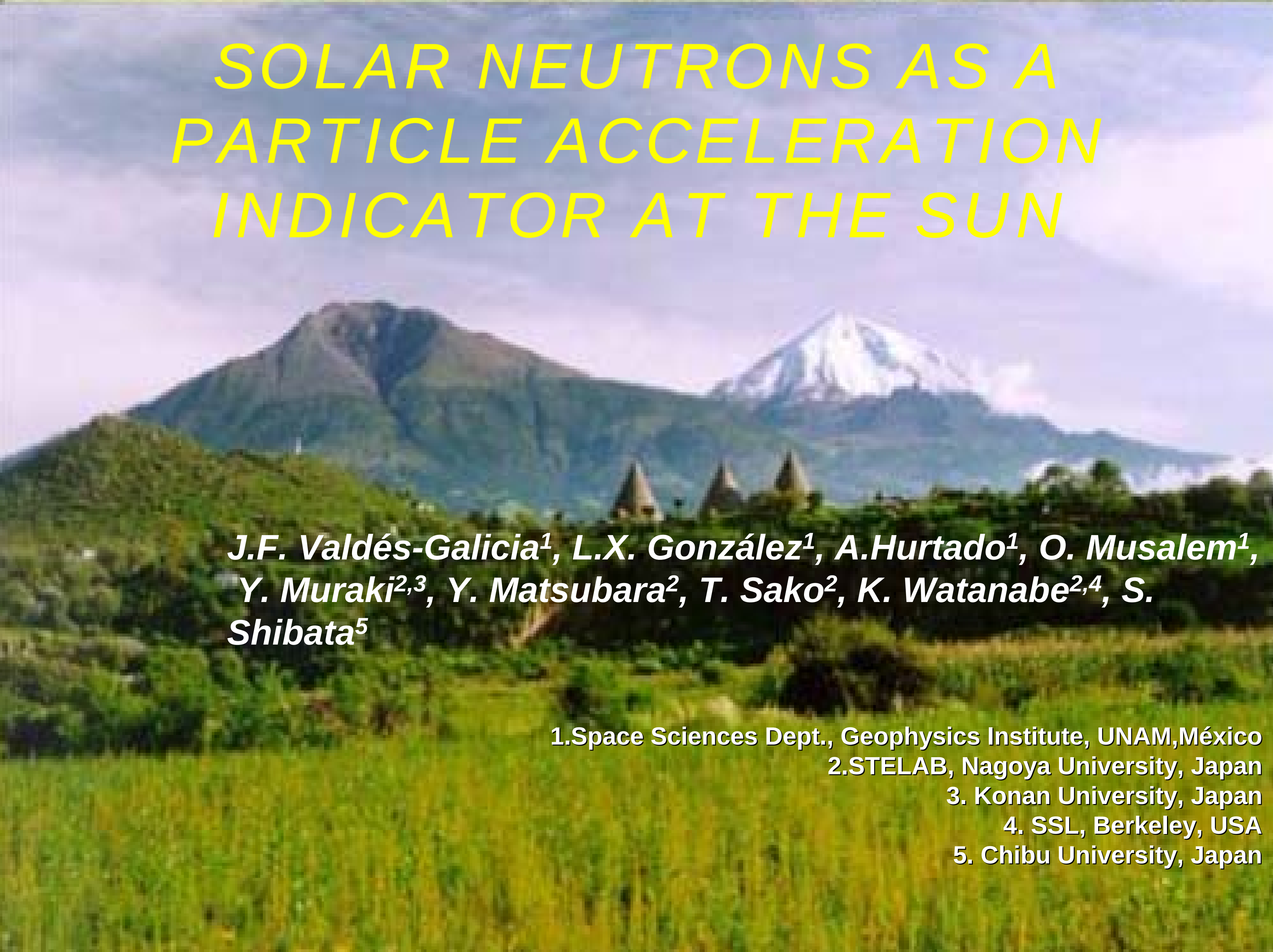


SOLAR NEUTRONS AS A PARTICLE ACCELERATION INDICATOR AT THE SUN

J.F. Valdés-Galicia[1], L.X. González[1], A.Hurtado[1], O. Musalem[1], Y. Muraki[2,3], Y. Matsubara[2], T. Sako[2], K. Watanabe[2,4], S. Shibata[5]

1.Space Sciences Dept., Geophysics Institute, UNAM,México
2.STELAB, Nagoya University, Japan
3. Konan University, Japan
4. SSL, Berkeley, USA
5. Chibu University, Japan

Main Solar Emmisions

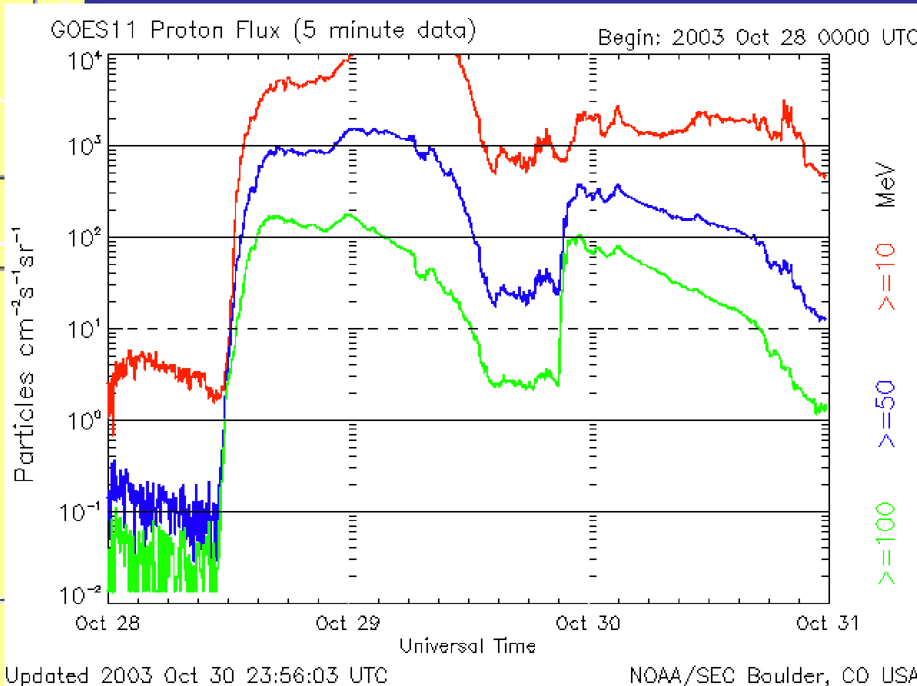
Spectral range	Source	Characteristics
Radio, mm, IR	"quiet" corona and chromosphere	electromagnetic radiation from moving charged particles (thermal radiation).
white light	photosphere	continuum, thermal radiation.
	chromosphere	line emission and absorption.
	K-corona	spectral lines from various ions.
	F-corona	continuum, photospheric light reflected from dust particles.
UV	chromosphere, transition region, corona	spectral lines from various ions at various ionization stages.
EUV	corona	see UV.
X-rays	upper corona	spectral lines as for UV, Bremsstrahlung.
	"hot" corona, flares etc.	Bremsstrahlung.
γ-rays	strong flares	Bremsstrahlung + line emission from nuclear processes.

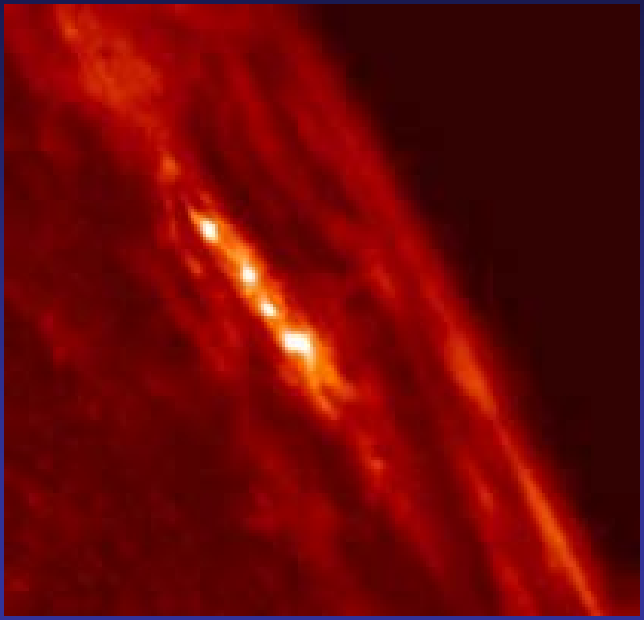
2. Particles

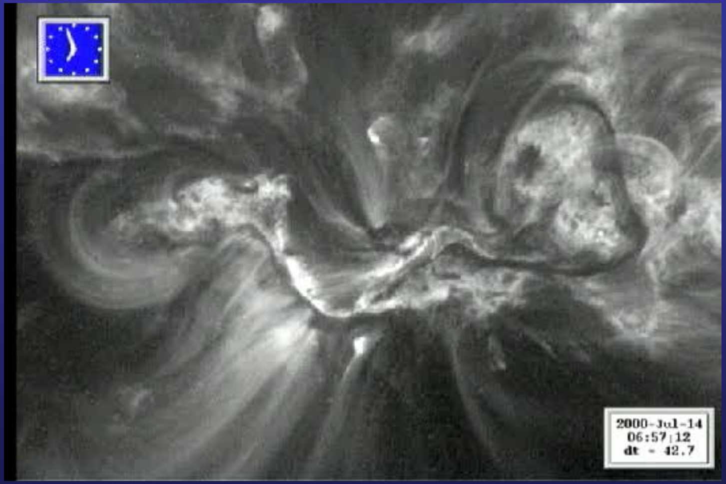
Type	Source	Characteristics
solar wind	corona	H^+ up to 2 keV, electrons up to 1 keV
"low energy" particles	transients, shocks	H,He,C,N,O up to ~ 100 keV
"energetic" particles	flares	energies up to ~ 100 MeV. ?

Table 2: Forms of solar output

Nobeyama RH a 17GHz







SOLAR FLARES

Short duration solar explosions:

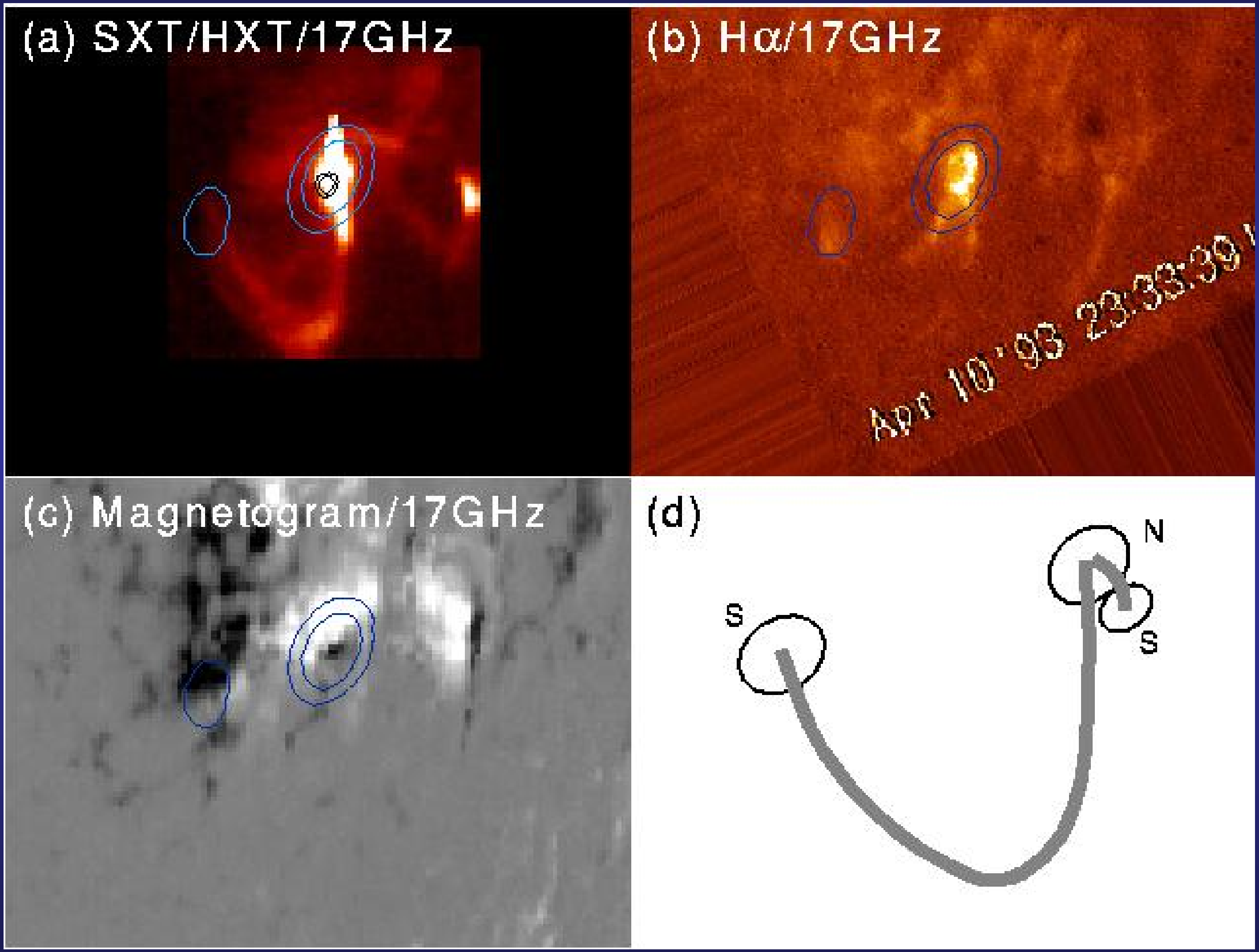
- *visible light,*
- *EUV*
- *X Rays*
- *Energetic protons*

