Relativity and dissipation in hydrodynamics and beyond

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Introduction

Schwinger-Keldysh field theories are interesting, see e.g.

talks at *Contours 2026*, Cambridge

Schwinger-Keldysh hydrodynamic EFTs are interesting, see e.g.

talks at *Contours 2026*, Cambridge

Riccardo Penco
Hong Liu
Luca Delacretaz
Akash Jain
Riccardo Rattazzi
Natalia Pinzani-Fokeeva
Inna Ivanova
Paolo Arcangeli
Atsuhisa Ota
Mike Blake

Schwinger-Keldysh hydrodynamic EFTs survive $\hbar \to 0$

Effective action

Two types of fields: “classical” (φ_r) and “stochastic” (φ_a).

$$S = \varphi_a F(\varphi_r) + \varphi_a^2 G_{\text{class.}}(\varphi_r) + \varphi_a^2 G_{\text{non-class.}}(\varphi_r) + \varphi_a^3 H(\varphi_r) + \dots$$

classical

bootstrapped from classical by KMS

invisible to classical EoM, but contribute to classical (retarded) response functions through loops at small ω and k

classical transport coef-s:

- visible in classical EoM,
- give rise to leading power-law correlations at long distances,
- match to UV through retarded functions (Kubo formulas)

stochastic transport coef-s:

- derivative-suppressed in 3+1,
- give rise to subleading power-law correlations at long distances,
- match to UV through non-retarded functions

Jain, Kovtun, arXiv:2009.01356

Effective action

Two types of fields: "classical" (φ_r) and "stochastic" (φ_a).

$$S = \varphi_a F(\varphi_r) + \varphi_a^2 G_{\text{class.}}(\varphi_r) + \varphi_a^2 G_{\text{non-class.}}(\varphi_r) + \varphi_a^3 H(\varphi_r) + \dots$$

classical

bootstrapped from classical by KMS

invisible to classical EoM, but contribute to classical (retarded) response functions through loops at sn

Ignore these for today

classical transport coef-s:

- visible in classical EoM
- aw
- es,
- match to UV through retarded functions (Kubo formulas)

This is classical MSR

stochastic transport coef-s:

- derivative-suppressed in 3+1,
- give rise to subleading power-law correlations at long distances,
- match to UV through non-retarded functions

Martin, Siggia, Rose, Phys. Rev. A 8, 423 (1973)

Effective action

Two types of fields: "classical" (φ_r) and "stochastic" (φ_a).

$$S = \varphi_a F(\varphi_r) + \varphi_a^2 G_{\text{class.}}(\varphi_r)$$

This talk:

$F(\varphi_r) = 0$ are classical eq-s of motion for relativistic hydro

$G_{\text{class}}(\varphi_r)$ contain viscosities, conductivities

Time evolution

SK path integral in "microscopic" QFT tells you about the evolution of an initial state.

SK path integral in "hydrodynamic" EFT should tell you about the evolution of an initial coarse-grained state.

Does it?

Classical equations of motion for SK EFT:

$F(\varphi_r) = 0 \leftarrow$ viscous hydro eq-s, by KMS of EFT

$\varphi_a = 0 \leftarrow$ no noise, deterministic equations

So, need viscous relativistic hydro eq-s

Part I: Relativistic hydrodynamics

Relativistic "perfect fluid" equations

Equilibrium: $$e^{-\beta H}/Z \;\rightarrow\; e^{\beta_\mu P^\mu}/Z(\beta^2)$$

$$\langle T^{\mu\nu}\rangle = A(\beta^2)\beta^\mu\beta^\nu + B(\beta^2)g^{\mu\nu}$$

$$\langle T^{\mu\nu}\rangle = \Big(\epsilon(T)+p(T)\Big)u^\mu u^\nu + p(T)g^{\mu\nu}$$

$$u^\mu \equiv \beta^\mu/\sqrt{-\beta^2}, \qquad T \equiv 1/\sqrt{-\beta^2}$$

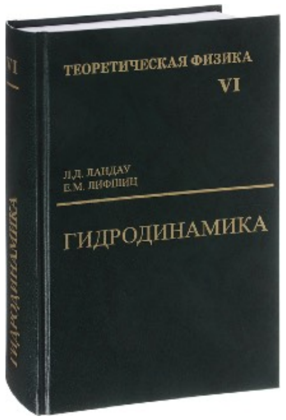
Non-equilibrium: $$u^\mu \rightarrow u^\mu(x), \qquad T \rightarrow T(x)$$

$$\nabla_\mu T^{\mu\nu} = 0$$

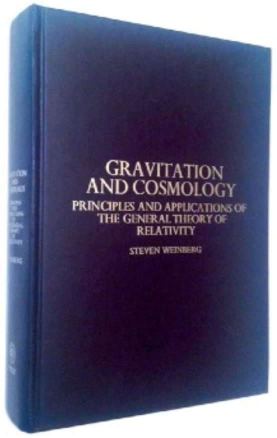
PDEs to find $u^\mu(x), T(x)$

Relativistic *dissipative* fluid equations

Open “Fluid Mechanics” by Landau and Lifshitz:
some fluid-dynamical equations



Open “Gravitation and Cosmology” by Weinberg*:
some fluid-dynamical equations



LL’s and Weinberg’s equations look very different!

*Formulation of hydrodynamics due to Eckart (1940)

So what?

Shut up and calculate. As a simple example, solve for linear perturbations of the thermal equilibrium state.

Both Landau-Lifshitz' and Eckart's equations predict that:

a) thermal equilibrium does not exist

b) things propagate faster than light

Hiscock, Lindblom Phys. Rev. D 31, 725 (1985)
Hiscock, Lindblom Phys. Rev. D 35, 3723 (1987)

What's the problem?

Plane waves $e^{-i\omega t+i\mathbf{k}\cdot\mathbf{x}}$, solve fluid-dynamical eq-s: $\omega=\omega(\mathbf{k})$

Gapless modes: $\omega(\mathbf{k}\to 0)=0$, b/c of conserved charges. These give normal fluid dynamics, e.g. sound $\omega(\mathbf{k}) = \pm c_s|\mathbf{k}| - i\gamma\mathbf{k}^2 + \ldots.$

Hydrodynamic equations also predict gapped modes $\omega(\mathbf{k}\to 0)\neq 0$, moreover with $\mathrm{Im}(\omega)>0$. These are unphysical modes.

$\omega(\mathbf{k}\to 0) = +ia/\eta$, $a>0$, and $\eta>0$ (dissipation)

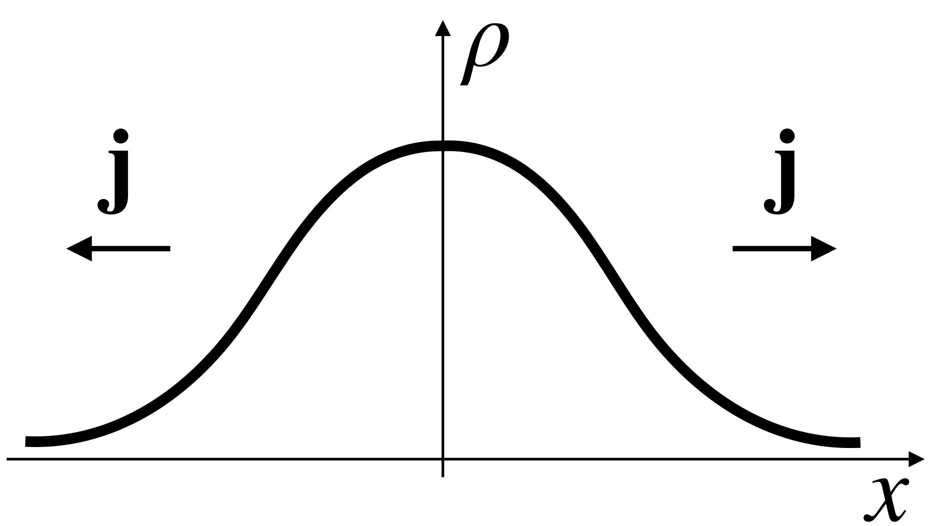
These "fake" modes are outside of the validity regime of the low-energy approximation: "UV" modes, ruin predictability.

Example: diffusion

Conservation law:

$$\partial_t \rho + \nabla \cdot \mathbf{j} = 0$$

"Classical" assumption: $\mathbf{j} = \mathbf{j}(\rho)$, e.g. Fick's law $\mathbf{j} = -D\nabla\rho$



$$\partial_t \rho - D\nabla^2 \rho = 0$$

diffusion equation

Example: diffusion

$$-i\omega + Dk^2 = 0$$

Galilean boost: $\omega \to \omega - kv, \qquad k \to k$

Lorentzian boost: $\omega \to \dfrac{\omega - kv}{\sqrt{1 - v^2/c^2}}\,, \qquad k \to \dfrac{k - \omega v/c^2}{\sqrt{1 - v^2/c^2}}$

Extra mode $\boldsymbol{\omega}(k)$ in a moving reference frame!

Small v : $\omega(k) = kv - iDk^2 + \ldots\,, \qquad \omega(k) = +i\dfrac{c^4}{Dv^2} + \ldots$

Comments

Deriving diffusion eq-n only uses rotation invariance

Can make look relativistic: $\left[u^\mu \partial_\mu - D(g^{\mu\nu} + u^\mu u^\nu)\partial_\mu \partial_\nu\right] \rho = 0$

$u^\mu = (1, \mathbf{v})/\sqrt{1-\mathbf{v}^2}$

E.g. Kostaedt, Liu, cond-mat/0010276

Same problems appear when u^μ is dynamical

E.g. Hiscock, Lindblom, Phys. Rev. D 31, 725 (1985)

(A)causality and (in)stability are related

E.g. Gavassino, arXiv:2111.05254

Analogy with classical gravity

Leading-order, perfect fluid:

$$T^{\mu\nu}_{(0)} = (\epsilon + p)u^\mu u^\nu + p g^{\mu\nu}$$

Causal, stable equilibrium, finite-time singularities

Leading-order gravity:

$$S_{(0)} = \frac{1}{16\pi G}\int \sqrt{-g}\, R$$

Causal, stable flat space, finite-time singularities

Next-order, viscous fluid:

$$T^{\mu\nu} = T^{\mu\nu}_{(0)} + O(\partial T, \partial u)$$

Unstable equilibrium, super-luminality. EoM are 2-nd order

Next-order gravity:

$$S = S_{(0)} + O(\mathrm{Riem}^2)$$

Negative energy states, super-luminality. Some EoM are 2-nd order (GB)

Textbook equations of viscous hydrodynamics have a problem. How do hydro practitioners fix it?

Fix #0: strict perturbative

- $$T^{\mu\nu} = T_0^{\mu\nu}[\beta] + \gamma T_1^{\mu\nu}[\beta] + \gamma^2 T_2^{\mu\nu}[\beta] + \ldots$$

  $O(\beta)$ $O(\partial\beta)$ $O(\partial^2\beta, (\partial\beta)^2)$

- $$\beta^\mu(x) = \beta_0^\mu(x) + \gamma\beta_1^\mu(x) + \gamma^2\beta_2^\mu(x) + \ldots$$

$\gamma =$ counting parameter

$\beta_{n+1} = O(\partial\beta_n)$

- $$T_n^{\mu\nu}[\beta] = T_n^{\mu\nu}[\beta_0] + \gamma\, T_{n,1}^{\mu\nu}[\beta_0, \beta_1] + \gamma^2\, T_{n,2}^{\mu\nu}[\beta_0, \beta_1, \beta_2] + \ldots$$

$$\begin{cases} \partial_\mu T_0^{\mu\nu}[\beta_0] = 0 \\ \partial_\mu \left(T_{0,1}^{\mu\nu}[\beta_0, \beta_1] + T_1^{\mu\nu}[\beta_0] \right) = 0 \\ \partial_\mu \left(T_{0,2}^{\mu\nu}[\beta_0, \beta_1, \beta_2] + T_{1,1}^{\mu\nu}[\beta_0, \beta_1] + T_2^{\mu\nu}[\beta_0] \right) = 0 \end{cases}$$

0-th order is singular;

∞-many cons. laws;

secular terms.

Fix #1: relax the flux

$$\begin{cases} \partial_t J^0 + \nabla\cdot\mathbf{J} = 0\,, \text{ plus } J^0 = \rho(\mu) \\ \tau\partial_t\mathbf{J} + \mathbf{J} = -\sigma\nabla\mu \end{cases}$$

$\mu = \bar{\mu} + \delta\mu$, "telegraph eq-n" for $\delta\mu$:

$$\tau\chi\partial_t^2\delta\mu + \chi\partial_t\delta\mu - \sigma\nabla^2\delta\mu = 0$$

$\chi \equiv \rho'(\mu)$

Maxwell-Cattaneo theory: "integrate in" extra d.o.f.

