

The missing link between exploding stars, clouds, and climate on Earth

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Cosmic rays interacting with the Earth's atmosphere producing ions that helps turn small aerosols into cloud condensation nuclei -- seeds on which liquid water droplets form to make clouds. A proton with energy of 100 GeV interact at the top of the atmosphere and produces a cascade of secondary particles who ionize molecules when traveling through the air. One 100 GeV proton hits every m² at the top of the atmosphere every second. Credit: H. Svensmark/DTU

A breakthrough in the understanding of how cosmic rays from supernovae can influence Earth's cloud cover and therefore its climate is published today in the journal *Nature Communications*. The study reveals

that atmospheric ions, produced by energetic cosmic rays raining down through the atmosphere, help the growth and formation of cloud condensation nuclei—the seeds necessary for forming clouds in the atmosphere.

When the ionization in the atmosphere changes, the number of cloud condensation nuclei changes, affecting the properties of clouds. More cloud condensation nuclei mean more clouds and a colder climate, and vice versa. Since clouds are essential for the amount of solar energy reaching the surface of Earth, the implications are significant for the understanding of past climate variation and also for future climate changes.

Cloud condensation nuclei can be formed by the growth of small molecular clusters called aerosols. It has until now been assumed that additional small aerosols would not become cloud condensation nuclei, since no mechanism was known to achieve this. The new results reveal, both theoretically and experimentally, how interactions between ions and aerosols can accelerate the growth by adding material to the small aerosols, and thereby help them survive to become cloud condensation nuclei. It gives a physical foundation to the large body of empirical evidence showing that solar activity plays a role in variations in Earth's climate. For example, the Medieval Warm Period around year 1000 AD and the cold period in the Little Ice Age 1300-1900 AD both fit with changes in solar activity.

"Finally, we have the last piece of the puzzle explaining how particles from space affect climate on Earth. It gives an understanding of how changes caused by [solar activity](#) or by supernova activity can change climate," says Henrik Svensmark, from DTU Space at the Technical University of Denmark, lead author of the study.

The fundamental new idea in the study is to include a contribution to

growth of aerosols by the mass of the ions. Although the ions are not the most numerous constituents in the atmosphere, the electromagnetic interactions between ions and aerosols compensate for the scarcity and make fusion between ions and aerosols much more likely. Even at low ionization levels, about 5 percent of the growth rate of aerosols is due to ions. In the case of a nearby supernovae, the effect can be more than 50 percent of the growth rate, which will have an impact on the clouds and the Earth's temperature.

To achieve the results, a theoretical description of the interactions between ions and aerosols was formulated along with an expression for the growth rate of the aerosols. The ideas were then tested experimentally in a large cloud chamber. Due to experimental constraints caused by the presence of chamber walls, the change in [growth rate](#) that had to be measured was of the order 1 percent, which poses a high demand on stability during the experiments, which were repeated up to 100 times in order to obtain a good signal relative to unwanted fluctuations. Data was taken over a period of two years with total 3100 hours of data sampling. The results of the experiments agreed with the theoretical predictions.

- Cosmic rays, high-energy particles raining down from exploded stars, knock electrons out of air molecules. This produces ions, positive and negative molecules in the atmosphere.
- The ions help aerosols—clusters of mainly sulphuric acid and water molecules—to form and become stable against evaporation. This process is called nucleation. The small aerosols need to grow nearly a million times in mass in order to have an effect on clouds.
- The second role of ions is that they accelerate the growth of the small aerosols into cloud condensation nuclei—seeds on which liquid water droplets form to make clouds. The more ions, the more aerosols become cloud condensation nuclei.

- Low clouds made with liquid water droplets cool the Earth's surface.
- Variations in the sun's magnetic activity alter the influx of cosmic rays to the Earth.
- When the sun is dormant, magnetically speaking, there are more cosmic rays and more low clouds, and the world is cooler.
- When the sun is active, fewer [cosmic rays](#) reach the Earth and, with fewer low [clouds](#), the planet warms up.

The implications of the study suggests that the mechanism could have affected:

- The climate changes observed during the 20th century
- The coolings and warmings of around 2°C that have occurred repeatedly over the past 10,000 years, as the sun's activity and the cosmic ray influx have varied.
- The much larger variations of up to 10°C occurring as the sun and Earth travel through the galaxy, visiting regions with varying numbers of exploding stars.

More information: H. Svensmark et al, Increased ionization supports growth of aerosols into cloud condensation nuclei, *Nature Communications* (2017). [DOI: 10.1038/s41467-017-02082-2](https://doi.org/10.1038/s41467-017-02082-2)

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