ALP Cogenesis

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DM Radio Collaboration Meeting   August 14th 2020

References:

arXiv: 1910.02080 Raymond Co, Keisuke Harigaya Phys. Rev. Lett. 124, 111602 (2020)

arXiv: 1910.14152 Raymond Co, Lawrence Hall, Keisuke Harigaya Phys. Rev. Lett. 124, 251802 (2020)

arXiv: 2006.04809 Raymond Co, Lawrence Hall, Keisuke Harigaya

ALP Cogenesis

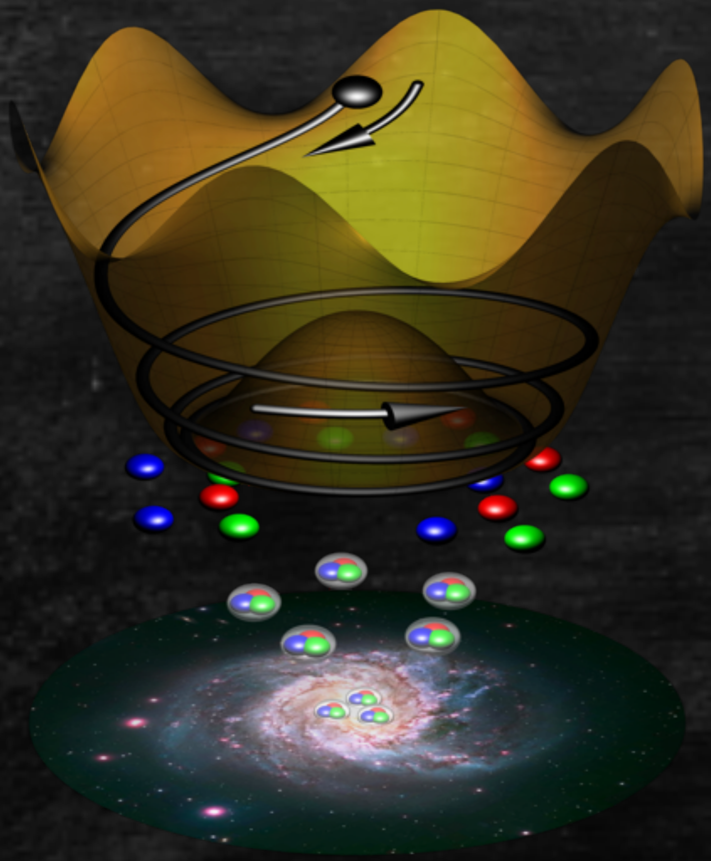
ALP

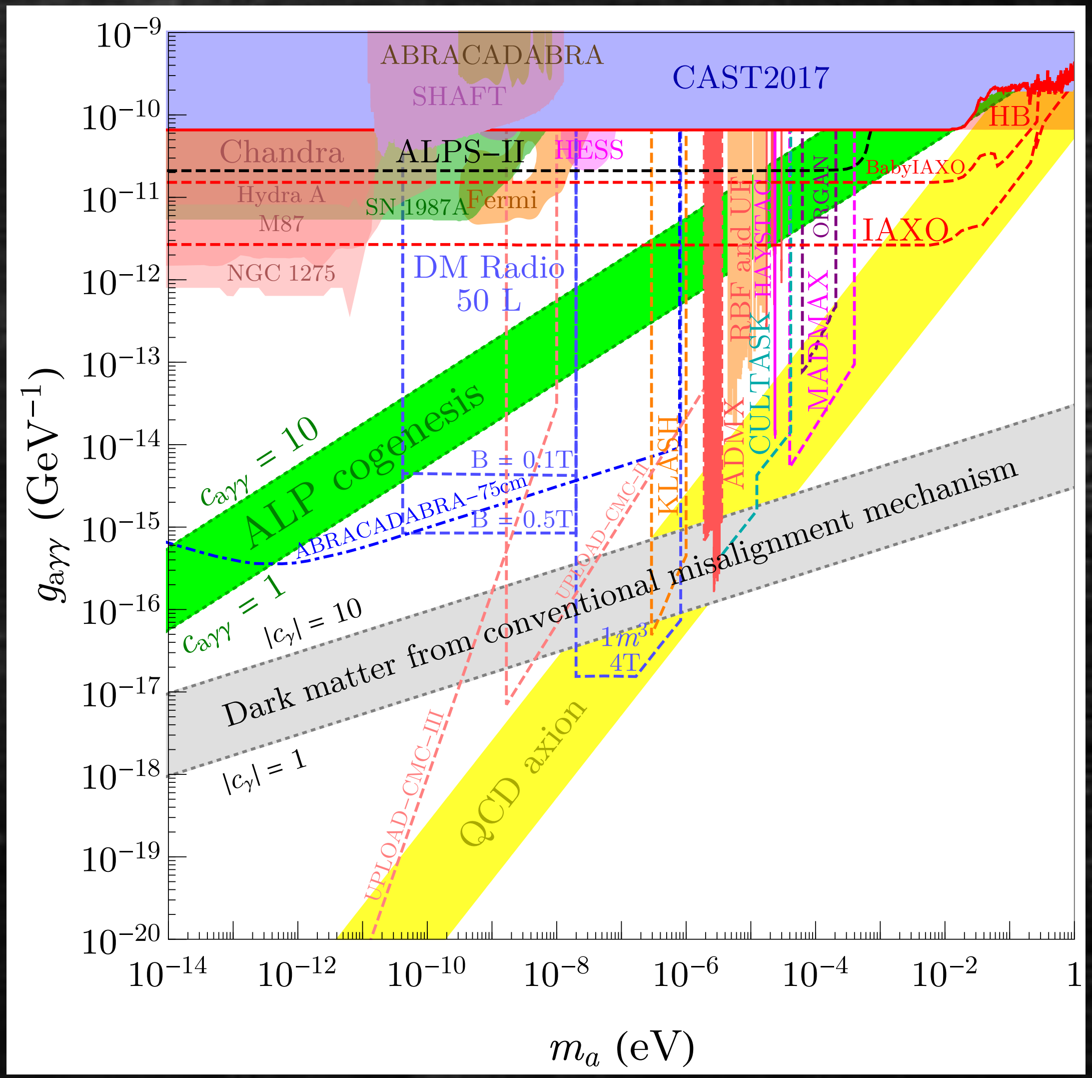
Axion-like particles

Cogenesis

Generation of both the baryon (baryogenesis) and dark matter abundances.

