JGRG20
25 September, 2010

Summary

of ...

JGRG, Nakamura, Maeda

and me

a bit about prehistory of JGRG

- **1960's (?) ~ mid 1970's**

1st GRG activities in Japan
lead by H Nariai and R Uchiyama

Nariai solution (1951) ⇨

Nariai with Chandra (1983)

On a New Cosmological Solution of Einstein's Field Equations of Gravitation.

Hidekazu NARIAI*)

(Received April 10, 1951)**)

§ 1. *Introduction.*

In the previous paper[1], the author obtained the following solution of Einstein's field equations for the homogeneous static universe exhibiting spherical symmetry:

$$ds^2 = \frac{1}{\Lambda}\left[(A\cos\log r + B\sin\log r)^2 dt^2 - \frac{1}{r^2}(dr^2 + r^2 d\theta^2 + r^2\sin^2\theta d\varphi^2)\right], \qquad (1)$$

where Λ is the cosmological constant and A and B are arbitary constants. We have shown that this solution corresponds to the empty universe and, moreover, this line element can not be transformed into the standard form.

The field equations in the empty universe which this solution must satisfy are, however, reduced to

$$R_{\mu\nu} = \Lambda g_{\mu\nu}, \qquad (2)$$

where $R_{\mu\nu}$ is the contracted Riemann-Christoffel tensor. In this paper, at first, we rederive the line element (1) as the solution of the field equations (2) starting from the isotropic static line element and then discuss in detail the geometrical and physical natures of the solution under consideration.

§ 2. *Field Equations for Static Empty Universe Exhibiting Spherical Symmetry.*

The static isotropic line element exhibiting spherical symmetry is written as follows:

$$ds^2 = e^{\nu}dt^2 - e^{\mu}(dr^2 + r^2 d\theta^2 + r^2\sin^2\theta d\varphi^2), \qquad (3)$$

with $\mu = \mu(r)$ and $\nu = \nu(r)$. And its field equations (2) for the empty matter-distribution are reduced to the following system of differential equations:

$$\mu'' + \frac{\nu''}{2} + \frac{\nu'^2}{4} - \frac{\mu'\nu'}{4} + \frac{\mu'}{r} = -\Lambda e^{\mu}, \qquad (4)$$

$$\frac{\mu''}{2} + \frac{\mu'^2}{4} + \frac{\mu'\nu'}{4} + \frac{\nu' + 3\mu'}{2r} = -\Lambda e^{\mu}, \qquad (5)$$

$$\frac{\nu''}{2} + \frac{\nu'^2}{4} + \frac{\mu'\nu'}{4} + \frac{\nu'}{r} = -\Lambda e^{\mu}, \qquad (6)$$

where primes denote differentiation with respect to r. Taking the difference of (4) and (6), we get

$$\mu'' - \frac{\mu'\nu'}{2} + \frac{\mu' - \nu'}{r} = 0. \qquad (7)$$

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*) 成相秀一: Institute of Astronomy, Faculty of Science, Tohoku University.
**) Communicated by Prof. Z. Hitotuyanagi.
1) H. Nariai, Sci. Rep. Tohoku Univ. Ser. 1, vol. XXXIV, No. 3, p. 160 (1950).

Uchiyama’s paper (1956) on general non-Abelian gauge theory (including gravity)

PHYSICAL REVIEW VOLUME 101, NUMBER 5 MARCH 1, 1956

Invariant Theoretical Interpretation of Interaction

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(Received July 7, 1955)

Some systems of fields have been considered which are invariant under a certain group of transformations depending on n parameters. A general rule is obtained for introducing a new field in a definite way with a definite type of interaction with the original fields by postulating the invariance of these systems under a wider group derived by replacing the parameters of the original group with a set of arbitrary functions. The transformation character of this new field under the wider group is determined from the invariance postulate. The possible types of the equations of the new fields can be also derived, giving rise to a certain conservation law owing to the invariance. As examples, the electromagnetic, the gravitational and the Yang-Mills fields are reconsidered following this line of approach.

