Update on Pluto and Its 5 Moons Obeying the Quantization of Angular Momentum per Unit Mass Constraint of Quantum Celestial Mechanics

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In July, 2015, the New Horizons spacecraft passing by Pluto did not discover any more moons. Therefore, we know the Pluto system total angular momentum to within 2.4%, more accurately than any other system with more than two orbiting bodies. We therefore update our previous analysis to determine whether a definitive test of the quantum celestial mechanics (QCM) angular momentum constraint can now be achieved.

1 Introduction

In 2012 we analyzed the angular momentum properties of the Pluto system with its 5 moons [1] not knowing the total angular momentum in the system. The New Horizons spacecraft passing by Pluto and its large moon Charon in July, 2015, did not discover any more moons than its earlier discovery of 4 additional tiny moons. Therefore, the Pluto system that we know is the final configuration of orbiting bodies, so we now know its total angular momentum to within 3%. Consequently, we can consider this gravitationally bound system as a possible definitive test of the theory called quantum celestial mechanics (QCM) first proposed in 2003 by H. G. Preston and F. Potter [2].

They derived a new gravitational wave equation from the general relativistic Hamilton-Jacobi equation for a test particle of mass μ as given by Landau and Lifshitz:

$$g^{\alpha\beta} \frac{\partial S}{\partial x^\alpha} \frac{\partial S}{\partial x^\beta} - \mu^2 c^2 = 0\,, \tag{1}$$

where $g^{\alpha\beta}$ is the metric of the general theory of relativity (GTR) and S is the action. This general relativistic Hamilton-Jacobi equation becomes a scalar wave equation via the transformation to eliminate the squared first derivative, i.e., by defining the wave function $\Psi(q, p, t)$ of position q, momentum p, and time t as

$$\Psi = e^{iS'/H} \tag{2}$$

with $S' = S/\mu c$. The H is defined as the Preston distance characterizing the specific gravitational system and is a function of *only two physical parameters* of the system

$$H = \frac{L_T}{M_T\, c}\,, \tag{3}$$

where M_T is the total mass of the system and L_T its total angular momentum. Only these two parameters of the system are required to define all the stable quantization states of the gravitationally bound system. We call the resulting theory quantum celestial mechanics or QCM.

The end result of the transformation is the new scalar "gravitational wave equation" (GWE)

$$g^{\alpha\beta} \frac{\partial^2 \Psi}{\partial x^\alpha\, \partial x^\beta} + \frac{\Psi}{H^2} = 0. \tag{4}$$

One can now consider the behavior of the test particle in different gravitational metrics. In the Schwarzschild metric, we find good agreement with predictions for all systems to which the QCM constraints have been applied.

There have been numerous applications of QCM to gravitationally bound systems, including multi-planetary exosystems [3], the Solar System [2], the five moons of Pluto [1], the S-stars at the galactic center [4], and circumbinary systems [5, 6] with planets. All these systems have been shown to obey the quantization of angular momentum per unit mass constraint dictated by QCM in the Schwarzschild metric approximation for each orbiting body μ_i, i.e.,

$$\frac{L_i}{\mu_i} = m_i\, c H. \tag{5}$$

Of course, one assumes that the body in consideration has been in an equilibrium orbit for at least tens of millions of years. Then if one knows the semi-major axis r, the eccentricity e, and the period of orbit, the QCM value for L_i in the specific equilibrium orbit equals the Newtonian value $L = \mu\, \sqrt{GM_T\, r\,(1 - e^2)}$. The value of M_T is nearly the central body mass for most cases.

Knowing the period of orbit is an additional constraint that allows one to determine a set of integers m for the QCM angular momentum per unit mass linear regression fit, with $R^2 > 0.999$, which we seek in all cases. Moreover, if one knows the total angular momentum for the gravitationally bound system, then a unique set of m values is possible. However, if the system total angular momentum is unknown, then several sets of integers could meet the liner regression fit, in which case we will accept the set beginning with the smallest integer.

From the slope of the resulting plot of $L/\mu c$ vs. m for all the known orbiting bodies in the system, one can calculate the predicted QCM total system angular momentum L_T and therefore can predict whether additional mass orbiting the star is needed to account for this total angular momentum value. Many m values for the gravitationally bound system will be unoccupied, for the occupancy of the specific QCM orbits depends upon the history of formation and the subsequent evolution of the planetary system.

For simplicity, applications have concentrated on circular or near-circular orbits only. Whereas in GTR and its Newtonian approximation all allowed circular or nearly-circular orbits about a massive central object are equilibrium orbits, QCM dictates that only a subset of these equilibrium orbits are permitted by the quantization of angular momentum per unit mass constraint.

With any new theory, one needs a definitive test. Until now there has been no laboratory test of QCM. Finding a convincing, definitive test for QCM has not been successful. As of this date, the satellites of Pluto actually offer the best test of QCM and its quantization of angular momentum per unit mass prediction. Why? Because the total angular momentum of the Pluto-Charon system with its 4 tiny moons is well-known now to within 2.4%.

One would expect that the Solar System as a whole or the many satellites of the Jovian planets would be a better test. However, one does not know the total angular momentum to within 10% of either the Solar System or each of the Jovian planets. The Jovian planets themselves dominate the angular momentum contributions in their systems but their internal differential rotations lead to large uncertainties in their total angular momentum.

And, unfortunately, we do we not know the total angular momentum of the Solar System to within 10%. Why not? Because the Oort Cloud dominates the Solar System angular momentum [7], providing about 50 times the total angular momentum contribution from the Sun and the planets! The total mass of the Oort Cloud is unknown but can be estimated by assuming perhaps 100 Earth masses of ice chunks at more than 40,000 AU. The dominance of the Oort Cloud can be verified by estimating the Newtonian value of its angular momentum.

