Finding Quantum States From Husimi-Q Distributions

Kaleb Campbell[1,2], Nathan Lysne[1], Dr. Poul Jessen [1]

[1]University of Arizona, Tucson AZ ; [2]Miami University, Oxford OH

Abstract

Developing techniques for accurate, arbitrary control of atoms is a necessity for Quantum Information Science.(2) We trap cesium atoms in a magneto optical trap and cool them down to micro-Kelvin temperatures. We then use microwave and radio frequency magnetic fields to control the state of the atoms. The state that we want to imprint on the atoms can be represented by a quasiprobability distribution in phase space. Using numerical searches, we can look for states that correspond to any arbitrary Husimi-Q quasiprobability distribution. We can write information, such as a "U," onto an Husimi-Q distribution, and then perform a search to find states corresponding to that distribution. We then perform tomography on the designer states implemented in the experiment to verify that our resulting distributions match our intended distributions.

Experiment and Background

Atomic Theory

We are controlling the atomic spin state of cesium atoms.

$$\hat{F} = \hat{J} + \hat{I}$$
$$\hat{J} = \hat{L} + \hat{S}$$
$$\hat{F}_Z|m_F> = \hbar m_F|m_F>$$

$\hat{F}$=total angular momentum
$\hat{I}$ =nuclear spin vector
$\hat{L}$=orbital angular momentum
$\hat{S}$=electron spin vector
$\hat{F}_Z$=total angular momentum in the $\hat{Z}$
m_F=magnetic sublevel

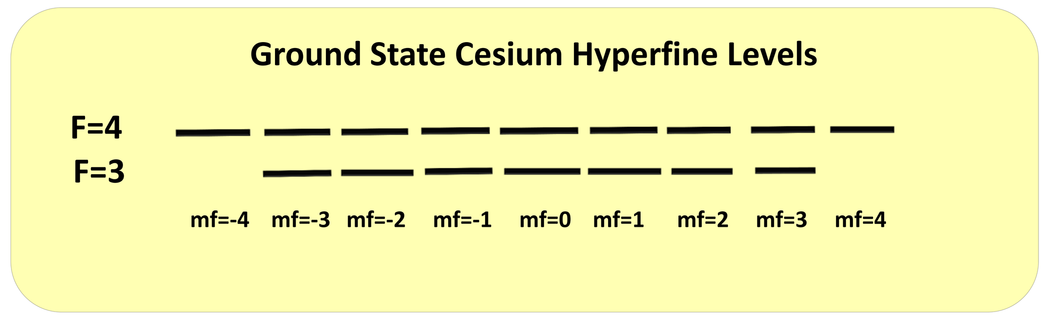

Figure 1: Hyperfine levels of cesium F=3 and F=4 ground states. F >= mf >= -F

Husimi-Q Distribution

- Classical probability distributions can be represented by points on a sphere, but in a quasiprobability distribution there are uncertainty patches.
- A Husimi-Q distribution represents the phase space distribution of a quantum state. (3)
- It's a distribution over a set of minimum uncertainty states called coherent states that are not orthogonal.

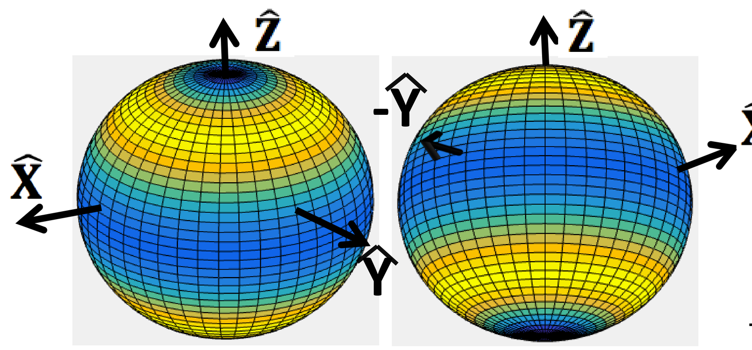

Figure 2: Example of an Husimi-Q probability distribution for F=4 with a superposition state

