Observation of High Energy Neutrons and Protons from the Sun
--- 1998.11.28 and 2003.10.28 events ---

@ SEE-2005, Sep. 29th

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- 1. Basic knowledge and some from histories
- 2. Scientific purposes
- 3. Results obtained in solar cycle 21-23
- 4. Events observed on 98.Nov 28th, 03.Oct 28th
- 5. Summary
- 6. next step

1. Basic knowledge and some from histories

about Neutrons

In 1951 Biermann et al pointed out….

Solar cycle	year	method
*21	1975-1985	neutron monitor, satellite
*22	1985-1996	scintillator
*23	1996-2007	neutron telescope
*24	2007-2018	γ/n separation, space station

First detection of solar neutrons. 1980, 1982

Are they produced impulsively or gradually?

----→ acceleration model

Let us remind of

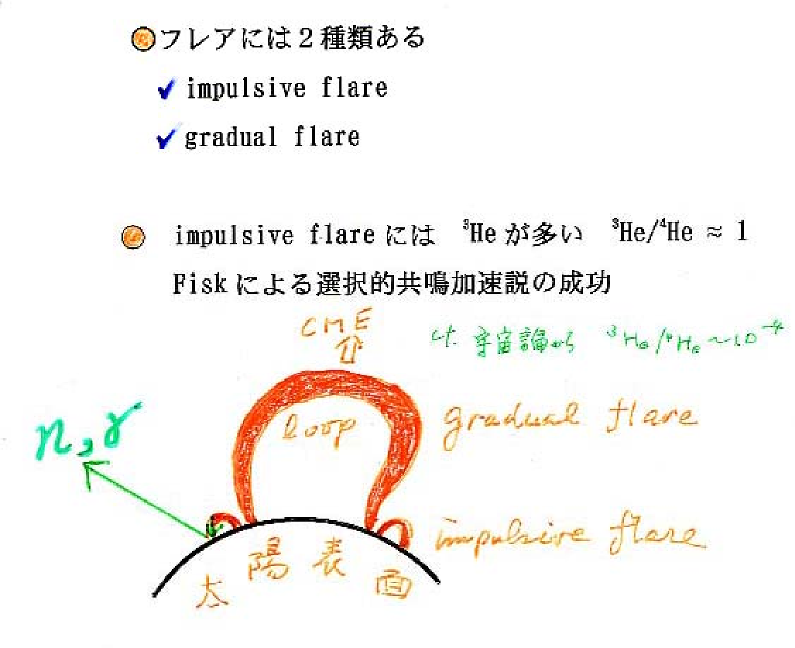
○Neutrons cannot run by the light speed

1 GeV → 1min
200MeV → 6min
100MeV → 11min
70MeV → 14min

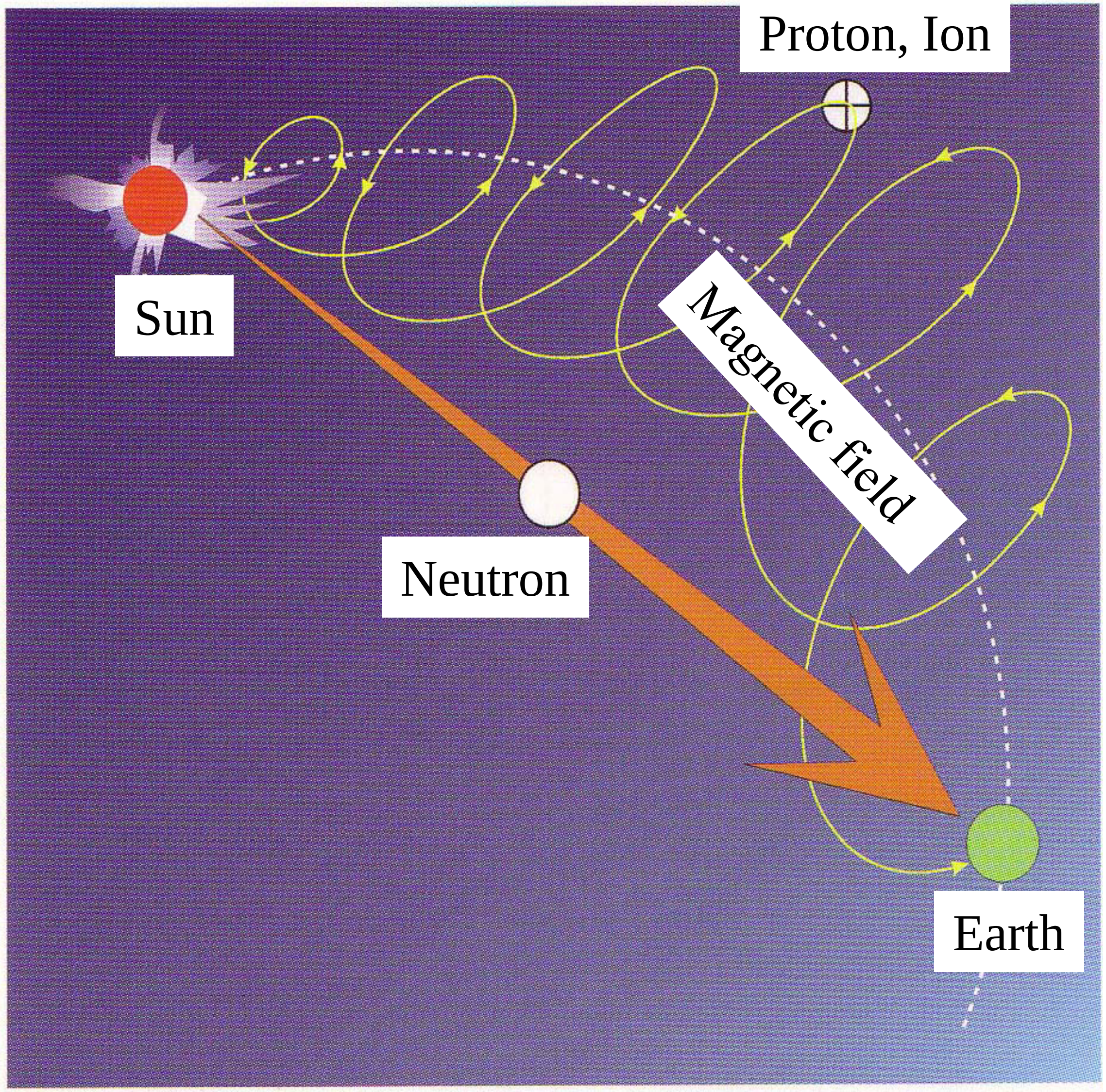
○ Therefore energy information is essential, so we have prepared a new solar neutron global network.

