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Near-equatorial protons: the local-time dependence

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Abstract. This work presents the experimental data of low-energy (E=55-550 keV) near-equatorial (L<1.15) proton fluxes observation at the altitudes 500-1500 km. More than 4000 passes of ACTIVE ("Intercosmos – 24") satellite (1989-1993 years) through the near-equatorial region at different altitudes used. The analysis of magnetic local time dependence of this proton flux is given. This analysis shows that there is strong local time dependence of high-energy (E>100 keV) proton fluxes. The night and day proton spectra indexes are approximately equal at 500-1000 km. The day spectra index monotonously increases when the altitude increases (at 1000-1500 km). The night spectrum index varies not monotonously. The near-equatorial proton flux at local night hours is bigger than at local day hours. The low-energy protons registered mainly at night hours. Directly at the geomagnetic equator (L<1.04) the proton flux is practically absent at all MLT sectors. There is a strong proton flux peak near the 11^h MLT sector.

Introduction

The phenomenon of existence of low-energy protons below the radiation belt was established by *Hovestadt et al.* [1972] and *Moritz* [1972] who reported their observations. These works inform us that protons in energy range from tens keV to several MeV has been registered with a solid state detector onboard the Azur satellite at L<1.12 - 1.15. The several satellite experiments later confirmed this fact. The list of these experiments is given in Table 1.

Table 1

Satellite	*Year*	*Altitude, km*	*Inclination*	*Parameter*
AZUR	1969	384-3145	103°	Ep=0.25-1.65 MeV
OV1-17	1969	398-468	85.5°	Ep=12.4-180 keV
OV1-19	1969	471-5796	100°	Ep=280-560 keV
Kosmos-378	1970	240-1770	71°	Ep~1 MeV
Kosmos-484	1972	220	81.3°	Ep>70 keV
Esro-4	1972-1973	245-1175	91°	Ep=0.2-1.3 MeV
S81-1	1982	170-290	85.5°	Ep>360 keV
OHZORA	1984-1987	320-850	73°	Ep=0.65-35 MeV
Active	1989-1992	500-2500	81.3°	Ep=55-550 keV
MIR station	1991	400	51.6°	Ep=0.1-8.0 MeV
KORONAS-I	1994	500	83°	Ep>1 MeV
SAMPEX	1992-1998	520x670	82°	Ep>770 keV
MIR station	1999	350	51.6°	Ep=0.3-5.0 MeV

To give an example of the near-equatorial proton flux registration, Figure 1 shows a several passes through the near-equatorial region. There are results of SPRUT-V experiment onboard MIR station (altitude ~ 400 km). This device registered protons in the energy range 0.1–5.0 MeV [*Biryukov et al.*, 1996]. It was installed on MIR in 1991. The maximum of proton flux (E=0.24-0.5 MeV) showed by arrows.

Moritz [1972] reported that the count rate at the maximum of near-equatorial flux increases shows with the limits of statistics no dependence on longitude, altitude or L-value. These protons could be registered at local evening and morning due to the satellite's orbit characteristics. The effect of proton count rate increasing at

L<1.15 could be seen on the morning and night side. He supposed that the proton population really exists all around the Earth.

Charge exchange processes in the outer atmosphere and exosphere explained their existence at low L-shells.

The proposed mechanism includes two stages. The first stage is the charge exchange interaction of radiation belt (or current ring) protons with the neutral hydrogen of geocorona. The radiation belt protons are converted to neutral energetic hydrogen atoms, according to the reaction:

$$p^* + H \rightarrow H^* + p,$$

where the asterisk indicates the energetic particle. These neutrals freely move in the Earth's magnetic field. Some part of these neutrals is directed toward the Earth.

They can lose their electrons by collision with the atmospheric oxygen (or other atoms):

$$H^* + O \rightarrow p^* + O^-.$$

After that the protons become trapped in the Earth's magnetic field.

