

## Ice Core Records – From Volcanoes To Supernovas

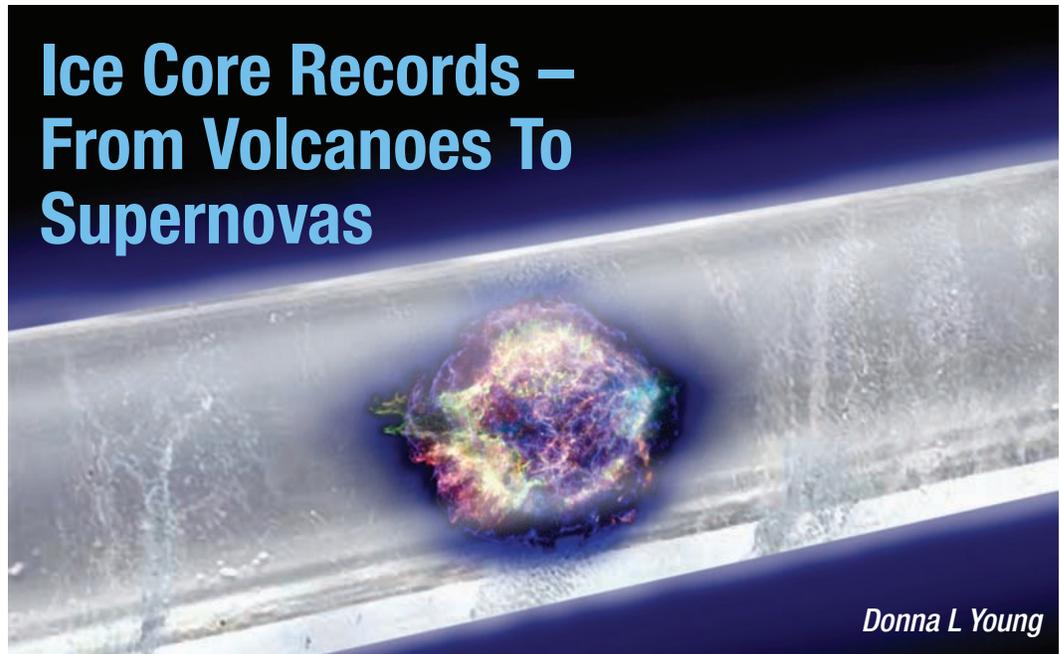


Figure 1. Illustration of the Cas A supernova remnant in the Ice Core Record.

Jean-Pierre Normand, artist, Montreal, Canada

### Abstract

An ice core – known as the GISP2 H-Core – was collected in June, 1992 adjacent to the GISP2 (Greenland Ice Sheet Project Two) summit drill site. The project scientists, Gisela A.M. Dreschhoff and Edward J. Zeller, were interested in dating solar proton events with volcanic eruptions. The GISP2-H 122-meter firn and ice core is a record of 415 years of liquid electrical conductivity (LEC) and nitrate concentrations – spanning the years from 1992 at the surface through 1577 at the bottom. The liquid electrical conductivity (LEC) sequence contains signals from a number of known volcanic eruptions that provide a dating system at specific locations along the core. The terrestrial and solar background nitrate records show seasonal and annual variations – as well as unique events. Several major nitrate anomalies within the record do not correspond to any known terrestrial or solar events, and there is evidence that some of the nitrate anomalies within the GISP2 H-Core could be a record of supernova events.

The Chandra Education and Public Outreach Office, in cooperation with the GISP2 H-Core project scientist Dr. Gisela A. M. Dreschhoff, has developed a classroom activity for middle school and high school students, utilizing absolute and relative dating techniques to examine several lines of evidence in the high resolution GISP2 H-Core data – discriminating among nearby and mid-latitude volcanic activity, solar proton events, and possible supernova events.

### Ice Core Records – From Volcanoes to Supernovas

Constructing a reliable record of the Earth's history only began in the 1880's.

