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Supernova Axion Emissivity with Δ(1232) Resonance in Heavy Baryon Chiral Perturbation Theory

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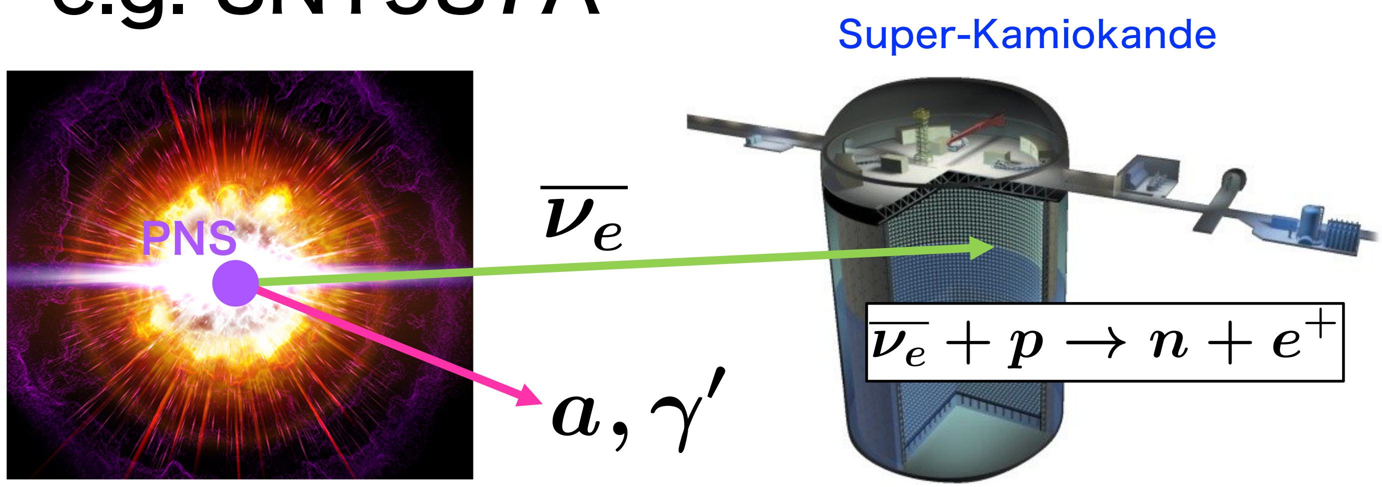
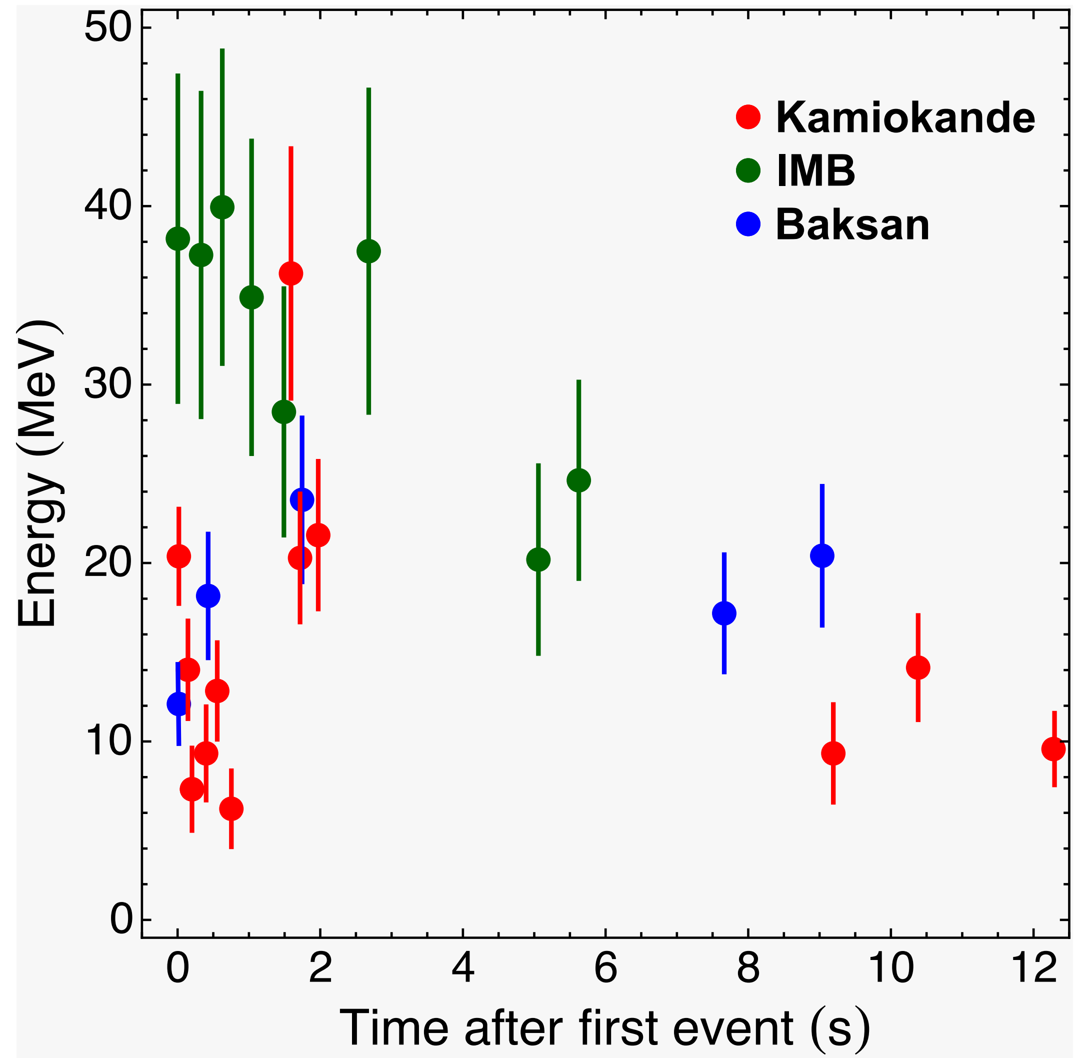
Axion emission from celestial bodies

