Encounters with Jihn E. Kim

Hans Peter Nilles

Bethe Zentrum für Theoretische Physik (bctp)

Physikalisches Institut, Universität Bonn

universitätbonn

bctp Bethe Center for Theoretical Physics

Outline

Jihn E. Kim and myself had a long friendship and fruitful collaboration. Here some recollections of our encounters

- Virtual encounter in Bonn in 1974
- Some work prior to 1983: axions and neutral currents
- Visit of Jihn to CERN in 1983-84
- Th μ-problem and the Strong CP-problem

My visit to Korea in summer 1984

- the land of the morning calm
- Seoul, SNU and the students
- Mount Sorak meeting

Outline

Interactions in 1987

- Kim at CERN and orbifold model building
- My visit to Korea

My move to Munich in 1988

- joint KOSEF-DFG exchange grant and student exchange
- more meetings in Korea and Europe
- Quintessential axion
- Kim-Nilles-Peloso axion alignment

Further fruitful collaboration with Kim and Choi

Virtual encounter 1974

Lecture Notes
in Physics

Edited by J. Ehlers, München, K. Hepp, Zürich and
H. A. Weidenmüller, Heidelberg
Managing Editor: W. Beiglböck, Heidelberg

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Trends in Elementary Particle Theory

International Summer Institute on
Theoretical Physics in Bonn 1974

Edited by H. Rollnik and K. Dietz

International Summer Institute Bonn

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Cologne 1974

Following Years

Jihn E. Kim started his exceptional career

- Peccei Quinn axion for the strong CP-problem
- axion searches in Kaon decay not successful
- axion emission and the stability of the sun
- extension of the axion sector necessary
- increase axion scale f_A to value larger than 10^9 GeV
- Jihn Eui Kim as the father of the "invisible" axion

Further influential work particularly in 1980:
Review about theory and experiment of weak neutral currents.

Kim Axion 1979

Weak-Interaction Singlet and Strong *CP* Invariance

Jihn E. Kim
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104
(Received 16 February 1979)

Strong *CP* invariance is *automatically* preserved by a spontaneously broken chiral $U(1)_4$ symmetry. A weak-interaction singlet heavy quark Q, a new scalar meson σ^0, and *a very light axion* are predicted. Phenomenological implications are also included.

Recent attempts[1-4] to incorporate the observed *CP*-invariance violation[5] in unified gauge theories of the weak and electromagnetic interactions can be classified into three broad categories:

(i) *Hard CP-invariance violation.*—The Lagrangian itself violates *CP* invariance, i.e., it contains complex Yukawa or scalar self-coupling constants. Though the exact meaning of *CP*-invariance property can only be given after all the physical particles acquire masses, one may include theories with complex coupling constants in this category. Effective complex gauge-boson couplings to quarks[1] and the complex Higgs scalar couplings[2] of Weinberg belong to this category.

(ii) *Dynamical CP-invariance violation.*—The theory conserves *CP* in the tree approximation, but it is not conserved when radiative corrections are included.[3] This theory is attractive in the sense that it automatically gives a small *CP*-invariance–violating phase, but has a drawback in the uncertainty of estimating radiative corrections. Further, there is a danger of too small[6] a *CP*-invariant–violating phase in the final result.

(iii) *Spontaneous CP-invariance violation.*—Before spontaneous symmetry breaking, the Lagrangian conserves *CP*, i.e., one can always find appropriate *CP* phases for various fields which made the Lagrangian *CP* invariant. In general, we can start with real coupling constants. The spontaneous symmetry breaking introduces complex vacuum expectation values which make the final Lagrangian *CP*-invariance violating.[4]

I wish to point out that a *simple* theory should belong to one of these classifications for *completeness* of the gauge theory of weak and electromagnetic interactions. (Of course, one can treat the *CP*-invariance violation separately from the known weak- and electromagnetic-interaction theory by introducing a superweak interaction.[7])

For some time, the above picture of weak and electromagnetic interactions had not seemed to induce any difficulties when quantum chromodynamics (QCD) was considered as the gauge theory of strong interactions. However, the recently discovered instanton solutions of QCD and associated quantum effects[8] lead to an effective interaction

$$\mathcal{L}_{\text{int}} = (\theta/32\pi^2) F_{\mu\nu}{}^a \tilde{F}^{a\mu\nu}, \tag{1}$$

which violates both *P* and *T* invariance but preserves *C* invariance. A limit on the parameter θ is about $<10^{-9}$–10^{-10} from a recently given bound on the electric dipole moment of neutron, $d_n < 1.24 \times 10^{-25}\ e \cdot \text{cm}$. To guarantee strong *CP* invariance *automatically*, Peccei and Quinn ob-

A theoretical and experimental review of the weak neutral current: a determination of its structure and limits on deviations from the minimal $SU(2)_L \times U(1)$ electroweak theory

Jihn E. Kim, Paul Langacker, M. Levine, and H. H. Williams

Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

A detailed analysis of existing neutral-current data has been performed in order (a) to determine as fully as possible the structure of the hadronic and leptonic neutral currents without recourse to a specific weak-interaction model; (b) to search for the effects of small deviations from the Weinberg-Salam (WS-GIM) model; and (c) to determine the value of $\sin^2\theta_w$ as accurately as possible. The authors attempt to incorporate the best possible theoretical expressions in the treatment of each of the reactions. For deep-inelastic scattering, for example, the effects of quantum chromodynamics, including the contributions of the s and c quarks, have been included. The sensitivity of the results both to systematic uncertainties in the data and to theoretical uncertainties in the treatment of deep-inelastic scattering, semi-inclusive pion production, ν elastic scattering from protons, and the asymmetry in polarized eD scattering have been considered; the systematic errors are generally found to be smaller than the statistical uncertainties. In the model-independent analyses the authors find that the hadronic neutral-current parameters are uniquely determined to lie within a small domain consistent with the WS-GIM model. The leptonic couplings are determined to within a twofold ambiguity; one solution, the axial-vector-dominant, is consistent with the WS-GIM model. If factorization is assumed then the axial-dominant solution is uniquely determined and null atomic parity violation experiments are inconsistent with other neutral-current experiments. Within generalized $SU(2)\times U(1)$ models we find the following limits on mixing between right-handed singlets and doublets: $\sin^2\alpha_u \leq 0.103$, $\sin^2\alpha_d \leq 0.348$, and $\sin^2\alpha_e \leq 0.064$. Assuming these mixing angles to be zero, a fit to the most accurate data (deep-inelastic and the polarized eD asymmetry) yields $\rho = 0.992 \pm 0.017$ (± 0.011) and $\sin^2\theta_w = 0.224 \pm 0.015$ (± 0.012), where $\rho = M_W^2/M_Z^2 \cos^2\theta_w$ and the numbers in parentheses are the theoretical uncertainties. The value of ρ is remarkably close to 1.0 and strongly suggests that the Higgs mesons occur only as doublets and singlets. If one makes this assumption, then the limit on ρ implies $m_L \leq 500$ GeV, where m_L is the mass of any heavy lepton with a massless partner. In addition, for $\rho = 1.0$, the authors determine $\sin^2\theta_w = 0.229 \pm 0.009$ (± 0.005). Fits which also include the semi-inclusive, elastic, and leptonic data yield very similar results. A two-parameter fit gives $\rho = 1.002 \pm 0.015$ (± 0.011) and $\sin^2\theta_w = 0.234 \pm 0.013$ (± 0.009), while a one-parameter fit to $\sin^2\theta_w$ gives $\sin^2\theta_w = 0.233 \pm 0.009$ (± 0.005). Finally, the authors have found no evidence for a violation of factorization or for the existence of additional Z bosons. Fits to two explicit two-boson models yield the lower limits $M_{Z_2}/M_{Z_1} > 1.61$ and 3.44 for the mass of the second Z boson. The desirability of a complete analysis of radiative and higher-order weak corrections, which have not been included in the authors' theoretical uncertainties, is emphasized.

