Introduction into Session “Analogue Gravity”

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Bill Unruh’s Idea

Sound waves in irrotational flow \( \delta \mathbf{v} = \nabla \phi \)

\[
\left( \frac{\partial}{\partial t} + \nabla \cdot \mathbf{v}_0 \right) \frac{\rho_0}{c^2_s} \left( \frac{\partial}{\partial t} + \mathbf{v}_0 \cdot \nabla \right) \phi = \nabla \cdot (\rho_0 \nabla \phi)
\]

Scalar field \( \phi \) in curved space-time

\[
\Box_{\text{eff}} \phi = \frac{1}{\sqrt{-g_{\text{eff}}}} \partial_\mu \left( \sqrt{-g_{\text{eff}}} g^{\mu\nu}_{\text{eff}} \partial_\nu \phi \right) = 0
\]

Painlevé-Gullstrand-Lemaître metric

\[
g^{\mu\nu}_{\text{eff}} = \frac{1}{\rho_0 c_s} \begin{pmatrix}
1 & \mathbf{v}_0 \\
\mathbf{v}_0 & \mathbf{v}_0 \otimes \mathbf{v}_0 - c_s^2 \mathbf{1}
\end{pmatrix}
\]

Phonons (quantised) \(\leftrightarrow\) Quantum fields

Fluid flow (classical) \(\leftrightarrow\) Gravitational field

Euler equation \(\neq\) Einstein equations

Generalizations

General linearized low-energy effective action for scalar Goldstone-mode quasi-particles (e.g., phonons) in arbitrary system (e.g., condensed matter)

\[ \mathcal{L}_{\text{eff}} = \frac{1}{2} (\partial_\mu \phi)(\partial_\nu \phi) G^{\mu\nu}(x) + \mathcal{O}(\phi^3) + \mathcal{O}(\partial^3) \]

Analogy to quantum fields in curved space-times

\[ G^{\mu\nu} \rightarrow g^{\mu\nu}_{\text{eff}} \sqrt{-g_{\text{eff}}} \rightarrow \text{Universal properties} \]

E.g., Ripplons, → talk by Rousseaux
Classical phonons, → talk by Das
Phonons in BEC, → talks by Uhlmann, Ishihara
Cold atoms, ions, → talks by Dumin, Horstmann
Magnons etc.

→ Analogue gravity concept

So far, spin-zero (scalar) fields...
Higher Spins?

Non-scalar fields with additional symmetries:

- spin-1/2: slow light (but: bosons)
- spin-1: Gordon metric in dielectrics
  \[ g_{\text{Gordon}}^{\mu\nu} = g_{\text{Minkowski}}^{\mu\nu} + (\varepsilon - 1) u^\mu u^\nu \]
  \[ \rightarrow \text{talks by Leonhardt, Novello, Marino} \]
- spin-2: dislocations in crystals (torsion?)
  \[ \rightarrow \text{talks by Kleinert, Katanaev} \]

\[ \rightarrow \text{Universal properties} \rightarrow \text{Analogue gravity:} \]

Black holes (Hawking radiation), White holes, Expanding universe (inflation), etc.
So What?

• better understanding of condensed matter
• experimental realizations: classical → quantum
  Hawking radiation in the lab?
• toy model for quantum gravity:
  + trans-Planckian problem
    (black holes and inflation, robustness?)
  + violations of Lorentz invariance at large $k$
  + quantum back-reaction problem
• bigger picture: Which microscopic models yield
  GR at macroscopic scales?
  → talk by Consoli
• new insights . . .

Enjoy this session!