Multiphoton microwave ionization of Li Rydberg atoms

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April 28, 2008

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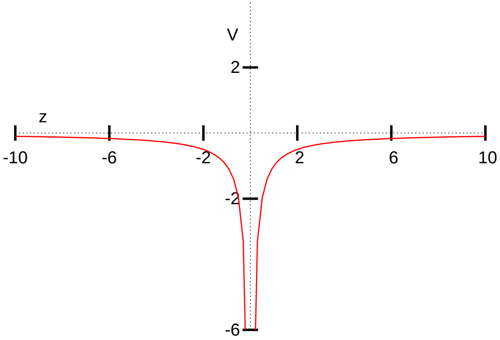
Outline

Rydberg atom overview

- $W = \frac{-1}{2n^2}$
- $r \propto n^2$
- $Lifetime \propto n^3$
- $\omega_{kepler} \propto 1/n^3$
- $V_{coulomb} = -\frac{1}{|z|}$



Rydberg atom overview

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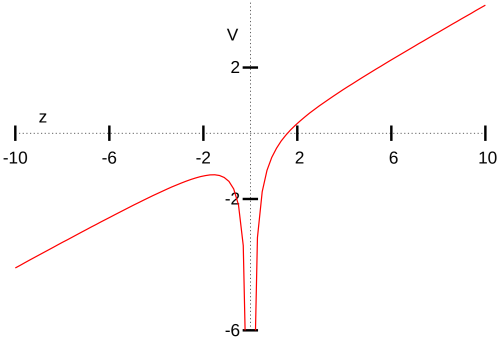
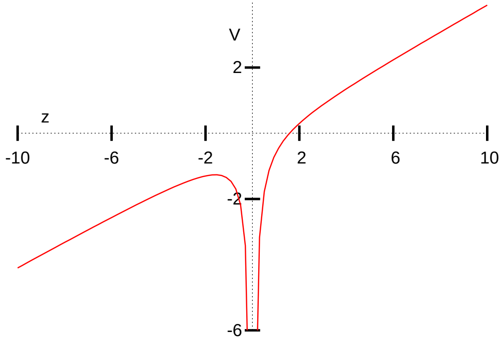
- $Lifetime \propto n^3$
- $\omega_{kepler} \propto 1/n^3$
- $V = -\frac{1}{|z|} + Ez$

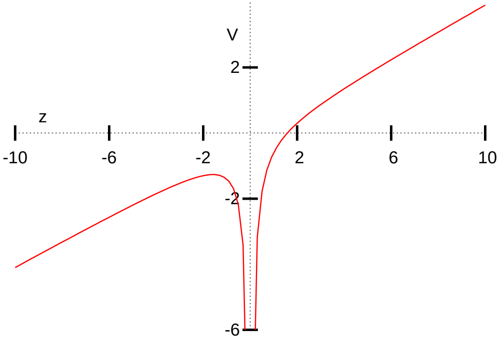


Field Ionization



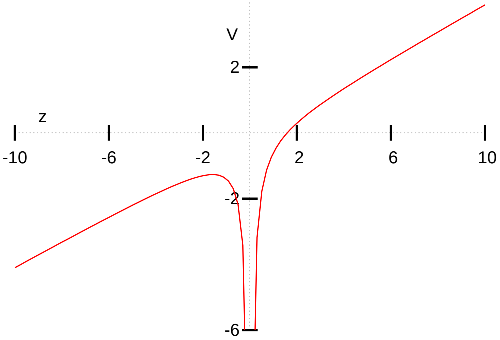
- $V = -\frac{1}{|z|} + Ez$
- $\frac{dV}{dz} = 0$

Field Ionization



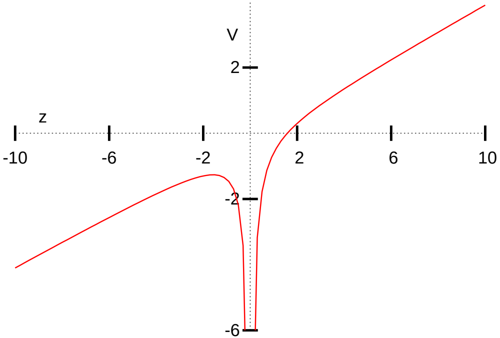
- $V = -\frac{1}{|z|} + Ez$
- $\frac{dV}{dz} = 0$
- $V = -2\sqrt{E}$

Field Ionization



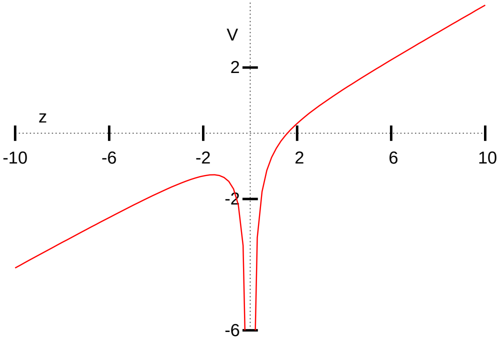
- $V = -\frac{1}{|z|} + Ez$
- $\frac{dV}{dz} = 0$
- $V = -2\sqrt{E}$
- $E = \frac{W^2}{4}$

