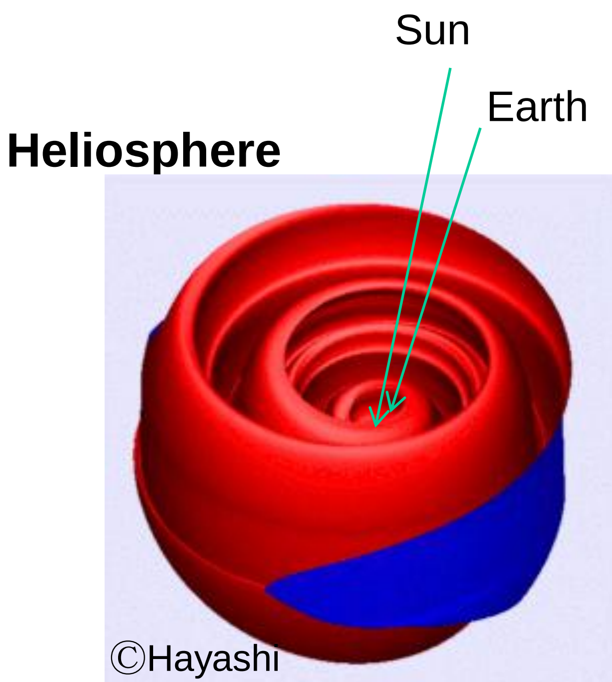
Possible effects of galactic cosmic rays on climate and weather



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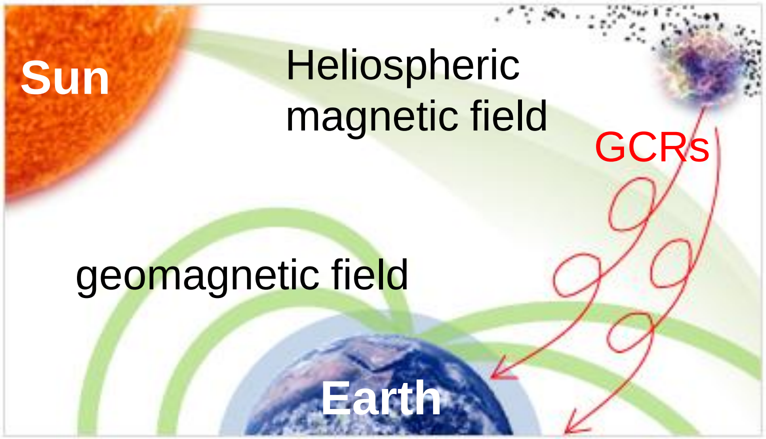
Kazuki Munakata (Shinshu Univ)
Ryuho Kataoka (Tokyo Tech)

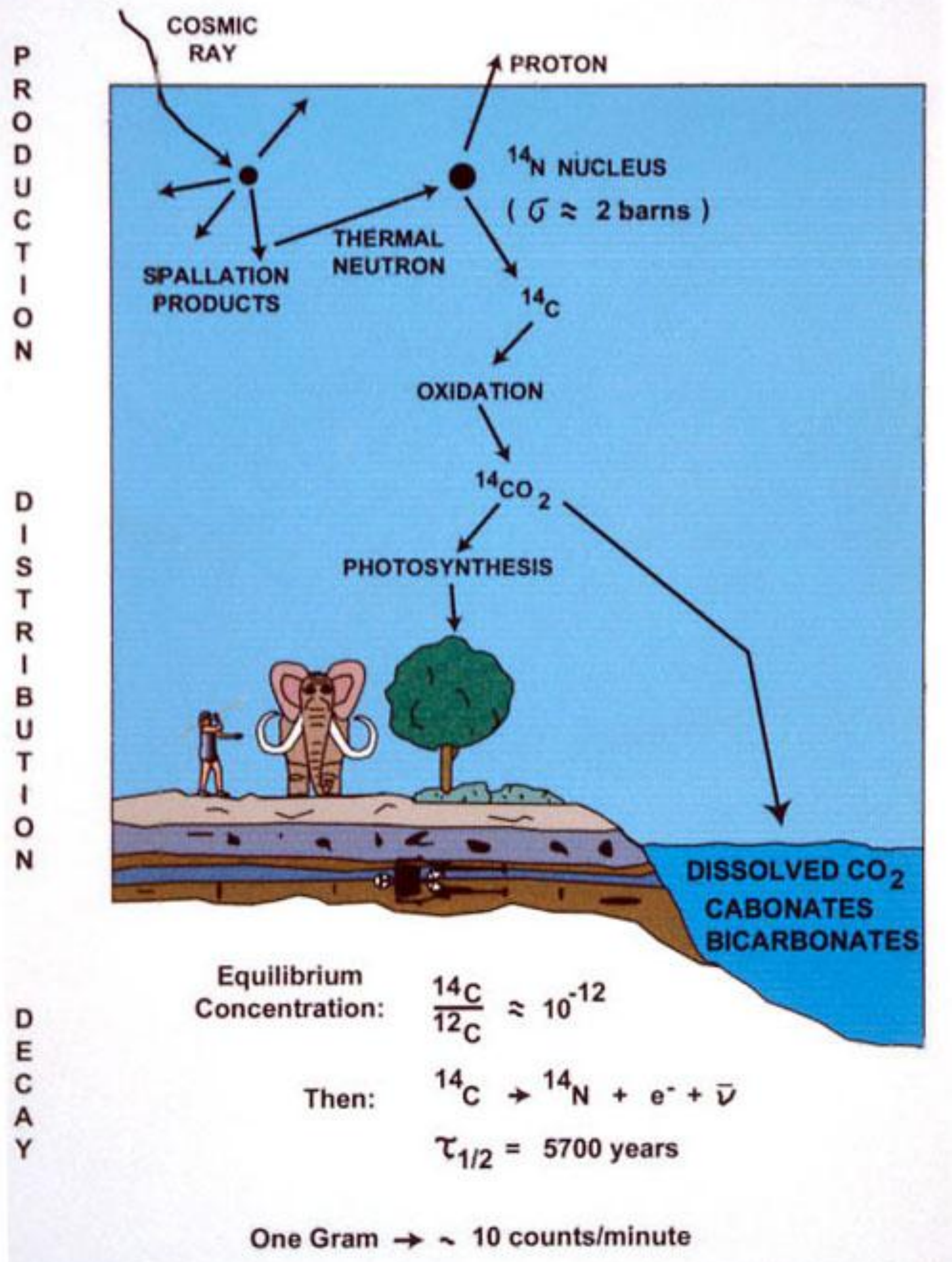
Topics

- Radiocarbon dating
- Reconstruction of Galactic Cosmic Rays (GCRs) and solar activity in the past
- GCR variations at the Maunder Minimum (AD1645-1715)
- Detecting the GCR impact on climate variations
- Possible pathway of GCR impact on climate system
- 27-day solar rotational period found in tropical cloud activities and global lightning activities

Production of carbon-14

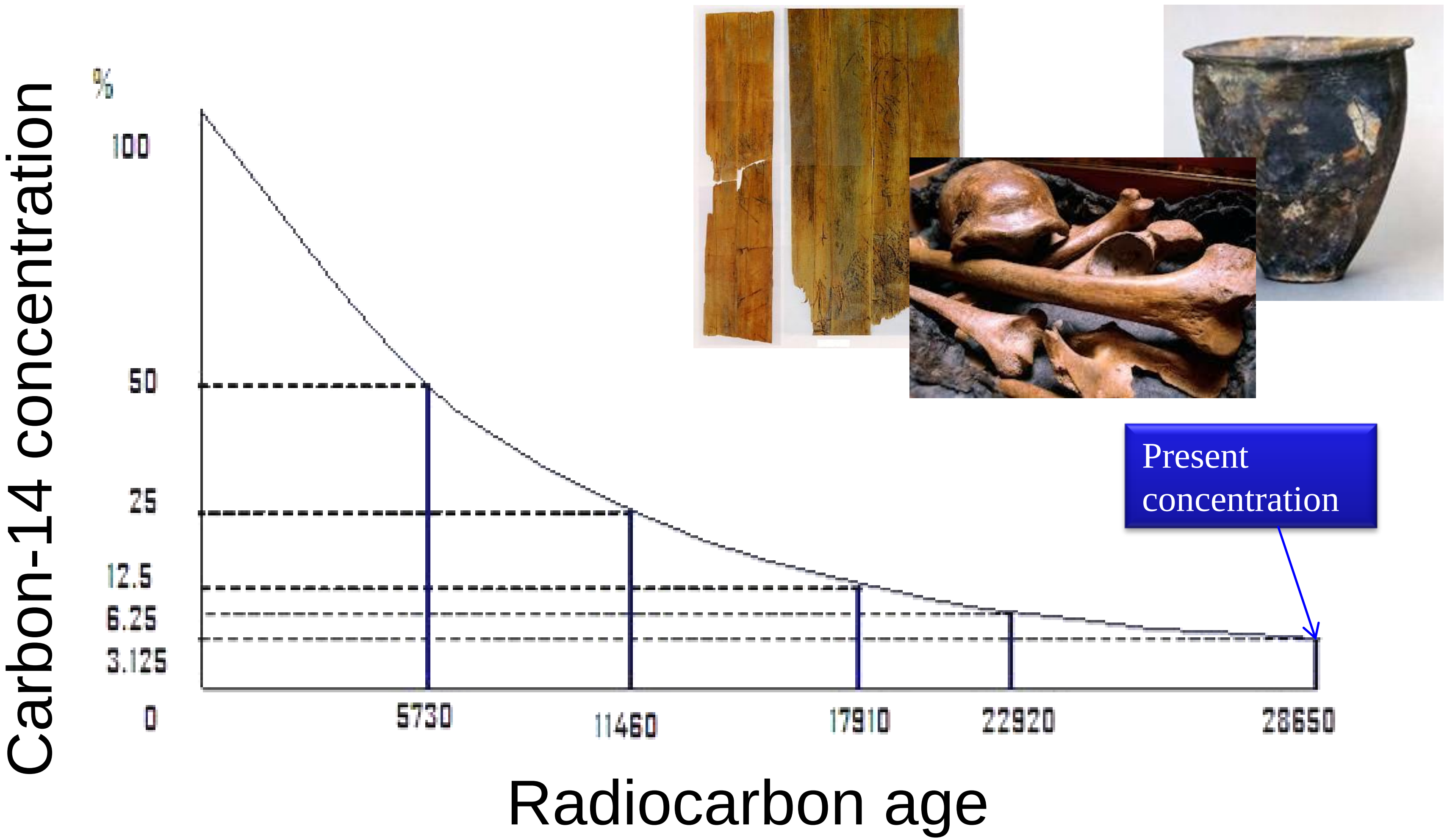


GCRs are modulated by heliospheric & geomagnetic magnetic field



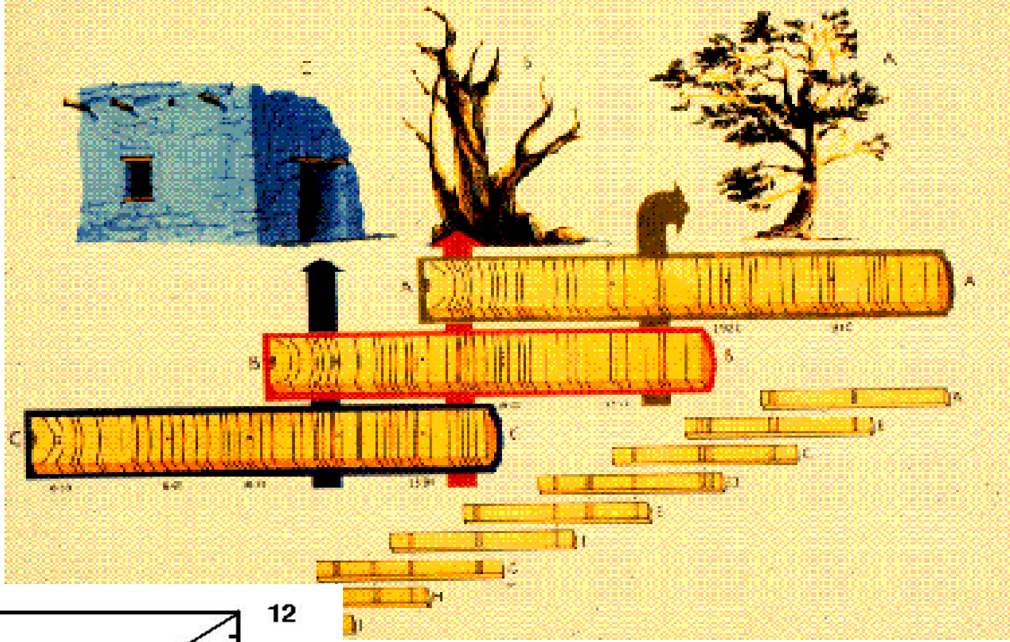
http://www.physics.arizona.edu/ams/education/product.htm

Radiocarbon dating



Before AD1993, the variations of carbon-14 production had not been taken into account.