About Protons

- There are two kinds of flares; impulsive flare and gradual flare. In impulsive flares ^3He are largely involved.
- The maximum energy is measured by the ground level detector, using geomag cut-off effect



2. Scientific purposes



Physics aim is to confirm particle acceleration model at the solar surface.

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When, How?

Positive astronomy

However observation of protons does not give us any message about it. Protons are usually coming a few hours later from the flare. This is the reason why we use neutron channel.

3. Results obtained in solar cycle 21-23

- The number of solar neutron events was limited in the solar cycle 21 and 22.

  Only 6 events were detected in association with large solar flares higher than intensity X>8.
- However in the solar cycle 23, due to our effort,

  about 40 ($\sigma>3$) new events have been collected

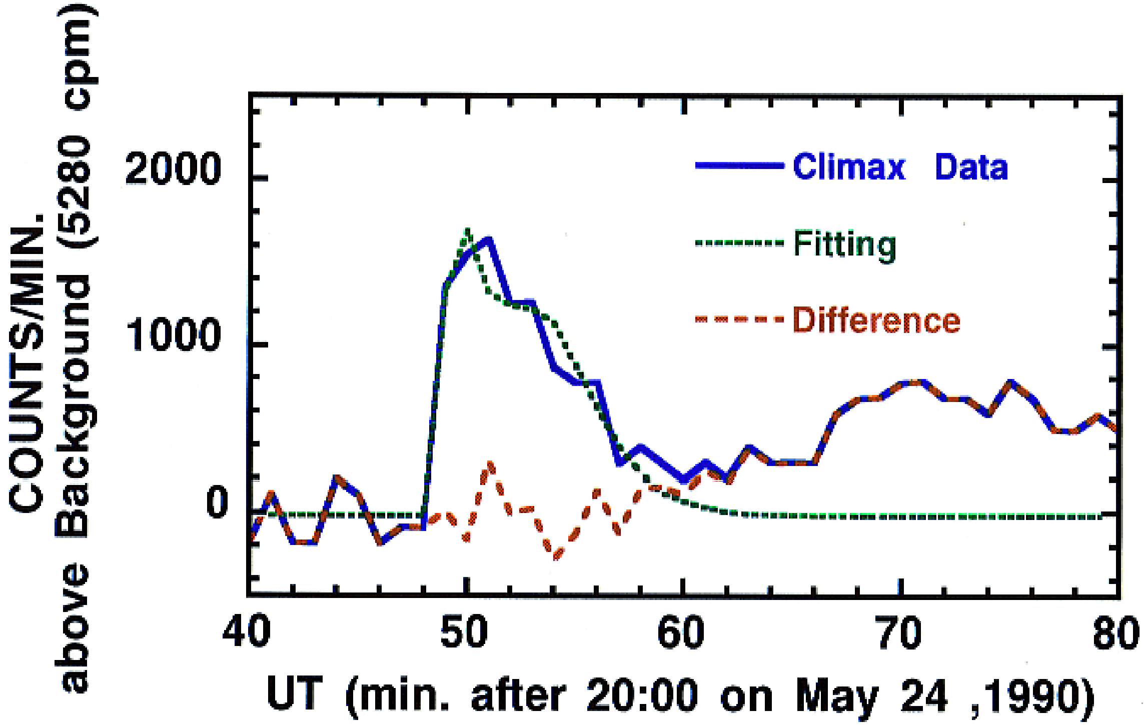
  and 15 ($\sigma>4$) new events have been added.
- In this talk, I will start from solar cycle 21.

May 24th 1990 event

By Muraki and Shibata

The event can be explained by impulsive production model.

