Rydberg Atom Spectroscopy Enabled by Blackbody Radiation Ionization

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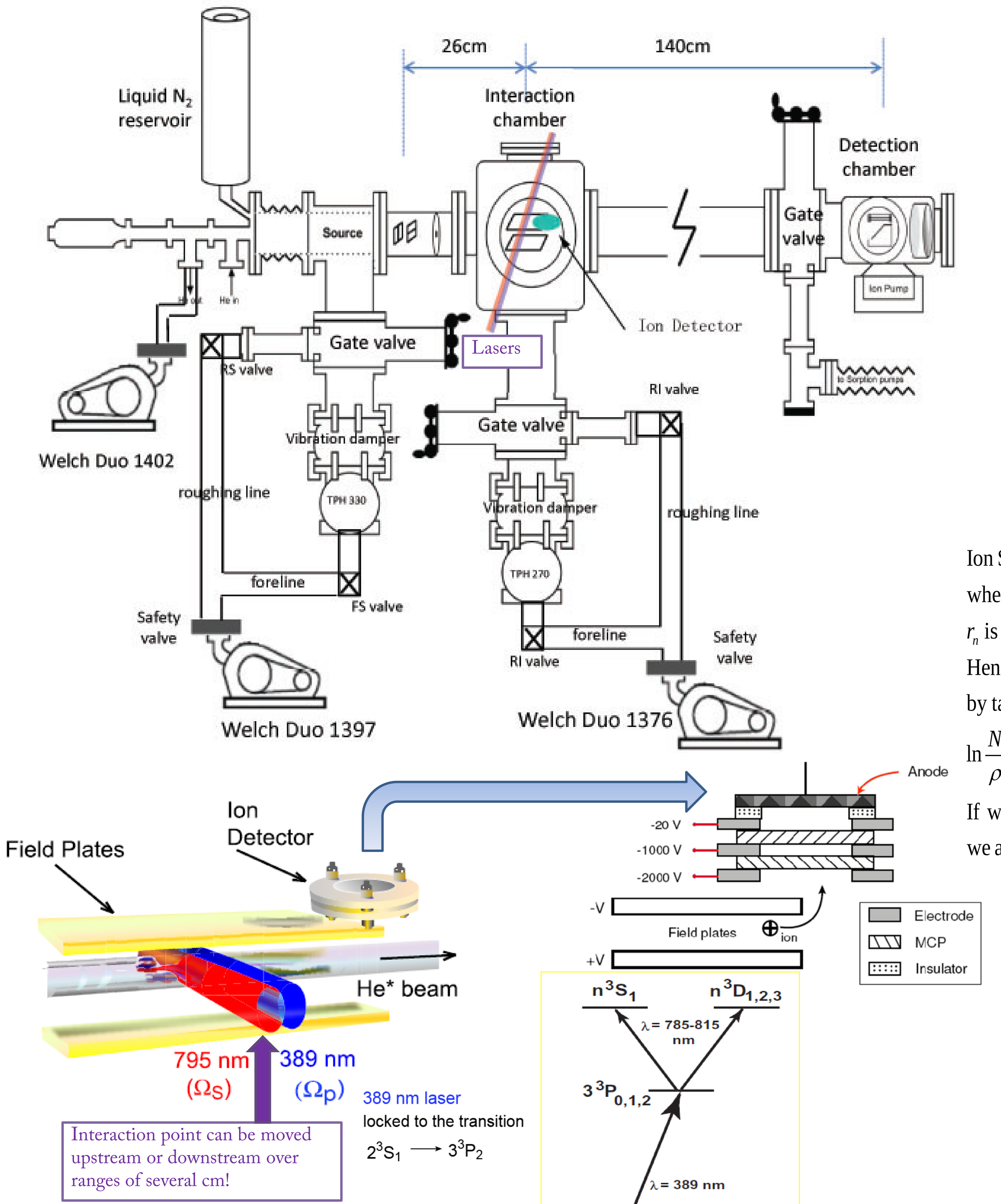
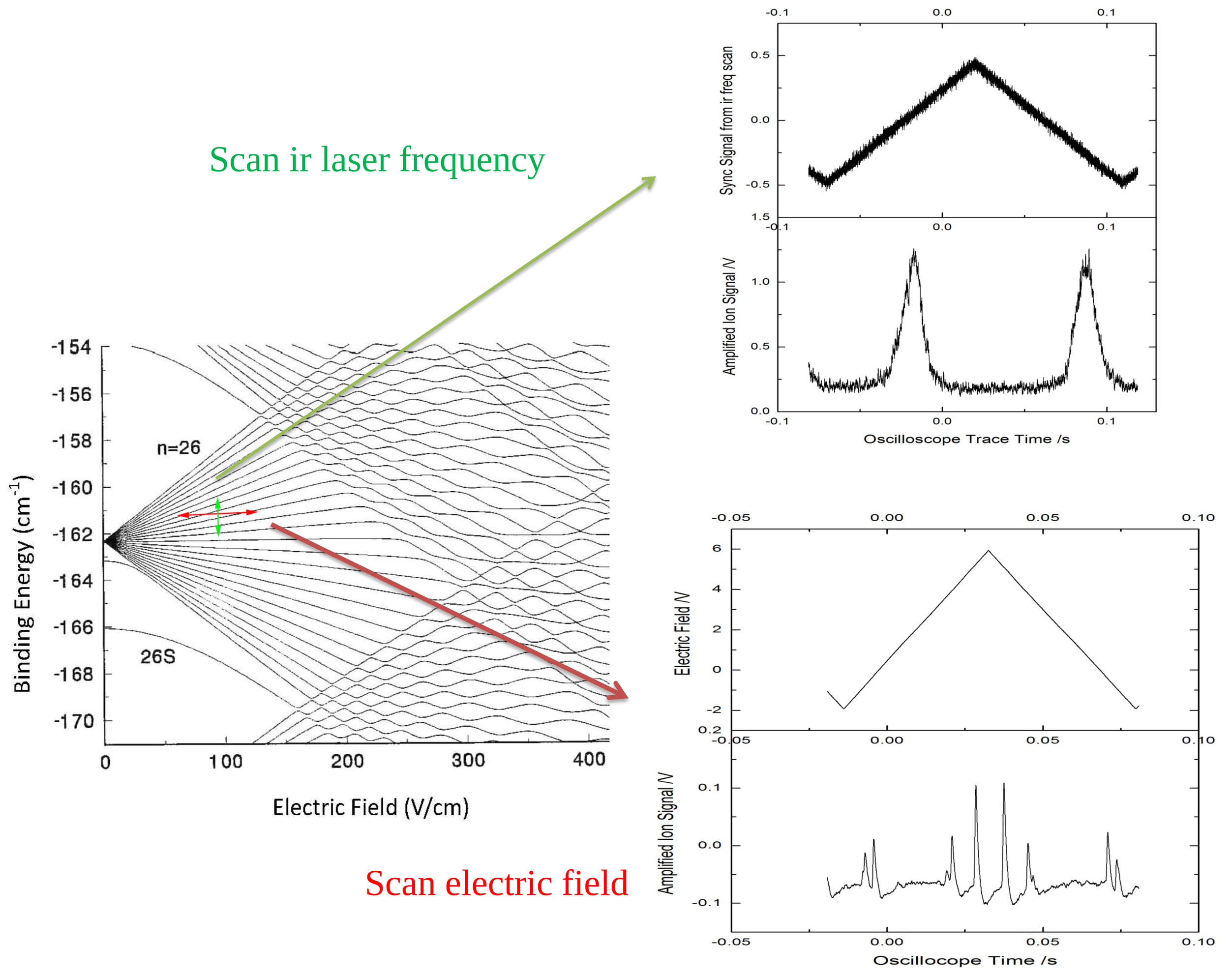
We have excited helium atoms from their metastable 2^3S_1 state to the Rydberg states in the range ~13 < n < ~50 in a two step process via the 3^3P_2 state using lasers at 398 nm and 798-815 nm. The interaction region is between two metal plates where electric field can be supplied to enable Stark tuning, or even induce field ionization. Ions from Rydberg atoms are observed experimentally when no other field or laser applied to them. Based on evidence we have we attribute this ion signal from black body radiation induced ionization of the Rydberg atoms we experimentally produced. By heating the plates we observe the expected signal increases. Instead of being noise, this ion signal serves in many aspects such as spectroscopy. Our experiments reinforce previous work where the interaction between Rydberg atoms and black body radiation is important for experiments, even at room temperature. This work in done in conjunction with STIRAP test and population separation techniques on the same apparatus for another project.

