

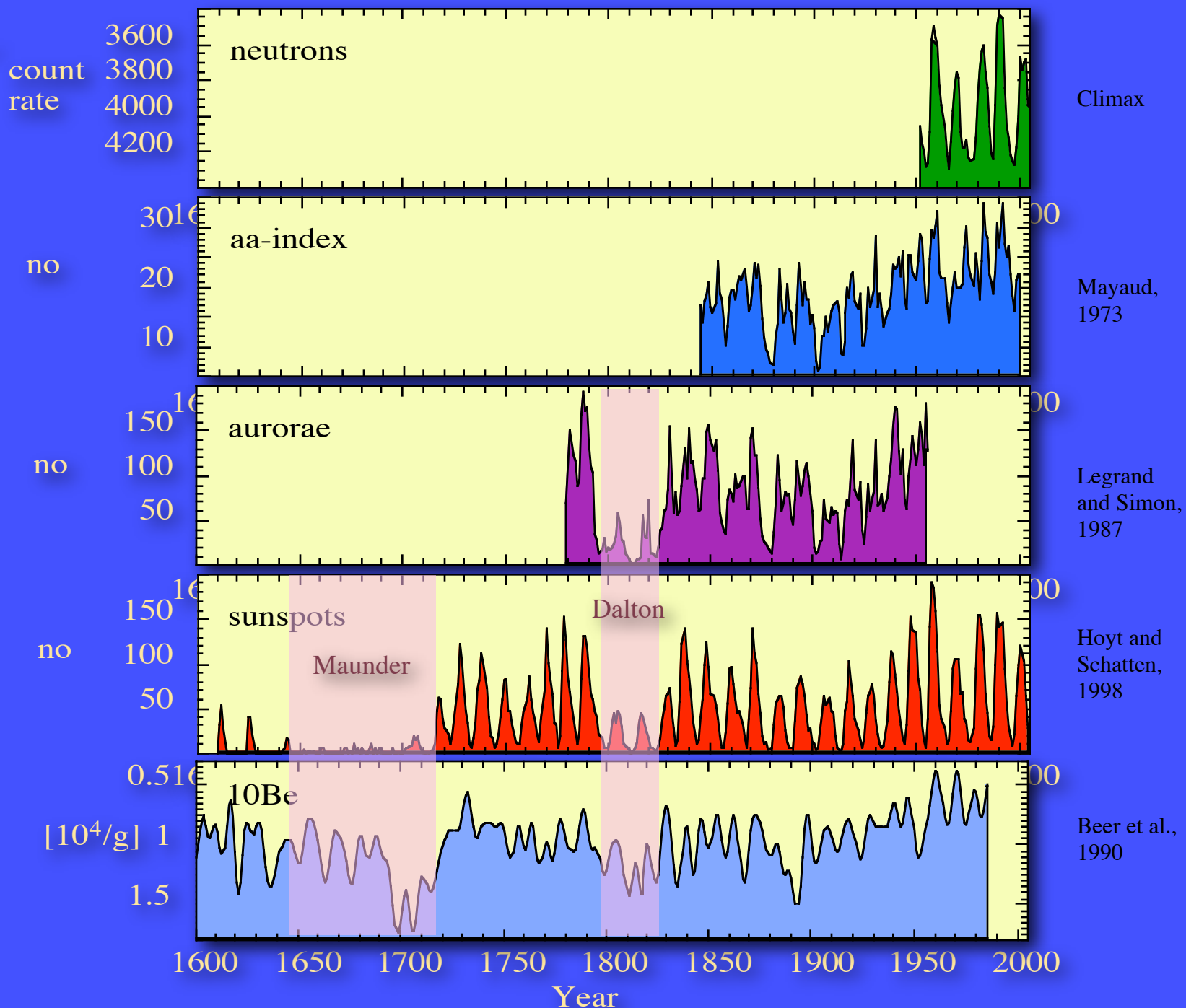
# Long-term Solar Variability Derived from Cosmogenic Radionuclides

Jürg Beer

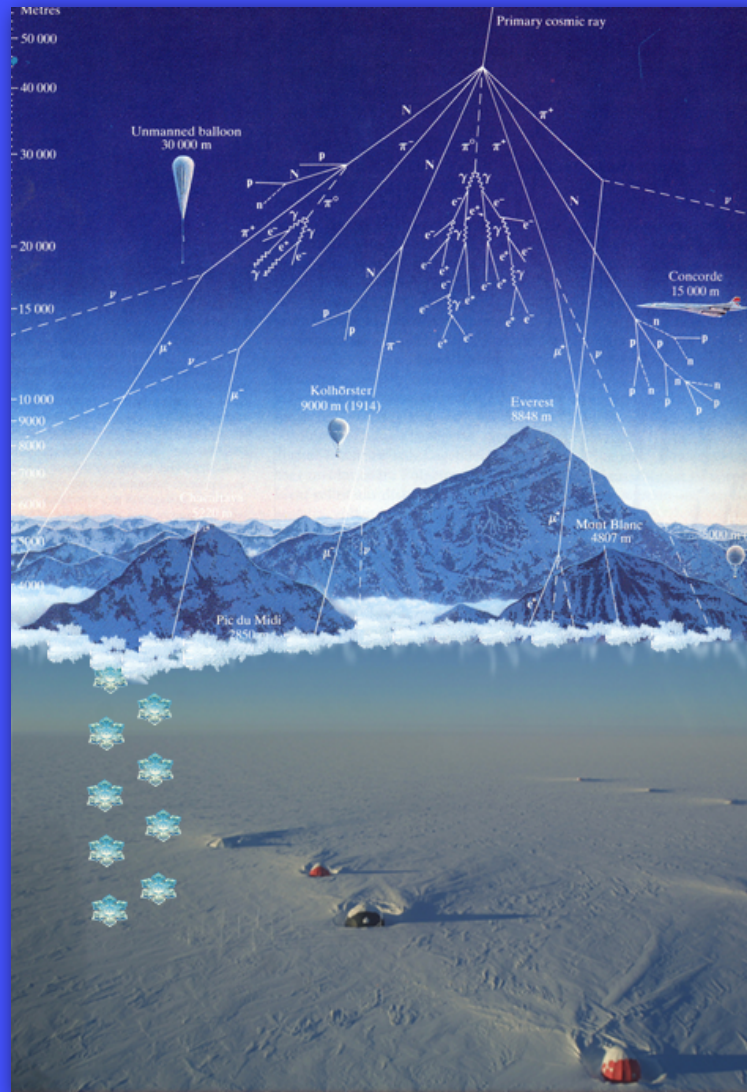
[beer@eawag.ch](mailto:beer@eawag.ch)

# Outline

- Proxies of solar activity
- Cosmogenic radionuclides
  - ◆ Production - transport effects
- 9000 years of solar activity
- Conclusions and outlook