But also:

- *γ Rays(1-100MeV)*
- *Neutrons (up to ~1GeV ?)*

Solar Flare on 10 april 1993 observed in

Soft X Rays, Hard X Rays, Hα and magnetic field



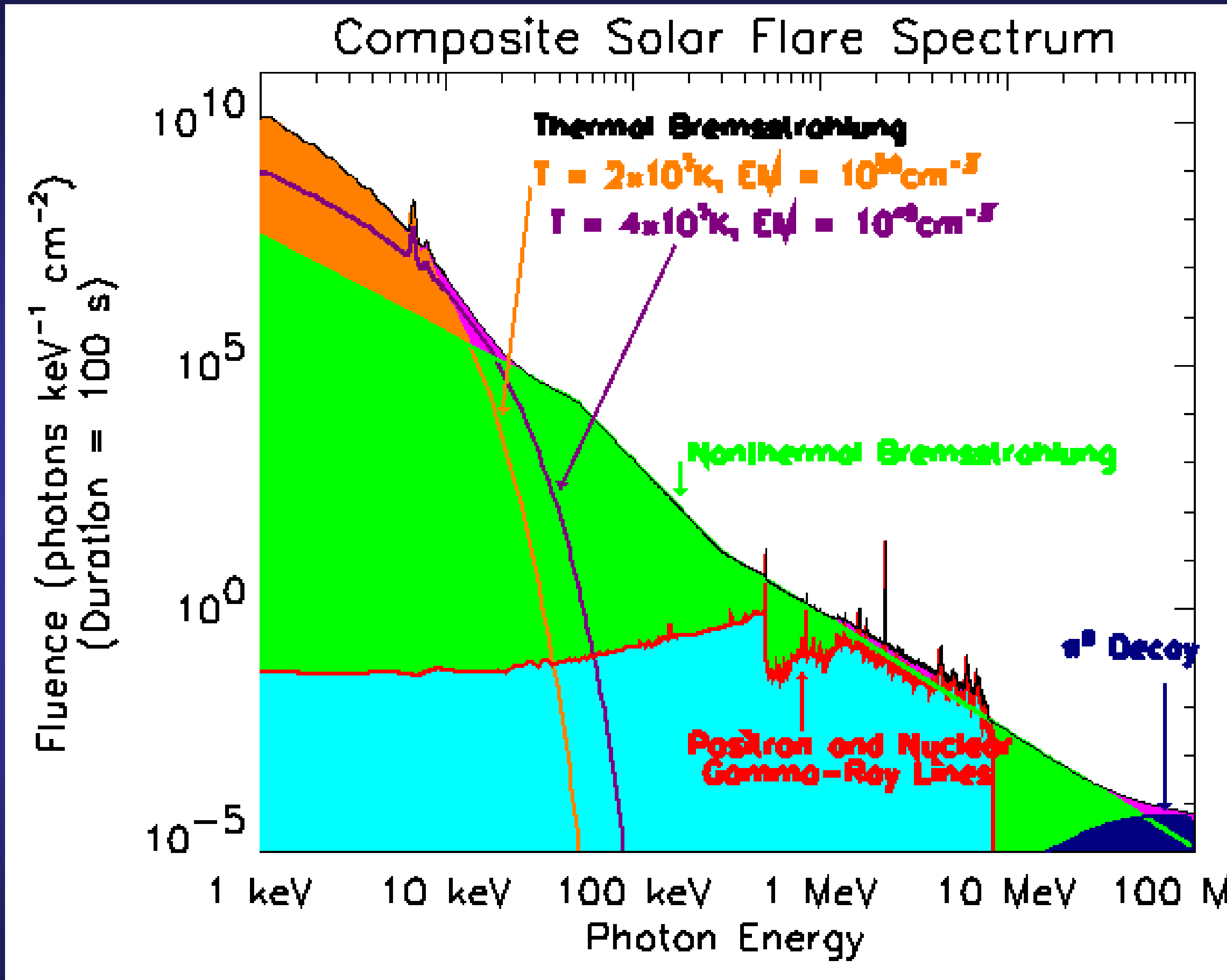
1951 Biermann, Haxel, Shulter pointed out the possibility of detection of solar neutrons at Earth

ENERGETIC PROTONS PRODUCE

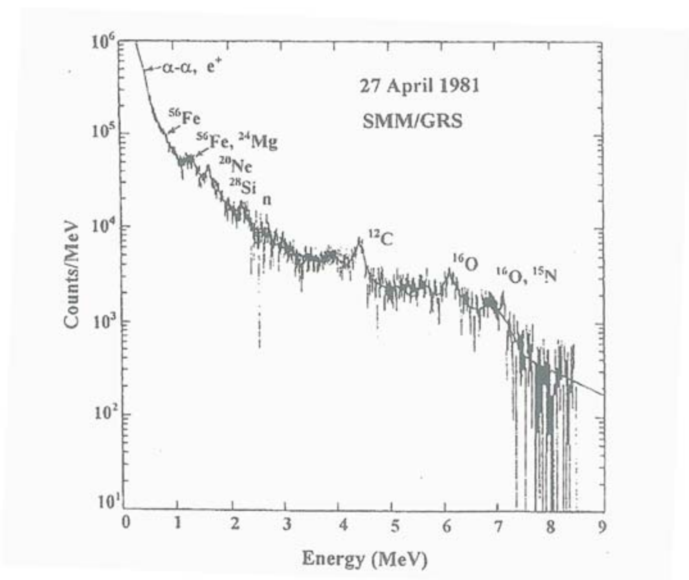
NUCLEAR REACTIONS IN THE SUN

Evidences:

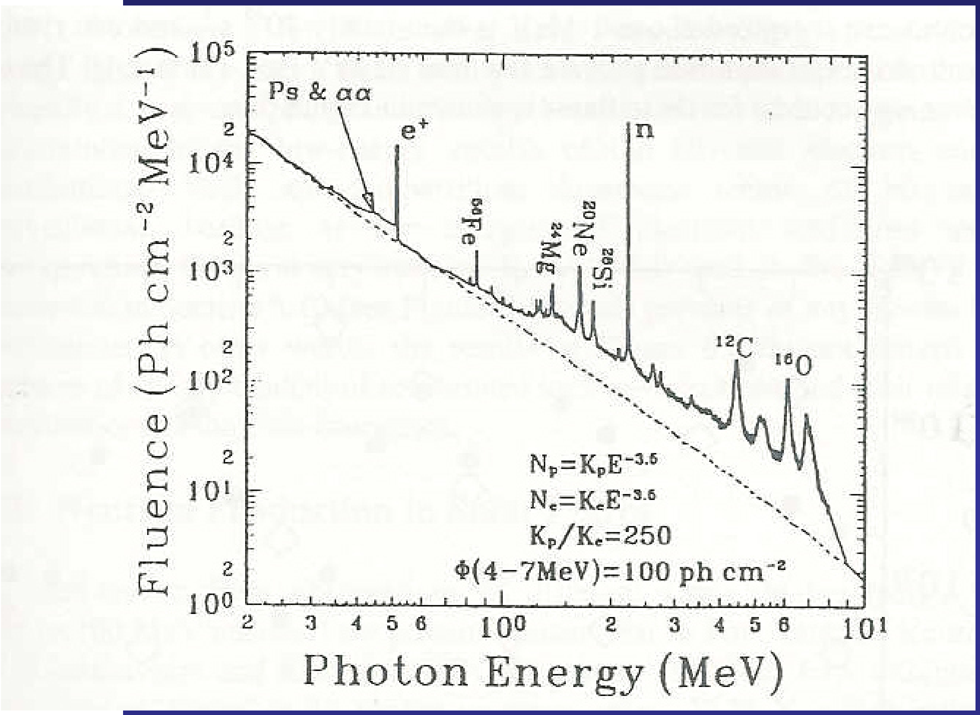
- ***Positron Anihilation***
  e^+, e^- (0.511MeV)
- ***Neutron capture lines***
  $^1H(n,\gamma)^2H$ (2.223 MeV)
- ***Gamma ray lines (nuclear deexitation)***
  ^{16}O(6.129 MeV) ^{12}C(4.438MeV)
- ***Gamma rays from π^0 , $\pi^{\pm}$ decay***
  (>1 MeV) (π^0 peak at 70 MeV)



Composite Solar Flare Spectrum
Thermal Bremsstrahlung
Nonthermal Bremsstrahlung
Positron and Nuclear
Gamma-Ray Lines
Decay
Fluence (photons keV^{-1} cm^{-2})
(Duration = 100 s)
10^{10}
10^{5}
10^{0}
10^{-5}
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 Me
Photon Energy



Observations
27 abril 1981
(Murphy et al, 1991)



Theoretical Calculations
(Ramaty et al, 1995)

How are neutrons produced at the solar surface?

