CRS4
IDEAS BECOME LIFE

CENTER FOR ADVANCED STUDIES, RESEARCH AND DEVELOPMENT IN SARDINIA

TWO QUANTUM ADIABATIC OPTIMIZATION USE CASES FOR THE ENERGY SECTOR

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Quantum computing use cases for the energy sector

About us: Interdisciplinary research center located in the Science and Technology Park of Pula, Sardinia, Italy. Founded in 1990; Carlo Rubbia, Nobel Prize, first President, RTD staff of ~130 people

Goals:

- applying quantum computing to solve new challenges for **real world use cases**
- quantum technologies in the CRS4's areas of expertise (**Information society, Biosciences, Aerospace, Visual computing, Energy & environment, Smart cities projects**)

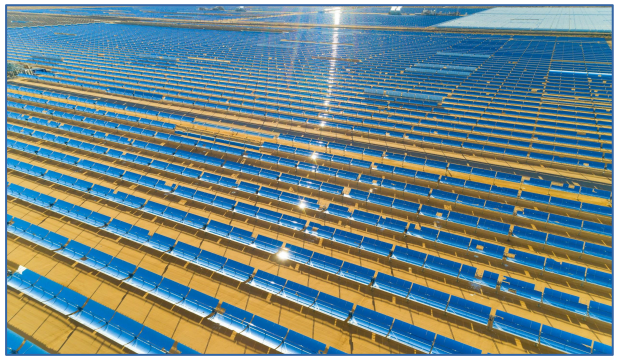
Use cases at at **CRS4**

- ***Multi-tower heliostat field adiabatic optimization [solar energy production]***
- ***Gravity data inversion as adiabatic optimization [geophysical prospection for fossil energy resources]***

Use case #1 at CRS4: solar energy production

Solar energy is a “free” and practically inexhaustible energy source

- Target: **Maximize** the collection efficiency
- Point concentration systems (solar towers) and modular systems (multi-tower) are **more efficient** than linear systems
- **Dynamic optimization** of the aim tower improves the **system efficiency**



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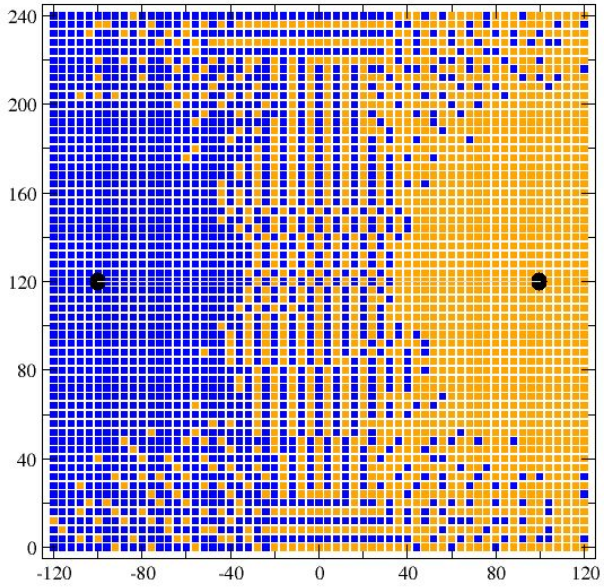
Use case #1 at CRS4: solar energy production

