Quantum simulation with ocean-sdk AQC 2025

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D:WAVE

In this talk

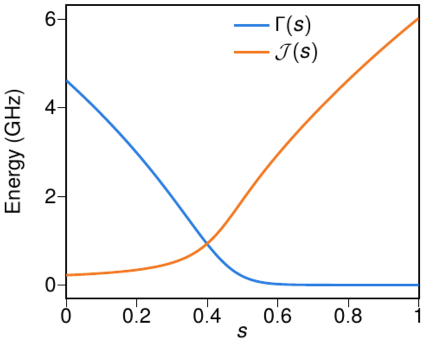
- A brief introduction to coherent annealing
- Run your own: Landau-Zener and Kibble-Zurek experiments
- Code walk through (Q & A)

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

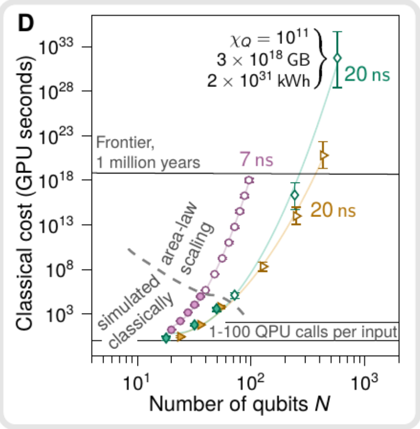
- Kadowaki and Nishimori, Phys. Rev. E 58, 5355 (1998)



Four recent papers

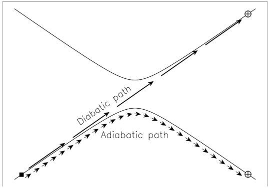
1. Coherent quantum annealing in a programmable 2,000 qubit Ising chain, Nature Physics (2022)
2. Quantum critical dynamics in a 5,000-qubit programmable spin glass, Nature (2023)
3. Quantum error mitigation in quantum annealing, npj Quantum Information (2025)
4. Beyond classical computation in quantum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

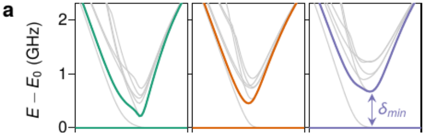
Projected classical resources to match QPU



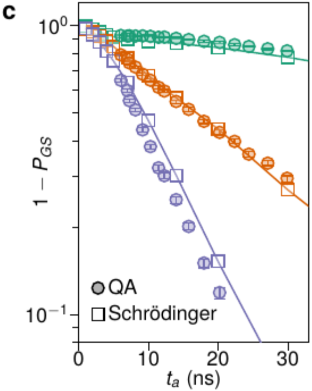
Landau-Zener dynamics with 16 qubit random models

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



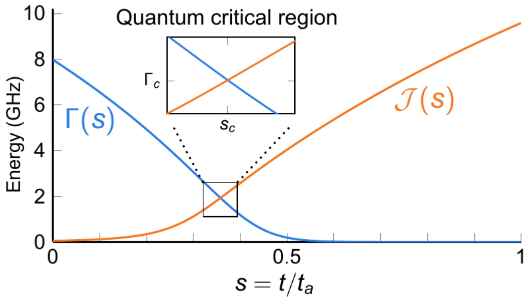


Quantum critical dynamics in a 5,000-qubit programmable spin glass, Nature (2023)

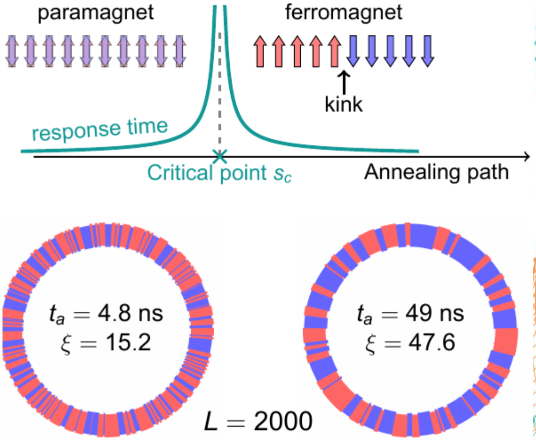


Kibble-Zurek dynamics in 1D

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

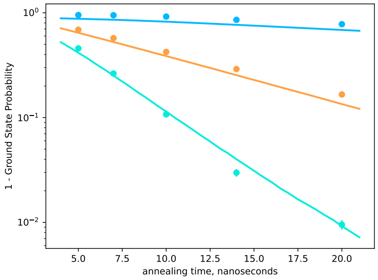


Coherent quantum annealing in a programmable 2,000 qubit Ising chain, Nature Physics (2022)



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

Conclusion

Use the latest features : Contribute to open source : Experiment

Thanks for attending!