Experimental setup

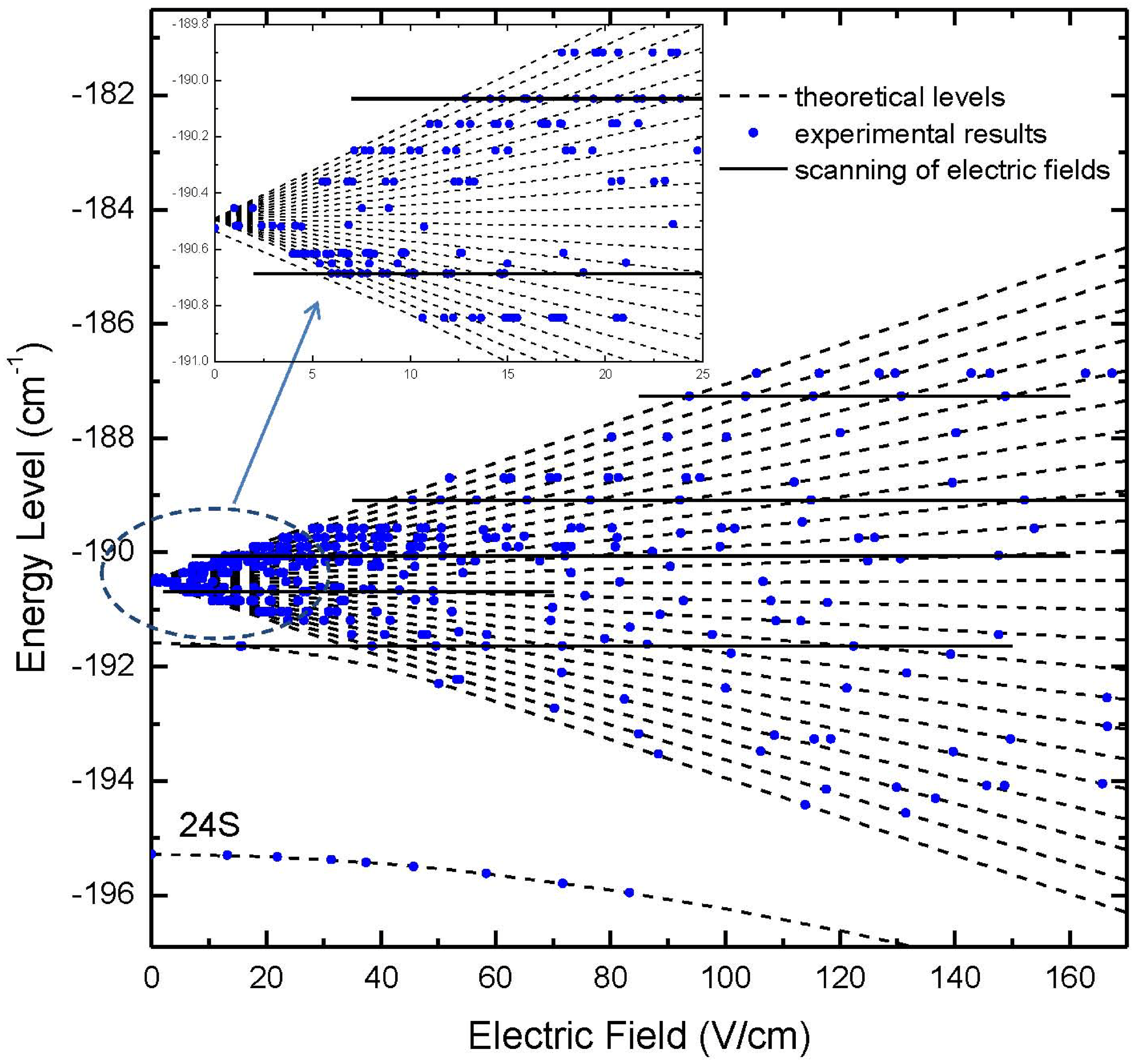


How do we get signal

By either scanning the ir laser frequency or the electric field between the plates, when the energy conservation relation is satisfied, an ion signal is observed.



Rydberg-Stark spectroscopy



Each of the measurements plotted as a dot represents the presence of a peak in the BBR (black body radiation) induced ion signal from the detector in the interaction region. The