Session We3A

Field Enhancement for Sensitivity Improvement of a Rydberg-Atom Receiver

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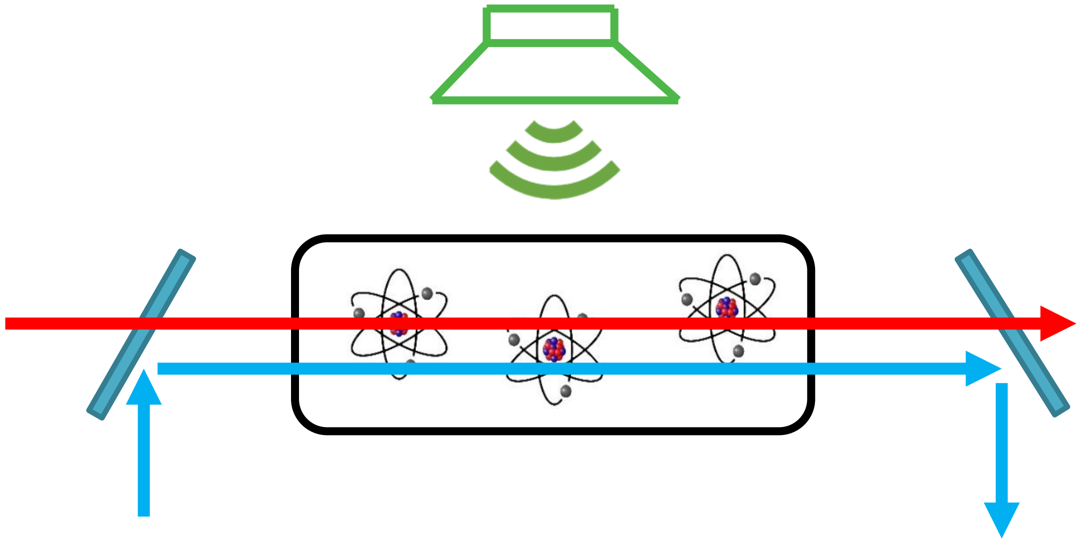
LOCKHEED MARTIN

Motivation

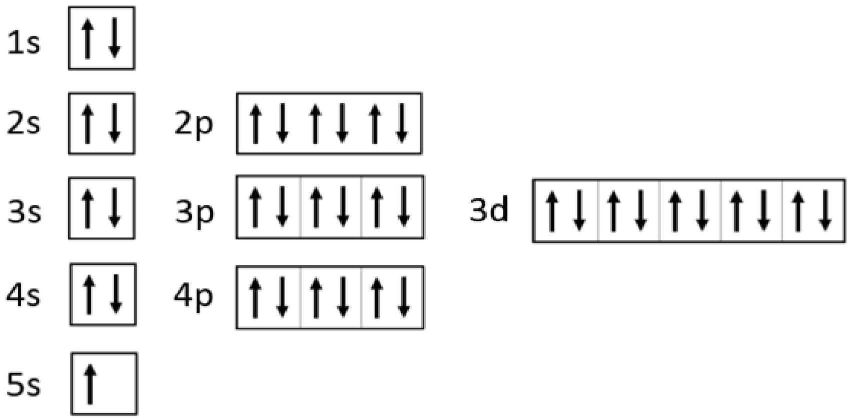
Rydberg receivers provide:

- Self calibrating measurements – directly correlated to atomic response
- Narrowband responses from MHz to THz
- A receiver configuration that does that scale in size with wavelength



Rydberg Atoms

Ground State Rubidium



Spectroscopic Notation: nL_j

n = principal (orbital size)

n = 1, 2, 3, ...

L= orbital angular momentum (orbital shape)

L= 0 to n-1

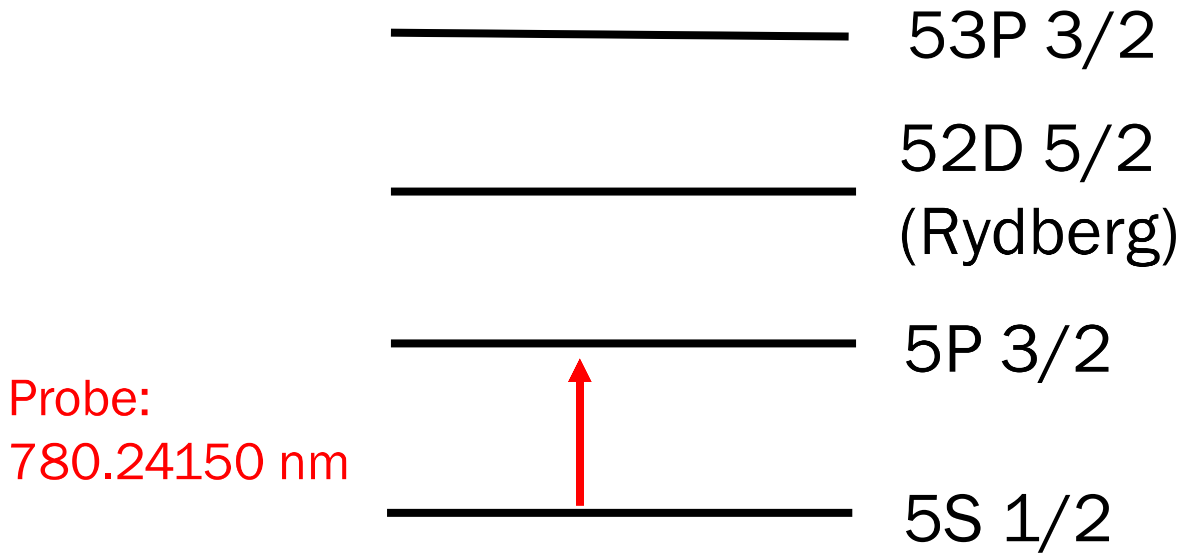
j = total angular momentum (orientation)

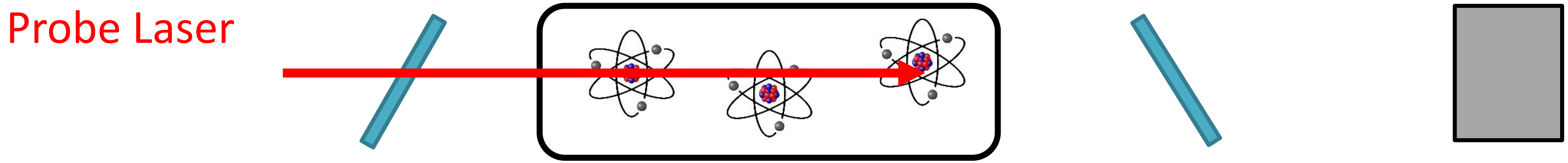
$j = |L - S|$ to $|L + S|$

- Highly excited atom, shown by principal quantum number “n”
- Any atom can be excited to the Rydberg state
- Rb and Cs are optimal for their single valence electron and readily available cells

