VISHv

Raymond R. Volkas

ARC Centre of Excellence for Dark Matter Particle Physics (CDM)

School of Physics, The University of Melbourne

TOPAC 2026, 16-21 April 2026, UESTC, Chengdu

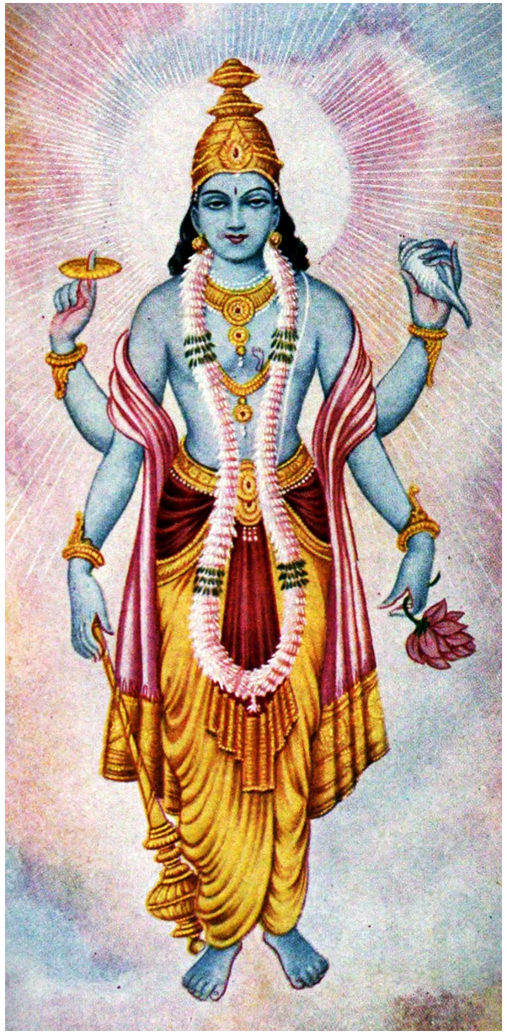


Image credit: Wikipedia

Hindu God of Preservation

“Vishnu is the supreme being who creates, protects and transforms the universe.” – Wikipedia

Let’s see if VISHν = Variant axIon Seesaw Higgs ν-trino lives up to its namesake …

Note: I have stolen some slides from my student Alexei Sopov.

1. The strong CP problem
2. The invisible DFSZ axion and technical naturalness
3. The νDFSZ model: successes and cosmological challenges
4. VISHν: meeting the cosmological challenges
5. Closing remarks

RV, Davies, Joshi: Naturalness of the invisible axion model, PLB 215 (1988) 133
Clarke, Foot, RV: Natural leptogenesis and neutrino masses with two Higgs doublets, PRD 92 (2015) 033006
Clarke, RV: νDFSZ: Technically natural nonsupersymmetric model of neutrino masses, baryogenesis, the strong CP problem and dark matter, PRD 93 (2016) 035001
Sopov, RV: VISHν: a unified solution to five SM shortcomings with a protected electroweak scale, PDU 42 (2023) 101381
Sopov, Tamarit, RV: The post-inflationary cosmology of the VISHν axion-majoron model, 2512.12627

Related to a KSVZ axion implementation (aka SMASH):
Salvio: PLB 743 (2015) 428; PRD 99 (2019) 015037
Ballesteros, Redondo, Ringwald, Tamarit: PRL 118 (2017) 071802; JCAP 08 (2017) 001; FASS 6 (2019) 55

1. The strong CP problem

QCD permits the term $\mathcal{L}_\theta = \bar{\theta}\frac{g^2}{32\pi^2}G^{\mu\nu}\tilde{G}_{\mu\nu}$ that violates CP (and P) and induces an electric DM for the neutron.

Experimentally $\bar{\theta} \lesssim 10^{-10}$. The $\bar{\theta} \to 0$ limit is not technically natural, because weak interactions violate CP and P.

The strong CP problem is why is $\bar{\theta}$ so small? (Note: in the SM, $\bar{\theta}$ running is generated only at 7 loops ...)

Ellis, Gaillard (1979)

In Peccei-Quinn axion models, a $U(1)_{PQ}$ that has a colour anomaly $\partial_\mu J^\mu_{\mathrm{PQ}} \propto G^{\mu\nu}\tilde{G}_{\mu\nu}$ is introduced, and the effective Lagrangian becomes $\mathcal{L}_\theta = \left(\frac{a(x)}{f_a} + \bar{\theta}\right)\frac{g^2}{32\pi^2}G^{\mu\nu}\tilde{G}_{\mu\nu}$ where a(x) is the axion.

The axion potential is minimised when $\langle a \rangle = -\bar{\theta} f_a$ thus removing the CP-violating term.

Peccei, Quinn (1977), Weinberg (1978), Wilczek (1978)

2. The invisible DFSZ axion and technical naturalness

DFSZ axion model: Peccei-Quinn symmetry using only standard quarks but two Higgs doublets Φ_1 and Φ_2. Axion made invisible by breaking PQ at high scale with gauge-singlet scalar S.

Zhitnitskii (1980) Dine, Fischler, Srednicki (1981)

Yukawa sector: $i\sigma_2\Phi_1^*$ couples to RH up-type and to Φ_2 RH down-type quarks (Type-II/Flipped 2HDM – flavour universal).

PQ charges:

q_L	u_R	d_R	Φ_1	Φ_2	S
0	$\cos^2\beta$	$\sin^2\beta$	$\cos^2\beta$	$-\sin^2\beta$	$\frac{1}{2}$ or 1

$$\langle S\rangle = \frac{v_s}{\sqrt{2}} \qquad \langle \Phi_i^0\rangle = \frac{v_i}{\sqrt{2}} \qquad \tan\beta = \frac{v_1}{v_2}$$

for $\Phi_1^\dagger\Phi_2 S^2$ term

vDFSZ

for $\Phi_1^\dagger\Phi_2 S$ term

VISHv

(Need cubic option as part of domain wall problem cure – see later)

Scalar potential: $$V = M_{11}^2 \Phi_1^\dagger \Phi_1 + M_{22}^2 \Phi_2^\dagger \Phi_2 + M_{SS}^2 S^* S + \frac{\lambda_1}{2}(\Phi_1^\dagger \Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger \Phi_2)^2 + \frac{\lambda_S}{2}(S^* S)^2$$
$$+ \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \lambda_{1S}(\Phi_1^\dagger \Phi_1)(S^* S) + \lambda_{2S}(\Phi_2^\dagger \Phi_2)(S^* S)$$
$$+ \begin{cases} \kappa \Phi_1^\dagger \Phi_2 S \;\; + \text{h.c.} & [\text{VISH}\nu] \\ \epsilon \Phi_1^\dagger \Phi_2 S^2 + \text{h.c.} & [\nu\text{DFSZ}] \end{cases}$$

VEV hierarchy: $\text{PQ scale} \sim v_s \gg v_i \sim \text{EW scale}$

How to generate this hierarchy at tree level?
What about radiative stability?

Potential minimisation:
$$M_{11}^2 = -\frac{1}{2} t_1 v_s^2 - \lambda_1 v_1^2 - \frac{1}{2}(\lambda_3 + \lambda_4) v_2^2$$
$$M_{22}^2 = -\frac{1}{2} t_2 v_s^2 - \lambda_2 v_2^2 - \frac{1}{2}(\lambda_3 + \lambda_4) v_1^2$$
$$M_{SS}^2 = -\frac{1}{2} t_1 v_1^2 - \frac{1}{2} t_2 v_2^2 - \lambda_S v_s^2$$

$$t_1 \equiv \epsilon \frac{v_2}{v_1} + \lambda_{1S}$$
$$t_2 \equiv \epsilon \frac{v_1}{v_2} + \lambda_{2S}$$

Generate hierarchy by $M_{SS} \gg M_{11,22}$

Need $t_{1,2} \lesssim \dfrac{v_{1,2}^2}{v_s^2}$

Is this VEV hierarchy technically natural?
Yes!

$$t_1 \equiv \epsilon \frac{v_2}{v_1} + \lambda_{1S}$$
$$t_2 \equiv \epsilon \frac{v_1}{v_2} + \lambda_{2S}$$

$t_{1,2} \lesssim \frac{v_{1,2}^2}{v_s^2} \ll 1$ achieved through $\epsilon, \ \lambda_{1S}, \ \lambda_{2S} \ll 1$

In that limit, S decouples from all the SM fields: hidden sector.

$$S = \int d^4x \, \mathcal{L}_{\rm SM}(x) + \int d^4x' \mathcal{L}_{\rm S}(x')$$

Independent Poincaré transformations in SM and S sectors: Poincaré protection.

RV, Davies, Joshi (1988) Georgi (private comm, 1988)
Foot, Kobakhidze, McDonald, RV (2014)
Sopov, RV (2023)

Note that $\epsilon = 0$ also enhances $U(1)_{PQ}$ to $U(1)'_{PQ} \times U(1)_S$.

Dangerous gravity effects?

Hidden sectors must interact with the SM sector through gravity.

Planck-suppressed effective operators that explicitly break $U(1)_{PQ}$?

"Axion quality problem" if the suppression is power law.

Kamionkowski, March-Russell (1992)
Barr, Seckel (1992)
Ghigna, Lusignoli, Roncadelli (1992)

But, Petrossian-Byrne & Villadoro JHEP 07 (2025) 049 argue that string UV completions can always be found where the suppression is *exponentially small*.

As for the string axiverse, the mechanism behind the open string axiverse can be fully understood within field theory. It can naturally be extended to protect any $U(1)$ global symmetry with exponentially high quality and it requires adding only a small extra dimension. An important point is that the high-quality global symmetry does not manifest itself in the effective 4D theory as an accidental symmetry, rather as a genuine global symmetry: symmetry breaking operators of low dimensionality are not forbidden, but their coefficient is exponentially suppressed. This reconciles the ancient QFT practice of imposing global symmetries by hand in low-energy effective field theories (EFTs) with the modern lore about the absence of exact global symmetries in a full theory of quantum gravity.

