"*Astro-Glaciology Data* Factory" Project：
南極アイスコア中の超新星痕跡同定への取り組み

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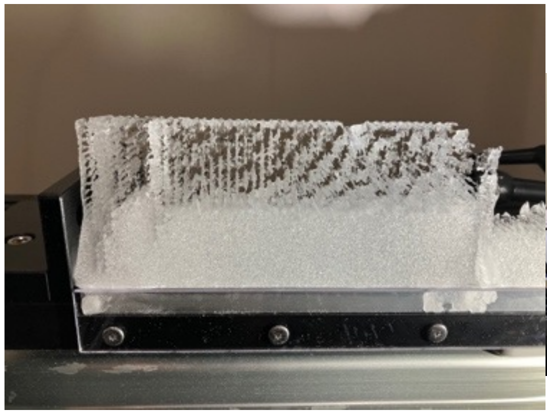


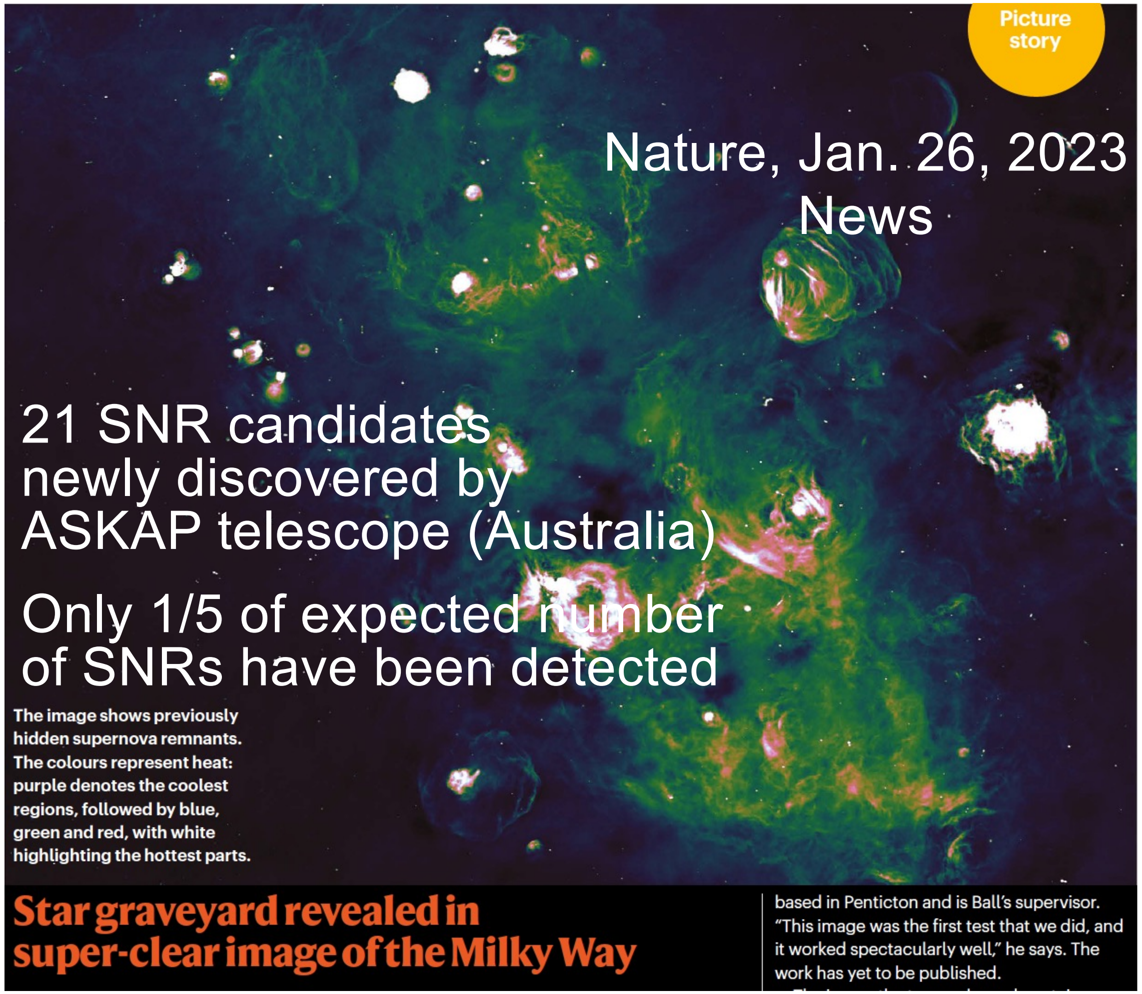
Antarctic Research and RIKEN 1956–1974

Ukichiro Nakaya
RIKEN 1925–
Torahiko Terada Lab.
⇄ **Yoshio Nishina Lab.**

Dr. Masahiro Kodama
Cosmic Radiation Lab.

