College of Arts & Sciences
Department of Physics and Astronomy

Hydrodynamics of Spinning Holographic Fluids

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[arXiv: 2007.04345]

Outline

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- Setup (Fluctuations)
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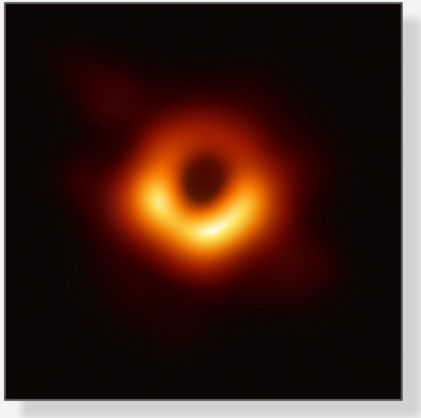
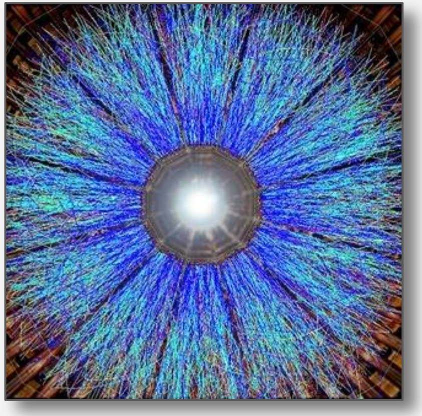
Credit: Event Horizon Telescope Collaboration



Credit: Brookhaven National Laboratory

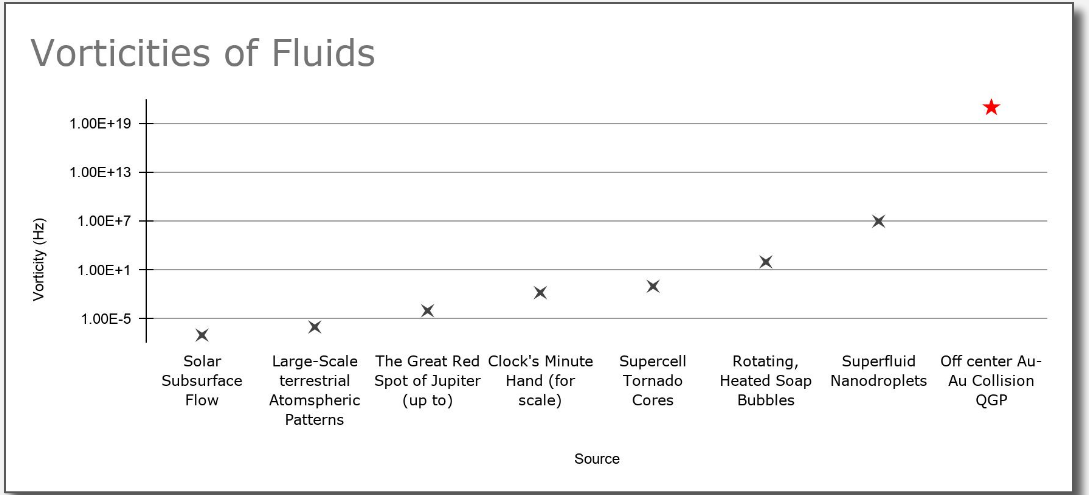


Motivation

Hyperon Polarization [2017 The STAR Collaboration]

Does a spinning 5D black hole correspond to a spinning strongly coupled fluid and what are it's hydrodynamics?

Credit: Brookhaven National Labs



Setup (Background) (Rotating)

- [1998 Hawking et at] for 5D
- [2004 Pope et al] for > 5D
  - In D dimensions: up to (D-1)/2 independent rotation parameters
- For 5D 2 independent rotation parameters {a, b}
- We set a = b for enhanced symmetry[2007 Soda et al] [2009 Murata]
- Linear superradiant instabilities when for D = 5 case [2009 Murata] [2005 Carter et al] [2014 Cardoso et al] at large enough a to constrain values a will take.

