C G P

Center for Gravitational Physics
Yukawa Institute for Theoretical Physics

YiTP

YUKAWA INSTITUTE FOR
THEORETICAL PHYSICS

インフレーションと重力波を巡って

some recollections and thoughts on inflation and gravitational waves

ジーミューニュー, ジーミューニュー, ジーミューニュー, …

gee mu nu, gee mu nu, gee mu nu,…

$$\left(g_{\mu\nu}, g_{\mu\nu}, g_{\mu\nu}, ... \right)$$
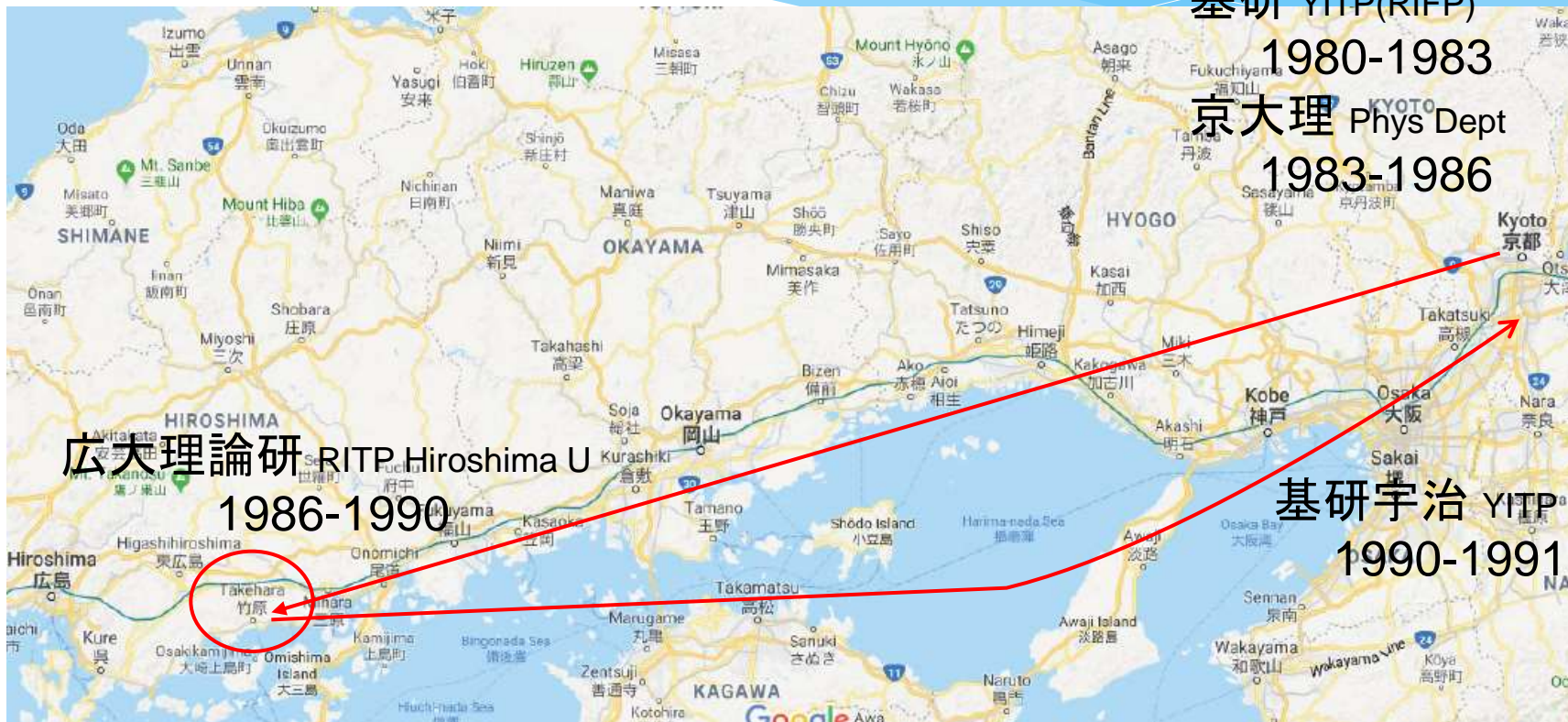
2018年3月19日

研究場所遍歴

moving around

京大理 Phys Dept
1976-1980
基研 YITP(RIFP)
1980-1983
京大理 Phys Dept
1983-1986

広大理論研 RITP Hiroshima U
1986-1990

基研宇治 YITP Uji
1990-1991

研究場所遍歴 2

moving around

京大理 Phys Dept
1991-1995

基研 YITP
2003-2018

基研宇治 YITP Uji
1990-1991

阪大理 Osaka U
1995-2003

重力波との出会い

1st encounter with GWs

1976.04 京大大学院入学（天体核）

joined theoretical astro group as grad student

- 周りは凄い人たちばかり。何をやっていいのか分からない。。。

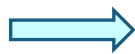 so many impressively talented members … couldn't imagine what I could do …

  スタッフ：林忠四郎・佐藤文隆（基研）・中野武宣・中沢清・池内了
  OD：佐藤勝彦(翌年助手着任)・…院生：高原文郎・中村卓史・前田恵一・小玉英雄・…

  C Hayashi, H Sato, K Sato, T Nakamura, …

- M2になった頃(?)中村さんに誘われる・・・何か新しくてできることをしよう！

  Nakamura-san proposed: let's work on something interesting and feasible!

  ⟹ 数値相対論
  numerical relativity

  4人組（中村・前田・観山・佐々木）
  Nakamura, Maeda, Miyama, Sasaki: "gang of four"

- しかし，まずは勉強・・・修論が書けない！　　　佐藤文隆さんに泣きつく

  But studying previous work took time…. couldn't find a theme for master thesis!　　Asked H Sato-san for help!

  ⬇

  重力波の計算でもやってみなさい

  How about doing some GW computations?

記念すべき論文第一号！

my memorable 1st paper !

## Conversion of Gravitational Waves into Electromagnetic Waves by a Moving Charge

Misao SASAKI and Humitaka SATO*

Department of Physics, Kyoto University, Kyoto 606
*Research Institute for Fundamental Physics, Kyoto University, Kyoto 606

Head-on collision of a charged particle with plane gravitational waves is considered. We calculate a cross section of conversion scattering from gravitational waves into electromagnetic waves by a particle with charge Ze. In the high-speed limit, this cross section is given as $\sigma \simeq (4/3)(4\pi) \cdot (e^2 G/c^4) Z^2 \gamma^4$, γ being the Lorentz factor.

重力波

電磁波 電子

electron

EMWs

GWs
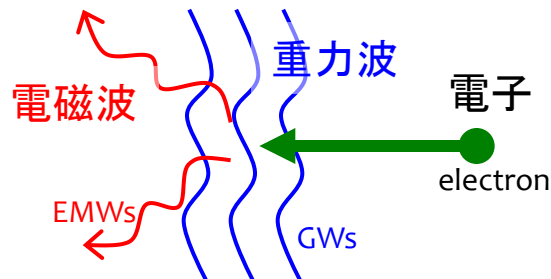
しかし，当然のことながら全く無名…
but (of course!) completely unknown...

ちなみにD論も重力波

my doctor thesis happened to be on GWs as well

The Radiation Reaction Effects in the Solutions of the Perturbed Einstein Equations

Misao SASAKI

Department of Physics, Kyoto University, Kyoto 606

The gravitational radiation reaction effects in the systems described by the perturbations of given solutions of the Einstein equations are considered. There are two kinds of perturbations to be considered; one is the perturbation induced by no external sour... other is the perturbation due to the presence of a source particle. For the former ca... that there exists a conserved current constructed from a quadratic combination of th... to the linearly perturbed equations, provided that the unperturbed geometry admit... vector. Thus, some effects of radiation reaction are found to be included in ... approximation. For the latter case, it is shown that the usual perturbation expansi... fails but there is a possible approach analogous to the one in the Lorentz-Dirac theory... particles in order to include the reactive effects. By this approach we find tha... argument on the energy conservation leads an additional reactive term which contributes to the energy equation. However this term is found to be negligible if the particle is under a quasi-periodic motion.

