Title: Fireslides

Speakers:

Collection: Quantum Simulators of Fundamental Physics

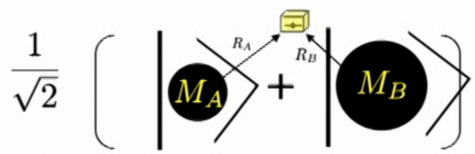
Date: June 06, 2023 - 2:00 PM

URL: https://pirsa.org/23060010

Quantum Superposition of Black Holes

- Quantum theory of gravity → Spacetime superposition → Black Hole Superpositions
- How might one observe this with a model detector?

Arabaci/Foo/RBM/Zych
PRL **129** (2022) 181301
2111.13315



$$|\psi(t_i)\rangle = \frac{1}{\sqrt{2}}(|M_A\rangle + |M_B\rangle)|0\rangle|g\rangle \Longrightarrow |\psi(t_f)\rangle = e^{-iH_{0,s}t_f}\hat{U}e^{iH_{0,s}t_i}|\psi(t_i)\rangle$$

Condition on $|\pm\rangle = (|M_A\rangle \pm |M_B\rangle)/\sqrt{2}$ and trace out the field

$$\mathrm{Tr}_\phi\left[\langle\pm|\psi(t_f)\rangle\langle\psi(t_f)|\pm\rangle\right] = \frac{|g\rangle\langle g|}{2}P_G^{(\pm)} + \lambda^2\frac{|e\rangle\langle e|}{2}P_E^{(\pm)}$$

Reduced Density Matrix of the Detector

$$= \frac{|g\rangle\langle g|}{2}\Big(1 \pm \cos(\Delta E \Delta t)\Big)\left[1 - \frac{\lambda^2}{2}\int_{-t_f}^{t_f} d\tau \int_{-t_f}^{t_f} d\tau' \eta(\tau)\eta(\tau')e^{-i\Omega(\tau-\tau')}\Big(W(x_A, x'_A) + W(x_B, x'_B)\Big)\right]$$

$$+ \frac{\lambda^2|e\rangle\langle e|}{4}\int_{-t_f}^{t_f} d\tau \int_{-t_f}^{t_f} d\tau' \eta(\tau)\eta(\tau')e^{-i\Omega(\tau-\tau')}\Big(W(x_A, x'_A) + W(x_B, x'_B) \pm 2\cos(\Delta E \Delta t)W(x_A, x'_B)\Big)$$

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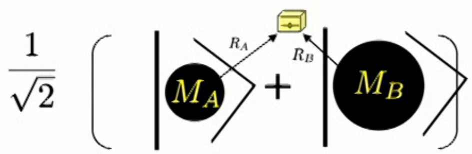

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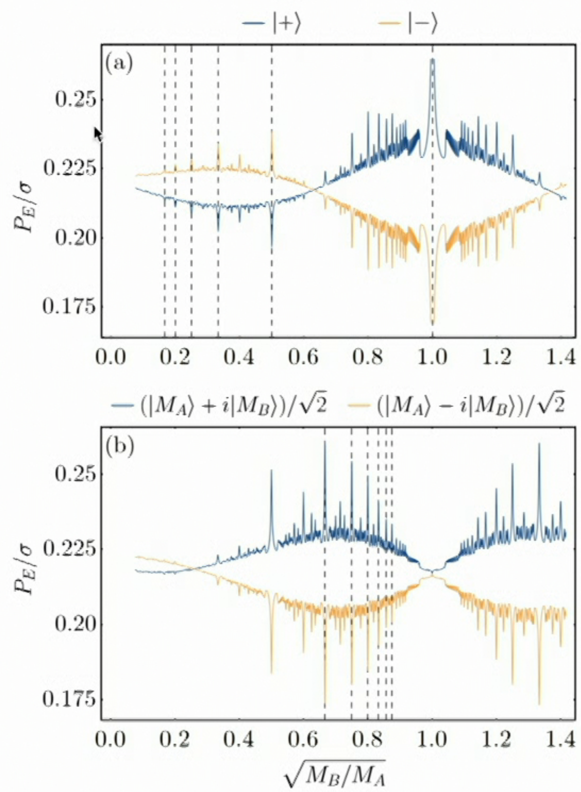
Result



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Dashed lines:
$\sqrt{M_B/M_A} = (n-1)/n$
where $n = \{3, \ldots 8\}$

Resonant peaks at integer values of (mass ratios)$^{1/2}$!

