太陽表面での高エネルギー粒子加速の現在と将来

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2004.3.9
(至 宇宙線研)

あらすじ

◎ 太陽フレアの特徴

- ✓ impulsive flare
- ✓ gradual flare
- ✓ energy spectrum

◎ 太陽中性子について

◎ 太陽中性子観測の流れと今までの研究成果

◎ 第24太陽活動期で何をねらうか？

1．今回の話に関連する太陽フレアの特徴

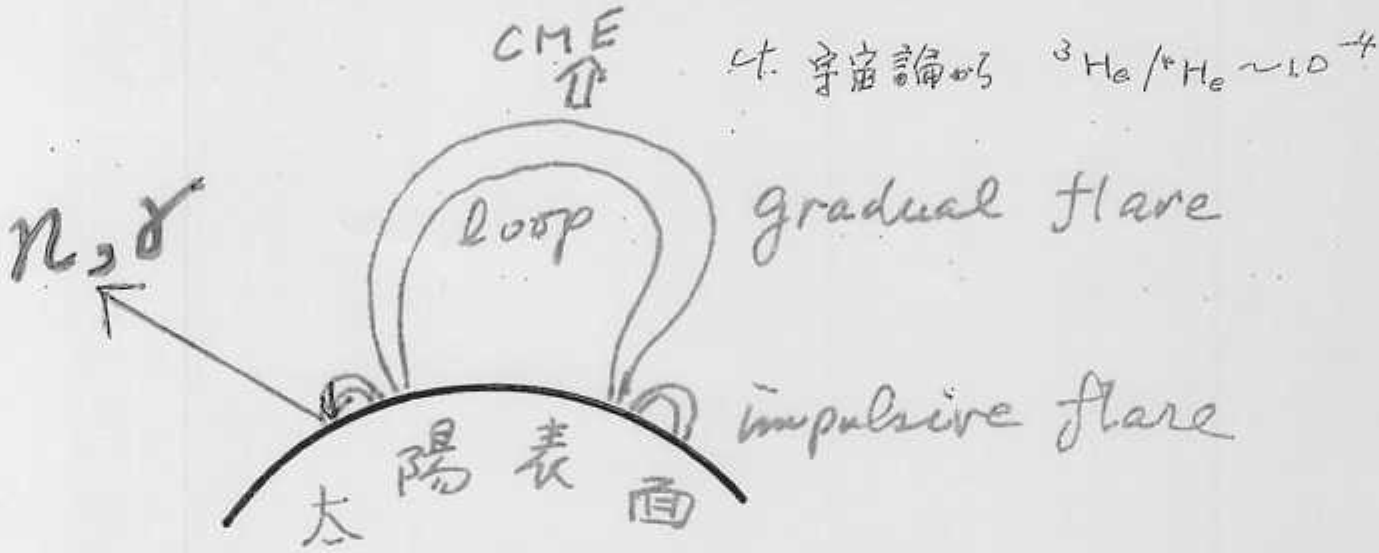
◎フレアには２種類ある

✓impulsive flare

✓gradual flare

◎ impulsive flare には ^3He が多い $^3He/^4He \approx 1$

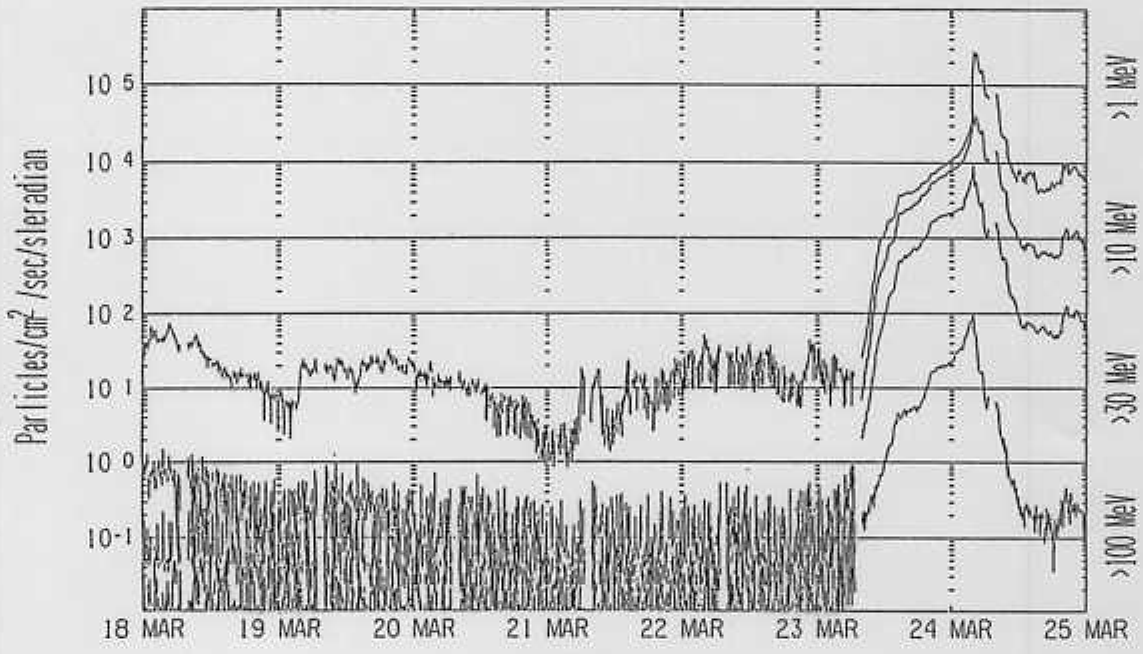
Fisk による選択的共鳴加速説の成功



GOES 衛星 (32,000km)

GOES PROTON FLUX

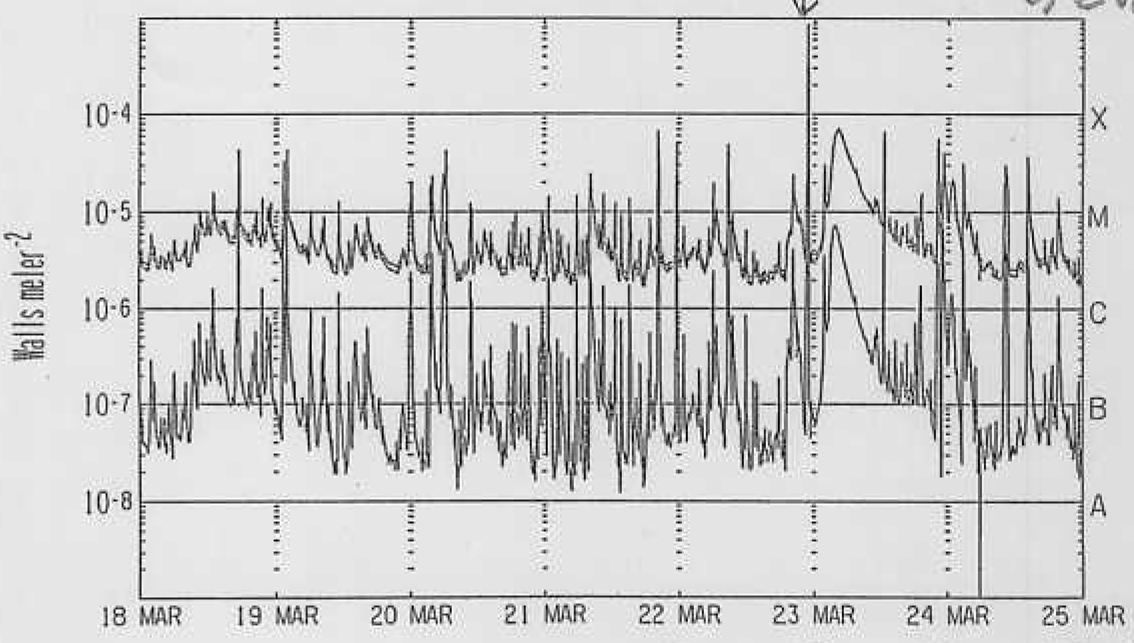
粒子線



GOES X-RAY FLUX

1991年3月23日のevent

X線



22 23 24 25 MAR

Weekly Goes Satellite X-ray and Proton Plots

Protons plot contains the five minute averaged integral proton flux (protons/cm²-sec-sr) as measured by GOES-7 (W108) for each of the energy thresholds: >1, >10, >30, and >100 MeV. P10 event threshold is 10 pfu (protons/cm²-sec-sr) at greater than 10 MeV.

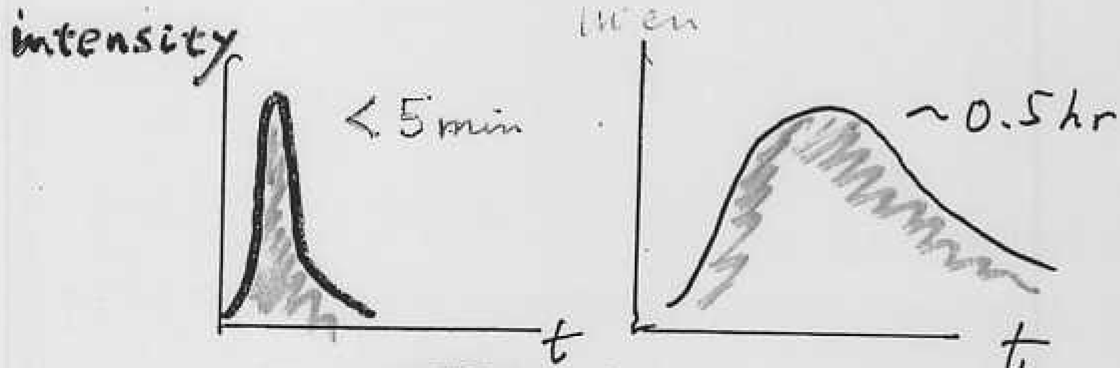
X-ray plot contains five minute averaged x-ray flux (watts/m²) as measured by Goes 6 and Goes 7 in two wavelength bands, 0.5 – 4.0 and 1.0 – 8.0 Angstroms. The letters A, B, C, M and X refer to x-ray event levels for the 1-8 Angstrom band.

