How Parallel are Parallel Universes?

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by

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Contents

Abstract

Current theories about the nature of the universe have been proposed that indicate that there exist extra spatial dimensions that we cannot ordinarily experience directly. Instead, we are confined to a 3-dimensional "brane" (short for membrane) that floats in a higher dimensional hyperspace or megaverse. There are possibly many of these 3-D branes floating in this hyperspace, perhaps even floating in close proximity to each other. This theory could help to explain many interesting problems in physics.

It has been hypothesized that a symmetry could exist on our brane, but a small leakage between a parallel brane (where this symmetry does not exist) and our own, could cause the break in the symmetry. If the dependence of the electron mass is dependant on the distance between the branes, and the branes are not exactly parallel, the electron would have a different mass in different parts of our universe.

In this paper, bounds for any change in the electron mass are explored. Beta decay half-lives depend fairly strongly on the mass of the electron. Supernovae light curves depend on the beta decay of ^{56}Co, and thereby could place a bound on the magnitude of δ. However, due to the error and fluctuation in the light curves, the bound provided by this phenomenon isn't very tight. An examination of absorption spectrums of distant quasars, that are also highly dependent upon the mass of the electron, provides a tighter bound: $\delta = (1.3814 \pm 8.6024) \times 10^{-5}$.

I. Introduction – Parallel Universes, Particle and Superstring Theory

The goal of physics is to explain how our universe works. In no area of physics is that more true than in elementary particle physics. Ever since J. J. Thomson's discovery of the electron in 1897, particle physicists have been trying to discover a model that accurately describes all of the matter that makes up the universe, as well as the forces that govern their interactions. There is a plethora of proposed models, ranging from the mundane, to the intriguing, to the ridiculous. The Standard Model has been supplemented and improved by some of these proposed models in an effort to find a Grand Unified Theory (GUT) or a Theory of Everything. Some of the models that are becoming more commonly accepted include Supersymmetry and Superstring (or string) theory. [1-7]

The concept of symmetry is very important in the description of the physical world. The idea of antimatter was first predicted on the basis of symmetry arguments. Supersymmetry is a similar idea that predicts symmetries between fermions and bosons. It proposes that all particles must come in pairs. These pairs are called superpartners. Each pair must be composed of one "real" and one "virtual" particle, with spins differing by ½; that is, one must be a fermion and the other a boson. The properties of this theory are such that they could help to unify the electromagnetic and weak forces with gravity. [2,3]

There exist five different superstring (or string) theories. Each is based on a few similar basic assumptions. [6] First, it is hypothesized that all matter is made up of tiny strings on the order of the Planck length (10^{-35} m). There are also two kinds of strings: open and closed loop. The open loop strings are theorized to make up particles such as electrons and quarks, while the closed loop strings make up gravitons, etc. These types of strings also vibrate at different frequencies, corresponding to different types of particles. Also, in order to include fermions in this theory, all particles must also have supersymmetric partners. Therefore, if supersymmetry is proven to be an attribute of our universe by the discovery of superpartners, the case for superstring theory would be strengthened.

In addition, for the mathematics to work, extra spatial dimensions must exist. The actual number of dimensions that are proposed to exist varies between the five superstring theories. [6] These dimensions could be curled up so tightly that they are too small to be observed directly. However, current theories hypothesize that these extra spatial dimensions could be as large as a millimeter. [8]

One newer theory [9,10] proposes an even more interesting scenario. According to this theory, our universe is a 3-dimensional membrane, or “brane,” that floats in a higher dimensional hyperspace or megaverse. Particles in our universe that make up matter, (open loop strings) such as electrons and quarks, are confined to this brane. Other particles, (corresponding to closed loop strings) such as gravitons, are not constrained to our brane, but are free to float away from our brane as well as in it. It is possible that our 3-D brane is not the only one floating in this hyperspace. Instead, there could be many, each with its’ own laws of physics. The laws in each of the different branes, although different from other branes, still would reflect the universal laws governing the higher dimensional megaverse. There could also be branes floating close to and parallel to each other. [9]

These branes floating in close proximity (within 1 "millimeter" in a higher dimension) to each other could help to explain many interesting problems in physics. One in particular is the rather unusual property of the electron having such a small mass in comparison to most other particles. It is easy to arrange a local symmetry on our brane that makes the electron exactly massless. However, it is difficult to understand why it would be so much lighter than the other particles, but not exactly massless. One possibility is that this symmetry could indeed exist on our brane. However if there is some sort of symmetry breaking mechanism, such as a small leakage of heavy closed loop particles between a parallel brane (where this symmetry does not exist) and our own, it could cause the break in the symmetry that results in this small electron mass. Since the amount of "leakage" that makes it across the gap between the parallel brane and our own depends on the distance between them, the mass of the electron would therefore be related to the distance between this other parallel brane and our own.

