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Cosmic ray measurements on a polar orbiting satellite

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Cosmic ray fluxes in the energy range above 13 MeV have been measured by means of a detector of high geometricl factor on a polar orbiting satellite. From the observed altitude dependence in the polar regions, a value of $31 \pm 0{\cdot}3\%$ for the contribution due to splash albedo particles to the total cosmic ray flux at the top of atmosphere, is derived. The experimentally observed cosmic ray flux leads to a value of $2{\cdot}858 \pm 0{\cdot}008$ particles ($cm^{-2}sec^{-1}$) for the cosmic ray flux in space. A comparison of this value with the Pioneer VI measurement of cosmic ray flux in the same energy range, leads to a value of $6{\cdot}92 \pm 2{\cdot}0\%$/A.U. for the radial cosmic ray density gradient.

1. Introduction

A significant proportion of cosmic rays observed at different levels in the atmosphere can be attributed to albedo particles (splash and re-entrant), which are produced by the primary cosmic rays. There have been several theoretical investigations (Griem & Singer 1955, Ray 1962) and experimental measurements (Verma 1967, Marayama 1967, George 1970) of albedo particles but the measurements are still insufficient to permit a reasonably accurate determination of the albedo contribution to the observed cosmic ray fluxes at different altitudes. For example, Neher & Anderson (1961) obtained a value of 21% for the splash albedo contribution at balloon altitudes, whereas Marayama (1967) obtained a value of 29% at 165 Km. Several workers (Anderson 1968, George 1970) have tried to estimate the cosmic ray radial density gradient by comparing the absolute value of primary cosmic ray flux measured by a near earth satellite, with the values measured by far earch satellites, and values in the range 2–10%/A.U. have been reported.

In the present work, cosmic ray observations from the omnidirectional detector on OGO-6 are used to study the altitude variation of total cosmic ray flux over the polar regions ($\lambda_m \geqslant 70°$). By making use of their different altitude variations, the observed cosmic ray flux is separated into its primary cosmic ray and aplash albedo components. The value of primary cosmic ray flux obtained in this manner is used to derive the relative albedo contribution and the cosmic ray radial density gradient. The analysis is limited to the polar regions because in this region the contribution due to re-entrant albedo is negligible due to the fact that the geomagnetic field lines are open.

2. Experimental Details

The measurement of cosmic ray fluxes in the polar regions was made by means of an omnidirectional charged particle detector on satellite OGO-6. The detector consisted of 22 proportional counters acting as the charged particle guard ring for a neutron detector. The detector system has been described in detail elsewhere (Kaul *et al* 1977). Figure 1 shows a section of the detector system and the arrangement of the proportional counters around the central neutron detector.

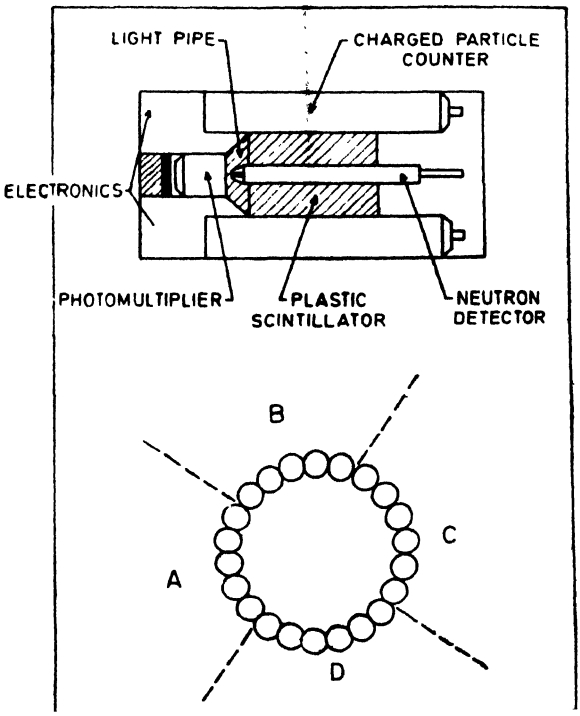

Fig. 1. OGO-6 neutron detector, showing details of the detector assembly and the arrangement of charged particle counters around the central neutron detector.