Field Ionization



- $E = \frac{W^2}{4}$
- $W = \frac{-1}{2n^2} + \frac{3}{2} nkE$

Field Ionization



- $E = \frac{W^2}{4}$
- $W = \frac{-1}{2n^2} + \frac{3}{2} nkE$
- $E = \frac{1}{9n^4}$

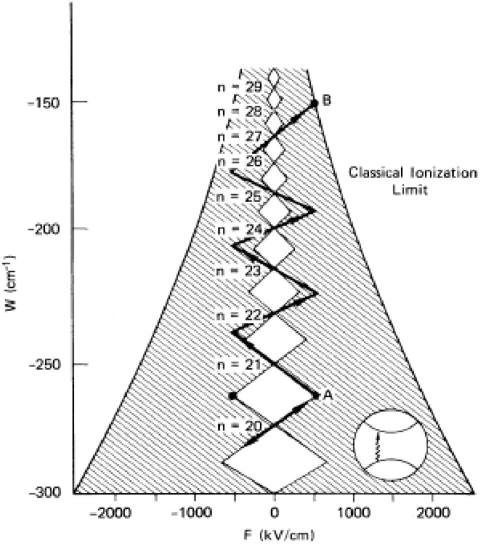
Scaled Frequency

Important characteristic: $\omega_0 = \frac{\omega}{\omega_{kepler}} = \omega n^3$

Previous work for $\omega_0 \leq 1$:

- van Leeuwen et al., PRL 55 (1985)
- Jensen et al., PRL 62 (1989)
- Pillet et al., PRA 30 (1984)
- Noel et al., PRA 62 (2000)

Microwave Ionization

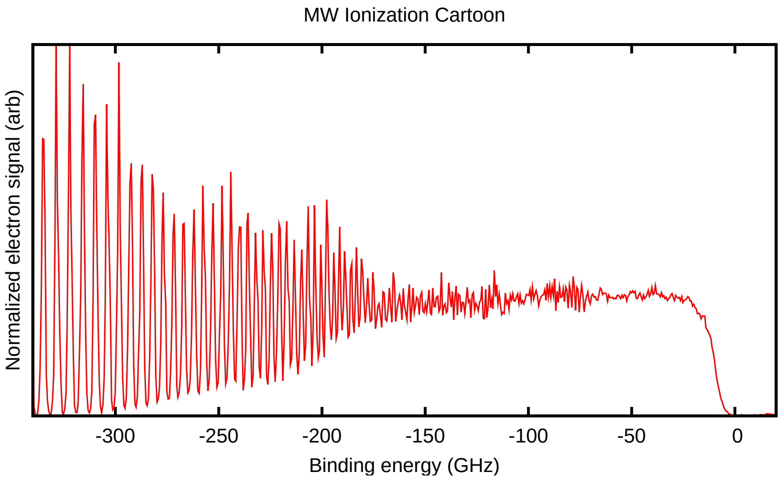


Pillet et al., PRA 30 (1984)

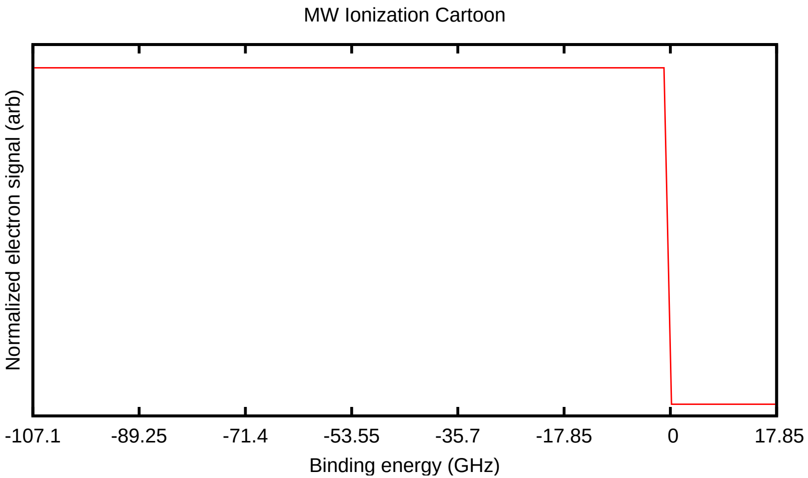
Photoionization limit?

What happens as we approach the photoionization limit, when $\omega_0 \rightarrow n$?

