A Dark Matter Hypothesis for the Cowan Effect – A Peak at 21 hr LST for μ-e Decay Events

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Abstract

A dark-matter (DM) hypothesis is proposed to explain several 1960's experiments in which Clyde L. Cowan's group observed μ-e decay events with a sharp, statistically significant intensity peak near 21 hr LST (denoted the Cowan Effect). The zenith happened to be near 39 deg N and 21 hr RA, remarkably close to the direction (∼47 deg N, ∼21 hr RA) of our galactic spiral arm and of the sun's motion in the galaxy. If galactic DM includes a nonrotating, strongly-interacting component (SIMPs), it would arrive at Earth as a highly directional "wind," peaking at ∼21 hr LST–a huge Compton-Getting Effect for DM $\frac{v}{c} \sim 1/1000$. The μ-e decay detectors were omnidirectional, but their response would be strongly peaked at the zenith if the atmosphere highly attenuated the primary particles. A model is presented in which the slowly-moving, neutral SIMPs are captured by N and O nuclei, emitting at least one pion or kaon which decays into a muon.

1 Introduction:

In the late 1960's Clyde Cowan's group in Washington, DC (38.8 deg N latitude), plotting their μ-e decay rates as a function of Local Sidereal Time [LST], observed a narrow peak near 21 hrs LST in three independent experiments [Ryan et al(1996); Buckwalter, Cowan & Ryan(1966): Buckwalter, Steffy & Steffy(1969)]. In the late 1980's astronomers and physicists began to seriously consider the evidence that ∼90 percent of a galaxy's mass resides in a halo of dark matter, and that our solar system's motion in the direction 20.9 hr RA, 47.6 deg N would appear at Earth as a DM wind from that direction [Primack, Seckel & Sadoulet(1988); Avignone & Collar(1992)]. Could this close agreement be more than a coincidence?

2 The Cowan Effect:

Cowan introduced a counter arrangement sensitive to muons produced by neutral particles in sea-level cosmic radiation. It consisted of a fairly large mass (∼200 to 600 kg) of plastic or liquid scintillator –the target– surrounded on all sides by scintillation counters connected in anticoincidence to veto events caused by charged particles: μ-e decay events were detected by observing pairs of target pulses separated by 0.3 to 6.3 μs. The experiments were located in a sub-basement with 5 floors above, corresponding to a thickness of 400 g/cm^2 of concrete above (but with a "window" opening between 30 deg to 50 deg from the zenith to the west with ∼35 g/cm^2 thickness). Originally, Cowan hoped that the shielded muon detector would respond to cosmological neutrinos, although he knew that the energetic neutrons in the cosmic radiation were causing at least some of his events, and late in his research program (and near the end of his life) his students found that a large fraction of his events were leakage of ordinary cosmic ray muons through the anticoincidence shield.

Of interest are two runs reported by the Cowan group for independent sets of equipment in 1965 and 1966, and another by his former student, Gary Buckwalter in 1968-1969. Experiment I ran 8 months from 11 May 1965 to 7 Jan 1966 with ∼240 kg target. Experiment II ran 2 months from 11 Jan 1966 to 15 Mar 1966 with ∼650 kg target. Each experiment observed a narrow peak near 21 hr Local Sidereal Time (LST): in Experiment I, its 5.1 standard-deviation peak was entirely within a 1.5 hr histogram interval; in Exp.II, the 4.2 σ peak had a FWHM ∼4 hr. The peak centers were at 20.75 hr LST for Experiment I and ∼21.8 hr LST for Experiment II. For convenience, these observations are denoted the Cowan Effect. In Experiment III (Buckwalter), which was conducted in Indiana, Pennsylvania at 40 deg N and 1450 ft. elevation, from 28 July 1968 through March, 1969, muons were required to enter the target from only a vertical direction. The 3.2 σ peak, located at ∼21.9 hr LST, had a FWHM ∼3 hr. The author is aware of only one independent effort, by

Subramanian and Verma [Subramanian & Verma (1983) and (1989)] in Bombay, India, attempting to confirm the Cowan Effect, but their latitude may have been too unfavorable for effects aligned with our galactic arm.

3 Possible astrophysical origin of the Cowan Effect:

For the purpose of designing experiments to confirm the Cowan Effect and, if confirmed, to investigate its astrophysical origins, a model hypothesis has been constructed in which a strongly-interacting component of dark matter (DM) interacts in the upper atmosphere, eventually giving rise to the muons causing the Cowan Effect. Such a model must account for why Cowan's omnidirectional μ-e detector would selectively respond to muons whose primaries entered the atmosphere near the zenith. If the primaries are DM particles (typical $\frac{v}{c}$ ~0.001), how could the isotropically produced muons communicate the DM anisotropy to the μ-e detector? Why might there be a DM anisotropy aligned with our galactic arm? Moreover, if most DM discussions feature neutrinos and weakly-interacting massive particles (WIMPs), is it possible for DM to include a component of strongly-interacting massive particles (SIMPs)? Let us consider these in reverse order.

