Earth's atmosphere is our best defense against nearby supernovae, study suggests

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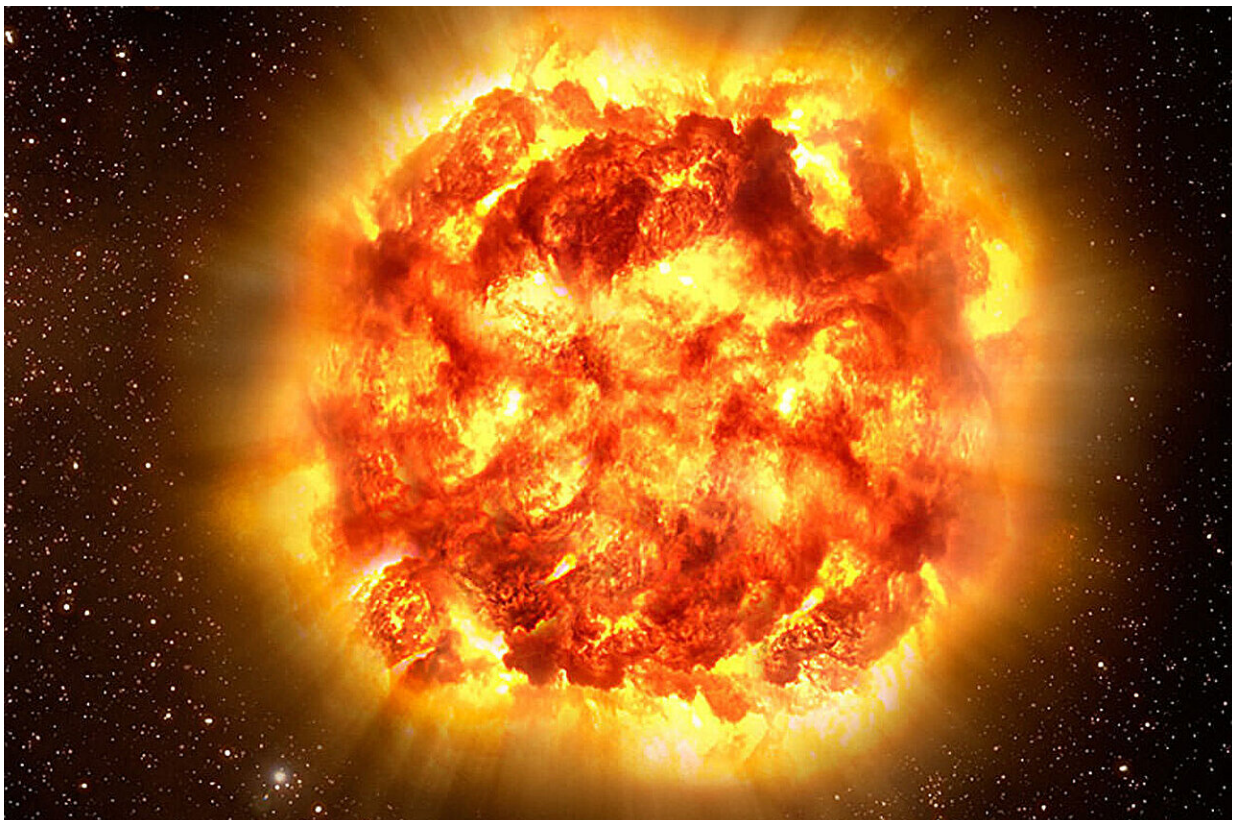


Artist's impression of a Type II supernova explosion. These supernova produce gamma rays and powerful ionizing radiation that's hazardous to life. Credit: ESO

Earth's protective atmosphere has sheltered life for billions of years, creating a haven where evolution produced complex lifeforms like us.

The ozone layer plays a critical role in shielding the biosphere from deadly UV radiation. It blocks 99% of the sun's powerful UV output. Earth's magnetosphere also shelters us.

But the sun is relatively tame. How effective are the ozone and the magnetosphere at protecting us from powerful supernova explosions?

Every million years—a small fraction of Earth's 4.5 billion-year lifetime—a massive star explodes within 100 parsecs (326 light-years) of Earth. We know this because our solar system sits inside a massive bubble in space called the Local Bubble.

It's a cavernous region of space where hydrogen density is much lower than outside the bubble. A series of supernovae explosions in the previous 10 to 20 million years carved out the bubble.

