Quantum Sensing for (Energy) Infrastructure

Ryan Chaban
Fellow, ARPA-E

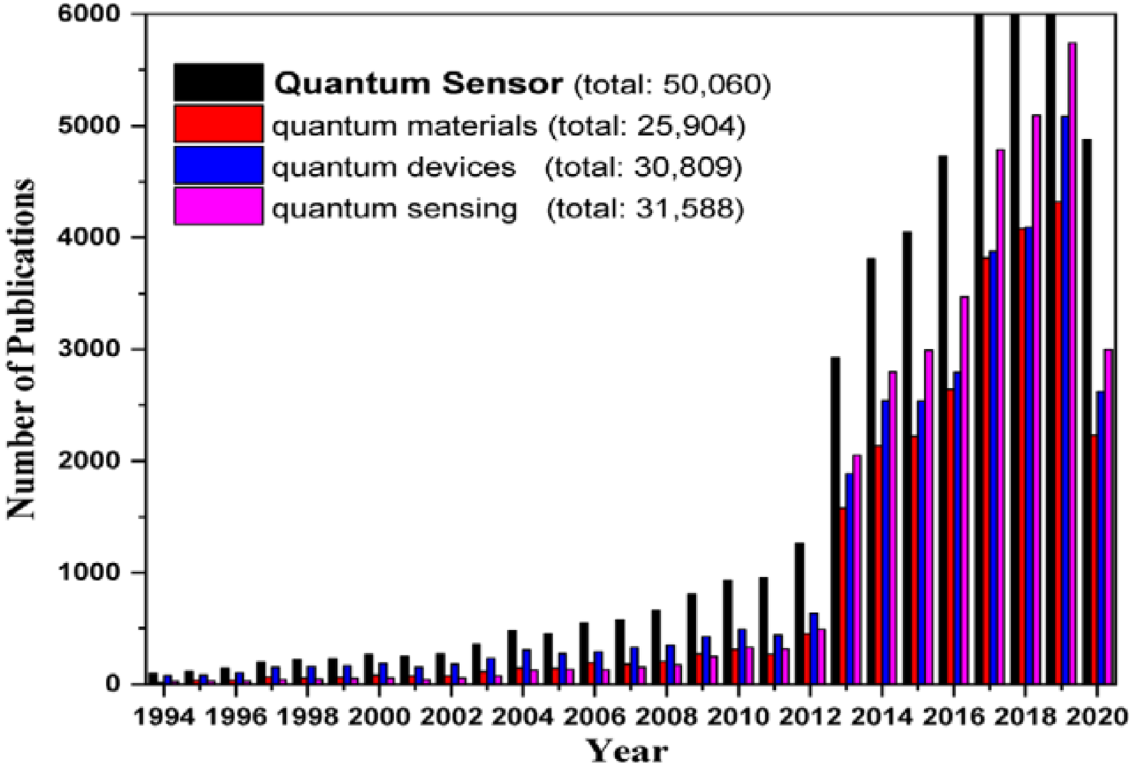
January 23, 2025

What is a quantum sensor?

- Exploiting the behavior or properties of a quantum system to increase the sensitivity compared to a classical sensor.
  - 👍 Decreased drift / less need for calibration
  - 👍 higher sensitivity or better S/N
  - 👎 Increased complexity
  - 👎 Larger and increased energy usage

A splattering of categories:

- Photonic vs. non-photonic (usually spin)
- Gravity, E-field, B-field, pressure, pH, conductivity, strain, force



Crawford, Scott E., et.al. "Quantum Sensing for Energy Applications: Review and Perspective." *Advanced Quantum Technologies* 4, no. 8 (August 2021): 2100049. https://doi.org/10.1002/qute.202100049.