Need $\tau > \sigma/\chi$ for causality

History review: Joseph, Preziosi, *Heat waves*, Rev. Mod. Phys. 1989

Fix #2: thermometers, etc

$$\begin{cases} \partial_t J^0 + \nabla\cdot\mathbf{J} = 0, \text{ plus } J^0(\mu), \mathbf{J}(\mu) \\ \mathbf{J}(\mu) = -\sigma\nabla\mu + O(\partial^2) \\ J^0(\mu) = \rho(\mu) + \lambda\dot{\mu} + O(\partial^2) \end{cases}$$

$\mu = \bar{\mu} + \delta\mu$, ignore the $\dot{\mu}$ term: parabolic eq-n for $\delta\mu$

keep the $\dot{\mu}$ term: hyperbolic eq-n for $\delta\mu$

Field redefinition of μ, with $\lambda > \sigma$ for causality

Can interpret $\lambda(\mu)$ as a convention specifying your μ-meter

History review: Joseph, Preziosi, *Heat waves*, Rev. Mod. Phys. 1989

Non-linear viscous hydrodynamics

$$\nabla_\mu T^{\mu\nu} = 0, \qquad \nabla_\mu J^\mu = 0$$

$$T^{\mu\nu} = (\epsilon + p)u^\mu u^\nu + pg^{\mu\nu} + \Pi^{\mu\nu}$$

$$J^\mu = nu^\mu + \chi^\mu$$

$\Pi^{\mu\nu} = 0,\ \chi^\mu = 0$: perfect-fluid hydrodynamics - causal!

Fix #1: $\Pi^{\mu\nu}, \chi^\mu$ dynamical: MIS fix of Navier-Stokes

Müller, Z.Physik (1967), Israel, Ann.Phys. (1976); Israel, Stewart, Phys. Lett. A (1976), Ann.Phys. (1979)

Fix #2: $\Pi^{\mu\nu}, \chi^\mu = O(\partial T, \partial u, \partial \mu)$: BDNK fix of Navier-Stokes

Bemfica, Disconzi, Noronha, arXiv:1907.12695
Kovtun, arXiv:1907.08191

Non-linear viscous hydrodynamics

$$\nabla_\mu T^{\mu\nu} = 0, \qquad \nabla_\mu J^\mu = 0$$

$$T^{\mu\nu} = (\epsilon + p) u^\mu u^\nu + p g^{\mu\nu} + \Pi^{\mu\nu}$$

$$J^\mu = n u^\mu + \chi^\mu$$

$\Pi^{\mu\nu} = 0,\ \chi^\mu = 0$: perfect-fluid hydrodynamics - causal!

Fix #1: $\Pi^{\mu\nu}, \chi^\mu$ ...

Add other degrees of freedom $\Psi(x)$ besides $T(x)$, $u^\mu(x)$, $\mu(x)$

Israel, Stewart, Phys. Lett. A (1976), Ann.Phys. (1979)

Fix #2: $\Pi^{\mu\nu}, \chi^\mu$ ...

T, u^μ, μ are intrinsically ambiguous in hydrodynamics

Kovtun, arXiv:1907.08191

Analogy with classical gravity

Leading-order, perfect fluid:

$$T^{\mu\nu}_{(0)} = (\epsilon + p)u^\mu u^\nu + p g^{\mu\nu}$$

Leading-order gravity:

$$S_{(0)} = \frac{1}{16\pi G}\int \sqrt{-g}\, R$$

Viscous fluid, fix #1:

$$T^{\mu\nu} = T^{\mu\nu}_{(0)} + \Pi^{\mu\nu}$$

$$\tau\dot{\Pi} + \Pi = O(\partial T, \partial u)$$

MIS, BRSSS, DNMR: integrate in extra d.o.f.

Higher-derivative gravity, fix #1:

$$\mathrm{EOM} = \mathrm{EOM}_{(0)} + \mathrm{stuff}$$

$$\tau^2 \ddot{\mathrm{stuff}} + \tau\, \dot{\mathrm{stuff}} + \mathrm{stuff} = \mathrm{EOM}_{(n)}$$

MIS-inspired modifications of GR

Cayuso, Ortiz, Lehner arXiv:1706.07421

Corman, Lehner, East, Dideron arXiv:2405.15581

Analogy with classical gravity

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Leading-order gravity:

$$S_{(0)} = \frac{1}{16\pi G} \int \sqrt{-g}\, R$$

Viscous fluid, fix #2:

$$T^{\mu\nu} = T^{\mu\nu}_{(0)} + O(\partial T, \partial u)$$

BDNK: suitable field redef-s bring in higher-derivative terms

Higher-derivative gravity, fix #2:

$$S = S_{(0)} + \sum_{n=1}^{N} S_{(n)} + S^{\text{fix}}$$

BDNK-inspired: Suitable field redef-s give S^{fix}, well-posed eq-s

Figueras, Held, Kovacs, arXiv:2407.08775

Comments

Making eq-s of dissipative hydrodynamics causal requires adding non-hydrodynamic parameters (λ, τ, etc) to PDEs

These parameters are cutoff-scale physics in EFT

Unclear if “RG” can be done to eliminate cutoff dependence

Relativistic viscous fluids exist. Relativistic version of the Clay Institute Navier-Stokes problem does not.

Part II: Hydrodynamics in SK EFT

Let's see how "fix #1" and "fix #2" perform in the EFT:

- Lorentz-invariance of the action?

- Causality of the classical equations of motion?

- Stability of perturbations in all reference frames?

- Analyticity of 2-point retarded functions for $\mathrm{Im}(\omega) > |\mathrm{Im}(\mathrm{k})|$?

Jain, Kovtun, arXiv:2309.00511

Mullins, Hippert, Gavassino, Noronha, arXiv:2309.00512

Example: "fix #2" (BDNK)

$$J^\mu = (n(\mu) + \mathcal{N})\, u^\mu + \mathcal{J}^\mu \quad \left[\begin{array}{l} \mathcal{N} = \lambda(\mu) u^\alpha \partial_\alpha \mu \\ \\ \mathcal{J}^\mu = -\sigma(\mu) \Delta^{\mu\nu} \left(\partial_\nu \mu - F_{\nu\alpha} u^\alpha\right) \end{array}\right.$$

$\lambda > \sigma > 0$ for causality of classical hydro

$$\text{Retarded:} \quad G^R_{nn} = \frac{-(1 - i\omega\tau)\sigma k^2}{i\omega(1 - i\omega\tau) - Dk^2}, \quad \tau = \lambda/n'(\mu),\ D = \sigma/n'(\mu)$$

$$\text{Symmetric:} \quad G^S_{nn} = 2T \frac{(1 + \omega^2\tau^2)\sigma k^2 - \lambda D^2 k^4}{|\, i\omega(1 - i\omega\tau) - Dk^2\,|^2}$$

$G^S_{nn} < 0$, at large k, bad. SK path integral diverges

Example: "fix #1" (MIS)

$$J^\mu = n(\mu, \mathcal{J}^2) u^\mu + \mathcal{J}^\mu \qquad \left[\begin{array}{l} \tau(\mu, \mathcal{J}^2) \Delta^{\mu\nu} u^\alpha \partial_\alpha \mathcal{J}_\nu + \mathcal{J}^\mu = \\ -\sigma(\mu, \mathcal{J}^2) \Delta^{\mu\nu} \left(\partial_\nu \mu - F_{\nu\alpha} u^\alpha \right) \end{array} \right.$$

$\tau > D > 0$ for causality of classical hydro

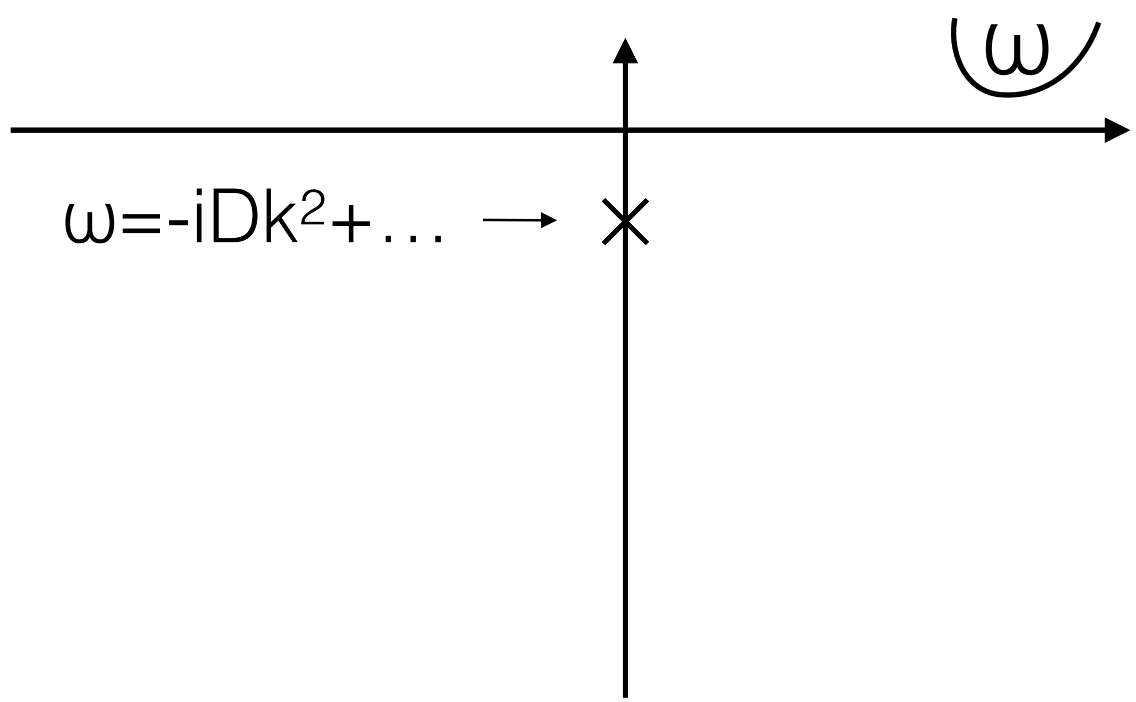
Retarded: $G^R_{nn} = \dfrac{-\sigma k^2}{i\omega(1 - i\omega\tau) - Dk^2}$, $\qquad D = \sigma / n'(\mu)$

Symmetric: $G^S_{nn} = \dfrac{2T\sigma k^2}{|\, i\omega(1 - i\omega\tau) - Dk^2 \,|^2}$

$G^S_{nn} > 0$, good. SK path integral converges

Implications of hydrodynamics for $\langle J^\mu J^\nu \rangle$

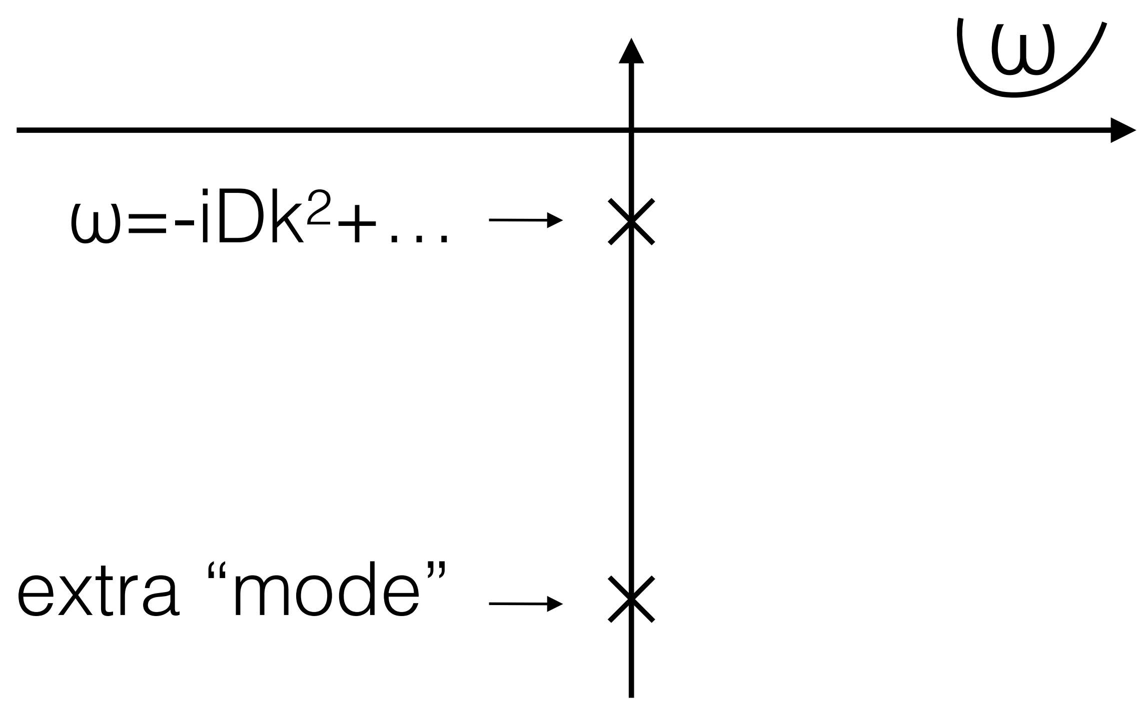
Small real k:



Pure hydrodynamics

Implications of hydrodynamics for $\langle J^\mu J^\nu \rangle$

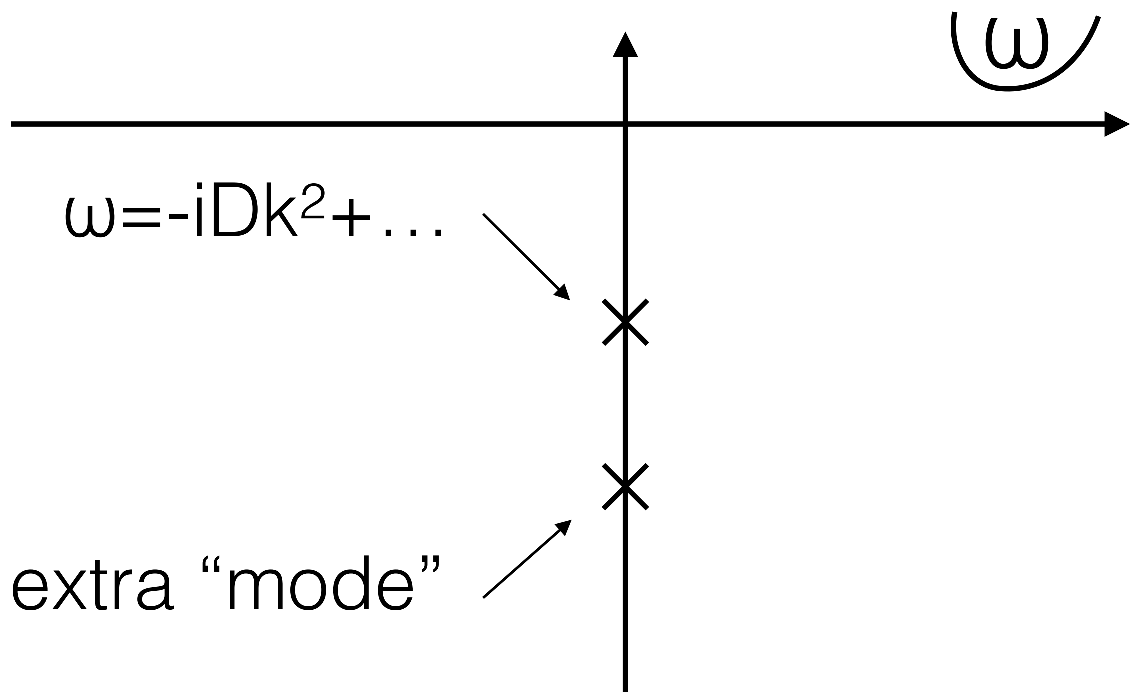
Small real k:



Causal hydrodynamic models

Implications of hydrodynamics for $\langle J^\mu J^\nu \rangle$

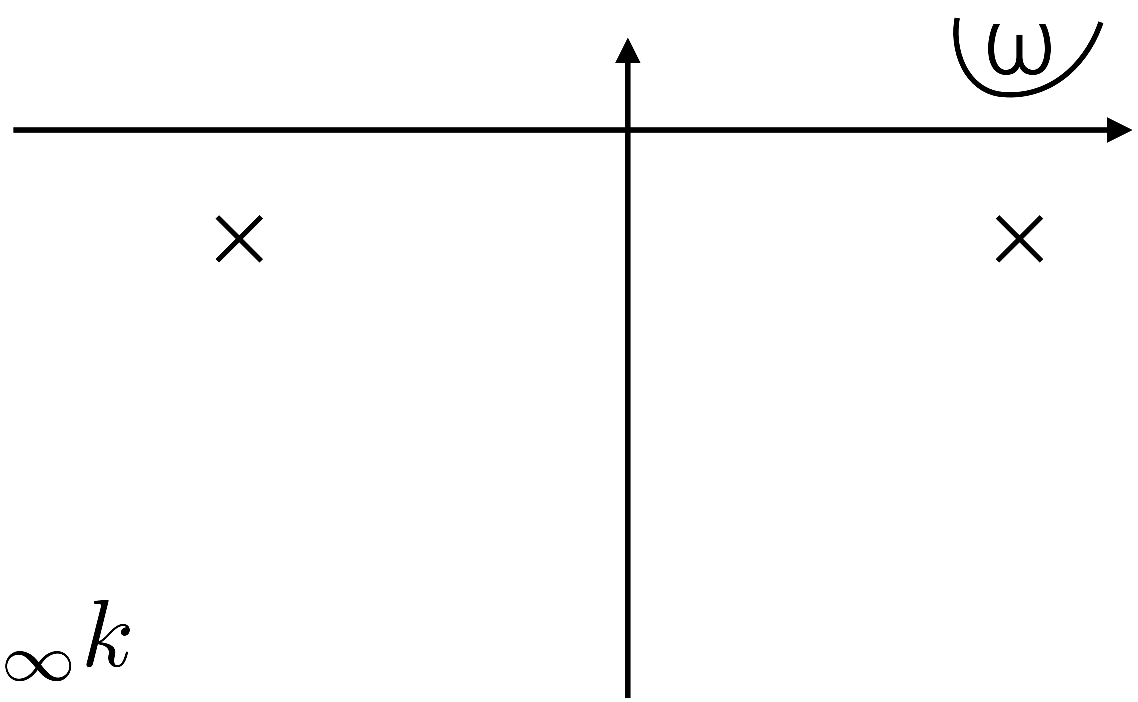
Larger real k:



Causal hydrodynamic models

Implications of hydrodynamics for $\langle J^\mu J^\nu \rangle$

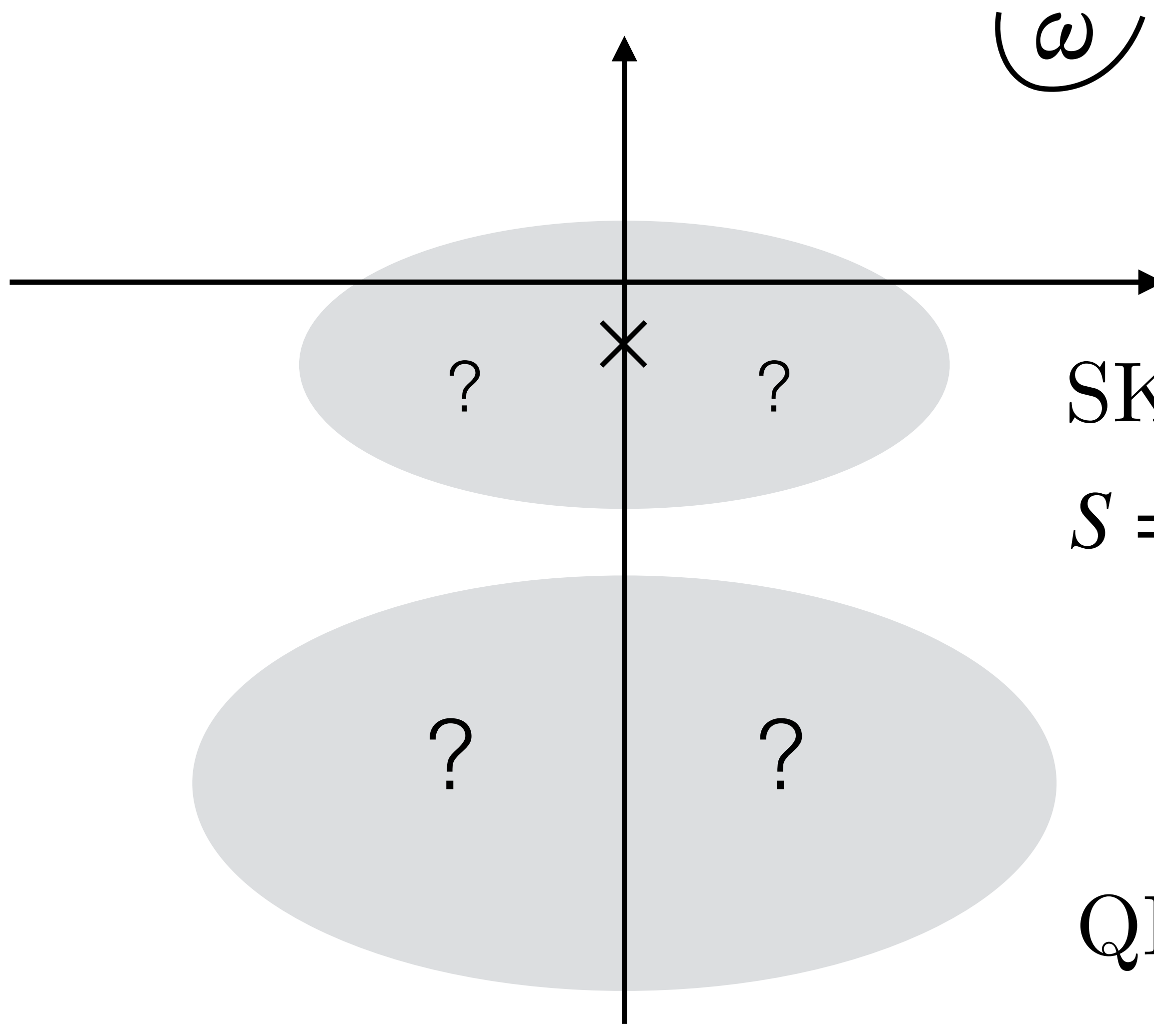
Large real k:



$\omega(k\to\infty) \sim \pm c_\infty k$

Causal hydrodynamic models

What are the *actual* singularities of $\langle J^\mu J^\nu \rangle$, $\langle T^{\mu\nu} T^{\alpha\beta} \rangle$?

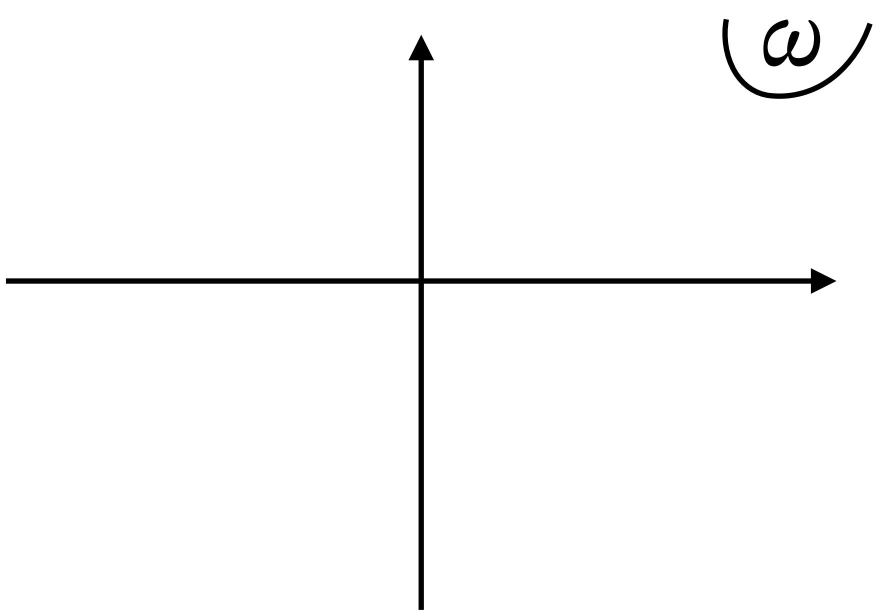


SK EFT, micro-agnostic

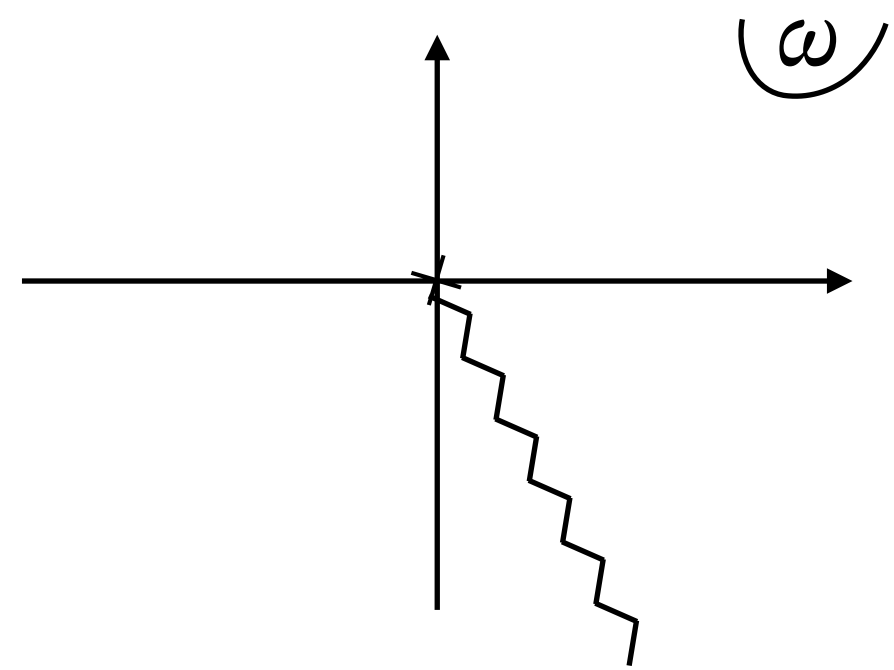
$S = \varphi_a F(\varphi_r) + \varphi_a^2 G_{\text{class.}}(\varphi_r)$

