# Rapid events in the carbon-14 content of tree-rings

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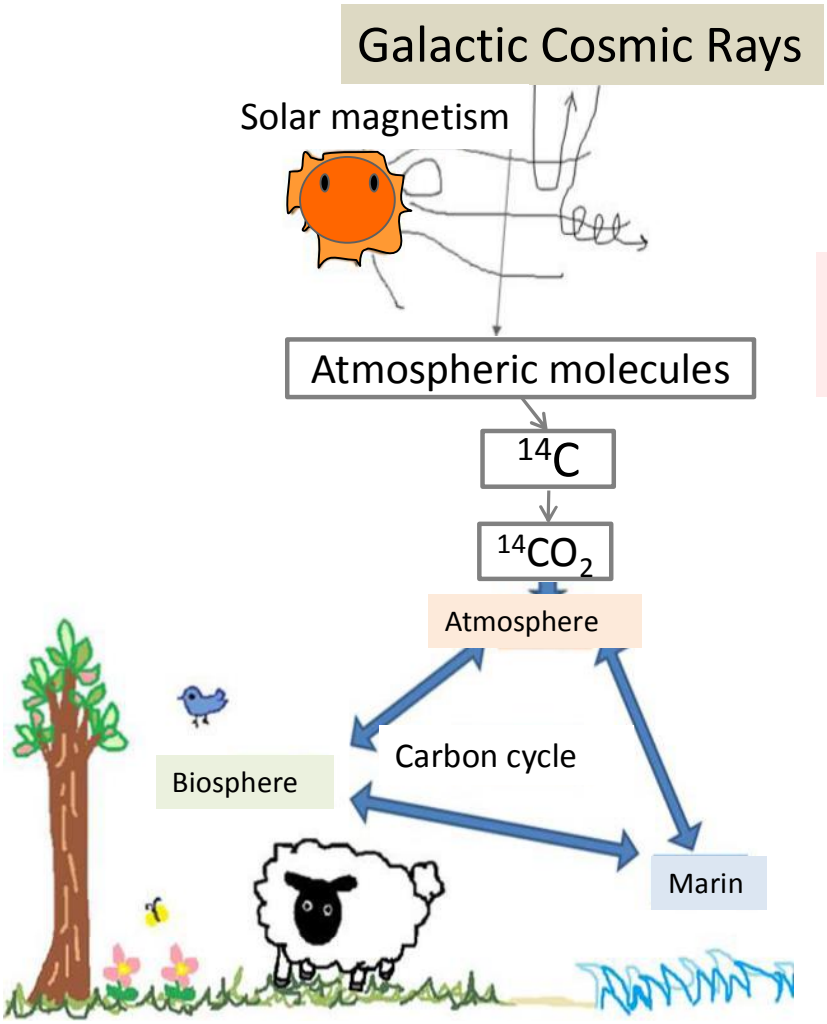
# Contents

- Motivation
- Measurements (AD600-1020)
- Rapid events
- Future project
- Conclusion

The stump of Tree-A

# Past CR intensity…$^{14}$C measurement




## Relation between $^{14}$C & CR

Cosmic rays produce $^{14}$C
（Neutron capture reaction）

$^{14}$C is oxidized to form $^{14}CO_2$ and taken by trees during the carbon cycle

$^{14}$C content in tree rings is retained and shows a record of the past CR intensity

# Cosmic ray events

Cosmic high energy phenomenon

→ Cosmic ray intensity rapidly increases

→ It is possible tree-rings record such an event

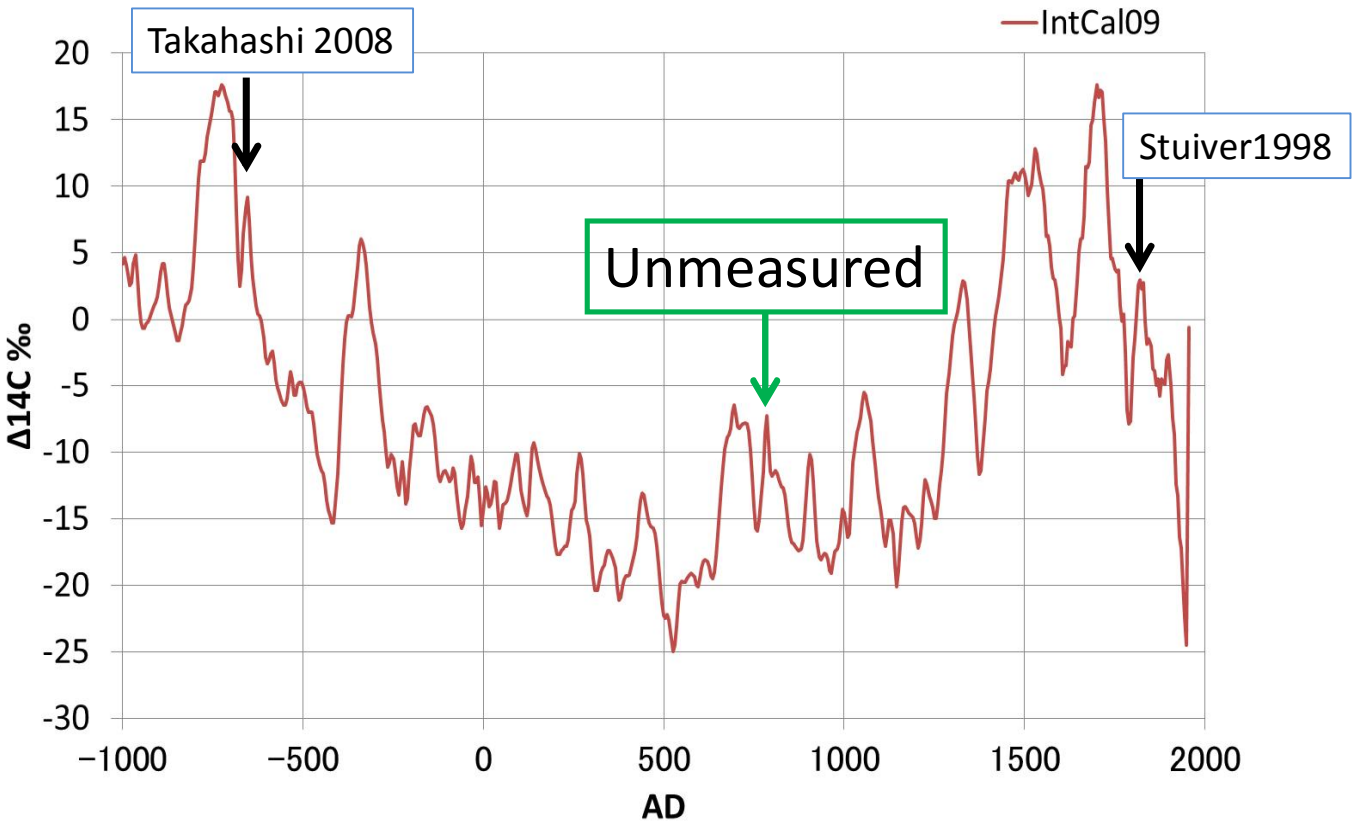
However such events have not been found before

There are a lot of periods of time where there are no yearly $^{14}C$ content measurements

