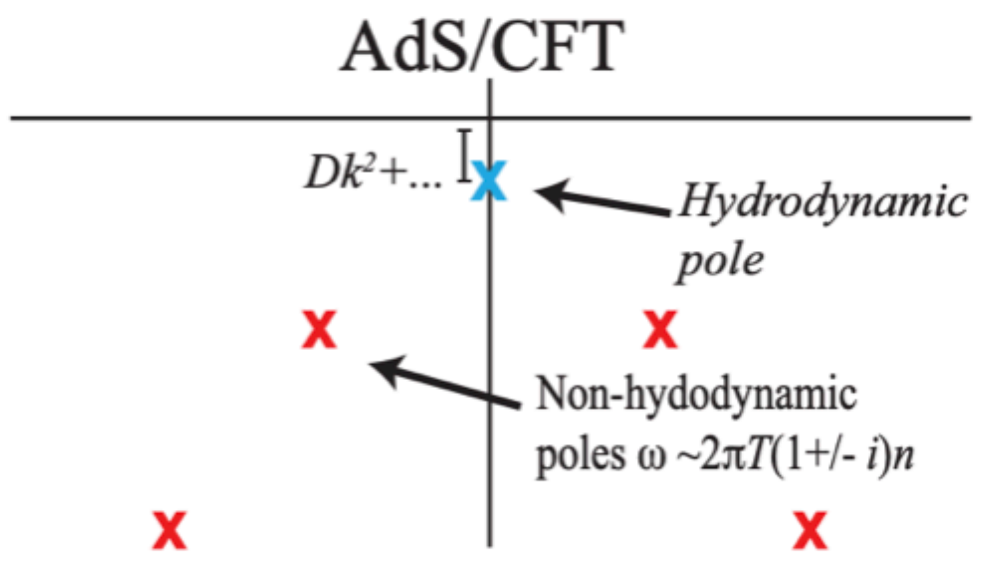
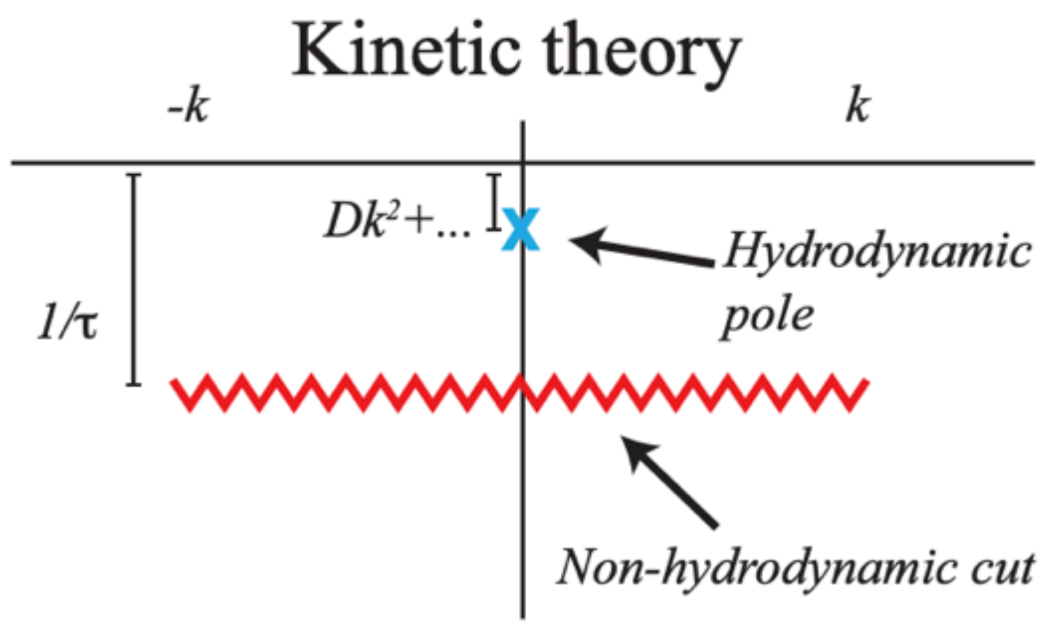
Non-hydrodynamics from Hidden Symmetries



Broken Hidden U(1)



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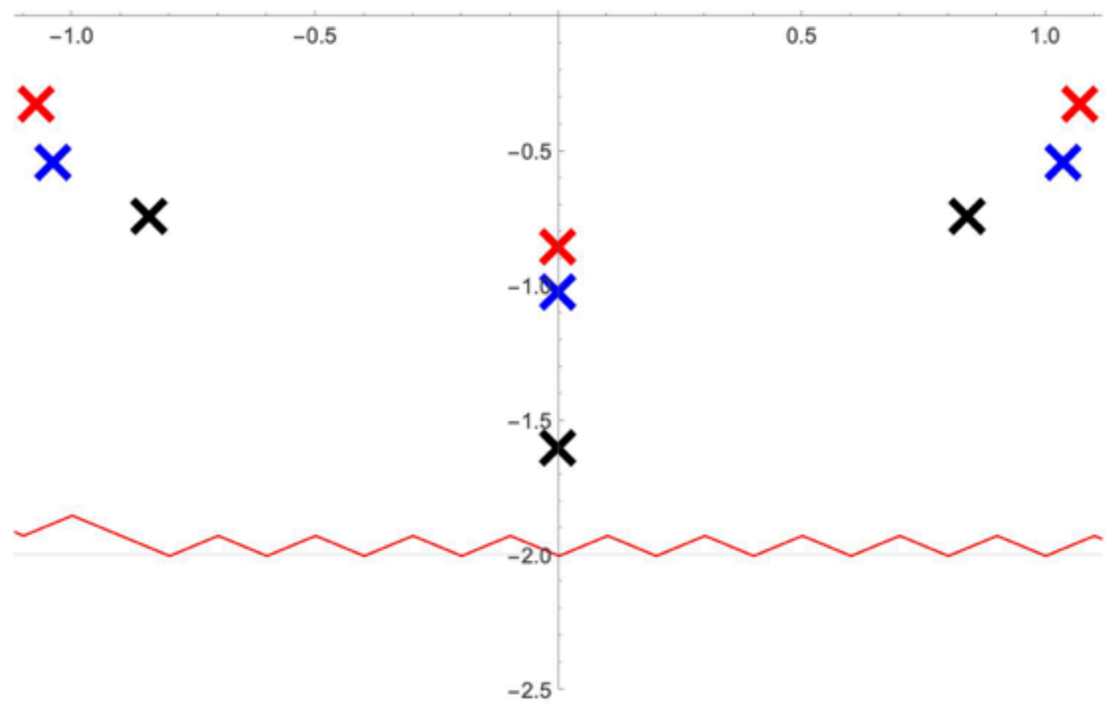


