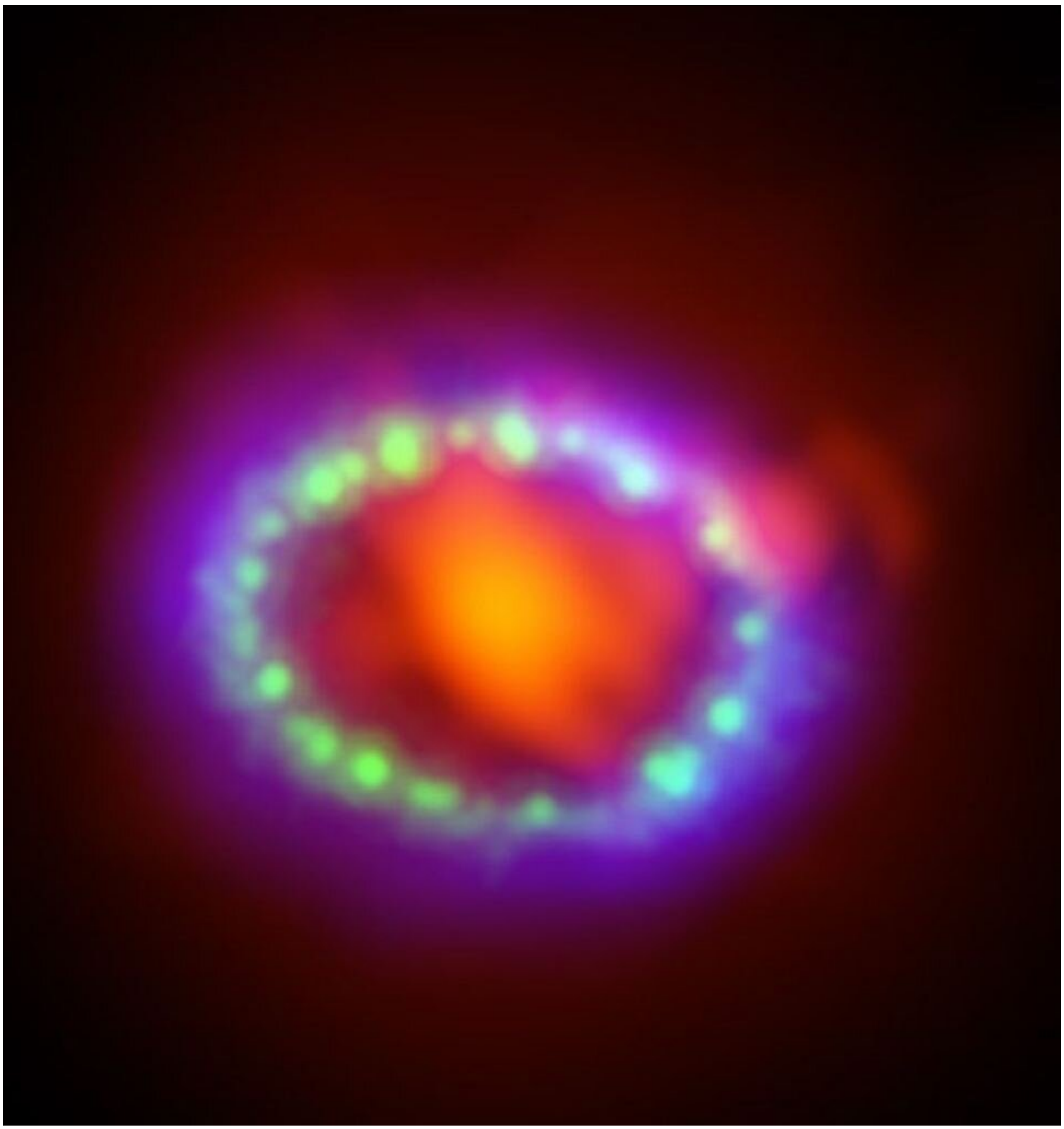
How dangerous are nearby supernovae to life on Earth?

October 27 2022, by Evan Gough



A composite image of SN 1987A from Hubble, Chandra, and ALMA. Credit: ALMA (ESO/NAOJ/NRAO)/A. Angelich. Visible light image: the NASA/ESA Hubble Space Telescope. X-Ray image: The NASA Chandra X-Ray Observatory - http://www.eso.org/public/images/eso1401a/, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=30512379

Life and supernovae don't mix.