INTRODUCTION

THE form of the interactions between some well known fields can be determined by postulating invariance under a certain group of transformations. For example, let us consider the electromagnetic interaction of a charged field $Q(x)$, $Q^*(x)$. The electromagnetic interaction appears in the Lagrangian through the expressions

$$\frac{\partial Q}{\partial x^\mu} - ieA_\mu Q \quad \text{or} \quad \frac{\partial Q^*}{\partial x^\mu} + ieA_\mu Q^*. \tag{1}$$

The gauge invariance of this system is easily verified in virtue of the combinations of Q, Q^*, and A_μ in (1), if this system is invariant under the phase transformation

$$Q \rightarrow e^{i\alpha}Q, \quad Q^* \rightarrow Q^* e^{-i\alpha}, \quad \alpha = \text{const.} \tag{2}$$

Reversing the argument, the combination (1) can be uniquely introduced by the following line of reasoning. In the first place, let us suppose that the Lagrangian $L(Q,Q_{,\mu})$ is invariant under the constant phase transformation (2). Let us replace this phase transformation with the wider one (gauge transformation) having the phase factor $\alpha(x)$ instead of the constant α. In order to make the Lagrangian still invariant under this wider transformation it is necessary to introduce the electromagnetic field through the combination (1). This combination and the transformation character of A_μ under the gauge transformation can be uniquely determined from the gauge invariance postulate of the Lagrangian $L(Q,Q_{,\mu},A_\mu)$.

This approach was taken by Yang and Mills[1] to introduce their new field $\mathbf{B}_\mu$ which interacts with fields having nonvanishing isotopic spins. The gravitational interaction also can be introduced in this fashion.

It may be worthwhile to investigate this approach for a more general case, for if there is a system of fields $Q^A(x)$ which is invariant under some transformation group depending on parameters $\epsilon_1, \epsilon_2, \cdots \epsilon_n$, then according to the aforementioned viewpoint we may have the possibility of introducing a new field, say $A(x)$, in a definite way. In addition, the transformation character of this new field and the interaction form with the Q's can be determined uniquely.

Let us tentatively call a family of the interactions derived in this way "the interactions of the first class," while other types of interactions are denoted as "the interactions of the second class." The electromagnetic, gravitational and $\mathbf{B}_\mu$-field interactions belong to the first class and the meson-nucleon interaction to the second class, at least at the present stage.

The main purpose of the present paper is to investigate the following problem. Let us consider a system of fields $Q^A(x)$, which is invariant under some transformation group G depending on parameters $\epsilon_1, \epsilon_2, \cdots \epsilon_n$. Suppose that the aforementioned parameter-group G is replaced by a wider group G', derived by replacing the parameters ϵ's by a set of arbitrary functions $\epsilon(x)$'s, and that the system considered is invariant under this wider group G'. Then, can we answer the following questions by using only the postulate of invariance stated above? (1) What kind of field, $A(x)$, is introduced on account of the invariance? (2) How is this new field A transformed under G'? (3) What form does the interaction between the field A and the original field Q take? (4) How can we determine the new Lagrangian $L'(Q,A)$ from the original one $L(Q)$? (5) What type of field equations for A are allowable?

The solution of these problems will be stated in Sec. 1. In Secs. 2, 3, and 4 the well-known examples of the interactions of the first class will be reconsidered following the line of reasoning of Sec. 1. We shall find an analogy between the transformation characters of the electromagnetic field A_μ, the Yang-Mills field $\mathbf{B}_\mu$, and Christoffel's affinity $\Gamma_{\mu\nu}{}^\lambda$ in the theory of the general relativity. Furthermore we shall understand the reason why in the Yang-Mills field strength the quadratic term, $\mathbf{B}_\mu \times \mathbf{B}_\nu$, appears which is quite similar to that occurring in the Riemann-Christoffel tensor $R^\lambda{}_{\mu\nu\rho}$, namely, to the term $\Gamma\Gamma - \Gamma\Gamma$ in R.

