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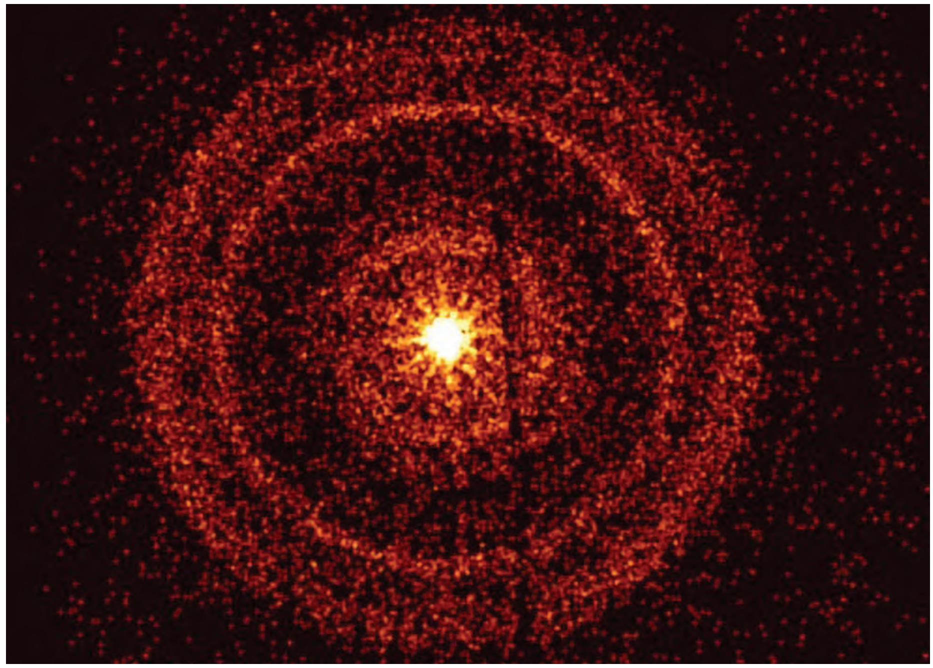
Did a Cosmic Explosion Make the Ionosphere Dance?

On 1 August 1983, Earth's atmosphere recoiled from a gamma ray burst (GRB) likely produced by the explosion of a nearby massive star. The high-energy photons disturbed the lower ionosphere—the partially ionized region of Earth's atmosphere—enough to affect low-frequency radio waves traveling around the planet.

In the 40 years since, astronomers have recorded an average of more than one GRB per day. However, none appeared to perturb the atmosphere in a noticeable way, until a group of researchers connected a bright GRB on 9 October 2022 with a disturbance in the uppermost ionosphere.

"It is, in general, a threshold problem," said space weather scientist Mirko Piersanti of the University of L'Aquila and the Italian National Institute of Astrophysics, who was the lead author of a study published in *Nature Communications* presenting the finding (bit.ly/ionosphere-GRB). He and his colleagues used data from the Chinese-Italian observatory China Seismo-Electromagnetic Satellite (CSES, also known as Zhangheng) to simulate how the ionosphere responds to gamma radiation from deep space.

The threshold problem, in Piersanti's view, is that only a very powerful GRB ionizes enough of the low-density upper atmosphere for long enough to be detectable. The difficulty, then, lies in detangling cosmic gamma rays from the many other phenomena that affect this region.



An X-ray image of the gamma ray burst detected on 9 October 2022 shows the explosion itself as the bright source at the center. The rings around it are where light bounced off dust in the Milky Way. Credit: NASA/Swift/A. Beardmore (University of Leicester)

Cosmic Satellite Killers

In addition to the value that understanding GRBs has to astrophysics, the human stakes are potentially high.

"More and more of our infrastructure and economy is parked in space and power systems, so more and more is at risk, globally," said Aaron Breneman, an atmospheric scientist at NASA's Goddard Space Flight Center who was not involved with the study.

Coronal mass ejections from the Sun disturb the atmosphere enough to disrupt communications and navigational satellites, as well as electrical power grids, and it would be good to know whether GRBs can do the same. (Some researchers have even speculated that a nearby powerful GRB could have contributed to a mass extinction about 450 million years ago (bit.ly/GRB-extinction, bit.ly/Ordovician-GRB)).

The best data for measuring the magnitude of the threat come from events like the 2022 GRB.

"It is, in general, a threshold problem."

Dance of the Ionosphere

In 1988, G. J. Fishman and U. S. Inan proposed using the ionosphere as a planetary-scale GRB detector (bit.ly/GRB-detector). Since then, astronomers have built many telescopes (including the space-based Swift and Fermi observatories) capable of characterizing GRBs, but none of those hundreds of events registered in ionospheric measurements.

