Searching for Relaxions through the Higgs Portal

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based on:

T. Flacke, C. Frugiuele, E. Fuchs, R. S. Gupta, G. Perez,
"Phenomenology of relaxion-Higgs mixing"
[arXiv:1610.02025]

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Outline

- Motivation
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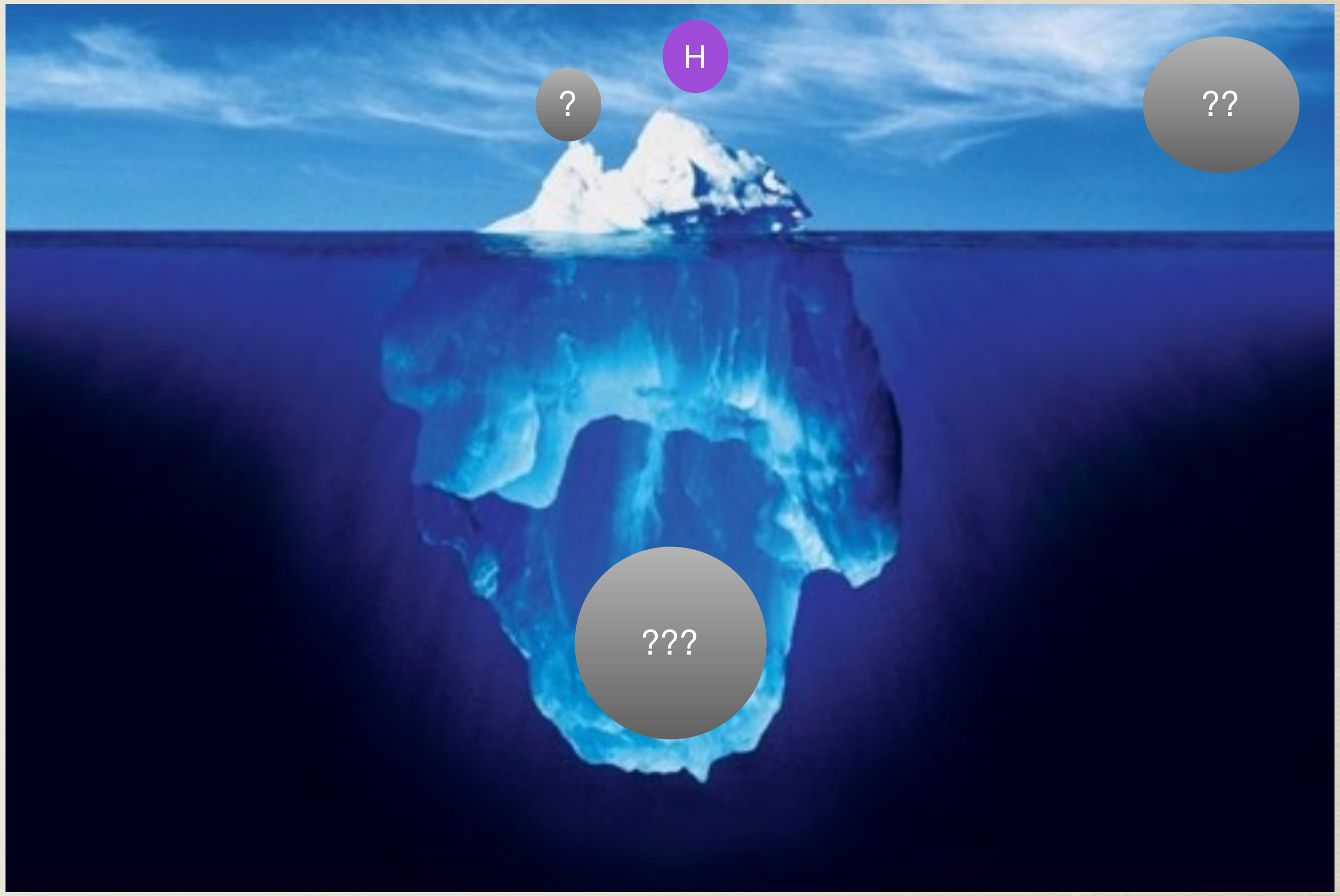
- Relaxion-Higgs phenomenology
- Conclusions



Motivation

The Standard Model works tremendously well, but we still have no indication what sets its mass scale.

$$V(H) = -\mu^2 H^\dagger H + \lambda(H^\dagger H)^2$$

Within the SM, μ receives quadratically divergent corrections

$\Rightarrow$ the natural scale for μ is the cutoff Λ of the SM.

Some known (but still unconfirmed) solutions:

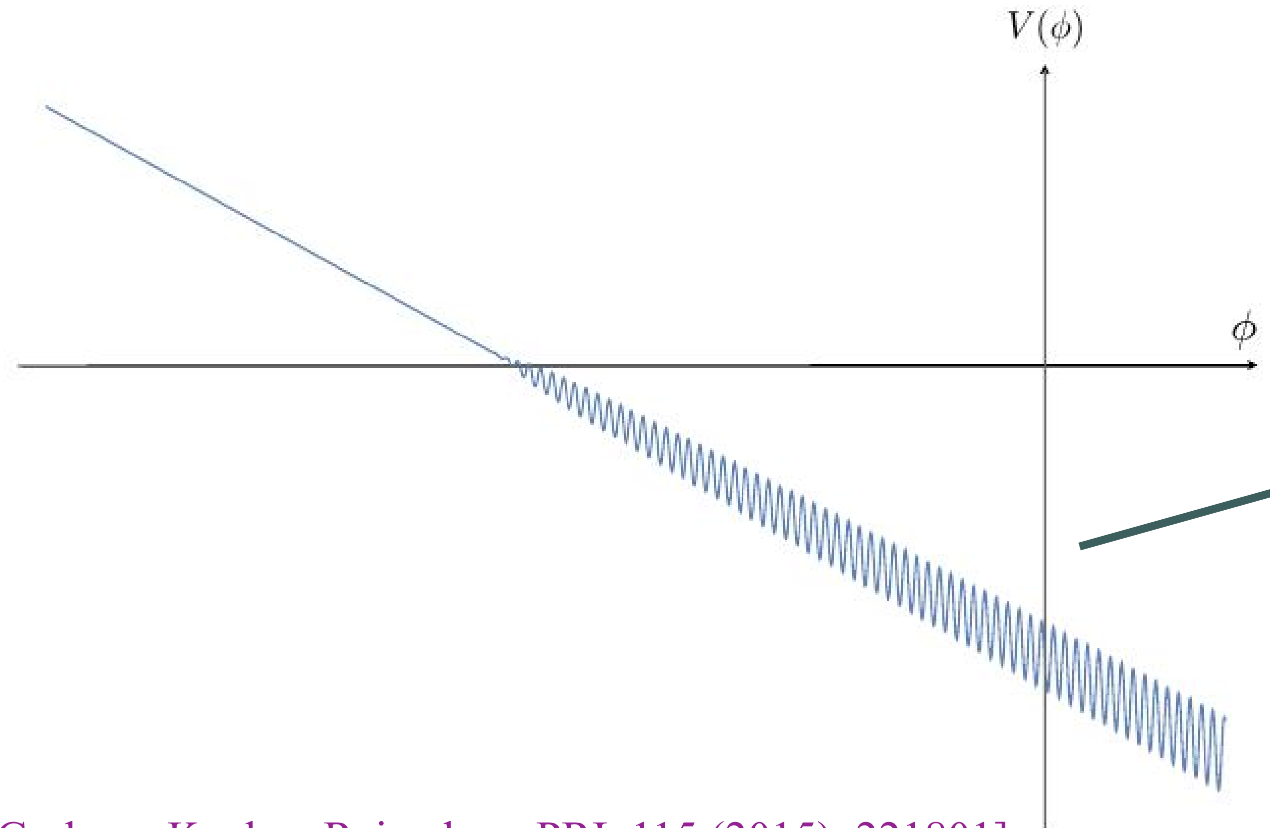
- Supersymmetry: "The divergence is not quadratic" (due to a symmetry)
- Composite Higgs Models: " The cutoff of the Higgs sector is a strong-coupling scale (like Λ_{QCD} but in the TeV regime)"

…

A different approach: Relaxion models attempt to couple the Higgs to a field which *dynamically* makes μ small.

Relaxions

[Graham, Kaplan, Rajendran, PRL 115 (2015), 221801]



[Graham, Kaplan, Rajendran, PRL 115 (2015), 221801]

dynamical μ

$$
\begin{aligned}
V(H) &= -\mu^2(\phi) H^\dagger H + \lambda (H^\dagger H)^2 \\
\mu^2(\phi) &= -\Lambda^2 + g\Lambda\phi + \ldots \\
V(\phi) &= rg\Lambda^3\phi + \ldots \\
\Delta V_{br} &= \tilde{M}^{4-j}\hat{h}^j \cos\left(\frac{\phi}{f}\right)
\end{aligned}
$$

osc. backreaction term

unavoidable contribution to the ϕ potential

Relaxion - Higgs mixing

Mixing term (when expanding around the vacuum (ϕ_0,v))

$$V(\phi,h) \supset \frac{\tilde{M}^{4-j} v^{j-1}}{\sqrt{2}^j f} \sin\left(\frac{\phi_0}{f}\right) \boldsymbol{h\phi}$$

Small-mixing approximation

$$\sin\theta \approx \tan\theta \approx \frac{M^2_{h\hat{\phi}}}{M^2_{hh}} \approx \frac{v}{f}\frac{\tilde{M}^2}{m_h^2} \sin\left(\frac{\phi_0}{f}\right)$$

$$m_\phi^2 \approx \frac{\tilde{M}^2 v^2}{2f^2}\left(\cos\left(\frac{\phi_0}{f}\right) - \frac{2\tilde{M}^2}{m_h^2}\sin^2\left(\frac{\phi_0}{f}\right)\right)$$

relaxion inherits Higgs couplings: $g_{\phi\psi,\phi V} = \sin\theta g_{h\psi,hV}$

