PsiQuantum

Quantum computing applications

Recent developments

Kamil Korzekwa, PsiQuantum

10 SEPTEMBER 2025

AGENDA

01 Building a quantum computer

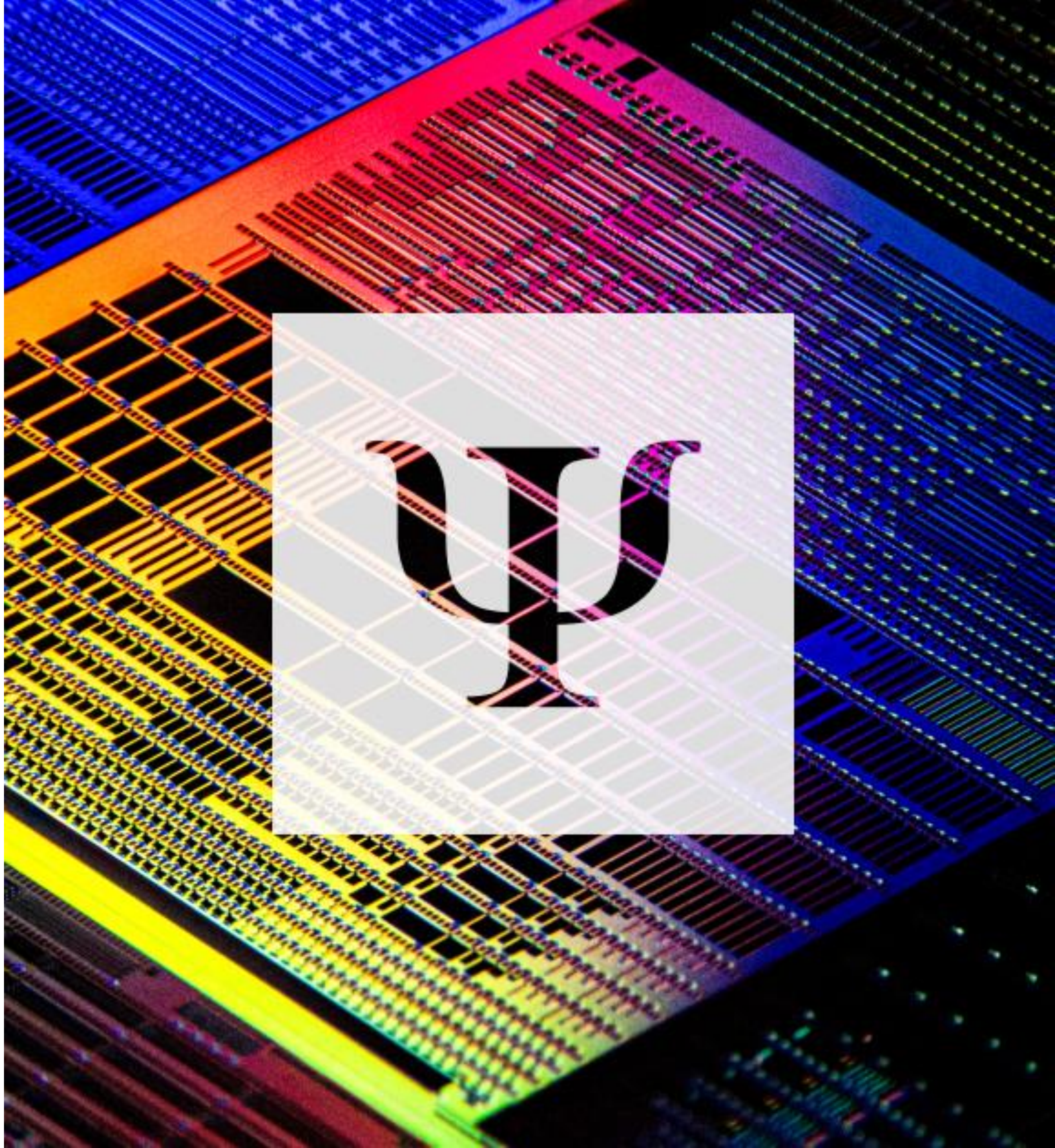
PsiQuantum's mission & hardware development

02 Overview of quantum applications

Our team & recent algorithmic developments

03 Quantum algorithms for nonlinear problems

Simulating nonlinear dynamics on a quantum computer



AGENDA

01 **Building a quantum computer**

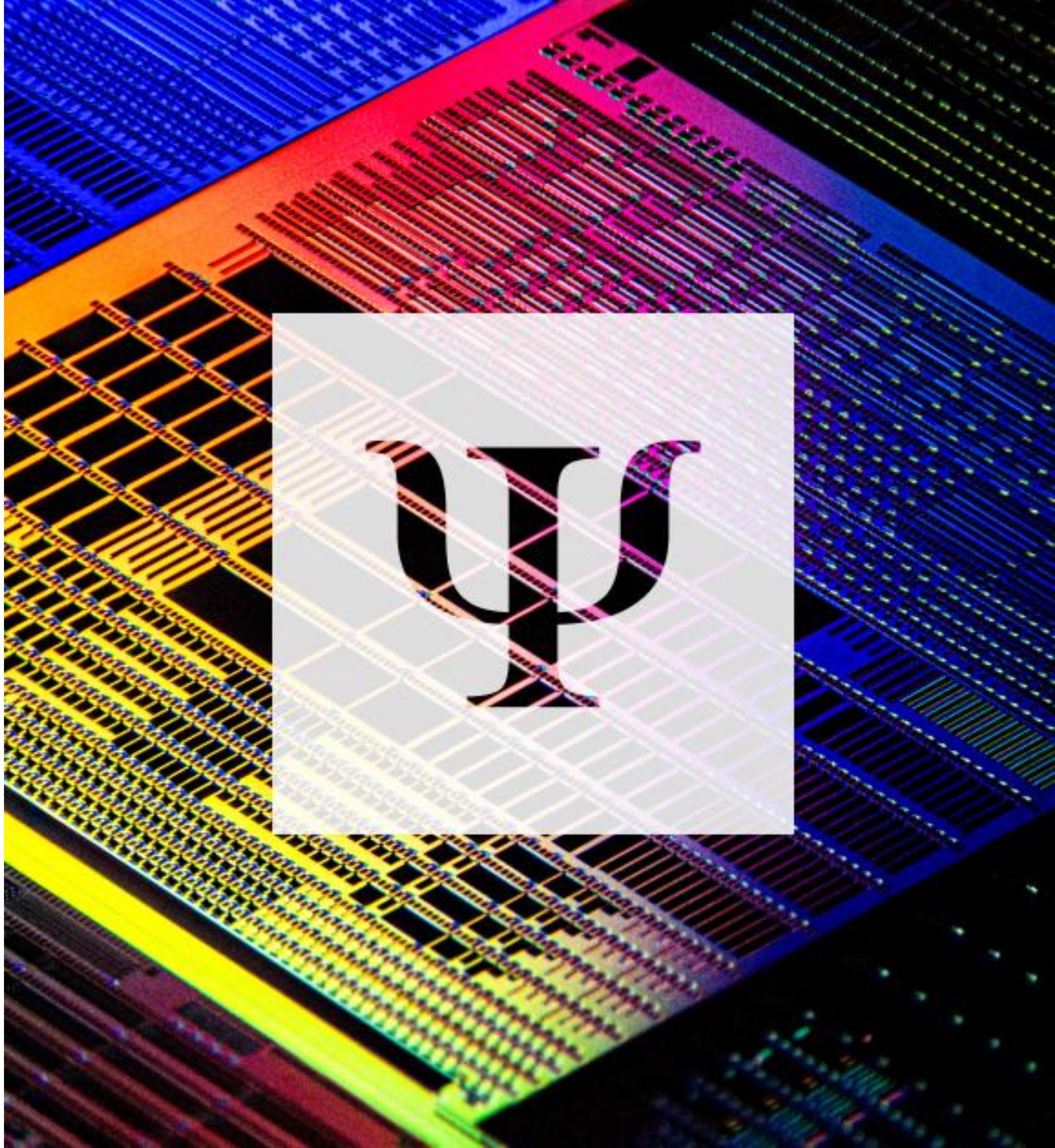
PsiQuantum's mission & hardware development

02 Overview of quantum applications

Our team & recent algorithmic developments

03 Quantum algorithms for nonlinear problems

Simulating nonlinear dynamics on a quantum computer



PsiQuantum's mission

PsiQuantum:

- A full-stack quantum company
- Employing 450+ experts
- With global presence in US, Europe and Australia

Mission: To build and deploy the first useful quantum computers

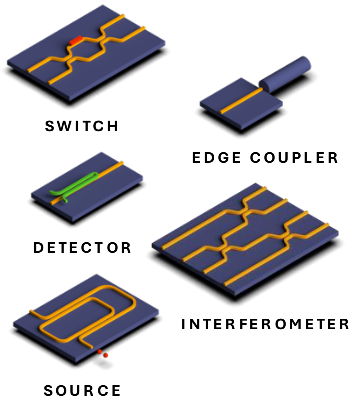
This means:

- Fault-tolerance: full error correction
- Large-scale: 1000000+ qubits

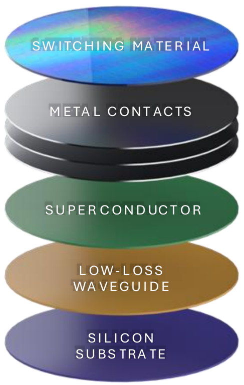
BUILDING A QUANTUM COMPUTER

Hardware development

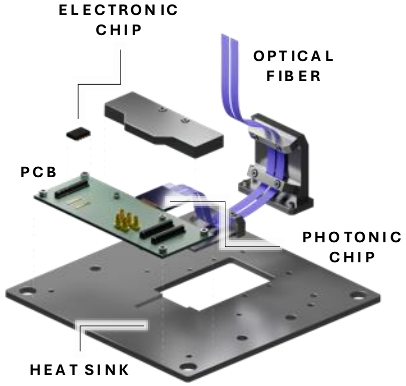
STATE-OF-THE-ART PHOTONICS PLATFORM

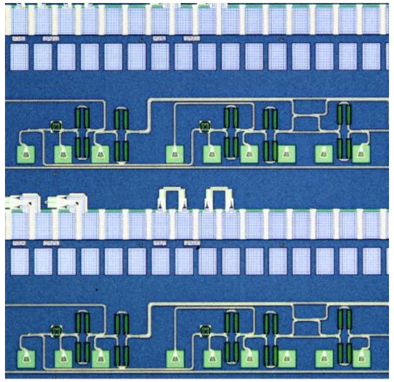


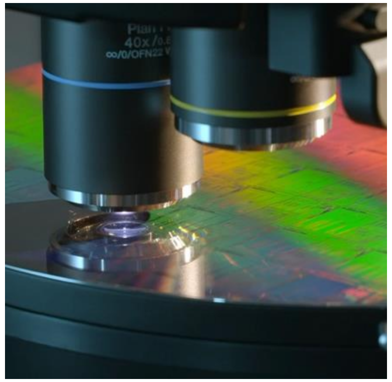
TIER-1 SEMICONDUCTOR MANUFACTURING

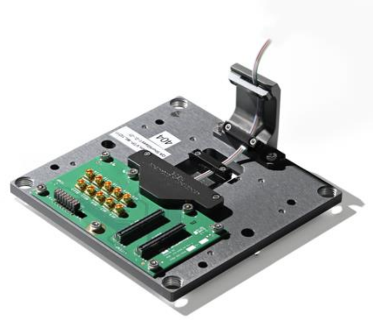


HIGH-VOLUME PACKAGING









PsiQuantum GlobalFoundries™

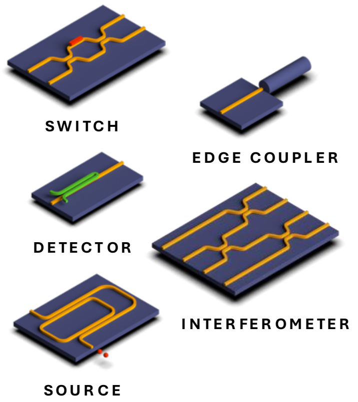
Fusion-based quantum computation, Nature Communications (2023).

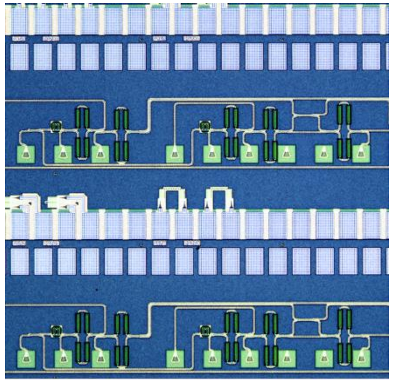
A manufacturable platform for photonic quantum computing, Nature (2025)