The dynamical motion of the magnetic loops is the origin of the solar flare and hence the origin of the particle acceleration

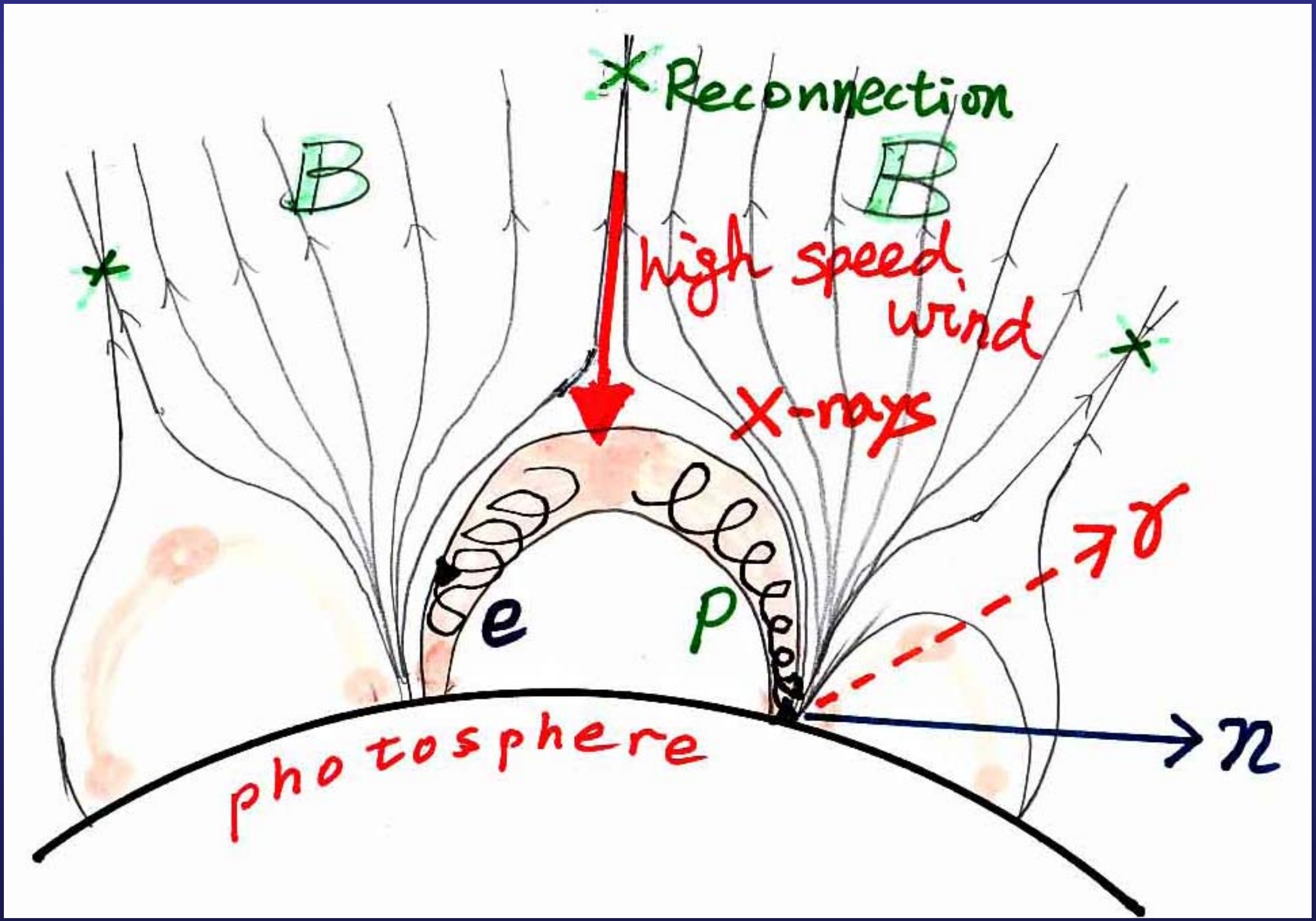
Micro processes

Tension
Plasma heating
~3000km/s

~70sec 20MeV
to 40 GeV

nuclear collisions

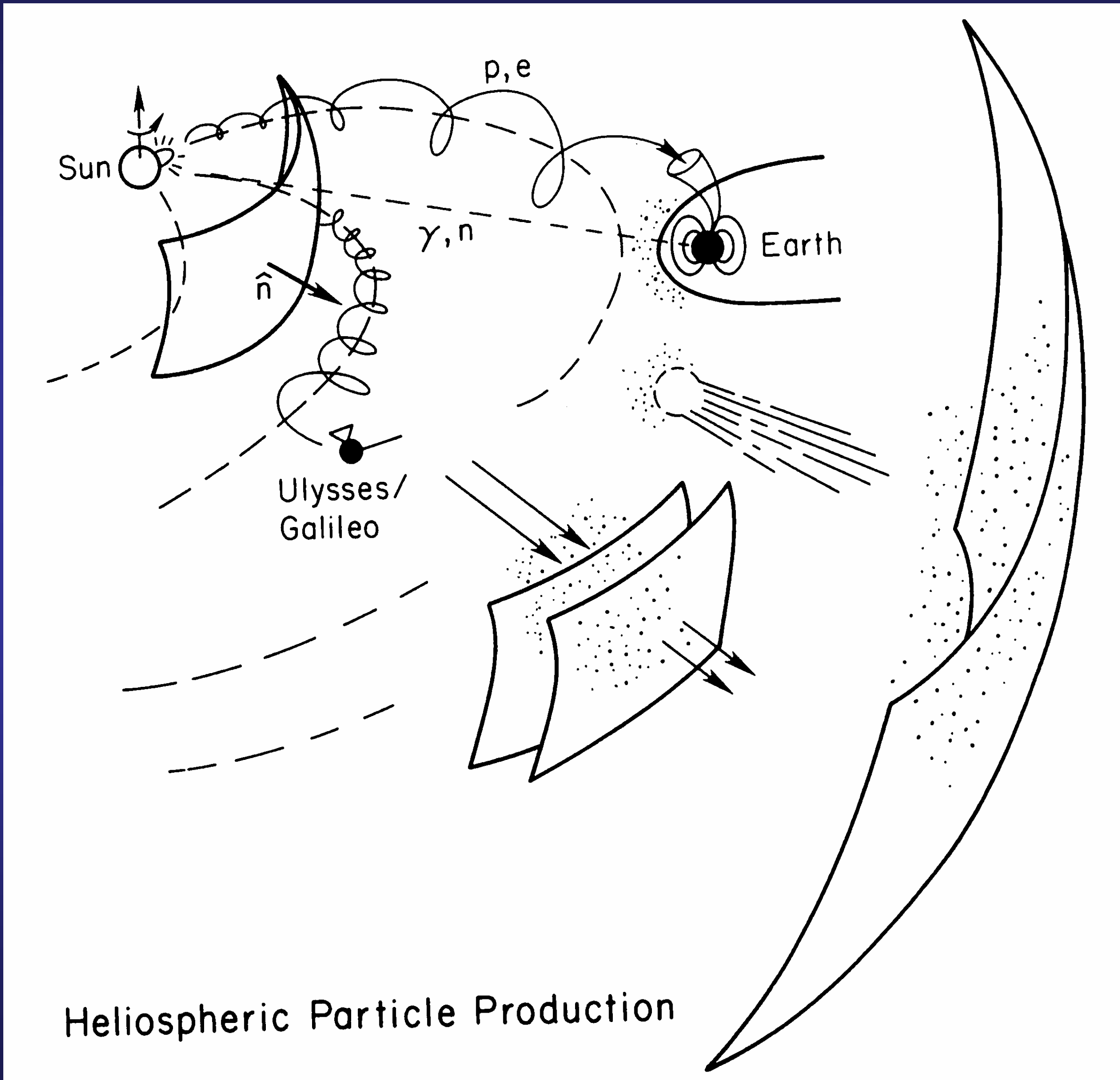
Charge exchange



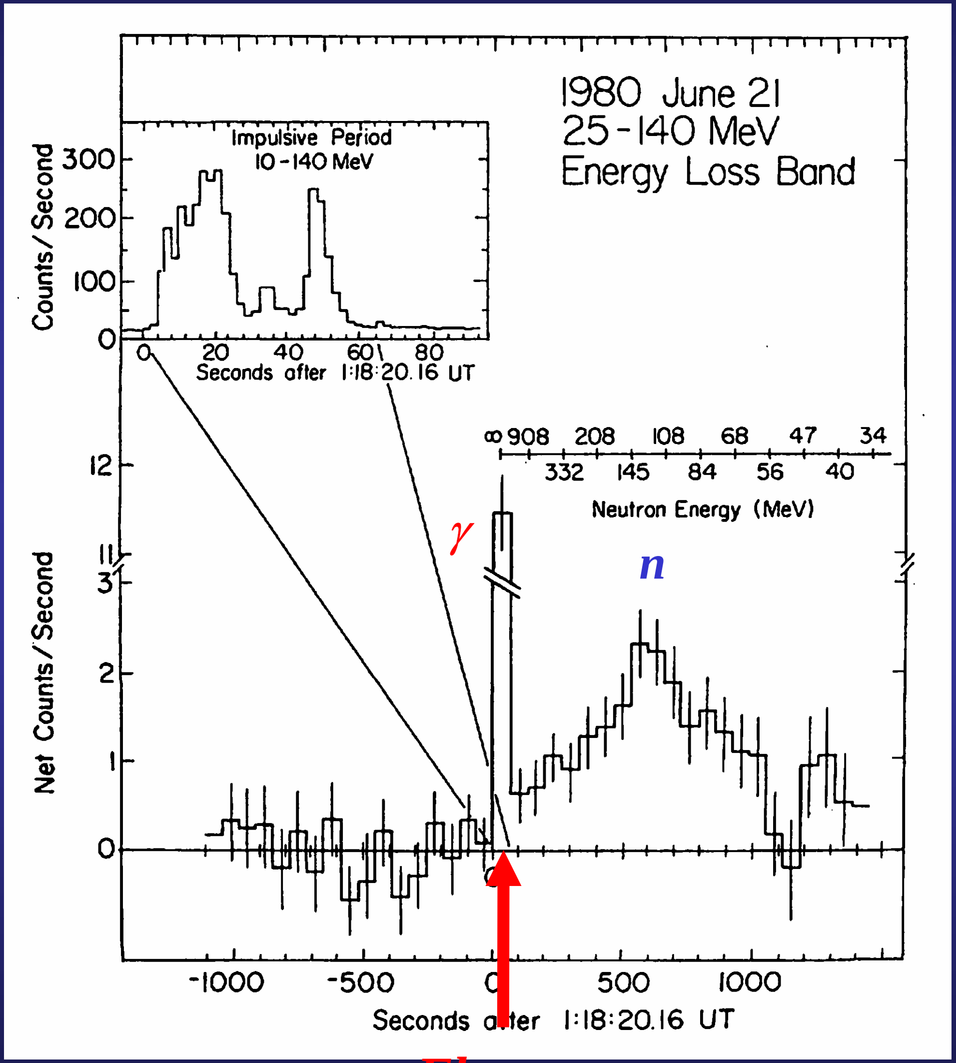
Protons and electrons are affected by the electromagnetic fields in the Sun and the Earth-Sun region

Neutrons are NOT

They preserve information of the acceleration site



Neutrons produced by energetic protons reach spacecrafts Near Earth



Flare start

Solar Maximum Mission Observations
25 – 140 MeV
21 june 1980
(Chupp et al, 1982)

This first observed solar neutron event may be explained by an impulsive production model with

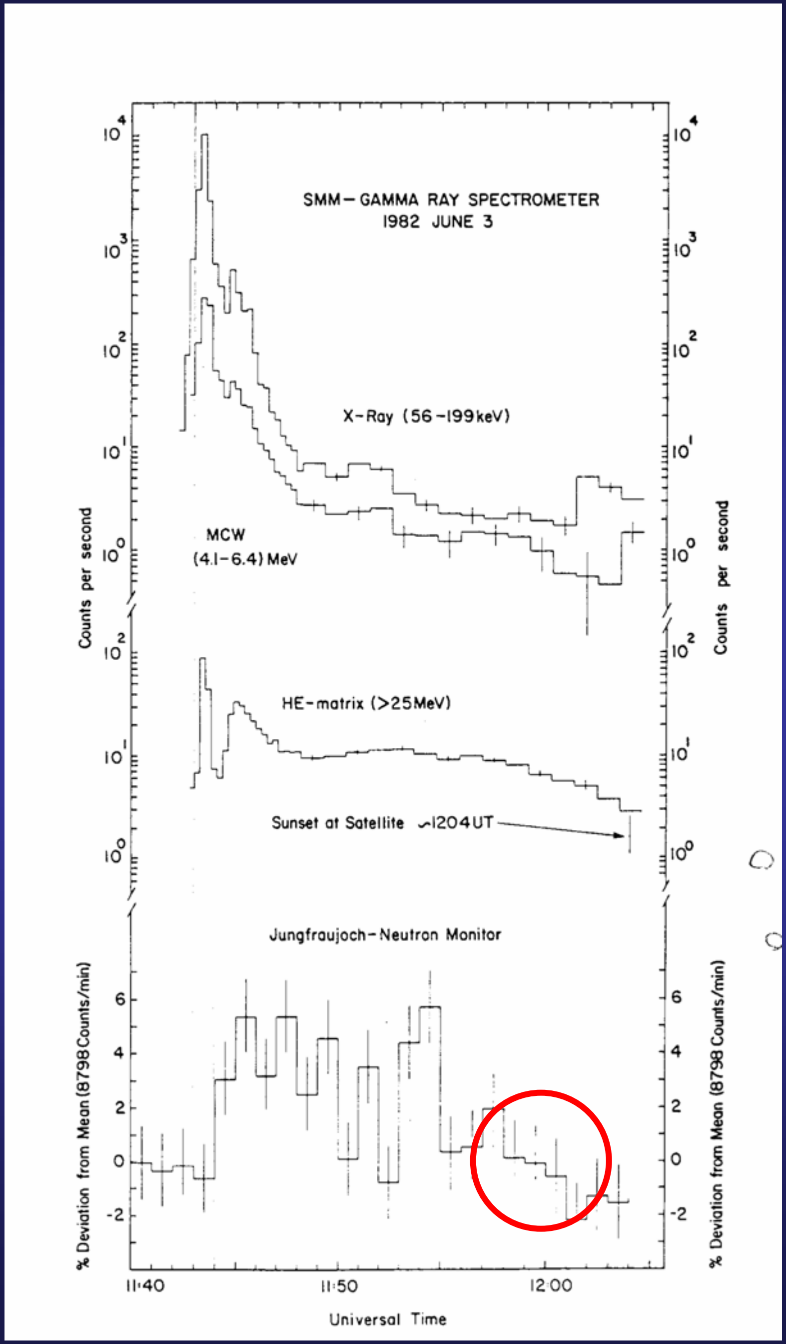
γ=-3.5±0.1 (diff.)