To reconstruct conditions and events further back in time, scientists use proxies – preserved physical characteristics of the past such as tree rings, lake and ocean sediments and

Figure 2. 191-year Longleaf Pine tree ring record from the Hope Mills, North Carolina

© 2012 Photo courtesy of Dr. Henri D. Grissino-Mayer, University of Tennessee



ice cores. The deposition or growth rates of proxy materials are influenced by the climatic conditions during the time they were deposited or grew. Ice cores can provide an annual record of temperature, precipitation, atmospheric composition, volcanic eruptions and solar activity. Snow contains the compounds that are in the air at the time – compounds ranging from sulfates, nitrates and other ions, to dust, radioactive fallout, and trace metals. In the Polar Regions, where temperatures above freezing are extremely rare, gravitational deposition (dry or snowfall) of the materials in the atmosphere fall on top of the previous year without melting.

The upper unconsolidated layers of snow are called firn. The upper layers of ice below the firn correspond to a single year or sometimes just a single season. Deeper into the ice the layers become more compressed and annual layers become indistinguishable. Any materials that were in the snow, such as dust, ash, bubbles of atmospheric gas and radioactive substances, remain in the ice. This information is used to determine temperature, precipitation, chemistry and gas composition of the lower atmosphere, volcanic eruptions, and solar variability.



Figures 3a and 3b.  
(a) Top 53 meters of the GISP2 ice core firn  
(b) Annual layers of the GISP2 ice core at a depth of 1837 meters

Photos courtesy of the U.S. National Ice Core Laboratory, Denver, CO

## The Greenland GISP2 H-Core Research Project

The original GISP2 H-Core data set consists of a total of 7,776 individual analyses. The upper 12 meters of firn were analyzed on-site in Greenland and the remaining core was sent to the National Ice Core Laboratory in Denver, Colorado. At the lab, the core was sliced into 1.5 cm thick samples, and each sample was inserted into a glass vial which was sealed and stored at -24°C. Approximately twenty vials were removed at a time from storage and allowed to melt at room temperature for one hour. The liquid samples were removed from the vials with a syringe and injected into a UV absorption cell (UV spectrophotometer) to determine the nitrate values in absorption units. After the nitrate values were obtained from the UV spectrophotometer, the samples were inserted directly into a micro-conductivity cell to measure the conductivity in micro Siemens per centimeter ( $\mu\text{S}/\text{cm}$ ). This ultrahigh resolution sampling technique resulted in a time resolution of one week near the surface and one month at depth. At a later time 3.6 meters of core were added, taking the time series back to the year 1561 – with a total of 8,002 samples analyzed.



Figure 4. Gisela Dreschhoff at Grinnell Lake in Glacier National Park 2009

Donna L Young, photographer

## The Liquid Electrical Conductivity (LEC) Record and Volcanoes

The liquid electrical conductivity measurements (LEC) measure the change in acidity along the length of the core. Numerous anomalies occur in the liquid electrical conductivity (LEC) records. The LEC sequence contains signals from a number of

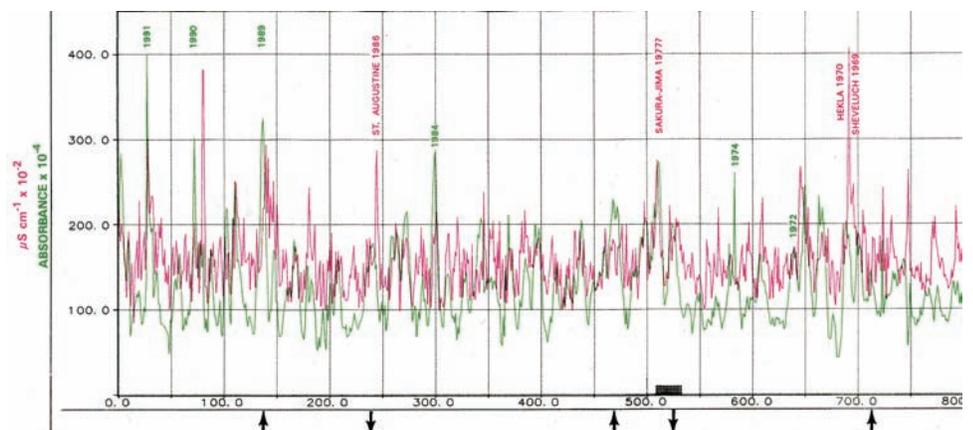


Figure 5. The first 800 samples of the GISP2 H-core showing the conductivity (red) and nitrate (green) records