Consistent with Bekenstein's black hole mass quantization conjecture

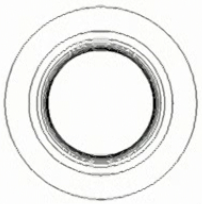
Could this be simulated in analogue gravity?

Event horizons as quantum catastrophes
(Duncan O'Dell, McMaster)

Liam Farrell
(McMaster)

Chris Howls
(Southampton)

Event horizon is a **phase singularity**



$$k \sim \frac{\omega}{z - z_h}$$

Expect: $\psi \sim e^{i\int[k(z)dz - \omega t]}$
$= e^{i[\omega \log(z - z_h) - \omega t]}$

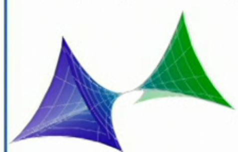
Flowing BEC, or black hole with dispersion:

$$\psi(z,\omega) \sim \int_{-\infty}^{+\infty} \frac{1}{k}\, e^{i[k^3/3 + kz - \omega\log(k)]} dk$$

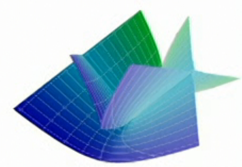
Logged Airy function

Catastrophe theory

fold (K=1) cusp (K=2) swallowtail (K=3)

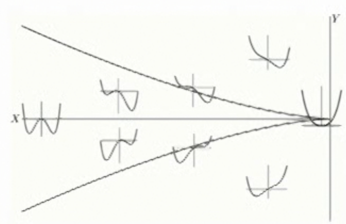


elliptic umbilic (K=3)

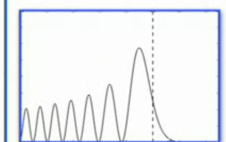


hyperbolic umbilic(K=3)

Example: cusp

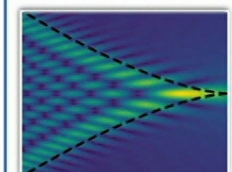


Wave catastrophes



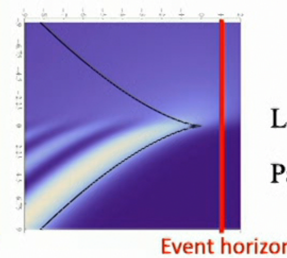
Airy function

$$\Psi_{\text{fold}}(C) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{i(s^3/3 + Cs)} ds$$



Pearcey function

$$\Psi_{\text{cusp}}(C_1, C_2) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} e^{i(s^4/4 + C_2 s^2/2 + C_1 s)} ds$$



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Particle production??

Logarithmic catastrophes and Stokes's phenomenon in waves at horizons, Farrell, Howls, O'Dell, J. Phys. A : Math. Theor. 56, 044001 (2023)

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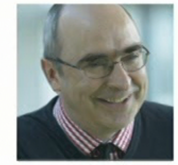

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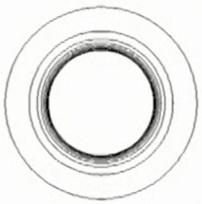

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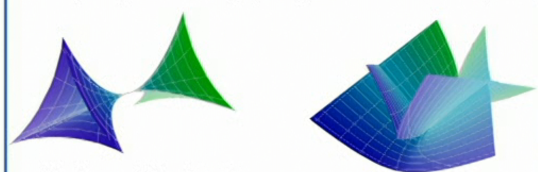

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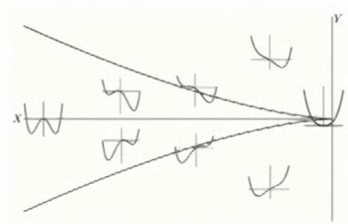

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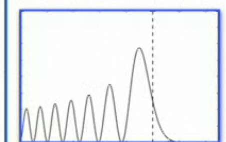