The power index was -2.5

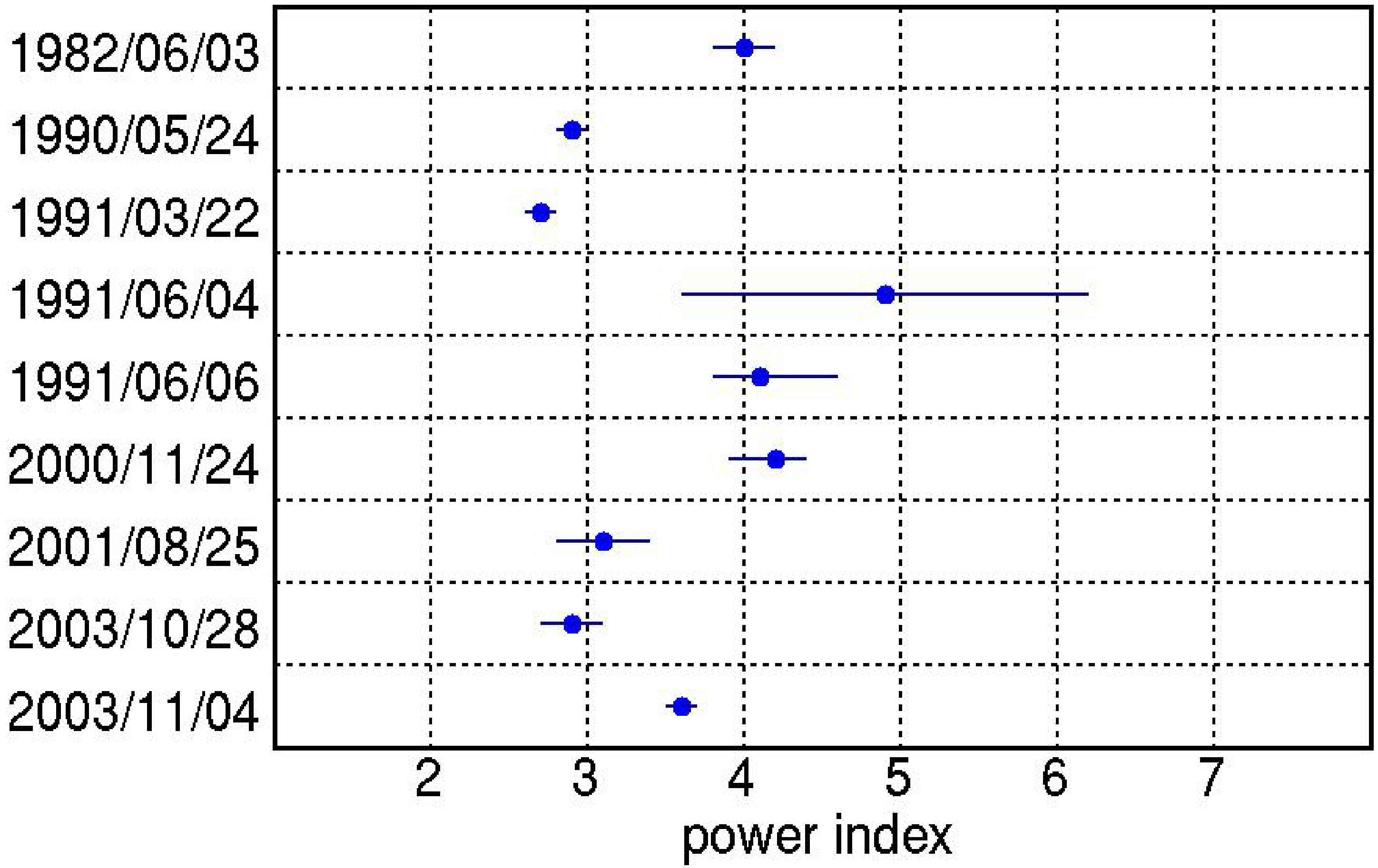


3. Summary of typical past neutron events

- Results obtained in the solar cycle 21-23
- event on 1980. 6.21 impulsive
- event on 1982. 6. 3 impulsive+gradual
- event on 1990. 5.24 impulsive
- event on 1991. 6. 4 impulsive
- event on 1998.11.28 impulsive

Solar neutron power index

by K. Watanabe



4. Important discovery by Tibet solar neutron telescope

- A solar neutron telescope was made

  at Yanbajing, Tibet 4300m in September 1998.
- In November 22nd,23rd and 28th1998, large solar flares occurred over the Tibet detector. By these flares, enhancements were observed in the flares of

  23rd and 28th Nov. 1998.
- Today we present results of November 28th.

The Nov 28 1998 event

The flare size was X3.3.
The position at the Sun was N17E32.

Batse observed hard X-rays at 5:31:36 and remarkable flare starts at 5:37:30 & the peak at 5:40:46UT.