ir laser frequency is fixed and the electric field is scanned. Watch for those double dots near a single theoretical line!

Ion Signal Strength $N_I = \gamma_i \times \rho_n \times \exp(-d/r_n)$

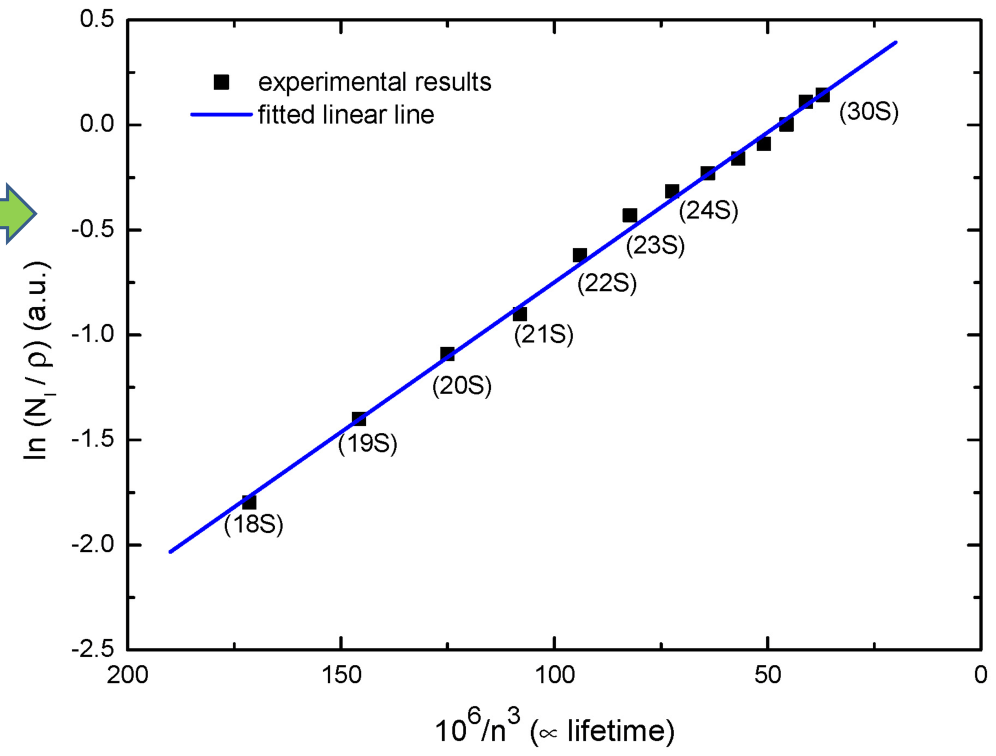
where ρ_n is the population of Rydberg atoms produced,

r_n is the lifetime translated into length in the experiment

Hence if the ionization rate remains constant over a range of n's, by taking the log, we have

