Gamma Rays under Radiation Belts: CORONAS-F Observations of the January 21, 2005 Event

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The intense solar eruptive events in January 2005 led to the geomagnetic storm on January 21st, when hard X/gamma-ray enhancements outside the stable trapping in wide L shell range were observed. These gamma rays are likely bremsstrahlung photons from relativistic electrons precipitating into the Earth's atmosphere. Observations are based on SOlar Neutrons and Gamma rays (SONG) experiment aboard low altitude (~380 km in January 2005) polar orbiting CORONAS-F satellite providing 1-s measurements in the energy bins between 30 keV and 200 MeV. By continuously remote sensing these gamma rays over a wide area from limb to limb beneath CORONAS-F, SONG provides a global monitor of atmospheric energy input. These observations can be complementary to the January 2005 MINIS balloon campaign measuring MeV precipitation during the same event [E. A. Bering et al., URSI GA2005, New Delhi, India].

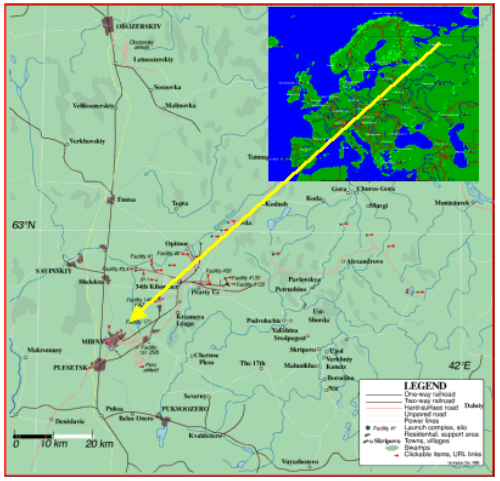
- The precipitation (losses) of electrons from the Earth's radiation belts

- Remotely (indirectly) by observing of bremsstrahlung X/gamma radiation from atmosphere

Outline

- CORONAS-F experiment
- Radiation belts in 2002
- Space weather in January 2005 (GOES protons, X rays)
- Response to solar flare X/gamma-rays & protons
- Storm on 21 January 2005
- Summary

Experiment

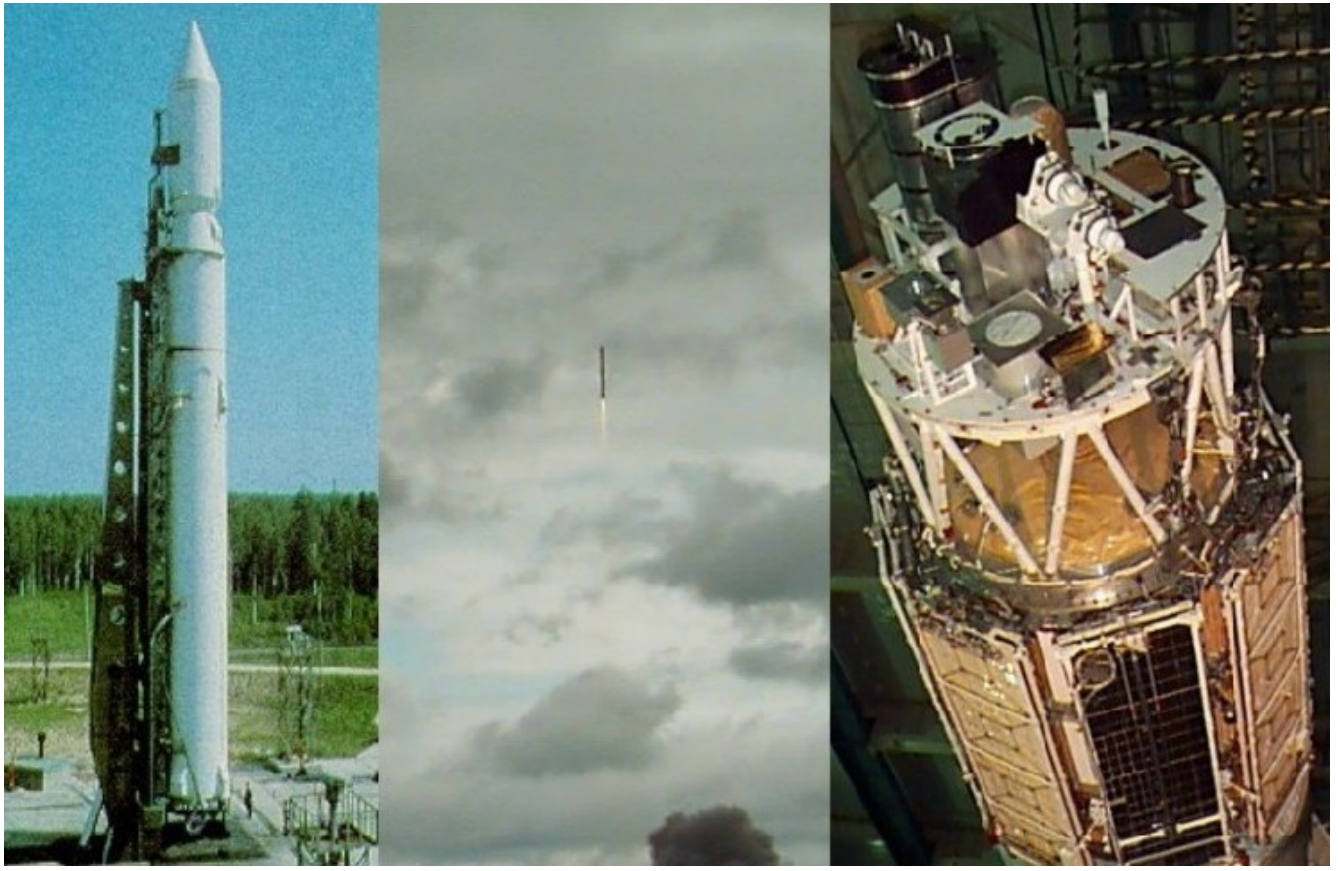


Left: The Cyclone SL-14 rocket on the launch pad at the Plesetsk Cosmodrome, northern Russia. *Centre:* Rocket after launch. *Right:* The instrument payload of CORONAS-F: the spacecraft is ~ 1.5 m in diameter and weighs ~ 2.5 tonnes.

Initial orbital parameters:

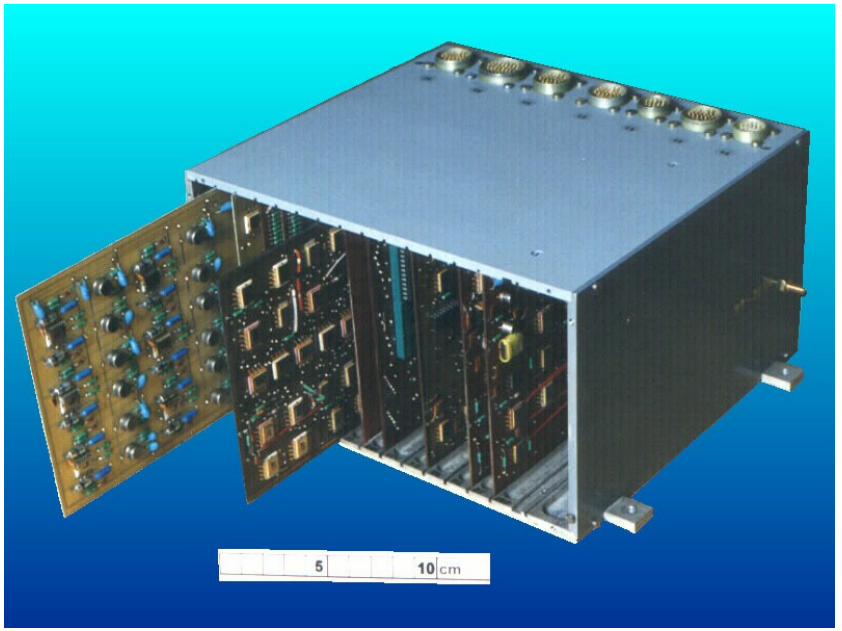
Period: 94.9 min
Apogee: 541 km
Perigee: 501 km
Inclination: 82.5˚