Mixture

Yi Yin

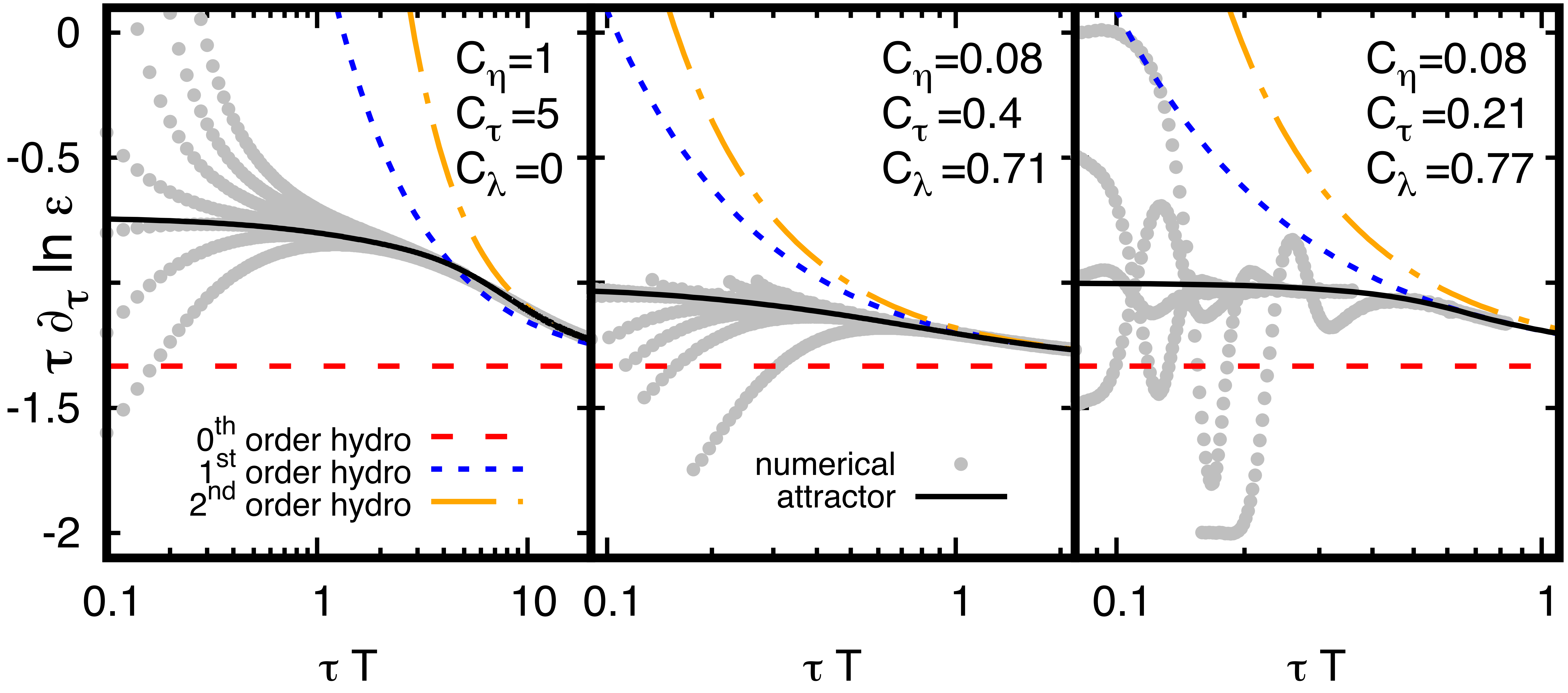
CUHK-SZ

ECT workshop Sep.22-26 2025*

An-Brants-Heller-YY, in preparation

Universality and Diversity of Attractors

Romatschke PRL2017



MIS-like eqn: adding relaxation modes to hydro.

Kinetic eqn

Holography: Einstein eqns around black hole background

Universality and Diversity of Medium's Excitations

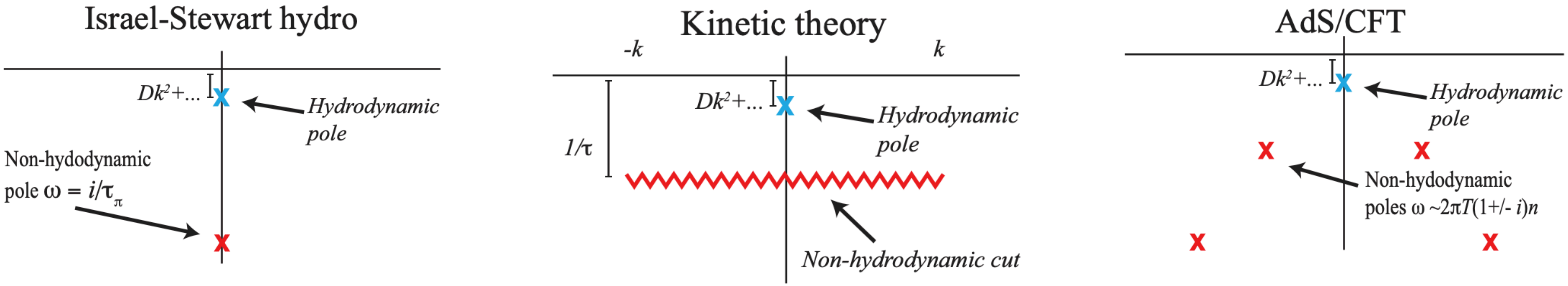


Fig. from Kurkela-Wiedemann-Wu, EPJC 19'

- Classification of non-hydro. behavior with simple guiding principles?
- Our work: action incorporating non-hydro. excitation by introducing hidden symmetries
- This talk: focus on E.o.M (saddle point); providing insight into attractor behaviors

EFT Action for Diffusion

Crossley et al, JHEP2015

- Dynamical variables: Schwinger-Keldysh (SK) $U(1)_V$ phase field φ^r (classical), φ^a (noise)

- The most general acton satisfying symmetry constraints

U(1) current $\quad n_V = \chi \partial_t \varphi^r, \qquad \vec{j} = -\sigma \partial_t (\vec{\partial} \varphi^r)$

- Shift symmetry for unbroken phase: $\varphi(x) \to \varphi(x) + \lambda(\vec{x})$

$$\omega_{\text{hydro}} = \cancel{\pm ck} - iDk^2$$

- Next: extension to non-hydro modes

Proposal

An-Brants-Heller-YY, in preparation

- Hidden symmetries: describing non-hydro. with finite (infinite) phase field φ_n of hidden U(1) symmetries $n = 1,, \ldots$
- Nearest-neighboring coupling among phase fields

Scenarios

- Hidden symmetry is spontaneously broken
  - Maxwell-Cattaneo equation (MIS for charge), holographic fluid
- Unbroken
  - kinetic theory, generalized hydro. with near-integrability (?)
- Mixture
  - QGP-like plasma