The 10th SN neutrino WS, Okayama, Feb. 29, 2024

"Missing SNR problem"



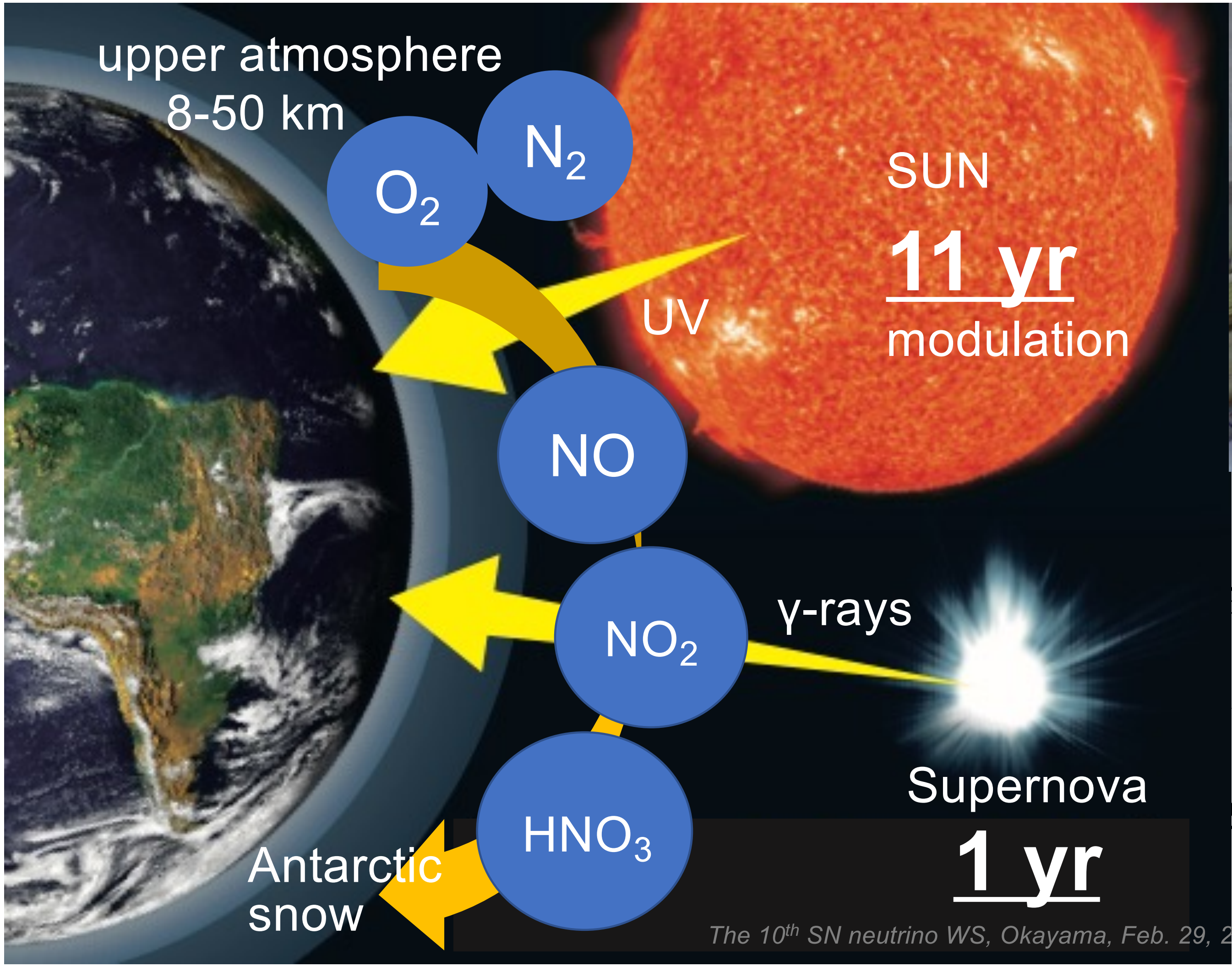
Ball+, MNRAS 524, 1396–1421 (2023)

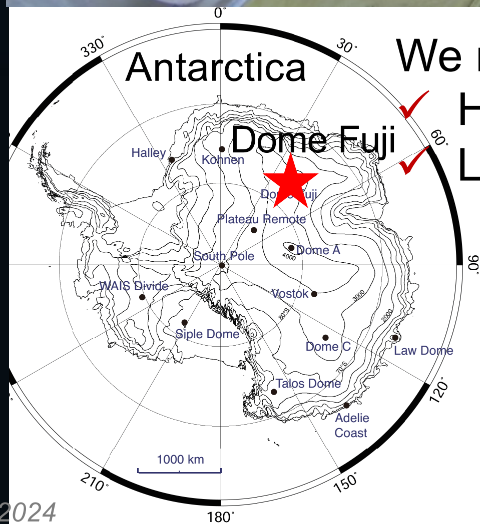
- SN rate: 1/(30–50) yr (Tammann+ 1994) based on extra-galactic SNe for the type of Milky Way galaxy
- 1000–2700 radio SNRs expected, but only 300–400 discovered

A pilot survey in a small field of the Galactic plane (323° < l < 330° ; -4° < b < 2°):
21 SNR candidates newly discovered
13 not previously discovered
4 have been observed as SNR candidates
3 have classed as a single SNR
1 has been studied as an infrared nebula
=> Full survey in the next few years

- Young SNRs: X-ray observations: consistent with a 1/35 yr rate (Leahy+ 2020)