Current State of the Art

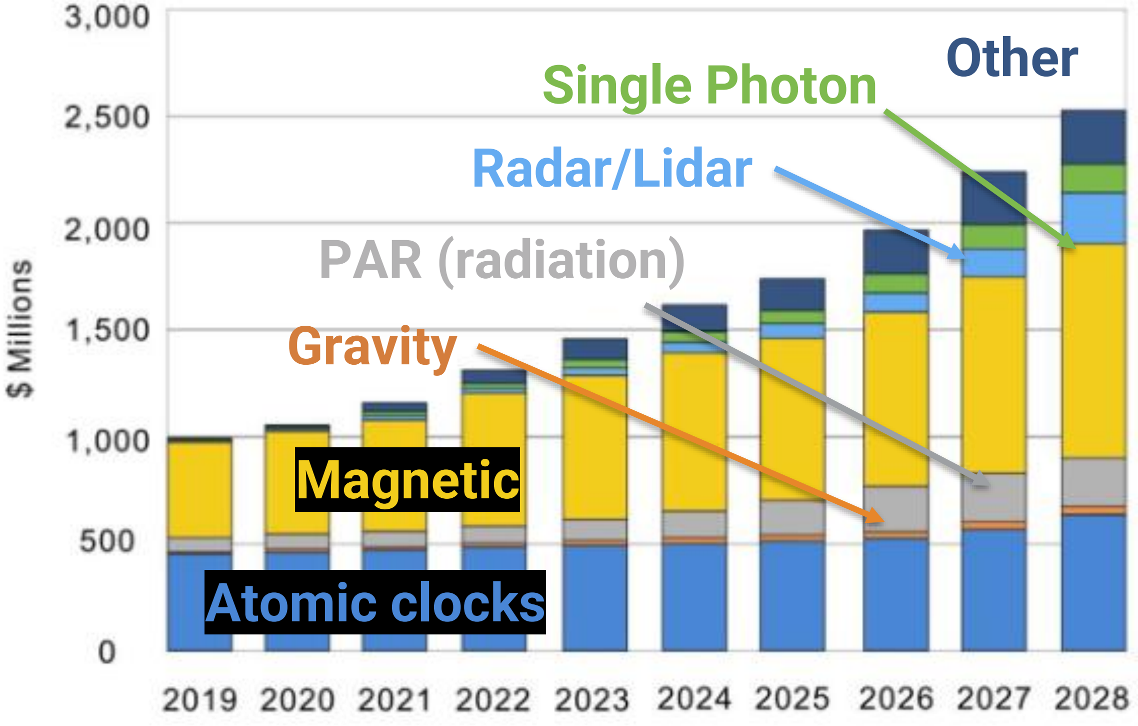
Technology	Implementation type	System description	Measured properties
Solid-state spins	NV[1] center in diamonds	Spin of one electron localized in an insulator defect	Magnetic field, electric field, temperature, pressure, rotation
Neutral atoms	Atomic vapor	Atoms in the vapor cell sense changes in the environment	Magnetic field, rotation, temperature, electric field, frequency, acceleration, rotation
	Cold cloud	Laser-cooled atoms sense changes in the environment	
Superconducting circuits	SQUIDs[2]	Difference in Cooper pairs between two islands of a Josephson tunnel junction	Magnetic field, electric field
Trapped ions[3]	Single atoms	Mapping of motional amplitude to spin as sensor for electromagnetic fields	Magnetic field, electric field

+ many other subtypes

Sensors sensitive to multiple variables – isolation required

Quantum Sensor Market is Growing

2023 study: $0.7-1.0 Billion in 2030 (15% CAGR)[3]



Crawford, Scott E., et.al. "Quantum Sensing for Energy Applications: Review and Perspective." *Advanced Quantum Technologies* 4, no. 8 (August 2021): 2100049. https://doi.org/10.1002/qute.202100049.

Future Applications

Central question:

Where can enhanced sensitivity meet a technological need and be a commercially viable?

Ulta Sensitive corrosion sensors (pH)

In-operando electrolysis sensors

Temperature in transformers (fault prediction)

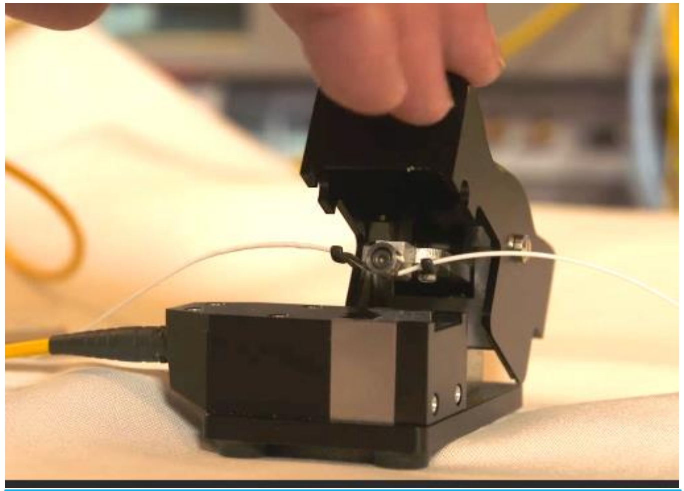
Nuclear PP isotopes detection w/in containment

