Gravitation Essay

APPENDIX 3A

STATIC SPHERICALLY SYMMETRIC GRAVITATIONAL FIELDS: New Closed-Form Solution in Standard Coordinates of a Physically Viable Modified Jordan-Brans-Dicke Type of Scalar-Tensor Field Theory

by

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Abstract. In a generalization of General Relativity (GR), a new physically viable scalar-tensor gravitational field theory is introduced in which, following Einstein, Mach's Principle is interpreted to imply that the Cavendish parameter G increases as a test-particle approaches a finite mass M (the exact opposite of the basic assumption -- elsewhere shown physically non-viable to two standard deviations -- of the Jordan-Brans-Dicke [JBD] theory). A new closed-form solution is presented, and a simple, direct, Helios satellite-borne Cavendish experiment which with present-day capabilities can conclusively confirm or refute it is announced. The true physical meaning of the Laplace-Schwarzschild "black hole" radius $r_{LS} = 2GM/c^2$ is thus, for the first time, made apparent: it is proved rigorously that, as an external test-particle approaches r_{LS}, G becomes positively infinite. Since this G does not appear in the equations of motion of a test-particle, there is no contradiction between the result just stated and the further rigorous corollary, to be proved elsewhere, that in proper time, gravitational attraction reverses polarity and becomes infinitely repulsive at r_{LS}, thereby seemingly exhibiting the strong nuclear force as a natural aspect of gravity at small distances. Furthermore (as previously argued by Einstein, Rosen and Hoyle) another quantitative corollary is that complete gravitational collapse is impossible: black holes do not exist. The present theory cannot be ignored because it is an unavoidable consequence of the experimental observations (analysed elsewhere) that the Eddington-Robertson (PPN) parameter $\gamma > 1$.

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ERRATA AND CORRIGENDA

1. Exhibit A

   a. Page 2, bottom line: strike out first factor 2.

   b. Page 8, line 8: insert [Our Maximum Likelihood estimate is $\gamma = 1.02 \pm 0.01$.]

   c. Page 14, next to bottom line: version[22].

2. Appendix 1

   a. Abstract, line 7: replace "weakens" by "changes" and ± 0.06 by ± 0.01; in next line replace 60% by 95%.

   b. Page 3: delete factors (1/N) from (6) and (7),

   c. Page 4, equation (8): replace $\pm 0.20 > 1.01$ by $\pm 0.06 > 1.15$; in (10): replace $\pm 0.088 > 0.92$ by $\pm 0.062 > 0.95$.

   d. Page 5, equation (11): replace $\pm 0.059 > 0.96$ by $\pm 0.018 > 1.004$; equation (12): replace $\pm 0.029 > 0.98$ by $\pm 0.011 > 0.99$; equation (13): replace $\pm 0.06 > 0.96$ by $\pm 0.01 > 1.01$; two lines below (13) replace 60% by 95%.

   e. Page 8: replace $\pm 0.20 > 1.01$ by $\pm 0.06 > 1.15$.

   f. Page 10: replace $\pm 0.088 > 0.92$ by $\pm 0.062 > 0.95$.

   g. Page 11: replace $\pm 0.059 > 0.96$ by $\pm 0.018 > 1.004$.

   h. Page 12: replace last column by 0.06, 0.015, 0.062, 0.018 and replace $\pm 0.029 > 0.98$ by $\pm 0.011 > 0.99$.

   i. Page 14: replace ± 0.055 by $\pm 0.011 > 1.006$.

3. Appendix 3A

   a. Page 2, equation (7): insert minus sign before right-hand side.

4. Appendix 3B

   a. Insert reference 11:

      A. Einstein, "Stationary systems with spherical symmetry consisting of many gravitating masses," *Annals of Mathematics*, Ser. 2, vol. 40 (1939), pp. 922-936.