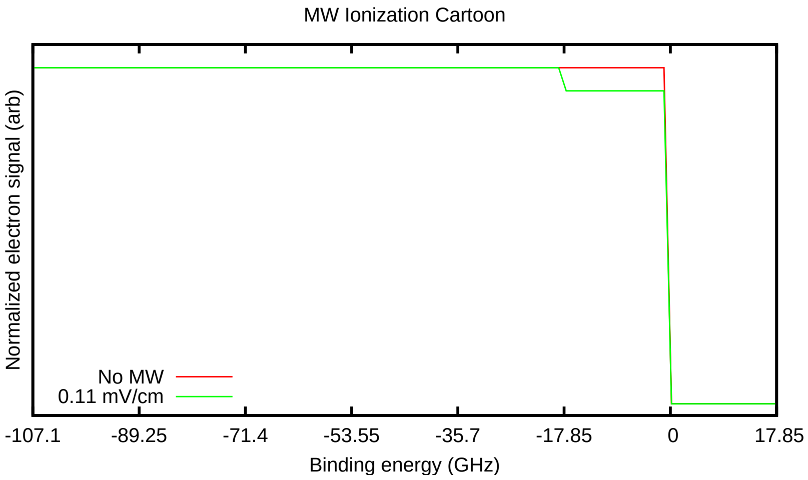
Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
-300
-250
-200
-150
-100
-50
0
Binding energy (GHz)

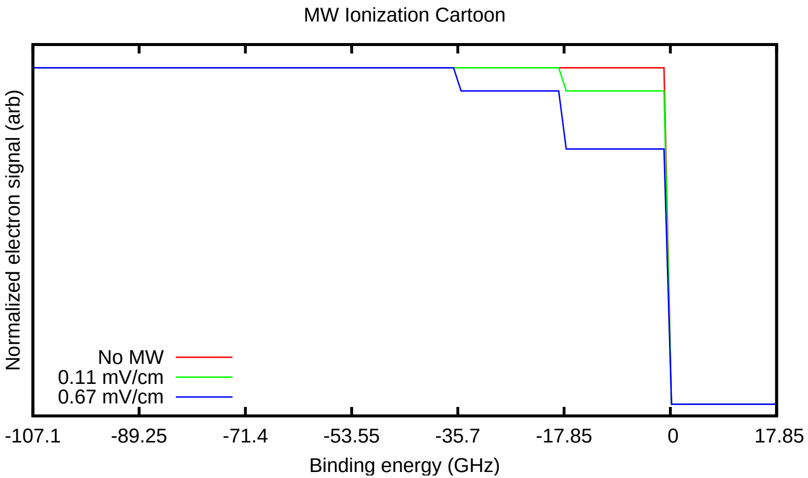
Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
17.85
Binding energy (GHz)

Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
No MW
0.11 mV/cm
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
17.85
Binding energy (GHz)

Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
No MW
0.11 mV/cm
0.67 mV/cm
-107.1
-89.25
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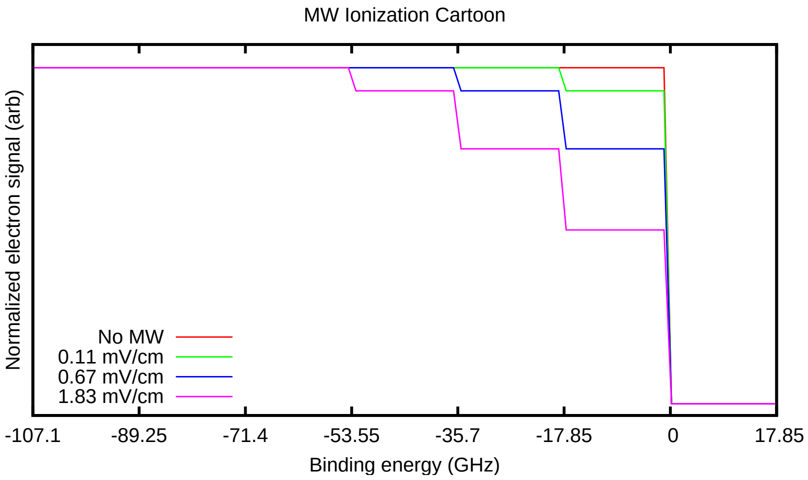
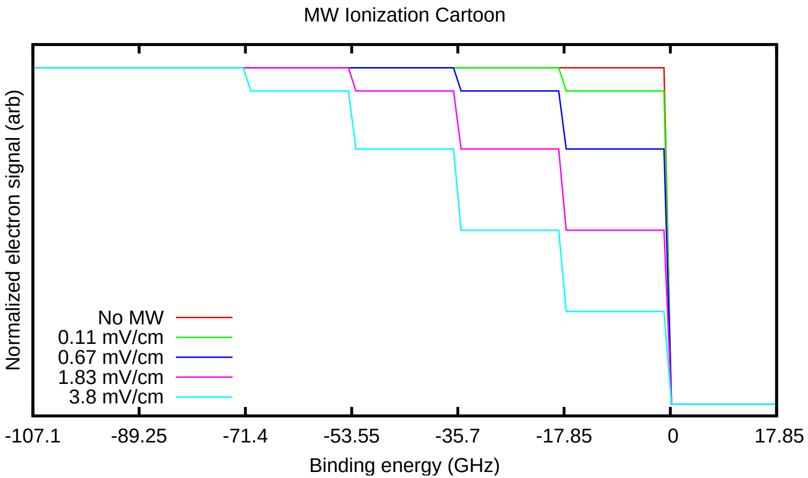
-17.85
0
17.85
Binding energy (GHz)