Navigation without GPS (e.g. submarine)

Geologic H2 exploration (magnetometers for Olivine)

Wellhead leak and safety detection

Long distance transmission strain monitoring (>100km)

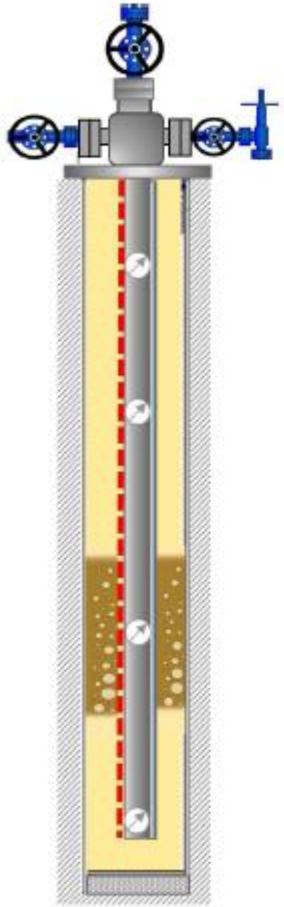


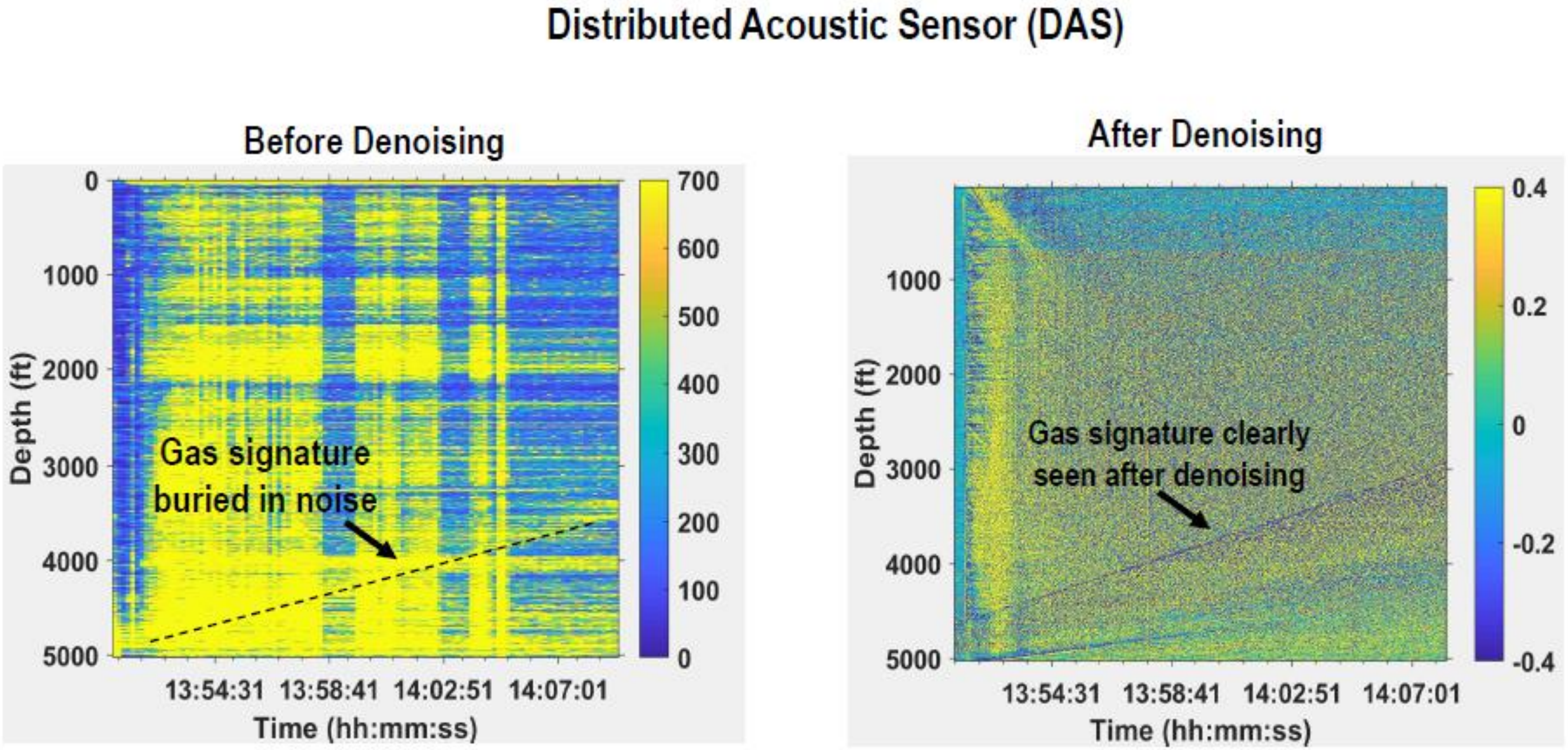
Fiber optic hacking detection (SiC) – emerging tech

