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# Quasinormal modes of nonthermal fixed points

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### Motivation

- Understand thermalization in quantum many body systems
- AdS/CFT: thermalization described by black hole QNMs



• Attractors: hydro, non-thermal

Can we identify QNMs that describe approach to **nonthermal attractors**?

# Holographic theories vs kinetic theory

Holography	Kinetic theory
Strongly coupled systems	Weakly coupled/dilute systems → Quasi-particles
Spacetime metric, fields	Distribution function: $f(t, p)$
Einstein eqs	Boltzmann eq: $\partial_t f(t, p) = -C[f](t, p)$
Infalling BC at horizon + normalizable at bdry ⇒ QNMs	Boltzmann eq is dissipative ⇒ QNMs
Single poles	Branch-cuts D. Moore [1803.00736] S. Rocha, Danhoni, Ingles, S. Denicol, Noronha [2404.04679]

# Nonthermal fixed points

- Far from equilibrium phenomenon
- Cold atom experiments, ultra-relativistic heavy-ion collisions, early universe dynamics
- Overoccupation
   + conservation laws





Gazo, Karailiev, Satoor, Eigen, Gałka, Hadzibabic [2312.09248] 3/11

# Self-similarity

$$f(t,p) = \left(\frac{t}{t_{ref}}\right)^{\alpha} f_s \left( \left(\frac{t}{t_{ref}}\right)^{\beta} p \right)$$

$$A(t) \qquad B(t)$$

• Universality



• Static frame:  $\bar{p} = B(t)p$   $\rightarrow$  analogous to static BH spacetime

 $A(t)^{-1}f(t,\bar{p}/B(t)) = f_s(\bar{p}) + \delta f(t,\bar{p})$ 

# **QNM** equation

- Time dependent operators appear as  $B(t)\partial_{B(t)}\delta f(t,\bar{p})|_{\bar{p}=const}$
- Equation dictates

$$\delta f(t,\bar{p}) = B(t)^{i\,\Omega} \delta f_{\Omega}(\bar{p})$$

**Power law** in time!  $\neq$  exponential for BHs/thermal state

• QNMs can be calculated from eigenvalue equation

$$i\Omega\delta f_{\Omega}(\bar{p}) = \hat{O}\delta f_{\Omega}(\bar{p})$$

• Pseudo-spectral method A. Janik, Plewa, Soltanpanahi, Spaliński [1503.07149]

#### Results

- Gluonic system dominated by small angle scatterings
- Discrete spectrum  $\Leftrightarrow$  BH spectrum
- Stable



#### Christmas tree structure

• Varying IR cut-off



# Pseudo-spectra

- Stability of QNM spectra
- Deeper  $\Rightarrow$  less stable

Arean, Garcia-Fariña, Landsteiner [2307.08751] Cownden, Pantelidou, Zilhão [2312.08352]



8/11

#### Mode collisions

• Observed/studied in holographic setting

Grozdanov, K. Kovtun, O. Starinets, Tadić [1904.01018]

• Modes settle on zero-cut off result after mode collision



# Conclusions

- Powerlaw decay  $\neq$  exponential
- Discrete spectrum  $\Leftrightarrow$  BHs



# Outlook

- Verify in cold atom experiments
- More realistic kinetic theories
- Hydrodynamic description
   near NTFPs
- NTFPs in holography

