Lifshitz holography for undoped Weyl semimetals

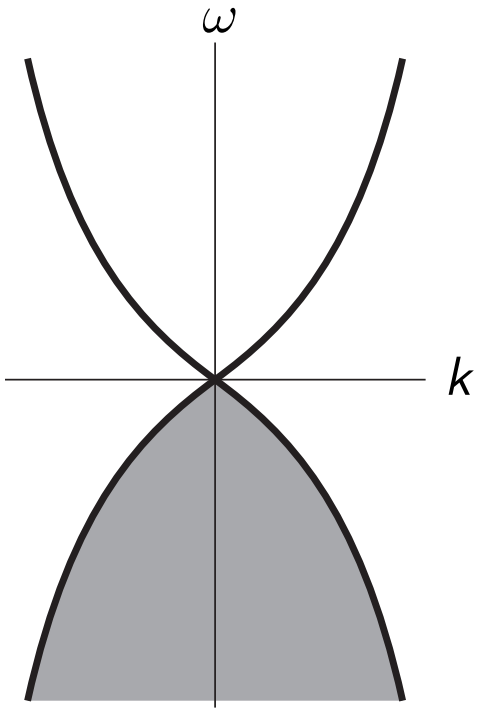
Umut Gürsoy, Vivian Jacobs, Erik Plauschinn, Henk Stoof, S.V.

Based on arXiv: 1209.2593 and 1112.5074.

October 16, 2012

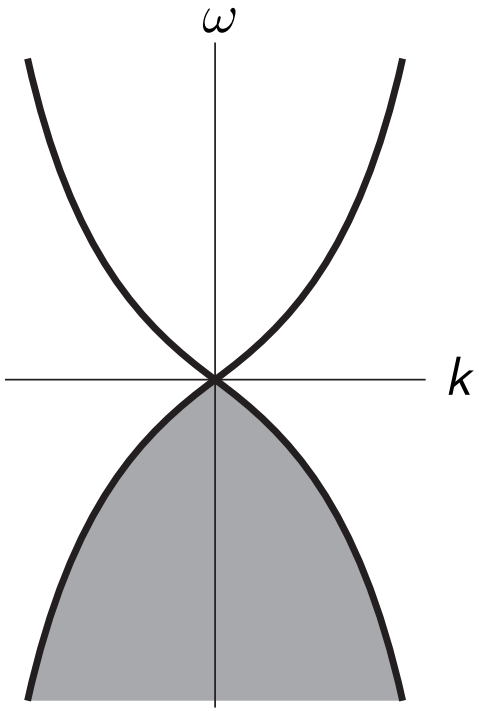
Semimetals

- Characterization by band structure.
- Semimetal: gapless semiconductor.
- Doping: μ.

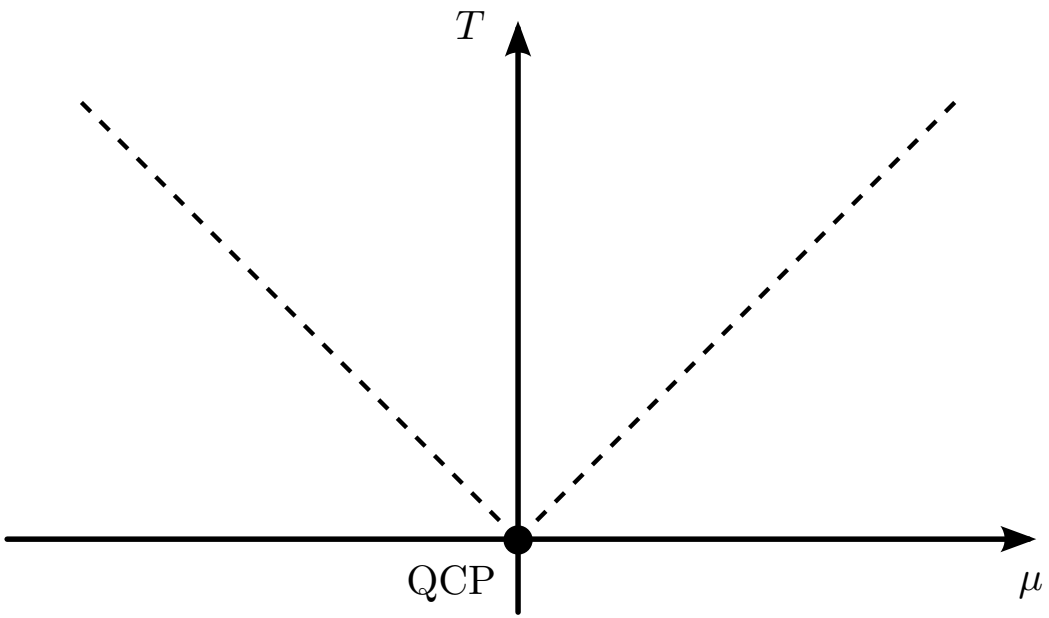


Weyl semimetal

- Chiral fermions (3+1 dim) with dispersion: $\sim \vec{\sigma} \cdot \vec{k}$.
- Theoretical treatment: ideal or weakly interacting case.
- Interesting topological transport phenomena.



