Anniversary of the 20th Japan General Relativity and Gravitation (JGRG)

2010 September 23 at YITP

Kyoto University
Takashi Nakamura

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- 1. How numerical relativity in Kyoto started ?
- 2. How the study of laser interferometer gravitational wave detectors started in Japan?
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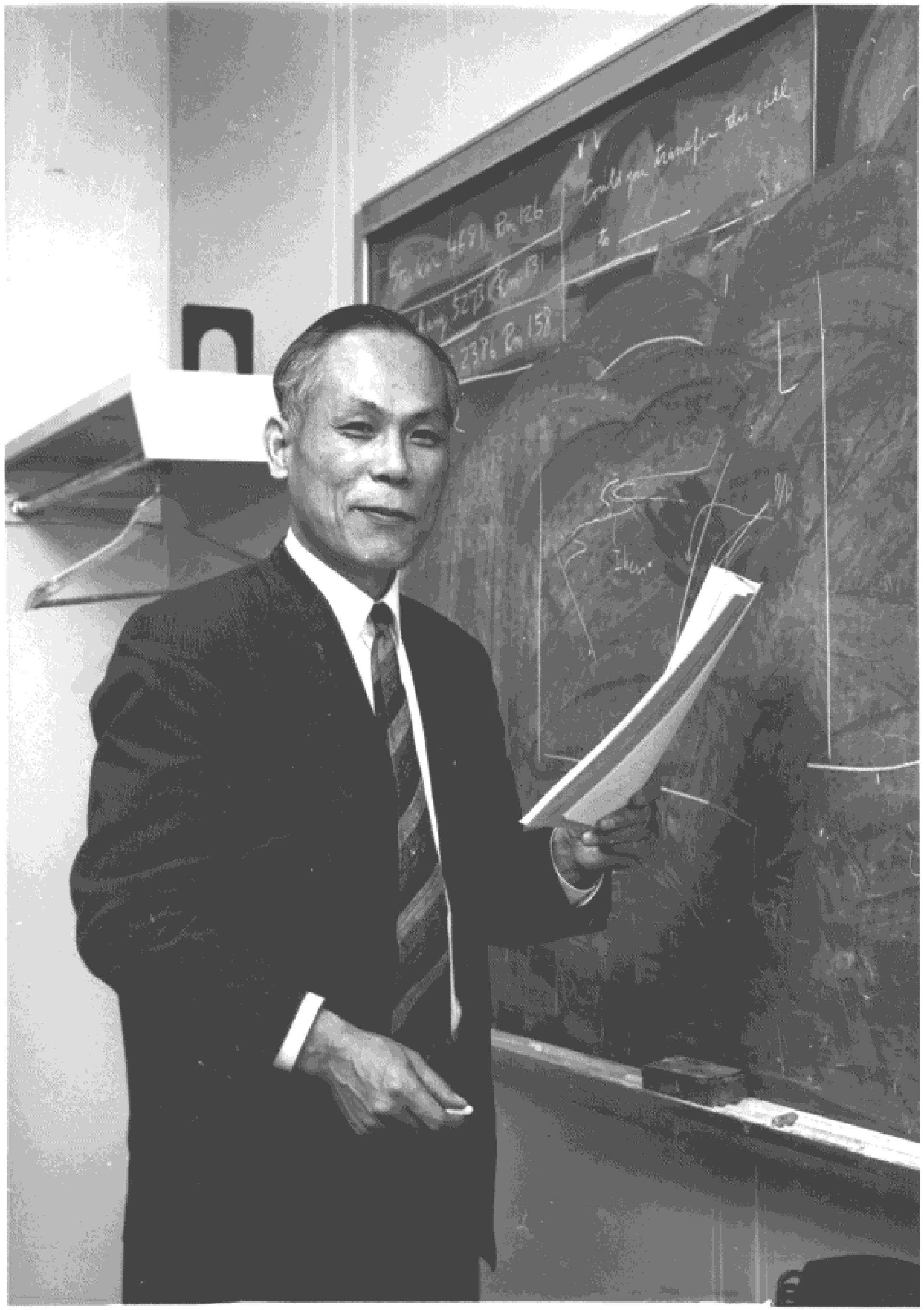
Prologue

- I was borne in 1950 September 18th.
- I was admitted to Faculty of Science , Kyoto University in 1969 April. (In Japan, university starts in April and ends in March)
- 1969 was an unusual year. In university of Tokyo, some radical students occupied the main buildings for an year or so. Finally the police entered the university to get rid of these students. In these confusions, the entrance examination to university of Tokyo had to be cancelled in 1969.
- In Kyoto university also, some radical students occupied many buildings so that there were no lectures for an year or so. I had only one minute entrance ceremony because the radical students were against the ceremony and lectures.

- In Faculty of Science, one can choose what one studies in university after one is admitted. My first plan was to study biophysics.
- However my high school teacher said to me that at first I had better study various fields of science in university so that I studied also astrophysics and found it very, very interesting.
- In 1970, professor C. Hayashi in our faculty got Eddington medal of Royal Astronomical Society for the discovery of “Hayashi Phase”. I noticed this fact through the scientific journal for non-experts .
- Then I attended Hayashi’s seminar in the fourth grade and was admitted to Hayashi group as an graduate student.

- C. Hayashi (borne 1920)
- 1957-1984 Professor in Department of Physics Kyoto University (Leader of Nuclear Astrophysics Group)
- 1977-1979 Dean of Faculty of Science
- 1970 Eddington Medal
- 1971 Japan Academy Prize and Imperial Prize
- 1987 Life member of Japan Academy
- 2010.2.28 Passed Away
- Stellar Evolution(Hayashi Phase) Origin of solar system (Kyoto model), Cosmology(p-n ratio)



NASA G-68-10,414

Prof. Hayashi
when he was young.
(48 years old ?)

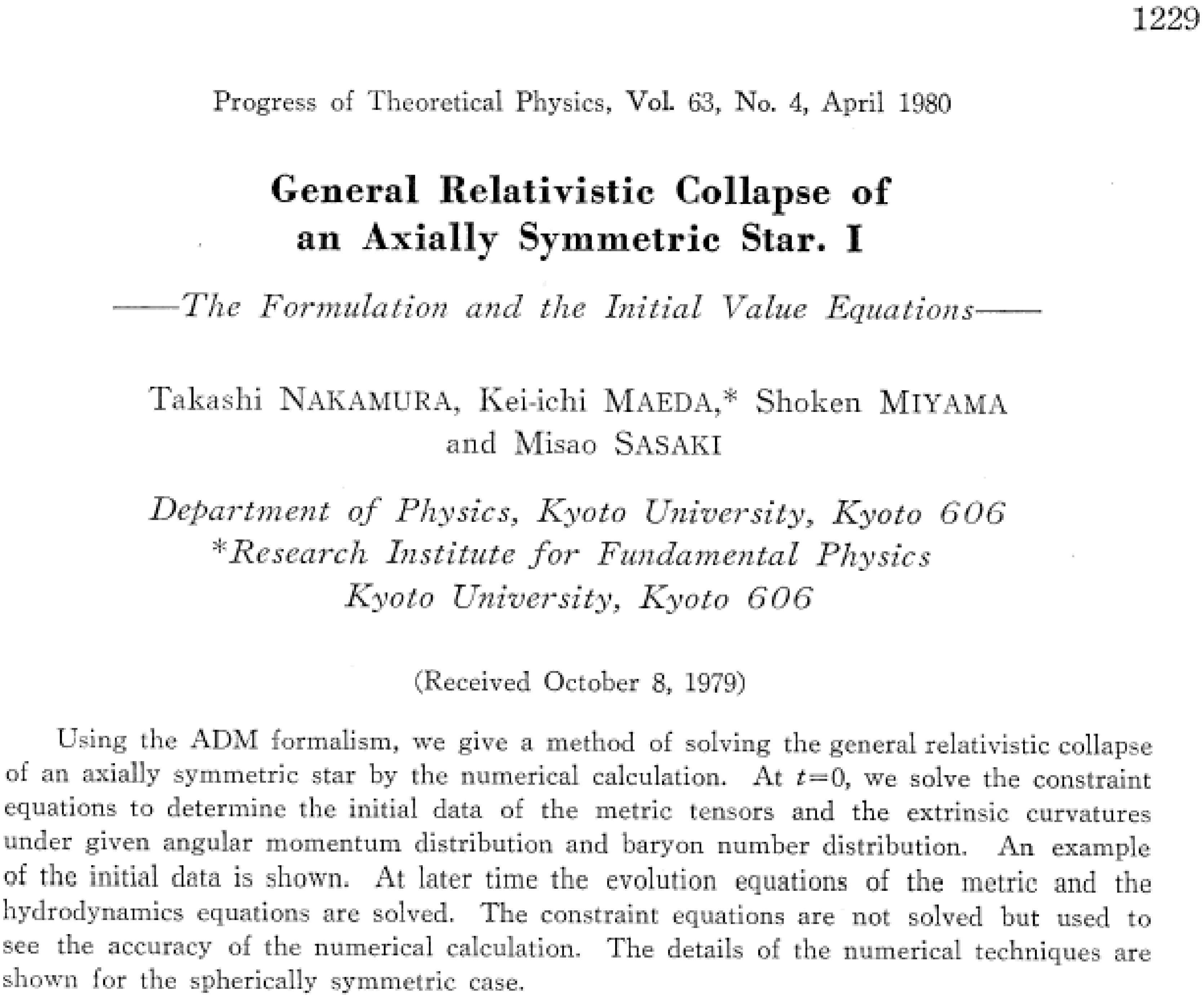
- In my undergraduate time, I had one unusual experience. I took the course of lectures on Lebesgue Integral by professor Mizohata. In the end of his last lecture he said “ I will retire this March so that this is the final lecture. Now I would like to say something to you. Suppose that there is a problem in mathematics that you can not solve. In this situation there are two attitudes to the problem. The first one is; You are bad. You should study harder to solve the problem. However there is another attitude; The problem is bad. You had better arrange the problem which you can solve.
- I had never considered the second attitude. I had never considered that the problem is bad so far. I supposed that this second attitude should be the research. I could understand what professor Mizohata wanted to say although I could not understand Lebesgue Integral itself almost everywhere.

- When I was in master course, over doctor problem became severe. Here the over doctor problem (=Japanese English?) means that many graduate students can not find permanent positions even after they received Ph.D. (At this time, the job meant the permanent position in Japan.) I wondered what would happen when I would receive Ph.D five years later. Then Professor Humitaka Sato in YITP said to me that the problem would be resolved when I would receive Ph.D..
- In my graduate student age, I first wrote papers on density wave theory of spiral arms with S. Ikeuchi and F. Takahara and the restoration of broken symmetry in astrophysical situation with K. Sato. However around the age of 26 or so, the over doctor problem became more severe since even K. Sato and K. Nomoto could not find permanent positions. I was deeply disappointed since K.Sato and K.Nomoto were already famous in the world.
- One day in such disappointed days, professor Hayashi came into the graduate student room and said to me “ What will happen when two rocks collide is a very important problem in relation to the formation theory of planets. Can you study this problem with us?”

- I answered “ Thank you and I will consider the problem for a while.” However I could neither find reference papers for this problem nor imagine what to do. Later I went to his office and said “I decline to study what will happen when two rocks collide since I could not find any reference papers. Then professor Hayashi said “A problem with no or little reference papers is a good problem. If there are many reference papers on the problem, that means that your contribution to the field will be very small .” This was completely unexpected statement for me. Usually graduate students like to study the problem with many references. What Professor Hayashi said is , however, in reality correct. He himself did study the problems with no or little references such as stellar evolution in 1960s and the origin of solar system in1980s.
- To overcome over doctor problem, I thought that I should do something big. For this purpose I combine the statements of professors Mizohata and Hayashi as ; Find the solvable problem for the important theme with no or little reference papers.

Kyoto Numerical Relativity Group

- I consulted Maeda what we should start.
- Three possible problems were considered. (Jet formation from accretion disk, High energy cosmic rays and numerical simulations of collapse of rotating stars to black holes.)
- Two graduate students Miyama and Sasaki joined.
- Finally we decided to study "non-spherical collapse of the star leading to the formation of black holes. (= called numerical relativity later)".
- We started seminars with no time limit in 1977.
- In reality we started from zero.
- Finally we submitted four papers in 1979 and also presented early results at Marcel Grossman Meeting at Trieste Italy in 1979 where I met Tsvi Piran.



Progress of Theoretical Physics, Vol. 63, No. 4, April 1980

General Relativistic Collapse of an Axially Symmetric Star. I

—*The Formulation and the Initial Value Equations*—

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and Misao SASAKI

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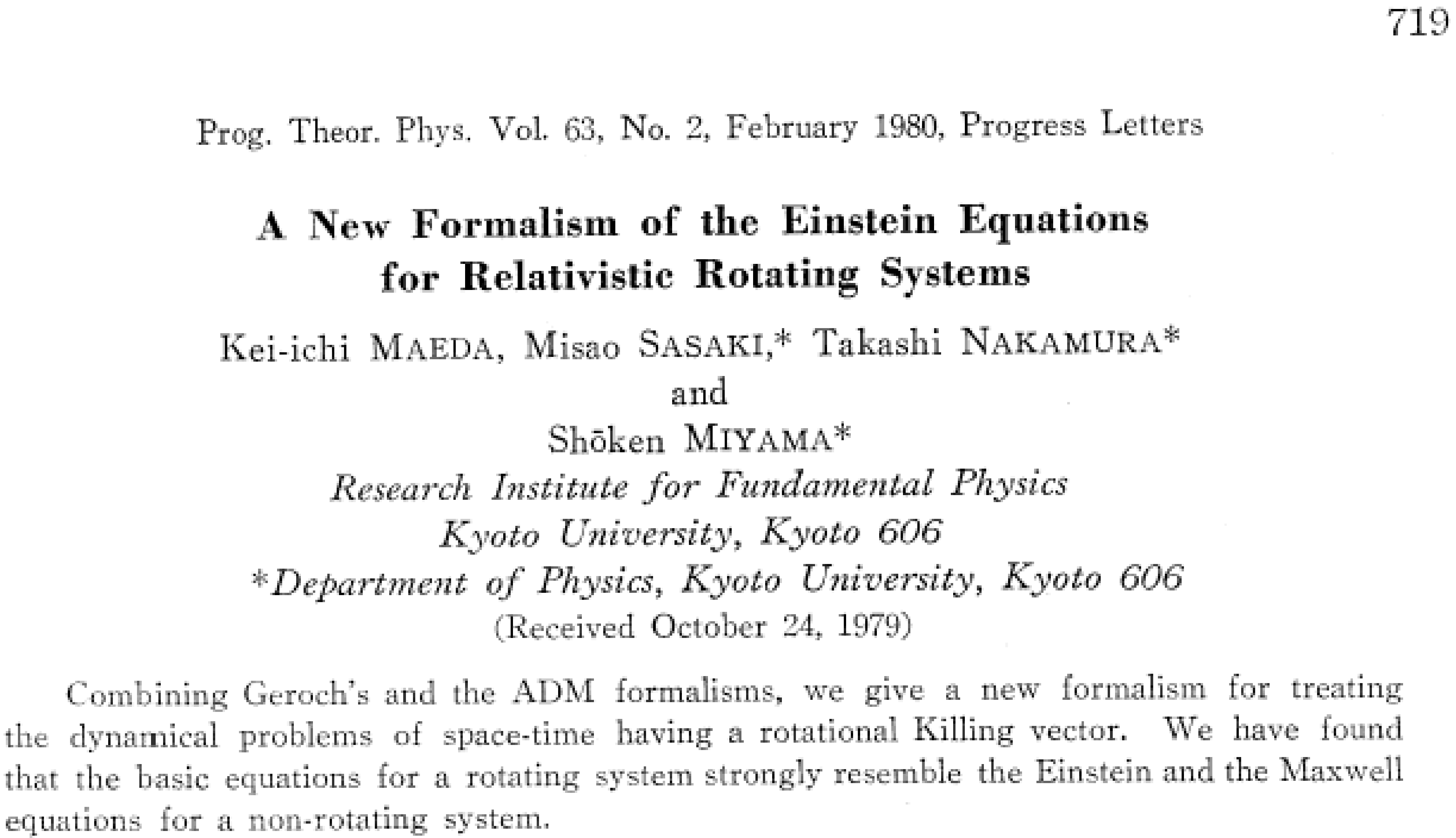
(Received October 8, 1979)

Using the ADM formalism, we give a method of solving the general relativistic collapse of an axially symmetric star by the numerical calculation. At $t=0$, we solve the constraint equations to determine the initial data of the metric tensors and the extrinsic curvatures under given angular momentum distribution and baryon number distribution. An example of the initial data is shown. At later time the evolution equations of the metric and the hydrodynamics equations are solved. The constraint equations are not solved but used to see the accuracy of the numerical calculation. The details of the numerical techniques are shown for the spherically symmetric case.