UNTITLED: Created by freeland at 9-JAN-04 10:18:21 UT 1/1 ページ

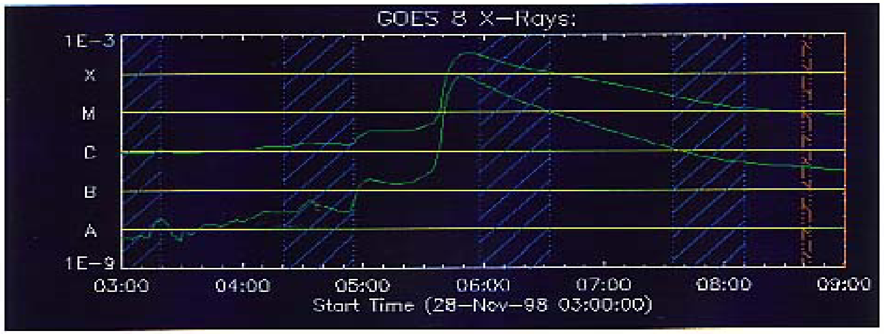
YOHKOH SXT

GOES Satellite X-Ray Data

Program run at: Fri Jan 9 02:18:21 2004

Blue diagonal (positive slope) lines = Yohkoh Night

Orange diagonal (negative slope) lines = Yohkoh SAA passage



Plot was made using one-minute averages of GOES 3 second data

The Above GIF File Program *www_get_gev* run at: Fri Jan 9 02:18:25 2004

GOES Event Listing for Period: 28-NOV-98 through 28-NOV-98 09:00:00

Date	DOY	Start	Peak	Stop	Class
28-NOV-98	332	04:54	05:52	06:13	X3.3

This Event Listing as Text File

freeland@sxt1.lmsal.com

CGRO Batse data on Nov 28th 1998

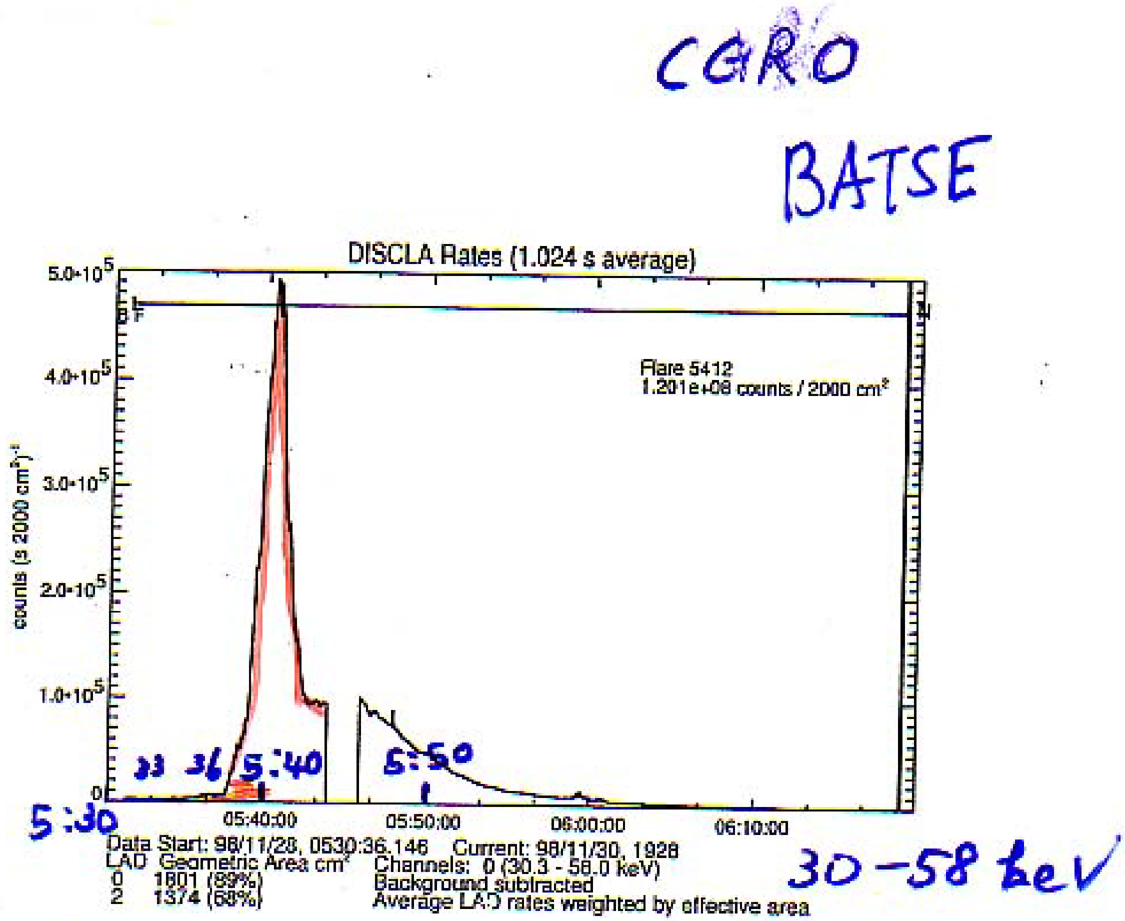
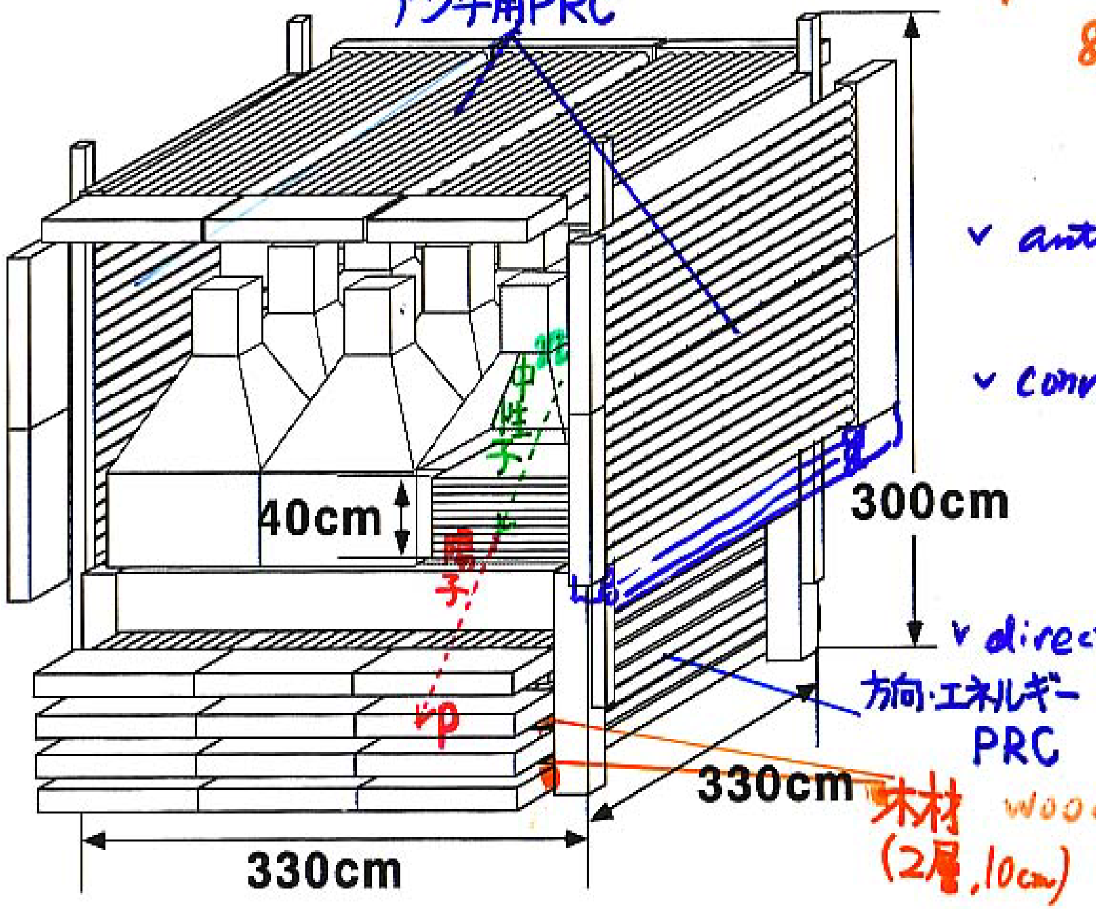


Figure 17: BATSE X ray(30 keV - 50 keV) data around the time of the solar flare. The horizontal axis represents Universal Time.