⇒It is possible that such events are hidden in these periods

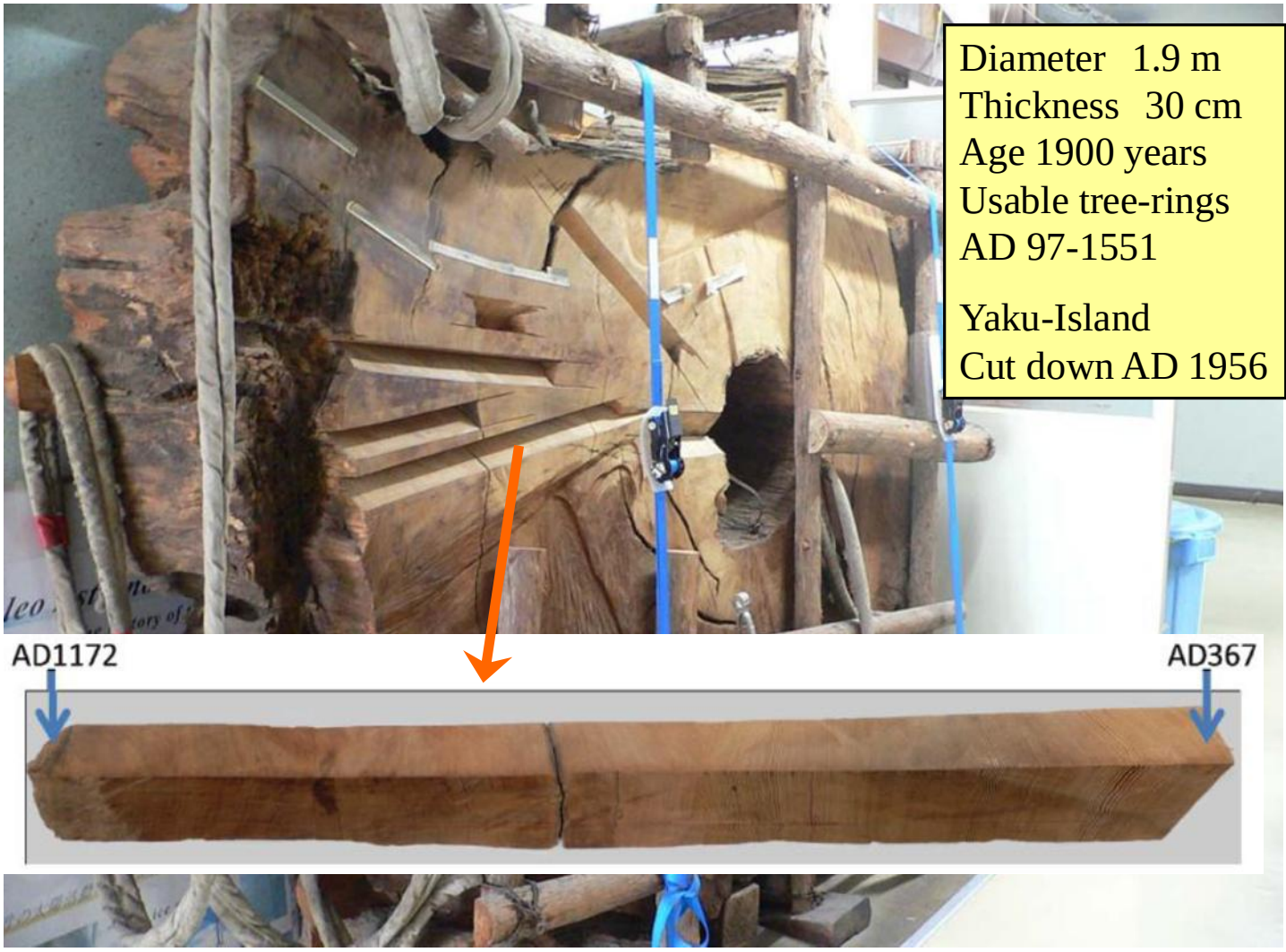
# $^{14}C$ content of this 3000years

Search for Cosmic Ray events→IntCal decadal $^{14}C$ dataset




Arrows show rapid increases（＞3‰/10yr）

# Sample Tree-A



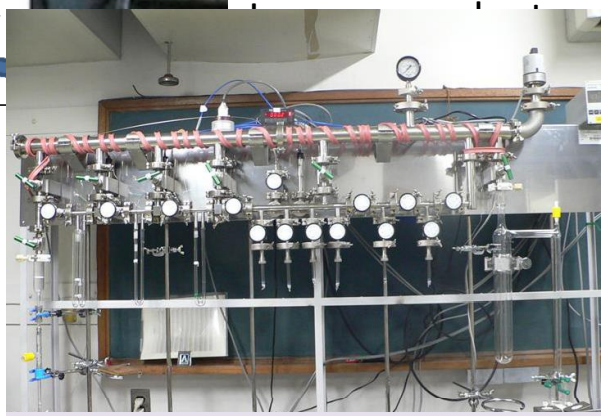
# Sample Tree-B

- Japanese cedar tree different from Tree-A
- Supplied by prof. Kimura (Fukushima University)

AD854 AD643

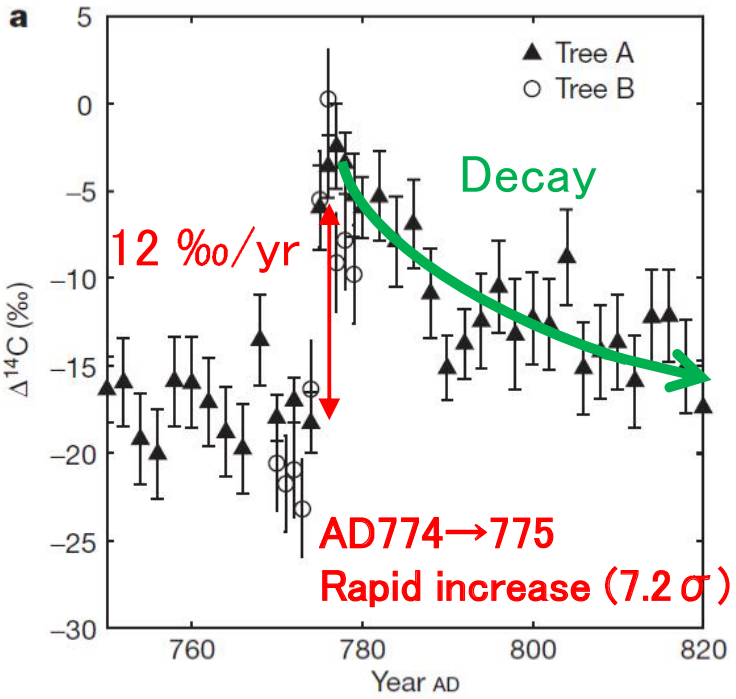
# Sample preparation

- **Slice** — Each ring is separated by a cutter knife
- **Chemical cleaning** — Extract cellulose which doesn't move between rings
- **To $CO_2$** — Cellulose is combusted to $CO_2$ at 850℃
- **Purification** — $CO_2$ is purified with cold traps
- **Graphitize** — $CO_2$ is graphitized by hydrogen reduction
- **Measurement** — $^{14}C$ content in graphite is measured by the AMS at Nagoya University

- We can measure 30 samples in each measurement run
- It takes about one month for 30 samples preparation

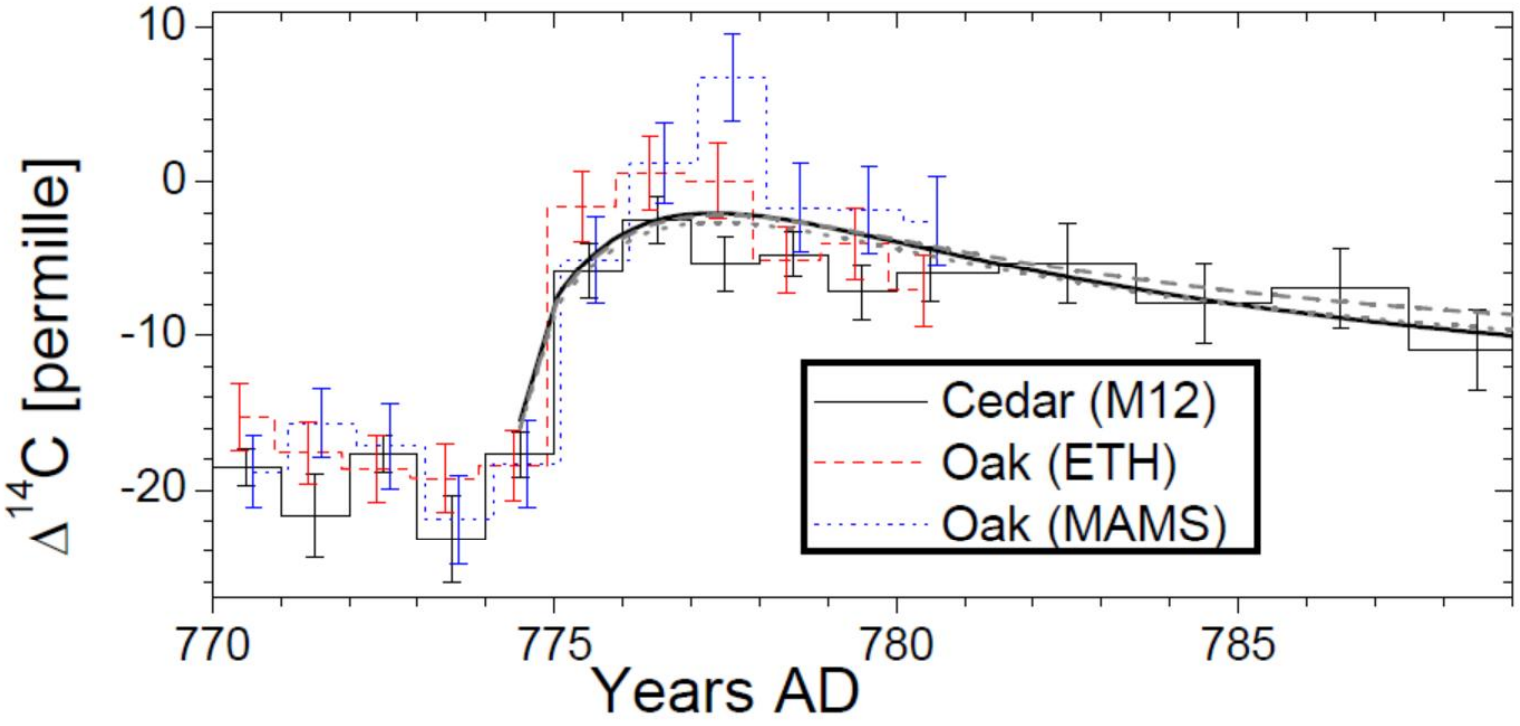
# AD775 event




a) Variation of $^{14}C$
（1-2 year data）

# European trees

Usoskin et al. (2013)



