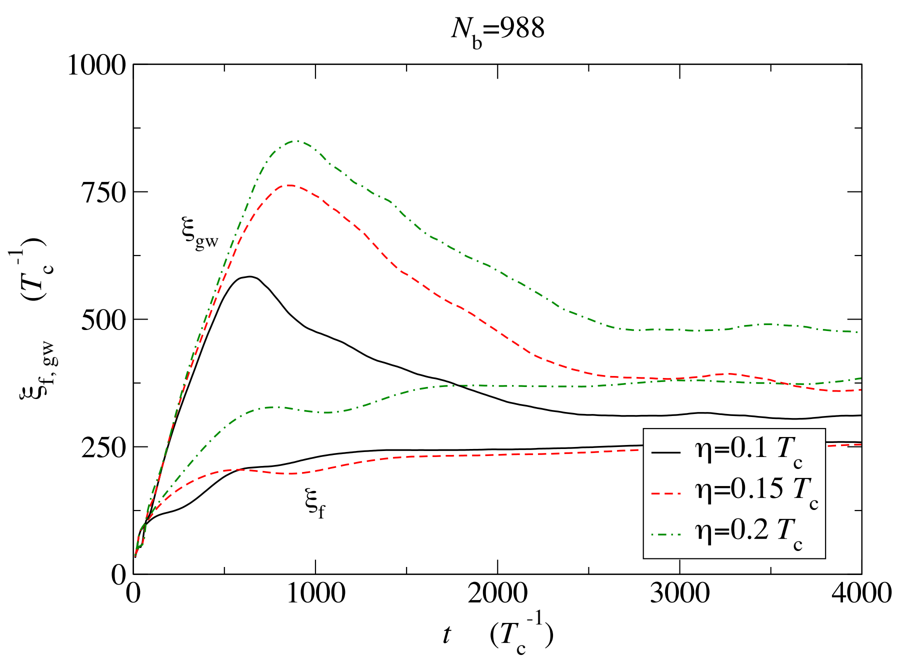
Results extra slides

Fluid characteristic length scale is imprinted in GW power spectrum

Define the fluid integral scale

$$\xi_\mathrm{f} = \frac{1}{\langle V^2 \rangle} \int \frac{d^3k}{(2\pi)^3} |k|^{-1} P_V(k)$$

and the analogous quantity ξ_GW for the gravitational wave power spectrum.