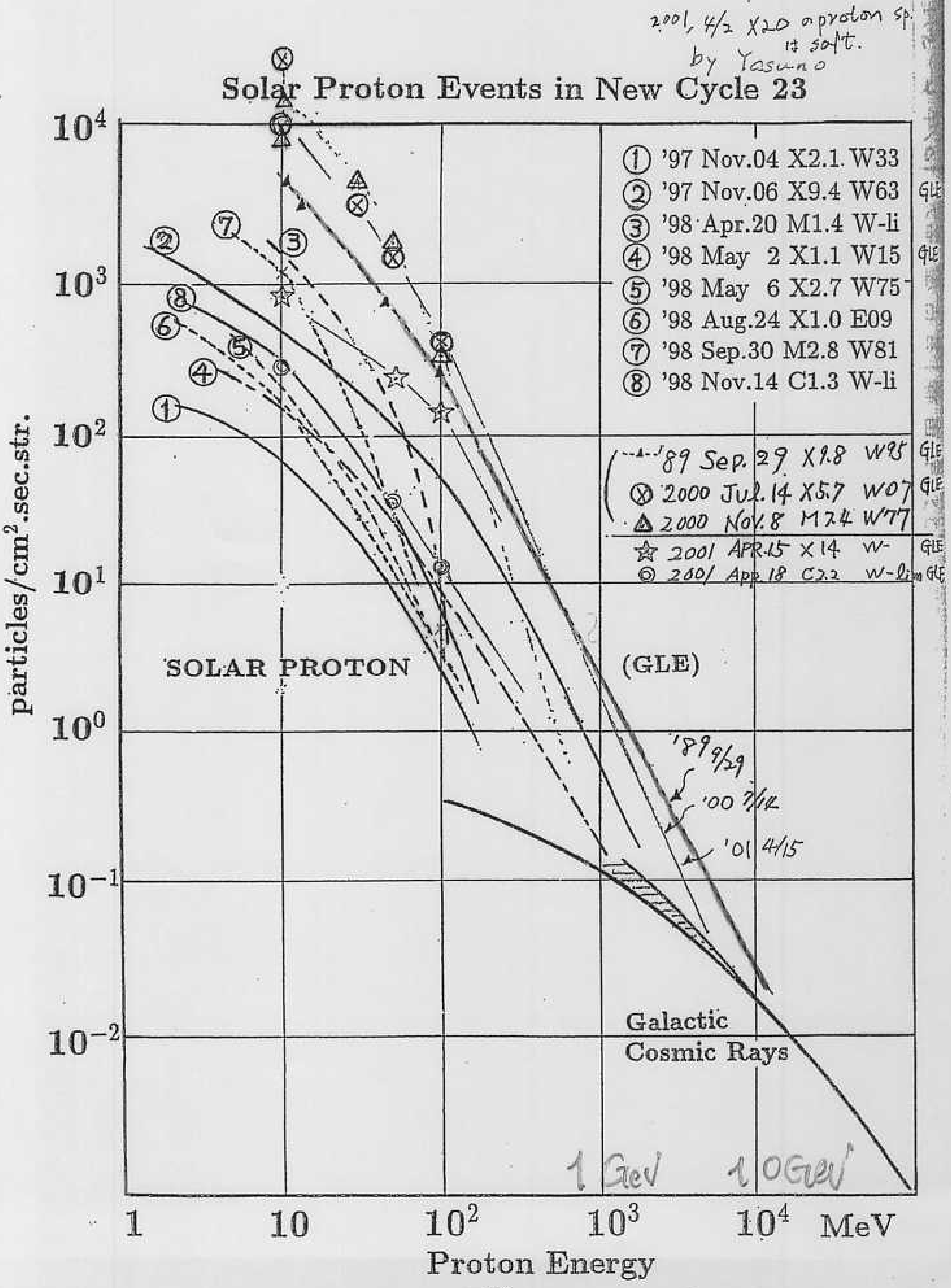
Type of Solar flares

by D. Reames (NASA) 1990

particle	e-rich	p-rich
particle	$^3He/^4He \sim 1$ $Fe/O \sim 1$ $H/He \sim 10$	0.0005 0.1 100
radio	III, V(II)	II, IV
X-ray	impulsive	gradual
corona		CME
solar wind		IP schock
flares/y	~1000 ?	~10 ?
hight	low	high
delay	~2 min	~10 min

He^3 の選択的加速 / 共鳴加速 の発見 by Fisk




2001, 4/2 X20 のproton sp. は soft.
by Yasuno
Solar Proton Events in New Cycle 23
① '97 Nov.04 X2.1 W33
② '97 Nov.06 X9.4 W63 GLE
③ '98 Apr.20 M1.4 W-li
④ '98 May 2 X1.1 W15 GLE
⑤ '98 May 6 X2.7 W75
⑥ '98 Aug.24 X1.0 E09
⑦ '98 Sep.30 M2.8 W81
⑧ '98 Nov.14 C1.3 W-li
'89 Sep. 29 X9.8 W25 GLE
2000 Jul. 14 X5.7 W07 GLE
2000 Nov. 8 M7.4 W77
2001 APR.15 X14 W- GLE
2001 Apr. 18 C2.2 W-lim GLE
SOLAR PROTON
(GLE)
'89 9/29
'00 7/14
'01 4/15
Galactic
Cosmic Rays
1 GeV
10 GeV
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
particles/cm^2.sec.str.
1
10
10^2
10^3
10^4
MeV
Proton Energy

2. 太陽中性子について

◎ 太陽中性子はどうして作られるのか？

◎ 何故中性子を測るのか？

イオンの加速過程を知りたい ⟶

イオンそのものは到着時間が遅れる ⟶

ようこうの X線画像 Video と比較できない

◎ 何故ガンマ線を測らないのか？

* ラインガンマ線はエネルギーが低い。
* ラインガンマ線は発生時刻が 100 秒程度遅れる。
* 時間分解能がそれ以上短くならない。
* ガンマ線は電子の制動放射のガンマをかぶる。

◎ 中性子観測の長所、短所

* 磁場の中を直進できる。
* しかし到来時間に差ができる。 質量があるから
* 従ってエネルギーを測る必要がある。
* 中性子の観測はガンマ線よりは難しい。
* しかし pure なイオン加速の情報をもたらす。

$E_p \approx$ a few GeV

３．中性子観測の流れ

― 私達がやってきたこと ―

◎ 太陽中性子は 1980 年 6 月 21 日に発見された

impulsive phase で加速された

◎ 1982 年 6 月 3 中性子モニターで始めて観測

impulsive + gradual phase で加速されたと結論

◎ インパルシブ か グラジュアルかを解明することが

課題となる

* 中性子モニターではエネルギーがわからない

* どちらでも解釈可能

* simulation code が悪い ⟶ 柴田祥一による計算

* エネルギーの測れる装置を展開する

* 最近の原子核散乱のモデルを採用 かつ

エネルギーの測定できる装置で測定したところ

インパルシブフレアで中性子が作られることが

確認された。

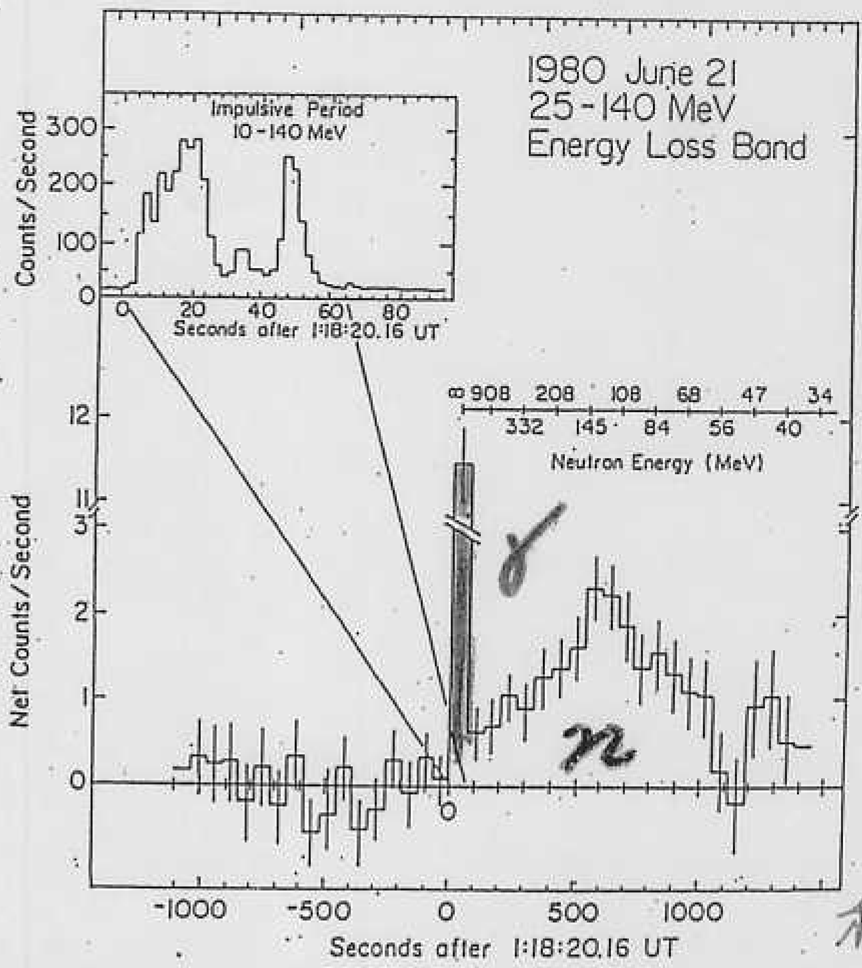
◎さらに上記仮説を裏付けデータが集積された

gy detector elements for the (*a*) impul-
is, (*b*) solar quiet background for the
nd (*c*) postimpulsive phase excess. The
a are similar and appear to decrease
vith increasing energy as expected for
On the other hand, the postimpulsive
ctrum has a different shape, consistent
ed for the nuclear fragment energy-loss
lting from energetic neutrons interact-
le scintillators (Forrest 1969).
f high-energy radiation cannot produce
e phase emission for the following rea-
is no increased rate in any portion of
article shield. For example, if the front
article shield had an efficiency of 96%
ible), then an increase of the local
rate of ~ 10% would be required to
igh-energy detector enhancement. On

source any excess high-energy charged particles. Second, there is no unexplained increase in the count rate of neutral events in the energy range 300 keV $< E <$ 20 MeV. This rules out both electron-produced high-energy bremsstrahlung and proton-produced π^0 decay photons since these would be accompanied by an intense flux of γ-rays in the 4–7 MeV range during the postimpulsive phase.

