Future of Solar neutron observation

Yasushi Muraki (STE lab., Nagoya Univ.)

- 1. Science stream
- 2. Scientific purposes
- 3. Results obtained in solar cycle 21-23
- 4. New event observed in Tibet (1998.Nov 28th)
- 5. What do we want to do in 24

1. Science stream

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	e/p separation, space station

1. Science stream

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First detection of solar neutrons. 1980, 1982

1. Science stream

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First detection of solar neutrons. 1980, 1982

Are they produced impulsively or gradually?

----→ acceleration model

Let us remind of

○中性子は光速度では走れない。

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

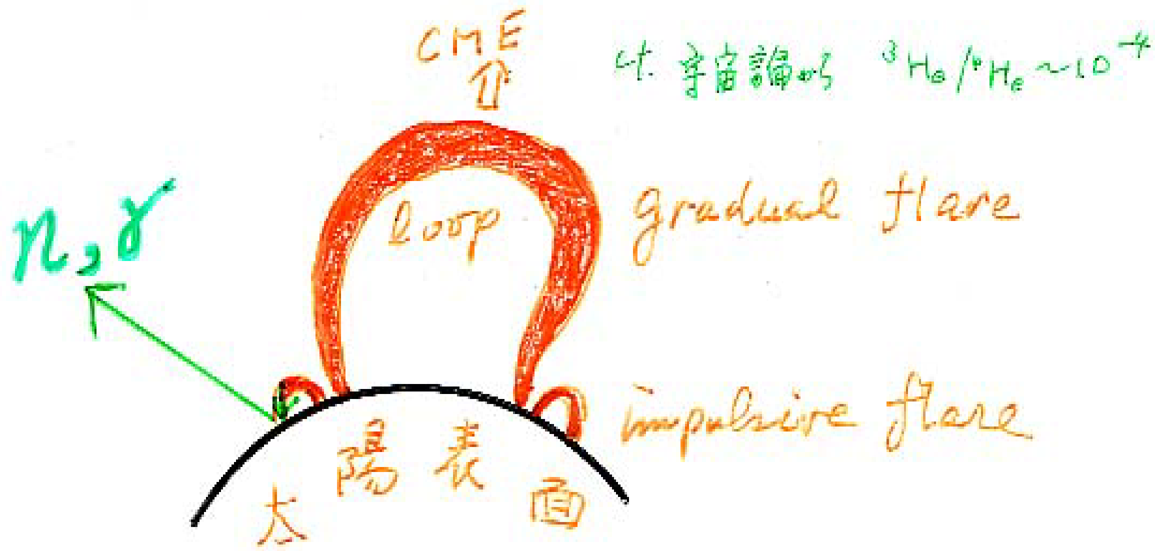
○エネルギーを測る必要がある

◉フレアには２種類ある

- ✓ impulsive flare
- ✓ gradual flare

◉ impulsive flare には ^{3}He が多い $^3He/^4He \approx 1$

Fisk による選択的共鳴加速説の成功



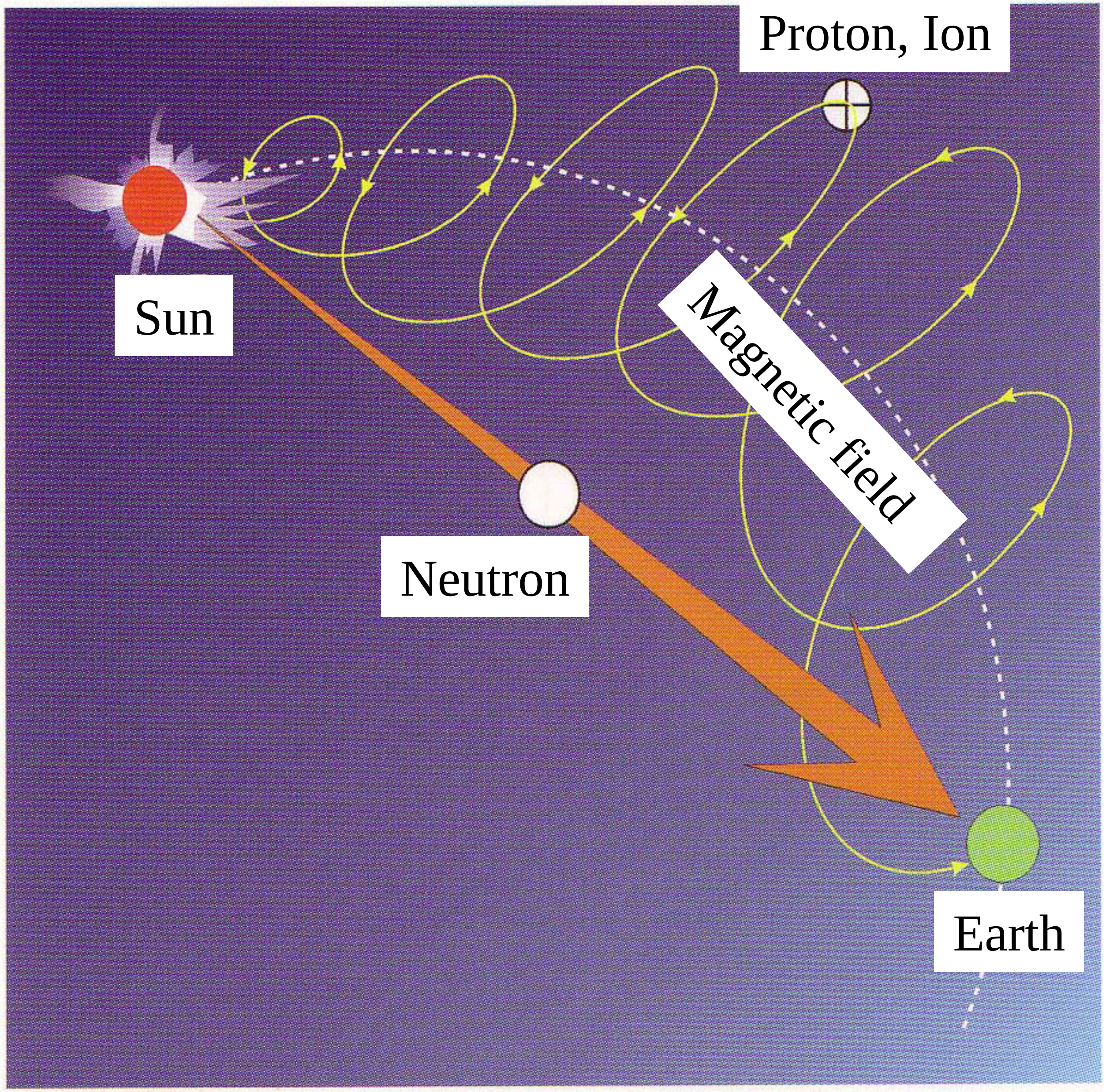
2. Scientific purposes

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

- When, How?

Positive astronomy

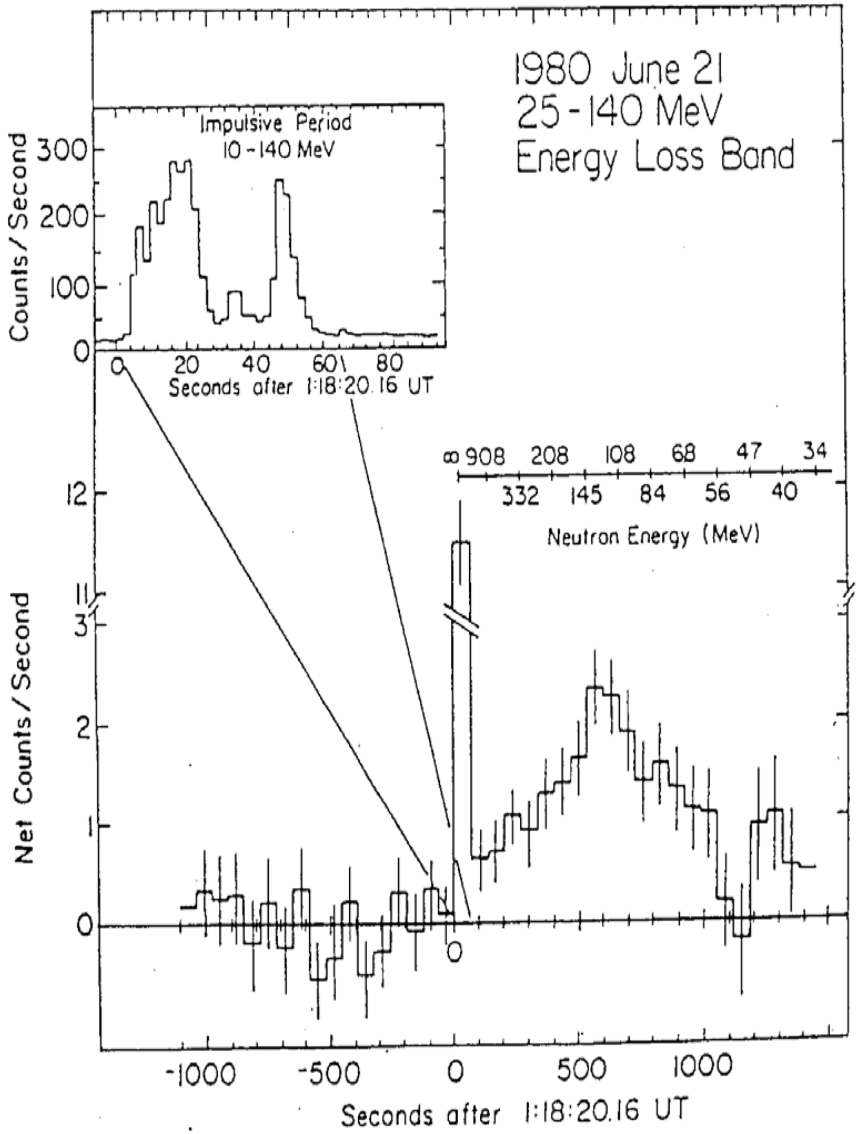
However observation of protons does not give us any message about it. Protons are usually coming a few hours later from the flare.



June 21st 1980 event

Satellite data
Solar Maximum Mission

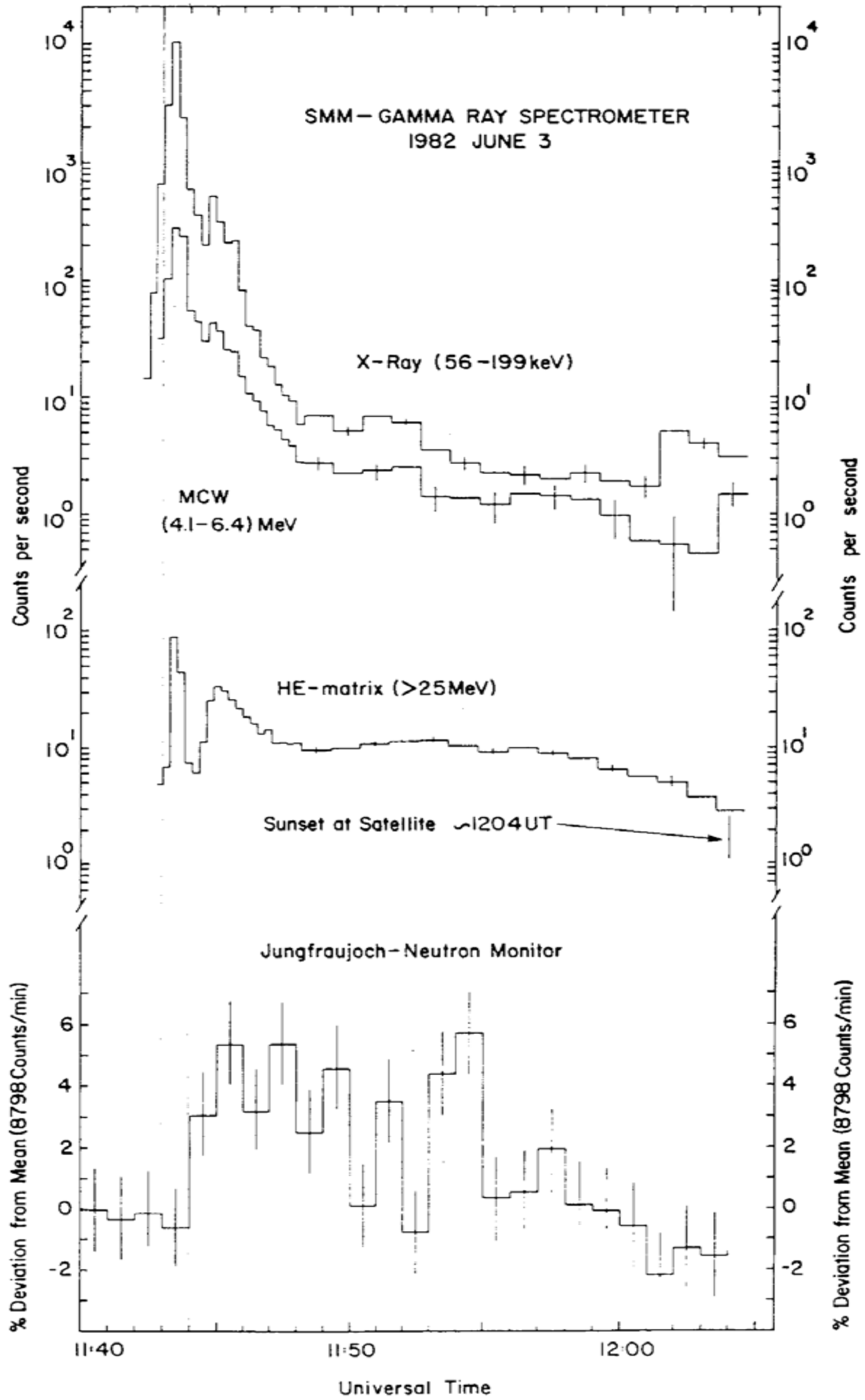
It is consistent by impulsive production model



June 3rd 1982 event

Jungfraujoch neutron monitor
+
SMM mission data

It is necessary to introduce gradual acceleration process. However S. Shibata confirmed that it is model dependent and not always necessary.



Sensitivity curve

By S. Shibata

A Monte Carlo result by Shibata can reproduce the accelerator result.

The attenuation of neutrons in the atmosphere depends on the interaction model.