# Cosmogenic Radionuclides

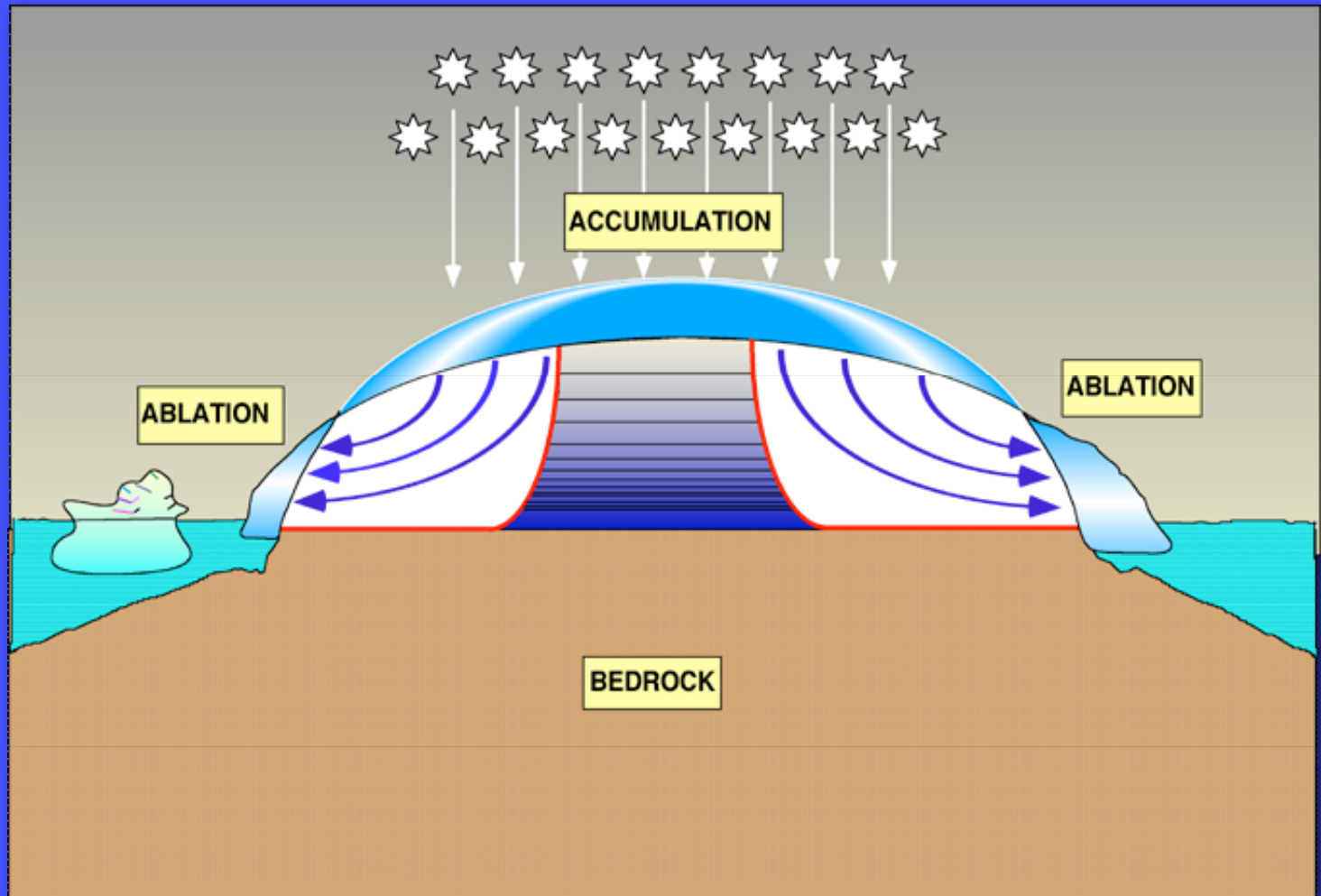


## Galactic cosmic rays

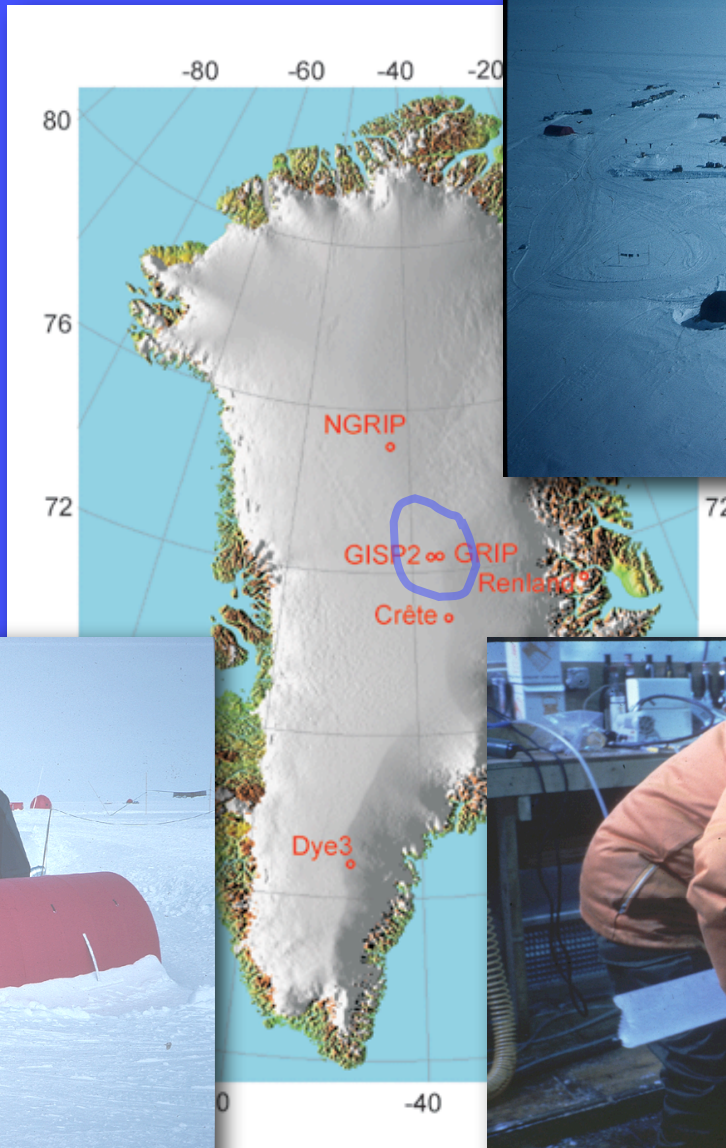
- Secondary particles
- Nuclear reactions
- Production of cosmogenic radionuclides
- Transport & deposition
- Storage in archives

