Probing Black Hole Microstates

Marcel Hughes

Supervisor: Dr Rodolfo Russo

m.r.r.hughes@qmul.ac.uk

Queen Mary University of London

Science & Technology Facilities Council

UK Research and Innovation

The Problem(s) with Black Holes

(Hawking `74)

GR $\Rightarrow$ Singularity + Horizon $\Longrightarrow \begin{cases} \text{Information loss} \\ S_{BH} \end{cases}$

https://rationalisingtheuniverse.org/2019/02/05/black-holes-5-fuzzballs

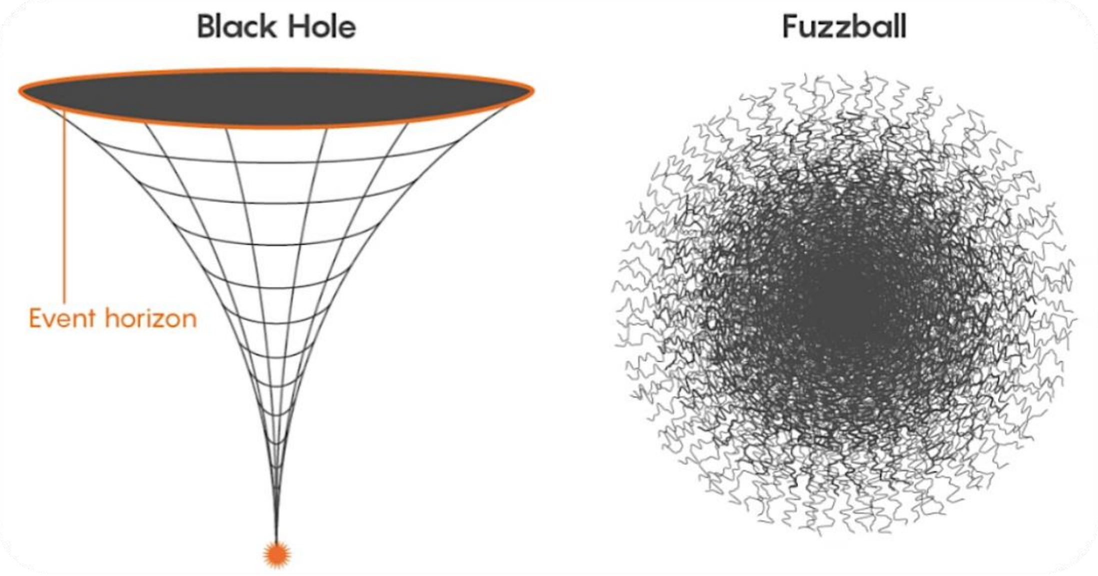
The Problem(s) with Black Holes

(Hawking `74)

GR ⇒ Singularity + Horizon ⟹ $\begin{cases} \text{Information loss} \\ S_{BH} \end{cases}$

Fuzzball Proposal

- A potential resolution within the framework of string theory.
- "A black hole is microscopically described by an ensemble of (**pure**) microstates".
- In the supergravity limit, a class are described by **regular** and **horizonless** microstate geometries.



https://rationalisingtheuniverse.org/2019/02/05/black-holes-5-fuzzballs

Queen Mary University of London

The Fuzzball Proposal

- One of the families of microstate geometries that have been explicitly constructed for the D1D5 system is (1/8th BPS case) (Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner)

Queen Mary
University of London

The Fuzzball Proposal

- One of the families of microstate geometries that have been explicitly constructed for the D1D5 system is ($1/8^{th}$ BPS case) (Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner)

$$ds_6^2 = -\frac{2}{\sqrt{\mathcal{P}}}(dv+\beta)(du+\omega) + \sqrt{\mathcal{P}}\,\Sigma\left(\frac{dr^2}{x} + d\theta^2\right) + \sqrt{\mathcal{P}}\left[x\,\sin^2\theta\,d\phi^2 + r^2\cos^2\theta\,d\psi^2\right]$$

