Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310010823

Supernovae and solar cycles embedded in a Dome F ice core

Yuko Motizuki, Yoichi Naka and Kazuya Takahashi for Dome F glaciological astronomy collaboration

RIKEN Nishina Center, Hirosawa 2-1, Wako, Japan
email: motizuki@riken.jp

Abstract. We have recently found signals of candidates for two historical supernovae and past solar cycles in a depth profile of nitrate ion concentrations in an ice core portion corresponding to the 10th and the 11th centuries. This ice core was drilled in 2001 at Dome Fuji (Dome F) station in Antarctica. We briefly review our findings and discuss why Dome F is appropriate for this study.

Keywords. Sun: general, Supernovae: individual (SN 1006, Crab Nebula)

1. Supernova and Solar Cycle Signals in Ice Cores

Ice cores are known to be rich in information regarding past climates, and the possibility that they record astronomical phenomena has also been discussed. Rood *et al.* (1979) were the first to suggest that nitrate ion (NO_3^-) concentration spikes observed in the depth profile of a South Pole ice core might correlate with the known historical supernovae: Tycho (AD 1572), Kepler (AD 1604) and SN 1181 (AD 1181). Their findings, however, were not supported by subsequent examinations by different groups using different ice cores (*e.g.*, Risbo *et al.* 1981; Herron 1982; Legrand & Kirchner 1990), and the results have remained controversial and confusing (Green & Stephenson 2004; Dreschhoff & Laird 2006).

Motizuki *et al.* (2009) presented a precision analysis of an ice core drilled in 2001 at Dome F station in Antarctica. It revealed highly significant three NO_3^- spikes dating from the 10th to the 11th century. Two of them were coincident with SN 1006 (AD 1006) and the Crab Nebula SN (AD 1054), within the uncertainty of their absolute dating based on known volcanic signals. They concluded that the coincidence had a confidence level much larger than 99%.

Moreover, by applying time-series analyses to the measured NO_3^- concentration variations, the authors discovered very clear evidence of an 11-year periodicity that can be explained by solar modulation. The 11-year periodicity was obtained with the 99.9 % confidence level by using the epoch-folding method, which has a clear mathematical basis. This was one of the first times that a distinct 11-year solar cycle has been observed for a period before the landmark studies of sunspots by Galileo Galilei with his telescope. See Motizuki *et al.* (2009) for details.

2. Uniqueness of the Precipitation Environment at Dome F

Dome F is located at 77.2°S, 39.4°E, and its altitude of 3,810 m is the highest point in east central Antarctica. It is natural to wonder whether Dome F site is unique enough to catch such astronomical phenomena. The crucial point here is the degree of stratospheric

Table 1. Tritium concentration in snow corresponding to the deposition in 1966 reported in Antarctica. Extracted from Table 1 of Kamiyama *et al.* (1989).

Point	Tritium, TU
DC (Dome F)	4,200
South pole [Pit A]	2,800
Dome C	700
Halley Bay	620

components contained in ice cores, because both supernovae and solar activities can affect nitrogen oxide production in the stratosphere.

The uniqueness of the precipitation environment of Dome F has been shown from ionic and tritium measurements - Kamiyama, Ageta & Fujii 1989. First, the chemical composition there differs sharply from sea salts. Second, as is shown in Table 1, at Point 'DC' (the site of Dome F) the measured tritium content deposited in 1966 in relation to nuclear weapon tests was much larger than those observed at Dome C and Halley Bay, a coastal site. The tritium content was also observed to increase rapidly in the region above 3600m, where the effects of katabatic wind and the circumpolar vortexes become small. All results indicate that most of the ions in the snow at Dome F precipitate directly from the stratosphere, not from the troposphere (see *e.g.*, Kamiyama *et al.* 1989).

3. Future Prospects

The extension of our analyses to deeper and shallower depths is in progress. Our preliminary results suggest several other historical supernova candidate spikes in the past 2,000 years. Next we are planning to analyse another fresh Dome F core with more detailed core dating. As noted above, Dome F may be an appropriate place to investigate stratospheric or astronomical information. We also encourage the examination of our results by using ice cores recovered from other sites in Antarctica.

Acknowledgements

This collaboration is organized by RIKEN, National Institute of Polar Research (NIPR), Shinshu University and National Institute for Environmental Studies (NIES) to perform ion concentration measurements of ice cores with high time resolution and to analyse the results, especially in relation to astronomical phenomena.

We would like to thank all members of Dome F glaciological astronomy collaboration. This work was supported in part by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science.

References

Dreschhoff, G. A. M. & Laird, C. M. 2006, *Advances in Space Res.* 38, 1307

Green, D. A. & Stephenson, F. R. 2004, *Astroparticle Phys.* 20, 613

Herron, M. M. 1982, *J. Geophys. Res.* 87, 3052

Kamiyama, K., Ageta, Y., & Fujii, Y. 1989, *J. Geophys. Res.* 94, 18, 515

Legrand, M. R. & Kirchner, S. 1990, *J. Geophys. Res.* 95, 3493

Motizuki, Y., Takahashi, K., Makishima, K., Bamba, A., Nakai, Y., Yano, Y., Igarashi, M., Motoyama, H., Kamiyama, K., Suzuki, K., & Imamura, T. 2009, submitted to *Nature*, http://arxiv.org/abs/0902.3446

Risbo, T., Clausen, H. B., & Rasmussen, K. L. 1981, *Nature* 294, 637

Rood, R. T., Sarazin, C. L., Zeller, E. J., & Parker, B. C. 1979, *Nature* 282, 701