Extreme solar particle storms studied using cosmogenic isotopes

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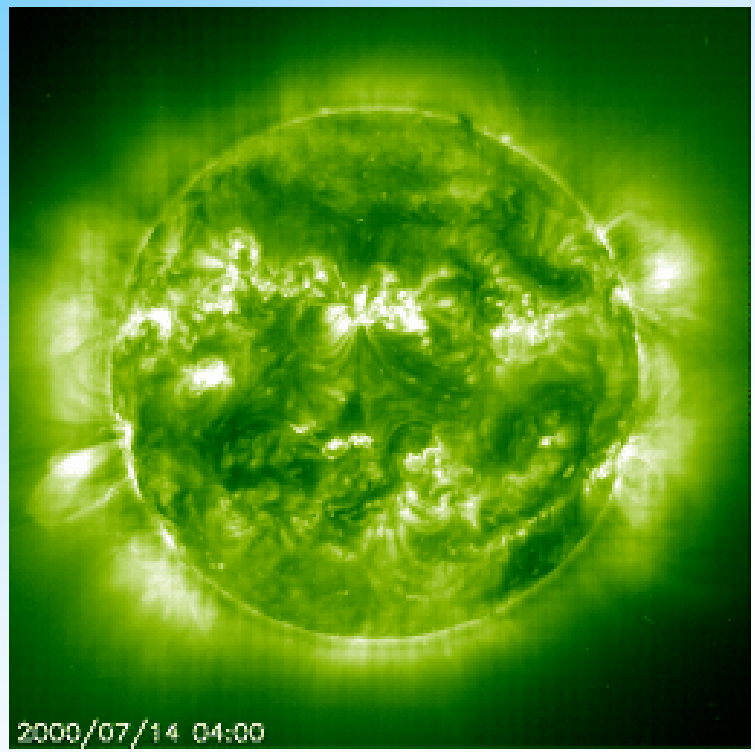
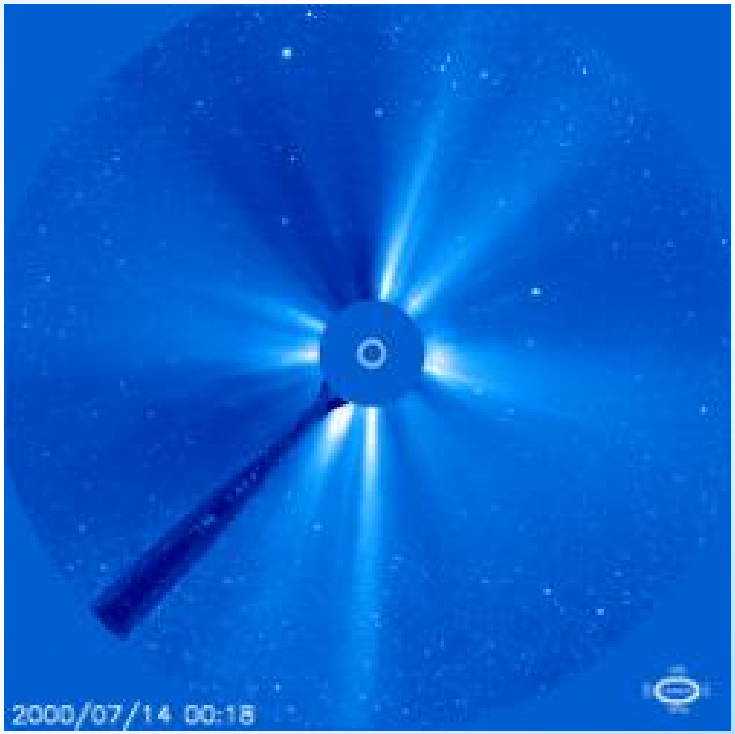
Solar flares and energetic particles