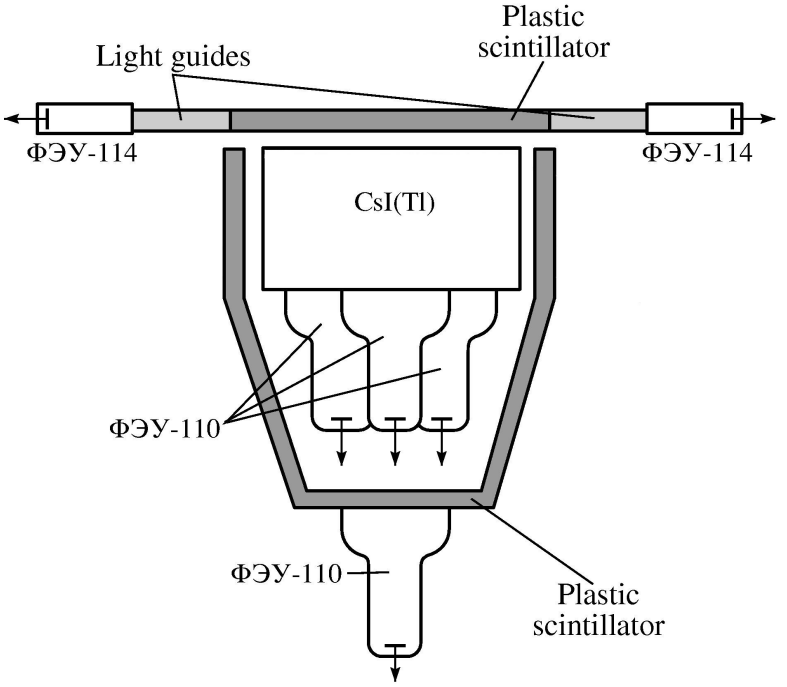
Launched: July 31, 2001



Sylwester et al., Solar Phys., 226, 2005

Experiment

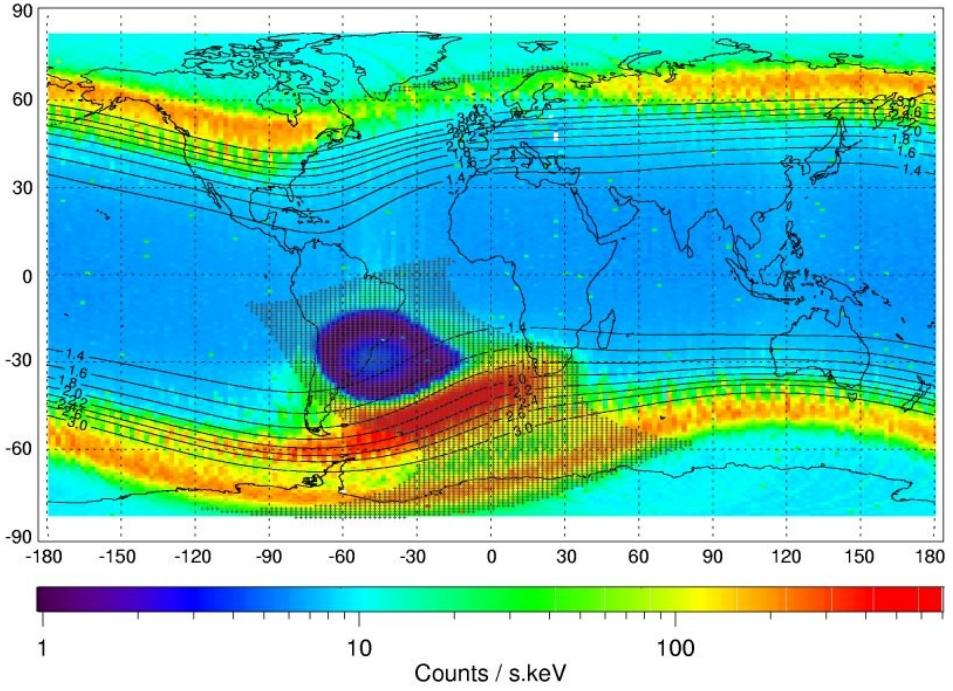


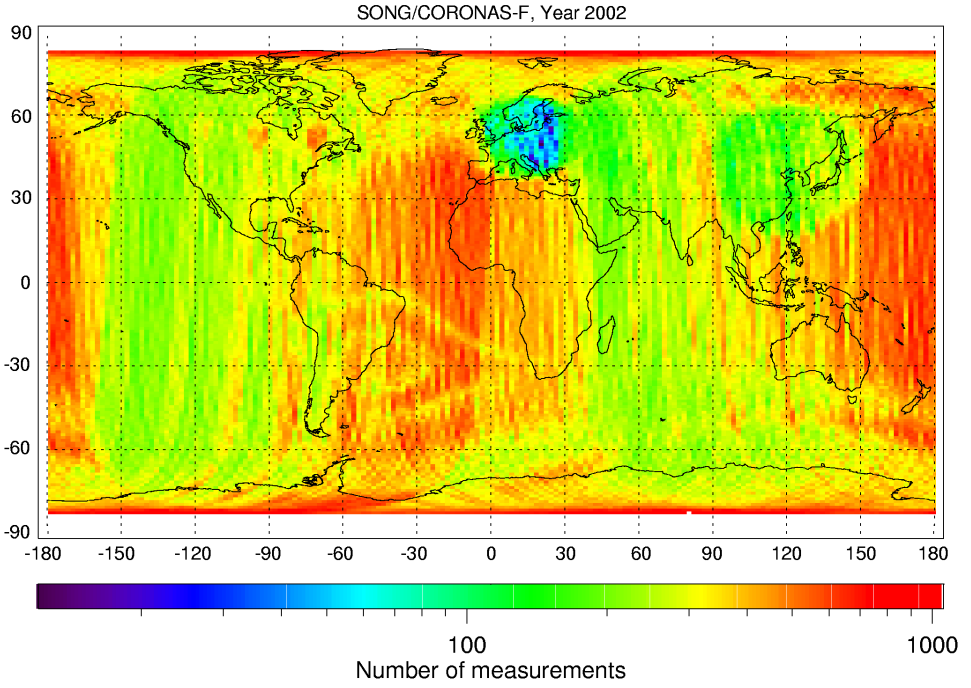


Electronic part SONG-E developed by IEP SAS, Košice, Slovakia. SONG experiment - one of the instruments of the SKL (Solar Cosmic Rays) complex (PI: S. N. Kuznetsov).

Detector part SONG-D developed at INP MSU, Moscow; SONG-D consists of CsI(Tl) crystal (20x10 cm) surrounded by 2-cm thick plastic scintillator active anti-coincidence shield. Energy range: 30keV -200 MeV in 9 energy bins. Temporal resolution: 1.(4.)-sec.

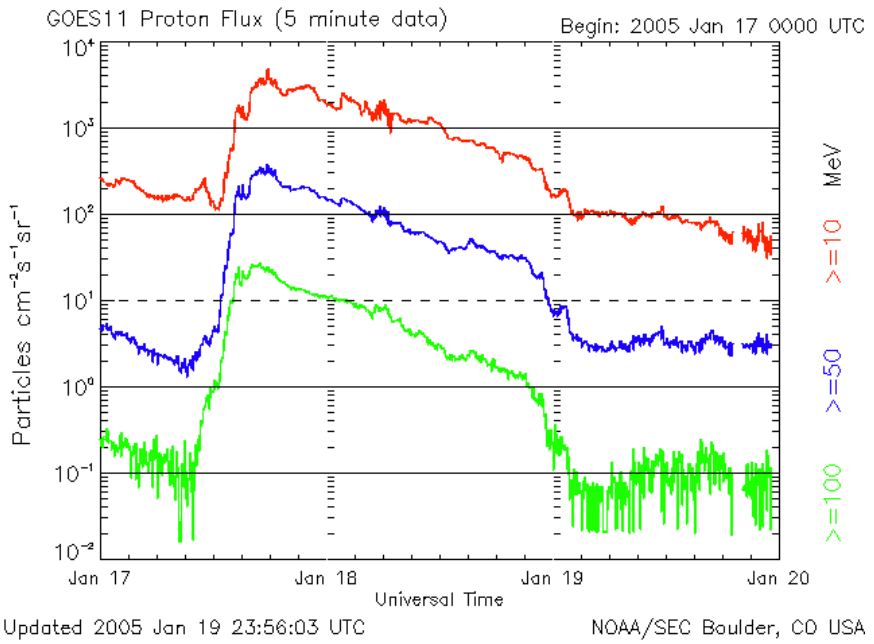
Radiation belts in 2002

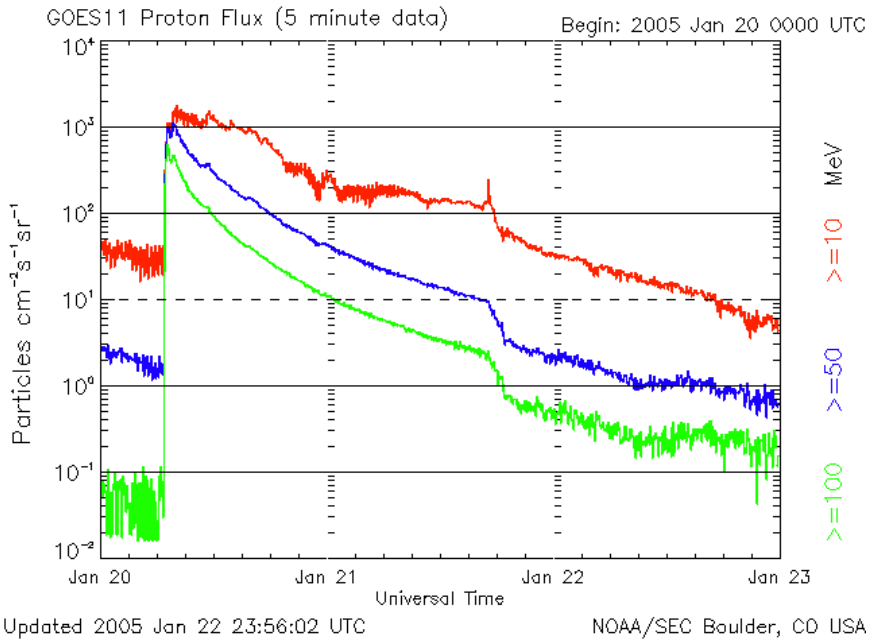




The colored geographical map of average counts for 60-150 keV X-rays measured by CORONAS-F throughout October-December, 2002 in the altitude range of 440-490 km. In the SAA the SONG instrument was saturated by high fluxes of energetic (>50 MeV) protons (purple and blue).

