UNDERSTANDING THE PARTICLE MASS SPECTRUM (100 – 1860 MeV)

> "There remains one especially unsatisfactory feature [of the Standard Model of particle physics]: the observed masses of the particles, m. There is no theory that adequately explains these numbers. We use the numbers in all our theories, but we do not understand them – what they are, or where they come from. I believe that from a fundamental point of view, this is a very interesting and serious problem." Richard Feynman

I. Introduction

The goal of the research presented below is to provide a basic and general first approximation explanation for the unique patterns of masses and stabilities found at the *lower end* of the subatomic particle mass spectrum, where the patterns are most restricted, unique and diagnostic. The Standard Model of particle physics has achieved limited success in this effort, but only by resorting to putting the hypothetical "quark" masses and numerous other parameters into the analysis "by hand". This way of doing science is *ad hoc* "model-building", at best, and possibly borders on Ptolemaic pseudo-science. Discrete Scale Relativity, on the other hand, may offer a more realistic potential for understanding how nature *actually works* in the Atomic Scale domain, and how the unique particle mass spectrum is the product of fundamental physics: General Relativity, Quantum Mechanics and Discrete Cosmological Self-Similarity.

The discussion below is based on the theory of Discrete Scale Relativity (DSR) which is described in a published paper available at http://arxiv.org/ftp/physics/papers/0701/0701132.pdf and is the primary topic at the Fractal Cosmology website: http://www3.amherst.edu/~rloldershaw . DSR identifies the correct value of the gravitational coupling factor that applies *within* Atomic Scale systems:

$$G_{-1} = 2.18 \times 10^{31} \text{ cm}^3/\text{g sec}^2 . \qquad (1)$$

When this corrected value of G is substituted in the formula for the Planck mass, we get a revised Planck mass of:

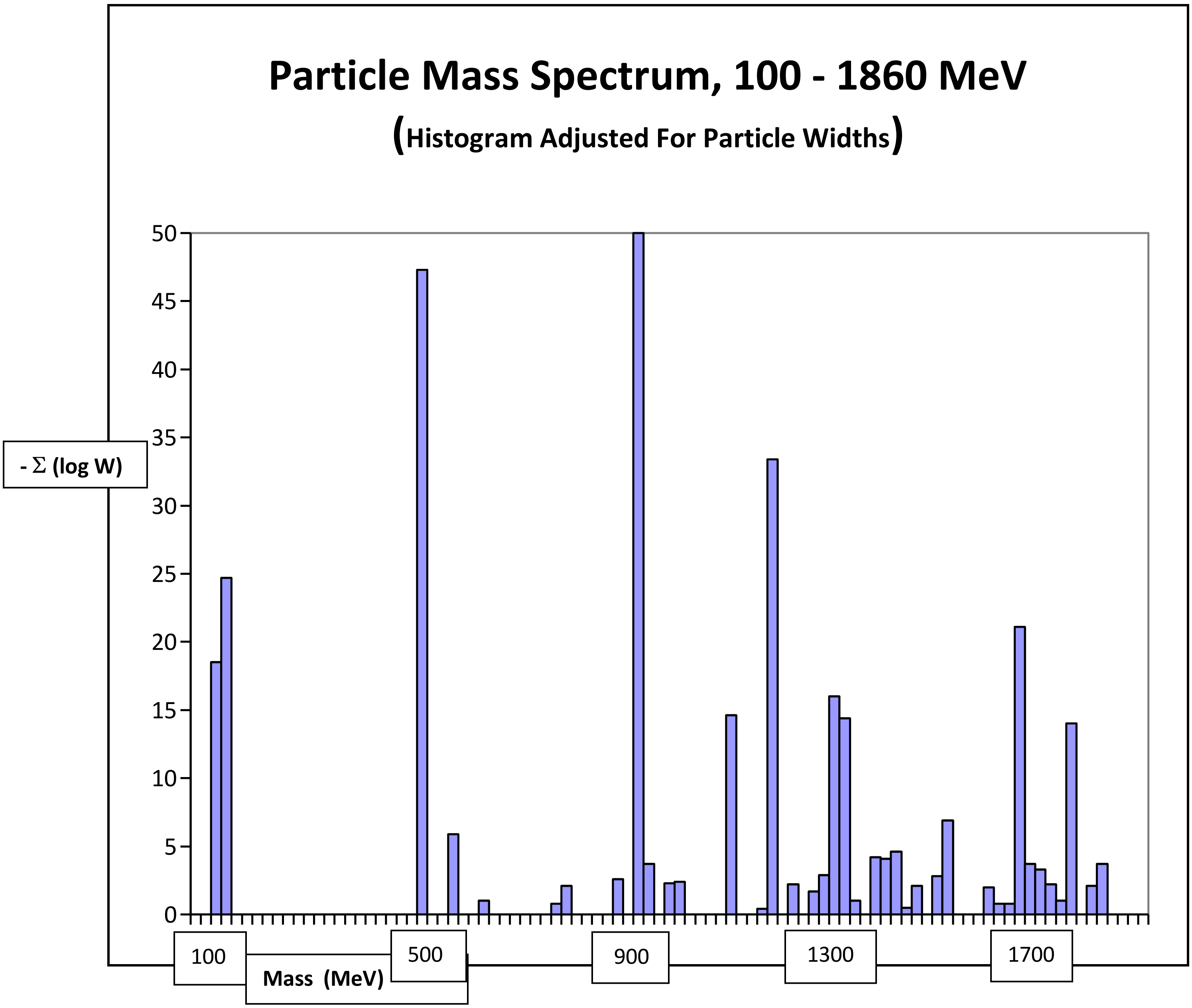
$$\mathfrak{M} = (\hbar c/G_{-1})^{1/2} = 1.20 \times 10^{-24} \text{ g} = 674.8 \text{ MeV}/c^2 \qquad (2)$$

