# What Temperature is Schrödinger's Cat?[†]

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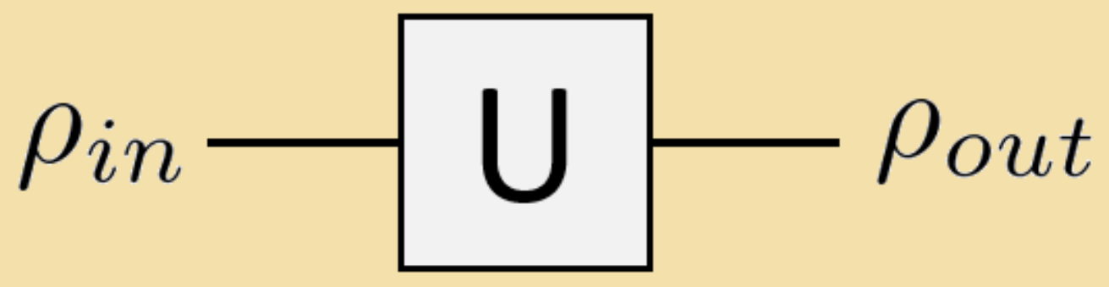
## Introduction: A Superposition of Temperatures

- Temperature & time are two important parameters in standard quantum physics
  - Time: Quantum clocks in superpositions
  - Insight into overlap between quantum and gravity
- What can we learn about temperature from a similar exploration?

## Thermal Channels and Thermalisation

- Probe interacts with bath via unitary evolution
  - Thermalises to temperature of bath

$$\rho_{in} = \rho_S \otimes \rho_B$$



- Effective map on the system (LHS) as Kraus decomposition (RHS):

$$\mathcal{E}(\rho_S) = \sum_{k,l} c_l^B M_{kl} \rho_S M_{kl}^\dagger \qquad M_{kl} = \langle k|U_{SB}|l\rangle$$

## Case 1: Two Baths (Superposition of Channels)

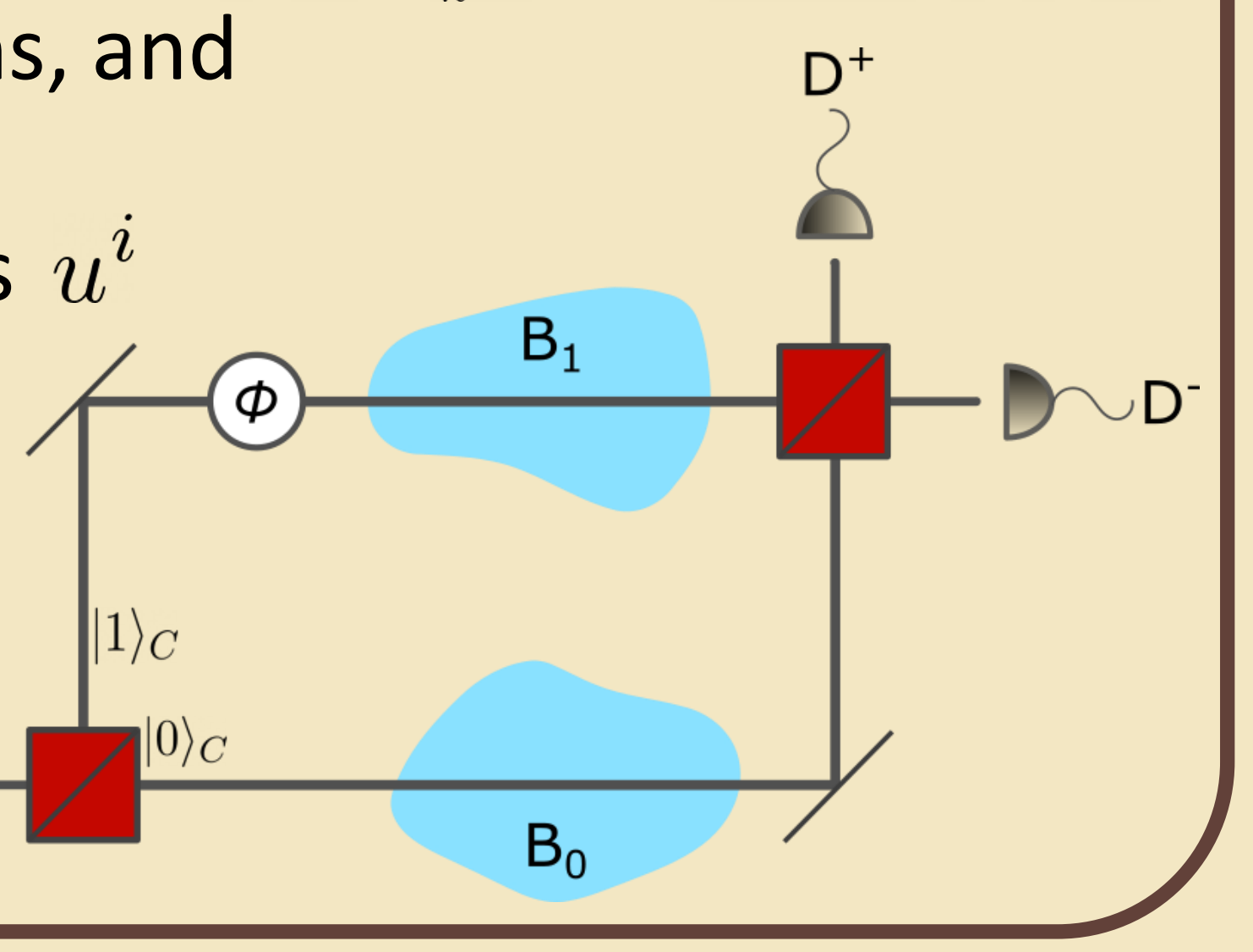
- Quantum-controlled interactions with baths, analogous to Mach-Zehnder interferometer
  - Initial state: $\rho = \underbrace{\boxed{\rho_S}}_{\text{Probe}} \otimes (\overbrace{\rho_{B_0} \otimes \rho_{B_1}}^{\text{Baths}}) \otimes \underbrace{\boxed{\rho_C}}_{\text{Control}}$
- Final state (after measuring control) is

