GP-PU Progress Report :
Overseas Visiting/Axion Portal Monopole Dark Matter

Shu-Yu Ho

Particle Theory and Cosmology Group

D2 Student (B7SD2707)

Advisor : Prof. Fuminobu Takahashi

05/08/2019

Content of my Progress Report

- Required Credits
- Overseas Visiting
- My recent research

Required Credits

- **GPPU seminar**
  - GSP 12 + GASP 6 (18/30)
- **Overseas visiting**
  - Germany 5w + Taiwan 3w + Italy 3w (11w/12w)

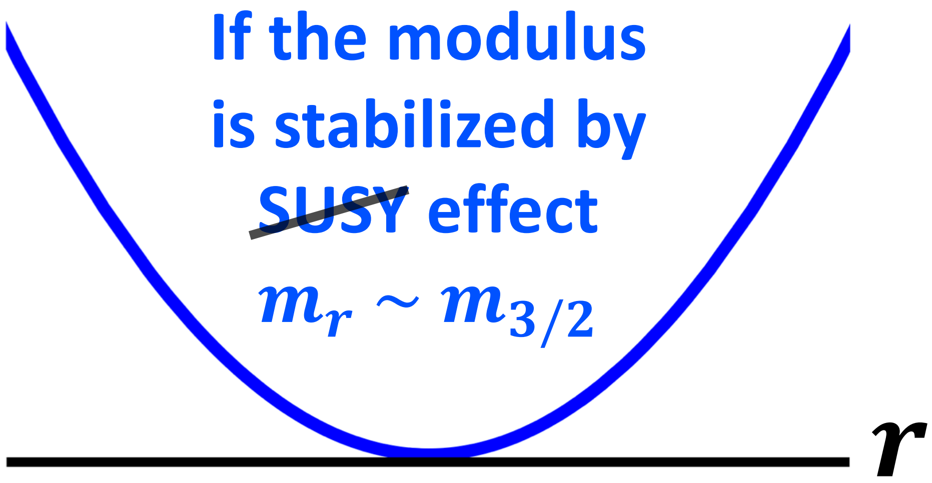
Overseas Visiting

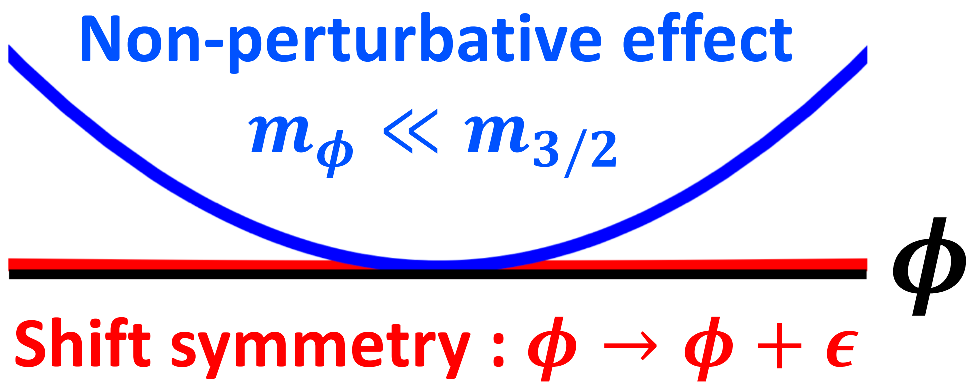
- NCTS (National Center for Theoretical Sciences), Taiwan
  - ✓ 12/26/2018～01/03/2019 (1 week)
  - ✓ The 5th International Workshop on Dark Matter, Dark Energy and Matter-antimatter Asymmetry (Fo Guang Shan, Kaohsiung)
- GGI (Galileo Galilei Institute), Florence, Italy
  - ✓ 01/06/2019～01/27/2019 (3 weeks)
  - ✓ GGI lectures on the theory of fundamental interactions

Modulus Field

- String theory predicts many light scalar moduli fields through compactification.
- In SUSY, a modulus forms a chiral supermultiplet, X.

