



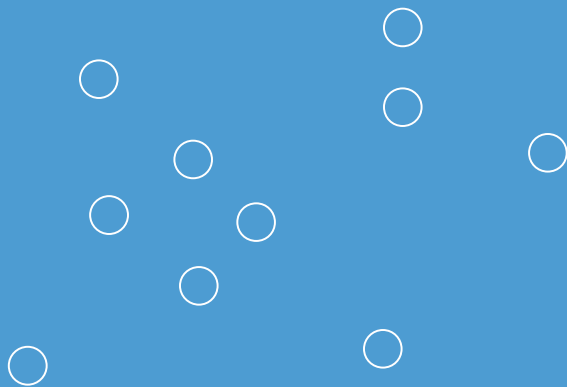
NCCR CLIMATE
Swiss Climate Research



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

eawag
aquatic research **ooo**

Reconstruction of solar magnetic activity based on cosmogenic radionuclides



Friedhelm Steinhilber
Group Jürg Beer

SVECSE 2008 – Bozeman / Montana

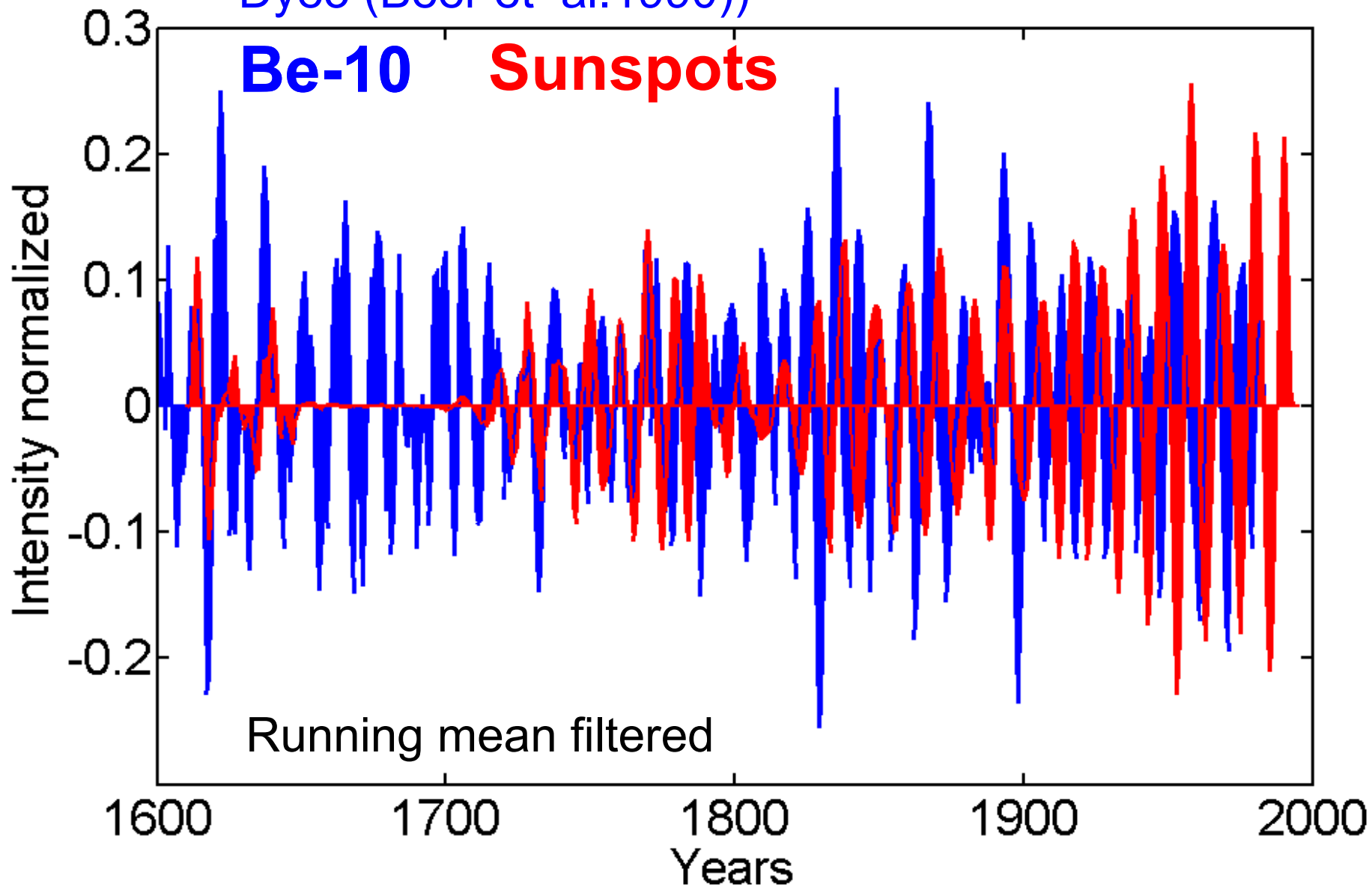
Research questions

- How strongly does the Sun influence the global climate?
- What was the solar irradiance during grand solar minima (like Maunder minimum) compared to today?
- What can cosmogenic radionuclides tell about past solar magnetic activity?
- What is the link between radionuclides and solar irradiance?

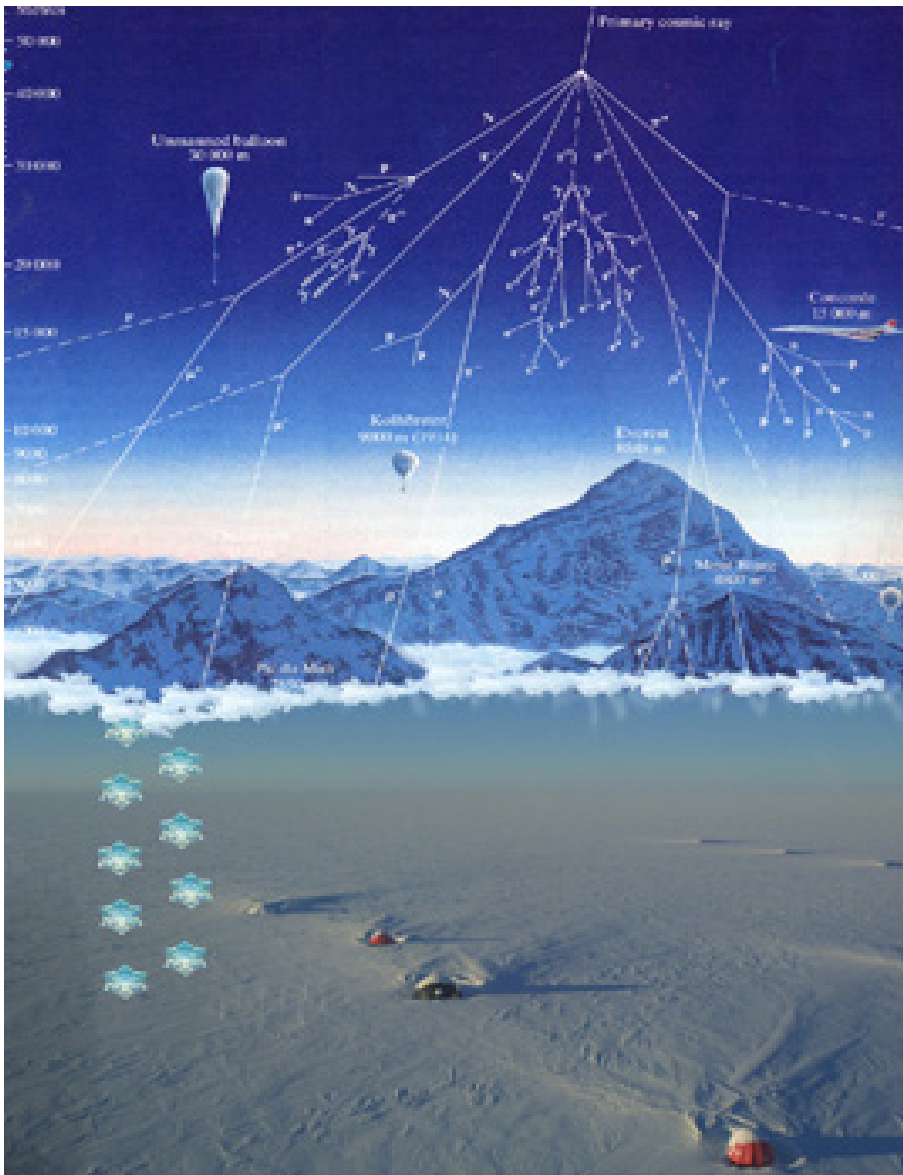
Aim: Reconstruction of TSI for past 10'000 years

Why radionuclides?