$$\rho_S^{(\phi)} = \frac{1}{4}\Big(\rho_S^{\beta_0} + \rho_S^{\beta_1} + e^{i\phi}\rho_S^{\beta_0} u^0 \rho_S u^{1\dagger} \rho_S^{\beta_1} + e^{-i\phi}\rho_S^{\beta_1} u^1 \rho_S u^{0\dagger} \rho_S^{\beta_0}\Big)$$

$$\rho_S^{\beta_i} = \sum_k c_k^{\beta_i} |k\rangle_S \langle k|_S; \quad \beta_i \equiv \frac{1}{T_i}$$

  - Not thermal
  - Dependent on states of both baths, and initial state of probe system
  - Dependent on local bath unitaries $u^i$
- Visibility

$$\mathcal{V} = \left|\mathrm{Tr}\left\{\rho_S^{\beta_0}\rho_S^{\beta_1} u^1 \rho_S u^{0\dagger}\right\}\right|$$



## Case 2: One Bath (Superposition of Purifications)

- Superposition of purifications: $|\Psi\rangle = \sum_i |\psi_{pf}^i\rangle|i\rangle_C$
  - Control state determines temperature of the bath
  - Purifications have the form:

$$|\psi\rangle = \sum_{x=0,1}\frac{1}{\sqrt{2}}\sum_b e^{-i\phi_x}\sqrt{c_b^{B_x}}\,\overset{\text{Ancilla}}{|b\rangle_A}\overset{\text{Bath}}{|b\rangle_B}\underset{\text{Control}}{|x\rangle_C}$$