Tibet solar neutron detector

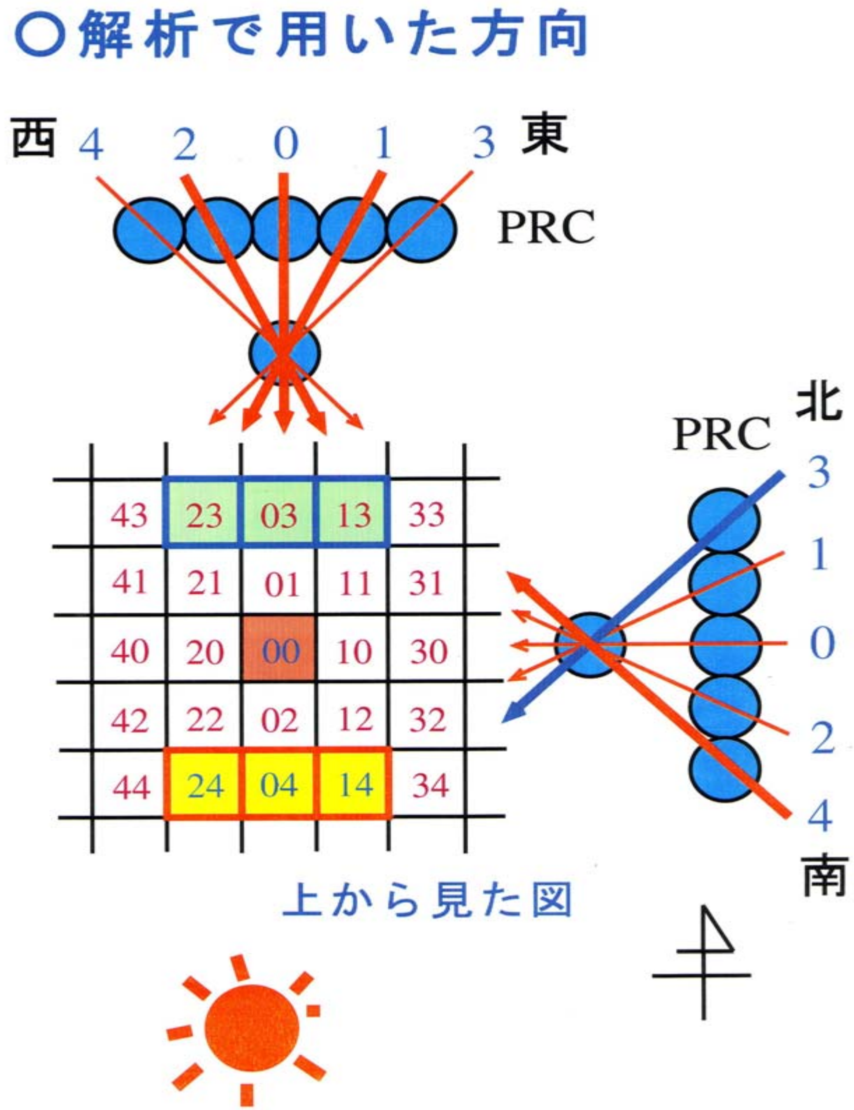


4300m
$S \sim 9\,m^2$
80% bkg rejection

- anti gondola
- converter
- directional detection

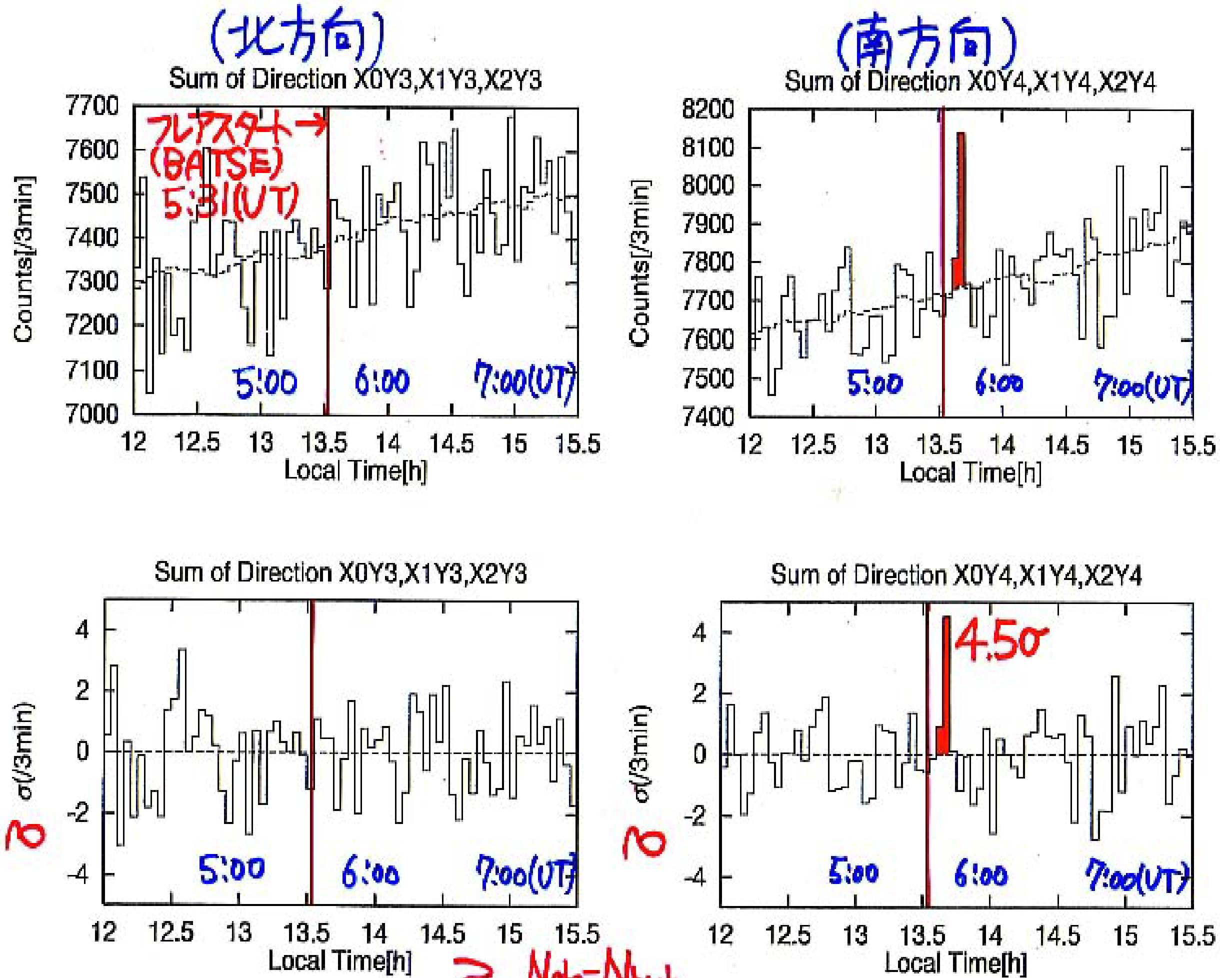
$\Delta\theta_x \sim \pm 8°$
$\Delta\theta_y \sim \pm 8°$