3.1 SIMPs: According to the Big Bang model for the evolution of our universe, ordinary matter gradually cooled and accumulated into stars and galaxies because a large amount of kinetic energy could be radiated as photons. Primordial elementary particles which were stable and neutral would remain as a gas of DM, some of which was gravitationally bound as a halo to each galaxy. It has been estimated [Goodman & Witten (1985); Goldberg & Hall (1986)] that SIMPs with an interaction cross section on protons as high as 10^{-23} cm^2 could remain in the galactic halo as a DM component. Such a SIMP component, even if minor, might be relatively easy to detect in a form such as the Cowan Effect, providing valuable, real-time information about DM.

If our galactic DM halo is non-rotating (or very slowly rotating), as seems likely if the rotational velocity of ordinary matter increased as it aggregated into a galaxy, there will be a very large Compton- Getting Effect [Compton & Getting (1935)] or DM wind due to the Earth's motion with respect to our galaxy–a motion almost parallel with our galactic arm, and in a direction revolving annually around 20.9 hr RA, 47.6 deg N declination; if gravitational bending of DM trajectories by the Sun and Earth is neglected, the RA ranges from 20.2 hr in late January to 21.6 hr in mid August and the declination from 41.7 deg N in mid April to 54.8 deg N in late October. Gravitational bending changes the phase of the seasonal variations and may enlarge the spread in directions. Slow seasonal position and amplitude shifts are expected because the Earth's velocity modulates the magnitude and direction of the Sun's velocity by ± 12 %.

When a SIMP, assumed to be neutral, interacts with N or O nuclei in the atmosphere, it is assumed that the cross sections are proportional to $1/v$, a characteristic of exothermic reactions. This implies that the most energetic SIMPs will, on average, penetrate most deeply into the atmosphere. In the direction of the DM wind, not only is the intensity greatest, but the distribution of velocities relative to Earth is shifted to its highest position. The SIMPs must also suffer elastic scattering, probably with cross sections comparable to the sizes of N and O nuclei. It is likely that the SIMPs have a mass comparable to the N and O nuclei so that they lose energy with each elastic collision, tending to result in a finite range, but still velocity-dependent so that the maximum depth of penetration is correlated with the DM wind direction's closeness to the local zenith. Thus, when the DM wind direction is aligned with the zenith, both the intensity and the depth of penetration are at their maxima.

3.2 Muons: No assumptions are made about the one or more steps initiated by the inelastic SIMP-nuclear interaction which leads to muons. However, the low center-of-mass momentum would insure an s-wave interaction if the interaction has the finite range typical for nuclear forces, so it is likely that the muons would be emitted isotropically.

Any μ-e decay detector, unlike most particle detectors, only counts muons which reach the end of their range within the target scintillator mass. Assume that the energy spectrum of the emitted muons is such that none reached Cowan's μ-e detectors vertically through the concrete floors of the building, above, but some muons could reach the target through the west window at 30 deg to the zenith. *If the production energy spectrum for these stopping muons rises rapidly with decreasing energy, the μ-e decay event rate will rapidly increase to a sharp peak as the DM wind direction approaches the zenith where the DM SIMPs reach their maximum depth* and will decrease just as rapidly as the wind direction moves away from the zenith. In addition, the fraction of mesons reaching the detector without decaying in flight is a maximum when DM reaches its maximum depth.

4 Information from search experiments affecting the hypothesis:

4.1 Upward Muons: During more than two years of experimentation [Young, McGuire, & Bowen (1999)] with μ-e detectors in Tucson, Arizona (32.3 deg N latitude, 945 g/cm^2 atmospheric depth) and on nearby Mt. Lemmon (750g/cm^2 atmospheric depth), the results have eliminated several scenarios and suggested others. Most importantly, we considered that Cowan's μ-e events might be neutral particles interacting within his target scintillator, as he intended. As we lacked the resources to provide an effective 4π anticoincidence shield for our 120 kg μ-e detector in Tucson, we reasoned that such neutral particles must also interact in the floor and other material below the target scintillator, emitting upward going secondaries. Since the muons might be the result of pion or kaon decay, an in-flight decay space was provided by mounting the target scintillator 1.2 m above floor level, with a 0.6 m square, 1 cm thick plastic scintillator directly underneath. The data for 148 days was examined for muons entering the bottom of the target scintillator and decaying; there was no evidence of a Cowan Effect enhancement near 21 hr LST.