Rydberg Receivers

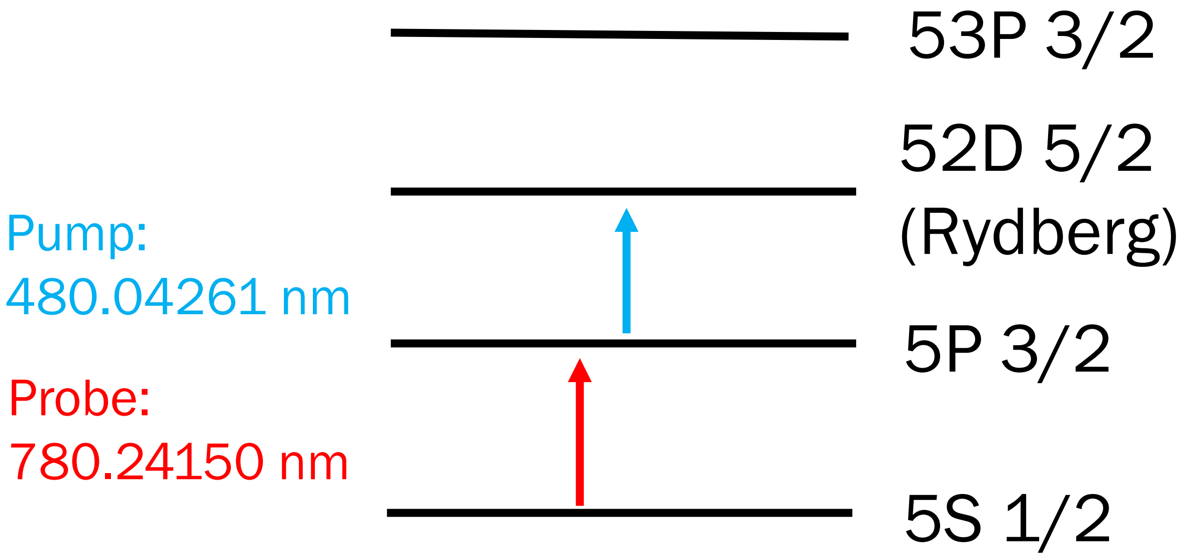
- A single red laser is insufficient to excite the Rubidium atoms to the Rydberg state from ground state

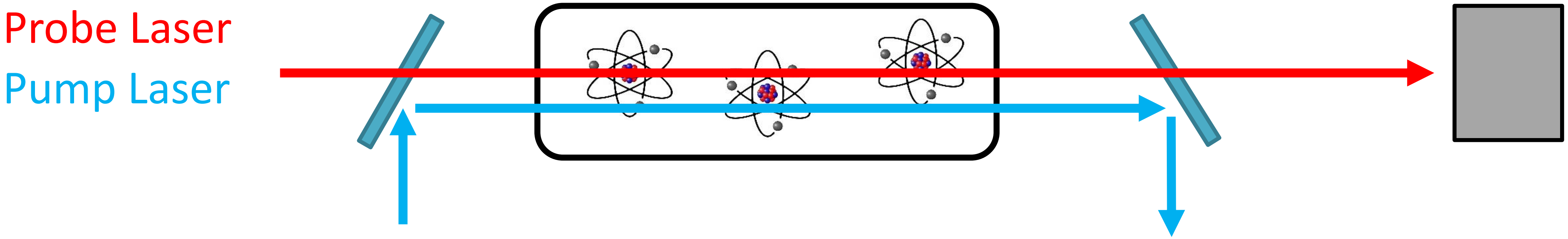




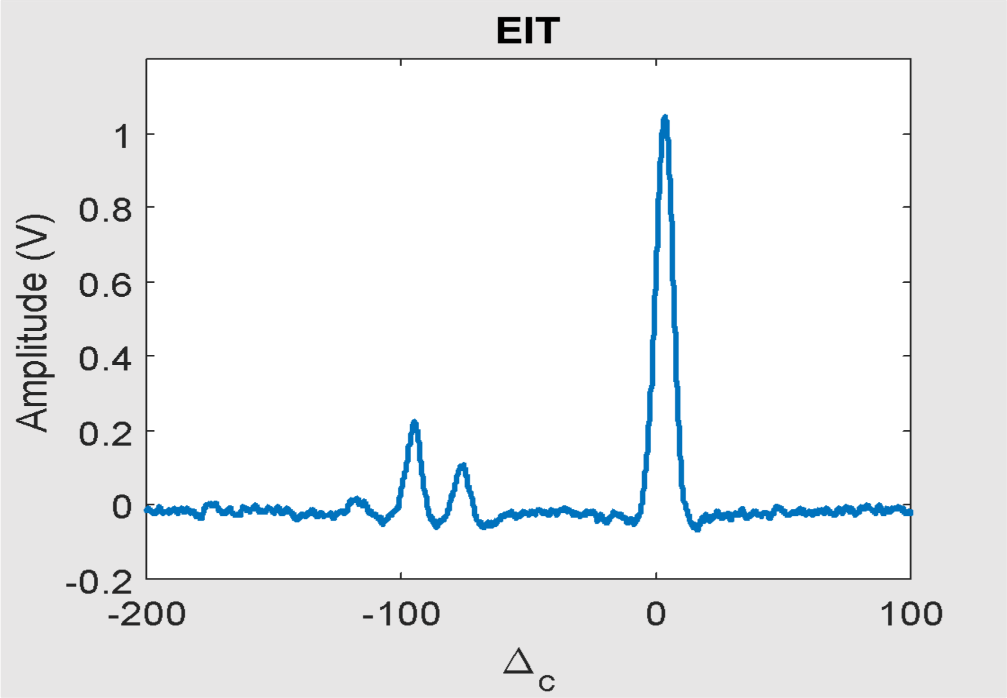
Rydberg Receivers

- A second blue laser excites the atoms to a Rydberg state
- Light from the red laser reaches the photodetector – "EIT"