Reference Slide (General 5D Myers Perry AdS)

$$ds^2 = -\frac{\Delta}{\rho^2}\left(dt_H - \frac{a\sin^2\theta_H}{\Xi_a}d\phi_H - \frac{b\cos^2\theta_H}{\Xi_b}d\psi_H\right)^2 +$$

$$\frac{\Delta_{\theta_H}\sin^2\theta_H}{\rho^2}\left(adt_H - \frac{r_H^2+a^2}{\Xi_a}d\phi_H\right)^2 + \frac{\Delta_{\theta_H}\cos^2\theta_H}{\rho^2}\left(bdt_H - \frac{r_H^2+b^2}{\Xi_b}d\psi_H\right)^2 +$$

$$\frac{\rho^2}{\Delta}d{r_H}^2 + \frac{\rho^2}{\Delta_{\theta_H}}d{\theta_H}^2 +$$

$$\frac{1+r_H^2/L^2}{r_H^2\rho^2}\left(abdt_H - \frac{b(r^2+a^2)\sin^2\theta_H}{\Xi_a}d\phi_H - \frac{a(r^2+b^2)\cos^2\theta_H}{\Xi_b}d\psi_H\right)^2,$$

Metric Function Defs

Reference Slide (Metric Functions Hawking)

$$\Delta = \frac{1}{r_H^2}(r_H^2 + a^2)(r_H^2 + b^2)(1 + r_H^2/L^2) - 2M\,,$$

$$\Delta_{\theta_H} = 1 - \frac{a^2}{L^2}\cos^2\theta_H - \frac{b^2}{L^2}\sin^2\theta_H\,,$$

$$\rho = r_H^2 + a^2\cos^2\theta_H + b^2 sin^2\theta_H\,,$$

$$\Xi_a = 1 - a^2/L^2\,,$$

$$\Xi_b = 1 - b^2/L^2$$

Setup (Background) (a = b 5D Myers Perry AdS) Sigma Defs

$$ds^2 = -\left(1+\frac{r^2}{L^2}\right)dt^2 + \frac{dr^2}{G(r)} + \frac{r^2}{4}\left(4\sigma^+\sigma^- + (\sigma^3)^2\right) + \frac{2\mu}{r^2}\left(dt + \frac{a}{2}\sigma^3\right)^2$$ [2009 Murata]

$$G(r_+) = G(r_-) = 0$$

Round 3-Sphere ie“dΩ^2”

Vanishes at r = ∞

μ ≡ Mass Parameter, a ≡ Angular Momentum Parameter

r_+ ≡ Outer Horizon Radius, L ≡ AdS Radius

$$G(r) = 1 + \frac{r^2}{L^2} - \frac{2\mu(1-a^2/L^2)}{r^2} + \frac{2\mu a^2}{r^4}$$

$$\mu = \frac{r_+^4(L^2+r_+^2)}{2L^2r_+^2 - 2a^2(L^2+r_+^2)}$$

$$L = 1$$

Reference Slide (Sigma Definitions)

$$\sigma^1 := -\sin\psi d\theta + \cos\psi \sin\theta d\phi\,,$$
$$\sigma^2 := \cos\psi d\theta + \sin\psi \sin\theta d\phi\,,$$
$$\sigma^3 := d\psi + \cos\theta d\phi\,,$$

$$\sigma^{\pm} := \frac{1}{2}\left(\sigma^1 \mp i\sigma^2\right)$$

$$\sigma^t := dt$$

$$\sigma^r := dr$$

Setup (Linear Perturbations)

$$i\partial_t h_{ab} = \omega h_{ab} \qquad -\partial_i \partial_i h_{ab} = \mathcal{J}(\mathcal{J}+1)h_{ab}$$

$$i\partial_3 \sigma^r = 0 \quad i\partial_3 \sigma^t = 0$$
$$i\partial_3 \sigma^3 = 0 \quad i\partial_3 \sigma^\pm = \pm\sigma^\pm$$
$$i\partial_3 D^{\mathcal{J}}_{\mathcal{K}} = \mathcal{K} D^{\mathcal{J}}_{\mathcal{K}}$$

$$h_{ab} \propto \sigma^{(a}\sigma^{b)} e^{-\omega t} D^{\mathcal{J}}_{\mathcal{K}-\sigma\text{s' charge}}$$

Find the equations of motion (EOM) at linear order. → Perform a large temperature limit on EOMs r,J,K,r+ → ∞. → Keep the leading order terms wrt r. → Solve for ω, the Quasinormal Modes at given parameters.