SN information in ice cores





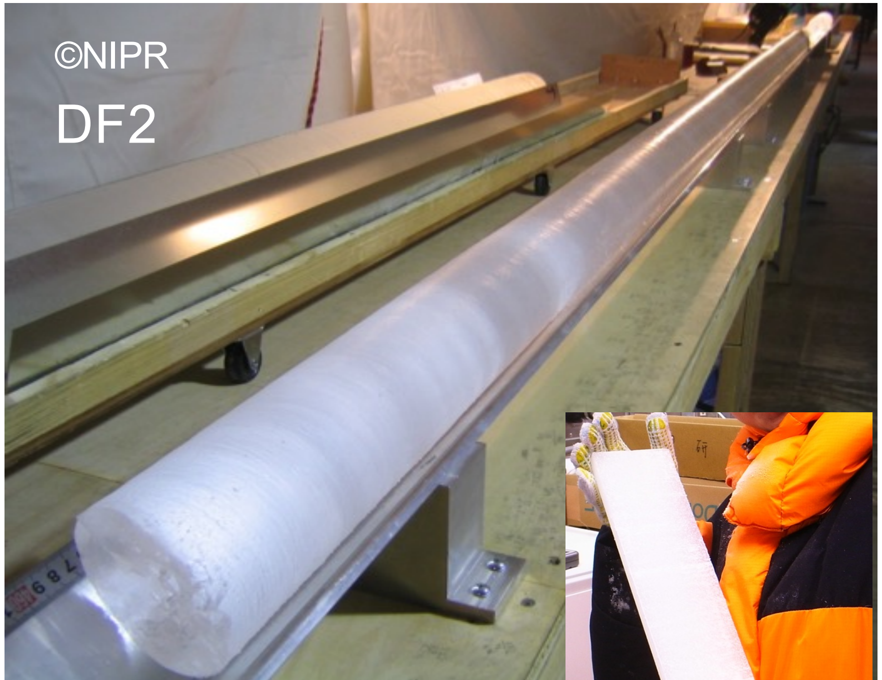
We need data of:

- ✓ High time-res.
- ✓ Long time-range

⬇

Ice cores

A Dome Fuji DEEP ice core



- Diameter: ~10cm

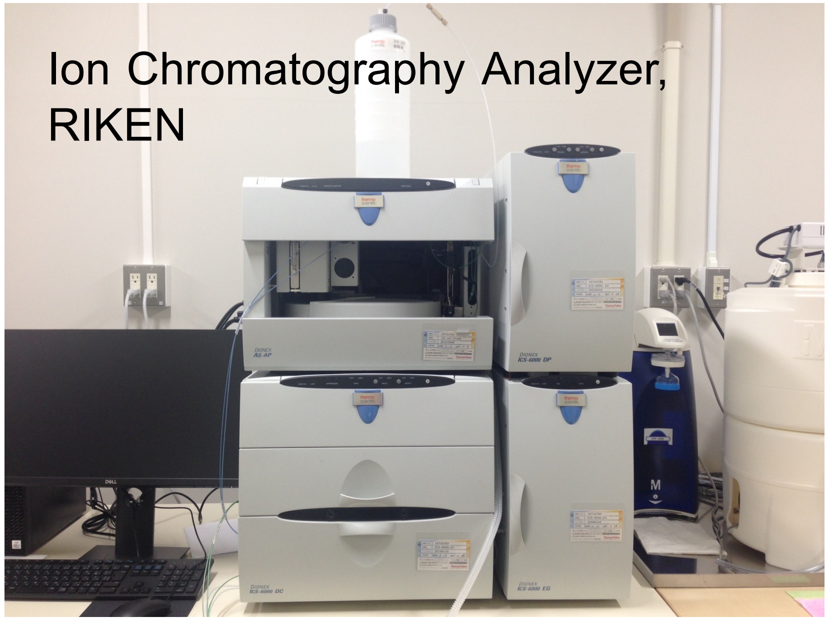
DF01: top part of DF2

- DF2 ice core: 3035.22 m (Drilling: 2001–2007)
- 0.72 million years (Kawamura+ 2017)
- New Dome Fuji (DF3) Project: targeting an ice core of 0.8–1.5 M years
- Advantage: Dome-Fuji area is mainly affected by <u>stratospheric components (not tropospheric, as almost all other ice cores)</u>

Evidence:

1. Tritium content from atomic bomb test (~1960) in the stratosphere: Highest among 16 sites over Antarctica (Fourre+ 2006)
2. A prominent early-spring peak of NO_3^- observed
3. Ionic ratios: different from those expected for the troposphere (Motizuki+ 2017)
4. No correlations with sea-ice conditions, wind strength, atmospheric circulation in the troposphere (Thomas, Motizuki+ 2023)