Example: 61x61 mirror, 2-towers system



Problem complexity

Example configuration: 3721 mirrors, 2 receivers

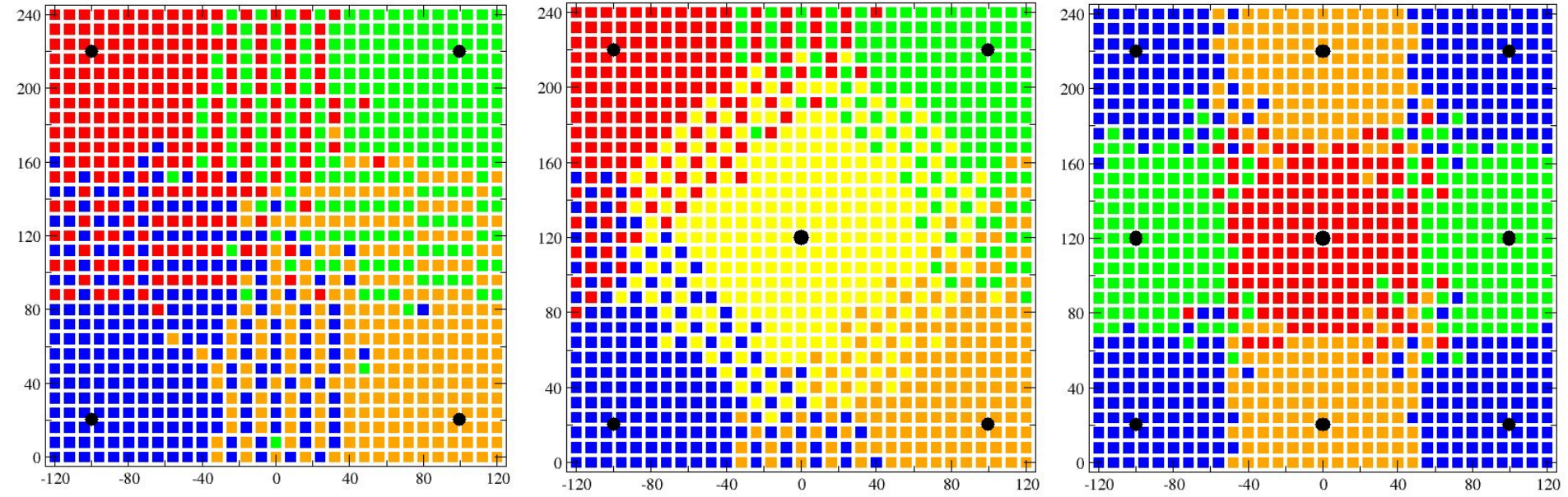
The number of possible **solutions grows exponentially** with the number of mirrors Nh ($\mathbf{Nt^{Nh} = 2^{3721} \approx 10^{1120}}$)

Numerical setup

- **Quadratic Unconstrained Binary Optimization** (QUBO) formulation solved in quantum annealers.
- Results for systems ranging **from 2 to 9 towers** and from tenths to thousands of heliostats.
- **Quantum annealers**, used in hybrid mode, are effective in **finding good solutions in seconds**.