Reference Slide (Large Temperature Limit)

Rescale

$$\omega \to \alpha 2\nu r_+/L$$

$$\mathcal{J} \to \alpha j r_+/L$$

$$r_+ \to \alpha r_+$$

$$r \to \alpha r$$

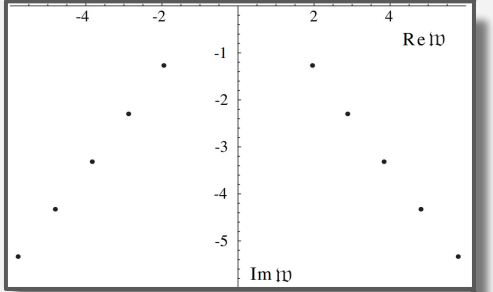
Then perform the α limit

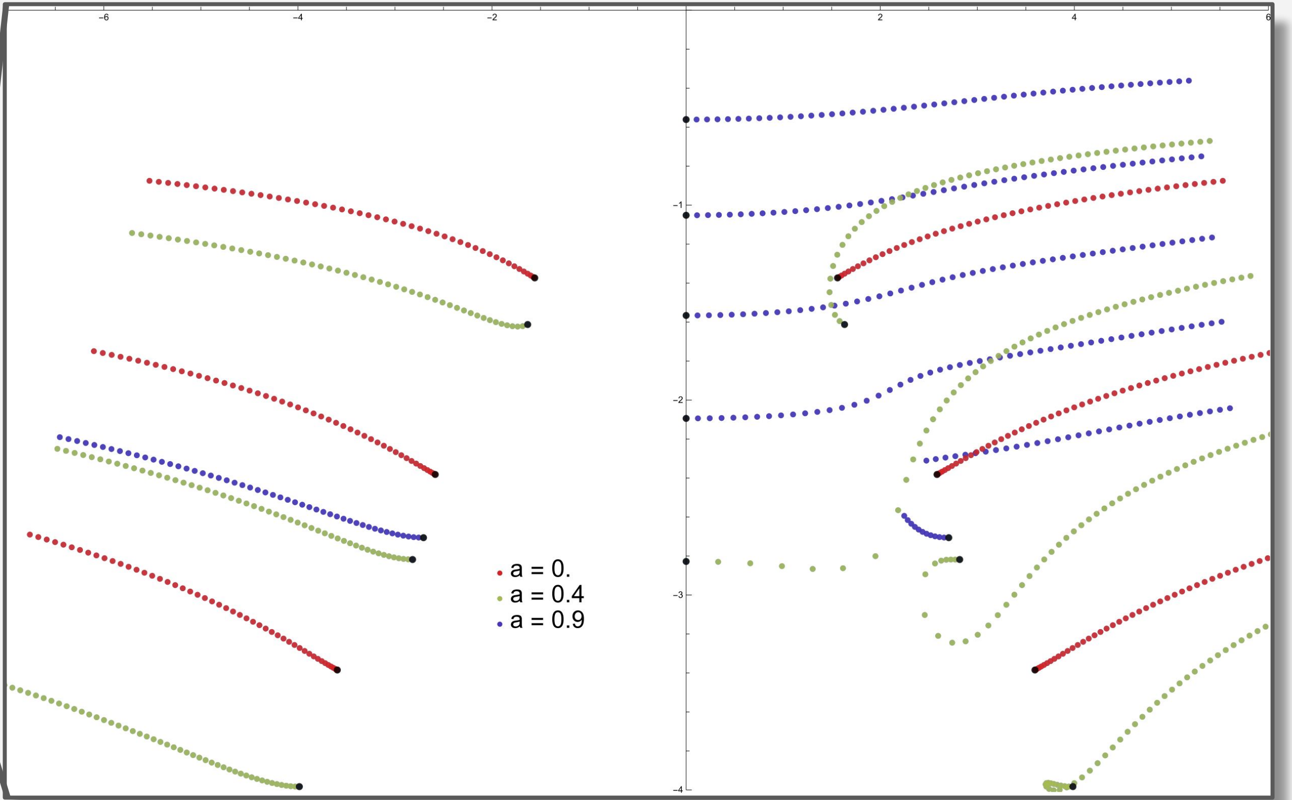
$$\alpha \to \infty$$

QNMs Example (Tensor Sector/Scalar Channel)

