Nikhef

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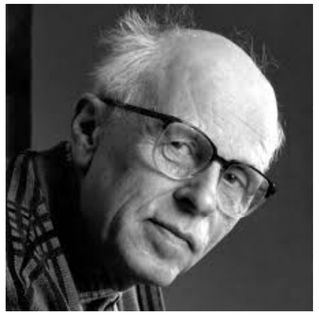
TESTING ELECTROWEAK BARYOGENESIS

Marieke Postma

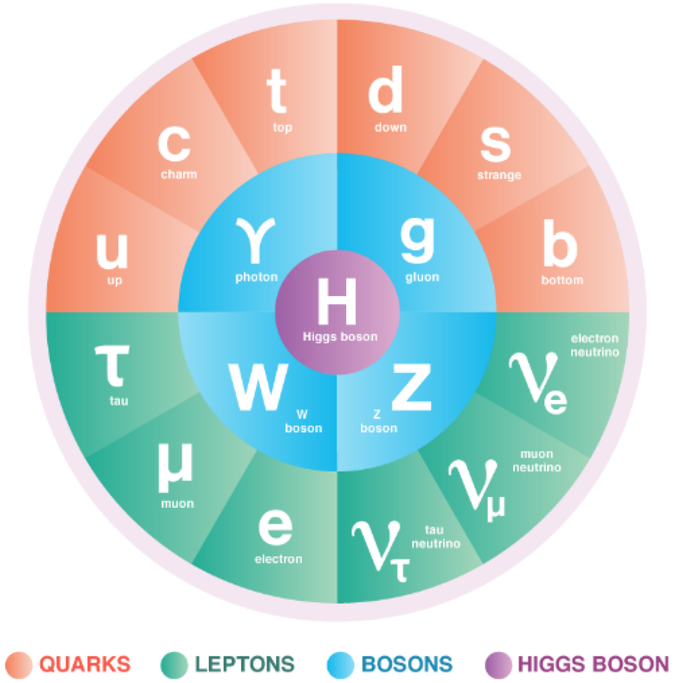
Shaping the universe 2026

$$\eta = \frac{n_b - \cancel{n_{\bar{b}}}}{n_\gamma} \approx 6 \times 10^{-10}$$

SAKHAROV CONDITIONS

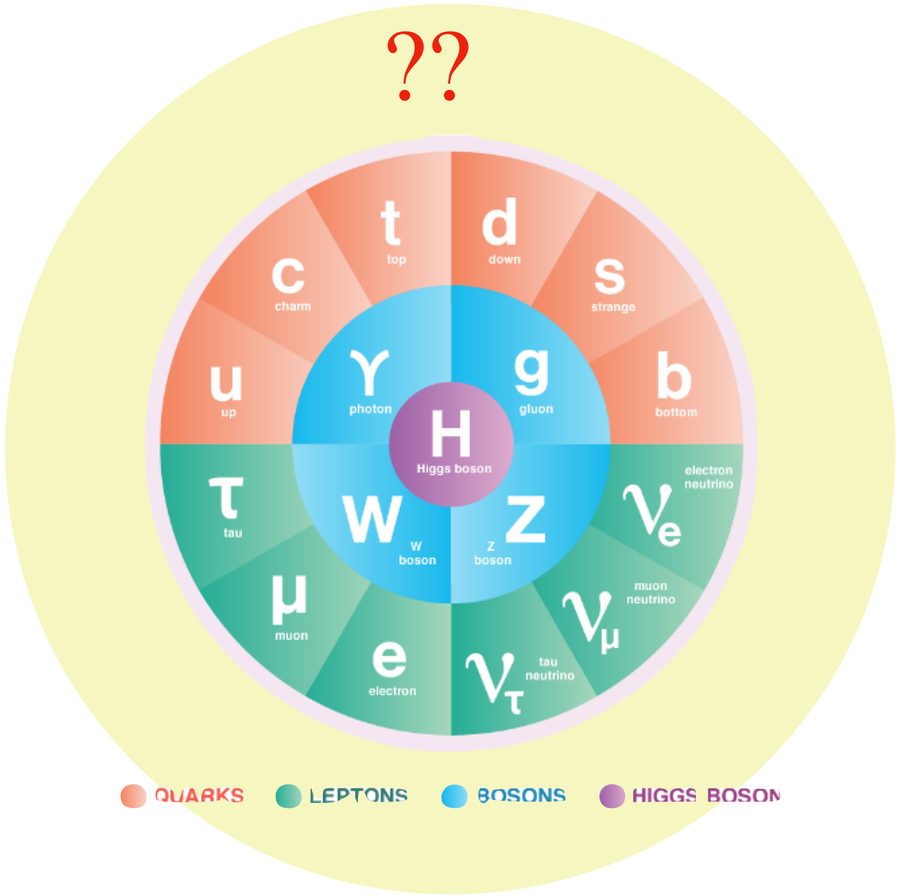


- baryon number violation ✓ sphalerons
- C, CP violation ✗
- out of equilibrium ✗



SAKHAROV CONDITIONS: NEED NEW PHYSICS

- baryon number violation ✓ sphalerons
- C, CP violation ✗
- out of equilibrium ✗



leptogenesis, Affleck-Dine baryogenesis, pangenesis, mesongenesis, electroweak baryogenesis, Wimpy baryogenesis, GUT baryogenesis, darkogenesis, cogenesis, gravitational baryogenesis, wash-in leptogenesis, axiogenesis, scotogenesis, spontaneous baryogenesis, domain-wall-genesis, topological leptogenesis, scalar-tensor baryogenesis, oogenesis, gravity assisted baryogenesis, phase separation baryogenesis, gravitational chargegenesis, sphaleron portal baryogenesis, clockwork neutrino genesis, freeze-in baryogenesis, fireball baryogenesis,…

