Alberto Nicolis - Columbia U.

The quantum mechanics of perfect fluids

w/ Endlich, Wang (Columbia)
Rattazzi, Pastras (EPFL)

Or:

Why for $T \rightarrow 0$,
ordinary fluids freeze
or become super

The quantum mechanics of perfect fluids

Warnings

- in progress (conclusions may evolve)
- no experts in cond-mat (trivial/trivially wrong statements?)

“Ordinary” fluid?

Dof: mapping internal $\longleftrightarrow$ target spaces

$$\phi^I(\vec{x}, t) \qquad I = 1, 2, 3$$

Symmetries: Poincaré + internal

$$\phi^I \to \phi^I + a^I$$

$$\phi^I \to SO(3)\, \phi^I$$

$$\phi^I \to \xi^I(\phi) \qquad \det \frac{\partial \xi^I}{\partial \phi^J} = 1$$

Action: $S = \int d^4x\, F(B)$ $B = \det \partial_\mu \phi^I \partial^\mu \phi^J$

Correct classical dynamics ($T_{\mu\nu}$ + eom)

with

$$
\begin{aligned}
\rho &= -F \\
p &= F - 2F' B \\
u^\mu &= \frac{1}{6\sqrt{B}}\, \epsilon\epsilon\, \partial\phi\partial\phi\partial\phi
\end{aligned}
$$

(w/ Dubovsky, Gregoire, Rattazzi '06)

ground state (at given p): $\phi^I = x^I$

Goldstones: $\phi^I = x^I + \pi^I$

$$\mathcal{L} \to (\dot{\pi}^I)^2 - c_s^2 (\partial_I \pi^I)^2 + \text{interactions}$$

longitudinal = sound
transverse = vortices

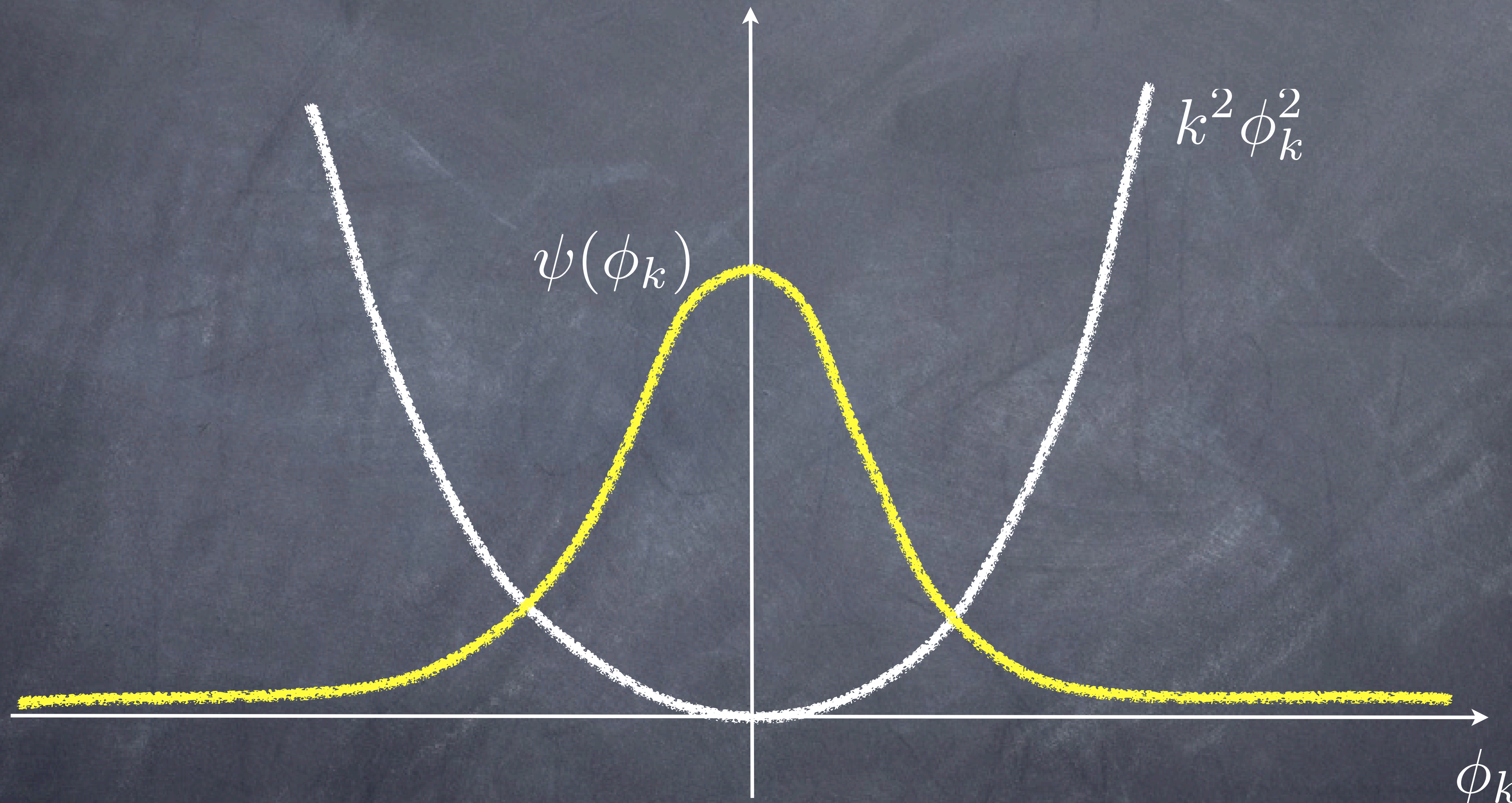
Derivatively coupled EFT ⇨ UV strong coupling