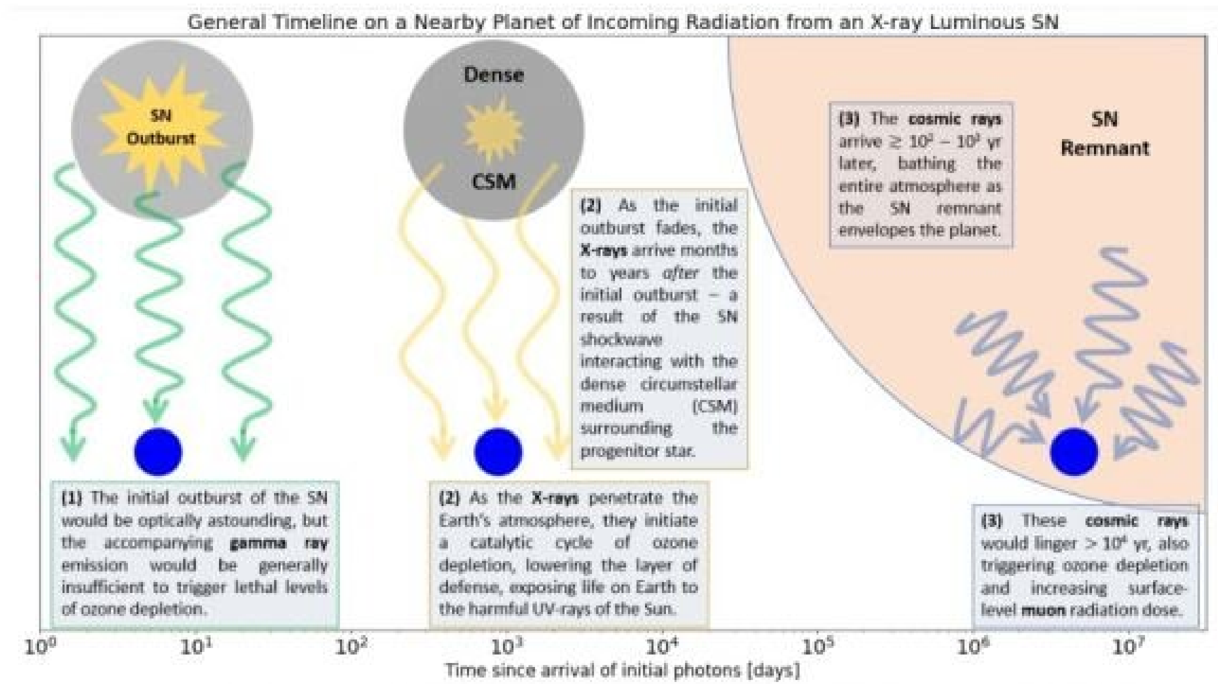
From a distance, supernovae explosions are fascinating. A star more massive than our sun runs out of hydrogen and becomes unstable. Eventually, it explodes and releases so much energy it can outshine its host galaxy for months.

But space is vast and largely empty, and supernovae are relatively rare. And most planets don't support life, so most supernovae probably explode without affecting living things.

But a new study, available on the preprint server arXiv, shows how one type of supernova has a more extended reach than thought. And it could have consequences for planets like ours.

Earth is no stranger to supernovae. One hasn't been close enough to sterilize Earth, but there's evidence showing supernovae have affected life on Earth.

A 2018 paper presented evidence of a supernova exploding near Earth about 2.6 million years ago. It was about 160 light-years away. The authors of that paper tied the supernova to the Pliocene marine megafauna extinction. In that event, up to a third of Earth's large marine species were wiped out, but only in shallow coastal waters.



This figure from the study shows a timeline of radiation exposure for a planet close to a luminous x-ray supernova. Credit: Brunton et al. 2022

Another paper showed up to 20 supernovae in the last 11 million years in the Scorpius-Centaurus OB association. Some of these were as close as 130 light-years to Earth. The paper's authors say that about 2 million years ago, one of the supernovae exploded close enough to our planet to damage the ozone layer.

But there are different types of supernovae. Some of them have a much longer reach and much greater duration. Scientists have long known about the powerful gamma rays that supernova release during the explosion. They also know about the cosmic rays that can arrive hundreds or thousands of years later. If this happens close enough to a planet like Earth, the cosmic rays can deplete the ozone layer and increase muon radiation at the surface.

A type IIn X-ray luminous supernova is different from other supernovae. When a supernova explodes, it emits gamma rays and other photons immediately. In an X-ray luminous supernova, gamma rays and photons are emitted, but some of the radiation from the explosion interacts with a dense circumstellar medium surrounding the progenitor star. This creates X-rays that can be lethal up to 160 light-years away.