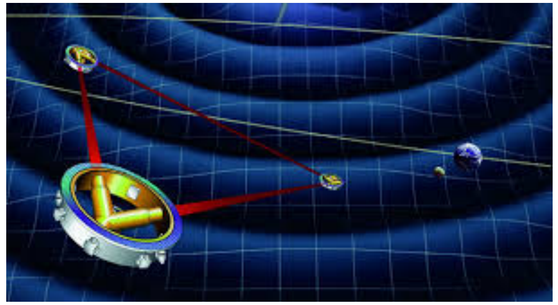
SAKHAROV CONDITIONS: ELECTROWEAK BARYOGENESIS

- baryon number violation ✓ sphalerons
- C, CP violation new CP sources
- out of equilibrium 1st order EW phase transitions

TESTING ELECTROWEAK BARYOGENES

electric dipole moment

colliders

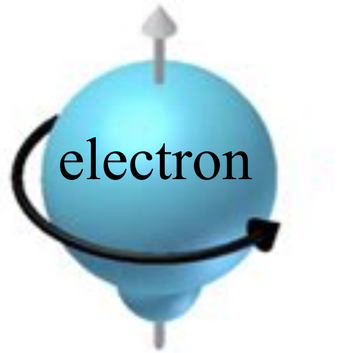


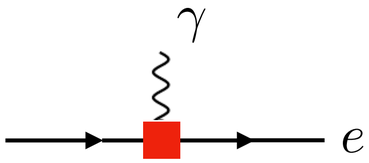
gravitational waves

ELECTRIC DIPOLE MOMENT

$$H = -\mu(\vec{S}\cdot\vec{B}) - d(\vec{S}\cdot\vec{E}) \quad \overset{\text{CP}}{\Rightarrow} \quad H = -\mu(\vec{S}\cdot\vec{B}) + d(\vec{S}\cdot\vec{E})$$

ELECTRIC DIPOLE MOMENT



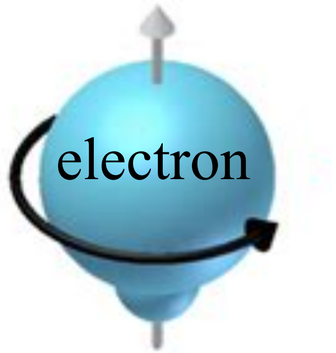


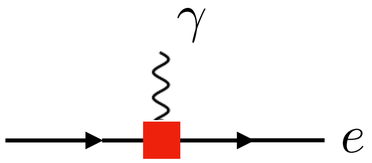
System	Group	Limit	C.L.	Value	Year
^{205}Tl	Berkeley	1.6×10^{-27}	90%	$6.9(7.4) \times 10^{-28}$	2002
YbF	Imperial	10.5×10^{-28}	90	$-2.4(5.7)(1.5) \times 10^{-28}$	2011
ThO	ACME	1.1×10^{-29}	90	$4.3(3.1)(2.6) \times 10^{-30}$	2018
HfF^+	Boulder	1.3×10^{-28}	90	$0.9(7.7)(1.7) \times 10^{-29}$	2017

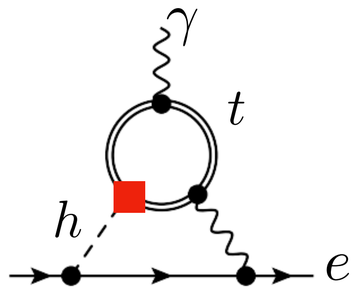
from J. de Vries

ELECTRIC DIPOLE MOMENT

e.g. $\mathcal{L} \supset \frac{y_t}{\sqrt{2}}\phi\left(1 + c\frac{\phi^2}{\Lambda^2}\right)\bar{t}_L t_R + \text{h.c.}$