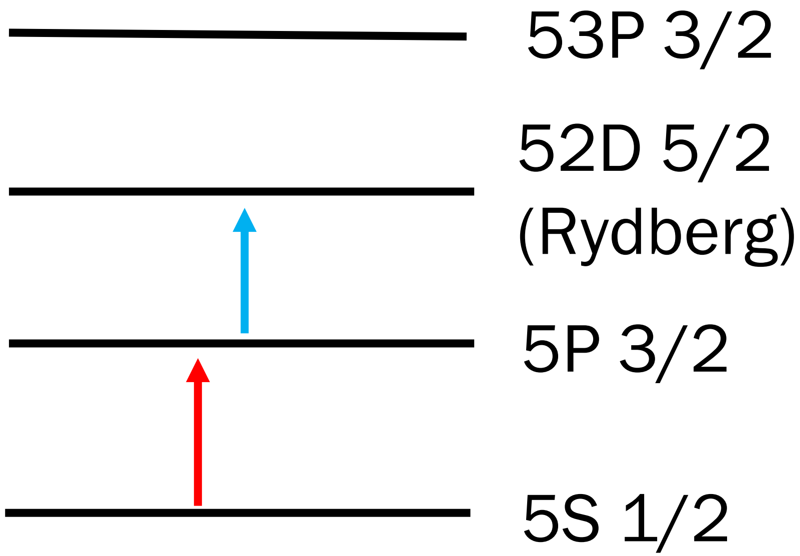


Rydberg Receivers

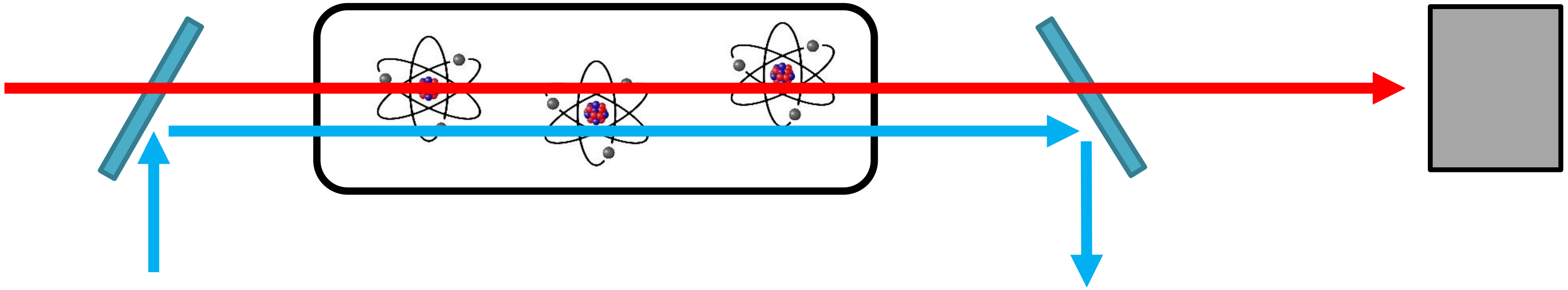


Pump:
480.04261 nm

Probe:
780.24150 nm

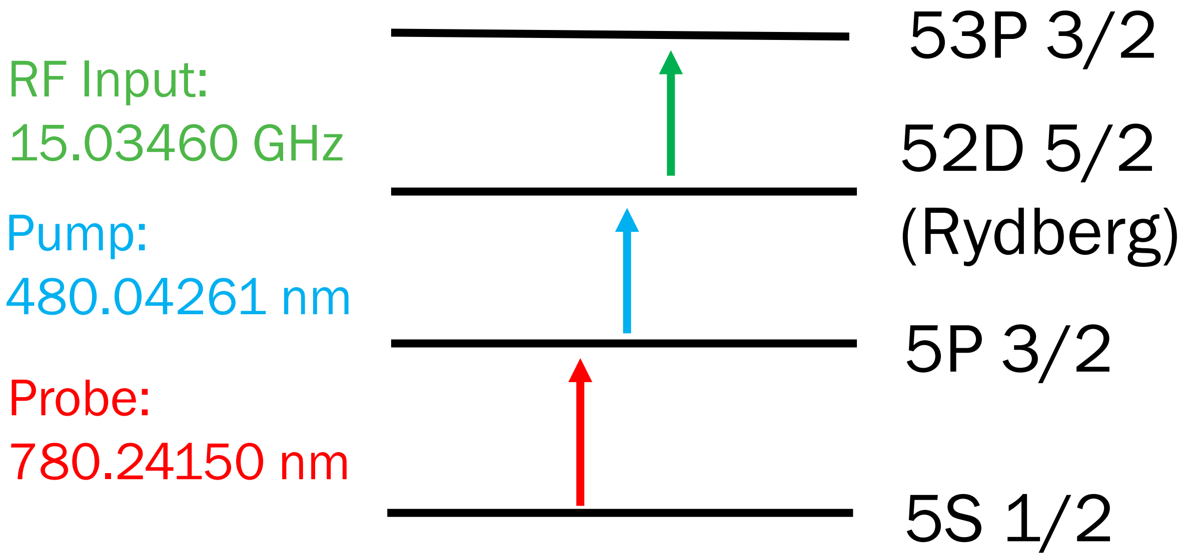


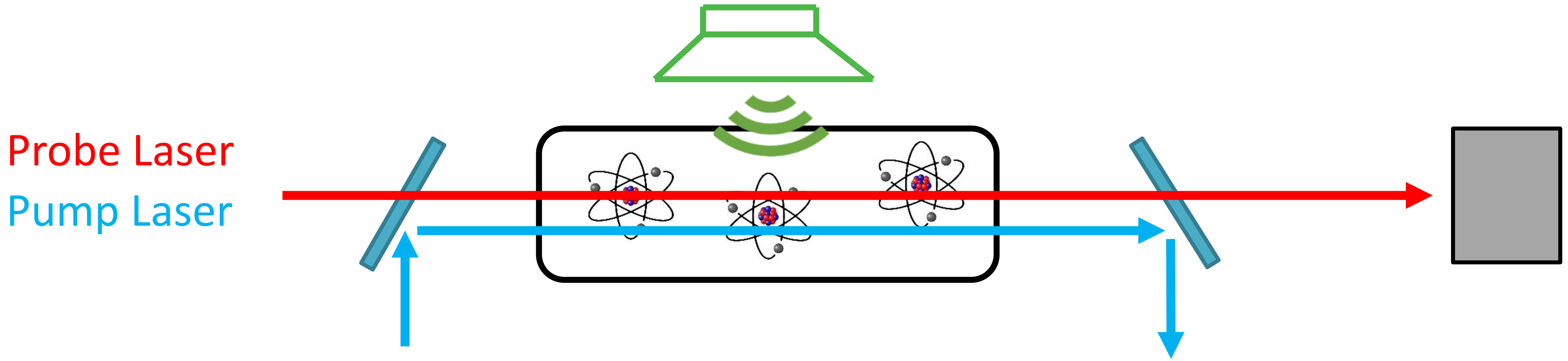
Probe Laser
Pump Laser



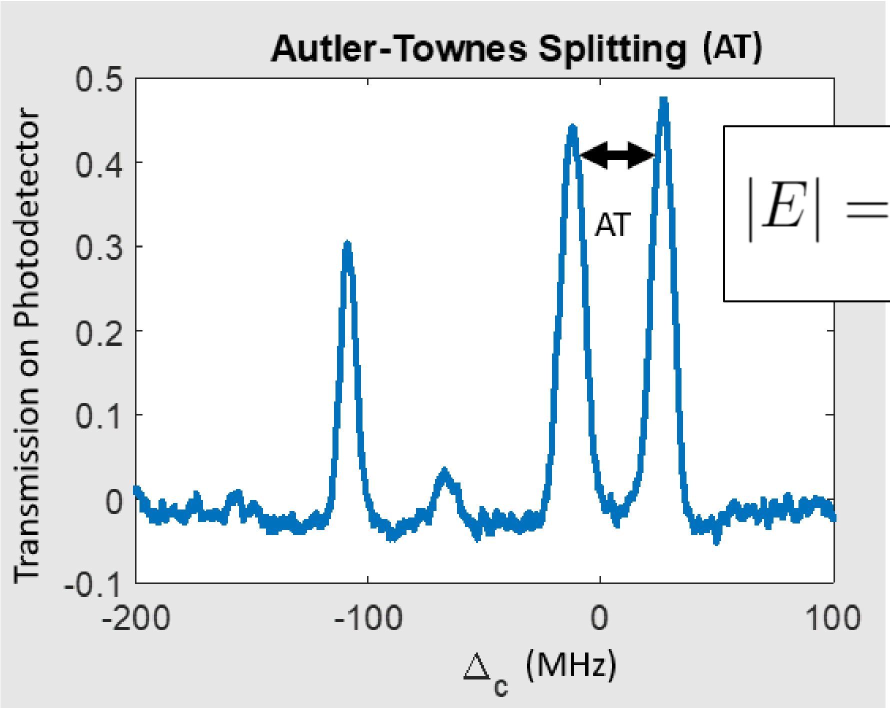
Rydberg Receivers

- Introducing an RF source, the singular EIT peak splits into two peaks – Autler Townes splitting