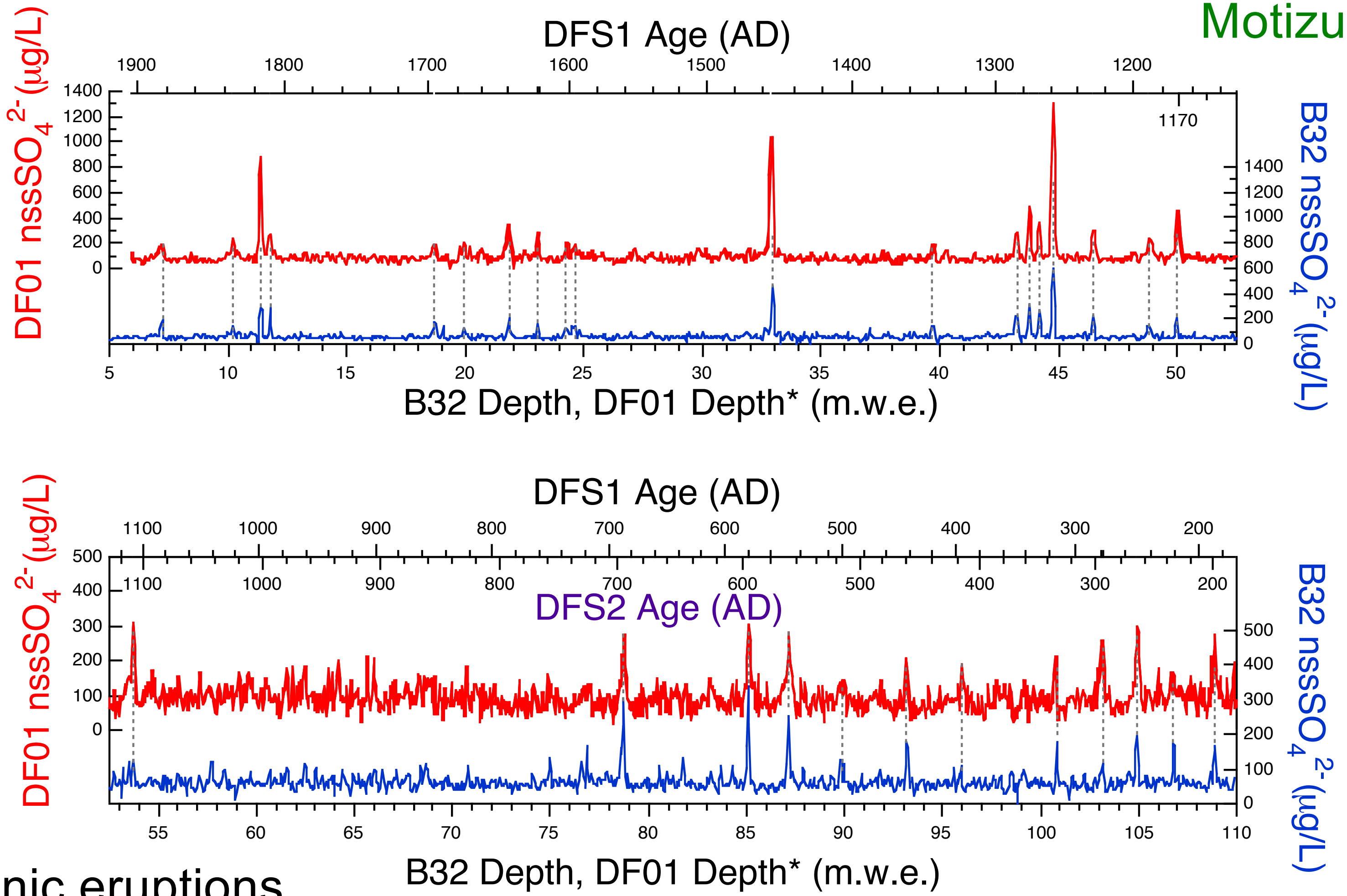
Obtaining ice-core data: exhaustive work



- Slice the ice cores by hand under −30℃ at NIPR (& −50℃ storage)
- Annual resolution: e.g., 2.5 cm (~2000 yr BP); ~5 mm (200,000 yr BP)
- ~5 years were required for 2,000 years of analyses at RIKEN ×2