which is discussed in a second published paper available at: http://arxiv.org/ftp/astro-ph/papers/0701/0701006.pdf . These values for G_{-1} and $\mathfrak{M}$ will play key roles in our new understanding of subatomic particles.

II. The Particle Mass Spectrum (100 – 1860 MeV)

In Figure 1 we plot the masses of the 95 *well-defined* particles in the mass range of 100 MeV to 1860 MeV listed by the Particle Data Group at the Lawrence Berkeley Lab (http://pdg.lbl.gov/). The data for Figure 1 are listed in Table 1. Rather than display a simple histogram of the masses, the graph is made 2-dimensional by summing the "particle widths" of the particles in each mass bin and plotting that as the y-parameter. Note that a particle "width" equals ħ divided by the particle lifetime, so a relatively stable particle has a small width and unstable particles have relatively large widths. The y-parameter is presented as – Σ (log width), with the minus sign making the sum of the widths a positive number for ease of presentation. The peaks in the spectrum represent "islands of stability".

FIGURE 1



The 2-dimensional mass/stability spectrum shows: (1) the distribution of the particle masses for this mass range and (2) the location of the "islands of stability". Therefore it is quite diagnostic and any theory that hopes to explain the particle mass spectrum should be able to reproduce the major features of this mass/stability spectrum. The range of 100 MeV to 1860 MeV is chosen for specific reasons. A lower limit at 100 MeV reflects the fact that particles with masses below that of the pion and muon, most notably the electron, are still quite enigmatic within the context of *any* available theory or model. The upper cutoff at 1860 MeV is arbitrary. Given the huge number of particles/resonances and their very broad mass range, it seems reasonable to focus on the most important segment of the full particle mass range. The restricted mass range of 100-1860 MeV contains the majority of the most stable and important leptons and hadrons. Any attempt to explain the full particle mass spectrum must *start* with a convincing retrodiction of the 100-1860 MeV segment.