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Broken Hidden Symmetry

- K hidden U(1) symmetries breaks into diagonal ones

$$U(1)_V \times U(1)_K \times \ldots U(1)_1 \to U(1)_{\rm dia}$$

- Building blocks: phase fields φ_m and hidden gauge fields A_n

$$\mathscr{A}_n \equiv \partial\varphi_n + A_n \,;\, \Delta\mathscr{A}_n = \mathscr{A}_{n+1} - \mathscr{A}_n \qquad\qquad n = 1,\ldots,K$$

$$\sum_n f_n^2\, \Delta\mathscr{A}^r_{t,n}\Delta\mathscr{A}^a_{t,n} - g_n^2\, \Delta\vec{\mathscr{A}}^r_n \cdot \Delta\vec{\mathscr{A}}^a_n + \epsilon_n \vec{E}^r_n \cdot \vec{E}^a_n - \frac{1}{\mu_n}\vec{B}^r_n \cdot \vec{B}^a_n + \text{disspation}$$

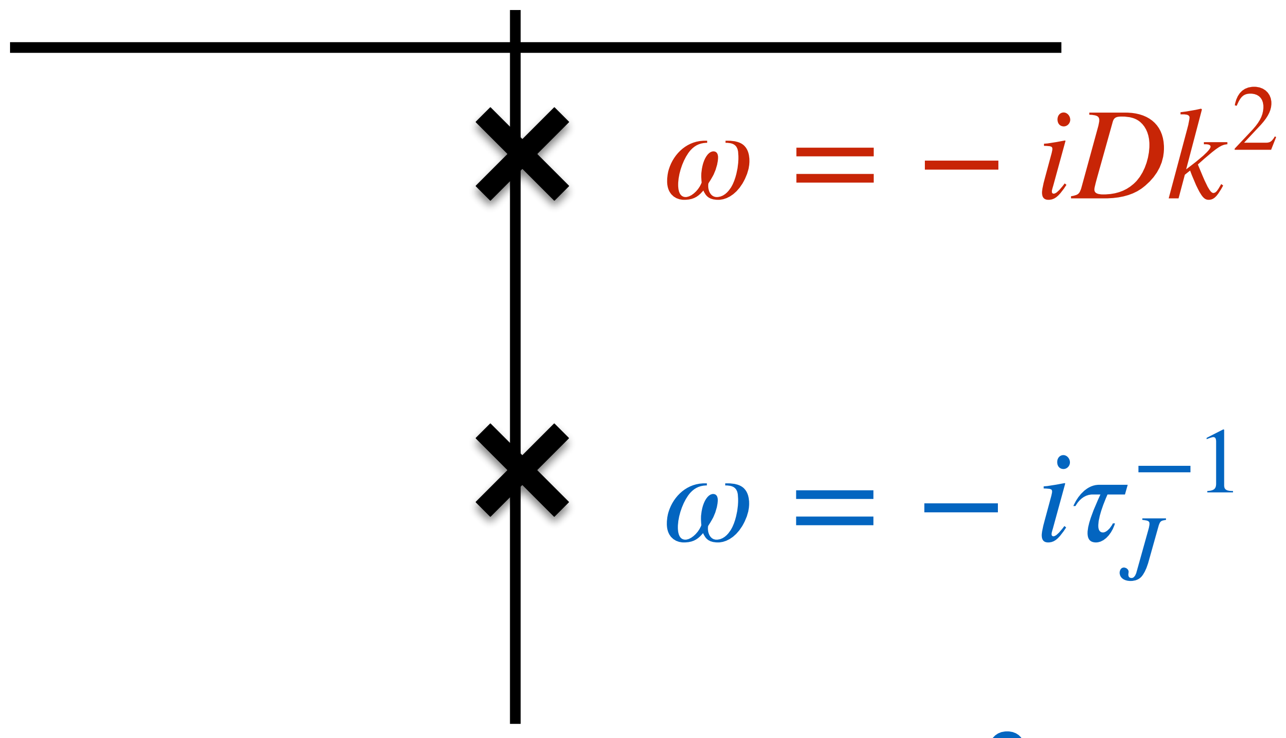
mass

$$\sim \lambda_n \vec{E}_n$$

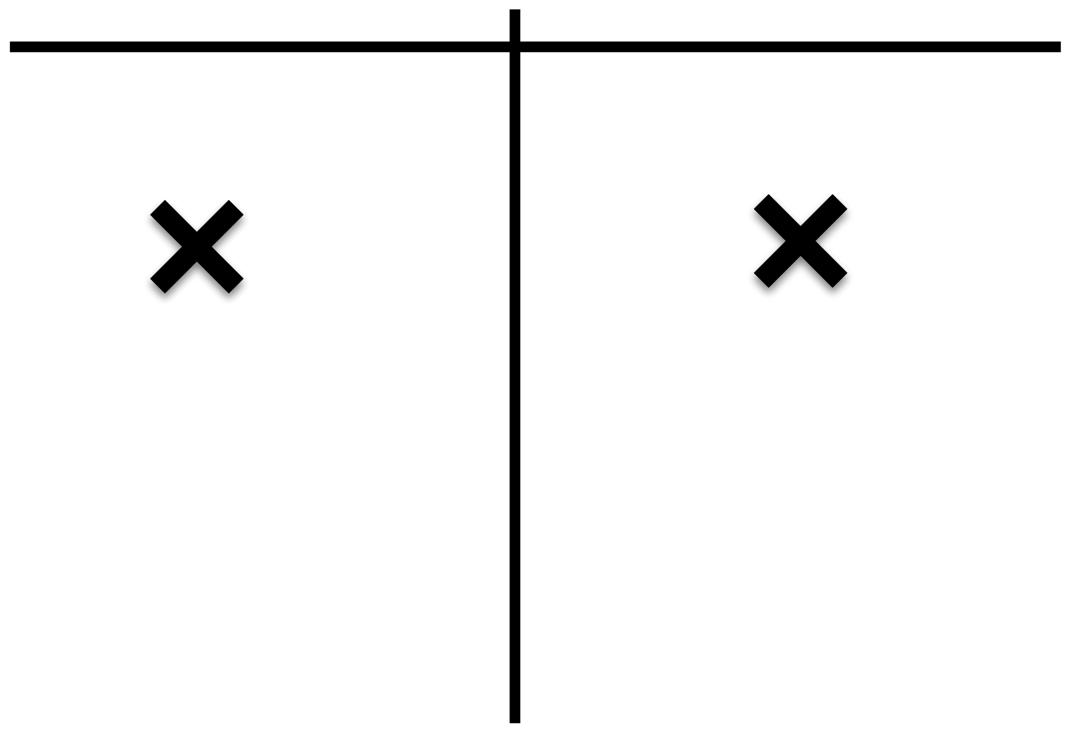
Describing massive hidden photons dissipated by the hidden Ohmic current