Rydberg Receivers

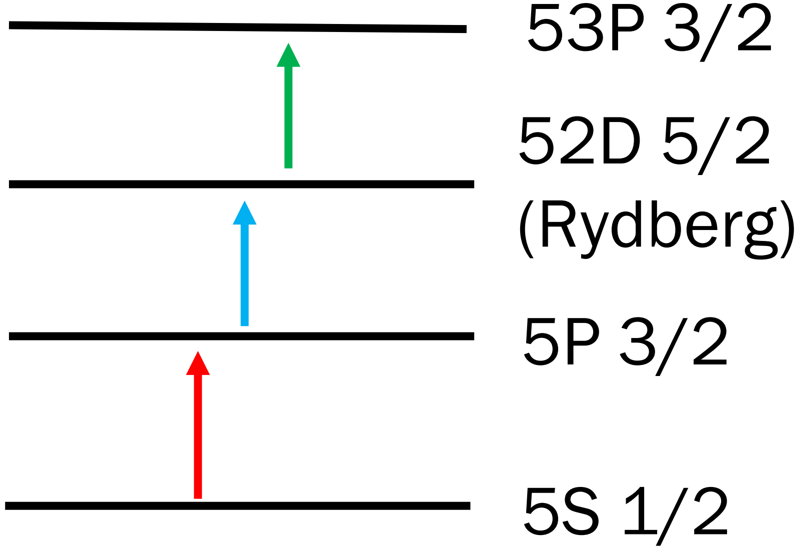


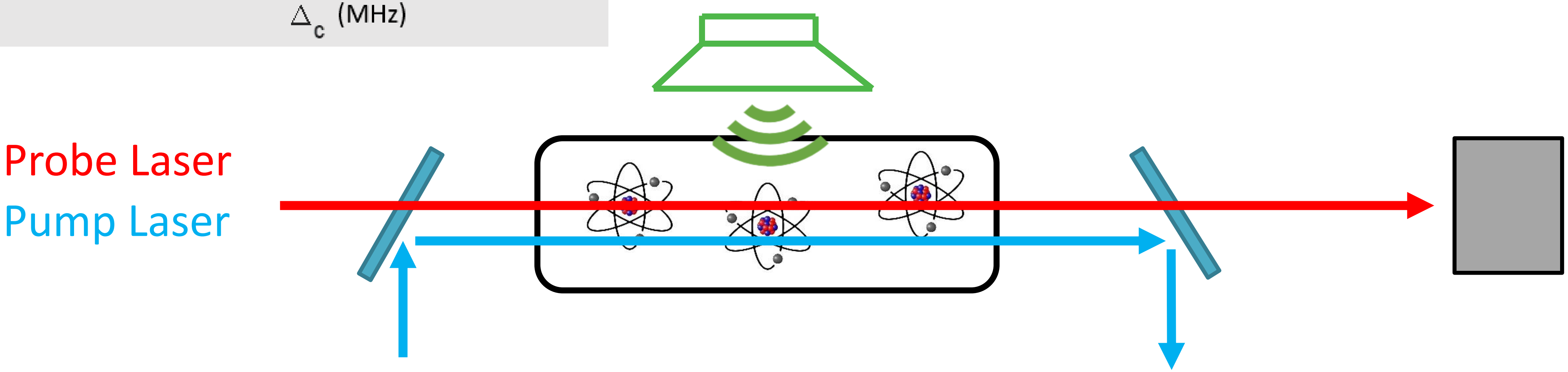
$$|E| = \frac{h}{\rho} AT$$

RF Input:
15.03460 GHz

Pump:
480.04261 nm

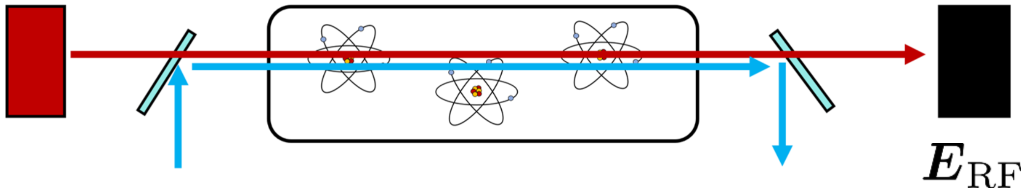
Probe:
780.24150 nm





Rydberg vs. Conventional RX

Rydberg-atom Receiver

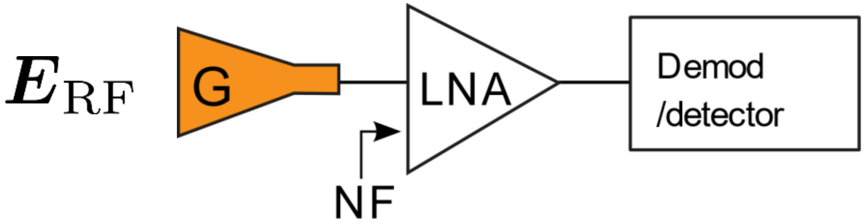


Sensitivity metric: minimum detectable electric field per unit bandwidth

$$\mathrm{V\,m^{-1}\,Hz^{-1/2}}$$

$$\mathrm{NF}_{LNA} = 10\log(1 + T_e/T_0)$$

Conventional Receiver



Sensitivity defined in terms of the noise figure of the LNA [W/Hz].