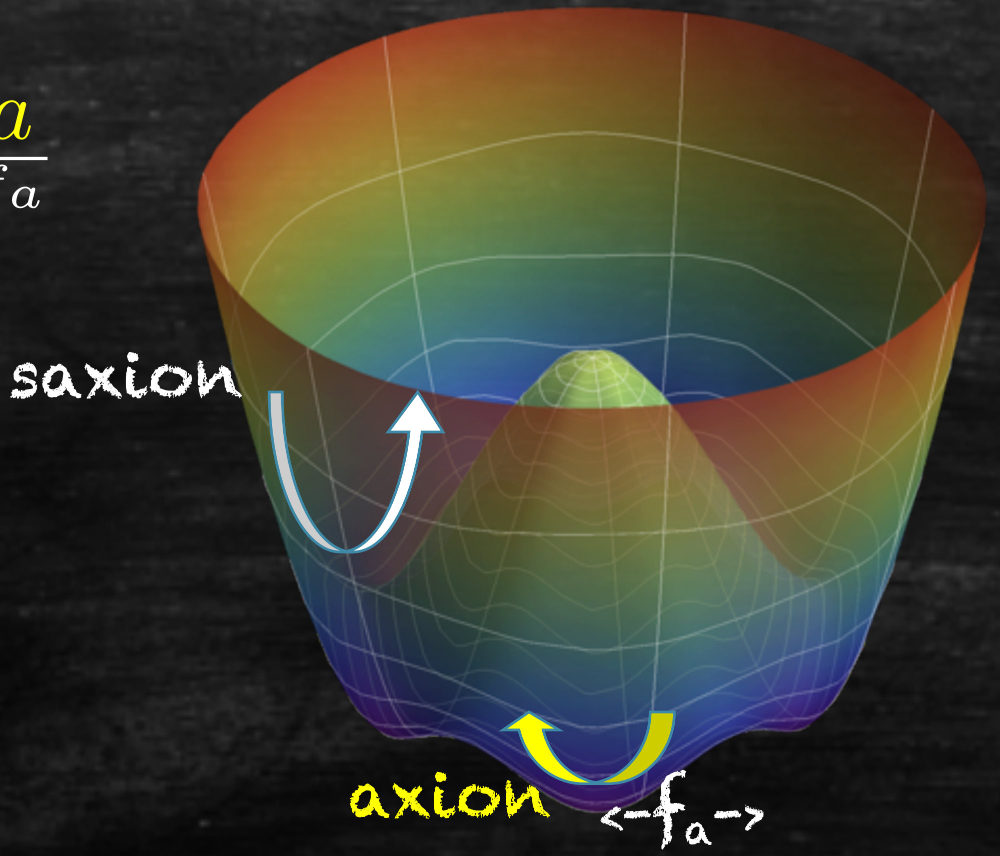
ALP Cogenesis





Axions

$$P = \frac{S + f_a}{\sqrt{2}} e^{i\frac{a}{f_a}}$$



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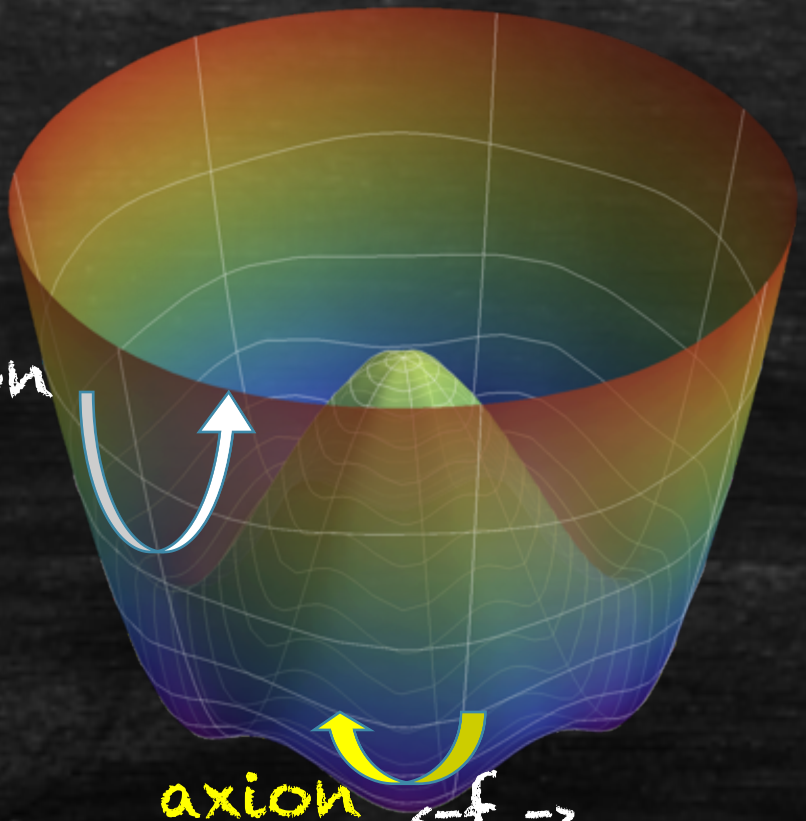
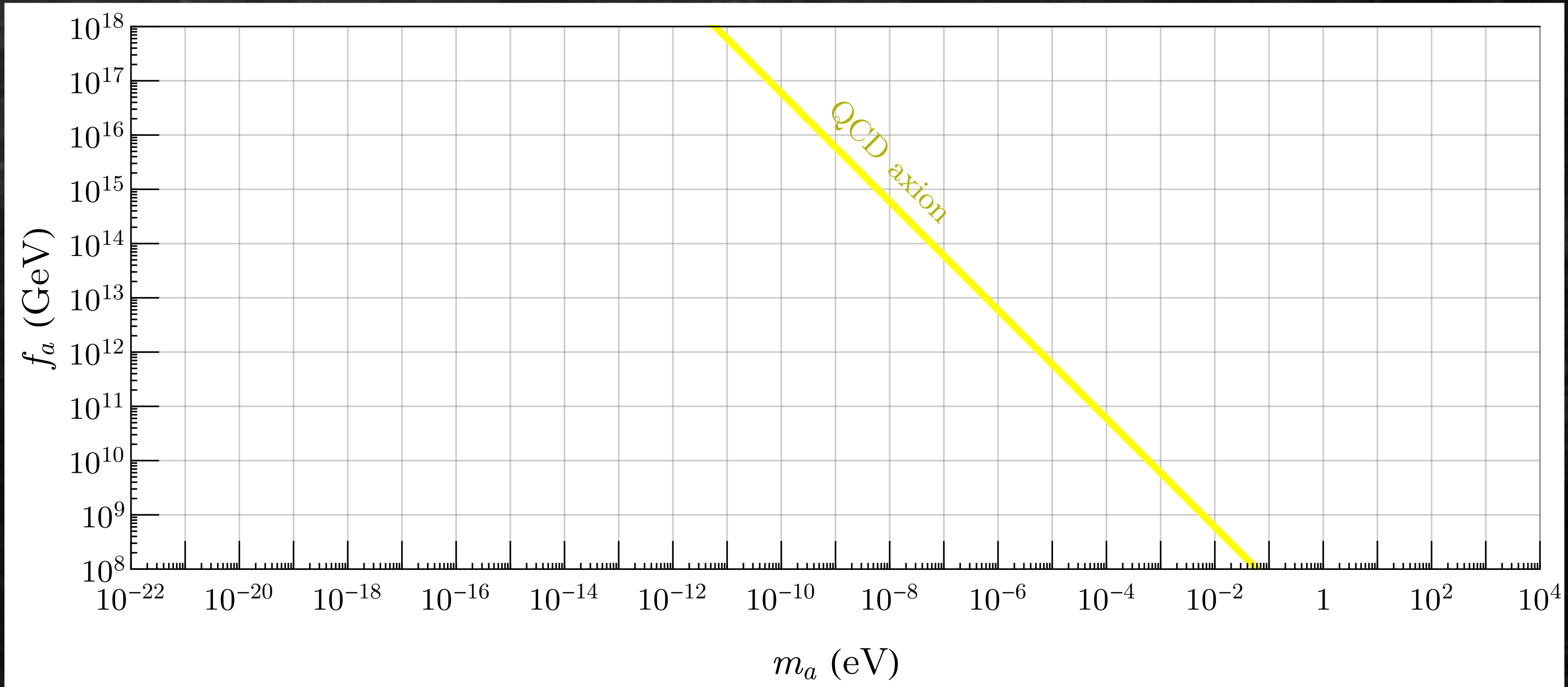


QCD axion

$$\mathcal{L} \supset \frac{\alpha}{8\pi} \frac{a}{f_a} G^{\mu\nu} \tilde{G}_{\mu\nu}$$

$$m_a = 6\,\mathrm{meV} \left(\frac{10^9\ \mathrm{GeV}}{f_a} \right)$$

Axions



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Misalignment Mechanism

$$\ddot{a} + 3H\dot{a} + m_a^2 a = 0$$

Early time

$$H \gg m_a$$

Hubble friction dominates

$$a = \text{constant}$$

Field value is "stuck"

$$\rho_a = m_a^2 a^2$$

Energy density

$$\rho_a = \text{constant}$$

is also "stuck"

Late time

$$m_a \gg H$$

Oscillations begin

$$a \propto R^{-\frac{3}{2}}$$

Field value redshifts

$$\rho_a = m_a^2 a^2$$

Energy density

$$\rho_a \propto R^{-3}$$

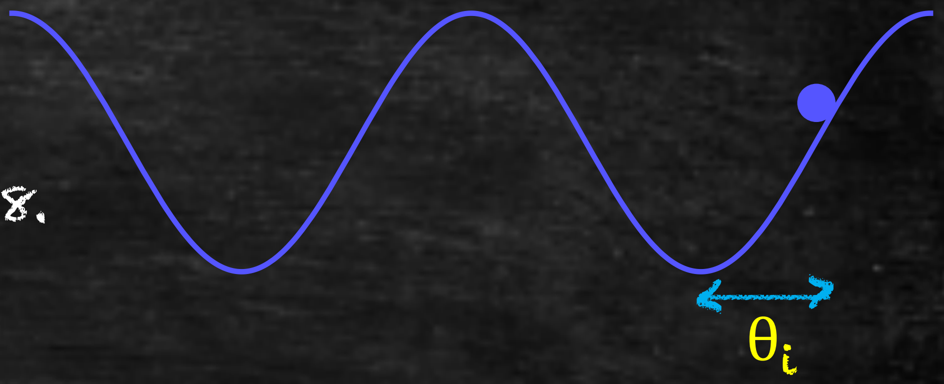
scales like matter

Preskill, Wise, Wilczek 1983
Abbott, Sikivie 1983
Dine, Fischler 1983

Misalignment Mechanism

$$\Omega_a h^2 \simeq 0.12\,\theta_i^2 \left(\frac{f_a}{10^{12}\ \mathrm{GeV}}\right)^2 \left(\frac{m_a}{22\ \mathrm{meV}}\right)^{\frac{1}{2}}$$

$\Omega_{\mathrm{DM}} h^2 \simeq 0.12$ observed value from Planck 2018.