In the usual textbooks of general relativity the covariant derivative of any tensor is introduced by

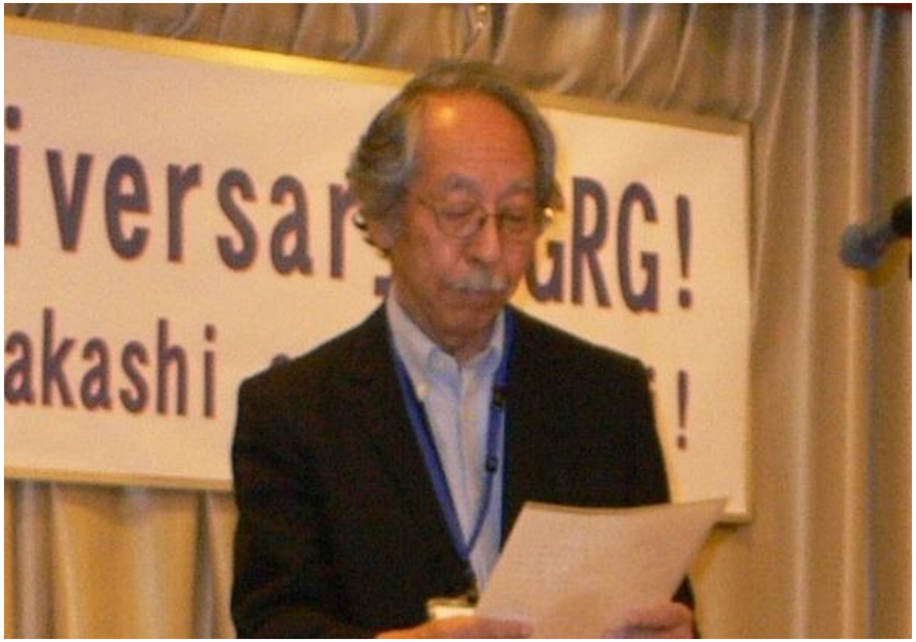
* On leave of absence from the University of Osaka, Osaka, Japan.
[1] C. N. Yang and R. L. Mills, Phys. Rev. 96, 191 (1954).

mid 1970’s ~ mid 1980’s

“New” GRG lead by Y Fujii and H Sato

a new model of modified gravity (1971)

⇨



Dilaton and Possible Non-Newtonian Gravity

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A model is proposed which allows a dilaton to show up in a possible non-Newtonian part of the gravitational force. By examining the available observational facts it can be shown that the force-range of the additional force, if it exists, will be either between 10 m and 1 km or smaller than ~1 cm.

A DILATON—a Nambu-Goldstone boson of dilatation invariance[1–6]—will, if it exists, couple to the graviton, because the dilaton dominates the energy-momentum tensor which is supposed to be a source of the graviton. The fact that the dilaton is a scalar particle does not prevent it from coupling to the graviton, which is described by a symmetric tensor field, but is not a genuine spin-2 particle because of its masslessness. As a consequence the dilaton may affect the gravitational force between two masses.

If the dilaton mass is of the order of hadronic masses, any modifications will occur only within the distances of the order of fm. The dilaton mass could be, on the other hand, of the order of $\kappa \sim [G\alpha'^{-2}]^{1/2}$ which is a typical combination of two fundamental constants in the gravitational and strong interactions. (G is the Newtonian gravity constant, α' is the universal slope of Regge trajectories. I use the unit system with $c=\hbar=1$.) Possible non-Newtonian behaviour will then occur for distances $\sim \kappa^{-1}$, which turns out to be of the order of km or less. In another paper[7] I propose a model in which this is the case. Although the argument is based on many speculative assumptions, it seems that the Newtonian gravity for such distances has never been checked by any unambiguous experimental tests. This particular model may therefore be considered as providing a motivation of studying this unexplored area on more general grounds. In this article I report results of further investigations on the upper and lower limits on the force-range. Some experiments are also proposed to narrow these limits.

