Effects of Laser Polarizations on Magnetic Sublevels in STIRAP

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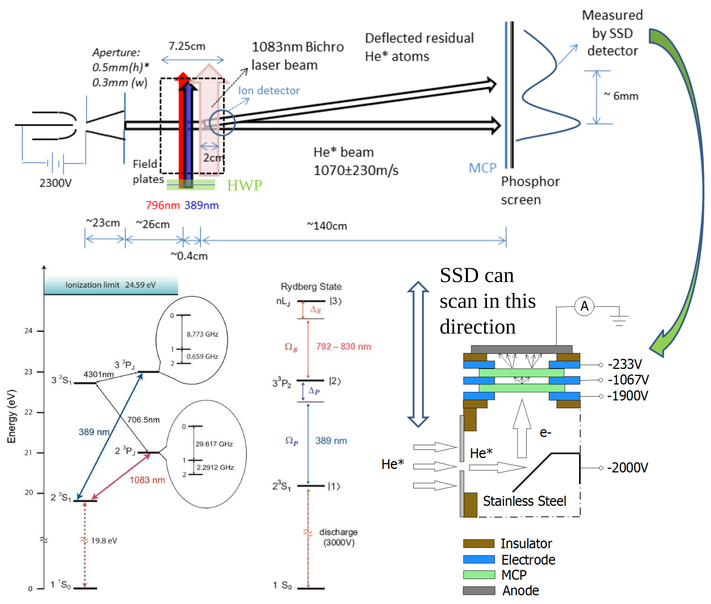
We have set up a STIRAP excitation mechanism for helium from the metastable 2^3S state into Rydberg states, via the intermediate level 3^3P . A uv laser at 389 nm and an ir laser at 780-815nm are used as the pump and Stokes beams respectively. Our purposes is to examine how well STIRAP works to efficiently produce the Rydberg atoms, and also to apply STIRAP for further coherent manipulations of helium. The polarizations of the lasers determine the structure of the couplings between those different energy levels' sublevels, and hence can form dark states and cause interference in different excitation paths. Rydberg atoms are suitable for this experiment because they have a long life time and are easily ionized therefore the population in the final level can be carefully measured. The correspondence between polarizations and excited Rydberg populations have been studied both theoretically and experimentally, and the interference patterns are revealed.

Experimental setup



STIRAP (in the usual sense)

Adiabatic States:

$$|+\rangle = \sin\theta\sin\varphi\,|1\rangle + \cos\varphi\,|2\rangle + \cos\theta\sin\varphi\,|3\rangle$$

$$|0\rangle = \cos\theta\,|1\rangle - \sin\theta\,|3\rangle$$

$$|-\rangle = \sin\theta\cos\varphi\,|1\rangle - \sin\varphi\,|2\rangle + \cos\theta\cos\varphi\,|3\rangle$$

$$H = \hbar\begin{pmatrix} 0 & \frac{1}{2}\Omega_p(t) & 0 \\ \frac{1}{2}\Omega_p(t) & \Delta & \frac{1}{2}\Omega_s(t) \\ 0 & \frac{1}{2}\Omega_s(t) & 0 \end{pmatrix}$$

where the mixing angles are:

$$\tan\theta = \Omega_p(t)/\Omega_s(t)$$

$$\tan 2\varphi = \sqrt{\Omega_p^2(t)+\Omega_s^2(t)}\,/\,\Delta$$

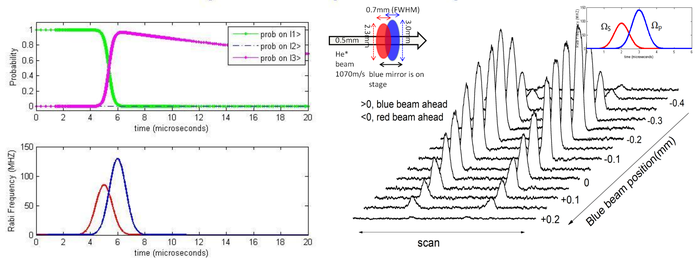
$t = -\infty$ *intermediate* $t = +\infty$

$$\begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta & \frac{1}{2}\Omega_s(t) \\ 0 & \frac{1}{2}\Omega_s(t) & 0 \end{pmatrix} \Rightarrow \begin{pmatrix} 0 & \frac{1}{2}\Omega_p(t) & 0 \\ \frac{1}{2}\Omega_p(t) & \Delta & \frac{1}{2}\Omega_s(t) \\ 0 & \frac{1}{2}\Omega_s(t) & 0 \end{pmatrix} \Rightarrow \begin{pmatrix} 0 & \frac{1}{2}\Omega_p(t) & 0 \\ \frac{1}{2}\Omega_p(t) & \Delta & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Energy Eigenstates: $|1\rangle,|2\rangle,|3\rangle$ — Adiabatic States, or "fake energy eigenstates": $|+\rangle,|0\rangle,|-\rangle$ — Energy Eigenstates: $|1\rangle,|2\rangle,|3\rangle$

