Gravity waves from 1st order PTs

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in collaboration with

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Research interests

worldline effective action

hidden sector

5D-RS

SUSY

Higgs pheno

EDMs

1st order (BSM) electroweak phase transition

gravitational waves

CP violation

baryogenesis

quantum transport

Outline

- Introduction
- GW spectra from bubble collisions
- Efficiency factors from hydrodynamics

Introduction

- 1st order phase transitions proceed by bubble nucleations

- In case of the electroweak PT, the bubble wall separates the symmetric from the broken phase

- This is a violent process ($v_b = O(1)$) and the kinetic energy in the bulk fluid motion and Higgs field is sizable

GW production by
- bubble collisions
- turbulence in the plasma
- magnetic fields

Weinbergs master formula

Using linearized GR and the wave zone approximation, the total energy radiated into a direction $\hat{\mathbf{k}}$ is given by

$$\frac{dE_{GW}}{d\omega d\Omega} = 2G\omega^2 \Lambda_{ij,lm}(\hat{\mathbf{k}}) T^*_{ij}(\hat{\mathbf{k}}, \omega) T_{lm}(\hat{\mathbf{k}}, \omega),$$

where $T_{ij}(\hat{\mathbf{k}}, \omega)$ denotes the stress-energy tensor in Fourier space and Λ is the projection tensor for the transverse-traceless part.

Spherical symmetric configurations do hence not contribute and the bubbles produce GWs only when they collide.

Back on the envelope

The tunnel probability usually increases exponentially

$$P \propto \exp(\beta\, t) \quad \text{and typically} \quad \beta/H = O(100).$$

The latent heat ρ_{vac} is with efficiency κ transformed into the bulk motion of the fluid

$$T_{\mu\nu} \propto \kappa\, \rho_{vac}, \quad G \propto H^2/(\rho_{vac} + \rho_{rad}).$$

For dimensional reasons we obtain for the energy fraction in GWs per frequency octave

$$\Omega_{GW} = \omega \frac{dE_{GW}}{d\omega} \frac{1}{E_{tot}} = \kappa^2 \left(\frac{H}{\beta}\right)^2 \left(\frac{\alpha}{\alpha + 1}\right)^2 \Delta(\omega/\beta, v_b),$$

with Δ some dimensionless function and $\alpha = \rho_{vac}/\rho_{rad} \lesssim 1$