The goals for the present research, and for future extensions of this research are:

1. Retrodict the main peaks of the particle mass spectrum (100-1860 MeV range).

2. Retrodict the mass of *any* particle (0 – 100 GeV) using the *same* DSR-based modeling.

3. Retrodict the peak heights (i.e., the stabilities) of the mass/stability spectrum.

TABLE 1 ALL PARTICLES LISTED FOR 100 MeV to 1850 MeV

(Narrow Width Particles in bold)

Name	Log Width	Mass (MeV)	n	$(n^{1/2})$(674.8 MeV)	% Error
mu(-)	**-18.5**	**105.7**	**$1/6^2$ or (1/9/4)**	**112.46**	**6.40**
pi(+)	**-16.6**	**139.6**	**$1/5^2$ or (1/6)/4**	**134.96**	**3.32**
pi(0)	**-8.1**	**135.0**	**$1/5^2$ or (1/6)/4**	**134.96**	**0.07**

K(+)	**-16.3**	**493.7**	**2/4**	**477.15**	**3.35**
K0S(0)	**-14.1**	**497.6**	**2/4**	**477.15**	**4.11**
K0L(0)	**-16.9**	**497.6**	**2/4**	**477.15**	**4.11**
eta(0)	**-5.9**	**547.9**	**3/4**	**584.39**	**6.66**
f(0) (600)	-1.0	~600			
rho (770)	-0.8	775.5			
omega(782;0)	**-2.1**	**782.7**	**5/4**	**761.40**	**2.72**
K*(+)	-1.3	891.7			
K*(0)	-1.3	896			
p(+)	**- ∞**	**938.3**	**2**	**954.31**	**1.71**
n(0)	**-27.1**	**939.6**	**2**	**954.31**	**1.57**
eta'(958; 0)	**-3.7**	**957.7**	**2**	**954.31**	**0.35**
f(0) (980)	-1.2	980			
a(0) (980)	-1.1	984.7			
phi(1020; 0)	**-2.4**	**1019.4**	**2**	**954.31**	**6.39**
Lambda(0)	**-14.6**	**1115.7**	**3**	**1167.75**	**4.67**
h(1) (1170)	-0.4	1170			
Sigma(+)	**-14.1**	**1189.4**	**3**	**1167.75**	**1.82**
Sigma(0)	**-5.0**	**1192.6**	**3**	**1167.75**	**2.08**
Sigma(-)	**-14.3**	**1197.4**	**3**	**1167.75**	**2.48**
b(1) (1235)	-0.9	1229.5			
a(1) (1260)	-0.4	1230			
Delta (1232)	-0.9	1232			
K(1) (1270)	-1.0	1272			
f(2) (1270)	-0.7	1275.1			
f(1) (1285)	-1.6	1281.8			
eta (1295)	-1.3	1294			
Pi (1300)	-0.4	1300			
Xi(0)	**-14.6**	**1314.9**	**4**	**1349.60**	**2.63**
a(2) (1320)	-1.0	1318.3			
Xi(-)	**-14.41**	**1321.7**	**4**	**1349.60**	**2.11**
f(0) (1370)	-0.5	1350			
pi(1) (1400)	-0.5	1351			
Sigma (1385) (+)	-1.4	1382.8			
Sigma (1385) (0)	-1.4	1383.7			
Sigma (1385) (-)	-1.4	1387.2			
K(1) (1400)	-0.8	1403			
Lambda (1405)	-1.3	1406			
eta (1405)	-1.3	1409.8			
K* (1410)	-0.7	1414			
K(0)* (1430)	-0.6	1420			
omega (1420)	-0.7	1425			
K(2)* (1430) (+)	-1.0	1425.6			
f(1) (1420)	-1.3	1426.4			