Construction of the Calibration Curve for the radiocarbon dating



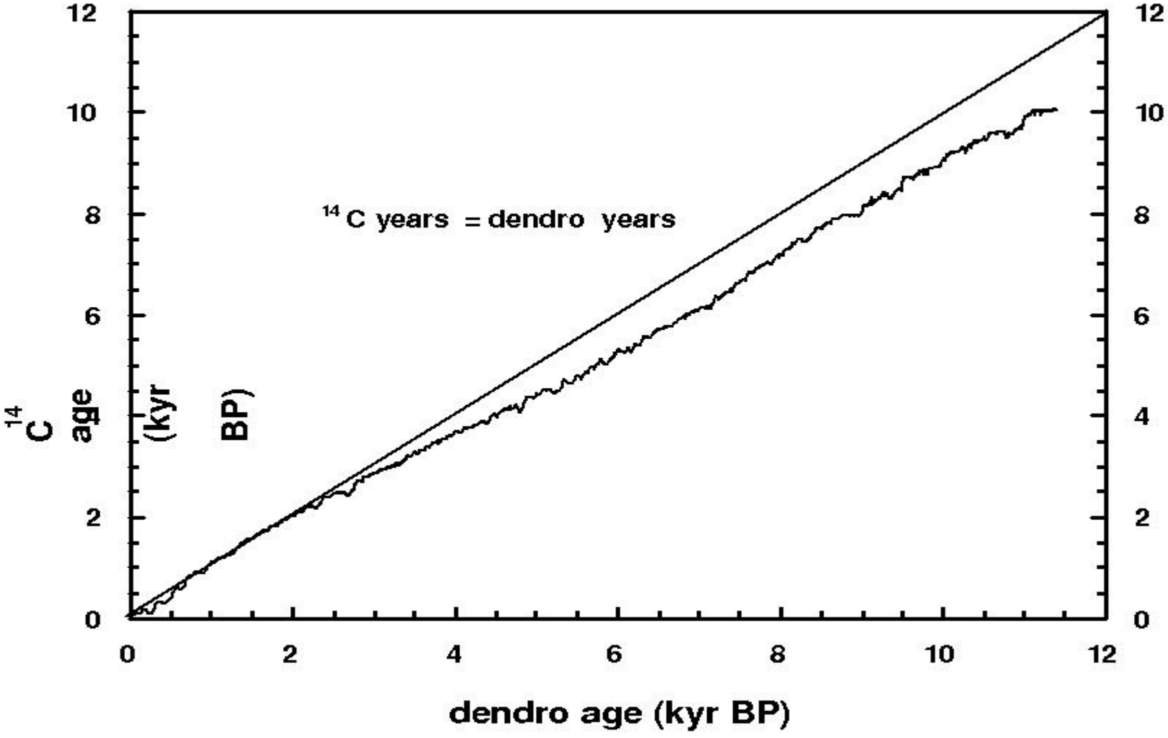
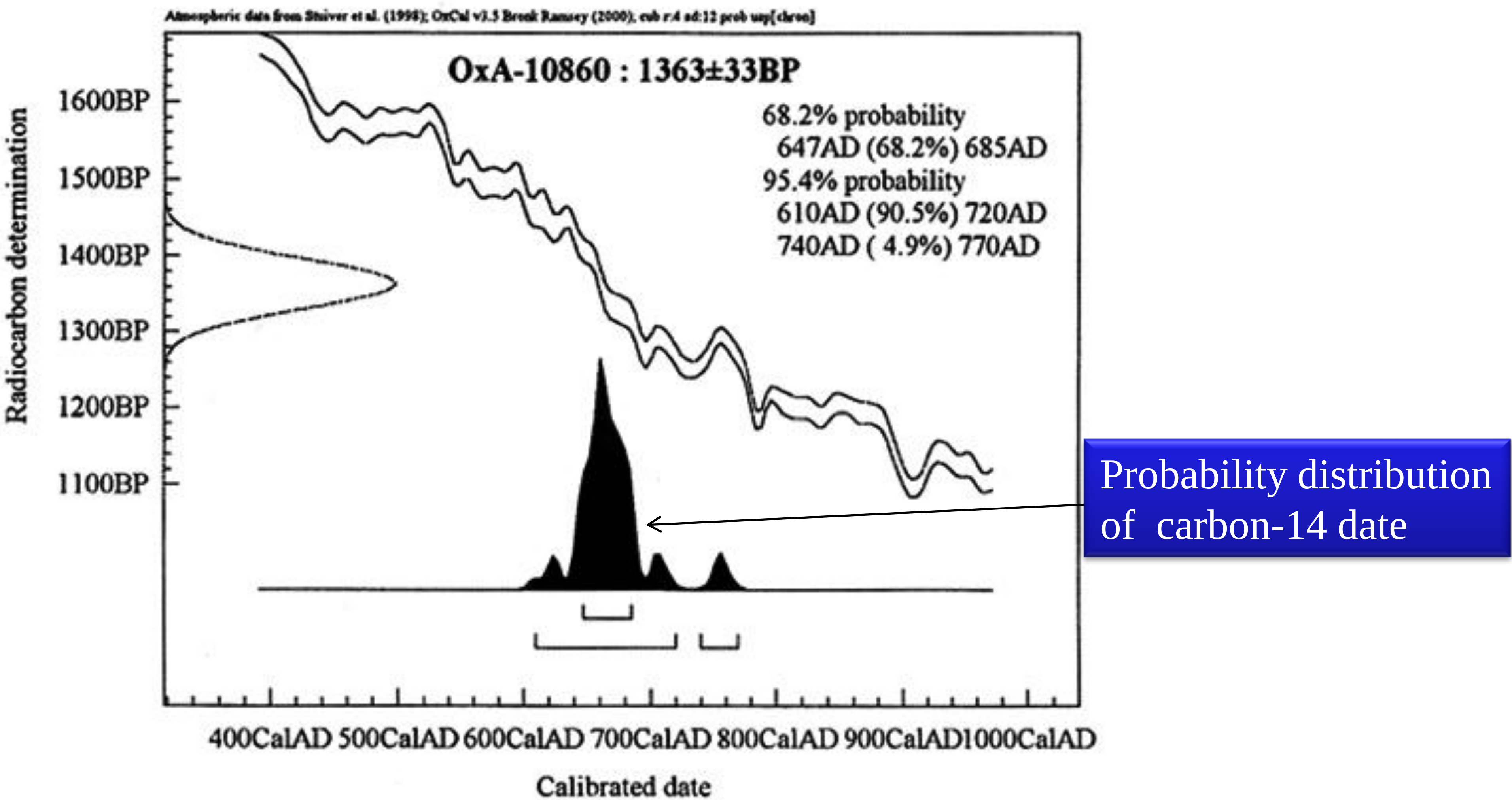


Figure 2. *Radiocarbon calibration curve obtained by dating tree rings (Stuiver and Kra 1986, Kromer and Becker 1993)* .

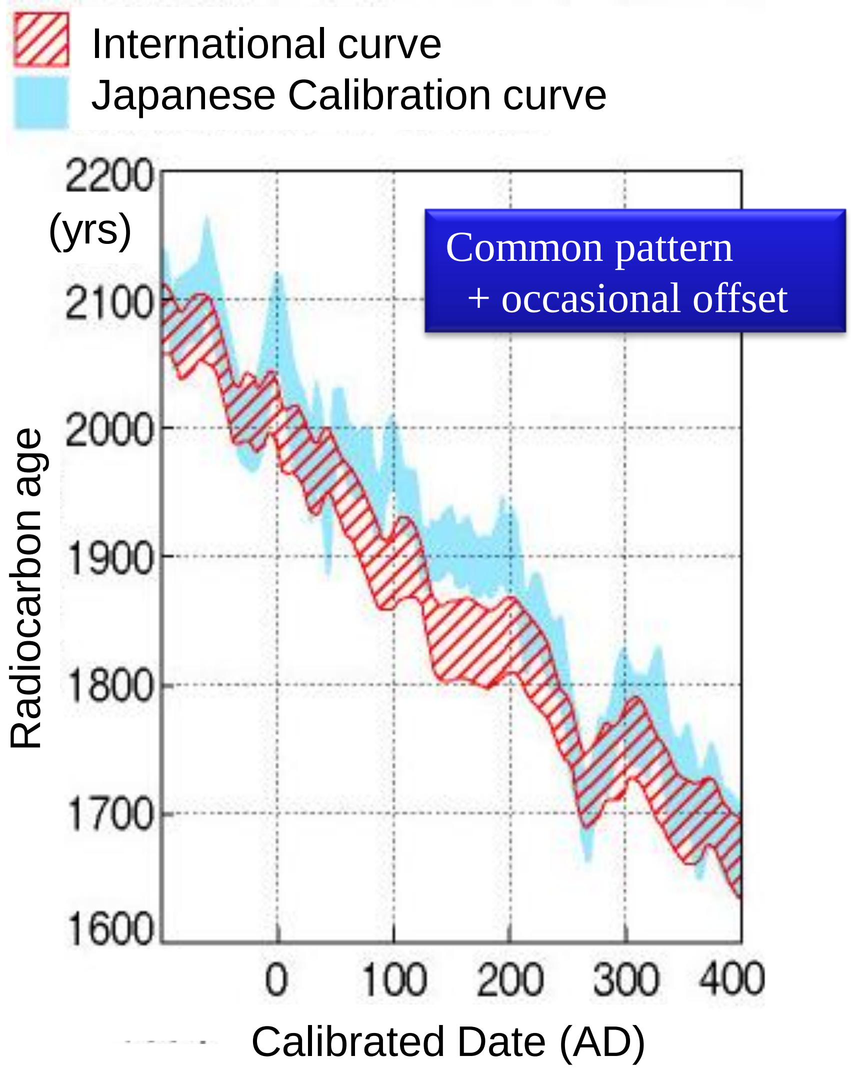
Long sequence of tree rings were obtained by matching the pattern of tree-ring widths (Dendro-chronology)

The “wiggles” in the calibration curve is due to

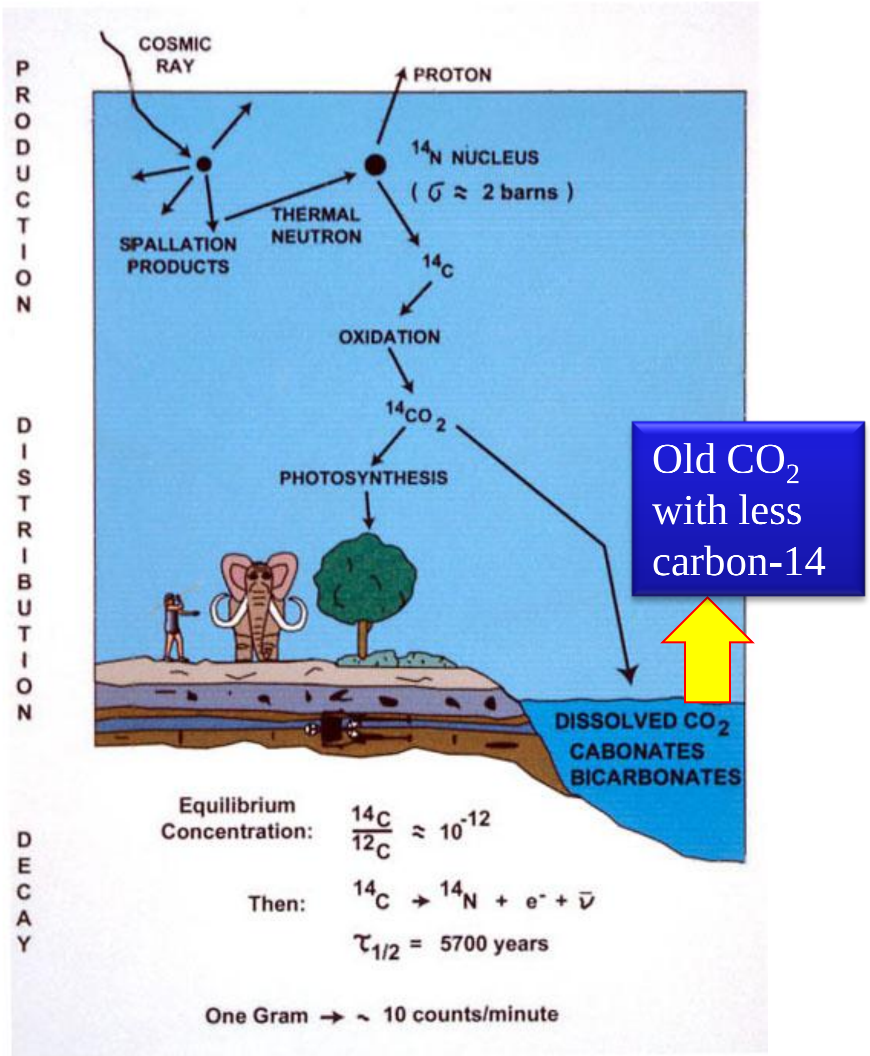
1. the secular variation of geomagnetic field intensity (>3000 yrs)
2. solar magnetic field variations (<3000 yrs)



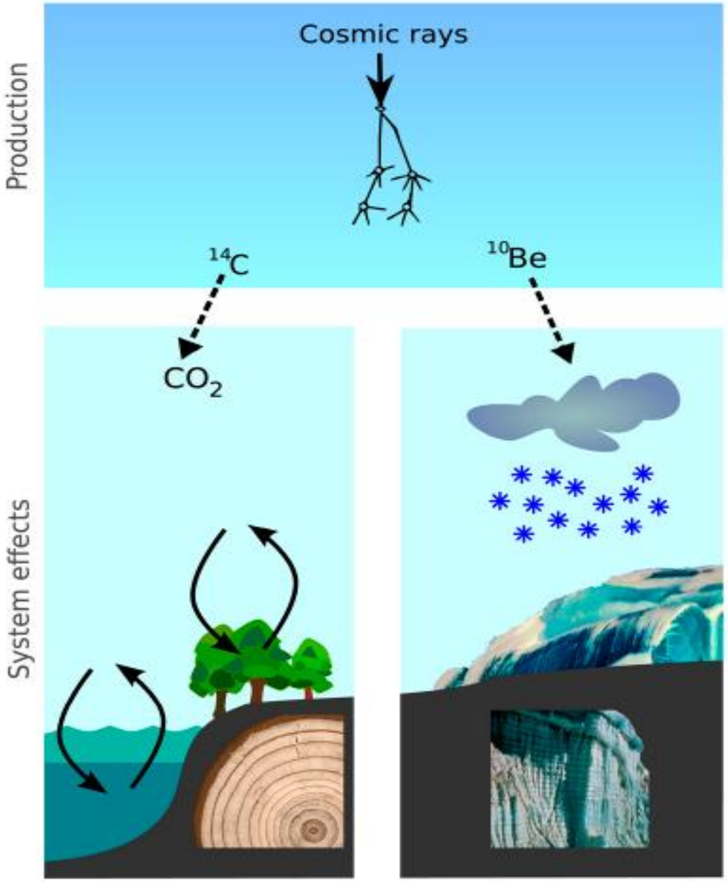
Regional offset of carbon-14 concentration



(National Museum of Japanese History)

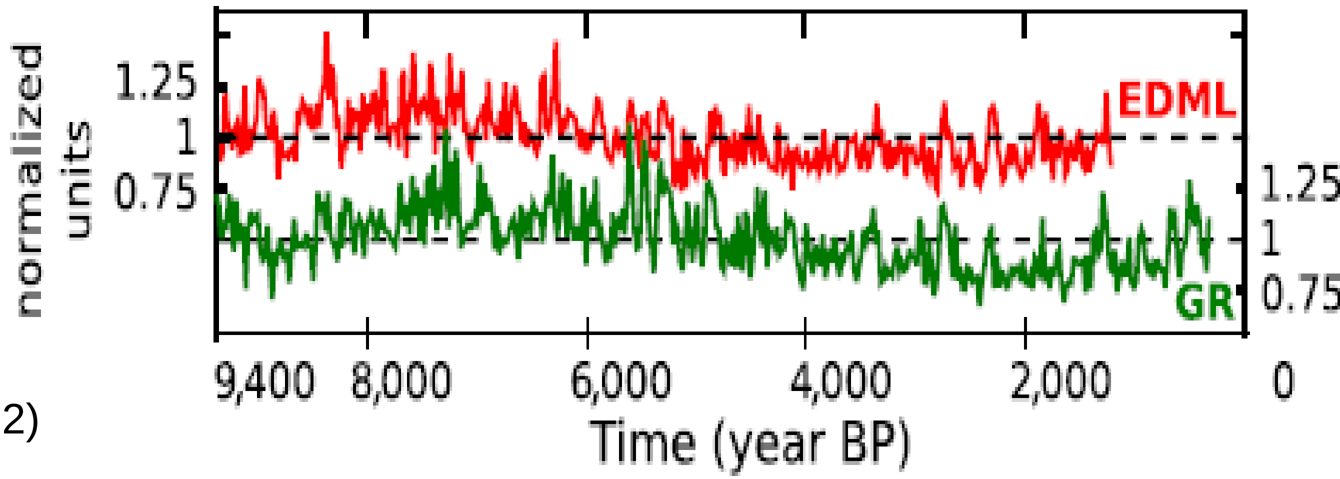


Regional effect of Beryllium-10 concentration in ice core



EDML: Antarctica
GR: Greenland

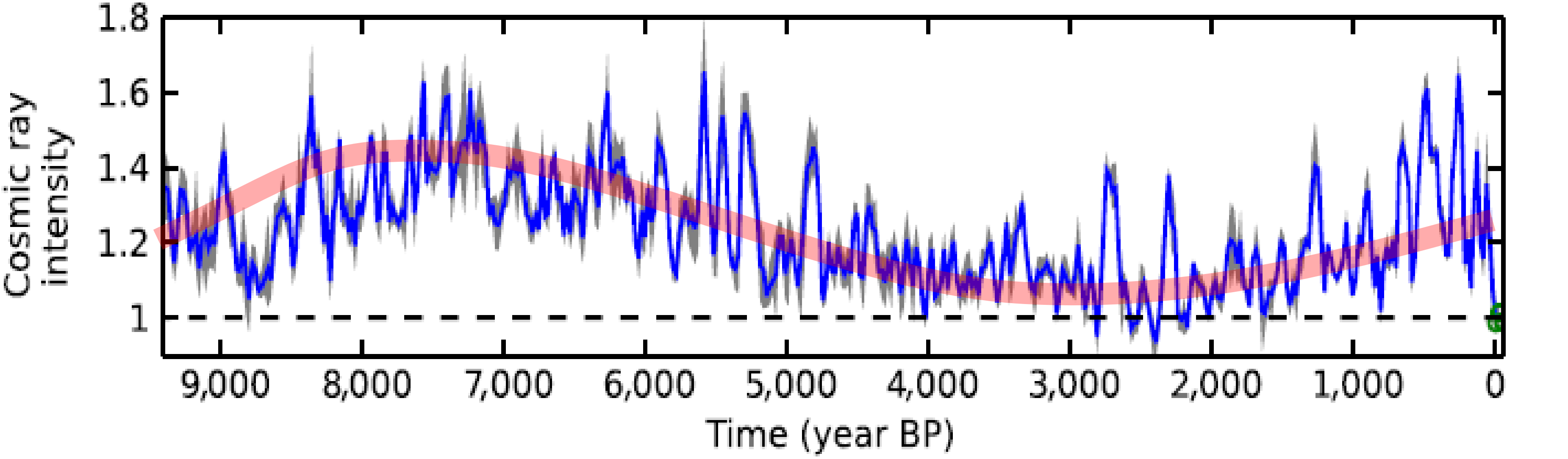
Common pattern
+ occasional offset



(Steinhilber et al., PNAS, 2012)

"Best" reconstruction of cosmic ray intensity obtained by Principal Component Analysis of all of the data available so far.

