Probing a cold Rydberg gas using autoionization

Matt Jones
Durham University

(Funding: EPSRC and Durham University)

The team

James Millen

Graham Lochead

Also:

Robert Potvliege

Guy Corbett

Charles Adams

Undergraduate students

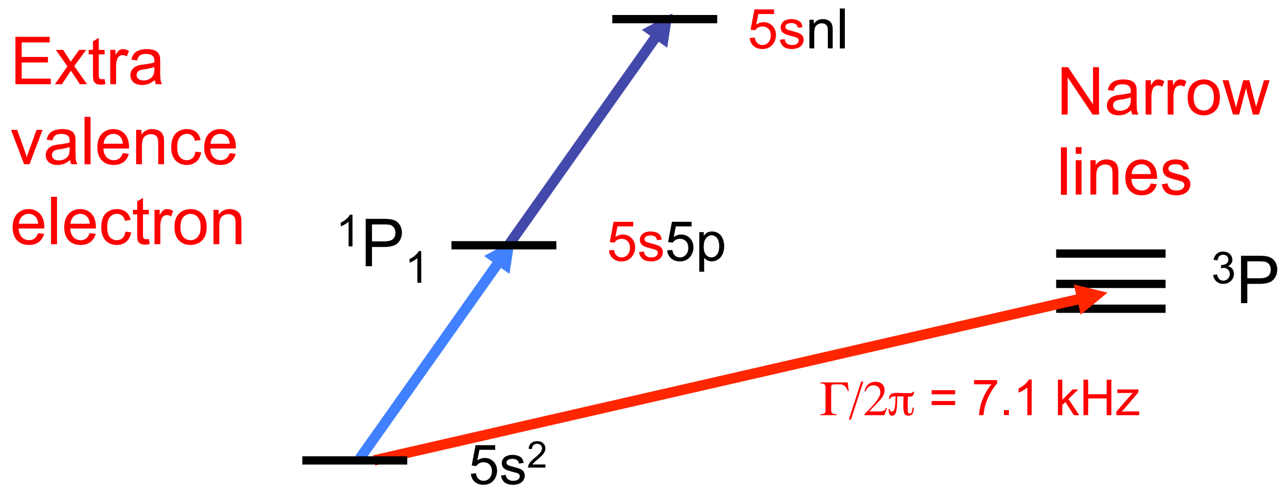
Sarah Mauger

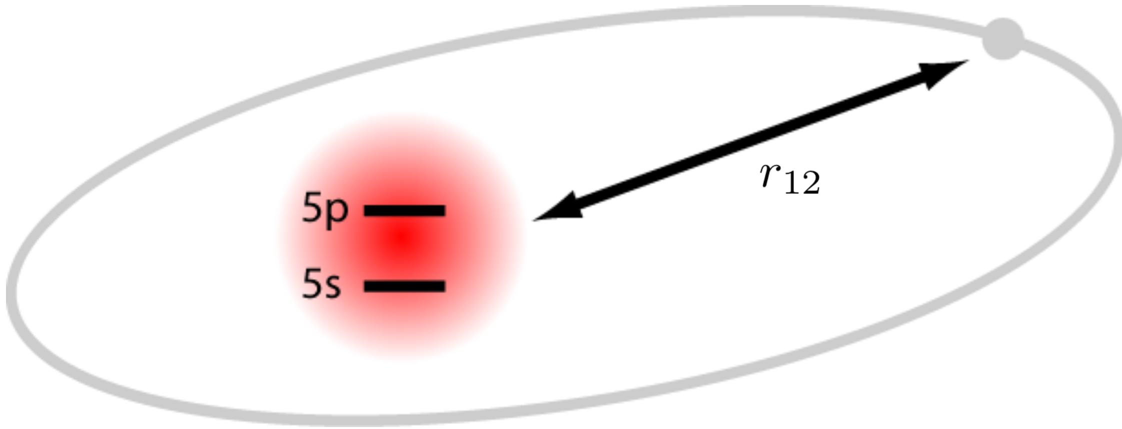
Clemetine Javaux

Elizabeth Bridge

Outline

1. Introduction – why strontium?
2. Exciting the second electron
3. Probing the strontium Rydberg gas
4. Population transfer


Extra
valence
electron
5snl
$^1P_1$
5s5p
Narrow
lines
^3P
$\Gamma/2\pi$ = 7.1 kHz
$5s^2$

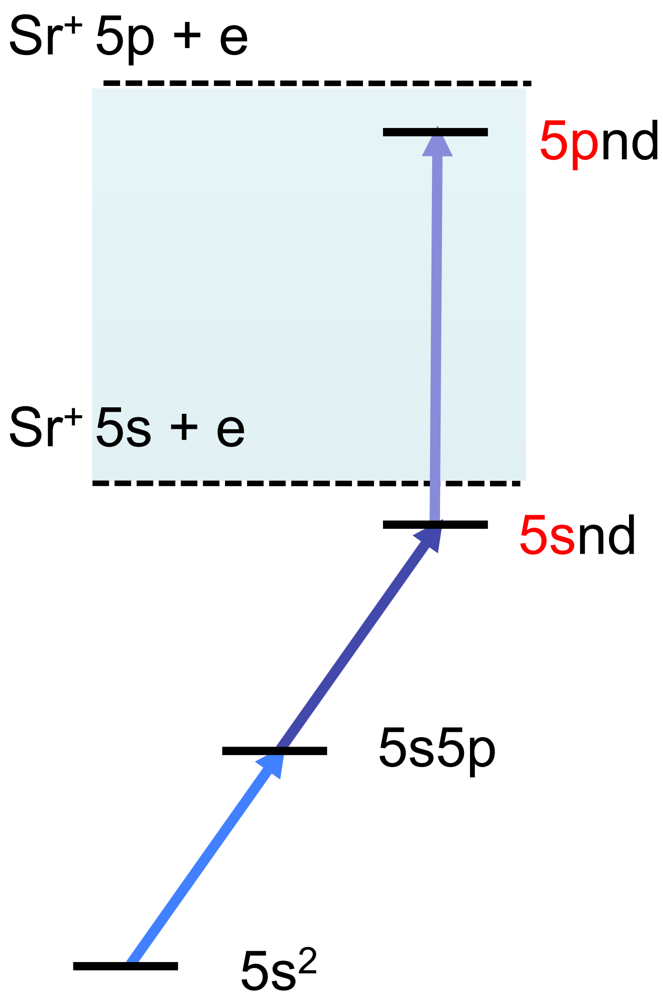


$$H' = \frac{1}{r_{12}}$$

Isolated Core Excitation (ICE)

Cooke et al., PRL **40**, 178 (1978)