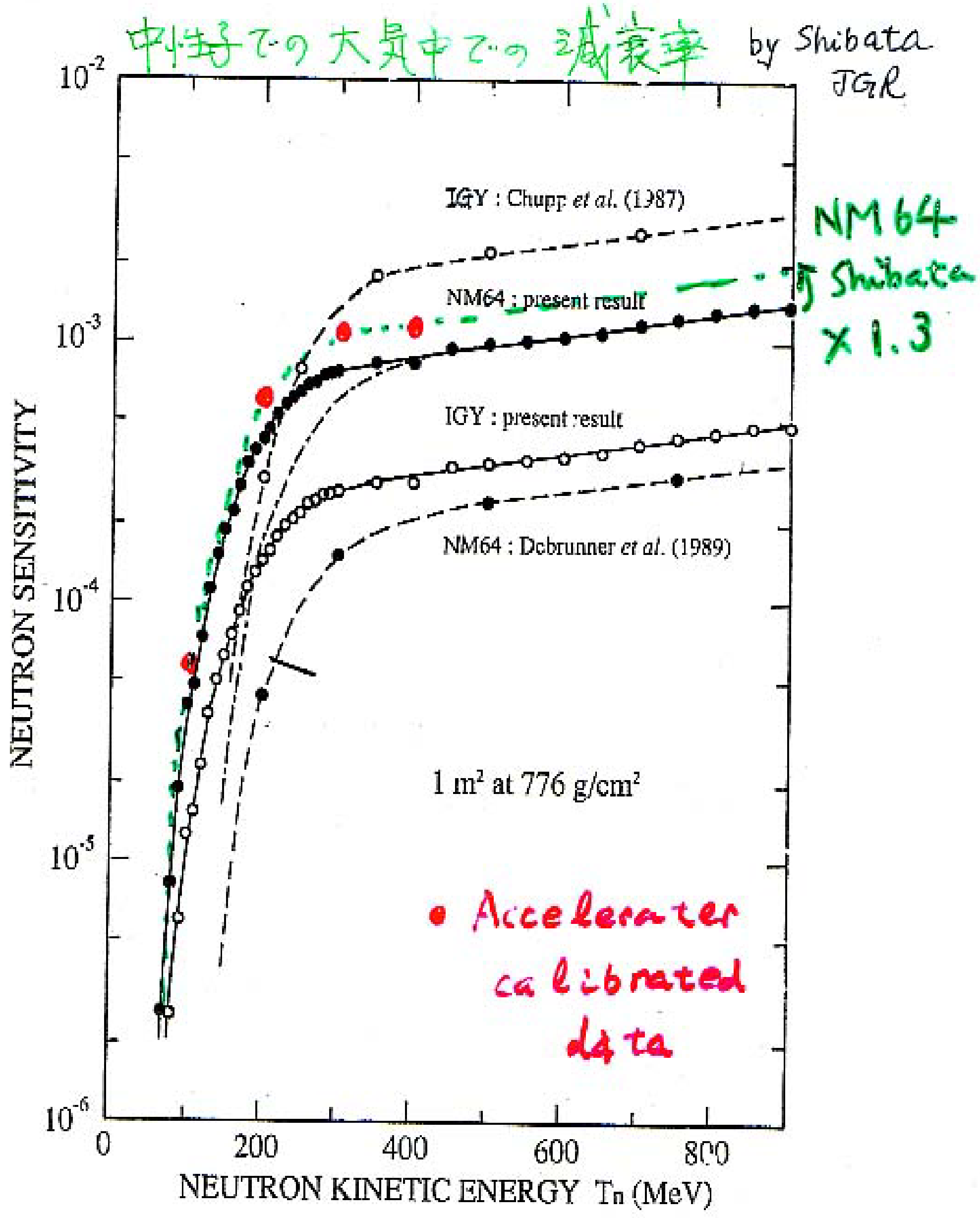
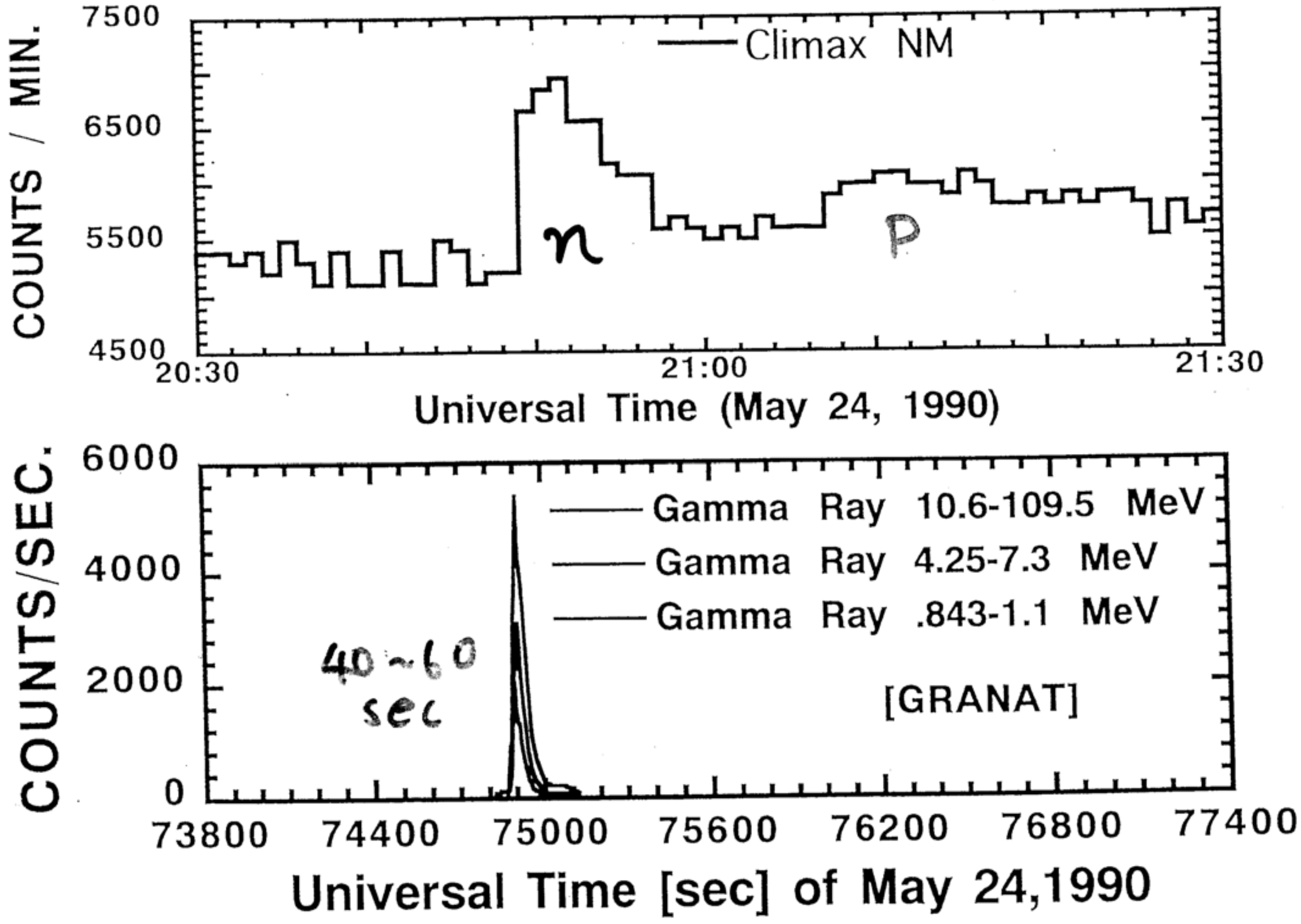


Figure 12. Sensitivity of neutron monitors normalized to 1-m² area. The abscissa indicates the kinetic energy of incident neutrons at the top of the atmosphere. Open circles indicate the IGY neutron monitor, and solid cir-

May 24th 1990 event

Climax neutron monitor + Russian satellite data

The event can be explained by the impulsive production model.

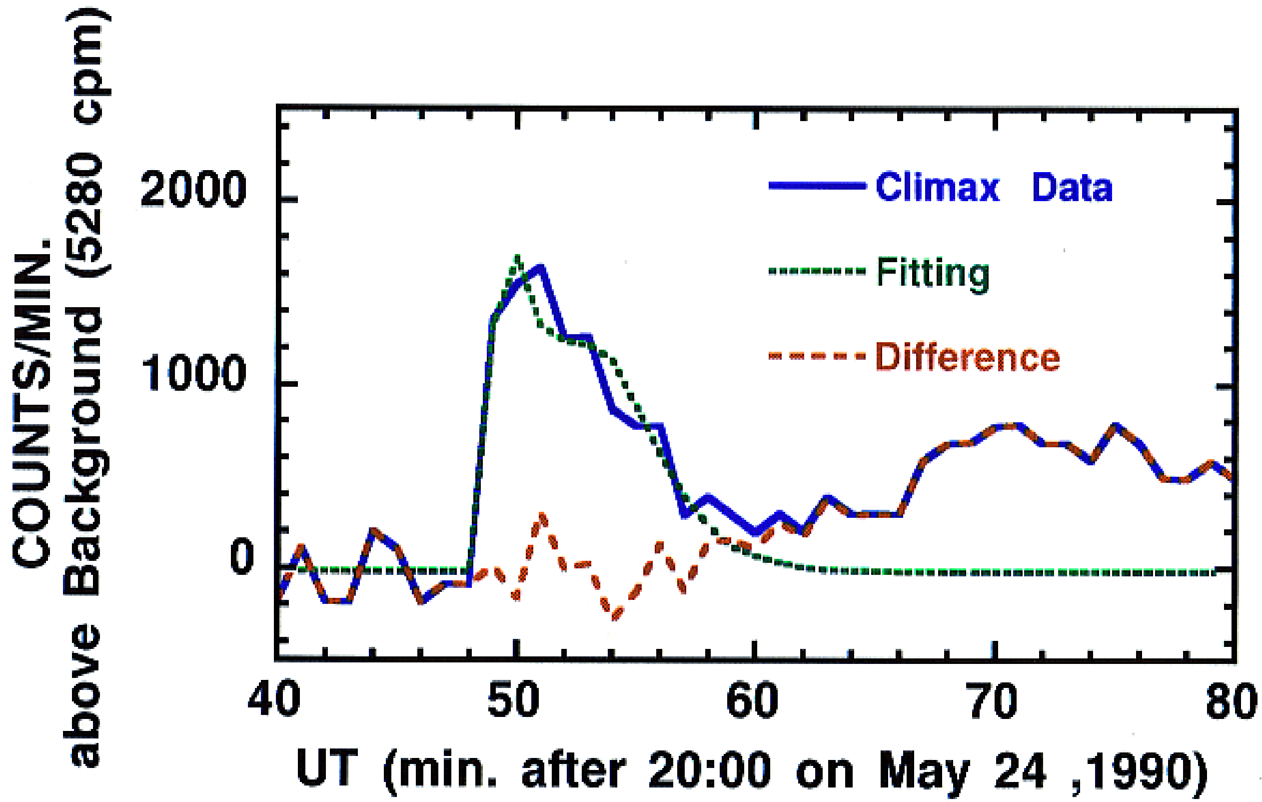


May 24th 1990 event

By Muraki and Shibata

The event can be explained by impulsive production model.

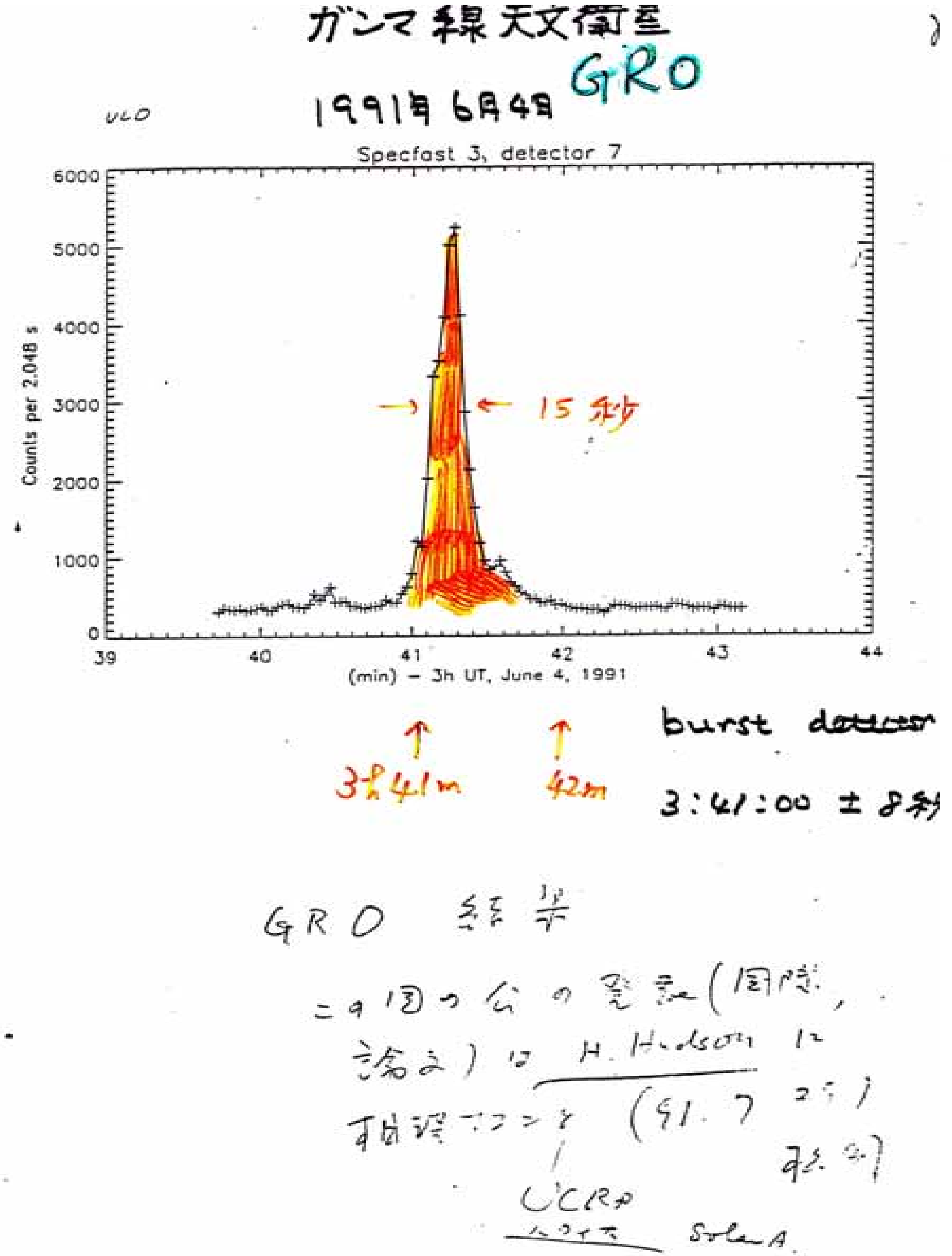
The power index was -2.5



June 4th 1991 event

The highest channel of Batse 1-10 MeV shows very impulsive feature.

So we have assumed solar neutrons must be produced during this time impulsively



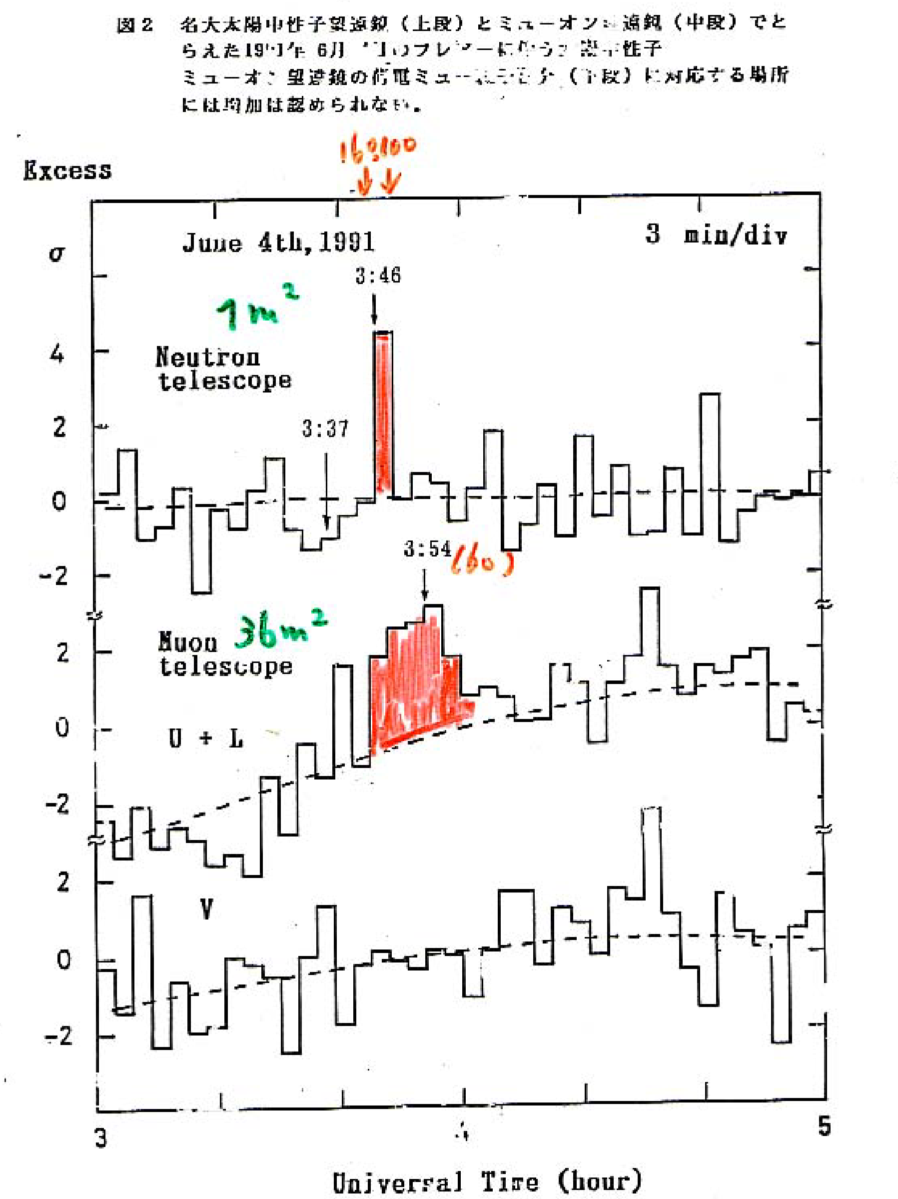
June 4th 1991 event

Norikura event

Then the time profile
by the ground level detector
can be explained.

However a problem remains
How to explain a long tail of
the Osse data. Probably
trapped particle effect.

Or long time acceleration?