K(2)* (1430) (0)	-1.0	1432.4			
N (1440)	-0.5	1440			
rho (1450)	-0.4	1465			
a(0) (1450)	-0.6	1474			
eta (1475)	-1.1	1476			
f(0) (1500)	-1.0	1505			
Lambda (1520)	-1.8	1519.5			
N (1520)	-0.9	1520			
f(2) (1525)	-1.2	1525			
Xi (1530) (0)	**-2.0**	**1531.8**	**5**	**1508.9**	**1.49**
N (1535)	-0.8	1535			
Xi (1530) (-)	**-2.0**	**1535**	**5**	**1508.9**	**1.70**
Delta (1600)	-0.5	1600			
Lambda (1600)	-0.8	1600			
eta(2) (1645)	-0.7	1617			
Delta (1630)	-0.8	1630			
N (1650)	-0.8	1655			
Sigma (1660)	-1.0	1660			
pi(1) (1600)	-0.6	1662			
omega(3) (1670)	-0.8	1667			
omega (1650)	-0.5	1670			
Lambda (1670)	-1.5	1670			
Sigma (1670)	-1.2	1670			
pi(2) (1670)	-0.6	1672			
Omega(-)	**-14.1**	**1672.4**	**6**	**1652.51**	**1.18**
N (1675)	-0.8	1675			
phi (1680)	-0.8	1680			
N (1680)	-0.9	1685			
rho(3) (1690)	-0.8	1688.8			
Lambda (1690)	-1.2	1690			
N (1700)	-1.30	1700			
Delta (1700)	-0.5	1700			
N (1710)	-1.0	1710			
K* (1680)	-0.5	1717			
rho (1700)	-0.6	1720			
N (1720)	-0.7	1720			
f(0) (1710)	-0.9	1724			
Sigma (1750)	-1.0	1750			
K(2) (1700)	-0.7	1773			
Sigma (1775)	-0.9	1775			
K(3)* (1780)	-0.8	1776			
tau(-)	**-11.6**	**1776.8**	**7**	**1785.35**	**0.48**
Lambda (1800)	-0.5	1800			
Lambda (1810)	-0.8	1810			

pi (1800)	-0.8	1816			
Lambda (1820)	-1.1	1820			
Xi (1820)	-1.6	1823			
Lambda (1830)	-1.0	1830			

III. Subatomic Particles and Discrete Scale Relativity

The Discrete Self-Similar Cosmological Paradigm, which is referred to as Discrete Scale Relativity when the cosmological self-similarity is *exact*, leads inexorably to the conclusion that subatomic particles are Kerr-Newman ultracompacts (black holes, and virtually naked singularities). A good reference source for these ideas is: http://arxiv.org/ftp/astro-ph/papers/0701/0701006.pdf . To keep matters as simple as possible, our first approximation model for the subatomic particles will be Kerr black holes (mass, spin). The next stage in the future development of this line of research will be to upgrade to a full Kerr-Newman metric (mass, spin, charge), but for now we will see how far we can get with the simpler Kerr metric.

For Kerr black holes there is a well-known relationship between their masses (M) and their angular momenta (J):

$$J = \mathbf{a}GM^2/c \quad , \qquad (3)$$

where **a** is the dimensionless rotation parameter, which can vary between 0.00 (no rotation) and 1.00 (maximum rotation) for stable Kerr ultracompacts. Since we want to retrodict subatomic particle masses, we use an approximate and generic discrete angular momentum expression taken from Quantum Mechanics:

$$J = n\hbar \quad . \tag{4}$$

We also have found that G_{-1}, which equals 2.18 x 10^{31} $cm^3/g\ sec^2$, is the proper value of the gravitational coupling parameter in this Atomic Scale domain. We can recast Eq. (3) for the subatomic domain as:

$$n\hbar = \mathbf{a}G_{-1}M^2/c \quad . \tag{5}$$

Then,

$$M = (n/\mathbf{a})^{1/2}\ (\hbar c/G_{-1})^{1/2} \quad . \tag{6}$$

We notice that $(\hbar c/G_{-1})^{1/2}$ is the equation for the Planck mass [see Eq. (2)], which equals 674.8 MeV. Finally, for *extremal* Kerr ultracompacts which have a = 1.00, we can write our first approximation expected mass formula:

$$M_n = (n)^{1/2}\ \mathfrak{M} = (n)^{1/2}\ (674.8\ \text{MeV}) \quad . \tag{7}$$