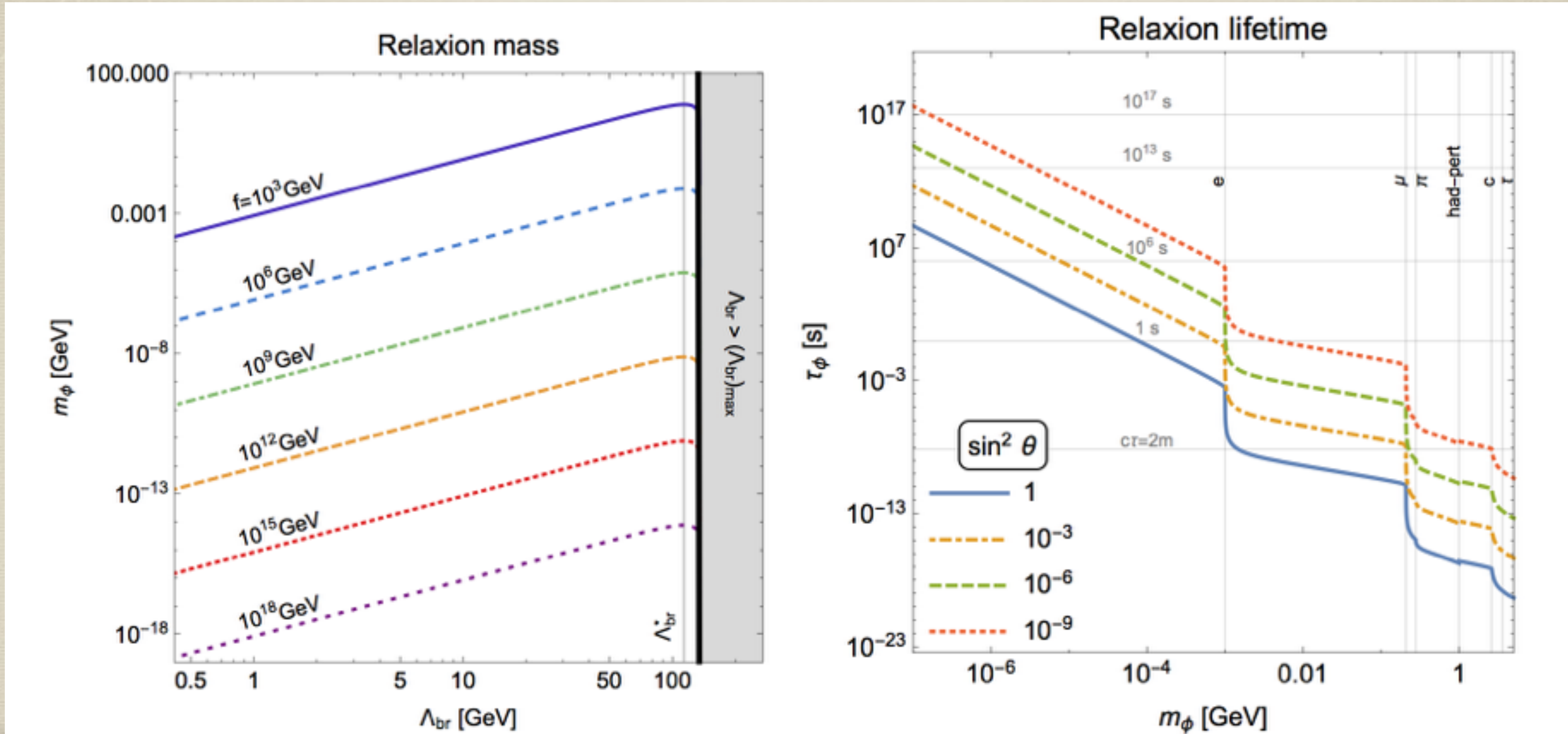
Note: In UV embeddings of relaxion models, additional couplings of the relaxion to the SM will be present. [c.f. e.g. Choi etal, 1610.00680]
In the following we focus on the “Higgs portal couplings” only.

Relaxion - Higgs mixing

Note:

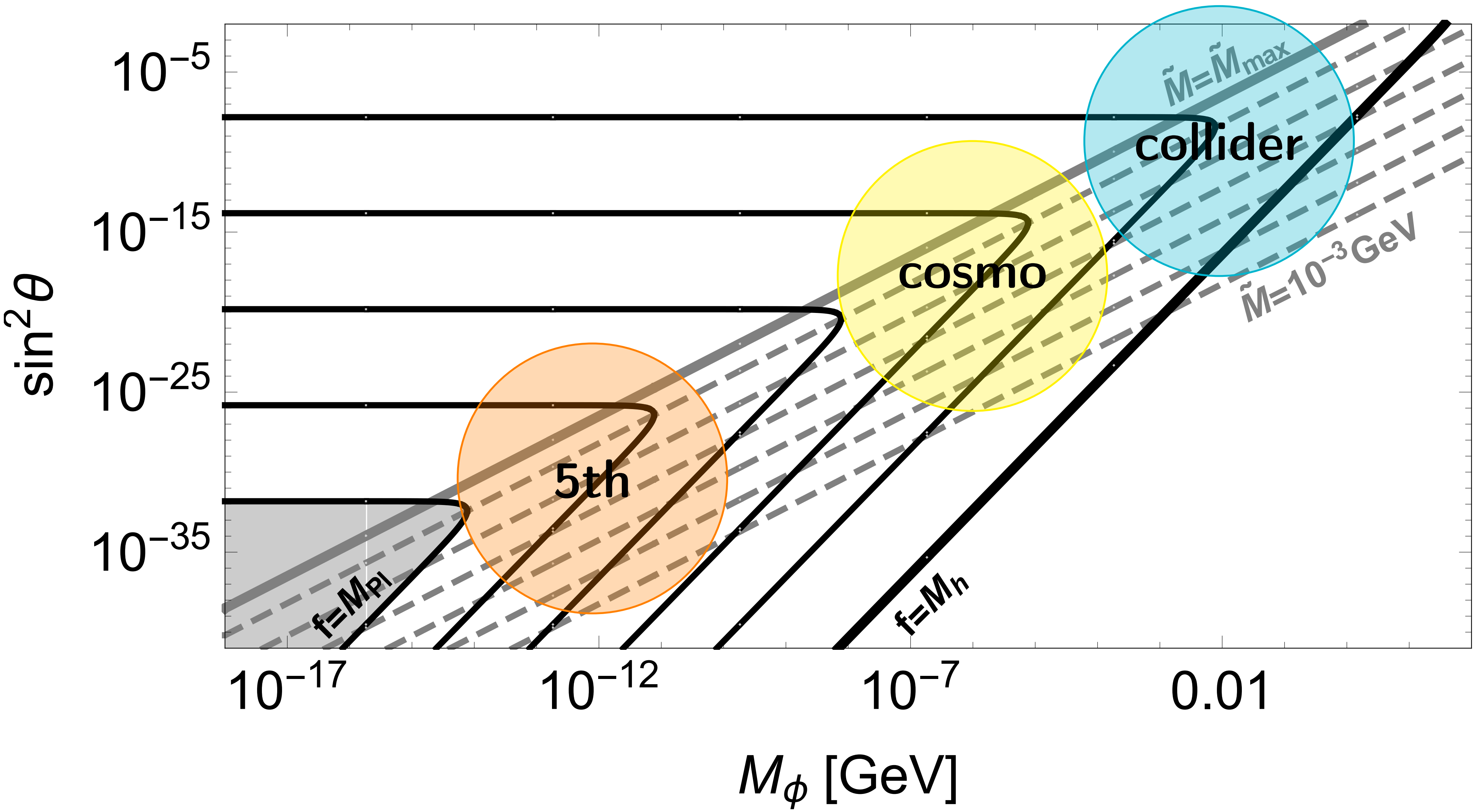
- The relaxion is typically thought of as "axion-like" (and thus a pseudo-scalar). The mixing with the Higgs shows that it has a scalar component.
- If the relaxion couples dominantly to the SM through the mixing with the Higgs, all its couplings are inherited from the Higgs, and its phenomenology depends only on the relaxion mass and the mixing angle (it is a Higgs-portal model, then).
- The mass and mixing angle are related to the relaxion model parameters f and $\Lambda_{\rm br}$ where $\Lambda_{br}^4 = \tilde{M}^{4-j}\left(\frac{v}{\sqrt{2}}\right)^j$. The Higgs portal bounds on relaxion mass and mixing can thus be translated into bounds on $\Lambda_{\rm br}$ and f.

Relaxion mass and lifetime in relation to relaxion parameters



Relaxion parameters and bounds (schematically)

translation $(m_\phi, s_\theta) \longleftrightarrow (\tilde{M}, f)$



given $(m_\phi, f) \longrightarrow$ 2 solutions of $\tilde{M}$

[courtesy to E. Fuchs, talk at DESY]

Relaxion bounds for GeV scale masses (collider physics)