This model leads to the height independent intensity and to a special source geometry that is given by the proton distribution in radiation belt and current ring. The protons of radiation belt fills all zones of magnetic local time. So the local-time dependence of near-equatorial proton fluxes is not expected.

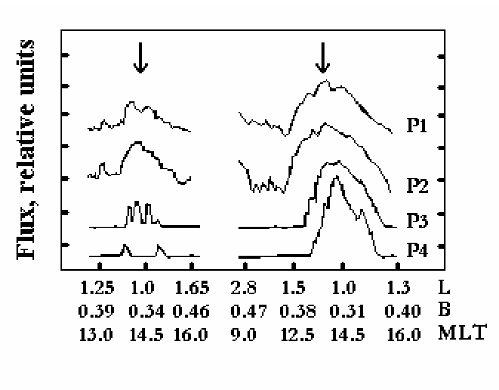

Figure 1. Example of near-equatorial proton registration by SPRUT on MIR. E_{p1}=0.1-0.24 MeV, E_{P2}=0.24-0.5 MeV, E_{P3}=0.5-1.0 MeV, E_{P4} > 1.0 MeV

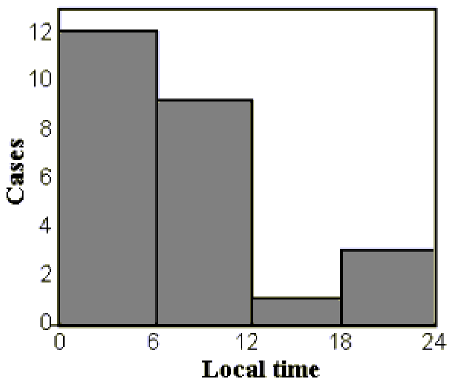

Figure 2. The distribution in local time of the storm-associated maximums in the solid state detector - *Greenspan et al., 1999.*

Greenspan et al [1999] used data from SAMPEX satellite to investigate storm time enhancements in low-equatorial proton fluxes. The LICA instrument onboard SAMPEX satellite observed the protons with energy ≤700 keV at the altitude from 520 to 670 km. The storm time associated equatorial flux has been found during all periods of satellite activity from 1992 though 1998 except for the 1-2 years around solar minimum. The local time distribution of equatorial protons is given in Figure 2. There is evident day-night asymmetry of proton flux distribution. The cases number of storm-associated increasing at 18-0-12^h MLT more than at 12-18^h MLT.

In this work we use data from ACTIVE satellite to investigate local time dependence of low-equatorial proton flux in wide altitude range.

Instrumentation and Orbit

The ACTIVE ("Interkosmos-24") satellite was launched into nearly polar orbit of 82.6° inclination with apogee altitude of 2500 km, perigee altitude of 500 km at the end of 1989 and works up to begin of 1993. In this work we present data for 1990 year mainly (about 4000 cycles around the Earth). The orbit precessing with the 5.5 month period for the latitude and 3 month for local time. The ACTIVE satellite was oriented using magnetic field as reference. The protons were observed in SPE-1 device by three silicon single surface barrier detectors. The orientation of the detectors is 99°, 69° and 39° (detectors 1, 2 and 3) with respect to the zenith axis of the satellite. The thickness of every detector is 300 µm, 8 mm diameter and 0.03 cm^{2}sr geometrical factor. The full acceptance angle of each detector is 20°. Detectors were covered by a Mylar foil stopping electrons up to 650 keV. The common energy interval covered for protons is 25-800 keV. Every detector returned 7 counting rates, corresponding to 7 different threshold settings for signal from detector. The energetic thresholds differs for different detectors due to it's individual characteristics [*Kudela et al.,* 1992].

Observations and Discussion

Using the one-year data from ACTIVE satellite we investigated the proton differential energy spectrum constructed for energetic threshold from 63.9 to 534.0 keV. In this work the counting rate in second detector analysed.

The whole day (0^h-24^h) conditionally divided into two zones of magnetic local time (MLT) - local night (from 21^h to 06^h - signed "N") and local day (from 06^h to 21^h - signed "D").

