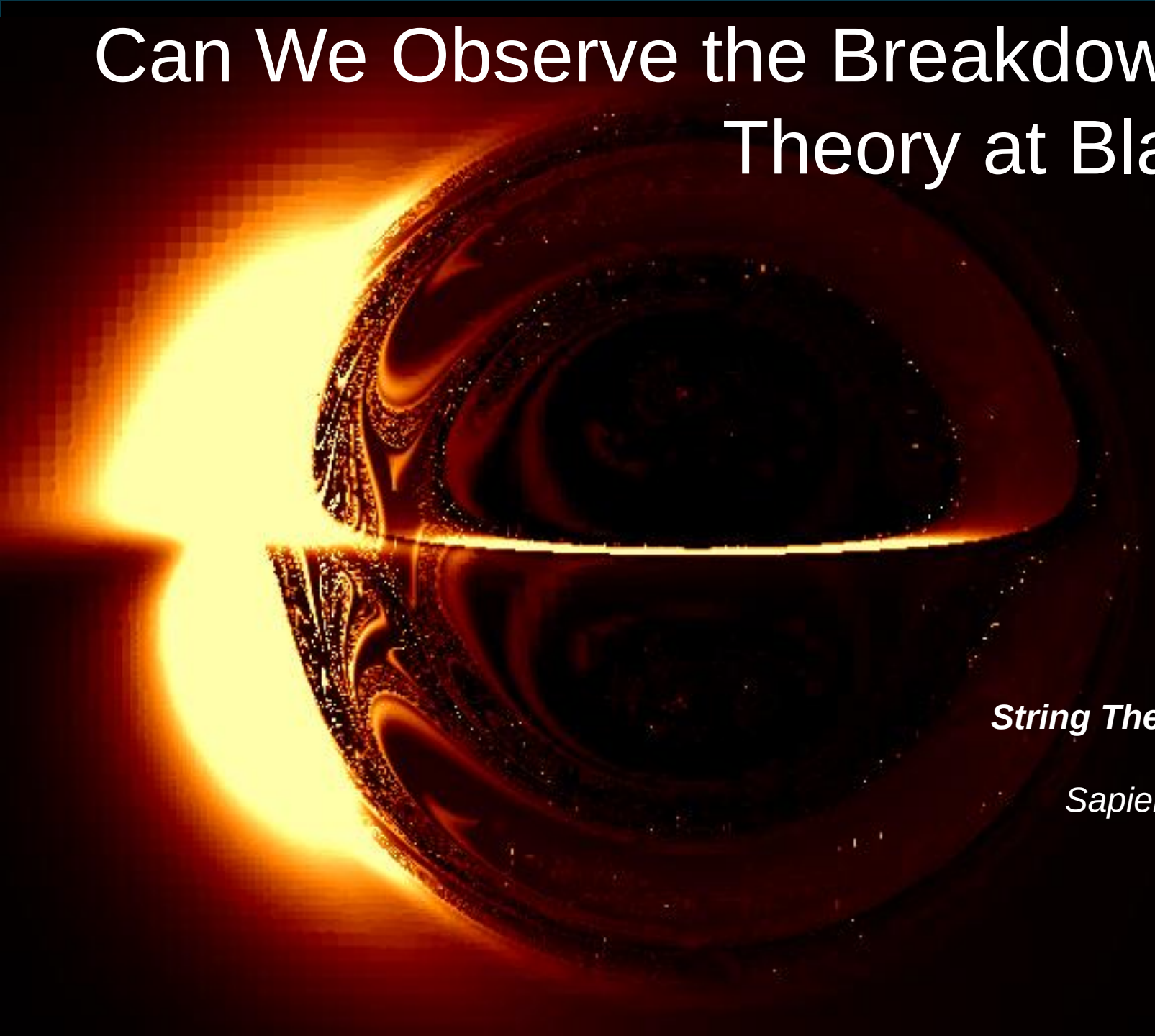
Can We Observe the Breakdown of Effective Field Theory at Black Hole Horizons?