Geographical covering of the SONG measurements in 2002. The logarithm of number of data points per one bin with size of 2° in longitude and 1° in latitude are color coded. The regions of the highest rate of the measurements concentrate to the day-time sector.

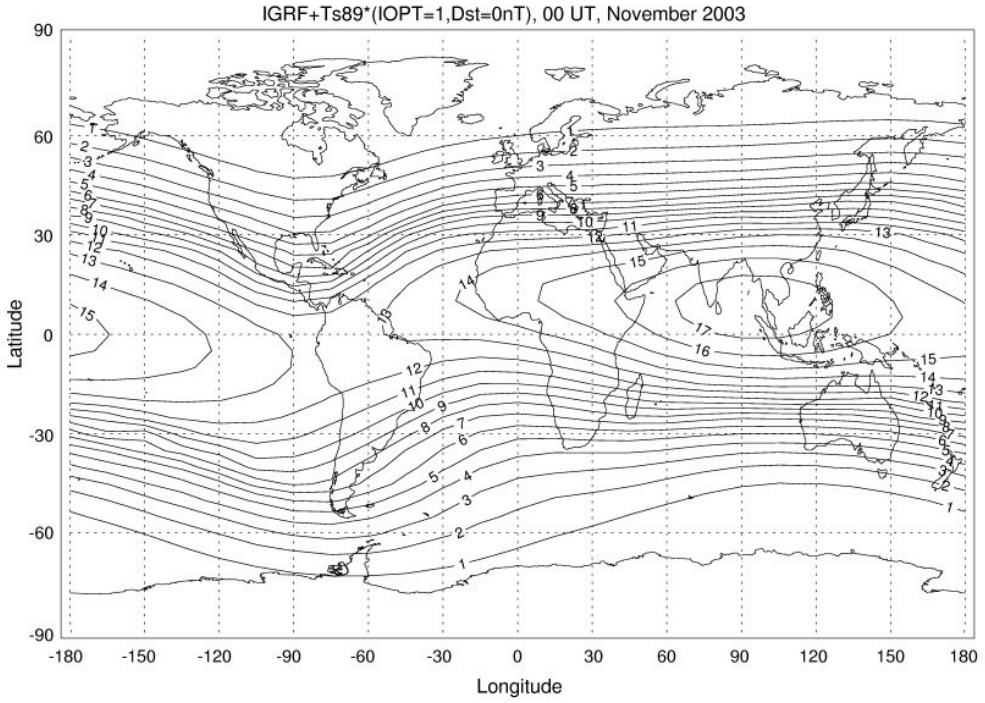


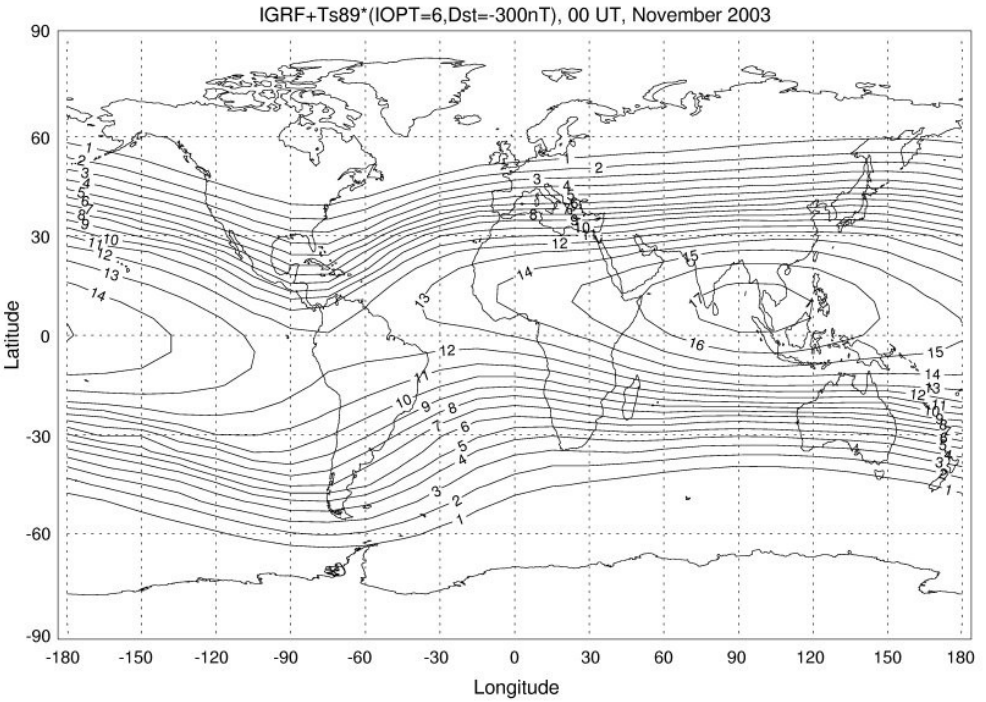


Enhanced level began at 0650 UT, 20 Jan

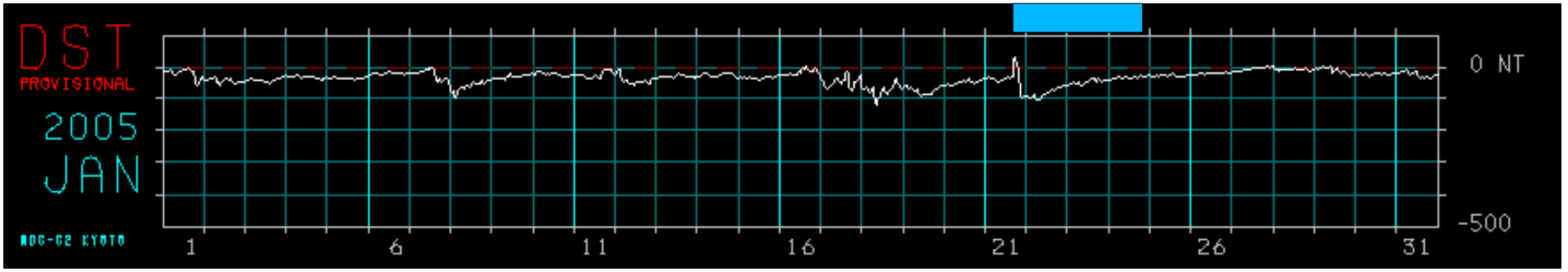
- Two separate solar proton events-different spectral slopes
- 20 Jan- The >100 MeV protons -the highest flux level since October 1989
- 20 Jan- N(>100 MeV) >100 protons /cm2.s.sr during 0650-1200 UT (long lasting event)
- 17 Jan- N(>100 MeV) >10 protons /cm2.s.sr during 1400-2400 UT