The Fuzzball Proposal

- One of the families of microstate geometries that have been explicitly constructed for the D1D5 system is (1/8th BPS case) (Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner)

$$ds_6^2 = -\frac{2}{\sqrt{\mathcal{P}}}(dv+\beta)(du+\omega) + \sqrt{\mathcal{P}}\,\Sigma\left(\frac{dr^2}{x} + d\theta^2\right) + \sqrt{\mathcal{P}}\left[x\,\sin^2\theta\,d\phi^2 + r^2\cos^2\theta\,d\psi^2\right]$$

$$\mathcal{P} = Z_1 Z_2 - Z_4^2 \qquad \beta = \frac{R\,a^2}{\sqrt{2}\,\Sigma}(\sin^2\theta\,d\phi - \cos^2\theta\,d\psi) \qquad \omega = \frac{R\,a^2}{\sqrt{2}\,\Sigma}(\sin^2\theta\,d\phi + \cos^2\theta\,d\psi)$$

$$Z_1 = 1 + \frac{R^2\,a_0^2}{Q_5\Sigma} + \frac{R^2\,a^2\,b^2\cos 2\phi\,\sin^2\theta}{2Q_5\,x\,\Sigma} \qquad Z_2 = 1 + \frac{Q_5}{\Sigma} \qquad Z_4 = R\,a\,b\,\frac{\cos\phi\,\sin\theta}{\sqrt{x}\,\Sigma}$$

$$\Sigma = r^2 + a^2\cos^2\theta \qquad a_0^2 = a^2 + \frac{b^2}{2} \qquad x = r^2 + a^2$$

Queen Mary University of London

The Fuzzball Proposal

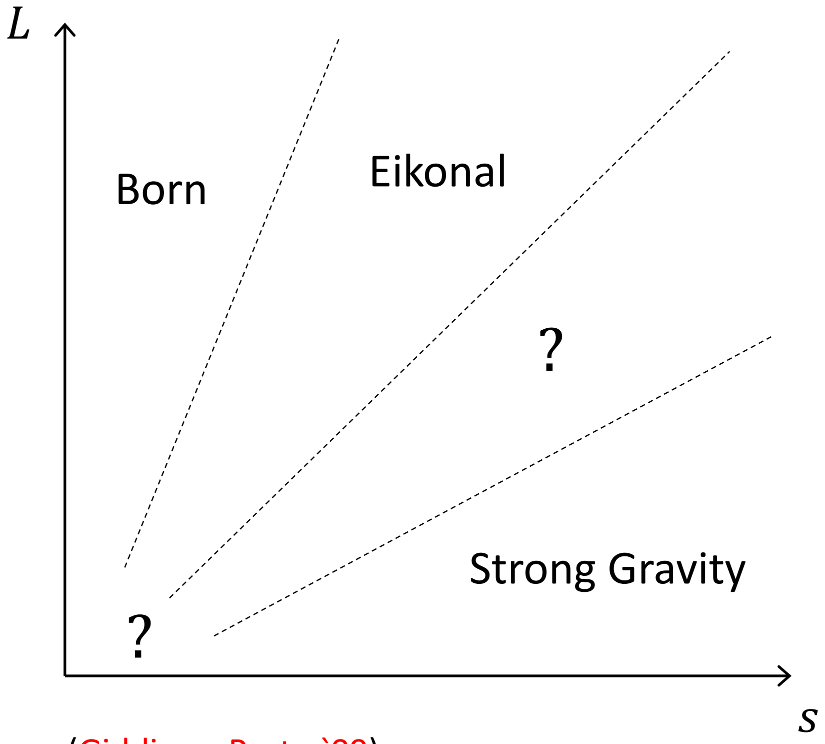
- One of the families of microstate geometries that have been explicitly constructed for the D1D5 system is (1/8th BPS case) (Bena, Giusto, Martinec, Russo, Shigemori, Turton, Warner)

$$ds_6^2 = -\frac{2}{\sqrt{\mathcal{P}}}(dv+\beta)(du+\omega) + \sqrt{\mathcal{P}}\,\Sigma\left(\frac{dr^2}{x} + d\theta^2\right) + \sqrt{\mathcal{P}}\left[x\,\sin^2\theta\,d\phi^2 + r^2\cos^2\theta\,d\psi^2\right]$$

Interested in how specific physics differs in these microstates as compared to classical black holes. To go beyond the counting problem.