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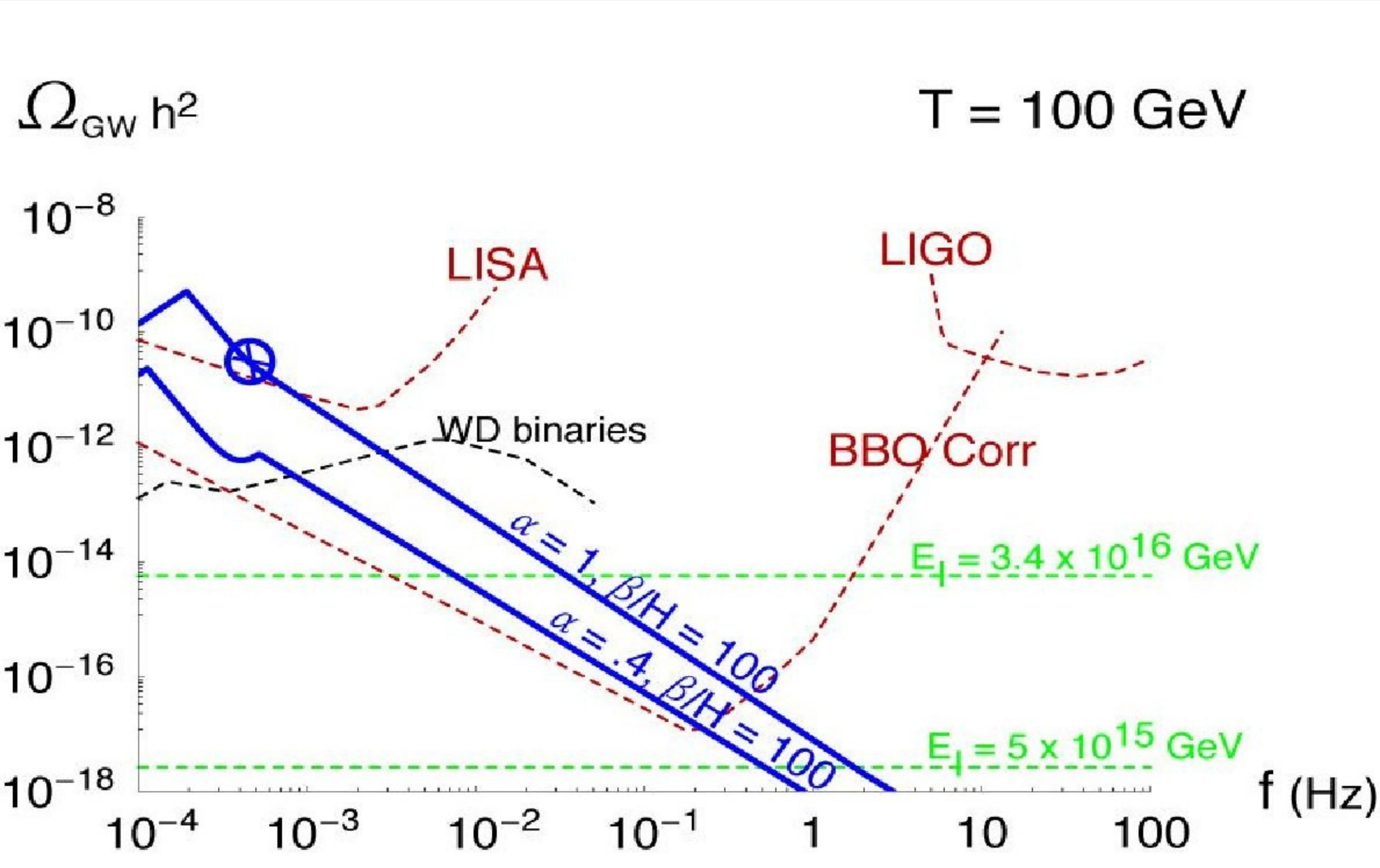
Example