Use case #1 at CRS4: solar energy production

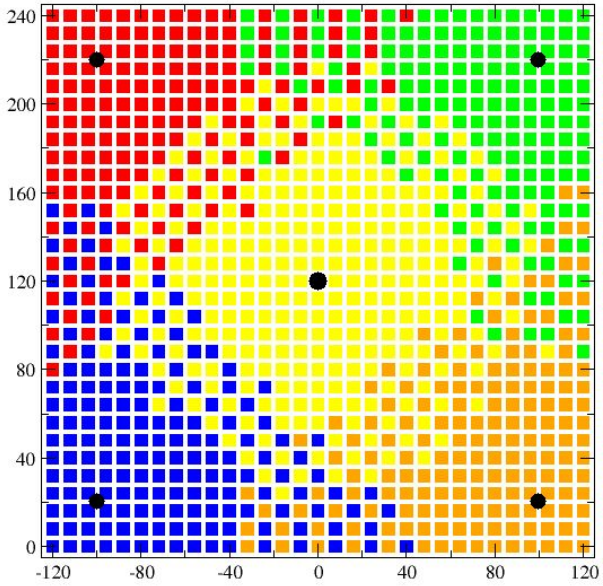
Results: Number of towers

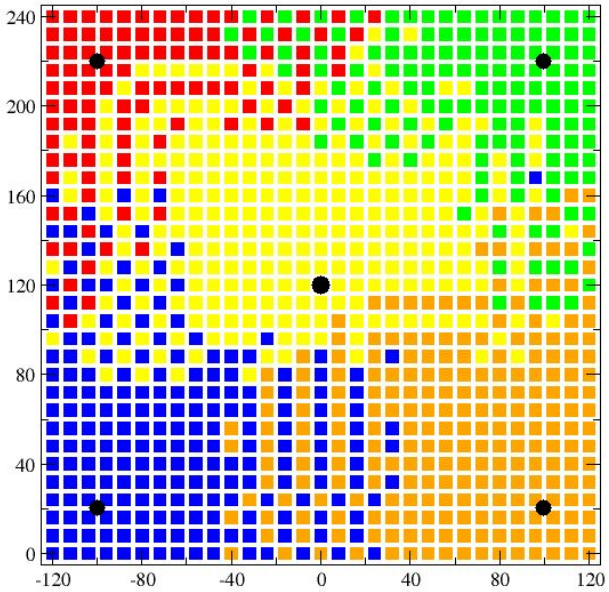


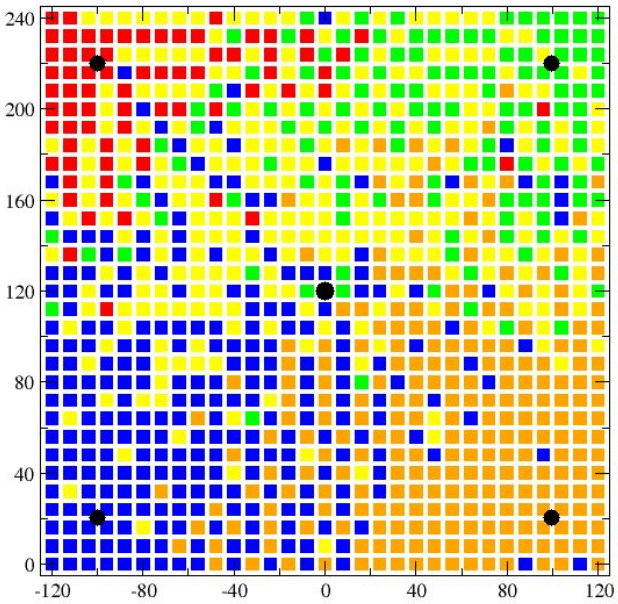
By increasing the number of towers (black circles), the complexity further increases. The model can still manage easily **systems with many towers**.

Use case #1 at CRS4: solar energy production

Results: configuration update according to sun direction







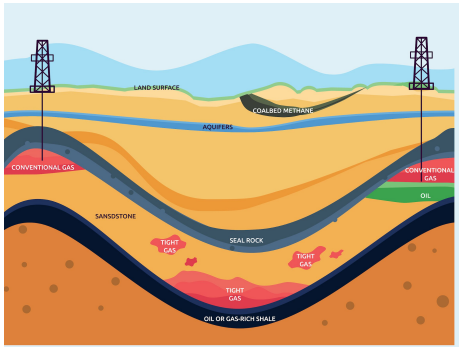
Calculation must be **fast** to pursue the **optimal configuration**

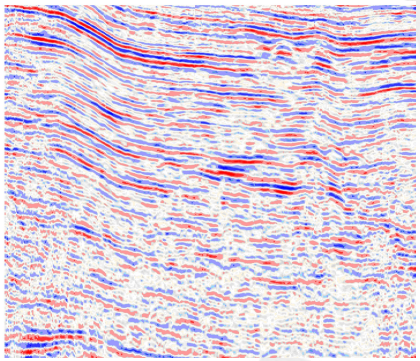
Results: **computational time** of **13 seconds** on a D-Wave adiabatic quantum computer

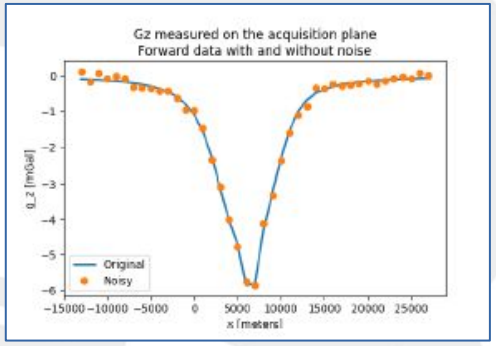
Use case #2 at CRS4: fossil energy resources

Geophysical methods are used for exploration of fossil energy resources

- Many **different methods** (seismic, EM, gravity) are **compared** for imaging
- **Gravity data inversion** reconstructs the shape of a density anomaly from surface acquisitions
- **Ill-posed** inversion problem, **mathematical constraints** to lower the dimensionality of the solution space, **sharp solutions** are lost in case of regularization