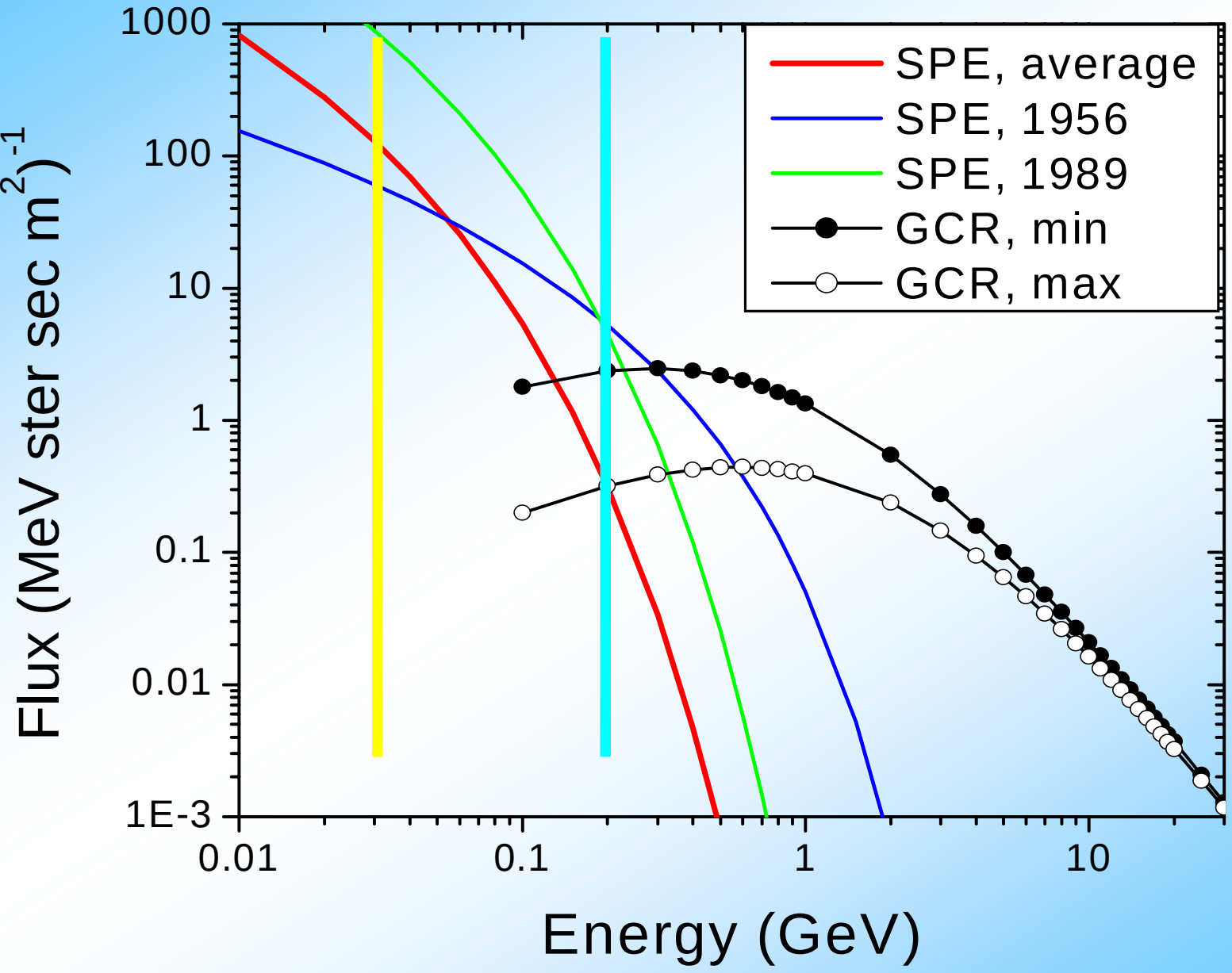


EIT 195 Å

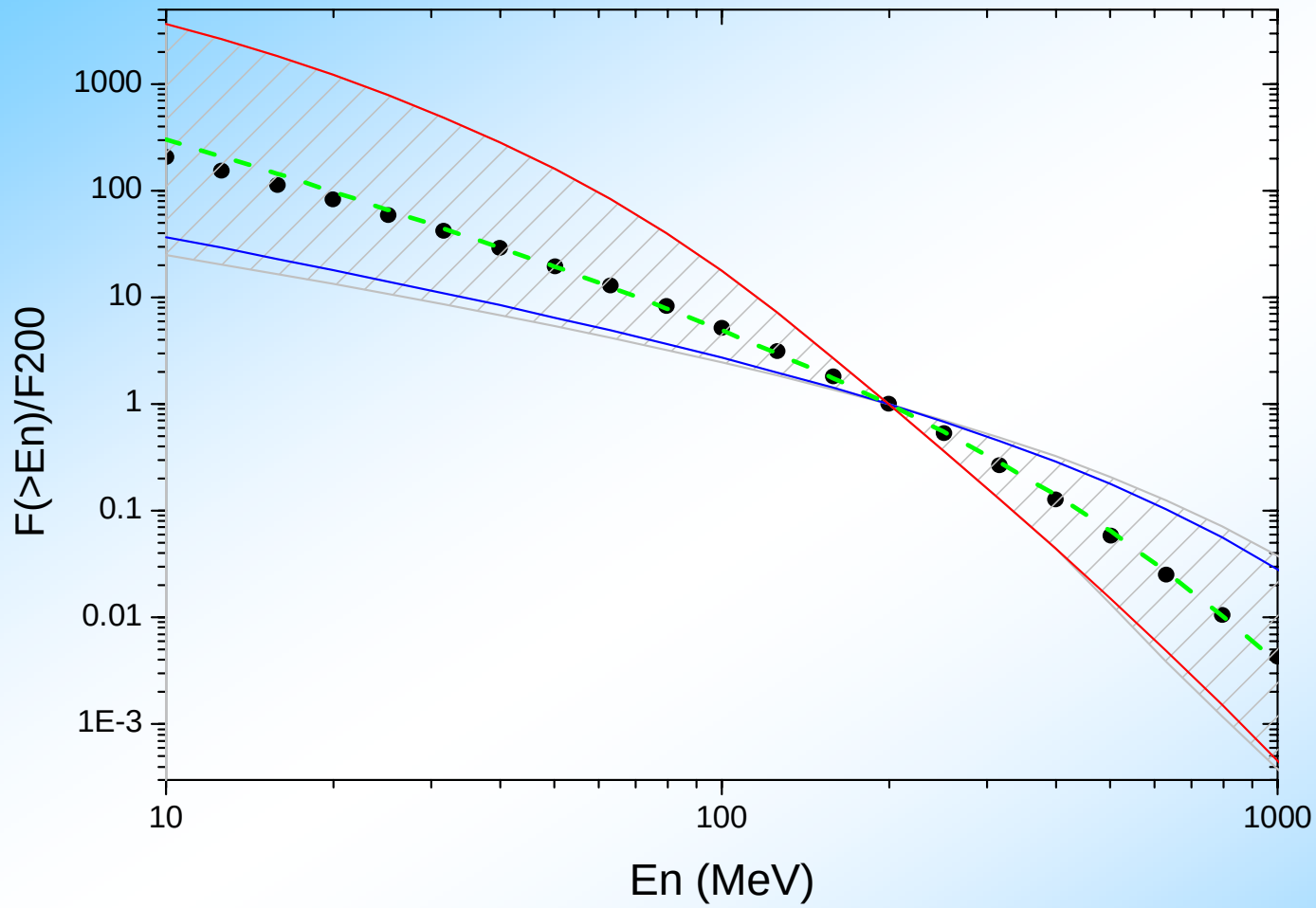


LASCO C3

SOHO (Credit NASA)

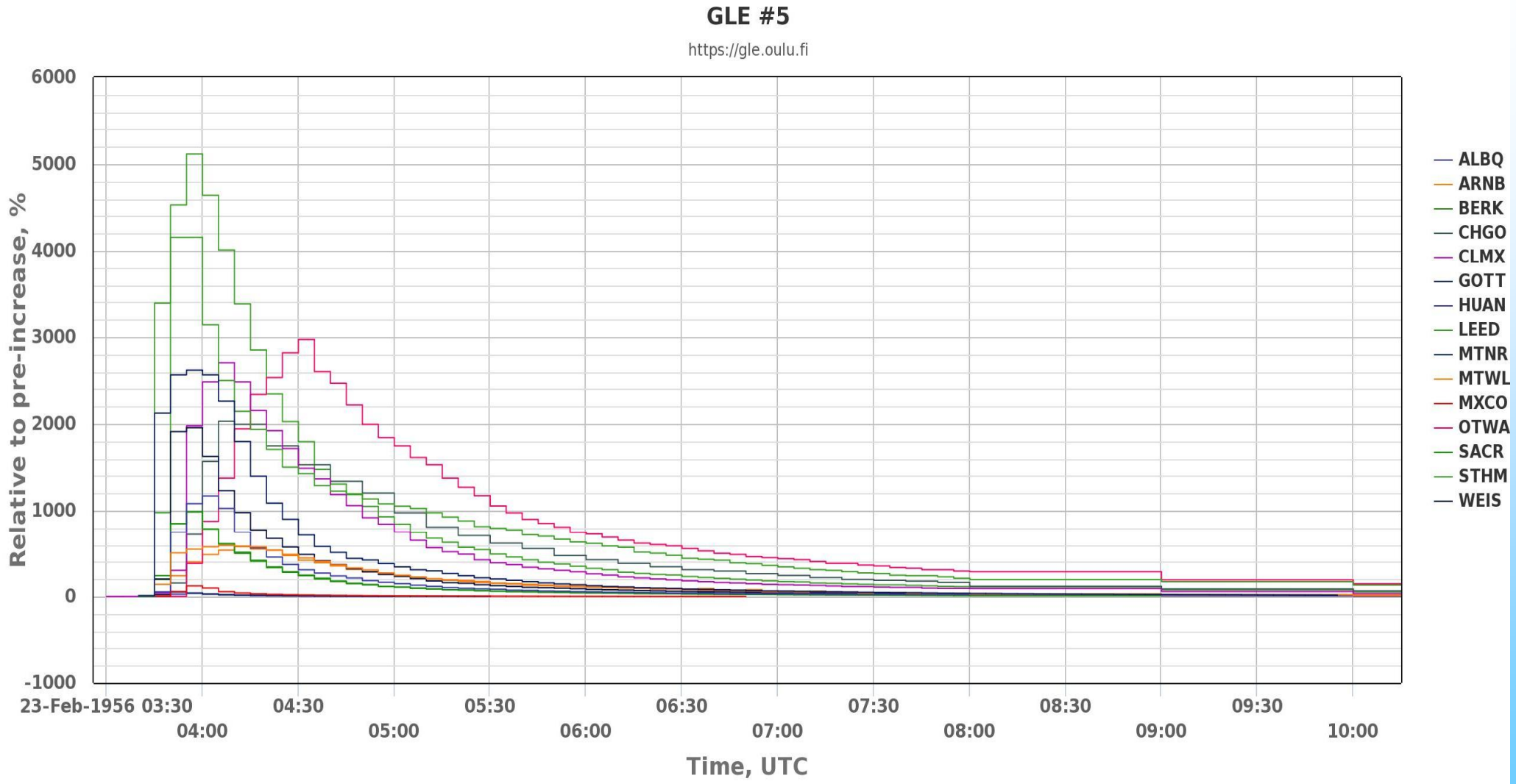

1000
100
10
1
0.1
0.01
1E-3
0.01
0.1
1
10
Flux (MeV ster sec m^2)$^{-1}$
Energy (GeV)
SPE, average
SPE, 1956
SPE, 1989
GCR, min
GCR, max