Cut-off for GOES protons



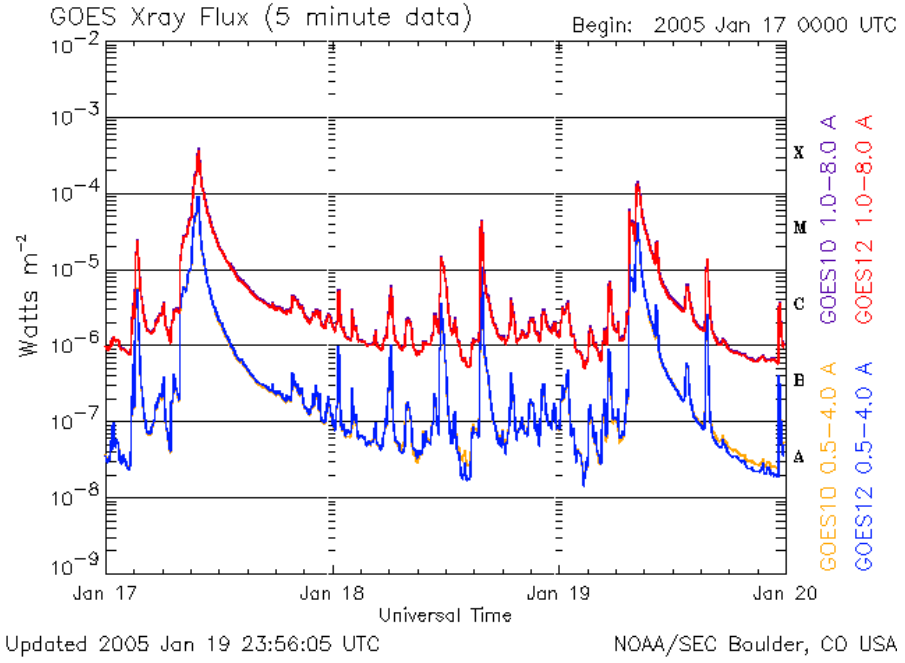


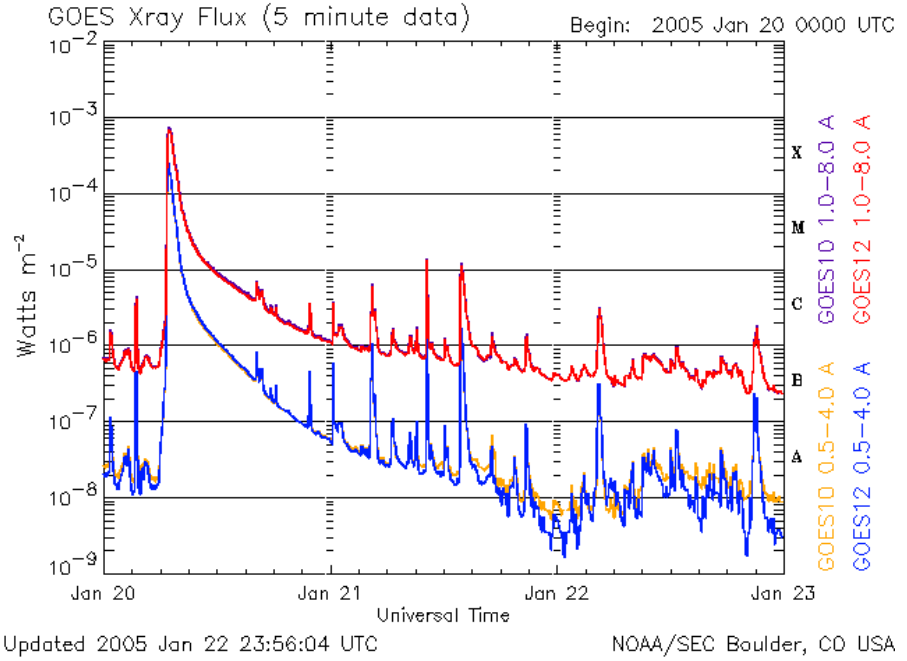
- Solar protons with energy >100 MeV (i.e. >0.45 GV) can penetrate during disturbed magnetosphere to lower latitudes at some longitudes
- They can generate nuclear gamma-rays (>100 keV) in upper atmosphere and in the instrumental matter



~1.5 -12.5 keV

~3.0-24.8 keV

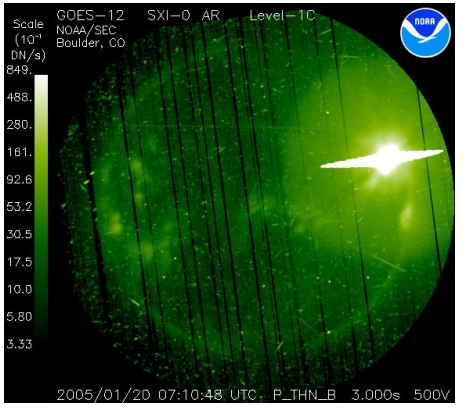




X3.8(0659 UT, 17Jan)

X1.5(0803 UT, 19Jan)

X7.1(began at 0636 UT, 20Jan)

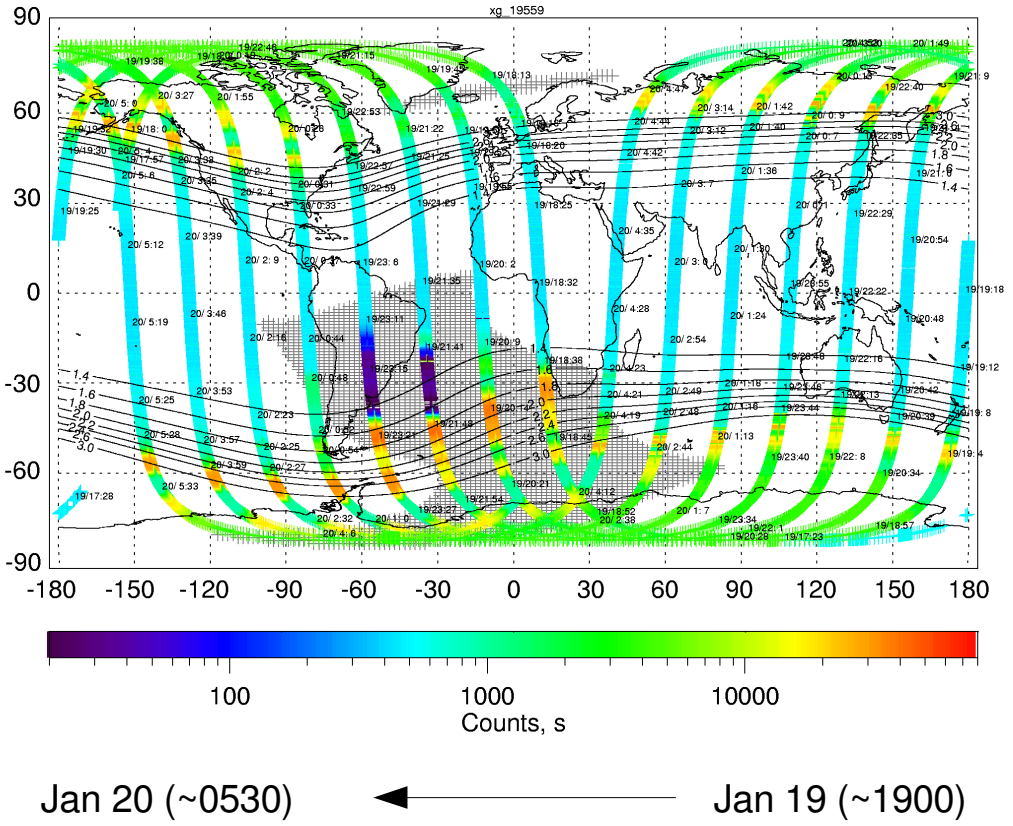


GOES-12 SXI image of the 20 January X class solar flare

Solar active region 10720

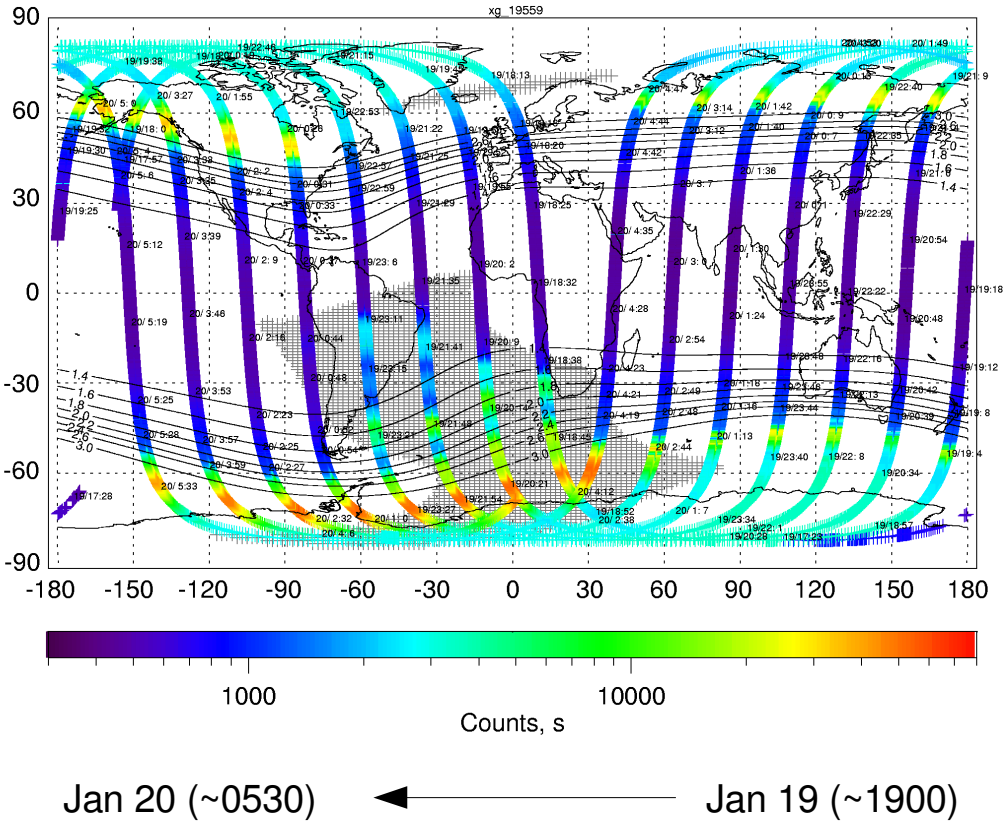
SONG response to solar X-rays & protons

60 -150 keV



Jan 20 (~0530) ← Jan 19 (~1900)