$$X = r + i\phi$$ Axion





Moduli Abundance

- We consider only one (string) axion ϕ with a potential

$$V(\phi) \simeq \frac{1}{2} m_\phi^2 \phi^2$$

- At $H(t_{osc}) \approx m_\phi$ ⟶ $\rho_{\phi,\,\mathrm{ini}} \simeq \frac{1}{2} m_\phi^2 \phi_{\mathrm{ini}}^2$

$$\Omega_\phi h^2 = \frac{\rho_{\phi,\,\mathrm{ini}}}{\rho_c}\frac{s_0}{s}h^2 \simeq \begin{cases} 3.0\times 10^{10}\left(\dfrac{g_{\star,\mathrm{osc}}}{106.75}\right)^{-1/4}\left(\dfrac{m_\phi}{0.1\,\mathrm{GeV}}\right)^{1/2}\left(\dfrac{\phi_{\mathrm{ini}}}{10^{16}\,\mathrm{GeV}}\right)^2 & \Gamma_{\mathrm{inf}} > m_\phi \\ 2.5\times 10\left(\dfrac{T_{\mathrm{RH}}}{20\,\mathrm{MeV}}\right)\left(\dfrac{\phi_{\mathrm{ini}}}{10^{16}\,\mathrm{GeV}}\right)^2 & \Gamma_{\mathrm{inf}} < m_\phi \end{cases}$$

The axion abundance Ω_ϕ can be suppressed if ϕ_{ini} is sufficiently small.

Cosmological Moduli Problem (CMP)

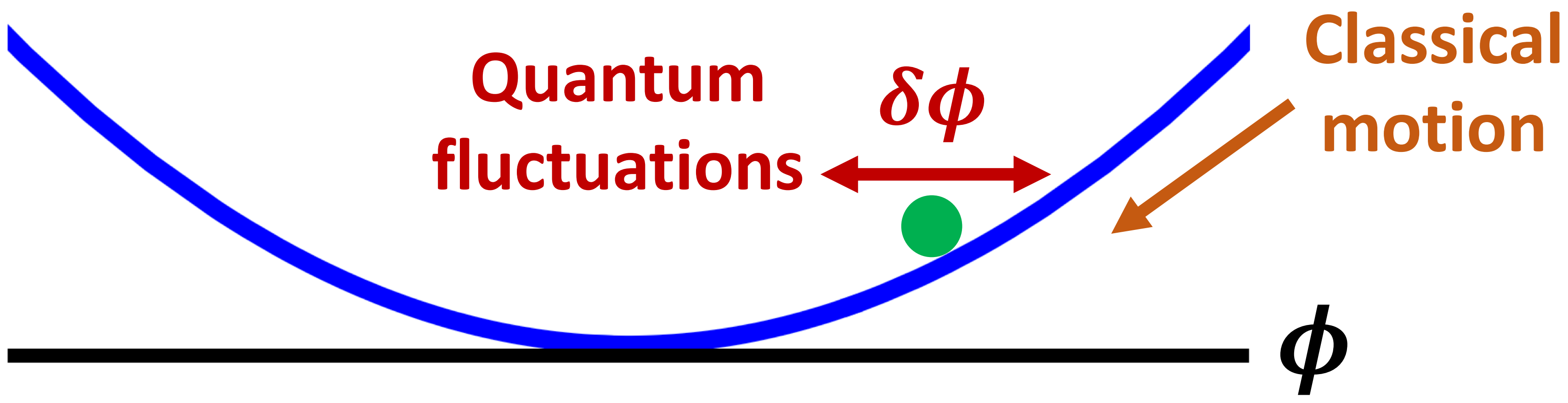
- **If the modulus is stable on a cosmological scale.**
  - ✓ Its abundance may exceed the observed DM density.
- **If the modulus is unstable and can decay into photons.**
  - ✓ It may spoil the success of big bang nucleosynthesis (BBN) due to the photo-dissociation of the light elements.
  - ✓ It may overproduce X-ray or gamma-ray fluxes.

⟶ **moduli problem in cosmology**

Bunch-Davies Distribution

Bunch & Davies `78

- Suppose that the axion already acquires its mass (or potential) during inflation.
- The quantum diffusion prevents the axion from falling into the potential minimum.