Grojean & Servant '06



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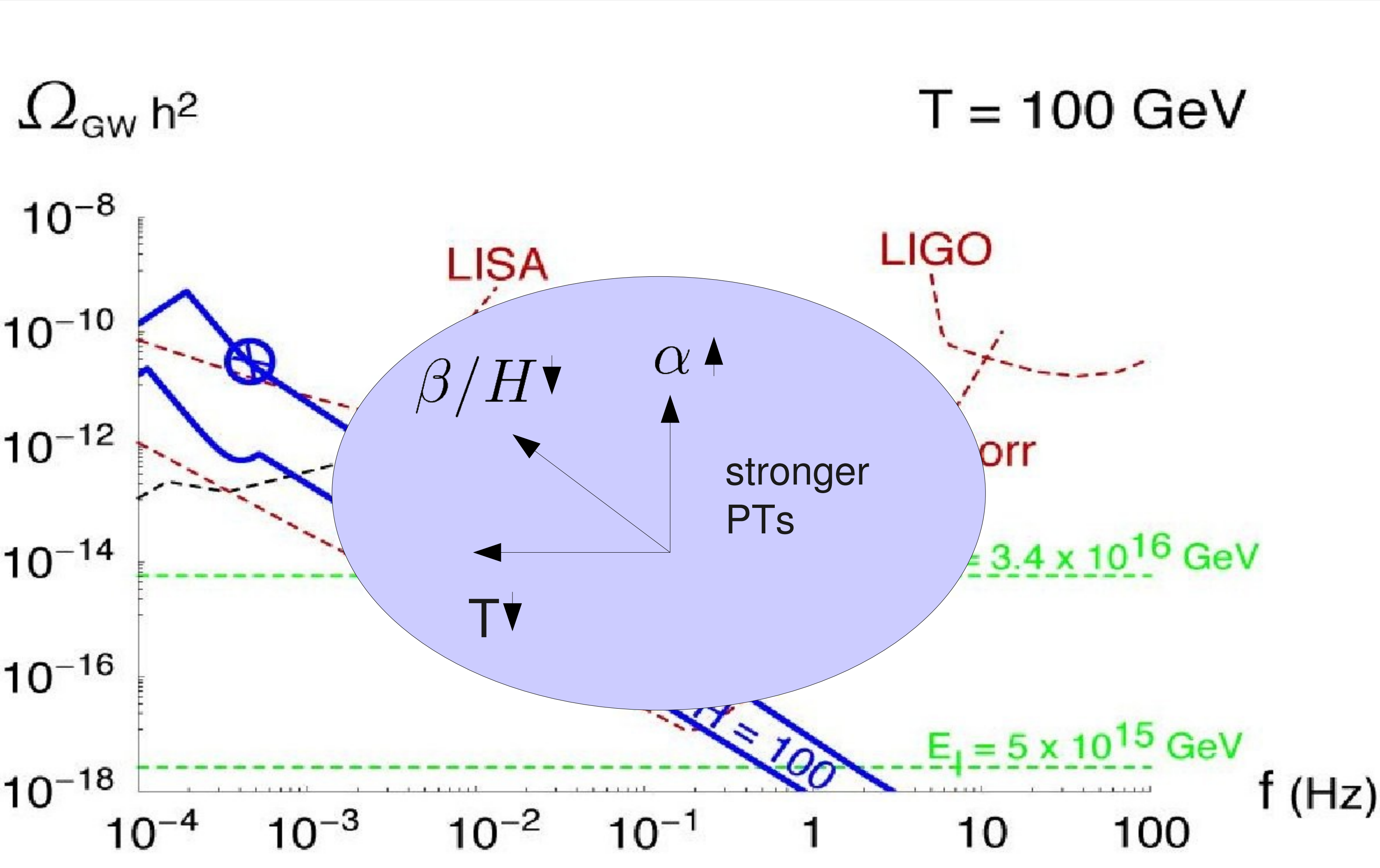

