Cosmic Rays and Cosmogenic Isotopes

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COSMOGENIC DATA

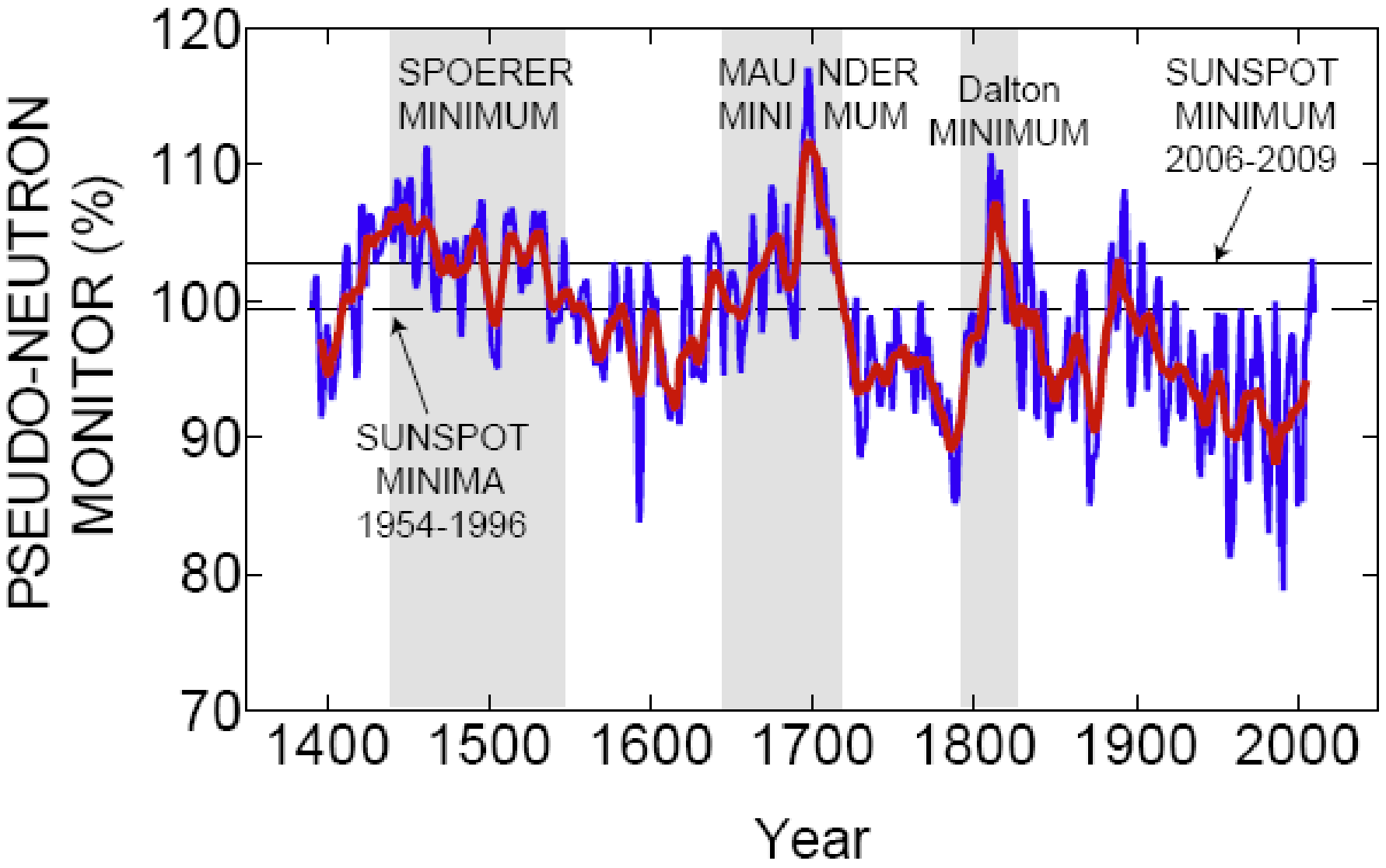
NOT OBSERVATIONS BY MANKIND-

BUT OBSERVATIONS BY NATURE

That we have learned to interpret

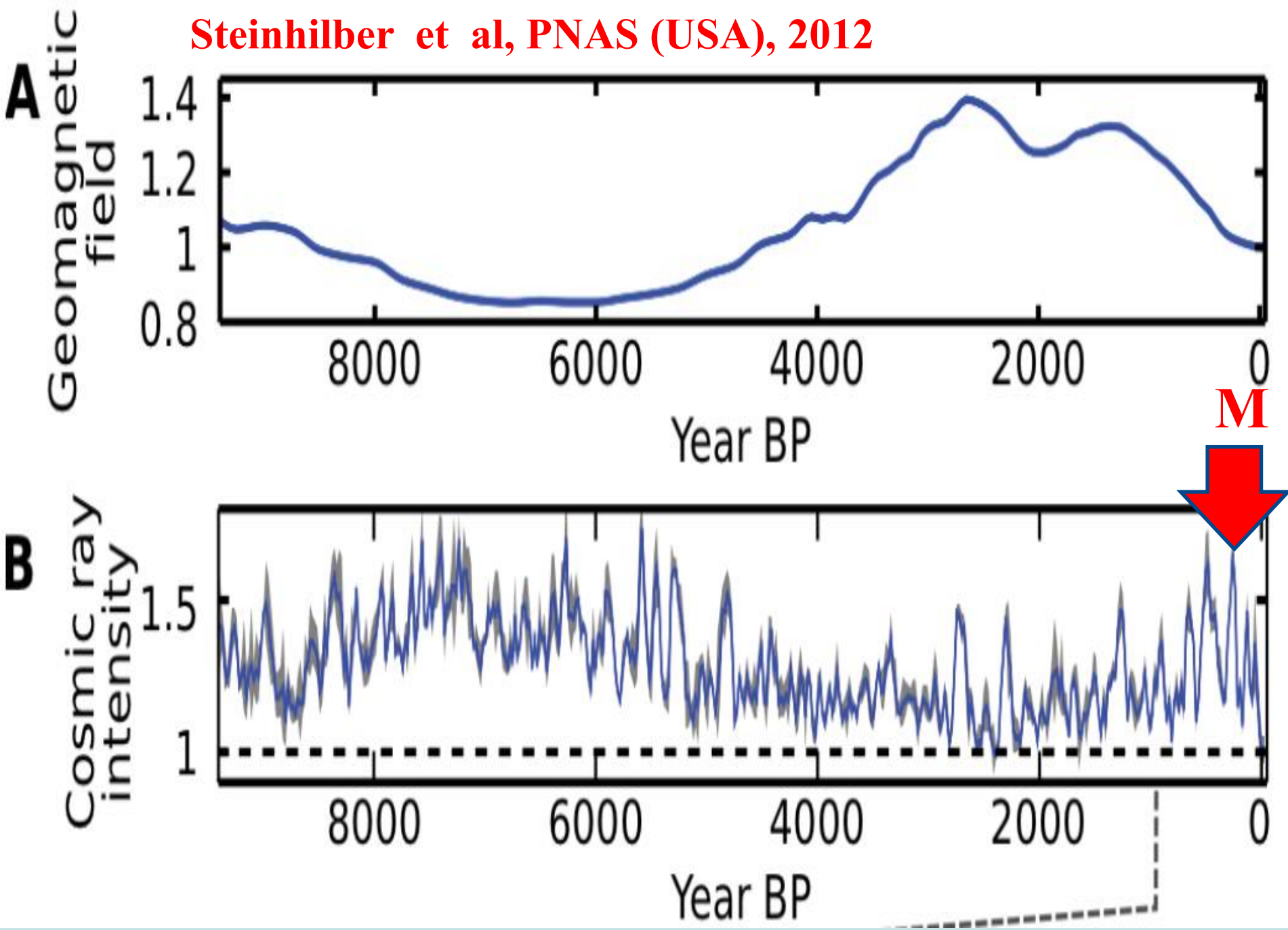
-SOME EXAMPLES OF DATA THAT NATURE HAS RECORDED FOR US

Dye 3 and North GRIP Annual Data

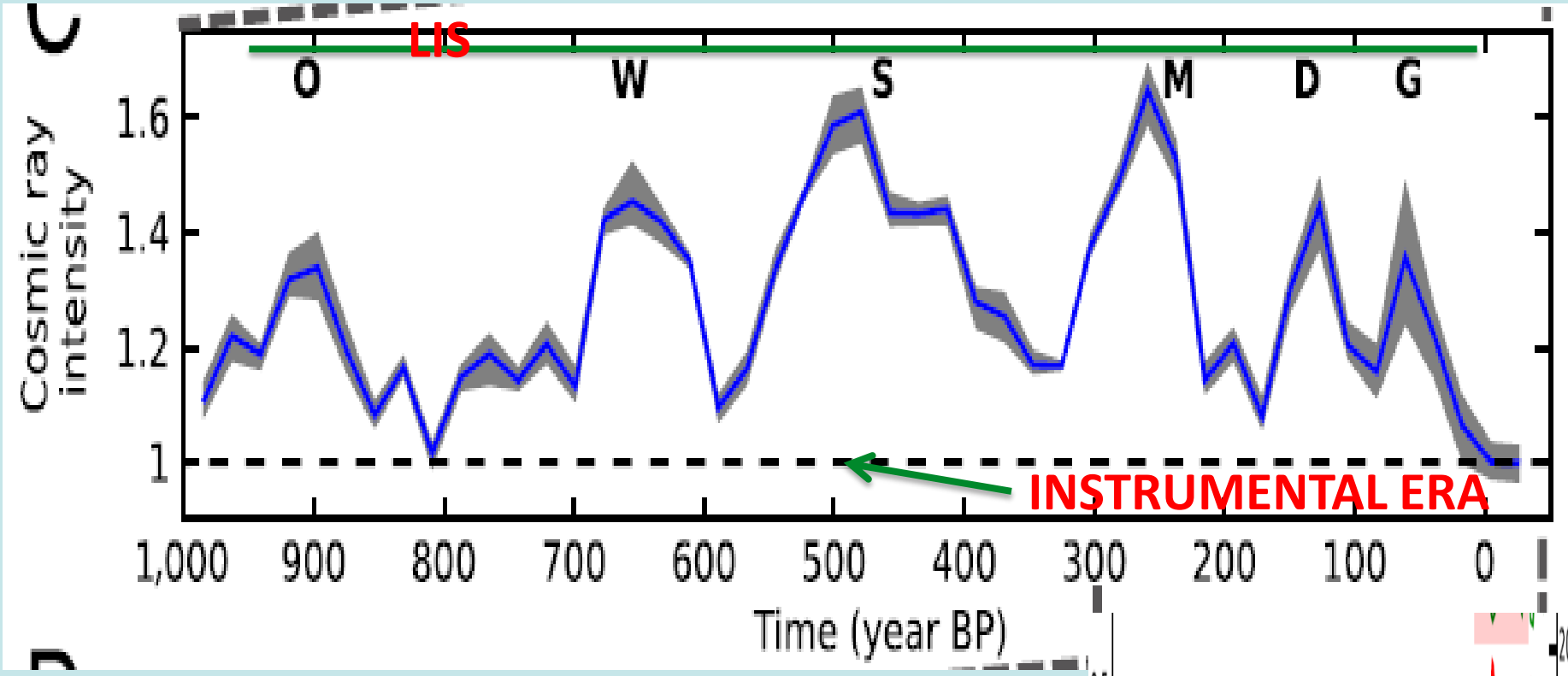


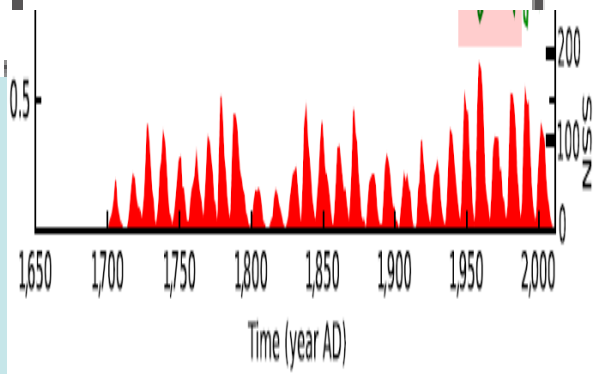
McCracken and Beer, JGR, 2014

Steinhilber et al, PNAS (USA), 2012



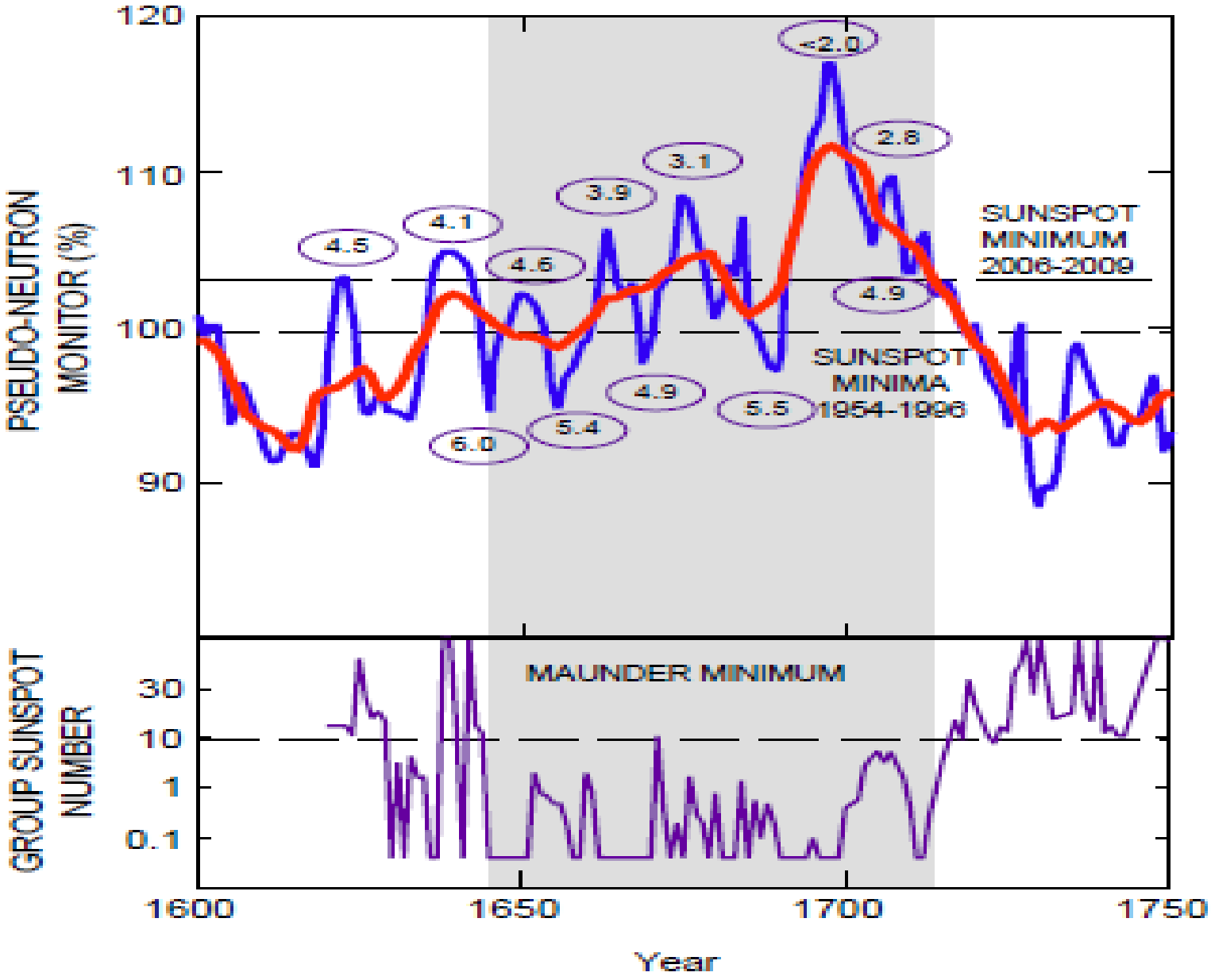
THE SEQUENCE OF GRAND MINIMA- 950-2000 AD