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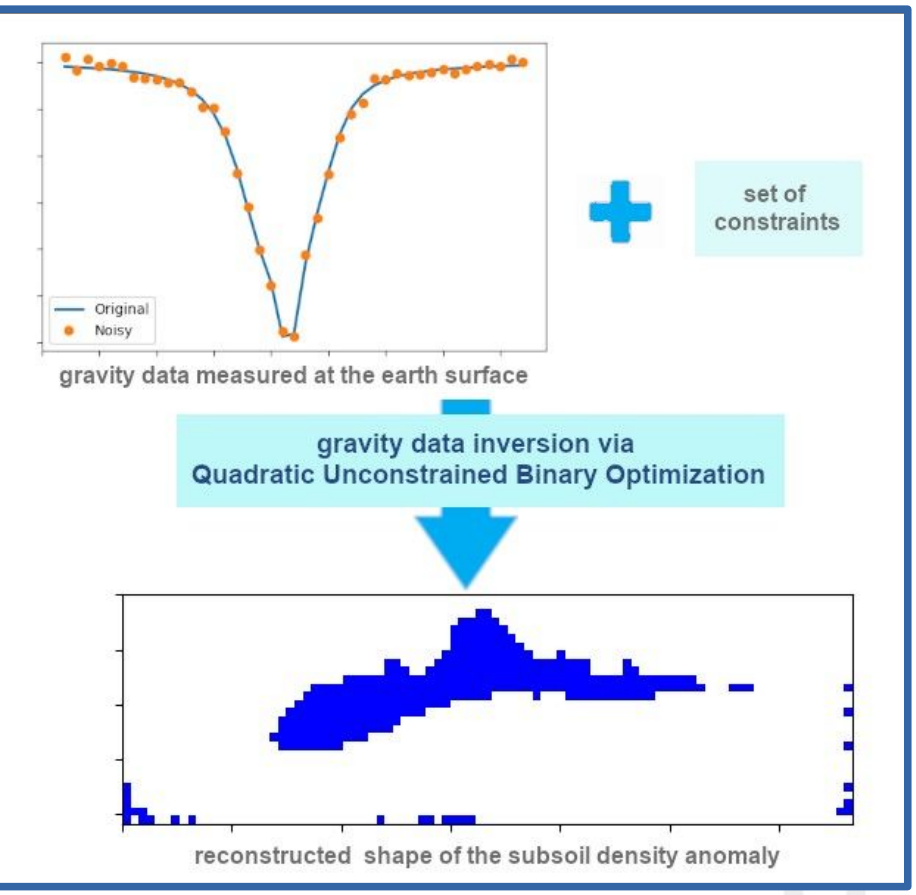
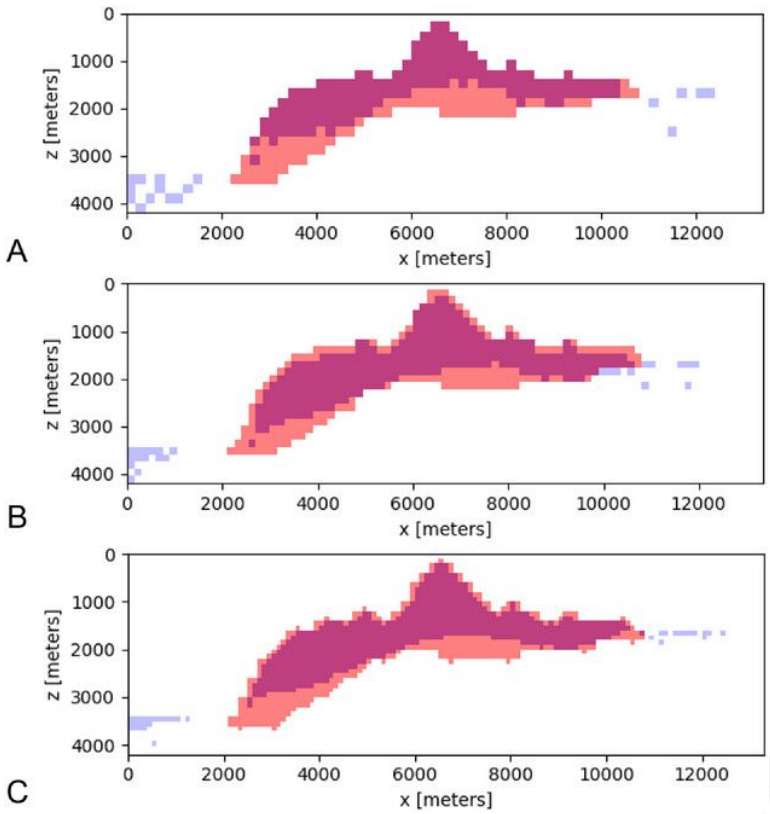
Use case #2 at CRS4: fossil energy resources



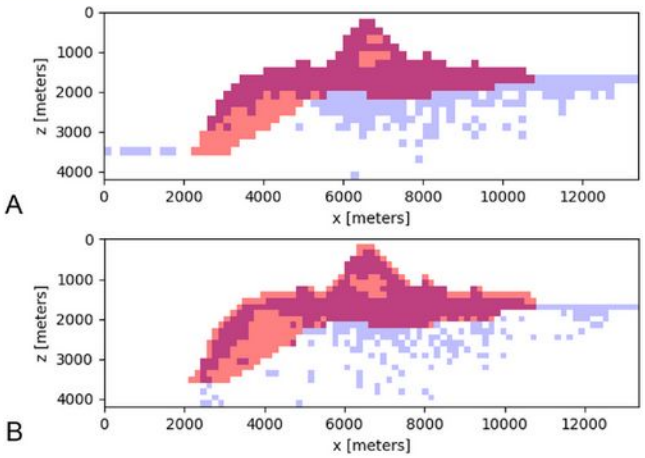
- **Gravity** quantum-enhanced binary **inversion** formulated as a Quadratic Unconstrained Binary Optimization (**QUBO**)
- **2** different realistic **test cases** characterized by an increasing complexity (**non-convexity** of the associated optimization problem).
- In the more complex case, a **hybrid implementation** coupling quantum adiabatic computing with classical annealing provides an **improved solution** with a reduced computational cost.

