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The Haug-Spavieri metric introduces in the Schwarzschild metric an observable term verifiable even in weak gravitational fields

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Abstract

Haug and Spavieri have recently presented a new exact solution to Einstein's field equation. In this paper, we will list multiple implications of this model concerning predicted: gravitational time dilation, redshift, light bending, escape velocity, and more. All the new results contain a relativistic correction term added to the Schwarzschild metric. The Schwarzschild metric can almost be seen as a weak gravitational field approximation of our mass-charge metric. The difference in predictions of the two metrics, can be verified even in the weak gravitational field of the Sun and also in the gravitational field of the Earth by utilizing atomic or optical clocks on board of satellites. Yet, in the gravitational field of the Earth the effect is so small, that to be detected, we must have access to the most advanced state of the art in modern optical clocks. However in the Sun's gravitational field it seems that even current cesium atomic clocks are good enough to test the differences in predictions between the two metrics.

Also, photons, sent out in a strong gravitational field close to the event horizon of black holes, can likely be used to verify what metric derived from general relativity theory is the best to explain observed phenomena in black holes, such as the lack of velocity time dilation in high- z quasars.

Key words: Mass-charge metric, time dilation, red-shift, light bending, black holes.

1 Predictions from the Haug-Spavieri metric versus the Schwarzschild metric

Einstein [1] field equation is given by

$$R_{\mu\nu} - Rg_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \quad (1)$$

The field equation must be solved based on certain boundary conditions to yield equations capable of predicting gravitational effects, which can then be verified through observations.

The most well-known and thoroughly tested solution is, by far, the Schwarzschild metric. It has undergone extensive testing in weak gravitational fields, confirming its accuracy in predicting gravitational time dilation, redshift, light bending, and more.

Recently, Haug and Spavieri [2] have derived a new exact solution to Einstein's field equation. This solution takes into account a stress-energy tensor that considers both the electric field energy of the charge and the gravitational field energy of the mass. To determine if this metric better describes the real world compared to the Schwarzschild metric, one must calculate predictable differences.

The new metric derived by Haug and Spavieri is given by in S.I. units:

$$ds^2 = - \left(1 - \frac{2GM}{c^2 r} + \frac{G^2 M^2}{c^4 r^2} + \frac{Q^2}{r^2} + \frac{P^2}{r^2} \right) c^2 dt^2 + \left(1 - \frac{2GM}{c^2 r} + \frac{G^2 M^2}{c^4 r^2} + \frac{Q^2}{c^2 r^2} + \frac{P^2}{c^2 r^2} \right)^{-1} dr^2 + r^2 \Omega^2 \quad (2)$$

We will focus here on the case when the charge Q and magnetic moment P are set to 0 ($Q = P = 0$). Then, the metric simplifies to

$$ds^2 = - \left(1 - \frac{2GM}{c^2 r} + \frac{G^2 M^2}{c^4 r^2} \right) c^2 dt^2 + \left(1 - \frac{2GM}{c^2 r} + \frac{G^2 M^2}{c^4 r^2} \right)^{-1} dr^2 + r^2 \Omega^2 \quad (3)$$

From this, we can easily derive predictions for gravitational time dilation, redshift, and the gravitational bending of light. The results, when compared to the Schwarzschild metric, are presented in Table 1.

Table 1: The table displays well-known predictions from the Schwarzschild metric and also from the metric proposed by Haug and Spavieri. In all the predictions, there is a second-order term in the Haug and Spavieri metric that is absent in the Schwarzschild metric. This additional term primarily leads to predictable differences in strong gravitational fields, especially for observations from photons emitted close to a black hole horizon. Alternatively, extremely precise measurement devices are required to detect the predicted difference in a weak gravitational field, such as experiments conducted in the gravitational field of the Earth or the Sun.