# Archive Ice

## Formation of an Ice Sheet



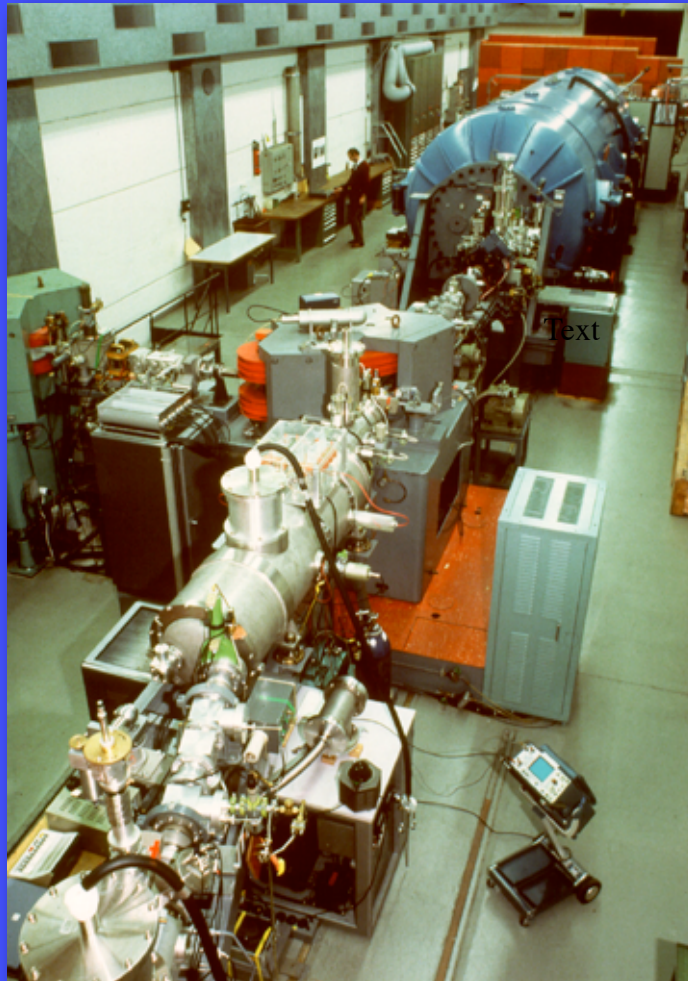
# GRIP Ice Core



Dome GRIP  
1990-1992

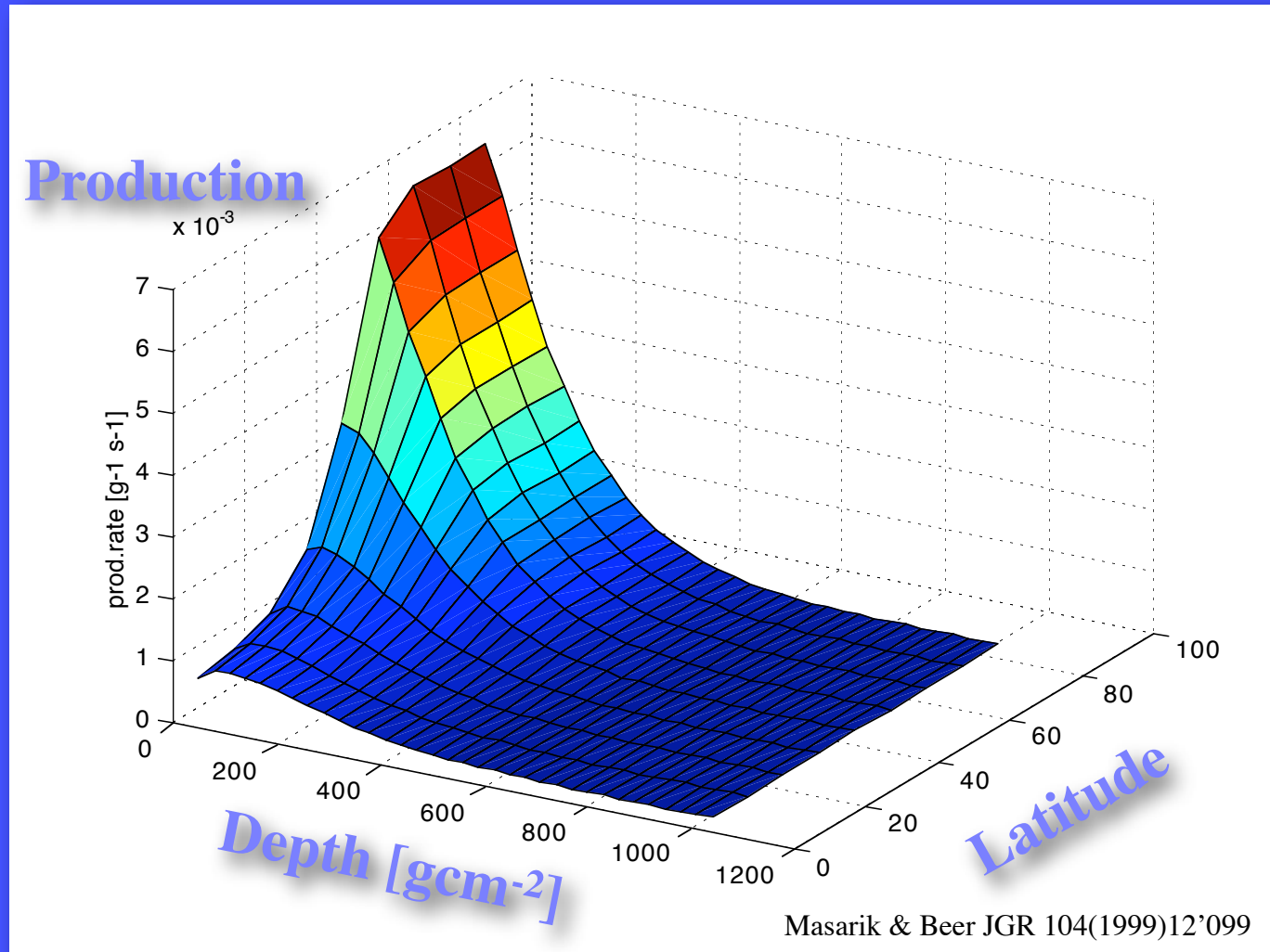


# Accelerator Mass Spectrometer ETH/PSI



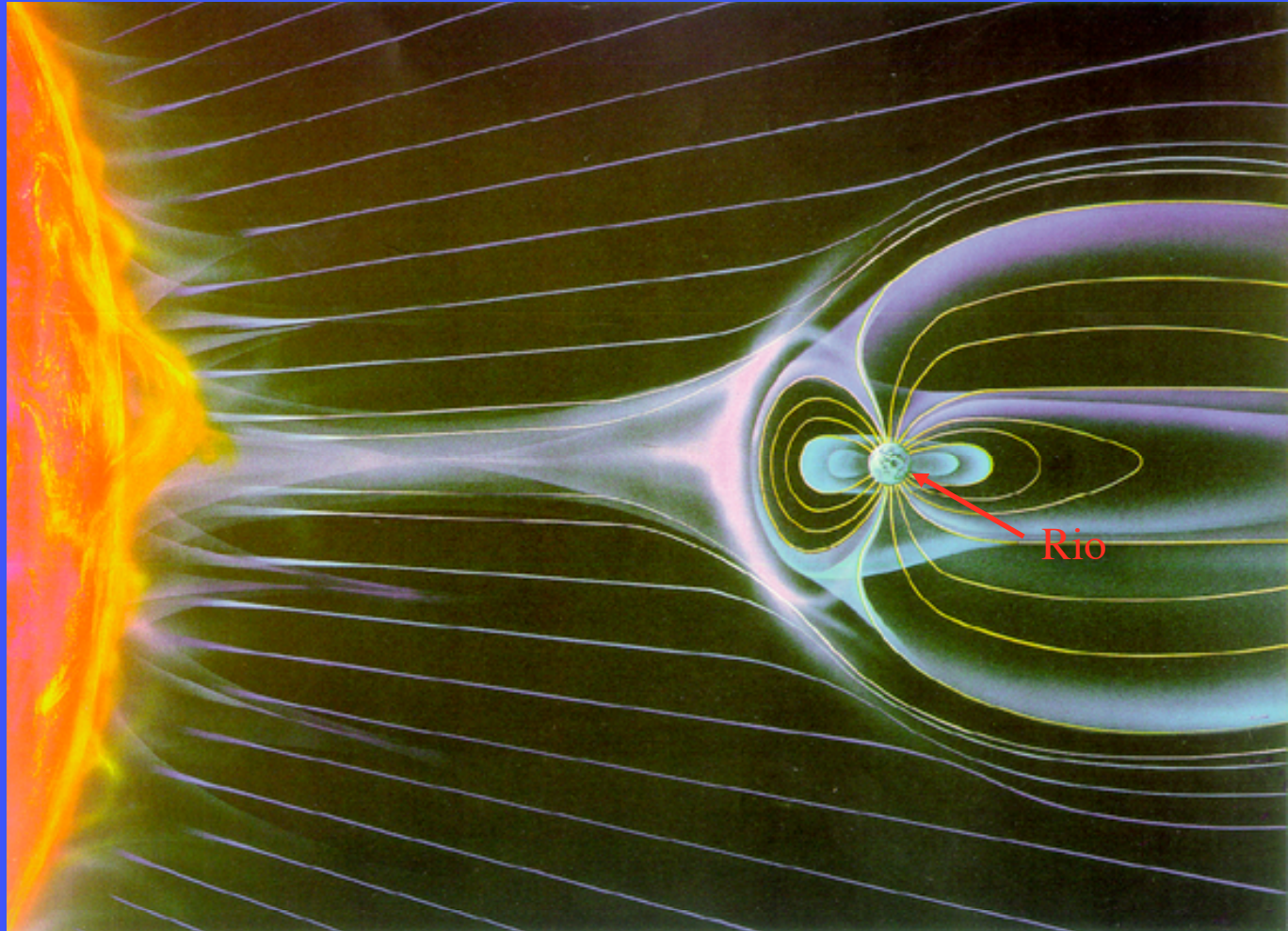
- Acceleration: 6 MV
- ~ 100 g of ice
- 1 Mio  $^{10}\text{Be}$  atoms
- $^{10}\text{Be}/^9\text{Be} > 10^{-14}$
- “1 person out of  $10^4$  Earth’s population”