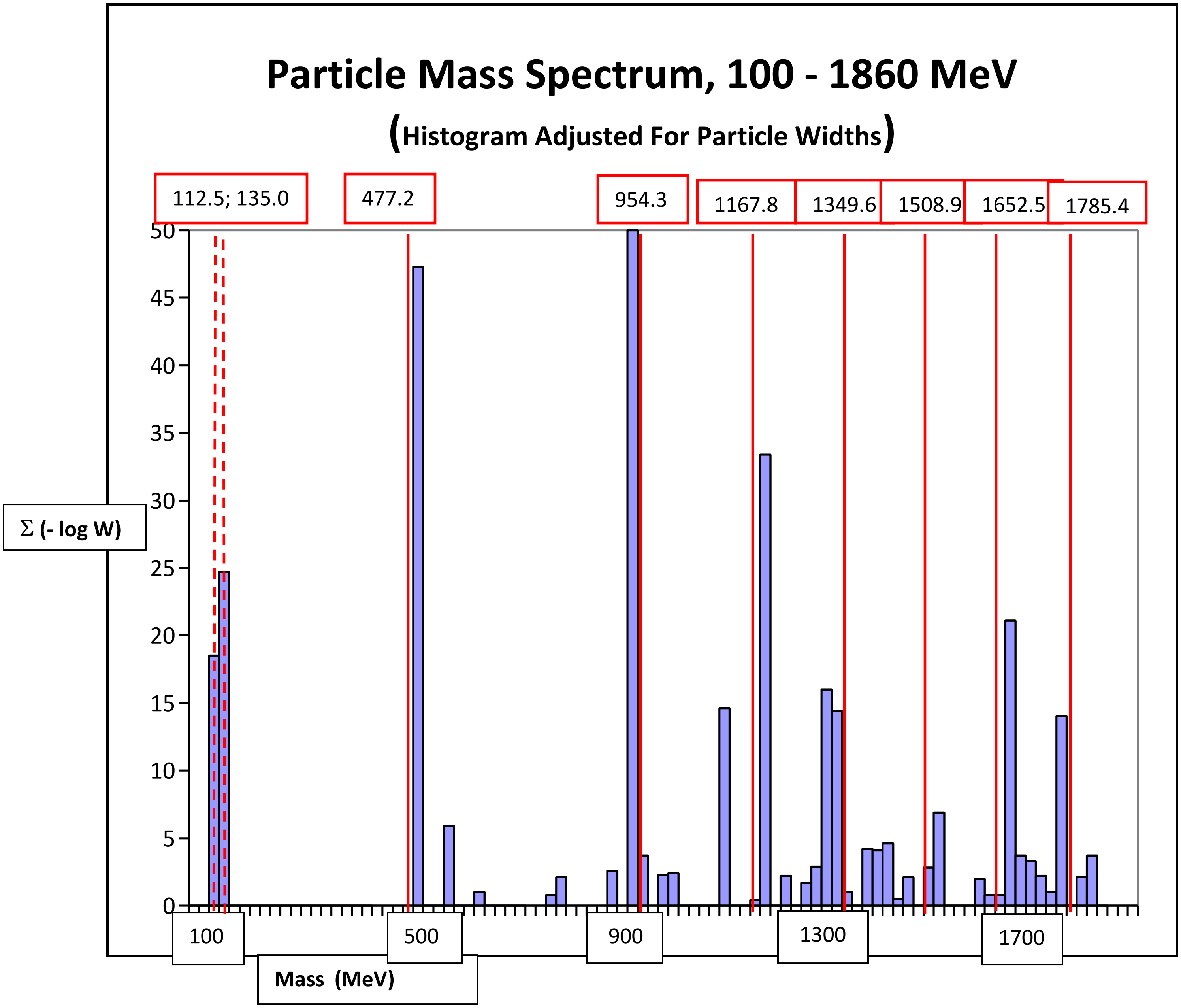
It is interesting and informative to compare this *incredibly simple* mass formula with the almost unbelievably hermetic and complicated analyses required by Quantum Chromodynamics to arrive at mass retrodictions of comparable or lower accuracy levels, even when many critical parameters like “quark” masses are “put in by hand”.

With Eq. (7) and the quite reasonable discrete n values of ½, 2, 3, 4, 5, 6 and 7 we are able to retrodict 7 of the 10 major peaks in the mass/stability spectrum at the <98.4%> level. Note that the n = 1 mass value is just the Planck Mass, which does not represent an actual particle, but rather defines the boundary between J > 0 ultracompacts with/without event horizons, as discussed in: [New Developments: March 2008 – “The Hidden Meaning of Planck’s Constant”].