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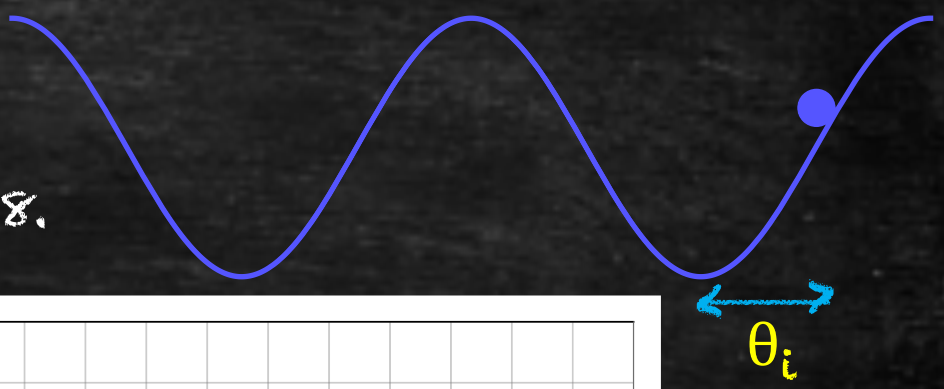
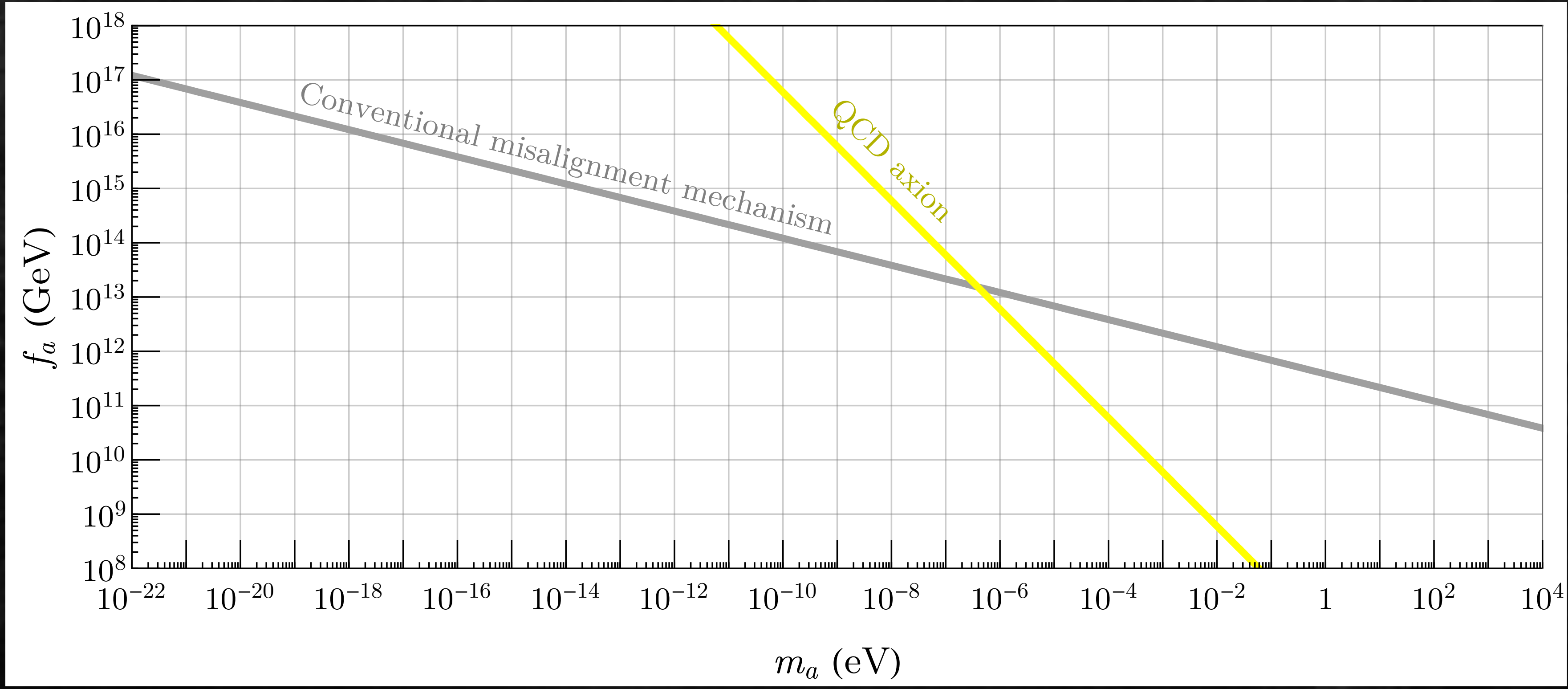
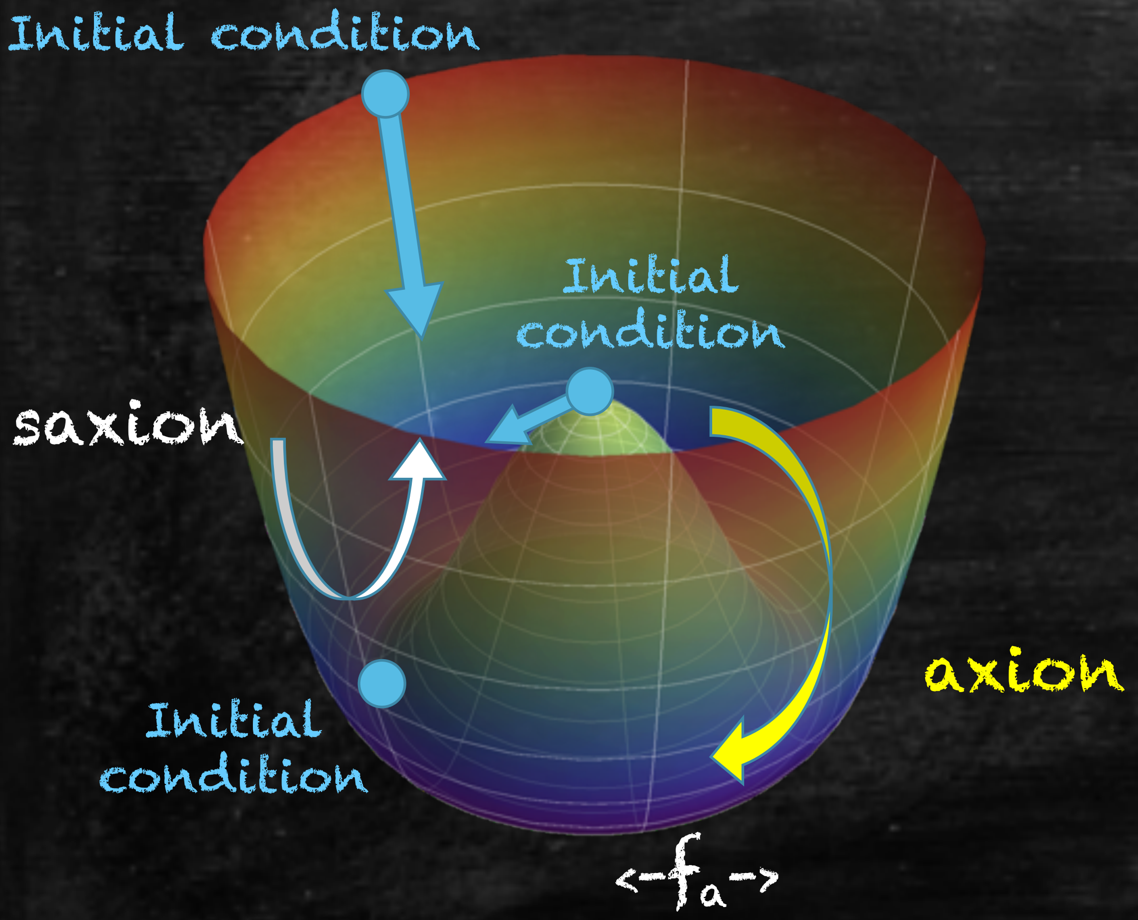
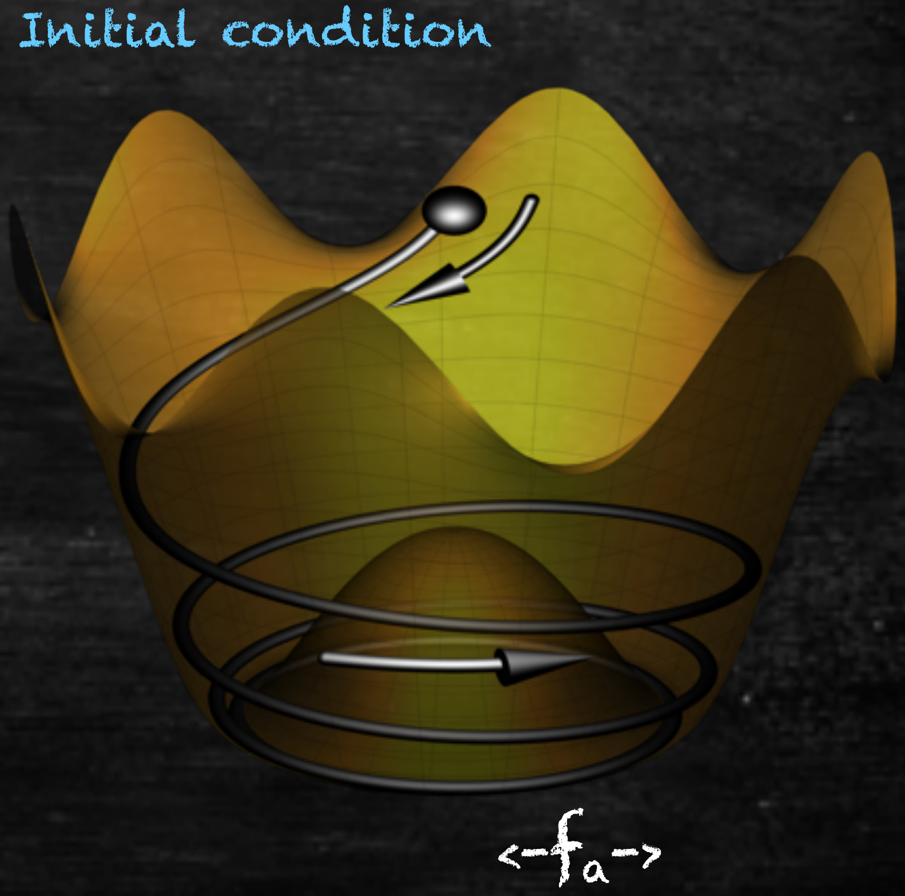




Rotation





PRL 124, 111602 (2020) RC and K. Harigaya

Why Rotation?