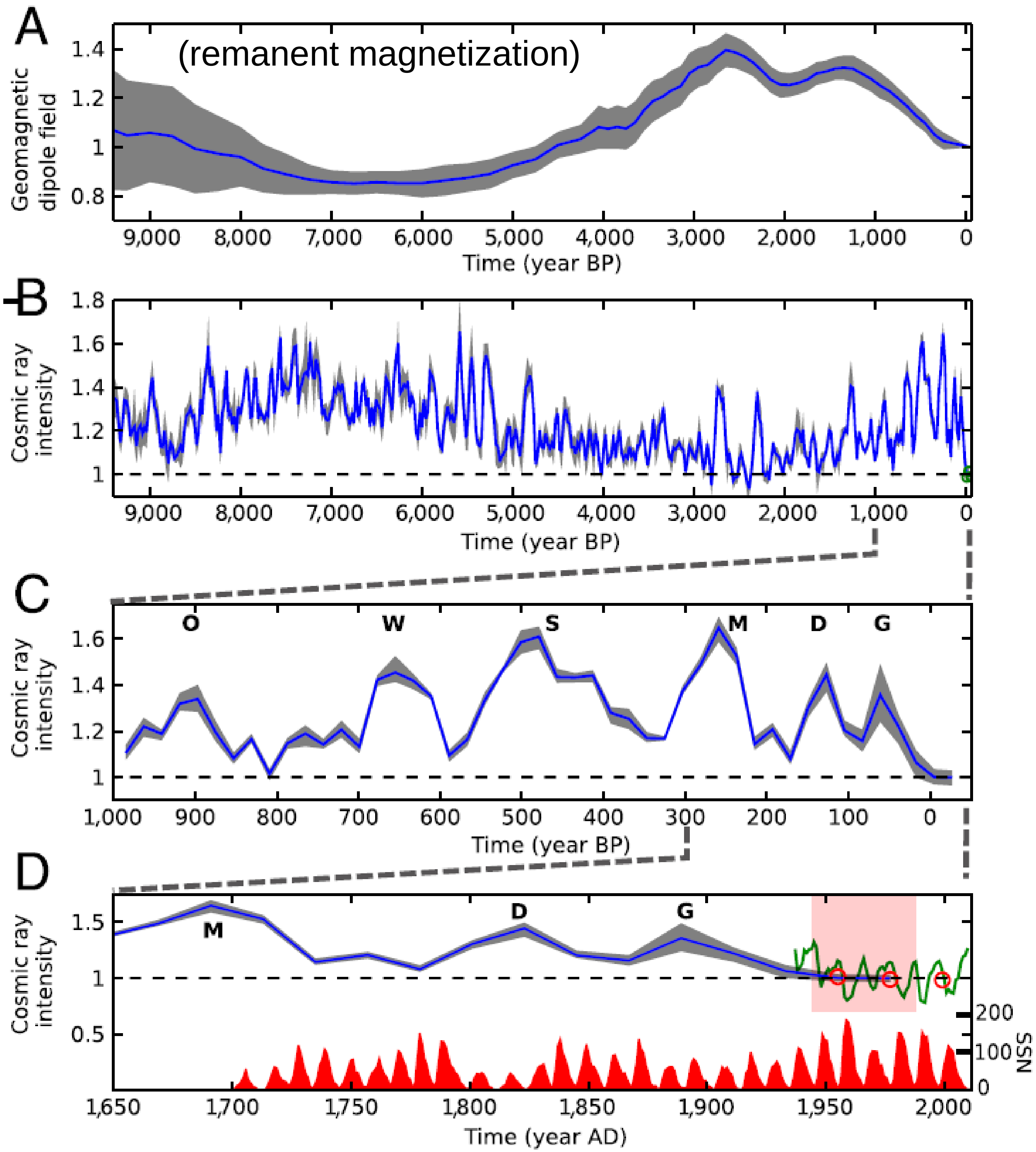
(Steinhilber et al., PNAS, 2012)



Red: Secular variation of geomagnetic field intensity

Residue: 100-300 yr variations of solar activity level

Uncertainty also comes from the secular variation of geomagnetic field intensity



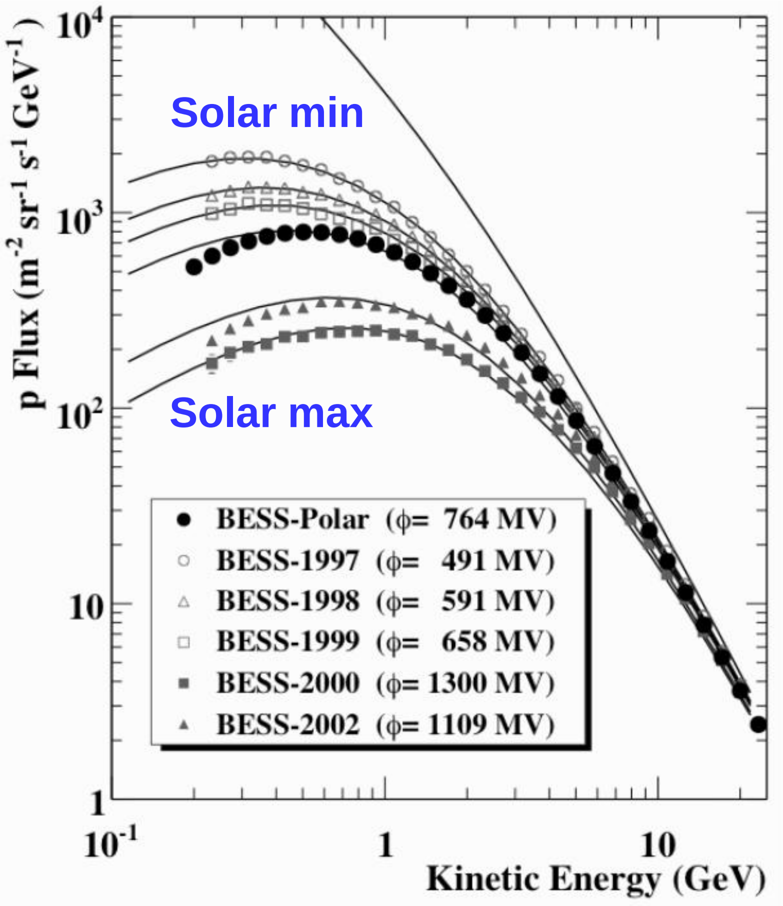
(Steinhilber et al., PNAS, 2012)

Cause of the uncertainties in the reconstructed incident GCR flux

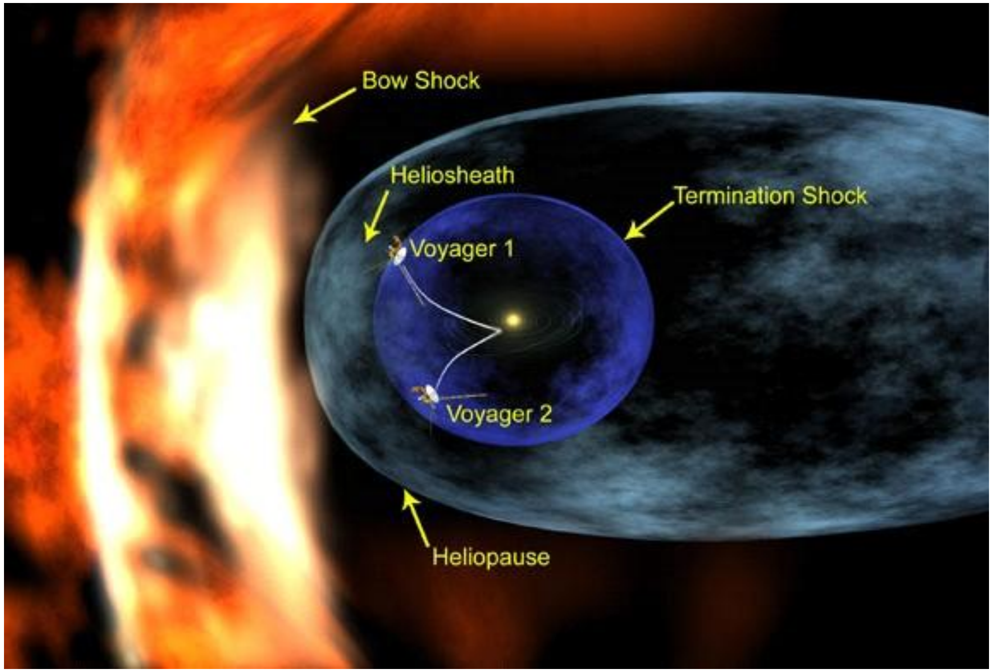
- Regional climate effect (geographical)
- Global climate effect (deduction of oceanic circulation, change in carbon cycle etc.)
- Uncertainty of reconstructed geomagnetic field intensity
- (Measurement errors)

Deriving the information of Galactic Cosmic Rays (GCRs) and solar activity

Solar modulation of Galactic Cosmic Rays (GCRs)

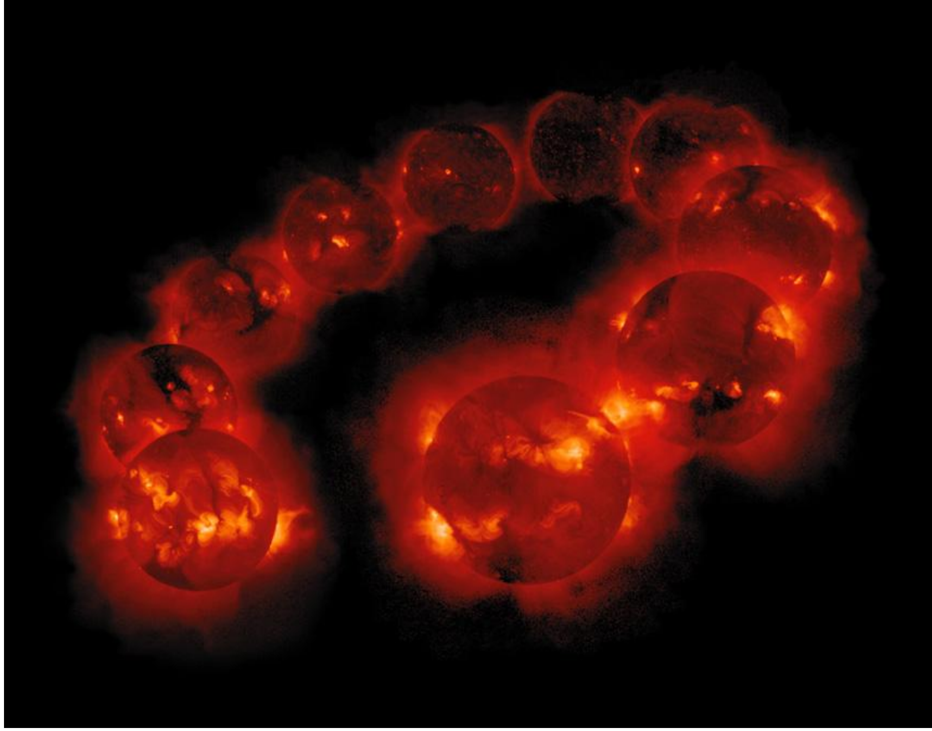


- Charged particles (mainly protons)
- Accelerated at supernova remnant

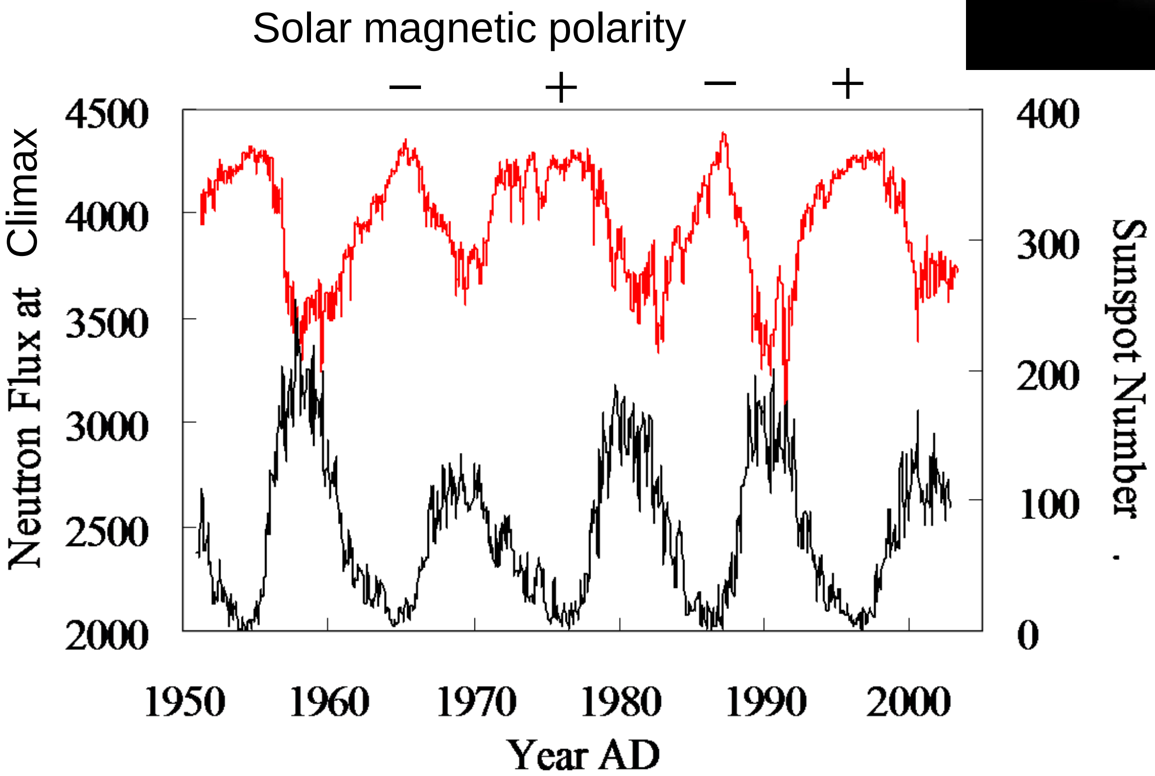


- **diffusion**
- **advection by solar wind**
- **$B \times \nabla B$ drift**

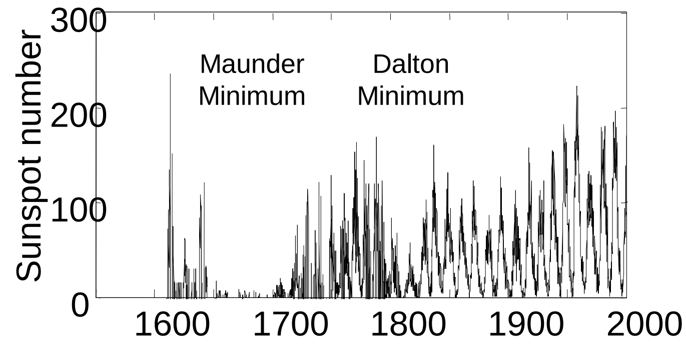
“11-year” cycles of solar activity and the flux of galactic cosmic rays



