Outline: KANs for resolving geoengineering PDEs

- Overview of quantum sensors and their applications in gravitational field mapping
- Importance of semiconductor devices in realizing quantum sensors
- Role of atom cooling techniques in achieving high-precision measurements
- Resolving relevant PDEs for semiconductor sensors with KANs
- Integrating results into CAD software

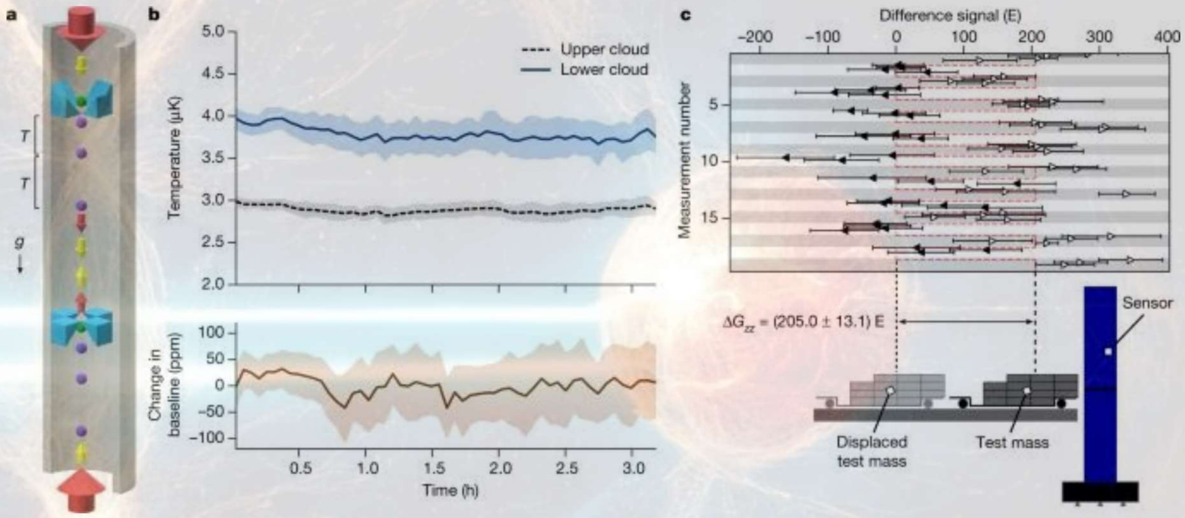
Geoengineering

- Researchers have estimated that current greenhouse gas levels will result in economic losses from climate change of 11 to 29 percent of the world’s income by 2050 [The economic commitment of climate change. Nature 628, 551–557 (2024)]

How to measure progress of greenhouse gas level and areas of improvements?

Sensing

- "The strength of our gravity field varies from place to place, and some of these tiny variations are actually linked to aspects of our planet that are connected to climate change. Variations in the gravity field are due to a number of factors such as the rotation of Earth, the position of mountains and ocean trenches and variations in the density of Earth's interior. But smaller variations in time and location are due to other factors such as fluctuations in underground water reservoirs and changes in ice mass."
- "The idea is that future quantum sensors would combine the principles of current gravimetry measurements with 'cold atom interferometry'."

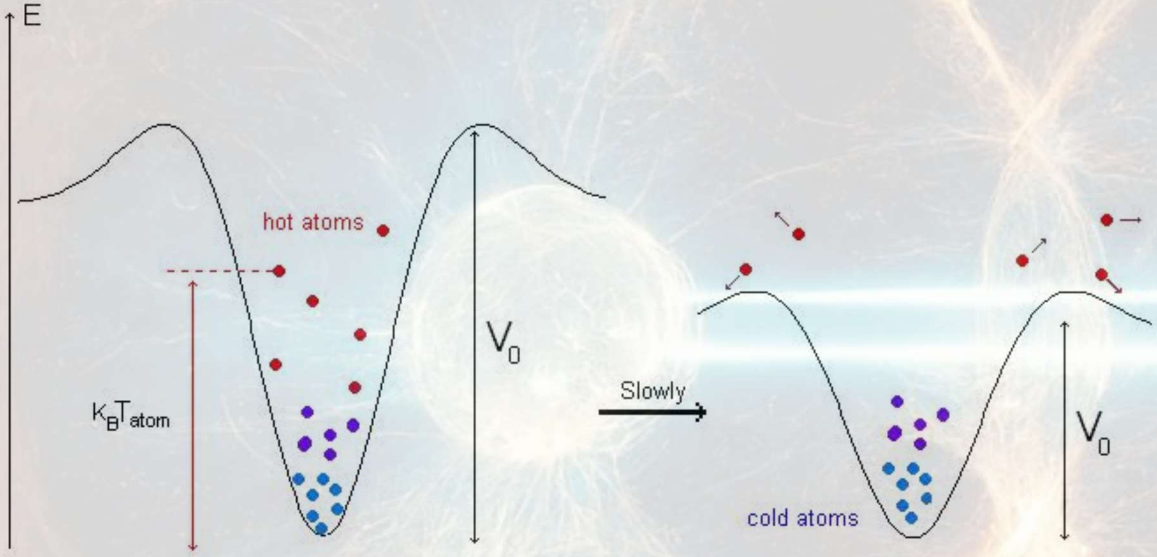


[Quantum sensing for gravity cartography | Nature]