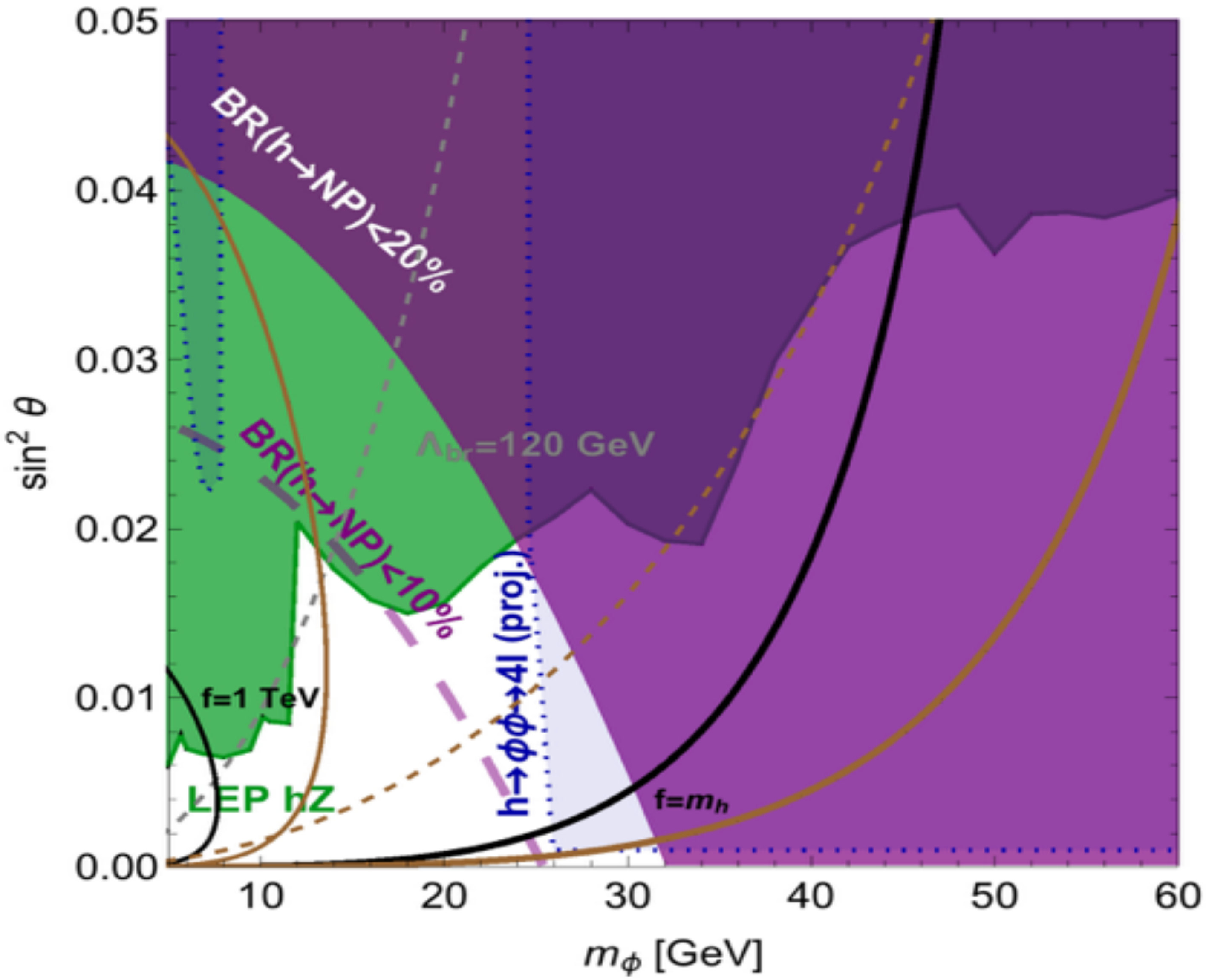


Figure 4. Constraints on the relaxion-Higgs mixing $\sin^2\theta$ for relaxions with m_ϕ between 5 GeV and 90 GeV from LEP and the LHC: 4-fermion final states from Higgs strahlung at LEP (green, labelled as LEP hZ); Higgs decays to NP with BR($\phi \to$ NP) $\leq 20\%$ at the LHC (purple, solid) as well as a projection for BR($\phi \to$ NP) $\leq 10\%$ (purple, dashed); explicit searches for $h \to \phi\phi$ with final states 4τ (dark blue, dotted, $m_\phi < 10$ GeV, Run 3 projection) and $2\mu 2b$ (dark blue, dotted, $m_\phi > 25$ GeV, Run 3 projection). Contours for $\Lambda_{br} = 120$ GeV (gray, dashed for $j = 2$; brown, dashed for $j = 1$), $f = m_h$ and $f = 1$ TeV (black for $j = 2$, brown for $j = 1$).

Relaxion bounds for MeV - GeV masses
(collider physics, beam-dump, flavor physics, astro physics / cosmology)