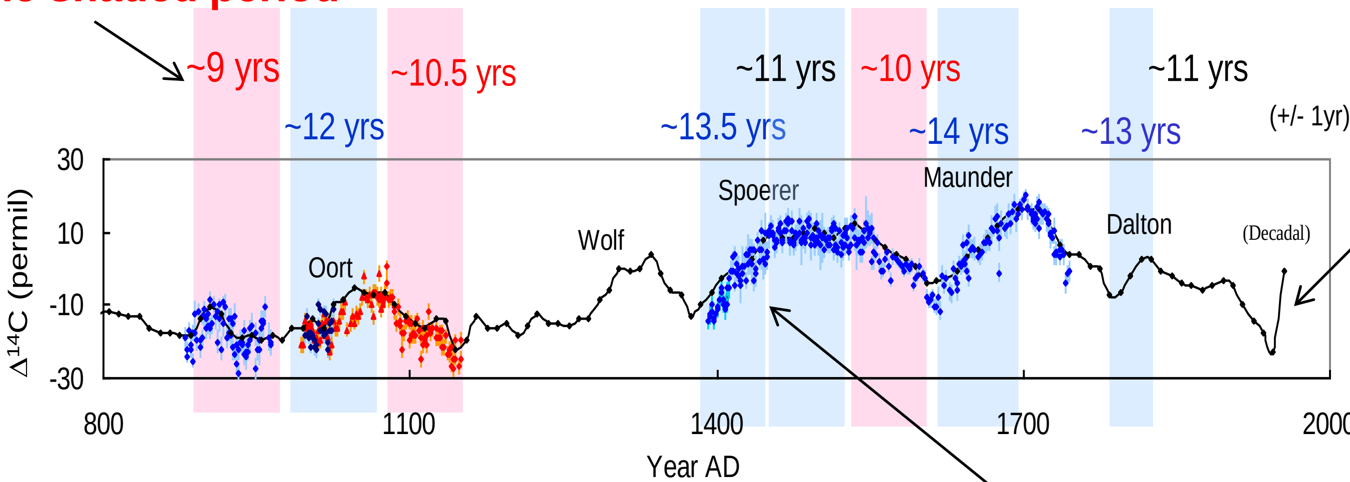
(SOHO)



Annually resolved measurement of carbon-14



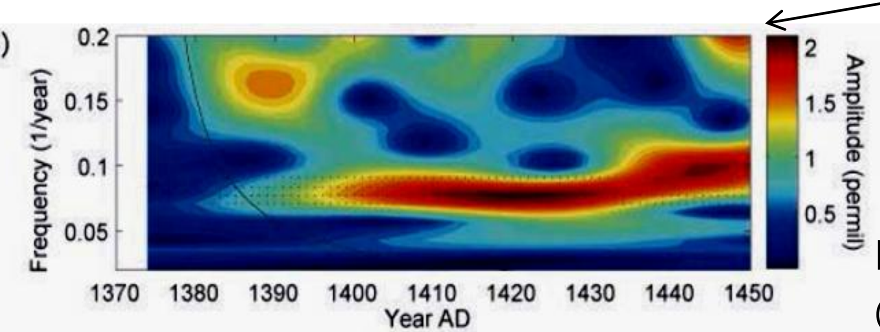
Actual mean length over the shaded period



Dacadal:
Stuiver et al., 1998

Annual:
Miyahara et al., 2004, 2006, 2007, 2008

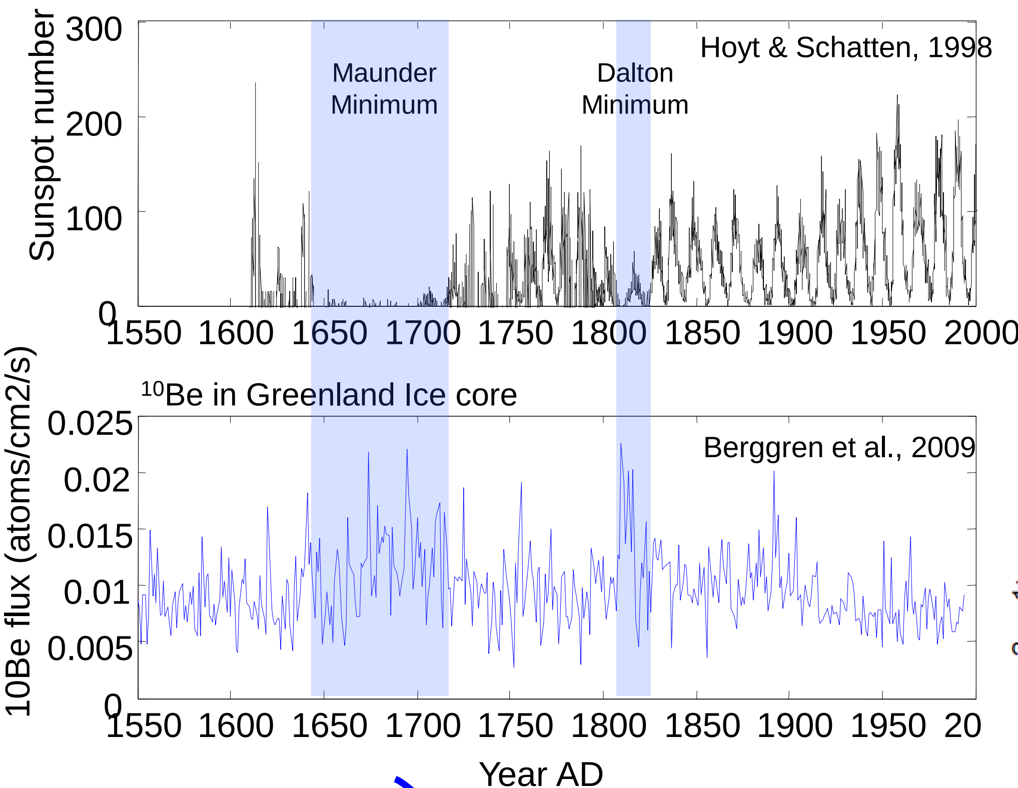
Carbon-14 in annual tree rings

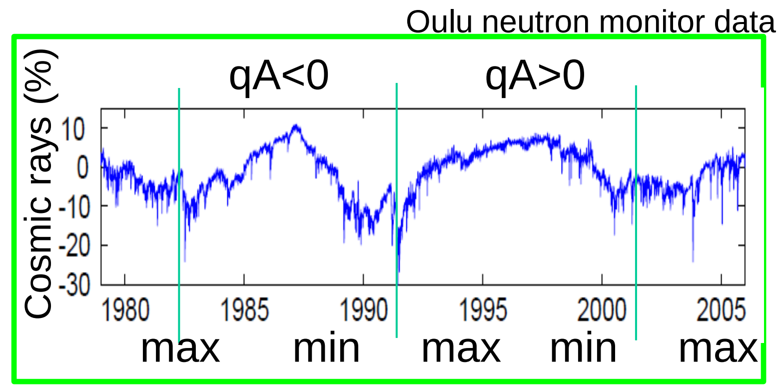


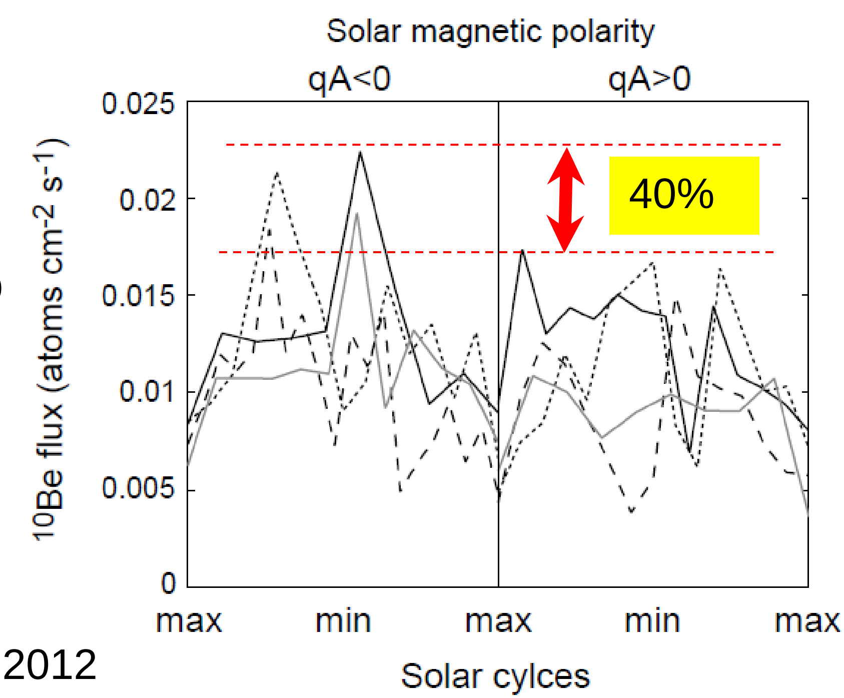
Example of spectral analysis (Wavelet transform)

(Miyahara et al., 2010)

Amplified “22-year” period in GCRs at the Maunder Minimum

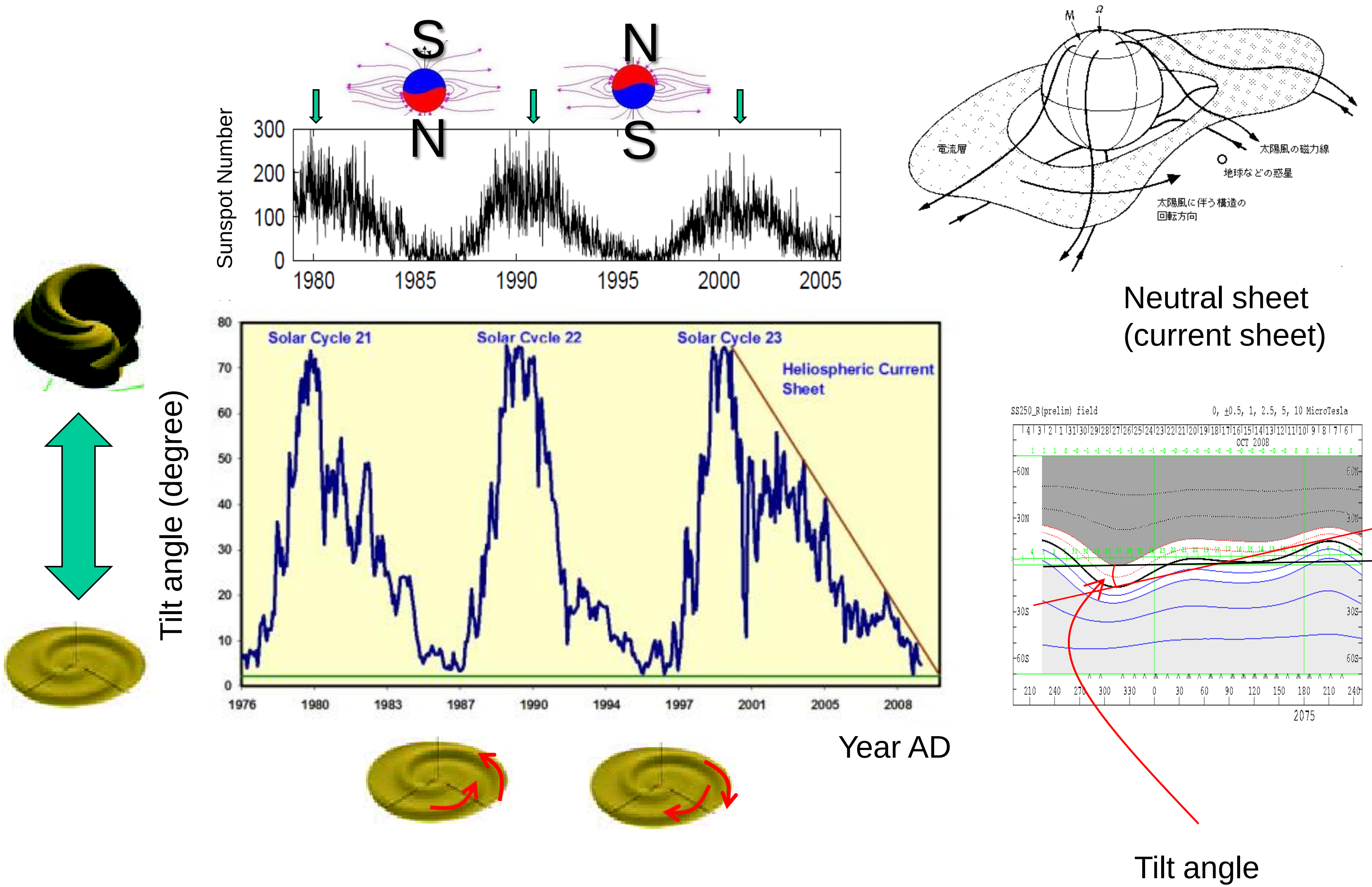






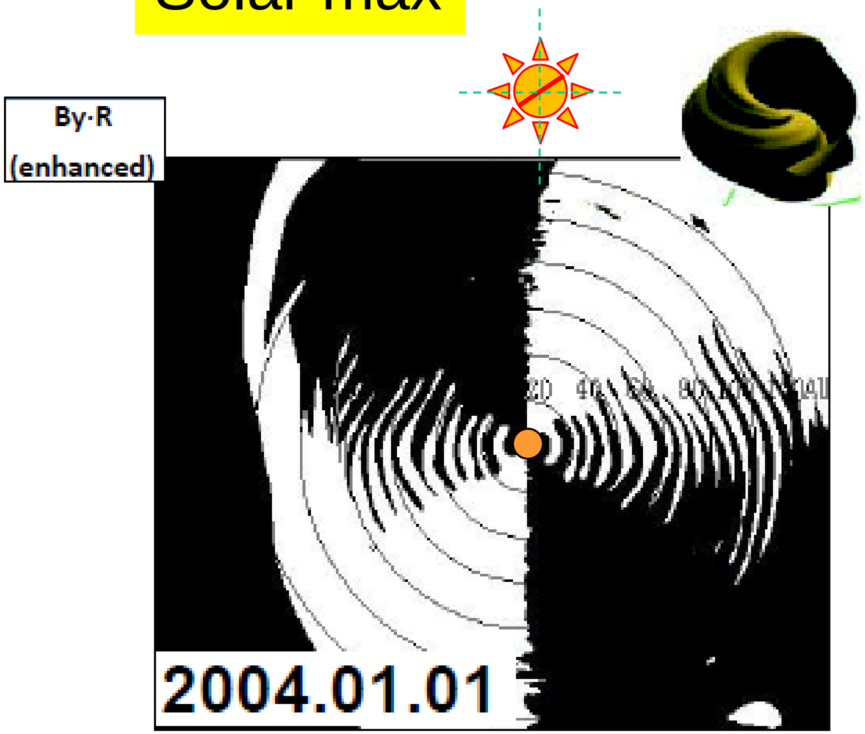
Kataoka, Miyahara et al., 2012

22-year period of solar magnetic polarity reversals

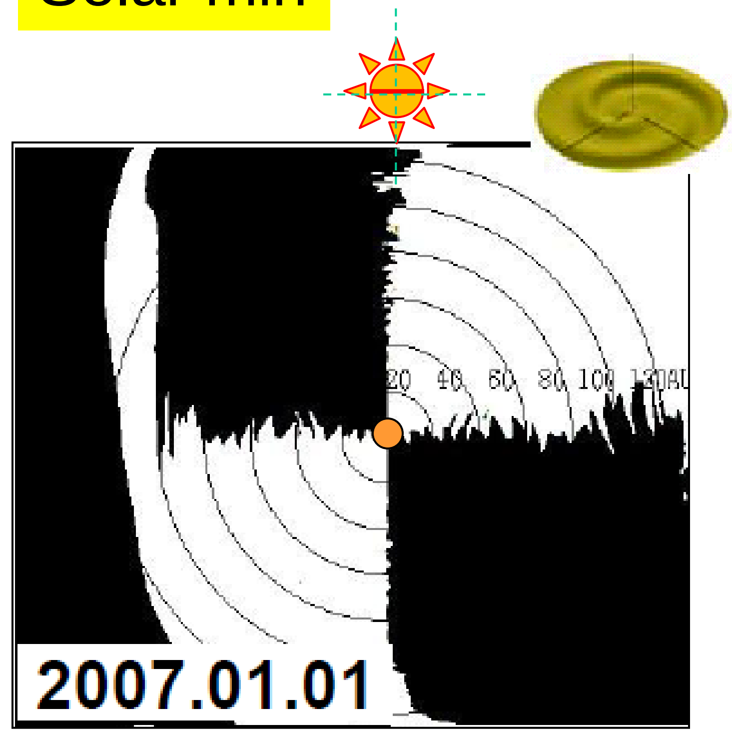


Heliospheric current sheet

Solar max



Solar min



(based on Washimi et al.)