Typical phase diagram



- Quantum critical point, scale invariance.
- Dynamical scaling exponent z: $k \to \ell k$ and $\omega \to \ell^z \omega$
- Strongly interacting: holographic description.

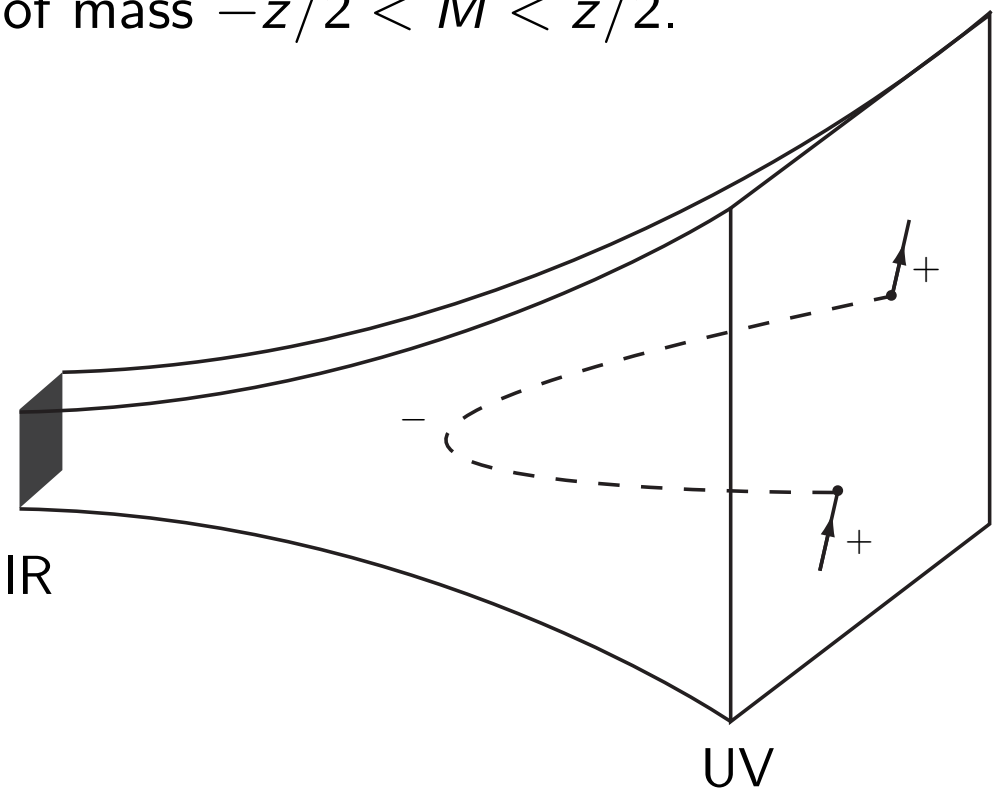
Outline

- AdS/CMT as a tool: phenomenological approach.
- Requires experimentally accessible observables.
- Calculate single-particle Green's function.
- Investigate single-particle spectra ($z = 2$).
- Quantum phase transition.

Some References

- Lifshitz holography and black holes:
  Kachru, Liu, Muligan; Taylor (2008); ...
  Hartnoll, Polchinski, Silverstein and Tong (2010);...
  Nordita (Keranen and Thorlacius (2012), Zingg,...)
- AdS/Lifshitz fermions:
  MIT, Leiden (2009); Alishahiha et al. (2012), ...
- Semi-holography, Arpes sum-rules:
  Faulkner, Polchinski (2011);
  Gursoy, Plauschinn, Stoof, S.V. (2012)
- Weyl semimetals:
  Burkov and Balents (2011);
  Wan, Turner, Vishwanath and Savrasov (2011)

Lifshitz background in 5D with Dirac fermions $\Psi = (\Psi_+, \Psi_-)$ of mass $-z/2 < M < z/2$.



Elementary fermion on boundary:

$$S_\delta = -\int d^4x\sqrt{-h}\left(\Psi_+^\dagger \not{D}_z \Psi_+ + \Psi_+^\dagger \Psi_-\right)$$

Solve Dirac equation in gravitational background: $\Psi_- = \Sigma\Psi_+$.