II. What if Parallel Universes aren't really "Parallel"

Although it is interesting to theorize that the electron has mass due to an interaction with a neighboring parallel brane, it is not necessarily very useful, as it would be very difficult to prove. However, what if the neighboring brane is not exactly parallel to our own? In a case as this, some very interesting phenomena could occur. For instance, since the distance between the branes would be changing, the amount of "leakage" experienced might not be constant throughout our universe. As a result, the mass of the electron would not be constant throughout our universe. If the electron mass is linearly dependant (to first order) on the distance between the branes such that the mass in our brane is

$$M = m_e(1-\delta^*z) \tag{1}$$

where m_e is the mass of the electron on earth and δ^*z is the change in mass at a particular distance z, then the electron would have a different mass in different parts of our universe. It is also assumed that a neighboring brane will not tilt enough such that it would have to intersect our own brane within the Hubble volume (the volume of our universe that we could possibly observe during the lifetime of the universe). An intersection would cause some sort of huge (and presumably observable) topological defect. Around this defect the mass of the electron could be near zero and stars would not form near the defect. Since this is not observed, it is assumed that the neighboring brane exists it does not intersect our own.

One way to test for this leakage is to try to measure variations in the electron's mass. For example, various astronomical phenomena are dependent on the mass of the electron. For instance, a change in the electron mass could modify energy levels in atoms, resulting in different atomic spectra, or it could change the electron degeneracy pressure in white dwarfs. In order to find a good bound on δ, and thus on the likelihood of the existence of a non-parallel neighboring brane, observations of phenomena far from earth that are sensitive to the electron mass are necessary. In this paper, two such phenomena are examined: the light curves of type IA supernovae, and quasar absorption systems.

III. Beta Decays and Supernovae

One process that is dependent on the mass of the electron and could exhibit a change in its behavior due to this symmetry breaking in an observable way is beta decay. In one type of beta decay, a neutron in the nucleus of an atom decays into a proton, an electron (or positron), and a neutrino. The resulting daughter nucleus is often in an excited state immediately after the decay, and will emit a photon as it returns to its ground state.

$$^{n}P \rightarrow {}^{n}D + e + \nu + \gamma \qquad (2)$$

Where n is the total number of nucleon in the atom, P is the parent element, D is the daughter, e an electron (or positron), ν is a neutrino, and γ is a photon.

Beta decays occur fairly frequently in stellar environments. There are certain decays that are characteristic in certain types of stellar events. For instance, the light curves of type IA supernovae seem to be dominated by the ^{56}Ni - ^{56}Co - ^{56}Fe decay chain. In particular, the decay of ^{56}Co determines the slope of the tail of the light curve of these types of supernovae. [11]

Type IA supernovae are thought to occur in accreting white dwarf systems. In these binary star systems, material from a large, probably red giant, companion star is being pulled away onto a small white dwarf. White dwarfs are small dense stars, near the end of their life cycles, with degenerate carbon cores. They are formed when a dying star collapses due to gravitational forces. For stars with a mass less than 1.44 solar masses, there is not enough energy to form neutrons (as in a neutron star) so the collapse is halted by electron degeneracy. This electron degeneracy is an application of the Pauli exclusion principle that states no two electrons may occupy identical states. As the star contracts, all the lowest electron energy levels are filled and the electrons are forced into higher and higher energy levels, filling the lowest unoccupied energy levels. This creates an effective pressure that prevents further gravitational collapse. [12] Hydrogen from the companion star swirls onto the surface of the white dwarf. This accreted material (which is non-degenerate) builds up relatively quickly on the surface of the white dwarf allowing temperatures to increase to as high as 10×10^9 K. The temperature inside the degenerate core also increases, but since it is degenerate, the core does not expand. So increases in temperature result in continuous increases in energy production. This is called “thermonuclear runaway.” As this occurs, the temperature can get high enough so that the carbon in the core of the white dwarf can start to fuse. When it does, the star expands explosively as the electron degeneracy is overcome. [12]