Telescope function of Tibet detector



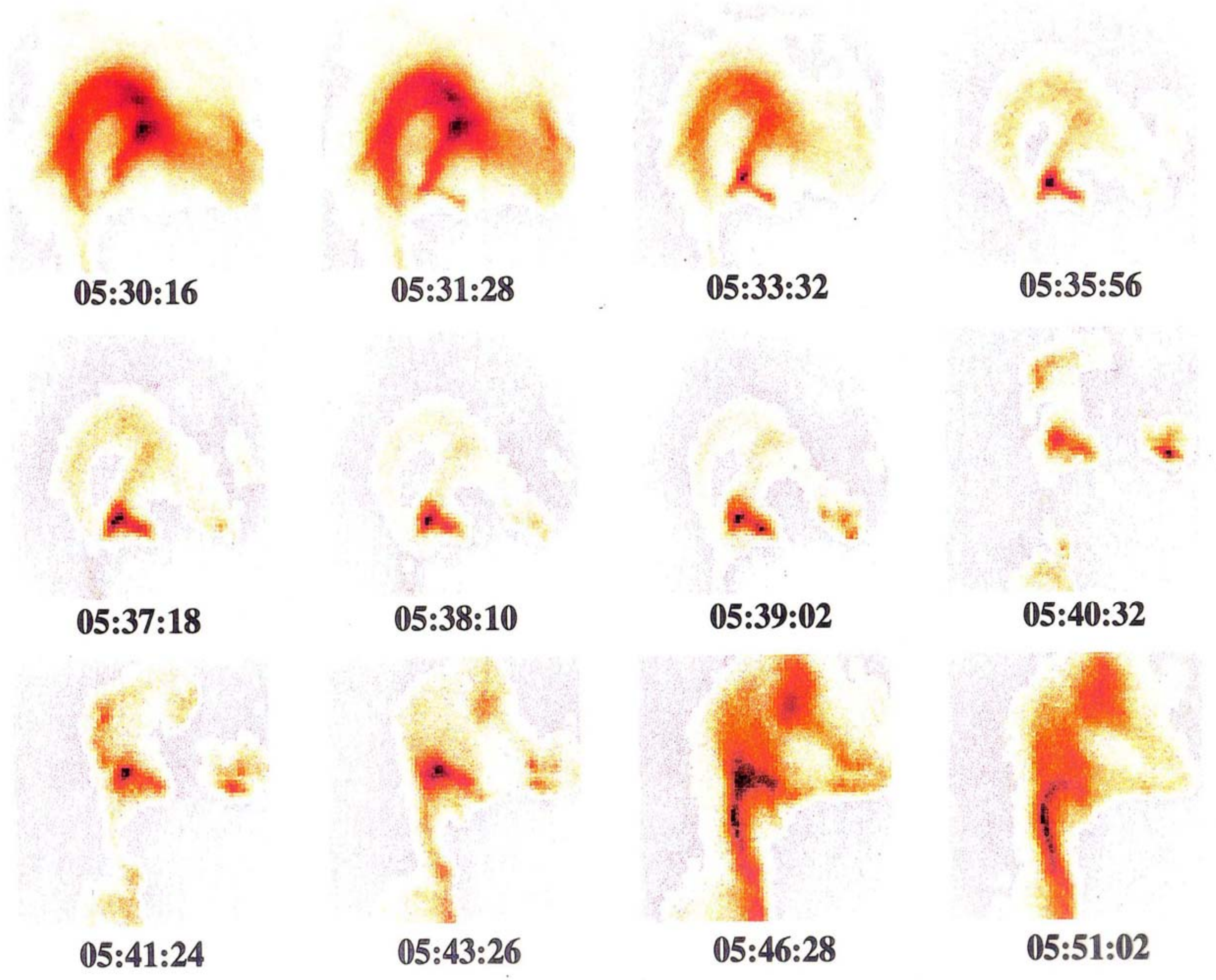
North-South comparison

1998/11/28 方向別(3分値) (>240MeV)