3. The νDFSZ model: successes and cosmological challenges

Successes of DFSZ model: (i) solves the strong CP problem

(ii) provides axion DM candidate for PQ scale of $10^{10} – 10^{11}$ GeV

There is an obvious extension: identify PQ and type-I seesaw scales and (iii) explain m_ν

Langacker, Peccei, Yanagida (1986)
Shin (1987)

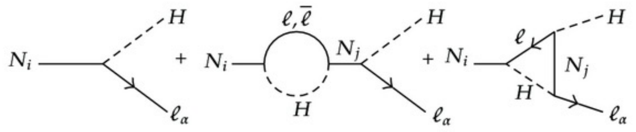
Then also: (iv) explain baryogenesis via type-I seesaw leptogenesis

Langacker, Peccei, Yanagida (1986)
Fukugita, Yanagida (1986)

The νDFSZ model is a detailed incarnation of these ideas.

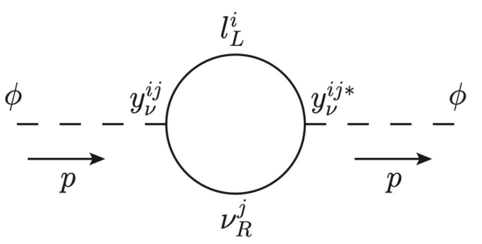
Clarke, RV (2016)

<u>Review of a problem with single Higgs-doublet leptogenesis</u>: $-\mathcal{L} \supset y_N \bar{\ell}_L \tilde{\Phi} \nu_R + \frac{1}{2} \bar{\nu}_R M_N \nu_R + h.c.$



Seesaw formula: $m_\nu = \frac{v^2}{2} y_N M_N^{-1} y_N^T$

Vissani naturalness bound:



$$\delta\mu^2 \simeq \frac{1}{4\pi^2} \frac{1}{\langle\phi\rangle^2} m_\nu M_N^3 < 1\ \mathrm{TeV}^2$$

$$\Rightarrow m_N < 3 \times 10^7\ \mathrm{GeV}$$

Vissani (1998)
Clarke, Foot, RV (2015a)

Davidson-Ibarra bound: standard hierarchical, thermal leptogenesis requires $M_N > 5 \times 10^8 - 2 \times 10^9$ GeV

Davidson, Ibarra (2002)
Giudice+ (2004)

Tension between leptogenesis and naturalness

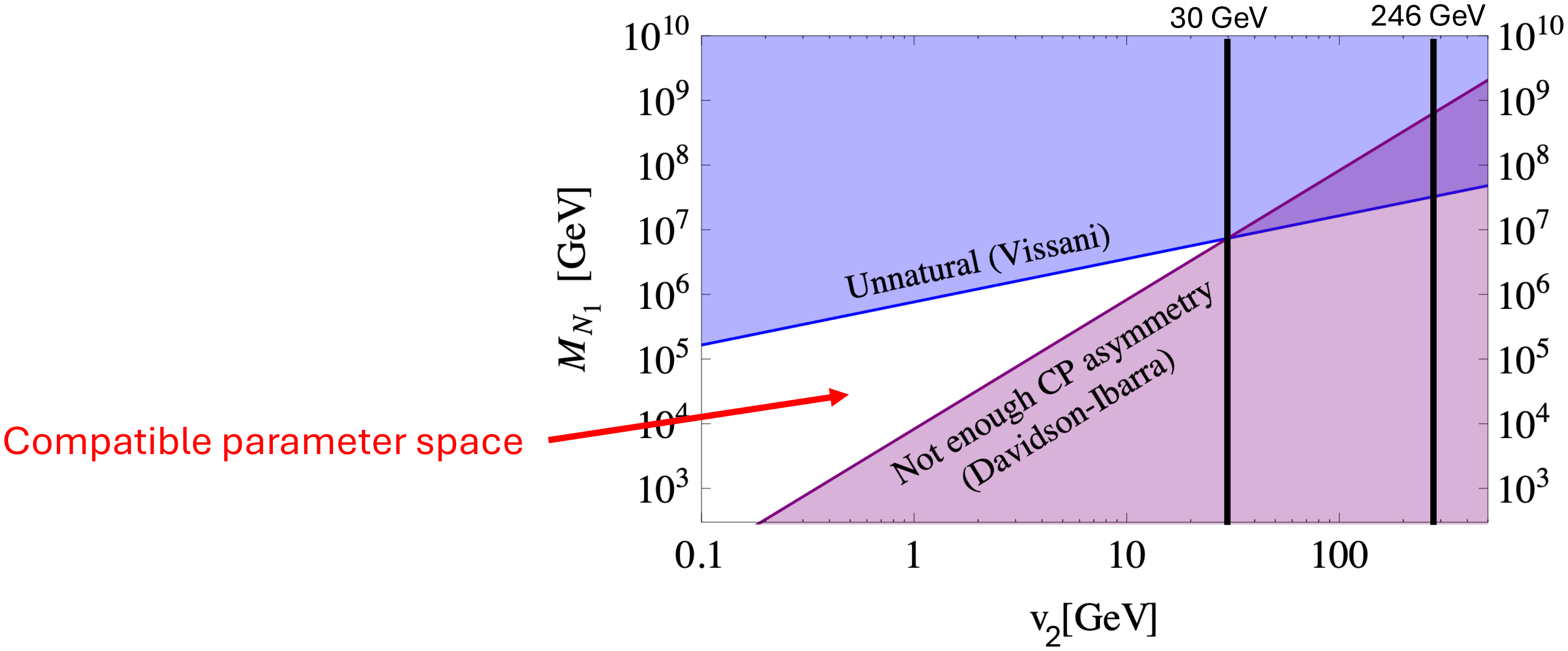
Two (non-susy) options: degenerate M_N, two Higgs doublets (our choice)

Consider two Higgs doublets with Φ_2 coupling to the RH neutrino:

Clarke, Foot, RV (2015b)

Vissani bound: $M_{N_1} \lesssim 3 \times 10^7 \text{ GeV} \left(\frac{v_2}{246 \text{ GeV}}\right)^{\frac{2}{3}}$

DI bound: $M_{N_1} \gtrsim 5 \times 10^8 \text{ GeV} \left(\frac{v_2}{246 \text{ GeV}}\right)^{2}$



Now use that idea in the DFSZ context to get the νDFSZ:

Clarke, RV (2016)

Take the 2HDM, add three RH neutrinos and a complex scalar singlet S, impose Peccei-Quinn symmetry. Axion is the phase of S.

$$-\mathcal{L}_Y = y_u \bar{q}_L \tilde{\Phi}_1 u_R + y_d \bar{q}_L \Phi_2 d_R + y_e \bar{\ell}_L \Phi_J e_R + y_\nu \bar{\ell}_L \tilde{\Phi}_2 \nu_R + \frac{1}{2} y_N \overline{(\nu_R)^c} S \nu_R + h.c.$$