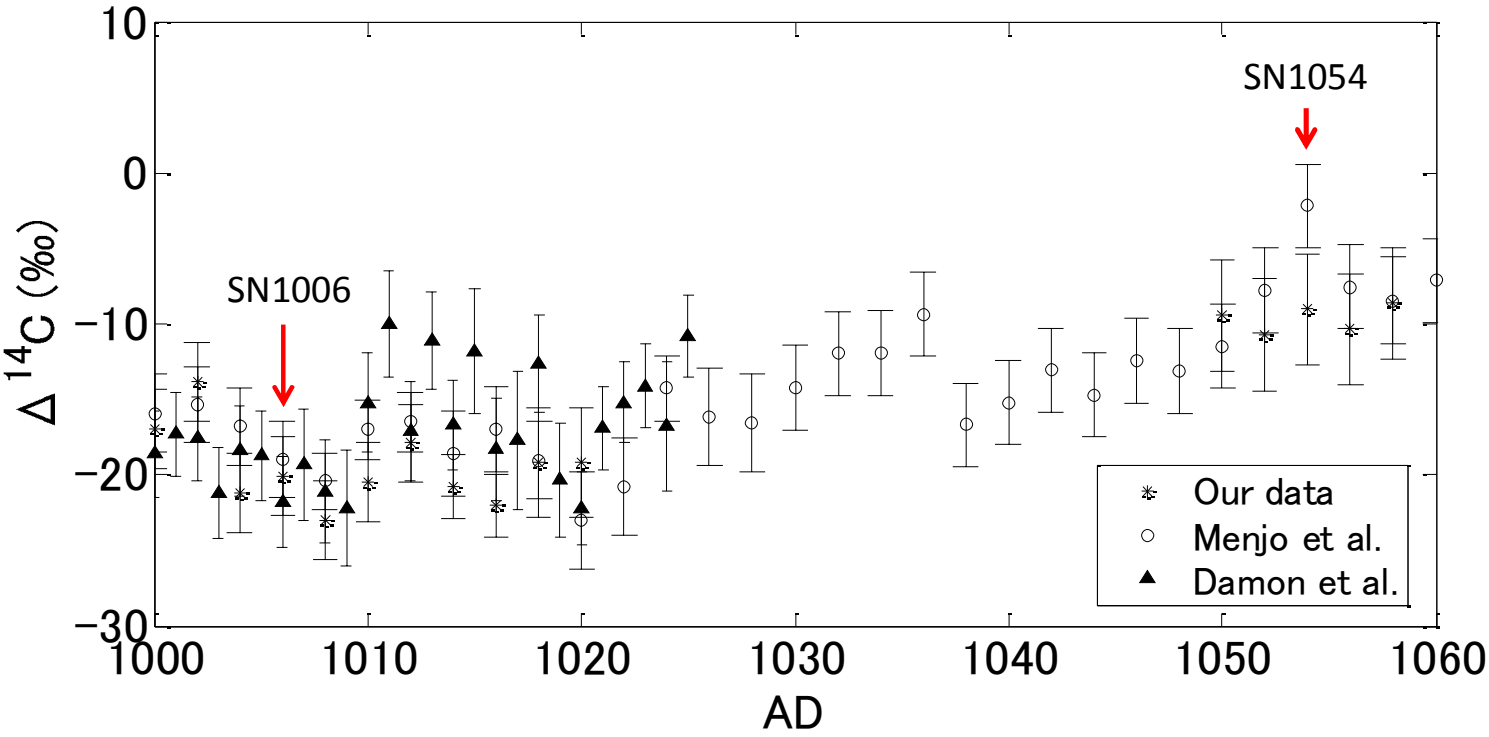

AD775 event is global

# Records of Supernova

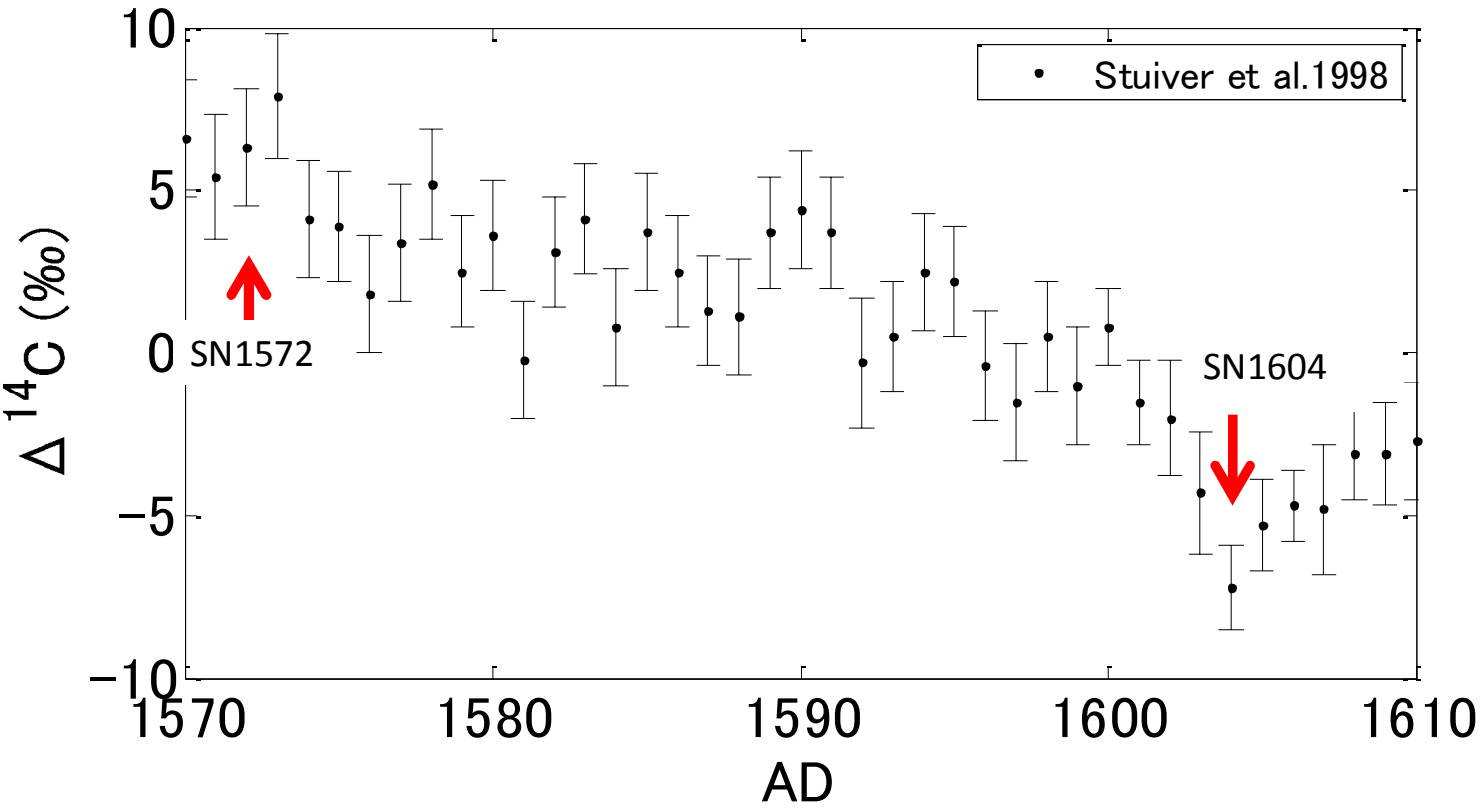
- Mainly recorded in China and Europe
- These are 7 SN records occurred in our galaxy

| Supernova | Year [AD] | Max. magnitude | Type | SN remnant | Distance [ly] |
|---|---|---|---|---|---|
| **SN 185** | 185 | -8 | | RCW 86 | 3000 |
| **SN 393** | 393 | -1 | | RX J1713.7-3946 ? | 3000 |
| **SN 1006** | 1006 | -9 | Ia | | 7000 |
| **SN 1054** | 1054 | -6 | II? | Crab Nebula | 6300 |
| **SN 1181** | 1181 | 0 | II | 3C58 | 10000 |
| **SN 1572** | 1572 | -4 | Ia | Tycho's Nova | 12000 |
| **SN 1604** | 1604 | -2.5 | Ia | Kepler's Star | 20000 |
| **Carrington flare** | 1859 | | | | |
| **1460 event** | ~1460 | | | Identified by $^{10}$Be | |