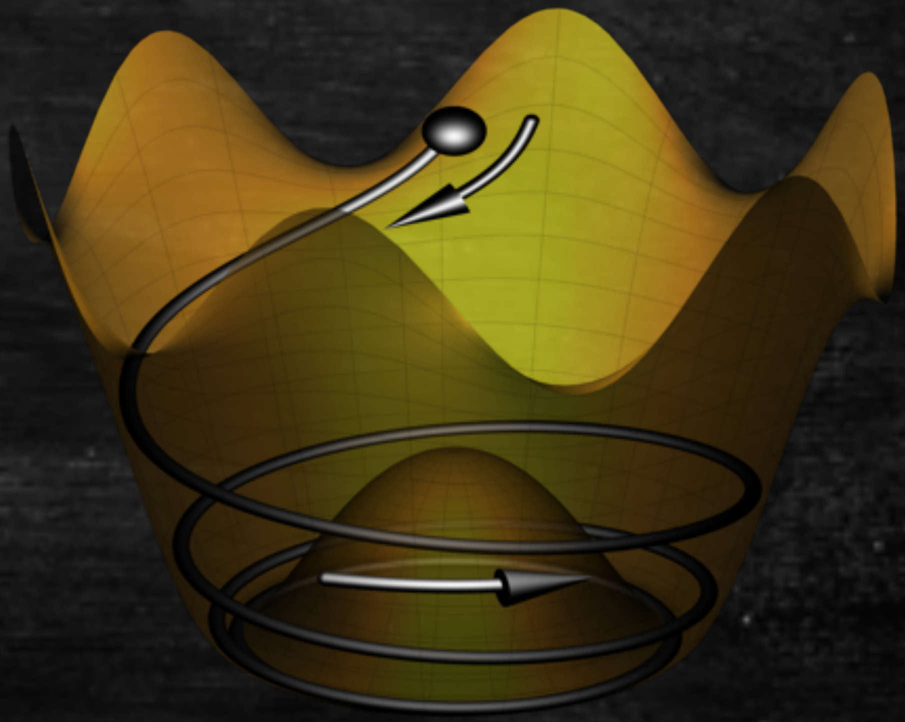
$$P = \frac{S + f_a}{\sqrt{2}} e^{i\frac{a}{f_a}}$$

Large field value : Flat potential

For example, as an initial condition or
set dynamically by the Hubble-induced mass

$$V(|P|) \sim -H_I^2 |P|^2 + \frac{|P|^{2d}}{M^{2d-4}}$$

Initial condition



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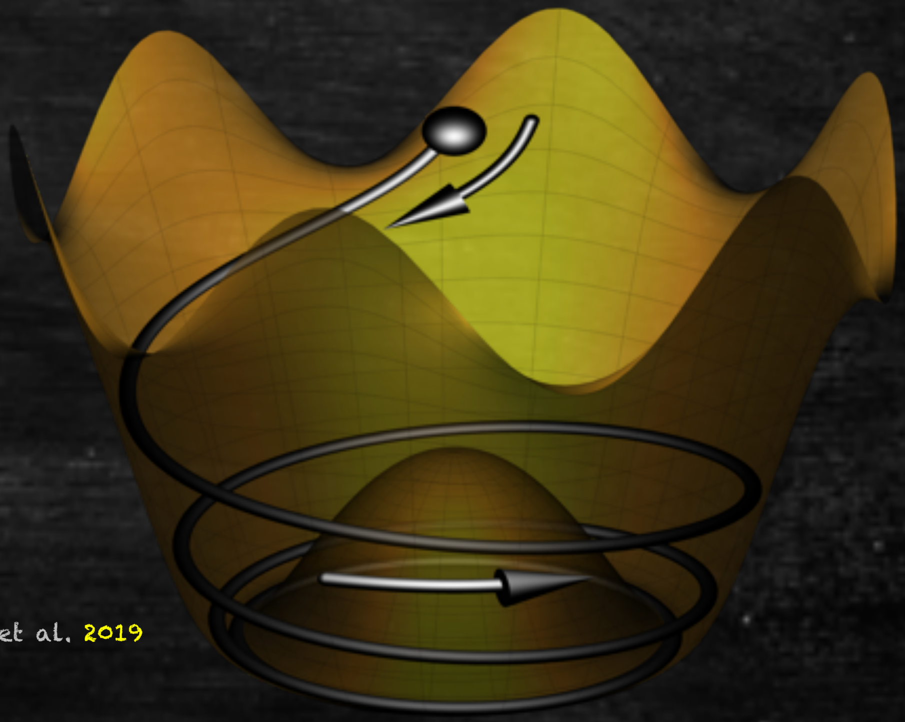
Angular motion : Explicit PQ breaking

$$V(P) \sim \frac{P^n}{M^{n-4}} + \mathrm{h.c.}$$

expected from quantum gravity
or PQ as an accidental symmetry

S. Giddings et al. 1988, S. Coleman 1988, G. Gilbert 1988, D. Harlow et al. 2019
R. Holman 1992, S. Barr 1992, M. Kamiokowski 1992, D. Dine 1992

Initial condition



Dynamics analogous to that in Affleck-Dine baryogenesis

I. Affleck and M. Dine 1991

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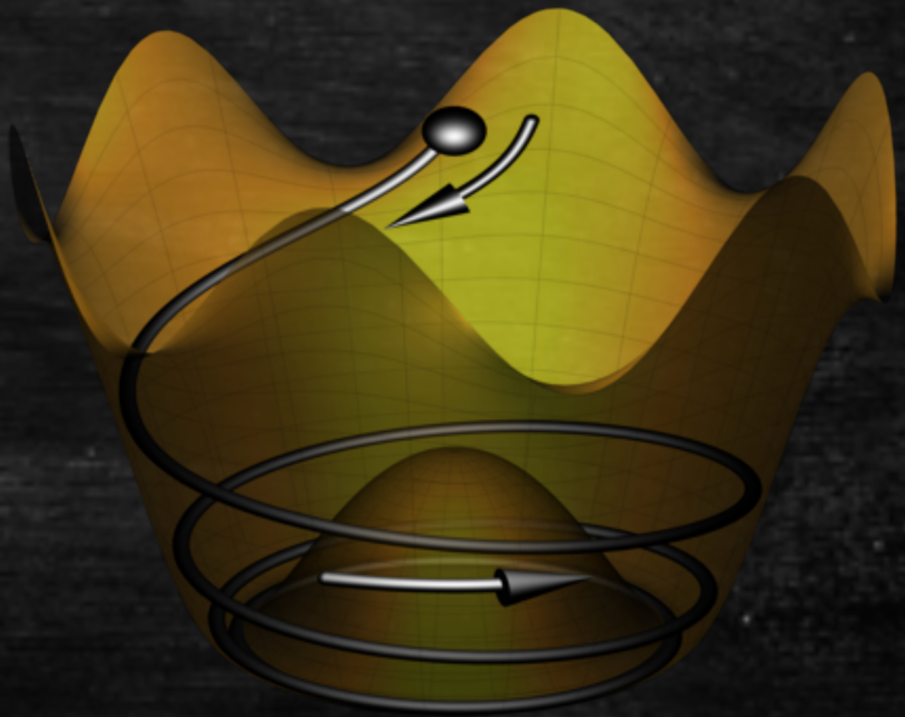
Asymmetry of PQ Charge

$$P = \frac{S + f_a}{\sqrt{2}} e^{i\frac{a}{f_a}}$$

Noether charge associated with the shift symmetry

$$n_{\rm PQ} = iP\dot{P}^* - iP^*\dot{P}$$

$$n_{\rm PQ} = S^2\dot{\theta}$$ "angular momentum"



PQ asymmetry
PQ charge density = Rotation of PQ field

PQ charge is conserved soon after the onset.

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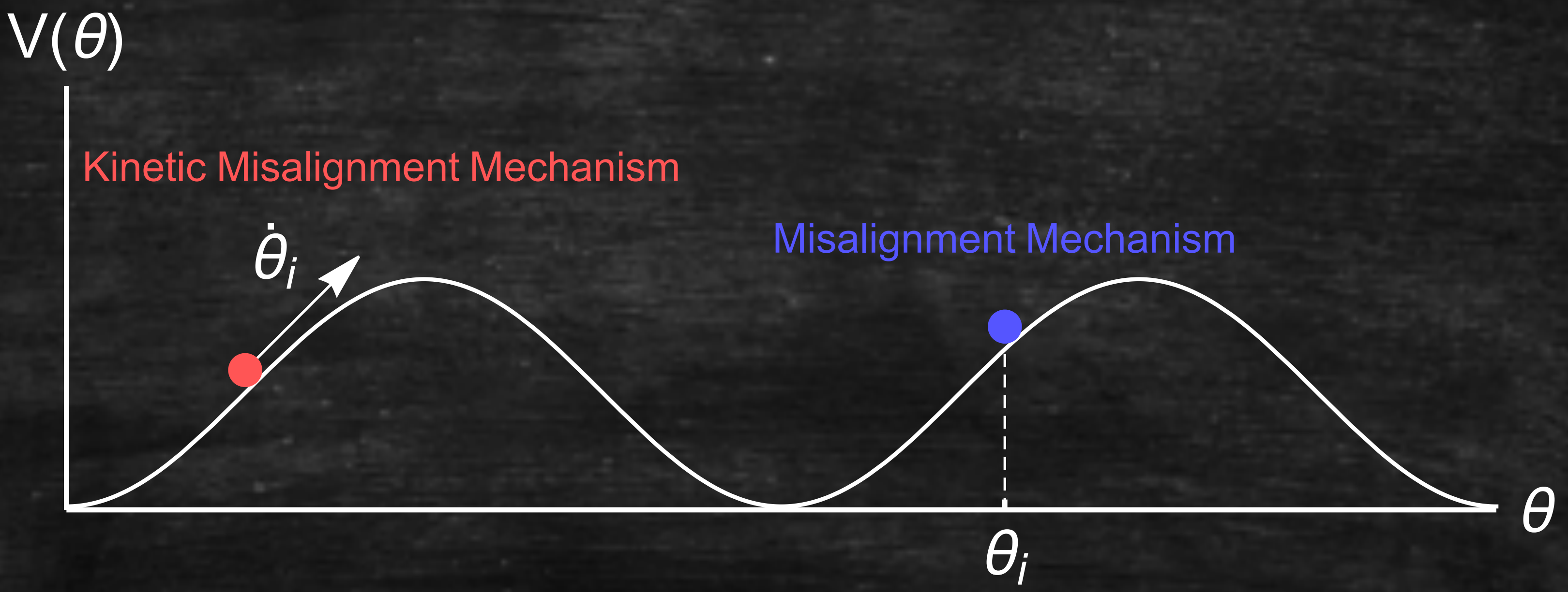
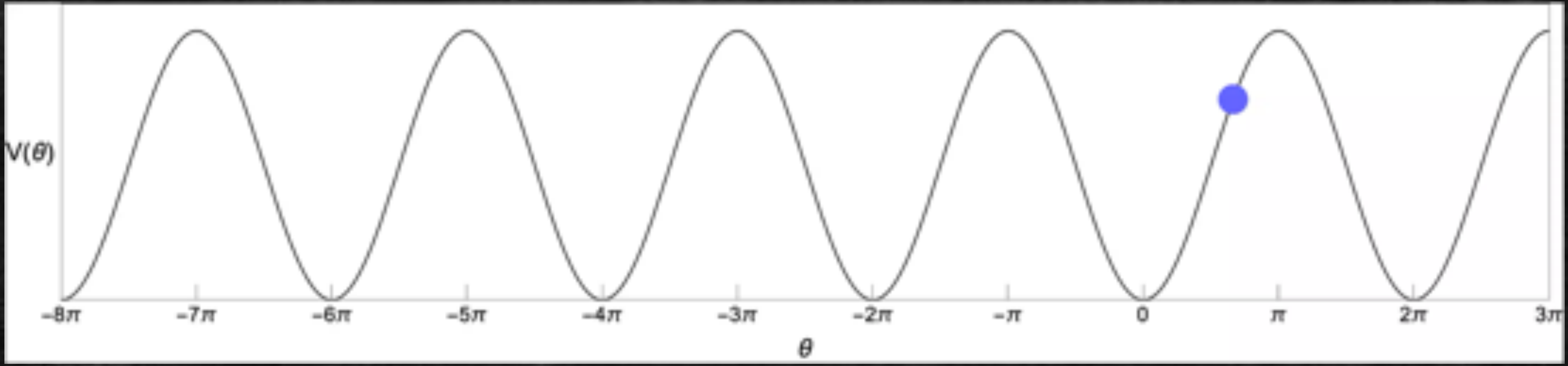