Based on the above discussion, we conclude that the excess high-energy flare radiation observed is due to a direct flux of solar neutrons. The excess count rate versus time, in a broad energy channel, 25–140 MeV, is plotted in Figure 3. Shown in the inset is the detailed time structure of the γ-radiation during the impulsive phase in the 10–140 MeV energy band. Also shown is a neutron energy scale obtained from time of flight where we have assumed a δ-function emission of neutrons on the Sun occurring a light travel time (i.e., 507 s) before

1980. 6. 21



En

impulsive ?
gradual ?

秒

xcess count rate vs. time is shown for electron equivalent energy loss events between 25 and 140 MeV before and after
ve flare at 0118:20 UT. The neutron energy scale, center, assumes the neutrons left the Sun at the light travel time (507
(*Inset*) The total count rate vs. time after 0118:20 UT for electron equivalent energy loss events between 10 and 140
phase only.

PHYSICAL JOURNAL, 318:913–925, 1987 July 15

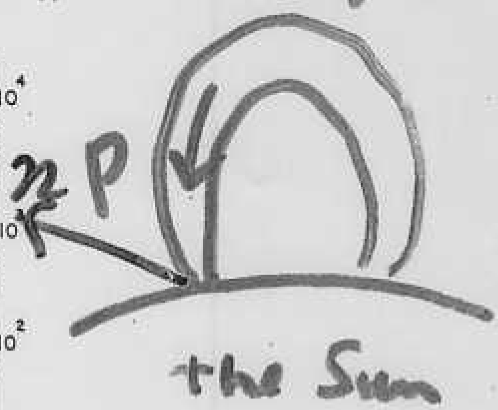
1982 June 3rd event

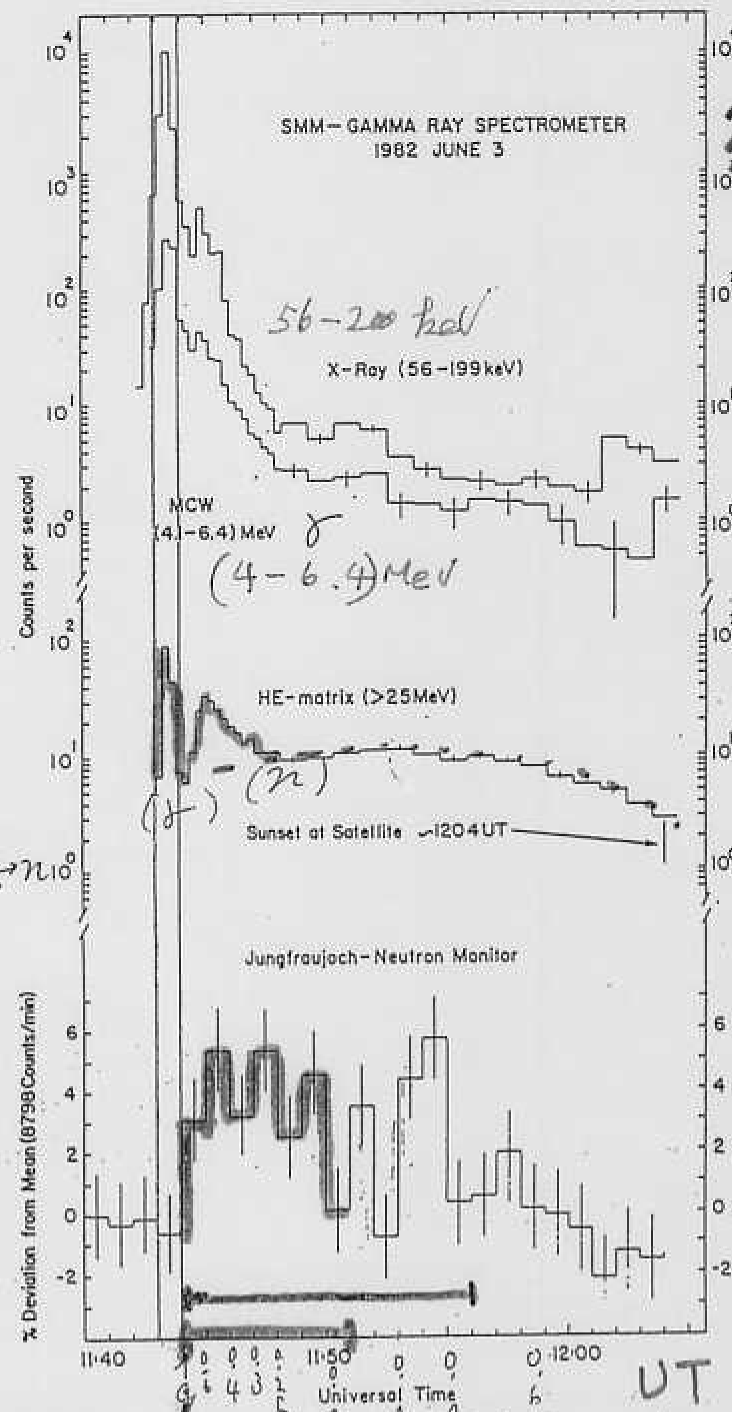
SOLAR NEUTRON EMISSIVITY DURING THE LARGE FLARE ON 1982 JUNE 3

E. L. CHUPP,[1] H. DEBRUNNER,[2] E. FLÜCKIGER,[2] D. J. FORREST,[1] F. GOLLIEZ,[2] G. KANBACH,[3]
W. T. VESTRAND,[1] J. COOPER,[3] and G. SHARE[4]
Received 1986 August 6; accepted 1987 January 6

E.L. Chupp et al, ApJ 318(1987) 913

Loop





○ n を観測した
○ p でも観測した
delay が示される

FIG. 1.—Time history for several data channels from the *SMM* GRS and for the Jungfraujoch neutron monitor count rate for the 1982 June 3 flare. Peak count rates in the GRS (X-ray) and MCW (4.1–6.4) MeV energy bands are uncertain because of pulse pile-up, excessive dead time, and photomultiplier gain shifts, and should be used with care. The highest MCW count rates have been estimated using measured live time values, averaged over 16.384 s, and a derived gain shift correction. Error bars are 1 σ based on count statistics only.