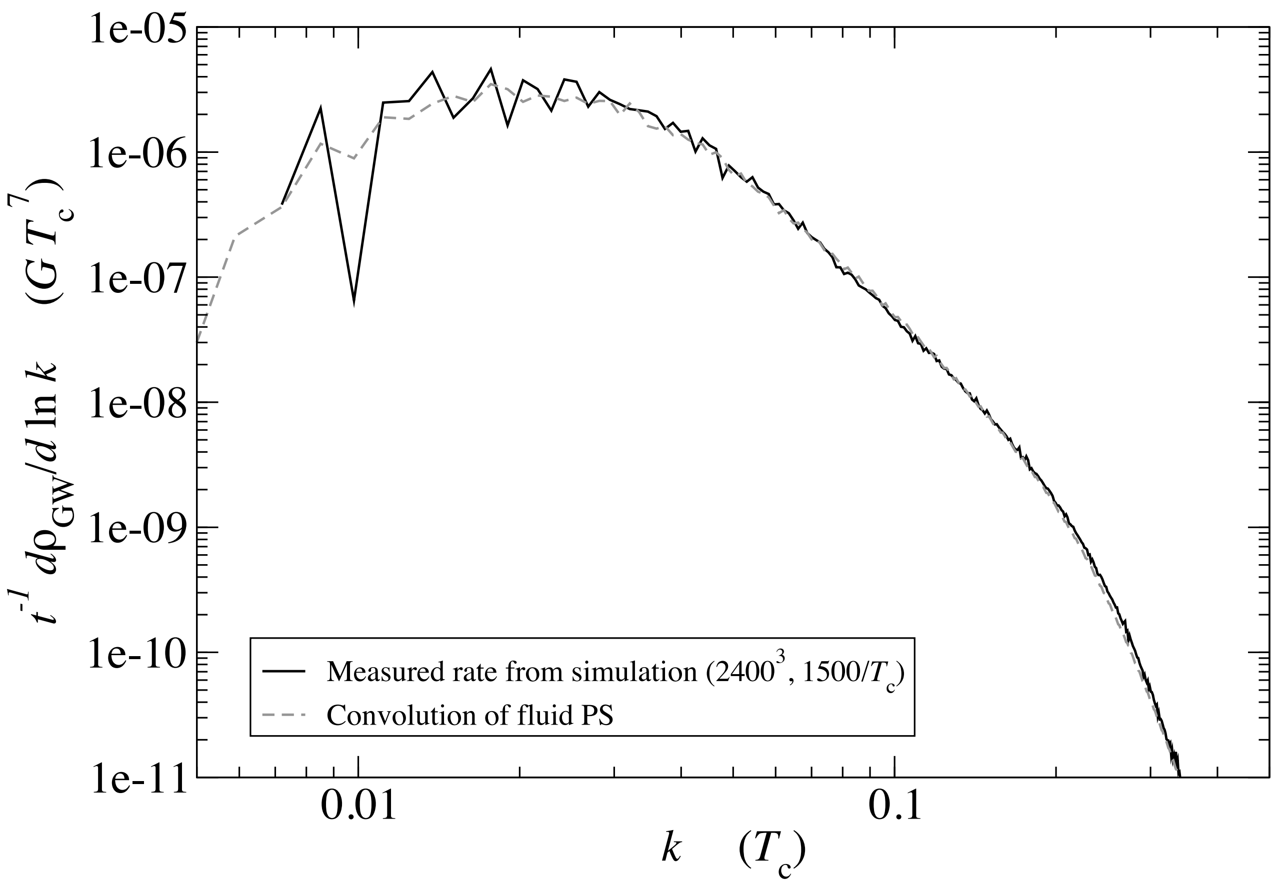
This length scale is what sets the peak of the fluid power spectrum.

extra slide

Going from the profile to fluid power to GW power

Going from a fluid power spectrum to the GW power spectrum is easy:

Hindmarsh; Caprini, Durrer, Servant



where the dashed curve is obtained by performing a numerical convolution of the fluid power spectrum.

extra slide

Lifetime of sound waves and increase in GW power

- Does the acoustic source matter?
  - Sound is damped by (bulk and) shear viscosity
    Arnold, Dogan and Moore; Arnold, Moore and Yaffe

$$\left(\frac{4}{3}\eta_{\rm s} + \zeta\right)\nabla^2 V^i_\parallel + \ldots \Rightarrow \tau_\eta(R) \sim \frac{R^2\epsilon}{\eta_{\rm s}}$$

  - Compared to $\tau_{H_*} \sim H_*^{-1}$, on length scales

$$R^2 \gg \frac{1}{H_*}\frac{\eta_{\rm s}}{\epsilon} \sim 10^{-11}\frac{v_{\rm w}}{H_*}\left(\frac{T_{\rm c}}{100\,\mathrm{GeV}}\right)$$

    the Hubble damping is faster than shear viscosity damping.