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String Theory as a Bridge between Gauge Theory and Quantum Gravity

Sapienza University, Rome - February 17, 2025

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Overview: Three hints of EFT breakdown

- Black hole EFTs vs quantum corrections?

- Fuzzballs and large phase spaces
- Phase spaces and the swampland
- Higher-derivative corrections to (near-)extremal KN

Current work with Matilda Delgado, Sebastien Reymond, Thomas Van Riet; Bogdan Ganchev, Ludovico Machet, Simon Maenaut

Black holes: problems and observations

Theoretical problems:

- Singularity
- Horizon - entropy
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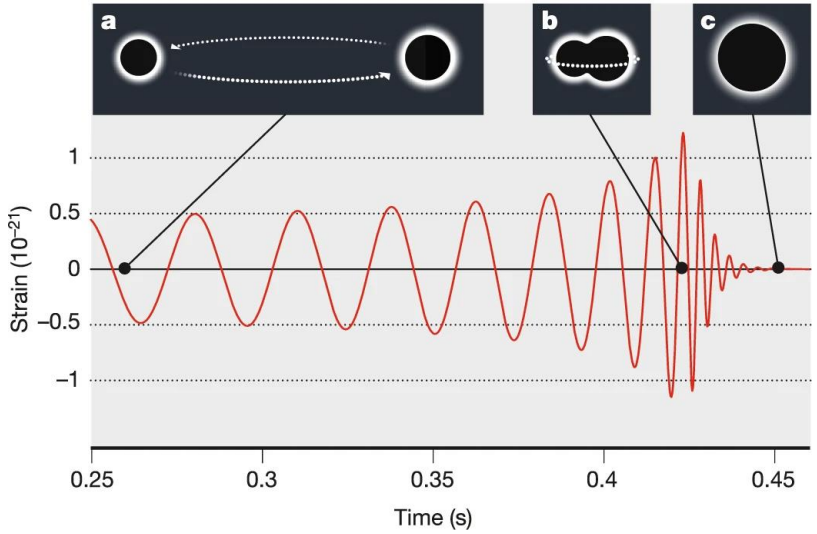
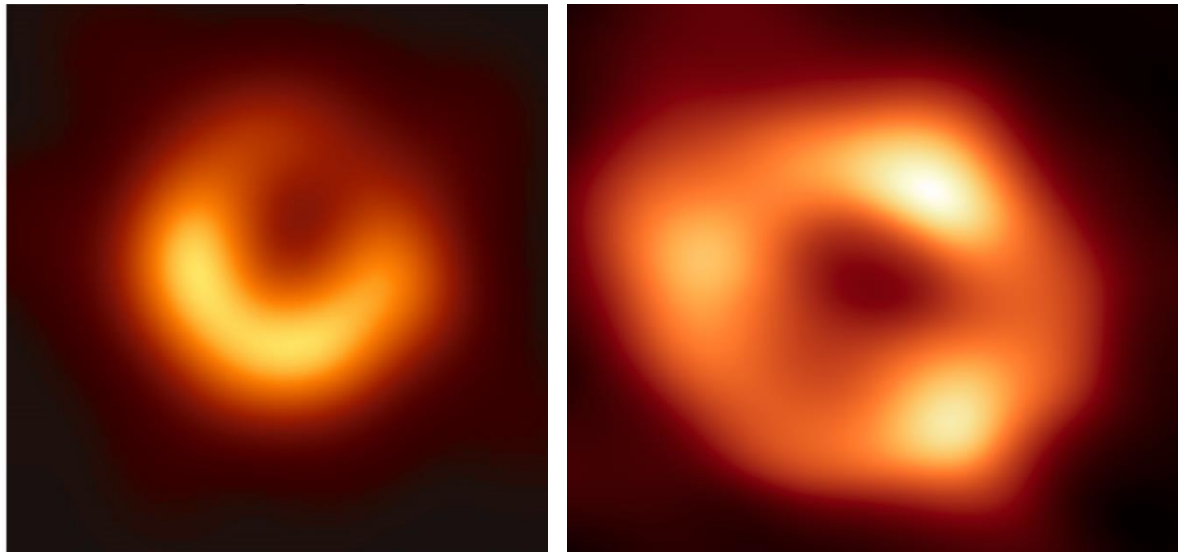


