Misao Sasaki, JGRG 22(2012)111505

"A few thoughts on gravity and cosmology"

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15 November, 2012

A Few Thoughts on Gravity and Cosmology

- geemunu, geemunu, geemunu...-

Misao Sasaki
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a bit of recollections

cosmological perturbation theory (CPT)

collaboration with H Kodama

Progress of Theoretical Physics Supplement No. 78, 1984

Cosmological Perturbation Theory

Hideo KODAMA and Misao SASAKI*

Department of Physics, University of Tokyo, Tokyo 11
**Department of Physics, Kyoto University, Kyoto 606*

(Received September 5, 1984)

The linear perturbation theory of spatially homogeneous and isotropic univer and reformulated extensively. In the first half of the article, a gauge-invariant for theory is carried out with special attention paid to the geometrical meaning of th In the second half of the article, the application of the theory to some importar models is discussed.

gravitational waves (GW)

collaboration with T Futamase through TAMA300

(+ gravitational lensing)

PHYSICAL REVIEW D VOLUME 40, NUMBER 8 15 OCTOBER 1989

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

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(Received 3 May 1989)

We investigate the propagation of light rays in a clumpy universe constructed by a cosmological version of the post-Newtonian approximation. We show that the linear approximation to the propagation equations is valid in the region $z \lesssim 1$ even if the density contrast is much larger than unity. Based on a general order-of-magnitude statistical consideration, we argue that the linear approximation is still valid for $z \gtrsim 1$. Then we give a general formula for the distance-redshift relation in a clumpy universe and derive an explicit expression for a simplified situation in which the effect of the gravitational potential of inhomogeneities dominates. In the light of the derived relation we discuss the validity of the Dyer-Roeder distance. Furthermore, we consider a simple model of an inhomogeneous universe and investigate statistical properties of light rays. We find that the result of this specific example also supports the validity of the linear approximation.

a bit of recollections

cosmological perturbation theory (CPT)

gravitational waves (GW)

- during 80's, GWs were regarded as more realistic, of firm GR foundation.
- during 90's, CPT became realistic, thanks to COBE/DMR measured anisotropy.
- during 00's, both became realistic. But...

fairy tales are necessary for healthy growth of children
(H Sato at a theory group workshop, 中間発表会, in '90s)

(chukan-happyo-kai)

so WE (at least I) need fairy tales...

Gravity Today

- No deviation from General Relativity

cf. Will's living review '06

- solar system tests – PPN parameters

$$g_{oo} = -1 + 2\psi - 2\beta\psi^2 + \cdots : \quad \beta_{GR} = 1$$
$$g_{ij} = \delta_{ij}\left(1 + 2\gamma\psi + \cdots\right) \quad : \quad \gamma_{GR} = 1$$

$|\gamma - 1| < 2.3\times10^{-5}$: Shapiro time delay (Bertotti et al. '03)

$|4\beta - \gamma - 3| < 4.4\times10^{-4}$: Strong EP (Baessler et al. '99)

- constancy of gravitational constant

$|d\log G/dt| < 10^{-12}$ yr^{-1}: Lunar laser ranging (Williams et al '04)

- binary pulsar – GW emission rate

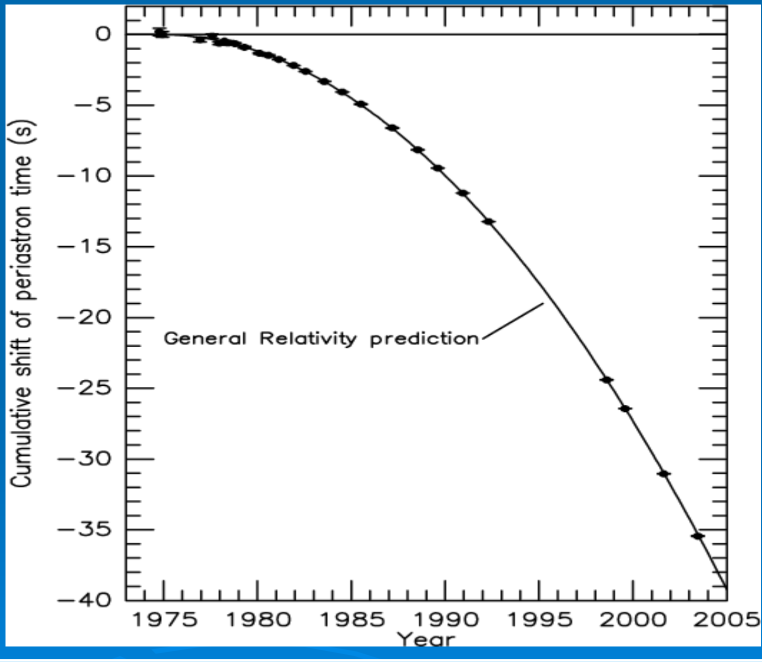
Hulse-Taylor binary (B1913+16)