Meanwhile

My encounter with axions in 1981:

- it was the time of early attempts to construct supersymmetric models
- Peccei-Quinn axion essentially ruled out
- extension of axion sector needed
- paper with Stuart Raby at SLAC
- invisible axion in a supersymmetric grand unified model
- first appearance of the axino

Supersymmetric model building became an important aspect in particle physics

Susy and the Axion 1981

SLAC-PUB-2743
May 1981
(T/E)

SUPERSYMMETRY AND THE STRONG CP PROBLEM*

H. Peter Nilles† and Stuart Raby#
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

We show how supersymmetric grand unified theories (SSGUT) provide a natural solution to the strong CP problem. Such theories contain an additional global $U(1)_{PQ}$ chiral (Peccei-Quinn) symmetry which is conserved up to color anomalies. Hence the QCD θ angle is irrelevant. Moreover the PQ symmetry is spontaneously broken at the grand unified scale. As a result the standard Weinberg-Wilczek axion has a mass

$$m_a \sim \frac{\Lambda_{QCD}^2}{\Lambda_{GUM}} \sim 10^{-10}\ \text{eV}$$

which effectively decouples from ordinary matter.

(Submitted to Nuclear Physics B)

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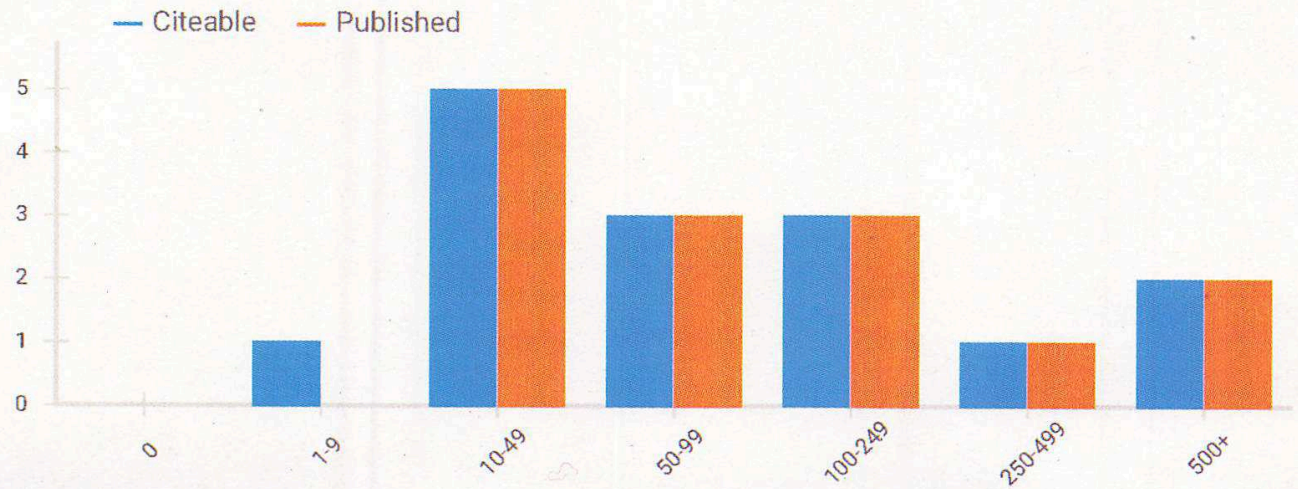
* Work supported by the Department of Energy, contract DE-AC03-76SF00515.
† Supported by the Deutsche Forschungsgemeinschaft.
# Supported by National Science Foundation Grant PHY78-26817.

We met in Geneva 1983

Citation Summary

Exclude self-citations

	Citeable	Published
Papers	15	14
Citations	2,925	2,918
h-index	13	13
Citations/paper (avg)	195	208.4



It was the starting point for a long and fruitful collaboration.

Geneva 1983

Visit of Kim to CERN

- SUSY model building, in particular gravity mediation
- Just started to write my Physics Reports
- Discussions with Jihn on axions in SUSY models
- Discussions about the role of string theory

The μ-problem in supersymmetric models

- needs new symmetry to control
- coincidence of "axion window" with scale of SUSY breakdown $M_{\rm SUSY}$
- μ of order of the gravitino mass $m_{3/2} \sim M_{\rm SUSY}^2/M_{\rm Planck}$

1983: Axion and the μ-problem

UNIVERSITÉ DE GENÈVE

SCHOLA GENEVENSIS MDLIX

The μ-problem and the strong CP-problem

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CERN, Genève, Switzerland

and

H.P. Nilles

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1211 Genève 4, Switzerland

UGVA-DPT 1983/10-410

Abstract

We investigate a possible connection of a solution of the strong CP-problem and the generation of a mass term μ in the low energy Higgs superpotential of supersymmetric models. This possibility comes from the fact that both supersymmetry and the Peccei Quinn symmetry (to give an acceptable invisible axion) are broken at the same scale.

* On leave from Department of Physics, Seoul National University, Seoul 151, Korea

Volume 138B, number 1,2,3 PHYSICS LETTERS 12 April 1984

THE μ-PROBLEM AND THE STRONG *CP*-PROBLEM

Jihn E. KIM [1]
CERN, Geneva, Switzerland

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Received 24 November 1983

We investigate a possible connection of a solution of the strong *CP*-problem and the generation of a mass term μ in the low energy Higgs superpotential of supersymmetric models. This possibility comes from the fact that both supersymmetry and the Peccei–Quinn symmetry (to give an acceptable invisible axion) are broken at the same scale.