These types of explosions are very bright, and are often seen associated with distant galaxies. Because of the belief that these explosions were very homogeneous, they have for many years been used as “standard candles” for determining absolute distances to various astronomical objects. However, they appear to be more heterogeneous than previously thought. Despite this, they still seem to have a fairly characteristic light curve shape. [12] Due to these qualities, these events could be good candidates for looking for a bound on δ. By looking for variations in the light curves of distant IA supernovae, the half-life of ^{56}Co can be extrapolated for locations far from the earth. First, however, it is necessary to find the dependence of the half life of ^{56}Co on the electron mass, and δ.

IV. Beta Decay Theory

Before looking at the half-life of ^{56}Co specifically, it is useful to briefly examine the method for calculating beta decay half-lives. In general, the full derivation starts from an examination of the scattering or S-matrix. [13] However, it is not necessary to follow all the details here. Instead, some basic and important sections will be presented.

The half-life of the decay of a particular element t is related to the decay constant λ by

$$t = \frac{\ln 2}{\lambda} = \frac{\ln 2}{dW/dt} \tag{3}$$

where dW/dt is the decay probability per unit time,

$$\frac{dW}{dt} = \frac{|T|^2}{(2\pi)^5} R \tag{4}$$

and T is the T-matrix. The T-matrix contains all the information about the dynamics of the decay process. In Equation (4) R is the phase space integral (containing the kinematics of the beta decay)

$$R = \int \delta^3 \; \mathbf{p}_f + \mathbf{p}_e + \mathbf{p}_\nu \;\; \delta \; W_f + W_e + W_\nu - \mathrm{M}_i \;\; d^3\mathbf{p}_f d^3\mathbf{p}_e d^3\mathbf{p}_\nu . \tag{5}$$

For all calculations it is assumed that initially the parent nucleus is at rest. Given this, in R, $\mathbf{p}_f$, $\mathbf{p}_e$, and $\mathbf{p}_\nu$, are the momentum of the daughter nucleus, of the electron/positron, and of the neutrino respectively. W_f, W_e, and W_ν, are the total energy of the daughter nucleus, of the electron/positron, and of the neutrino respectively, and M_i is the rest mass of the parent nucleus. For beta decays, the T-matrix is approximately constant, so the decay is governed by this phase space factor.[1] [13]

Following Behrens and Bühring, [13] solutions for the above phase space integral, one finds that

$$R = 16\pi^2 \int_{m_e}^{E} (W_0 - m_e)^2 \sqrt{W_0^2 - m_e^2}\, W_0 dW_0 \tag{6}$$

where E is the mass difference between the parent and daughter nuclei. Integrating Equation (6) yields

$$R = 16\pi^2 \left[\begin{array}{l} \frac{1}{5}E^2\left(E^2 - M^2\right)^{3/2} + \frac{7}{15}M^2\left(E^2 - M^2\right)^{3/2} - \frac{1}{2}ME\left(E^2 - M^2\right)^{3/2} \\ -\frac{1}{4}M^3 E\sqrt{E^2 - M^2} + \frac{1}{4}M^5 \ln\left(E + \sqrt{E^2 - M^2}\right) \end{array} \right] - 4\pi^2 M^5 \ln(M) \tag{7}$$

where m_e has been replaced with $M = m_e(1 - \delta)$.

V. The Half-Life of ^{56}Co

$$^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe} + e^+ + \nu + \gamma \tag{8}$$

^{56}Co decays with a characteristic half-life of approximately 77 days (on earth). Following the procedure described in the previous section, and using the half-life on earth to determine the T-Matrix constant, it is possible to calculate the dependence of

[1] Solutions for phase space integrals in general are discussed in detail by Hagedorn (1963) and Byckling and Kajantie (1974)

the half-life of ^{56}Co on δ. Values for the masses for the various atoms and particles were obtained from the online Table of the Nuclides from Brookhaven National Laboratory. [16]

$$M_p\,(^{56}Co) = 52.1080\ GeV/c^2$$
$$M_d\,(^{56}Fe) = 52.10347\ GeV/c^2 \qquad (9)$$
$$E\,(M_d - M_p) = 4.53\ MeV/c^2$$
$$m_e = 0.511\ MeV/c^2$$

By substituting the above values into equation (7), setting δ equal to zero, and then substituting equations (7) and (4) into (3), an approximate value for T was obtained. With this information, Maple was used to plot the dependence of the half-life of ^{56}Co on δ. (Figure 1) The calculation of the theoretical value of the half-life of ^{56}Co as a function of δ indicates that a 10% change in the mass of the electron (corresponding to δ = 0.1) results in a change of approximately 2.7 days to the half-life. This is a fairly significant change.

