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Anomalous Kolar events revisited: Dark matter?

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Abstract. The possibility of the unexplained Kolar events, recorded in the 1970s and 1980s, being due to the decays of dark matter particles of mass in the range of 5–10 GeV, is pointed out.

Keywords. Dark matter; Kolar events.

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1. Introduction

Many years ago, in the cosmic ray neutrino experiments [1] and later in the proton decay experiment [2], both at Kolar gold fields (KGF) in South India, some unusual events, the so-called Kolar events, were seen. The neutrino experiments at KGF were conducted by groups from Tata Institute of Fundamental Research, India, Durham University, UK and Osaka City University, Japan. They used techniques that were perfected over many years for detecting muons with scintillation triggers and Neon Flash Tubes for tracking. Starting by the end of 1964, seven such detectors were deployed in a long tunnel at a depth of 2300 m in Champion reef mines. The Kolar events were multitrack events with some unusual features which could not be explained away by any known processes of muons or neutrinos. The two sets of Kolar events were interpreted [3–5], at that time, as due to the possible decay of a new, massive, long-lived particle produced mostly in neutrino or antineutrino collisions within the surrounding rock of the mine. We however note that searches were also made at the ν-beam experiments at CERN [6] and at Fermilab [7] but they led to negative results with bounds on cross-sections (and masses) to produce such neutral, long-lived particles in neutrino interactions. Thus, the events were neither confirmed in other experiments nor shown to be spurious by any further analyses.

Individually, such events could be caused by neutrinos (or antineutrinos) interacting with air molecules in the gap between rock wall and the detectors. Such events are rare and occur with a probability less than one in hundred years. Thus, the cause of events numbering close to ten in as many years (live time) has remained a source of puzzle since their observation.

In this short note we speculate on the possibility of these anomalous events being due to the decay of dark matter particles. Dark matter particles are ubiquitous and are present everywhere with varying densities. This also naturally explains why they were not seen in accelerator experiments with neutrino beams [6,7]. In §2, we give a brief description of the Kolar events and why they were considered anomalous. In §3, we discuss the possibility that these events may be caused by the decay of dark matter particles and make some remarks about further investigations in this direction.

2. Kolar events

The Kolar events were recorded over two periods: The first period corresponds to the period starting from the end of 1964 (for a review of KGF experiments and details of detectors, see ref. [8]). In all, seven neutrino telescopes, with a geometry that is sensitive to horizontal tracks, were installed over a period of two years in a long tunnel at a depth of 2300 m underground. The live time of all detectors combined was more than ten years. The first results on Kolar events from this period were published in 1975 [1].

The second period refers to the experiments set up to look for proton decay at 2300 m depth. Proton decay experiments were done in two phases with a live time of 8.41 yr and 5.53 yr respectively from 1980 to 1990. In all, about eight events, encompassing both periods, were found anomalous and these were referred to as Kolar events.

A few examples of such events recorded by telescopes 1 and 2 at 2300 m depth are shown in figure 1.

The characteristics of the five events reported in 1975 [1] are as follows:

(1) In the observed decays, the events consisted of two or more tracks with a large opening angle with at least one being a muon as seen from the penetrating power.
(2) All tracks of an event seemed to originate from a vertex located either in air or in the thin detector materials based on an extrapolation of projected angles of tracks. This is the most crucial fact about these events which renders them anomalous.
(3) The ratio of the number of events containing such tracks to the total number of events recorded by the detectors was about 25%. Such a rate cannot be explained by direct neutrino or antineutrino interactions.
(4) On the other hand, in the initial explanations, it was assumed that a new particle was produced in the neutrino interaction with the rock which eventually decayed in the air. The estimated cross-section for the production of an assumed new particle multiplied by the branching ratio for the observed modes was estimated to be 10^{-37} cm^2 per nucleon, similar to the weak interaction cross-section.

During the second period, each of the three events reported in 1986 [2] at a depth of 2.3 km at KGF had a penetrating track and an associated shower. The details of the events are given in table 1.

Several theoretical attempts were made [3–5,9,10] to understand the Kolar events. Both sets of events reported in 1975 and 1986 were interpreted as due to the decays of an