Prediction	Schwarzschild:	Haug-Spavieri:
Gravitational red shift	$z = \frac{\sqrt{1 - \frac{2GM}{R_1 c^2}}}{\sqrt{1 - \frac{2GM}{R_2 c^2}}} - 1$	$z = \frac{\sqrt{1 - \frac{2GM}{r_1 c^2} + \frac{G^2 M^2}{r_1^2 c^4}}}{\sqrt{1 - \frac{2GM}{r_2 c^2} + \frac{G^2 M^2}{r_2^2 c^4}}} - 1$
Time dilation	$T_1 = T_2 \frac{\sqrt{1 - \frac{2GM}{r_2 c^2}}}{\sqrt{1 - \frac{2GM}{r_1 c^2}}}$	$T_1 = T_2 \frac{\sqrt{1 - \frac{2GM}{r_2 c^2} + \frac{G^2 M^2}{r_2^2 c^4}}}{\sqrt{1 - \frac{2GM}{r_1 c^2} + \frac{G^2 M^2}{r_1^2 c^4}}}$
Gravitational deflection	$\theta = \frac{4GM}{c^2 r}$	$\theta = \frac{4GM}{c^2 r} - \frac{2G^2 M^2}{c^4 r^2}$
Escape velocity	$v_e = \sqrt{\frac{2GM}{r}}$	$v_e = \sqrt{\frac{2GM}{r} - \frac{G^2 M^2}{r^2 c^2}}$
Event horizon black-hole	$R_s = \frac{2GM}{c^2}$	$R_h = \frac{GM}{c^2}$
Mass from horizon radius	$M = \frac{c^2 R_s}{2G}$	$M = \frac{c^2 R_h}{G}$

2 The Haug-Spavieri metric is likely verifiable relative to the Schwarzschild metric even in weak gravitational field

Theoretically, there is a clear distinction in the formulas between the Schwarzschild and Haug-Spavieri metric. However, it is important to inquire about the magnitude of the pre-

dicted differences. Since it is a second-order term that creates the difference in predictions between the two metrics, it is evidently a relativistic effect that will predominantly have significant implications in strong gravitational fields. Nevertheless, it will also exhibit some minor observable effects in weak gravitational fields, the magnitude of which we can easily calculate.

In Earth's gravitational field, if we examine the gravitational time dilation between a clock placed at sea level and another one at a 1000-meter tower (or mountain top), we would only expect to observe approximately 7.6×10^{-23} seconds of difference in time dilation over a second. This is considerably outside the precision of the current best atomic and optical clocks, which have a precision of approximately 10^{-18} per second. See, for example, [3–6]. To increase precision, one can increase the distance between the clocks, for example, by synchronizing an atomic clock on the surface of the Earth with an atomic clocks placed on board of a geostationary satellite. Geostationary satellites are about 35,786 km out in space, so this is the distance between the clocks. Then the predicted difference is about 2.367×10^{-19} seconds per second. Over a month (30 days), it amounts to 6.13×10^{-13} seconds. This could be possible with clocks better than the off-the-shelf atomic clocks, as it is well within the limit of precision in today's best atomic and optical clocks (10^{-18}). The predicted difference arises from the difference between the gravitational time-dilation foreseen by the Schwarzschild metric and that of the Haug-Spavieri metric. This predicted difference is after properly adjusting for velocity time dilation as well as the Sagnac effect [7]. Table 2 gives examples of predicted differences for gravitational time dilation from the Schwarzschild metric and the Haug and Spavieri metric in clocks placed distance d apart from each other.

Table 2: The table shows predicted gravitational time dilation differences between initial Einstein synchronized clocks placed distance (altitude) d apart in the Earth gravitational field. The difference represents the prediction of the Schwarzschild metric versus the Haug-Spavieri metric.