# $^{10}\text{Be}$ production versus Depth and Latitude ( $M=1, \Phi=550$ )

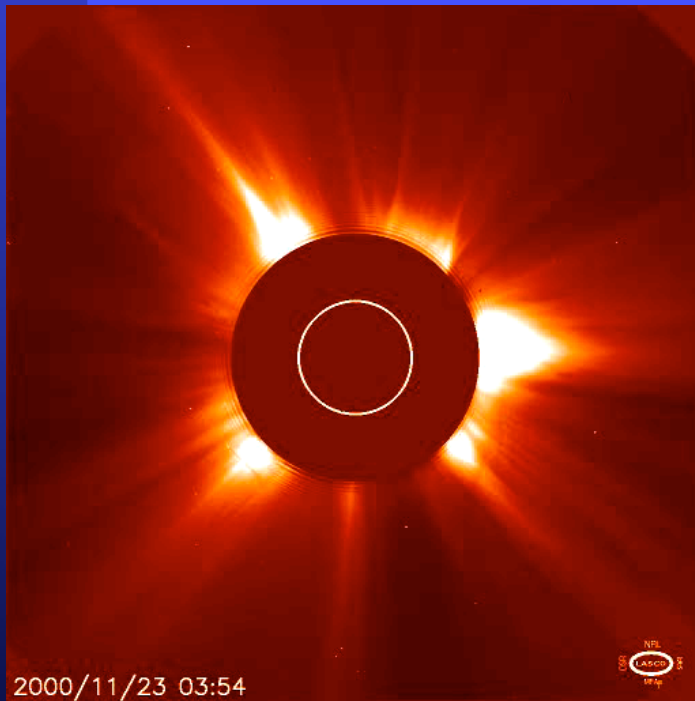




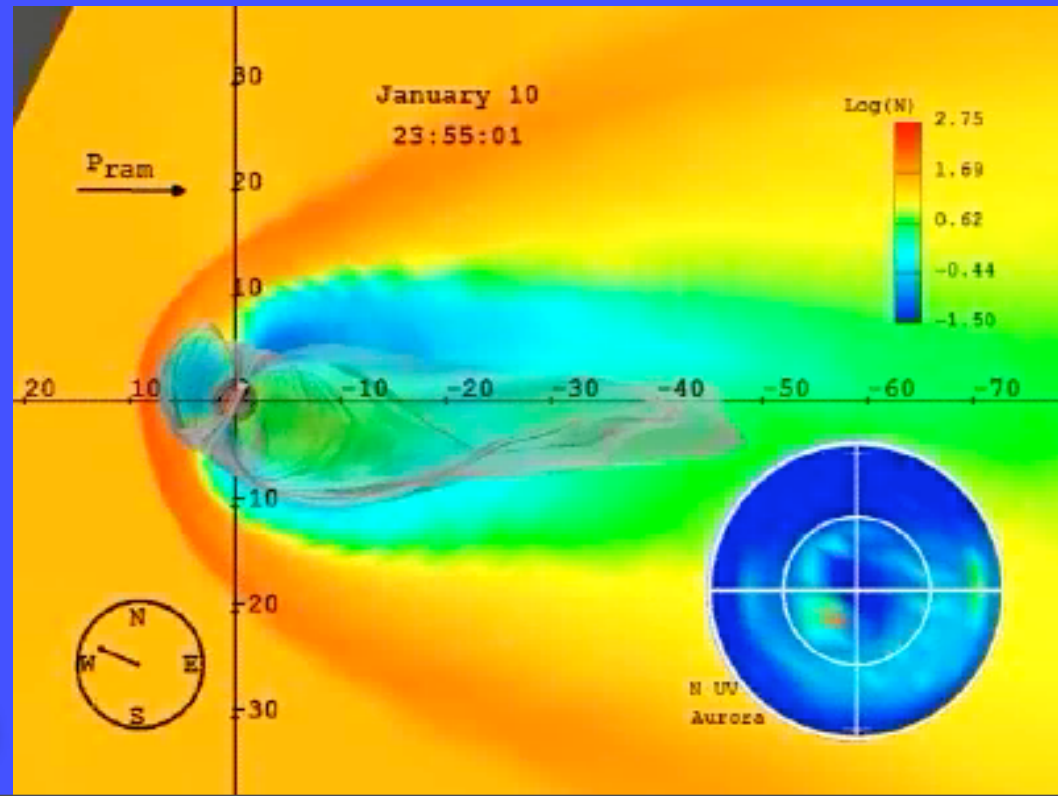
# Modulation of Cosmic Rays



# Solar Modulation



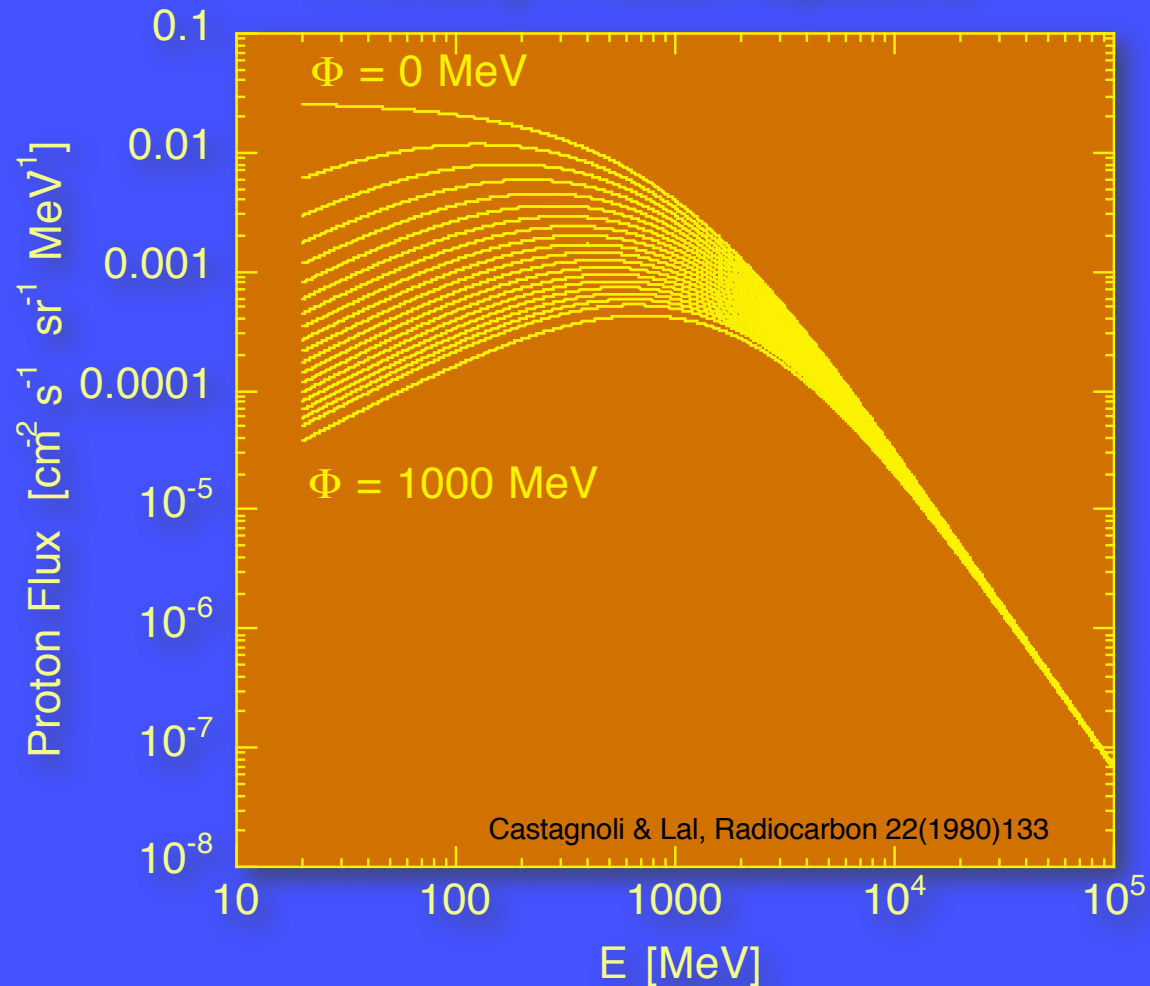
## Solar wind emission



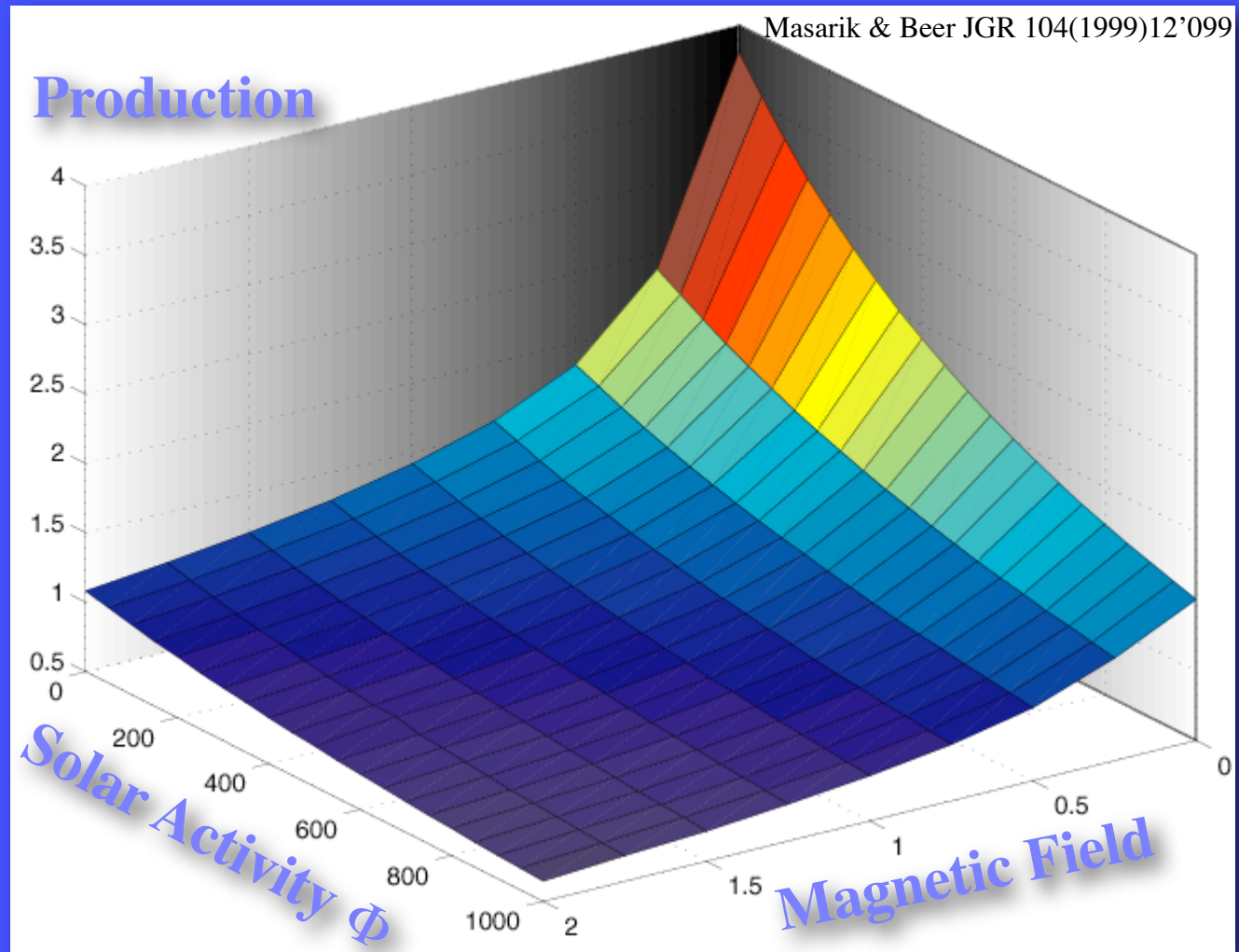
## Solar wind - geomagnetic field interaction