Courtesy of Dr. Gisela Dreschhoff

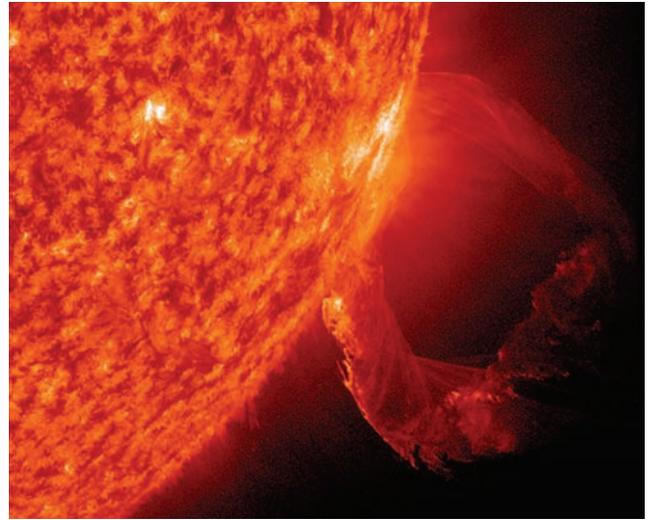


Figure 6 (left). Aerial photo of the onset of the Grimsvotn volcano eruption, Iceland, 2011

Olafur Sigurjonsson, photographer

Figure 7 (right). Solar prominence eruption on March 19, 2011, SOHO spacecraft

Courtesy of NASA

known volcanic eruptions and provides a dating system at specific locations along the core. An especially distinctive signal in both records marks volcanic eruptions in Iceland. Nearby Icelandic volcanic eruptions release most of their products into the upper troposphere, and deposition onto the Greenland ice sheet happens within a week. Because the Icelandic eruptions occur geographically close to the GISP2 H-core drill site, they produce large and distinctive conductivity anomalies accompanied by very sharp reductions in nitrate concentrations. The reason is that the hydroxyl ions (OH<sup>-</sup>) are preferentially used in the oxidation of volcanic SO<sub>2</sub> and therefore are unavailable for the production of nitrates. The Icelandic volcano signature – opposed dual anomalies of high conductivity and low nitrates – provide time markers to use absolute dating techniques for events recorded within the Greenland ice core.

### The Nitrate Record and Solar Proton Events

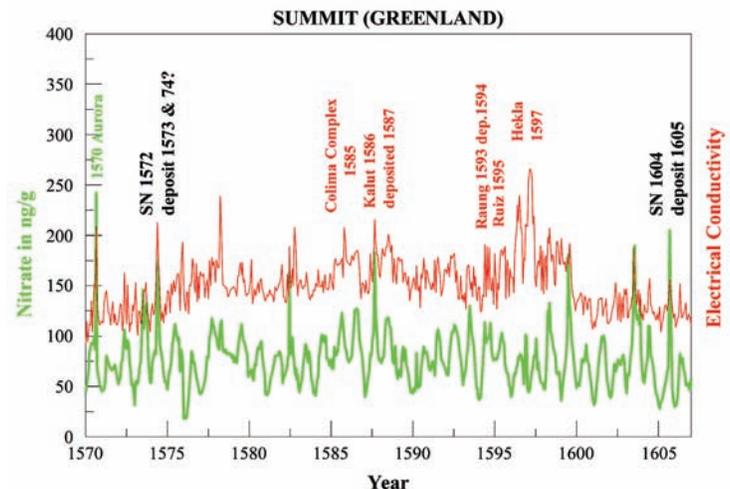
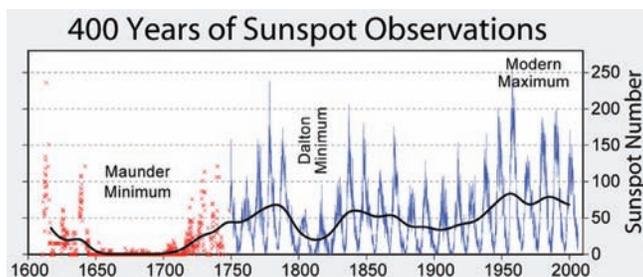
Charged particles from solar activity follow the Earth’s magnetic field lines and enter the atmosphere above the Polar Regions. The particles ionize nitrogen and oxygen, generating oxides of nitrogen with nitrates (NO<sub>3</sub><sup>-</sup>) as the end product. Changes in solar activity lead to changes in the amount of nitrates in the atmosphere; and therefore in the amount of nitrates that get deposited in the Polar Regions. Solar activity and the resulting solar proton events leave a continuous record of nitrate deposits within the polar ice; therefore, a measurement of the nitrate record is a reflection of solar activity. Prolonged and sustained solar observations are fairly recent – since the early 1600’s – and ice core data provides evidence of solar behavior that pre-dates telescopes and satellites.