BUILDING A QUANTUM COMPUTER

Hardware development

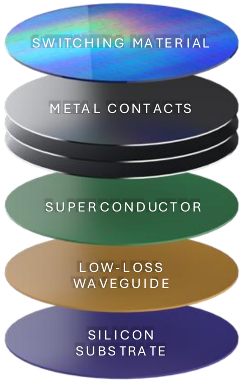
STATE-OF-THE-ART PHOTONICS PLATFORM

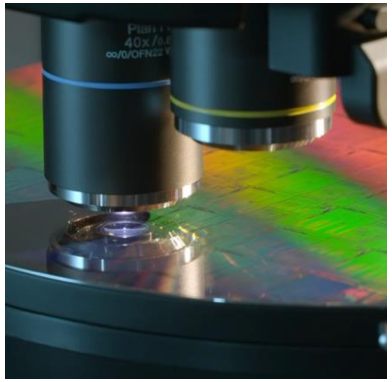




$O(10^7)$

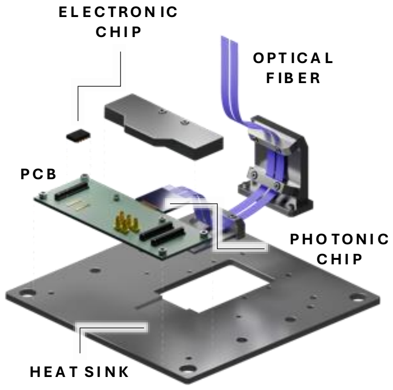
TIER-1 SEMICONDUCTOR MANUFACTURING

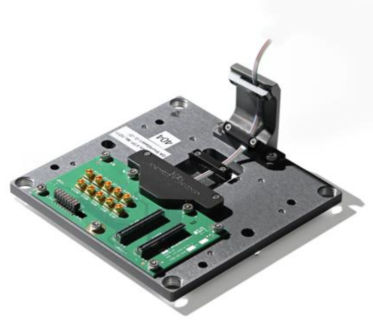




$O(10^3)$

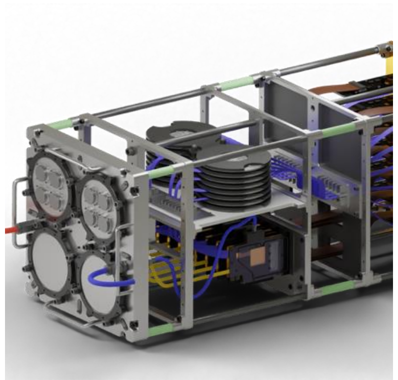
HIGH-VOLUME PACKAGING

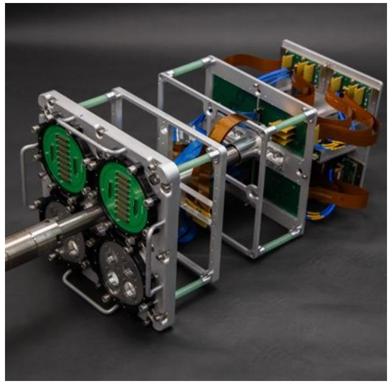




$O(10^2)$

MODULAR BLADE ASSEMBLIES



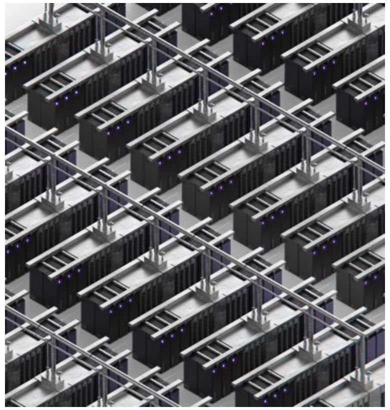


HIGHEST-POWER CRYOGENIC CABINETS

1 in UK

1 in SLAC

SCALABLE QUANTUM COMPUTER



2 sites

AGENDA

01 Building a quantum computer

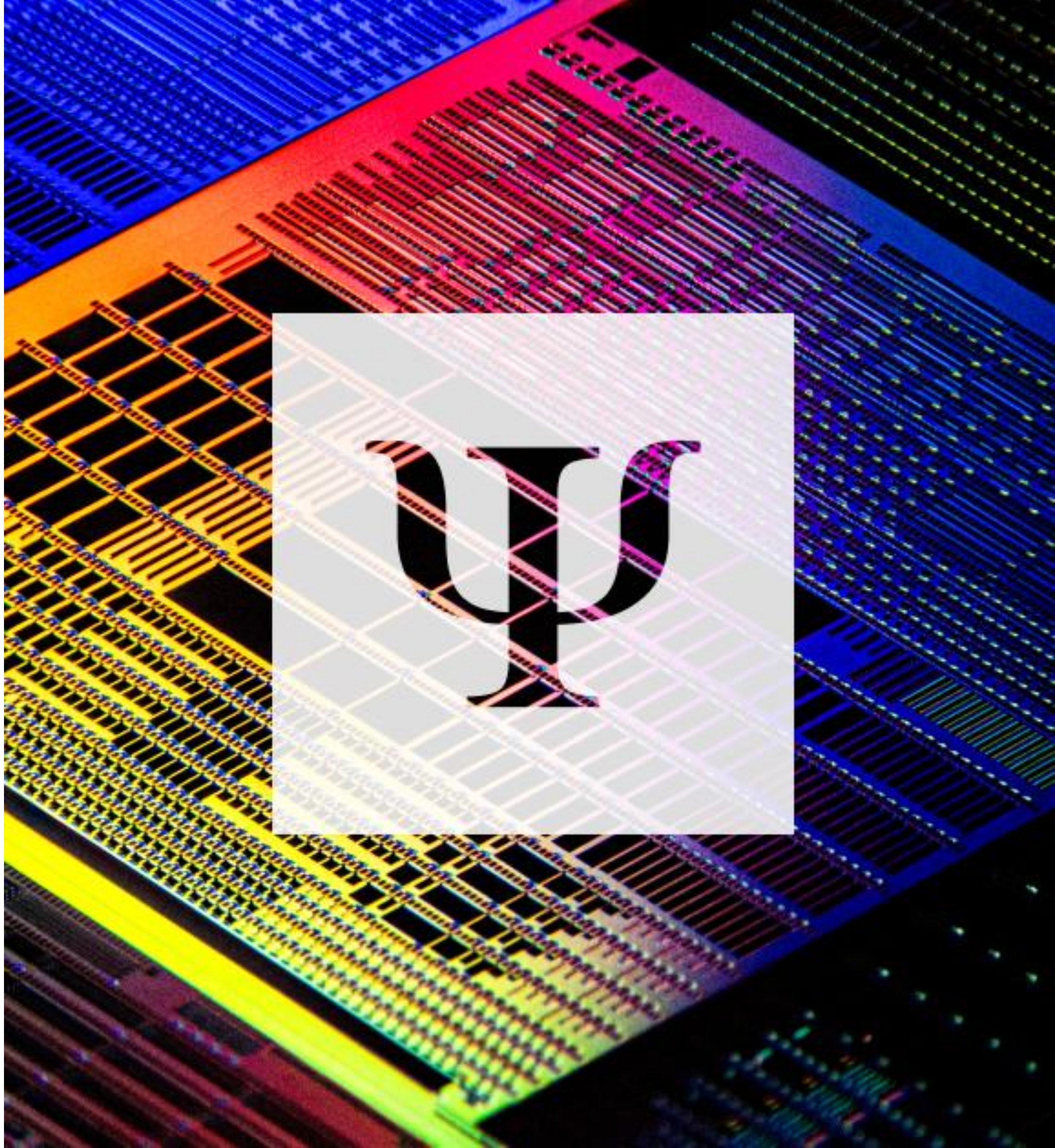
PsiQuantum's mission & hardware development

02 Overview of quantum applications

Our team & recent algorithmic developments

03 Quantum algorithms for nonlinear problems

Simulating nonlinear dynamics on a quantum computer



OVERVIEW OF QUANTUM APPLICATIONS

Our team

APPLICATIONS

50+ | EOY 2025

35+ | TODAY

APPLICATIONS EXPERTISE:

- Fault-tolerant Algorithms
- Active-volume Compilation
- Expert-driven Tools

Massachusetts Institute of Technology
Stanford University
University of Oxford
The University of Chicago
Università degli Studi di Milano
University of Bristol
Caltech
Penn
University of Cambridge
Harvard University
ETH zürich
universität wien
Imperial College London
UC Berkeley
Maastricht University
Purdue University
TU Delft
Yale
University of Notre Dame
University of Toronto

SOLUTIONS EXPERTISE:

- Domain expertise
- Industry-Specific Solutions
- Groundbreaking Methodologies

SOLUTIONS

30+ | EOY 2025

15+ | TODAY

Development lifecycle

Quantum Solutions → **Quantum Applications** → **Quantum Architecture** →

PROBLEM DEFINITION

Translation of commercial need into precise computational problem.

ALGORITHM SELECTION

Identification of most appropriate known quantum algorithm, or specification of new quantum algorithm, to solve the problem.

ALGORITHM CONSTRUCTION

Construction, either mathematically or in code, of the algorithm, in terms of ubiquitous subroutines.

COMPILATION

Unpacking of the constructed algorithms down to fundamental FTQC instructions, either manually or by automated compilation procedures. Prescription complete enough to deploy on an FTQC.

RUNTIME ESTIMATION

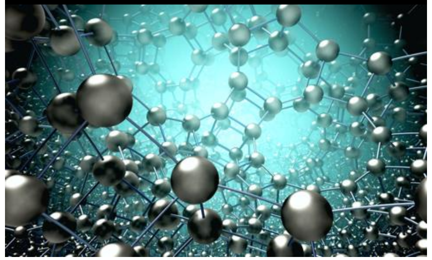
Estimation of computational resources needed to solve the problem on an FTQC.

OVERVIEW OF QUANTUM APPLICATIONS

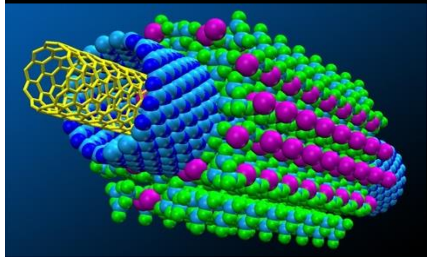
Quantum computing use-cases

Quantum Chemistry

Molecular Properties



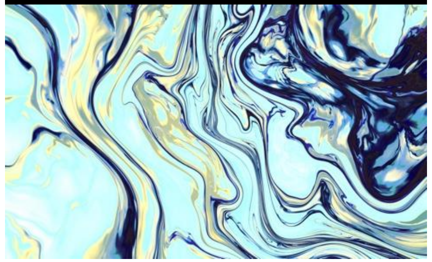
Materials Screening



Exponential

Quantum PDE Solvers

Fluid Dynamics

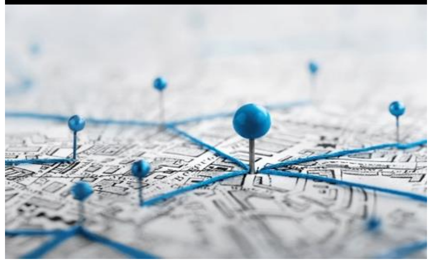


Plasma Physics

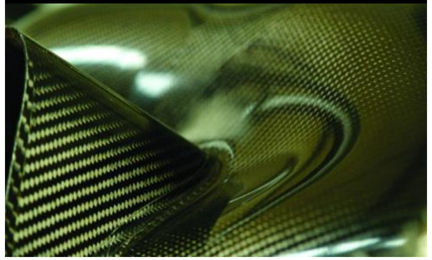
High-Degree Polynomial

Quantum Optimization

Logistics & Routing



Structure Design



Low-Degree Polynomial

Quantum ML

Predictive Maintenance

Neural Networks

TBD?

$\underbrace{\hspace{20em}}$

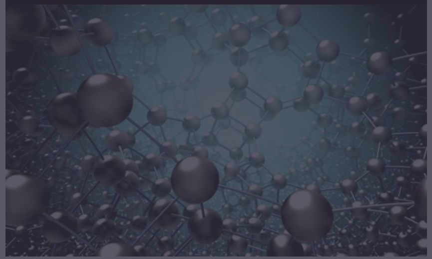
Expected Quantum Speed Up

QUANTUM APPLICATIONS - OVERVIEW

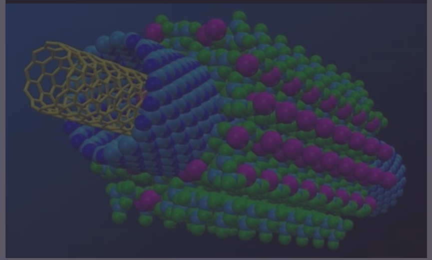
Quantum computing use-cases

Quantum Chemistry

Molecular Properties



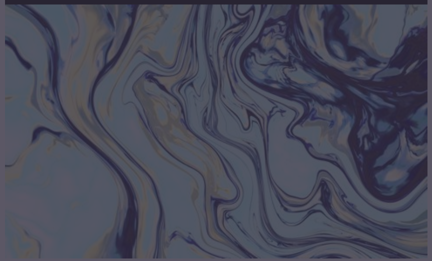
Materials Screening



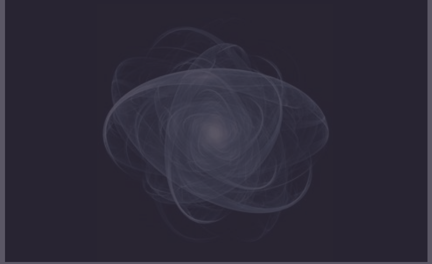
Exponential

Quantum PDE Solvers

Fluid Dynamics



Plasma Physics



High-Degree Polynomial

Quantum Optimization

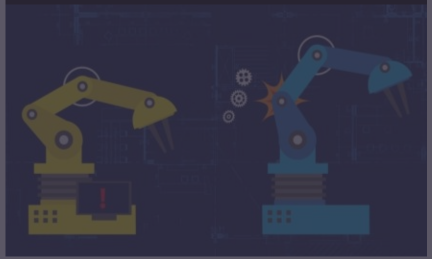
Logistics & Routing

Structure Design

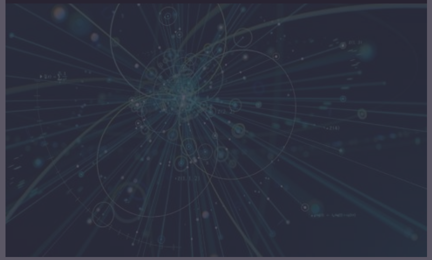
Low-Degree Polynomial

Quantum ML

Predictive Maintenance



Neural Networks



TBD?