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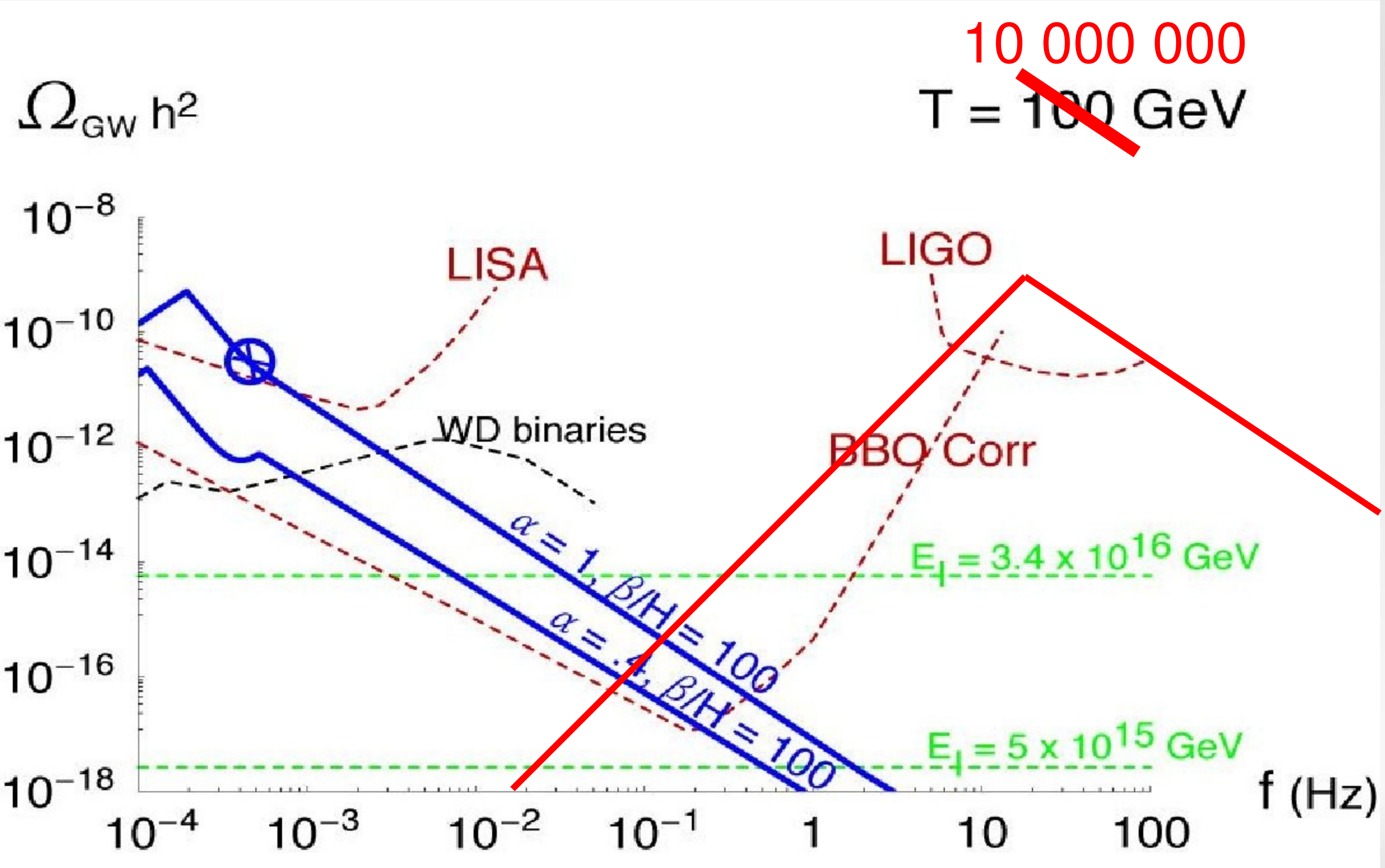