J=2 (1) is Type-II (Flipped) ν2HDM

generates $M_N < 3 \times 10^7$ GeV

EW scale ~ – (88 GeV)^2

+(10^3 GeV)^2

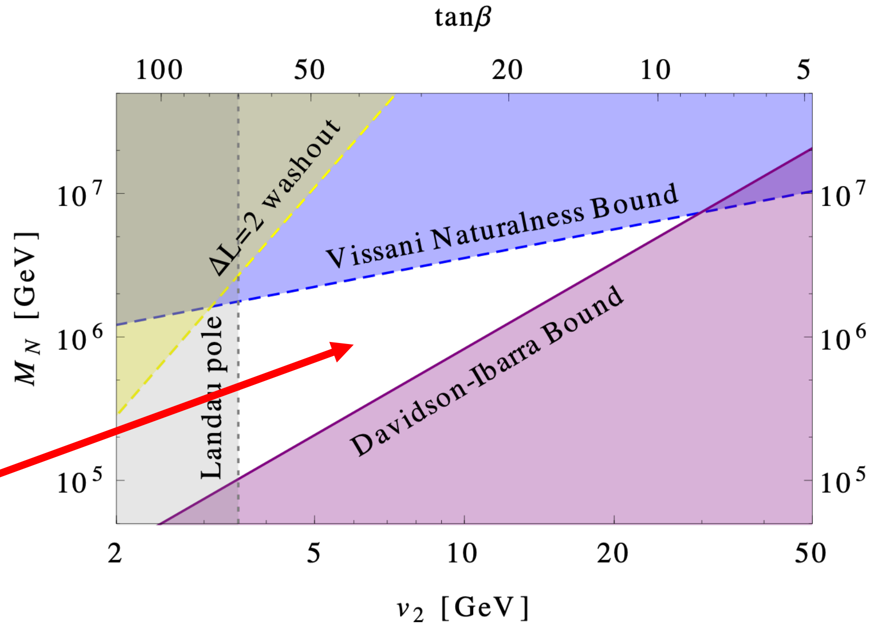
PQ scale ~ –(10^{11} GeV)^2

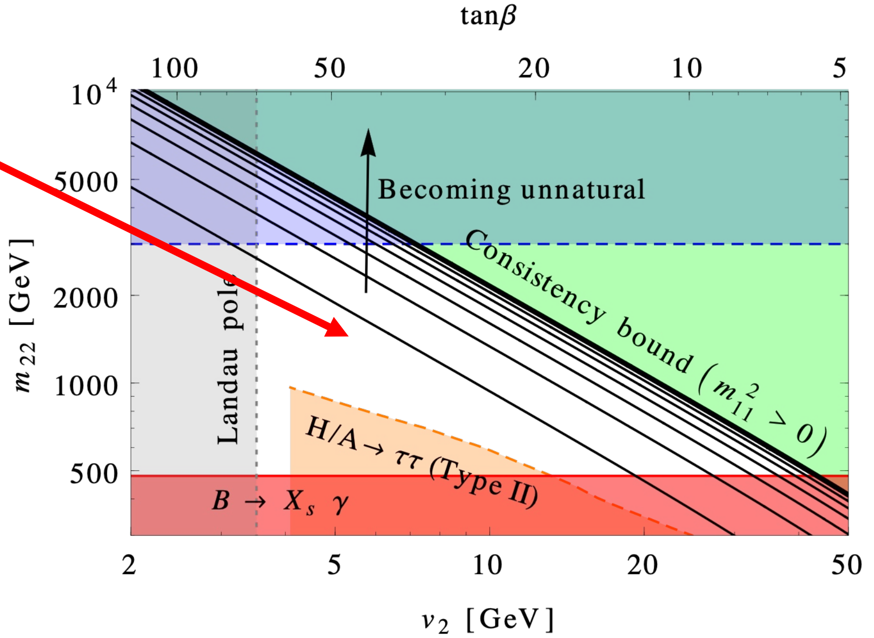
$$V = M_{11}^2 \Phi_1^\dagger \Phi_1 + M_{22}^2 \Phi_2^\dagger \Phi_2 + M_{SS}^2 S^* S + \frac{\lambda_1}{2}(\Phi_1^\dagger \Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger \Phi_2)^2 + \frac{\lambda_S}{2}(S^* S)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2)$$
$$+ \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \lambda_{1S}(\Phi_1^\dagger \Phi_1)(S^* S) + \lambda_{2S}(\Phi_2^\dagger \Phi_2)(S^* S) + \epsilon \Phi_1^\dagger \Phi_2 S^2 + \text{h.c.}$$

tiny inter-sector couplings

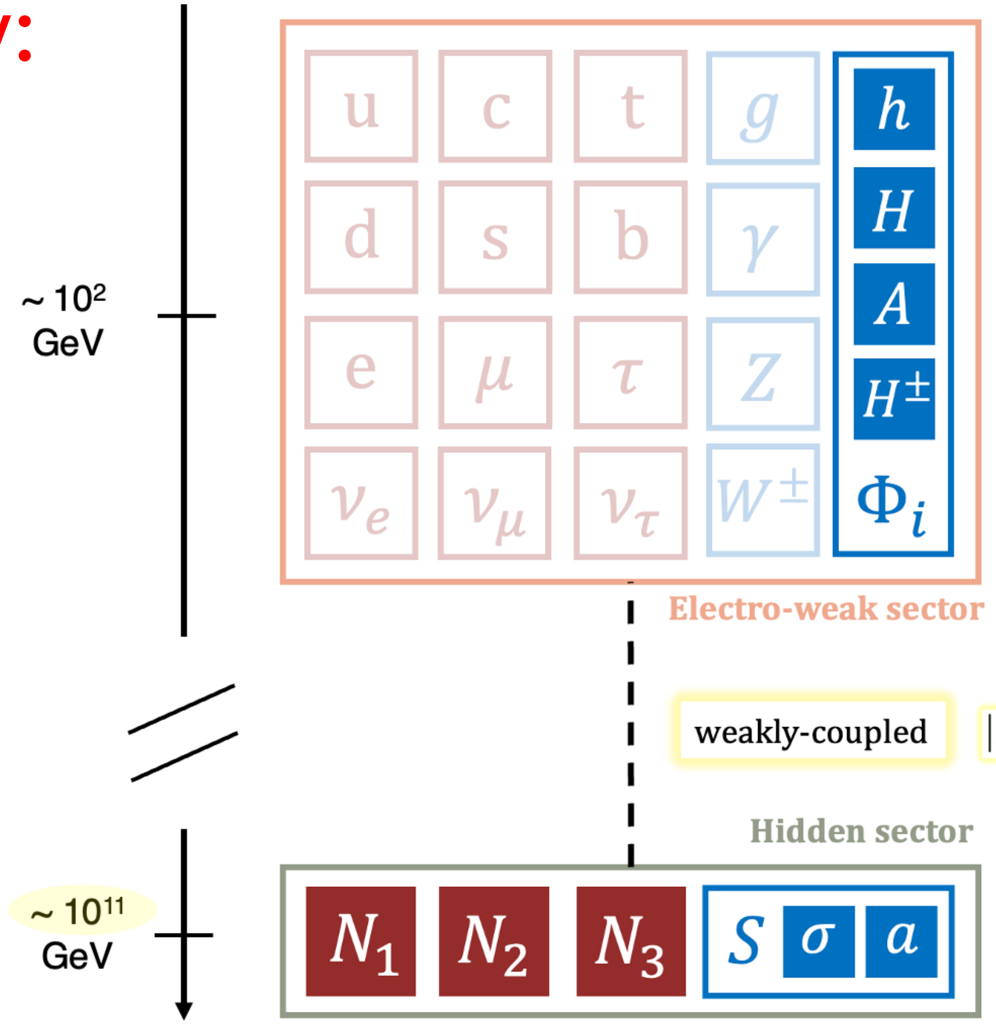
induces linear term for Φ_2 and thus small v_2

Acceptable regions





In summary:



$$
\begin{aligned}
V = &\; M_{11}^2 \Phi_1^\dagger \Phi_1 + M_{22}^2 \Phi_2^\dagger \Phi_2 + M_{SS}^2 S^* S \\
&+ \frac{\lambda_1}{2}(\Phi_1^\dagger \Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger \Phi_2)^2 + \frac{\lambda_S}{2}(S^* S)^2 \\
&+ \lambda_3(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4(\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\
&+ \lambda_{1S}(\Phi_1^\dagger \Phi_1)(S^* S) + \lambda_{2S}(\Phi_2^\dagger \Phi_2)(S^* S) \\
&+ \begin{cases} \kappa \Phi_1^\dagger \Phi_2 S \; + \text{h.c.} & [\text{VISH}\nu] \\ \epsilon \Phi_1^\dagger \Phi_2 S^2 + \text{h.c.} & [\nu\text{DFSZ}] \end{cases}
\end{aligned}
$$

$$
\begin{aligned}
m_{ii}^2 &= M_{ii}^2 + \lambda_{iS}\langle S \rangle^2 \\
m_{12}^2 &= \kappa \langle S \rangle
\end{aligned}
$$

$$|\lambda_{1S}| \lesssim 10^{-18}, \; |\lambda_{2S}| \lesssim 10^{-16} \text{ and } |\kappa| \ll O(0.1) \text{ keV}$$

Type II setup with:

$$-\mathcal{L}_Y \supset y_\nu \overline{l_L} \tilde{\Phi}_2 \nu_R + \frac{1}{2} y_N \overline{(\nu_R)^c} S \nu_R + H.c.,$$

y_N small if S hidden from neutrinos

vDFSZ successes: strong CP solution, DM, neutrino masses, non-fine-tuned leptogenesis.

vDFSZ challenges: cosmological history prior to leptogenesis

(i) potential domain wall problem

(ii) viable inflation

VISHν is motivated by these challenges.

4. VISHv: meeting the cosmological challenges

Sopov, RV (2023)
Sopov, Tamarit, RV (2025)

The DFSZ domain wall problem:

Sikivie 1982

QCD instantons explicitly break $U(1)_{PQ}$ through the colour anomaly.

However, for standard DFSZ, there is an anomaly-free and hence not explicitly broken Z_6 subgroup.

Quark condensates spontaneously break this Z_6, producing cosmologically bad stable domain walls.

Elegant solution:

Make $U(1)_{PQ}$ flavour-dependent such that the colour anomaly fully breaks it.

Davidson, Vozmediano (1984a, 1984b)
Geng, Ng (1989, 1990)

There is a class of such theories. The "top-specific" model is a simple (interesting!) example that we adopt.

Peccei, Wu, Yanagida (1986)
Krauss, Wilczek (1986)

Chiang+ (2015, 2018)

Cox, Dolan, Hayat, Thamm, RV (2024)

q_L	u_R^a	u_R^3	d_R	l_L	e_R	ν_R	Φ_1	Φ_2	S
0	$-\sin^2\beta$	$\cos^2\beta$	$\sin^2\beta$	$\frac{1}{2}-\cos^2\beta$	$\frac{3}{2}-2\cos^2\beta$	$-\frac{1}{2}$	$\cos^2\beta$	$-\sin^2\beta$	1

RH top has distinct PQ charge

Only Φ_1 couples to RH top

$$-\mathcal{L}_Y = \overline{q_L}^j y_{u1}^{j3}\tilde{\Phi}_1 u_R^3 + \overline{q_L}^j y_{u2}^{ja}\tilde{\Phi}_2 u_R^a + \overline{q_L}^j y_d^{jk}\Phi_2 d_R^k + \overline{l_L}^j y_e^{jk}\Phi_2 e_R^k$$
$$+ \overline{l_L}^j y_\nu^{jk}\tilde{\Phi}_2 \nu_R^k + \tfrac{1}{2}\overline{(\nu_R)^c}^j y_N^{jk} S \nu_R^k + \text{h.c.}$$

Collider signatures and constraints: $t \to hc$ and $t \to hu$

$cg \to tH$ or tA and $cg \to bH^+$

Chiang+ (2015, 2018)
Hou, Modak (2021)
Ghosh, Hou, Modak (2020)
Kohda, Modak, Hou (2018)

With $v_2 << v_1$, VISHν inherits the successes of νDFSZ.
And, get a nice explanation for why m_t >> other fermion masses!