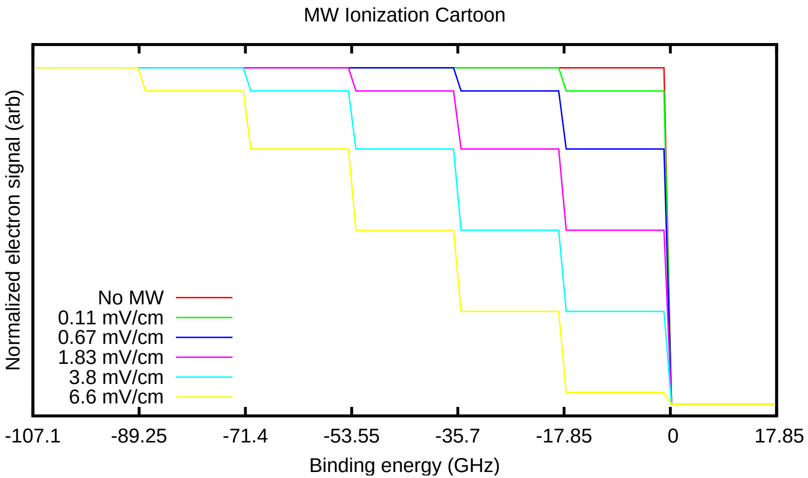
Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
No MW
0.11 mV/cm
0.67 mV/cm
1.83 mV/cm
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
17.85
Binding energy (GHz)

Cartoon


MW Ionization Cartoon
Normalized electron signal (arb)
Binding energy (GHz)
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
17.85
No MW
0.11 mV/cm
0.67 mV/cm
1.83 mV/cm
3.8 mV/cm

Cartoon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No MW
0.11 mV/cm
0.67 mV/cm
1.83 mV/cm
3.8 mV/cm
6.6 mV/cm
-107.1
-89.25
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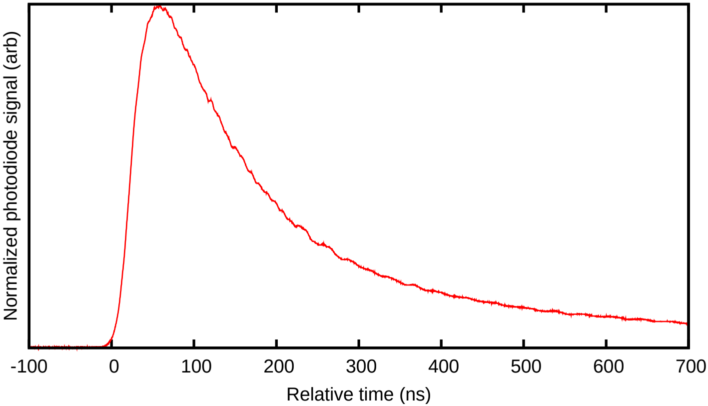
-17.85
0
17.85
Binding energy (GHz)

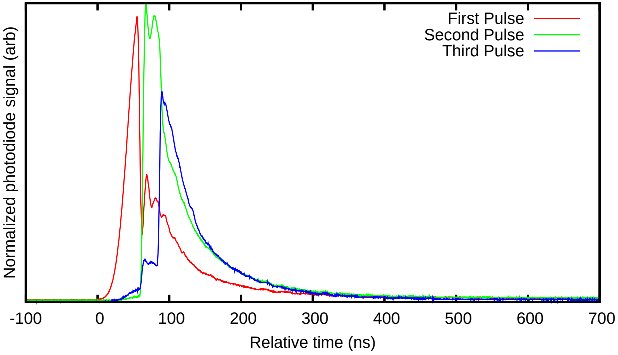
Outline

Coherent Evolution-30 Nd:YLF Laser

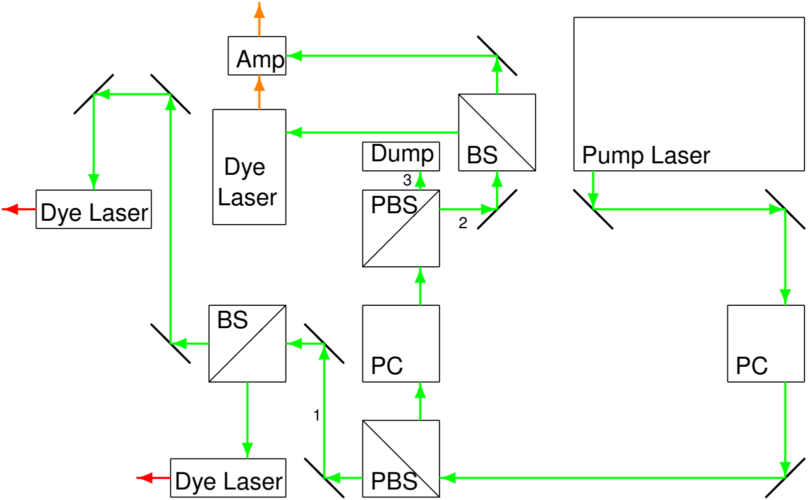


Coherent Evolution-30 Nd:YLF Laser

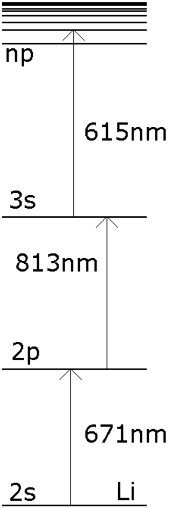
- 1st Pulse: 20ns
- 2nd Pulse: 35ns
- 3rd Pulse: 41ns