Challenges

- Connectivity and/or edge computing
- **RELIABILITY (3-500M)**
- Power consumption

In-well monitoring during geoH2 exploration

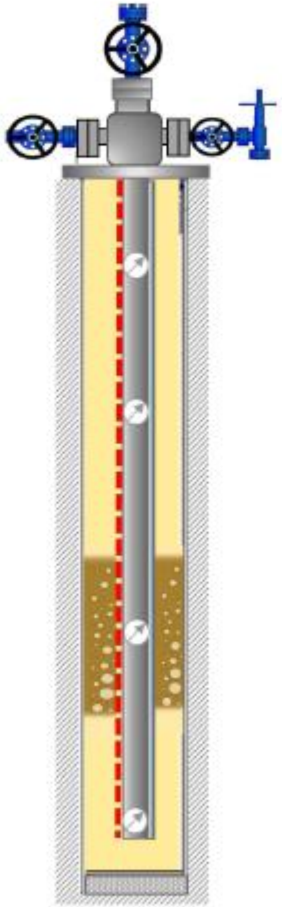




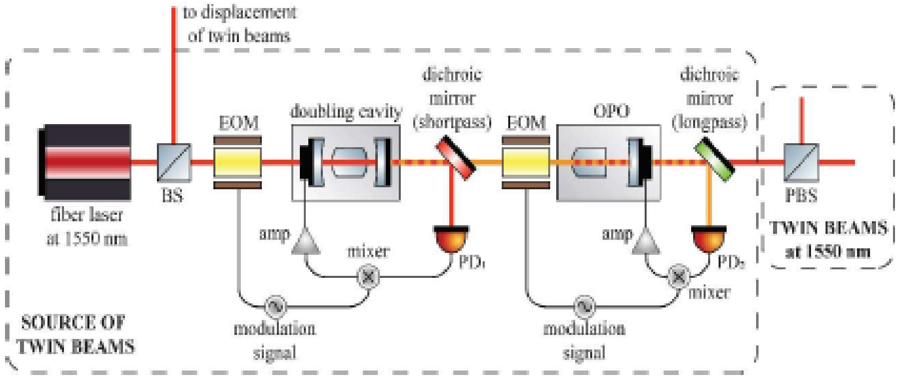
Publication: Tabjula, J., Sharma, Jyotsna*. 2023. Feature Extraction Techniques for Noisy Distributed Acoustic Sensor Data Acquired in a Wellbore. Applied Optics 62(16), E51-E61.