Ice core depth-date relation

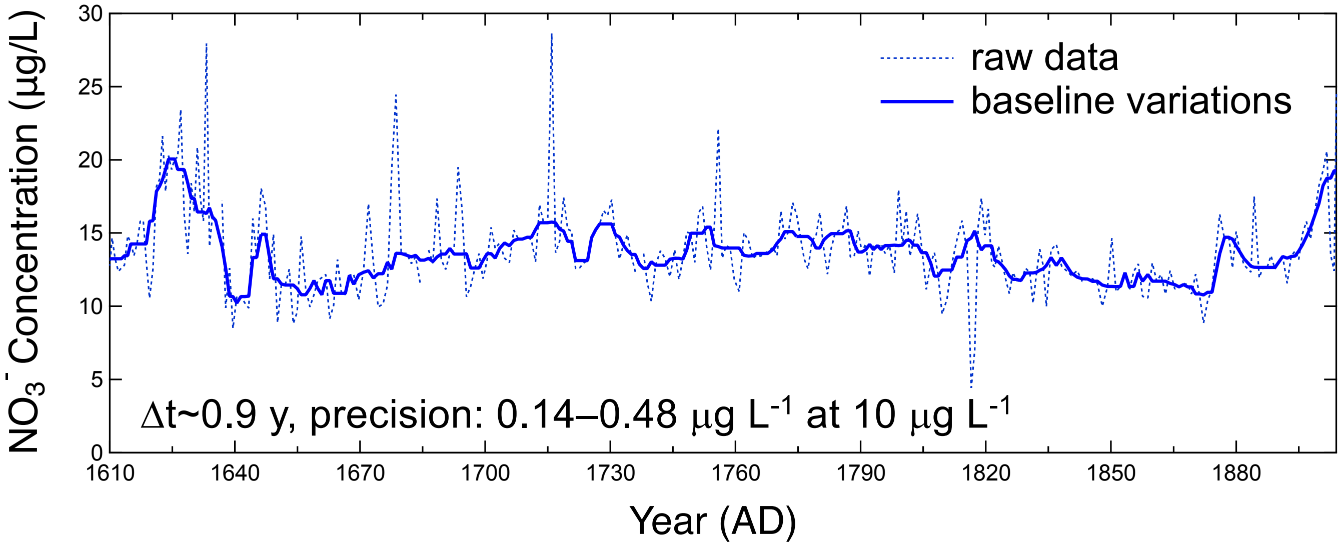
Motizuki et al. 2014

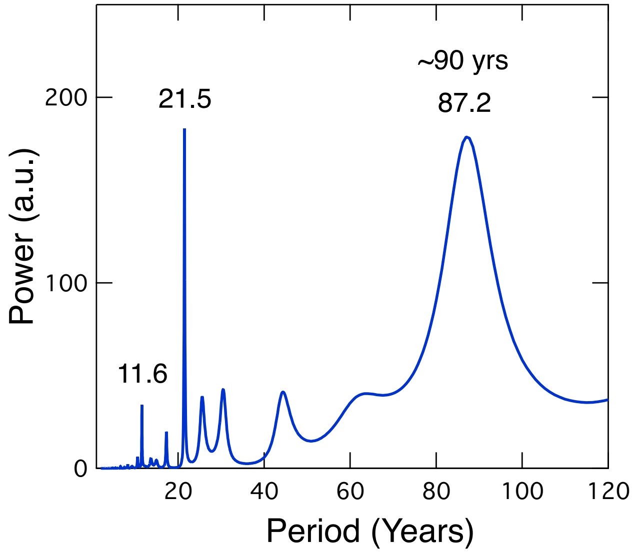


Δt~0.9yrs

31 volcanic eruptions

Discovery of 11-yr, 22-yr, ~90-yr solar cycles in NO_3^-



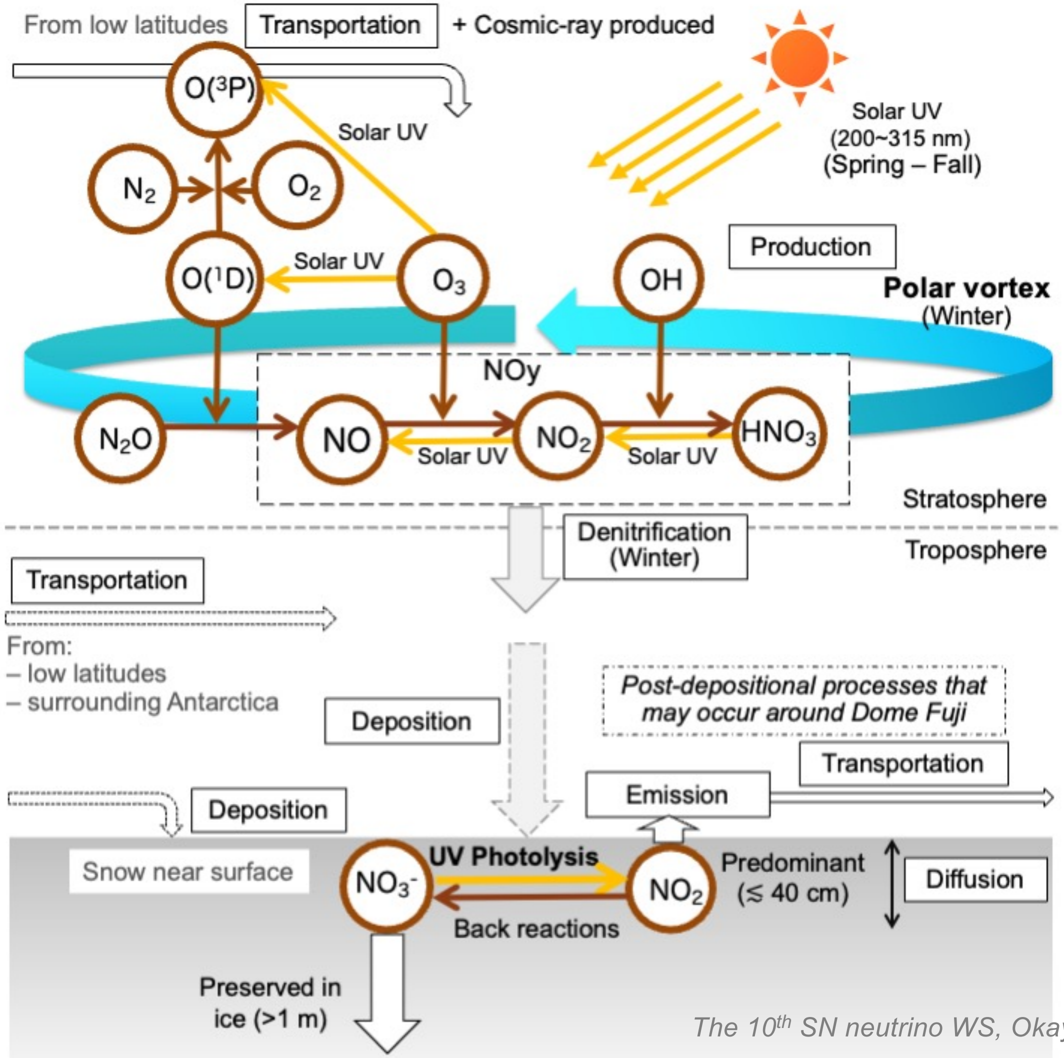


- 11-year, 22-year, and ~90-year periodicities detected as well-known solar cycles
- Discovery of smallest *three* solar cycles: for the first time in ice cores

Established the method how to extract the solar modulations

Motizuki+, submitted to PJA, Ser. B

NOy production and precipitation



- A prominent early-spring peak of NO_3^- was observed at Dome Fuji (Motoyama, Motizuki+, in prep.)