Many factors could explain that dearth of data. Though GRBs are among the most luminous events in the cosmos, peak gamma ray emissions from so-called long GRBs last only a few minutes. Their short duration, combined with Earth's great distance from most of the stars whose explosions exist there—millions or billions of light-years—makes it likely that few GRBs produce enough photons to make the ionosphere dance.

When high-energy photons strike the atmosphere, they strip electrons from some atoms, forming the ionized gas known as plasma; this process is called photoionization. Over time, electrons rejoin nuclei (known as neutralization). CSES includes an electric field instrument that can measure these processes.

The density of gas in the upper atmosphere is low, so even dramatic events such as GRBs might not produce a lot of plasma. The researchers' simulation shows that the photoionization rate needs to be at least 5 times faster than neutralization for the GRB's effect to be detectable in the ionosphere.

Typically, Piersanti pointed out, only solar events—which last on the order of hours—affect the atmosphere that strongly.

In contrast, the atmospheric response is too slow for most GRBs to produce a similar effect. In one sense, that's reassuring: If GRBs are common in a cosmic sense but their ionospheric effects are rare, the danger to the planet is low for the foreseeable future.

If Piersanti and his collaborators are correct, the 1983 and 2022 bursts just happened to be powerful enough to flood the ionosphere with ionizing radiation faster than recombination could erase the evidence.

That's a big if.

Complications

"There are so many more things that weren't even considered here that could be affecting their results," said space weather researcher Alexa Halford, also at NASA's Goddard Space Flight Center, who was not involved in the study. The ionosphere itself is a big part of the problem, she said. "It's really hard to get in situ measurements globally all the time."

"There are so many more things that weren't even considered here that could be affecting their results."

To make matters worse, other things far closer to home can increase or decrease ionization. The Sun is by far the most significant source of gamma rays and electrically charged particles that affect the ionosphere. Depending on whether it's day or night and how much solar activity or how many terrestrial storms are in effect, the amount of ionized gas in the upper atmosphere can vary significantly.

"Even lightning can cause lots of really cool [ionospheric] effects," Halford said. "We don't fully understand that either."

Part of the problem is that the ionosphere is difficult to reach. Much of the data comes from the transmission of long-wavelength radio waves, which interact with the ionized gas. Other experiments involve high-altitude sounding rockets that fly directly through the lower ionosphere. The CSES spacecraft used by Piersanti and his collaborators flies through the topmost layer of the atmosphere. None of these methods provide global 24-hour views of the ionosphere, though, leaving gaps in the data that need to be filled with statistical inference or theoretical models.

With these uncertainties and only two GRBs to work from, Halford and Breneman joined Piersanti in calling for wider collaborations among atmospheric, space weather, plasma physics, and astrophysics researchers.

"The ionosphere as a [GRB] detector is still something that is highly desirable and something that we definitely need to do more to understand," Halford said.

By **Matthew R. Francis** (@DrMRFrancis), Science Writer

Microplastics Are the Not-So-Secret Ingredient in Marine Snow

An octopus swims through marine snow. Credit: NOAA Office of Ocean Exploration and Research

In 2020, scientists discovered that plastics had infiltrated our planet's water cycle, hitching a ride through clouds and rain. Research has shown that the carbon cycle is chock-full of plastic as well: Microscopic particles are drifting to the seafloor with natural organic debris called marine snow.

In a study presented at AGU's Annual Meeting 2023, scientists showed how bacteria and phytoplankton colonize the surfaces of sunburned bits of microplastic and drift to the bottom of the ocean (bit.ly/marine-plastic-snow). This debris-driven flux potentially upsets the delicately balanced system that removes carbon from the atmosphere.

Ocean carbon goes through a cyclical process called the biological carbon pump. Plantlike organisms called phytoplankton float near the surface and use carbon from the air in photosynthesis. Zooplankton consume phytoplankton and excrete fecal matter into the water. Their poop combines with tiny bits of dead plants and animals and sinks to the seafloor in microscopic flakes called marine snow. Upwelling eventually cycles them back to the surface.

To understand how microplastics have affected this vital system, oceanography graduate student Astrid Zapata De Jesús of the University of New Hampshire and her colleagues studied biofouling—the process that envelops microplastics in marine snow.

"This study will form one of the building blocks of this emerging understanding of how microplastic pollution may be affecting natural carbon cycling."

Biofouling happens when anything floating in the ocean—from boats and buoys to microscopic plastics—gets colonized by bacteria and phytoplankton that collect on the surface of the foreign object. These cells combine to produce a sticky organic ooze called biofilm.

The researchers hypothesized that microplastic marine snow forms as microorgan-