11 of 32

In-well monitoring during geoH2 exploration

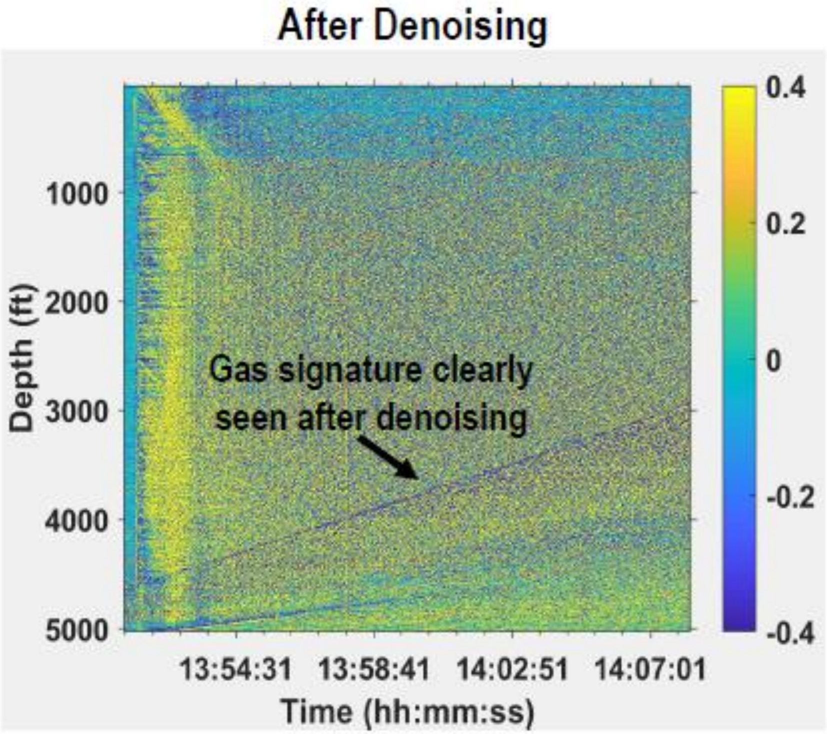


Distributed Acoustic Sensor (DAS)



TWIN BEAMS
at 1550 nm

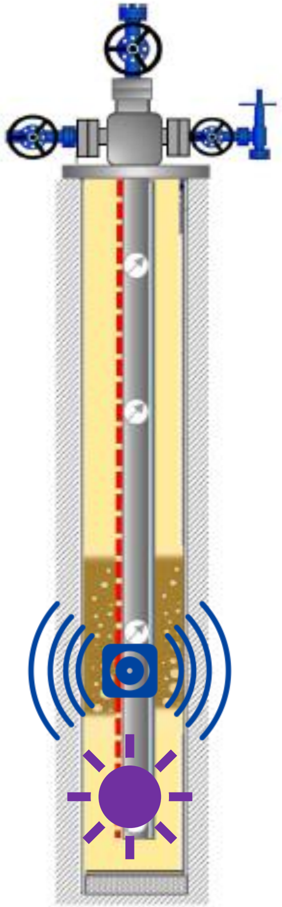
By replacing conventional laser by squeezed light we can lower the noise floor (x 1/2).



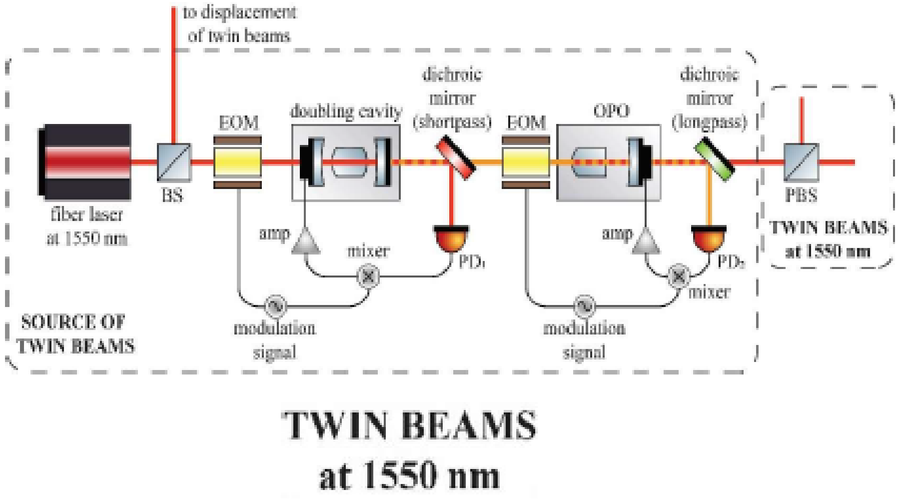
Publication: Tabjula, J., Sharma, Jyotsna*. 2023. Feature Extraction Techniques for Noisy Distributed Acoustic Sensor Data Acquired in a Wellbore. Applied Optics 62(16), E51-E61.