Figure 8 (left). The 400 year sunspot record from 1600 – 2000 with the more unreliable observations plotted in red

Courtesy of Hoyt & Schatten, *Solar Physics*, 1998

Figure 9 (right). A 37.5 year section of the GISP2 H-core with nitrate anomalies that correlate to the Tycho and Kepler supernova events

Courtesy of Dr. Gisela Dreschhoff



The main feature in the 415-year nitrate concentration record is the prominent yearly cycle – with the spring/summer values higher than the fall/winter values. Volcanic episodes and other terrestrial processes add nitrates to the atmosphere that are deposited and recorded in the ice sheets. The annual solar nitrate record also includes concentration variations produced by unique solar activity. One example is the solar proton nitrate concentration fluctuations that remain consistent through the Dalton (1833 – 1798) and Maunder (1715-1645) Minima – periods of unusually low solar activity. A major nitrate anomaly in 1859 is related to a solar flare that was optically observed by Richard Carrington in England.

A few large nitrate anomalies accompanied by comparable and sharply defined anomalies in the conductivity occur simultaneously and are not connected to any known volcanic eruptions or unique solar proton events. These peaks are several standard deviations above the mean. It is likely that these anomalies result from the primary production of nitrate ( $\text{NO}_3^-$ ) in the atmosphere – therefore there has to be an enhanced supply of nitrate in the stratosphere. In the GISP2-H core segment shown, there are major dual nitrate and conductivity anomalies at the times of the Tycho and Kepler supernovas. There are no known terrestrial or solar events that could have produced nitrate spikes of this magnitude, and they occur with the correct time separation of 32 years and one year after Tycho and Kepler observed and recorded these two events. Supernova events produce high energy photons (X-rays and gamma rays) that enter the stratosphere and ionize atmospheric nitrogen – producing excess nitrates that are then gravitationally deposited in the Polar Regions with up to a one-year time delay. Supporting evidence from two ice cores drilled in Antarctica contains nitrate anomalies at the same time equivalent locations.

## The GISP2 H-Core Classroom Materials

At the 2005 American Association of Physics Teachers (AAPT) winter meeting in Albuquerque, New Mexico, the author attended an invited talk by Dr. Gisela Dreschhoff. The title of her talk was irresistible – *Evidence for a Stratigraphic record of Supernovae in Polar Ice*. The description mentioned the possibility that the Cassiopeia A (Cas A) supernova event was part of the ice core record. After corresponding with Gisela, reading the research and studying the high resolution ice core data, it was decided the materials would provide the basis for an interesting interdisciplinary classroom investigation. *The Ice Core Record – From Volcanoes to Supernovas* is the end result and is available at <http://chandra.si.edu/edu/formal/icecore/>

In this investigation, students examine the seasonal/annual nitrate record and use information from known volcanic eruptions to date the unique signature of the Icelandic volcanoes. Data is also provided for known volcanic eruptions from other latitudes which can be used throughout the activity to date major conductivity spikes to further refine the time locations. Solar proton data, including the Carrington superflare and the Dalton and Maunder Minima are used to date both solar activity and unique solar events.