QFT, micro-specific

Example: $\langle T^{ij} T^{kl} \rangle (\omega, k{=}0)$



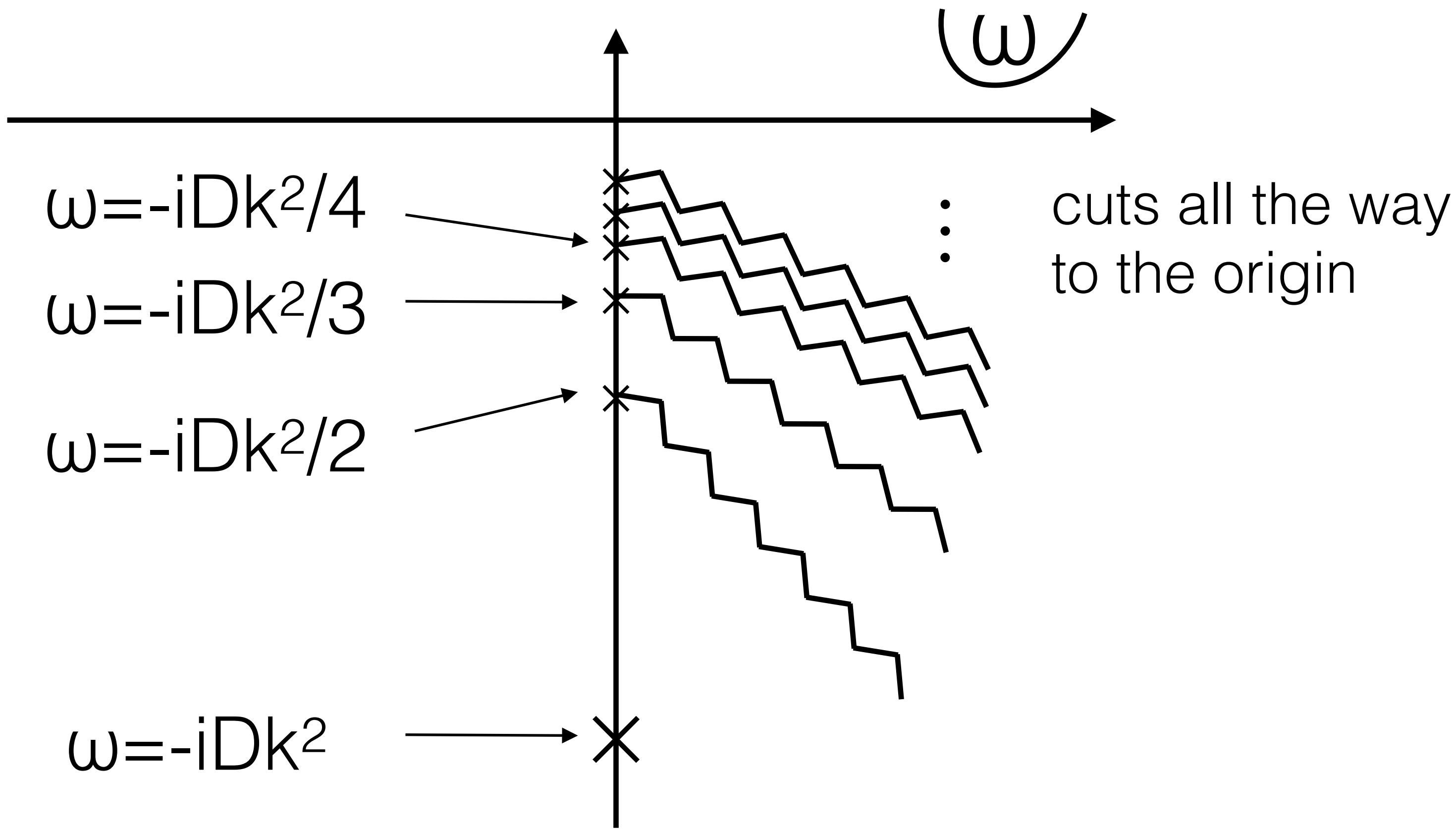
Hydrodynamics = PDEs only



Hydrodynamics = PDEs plus one-loop EFT

Kovtun, Yaffe, arXiv:hep-th/0303010

Example: $\langle J^0 J^0 \rangle(\omega, k)$

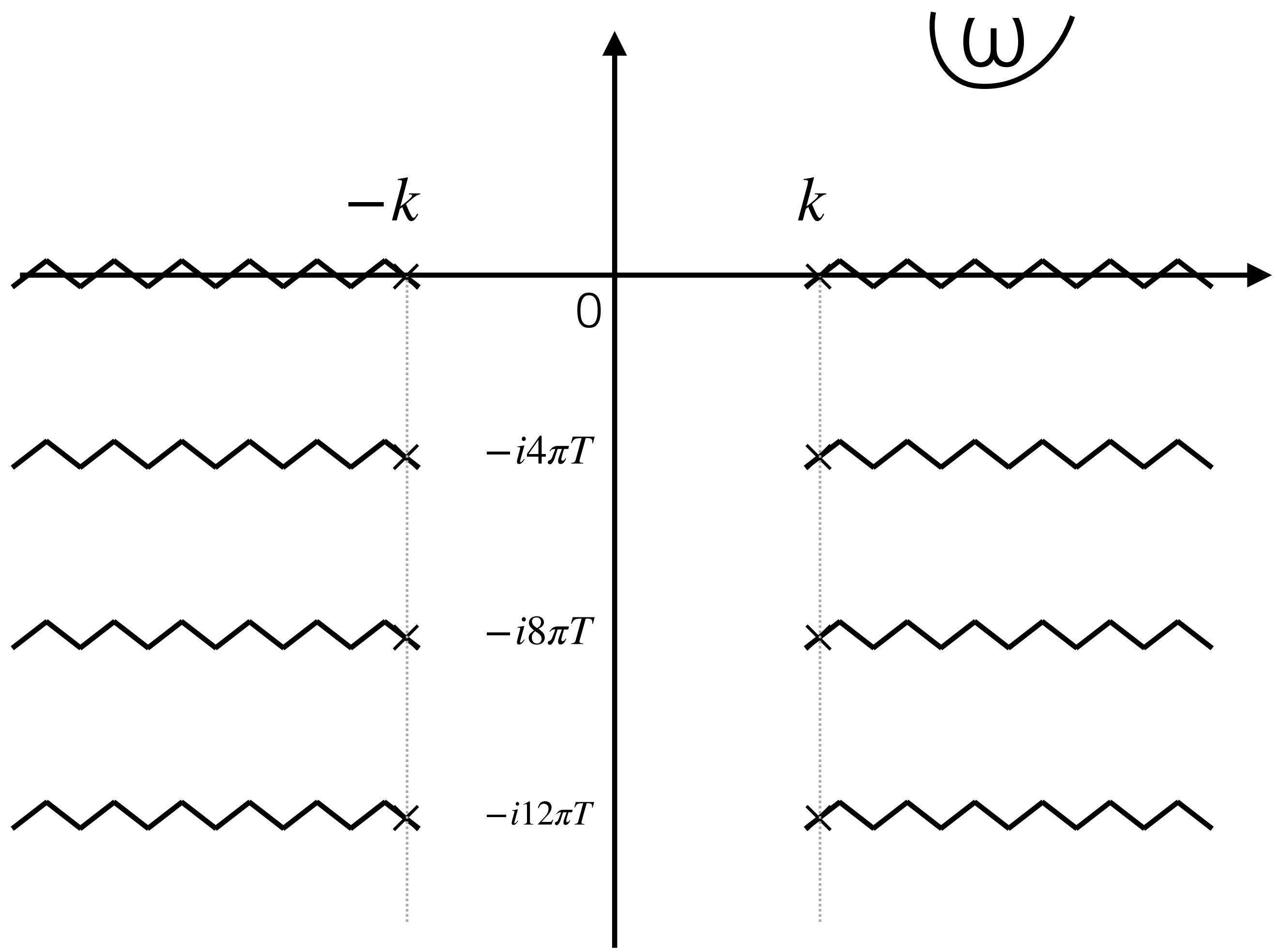


Chen-Lin, Delacrétaz, Hartnoll, arXiv:1811.12540

Delacrétaz, arXiv:2006.01139

Grozdanov, Lemut, Pelaic, Soloviev, arXiv:2407.13550

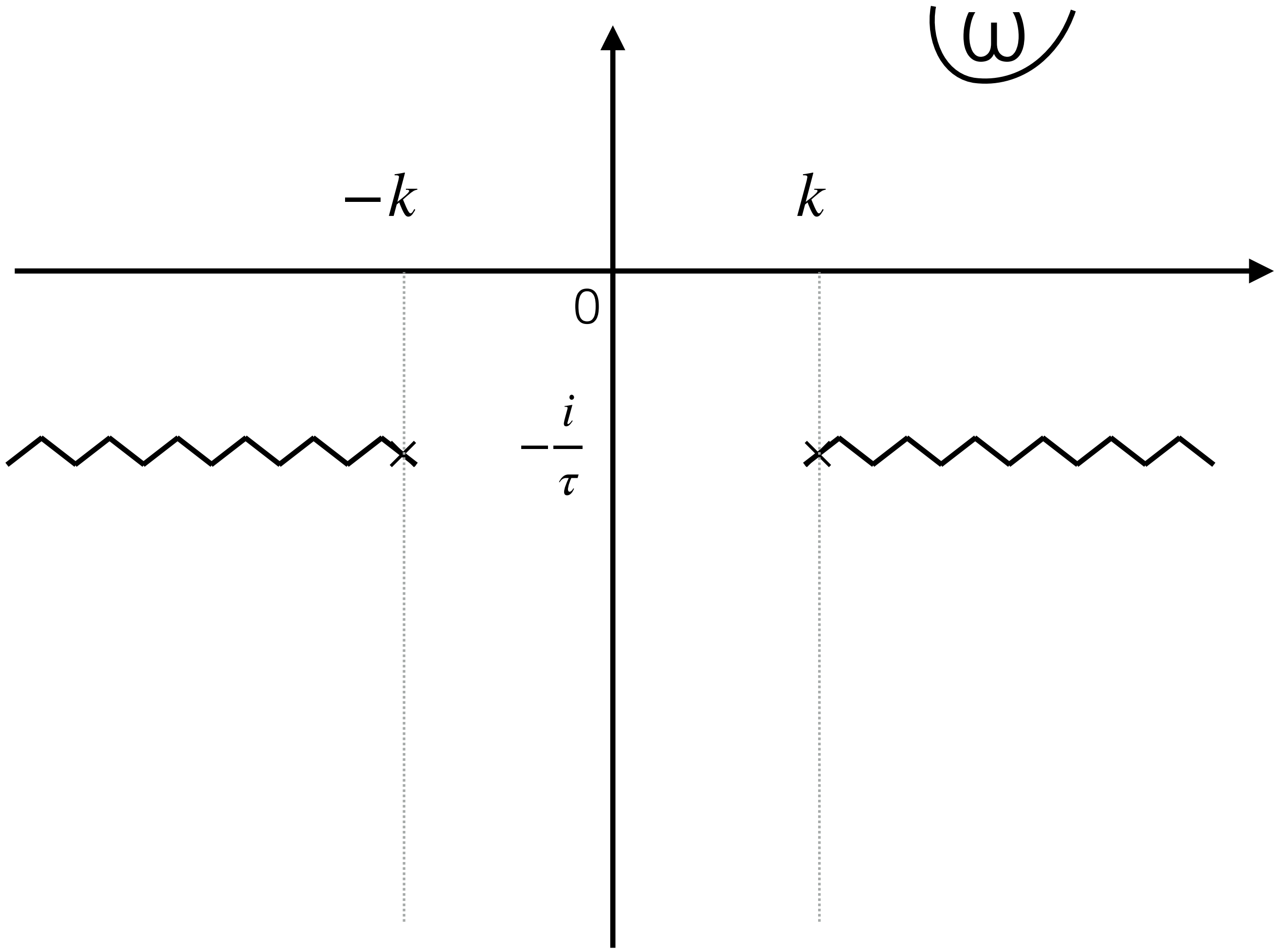
Outside the EFT regime



free field theory

Hartnoll, Kumar, arXiv:hep-th/0508092

Outside the EFT regime



baby kinetic theory

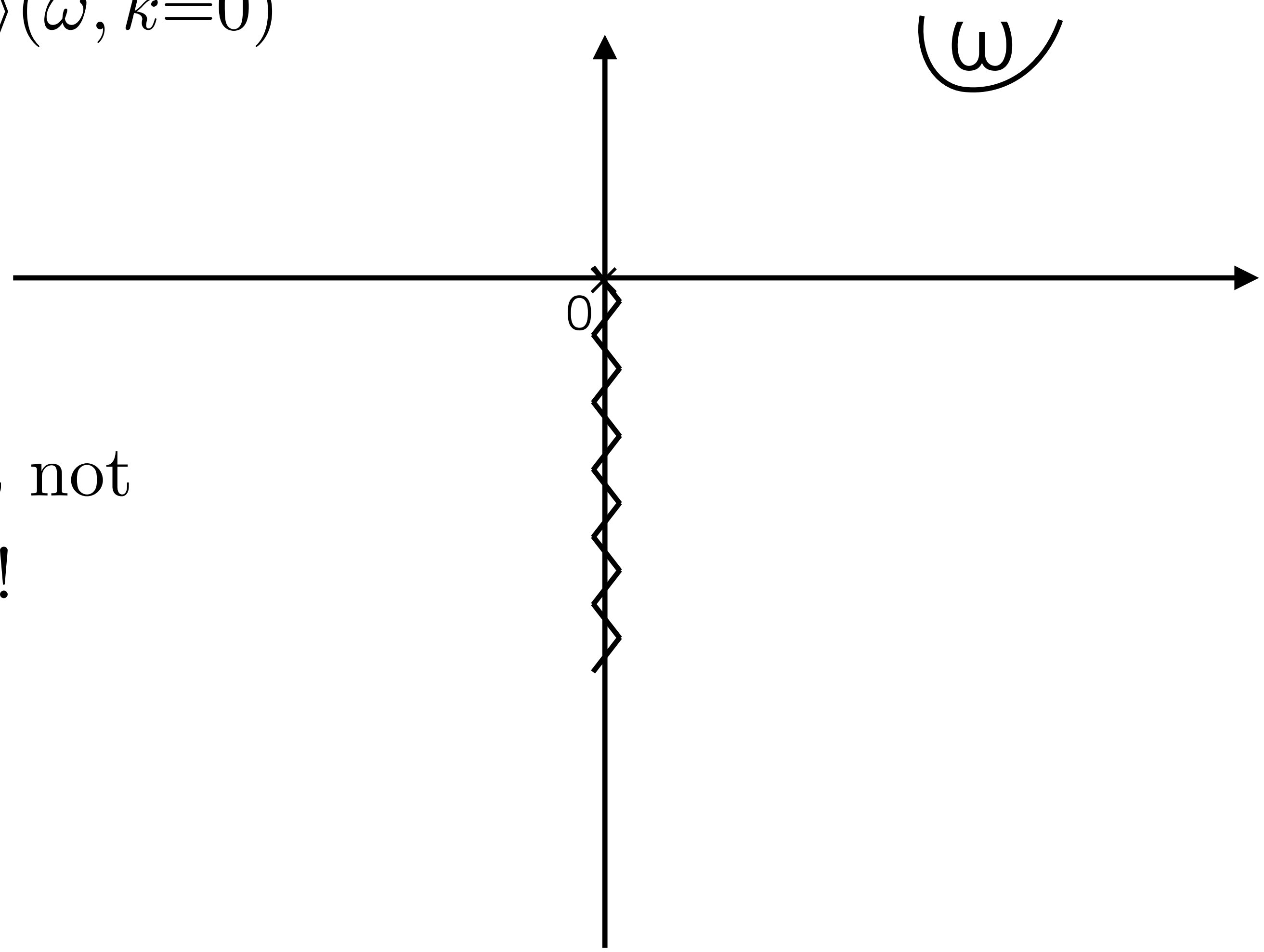
Romatschke, arXiv:1512.02641

Kurkela, Wiedemann, arXiv:1712.04376

Bajec, Grozdanov, Soloviev, arXiv:2403.17769

Outside the EFT regime

$\langle T^{ij} T^{kl} \rangle(\omega, k{=}0)$