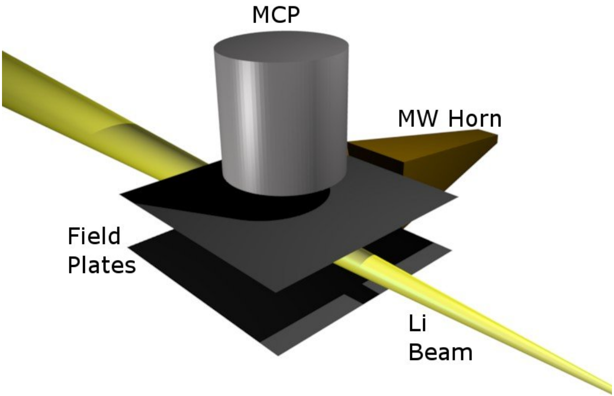


Laser Setup

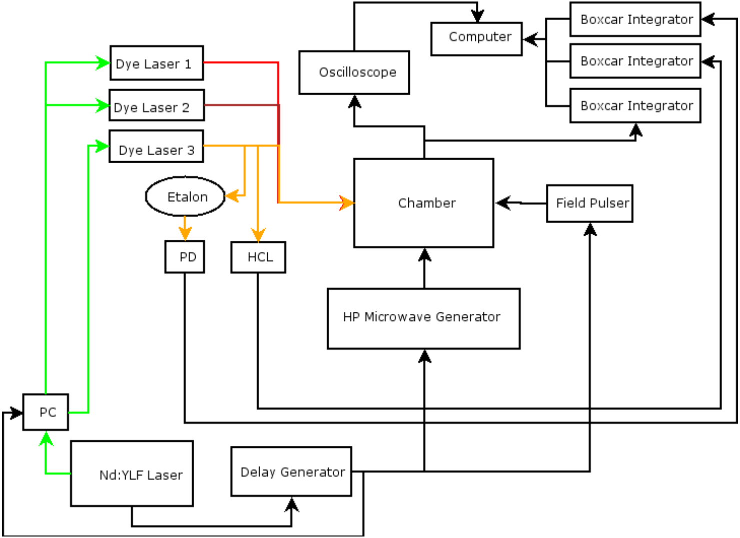

Amp
Dye Laser
Dump
BS
Pump Laser
3
PBS
2
Dye Laser
BS
PC
PC
1
Dye Laser
PBS

Experimental Setup

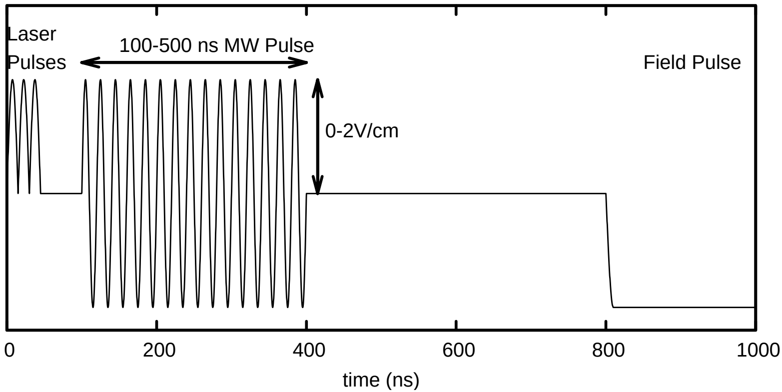




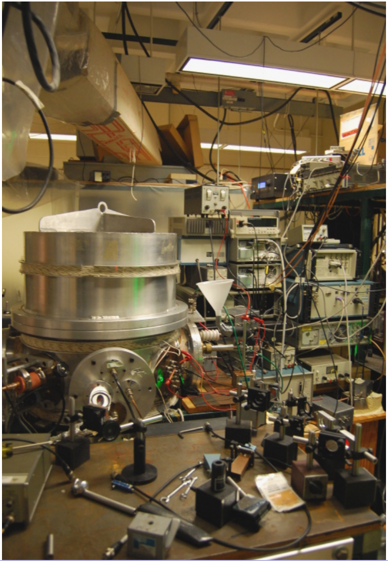
Experimental Setup

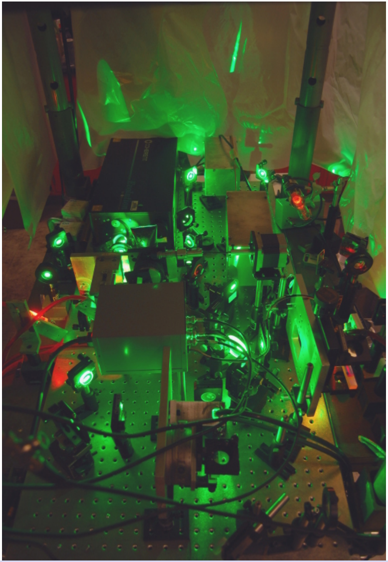


Timing


Laser
Pulses
100-500 ns MW Pulse
Field Pulse
0-2V/cm
0
200
400
600
800
1000
time (ns)