反作用を取り入れた方程式の導出！
field eqs with backreaction!

$$G^{\mu\nu}(\bar{g}) = 8\pi \left[T^{\mu\nu}(\bar{\phi}; \bar{g}) + \varepsilon^2 \overset{\text{eff}}{T}{}^{\mu\nu}(\overset{1}{h}, \overset{1}{\phi}; \bar{g}) \right]$$

$$F^A(\bar{\phi}; \bar{g}) = \varepsilon^2 \overset{\text{eff}}{J}{}^A(\overset{1}{h}, \overset{1}{\phi}; \bar{g})$$

しかし，この論文も全く知られていない…
which also is completely unknown…

助言：博士課程で大した業績がなくても落胆するな！
a word of advice: don't be discouraged by not being able to do much during your PhD years!
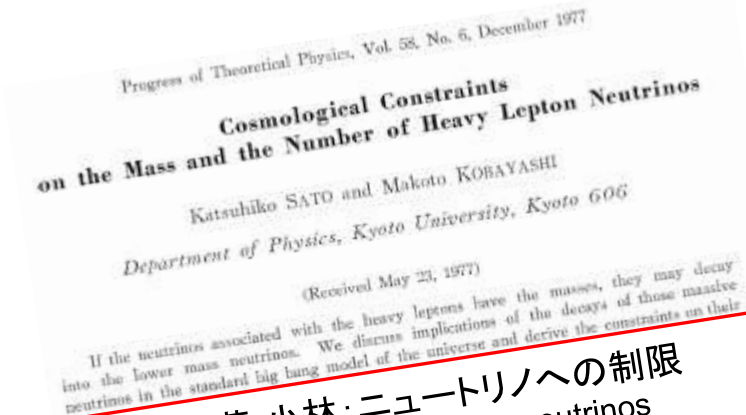
インフレーションとの出会い

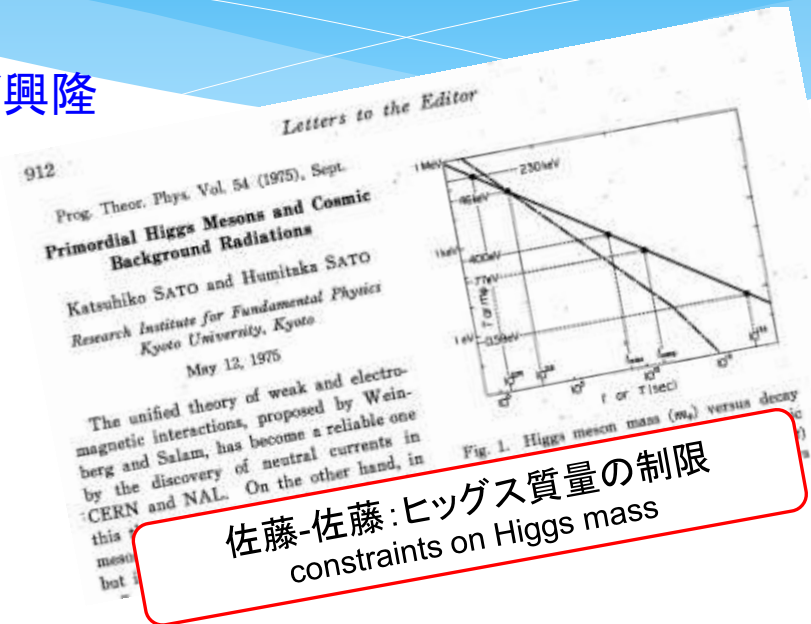encountering inflation

1978.04 博士後期課程進学

entered doctor course

- この頃，（今で言う）素粒子宇宙物理学が興隆

areas of particle astrophysics/cosmology were growing rapidly

Progress of Theoretical Physics, Vol. 58, No. 6, December 1977

Cosmological Constraints on the Mass and the Number of Heavy Lepton Neutrinos

Katsuhiko SATO and Makoto KOBAYASHI

Department of Physics, Kyoto University, Kyoto 606

(Received May 23, 1977)

If the neutrinos associated with the heavy leptons have the masses, they may decay into the lower mass neutrinos. We discuss implications of the decays of those massive neutrinos in the standard big bang model of the universe and derive the constraints on their

佐藤-小林：ニュートリノへの制限
constraints on heavy neutrinos

Letters to the Editor

912

Prog. Theor. Phys. Vol. 54 (1975), Sept.

Primordial Higgs Mesons and Cosmic Background Radiations

Katsuhiko SATO and Humitaka SATO

Research Institute for Fundamental Physics
Kyoto University, Kyoto

May 12, 1975

The unified theory of weak and electromagnetic interactions, proposed by Weinberg and Salam, has become a reliable one by the discovery of neutral currents in CERN and NAL. On the other hand, in this

Fig. 1. Higgs meson mass (m_ϕ) versus decay

佐藤-佐藤：ヒッグス質量の制限
constraints on Higgs mass

- 対称性の破れの宇宙論！

cosmological consequences of symmetry breaking!

Unified Gauge Theories and the Baryon Number of the Universe

PRL41(1978)

Motohiko Yoshimura

Department of Physics, Tohoku University, Sendai 980, Japan

(Received 27 April 1978)

I suggest that the dominance of matter over antimatter in the present universe is a consequence of baryon-number-nonconserving reactions in the very early fireball. Unified guage theories of weak, electromagnetic, and strong interactions provide a basis for such

吉村：物質－反物質の非対称性の起源
origin of matter-antimatter asymmetry

出会いの前の接近遭遇

close encounter with inflation

- ## M2から佐藤勝さんの宇宙論ゼミに参加
  joined Sato Katsu-san's seminar

佐藤： 面白い論文がある。読んでみないか？
佐々木：はい！（今も昔も返事だけはよい）

Sato: There appeared an interesting paper. Why not taking a look?
Sasaki: Yes, sir!

the quantum field theory (i.e., as long as one does not take into account its influence on the space–time curvature connected with a nonzero energy-momentum tensor of the condensate or of vacuum, see below).

時空曲率の影響を無視する限り

もしもこの時，この一文の重要性に気が付いていたら，インフレーション宇宙の「父」の一人になれたかもしれない。。。

If I were smart enough to note the importance of this sentence, I could have been one of the founding fathers of inflation…

ANNALS OF PHYSICS 101, 195-238 (1976)

Symmetry Behavior in Gauge Theories

D. A. KIRZHNITS AND A. D. LINDE

P. N. Lebedev Physical Institute, Academy of Sciences, USSR

Received March 19, 1976

p.224

...y of phase transition with symmetry restoration in gauge theories at high tem...ature is investigated. The phase transition may be of the first or of the second order depending on relations between coupling constants. It is noted that the possible existense of a limiting temperature cannot prevent the high-temperature symmetry res-toration. In the theories without neutral currents, symmetry also can be affected b... magnetic field. However in most of the models with neutral curren... toration takes place not due to a magnetic field but d... simultaneously by the magnetic field ... with neutral currents ... while an i...

...corrections ...factors. Strong constraints on masses and ...ymmetry in the Higgs model to be broken are obtained. It is ...rgy of substance is nonconserved due to energy "pumping" from the non-...servable Bose-condensate in the processes under consideration.

キリツニッツ-リンデ：対称性の破れの宇宙論的考察
discussing symmetry breaking in cosmology

失敗から学ぶこと
something you can learn from this

（良質の）論文を読む際には，結論に至る上での仮定や条件に常に注意！

When reading a paper (of high quality), don't overlook the assumptions and conditions!

そして，ついに。。。

and then, at last…

- '79（D2）の秋から'80夏までローマへ（結婚したばかりの中村さんの代わり）

  spent 10 months from autumn of '79 at Rome
  (in place of Nakamura-san who declined to go because he was just married)

- ちょうど同時期に佐藤勝さんは，ノルディタ（デンマーク）に長期滞在

  Sato-san was visiting Nordita (Denmark) for a year at the same time.