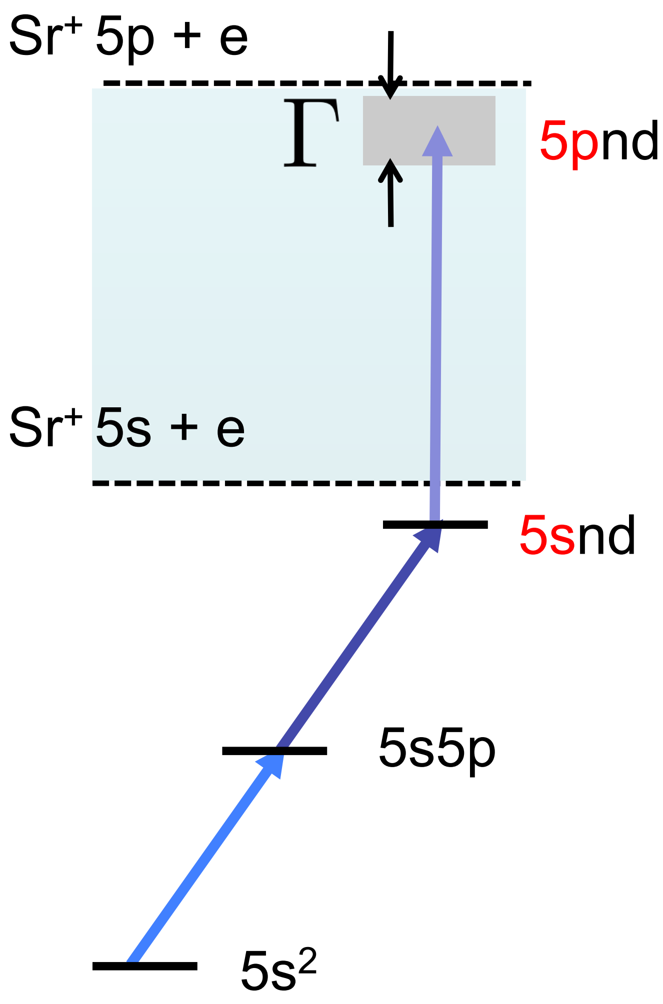
Autoionization



$$H' = \frac{1}{r_{12}}$$

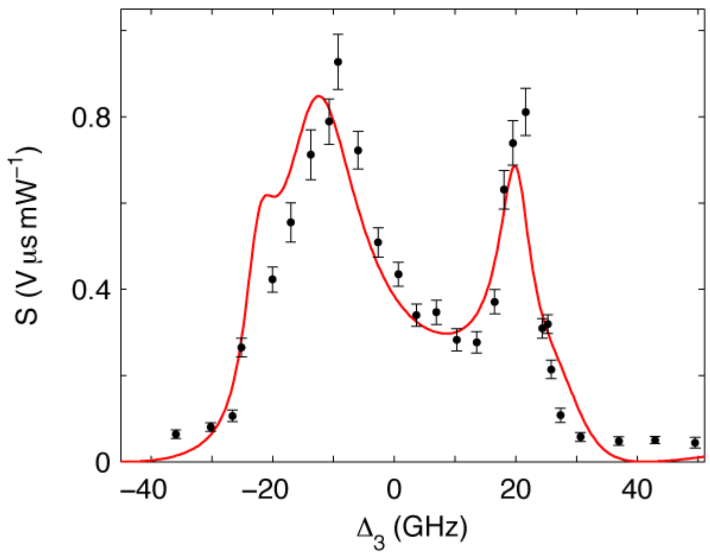
couples to continuum

Autoionization

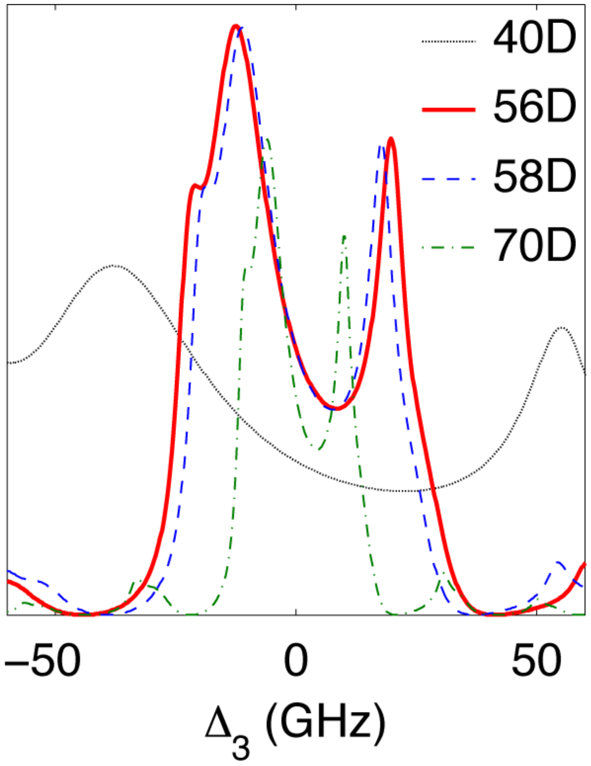


$$H' = \frac{1}{r_{12}}$$

couples to continuum

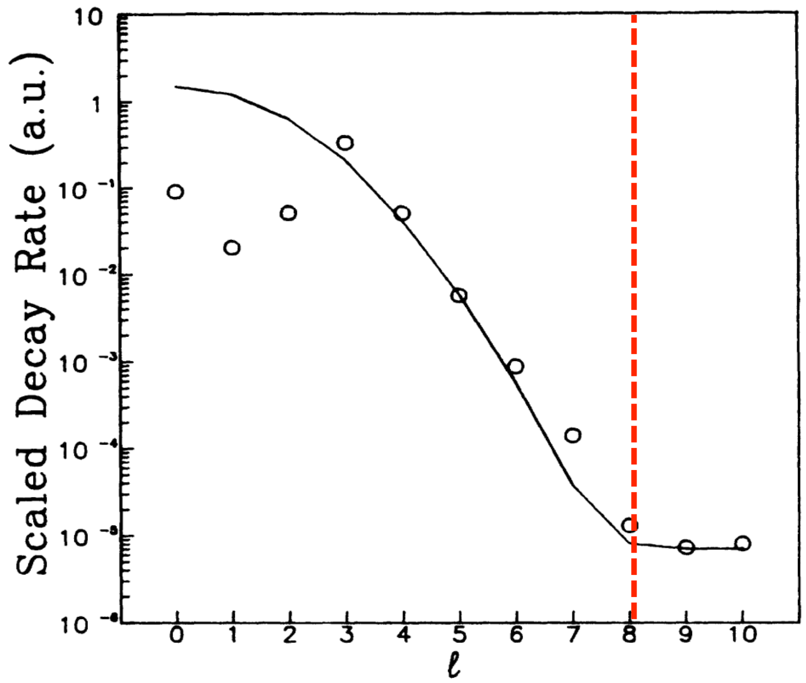


Sr 5pnd



$$\Gamma_{\rm auto} \propto n^{*\,-3}$$

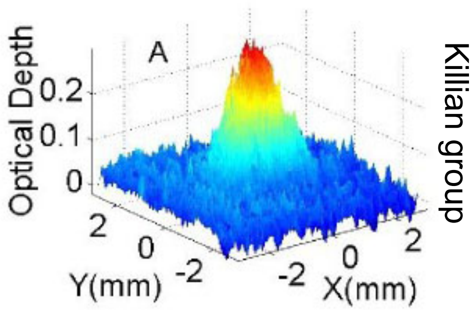
Ba 6pnl



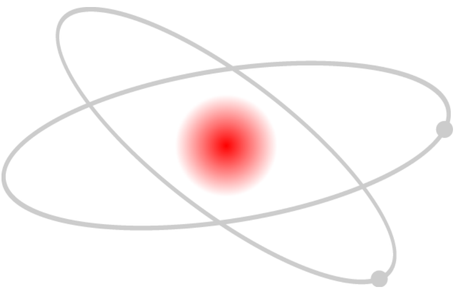
R. R. Jones *et al.*, PRA **41**, 316 (1990)

$$\Gamma_{\rm auto} < \Gamma_{\rm spont}$$

High I $\Gamma_{\text{auto}} < \Gamma_{\text{spont}}$

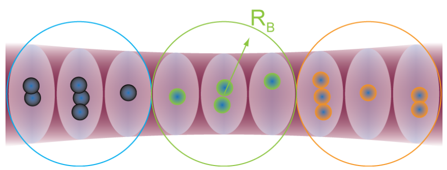


Imaging

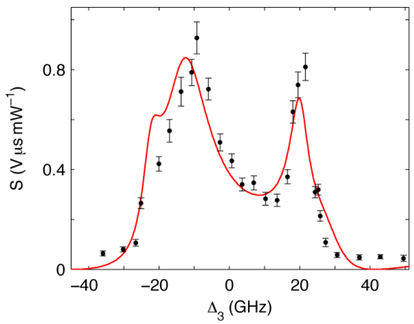


Planetary Rydbergs

Low I $\Gamma_{\text{auto}} > \Gamma_{\text{spont}}$

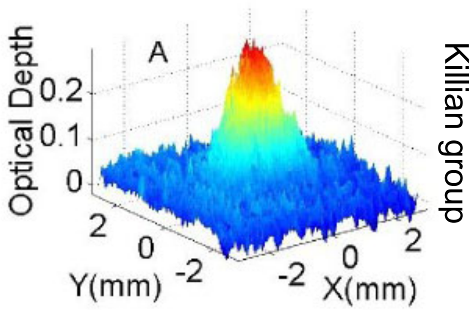


Optical traps

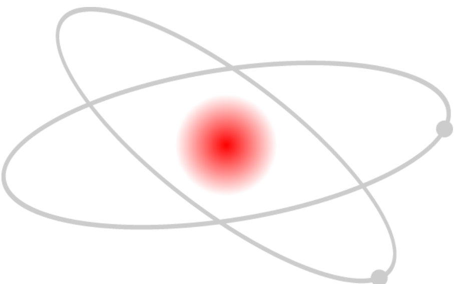


Probing Rydberg gases

High I $\Gamma_{\text{auto}} < \Gamma_{\text{spont}}$

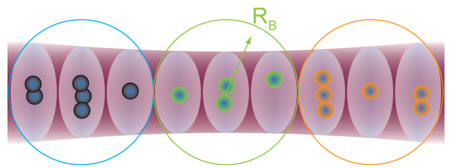


Imaging

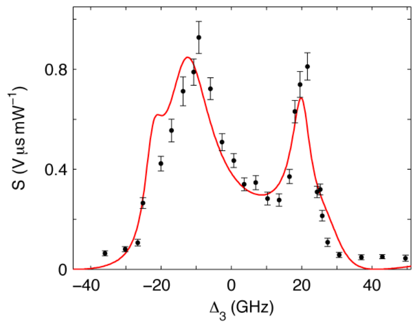


Planetary Rydbergs

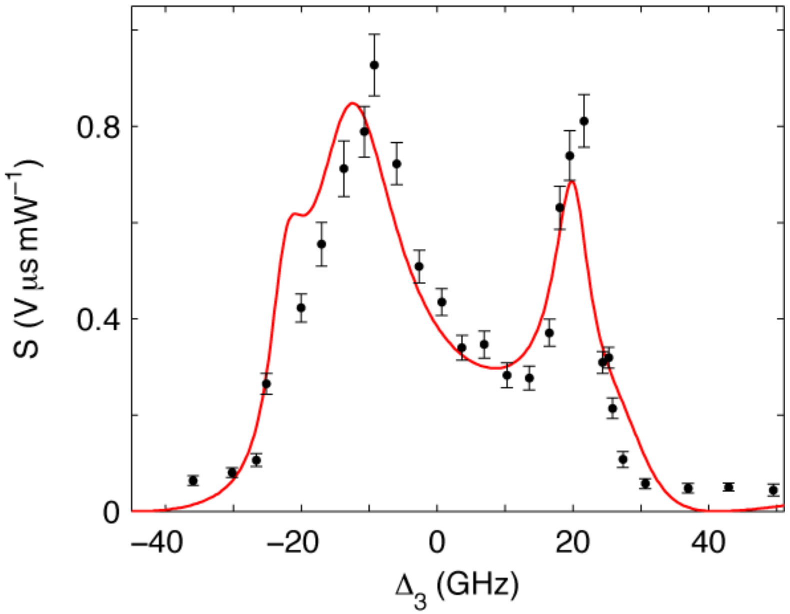
Low I $\Gamma_{\text{auto}} > \Gamma_{\text{spont}}$