In a scenario where an SN exploded close to Earth, it can take months or years following the initial explosion for the X-rays to arrive. Interactions with the circumstellar debris cause a delay. The X-rays can deplete Earth's ozone layer, allowing harmful UV radiation from the Sun to reach the planet's surface.

After the X-rays arrive, the cosmic rays arrive, similar to other SN. This is a double whammy for Earth's ozone layer.

Researchers aren't sure about the lethal distances of supernovae. There are many variables, both in the progenitor star and its environment. The progenitor star's mass loss is especially important. But by characterizing the lethal X-ray dose for Earth's stratosphere and the energy output of some of the brightest SN, the authors calculated the lethal distance for some well-known supernovae.

SN 1987A exploded in the Large Magellanic Cloud, and the light reached Earth in 1987. Scientists observed the explosion and confirmed the source of energy for the SN's visible light for the first time. It proved that the long-duration glow after an SN explosion is radioactive.

SN1987A wasn't very lethal, according to the authors. They say the SN was only deadly to a distance of less than one light-year. It was the least dangerous SN out of the 31 the team characterized.

The most lethal of the 31 was SN2006jd. It exploded in the galaxy NGC 4179, about 57 million light-years away, and the light reached Earth in 2006. According to the researchers, SN2006jd was lethal to almost 100 light-years.

The five most lethal SNs in this study are all Type IIn supernovae, as are seven of the top ten.

Supernova (Name)	Classification (Spectral Type)	Total X-ray Energy E_X [$\times 10^{46}$erg]	Lethal Distance $D_X^{\rm leth}(\mathcal{F})$ [pc]
2006jd	IIn	4300	30
2010jl	IIn	4200	29
2005ip	IIn	2900	25
1995N	IIn	2200	21
2005kd	IIn	1600	18
2001em	Ib/c	1400	17
2014C	Ib	790	13
1988Z	IIn	300	7.9
1986J	IIn	130	5.2
2004dk	Ib	82	4.1

This figure shows the ten most lethal SN in the study. The top five are all Type IIn x-ray luminous supernovae, and so are seven of the top ten. Credit: Brunton et al. 2022.

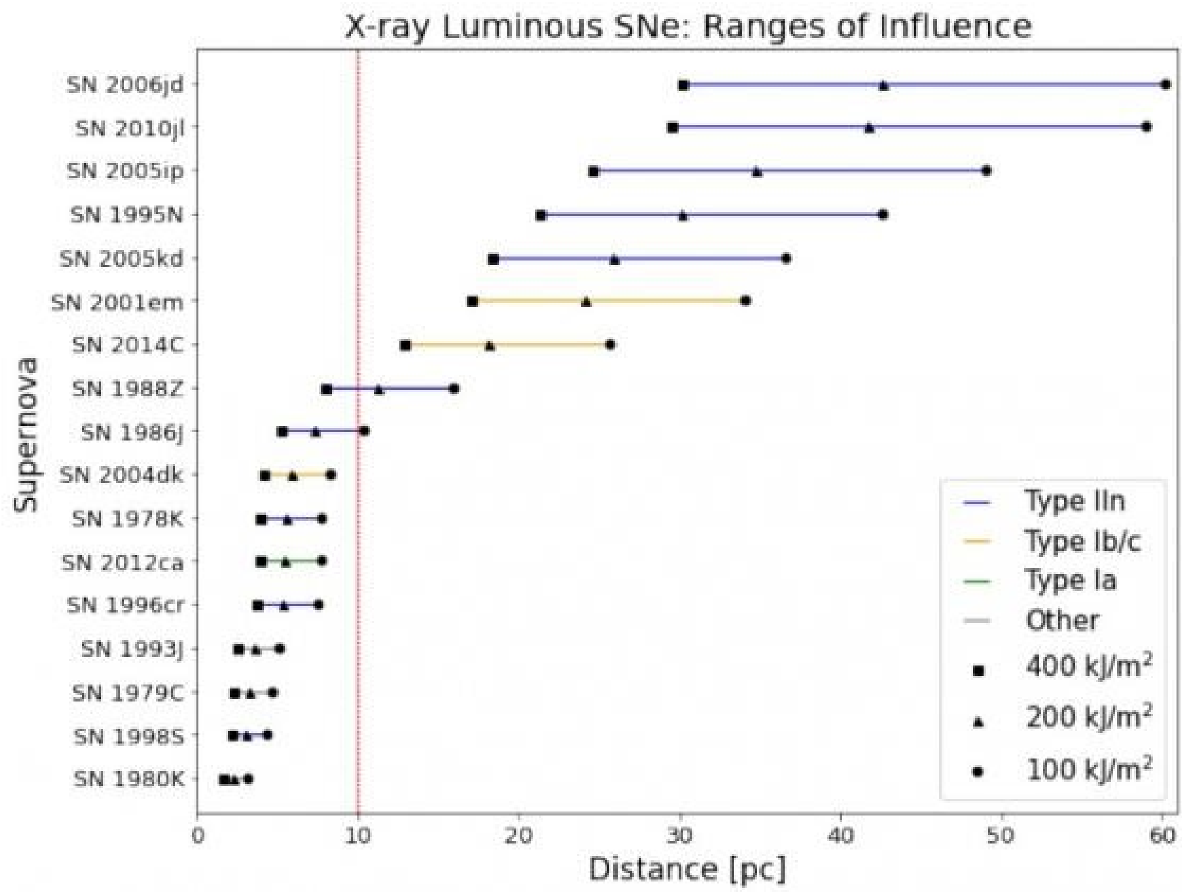
Type IIn supernovae also have the greatest range of influence. This shows that these SN could significantly influence Earth's biosphere from greater distances.