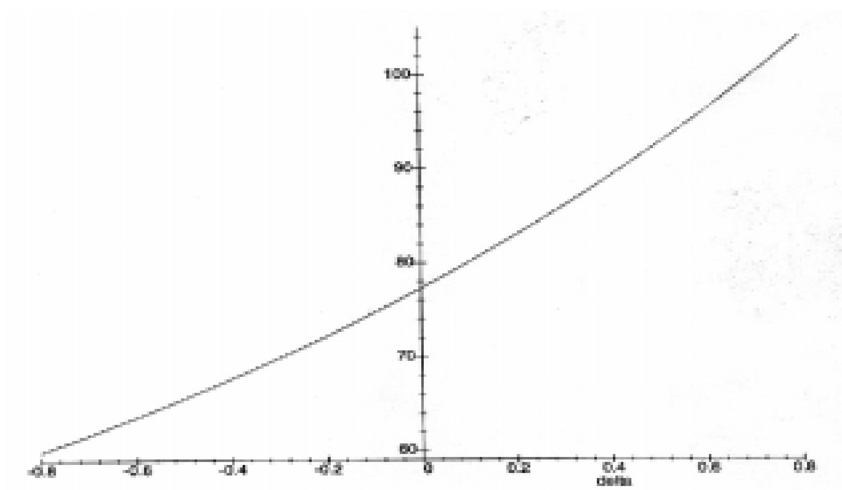

Figure 1: Half-life of ^{56}Co in days as a function of δ

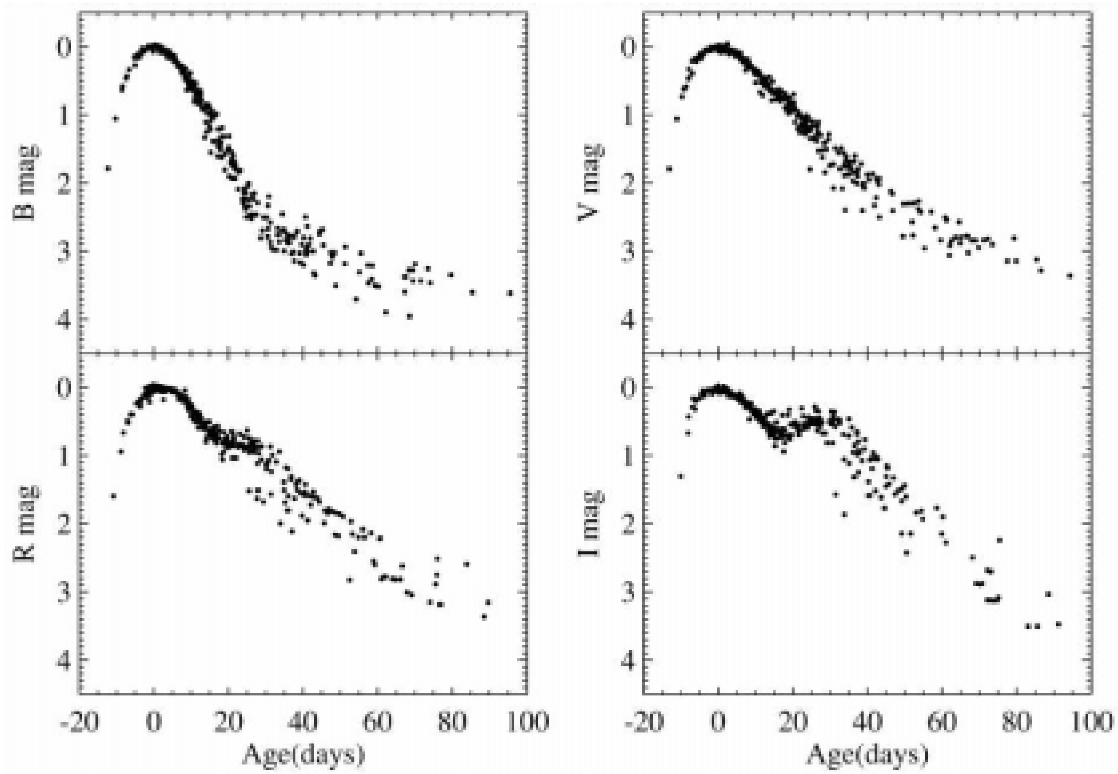

Figure 2: Light curves obtained from filters to examine curves in different parts of the electromagnetic spectrum (B – blue, V – visible, R – red, I – infrared) from [from 17]