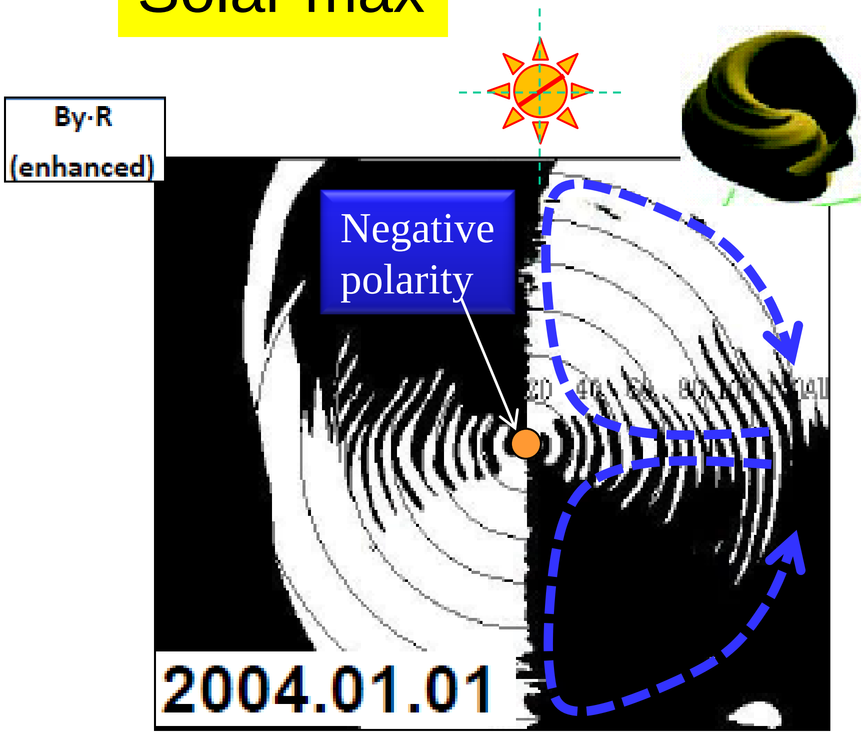
One wave = ~ 5AU

⇒100AU = 20 months

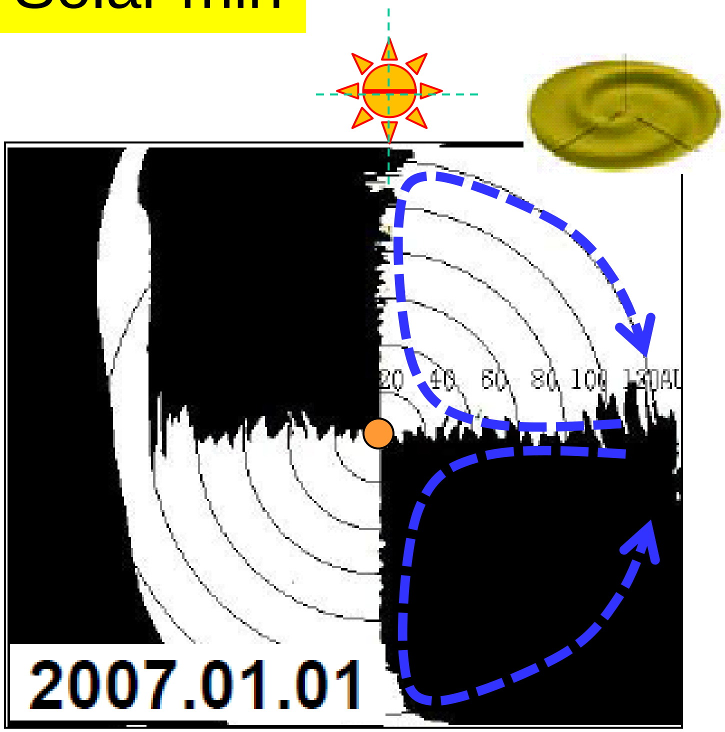
Drift effect of cosmic rays

※ B × ∇B drift

Solar max



Solar min

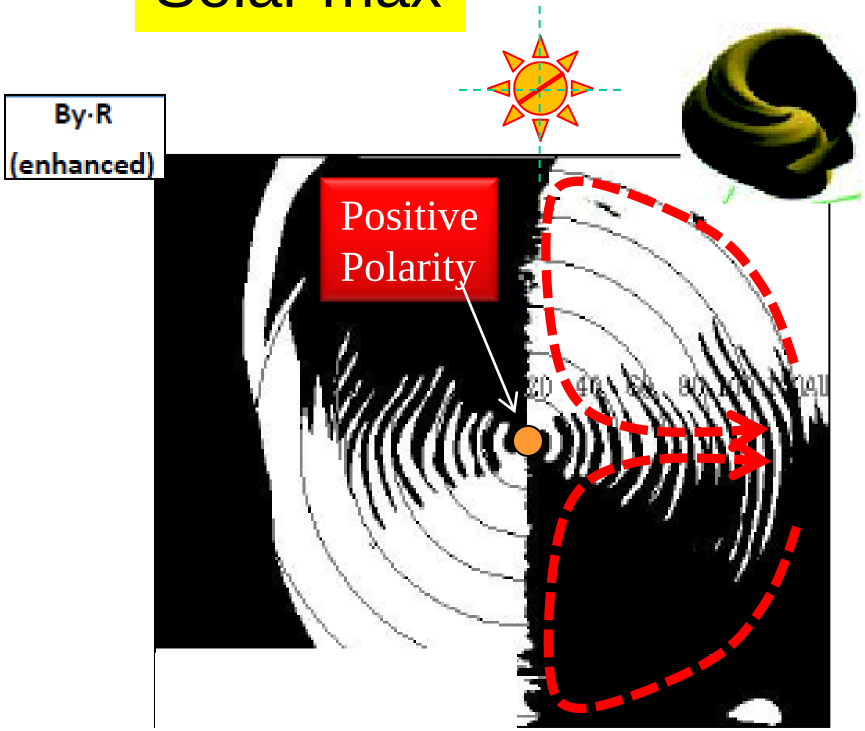


（based on Washimi et al.)

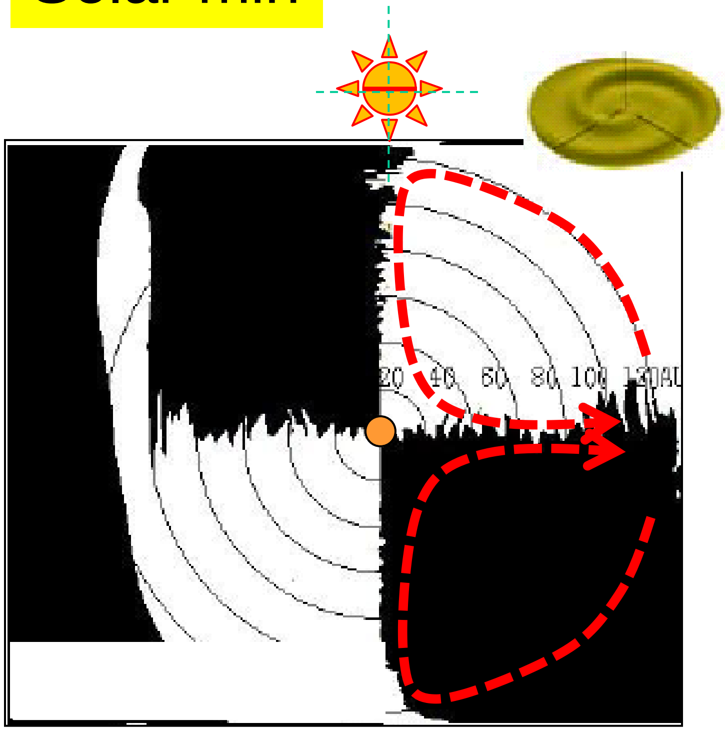
Drift effect of cosmic rays

※ B × ∇B drift

Solar max



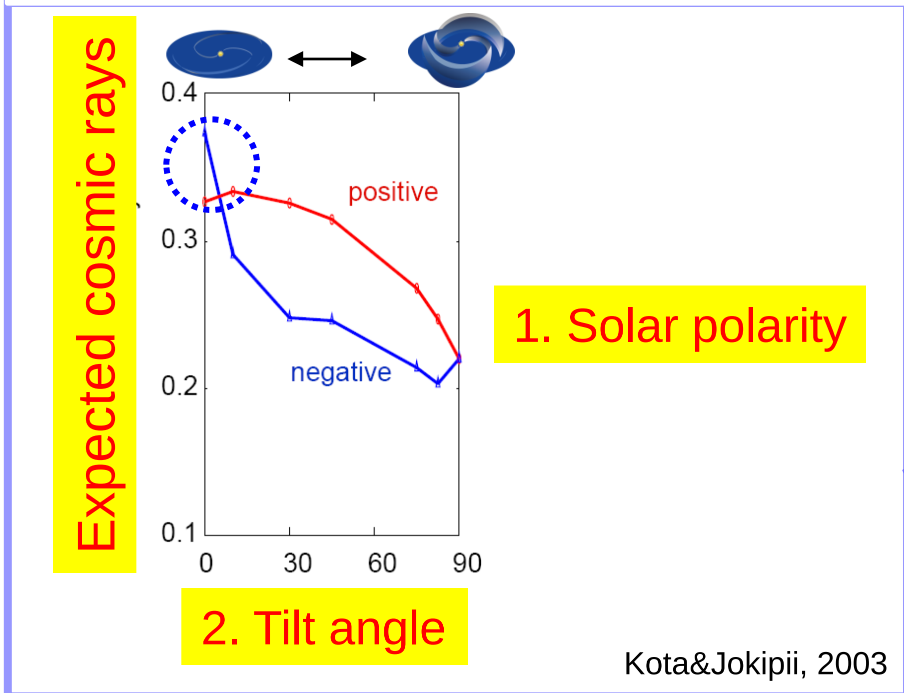
Solar min



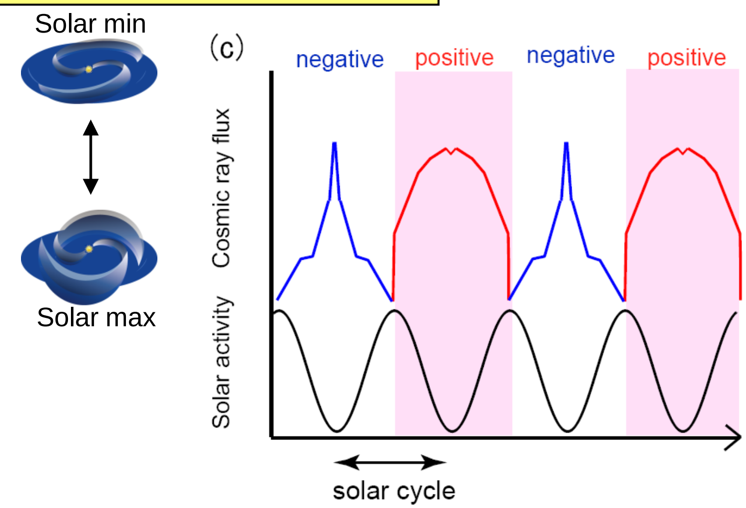
（based on Washimi et al.)

Tilt angle vs GCR flux

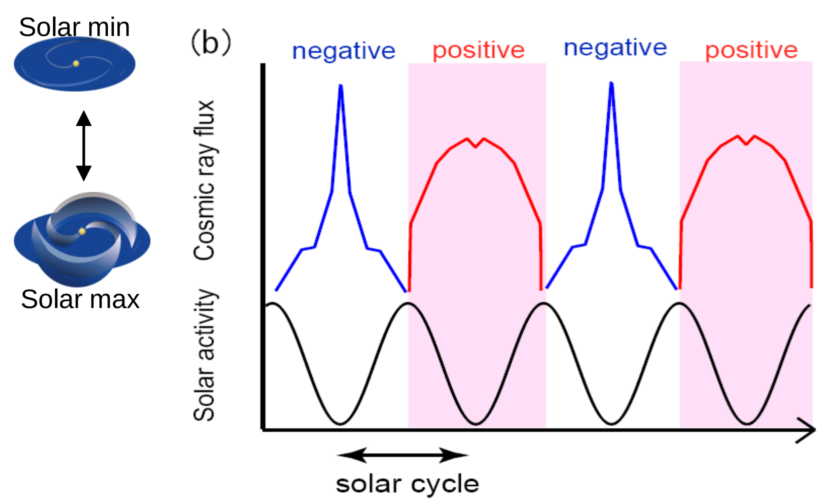
Miyahara et al., 2010



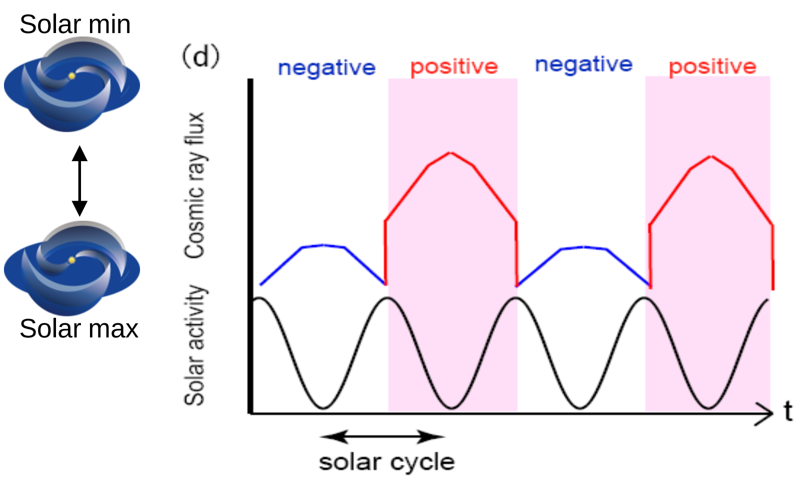
Modern: 5-75 degrees



If 0-75 degrees



If 30-75 degrees

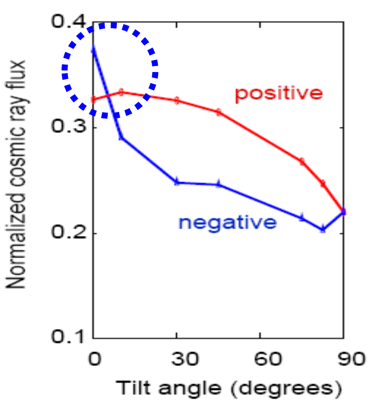


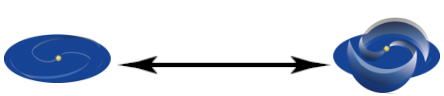
Possibly extremely flattened current sheet at the Maunder Minimum