44 51 56

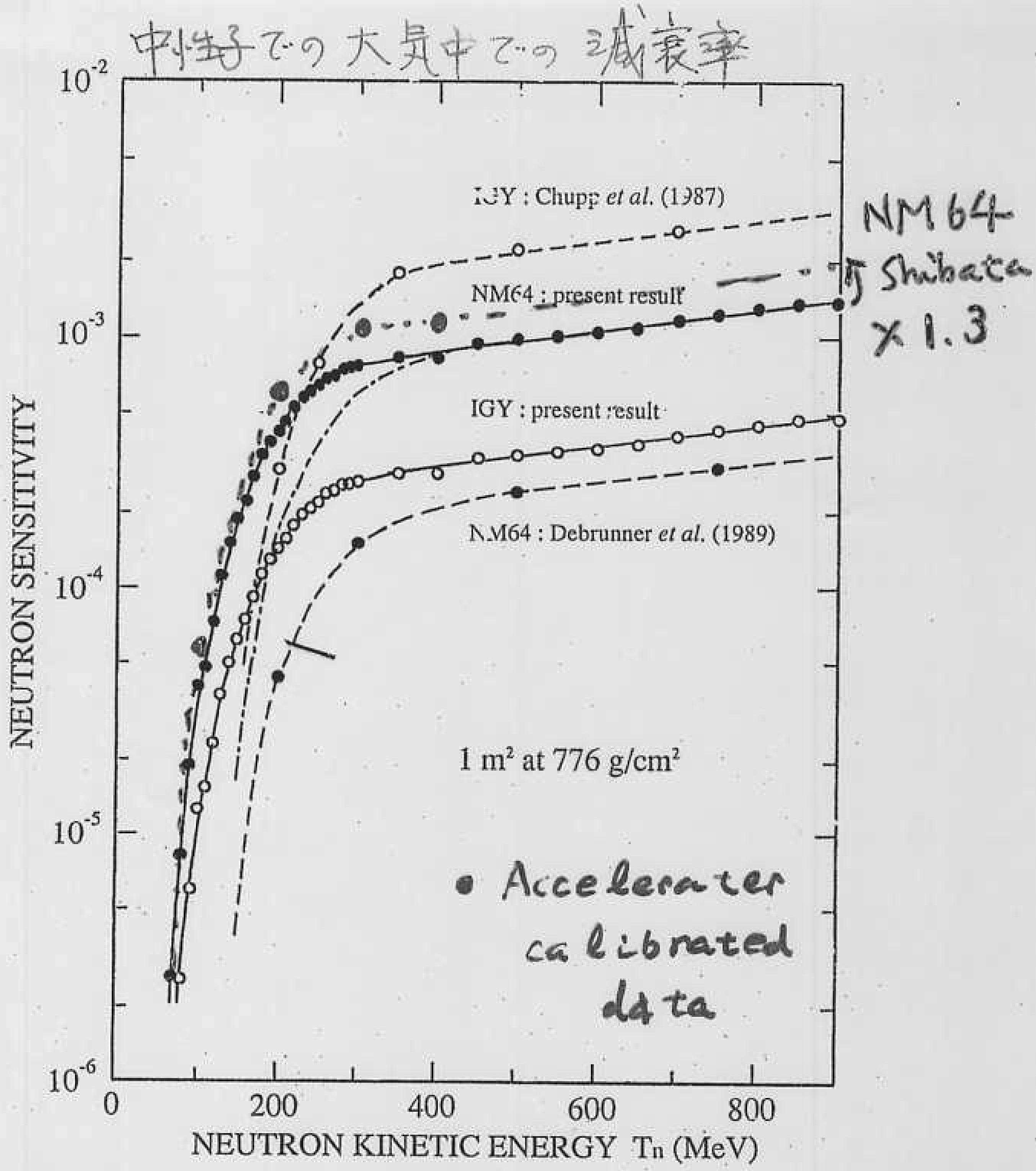
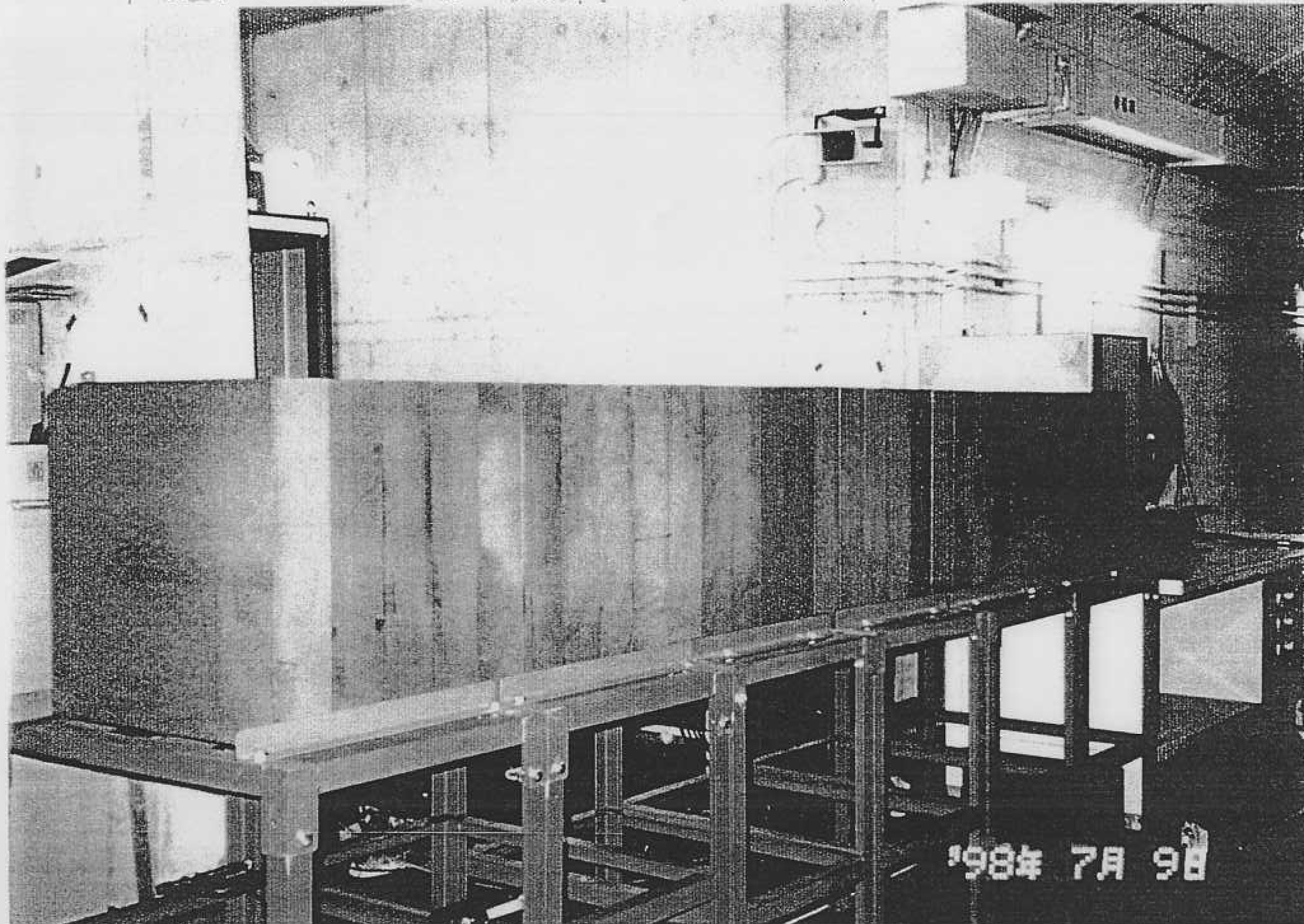


Figure 12. Sensitivity of neutron monitors normalized to 1-m^2 area. The abscissa indicates the kinetic energy of incident neutrons at the top of the atmosphere. Open circles indicate the IGY neutron monitor, and solid cir-

Nucl. Inst. Meth. Vol 459 (2001) 63. at RCNP



International Network of SONTEL

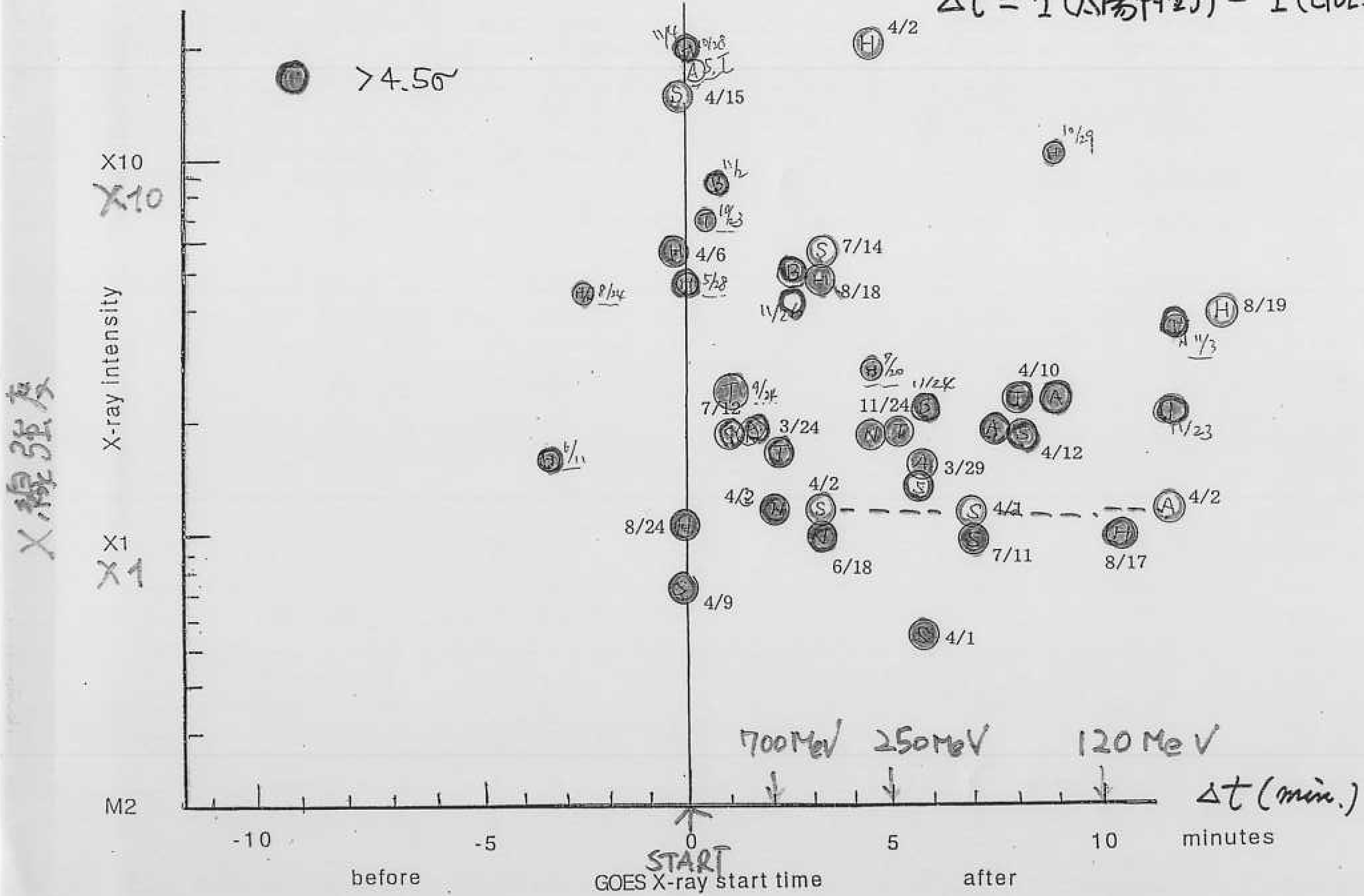
国際観測ネットワークの太陽中性子検出器

	緯度	経度	高度	
Gornergrat ($4m^2$)	46.5N	7.9E	3250m	
Aragatz ($4m^2$)	40.8N	49.3E	3500m	
Tibet ($9m^2$)	30.1N	90.5E	4300m	
Norikura ($1m^2$, $64m^2$)	36.0N	137.1E	2770m	
Mauna Kea ($8m^2$)	19.8N	203.7E	4200m	
Chacaltaya ($4m^2$)	16.2S	292.0E	5250m	
Shera Negura ($4m^2$)	19.0N	97.3W	4600m	New!!!

The duration between GOES start time and neutron start time

2004.1.7 (Y.m.)