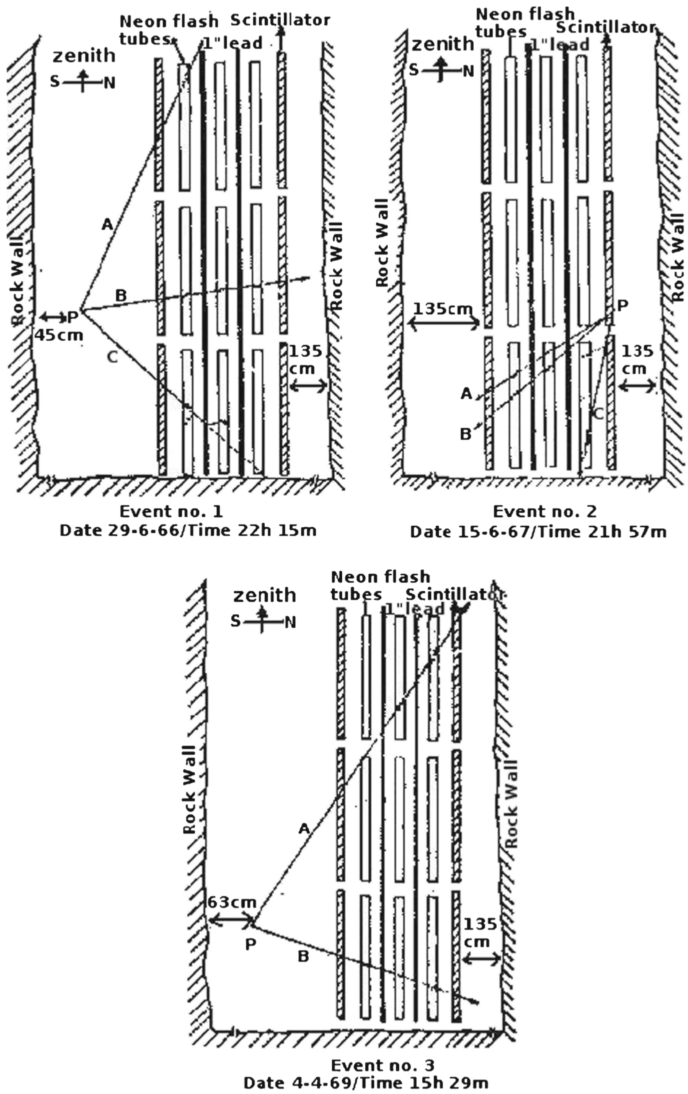

Figure 1. Multitrack (Kolar) events recorded in KGF neutrino detectors in the first period (reproduced from ref. [8] (not to scale)).

Table 1. Summary of the three events reported in 1986. The track and shower energies are given in GeV.

Event number	Penetrating track (GeV)	Shower (GeV)	Opening angle (deg)	Vertex
1	> 1.3	> 2.6	32	Air
2	> 0.4	> 2.5	69	Air or rock
3	> 1	≥ 5	41	Inside detector

unstable particle, produced in the rock medium by neutrino interactions, with a lifetime of approximately 10^{-8} s and with a mass in the range of 2–5 GeV. The decay of this new particle, in air or in the thin part of the detector, was expected to produce the signature as seen in Kolar events. While the events reported in 1975 were assumed to be due to the decays of a charged particle as there were three visible charged tracks, the later events were interpreted as due to a neutral particle decaying into a muon and possibly an electron, the electron producing the shower. However, the Kolar events have so far remained an enigmatic puzzle with no conclusive evidence emerging from other such detectors around the world. As the Standard Model is now firmly established, any attempt to introduce a new particle with mass in GeV range and Standard Model interaction will be suspect.

3. Reinterpretation – Decay of dark matter particles

In the present note, we attempt a reinterpretation of these eight Kolar events as due to the possible decay of a neutral dark matter particle (DMP), at rest, of mass around 5–10 GeV and with a very long lifetime of the order of the lifetime of the Universe, that is $\geq 10^{10}$ years. Though the existence of dark matter has been established beyond doubt, the nature of DMP is yet to be understood. In particular, not much attention has been paid to the possibility of DMP decays. A nominal lower limit on its lifetime, $\tau > 10^9$ yr [11], emerges from very simple considerations of observed dark matter density at present time. A detailed model-independent analysis of cosmological constraints on decaying dark matter gives a bound on the lifetime of decaying dark matter as $\tau \geq 10^{11}$ yr [12]. However, a combination of stable and decaying dark matter scenario relaxes the constraint on the lifetime and yields $\tau \geq 5 \times 10^9$ yr [13].

In contrast to the earlier interpretation of the Kolar events, we are now disassociating the events from neutrinos interacting in the surrounding rock. It had an inherent difficulty of explaining the large (25%) production cross-section of the new particle and that difficulty disappears with the DMP interpretation now. The DMP is present everywhere. Since the DMPs are mostly nonrelativistic, their decays must be isotropic. In the Kolar events, the tracks were seen only in one hemisphere; it is therefore possible that there were other unobserved tracks, particles not going through the detector, that would make the decay isotropic. As a result, the earlier estimates of the mass of around 2–5 GeV, using visible energy, must be regarded as a lower limit.

Invoking the isotropy of events for DMP decay, it is more likely that the mass of DMP will be in the range of 5–10 GeV of which about 2–5 GeV is assumed to be deposited in the detectors situated in one hemisphere. Furthermore, these unobserved particles in the decay must be charged in the events reported in 1975 so that it is consistent with the hypothesis of a neutral DMP overall. We note that the CDMSII Collaboration [14] has recently claimed the observation of three events in a Si detector which are interpreted as due to the nuclear recoil induced by a DMP with a most probable mass of 8.2 GeV. This mass is well within the range that one would estimate from the Kolar events after accounting for isotropy. The announcement of this result, in fact, provided the motivation for us to go back and take a re-look at the Kolar events. However, some doubt about these events has been cast by the recent results from the Large Underground Xenon (LUX) experiment [15]. No final word on CDMSII result has, however, been said yet.