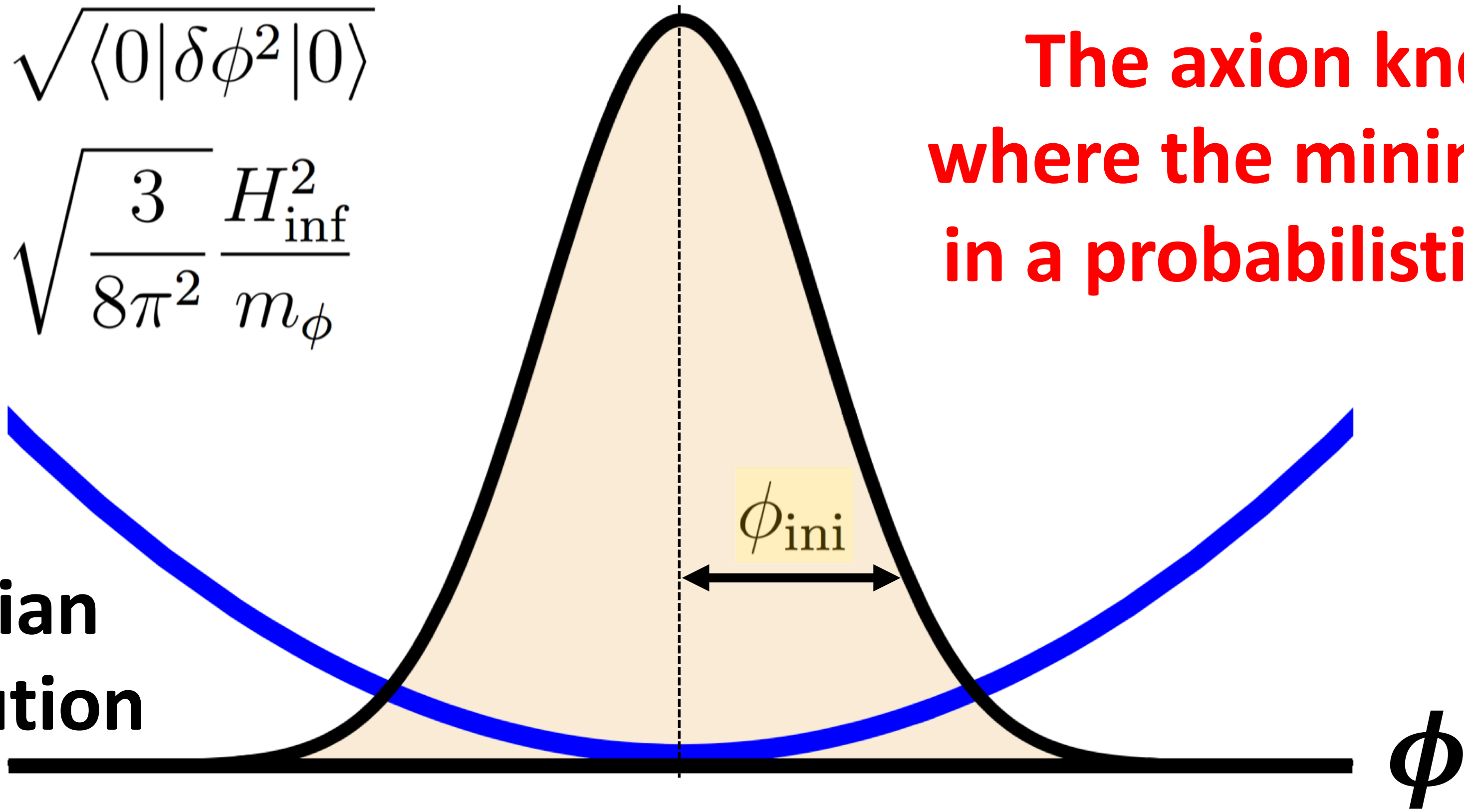
Bunch-Davies Distribution

Bunch & Davies `78

Quantum fluctuations ⟷ Classical motion

$$\phi_{\rm ini} \simeq \sqrt{\langle 0|\delta\phi^2|0\rangle}$$
$$\simeq \sqrt{\frac{3}{8\pi^2}\frac{H_{\rm inf}^2}{m_\phi}}$$

The axion knows where the minimum is in a probabilistic way.