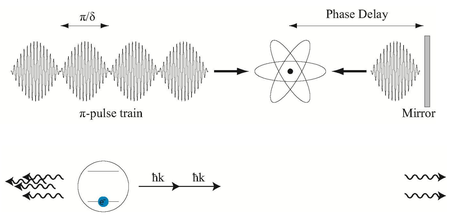
Wavefunction of the system $|1\rangle \Rightarrow |0\rangle \Rightarrow |3\rangle$

$$|0\rangle = \cos\theta\,|1\rangle - \sin\theta\,|3\rangle$$



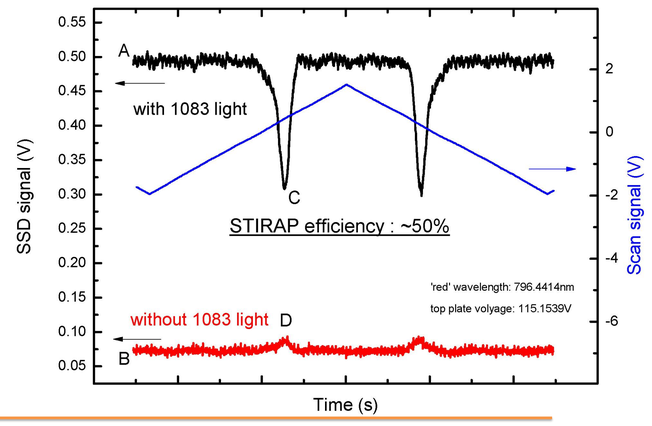
Numerical *Experiment data, from BBR ion signal*

Physical separation: the bichromatic force

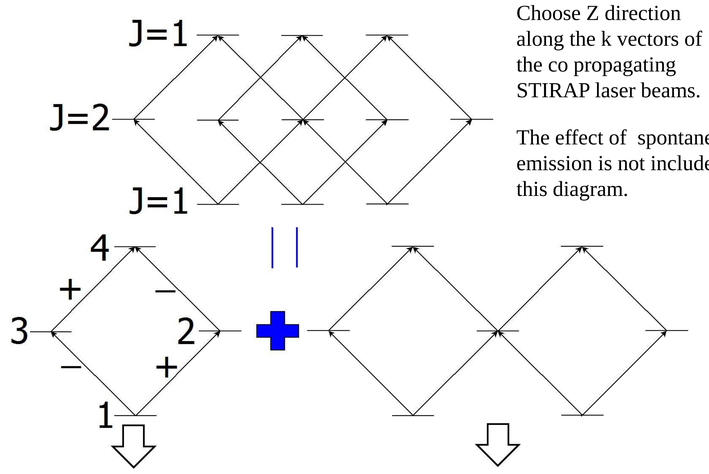


Absolute efficiency measurement results

Typical Data, as shown on oscilloscope



Magnetic sublevels and path interference



Choose Z direction along the k vectors of the co propagating STIRAP laser beams.

The effect of spontaneous emission is not included in this diagram.

Interference!

Caused by polarization direction differences of the two STIRAP lasers

Example of dark states, as a result of sublevels

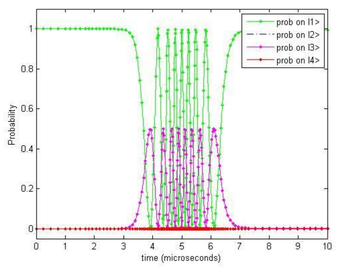
The state with magnetic number zero among the final Rydberg states experiences an interference. The simplest model can be given under circular polarization basis.

$$|\mathrm{uv}\rangle = \eta_{uv}(|+\rangle + \alpha|-\rangle)$$

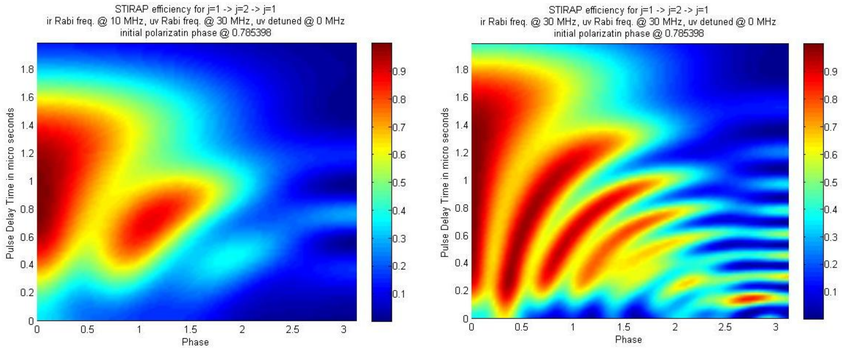
$$|\mathrm{ir}\rangle = \eta_{ir}(|+\rangle + \beta|-\rangle), |\alpha| = |\beta| = 1$$

$$i\frac{d}{dt}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} = \begin{bmatrix} & & \Omega_p & \alpha\Omega_p \\ \Omega_p & & & \beta\Omega_s \\ \bar{\alpha}\Omega_p & & & \Omega_s \\ & \bar{\beta}\Omega_s & \Omega_s & \end{bmatrix}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix}$$