$$\frac{1}{\sqrt{2}}[|m_F = 3> + |m_F = -3>]$$

Experimental Setup

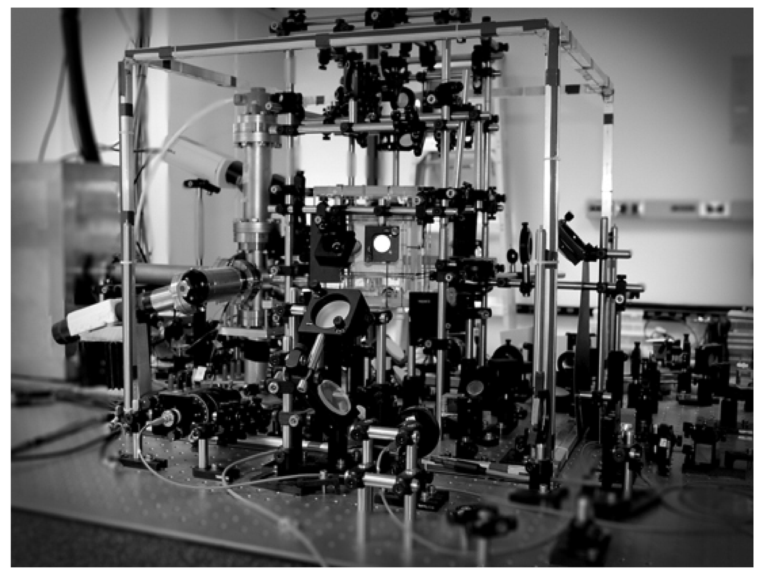

Figure 3: Photograph of experiment with optical trap (4)

How we measure

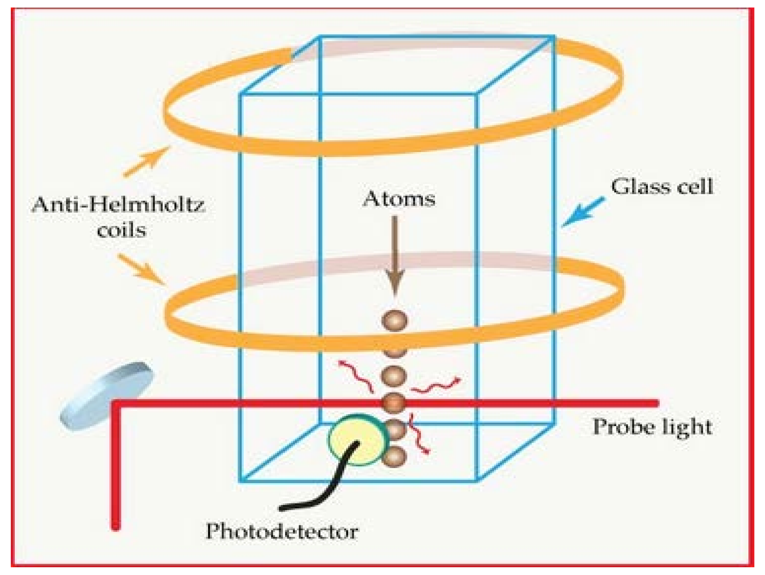

Figure 4: Cartoon of Stern-Gerlach measurement technique (4)

- Trap cesium atoms in a magneto optical trap using frequency detuned lasers
- Cool around a million atoms to mico-Kelvin temperatures
- Use radio frequency and microwave frequency magnetic fields to put the atoms in a specific state
- Measure quantum state of the atoms using Stern-Gerlach technique

- Atom cloud falls due to the effects of gravity after state preparation
- The atoms spatially split according to their magnetic sublevel and fall through lasers resonant with each hyperfine level. (4)

Implementation

1. Make a target distribution with some shape such as a "U"
2. Load the "U" shaped distribution into the code
3. Use numerical searches to find states corresponding to the target distribution
4. Put cesium atoms in the state found by MATLAB using rf and μw fields
5. Reconstruct state and compare distribution

Results

Simple States

Target Husimi-Q Distribution / **Found Husimi-Q Distribution**

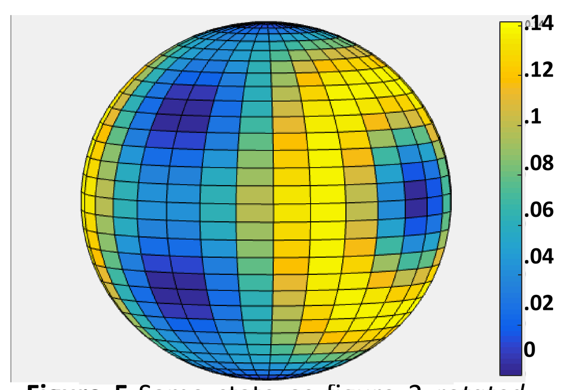

Figure 5-Same state as figure 2 *rotated by pi/2.*

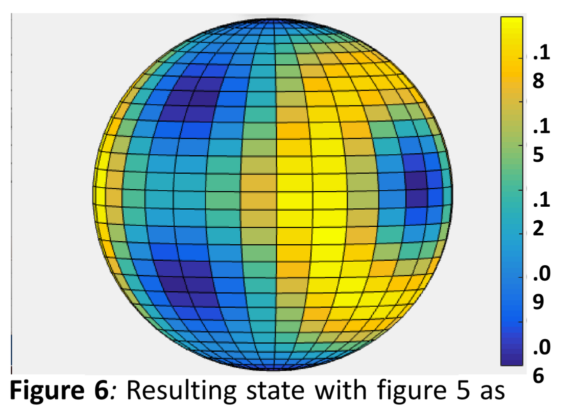

Figure 6: Resulting state with figure 5 as a target.