The Axion Abundance with BD Distribution

- **The energy density of the axion with BD distribution**

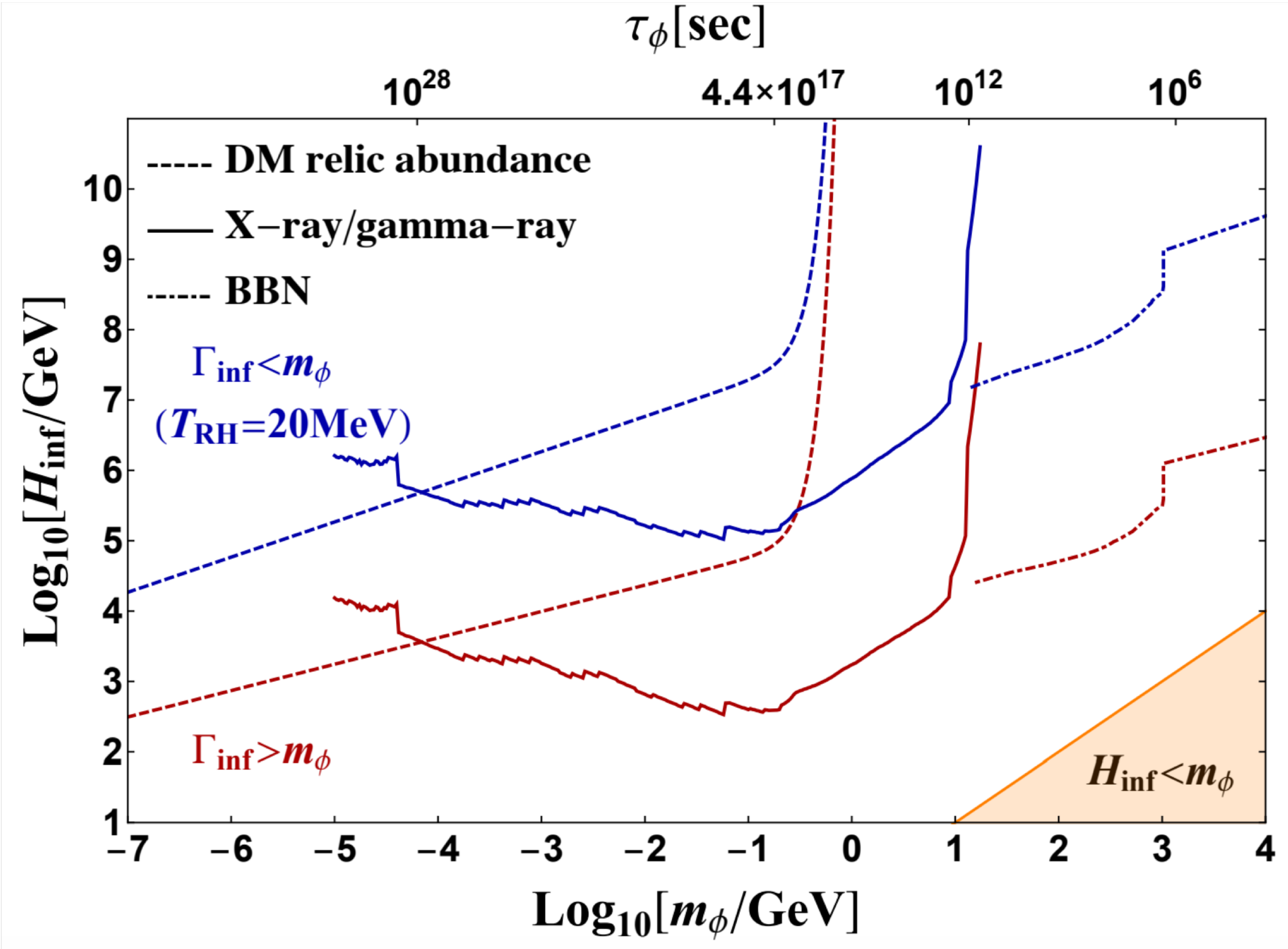
$$\phi_{\rm ini} \simeq \sqrt{\frac{3}{8\pi^2}\frac{H_{\rm inf}^2}{m_\phi}} \;\Longrightarrow\; \rho_{\phi,\,{\rm ini}} \simeq \frac{3}{16\pi^2}H_{\rm inf}^4 \qquad H(t_{\rm osc}) \approx m_\phi$$

- **The axionic moduli problem is relaxed if** $H_{\rm inf} \ll \sqrt{m_\phi f_\phi}$ **.**

$$\Omega_\phi h^2 \simeq \begin{cases} 1.1\times 10^{-20}\,{\rm GeV}\left(\frac{g_{\star,{\rm osc}}}{106.75}\right)^{-1/4}\left(\frac{m_\phi}{0.1\,{\rm GeV}}\right)^{-3/2}\left(\frac{H_{\rm inf}}{\rm GeV}\right)^4 & \Gamma_{\rm inf} > m_\phi \\ 9.6\times 10^{-31}\,{\rm GeV}\left(\frac{T_{\rm RH}}{20\,{\rm MeV}}\right)\left(\frac{m_\phi}{0.1\,{\rm GeV}}\right)^{-2}\left(\frac{H_{\rm inf}}{\rm GeV}\right)^4 & \Gamma_{\rm inf} < m_\phi \end{cases}$$