Using seasonal nitrate cycles and the volcanic eruptions that have been labeled on the ice core strip, students search for unlabeled nitrate anomalies that correlate to the Tycho and Kepler supernova events of 1572 and 1604 respectively. The final task for students is to search for evidence of an anomaly that could be correlated to the Cassiopeia A supernova and determine the date of the event. After reading the possible evidence for different dates of the Cas A supernova, students can decide for themselves which date they support. Cassiopeia A has been observed by the Chandra X-ray telescope multiple times, and each observation increases our knowledge of the remnant

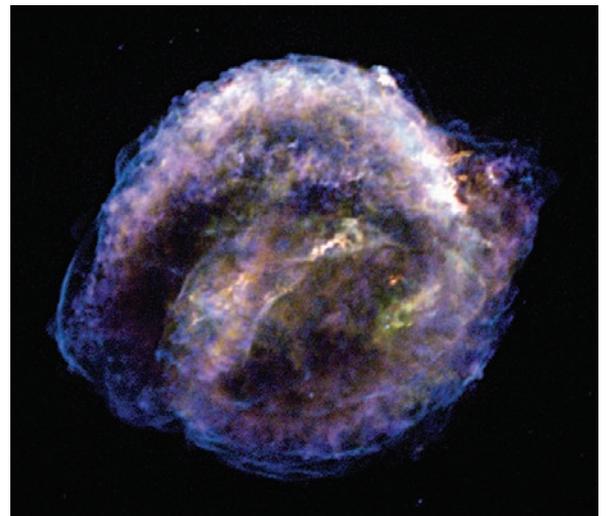


Figure 10. Kepler's Supernova Remnant

NASA/CXC/NCSU/S.Reynolds et al.

and neutron core. Knowing the *exact* date of the event would increase our understanding of the processes that produced the present structure of Cas A. However, even after decades of multi-wavelength observations of Cassiopeia A, the exact date of the collapse of the progenitor star that produced the remnant remains a mystery!

## Using *Ice Core Records – From Volcanoes to Supernovas in the Classroom*

This student investigation is an application of absolute and relative dating techniques – a skill taught within multiple disciplines – and includes concepts relating to cryology, chemistry, meteorology and astronomy. Educators can use the investigation as a springboard to the associated sciences – but that is not the intended focus of the materials. The GISP2 H-core contains suspected supernova events, and there are other research projects that support the correlation of nitrates with supernovas; however, within the scientific community there are those who disagree. Controversial science is great science; often, serendipitous discoveries that cross disciplinary boundaries produce years of additional research, analysis, investigation and debate before a final consensus is reached. Sometimes there is no one definitive answer unless other supporting evidence is found. This investigation provides a more realistic view of how science works.

The GISP2 H-core also contains nitrate anomalies that are as yet unidentified and are not correlated with any known terrestrial or extra-terrestrial event – providing students with the opportunity for research projects. The power of *Ice Core Records – From Volcanoes to Supernovas* is that it does not provide all the answers; it is an open-ended inquiry into possibilities.

There are interesting and rich historical connections during the timeframe represented in the core – including the first ice core data from Greenland, Icelandic volcanism, the historical sunspot record, the lives of Tycho Brahe and Johannes Kepler, John Flamsteed the First Royal Astronomer, and King Charles II of Great Britain. The detonation of the RDS-220 hydrogen bomb and the Tunguska Event also occurred within the timeframe of the GISP2 H-Core. The core is embedded within a historical context of changing world views and paradigm shifts. The introductory sections provide a historical context and perspective of the individuals and/or locations related to the investigation. The associated histories help illuminate science as an extension of the prevailing culture of the times.

A major focus of the Chandra X-Ray mission is to study the cycles of matter and energy that drive the evolution of the universe – and supernovas are funda-

mental to that process. Supernova events create elements through nucleosynthesis which travel into the interstellar medium and become incorporated into the next generation of stars and planetary systems. The high energy X-rays and gamma rays generated by supernovas several light years away impact the Earth – and leave their signatures within the ice sheets of the Polar Regions.

Figure 11. Artist's conception of a supernova event as seen from the Earth's northern Polar Region.