3. Summary of typical past neutron events

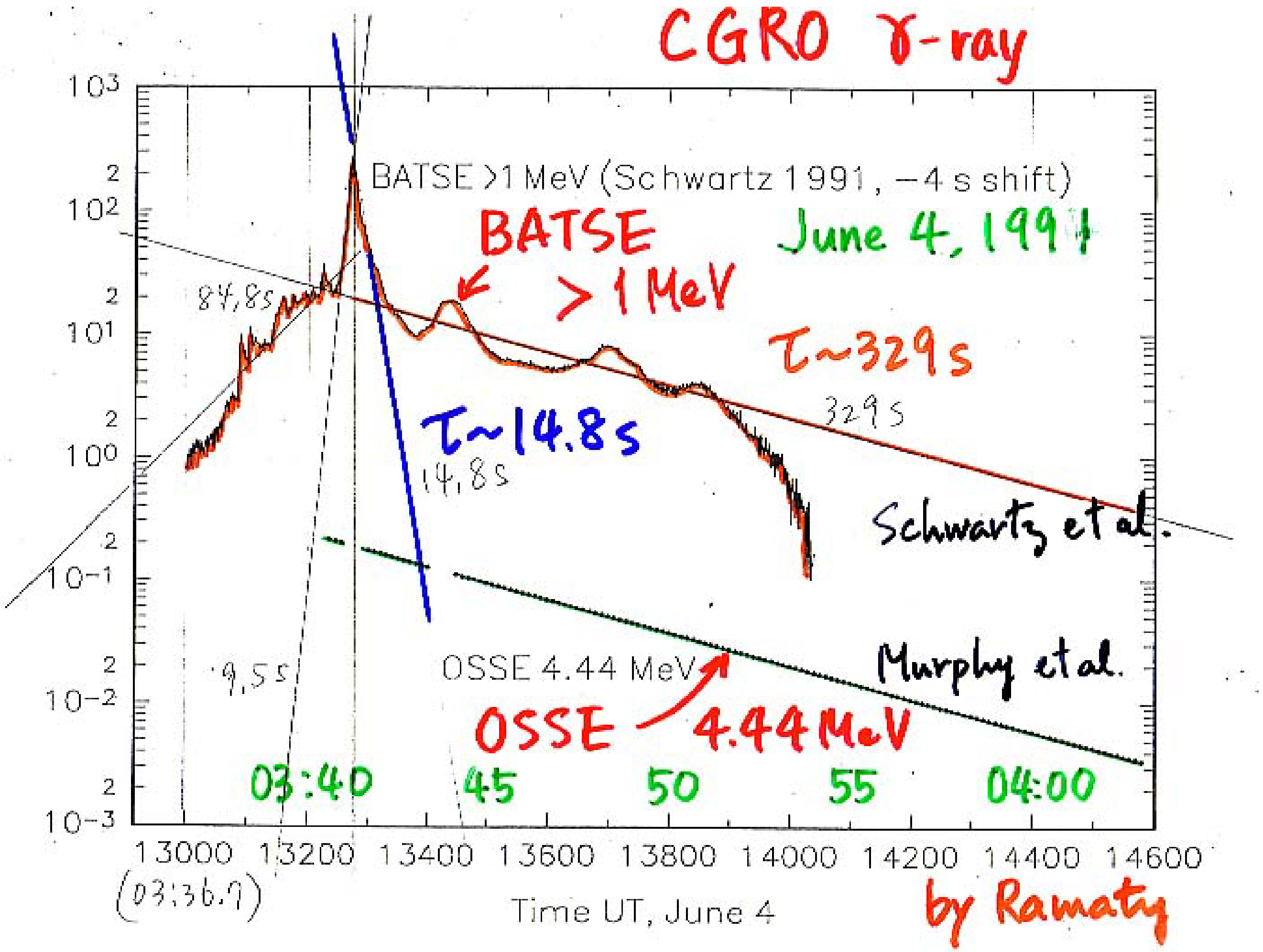
- Results obtained in the solar cycle 21-23
- event on 1980. 6.21 impulsive
- event on 1982. 6. 3 impulsive+gradual
- event on 1990. 5.24 impulsive
- event on 1991. 6. 4 impulsive
- event on 1998.11.28 impulsive

June 4th 1991 event

Summarized by Shibata

The long tail reflects trap of particles

or continuous acceleration?



4. Important discovery by Tibet solar neutron telescope

- A solar neutron telescope was made at Yanbajing, Tibet in September 1998.
- In November 22nd,23rd and 28th 1998, 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

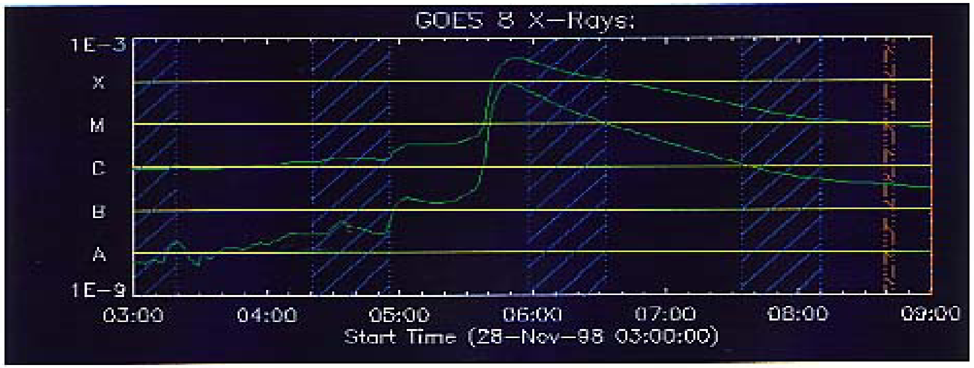
YOHKOH SXT

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

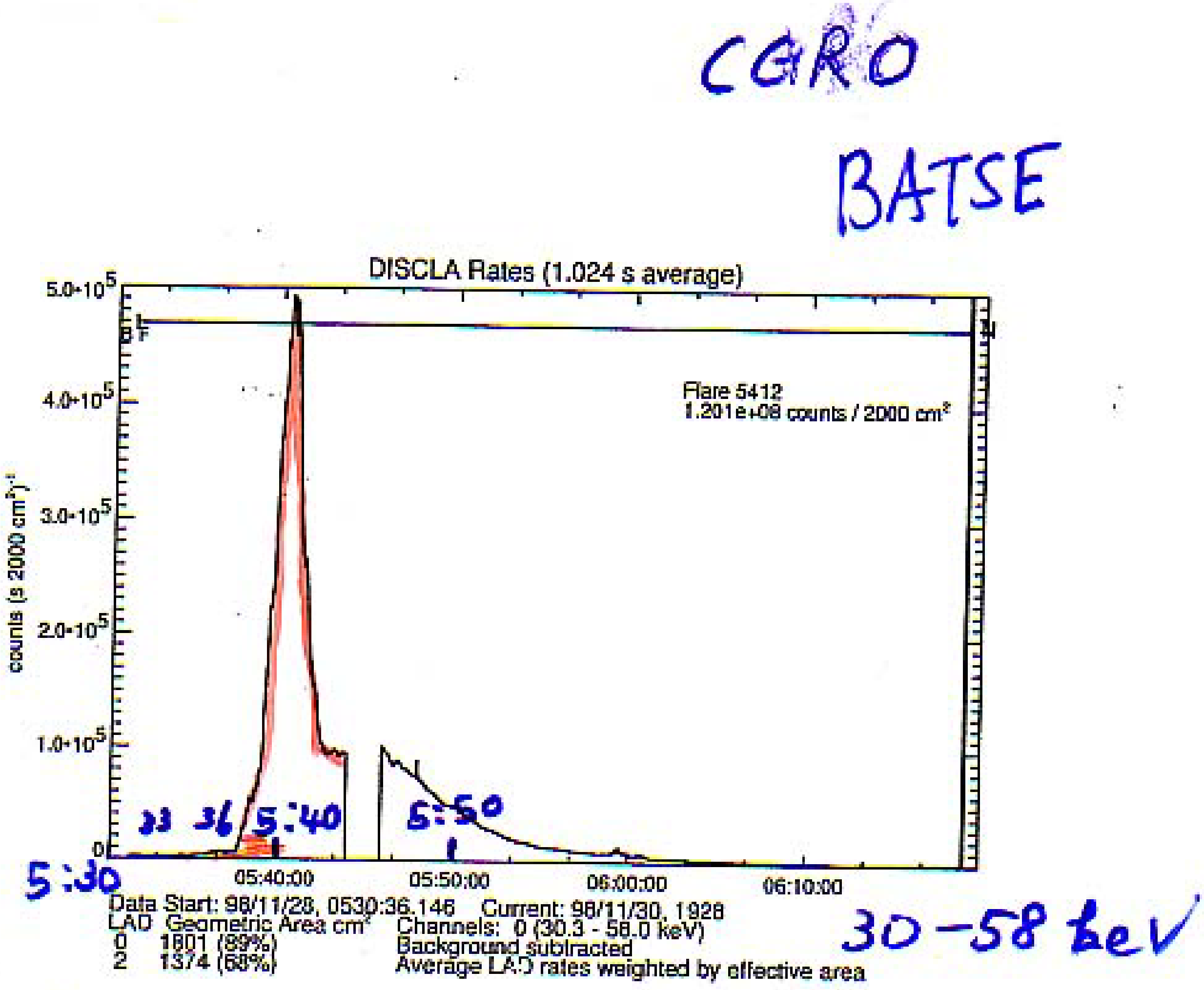
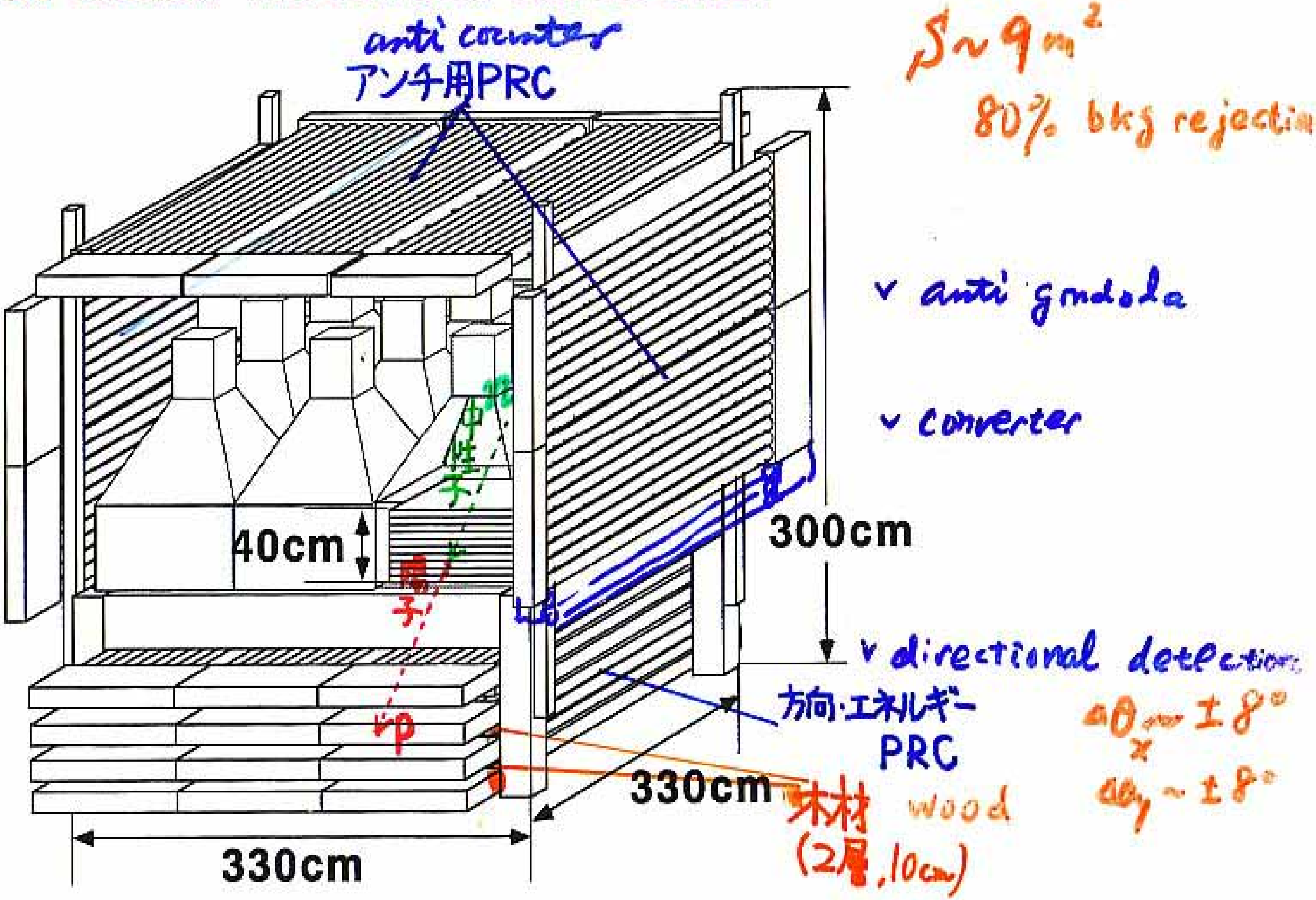
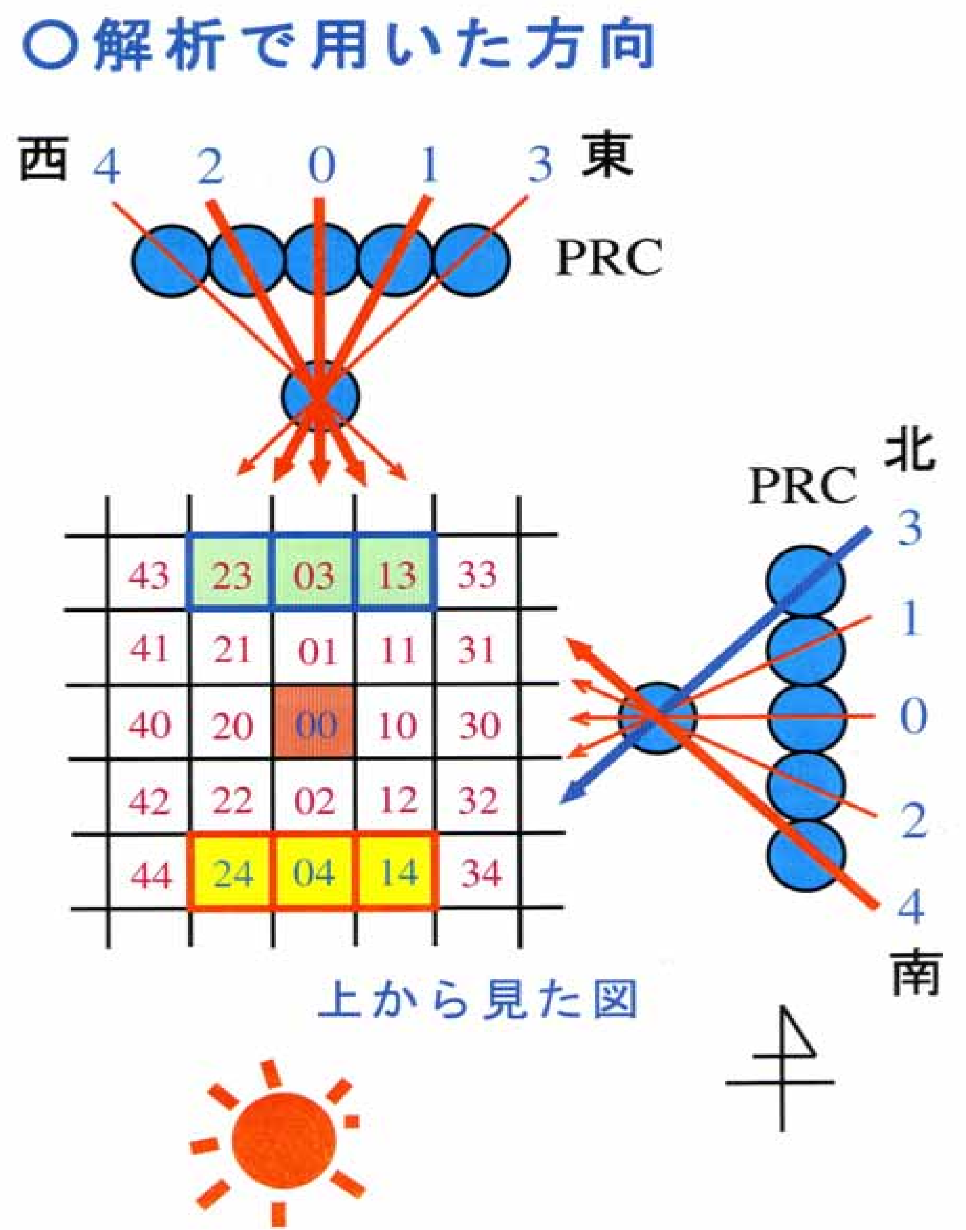


Figure 17: BATSE X ray(30 keV - 50 keV) data around the time of the solar flare. The horizontal axis represents Universal Time.