# Primary Cosmic Rays

## Primary Proton Spectra



# Modulation of the $^{10}\text{Be}$ production rate



# Cosmogenic radionuclides in ice

*PRODUCTION  
EFFECTS*

**SPACE**

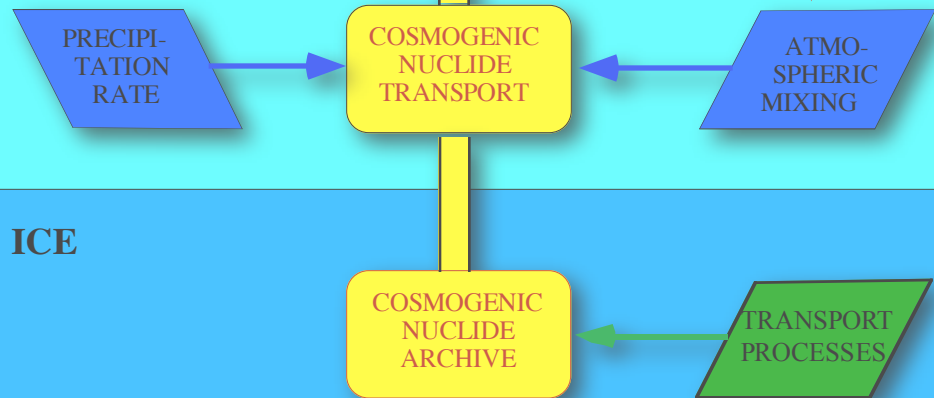


**ATMOSPHERE**

COSMOGENIC  
NUCLIDE  
PRODUCTION

*SYSTEM  
EFFECTS*

**ICE**



# Comparison of C-14 with Be-10

C-14