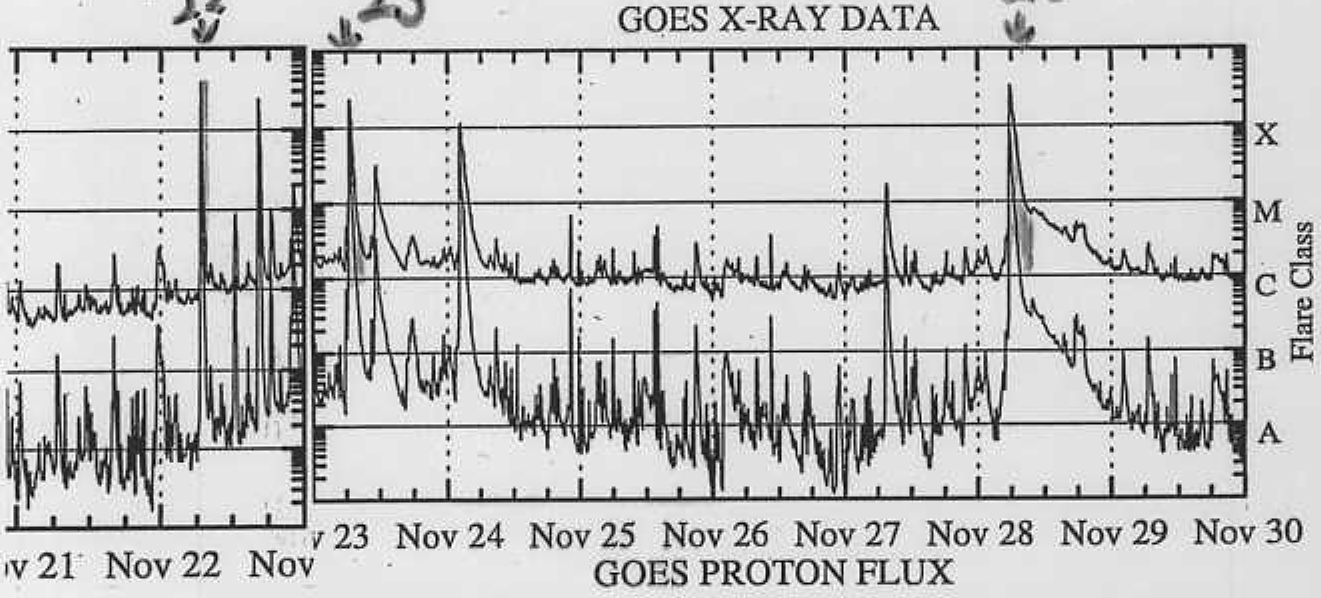
Δt = T(太陽中性子) − T(GOES)

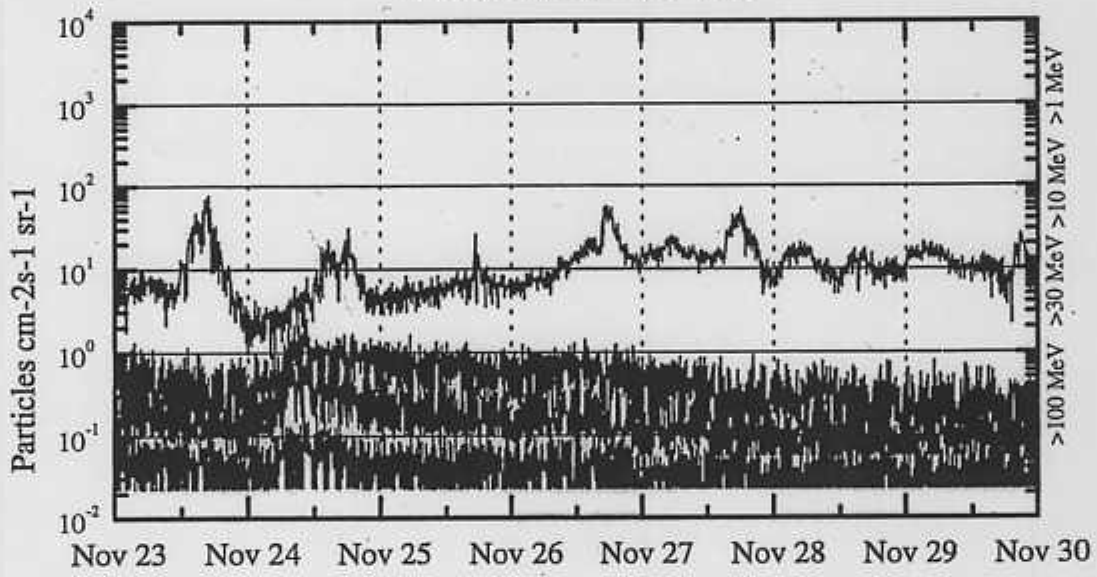


1998. Nov

n: observed

X 22 O 23 O 28





Weekly GOES Satellite X-ray and Proton Plots

X-ray plot contains five minute averaged x-ray flux (watts/m^2) as measured by GOES 8 and 10 in two wavelength bands, .05 -.4 and .1 - .8 nm. The letters A, B, C, M and X refer to x-ray event levels for the .1 - .8 nm band.

Proton plot contains the five minute averaged integral proton flux (protons/cm^2-sec-sr) as measured by GOES-8 (W75) for each of the energy thresholds: >1, >10, >30 and >100 MeV. P10 event threshold is 10 pfu (protons/cm^2-sec-sr) at greater than 10 MeV.

Tibet solar neutron telescope

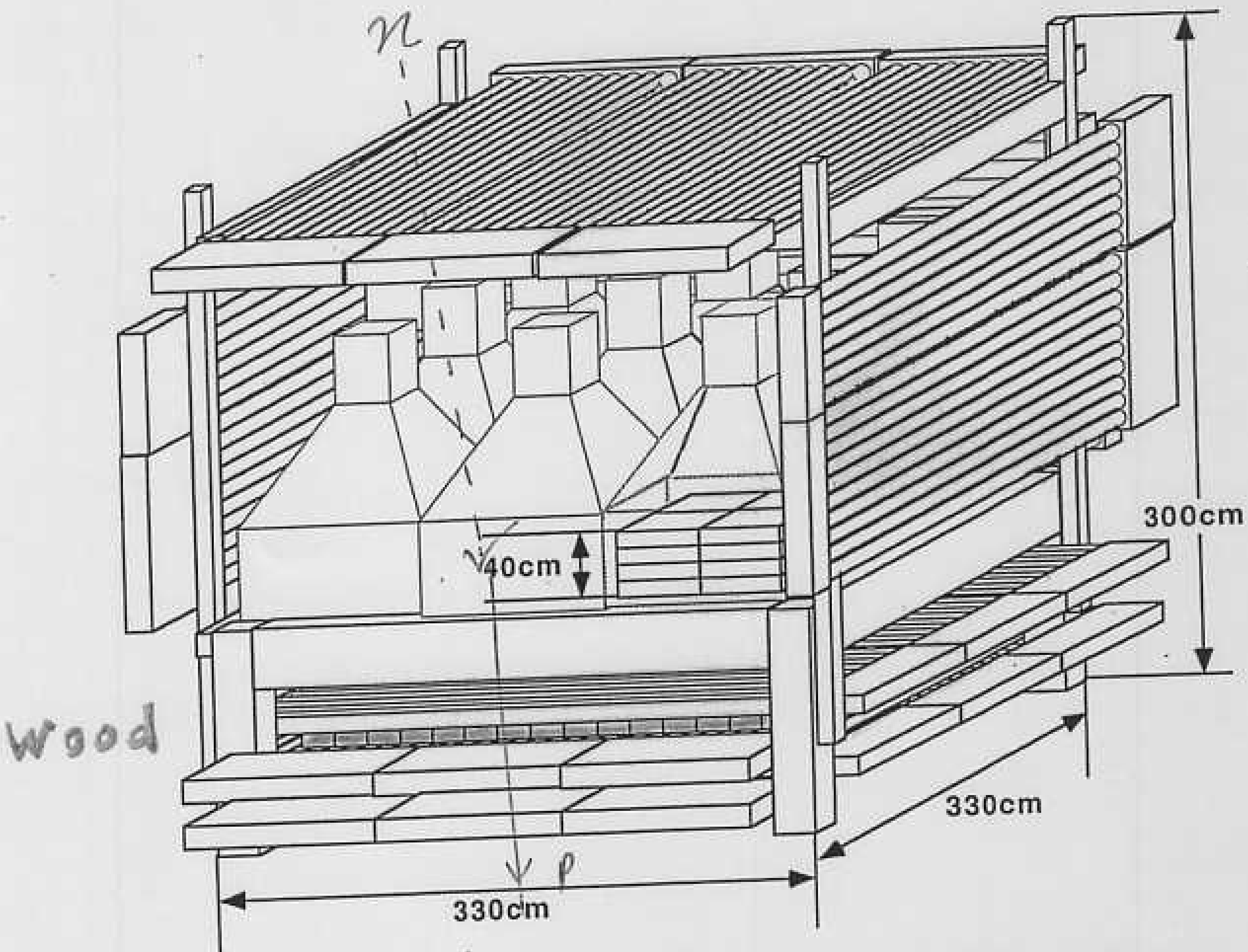


Fig. 3. Schematic view of solar neutron detector installed at Yangbajing in Tibet. The energy deposition measured by each scintillation counter is higher than 40 MeV, 80 MeV, 120 MeV and 160 MeV. The layers of proportional counters and wood under the scintillation counters are used to measure the energies and directions of incident neutrons. The first and the second layers of wood are placed between the second and the third layers of proportional counters and between the third and the fourth layers of proportional counters respectively.