Kinetic Misalignment Mechanism

(Misalignment + non-zero kinetic energy)

PRL 124, 251802 (2020) RC, L. Hall, K. Harigaya



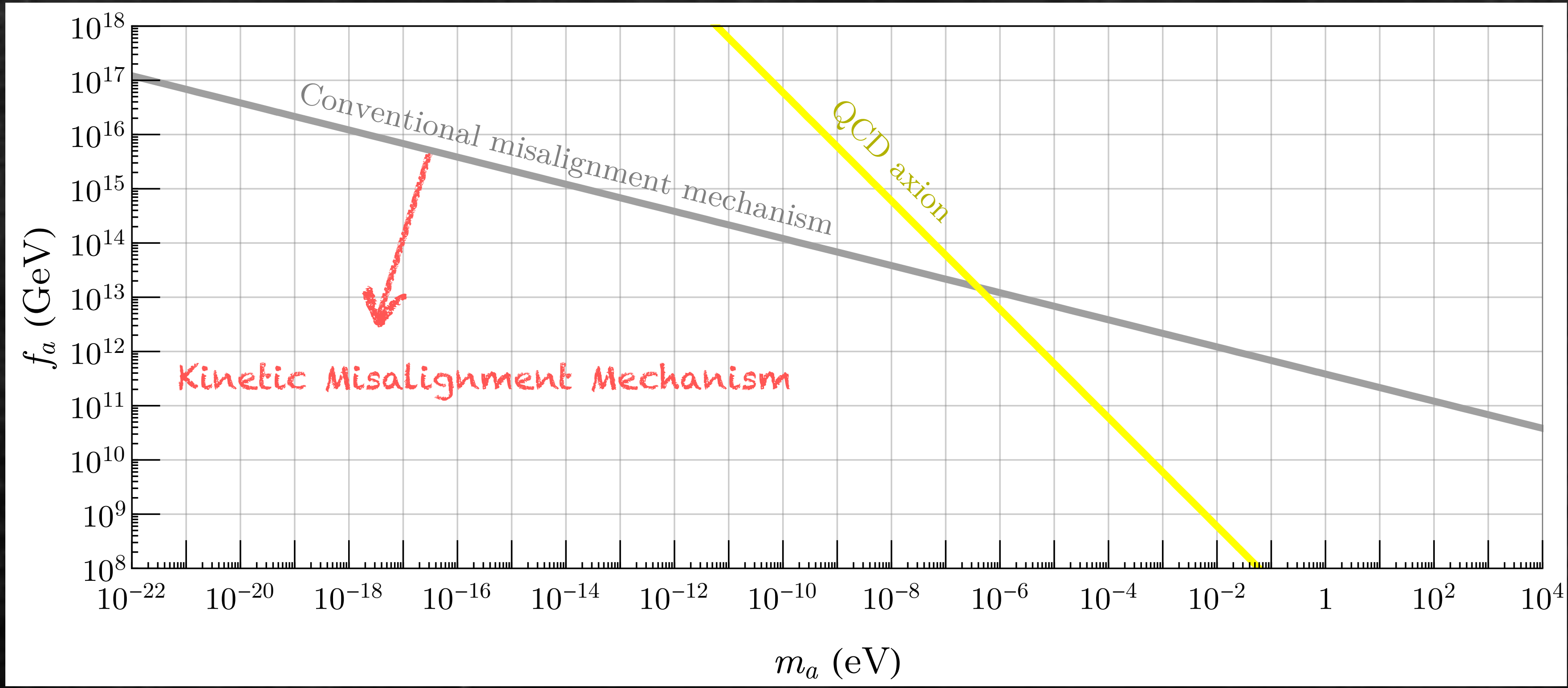
Kinetic Misalignment Mechanism

Consequence: delaying usual T_{osc} until KE = PE, enhancing the dark matter abundance

Abundance: $\Omega_a h^2 \propto \dot{\theta}$

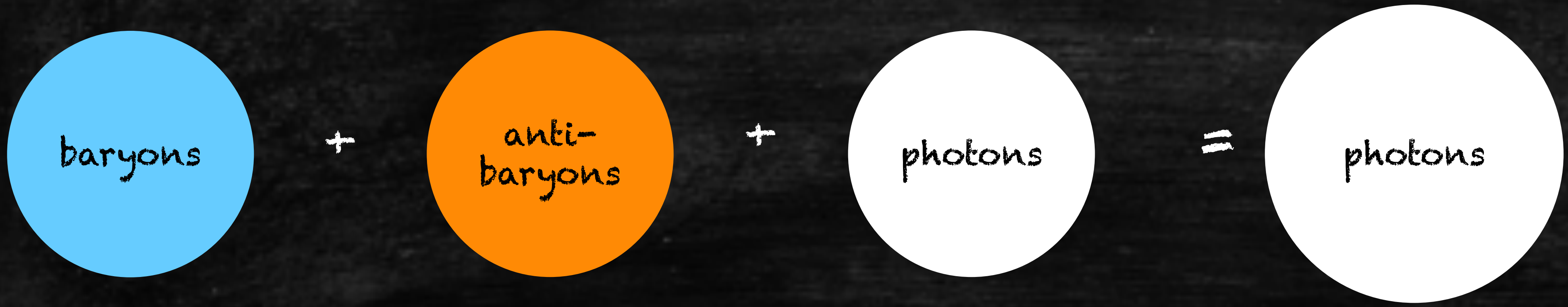
PRL 124, 251802 (2020) RC, L. Hall, K. Harigaya

Kinetic Misalignment Mechanism



Baryon Asymmetry of the Universe

Standard Model predicts that baryons and antibaryons would have annihilated.



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Both CMB and BBN measurements indicate $$Y_B \equiv \frac{n_B - n_{\bar{B}}}{s} \sim 10^{-10}$$