One can suppress Ω_ϕ by low inflation scale

Upper Bound on $H_{\rm inf}$ for Solving CMP



Overseas Visiting

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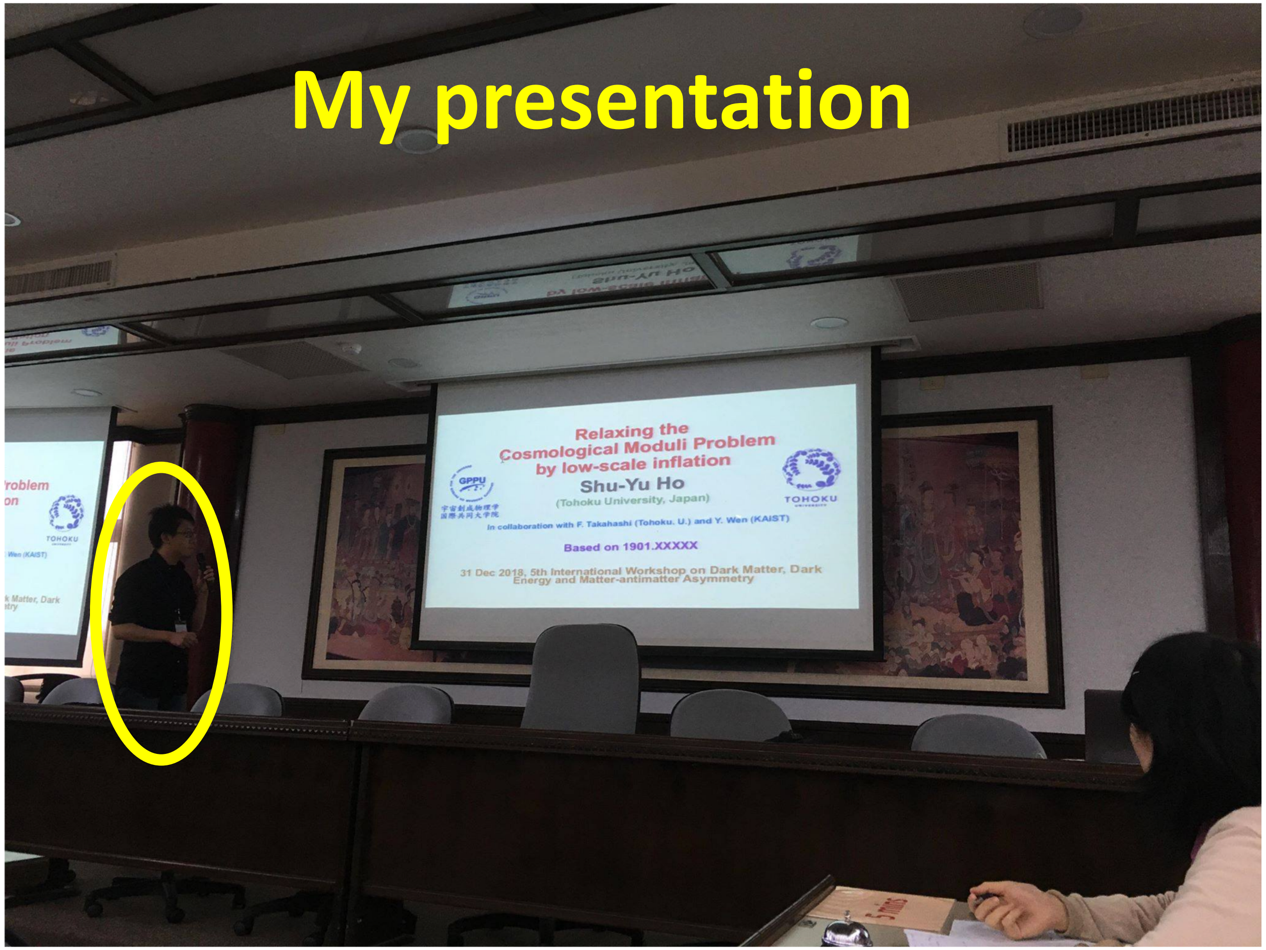

