

Universal Spectrum of 2d Conformal Field Theory in the Large c Limit

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Joint work with **Thomas Hartman** and **Christoph A. Keller**,
[arXiv:1405.5137](https://arxiv.org/abs/1405.5137).

The Cardy limit

- Black hole entropy in AdS_3 gravity matches the Cardy formula for a modular invariant CFT_2 [Strominger 1998],

$$S_{\text{BH}}(E_L, E_R) = S_{\text{Cardy}}(E_L, E_R) = 2\pi\sqrt{\frac{c}{6}E_L} + 2\pi\sqrt{\frac{c}{6}E_R}.$$

- However, the Cardy formula applies in the Cardy limit

$$c \text{ fixed}, \quad E_{L,R} \rightarrow \infty$$

while the match to Bekenstein-Hawking holds for

$$c \rightarrow \infty, \quad E_{L,R} \sim c.$$

- Our work extends the Cardy formula to the semiclassical regime under mild assumptions on the light spectrum.

Light spectrum and modular invariance

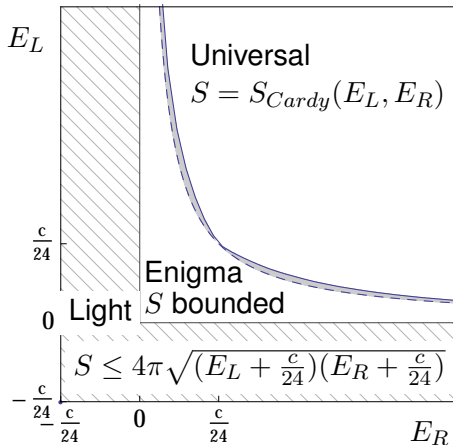
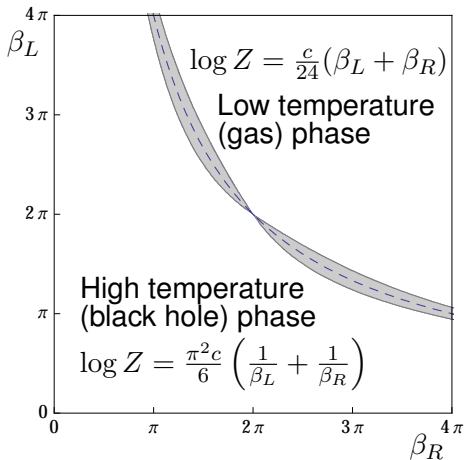
- Consider angular potential with real temperatures $\beta_{L,R} \geq 0$ (Lorentzian signature).
- Assume light spectrum is sparse,

$$\rho(E_L, E_R) \lesssim \exp \left[4\pi \sqrt{\left(E_L + \frac{c}{24}\right) \left(E_R + \frac{c}{24}\right)} \right], \quad E_{L,R} < 0.$$

- Demand real modular invariance of the partition function,

$$Z(\beta_L, \beta_R) = Z\left(\frac{4\pi^2}{\beta_L}, \frac{4\pi^2}{\beta_R}\right).$$

Bounds on partition function and spectrum



Bounds on partition function and spectrum

- The partition function exhibits universal behavior

$$\log Z(\beta_L, \beta_R) = \frac{c}{24} \max \left(\beta_L + \beta_R, \frac{4\pi^2}{\beta_L} + \frac{4\pi^2}{\beta_R} \right) + \mathcal{O}(c^0)$$

outside a small sliver surrounding the line $\beta_L \beta_R = 4\pi^2$.

- The entropy equals $S_{\text{Cardy}}(E_L, E_R)$ at high enough energies and is bounded above for intermediate values.
- Numerical evidence suggests the sliver is an artifact of our method, in which case the partition function is universal for all $\beta_L \beta_R \neq 4\pi^2$ and the Cardy entropy formula holds for all $E_L E_R > (c/24)^2$.

Comparison to AdS_3 gravity

- The two regions of universal behavior in the CFT free energy correspond to the thermal AdS and BTZ black hole phases in Lorentzian AdS_3 in the canonical ensemble.
- 3d gravity exhibits other solutions with $\mathcal{O}(c)$ entropy that obey our assumptions, e.g. S^2 -localized black holes [de Boer *et al.* 1998], moulting black holes [Bena *et al.* 2012].
- These “enigma” phases never dominate the canonical ensemble, however they do dominate over the Cardy entropy in small intervals at intermediate energies.

Thank you!