Optical traps



Probing Rydberg gases

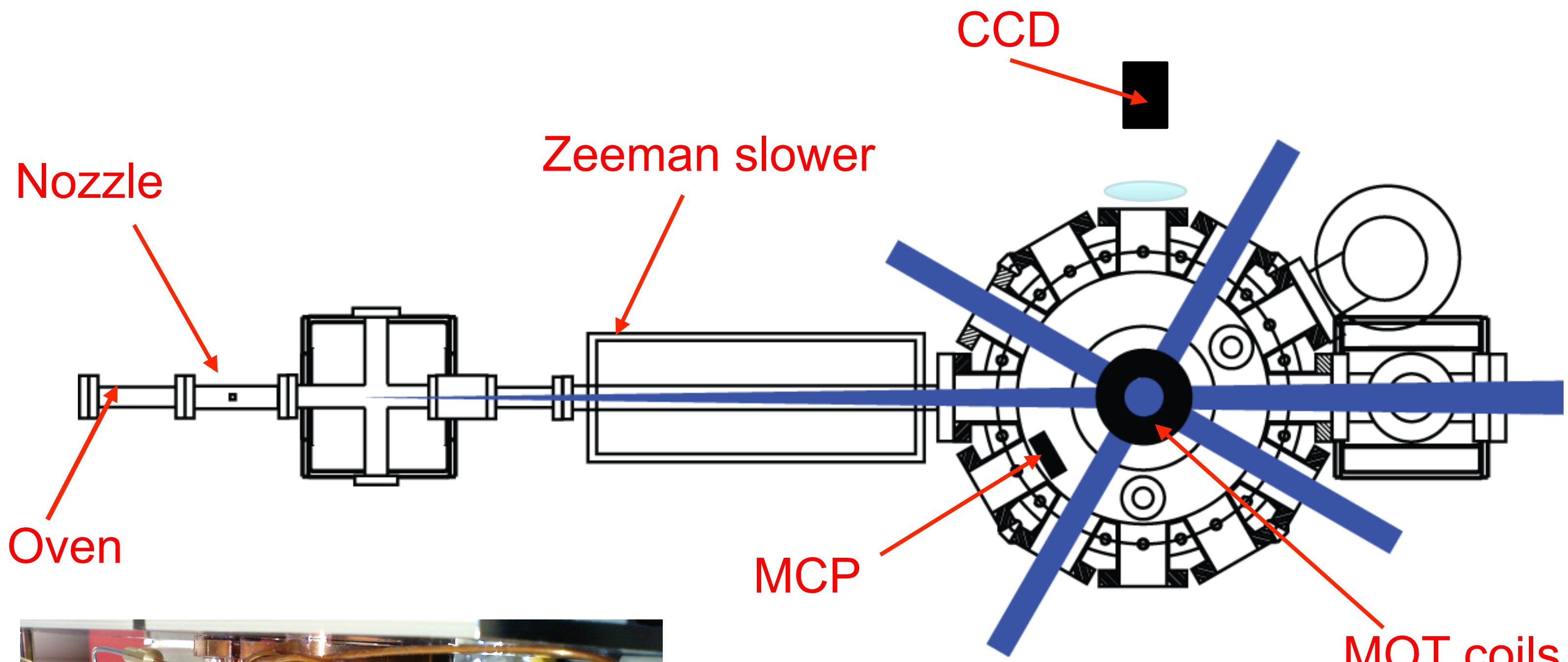


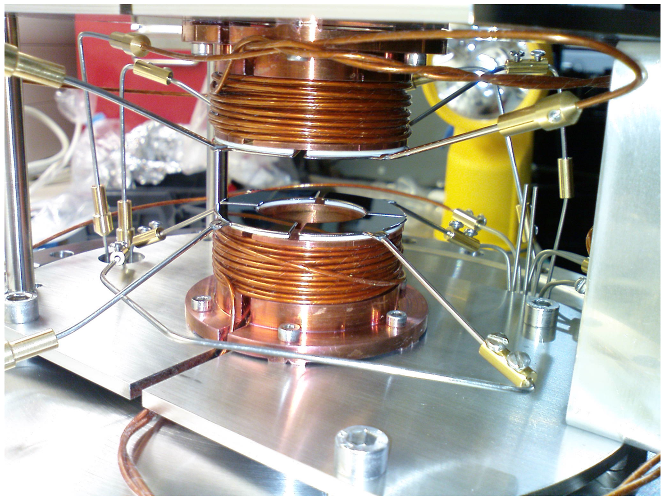
Probing a cold Rydberg gas using autoionization

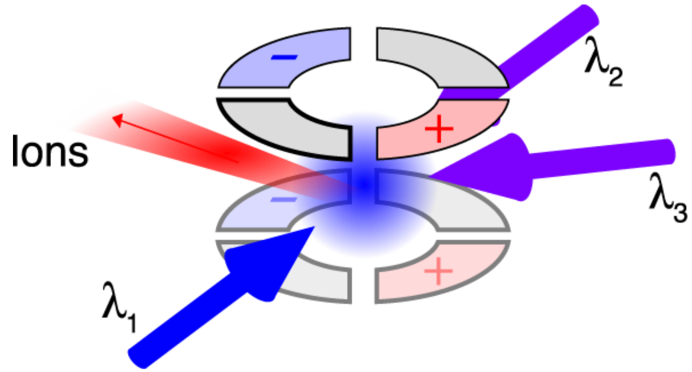
physics/1008.4512

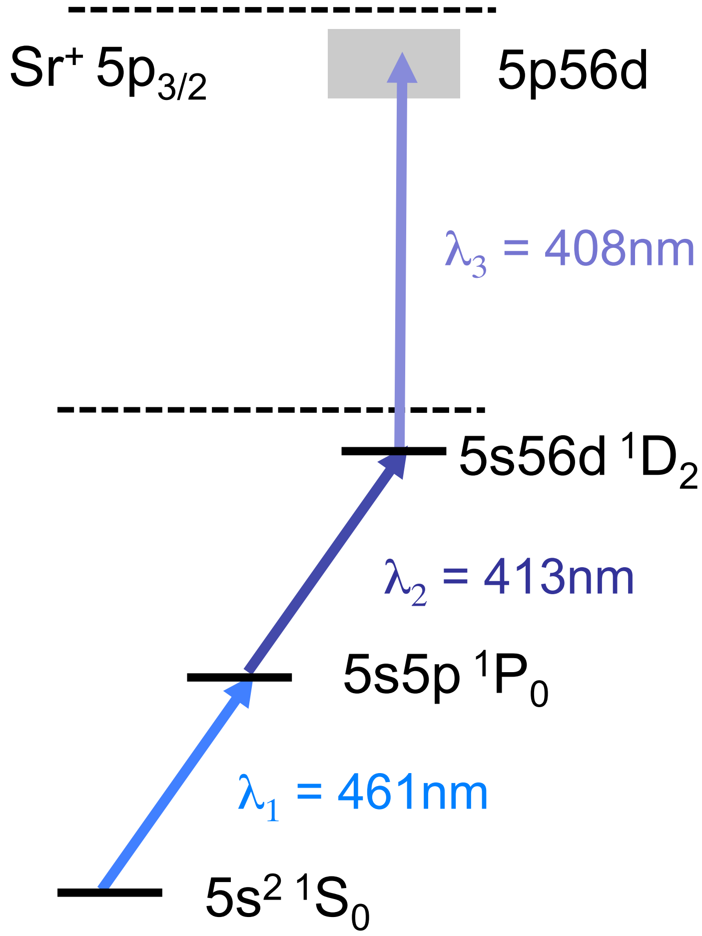
Also poster by James Millen & Graham Lochead