Expected Quantum Speed Up

Recent algorithmic developments

Chemistry (dynamics)

- Quantum algorithms for dynamical simulation of catalysis (2504.06348)

Chemistry (statics)

- Record efficiency for GSEE (2501.06165)
- Symmetry-adapted perturbation theory (2305.07009)
- Observable estimation (2303.14118)
- Electrolytic battery chemistry (2104.10653)
- Observable estimation with windowing (2508.06677)

Lattice models

- Improved compilation of the Schwinger model (2508.16831)
- Algorithms for superconductivity models (2411.02160)
- DMERA resource estimates (2404.10050)

Dynamical systems

- Quantum algorithms for general nonlinear dynamics (2509.07155)
- Explicit costs for simulating ODEs (2309.07881)
- Linear solver with explicit query costs (2305.11352)
- Quantum algorithms for plasma and fluids (to appear)

Compilation

- Structured state preparation and block encoding (2405.11436)
- Explicit costs of QPE via signal processing (2404.01396)
- Explicit costs for prime-field ECC (2306.08585)

Recent algorithmic developments

Chemistry (dynamics)

- **Quantum algorithms for dynamical simulation of catalysis (2504.06348)**

Chemistry (statics)

- Record efficiency for GSEE (2501.06165)
- Symmetry-adapted perturbation theory (2305.07009)
- Observable estimation (2303.14118)
- Electrolytic battery chemistry (2104.10653)
- Observable estimation with windowing (2508.06677)

Lattice models

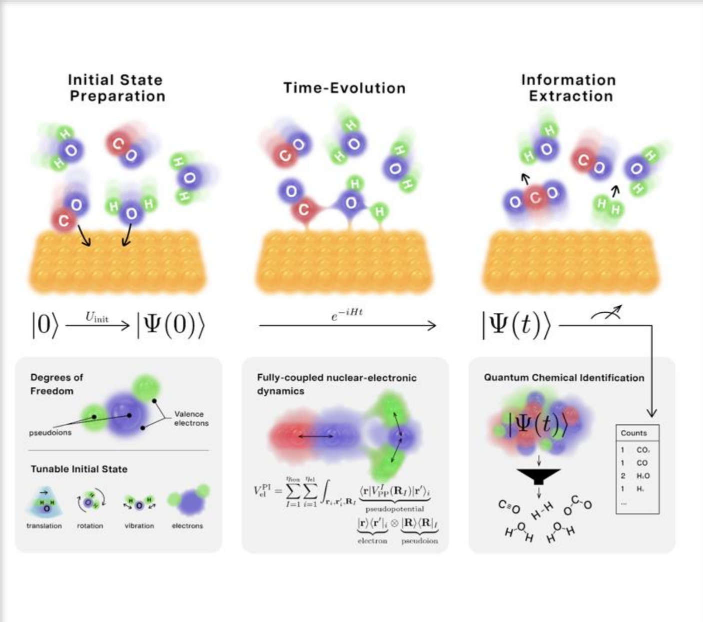
- Improved compilation of the Schwinger model (2508.16831)
- Algorithms for superconductivity models (2411.02160)
- DMERA resource estimates (2404.10050)

Dynamical systems

- Quantum algorithms for general nonlinear dynamics (2509.07155)
- Explicit costs for simulating ODEs (2309.07881)
- Linear solver with explicit query costs (2305.11352)
- Quantum algorithms for plasma and fluids (to appear)

Compilation

- Structured state preparation and block encoding (2405.11436)
- Explicit costs of QPE via signal processing (2404.01396)
- Explicit costs for prime-field ECC (2306.08585)



Developed a comprehensive end-to-end framework for chemical dynamics simulations

Recent algorithmic developments

Chemistry (dynamics)

- Quantum algorithms for dynamical simulation of catalysis (2504.06348)

Chemistry (statics)

- **Record efficiency for GSEE (2501.06165)**
- Symmetry-adapted perturbation theory (2305.07009)
- Observable estimation (2303.14118)
- Electrolytic battery chemistry (2104.10653)
- Observable estimation with windowing (2508.06677)

Lattice models

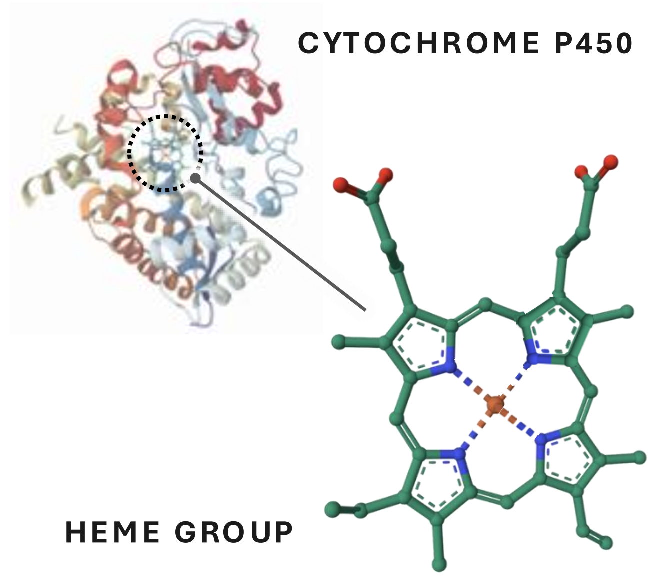
- Improved compilation of the Schwinger model (2508.16831)
- Algorithms for superconductivity models (2411.02160)
- DMERA resource estimates (2404.10050)

Dynamical systems

- Quantum algorithms for general nonlinear dynamics (2509.07155)
- Explicit costs for simulating ODEs (2309.07881)
- Linear solver with explicit query costs (2305.11352)
- Quantum algorithms for plasma and fluids (to appear)

Compilation

- Structured state preparation and block encoding (2405.11436)
- Explicit costs of QPE via signal processing (2404.01396)
- Explicit costs for prime-field ECC (2306.08585)



Improved runtime for GSEE of CYP450 compared to previous state of the art by ~230x

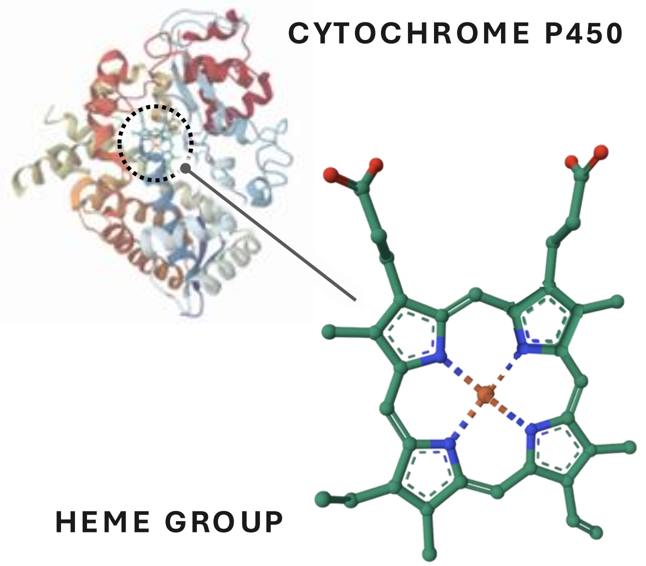
Recent algorithmic developments

A KEY TO SAFER AND MORE EFFECTIVE MEDICINES:

- **>70% of commercially available drugs today** are metabolized by CYP450 enzymes
- **Heme group enables the CYP450 enzymes to catalyze reactions** with drugs in the metabolic process
- **Understanding drug interactions and toxicity is crucial** for bringing and letting a drug on the market

CLASSICALY INTRACTABLE PROBLEM:

Classical | GPU (brute force approach)	Quantum | FTQC (our goal)
Intractable	4 MINUTES



Improved runtime for GSEE of CYP450 compared to previous state of the art by ~230x

OVERVIEW OF QUANTUM APPLICATIONS

Recent algorithmic developments

SPEEDUP RESULTS:

>200x
TOTAL SPEEDUP
For electronic structure calculation on a quantum computer

25-31x
SPEEDUP
PsiQuantum's Active Volume architecture

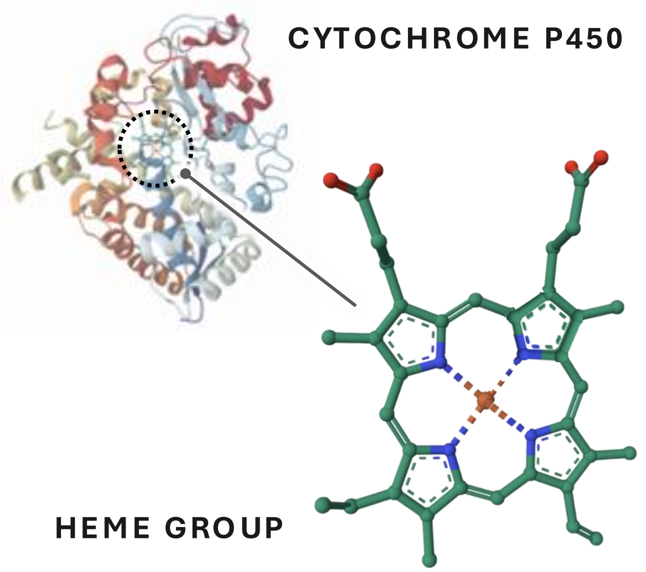
>8x
SPEEDUP
Combining BLISS and THC techniques

1.1x
SPEEDUP
Circuit optimization

PROJECTED RUNTIME FOR PSIQUANTUM MACHINE:

9 months → **<1 day** → **4 mins**

PRIOR ART — PSIQUANTUM LATEST — PSIQUANTUM ROADMAP



Improved runtime for GSEE of CYP450 compared to previous state of the art by ~230x

Recent algorithmic developments

Chemistry (dynamics)

- Quantum algorithms for dynamical simulation of catalysis (2504.06348)

Chemistry (statics)

- Record efficiency for GSEE (2501.06165)
- Symmetry-adapted perturbation theory (2305.07009)
- Observable estimation (2303.14118)
- Electrolytic battery chemistry (2104.10653)
- Observable estimation with windowing (2508.06677)

Lattice models

- **Improved compilation of the Schwinger model (2508.16831)**
- Algorithms for superconductivity models (2411.02160)
- DMERA resource estimates (2404.10050)

Dynamical systems

- Quantum algorithms for general nonlinear dynamics (2509.07155)
- Explicit costs for simulating ODEs (2309.07881)
- Linear solver with explicit query costs (2305.11352)
- Quantum algorithms for plasma and fluids (to appear)

Compilation

- Structured state preparation and block encoding (2405.11436)
- Explicit costs of QPE via signal processing (2404.01396)
- Explicit costs for prime-field ECC (2306.08585)

$$H = H_E + H_I + H_M$$

$$\sum_r E_r^2 + x\sum_r \left(U_r \psi_r^\dagger \psi_{r+1} - U_r^\dagger \psi_r \psi_{r+1}^\dagger\right) + \mu \sum_r (-1)^r \psi_r^\dagger \psi_r$$

Created fully compiled QREs for two different methods of simulating the Schwinger effect

Recent algorithmic developments

Chemistry (dynamics)

- Quantum algorithms for dynamical simulation of catalysis (2504.06348)

Chemistry (statics)

- Record efficiency for GSEE (2501.06165)
- Symmetry-adapted perturbation theory (2305.07009)
- Observable estimation (2303.14118)
- Electrolytic battery chemistry (2104.10653)
- Observable estimation with windowing (2508.06677)

Lattice models

- Improved compilation of the Schwinger model (2508.16831)
- Algorithms for superconductivity models (2411.02160)
- DMERA resource estimates (2404.10050)

Dynamical systems

- **Quantum algorithms for general nonlinear dynamics (2509.07155)**
- Explicit costs for simulating ODEs (2309.07881)
- Linear solver with explicit query costs (2305.11352)
- Quantum algorithms for plasma and fluids (to appear)

Compilation

- Structured state preparation and block encoding (2405.11436)
- Explicit costs of QPE via signal processing (2404.01396)
- Explicit costs for prime-field ECC (2306.08585)

AGENDA

01 Building a quantum computer

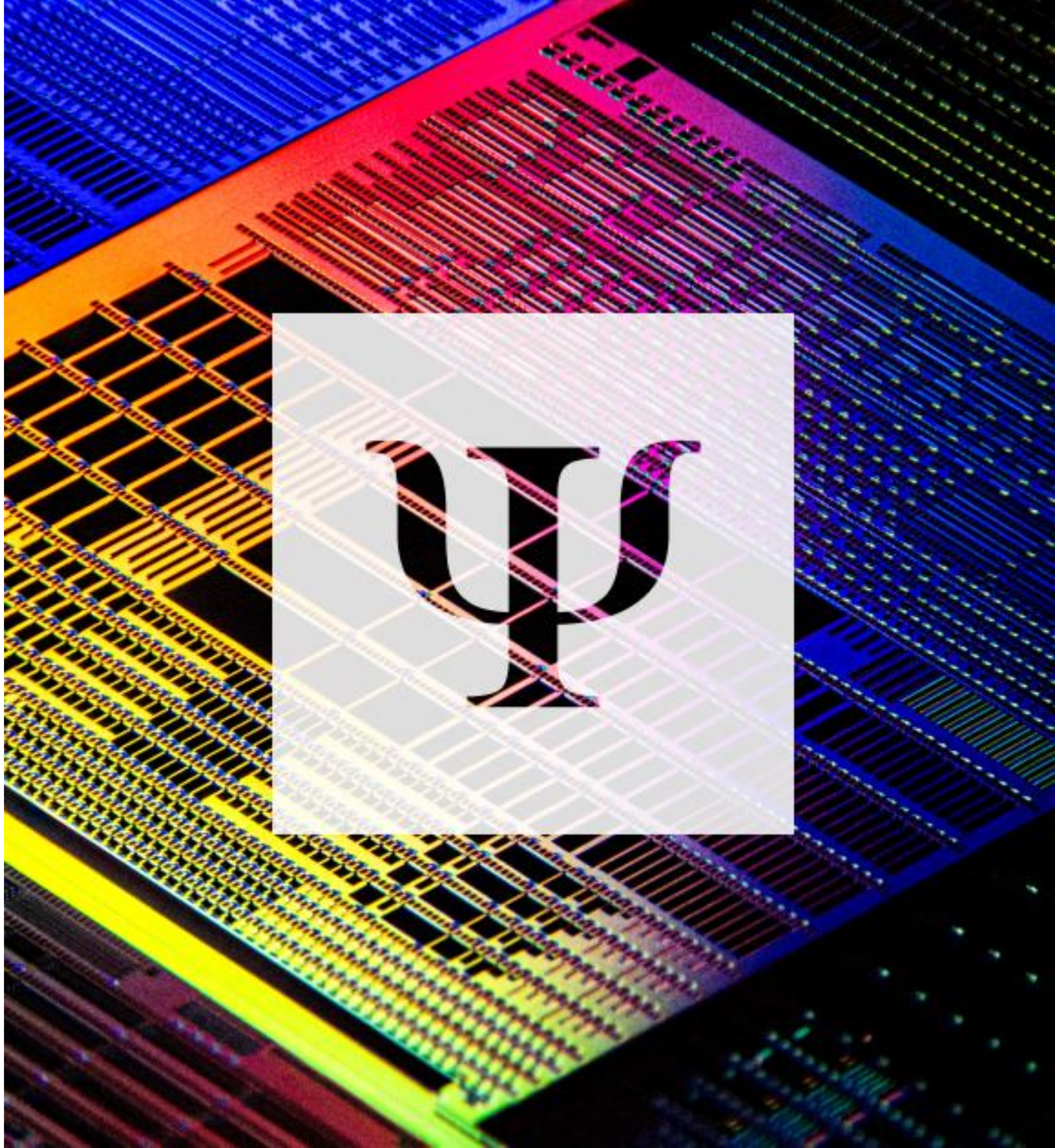
PsiQuantum's mission & hardware development