$$\ln\frac{N_I}{\rho_n} = \ln\gamma_i + (-d/r_n)$$

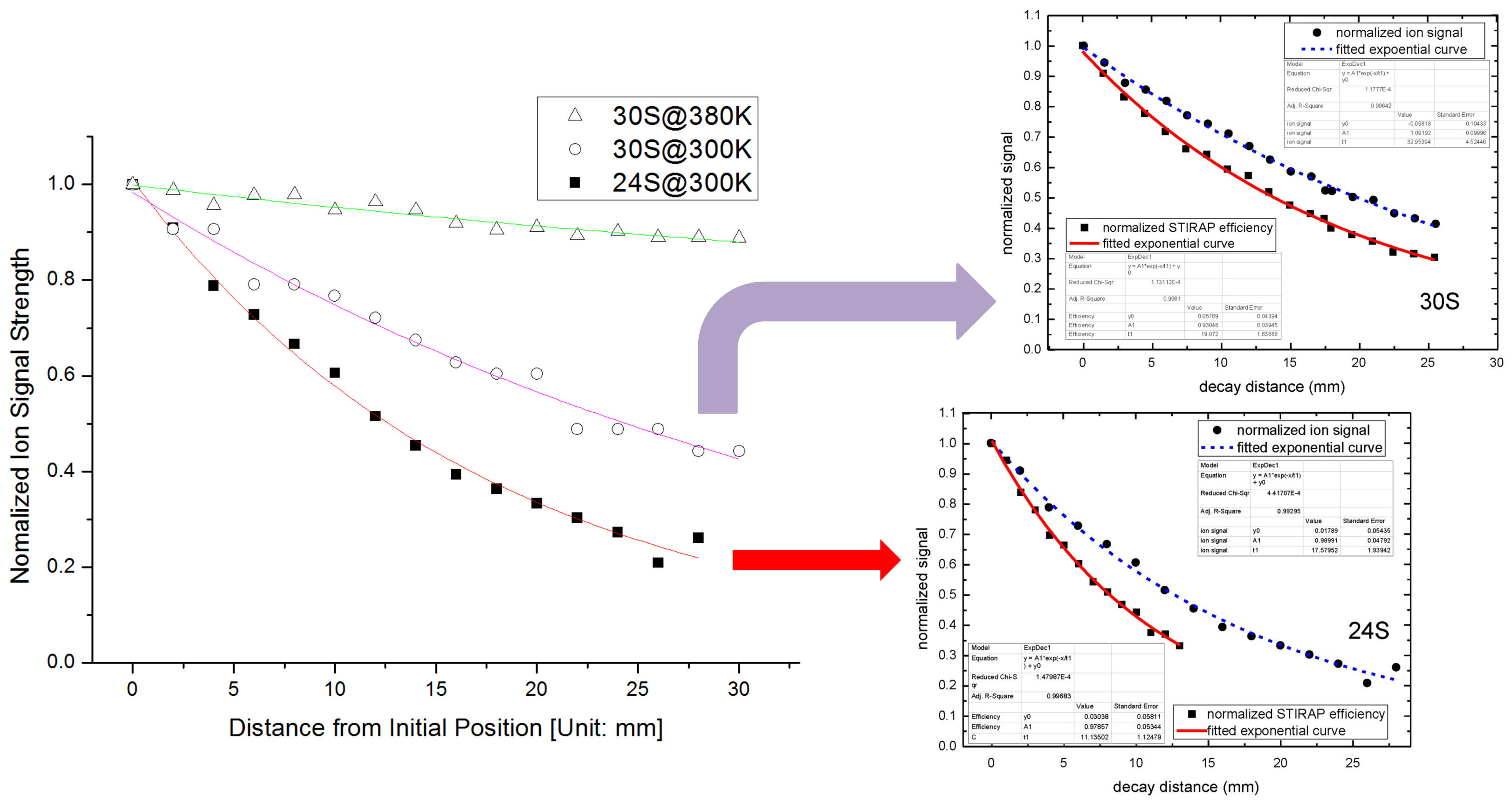
If we plot this vs n^{-3} with respect to principle quantum number n, we are expecting a straight line.