Hardness of spectra

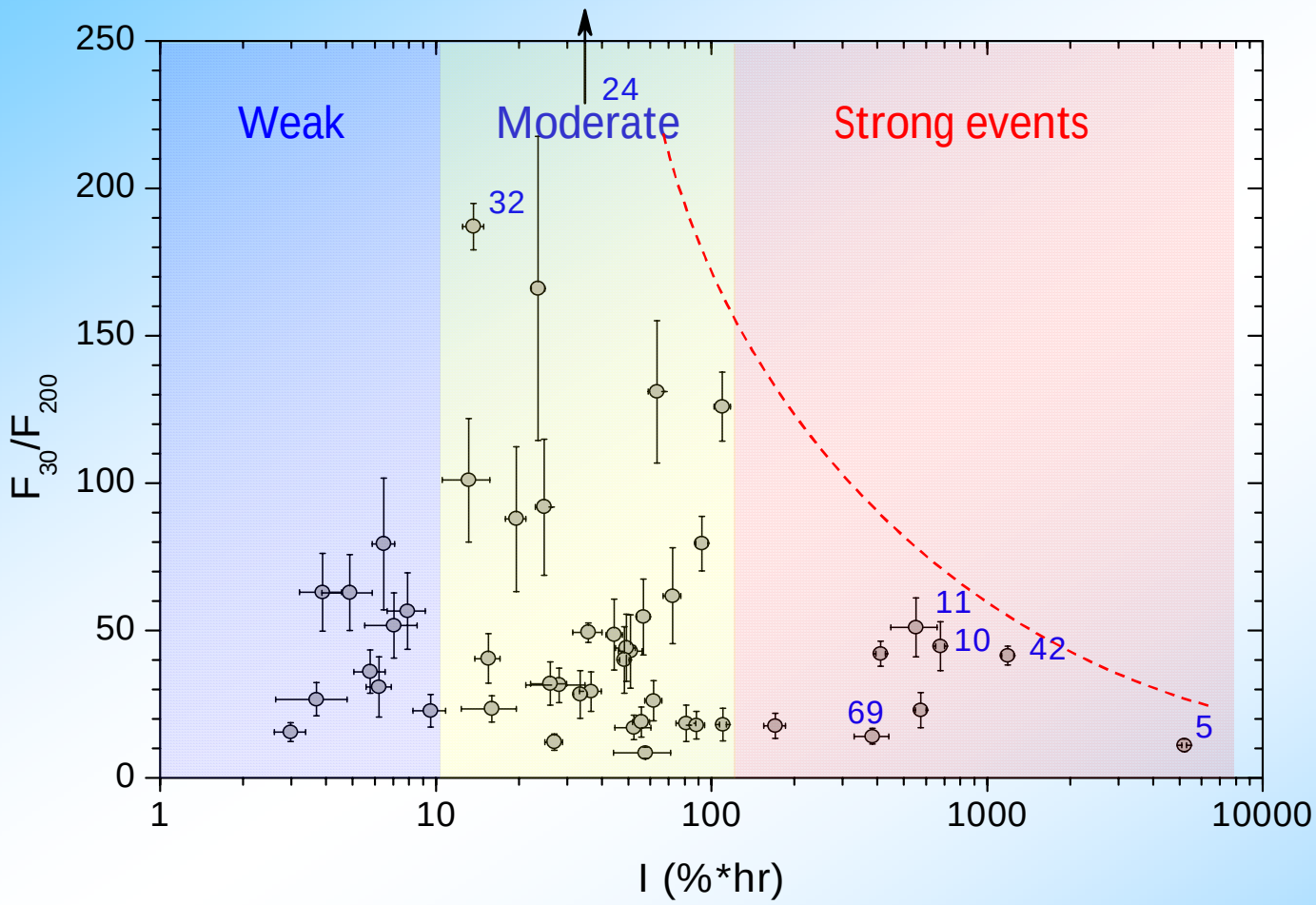


1956
1960
1972

GLE (Ground Level Enhancement) 23-02-1956

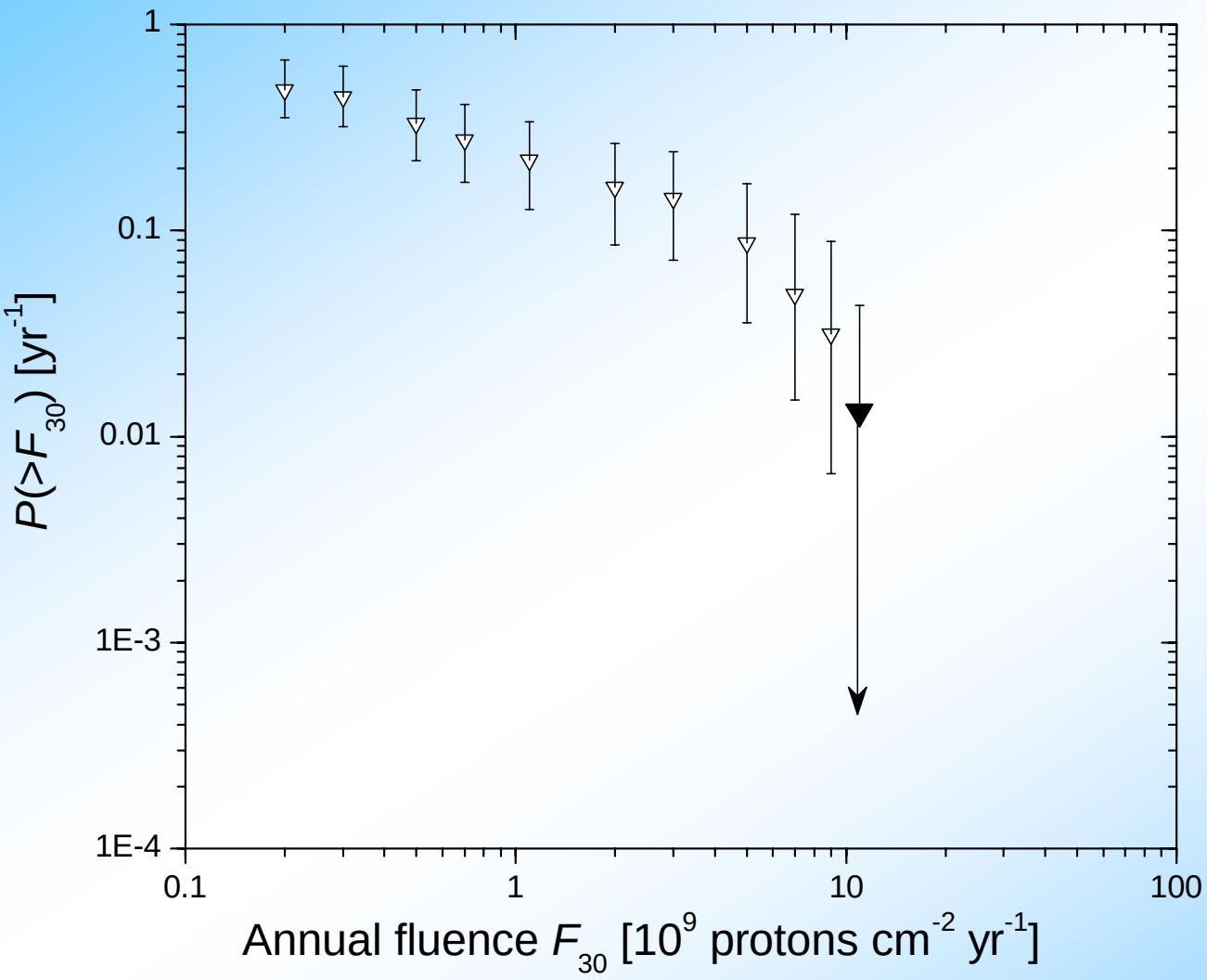


Hardness of GLE events



- Strong GLE (Ground Level Enhancement) events are hard;
- Moderate events are uncertain;
- Weak events are hard;

SPE: space era



Shea & Smart (1990, 2012), Reedy (2012):
No events with $F_{30}>10^{10}$ cm^{-2} since 1956.