- orbital change due to GW emission

$$\frac{\dot{P}_{\mathrm{B1913+16}}}{\dot{P}_{GR}} = 1.0013 \pm 0.0021$$

perfect match with GR predictions

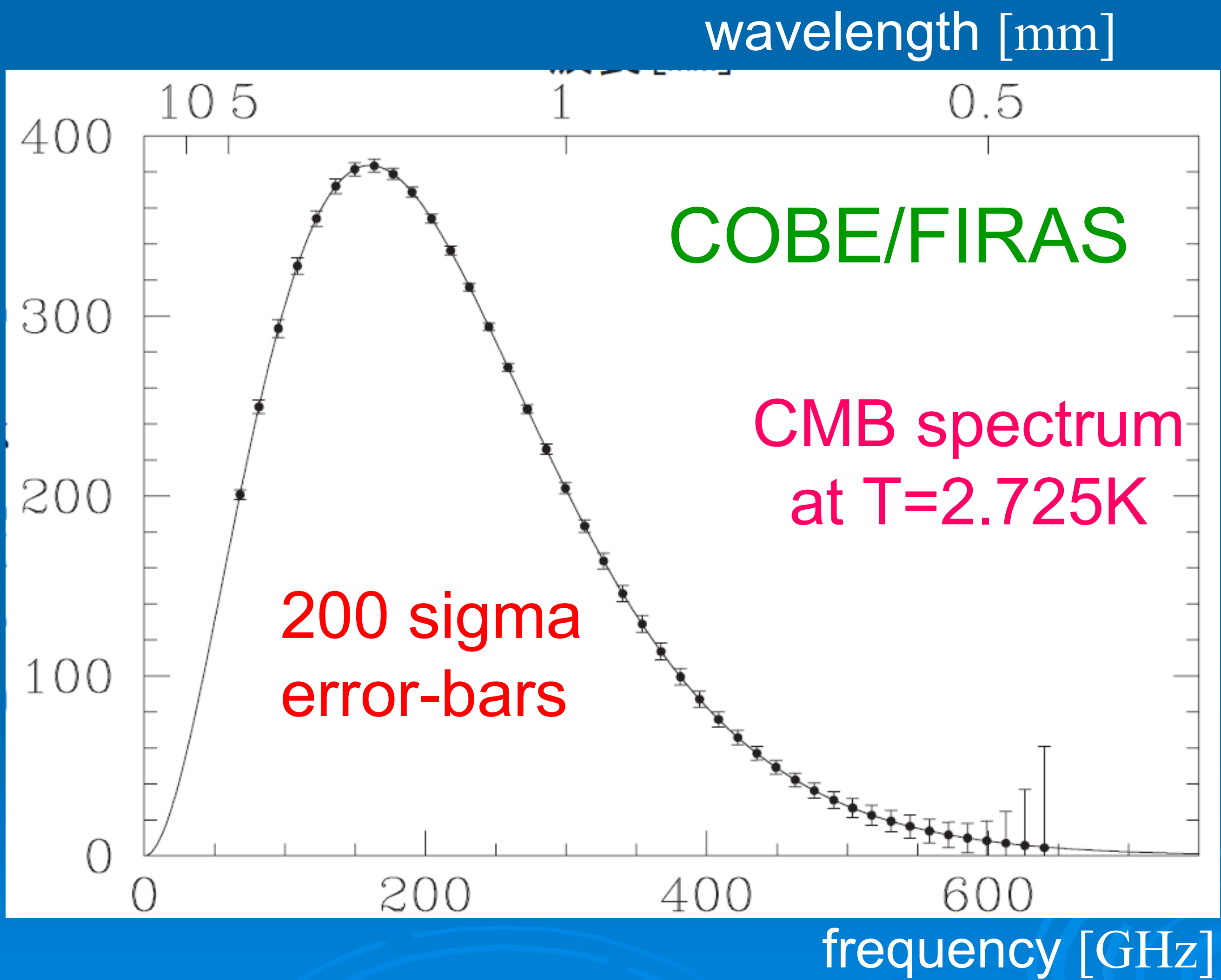
- periastron time shift



gravitational wave astronomy will further test GR

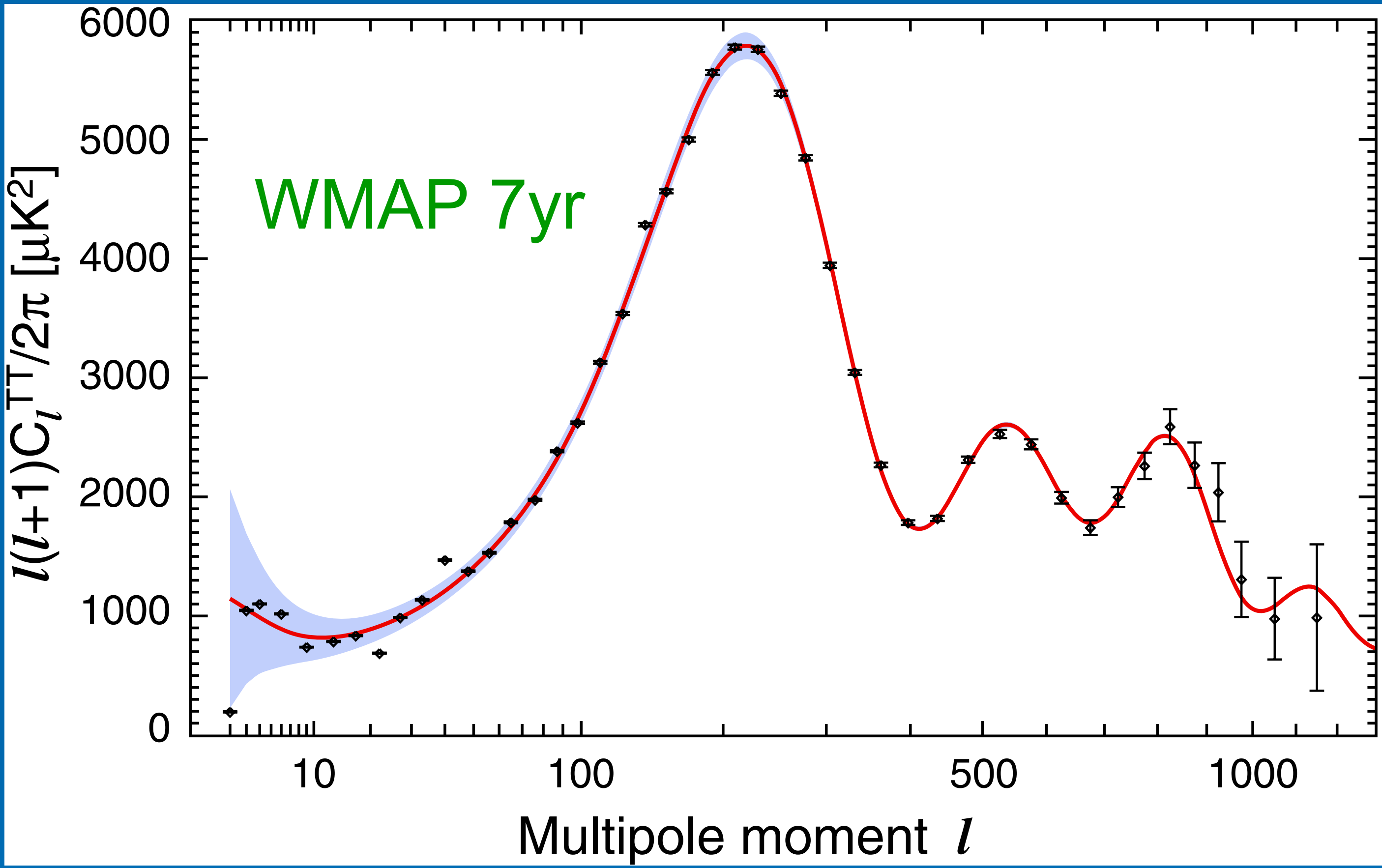
Cosmology Today

- Big Bang theory has been firmly established



another strong evidence for GR

Strong evidence for Inflation



$$\langle \Delta T(\vec{n}_1)\Delta T(\vec{n}_2)\rangle = \sum_{\ell=0}^{\infty} \frac{2\ell+1}{4\pi} C_\ell P_\ell(\cos\theta).$$

- highly Gaussian fluctuations
- almost scale-invariant spectrum

only to be confirmed (by tensor modes?)

Fundamental(?) Issues

- Dark Matter

Is it really `matter’?