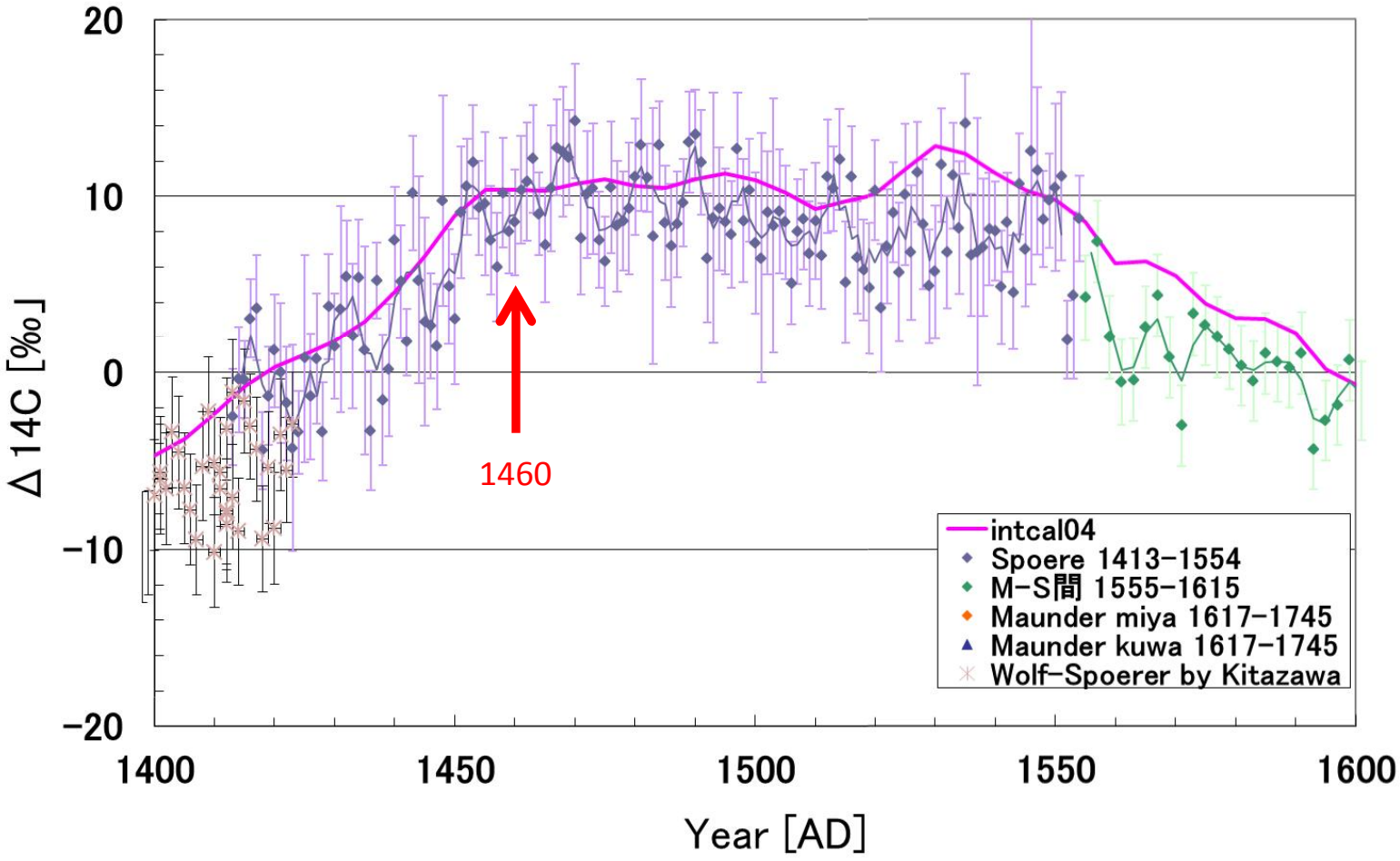
# SN1006, SN1054



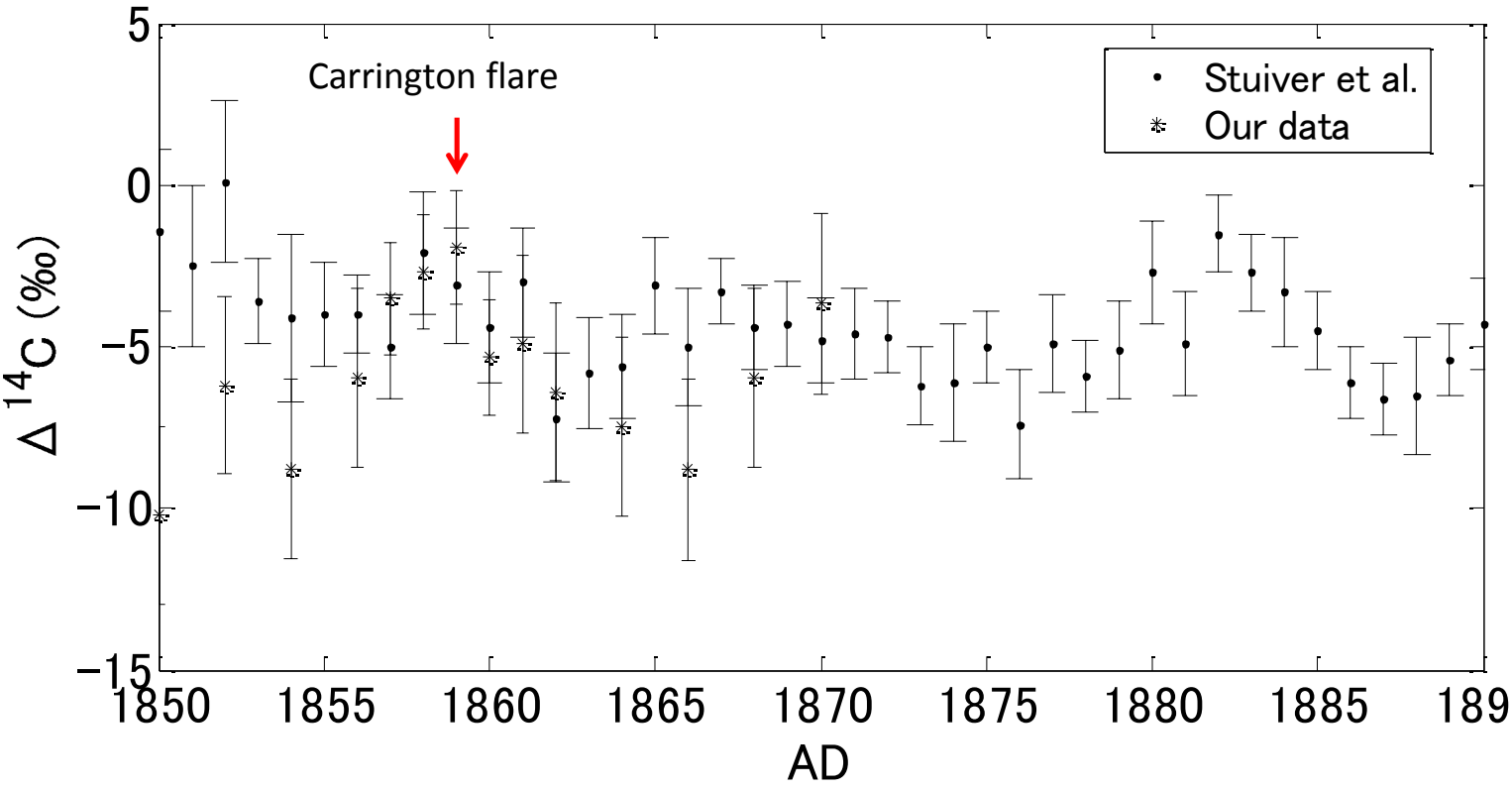
# SN1572, SN1604



# AD1460 event

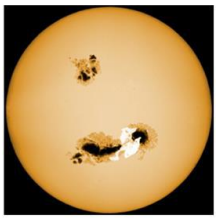


# Carrington flare(SPE1859), SN1885




Much higher energy than recorded events

## Cause of these events?



Maehara et al. 2012

- **Large SPE (Solar Proton Event)?**

  One order of magnitude beyond SPE 1989 (Thomas et al. 2013)

  25-50 times larger than SPE1956 (Usoskin et al. 2012, 2013)