Our "most influential" paper

Summer 1984: Visit to Korea

For me this was an exotic experience

- the land of the "morning calm"
- the weather and the food
- "unknown" companies:
  Hyundai, Daewoo, Samsung, LG, Lotte
- Hotel Sam Jung and temple Pongunsa

Seoul National University

- seminars at other places around the city
- students Choi and Hong

Touristic experiences

Mount Sorak meeting

PROCEEDINGS OF THE THIRD SYMPOSIUM ON THEORETICAL PHYSICS

Mt. Sorak, July 30 – August 3, 1984

SUPERSYMMETRY

EDITED BY H.S. SONG

Department of Physics, Seoul National University

Mount Sorak meeting 1984

머 리 말

제 3 회 이론물리학 심포지움은 1984 년 7 월 30 일부터 8 월 3 일까지 사십여명의 물리학자들이 모인 가운데 설악산의 파크 호텔에서 성황리에 열렸고 12 월 10, 11 일 양일간에 서울대학교에서 또한 추가 강의가 있었다.

이번 심포지움의 주제는 초대칭성 (超對稱性) 으로 정하였다. 이 분야는 입자물리학의 주된 연구 대상 중의 하나이고 최근 많은 국내학자들이 관심을 가지고 연구하고 있는 분야이기도 하다.

심포지움은 지난 1, 2 회에서와 마찬가지로 주제 강연과 세미나로 이루어졌다. 주제강연에서는 이 분야에서 활발히 연구하고 계신 여섯분의 연사가 각기 3 시간씩의 강연을 하였으며 특히 제네바 대학의 Nilles 교수와 존스홉킨스 대학의 김정욱 교수의 명쾌한 강연은 심포지움의 큰 활력소가 되었다. 앞으로는 세계각국에서 보다 많은 물리학자를 초청하여 이 심포지움을 명실공히 국제적인 모임으로 발전시키는 것이 우리의 바람이다. 세미나에서는 참석자들 중에서 열두분이 연구발표를 하여 주셨다. 이 책자는 주제 연사의 강연을 토대로 만들어졌으며 이에 협조하여 주신 연사님들께 감사를 드린다.

또한 제 1 회부터 계속 이론물리학 심포지움에 재정적인 도움을 주고 있는 대우재단과 이번 이 책자를 출판하여 준 서울대학교 출판부에도 심심한 사의를 표하는 바이다.

1984 년 12 월

이론물리학 심포지움 편집인

머 리 말

제 3 회 이론물리학 심포지움은 1984 년 7 월 30 일부터 8 월 3 일까지 사십여명의 물리학자들이 모인 가운데 설악산의 파크 호텔에서 성황리에 열렸고 12 월 10,11 일 양일간에 서울대학교에서 또한 추가 강의가 있었다.

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Mount Sorak 1984

Waiting for the bus

In the mountains

Temples

Temples

Jihn at CERN again in 1987

String theory had reached particle physics

- after Scherk-Schwarz paper
  and the construction of the heterotic string in 1984
- orbifold compactification by
  Dixon, Harvey, Vafa and Witten in 1985
- Wilson lines by Ibanez, Quevedo and myself in 1986
- WL allow controlled breakdown of gauge symmetries
  and the reduction of the number of families to 3
- Jihn insisted to construct an explicit model

The result was the first "semi"-realistic model with standard model gauge group and 3 families of quarks and leptons

Standard Model from Strings

CERN-TH.4661/87

ORBIFOLD COMPACTIFICATIONS WITH THREE FAMILIES OF SU(3) × SU(2) × U(1)^n

L.E. Ibàñez, Jihn E. Kim*), H.P. Nilles and F. Quevedo

CERN — Geneva

ABSTRACT

We construct several N = 1 supersymmetric three-generation models with SU(3) × SU(2) × U(1)^n gauge symmetry, obtained from orbifold compactification of the heterotic string in the presence of constant gauge-background fields. This Wilson-line mechanism also allows us to eliminate extra colour triplets which could mediate fast proton decay.

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*) Permanent address: Dept. of Physics, Seoul National University, Seoul 151, Korea.

CERN-TH.4661/87
February 1987

The Authors in 2015

My second visit to Korea 1987

In summer of 1987 I visited Korea again

- it was the time of the Pre-Olympic games
- Korea had changed a lot already compared to 1984
- but this time I was already accustomed to many things like food and climate
- it allowed me to see more of Korea including the southwestern part

I gave some blackboard lectures at a physics meeting sponsored by the Daewoo foundation somewhere in the city center

Seoul: Daehoo foundation 1987

Kim's place

Move to Munich in 1988

In 1988 I moved from CERN to TUM and MPI in Munich

- joined KOSEF-DFG grant for visits
- extended visit of Jihn and family to Munich
- first student from Korea was Eung Jin Chun
- first visit of student to Korea by Andre Lukas

We had regular visits and exchange with several students including joint papers, among others

- Composite Axion in 1991
- Axino mass in 1992

both with E. J. Chun and Jihn E. Kim

Composite Hidden Sector Axion

SNUTP 91/25
TUM-TH-124/91

A Natural Solution of the μ Problem with a Composite Axion in the Hidden Sector

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Seoul National University, Seoul 151-742, Korea

[3]*Physik Department, Technische Universität München*
D-8046 Garching

[4]*Max-Planck-Institut für Physik*
– Werner-Heisenberg-Institut –
P.O.Box 40 12 12, Munich (Fed. Rep. Germany)

ABSTRACT

Some superstring models with an intermediate scale hidden sector for supersymmetry breaking can provide a global symmetry which induces the needed μ term of the supersymmetric standard model in terms of the hidden sector scale. We discuss the μ problem and its solution within the low energy supersymmetric standard model with an intermediate scale (10^{10}–10^{13} GeV) hidden sector. We also present this realization in an orbifold model with a gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1) \otimes SU(5)_h$ with possible extra $U(1)$'s.

Neuschwanstein

More joint activities

Joint papers

- Choi/Kim/Nilles in March 1994
- Georgi/Kim/Nilles in May 1998

Meanwhile (in fall 1997) I had moved to Bonn.