The outputs from the proportional counters are connected in parallel to form an approximately omnidirectional charged particle detector of geometrical factor 950 cm^2sr and energy thresholds of 1·5 MeV for electron and 13 MeV for proton detector. OGO-6 was launched on June 5, 1969, into a nearly polar orbit of inclination 82°, with apogee at 1100 Km and perigee at 400 Km. The detector was mounted on a boom at a distance of 4·5 meters from the main body of the satellite to reduce contamination of observed fluxes by satellite radioactivity.

3. Results and Discussion

Figure 2 shows the observed altitude variation of the total cosmic ray flux at $\lambda_m \geqslant 70°$N, for the period 7 June–17 Dec., 1969. The results for the southern polar region are exactly similar. In the above plot we have eliminated days

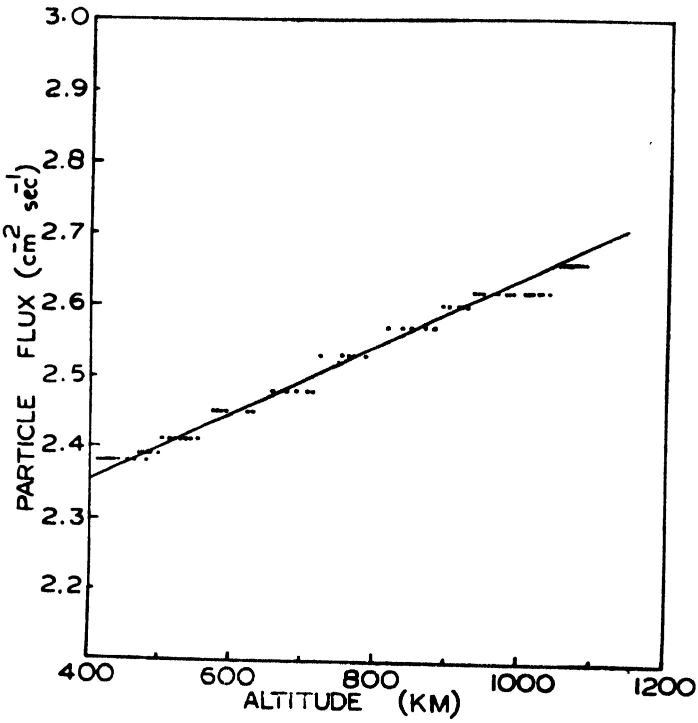

Fig. 2. Variation of proton flux with altitude. Data are taken up geomagnetic latitudes > 70°N.

when significantly large fluxes due to solar cosmic rays are observed. Each point represents the average flux for a number of orbits during the day. The average value of total cosmic ray flux for each day at different altitudes is found in the following way. First, counting rates at geomagnetic latitudes $\geqslant$ 70°N are averaged for each orbit and then converted to the omnidirectional flux by making use of the relation

$$J(h) = \text{Counting rate} \times \Omega(h)/950 \text{ cm}^{-2}\text{sec}^{-1}$$

where 950 cm^{2}sr is the geometrical factor of the detector and $\Omega(h)$ represents the solid angle of open sky visible from the satellite altitude h, and is given by

$$(h) = 2\pi[1+\{1-(R_E+t/R_E+h)^2\}]^{\frac{1}{2}}$$

where R_E is the radius of earth and t = 40 Km is taken as the effective thickness of the atmosphere.

From the values of omnidirectional flux obtained in this manner for different orbits during a day, the value of daily average omnidirectional flux at height h is evaluated. From Figure 2, we find that the flux at 1000 Km is $2{\cdot}62 \pm 0{\cdot}002$ particles ($cm^{-2}sec^{-1}$), whereas at 400 Km, it is $2{\cdot}35 \pm 0{\cdot}002$ particles ($cm^{-2}sec^{-1}$).