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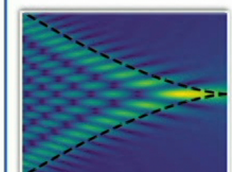

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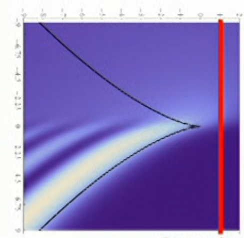

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Victor Wei[1, 2, †], W. A. Coish[1], Pooya Ronagh[2, 3, 4, 5], Christine A. Muschik[2, 3, 4]

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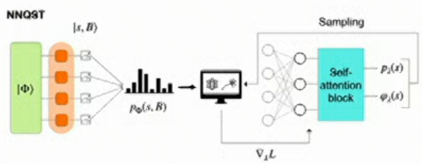

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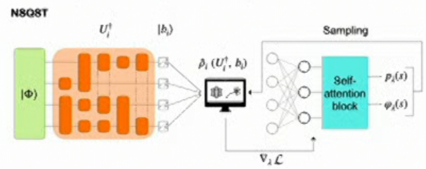

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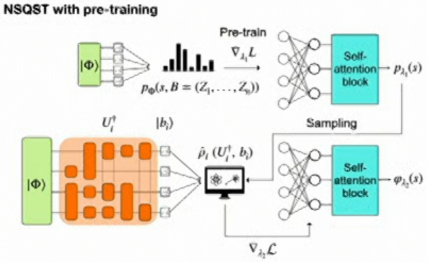
NSQST with pre-training



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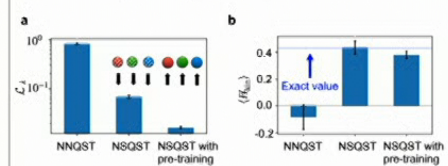

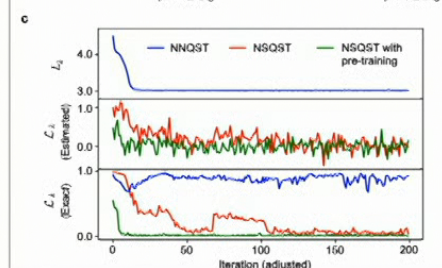

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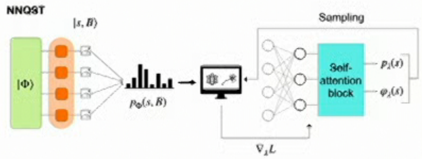

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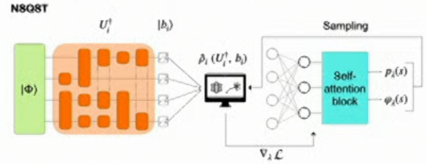

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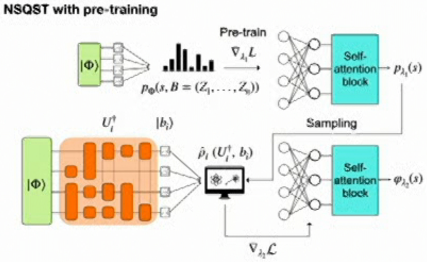

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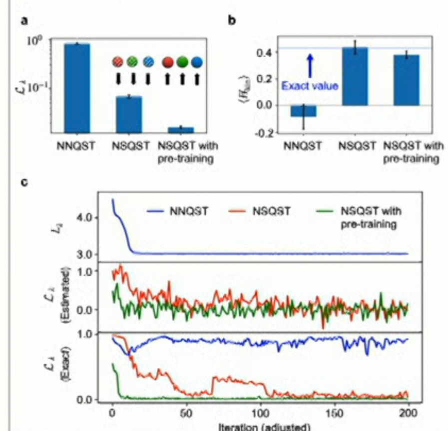

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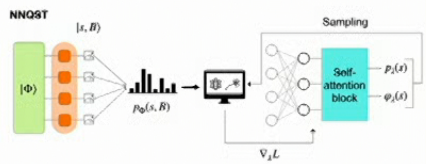