For simple target distributions, like the superposition state above, our numerical search program found states that produced a nearly identical distribution.

Husimi-Q With Letter "U" Target

Target Husimi-Q Distribution / **Found Husimi-Q Distribution**

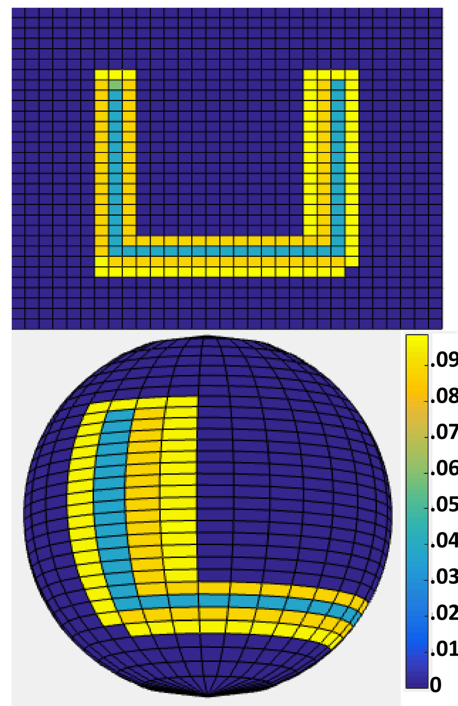

Figure 7: Target Husimi-Q shaped like a "U." The bottom image is the top image distributed on a sphere

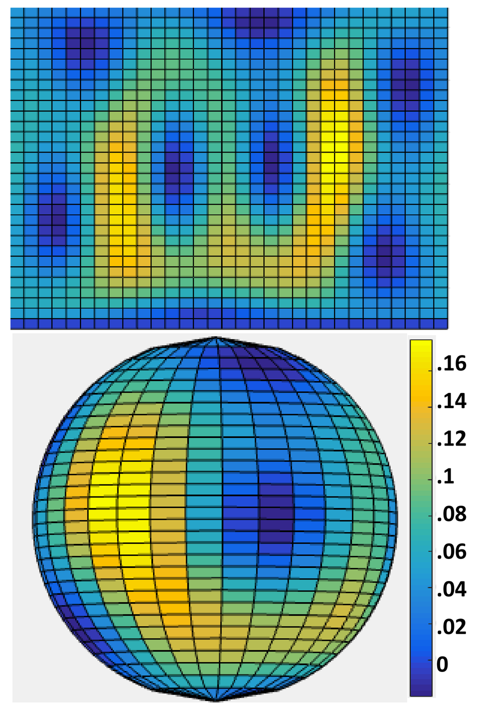

Figure 8: Found state from the target in figure 7. Bottom image is the top distributed on a sphere

The results show that our numerical search program had a more difficult time finding distributions closely resembling our self-made "U" distribution. Coherences and interferences in the distributions caused features to appear that do not exist in our target distribution. The program did its best to maximize the target regions and suppress the regions where features should not appear.