💥 The axions can be produced copiously from some and hot dense celestial objects such as supernovae (SNe), neutron stars, and white dwarfs.

➤ e.g. SN1987A





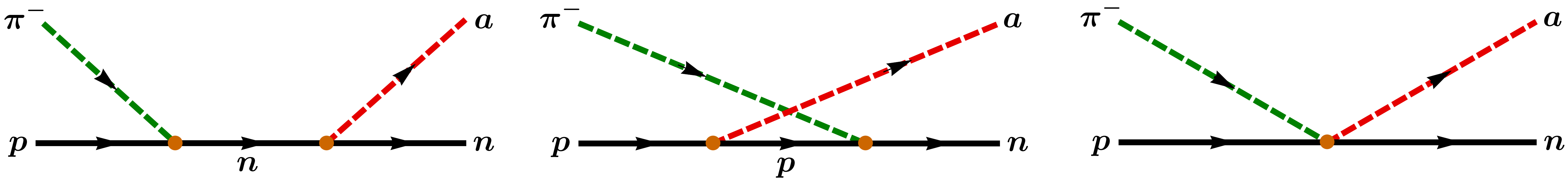
➤ Raffelt's criteria

$$L_{\text{new particle}} < L_\nu \sim 3 \times 10^{52} \text{erg/s}$$

Raffelt `90

What we did

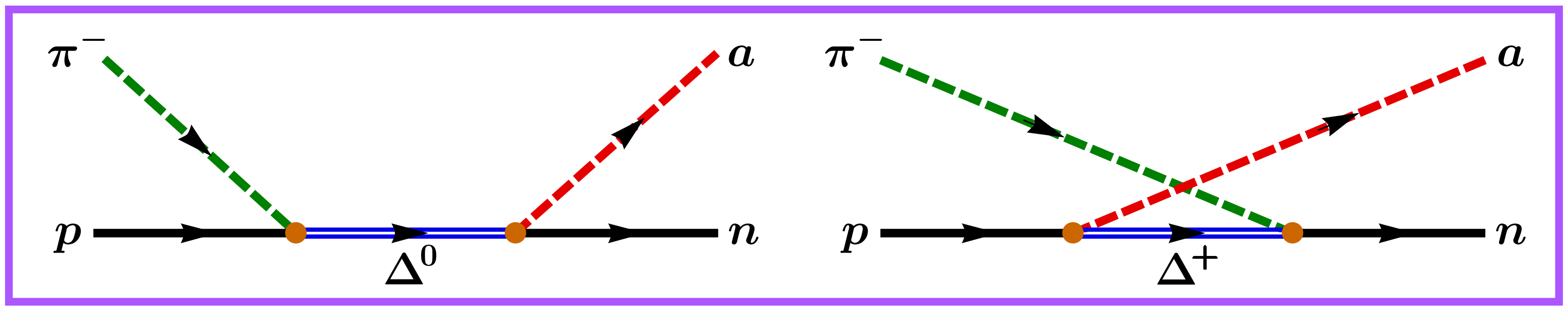
💥We evaluate the supernova axion emission rate including the Δ resonance in the heavy baryon chiral perturbation theory