150-500 keV



Jan 20 (~0530) ← Jan 19 (~1900)

The X-ray counts during the several CORONAS-F orbits before the solar flare on 20 January 2005 measured by SONG (to see the background at low latitudes)

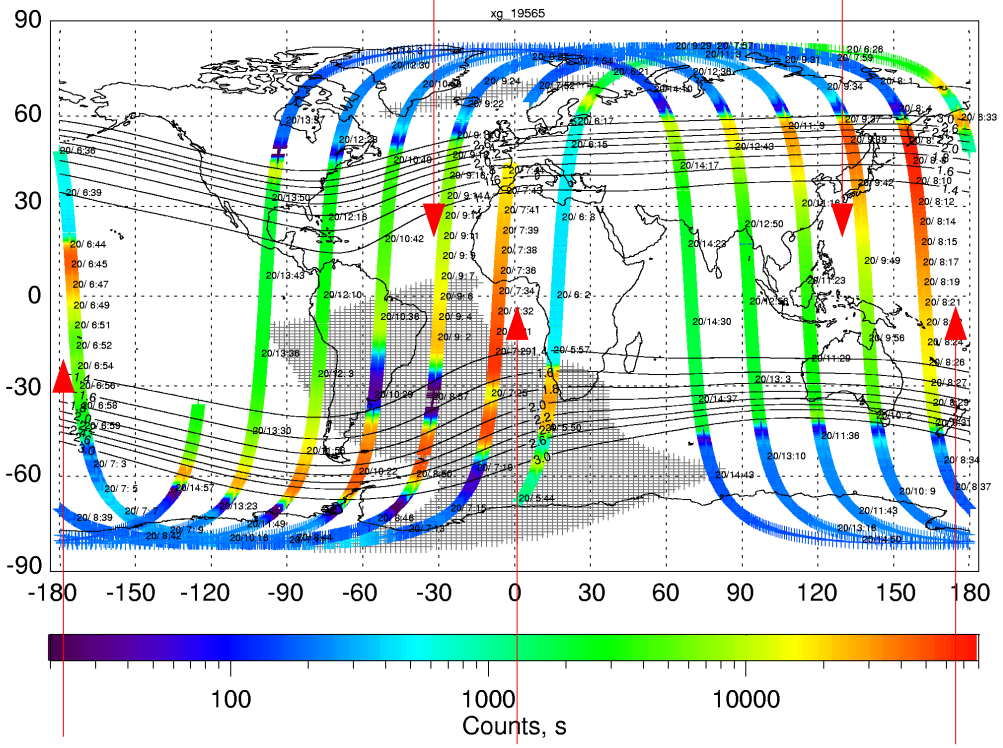
SONG response to solar X-rays & protons

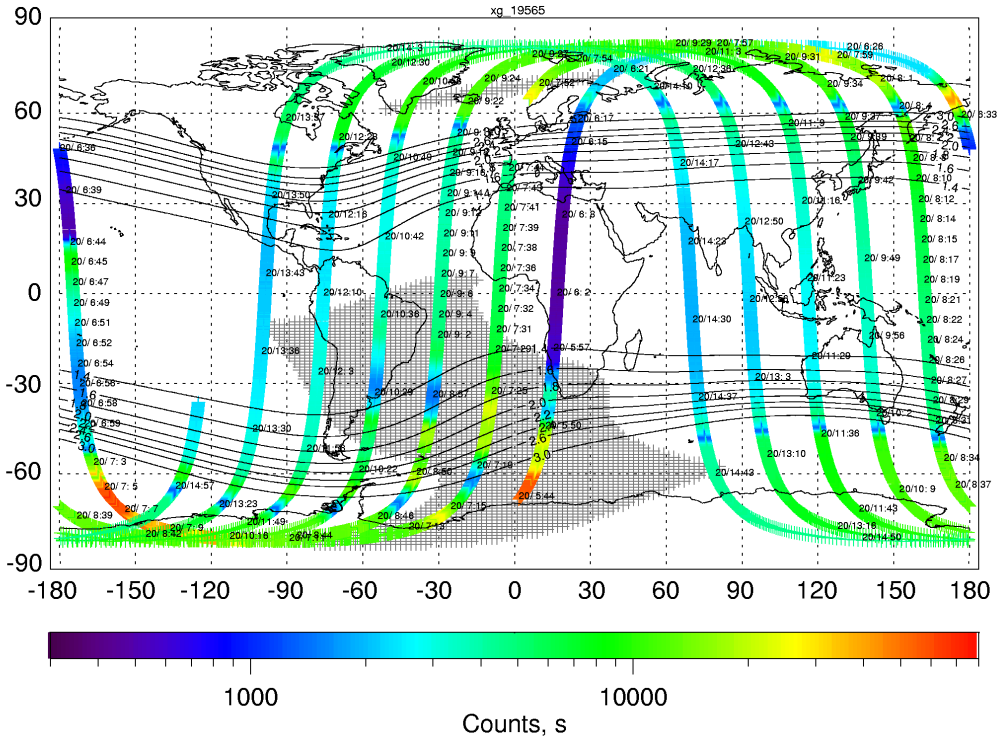
60 -150 keV

0910-0920 UT
0720-0750 LT

0940-1000 UT
1830-1930 LT

150-500 keV





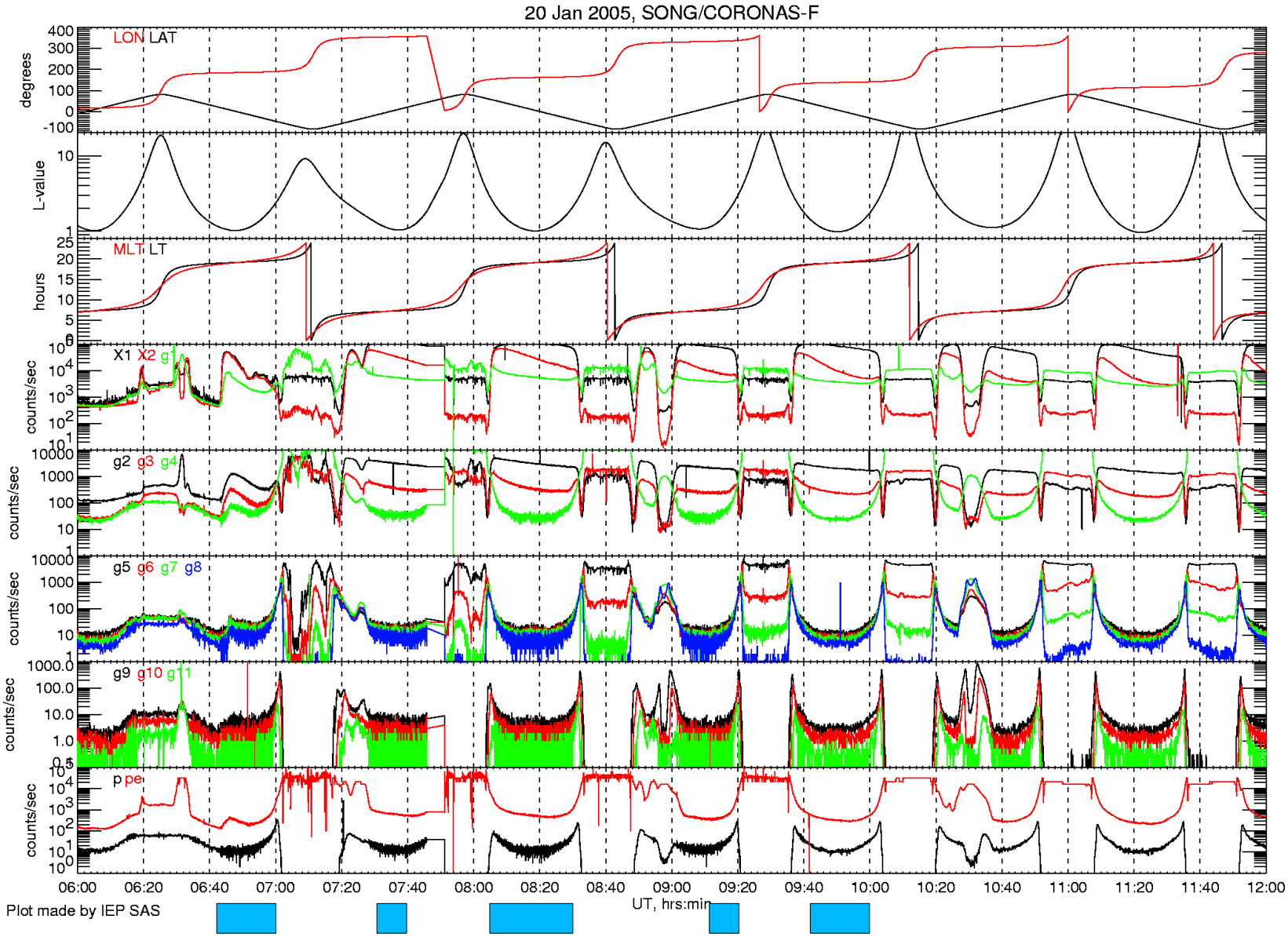
0644-0700 UT
1900-1940 LT
before SEP

0730-0740 UT
0700-0720 LT

0805-0830 UT
1820-1930 LT

CORONAS-F was on 20 January 2005 in dawn-dusk LT sector, not in the Earth shadow and capable to observe solar flare X rays by SONG