Based on
Kota&Jokipii, 1983; 2003

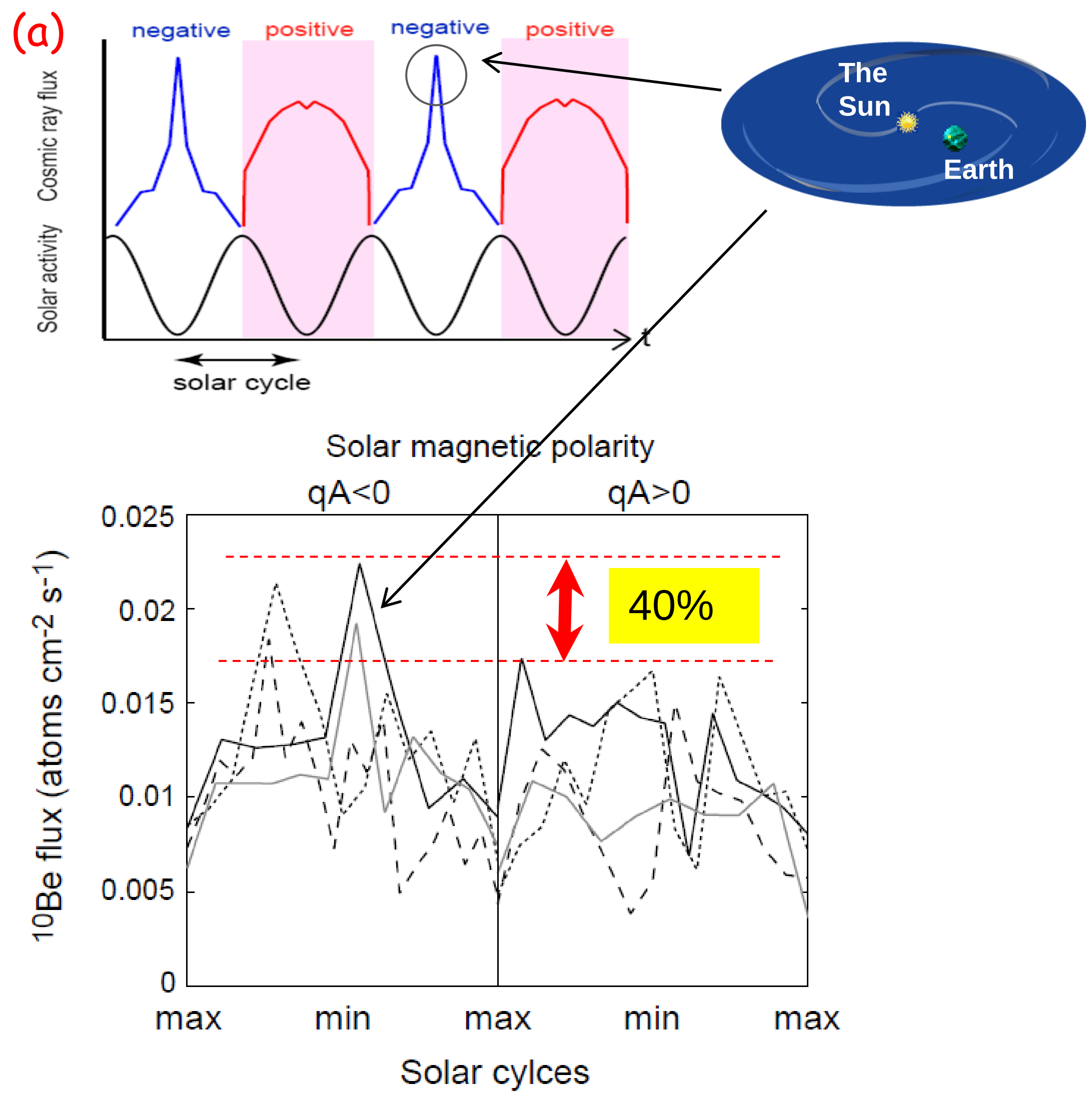
(a) 0 deg. at cycle min

(b) 5 degs. at cycle min





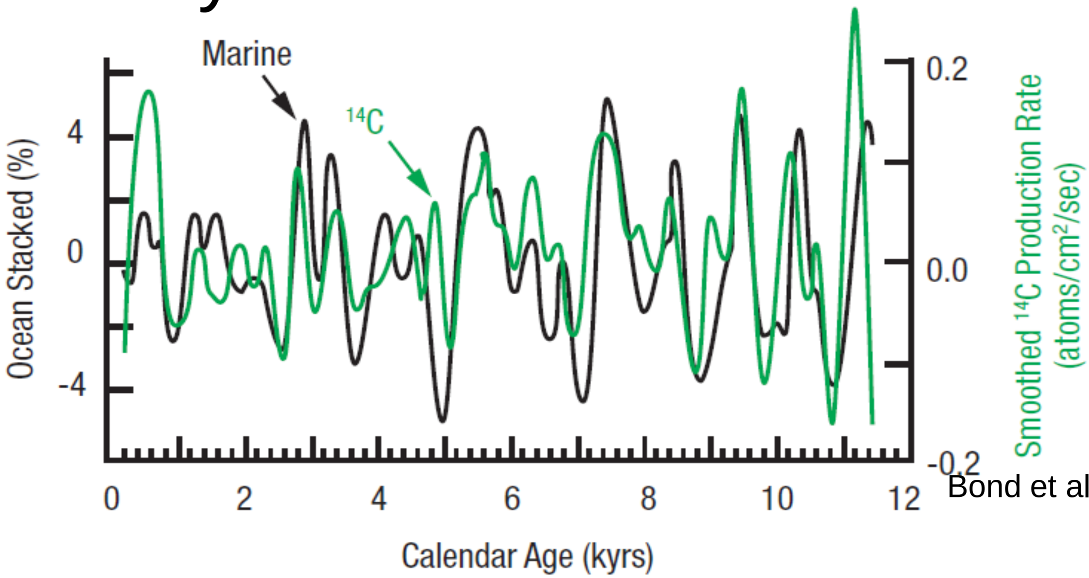
Heliospheric
Magnetic field



Kataoka, Miyahara et al., 2012

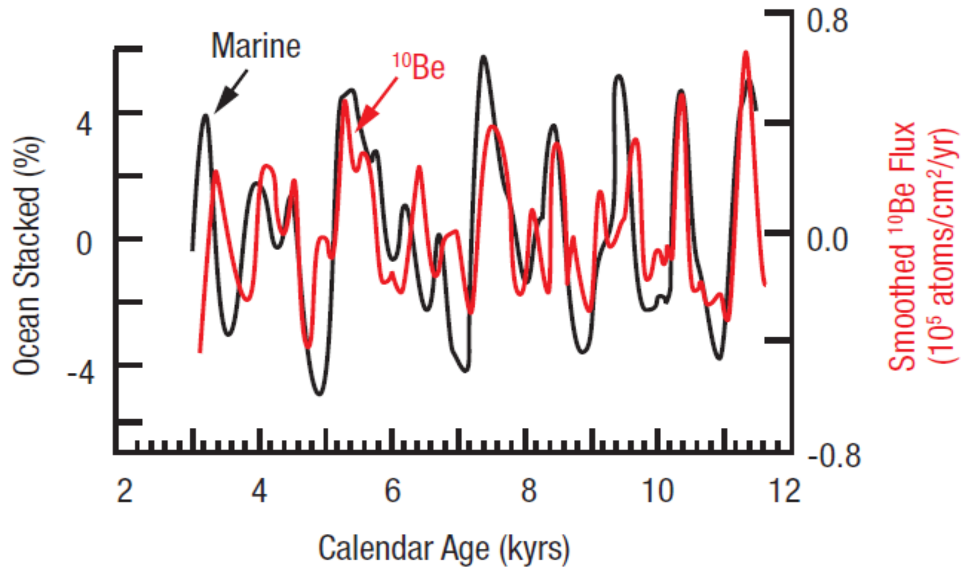
Detecting the GCR impact on climate variations

Evidence from the past:
Influence of Solar activity on climate variations



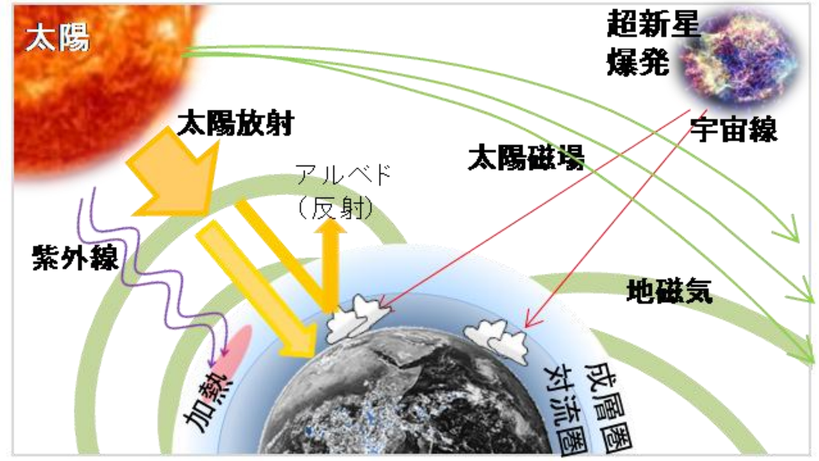
Bond et al., 2001

Ice Rafted Debris



Bond et al., 2001

Possible mechanisms of solar influence on climate change



Solar activity

- Solar irradiance
  Total / **UV**
  ～0.1%
  - (Total) → Climate change
  - (UV) → Promotion of chemical reaction in the stratosphere
    Ozone formation
    Ozone heating
    → Climate change
- Solar wind
  Particles
  (proton, etc.)
  → Promotion of chemical reaction in the mesosphere
  NOx formation
  Ozone destruction
  → Climate change
- Solar/heliospheric magnetic field
  → Attenuation of **cosmic rays**
  unknown ～20%
  → Nucleation / Coagulation
  → Cloud properties
  → Climate change

Climate change

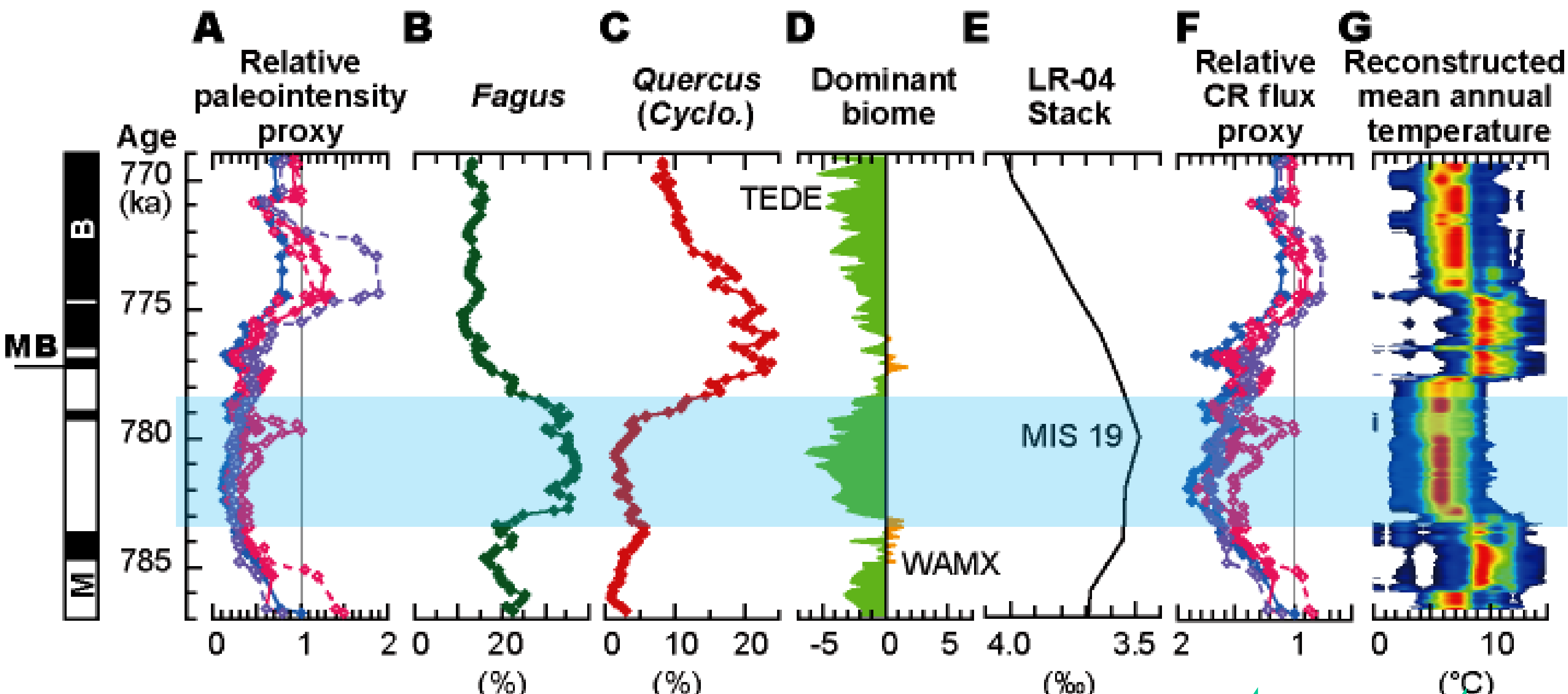
How to detect the cosmic ray effect?

- Astronomical phenomena
  - Crossing the galactic arms (Shaviv, 2003)
  - Vertical oscillation of solar system in the galaxy (Medvedev & Melott, 2007)
- Geomagnetic Excursions / M-B Geomagnetic Reversal
  - Some evidence of cooling from low latitude region (Kitaba et al., 2010; 2012)
- Forbush Decrease (daily)
  - Positive results (Kniveton , 2004; Svensmark, 2009; Kataoka 2010)
  - Negative results (Sloan & Wolfendale, 2008; Kristjánsson+, 2008; Calogovic+, 2010)
- Maunder Minimum/Medieval Period
  - unique periodicities ~22-years in cosmic rays (Miyahara+, 2008; Yamaguchi+, 2010)
- Maunder-like period during the Glacier period
  - Under much more ice forming condensation nuclei (suggested by Tinsley, 2009)
- Nuclear bomb test/nuclear power plant accident
  - No effect found (Erlykin et al., 2009)

How to detect the cosmic ray effect?

Evidence from the Matsuyama-Burunhes Geomagnetic reversal

Kitaba et al., PNAS, 2012



40%↓

TEDE: 冷温帯落葉広葉樹林
WAMX: 暖温帯常緑広葉樹林

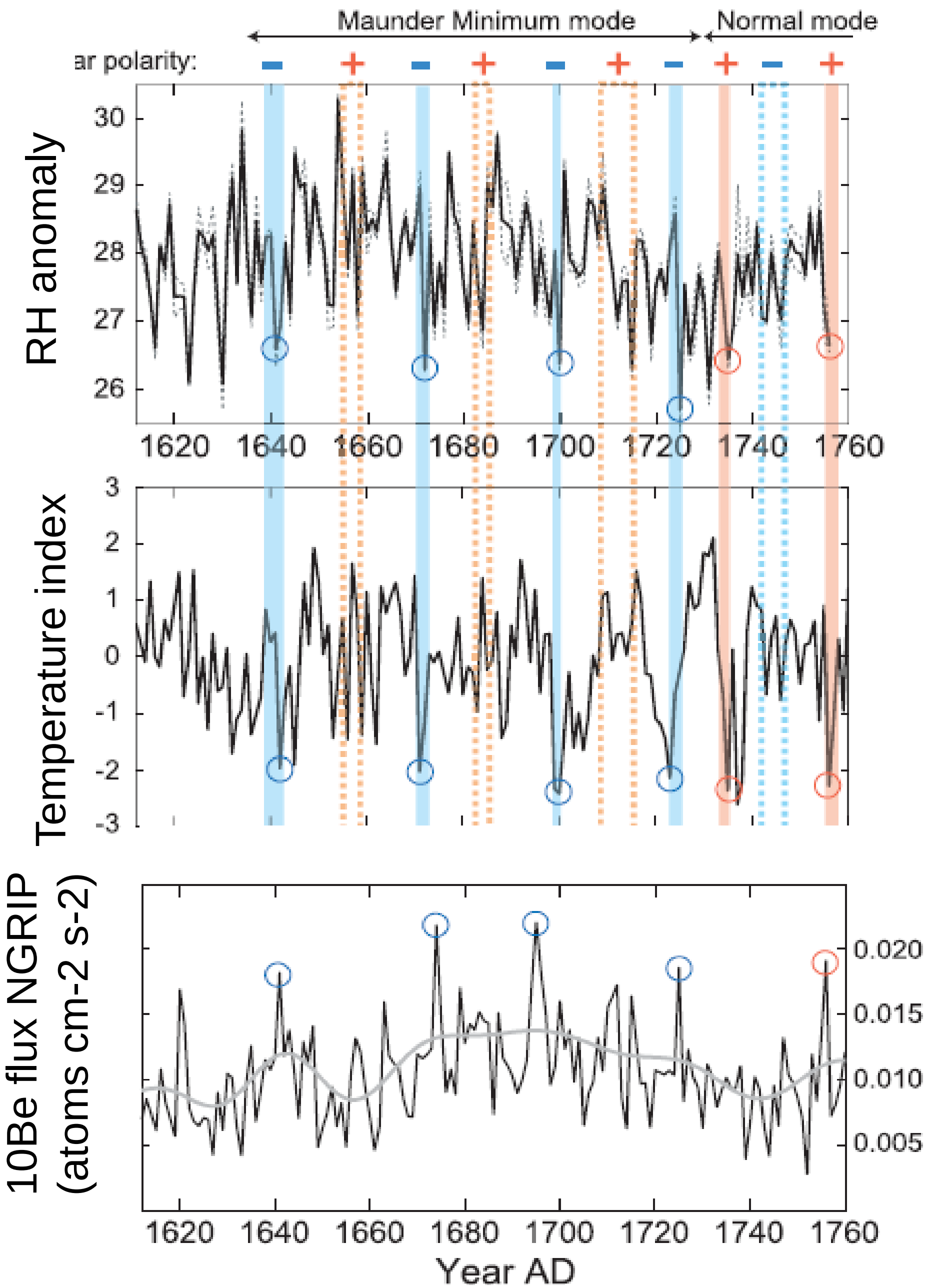
50%↑

1-4℃↓

A: Paleo-geomagnetic field intensity anomaly (Hyodo et al., 2006)
F: Calculated galactic cosmic ray intensity (inverted)
G: Reconstructed annual mean temperature around Osaka (Kitaba, 2010, Kitaba et al., 2012)

