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Solar Variations and Climate Change: The View from Ice Cores

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How much Sun is in the Ice?

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Thanks

- Eawag-Group
- AMS-Group ETH Zürich
- SORCE

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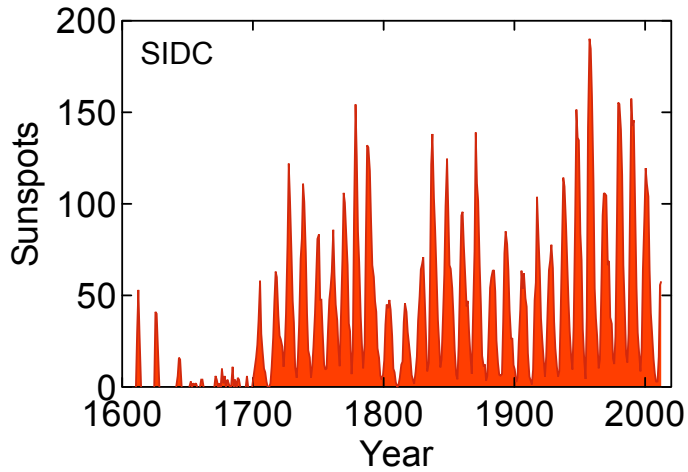
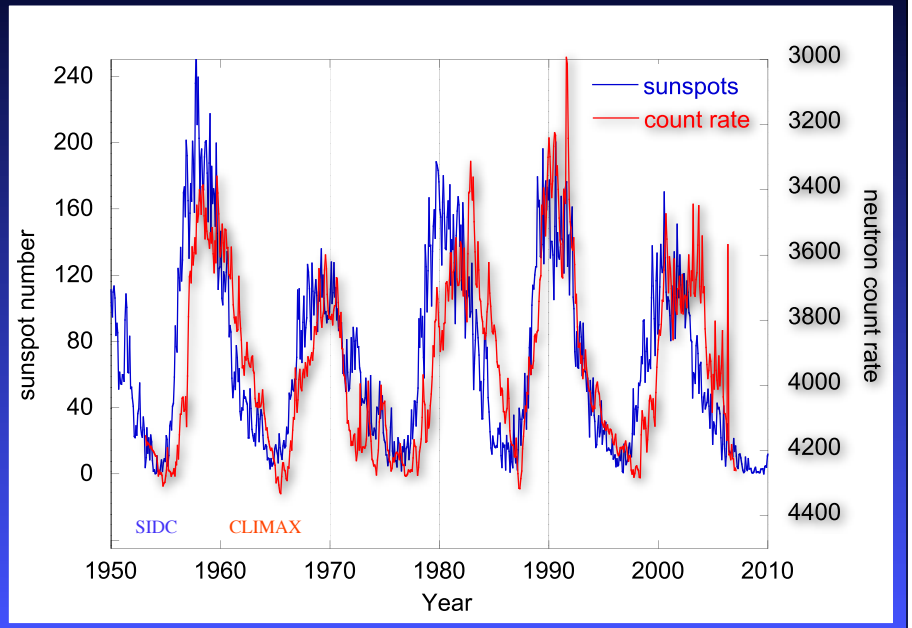
Outline

- Solar Variations: Direct Observations
- Solar Variations: Indirect Observations
  - Cosmogenic Radionuclides
- Ice as an Archive of Solar Variation and Climate Change
- Some Results
- Summary and Outlook

Sunspots



Solar Variability and Cosmic Rays



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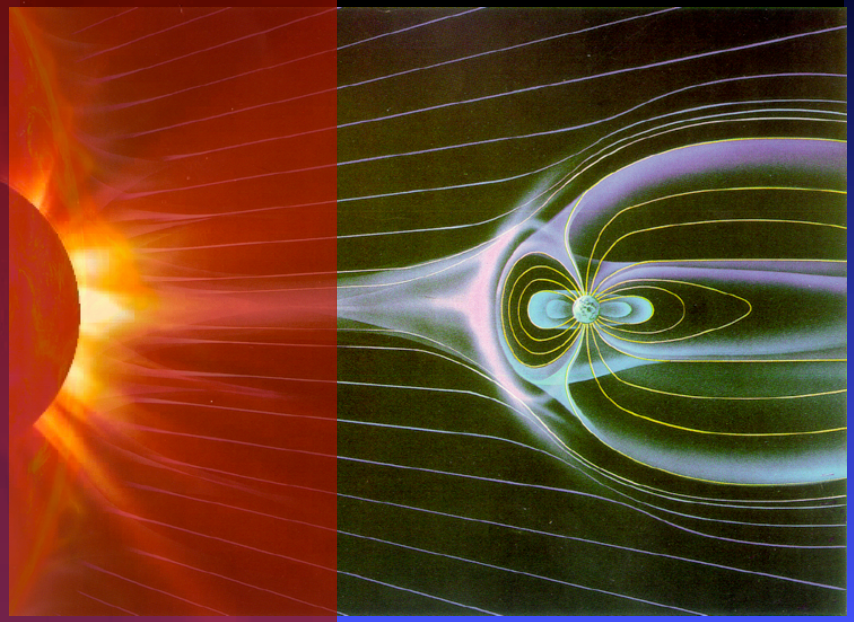
Cosmic Rays in the Heliosphere