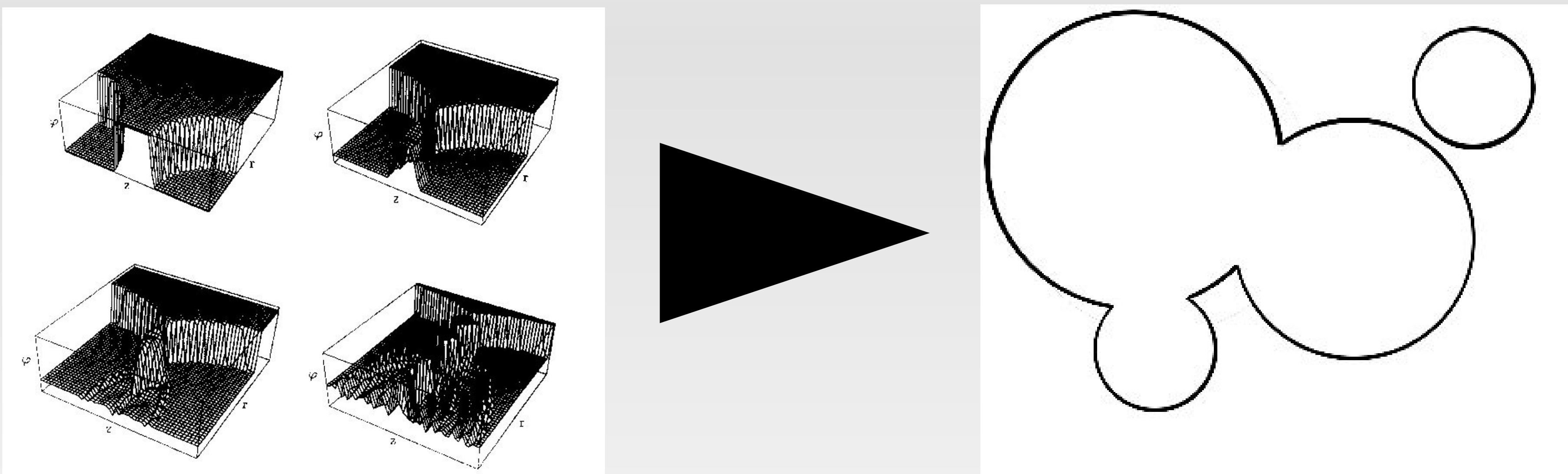
GW spectra

GWs from bubble collisions

$$\kappa^2 \left(\frac{H}{\beta}\right)^2 \left(\frac{\alpha}{\alpha+1}\right)^2 \Delta(\omega/\beta, v_b),$$

