Classically Conformal U(1) model: Lessons from Collider and Cosmology

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Conformal Model: Why

The gauge hierarchy problem has been the motivation us to seek new physics

The problem appears in the only mass scale in the SM Lagrangian: The Higgs mass term

However, the SM Lagrangian at the classical level possesses the conformal invariant

Conformal Model: Why

Once we impose classical conformal invariance and allow its minimal violation by quantum anomalies on the SM, it can be free from the quadratic divergences

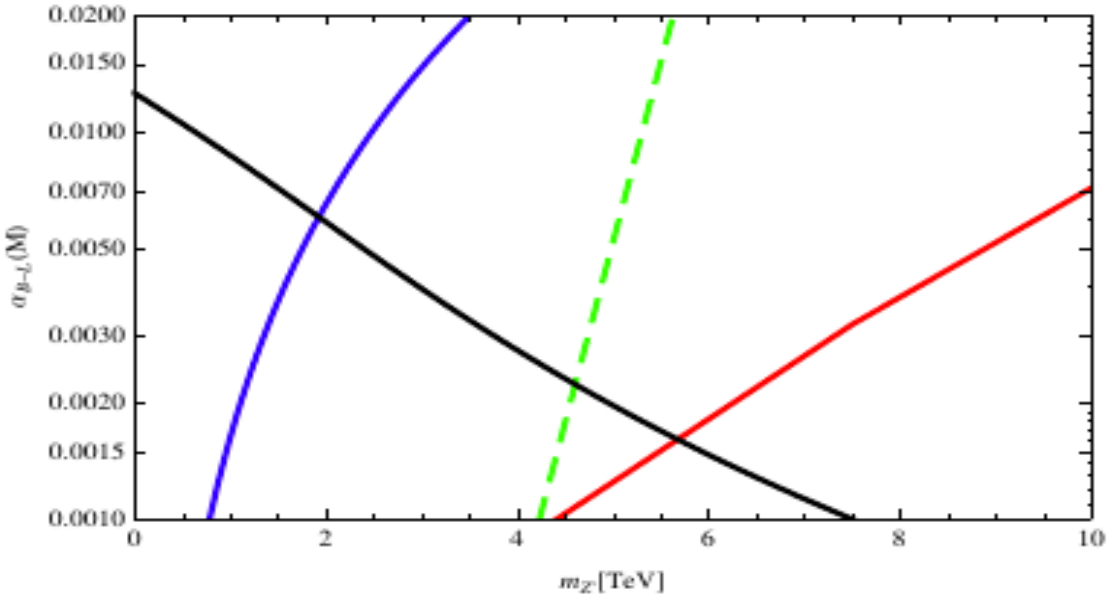
$$V = \lambda_H |H|^4 + \lambda |\Phi|^4 - \lambda' |\Phi|^2 |H|^2,$$

Gauged (B-L) is a simplest Anomaly free realization

	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_{B-L}$
q_L^i	**3**	**2**	$+1/6$	$+1/3$
u_R^i	**3**	**1**	$+2/3$	$+1/3$
d_R^i	**3**	**1**	$-1/3$	$+1/3$
ℓ_L^i	**1**	**2**	$-1/2$	-1
N^i	**1**	**1**	0	-1
e_R^i	**1**	**1**	-1	-1
H	**1**	**2**	$-1/2$	0
Φ	**1**	**1**	0	$+2$

Staus of classically conformal U(1) B-L model

Okada et. al. (PLB)



Blue: LEP, Green: LHC, Red: ILC (@1 TeV)

Structure of effective potential

$$V_{\text{eff}} = \frac{\lambda_\phi(t)}{4}\varphi^4 + \frac{T^4}{2\pi^2}\sum_j k_j J_T\left(m_j(\varphi)^2 + \Pi_j(T)\right)$$

RG improved scalar pot.

1-loop finite temp. Corr.