SONG response to solar X-rays & protons



30-500 keV

0.5-7 MeV

7-60 MeV

60 -200MeV

>200 MeV

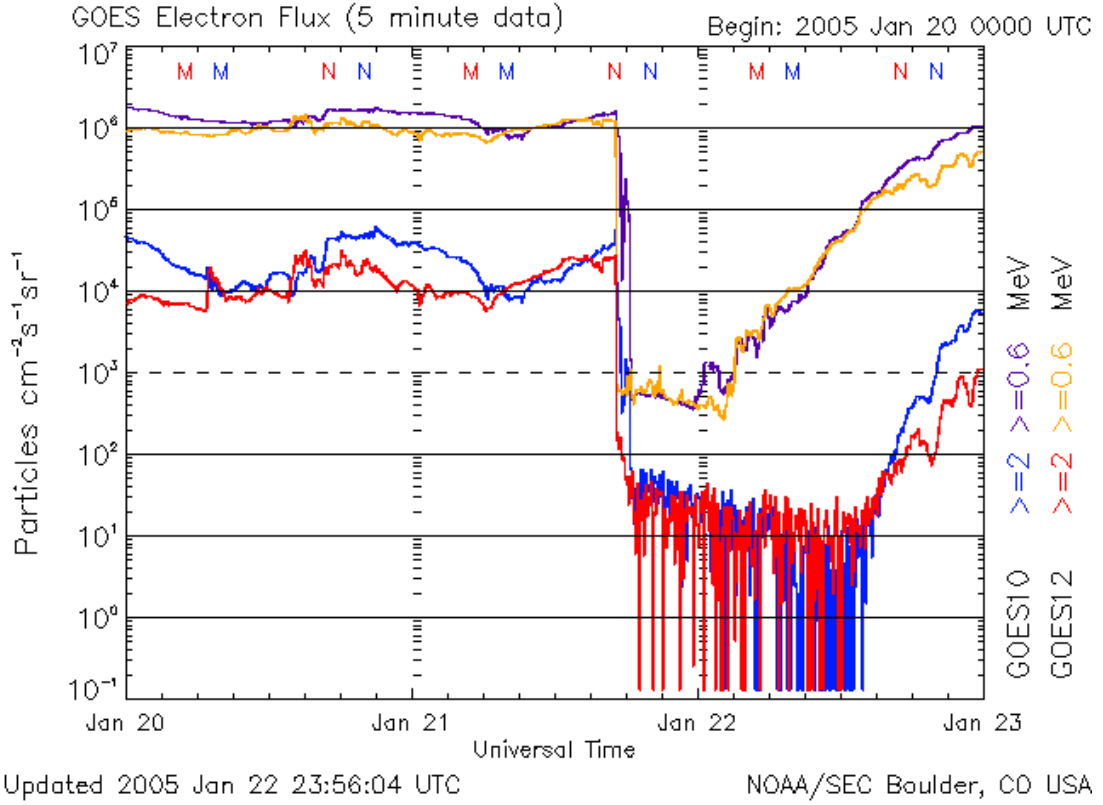
200-300 MeV

>70 MeV

Solar X

Due to solar protons ?

Relativistic electron drop-out starting at ~1710-1720 UT, January 21 2005
Satellites in dayside: GOES-12 (~1500MLT) & GOES-10 (~1100MLT), L~6.6



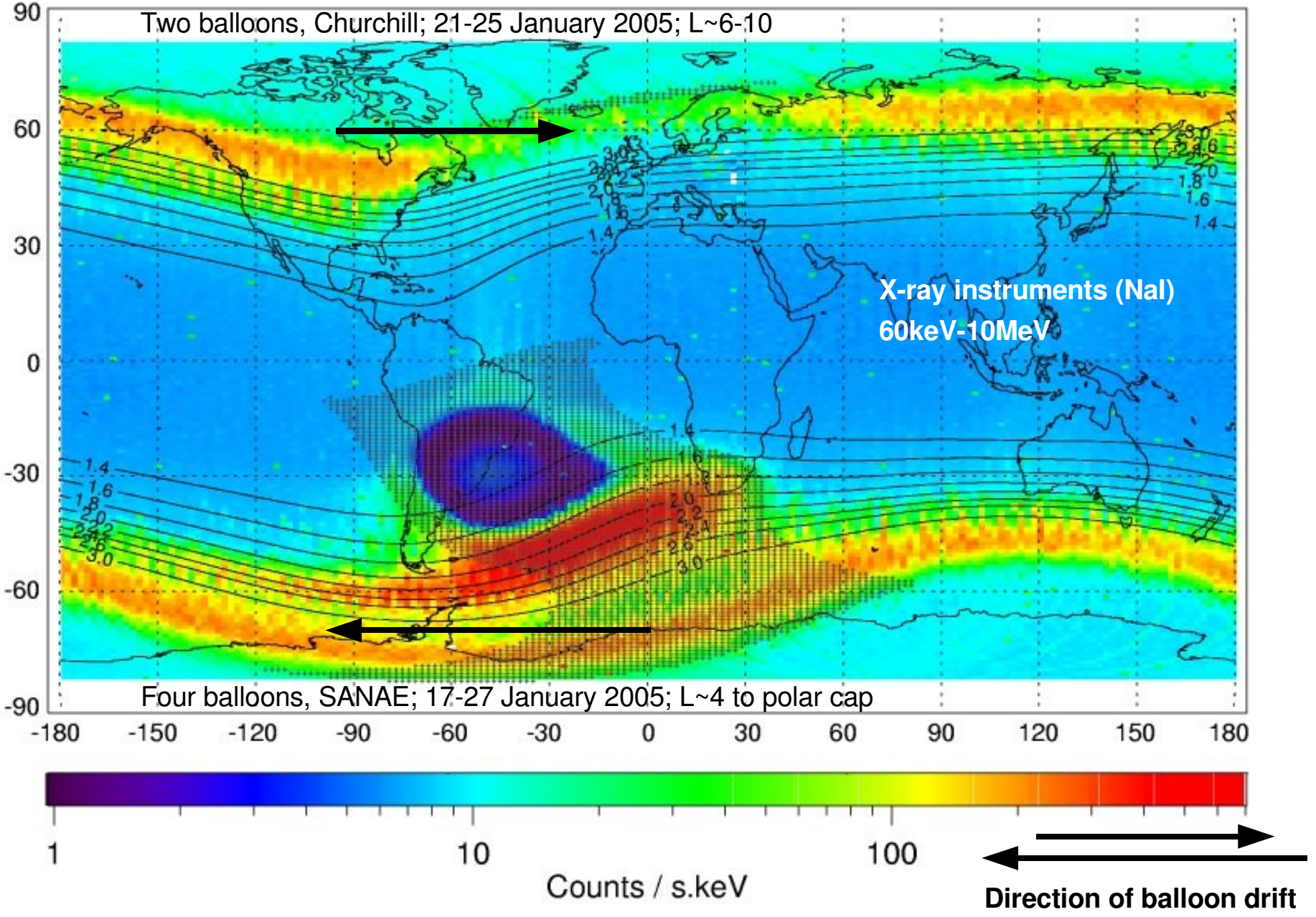
Green et al., JGR, 2004 have shown these are most likely due to precipitation