June 3, 1982 event

Jungfraujoch neutron monitor
+
SMM mission data

Neutons fast arrival
may be explained by impulsive production with
γ=-4.0±0.2 (diff.)

but there must be another process to explain the late arrival.



24 may 1990 event

Increase is observed in the American Sector stations.

The intensity of the event is proportional to the atmospheric depth NOT to the cut-off rigidity.

HIGH MOUNTAIN, EQUATORIAL SITES ARE GOOD FOR SOLAR NEUTRON OBSERVATIONS

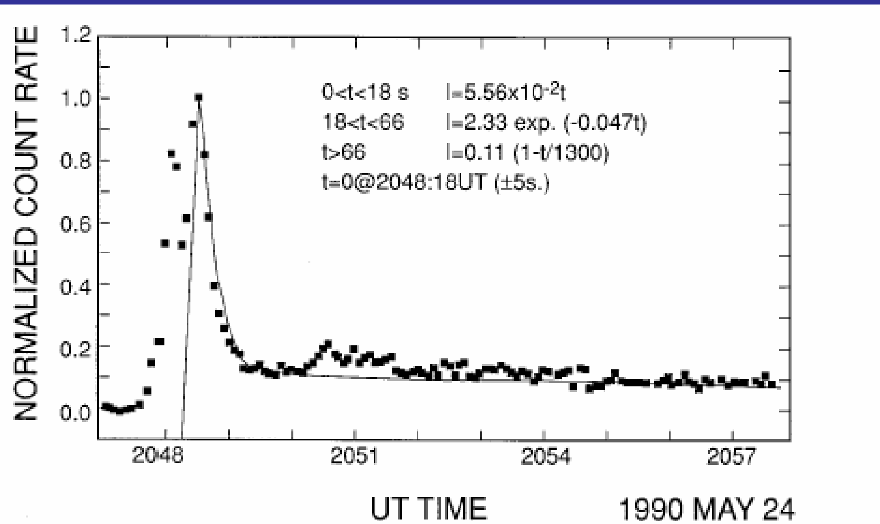
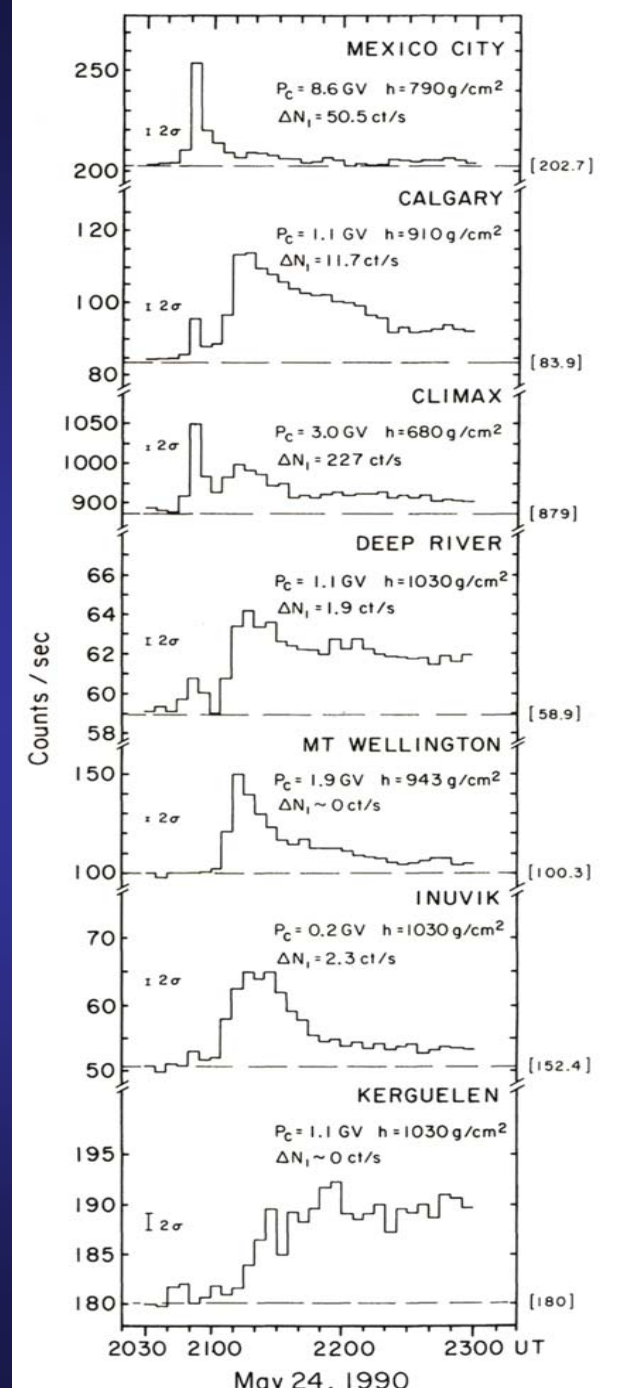
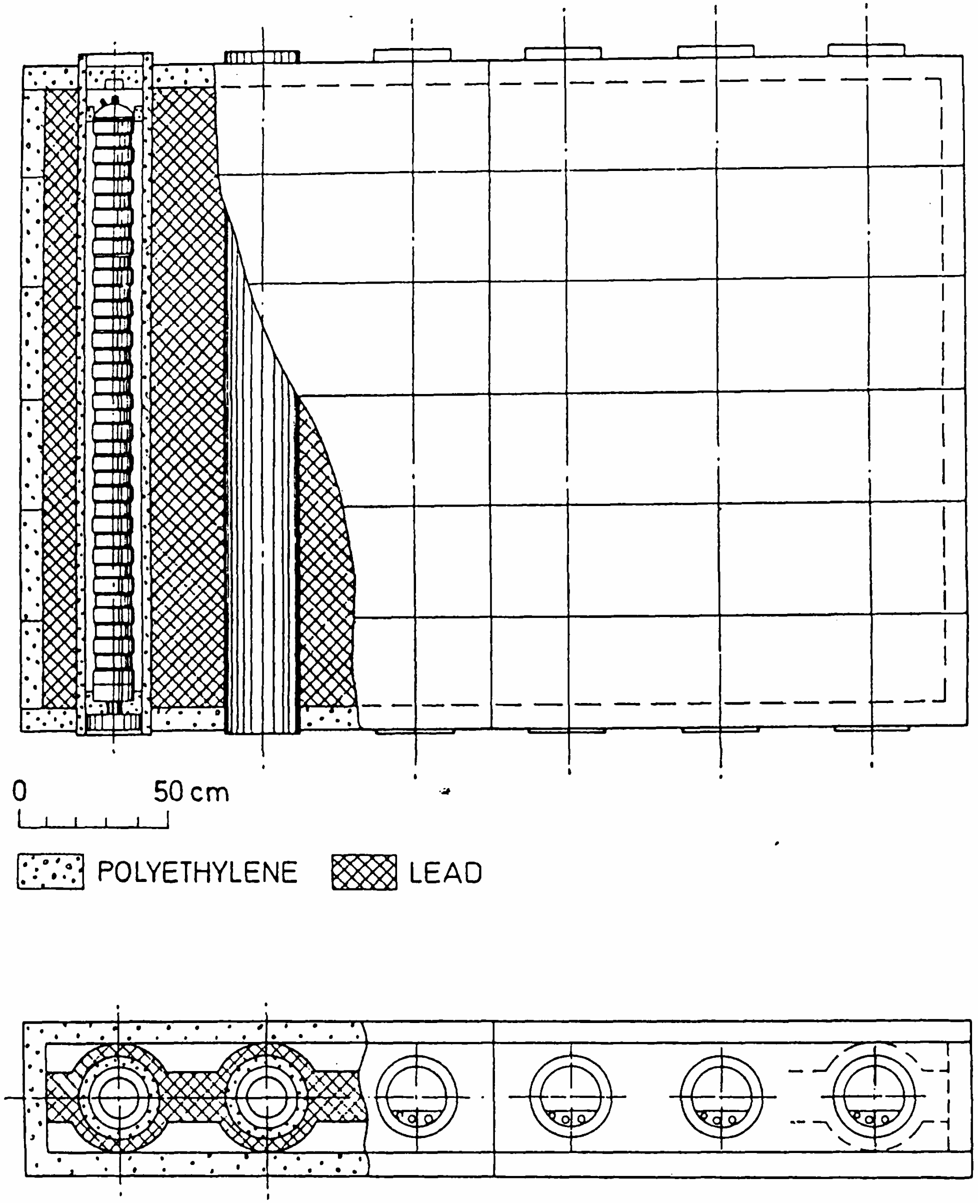


Figure 5. Normalized 60–95 MeV 5 s average count rate from 20:47 UT on May 24, 1990 and the pion production profile deduced from the data of the PHEBUS detector (heavy line) (Debrunner et al., 1997).