Although we have determined excellent linear regression fits to all planetary-like systems by the QCM angular momentum constraint, there remain two limitations of the fits: (1) they are not unique and (2) all integers are candidates for m, i.e., there being no upper limit. For example, even with a linear regression fit $R^2 = 1.000$ for the set of m values 3, 5, 8, 14, 17, for a 5 planet system, the set of double values 6, 10, 16, 28, 34, fits equally well. The slope of the graph of $L/\mu c$ versus m is used to predict the total angular momentum of the system, the former set predicting twice the angular momentum. However, if one knows the total system angular momentum value, such as we do now for the Pluto system, then the set of m values is unique.

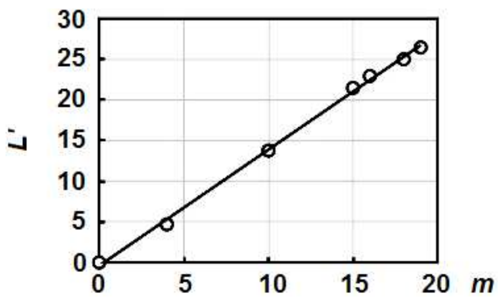

Fig. 1: The Pluto System fit to QCM.

	$r \times 10^6$ m	Period (d)	m	P_2/P_1	$(n_2/n_1)^3$
Pluto	2.035	6.38723	4		
Charon	17.536	6.38723	10	1	1
Styx	42.656	20.16155	15	3.156	3.077
Nix	48.694	24.85463	16	3.891	3.691
Kerberos	57.783	32.16756	18	5.036	5.153
Hydra	64.738	38.20177	19	5.981	6.011

Table 1: Pluto system orbital parameters and QCM m values.

2 Pluto and its 5 moons

Will a *random* set of orbital distances fit the QCM angular momentum quantization constraint? Yes, because there is no upper limit to the integers available for the m values. One can always fit the constraint using very large integers! This possibility is eliminated when the total angular momentum is known. If one uses this random set of orbital distances with a specific mass for the central star but the other masses are unknown, the system obeys Newton's law of universal gravitation and the angular momentum *per unit mass* is known but the unique set of integer values for m cannot be achieved.

The New Horizons spacecraft passing Pluto in July, 2015, did not discover any more moons. The Pluto satellite system [8] has five moons, Charon, Styx, Nix, Kerberos, and Hydra, which are nearly in a 1:3:4:5:6 resonance condition! The orbital behavior of the five moons is considered by using distances from the Pluto-Charon barycenter. The important physical parameters of the Pluto system satellites are given in Table 1. The orbits are very close to circular.

The system total mass is essentially the combined mass of Pluto (13.05×10^{21} kg) and Charon (1.52×10^{21} kg). The QCM values of m in the fourth column were determined by the linear regression fit ($R^2 = 0.998$) to the angular momentum quantization per mass equation as shown in Figure 1 with $L' = L/\mu c$ plotted against m with resulting slope $H = 1.43$ meters. The uncertainty bars are within the circles. Our previous fit [1] of these Pluto moons proposed the m values 2, 6, 9, 10, 11, 12, with $R^2 = 0.998$ also.

This new value of H produces a total angular momentum value $L_T = 6.28 \times 10^{30}$ kg m^2/s that is commensurate with the total angular momentum of $6.26(\pm 0.14) \times 10^{30}$ kg m^2/s for the known Pluto system when both orbital and rotational angular momentum are included.

In QCM the predicted period ratios for the orbital resonance conditions in the last column of Table 1 are calculated from the m values using

$$\frac{P_2}{P_1} = \frac{(m_2 + 1)^3}{(m_1 + 1)^3}\,. \tag{6}$$

With Charon as the reference, this system of moons has nearly a 1:3:4:5:6 commensuration, with Kerberos having the largest discrepancy of about 5.2%.

These moons have distances from the barycenter that are within 2.4% of their QCM equilibrium orbital radii. If in the next few million years they adjust their orbital semi-major axes, their positions on the plot may improve to increase the R^2 value but their m values will remain the same. Dynamic analysis via the appropriate QCM equations could be done to predict their possible movements.

Note that some additional extremely tiny moons of Pluto may be found at some of the non-occupied m values, but their angular momentum contributions will be very small. The formation history of Pluto determines which m values are actually occupied by orbiting bodies.

3 Discussion

QCM predicts the quantization of angular momentum per unit mass for all orbiting bodies in gravitationally bound systems. Unfortunately, the total angular momentum of planetary-like systems is usually not known to within 10%. Fortunately, the New Horizons spacecraft passing by Pluto in 2015 did not discover any additional moons of Pluto, so we now know the extent of this system and its total angular momentum to within 2.4%.

We have determined the best set of m integers for a fit to the QCM angular momentum constraint, and the predicted resonances in its moon system are in agreement with the measured period ratios to within 5.2%.

Therefore, we claim to have a definitive test of QCM in the Schwarzschild metric in a planetary-like system because the best understood system, Pluto and its 5 moons, obeys the quantization of angular momentum per unit mass constraint. Consequently, we expect that all such systems obey QCM, and in the future we will search for systems that seem to violate the angular momentum constraint.

One would prefer the ability to vary the parameters in a gravitationally bound system, but we do not have that luxury in astronomical systems. A laboratory test would allow the variation of the system parameters in a controlled manner and should be undertaken with perhaps a pendulum in a vacuum chamber near to a rotating mass. In the ideal case one would expect the maximum repulsion of the pendulum to occur when the angular momentum constraint is met and its magnitude to be comparable to the Newtonian attraction. This type of additional definitive test of QCM might be able to achieve an reduced uncertainty down to about 0.1%.

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