Cosmogenic radionuclides

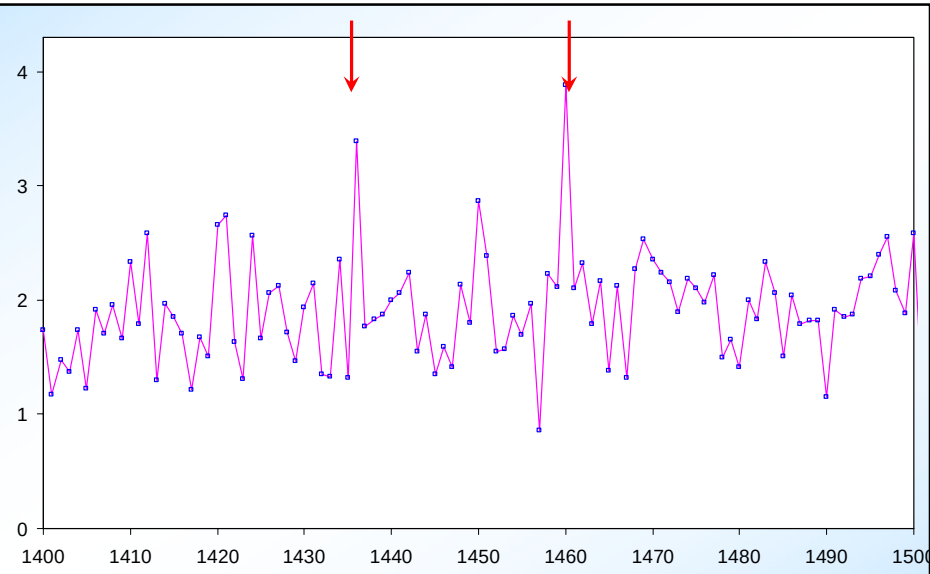
^{14}C and ^{10}Be:

last 11 millennia

Potential signature in annual ^{10}Be

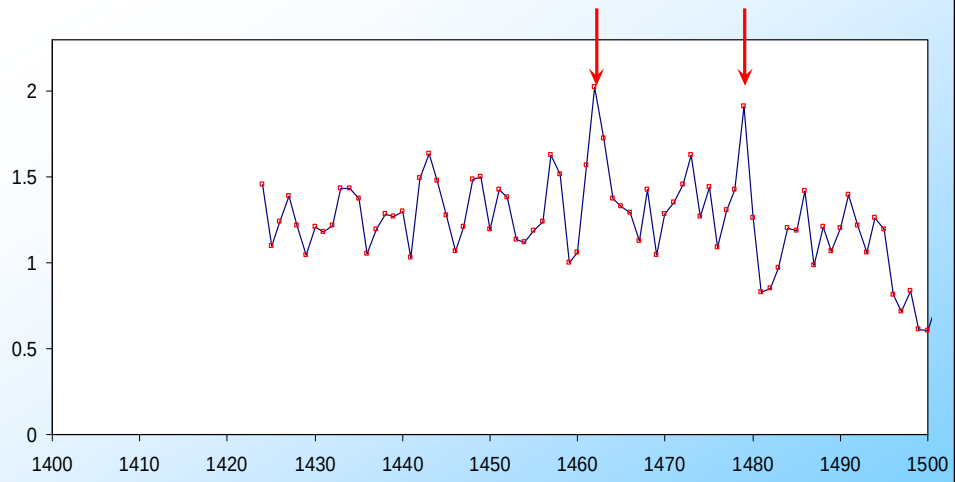
- ***NGRIP*** series: peaks > $1.3*10^4$ at/g

  1436, 1460, 1650, 1719, 1810, 1816, 1965



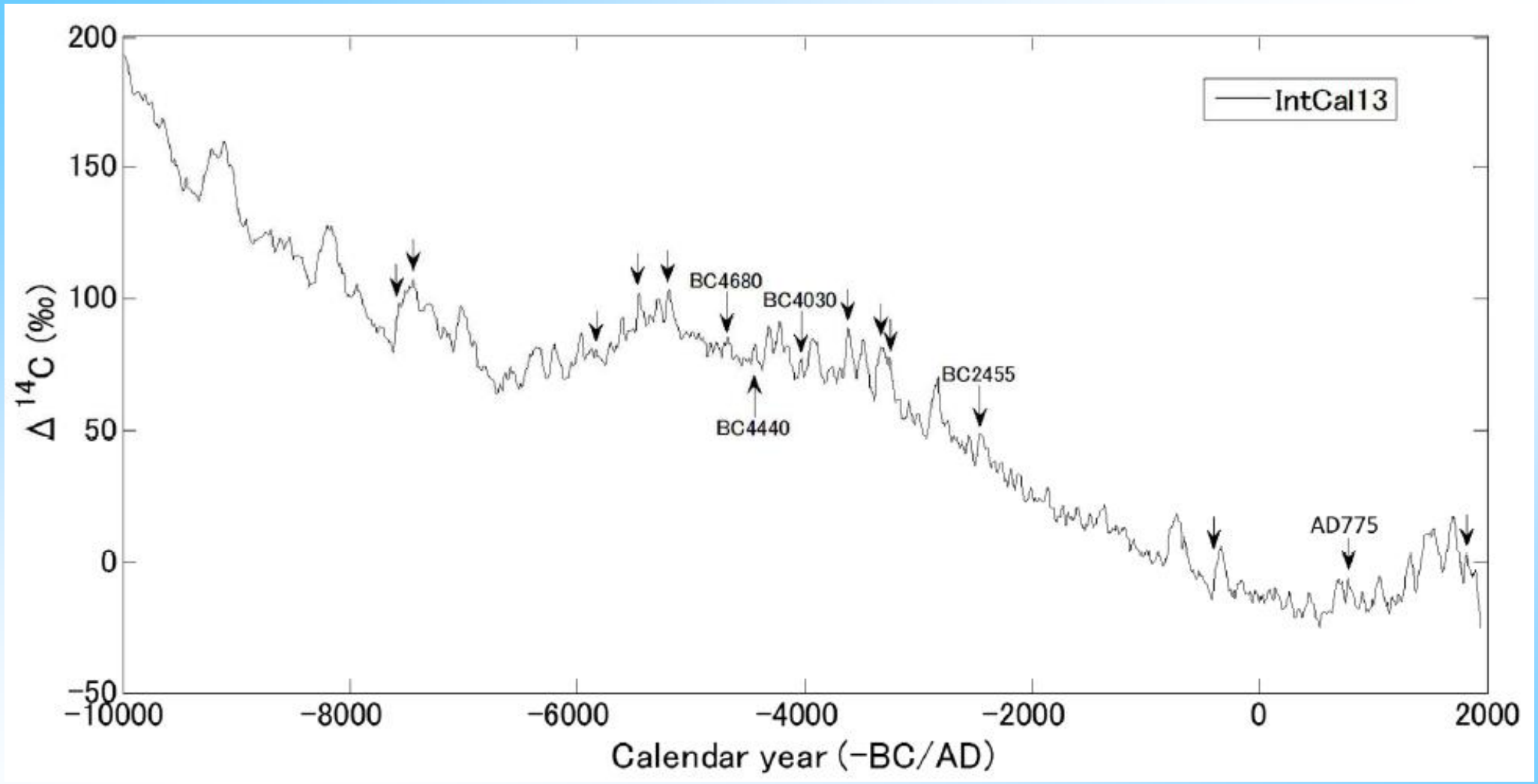
- ***Dye3*** series: peaks > $0.6*10^4$ at/g

  1462, 1479, 1505, 1512, 1603



Cross-check performed

Some candidates in IntCal13 series



Miyake et al. Radiocarbon, (2017)

Candidates from rougher series

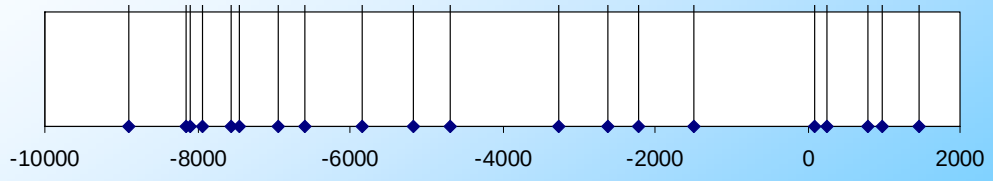
8910 BC	IntCal09	$2.0*10^{10}$
8155 BC	IntCal09	$1.3*10^{10}$
8085 BC	IntCal09	$1.5*10^{10}$
7930 BC	IntCal09	$1.3*10^{10}$
7570 BC	IntCal09	$2.0*10^{10}$
7455 BC	IntCal09	$1.5*10^{10}$
6940 BC	IntCal09	$1.1*10^{10}$
6585 BC	IntCal09	$1.7*10^{10}$
5835 BC	IntCal09	$1.5*10^{10}$
5165 BC	GRIP	$2.4*10^{10}$
4680 BC	IntCal09	$1.6*10^{10}$
3260 BC	IntCal09	$2.4*10^{10}$
2615 BC	IntCal09	$1.2*10^{10}$
2225 BC	IntCal09	$1.2*10^{10}$
1485 BC	IntCal09	$2.0*10^{10}$
95 AD	GRIP	$2.6*10^{10}$
265 AD	IntCal09	$2.0*10^{10}$
780 AD	IntCal09/DF	$2\text{-}5*10^{10}$
990 AD	M13	$2.5*10^{10}$
1455 AD	SP	$7.0*10^{10}$ overestimate??