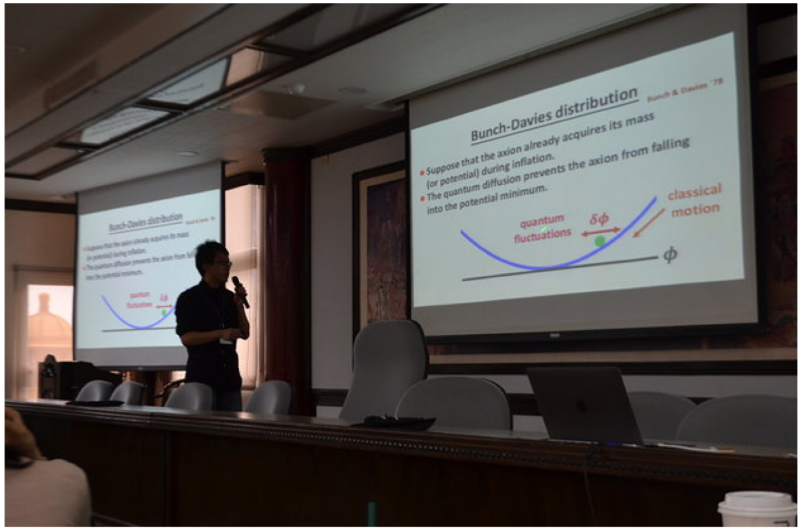

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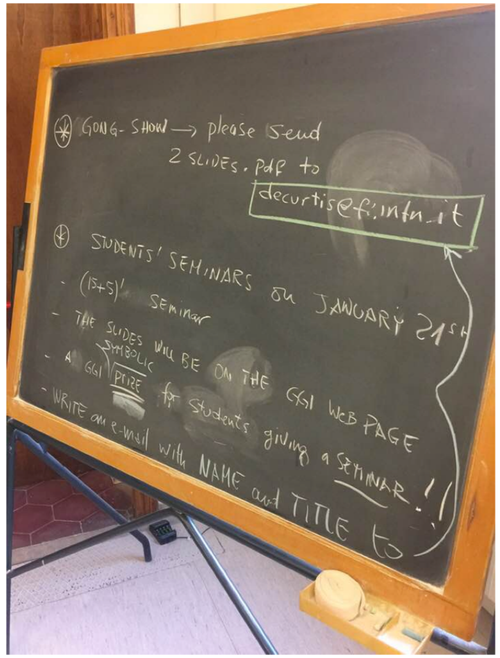
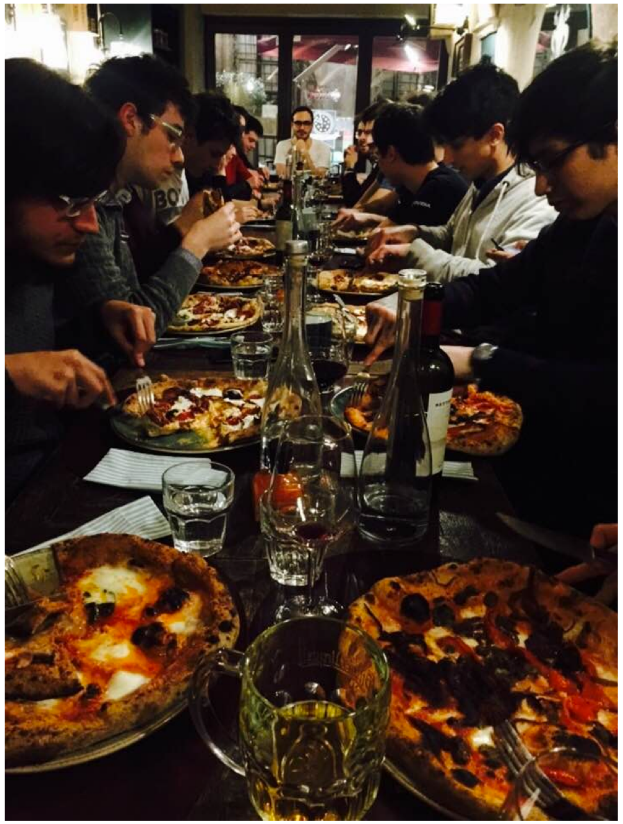


Overseas Visiting

GGI symbolic prize (GGI T-shirt + pen)

Overseas Visiting

New last supper



Overseas Visiting

Resonant instabilities in cosmology and their observational consequences

Yukawa Institute for Theoretical Physics, Kyoto University
May 7 - 20, 2019

Program

May 14 (Day 1) at Panasonic Auditorium, Yukawa Hall

9:50 - 10:00 **Opening remarks**
Jiro Soda (Kobe University)

Chair: Jiro Soda

10:00 - 11:00 **Peter Adshead (University of Illinois)**
Inflation with non-Abelian gauge fields and the origin of the matter-antimatter asymmetry

11:00 - 11:30 **Kohei Kamada (RESCEU, University of Tokyo)**
Magnetogenesis for Baryogenesis from Axion Inflation

11:30 - 12:00 **Teerthal Patel (Nagoya University)**
(20+10) **Resonant magnetic field generation from axions**