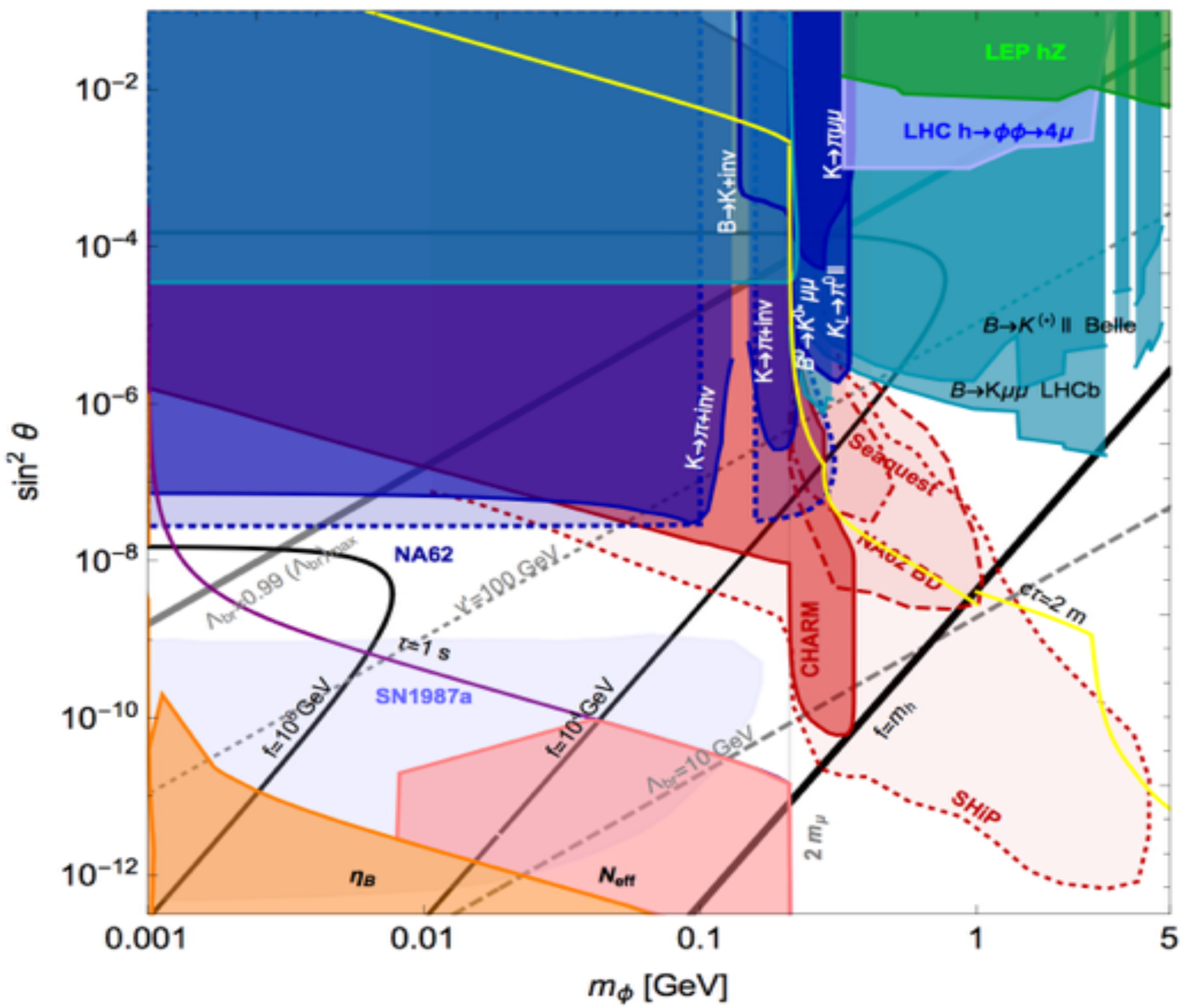


Figure 3. Constraints on the relaxion-Higgs mixing $\sin^2\theta$ for relaxions with m_ϕ between MeV and GeV by the CHARM beam dump experiment (dark blue), rare B- and K-meson decays (light blue, labelled by B, K and numbers 1-6), B-meson decays (labelled by B) at LHCb (turquoise) and Belle (turquoise, dashed), the Supernova 1987a (red, labelled as SN) and by the future experiment SHiP as a projection (yellow, dotted). The green line (labelled by 1 s) indicates a lifetime of $\tau_\phi = 1\,\mathrm{s}$. Contours of constant Λ_{br} (gray) for $\Lambda_{br} = 0.99(\Lambda_{br})_{\max} \simeq 104\,\mathrm{GeV}$ (gray, thick, solid), $\Lambda_{br} = \Lambda^*_{br} \simeq 74\,\mathrm{GeV}$ and $\Lambda_{br}/(\Lambda_{br})_{\max} = 10^{-1}, 10^{-2}$ (gray, dashed). Contours of constant $f/\mathrm{GeV} = 10^6, 10^5, 10^4, 10^3$ (black, solid).

Light relaxions (astrophysics and cosmology)