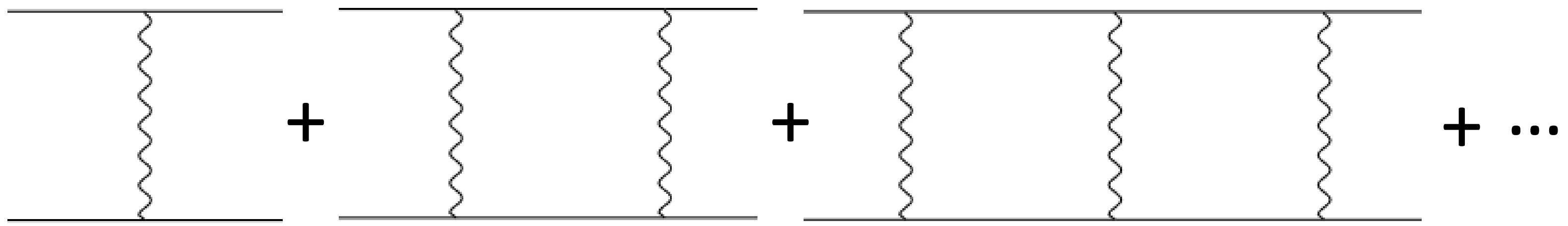
The Eikonal (Flat Space)

$2 \to 2$ Scattering

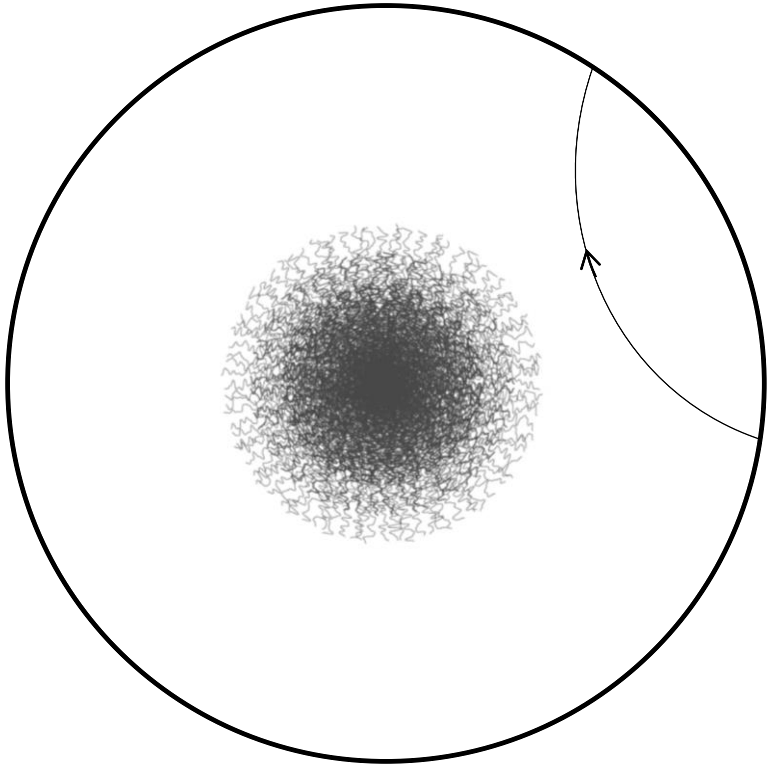


(Giddings, Porto `09)

- An observable that originated in the study of flat space scattering with $|s| \gg |t|$
- Leading contributions in energy at each order in $1/N$ resum to a phase $e^{i\delta(s,L)}$ ('t Hooft `87; Amati, Ciafaloni, Veneziano `87)
- At leading order, $\delta(s, L)$ is the tree level graviton ladder diagram



The Eikonal (AdS)



- For the case of scattering from a black hole, $\delta(s, L)$ can be computed from the geodesic length in a (GR) black hole background. (Parnachev et al.)

- We are generalising this to a classical action of the probe in a microstate geometry. (Stay tuned…)

Dual CFT Picture

- Can also study microstates using the 2d affine SCFT dual to their asymptotically $\mathrm{AdS}_3 \times S^3$ decoupling region.
- It was shown that the phase shift in a CFT is related to the Fourier transform of a 4-point correlator in the Regge limit. (Cornalba, Costa, Penedones, Schiappa `07)

$$e^{i\delta(\mathbf{p})} \propto \int d\mathbf{x}\, e^{-i\mathbf{p}\cdot\mathbf{x}} \langle \mathcal{O}_H \mathcal{O}_L \mathcal{O}_L \mathcal{O}_H \rangle_{\circlearrowleft}$$

- Has been studied using the Virasoro vacuum block contribution and matched to $\delta(s, L)$ for AdS black holes in Einstein gravity. (Kulaxizi, Seng Ng, Parnachev `18)
- Explicit D1D5 HHLL correlators have been constructed for certain classes of heavy operators $\mathcal{O}_H \Rightarrow$ can study δ beyond the classical black hole.