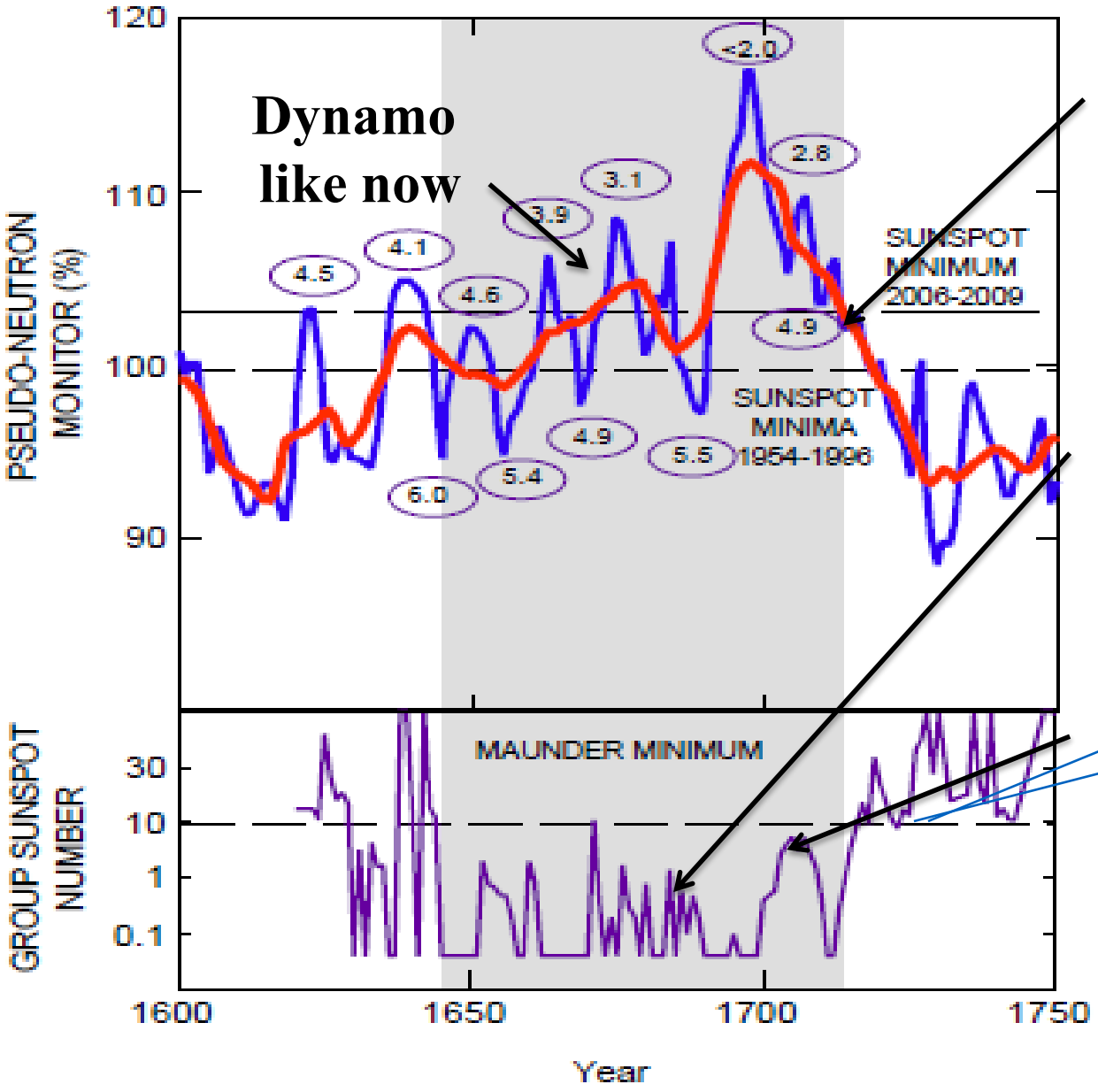
Steinhilber et al, PNAS (USA), 2012

THE MAUNDER MINIMUM – UP CLOSE.



McCracken and Beer, JGR, 2014

RASH SPECULATION- Extending our horizons



Minor solar activity
Major PCR decrease

"Huge" sunspot (Cassini)
Large ^{10}Be burst

White light flare
Large ^{10}Be burst

THIS TALK

WHAT ARE THE COSMOGENIC NUCLIDES…..

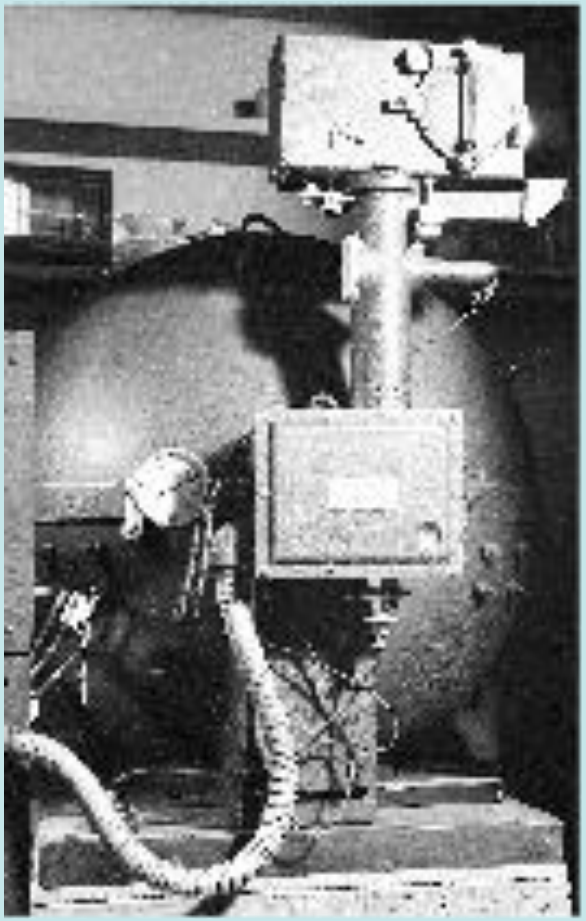
HOW DO WE MEASURE THEM

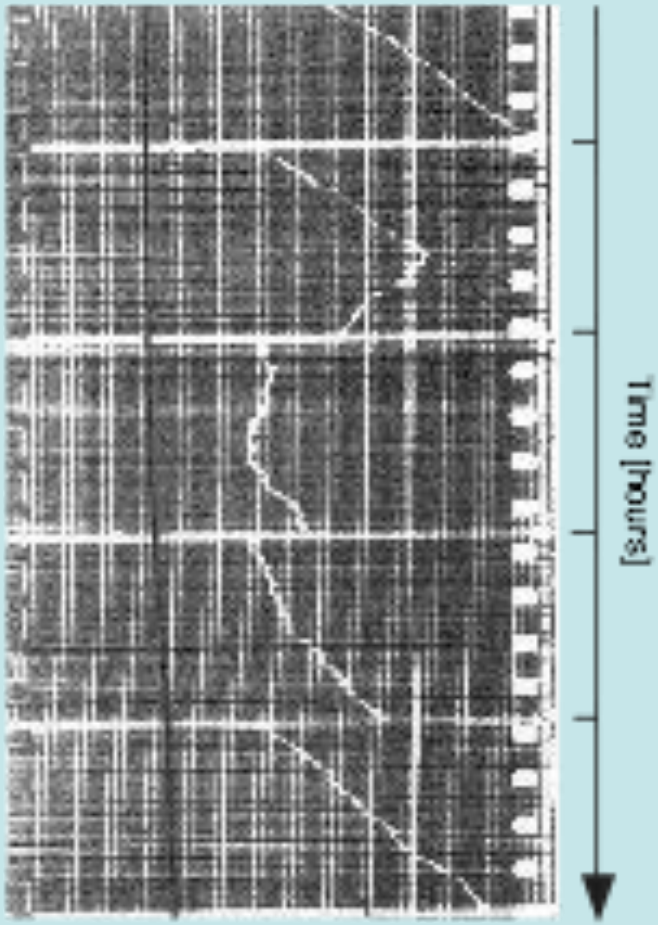
HOW WE CALIBRATE THEM TO THE PRESENT,

AND WHAT THEY TELL US ABOUT SPACE CLIMATE

(and Physics can be fun).

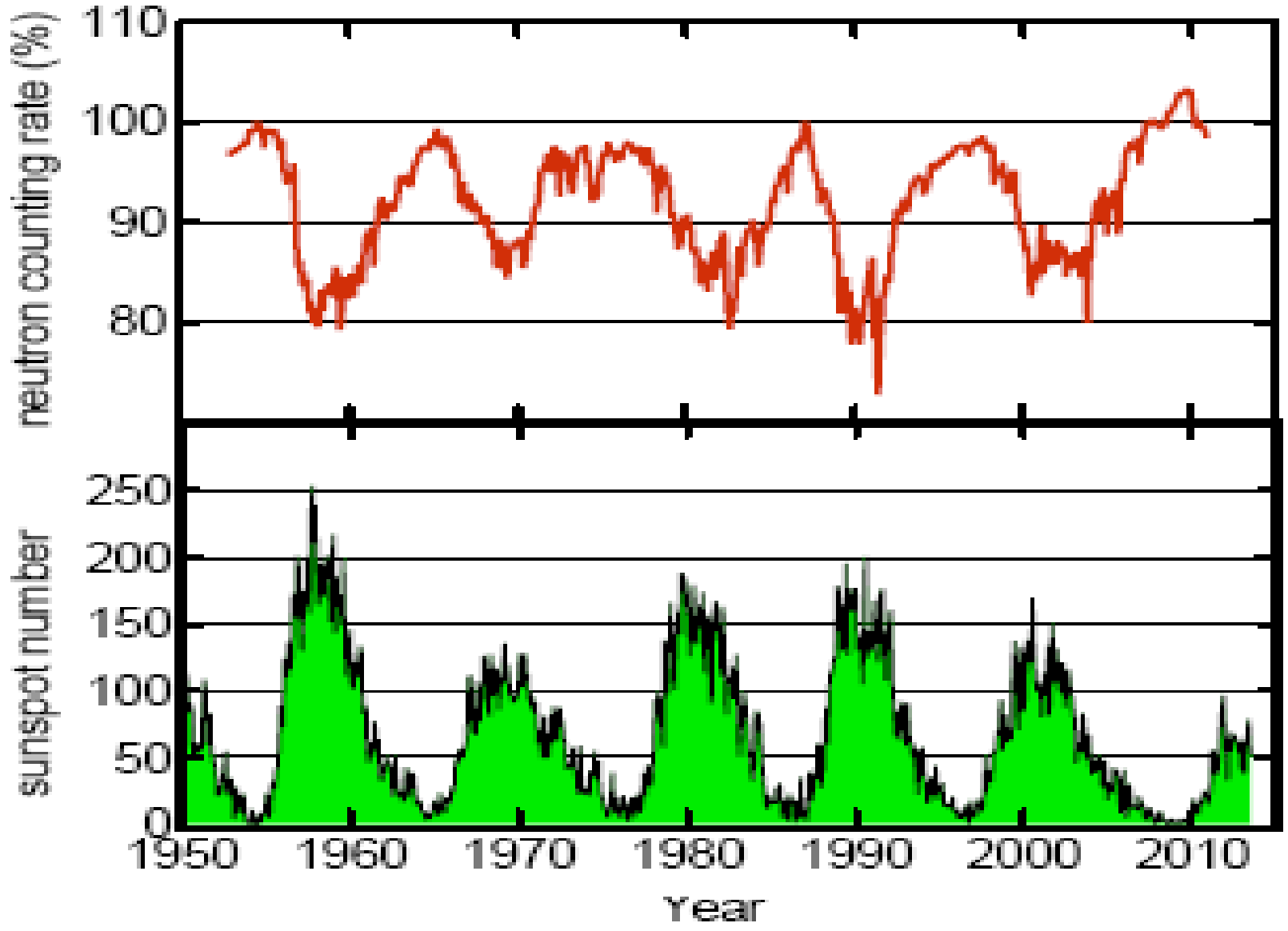
Ionization Chamber, Huancayo, Peru. 1935-1970.