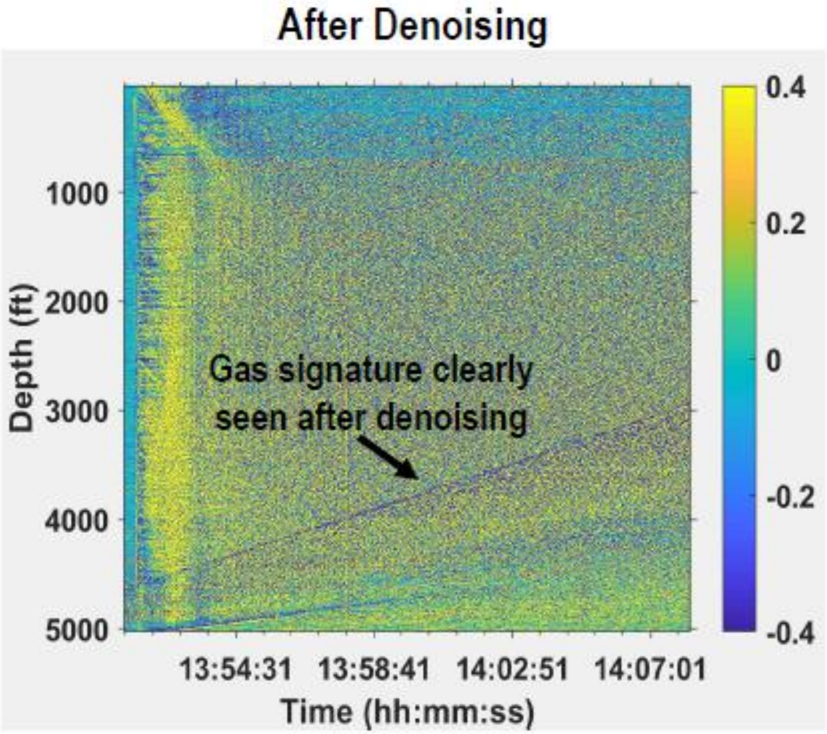
11 of 32

In-well monitoring during geoH2 exploration



Distributed Acoustic Sensor (DAS)





By replacing conventional laser by squeezed light we can lower the noise floor (x 1/2).

Publication: Tabjula, J., Sharma, Jyotsna*. 2023. Feature Extraction Techniques for Noisy Distributed Acoustic Sensor Data Acquired in a Wellbore. Applied Optics 62(16), E51-E61. 11 of 32