02 Overview of quantum applications

Our team & recent algorithmic developments

03 Quantum algorithms for nonlinear problems

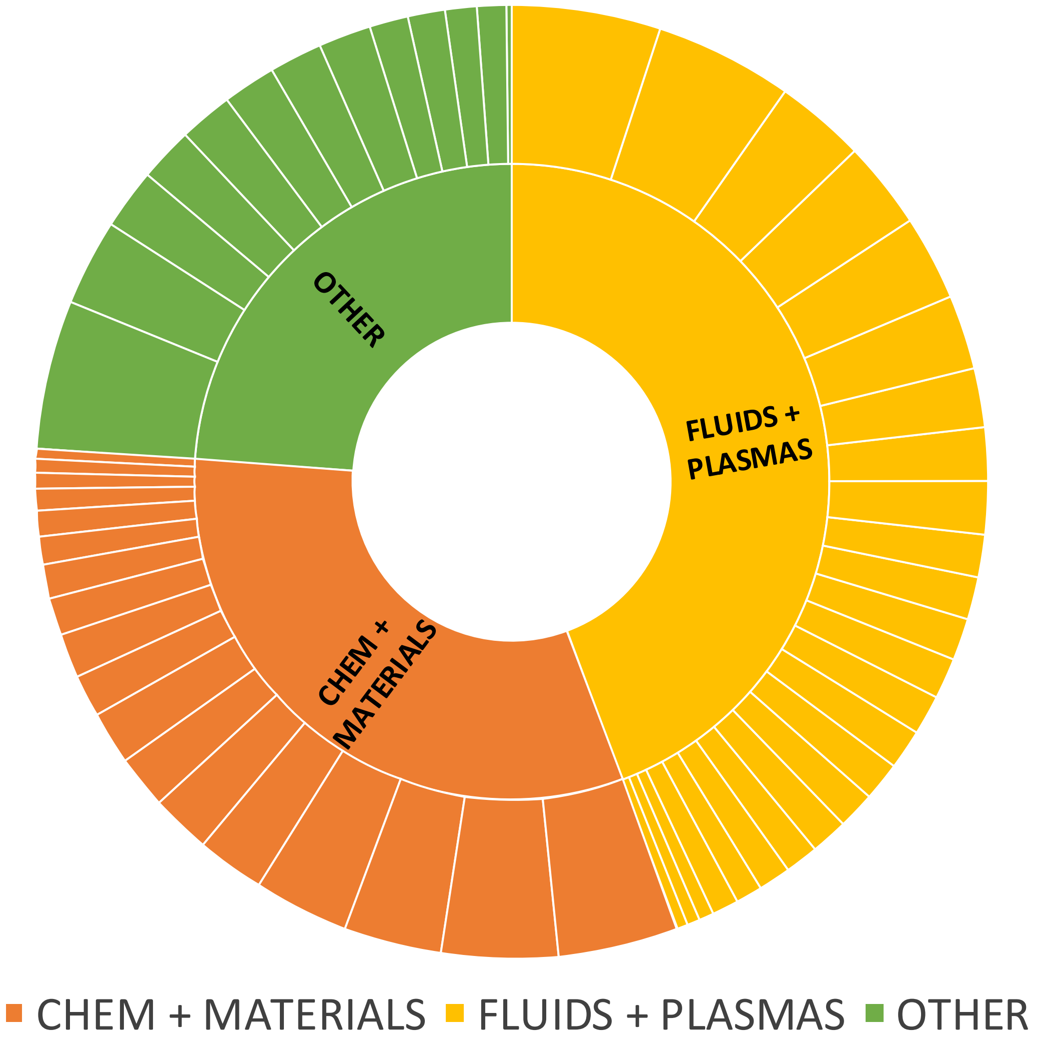
Simulating nonlinear dynamics on a quantum computer



Motivation

A substantial fraction of today's high-performance supercomputing is devoted to the resolution of these problems

DOE INCITE 2023 projects by core hours:
>55M core-hours allocated over 56 projects



Goal: Provable quantum advantage on high-impact classical dynamical system, with detailed costing and no caveats