Σ couples to operators with $\Delta_{\mathcal{O}}(M)$. Interactions of Ψ_+ with CFT.

$$G_R(\vec{k},\omega) = -\frac{1}{\omega - \frac{1}{\lambda}\vec{\sigma}\cdot\vec{k}|k|^{z-1} - \Sigma(\vec{k},\omega)}$$

Single-particle spectra

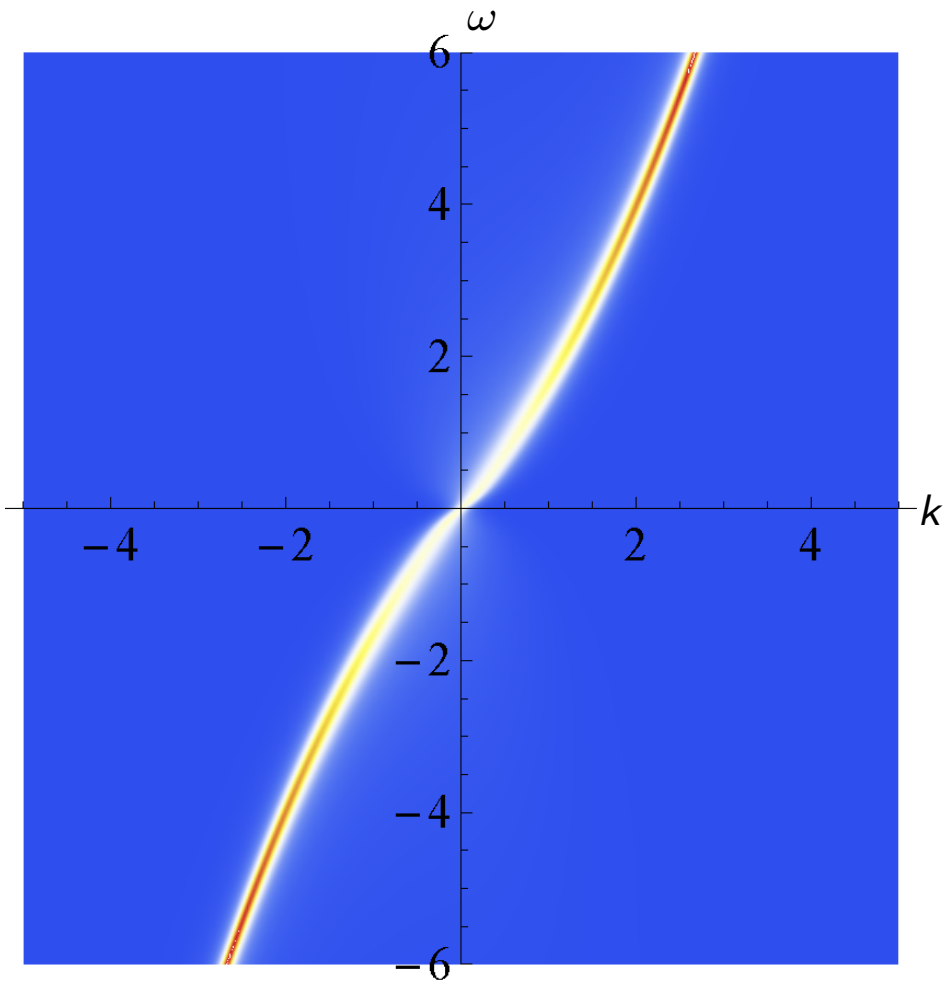
$$G_R(\vec{k},\omega) = -\frac{1}{\omega - \frac{1}{\lambda}\vec{\sigma}\cdot\vec{k}|k|^{z-1} - \Sigma(\vec{k},\omega)}$$

- Spectral-weight function:

$$\rho(\vec{k},\omega) = \frac{1}{\pi}\,\mathrm{Im}\,G_R(\vec{k},\omega) = -\frac{\mathrm{Im}\,\Sigma}{(\,\mathrm{Re}\,G_R^{-1})^2 + \,\mathrm{Im}\,\Sigma^2}$$