Envelope approximation

Kosowski, Turner, Watkins '91

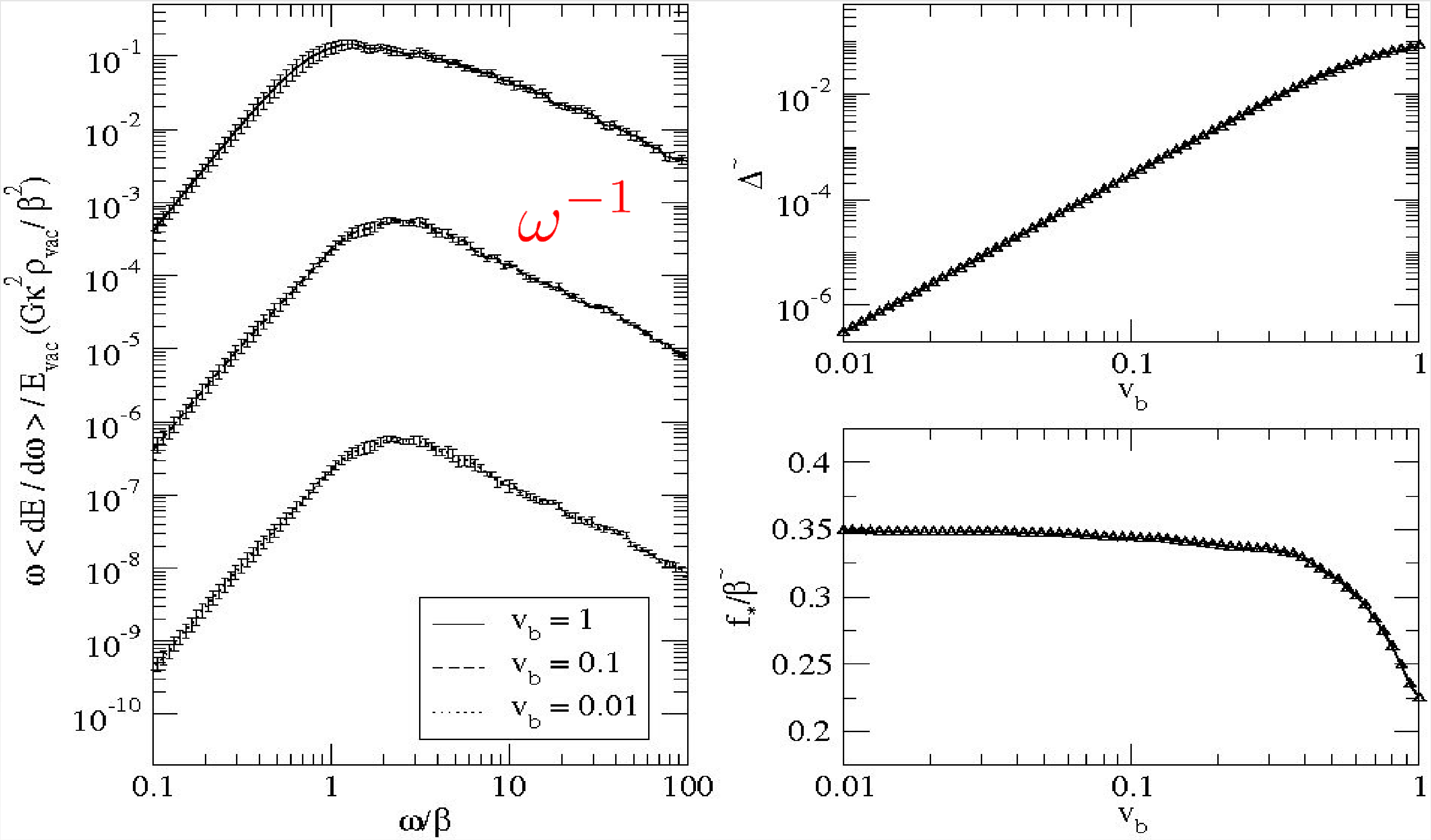


Simulations show that for the production of GWs the energy of the Higgs field can be approximated by its envelope.

Still, simulations with many bubbles and high accuracy have been too demanding in the 90s.

Bubble collisions

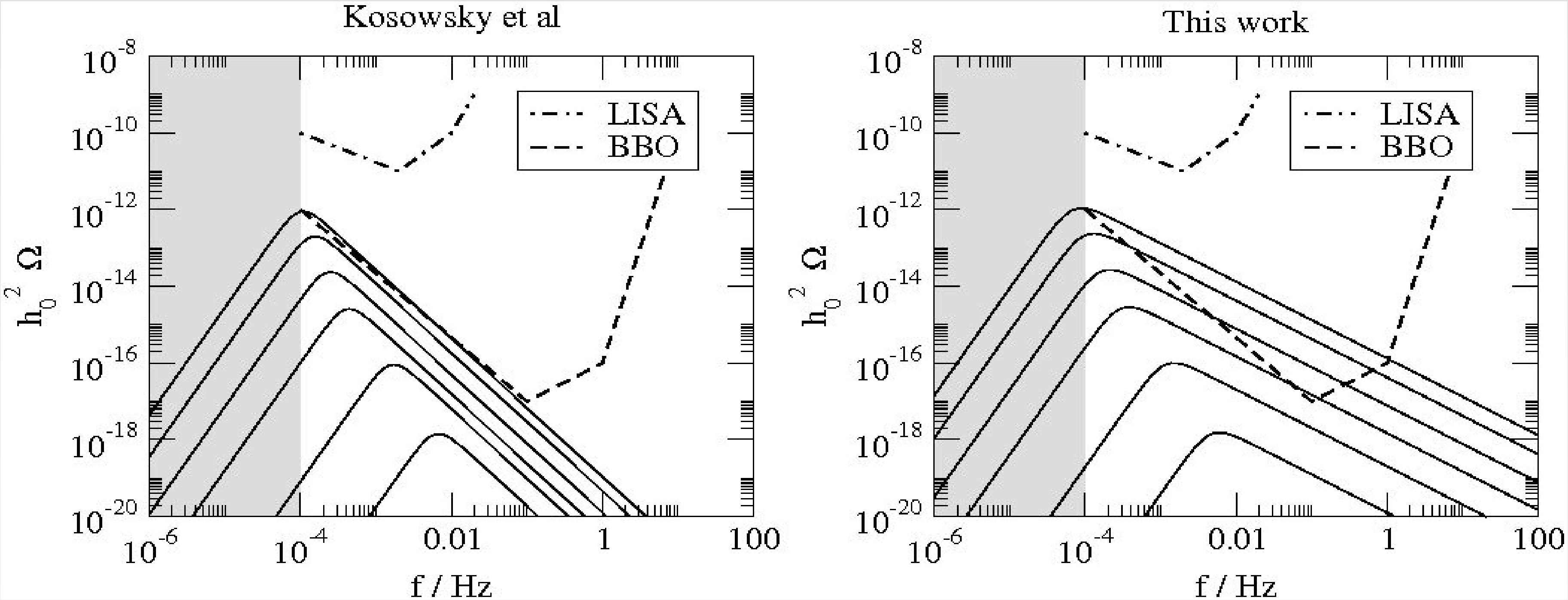
S.J. Huber and TK '08



Our results show that the spectrum scales as ω^{-1} for large frequencies unlike earlier results.