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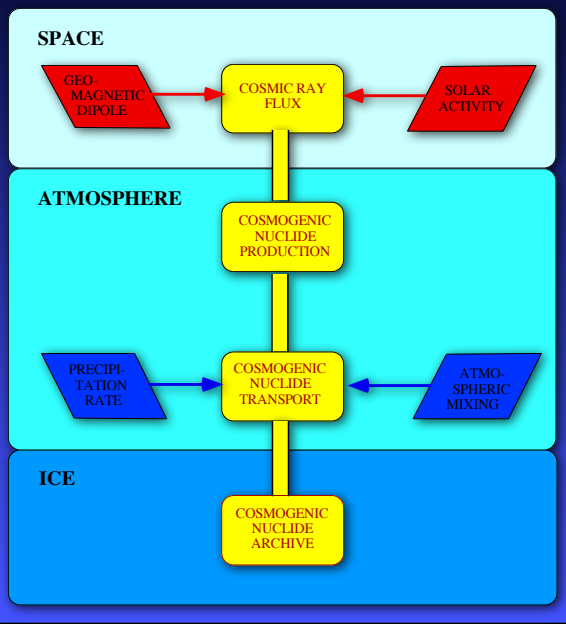
Cosmogenic Radionuclides: Production & Transport

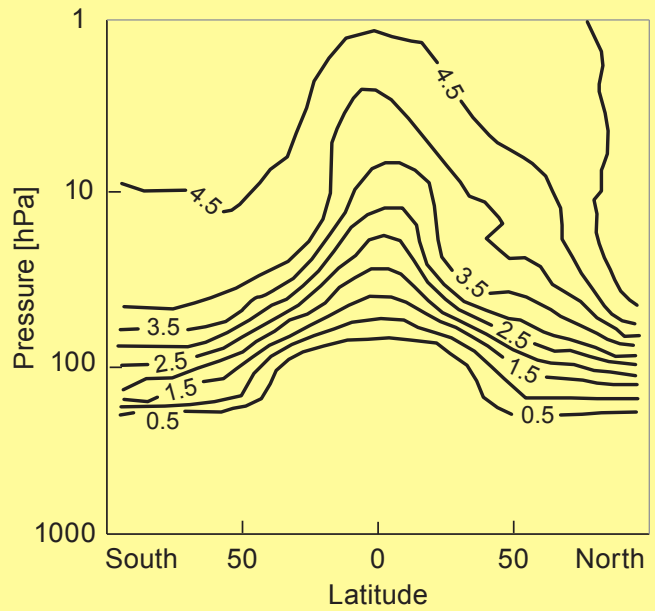
Galactic cosmic rays

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

^{10}Be Information from Cosmogenic Radionuclides



Mean Atmospheric Residence Time



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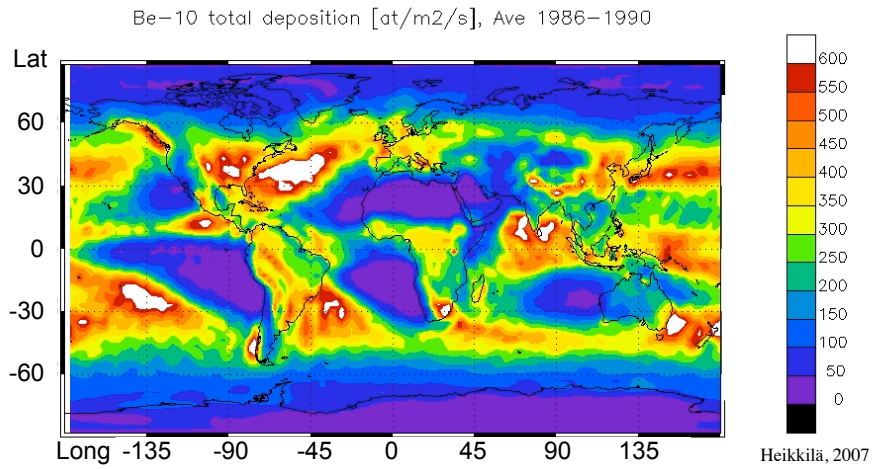
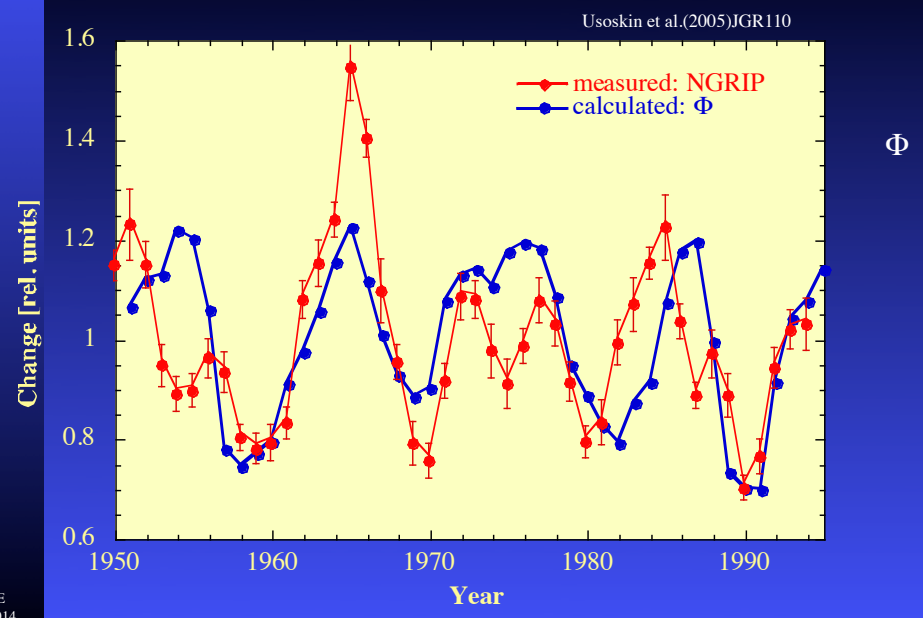
^{10}Be Deposition Flux 1986-1990