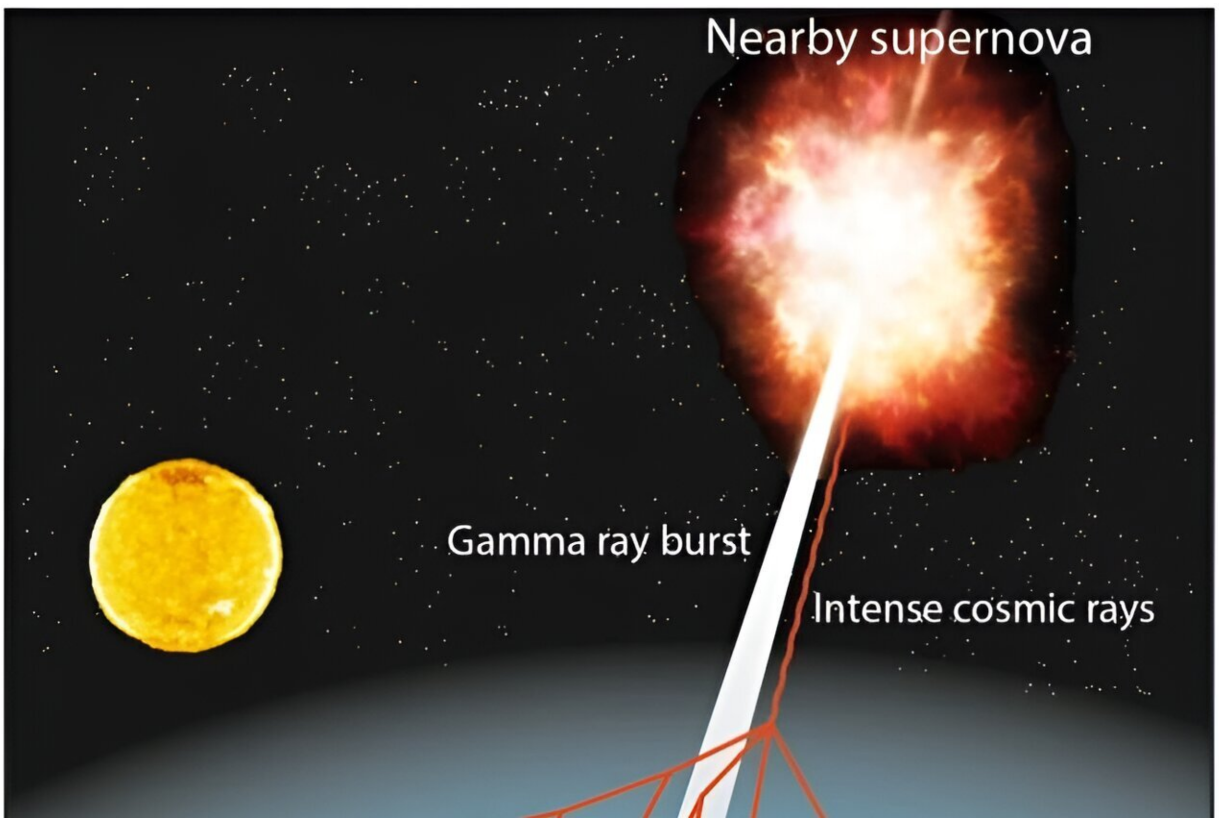
Supernovae are dangerous, and the closer a planet is to one, the more deadly its effects. Scientists have speculated on the effects that supernova explosions have had on Earth, wondering if they have triggered mass extinctions or at least partial extinctions.

A supernova's gamma-ray burst and cosmic rays can deplete Earth's ozone and allow ionizing UV radiation to reach the planet's surface. The effects can also create more aerosol particles in the atmosphere, increasing cloud coverage and causing global cooling.

A new research article published in *Communications Earth & Environment* examines supernova explosions and their effect on Earth. It is titled "Earth's atmosphere protects the biosphere from nearby supernovae." The lead author is Theodoros Christoudias from the Climate and Atmosphere Research Center, Cyprus Institute, Nicosia, Cyprus.

The Local Bubble isn't the only evidence of nearby core-collapse supernovae (SNe) in the last few million years. Ocean sediments also contain ^{60}Fe, a radioactive isotope of iron with a half-life of 2.6 million years.

SNe expel ^{60}Fe into space when they explode, indicating that a nearby supernova exploded about 2 million years ago. There's also ^{60}Fe in sediments that indicate another SN explosion about 8 million years ago.