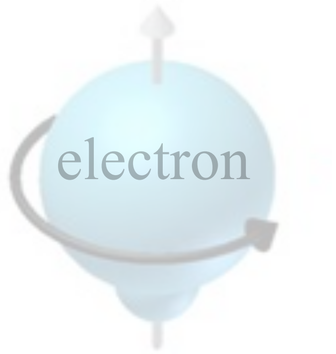






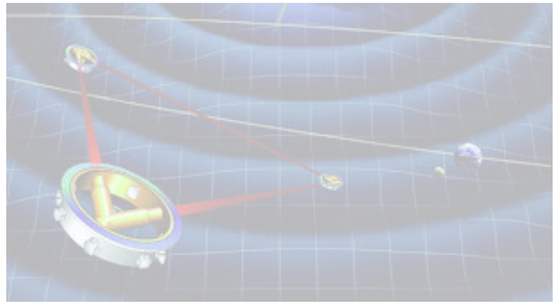
$\Lambda \gtrsim 10\,\text{TeV}$

TESTING ELECTROWEAK BARYOGENES



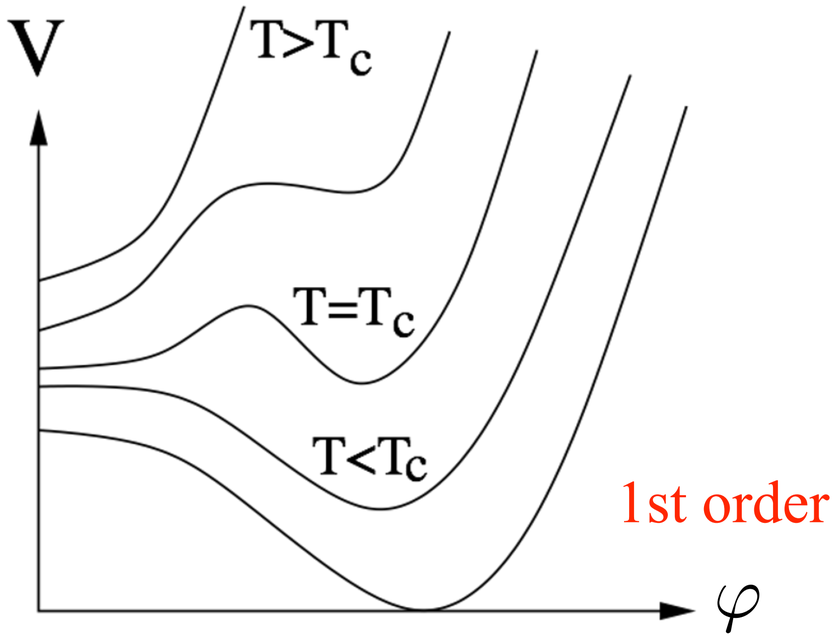
electric dipole moment

colliders

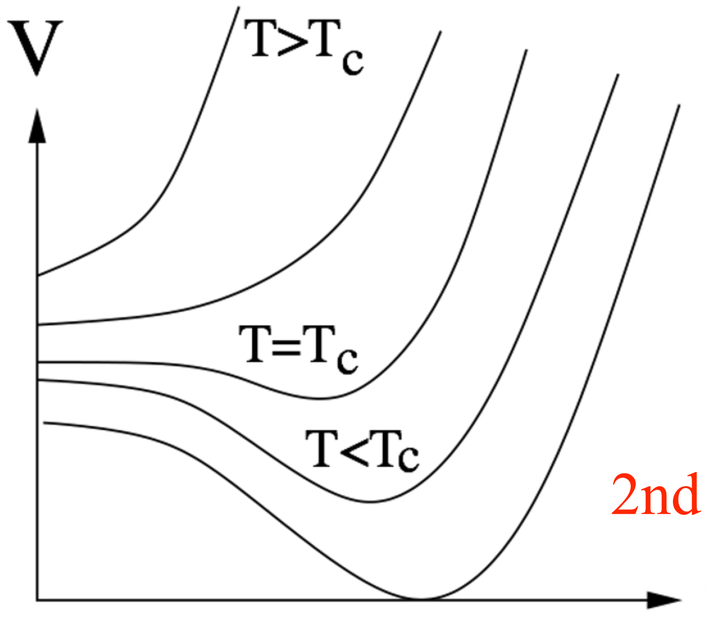


gravitational waves

1ST ORDER PHASE TRANSITION



1st order

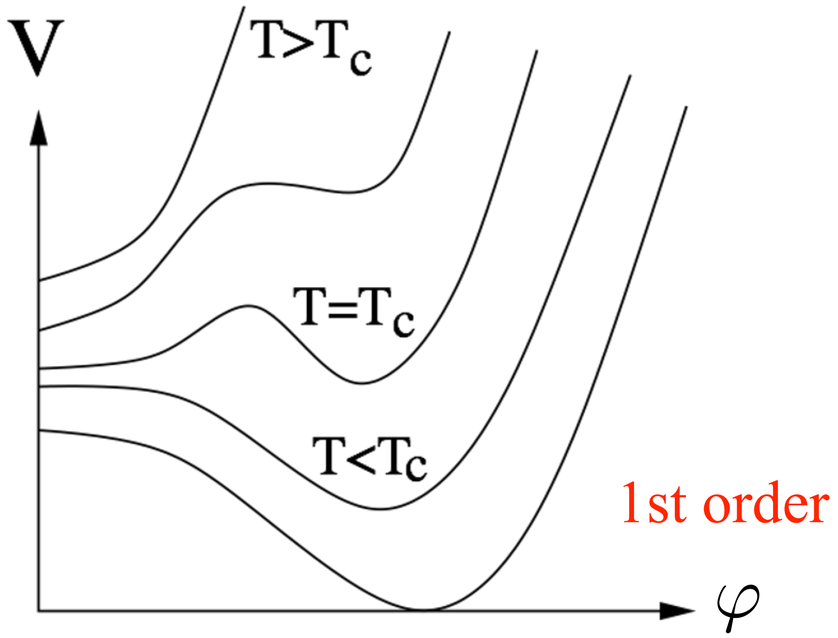


2nd order/cross over

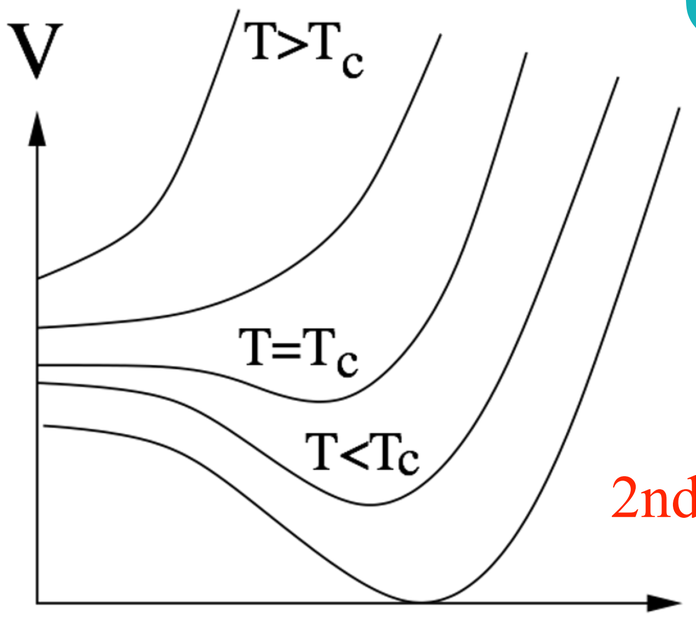
1ST ORDER PHASE TRANSITION

Standard Model
($m_h \gtrsim 65$ GeV)

