# Gravitational waves from first-order phase transitions

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Work in progress.

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In this work:

We determine the type of phase transitions which could be detected by LISA, LIGO, BBO in terms of the amount of supercooling and the duration of the phase transition.

BBO: Big Bang Observer,
second generation of space-interferometers

We point out that the characteristic frequency of the GW spectrum due to phase transitions in the temperature range 100 GeV-10^7 GeV is in the window that will be probed by BBO.

initial motivation:

*Is the electroweak phase transition 1rst or $2^{nd}$ order?*

LHC might answer as it will shed light on the Higgs sector

Question intensively studied within the Minimal Supersymmetric Standard Model (MSSM).

However, not so beyond the MSSM:

It is timely to investigate whether the recently proposed new models of Electroweak symmetry breaking (gauge-higgs unification in extra dimensions, composite Higgs, Little Higgs...) can lead to a first order electroweak phase transition.

Cohen-Kaplan-Nelson '90

# *Electroweak baryogenesis :*

A beautiful mechanism to generate the matter-antimatter asymmetry of the universe involving EW physics only.

CP violation at phase interface,
responsible for mechanism
of charge separation

(CP violation)

$$\Gamma \propto \alpha_W^5 T^4$$

Very active sphalerons
(C & B violation)

Convert chiral asymmetry
into baryon asymmetry

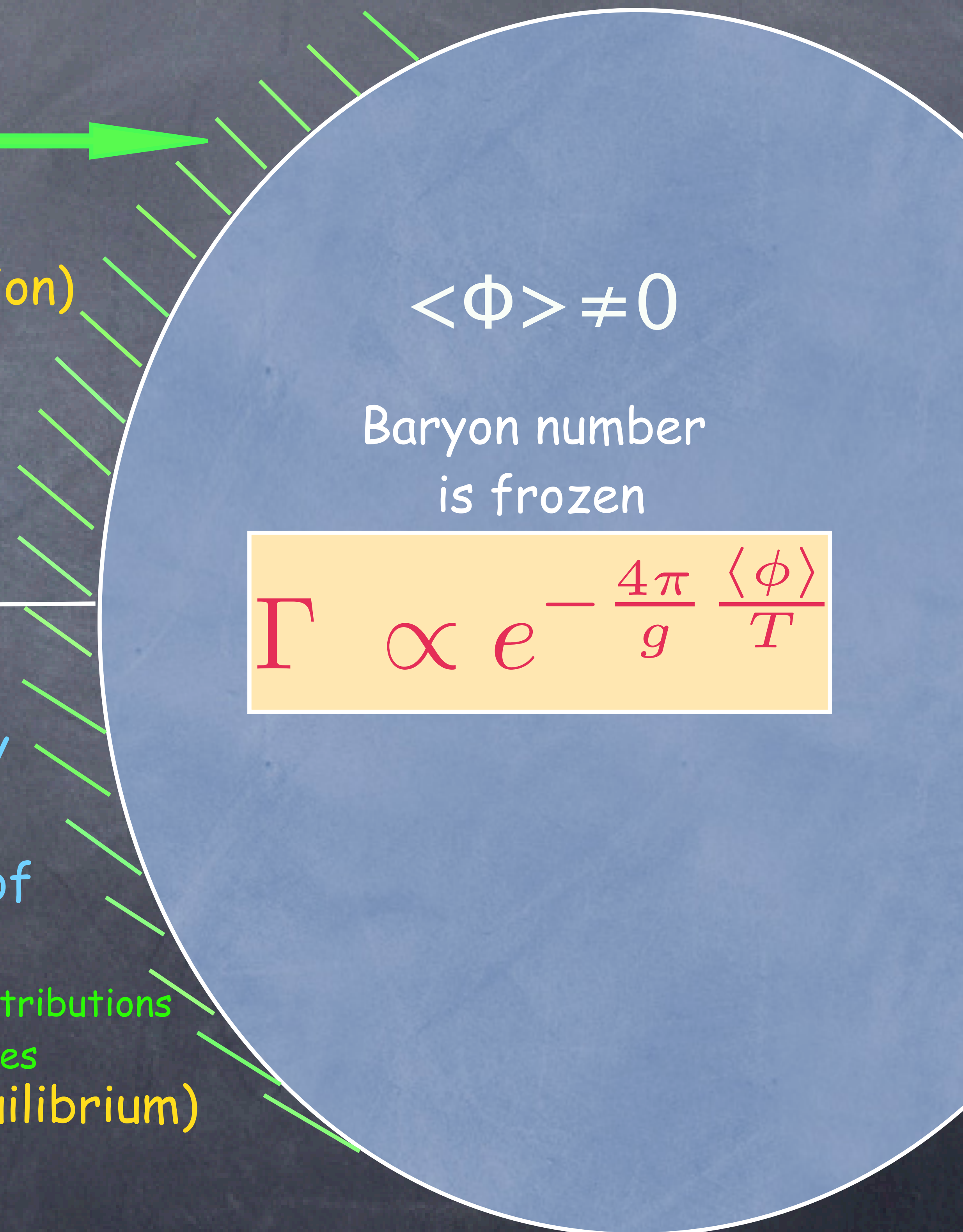
$$\frac{dn_B}{dt} \propto n_L$$

*left-handed fermions*

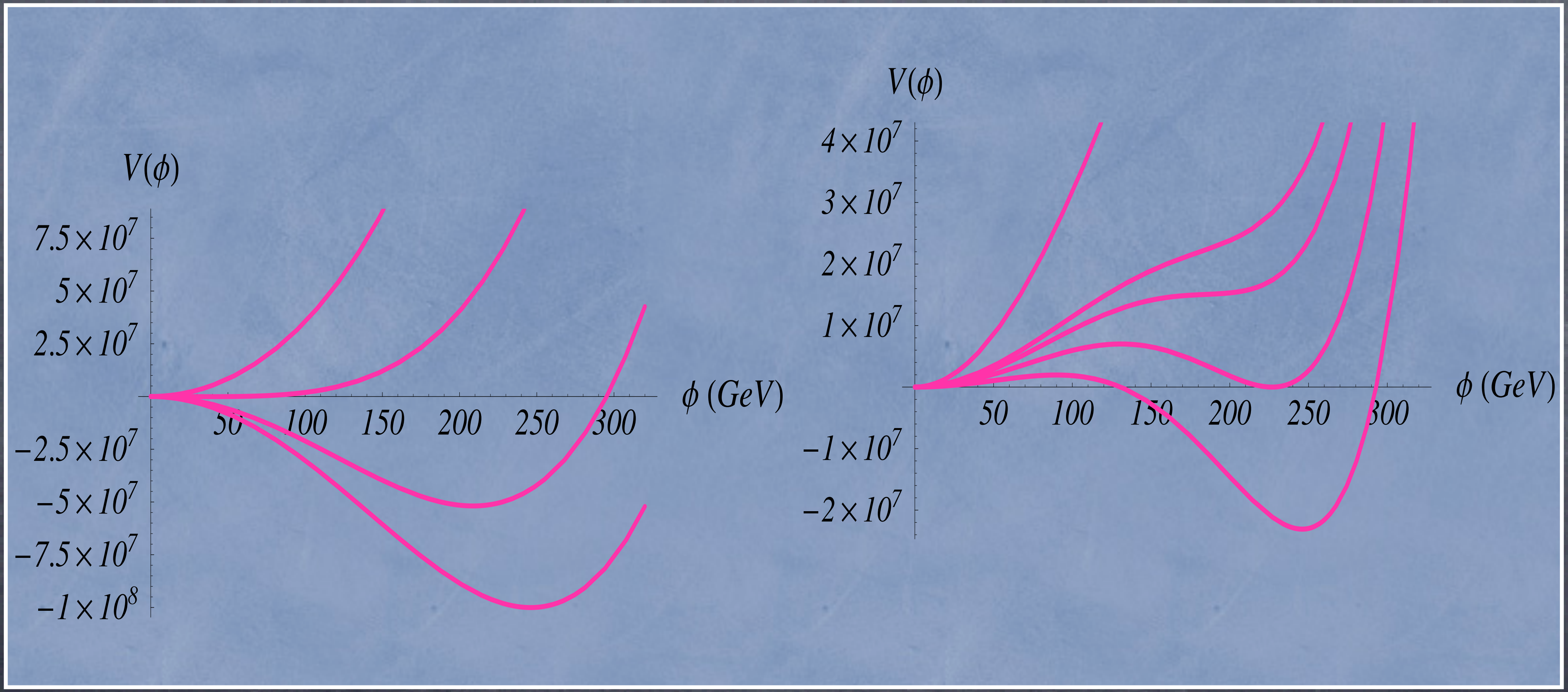
v

Chirality
Flux
in front of
the wall

NON thermal distributions
of particles
(Out-of-equilibrium)