Climate response to cosmic-ray spikes during the Maunder Minimum

Yamaguchi, Miyahara et al., PNAS, 2010



Dry

Humidity in Japan around June

Humid

Warm

Greenland winter temperature

Cold

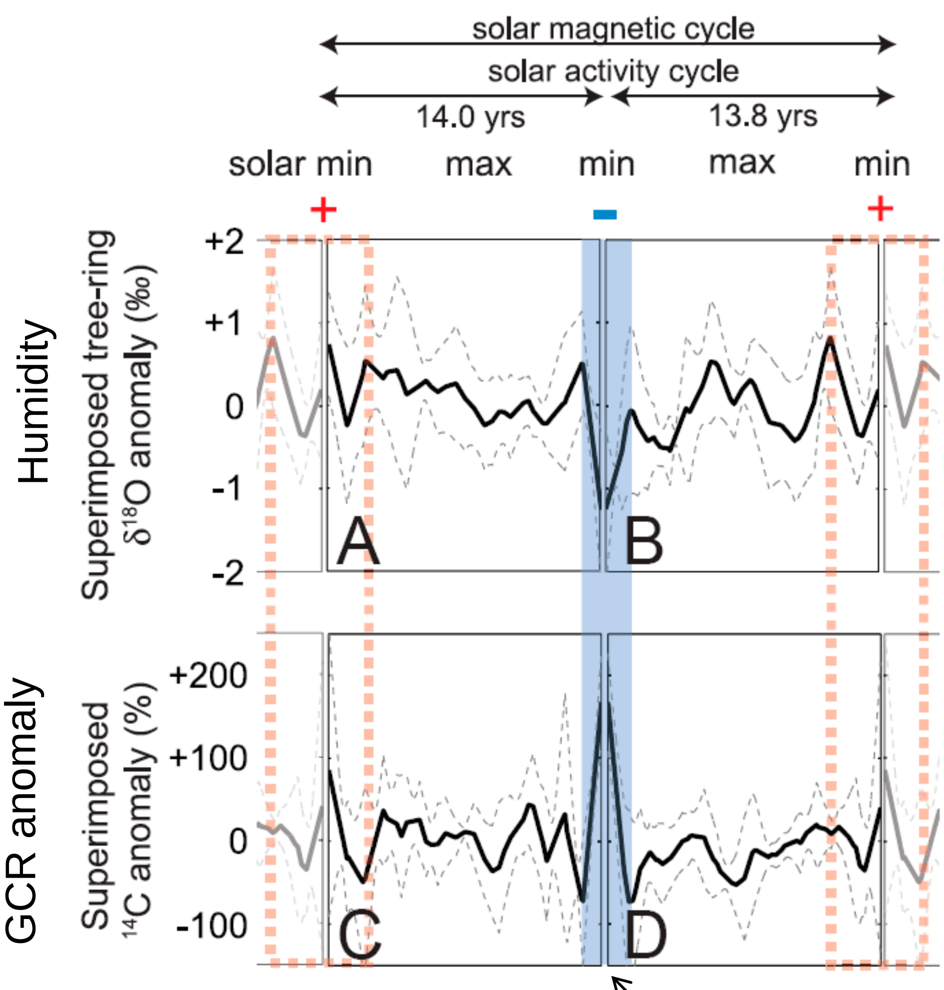
High

GCR flux (with dating errors of 3-5yrs)
(Berggren et al., 2009)

Low

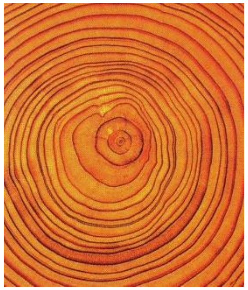
These spikes can be utilized to trace GCR effect on ***climate system***

Superposition of four 1-year spikes for ^{14}C (GCR) and ^{18}O (climate)



~4 sigma

Oxygen-18/Oxgen-16



Carbon-14/Carbon-12

(shifted by 1yr for the delay in carbon cycle)

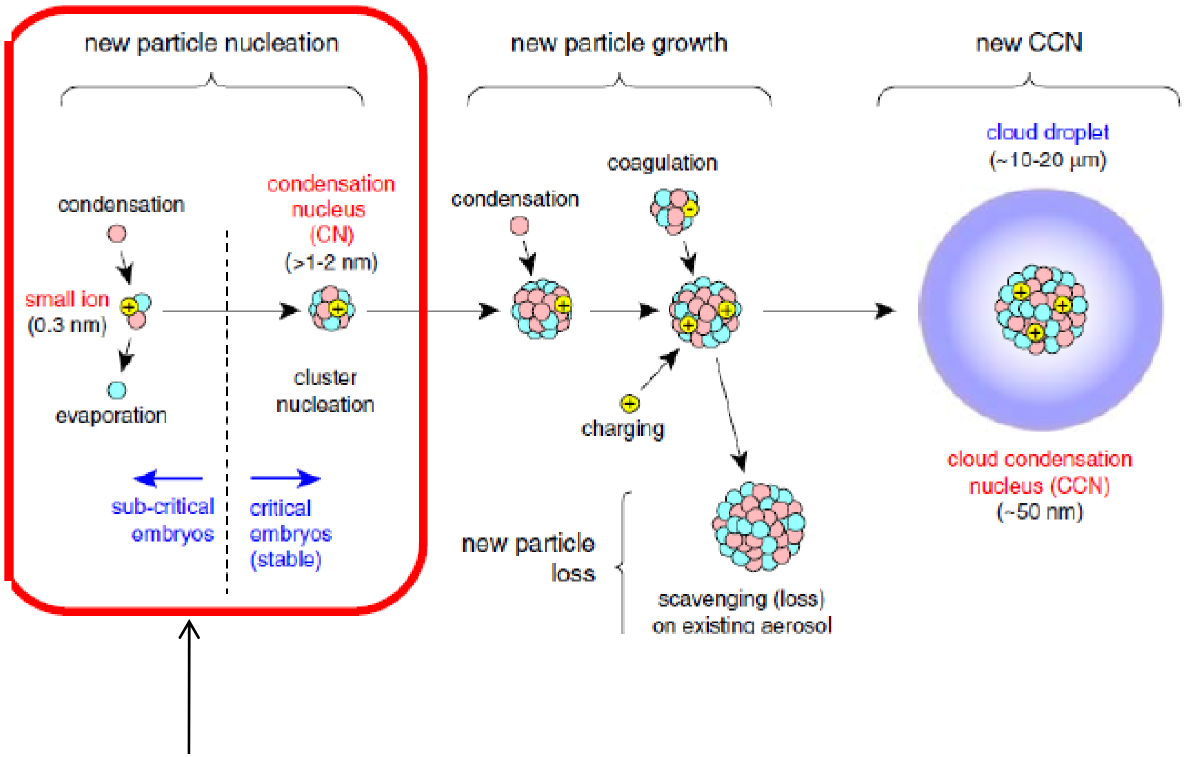
Yamaguchi, Miyahara et al., PNAS, 2010

Climate system responds to GCR with no time lag

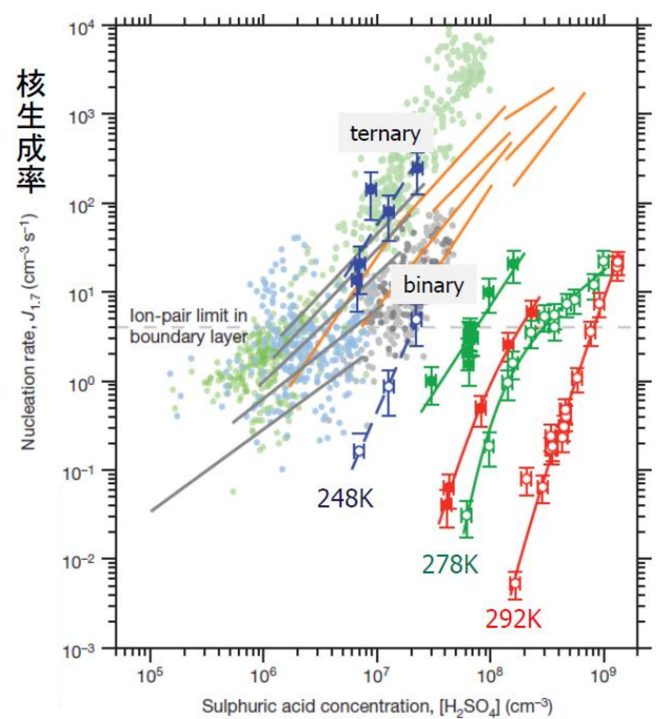
How GCRs affect climate system?

- Possible impact of GCRs on tropical cloud activities

Important findings of CLOUD experiment at CERN



Kirkby et al., Nature 2011

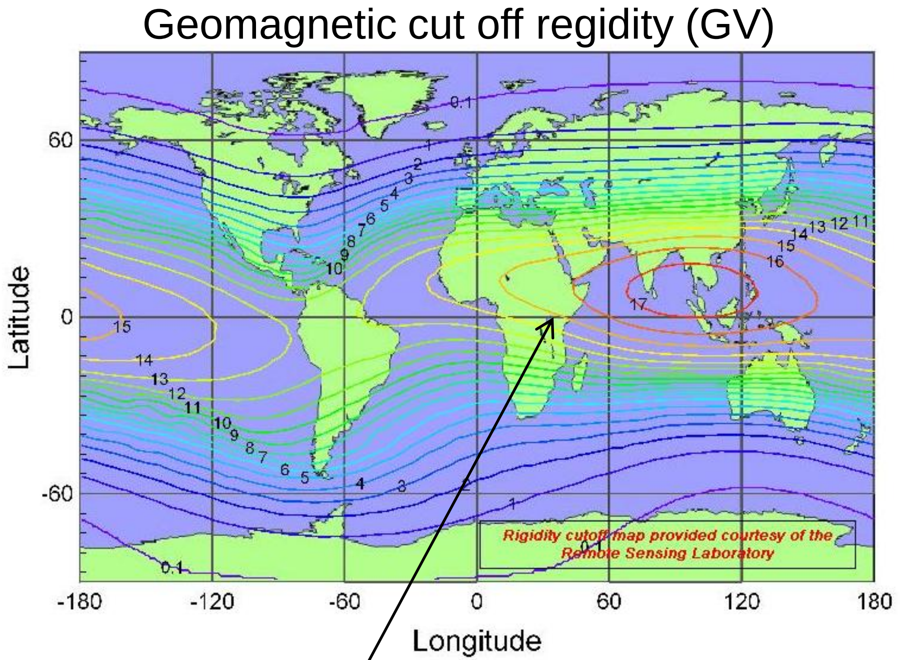


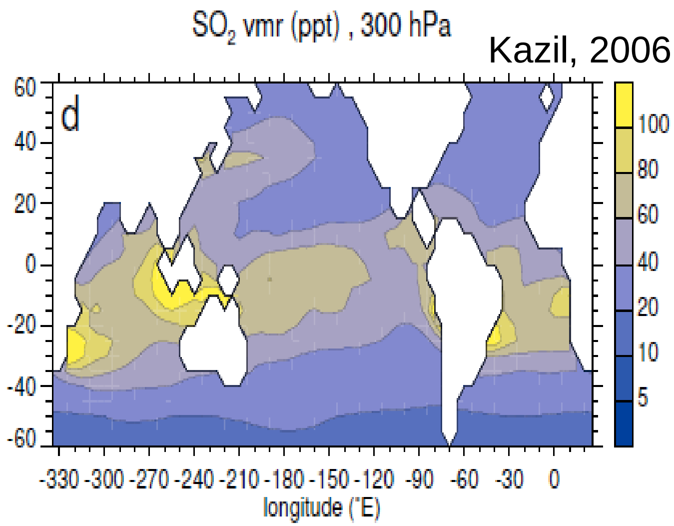
CERN experiment finds

- Nucleation is more efficient at lower temperature (correspond to middle to upper troposphere)
- NH_3 in addition to SO_2 is needed for efficient nucleation

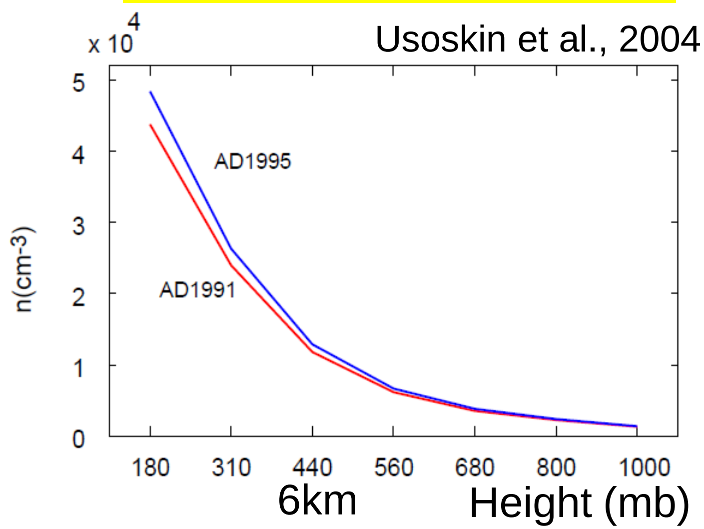
Where can be the most sensitive place?