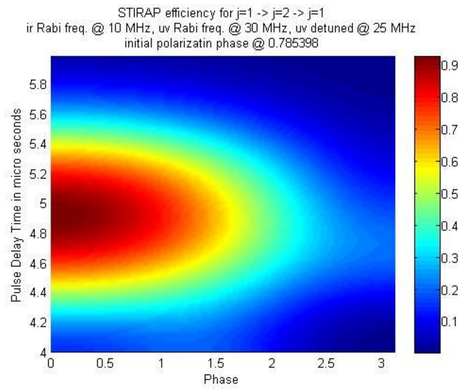
Numerical results on the extreme destructive interference case. The final m=0 state is never populated when the polarizations are orthogonal to each other, hence the Rydbergs we get is automatically polarized!



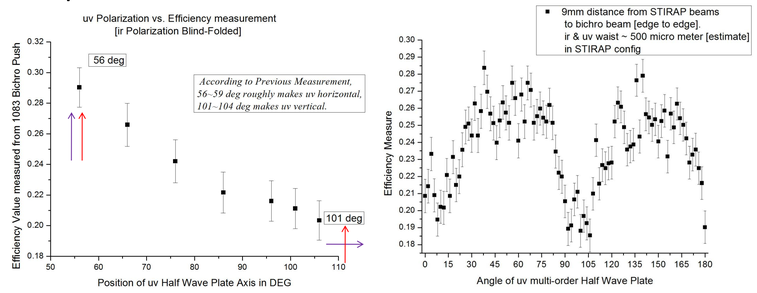
Numerical Results:



But if uv laser is detuned? (Numerical)

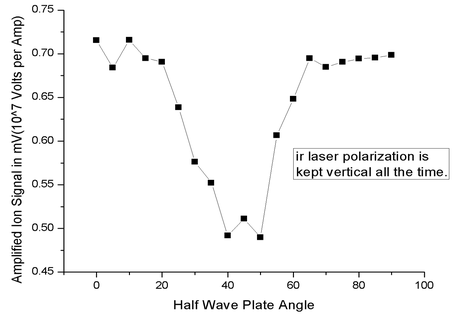


Experimental Data



Measured by efficiency

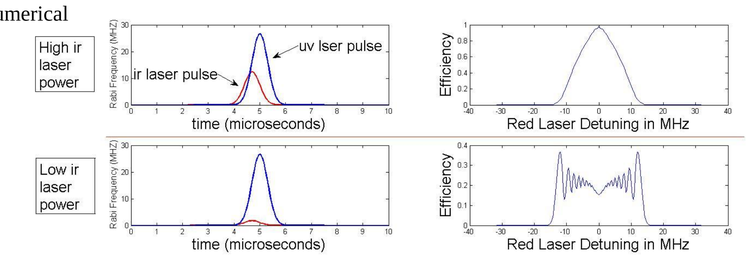
Measured by ion signal



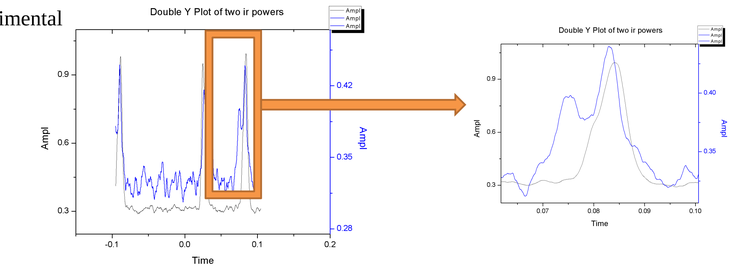
STIRAP and Autler-Townes effect

Typically we think that Autler-Townes Effect does not occur in STIRAP, but…

Numerical



Experimental Data



Conclusion

By physically separating the Rydberg and metastable ground state atoms using bichromatic force and ionization by thermal radiation, we can study the effect of laser polarizations on magnetic sublevels, the efficiency, the dark states and many other coherent phenomena associated with STIRAP. The experimental data qualitatively agree with numerical expectations.

References

[1] B.W. Shore et al, Coherent population transfer in multilevel systems with magnetic sublevels.(1995)
[2] K. Bergmann et, al. Coherent manipulation of atoms and molecules by sequential laser pulses.
[3]J. R. Morris et al, Reduction of degenerate two-level excitation to independent two-state systems.(1983)

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