Cosmic ray fluxes measured at a height h in the atmosphere are essentially due to primary cosmic rays, splash albedo particles and re-entrant albedo. However, at high geomagnetic latitudes, the field lines are open and so the re-entrant albedo contribution is negligible. We may, therefore, write

$$J_0(400) = C_p F_p(400) + C_A F_A(400) \qquad \dots (1)$$

and

$$J_0(1000) = C_p F_p(1000) + C_A F_A(1000) \qquad \dots (2)$$

where $F_p(h)$ and $F_A(h)$ describe the altitude dependences of primary and splash albedo cosmic rays respectively, and C_p and C_A are constants normalised to have a value of unity at 40 Km.

The altitude dependence of the primary cosmic ray counting rate is due to the change of shadow effect of the earth with altitude. For particles of low rigidity the counting rate is proportional to the solid angle of allowed trajectories at height h, and if the geomagnetic field strength varies as $(R_E+h)^{-3}$, it can be shown that

$$F_p(h) = 1 + [1 - (R_E + t/R_E + h)^3]^{\frac{1}{2}}. \qquad \dots (3)$$

The altitude variation of splash albedo flux has been derived by George (1970) and can be represented as

$$F_A(h) = C_N/a \int_0^{\pi/2} f(\theta)(a^2 - \sin^2\theta)^{-\frac{1}{2}} \sin\theta \, d\theta \qquad \dots (4)$$

where $f(\theta) = (1 + \sin^2\theta + \sin^4\theta + \sin^6\theta)\cos\theta$ describes the pitch angle distribution of albedo particles at the top of atmosphere, C_N is a normalisation constant such that $F_A(40) = F_p(40)$ 1 and $a = (R_E+h)/R_E+t)^{3/2}$

Solving eqs. (1), (2), (3) and (4) for $h_1 = 400$ Km and $h_2 = 1000$ Km, we get

$$C_p = 1{\cdot}429 \pm 0{\cdot}004$$

$$C_A = 0{\cdot}631 \pm 0{\cdot}004$$

Since at $h = 40$ Km, assumed to be the top of the atmosphere, $F_A(40) = F_p(40) = 1$ the total cosmic ray flux $J_0(40)$ is $C_p + C_A = 2{\cdot}06 \pm 0{\cdot}008$ particles ($cm^{-2}sec^{-1}$) and the ratio $C_A/C_A + C_p = 0{\cdot}31 \pm 0{\cdot}003$. This gives a value of $31 \pm 0{\cdot}03\%$ for the fractional albedo at the top of the atmosphere. This value compares very well with a value of 29% observed by Murayama (1967) at 165 Km and a value of 21% at balloon altitudes by Neher & Anderson (1961).

From eq. (1), we find that the cosmic ray flux in space ($h \gg t$) is given by $J(\infty) = 2.C_p = 2{\cdot}858 \pm 0{\cdot}008$ particles ($cm^{-2}sec^{-1}$). During June-Dec., 1969 the cosmic ray proton detectors on Pioneer 6 satellite were measuring steady fluxes of 0·61 protons ($cm^{-2}sec^{-1}$ in the 13–175 MeV channel and 2·22 protons ($cm^{-2}sec^{-1}$) in the > 175 MeV channel (CRPL reports, 1969), leading to a flux of 2·83 ($cm^{-2}sec^{-1}$) for protons with energy $\geqslant$ 13 MeV. This value is in excellent agreement with the value of $J(\infty)$ derived from OGO-6 measurements. If we consider that the difference between the values determined from the OGO-6 measurement and the Pioneer 6 measurement is due to the cosmic ray radial density gradient, then taking note of the Pioneer 6 position in June-Dec., 1969, we arrive at a value of $6{\cdot}92 \pm 2{\cdot}0\%$/A.U. for the gradient. This value compares well with the recently measured value of $5{\cdot}1 \pm 2{\cdot}9\%$/A.U. for protons in the energy range 29–67 MeV and $4{\cdot}4 \pm 0{\cdot}4\%$/A.U. for protons with energy $\geqslant$ 70 MeV, from Pioneer 10 and Pioneer 11 observations by McKibben *et al* (1975).

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