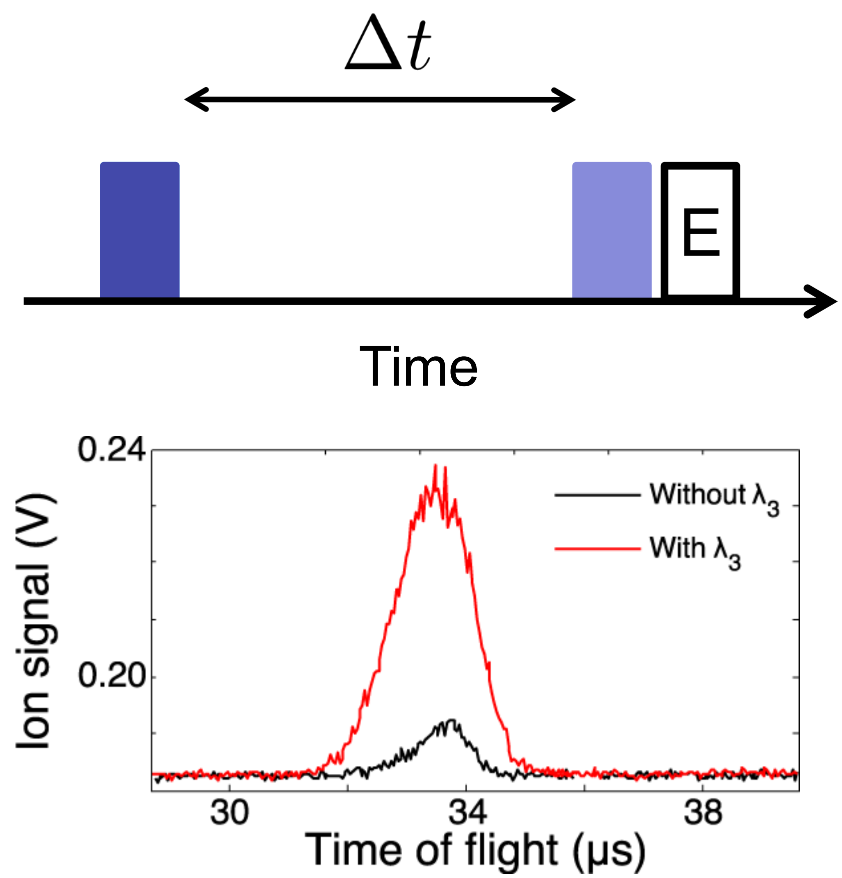
Making a cold strontium Rydberg gas





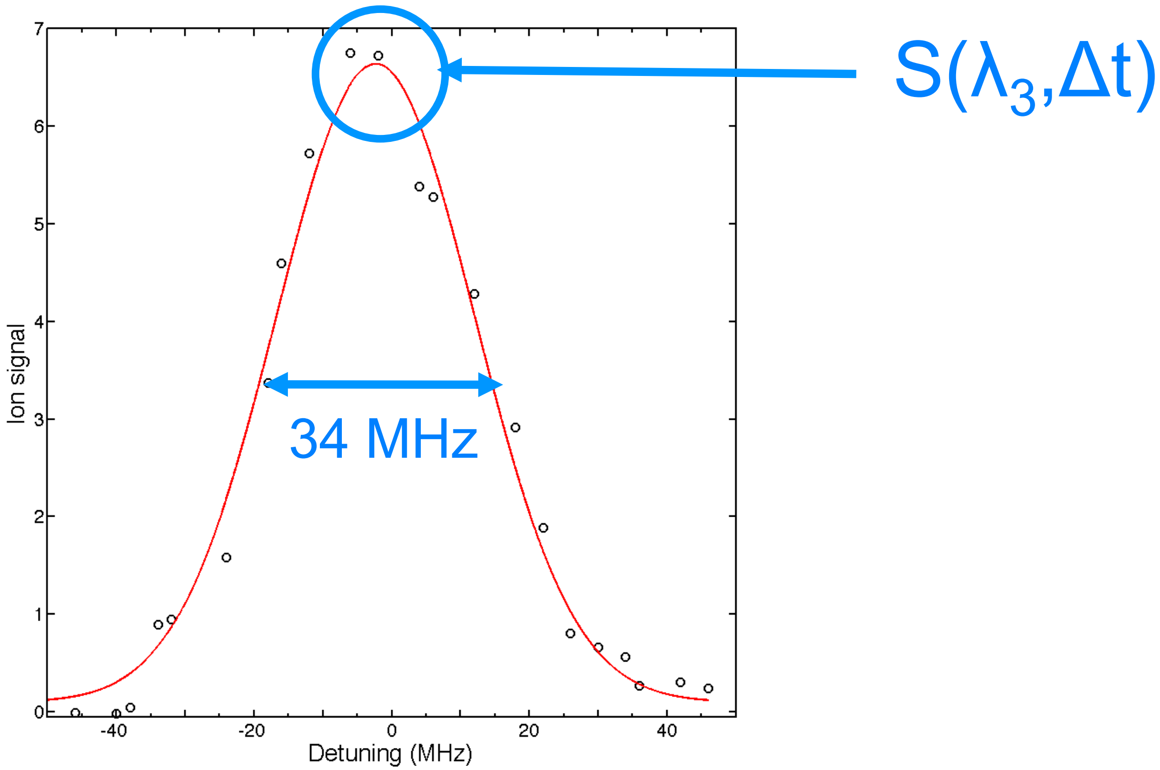






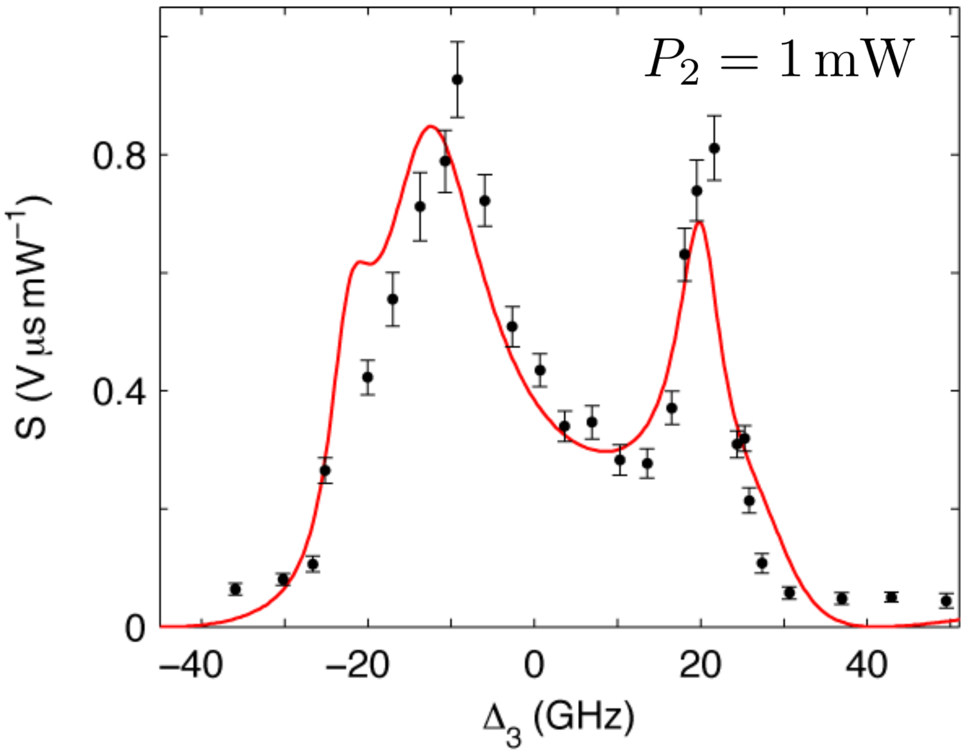
Vary λ_3 and Δt

Variation with λ_2 (413nm)



The low density autoionization spectrum

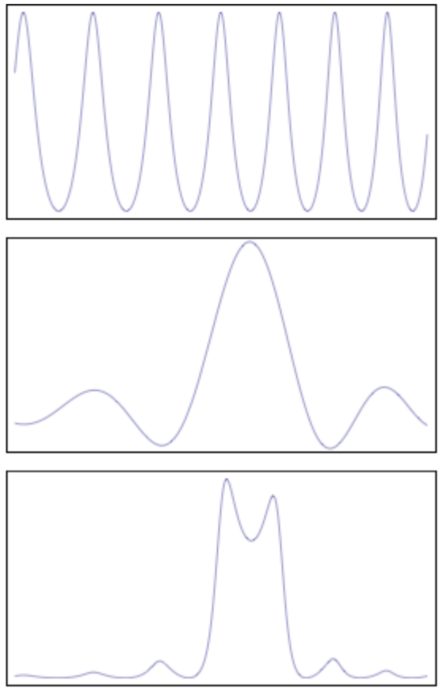
$$\Delta t = 0.5\,\mu\mathrm{s}$$



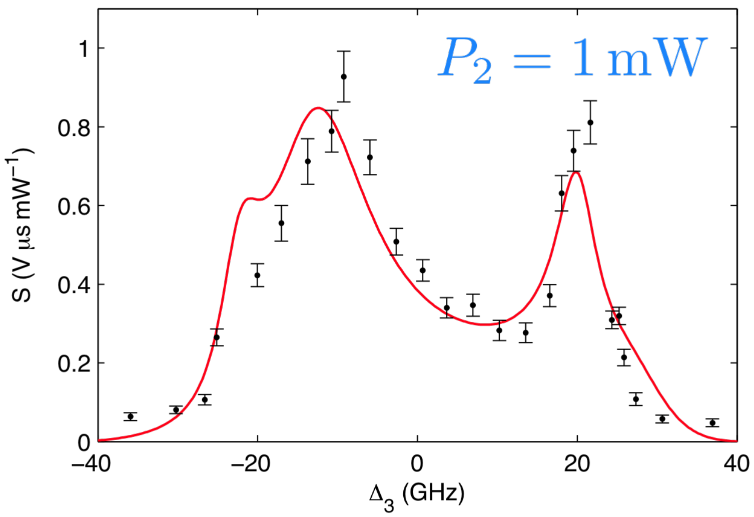
$$\Delta_3 = \lambda_3 - \lambda_{\mathrm{ion}}$$

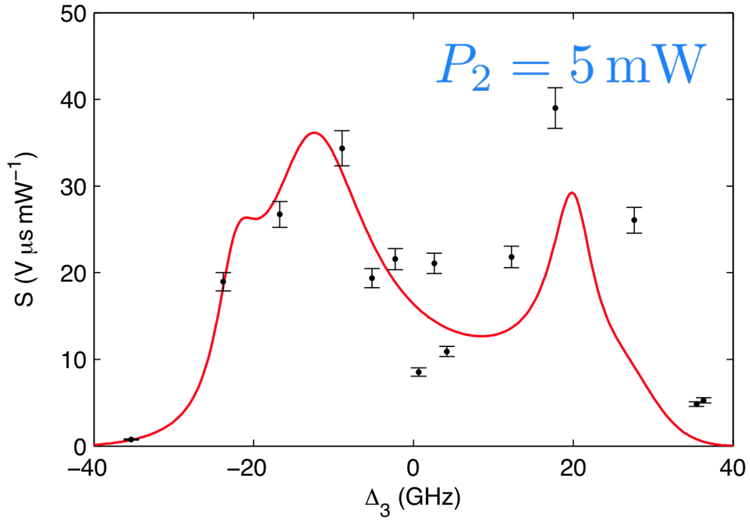
Fit is 6-channel MQDT for 5snd states

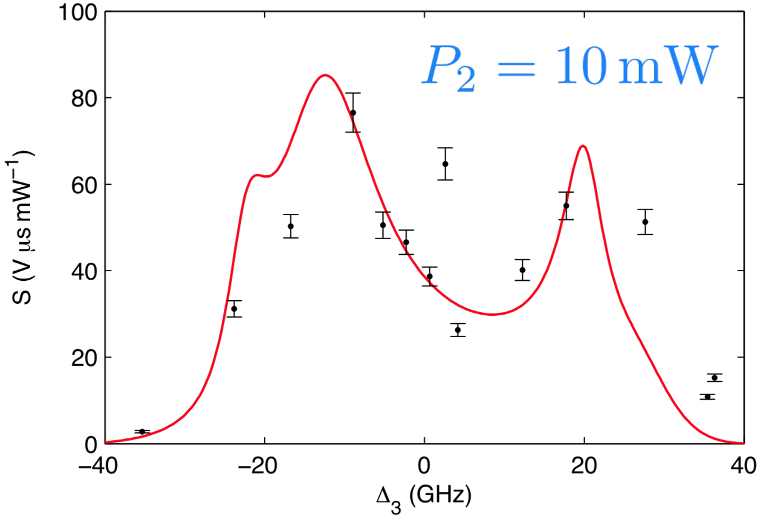
(Xu et al., PRA **35**, 1138 (1987))