Branch cut, but not
1-loop EFT cut!

grown-up kinetic theory in φ^4 field theory

Moore, arXiv:1803.00736

Part III: Connection to black holes

Thermodynamics on the boundary

“boundary”: matter lives here, 3+1 dim

gravity
pulls
down

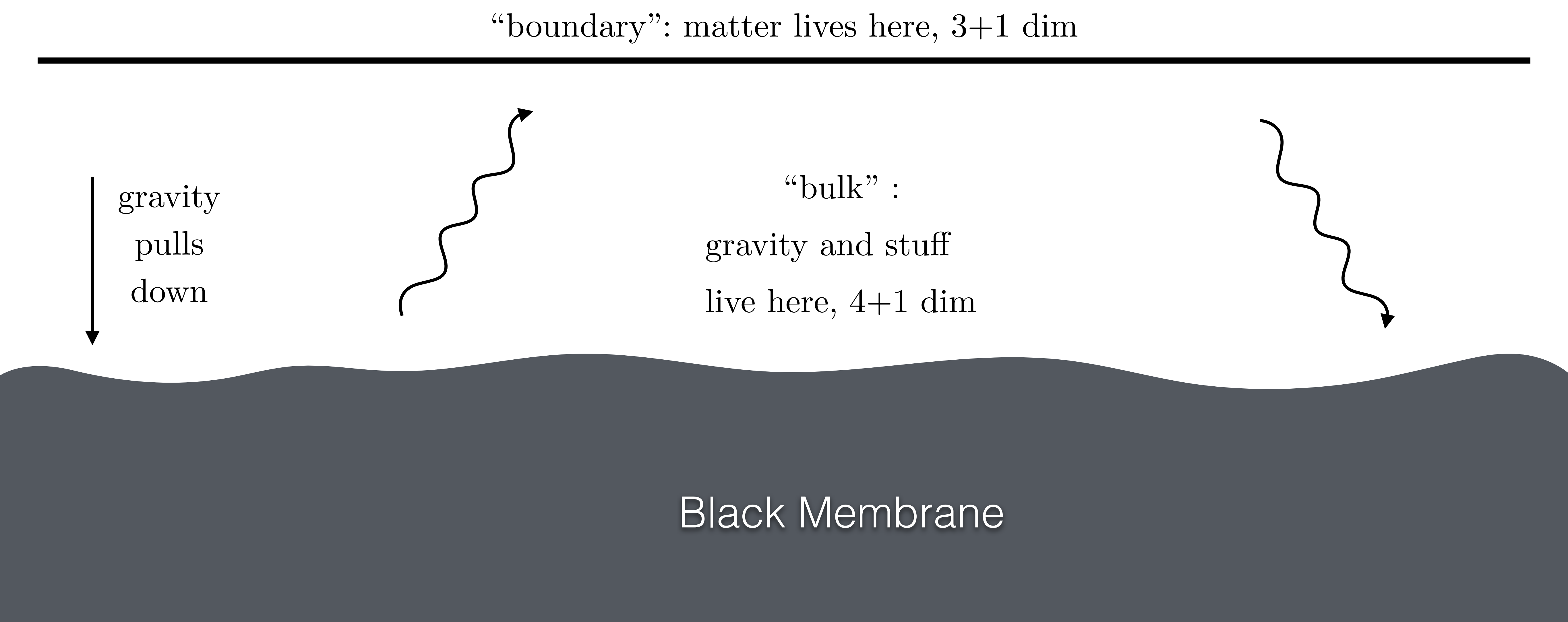
“bulk” :

gravity and stuff

live here, 4+1 dim

Black Membrane

Hydrodynamics on the boundary



Learn about strongly coupled fluids from gravity:

Eq-n of state

Transport coef-s (η, etc)

Hydrodynamic equations

Singularities of response functions

Form of SK effective actions

Connections to OTOCs and quantum chaos

Entanglement entropy

...

Learn about strongly coupled fluids from gravity:

Eq-n of state

Transport coef-s (η, etc)

Hydrodynamic equations

Singularities of response functions ← Causal UV completion of acausal hydrodynamics