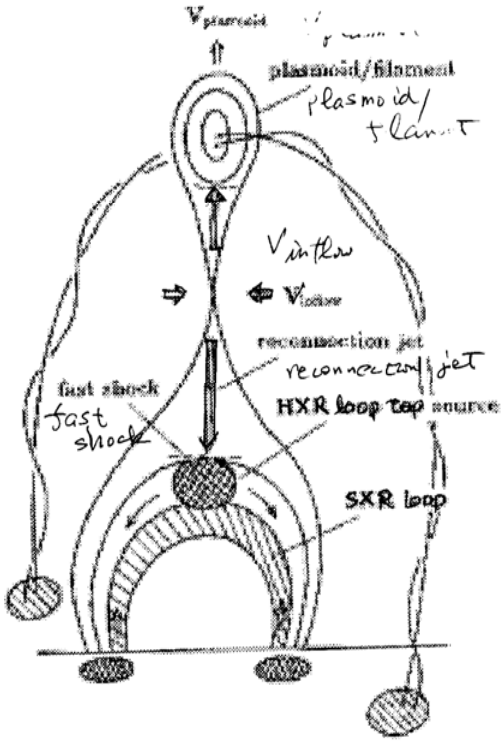


$$\sigma = \frac{N_{obs} - N_{back}}{\sqrt{N_{back}}}$$

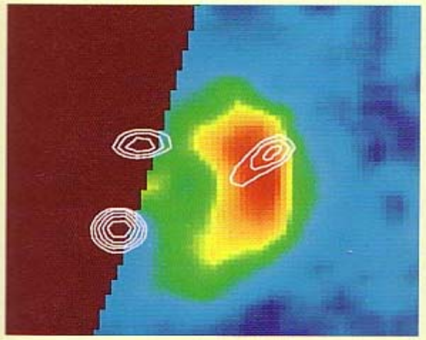
Yohkoh/SXT Nov. 28th, 1998 flare (by S. Masuda)



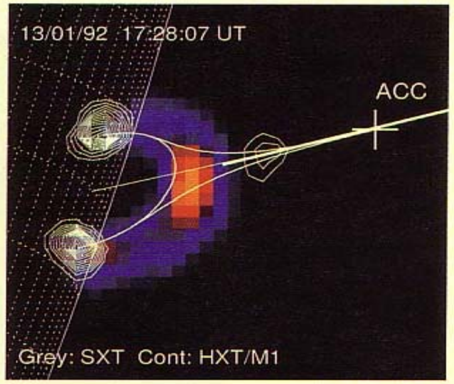
a top-down scenario



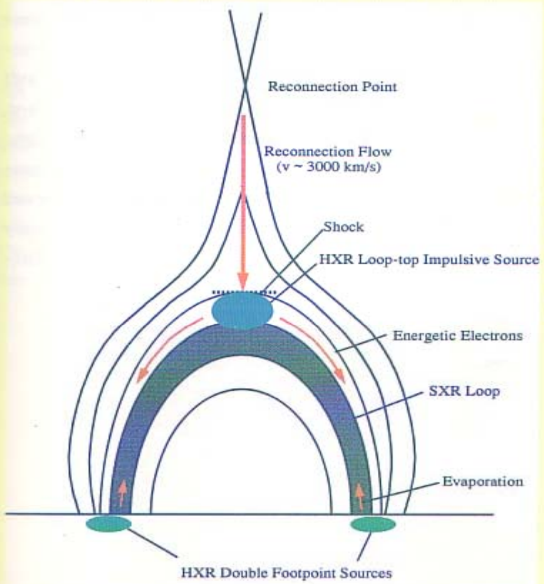
FLARES



Left, a temperature map generated from soft X-ray images, showing that the domain of highest temperatures ($\sim 20 \times 10^6$ K) includes the location (contours) of the coronal hard X-ray source.



Right, an analysis of the coronal hard X-ray flare using precise timing of hard X-ray variability detected by large-area hard X-ray detectors aboard the Compton Observatory. Time-of-flight localization of the acceleration site (labeled with a cross) is consistent with the above-the-loop location of the hard X-ray source observed by Yohkoh HXT.



Left, the geometry synthesized from the observations. A reconnection site in the corona above the soft X-ray source drives a rapid flow, which impinges on the denser material in the magnetic loop and creates both hard X-rays and high temperatures.

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Estimation of particle acceleration time

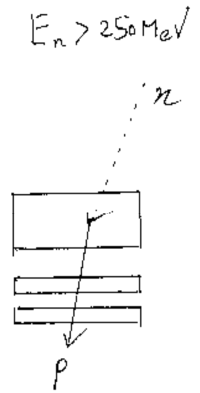
- Typical radius of magnetic loop 10^4 km
- Travel time $2\pi r/c \approx 6x10^4 km/3x10^5 km \approx 0.2 sec$
- $V / c \approx 0.01$ (high speed solar wind 3000km/s)
- $v/c \approx 0.1$: speed of charged particles
- First Fermi : $\Delta E/E \approx 2V/c \approx 1/50$
- Second Fermi: $\Delta E/E \approx 2(V/c)(v/c) \approx 1/50*1/10 \approx 1/500$
- The time needed for the acceleration of particles
- From 20 MeV to 40 GeV are

10 minutes for second and 1.1 minute for first Fermi.