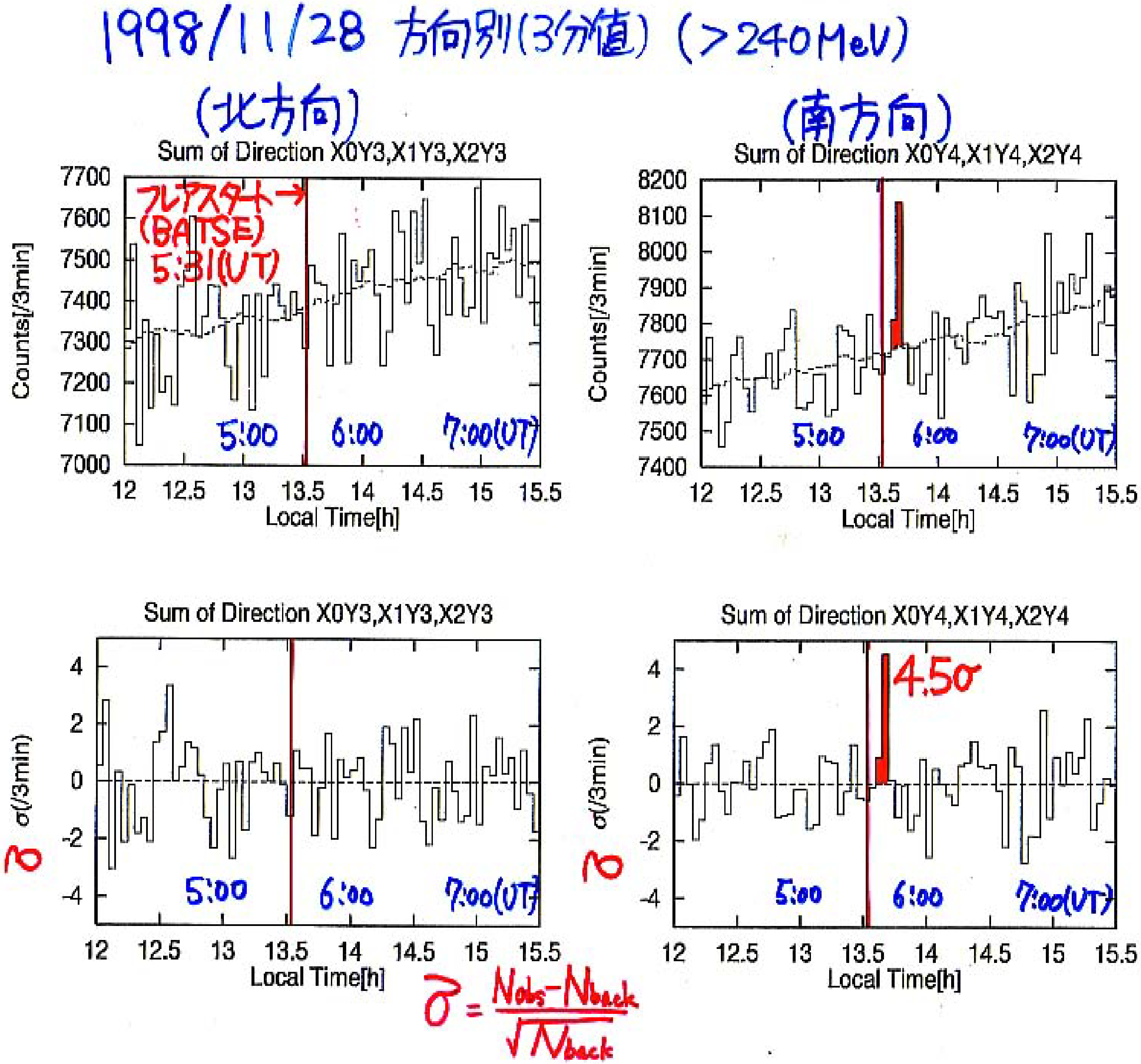
Tibet solar neutron detector



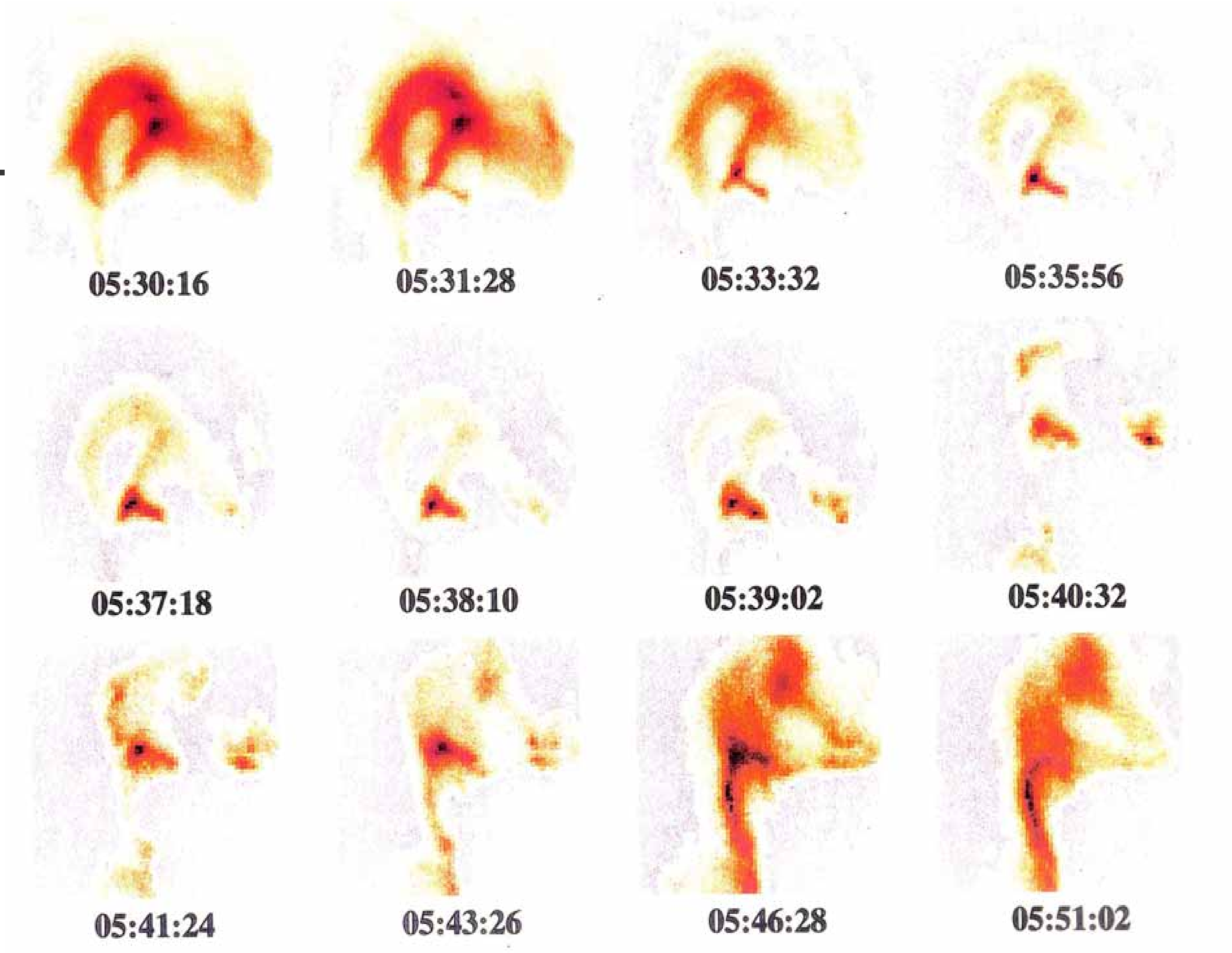
Telescope function of Tibet detector



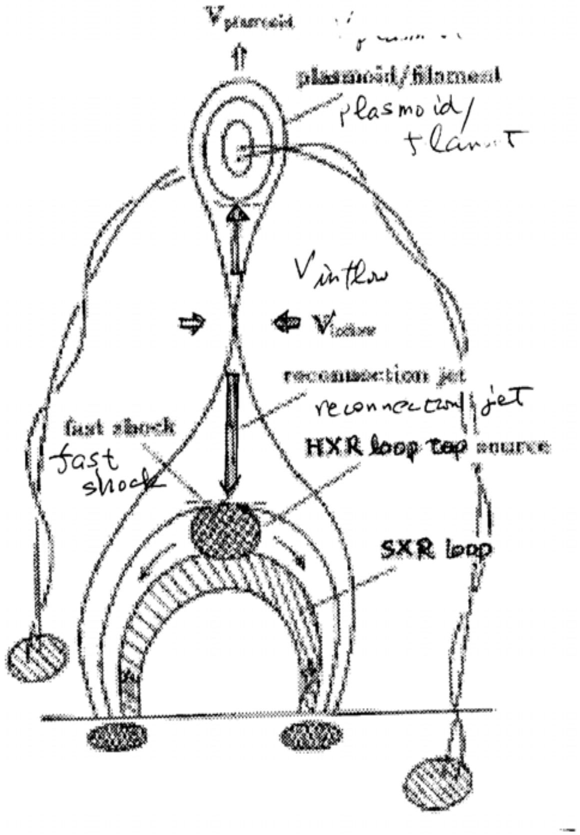
North-South comparison



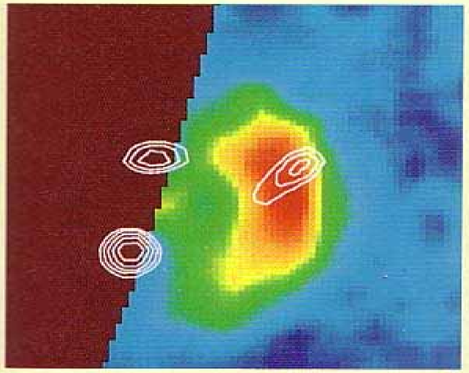
Yohkoh/SXT Nov. 28th, 1998 flare (by S. Masuda)



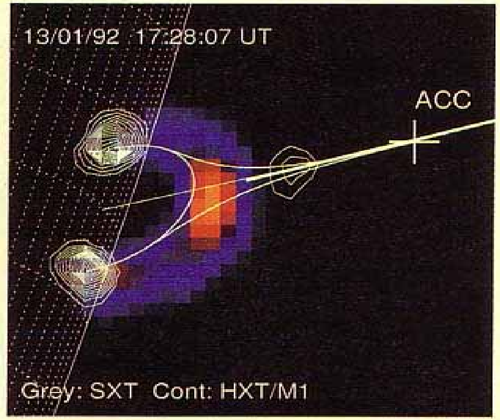
a top-down scenario



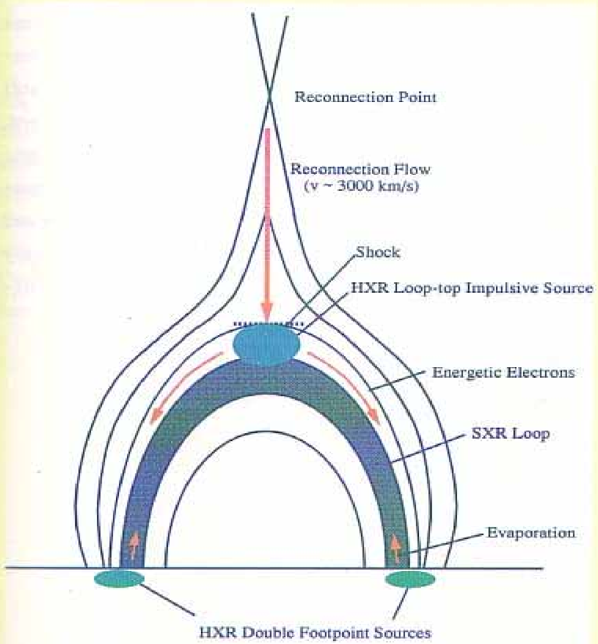
FLARES



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.

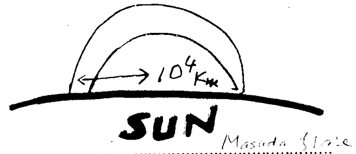


Left, the geometry synthesized from the observations. A reconnection site in the corona above the soft X-ray source drives a rapid flow, which impinges on the denser material in the magnetic loop and creates both hard X-rays and high temperatures.

A076 A162 A227 C004 A171

acceleration time

フェルミ加速に要する時間



磁気ループの半径　　$r \approx$ 約 10^4 Km（1万 Km）

ループ内で荷電粒子が一往復する距離　　$\ell = 2\pi r \approx 6 \times 10^4$ Km

光速で走ると一往復するのに要する時間　　$t \approx 6 \times 10^4\ \mathrm{Km} / 3 \times 10^5\ \mathrm{Km} \approx 0.2$ 秒

$\beta = \frac{v}{c}$ が 0.1 の荷電粒子が一往復に要する時間　　約2秒 → 1 sec

20MeV, $V_p \sim \frac{1}{3} c$

高速太陽風　3000Km／秒 → $V \approx \frac{1}{100} C$ ＝ β

(Masuda flare)

フェルミの二次加速モデル	$\frac{\Delta E}{E} \approx 2\frac{V}{C}\left(\frac{v}{c}\right) \approx \frac{2}{100} \cdot \left(\frac{1}{10}\right) \approx \frac{1}{500}$
フェルミの一次加速モデル	$\frac{\Delta E}{E} \approx 2\frac{V}{C} \approx \frac{1}{50}$

エネルギーが 20MeV → 40GeV　加速に要する衝突回数を求める。

$\left(1+\frac{1}{500}\right)^n \to \left(1+\frac{1}{500}\right)^n \approx 2000$ for　二次加速 $n \approx 3000$ （$n \approx 10000$ 回）	$\left(1+\frac{1}{50}\right)^n \to \left(1+\frac{1}{50}\right)^n \sim 2000$ for　一次加速 $n \approx 300$ （$n \approx 1000$回）
加速に要する時間 $t \approx$ 10 min	加速に要する時間 $t \approx$ 70秒 (sec)　1.1 分 (min)

Summary of the Tibet event → future tasks

- まだ加速のあった時間がわからないーーー　5分間の謎
  5h31mにすでに加速がすでにあったのか
  それとも5h36mの一回きりだったのか？
- 5h31mに仕込があって、5h36mに磁気loopから脱出したのか？
  → 今後Solar Bとの共同研究が楽しみ。
- Model discriminationが可能となる。
  常田ー内藤modelはかなりいい線を行っている。
  → 絶対に正しいという保障はない。
  → 実証的天文学を目指す

June 4th 1991 event

The highest channel of Batse detector shows only 15 seconds spike structure

So we assumed solar neutrons must be produced during this time impulsively.

GRO γ線

BATSE FLARE OBSERVATIONS IN SOLAR CYCLE 22

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[2]Hughes STX, Lanham, MD
[3]Space Science Laboratory, NASA Marshall Space Flight Center, Huntsville, AL, 35812
[4]Dept. of Physics, University of Alabama in Huntsille, AL, 35899

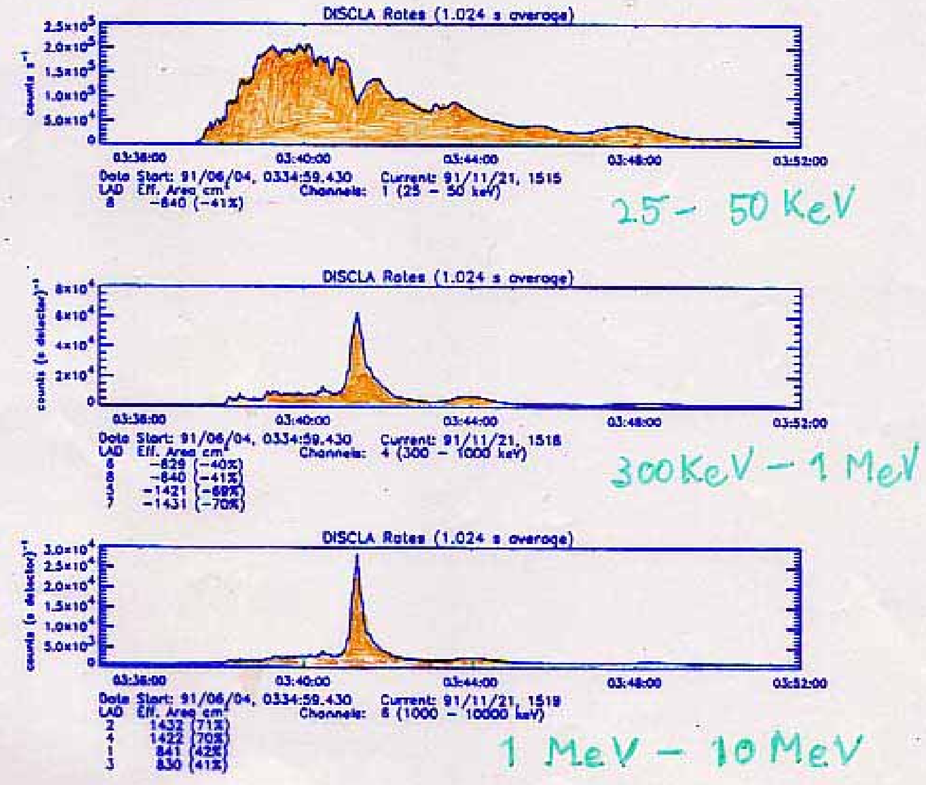


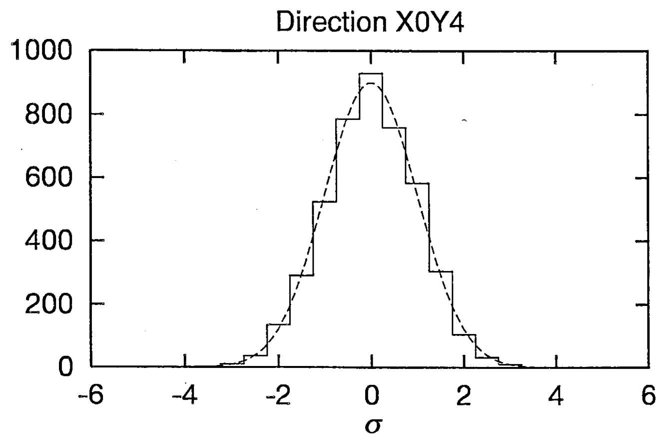
Fig. 4. Hard x-ray count rate history of the giant flare of 4 June 1991. The top two frames are the energy-loss rates in the backside detectors in two energy channels, 25-50 keV and 300-1000 keV. Although these detectors are shielded from the direct flare flux, the count rates were still too high to accurately measure the peak at 3:41 UT. The bottom rate was obtained from the sum of all of the frontside charged-particle detectors which are sensitive to photons of energies greater than 1 MeV and therefore did not become saturated by the lower energy photons. The peak corresponds to a photon rate of more than 300 cm^{-2} s^{-1} above an MeV.