Observations:

- Gravitational waves from mergers
- BH imaging



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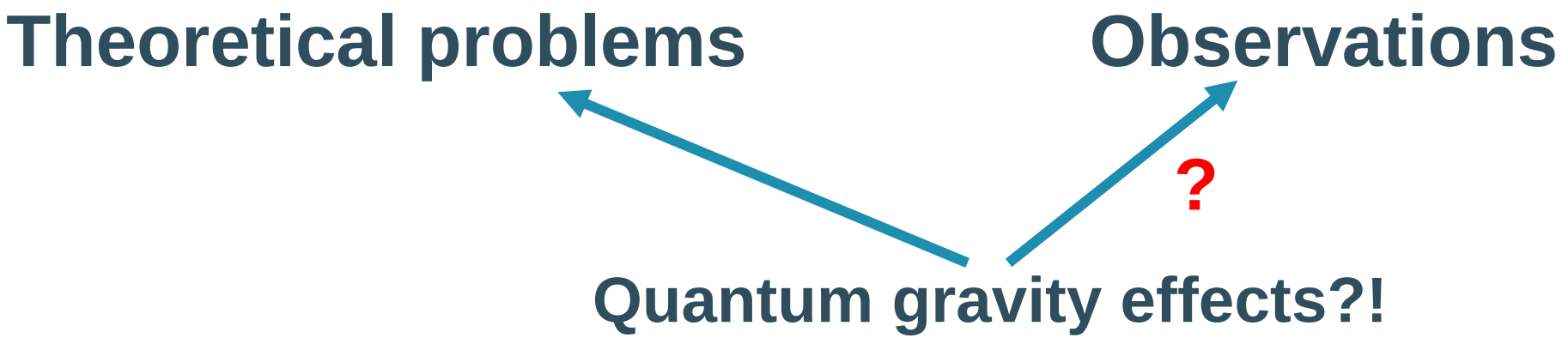

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- EFT mindset: low curvature – small corrections

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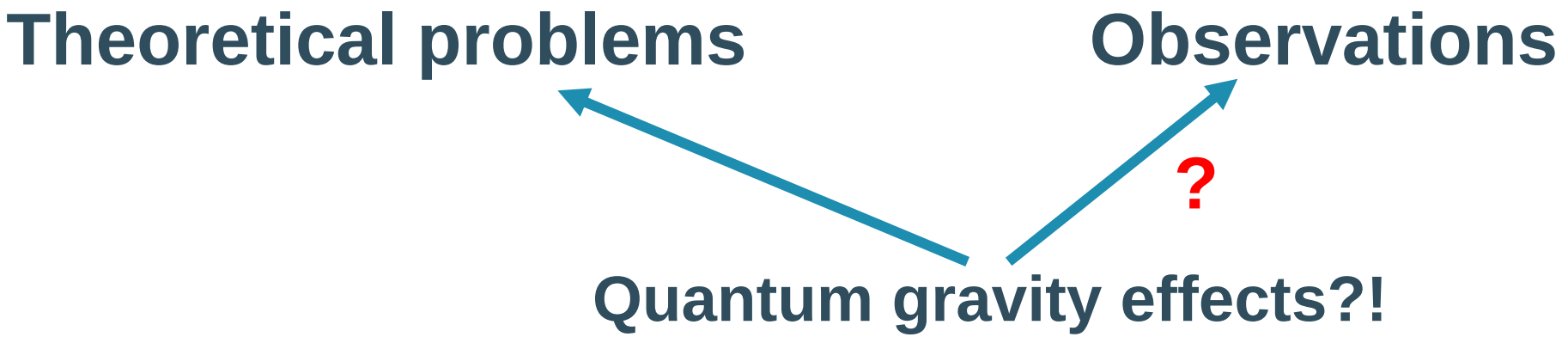

- Can we see QG effects in observations?
- EFT mindset: low curvature – small corrections
- But: EFT breakdown at horizon?