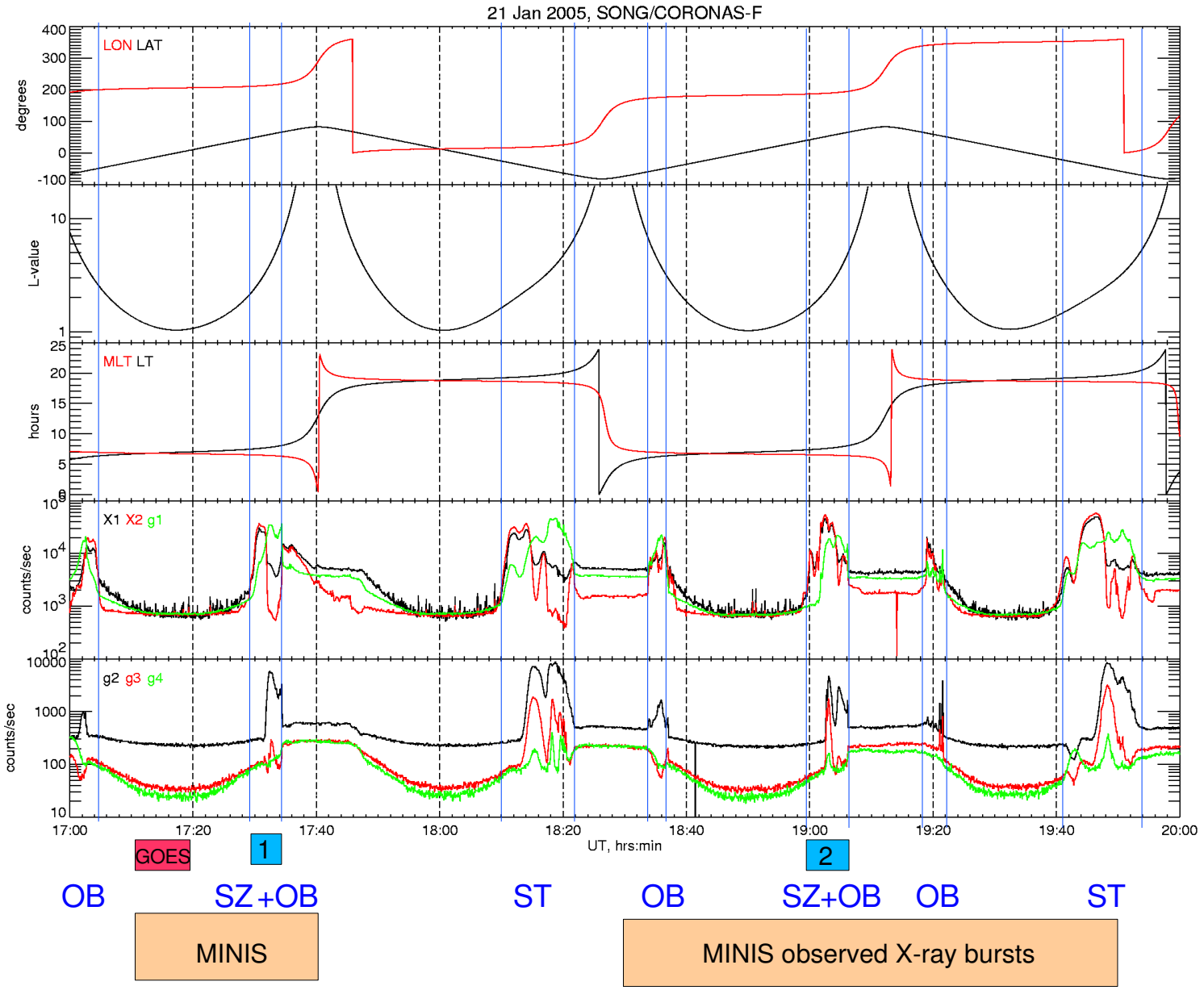
Note: decreases are observed over broad range of L-shells down to at least L~ 4
(Li et al., JGR, 1997; Reeves et al., GRL, 2003)

- MINIS observed precipitation < 1.5 MeV simultaneously at L~3.5 and 4.0; and at L~10 softer one, during both 1710-1740 UT and 1830-1950 UT in dusk sector [E. A. Bering et al., URSI GA2005, New Delhi, India]

- Perturbation in amplitudes of subionospheric VLF signals in coincidence with geosynchronous flux decrease on January 21, 2005 [Clilverd et al., GRL, 2006]

