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Observation of a rare cosmic ray event at mountain altitude

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ABSTRACT

Existence of strangelets in cosmic rays has been predicted even at mountain altitudes ~ 3–4 km with extremely low abundance. We exposed an appropriate passive detector to cosmic rays at Darjeeling, India, at an atmospheric pressure of 765 hPa, as a pilot study to determine its suitability for the detection of strangelets in a large area detector array through long-term exposure. During the analysis we found a highly unusual event consisting of a cluster of six identical nuclear tracks. We argue that even the most mundane explanation of this event requires unusual physics, the first possible observation of multifragmentation involving cosmic rays.

1. Introduction

Search for massive exotic particles in cosmic rays continues to be an active field of research. Different groups have reported observations of massive particles; many authors [1] have suggested that these could be stable lumps of strange quark matter (SQM) or strangelets. Existence of significant amount of SQM has been suggested in our part of the galaxy [2]. A theoretical study [3] has suggested the possible existence of strangelets in cosmic rays even at mountain altitudes, albeit with extremely low abundance (5–$10/100\text{m}^2/\text{year}$), compared to that of primary cosmic rays ($1000/\text{cm}^2/\text{sec}$). The authors of Ref. [3] have argued that under suitable conditions, small strangelets of initial mass $A \sim 64$ amu and charge $Z \sim 2$, arriving at the top of the terrestrial atmosphere with $\beta \sim 0.6$, could grow to $A \sim 300$–400 and $Z \sim 10$–20 at mountain altitude ~ 3–4 km and be left with a $\beta \sim 0.01$.

To investigate such rare events, one requires a large area, hence ground-based, detector array. We are planning to set up such large area arrays at high mountain altitudes. The appropriate detector for such large area cosmic ray exposure at high altitude is clearly polymer or plastic detectors, called Solid State Nuclear Track Detectors (SSNTD). SSNTDs are dielectric materials. Heavily ionizing particles leave behind narrow damage trails when they impinge on such materials. These damage trails are then made visible in an optical microscope by treatment with properly chosen chemical reagent (etchant) that preferentially attacks the damage trail as compared to the bulk material. By studying the geometry of such etch pits one can get an idea of the charge, energy and mass of the ionizing particles.

Although several standard SSNTDs, e.g. CR-39, Lexan Polycarbonate, etc., are available for nuclear track detection, none of these are suitable for the planned experiment for the following reason. For a given SSNTD detection of a charged particle becomes possible only if its Z/β value is above a certain number known as the detection threshold of that SSNTD. Due to very low detection thresholds (Z/β) of widely used SSNTDs, as compared to the

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predicted Z/β range of 1000–2000 for strangelets, these detectors will record a huge low-Z noise. A SSNTD with a high threshold of Z/β is thus of prime importance in the search for SQM. Detection thresholds for some widely used SSNTDs are as follows: CR-39(DOP 1%): $Z/\beta \sim 6$ [4], CR-39(HCB 0.5%): $Z/\beta \sim 10$ [5] and Lexan Polycarbonate: $Z/\beta \sim 57$ [6].

We investigated a commercially available polymer [Century de'Smart, India] that was identified to be Polyethylene Terephthalate (PET) by elemental analysis and FTIR spectroscopy with chemical formula $(C_{10}H_8O_4)_n$ and found that it could be used as a SSNTD [7]. An important quantity for an SSNTD is its charge response characteristic defined as the ratio of the track etch rate to the bulk etch rate V_t/V_g. We studied the (V_t/V_g) of this detector with different ions such as ^{16}O from IUAC, New Delhi, ^{238}U from GSI, Darmstadt and fission fragments from a standard ^{252}Cf source and established that PET has a much higher detection threshold ($Z/\beta > 120$) than any standard SSNTD [8]; these details have been published elsewhere [9,10]. During standardisation, we subjected the PET detector to different types of tests, including open air cosmic ray (CR) exposures at mountain altitude (Darjeeling in the Eastern Himalayan Range: atmospheric pressure 765 hPa, altitude ~ 2.2 km). The purpose was to find out whether PET could detect any CR nuclear track at all and if it did, whether the quality of the recorded tracks was sufficiently good for measurements of track parameters. We found that it recorded good quality tracks with much less track density in comparison to those recorded by standard CR-39 (Intercast Europe Co., Italy) exposed simultaneously. During the analysis of one such exposed detector, we have found an interesting, highly unusual event. We report this observation in this paper.

Three rectangular detector stands made of Perspex were placed in Darjeeling in a row, 3 feet apart from each other. These detector stands contained PET films of dimension $21 \times 30\,\mathrm{cm}^2$ and CR-39 films of dimension $21 \times 24\,\mathrm{cm}^2$ such that the detecting surface remained horizontal with 2π steradian exposure to the open air. In Stand-I there was a 100 μm thick PET film at the top, below which a 630 μm thick CR-39 film was placed. In Stand-II there was a 630 μm CR-39 film at the top, below which two 100 μm thick sheets of PET were kept. In Stand-III only one PET sheet of 175 μm was placed.