Statistics for 11400 years:

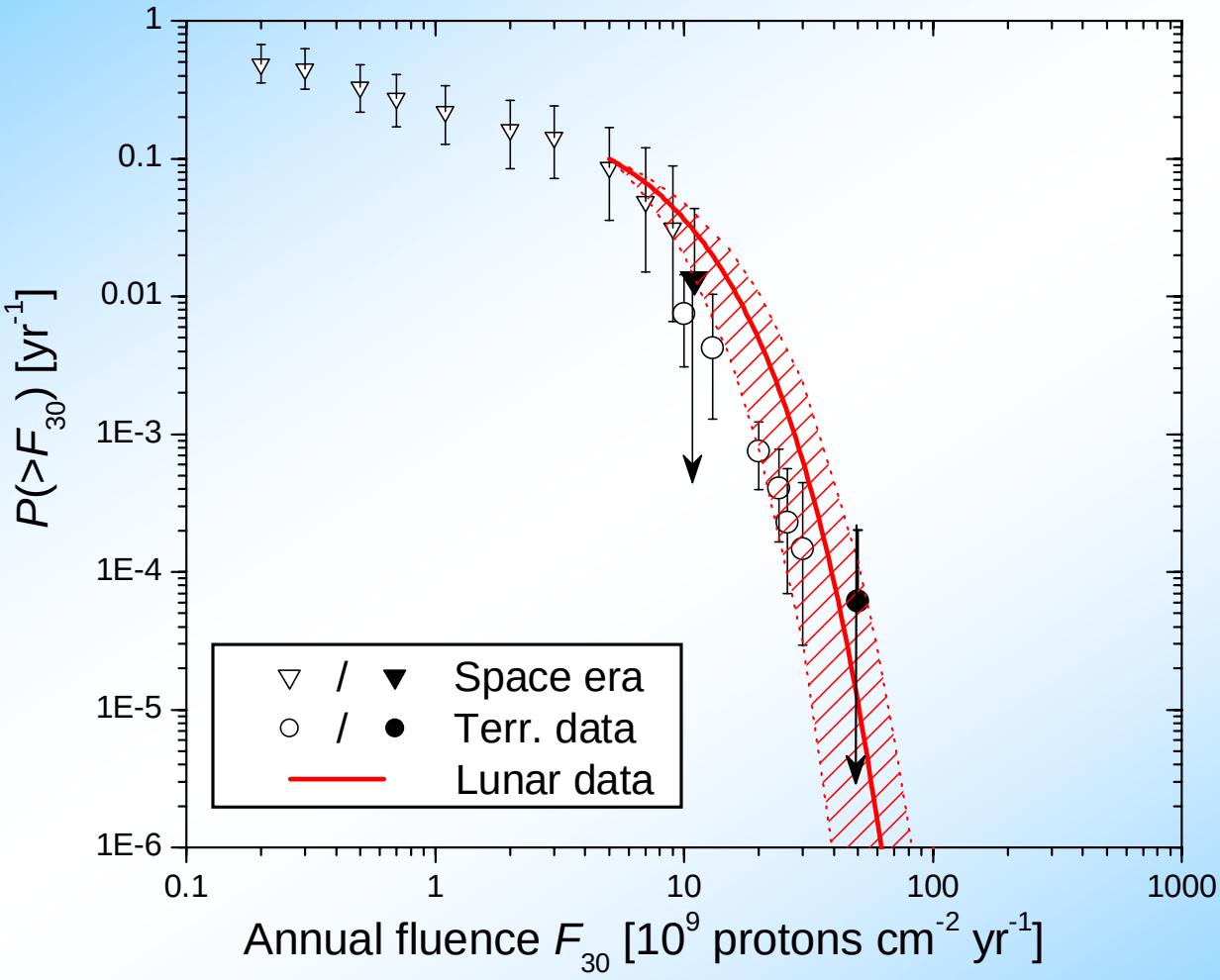
19 events $F_{30}=(1\text{-}3)*10^{10}$ cm^{-2}