Perhaps yes, because it gravitates.

fermion? boson? primordial BH?
something else?

Is there a way to generically distinguish them?

- Dark Energy

  - apparent accelerated expansion of the universe

    Is the expansion really accelerating?

    e.g. inhomogeneous universe models

How can we confirm acceleration?

  - modified gravity vs unknown matter field

    How to distinguish?

    large scale structure formation

    $w<-1$ implies modified gravity,etc...

    Can we falsify GR?

any other effective discriminators?

comments on modified gravity

IR modification ⟵ GR ⟶ UV modification

↕ ? ↕ ?

long distance short distance

- time is important in spacetime!
- any smooth function f(x) contains infinitely large Fourier modes...
- amplitude of Riemann? in which frame?

- Inflation

- How did inflation begin?
  what guarantees homogeneity and isotropy?
  quantum cosmology/gravity?

- What is 'inflaton'?
  what determines the end of inflation?
  flatness / open inflation?
  non-Gaussianity? tensor-scalar ratio?

  eternal inflation, anthropic principle,
  probability measure,...

new guiding principle / working hypothesis?

What's next?
Which direction?

With a bit of 我田引水 (ga den-in sui)

which means ‘self advocacy’, more or less...

String Theory Landscape!

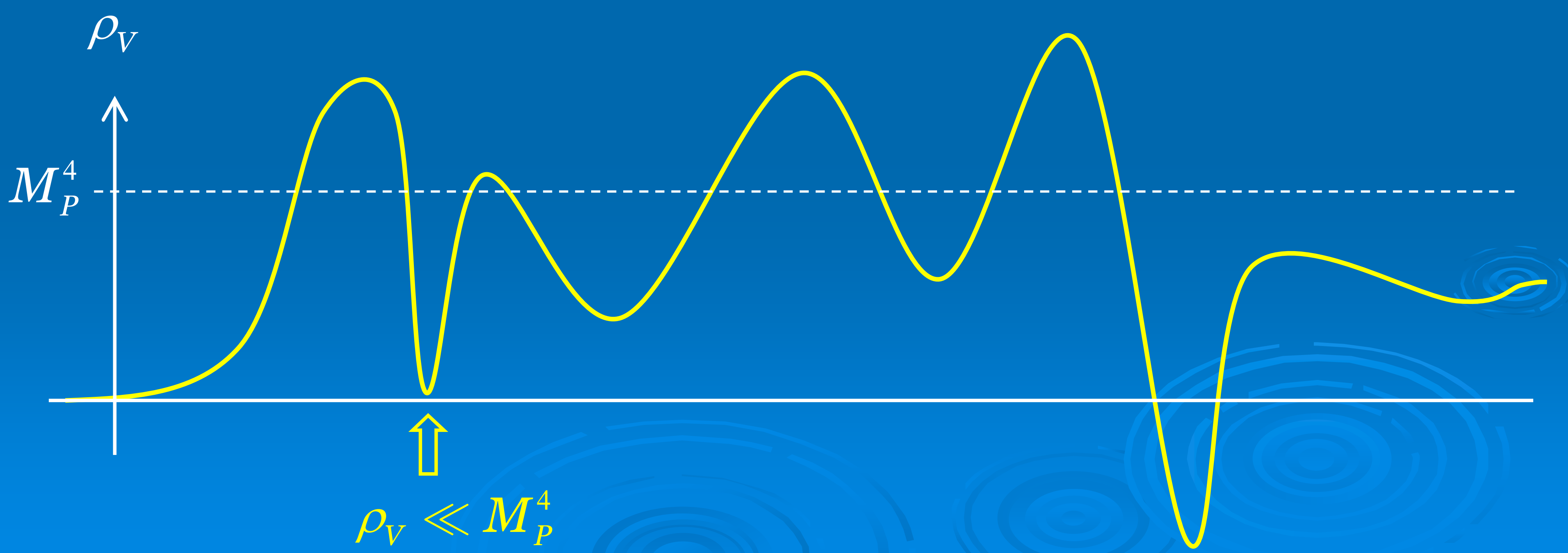
Isn’t there a landscape in LQG?

(a question to Abhay)

String theory landscape

Bousso & Pochinski ('00), Susskind, Douglas, KKLT ('03), ...