Form of SK effective actions

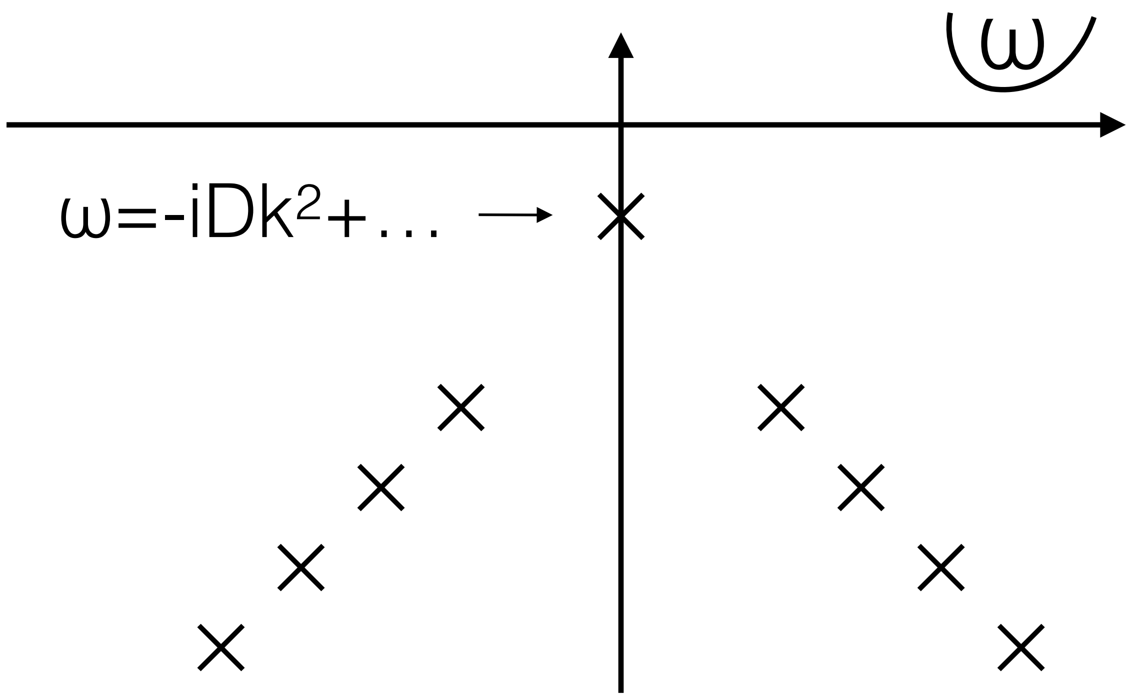
Connections to OTOCs and quantum chaos

Entanglement entropy

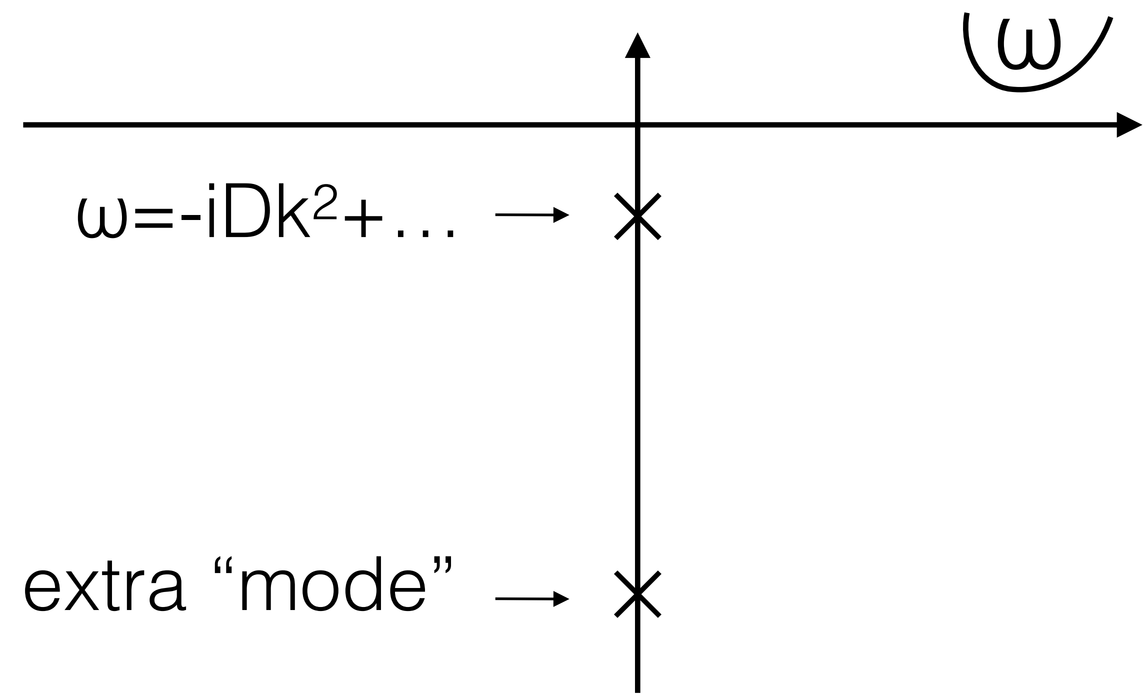
...

Singularities of response functions

Small real k :



holographic theories, 3+1dim

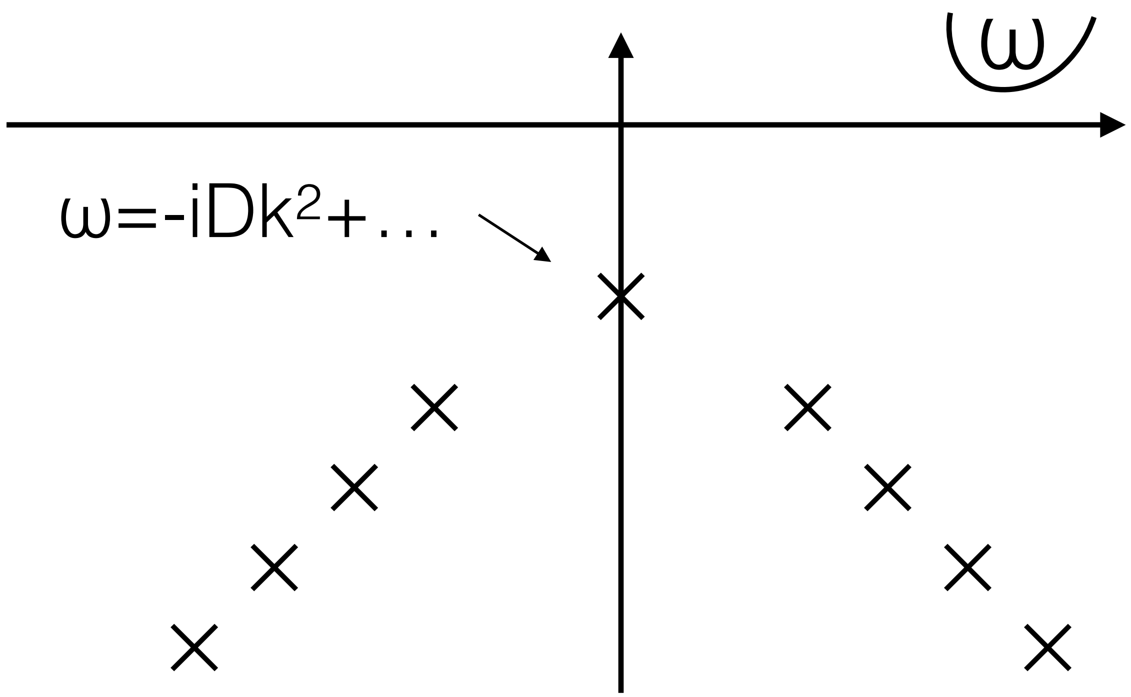


causal hydro models

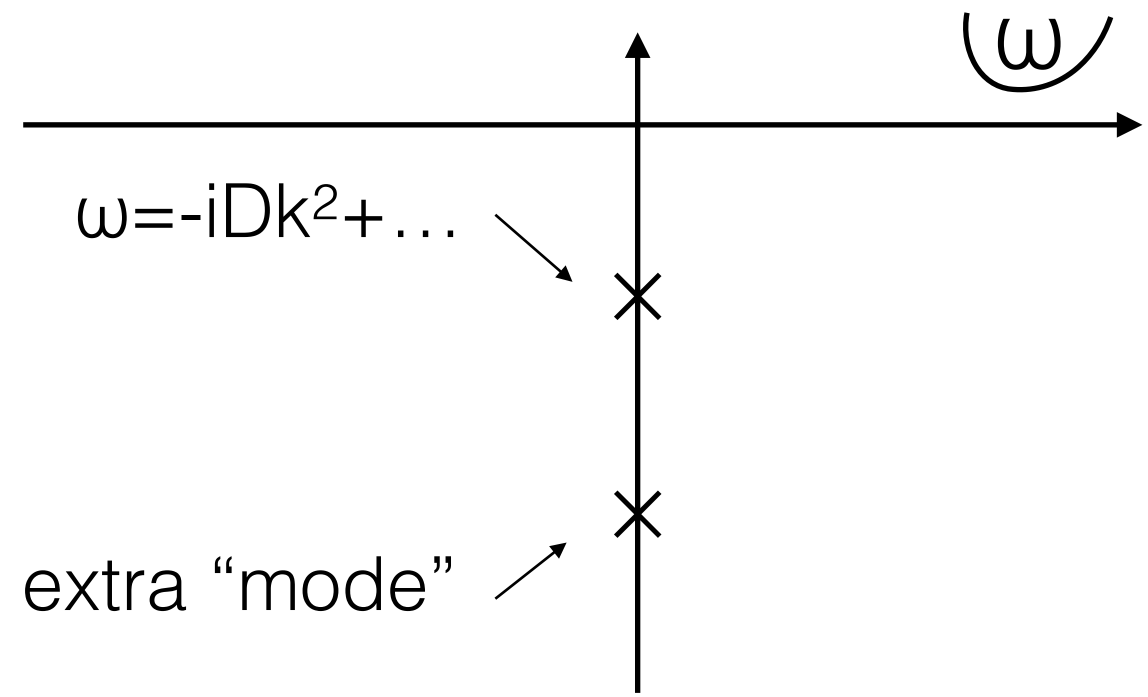
Kovtun, Starinets, arXiv:hep-th/0506184

Singularities of response functions

Larger real k :



holographic theories, 3+1dim

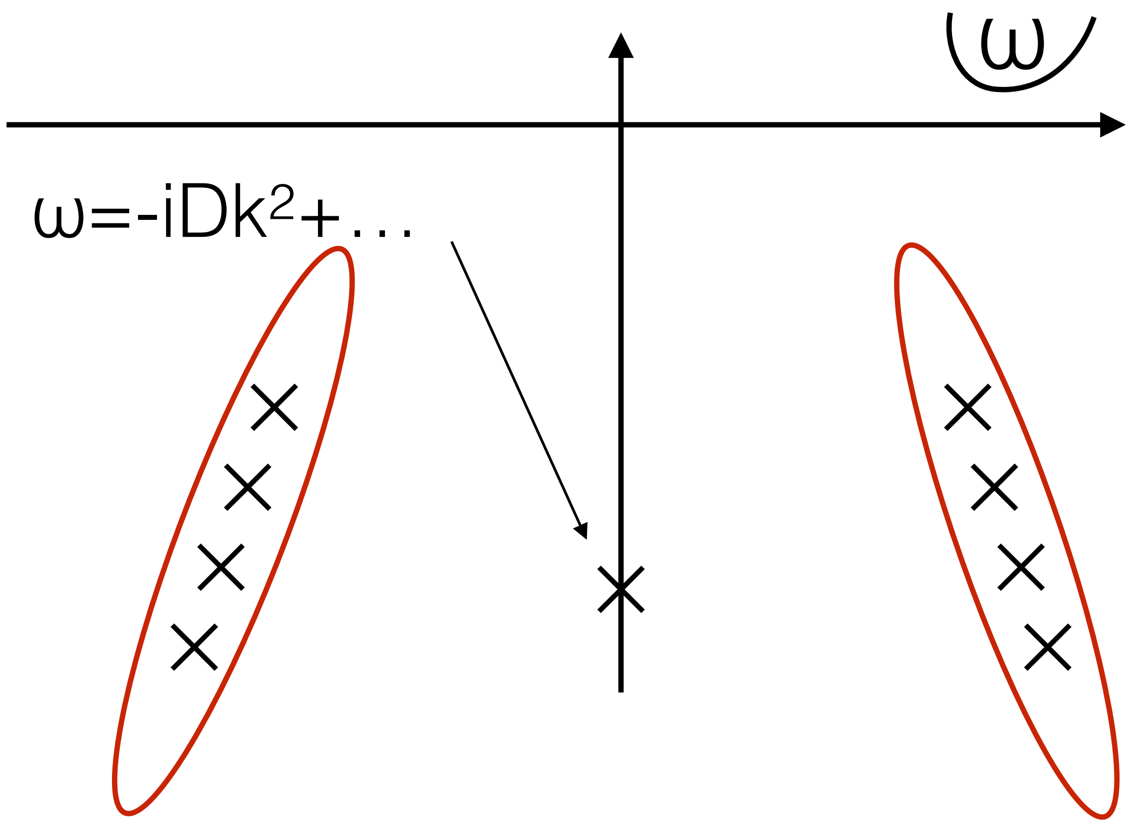


causal hydro models

Kovtun, Starinets, arXiv:hep-th/0506184

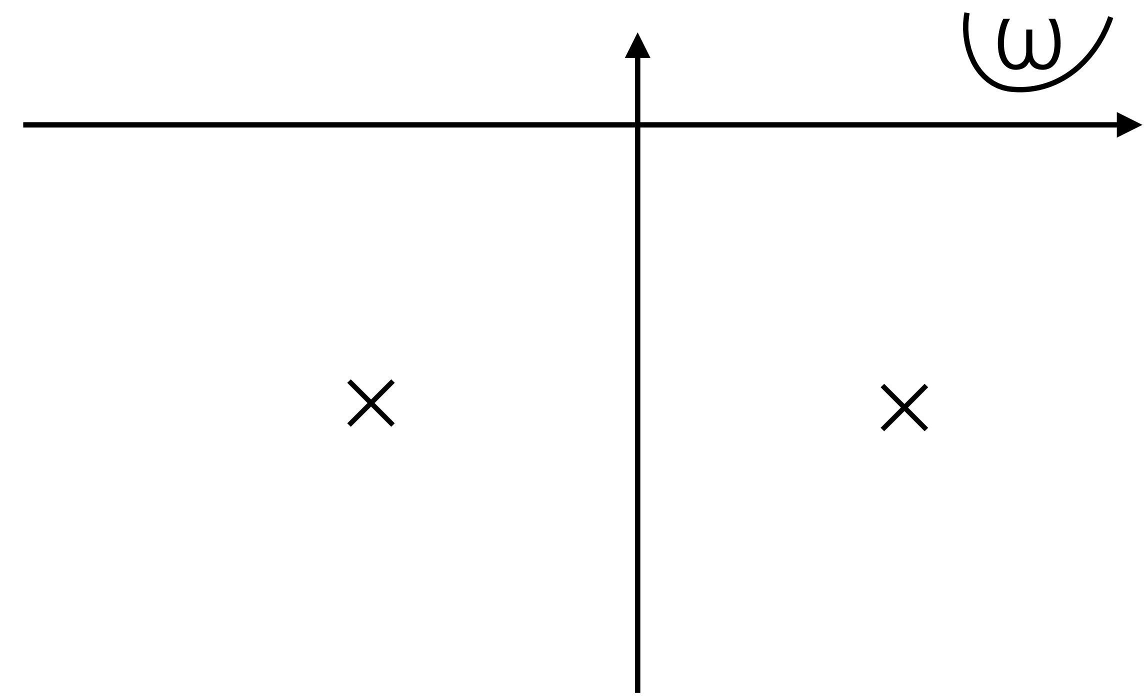
Singularities of response functions

Large real k :