This graphic from the research article shows the potential atmospheric and climate impacts of a nearby supernova. Gamma rays can deplete the ozone, allowing more UV radiation to reach Earth’s surface. Some UV radiation is ionizing, meaning it can damage DNA. Cosmic rays can also create more condensation nuclei, meaning more clouds and potential global cooling. Credit: *Communications Earth & Environment* (2024). DOI:

10.1038/s43247-024-01490-9

Researchers have correlated an SN explosion with the Late Devonian extinction about 370 million years ago. In one paper, researchers found plant spores burned by UV light, an indication that something powerful depleted Earth's ozone layer. In fact, Earth's biodiversity declined for about 300,000 years prior to the Late Devonian extinction, suggesting that multiple SNe could've played a role.

Earth's ozone layer is in constant flux. As UV energy reaches it, it breaks ozone molecules (O_3) apart. That dissipates the UV energy, and the oxygen atoms combine into O_3 again. The cycle repeats.

That's a simplified version of the atmospheric chemistry involved, but it serves to illustrate the cycle. A nearby supernova could overwhelm the cycle, depleting the ozone column density and allowing more deadly UV to reach Earth's surface.

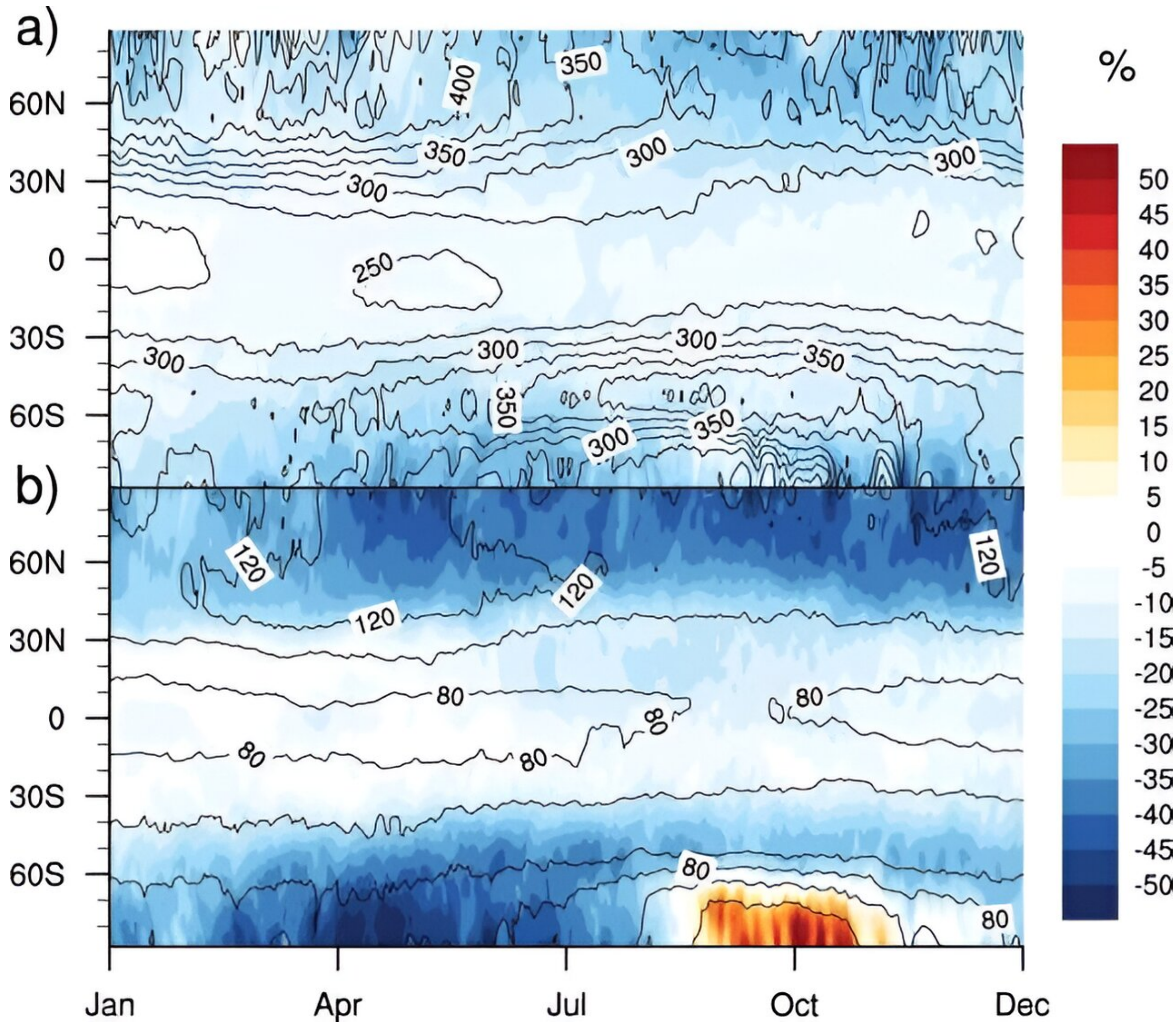
But in the new paper, Christoudias and his fellow authors suggest that Earth's ozone layer is much more resilient than thought and provides ample protection against SNe within 100 parsecs. While previous researchers have modeled Earth's atmosphere and its response to a nearby SN, the authors say that they've improved on that work.