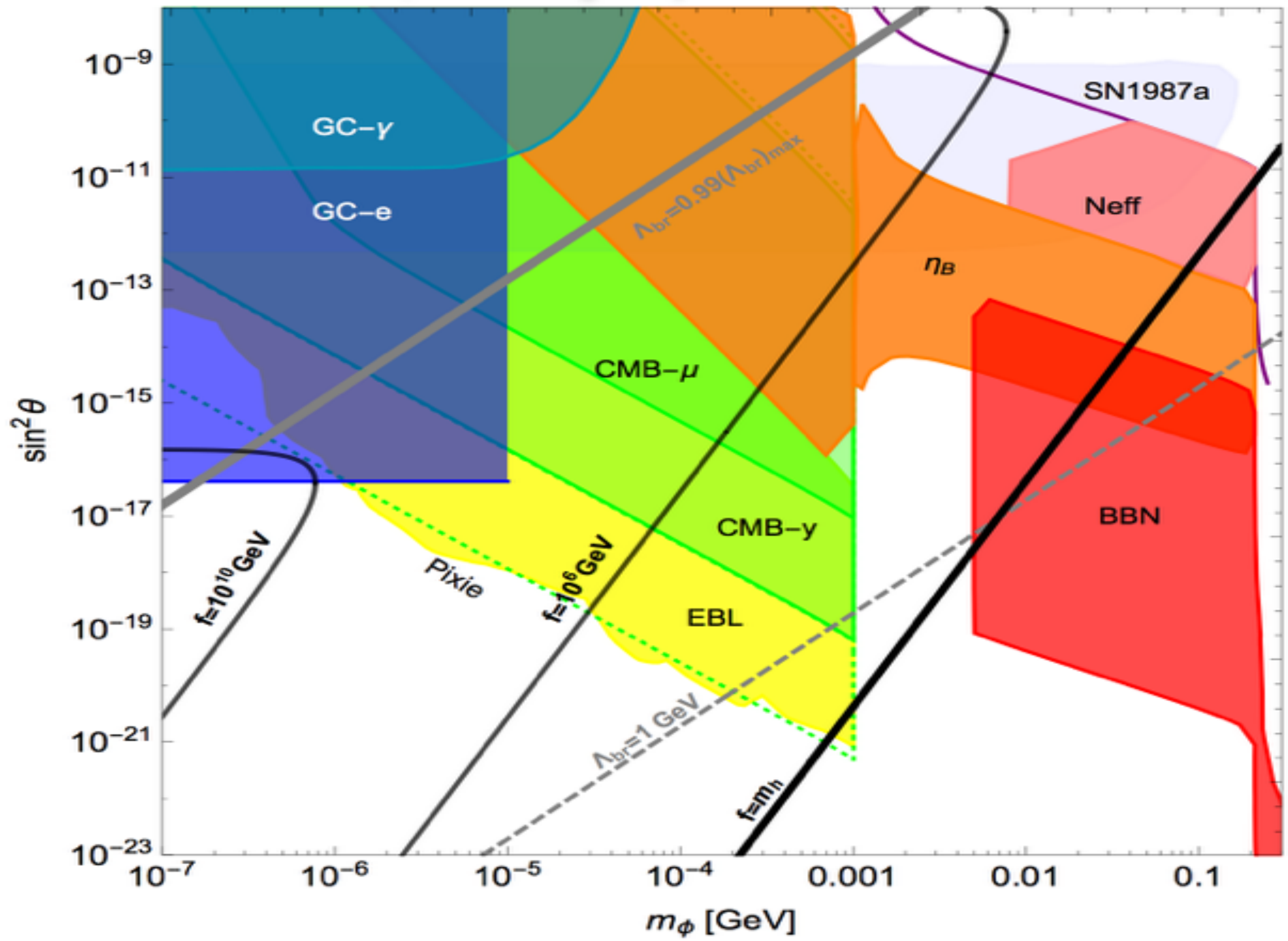


Figure 5. Cosmological and astrophysical bounds on s_θ and m_ϕ from 100 eV to 0.3 GeV: globular cluster via coupling to electrons (blue) or coupling to photons (turquoise), supernova 1987a (light blue), extragalactic background light (EBL, yellow), CMB y-distortion (light green) and μ-distortion (green), entropy injection $\Delta S/S$ bounded by the baryon-to-photon ratio η_B (orange) and by $N_{\rm eff}$ (pink), BBN (red). The light gray band indicates the possible range of s_θ for $j = 1$, i.e. the QCD case. The gray lines (from top to bottom) are contours of constant $\Lambda_{br} = 0.99(\Lambda_{br})_{\max}$ (thick, solid), Λ^*_{br}, 0.01 GeV (dashed). The black lines (from left to right) are contours of constant $f = 10^{10}$ GeV, 10^6 GeV (thin) and $f = M_h$ (thick).

very light relaxions (5th force and Eq. principle)

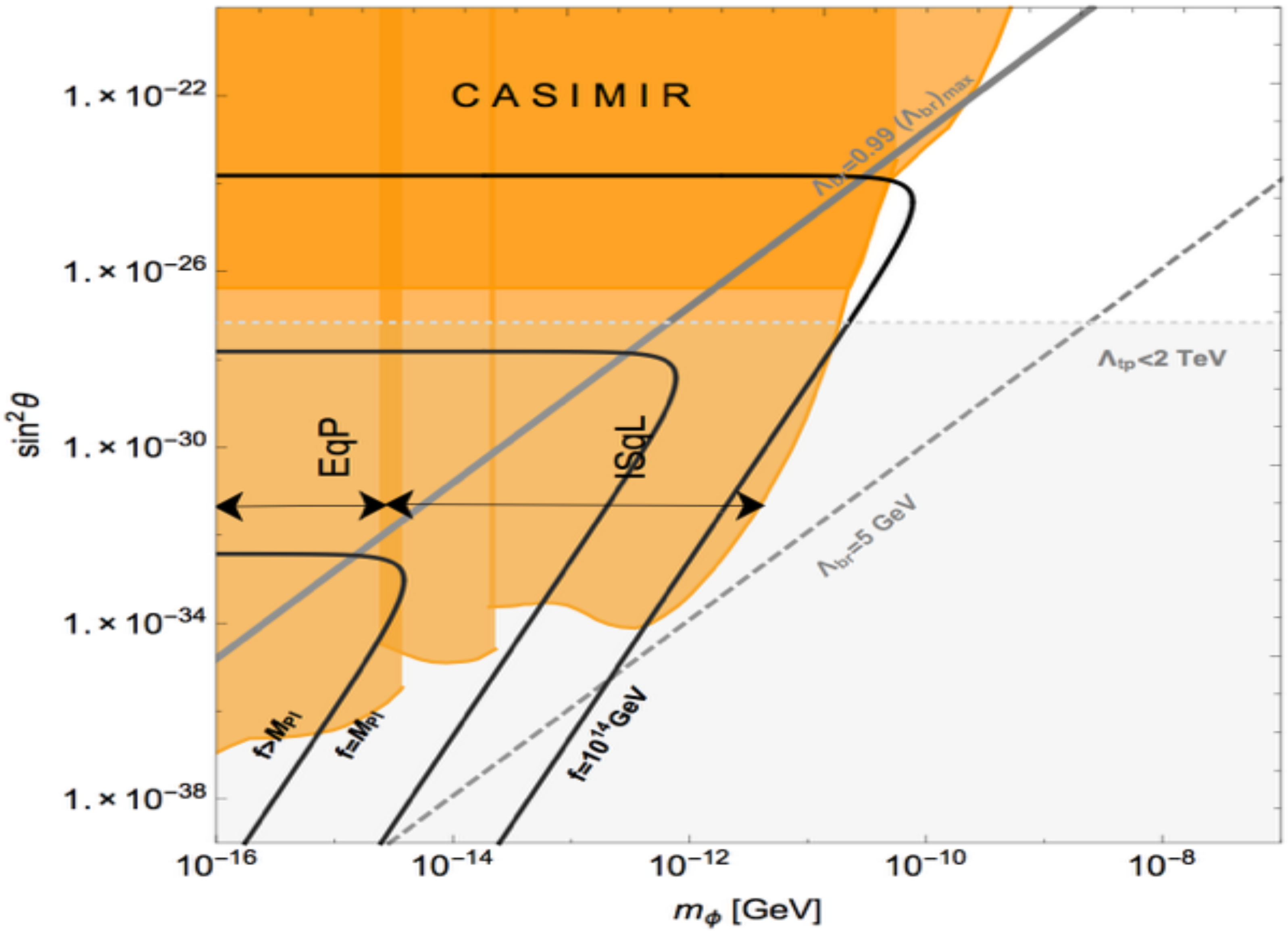
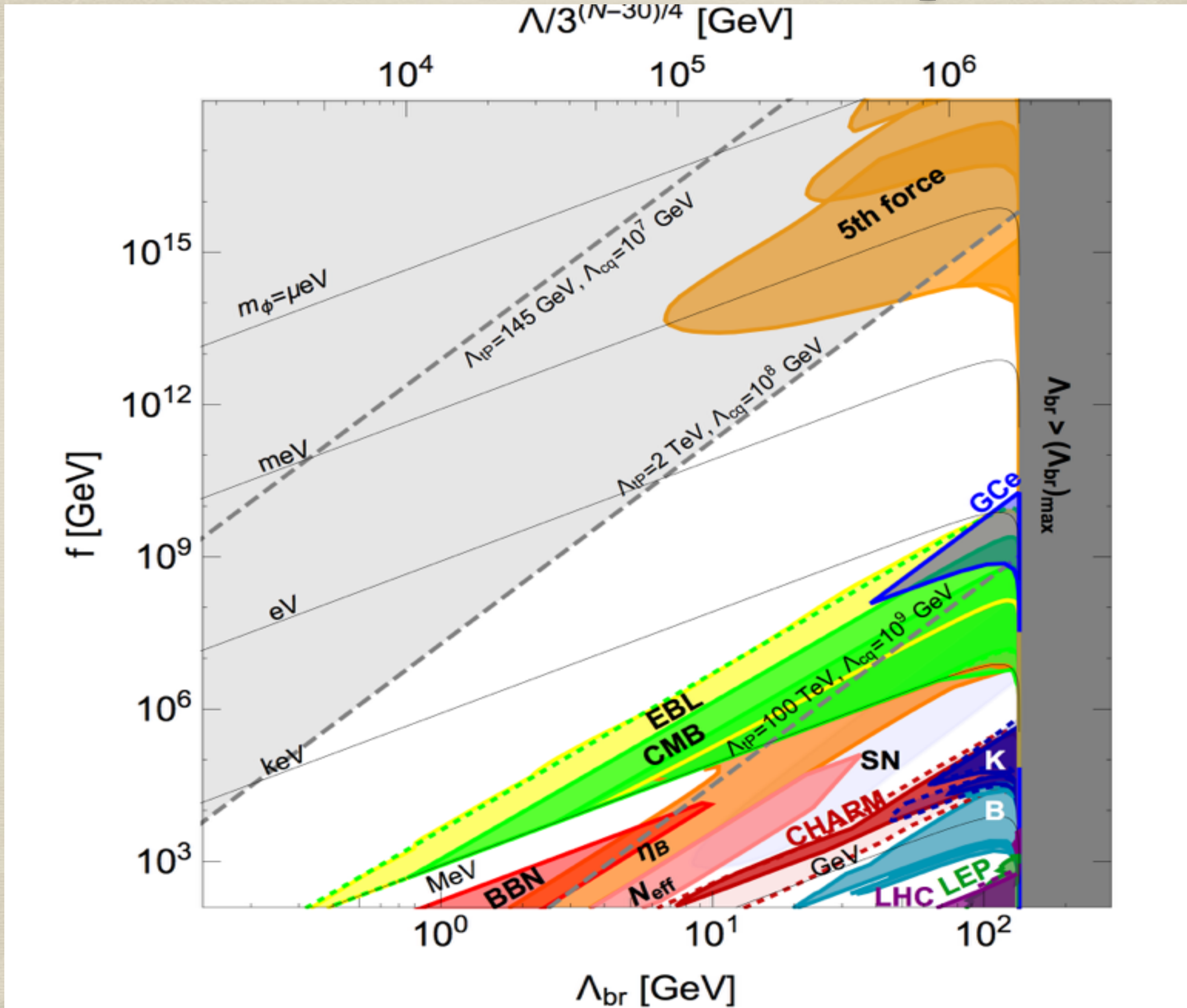