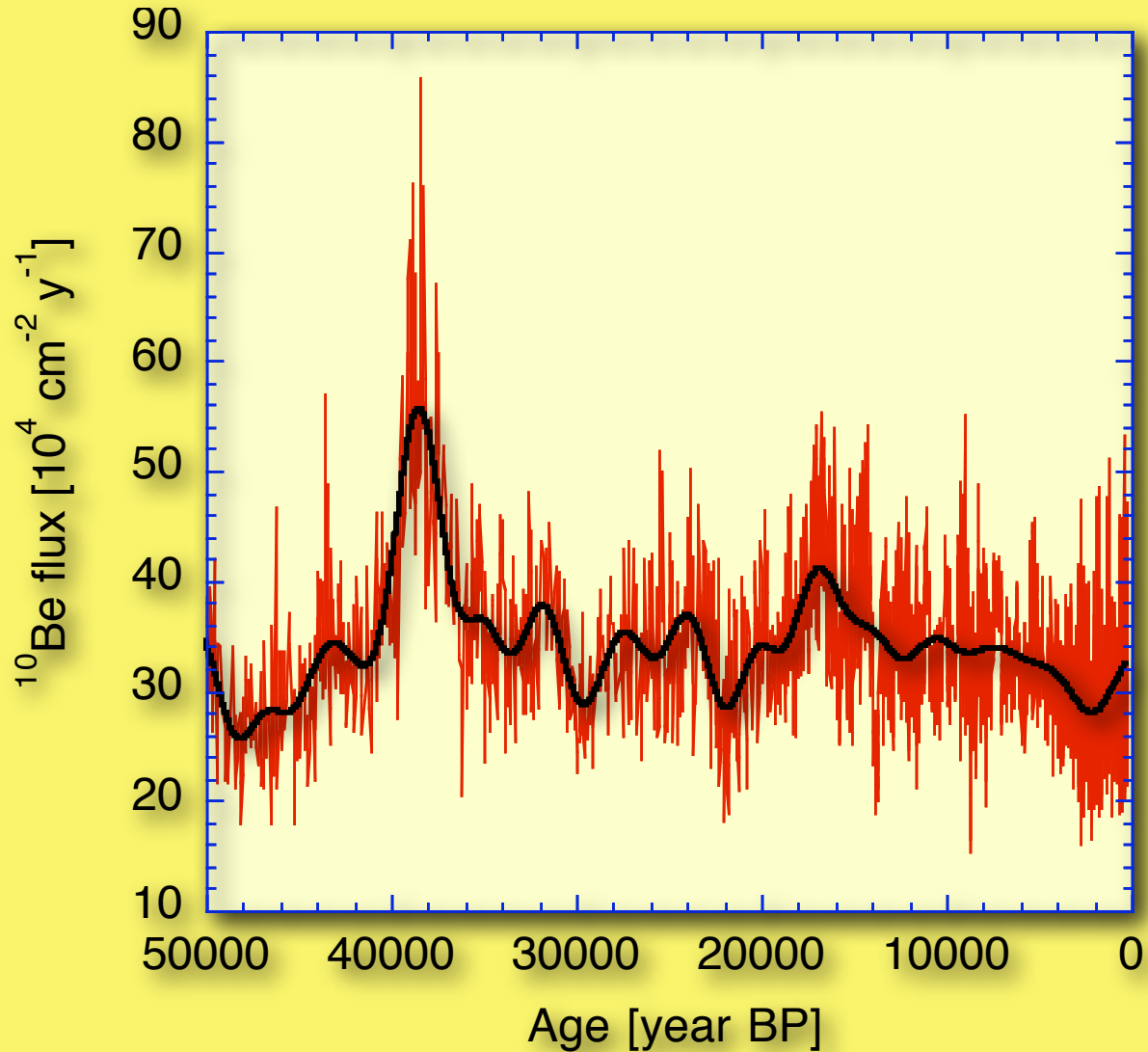
German oak

Be-10

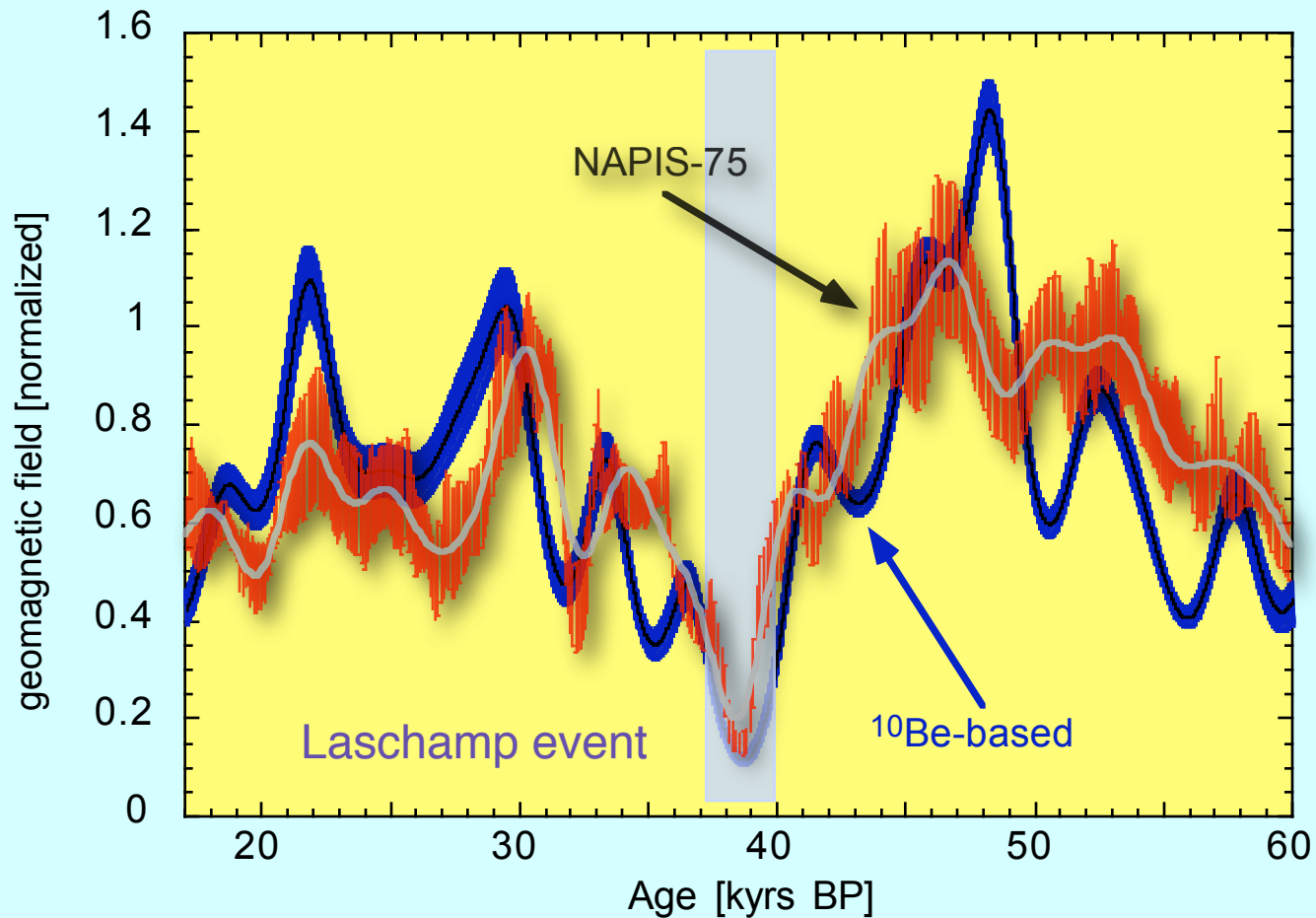


Quelcaya glacier

# $^{10}\text{Be}$ flux from GRIP



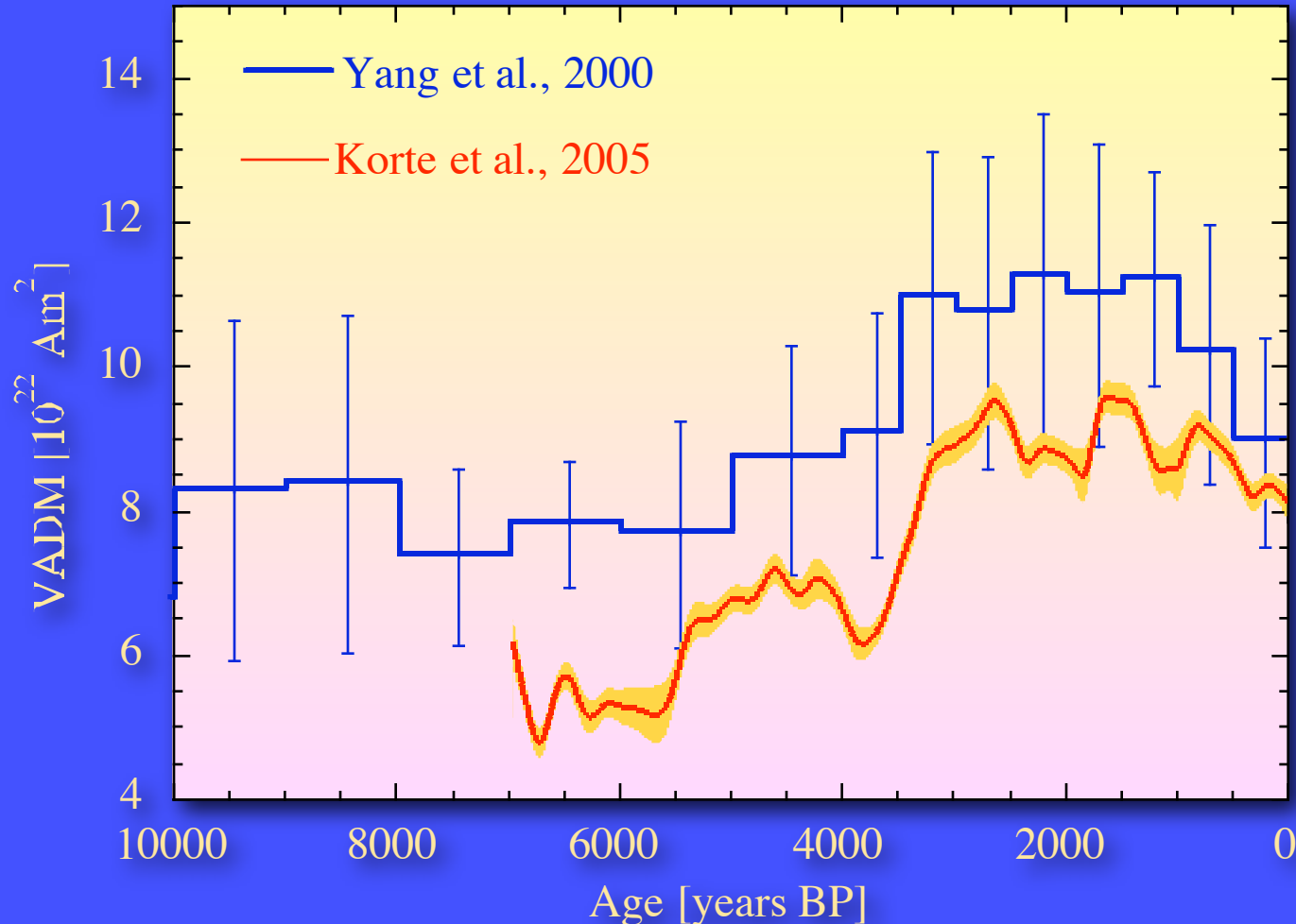
# Paleomagnetic Field Reconstruction



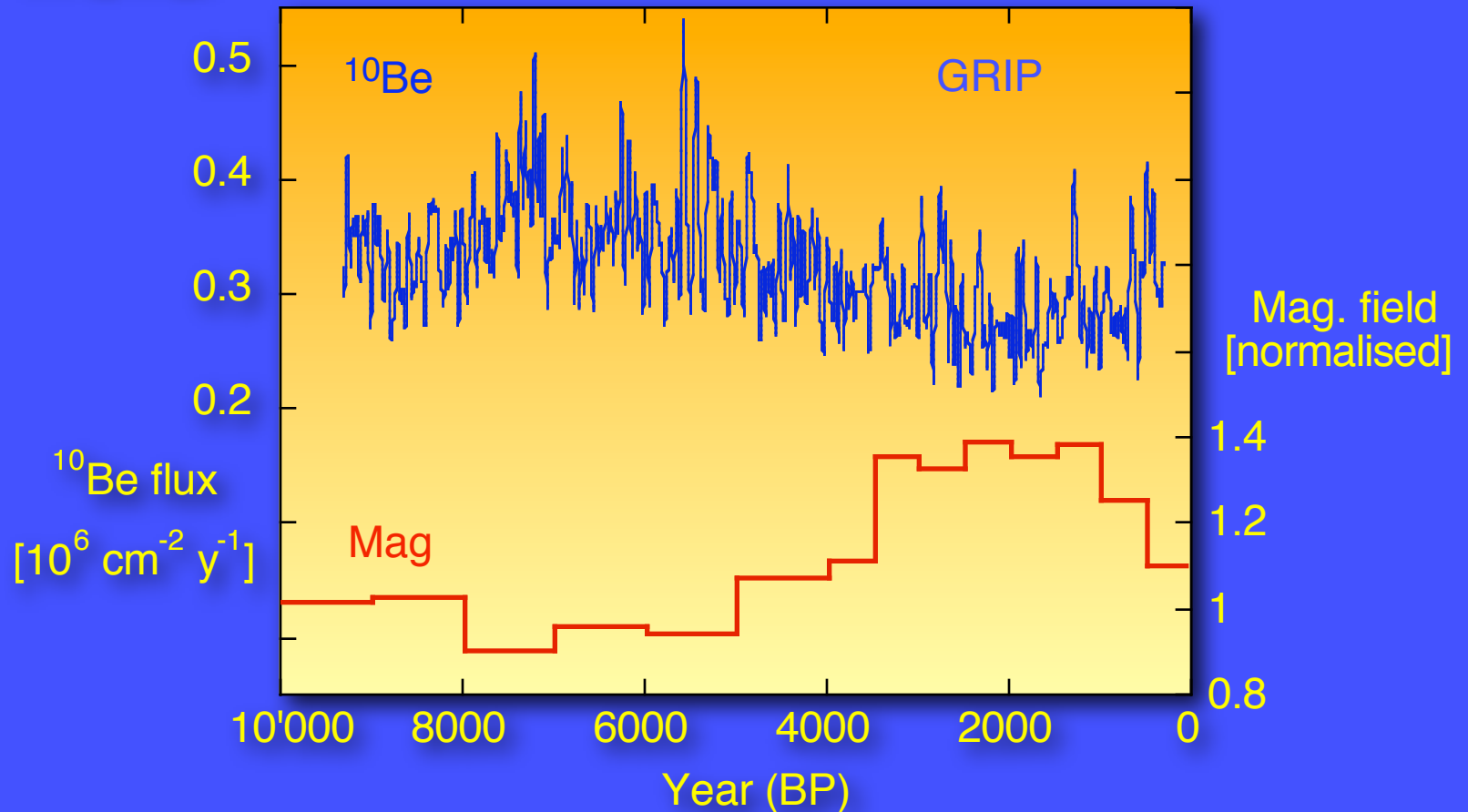
NAPIS-75: Laj et al. Phil. Trans. R. Soc. Lond. A 358 (2000) 1009-1025