- we continued with our collaborations between various members of our groups including most notably with Kiwoon Choi, Hyun Min Lee and Kang-Sin Choi
- we visited each other regularly
- and organized various conferences ourselves

KIAS 1998


October 29~30, 1998 KIAS International Conference Hall
KAIST

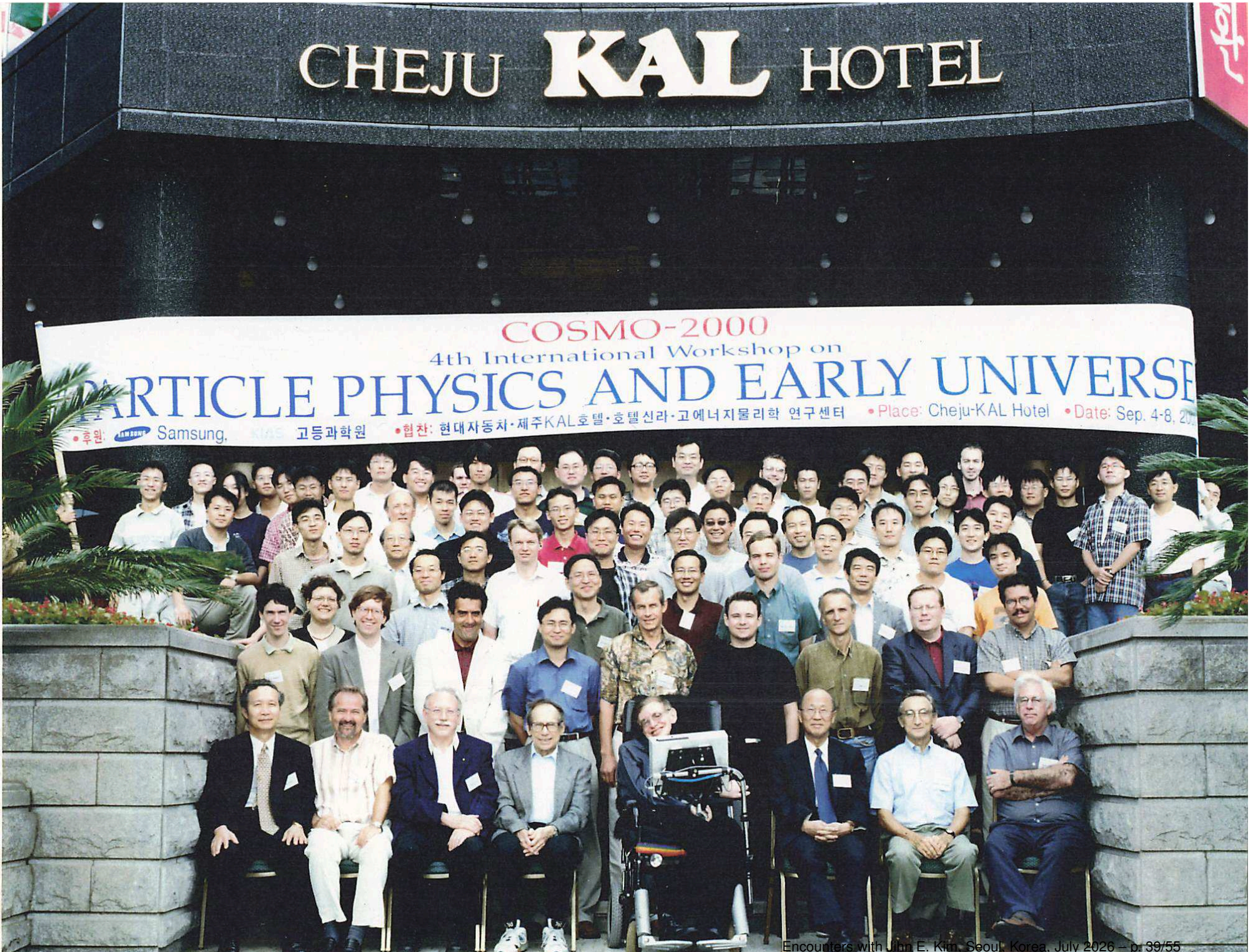
PLANCK99 Bad Honnef

SNU Symposium 1999

SSS−99 International Symposium

Sangsan Math Science Bldg., Seoul National Univ., June 23−26, 1999

Where and When?


CHEJU KAL HOTEL
COSMO-2000
4th International Workshop on
PARTICLE PHYSICS AND EARLY UNIVERSE
•후원: SAMSUNG Samsung, KIAS 고등과학원
•협찬: 현대자동차·제주KAL호텔·호텔신라·고에너지물리학 연구센터
•Place: Cheju-KAL Hotel
•Date: Sep. 4-8, 20

But there was more to come

Meanwhile it was observed that the Universe was undergoing an accelerated expansion

- cosmological constant?
- quintessence field?

Quintessence introduces a light scalar field that would lead to a "fifth force".

- an axion would only have derivative couplings and it avoids this problem
- but it requires a huge axion decay constant to lead to a sufficiently flat potential

Quintessential Axion 2002

SNUTP 02/032

A Quintessential Axion

[a,b]Jihn E. Kim* and [a]Hans-Peter Nilles†
[a] *Physikalisches Institut, Universität Bonn, D-53115 Bonn, Germany, and*
[b] *School of Physics, Seoul National University, Seoul 151-747, Korea*

Abstract

The model independent axion of string theory has a decay constant of order of the Planck scale. We explore the properties of this quintessence candidate (quintaxion) in the scheme of hidden sector supergravity breakdown. In models allowing for a reasonable μ term, the hidden sector dynamics may lead to an almost flat potential responsible for the vacuum energy of $(0.003\ \mathrm{eV})^4$. A solution to the strong CP-problem is provided by an additional hidden sector pseudoscalar (QCD axion) with properties that make it an acceptable candidate for cold dark matter of the universe.

[Key words: axion, quintessence, vacuum energy, hidden sector]

11.40.Mz, 11.30.Rd, 11.30.Pb, 98.80.-k

Extremely flat axion potential

Such a situation had occurred already earlier

- axionic (natural) inflation also requires an axion decay constant as large as (or even larger than) the Planck scale
- gravitational corrections could spoil the flatness of the axionic potential
- there are also restrictions from arguments based on quantum gravity like the weak gravity conjecture

The alignment of axions can solve the problem.