Like SMASH, we explore variants of "Higgs inflation", through non-minimal couplings of scalar fields to gravity:

$$\frac{\mathcal{L}^{\mathcal{J}}}{\sqrt{-g^{\mathcal{J}}}} \supset \left(\frac{M_P^2}{2} + \xi_1 \Phi_1^\dagger \Phi_1 + \xi_2 \Phi_2^\dagger \Phi_2 + \xi_S S^\dagger S\right) R^{\mathcal{J}}$$

(J = Jordan frame)

Let $\Phi_1^0 = \frac{\rho_1}{\sqrt{2}} e^{i\vartheta_1/v_1},\ \Phi_2^0 = \frac{\rho_2}{\sqrt{2}} e^{i\vartheta_2/v_2},\ S = \frac{\sigma}{\sqrt{2}} e^{i\vartheta_S/v_S}$

Go to Einstein (E) frame: $g_{\mu\nu}^{\mathcal{J}} \to g_{\mu\nu}^{\mathcal{E}} = \Omega^2(\rho_1,\rho_2,\sigma) g_{\mu\nu}^{\mathcal{J}} \quad \text{where} \quad \Omega^2 \equiv 1 + \frac{\xi_1\rho_1^2 + \xi_2\rho_2^2 + \xi_S\sigma^2}{M_P^2}.$

Then: $\frac{\mathcal{L}^{\mathcal{E}}}{\sqrt{-g^{\mathcal{E}}}} \supset \frac{M_P^2}{2} R^{\mathcal{E}} - \frac{1}{2}\mathcal{G}_{IJ}^{\mathcal{E}} \partial_\mu \varphi^I \partial^\mu \varphi^J - V^{\mathcal{E}}(\varphi^I)$

$$V^{\mathcal{E}}(\varphi^I) = \Omega^{-4}(\varphi^I) V^{\mathcal{J}}(\varphi_I) \simeq \frac{M_P^4}{8} \frac{\lambda_i \rho_i^4 + 2\lambda_{34}\rho_1^2\rho_2^2 + 2\lambda_{iS}\rho_i^2\sigma^2 + \lambda_S\sigma^4}{(M_P^2 + \xi_i\rho_i^2 + \xi_S\sigma^2)^2}$$

$(\lambda_{34} \equiv \lambda_3 + \lambda_4)$

Potential is flat at large moduli: good for inflation

Convenient to do a field redefinition: $\chi/M_P \equiv \sqrt{3/2}\log\Omega^2, \quad r_i/M_P \equiv \rho_i/\sigma$

to get: $V^{\mathcal{E}}(\varphi^I) \simeq [\Lambda(r_1, r_2)]^4 \left[1 - e^{-\frac{2}{\sqrt{6}}\frac{\chi}{M_P}}\right]^2$ χ is the inflaton; this specific V holds for large ξ

$$\Lambda^4(r_i) \simeq \frac{M_P^4}{8}\frac{\lambda_i r_i^4 + 2\lambda_{34} r_1^2 r_2^2 + 2\lambda_{iS} M_P^2 r_i^2 + \lambda_S M_P^4}{(\xi_i r_i^2 + \xi_S M_P^2)^2}$$

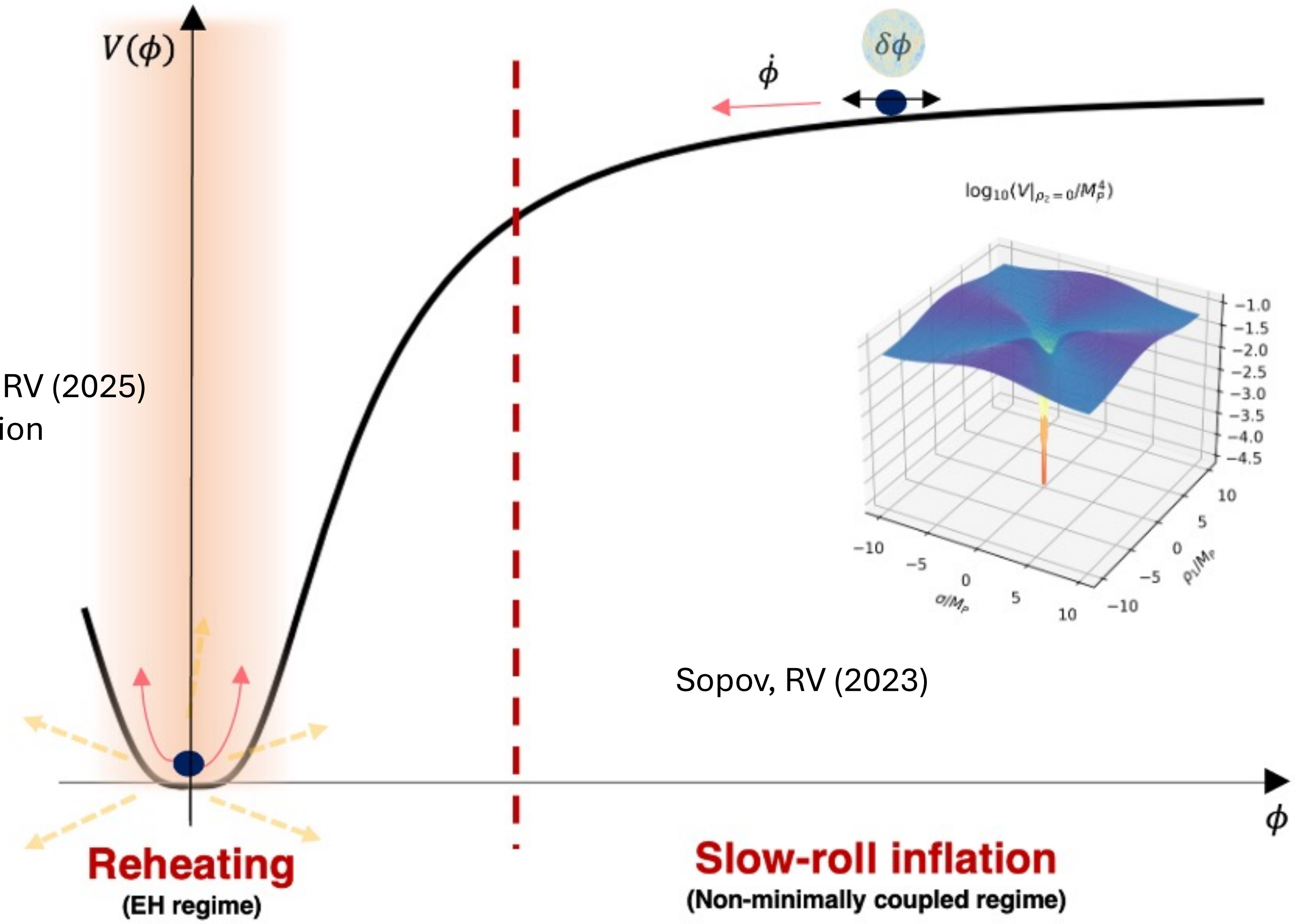
Work out the minima of Λ^4 in various parameter regimes to determine the inflaton trajectories in field space.

Get 7 possibilities for χ: $\rho_1,\ \rho_2,\ \rho_1\&\rho_2$ Higgs doublet inflation driven by large ρ_1 or ρ_2 or combination.

$\rho_1\&\sigma,\ \rho_2\&\sigma,\ \rho_1\&\rho_2\&\sigma,\ \sigma$ S-Higgs or S inflation

Note that inflation is effectively single-field.

Sopov, Tamarit, RV (2025)
Choose S-inflation



Sopov, RV (2023)

- **Non-minimal couplings** of scalars to gravity generically arise in curved spacetime:

$$\frac{\mathcal{L}^{\mathcal{J}}}{\sqrt{-g^{\mathcal{J}}}} \supset \left(\frac{M_P^2}{2} + \xi_1 \Phi_1^\dagger \Phi_1 + \xi_2 \Phi_2^\dagger \Phi_2 + \xi_S S^\dagger S \right) R^{\mathcal{J}}$$

Manifest in Jordan frame

Along each inflaton trajectory: $$V^{\mathcal{E}}(\chi) \simeq \frac{M_P^4}{8}\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2}\left[1-e^{-\frac{2}{\sqrt{6}}\frac{\chi}{M_P}}\right]^2$$

$$\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2} \simeq \frac{\lambda_S L}{\lambda_S(\lambda_2\xi_1^2 - 2\lambda_{34}\xi_1\xi_2 + \lambda_1\xi_2^2) + \xi_S^2 L}$$

$\Phi_1\Phi_2 S$ inflation

$$L \equiv \lambda_1\lambda_2 - \lambda_{34}^2$$

$$\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2} \simeq \frac{\lambda_S\lambda_i}{\lambda_S\xi_i^2 + \lambda_i\xi_S^2}$$

$\Phi_i S$ inflation

$$\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2} \simeq \frac{L}{\lambda_2\xi_1^2 - 2\lambda_{34}\xi_1\xi_2 + \lambda_1\xi_2^2}$$

$\Phi_1\Phi_2$ inflation

$$\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2} = \frac{\lambda_{i,S}}{\xi_{i,S}^2}$$

Φ_i or S inflation

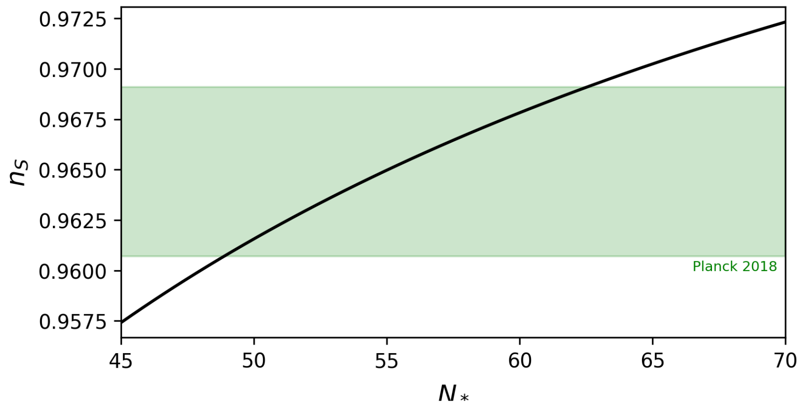
<u>Fit to cosmological observables</u>:

large ξ cases

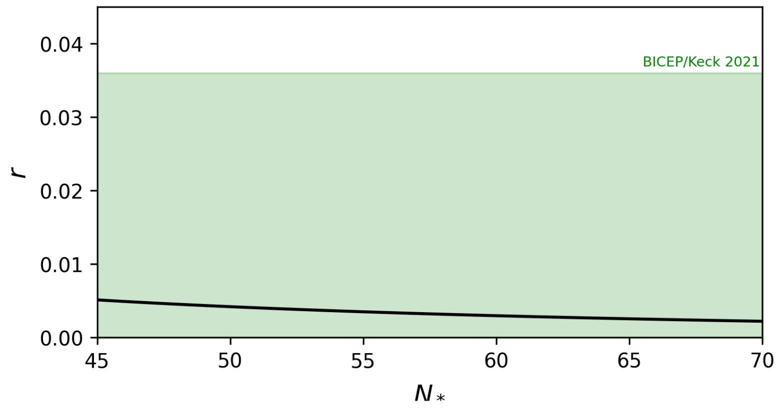
scalar amplitude

$$\boxed{\frac{\lambda_{\rm eff}}{\xi_{\rm eff}^2} \sim 8.9\times 10^{-10}}$$

scalar spectral index



tensor-to-scalar ratio

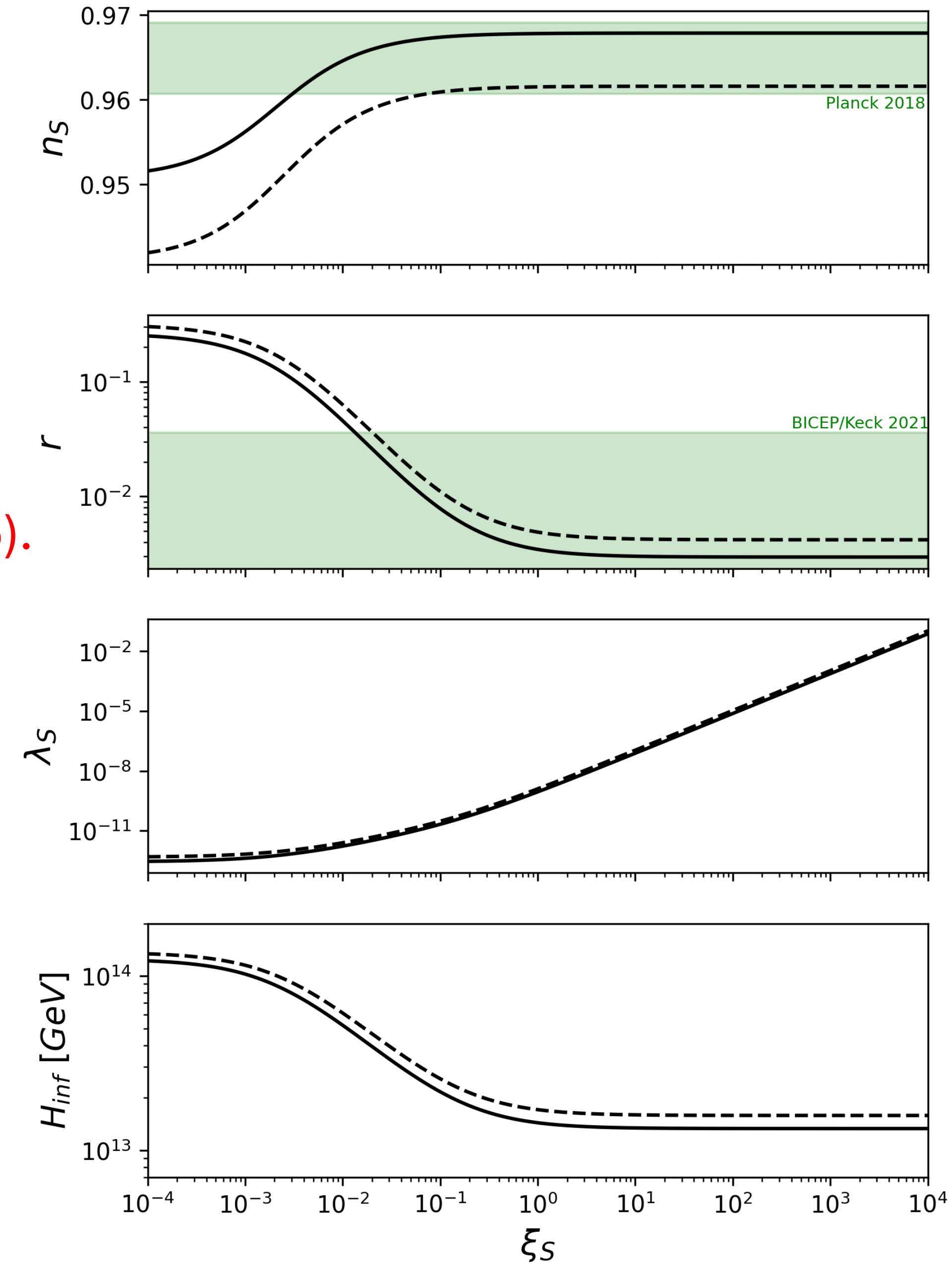


number of e-folds

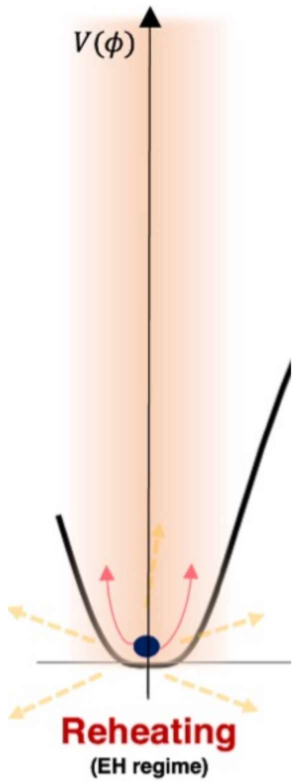
For Φ_i and $\Phi_1\Phi_2$ inflation, large ξ necessary to fit the scalar amplitude data – concerns about unitarity violation.

Small ξ possible for inflatons involving large S, since λ_S is free. This is why we chose S-inflation in Sopov, Tamarit and RV (2025). Good for avoiding possible unitarity problems.

Small λ_S is OK here – see Sopov and RV (2023) for discussion.



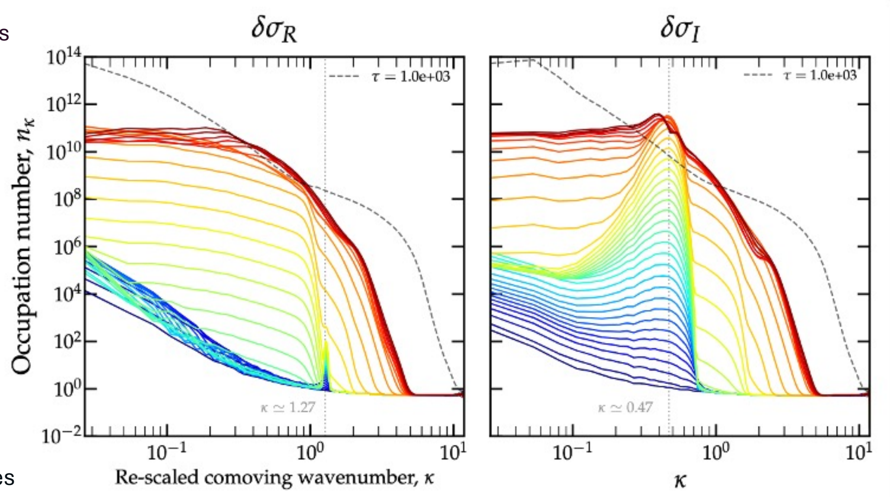
VISHν: reheating from a dark sector



$V \propto \lambda\phi^4$
Radiation domination
(Approx. conformal)