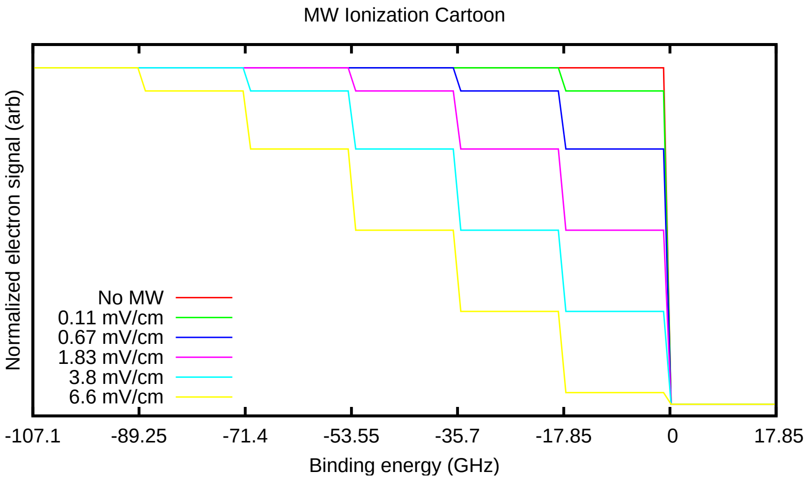
Experimental Setup





Outline

Cartoon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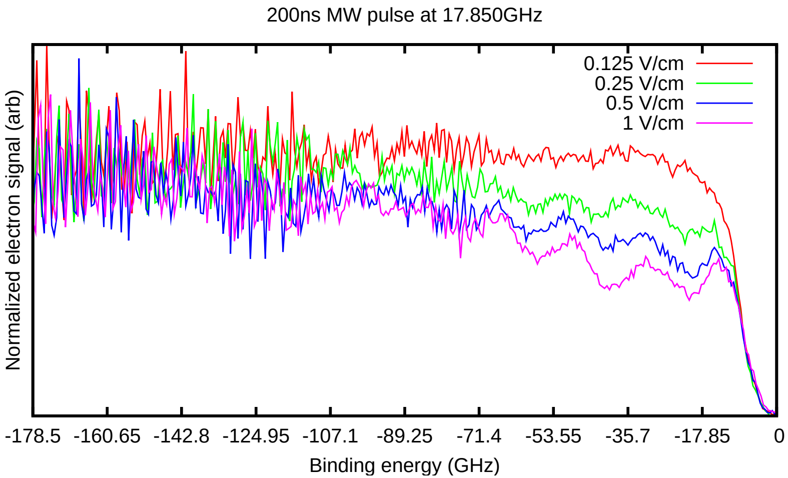
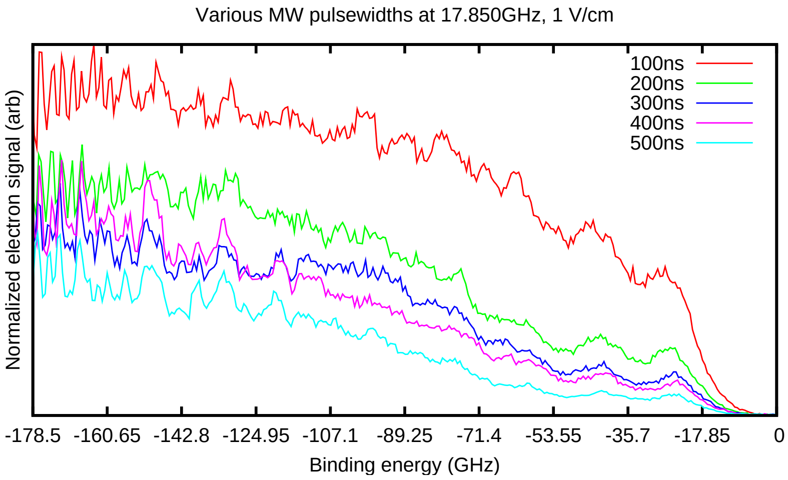
Normalized electron signal (arb)
No MW
0.11 mV/cm
0.67 mV/cm
1.83 mV/cm
3.8 mV/cm
6.6 mV/cm
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
17.85
Binding energy (GHz)