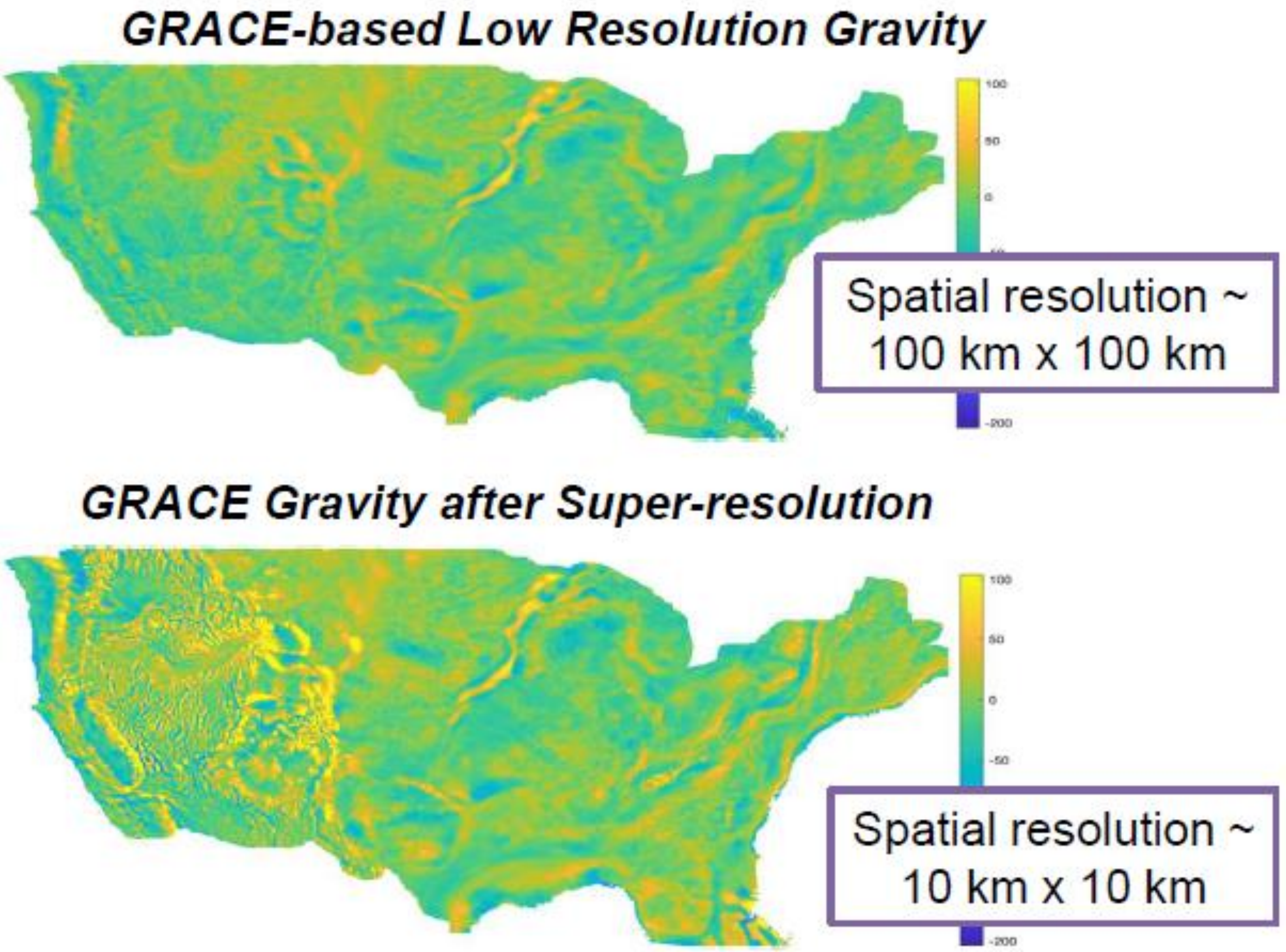
A rising tide lifts all boats

1. Incorporating multiple modalities of sensors and using ML/AI to combine them enhances pattern fidelity

2. Enhanced pattern fidelity leads to better guesses for where to look

3. Better sensor datapoints are used to retrain the model

4. Remember: There will always be things that surprise us ☺



Alaofin, O., Zhang, Y., Sharma,Jyotsna.*, Li, X. 2022. Cross-Modality Super-Resolution of Gravity Data for Geophysical Exploration. IEEE International Geoscience and Remote Sensing Symposium, 17-22 July

Sources

1. Crawford, Scott E., Roman A. Shugayev, Hari P. Paudel, Ping Lu, Madhava Syamlal, Paul R. Ohodnicki, Benjamin Chorpening, Randall Gentry, and Yuhua Duan. “Quantum Sensing for Energy Applications: Review and Perspective.” *Advanced Quantum Technologies* 4, no. 8 (August 2021): 2100049. https://doi.org/10.1002/qute.202100049.
2. Degen, C. L., F. Reinhard, and P. Cappellaro. “Quantum Sensing.” *Reviews of Modern Physics* 89, no. 3 (July 25, 2017): 035002. https://doi.org/10.1103/RevModPhys.89.035002.
3. Gschwendtner, Martina, Yannick Bormuth, Henning Soller, Amanda Stein, and Ronald L. Walsworth. “Quantum Sensing Can Already Make a Difference. But Where?” *Journal of Innovation Management* 12, no. 1 (September 24, 2024): I–XI. https://doi.org/10.24840/2183-0606_012.001_L001.
4. Alaofin, O., Zhang, Y., Sharma,Jyotsna.*, Li, X. 2022. Cross-Modality Super-Resolution of Gravity Data for Geophysical Exploration. IEEE International Geoscience and Remote Sensing Symposium, 17-22 July