Kajantie et al. ’96
Csikor et al. ‘98



1st order



2nd order/cross over

TESTING EXTENDED HIGGS SECTOR

$$V_{\rm eff}(\varphi, T) = V_0(\varphi) + V_T(\varphi, T)$$

- need order one corrections: SMEFT fails, model dependent G. White & MP 2020

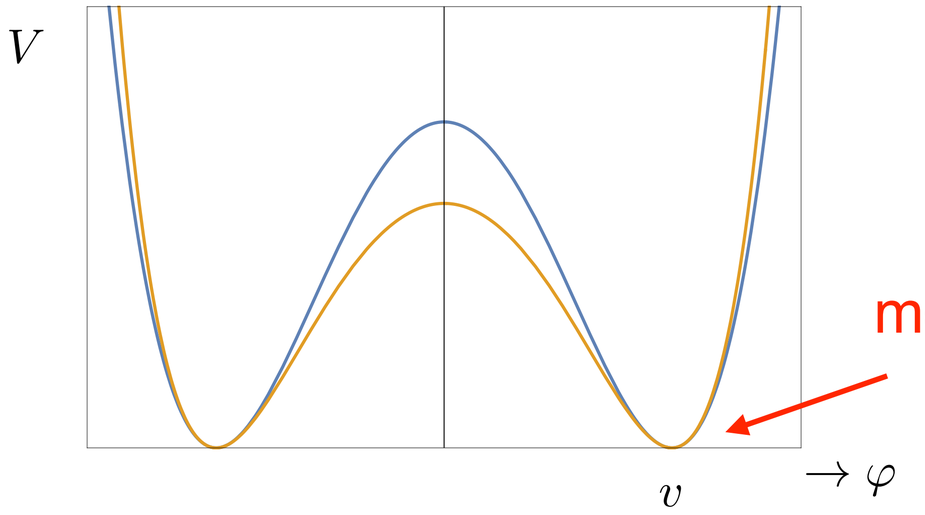
- new contributions to red: large couplings, hard to probe

- new contributions to black: mixing, direct probe of potential

TESTING EXTENDED HIGGS SECTOR

exact nature of Higgs potential unknown

$$-1 \lesssim \frac{\lambda_{\varphi\varphi\varphi}}{\lambda^{\mathrm{SM}}_{\varphi\varphi\varphi}} \lesssim 7$$

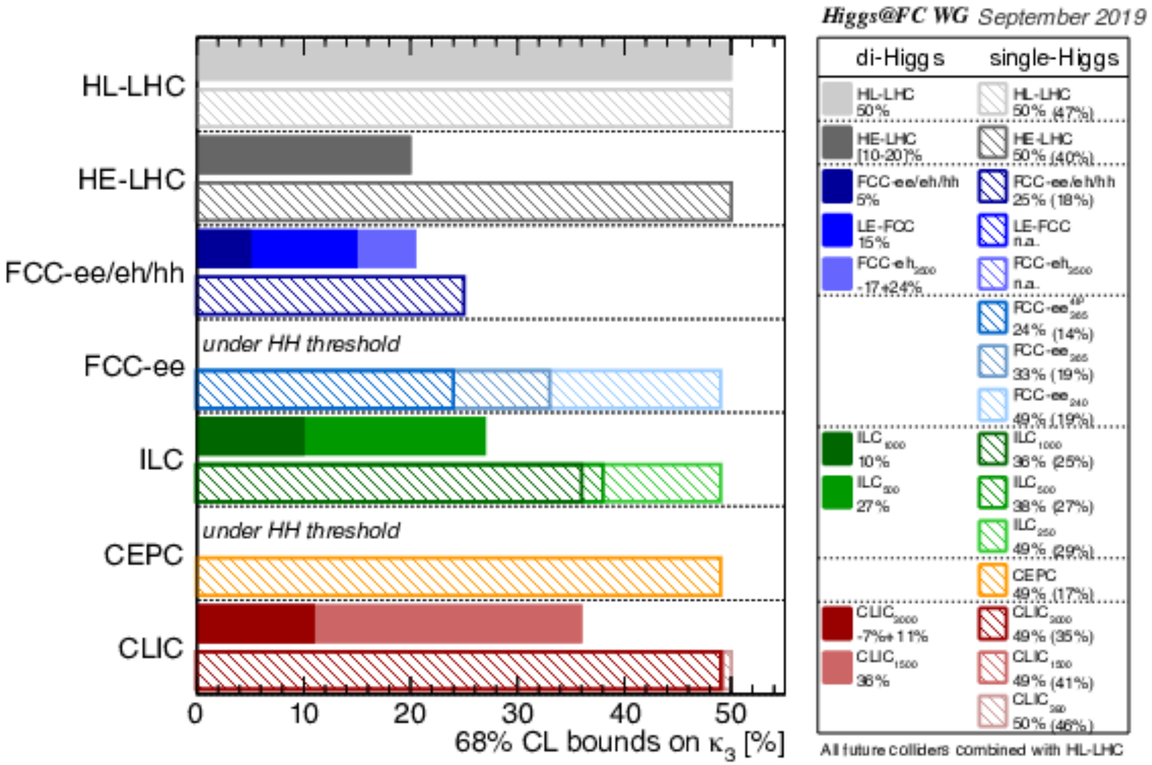


$$m_h = 125.3\,\mathrm{GeV}$$

$$v = 246\,\mathrm{GeV}$$

TESTING EXTENDED HIGGS SECTOR

exact nature of Higgs potential unknown



$$\kappa_3 = \frac{\lambda_{\varphi\varphi\varphi}}{\lambda^{\mathrm{SM}}_{\varphi\varphi\varphi}}$$

sensitivity at 68% probability on the Higgs cubic self-coupling at future colliders (Blas et al. ’19)