Increasing the Rydberg density

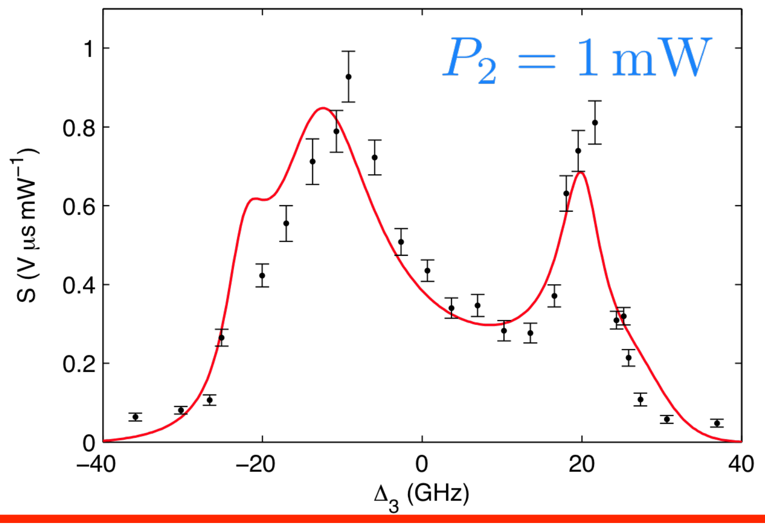


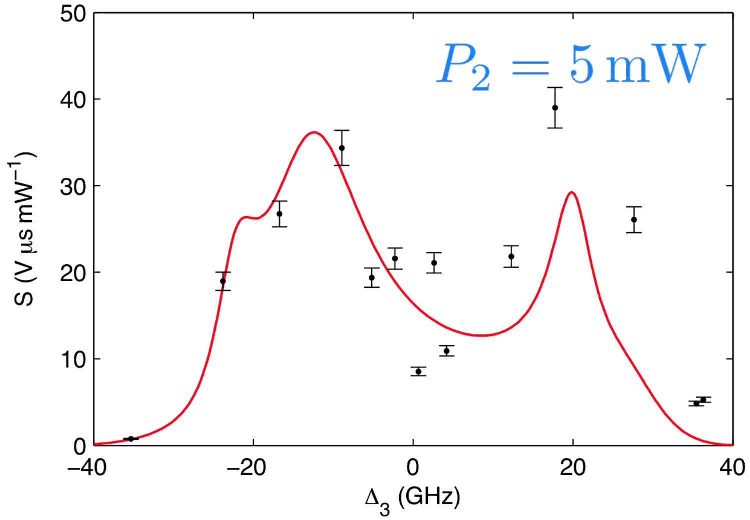


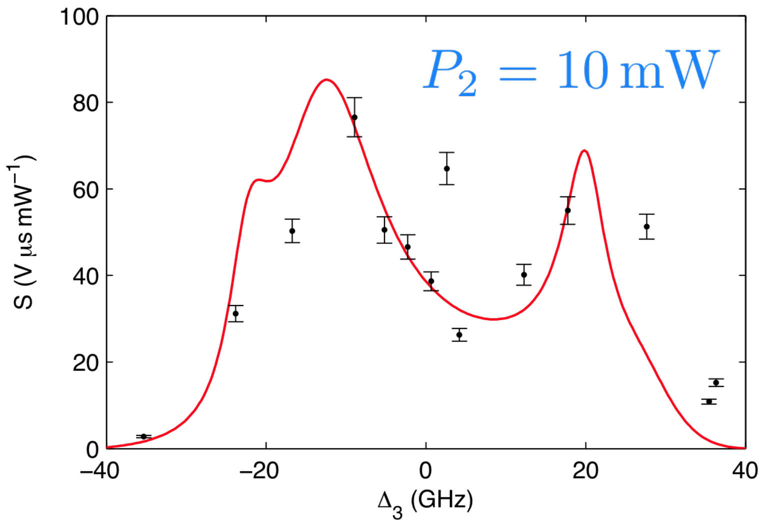


$$\Delta t = 0.5\,\mu\mathrm{s}$$

Increasing the Rydberg density







Increasing the delay

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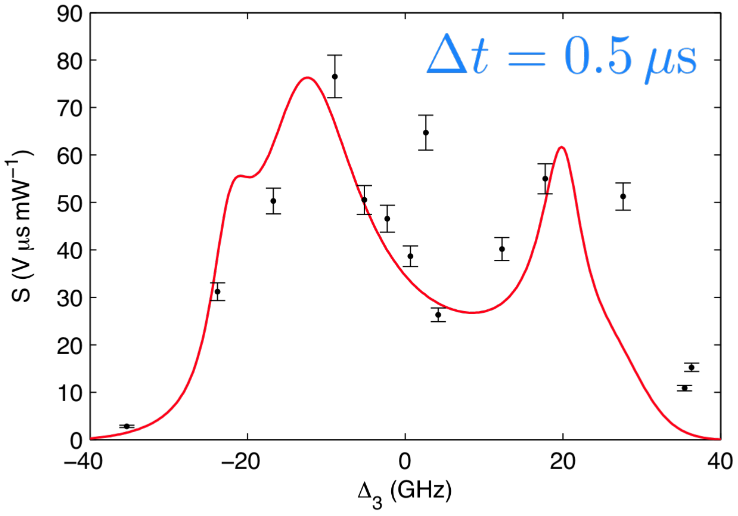