K=1 with $\epsilon = 0$

Longitudinal Channel



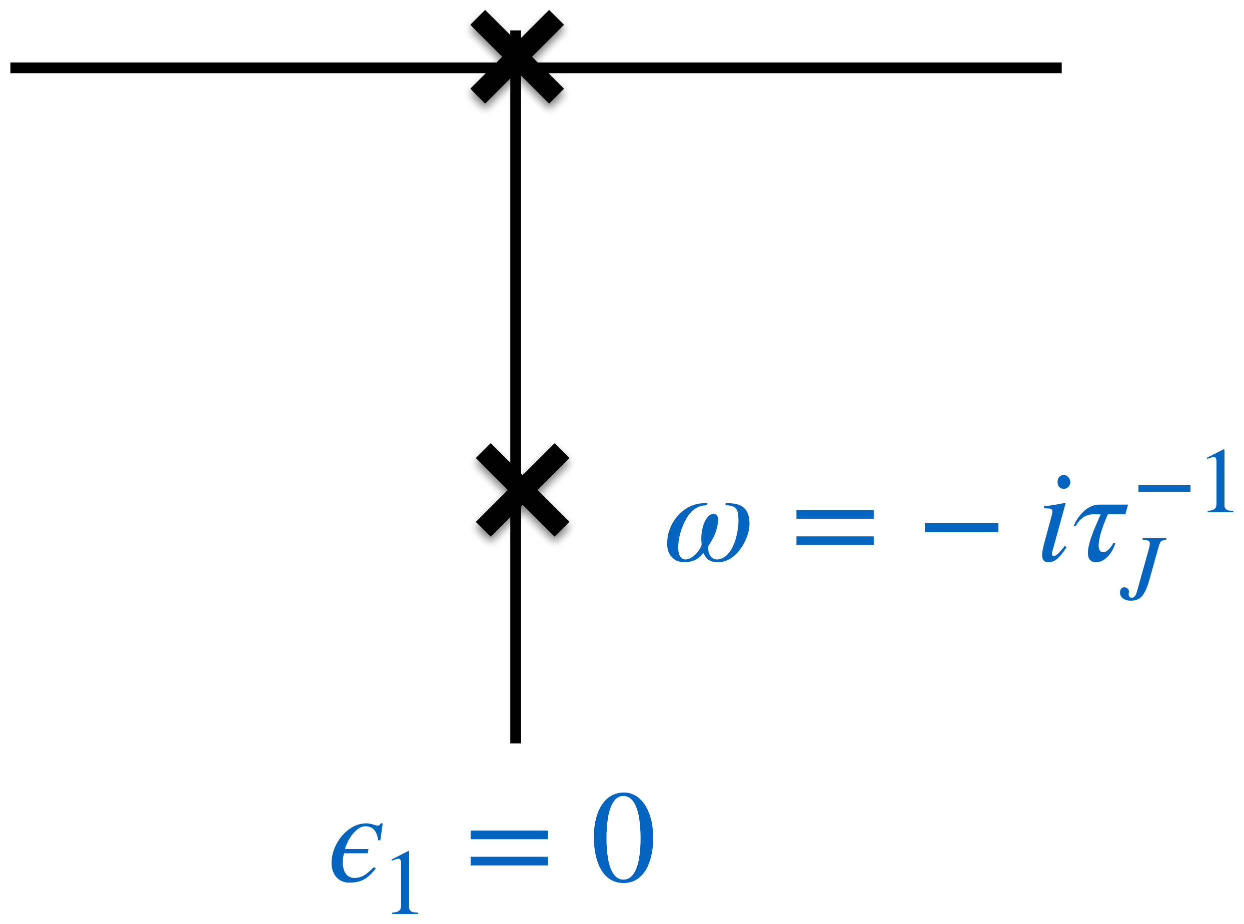
low ω $\lambda/g^2 = \tau_J, D = \lambda/f^2$