holographic theories, 3+1dim

will become branch cuts at $\omega = \pm k$



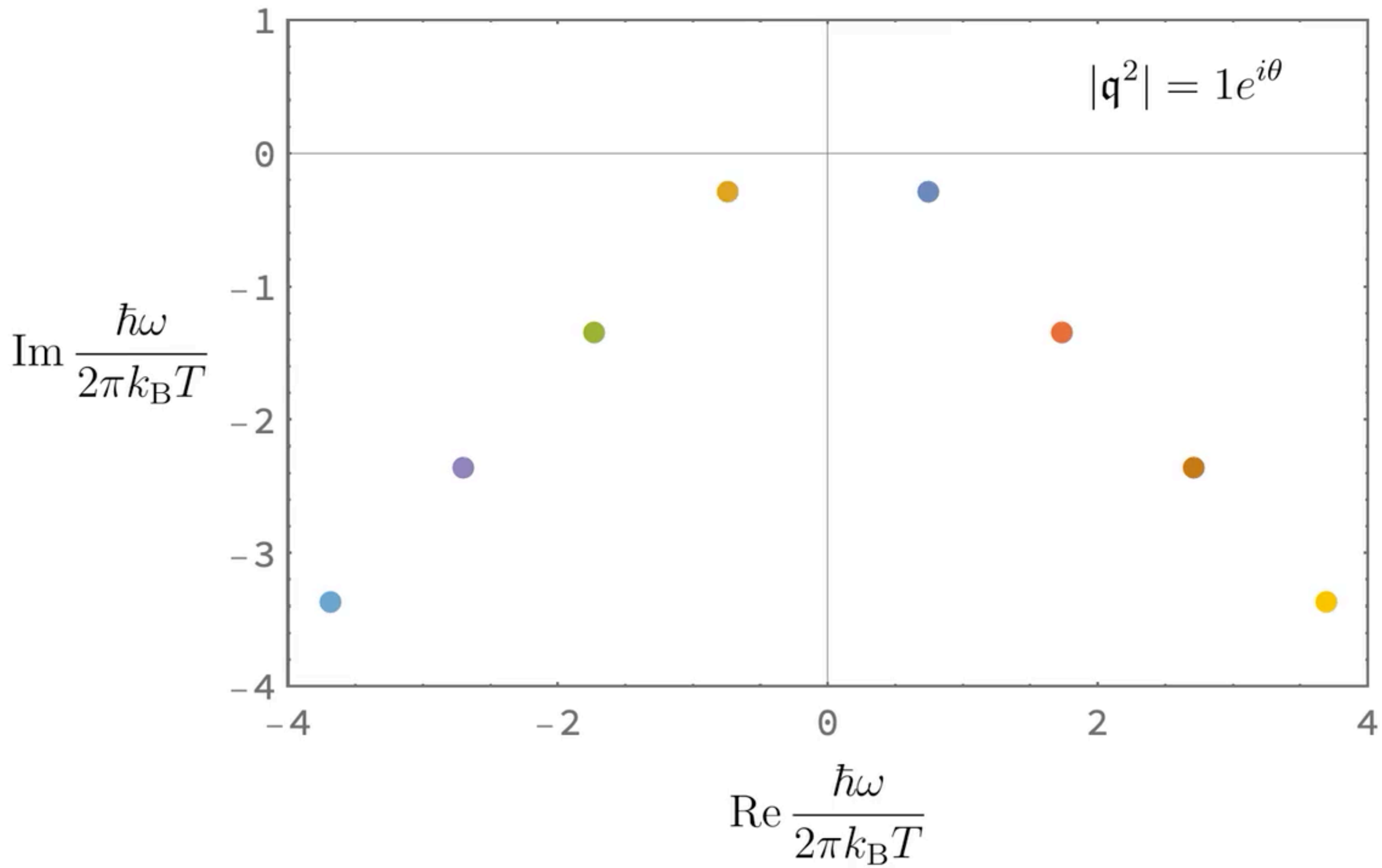
causal hydro models

Kovtun, Starinets, arXiv:hep-th/0506184

Oscillation modes of a fluid, complex k

Now take k to be complex, $|\mathfrak{q}^2| = 1e^{i\theta}$, and vary θ from $0 \to 2\pi$.

$$\mathfrak{q} \equiv \frac{\hbar c\, k}{2\pi k_B T}$$

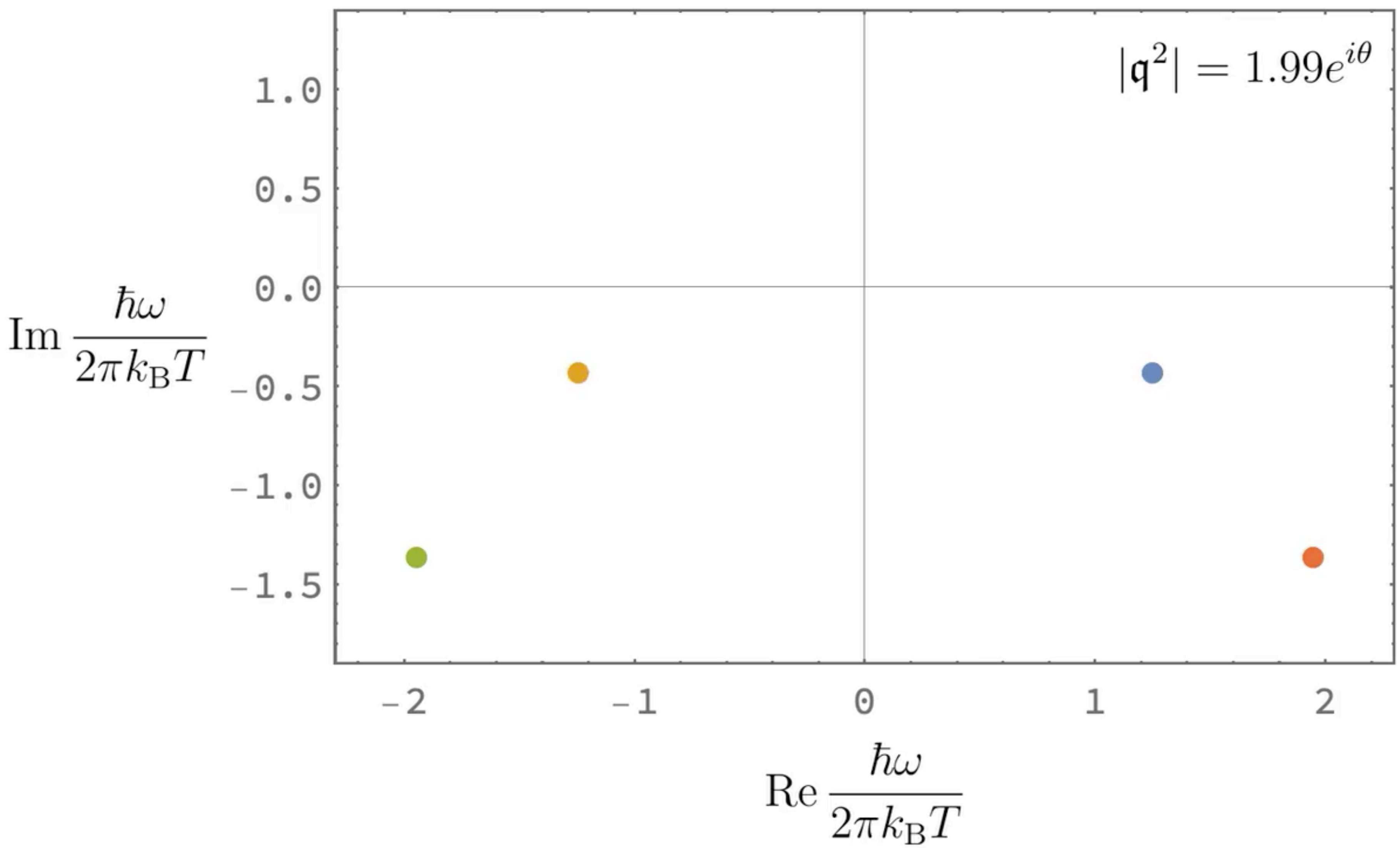


Sound modes (blue and gold) swap places, but remain sound modes when θ becomes 2π.

Oscillation modes of a fluid, complex k

Now take k to be complex, $|\mathfrak{q}^2| = 1.99\, e^{i\theta}$, and vary θ from $0 \to 2\pi$.

$$\mathfrak{q} \equiv \frac{\hbar c\, k}{2\pi k_B T}$$

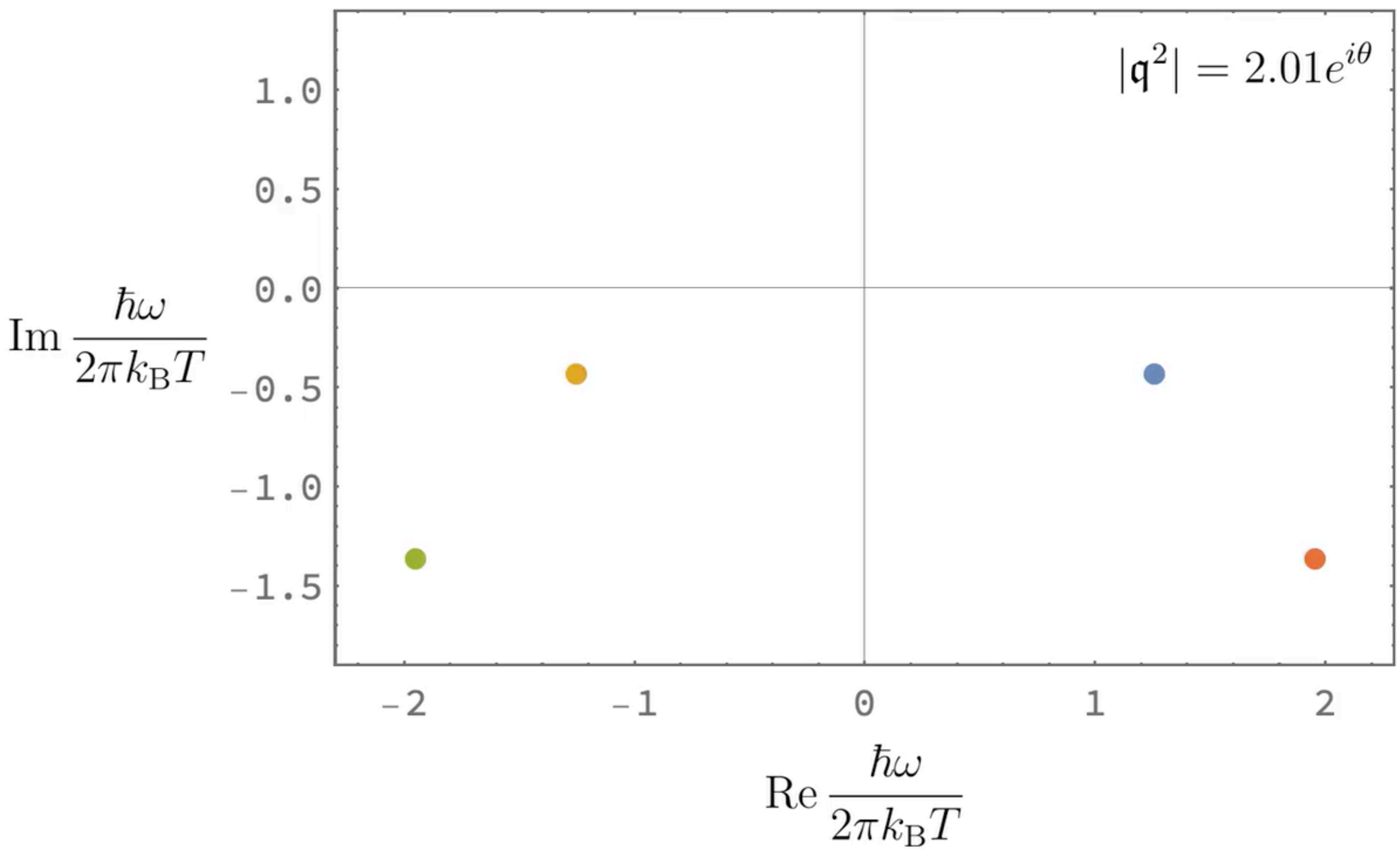


Sound modes (blue and gold) swap places, but remain sound modes when θ becomes 2π.