# $2^{nd}$ order versus 1rst order



# Gravitational wave background from a strong 1rst order PT

Kosowsky, Turner, Watkins'92
Kamionkowski, Kosowsky Turner '94

2 contributions: -from bubble collisions

-from turbulent fluid motions

Kosowsky, Mack, Kahniashvili'02
Dolgov, Grasso,Nicolis'02

# 2 basic quantities determine the GW background generated during a 1rst order PT

⇒ $\alpha$ : ratio of energy density of false vacuum to thermal energy density of the plasma

⇒ $\beta$ : rate of variation of nucleation rate $\Gamma$: ( $\Gamma = \Gamma_0 \; e^{-\beta t}$ )

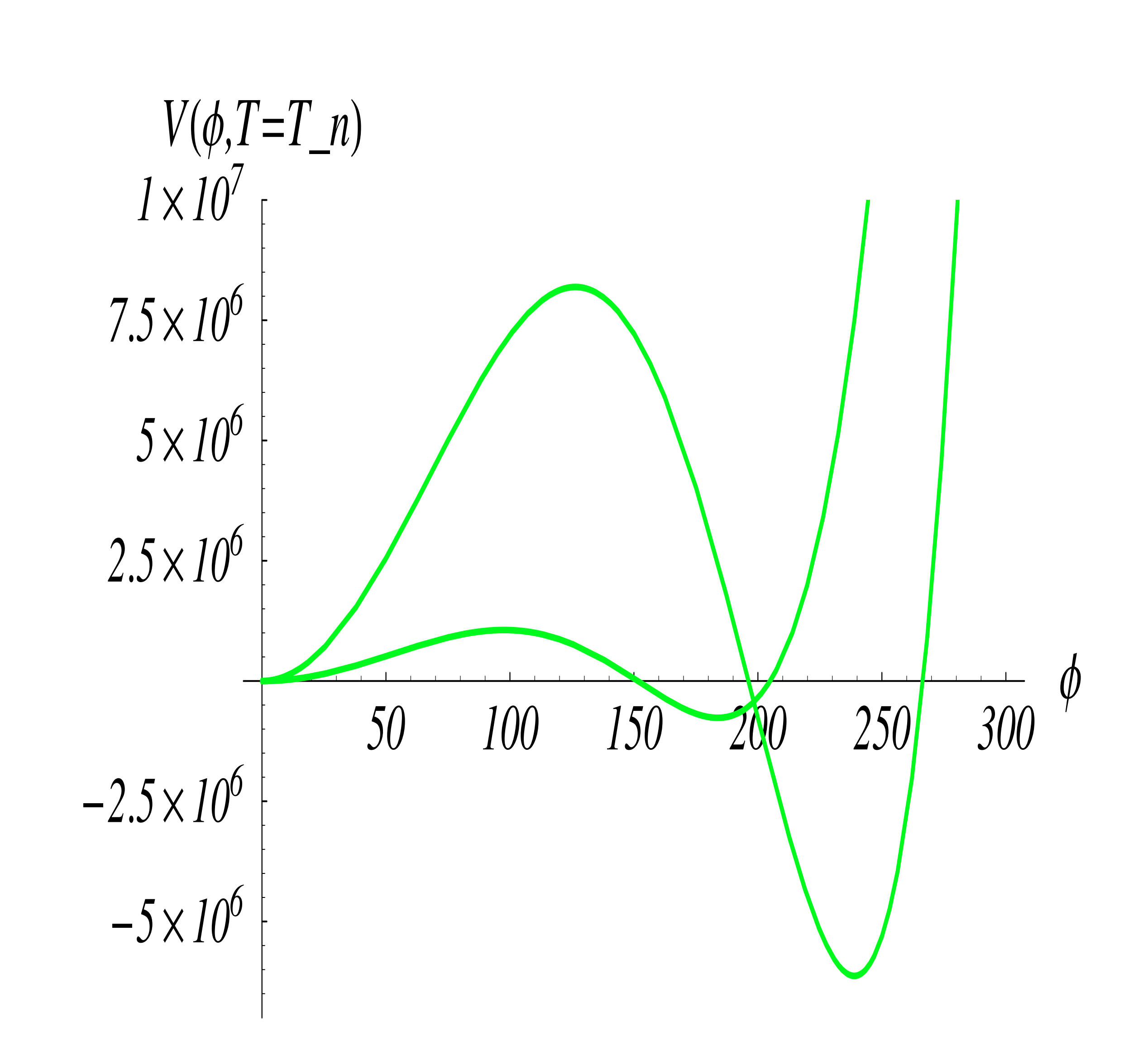
$\beta^{-1} = \Gamma / \dot{\Gamma}$ : ~duration of PT

