1993ICRC....4..621M

1993-20

High-Altitude Time-of-Flight Search for Non-Weakly-Interacting Dark Matter in Cosmic Rays

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ABSTRACT

Supermassive electrically- or strongly-charged particles might constitute the missing matter in the galaxy. These particles would be non-relativistic, but nevertheless if these hypothetical particles have high enough mass, they might have enough momentum to be detectable below 5 g/cm^2 of atmosphere. We apply the time-of-flight technique to search for these hypothetical slow-moving, supermassive, highly-interacting particles at balloon altitude. We present un-cut histograms and a scatterplot of actual flight data, showing that we can account for most of the events as accidental coincidences. We can reject most (if not all) of these accidental coincidences by requiring a 4-counter coincidence, and by requiring very small changes in velocity in the interior detectors.

1. Introduction

Contrary to popular prejudice that dark matter must be weakly interacting (e.g., WIMPs, light neutrinos), long-lived strongly or electrically *interacting massive particles* (IMPs) might be the *dominant* cold dark matter (DCDM) in the galactic halo[1,2,3,4]. Examples of IMPs include: CHAMPs (electrically CHarged Massive Particles), SIMPs (Strongly Interacting Massive Particles) and "strange" quark nuggets. Since their high interaction cross-section would have easily observable consequences, one can readily reinterpret past experiments[5,6], or invent clever arguments[7,8], to rule out these hypothetical IMPs as the DCDM, within the theoretically favored ranges of IMP mass, M_{IMP}, and number density, n_{IMP}.

However, several ideas point to an IMP mass or number density outside their current theoretically favored ranges. First, the COBE experiment suggests that CDM alone cannot explain the clumping of galaxies; hot dark matter (HDM) (e.g., light neutrinos) might be 30% of all dark matter[9]. Therefore, the IMP number density required to be the DCDM is lowered. Second, the theoretical estimates of the mass range for IMPs-as-DCDM might be too low, and the density or flux range too high. Third, the simplest models have always assumed that there is a DCDM. Why not search for the less dominant forms? Fourth, even if IMPs are not a substantial minor component of the CDM, they might exist (especially at very low number density and/or very high mass, and probably at low velocities). Therefore, IMP search experiments need a sensitivity many orders-of-magnitude better than the previously expected flux above the atmosphere of $J_{IMP} \sim 1$ cm^{-2}s^{-1}sr^{-1} (for $M_{IMP} \sim 1$

PeV). Due to the high interaction cross-section of IMPs, and the non-relativistic nature ($\beta_{CDM} \sim 0.001$, $v_{CDM} \sim 300$ km/s) of any CDM candidate, a high-altitude time-of-flight search for very slow IMPs is a plausible method to search for such low fluxes, and is discussed at length elsewhere in these proceedings[10].

2. Flight Parameters

At 2.6 UT on July 17,1992, the IMAX payload was launched on a balloon from Lynn Lake, Manitoba, Canada (56.5° LAT, 101° LON). Part of the IMAX payload included a special-purpose, low-power, lightweight, electronic slow-pulse-sequence detector module (D-module)[9], which used signals from a stack of four widely spaced 1 cm scintillator detectors, to search for slow-moving IMPs.

The balloon ascended slowly, reaching float ~7.5 hours after launch (Fig.1). Fortunately for the IMP search, the slow ascent gives us much valuable information as to a possible altitude dependence of a hypothetical IMP signal. For example, if we can measure the IMP velocity spectrum at each altitude, we might be able to estimate the velocity spectrum of IMPs before encountering the atmosphere, and perhaps even the IMP mass.