LHC constraints on Z' mass can be traded against the vev of (B-L) breaking scalar ==> requiring vev > O(1 TeV)

The vacuum expectation value of φ induces a negative mass term for the Higgs field ==> Usual EWSB takes place

Scenario: $T < T_{QCD}$

However, B−L breaking can be delayed to temperatures below the QCD phase transition

In such case, QCDPT occurs first, then EWSB

$$V_{\text{eff}}(T < T_{\text{QCD}}) = -\frac{\lambda_p(t) v_{\text{QCD}}^2}{4}\varphi^2 + V_{\text{eff}}(T > T_{\text{QCD}})$$

After the transition the QCD and electroweak symmetries are restored as the decay of the vacuum energy reheats the plasma, and, again, the evolution proceeds as in the SM

Scenario: $T < T_{QCD}$

After T > TQCD is controlled by the B-L breaking potential

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Scenario: $T < T_{QCD}$

Kinetic mixing of SM U(1) bosons and BSM U(1) bosons are negligible

We do neglect the effects of RHN Yukawa coupling

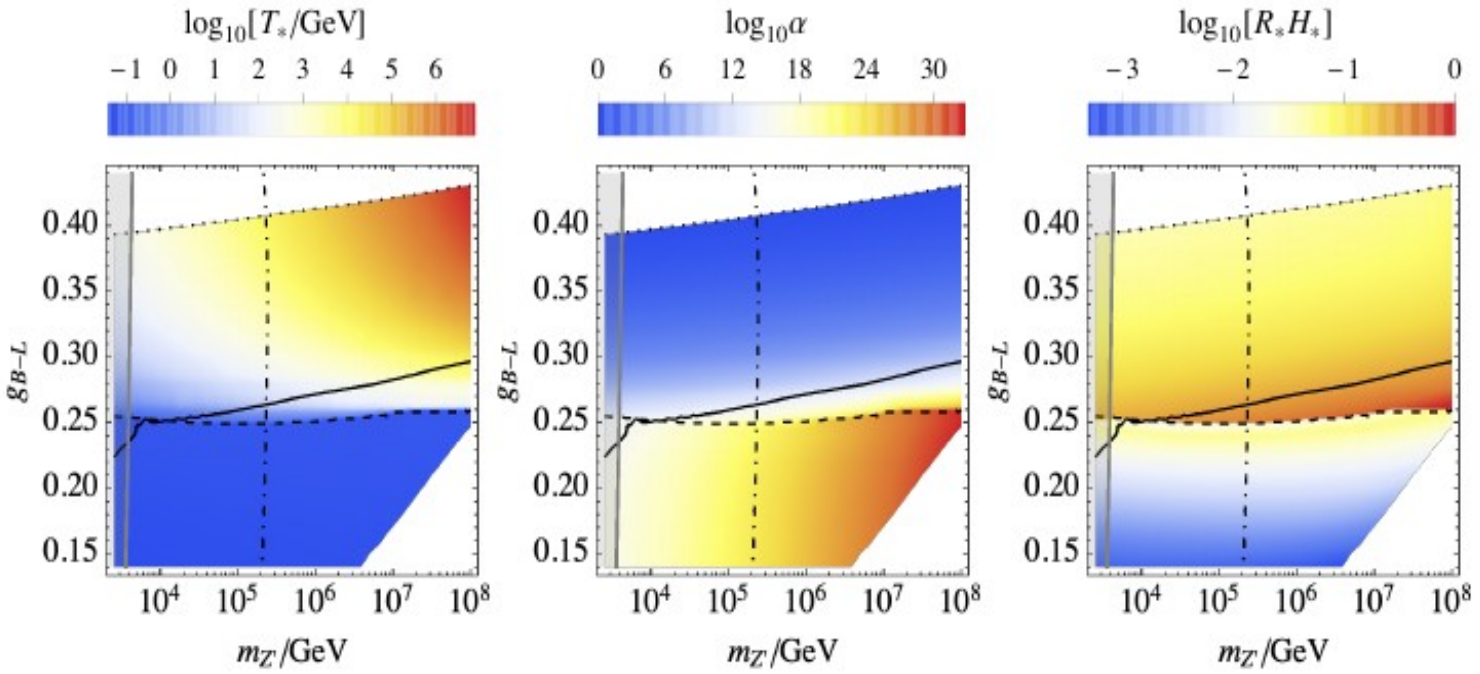
Particle physics parameters:

$$g_{B-L} \quad m_{Z'} \quad \lambda_H, \lambda_\phi, \lambda_p$$

GW related observables:

$$T_* \quad \alpha \quad R_* \quad \beta$$

Parameters for SFOPT

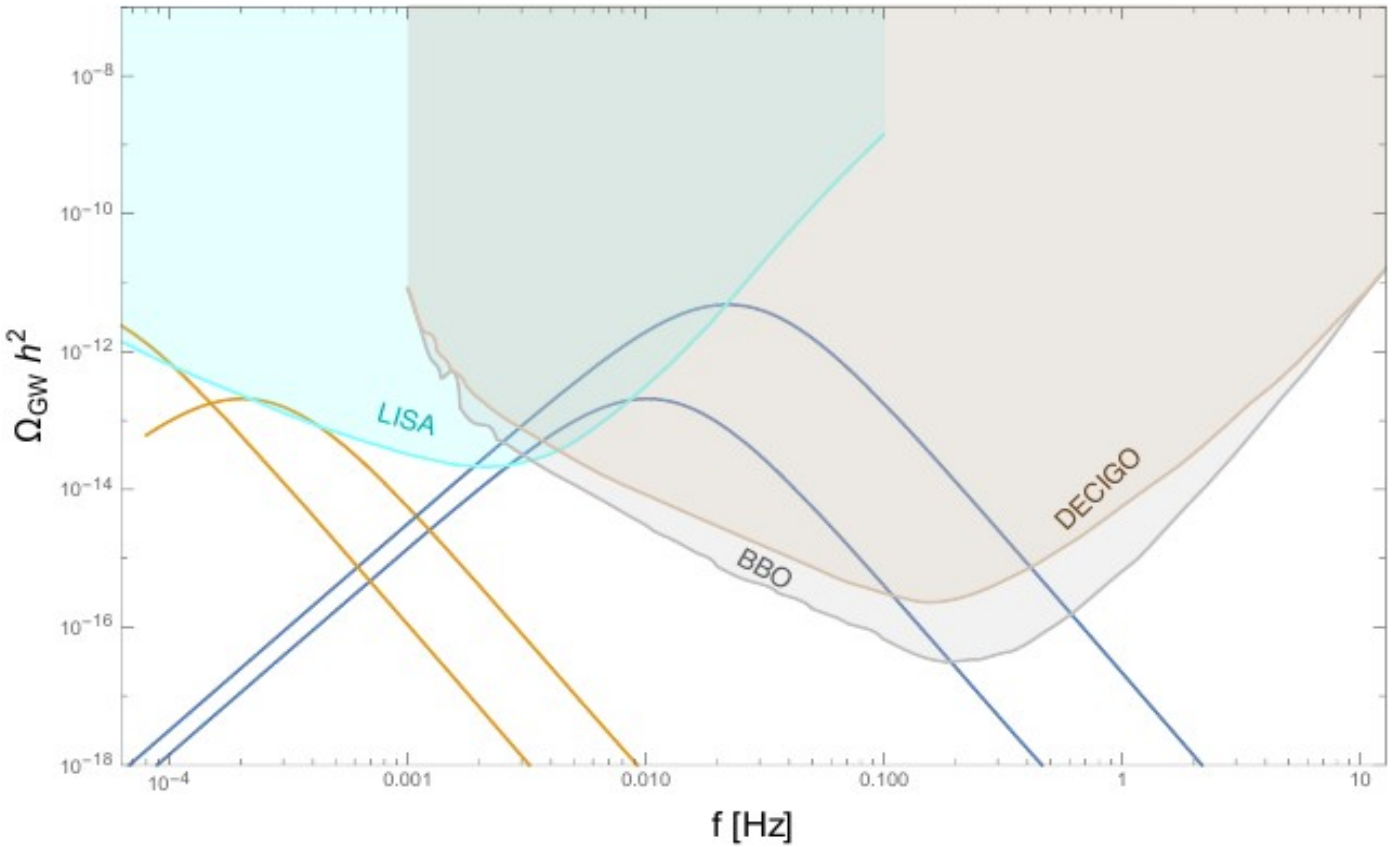


Large α (dotted line) gives favorable GW

Dashed curve indicates $T_* < T_{\mathrm{QCD}}$,

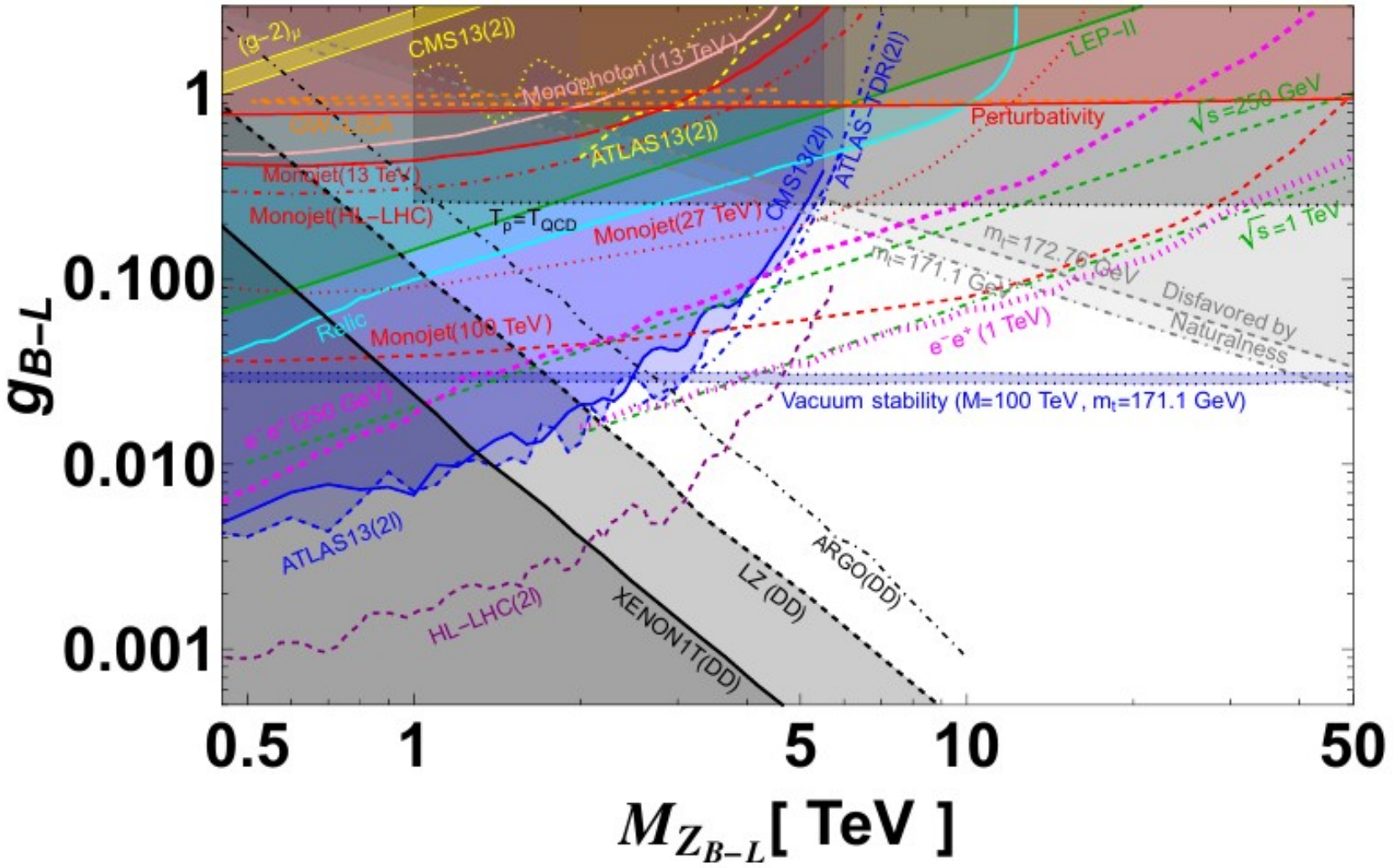
Ellis et. al. JCAP, 2020

GW Signal

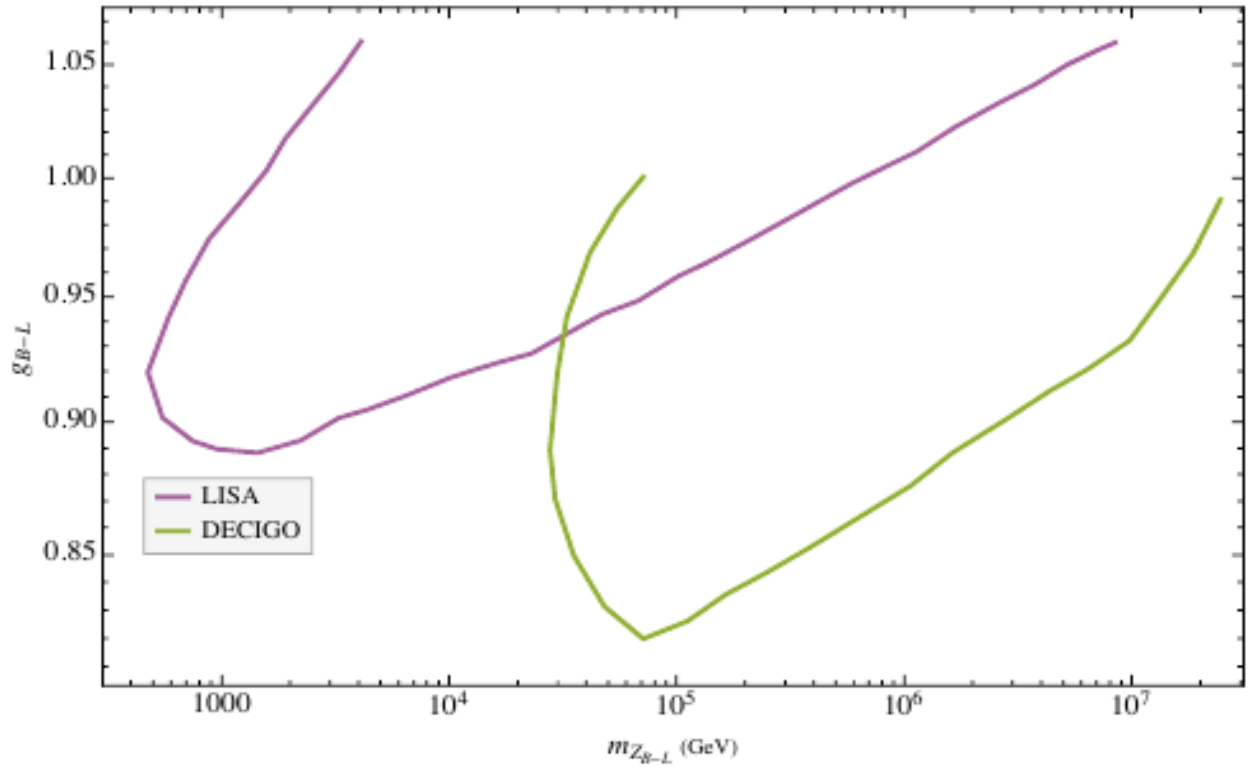


Das, Dev, Ghoshal, SN

Constraints from colliders



Constrants from GW detectors



Das, Dev, Ghoshal, SN

Conclusion

A Conformal theory is free of so called free of hierarchy problem

U(1) B-L is an anomaly free model

There is a good chance of observing signatures of classically conformal U(1) model at LISA, eLISA, DECIGO, AEDGE etc.

However, collider searches has mostly ruled out large part of parameter space in the low mass region

Complimentarity of GW detection comes into the picture that they try to cover the high mass region

References

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3) R. Jinno and M. Takimoto, Phys. Rev. D 95 (2017) 015020

4) J. Ellis, M. Lewiki, V. Vaskonen JCAP11 (2020) 020

5) A. Das, P.S. Bhupal Dev, A. Ghoshal, SN (under preparation)

Thank you