Bubble collisions

This is essential for the prospects of GW detection in many models



The flat spectrum is due to quite a peculiar time dependence of the anisotropic stress (Caprini, Durrer, TK, Servant '09).

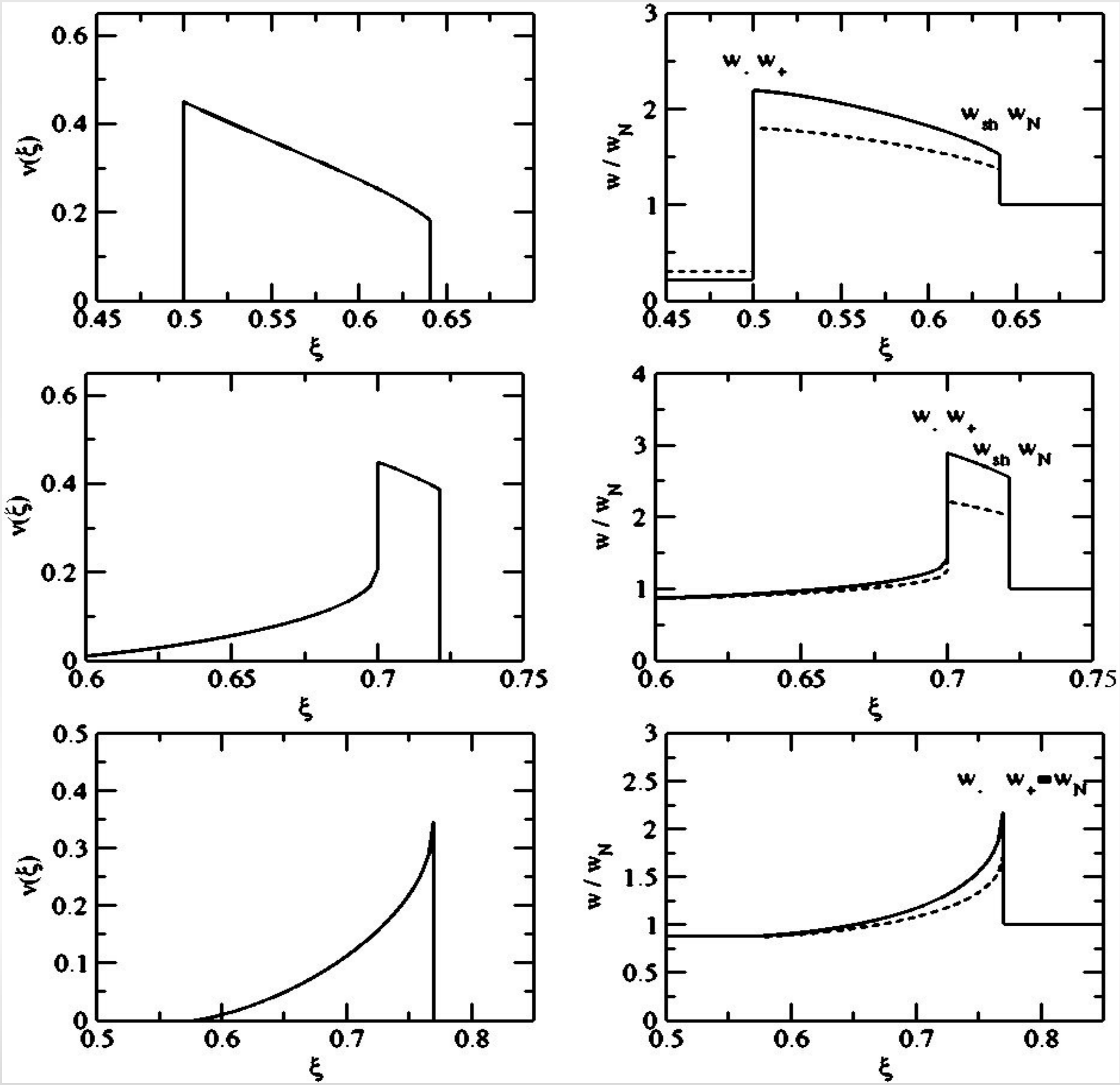
Efficiency coefficient

bulk flow and hydrodynamics

$$\kappa^2 \left(\frac{H}{\beta}\right)^2 \left(\frac{\alpha}{\alpha+1}\right)^2 \Delta(\omega/\beta, v_b),$$