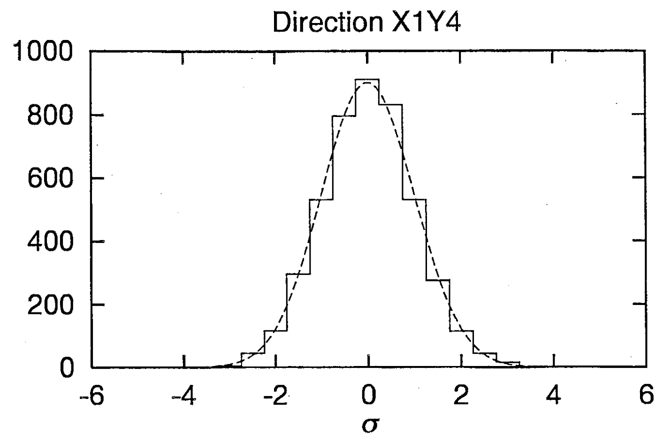
Statistical Significance

1998/11/19～28　10日間

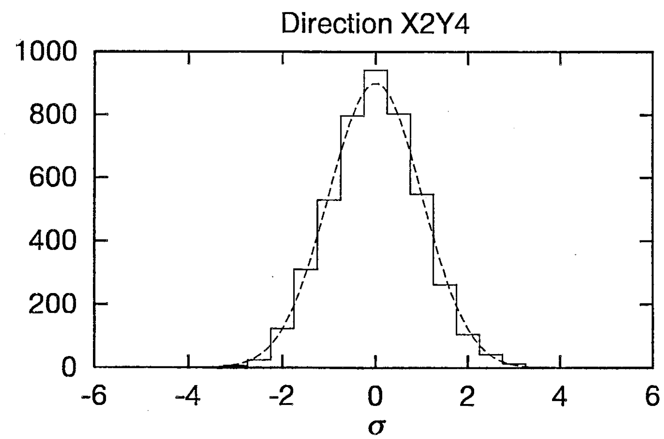
4800 bins　3分値

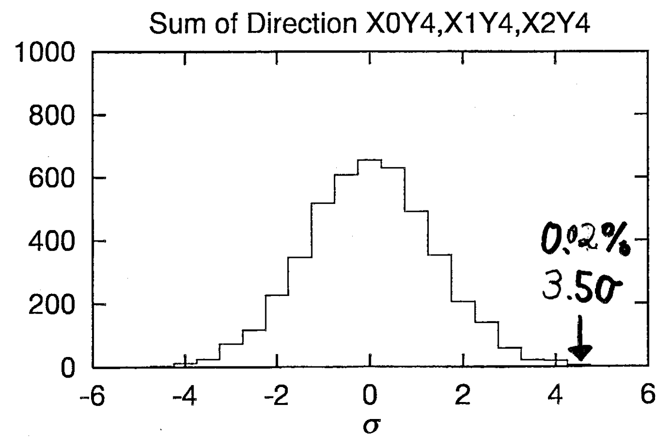
3.5σ ～ 0.0002 ～ 1/5000 ～0.02%





double counting

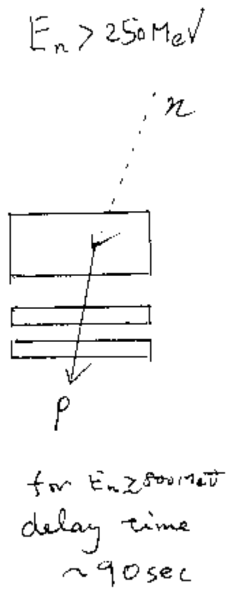




Problem of 1998 Nov 28th event

Event Profile

	N(3min value)	root√N	E> MeV
ch 1	240,000	490	> 40
ch 2	96350	390	> 80
	- 95800		
	550		
ch 3	49900	220	>120
	- 49500		
	400		
ch 4	23750	150	>160
	- 23450		
	330		
south	8140	90	>120
	- 7330		
	410		



A Gap between data and MC

Monte Carlo calculation was made by Tsuchiya.

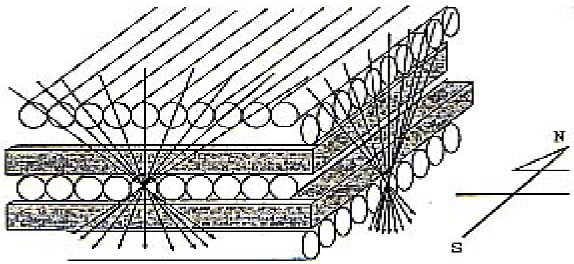


Figure 11: Schematic view of the measurement of the arrival directions for neutrons using the Tibet solar neutron detector. The arrows represent moving directions of recoil protons produced by incident neutrons.

Simulation by Tsuchiya

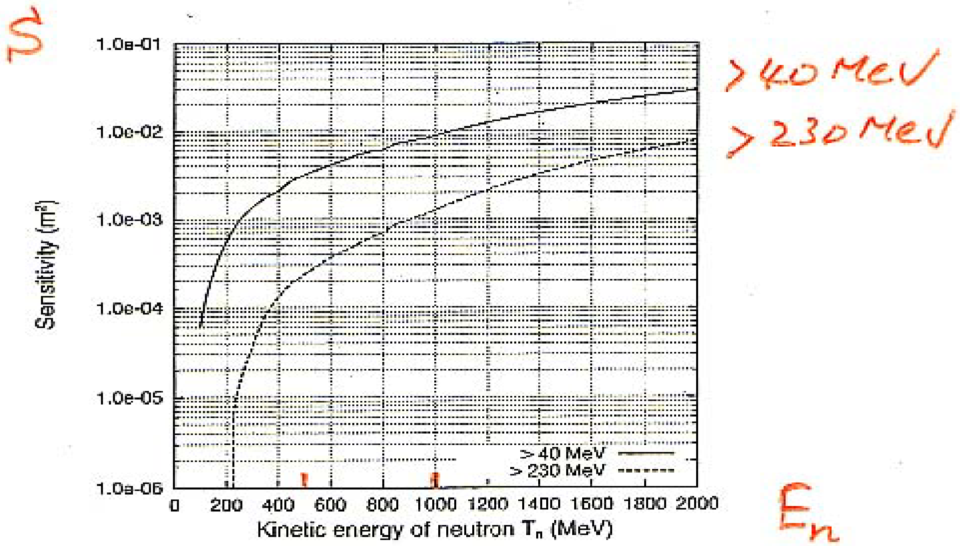
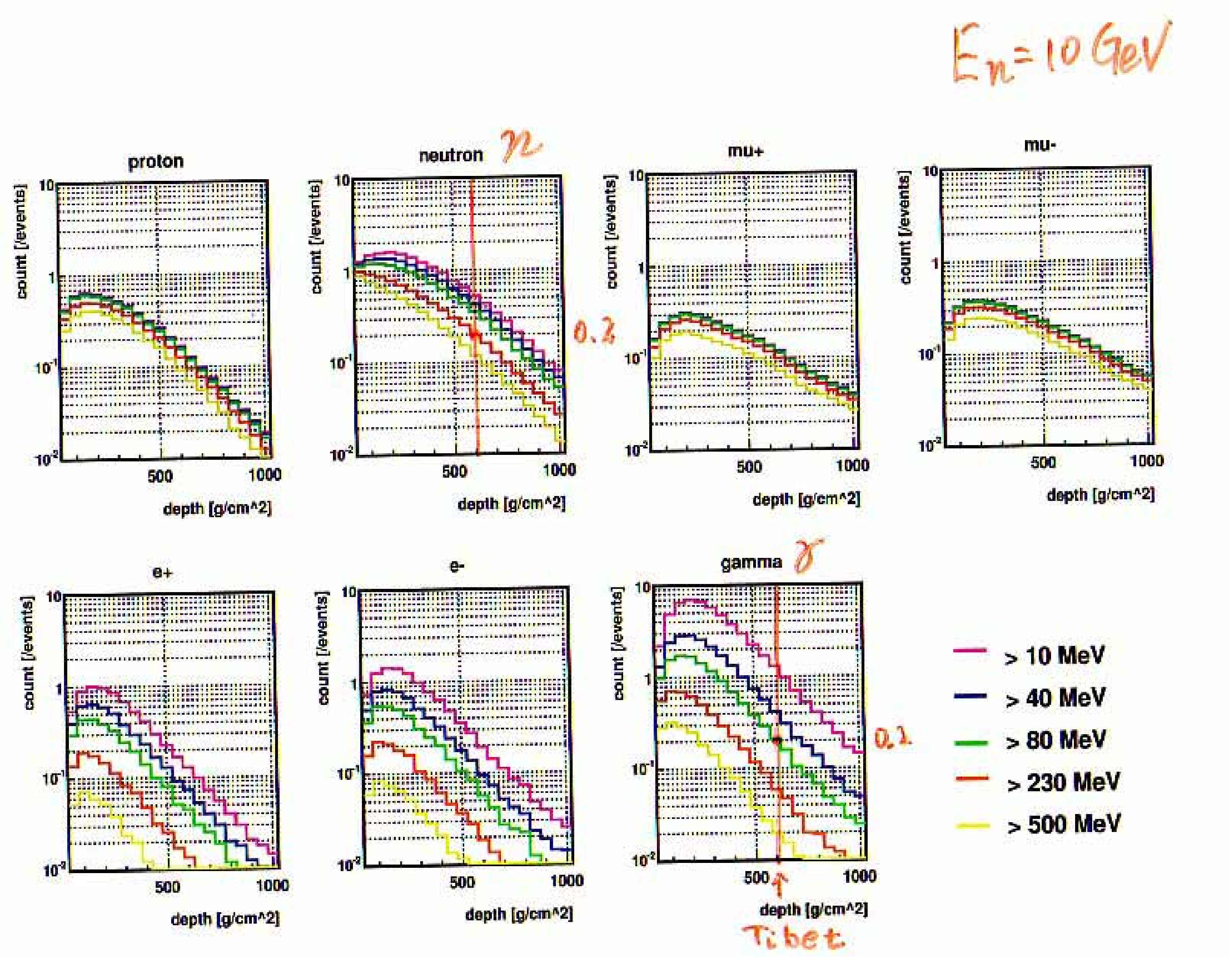


Figure 12: The sensitivity of Tibet solar neutron detector to neutrons. Upper and lower lines correspond to the sensitivity for the lowest (> 40 MeV) channel and the highest (> 230 MeV) energy channel respectively.

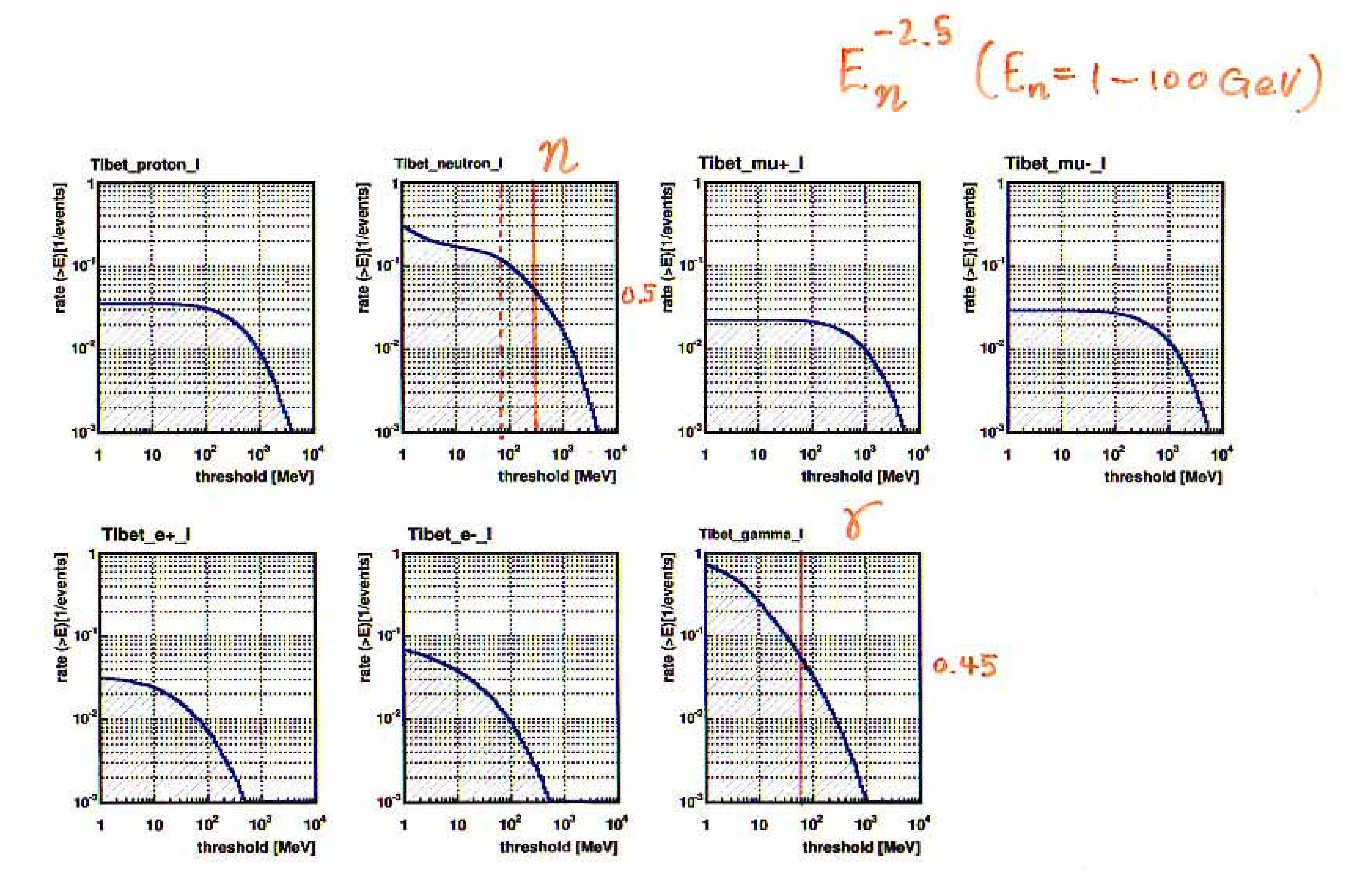
10GeV neutrons are injected at the top of the atmosphere

Simulation was made by Menjyo using Geant 4.