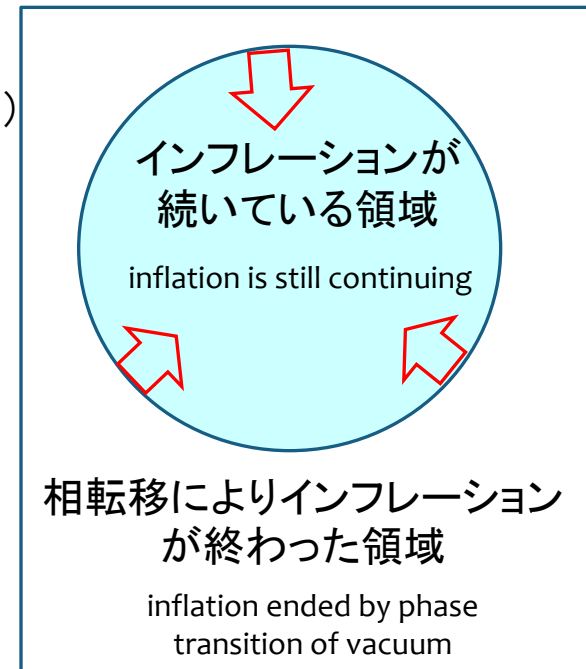佐藤さんがローマに来て「インフレーション宇宙」に関するセミナー
（もちろん，当時は単に「指数関数的膨張をする宇宙」と呼んでいた）

  Sato-san came to Rome and gave a seminar on "inflationary universe"
  (of course, he simply called it an "exponentially expanding universe" at that time)

その前後に佐藤さんから「インフレーションが続いている球状
領域が残された時空はどうなるか？」という質問をされる。

  Around that time, Sato-san asked me "what kind of spacetime structure would
  appear if a spherical region is left behind in which inflation is continuing?"

> ## 表面積は減るのに体積は指数関数的に増える！

Surface area decreases while the volume is exponentially increasing!

インフレーションが
続いている領域

inflation is still continuing

相転移によりインフレーション
が終わった領域

inflation ended by phase
transition of vacuum

宇宙の多重発生

multi-production of universes

Prog. Theor. Phys. Vol. 65, No. 4, April 1981, Progress Letters

Creation of Wormholes by First Order Phase Transition of a Vacuum in the Early Universe

Katsuhiko SATO, Misao SASAKI, Hideo KODAMA and Kei-ichi MAEDA

Department of Physics, Kyoto University, Kyoto 606

MULTI-PRODUCTION OF UNIVERSES BY FIRST-ORDER PHASE TRANSITION OF A VACUUM

Katsuhiko SATO, Hideo KODAMA, Misao SASAKI [a] and Kei-ichi MAEDA

Department of Physics, Kyoto University, Kyoto 606, Japan
[a] Research Institute for Fundamental Physics, Kyoto University, Kyoto 606, Japan

ward as a result of the phase transition.

我が家では'82年3月に双子が生まれる！
became a father of twin girls in March '82 !
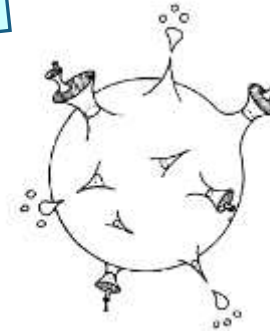
One easily arrives at an idea that wormholes are further created by the phase transition in the child universes and they also evaporate to produce grandchild universes. This sequential production of universes may continue on and on (see fig. 2). Now a very peculiar consequence of a cosmological first-order phase transition is at hand; although the Creator might have made a unitary universe, the universe itself is also capable of bearing child universes, which are again capable of bearing universes, and so on. Our universe is too old to bear more child universes at present, though it might have born them during the period of the phase transition or/and it might have been born as one of the child universes in this sequence.

Fig. 3. A conformal diagram for de Sitter-like universe with the Schwarzschild wormhole. Null lines are at ±45°. A space-like hypersurface represented by the dashed line is shown schematically in Fig. 4.

インフレーションの永続性
eternal nature of inflation

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閑話休題

back on track

再び重力波

GWs again

- '81春，晴れてOD。基研所属。中村さんと同室（現在のY308）。

  became postdoc at YITP in spring '81. happened to be in the same room (current Y308) with Nakamura-san.

  4人組時代からの課題　an unsolved issue from the time of "gang of four".

  1. ブラックホール（BH）形成時の放出重力波を定量的に評価したい。

     need to make quantitative estimate of GW emission at BH formation.

  2. そのために，まずBHに粒子が落ち込む際の重力波を計算したい。

     for this purpose, evaluate GWs emitted from a particle falling into a BH.

  3. しかし，知られているチューコルスキー方程式は無限遠とホライズンが特異点。

     but Teukolsky eq. is singular both at infinity and horizon.

  ⇨ **無限遠で振舞いの良い波動方程式を導出すべし！**
  must derive GW equation regular at infinity and horizon

  初めての"本格的"な共同研究プロジェクト
  （答えがあるかどうか分からない）

  my first experience of "full-scale" collaboration
  (didn't know if a solution really exists)

  数か月間，朝から晩まで計算，計算，計算…

  calculating from morning till night for several months…

  ついに発見！
  found at last!

$$d^2X/dr^{*2} - \mathcal{F}\,dX/dr^* - \mathcal{U}\,X = \mathfrak{d},$$

Sasaki-Nakamura equation

信念と忍耐！
confidence and perseverance!

26 April 1982

PHYSICS LETTERS

Volume 89A, number 2

A CLASS OF NEW PERTURBATION EQUATIONS FOR THE KERR GEOMETRY

Misao SASAKI and Takashi NAKAMURA
Research Institute for Fundamental Physics, Kyoto University, Kyoto 606, Japan

宇宙論的摂動論

cosmological perturbation theory

- その頃，前田さんが天体核コロキウムでバーディーンの論文を紹介

  around that time Maeda-san introduced Bardeen's paper at Astro group seminar.

  例によってその重要性はすぐには分からず
   as usual, didn't understand its importance at all at that moment

  インフレーション宇宙の揺らぎを考え始めて，
  やっと重要性に気付く
  thinking about perturbations from inflation, finally realized
  its importance

  あちらこちらで言いふらす
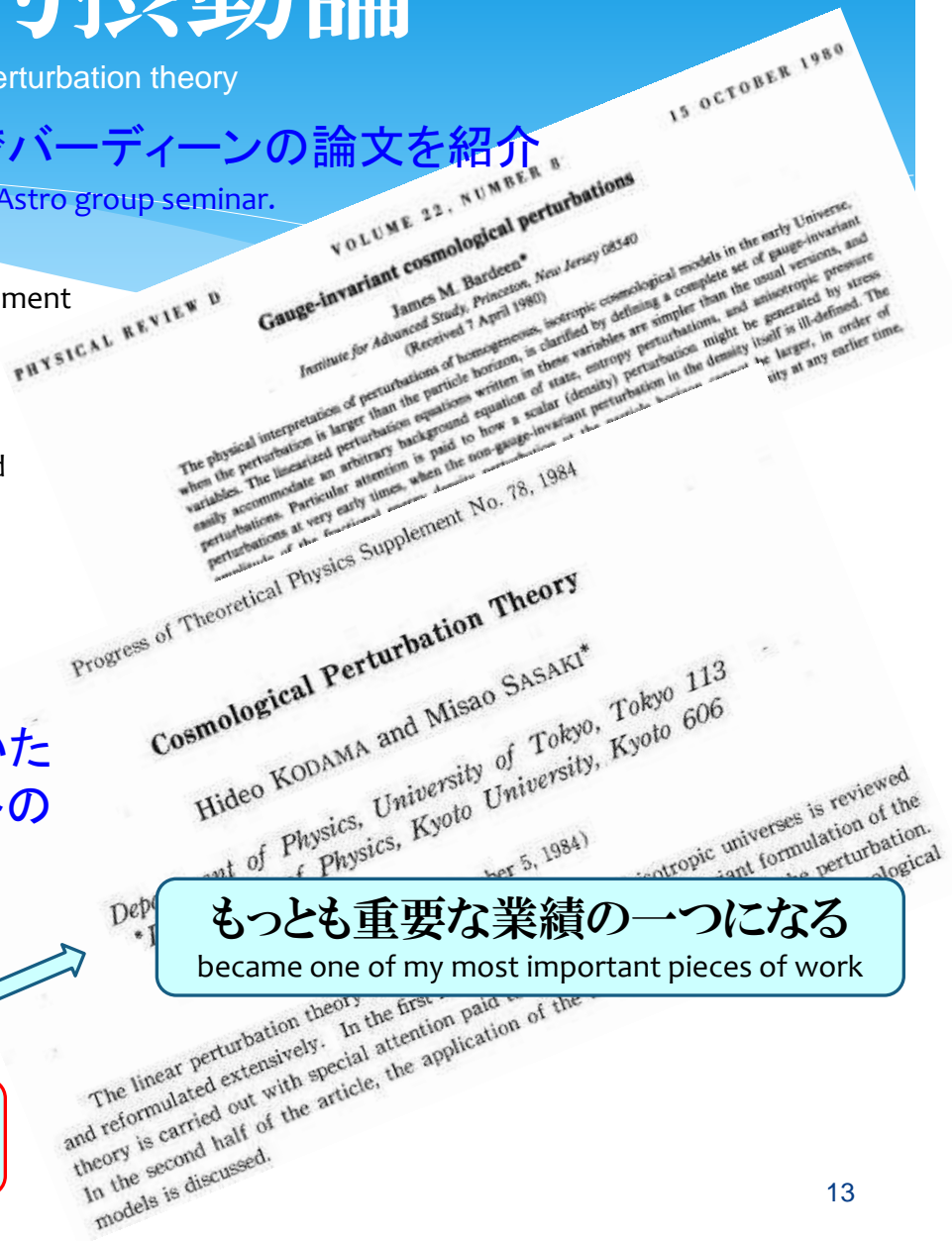 began advocating it here and there.