- Does the acoustic source enhance GWs?
  - Yes, we have

$$\Omega_{\rm GW} \approx \left(\frac{\kappa\alpha}{\alpha+1}\right)^2 (H_*\tau_{H_*})(H_*\xi_{\rm f}) \Rightarrow \frac{\Omega_{\rm GW}}{\Omega_{GW}^{\text{envelope}}} \gtrsim 60\frac{\beta}{H_*}.$$

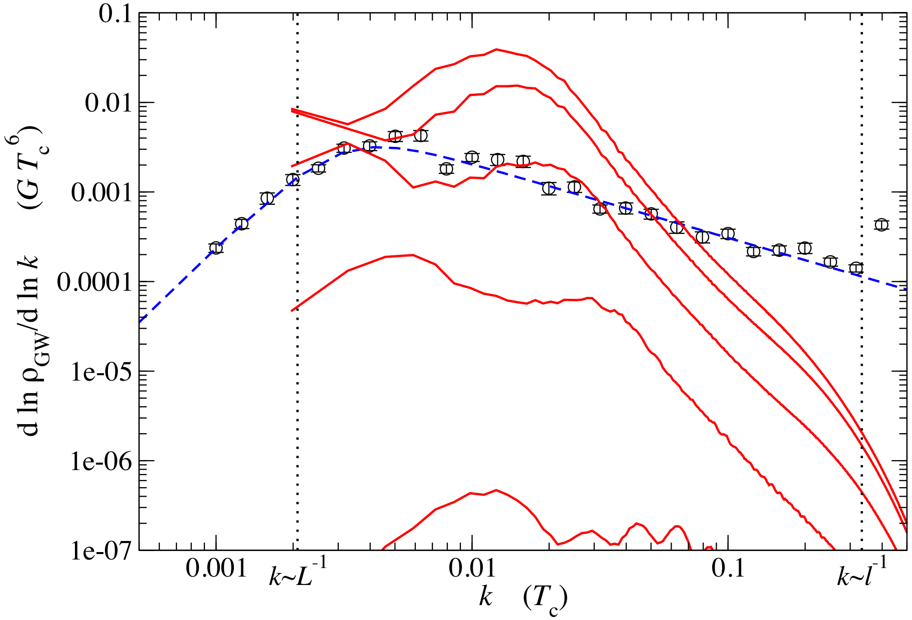
extra slide

Envelope approximation extra slides

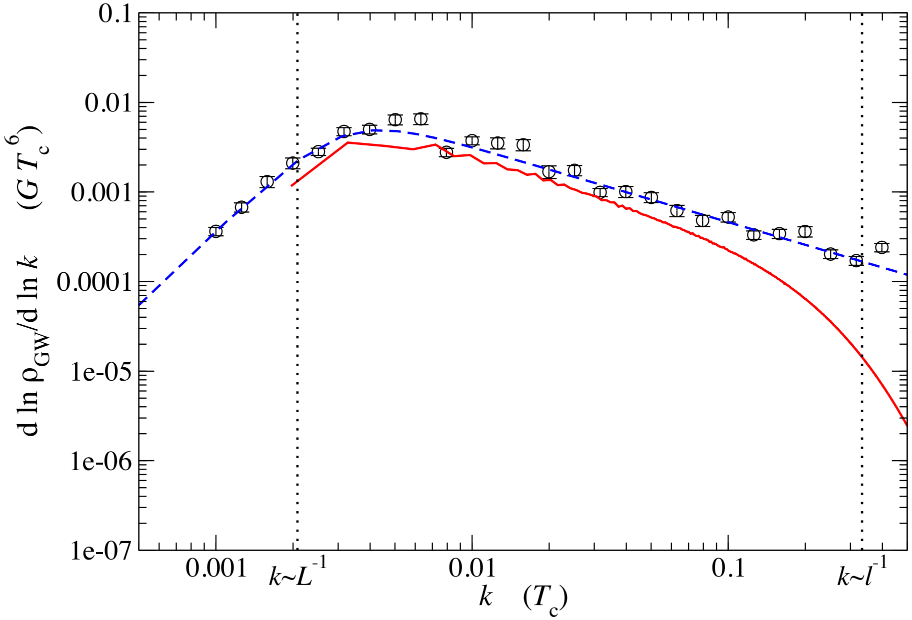
So does the envelope approximation really work?