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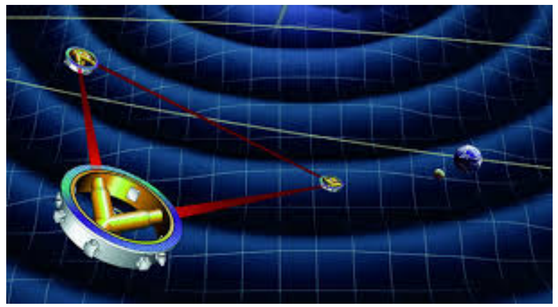
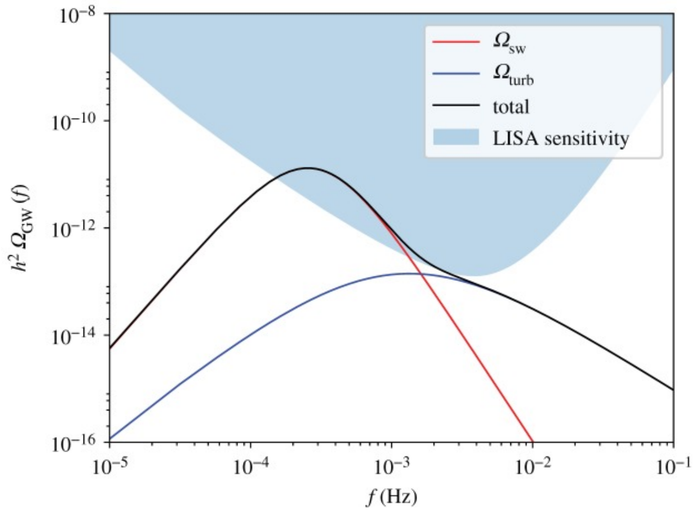