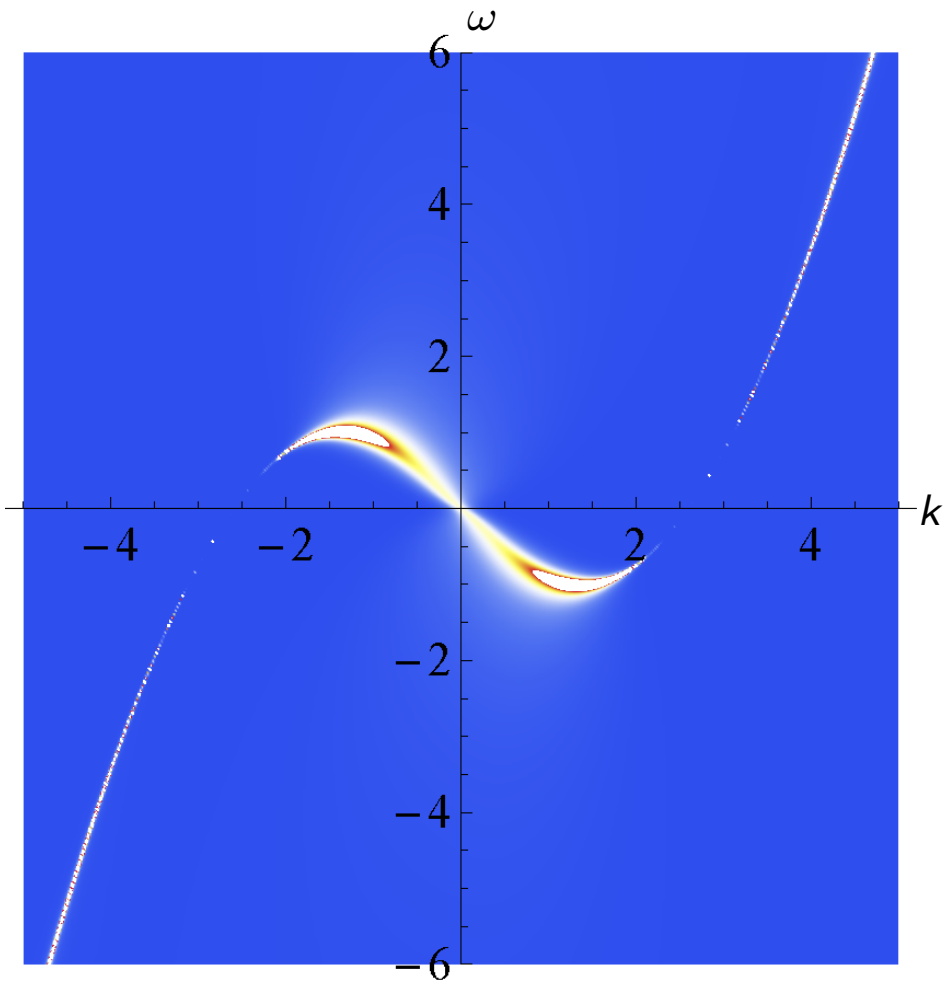
- Quasiparticles: $\mathrm{Im}\,\Sigma$ related to lifetime.
- Experimentally accessible (e.g. with ARPES).

$\lambda > 0$



$$G_R(\vec{k},\omega) = -\frac{1}{\omega - \frac{1}{\lambda}\vec{\sigma}\cdot\vec{k}|k| - \Sigma(\vec{k},\omega)}$$

$\lambda < 0$



$$G_R(\vec{k},\omega) = -\frac{1}{\omega - \frac{1}{\lambda}\vec{\sigma}\cdot\vec{k}|k| - \Sigma(\vec{k},\omega)}$$