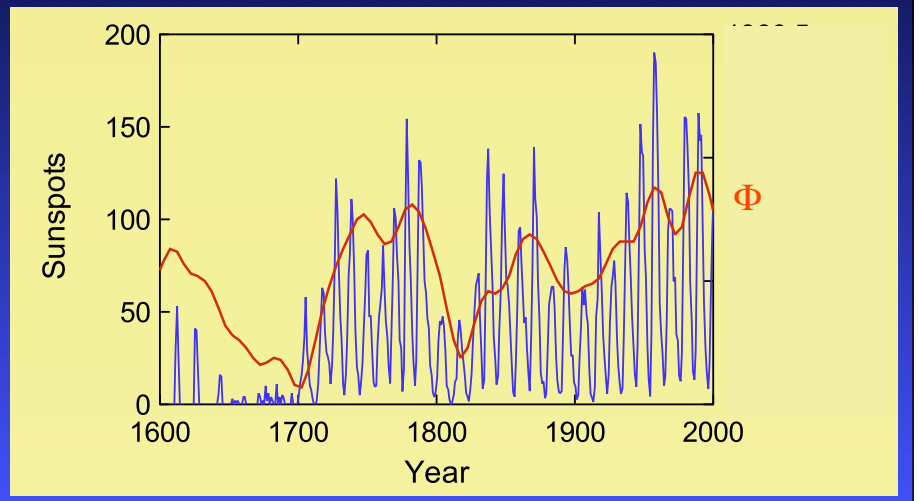


Heikkilä, 2007

^{10}Be expected versus measured

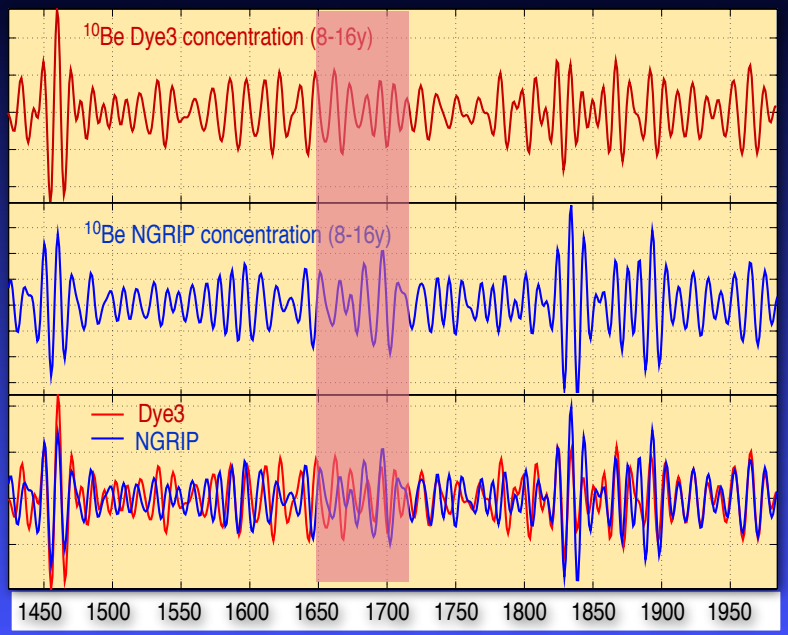


Sunspots and Φ (1600 - 2000)