Later times

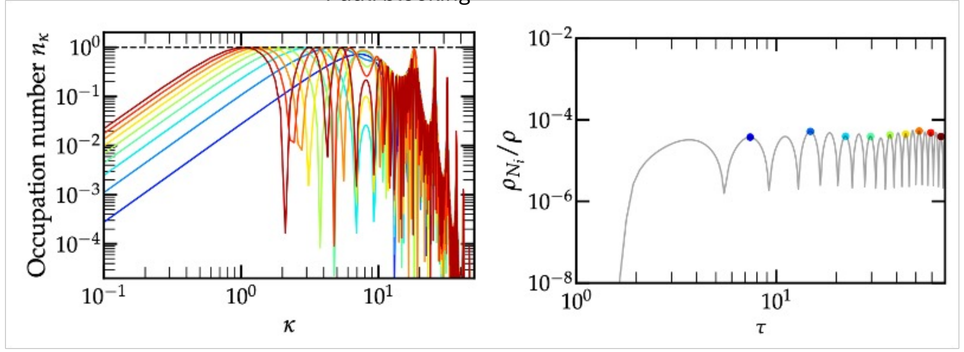
Earlier times



Inflatons **Axions**

Bosonic preheating

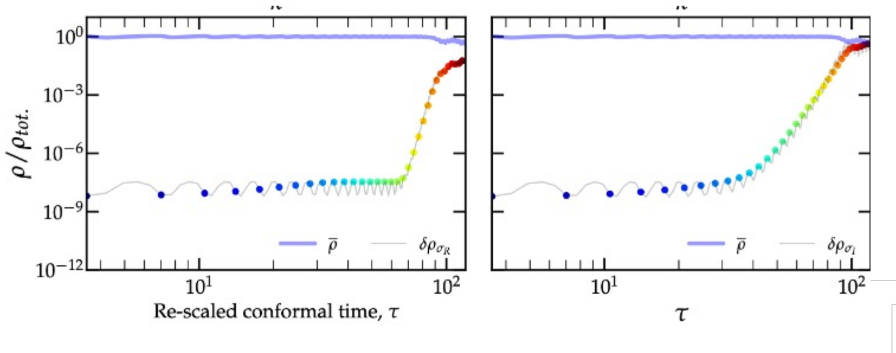
Pauli blocking

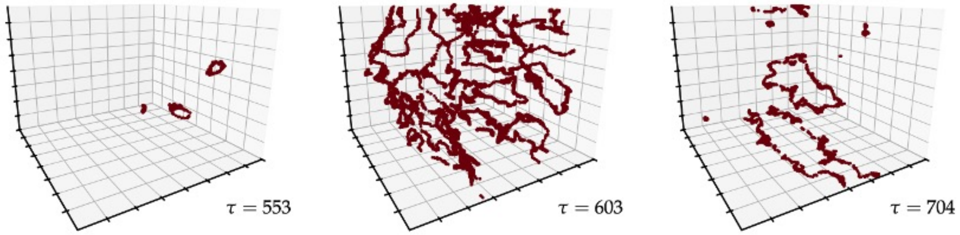


Fermionic preheating

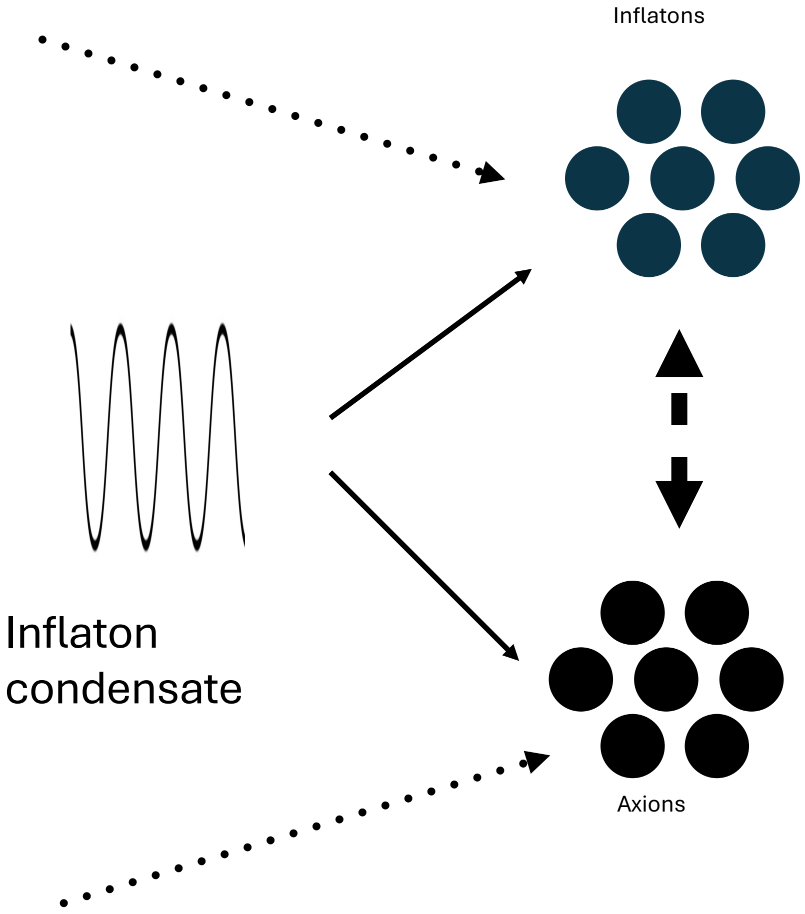
String production at PT

Fluctuation energy overcomes condensate

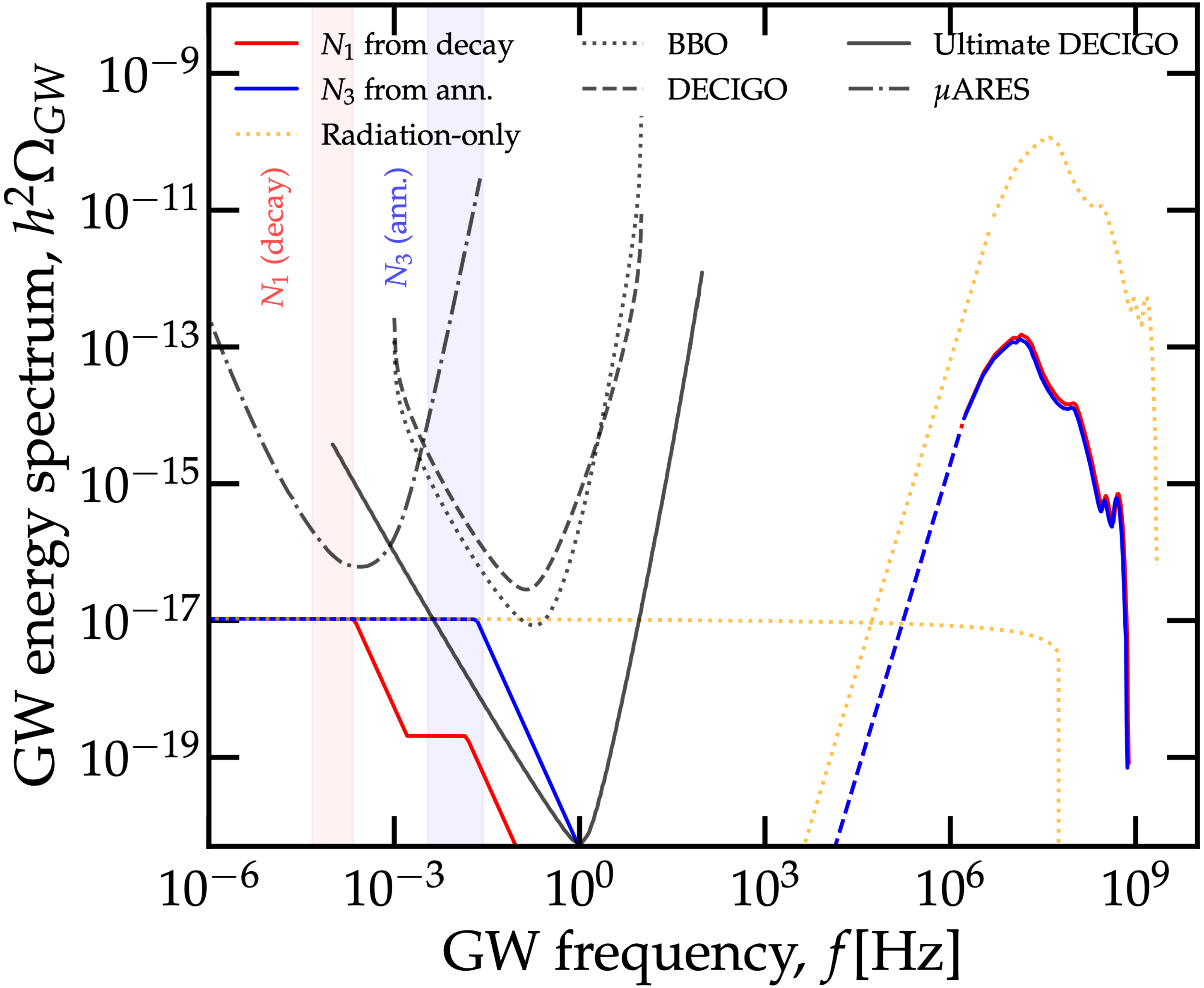




VISHν: reheating from a dark sector

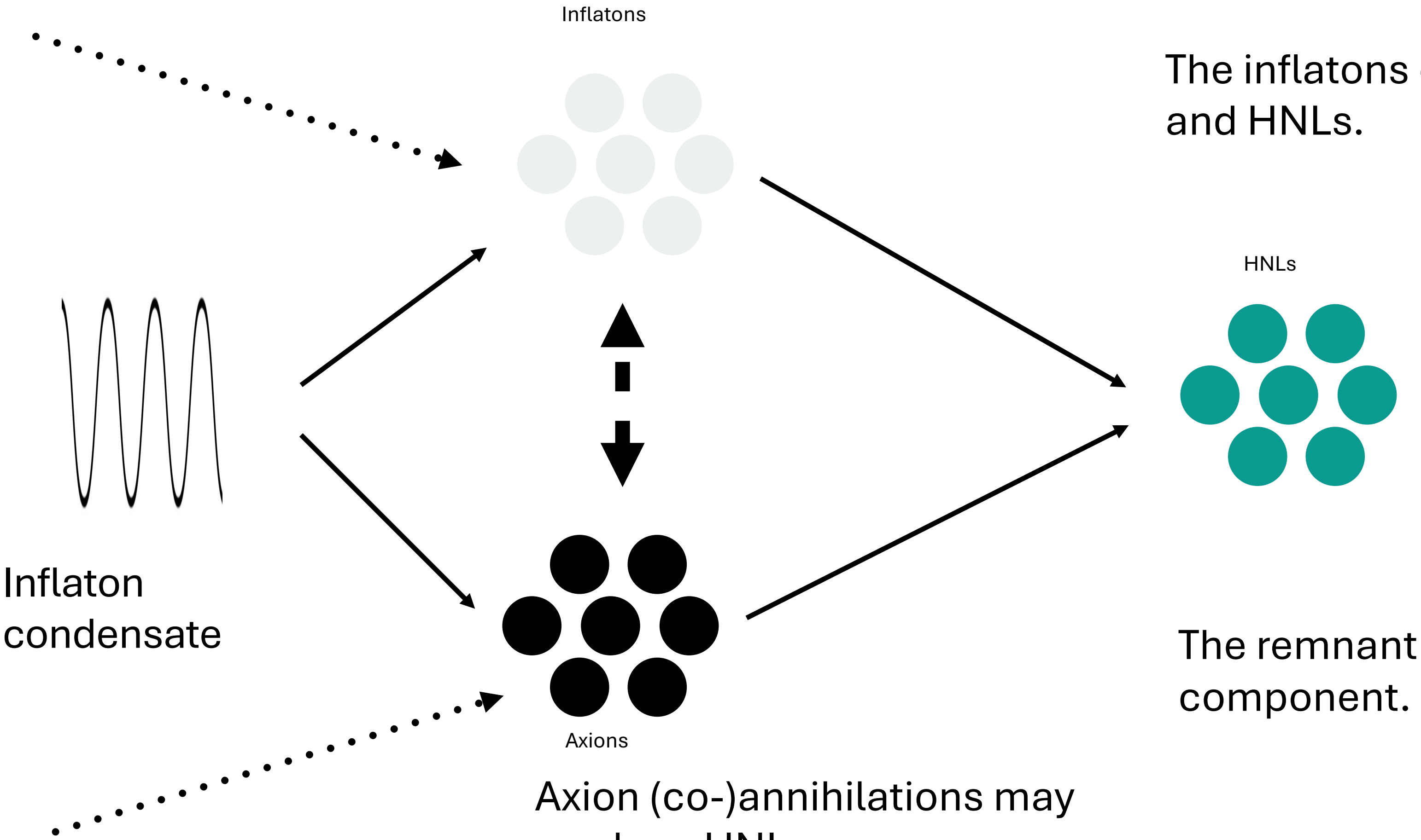


GWs arise from inflation itself, the large field gradients generated during preheating, turbulence and cosmic string evolution.