$\Sigma \sim k^{2M}$

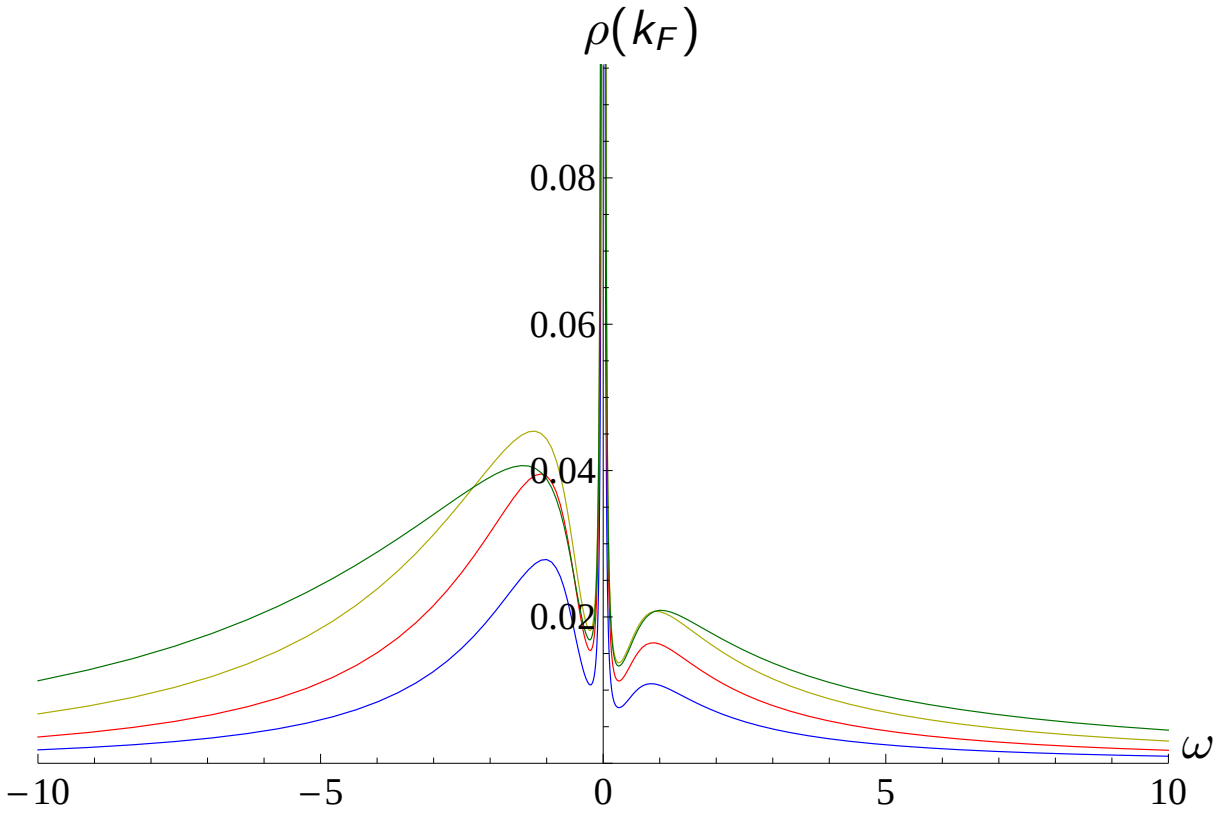
Kinetic $\sim k^2$

Fermi surfaces:

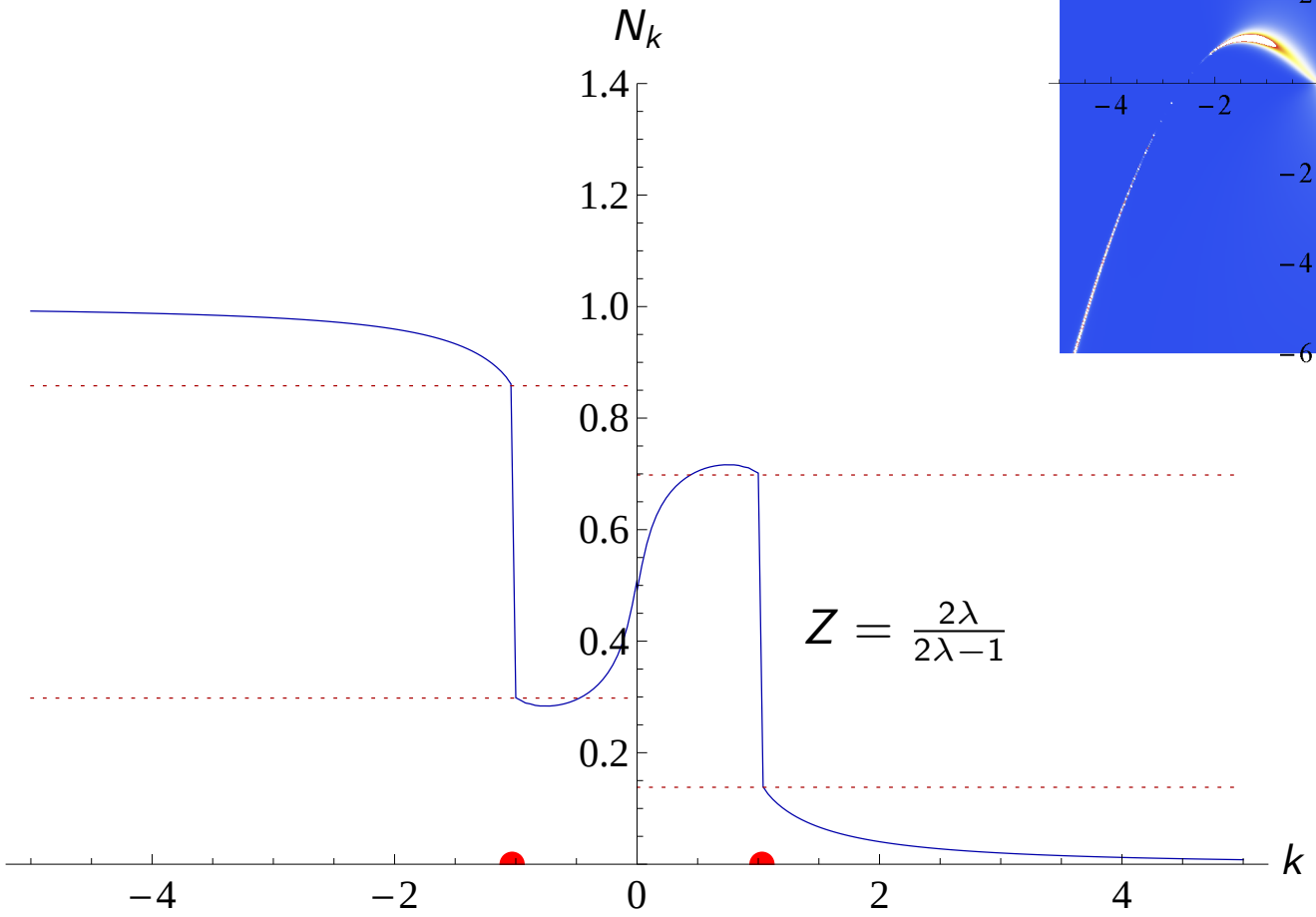
$k_F = |\lambda|^{\frac{1}{2-2M}}$

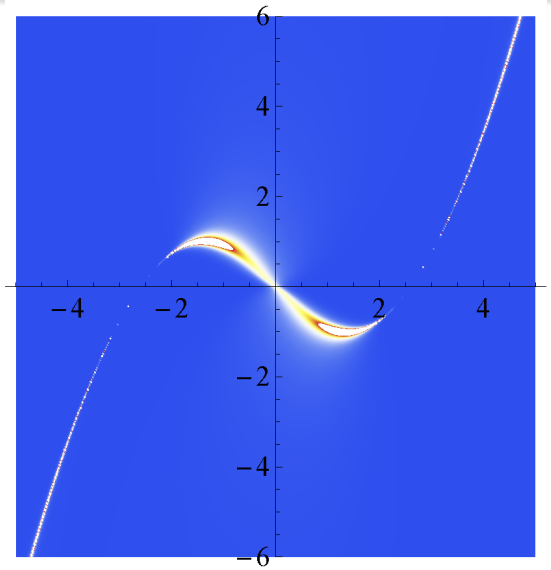
Fermi surface

- Long-living quasiparticles: sharp peak in ρ.
- Decay rate $\Gamma(\omega) \sim \mathrm{Im}\,\Sigma(k_F, \omega)$ vanishes (as ω^2).