I shall begin with a brief summary of the arguments in ref. 7. Assume[8] that there is a Regge trajectory which is almost degenerate with, and shares the same properties as, the $\varphi - f'$ trajectory, but transforms differently under SU_3. We can imagine that, corresponding to a nonsense zero point of this trajectory, there is a scalar (0^+) object θ with squared mass t_0 which is almost zero ($\lesssim m_\pi^2$). Such a θ never behaves as an ordinary particle as far as the strong interaction is concerned. We now assume that this θ is a dilaton. The θ-graviton mixing interaction is given by $\sim \sqrt{G} f_\theta (k^2 \delta_{\mu\nu} - k_\mu k_\nu)$, where f_θ is defined by

$$\langle 0 | \theta_{\mu\nu} | \theta(k) \rangle = -f_\theta (k^2 \delta_{\mu\nu} - k_\mu k_\nu)$$

$\theta_{\mu\nu}$ being the energy-momentum tensor. In accordance with the nonsense mechanism we assume that f_θ is not a constant, but depends on $k^2 = -t$ as given by

$$f_\theta(t) = (t - t_\theta)^{-1/2} F_\theta$$

We have an order of magnitude estimate of the constant F_θ[7,9]

$$F_\theta \sim \alpha'^{-1} \quad (1)$$

The θ-graviton mixing problem is then resolved to give a gravity potential

$$V(r) = -\frac{3}{4} G \frac{1}{r} \left[1 + \frac{1}{3} \left(\cos \kappa r - \frac{1 - t_\theta/2\kappa^2}{\sqrt{-D}} \sin \kappa r \right) e^{-\kappa\sqrt{-D} r} \right] \quad (2)$$

where $\kappa^2 = (3/8) G F_\theta^2$, and $-D = t_\theta/\kappa^2 - 1$ with the restriction $t_\theta > \kappa^2$. From (1), with $G = 6.67 \times 10^{-8}$ cm^3 g^{-1} s^{-2} from the Cavendish experiment, we obtain $\kappa \sim 10^{-20} m_N$ or $\kappa^{-1} \sim 10^5$ cm = 1 km.

If the “bare” dilaton mass squared (t_θ) vanishes, that is, dilatation invariance is strict, there is no change in the gravitational interaction. If t_θ is of the order of a hadronic mass squared, then $\kappa\sqrt{-D} \sim \sqrt{t_\theta}$ in the exponent in (2), because $t_\theta \gg \kappa^2$. The finite-range part vanishes for any macroscopic distance. On the other hand, t_θ may be of the same order of, but still larger than, κ^2. We obtain $\kappa\sqrt{-D} \sim \kappa$, because $-D \sim 1$. The force-range is of the order of $\kappa^{-1} \sim$ km. We have then an entirely new situation.

Consider the Cavendish experiment with the distance $r \sim 10$ cm. The potential (2) becomes

$$V(r) \sim -G \frac{1}{r}$$

For planetary motions, on the other hand, the finite-range part is negligibly small so that we have

$$V(r) \sim -G_\infty \frac{1}{r}$$

where

$$G_\infty = \frac{3}{4} G \quad (3)$$

It is convenient for approximate calculations to replace (2) by

$$V(r) = -\frac{3}{4} G \frac{1}{r} \left(1 + \frac{1}{3} e^{-\mu r} \right) \quad (4)$$

with

$$\mu = \frac{t_\theta/\kappa^2}{2\sqrt{-D}} \kappa \sim \kappa$$

Gravity and the Size of the Earth

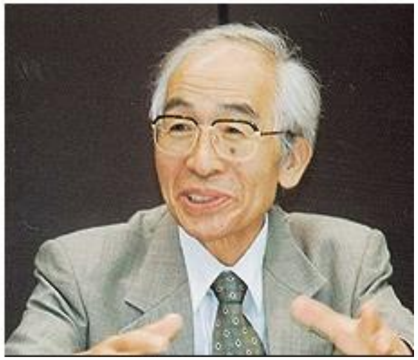
The gravity at altitude z above the Earth’s surface is given by

$$g(z) = g_1(z) + g_2(z)$$
$$g_1(z) = \frac{G_\infty M_E}{(R + z)^2} \quad (5)$$
$$g_2(z) = \frac{\pi}{2} G \rho \mu^{-1} e^{-\mu z}$$

