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Was dark matter detected in India 40 years ago?

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Abstract. This paper is based on a paper written by M V N Murthy and G Rajasekaran, *Pramana– J. Phys.* **82**, L609 (2014); arXiv:1305.2715. The possibility of the unexplained Kolar events, recorded in the 1970s and 1980s, being due to the decay 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, so called Kolar events, were seen. The Kolar events were multitrack events with some unusual features which could not be explained by any known processes of muons or neutrinos.

At that time, the two sets of Kolar events were interpreted [3–5], 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. However, searches were made at the ν-beam experiments at CERN [6] and at Fermilab [7] but they led to negative results with bounds on cross-sections to produce such long-lived particles in neutrino interactions. Thus, the events were neither confirmed in other experiments nor shown to be spurious by any further analyses and so they remained as anomalous Kolar events for all these 40 years.

Now we speculate on the possibility of these events being due to the decay of dark matter particles. Dark matter particles are ubiquitous and are present everywhere. We now decouple them from neutrino interactions. This also naturally explains why they were not seen in accelerator experiments with neutrino beams.

2. Kolar events

The Kolar events were recorded over two periods: The first period corresponds to the period starting from the end of 1964. 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]. 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%.

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 y and 5.53 y respectively from 1980 to 1990. During this 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.

So, a total of eight anomalous Kolar events were seen. 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 unstable particle, produced in the rock medium by neutrino interactions, with a lifetime of $\sim 10^{-8}$ s and with a mass in the range

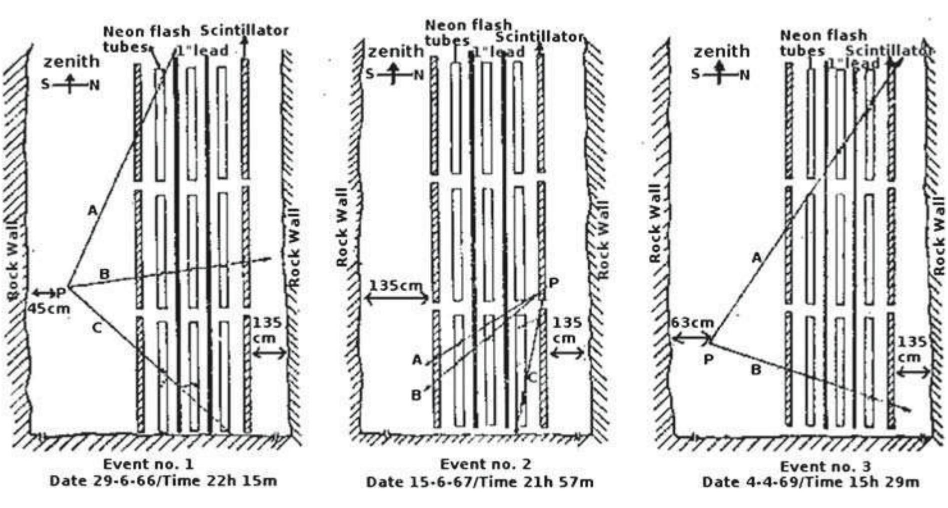

Figure 1. Multitrack (Kolar) events recorded in KGF neutrino detectors in the first period (reproduced from ref. [8] (not to scale)).

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 (°)	Vertex
1	> 1.3	> 2.6	32	Air
2	> 0.4	> 2.5	69	Air or rock
3	> 1	≥ 5	41	Inside detector

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.

3. Reinterpretation – Decay of dark matter particles

We now 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 $\geq 10^{10}$ y. 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.

In contrast to the earlier interpretation of the Kolar events, we are now disassociating the events from neutrinos interacting in the surrounding rock. The earlier interpretation 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. As DMPs are mostly nonrelativistic, their decays must be isotropic. In the Kolar events, the tracks were seen only in one hemisphere that contains the detector. 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 mass 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 was 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 [11] 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 the CDMSII events has been cast by the recent results from the large underground Xenon (LUX) experiment [12]. 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. 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

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

If we choose $V = 10\,\mathrm{m} \times 10\,\mathrm{m} \times 10\,\mathrm{m} = 10^9\ \mathrm{cm}^3$, $n = 1/\mathrm{cm}^3$, $B \approx 1$ and $\tau \approx 10^{10}$ y, 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.

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. Since 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 could be seen 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 the 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 that in 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 $\sim$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 the 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} cm^3. This would immediately increase the rate to 10 events per year.

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

A dedicated experiment has to be mounted, in INO as well as elsewhere, to either prove or disprove it. Therefore, we have one more window for searching for DMP provided it decays. Non-observation of the decays may be used to set laboratory-based 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} y or less, for heavy DMPs of mass larger than 100 GeV.

4. Theoretical models for light unstable DMP

Many models are possible. One such model is described here. We take the light DMP to be a real scalar χ which is a singlet under the SM group $SU(3) \times SU(2) \times U(1)$. Its only coupling to the SM is via the 'Higgs-portal' $\phi^\dagger\phi$, where ϕ is the usual Higgs doublet, as there are no other SM singlets. The only couplings are $\chi\phi^\dagger\phi$ and $\chi^2\phi^\dagger\phi$. It is $\chi\phi^\dagger\phi$ which will allow χ to decay.

If we impose a Z_2 symmetry under which χ has -1 quantum number, while all the SM particles have $+1$ quantum number, then χ will become absolutely stable. We shall allow Z_2 to be broken softly, but by taking the coefficient of $\chi\phi^\dagger\phi$ to be sufficiently small, the lifetime of χ will be made long enough. This is a very elegant and simple model.

But, there is a problem with this model. The constraint on the invisible width of the Higgs is in conflict with the required annihilation rate of $\chi\chi$ to provide the observed abundance of DMP. This can be fixed by adding another singlet ξ which is even under Z_2. Details will be presented in [13].

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