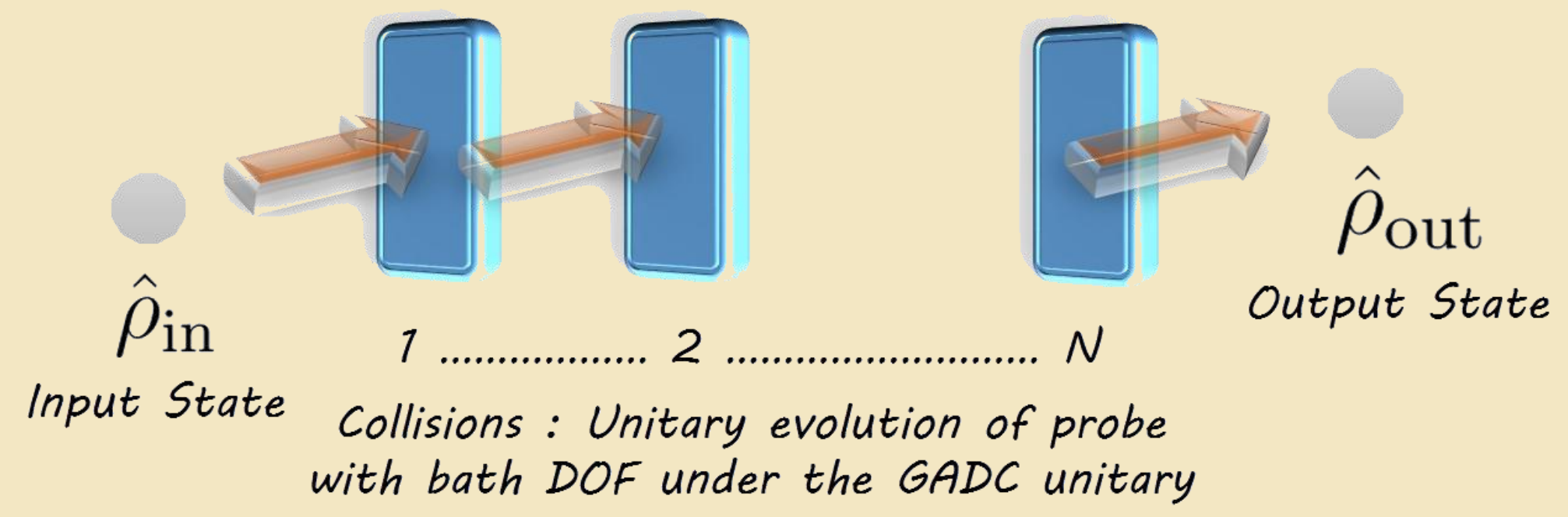
- Final state

$$\tilde{\rho}_S^{(\phi)} = \frac{1}{4}\left[\rho_S^{\beta_0} + \rho_S^{\beta_1} + 2\sqrt{\rho_S^{\beta_0}\rho_S^{\beta_1}}\left|\mathrm{Tr}_S\left\{u^0\rho_S u^{1\dagger}\right\}\right|\cos(\phi)\right]$$

