Solar System Velocity from Muon Flux Anisotropy

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The cosmic-ray muon half-life, being proportional to $g = 1/\sqrt{1-v^2/c^2}$ *, depends upon its absolute velocity* $v^2 = v'^2 + 2\mathbf{v}'\cdot\mathbf{v}_o + v_o^2$*, where* $\mathbf{v}'$ *is the muon velocity relative to the Earth and* $\mathbf{v}_o$ *is the absolute velocity of the solar system. The sea-level muon flux then depends upon* $\mathbf{v}_o$ *through* $\mathbf{v}'\cdot\mathbf{v}_o$*. An approximate theory is presented for the absolute velocity of the solar system* $\mathbf{v}_o$ *as a function of the expected anisotropy of the sea-level flux of muons as a function of the celestial direction of* $\mathbf{v}'$*. A cosmic ray telescope was used to measure the muon flux as a function of the celestial direction. The observations yield a solar system velocity of* $\mathbf{v}_o = 359 \pm 180$ *km/s in the direction of right ascension* $a_o = 8.7 \pm 3.5^h$ *and declination* $d_o = -1.1 \pm 10.0°$ *in reasonable agreement with results reported involving other methods.*

I. Significance of this research

It is of interest to know the absolute velocity of the solar system for a number of reasons: The fact that a solar system velocity can be observationally determined is further evidence for the existence of absolute space, a stationary ether, or a preferred zero velocity frame of reference, and it provides evidence against relativity theories. The measured value of the absolute velocity of the solar system, after subtracting off the velocity due to the general Milky-Way galactic rotation and translation, might provide an indication of dark neighbors to the solar system. Observations continued over the years might provide additional information.

Bradley stellar aberration due to the absolute uniform motion of the solar system produces a small ($v_o/c \sim 10^{-3}$) fixed distorted or astigmatic view of the position of stars and planets (Wesley 1991a). To obtain accurate predictions based upon classical celestial mechanics observations should be corrected for this aberration. For example, an adequate prediction of the precession of the perihelion of Mercury requires this correction using a reasonably accurate value of the absolute velocity of the solar system.

The present measurement sheds light upon the long-standing important question: What velocity should be used in the gamma factor, $g = 1/\sqrt{1-v^2/c^2}$? This factor occurs in the Voigt-Doppler effect for light (Wesley 1980, 1983, 1986, 1987, 1991b) (usually inappropriately referred to as the "relativistic" Doppler effect) and in the mechanics of fast particles, where the momentum is $\mathbf{p} = mg\,\mathbf{v}$, where m is the rest mass. The present results indicate experimentally for the first time that the velocity to be used in the g factor is the absolute velocity. Ordinarily laboratory or relative velocities have been used in the g factor. The justification for using such partial velocities should now be checked out by first introducing the complete absolute velocity. It may be shown, for example, that the constant absolute velocity of the laboratory (equal to that of the solar system of about 300 km/s) will ordinarily play no role.

2. Other determinations of the absolute velocity of the solar system

Since an observer moving toward a source sees light Doppler shifted toward the violet and moving away sees a Doppler shift toward the red, de Vaucouleurs and Peters (1968) examined the red shifts of 204 galaxies within 75 Mps. Optimizing the isotropy they estimated the solar system to have the absolute velocity shown in Table 1 below. Similarly Rubin *et al.* (1976), considering a shell of 200 galaxies at a distance of 100 Mps, obtained the estimate of the velocity also shown in Table 1.

A more reliable estimate of the solar system velocity was obtained by Conklin (1969) by measuring the anisotropy of the 2.7 K cosmic thermal background radiation from the ground. Henry (1971), making observations from a balloon, obtained the best value to date using the 2.7 K anisotropy. Others, such as Smoot *et al.* (1977), have also made measurements using the 2.7 K background anisotropy.

Marinov (1974, 1977, 1980a), with a "coupled mirrors" device, determined the absolute velocity of the solar system from the anisotropy of the one-way speed of light c^* observed in opposite directions, where

$c^{\star}(\pm) = c \pm \mathbf{c}\cdot\mathbf{v}_o/c$ where $\mathbf{c}$ is the velocity of light relative to absolute space and $\mathbf{v}_o$ is the absolute velocity of the laboratory or solar system. Marinov (1980b, 1984) again determined the absolute velocity of the solar system from the anisotropy in the observed one-way velocity of light using two toothed wheels on the ends of a rotating cylinder. Marinov's "coupled mirrors" result is the most accurate measurement of the absolute velocity of the solar system to date. This simple elegant experiment can be repeated with improvements (Wesley 1991c) to obtain a still more accurate value.