Efficiency coefficient

Espinosa, TK, No, Servant

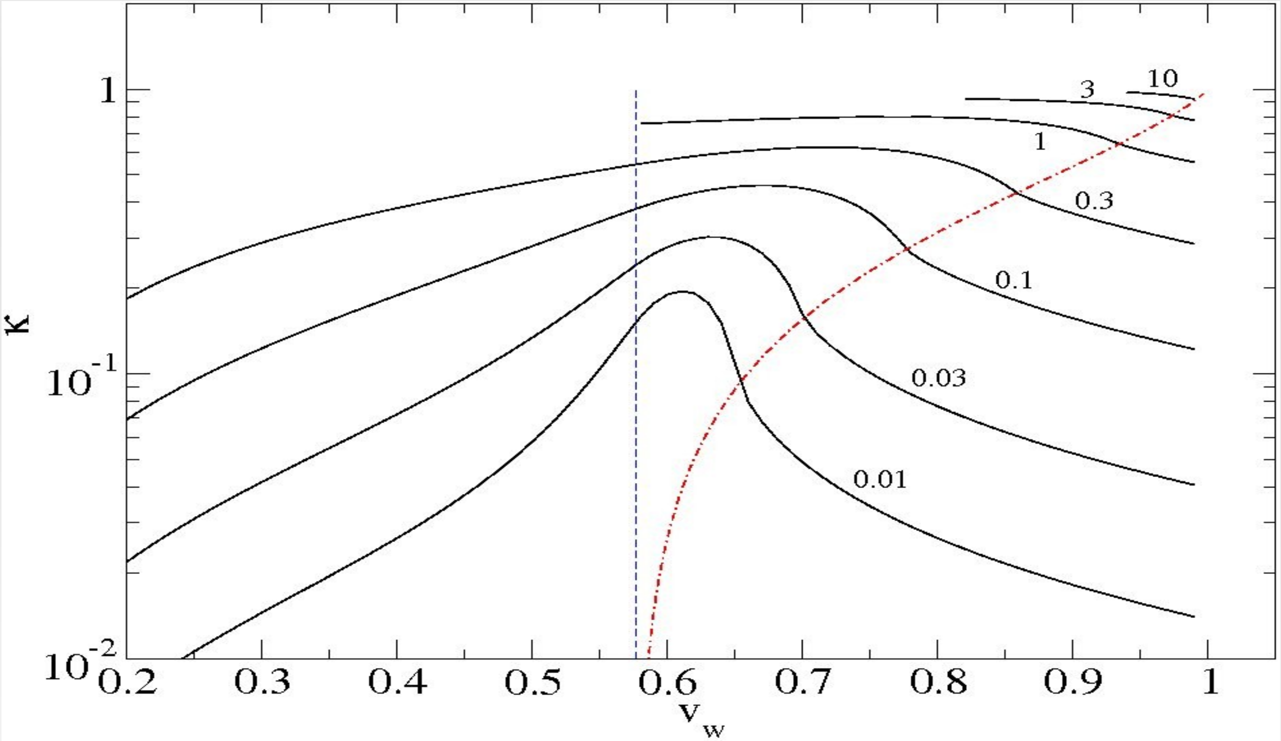


The vacuum energy of the Higgs field is transformed into heat and bulk motion.

For given latent heat, there are several hydrodynamic solutions possible in the plasma depending on the wall velocity.

The wall velocity depends on microphysics in the wall (friction).

Efficiency coefficient



The efficiency can be quite different than for Jouget detonations (=red line).

Conclusions / motivation

Gravitational waves observations open up the unique possibility to probe

- the process of electroweak symmetry breaking in the early Universe
- particle physics at scales significantly higher than the electroweak scale