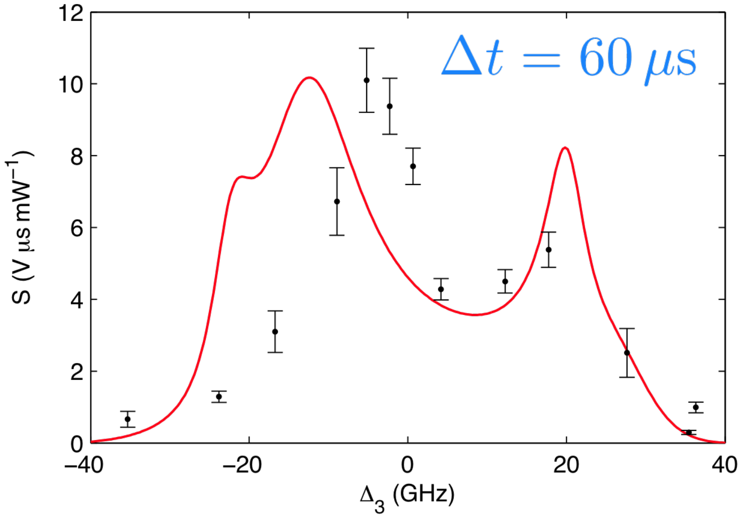

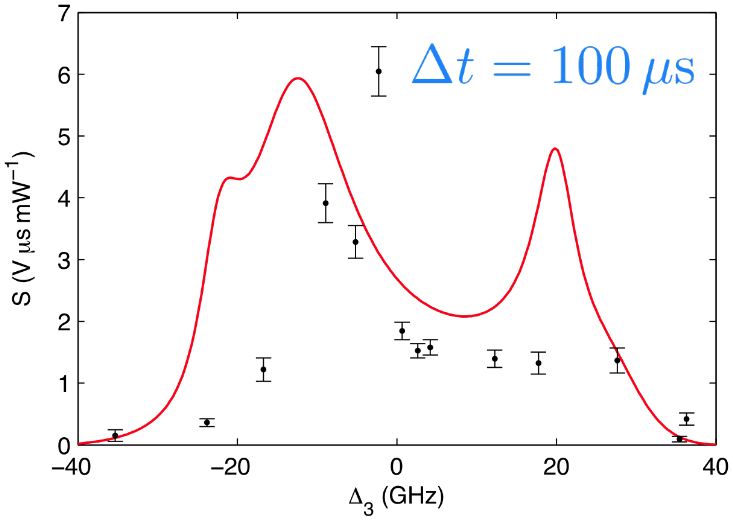

Narrow peak ≠ 5s56d

Decay of the autoionization signal

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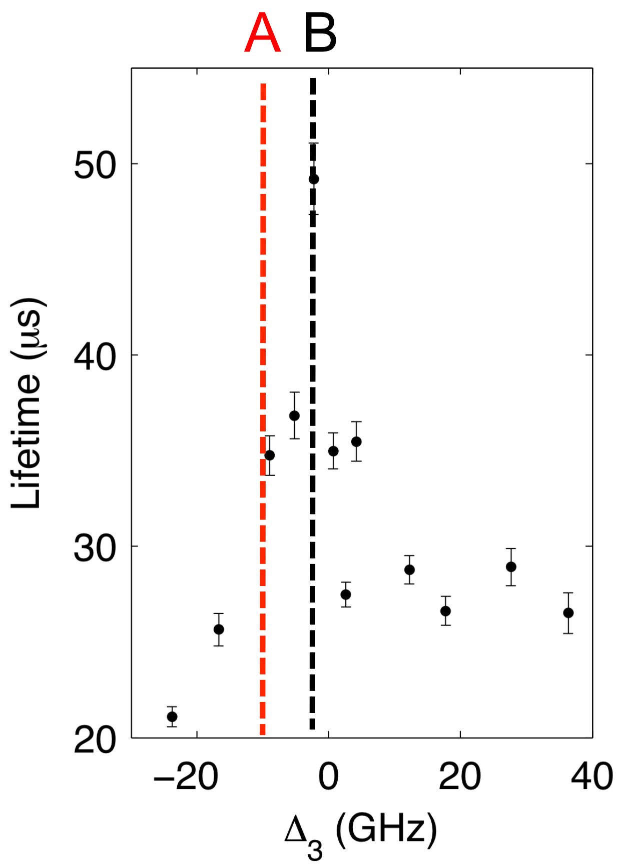
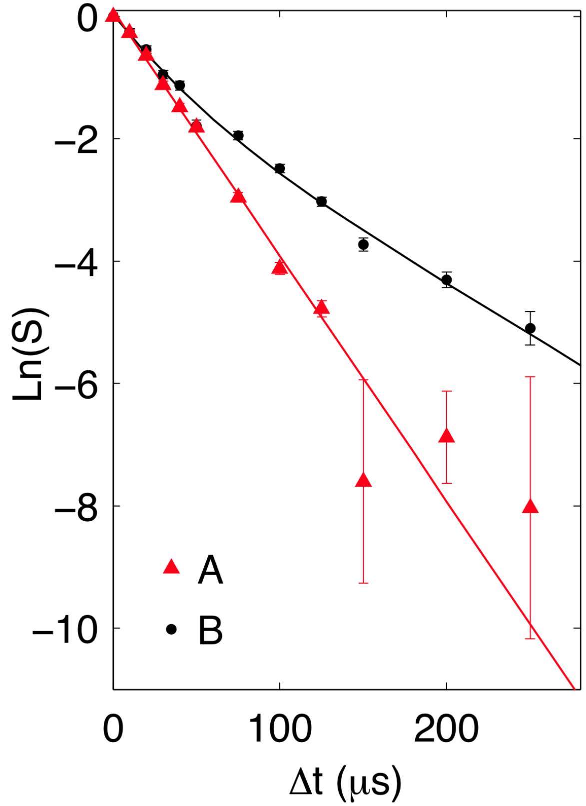




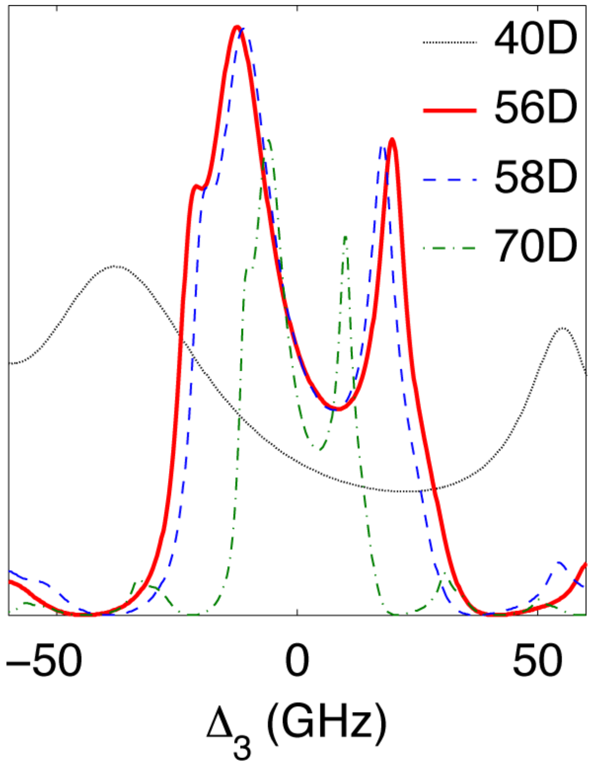
$$\tau_{56\mathrm{D}} = 25.0 \pm 0.5\,\mu\mathrm{s}$$

$$\tau_1 = 24 \pm 4\,\mu\mathrm{s}$$

$$\tau_2 = 60 \pm 7\,\mu\mathrm{s}$$

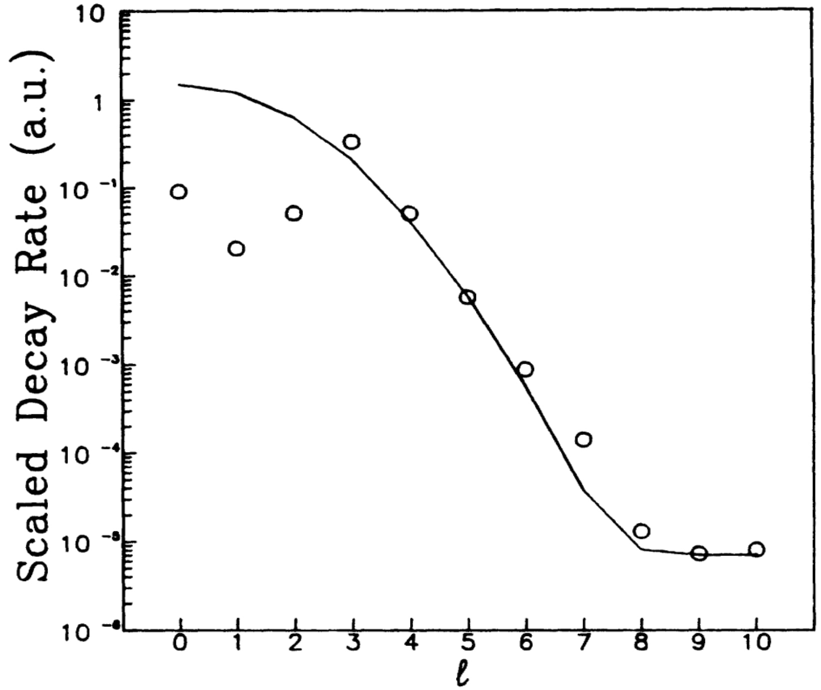
- State(s) populated
- Amount of population transfer
- Mechanism(s)

Sr 5pnd



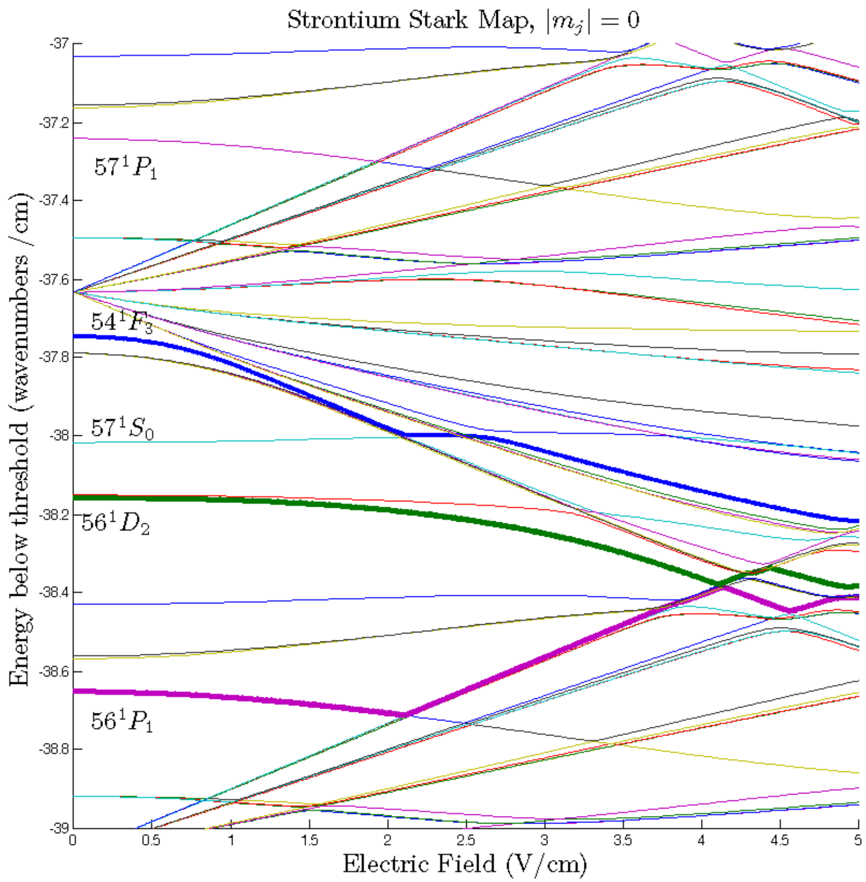
$$\Gamma_{\text{auto}}, \tau \propto n^{*-3}$$