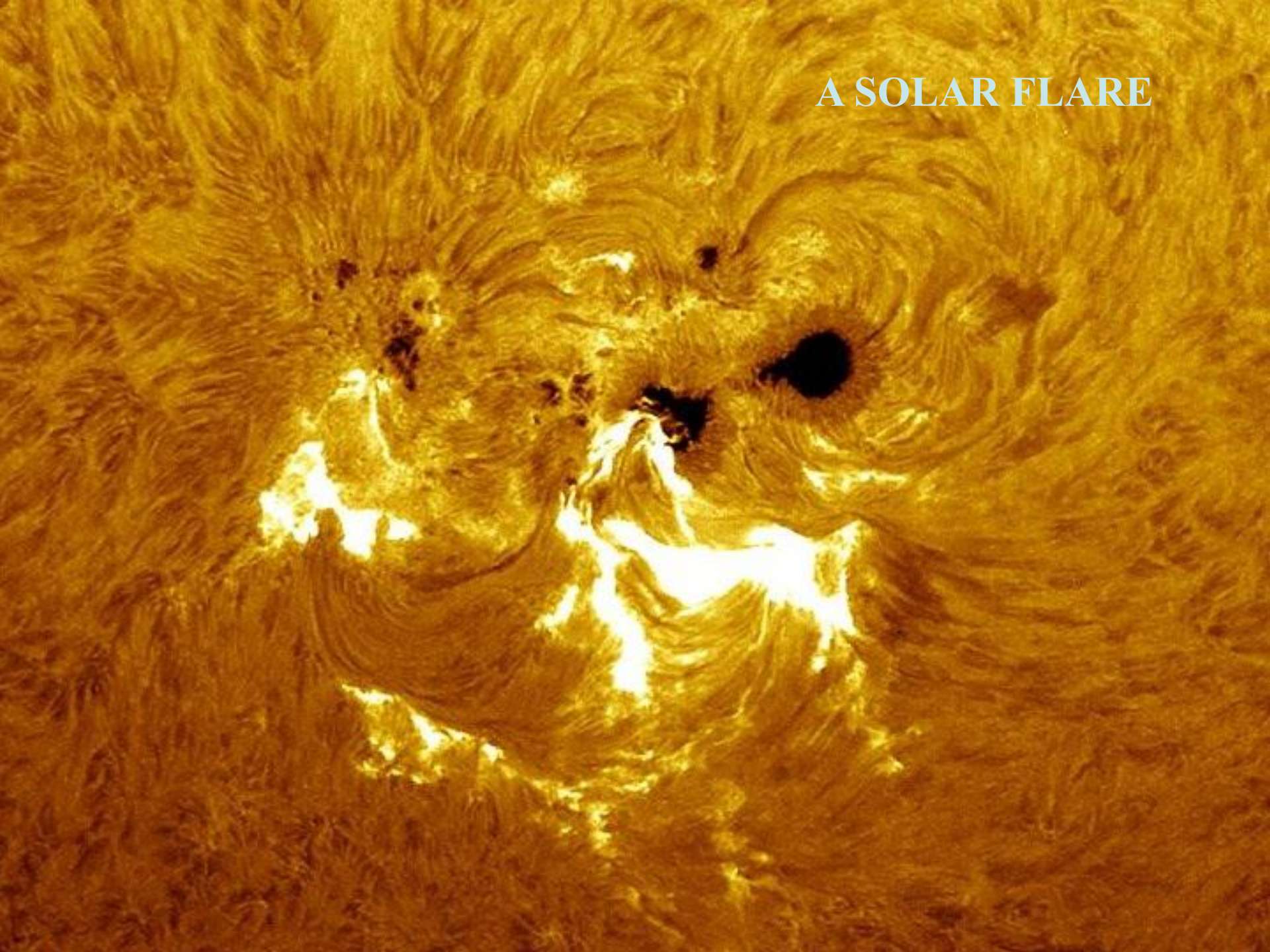


Neutron Monitor, Tasmania, 1956

THE COSMIC RAYS-NEUTRON MONITOR DATA



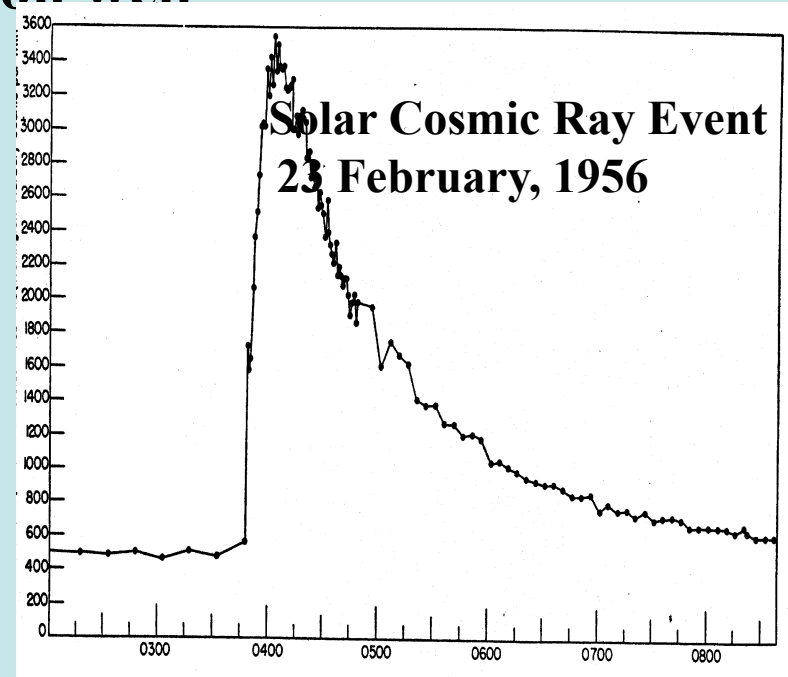
McCracken and Beer, 2014


A SOLAR FLARE

Keeping the Right Stuff - Right

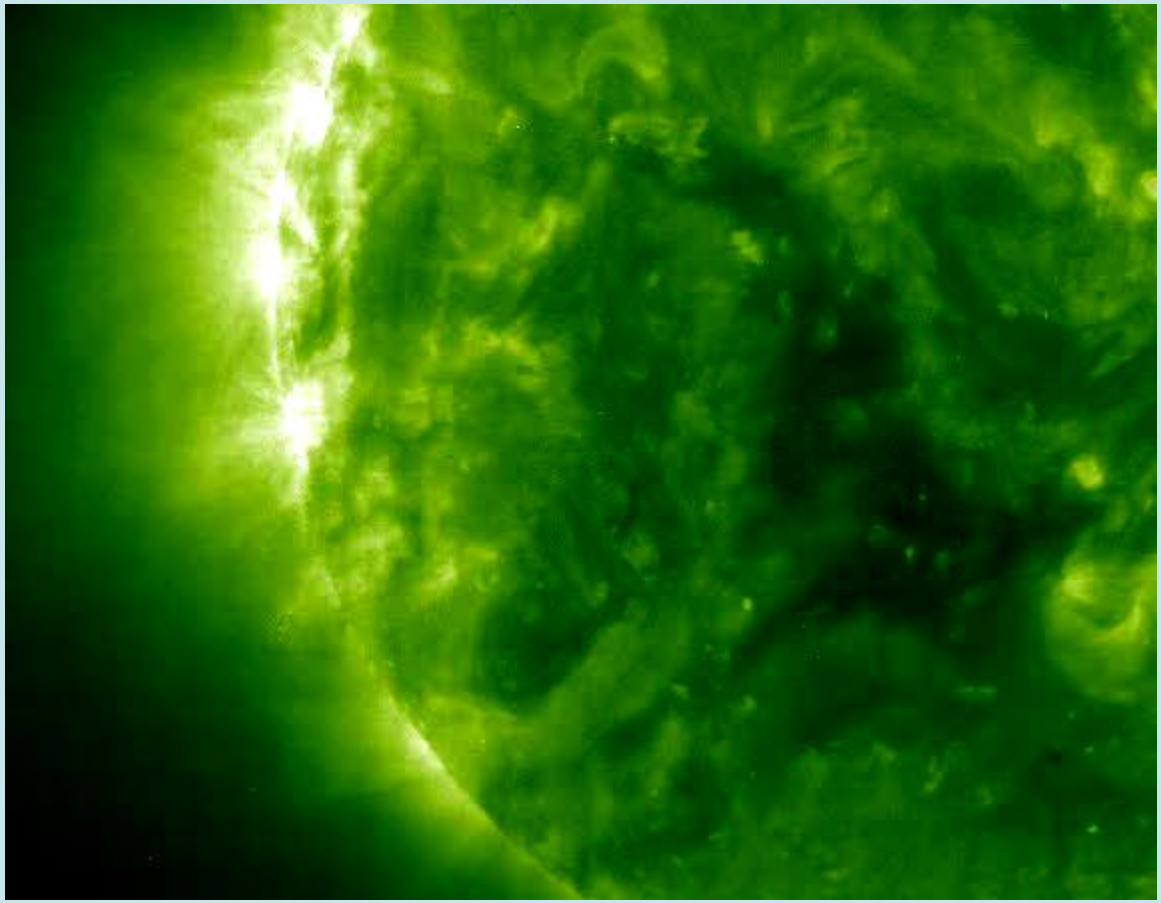
Problem - To protect the Apollo astronauts if a solar flare blasts the Moon with intense cosmic rays

Answer - Set up an expert committee
- Choose the time to go to the Moon well
- Give them a shovel.



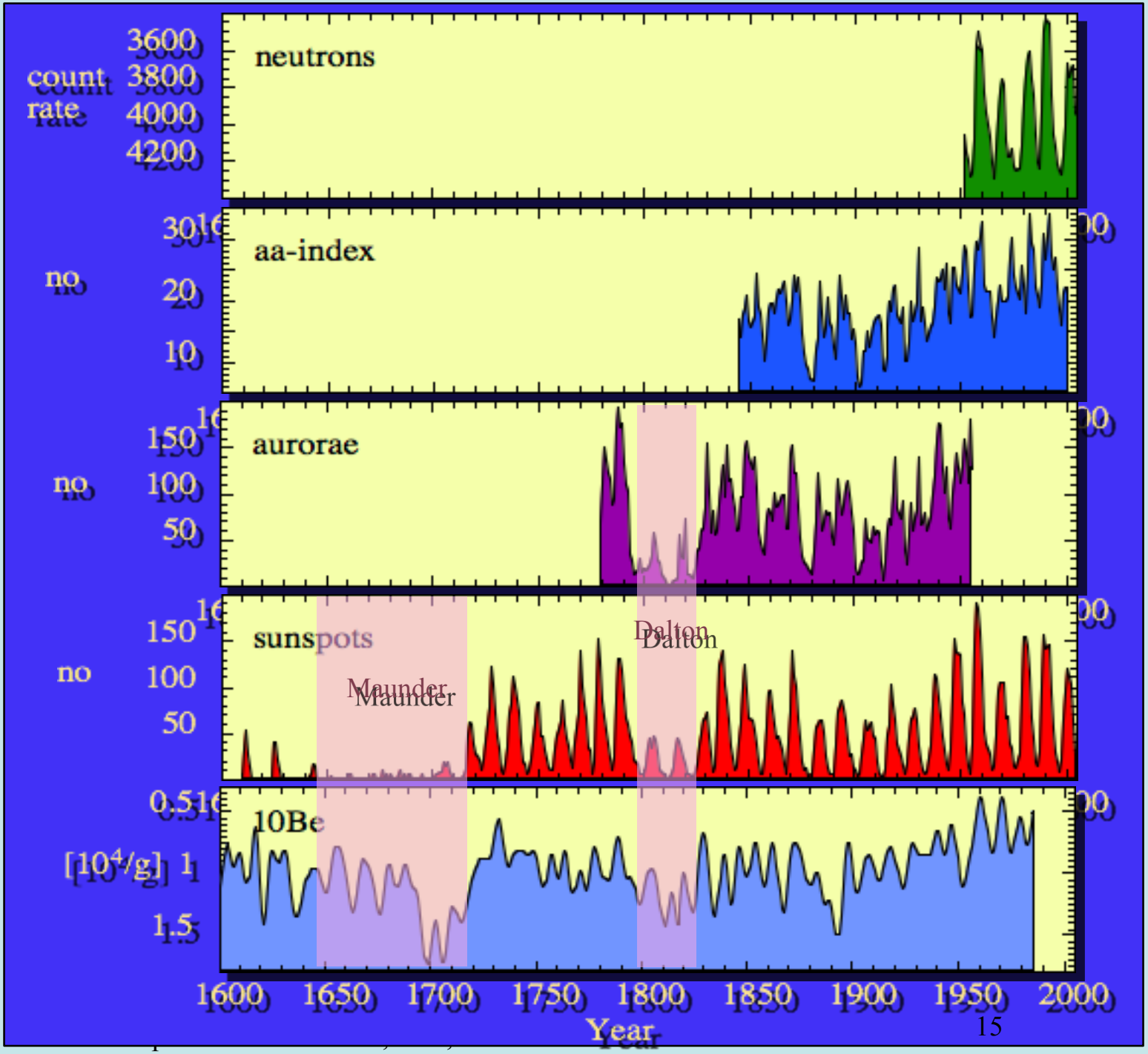
Heliomagnetic Modulation

- *Forbush Decrease*: Reduction of the cosmic ray intensity by eruptions of solar plasma. Time scale: days.

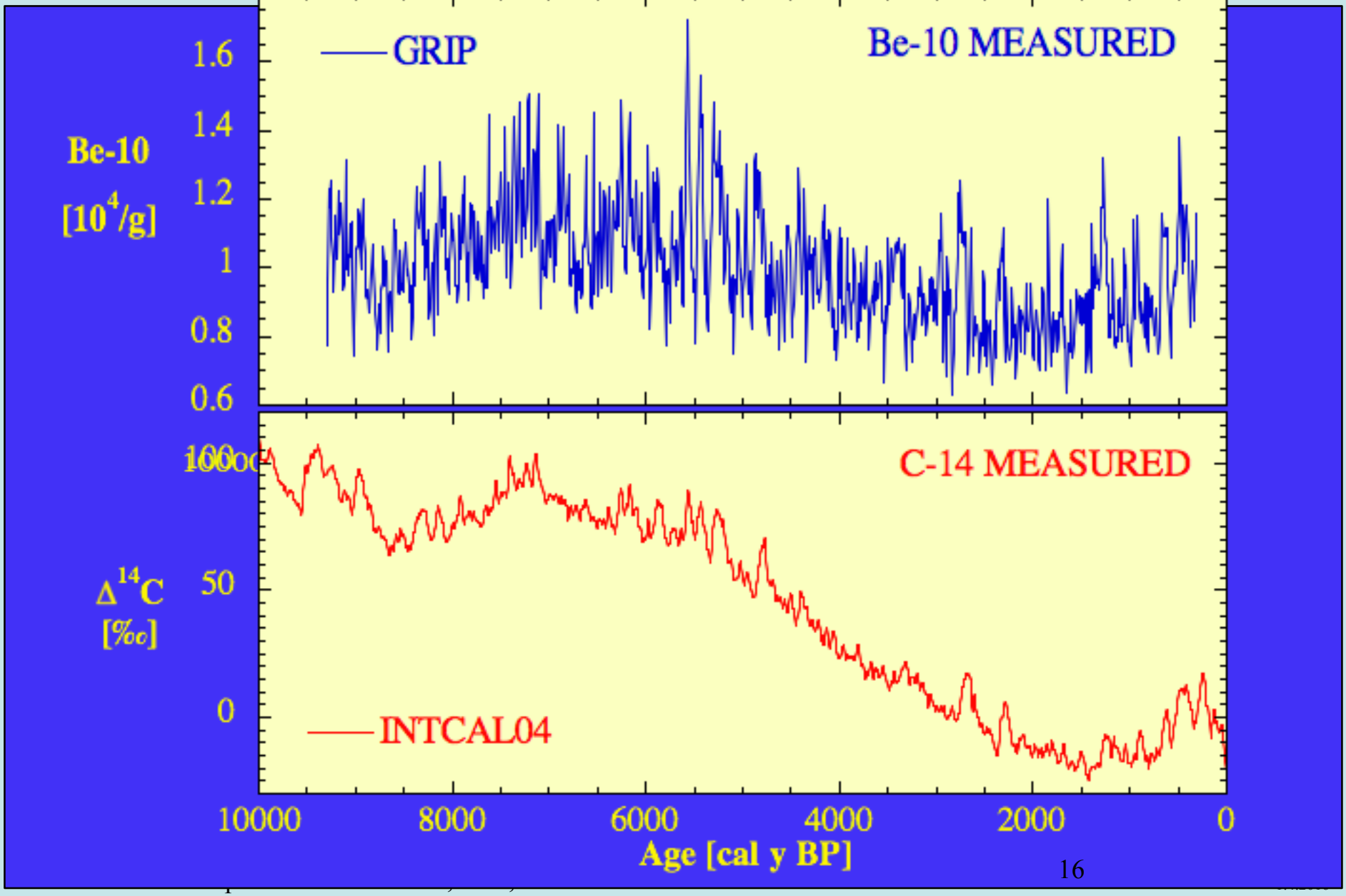


An extreme-ultraviolet telescope onboard the orbiting Solar and Heliospheric Observatory (SOHO) captured this false-color movie of the Nov. 4, 2003, X28 superflare near the sun's limb.

http://science.nasa.gov/headlines/y2003/12nov_haywire.htm?list23606


neutrons
count rate
3600
3800
4000
4200
Climax
aa-index
no
20
10
Mayaud, 1973
aurorae
no
150
100
50
Legrand and Simon, 1987
sunspots
Maunder
Dalton
no
150
100
50
Hoyt and Schatten, 1998
10Be
[10⁴/g]
1
1.5
Beer et al., 1990
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year

Measured Signals



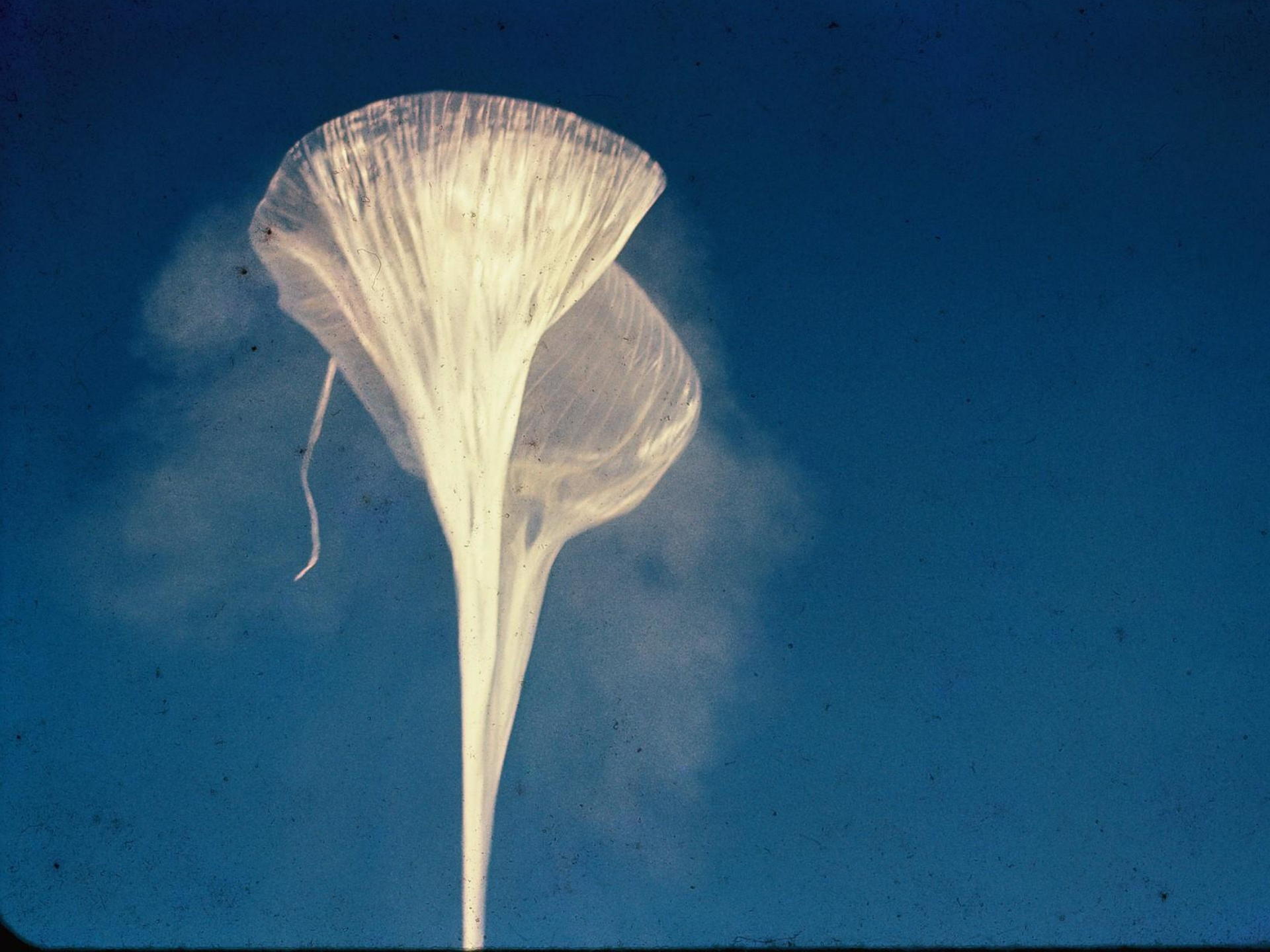
CALIBRATING THE COSMOGENIC DATA TO THE MODERN INSTRUMMENTAL MEASUREMENTS OF THE COSMIC RADIATION.