11-y Schwabe cycle

Berggren et al, GRL, 2009



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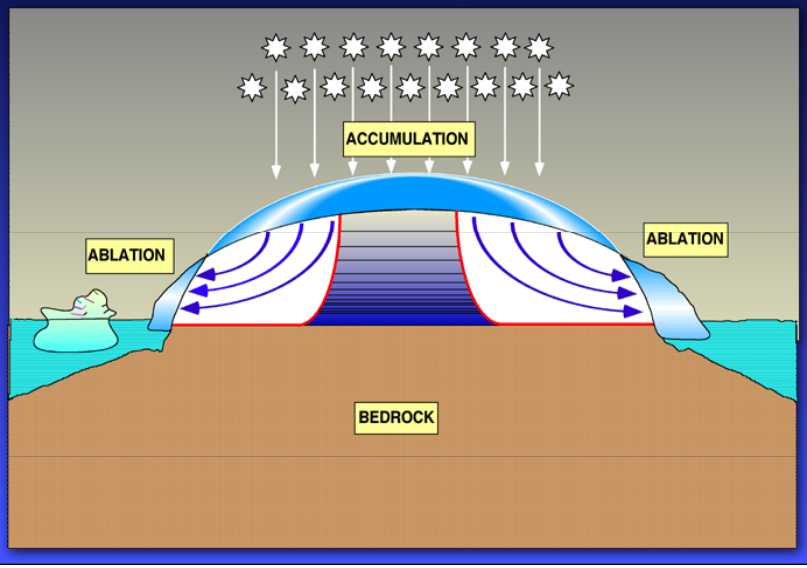
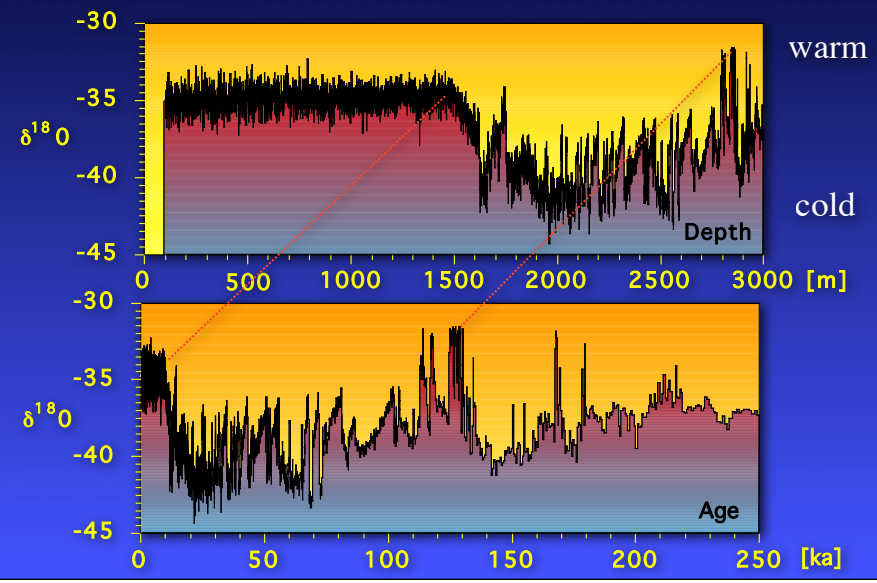
Archive Ice
Formation of an Ice Sheet



$\delta^{18}O$ GRIP versus Depth and Age



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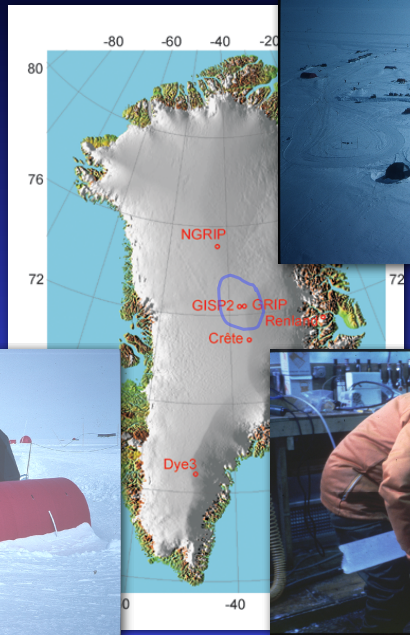
GRIP Ice Core



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Lab at Summit 1992

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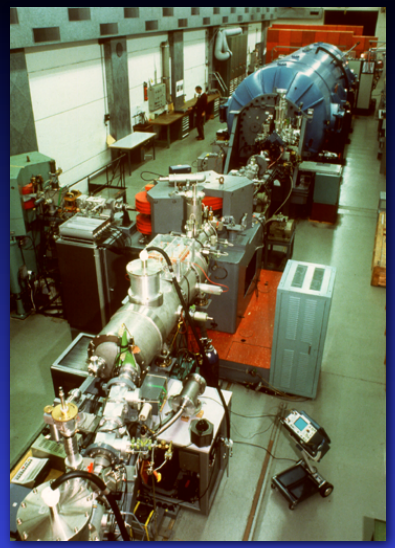
Detection