1 event $F_{30}=(4\text{-}5)*10^{10}$ cm^{-2}

no events with $F_{30}>5*10^{10}$ cm^{-2}

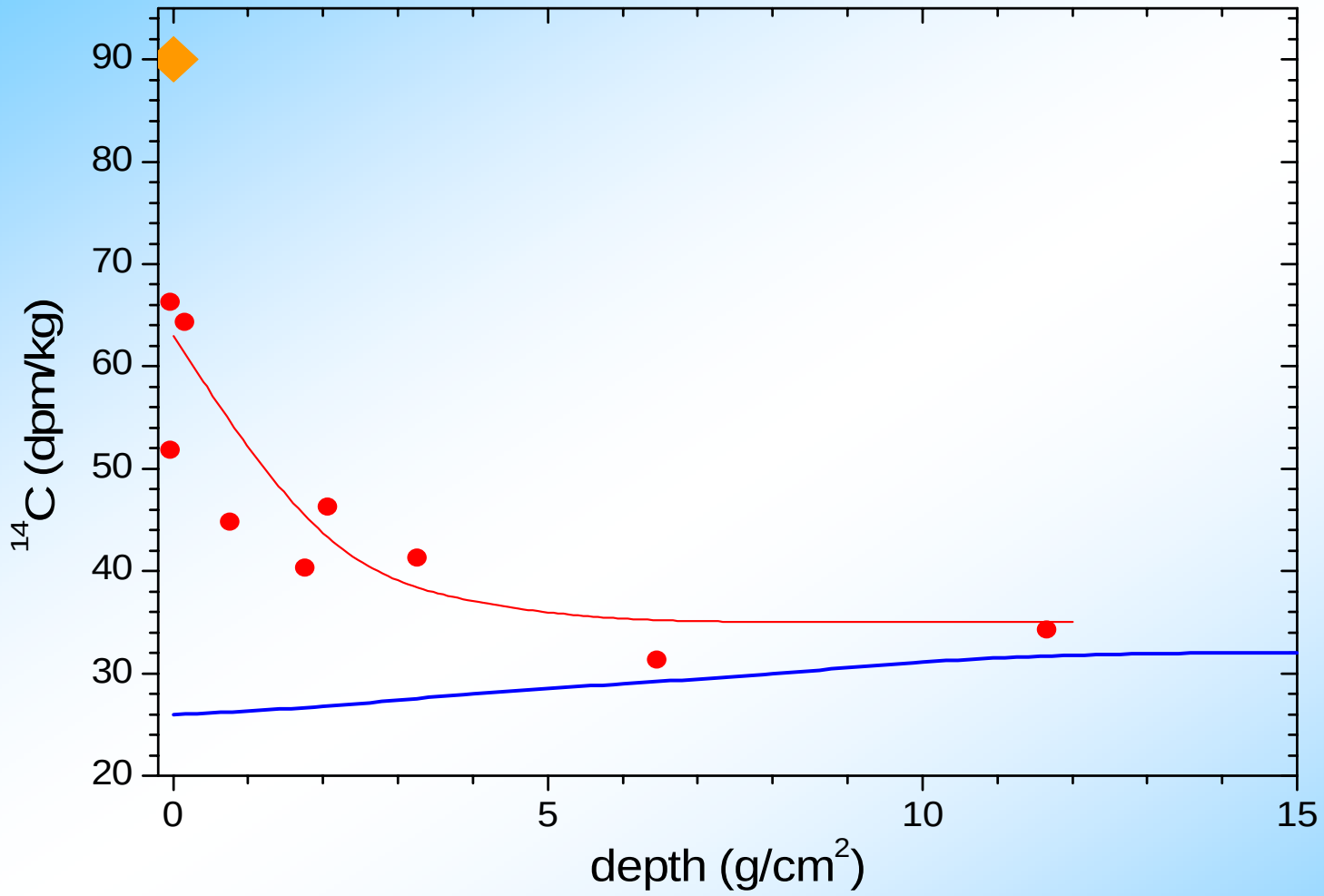


Final result



Kovaltsov & Usoskin, Sol.Phys, 2014

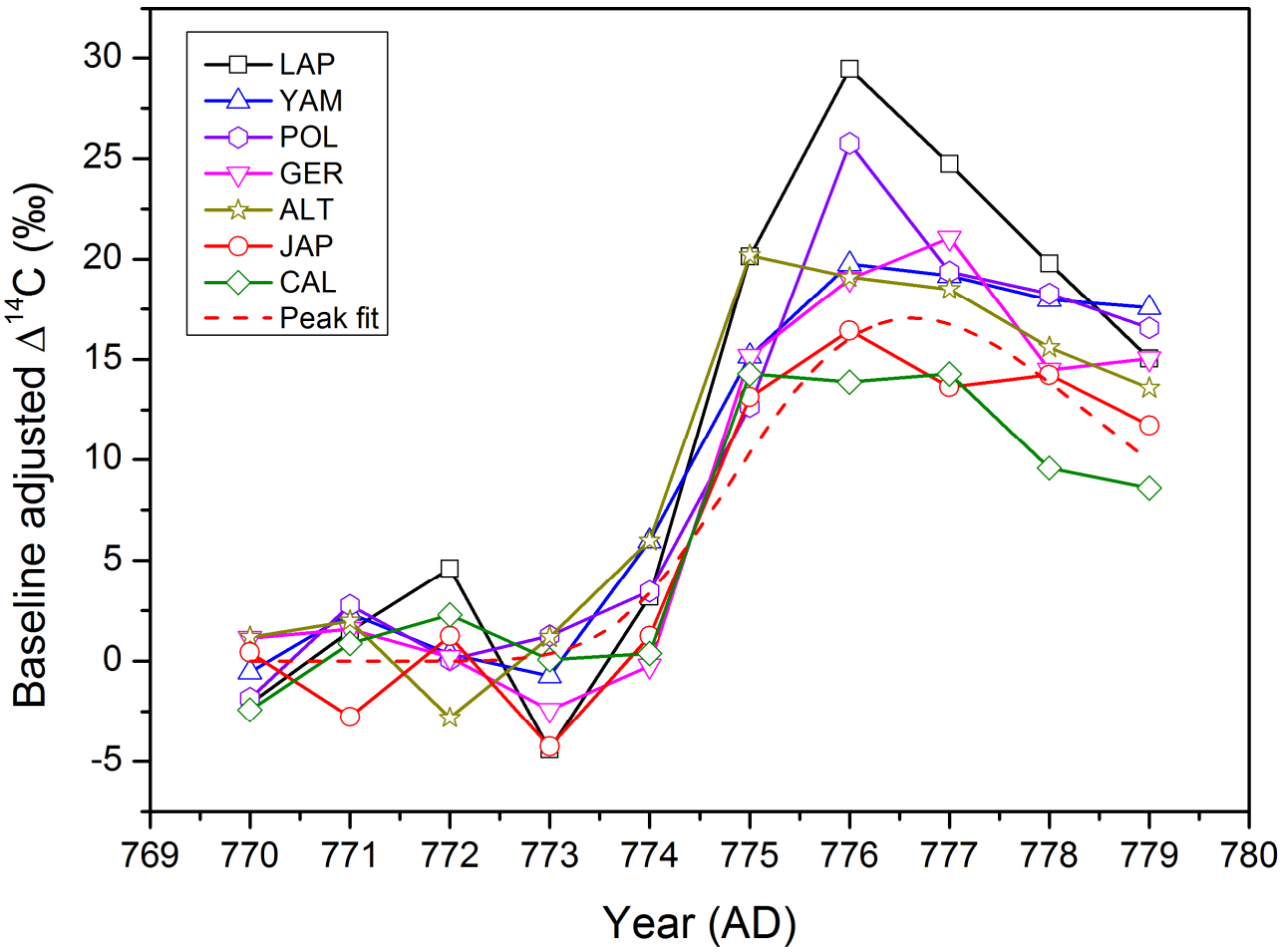
Lunar/meteoritic samples



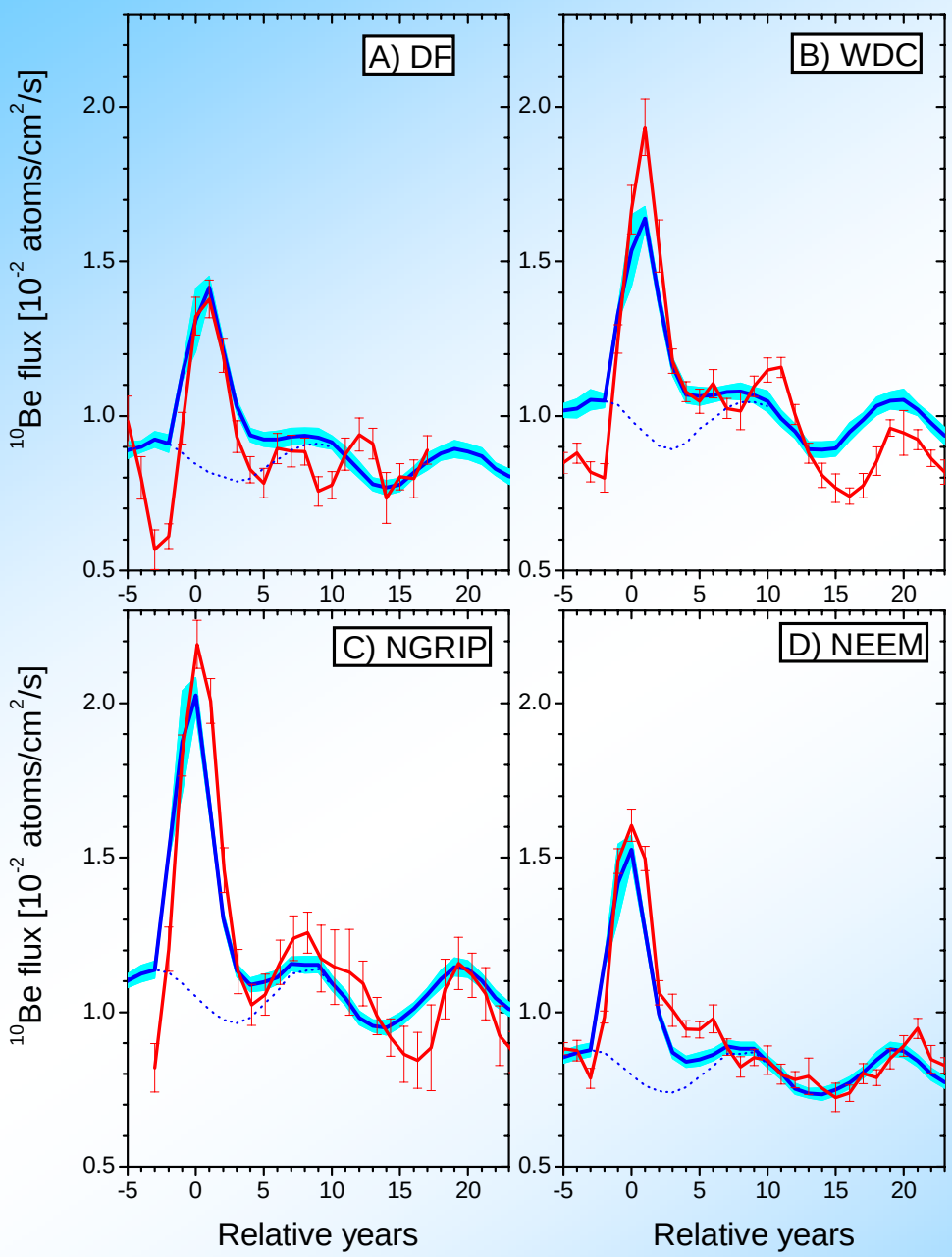
^{14}C activity in a lunar sample 68815 (Jull et al., 1998).