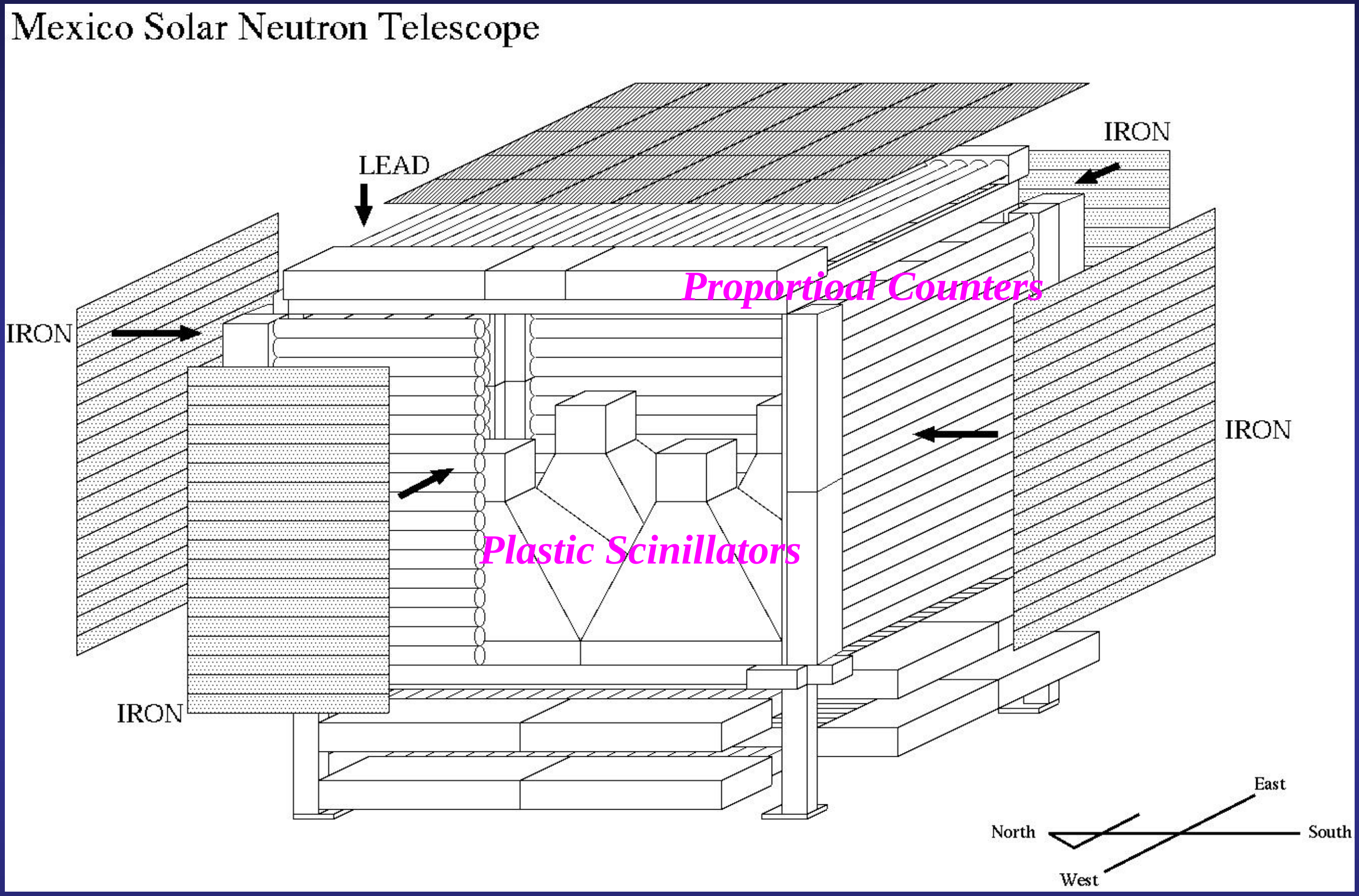
NEUTRON MONITOR

- *High sensitivity*
- *No energy resolution*
- *Omnidirectional*
- *No p, n discrimination*



A 6-NM64 monitor (CARMICHAEL [1964]).

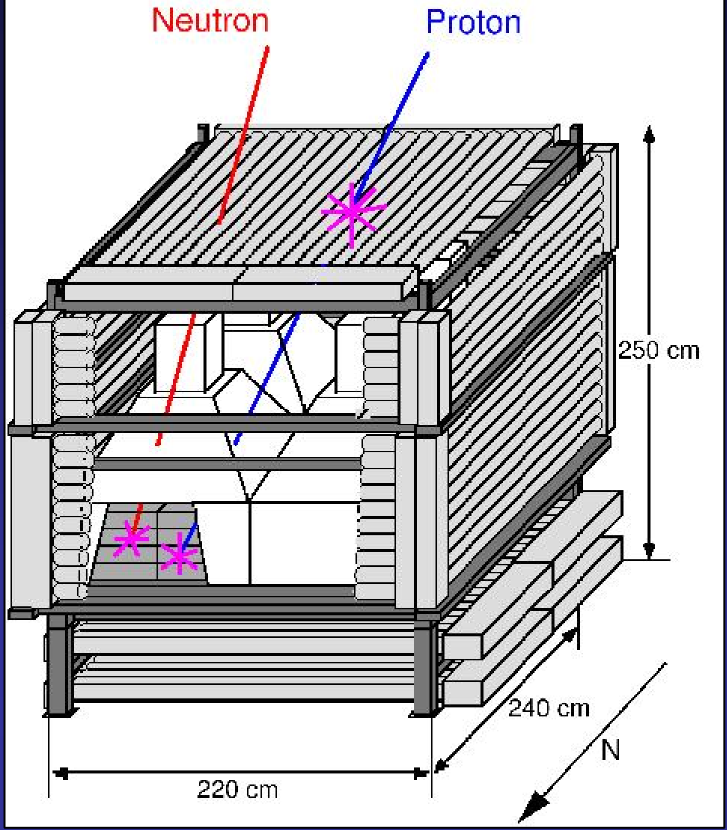
SOLAR NEUTRON TELESCOPE

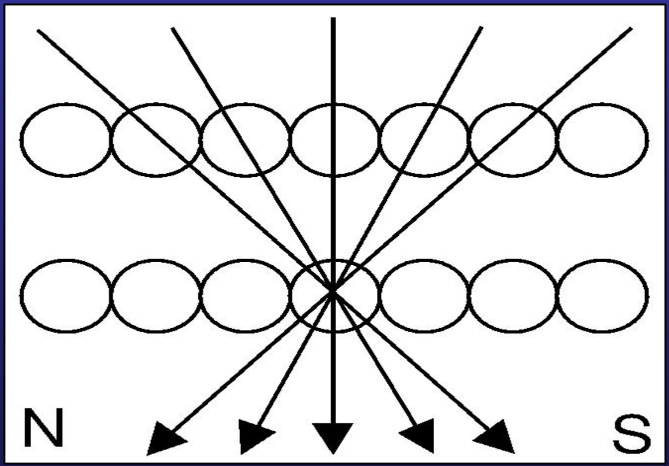


- *p, n discrimination*
- *Energy measurement*
- *Arrival direction determination*

•Proportional Counters work as proton veto

•Energy is resolved by pulse height discriminator (40cm of plastic scintillator).





•Arrival direction is obtained by the four inferior gondolas:

2 resolve N-S
2 resolve E-W

PCs in coincidence with plastic scintillators

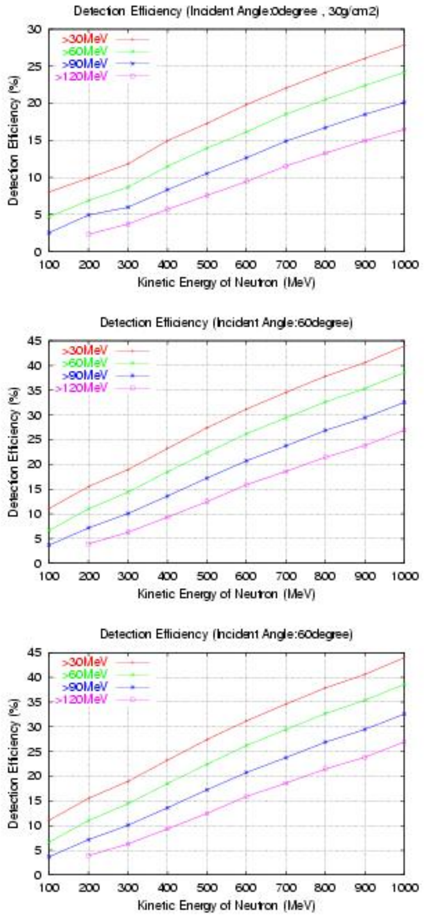
DETECTION

EFFICIENCY

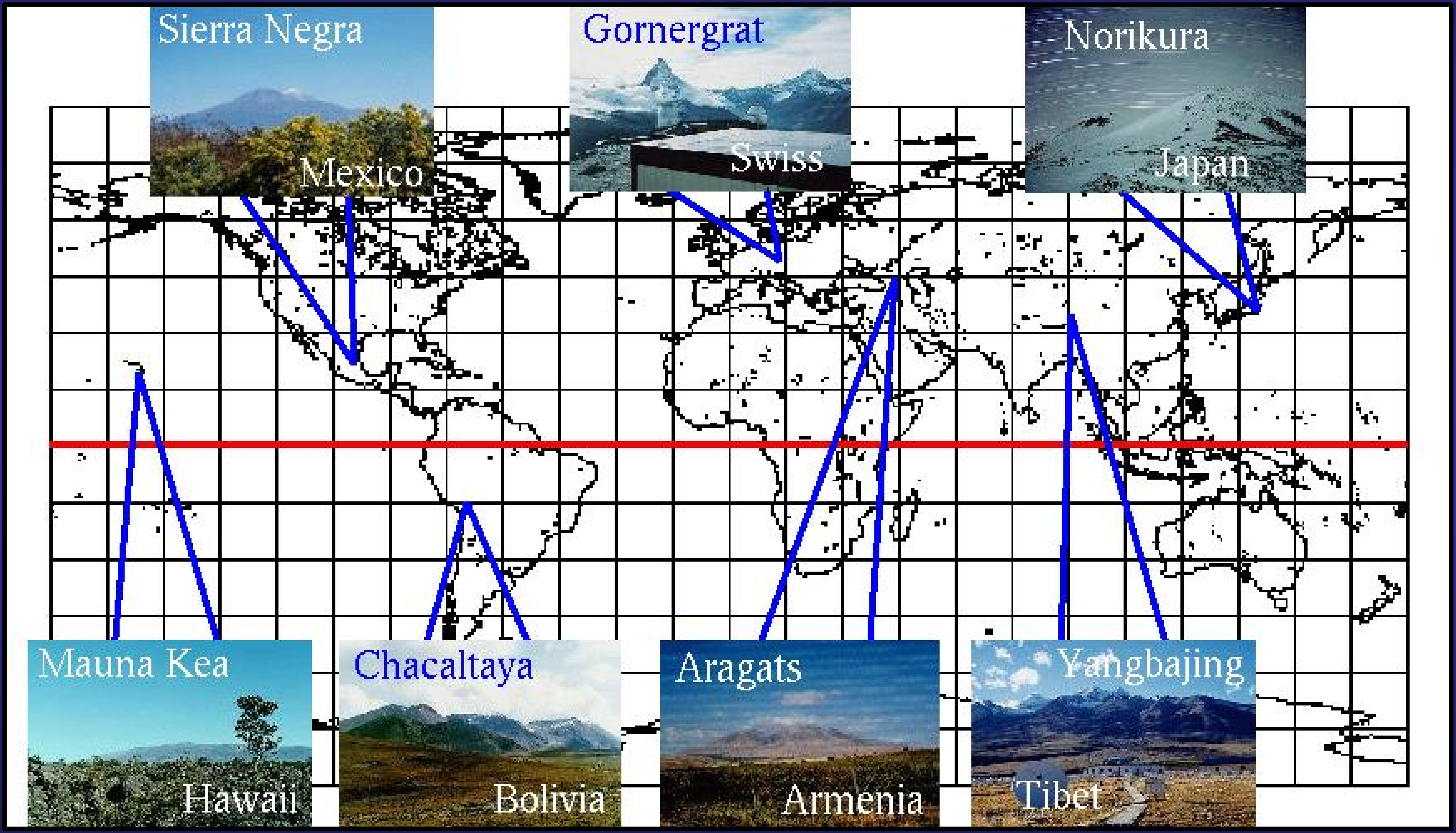
OF

PLASTIC

SCINTILLATORS

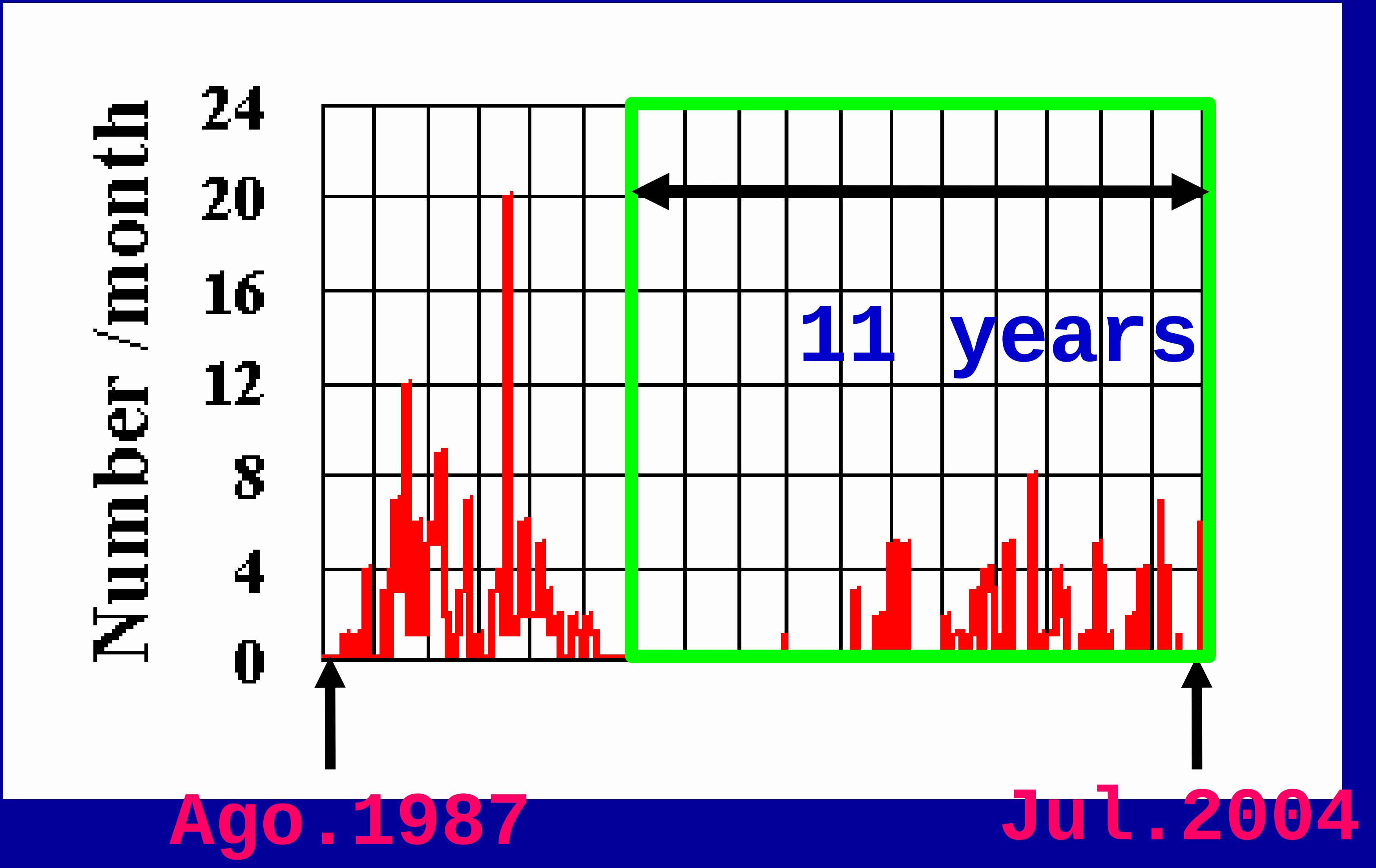


World Wide Network of Solar Neutron Telescopes



Site	Height (g/cm^2)	Longitude	Latitude	Area (m^2)	Counts without Anti (m^2 /min)	Counts with (m^2 /min)
Gronergrat Suiza	700	7.8° E	46.0° N	4	33,000	12,000
Aragats Armenia	700	40.5° E	44.2° N	4	23,000	15,000
Yanbajing Tibet	600	90.5° E	30.0° N	9	34,000	8,900
Mt. Norikura Japón	730	137.5° E	36.1° N	64	19,000	2,600
Mauna Kea Hawaii	610	156.3° W	19.8° N	8	25,000	12,000
Sierra Negra, México	575	97.3° W	19.0° N	4	47,000	20,000
Chacaltaya Bolivia	540	68° W	16.2° S	4	56,000	26,000

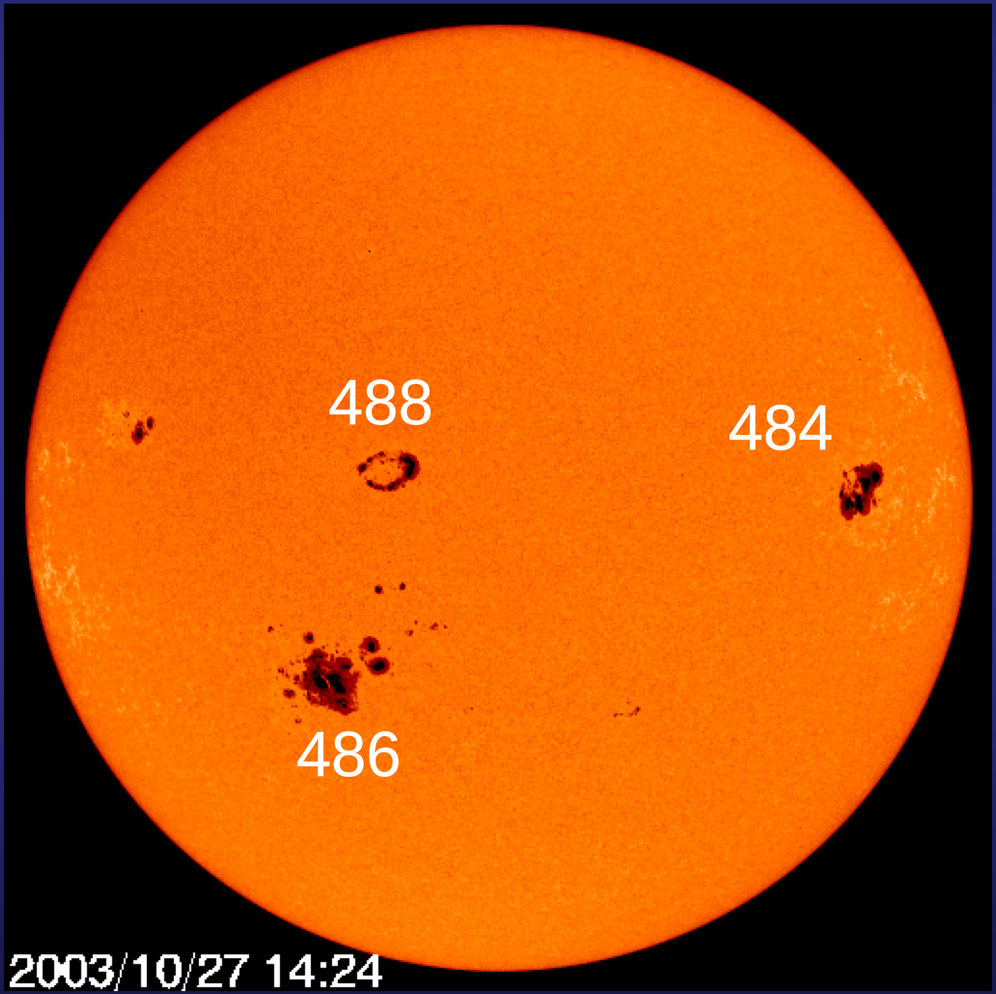
X-Ray Solar Flare Frequency



Solar Activity
20 october – 5 november 2003

Solar Flares
2003/10/19 - 2003/11/05

Class X : 11
Class M : 46



SOHO

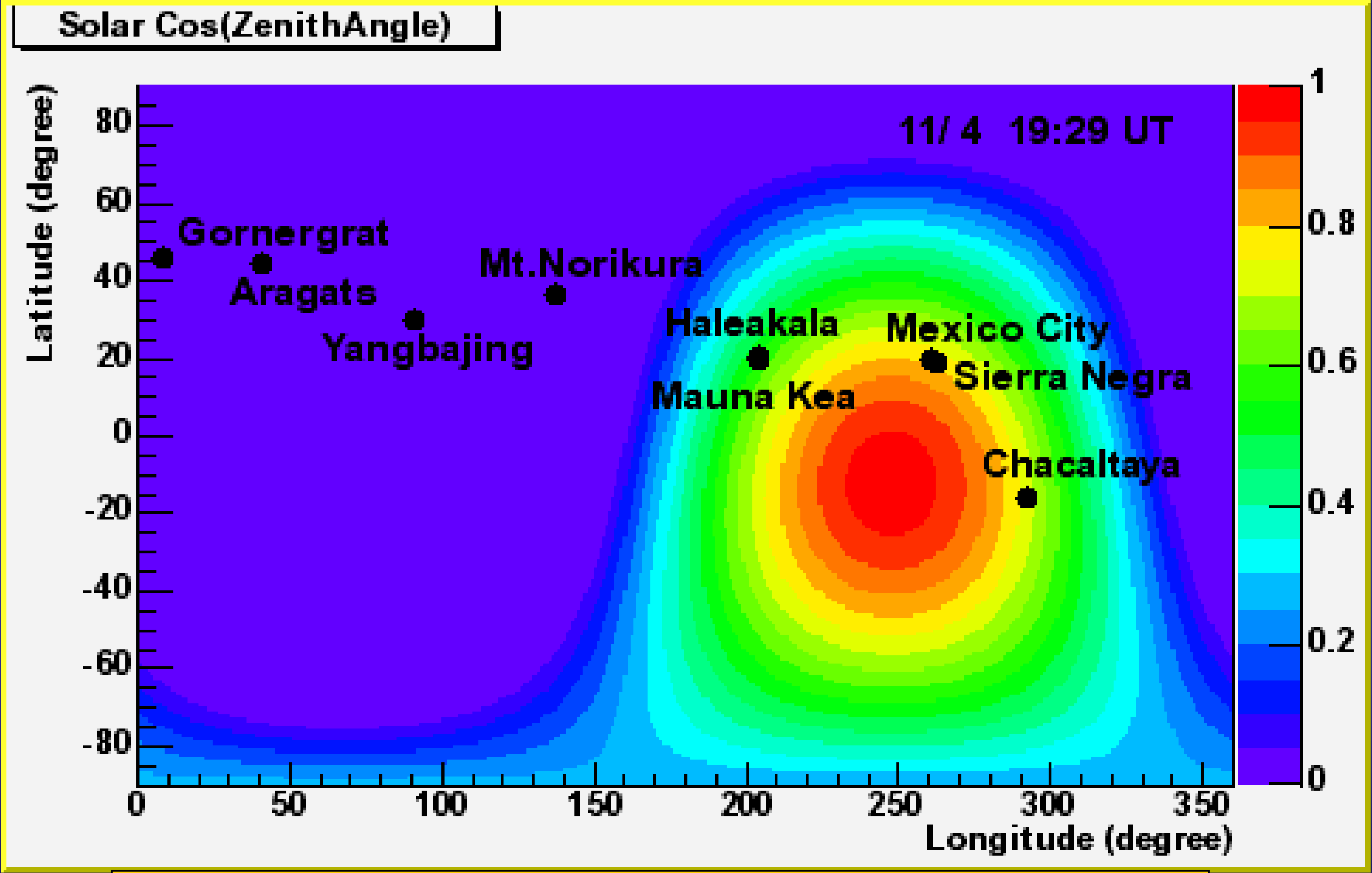
Aurora at Innsbruck, Austria

October-Noviembre, 2003

Date	Start	MAX	Class	Coord
031019	1629	1650	X 1.1	N08E58
031023	0819	0835	X 5.4	S21E88
031023	1950	2004	X 1.1	S17E84
031026	0557	0654	X 1.2	S15E44
031026	1721	1819	X 2.1	N02W38
031028	0951	1110	X17.0	S16E08
031029	2037	2049	X10.0	S15W02
031102	1703	1725	X 8.3	S14W56
031103	0109	0130	X 2.7	N10W83
031103	0943	0955	X 3.9	N08W77
031104	1929	1950	X28.0	S19W83

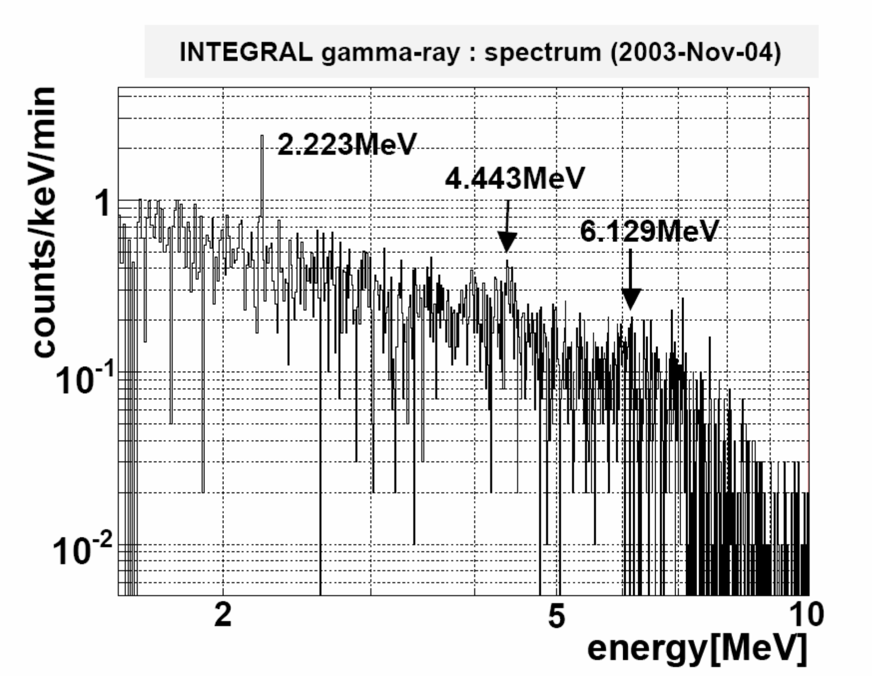
¡¡Record !!