Dye3 (Beer et al.1990))

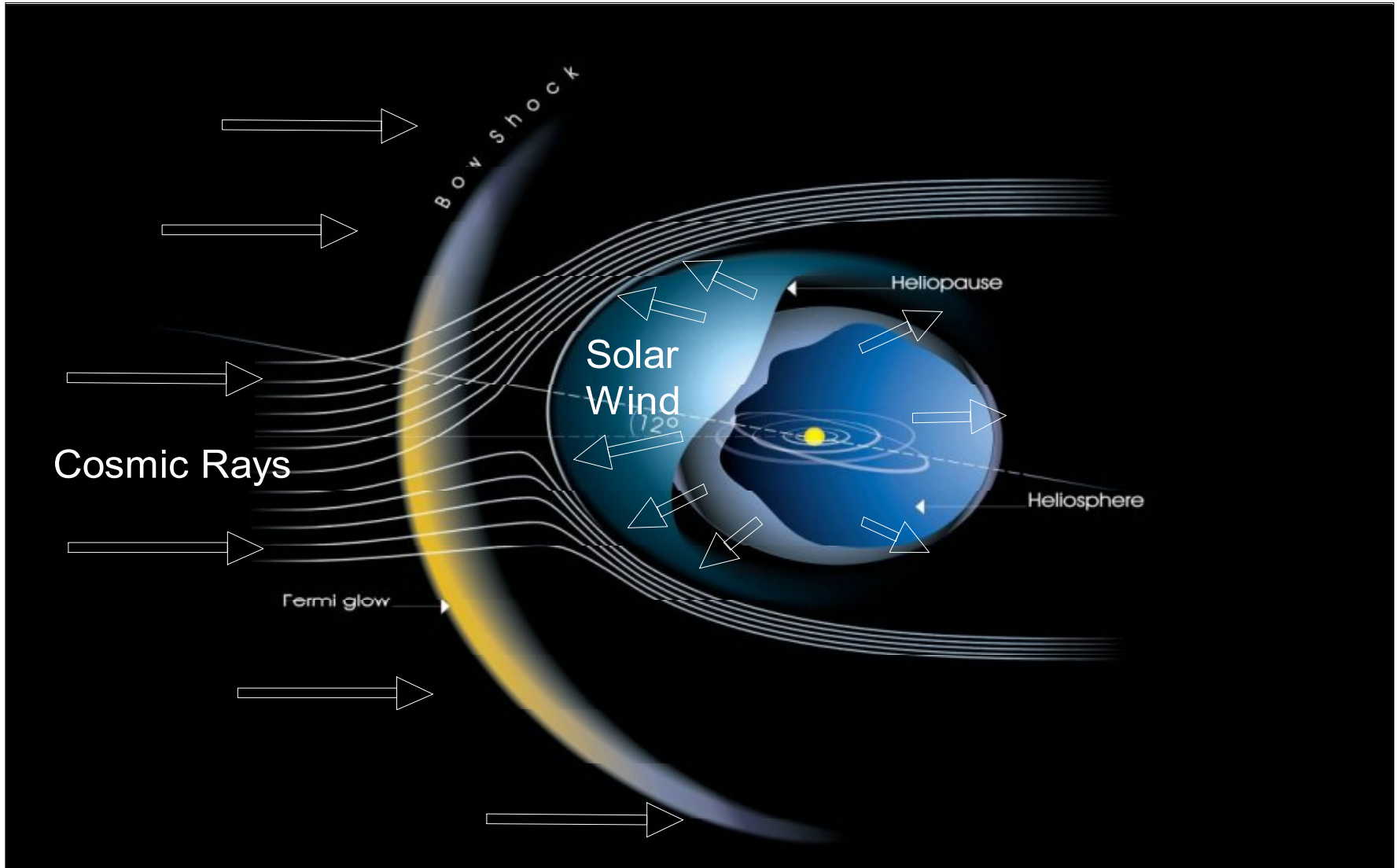


Cosmic rays in the atmosphere



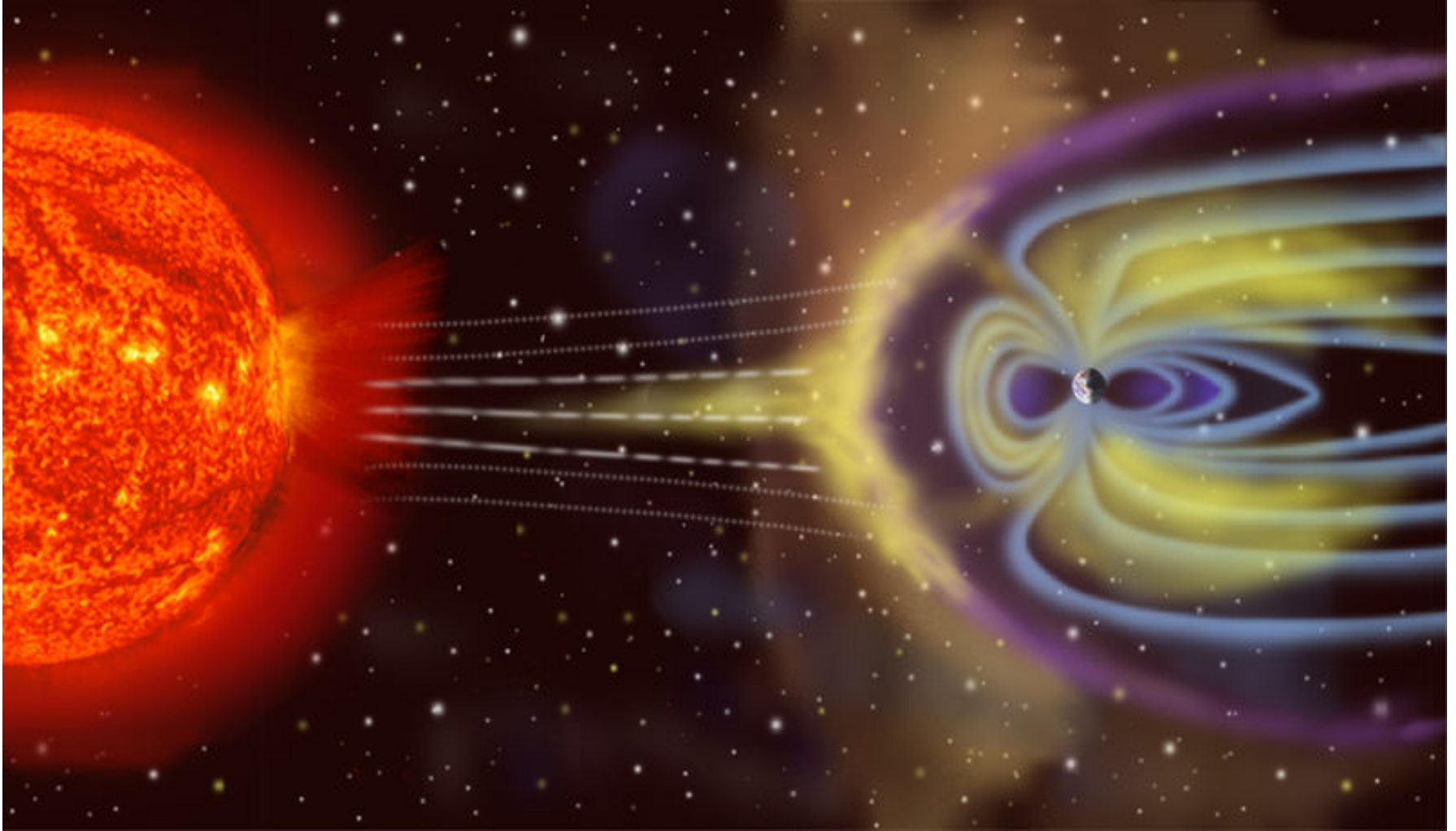
- Penetrating cosmic rays
- Nuclear reactions
- Production of cosmogenic radionuclides
- Transport / deposition
- Archive