  →Below the extinction level and a possible cause


- **Short GRB (gamma-ray burst)?**

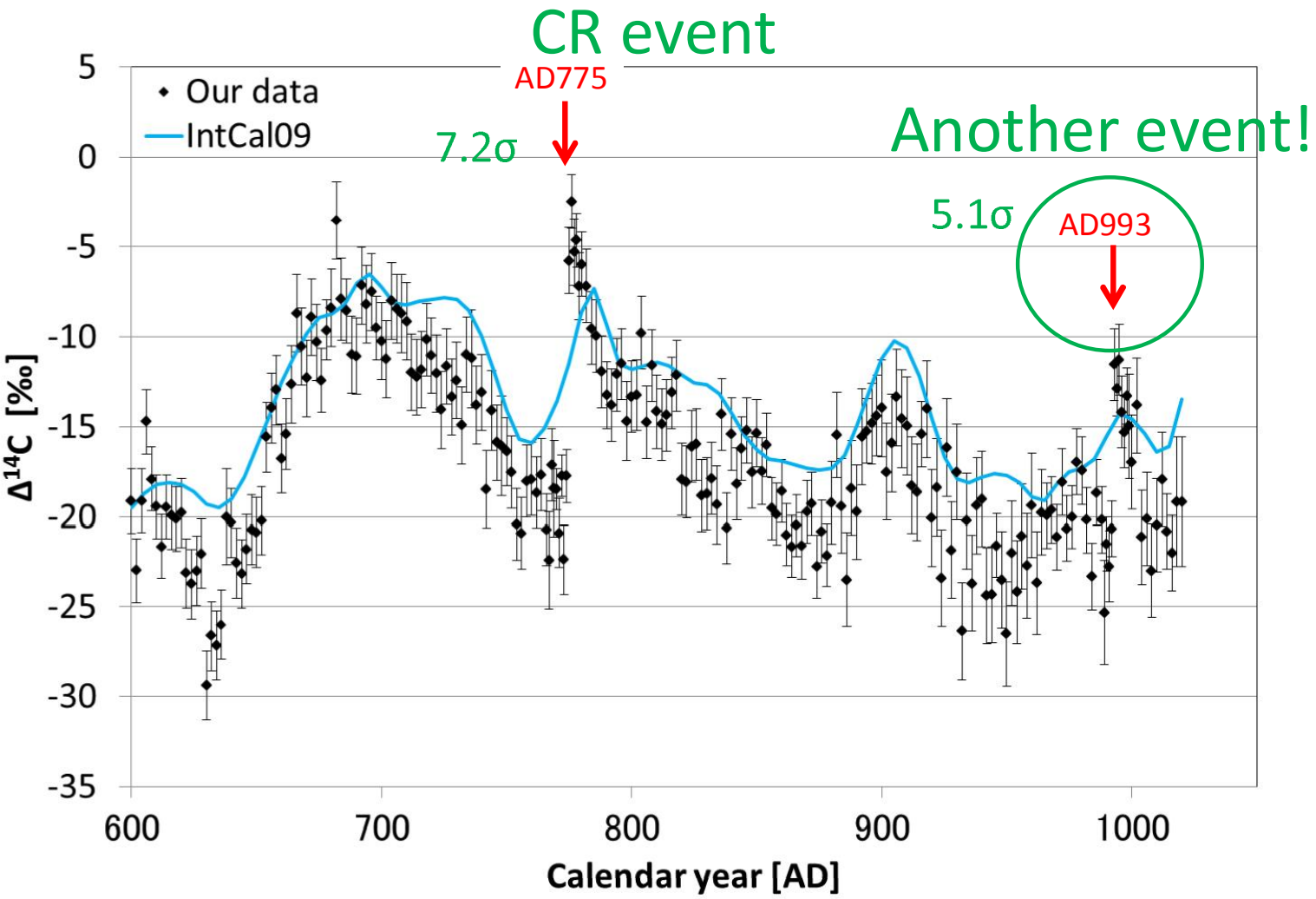
  Hambaryan & Neuhäuser (2013)

  Explain that at the time of the 2 events there were no SNRs and no historical record

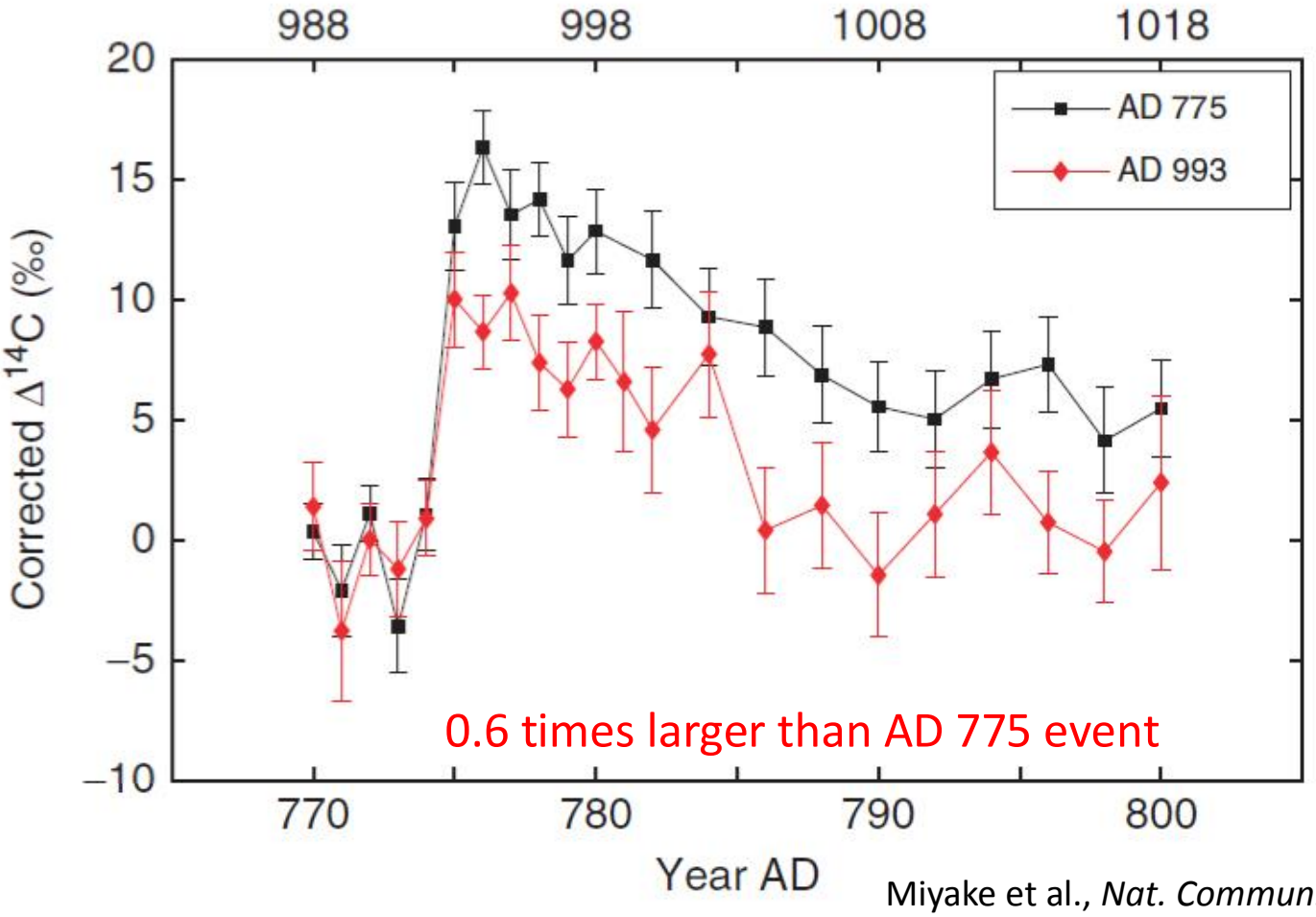
  →However, observed rate of short GRB is very low

$^{14}C$ event rate is very important!