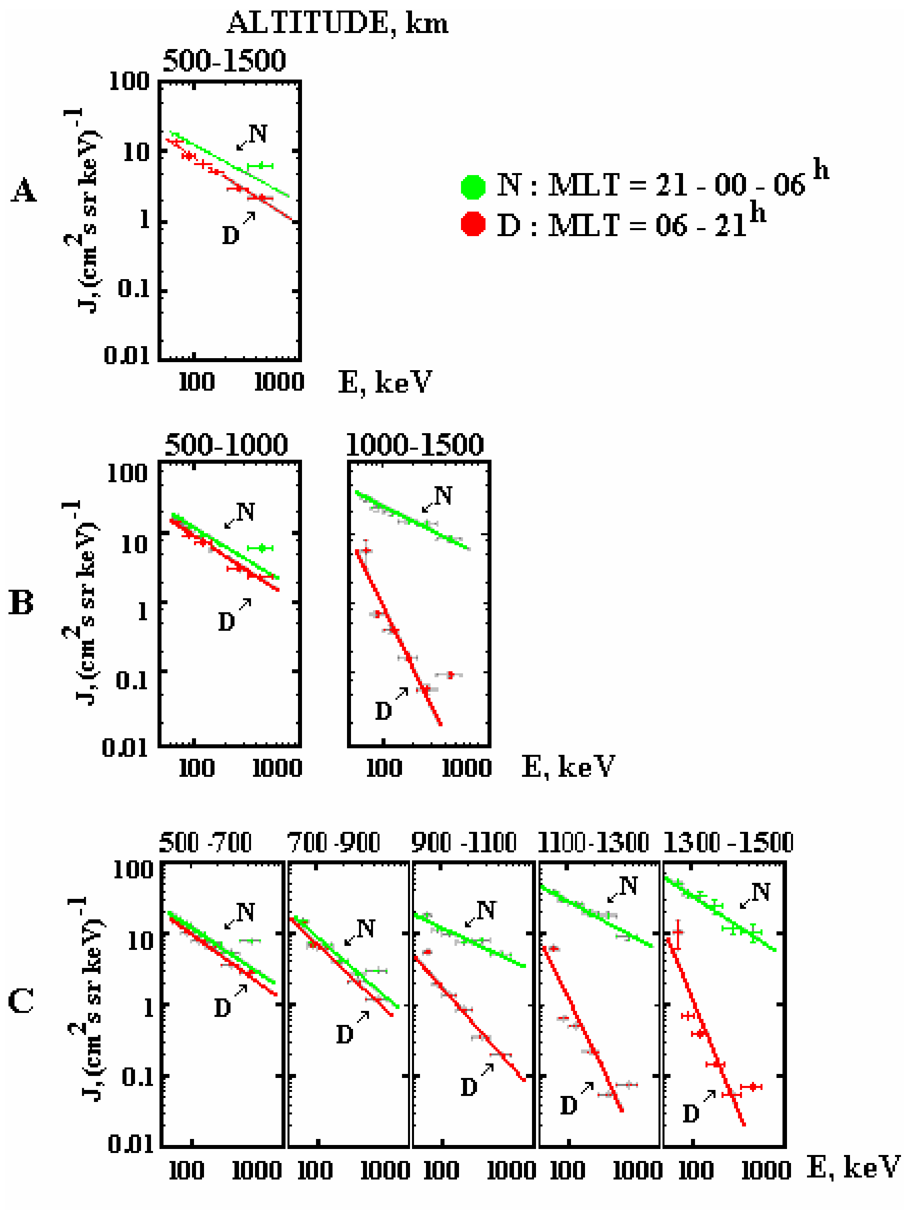

Figure 3. Differential energy spectra of protons at L≤1.15 for different local time and different altitude range: a) 500-1500 km, b) 500-1000 and 1000-1500 km, c) 500-700, 700-900, 900-1100, 1100-1300, 1300-1500 km (SPE-1 on ACTIVE).