Cosmic rays in the heliosphere



Intensity (out) > Intensity (in heliosphere)

Cosmic rays in magnetosphere



Intensity (out) > Intensity (in heliosphere) > Intensity (in magnetosphere)

Summary: radionuclides

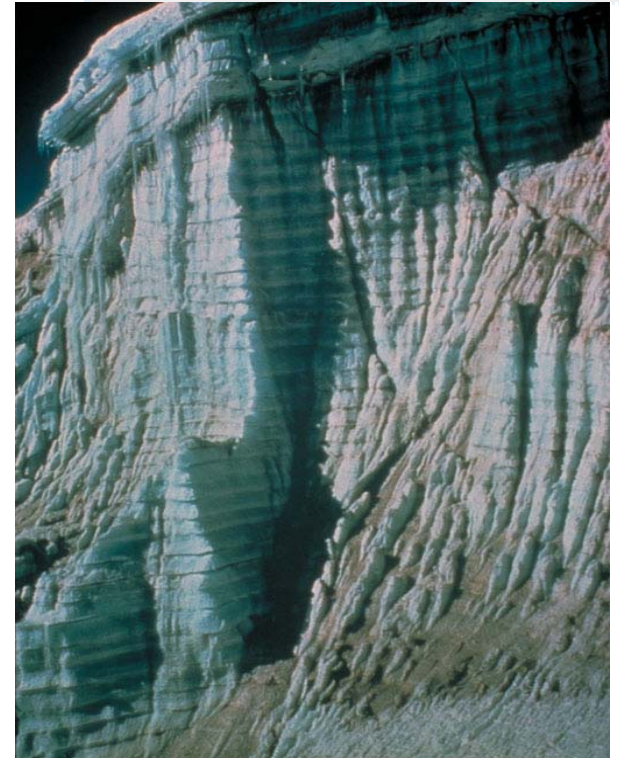
- Ice cores: Be-10, Cl-36
 - Measured by our group