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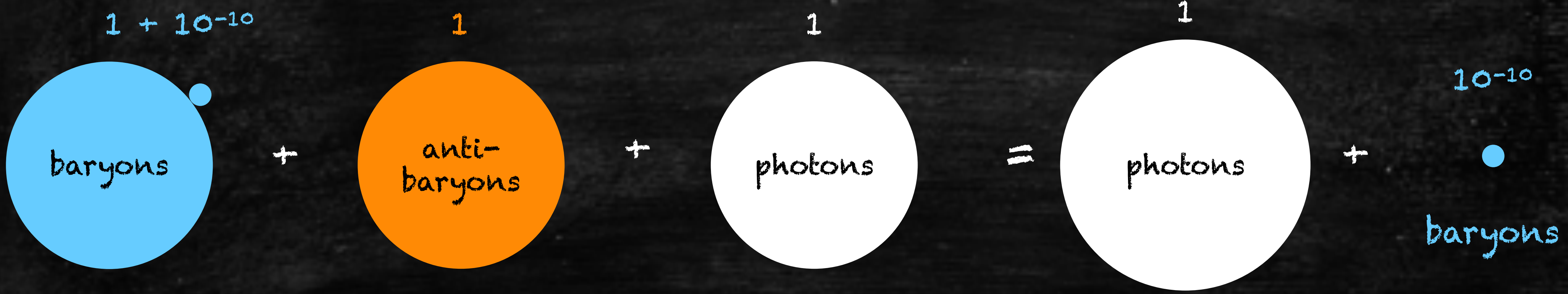
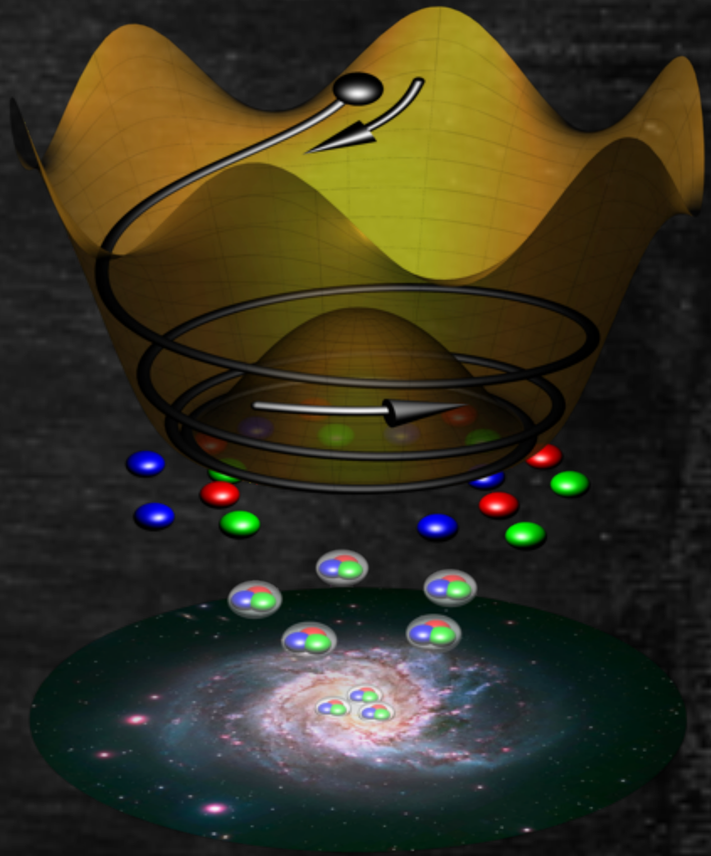


Baryogenesis

R. Co Michigan



Axiogenesis

(QCD axion + baryogenesis)

R. Co Michigan

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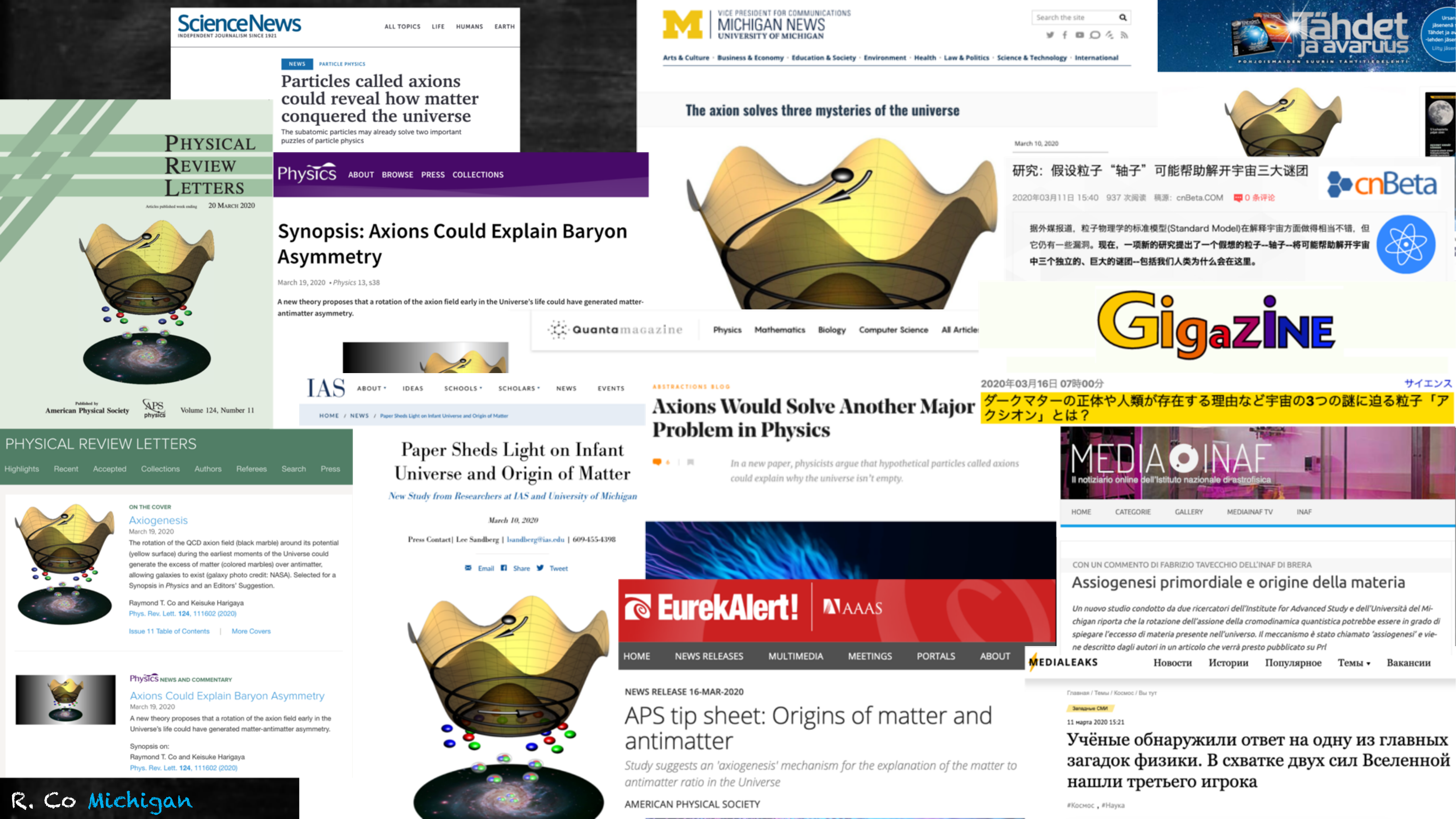
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Particles called axions could reveal how matter conquered the universe
The subatomic particles may already solve two important puzzles of particle physics
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The axion solves three mysteries of the universe
March 10, 2020
Tähdet ja avaruus
研究：假设粒子“轴子”可能帮助解开宇宙三大谜团
2020年03月11日 15:40 937 次阅读 稿源：cnBeta.COM 0 条评论
据外媒报道，粒子物理学的标准模型(Standard Model)在解释宇宙方面做得相当不错，但它仍有一些漏洞。现在，一项新的研究提出了一个假想的粒子--轴子--将可能帮助解开宇宙中三个独立的、巨大的谜团--包括我们人类为什么会在这里。
cnBeta
PHYSICAL REVIEW LETTERS
20 March 2020
Published by American Physical Society
Volume 124, Number 11
Physics ABOUT BROWSE PRESS COLLECTIONS
Synopsis: Axions Could Explain Baryon Asymmetry
March 19, 2020 • Physics 13, s38
A new theory proposes that a rotation of the axion field early in the Universe's life could have generated matter-antimatter asymmetry.
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Axions Would Solve Another Major Problem in Physics
In a new paper, physicists argue that hypothetical particles called axions could explain why the universe isn't empty.
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ON THE COVER
Axiogenesis
March 19, 2020
The rotation of the QCD axion field (black marble) around its potential (yellow surface) during the earliest moments of the Universe could generate the excess of matter (colored marbles) over antimatter, allowing galaxies to exist (galaxy photo credit: NASA). Selected for a Synopsis in Physics and an Editors' Suggestion.
Raymond T. Co and Keisuke Harigaya
Phys. Rev. Lett. 124, 111602 (2020)
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Axions Could Explain Baryon Asymmetry
March 19, 2020
A new theory proposes that a rotation of the axion field early in the Universe's life could have generated matter-antimatter asymmetry.
Synopsis on:
Raymond T. Co and Keisuke Harigaya
Phys. Rev. Lett. 124, 111602 (2020)
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CON UN COMMENTO DI FABRIZIO TAVECCHIO DELL'INAF DI BRERA
Assiogenesi primordiale e origine della materia
Un nuovo studio condotto da due ricercatori dell'Institute for Advanced Study e dell'Università del Michigan riporta che la rotazione dell'assione della cromodinamica quantistica potrebbe essere in grado di spiegare l'eccesso di materia presente nell'universo. Il meccanismo è stato chiamato 'assiogenesi' e viene descritto dagli autori in un articolo che verrà presto pubblicato su Prl
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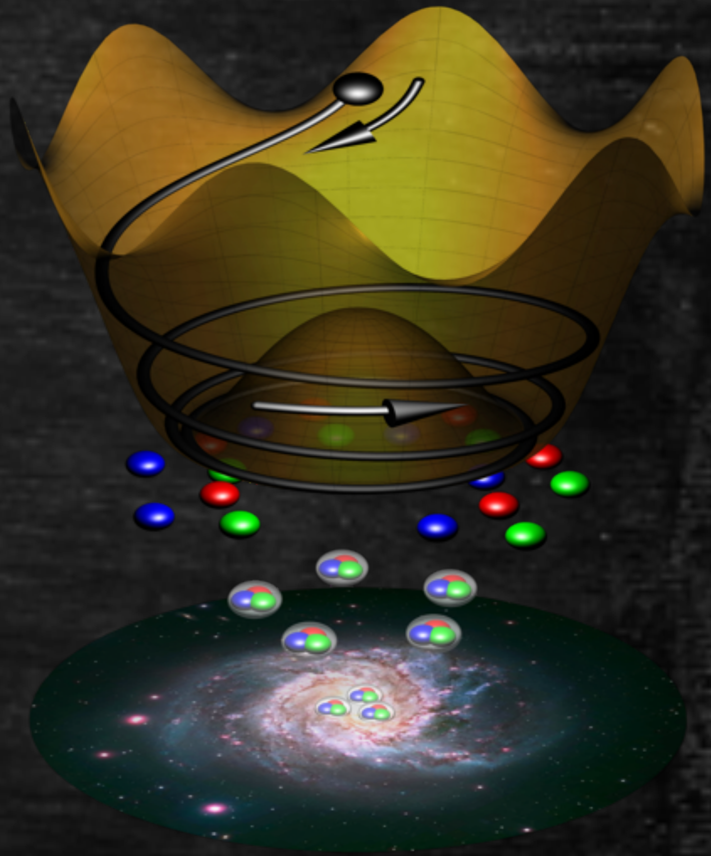
NEWS RELEASE 16-MAR-2020
APS tip sheet: Origins of matter and antimatter
Study suggests an 'axiogenesis' mechanism for the explanation of the matter to antimatter ratio in the Universe
AMERICAN PHYSICAL SOCIETY
MEDIALEAKS Новости Истории Популярное Темы Вакансии
11 марта 2020 15:21
Учёные обнаружили ответ на одну из главных загадок физики. В схватке двух сил Вселенной нашли третьего игрока
#Космос, #Наука
R. Co Michigan