All the three stacks were recovered after 171 days ($\sim 1.5 \times 10^7$ s). To see the quality of the nuclear tracks recorded, several small portions ($4 \times 4\,\mathrm{cm}^2$) from the top sheet of Stand-I were etched in 6.25 N NaOH solution at $55.0 \pm 0.5\,^\circ$C for 3 h. The etching condition was kept identical to our calibration experiments for the same PET detector with ^{16}O and ^{238}U ions [7,8]. Etch-cones of different diameters and cone-lengths were seen on the detector when viewed under a Leica DMR microscope, interfaced with a computer preloaded with image analysis software. The diameters and cone-lengths were measured under ×100 dry objective of the microscope. The error in diameter measurement was 1 pixel (0.15 μm), and for depth measurement it was 1 μm.

The actual area of a single image frame was $4.5 \times 10^{-9}\,\mathrm{m}^2$. For only 2% of the image frames scanned, there was generally only one track, as shown in Fig. 1. The image frames for the rest 98% of the scanned area had no tracks at all. However, in one image frame, we found six very similar nuclear tracks, very close to each other; see Fig. 2.

There was only one such event over a scanned area of $6.4 \times 10^{-3}\,\mathrm{m}^2$, the corresponding flux being $3.47 \times 10^{-6}/\mathrm{m}^2/(\mathrm{sr/sec})$. Incidentally, the flux of the single isolated tracks was $\sim 1.13 \times 10^{-1}/\mathrm{m}^2/(\mathrm{sr/sec})$, at least $\sim 3 \times 10^4$ times higher than that of the unusual event. In a second set of exposure at Darjeeling lasting 526 days, we measured a flux of $\sim 0.9 \times 10^{-1}/\mathrm{m}^2/(\mathrm{sr/sec})$ for the isolated tracks but no unusual event.

CR-39 sheets, exposed simultaneously with the PET detector at Darjeeling, recorded about equal number of heavy ion tracks per unit area plus light ion tracks (apparently proton tracks) with a track density about 70 times that of the heavy ions. The light ion track density in CR-39 is consistent with the known flux density of protons at Darjeeling. PET did not detect any light ion (i.e proton or alpha particle) track. These are consistent with expectations. We have given the angle of incidence and V_t/V_g distributions of the tracks on PET in Fig. 3, while Fig. 4 gives the major axis and track length distributions of those tracks. The tracks due to the isolated events have smaller dimensions on average compared to the six

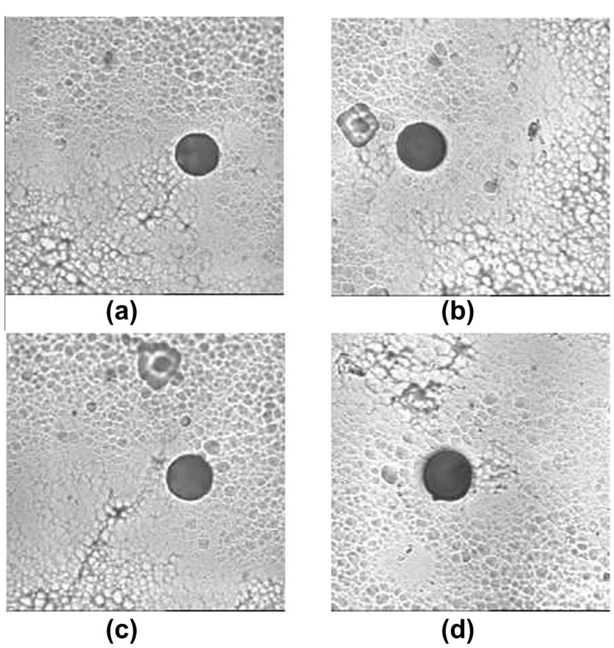

Fig. 1. (a)–(d) Four image frames of the PET detector, each with one track. In general, either no track (in 98% of the cases) or only one track (in 2% of the cases) is observed in a single image frame of the PET detector. The size of each of the four image frames is 67 μm × 67 μm.

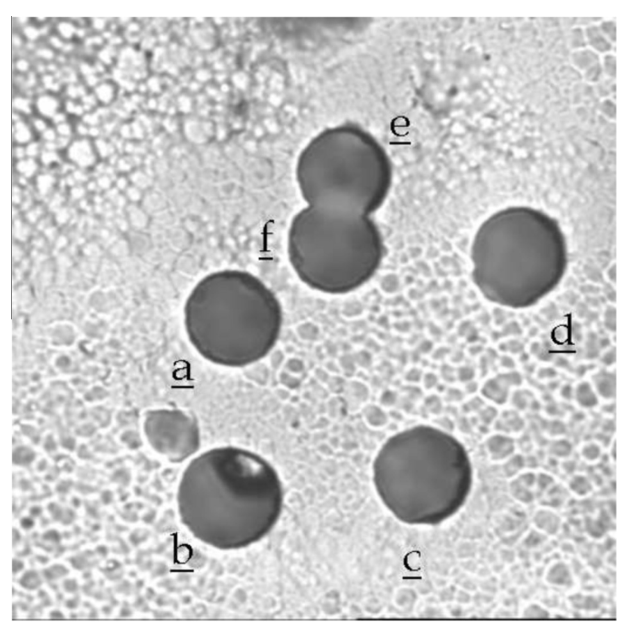

Fig. 2. The unusual event showing six similar tracks in a single image frame of the PET detector. The size of the image frame is 67 μm × 67 μm.