- Compare field+fluid simulation with envelope approximation
- Nucleate 125 bubbles in same locations

Fluid source



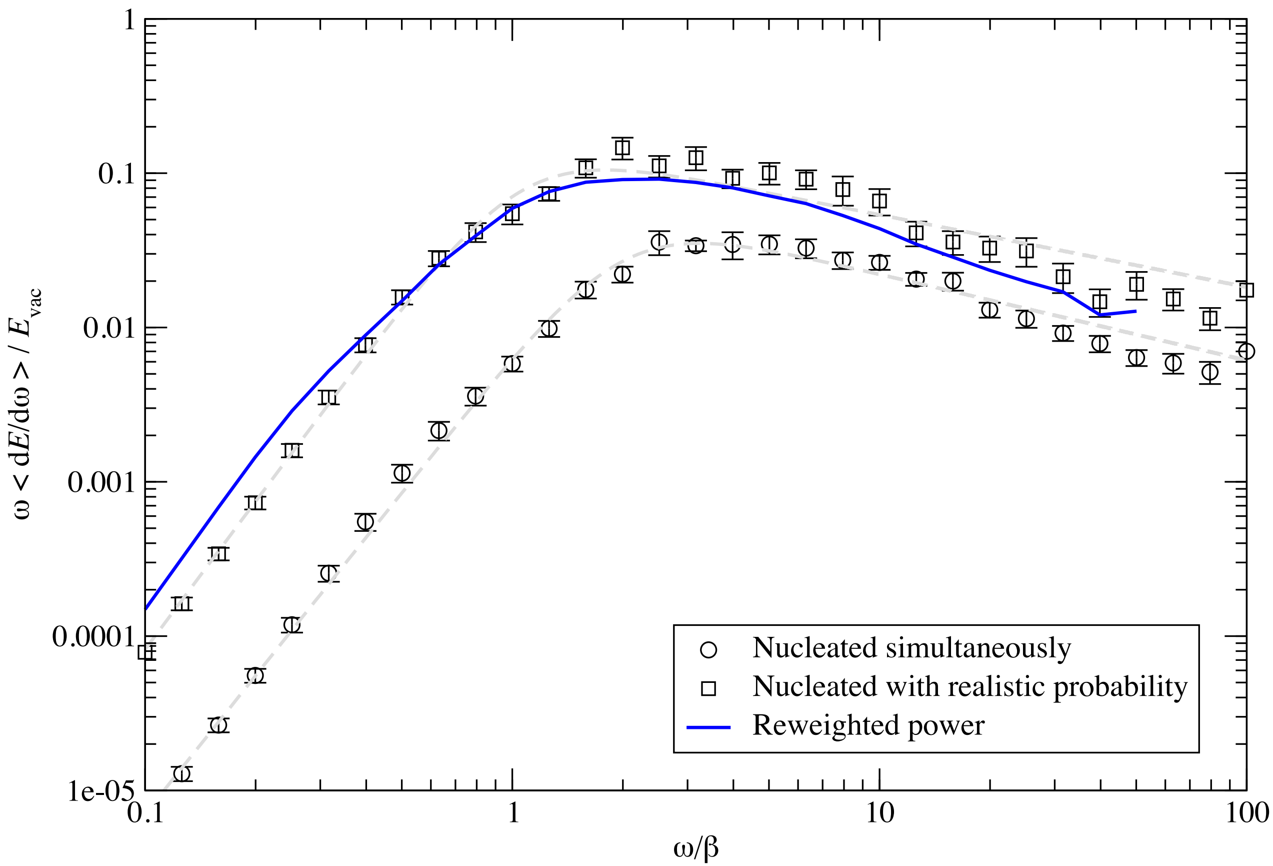
Field source



- Power laws for fluid source totally different
- Field source OK (overestimated), but will be subdominant anyway

extra slide

Envelope approximation power laws do not depend on nucleation



- Re-implemented the method of Huber and Konstandin
- Bubbles nucleated at the same time have same power laws as bubbles nucleated 'properly'
- Can re-weight from equal time nucleation case to unequal time

extra slide