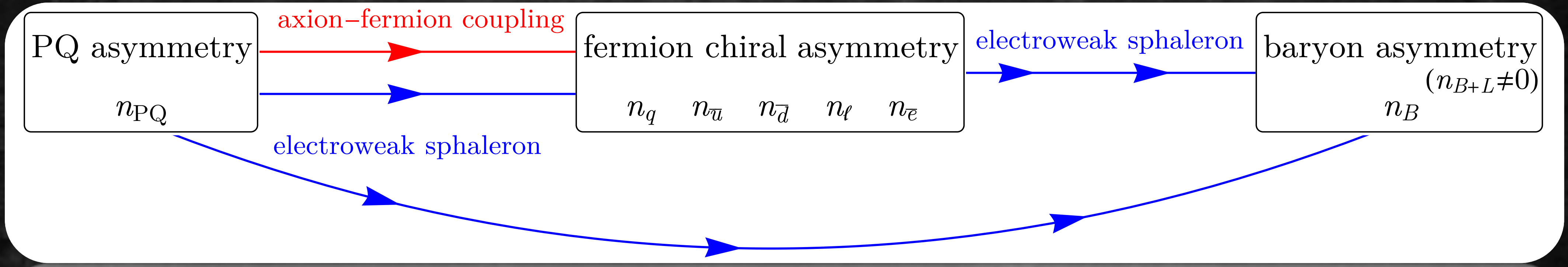
ALP-genesis

(Axion-like particle + baryogenesis)

R. Co Michigan

2006.04809 RC, L. Hall, K. Harigaya

ALP-genesis



Observed baryon asymmetry: $Y_B \simeq 8.7 \times 10^{-11}$ from Planck 2018.

ALP-genesis: $Y_B \simeq 8.7 \times 10^{-11} \left(\frac{c_B}{0.1}\right) \left(\frac{130 \text{ GeV}}{T_{\rm EW}}\right) \left(\frac{\dot\theta(T_{\rm EW})}{5.3 \text{ keV}}\right)$

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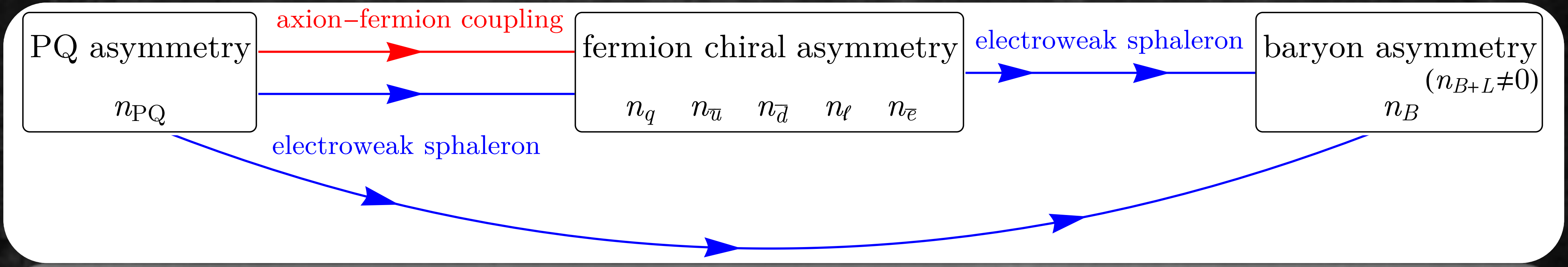

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→ model-dependent constant: c_B

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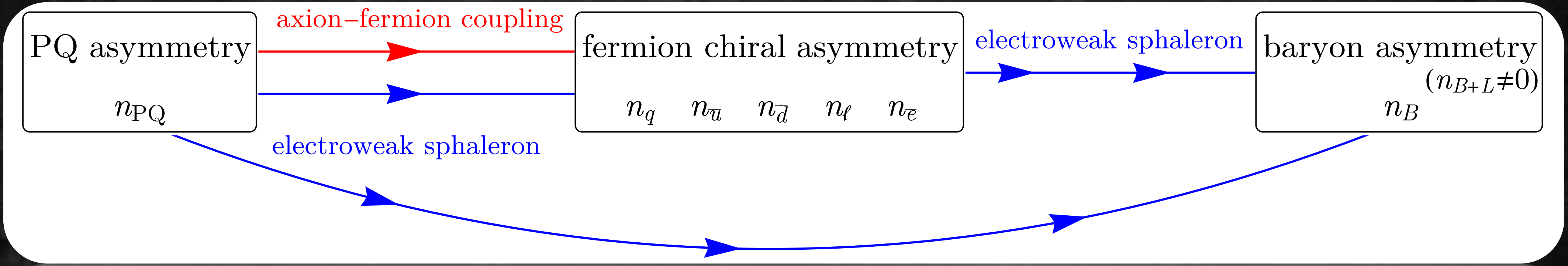

axion-fermion coupling: $\dfrac{\partial_\mu a}{f_a}\sum_{f,i,j} c_{f_{ij}}\, f_i^\dagger \bar{\sigma}^\mu f_j$

electroweak anomaly: $\dfrac{a}{32\pi^2 f_a}\left(c_Y\, g'^2 B^{\mu\nu}\widetilde{B}_{\mu\nu} + c_W g^2\, W^{\mu\nu}\widetilde{W}_{\mu\nu}\right)$

→ model-dependent constant: $c_B = -\dfrac{12}{79}c_W + \sum_i\left(\dfrac{18}{79}c_{q_{ii}} - \dfrac{21}{158}c_{\bar{u}_{ii}} - \dfrac{15}{158}c_{\bar{d}_{ii}} + \dfrac{25}{237}c_{\ell_{ii}} - \dfrac{11}{237}c_{\bar{e}_{ii}}\right)$

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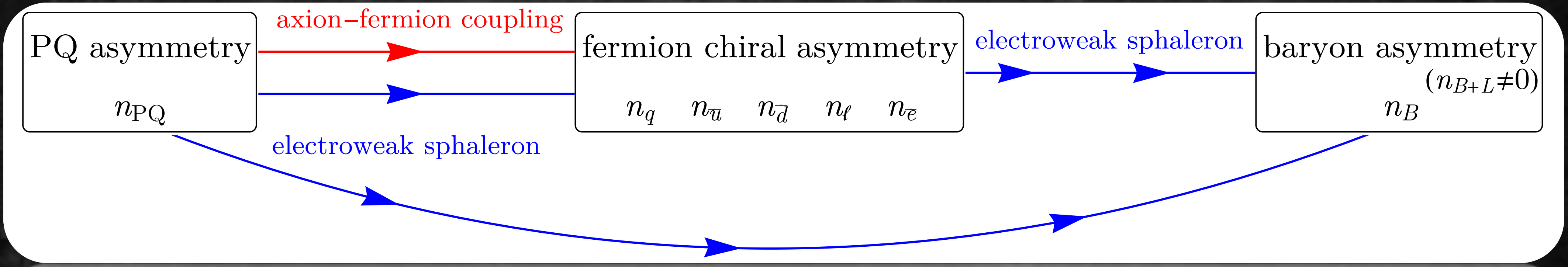

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Baryon asymmetry fixes rotational speed at electroweak scale.

R. Co Michigan

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Kinetic misalignment mechanism: $\Omega_a h^2 \simeq 0.12 \left(\frac{f_a}{10^{10}\ \text{GeV}}\right)^2 \left(\frac{m_a}{43\ \text{neV}}\right) \left(\frac{130\ \text{GeV}}{T_{\rm EW}}\right)^3 \left(\frac{\dot\theta(T_{\rm EW})}{5.3\ \text{keV}}\right)$

Prediction!

