Measurements of the Gamma-Ray Spectrum in the Range 3-15 MeV at Different Atmospheric Depths

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Abstract

Since 1995 we have carried out measurements of the gamma ray flux in the 3-15 MeV energy range at six different atmospheric depths, from ground level to aircraft altitude, and at different geomagnetic cut-off. We estimate the attenuation length of the gamma-ray component in the atmosphere and make a comparison with previous results.

1. Introduction

The interaction of cosmic rays with atmospheric nuclei and terrestrial matter originates different radiation components that, together with the products of natural and/or artificial radioactivity sources constitute a variable radiation background, that has been named Environmental Radiation (ER)[5]. The very low energy component of secondary cosmic rays (CR) was called *mollissima*, or ultrasoft, by [1]. The monitoring of the ER intensity and of its time variation is interesting not only *per sé*, but also for its influence on human life and activity.

Since 1995 we have started a world-wide survey of the ER in order to study, in a systematic way, the time and spatial variations of its both components: in Italy (at sea level in Bologna, at the Laboratorio Mt. Cimone and at Gran Sasso National Laboratories), at Terra Nova Bay in three different italian expeditions to Antarctica and even during the sea voyages from Italy to Antarctica and back, at the Svalbard Islands in the Arctic region, in Nepal at 5050 m a.s.l. and in Tunguska (Central Siberia). During the latter expedition one detector was operated on board an aircraft that attained the maximum altitude of 8400 m.

Here we present the study of the altitude dependence of the energy spectra of the $\gamma-$ rays with E $>$ 3 MeV originated by CR, after taking into account that the measurements were made at different locations and at different times of a solar activity cycle (see Table 1). Corrections for different detector design (mainly the shield) were also applied. From the spectra observed at several heights we are able to deduce the atmospheric attenuation length of this component. Finally we could investigate the presence of γ-lines in the spectra taken at aircraft altitudes.

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Site	m a.s.l.	Lat.N	Long.E	P_c[GV]	Year	Detect.
Bologna	45	44°.5	11°.4	6.2	95-96-97	1
Indian Ocean	0	6°.4	59°.3	16.6	95-96-97	1
Ny Alesund	10	78°.9	11°.9	<0.2	99-00-01-02	1
Gran Sasso Lab.	1000	42°.5	13°.9	6.3	1996	1
EASTOP Lab.	2050	42°.5	13°.9	6.3	1996	1
Mt. Cimone Obs.	2165	44°.2	10°.7	6.2	2002	1
Piramide-Nepal	5050	28°	86°.5	14.4	1997	2
Aircraft	>7000	58°	80°	1.7-2.4	1999	3

2. Description of the detectors and of data acquisition

As it can be seen in Table 1 we have used 3 different types of detector, all based on a NaI(Tl) monocrystal. The first type has been already described in [8]. The detector identified as type 2 has been described in [2]. The third type is a recent evolution with a Pb shield whose thickness has been increased to 2.5cm [6]. The data acquisition (DAQ) system has also been changed during the period from 1995 to 1998. Whereas the first DAQ system allowed the recording of pulse spectra only on a hourly scale [8], with the second one is possible to select the accumulation time interval from few minutes onward [3].

3. The observations on board the aircraft

In July 1999, during the TUNGUSKA-99 expedition in the Vanavara region (Siberia) one detector type-3 was operated on board the aircraft that took the expedition from Forli (Italy) to Krasnoyarsk (Siberia) and back. The detector was located in the aircraft main cabin that was pressurised at 940 mbar. The total thickness of the body was estimated of about 3mm of Al. The data concerning altitude and position of the aircraft were made available by the crew. The outward flight took place July on 14th-15th and the return journey on July 29th-30th, 1999. The maximum altitude reached by the aircraft was about 8400 m a.s.l. The sampling time was 15 min and the pulse gain was set in order to have roughly 5.1 keV per channel. The maximum detectable energy was 10.2 MeV.