Still other practical methods are readily available to measure the absolute velocity of the solar system, such as comparing the interference intensities produced by oppositely directed beams passing through the one-way Sagnac device (Wesley 1991d), or by measuring terrestrial Bradley aberration from its effect on parallax (Wesley 1992).

3. Theory

Muons are created high in the Earth's atmosphere from the decay of pions with a minimum kinetic energy (Leighton 1959a) of 33.9 Mev. Muons decay rapidly with a half-life for stationary muons (Leighton 1959b) of $t_o = 2.22\times10^{-6}$ s. The flux of muons at sea level is, thereby, reduced during the transit time from the point of creation of the muon to sea level. Considering the half-life t_o and the time of flight of the muons, an excess of muons is observed at sea level. In particular, the half-life of a radioactive particle moving with the velocity v, as observed by Bailey *et al.* (1977), is given by

$$t = g t_o = t_o\left(1-\frac{v^2}{c^2}\right)^{-1/2}. \qquad (1)$$

The g factor in Equation (1) arises as a statistical mechanical effect in neomechanics, where $\mathbf{p} = mg\,\mathbf{v}$ and absolute space and time is assumed (Wesley 1991e). This effect, Equation (1), does not constitute evidence for "time dilation."

Assuming the muon velocity in the g factor occurring in Equation (1) is the absolute velocity, then

$$\mathbf{v} = \mathbf{v}' + \mathbf{v}_o, \qquad (2)$$

where $\mathbf{v}'$ is the muon velocity relative to the Earth and $\mathbf{v}_o$ is the absolute velocity of the Earth or solar system. The absolute velocity of the Earth is essentially the absolute velocity of the solar system of about 300 km/s, the Earth's orbital velocity about the Sun being 30 km/s and its tangential velocity of rotation being only 0.5 km/s.

Since it is generally accepted that the g factor in Equation (1) produces a large effect on the sea-level flux of muons, and the absolute velocity of the solar system $\mathbf{v}_o$ enters in through Equation (2), the absolute velocity of the solar system should produce a large effect on the observed sea-level muon flux. In particular, the muon flux should be a function of the direction, since v^2/c^2, occurring in Equation (1) from Equation (2) yields

$$v^2 = v'^2 + v_o^2 + 2\mathbf{v}_o\cdot\mathbf{v}' \cong v'(v' + 2\mathbf{n}\cdot\mathbf{v}_o), \qquad (3)$$

where $\mathbf{n}$ is a unit vector in the direction of $\mathbf{v}'$ and where v_o has been neglected compared with the muon speed v', which for a muon of energy in excess of 33.9 Mev is about the speed of light c.

The magnitude and direction of the muon flux were measured with a cosmic ray telescope, as described below.

The flux of muons generated at the altitude h in the range dh with the kinetic energy E in the range dE in the direction $\mathbf{n}$, the direction of the cosmic ray telescope, is given by

$$\frac{\mathrm{d}^2U}{\mathrm{d}h\,\mathrm{d}E}. \qquad (4)$$

Due to radioactive decay in flight the flux at sea level is reduced by the factor

$$f = \exp\left(-\frac{t}{t}\right), \qquad (5)$$

where t is the time to travel the distance from the source to the point of observation at sea level and where t is the half-life given by Equation (1). In particular,

$$t = \frac{h}{v\cos q}, \qquad (6)$$

where $h/\cos q$ is the slant distance from the source to the point of observation and q is the zenith angle of the telescope. Since the cosmic ray telescope was arbitrarily chosen to lie in a meridian plane, the zenith angle q equals the difference between the latitude of the observatory on the Earth $d = 47.206°$ north and the chosen declination d of the telescope, or $q = |d - d'|$. The time needed for the muon to proceed from the source to the sea level observer from Equation (6) is then

$$t = \frac{h}{v\cos(d - d')}. \qquad (7)$$

Combining Equations (7), (5), and (1), the decay factor becomes

$$f = \exp\left\{-\frac{h}{t_o v g\cos(d - d')}\right\}. \qquad (8)$$

Multiplying Equations (4) and (8) for the sea-level flux S in the direction $\mathbf{n}$ (whose declination is d), noting that the solid angle subtended at the telescope by the horizontal source element of thickness dh is

$\mathrm{d}h\cos(d-d')$, and integrating over all altitudes h and all energies E, yields

$$S=\int \mathrm{d}h\cos(d-d')\int \mathrm{d}E\, f\,\frac{\mathrm{d}^2U}{\mathrm{d}h\,\mathrm{d}E}\,. \qquad (9)$$

To a first approximation these integrations may be evaluated by the mean value theorem for integrals to yield the sea-level muon flux in the direction **n** as

$$S=\cos(d-d')\bar{f}\overline{U}\,. \qquad (10)$$

where $\bar{f}$ and $\overline{U}$ are computed from appropriately chosen mean values for h and v.