Prog. Theor. Phys. Vol. 63, No. 2, February 1980, Progress Letters

A New Formalism of the Einstein Equations for Relativistic Rotating Systems

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and
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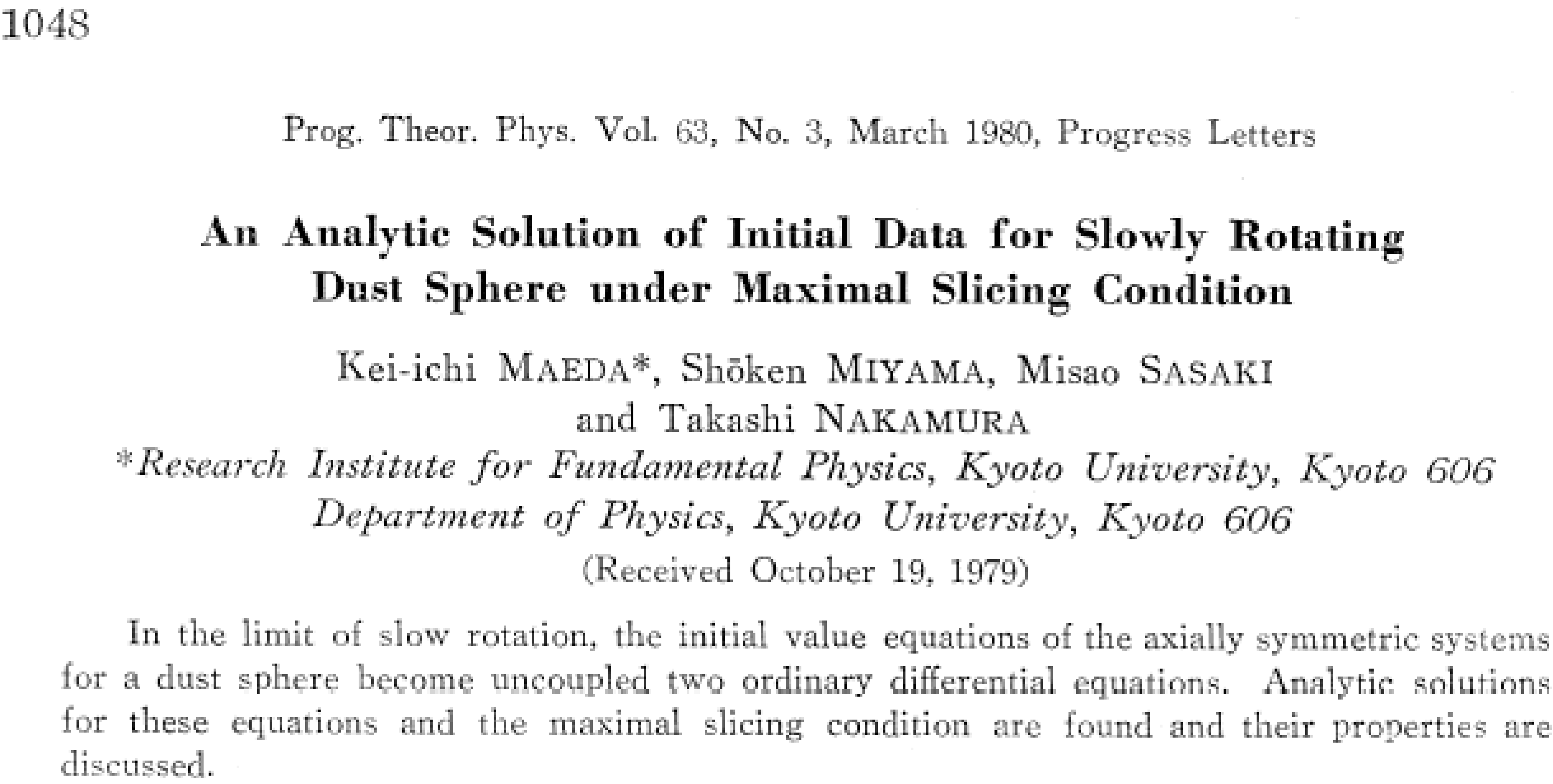
(Received October 24, 1979)

Combining Geroch's and the ADM formalisms, we give a new formalism for treating the dynamical problems of space-time having a rotational Killing vector. We have found that the basic equations for a rotating system strongly resemble the Einstein and the Maxwell equations for a non-rotating system.

This is called (2+1)+1 formalism.



Prog. Theor. Phys. Vol. 63, No. 3, March 1980, Progress Letters

An Analytic Solution of Initial Data for Slowly Rotating Dust Sphere under Maximal Slicing Condition

Kei-ichi MAEDA*, Shōken MIYAMA, Misao SASAKI
and Takashi NAKAMURA
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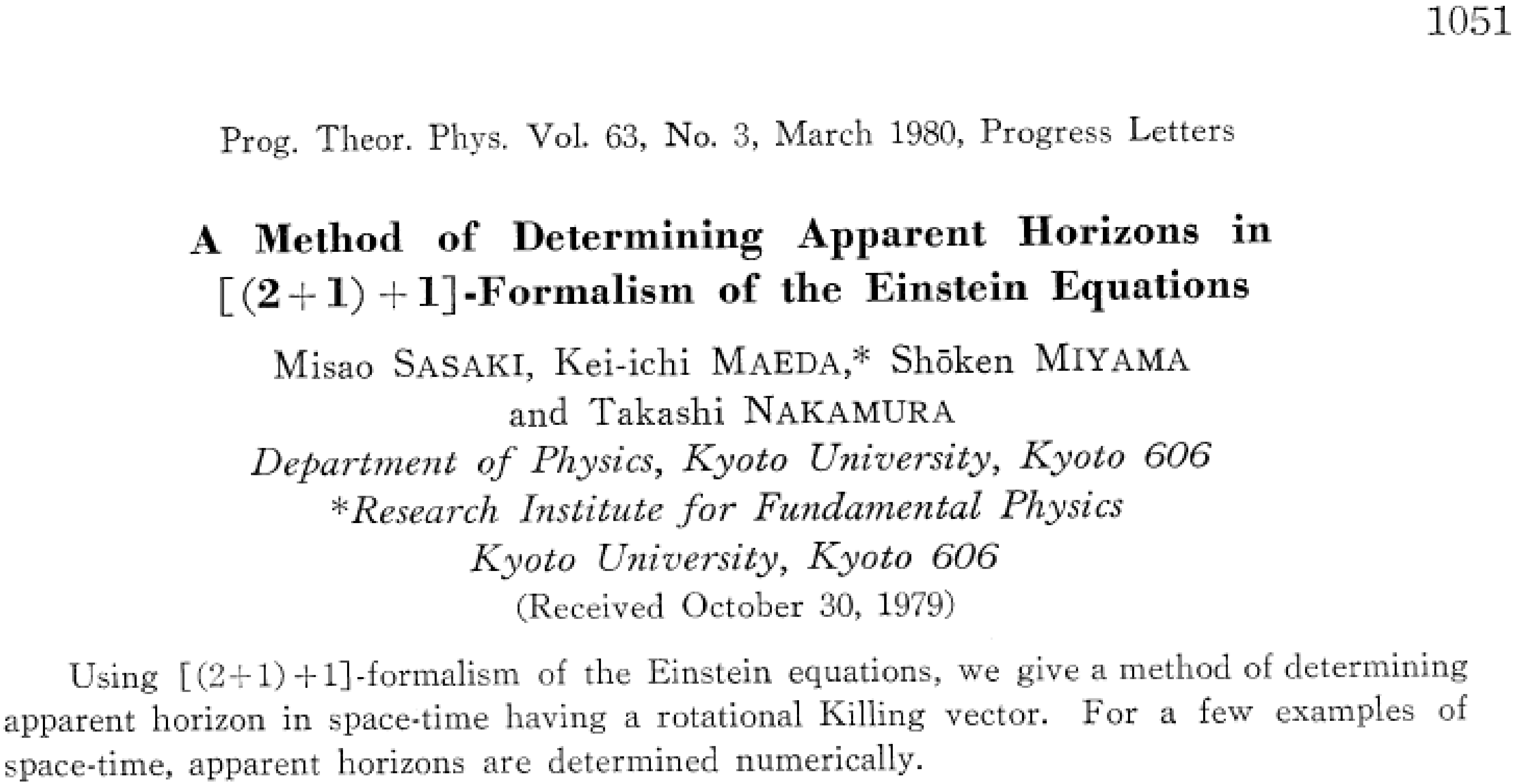
Department of Physics, Kyoto University, Kyoto 606

(Received October 19, 1979)

In the limit of slow rotation, the initial value equations of the axially symmetric systems for a dust sphere become uncoupled two ordinary differential equations. Analytic solutions for these equations and the maximal slicing condition are found and their properties are discussed.



Prog. Theor. Phys. Vol. 63, No. 3, March 1980, Progress Letters

A Method of Determining Apparent Horizons in [(2+1)+1]-Formalism of the Einstein Equations

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(Received October 30, 1979)

Using [(2+1)+1]-formalism of the Einstein equations, we give a method of determining apparent horizon in space-time having a rotational Killing vector. For a few examples of space-time, apparent horizons are determined numerically.

Progress of Theoretical Physics, Vol. 65, No. 3, March 1981

Time Evolution of Pure Gravitational Waves

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(Received November 8, 1980)

Numerical solutions to the Einstein equations in the case of pure gravitational waves are given. The system is assumed to be axially symmetric and non-rotating. The time symmetric initial data and the conformally flat initial data are obtained by solving the constraint equations at $t=0$. The time evolution of these initial data depends strongly on the initial amplitude of the gravitational waves. In the case of the low initial amplitude, waves only disperse to null infinity. By comparing the initial gravitational energy with the total energy loss through an $r=$constant surface, it is concluded that the Newman-Penrose method and the Gibbon-Hawking method are the most desirable for measuring the energy flux of gravitational radiation numerically. In the case that the initial ratio of the spatial extent of the gravitational waves to the Schwarzschild radius ($M/2$) is smaller than about 300, the waves collapse by themselves, leading to formation of a black hole. The analytic solutions of the linearized Einstein equations for the pure gravitational waves are also shown.

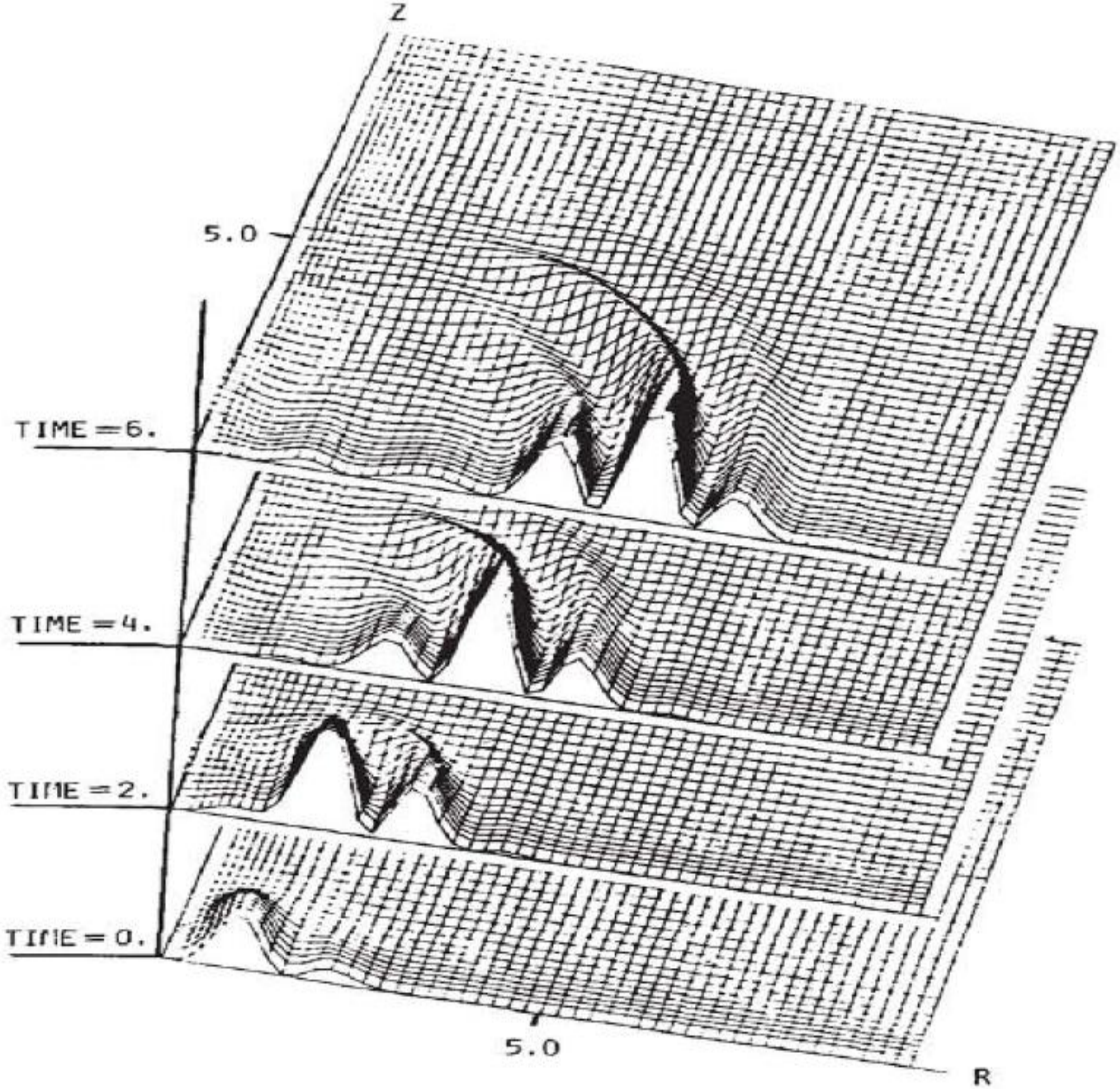

Fig. 1. A plot of the quadratic Riemann invariant $I(R, Z)$ times r^2 at $t = 0, 2.0, 4.0$ and 6.0 for the case of CFID ($A = 0.1$). The vertical distance represents $r^2 I$ on the R-Z coordinate.

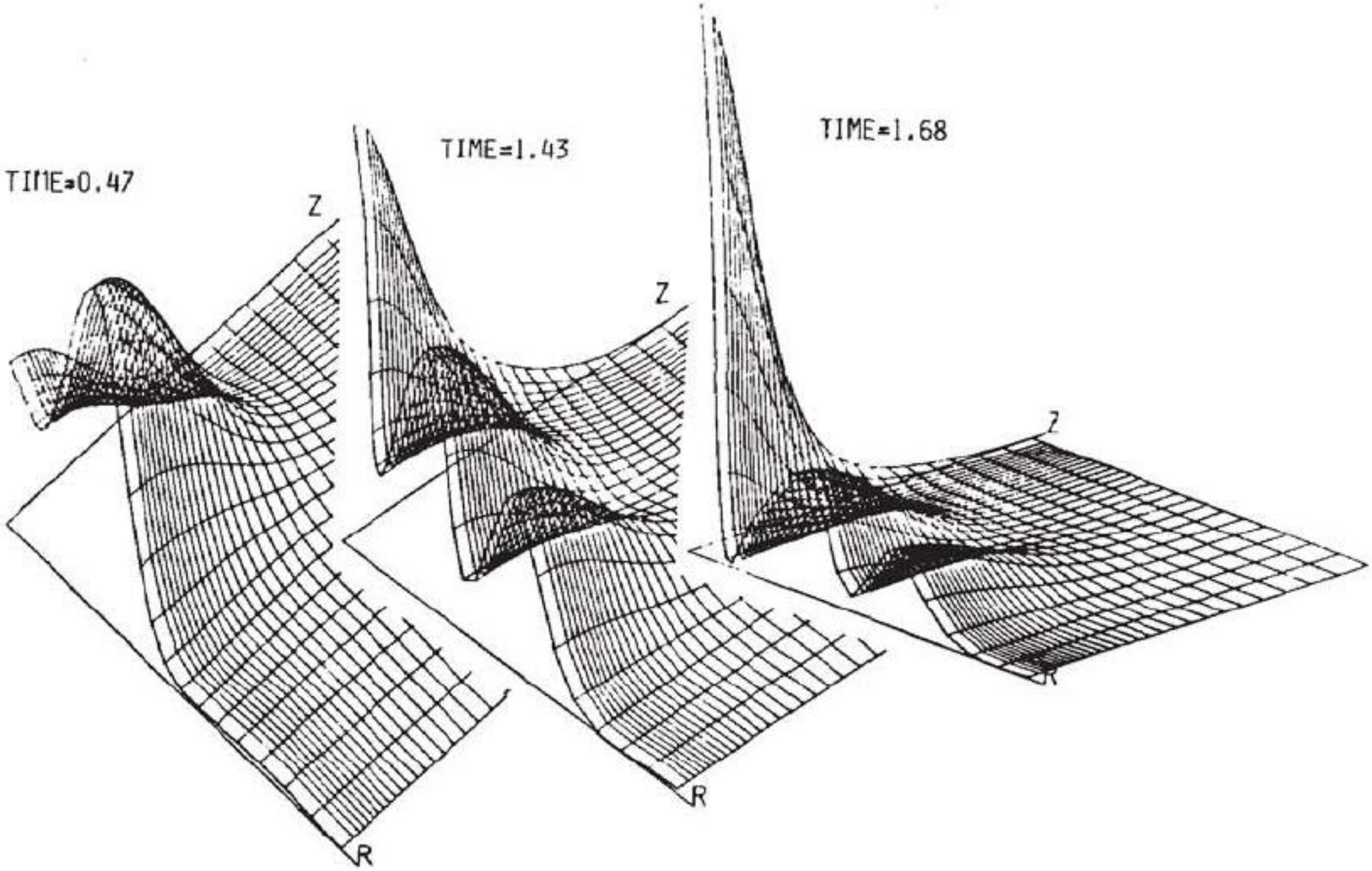

Fig. 4. A plot of the quadratic Riemann invariant $I(R, Z)$ at $t=0.47$, 1.43 and 1.68 for the case of TSID ($A=1$).