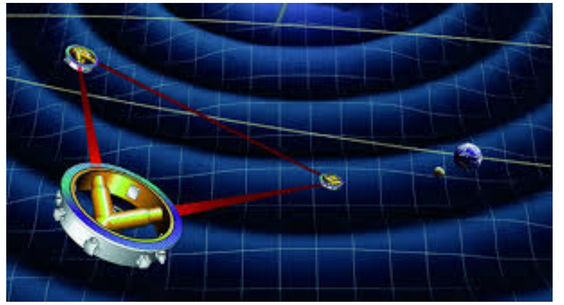
gravitational waves

TESTING ELECTROWEAK BARYOGENES

- peak in LISA frequency range

- tension between efficient GW and baryon asymmetry

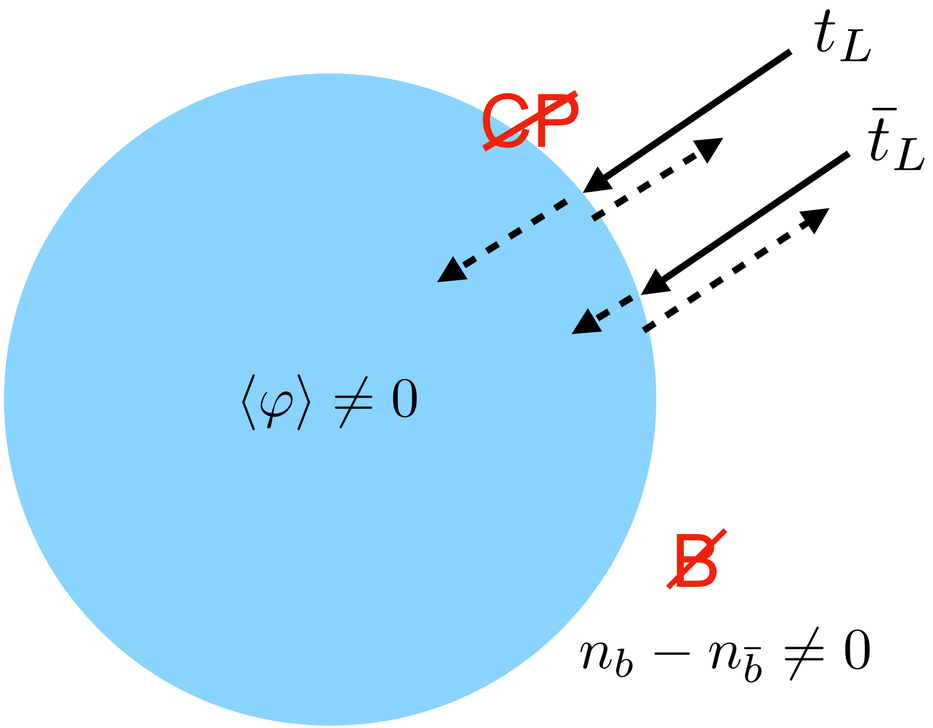




gravitational waves

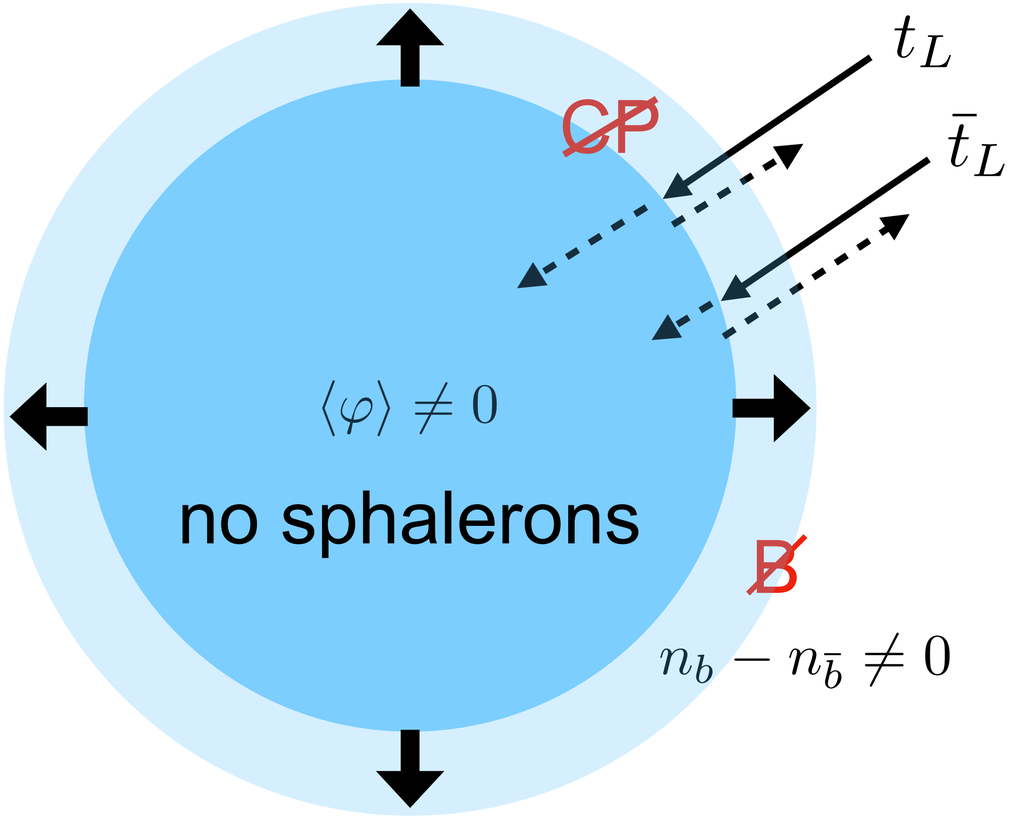
PRECISION MATTERS

WHAT TO CALCULATE



$\langle\varphi\rangle = 0$

WHAT TO CALCULATE

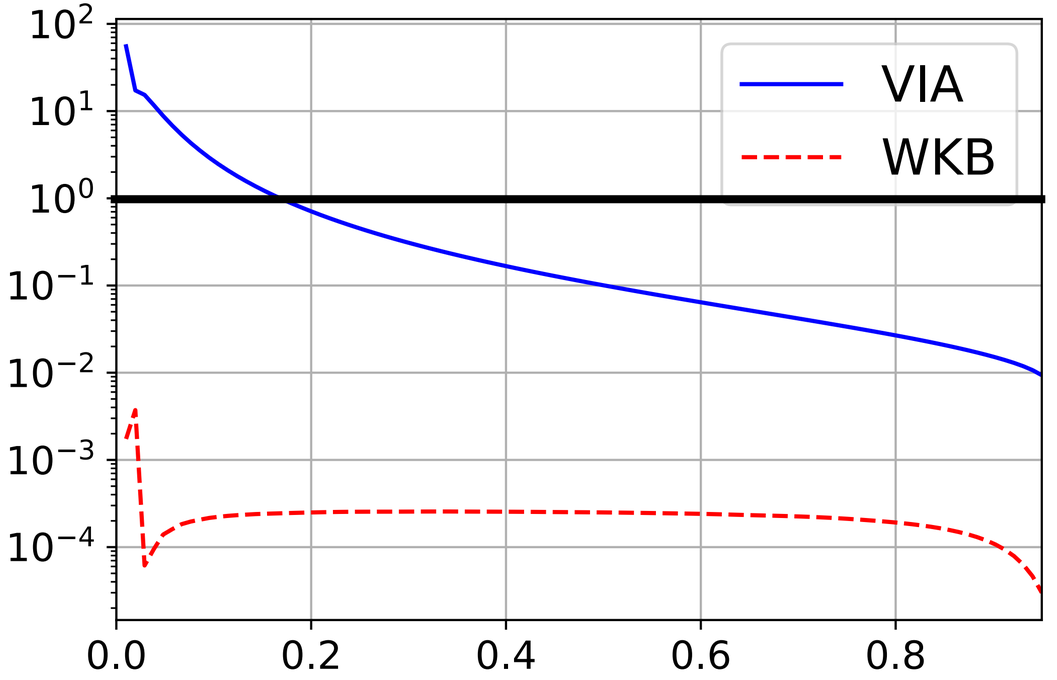


$\langle\varphi\rangle = 0$

TESTING ELECTROWEAK BARYOGENESIS

observed asymmetry →

Cline & Laurent ‘21