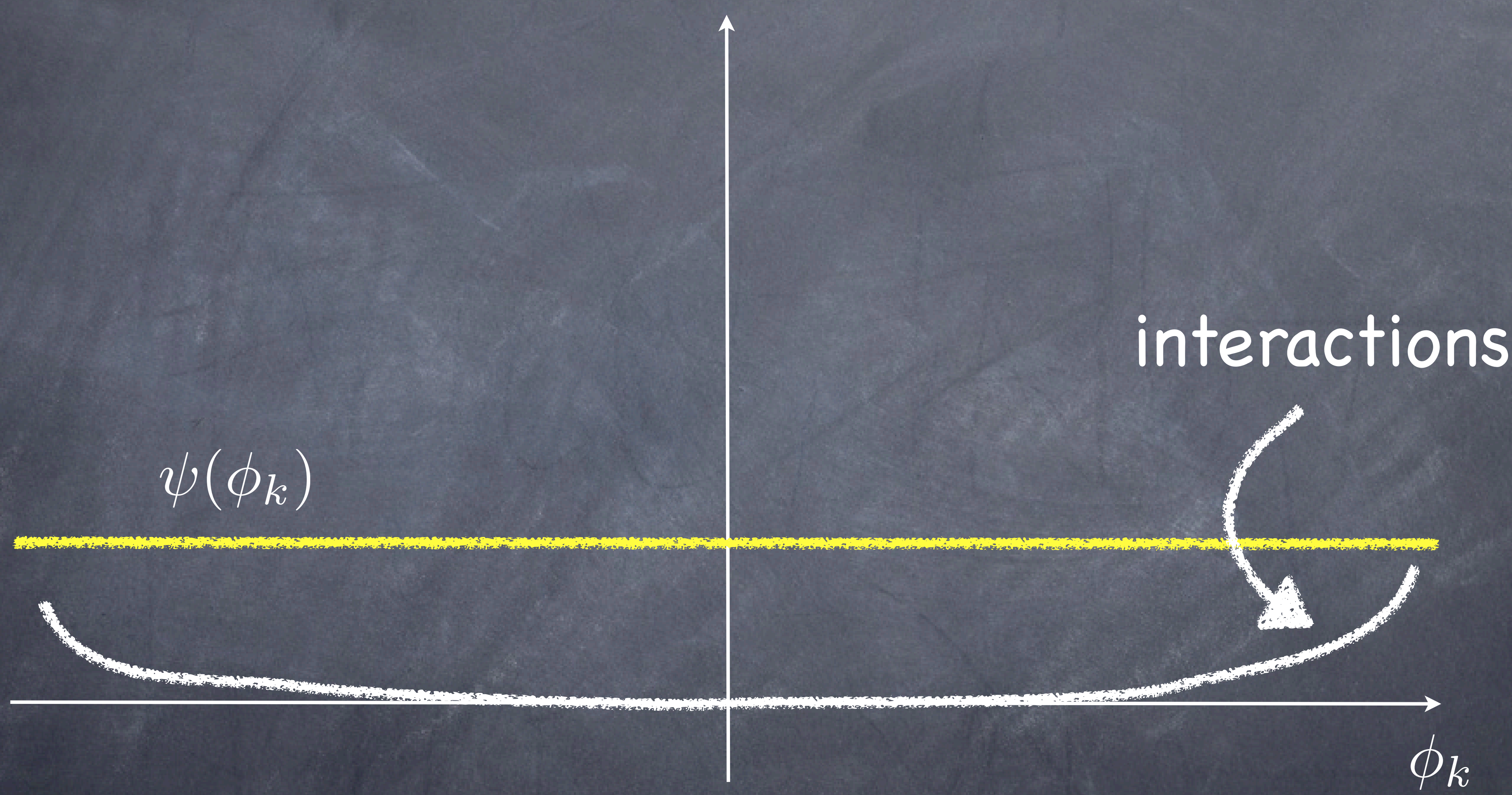
For longitudinal phonons

$$\mathcal{M} \sim \frac{k^4}{\rho_0 \, c_s}$$

For vortices?

absence of gradient energy ⇒ ? (very) premature strong-coupling


$k^2\phi_k^2$
$\psi(\phi_k)$
ϕ_k


interactions
$\psi(\phi_k)$
ϕ_k

How to check this?

No gradient energy =
no waves =
no asymptotic states =
no S-matrix

Deform the theory

$$\mathcal{L} \to \mathcal{L} + c_T^2 \, \mathrm{tr}\{\partial_\mu \phi^I \partial^\mu \phi^J\}$$

Simplest processes OK for $c_T \to 0$

First problematic process: $TT \to TT$

$$\sigma \sim \frac{1}{c_T^2} \times \frac{k^6}{\rho_0^2}$$

$$\sim \frac{1}{c_T^8} \times \frac{E^6}{\rho_0^2}$$

Possible interpretations

- A perfect fluid is strongly coupled at arbitrarily low energy/momentum, or
- our deformation does not have a continuous limit:

  asymptotic states change (... big deal)

  the vacuum may change: Fock to ?
  (Goldstones?)
- Either implies O(1) deviations from classical behavior

Why T = 0 ?

Or: what saves the day at T > 0 ?

Our guess: dissipation

Conclusions

?