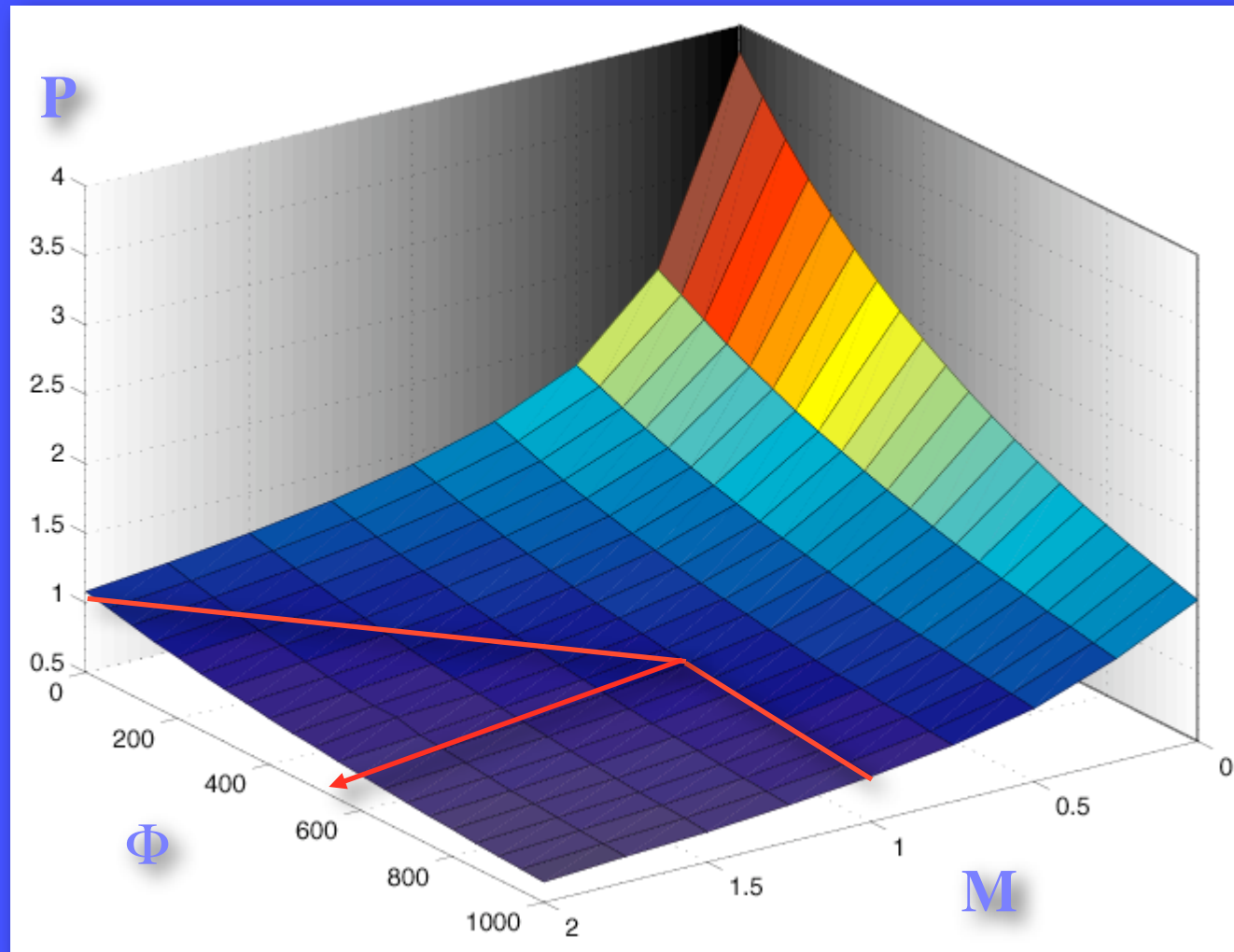
# Paleomagnetic Dipole Moment



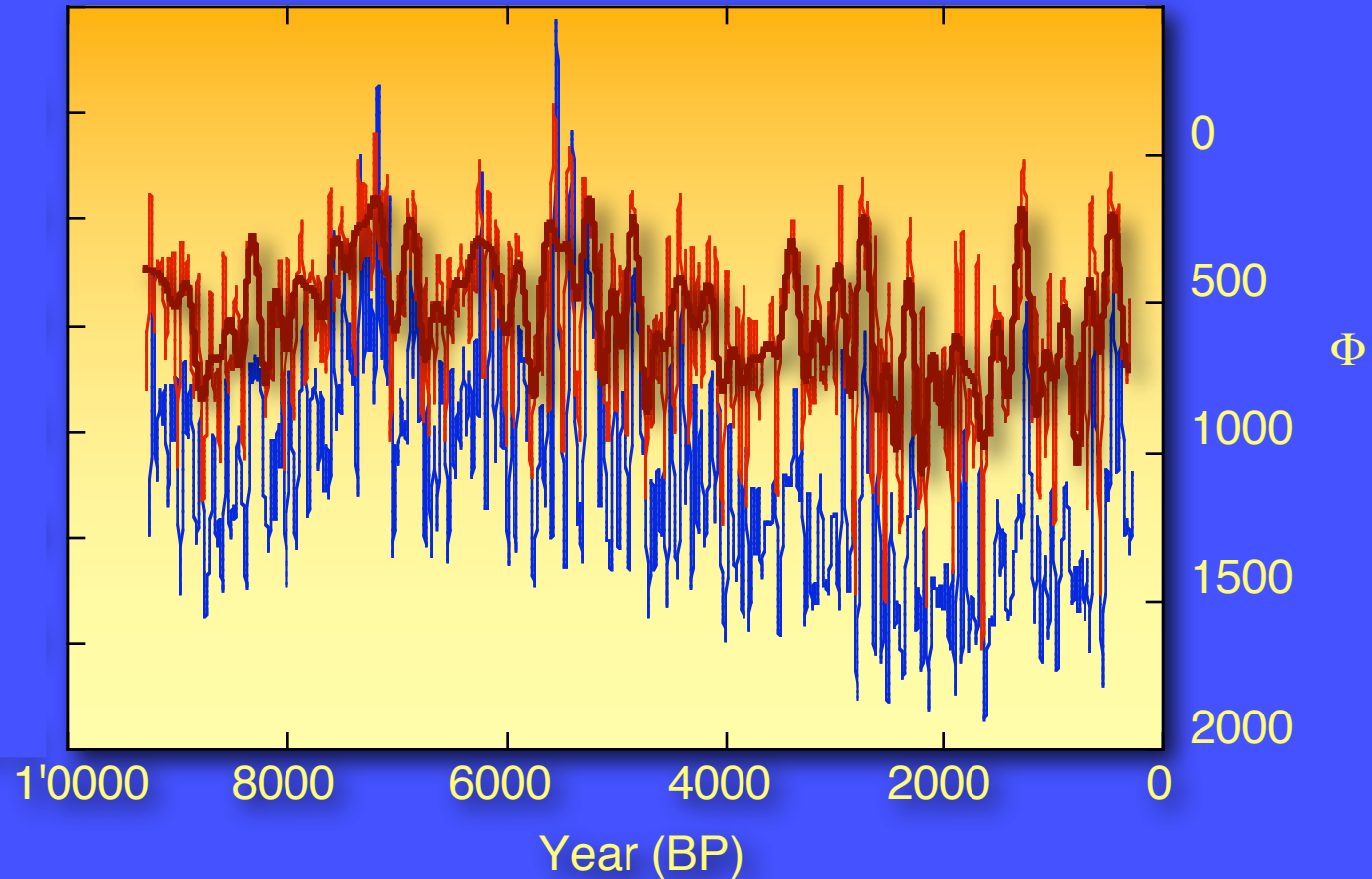
# $^{10}\text{Be}$ flux and geomagnetic field