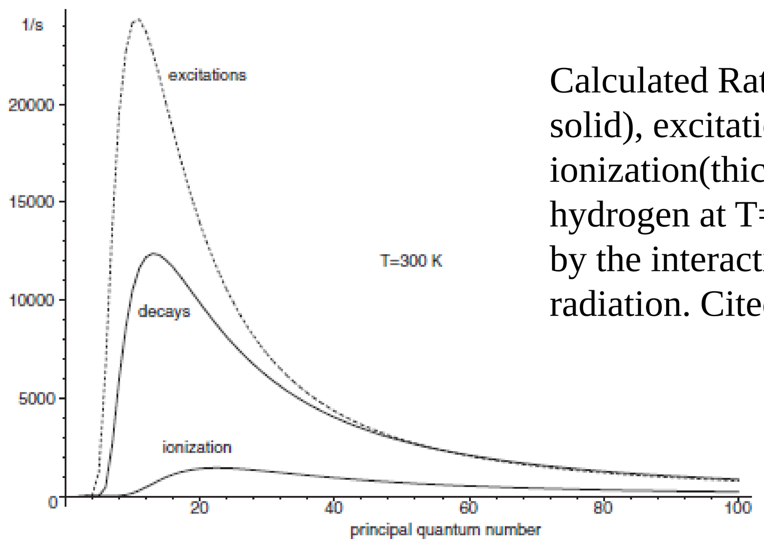
Those BBR induced ion signals are ~10-100 times weaker than the ion signals induced from field ionization!

Detection of ionized Rydberg Atoms

An interesting result arose when we move the lasers excitation region upstream further away from the ion detector and measure the decrease of the ion signal strength. The data is presented in the next graph and we find out that the exponential fits well. After we convert the distance into time by the velocity of the metastable helium atoms we can get the decay lifetimes. We found 16(1) and 34(1) for the 24S and 30S states respectively which are significantly longer than the calculated lifetimes.



BBR interaction with helium Rydberg atoms



Calculated Rates of decay(thin solid), excitation(dashed) and ionization(thick solid) for hydrogen at T=300K, as induced by the interaction with black body radiation. Cited from Ref [2].

The estimated rate of direct photo ionization of 24S Rydberg atoms is 300/s and in the 15 s that our atoms travelling at 1070 m/s are in the 15 mm field of view of our ion detector, we would expect 0.45% of them to be ionized. Using the results from Ref. [2] to sum the rates of BBR- induced transitions from 24S to other S and D states with 20 < n < 30, and then including the ionization rates of those secondary states, results in another 0.50% ionization.

Our ion detector count rate is 10^5/s for the 24S Rydberg state. The estimated Rydberg production rate is 10^8/s because other measurements suggest that we can excite about half of the 2:5 *10^8 He* emerging from the rectangular aperture. The 24S measurements were made ~28 mm downstream from the excitation region, and as previous figures show, ~75% of the atoms have either decayed or been ionized in this distance, suggesting a flux of ~3*10^7 Rydberg atoms/s at this 28 mm point. Our count rate of ~0.4% of this is in reasonable agreement with the theoretical calculated value, shown in the above paragraph.

Rate equation description of the redistribution

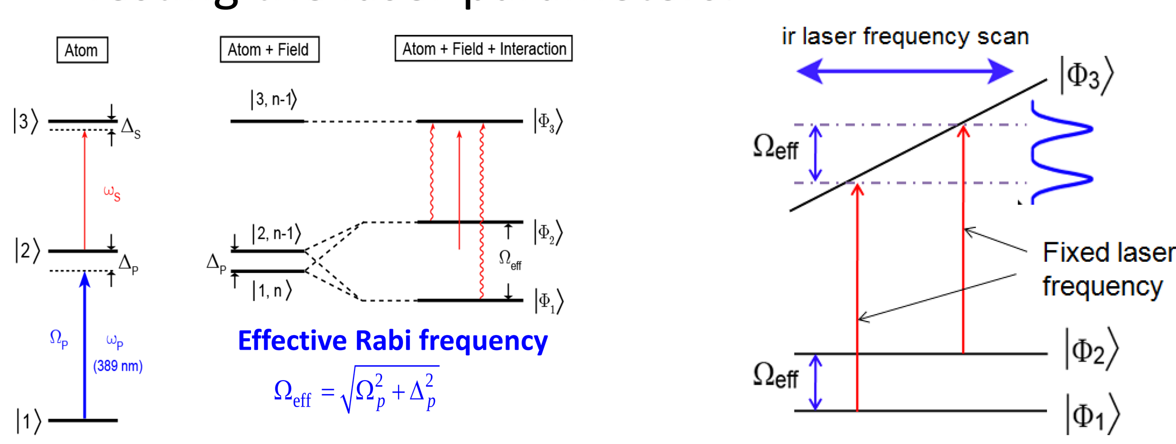
$\dot N_e(t) = -\gamma_{eg}N_e - \gamma_{er}N_e - \gamma_{ei}N_e \equiv -\gamma_e N_e$ Rydberg State