P. Carenza, B. Fore, M. Giannotti, A. Mirizzi and S. Reddy (2021)

K. Choi, H. J. Kim, H. Seong & C. S. Shin (2022)

$|\boldsymbol{k}_\pi| \simeq m_\pi \ll m_p$



In our work

- For $T_{\mathsf{SN}} \sim 30\,\text{MeV}$, $|\boldsymbol{k}_\pi| \simeq \sqrt{3 m_\pi T_{\mathsf{SN}}} \simeq m_\pi$, $E_\pi \sim 180\,\text{MeV}$
- The $m_{\pi^- p}$ is somewhere in the middle of Δ and N masses.

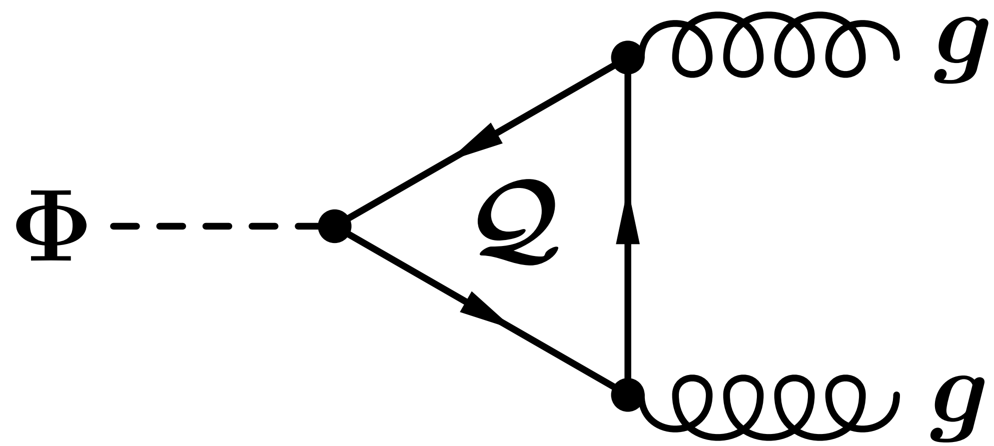
Axion models

💥KSVZ model

Kim `79,
Shifman, Vainshtein, Zakharov `80

- The QCD anomaly is realized by introducing a heavy vector-like fermion.

$$\mathcal{Q} = \mathcal{Q}_L + \mathcal{Q}_R \sim (\mathbf{3}, \mathbf{1})_0$$



- Interactions : $y_Q \Phi \overline{\mathcal{Q}_L} \mathcal{Q}_R + \mathrm{h.c.}$
- Under PQ symmetry

$$\Phi \to e^{iq_{\mathsf{PQ}}} \Phi \quad \mathcal{Q}_L \to e^{iq_{\mathsf{PQ}}/2} \mathcal{Q}_L \quad \mathcal{Q}_R \to e^{-iq_{\mathsf{PQ}}/2} \mathcal{Q}_R$$

- Only $\boldsymbol{\Phi}$ and $\boldsymbol{\mathcal{Q}}$ have PQ charges : $X_u = X_d = X_s = 0$

(at tree level)