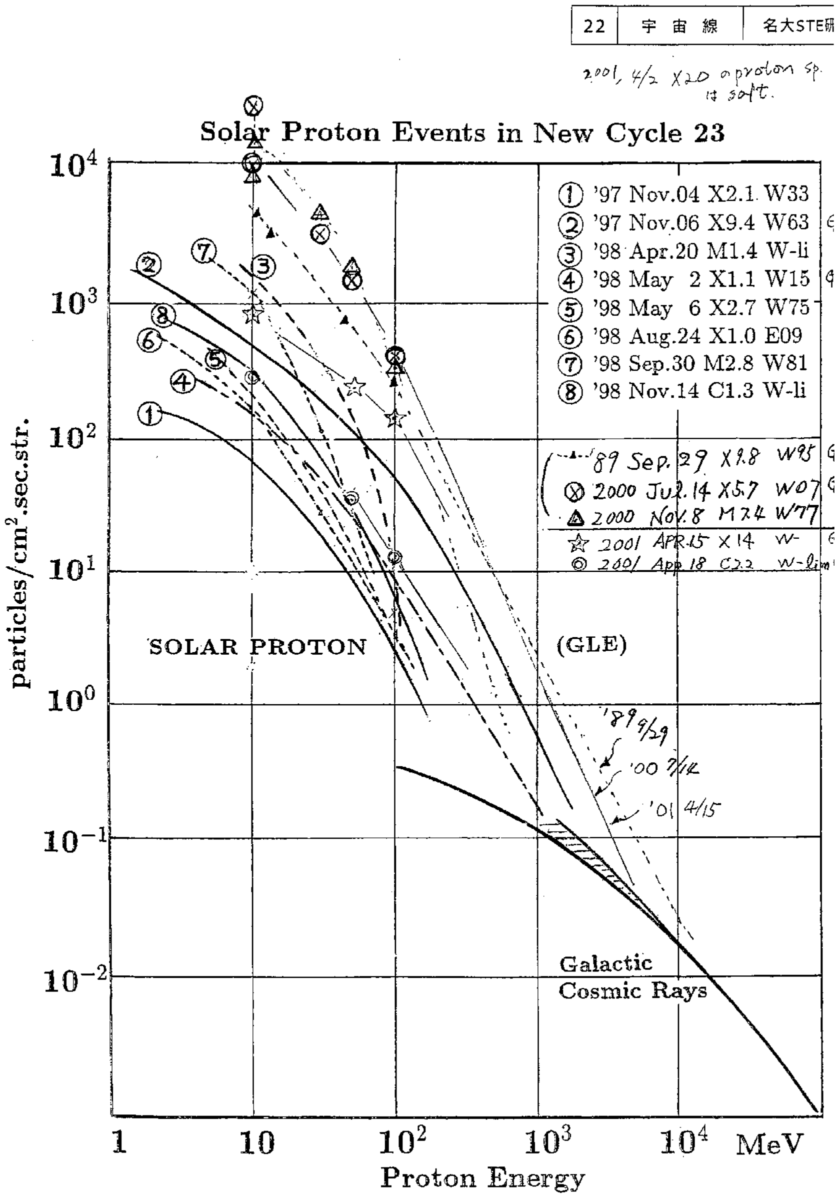
E_n= 1-100GeV neutrons are injected at the top of the atmosphere

Simulation
Was made by
Menjyo
using Geant 4



Solar proton spectra induced by flares

summarized
by Yasuno

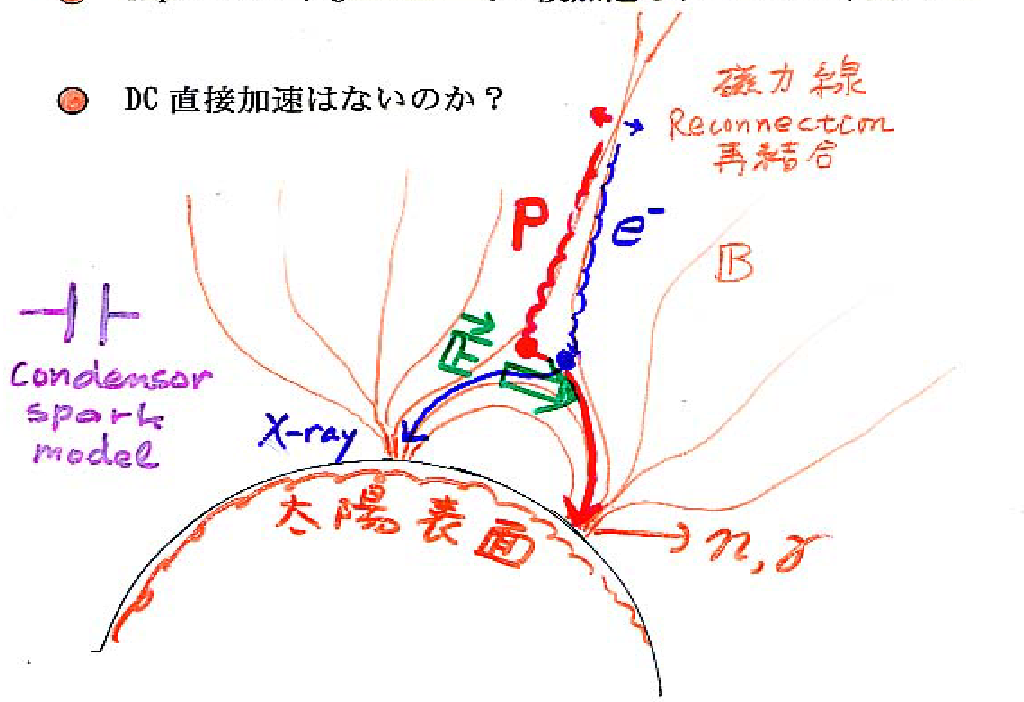


5. 今後の観測で目指すもの

Future tasks

1. 加速のモデルの検証
2. 最高エネルギー
   太陽宇宙線の観測
3. 拡散γ線成分の検出

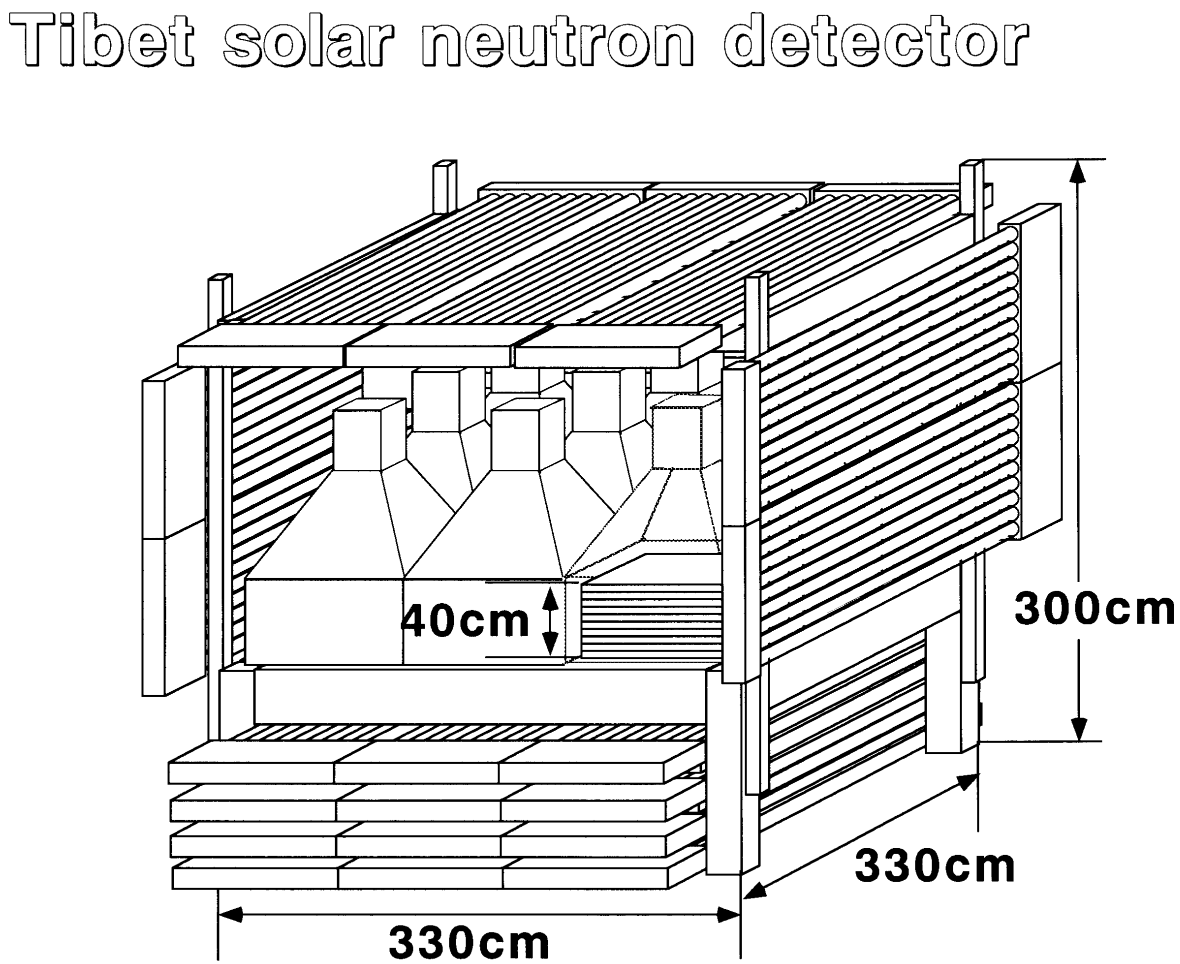
- Solar B との共同研究
  Limb events をねらう
  そして model の選別を目指す
- Solar B ではもっと暗い events が重要に
  なるだろう。　そこにイオン加速の本当の
  姿が見られるだろう。
- impulsive → gradual　で２段加速されているのだろうか
- DC 直接加速はないのか？



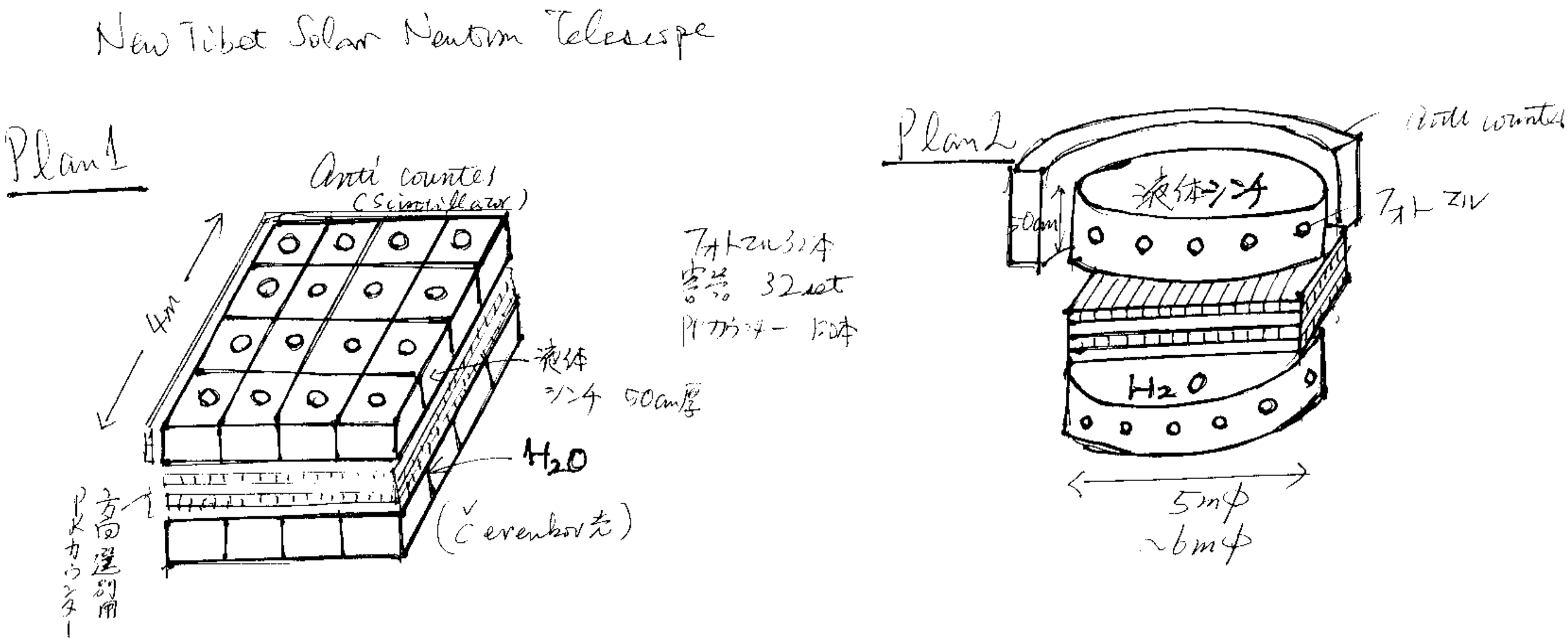
Future plan　(後輩に贈る図)

- 1. Improvement of current detector
- Tibet 1500万円
- Norikura 2000万円
- 2. Construction of new detector
- Atakama 2000万円
- Tibet 2500万円
- 3. Use of International Space Station

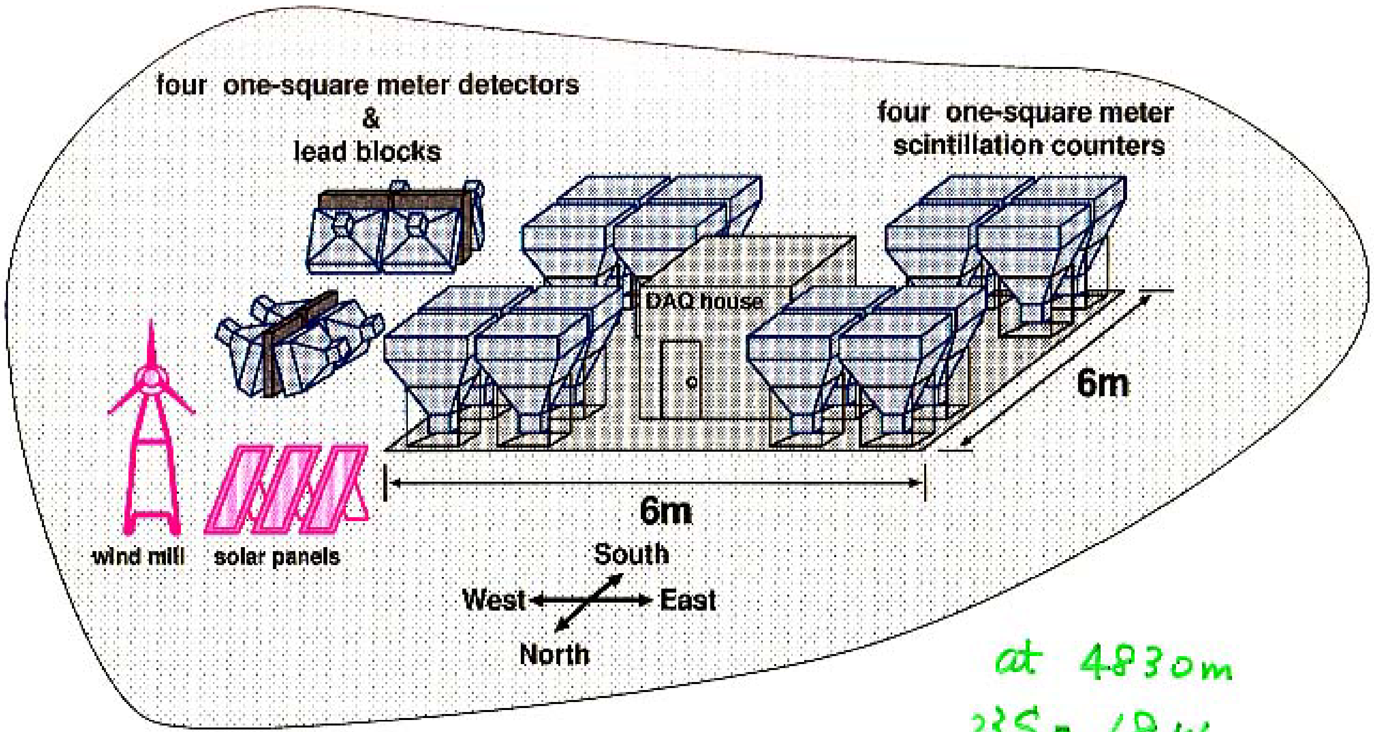
Tibet solar neutron telescope



Tibet new solar neutron telescope



Atakama用　観測装置



at 4830m

23S, 68W

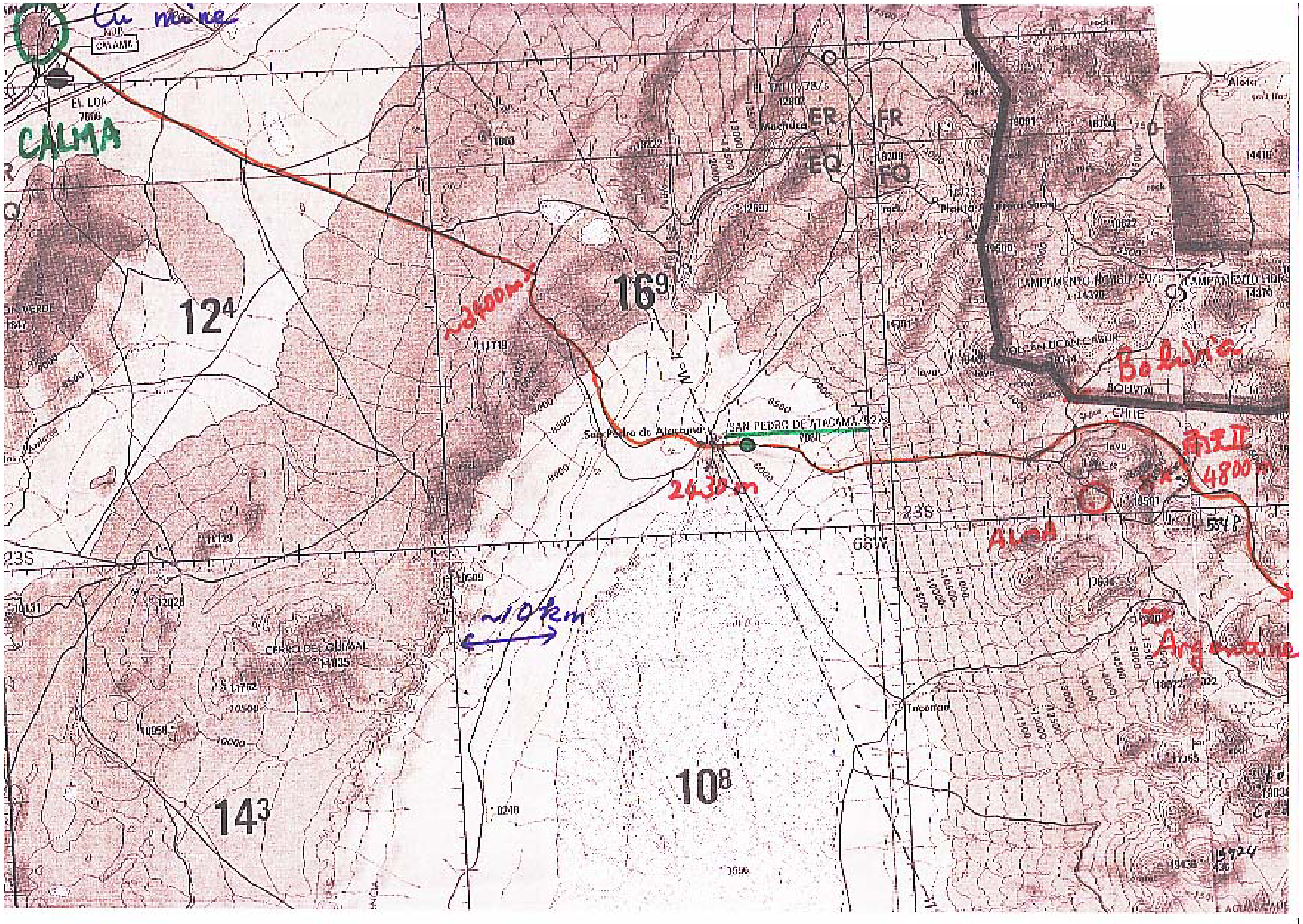
$16 m^2$ plastic scintillator (20 cm thick)