$$S_{min} = \frac{|E|^2}{2\eta} A_{\text{eff}} = kT_e$$

$$E_{min} = \sqrt{\frac{8\eta\pi k T_e}{G\lambda^2}}$$

$$\mathrm{V\,m^{-1}\,Hz^{-1/2}}$$

Rydberg vs. Conventional RX

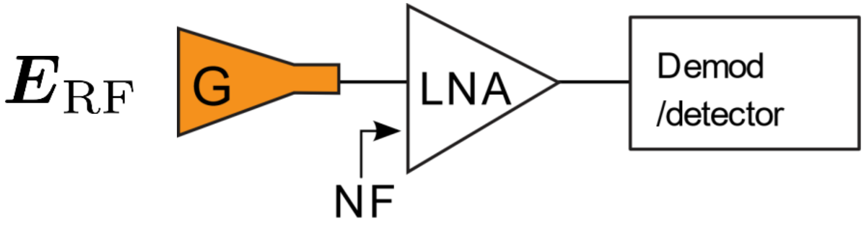
Rydberg-atom Receiver

Resonator

Sensitivity metric: minimum detectable electric field per unit bandwidth

$$\mathrm{V\,m^{-1}\,Hz^{-1/2}}$$

Conventional Receiver



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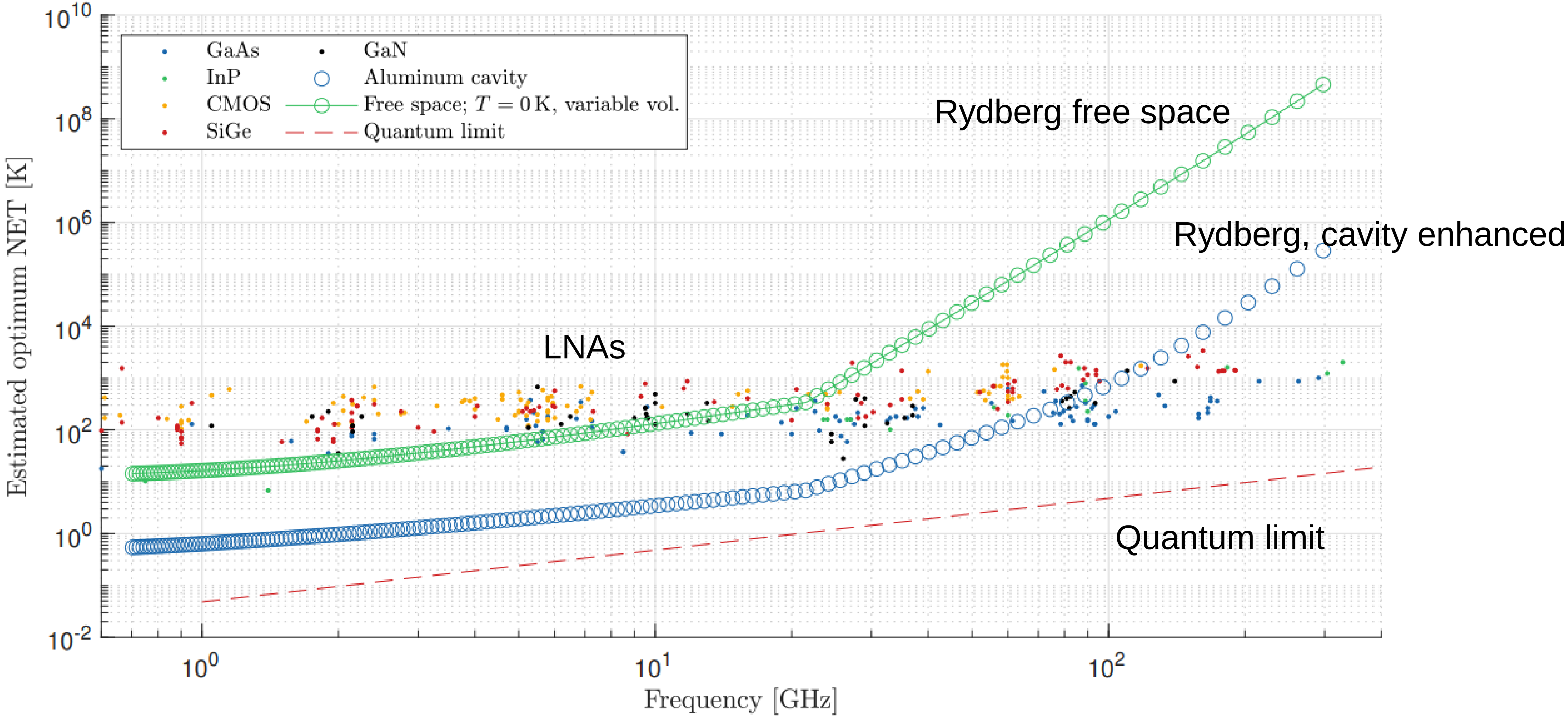
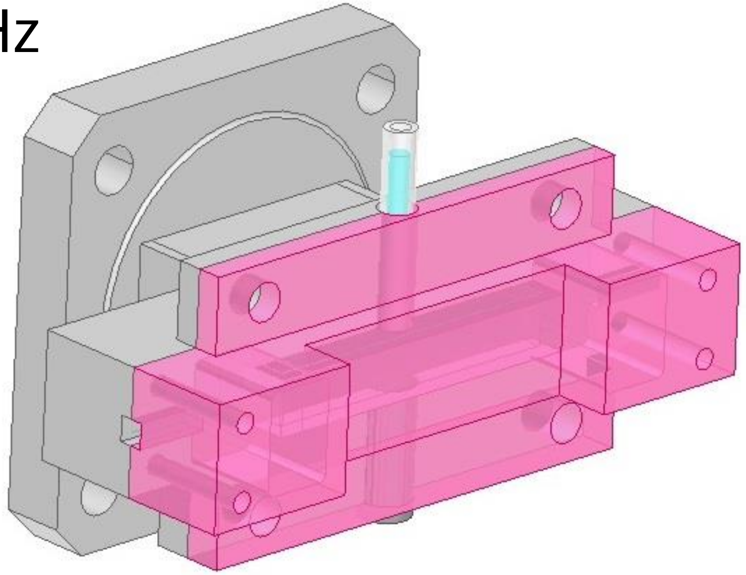
Sensitivity Comparison

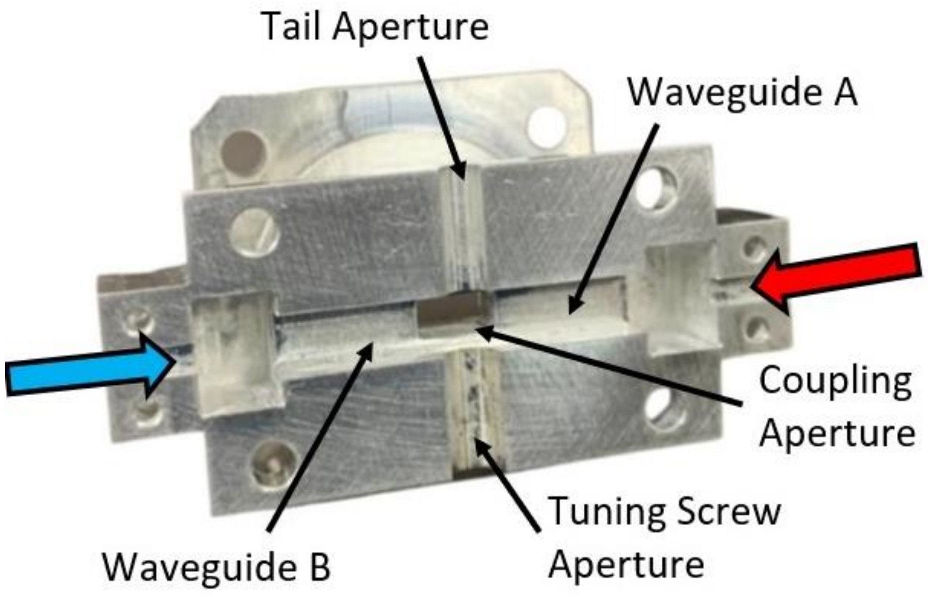


G. Santamaria-Botello, S. Verploegh, E. Bottomley, and Z. Popovic, “Comparison of noise temperature of rydberg-atom and electronic microwave receivers,” 2022. [Online]. Available: https://arxiv.org/abs/2209.00908

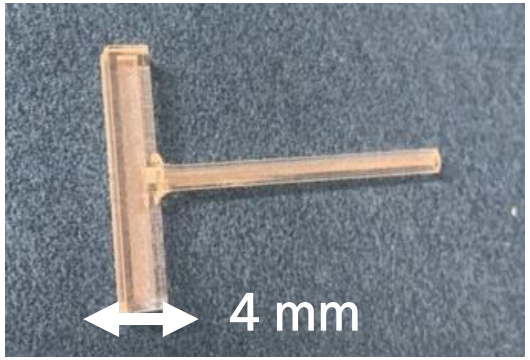
Resonator Geometry

15.096-GHz cavity



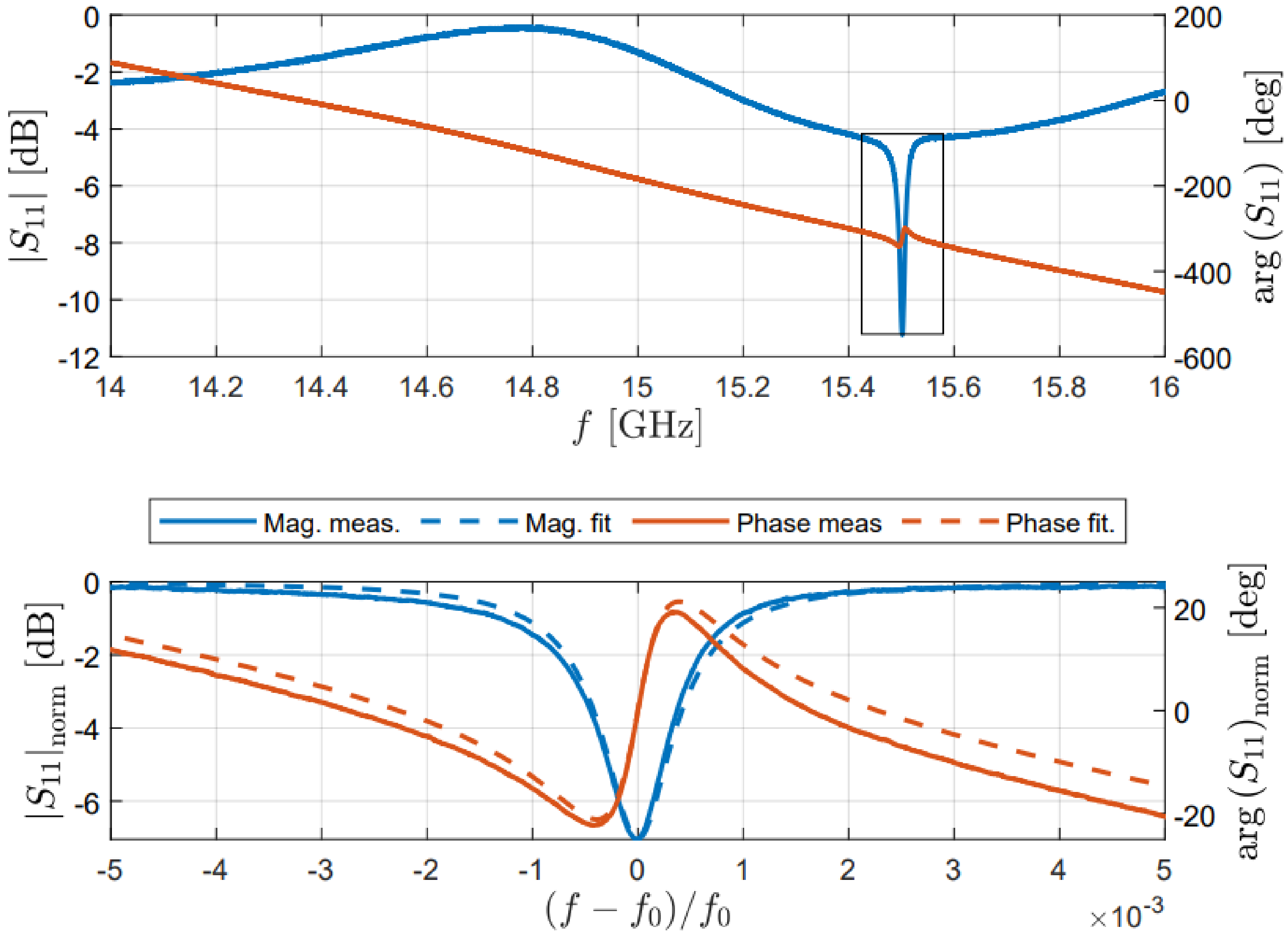


One half of the split-block machined cavity



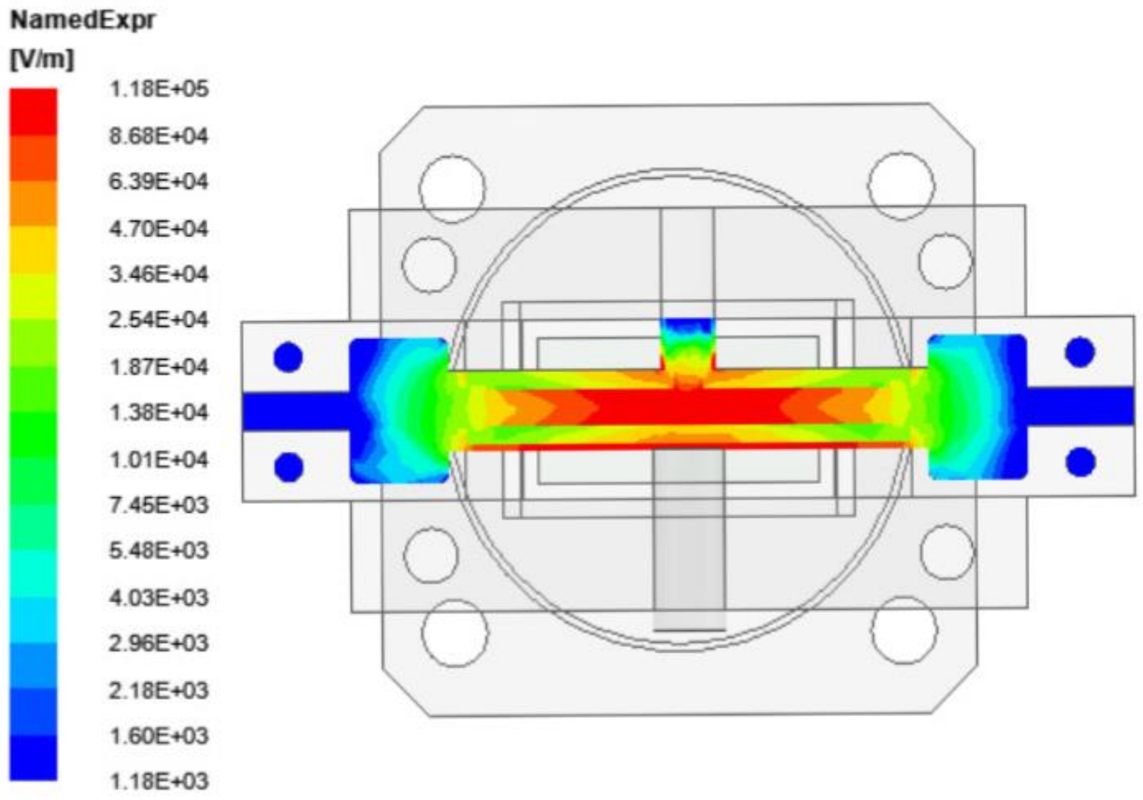
The unfilled fused silica vapor cell

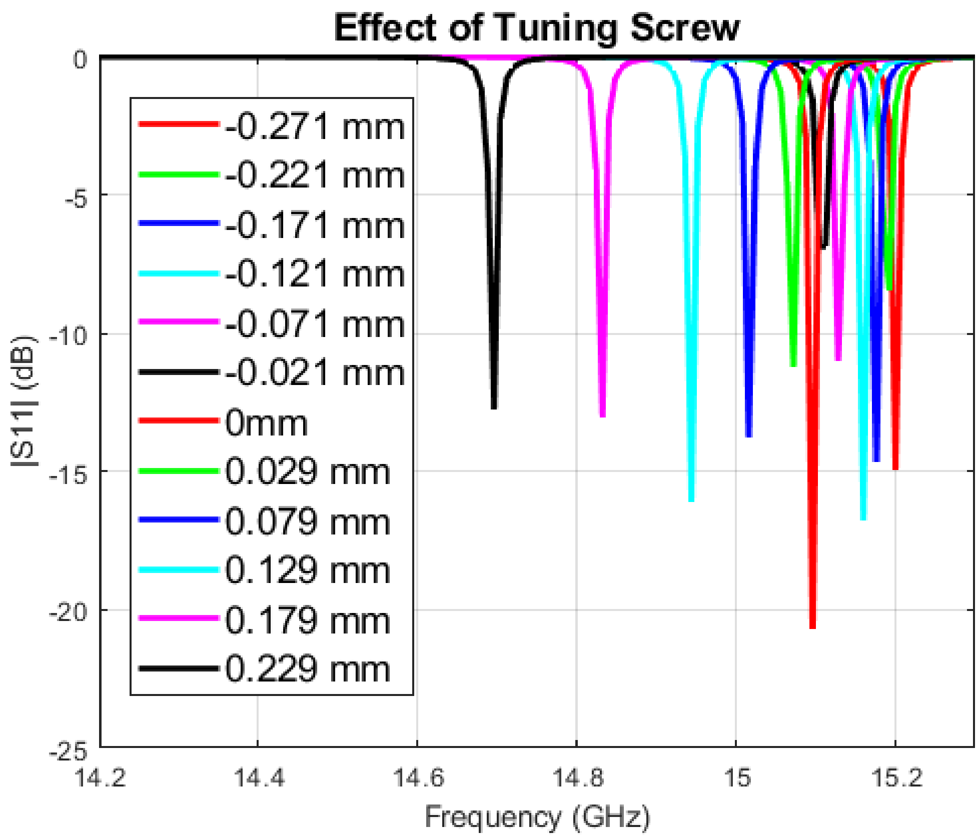
Resonator Performance



- S11 is -18.0793 at 15.5106 GHz
- Q_i = 1100
- Q_c = 2860
- Field enhancement factor of 20.4
- T_e equivalent to 110 K
- Half the intended Q_i but still significant noise improvement over non-enhanced counterpart