In standard General Relativity (GR) the gravitational field equations are (with c = 1)

$$(1) \qquad R_{\mu\nu} = -8\pi G\,[T_{\mu\nu} - \tfrac{1}{2}\, g_{\mu\nu}(T^{\lambda}{}_{\lambda})]$$

where $T_{\mu\nu}$ is the energy-momentum tensor of matter, assumed to satisfy the conservation laws

$$(2) \qquad T^{\mu}{}_{\nu;\,\mu} = 0\ .$$

Here (1) can be solved readily for $T_{\mu\nu}$ to yield, equivalently,

$$(3) \qquad G_{\mu\nu} \overset{d}{=} R_{\mu\nu} - \tfrac{1}{2}\, g_{\mu\nu}(R^{\lambda}{}_{\lambda}) = -8\pi G T_{\mu\nu},$$

where the fact that the Einstein tensor $G_{\mu\nu}$ satisfies the Bianchi identities

$$(4) \qquad G^{\mu}{}_{\nu;\mu} \equiv 0$$

then implies (2) as an immediate corollary of (3); hence (3) is a more compact formulation than (1)-(2).

In attempting to incorporate into GR Mach's Principle that the local inertial properties of matter (say the rest masses of local bodies) are determined completely by the distribution of all the matter in the universe, it was noted by Dicke (using Fierz's scale-change theory) that an equivalent postulate would be to regard rest masses as fixed and to allow distant matter to determine the local value of the Cavendish parameter G. A formalism due to Jordan was adopted by Brans and Dicke for this purpose; however, the Brans-Dicke theory (which implies that the Eddington-Robertson parameter (PPN:)$\gamma < 1$) is not physically viable since it contradicts the result of all twenty-four known solar system experimental tests of metric gravitational theories to two standard deviations which (as is shown elsewhere), with 95% probability imply that $\gamma > 1$.

Consequently, it is necessary to re-think the scalar-tensor theory from first principles and to make a fresh start. The theory presented here has a certain formal similarity to the theories of Jordan and of Brans-Dicke (JBD), but its physical interpretation and conclusions are profoundly different. The observed hyperbolicity of the universe (Sandage, 1974; Gunn, 1974) also yields a physical contradiction to either GR or the JBD theories, unless (as shown elsewhere) it is assumed that G increases with cosmic time t (the exact opposite of the postulates of Jordan and of Brans-Dicke). Hence we shall incorporate Mach's Principle in the present physically viable generalization of GR by the assumption that G increases as a test-particle approaches any finite mass (the exact opposite of the basic hypothesis of Brans and Dicke).

Let $\mathcal{G}$ denote a constant of the order of magnitude of the Cavendish parameter observed on Earth; physically, $\mathcal{G}$ will denote the Cavendish parameter, due to the rest of the matter in the universe, that would be observed at Earth's present locus in space-time if the Sun and planets were removed. The actual value of this parameter, G which appears in (3) must then, according to Mach, represent a perturbation of $\mathcal{G}$ due (principally) to the Sun's mass, so we write

(5) $$G \overset{d}{=} \frac{1}{\phi} \overset{d}{=} \frac{\mathcal{G}}{(1+\xi)}\,, \quad \phi \overset{d}{=} \mathcal{G}^{-1}\,(1+\xi)$$

where, near Earth,

(6) $$|\xi| << 1 \quad .$$

Following the Brans-Dicke approach to Mach's Principle, we assume that the total distribution of mass in the universe determines ξ via a D'Alembert-Poisson scalar wave equation,

(7) $$\mathcal{G}\Box^2\phi \equiv \Box^2\xi = \frac{8\pi\mathcal{G}}{(2|\omega| - 3)}\,(T^{\mu}{}_{\mu})\ ,$$

where $\Box^2$ is the space-time D'Alembertian, i.e.,

(8) $$\Box^2\xi \overset{d}{=} \xi^{;\mu}{}_{;\mu}\ ,$$

but, in contradistinction to the previous theories, we assume a different sign for the coupling constant between the mass-density ($-T^{\mu}{}_{\mu}$) and the propagation of the ξ-wave. Specifically we require that the dimensionless parameter $|\omega|$ satisfy

$$(9) \qquad 0 < 2 < |\omega| < +\infty \quad ,$$

$$(10) \qquad \xi \to 0 \quad \text{as} \quad r \to +\infty \; .$$

Thus, for distances over which the speed of light may be regarded as infinite, and space as Euclidean, an Einstein-Poisson integration of (7) shows that,

$$(11) \qquad G < \mathrm{G} = G\left(1 + \frac{MG}{(|\omega| - 2)} \cdot \frac{1}{r} + \cdot\cdot\cdot\right) \quad ,$$

a result which is in complete contradistinction to the prior theories, in which

$$(12) \qquad \mathrm{G} < G$$

was assumed.