Tomimatsu-Sato solution (1971)

generalization of Kerr to include
a deformation parameter (Kerr+Weyl)

A Tomimatsu



H Sato

[2] R. Stokstad, D. Shapira, L. Chua, P. Parker, M. W. Sachs, R. Wieland, and D. A. Bromley, Phys. Rev. Lett. 28, 1523 (1972).
[3] E. R. Cosman, A. Sperduto, W. H. Moore, T. N. Chin, and T. M. Cormier, Phys. Rev. Lett. 27, 1074 (1971).
[4] R. Middleton, J. D. Garrett, and H. T. Fortune, Phys. Rev. Lett. 24, 1436 (1970); E. R. Cosman, H. A. Enge, and J. C. Britt, unpublished.
[5] Preliminary results have been reported: E. R. Cosman, A. Sperduto, T. M. Cormier, T. N. Chin, H. Wegner, M. LeVine, and D. Schwalm, Bull. Amer. Phys. Soc. 17, 489 (1972).
[6] Results from Hauser-Feshbach Program SERENA; T. N. Chin, T. M. Cormier, and E. R. Cosman, to be published.
[7] R. G. Stokstad, D. Shapira, L. Chua, A. Gobbi, P. Parker, M. Sachs, R. Wieland, and D. A. Bromley, Bull. Amer. Phys. Soc. 17, 529 (1972).
[8] R. E. Malmin, K. Katori, L. R. Greenwood, T. H. Braid, and R. H. Siemssen, in Proceedings of the Symposium on Heavy-Ion Reactions and Many-Particle Excitations, Saclay, France, 1971 [J. Phys. (Paris), to be published].
[9] L. R. Greenwood, T. H. Braid, K. Katori, R. H. Siemssen, and J. C. Stoltzfus, Bull. Amer. Phys. Soc. 16, 645 (1971), and Phys. Rev. C (to be published).
[10] A. Gobbi, P. R. Maurenzig, L. Chua, R. Hadsell, P. D. Parker, M. W. Sachs, D. Shapira, R. Stokstad, R. Wieland, and D. A. Bromley, Bull. Amer. Phys. Soc. 26, 306 (1971); D. P. Balamuth, J. E. Holden, J. W. Noé, and R. W. Zurmühle, Phys. Rev. Lett. 26, 1271 (1971); M. J. LeVine and D. Schwalm, Bull. Amer. Phys. Soc. 16, 1421 (1971).
[11] E. R. Cosman, Bull. Amer. Phys. Soc. 16, 1421 (1971); R. Middleton, J. D. Garrett, H. T. Fortune, and R. R. Betts, J. Phys. (Paris), Colloq. 32, C6-39 (1971).
[12] For a thorough account of this point, see the *Proceedings of the Symposium on Heavy-Ion Scattering, Argonne National Laboratory, 1971*, edited by R. H. Siemssen (Argonne National Laboratory, Argonne, Ill., 1971.
[13] The MIT multiple-gap spectrograph now installed at BNL has a unique rotating emulsion-holder carousel, such that by masking off all but one gap, 72 broad-range spectra for that gap can be taken in sequence without breaking vacuum. This feature was used to obtain the finer stepped excitation function of $^{12}C(^{16}O, p)^{27}Al$ shown in Fig. 3.
[14] B. Imanishi, Nucl. Phys. A125, 33 (1969); W. Scheid, W. Greiner, and R. H. Lemmer, Phys. Rev. Lett 25, 176 (1970).
[15] G. Michaud and E. W. Vogt, Phys. Lett. 30B, 85 (1969), and Phys. Rev. C 5, 350 (1972).