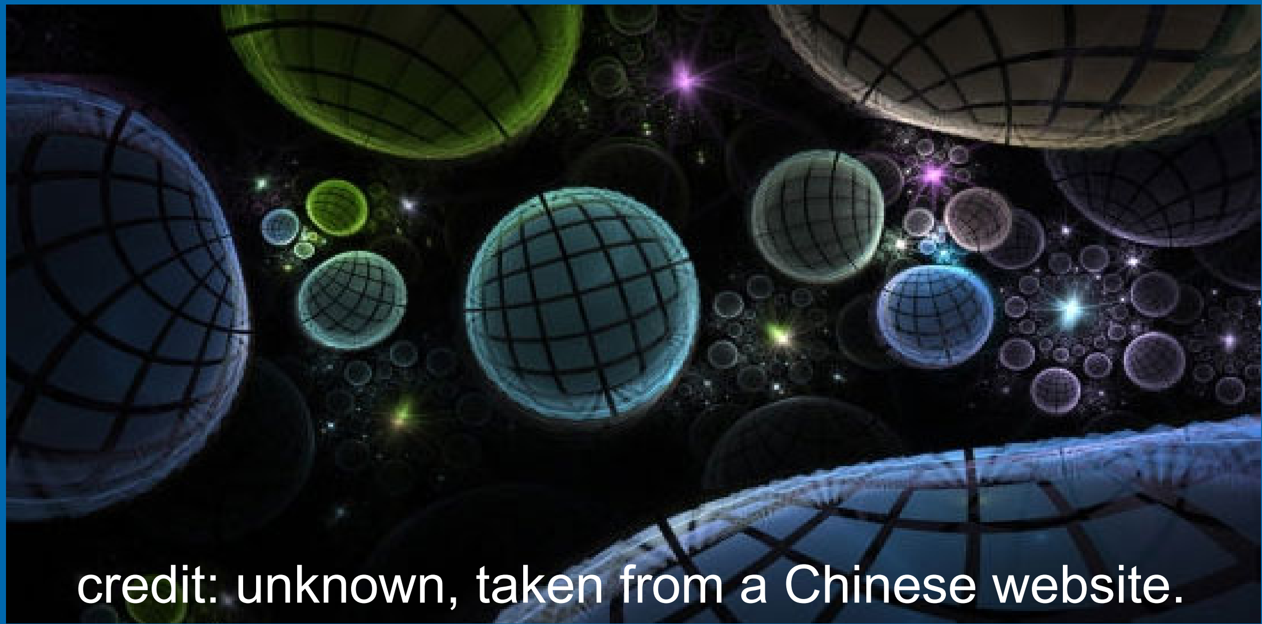
- There are ~ 10^{500} vacua in string theory
  - vacuum energy ρ_V may be positive or negative
  - typical energy scale ~ M_P^4
  - some of them have $\rho_V \ll M_P^4$



testing string theory landscape in cosmology?

Cosmic Landscape

various vacua realized in the early universe



credit: unknown, taken from a Chinese website.

distribution determined by various factors

probability measure, density of states,
quantum equilibrium, ...