- Tree rings: C-14

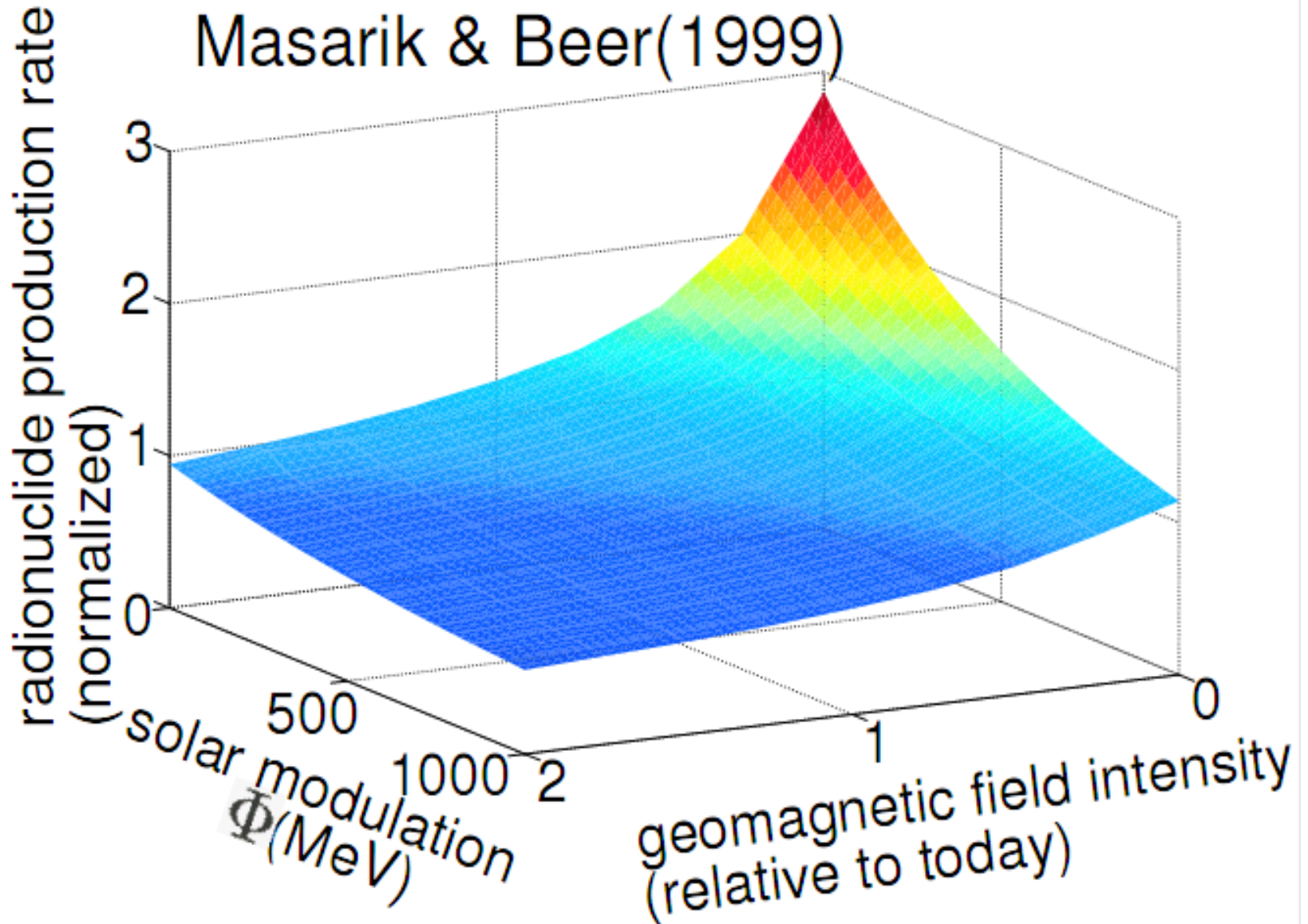
due to cosmic rays

include information about

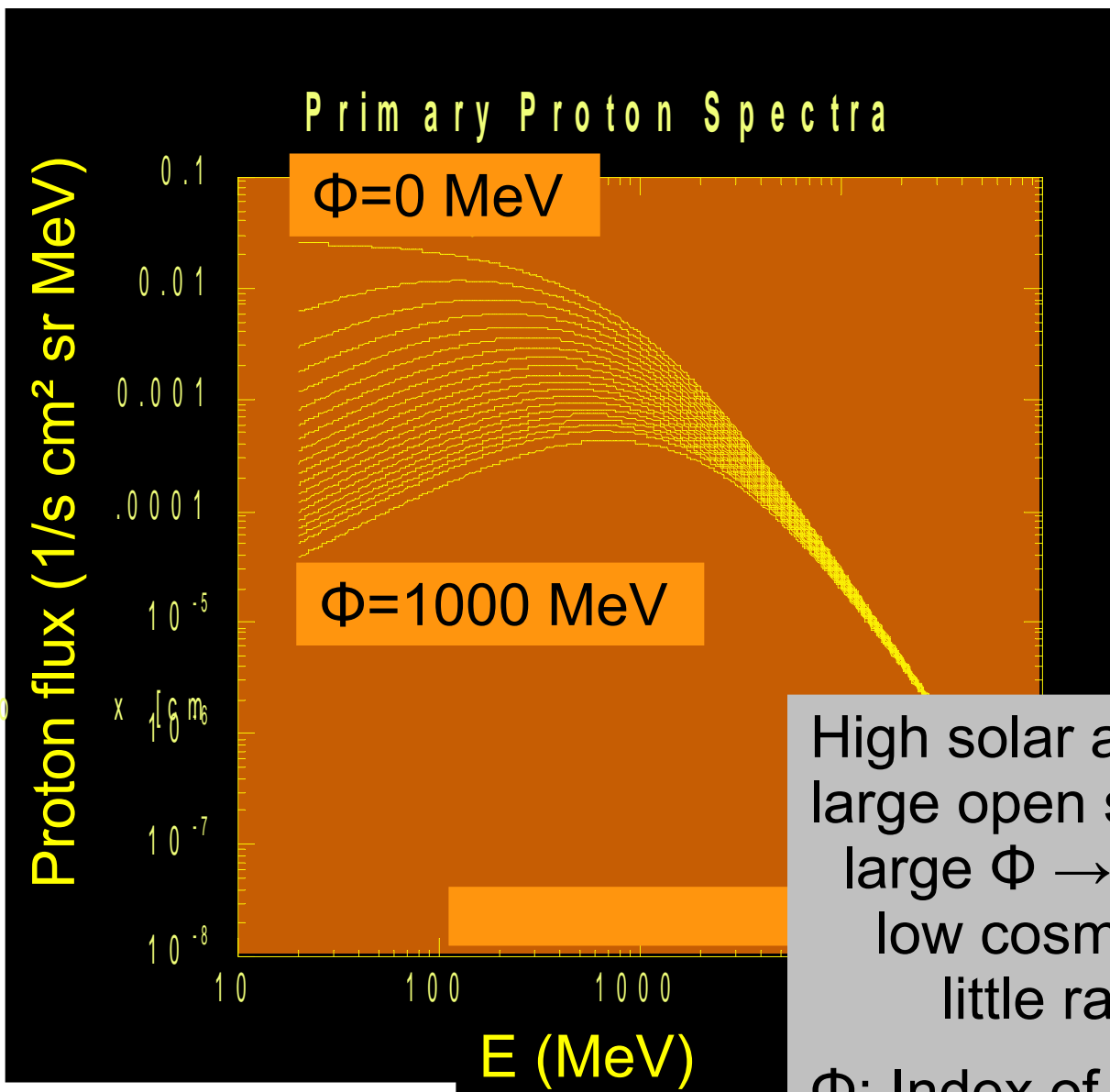
- Solar magnetic activity
- Geomagnetic field intensity



Production of radionuclides



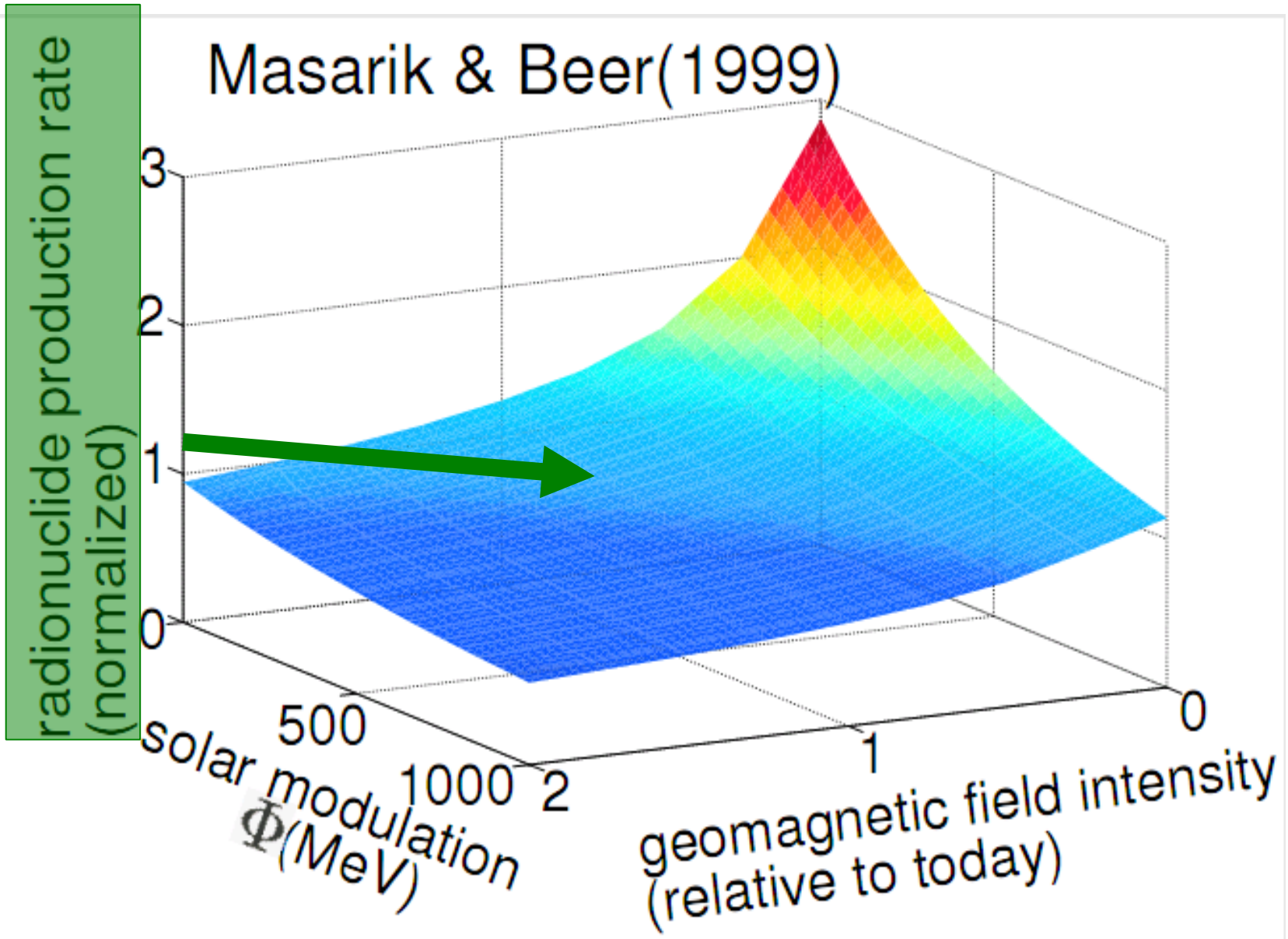
What is solar modulation Φ ?