$2\pi f \approx \beta$ characteristic frequency of GW @ time of production

The stronger is the transition, the larger is α and the smaller is β (the larger amount of supercooling)

α and β : entirely determined by the effective scalar potential at high temperature

# Shape of the potential at the nucleation temperature



- *Frequency of the signal*

$$f_{\rm coll} \approx 5.2 \times 10^{-3} {\rm mHz} \frac{\beta}{H_*} \frac{T_*}{100{\rm GeV}} \left[\frac{g_*}{100}\right]^{1/6}$$

$$f_{\rm turb} \approx 0.65 \frac{u_s}{v_b} f_{\rm coll}$$

from, e.g, A. Nicolis '03

- *Amplitude of the signal at the peak frequency*

$$\Omega_{\rm gw}\, h^2 \propto \left[\frac{H_*}{\beta}\right]^2 \times f(\alpha)$$

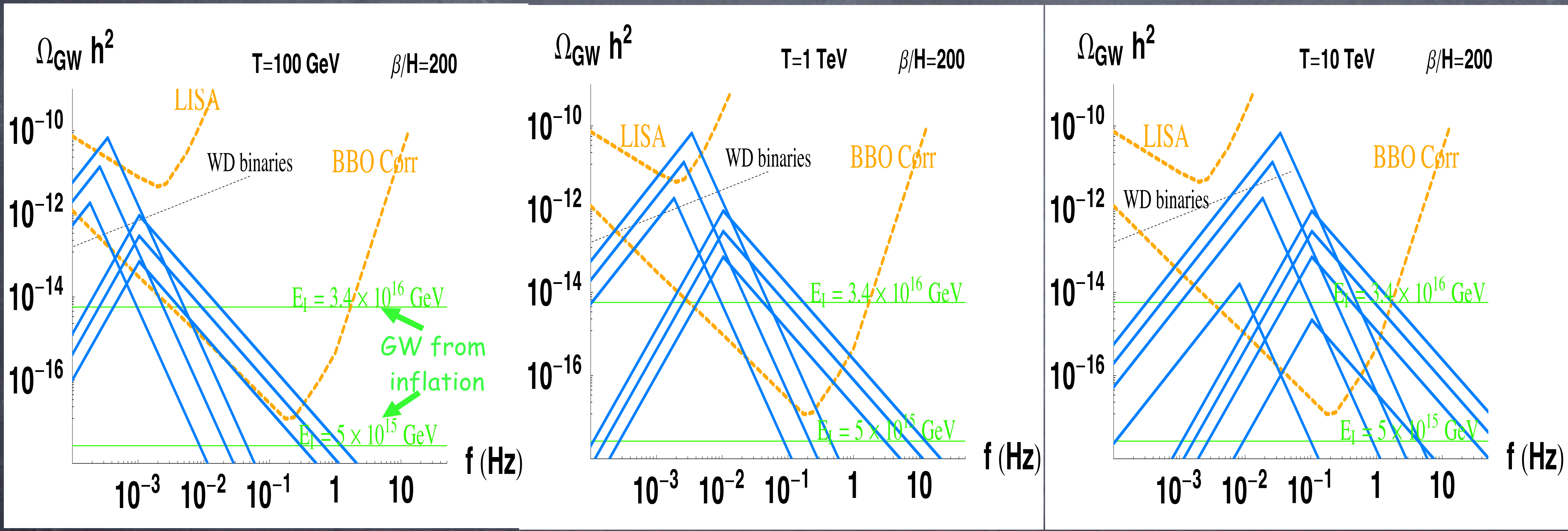
where $f(\alpha)$ increases with $\alpha$

The gravitational wave spectrum from a 1rst order electroweak PT is peaked around the milliHertz frequency, just in the band of the planned space interferometer LISA.