This research has some implications for Earth.

Our solar system is inside what's known as the Local Bubble. It's a cavity carved out of the ISM in the Milky Way's Orion Arm. Multiple supernovae explosions created the bubble in the last 10 to 20 million years. Did those SN affect Earth?

Advances in X-ray astronomy will shed more light on the consequences for terrestrial planets, and the authors think there's lots more to uncover. But their observations show that "… the interacting X-ray phase of an SN's evolution can entail significant consequences for terrestrial planets. We limit any further speculation until further developments in X-ray astronomy are made; however, the evidence presented here certainly points to this process as capable of imposing lethal consequences for life at formidable distances."

Scientists know that supernovae have had some effect on Earth. The presence of the radioactive isotope ^{60}Fe has a half-life of 2.6 million years, yet researchers found undecayed ^{60}Fe in ocean samples dating from 2 to 3 Myr ago. It should've decayed into nickel long ago. Supernovae can create ^{60}Fe through nucleosynthesis when they explode.



This figure from the study shows the most powerful of the17 SN in the sample of 31 and their range of influence. The authors say their calculations are conservative, yet SN 2006jd still has a range of influence that spans from 30 parsecs to 60 parsecs (100 light-years to 200 light-years.) Credit: Brunton et al. 2022

But other things can create ^{60}Fe. Asymptomatic giant branch stars can make it, too, so by itself, it's not a smoking gun for a nearby supernova.

Researchers also found ^{53}Mn in the same samples of ferromanganese crust that hold the ^{60}Fe. It's also a radioactive isotope that should've decayed by now. Unlike ^{60}Fe, only supernovae can create ^{53}Mn. Its presence is definite proof of nearby supernovae in the recent geological past.

It's not the presence of these radioactive isotopes that poses a threat to life. It's the radiation that must've struck Earth, and if the supernova that created the isotopes was close enough to spread them to Earth, then the radiation must've struck Earth, too.

Ionizing radiation from supernovae can alter Earth's atmospheric chemistry from substantial distances. The initial burst of energy from an SN poses one threat, and so do the cosmic rays that arrive hundreds or thousands of years later and linger. But this research adds another threat: X-rays that arrive months or years after the initial outburst. "Therefore, a corollary of the formidable threat found here is that this alters the timeline by which we know an SN can influence a nearby planet, adding an additional phase of adverse effects."

Artist view of a supernova explosion. Some radioactive isotopes, like ^{53}Mn, can only be synthesized in supernova explosions. Credit: NASA