MINIS balloons vs. CORONAS-F

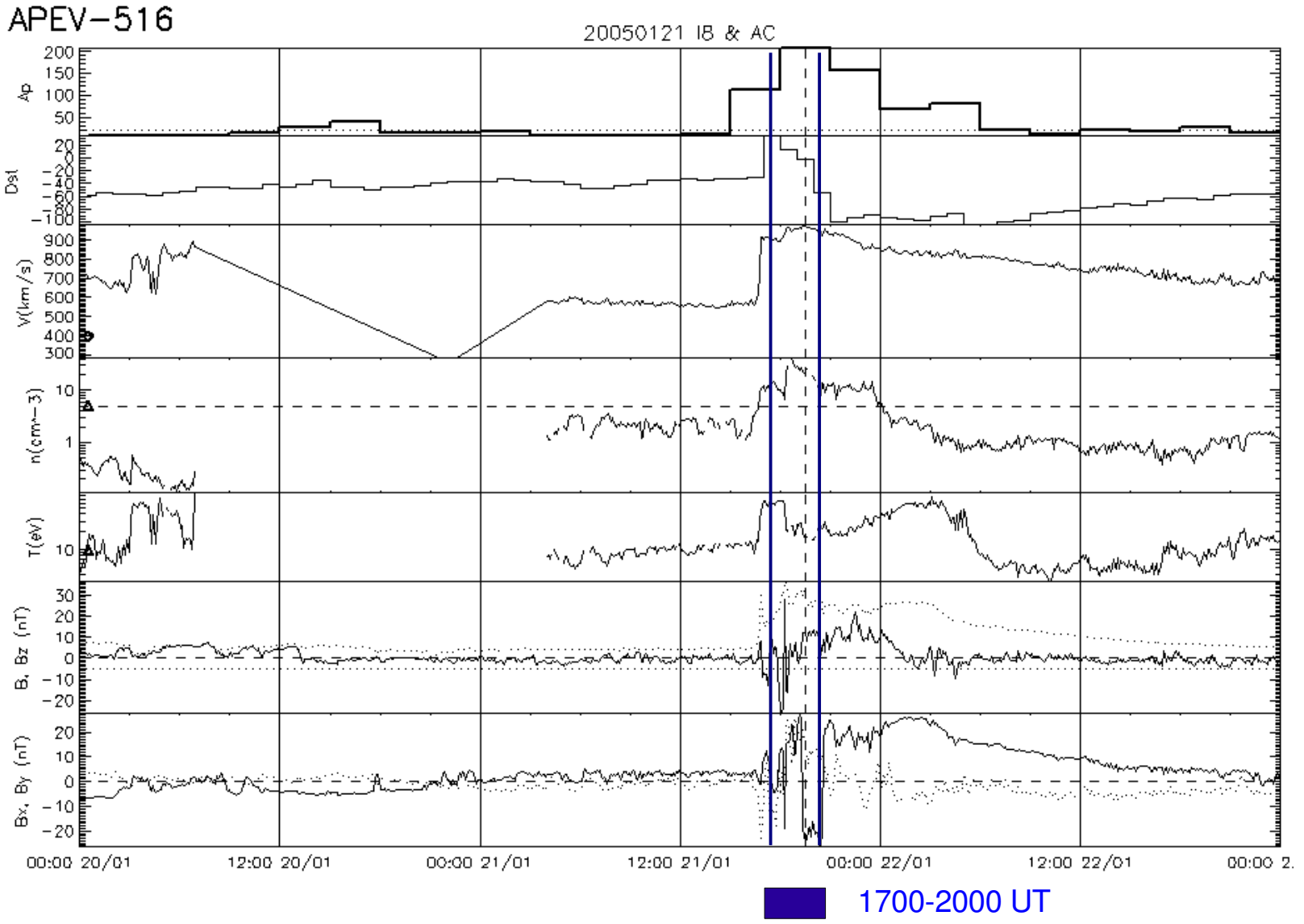




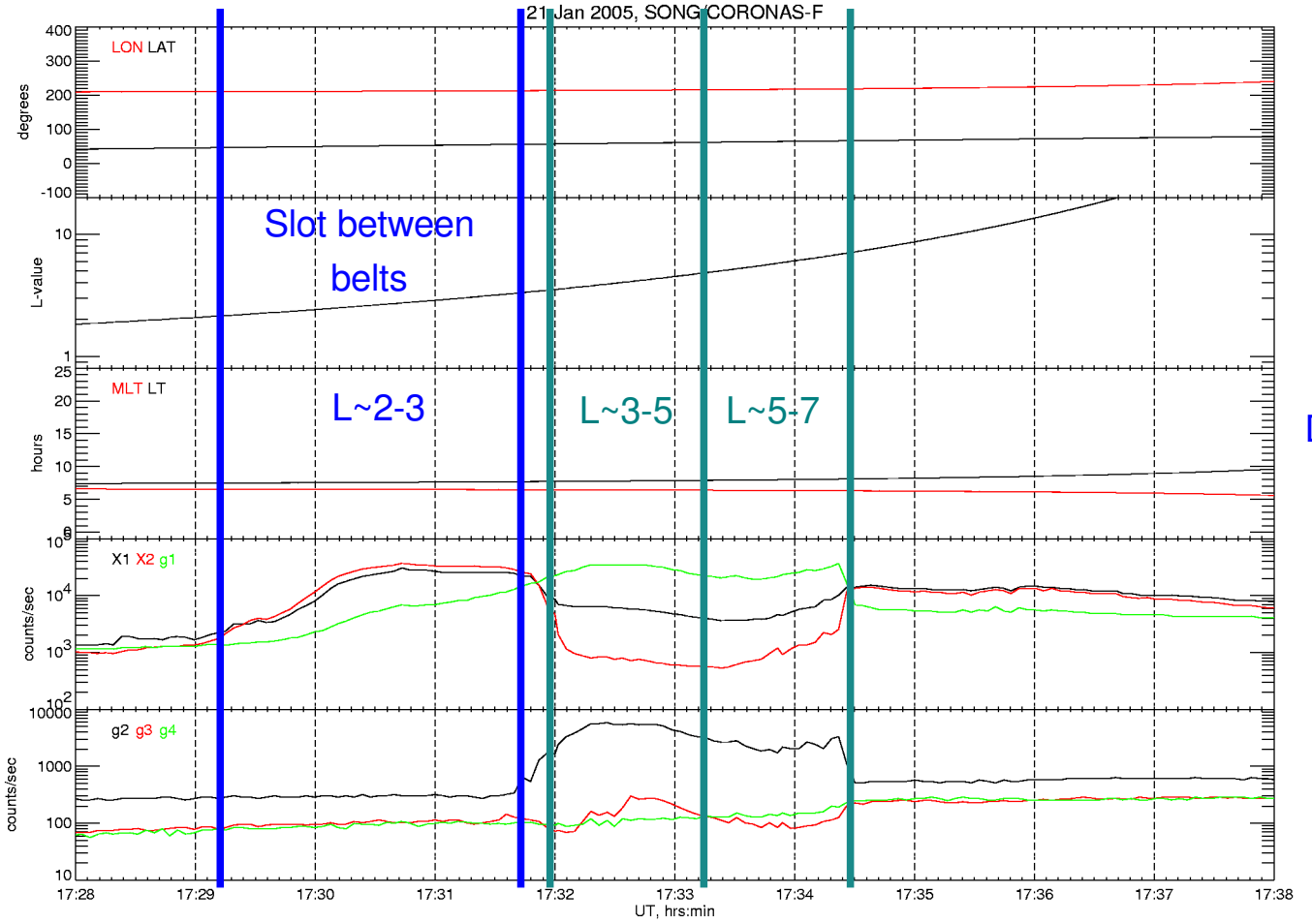
X1 30-60 keV
X2 60-150 keV
g1 150-500 keV
g2 500-1500 keV
g3 1500-4000 keV
g4 4000-7000 keV

ST-stable trapping
OB-outer belt
SZ-slot zone

1 & 2 -same MLTs, northern hem.


APEV−516
20050121 IB & AC
Ap
Dst
V(km/s)
n(cm^−3)
T(eV)
B, Bz (nT)
Bx, By (nT)
00:00 20/01
12:00 20/01
00:00 21/01
12:00 21/01
00:00 22/01
12:00 22/01
1700-2000 UT

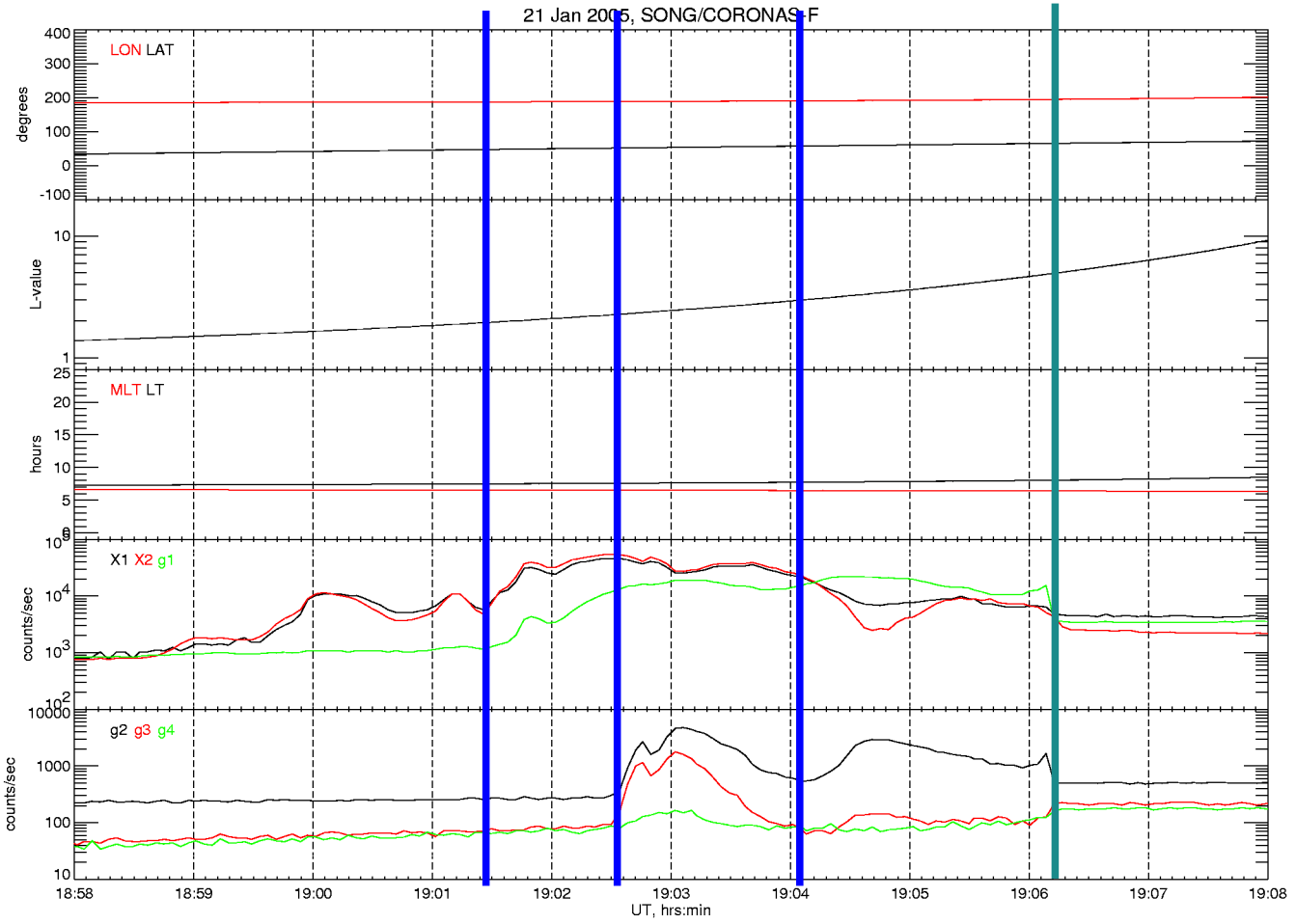
Observations ~15 min after drop-out



Dawn sector

- 30-150 keV X-ray enhancement at L>2 & up to polar region; L~3-7 saturation, where probably flux has maximum
- 0.15-4 MeV gamma-ray enhancement at L~3-7 with maximum at L~4

Observations ~100 min after drop-out



- 30-500 keV X-ray enhancement at L~2-5
- 0.5-4(7) MeV gamma-ray enhancement at L~2.3-5

Summary: Solar Flare Events

- CORONAS-F observed solar flare gamma rays from 30 keV to 100 MeV
- High fluxes of solar protons saturated the detector at polar regions for X-ray energies < 150 keV
- Enhanced gamma rays (30-500 keV) in regions of high cutoff are probably not due to direct penetration of solar protons but rather due to delayed gamma rays from radioactive nuclei in instrument and spacecraft matter

Summary: Magnetic Storm

- SONG's observed X/gamma rays on January 21, 2005 occurred during a flux dropout as seen by GOES-12 and GOES-10 at L~6.6.
(need to check electron observations at lower L-shells)

- In the outer belt (L~3-5), MeV precipitation was observed 15 min and also 100 min after onset of geosynchronous flux decrease (during main phase of the storm).

- In the slot between the belts (L~2-3), MeV precipitation was observed only 100 min after onset (after transport from high L shells ?). There were no MeV precipitation at least 12 hours before the storm in the slot.

The event on January 20, 2005 allowed us to observe:

- Gamma rays from Sun at the Earth
- Secondary gamma rays both from solar protons and radiation belt electrons