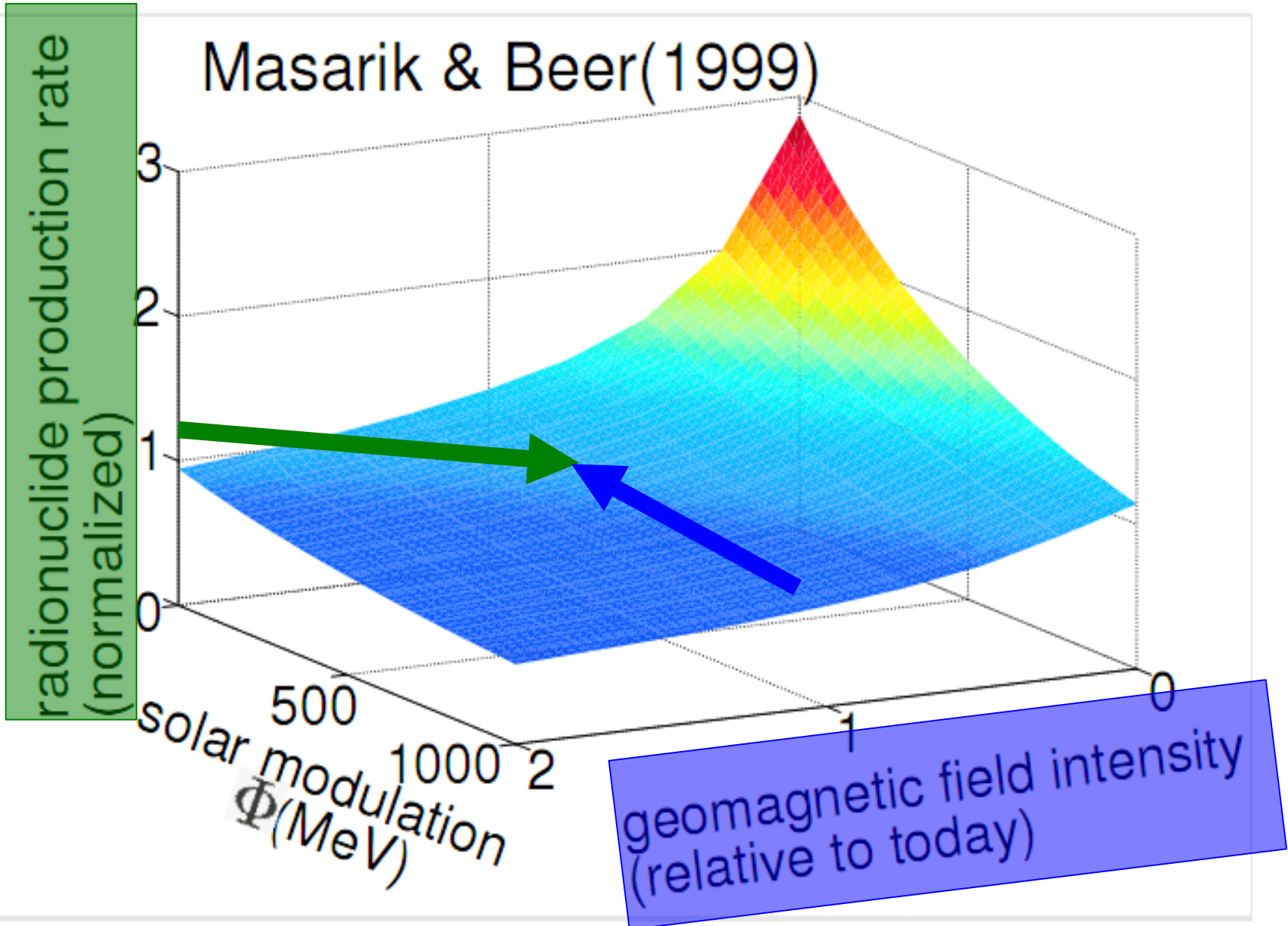
High solar activity \rightarrow
 large open solar magnetic field \rightarrow
 large Φ \rightarrow
 low cosmic ray intensity \rightarrow
 little radionuclide production