The parameters of satellite's orbit allow investigating near-equatorial proton flux at wide range of altitudes. The proton differential energy spectrum constructed for all altitude range (500-1500 km) shown in Figure 3a. So, the first result is that proton flux at night hours is bigger than at day hours. The power-law approximation of spectrum is $J \sim E^{-\alpha}$ where $\alpha=0.84\pm0.06$ for night hours and $\alpha=0.97\pm0.07$ for day hours. The spectrum is softer in day hours than in the night hours. The pictures of local-time dependence of near-equatorial protons after dividing the whole altitude range into two intervals - from 500 to 1000 km and from 1000 to 1500 km are given in Figure 3b. It can be seen that spectrum indexes are approximately equal at the altitudes 500-1000 km. The difference between day and night spectra became essential at the altitude 1000-1500 km - the spectrum at day hours is softer than at the night hours. The list of the night and day spectrum indexes is given in Table 2.

Table 2

Altitude range	500-1500 km	500-1000 km	1000-1500 km
Night index α	0.84 ± 0.06	0.95 ± 0.07	0.6 ± 0.1
Day index α	0.97 ± 0.07	0.90 ± 0.05	2.1 ± 0.5

The spectra for the whole altutude range 500-1500 and for small altutudes 500-900 are similar. It can be explained that the portion of measuremnts carried out above 900 km is rather small. The number of measurements in different altitude range is given in Table 2.1.

Table 2.1

Altitude range	500-700 km	700-900 km	900-1100 km	1100-1300 km	1300-1500 km
Measurements number	50083	16094	7275	2257	1004

To investigate more precisely this difference between night and day spectra the altitude range 500-1500 km was binned in 200-km wide intervals. The proton flux at L<1.15 in given altitude bin was superposed and the average flux as function of energy was determined. The energy spectra indexes are given in Figure 3c for different altitudes. The detail studying confirmed that near-equatorial proton flux at local night hours is bigger than at local day hours. This difference increased with the altitude increasing. We can see that index of energy spectrum of low-energy (63.9-534.0 keV) protons at night hours varies more slowly than at day hours.

The list of indexes is given in Table 3.

The main observational result is that in altitude range from 500 to 900-1000 km the indexes of night and day spectra are equal with the limits of statistics. The altitude range from 900-1000 to 1500 km characterised by strongly different indexes. The spectrum is always softer in day hours than in night hours for the 900-1500 altitude range. The day spectrum index monotonously increases when the altitude increases. The night spectrum index varies not monotonously. The night spectrum is the softest at 700-900. The night spectrum is hardest at 900-1300 km. The night spectrum indexes at 500-700 km and at 1300-1500 km are approximately equal and they are occupy average position between softest and hardest spectra.

Table 3

Altitude range	500-700 km	700-900 km	900-1100 km	1100-1300 km	1300-1500 km
Night index α	0.85±0.02	1.20±0.17	0.58±0.18	0.57±0.08	0.98±0.13
Day index α	0.89±0.06	1.29±0.11	1.71±0.16	2.3±0.5	2.5±0.7