Progress of Theoretical Physics, Vol. 65, No. 6, June 1981

General Relativistic Collapse of Axially Symmetric Stars Leading to the Formation of Rotating Black Holes

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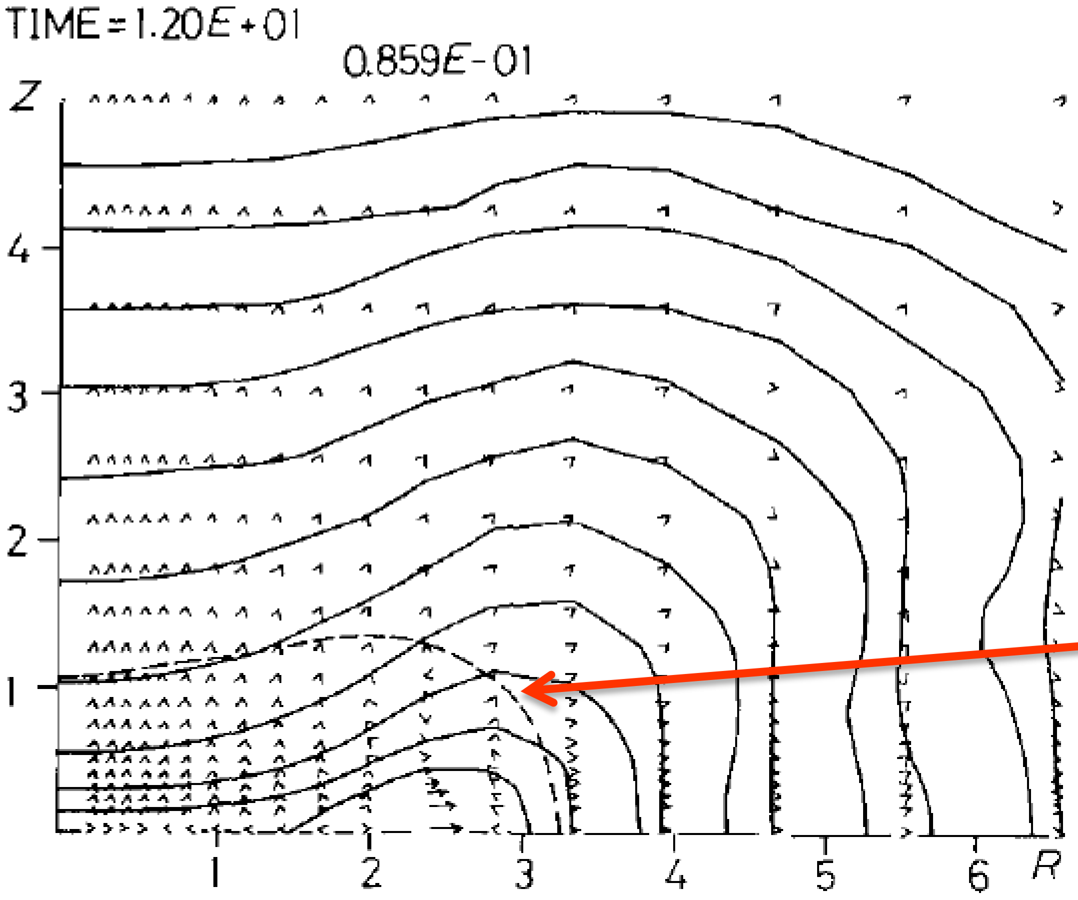
(Received November 1, 1980)

Numerical calculations have been made for the formation process of axisymmetric, rotating black holes of $10M_\odot$. The initial density of a star is about 3×10^{13} g/cm^3. Numerical results are classified mainly by q which corresponds to $|a|/M$ in a Kerr black hole. For $q\lesssim 0.3$, the effect of rotation to the gravitational collapse is only to make the shape of matter oblate. For $0.3\lesssim q\leq 0.95$, although the distribution of matter is disk-like, a ring-like peak of proper density appears. This ring is inside the apparent horizon, which is always formed in the case $q\lesssim 0.95$. For $q\gtrsim 0.95$, no apparent horizon is formed. The distribution of matter shows a central disk plus an expanding ring. It is found that electromagnetic-like field in the $[(2+1)+1]$-formalism plays an important role in a formation of a rotating black hole. Local conservation of angular momentum is checked. Accuracy of constraint equations is also shown to see the truncation error in the numerical calculations.

The first numerical example of the formation of rotating Black Hole

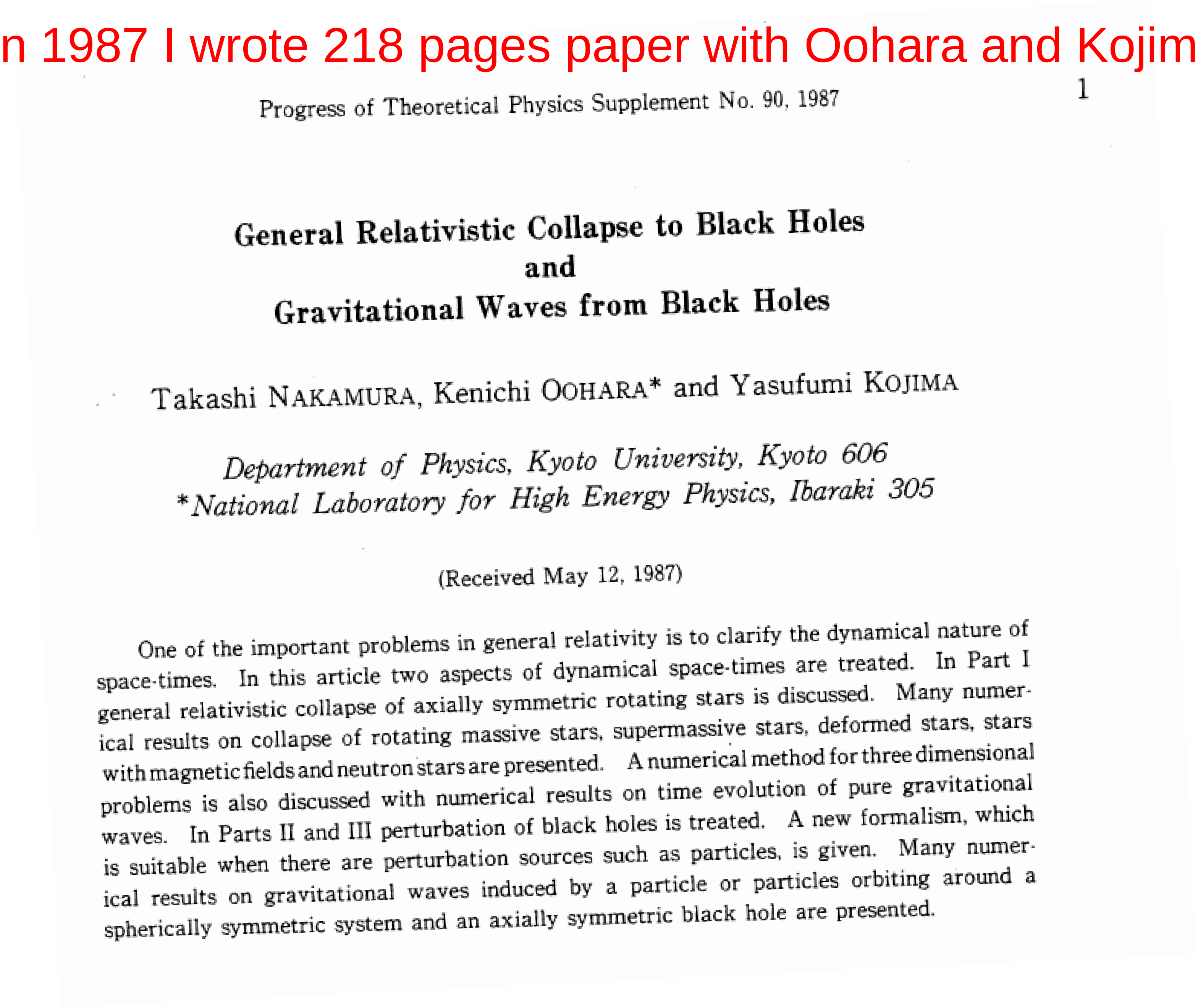


(b) Contour lines of proper density (ρ) for M80 at $t=12.0$. Each line corresponds to $\rho=\rho_{\max}\cdot 10^{-n/2}$ where $\rho_{\max}=8.59\cdot 10^{-2}$ for $n=1$, 2, $\cdots$, 11. The apparent horizon is shown by the dashed line. Arrows show vectors E^{A}.

Contour of proper density for a/m=0.8

Apparent Horizon

In 1987 I wrote 218 pages paper with Oohara and Kojima



Progress of Theoretical Physics Supplement No. 90, 1987

General Relativistic Collapse to Black Holes
and
Gravitational Waves from Black Holes

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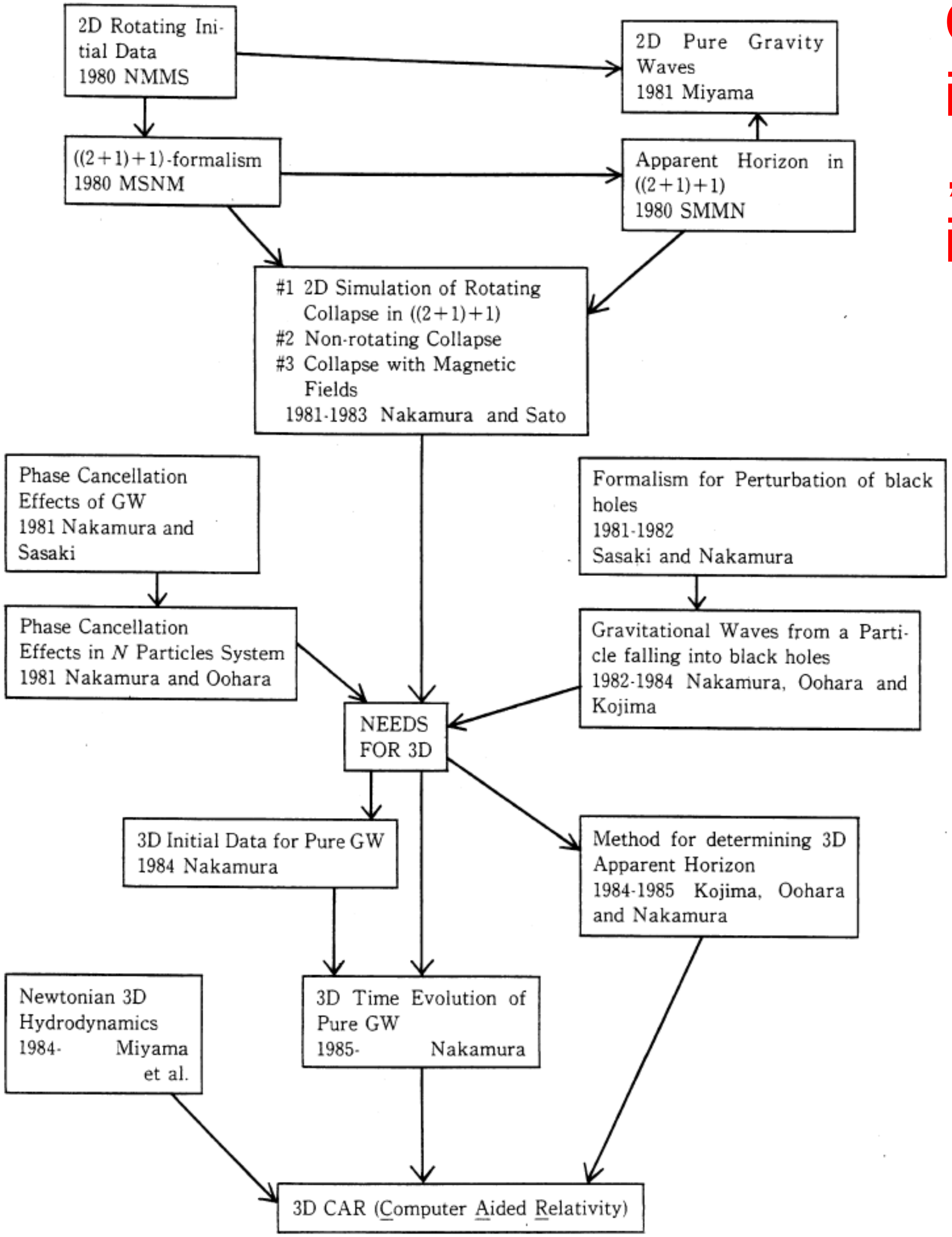
(Received May 12, 1987)

One of the important problems in general relativity is to clarify the dynamical nature of space-times. In this article two aspects of dynamical space-times are treated. In Part I general relativistic collapse of axially symmetric rotating stars is discussed. Many numerical results on collapse of rotating massive stars, supermassive stars, deformed stars, stars with magnetic fields and neutron stars are presented. A numerical method for three dimensional problems is also discussed with numerical results on time evolution of pure gravitational waves. In Parts II and III perturbation of black holes is treated. A new formalism, which is suitable when there are perturbation sources such as particles, is given. Many numerical results on gravitational waves induced by a particle or particles orbiting around a spherically symmetric system and an axially symmetric black hole are presented.

Table I. Numerical relativity in Kyoto.



One of the conclusions is that non-axiallysymmetric , i.e. ,3D numerical relativity is strongly needed.

I first solved time evolution of 3D pure gravitational wave

$$\eta_{ij}=\delta_{ij} \quad \text{and} \quad |\hat{\gamma}_{ij}|\ll 1 .$$

From Eq. (5·48), we can see K_{ij} for large r is the first order quantity concerning γ_{ij}. Now let us consider the evolution of $K\equiv\gamma^{ij}K_{ij}$ and $\gamma\equiv\det(\gamma_{ij})$. From Eq. (5·48), we have

$$\frac{\partial\gamma}{\partial t}=-2K\gamma \tag{5·72}$$

and

$$\frac{\partial K}{\partial t}={}^{(3)}R+K^2 . \tag{5·73}$$

Inserting the Hamiltonian constraint equation (Eq. (5·1)), we obtain

$$\frac{\partial K}{\partial t}=K_{ij}K^{ij} . \tag{5·74}$$

Equation (5·74) shows that for large r K is the second order quantity although K_{ij} itself is the first order one. This means that $\gamma-1$ is also the second order. Now let us rewrite the momentum constraint equations as

$$\frac{\partial K_{ij}}{\partial x^j}=-\hat{\gamma}^{jl}\frac{\partial}{\partial x^l}K_{ij}+\gamma^{lj}(\Gamma^m_{jl}K_{im}+\Gamma^m_{il}K_{mj})+\frac{\partial K}{\partial x^i}\equiv F_i , \tag{5·75}$$

where

$$\hat{\gamma}^{jl}=\gamma^{jl}-\eta^{jl} .$$

Since the Christoffel symbols and $\hat{\gamma}_{ij}$ are the first order quantities, F_i is the second order quantity. Using the first part of Eq. (5·48), we have

$$\frac{\partial}{\partial x^j}\gamma_{ij}=\left(\frac{\partial\gamma_{ij}}{\partial x^j}\right)_{t=0}-2\int_0^t F_i dt . \tag{5·76}$$

Equation (5·76) tells us that $\partial\gamma_{ij}/\partial x^j$ is the second order quantity except for the initial value. Equations (5·74) to (5·76) guarantee the transverse traceless nature of the metric as it should be even in numerical version of the Einstein equations.

Ricci tensor is the most complicated source term for K_{ij}. The explicit form of R_{ij} is

$$R_{ij}=\gamma^{km}\left[\frac{1}{2}\left(\frac{\partial^2\gamma_{im}}{\partial x^k\partial x^j}+\frac{\partial^2\gamma_{kj}}{\partial x^i\partial x^m}-\frac{\partial^2\gamma_{ij}}{\partial x^k\partial x^m}-\frac{\partial^2\gamma_{km}}{\partial x^i\partial x^j}\right)+(\Gamma_{n,kj}\Gamma^n_{im}-\Gamma_{n,km}\Gamma^n_{ij})\right] . \tag{5·77}$$

We define $(R_{ikjm})_{\text{lin}}$ and $(R_{ikjm})_{\text{Nonlin}}$ by

$$(R_{ikjm})_{\text{lin}}=\frac{1}{2}\left(\frac{\partial^2\gamma_{im}}{\partial x^k\partial x^j}+\frac{\partial^2\gamma_{kj}}{\partial x^i\partial x^m}-\frac{\partial^2\gamma_{ij}}{\partial x^k\partial x^m}-\frac{\partial^2\gamma_{km}}{\partial x^i\partial x^j}\right) \tag{5·78}$$

and

$$(R_{ikjm})_{\text{Nonlin}}=\Gamma_{n,kj}\Gamma^n_{im}-\Gamma_{n,km}\Gamma^n_{ij} . \tag{5·79}$$

It is clear that $(R_{ikjm})_{\text{lin}}$ is the first order quantity while $(R_{ikjm})_{\text{Nonlin}}$ is the second order one. Using $(R_{ikjm})_{\text{lin}}$ and $(R_{ikjm})_{\text{Nonlin}}$, we can rewrite Eq. (5·77) as

$$\begin{aligned}R_{ij}=&-\frac{1}{2}\Delta\hat{\gamma}_{ij}+\frac{1}{2}\frac{\partial}{\partial x^j}\left(\frac{\partial\gamma_{ik}}{\partial x^k}\right)+\frac{1}{2}\frac{\partial}{\partial x^i}\left(\frac{\partial\gamma_{jk}}{\partial x^k}\right)\\&-\frac{1}{2}\frac{\partial^2}{\partial x^i\partial x^j}(\hat{\gamma}_{11}+\hat{\gamma}_{22}+\hat{\gamma}_{33})+\hat{\gamma}^{km}(R_{ikjm})_{\text{lin}}+\gamma^{km}(R_{ikjm})_{\text{Nonlin}} .\end{aligned} \tag{5·80}$$

We first see the last two terms are second order. The $\det(\gamma_{ij})(=\gamma)$ is written explicitly as

$$\begin{aligned}\gamma-1=&(1+\hat{\gamma}_{11})(1+\hat{\gamma}_{22})(1+\hat{\gamma}_{33})+2\hat{\gamma}_{12}\hat{\gamma}_{23}\hat{\gamma}_{31}\\&-(1+\hat{\gamma}_{11})\hat{\gamma}^2_{23}-(1+\hat{\gamma}_{22})\hat{\gamma}^2_{13}-(1+\hat{\gamma}_{33})\hat{\gamma}^2_{12}-1\\\equiv&\,\hat{\gamma}_{11}+\hat{\gamma}_{22}+\hat{\gamma}_{33}+\text{det2} .\end{aligned} \tag{5·81}$$

Since $\gamma-1$ and det2 are the second order, $\hat{\gamma}_{11}+\hat{\gamma}_{22}+\hat{\gamma}_{33}$ is the second order. Using Eq. (5·81), we can rewrite the third term of Eq. (5·80) as

$$\frac{\partial^2}{\partial x^i\partial x^j}(\hat{\gamma}_{11}+\hat{\gamma}_{22}+\hat{\gamma}_{33})=\frac{\partial^2\gamma}{\partial x^i\partial x^j}-\frac{\partial^2}{\partial x^i\partial x^j}\text{det2} . \tag{5·82}$$

If one uses the expression of the r.h.s. of Eq. (5·82), the second order nature of this term is guaranteed numerically. However if one uses the l.h.s. expression, the second order nature is not guaranteed numerically because each term is the first order. A slight truncation error makes this term the first order and violates the traceless nature of the waves. Although on the r.h.s. the expression of the second derivatives of det2 becomes very complicated, REDUCE is very powerful in the calculation of this term. The results in the FORTRAN statements are shown in Appendix C. There the notation as

$$\gamma_{ij}=\begin{pmatrix}\gamma_1 & \gamma_2 & \gamma_3\\ \gamma_2 & \gamma_4 & \gamma_5\\ \gamma_3 & \gamma_5 & \gamma_6\end{pmatrix} \tag{5·83}$$

is used.