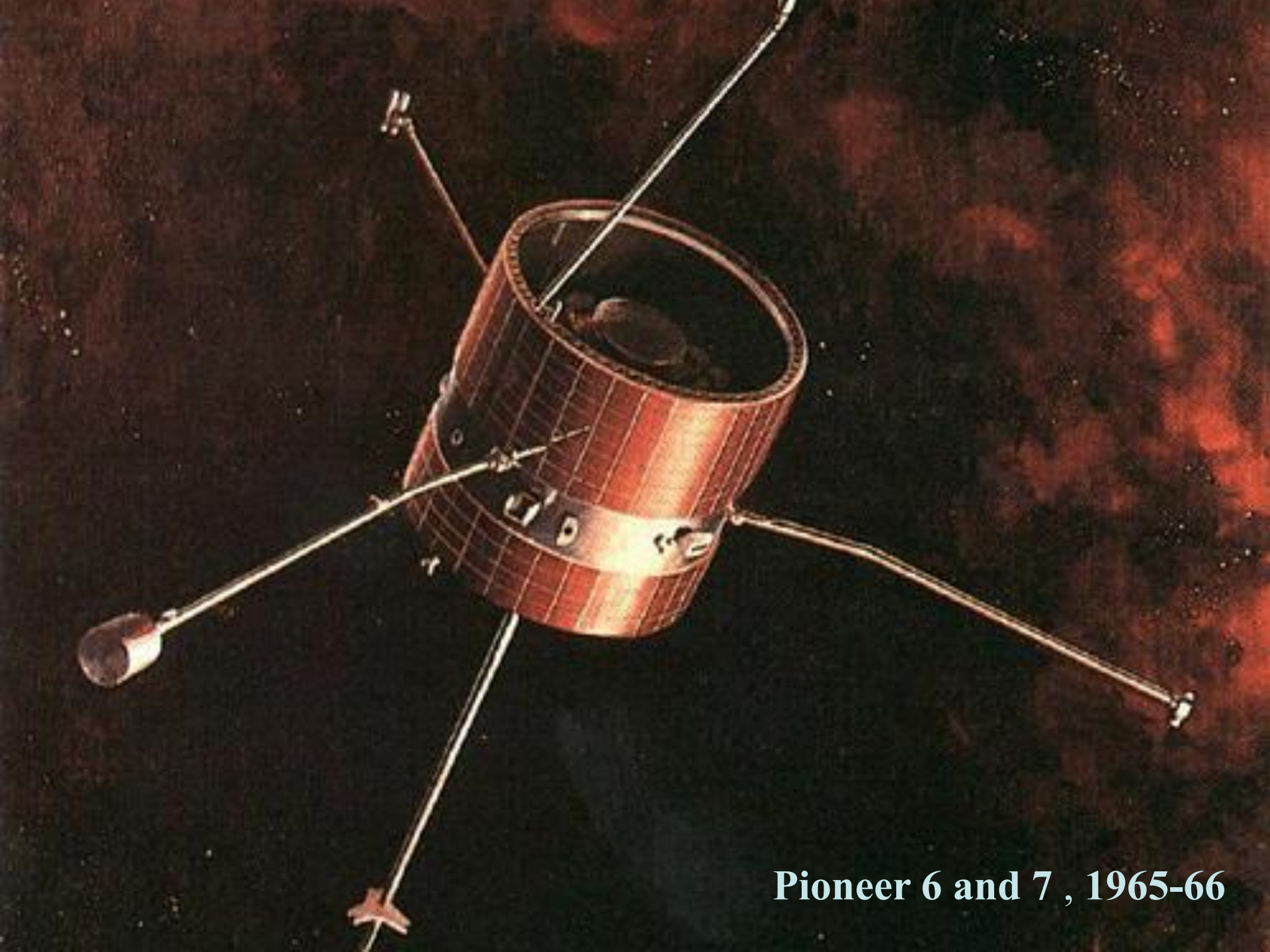
(1)Measure the cosmic radiation spectrum using balloon and satellite instruments(1960-2010).

(2)Determine how it varies with solar activity and parameterise it with the "Modulation Function",1960-70. (Gleeson and Axford, 1967))

(3)Use mathematical codes to compute the production rates of ^{10}Be and ^{14}C as a function of cosmic radiation flux ,1990-2000. (Masarik and Beer,1999)

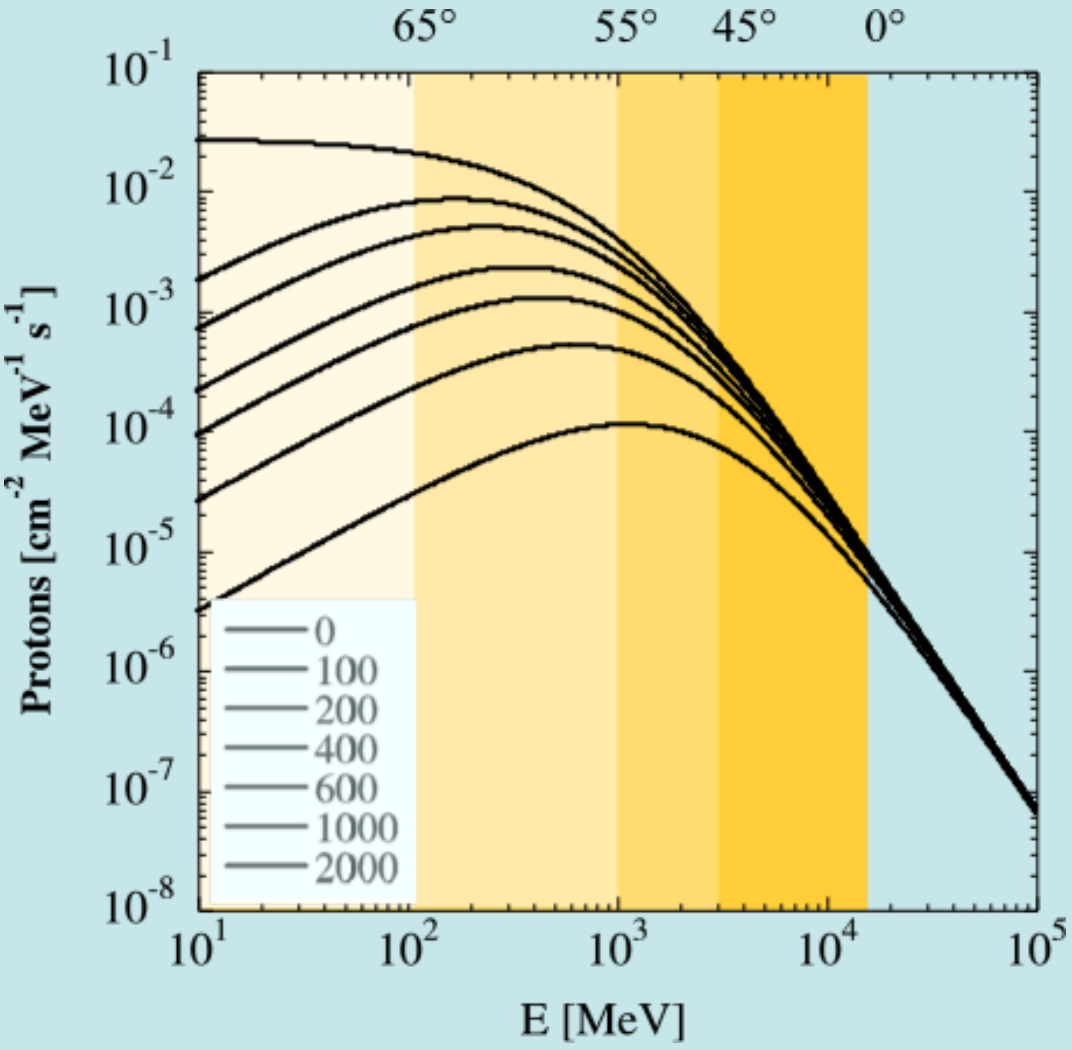

Hudson Bay, Northern Canada



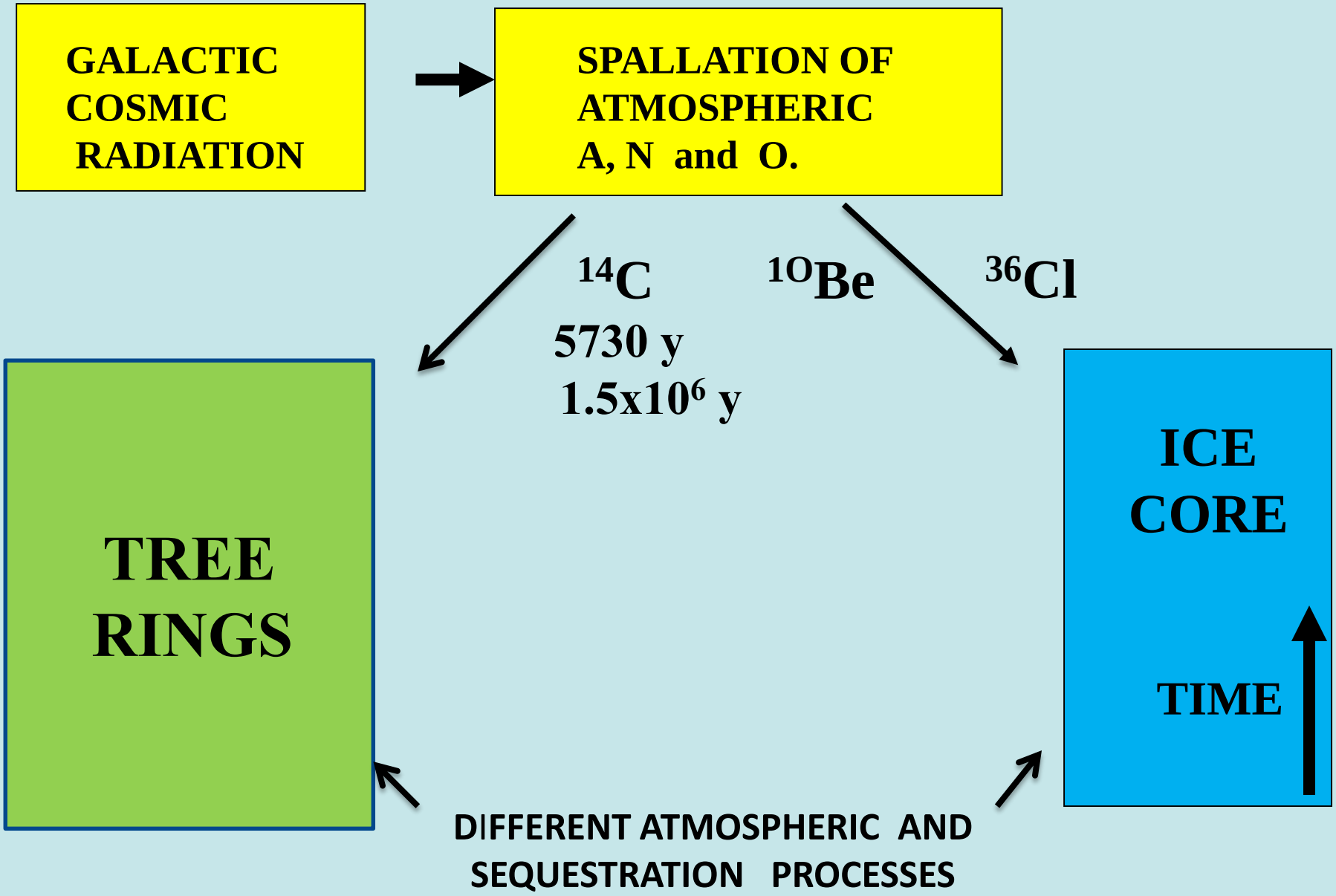


Pioneer 6 and 7 , 1965-66

Solar Modulation and Modulation Function



THE PALEO- COSMIC RADIATION RECORD

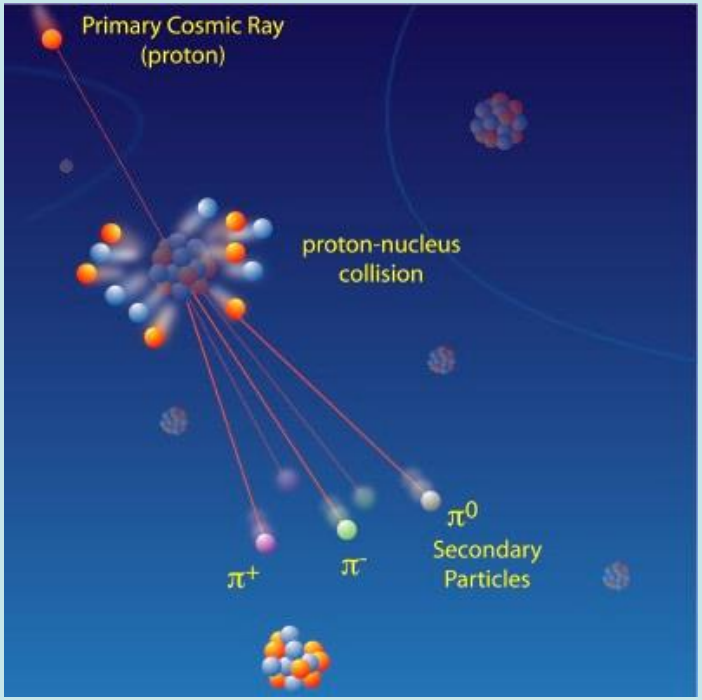


> 120 investigator years of data

1. Sources of Cosmogenic Isotopes

cosmogenic: produced by cosmic rays

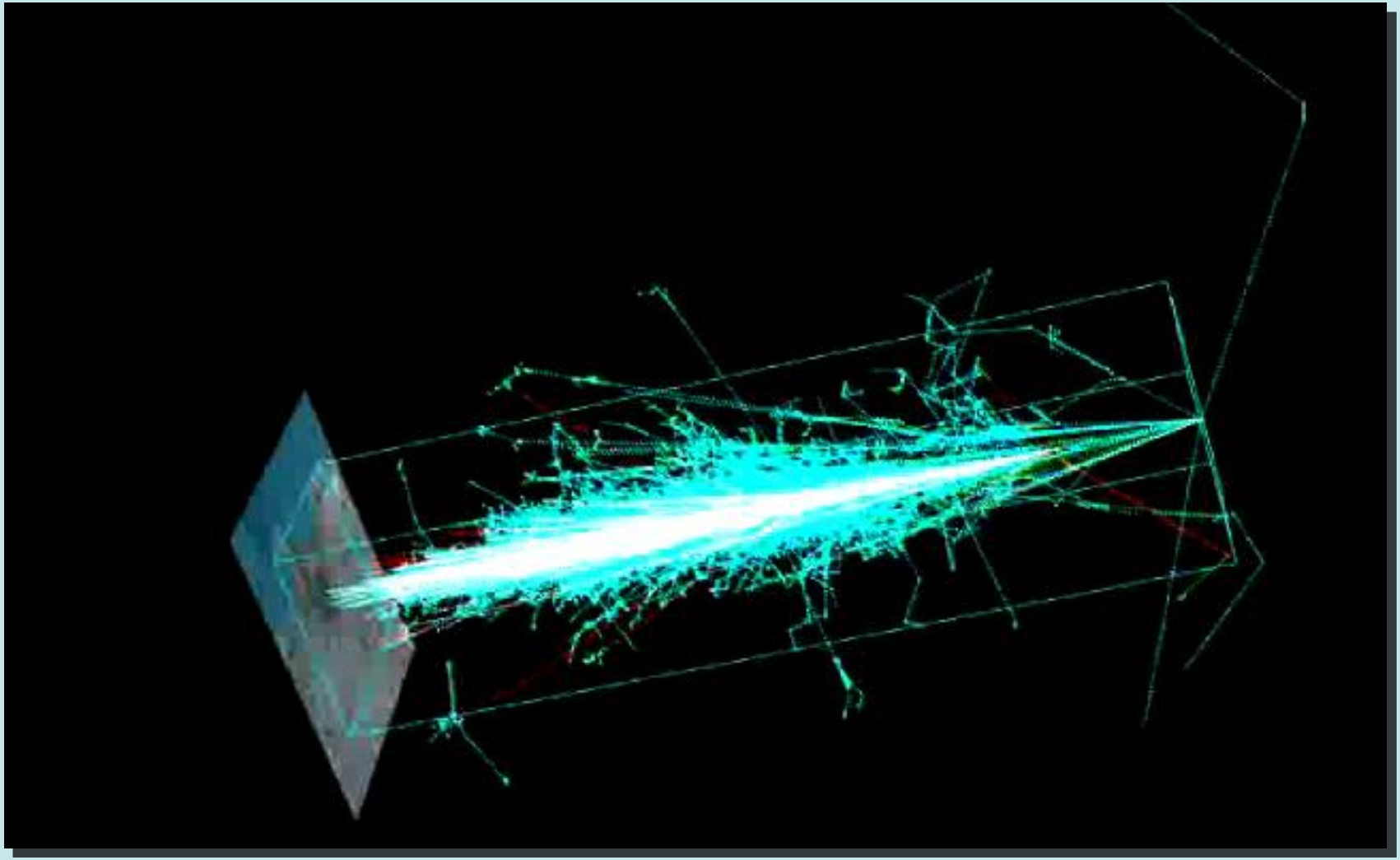
- Interaction cosmic rays - *atmosphere:* dominant
- Interaction cosmic rays - *lithosphere* (crust):1-2 m: reaction rate 2-3 orders of magnitude smaller than in atmosphere. But: different elemental composition -> different reaction products (^{36}Cl).