Decay counting technique: 10 tons of ice

AMS technique: <1 kg of ice

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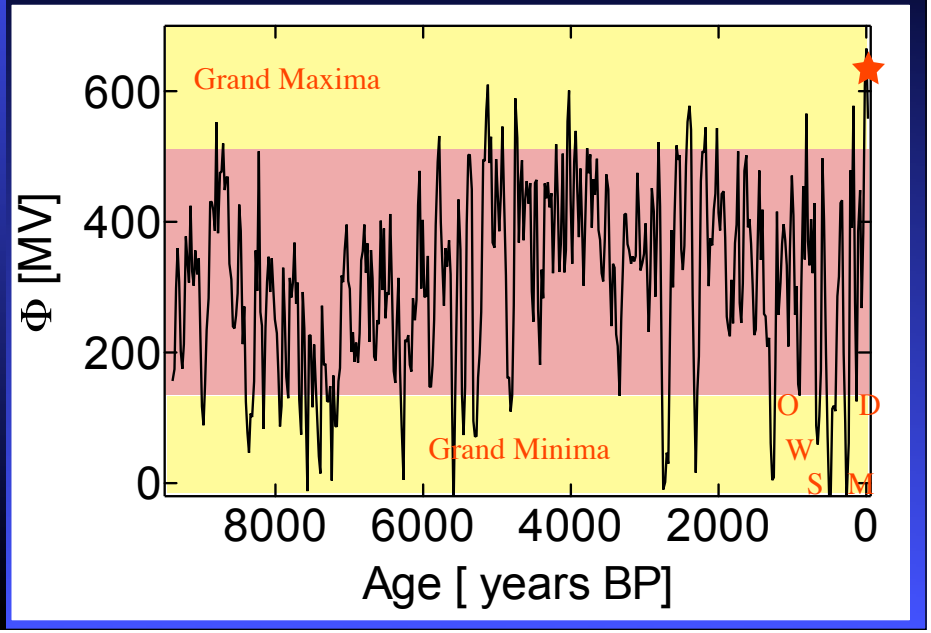
Solar Modulation Potential Φ



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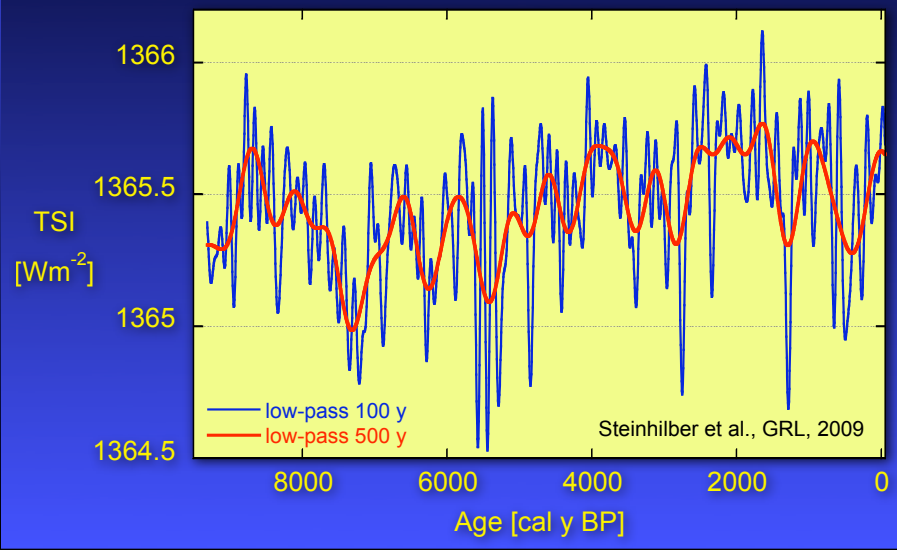
Total Solar Irradiance (TSI)