# Discovery of another event

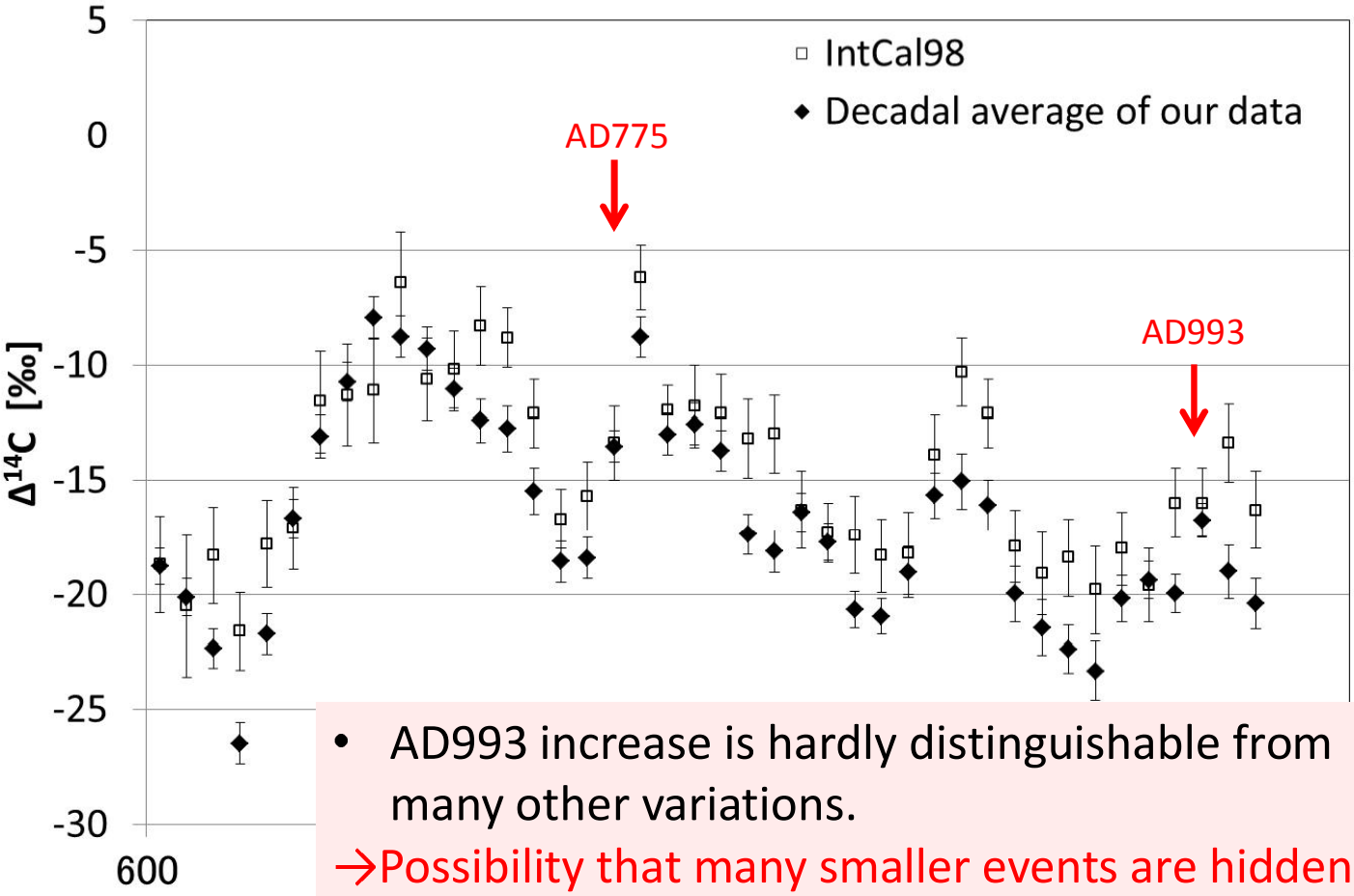


# Comparison of AD775 & 993




Miyake et al., *Nat. Commun.* 2013

# Comparison with IntCal98

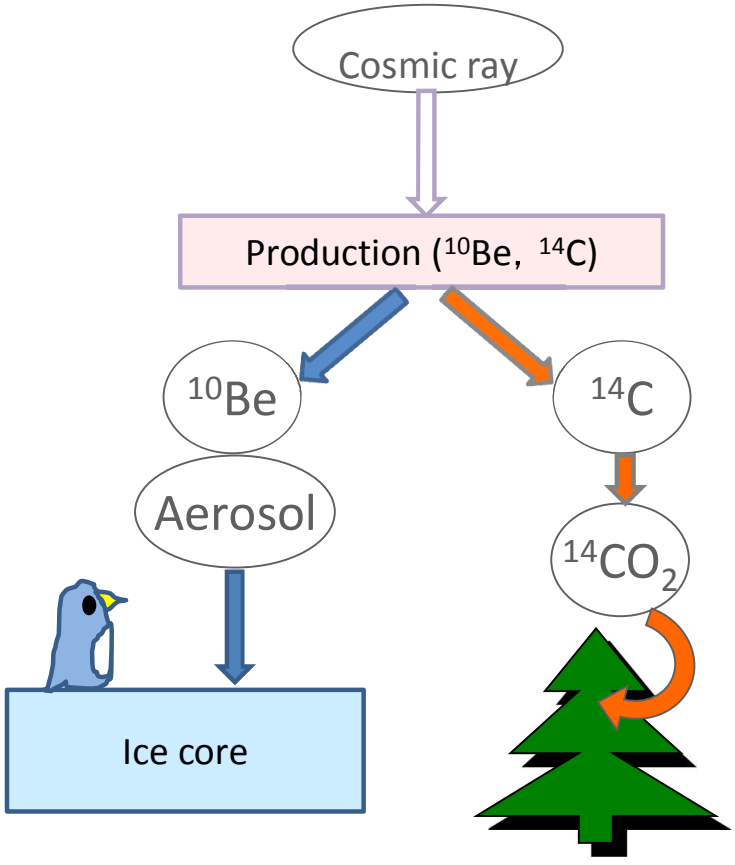



- AD993 increase is hardly distinguishable from many other variations.

→Possibility that many smaller events are hidden !

→1-yr resolution measurement is important

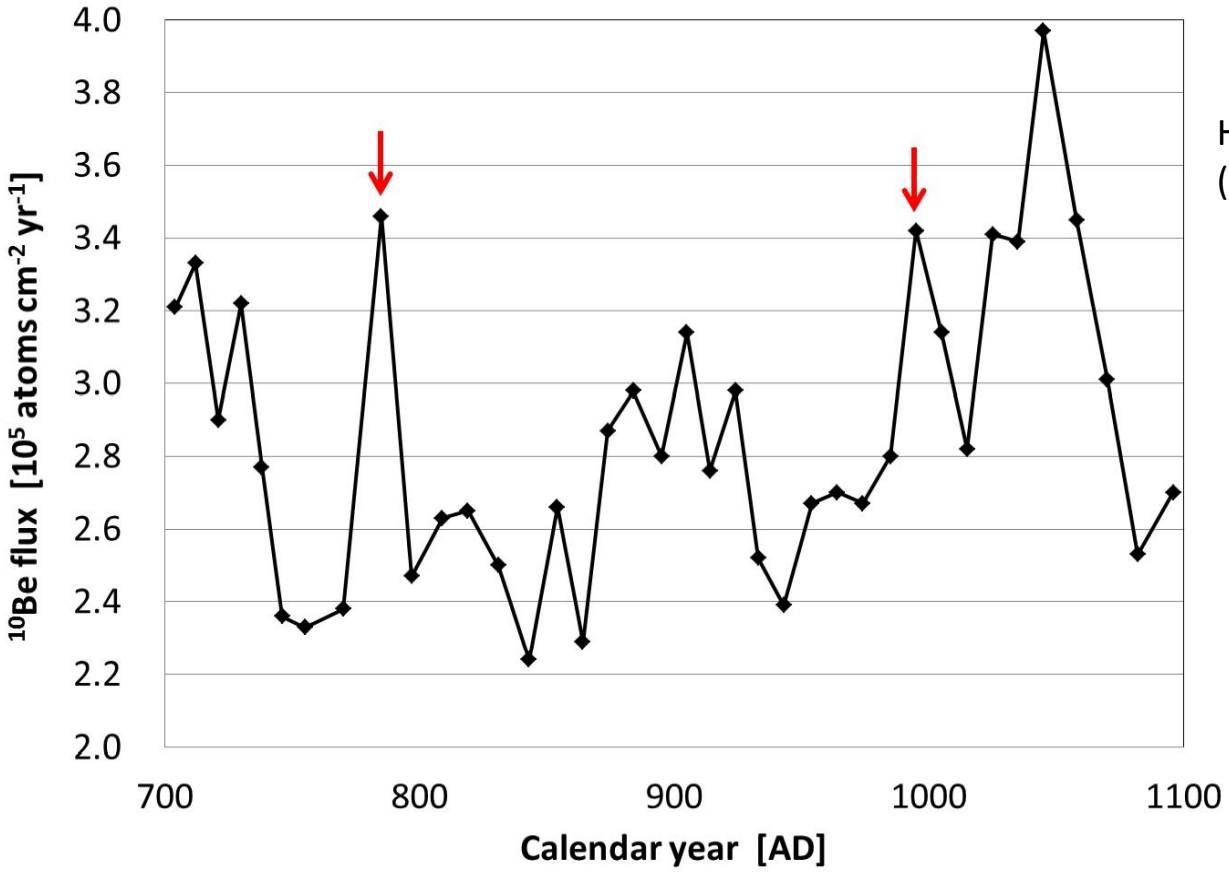
# $^{10}$Be data in Antarctic ice core




- Cosmogenic nuclide

- Dome Fuji in Antarctica
- Decadal data (Horiuchi et al. 2008)