12:00 - 12:30 **Shu-Yu Ho (Tohoku University)**
(20+10) **Relaxing the Cosmological Moduli Problem by Low-scale Inflation**

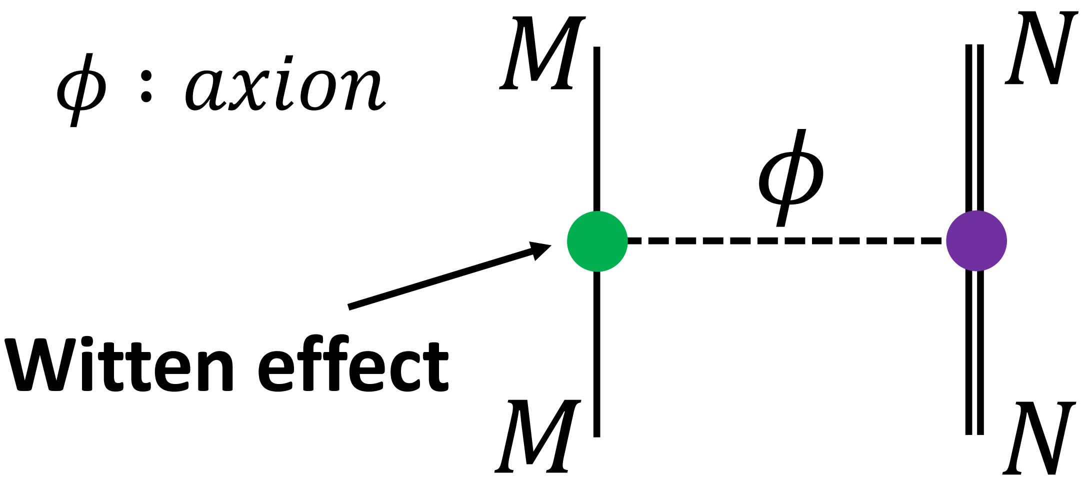
My recent research

- **Axion portal (hidden) monopole dark matter (DM):**
  - ✓ The monopoles with mass around 1-10 PeV can account for the observed DM.

Murayama, Shu 0905.1720

  - ✓ The monopole DM can couple to nucleon via axion portal.