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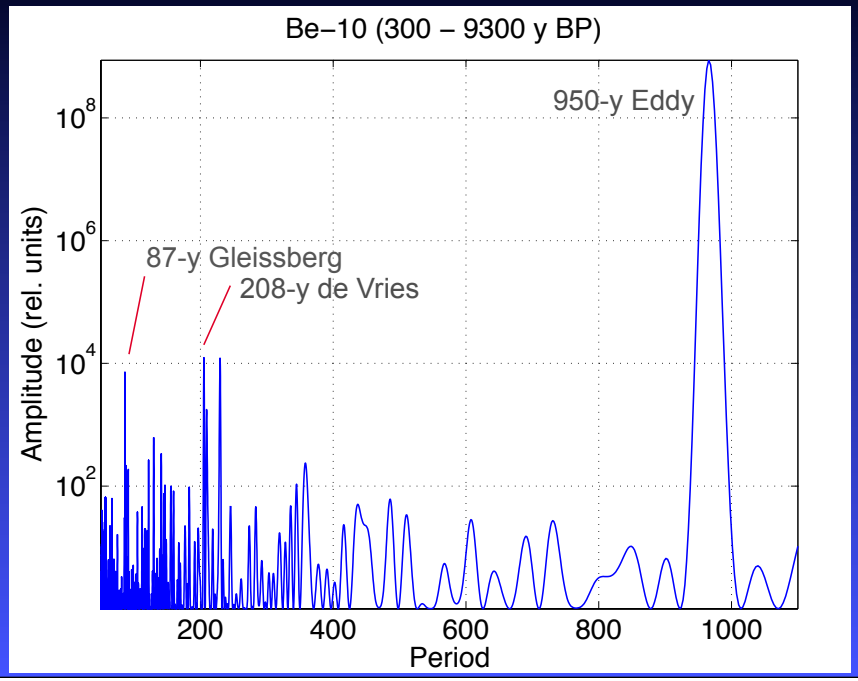
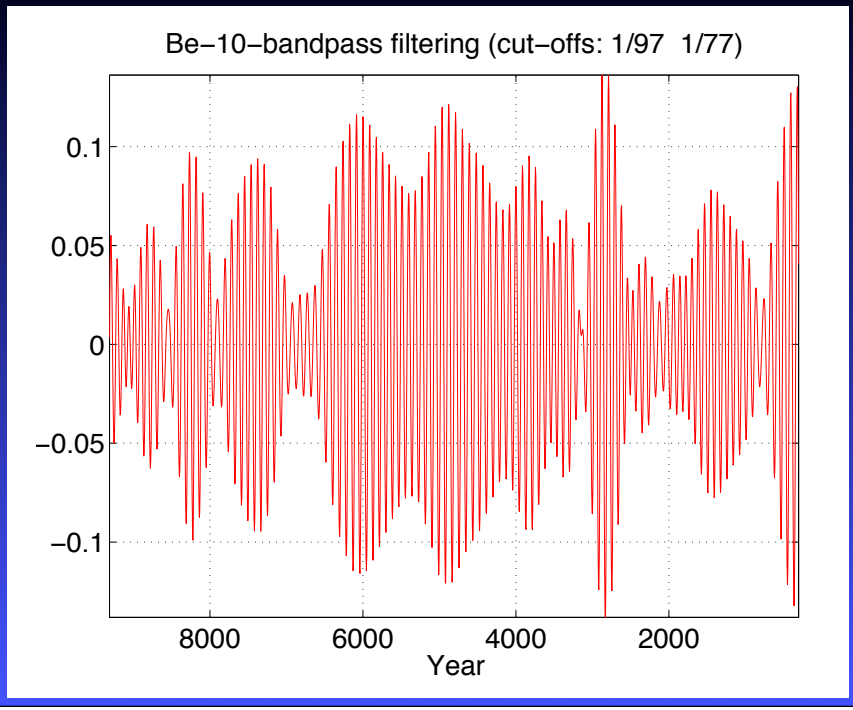
Powerspectrum ^{10}Be (GRIP Ice Core)

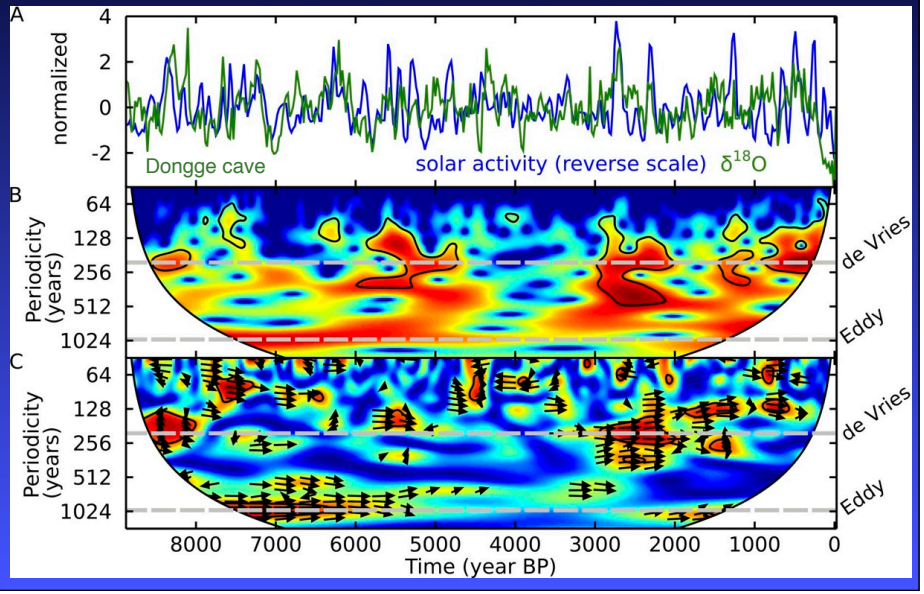


87-y Gleissberg Cycle



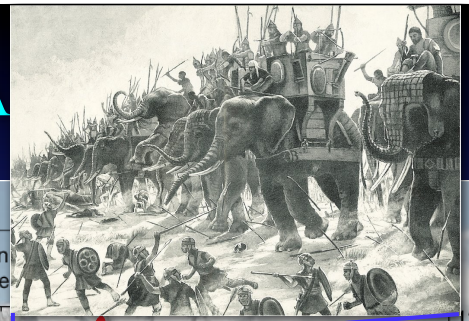
Solar Variation (TSI) and Climate Change (Asian Monsoon)