- 佐藤文隆さんが，同様の考えを持っていた
  小玉さんと僕に「プログレス・サプリメントの
  レビュー論文を書かないか」と提案
    Sato Humitaka-san proposed Kodama-san, who had
    similar ideas, and me to write a review on cosmological
    perturbations for Progress of Theoretical Physics,
    Supplement

  もっとも重要な業績の一つになる
  became one of my most important pieces of work

  教訓：もらったチャンスは逃すな！
  lesson: don't waste a chance when it's given to you!

15 OCTOBER 1980

VOLUME 22, NUMBER 8

PHYSICAL REVIEW D

Gauge-invariant cosmological perturbations

James M. Bardeen*

Institute for Advanced Study, Princeton, New Jersey 08540

(Received 7 April 1980)

Progress of Theoretical Physics Supplement No. 78, 1984

Cosmological Perturbation Theory

Hideo KODAMA and Misao SASAKI*

Department of Physics, University of Tokyo, Tokyo 113
*Department of Physics, Kyoto University, Kyoto 606

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インフレーションと宇宙論的摂動

inflation and cosmological perturbations

1983.08 運よく天体核助手に採用される

appointed as an assistant professor of theoretical astro group at Kyoto

- **サプリメントを書きながら，インフレーションと宇宙論的摂動にのめり込む**
  while writing the PTP Supplement paper, indulged in inflation and cosmological perturbations.

tions. The result for the isocurvature case is that the Sachs-Wolfe effect is enhanced six times as much as that of the adiabatic case. Apparently this is due to large Δ_T on super-horizon scales as discussed shortly before and may lead to difficulties against a galaxy-formation scenario based on isocurvature perturbations.

大スケールでの等曲率揺らぎの増幅効果の発見

discovery of isocurve. pert. enhancement on large scales

EVOLUTION OF ISOCURVATURE PERTURBATIONS 1: PHOTON-BARYON UNIVERSE

HIDEO KODAMA

Department of Physics, Faculty of Science, University of Tokyo, Tokyo 113, Japan

MISAO SASAKI

Department of Physics, Faculty of Science, Kyoto University, Kyoto 606, Japan

Entropy Production in the Inflationary Universe

Masahiro MORIKAWA and Misao SASAKI

Department of Physics, Kyoto University, Kyoto 606

Entropy production mechanism during the vacuum energy dominated stage of the inflationary universe is considered. We propose a thermalization mechanism of vacuum energy due to Higgs particles produced by the temporal change of the background classical Higgs field which subsequently decay into other particles. Then the dissipation coefficient associated with the classical Higgs field is evaluated for an specific decay process and implications of the result are discussed.

$$(\Box + m_R{}^2)\phi_c + \frac{\lambda}{3!}\phi_c{}^3 + F(\phi_c)\dot{\phi_c} = 0 ,$$

where the dissipation coefficient $F(\phi_c)$ is given by

$$F(\phi_c) = \frac{\lambda^2 \phi_c{}^2}{16\pi^3} \int_0^\infty dk \frac{k^2 \tau_k(t)}{\omega_k{}^3(t)} (2x_k(t)+1).$$

"量子的"散逸項の導出

derivation of "quantum" dissipation coefficient

14

休憩: ホーキングの思い出

intermission: in memory of Stephen Hawking.

この頃（1985年5月），稲見武夫・佐藤文隆共同主宰で「量子重力と宇宙論」
京都サマー・インスティテュートがあり，ホーキングが参加

In May 1985, Inami-san and Sato-san co-organized a workshop:
Kyoto Summer Institute on "Quantum Gravity and Cosmology"

ホーキングは彼の「無境界境界条件」に基づいた量子宇宙論を講義

Hawking came and gave a lecture on quantum cosmology
based on his "no-boundary boundary condition".

その時の写真

佐藤文隆
Humitaka Sato

この論文の内容
about this paper

大栗博司
Hirosi Ooguri

稲見武夫
Takeo Inami

大原謙一
Ken-ichi Oohara

PHYSICAL REVIEW D
PARTICLES AND FIELDS

THIRD SERIES, VOLUME 31, NUMBER 8   15 APRIL 1985

Origin of structure in the Universe

J. J. Halliwell and S. W. Hawking

*Department of Applied Mathematics and Theoretical Physics, Silver Street, Cambridge CB3 9EW, United Kingdom
and Max Planck Institut for Physics and Astrophysics, Foehringer Ring 6, Munich, Federal Republic of Germany*
(Received 17 December 1984)

It is assumed that the Universe is in the quantum state defined by a path integral over compact four-metrics. This can be regarded as a boundary condition for the wave function of the Universe on superspace, the space of all three-metrics and matter field configurations on a three-surface. We extend previous work on finite-dimensional approximations to superspace to the full infinite-dimensional space. We treat the two homogeneous and isotropic degrees of freedom exactly and the others to second order. We justify this approximation by showing that the inhomogeneous or anisotropic modes start off in their ground state. We derive time-dependent Schrödinger equations for each mode. The modes remain in their ground state until their wavelength exceeds the horizon size in the period of exponential expansion. The ground-state fluctuations are then amplified by the subsequent expansion and the modes reenter the horizon in the matter- or radiation-dominated era in a highly excited state. We obtain a scale-free spectrum of density perturbations which could account for the origin of galaxies and all other structure in the Universe. The fluctuations would be compatible with observations of the microwave background if the mass of the scalar field that drives the inflation is 10^{14} GeV or less.

15

再び閑話休題

back on track again

1986.03 広島大学理論物理学研究所助教授に着任 (~ 1990.06)

moved to Research Institute for Theoretical Physics, Hiroshima U. as an associated professor

- 非常に刺激的環境。最も自由に研究を楽しんだ時代
  highly inspiring atmosphere. most enjoyable time in my early research career

  成相，木村，冨田，藤川，細谷，…そして多くの優秀な学生
  Nariai, Kimura, Tomita, Fujikawa, Hosoya, … and many very good students

本格的な揺らぎの進化とCMB
evolution of perturbations and CMB

Progress of Theoretical Physics, Vol. 76, No. 5, November 1986

Evolution of Gauge-Invariant Cosmological Density Perturbations through Decoupling Era

Naoteru GOUDA and Misao SASAKI[*]

Department of Physics, Kyoto University, Kyoto 606
Research Institute for Theoretical Physics, Hiroshima University
Takehara, Hiroshima 725

Progress of Theoretical Physics, Vol. 76, No. 5, November 1986

Large Scale Quantum Fluctuations in the Inflationary Universe

Misao SASAKI

Research Institute for Theoretical Physics
Hiroshima University, Takehara, Hiroshima 725

CLASSICAL BEHAVIOR OF A SCALAR FIELD IN THE INFLATIONARY UNIVERSE

Misao SASAKI, Yasusada NAMBU and Ken-ichi NAKAO
Research Institute for Theoretical Physics, Hiroshima University, Takehara, Hiroshima 725, Japan

Received 25 September 1987
(Revised 11 January 1988)

The magnitude–redshift relation in a perturbed Friedmann universe

Misao Sasaki Research Institute for Theoretical Physics, Takehara, Hiroshima 725, Japan.

インフレーション揺らぎの量子化
quantization of inflationary fluctuations

Mukhanov-Sasaki var./eq.