Altitude distance d between clocks one ground based	Predicted difference per second :	Predicted difference per day:	Predicted difference per month (30 days):
Altitude of tower or mountain clock: 1 km	7.6×10^{-23} s	6.57×10^{-18} s	1.97×10^{-16} s
Altitude of airplane clock: 10 km	7.59×10^{-22} s	6.56×10^{-18} s	1.97×10^{-15} s
Altitude of air-balloon clock: 30 km	2.27×10^{-21} s	1.96×10^{-16} s	5.88×10^{-15} s
Altitude satellite clock: 20,000 km	2.28×10^{-19} s	1.97×10^{-14} s	5.91×10^{-13} s
Altitude geostationary satellite clock: 35 786 km	2.37×10^{-19} s	2.05×10^{-14} s	6.14×10^{-13} s

In the Sun's gravitational field, at a distance of 6.9 million kilometers from the center of the sun—this is the distance at which observational solar satellites orbit the sun—we find a predicted time-dilation difference of about 3.1×10^{-14} seconds per second when using two satellites with clocks 1 km apart from each other (one further out from the sun). If the satellites are placed 100 km apart, one at 6.9 million kilometers from the sun and one 100 km further out, then the predicted time dilation difference between the Schwarzschild metric and the Haug-Spavieri metric is about 3.1×10^{-12} seconds per second.

The predicted differences are well within the measurement capabilities of the best atomic and optical clocks with precision of approximately 10^{-18} s. If the satellites are placed at 100,000 km apart, then we only need clocks with nanosecond accuracy, 10^{-9} , which is achiev-

Table 3: The table shows predicted time dilation differences between clocks placed a distance d apart on board solar satellites. The inner satellite is assumed to be placed at a distance of 6.9 million kilometers from the sun, and the next one is located a distance d further out from that. The clocks on the two satellites are Einstein synchronized and then compared after 1 second or after 1 day or after 30 days, the longer one wait the bigger the predicted difference between the two metrics

Altitude distance d between clocks	Predicted difference per second :	Predicted difference per day:	Predicted difference per month (30 days):
1 km	3.1×10^{-14} s	2.69×10^{-9} s	8.04×10^{-6} s
10 km	3.1×10^{-13} s	2.69×10^{-8} s	8.04×10^{-5} s
100 km	3.1×10^{-12} s	2.69×10^{-7} s	8.04×10^{-4} s
1,000 km	3.1×10^{-11} s	2.69×10^{-5} s	8.04×10^{-3} s
10,000 km	3.1×10^{-10} s	2.69×10^{-4} s	8.04×10^{-2} s
100,000 km	3.1×10^{-9} s	2.69×10^{-3} s	8.04×10^{-1} s
1000,000 km	3.1×10^{-8} s	2.69×10^{-2} s	8.04 s

able with off-the-shelf atomic clocks. If measured over a day (24 hours), all differences of the clocks placed distance d apart as shown in table 3, are 10^{-9} seconds or larger. This implies that standard off-the-shelf atomic clocks and even chip-sized atomic clocks can likely be used to verify if the Haug-Spavieri metric models reality more accurately than the Schwarzschild metric. Organizations like NASA should be able to conduct such experiments. Naturally multiple factors must be included such as clock-stability, velocity time dilation and the Sagnac effect in addition to gravitational time dilation. Therefore, errors in other factors must be smaller than the predicted difference. The predicted difference can be further reduced, for example, by letting the experiment run for a whole month, as shown in the last column. Then, we go down to the need of a reduced accuracy of 10^{-2} seconds per month.

There are multiple methods to reduce errors in clocks. For example one would typically have at least three or even whole clusters of initially synchronized clocks on each satellite for control and error reduction. This should be no big task for NASA and could be one of the most important breakthroughs in gravity for decades if the Haug-Spavieri metric is verified to be a more accurate model of reality.

3 The Haug-Spavieri metric is likely verifiable relative to the Schwarzschild metric in strong gravitational fields

When close to a black hole horizon, the term $\frac{G^2 M^2}{r^2 c^4}$ that appears in most formulas as an additional relativistic term relative to the Schwarzschild predictions, suddenly becomes very significant. Another important way to test the Haug-Spavieri metric against the Schwarzschild metrics is therefore from photons sent out close to the horizon of black holes.