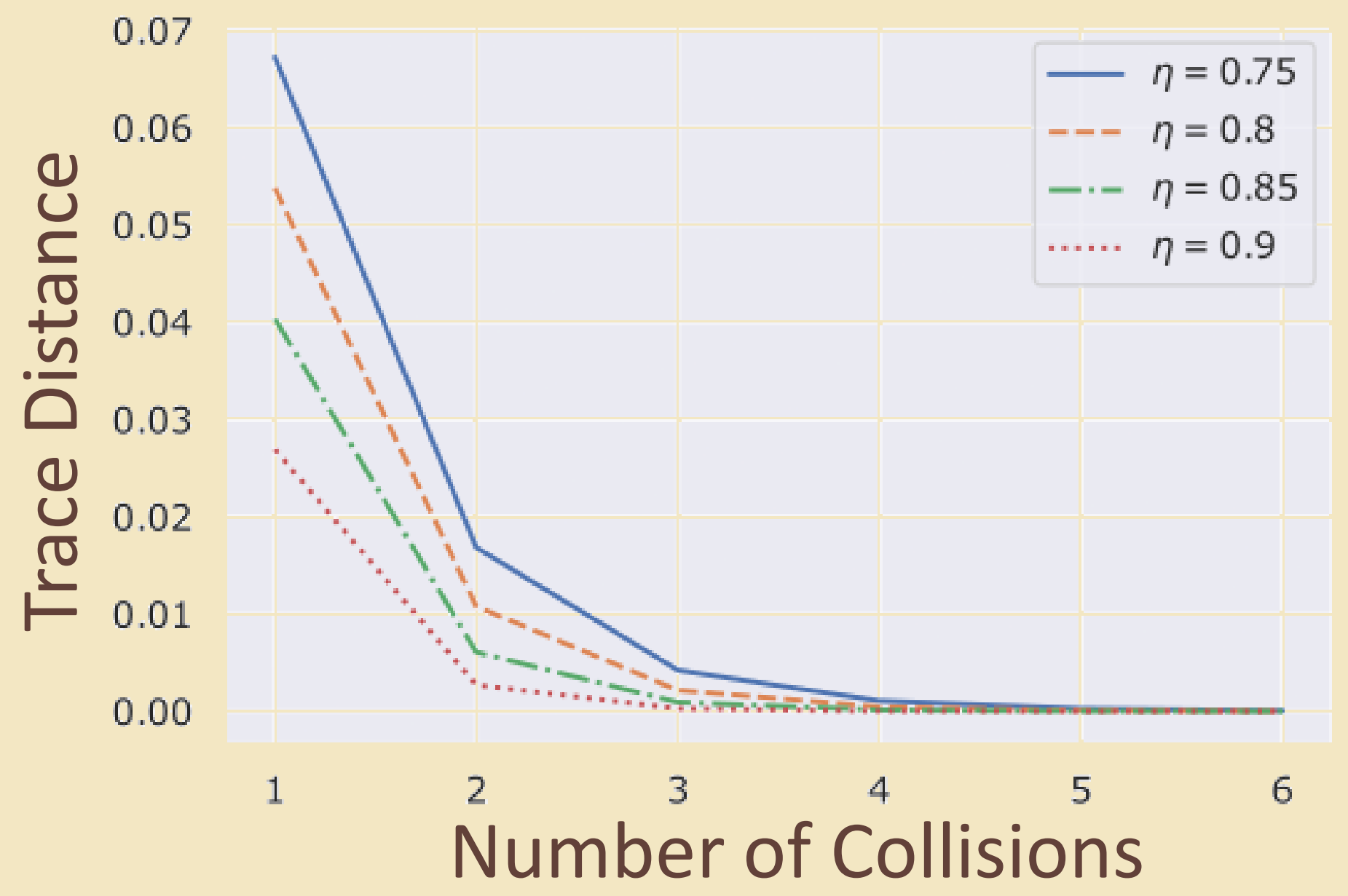
  - Can be thermal (if $\beta_0$=$\beta_1$)
  - Still dependent on local unitaries
- Visibility $\tilde{\mathcal{V}} = \sum_b \sqrt{c_b^{\beta_0} c_b^{\beta_1}}\left|\mathrm{Tr}_S\left\{u^0\rho_S u^{1\dagger}\right\}\right|$

## Partial and Pre-Thermalisation

- Collisional model of gradual thermalisation
  - Successive application of $U_{SB}$
- Each interaction occurs in finite time, with interaction parameter $\eta < 1$



