

Quantum simulation
with ocean-sdk
AQC 2025

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13 June, 2025

D-WAVE

In this talk

- A brief introduction to coherent annealing
- Run your own: Landau-Zener and Kibble-Zurek experiments
- Code walk through (Q & A)

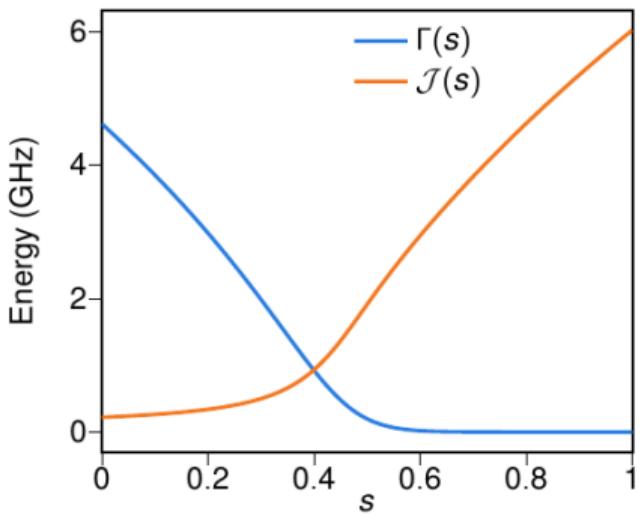


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Transverse-field Ising model annealing

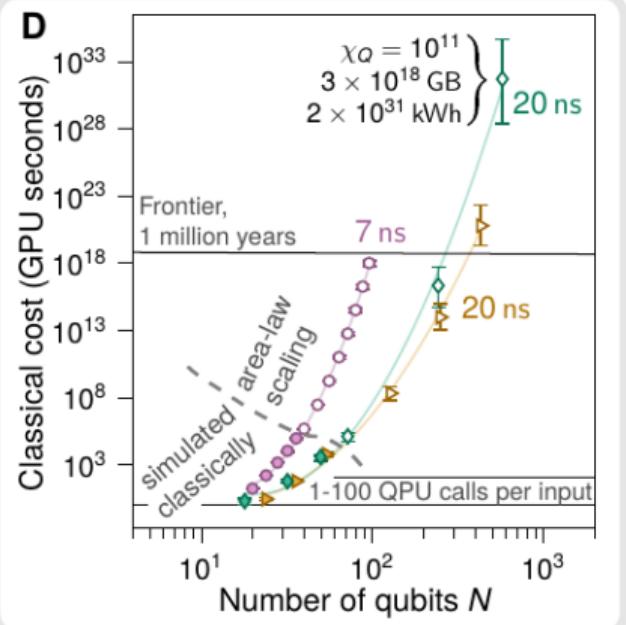
- Evolve a multi-spin system for time t_a ,
 $H(s = t/t_a) = -\Gamma(s) \sum_i \sigma_i^x + \mathcal{J}(s) H_p$
- 1 Program a problem Hamiltonian
 $H_p = \sum_{ij} J_{ij} \sigma_i^z \sigma_j^z + \sum_i h_i \sigma_i^z$
- 2 Prepare a ground state at (large $\Gamma(s = 0)$ and small $\mathcal{J}(s = 0)$)
- 3 Evolve to large $\mathcal{J}(s = 1)$ and small $\Gamma(s = 1)$
- 4 Measure in the computational basis
- Kadowaki and Nishimori, Phys. Rev. E 58, 5355 (1998)



Four recent papers

- 1 Coherent quantum annealing in a programmable 2,000 qubit Ising chain, Nature Physics (2022)
- 2 Quantum critical dynamics in a 5,000-qubit programmable spin glass, Nature (2023)
- 3 Quantum error mitigation in quantum annealing, npj Quantum Information (2025)
- 4 Beyond classical computation in quantum simulation, Science (2025)