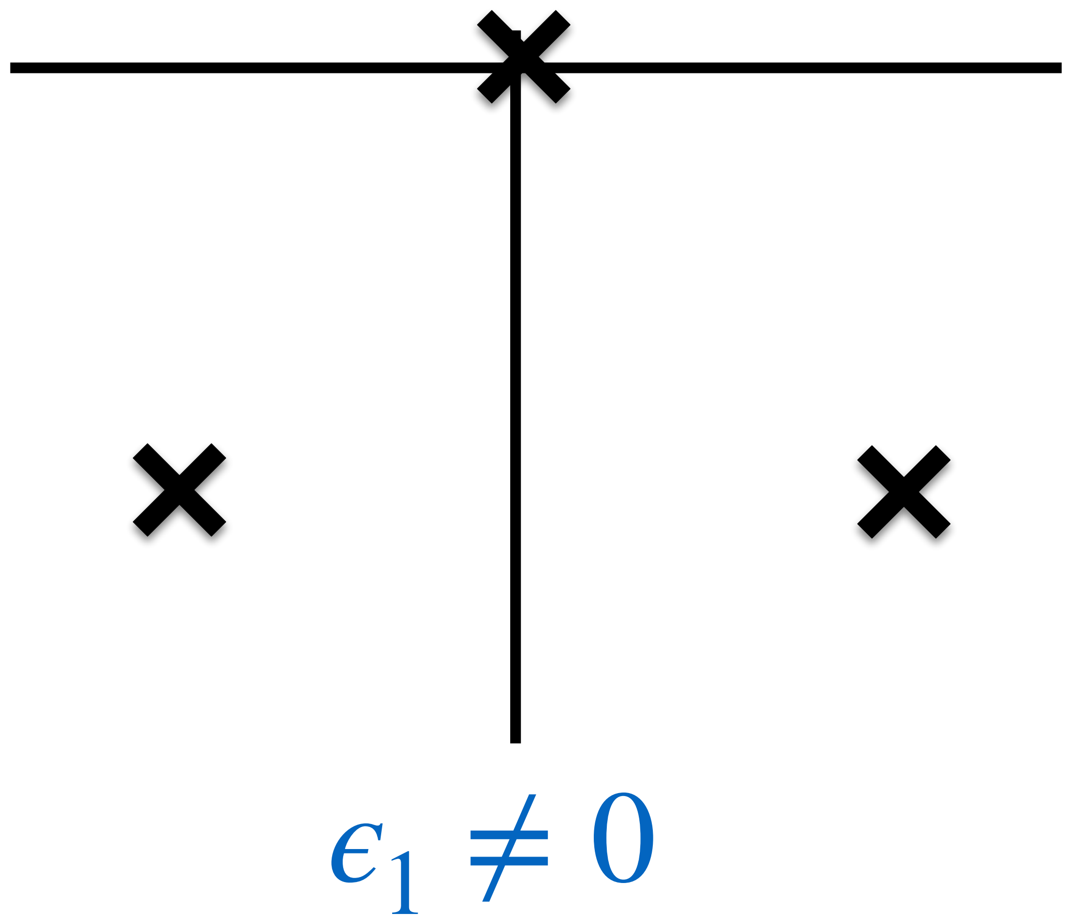


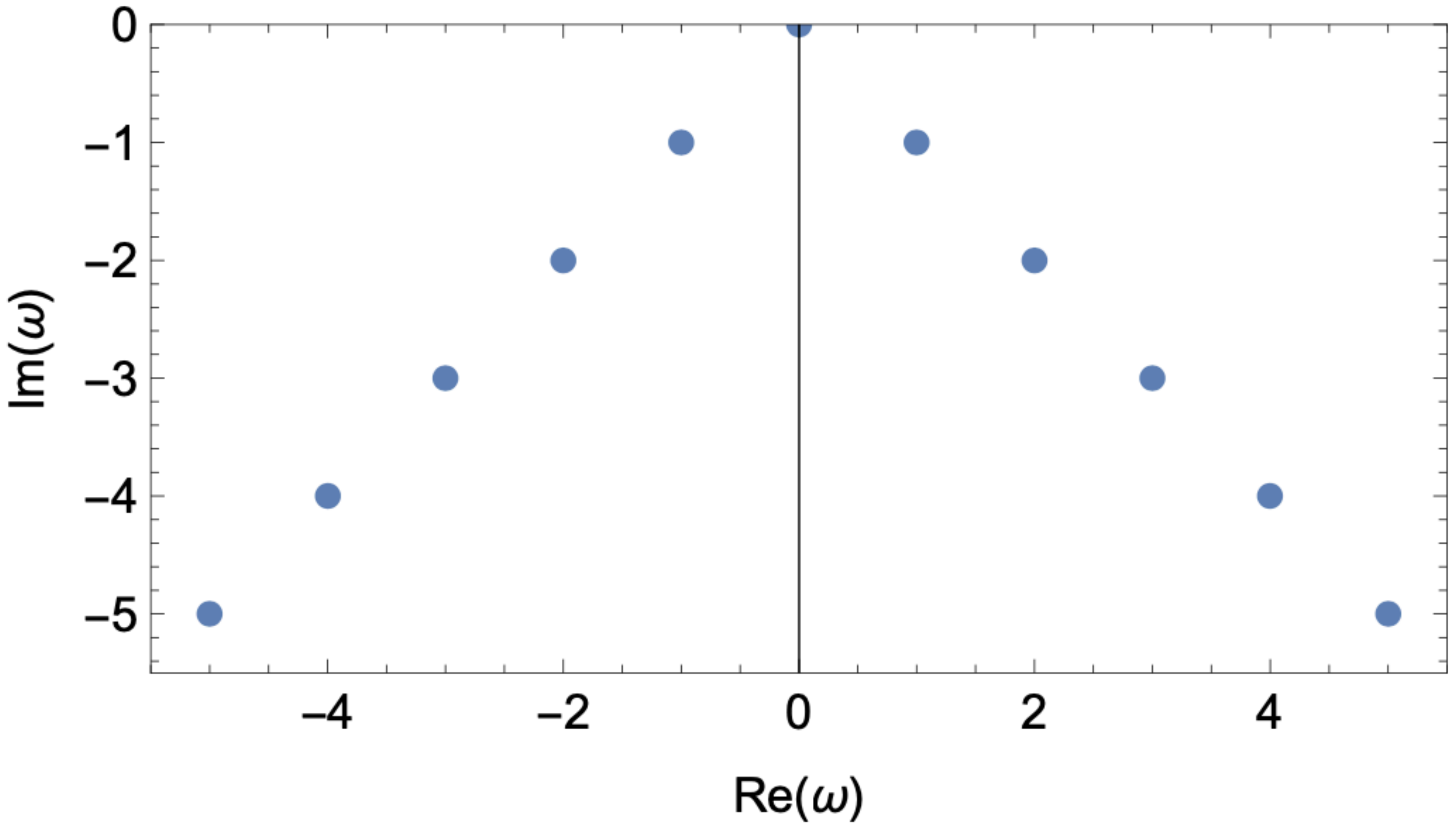
hight $\omega \sim k$

- low-ω: diffusive+ damping modes (relaxation of hidden E-fields)
- high-ω: propagation of hidden goldstone with velocity g^2/f^2
- Equivalent to Maxwell-Cattaneo $\partial_t \vec{j} = -\frac{1}{\tau_J}(\vec{j} - D\vec{\partial}n); \partial_\mu J^\mu = 0$

Quasi-normal Modes as Massive Photons







- Holo-like (Christmas tree) modes by tuning f_n, g_n, ϵ_n

Continuum limit $K \to \infty$

- 4+1d gauge theory in curved spacetime: "n" labels fifth coord. $\rho_n = na$

$$\mathscr{L} \sim \sqrt{-h}\, h^{MP} h^{NQ} F_{MN} F_{PQ} \quad (f(\rho), g(\rho), \epsilon(\rho), \kappa(\rho)) \to \text{metric}$$

  - Nearest neighboring=> locality in ρ
  - Hidden photons lives on the slices along ρ
- Holo. model is a subclass of theories with breaking hidden symmetry
  - Dissipation from $\mathscr{A}_1$ (horizon)

$$V \text{ - - - - - - } A_K \quad \ldots \quad A_n \text{ - - - - - } A_{n-1} \quad \text{ - - - - - } (A)^1$$

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Unbroken Hidden Symmetry

- No hidden gauge fields : $\varphi_m(x)$, ~~$A_{\mu,m}$~~
- Enhanced shift symmetry: $\varphi_m(x) \to \varphi_m(x) + \lambda_m(\vec{x})$.

~~$m^2(\varphi_m - \varphi_{m+1})^2$~~ $\longrightarrow$ $Re\,\omega_{\text{mode}}(q=0) = 0$

E.o.M: $\partial_t(\tilde{f}^2\partial_t\varphi_m) + d\vec{v}_m \cdot \partial_t\vec{\partial}\varphi_m =$ dissipation

($\vec{\partial}\varphi_m$: no ; $\partial_t\vec{\partial}\varphi_m$:Yes)

$\Downarrow$ $m \sim \vec{p}, n(x,\vec{p}) \sim f^2\partial_t\varphi_m(x)$

Kinetic theory: $\partial_t n(t,\vec{x},\vec{p}) + \vec{v}\cdot\vec{\partial}n(t,\vec{x},\vec{p}) = \ldots$

Else et al 2402.14066;
Delacretaz et al, 2203.05004

Hidden U(1) and Liouville Theorem

Else et al 2402.14066;
Delacretaz et al, 2203.05004

- The origin of hidden U(1) in kinetic theory: quasi-particles at different patches of Fermi surface (F.S.) can choose their phase independently
- The resulting Noether current represents the preservation of phase space volume without collision (Liouville theorem)
- Possible applications in strongly coupled system such as Landau Fermi liquid, non-Fermi liquid

From NTFPs to (generalized) Hydrodynamics

A lot of citations the last years! For an easy intro/review see: B. Doyon, et. al Phys. Rev. X **15**, 010501 (2025)

Generalized Hydrodynamics $\leftrightarrow$ Hydro for **integrable systems**

$$\partial_t q_n + \partial_x j_n = 0$$

Follows same logic as usual hydrodynamics but taking into account all conserved quantities

$\rightarrow$ **local GGE instead of thermal state**

➡ Large/infinite number of extensive conserved quantities

➡ strongly restricts dynamics (Gibbs ensemble $\rightarrow$ Generalized Gibbs ensemble)

➡ Long-lived quasiparticles

Gradient expansion of currents leads to simplified equations at Euler scale

$$\partial_t \rho_\lambda + \partial_x \left(v_\lambda^{\text{eff}}[\rho]\rho_\lambda \right) = 0$$

Generally: integrability is rare, but **near-integrability** has pretty large regime of applicability

$$\partial_t q_n + \partial_x j_n = \mathcal{I}_n\,[q]$$

Integrability breaking terms $\leftrightarrow$ generalized Boltzmann collision term $\mathcal{I}_n$

Can universality of the quasi-1D NTFP be phrased as universality of integrability breaking corrections?