Now, by (3) and (5),

$$(13) \qquad \mathrm{G}_{\mu\nu} = -\frac{8\pi}{\phi}\,[T_{\mu\nu} + \hat{T}_{\mu\nu}]$$

where $\hat{T}_{\mu\nu}$ is the energy-momentum tensor of the new ϕ-field. Hence, if we desire to preserve the conservation laws for matter (2) as a corollary of the Bianchi identities (4), there is only one possible physically reasonable definition of $\hat{T}_{\mu\nu}$, namely

$$(14) \qquad 8\pi\,\hat{T}_{\mu\nu} = -\frac{|\omega|}{\phi}\,(\phi_{;\mu}\,\phi_{;\nu} - \tfrac{1}{2}\,g_{\mu\nu}\,[\phi^{;\lambda}\,\phi_{;\lambda}] \; + $$
$$+ \; (\phi_{;\mu;\nu} - g_{\mu\nu}\,[\phi^{;\tau}{}_{;\tau}]) \; ,$$

as shown by a straightforward calculation similar to that presented by Weinberg (1972), pp. 159-160. Upon solving (13) for $R^{\lambda}{}_{\lambda}$ and re-arranging, we obtain, finally, the new scalar-tensor gravitational field equations (7), (9), (10), (13), (14) in the equivalent form

$$(15) \qquad \mathrm{G} = \frac{1}{\phi} = \frac{G}{(1 + \xi)} \; , \quad \phi = G^{-1}(1 + \xi) \; ,$$

(16) $$\xi^{;\mu}{}_{;\mu} = -\frac{8\pi G}{(2|\omega| - 3)}(T^{\mu}{}_{\mu}) , \quad (0 < 2 < |\omega| < +\infty)$$

(17) $$R_{\mu\nu} = -\frac{8\pi G}{(1+\xi)}[T_{\mu\nu} - \tfrac{1}{2}\left(\frac{2|\omega| - 2}{2|\omega| - 3}\right) g_{\mu\nu}(T^{\lambda}{}_{\lambda})] + + |\omega| \frac{\xi_{;\mu}\,\xi_{;\nu}}{(1+\xi)^2} - \frac{\xi_{;\mu;\nu}}{(1+\xi)} ,$$

(18) $$\xi \to 0 \quad \text{as} \quad r \to +\infty .$$

This theory is so constructed that GR is recovered as a special case as $|\omega| \to +\infty$. However, Mach's Principle is obeyed in that, unlike GR, if there is no mass in the universe, then (15)-(18) have no regular solutions. (In fact, if $T_{\mu\nu} \equiv 0$, then by (16) and (18), $\xi \equiv 0$, i.e., $R_{\mu\nu} \equiv 0$, which as Einstein knew, has no singularity-free solutions $g_{\mu\nu}$.)

There is an apparent formal similarity between the present theory and the Brans-Dicke theory, in that if one makes the [trivially simple] transformation

(19) $$|\omega| = -\omega$$

and then follows this by the [radical] change from the present parameter region

(20) $$-\infty < \omega < -2 < 0$$

to the disconnected parameter region

(21) $$-(3/2) < \omega < +\infty ,$$

one recovers the Brans-Dicke theory. However, in many articles and a book, Dicke has stressed repeatedly the physical consequences of (21), including the fact that

(22) $$\text{(PPN:)} \quad \gamma = \frac{\omega + 1}{\omega + 2} \equiv 1 - \frac{1}{\omega + 2} < 1$$

(which is contradicted by observations); in fact, he has claimed $\omega \geqq 6$. Also, a recent brief popular survey of metric gravitational theories mentions no less than three times the restrictions (21)-(22) on the Brans-Dicke theory. Hence it seems necessary to emphasize that the present theory is not just a special case of the Brans-Dicke theory, but is an entirely different theory, having radically different observational bases ($\gamma > 1$, $q < \frac{1}{2}$), different physical motivations and interpretations, a different parameter-regime of validity, and profoundly different physical conclusions [e.g., black holes are impossible].

Furthermore, although Brans and Dicke (with the assistance of C. W. Misner) found, in isotropic coordinates, a spherically symmetric static solution to their theory, they specifically disavowed its putative meaningfulness near $r = 0$, i.e., its applicability to black-hole theories.