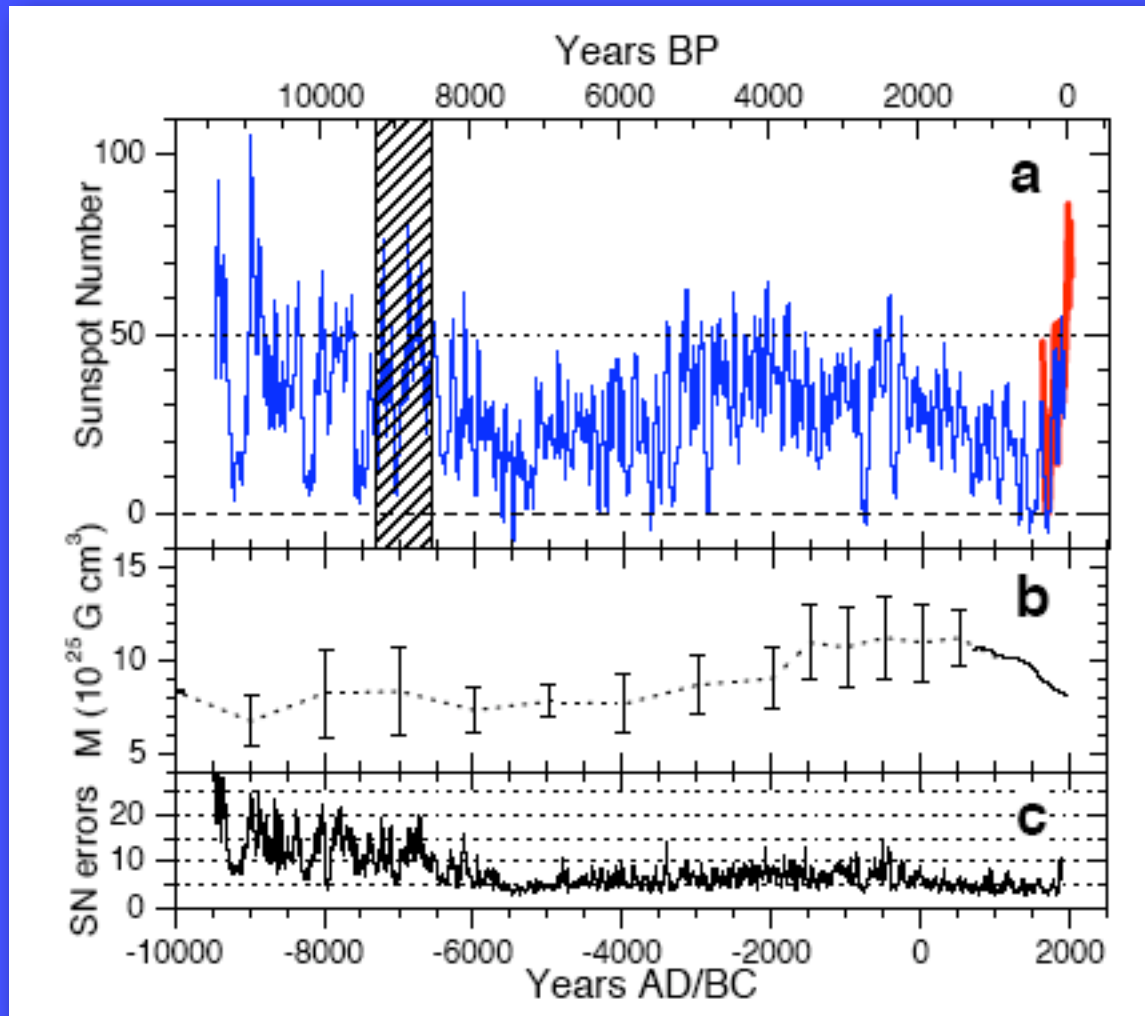
# Modulation of the $^{10}\text{Be}$ production rate



# Conversion of $^{10}\text{Be}$ flux into $\Phi$

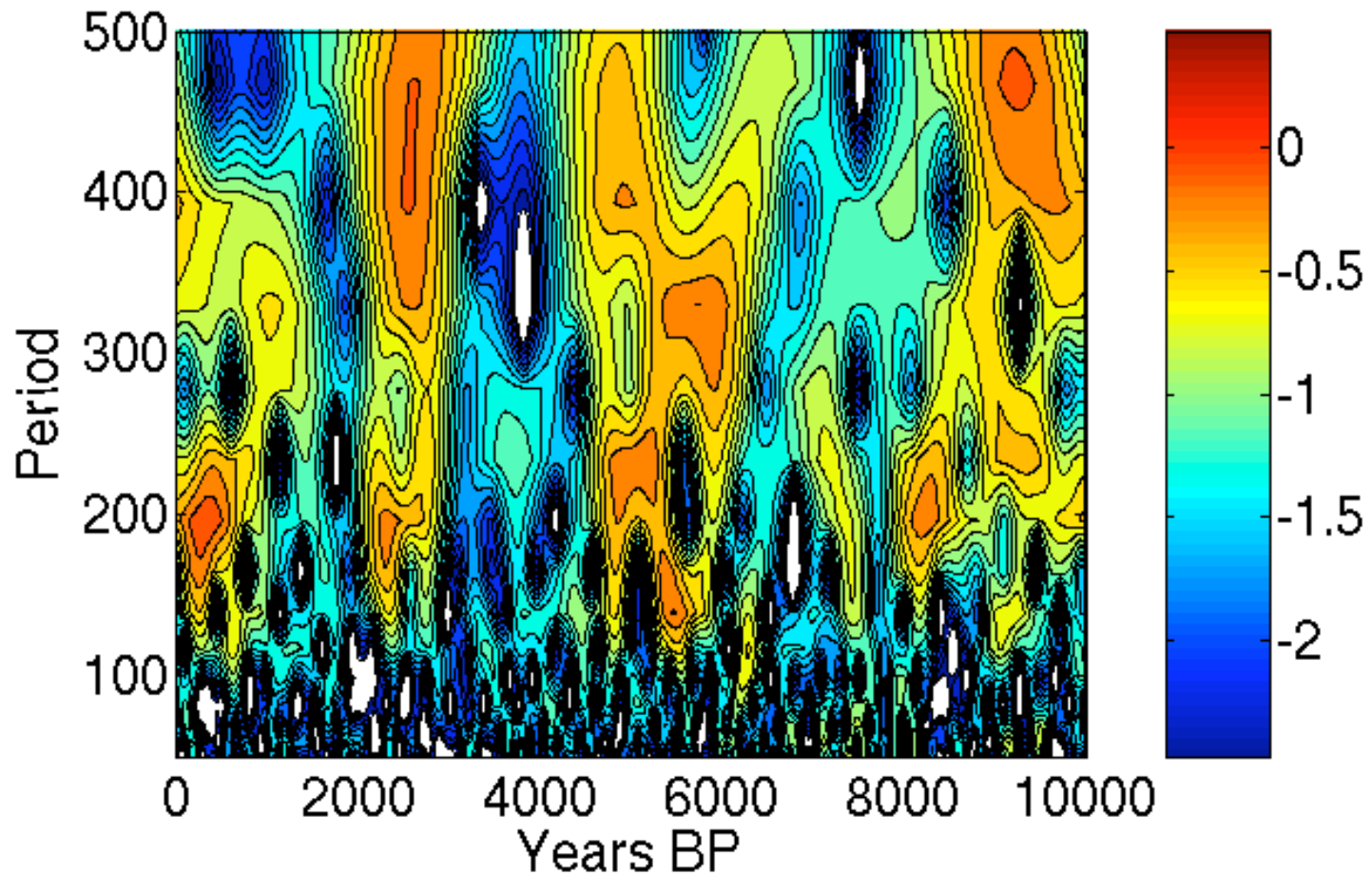


# Reconstructions of Sunspots



S.K. Solanki et al., Nature  
431 (2004) 1084-7

# Wavelet analysis of $^{14}\text{C}$ production



# Conclusions

- Cosmogenic radionuclides: useful tools to reconstruct solar variability over 10'000 years
- Limitations:
  - ◆ Geomagnetic dipole field
  - ◆ System effects
  - ◆ Time resolution: ~years

# Outlook

- Improved geomagnetic data
- System effects:
  - ◆ Comparison  $^{10}\text{Be}$  -  $^{14}\text{C}$  ✓
  - ◆ Additional  $^{10}\text{Be}$  records ✓
  - ◆ Transport models (GCM) ✓
- Relationship solar activity - solar irradiance