Progress of Theoretical Physics, Vol. 80, No. 6, December 1988

Stochastic Dynamics of New Inflation

Ken-ichi NAKAO, Yasusada NAMBU and Misao SASAKI
Research Institute for Theoretical Physics
Hiroshima University, Takehara, Hiroshima 725

STOCHASTIC APPROACH TO CHAOTIC INFLATION AND THE DISTRIBUTION OF UNIVERSES

Yasusada NAMBU and Misao SASAKI
Research Institute for Theoretical Physics, Hiroshima University, Takehara, Hiroshima 725, Japan

アキシオンCMD
axion CDM

宇宙論的重力レンズ効果
cosmological gravitational lensing

PHYSICAL REVIEW D

VOLUME 42, NUMBER 12

15 DECEMBER 1990

Quantum treatment of cosmological axion perturbations

Yasusada Nambu[*] and Misao Sasaki[†]
Research Institute for Theoretical Physics, Hiroshima University, Takehara, Hiroshima 725, Japan
(Received 14 December 1989)

PHYSICAL REVIEW D

VOLUME 40, N

15 OCTOBER 1989

Light propagation and the distance-redshift relation in a realistic inhomogeneous universe

Toshifumi Futamase
Department of Physics, Faculty of Science, Hirosaki University, Hirosaki 036, Japan

Misao Sasaki
NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, Illinois 60510
and Research Institute for Theoretical Physics, Hiroshima University, Takehara, Hiroshima 725, Japan[*]
(Received 3 May 1989)

17

重力・重力・重力…

gravity, gravity, gravity,…

1990.06 広大理論研が基研と合併。基研宇治へ

RITP Hiroshima U was merged to YITP. moved to YITP Uji.

1991.04 天体核に強制連行（？）される

forced(?) to move to Theoretical Astro Group

- 基研（北白川）には中村卓史，横山順一，小玉英雄。
Takashi Nakamura, Jun'ichi Yokoyama, Hideo Kodama at YITP (Kitashirakawa)

Progress of Theoretical Physics, Vol. 86, No. 1, July 1991

The Density Perturbation in the Chaotic Inflation with Non-Minimal Coupling

Nobuyoshi MAKINO*) and Misao SASAKI

Uji Research Center, Yukawa Institute for Theoretical Physics, Kyoto University, Uji 611

曲率揺らぎの共形不変性
conformal invariance of curvature pert.

Progress of Theoretical Physics, Vol. 88, No. 3, September 1992

False Vacuum Decay with Gravity
—— Negative Mode Problem ——

Takahiro TANAKA and Misao SASAKI

University, Kyoto 606-01

重力入り真空崩壊
false vacuum decay with gravity

Progress of Theoretical Physics, Vol. 90, No. 1, July 1993

Gravitational Wave Induced by a Particle Orbiting around a Schwarzschild Black Hole

Takahiro TANAKA, Masaru SHIBATA, Misao SASAKI, Hideyuki TAGOSHI and Takashi NAKAMURA*

Department of Physics, Kyoto University,
*Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-01

ブラックホール周回粒子からの重力波
GWs from a particle orbing a BH

オープンインフレーション
open inflation

Quantum state inside a vacuum bubble
and the creation of an open universe

Misao Sasaki a,1, Takahiro Tanaka a,2, Kazuhiro Yamamoto b,3 and Jun'ichi Yokoyama b,4

a Department of Physics, Faculty of Science, Kyoto University, Kyoto 606-01, Japan
b Uji Research Center, Yukawa Institute for Theoretical Physics, Kyoto University, Uji 611, Japan

Received 23 July 1993
Editor: M. Dine

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重力波のポスト・ニュートン展開

post-Newtonian expansion of gravitational wave forms

田越−中村論文：log項を数値的に発見

Tagoshi-Nakamura: numerically discovered log terms

中村：log項を解析的に導出せよ！

Nakamura: derive log-term analytically!

できました！

done!

15 APRIL 1994

PHYSICAL REVIEW D VOLUME 49, NUMBER 8

Gravitational waves from a point particle in circular orbit around a black hole:
Logarithmic terms in the post-Newtonian expansion

Hideyuki Tagoshi
Department of Physics, Kyoto University, Kyoto 606-01, Japan

Takashi Nakamura
for Theoretical Physics, Kyoto University, Kyoto 606-01, Japan
(Received 1 November 1993)

Progress of Theoretical Physics, Vol. 92, No. 1, July 1994

Post-Newtonian Expansion of the Ingoing-Wave Regge-Wheeler Function

Misao SASAKI

Department of Physics, Kyoto University, Kyoto 606-01

基本は光円錐のlog補正 $r^* = r + 2M\ln(r - 2M)$

basically due to log−corr. to light cone

ポスト・ニュートン3次で現れる appears at 3PN

$$+ v^6\Big(\cos(2\phi)\Big(\frac{49928027}{1940400} - \frac{856\gamma}{105} + \frac{2\pi^2}{3} + \frac{668\ln 2}{105} - 8(\ln 2)^2 - \frac{856\ln v}{105}\Big)$$

Progress of Theoretical Physics, Vol. 92, No. 4, October 1994

Post-Newtonian Expansion of Gravitational Waves from a Particle
in Circular Orbit around a Schwarzschild Black Hole

Hideyuki TAGOSHI and Misao SASAKI
Department of Physics, Kyoto University, Kyoto 606-01

PHYSICAL REVIEW D VOLUME 51, NUMBER 4

Gravitational waves from a particle orbiting around a rotating black hole:
Post-Newtonian expansion

Masaru Shibata
Department of Earth and Space Science, Osaka University, Toyonaka, Osaka 560, Japan

Misao Sasaki, Hideyuki Tagoshi, and Takahiro Tanaka
Department of Physics, Kyoto University, Kyoto 606-01, Japan
(Received 5 October 1994)

PHYSICAL REVIEW D VOLUME 51, NUMBER 10 15 MAY 1995

Gravitational radiation from a particle in circular orbit around a black hole.
V. Black-hole absorption and tail corrections

Eric Poisson
McDonnell Center for the Space Sciences, Department of Physics, Washington University, St. Louis, Missouri 63130

Misao Sasaki*
Department of Physics, Faculty of Science, Kyoto University, Kyoto 606, Japan
(Received 8 December 1994)

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重力波・インフレーション・ブレーン

GWs, inflation, and braneworld

1995.01 阪大宇宙進化G教授に着任 (~ 2003.03)

moved to Astro-Cosmo G at Osaka U

LARGE-ANGLE COSMIC MICROWAVE BACKGROUND ANISOTROPY IN AN OPEN
UNIVERSE IN THE ONE-BUBBLE INFLATIONARY SCENARIO

KAZUHIRO YAMAMOTO,[1] MISAO SASAKI,[2] AND TAKAHIRO TANAKA[1]
Received 1995 February 6; accepted 1995 June 30

- 出来立てのグループ：池内了，郷田直輝，柴田大
  Newly formed group: S Ikeuchi, N Gouda, M Shibata

- 池内さんの誘い文句「国内最強の拠点を作ろう！」
  Ikeuchi-san enthusiastically invited me saying "let's make our group strongest in Japan!"

オープン・インフレーション
open inflation

しかし，池内さんはすぐに転出…
but Ikeuchi-san moved out soon after I joined the group…

PHYSICAL REVIEW D, VOLUME 59, 123522

CMB in open inflation

Progress of Theoretical Physics, Vol. 95, No. 1, January 1996

A General Analytic Formula for the Spectral Index
of the Density Perturbations Produced during Inflation

Misao SASAKI and Ewan D. STEWART[*,**]

Department of Earth and Space Science, Osaka University, Toyonaka 560
*School of Physics and Chemistry, Lancaster University, Lancaster, LA1 4YB

Andrei Linde
Department of Physics, Stanford University, Stanford, California 94305

Misao Sasaki and Takahiro Tanaka
School of Science, Osaka University, Toyonaka 560-0043,

PHYSICAL REVIEW D, VOLUME 62, 024012

The Einstein equations on the 3-brane world

Tetsuya Shiromizu
DAMTP, University of Cambridge, Silver Street, Cambridge CB3 9EW, United Kingdom;
Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan;
and Research Centre for the Early Universe (RESCEU), The University of Tokyo, Tokyo 113-0033, Japan

Progress of Theoretical Physics, Vol. 99, No. 5, May 1998

Super-Horizon Scale Dynamics of Multi-Scalar Inflation

Misao SASAKI[*] and Takahiro TANAKA[**]

Department of Earth and Space Science, Graduate School of Science,
Osaka University, Toyonaka 560, Japan

Kei-ichi Maeda
Institute, University of Cambridge, 20 Clarkson Road, Cambridge
and Department of Physics, Waseda University, Shinjuku, Tokyo

Misao Sasaki
Isaac Newton Institute, University of Cambridge, 20 Clarkson Road, Cambridge
Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan;
and Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan;
(Received 21 October 1999; published 22 June 2000)

δN 形式
δN formalism

ブレーン・ワールド
brane-world

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重力波にのめり込む

indulging in GWs

- すべて優秀な共同研究者のおかげ!
  thanks to exceptionally good collaborators!