In contradistinction, the principal motivation and chief goal of the present theory is to obtain a static spherically symmetric solution of (15)-(18) which, in standard coordinates, is rigorously valid in any neighborhood of $r = 0$ (except at $r = 0$), and so is applicable to considerations of gravitational collapse and other phenomena near the Laplace-Schwarzschild radius.

THEOREM. Consider the system (15)-(18) in standard coordinates (r, θ, ϕ), and suppose that $T_{\mu\nu} = 0$ except at $r = 0$, i.e., that

(23) $$T^{\mu\nu} = \rho U^{\mu} U^{\nu} , \quad (U_{\alpha} U^{\alpha} = -1) ,$$

(24) $$\rho = M\delta(r)$$

where $\delta = \delta(r)$ denotes the Dirac delta-function. Then the unique static spherically symmetric solution of (15)-(18), which corresponds to the 1916 Schwarzschild solution of GR as $|\omega| \to +\infty$, is given by the spacetime line element

(25) $$-ds^2 = d\tau^2 = Bdt^2 - Adr^2 - r^2(d\theta^2 + \sin^2\theta d\phi^2) ,$$

(26) $$B = B(r) = B_*(1/r), \quad A = A(r) = A_*(1/r)$$

and the scalar fields

(27) $$\xi = \xi(r) = \xi_*(1/r), \quad G = G(r) = G(1 + \xi)^{-1} ,$$

defined in closed form in terms of positive constants (α, β, γ, δ, ε, η, σ) [NOT PPN parameters] as follows:

(28) $$0 \leqq \zeta = \frac{1}{r} \quad ,$$

(29) $$\xi_* = \xi_*(\zeta) \quad , B_* = B_*(\zeta), \quad A_* = A_*(\zeta) \quad ,$$

(30a) $$\xi_* = -1 + \frac{(1 - \alpha\zeta)^\gamma}{(1 + \beta\zeta)^\delta} \leqq 0 \quad ,$$

(30b) $$0 < G_* = G \frac{(1 + \beta\zeta)^\delta}{(1 - \alpha\zeta)^\gamma} =$$

$$= G(1 + \varepsilon\zeta + \cdot \cdot \cdot) \; , \quad (|\zeta| << 1) \; ,$$

$$\rightarrow +\infty \quad \text{as} \quad \zeta \rightarrow (1/\alpha), \quad (r \rightarrow \alpha) \quad ,$$

(31) $$0 \leqq B_* = (1 + \xi_*)^{2|\omega| - 4} =$$

$$= \left[\frac{(1 - \alpha\zeta)^\gamma}{(1 + \beta\zeta)^\delta}\right]^{2|\omega| - 4} =$$

$$= \frac{[(1 - \alpha\zeta)^2]^{\gamma(|\omega| - 2)}}{[(1 + \beta\zeta)^2]^{\delta(|\omega| - 2)}} \quad ,$$

(32a) $$\xi_*' = \xi_*'(\zeta) \overset{d}{=} \frac{d\xi_*}{d\zeta} =$$

$$= - \frac{\varepsilon(1 + \eta\zeta)}{(1 - \alpha\zeta)^{1 - \gamma}(1 + \beta\zeta)^{\delta + 1}} < 0 \quad ,$$

(32b) $$r \frac{d\xi}{dr} \equiv - \zeta\xi_*'(\zeta) > 0 \quad ,$$

(33a) $$0 \leqq A_* =$$

$$= 1 + 2\left(\frac{|\omega| - 1}{|\omega| - 2}\right)\left[\frac{(1 + \eta\zeta)\zeta}{(1 - \alpha\zeta)(1 + \beta\zeta)}\right] MG + \left\{\frac{(3|\omega| - 4)}{(|\omega| - 2)^2}\right\}\left[\frac{(1 + \eta\zeta)\zeta}{(1 - \alpha\zeta)(1 + \beta\zeta)}\right]^2 M^2G^2 =$$

$$\equiv \left(\frac{|\omega| - 2}{MG}\right)^2 [\xi_*'(\zeta)]^2 B_* \quad ,$$

<u>where the positive constants</u> $(\alpha, \beta, \gamma, \delta, \varepsilon, \eta, \sigma)$ <u>satisfy</u>

(34) $\alpha > \beta > 0 \;,\; 1 > \gamma > \delta > 0 \;,\; \varepsilon > 0, \eta > 0, \sigma > 0 \;,$

(35a) $\alpha\gamma + \beta\delta = \varepsilon = \frac{MG}{(|\omega| - 2)} > 0 \;;$