Solar Position: 4 nov 2003, 19:30 UT



X28 Flare (record) con máximo a las 19:45

4 november 2003 (Impulsive injection)



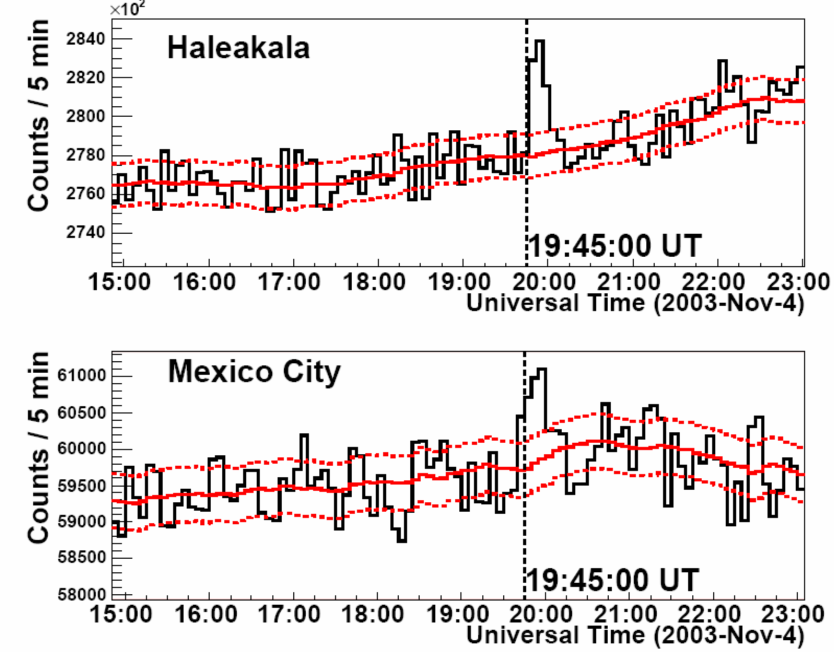
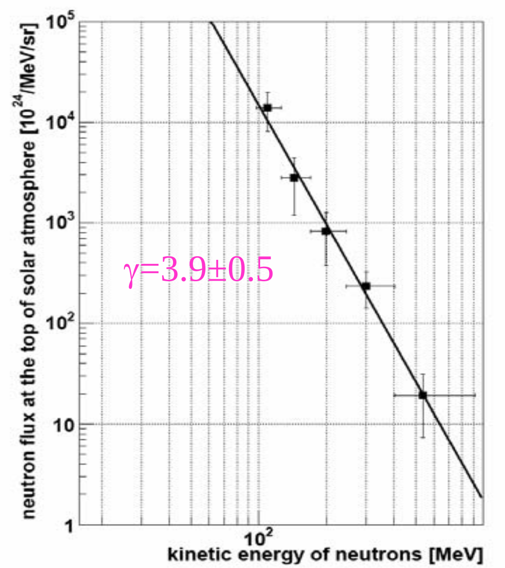


Fig. 5.— Five minute averages of the counting rate observed by the Haleakala (top) and Mexico City (bottom) neutron monitors on November 4, 2003. The solid smooth line is the averaged background and the dashed lines are $\pm 1\sigma$ from the background.

Spectrum determined by TOF



ig. 7.— The energy spectrum of neutrons at the solar surface on November 4, 2003, lculated from the data of the Haleakala neutron monitor.

Mauna Kea, Chacaltaya & Sierra Negra No Data


Tijuana
Ensenada
UNITED STATES
Ciudad Juárez
Guaymas
Chihuahua
Topolobampo
Monterrey
Matamoros
Gulf of Mexico
CUBA
La Paz
Durango
Mazatlán
North Pacific Ocean
Tampico
Progreso
Mérida
León
Tuxpan
Guadalajara
LMT
Caribbean Sea
MEXICO
Veracruz
Puebla
Manzanillo
BELIZE
Lázaro Cárdenas
Oaxaca
0 200 400 km
0 200 400 mi
Acapulco
Salina Cruz
GUATEMALA
HONDURAS


SNT


Hugo Delgado Granados

March 2003

November 2004

September 7 2005 X-Ray (17) flare

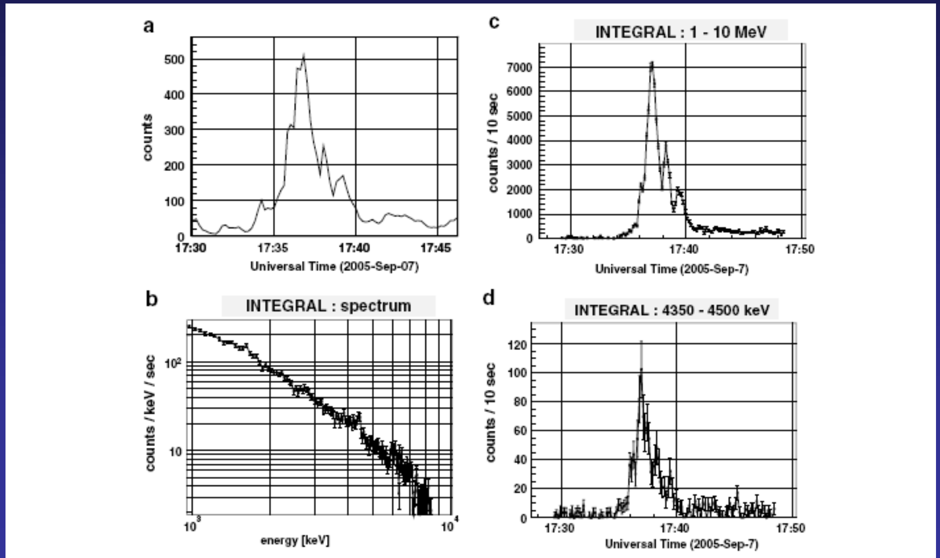
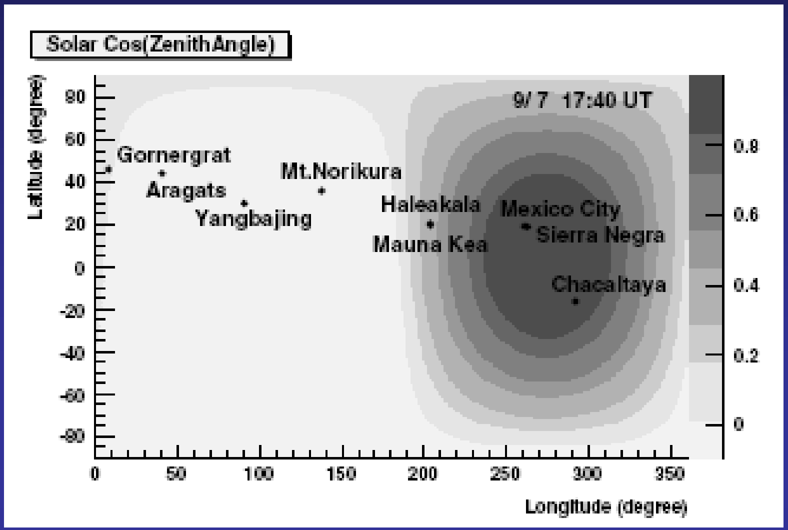
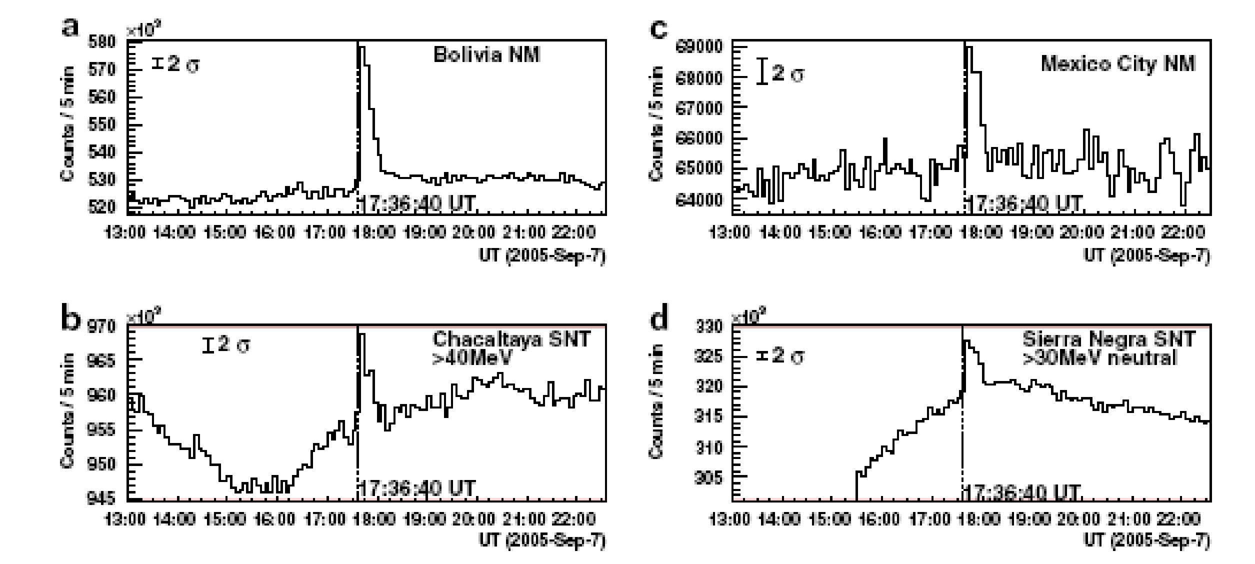
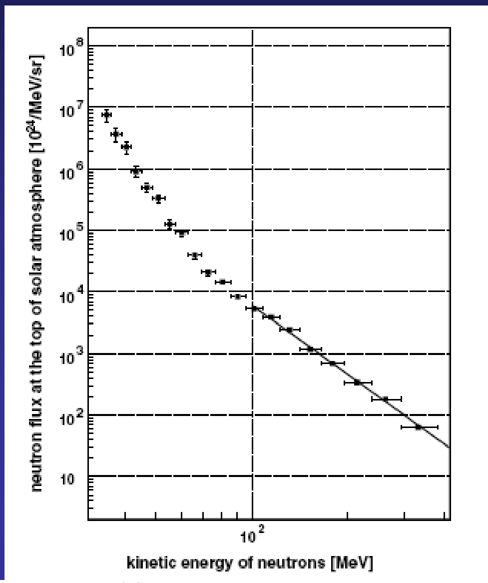


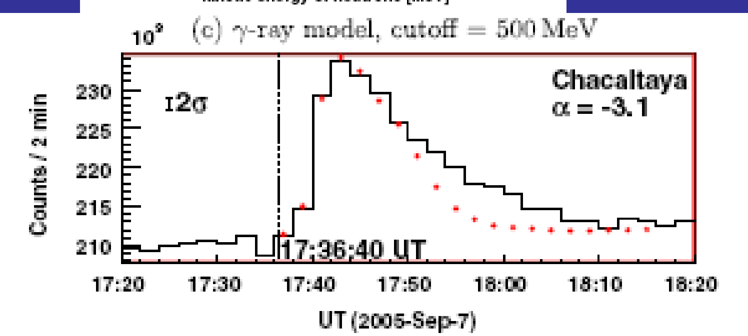
Fig. 1. (a) The time profile of hard X-rays (>50 keV) observed by the *GEOTAIL* satellite. (b) The energy spectrum of γ-rays observed by the *INTEGRAL* satellite. The γ-ray time profiles for the energy range between 1 and 10 MeV (c), and around 4.4 MeV (d) observed by the *INTEGRAL* satellite on 2005 September 7.