良い共同研究者を見つけるべし!
find good collaborators at all cost!

The Spectrum of Gravitational Wave Perturbations in the One-Bubble Open Inflationary Universe

Takahiro TANAKA and Misao SASAKI

Department of Earth and Space Science, Osaka University, Toyonaka 560

(Received November 1, 1996)

We give the initial spectrum of quantized gravitational waves in the context of the one-bubble open inflationary universe scenario. In determining the quantum state after the bubble nucleation, we adopt the prescription to require the analyticity of positive frequency functions in half of the Euclidian extension of the background $O(3,1)$-symmetric spacetime. We find the spectrum is well behaved at the infrared limit and there appears no supercurva-

オープンインフレーションの重力波
GWs from open inflation

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
KIP S. THORNE
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 ~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 ~5 × 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 ~5 × 10^{-2} events yr^{-1} per galaxy. This suggests that we can expect a few events per

原始ブラックホール連星からの重力波
GWs from primordial BH binaries

Gravitational radiation reaction to a particle motion

Yasushi Mino*
Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560, Japan
and Department of Physics, Faculty of Science, Kyoto University, Kyoto 606-01, Japan

Misao Sasaki† and Takahiro Tanaka‡
Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560, Japan

重力的自己力の導出
gravitational self-force

$$\delta\Gamma_{(v)}{}^{\alpha}{}_{\beta\gamma} := \frac{1}{2}(h_{(v)}{}^{\alpha}{}_{\beta;\gamma} + h_{(v)}{}^{\alpha}{}_{\gamma;\beta} - h_{(v)\beta\gamma}{}^{;\alpha})$$

MiSaTaQuWa equation

Calculating the Gravitational Self-Force in Schwarzschild Spacetime

Leor Barack,[1] Yasushi Mino,[2] Hiroyuki Nakano,[3] Amos Ori,[4] and Misao Sasaki[3]
[1]Albert-Einstein-Institut, Max-Planck-Institut für Gravitationsphysik, Am Mühlenberg 1, D-14476 Golm, Germany
[2]Theoretical Astrophysics, California Institute of Technology, Pasadena, California 91125
[3]Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan
[4]Department of Physics, Technion–Israel Institute of Technology, Haifa 32000, Israel
(Received 1 November 2001; published 19 February 2002)

We present a practical method for calculating the local gravitational self-force (often called "radiation-reaction force") for a pointlike particle orbiting a Schwarzschild black hole. This is an implementation of the method

自己力の計算法
method for computing self-force

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そして。。。

And,…

2003.04 再び基研に。現在に至る。
back to YITP, until now.

- 再び最高の研究環境!
  The best research environment again!

Progress of Theoretical Physics, Vol. 110, No. 3, September 2003

Newton's Law on an Einstein "Gauss-Bonnet" Brane

Nathalie DERUELLE[1,2] and Misao SASAKI[1]

[1] Yukawa Institute for Theoretical Physics, Kyoto University,
Kyoto 606-8502, Japan
[2] Institut d'Astrophysique de Paris, GReCO, FRE 2435 du CNRS,
98 bis Boulevard Arago, 75014 Paris, France

修正重力
modified gravity

PHYSICAL REVIEW D 71, 123509 (2005)

Gauss-Bonnet dark energy

Shin'ichi Nojiri*

Department of Applied Physics, National Defence Academy, Hashirimizu Yokosuka 239.8686, Japan

Sergei D. Odintsov†

Catalana de Recerca i Estudis Avançats (ICREA) and Institut d'Estudis Espacials de Catalunya (IEEC/CE), Edifici Nexus
Gran Capità 2-4, 08034 Barcelona, Spain

Misao Sasaki

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
(Received 6 April 2005; revised manuscript received 26 May 2005; published 7 June 2005)

A general proof of the conservation of the curvature perturbation

David H Lyth[1], Karim A Malik[1] and Misao Sasaki[2]

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[2] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
E-mail: d.lyth@lancaster.ac.uk, k.malik@lancaster.ac.uk and misao@yukawa.kyoto-u.ac.jp

$$\zeta(x^i) \equiv \psi(t, x^i) + \frac{1}{3} \int_{\rho(t)}^{\rho(t,x^i)} \frac{d\rho}{\rho + P}$$

非線形δN形式
nonlinear δN formalism

Graviton emission from a higher-dimensional black hole

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Wade Naylor
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Misao Sasaki
Yukawa Institute for Theoretical Physics, Kyoto University
Kyoto 606-8502, Japan
E-mail: misao@yukawa.kyoto-u.ac.jp

高次元ブラックホール
GWs from higher dim BH

Large-scale magnetic fields in the inflationary universe

Kazuharu Bamba[1] and Misao Sasaki

Yukawa Institute for Theoretical Physics, Kyoto Univer
Japan

宇宙磁場の起源
origin of magnetic field

Diagrammatic approach to non-Gaussianity from inflation

Christian T Byrnes[1], Kazuya Koyama[1], Misao Sasaki[2] and David Wands[1]

[1] Institute of Cosmology and Gravitation, Mercantile House, University of Portsmouth, Portsmouth PO1 2EG, UK
[2] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
E-mail: Chris.Byrnes@port.ac.uk, kazuya.koyama@port.ac.uk, misao@yukawa.kyoto-u.ac.jp and David.Wands@port.ac.uk

PHYSICAL REVIEW D 78, 103522 (2008)

Effects of particle production during inflation

Antonio Enea Romano and Misao Sasaki

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
(Received 9 October 2008; published 20 November 2008)

Impact of particle production during inflation on the primordial curvature perturbation spectrum is investigated both analytically and numerically. We obtain an oscillatory behavior on small scales, while on large scales the spectrum is unaffected. The amplitude of the oscillations is proportional to the number of coupled fields, their mass, and the square of the coupling constant. The oscillations are due to a discontinuity in the second time derivative of the inflaton, arising from a temporary violation of the slow-roll conditions. A similar effect on the power spectrum should be produced also in other inflationary models where the slow-roll conditions are temporarily violated.

そしてもっと。。。

And more…

Progress of Theoretical Physics, Vol. 123, No. 1, January 2010

Hamiltonian Formulation of f(Riemann) Theories of Gravity

Nathalie DERUELLE,[1] Misao SASAKI,[2] Yuuiti SENDOUDA[2] and Daisuke YAMAUCHI[2]

Paris 7, 75205 Paris, France
Physics, Kyoto University,
Japan

正準形式
Hamiltonian formalism

Hamiltonian approach to second order gauge invariant cosmological perturbations

Guillem Domènech[1,2,*] and Misao Sasaki[1,2,†]

[1]Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto 606-8502, Japan
[2]International Research Unit of Advanced Future

Resonant primordial gravitational waves amplification

CrossMark

Chunshan Lin*, Misao Sasaki

Yukawa Institute for Theoretical Physics, Kyoto University, Japan

ARTICLE INFO

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Available online 11 November
Editor: S. Dodelson

ABSTRACT

models of inflation. We minimally extend
ativity (GR) to a theory with non-vanishing
imarily affects the tensor perturbation, while
10.1088/0264-9381/30/23/232001

Class. Q

有質量重力
massive gravity

Hartle–Hawking no-boundary proposal in dRGT massive gravity: making inflation exponentially more probable

Misao Sasaki, Dong-han Yeom and Ying-li Zhang

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

E-mail: misao-AT-yukawa.kyoto-u.ac.jp, innocent.yeom-AT-gmail.com and yingli-AT-yukawa.kyoto-u.ac.jp

PHYSICAL REVIEW D 84, 123503 (2011)

Large and strong scale dependent bispectrum in single field inflation from a sharp feature in the mass

Frederico Arroja,[1,*] Antonio Enea Romano,[2,3] and Misao Sasaki[3,1]

[1]Institute for the Early Universe, Ewha Womans University, Seoul 120-750, Republic of Korea
[2]Leung Center for Cosmology and Particle Astrophysics, National Taiwan University, Taipei 10617, Taiwan;
Instituto de Física, Universidad de Antioquia, A.A.1226, Medellin, Colombia
[3]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan;
Korea Institute for Advanced Study, 207-43 Cheongnyangni 2-dong, Dongdaemun-gu,
Seoul 130-722, Republic of Korea