quantum transitions between various vacua

Creation of open universe

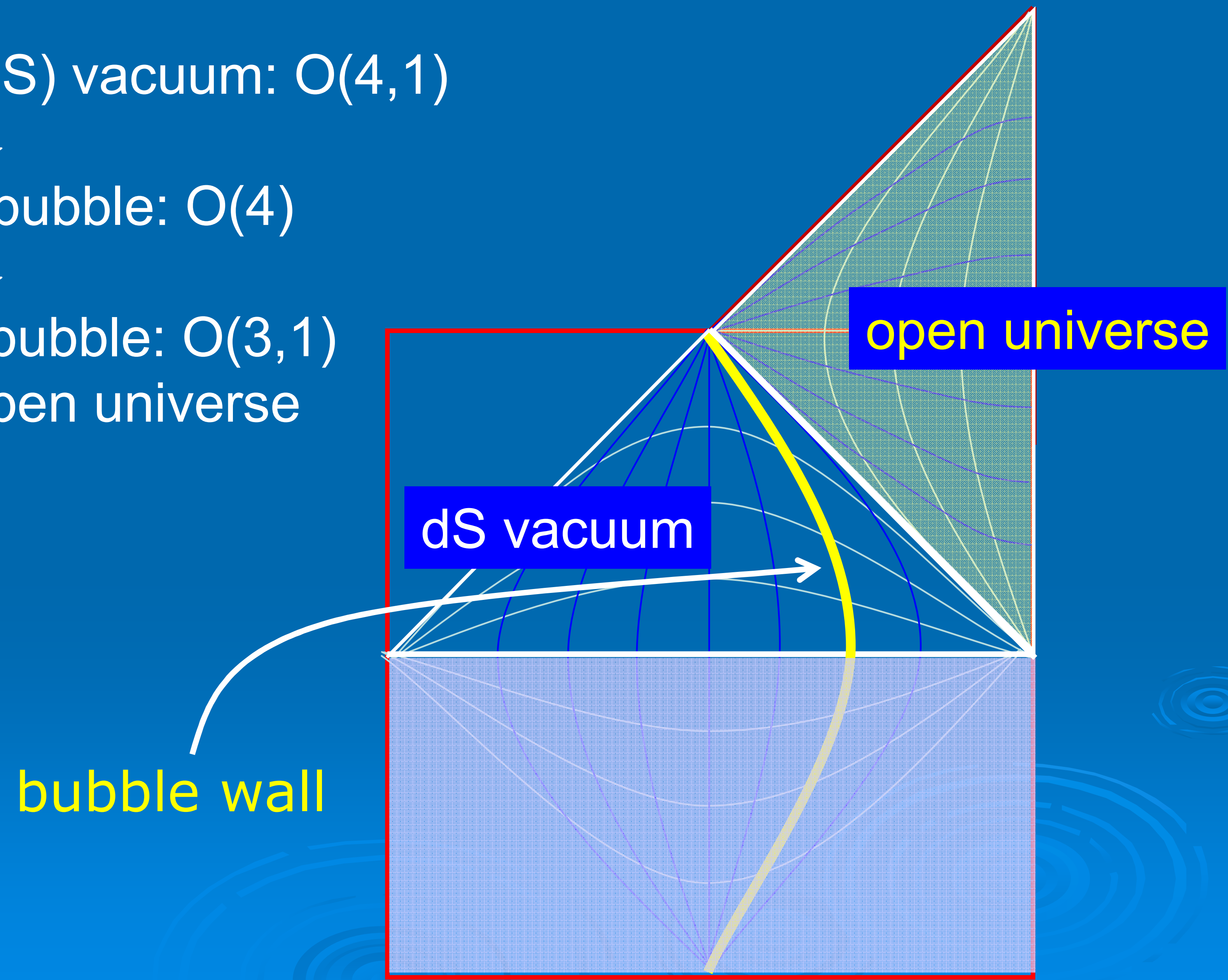
de Sitter (dS) vacuum: O(4,1)

⇓

Euclidean bubble: O(4)

⇓

nucleated bubble: O(3,1)
=open universe



Our Universe was born out of quantum tunneling!

- two possibilities

1. inflation after tunneling was short enough (N~60)

$$1-\Omega_0 = 10^{-2} \sim 10^{-3}$$ "open universe"

➡ signatures in large angle CMB anisotropies

Yamauchi, Linde, Naruko, Tanaka & MS (2011)

2. inflation after tunneling was long enough (N>>60)