$4 m^2$ directional detector

$16 m^2$ anti counter

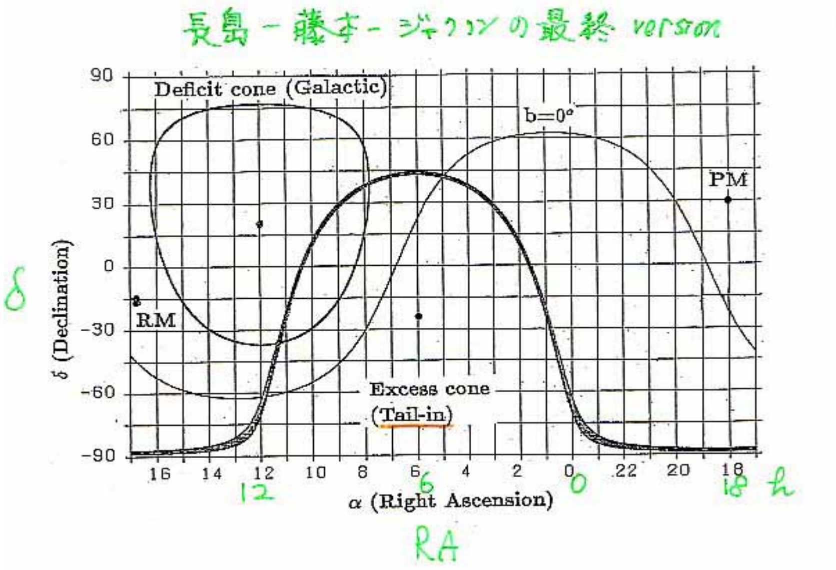
Solar + wind generator

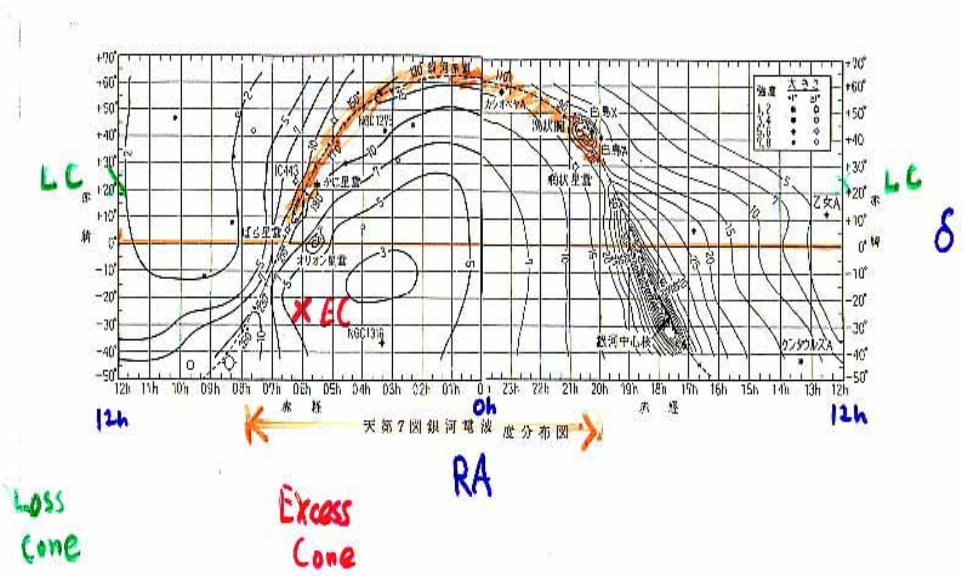
Atakama砂漠周辺

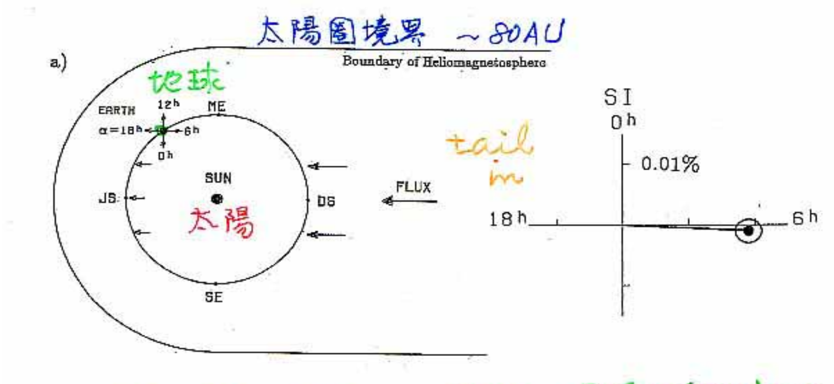


現地の写真 (2004.6)

Nagashima-Fujimoto-Jacklyn model

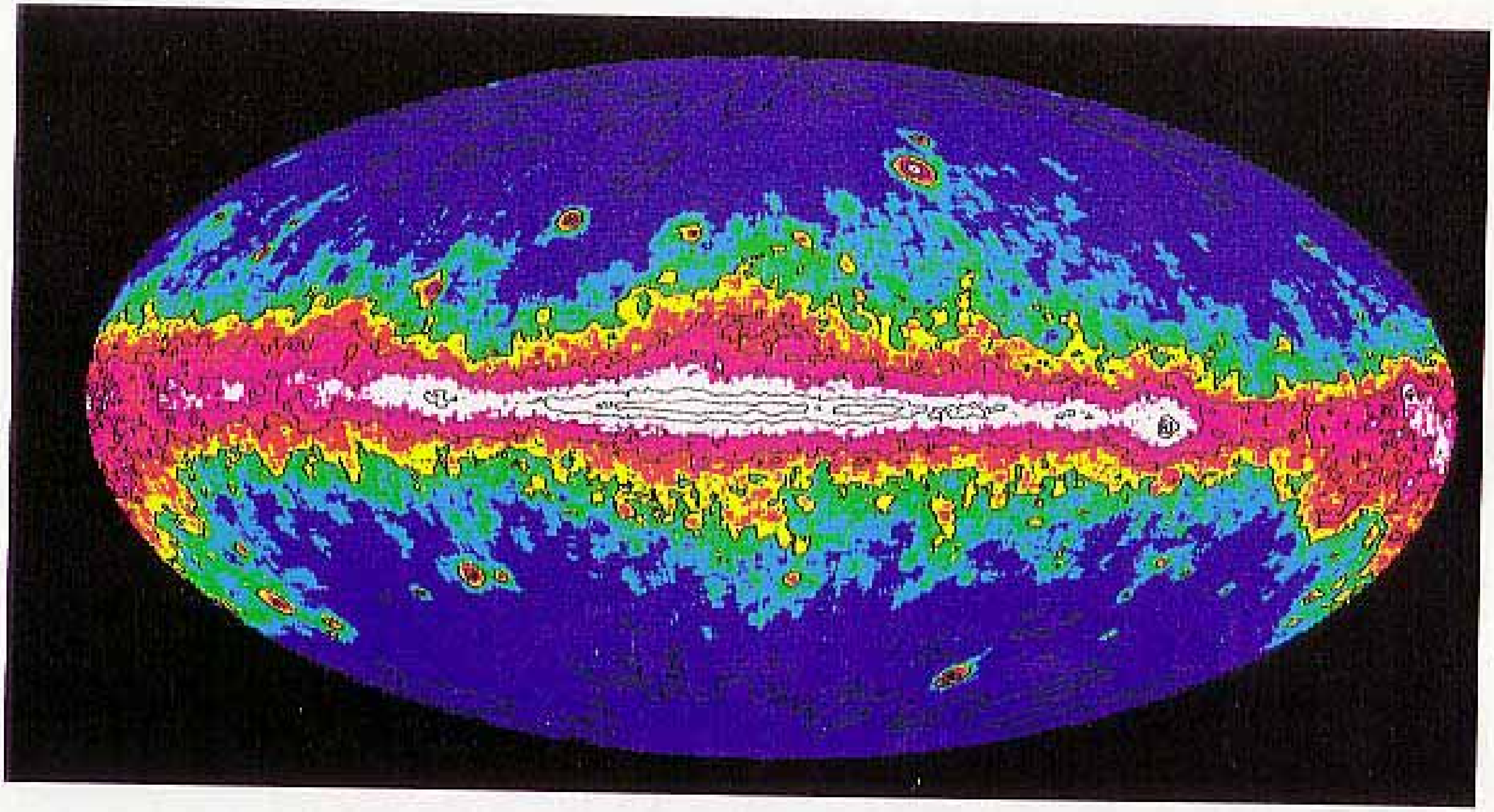






Nagashima-Fujimoto-Jacklyn JGR 17 (1998) 429

CRGO-EGRET data on diffuse gamma-rays



Alexenco-Navarra model

Alexeenko + Navarra

observations (2-4) at primary energies $E_0 = (10^{13} \div 10^{14})$ eV. We will use the results obtained by means of the Baksan EAS array, where the counting rate as a function of the local sidereal time has been measured with good statistical accuracy (5) (see fig. 1).

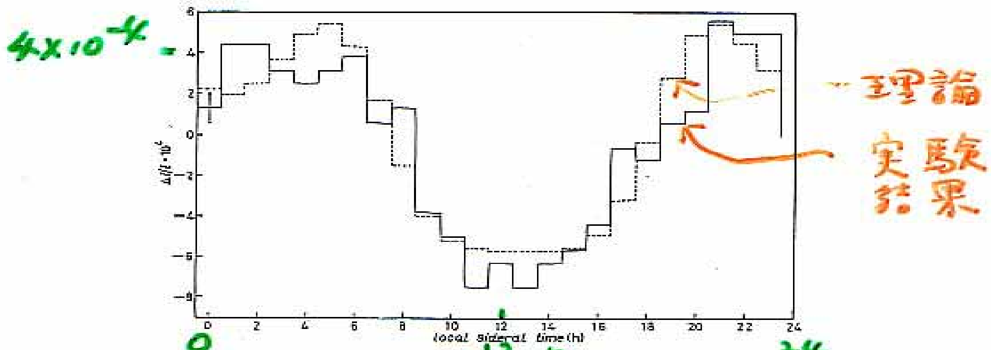


Fig. 1. – The cosmic-ray sidereal daily variation shown as percentage departures from the mean. Full lines: Baksan experimental data (typical statistical error is shown); broken lines: calculated variation obtained by extrapolating the COS B gamma-ray flux from the galactic disk, assumed uniform.

From the usual Fourier analysis evidence is obtained of a first and a second harmonic of amplitudes and phases (5)

$$A_1 = (5.8 \pm 0.3) \cdot 10^{-4}, \quad \varphi_1 = (1.2 \pm 0.2)\ \text{h},$$

$$A_2 = (1.6 \pm 0.3) \cdot 10^{-4}, \quad \varphi_2 = (6.1 \pm 0.5)\ \text{h}.$$

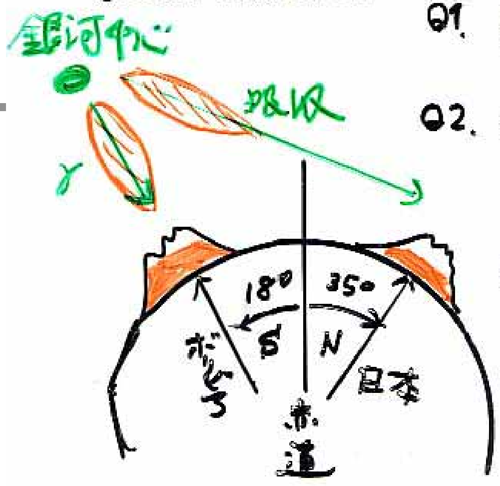
The gamma-ray contribution to the counting rate is calculated by extrapolating the differential gamma-ray flux from the galactic plane obtained by COS B satellite (6)

(2) T. Gombosi, J. Kota, A. J. Somogyi, A. Varga, B. Betev, L. Katanski, S. Kavlakov and I. Khirov: *Proceedings of the International Cosmic Ray Conference*, Vol. 4 (1975), p. 1182.
(3) S. Sakakibara, K. Fujimoto, Z. Fujii, H. Ueno, I. Kondo and K. Nagashima: *Proceedings of the International Cosmic Ray Symposium on High-Energy Cosmic Ray Modulation* (Tokyo, 1976), p. 316.
(4) V. V. Alexeenko, A. E. Chudakov, E. N. Gulieva and V. G. Sborshikov: *Proceedings of the XVII International Cosmic Ray Conference*, Vol. 2 (1981), p. 146.
(5) V. V. Alexeenko, A. E. Chudakov, E. N. Gulieva and V. G. Sborshikov: *Izv. Akad. Nauk SSSR, Ser. Phys.*, 48, 2136 (1984).
(6) K. Bennett, G. F. Bignami, R. Buccheri, W. Hermsen, G. Kanbach, F. Lebrun, H. A. Mayer-Hasselwander, J. A. Paul, G. Piccinotti, L. Scarsi, F. Soroka, B. N. Swanenburg and R. D. Wills: *Proceedings of the XII ESLAB Symposium* (Frascati, Roma, 1977), p. 83.