- Sufficient water vapor & SO_2
- Low temperature
- Sufficient ionization

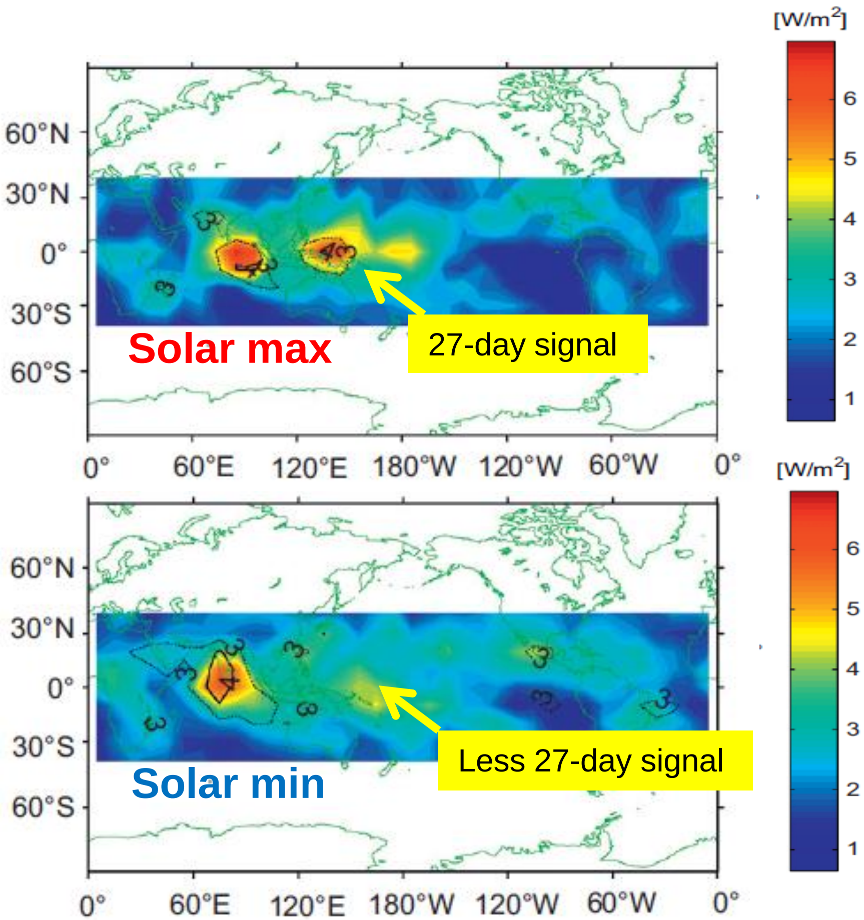


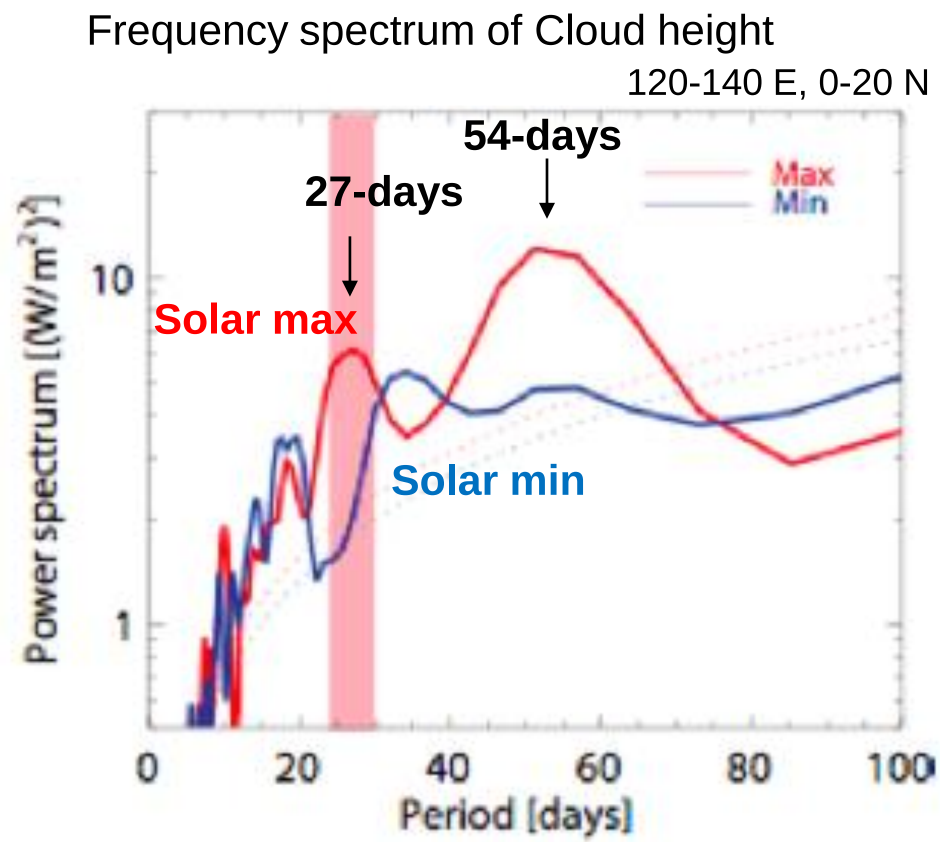


Ionization by GCR at 15GV



Solar rotational period in tropical cloud activity





Takahashi et al., ACP, 2010
Hong, Miyahara et al., JASTP, 2010

※Monthly-scale cloud activity is known to present at Equatorial region (Madden-Julian Oscillation) but the origin of the cyclicity is unknown.

Solar rotational period in lightning activity

Sato et al., 2005

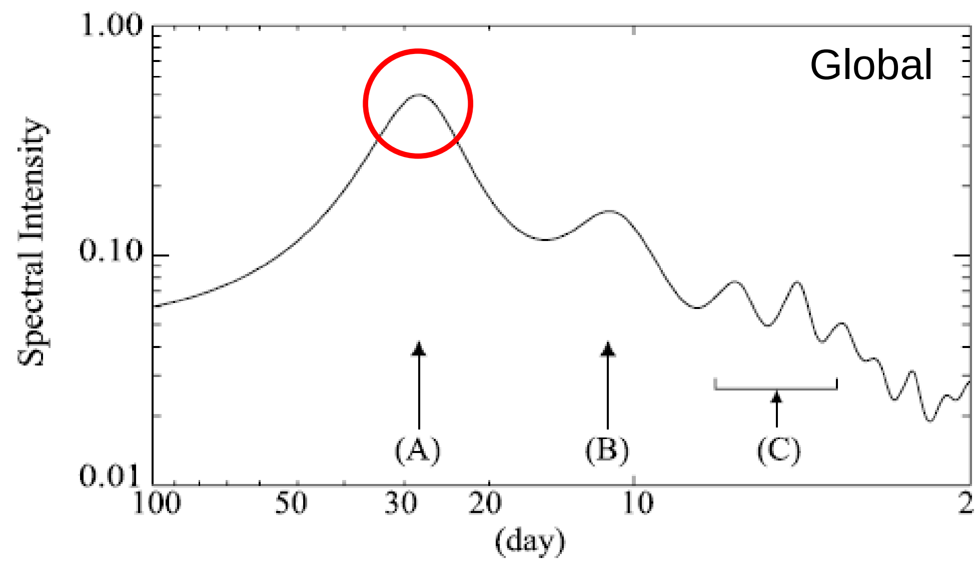


Figure 2. Plot of SR power spectrum. Spectral peaks (A), (B), and (C) correspond to the periods of 28, 12, and ~4–6 days, respectively.

Muraki et al., 2004

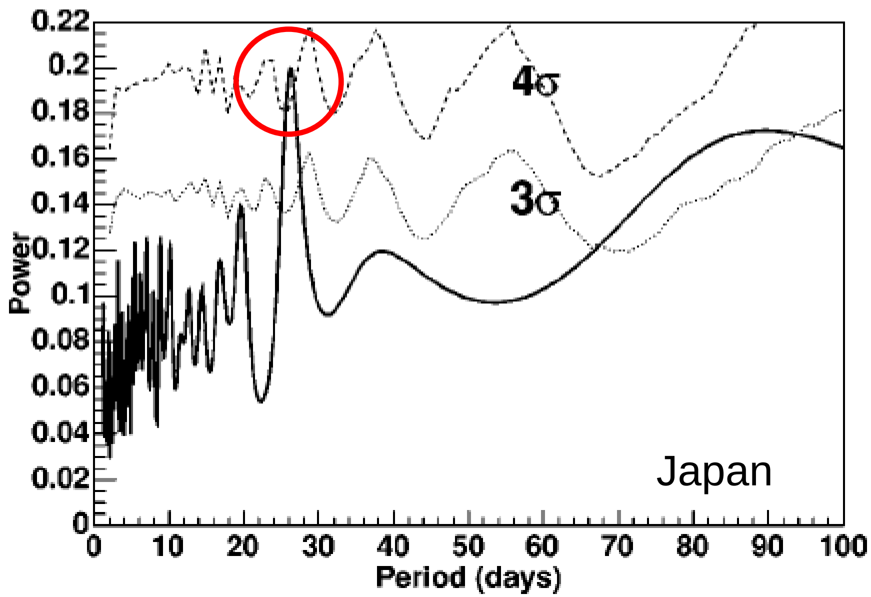
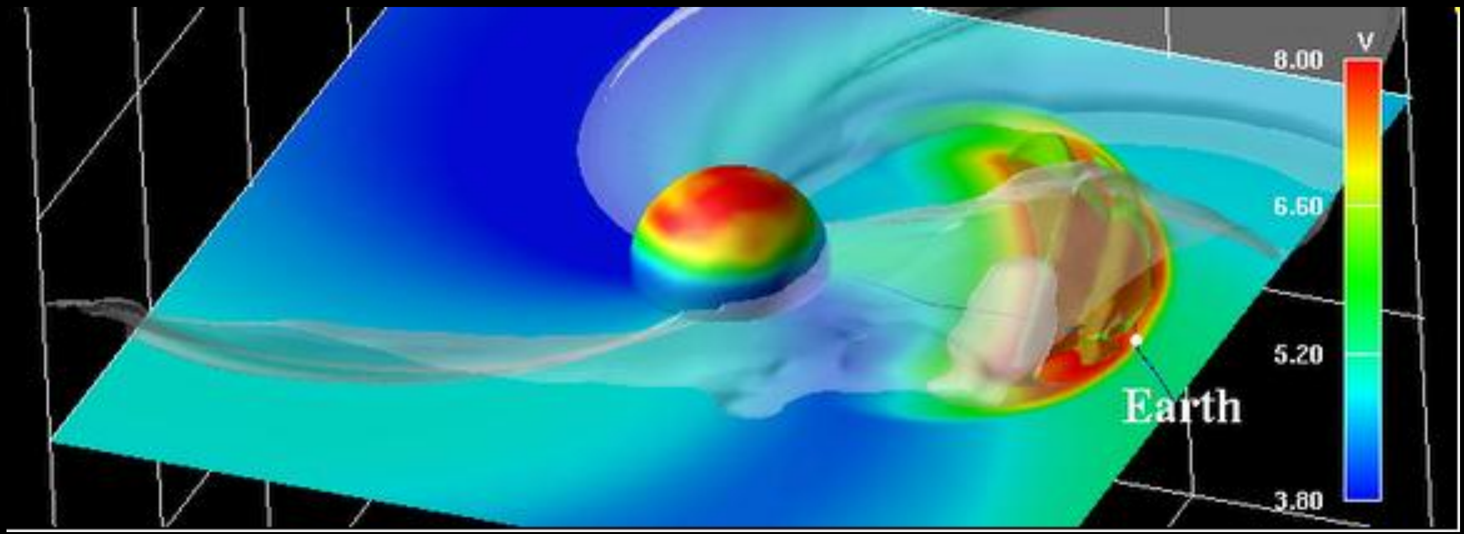
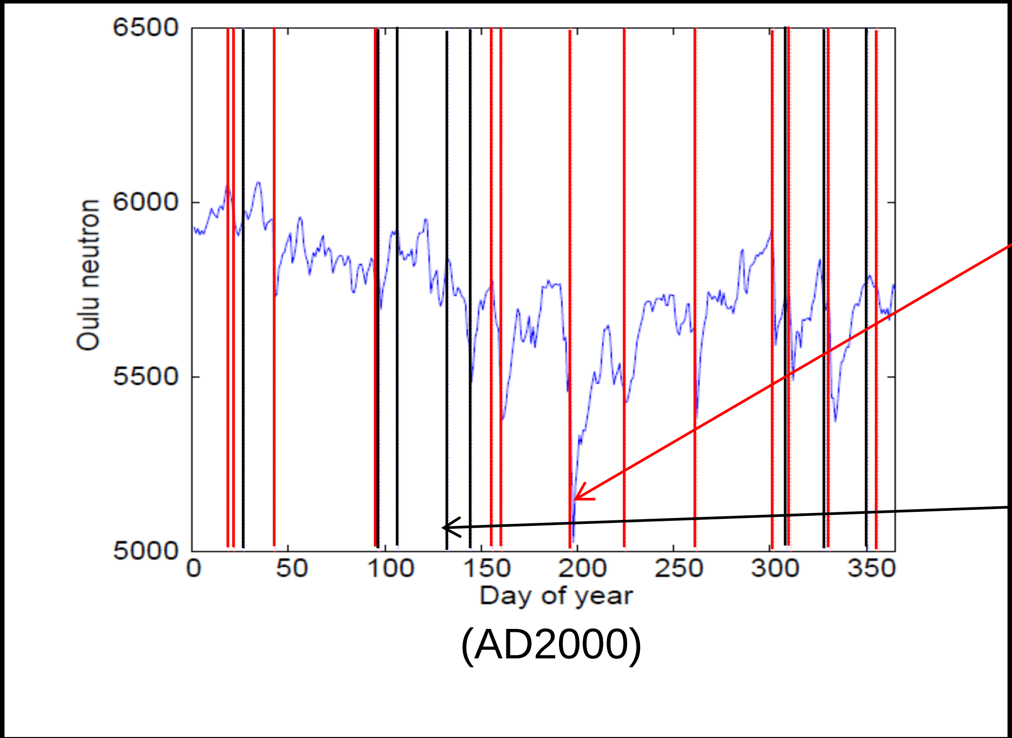


FIG. 12. A maximum entropy analysis of periodicities in the thunderstorm-related events shown in Fig. 11, showing the presence of a 26-day period (line). The dashed line and dotted line correspond to 4σ and 3σ fluctuations expected for white noise in each period, respectively.

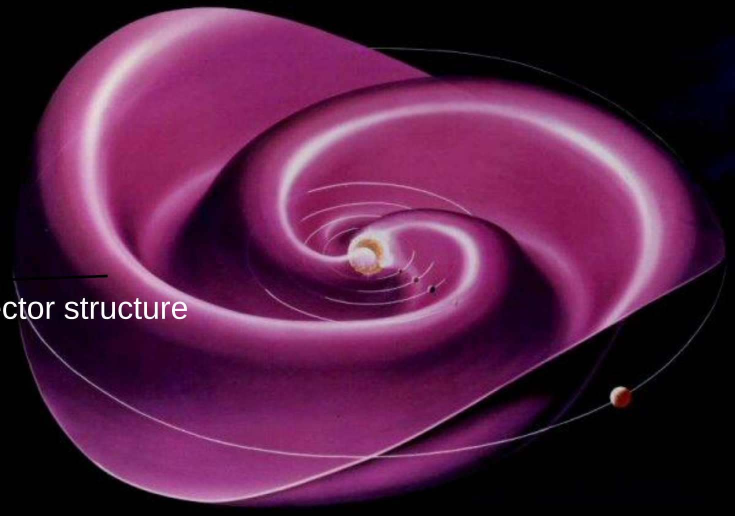
Solar flare and Forbush decrease

Kataoka 2009

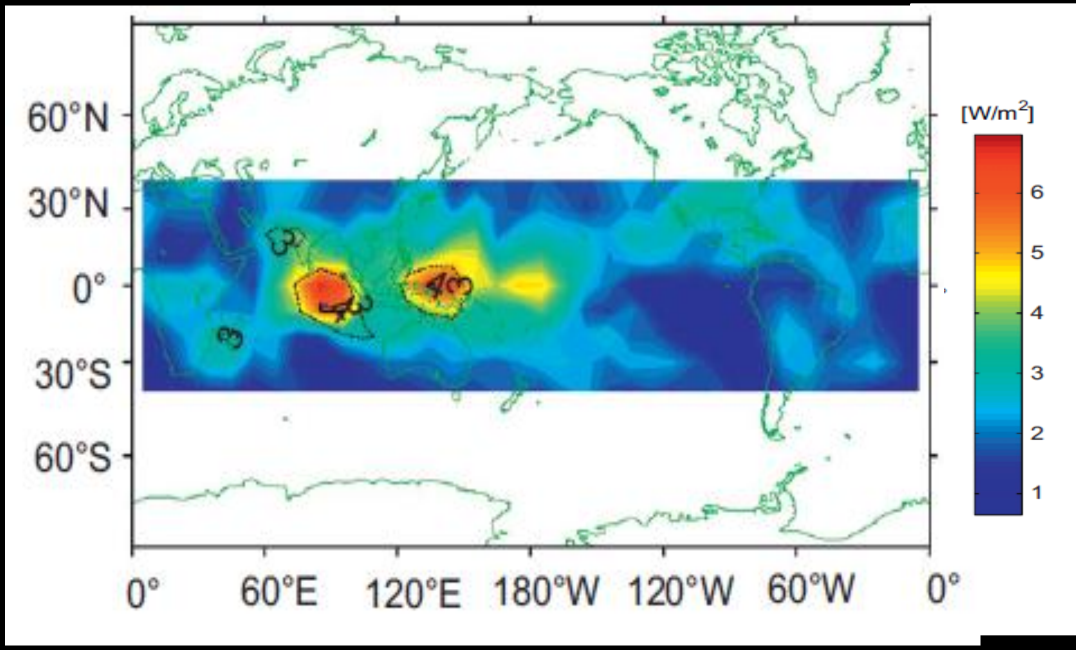




Forbush decreases



Next step:
Observational study on the GCR effects on cloud microphysics



Future prospects

- Trace the impact of GCR on equatorial cloud activities and its propagation by utilizing the 27-day GCR variations
- Improve the accuracy of climate and weather forecast
- Search for the impact of astrospheres on the climate condition of extra-solar planets
- Reinterpretation of the history of the Earth