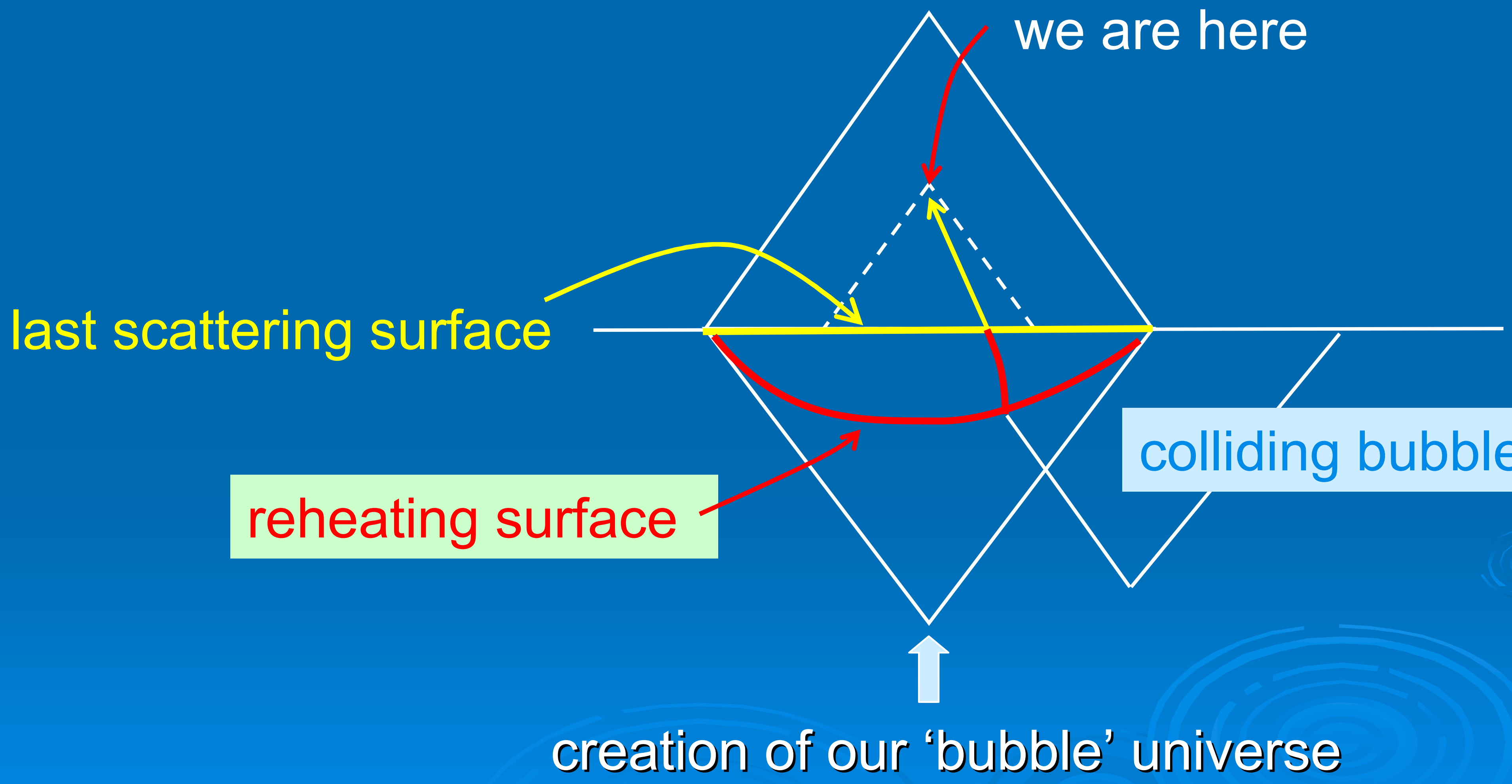
$$1-\Omega_0 \ll 1$$ "flat universe"

➡ signatures from bubble collisions

Sugimura, Yamauchi & MS (2012)

Sugimura's talk: parallel session on Monday

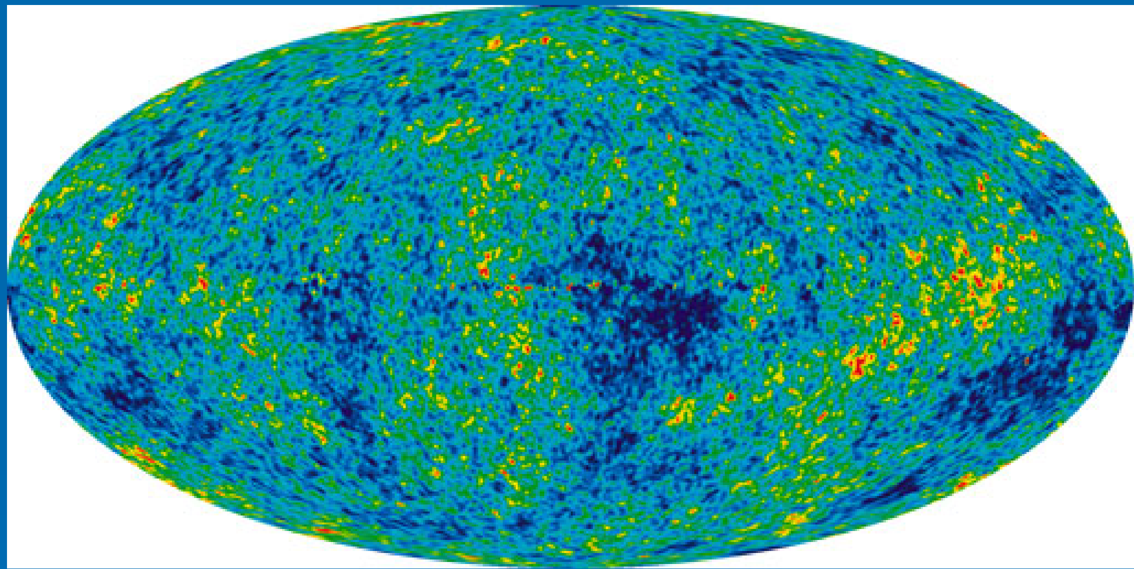
trace of bubble collisions



➢ simple model

- no (spherically symmetric) bubble seen in the CMB map

⇎ negligible effect on curvature perturbation (~Newton potential) at leading order