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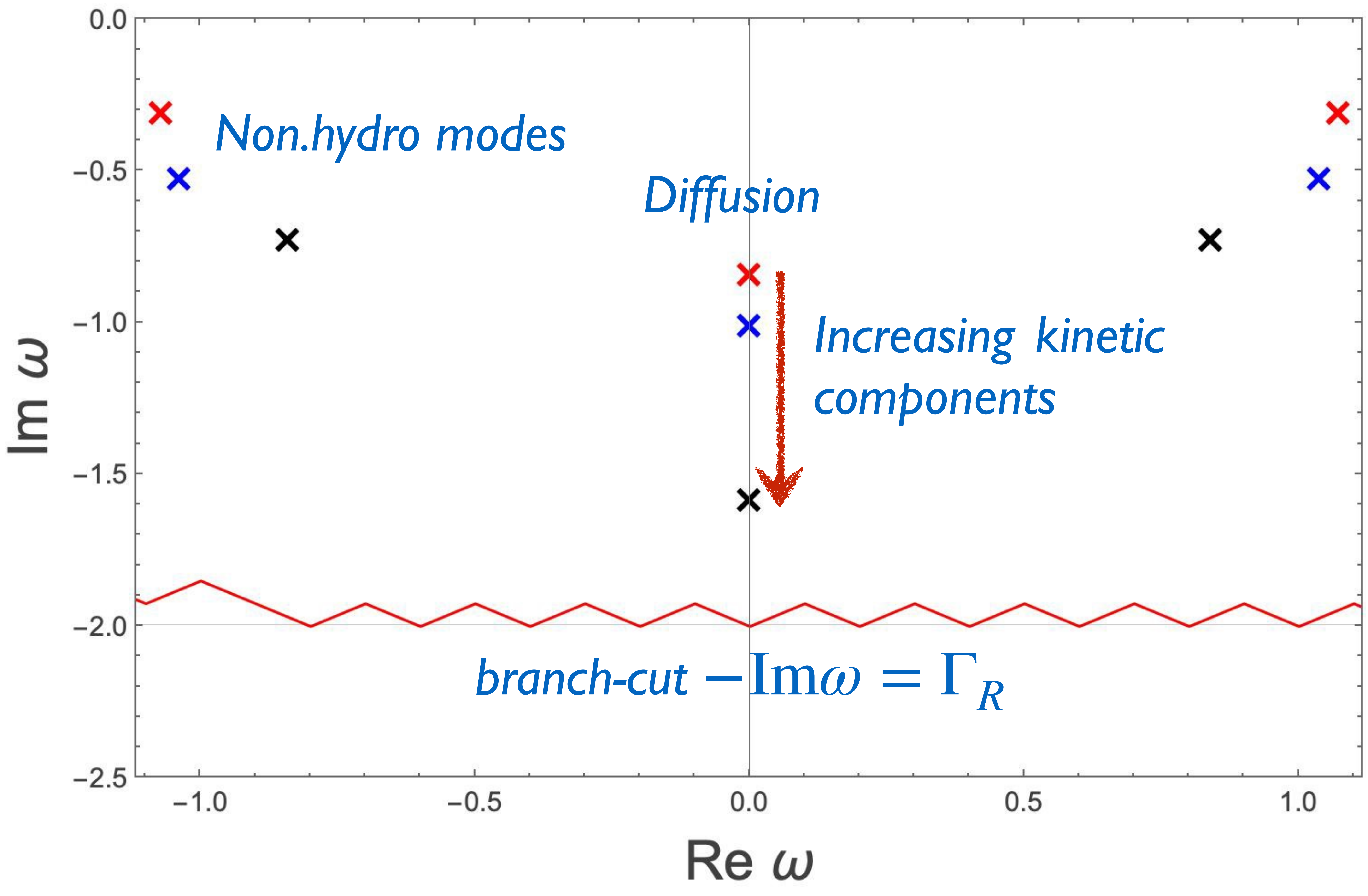
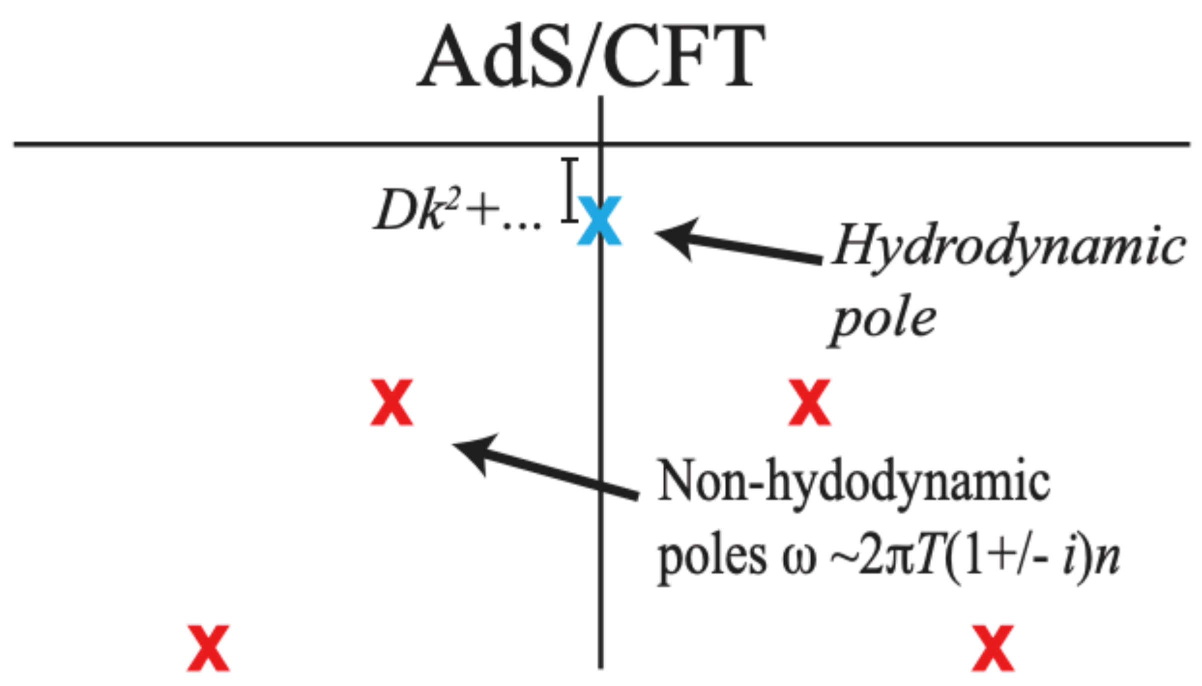
Mixture

j^μ= phase fields of unbroken symmetry + gauge fields of broken phase

- Application:
  - QGP which is kinetic-theory like in UV and holo.-like in IR
  - Unitary fermi gas?