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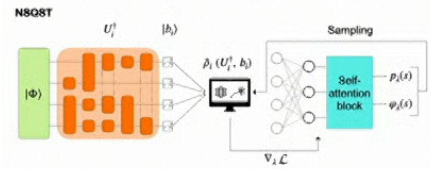
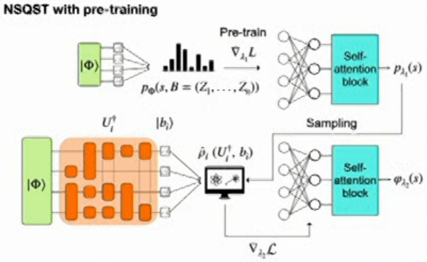


- By the proven property of (Clifford) classical shadows, the number of shadows needed to predict infidelity to a pure state with small additive error is independent of the system size.

$$\begin{aligned}\mathcal{L}_\lambda(\mathcal{E}) &:= 1 - |\langle\psi_\lambda|\Phi\rangle|^2 \\ &\approx 1 - \frac{1}{N}\sum_{i=1}^{N}\mathrm{Tr}(O_\lambda\hat{\rho}_i) \\ &= 1 - \frac{1}{N}\sum_{i=1}^{N}\langle\psi_\lambda|\,\hat{\rho}_i(\mathcal{E},U_i,b_i)\,|\psi_\lambda\rangle \\ &= 1 - \frac{1}{2^n}\left(1-\frac{1}{f(\mathcal{E})}\right) - \frac{1}{Nf(\mathcal{E})}\sum_{i=1}^{N}|\langle\phi_i|\psi_\lambda\rangle|^2.\end{aligned}$$

NSQST with pre-training



4. SU(3) Trotterized time evolution

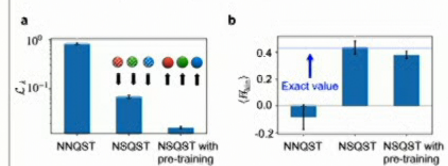
- We perform tomography of a 6-qubit time-evolved state (with four Trotter steps) under the SU(3) Hamiltonian.

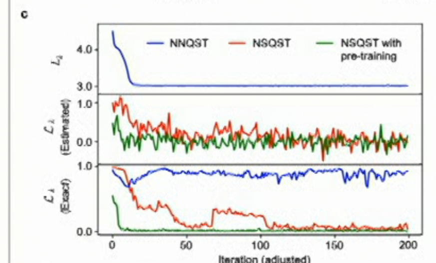
$$H_{SU(3)} = H_{kin} + \tilde{m}H_m + \frac{1}{2x}H_e,$$

where

$$\begin{aligned}H_{kin} &= -\frac{1}{2}(\sigma_1^+\sigma_2^z\sigma_3^z\sigma_4^- - \sigma_2^+\sigma_3^z\sigma_4^z\sigma_5^- \\ &\qquad + \sigma_3^+\sigma_4^z\sigma_5^z\sigma_6^- + \mathrm{H.c.}), \\ H_m &= \frac{1}{2}(6 - \sigma_1^z - \sigma_2^z - \sigma_3^z + \sigma_4^z + \sigma_5^z + \sigma_6^z), \\ H_e &= \frac{1}{3}(3 - \sigma_1^z\sigma_2^z - \sigma_1^z\sigma_3^z - \sigma_2^z\sigma_3^z),\end{aligned}$$

- Reconstructed state using NSQST yields accurate observable prediction, while NNQST fails.





References:

1. Victor Wei, W. A. Coish, Pooya Ronagh, and Christine A. Muschik, "Neural-Shadow Quantum State Tomography", arXiv preprint arXiv:2305.01078 (2023).
2. Y. Y. Atas, J. F. Haase, J. Zhang, V. Wei, S. M.-L. Pfaendler, R. Lewis, and C. A. Muschik, "Real-time Evolution of SU(3) Hadrons on a Quantum Computer", arXiv preprint arXiv:2207.03473 (2022).