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- exp(S) = (# of microstates) = (# configurations of microstructure)
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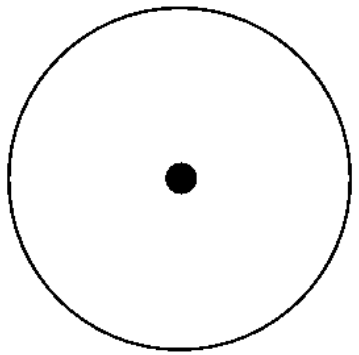

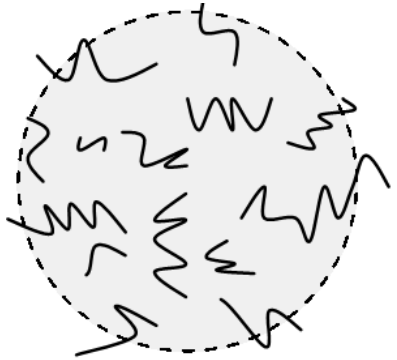

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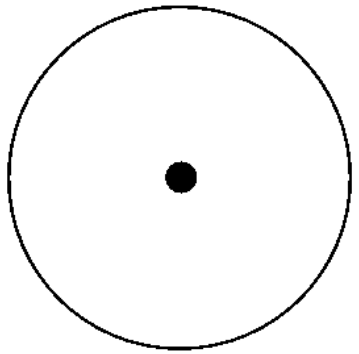

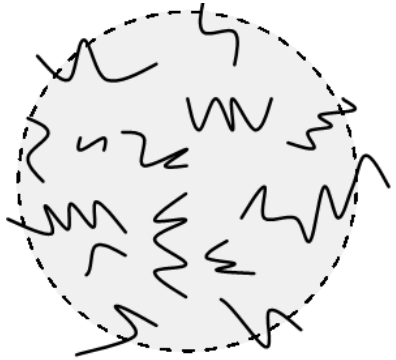

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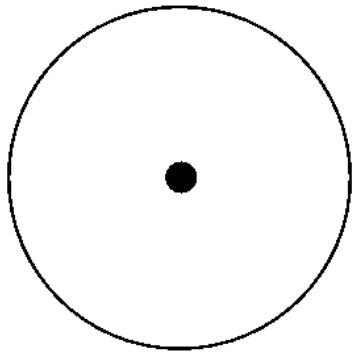
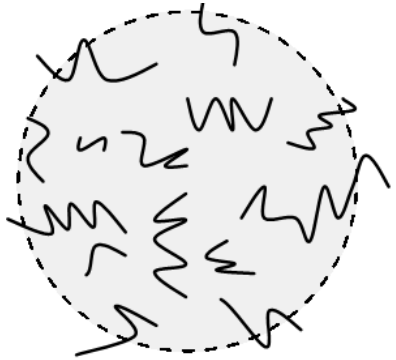
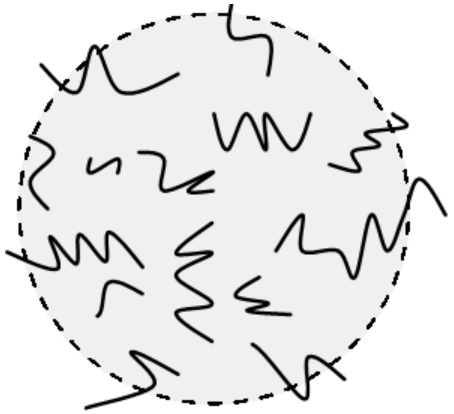
- However: Again breakdown of EFT…?