N. C. L. 42 (1985) 321.

Science purpose

○どうして問題なのか



10 – 100 TeV の

Q1. 異方性はなぜ作っているのか？

Q2. C.R.は完全に isotropic ではないのか？ $< 1 \times 10^{-4}$

Q3. 6hの tail in excessは本当に tail inか？

Q4. 装置の角度分解能が悪いからではないか？

○BASJEの結果重要

まだ知らないから、ここではブランク

Q　10^{-4}の異方性が検出できる方法を採用しているのか？

理想的な装置

1×10^{-4}の異方性が検出できる

多方向宇宙線望遠鏡が必要。

expected event rate

3 Fold coincidence　1.2×10^{5} /hour

4.4×10^{9} /year /hour di…

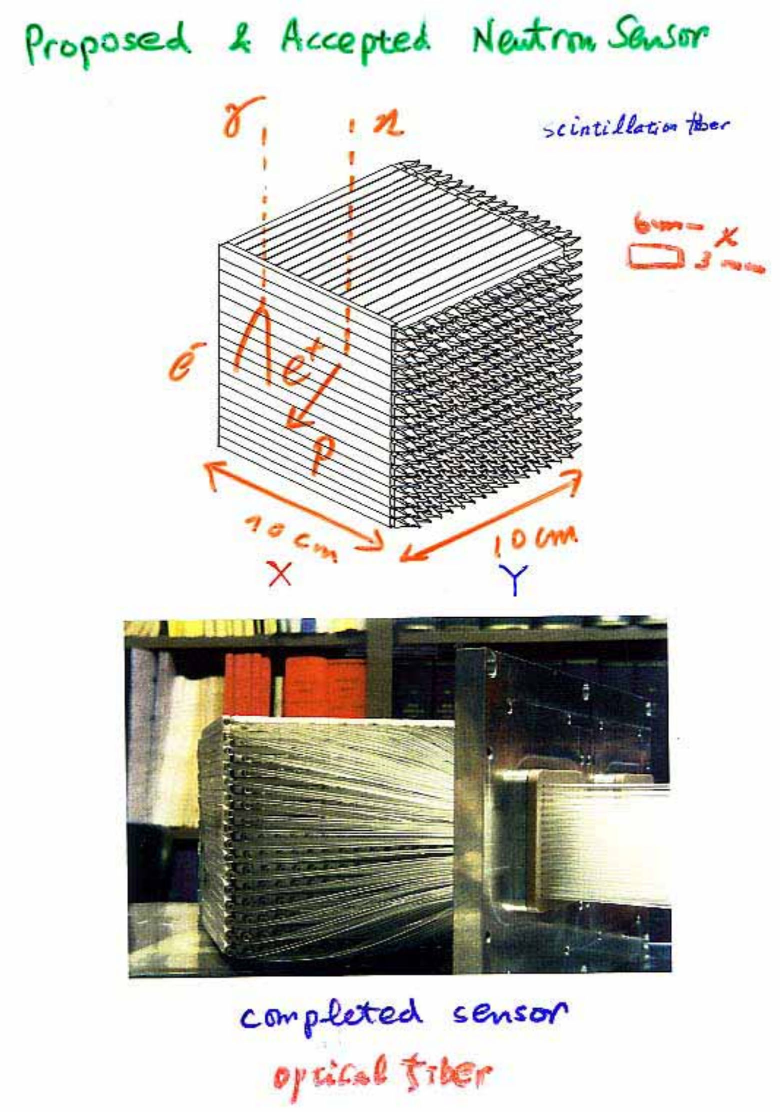
$\Delta N/N = 1.5 \times 10^{-4}$

シャワーの発達の差から　probably ↓ 1.0×10^{-4}

$\sim 0.5 \times 10^{-4}$

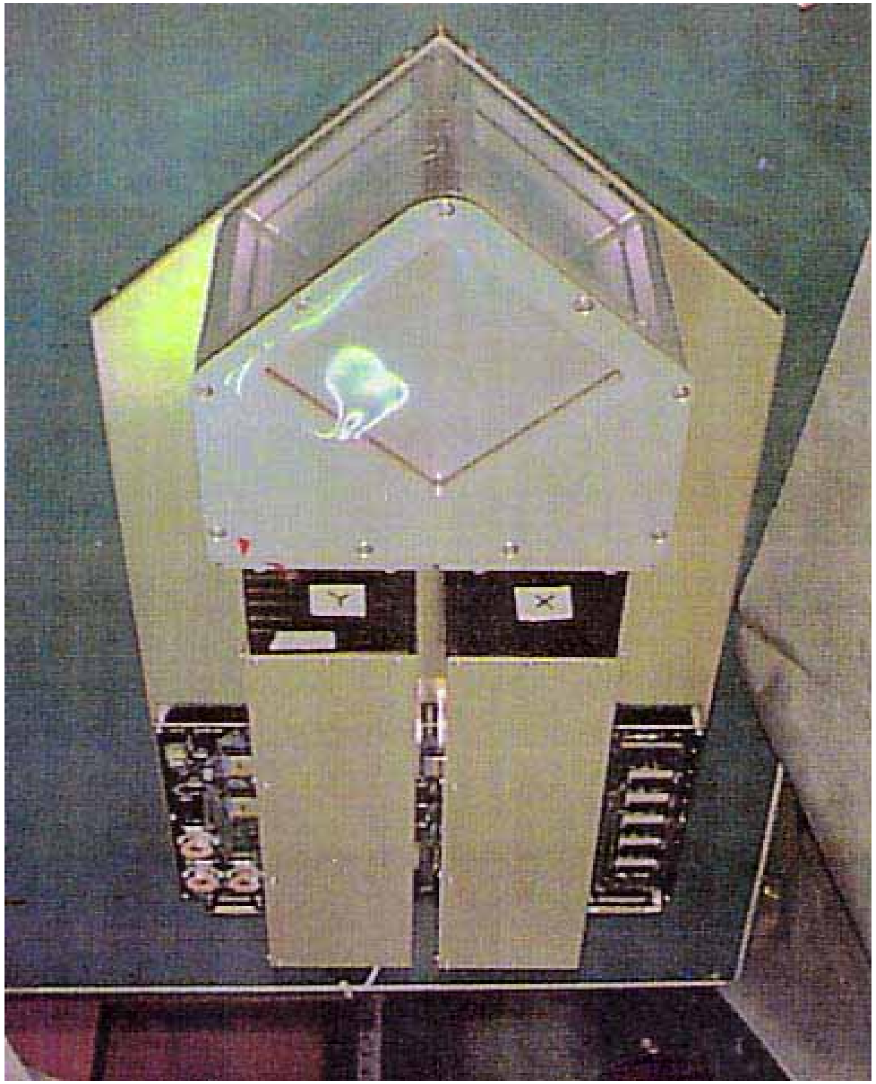
Solar neutron detection by International Space Station

E_n = 30 MeV – 100 MeV



Solar neutron detector at ISS

We expect on board ISS by the space shuttle in 2007.



Future plans(後輩に贈る計画)

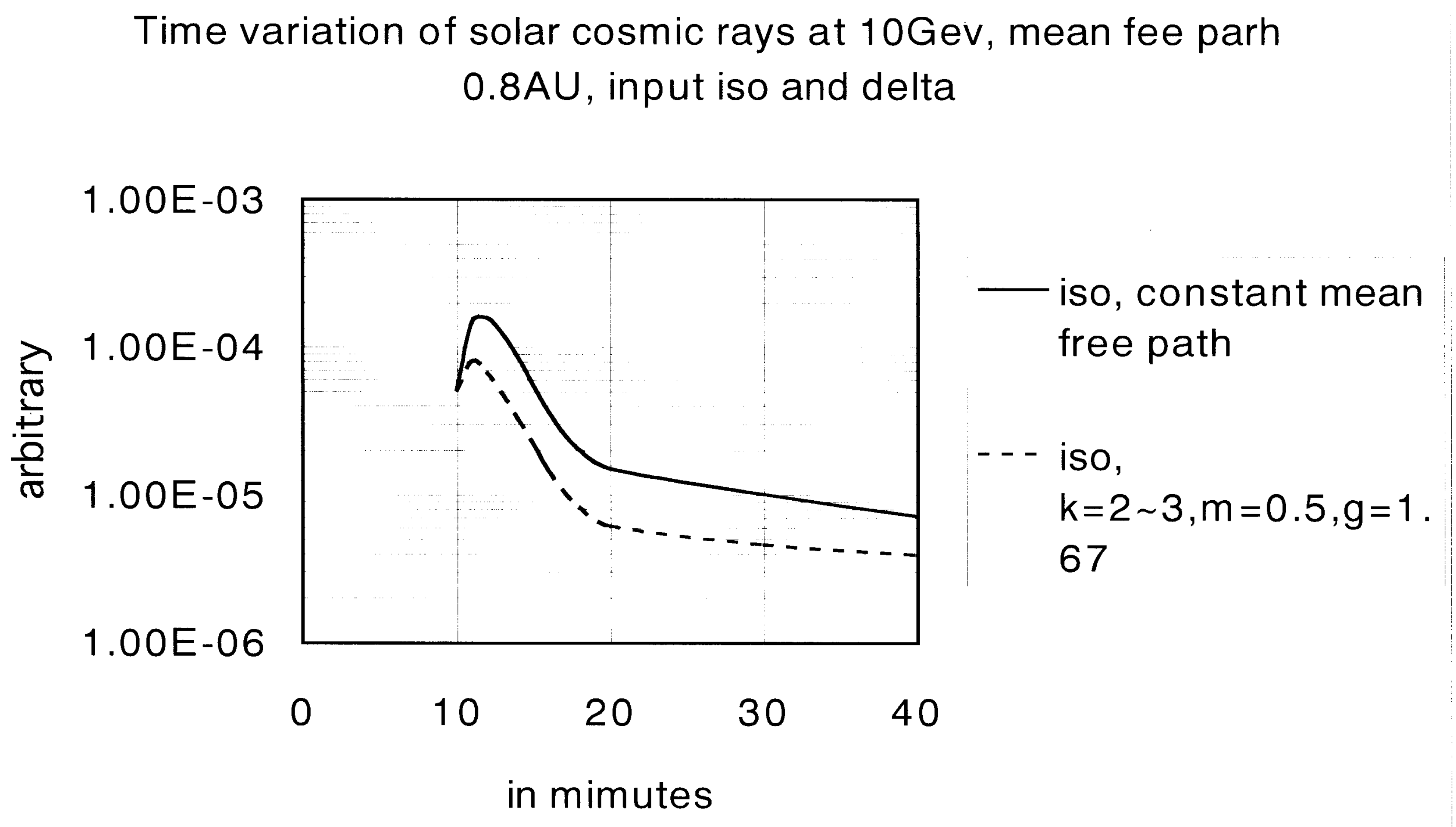
- 1. Improvement of current detector
- Tibet, Norikura
- 2. Construction of new detector
- Atakama, Tibet
- 3. Use of International Space Station

皆さん、がんばってお金とってね！

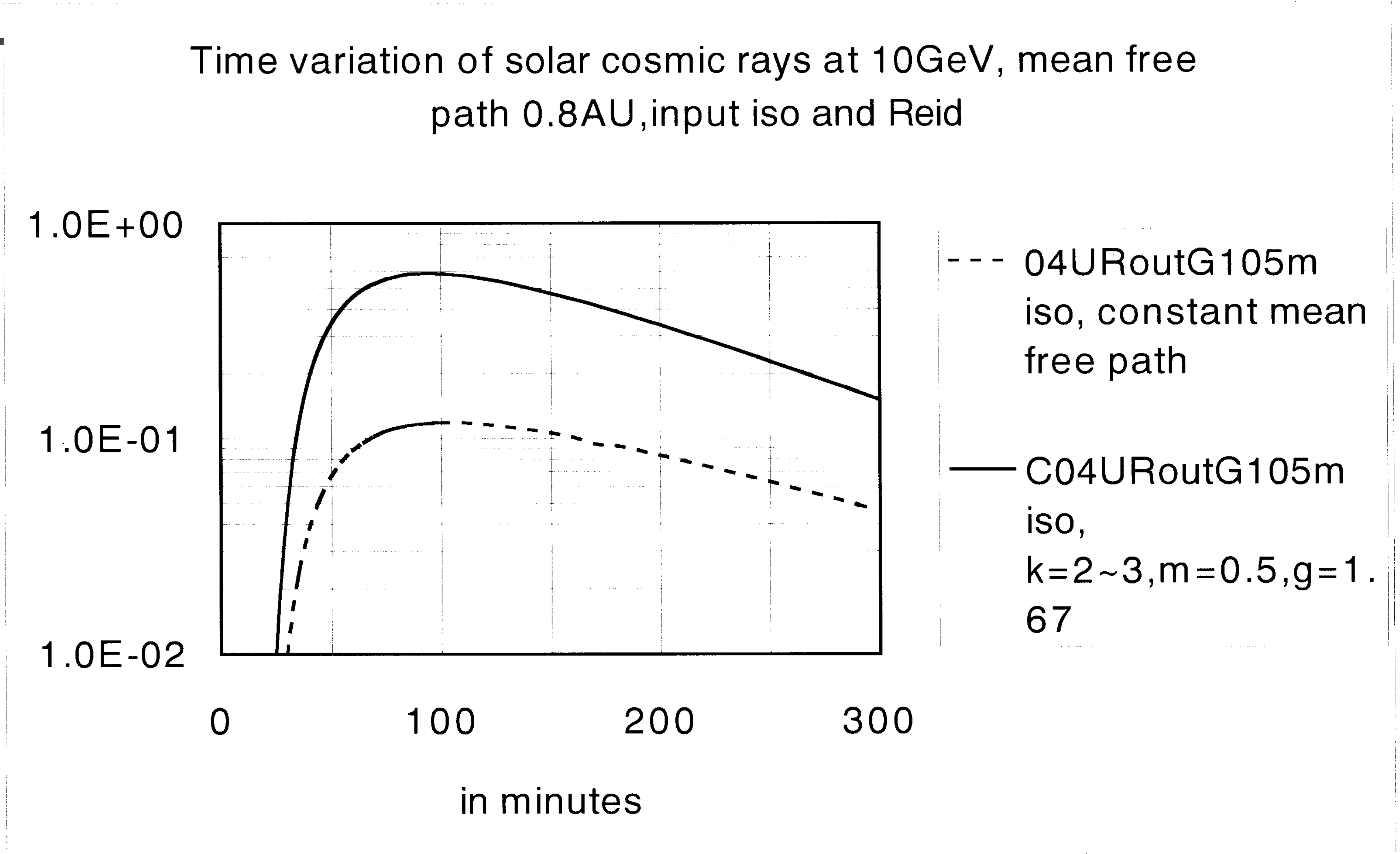
STEL

STEL

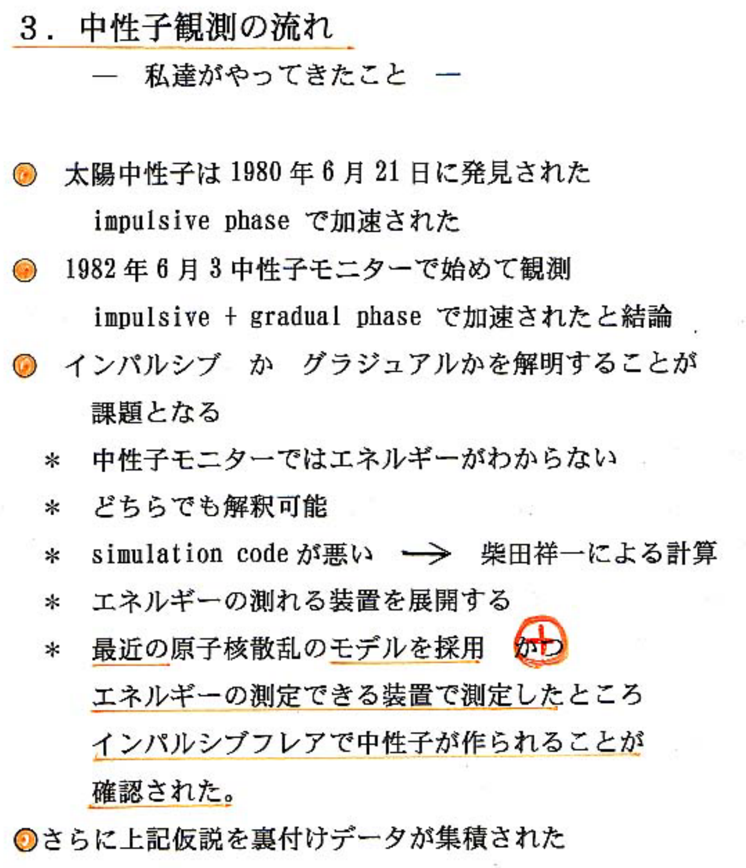
Calculated by Sakai (model 1)



Calculated by Sakai (model 2)



3. 中性子観測の流れ


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

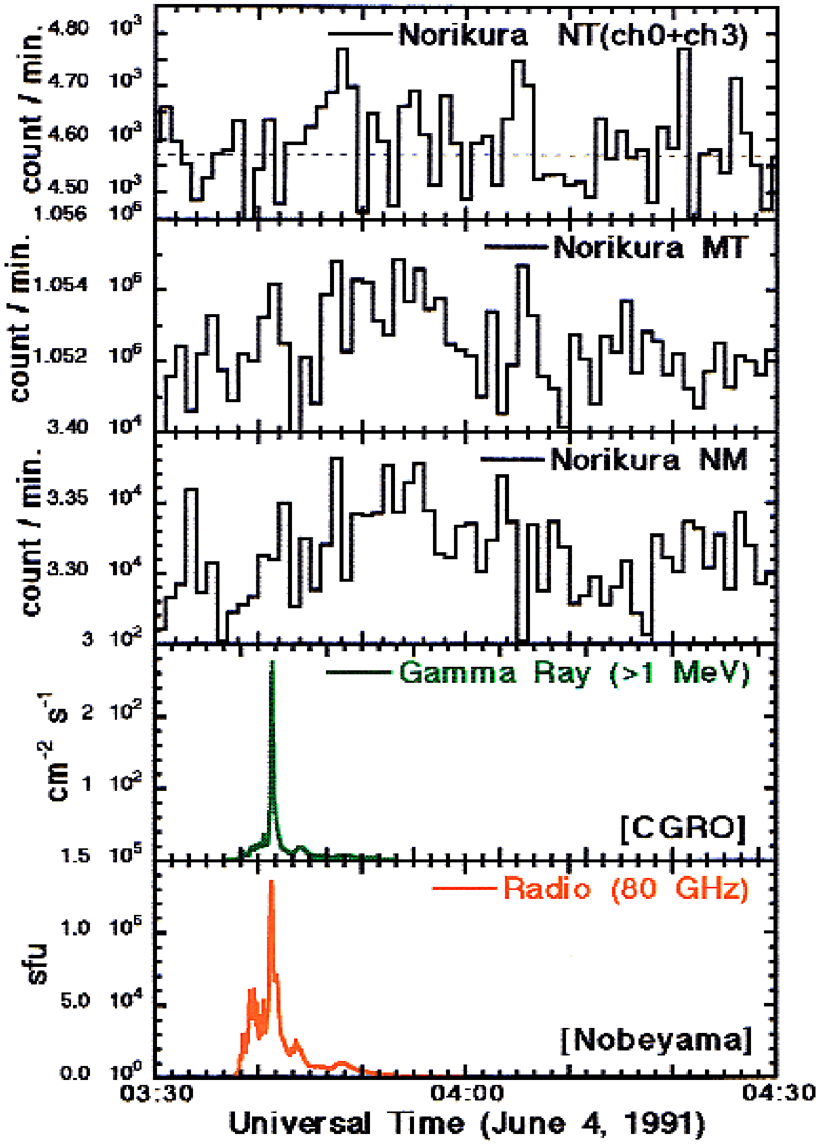
インパルシブフレアで中性子が作られることが

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

June 4th 1991 event

The neutron event is consistent with impulsive production model.



June 6th 1991 event

The event could be explained by slightly extended impulsive production model.

Or multiple impulsive flare Process.