- two axions with sub-Planckian scales can align to create a flat direction with effective super-Planckian scale

Axion Alignment: KNP

Completing natural inflation

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[3] School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA
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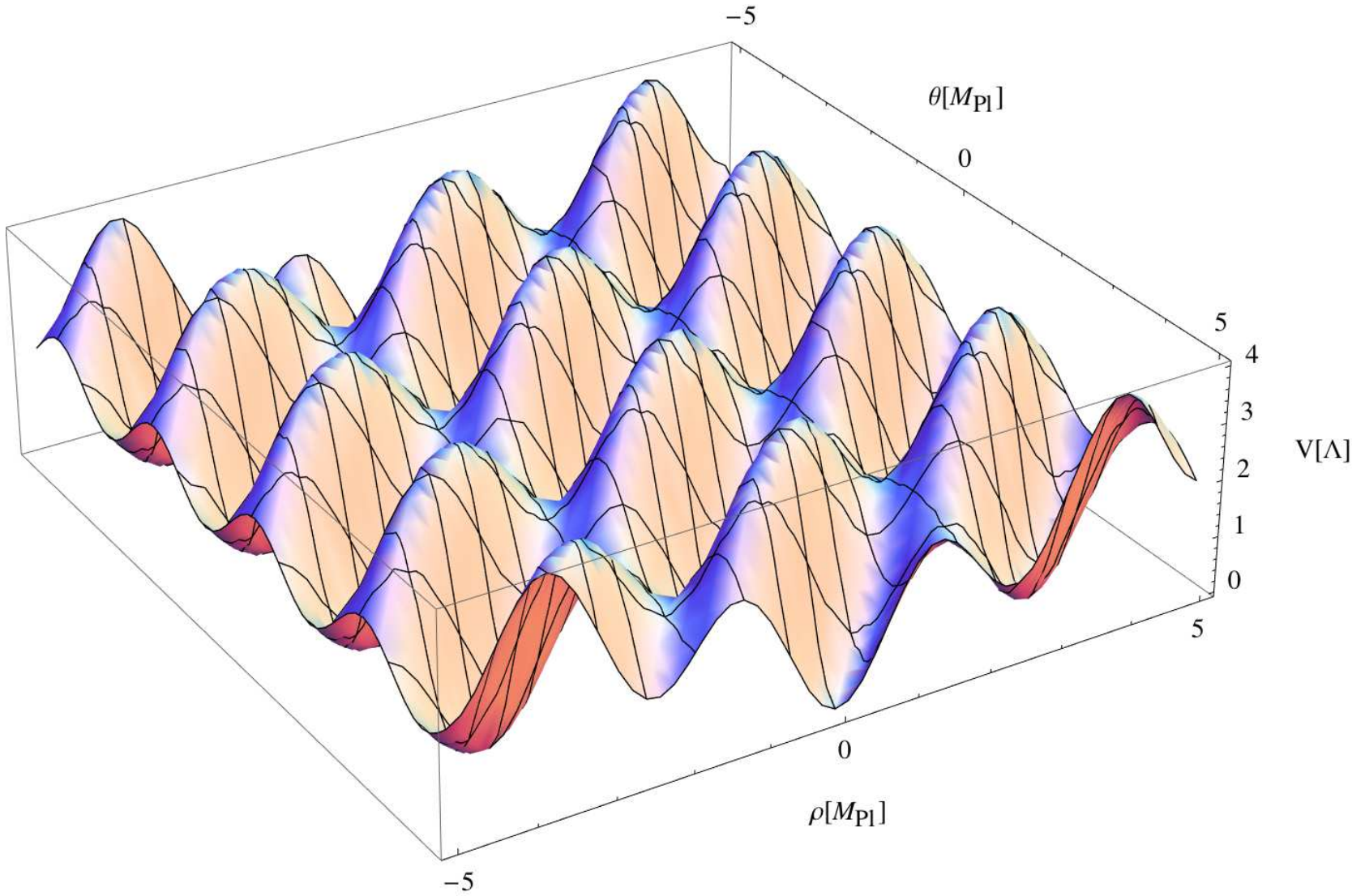
Abstract. If the inflaton is a pseudo-scalar axion, the axion shift symmetry can protect the flatness of its potential from too large radiative corrections. This possibility, known as natural inflation, requires an axion scale which is greater than the (reduced) Planck scale. It is unclear whether such a high value is compatible with an effective field theoretical description, and whether the global axionic symmetry survives quantum gravity effects. We propose a mechanism which provides an effective large axion scale, although the original one is sub-Planckian. The mechanism is based on the presence of two axions, with a potential provided by two anomalous gauge groups. The effective large axion scale is due to an almost exact symmetry between the couplings of the axions to the anomalous groups. We also comment on a possible implementation in heterotic string theory.