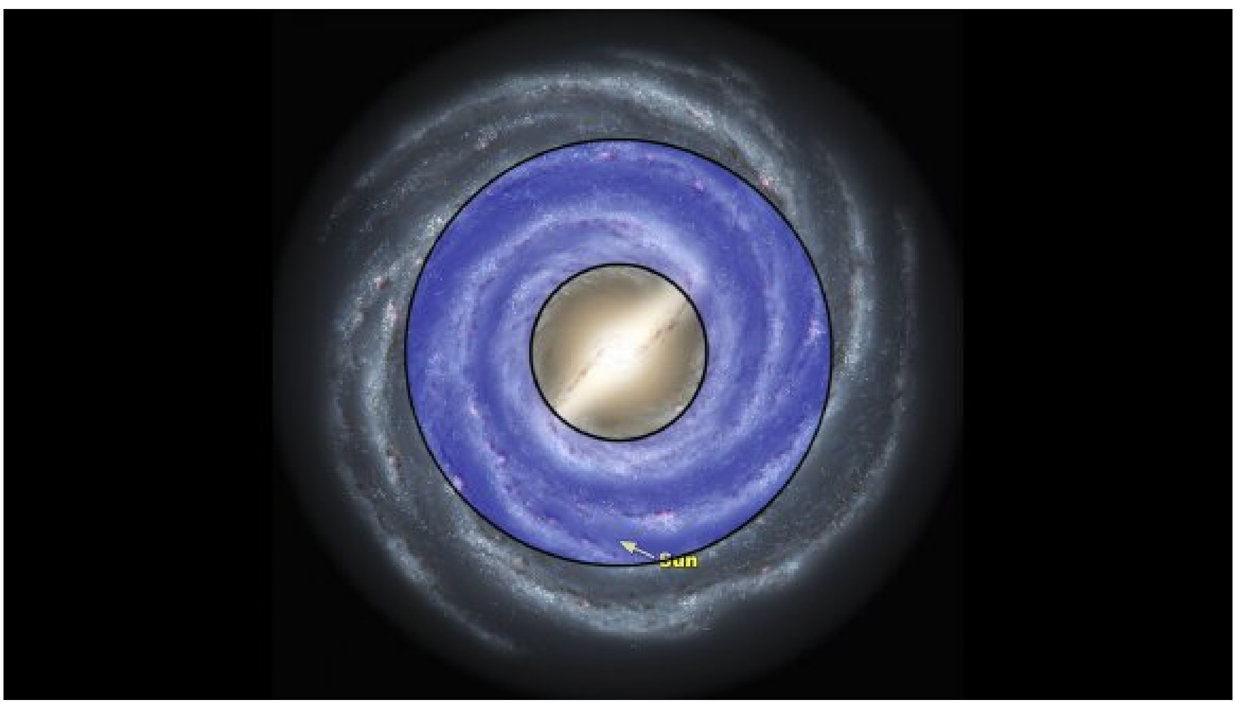
Exactly what effect did it have?

"Combining these findings with our threat assessment here, it is possible that one or more of these SNe were interacting, and thus inflicted a high dosage of X-ray radiation on Earth's atmosphere. This would imply that SN X-ray emission has had a notable impact on Earth and potentially played a role in the evolution of life itself," they write.

SN outbursts have almost certainly struck our planet. The exact consequences are difficult for scientists to untangle. But if the radiation weakened the ozone layer, allowing more UV radiation to reach the Earth's surface, it would've caused mutations. It's called UV mutagenesis, which may have driven molecular evolution and been critical in the origin of sex. In fact, mutation is evolution's primary driver.

The fact that supernovae can lead to mutations is the backdrop for the authors' concluding remarks.

"We thus conclude with the comment that further research into SN X-ray emission has value not just for stellar astrophysics but also for astrobiology, paleontology, and the Earth and planetary sciences as a whole."



This image shows the Milky Way’s habitable zone. Our understanding of the Galactic Habitable Zone has a long way to go before it’s definitive, and this research into supernova lethality will probably change it. Credit: NASA/Caltech

This research has implications for habitability throughout the galaxy, too. The Galactic Habitable Zone (GHZ) is a region in a galaxy where habitability is most likely. Since supernovae can be fatal for life if close enough, regions with many stars that can potentially explode as supernovae are less habitable. If this research is correct, then supernovae can be lethal at greater distances than thought and can be fatal in the period of a few months or years after the initial outburst due to the X-rays. That alters the shape and location of a galaxy's GHZ.

The researchers urge more long-term study of supernovae for months and years after an outburst and plea for more advancements in X-ray observation to aid the study. "These observations and innovations will shed light on the physical nature of SN X-ray emission and will clarify the danger that these events pose for life in our galaxy and other star-forming regions," they write.

More information: Ian R. Brunton, Connor O'Mahoney, Brian D. Fields, Adrian L. Melott, Brian C. Thomas, X-Ray Luminous Supernovae: Threats to Terrestrial Biospheres. arXiv:2210.11622v1 [astro-ph.HE], arxiv.org/abs/2210.11622

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