- Changes in $\eta$ alter number of collisions to reach full thermalisation



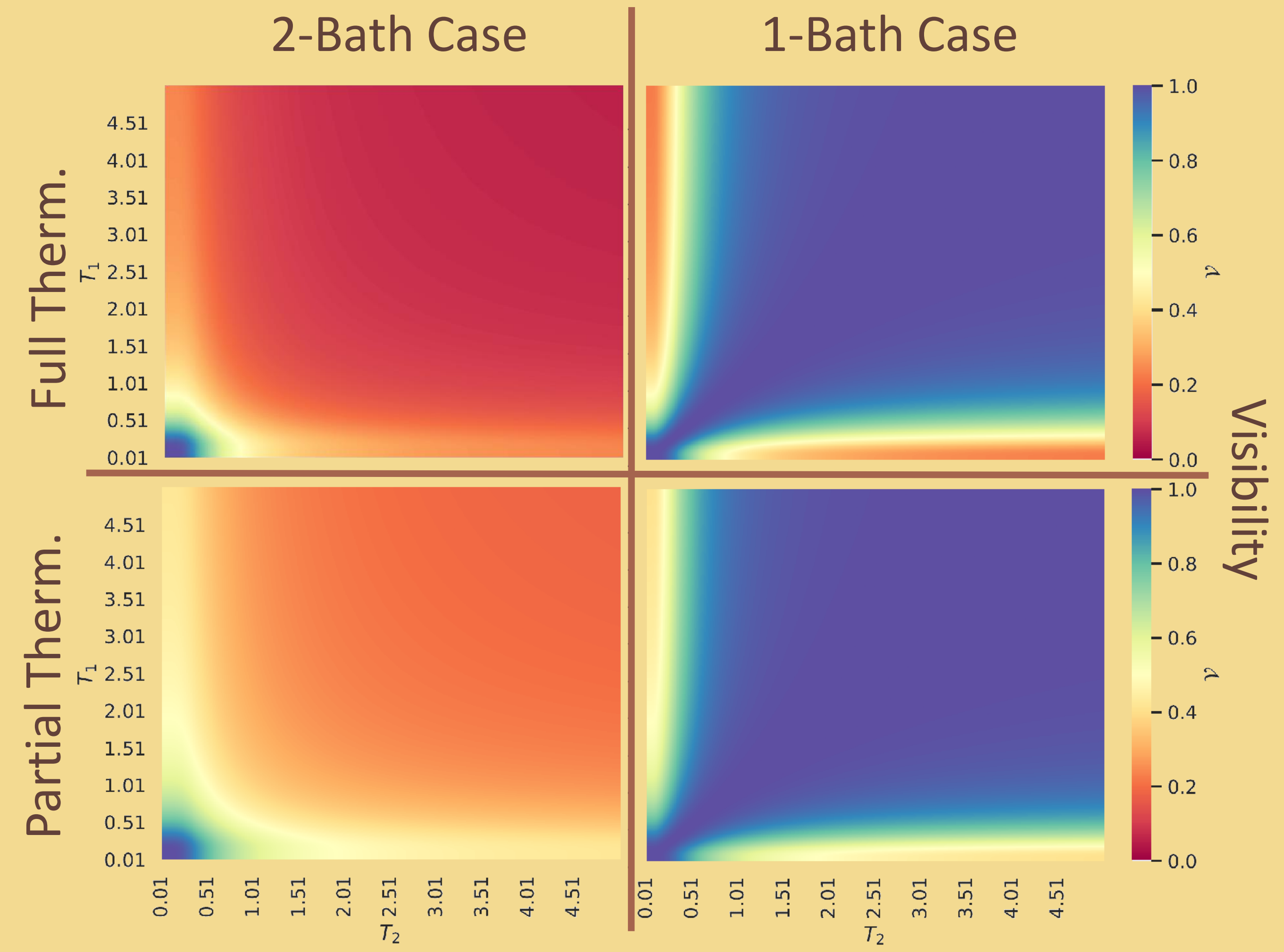
## Results: Comparing Cases through Visibility

- Visibility as an indicator of 'temperature coherence'
- Two-bath case
  - No thermalisation
  - Low visibility, except at low temps

$$\mathcal{V} = \left|\mathrm{Tr}\left\{\rho_S^{\beta_0}\rho_S^{\beta_1} u^1 \rho_S u^{0\dagger}\right\}\right|$$

- One-bath case
  - Thermalisation possible
  - Max. visibility possible, except when one temperature low

$$\tilde{\mathcal{V}} = \sum_b \sqrt{c_b^{\beta_0} c_b^{\beta_1}}\left|\mathrm{Tr}\left\{u^0\rho_S u^{1\dagger}\right\}\right|$$



## Summary and Conclusions

- Two situations which result in a 'Superposition of Temperatures'
  - Two separated baths: thermalisation is suppressed
  - One bath in superposition: thermalisation can be reached
  - Both depend on local unitaries
- Implications:
  - Pathway to greater understanding of bath dynamics
  - Sensitivity to local unitaries
- Future directions
  - Unruh-deWitt detectors
  - Tolman-Ehrenfest effect

Image credit: Graham Foster

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