A puzzle on 1998 Nov 28th event

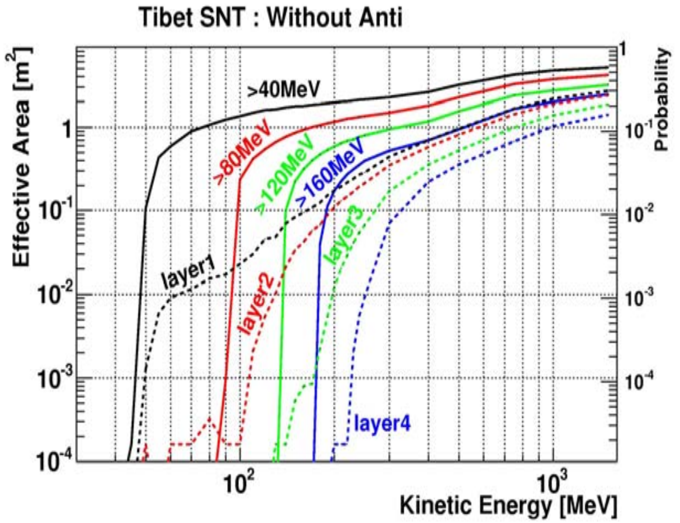
Event Profile

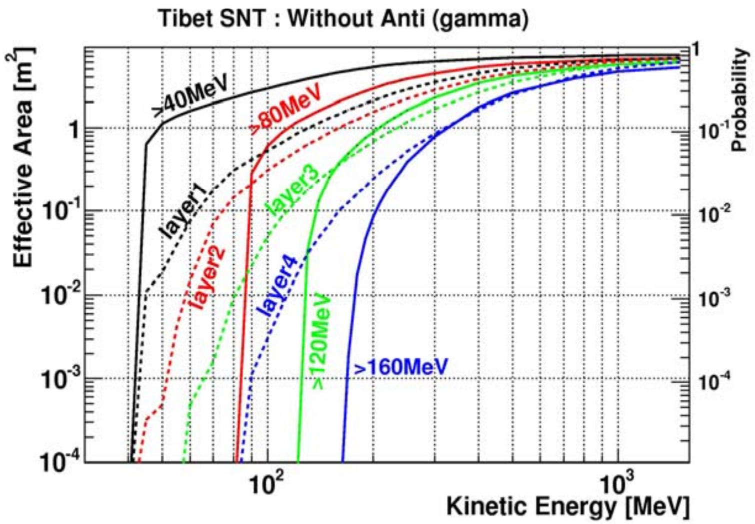
	N(3min value)	root$\sqrt{N}$	E> MeV
ch 1	240,000	490	> 40
ch 2	96350 - 95800 550	390	> 80
ch 3	49900 - 49500 400	220	>120
ch 4	23750 - 23450 330	150	>160
south	8140 - 7730 410	90	>120

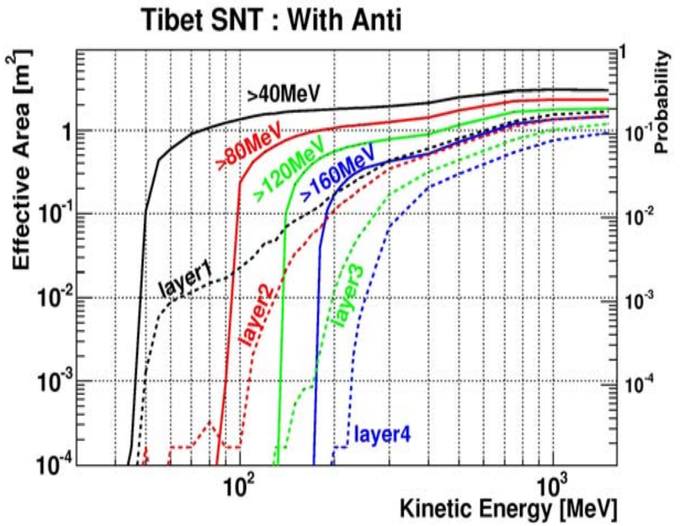


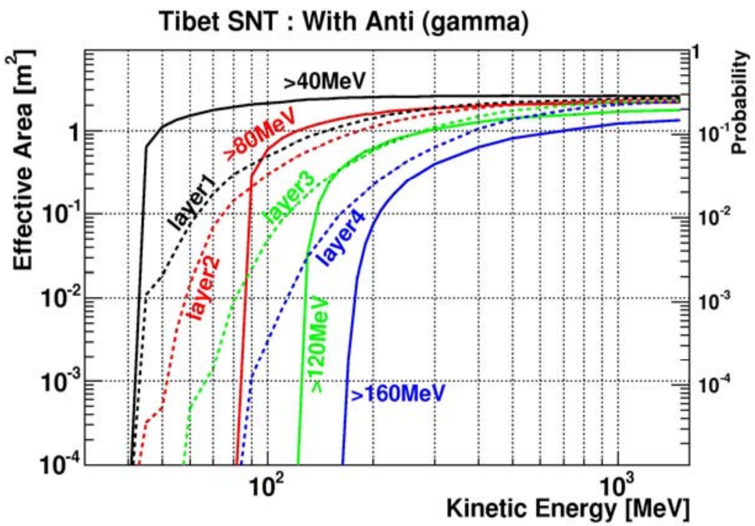
for $E_n \geq 800MeV$
delay time
~90sec

Detection efficiency for n and γ by Sako









5. Conclusion for Tibet event

- In this flare protons was accelerated beyond 20 GeV They collide with the atmosphere of the Sun and produced high energy neutrons (say > 10 GeV).
- They came to the Earth and collide with the atmosphere of the Earth and produced high energy photons. Those photons have detected together with neutrons. The ratio would be approximately 1:1.
- High energy protons were accelerated at the Sun in this flare, probably up to 100 GeV. This is the first event to have been detected such high energy neutrons.

Summary of the Tibet event → future tasks

- 5 minutes puzzle does exist.
  - Whether or not the particle acceleration started at 5:31UT (twice) or 5:36 UT (one time).
- Did particle leave from the loop at 5:36 UT after the injection at 5:31UT ?
- By coincidence observation with Solar-B, it will be possible to identify each model.
- There is no concrete evidence that Tsuneta-Saito model is correct. However it must be a good model.
- We aim positive astronomy (実証的天文学).