$$\mathcal{K} = \mathcal{J} + 2$$

compare with the QNM "Christmas Tree"
[2002 Starinets]





Results (Shear Channel/Vector Sector)

Defines Sector

$$\mathcal{K} = \mathcal{J} + 1$$

Dispersion Relations

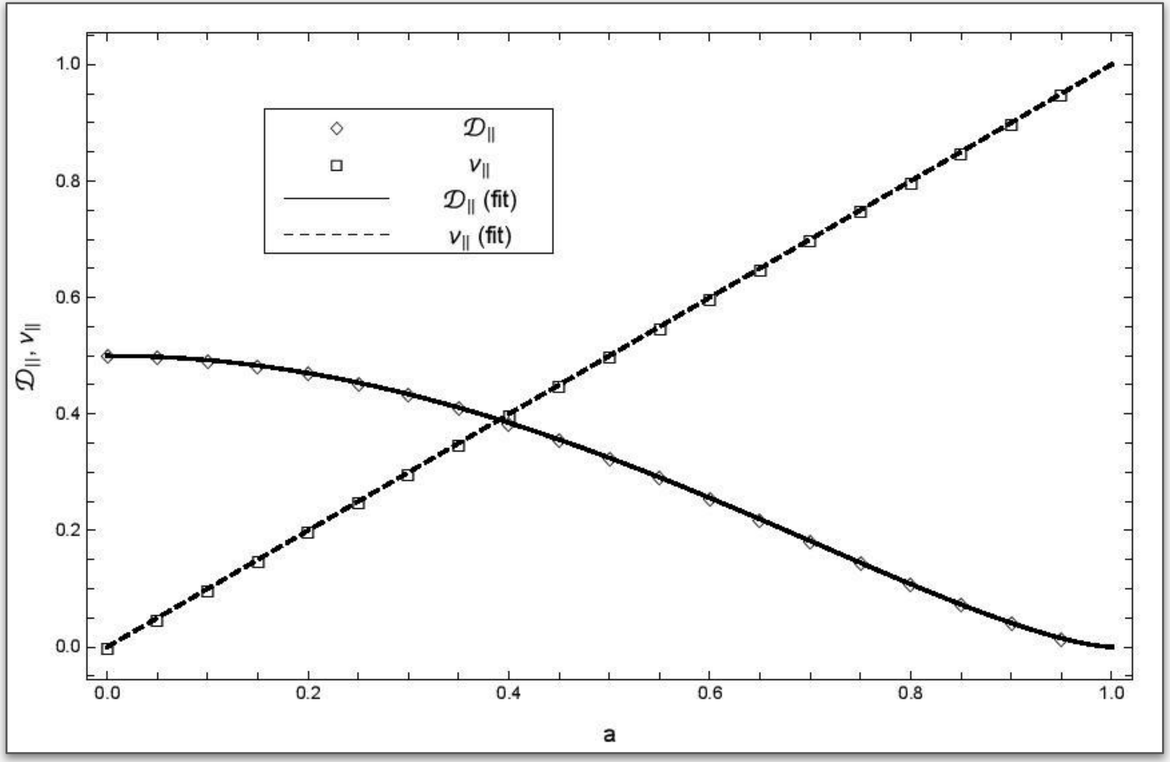
$$\nu = v_{||} j - i\mathcal{D}_{||} j^2$$