2-5000 m:
⌈ -reactions
(rare)

>5000 m:
⌇ -reactions
(very rare)

Monte Carlo Simulation



http://astro.uchicago.edu/cosmus/projects/aires/

Additional sources of radioactive isotopes in the lithosphere:

- Nuclear reactions induced by U, Th-decay
- Fission

Extraterrestrial Material

- ca. 5-200 tons/day
- High production rate of radioisotopes, due to missing shielding (atmosphere, magnetic field).

- Exposure times of meteorites:
  - Stone meteorites: 20-30 10^6 years.
  - Iron meteorites: 10^8-10^9 years.

Cosmic ray flux: over 10^8-10^9 years relatively constant.

Cosmogenic Isotopes with $T_{1/2}$ > 1 Month

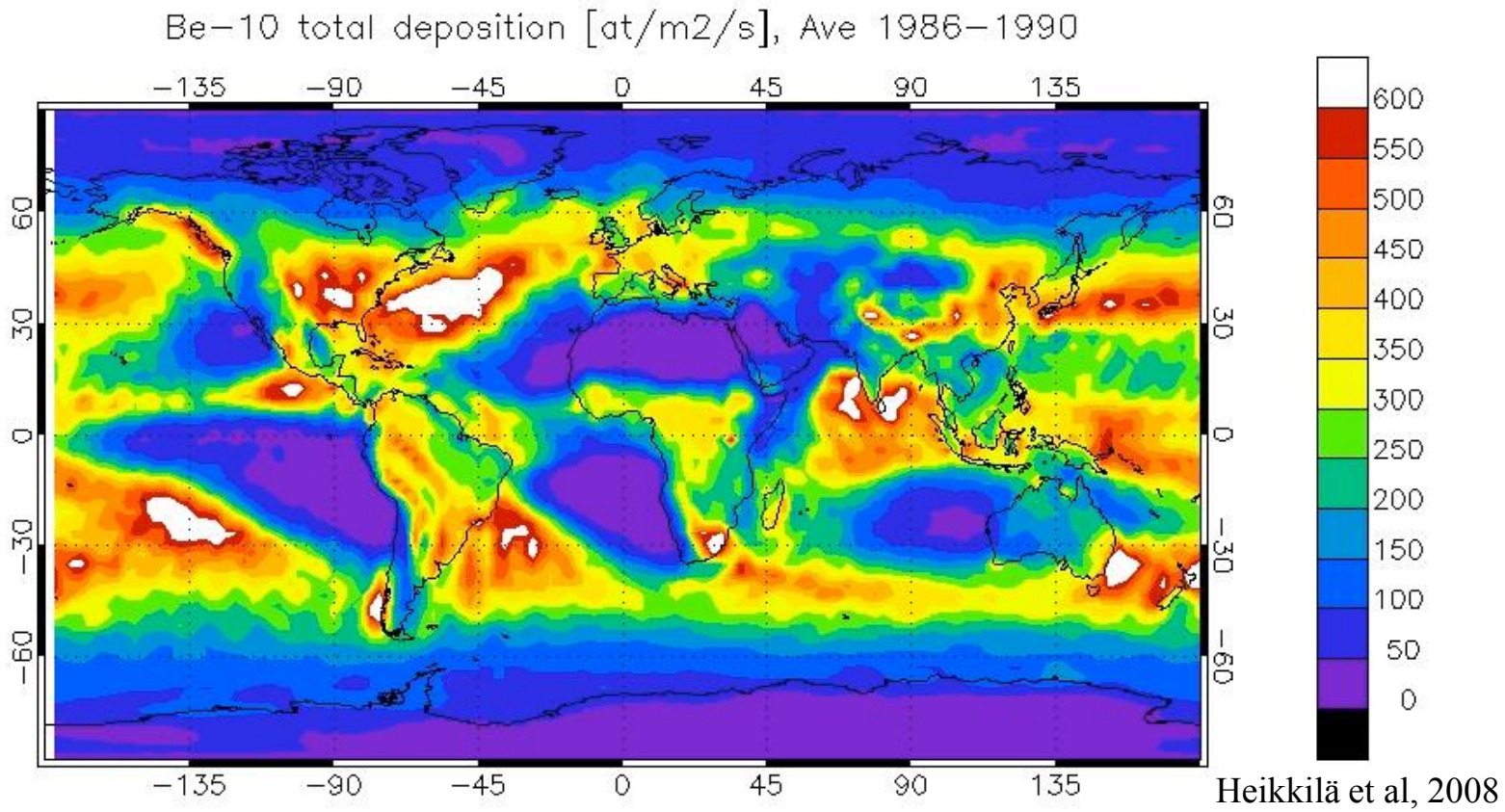
Isotope	$T_{1/2}$	Decay	Target	Prod.rate [atoms cm^{-2} s^{-1}]
^{3}H	12.4 a	®	N, O	0.28
^{7}Be	53 d	EC	N, O	0.035
^{10}Be	1.5 Ma	®	N, O	0.018
^{14}C	5730 a	®	N, O	2.02
^{22}Na	2.6 a	EC	Ar	
^{26}Al	730 ka	EC	Ar	0.00014
^{32}Si	145 a	®	Ar	0.00016

Cosmogenic Isotopes with $T_{1/2}$ > 1 Month

Isotope	$T_{1/2}$	Decay	Target	Prod.rate [atoms cm^{-2} s^{-1}]
^{35}S	87 d	®	Ar	
^{36}Cl	201 ka	®, EC	Ar	0.0019
^{37}Ar	35 d	EC	Ar	0.00041
^{39}Ar	269 a	®	Ar	0.013
^{81}Kr	201 ka	EC	Kr	0.0000015
^{129}I	15.8 Ma	®	Xe	

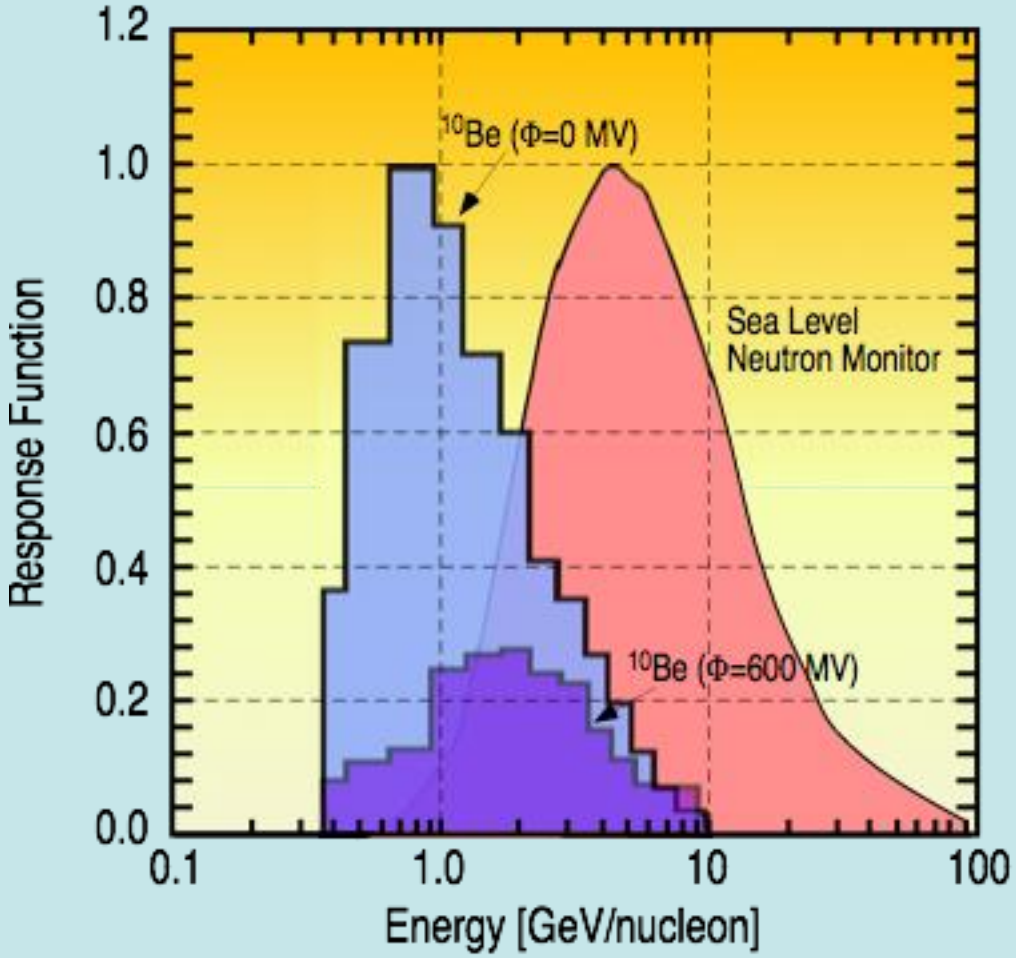
Radioisotopes with $T_{1/2}$ > 1 month produced by cosmic rays in the atmopshere. (Lal & Peters, Masarik & Beer)