The NL and NG Quantum Early Universe

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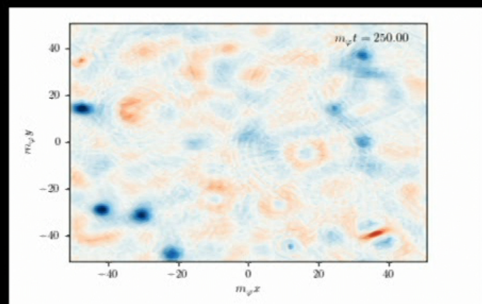
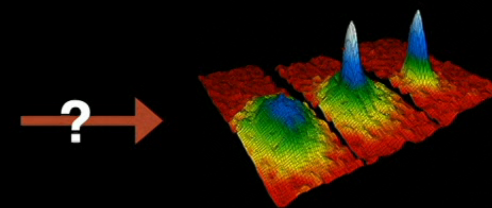
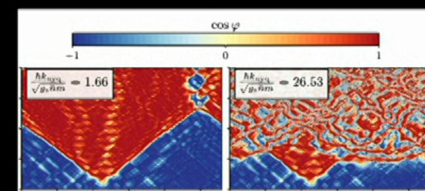
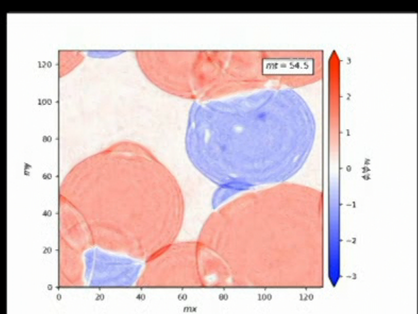


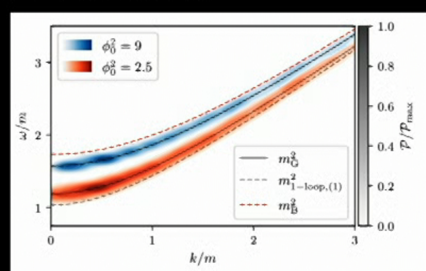
Analog Early Universe



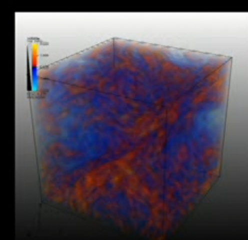


Relativistic Phase Transitions





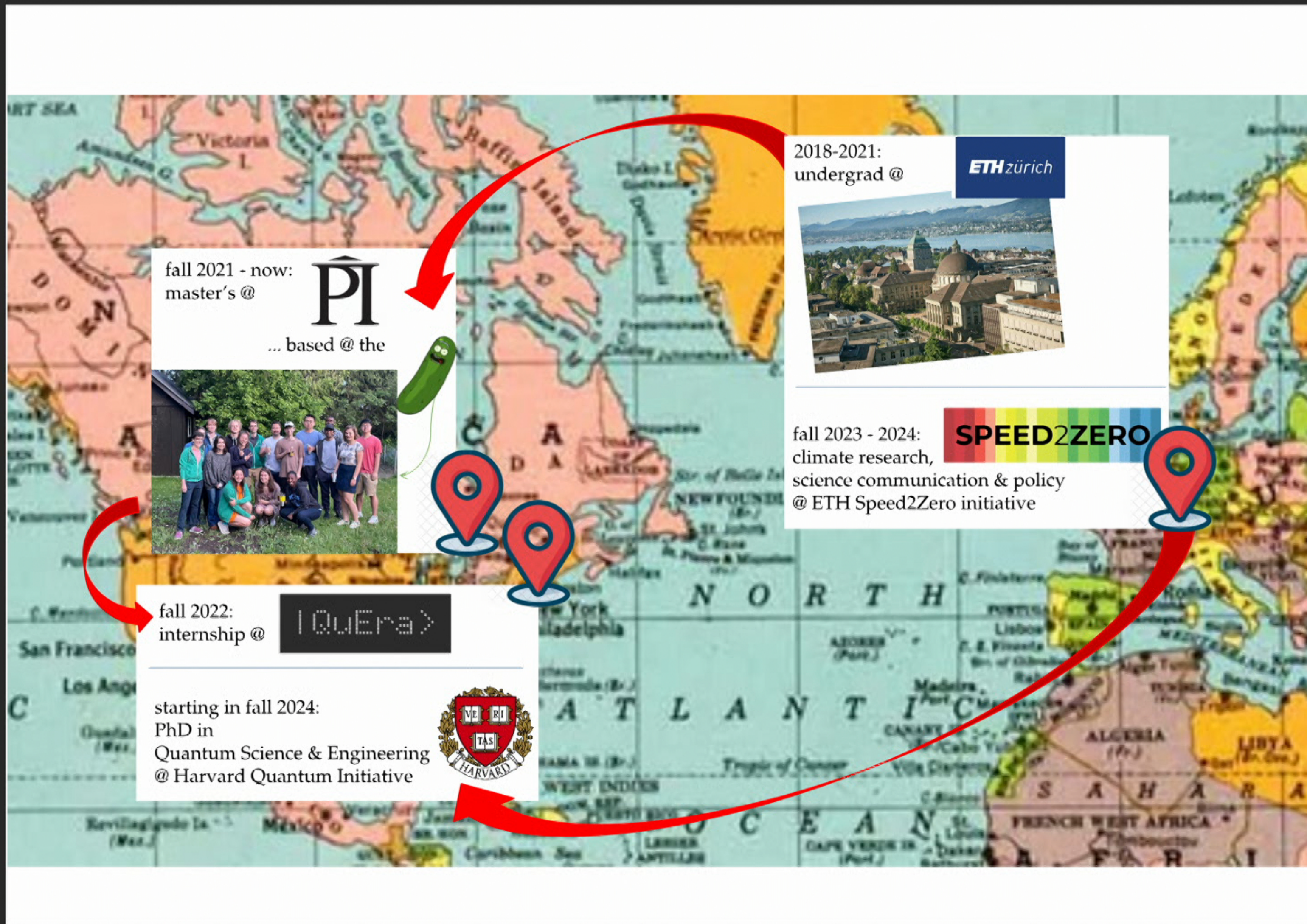
End-of-Inflation / Nonlinearity During Inflation