Algorithmic pipeline

Problem encoding

↓

Linear embedding

↓

Dynamical system mapping

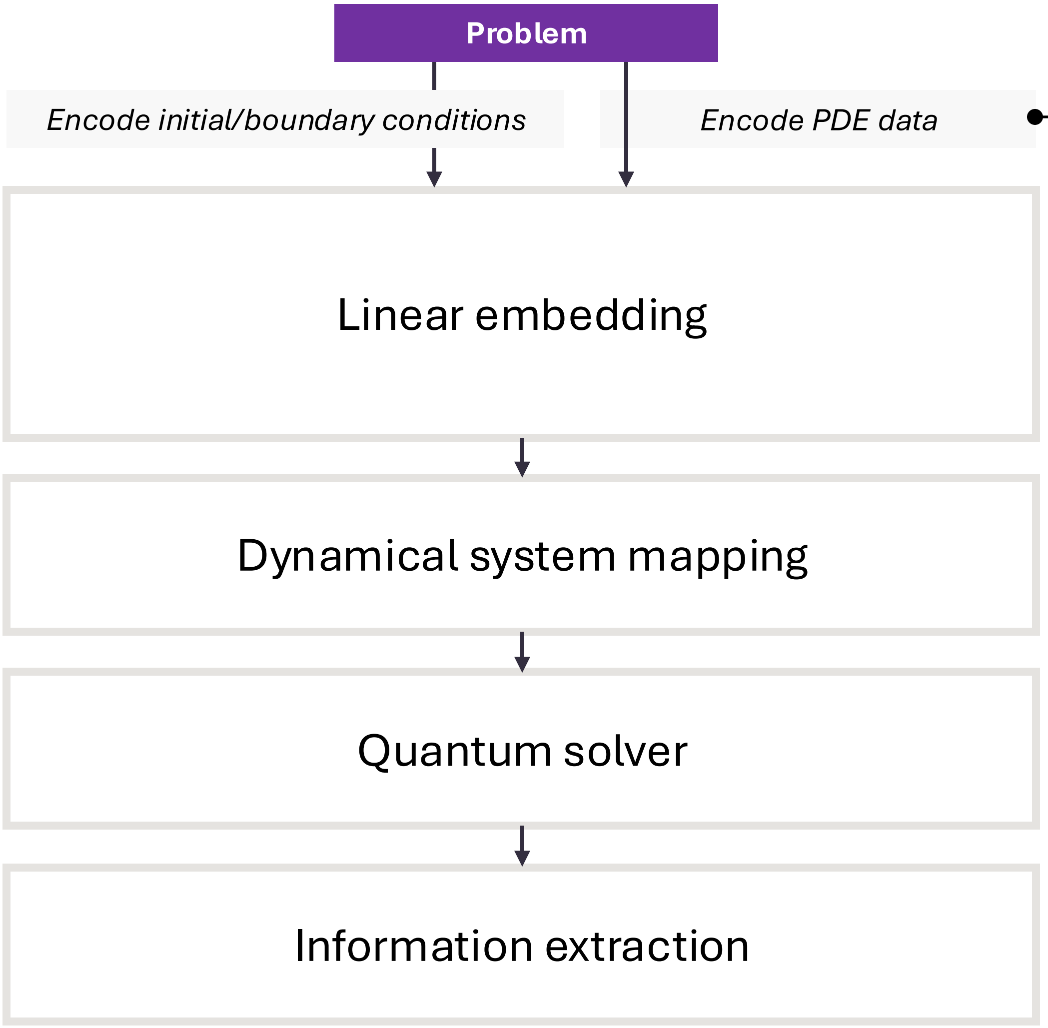
↓

Quantum solver

↓

Information extraction

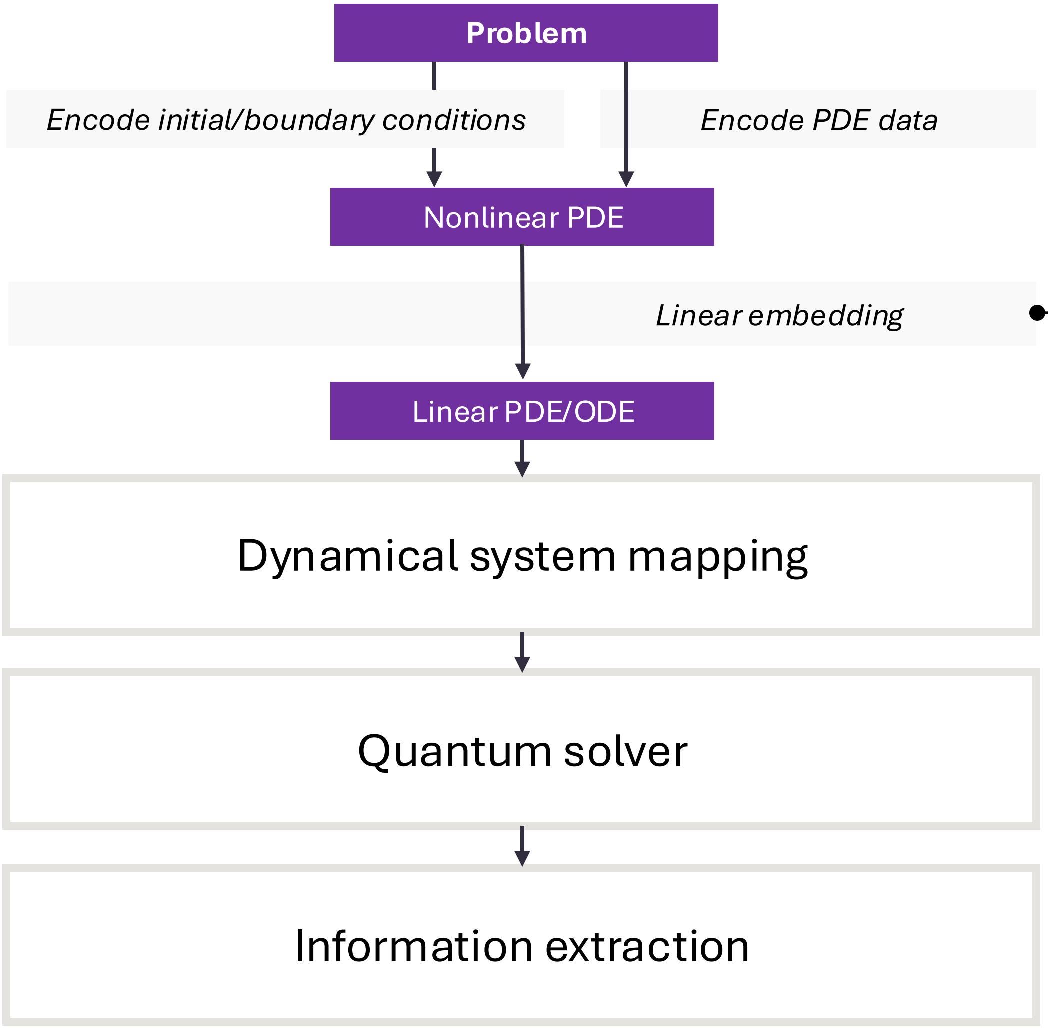
Algorithmic pipeline



Problem encoding

Problem data such as initial and boundary conditions and geometry need to be encoded on the quantum computer. Techniques for this include Quantum Rejection Sampling for state vector preparation and matrix block encoding (PsiQuantum, 2024, arXiv:2405.11436).

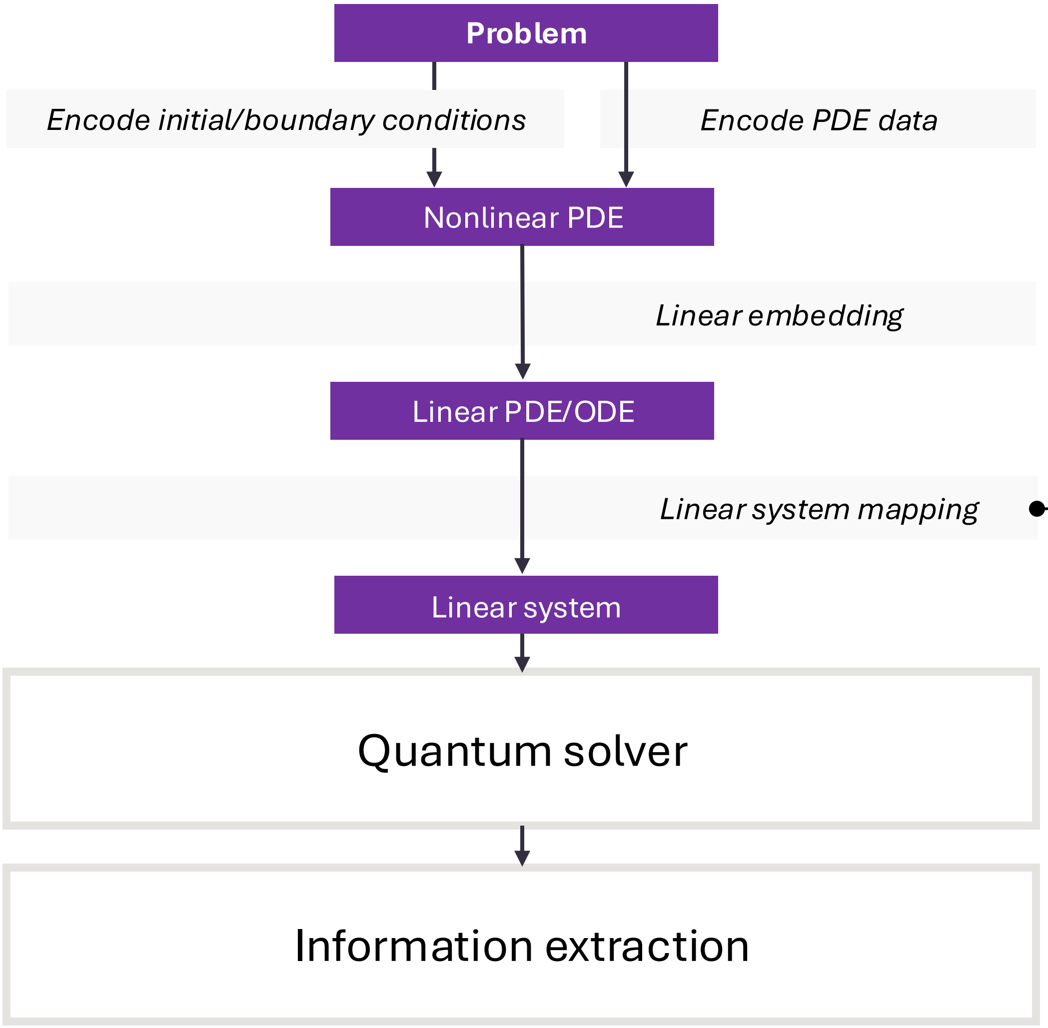
Algorithmic pipeline



Linear embedding

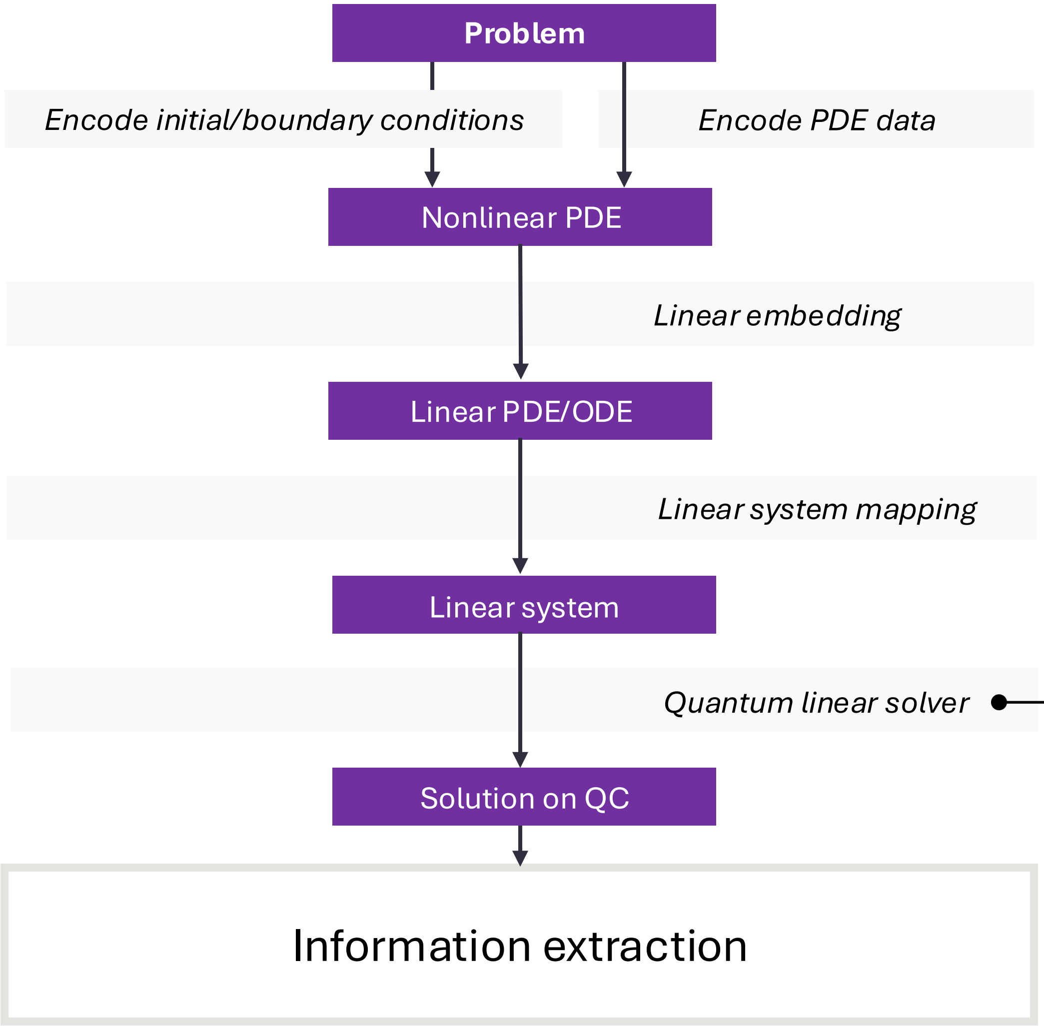
To be tackled by a quantum computer, a (system of) nonlinear PDEs needs to be transformed into a system of linear ODEs/PDEs. The transformation may lead to an infinite number of variables, which can be truncated to approximate the problem. These linearization methods include Carleman Linearization and Koopman von Neuman/Liouville embedding (PsiQuantum, to appear soon).

Algorithmic pipeline



Linear system mapping
Consists of discretizing the continuous equations into discrete equations which can be cast as a linear system of algebraic equations (fast-forwarding and first in the world quantum computational resource estimate: PsiQuantum 2024, arXiv:2309.07881).