At first sight, the second term of Eq. (5·80) seems to be the first order. However inserting Eq. (5·76) into this term, we have

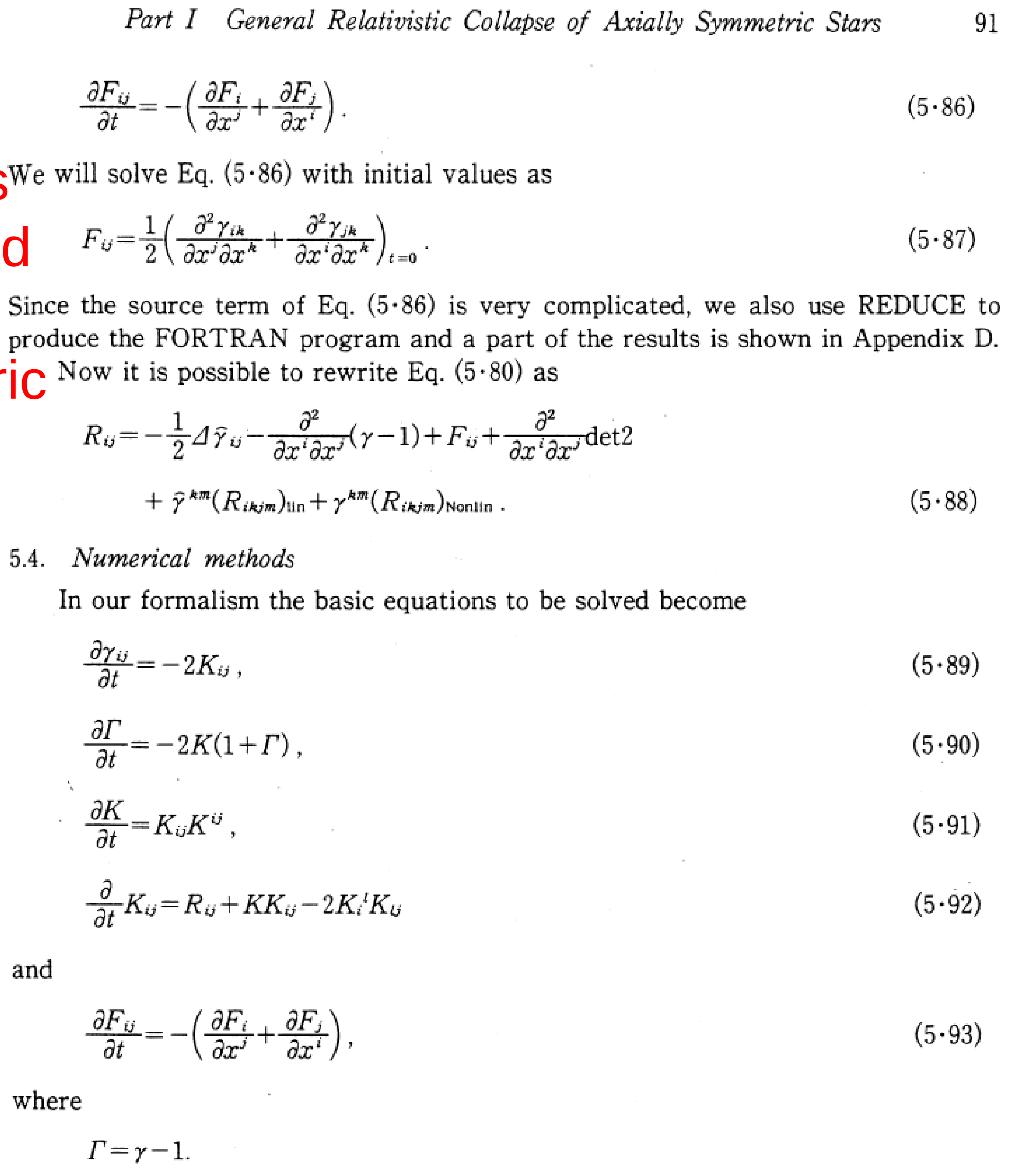
$$\left[\frac{1}{2}\left(\frac{\partial^2\gamma_{ik}}{\partial x^j\partial x^k}+\frac{\partial^2\gamma_{jk}}{\partial x^i\partial x^k}\right)\right]^t_{t=0}=-\int_0^t\left(\frac{\partial F_i}{\partial x^j}+\frac{\partial F_j}{\partial x^i}\right)dt , \tag{5·84}$$

which shows this term is also the second order except for the initial value. In reality we define F_{ij} by

$$F_{ij}\equiv\frac{1}{2}\left(\frac{\partial^2\gamma_{ik}}{\partial x^j\partial x^k}+\frac{\partial^2\gamma_{jk}}{\partial x^i\partial x^k}\right) . \tag{5·85}$$

From Eq. (5·84), we have the evolution equation for F_{ij} as

The basic idea called BSSN formalism now was shown in 1987 and applied to the time evolution of pure non-axially symmetric gravitational waves



$$\frac{\partial F_{ij}}{\partial t}=-\left(\frac{\partial F_i}{\partial x^j}+\frac{\partial F_j}{\partial x^i}\right). \tag{5·86}$$

We will solve Eq. (5·86) with initial values as

$$F_{ij}=\frac{1}{2}\left(\frac{\partial^2\gamma_{ik}}{\partial x^j\partial x^k}+\frac{\partial^2\gamma_{jk}}{\partial x^i\partial x^k}\right)_{t=0}. \tag{5·87}$$

Since the source term of Eq. (5·86) is very complicated, we also use REDUCE to produce the FORTRAN program and a part of the results is shown in Appendix D. Now it is possible to rewrite Eq. (5·80) as

$$R_{ij}=-\frac{1}{2}\Delta\tilde{\gamma}_{ij}-\frac{\partial^2}{\partial x^i\partial x^j}(\gamma-1)+F_{ij}+\frac{\partial^2}{\partial x^i\partial x^j}\mathrm{det2}$$
$$+\tilde{\gamma}^{km}(R_{ikjm})_{\mathrm{lin}}+\gamma^{km}(R_{ikjm})_{\mathrm{Nonlin}}. \tag{5·88}$$

5.4. *Numerical methods*

In our formalism the basic equations to be solved become

$$\frac{\partial\gamma_{ij}}{\partial t}=-2K_{ij}, \tag{5·89}$$

$$\frac{\partial\Gamma}{\partial t}=-2K(1+\Gamma), \tag{5·90}$$

$$\frac{\partial K}{\partial t}=K_{ij}K^{ij}, \tag{5·91}$$

$$\frac{\partial}{\partial t}K_{ij}=R_{ij}+KK_{ij}-2K_i{}^lK_{lj} \tag{5·92}$$

and

$$\frac{\partial F_{ij}}{\partial t}=-\left(\frac{\partial F_i}{\partial x^j}+\frac{\partial F_j}{\partial x^i}\right), \tag{5·93}$$

where

$$\Gamma=\gamma-1.$$

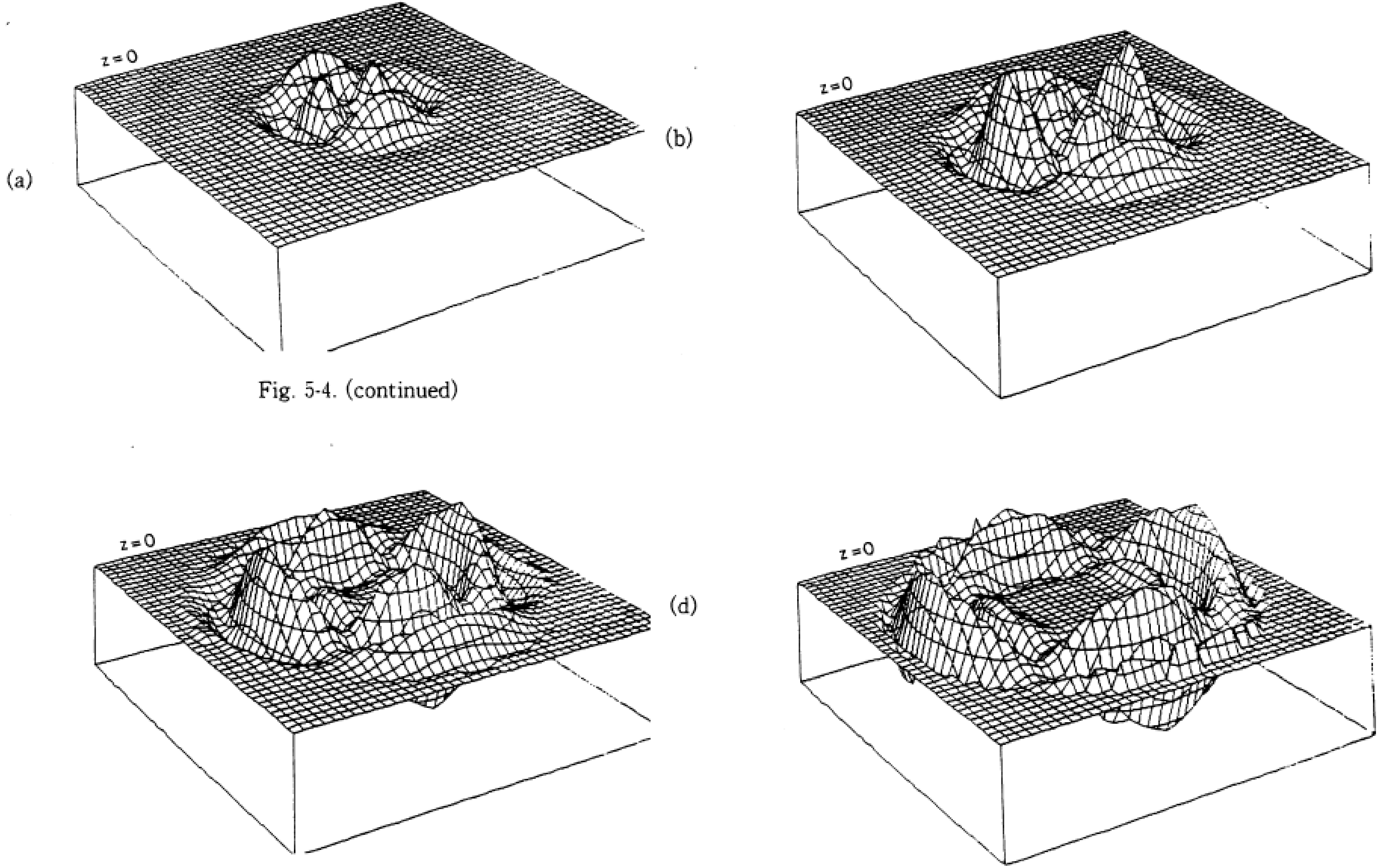


Fig. 5-4. (continued)

Evolution of $(\gamma_{xx}-1)r$ in the equatorial plane

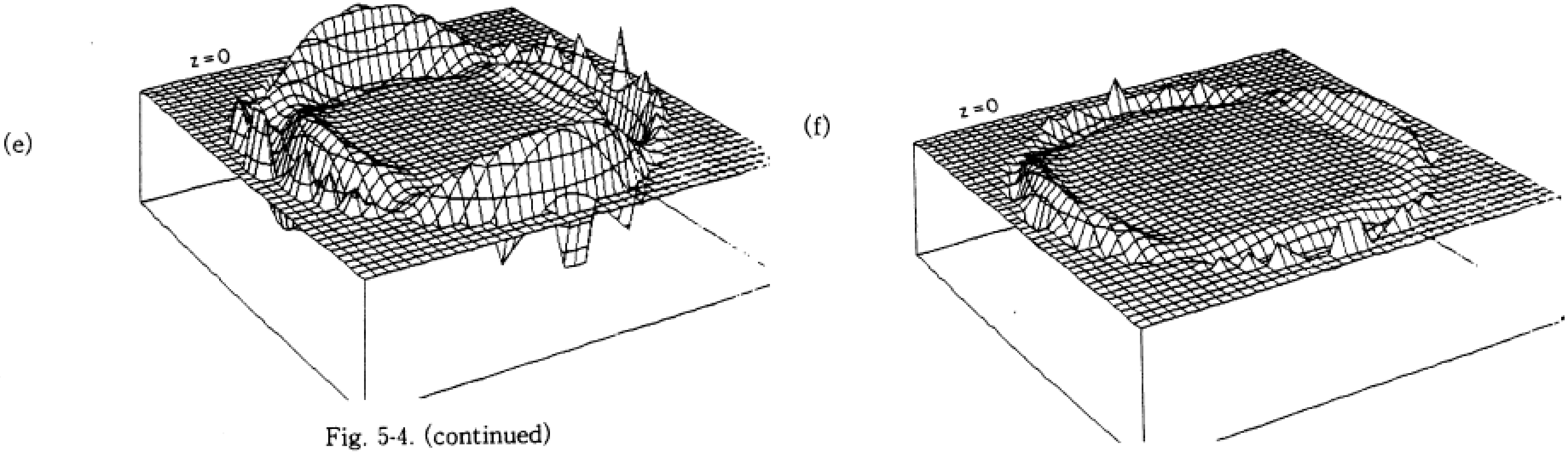


Fig. 5-4. (continued)

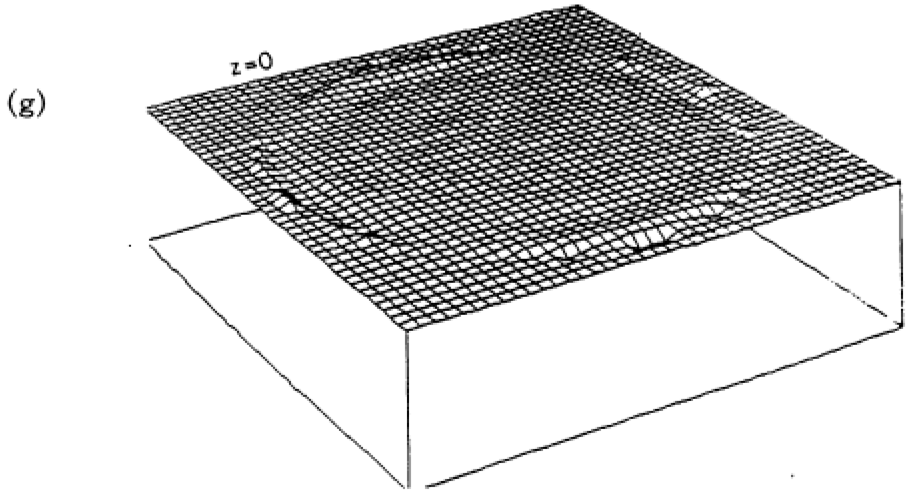


Fig. 5-4. (a)~(g) Evolution of metric tensor $(\gamma_{xx}-1)\times r$ in the equatorial plane.

When and How the study of laser Interferometer gravitational waves detector in Japan started ?

- In 1988 March 23, I received a letter from President of Nagoya University, Sachio Hayakawa . He met Hayashi on his way to Tokyo and back to Nagoya and knew that I was interested in gravitational waves.
- His friend Mizushima in Colorado, asked Hayakawa to organize the research group on the laser interferometer gravitational wave detectors in space using two artificial satellites. He already discussed this with laser physicist professor Takuma in Univ. Electro-Communication, M. Fujimoto in national astronomical observatory and ATR(Advanced Telecommunication Research) company.
- Hayakawa answered to Mizushima that he wanted to organize the research group on the laser interferometer in Japan after the discussion with Takuma . He was impressed by the talk of Kip Thorne when he invited Kip to talk on LIGO at Nagoya University in 1986 after Yamada conference in Kyoto.
- In the letter, Hayakawa asked me to join the group . I answered “Yes”.
- In 1988 June, we first had a small meeting at ATR in Osaka. We felt that we had a bigger meeting with more experts to discuss what and how we should start the research on laser interferometer gravitational wave detector.
-

- S. Hayakawa (borne 1923)
- 1954-1959 Professor in YITP
- 1959- 1987 Professor in Nagoya University
- 1987-1992 President of Nagoya University
- 1991 Japan Academy Prize
- Passed away 1992 March 5
- Elementary Particle Physics, Cosmic Ray Physics, Gamma Ray and X-Ray Astronomy