One hidden gauge field hybrids with RTA kinetic theory





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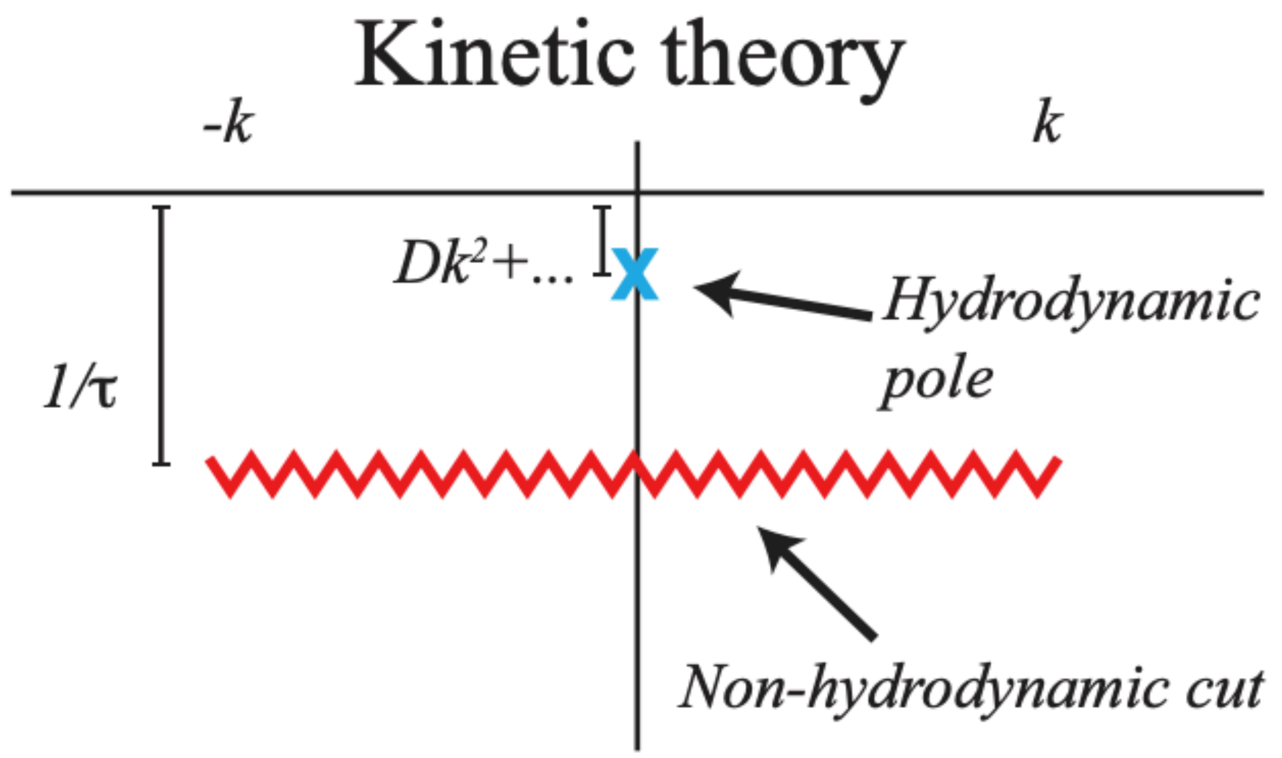

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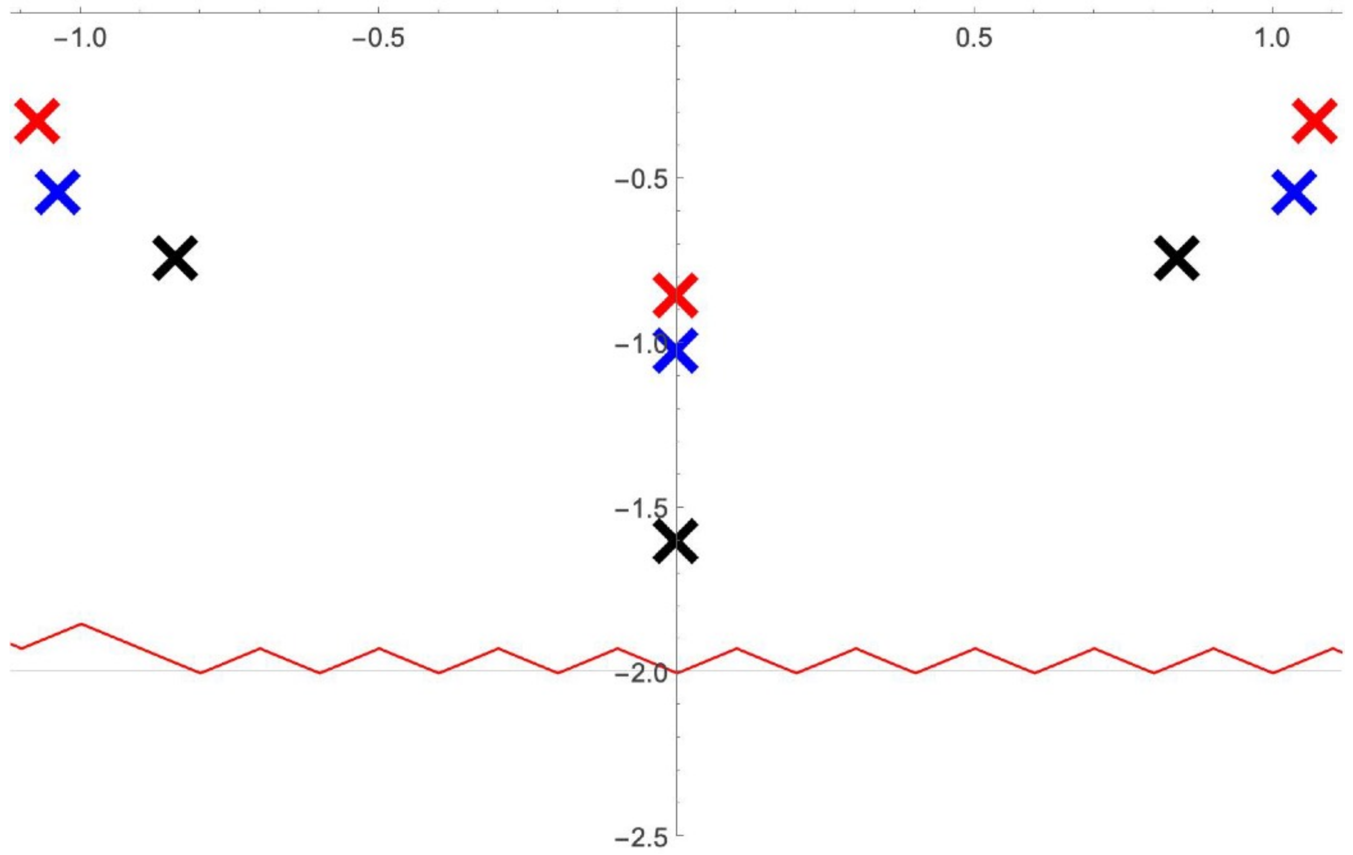