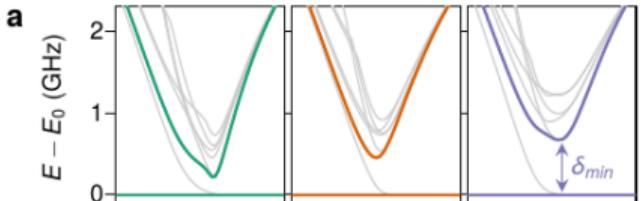
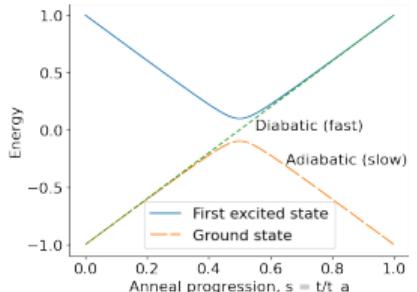
Projected classical resources to match QPU



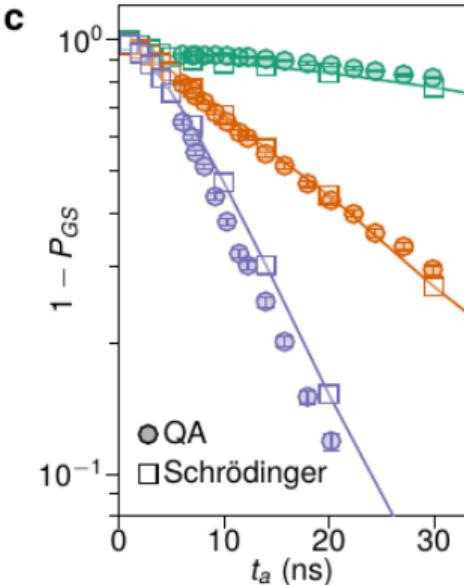
Landau-Zener dynamics with 16 qubit random models



The probability to excite away from the ground state decays exponentially with the annealing time: the exponent determined by the inverse square gap.



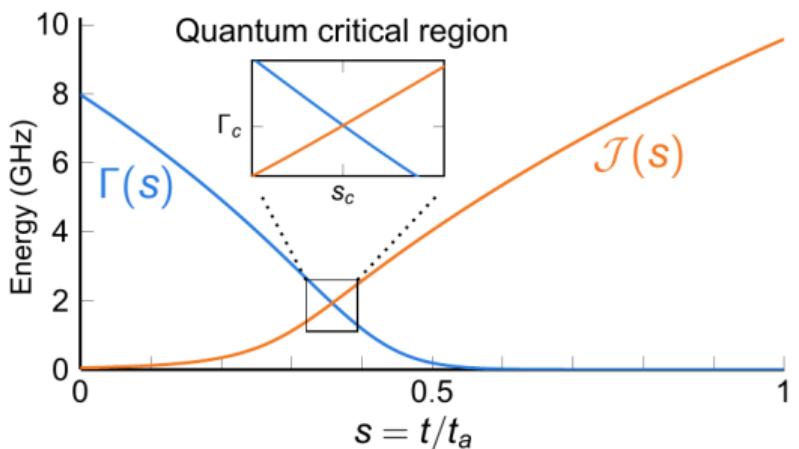
Quantum critical dynamics in a 5,000-qubit programmable spin glass, Nature (2023)



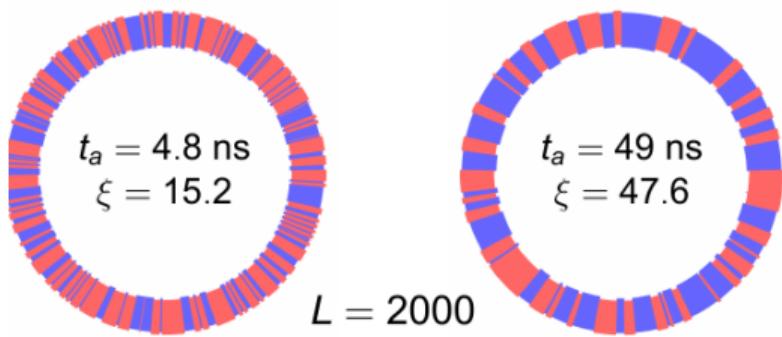
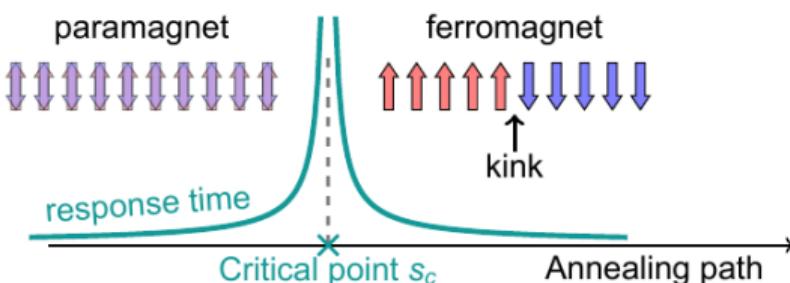
Kibble-Zurek dynamics in 1D