YOHKOH SXT

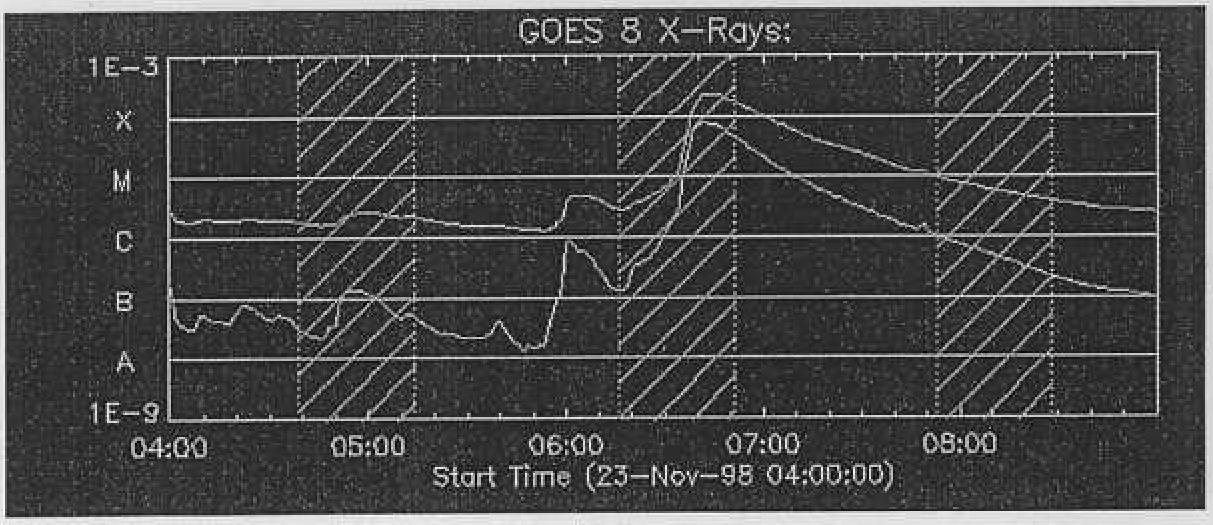
GOES Satellite X-Ray Data

Program run at: Fri Jan 9 02:17:08 2004

Blue diagonal (positive slope) lines = Yohkoh Night

98/11/23

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 02:17:11 2004

GOES Event Listing for Period: 23-NOV-98 through 23-NOV-98 09:00:00

Date	DOY	Start	Peak	Stop	Class
23-NOV-98	327	00:22	00:28	00:35	C2.8
23-NOV-98	327	03:57	04:00	04:02	C2.9
23-NOV-98	327	05:56	06:04	06:13	C4.9
23-NOV-98	327	06:28	06:44	06:58	X2.2

This Event Listing as Text File

freeland@sxt1.lmsal.com

YOHKOH SXT

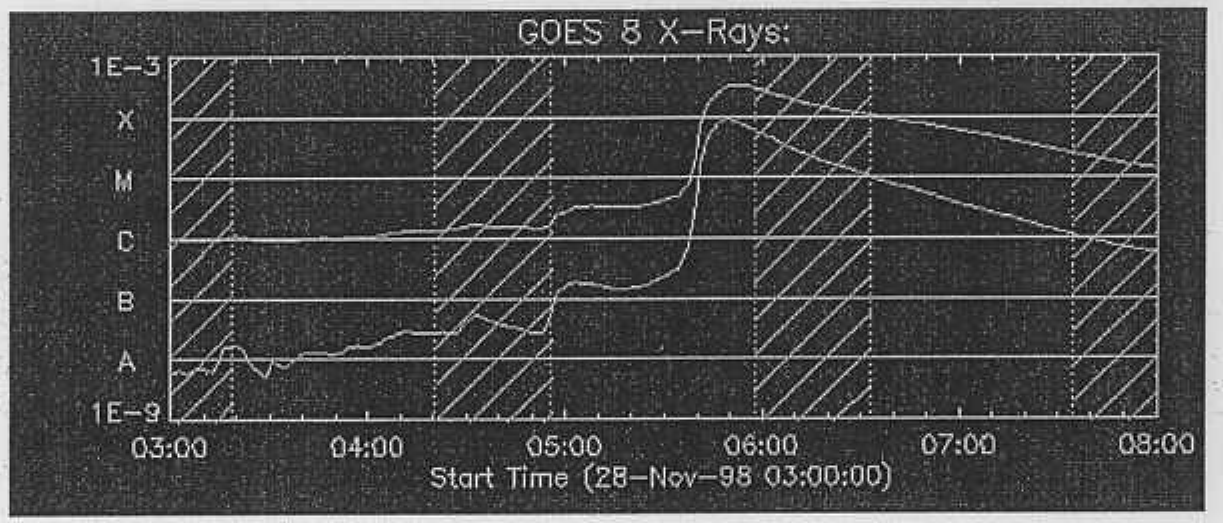
GOES Satellite X-Ray Data

Program run at: Fri Jan 9 02:18:54 2004

Blue diagonal (positive slope) lines = Yohkoh Night

98/11/28

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 02:18:57 2004

GOES Event Listing for Period: 28-NOV-98 through 28-NOV-98 08:00:00

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

98/11/28 Tibet event

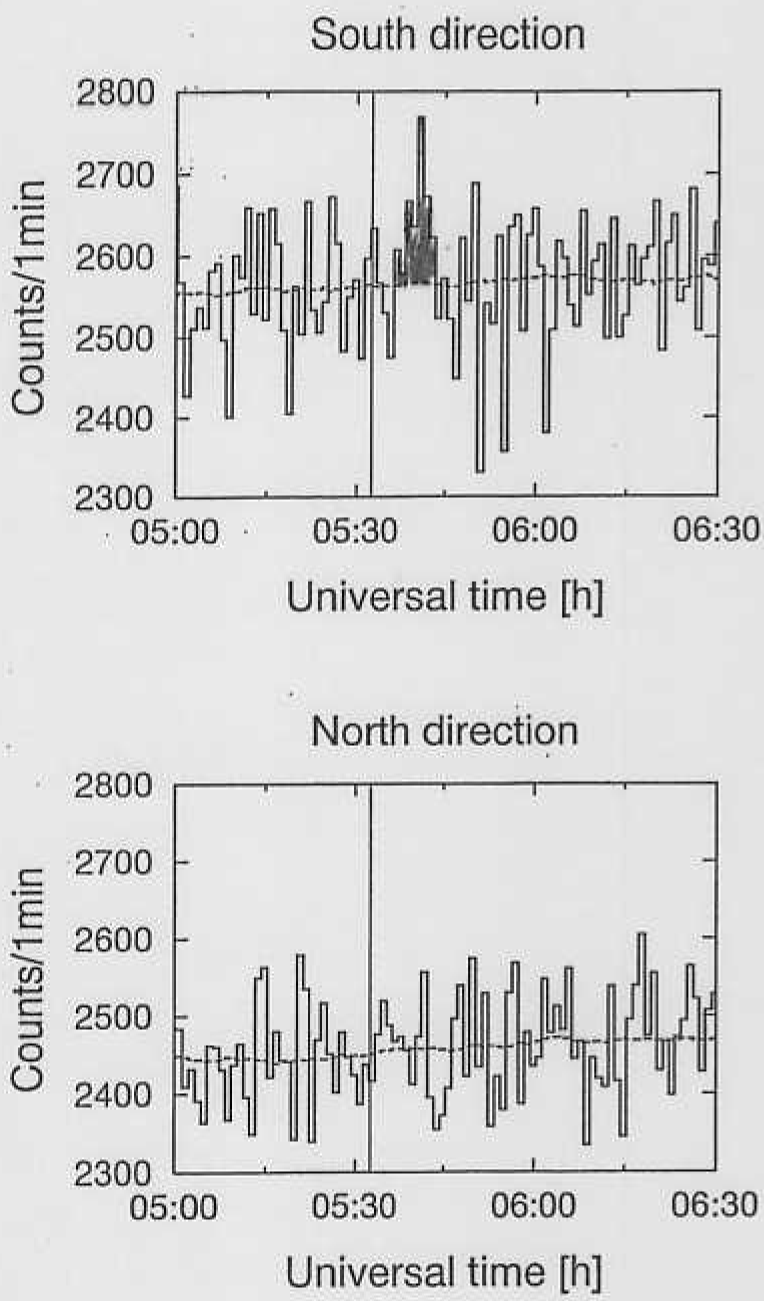


Figure 22: 1 minute counting rate of neutrons for the south and the north directions. The dashed line in the graph represents the average counting rate and the vertical thin line shows the BATSE flare onset time. $5^h 31^m 36^s$ UT