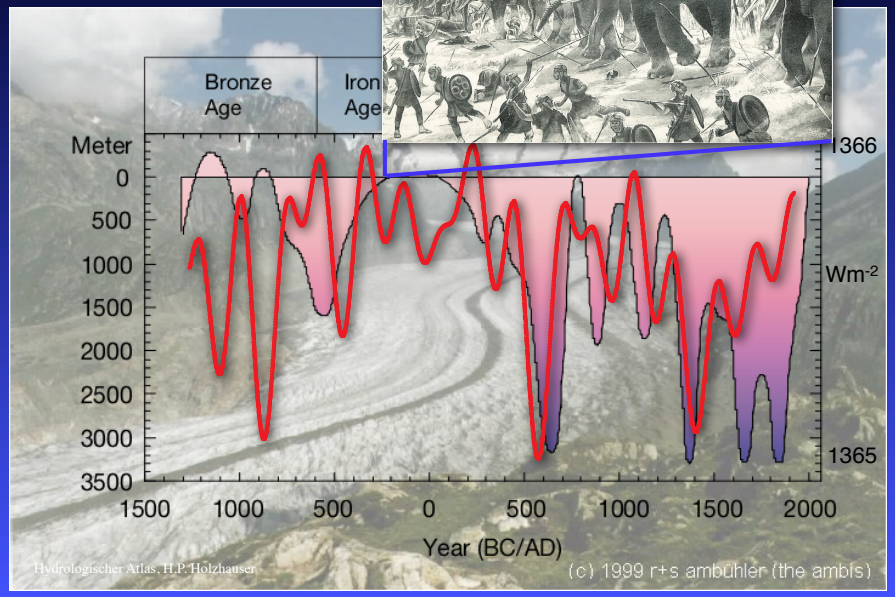
Steinhilber et al, PNAS,2012
Wang et al, Science,2005



Evidence from glacier (Aletsch)

Length of the A





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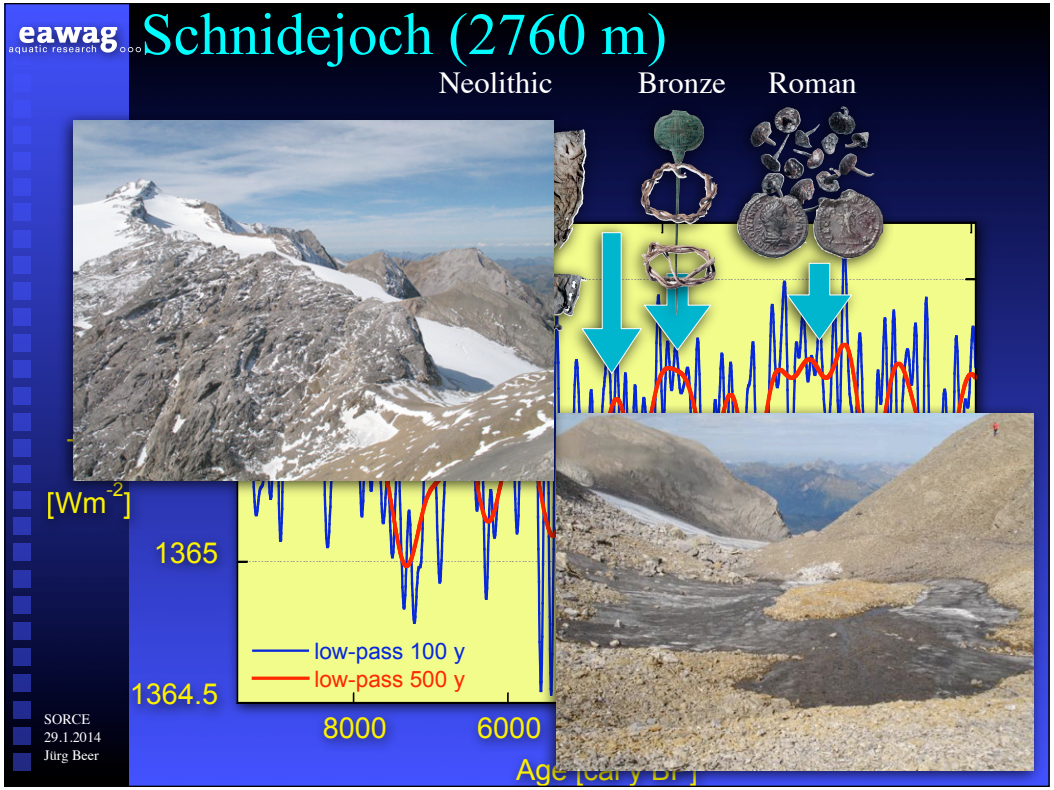
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Schnidejoch (2760 m)
Neolithic
Bronze
Roman
[Wm-2]
1365
1364.5
low-pass 100 y
low-pass 500 y
8000
6000
Age [cal y BP]
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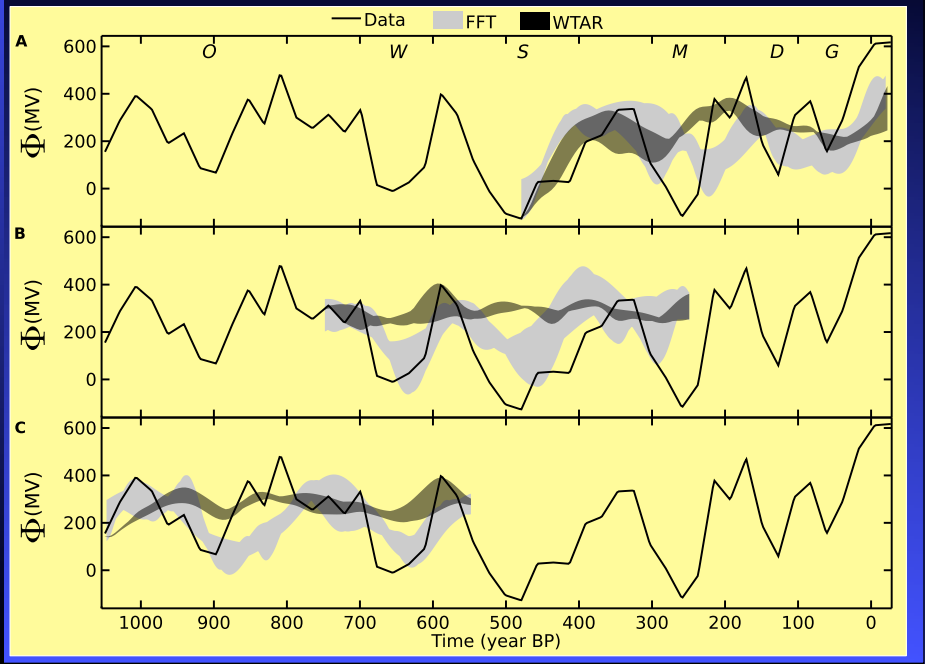
Summary and Outlook