⇒ DF域では、冬場の「極渦」形成による「極域成層圏雲粒子」(PSC)の脱窒により生じたNO_3^-を、直接的に捉えていると考えられる

- 太陽11年周期を捉えることができて初めて超新星痕跡(～1yスパイク)を捉えることができる

Motizuki+, submitted to PJA, Ser. B

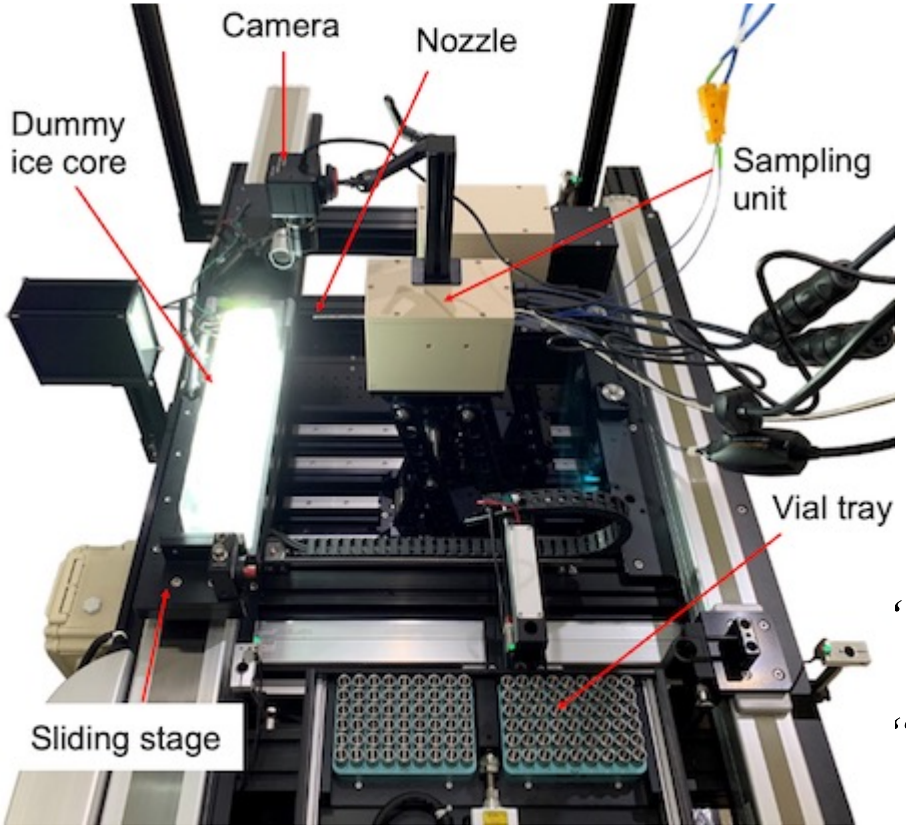
Achievement 12/15

Invention of Laser Melting Sampler (LMS)

Motizuki and 11 others, *J. of Glaciology, 2023*

- Took 6 years for the development
- Attained an Altmetric score 150

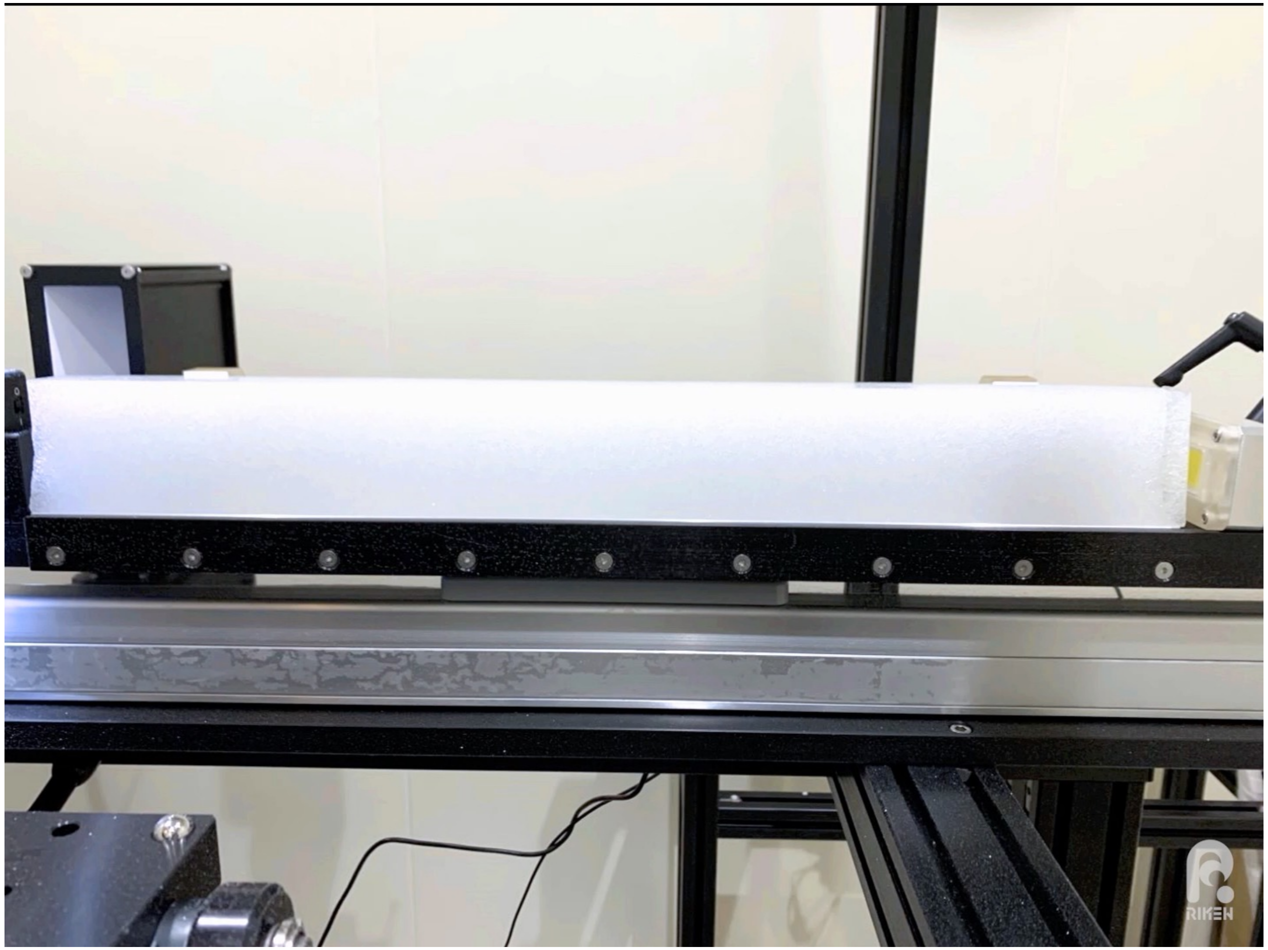
Collaboration with RAP Wada Team
RIKEN Center for Advanced Photonics