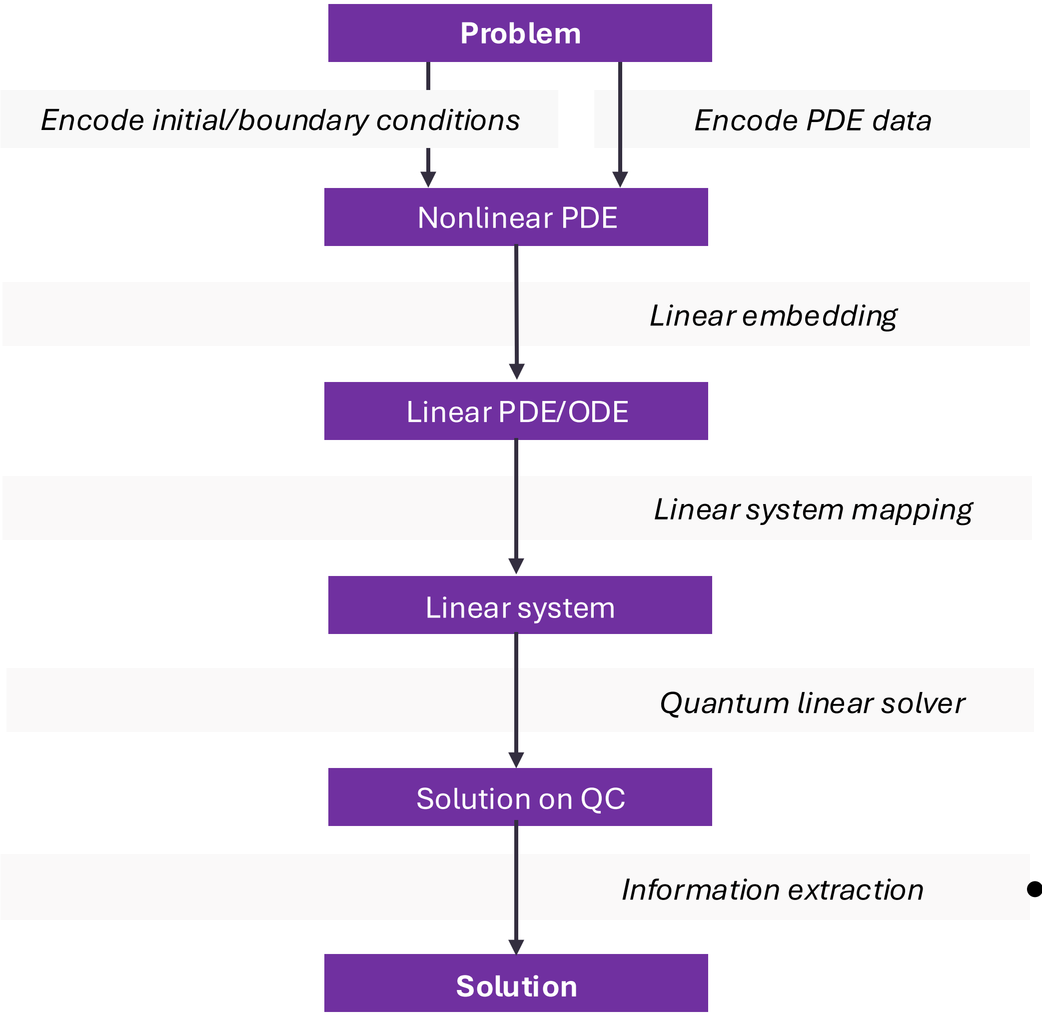
Algorithmic pipeline



Quantum linear solver

The first approach to a quantum solver for linear problems was the HHL algorithm (Harrow Hassidim and Lloyd.) Until recently, PsiQuantum had the state-of-the-art solver for ODEs (PsiQuantum 2023 arXiv:2305.11352), with further improvements by Dalzell 2024.

Algorithmic pipeline



Information extraction

The solution on the quantum computer exists in an n-qubit register and relevant information needs to be extracted via measurements. Crucially, not the entire (very large) solution can be extracted (or even stored classically), but only a low-dimensional representation of interest, to achieve exponential or polynomial speedups over classical methods.

Carleman embedding

Consider a nonlinear ODE:

$$\frac{d}{dt} x_1(t) = a\, x_1(t) + b\, x_1^2(t)$$

Introduce new variable:

$$x_2(t) := x_1^2(t)$$

Get a linear ODE for the old variable:

$$\frac{d}{dt} x_1(t) = a\, x_1(t) + b\, x_2(t)$$

But a nonlinear ODE for the new variable

$$\frac{d}{dt} x_2(t) = 2\, a\, x_2(t) + 2\, b\, x_1(t)\, x_2(t)$$

$$x_3(t) := x_1^3(t)$$

$$\frac{d}{dt} x_2(t) = 2\, a\, x_2(t) + 2\, b\, x_3(t)$$

$$\vdots$$

$$\frac{d}{dt} x_k(t) = k\, a\, x_k(t) + 2\, \cancel{k\, b\, x_1(t)\, x_k(t)}$$

Nonlinear ODE with N variables → **Linear ODE with $\sim N^k$ variables**

Convergence question: how does the truncation error behave with growing k?

Convergence and algorithmic results

Consider a general quadratic ODE:

$$\frac{d}{dt}x(t) = \underbrace{F_0}_{\text{Driving}} + \underbrace{F_1}_{\text{Linear coupling}} x(t) + \underbrace{F_2 x^{\otimes 2}}_{\text{Nonlinearity}}(t), \qquad x(t) \in \mathbb{C}^N$$

Quantum algorithms for general nonlinear dynamics based on the Carleman embedding

David Jennings[1], Kamil Korzekwa[1], Matteo Lostaglio[1], Andrew T Sornborger[2], Yiğit Subaşi[2], and Guoming Wang[*1]

[1]PsiQuantum, 700 Hansen Way, Palo Alto, CA 94304, USA
[2]Computer, Computational, and Statistical Sciences Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

arXiv:2509.07155

Central Question 1: Carleman convergence

Central Question 2: Algorithmic efficiency

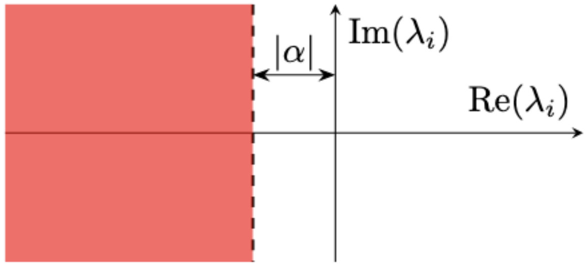
Central Question 3: Exponential advantage in the nonlinear regime

Convergence and algorithmic results

Central Question 1: Carleman convergence

λ_i: Eigenvalues of F_1

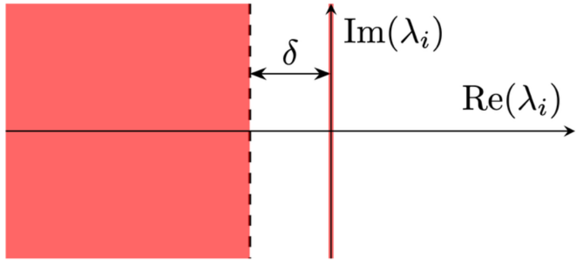
Stable systems



$R_P < 1$

$$R_P = \frac{\text{nonlinearity strength}}{\text{stability parameter}}$$

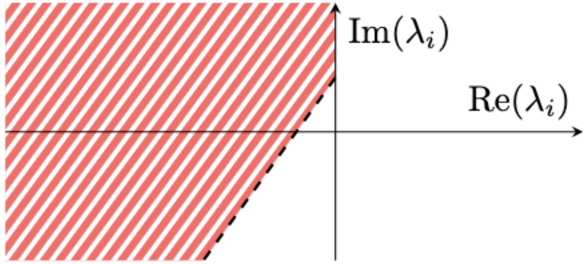
Conservative systems



$R_\delta < 1$

$$R_\delta = \frac{\text{nonlinearity strength}}{\text{dissipation parameter}}$$

Nonresonant systems



$R_\Delta < 1$

$$R_\Delta = \frac{\text{nonlinearity strength}}{\text{nonresonance parameter}}$$

Convergence and algorithmic results

Central Question 2: Algorithmic efficiency

Algorithm 1:

- Assumes F_1 close to a normal matrix.
- Runtime polynomial in T/ϵ.
- Applicable, e.g., to nonlinear Schrödinger equations.

Algorithm 2:

- Applicable only to dissipative systems.
- Assumes access to the Lyapunov matrix for F_1.
- Runtime logarithmic in T/ϵ.

Central Question 3: Exponential advantage in the nonlinear regime

We introduce a class of nonlinear oscillator problems that are:

- Exponentially hard to simulate classically.
- Efficiently simulated by our quantum algorithm
- Contain a BQP-complete problem.

Thank you!

PsiQuantum