Global ^{10}Be Deposition Flux



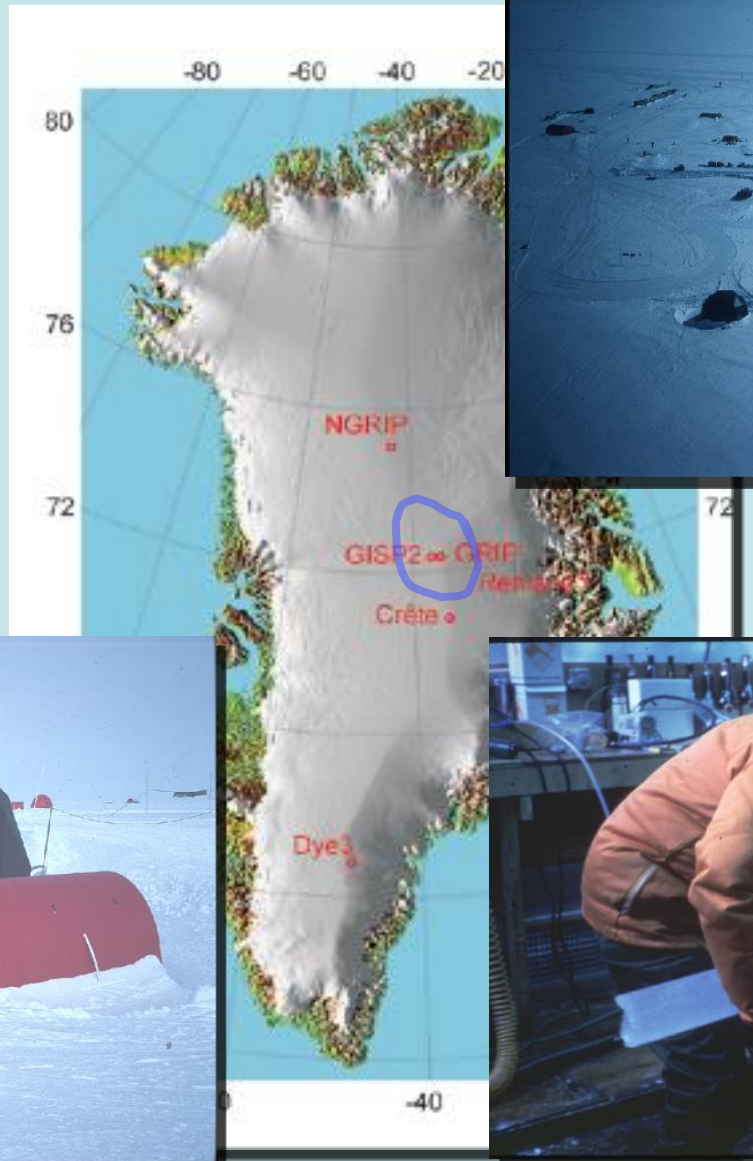
Heikkilä et al, 2008

^{10}Be Response Function



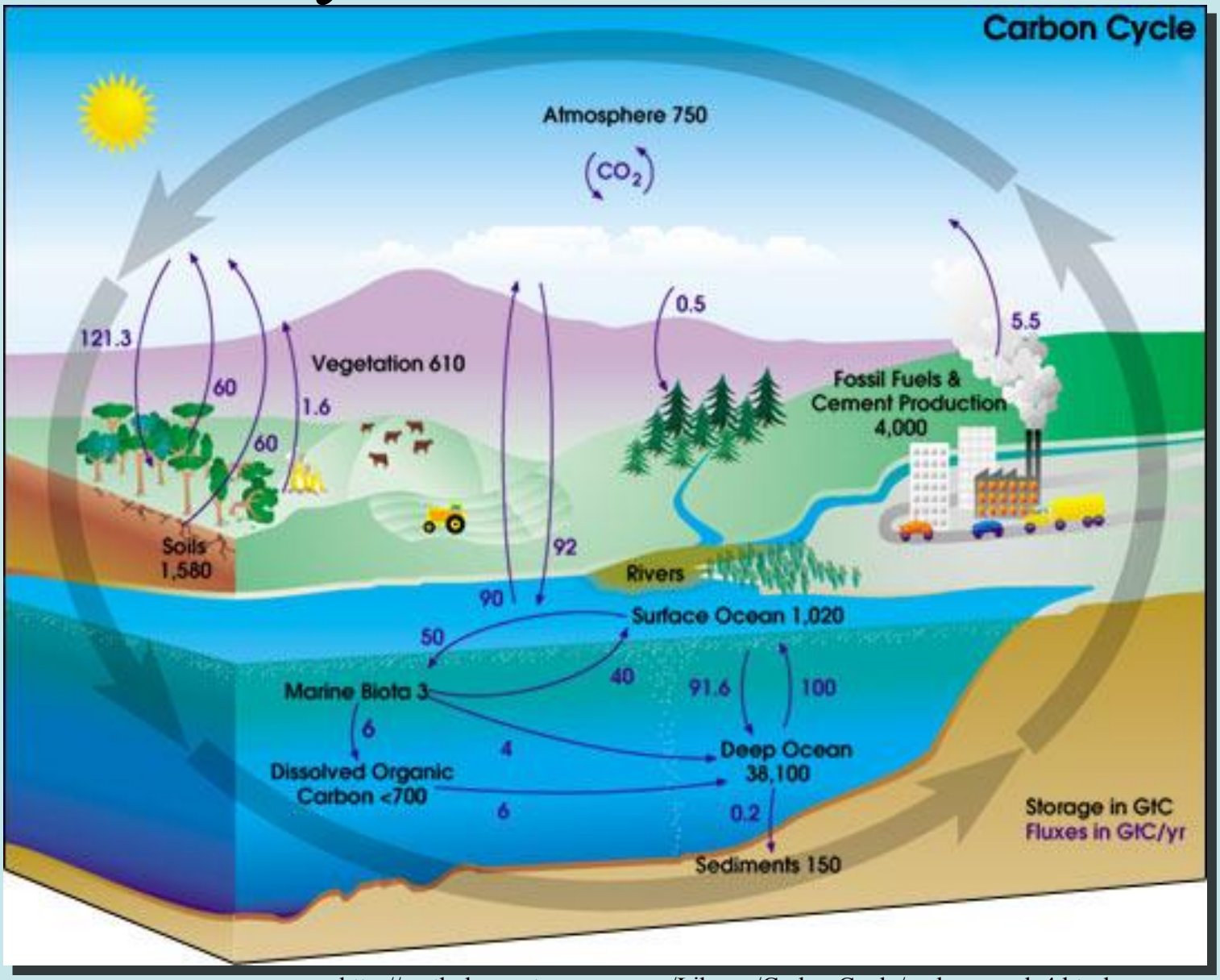
^{10}Be Lab at Summit

GRIP Ice Core



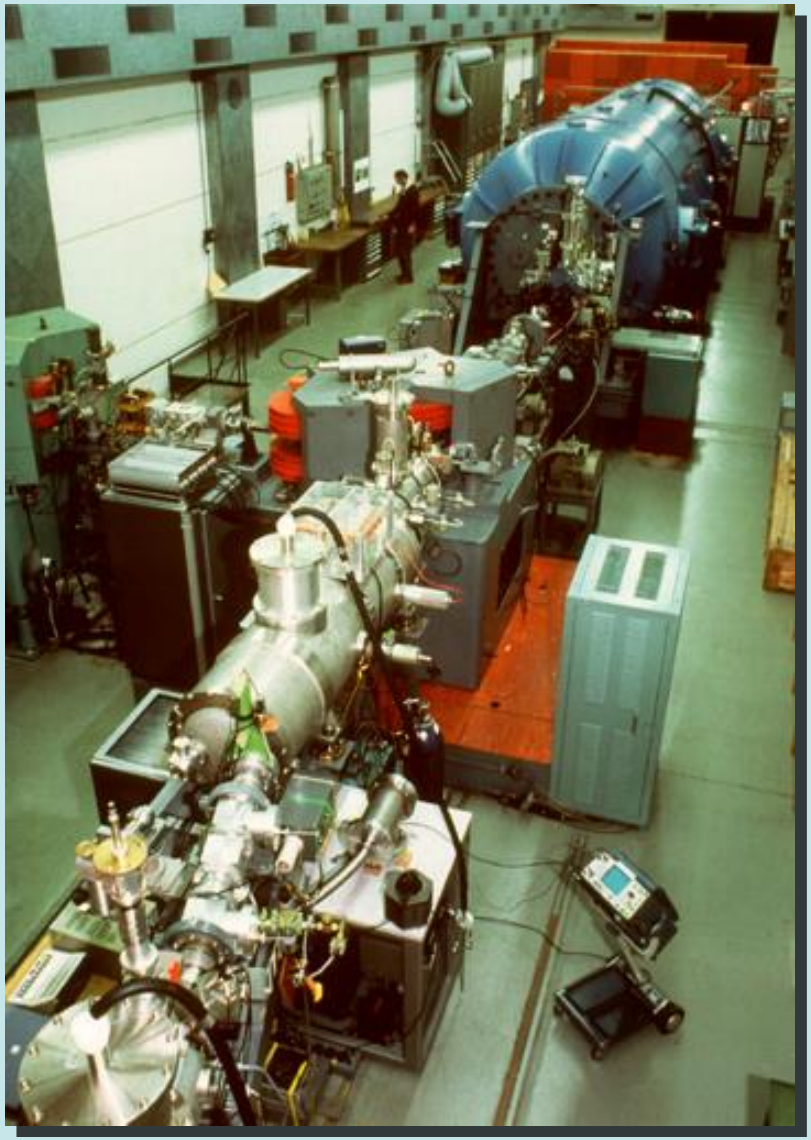
^{14}C FROM TREE RINGS

Carbon Cycle- **Averages over >1000 years.**



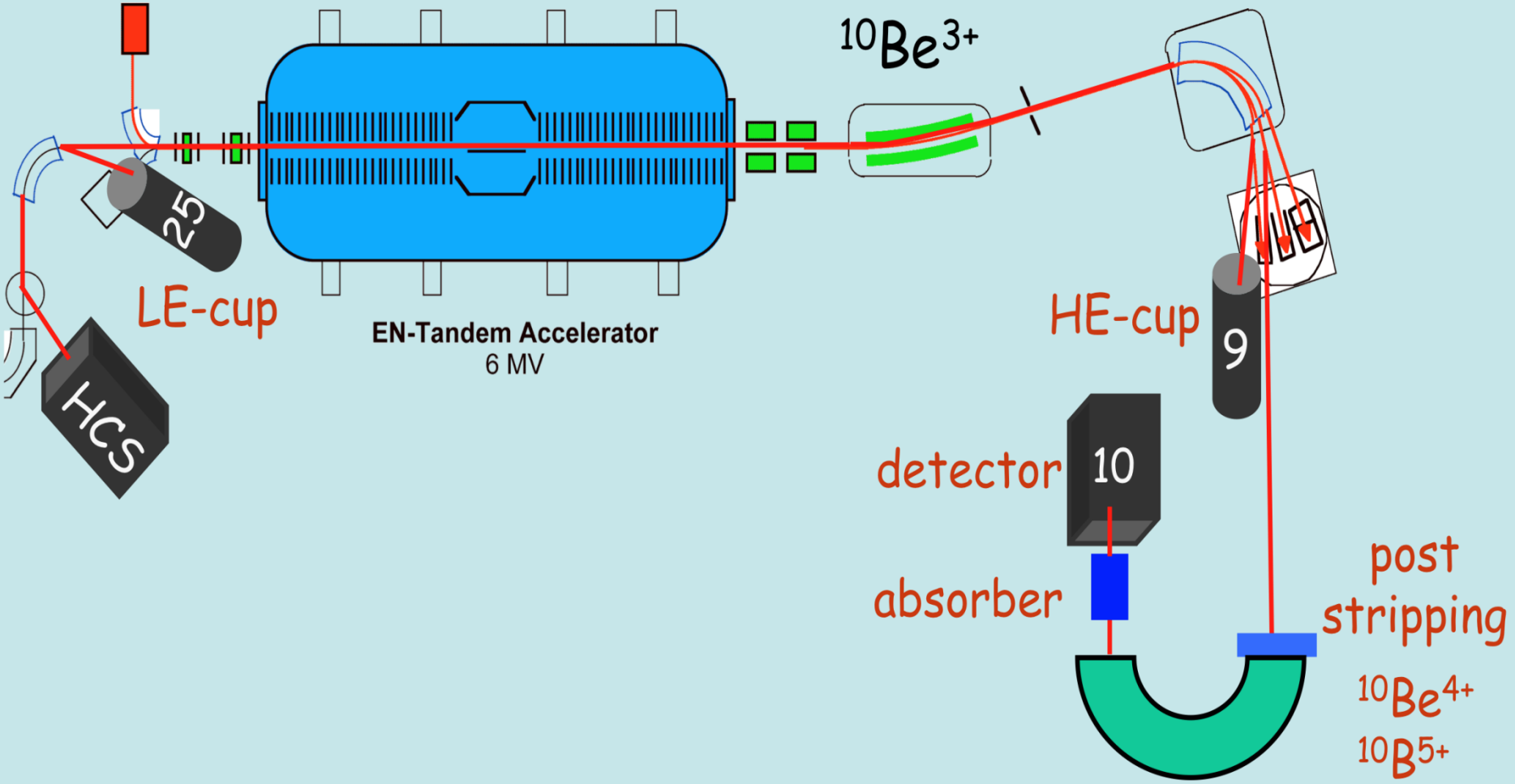
http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle4.html

Accelerator Mass Spectrometer ETH

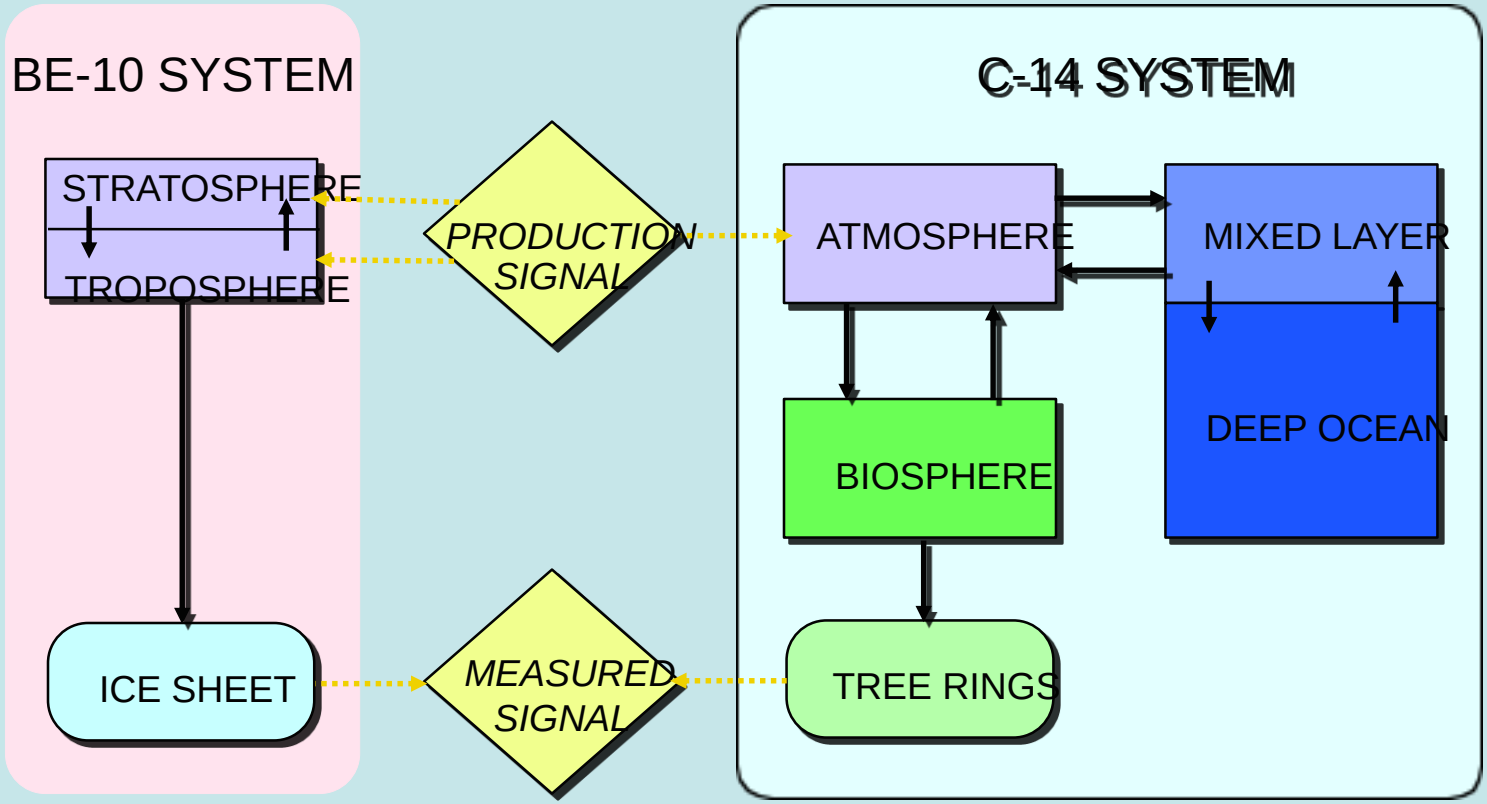


- Acceleration: 6 MV
- 1 Mio ^{10}Be atoms
- $^{10}Be/^{9}Be > 10^{-14}$
- <1 kg of ice