Since for fast muons the kinetic energy E is given by

$$h=\frac{E}{mc^2}=g-1, \qquad (11)$$

the mean muon velocity in terms of the mean kinetic energy is given by

$$\frac{v^2}{c^2}=\frac{h(2+h)}{(1+h)^2}=1-\frac{1}{g^2}\,. \qquad (12)$$

Since the absolute velocity of the solar system is known to be about $10^{-3}c$, the absolute velocity of the muon is only slightly less than c, the absolute velocity of the solar system v_o may be regarded as a differential of the absolute velocity of the muon itself. Thus, from Equation (3)

$$\mathrm{d}v=\left|\mathbf{v}'+\mathbf{v}_o\right|-v'=\mathbf{n}\cdot\mathbf{v}_o\,, \qquad (13)$$

where $v'\sim v$ and where $\mathbf{n}\sim\mathbf{v}/v$ is the direction of the muon and the telescope.

The effect of the absolute velocity of the solar system on the sea-level muon flux may then be obtained by taking the differential of Equation (10). Thus, the difference between the flux S in the direction **n** and the muon flux $\overline{S}$ averaged over all directions is then

$$\Delta S=S-\overline{S}=\frac{\mathrm{d}S}{\mathrm{d}v}\mathrm{d}v=\frac{\mathrm{d}S}{\mathrm{d}v}\mathbf{n}\cdot\mathbf{v}_o\,. \qquad (14)$$

Taking the derivative of Equation (10) with respect to v, the fractional difference becomes

$$\frac{\Delta S}{S}=\frac{\mathbf{n}\cdot\mathbf{v}_o g^3 h}{c^2 t_o(g^2-1)\cos(d-d')}\,. \qquad (15)$$

Inverting Equation (15) then yields the desired velocity; thus,

$$\frac{\mathbf{n}\cdot\mathbf{v}_o}{c}=K\cos(d-d')\frac{\Delta S}{S}\,, \qquad (16)$$

where K is given by

$$K=\frac{ct_o(g^2-1)}{hg^3}\,, \qquad (17)$$

where appropriate mean values must be chosen for h and g.

The peak ionization (Leighton 1959c) occurs around an altitude of about 16 km, where the incident primary protons and other nuclei generate the most pions and muons. Since most muons are created at about 16 km and few are created below, the mean effective value for h that is appropriate for evaluating the integral in Equation (9) may be taken as simply

$$h(\text{mean}) = 16\text{ km}. \qquad (18)$$

The surviving muon flux at sea level may be attributed primarily to radioactive decay, the interaction of muons with matter being small.

The kinetic energy (Leighton 1959a) given to a muon by a stationary pion is 33.9 Mev, so the minimum value of g from Equation (11) is then $g(\text{min}) = 4/3$. There is no particular upper limit to the muon energy, but the number of muons with higher energies drops off rather rapidly with energy. For a 200 Mev muon $g = 3$. Assuming a reasonable kinetic energy appropriate for evaluating the integral in Equation (9) of E = 100 Mev, the mean value of y becomes

$$g(\text{mean}) = 2. \qquad (19)$$

Substituting Equations (18) and (19) into (17) yields the estimate

$$K = 0.016, \qquad (20)$$

where a fractional uncertainty of 20 percent might be appropriate. The theoretical prediction from Equations (16) and (20) then becomes

$$\frac{\mathbf{n}\cdot\mathbf{v}_o}{c}=0.016\cos(d-d')\frac{\Delta S}{\overline{S}}\,. \qquad (21)$$

4. The Experiment

The cosmic ray telescope consisted of two gamma-ray sensitive (above about 40 KeV) Geiger-Müller counters (Philips Type 18503, cylinders of length 4 cm and radius 1.5 cm) aligned with their axes parallel to each other a perpendicular distance 53 cm apart. The axis of the telescope, the perpendicular through the center of the two counters, was mounted to lie in a meridian plane (a vertical north-south plane where a, the right ascension, is constant), such that the axes of the two counters were also in the meridian plane. From this geometry the acceptance angle in right ascension was Δa = 3.2° and in declination was Δd = 8.8°.