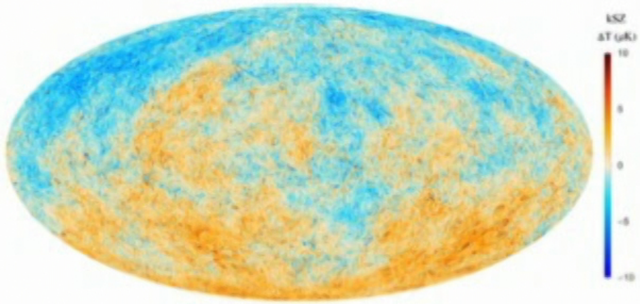
$$\zeta = \zeta_G + F_{NL}(\chi)$$

$$\zeta = \zeta_G + \sum \zeta_{peak}(x - x_i)$$

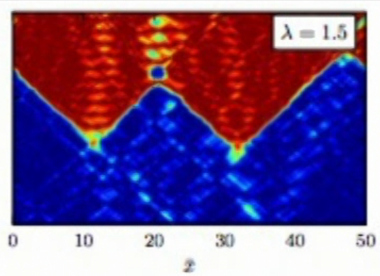
Novel Forms of NonGaussianity, motivated by detailed numerical calculations, characterization w/ ML techniques


2018-2021:
undergrad @
ETH zürich
fall 2023 - 2024:
climate research,
science communication & policy
@ ETH Speed2Zero initiative
SPEED2ZERO
fall 2021 - now:
master's @
PI
... based @ the
fall 2022:
internship @
|QuEra>
starting in fall 2024:
PhD in
Quantum Science & Engineering
@ Harvard Quantum Initiative
VE RI TAS
HARVARD
N O R T H
A T L A N T I C
O C E A N

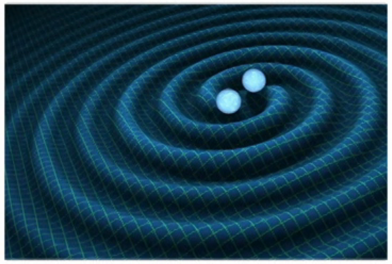
Matthew Johnson
York/Perimeter Institute



Mapping the Universe on LARGE scales



Universes in the lab with BECs



Testing GR with gravity waves