Figure 2. Constraints on the relaxion-Higgs mixing $\sin^2\theta$ for light relaxions with m_ϕ between 10^{-16} GeV and 10^{-7} GeV. Fifth-force experiments (orange) probe the lightest mass range via the equivalence principle (labelled as EqP), the inverse square law (ISqL) and the Casimir effect (Casimir). Contours of constant Λ_{br} (gray) for $\Lambda_{br} = 0.99(\Lambda_{br})_{\max} \simeq 104\,\text{GeV}$ (gray, thick, solid), $\Lambda_{br} = \Lambda^*_{br} \simeq 74\,\text{GeV}$ and $\Lambda_{br}/(\Lambda_{br})_{\max} = 10^{-1}, 10^{-2}, 10^{-3}$ (gray, dashed). Contours of constant $f = M_{\text{Pl}}, 10^{16}\,\text{GeV}, 10^{14}\,\text{GeV}$ (black, solid), the area of $f > M_{\text{Pl}}$ is shaded in dark gray. The light gray region below the dotted gray line corresponds to trans-Planckian field excursions $\Delta\phi > M_{\text{Pl}}$ for $\Lambda = 5\,\text{TeV}$.

Translation to relaxion model parameters



Conclusions and Outlook

- Relaxions might be able to provide a new approach to the hierarchy problem.
- Relaxions mix with the Higgs and can have interesting phenomenology in cosmology, astro physics and “low energy - high precision physics”.
- Relaxions will have additional (pseudo-scalar) couplings to SM particles which are to be determined from the UV-completion of the relaxion model.
  These coupling can lead to additional bounds … or ways to discover relaxions.