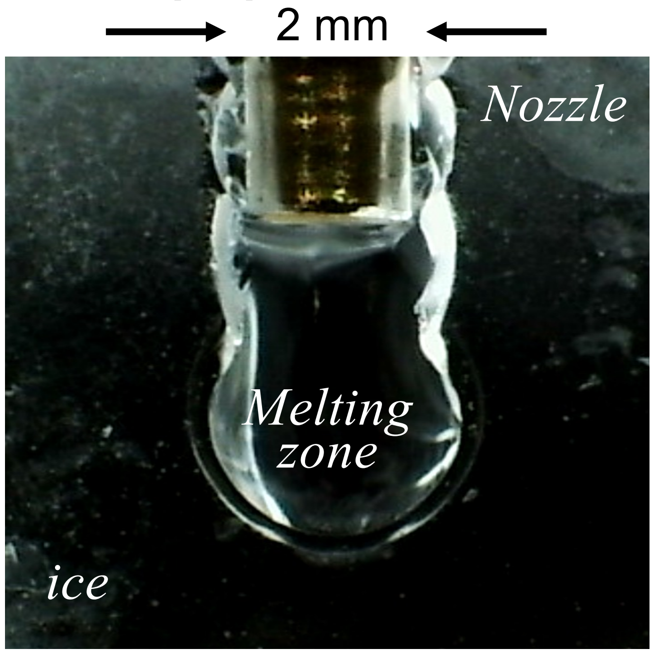


- World's first laser melting sampling device
- Laser wavelength: 1.55μm
- Attained a few mm-res. analysis of oxygen isotopes, $^{18}O/^{16}O$ in ice (*well-established temperature proxy*) ⇦ Incapable so far!
- 5 years were required for 2,000 years of analyses by hand segmentation ⇨ 30 working days!

From reviewers' comments:
*"Authors did a **remarkable job** designing a* **very clever novel sampling tool** *for ice cores."*
*"Important for international **Oldest Ice Project**"*
(see e.g., Physics Today 76, 4, 18, April 2023)

RIKEN-LMS and beyond (1)