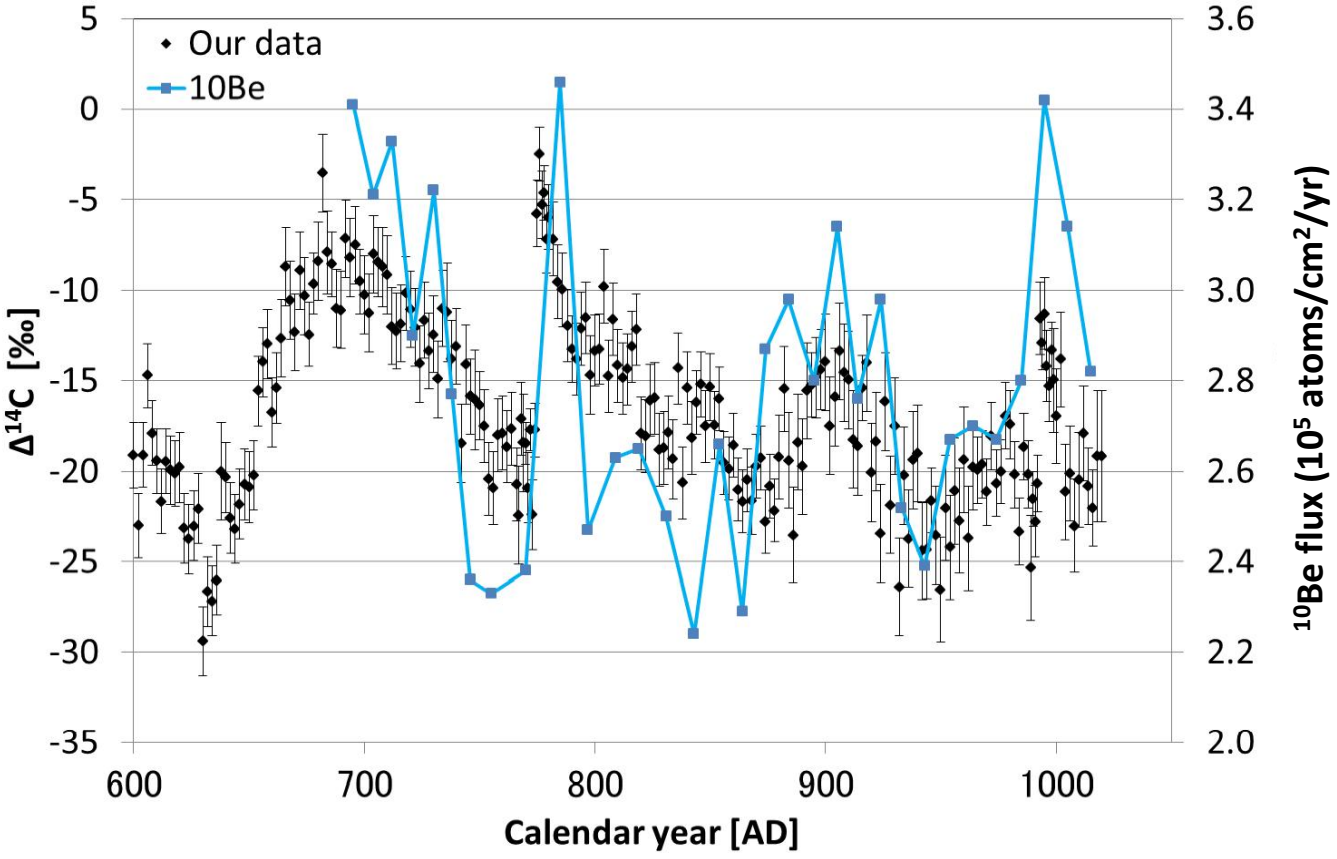
# $^{10}$Be decadal data in Antarctic ice core




Horiuchi et al. (2008)

There are increases around AD775 & 993

# Comparison between $^{14}C$ & $^{10}Be$

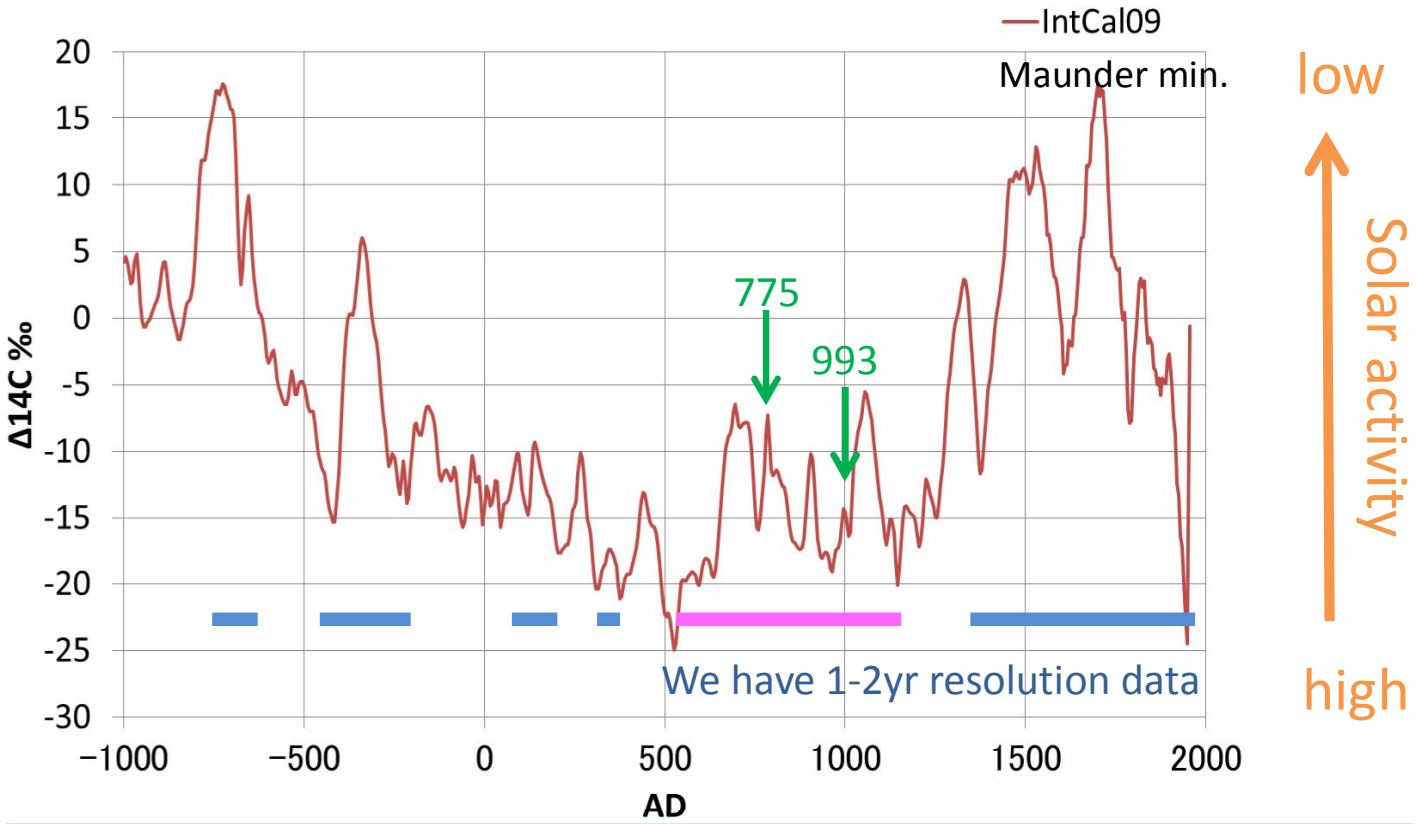



**Proportions of flux increase ($^{14}C/^{10}Be$) of two events are consistent with each other**

**→Two events must have the same origin!**

# When did two events occur?

2 events occurred in higher solar activity period




Occurrence rate of $^{14}C$ event → 2 events / ~1600 years

# Cause of $^{14}C$ event

- Higher solar activity period
  （Two events are not in a grand solar minimum period）

- 1 event / 800 years

Inconsistency between
a short GRB rate and $^{14}C$ event rate

**Solar activity is a more plausible cause!**

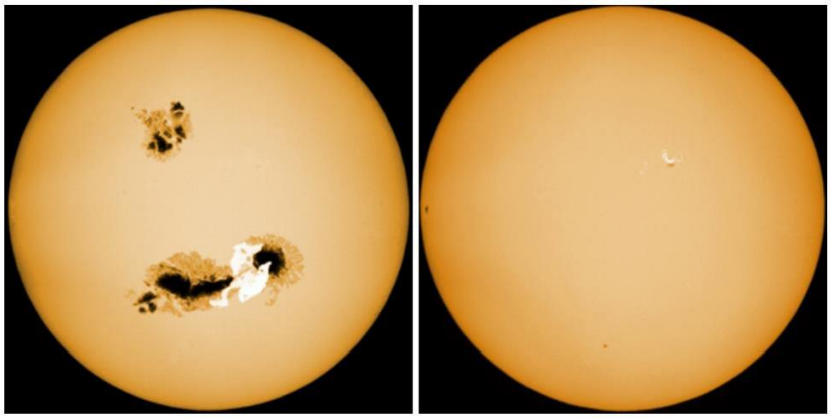
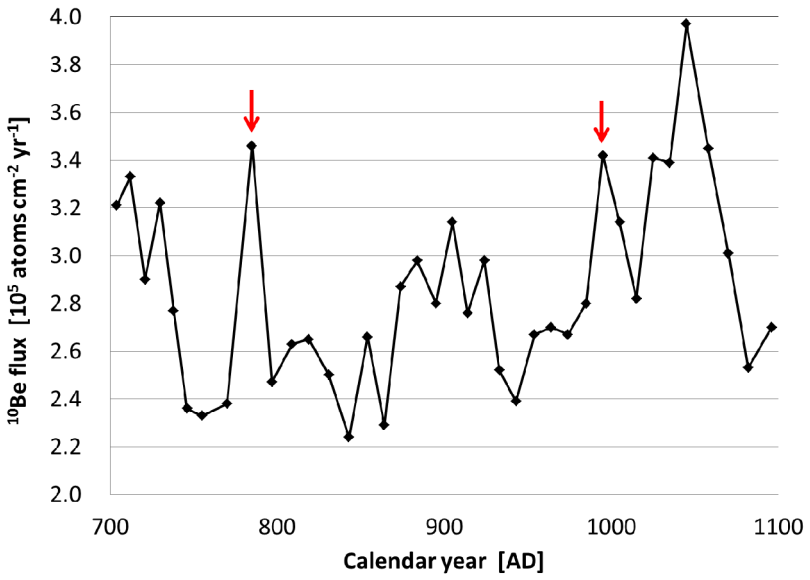