There are multiple interesting types of black holes that could be worth investigating. For example, in high- z quasars (which all likely have black holes at their center), surprisingly, velocity time dilation [9, 10] has not been observed. Based on the results foreseen by our metric, photons can be sent out closer to the center of the mass of the quasar black holes than what possible in the Schwarzschild metric. The reason is that in our metric, the event horizon is only half of that of the Schwarzschild horizon, and photons can then be sent out closer to the center of the black hole without being inside the horizon. So, this is one possibility that can be more carefully investigated by researchers.

It has also been pointed out by many researchers [11–17] that the Hubble sphere has many mathematical properties similar to a black hole, but the Schwarzschild black hole does not seem to be able to fit observations that well. One possibility is therefore to investigate if the Hubble sphere resembles more closely to a Haug-Spavieri black hole; we have outlined this possibility in a tentative theory for it in [18], which should also be investigated further.

When it comes to gravitational light bending (deflection), our preliminary result (which we will have to carefully check later on) shows that the deflection is $\theta = \frac{4GM}{c^2 r} - \frac{2G^2 M^2}{c^4 r^2}$. In a weak gravitational field, the extra term $-\frac{2G^2 M^2}{c^4 r^2}$ has too little impact to be tested, for example, from the bending of light around the sun. Here, the two models are currently indistinguishable. In a very strong gravitational field, it is interesting that the Schwarzschild metric predicts light bending at the event horizon itself (or just outside) as $\theta = \frac{4GM}{c^2 r_s} = 2$. A light bending of 2 basically means a photon could orbit the black hole. We get the identical result at the horizon from our new metric, namely $\theta = \frac{4GM}{c^2 r_h} - \frac{2G^2 M^2}{c^4 r_h^2} = 2$. However, for a Planck mass black hole, in our theory, we can go all the way down to the Planck length radius, while the Schwarzschild metric can only go down to twice the Planck length. This could possibly indicate that our model is better suited to fit the Planck scale properties than the Schwarzschild metric; see also the table about micro black holes in [19].

We hope that other researchers will closely investigate our metric and compare carefully its predictions with observations from black holes and the Schwarzschild metric. The comparison can, hopefully, be extended to other metrics such as the Reissner-Nordström [20, 21], Kerr [22] metric, the Kerr-Newman [23, 24] metric, and even our new generalized rotation metric [19].

4 Conclusions

We have shown that, with present technology, the metric derived by Haug-Spavieri appears to be verifiable relative to the Schwarzschild metric, even in the weak gravitational field of the Sun or the Earth. This can be achieved using just two Einstein-synchronized standard atomic clocks at normal orbital altitudes around the Sun. If one wishes to test the metrics in the Earth’s gravitational field, it is necessary to maximize the distance and employ very modern equipment—likely requiring the use of state-of-the-art optical or atomic clocks, as achieving an observable minimum precession of 10^{-13} seconds per month is essential. Solar satellite experiments are possibly preferable, as such experiments meet accuracy requirements well within the reach of standard atomic clocks.

Additionally, observations from photons sent out close to the horizon of a black hole can likely help us distinguish which metric is best suited to describe reality. It seems that the Haug-Spavieri metric possibly interprets more effectively the lack of observed time dilation in High z quasars. Furthermore, if the Hubble sphere is taken to represent a black hole, then photons sent out close to the Hubble horizon could possibly be better described through the Haug-Spavieri metric. Our tentative considerations about some cosmological and gravitational phenomena, related to the Haug-Spavieri metric, need to be scrutinized by multiple researchers over time before drawing any conclusions.

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Declarations

Competing interests

The authors have no competing interests to report.

Availability of data and materials

The study contains no new data.