TABLE 2 Narrow Width Particles 100 MeV to 1860 MeV

Name	Log Width	Mass (MeV)	n	($n^{1/2}$)(674.8 MeV)	% Error
mu(-)	-18.5	105.7	$1/6^2$ or (1/9/4)	112.46	6.40
pi(+)	-16.6	139.6	$1/5^2$ or (1/6)/4	134.96	3.32
pi(0)	-8.1	135.0	$1/5^2$ or (1/6)/4	134.96	0.07
K(+)	-16.3	493.7	1/2	477.15	3.35
K0S(0)	-14.1	497.6	1/2	477.15	4.11
K0L(0)	-16.9	497.6	1/2	477.15	4.11
p(+)	$-\infty$	938.3	2	954.31	1.71
n(0)	-27.1	939.6	2	954.31	1.57
Lambda(0)	-14.6	1115.7	3	1167.75	4.67
Sigma(+)	-14.1	1189.4	3	1167.75	1.82
Sigma(0)	-5.0	1192.6	3	1167.75	2.08
Sigma(-)	-14.3	1197.4	3	1167.75	2.48
Xi(0)	-14.6	1314.9	4	1349.60	2.63
Xi(-)	-14.41	1321.7	4	1349.60	2.11
Xi (1530) (0)	-2.0	1531.8	5	1508.9	1.49
Xi (1530) (-)	-2.0	1535	5	1508.9	1.70
Omega(-)	-14.1	1672.4	6	1652.51	1.18
tau(-)	-11.6	1776.8	7	1785.35	0.48

FIGURE 2



Peaks for the muon, pions, eta(0) and omega(782;0) can be retrodicted using n values of (1/9)/4, (1/6)/4, 3/4 and 5/4, see http://journalofcosmology.com/OldershawRobert.pdf , but these expectation values can only be considered as *heuristic* results, for reasons that will be explored as we progress to a more sophisticated mass formula.

The results presented in Table 2 and Figure 2 demonstrate that the very simple mass formula of Eq. (7) is surprisingly successful at retrodicting the majority of the main peaks in the mass/stability spectrum. It is also clear that there is a very regular discrete pattern to the mass/stability spectrum based on integer quantum numbers and/or rational fractions. These initial results motivate us to refine the mass formula by looking for additional theoretical guidance.

IV. A MORE RIGOROUS MASS FORMULA

One way to refine our mass formula and make it less heuristic is to relax the restriction to *extremal* Kerr ultracompacts with **a** = 1.00. In the general case, **a** can vary between 0.00 (no rotation) and 1.00 which designates the maximal rotation for a *stable* Kerr ultracompact. Since we are modeling quantum particles, we will allow **a** values to vary between 0.00 and 1.00, with the values having the form x/y where x and y are integers and y > x.

Another important refinement to our first approximation modeling of subatomic particles using the Kerr metric will be to adopt a more rigorous expression for the total angular momentum of a particle:

$$J = (j\{j+1\})^{1/2}\,\hbar \quad . \tag{8}$$

Using this formal definition of J from Quantum Mechanics in place of $n\hbar$ in Eq. (6), our final mass formula becomes:

$$M = (j\{j+1\}/\mathbf{a}^2)^{1/4}\ (674.8\ \text{MeV}) \qquad (9)$$

We will only allow the conventionally assigned *canonical* j values for the specific particles, and **a** values will have the x/y format, with x and y restricted to integers and x < y.

Using Eq. (9) as our more sophisticated mass formula rules out retrodicting the masses of particles with j = 0, such as spin 0 mesons. Therefore we are primarily restricted to retrodicting the masses of baryons, which have j > 0.