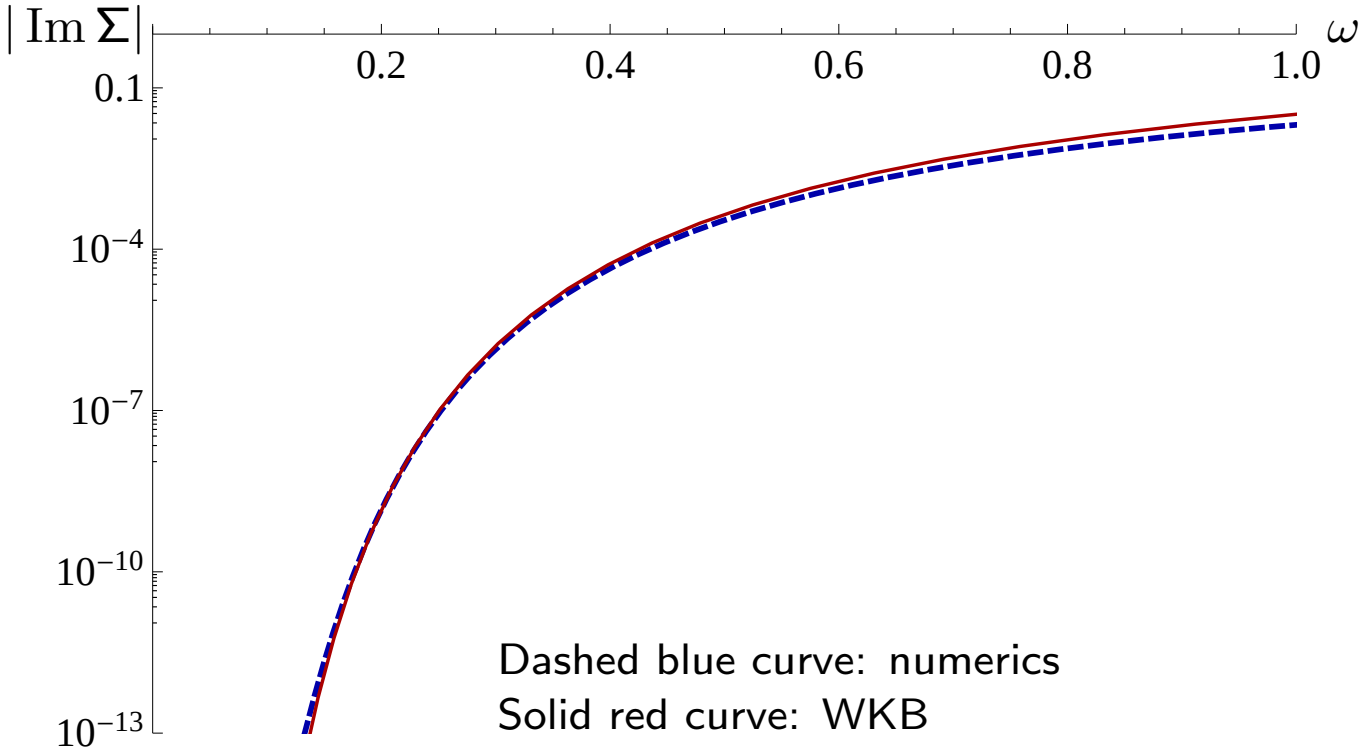


- $N_k = \int_{-\infty}^{0} d\omega \rho(k,\omega)$.
- $Z << 1$: strong interactions.

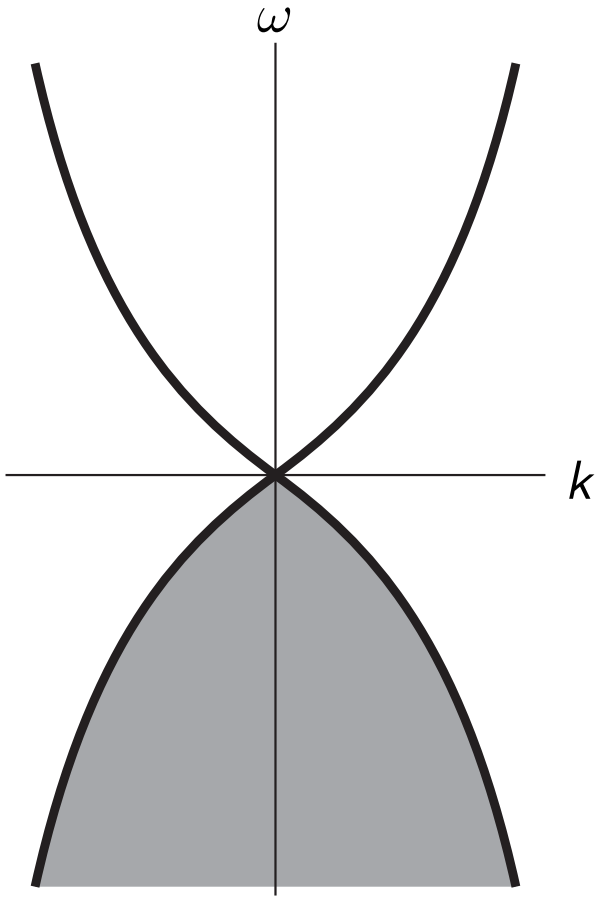




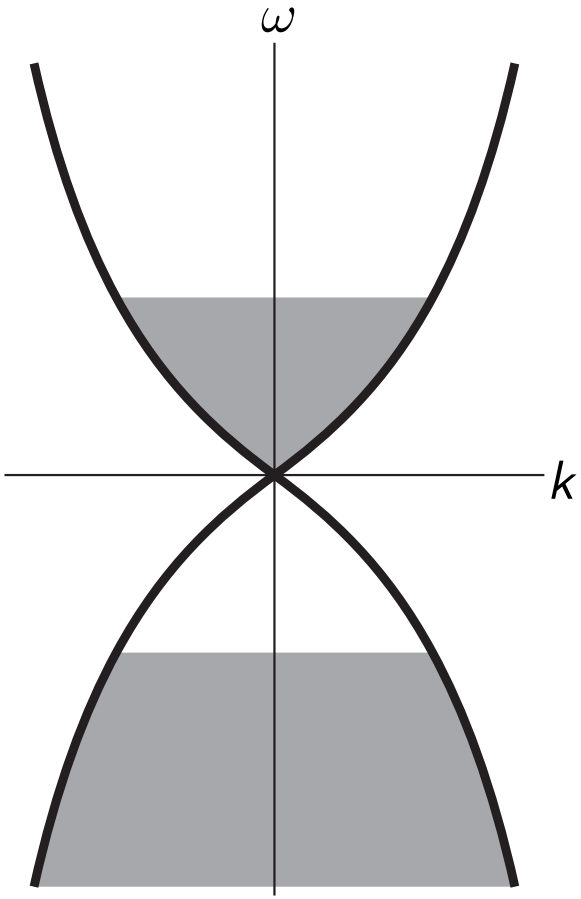
- $\mathrm{Im}\,\Sigma(k_F, \omega)$ vanishes exponentially for $\omega \to 0$.
- Analytic WKB calculation confirms this.
- General feature of holographic Fermi liquids.