All values of the right ascension were attainable as the Earth rotated through 360° in a day. Different values of the declination were obtained by tilting the telescope with respect to the vertical (the zenith in the meridian plane with a declination of d' = 47.2°, the latitude of the observatory in Freienbach, Switzerland).

Since about 80 percent of the cosmic ray particles observed at sea level (or at 420 m above sea level where the telescope was located) are muons, the cosmic ray telescope, being sensitive to such penetrating ionizing particles, registered counts proportional to the muon flux in the direction of the telescope. Moreover, the knock-on electrons and gamma rays, as well as the decay electrons of more than 100 Mev, proceeding in the same general direction as the original muons themselves, also contribute to the effective telescope counts. Since only the directional variation in the muon flux is needed and not the absolute magnitude of the flux, as indicated by Equation (21), results were essentially independent of the sensitivity of the Geiger-Müller counters used.

The Geiger-Müller counters registered a background count due to radioactivity in the air, earth, laboratory walls, equipment, and the counters themselves. This background can lead to false coincidence counts between the two counters in the cosmic ray telescope. These background coincidences, which are independent of the celestial direction, must be subtracted from the observed coincidences to obtain the true signal desired. Hills to the south of the observatory blocked a view of the open sky at angles close to the horizontal, 5°, making a direct measurement of this accidental background possible without having to alter any of the other parameters of the setup. A mean background of 1.8 coincidences/day was measured, 15 percent of the maximum observed signal, or 20 percent of the maximum true signal. Considering the recovery time between counts of the Geiger-Müller counters of about 200 ms and the coincidence window of the electronic setup of about 260 ms such an accidental coincident rate would be expected if each unshielded counter registered about 9 accidental counts/min, which is in reasonable agreement with the manufacturer's 10 counts/min for a shielded counter.

Considering the acceptance angles of the telescope ($\Delta d = 3.2°$ and $\Delta d = 8.8°$), measurements were made every 6 degrees in right ascension (60 values) and in declination (22 values). Data covering the whole sky was accumulated over an 18 year period involving 3600 days and a total of 32,369 coincident counts. The recording of the data and the motion of the telescope were automated. Little human intervention was required.

5. Computations

For a particular telescope direction of right ascension $a = a_i$ and declination $d = d_j$ where the absolute velocity of the solar system $\mathbf{v}_o$ is in the direction a_o, d_o and the declination of the observatory is d', Equation (21) becomes

$$V\left[\cos(a_i - a_o)\cos d_o \cos d_j + \sin d_o \sin d_j\right] = X_{ij}, \quad (22)$$

where

$$V = \frac{v_o}{cK} \text{ and } X_{ij} = \frac{\cos(d_j - d')\Delta S_{ij}}{\overline{S}}, \quad (23)$$

where $\Delta S_{ij} = S(a_i, d_j) - \overline{S}$ and K is defined by Equations (17) and (20).

It is convenient to divide the data into two groups, a_i and a_i', one for $0 \le a_i \le p$ and the other for $p \le a_i' = a_i + p \le 2p$, to form the sum and difference defined as follows:

$$\begin{aligned} P_{ij} \sin d_j &= V \sin d_o \sin d_j \\ &= \frac{X_{ij}(a_i, d_j) + X_{ij}(a_i + p, d_j)}{2}, \\ A_{ij} \cos d_j &= V \cos d_o \cos d_j \cos(a_i - a_o) \\ &= \frac{X_{ij}(a_i, d_j) - X_{ij}(a_i + p, d_j)}{2}. \end{aligned}, \quad (24)$$

Similarly it is convenient to divide the data into two groups, a_i'' and a_i''', one for $-p/2 \le a_i'' = a_i - p/2 \le p/2$ and the other for $p/2 \le a_i''' = a_i + p/2 \le 3p/2$, where again $0 \le a_i \le p$, and to form the difference defined by

$$\begin{aligned} B_{ij} \cos d_j &= V \cos d_o \cos d_j \sin(a_i - a_o) \\ &= \frac{\left[X_{ij}(a_i - p/2, d_j) - X_{ij}(a_i + p/2, d_j)\right]}{2}. \end{aligned} \quad (25)$$