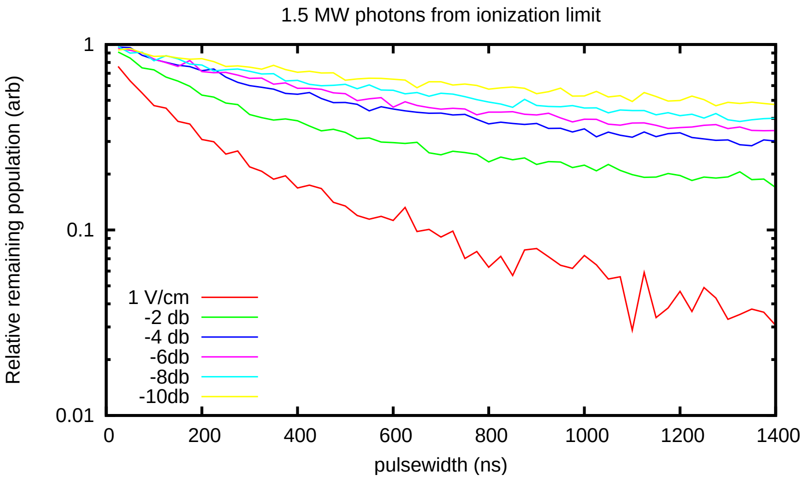
Microwave Ionization Steps - Powers



Pulsewidths



Ionization Rate



Theoretical Predictions

$$\Gamma_{exp}(n \approx 360, E \approx 0.8V/cm, 50ns) = 5.6 \times 10^6 s^{-1}$$

Hoogenraad and Noordam, PRA 57 (1998):

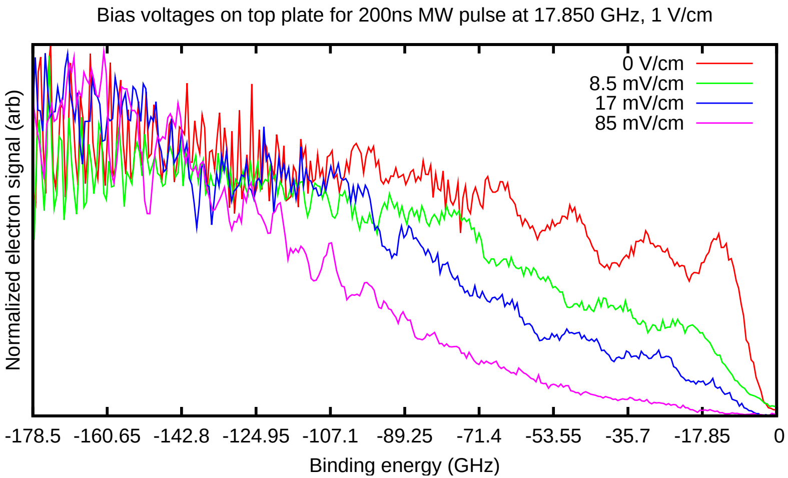
$$< n|r|n' > \approx \frac{0.4108 n^{-3/2} n'^{-3/2}}{\omega^{5/3}}$$

We can calculate the ionization rate: $\Gamma = 2\pi| < n|r|\epsilon > E|^2$

$$\Gamma(n = 360, E = 0.8V/cm) = 8.2 \times 10^7 s^{-1}$$

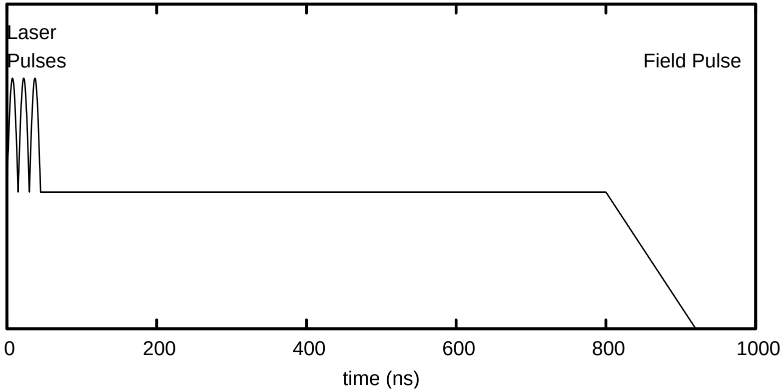
$$\boxed{\Gamma(n = 360, E = 0.2V/cm) = 5.6 \times 10^6 s^{-1}}$$

Bias Field

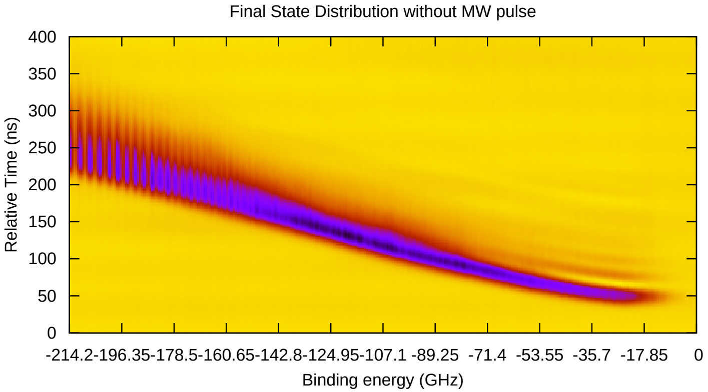

Bias voltages on top plate for 200ns MW pulse at 17.850 GHz, 1 V/cm
0 V/cm
8.5 mV/cm
17 mV/cm
85 mV/cm
Normalized electron signal (arb)
-178.5
-160.65
-142.8
-124.95
-107.1
-89.25
-71.4
-53.55
-35.7
-17.85
0
Binding energy (GHz)