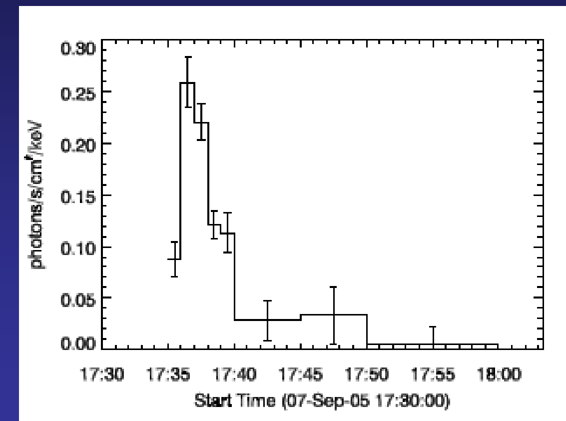


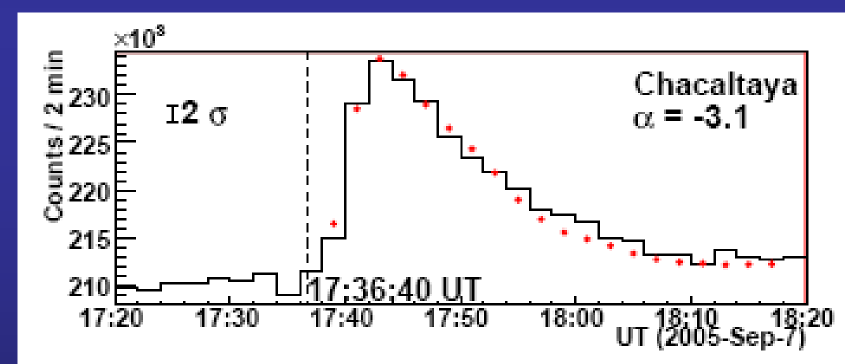
Impulsive injection



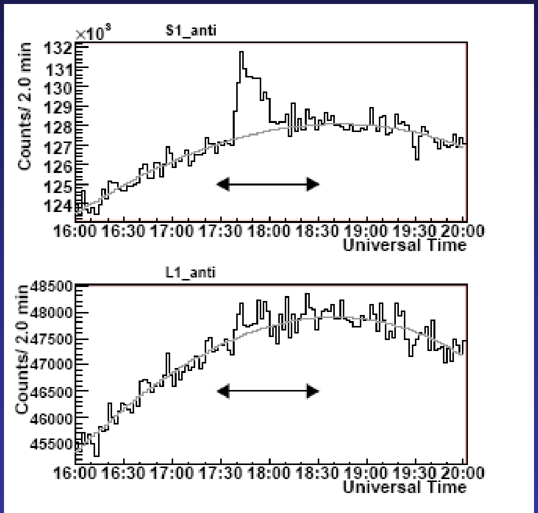


4.4 MeV time profile injection

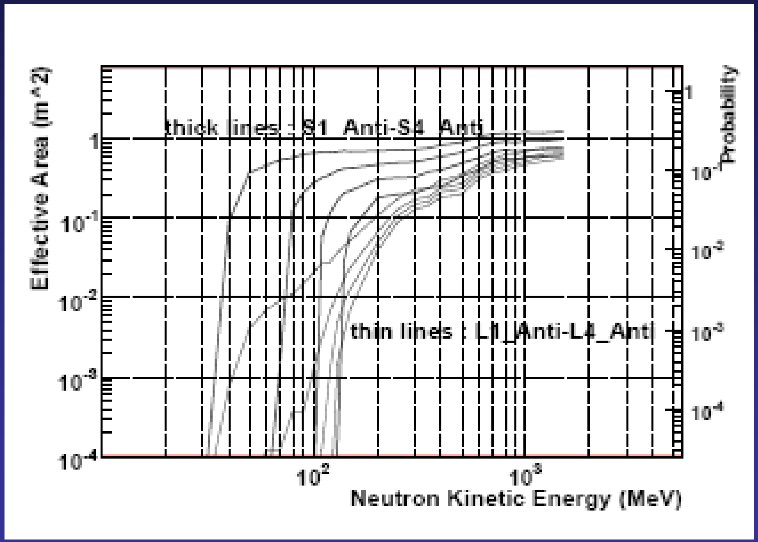




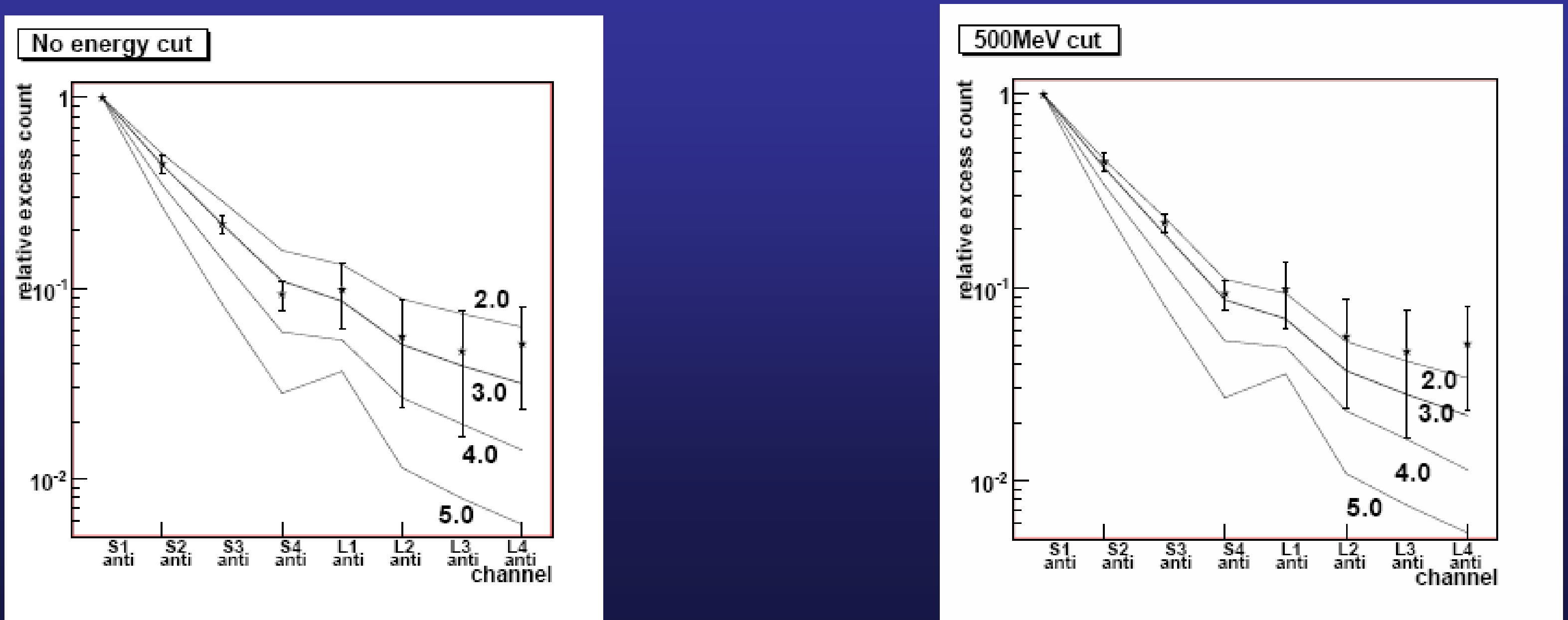
Sierra Negra count rates



Response Functions



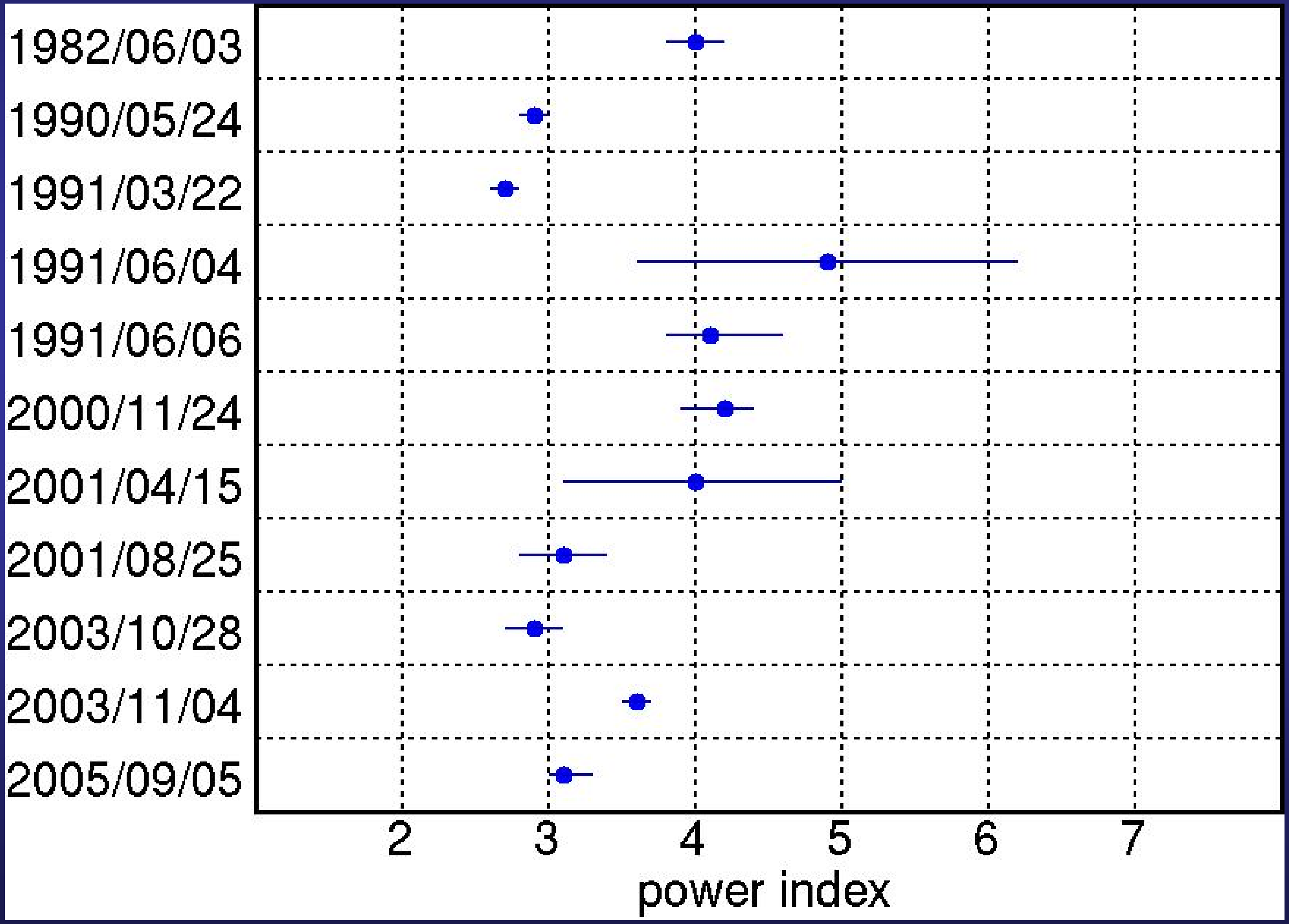
Expected counts on SNT based on different injection sspectra



Differential power index of solar neutrons

neutron monitors only (En≈100-500MeV)

by K. Watanabe



Summary and Conclusions

- *Solar neutron observation is a crucial tool to understand Solar acceleration mechanisms.*
- *Solar neutrons carry unmodulated information from the solar source.*
- *We need more simultaneous observations of SXT and γ together with ground located neutron detectors.*
- *Most solar neutron events may be fitted with an impulsive injection model*
- *The event on september 7, 2005 (and others) are evidence of extended injection.*
- *Further analysis is needed to determine the injection profile and energy spectrum for extended injection.*