Ground state occupation

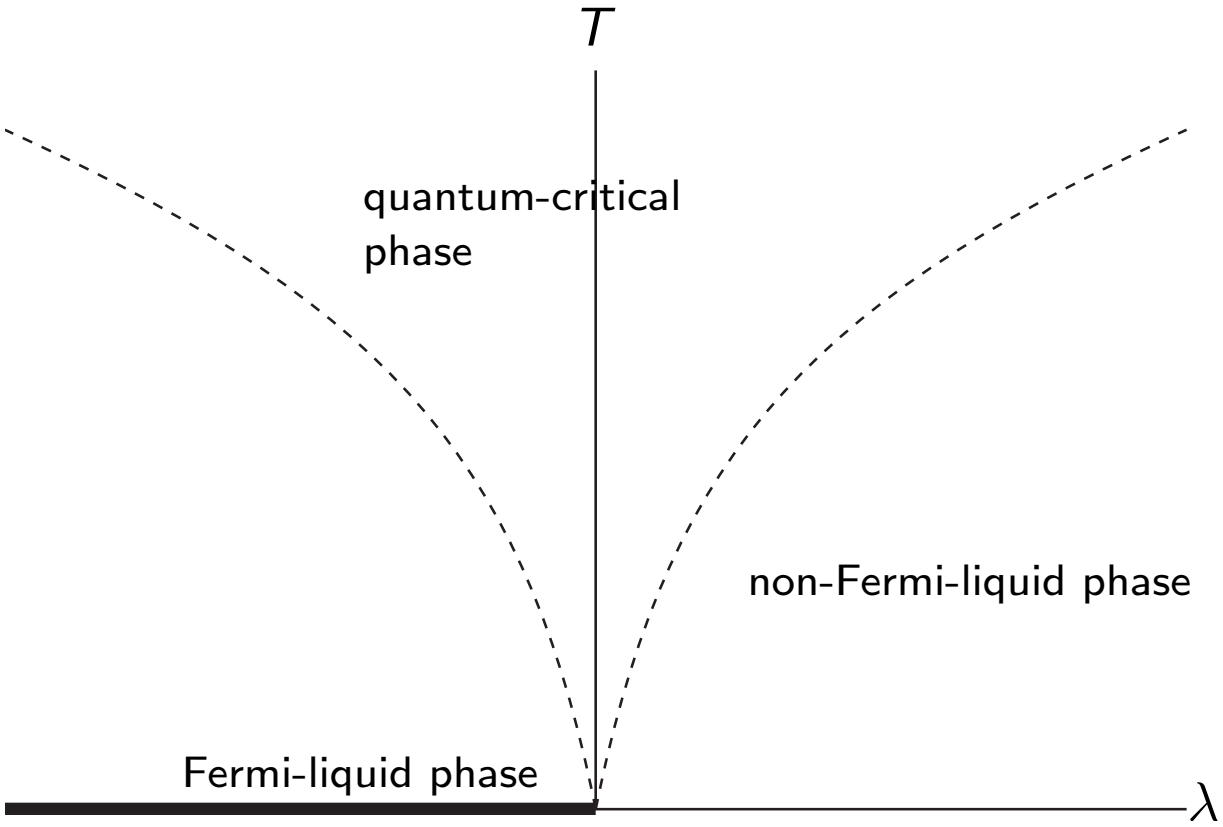


$\lambda > 0$



$\lambda < 0$

Phase diagram



Summary

- Prescription for single-particle Green's function from holography.
- Phenomenological model for class of Weyl semimetals at strong coupling.
- Fermi-liquid and non-Fermi-liquid phases.

Outlook

- How to create gaps, shifts in band structure, non-chiral systems,...
- Investigate topological transport properties.
- Non-zero doping: add chemical potential.
- Feedback from experiments.