Hints of EFT breakdown at the horizon

Fuzzballs and surprising phase spaces



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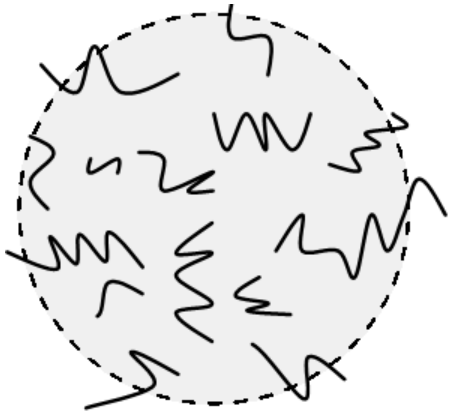

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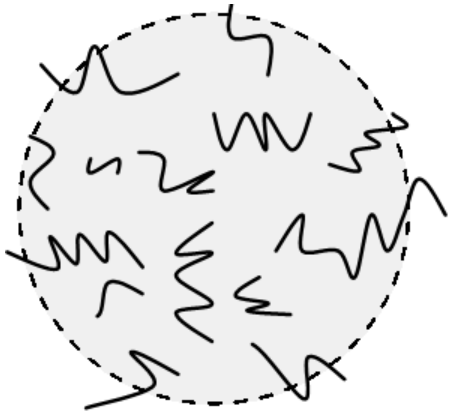

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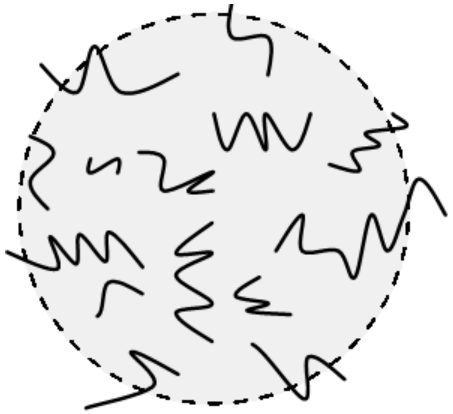

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  - *No effect within a single MG*
- **Mesoscopic observables**: like Brownian jittering particles in fluid
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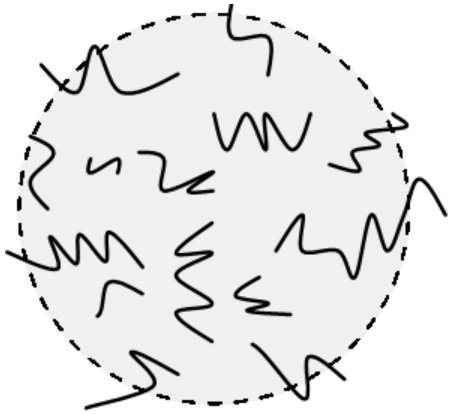

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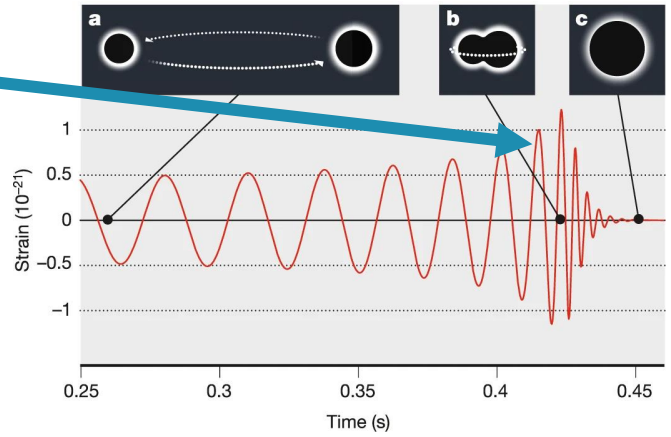
- Example: **Merger effects**?
  - Caught in meta-stable “glassy” state?
    (long-lived, less radiated energy)
    [Charles, **DRM** 1812.09328]
  - (Quantum) GW “bursts” from tunneling
    [Hertog, Hartle 1704.02123]