- Grand Minima
  - ~20 per 10,000 y
  - 70-110 y duration, cluster
  - Dynamo running
- Grand maxima
  - ~all instrumental information: active Sun
- long-term periods: 87, 104, 150, 208, 506, 950, 2200-y cyles
  - stable periodicities, variable amplitudes

Prediction of past 500 y intervals



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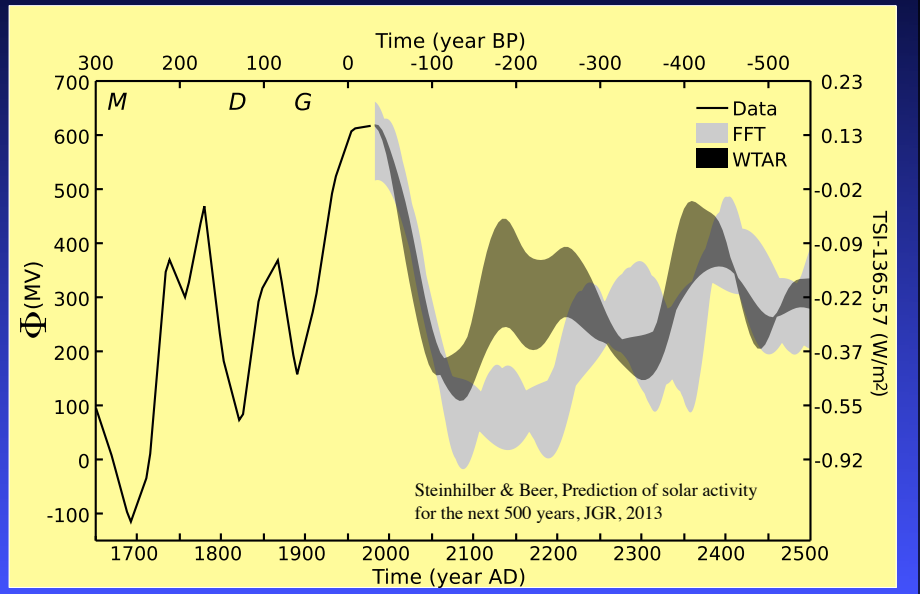
Predictions of future 500 y



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Kauri trees: ^{14}C back to 50,000 BP

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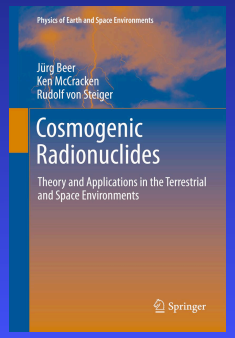
Literature