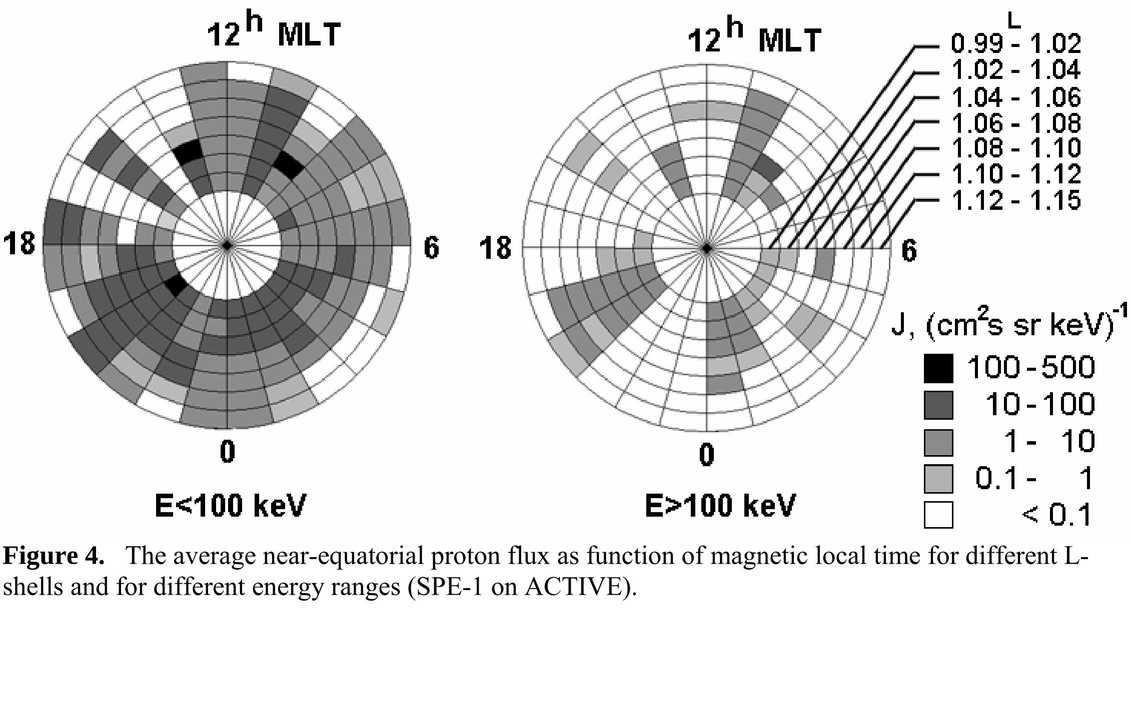

Figure 4. The average near-equatorial proton flux as function of magnetic local time for different L-shells and for different energy ranges (SPE-1 on ACTIVE).

The previous works [*Moritz,* 1972] and [*Greenspan et al.,* 1999] reports that near-equatorial proton flux increased markedly with increasing geomagnetic activity. *Mizera and Blake*, [1973] found that fluxes of quasi-trapped protons with energies below 100 keV increased with increasing geomagnetic activity, while protons above 200 keV showed a much smaller increase. So, that works showed the difference in protons behaviour. The proton flux with E>100 keV and E<100 keV reacts on the geomagnetic disturbances differently.

In this work we examined the low-energy and high-energy proton flux as function of magnetic local time. Used the energy channels from 55.2 keV to 103 keV and energy channels from 103 to 564 keV of second detector of ACTIVE satellite.

Figure 4 shows the local time dependence of near-equatorial proton for high and low energy. The round diagram shows the whole day binned in 1 hour intervals. The left round corresponds to low-energy protons (E < 100 keV) and the right round corresponds to high-energy protons (E > 100 keV). Every round binned in 7 L rings corresponds to different radius. The L-shell number for every ring is given at the left-top corner of figure. These L-shell numbers are: 0.99-1.02, 1.02-1.04, 1.04-1.06, 1.06-1.08, 1.08-1.10, 1.10-1.12, 1.12-1.15. The average proton flux in $(cm^2 s\ sr\ keV)^{-1}$ units showed by colour in given L and MLT point.

We can see that local time dependence of near-equatorial proton flux is strong.

The results of proton flux investigation as function of MLT, L and energy are:

- The protons registered mainly at evening and night hours and there is a strong peak of proton flux at 10^h-11^h MLT on wide L range.
- The proton flux at 11^h-19^h MLT and at 02^h-10^h is essentially smaller than at other hours for high energies. The low-energy protons not registered at 13^h-17^h MLT except the 15^h-16^h MLT region.
- The proton flux registered at 19^h-21^h at wide L range than at other night and evening hours.