VI. Supernovae Results

Light curves from twenty-two supernovae [17] (see Figure 2) were examined to find a range of values for the half-life of ^{56}Co. First, straight lines were fit to the portion of the light curve dominated by the beta-decay of ^{56}Co (approx. 30-60 days after the peak of the light curve). To do this data from the light curves was inputted into Excel spreadsheets. Then extraneous data from before and after the segment dominated by this decay was removed. The log of the luminosity verses days for the remaining data from each supernovae was plotted and fit with a straight line. (see Figure 3 for an example). The inverse of the slope of the fit line is the half-life for each.

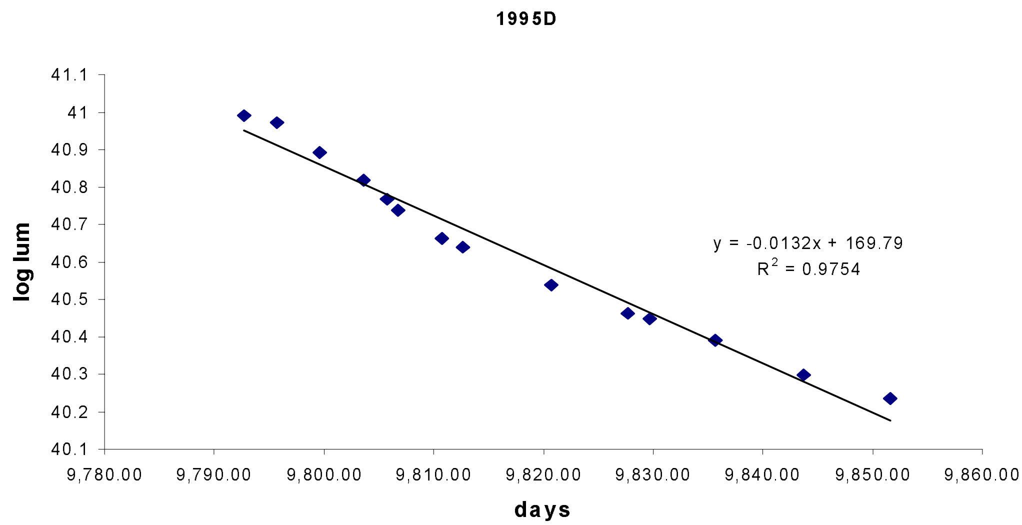

Figure 3: line fit to observational data (day of observation vs log of luminosity) for supernova 1995D

The analysis shows great variation in the range of values for the half-life of ^{56}Co, from approximately 97 days to 34 days. (Table 1) This could correspond to values of δ ranging from approximately +0.9 to -3.0. However, there is probably significant error in the half-life calculations. It is difficult (perhaps impossible) to quantify the absolute error. However, it can be expected that these errors are fairly significant. The fitting techniques available were fairly crude, and observational data in the timeframe of interest is rather sporadic. The error in the half-lives due strictly from the line fitting is somewhere around 20-30 days for most of the supernovae examined. Also understanding of the complete mechanisms causing these explosions is not complete. Given this, it could be estimated that the error on each measurement of the half-life is approximately ± 25 to 40 days. (Figure 4) This would correspond to errors on δ of around ± 0.8 to 3.0. This is a very broad bound, which includes values that would indicate a change in the electron mass of over a 100% and an intersection of the neighboring brane with ours. These possibilities were already excluded as mentioned earlier. Therefore, this bound doesn't provide any new or useful information in looking for evidence of a tilted neighboring brane.

It might be possible to re-examine this phenomena at some later point. However, the error on any bound from this phenomenon is probably at least 4 orders of magnitude less accurate than the fit from the quasar absorption systems. As any fits from these supernovae will always have a large amount of inherent uncertainty involved in its calculation, a closer analysis of this would not be necessary.