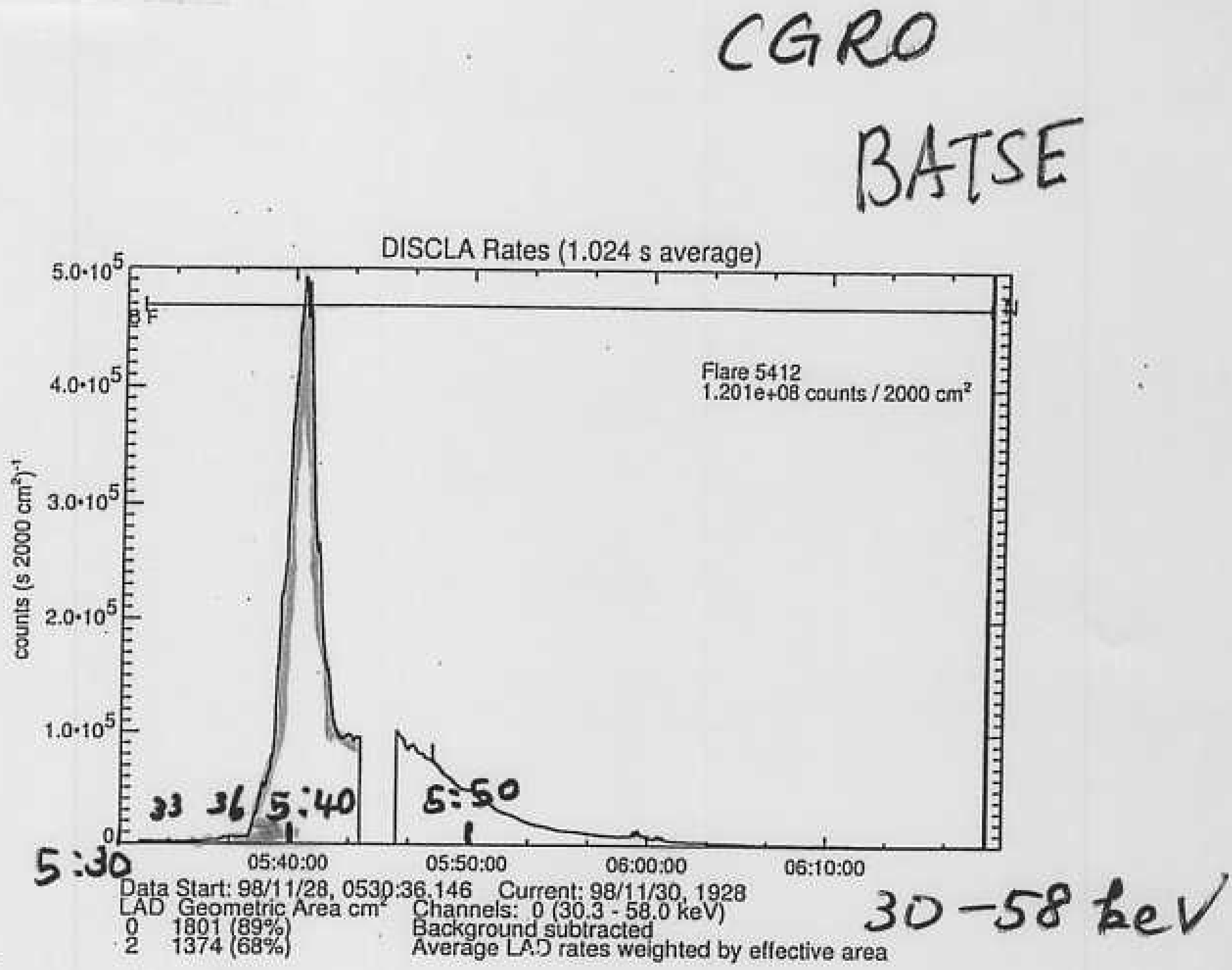
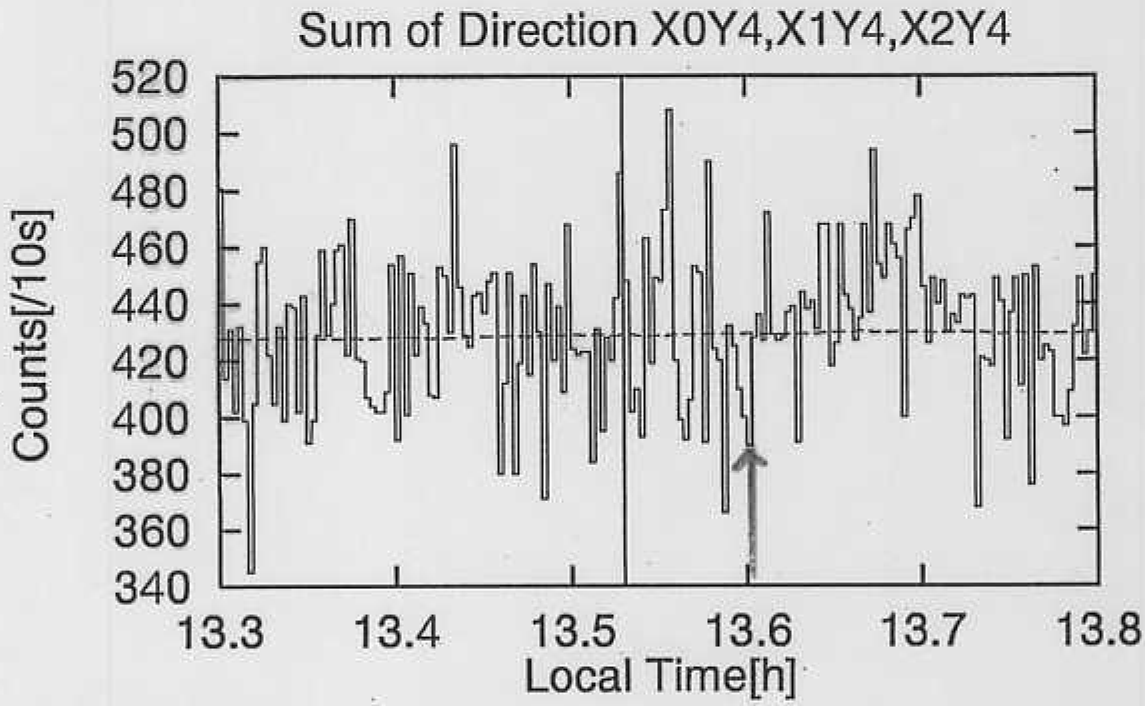
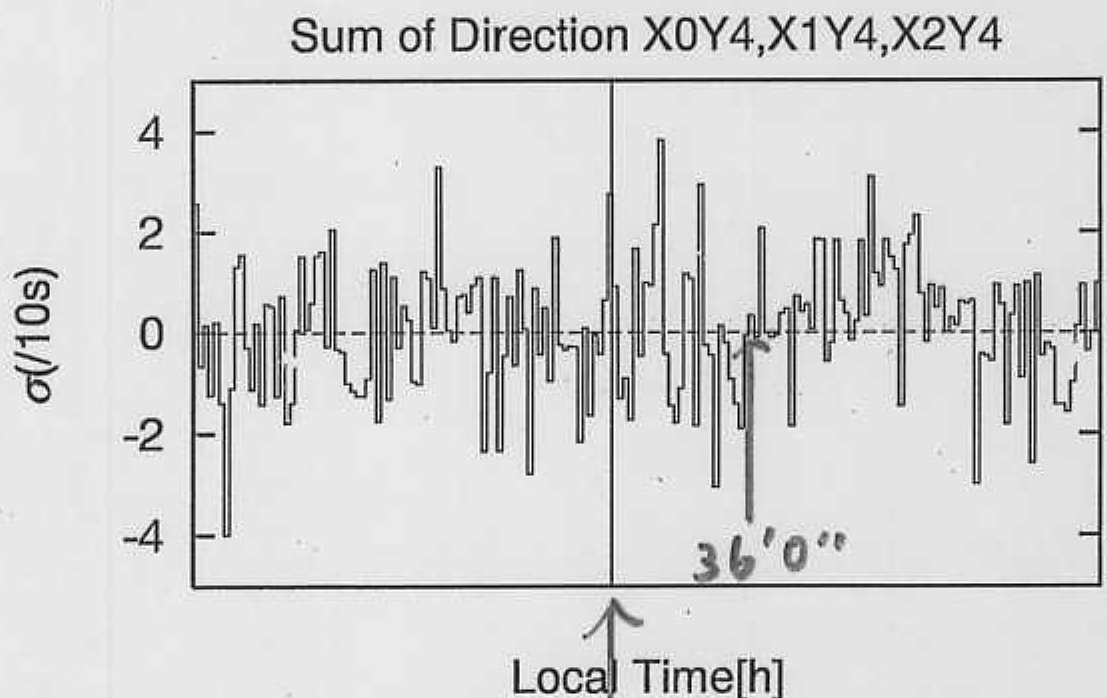


Figure 17: BATSE X ray(30 keV - 50 keV) data around the time of the solar flare. The horizontal axis represents Universal Time.