They modeled Earth's atmosphere with an Earth Systems Model with Atmospheric Chemistry (EMAC) model to study the impact of nearby SNe explosions on Earth's atmosphere. Using EMAC, the authors say they've modeled "the complex atmospheric circulation dynamics, chemistry, and process feedbacks" of Earth's atmosphere.

These are needed to "simulate stratospheric ozone loss in response to elevated ionization, leading to ion-induced nucleation and particle growth to CCN" (cloud condensation nuclei).

"We assume a representative nearby SN with GCR (galactic cosmic ray) ionization rates in the atmosphere that are 100 times present levels," they write. That correlates with a supernova explosion about 100 parsecs or 326 light-years away.

"The maximum ozone depletion over the poles is less than the present-day anthropogenic ozone hole over Antarctica, which amounts to an ozone column loss of 60–70%," the authors explain. "On the other hand, there is an increase of ozone in the troposphere, but it is well within the levels resulting from recent anthropogenic pollution."



These panels from the research letter show the ozone column percentage decrease from a 100-fold increase in GCR intensity over nominal. The left vertical axis represents Earth's latitude, and the x-axis shows the time of year. Ozone loss is more pronounced over the poles due to the effect of Earth's magnetosphere, where it's weaker. a is present-day Earth, while b represents an ancient Earth with only 2% oxygen during the pre-Cambrian. Credit: *Communications Earth & Environment* (2024). DOI: 10.1038/s43247-024-01490-9

But let's cut to the chase. We want to know if Earth's biosphere is safe or not.

The maximum mean stratospheric ozone depletion from 100 times more ionizing radiation than normal, representative of a nearby SN, is about 10% globally. That's about the same decrease as our anthropogenic pollution causes. It wouldn't affect the biosphere very much.