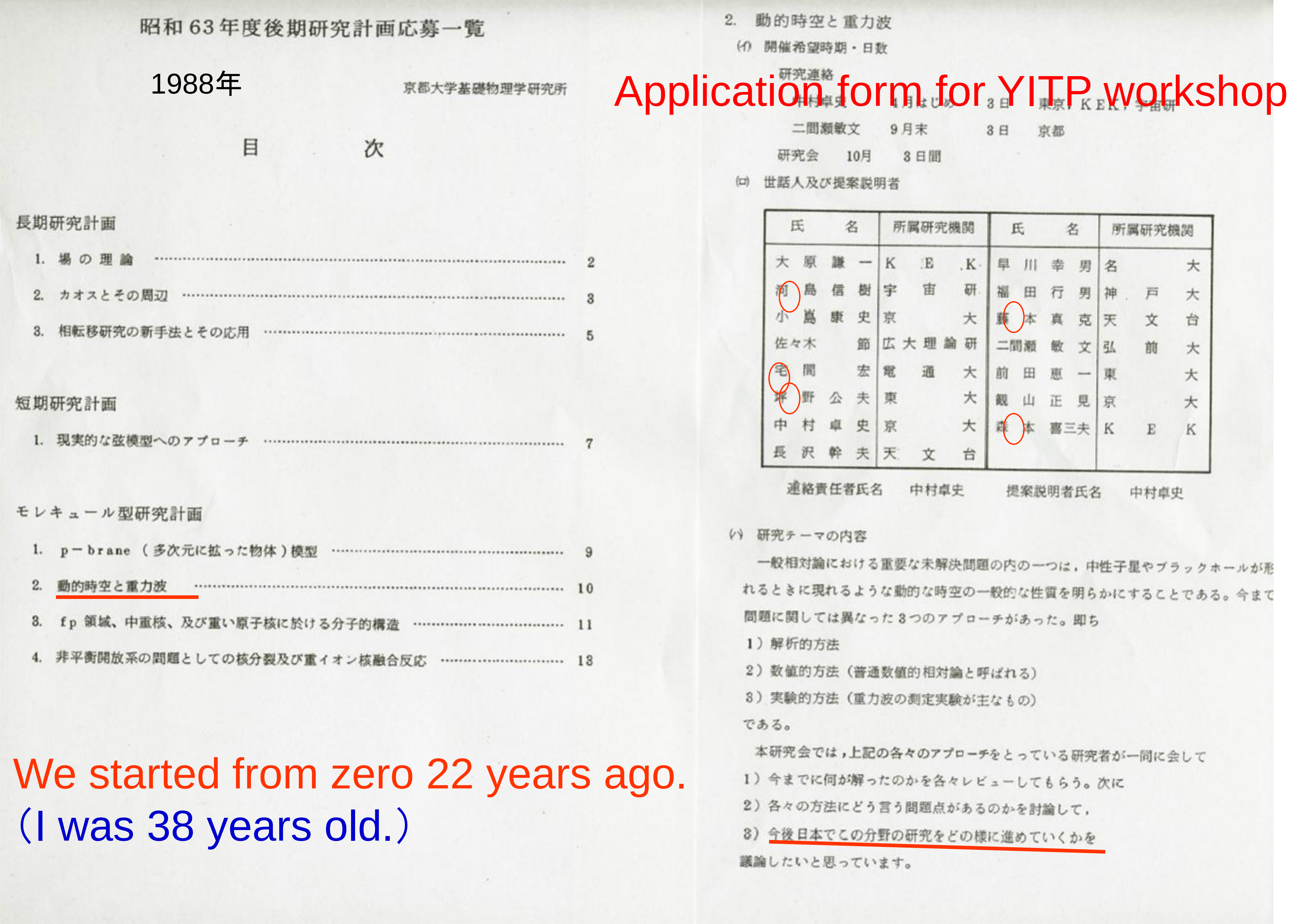

Hayashi
Hayakawa
Yukawa

We had Molecule Type workshop * in YITP "Dynamical Space Time and Gravitational Waves

- We had the workshop in 1988 September.
- Participants: Hayakawa, Kawashima(ISAS), Takuma(Univ,ElectroCommunication),Tsubono(Univ.Tokyo), Fujimoto(NAO), Morimoto(KEK), Nakamura, Madea, Sasaki, Miyama, Kojima, Oohara, Futamase,&Nagasawa
- Professor Hirakawa in Univ. Tokyo had been trying to observe the continuous gravitational waves from Crab pulsar using cooled resonant type antenna. Unfortunately he passed away in 1986. Tsubono succeeded to Hirakawa's group in Univ. Tokyo.
- Morimoto continued the experiment by Hirakawa in KEK.
- Kawashima made 10m delay line laser interferometer in ISAS.
- The main purpose of this workshop was to discuss and decide what we should do next several years.
- *Molecule type means that the participants is 10 or so

Application form for YITP workshop

1988年



昭和63年度後期研究計画応募一覧

京都大学基礎物理学研究所

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長期研究計画

短期研究計画

モレキュール型研究計画

2.　動的時空と重力波

(イ)　開催希望時期・日数

研究連絡
中村卓史　4月はじめ　3日　東京，KEK，宇宙研
二間瀬敏文　9月末　3日　京都
研究会　10月　3日間

(ロ)　世話人及び提案説明者

氏名	所属研究機関	氏名	所属研究機関
大原謙一	KEK	早川幸男	名大
河島信樹	宇宙研	福田行男	神戸大
小嶌康史	京大	藤本眞克	天文台
佐々木節	広大理論研	二間瀬敏文	弘前大
宅間宏	電通大	前田恵一	東大
坪野公夫	東大	観山正見	京大
中村卓史	京大	森本喜三夫	KEK
長沢幹夫	天文台		

連絡責任者氏名　中村卓史　　提案説明者氏名　中村卓史

(ハ)　研究テーマの内容

一般相対論における重要な未解決問題の内の一つは，中性子星やブラックホールが形れるときに現れるような動的な時空の一般的な性質を明らかにすることである。今まで問題に関しては異なった3つのアプローチがあった。即ち

1）解析的方法
2）数値的方法（普通数値的相対論と呼ばれる）
3）実験的方法（重力波の測定実験が主なもの）

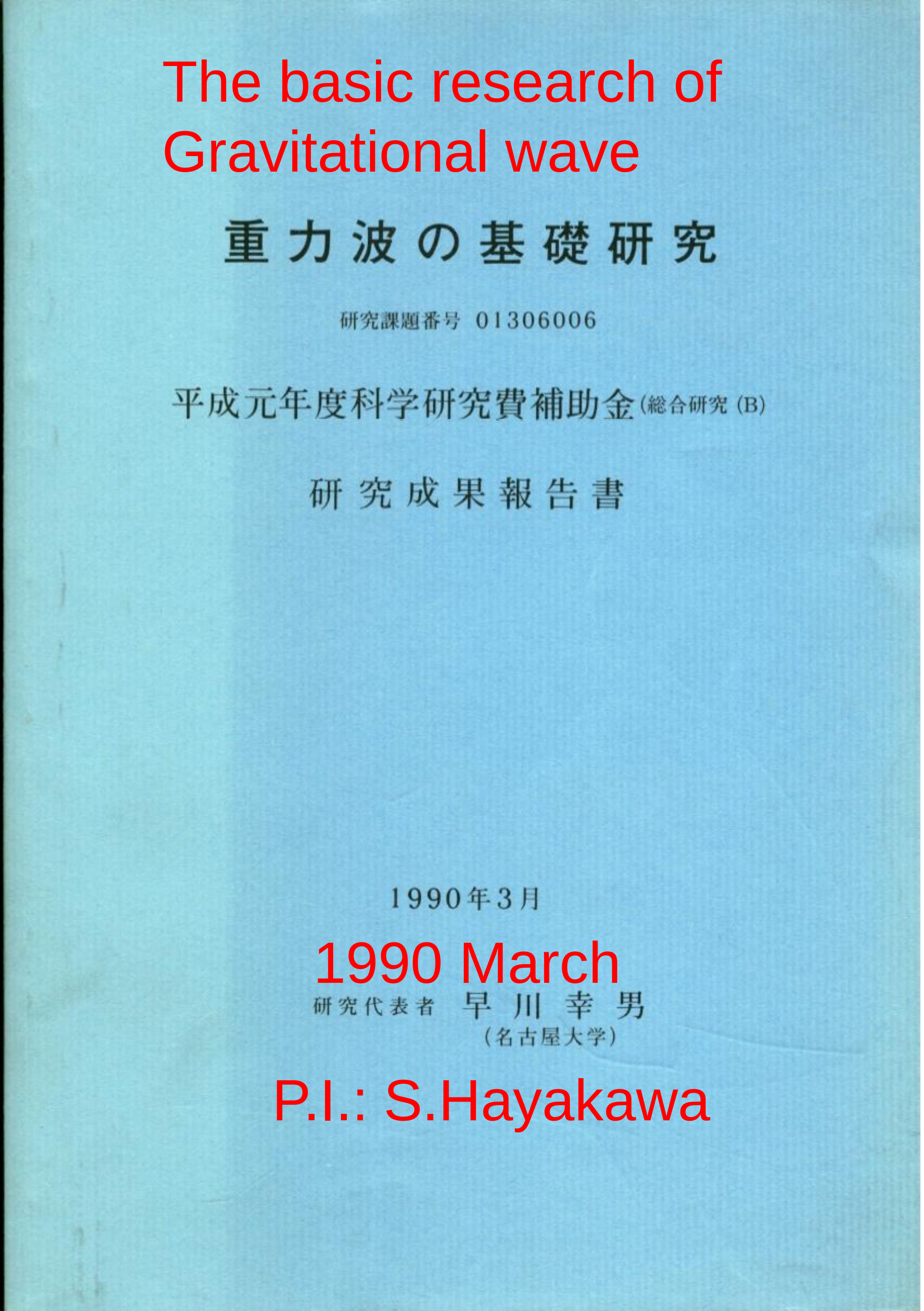
である。

本研究会では，上記の各々のアプローチをとっている研究者が一同に会して
1）今までに何が解ったのかを各々レビューしてもらう。次に
2）各々の方法にどう言う問題点があるのかを討論して，
3）今後日本でこの分野の研究をどの様に進めていくかを

議論したいと思っています。

We started from zero 22 years ago.
（I was 38 years old.）

- Resolutions were:
- 1) Apply to the grant-in-aid of Type B with 3M YEN(about 30,000 Euro now) to prepare for the bigger grant-in-aid.
- 2) Simultaneously apply to the grant-in-aid on Priority Area of ministry of education with 600M YEN(about 6M Euro now).
- 3) P.I : prof. Hayakawa.
- Next year(1989) we were informed that the Type B grant was approved but the priority area was not.
- In 1989 June, prof. Hayakawa proposed to write a conceptual design of the interferometer. The design started in June mainly by Mio and Ohashi and ended in February 1990.
- However the ministry of education was anxious about the research by the president of the university. In short, the president of the university should not be the leader of the big grant-in-aid such as priority area.
- Hayakawa then asked me to be P.I. We again applied to the grant-in –aid on Priority Area “gravitational wave astronomy” in1990 with 600M YEN(about 6M Euro now)



The basic research of Gravitational wave

重力波の基礎研究

研究課題番号 01306006

平成元年度科学研究費補助金(総合研究 (B)

研究成果報告書

1990年3月

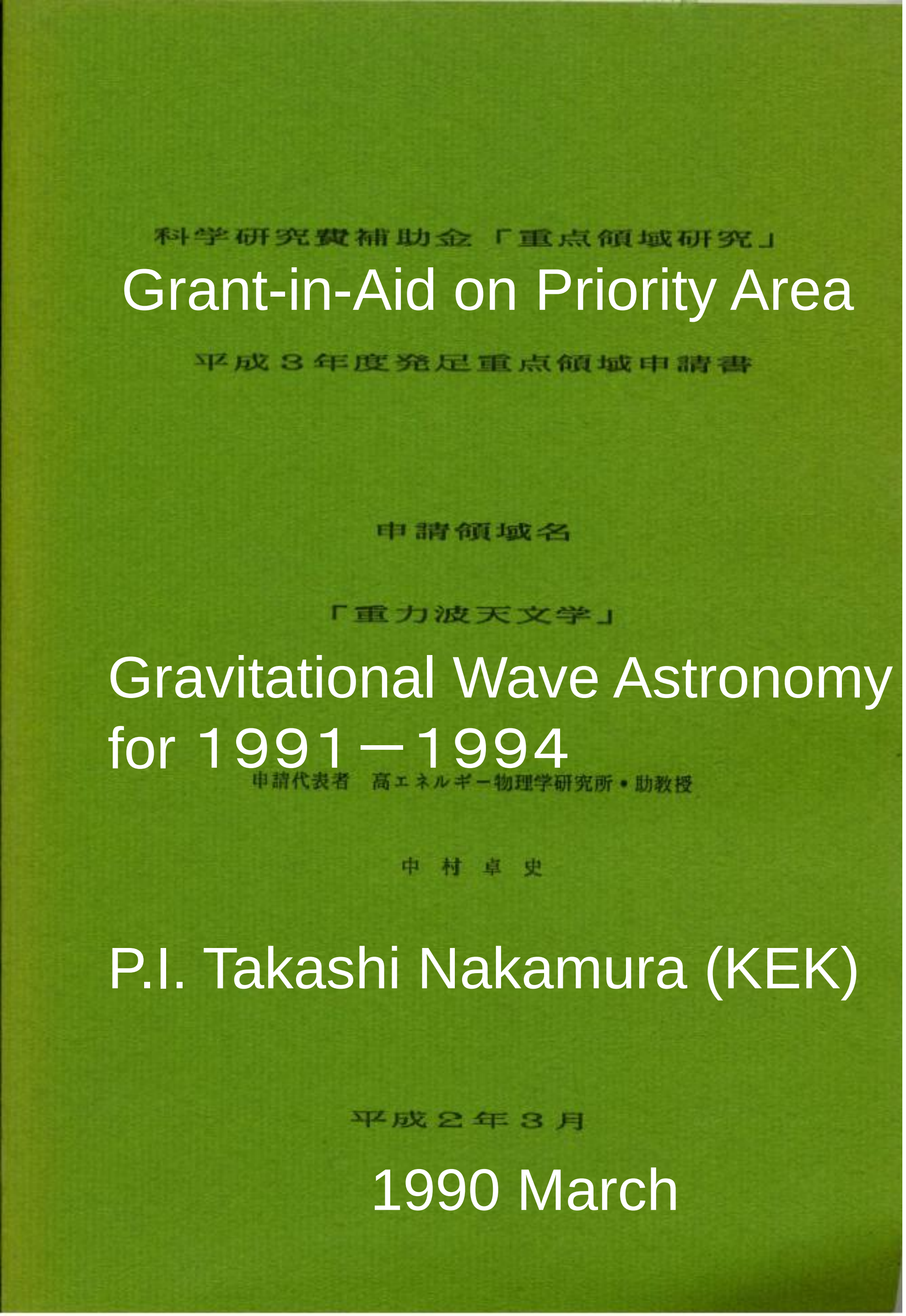
1990 March

研究代表者 早川幸男
（名古屋大学）

P.I.: S.Hayakawa

The cover title of the report of the grant-in-Aid of Type(B) in March 1990.

P.I.: S.Hayakawa.



科学研究費補助金「重点領域研究」

Grant-in-Aid on Priority Area

平成３年度発足重点領域申請書

申請領域名

「重力波天文学」

Gravitational Wave Astronomy
for 1991－1994

申請代表者　高エネルギー物理学研究所・助教授

中村卓史

P.I. Takashi Nakamura (KEK)

平成２年３月

1990 March

The cover title of application form for the grant-in-aid on the priority area “Gravitational Wave Astronomy” in March 1990 for 1991-1994.

This was approved.

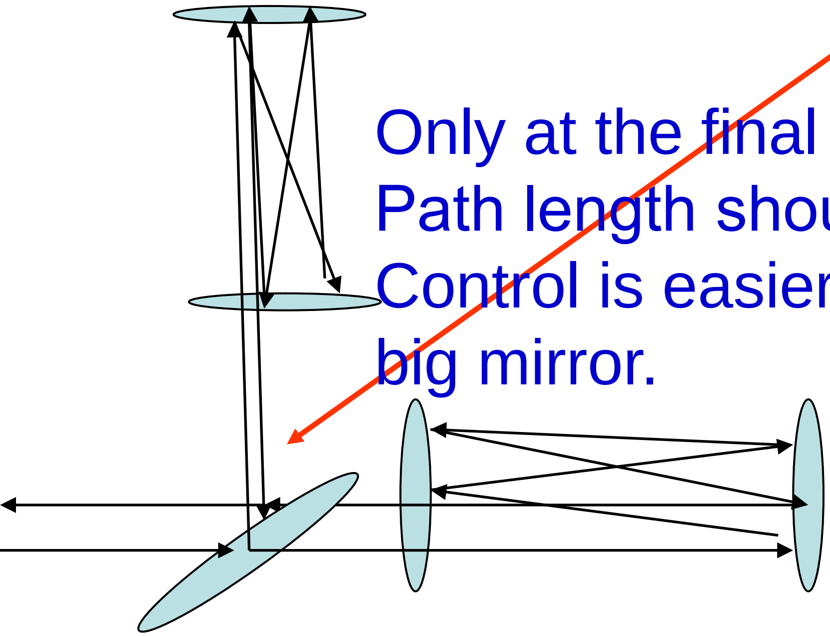
In 1988, I was invited by M. Kobayashi to come to KEK where the most powerful computer was, as an associate professor . However, I came back to YITP in 1990 July as a professor.

Priority Area (1991-1994) with 600M YEN(about 6M Euro now).

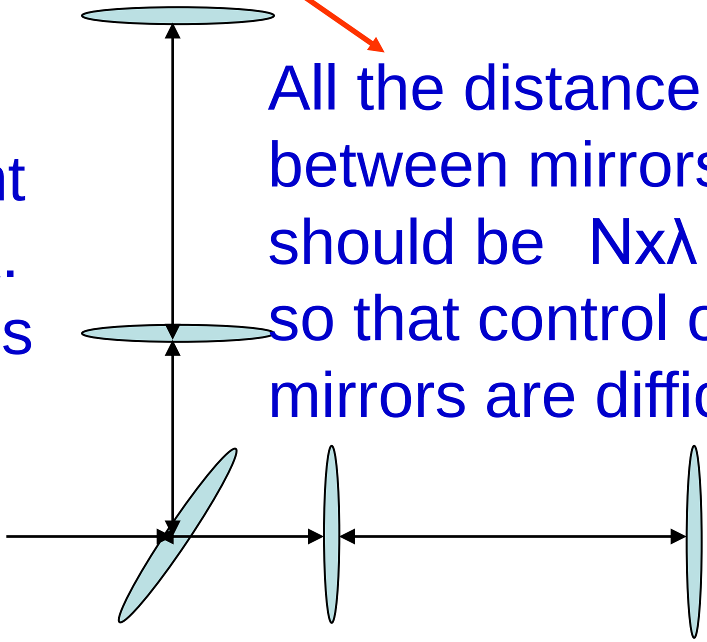
At that time, we do not know which is better, Fabry Perot or Delay Line? The best interferometer then was MPI 30m in which Delay Line was adopted. We decided to develope both as

Sub Project A1) Construction of FP type 20m interferometer
(leader Fujimoto in NAO)

Sub Project A2) Construction of 100m Delay Line interferometer
(Leader Kawashima in ISAS)



Only at the final cross point Path length should be Nxλ. Control is easier but needs big mirror.