Final State Distribution

$$E = 1/9n^4$$



Final State Distribution



Final State Distribution

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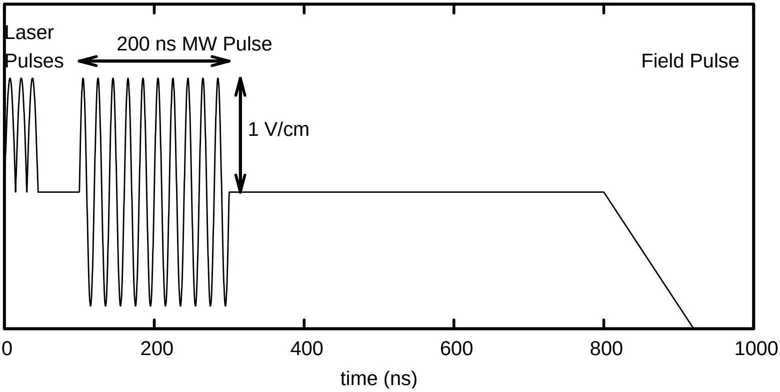
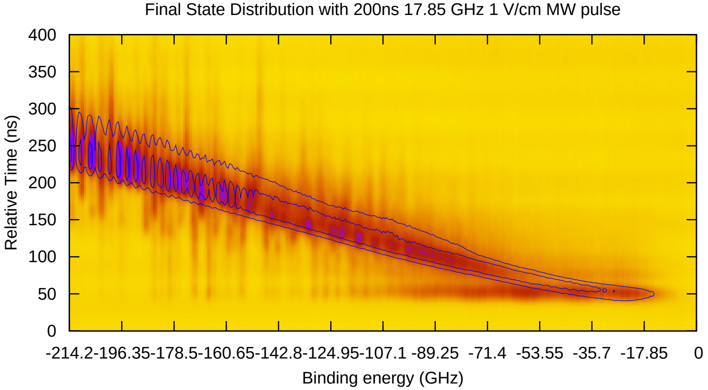


Final State Distribution



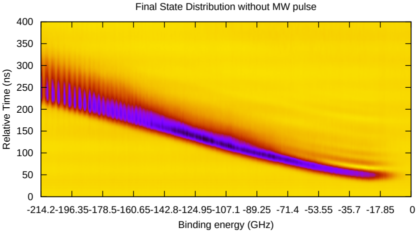
Summary

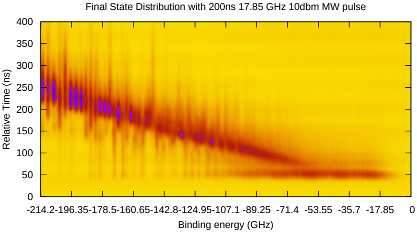
- Introduction to Rydberg field ionization
- Overview of microwave ionization
- Experiment setup
- First results for microwave multiphoton ionization of Rydberg Li atoms

Thanks

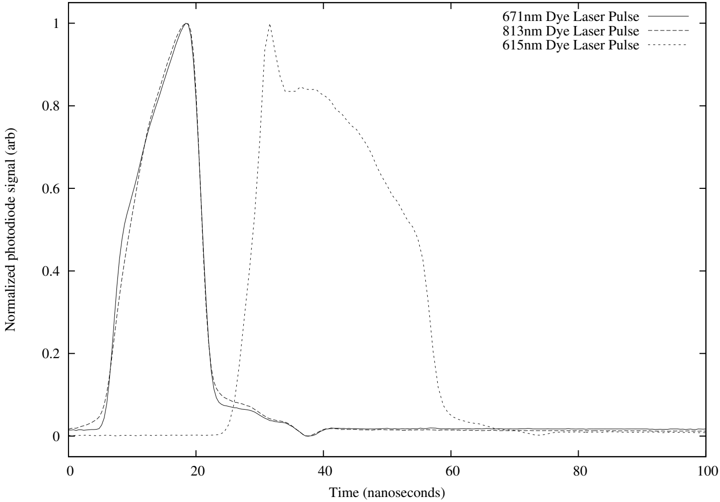
Professor Tom Gallagher
Dr. Haruka Maeda
Dr. Ed Shuman
Paul Tanner
Jianing Han
Jirakan Nunkaew
Don Norum
Hyunwook Park
National Science Foundation

Final State Distribution Comparison





Dye laser output



Atomic Conductance

Schelle, Delande, and Buchleitner: