Quantum Valley
Ideas Lab

Introduction to quantum RF sensors using Rydberg atom technology

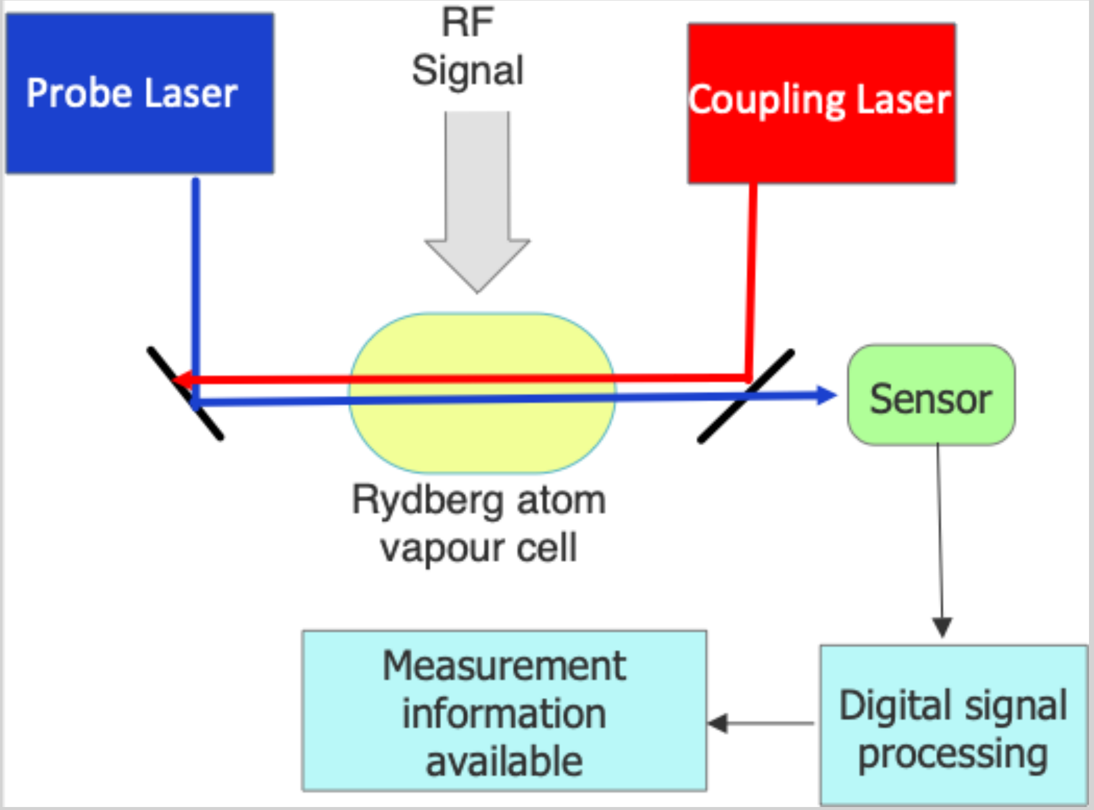
Mark Pecen, June 2021

What are Rydberg atoms?

- **Rydberg atoms** are highly-excited atoms of a material, such as cesium, in which one or more electrons would have a very high principal quantum number
- The higher this quantum number, the farther the electron(s) would be from the nucleus
- This causes Rydberg atoms to have an exaggerated response to electric and magnetic fields, which is the property that allows us to implement RF sensors.

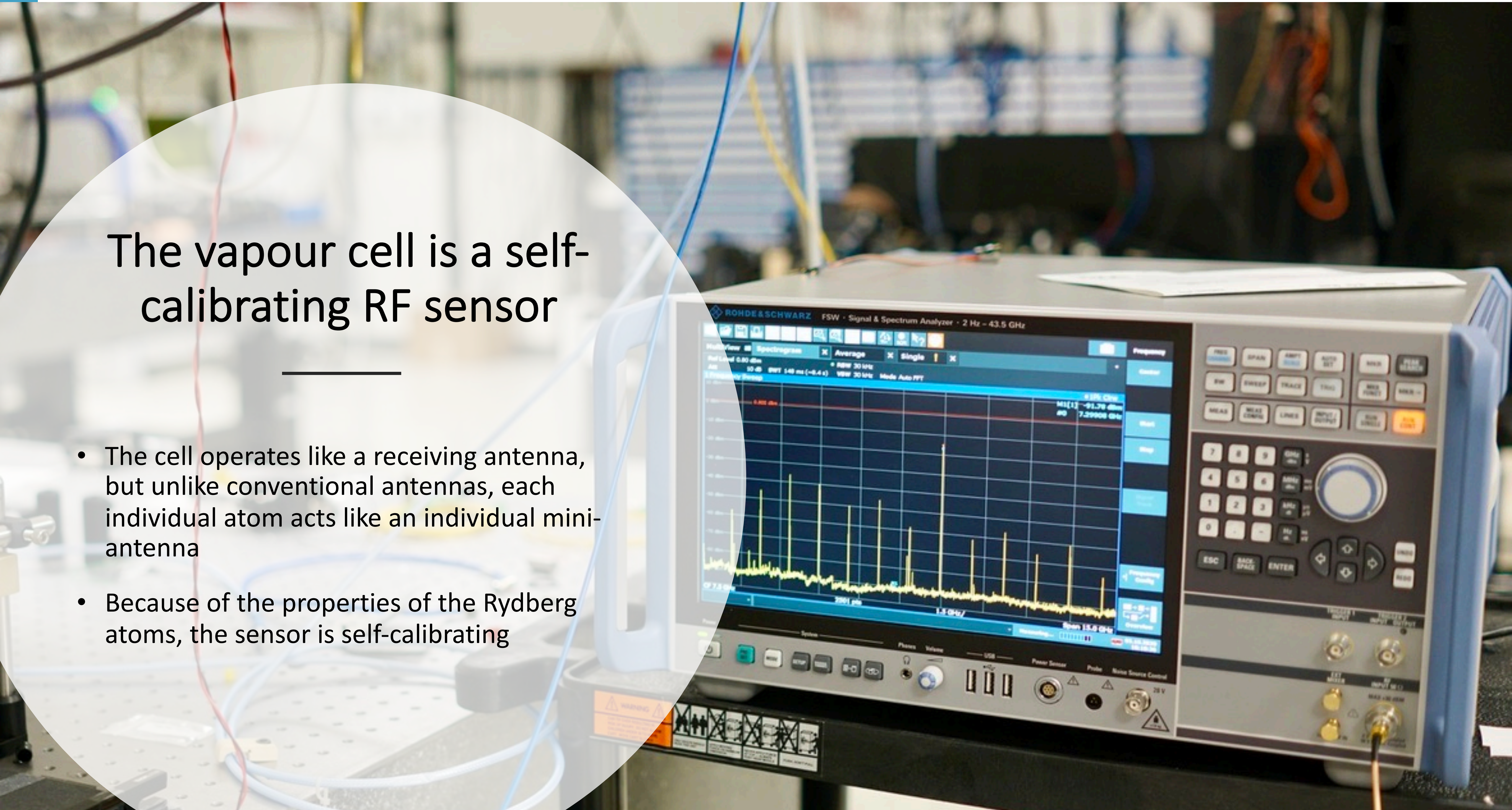
Rydberg atoms depend on external excitation

- The vapour cell is illuminated by two or more lasers of different wavelengths, creating the Rydberg atoms
- RF energy is downconverted to a lower baseband frequency at which processing may be easily performed



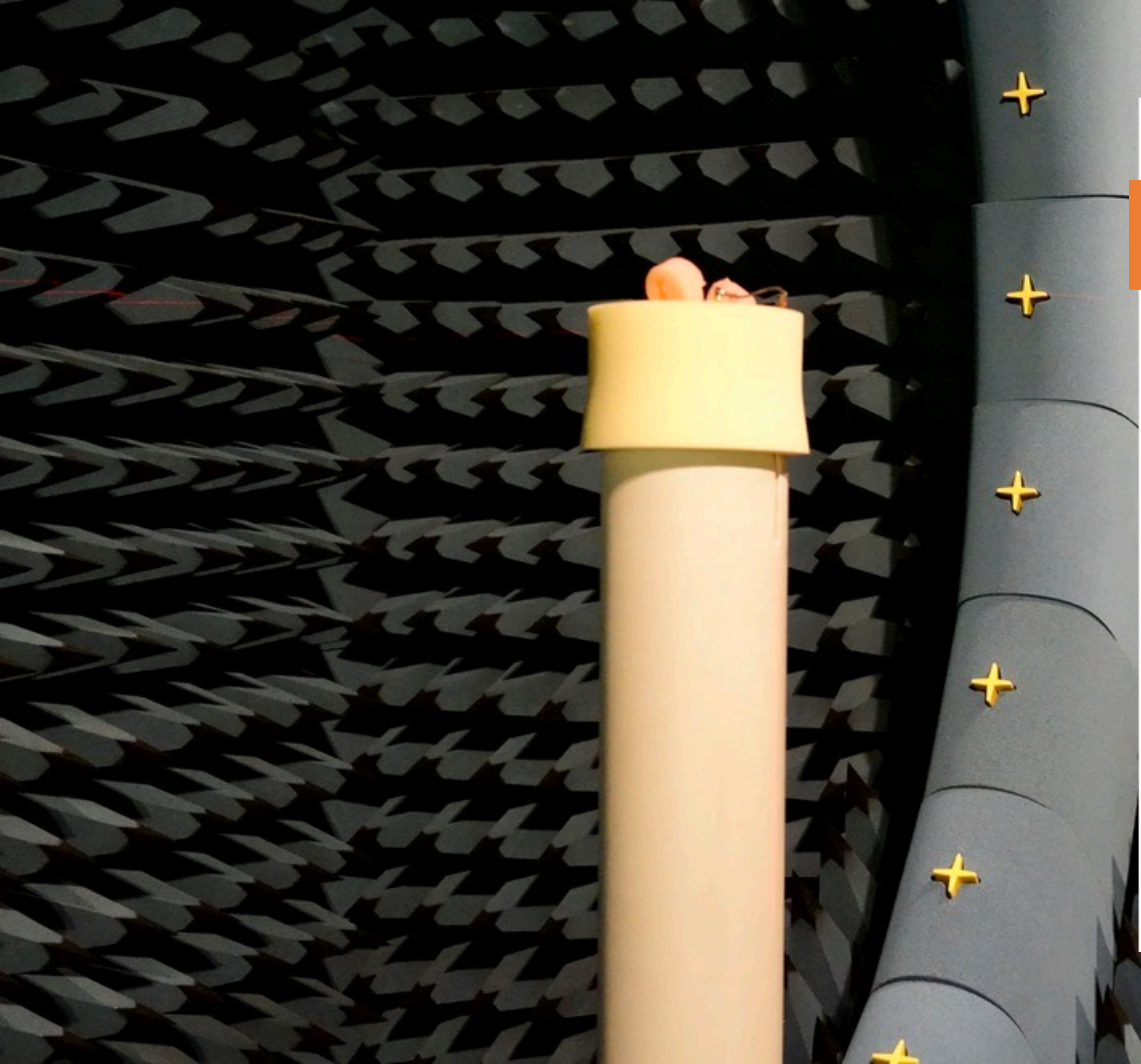
Capabilities beyond those of conventional antennas, especially at the millimetre wave and higher frequencies, such as 20 GHz to 100+ GHz

- Self-calibration for given received input power
- High sensitivity to RF fields
- Super-high spatial resolution – ability to perform high-resolution field mapping
- Arrays can be constructed for special-purpose RF field mapping
- Dielectric construction – prevents perturbation of other electric fields
- Optical coupling – resistant to interference from other RF sources
- Ability to resolve phase and polarization of signals
- Extremely small size possible – less then 1 cubic millimetre volume possible today



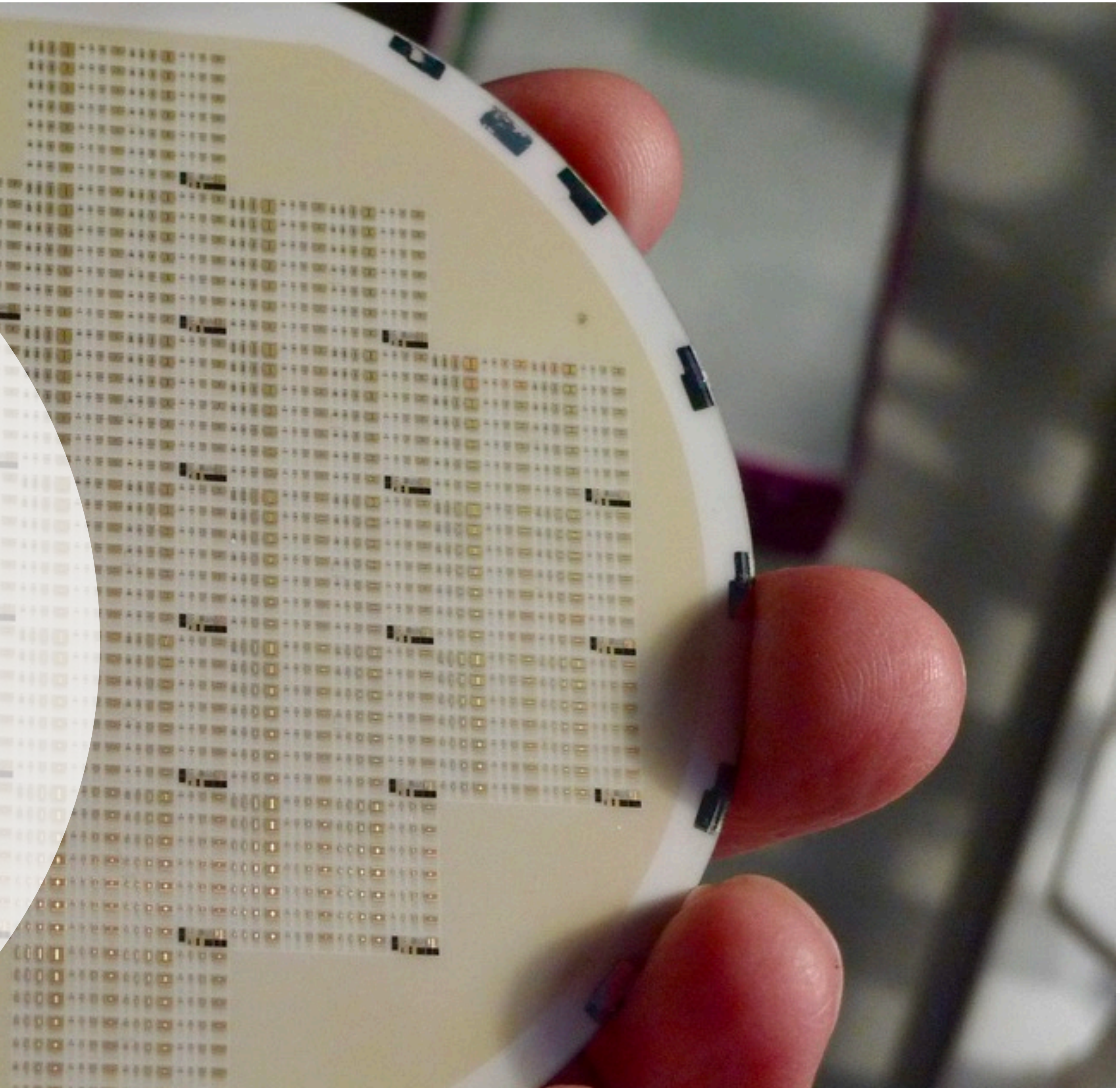
The vapour cell is a self-calibrating RF sensor

- The cell operates like a receiving antenna, but unlike conventional antennas, each individual atom acts like an individual mini-antenna
- Because of the properties of the Rydberg atoms, the sensor is self-calibrating



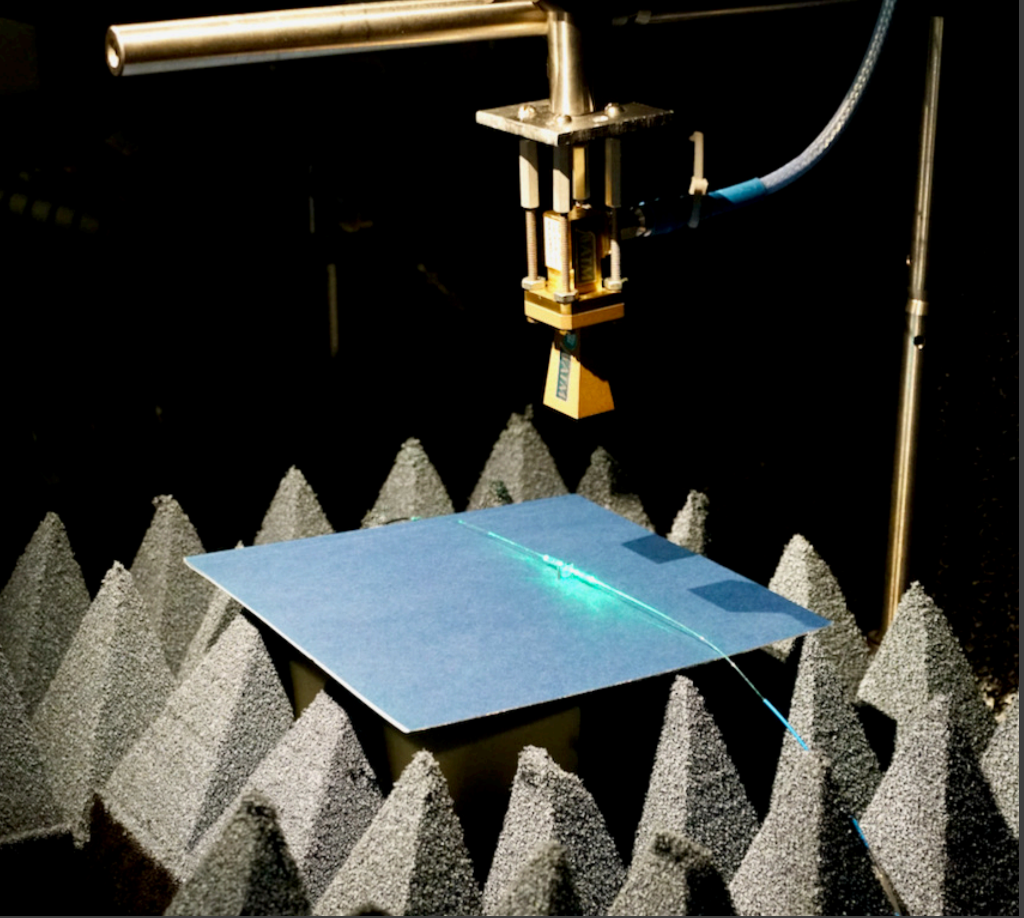
Sensitivity, resolution – field mapping

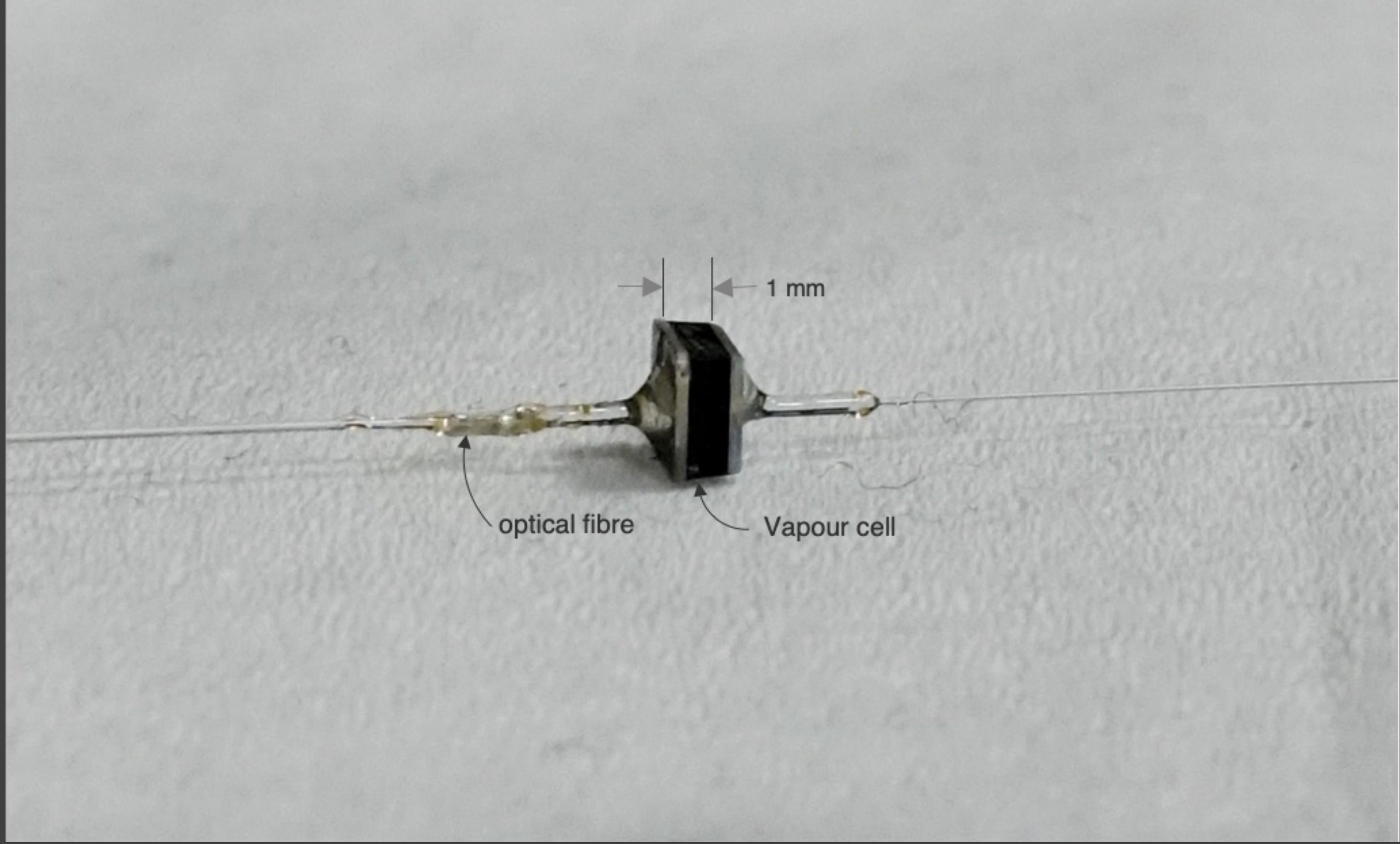
- 300 times more sensitive, and 70 times better detectable field resolution, and has 300 times better spatial resolution than standard dipole antennas
- High resolution imaging of the electric field at $\lambda/650$ resolution, far in the sub-wavelength regime, without interfering with the characterization of the device under test

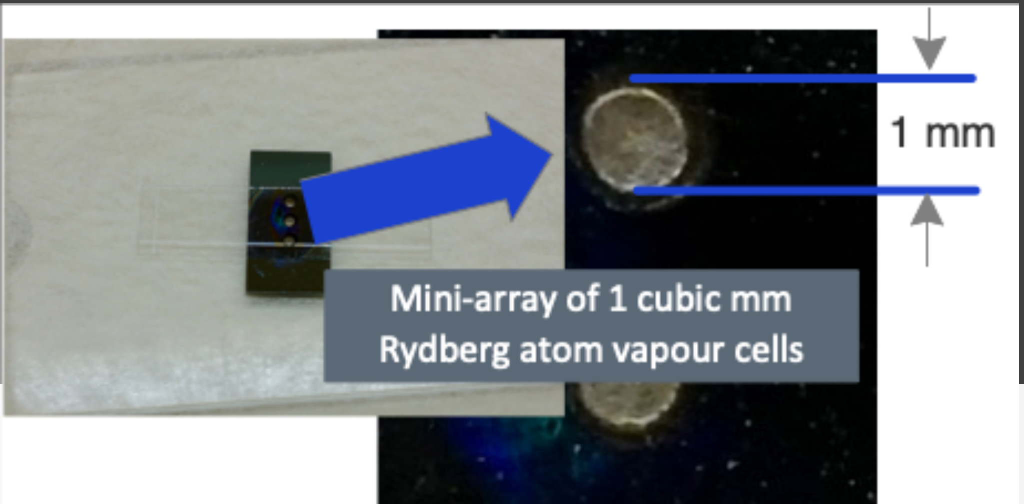


Arrays can be constructed & polarization data are available

- Arrays of Rydberg sensors can be implemented to accurately construct 3-dimensional maps of electric field images produced by transmitting antennas and other devices, all without any moving parts or metal that can perturb the field.
- Polarisation and phase information are available, enabling sophisticated mapping of RF field patterns, as well as certain applications such as radar.







Sensors can be extremely small

The Rydberg atom quantum RF sensor uses cesium sealed in tiny glass beads

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Dielectric material minimally perturbs the surrounding electrical environment - perfect for OTA applications

- It's difficult or impossible to make meaningful conducted RF power measurements at millimetre wave frequencies like 60 GHz using conventional methods
- Rydberg sensors are well adapted to this domain
    - Dielectric – minimal perturbation of the electrical field of the device under test
    - Self-calibration means less down-time calibrating equipment

Rydberg sensors operate up to THz frequencies

- The sensors operate extremely well in the millimetre wave frequency range (30 GHz to 300 GHz) and can easily detect RF fields at frequencies well into the terahertz (THz) range
- This aspect is important as national regulators and the International Telecommunications Union (ITU) continue to define world-wide radio spectrum allocations at higher and higher frequencies over time