From Equations (24) and (25), a_i may be eliminated and the following average quantities formed:

$$\begin{aligned} P_j \sin d_j &= V \sin a_o \sin d_j = \\ &\sum_i \frac{\left[X_{ij}(a_i, d_j) - X_{ij}(a_j + p \cdot d_j)\right]}{2M}, \\ Q_j \cos d_j &= V \cos a_o \cos d_o \cos d_j \\ &= \sum_i \frac{(A_{ij} \cos a_i + B_{ij} \sin a_i)}{M}, \\ R_j \cos d_j &= V \cos a_o \cos d_o \cos d_j \\ &= \sum_i \frac{(A_{ij} \sin a_i - B_{ij} \cos a_i)}{M}, \end{aligned} \quad (26)$$

where the summations are taken over the M values of a_i equal to one half the total number of values over 360°.

A value of the absolute velocity of the solar system $\mathbf{v}_o$ may be obtained from Equations (26) for each value of d_j (except $d_j = p/2$), thus,

$$\begin{aligned} (v_o)_j &= cK\sqrt{P_j^2 + Q_j^2 + R_j^2}, \\ (a_o)_j &= \tan^{-1}\left(\frac{R_j}{Q_j}\right), \\ (d_o)_j &= \tan^{-1}\left(\frac{P_j}{\sqrt{Q_j^2 + R_j^2}}\right), \end{aligned}, \quad (27)$$

where the signs of the square roots in Equation (27) are to be taken as positive. When P_j is positive, $(d_o)_j$ is directed north; and when P_j is negative, $(d_o)_j$ is directed south. The quadrant in which $(a_o)_j$ lies is given as follows:

$$\begin{array}{c} \text{first quadrant: } Q_j \text{ plus and } R_j \text{ plus,} \\ \text{second quadrant: } Q_j \text{ minus and } R_j \text{ plus,} \\ \text{third quadrant: } Q_j \text{ minus and } R_j \text{ minus,} \\ \text{fourth quadrant: } Q_j \text{ plus and } R_j \text{ minus.} \end{array} \qquad (28)$$

The final experimental values for v_o, a_o, and d_o were obtained as the average of the j values weighted according to the fraction of the data available for each j. The experimental error was calculated as the standard deviation correspondingly weighted. The results are presented in Table 1.

6. Conclusions and Discussion

The absolute velocity of the solar system measured using the anisotropy of the cosmic-ray muon flux is presented in Table 1. The error involved is rather large. Yet the anisotropy, while broad, is quite real, and the mean value observed agrees with measurements using other methods. The present results thus serve to confirm the value of the absolute velocity of the solar system obtained by other (more accurate) methods.

The present result demonstrates empirically for the first time the fact that the appropriate particle velocity to be used in the g factor, $g = 1/\sqrt{1-v^2/c^2}$, is the absolute velocity of the particle.

Results might be improved by eliminating more of the background coincidences by using an improved cosmic ray telescope. An appropriate array of Geiger-Müller counters registering muon produced cosmic ray "showers" might serve the purpose.

A large uncertainty exists in the estimate of the value of K, defined by Equations (17) and (20), which produces a corresponding uncertainty in the reported magnitude of the absolute velocity of the solar system v_o, as indicated by the first of Equations (27). The reported direction, a_o and d_o, is independent of this uncertainty. A more detailed analysis of the various processes involving muons in the atmosphere should be able to reduce this uncertainty.

Table 1. Absolute velocity of the solar system

method	observer	year	v_o km/s	a_o hour	d_o deg
galactic	de Vaucouleurs				
red	and Peters	1968	300 ± 50	7 ± 1	50 ± 10
shifts	Rubin *et al.*	1976	600 ± 100	2 ± 2	50 ± 20
2.7 K	Conklin				
cosmic	(ground)	1969	200 ± 100	13 ± 2	30 ± 30
back-	Henry				
ground	(balloon)	1971	320 ± 80	10 ± 4	–30 ± 25
	Smoot *et al.*				
	(airplane)	1977	390 ± 60	11.0 ± 0.5	5110
one-way	Marinov				
light	(coupled				
velocity	mirrors)	1974	300 ± 20	13.3 ± 0.3	–20 ± 4
	(toothed				
	wheels)	1984	360 ± 40	12 ± 1	–24 ± 7
muon	Monstein				
flux	and Wesley	1995	359 ± 180	8.7 ± 3.5	–1.1 ± 10.0

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