Gravitational waves from phase transitions

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Lecture topics

1. Thermodynamics and hydrodynamics in the early Universe
2. Dynamics of first order phase transitions
3. Gravitational waves from 1st order phase transitions

Assumed knowledge

- A first course in statistical physics, including Bose-Einstein and Fermi-Dirac distributions
- A first course in General Relativity (including gravitational waves)
- Elementary knowledge of cosmology (Friedmann equation and simple solutions)
- Some field theory (mainly for the plain wave decomposition of fields)

Useful for this brief course:

- Willingness to fill in the gaps in the algebra yourself (exercises)
- Patience with my mistakes

Background reading

Based on selected parts of

- *Phase transitions in the early Universe*, MH, M. Lüben, J. Lumma, M. Pauly [arXiv:2008.09136]

Statistical physics

- *Statistical Mechanics*, K Huang (Wiley, 1987)

Thermal quantum field theory

- *Basics of Thermal Field Theory*, M. Laine and A. Vuorinen (Springer, 2016) [arXiv:1701.01554]

Relativistic hydrodynamics

- *Relativistic Hydrodynamics*, L. Rezzolla and O. Zanotti (OUP, 2013)

Conventions

- Natural Units: $\hbar = 1$, $c = 1$, $k_B = 1$
- Natural Unit converter:

Quantity	Nat. U.	S.I. Conversion	
Energy:	GeV	1.6022×10^{-10}	Joule
Temperature:	GeV	1.1605×10^{13}	K
Mass:	GeV	1.7827×10^{-27}	kg
Length:	GeV^{-1}	1.9733×10^{-16}	m
Time:	GeV^{-1}	6.5822×10^{-25}	s

- Planck Mass (Energy): $M_P = \sqrt{\hbar c^5 / G} = 1.2211 \times 10^{19}$ GeV
- Reduced Planck Mass: $m_P = \sqrt{\hbar c^5 / 8\pi G} = 2.436 \times 10^{18}$ GeV
- $đp = \frac{dp}{2\pi}$
- $\delta(p) = 2\pi\delta(p)$
- Metric $-+++$