Summary

- Flexible frequency range
- 20 GHz to 100+ GHz
- Even into the THz range

- High sensitivity to RF fields
- Self-calibration for given received input power
- Dielectric construction – prevents perturbation of other electric fields
- Optical coupling – resistant to interference from other RF sources
- Ability to resolve phase and polarization of signals
- Super-high spatial resolution – ability to perform high-resolution field mapping
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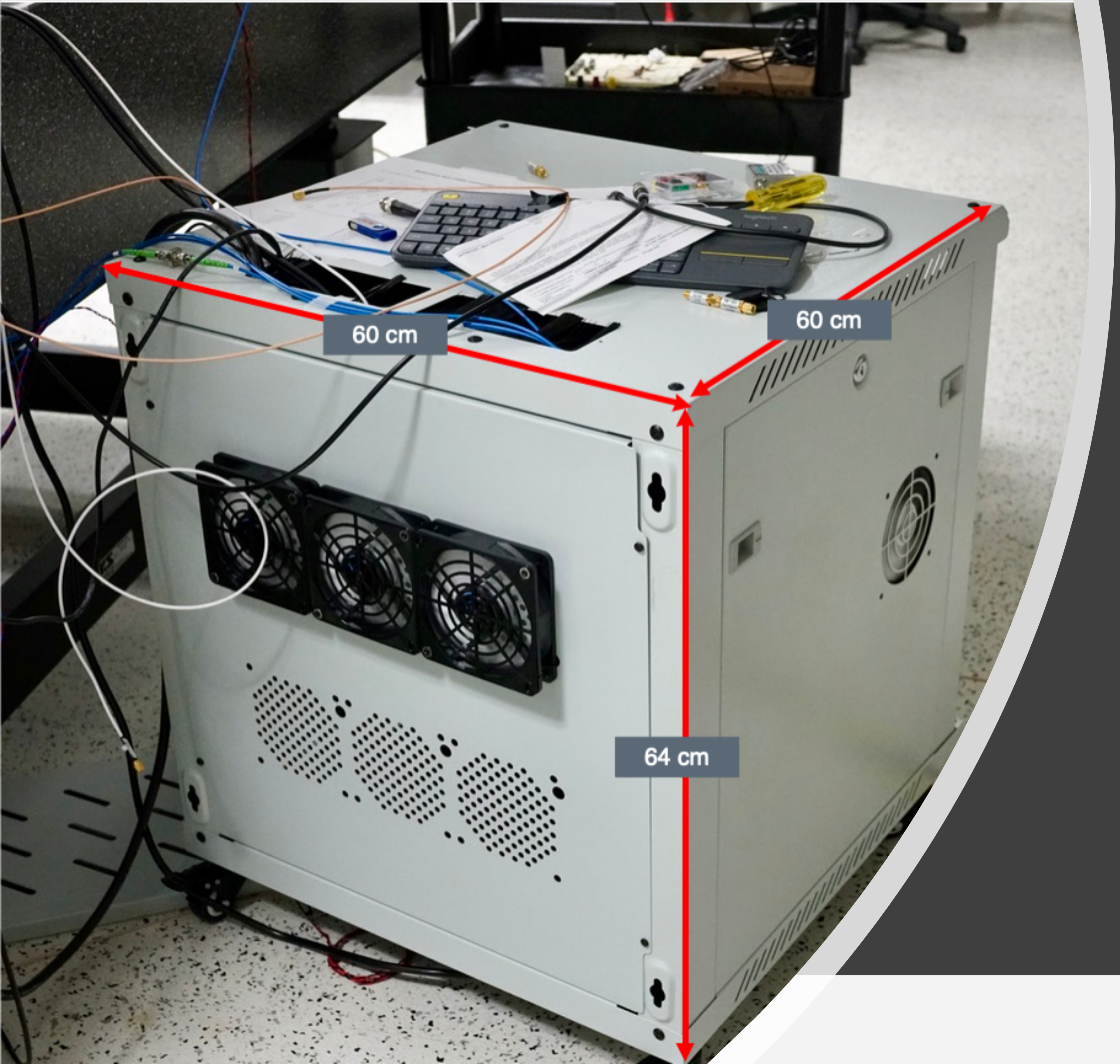

Quantum Valley Ideas Lab proof-of-concept Rydberg measurement sub-system

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