In Fig. 1a we show one of the recorded spectra where the 0.511 MeV annihilation line is evident. In Fig. 1b we show the spectra in the range 1-10MeV observed at different altitudes (around 8400, 7700 and 7350 m. a.s.l.), at latitudes greater than 55° N and for longitudes in the interval $60° - 80°$ East. As one can see the difference in the cut-off values [10] for the same altitudes introduces a small variation in the intensity. The value of the index of the power law ($E^{-\gamma}$) that fits the spectral shape at all altitudes is $\gamma = 1.18 \pm 0.03$. The attenuation length for the photon component of the cosmic rays, results $\lambda = 188 \pm 7$ [g/cm^2]

and is in agreement with previous observations by other authors and theoretical calculations [9, see also 8].

4. The observations made with other detectors

When considering observations made with different detectors, at different times and locations other effects due to atmospheric pressure variations, cut-off changes and modulation level at the time of measurement have to be taken into account. All our data have been corrected for the pressure effect with the coefficient [2,3,7]

b_p= -(0.37± 0.02) %/mbar

The spectra at different depths have been corrected for the latitude effect, by using the latitude dependence measured during the two latitude surveys made during the two expeditions to Antarctica in 1995-96 and 1996-97[7]. Finally we have considered the variation induced by the solar modulation change between the years of observations, which can be as large as $\sim$ 12% going from 1997 to 2002[4]. The final result for the energy range 1-15MeV is shown in Fig. 2. The levels of photon counting rate are in agreement with the observations by [9] when the difference in the cut-off rigidity is taken into account.

5. Conclusions

In the energy range 3-15 MeV the spectra at different altitude look very similar indicating the equilibrium nature of the atmosphere for downward γ rays. The intensity level and the attenuation length are comparable to the previously reported measurements. No γ line other than the 0.511 MeV has been observed in the spectra.

6. Acknowledgements

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7. References

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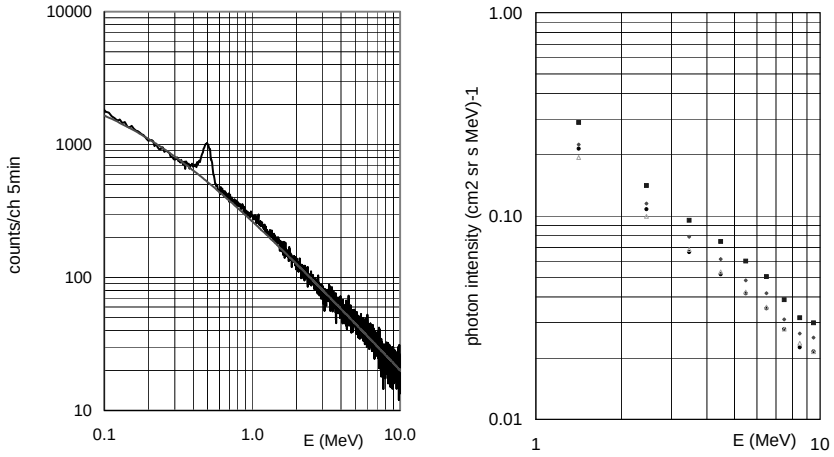

Fig. 1. **left**- The measured spectrum at 8400 m a.s.l. The continuous curve is the fit spectrum $A/(1+BE)^{\gamma}$.**right**- The spectra have been measured at 4 altitudes (from top to bottom): 8400, 7700, 7350, 7400 at rigidities 1.93, 1.87, 1.67, 2.41 GV respectively.

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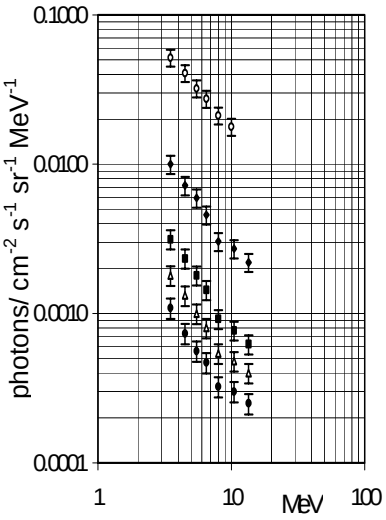

Fig. 2. Comparison of γ-ray spectra measured at different altitude; from top to bottom: aircraft, Piramide, EASTOP, LNGS, sea level. The attenuation length calculated from these spectra resulted $\lambda = 177 \pm 8\ g/cm^2$