Results for convex optimization

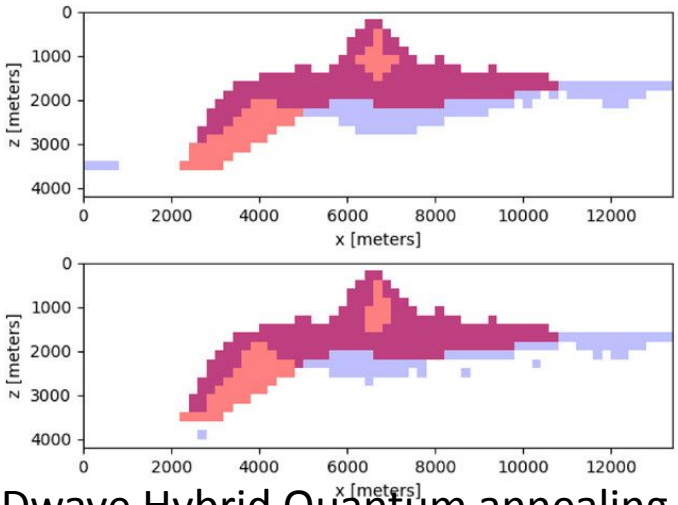


- The results of the imaging on the are improvable, using a different representation of the surface data tp counteract Green's function decay.
- There is a weak computational advantage on the quantum annealer.
- HPC methods are very effective for convex optimization..
- In the non-convex optimization use case, imposing the quantum computing solution as the initial solution for HPC solvers can provide better solutions.

Results for non-convex optimization

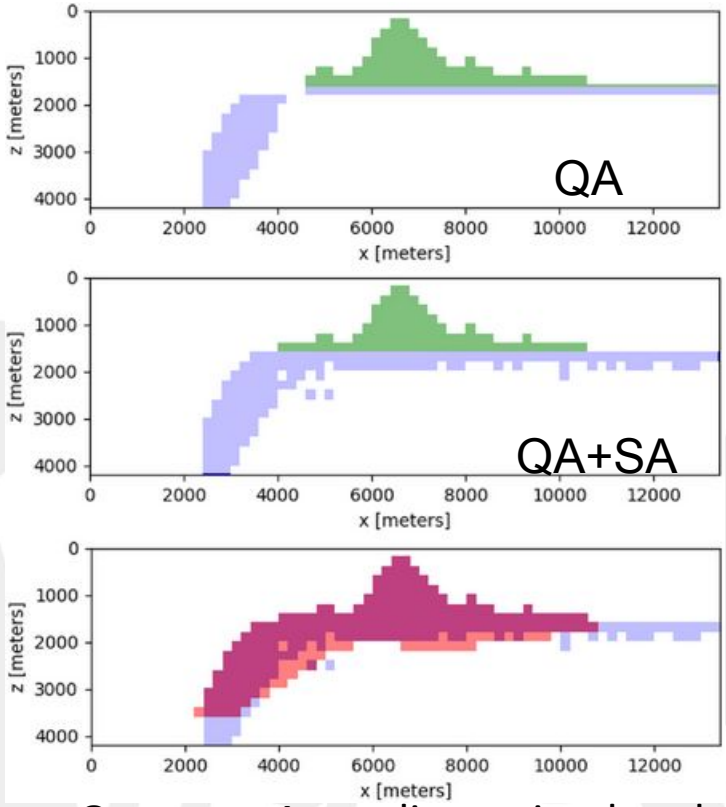


Simulated annealing (SA)



Dwave Hybrid Quantum annealing (HQA)

Improved imaging



Quantum Annealing + simulated annealing postprocessing (QA+SA)

Conclusions

Quantum computing applications for the energy sector can be beneficial:

- for combinatorial problems, especially if you have to perform **real-time calculations** and you are interested in a good local minimum close to the global minimum.
- many problems that feature **non-convex optimization** can benefit of hybrid quantum methods.

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Thank you for your attention

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