4.2 Magnetic Bending: In our more recent mountain experiment with four 205 kg target cells arranged in a square, there is strong evidence in 30 days of data of a peak in the 18 to 20 hr LST histogram bin of a Cowan Effect candidate for muons entering through a 0.6 m square counter centered over the group of four cells, but located 1.86 m above the target scintillators. When the data is plotted separately for the four cells, most of the enhancement appears in the two cells displaced to the east. This may indicate that the muon trajectories are affected by the Earth's magnetic field. This also seems consistent with our interpretation in Cowan's original experiments that the muons entered from the west at 30 deg from the zenith. Since the muons slow down in the atmosphere, most of the bending occurs near the end of the trajectory. It is assumed that the atmospheric density profile can be approximated using a straight-line trajectory by ρ(s)$\approx$ [ρ(ground)][exp$(-s \times \cos\theta/h_0)$], where θ is the inclination of the muon trajectory with respect to the zenith, $h_0 \approx 8 \times 10^5$ cm, and the muon momentum loss is approximated as a constant $\approx$ 1.82 MeV/(g/cm^2). The total bend Θ in radians is

$$\Theta \approx [(71.1\cos\lambda)/(P_{target} + 1.67D)][s \times \cos\theta/h_0 + ln[(a - exp(-s \times \cos\theta/h_0))/(a-1)]] \qquad (1)$$

where λ is the magnetic latitude of the detector, P_{target} is the muon momentum in MeV/c as it leaves the air into condensed matter, D is the detector's atmospheric depth in g/cm^2, s is the muon's trajectory length in cm, and $a = 1 + 0.6P \times \cos\theta/D$. Typical predictions for the Mt. Lemmon detector are: first 8 km above detector, 6.5 deg; second 8 km, 3.0 deg; third 8 km, 2.6 deg; fourth 8 km, 2.5 deg and for Cowan's detector: 5.2 deg, 2.1 deg, 2.0 deg, 1.7 deg. These figures show that, if the Cowan Effect is confirmed for muons near the zenith entering the μ-e detector, μ^+ and μ^- should be resolvable into separate westward and eastward peaks.

4.3 Narrow Peaks: The observations, both in the original Cowan experiment and in several Arizona runs, indicated that a very narrow peak, with a FWHM less than 2 hr, was sometimes possible. This suggested that, in addition to the $1/v$ law for SIMP attenuation by absorption, another mechanism, such as a finite SIMP range due to elastic scattering, discussed earlier, also must be invoked in this model. Then, each SIMP not only has a distribution of ranges whose average increases with initial velocity, but the distribution's upper tail decreases toward zero more rapidly than exponential in g/cm^2 of atmospheric depth. If, on the other hand, only the $1/v$ absorption attenuates SIMPs with the highest velocities, and if the μ-e detector responds only to muons near the zenith, then the μ-e rate will depend exponentially on depth with the same exponent as the SIMPs. This case has been investigated in detail using a Maxwellian velocity of galactic DM transformed to the Earth frame. It was found that for realistic amounts of attenuation ($\sim 10^{-8}$), the FWHM of the peak in LST would be ∼4 hr, and that further narrowing was proportional to the square root of the exponent.

4.4 Seasonal Depth Variation: In a second 20 day mountain experiment run April 20 to May 9, 1999, no peak was observed near 21 hr LST. This alerted the author to note that the Sun + Earth velocity in the galaxy is a minimum each December 4th and 13 % higher at a maximum each June 4th [Primack, Seckel & Sadoulet, 1988]. This suggests that the g/cm2 depth of the μ-e detector may be critical for observation of the Cowan Effect with vertical muons – least near December 4th and greatest near June 4th.

4.5 Muon proper times in flight: Calculating the duration of the proper time for muon's flight employs the same integrals used for the bend angle, so the proper time duration in units of the muon mean lifetime is given by substituting 17.8 for $\cos\lambda$ in the above formula for Θ, the total bend in radians. Typical predictions, corresponding to the bend-angle figures above, are for Mt. Lemmon: 2.4, 1.1, 1.0, 0.9 lifetimes and for Cowan: 2.1, 0.8, 0.7, 0.7 lifetimes. It is evident that muon decay is more effective in further narrowing the Cowan-Effect peak if the DM can penetrate to less than 8 km above the detector.

5 Summary:

The hypothesis has been presented that galactic DM may contain a strongly-interacting component, SIMPs, which interact in the atmosphere to directly or indirectly produce muons. Both the DM flux and depth of penetration would be at maximum when the DM wind direction coincides with the local zenith. If the μ-e detector has a suitable combination of location, depth, and aperture, the μ-e rate may be very sensitive to the depth reached by the SIMPs both due to a steep muon energy spectrum and to muon decay in flight. If one could design a SIMP with the properties required by this model, it might be a *stable, massive anti-neutron.*

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