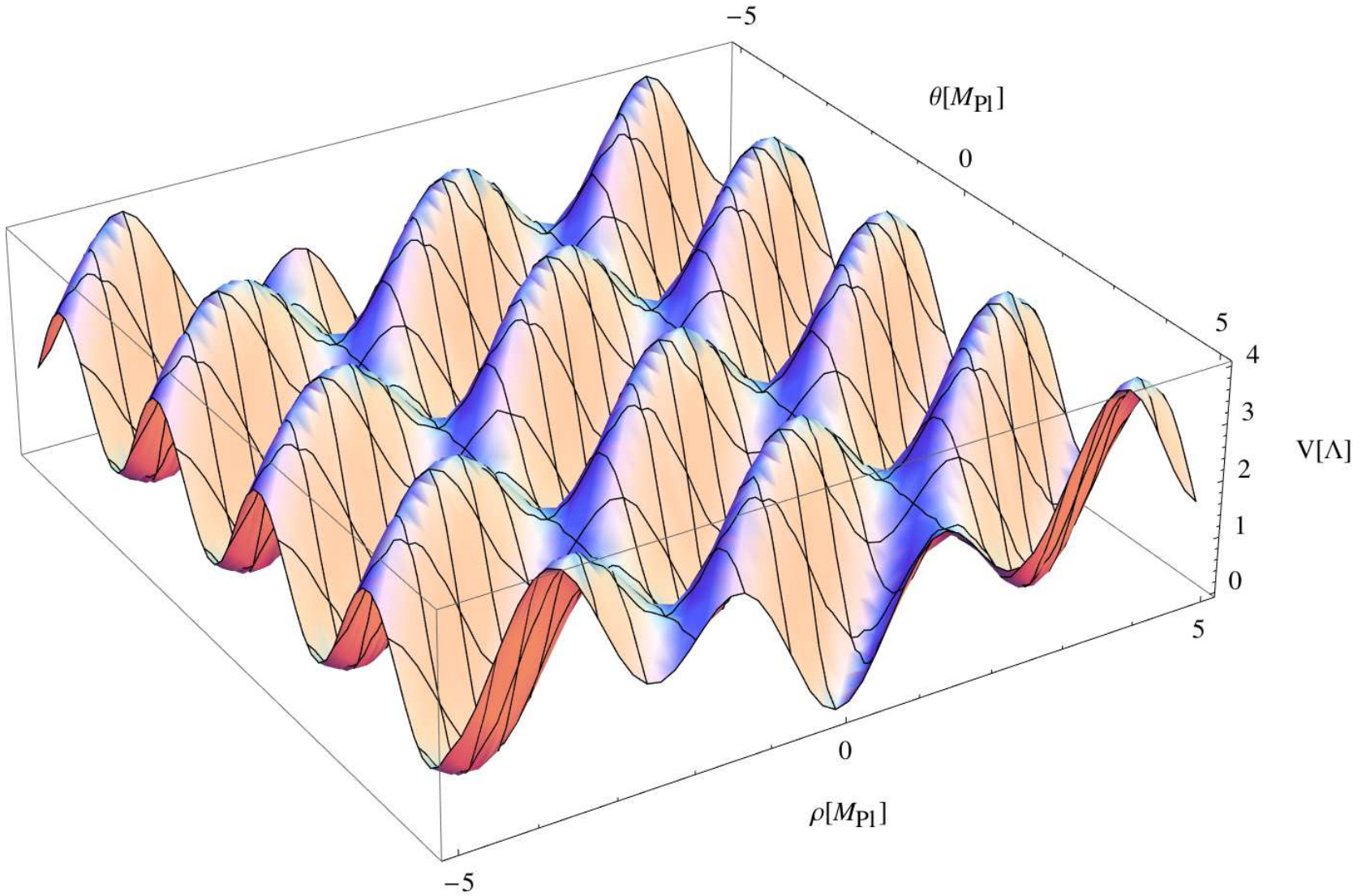
Keywords: inflation, axions

ArXiv ePrint: hep-ph/0409138

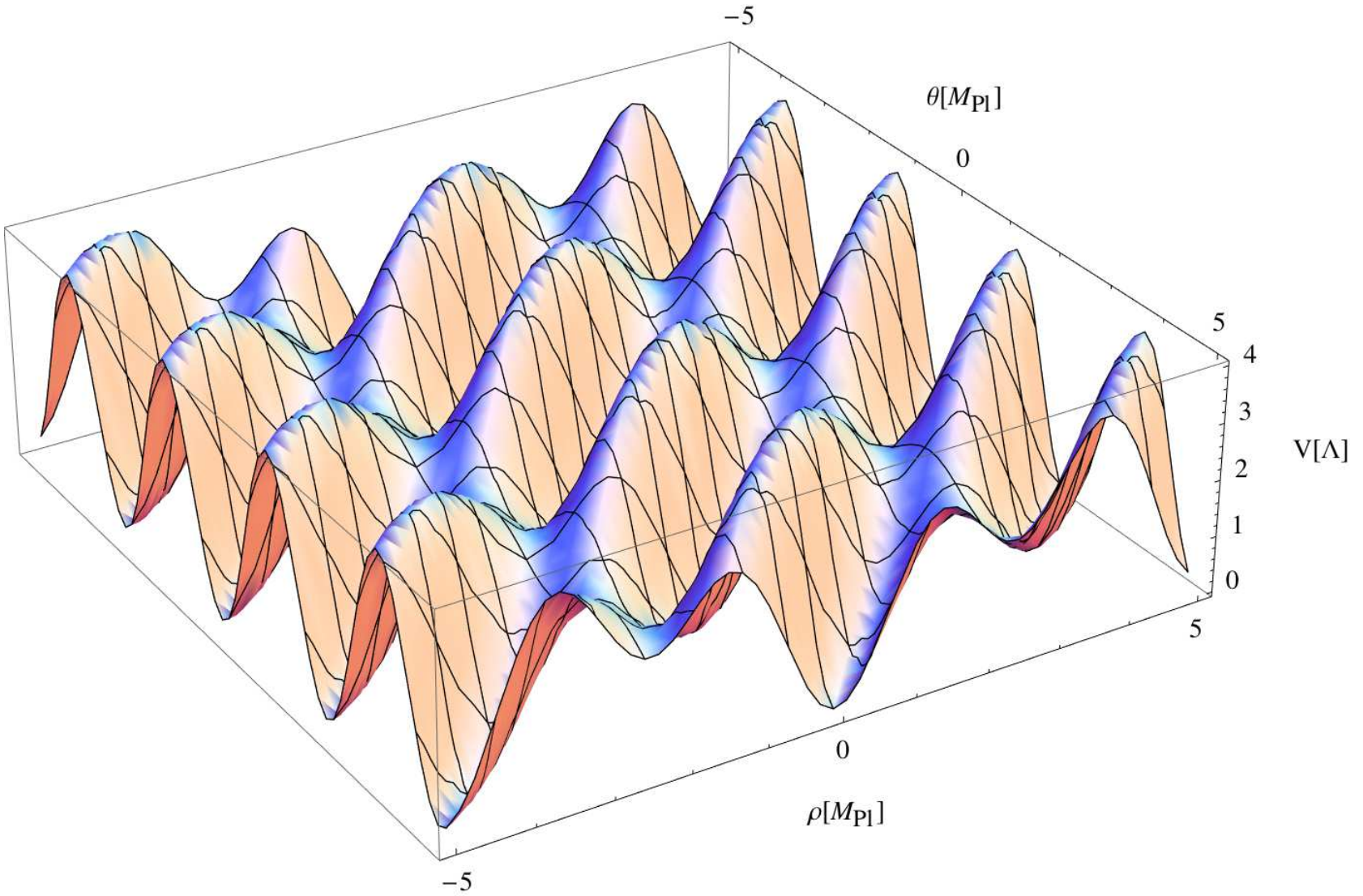
Potential for $\alpha = 1.0$



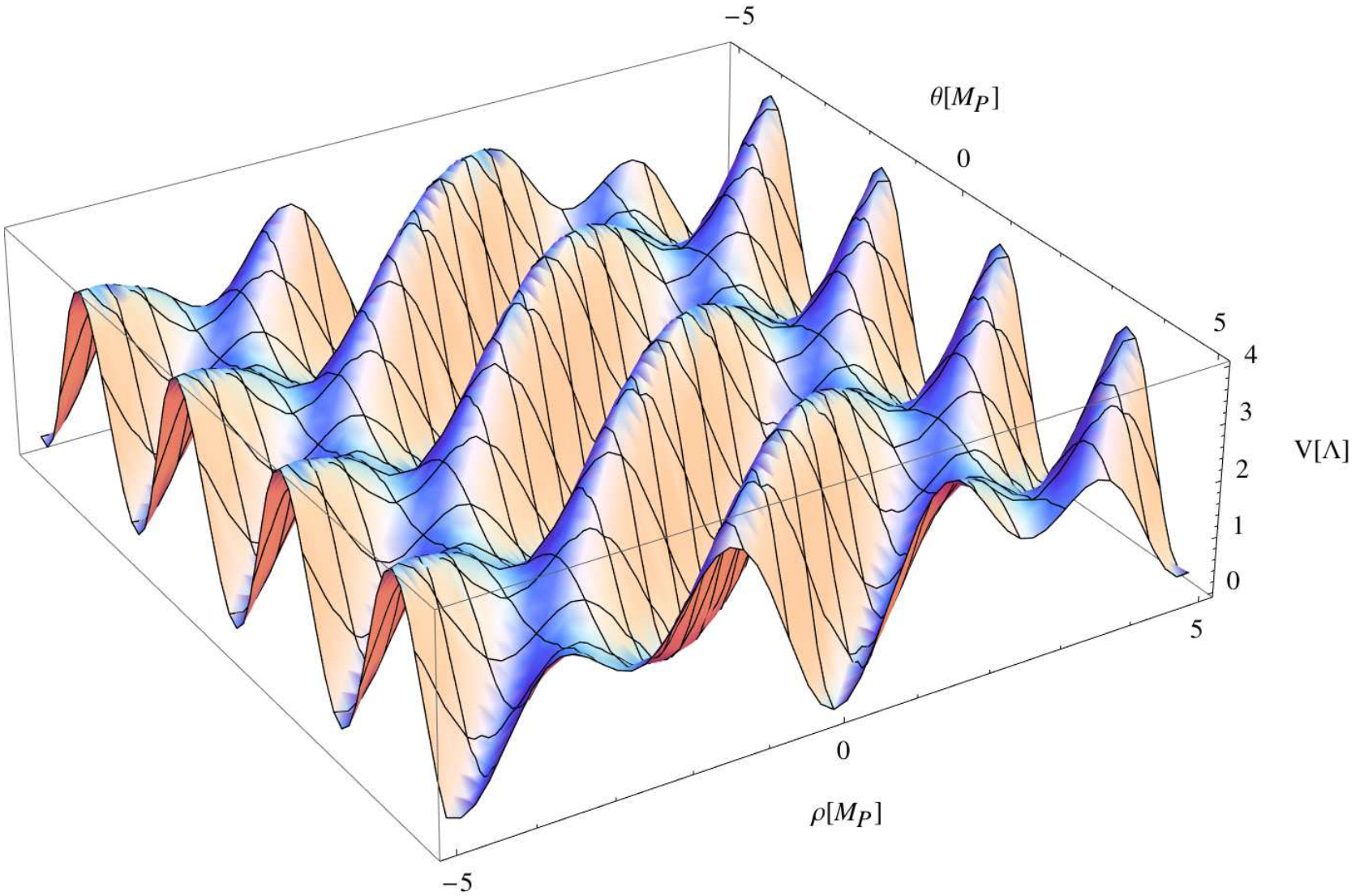
Potential for $\alpha = 0.8$



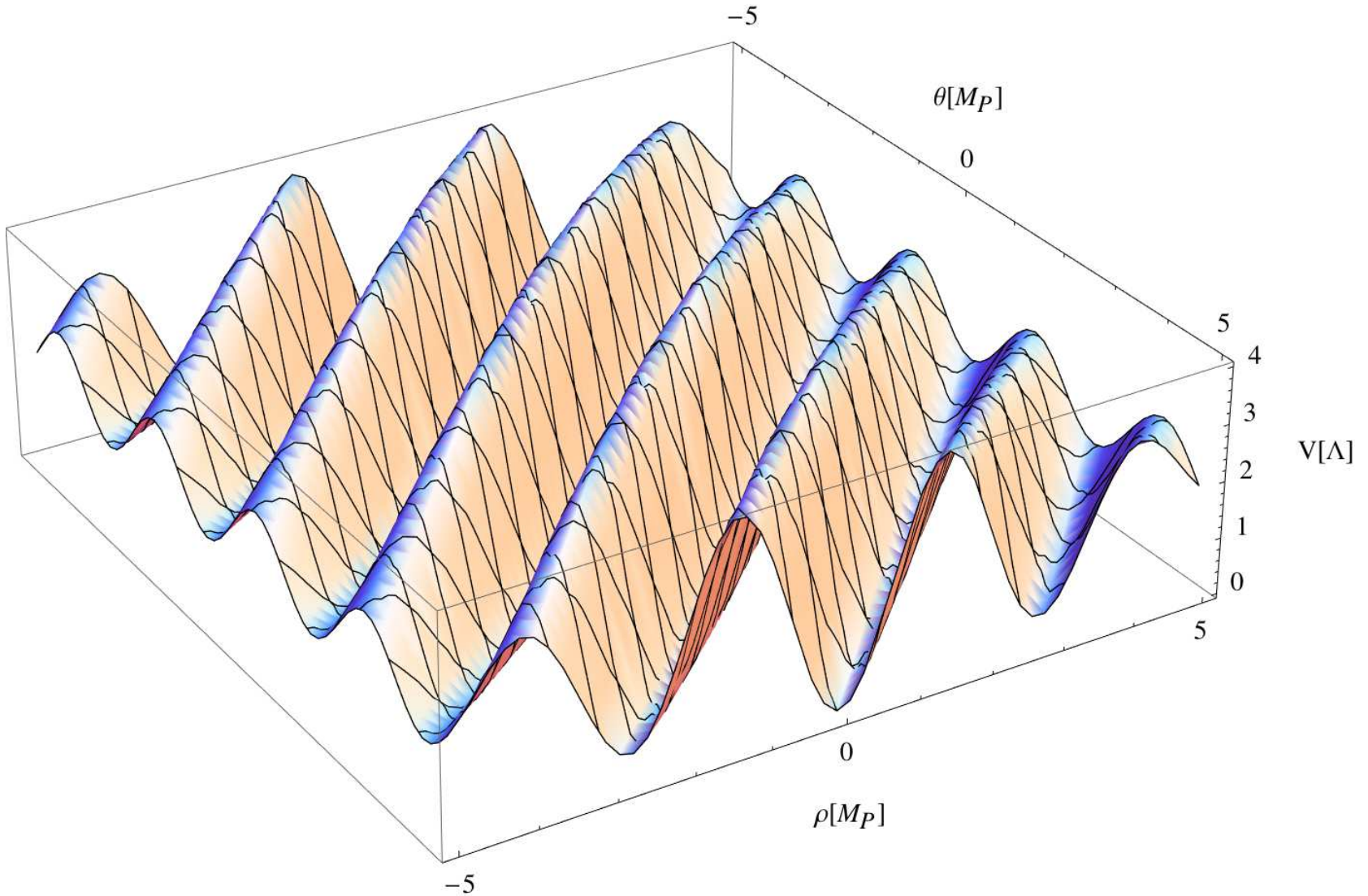
Potential for $\alpha = 0.5$



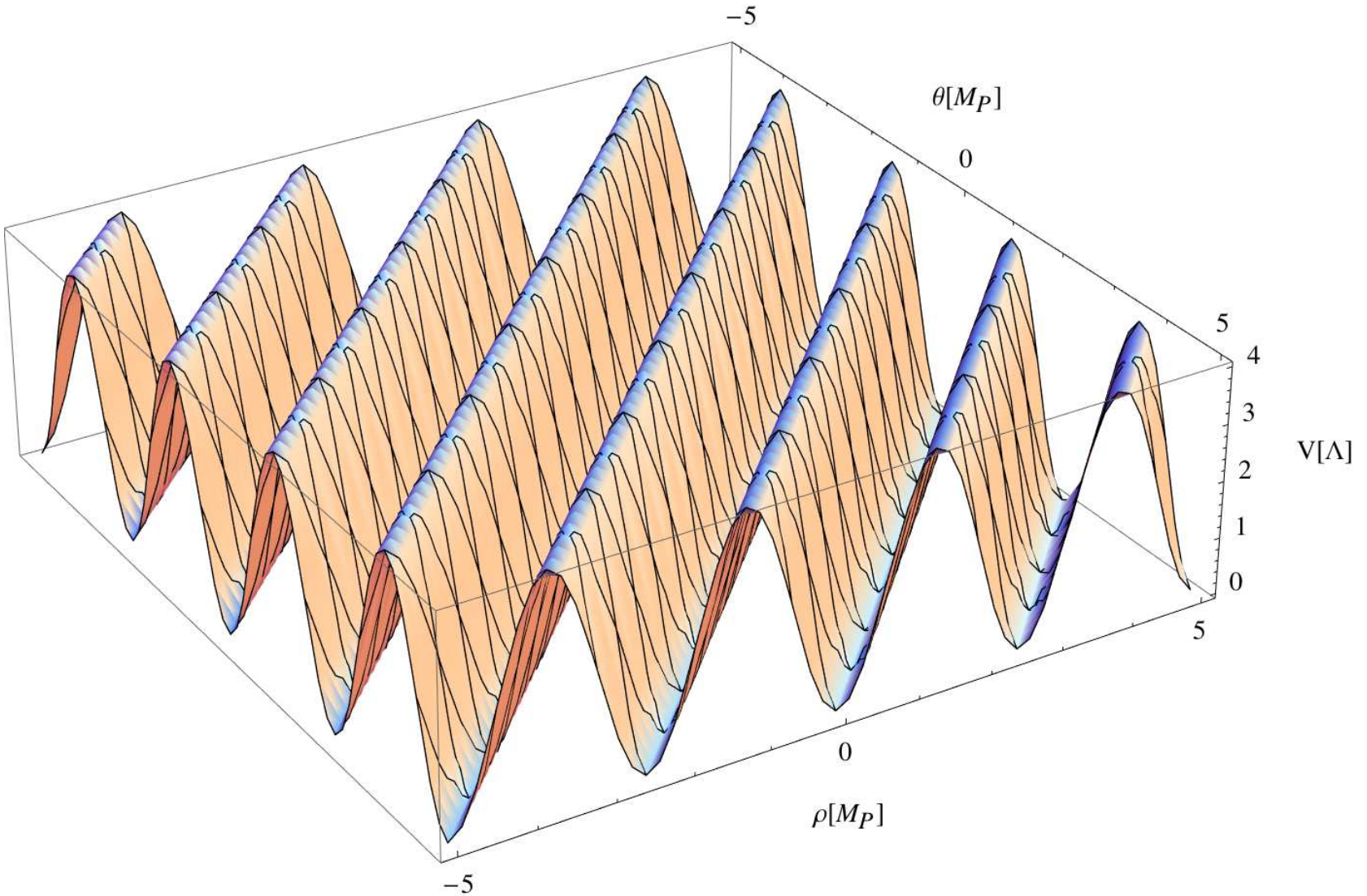
Potential for $\alpha = 0.3$



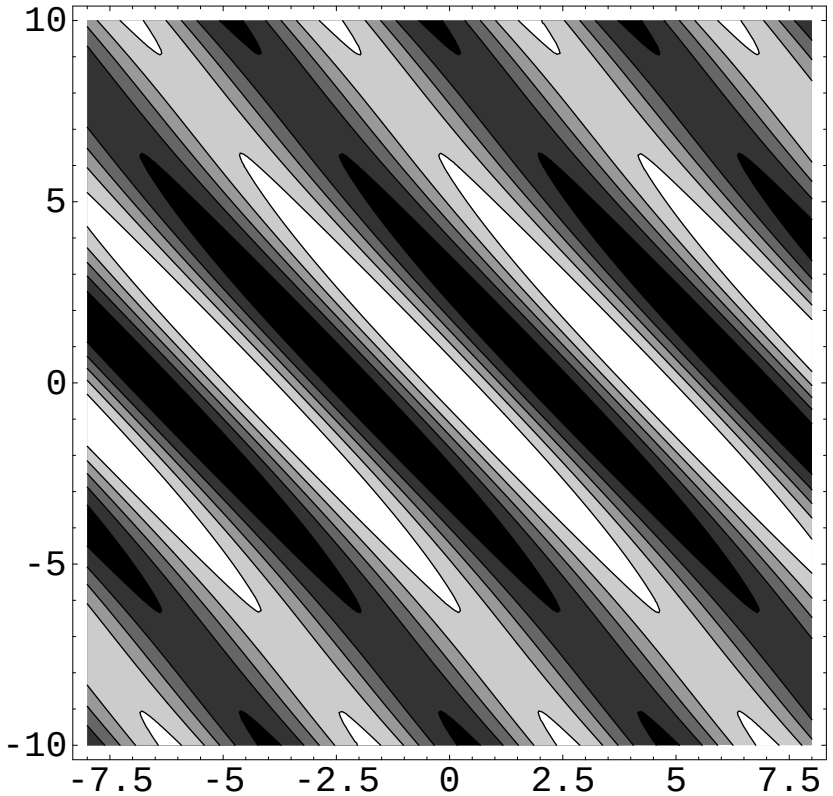
Potential for $\alpha = 0.1$



Potential for $\alpha = 0$



Axion landscape of KNP model



The aligned field ξ rolls within the valley of ψ.
The motion of ξ corresponds to a motion of the original axions θ and ρ over many cycles.

Large tensor modes in CMB

This paper finally received more attention in 2014

- BICEP announced tensor modes as large as $r \sim 0.1$ in the cosmic microwave background
- this has not been confirmed (limits for r much smaller)

But the mechanism could still be useful.

- Kiwoon Choi and Sang Hui Im generalized it to multi-axion systems in 2015
- today it is usually called the "clockwork mechanism"

It might be useful to create a hierarchy of scales in various applications

More collaboration and meetings

In the following years we continued collaboration between Korea and Germany

- several papers with Jihn
- some successful papers with Kiwoon Choi as well

And we kept organizing meetings like

- SUSY 2008 in Seoul and 2010 in Bonn
- Planck 2013 an 2018 in Bonn
- creation of Bethe Center
- creation of the IBS institutes

Thank you for your collaboration and friendschip

Boston 2009

Bonn 2016

Thank you