SN	log cz	56Co half-life, days	h-l error, days
1993ac	4.170	53.76	35
1993ae	3.757	89.29	30
1994M	3.838	44.44	40
1994S	3.658	43.67	40
1994T	4.017	33.90	45
1994Q	3.939	55.87	35
1994ae	3.107	91.74	25
1995D	3.293	75.76	20
1995E	3.540	67.57	25
1995al	3.188	97.09	25
1995ak	3.839	54.95	30
1995ac	4.176	56.50	30
1995bd	3.681	75.19	30
1996C	3.948	76.92	32
1996X	3.308	70.92	35
1996Z	3.357	58.14	30
1996ab	4.571	42.19	40
1996ai	2.978	54.38	35
1996bk	3.310	91.74	35
1996bl	4.033	48.78	35
~1996bo	3.714	37.74	50
1996bv	3.700	65.79	30

Table 1: 22 supernovae (Riess, et al), values of log of c times the distance to SN, half-life, and approx total error on the half-lives.

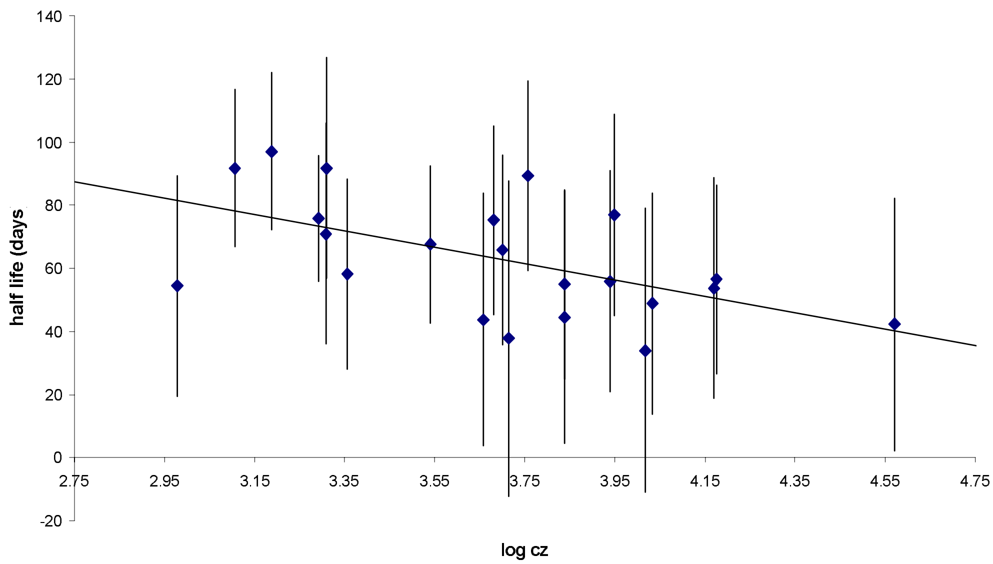

Figure 4: Calculated half-life of ^{56}Co vs. log cz

VII. Quasar Absorption Systems

Quasars are the brightest, most powerful objects known in the universe. They are star sized objects, generally believed to be embedded in the central regions of galaxies and to be powered by super-massive black holes. Other defining characteristics are the presence of strong, broad, redshifted emission lines in the optical/ultra-violet spectrum, a flat, often blue, optical continuum, and roughly equal energy output per decade in frequency from far-infrared (IR) to X-ray. The continual spectrum of these objects was formed at an epoch corresponding to the redshift z of the main emission details. This is specified by the relationship [18]

$$\lambda_{obs} = \lambda_{lab}(1 + z). \tag{10}$$

Quasar spectra show the absorption resonance lines of various ions. In particular, observation of molecular hydrogen 21-cm line in quasar absorption line systems is very interesting. The ratio of frequencies for the hyperfine 21-cm absorption transition of neutral hydrogen to an optical resonance transition is proportional to

$$x = \alpha^2 g_p\, m_e/m_p \tag{11}$$

where α^2 is the fine structure constant, g_p the proton g factor, m_e is the electron mass and m_p the proton mass. By looking at the coincidence of redshifts of optical resonant lines of ions with the redshifts of the hydrogen 21 cm radio lines in these distant systems, it is possible to derive an upper limit for the above combination such that [19]:

$$\frac{\Delta x}{x} = \frac{z_{opt} - z_{21}}{1 + z_{opt}} \tag{12}$$

in which z_{opt} is the QSO's optical redshift, and z_{21} is the redshift of the 21cm line. Assuming that the mass of the proton, the proton g factor, and the fine-structure constant do not vary with time or distance, we therefore arrive at a useful relation with which to place a bound on δ.