Target Husimi-Q / **Found Husimi-Q**

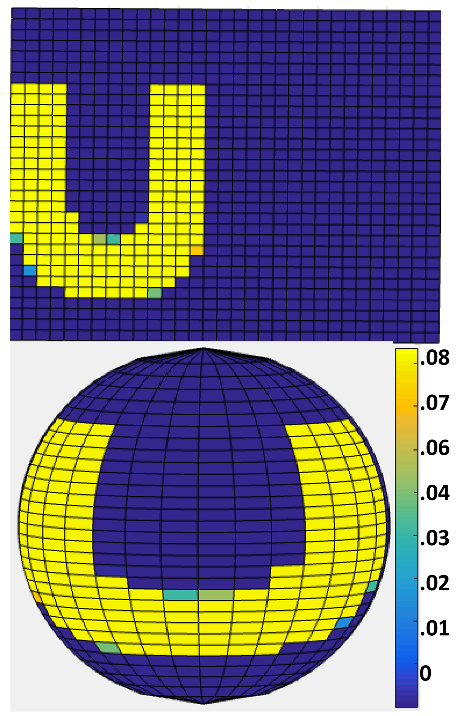

Figure 9 (Left): Target Husimi-Q with a "U" shaped feature

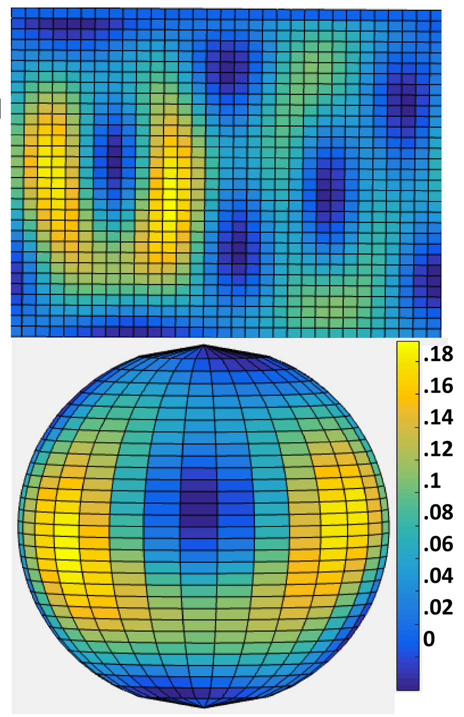

Figure 10 (Right): Resulting state with figure 11 as the target distribution

This target has a feature width more typical of the size of the known states'. The search program was able to find a state that looked relatively similar to the target, and the data served as a proof of concept for the project.

Experimental Results From State Tomography

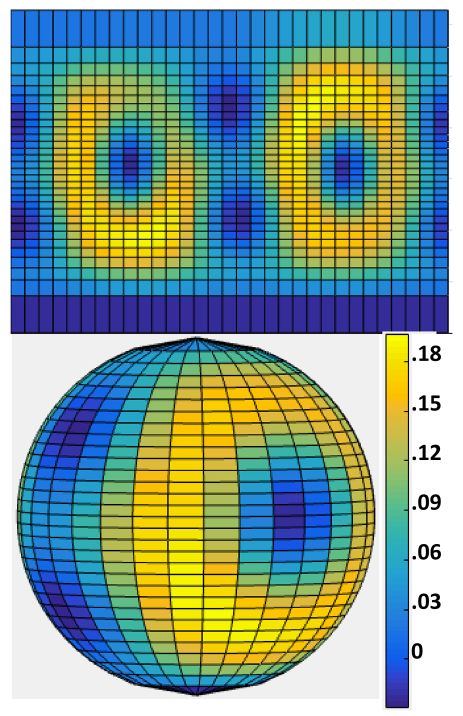

Figure 11 (Left): Reconstructed state from target in figure 6

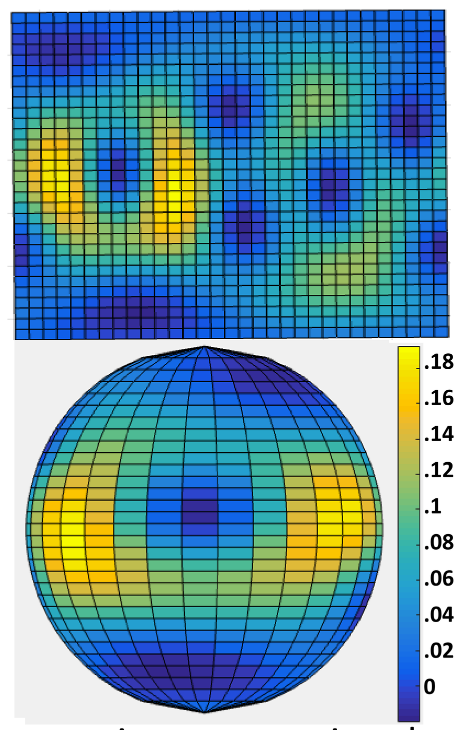

Figure 12 (Right): Reconstructed state from target in figure 10

In order to verify the search routine, we ran an experiment mapping the states our routine found onto Cesium atoms. We then performed state tomography on those prepared atoms to compare the Husimi-Q from our experimental implementation with our target distributions.

Conclusion

Our numerical search program successfully found states that generate distributions closely resembling simple distributions. However, arbitrary distributions were harder to find, and had structure not found in the target. Arbitrary targets more closely resembling the thickness of known states were more successful, indicating that there may not exist physical states corresponding to our targets. Finally, state tomography verified that found states reproduced our intended distributions.

Future Work

One way to improve how close we can get to our target is to use states of higher dimension. This gives us more parameters to change, increasing the likelihood we could get closer to our target state. Instead of just a "U", a more complex image could be written on the quantum state such as "UA". Interferences in those states would be more difficult to overcome, but a combination of increased state dimension and more numerical searches would help us attain that goal.

Support

Nathan Lysne[1]
Dr. Poul Jessen[1]
Research in Optics (RiO)
Grant # 1460723
Dr. John Koshel
Melissa Sarmiento Ayala, M.Ed.

References

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[4]Quantum Information and Control Group, http://web.arizona.edu/~lascool/