New Exact Solution for the Gravitational Field of a Spinning Mass

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(Received 11 September 1972)

A solution for the gravitational field is presented, which reduces to one of the Weyl metrics in the limit of angular momentum $J=0$ and reduces to the Kerr metric in the limit of $J=m^2$.

The Kerr metric has been the only known example[1] of an exact exterior solution representing the gravitational field of a spinning mass. In this note we shall present a solution for the metric which does not reduce to the Schwarzschild metric in the limit of angular momentum $J=0$, unlike the case of the Kerr metric, but does reduce to one of the Weyl metrics[2] representing fields of deformed masses.

According to the formulation of Ernst,[3] stationary axisymmetric solutions in empty space can be derived from a complex function ξ which satisfies the following equation:

$$(\xi\xi^* - 1)\nabla^2\xi = 2\xi^*\nabla\xi\cdot\nabla\xi. \qquad (1)$$

A solution of Eq. (1) has been obtained as $\xi = px - iqy$,[3] where x and y are the coordinate variables, and p and q are the parameters defined by J and gravitational mass m: $q = J/m^2$ and $p = (1-q^2)^{1/2}$. Besides the above Ernst solution from which the Kerr metric is derived, we found a new solution given by

$$\xi = \frac{p^2x^4 + q^2y^4 - 2ipqxy(x^2-y^2) - 1}{2px(x^2-1) - 2iqy(1-y^2)}. \qquad (2)$$

JGRG, Nakamura & Maeda

dawn of Numerical relativity in Japan Gang of Four (1977~)

T Nakamura, K Maeda, S Miyama & me

Boss

semi-Boss

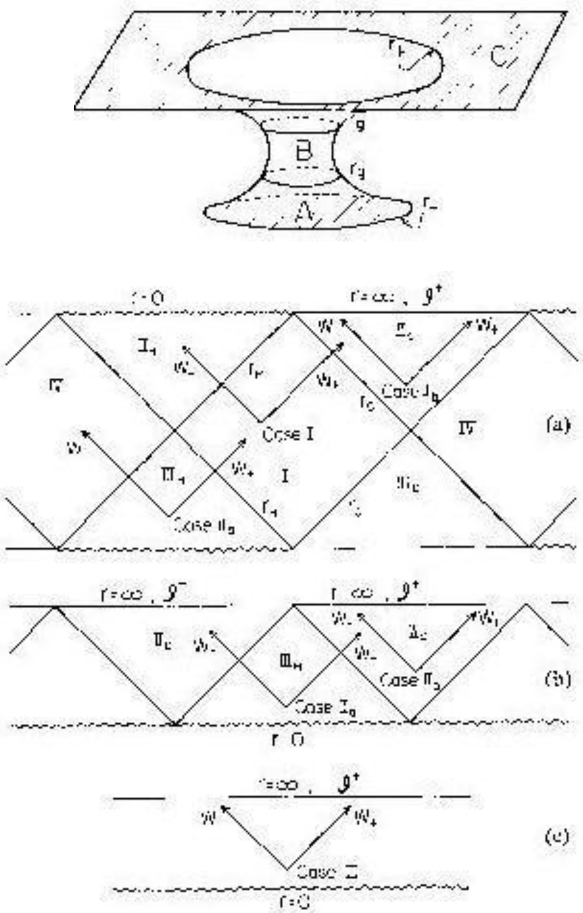
privates ...

S Miyama

better known (?) as Buddhist monk

Kei-ichi and me

Through this work Maeda-san taught me conformal (Carter-Penrose) diagrams



Volume 108B, number 2 PHYSICS LETTERS 14 January 1982

CREATION OF SCHWARZSCHILD–DE SITTER WORMHOLES BY A COSMOLOGICAL FIRST-ORDER PHASE TRANSITION

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Received 8 June 1981

It has been pointed out that the universe may contain Schwarzschild wormholes produced by first-order phase transitions of a vacuum. In this letter, we consider this possibility for the more general case in which the vacuum energy density inside growing bubbles remains finite. We show that (1) Schwarzschild–de Sitter wormholes are created instead of simple Schwarzschild ones, and (2) if the remaining vacuum energy density is greater than a critical value, no wormholes are created.