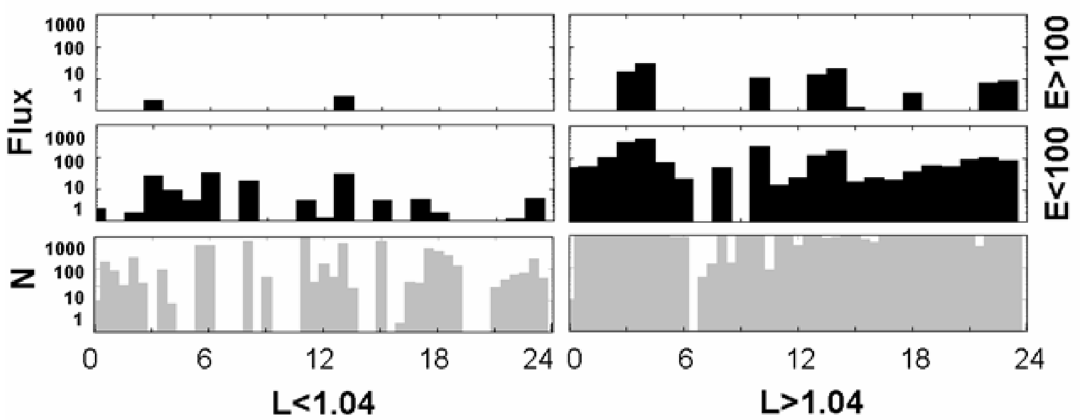

Figure 5 summarise the L-distribution of near-equatorial proton flux for the high and low-energies. It shows the average flux at L<1.04 and 1.04<L<1.15. “N” is the number of passes through the selected MLT bin. The results are:

- Directly at the geomagnetic equator (L<1.04) the high-energy and low-energy proton flux is practically absent at all MLT sectors. The proton flux appears at L>1.04. This fact confirm the MIR station data [*Biryukov et al.,* 1996].
- The low-energy proton flux registered mainly at night hours.
- There is a strong peak near the 11^h MLT for low-energy and high-energy protons.

Summary

The low-energy (E=55-550 keV) near-equatorial (L<1.15) proton flux investigation gives us important information about the dependence of these flux on local time, altitude and energy. The main observational results are:

1. There is strong local time dependence of low-energy (E=55-550 keV) proton fluxes:
   - The low-energy protons registered mainly at night hours
   - The near-equatorial proton flux at local night hours is bigger than at local day hours
   - There is a strong proton flux peak near the 11^h MLT sector.
2. There is difference in night and day spectra:
   - The night and day proton spectra indexes are approximately equal at 500-1000 km
   - The day spectra index monotonously increases when the altitude increases (at 1000-1500 km)
   - The night spectrum index varies not monotonously with the altitude increasing.
3. Directly at the geomagnetic equator (L<1.04) the proton flux is practically absent at all MLT sectors

References

Biryukov A.S., O.R.Grigoryan, S.N.Kuznetsov, A.V.Ryaboshapka, and S.B.Ryabukha. Low-energy charged particles at near equatorial latitudes according to MIR orbital station data. *Adv.Space Res.*, 10, 10189 (1996).

Greenspan, M. E., G. M. Mason, and J. E. Mazur, Low-altitude equatorial ions: A new look with SAMPEX, *J. Geophys. Res.,* 104, 19,911, 1999.

Hovestadt, D., B. Hausler, and M. Sholer, Observation of energetic particles at very low altitudes near the geomagnetic equator, *Phys. Rev. Lett.,* 28, 1340, 1972.

Kudela K., J. Matishin, F. K. Shuiskaya, O. S. Akentieva, and T. V. Romantsova, Inner zone electron peaks observed by the "Active" satellite, *J.Geophys.Res.,* 97, 8681.

Mizera, P. F., and J. B. Blake, Observations of ring current protons at low altitudes, J. Geophys. Res., 78, 1058, 1973.

Moritz, J., Energetic protons at low equatorial altitudes: A newly discovered radiation belt phenomenon and it's explanation, *Z. Geophys*., 38, 701, 1972.