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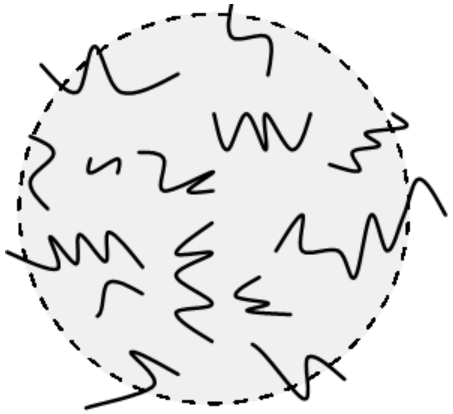

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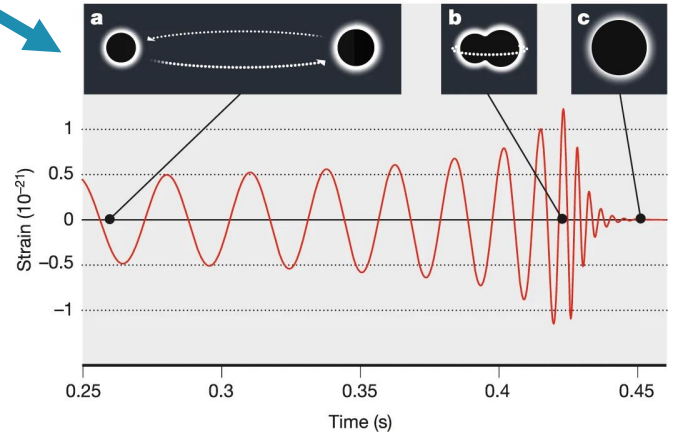

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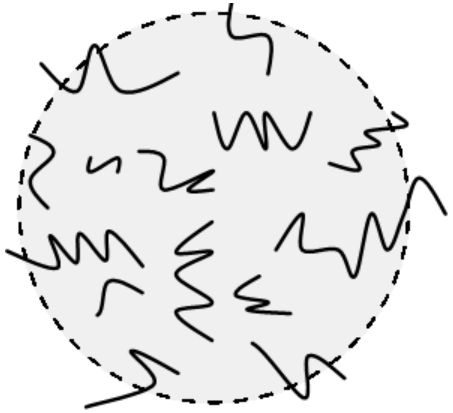

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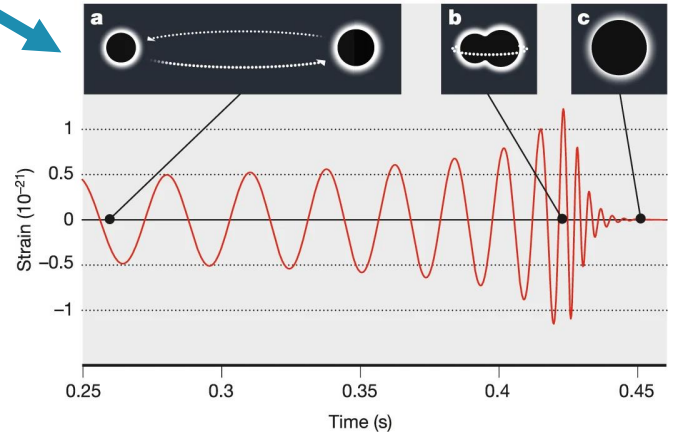