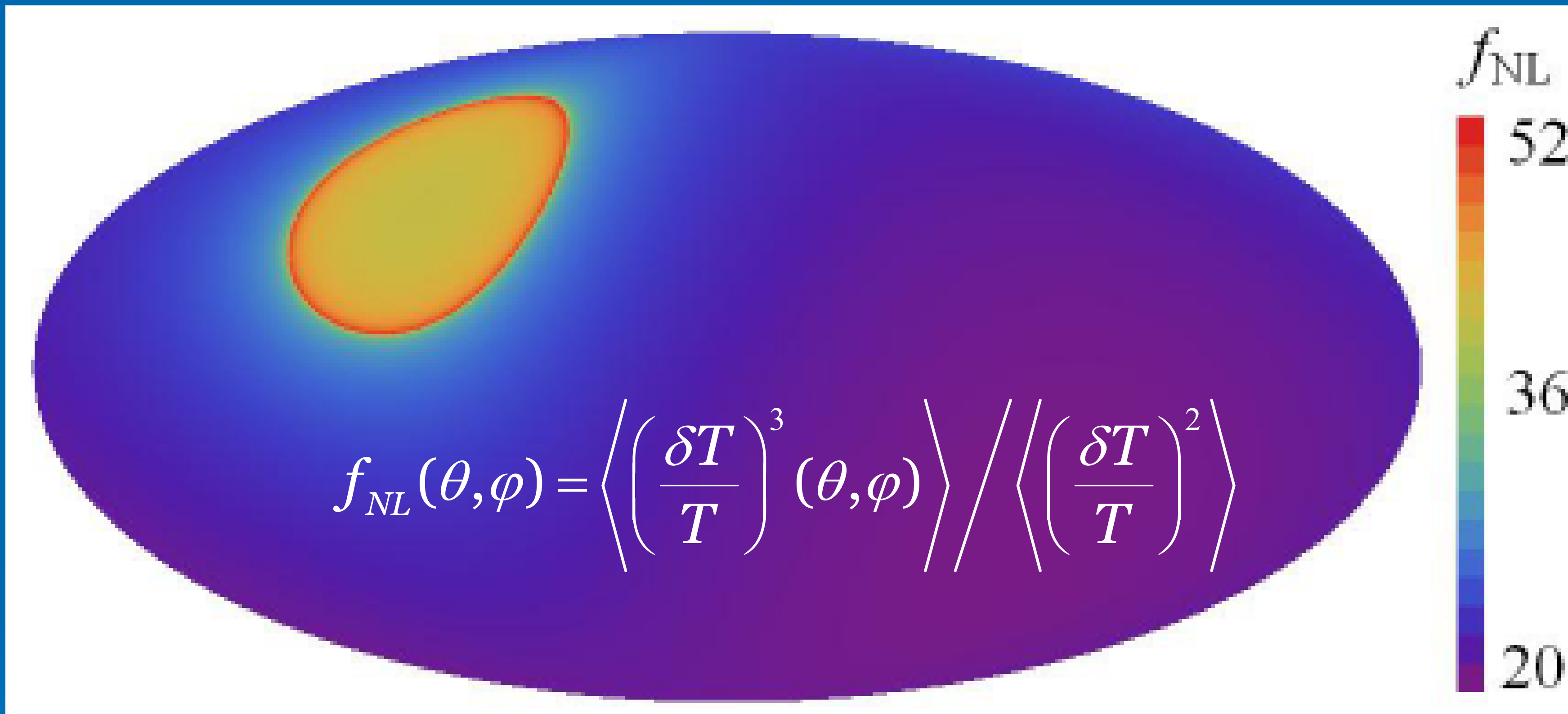
bubbles may be seen as "localized" non-Gaussianity

$$\Phi(x) = \Phi_{Gauss}(x) + \underline{f_{NL}(x)}\Phi^2_{Gauss}(x) + \ldots$$

↑ space-dependent

Non-Gaussian bubbles in the CMB Sky

Sugimura, Yamauchi & MS (2012)



detection of a spherically symmetric “localized” non-Gaussianity will be the first observational signature of string theory!

Summary without summary...

We are entering an era of

precision cosmology

gravitational wave astronomy

any tiny deviation from GR would be revolutionary

develop 'realistic' GR cosmology

perturbative, non-perturbative, numerical, observational...

continued to T Futamase's talk