Φ : Index of solar magnetic activity

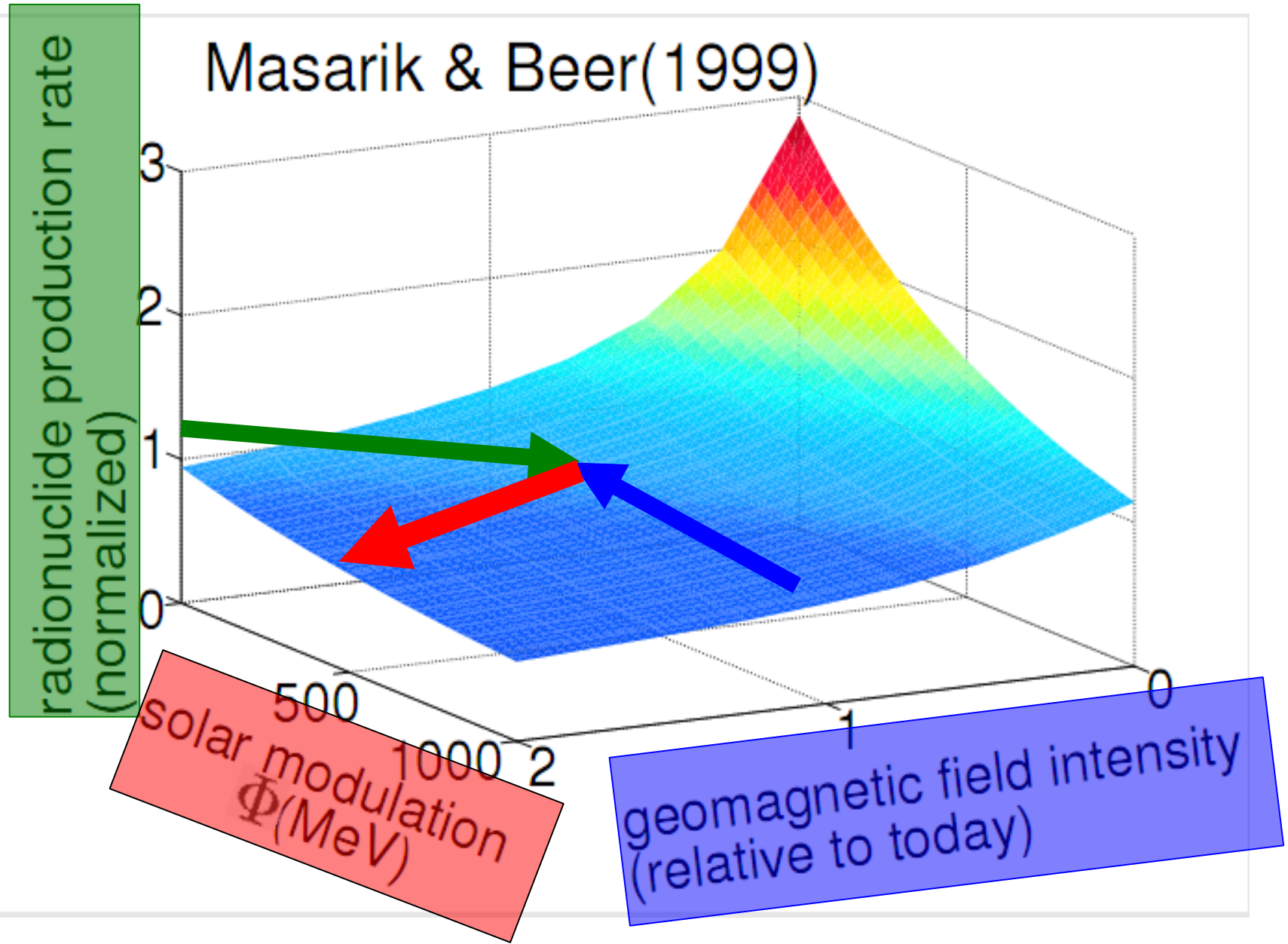
Modulation of production rate



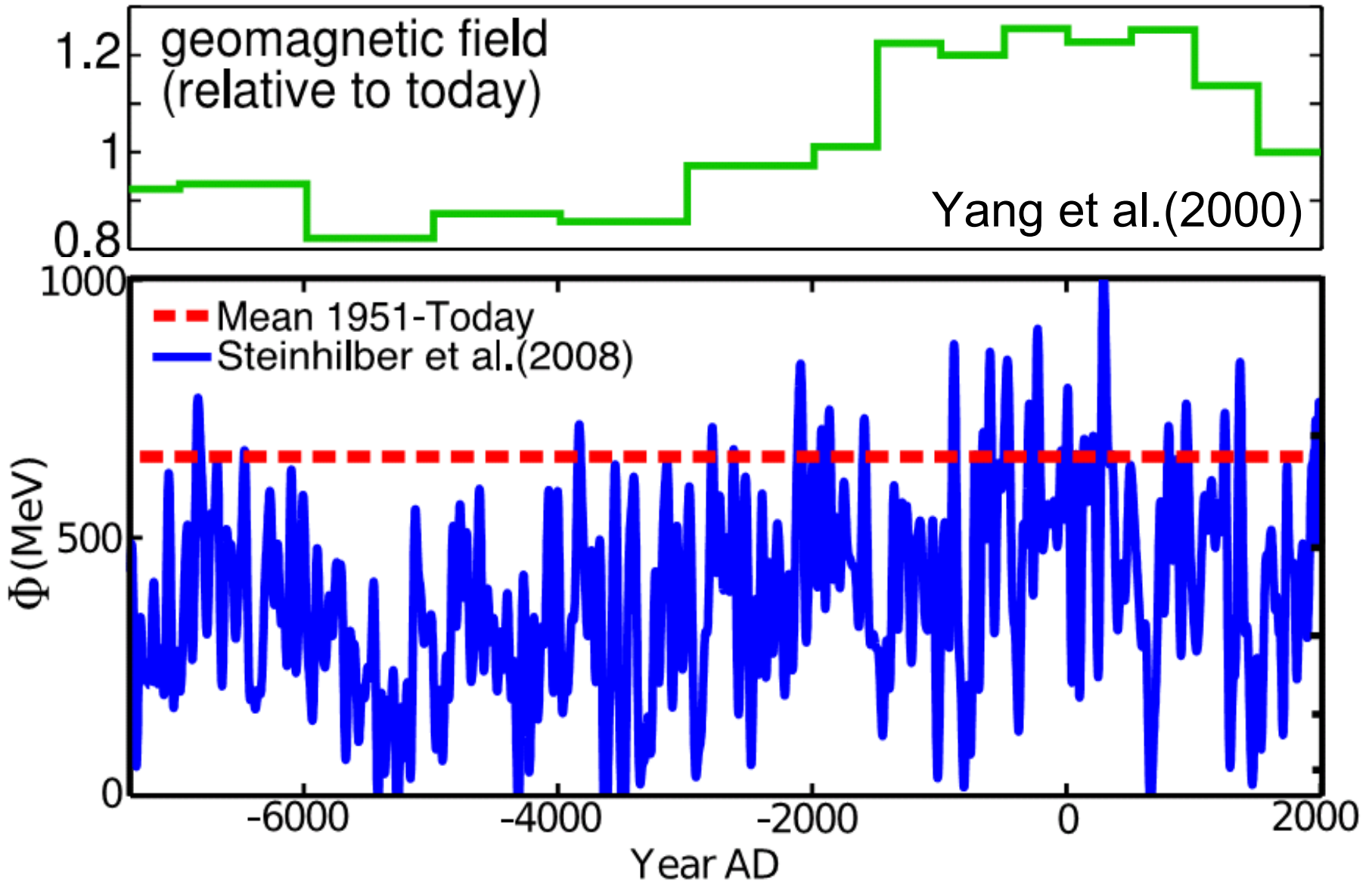
Modulation of production rate



Modulation of production rate



Solar modulation reconstruction



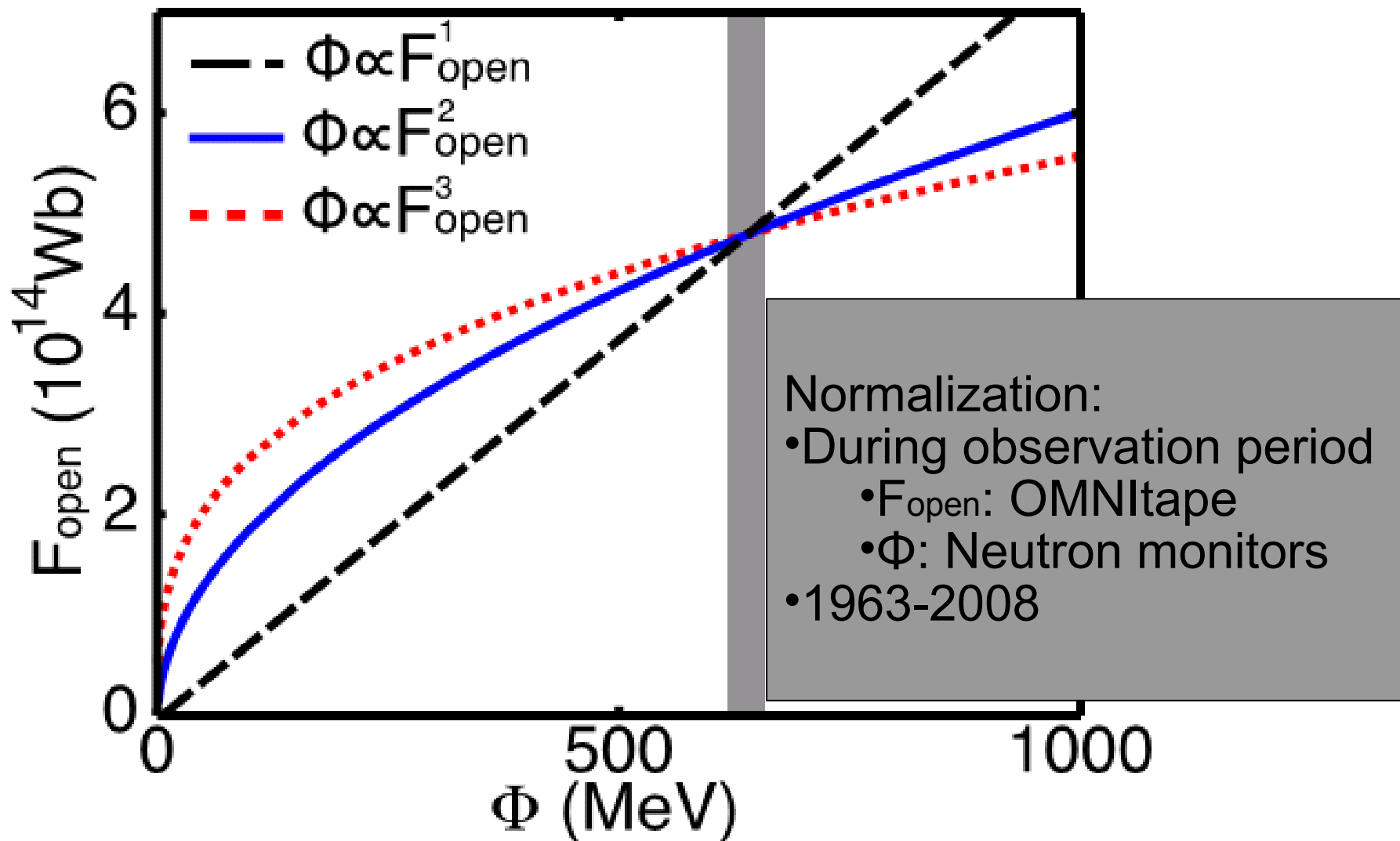
Link: solar modulation – open solar magnetic flux

- From Parker spiral theory and Gleeson-Axford approximation:

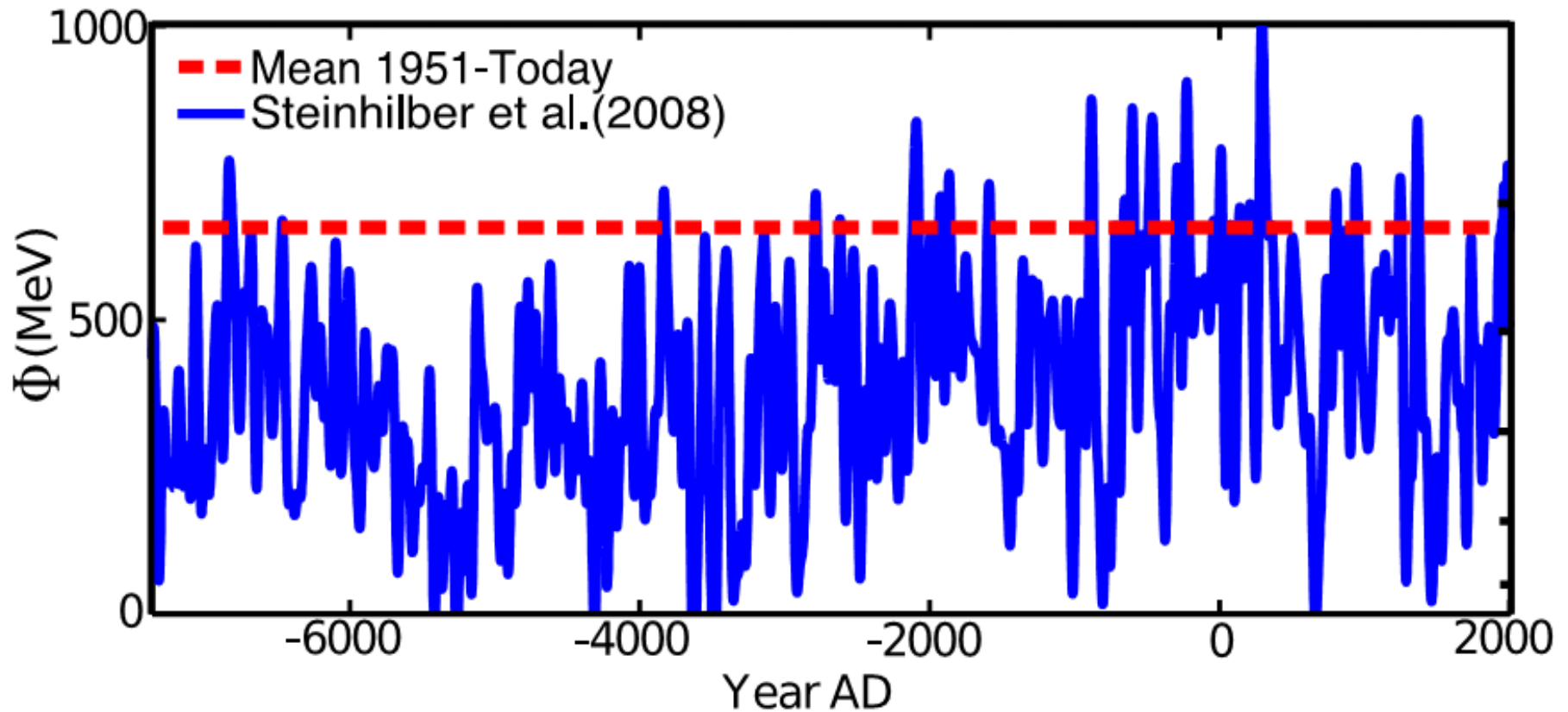
$$\Phi = \beta \cdot F_{\text{Open}}^{\alpha}$$

- α, β :
 - Free parameters
 - Assumed to be time independent
- $\alpha = 1..3$

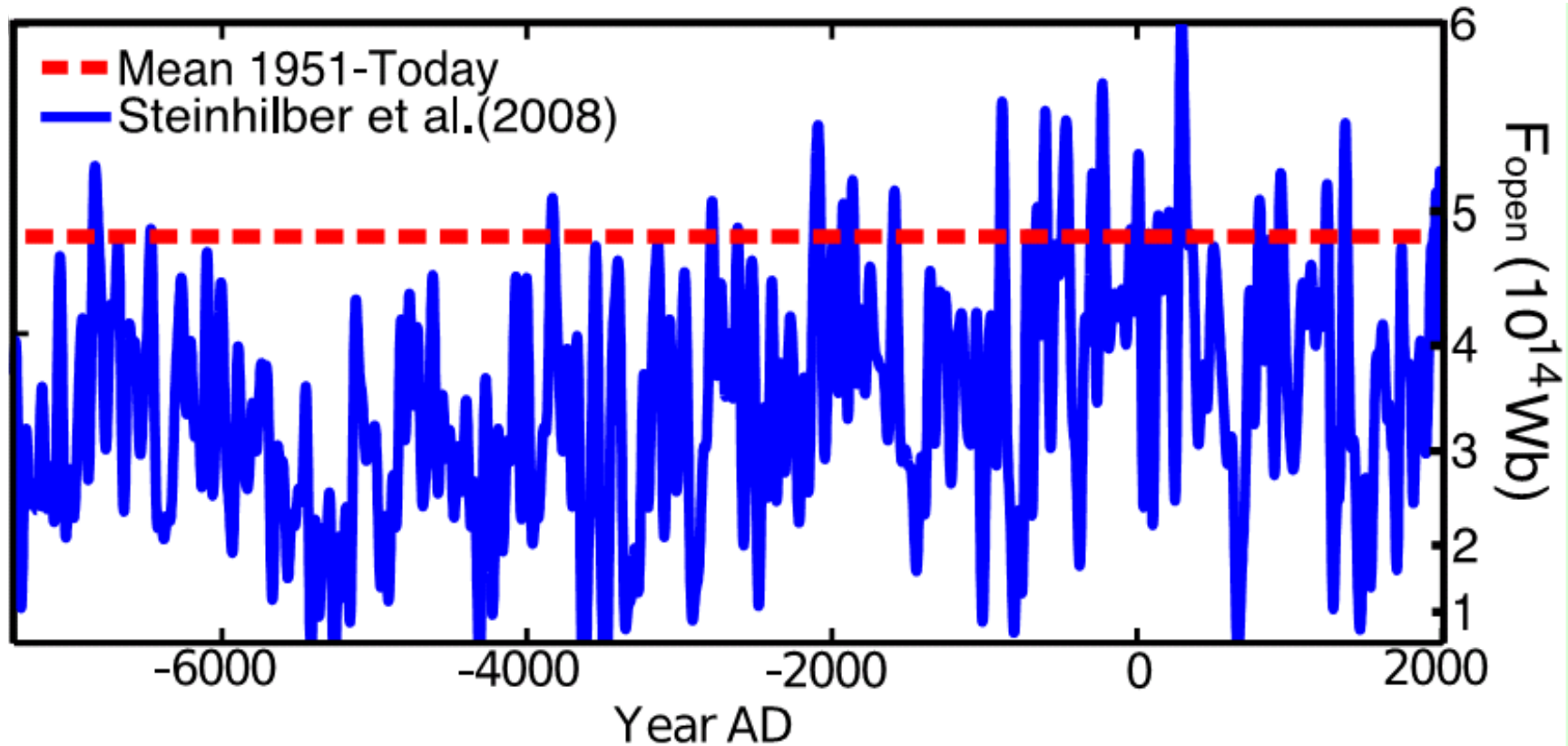
Link: solar modulation – open solar magnetic flux



Open solar magnetic flux ($\alpha=2$)



Open solar magnetic flux ($\alpha=2$)