We denote the local number density of DMP in the solar system as n. Note that this is not the average density in the Universe which is much smaller than this. The local DMP energy density in the solar system is expected to be in the range of GeV/cc [16]. If the effective volume of the detector chamber sensitive to the decay events of DMP is V, the mean life of DMP is τ and the branching ratio to the decay into visible modes is B, then the rate of decay events seen is given by

$$R = \frac{nVB}{\tau}. \tag{1}$$

Furthermore, if we choose $V = 10\text{ m} \times 10\text{ m} \times 10\text{ m} = 10^9$ cc, $n = 1/\text{cc}$, $B \approx 1$ and $\tau \approx 10^{10}$ yr, we get a rate $R \approx 0.1$ decays per year. It is remarkable that such a crude estimate agrees roughly with the order of magnitude of the rate of events seen in Kolar.

A few points are in order here:

(1) The estimated volume $V = 10^9$ cc is probably an underestimate. It is more likely to be around 10^{10} cc. The experiments were carried out at different times with different sized chambers and over a period of several years. Hence, the volume estimate is at best crude.
(2) The number density n of DMP locally is less than 1/cc if we assume the DMP mass in the range of 5–10 GeV. The most recent estimates, based on a detailed model of our galaxy including rotation curves, give the local DM density to be around 0.39 ± 0.03 GeV/cc [16]. This reduction will be compensated by a possible underestimation in the volume under consideration.
(3) For simplicity, we have assumed the branching ratio to visible modes to be unity.
(4) The lifetime of about 10^9–10^{10} yr, approximately the age of the Universe, for DMP decay is tantalising. This is well within the lifetime bound based on cosmological constraints with stable and unstable dark matter scenarios [13]. On the other hand, if the lifetime is much more, say about 10^{11} yr or more, then it may be impossible to observe such decays given their density at the present epoch. The present interpretation of Kolar events as due to DMP decay will not be valid any more.
(5) It is possible that not all Kolar events may be interpreted as DMP decays. If we restrict to those with vertex in the air, not in rock or inside the detector material, then the observed rate of Kolar events is lower and closer to the estimate of R obtained from eq. (1). This is a more likely scenario since the events in rock and detector material could be caused by neutrino interactions. The probability of the Kolar events being due to atmospheric neutrino interactions in the surrounding air is $\leq 10^{-3}$ events per year for neutrino energies greater than 5 GeV.

One apparent problem with the interpretation of Kolar events as due to DMP decay is its non-observation in other detectors. Earlier searches at CERN and Fermilab proved negative but they were looking for a short-lived particle produced in neutrino interactions at accelerators following early theoretical interpretations based on models which are now discarded. As these experiments specifically involved neutrino beams interacting with target material inside the detector, the negative result is easily understood.

It is also unlikely that such events may be identified in neutrino detectors such as Super Kamioka (SK) or Sudbury Neutrino Observatory (SNO) as there is no (or very little) air gap between the detector material (water) and the surrounding rock. As such, even if a DMP decays, its signature would be submerged in the huge background of neutrino events unless back-to-back geometry can be used to isolate such events. Therefore, it may be useful to have a re-look at those events which conform to the isotropy of all decay products.

On the other hand, it is possible that such anomalous events may be seen at MINOS or OPERA, where the detector position is similar to the KGF experiment – the detector is placed in a chamber with a large air gap between the detector and the rock. However, as the rate is approximately 0.1 events a year or less, any non-observation of such events in these detectors may still lie within statistical fluctuations. Nevertheless, the scenario outlined by us in this note should provide motivation for such searches at existing detectors or in the proposed future underground neutrino detectors like NOVA and INO. The effective volume at INO, due to the size of the proposed chamber, is at least 10^{11} cc. This would immediately increase the rate to 1 event per year without compensating for the aperture.

It is difficult to make clear prediction about such searches without using a consistent model for a light, 5–10 GeV, DMP decay. The models with heavy DMP decay predict a lifetime which is much higher ($\geq 10^{26}$ s) than required for explaining Kolar events [11] and therefore are not of much use in the present context.

Finally, we conclude with some general remarks. Independent of the estimates given above, the DMP decay hypothesis should be examined more closely as all the Kolar events could not have been caused by neutrinos or antineutrinos. As such, there are no other known sources or explanation of these events. The veracity of this claim can only be established by new and dedicated experiments.

If the speculation outlined in this paper is proved correct, it solves two problems in one stroke – interpretation of anomalous Kolar events and the observation of dark matter particle.

In the same vain and even independent of the Kolar events and their interpretation, any large underground detector must be in a position to see the decays of an unstable DMP. Therefore, we have one more window for searching for DMP provided it decays. Non-observation of the decays may be used to set limits on its lifetime. In fact, the absence of spectacular high-energy decay events in the past and the present large underground detectors already rules out lifetimes of the order of 10^{10} yr or less, for heavy DMPs of mass larger than 100 GeV.

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