Axion models

💥DFSZ model

Dine, Fischler, Srednicki `81
Zhitnitsky `80

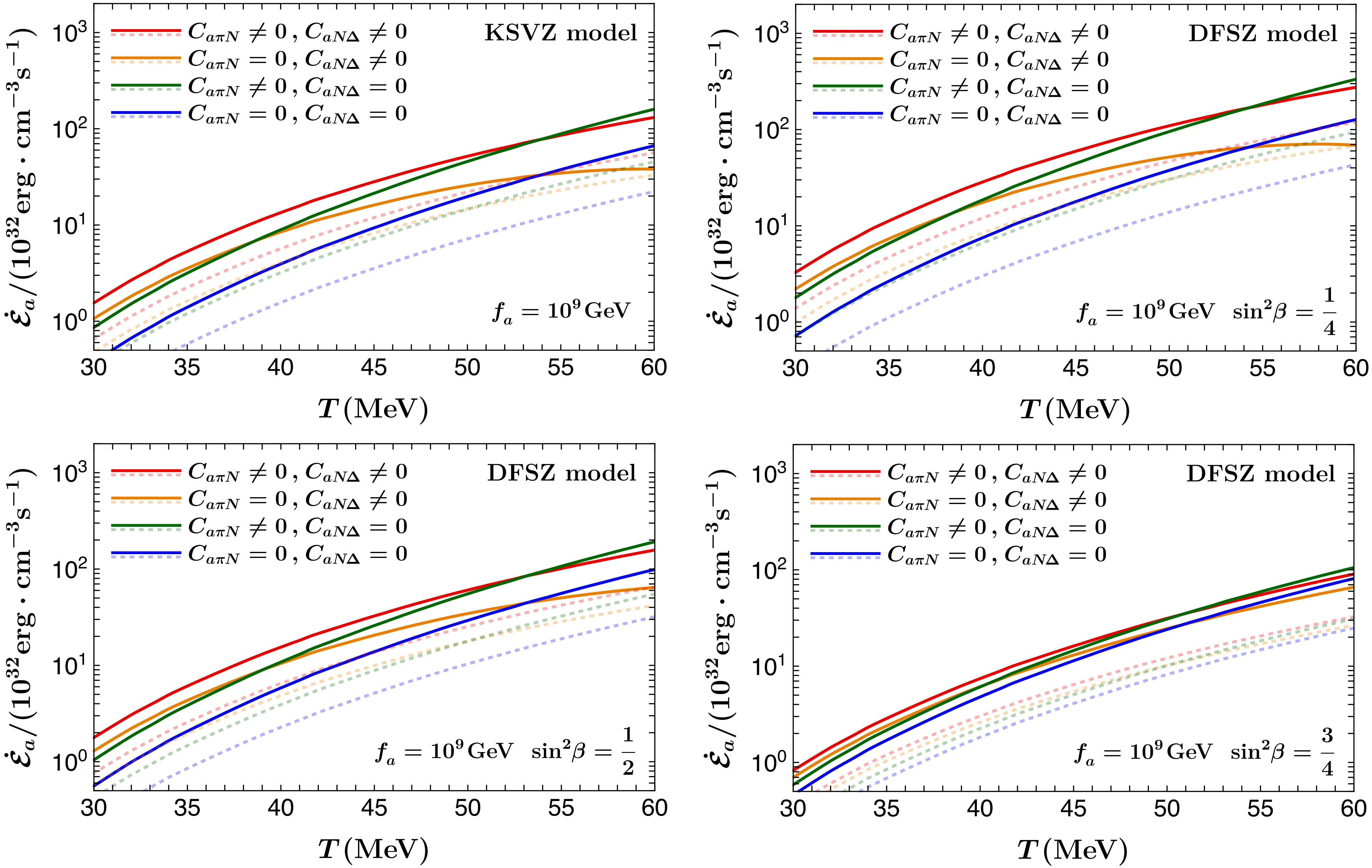
- The QCD anomaly is induced by assuming 2HDM $\boldsymbol{H_u}$ & $\boldsymbol{H_d}$ couples to the SM quark fields.
- Interactions : $H_u^\dagger H_d (\Phi^*)^2$ $\quad \overline{Q_L}(\mathcal{Y}_u \widetilde{H}_u U_R + \mathcal{Y}_d H_d D_R) + \mathrm{h.c.}$
- Under PQ symmetry