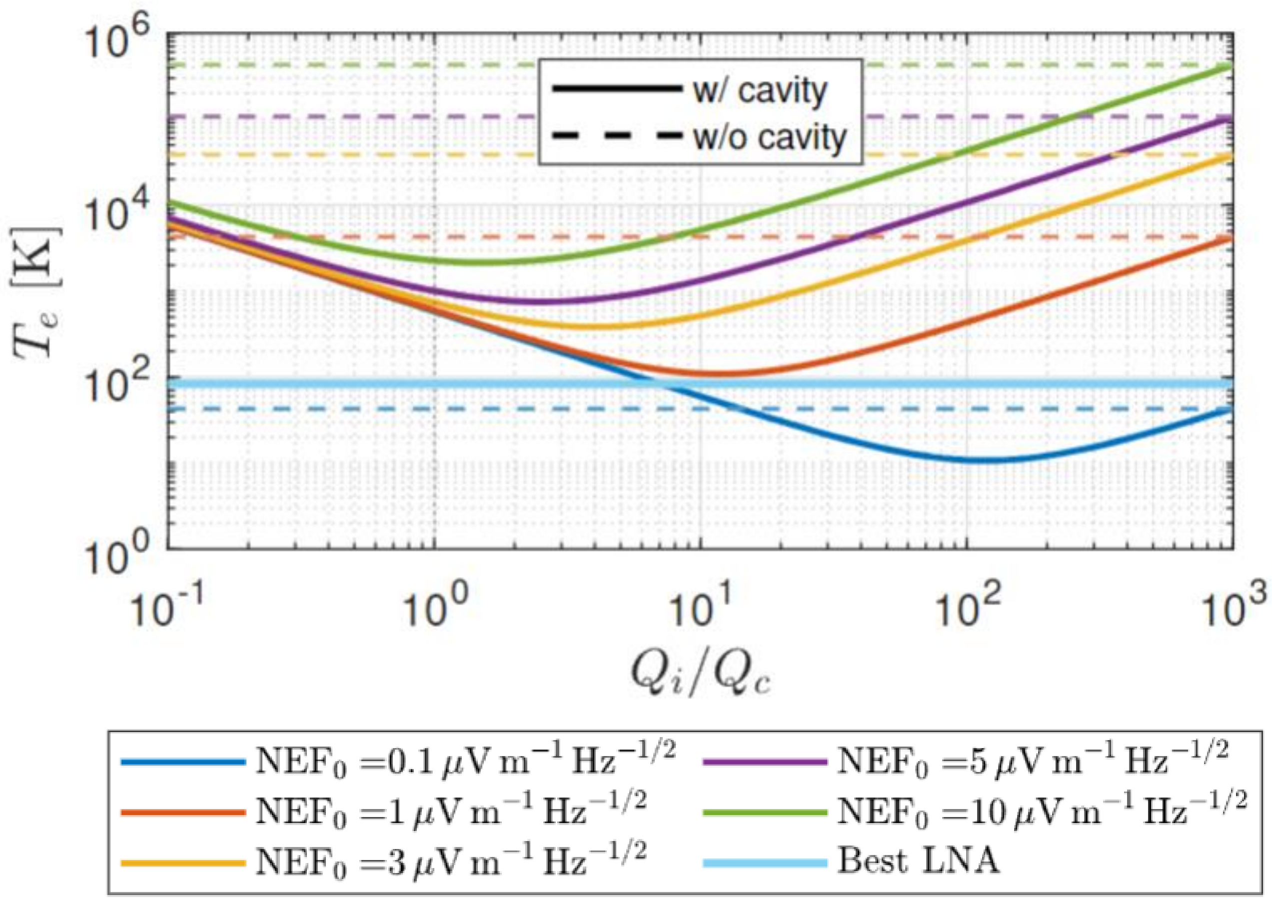
Resonator Tuning

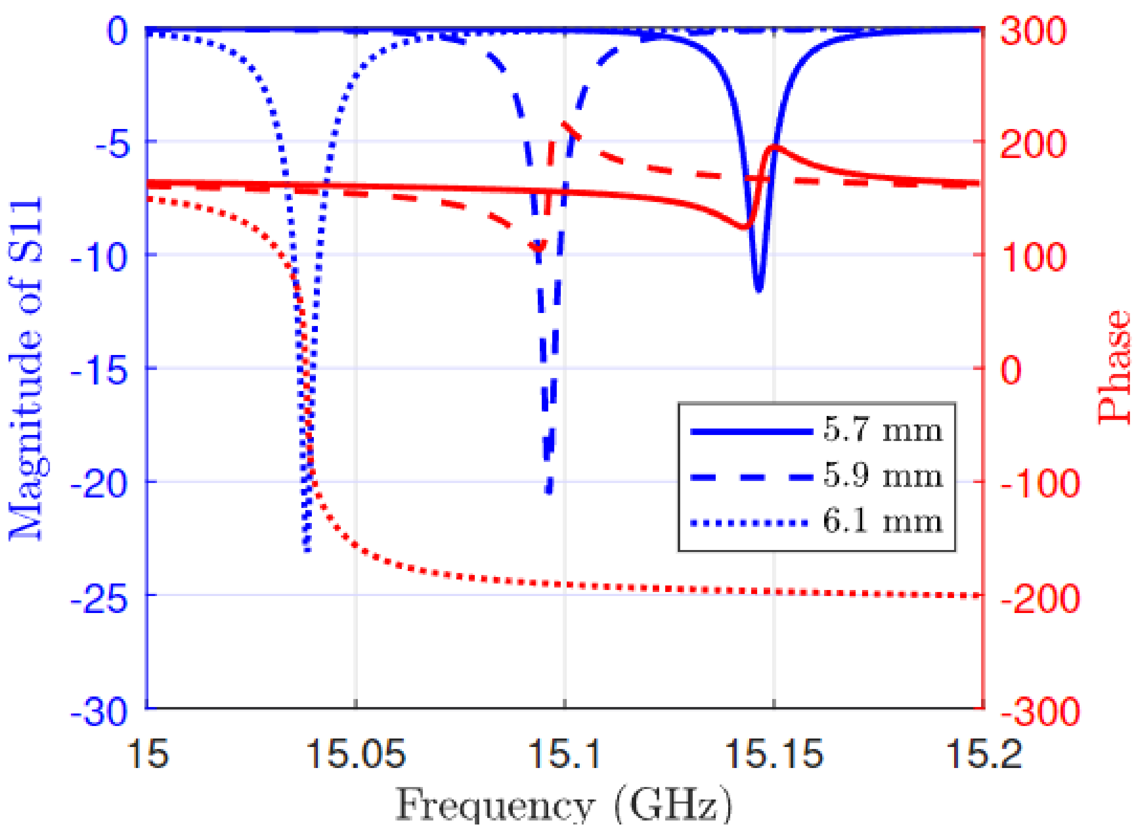




- Resonance can be shifted using tuning screw
- Screw displacement from 0.271 mm insertion to 0.229 withdrawal allows 216 MHz of tuning
- Resonant cavity provides a high degree of uniformity i.e., better AT splitting resolution

Resonator Coupling

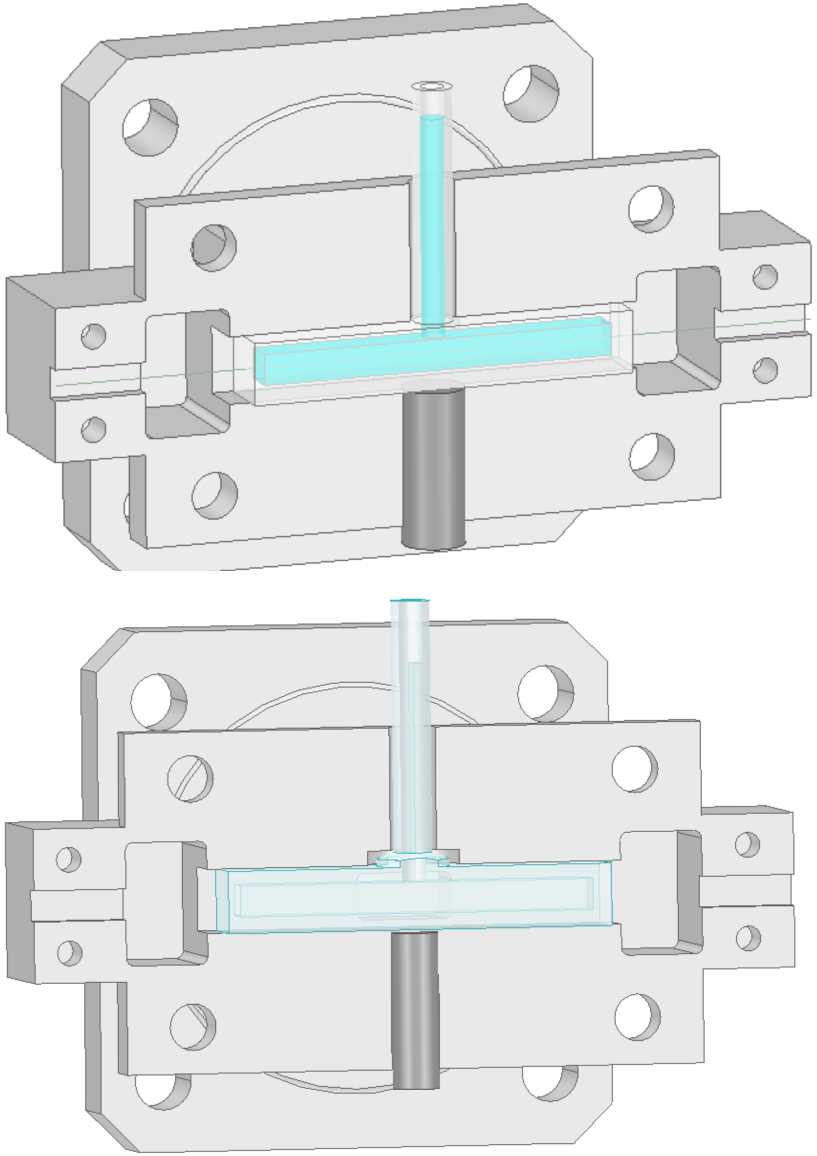




- Coupling aperture allows critical, over, and under-coupled regimes
- Important for sensitivity enhancement – critical coupling is not always best

Resonator #1

A defect that created a bulge of material between the vapor cell and tail



Manually drilled a taper to accommodate the bulge between the cell and the tail

Conclusion

- Demonstrated Rydberg receiver sensitivity enhancement using a resonating cavity
  - 216 MHz tuning range
  - Access to over, critical, and under-coupled regimes
  - Resonance is measured at 15.5016 GHz, less than 4% (412 MHz) above the target frequency, with significant hand-made modifications
  - Noise temperature of ~110 K (without cavity, 4160 K)
- Future work
  - Integration of this cavity into an AT set up on an optical table

Thank you!

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