Profiling the largest solar explosions

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This aurora over Valkeakoski, Finland on September 15, 2000 resulted from the September 12 coronal mass ejection featured in the video above. Credit: Tom Eklund

Solar flares – they're big and they're fast. They can knock out a satellite or create a beautiful aurora. And the jury is still out on what causes these explosions.

Flares, and the related coronal mass ejection, shoot energy, radiation, and magnetic fields out into space that can harm satellites or humans in space. Current observations aren't precise enough to determine whether the eruptions are driven by energy surging through the sun's surface, or by the sudden release of energy that has slowly accumulated in the atmosphere.

Now, a new way of looking at old data has changed all that, but the results have created more mystery: There isn't enough energy passing through the surface during the eruption to drive the explosion.

"In some sense, the idea that energy from below triggers the eruption is the easiest explanation – like a geyser," says Peter Schuck, a physicist who studies space weather at NASA's Goddard Space Flight Center in Greenbelt, Md. "But if the idea doesn't agree with what's observed, then it's wrong. End of story."

Schuck's research indicates that, instead, the trigger occurs in the sun's atmosphere. "Our result shows that observations are more consistent with a slow accumulation of energy in the atmosphere," Schuck said, "and then a sudden explosion triggered from above, more like lightning."

Schuck studies coronal mass ejections, or CMEs, and solar flares at the place where theory and observation overlap. His latest work on CMEs appeared in the Astrophysical Journal on May 1. Schuck constructed a way to test CME and flare observations in order to limit which group of hypotheses fit the data, even when there's not enough evidence to conclusively pick a single theory.

In the case of CMEs, the data is limited to distant movies captured by spacecraft such as the Solar and Heliospheric Observatory (SOHO). These movies show that CMEs begin as a gigantic arch, some 50 times larger than Earth, with each of its feet planted on the sun's surface, or "photosphere."

Two broad camps of theories have been developed to explain these so-called coronal loops. "The energy is built up by either a twisting motion below the surface or the release of magnetic energy in the solar atmosphere," says Haimin Wang, a physicist at the New Jersey Institute of Technology, whose work focuses on the characteristics of the photosphere before and during solar ejections.

Either way, the energy originally comes from the surface. The question is simply whether it surges through directly before the appearance of the coronal loop or oozes up slowly over time, storing up in the atmosphere until released in a massive explosion of light, plasma, magnetic fields and high energy particles.

Distinguishing between the two options based solely on a distant movie isn't easy. Imagine trying to figure out what powers a car when all you've got to go on is a movie of a highway. Worse, that movie isn't from above, so you might easily determine the direction and speed of those cars, but from head-on or a side view where you're not even sure of the angle.

If, however, you can infer the speed of the car, you could at the very least figure out how much energy it has and, in turn, rule out any power source that didn't jibe with what you saw.

Schuck has done exactly that. "I developed a way to infer magnetic field motion, and therefore energy amounts, from the velocities we observe in the photosphere," he says.

Imagine the cars again. If the cars were coming directly toward you, you could measure the wavelength of the headlights and by determining how strongly they'd been shifted by the Doppler effect (that same wave-changing effect that causes sirens to sound higher as they come toward you and lower as they move away) you could measure the car's speed.

Schuck used similar, head-on Doppler measurements to find the velocity of solar material on the surface of the sun. This material moves perpendicular to the magnetic field at the base of the coronal loop -- the crux of what Schuck is trying to understand. He can convert those initial velocities of the sun's surface into information about the motion and energy of the magnetic field. This analysis may not spit out an exact number for the energy, but it does give a precise, accurate range of energy possibilities.

And so, for the first time, one can look at images of the sun and set firm limits on the maximum energy at a given spot – at least if the material was moving directly towards the camera to provide an accurate Doppler measurement.

The next step applies the analysis to an actual coronal mass ejection. Schuck looked at the data from a CME on September 12, 2000. This was an M-class ejection -- meaning it was fairly intense, but one step below the strongest X-class -- that moved directly towards Earth. Conveniently, this was also a well-studied flare, so other scientists had already examined SOHO images to measure the path, speed, and energy of the CME. This information, in turn, implies how much energy would have come through the photosphere at the start of the process had it indeed initiated from below.

The results were dramatic. The SOHO images showed the photosphere moving at speeds 10,000 times less slowly than would have been expected if it were directly triggering the eruption. "The velocity you'd need to see on the photosphere would be a thousand kilometers per second," says Shuck. "Not only are these speeds easily detected but they would be greater than the standard measurement range of the instrument. You'd see really weird stuff in the data readouts."

There is always the slim chance that somehow the instruments didn't catch the extreme motion, but given how large the velocities would have had to be, Schuck thinks this is unlikely.

This still leaves a variety of theories on just how the energy is stored and what triggers its release in the atmosphere. Distinguishing between those theories will require more detailed data—something scientists hope

NASA’s Solar Dynamics Observatory, launched in February 2010 will be able to provide.

Unlike previous missions, SDO will be able to directly measure the energy in the photosphere – as opposed to Schuck's present method of inferring that energy from velocity measurements -- and it will do so with 20 times the resolution of the data on which Schuck based his current work. Such information will help narrow down what triggers a CME or solar flare even more precisely.

"Now we just need some really big CMEs to work with," says Schuck.

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