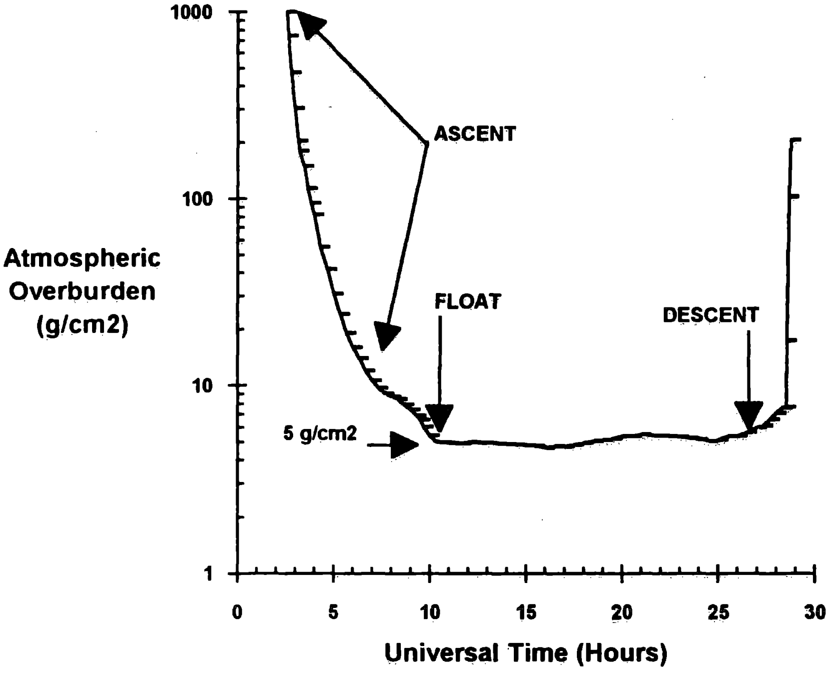

Fig. 1: Atmospheric overburden versus universal time during the IMAX flight, July 17-18,1992 (0.0 UT = Midnight on 7/16/92). Arrows indicate the times when the payload reached float altitude, and when the payload began to descend. Note the rather long ascent.

Soon after dawn (~10 UT), the IMAX payload finally reached float altitude, 5 g/cm^2, and remained at float for ~15 hours. At 15.1 UT, there was a sudden onset of subtle electrical noise in the D-module in the IMAX payload, as evidenced by more RMS scatter and a slight upward shift in the D-module's time-delay pedestals. The internal payload temperature increased significantly during the flight, heating the electronics to above 45°C. At ~2.5 UT, 7/18/92, the bending magnet was turned off, and the balloon operators commanded a partial release of helium from the balloon, which caused the payload to gradually descend to ~8 g/cm^2, over a 2 hour period.

At 4.5 UT, the balloon payload was cut-down, over Peace River, Alberta (56.6° LAT, 118° LON).

3. IMP Search Data

In Figure 2, we present a ~2 hour sample of the IMP search data from the IMAX flight. At the Calgary ICR conference, we will present an analysis of the complete IMP/IMAX data set. This analysis should be sensitive to IMP fluxes, $J_{IMP} \geq J_{IMP,min} = 10^{-7}\ cm^{-2}s^{-1}sr^{-1}$, only limited by the length of the flight[10].

The *uncut* data in figure 2 includes histograms of the D-module's time delay measurements. For accidental coincidences, we expect uniform (flat) distributions for all three channels (Δt_{12}, Δt_{23}, Δt_{34}). Within statistical fluctuatations, all three histograms seem to be nearly uniform. A cross-correlation scatterplot of reciprocal velocities ("slownesses"), $s_{12} = 1/v_{12}$ vs. $s_{23} = 1/v_{23}$, is also shown in Figure 2. A hypothetical IMP signal might show an excess darkening along the diagonal from $(s_{12},s_{23}) = (1,1)$ µs/m to $(s_{12},s_{23}) = (10,10)$ µs/m. No such signal is clearly visible.

We will quantitatively refine our analysis of the IMP search data set for the Calgary 1993 ICRC. With the complete IMP/IMAX data set, we will demand that any candidate IMP event be closer than ~0.03 µs/m to the above "no-delta-slowness" diagonal ($\Delta s \equiv s_{23} - s_{12} \approx 0$), *and* also require that $s_{34} \approx s_{23} \approx s_{12}$. These stringent requirements should give us the the sensitivity to see *single* IMP events during a 24 hour flight.

ACKNOWLEDGEMENTS

We would like to thank T. Metcalfe, P. Halverson, R. Norton, A. Pifer, L.Russo, J. Pando, R. Hall, D. Righter, R. Park, G. Albritton, S. Holder, M. Simon, O. Reimer, W. Menn, B.Kimbell, R. Golden, and "Max" for their assistance in preparing for the balloon flight, and the University of Arizona Experimental Elementary Particles Group for access to their more-than-adequate VAX-cluster for post-flight data analysis. A U.S. Dept. of Education/NSF fellowship supported P. McGuire for much of the pre-flight preparations. This work is also supported by NSF Grant 91-21427.

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Fig. 2 (Descent Data) Time Delay Histograms and Slowness Scatterplot.