97.11.28
Tibet

10秒の値

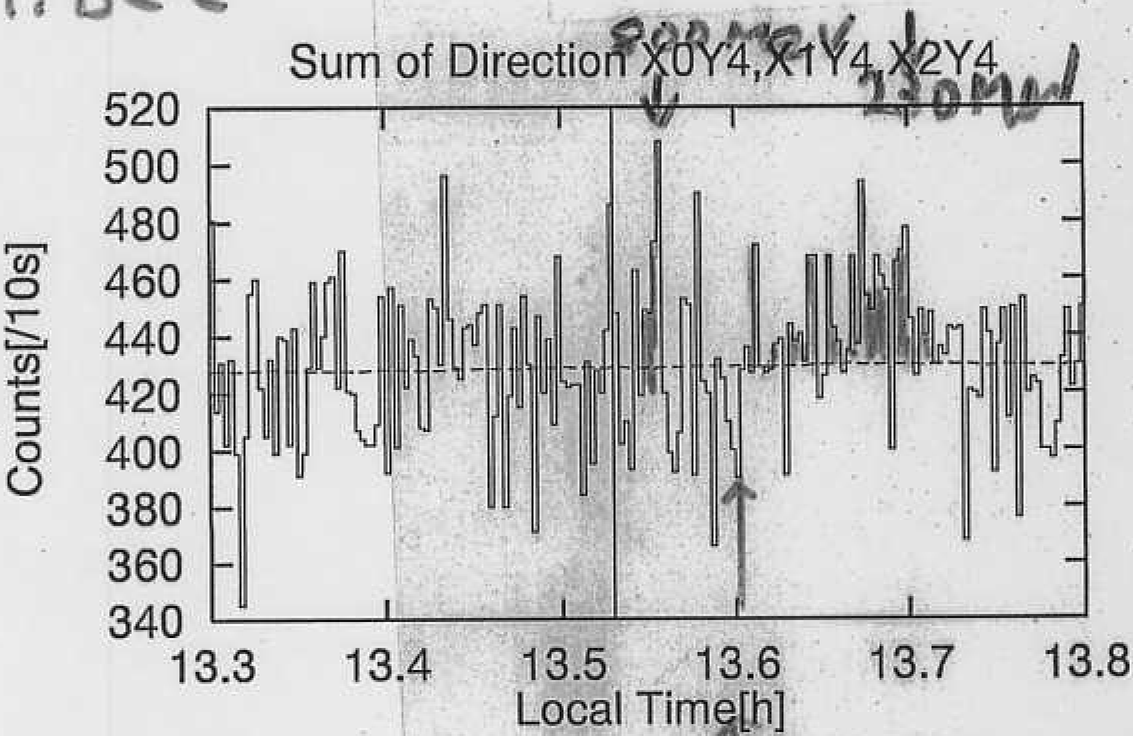




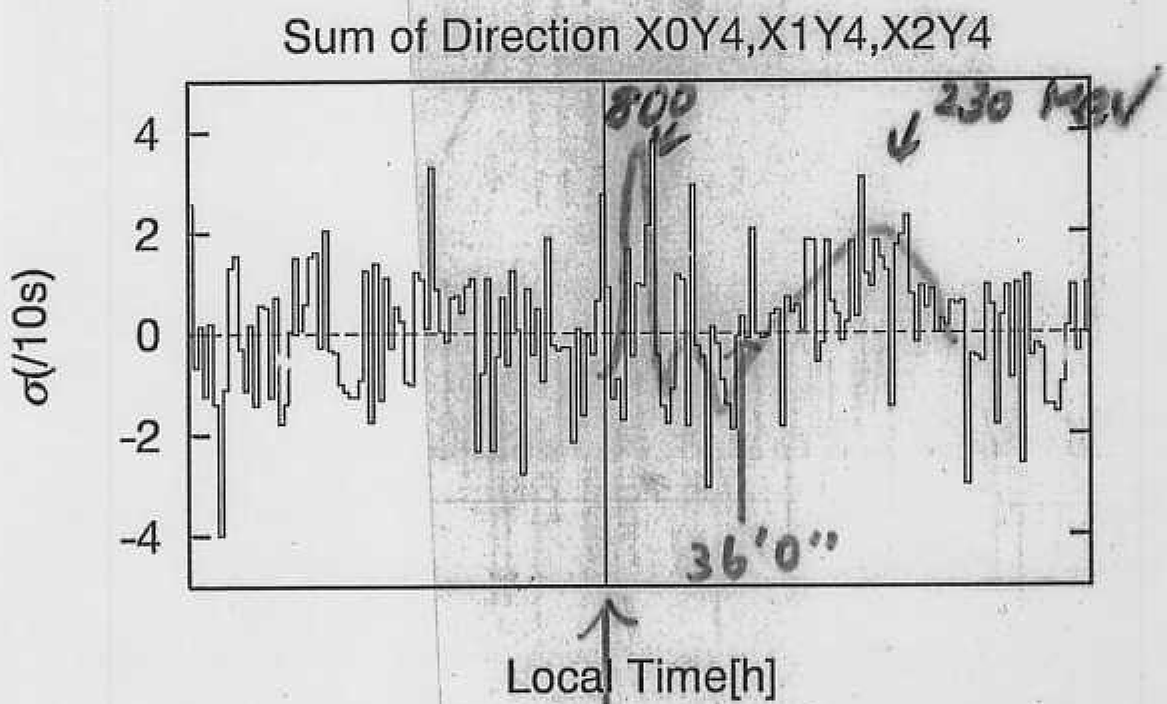
Batse start time
5h31'36"

97.11.28
Tibet

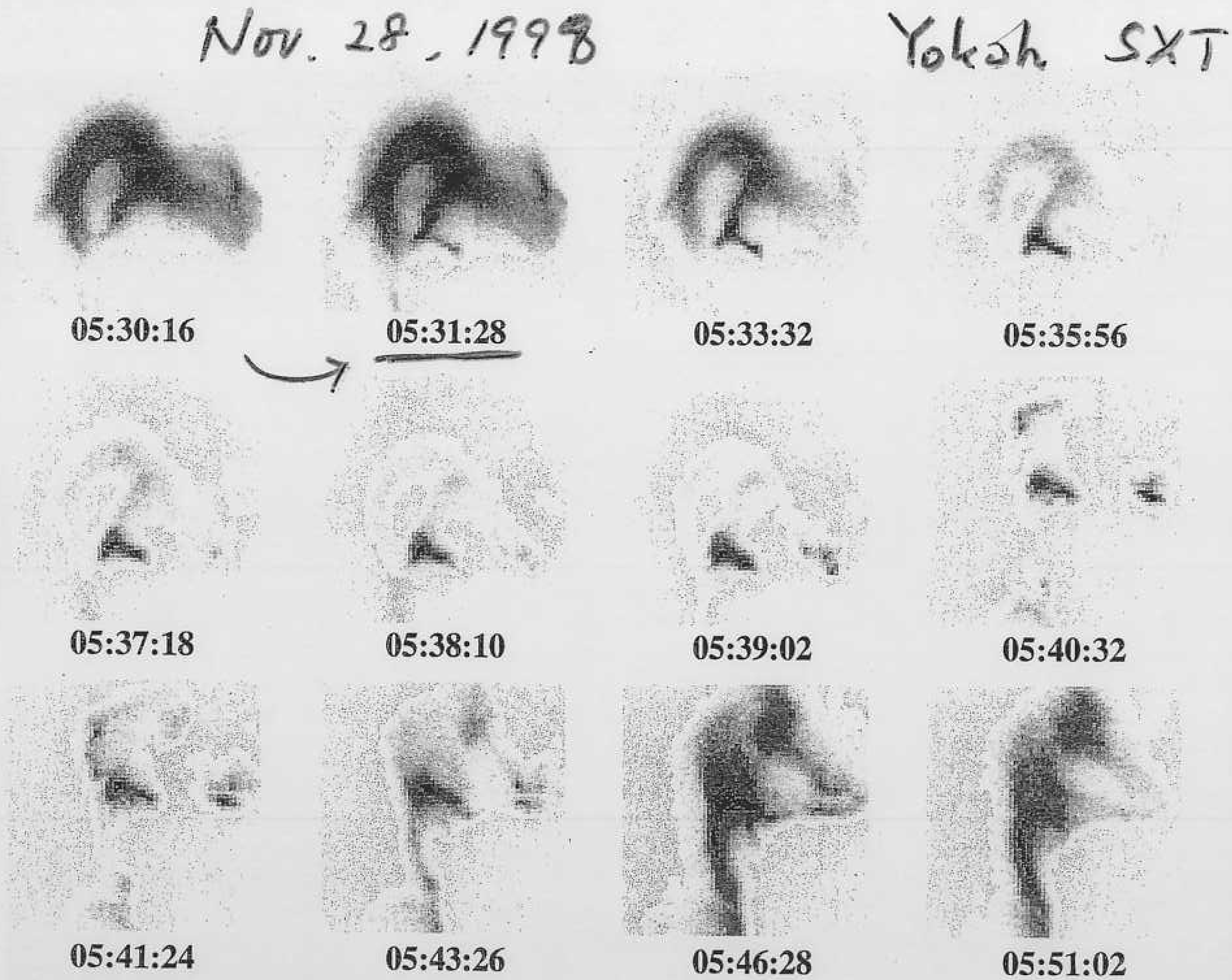
10秒値
10秒値



5h 36' UT



Batse start time
5h 31' 36"


Nov. 28, 1998
Yokoh SXT
05:30:16
05:31:28
05:33:32
05:35:56
05:37:18
05:38:10
05:39:02
05:40:32
05:41:24
05:43:26
05:46:28
05:51:02

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FACSIMILE: 81-52-789-4313

Measurements of Solar Neutrons
--the scientific meaning and future---

Yasushi Muraki (STEL, Nagoya univ.)

~~July 18th, 2001 at Hilo~~
Jan. 7th, 2004 at Nagoya

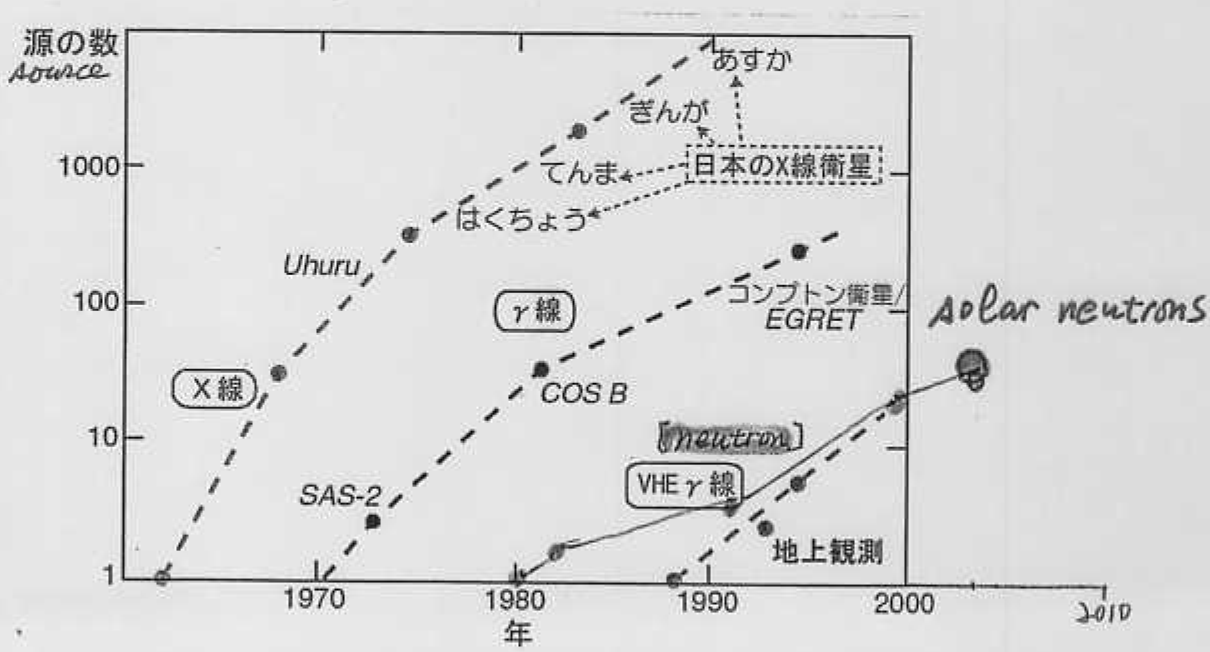
1. Scientific Purpose of Experiment — Solar cycle

2. Past Results of Measurement
   from 1980 to 1990 --> 3 events + 3events (1991) 21+22

3. New results by a new technique
   from 1991 to 2004 --> 28 +12 events 23

4. Future Prospect

Kifune-plot



4．今後の太陽中性子観測が目指すもの

- Solar B との共同研究
  Limb events をねらう
  そして model の選別を目指す

- Solar B ではもっと暗い events が重要に
  なるだろう。　そこにイオン加速の本当の
  姿が見られるだろう。

- impulsive → gradual で２段加速されているのだろうか

- DC 直接加速はないのか？