$$v_{||} = a$$

$$\mathcal{D}_{||} = \frac{1}{2}(1 - a^2)^{3/2}$$

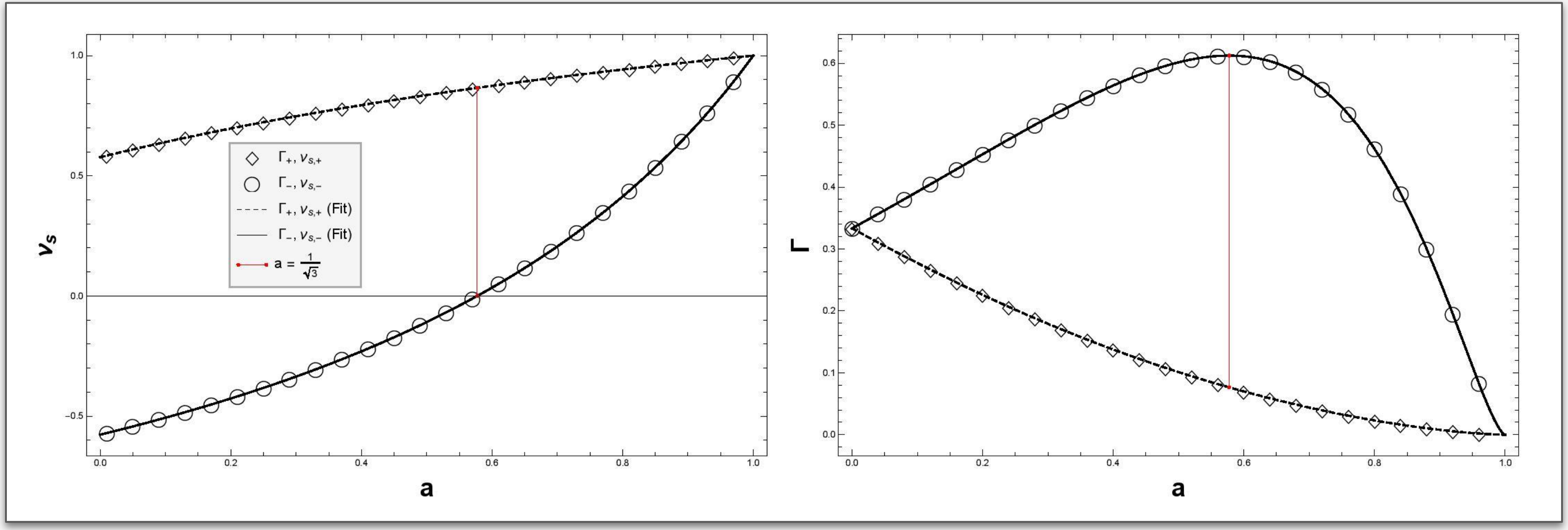
compare to [2019 Kovtun see eq (4.4)] [2020 Hoult et al]

$$\frac{\eta_{||}}{s} = \frac{1}{4\pi}(1 - a^2)$$



[2010 Natsuume et al] [2012 Rebhan et al] [2011 Erdmenger et al]

Results (Sound Channel/Scalar Sector)



Defines Sector $\mathcal{K} = \mathcal{J}$

compare to [2019 Kovtun see eq (4.16)] [2020 Hoult et al]

Dispersion Relations

$$\nu = v_{s,\pm} j - i\Gamma_{s,\pm} j^2 \,,$$

$$v_{s,\pm} = \frac{a \pm \frac{1}{\sqrt{3}}}{1 \pm \frac{a}{\sqrt{3}}} \,,$$

$$\Gamma_{s,\pm} = \frac{1}{3} \frac{\left(1 - a^2\right)^{3/2}}{\left(1 \pm \frac{a}{\sqrt{3}}\right)^3} \,,$$

Conclusion

We find that a spinning large temperature black hole has hydrodynamic modes, depending on a.

Should be identified with modes of a relativistic spinning (strongly coupled) fluid.

There are two speeds of sound and two sound attenuation coefficients and two shears.

Transport coefficients are determined by their value at rest: $\eta_{||}(a) = \eta_0\sqrt{1 - a^2}$.

Outlook: Non-hydrodynamic modes, hydrodynamic convergence radius [2019 Grozdanov et al JHEP] [2019 Grozdanov et al PRL], Complexity?! [2020 Balushi et al ArXiv]

Thank you for listening to my talk!

Credit David Madore