Recently, a first-order phase transition of a vacuum has become a topic of great interest, because it predicts the existence of a cosmological period in which the universe expands exponentially due to the energy density of a false vacuum. The existence of such a period provides an idea on the origin of galaxies [1], a reason for homogeneity and isotropy of the universe [1–4], a suppression mechanism against overproduction of monopoles [5], and a possibility that the universe has a baryon-number domain structure [6,7].

As discussed by Coleman [8], the first-order phase transition proceeds by nucleation and subsequent expansion of bubbles. In the period of the phase transition, the universe is never homogeneous, but is extremely bumpy; the contrast between the energy densities of the inner and the outer regions is very huge. What is then the space–time structure of the universe and how is the present homogeneous universe recovered? In a previous paper [9], we discussed these problems and found that wormholes and/or black holes are created in this period. In that paper [9], however, it was assumed that the energy density of vacuum vanishes completely inside the bubbles. Strictly speaking, this assumption is not valid. Instead, one has situations represented by the following two cases.

[1] Fellow of the Japan Society for the Promotion of Science.

Case (A). At the absolute minimum of the effective potential of a Higgs field the vacuum has a finite energy density if the temperature is finite (see fig. 1a). Thus, if the nucleation rate of bubbles becomes high at once so that the phase transition finishes when the temperature is still high, the vacuum energy density within the bubbles cannot be neglected.

Case (B). In grand unified theories, the gauge symmetry is broken sequentially, i.e. $G \to H_n \to H_{n-1} \to \cdots \to H_1$, as the universe expands and cools. This predicts the universe has undergone a number of phase transitions sequentially. By these phase transitions, the vacuum energy density decreases step by step and eventually must vanish (or must become smaller than the upper limit obtained from the observation of the deceleration parameter [10]). Thus the vacuum energy density after some phase transition ρ_2 does not vanish except for the last phase transition.

The purpose of the present paper is to extend the previous consideration [9] to the case in which the vacuum energy density inside the bubbles is non-vanishing.

1. Geometry of an isolated bubble in the false vacuum background. At the early stage of the phase transition, overlapping of the bubbles can be neglected, because the volume occupied by each bubble is very

Takashi and me

This was my first work after I became a postdoc

Volume 89A, number 2 PHYSICS LETTERS 26 April 1982

A CLASS OF NEW PERTURBATION EQUATIONS FOR THE KERR GEOMETRY

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Received 23 November 1981
Revised manuscript received 15 January 1982

A class of new inhomogeneous equations governing gravitational perturbations of the Kerr geometry is presented. It is shown that, contrary to the case of the Teukolsky equation, these new equations are of short-range nature and exhibit no divergence difficulty associated with the source term.

Ever since Teukolsky discovered the master equations for perturbations of the Kerr geometry [1], perturbations of this geometry have been studied from many aspects [2]. However one of the most important problems has been left unsolved, i.e. the gravitational radiation induced by a test particle falling from infinity. The main difficulty associated with this problem is due to the fact that the potential of the Teukolsky equation is of long-range nature and the source is divergent for $r \to \infty$. Thus the Teukolsky equation in its original form is inadequate for numerical analysis which is essential for the above mentioned problem.

Although Chandrasekhar and Detweiler [3] and Detweiler [4] succeeded in transforming the Teukolsky equation into an equation with a short-range potential, their transformations do not work well when a source is present.

Recently, we have succeeded in providing a new equation with the Regge- Wheeler potential and with a short-range source in case of the Schwarzschild geometry [5]. In this letter, we generalize the result of ref. [5] to the case of the Kerr geometry and present a class of transformations which brings the inhomogeneous Teukolsky equation into a form analogous to the Regge -Wheeler equation.