(35b) $\varepsilon \to 0 \;, \quad (|\omega| \to +\infty) \;,$

(36) $0 < \gamma - \delta = \sigma < \varepsilon/\alpha \;,$

$$\alpha \to \left(\frac{|\omega| - 1}{|\omega| - 2}\right) r_{LS} \to r_{LS} \;, \quad (|\omega| \to +\infty) \;,$$

(38) $r_{LS} \overset{d}{=} 2GM \;,$

(39) $\delta \to \gamma \;,\; \gamma \to (2|\omega| - 2)^{-1} \to 0 \;,\; (|\omega| \to +\infty) \;,$

(40a) $\sigma \to 0, (\beta/\varepsilon) \to 0 \;,\; (\eta/\varepsilon) \to 0, \quad (|\omega| \to +\infty) \;,$

(40b) $\alpha + \beta \to (2|\omega| - 2)\,\varepsilon \to r_{LS}' \;, \quad (|\omega| \to +\infty) \;,$

(40c) $\alpha - \beta \to (2|\omega| - 2)\,\varepsilon \to r_{LS} \;, \quad (|\omega| \to +\infty) \;,$

<u>and are defined explicitly by</u>

(41) $0 < \varepsilon = \frac{MG}{(|\omega| - 2)} \;,$

(42) $0 < \sigma = \frac{(2|\omega| - 2) - [(2|\omega| - 4)(2|\omega| - 3)]^{\frac{1}{2}}}{(3|\omega| - 4)} \;,$

$$(43)\qquad 0 < \tau = \frac{(3|\omega| - 4)}{4[1 - \sigma(2|\omega| - 2)]} \quad ,$$

$$(44)\qquad 0 < \alpha = \tfrac{1}{2}\{[(2|\omega| - 2) - \sigma\tau] + ([(2|\omega| - 2) - \sigma\tau]^2 + 4\tau)^{\frac{1}{2}}\}\ \varepsilon \ ,$$

$$(45)\qquad 0 < \beta = \tfrac{1}{2}\{[(2|\omega| - 2) - \sigma\tau] - ([(2|\omega| - 2) - \sigma\tau]^2 + 4\tau)^{\frac{1}{2}}\}\ \varepsilon \ ,$$

$$(46)\qquad 0 < \alpha + \beta = ([(2|\omega| - 2) - \sigma\tau]^2 + 4\tau)^{\frac{1}{2}}\ \varepsilon \quad ,$$

$$(47)\qquad 0 < \alpha - \beta = [(2|\omega| - 2) - \sigma\tau]\ \varepsilon \quad ,$$

$$(48)\qquad 0 < \gamma = \frac{\varepsilon + \sigma\beta}{\alpha + \beta} \quad ,$$

$$(49)\qquad 0 < \delta = \frac{\varepsilon - \sigma\beta}{\alpha + \beta} \quad ,$$

$$(50)\qquad 0 < \eta = \{\frac{(3|\omega| - 4)}{4[1 - \sigma(2|\omega| - 2)]}\}\ \varepsilon \quad .$$

PROOF. Verification by direction substitution.

REMARK. The equations of equatorial geodesic motion based on (25)-(50) are, in terms of standard coordinate time t,

$$(51)\qquad d\tau^2 = E\, B_*^2(1/r)dt^2 \quad , \qquad \theta \equiv \pi/2 \quad ,$$

$$(52)\qquad r^2 \frac{d\phi}{dt} = J\, B_*(1/r) \quad ,$$

$$(53)\quad \left(\frac{dr}{dt}\right)^2 = \left[\frac{MG}{(|\omega| - 2)}\right]^2 \frac{1}{[\xi_*'(\zeta)]^2} \left\{1 - B_*(\zeta)\left[E + \frac{J^2}{r^2}\right]\right\} ,\ \zeta = 1/r \quad ,$$

where the constants J and E are defined by

(54) J = angular momentum per unit mass ,

(55) $[(1 - E)/2]$ = energy per unit mass, $E \geq 0$,

(56) $E > 0$ for material particles ,

(57) $E = 0$ for photons .