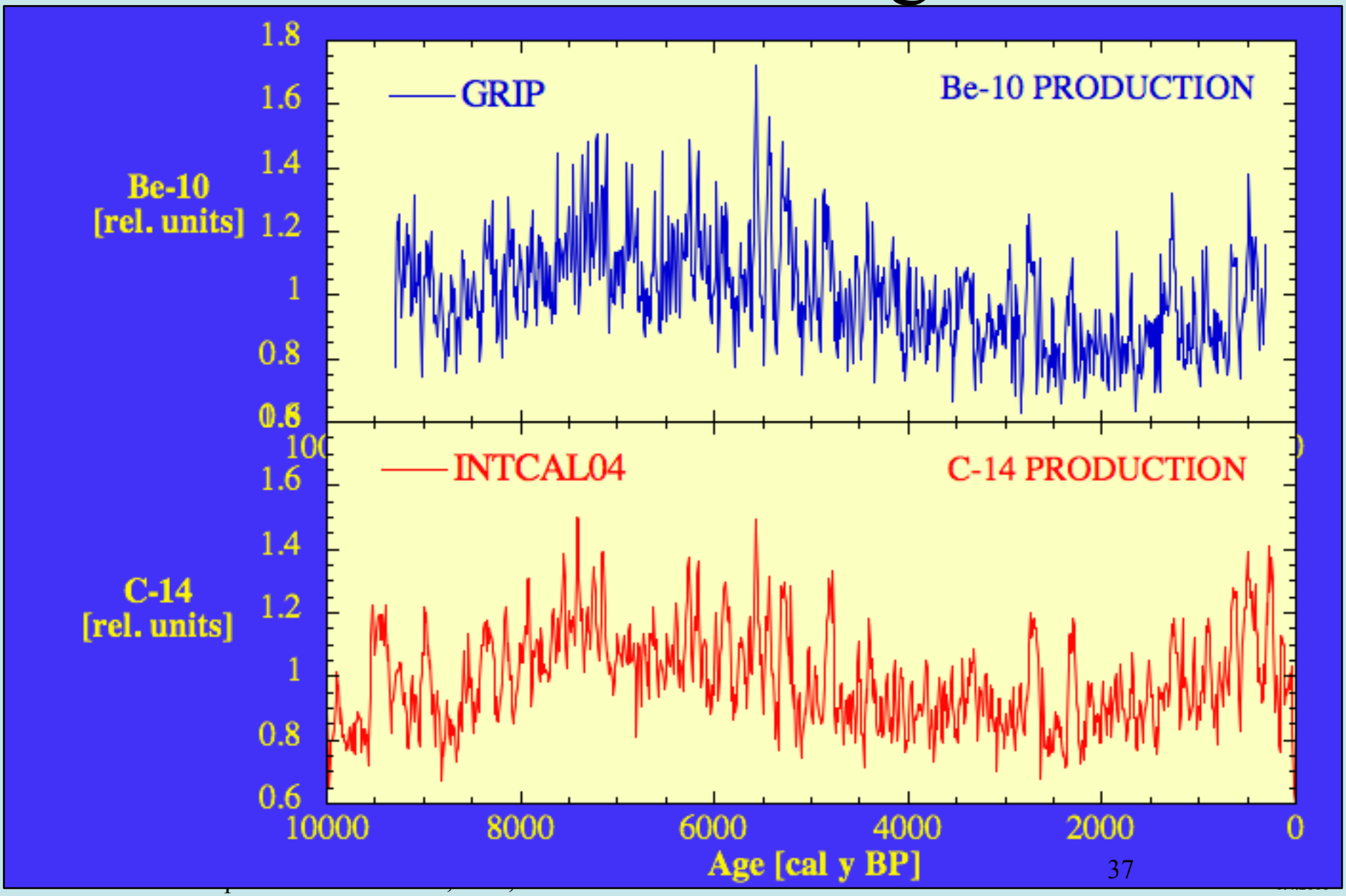
AMS- ETH , Zurich



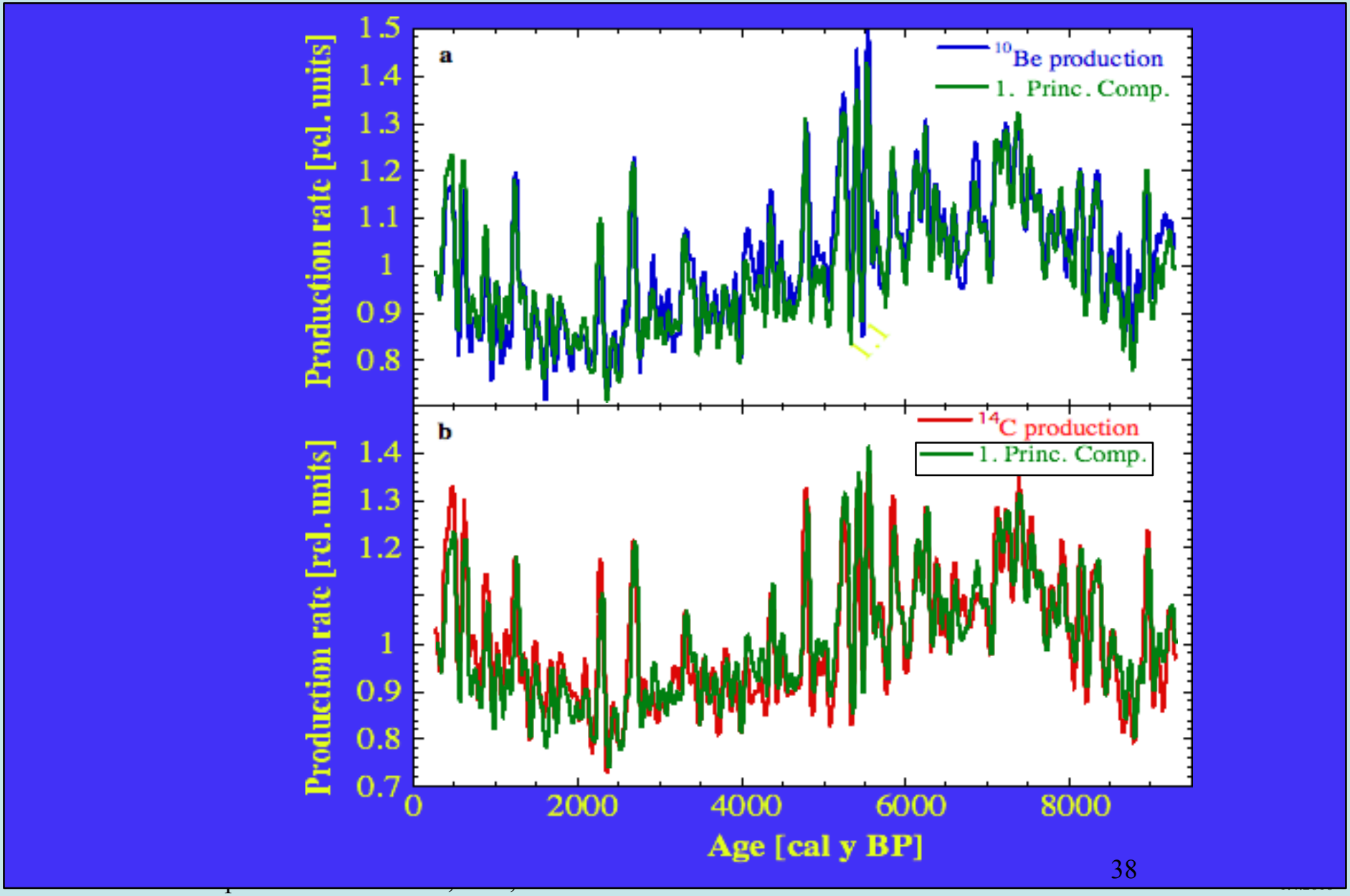
Comparison ^{10}Be - ^{14}C



Production Signals

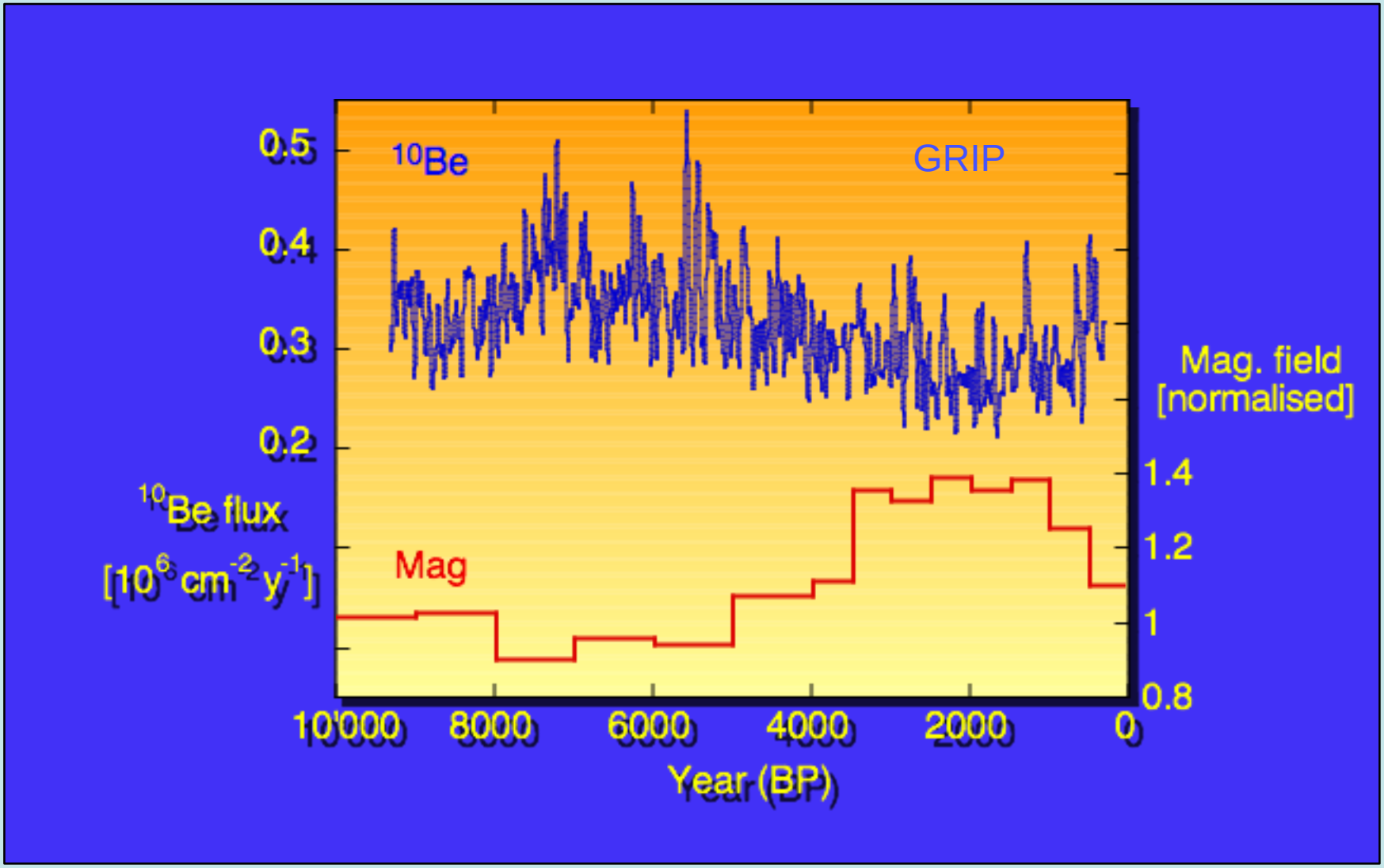


First Principal Component

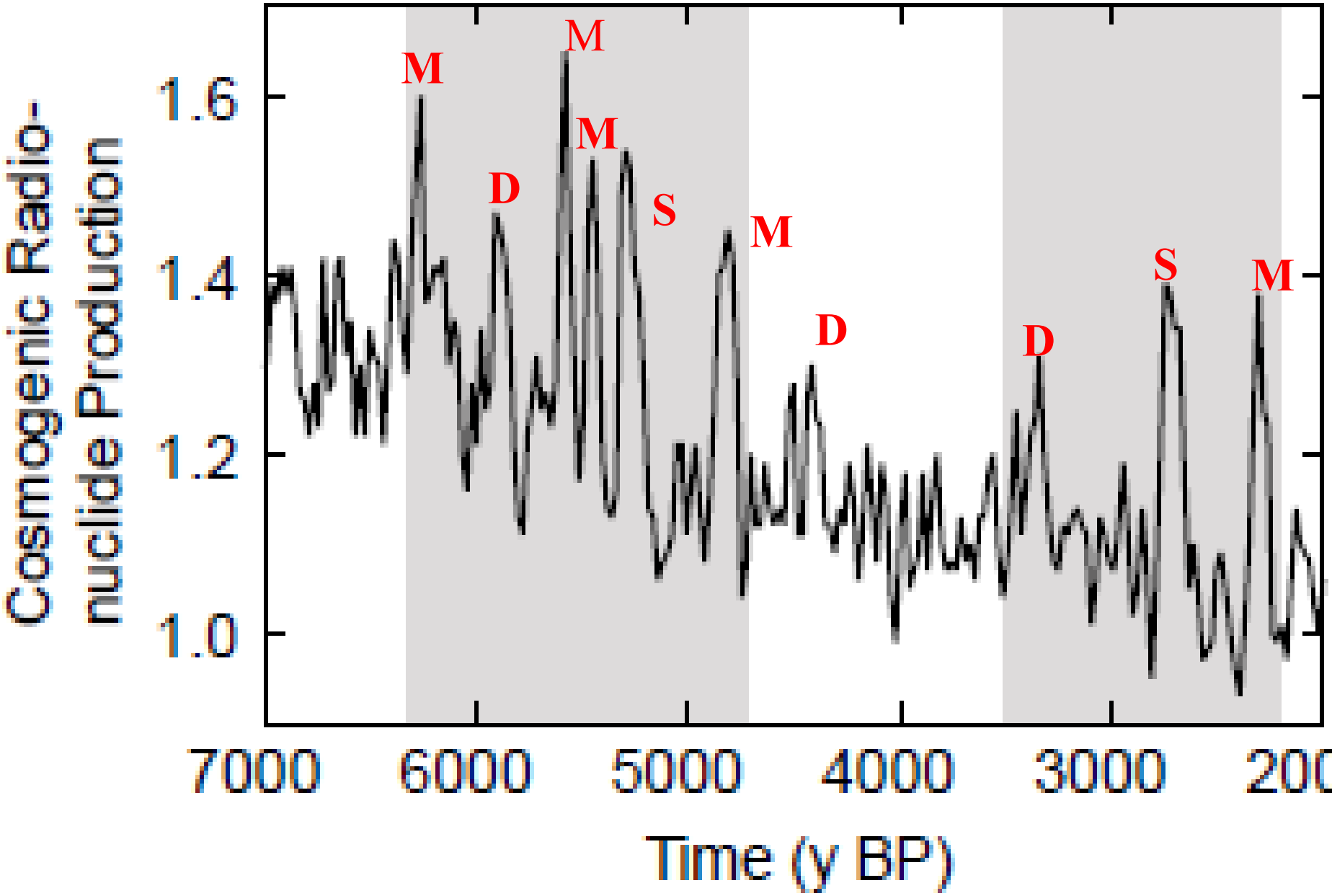


STUDIES IN THE TIME DOMAIN

^{10}Be flux and geomagnetic field



OTHER SEQUENCES OF GRAND MINIMA- AND >1000 YR LONG INTERVALS BETWEEN



THE STATISTICS OF GRAND MINIMA

Number in 9400 years = about 24

Duration of Grand Minima

Duration (yr)	Number
50	3
70	9
90	6
110	2
130	2

Total time Sun was in Grand Minimum = 1540 years = 16%

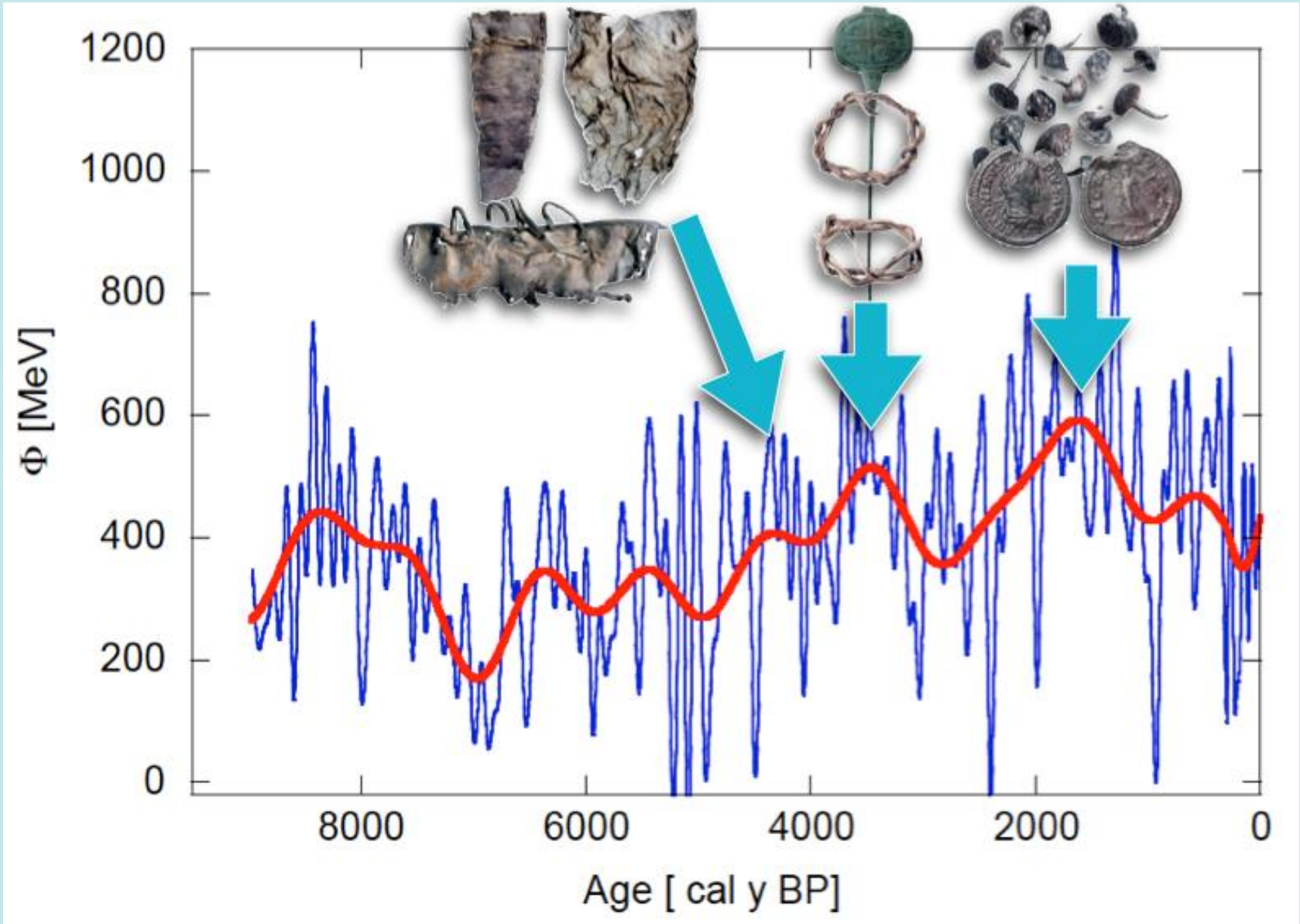
Intervals between GM sequences ≈ 1200-1500 yr

Repetition period of GM sequences = 2310 y (Hallstatt Cycle)

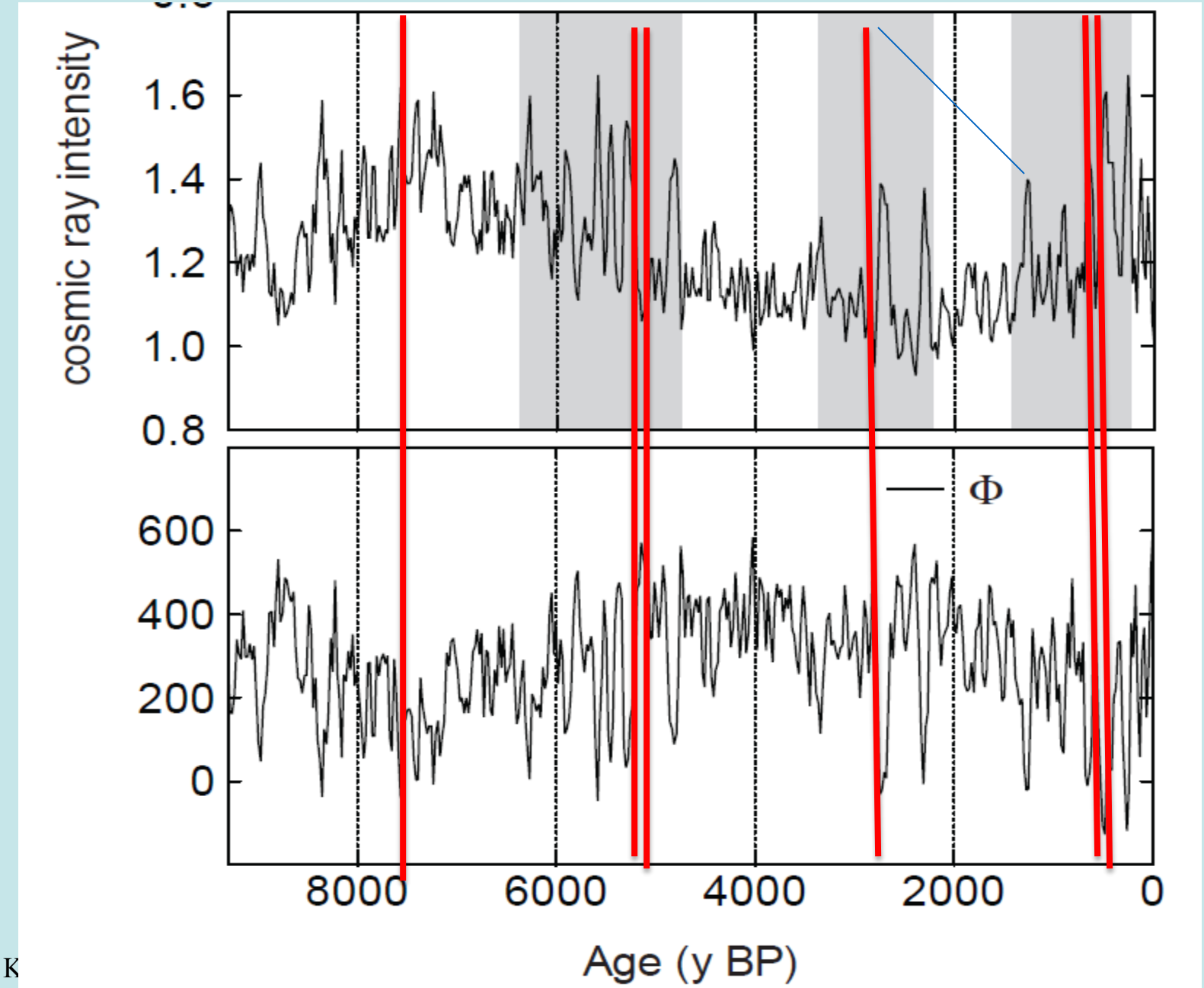
During GM sequence in GM condition 40-42% of time