All the distance between mirrors should be Nxλ so that control of mirrors are difficult

Sub project B) Development of high power&stable laser

(Leader K. Ueda in Univ, electro-communications)

Nd :YAG laser 200mW $\delta\nu / \nu \sim 10^{-19}$sqrt(Hz)

Sub project C) Development of various elements such as seismic isolation, control of mirror

(Leader K. Tsubono in Univ. Tokyo)

Sub project D) Research on sources of gravitational waves and numerical simulations

(Leader T. Nakamura in YITP)

Hayakawa passed away in 1992

Prof. Hayakawa passed away in 1992 March 5.

What he did was extremely important. Without his activity present gravitational wave research group in Japapan could not exist.

Especially important is that he proposed to exchange MOU(Memorandum Of Understanding) among NAO, KEK and ICRR. This MOU has been continuing even now. Its content is:

“ The presidents(directors) of NAO, KEK and ICRR (three big institutes in Japan) agree to work and cooperate together to construct the ground based 3km size gravitational wave detector in Japan.”

He also encouraged to write the conceptual design.

This was also very ,very important.

How about cooling the mirror?

- I did not expect that I became P.I. of the experimental project. Moreover the ministry of education requested me to achieve something very new in the world. I knew nothing about the laser interferometer so that I began to read the document of the conceptual design. I found that the thermal noise was important so that I proposed to cool down the mirror to 4K. Then I received many objections;
- “ How do you cool the mirror in the vacuum? Do you shed the cool gas to the mirror and absorb it from somewhere to keep the level of vacuum? That is extremely difficult.”
- “ How about keeping all the vacuum tube 4K and cooling the mirror by its emission of radiation?”
- .

- “It would be OK for end mirror disregarding the cost. However near mirror should absorb the laser light more or less so that the temperature of the near mirror would be at most 200K or so. 200K mirror does not help to increase the sensitivity.”

- “We have been studying the resonant detectors to catch the continuous gravitational wave from Crab pulsar. We knew various problems in cooling the detector. We started the study of laser interferometer since we heard that the cooling is not needed. Are you saying that we should cool again?”
- The discussions ended at this time.
- However ten years later in 2000, Kuroda in ICRR succeeded in cooling the mirror to 20K by the conduction of the wire which sustains the mirror. This opened the way to LCGT.

The birth of JGRG

- To support the experimental effort for the detection of gravitational waves, Maeda and I considered to make the theoretical community related to general relativity and gravitation.
- Contents:
- Once a year we will have 5days or so conference.
- We will publish the proceedings in English.
- Priority Area “Gravitational Wave Astronomy” will support the cost of the proceedings and a part of the travel and living expenses for invited speakers.
- The place of conference will be changed every year.
- The contents of the conference should be as wide as possible. Any talks related to general relativity and gravitation are OK.
- We also expected that some young people in JGRG move to data analysis and experiments.

- List of JGRG(Japan General Relativity and Gravitation)
- 1st :1991.12.4-6 ,Tokyo Metropolitan Univ. , 44 talks,120 participants , 399 page English proceedings, supported by Priority Areas “Gravitational Wave Astronomy”
- 2nd: 1993. 1.18-20, Waseda Univ. , 57 talks, 142 participants, 476 page English proceedings, supported by Priority Areas “Gravitational Wave Astronomy”
- 3rd: 1994. 1. 17-20, Univ. Tokyo, 64 talks, 155 participants, 516 page English proceedings, supported by Priority Areas “Gravitational Wave Astronomy”
- 4th: 1994. 11.28-12.1, Kyoto Univ. YITP , 56 talks, 105 participants, 475 page English proceedings, supported by Priority Areas “Gravitational Wave Astronomy”
- 5th: 1996. 1.22-25, Nagoya Univ., 57 talks, 110 participants, 463 page English proceedings, supported by New Program “Gravitational Wave Astronomy” (TAMA project was started as a part of this program.)
- 6th: 1996. 12.2-5, Tokyo Inst. Tech., 60 talks, 120 participants, 481 page English proceedings, supported by New Program “Gravitational Wave Astronomy”
- 7th: 1997. 10.27-30, Kyoto Univ. YITP, 52 talks, 93 participants, 364 page English proceedings, supported by New Program “Gravitational Wave Astronomy”
- 8th: 1998. 10.19-22, Niigata Univ., 59 talks, 110 participants, 392 page English proceedings, supported by New Program “Gravitational Wave Astronomy”
- 9th: 1999. 10.27-30, Hiroshima Univ., 74 talks, 120 participants, 502 page English proceedings, supported by New Program “Gravitational Wave Astronomy”
- 10th: 2000. 9.11-14, Osaka Univ., 60 talks, 120 participants, 431page English proceedings, supported by New Program “Gravitational Wave Astronomy”

- From JGRG10 Talks should be in English .
- 11th: 2002. 1.9-12, Waseda Univ., 79 talks, 150 participants, 445 page English proceedings, supported by New Program “Gravitational Wave Astronomy”
- 12th: 2002. 11.25-28, Univ. Tokyo Komba, 67 talks, 150 participants, 469 page English proceedings, supported by “New Development of GW Research ”
- 13th: 2003. 12.1-4, Osaka City Univ., 55 talks, about 150 participants, 307 page English proceedings, supported by “New Development of GW Research ”
- 14th: 2004. 11.29-12.3, Kyoto Univ. YITP, 49 talks, about 150 participants, 465 page English proceedings, supported by “New Development of GW Research ”
- 15th: 2005. 11.28-12.2, Tokyo Inst. Tech., 47 talks, about 150 participants, 347 page English proceedings, supported by “New Development of GW Research ”
- 16th: 2006. 11.27-12.1, Niigata Univ. 57 talks, 150 participants, 282page English proceedings, supported by funds from MEXT.
- 17th: 2007. 12.3-7, Nagoya Univ. , 62 talks, 170 participants, 396 page English proceedings, supported by JSPS Scientific Research(B) and MEXT Creative Scientific Research
- 18th: 2008. 11.17-21, Hiroshima Univ. , 69 talks, about 150 participants, 318 page English proceedings, supported by JSPS Scientific Research(B) and MEXT Creative Scientific Research
- 19th: 2009. 11.20-12.4, Rikkyo Univ. , 70 talks, 185 participants, 427 page English proceedings, supported by Rikkyo Univ. and MEXT Creative Scientific Research

- Proceedings are avilable (http://www-tap.scphys.kyoto-u.ac.jp/jgrg/pastjgrg.html)

The Priority Area ended with great success.

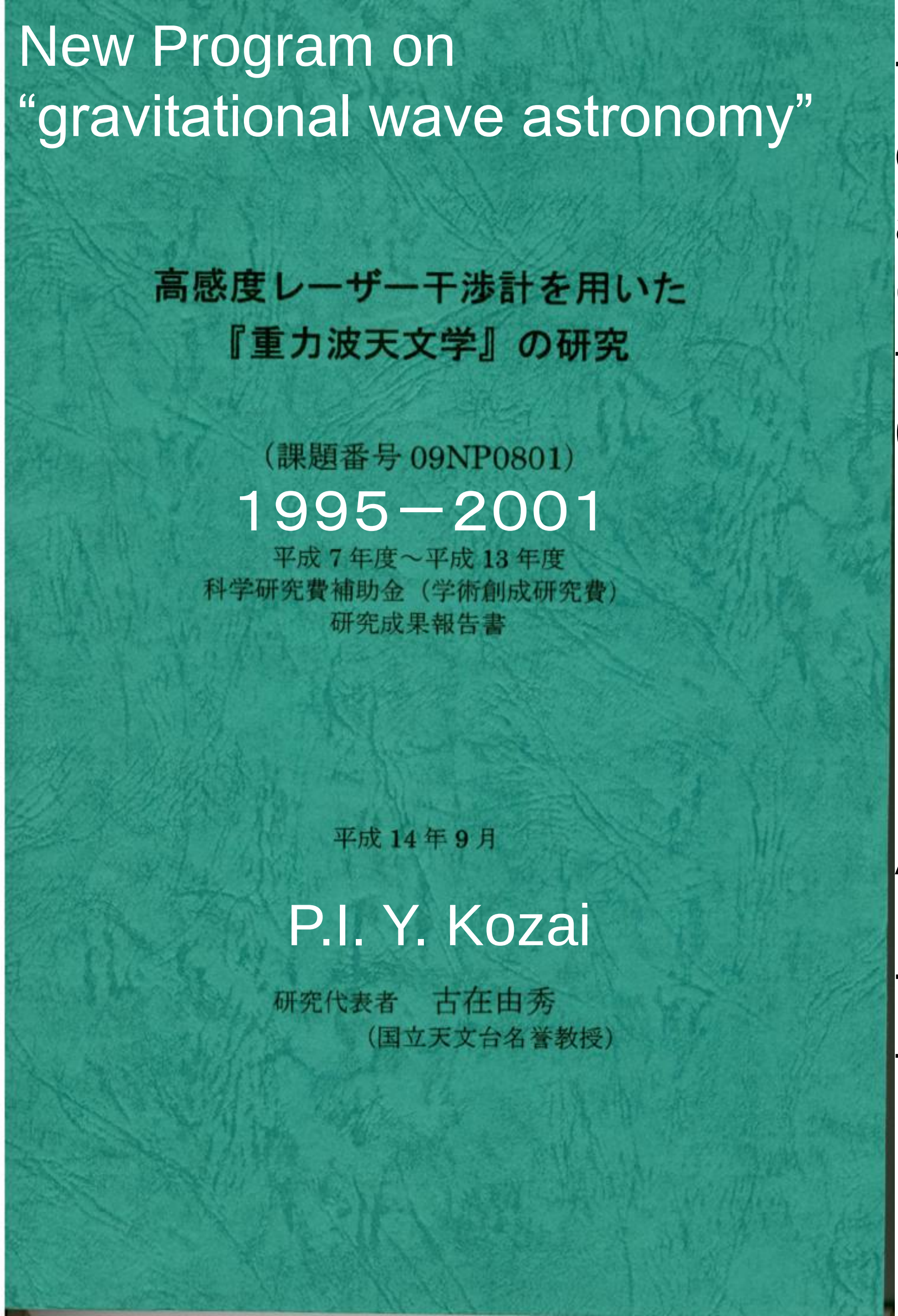
The judge of the priority area , Takuma (laser physicist) and I agreed as

“Any apparatus considered by scientists will be constructed sooner or later, unless it conflicts with major laws of physics such as energy conservation, uncertainty principle and the principle of increase of entropy .”

New program Followed

- New Program on “gravitational wave astronomy” (a Grant–in-Aid for Creative Basic Research from the Ministry of Education 09NP0801)
- Top-down program. One could not apply.
- 1995-2001
- Principal Investigator : Y. Kozai (Former Director of National Astronomical Observatory)
- The total cost: 1560M Yen (about 15.6M Euro now)
- The TAMA 300 was constructed by this program.
- Nakamura was a leader of theory group.

New Program on “gravitational wave astronomy”



高感度レーザー干渉計を用いた
『重力波天文学』の研究

（課題番号 09NP0801）

1995－2001

平成７年度～平成13年度
科学研究費補助金（学術創成研究費）
研究成果報告書

平成14年9月

P.I. Y. Kozai

研究代表者　古在由秀
（国立天文台名誉教授）

The cover title of New Program on “gravitational wave astronomy” (a Grant–in-Aid for Creative Basic Research from the Ministry of Education 09NP0801)

1995-2001

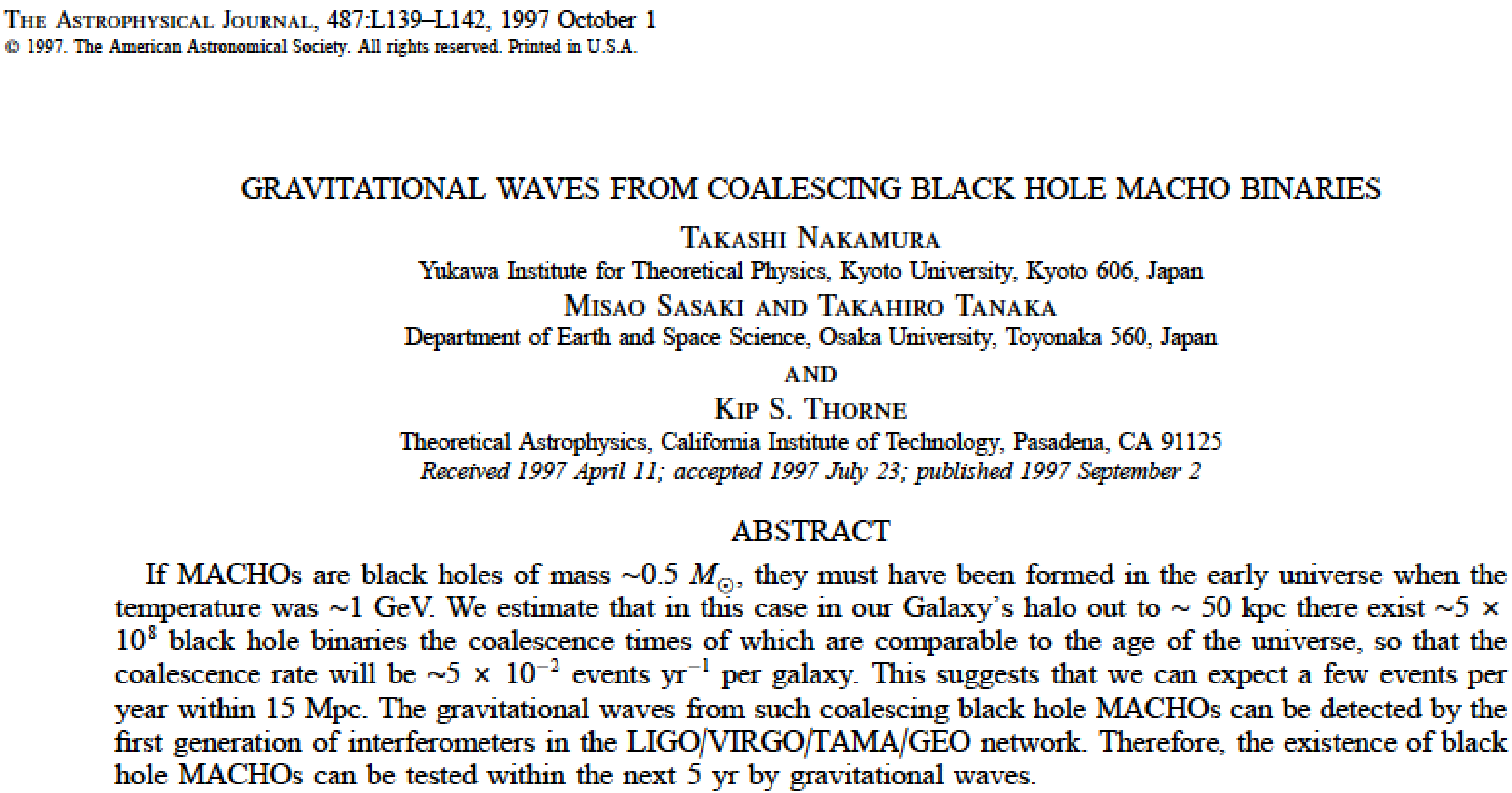
Principal Investigator. Y.Kozai (Former Director of National Astronomical Observatory)

TAMA300 was constructed in this program.

I was against TAMA300 Project

- I was against this project since 300m is not long enough to detect gravitational waves. I said “ Although this is a top down project, please reject the proposal. We had better ask and wait for the funding of 3km size interferometer.”
- Answer was:
- “ It is too risky to extend the arm length two orders of magnitude (from 20m to 3km). Even by TAMA 300, if we are lucky enough we may detect the gravitational wave first in the world. Then we can ask for 3km size antenna”
- “If we reject the project , how can we get the fund for experiments? ”
- My answer to this question is “…………….”

Then let us consider the source of gravitational waves that TAMA300 might detect.



THE ASTROPHYSICAL JOURNAL, 487:L139–L142, 1997 October 1

GRAVITATIONAL WAVES FROM COALESCING BLACK HOLE MACHO BINARIES

TAKASHI NAKAMURA
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606, Japan
MISAO SASAKI AND TAKAHIRO TANAKA
Department of Earth and Space Science, Osaka University, Toyonaka 560, Japan
AND
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Theoretical Astrophysics, California Institute of Technology, Pasadena, CA 91125

Received 1997 April 11; accepted 1997 July 23; published 1997 September 2

ABSTRACT

If MACHOs are black holes of mass $\sim 0.5\ M_\odot$, they must have been formed in the early universe when the temperature was ~1 GeV. We estimate that in this case in our Galaxy's halo out to ~ 50 kpc there exist $\sim 5 \times 10^8$ black hole binaries the coalescence times of which are comparable to the age of the universe, so that the coalescence rate will be $\sim 5 \times 10^{-2}$ events yr^{-1} per galaxy. This suggests that we can expect a few events per year within 15 Mpc. The gravitational waves from such coalescing black hole MACHOs can be detected by the first generation of interferometers in the LIGO/VIRGO/TAMA/GEO network. Therefore, the existence of black hole MACHOs can be tested within the next 5 yr by gravitational waves.

１）At this time,using gravitational microlensing , dark matter in our galaxy might consist of MACHO (MAssive Compact Halo Object) of mass about 0.5 solar mass.

２）If MACHO is a black hole , it should have been formed in the early universe when the temperature was T~1Gev

３）MACHO black holes were formed randomly in space so that binary black hole was formed due to the tidal force of the third near-by black hole.

4) Coalescence rate would be about once per 20 years by TAMA300.That is, the probability of detection is 5% per year or so, which is the same as the consumer tax at present in Japan. Neither large nor small.