Curvature perturbation spectrum in two-field inflation with a turning trajectory

Shi Pi[a] and Misao Sasaki[b]

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State Key Laboratory of Nuclear Physics and Technology,
Peking University, Beijing 100871, China
[b]Yukawa Institute for Theoretical Physics, Kyoto University,
Kyoto 606-8502, Japan

非標準インフレーション
non-standard inflation

www.epljournal.org

EPL, 102 (2013) 59001
doi: 10.1209/0295-5075/102/59001

A single field inflation model with large local non-Gaussianity

XINGANG CHEN[1], HASSAN FIROUZJAHI[2], MOHAMMAD HOSSEIN NAMJOO[3,4] and MISAO SASAKI[4]

[1]Centre for Theoretical Cosmology, DAMTP, University of Cambridge - Cambridge CB3 0WA, UK, EU
[2]School of Astronomy, Institute for Research in Fundamental Sciences (IPM) - P. O. Box 19395-5531, Tehran, Iran
[3]School of Physics, Institute for Research in Fundamental Sciences (IPM) - P. O. Box 19395-5531, Tehran, Iran
[4]Yukawa Institute for Theoretical Physics, Kyoto University - Kyoto 606-8502, Japan

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学生との楽しい時間…

enjoyable time with students…

Progress of Theoretical Physics, Vol. 117, No. 4, April 2007

Gradient Expansion Approach to Nonlinear Superhorizon Perturbations

Yoshiharu TANAKA and Misao SASAKI

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

Progress of Theoretical Physics, Vol. 123, No. 1, January 2010

Hamiltonian Formulation of f(Riemann) Theories of Gravity

Nathalie DERUELLE, Misao SASAKI, Yuuiti SENDOUDA and Daisuke YAMAUCHI

[1] APC, UMR 7164 du CNRS, Université Paris 7, 75205 Paris, France
[2] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

Quantum fluctuations on a thick de Sitter brane

Masato Minamitsuji [a],*, Wade Naylor [c], Misao Sasaki [b]

[a] Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0
[b] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
[c] Department of Physics, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan

Received 24 August 2005; received in revised form 18 November 2005; accepted 21 December 20
Available online 17 January 2006

Progress of Theoretical Physics, Vol. 121, No. 1, January 2009

Large Non-Gaussianity from Multi-Brid Inflation

Atsushi NARUKO and Misao SASAKI

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

FAST TRACK COMMUNICATION

Conservation of the nonlinear curvature perturbation in generic single-field inflation

Atsushi Naruko and Misao Sasaki

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

E-mail: naruko@yukawa.kyoto-u.ac.jp and misao@yukawa.kyoto-u.ac.jp

Received 24 January 2011, in final form 15 February 2011
Published 3 March 2011
Online at stacks.iop.org/CQG/28/072001

EPL, 100 (2012) 29004
doi: 10.1209/0295-5075/100/29004

Non-Gaussian bubbles in the sky

KAZUYUKI SUGIMURA [3], DAISUKE YAMAUCHI [2] and MISAO SASAKI [1]

[1] Yukawa Institute for Theoretical Physics, Kyoto University - Kyoto, Japan
[2] Institute for Cosmic Ray Research, University of Tokyo - Chiba, Japan

PHYSICAL REVIEW D 84, 043513 (2011)

Open inflation in the landscape

Daisuke Yamauchi [1,2,*], Andrei Linde, [3] Atsushi Naruko, [1,‡] Misao Sasaki, [1,§] and Takahiro Tanaka [1,||]

[1] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan
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[3] Department of Physics, Stanford University, Stanford, California 9430
(Received 26 May 2011; published 10 August 2011)

Conformal frame dependence of inflation

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epl   A Letter Journal Exploring the Frontiers of Physics

EPL, 115 (2016) 19001
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THE ASTROPHYSICAL JOURNAL, 607:32–39, 2004 May 20
© 2004. The American Astronomical Society. All rights reserved. Printed in U.S.A.

RECONSTRUCTING THE PRIMORDIAL SPECTRUM FROM *WMAP* DATA BY THE COSMIC INVERSION METHOD

NORIYUKI KOGO, [1] MAKOTO MATSUMIYA, [1] MISAO SASAKI, [2] AND JUN'ICHI YOKOYAMA [1]
Received 2003 September 24; accepted 2004 February 4

SCREENING OF COSMOLOGICAL CONSTANT IN NON-LOCAL COSMOLOGY

YING-LI ZHANG* and MISAO SASAKI†

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Kyoto University, Kyoto 606-8502, Japan
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†misao@yukawa.kyoto-u.ac.jp

Curvature perturbation in multi-field inflation with non-minimal coupling

Jonathan White, Masato Minamitsuji and Misao Sasaki

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July 2016
www.epljournal.org

Inflationary magnetogenesis with broken local $U(1)$ symmetry

GUILLEM DOMÈNECH, CHUNSHAN LIN and MISAO SASAKI

Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto University
Kitashirakawa Oiwakecho, Sakyo-ku, Kyoto 606-8502, Japan

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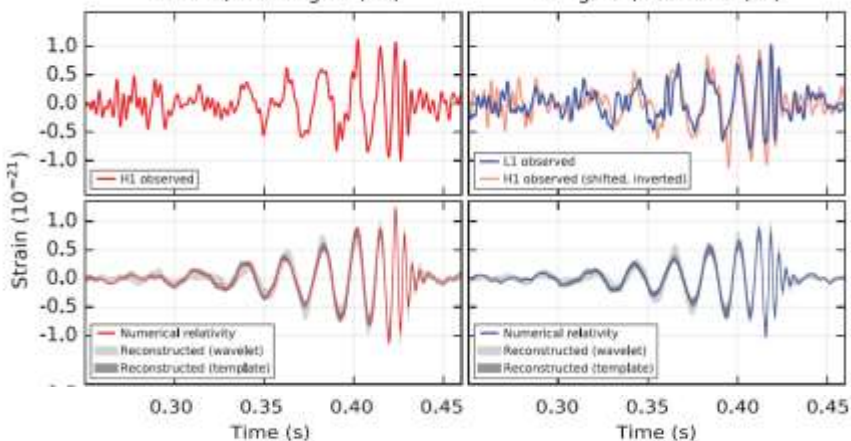# 再々度，閑話休題

back on track, once again

今，重力波が熱い!

GW is "hot" now!

LIGO: GW150914,...

ブラックホール連星合体からの重力波検出
1st detection of GWs from coalescence of binary BHs

発見されたブラックホールは
初期宇宙起源かもしれない

detected BHs may be primordial

PRL 117, 061101 (2016)   PHYSICAL REVIEW LETTERS   week ending 5 AUGUST 2016

Primordial Black Hole Scenario for the Gravitational-Wave Event GW150914

Misao Sasaki,[1] Teruaki Suyama,[2] Takahiro Tanaka,[3,1] and Shuichiro Yokoyama[4]
[1]Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
[2]Research Center for the Early Universe (RESCEU), Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan
[3]Department of Physics, Kyoto University, Kyoto 606-8502, Japan
[4]Department of Physics, Rikkyo University, Tokyo 171-8501, Japan

宇宙論的背景重力波の検出も近い！
cosmological GW background may be detected soon!

LiteBIRD
2030~?
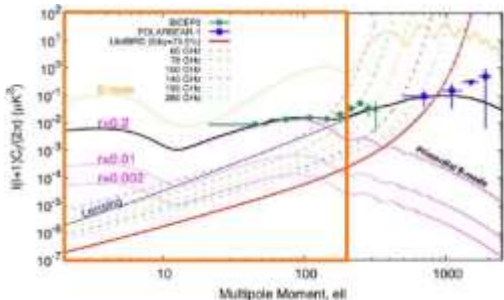
PHYSICAL REVIEW D 97, 023516 (2018)

Observational signatures of the parametric amplification of gravitational waves during reheating after inflation

Sachiko Kuroyanagi,[1] Chunshan Lin,[2,3] Misao Sasaki,[2] and Shinji Tsujikawa[4]
[1]Department of Physics, Nagoya University, Chikusa, Nagoya 464-8602, Japan
[2]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
of Theoretical Physics, Faculty of Physics, University of Warsaw,
Ludwika Pasteura 5, 02-093 Warsaw, Poland
ment of Physics, Faculty of Science, Tokyo University of Science,
1-3, Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan

理論が楽しい！

theory is fun!