In order to place a bound on δ, it is necessary to solve for both the magnitude and direction of any change. If, in the linear approximation, the electron mass at the location of a particular quasar is

$$m_e(r) = m_e \; 1 + z \cdot \delta \cdot \hat{n}_q \bullet \hat{n} \tag{13}$$

where

$$\hat{n} = \left(\cos\theta \cdot \sin\phi, \sin\theta \cdot \sin\phi, \cos\phi\right)$$
$$\hat{n}_q = \; \cos\theta_q \cdot \sin\phi_q, \sin\theta_q \cdot \sin\phi_q, \cos\phi_q \tag{14}$$

are the vectors in the direction of maximum change and direction of a particular quasar, respectively.

In order to solve for our δ and direction, it is necessary to minimize the related χ^2 function

$$\chi^2 = \sum_i \frac{\left(m_e^{\,i} \left(1 - z \cdot \delta \cdot \hat{n}^i{}_q \bullet \hat{n} \right) \right)^2}{\left(\Delta m_e^{\,i} \right)^2} \qquad (15)$$

Where z is the redshift, m_e^i is the mass of the electron at the absorption system, Δm_e^i is the error in the mass. In terms of the observational data obtained (Δx/x, its' error, and right ascension and declination for each quasar) these variables are:

$$\begin{gathered} m_e^i = m_e * (1 + \Delta x/x) \\ \Delta\, m_e^i = m_e * (\text{error } \Delta x/x) \\ \text{Right Ascension and Declination} = \theta, \text{ and } \phi \end{gathered} \qquad (16)$$

Right Ascension (RA) is the celestial longitude measured eastward along the celestial equator in hours of time from the vernal equinox. Declination (Dec) is celestial latitude measured in degrees north or south of the celestial equator. To use these in calculations, they were converted into decimal degrees, and for Dec re-centered so that it is measured in degrees south from the celestial north pole. Then, using the values for Δ*x/x,* and the RA and Dec for each quasar (obtained from NED [20] and converted as above), the direction and δ that best fit the available data can be determined.

VIII. Quasar Results

Three quasar absorption systems, QSO 3C 286, QSO 1331+170, and AO 0235+164 [19, 21], were examined in this study (see Table 2). The experimental data (Equation 16 and values from Table 2) was substituted into the χ^2 function. (15) This was minimized using the function minimization and error analysis program MINUIT (Appendix A). This program is a tool to find the minimum value of a multi-parameter function and analyze the shape of the function near that minimum. It offers several minimization algorithms. The one used for this minimization is called MIGRAD. It is a variable-metric method with inexact line search, stable metric updating scheme, and checks for positive-definiteness. It outputs its various guesses with the corresponding error for each variable. It repeats the guessing and checking process, moving along directions indicated by the first derivative of the function, until it finds what appears to be a minimum. [22] In our case, the results tell us the direction and magnitude of δ that best fits the data from the three quasar absorption systems.

quasar	RA	DEC	dx/x	Z
QSO 3C 286	202.7846	30.5092	(0+/-1.2)+10^-4	0.69
AO 0235+164	39.6621	16.7639	(0+/-2.8)*10^-4	0.524
QSO 1331+170	203.3992	16.8278	(0.7+/-1.1)*10^-5	1.776

Table 2: QSO information with RA and Dec in degrees [19,20,21]

The examination of the three quasar absorption systems has yielded a tight bound on the value of δ, although the directional fit was less satisfactory:

$$\delta = (1.3814 \pm 8.6024)\times 10^{-5}$$
$$RA = 05h49m41.1s \pm 19h19m39.4s$$
$$Dec = 89d14m38s \pm 144d12m43s$$

Essentially, with the errors on the directions, the entire sky is included. This gives no real indication as to which direction a parallel brane could be tilting. However, the very small value of δ, coupled with a small error has interesting implications. First, if a parallel brane exists, it has to be very nearly parallel with our own. It could, in fact, be parallel with ours, as the error includes $\delta=0$. However, a parallel brane would be difficult to distinguish from a case in which no parallel brane existed and the symmetry was broken by some other method than that which has been proposed here.