VOLUME 86, NUMBER 18 PHYSICAL REVIEW LETTERS 30 APRIL 2001

Stable Operation of a 300-m Laser Interferometer with Sufficient Sensitivity to Detect Gravitational-Wave Events within Our Galaxy

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Nobuyuki Kanda,[3] Hideyuki Tagoshi,[4] Akito Araya,[5] Hideki Asada,[6] Youich Aso,[1] Mark A. Barton,[7]
Masa-Katsu Fujimoto,[2] Mitsuhiro Fukushima,[2] Toshifumi Futamase,[8] Kazuhiro Hayama,[9] Gen'ichi Horikoshi,[10,†]
Hideki Ishizuka,[7] Norihiko Kamikubota,[10] Keita Kawabe,[1] Nobuki Kawashima,[11] Yoshinori Kobayashi,[1]
Yasufumi Kojima,[12] Kazuhiro Kondo,[7] Yoshihide Kozai,[2] Kazuaki Kuroda,[7] Namio Matsuda,[13] Norikatsu Mio,[14]
Kazuyuki Miura,[3] Osamu Miyakawa,[7] Shoken M. Miyama,[2] Shinji Miyoki,[7] Shigenori Moriwaki,[14] Mitsuru Musha,[15]
Shigeo Nagano,[16] Ken-ichi Nakagawa,[15] Takashi Nakamura,[17] Ken-ichi Nakao,[18] Kenji Numata,[1] Yujiro Ogawa,[10]
Masatake Ohashi,[7] Naoko Ohishi,[2] Satoshi Okutomi,[7] Ken-ichi Oohara,[19] Shigemi Otsuka,[1] Yoshio Saito,[10]
Misao Sasaki,[4] Shuichi Sato,[7] Atsushi Sekiya,[1] Masaru Shibata,[4] Kentaro Somiya,[14] Toshikazu Suzuki,[10]
Akiteru Takamori,[1] Takahiro Tanaka,[17] Shinsuke Taniguchi,[1] Souichi Telada,[20] Kuniharu Tochikubo,[1]
Takayuki Tomaru,[7] Kimio Tsubono,[1] Nobuhiro Tsuda,[21] Takashi Uchiyama,[10] Akitoshi Ueda,[2] Ken-ichi Ueda,[15]
Koichi Waseda,[2] Yuko Watanabe,[3] Hiromi Yakura,[3] Kazuhiro Yamamoto,[1] and Toshitaka Yamazaki[2]
(TAMA Collaboration)

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[2] National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
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Precision Engineering Division, Tokai University, Hiratsuka, Kanagawa 259-1292, Japan

(Received 23 January 2001)

TAMA300, an interferometric gravitational-wave detector with 300-m baseline length, has been developed and operated with sufficient sensitivity to detect gravitational-wave events within our galaxy and sufficient stability for observations; the interferometer was operated for over 10 hours stably and continuously. With a strain-equivalent noise level of $h \sim 5 \times 10^{-21}/\sqrt{\mathrm{Hz}}$, a signal-to-noise ratio of 30 is expected for gravitational waves generated by a coalescence of $1.4M_\odot$-$1.4M_\odot$ binary neutron stars at 10 kpc distance. We evaluated the stability of the detector sensitivity with a 2-week data-taking run, collecting 160 hours of data to be analyzed in the search for gravitational waves.

DOI: 10.1103/PhysRevLett.86.3950 PACS numbers: 04.80.Nn, 95.55.Ym

2001 was 13 Years after we started from zero.

1038 hours operation with 87% duty cycle in 2001. We theoretical group also took part in 8-hours shift of operation.

In 2003 1157hours Operation

TAMA300 project was a great success in 2001

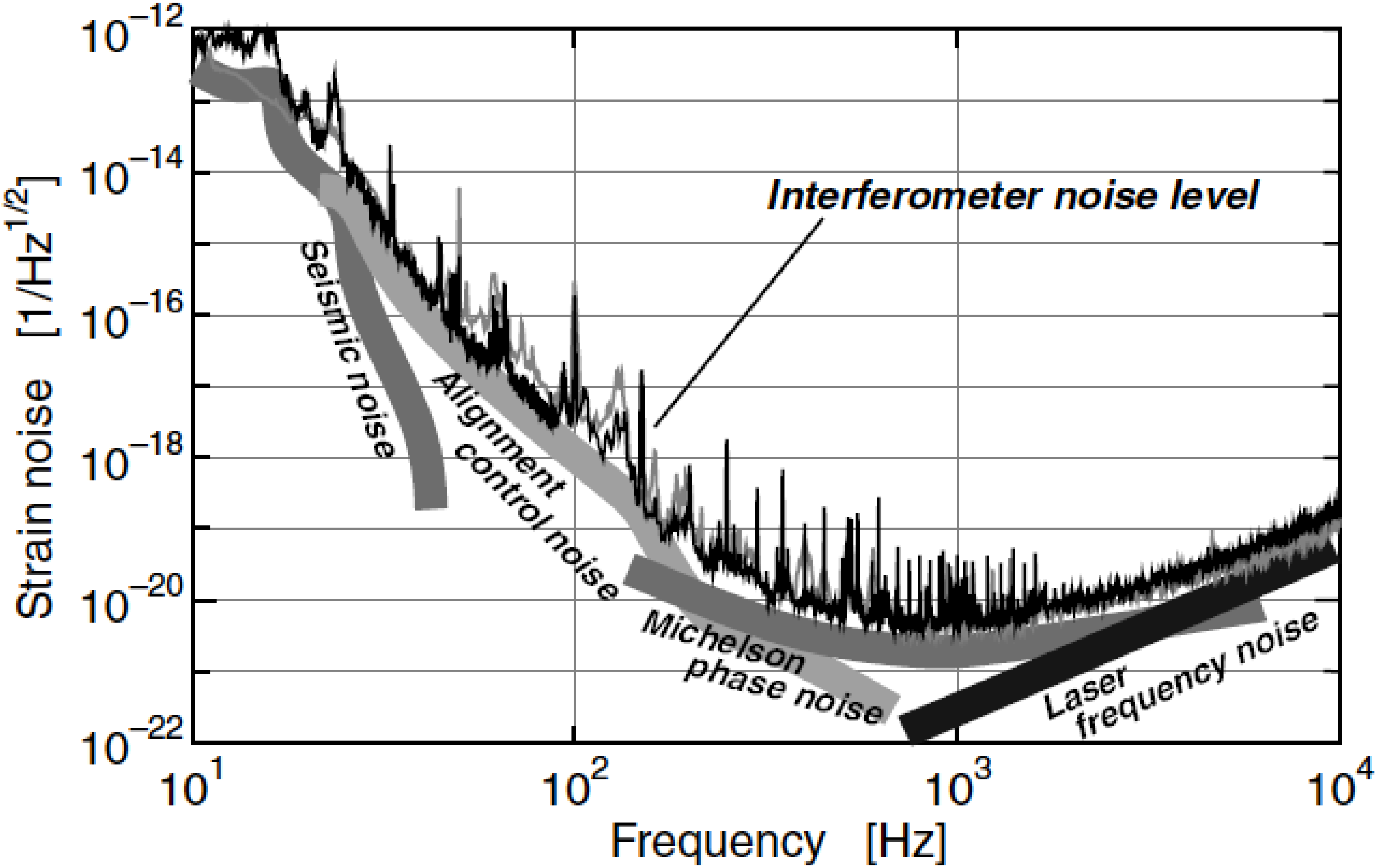


FIG. 2. Noise level of the TAMA300 interferometer (black curve) and the total contribution of identified noise sources (gray curve). The floor level is $5 \times 10^{-21}/\sqrt{\mathrm{Hz}}$ in strain. The thick curves represent the contribution of the noise sources.

The cover title of ” New development in the research of gravitational wave” (Grant-in- Aid for Scientific Research on Priority Area of Ministry of Education)

文部科学省科学研究費補助金・特定領域研究

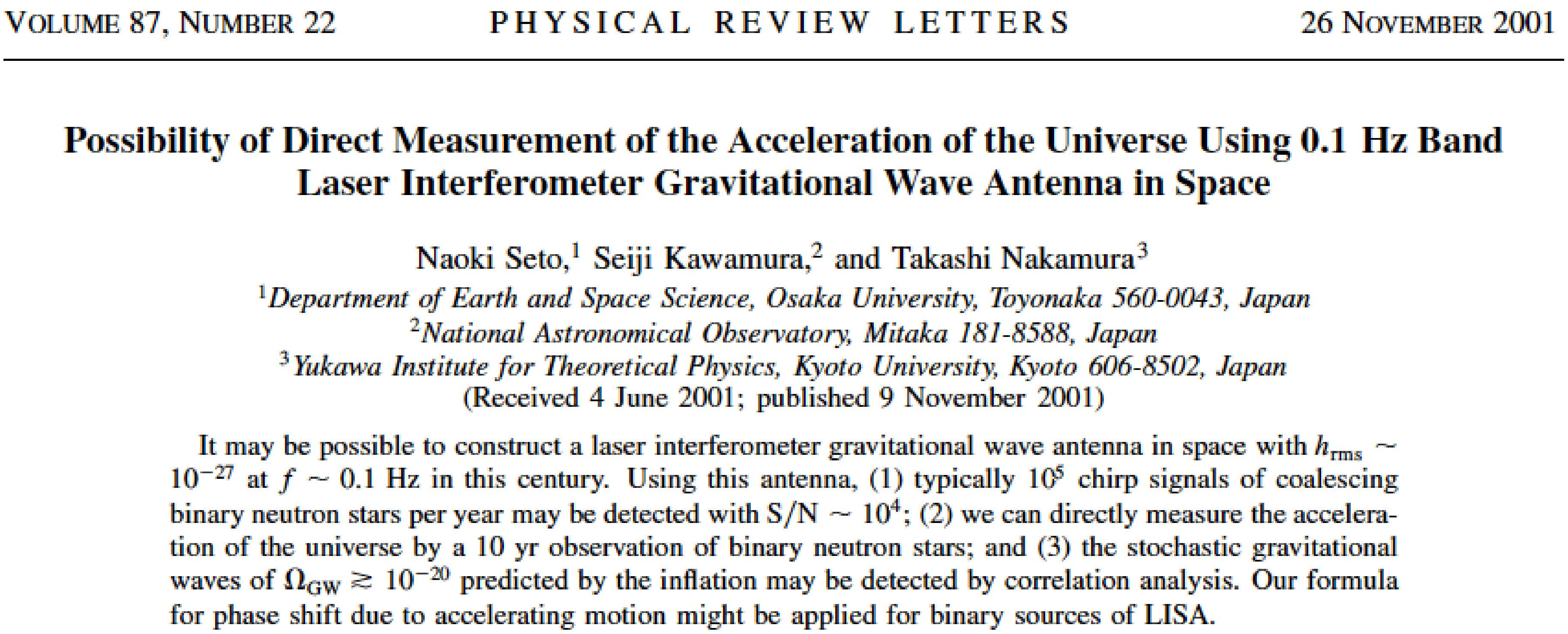
重力波研究の新しい展開

2002-2005

領域番号　415　　課題番号13048101
研究期間　　平成13年度－17年度
領域代表　　東京大学大学院理学系研究科　教授　坪野 公夫

P.I. K. Tsubono

- ” New development in the research of gravitational wave” (Grant-in- Aid for Scientific Research on Priority Area of Ministry of Education) was approved for 2002-2005.
- We can apply to this program.
- 2002-2005
- Principal Investigator: Kimio Tsubono (Univ. Tokyo)
- The total cost: 1430M Yen (about 14.3M Euro now)
- Purpose
- 1) Observation using TAMA300
- 2) Basic technical research on LCGT using CLIO
- 3) Theory and Data Analysis (Nakamura and Sasaki were leaders)
- Project DECIGO was born in this priority area.



VOLUME 87, NUMBER 22 PHYSICAL REVIEW LETTERS 26 NOVEMBER 2001

Possibility of Direct Measurement of the Acceleration of the Universe Using 0.1 Hz Band Laser Interferometer Gravitational Wave Antenna in Space

Naoki Seto,[1] Seiji Kawamura,[2] and Takashi Nakamura[3]
[1]*Department of Earth and Space Science, Osaka University, Toyonaka 560-0043, Japan*
[2]*National Astronomical Observatory, Mitaka 181-8588, Japan*
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(Received 4 June 2001; published 9 November 2001)

It may be possible to construct a laser interferometer gravitational wave antenna in space with $h_{\rm rms} \sim 10^{-27}$ at $f \sim 0.1$ Hz in this century. Using this antenna, (1) typically 10^5 chirp signals of coalescing binary neutron stars per year may be detected with $S/N \sim 10^4$; (2) we can directly measure the acceleration of the universe by a 10 yr observation of binary neutron stars; and (3) the stochastic gravitational waves of $\Omega_{\rm GW} \gtrsim 10^{-20}$ predicted by the inflation may be detected by correlation analysis. Our formula for phase shift due to accelerating motion might be applied for binary sources of LISA.

DECIGO=DECi hertz laser Interferometer
Gravitational wave Observatory

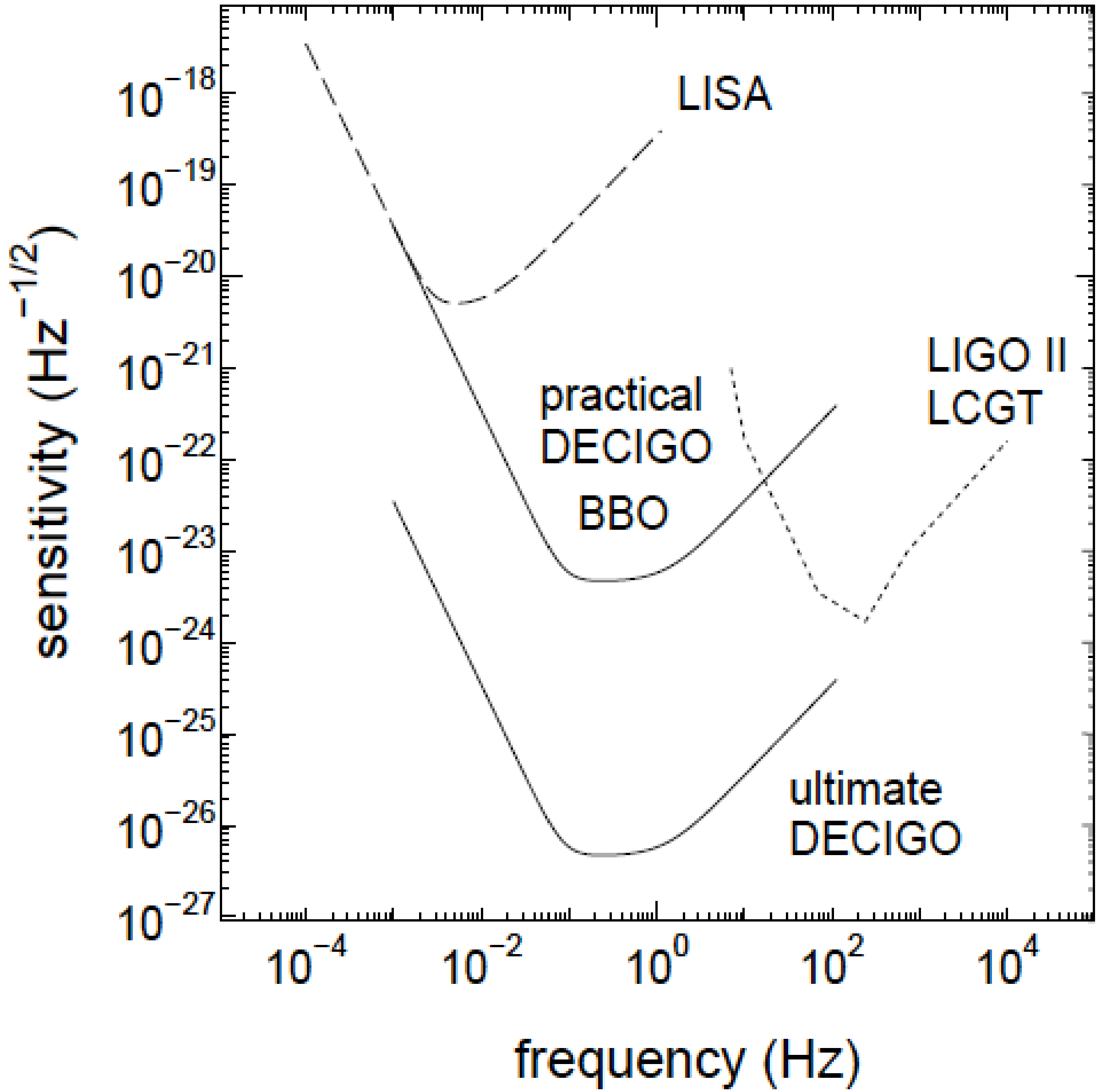


Fig. 1. Sensitivity of DECIGO/BBO.