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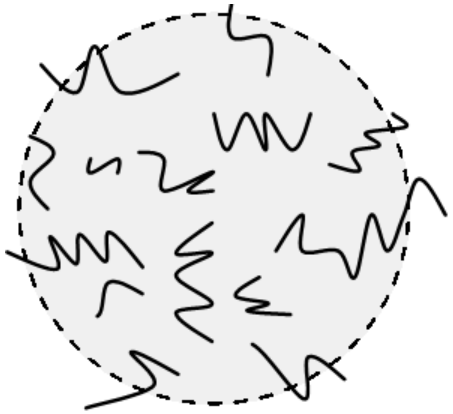

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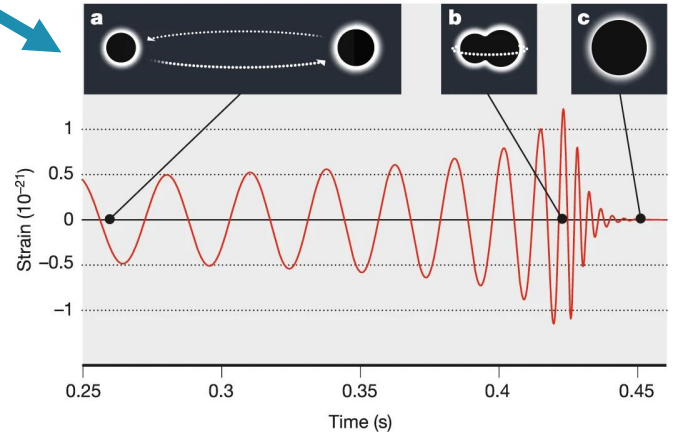
- Not $\langle \Psi | O\, O | \Psi \rangle$ but $\langle \Psi | O\, O | \Psi' \rangle$
- Indeed: TLNs in ONE typical state $\langle \Psi | O\, O | \Psi \rangle \to 0$
  [Bianchi, Di Russo 2212.07504]



Hints of EFT breakdown at the horizon

Phase spaces and the swampland

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  ~ tower of particles become massless
  ~ EFT breaking $g \sim \exp(\alpha\varphi) \sim m^2$
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- **Neutral** BHs? Scalar coupling to fermion condensate?! $\sim \phi\langle\bar{\psi}\psi\rangle$
- Relevant for primordial BHs at Higgs scale?

Hints of EFT breakdown at the horizon

Higher-derivative corrections to (near)-extremal BHs

[Horowitz, Kolanowksi, Remmen, Santos 2403.00051; 2303.07358]

- HD corrections in Kerr-Newman $\int_{\mathcal{M}} \mathrm{d}^4x\sqrt{-g}\left(c_6\, R^{abcd}\, F_{ab}\, F_{cd} + c_7\, F_{ab}\, F^{ab}\, F_{cd}\, F^{cd} + c_8\, F_{ab}\, F^{bc}\, F_{cd}\, F^{da}\right).$

(Exact near-horizon; numerical otherwise)

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Regular **Extremal** horizon!

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- Note: far from extremality – no issues (expansion in a/M)
  [Cano, Ruiperez 1901.01315; Cano, Fransen, Hertog 2005.03671; Cano, Ganchev, **DRM**, Ruiperez 2208.01044; Ma, Pang, Lu, 2411.13639]

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HD scale

KN **charge/mass**

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- "Feel" this?
  - Need orbit near ISCO/horizon
  - How near to extremal can physical BH be?

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  - Primary near-extremal KN
  - Secondary ~ NS (large TLN)
  - GW Fluxes ~ non-corrected, near-extremal Kerr (i.e. small charge)

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- Dephasing ~ compare to other HD scale bounds **~ 100m** *(in progress…)*

Summary

- Fuzzballs and large phase spaces
  - (Mesoscopic) observables must probe non-trivial phase space
  - Merger effects? Tidal effects?
- Phase spaces and the swampland
- Higher-derivative corrections to (near-)extremal KN
  - EMRIs around near-extremal BH can probe HD scale

- Black holes EFTs vs quantum corrections…?
  To be continued…