Queen Mary University of London

Summary

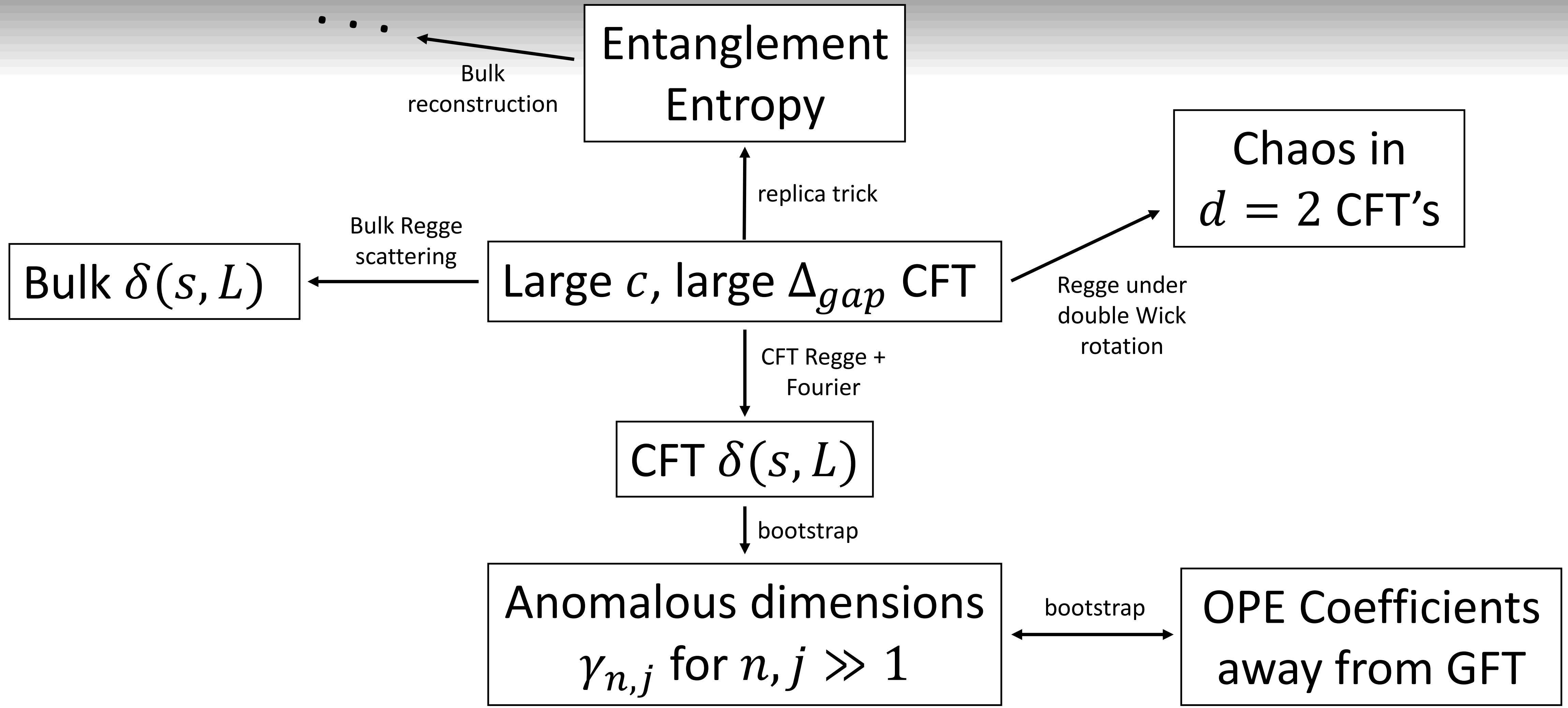
- The fuzzball proposal is one program of work to resolve the problems with our current description of black holes.

- Scattering in the eikonal regime is **one** piece of physics to study black holes beyond the thermal ensemble.

- The eikonal can be studied in both the **known** microstate geometries and from **known** HHLL correlators in the dual CFT.

Queen Mary University of London

Thank you for listening!


Entanglement Entropy
. . .
Bulk reconstruction
replica trick
Chaos in $d = 2$ CFT’s
Bulk Regge scattering
Bulk $\delta(s, L)$
Large c, large Δ_{gap} CFT
Regge under double Wick rotation
CFT Regge + Fourier
CFT $\delta(s, L)$
bootstrap
Anomalous dimensions $\gamma_{n,j}$ for $n, j \gg 1$
bootstrap
OPE Coefficients away from GFT