# Spectrum of gravitational waves produced at 1rst order phase transitions

1rst blue peak: GW from bubble collisions

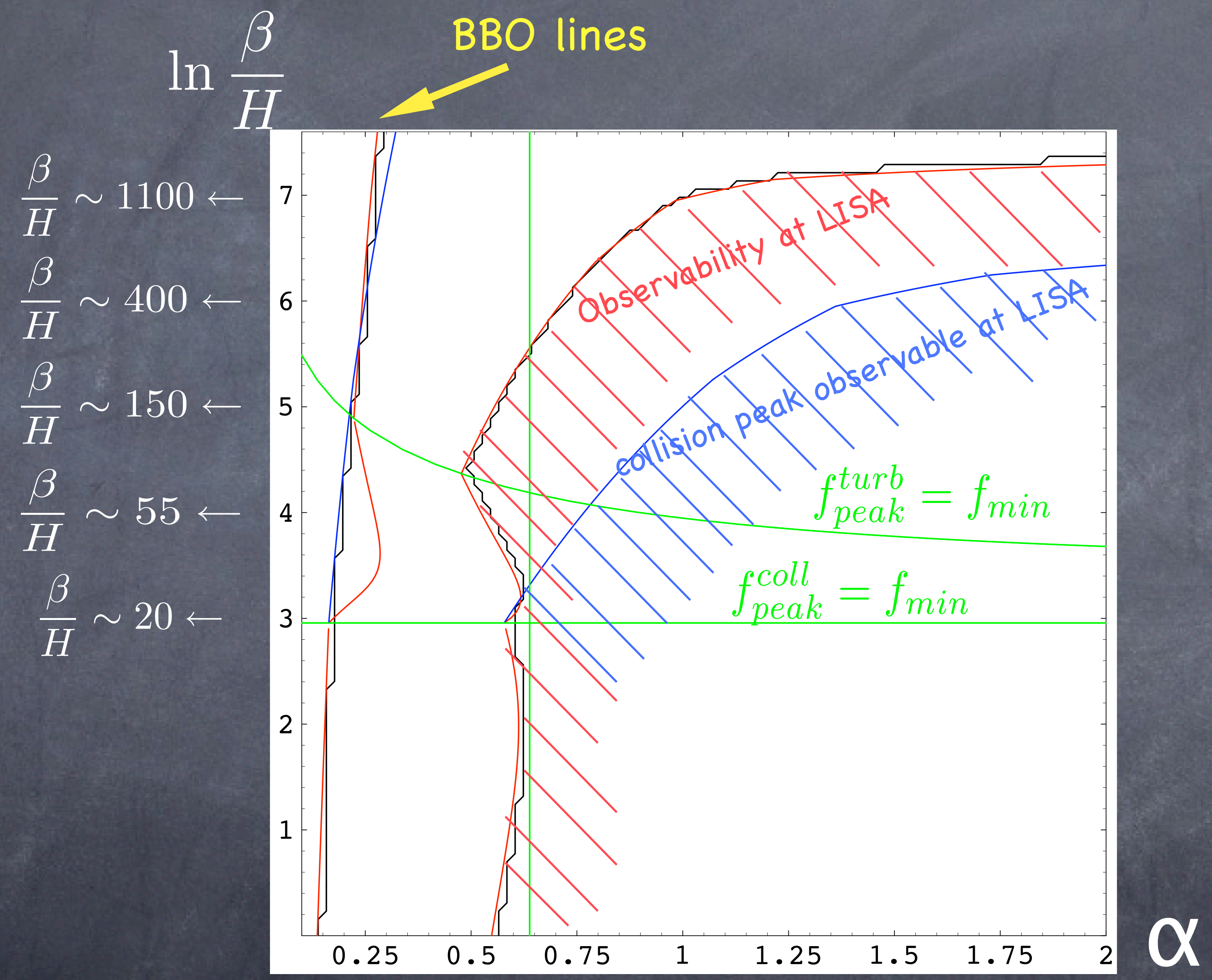
2nd blue peak: GW from turbulence



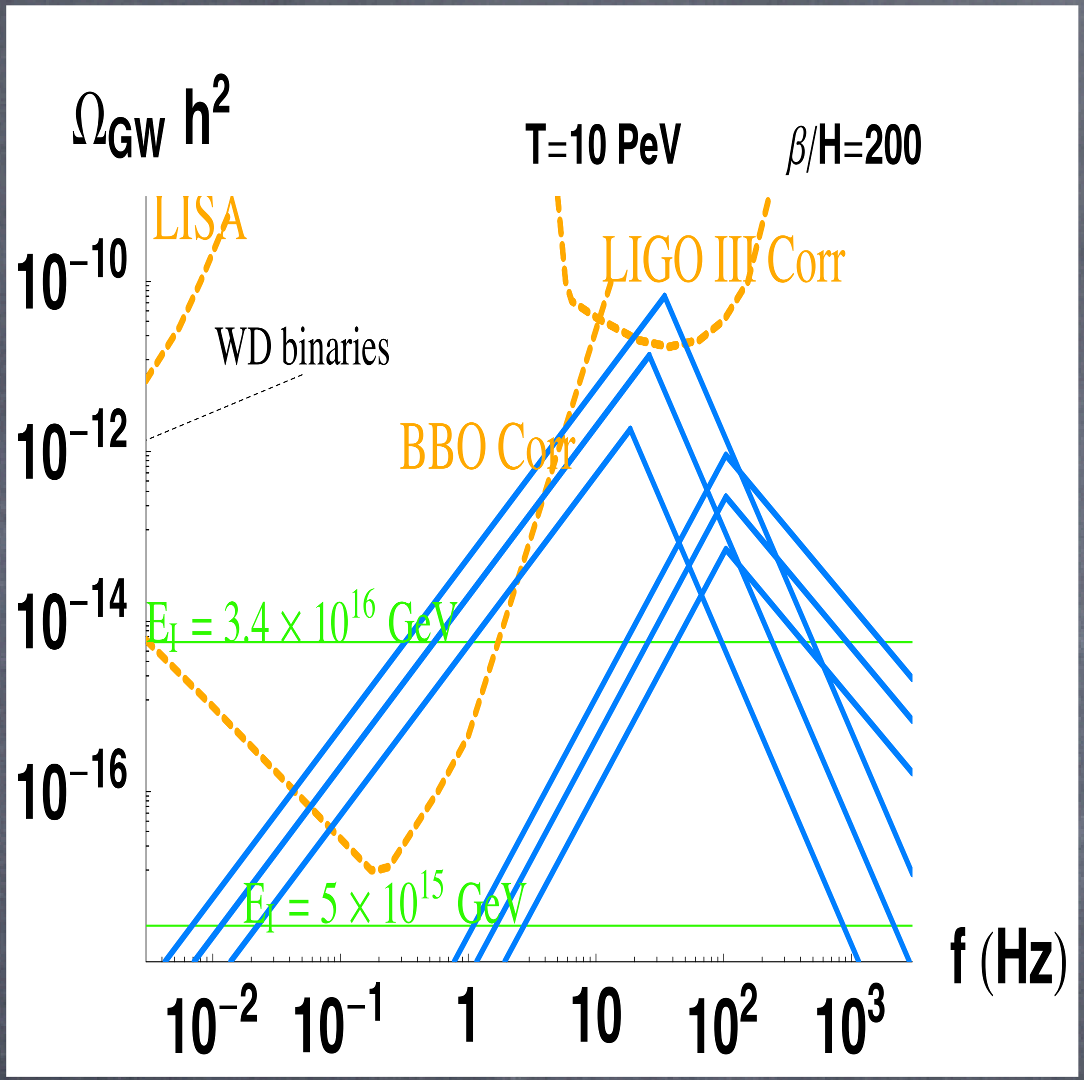

$\alpha = 0.3, 0.5, 0.8$

# Observability of the EWPT at LISA and BBO in the α–β/H plane

T=100 GeV



A phase transition at T=10^7 GeV could be observed both at LIGO and BBO:




α =0.3,0.5,0.8

# *Summary*

- LISA, LIGO and BBO: can probe phase transitions in the temperature range 100 GeV-10^7 GeV
- The GW spectrum is a function of 2 quantities: α (latent heat) and $\beta^{-1}$ (duration of PT) which can be computed for any given scalar potential.
- For each T, we determined the region in the (α,β) plane leading to an observable signal. Observation or non-observation of GW will put constraints on the parameters of these potentials.
- At LHC, the higgs mass is measured but not the quartic or cubic Higgs self coupling. A linear collider can provide this information, which timescale is even beyond LISA. LISA could start constraining parameters of the Higgs sector before a linear collider...
- The signal from PT at T~1-100 TeV could entirely screen the relic GW background expected from inflation.