Motivation to DECIGO comes from extra solar planets

- Many extra solar planets are found using many absorption lines (5000) of nearby G type stars

since small orbital motion up to 10m/s can be measured

- Loeb (1998) proposed to apply this techniques to many QSO absorption lines so that two observations between years or so yield direct measurement of Cosmic Acceleration and thus dark energy

Our point is

- Use gravitational waves from coalescing binary neutron stars at z=1 instead of QSO absorption lines
- Then a year to ten years before coalescence the frequency of GW should be 0.1 Hz band where little proposal for detectors existed

Punch Point of Ultimate DECIGO

a) 100,000 mass of neutron stars per and Black Hole per year will give us mass function of NS and BH

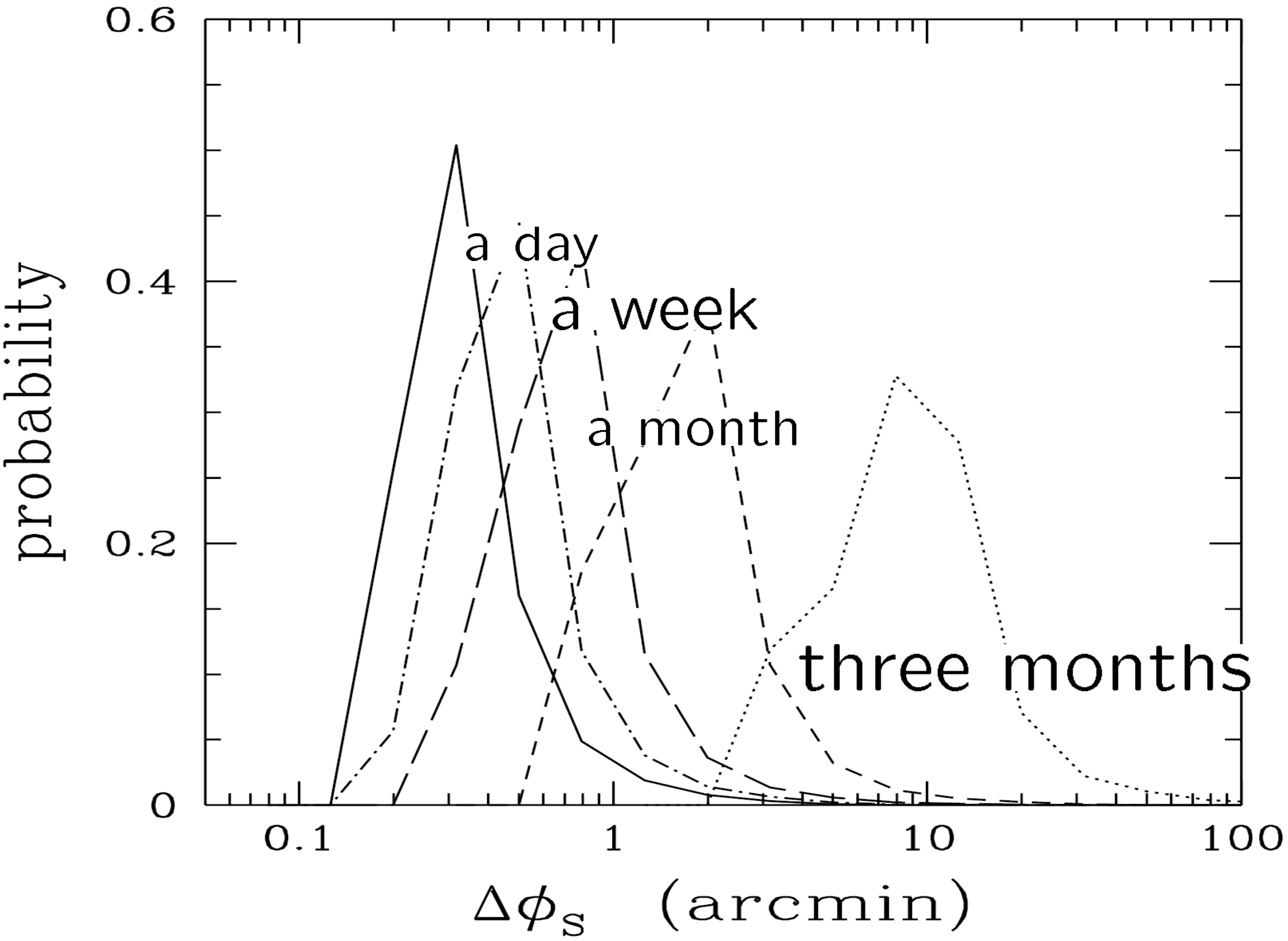
b) Direct measurement of Acceleration of the universe; Independent measurement of the curvature of the universe, independent information of EOS of the universe

c) Background gw predicted by inflation model

up to $\Omega_{GW} \sim 10^{-20}$

Completely independent information from WMAP and PLANCK

d) If the fundamental scale is Tev, then the redshifted GW at T=Tev is just 0.1Hz Band. We may see something.



The angular resolution $\Delta\phi_S$ for the neutron star binary $(1.4 + 1.4M_\odot)$ at $200h^{-1}$ Mpc $(h = 0.7)$. The observational period is
fore the final merging to three months (the dotted line), a month (the short dashed line) , a week (the long dashed line) and a
-dashed line) before the merging. The solid line shows for the case of full one year observation up to the cut-off frequency.

Practical DECIGO

$$\lambda \sim 0.01D$$

$$\delta\theta \sim 0.01 S/N^{-1} \sim 1\mathrm{arcmin}$$

is expected for S/N=100

- Consider 1.4 solar mass binary neutron star at 300Mpc

$$f_{init} = 0.23(\mathcal{M}_z/M_\odot)^{-5/8}(T_{obs}/1\mathrm{yr})^{-3/8}\mathrm{Hz}$$

Point All the Detectors to coalescing binary neutron star (black hole) event !!

- The direction as well as the time of the event are known beforehand
- All band electromagnetic detectors from radio to ultrahigh energy gamma rays
- Possible neutrino detectors
- Tune the high frequency gravitational wave detectors to catch ISCO, QNM and so on

The dark age of Japanese GW group

- In 2005, we applied to Grant-in- Aid for Scientific Research on Priority Area of Ministry of Education “Frontiers of all wave length gravitational waves astronomy” with 2100 M Yen(about 21M Euro now) for 2006 to 2011.
- P.I. T. Nakamura
- Sub Project A01) Pulsar Timing Array (Leader T. Daishido)
- Sub Project A02) DECIGO (Leader S. Kawamura)
- Sub Project A03) CLIO&LCGT (Leader M. Oohashi)
- Sub Project A04) High Frequency GW (K. Arai)
- Sub Project A05) Theory and Data Analysis (T. Tanaka
- and N.Kanda)

Frontiers of all wavelength Gravitational Wave Astronomy

All band electromagnetic astronmy

Gravitational Wave	⇔	Electro Magnetic wave	
GHz GW?	←	γ ray Astronomy	$\sim 10^{20}$Hz
MHz GW?	←	X ray Astronomy	$\sim 10^{17}$Hz
10kHz GW	←	UV Astronomy	$\sim 10^{15}$Hz
Ground Detectors ～100Hz	⇔	Optical Astronomy	$\sim 10^{14}$Hz
Deci Hertz GW	⇔	Infrared Astronomy	$\sim 10^{12}$Hz
LISA mHz Band	⇔	Radio Astronomy	$\sim 10^{9}$Hz
Pulsar Timing 10nHz Band	→	Low Frequency Array	10MHz

Priority Area
Frontier of all wavelength
Gravitational wave astronomy
（2006-2011）　Not approved

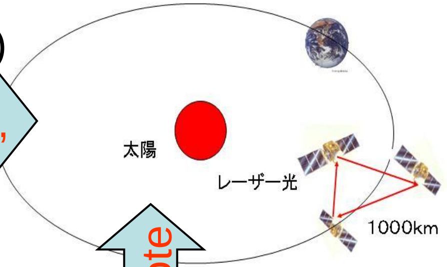
DECIGO Project

(DECi hertz Interferometer
Gravitational wave Observatory)

LCGT Project

(Large-scale Cryogenic
Gravitational wave Telescope)

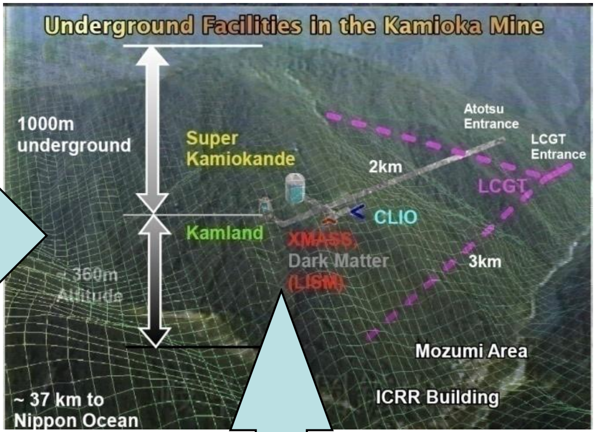
PTA （Pulsar Timing Array)



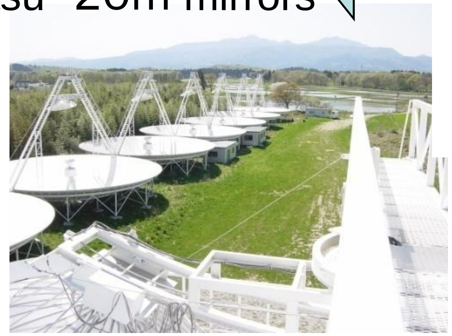
Launch
in 2020

Co Obs,

Co Obs.



Nasu　20m mirrors



30mX8～80mEquiv.
Pulsar search and
GW Observation

promote

Detailed Design of DECIGO
Simulation on ground
Test satellite
（laser, drag free, Frequency
Stability)

LCGT Project

up to 2008

Co. Obs.

TAMA300

CLI（mini
LCGT）

A01
Observation of 10nHz
GW using PTA

A02
Space Laser Interferometer
DECIGO

A03
Observation of 100－kHz GW
By ground based interferometer

Head quarter

A04
Basic research on
High frequency (>10kz)
GW

A05
Theory and Data analysis of
GW

International simultaneous
Observation

- In 2006, we were informed that the project was not approved. The comment of the judges was “ We understand the scientific purposes but it is too early to start all wave length gravitational wave astronomy simultaneously.” However in electromagnetic waves all wave length astronomy started almost simultaneously in Japan.
- We proposed similar priority areas in 2007,2008 and 2009 changing P.I. . However they were not approved.
- ICRR also requested the construction of LCGT to Ministry of Education in these years but LCGT was not approved in spite of recommendation by GWIC and Science Council of Japan.

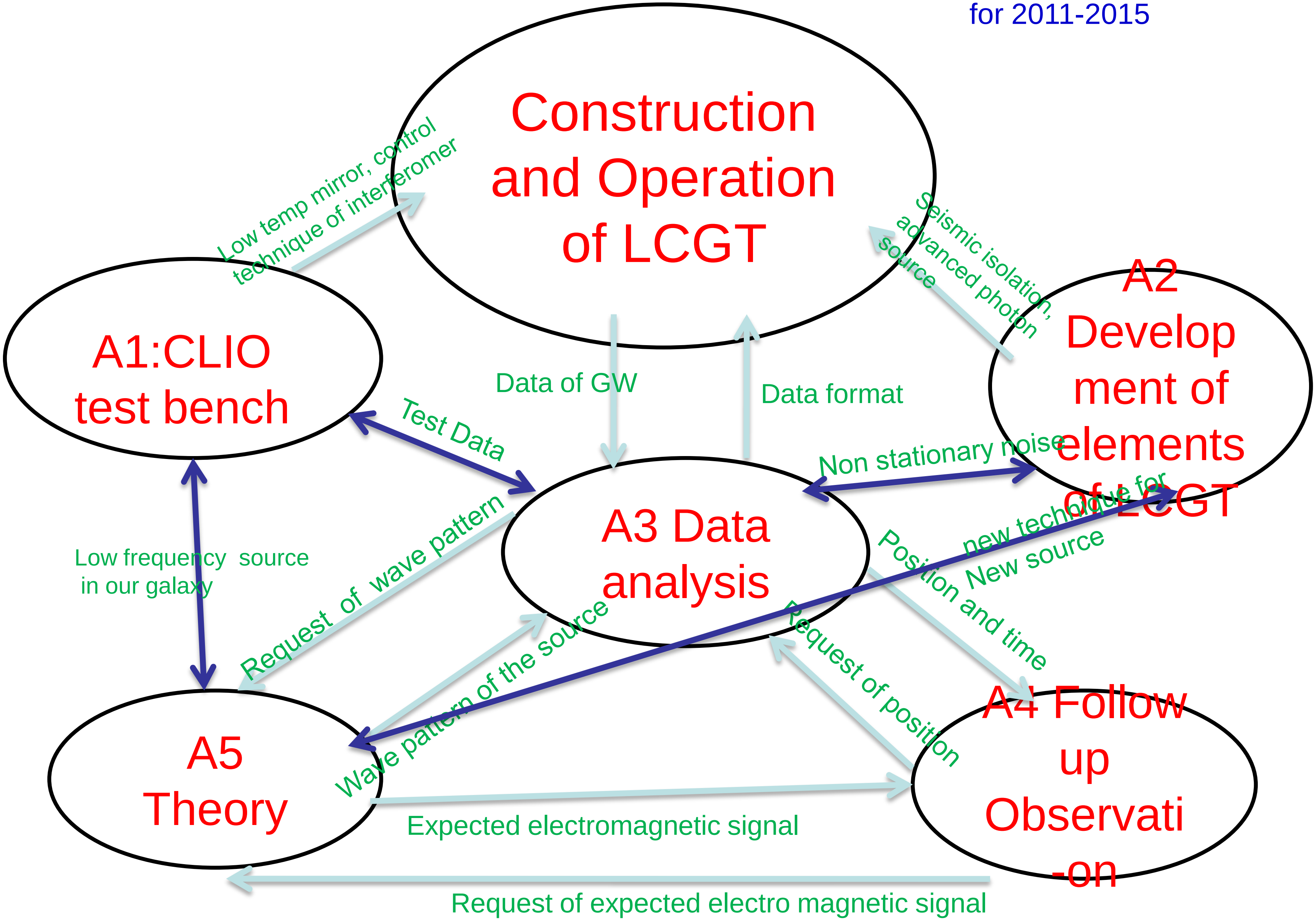
Dark age ended in July 2010

- Very recently a part of LCGT plan was approved (9800M Yen = about 98 M Euro) .

- We are now preparing application form to the Grant-in-Aid for Scientific Research on Priority Area of Ministry of Education "Frontier of physics and astronomy opened by the detection of gravitational waves. " for 2011-2015.

- This Priority Area will support the construction and operation of LCGT in every sense.

Priority Area “Frontier of physics and astronomy opened by the detection of gravitational waves.” for 2011-2015



Construction and Operation of LCGT

A1:CLIO test bench

A2 Development of elements of LCGT

A3 Data analysis

A4 Follow up Observati-on

A5 Theory

Low temp mirror, control technique of interferomer

Seismic isolation, advanced photon source

Data of GW

Data format

Test Data

Non stationary noise

new technique for New source

Low frequency source in our galaxy

Request of wave pattern

Wave pattern of the source

Position and time

Request of position

Expected electromagnetic signal

Request of expected electro magnetic signal

Conclusion

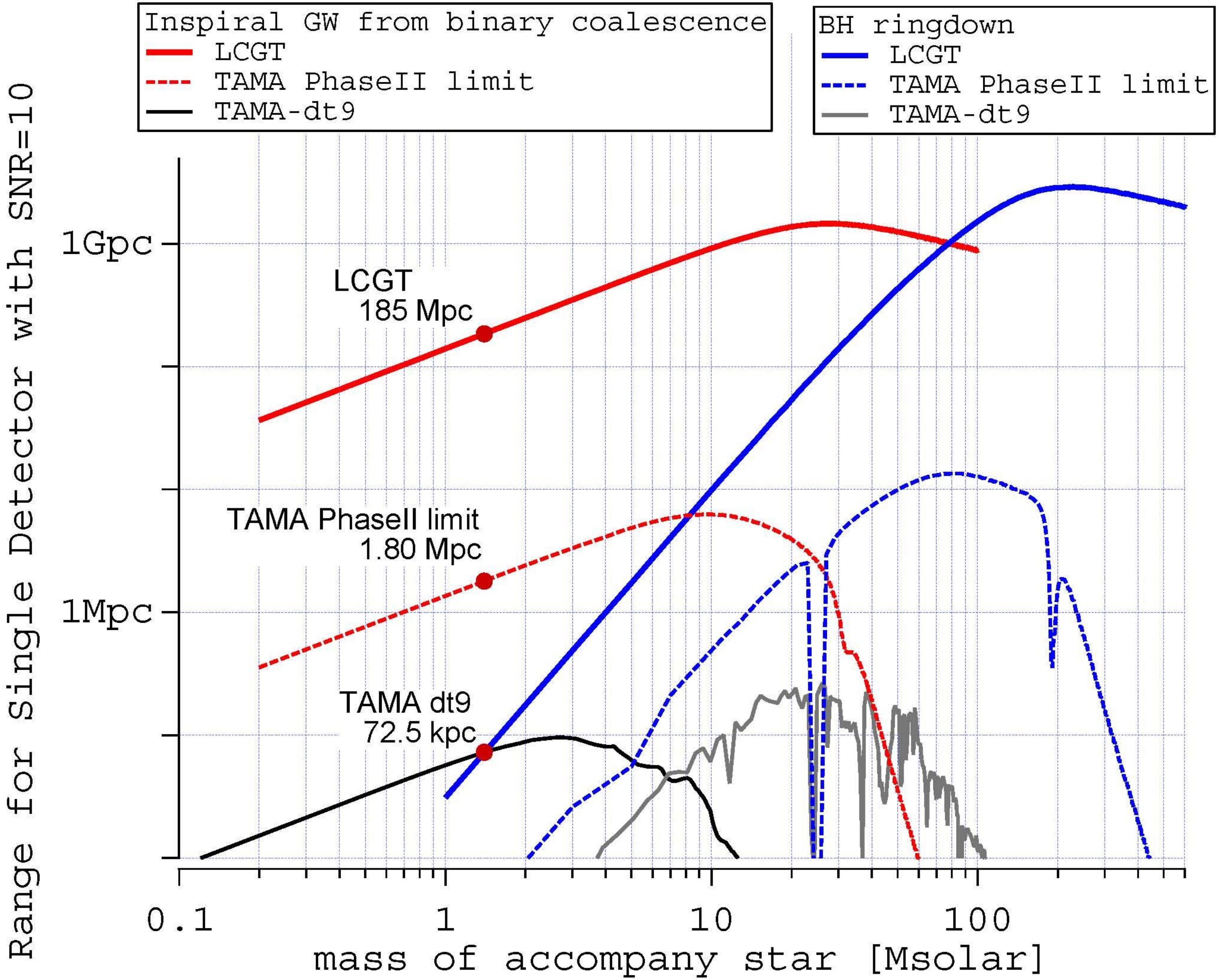
- JGRG was born 20 years ago in relation to start of the research on detection of gravitational waves in Japan.

- This year a part of LCGT was approved.
- JGRG will support LCGT in every sense.

- We will apply to grant–in-aid on priority area to support LCGT and JGRG. We hope that this will be approved.

- Next project after LCGT will be DECIGO in 2020's.

- In Japan, one has the right to vote after 20 years old.
- In this sense, JGRG becomes an adult this year.


Inspiral GW from binary coalescence
LCGT
TAMA PhaseII limit
TAMA-dt9
BH ringdown
LCGT
TAMA PhaseII limit
TAMA-dt9
LCGT
185 Mpc
TAMA PhaseII limit
1.80 Mpc
TAMA dt9
72.5 kpc
1Gpc
1Mpc
Range for Single Detector with SNR=10
0.1
1
10
100
mass of accompany star [Msolar]

- 1988 November move to KEK as associate professor
- 1990 July move to YITP as professor