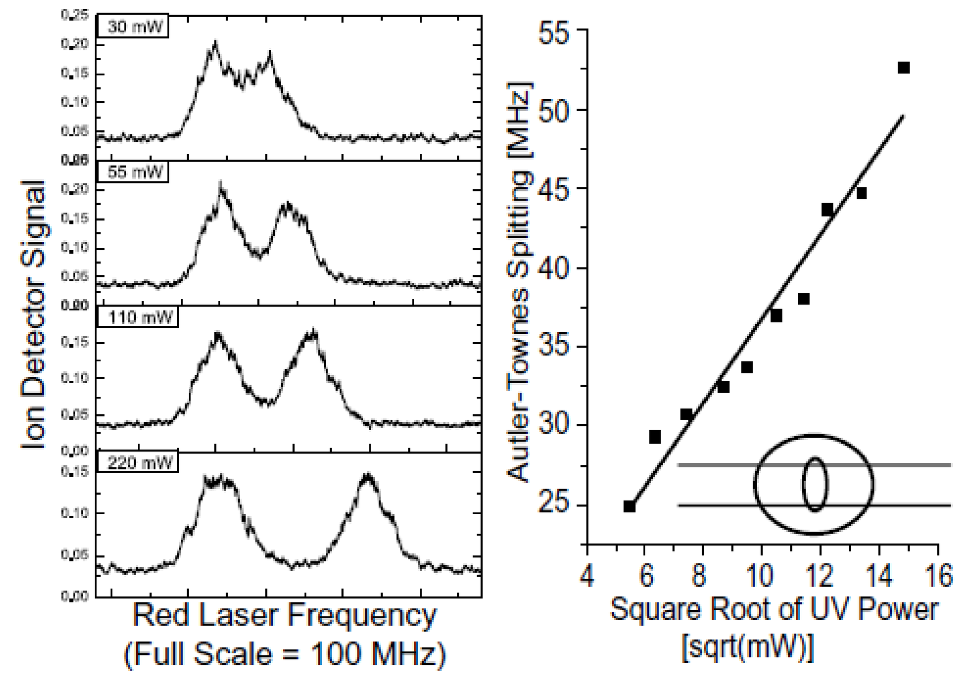
$\dot N_r(t) = \gamma_{er}N_e - \gamma_{rg}N_r - \gamma_{ri}N_r \equiv \gamma_{er}N_e - \gamma_r N_r$ Rservoir State(s)

$\dot N_g(t) = \gamma_{eg}N_e + \gamma_{rg}N_r$ Ground State Population

$\dot N_i(t) = \gamma_{ei}N_e + \gamma_{ri}N_r$ Ion Signal Production

Testing the laser parameters: Autler-Townes





Conclusion

BBR induced ionization on helium Rydberg atoms has been studied in details. It has been demonstrated that BBR ionization mechanism can be important and also a useful tool, quite a contrary to its noise role in many other experiments.

References

[1] *Rydberg Atom Spectroscopy Enabled by Blackdody Radiation Ionization, H. Metcalf et al, manuscript in preparation.*

[2] *I. L. Glukhov et al, Blackbody-Induced Decay, Excitation and Ionization Rates for Rydebrg States in Hydrogen and Helium Atoms. J. Phys. B 43, 125002 (2010).*

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