TOURIST JUNK

SCHNIDEJOCH PASS OPEN (Suter et al, 2007)

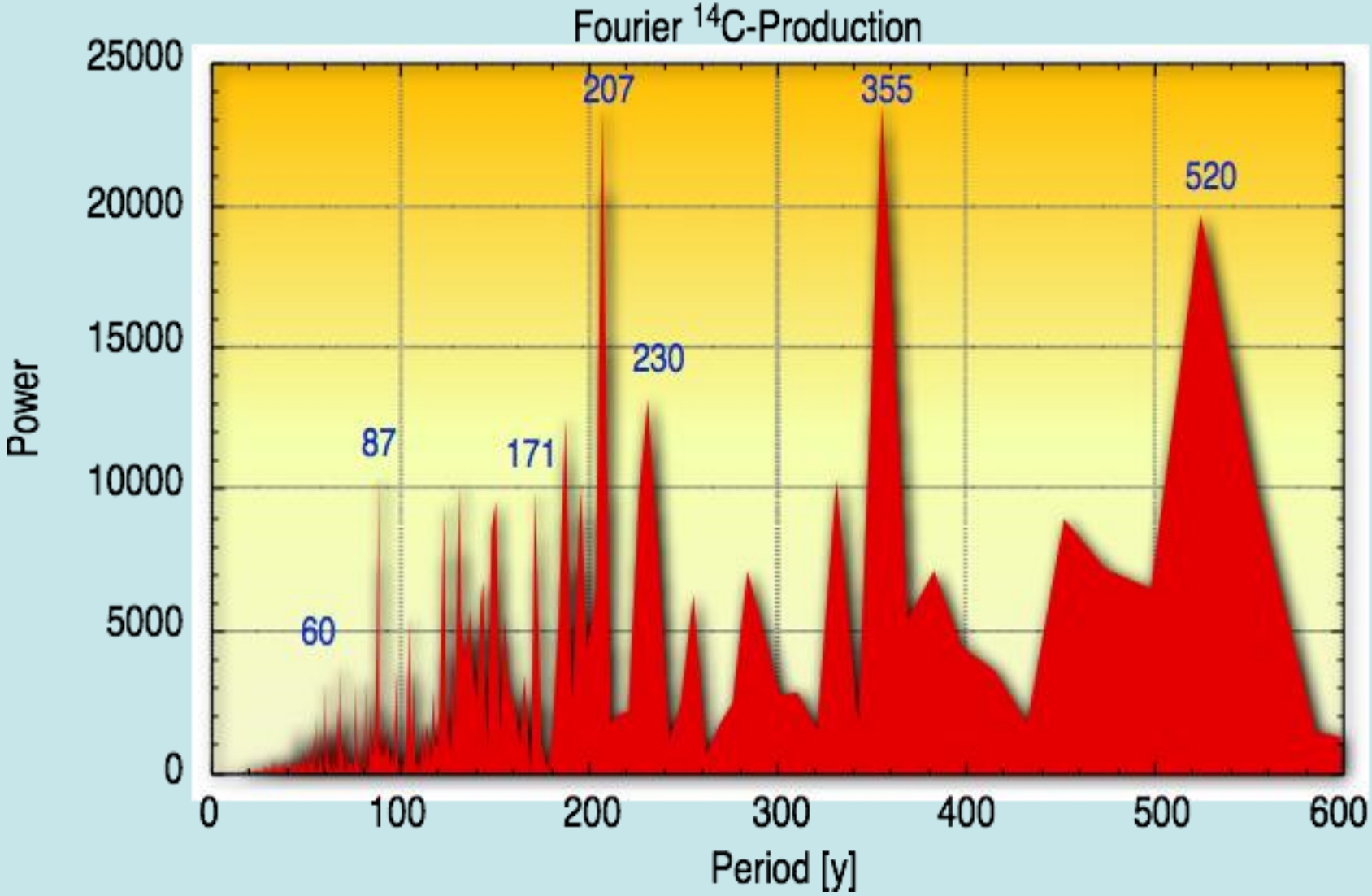


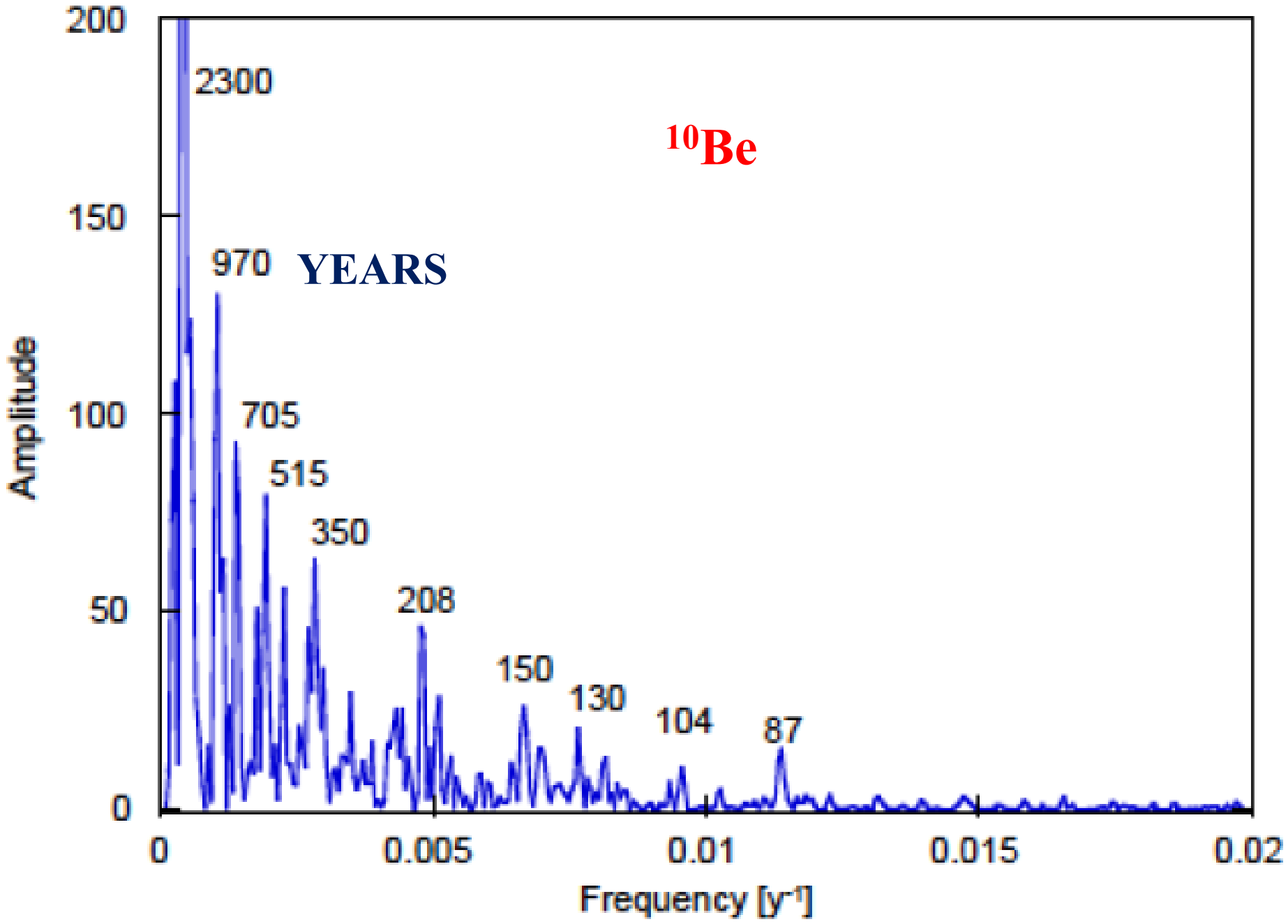
CORRELATION 3- GRAND JOVIAN ALIGNMENT "Syzygy"



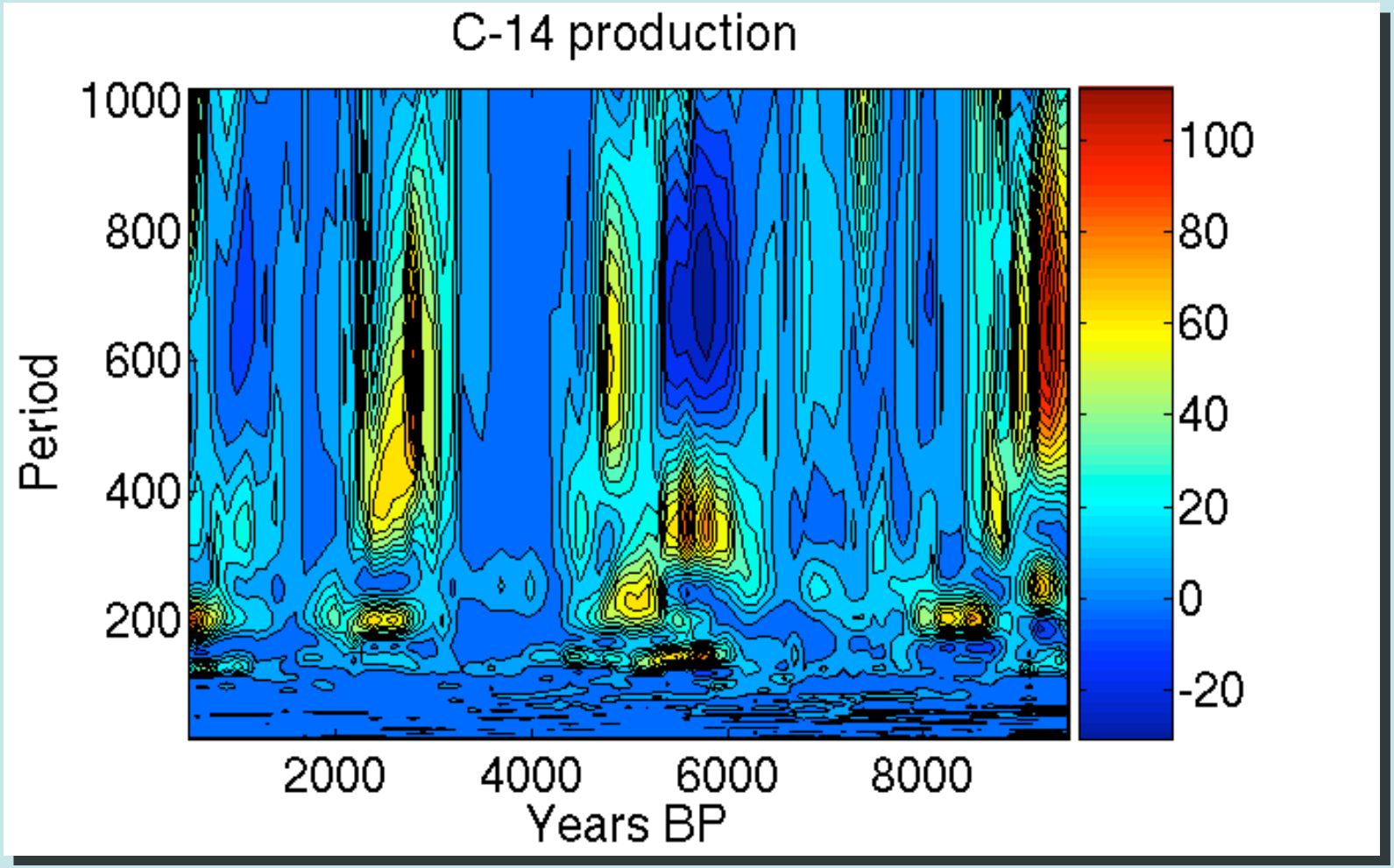
STUDIES IN THE FREQUENCY DOMAIN

^{14}C Power Spectrum



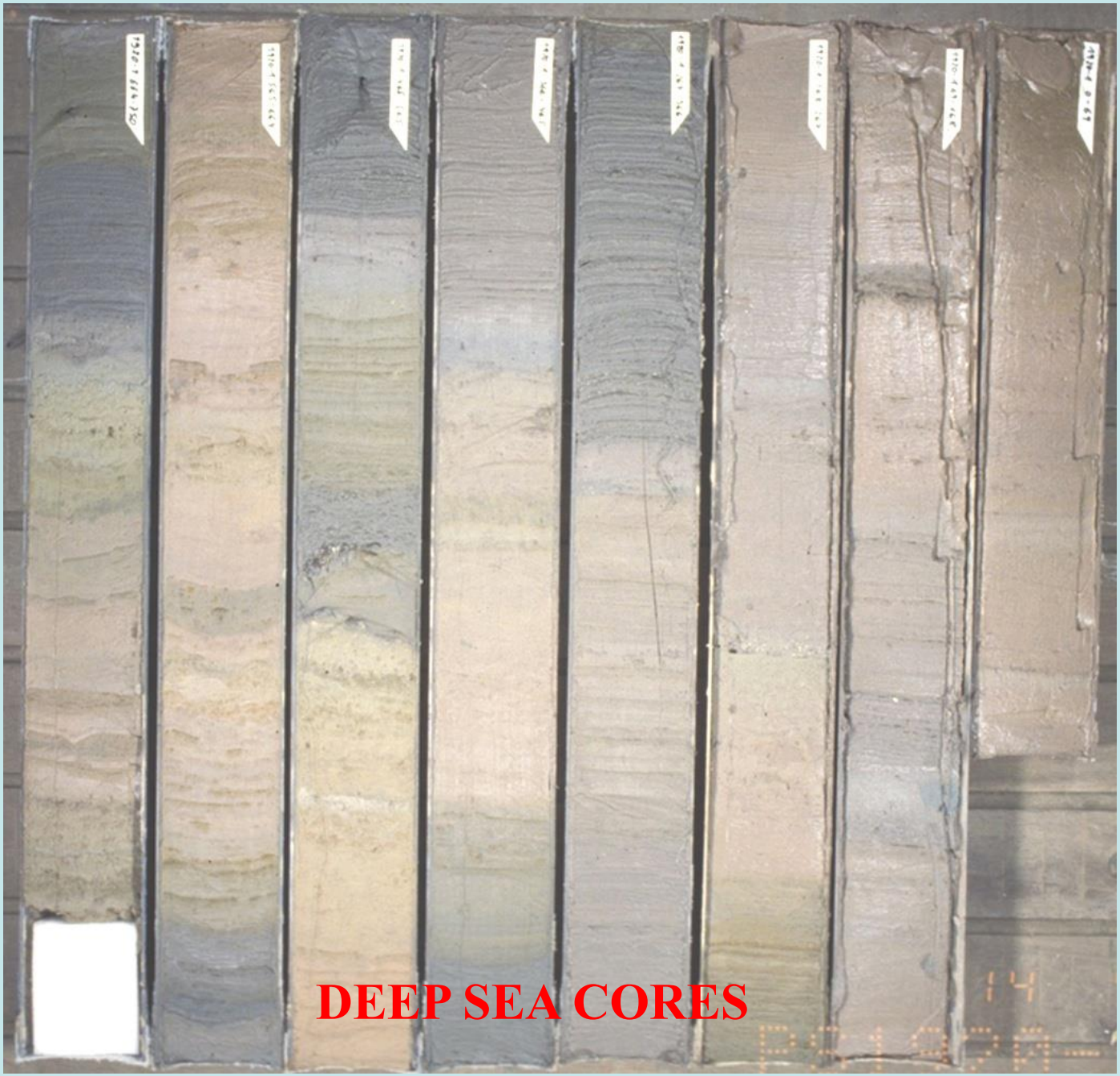

200
150
100
50
0
Amplitude
2300
970
YEARS
705
515
350
208
150
130
104
87
^{10}Be
0
0.005
0.01
0.015
0.02
Frequency [y^{-1}]

Fourier spectrum of ^{14}C production (1 ky windows)



WHAT ABOUT EARLIER IN TIME???

ICE, AND OTHER HOSTS


DEEP SEA CORES


LIBERTY

Summary and Conclusions - 1

- Cosmogenic Isotopes:
  - produced by cosmic rays
  - cosmic rays modulated by solar magnetic field
  - cosmogenic isotopes stored in natural archives
- Main Results on Solar activity:
  - short and long-term variability
  - cyclic: 11-y, 87-y, 208-y, 2300-y,....
  - amplitude modulation
  - grand minima
  - dynamo never stops

Summary and Conclusions - 2

- Potential:
  - extension of solar activity record from 400 y to 100,000 y and beyond.
  - Sun: physics, characteristics of dynamo
  - Space: climate history and weather forecast
  - Earth: solar effects; past, present, and future solar forcing


THANK YOU
2001/03/29 09:36 UT