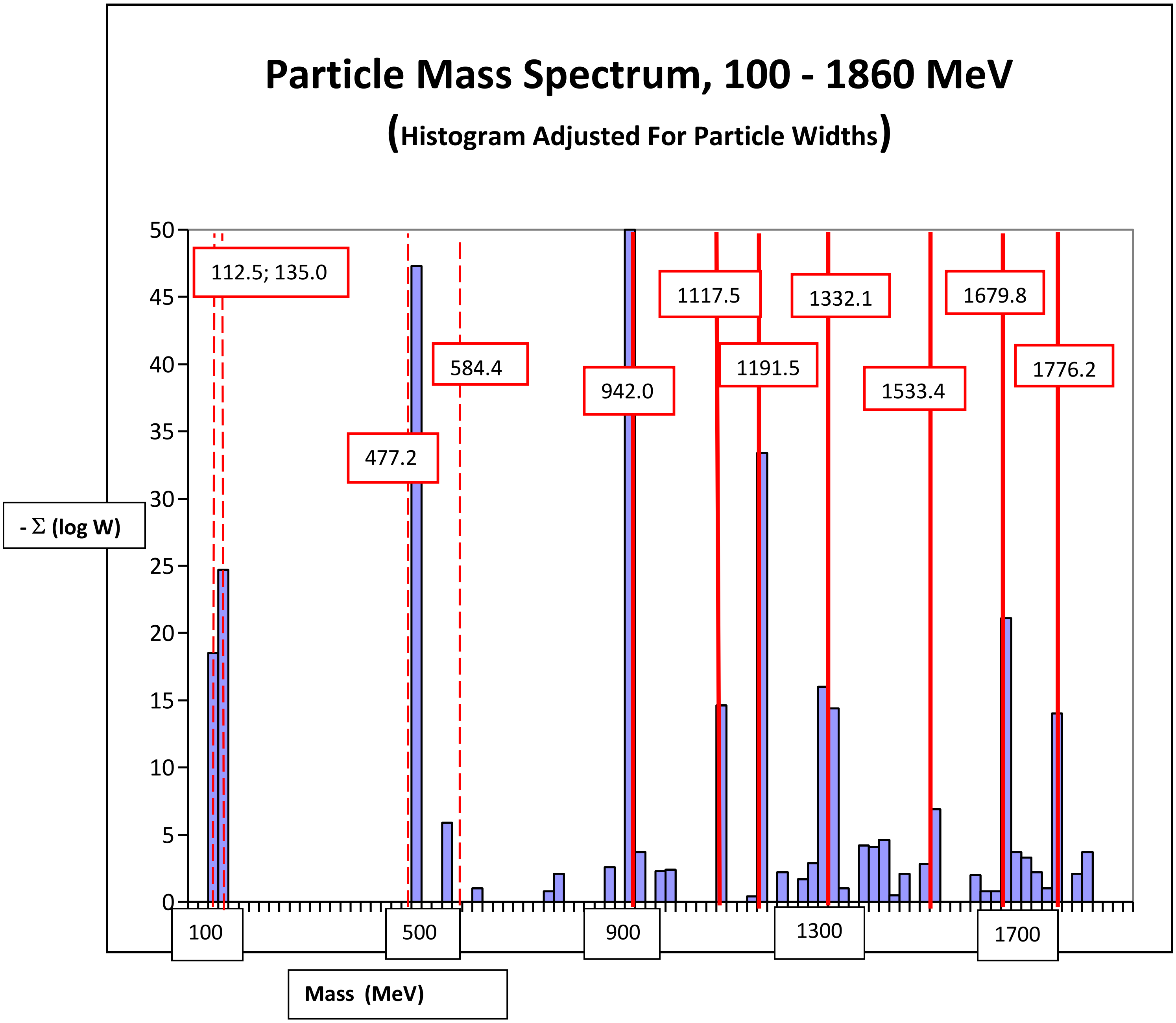
Table 3 lists the results for the main j > 0 peaks in the 900-1860 MeV range of the particle mass/stability spectrum. With Eq. (9), using canonical j values and very reasonable values of **a**, we are able to retrodict 7 of the 11 major peaks in the mass/stability spectrum with an average relative error of only 0.3 %, i.e., theoretical/empirical agreement at the < 99.7 % > level. These results are visualized in Figure 3.