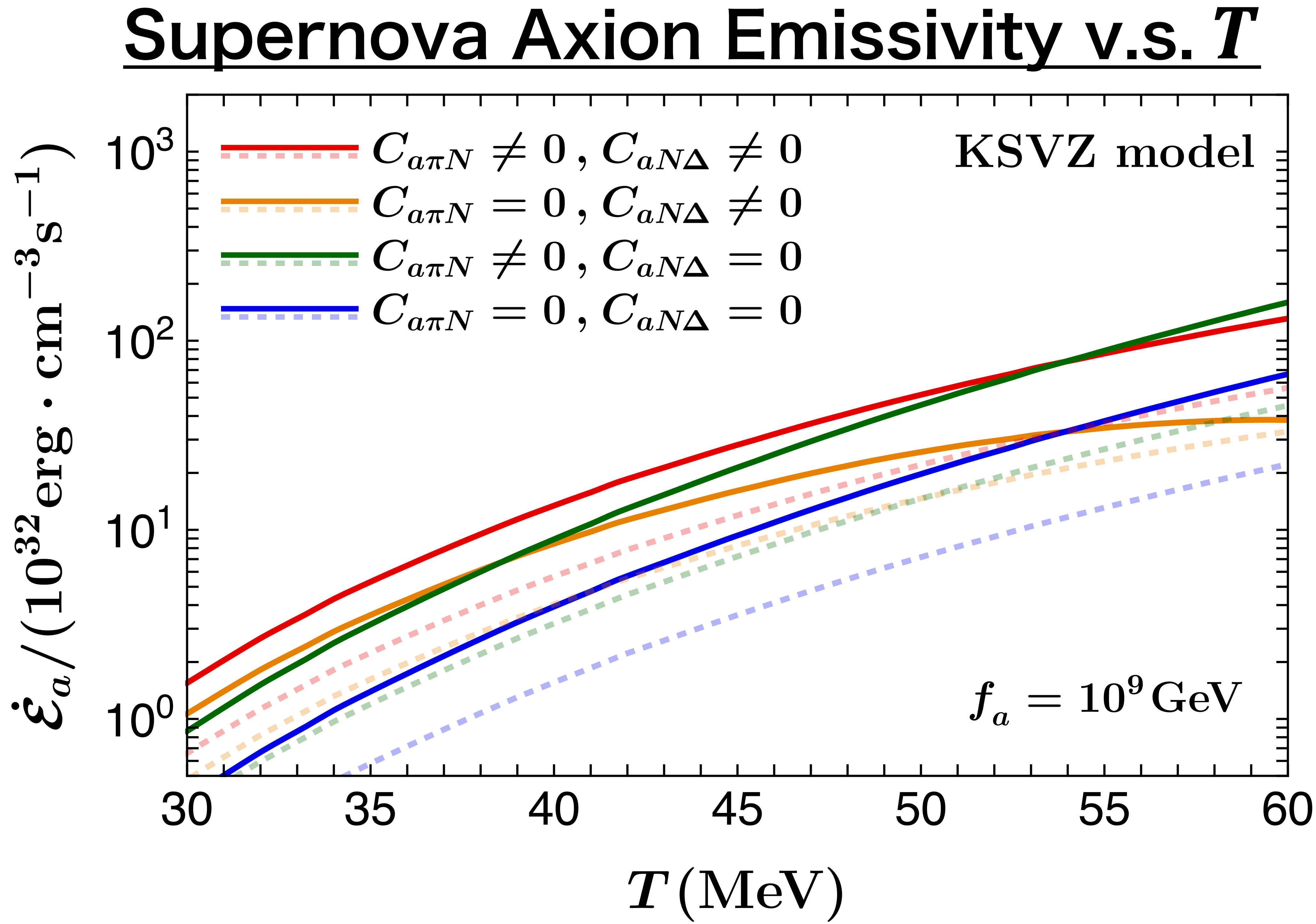
$$\Phi \to e^{iq_{\mathsf{PQ}}}\Phi \quad H_u \to e^{-iq_{\mathsf{PQ}}} H_u \quad H_d \to e^{iq_{\mathsf{PQ}}} H_d$$

$$Q_L \to Q_L \quad U_R \to e^{-iq_{\mathsf{PQ}}} U_R \quad D_R \to e^{-iq_{\mathsf{PQ}}} D_R$$

- The axion as a linear combination of the CP-odd scalars can couple to the SM quarks : $X_u = \dfrac{\cos^2\beta}{3}\ , \ \ X_{d,s} = \dfrac{\sin^2\beta}{3}$ $\quad \tan\beta = \dfrac{\langle \boldsymbol{H_u}\rangle}{\langle \boldsymbol{H_d}\rangle}$

Supernova Axion Emissivity v.s. T





Supernova Axion Emissivity v.s. T
$C_{a\pi N} \neq 0\,, C_{aN\Delta} \neq 0$
$C_{a\pi N} = 0\,, C_{aN\Delta} \neq 0$
$C_{a\pi N} \neq 0\,, C_{aN\Delta} = 0$
$C_{a\pi N} = 0\,, C_{aN\Delta} = 0$
KSVZ model
$f_a = 10^9\,\mathrm{GeV}$
$\dot{\mathcal{E}}_a/(10^{32}\mathrm{erg}\cdot\mathrm{cm}^{-3}\mathrm{s}^{-1})$
10^0
10^1
10^2
10^3
30
35
40
45
50
55
60
$T\,(\mathrm{MeV})$