Ba 6pnl



R. R. Jones *et al.*, PRA **41**, 316 (1990)

Dipole-coupled states

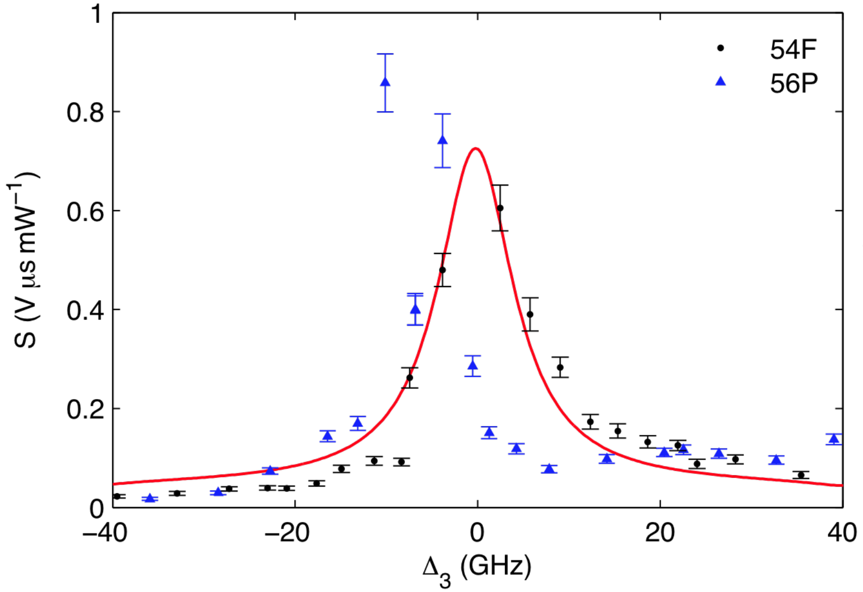


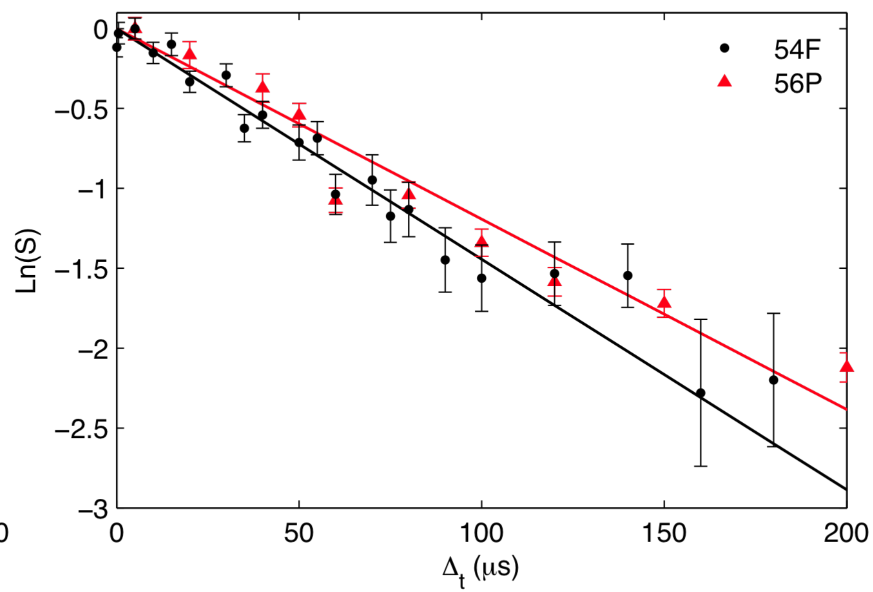
Nearest states:

5s56p $^1P_1$ and 5s54f $^1F_3$

Förster defect = -2.5 GHz

Dipole coupled states



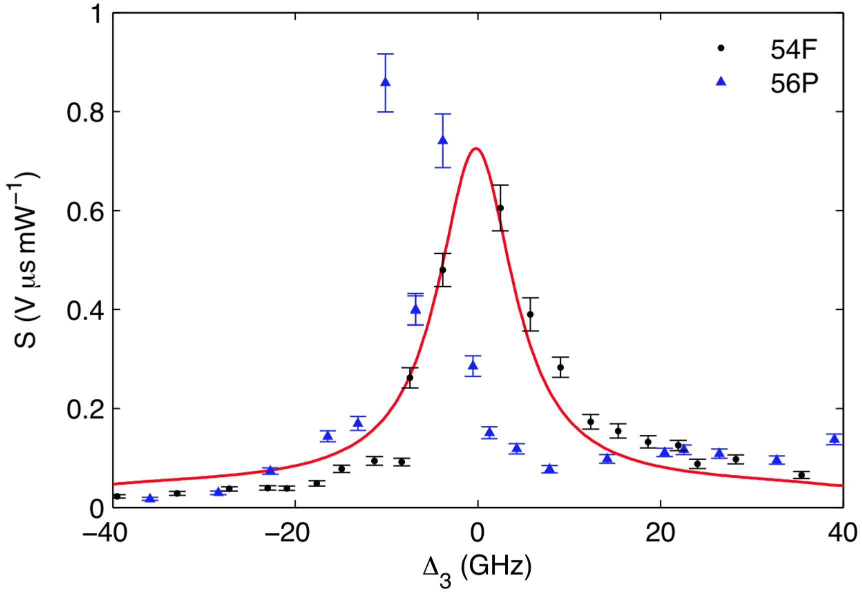


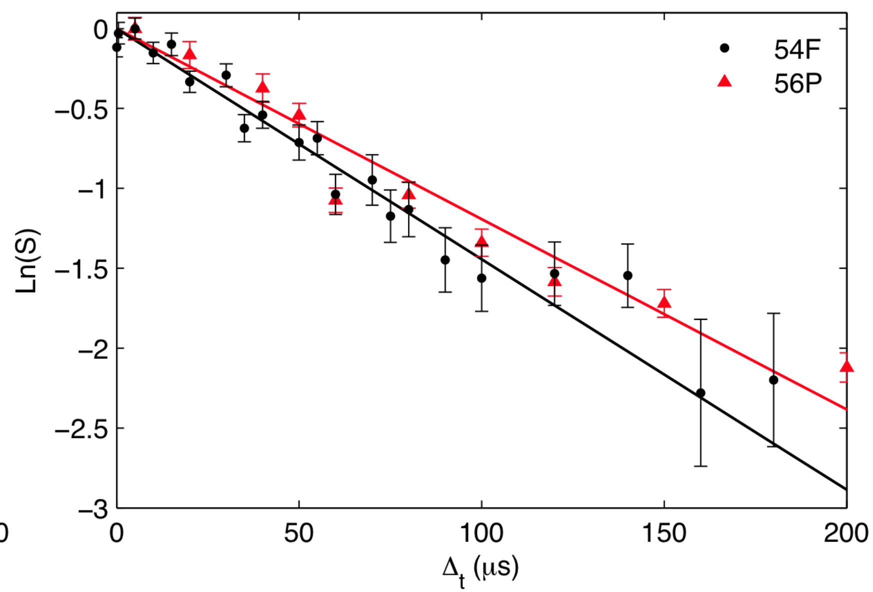
2-channel MQDT fit

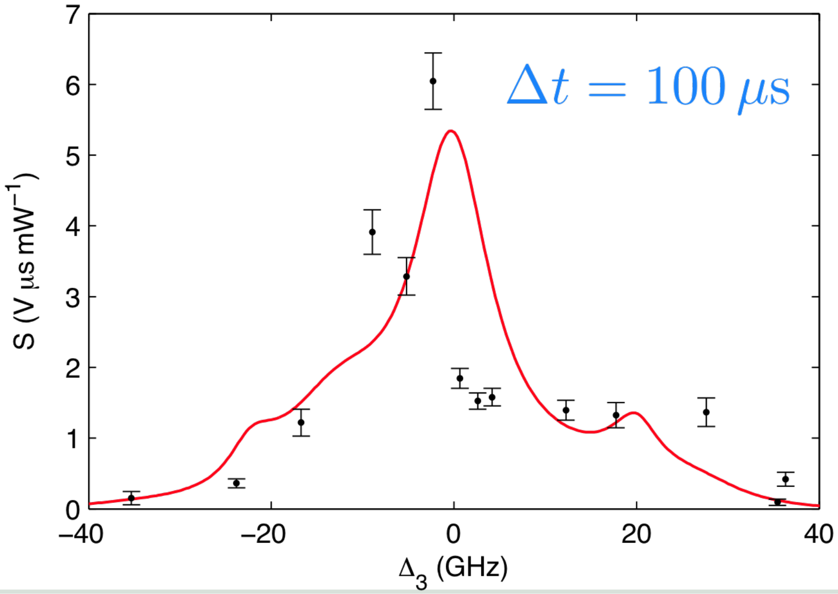
$$\tau_{54\mathrm{F}} = 64 \pm 4\,\mu\mathrm{s}$$

$$\tau_{56\mathrm{P}} = 84 \pm 2\,\mu\mathrm{s}$$

Dipole coupled states







$$\tau_{54F} = 64 \pm 4\ \mu s$$

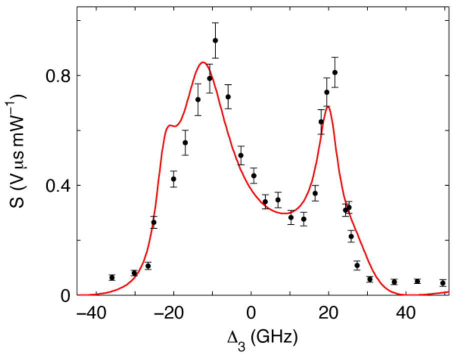
$$\tau_{56P} = 84 \pm 2\ \mu s$$

$$\tau_2 = 60 \pm 7\ \mu s$$

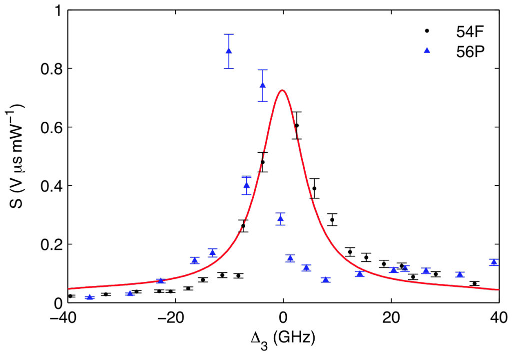
Population transfer

- State(s) populated mainly $5s54f\ ^1F_3$
- Amount of population transfer
- Mechanism(s)