Observation is challenging. Ultimate DECIGO has some sensitivity.

VISHν: reheating from a dark sector



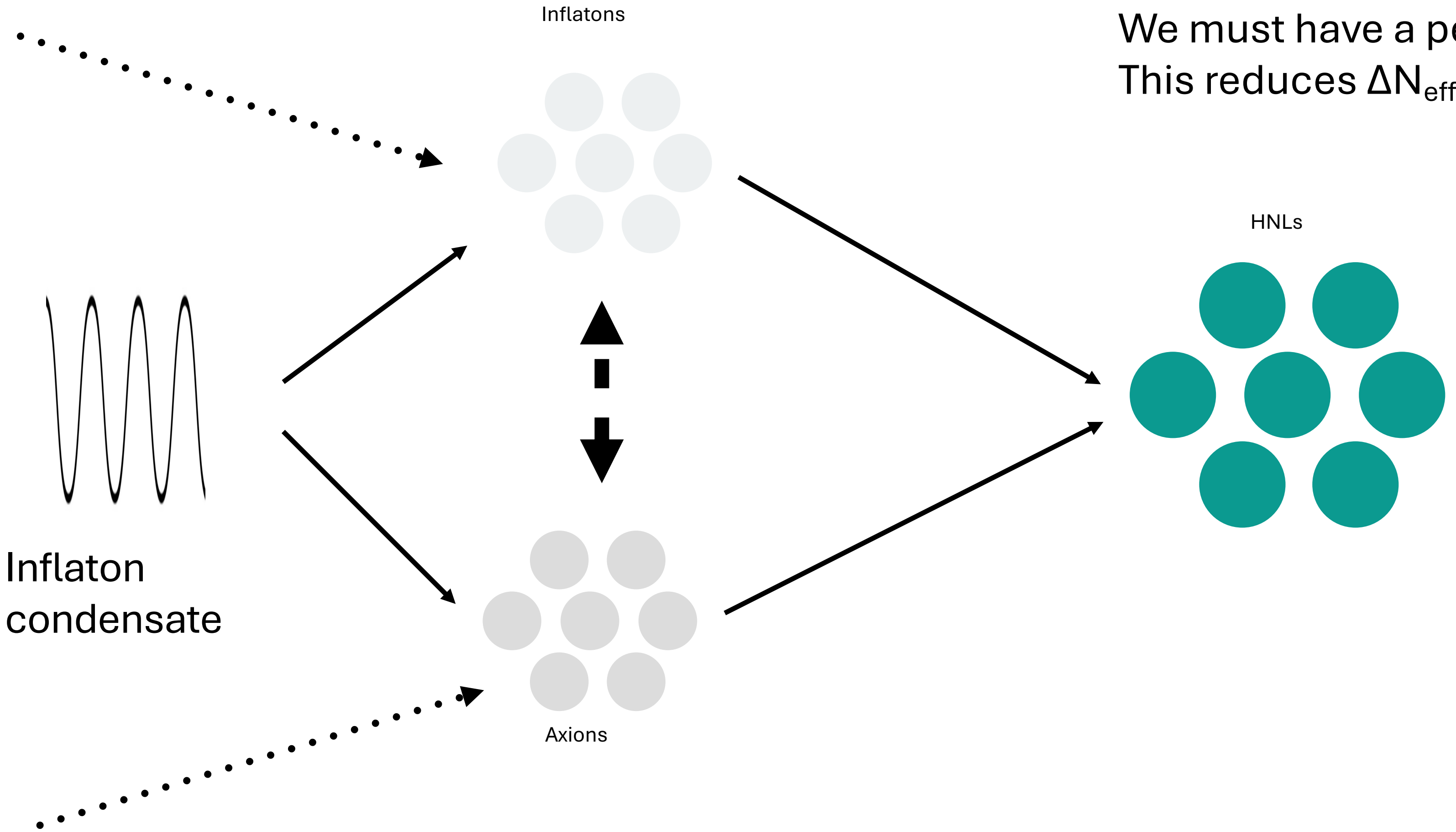
Inflaton condensate

The inflatons eventually decay completely to axions and HNLs.

The remnant axions are a dominant dark radiation component.

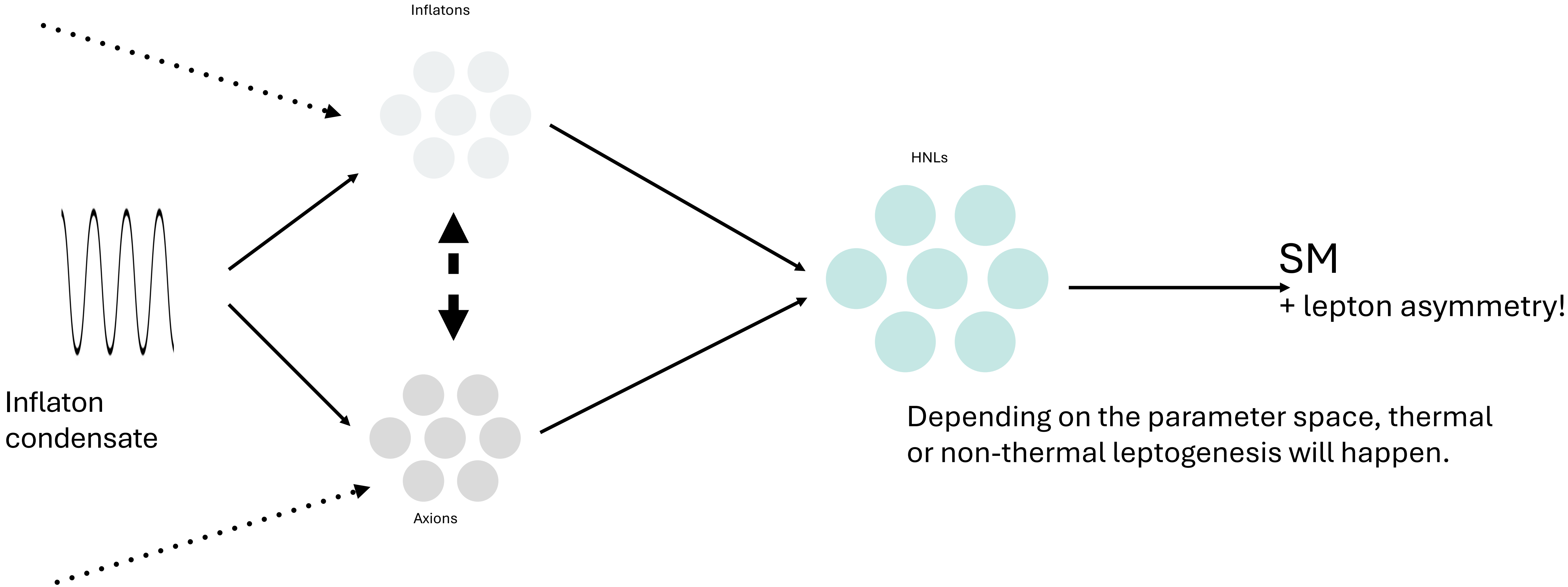
Axion (co-)annihilations may produce HNLs.

VISHν: reheating from a dark sector



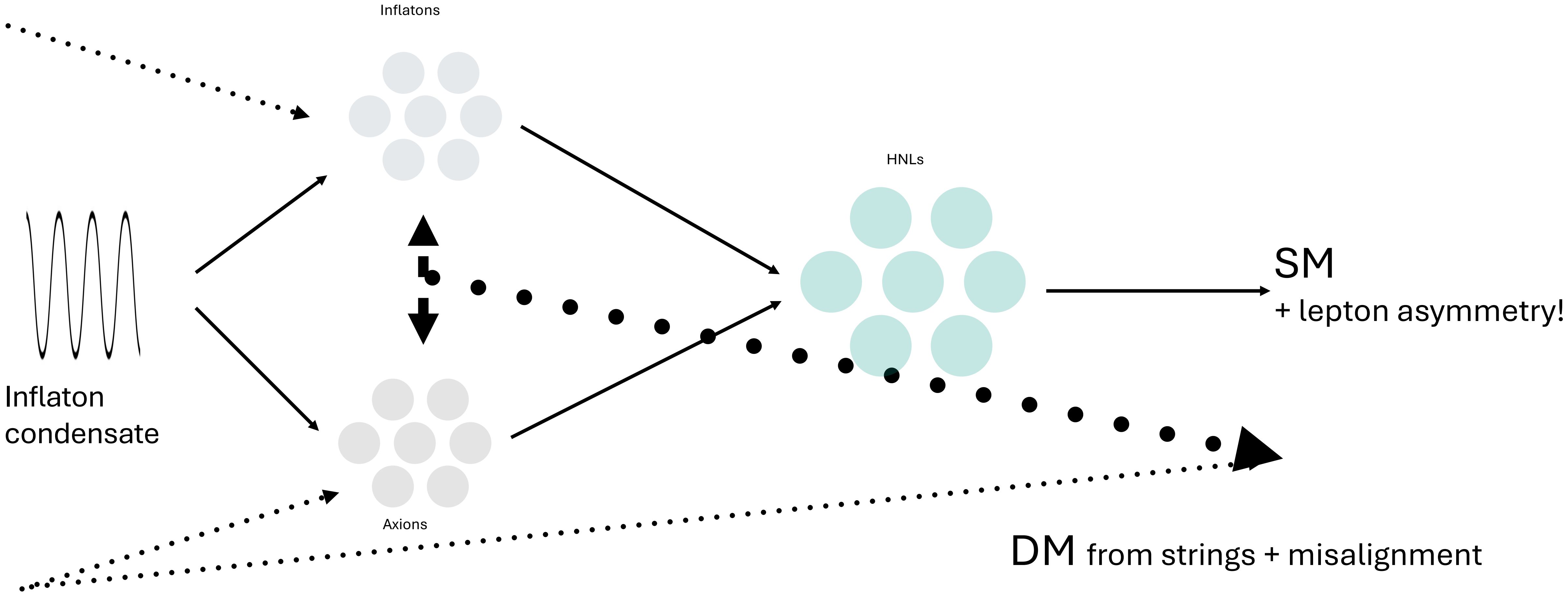
We must have a period of HNL domination.
This reduces ΔN_{eff} as the dark axion radiation red shifts.