The Teukolsky equation has the form [1]

$$\Delta^{-s}(\Delta^{s+1}\,{}_sR')' - {}_sV\,{}_sR = -{}_sT, \quad (1)$$

where

$${}_sV = (iK)^2/\Delta + isK\Delta'/\Delta - 2isK + {}_s\lambda, \quad (2)$$

with

$$K = (r^2+a^2)\omega - am, \quad \Delta = r^2 - 2Mr + a^2,$$

and m and ${}_s\lambda$ are the separation constants arising from the azimuthal function $e^{im\phi}$ and the angular eigenfunction ${}_sZ^{a\omega}_{lm}(\theta,\phi)$ (the spin-weighted spheroidal harmonic), respectively. For gravitational perturbations, it is enough to consider only the $s = -2$ case. Therefore we omit the spin index s hereafter.

Let us first consider the source free case of eq. (1). The general transformation of R which preserves the form of the linear wave equation takes the form

$$\chi = \alpha(r)R + [\beta(r)/\Delta]\,R', \quad (3)$$

with arbitrary functions α and β. By taking the first and second derivatives of eq. (3) with respect to r and using eq. (1) with ${}_sT = 0$, one finds that χ satisfies the equation

$$\Delta^2(\Delta^{-1}\chi')' - \Delta F\chi' - U\chi = 0, \quad (4)$$

where

$$F = \gamma'/\gamma, \quad (5a)$$

$$U = V + (\Delta^2/\beta)[(2\alpha + \beta'/\Delta)' - (\gamma'/\gamma)(\alpha + \beta'/\Delta)], \quad (5b)$$

with

$$\gamma = \alpha(\alpha + \beta'/\Delta) - (\beta/\Delta)[\alpha' + (\beta/\Delta^2)V]. \quad (5c)$$

- Teukolsky equation has singular asymptotic behavior
- necessary to make it regular for numerical implementations

Writing equations after equations everyday from morning to night...

It took us a few months to find the transformation.

This was my first experience in research in which I had no idea if there would really be a solution...

a few quotes from Masters...

T Nakamura

If physically correct, the essence should be describable within three lines.

If necessary, we must do it by any means, even by a brute force attack.

K Maeda

GR is geometry and causality. Draw a conformal diagram.

JGRG and me

- **1990 ~**

Current JGRG founded by Kei-ichi Maeda and Takashi Nakamura

This time, Kei-ichi was the boss, Takashi was the CFO.

A new turning point came in late 1980's. The idea to build large-scale interferometers for direct detection of gravitational waves became more realistic, and research on gravitation itself started to attract attention again. In Japan, a program supported by a grant-in-aid for scientific research on priority areas, ``gravitational wave astronomy'', had started, which later developed into the TAMA project. Simultaneously with this movement toward research on gravitational waves, the importance of research in gravitational physics in general was recognized from new perspectives; from precision observation of relativistic objects such as black holes and neutron stars, and from progress in numerical relativity, theoretical cosmology, and particle astrophysics. This trend motivated several members of the above-mentioned program to start a renewed series of workshops on general relativity and gravitation. The first JGRG workshop (JGRG1) was then held at Tokyo Metropolitan University, from 4 to 6 December, 1991. There were about 120 participants in this workshop, indicating that there was indeed a high need for such a workshop from the community already at that time. Since then workshops of similar size have been held annually at different universities in turn. From JGRG10, held at Osaka University in 2000, we began to invite a few speakers from abroad and designated English as the language to be used in presentations.

From http://www-tap.scphys.kyoto-u.ac.jp/jgrg/about.html

And after twenty years,
I am still a private...

a faithful servant to JGRG.

Happy 60th birthday Kei-ichi and Takashi!

See you in Sendai next year!

O Matsushima! O Matsushima! O Matsushima!
Haiku poem by Matsuo Basho (17th century)