Now by (32a), (46) and (37), the result (53) implies that

(58) $$B(r) \to 0 \ , \qquad (B(\tilde{r}_{LS}) = 0) \ ,$$

(59a) $$\frac{dr}{dt} \to 0 \ , \qquad \left(\left(\frac{dr}{dt}\right) \Big|_{\tilde{r}_{LS}} = 0\right) \ ,$$

(59b) $$t \to +\infty \ ,$$

as

(60) $$r \to \tilde{r}_{LS} \overset{d}{=} \alpha = \alpha(|\omega|) \ ,$$

given by (46), where also

(61) $$\tilde{r}_{LS} \to \left(\frac{|\omega| - 1}{|\omega| - 2}\right) r_{LS} \to r_{LS} \ , \qquad (|\omega| \to +\infty) \ .$$

Hence neither matter nor light can penetrate the sphere

(62a) $$r = \tilde{r}_{LS} \approx r_{LS} = 2GM$$

in a finite duration of standard coordinate time t. When $E > 0$ we shall demonstrate elsewhere that the same result holds for the test-particle's proper time τ. Also, by (30b), the Cavendish parameter G satisfies

(62b) $$G \to +\infty, \quad \text{as} \quad r \to (\tilde{r}_{LS} + 0) \ .$$

This means that two test-particles have an infinite acceleration toward one another near the Laplace-Schwarzschild radius of a third (finite) mass. Furthermore, we shall demonstrate elsewhere that in proper time τ the radial acceleration experienced by a test particle near $\tilde{r}_{LS}$ reverses polarity and becomes centrifugal repulsion which, moreover, becomes infinitely great as $(\tilde{r}_{LS} + 0)$ is approached. The possible implications of the last two sentences (why do quarks occur in triplets? why is the strong nuclear force ultimately repulsive?) for nuclear physics are obvious, but beyond the scope of the present treatment. However, it will be shown elsewhere that the infinite repulsion implies that complete gravitational collapse is impossible: black holes do not exist.

CRITICAL EXPERIMENTAL TEST

There is an obvious and relatively simple definitive direct experiment which can test conclusively the main result of the present theory, namely (30a,b), in the particular case of the Solar System, with $M = M_{\odot}$ in (62) denoting the mass of the Sun. One needs an apparatus which can measure the local Cavendish parameter G, not in absolute units, but with a sensitivity capable of relative discrimination of one part in a billion between two different locations. (The Dicke torsion pendulum, used in his version of the Eötvös experiment, could sense pendulum motions of 10^{-9} radians and discriminate between the G corresponding to different metals with an error less than one part in 10^{-11}; an obvious simplification of a similarly designed device could be used.) Now place such an apparatus in a Helios class satellite, whose aphelion is 1 AU and whose perihelion (inside the orbit of Mercury) is about (1/3 AU), and measure the relative values of G at perihelion and aphelion. Specifically, let

$$r_{\odot} = \text{Laplace-Schwarzschild radius of Sun} =$$

$$= 2.950 \text{ km} = 2.950 \times 10^{5} \text{ cm},$$

$$r_a = r_{aph} = 1.49598 \times 10^{13} \text{ cm},$$

$$r_p = r_{per} = 45 \times 10^{6} \text{ km} = 4.5 \times 10^{12} \text{ cm}.$$

Then by (30b), in the form (11), we have

(63) $$\frac{G_{per}}{G_{aph}} = 1 + \frac{r_{\odot}}{(|\omega| - 2)}\left(\frac{1}{r_p} - \frac{1}{r_a}\right) + \cdot \cdot \cdot \cdot =$$

$$= 1 + \frac{46 \times 10^{-9}}{(|\omega| - 2)} + \cdot \cdot \cdot ,$$

or

(64) $$\boxed{\frac{G_{per}}{G_{aph}} = 1 + 0.9 \times 10^{-9}}$$

where in the last step we have used the conservatively estimated value

(65) $$-\omega = |\omega| \cong 52 \qquad (\gamma = 1.02 > 1)$$

derived from a previous analysis (presented elsewhere) of solar system experiments in terms of the present theory. Since it is clearly within present-day capabilities to confirm or refute (64), the present theory satisfies Sir Karl Popper's celebrated criterion for prime viability of a scientific theory, namely it is readily falsifiable, if false.

REFERENCES

1. P. Jordan, Schwerkraft und Weltall, Vieweg, 1955.

2. R. H. Dicke, The Theoretical Significance of Experimental Relativity, Gordon & Breach, 1964.

3. S. Weinberg, Relativity and Cosmology, Wiley, 1972.