TABLE 3 DATA FOR MAJOR MASS/STABILITY PEAKS

Particle(s)	j	a	Retrodicted Mass (MeV)	Empirical Mass (MeV)	Relative Error
Proton (+)	1/2	4/9 (~1/2)	941.96	938.3	0.4 %
Neutron (0)	1/2	4/9 (~1/2)	941.96	939.6	0.3 %
Lambda (0)	1/2	6/19 (~1/3)	1117.48	1115.7	0.2 %
Sigma (+,-,0)	1/2	5/18 (~1/3)	1191.49	< 1193.1 >	< 0.1 % >
Xi (0,-)	1/2	2/9 (~1/5)	1332.13	< 1318.3 >	< 1.0 % >
Xi (0,-;1530)	3/2	3/8	1533.44	< 1533.4 >	< 0.003 % >

Omega (-)	3/2	5/16 (~1/3)	1679.80	1672.5	0.4 %
Tau (-)	1/2	1/8	1776.20	1776.8	0.04%

FIGURE 3



V. THE PRIMARY BARYONS

It appears that the Kerr metric approach to modeling subatomic particles is most effective in retrodicting the masses of baryons, which have j > 0 and are not “point-like” particles as the case with leptons. Table 4 lists the data for 8 of the most well known and relatively stable baryons.

TABLE 4 DATA FOR THE PRIMARY BARYONS

Particle(s)	j	a	Retrodicted Mass (MeV)	Empirical Mass (MeV)	Relative Error
Proton (+)	1/2	4/9 (~1/2)	941.96	938.3	0.4 %
Neutron (0)	1/2	4/9 (~1/2)	941.96	939.6	0.3 %
Lambda (0)	1/2	6/19 (~1/3)	1117.48	1115.7	0.2 %
Sigma (+,-,0)	1/2	5/18 (~1/3)	1191.49	< 1193.1 >	< 0.1 % >
Delta (++,+,0,-)	3/2	7/12 (~1/2)	1229.49	< 1232.0 >	< 0.2 % >
Xi (0,-)	1/2	2/9 (~1/5)	1332.13	< 1318.3 >	< 1.0 % >
Xi (0,-;1530)	3/2	3/8	1533.44	< 1533.4 >	< 0.003 % >
Omega (-)	3/2	5/16 (~1/3)	1679.80	1672.5	0.4 %

With Eq. (9) we are able to retrodict the masses of this archetypal set of baryons at the < 99.67 % > level. Technically there are 15 distinct particles in this set of baryons, but it appears that the Sigma, Delta and Xi subsets are “fine structure” variations on a “generic” particle, given the closeness of the masses in each subset. It will be interesting to explore the hypothesis that the full Kerr-Newman metric solutions will offer unique explanations for this type of fine structure in the mass/stability spectrum.

VI. CONCLUSIONS

1. With the heuristic mass formula: $M = (n)^{1/2}\, \mathfrak{M}$, we can retrodict 7 of the 10 major peaks in the mass/stability spectrum (100 – 1860 MeV) at the < 98.4 % > level.

2. With our more rigorous mass formula: $M = (j\{j+1\}/\mathbf{a}^2)^{1/4}\, \mathfrak{M}$, we can successfully retrodict 7 out of 7 major peaks associated with non-point-like particles with j > 0. The agreement between the theoretical and empirical masses for these peaks is at the < 99.7 % > level, and the analysis has been constrained by using canonical j values and reasonable values of **a** that obey the Kerr metric restrictions.

3. Further refinements require going to a full Kerr-Newman metric which includes charge and charge-related phenomena, as well as M and J. For spin = 0 particles like pions and kaons, the Reissner-Nordstrom metric would seem to be the most reasonable modeling approach.

4. The good agreement of the theoretical results listed above, when compared with the mass values that *can be measured* reasonably directly, argues that “strong gravity” and Discrete Scale Relativity offer a radical new way of understanding subatomic particles and the particle mass/stability spectrum.

Discrete Scale Relativity has the potential to unify high-energy physics, Quantum Mechanics and General Relativity. "String theory" has promised to deliver this new unified paradigm for over 3 decades without producing a convincing empirical discovery or any definitive predictions. Discrete Scale Relativity, on the other hand, has passed numerous retrodictive and predictive tests, demonstrating a credible potential for completing Einstein's relativity program and identifying a promising path to his vision of a unified understanding of nature.