Specific event of 775 AD

^{14}C signal

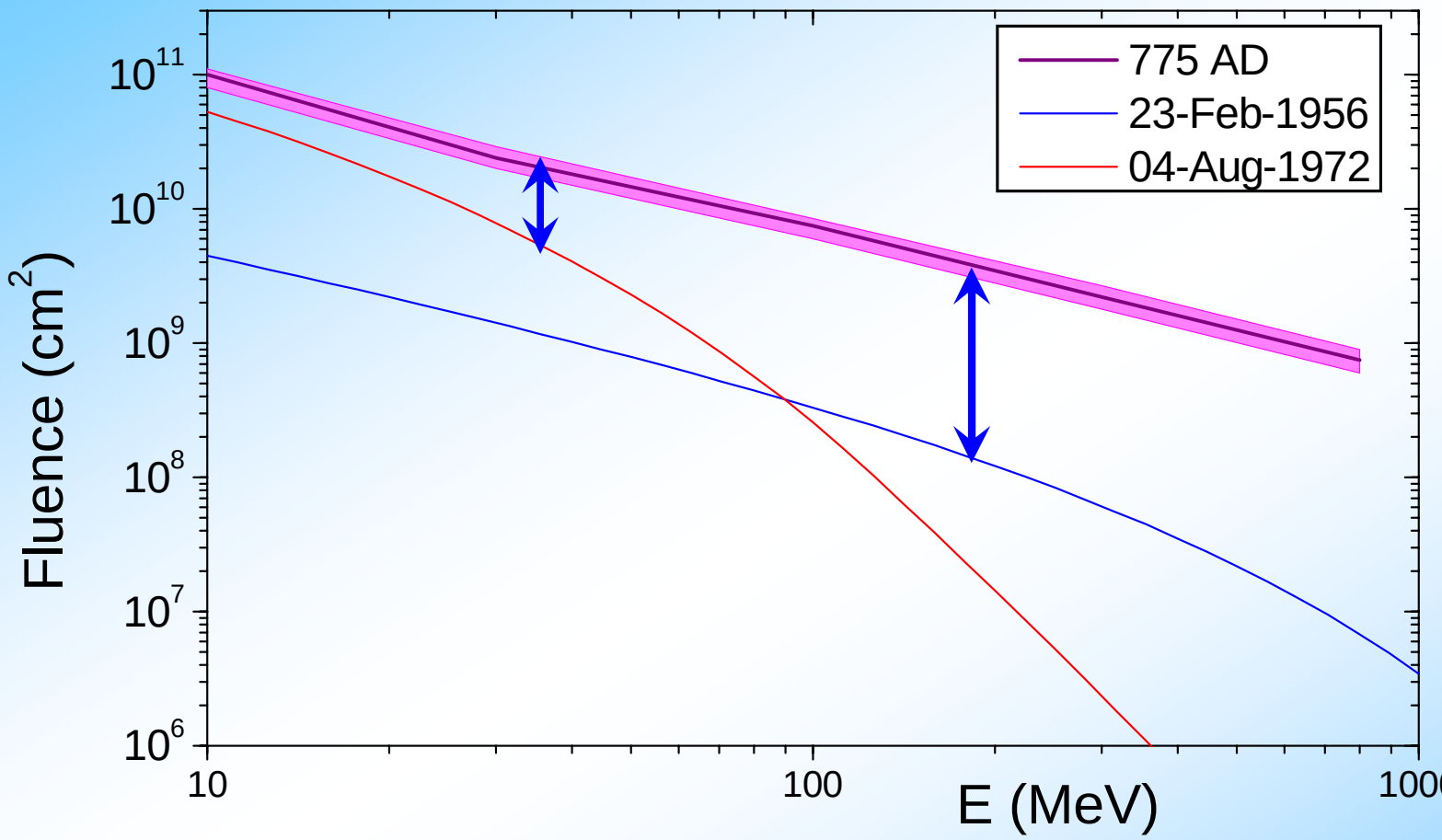

LAP
YAM
POL
GER
ALT
JAP
CAL
Peak fit
Baseline adjusted Δ14C (‰)
30
25
20
15
10
5
0
-5
769
770
771
772
773
774
775
776
777
778
779
780
Year (AD)