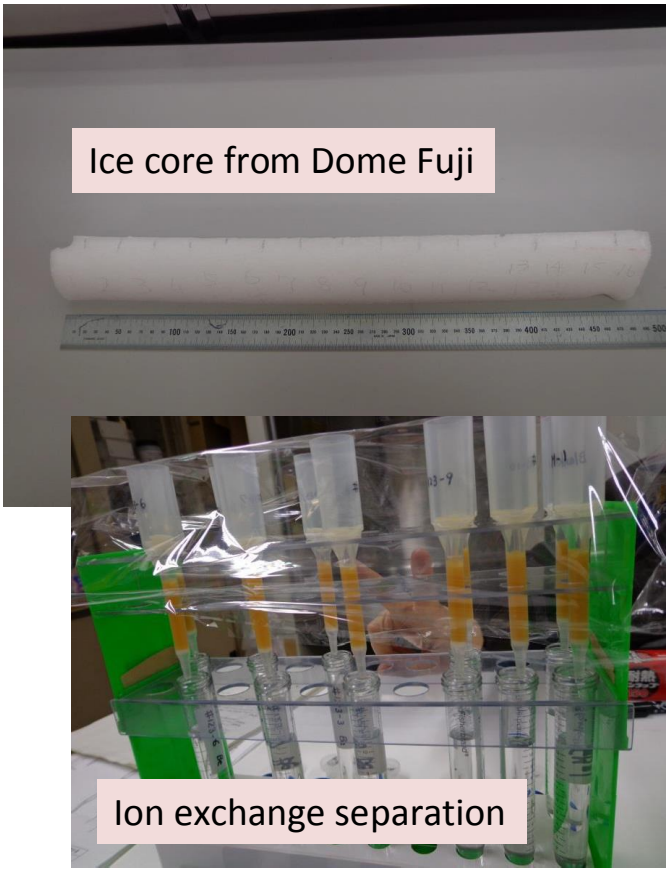
図1：（左）太陽型星のスーパーフレアの想像図（右）京都大学飛騨天文台の太陽磁場活動望遠鏡（SMART）で撮影された2011年9月7日の太陽フレア（Hα+1.2Åの単色像）Maehara et al.2012

# $^{10}$Be measurement（with 1-yr resolution）

Antarctica Dome F. decadal data



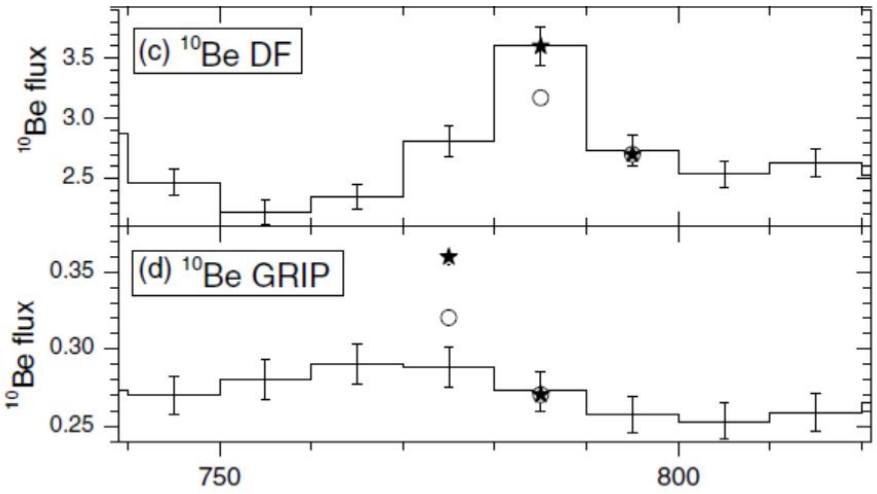

Collaborate with Hirosaki Uni.




- Are they really 1-yr increases?
  →Determine the absolute date of the core

# For Further study

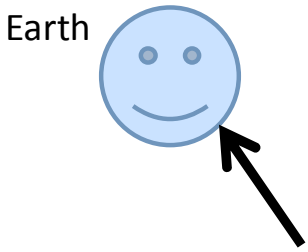
- Difference between both hemispheres (Antarctica and Greenland) ?



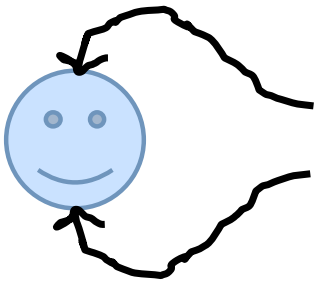

Usoskin & Kovaltsov 2012

- More $^{10}$Be measurements in some cores will be necessary

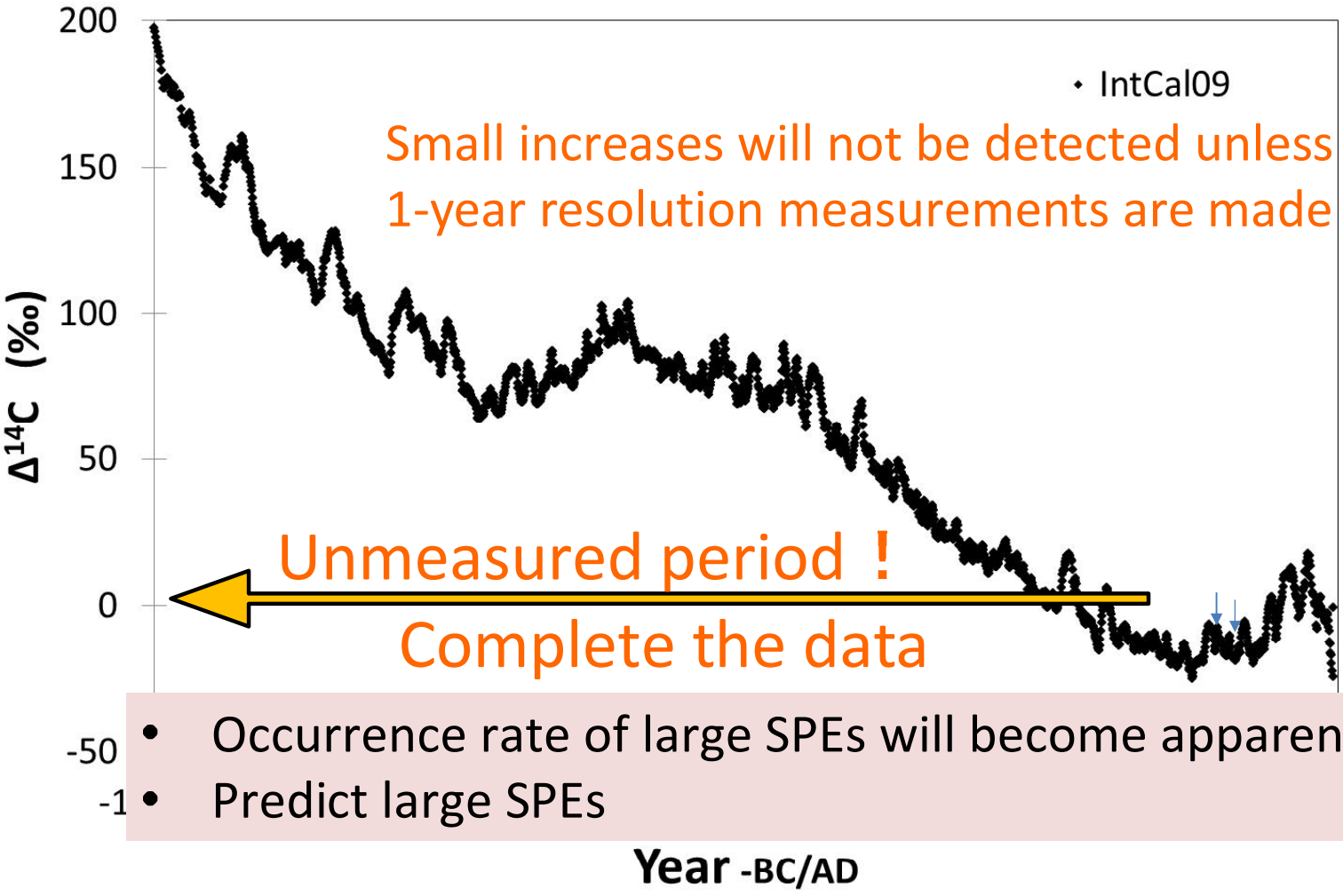
- Gamma-ray asymmetry




- Proton symmetry



# Future work




- Occurrence rate of large SPEs will become apparent
- Predict large SPEs

# Conclusion

- We measured $^{14}C$ content from AD 600 to 1020
- We found two rapid increases in the $^{14}C$ content (AD775, AD993)
- IntCal and $^{10}Be$ decadal data, and European yearly $^{14}C$ data also show the rapid increases
- Considering the occurrence rate of $^{14}C$ events, the cause of $^{14}C$ events must be due to large Solar Proton Events

# We need old trees

- Do you have any old trees?
- Or do you know where any old trees can be found?

- If you have any information, please contact us.
- We will be sure to measure $^{14}C$ content for the past 10,000 year
- Let's work together!

- Contact email:
fmiyake@stelab.nagoya-u.ac.jp

- For Question