IX. Conclusions

The ideas proposed by various theories mentioned in this paper have been, largely, unsupported by observational data. In particular, the theory that our universe is a 3-D brane located in a higher dimensional hyperspace, although intriguing, has lacked any substantive evidence for or against it. This has largely because the observational data available was too poor to support the theory or even provide a good bound. Although no definite conclusion about the existence of a parallel brane could be reached with the data examined, a good bound on the magnitude of δ has been obtained. The limit on δ obtained by looking at the quasar absorption systems probably provides the tightest astrophysical constraint for this phenomenon. This bound is a step towards a more complete understanding of the possibilities that are presented in this theory. However, further examination of other astrophysical phenomena should be examined in order to try to give a more definite conclusion about the possibility of parallel branes.

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Appendix A

Fortran program for use with MINUIT

```
C      MAIN PROGRAM

       character*10 pnam(3),out1(3)
       double precision vstrt(3),stp(3),bndl(3),bnd2(3),arglis(1),zero,
        +d,t,p,fval
       integer nprm(3),ierflg,i
C
       external fcn
       double precision out2(3),out3(3),out4(3),out5(3),out6(3)
C
       data nprm / 1 , 2 , 3 /
       data pnam / 'd' , 't' , 'p' /
       data vstrt / 0.5DOO , 3.0DOO ,1.5 DOO/
       data stp / 0.0lDOO, 0.0lDOO , 0.0lDOO /
       data bndl / 0.OODOO , 0.OODOO , 0.OODOO /
       data bnd2 / 1.OODOO , 6.28318DOO , 3.141S9DOO
C
       open!unit=6,file='QSO.out',status='old',form='formatted')
       call mninit!5,6,7)
       zero=O.ODOO
       do 11 i=1,3
       call mnparm!nprm!i),pnam!i),vstrt!i),stp!i),bnd1!i),
        #bnd2!i),ierflg)
       if !ierflg .ne. 0) then
       print*, 'Unable to define parameter No.',i
       endif
 11    continue
C
       arglis(l)=O.O
       call mnexcm(fcn,'migrad',arglis,zero,ierflg,zero)
       call mnpout(1,outl(1),out2(1),out3(1),out4(1),out5(1),out6(1))
       call mnpout (2,outl(2),out2(2),out3(2),out4(2),out5(2),out6(2))
       call mnpout(3,outl(3),out2(3),out3(3),out4(3),out5(3),out6(3))
C
C      print*,outl(1),out2(1)
C      print*,outl(2) ,out2 (2)
C      print*,outl(3),out2(3)
C
       end
C
       subroutine fcn(npar,grad,fval,x,iflag)
       double precision grad(3) ,x(3)
C
       double precision ral,dl,zl,dml,dmla,ra2,d2,z2,dm2,dm2a,
        +ra3,d3,z3,dm3,dm3a,d,t,p,fval
C
       d=x(l)
       t=x(2)
       p=x(3)
C
C   these are the quasars I'm looking at and their respective RA, dec,z
C   percent change in the electron mass, and error on that change.
C
C      qso 1331+170
       ra1=3.54932
       d1=1.27685
       zl=1.776
       dm1=0.000007
       dm1a=0.000011
C
```

```
C      ao 0235+164
       ra2=0.692103
       d2=1.27797
       z2=0.524
       dm2=0.000
       dm2a=0.00028
C
C      qso 3c 286
       ra3=3.53859
       d3=1.038115
       z3=0.690
       dm3=O.OOO
       dm3a=O.OOO12
C
C
C   This is the chi**2 function that I will be minimizing
C
       fval=(((dml-d*zl*(cos(ral)*sin(dl)*cos(t)*sin(p)+
      +sin(ral)*sin(dl)*sin(t)*sin(p)+cos(dl)*cos(p)))**2/((dmla)**2))
      ++((-d*z2*(cos(ra2)*sin(d2)*cos(t)*sin(p)+
      +sin(ra2)*sin(d2)*sin(t)*sin(p)+cos(d2)*cos(p)))**2/((dm2a)**2))
      ++((-d*z3*(cos(ra3)*sin(d3)*cos(t)*sin(p)+
      +sin(ra3)*sin(d3)*sin(t)*sin(p)+cos(d3)*cos(p)))**2/((dm3a)**2)))
C
       return
       end
```

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