size, equivalent to a million books. Visualization experts turned the model results into images we all could see.

From all these instruments, data, images, people, and perspectives, we have a new view for understanding the Sun-Earth system, a view that also may help explain features that are seen on Saturn and Jupiter.

Amazing advances in technology have made such things possible. But what it really enables is creativity.

In his book, the *Rise of the Creative Class*, Richard Florida wrote that

> "Creativity involves the ability to synthesize. Einstein captures it nicely when he called his own work 'combinatory play.' It is a matter of sifting through data, perceptions, and material to come up with combinations that are new and useful."

One of the things I learned on the Sun-Earth project was how creativity flourishes when a diversity of data and perceptions, are synthesized from a diversity of places and directions.

We are going to need a lot of creativity and collaboration to solve an imminent problem: global climate change.

There is a movement to usher in a new era of geologic time, to give the most recent period in Earth history a new name: the Anthropocene – the era of humans. It would mark the era when activities of humans first began to have a significant global impact on Earth's climate and ecosystems. Your own brilliant earth scientist, Richard Alley, is a proponent. He said,

> "A geologist from the far distant future almost surely would draw a new line, and begin using a new name, where and when our impacts

> show up. In land, water, air, ice, and ecosystems the human impact is clear, large, and growing."

"Land, water, air, ice, and ecosystems." Yes, you guessed it: what we're dealing with here is another system of systems. I submit that cyberinfrastructure used to integrate data, models, and people can be a means to create collaboratories and informatics that will advance our understanding and lead to solutions.

Right here at Penn State, professors and graduate students in the Department of Geography have worked on a proof-of-concept co-laboratory called HERO, the Human-Environment Regional Observatory — with the University of Arizona, Clark University in Massachusetts, and Kansas State University. Each of these is located in a dramatically different physical setting, so that researchers can explore environmental change from different perspectives.

But they also represent different social landscapes. The researchers here recognize that they are not just trying to create technological infrastructure, but also social infrastructure, which helps people from different settings learn from each other and work with each other.

The Penn State researchers put it this way:

> "Tools are only tools. They cannot make things happen. Only people can do that."

People working together.

These co-laboratories need not — in fact, should not — Be limited to scientists. At the Massachusetts Institute of Technology, which shares a joint graduate degree program with Woods Hole Oceanographic Institution, scientists are setting up what they call a "Climate Collaboratorium." In it, experts from all areas – the humanities and fine arts, social sciences, business and engineering, journalism, law and medicine, and the natural science - will hopefully engage stakeholders, and concerned citizens in effective — creative — problem-solving and decision-making on a global and regional scale.

As you graduate, you are entering a time that's never been entered by humans in the past. At the dawn of the Anthropocene, master the technology at your disposal; harness your energy and excitement; round up all the diversity you can find. Build a system of systems of human beings, to foster creativity.

Humanity has conspired to present you with some of the hardest problems the world has ever seen. Working together you can solve them.

Congratulations on your achievements and those to come.

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