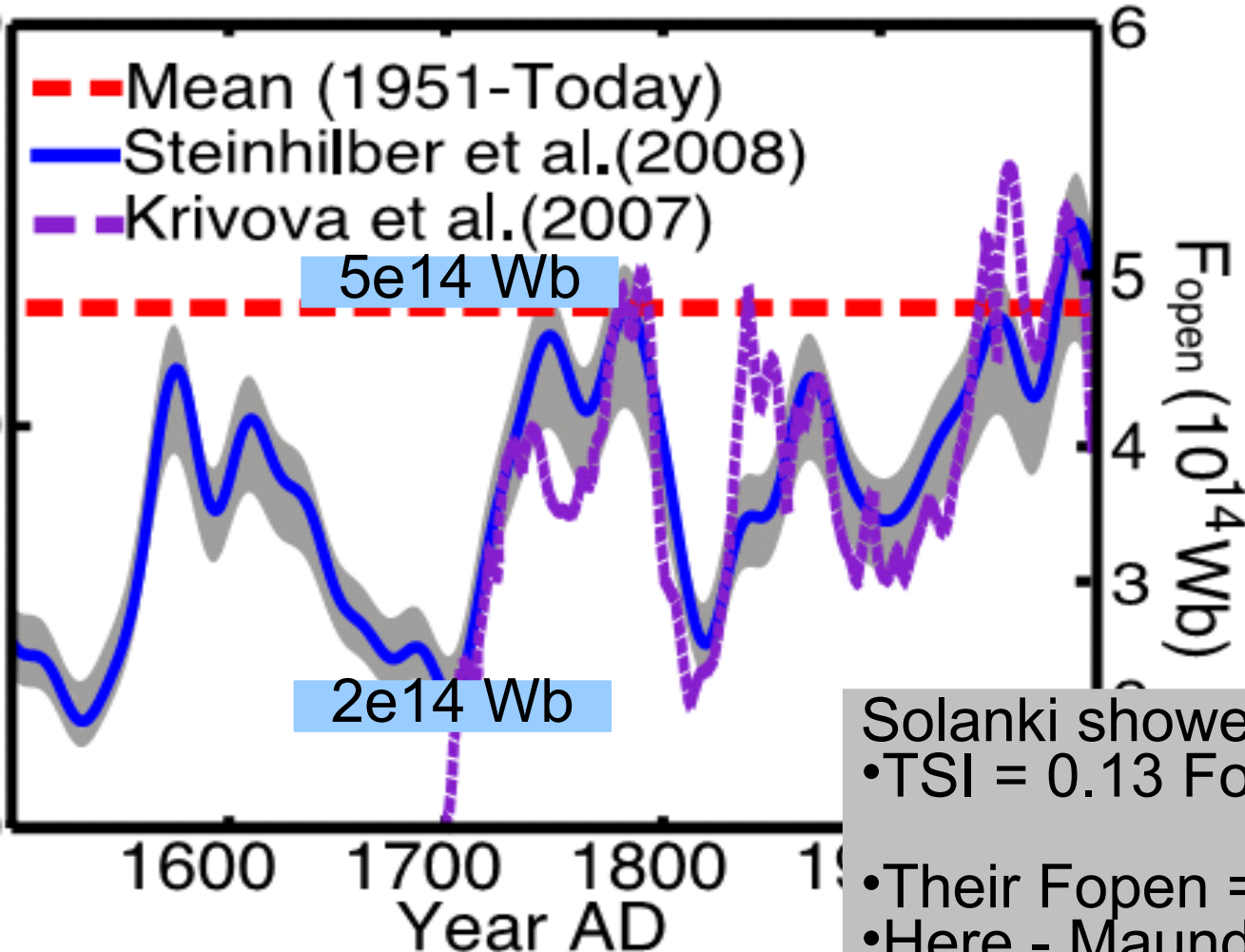


Conclusions / Outlook

- Reconstruction of solar activity for last 9'300 years based mainly on Be-10 from GRIP ice core
- Theoretical link between solar modulation and open solar magnetic flux:
 - Non-zero flux during Maunder minimum
 - No indication of solar magnetic floor
- Improvement of solar modulation by using
 - Data from different ice cores
 - Different radionuclides (Be-10, Cl-36, C-14)
- Work out open solar magnetic flux
- ... and irradiance



Open solar magnetic flux ($\alpha=2$)



Solanki showed Tuesday:

- $TSI = 0.13 F_{open} + 1364.77 \text{ W/m}^2$

- Their $F_{open} = 2 \times$ our F_{open} !

- Here - Maunder minimum TSI:

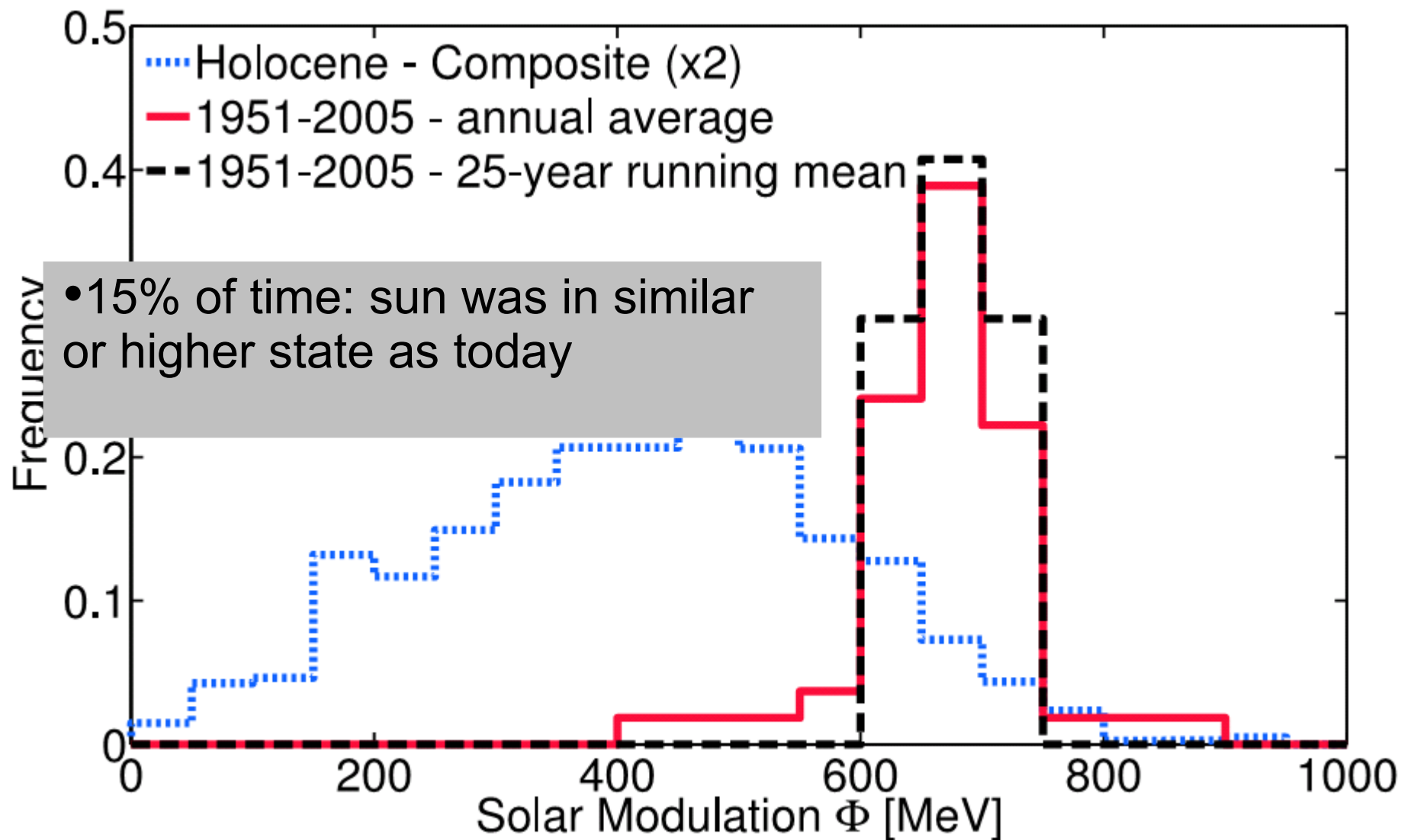
- 1365.29 W/m^2

- Today:

- 1366.07 W/m^2

- **Difference: 0.78 W/m^2**

Solar modulation reconstruction



Steinhilber et al.(2008)