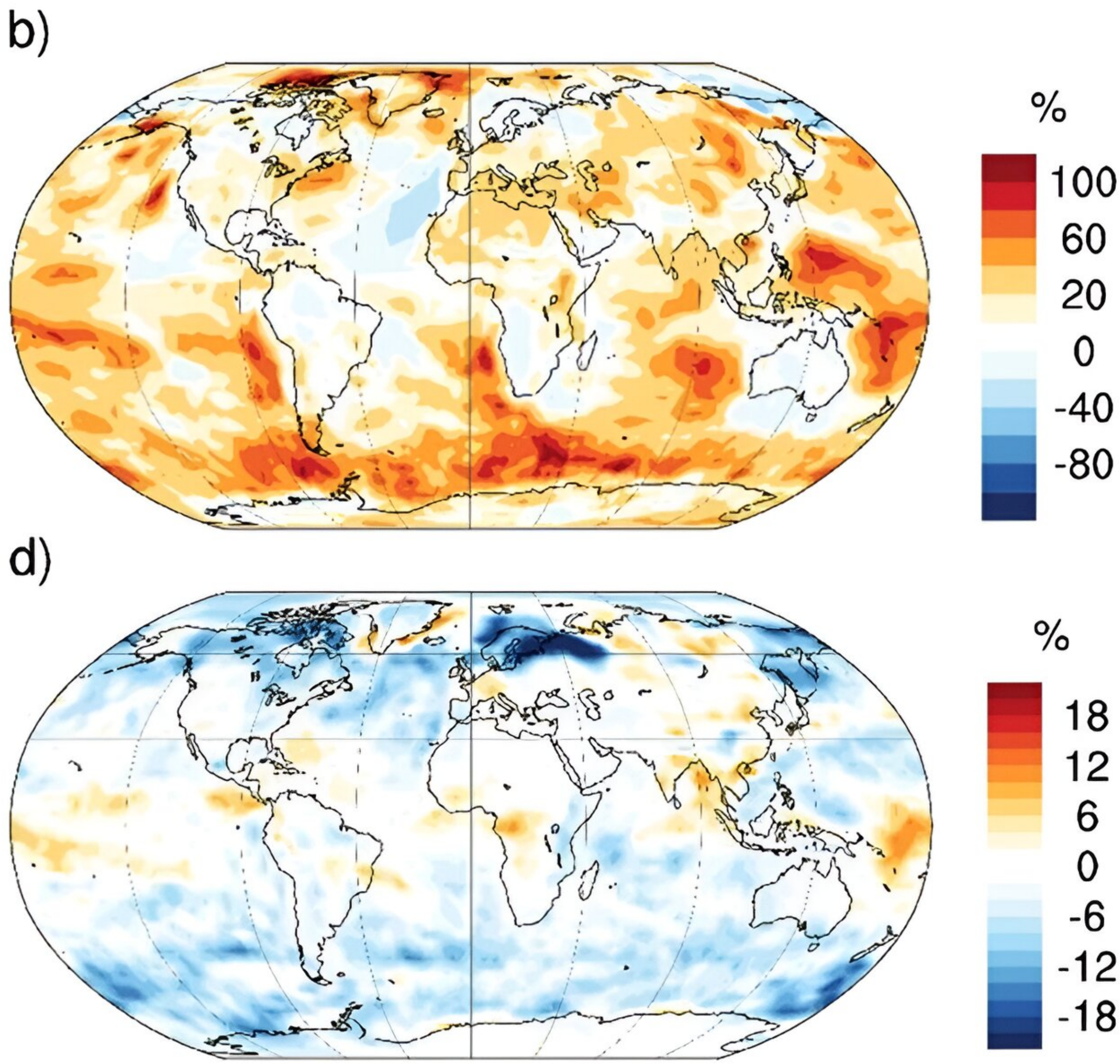
"Although significant, it is unlikely that such ozone changes would have a major impact on the biosphere, especially because most of the ozone loss is found to occur at high latitudes," the authors explain.

But that's for modern Earth. During the pre-Cambrian, before life exploded in a multiplication of forms, the atmosphere had only about 2% oxygen. How would an SN affect that? "We simulated a 2% oxygen atmosphere since this would likely represent conditions where the emerging biosphere on land would still be particularly sensitive to ozone depletion," the authors write.

"Ozone loss is about 10%–25% at mid-latitudes and an order of magnitude lower in the tropics," the authors write. At minimum ozone levels at the poles, ionizing radiation from an SN could actually end up increasing the ozone column. "We conclude that these changes of atmospheric ozone are unlikely to have had a major impact on the emerging biosphere on land during the Cambrian," they conclude.

What about global cooling?

Global cooling would increase, but not to a dangerous extent. Over the Pacific and Southern oceans, CCN could increase by up to 100%, which sounds like a lot. "These changes, while climatically relevant, are comparable to the contrast between the pristine pre-industrial atmosphere and the polluted present-day atmosphere." They're saying that it would cool the atmosphere by about the same amount as we're heating it now.



These two panels from the research help illustrate the global cooling effect from a nearby SN exposing Earth to 100 times more ionizing radiation. b shows the fractional change in CCN relative to the present day. d shows the fractional change in outgoing solar radiation relative to the present day due to increased cloud albedo. Credit: *Communications Earth & Environment* (2024). DOI:

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The researchers point out that their study concerns the entire biosphere, not individuals. "Our study does not consider the direct health risks to humans and animals resulting from exposure to elevated ionizing radiation," they write.

Depending on individual circumstances, individuals could be exposed to dangerous levels of radiation over time. But overall, the biosphere would hum along despite a 100-fold increase in UV radiation. Our atmosphere and magnetosphere can handle it.

"Overall, we find that nearby SNe are unlikely to have caused mass extinctions on Earth," the authors write. "We conclude that our planet's atmosphere and geomagnetic field effectively shield the biosphere from the effects of nearby SNe, which has allowed life to evolve on land over the last hundreds of million years."

This study shows that Earth's biosphere will not suffer greatly as long as supernova explosions keep their distance.

More information: Theodoros Christoudias et al, Earth's atmosphere protects the biosphere from nearby supernovae, *Communications Earth & Environment* (2024). DOI: 10.1038/s43247-024-01490-9

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