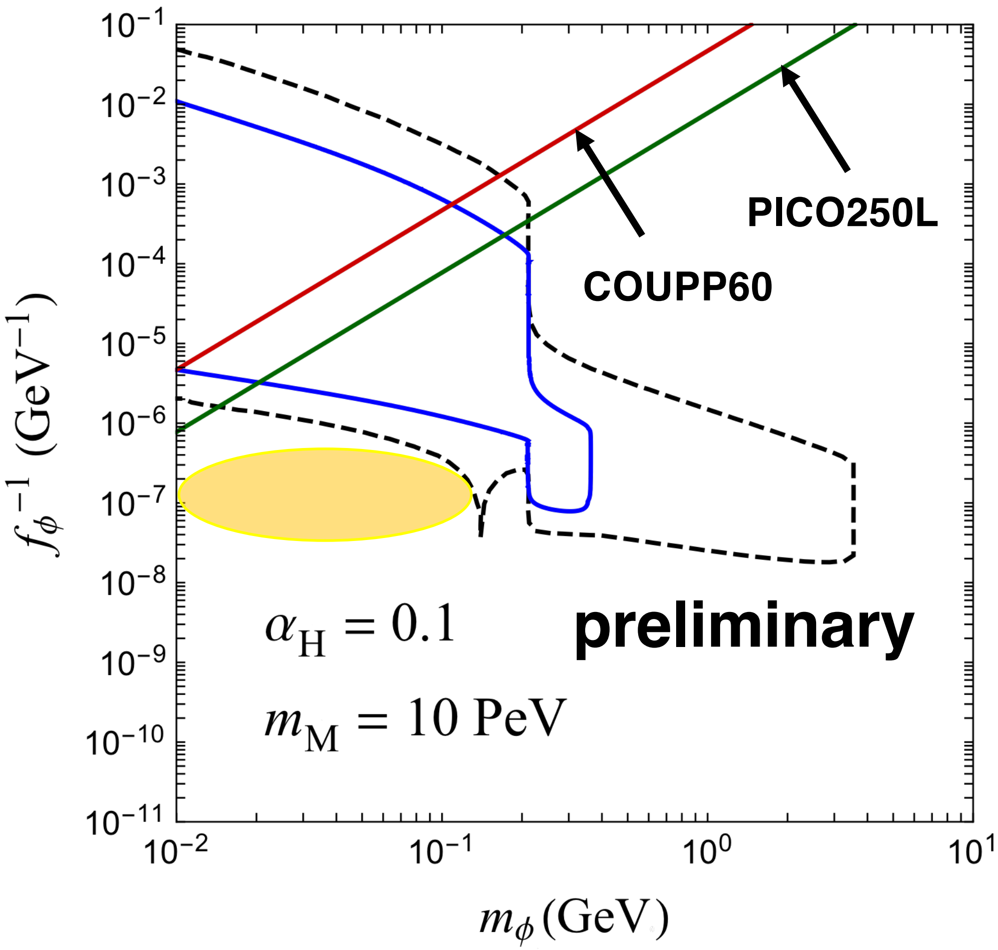
ϕ : *axion*



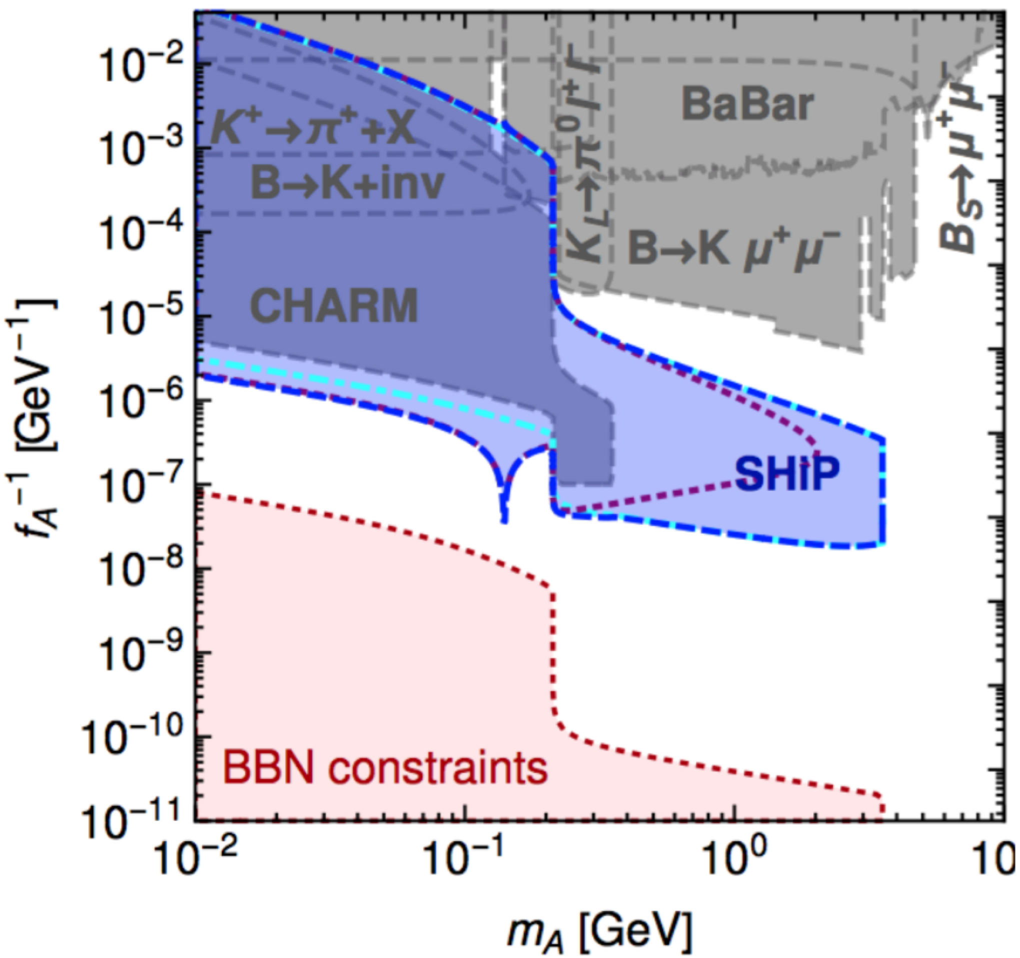
$$H_{\phi-\mathrm{N}} = \int d^3x \left(g_{\phi\mathrm{N}} \phi \, \overline{\psi}_{\mathrm{N}} \gamma^5 \psi_{\mathrm{N}} \right)$$

$$g_{\phi\mathrm{N}} = C_{\phi\mathrm{N}} \frac{m_{\mathrm{N}}}{f_\phi}$$

My recent research



Sergey Alekhin (DESY & Serpukhov, IHEP) et al.. 16'



My recent research