VISHν: reheating from a dark sector



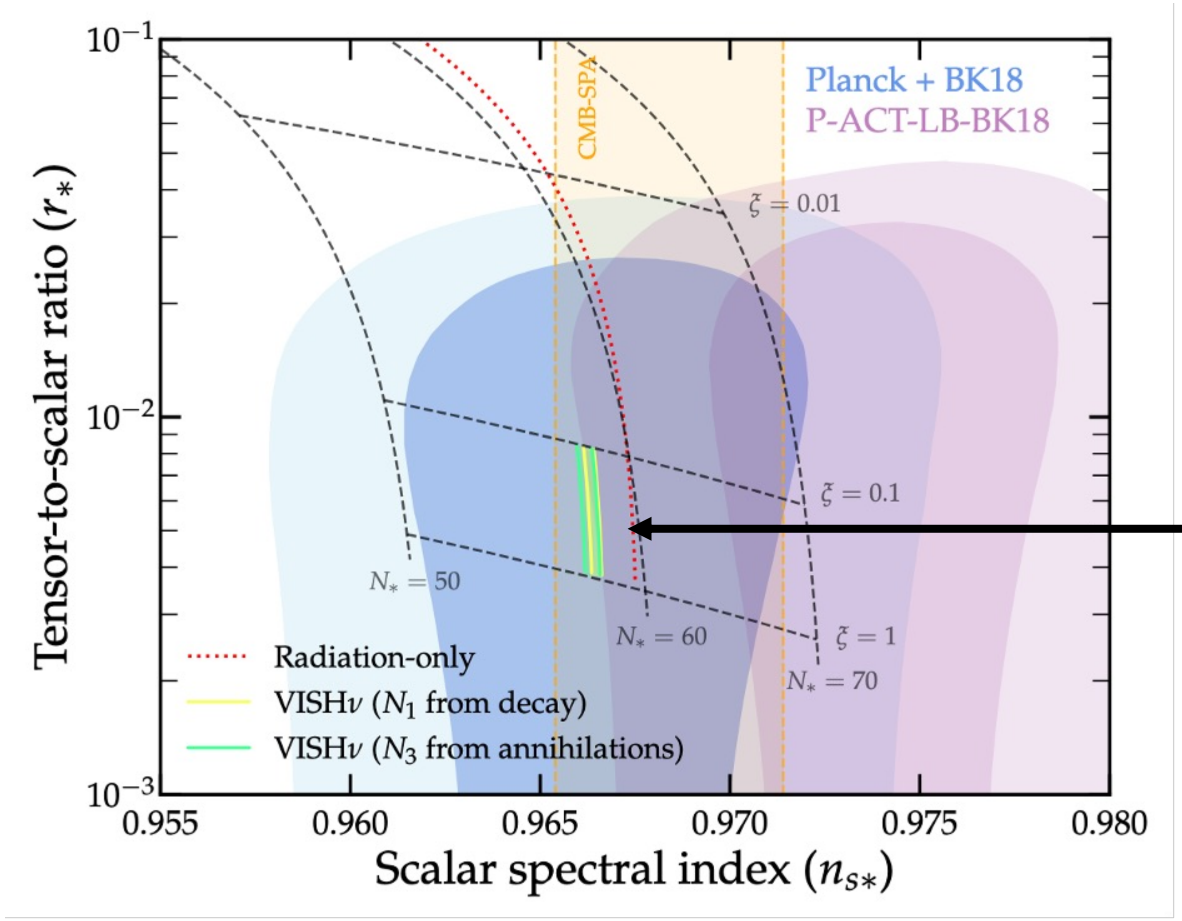
Depending on the parameter space, thermal or non-thermal leptogenesis will happen.

VISHν: reheating from a dark sector



VISHν: reheating from a dark sector

Early matter domination (HNLs) modifies inflationary predictions.
Constrained by suppression of dark radiation, and sufficient asymmetry in decays.

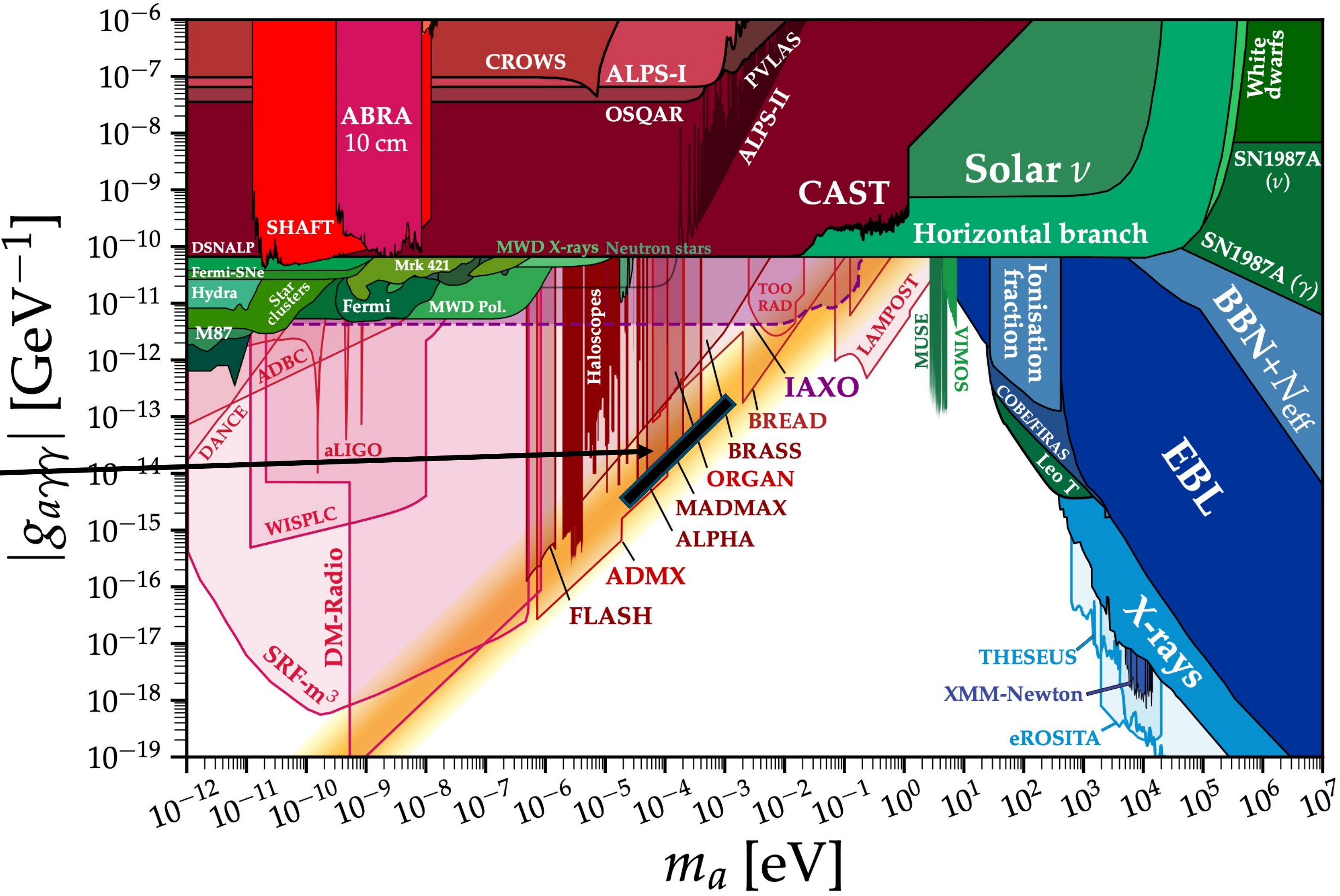


The green and yellow regions denote two viable reheating scenarios that hold in different parameter space regions.

Signatures: (a) axion DM, (b) additional EW Higgs states, (c) t→cH, uH, (d) cosmo fits remaining good – currently challenged by ACT and DESI, requires confirmation.

VISHv parameter range

$m_A \in (40\ \mu\mathrm{eV},\ \sim 2\ \mathrm{meV})$



5. Closing remarks

- VISHv and SMASH are interesting, economical models for solving 5 important problems.
- VISHv uses interesting PQ/flavour interplay to avoid domain wall problem (1980s!).
- Consequently, VISHv has good rationale for why $m_t >> $ other fermion masses.
- S-inflation works well.
- VISHv produces successful leptogenesis in some regions of parameter space.
- There are GW signals, though challenging to detect.

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Australian Government
Australian Research Council

National Partners

THE UNIVERSITY OF WESTERN AUSTRALIA

Australian National University

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF SYDNEY

Adelaide University

SWINBURNE UNIVERSITY OF TECHNOLOGY

Australian Government
Department of Defence

Australian Government
ANSTO

International Partners

UvA

UNI FREIBURG

MIT

Stockholm University

INFN

The University Of Sheffield.

HZDR

UNIVERSITY of WASHINGTON

Caltech