Jean-Pierre Normand, artist, Montreal, Canada



## Materials and Supporting Resources

*Ice Core Records – From Volcanoes to Supernovas:* An activity that applies absolute and relative dating techniques to high resolution ice core data to identify Icelandic and mid-latitude volcanic eruptions and solar proton events, and correlate unidentified anomalies within the core with supernova events. The investigation includes extensive background information, student ice core worksheets and labeled ice cores in HTML and PDF. <http://chandra.si.edu/edu/formal/icecore/>

*Cassiopeia A (Cas A)—The Death of a Star:* A timeline that describes the Cas A supernova event. [http://chandra.harvard.edu/edu/formal/casa\\_timeline/](http://chandra.harvard.edu/edu/formal/casa_timeline/)

*Stellar Evolution: A Journey with Chandra:* A poster which displays the cycles of the evolutionary stages of stars of different masses. [http://chandra.harvard.edu/edu/prod\\_descriptions.html](http://chandra.harvard.edu/edu/prod_descriptions.html)

Poster Request Form: <http://chandra.harvard.edu/edu/request.html>

*Podcasts: Supernovas and Supernova Remnants:* A list of podcasts that highlight Chandra observations of supernovas. [http://chandra.harvard.edu/resources/podcasts/by\\_category.html?catid=4](http://chandra.harvard.edu/resources/podcasts/by_category.html?catid=4)

*The Story of Stellar Evolution:* A complete introduction that describes the stages of stellar evolution of all stars. [http://chandra.harvard.edu/edu/formal/stellar\\_ev/story/](http://chandra.harvard.edu/edu/formal/stellar_ev/story/)

*Investigating Supernova Remnants:* An activity that uses Chandra data and ds9 image analysis software to investigate supernova remnants to determine if they are Type II core collapse or Type Ia thermonuclear events. <http://chandra.harvard.edu/edu/formal/snr/>

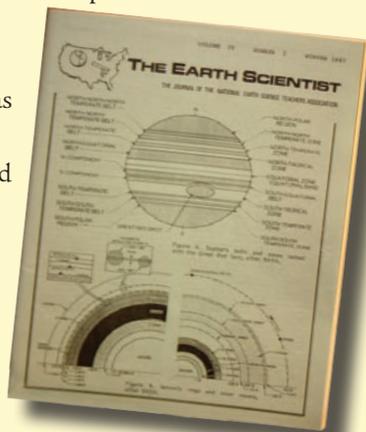
## About the Author

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Donna Young develops educational materials for the Chandra X-ray mission, and is a staff member at the American Association of Variable Star Observers in Cambridge, MA. She is the National Science Olympiad astronomy event supervisor. She presents Chandra and AAVSO educational materials to formal and informal educators and Science Olympiad coaches and teams at national workshops and conferences. She can be reached at [donna@aavso.org](mailto:donna@aavso.org).

## Twenty Five Years Ago in TES

Twenty Five years ago, TES was in its fourth year of publication. In 1987, the cover of Volume 4, issue 1 featured a map of the planet Jupiter detailing the belts and zones as determined by NASA. To accompany the cover, inside the TES there was a seven page article summarizing the newest information about Jupiter and the other outer planets. The issue also featured an eight page article detailing the history of the Scientific Approach. There was an article explaining how the Accu-Weather© database could be used in the classroom. The article marvelled at the fact that the database featured **hourly** weather readings. An article discussed how popping popcorn could be used to teach conduction, convection and radiation, after which the class could eat the popcorn. And finally, an update on Mount St. Helens was presented, reporting the seismic activity in the 7 years since its 1980 eruption as well as using “dome growth” to predict eruptions.



## HELP WANTED!

NESTA needs you to help us run our events at the NSTA Conference in Indianapolis. We need volunteers to help with our Share-a-thons, Rock Raffle, and at our Exhibit Hall booth. If you feel that you can help, contact Joe Monaco, NESTA Volunteer Coordinator: [monacoj@aol.com](mailto:monacoj@aol.com)

## Why should I open and read the NESTA ENews emails?

NESTA's monthly *ENews* provides brief summaries of stories and projects that have a direct link to the Earth Sciences and or the teaching of Earth Sciences. Many of these short articles provide links to more information or complete websites that those interested can follow. The *ENews* also contains information regarding teacher opportunities for research, professional development, and even grants. The reader will also find a calendar with items that have time critical information or may be occurring later that month or the next month. The *ENews* will also be adding state related links each month. The goal is to provide links to two states' Earth Science sites each month. For example, in the June 2011 issue we focused on Earth Science resources in Alabama and Colorado.