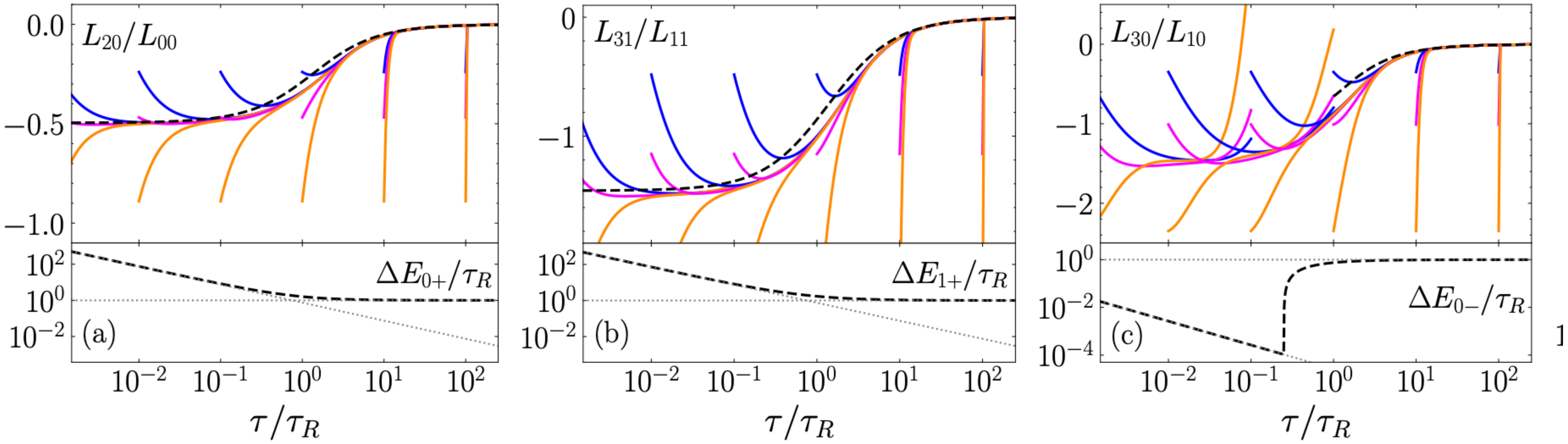
Mixture

Hidden symmetry tightly constrains excitations structure

Hidden Symmetry and Attractors

Non-hydro. attractor are observed in kinetic theory

Brewer-Weiyao Ke-Li Yan-YY, PRD Letter 2024



P_L/ϵ

Ratios of other moments

$$L_{m,l}(\tau) \equiv \int_{\vec{p}} p\, P_l^m(\theta)\cos(m\phi)\, f(\vec{p};\tau)$$

Seel also Kurkela et. al, PRL 2020

Preservation of transverse phase space volume —— Unbroken U(1)

Summary and outlook

- Introducing hidden symmetry to describe diverse non-hydro. behavior in one and the same conceptual framework
- Future: extension to non-abelian symmetries
  - diffeomorphism: non-linear coupling among non-hydro. modes
  - $SU(N)$ (spin) *Zonglin Mo, YY in preparation*

Phonons as Goldstone Bosons

H. Leutwyler (University of Bern and CERN)

- Classification of attractors (universality class of NTFP) based on the hidden symmetry?
- Generative AI (organizing hidden layers in the neural network by symmetries)

Back-up

Nonlinear Bosonization of Fermi Surfaces: The Method of Coadjoint Orbits

Luca V. Delacrétaz,[1,2] Yi-Hsien Du,[1] Umang Mehta,[1,3] and Dam Thanh Son[1,2,4]

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Collisionless dynamics of general non-Fermi liquids from hydrodynamics of emergent conserved quantities

Dominic V. Else
Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada

Motivation for Non-hydro.

- Beyond "vanilla" hydro. : chaos, spin, critical dynamics, neuron network
- Studying the evolution of matter (e.g. QCD matter) with varying scale
- Thermalization and hydrodynamization
- This talk: behavior outside hydro. Regime
- (Not covered: including additional slow modes in hydro. regime)

e.g. Stephanov-Yin, 2018

Hidden Symmetry and Canonical Transformation

- Distribution at different time are related by canonical transformation in collisionless regime

$$f(t_0, \vec{x}, \vec{p}) = f(t, \vec{x} - \nabla^p \varphi(t, \vec{x}, \vec{p}), \vec{p} + \nabla \varphi(t, \vec{x}, \vec{p}))$$

- Kinetic equation can be equivalently formulated with infinite number of scalar fields $\varphi(t, x, \hat{p})$

- Linearized C.T. corresponds to infinite $U(1)$ (independent phase choice in phase space)

$\varphi(t, \vec{x}, \hat{p}) \leftrightarrow$ Hidden Goldstones $\phi^n(t, \vec{x})$ $(\hat{p} \sim n)$

Sum Rule for Transport Coefficients

$$\sigma = \sum_n \lambda_n$$ c.f. parallel circuit

$$\kappa = \sum_n \mu_n^{-1}$$ $G_R = \ldots + \kappa k^2$

$$\chi^{-1} = \sum_n (f_n)^{-2}$$

$$\frac{\tau_J}{\sigma} = \sum_n \left(\frac{\lambda_n}{\sigma}\frac{1}{g_n^2} - \epsilon_n\right)$$

- Second-order transport coeff. are sensitive to non-hydro excitations
  - Without "hidden photon", $\kappa = 0$
  - $g_n/f_n, (\mu_n \epsilon_n)^{-1} \leq 1$ (causality) constraints $\tau_J/D, \kappa$
- NB: AdS/CFT: $\tau_J/D = \pi/2$; kinetic theory: $\tau_J/D \geq 3, \kappa = 0$

Hidden Gauge Symmetry and Massive Vector Mesons

- Massive meson like ρ, a_1 can be treated as the vector boson of spontaneously breaking hidden local $SU(2)$

Bando et al, 1980s

- Generalization to finite (infinite) number of HLS (predecessor of AdS/QCD)

Son-Stephanov, 2004

Reproducing a host of hadronic phenomena with acceptable precision

Pion ~ hydro. modes

Massive meson ~ non-hydro. modes

Message