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ALP Cogenesis: $$f_a \simeq 2.1 \times 10^9\ \mathrm{GeV} \left(\frac{\mu\mathrm{eV}}{m_a} \right)^{\frac{1}{2}} \times \left(\frac{c_B}{0.1} \right)^{\frac{1}{2}} \left(\frac{T_{\rm EW}}{130\ \mathrm{GeV}} \right) \left(\frac{f_a}{f_a(T_{\rm EW})} \right)$$

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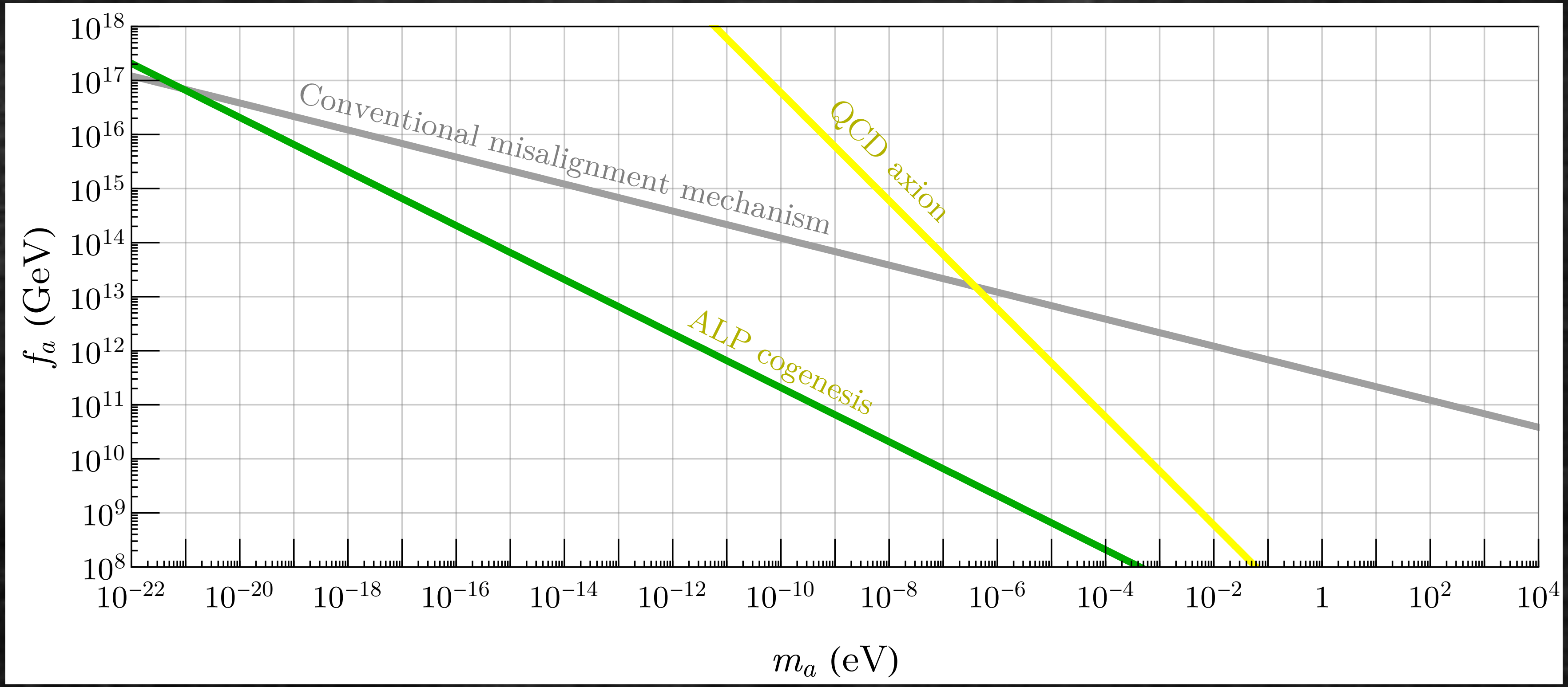

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Axion-Photon Coupling

ALP Cogenesis:

$$|g_{a\gamma\gamma}| = \frac{\alpha|c_\gamma|}{2\pi f_a} \simeq 1.8 \times 10^{-11}\mathrm{GeV}^{-1}|c_\gamma| \quad \left(\frac{m_a}{\mathrm{meV}}\right)^{\frac{1}{2}} \left(\frac{130\mathrm{GeV}}{T_{\mathrm{EW}}}\right)\left(\frac{f_a(T_{\mathrm{EW}})}{f_a}\right)\left(\frac{0.1}{c_B}\right)^{\frac{1}{2}}$$

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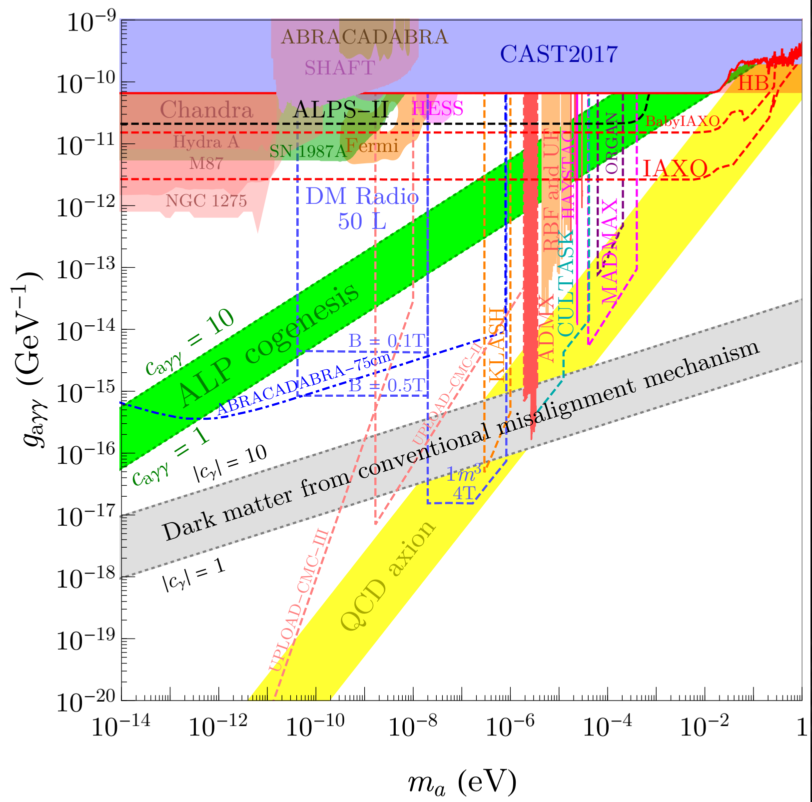
$$|g_{a\gamma\gamma}| = \frac{\alpha |c_\gamma|}{2\pi f_a} \simeq 1.8 \times 10^{-11} \mathrm{GeV}^{-1} |c_{a\gamma\gamma}| \left(\frac{m_a}{\mathrm{meV}}\right)^{\frac{1}{2}} \left(\frac{130\mathrm{GeV}}{T_{\mathrm{EW}}}\right)$$

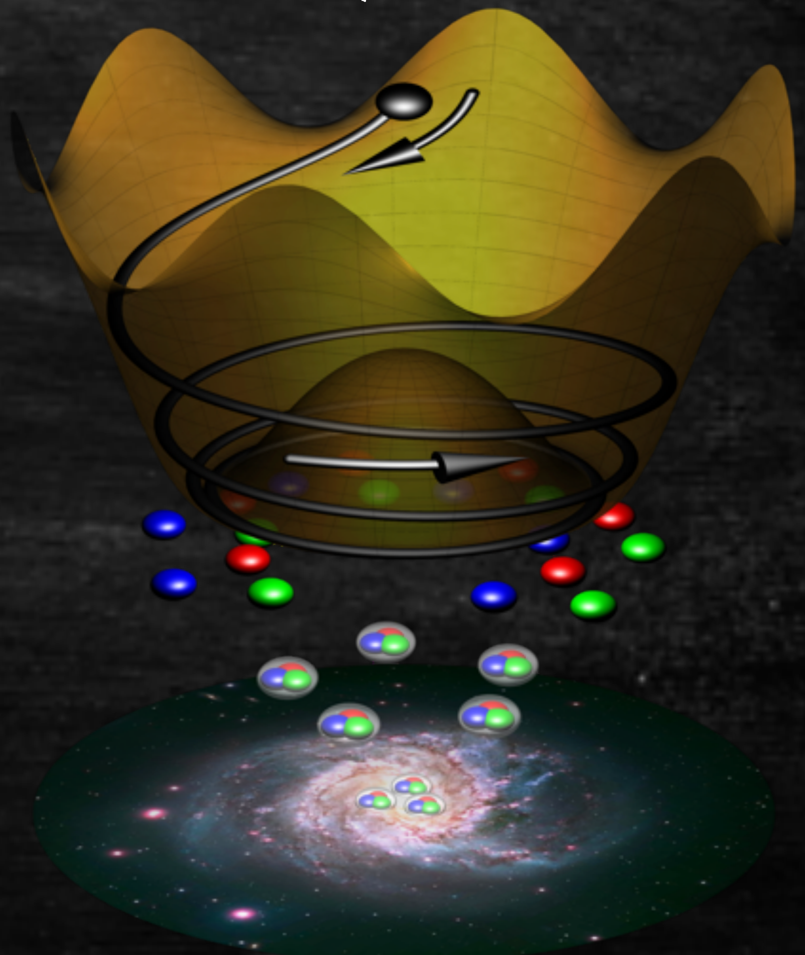
$$c_{a\gamma\gamma} \equiv |c_\gamma| \left(\frac{f_a(T_{\mathrm{EW}})}{f_a}\right) \left(\frac{0.1}{c_B}\right)^{\frac{1}{2}}$$



2006.04809 RC, L. Hall, K. Harigaya

Conclusions

- ✓ ALP cogenesis allows the axion to simultaneously explain
  - ✓ the dark matter abundance
  - ✓ the baryon asymmetry
- ✓ ALP cogenesis predicts axions with much stronger couplings with the Standard Model, implying a greater potential for discovery, possibly made by DM Radio!



Thank you!