Quantum Sensors for Gravitational Sensing

- Key components: Atom cooling systems, laser manipulation, and detection optics
- Advantages over classical sensors: High sensitivity, long-term stability, and absolute measurements

Cooling and Trapping Techniques with Ultracold Atoms



Evaporating Cooling

[Cold Atom Interferometry in Satellite Geodesy for Sustainable Environmental Management | SpringerLink]

Partial Differential Equations in Quantum Sensor Design

- Schrödinger Equation: Governing the quantum mechanical wave behavior of atoms
- Optical Bloch Equations: Modeling atom-light interactions for cooling and manipulation
- Fokker-Planck Equation: Describing the evolution of atomic velocity distributions
- Coupled PDEs: Heat transfer, electromagnetic wave propagation, and fluid dynamics

Computer-Aided Design for Quantum Sensor Fabrication

- Semiconductor device design and simulation tools (e.g., Sentaurus, Silvaco)
- Integrating QPINNs into CAD workflows for optimized sensor design
- Challenges and considerations: Multiphysics modeling, scalability, and computational efficiency

Kolmogorov-Arnold Networks (KANs)

- [2404.19756] KAN: Kolmogorov-Arnold Networks (arxiv.org)
- Overview of Kolmogorov-Arnold Networks (KANs)
- Incorporating quantum mechanical PDEs into neural network architectures
- Training KANs using experimental data and physical constraints

KAN Implementation in Engineering

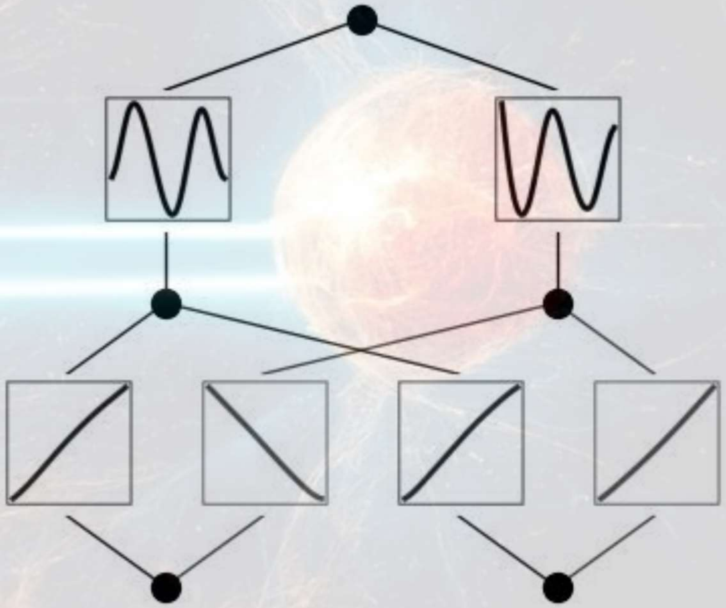
- How to utilize KANs for equations important for engineering quantum sensor devices, for the purpose of geoengineering?
- Demonstration of a KAN implementation for modeling atom cooling processes
- Solving
  - 2D Poisson Equation
  - Schrödinger equation
  - Semiconductor Optical Bloch
- Visualizing the atomic wave functions and velocity distributions

KAN Implementation for 2D Poisson equation

Objective function: 2D Poisson equation: $\nabla^2 f(x,y) = -2\pi^2 \sin(\pi x)\sin(\pi y)$

Boundary conditions: $f(-1,y) = f(1,y) = f(x,-1) = f(x,1) = 0.$

Ground truth solution: $f(x,y) = \sin(\pi x)\sin(\pi y)$



pde loss: 1.37e-16 | bc loss: 3.89e-18 | l2: 7.38e-18 : 100%|█| 20/20 [00:07<00:

$$0.5\sin(3.14159x_1 - 3.14159x_2 + 7.85398) - 0.5\sin(3.14159x_1 + 3.14159x_2 + 1.5708)$$

Source: [pykan/tutorials/Example_6_PDE.ipynb at master · KindXiaoming/pykan (github.com)]()

Future Directions and Challenges

- Miniaturization and integration of quantum sensors into semiconductor devices
- Scalability and parallelization of QPINN simulations for large-scale sensor arrays
- Potential applications beyond gravitational sensing (e.g., quantum computing, metrology)