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連星中性子星合体 GW170817

binary neutron star merger GW170817

A GRAVITATIONAL-WAVE STANDARD SIREN MEASUREMENT OF THE HUBBLE CONSTANT

THE LIGO SCIENTIFIC COLLABORATION AND THE VIRGO COLLABORATION, THE 1M2H COLLABO
THE DARK ENERGY CAMERA GW-EM COLLABORATION AND THE DES COLLABORATION,
THE DLT40 COLLABORATION, THE LAS CUMBRES OBSERVATORY COLLABORATION,
THE VINROUGE COLLABORATION, THE MASTER COLLABORATION, et al.
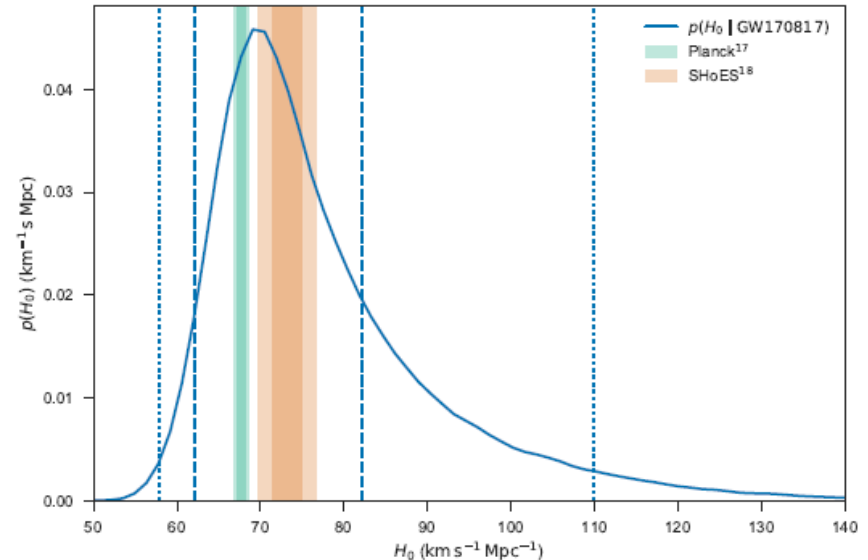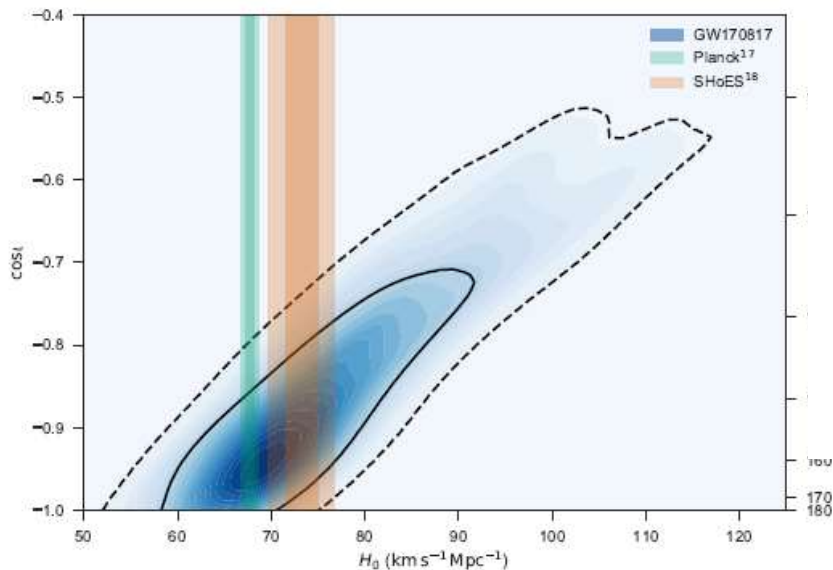
$$H_0 = 70.0^{+12.0}_{-8.0} \ \mathrm{km\,s^{-1}\,Mpc^{-1}}.$$

重力波と電磁波の同時観測の威力

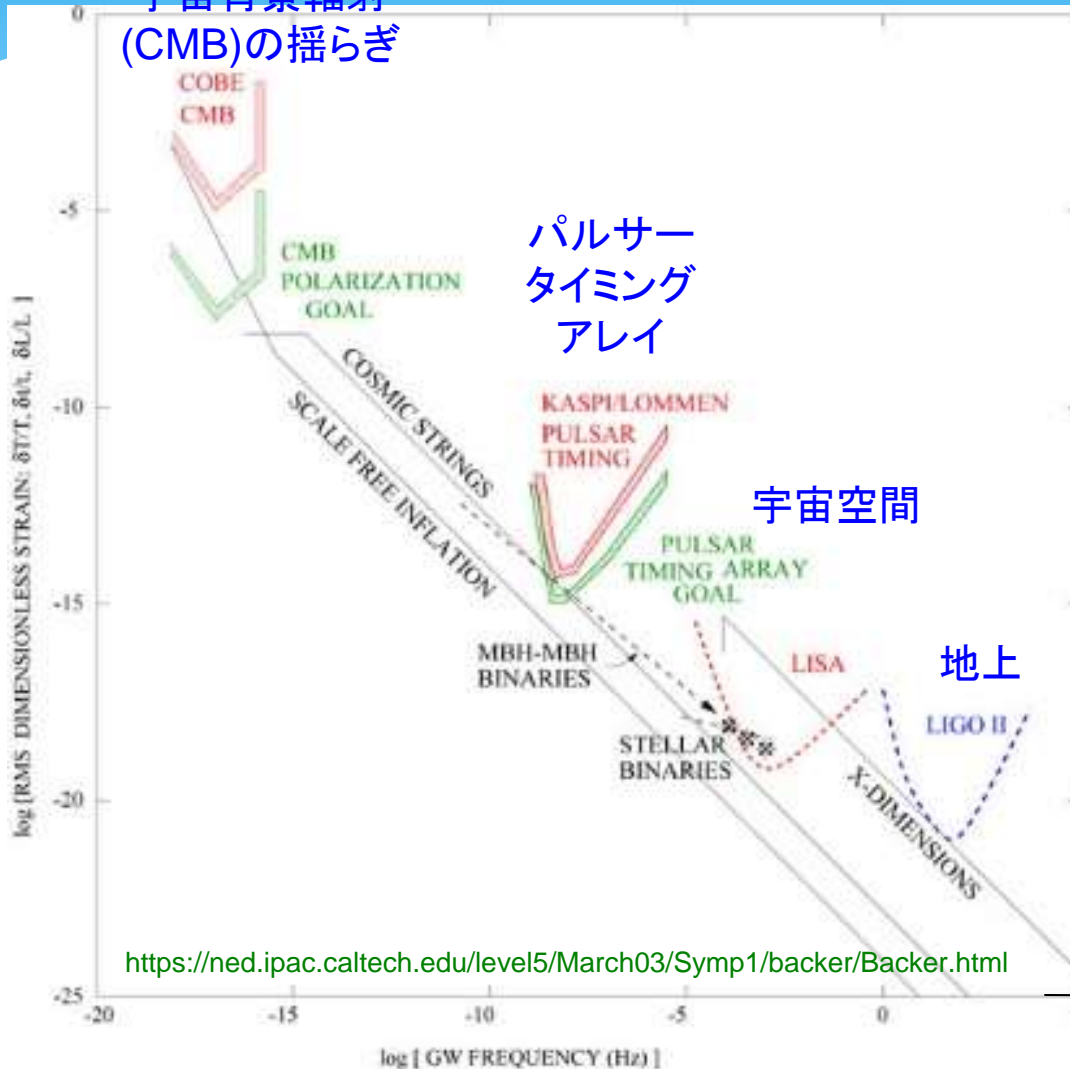power of simultaneous observation by GWs and EMWs

たった一つの観測でこの精度！

from just a single event!

重力波「宇宙論」の夜明け

The dawn of GW "cosmology"

宇宙背景輻射
(CMB)の揺らぎ

パルサー
タイミング
アレイ

宇宙空間

地上

https://ned.ipac.caltech.edu/level5/March03/Symp1/backer/Backer.html

重力波天文学の時代到来
an era of GW astronomy has arrived

重力波の観測・検出が
宇宙論を変える！

observations/detections of GWs
will change cosmology!

高振動数重力波検出器で
インフレーションを「直接」検証？

direct test of inflation by
High Frequency GW detector?

- これから益々面白くなりそう！

  a more exciting time is coming!

- 基研からは離れますが，まだまだ研究を楽しみます！

  although I have to leave YITP, I will still continue to enjoy research.

長い間，ありがとうございました！

Thank you for your continued support!