Oscillation modes of a fluid, complex k

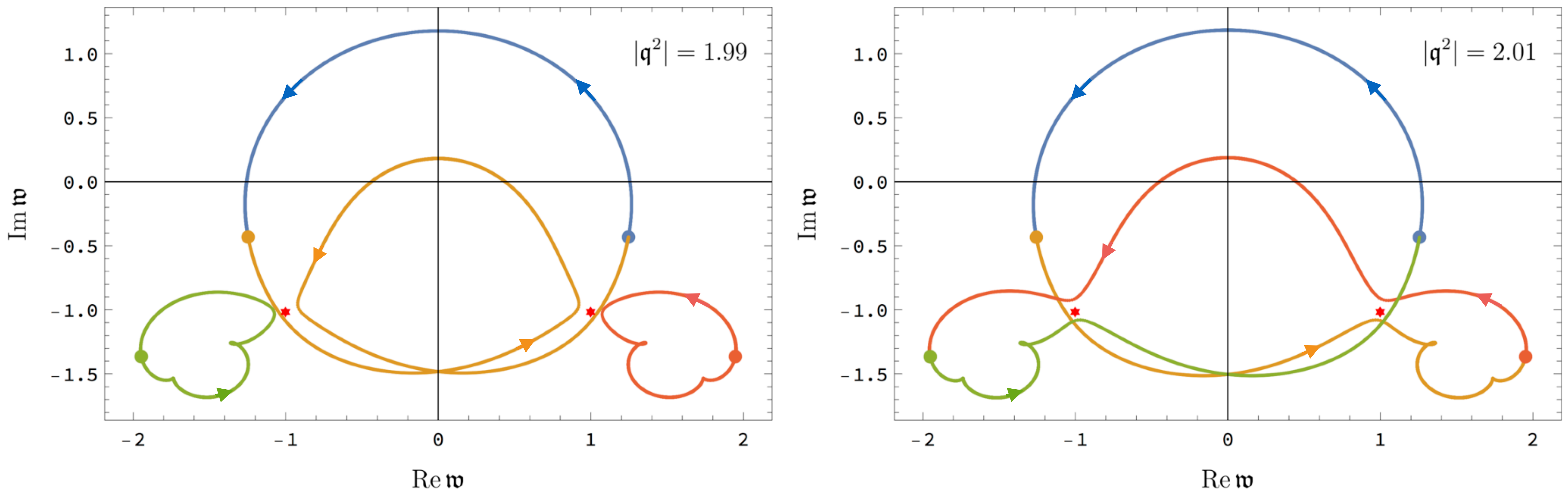
Now take k to be complex, $|\mathfrak{q}^2| = 2.01\, e^{i\theta}$, and vary θ from $0 \rightarrow 2\pi$.

$$\mathfrak{q} \equiv \frac{\hbar c\, k}{2\pi k_{\mathrm{B}} T}$$



Sound mode (gold) becomes one of the non-classical modes when θ becomes 2π!

Trajectories of the modes at $|\mathfrak{q}^2|$=1.99 and $|\mathfrak{q}^2|$=2.01

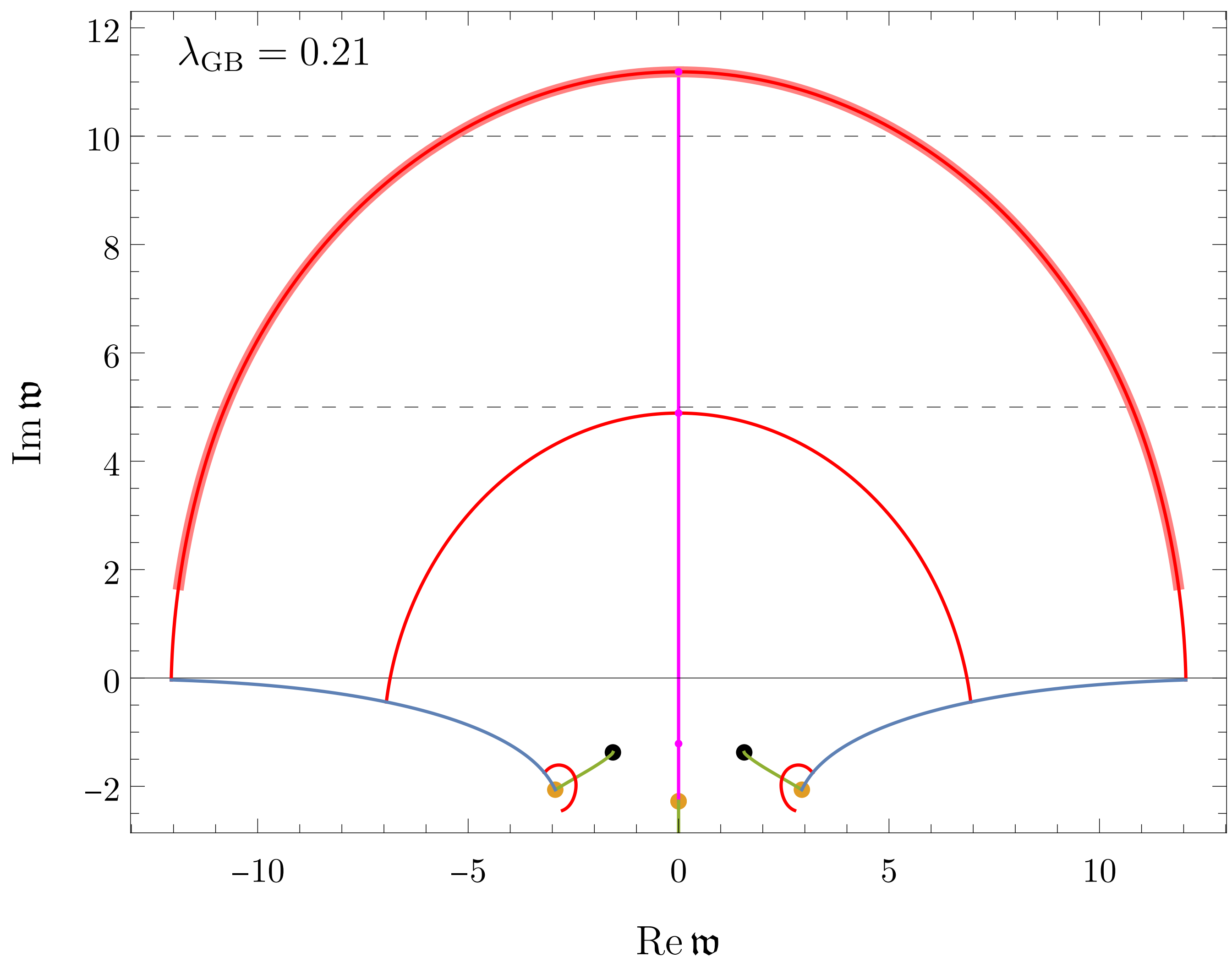


Poles of in $G^{\text{ret.}}(\omega, k)$ in upper half-plane, ok because k is complex

Dancing singularities determine the radius of convergence of the small-k expansion of $\omega_{\text{hydro}}(k)$

Grozdanov, Kovtun, Starinets, Tadić, arXiv:1904.01018

Not everything you make up in holography is good



Gauss-Bonnet gravity in 5D can violate boundary causality

Brigante, Liu, Myers, Shenker, Yaida, arXiv:0712.0805

Buchel, Myers, arXiv:0906.2922

Predicts singularities in $G^{\rm ret.}(\omega, k)$ with $\mathrm{Im}(\omega) > |\,\mathrm{Im}(k)\,|$, instability

Buchel, Hoult, Kovtun, arXiv:2606.19049

Other fun things with singularities

Analytic structure of $\omega(k)$

Grozdanov, Kovtun, Starinets, Tadić, arXiv:1904.12862

Indeterminate correlation functions at complex ω and k

Blake, Davison, Vegh, arXiv:1904.12883

Causality constraints on $\omega_{\mathrm{diff}}(k)$ at small k

Heller, Serantes, Spalinski, Withers, arXiv:2212.07434

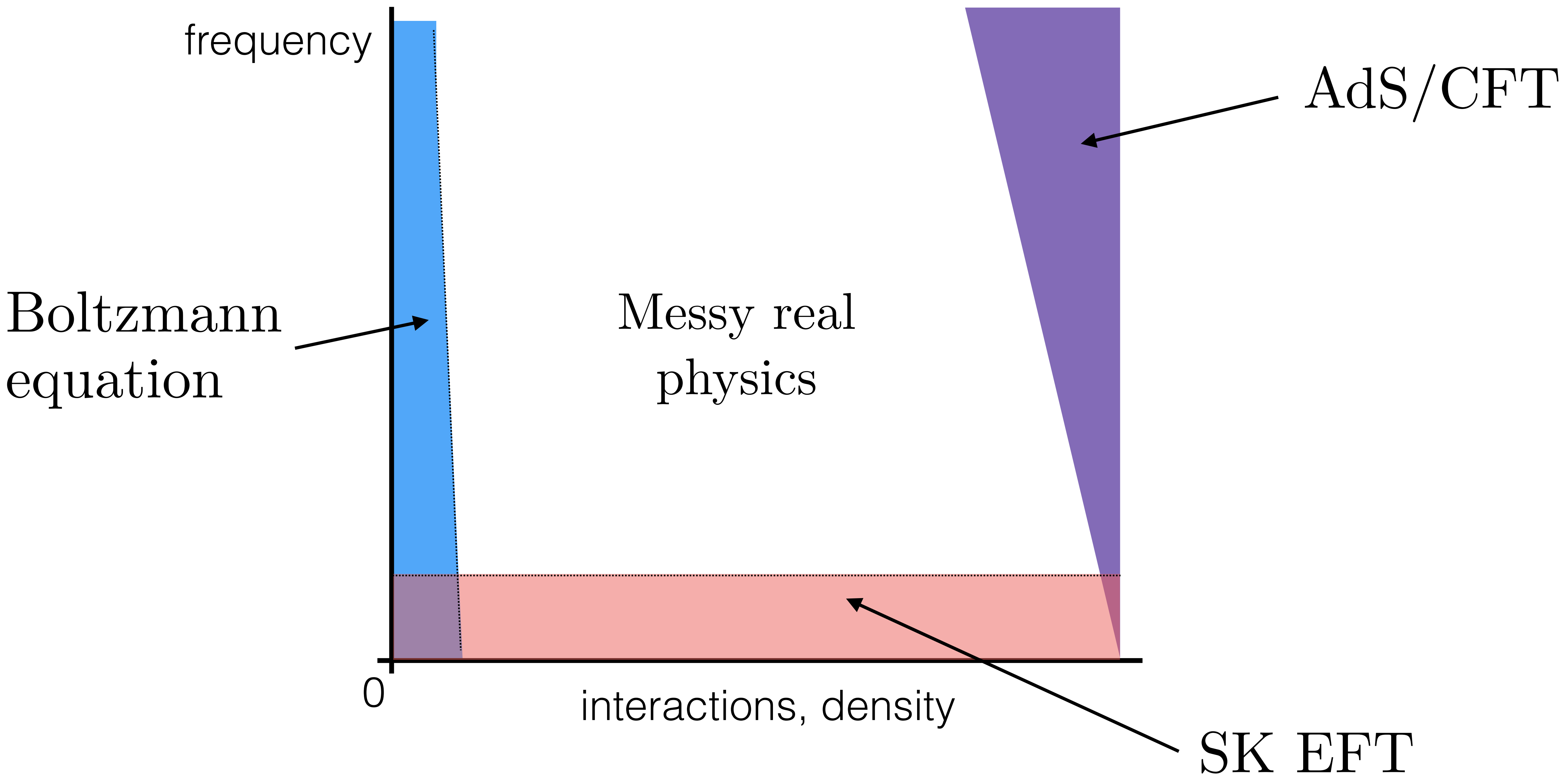
Expansions of $\omega_n(k)$ at large k

Festuccia, Liu, arXiv:0811.1033

Fuini, Uhlemann, Yaffe, arXiv:1610.03491

Aniceto, Arnaudo, Ratcliffe, Spaliński, arXiv:2606.12529

Theories of hot and dense matter



That's all!