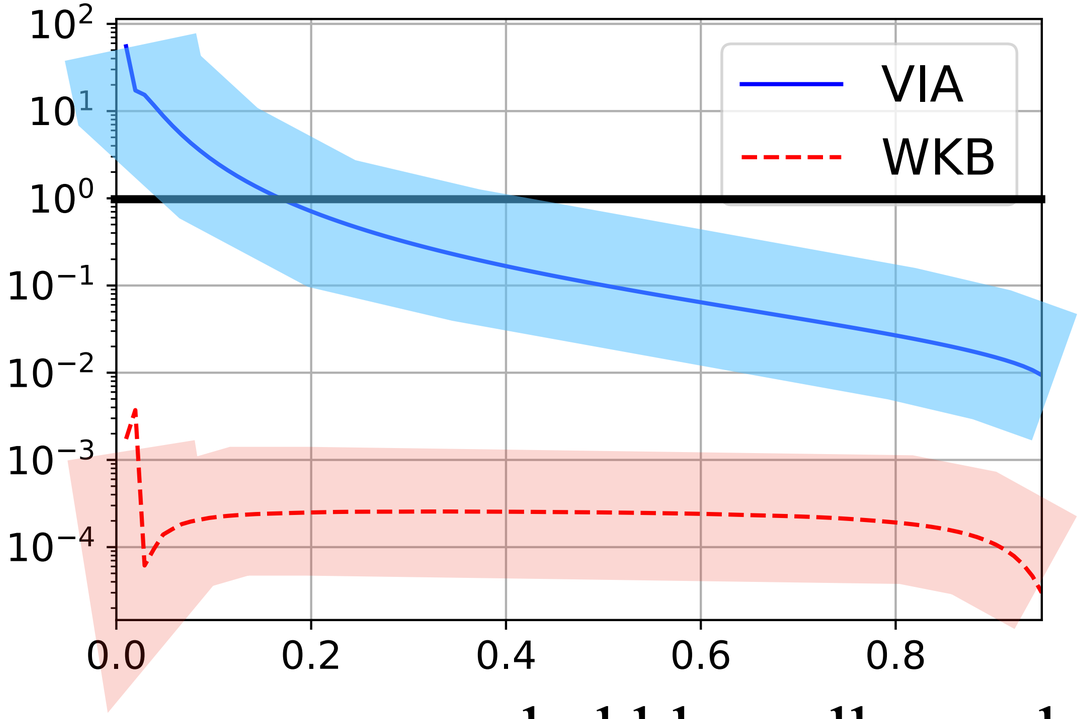


→ bubble wall speed

TESTING ELECTROWEAK BARYOGENESIS

observed asymmetry →

Cline & Laurent ‘21

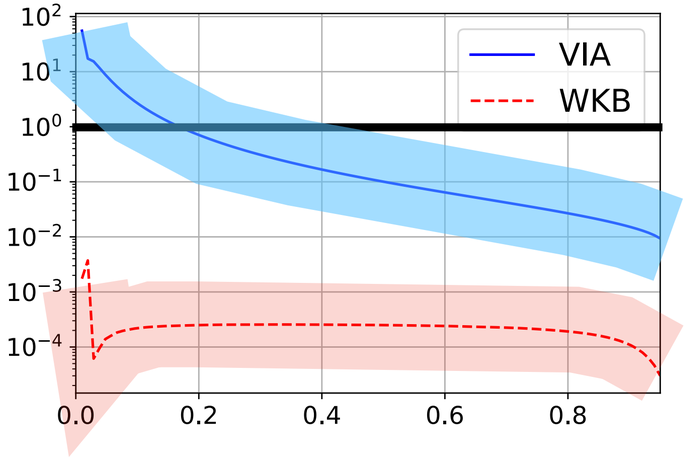


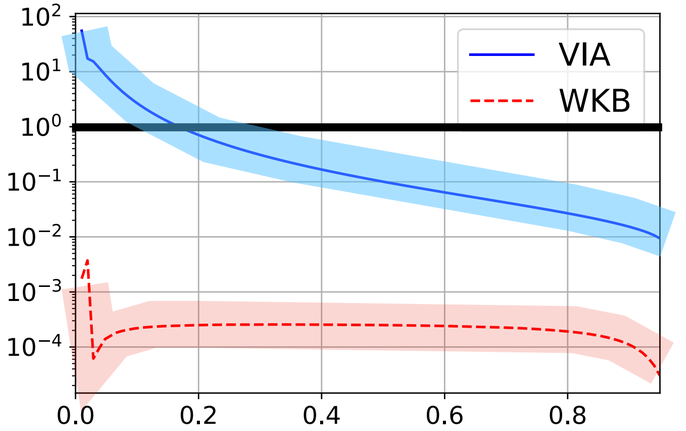
→ bubble wall speed

RECENT PROGRESS

- phase transition dynamics

`DRalgo, BSMPT, …`

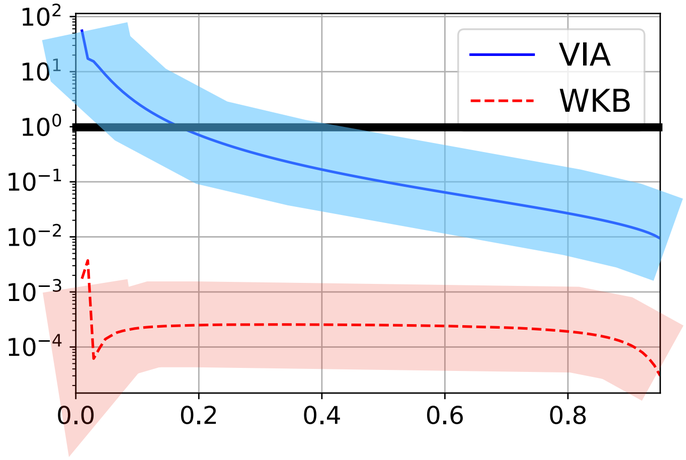


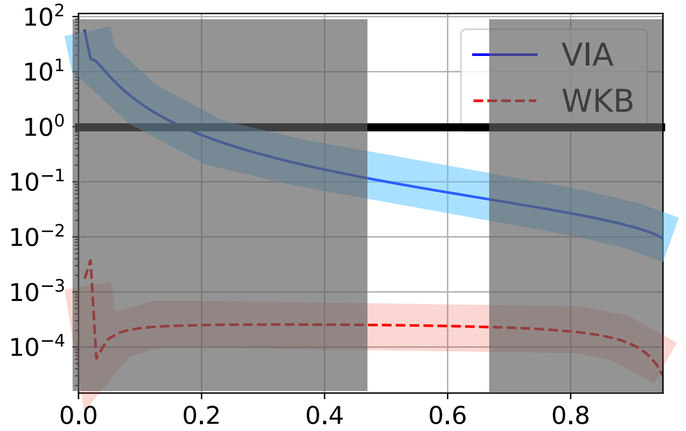


RECENT PROGRESS

- bubble wall velocity

`WallGo, …`

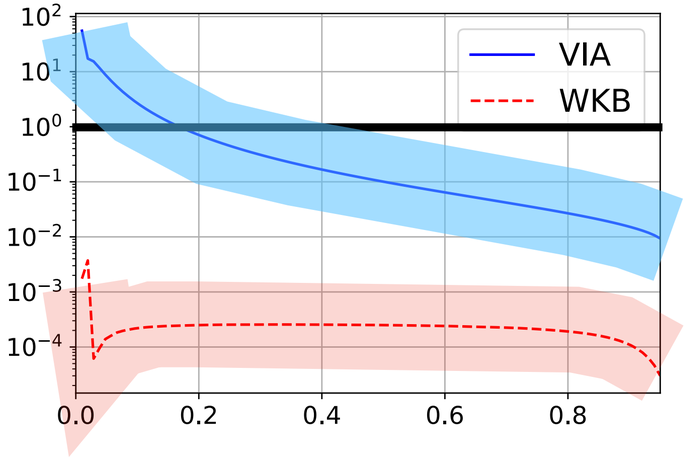


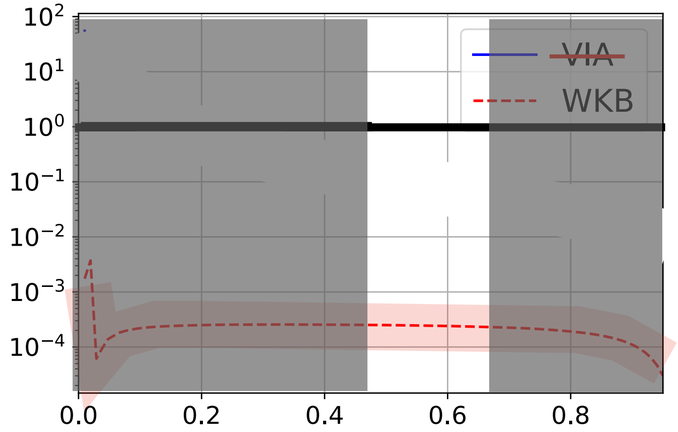


RECENT PROGRESS