Defect rate decays as a power of the annealing time: the power determined by the universality class of the phase transition.



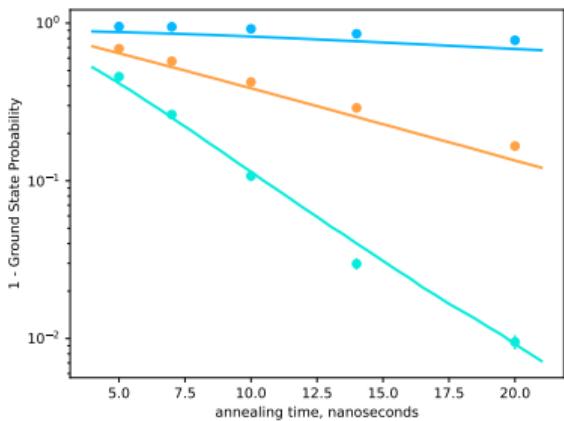
Coherent quantum annealing in a programmable 2,000 qubit Ising chain, Nature Physics (2022)





Implementing experiments (AQC2024)

- Fast anneal newly (AQC 2024!) released in all online QPU solvers
- Allows simple reproduction of earlier results
- E.g. Probability of the ground state
- 3 spin-glass models (different colors): 16 variables, 52 couplers (+/-1), various gaps
- Schedule $\{\Gamma(s), \mathcal{J}(s)\}$ as published on the website; Matching annealing_time; J modelled == J programmed
- Lines are exact closed system dynamics, points are single-programming QA data



(reproduction of Figure 2c)

Quantum critical dynamics in a 5,000-qubit programmable spin glass, Nature (2023)

Under 20 lines of code, a 1D experiment



```
import numpy as np
import networkx as nx
import minorminer.subgraph # Thank you McCresh et al., Glasgow U.
import dwave.system
num_vars = 1024
h = {x: 0 for x in range(num_vars)}
J = {(x, (x+1)%num_vars) : -1 for x in range(num_vars)} # 1D ring
qpu = dwave.system.DWaveSampler(solver='Advantage2_prototype2.3')
source_graph = nx.from_edgelist(J.keys())
target_graph = qpu.to_networkx_graph()
embedding = minorminer.subgraph.find_subgraph(source_graph, target_graph)
sampler = dwave.system.FixedEmbeddingComposite(
    qpu, embedding={k: (v,) for k,v in embedding.items()})
for ta_nanosec in [5, 7, 10, 14, 20]:
    ss = sampler.sample_ising(h, J, num_reads=1000, answer_mode='raw',
        fast_anneal=True, annealing_time=ta_nanosec/1000)
    kink_density = (np.mean(ss.record.energy) + num_vars)/(2*num_vars)
```

This Kibble-Zurek (and previous slide Landau-Zener) code, are the subject of the code walk through.



Run the code



Run the code (locally or codespaces)

At github.com/jackraymond/AQC2025workshop

Code > codespace > +

```
dwave setup - -oob # Paste the workshop token for Leap access
```

```
python main.py - - help # Show experiment options
```

```
python main.py # Run with defaults
```

- solver_name: e.g. Advantage2_prototype2.6
- model: 'Landau-Zener' or 'Kibble-Zurek'
- use_srt: Randomize (sign flip) the computational basis definition.
- parallelize_embedding: embed more than once, as allowed

For links and further examples see the jupyter notebook:
[physics-experiments-ocean-sdk.ipynb](#)



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Conclusion



Use the latest features : Contribute to open source : Experiment
Thanks for attending!