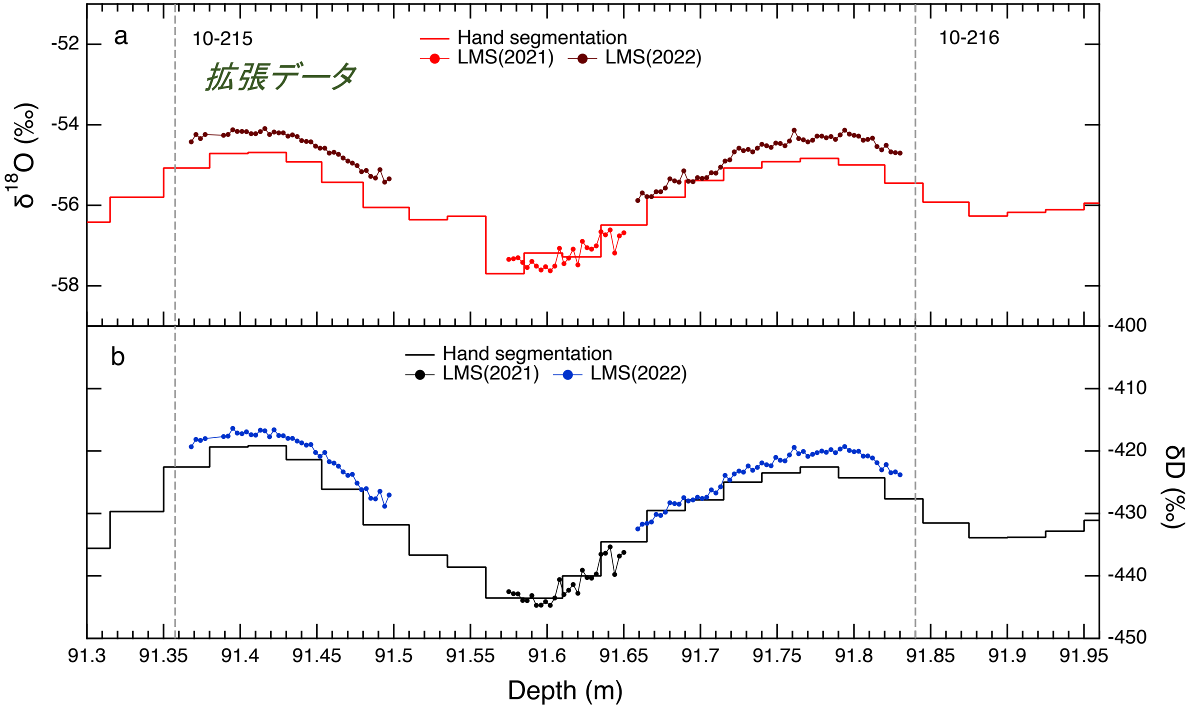


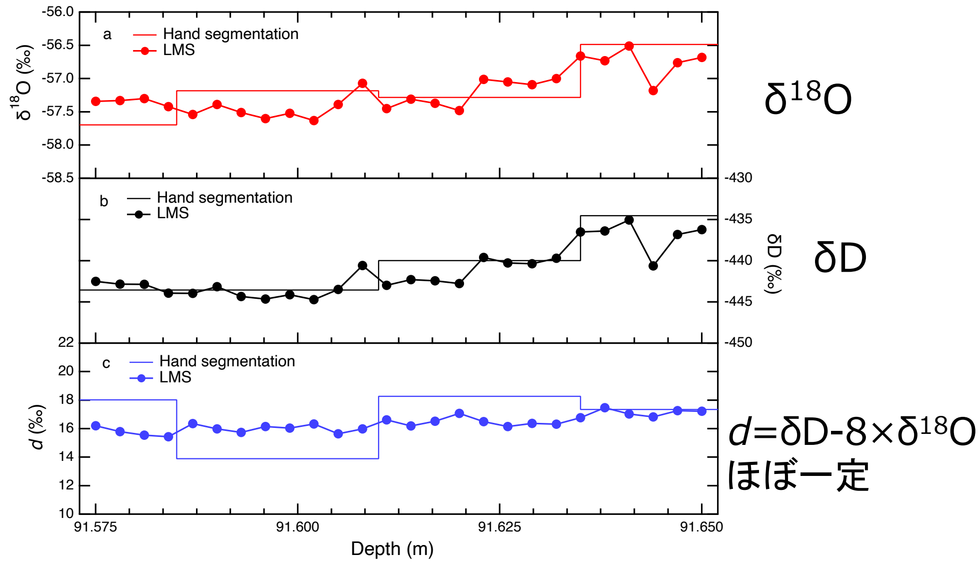


Motizuki+, *J. of Glaciology, 2023*

Movie in the press release:
https://www.riken.jp/press/2023/20230919_2/(Jap)
https://www.riken.jp/en/news_pubs/research_news/pr/2023/20230919_2/(Eng)

RIKEN-LMS and beyond (2)





Motizuki+, *J. of Glaciology, 2023*

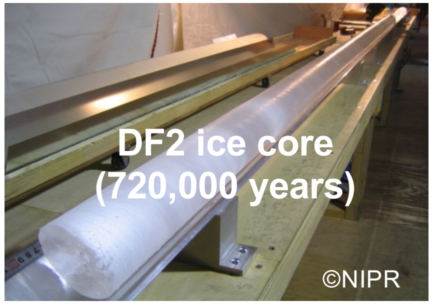
階段状の直線が約1年分解能の手分離による分析、点状のものがRIKEN-LMSによる3mmピッチ分析の結果。LMS分析(茶点、青点)が手分離の値に比べ少し重い方向に(ゼロに近い方向に)ずれているのは、(コロナ禍の影響で実験ができず)アイスコアの長期保存中にコアが昇華してしまったためと考えられる。
⇨ 今後に備えて対策済み

- 水同位体比(気温)にも約10年周期変動
- 数十万年の長期解析が視野に入る
- Ready for NO_3^- ionic analyses

Motizuki, Nakai, Ito, Yano+, in prep.

RIKEN “*Astro-Glaciology Data* Factory” Project

- Application of “RIKEN-LMS” to the DF2 deep ice core based on analyses of the 2000-yr hand-segmentation data
- Repeats of 1,000-yr LMS analyses of intriguing periods back to 720,000 yrs ago **on a piecemeal basis**
  1. *8100–8300 BCE; 312－317m depth (0.5 y=1.3 cm; solar cycle/ SN G106.3+2.7 (Boomerang SN)?: Dasari+ 2022*
  2. ~14,000 yrs ago (Annual layer thickness >1 cm) (SN)
  3. ~200,000 yrs ago (~5 mm)
  4. ~50,000 yrs ago (~1 cm)
  5. ~500,000 yrs ago (~5 mm?)
  6. ~1,000,000 yrs ago (~5 mm?) by DF3



- Analyzing ^{15}N in NO_3^- as a second indicator of SNe
  ($^{33,34}S$ in SO_4^{2-} also: annually-resolved profiles of ^{34}S can be measured at RIKEN; Takahashi, Nakai, Motizuki+, 2022)
- Seek the relationship of climate change with solar activity as a sub-product