- VIA method vanishes

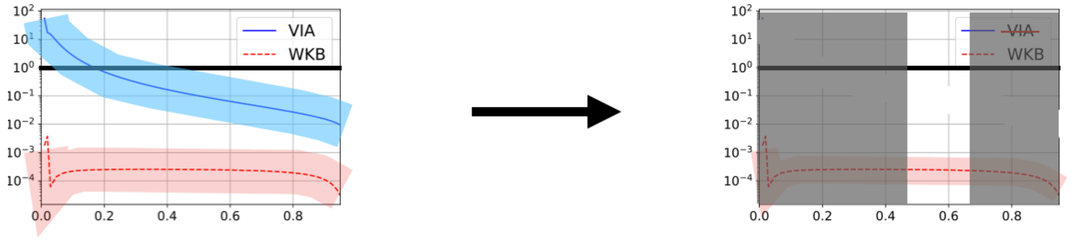
Kainulainen 2108.08336, White, MP & v/d V
2107.05971, 2206.01120





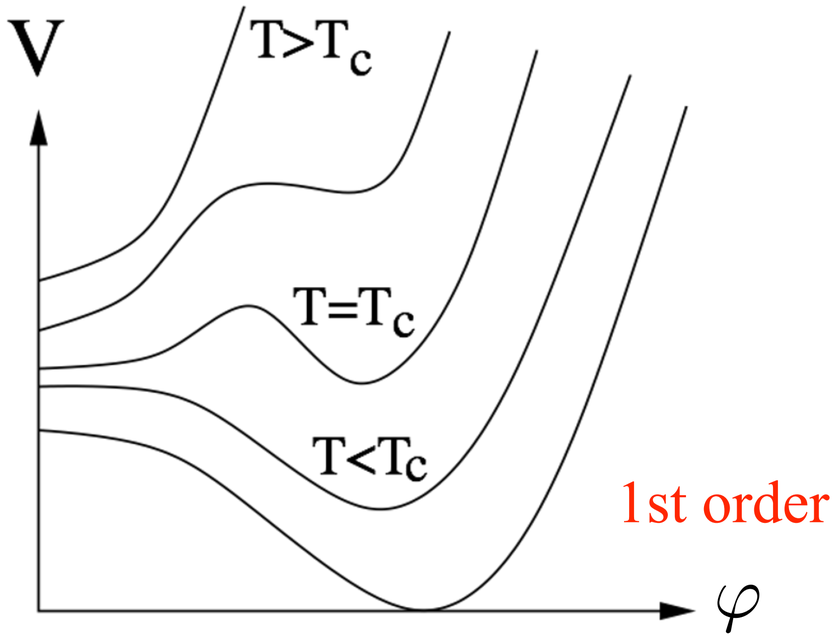
CONCLUSION

- baryogenesis requires new physics
- EW baryogenesis is testable: EDM's, colliders, GW
- precise theoretical predictions (needed)

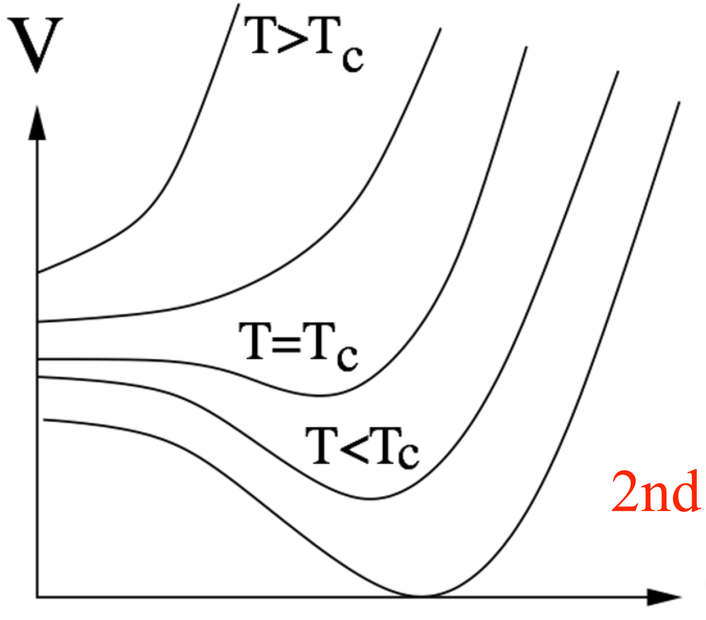


1ST ORDER PHASE TRANSITION

$$V = aT^4 + \frac{1}{2}(-\mu^2 + bT^2)\varphi^2 + cT\varphi^3 + \frac{1}{4}\lambda\varphi^4 \quad +\ldots$$



1st order



2nd order/cross over