^{10}Be signal



Sukhodolov, Usoskin, Rozanov et al., Sci. Rep., 2017

Energy spectrum of 775 AD event

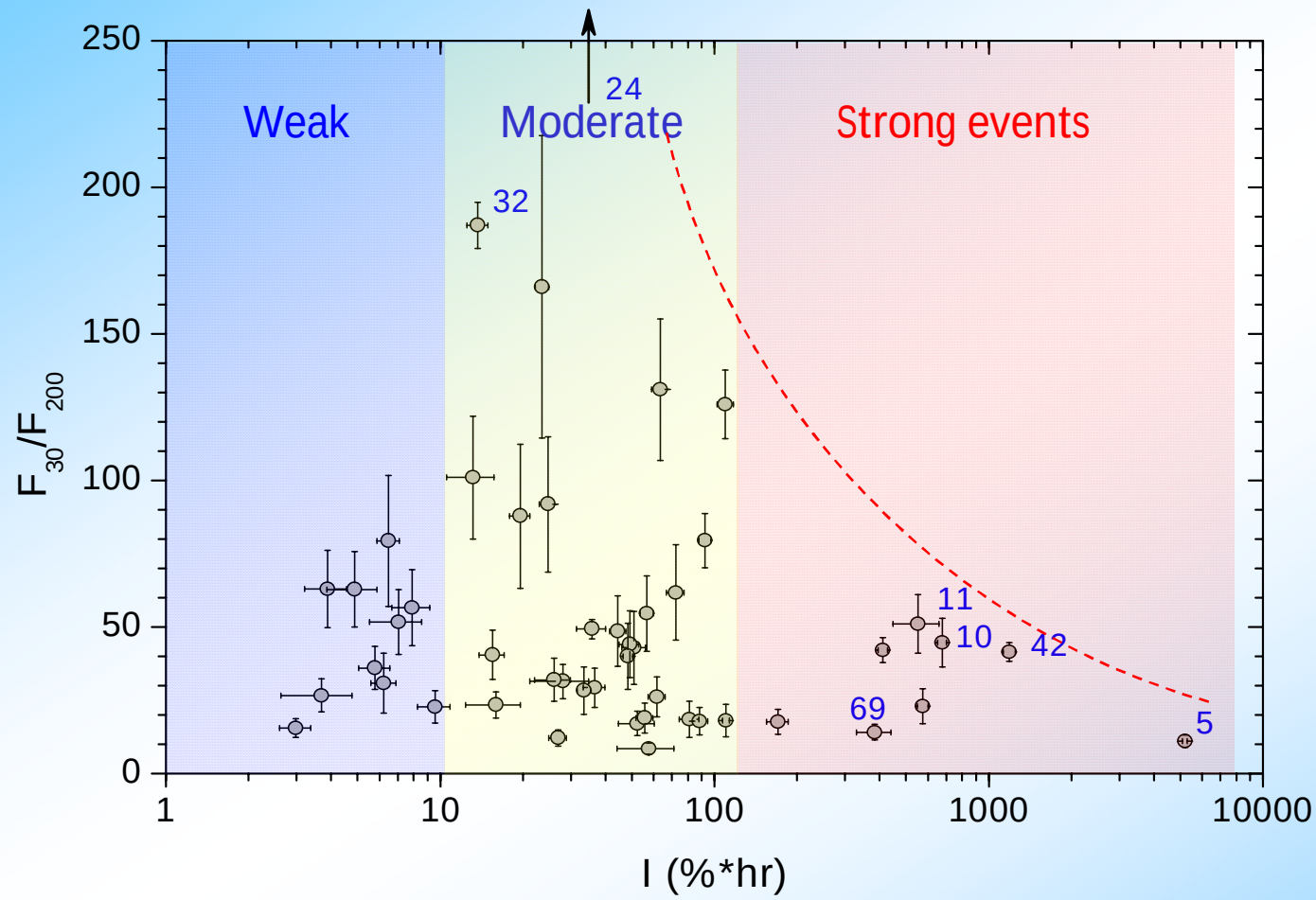


30 MeV – a factor of **2**;

200 MeV – a factor of **40**

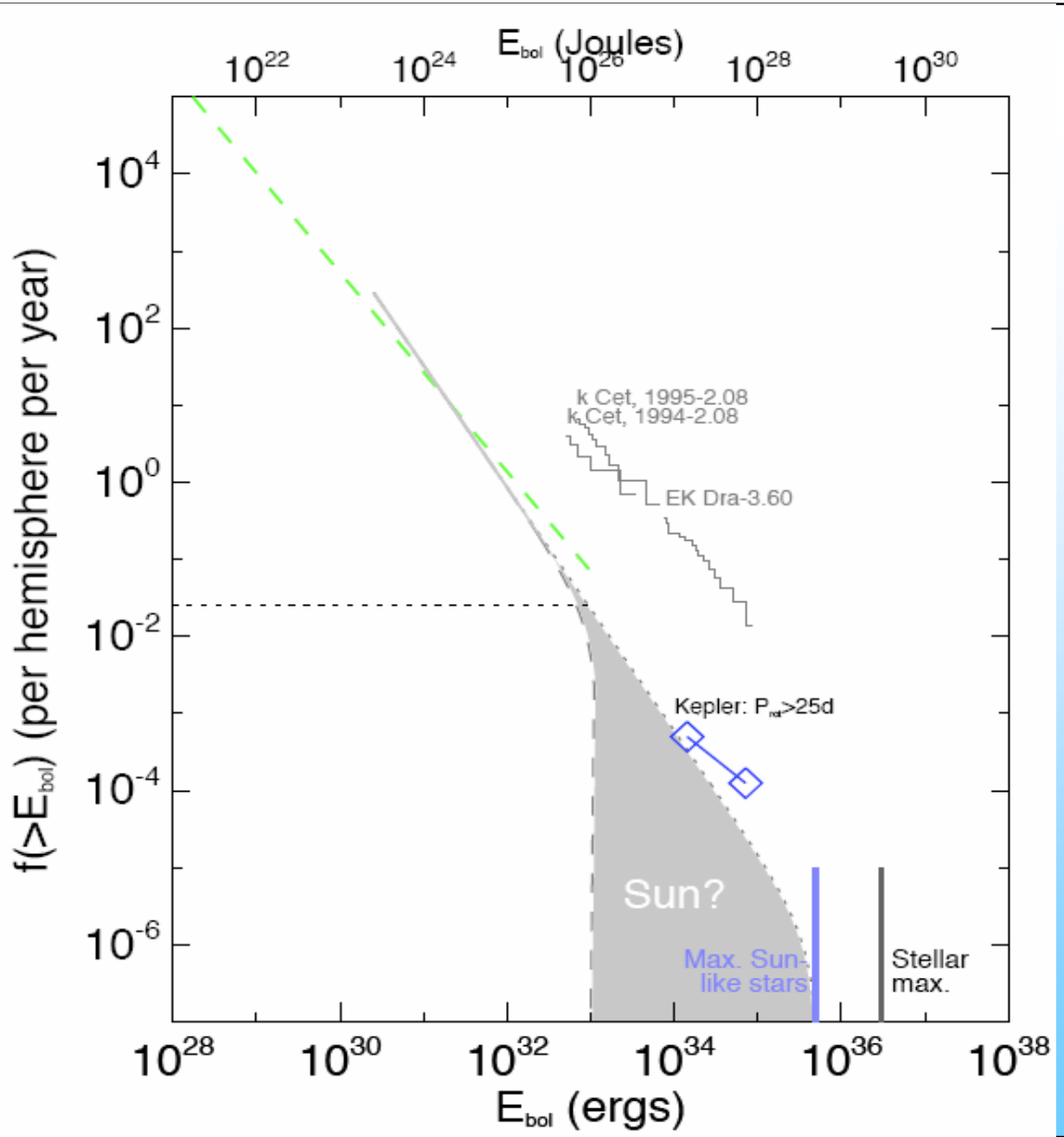
Mekhaldi et al. (2015)

Hardness of GLE events



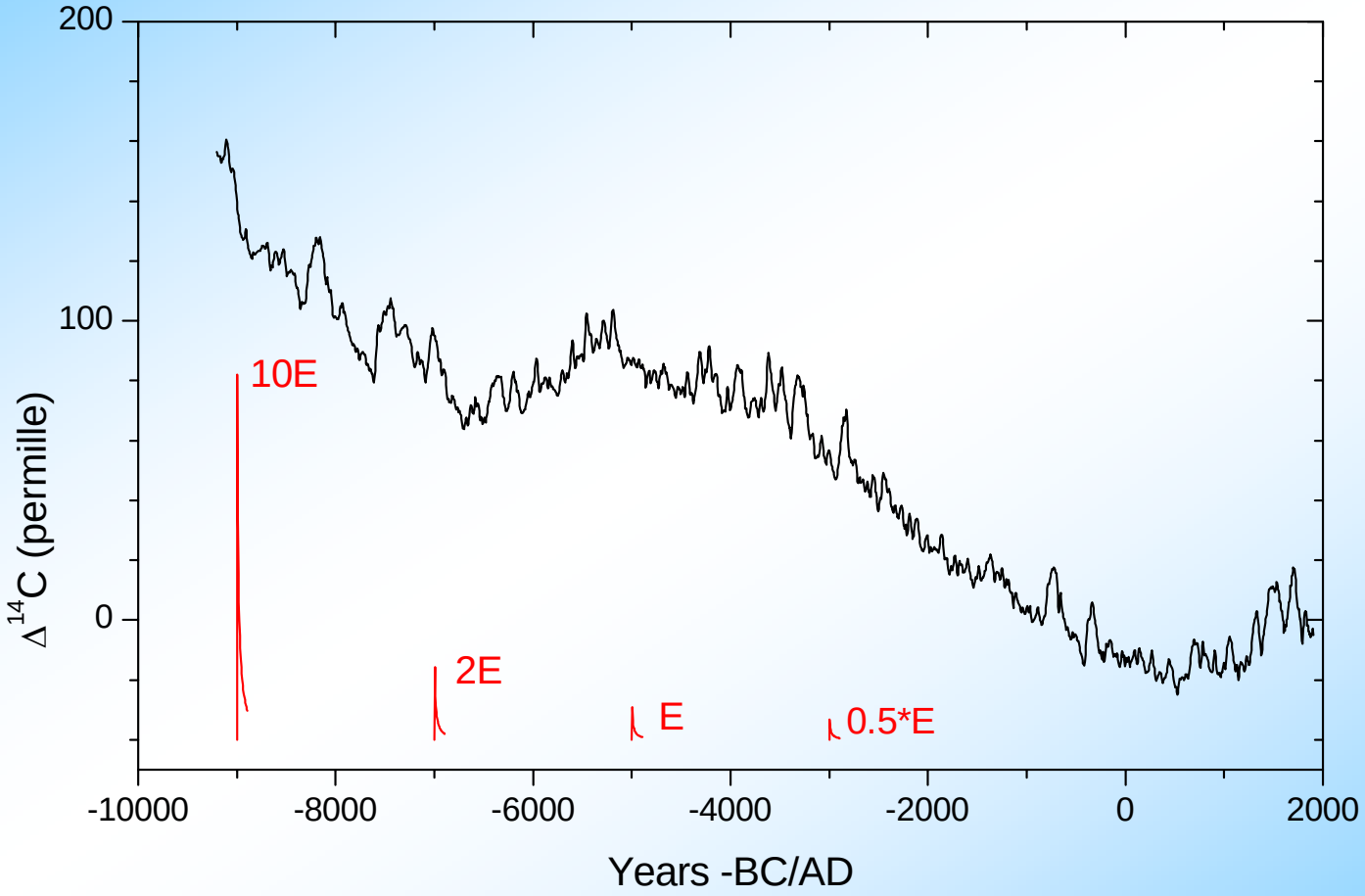
The worst case scenario?

OPDF of solar flares



Schrijver & Beer, EOS, 2014

Events to look for in $\Delta^{14}C$



Summary

- **Four** potential candidates with $F_{30}=(1\div1.5)*10^{10}$ cm^{-2} and no events with $F_{30}>2*10^{10}$ cm^{-2} identified since 1400 AD in the annually resolved ^{10}Be data.

- For the Holocene, **20** SPE candidates with $F_{30}=(1\div5)*10^{10}$ cm^{-2} are found in the ^{14}C and ^{10}Be data and clearly no event with $F_{30}>5*10^{10}$ cm^{-2}.

- The greatest event was ca. 775 AD $F_{30}\sim5*10^{10}$ cm^{-2}. It may serve as the worst case scenario.

- On average, extreme SPEs contribute about 10% to the total SEP flux.

- Practical limits are: $F_{30}\approx1$, $2\div3$, and $5*10^{10}$ cm^{-2} for the occurrence probability ≈ 10^{-2}, 10^{-3} and 10^{-4} year^{-1}, respectively.

From candidates →

case studies of all events.


THANK YOU !