Quantitative analysis



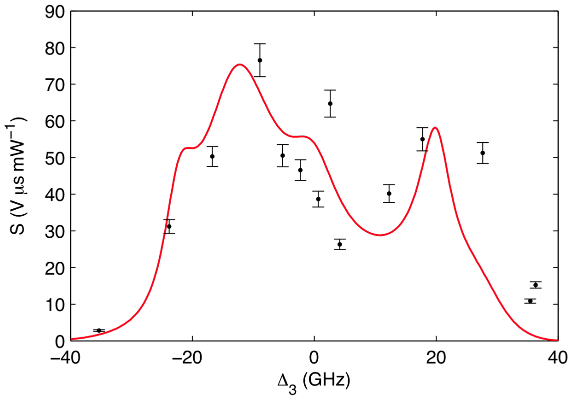
56D 6-channel MQDT



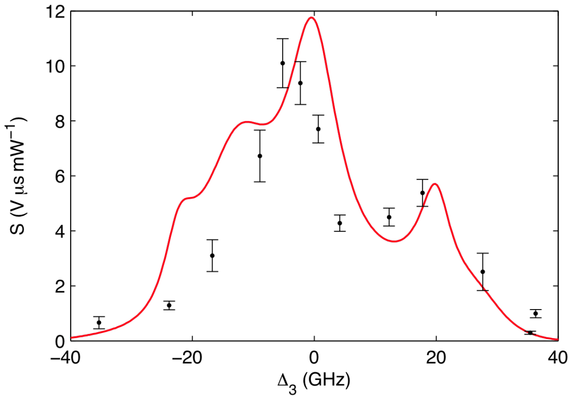
54F 2-channel MQDT

$\tau_{56\mathrm{D}}, \tau_{54\mathrm{F}}$

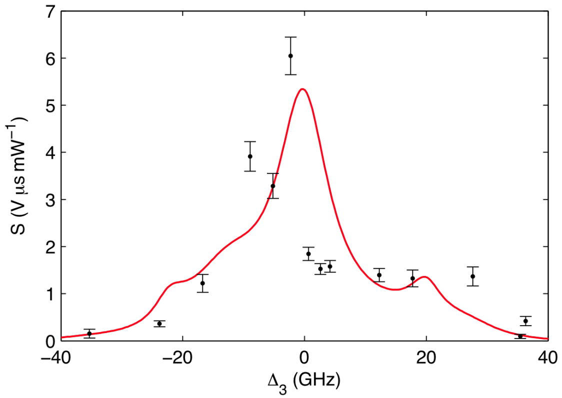
Measured lifetimes



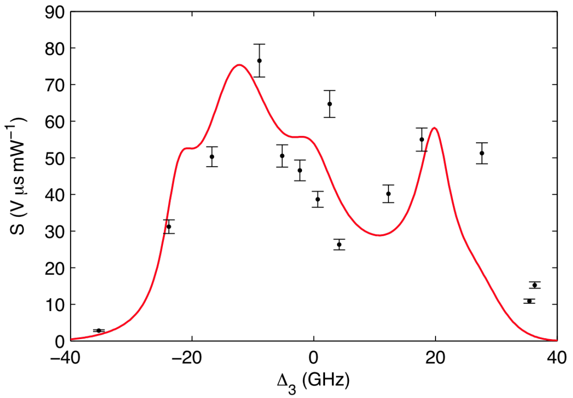
$\Delta t = 0.5\,\mu s$



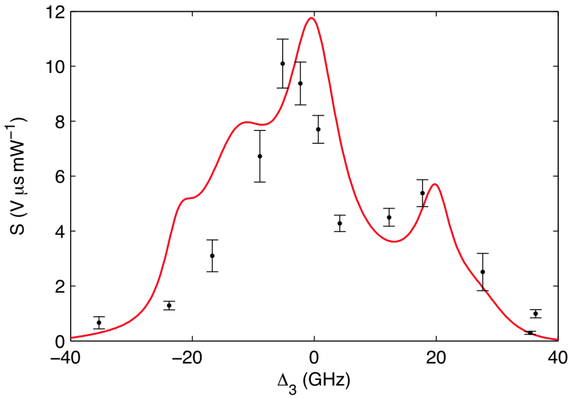
$\Delta t = 60\,\mu s$



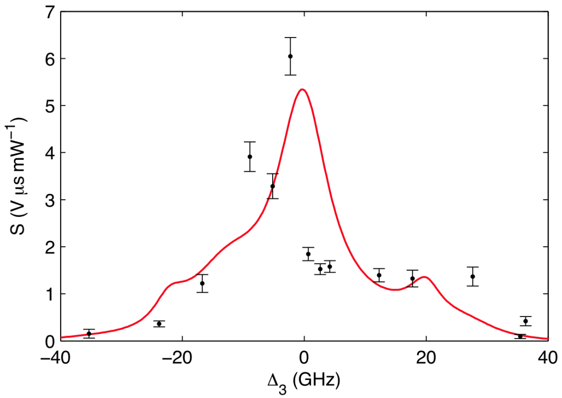
$\Delta t = 100\,\mu s$



$\Delta t = 0.5\ \mu s$



$\Delta t = 60\ \mu s$



$\Delta t = 100\ \mu s$

$$\frac{N_F}{N_D} = \frac{\sigma_D}{\sigma_F}(\lambda_3)\,\frac{S_F}{S_D}(\lambda_3)$$

13±3% of the Rydberg atoms are transferred

- State(s) populated mainly 5s54f $^1F_3$
- Amount of population transfer 13±3%
- Mechanism(s)

Mechanisms

- ~~Black body~~
- ~~Superradiance~~
- Stark mixing due to ions
- Dipole-dipole interactions
- l-changing electron-Rydberg collisions

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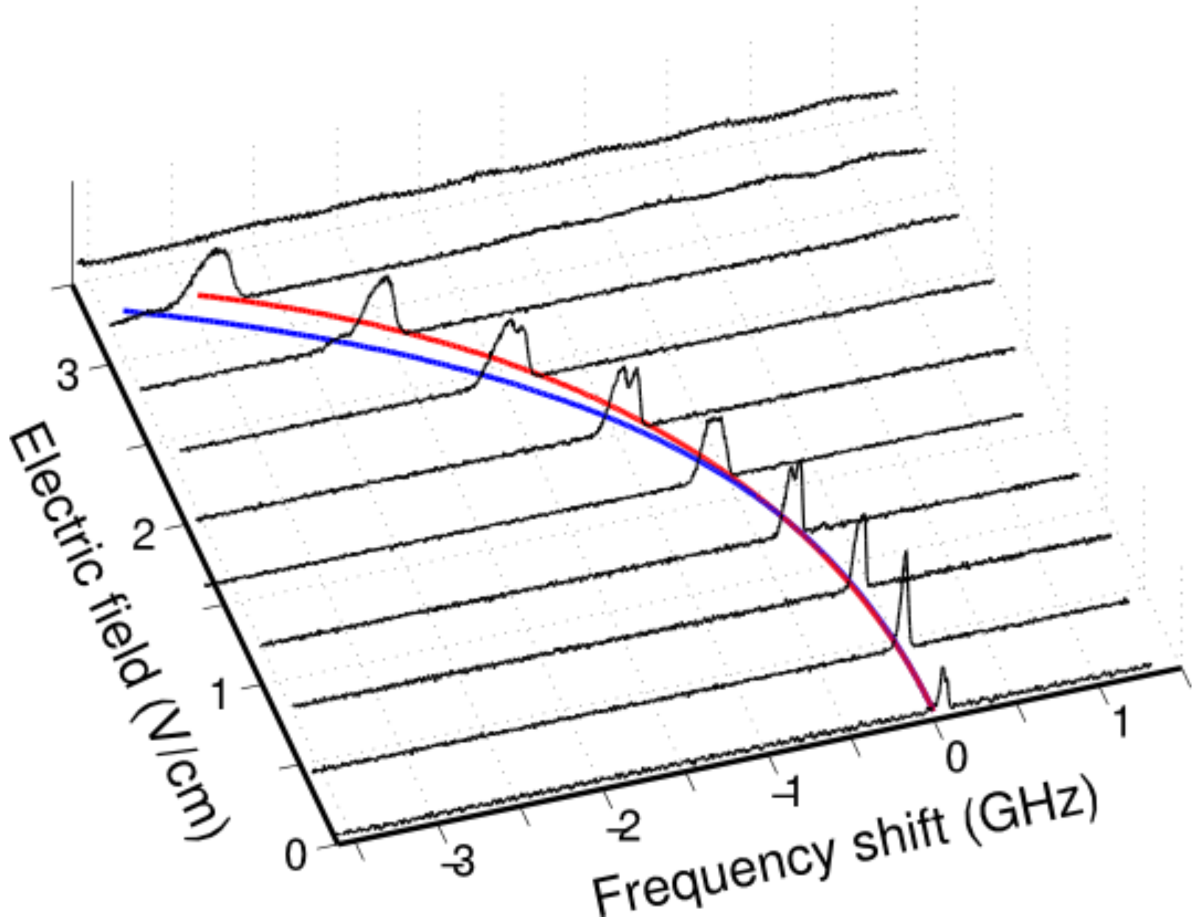
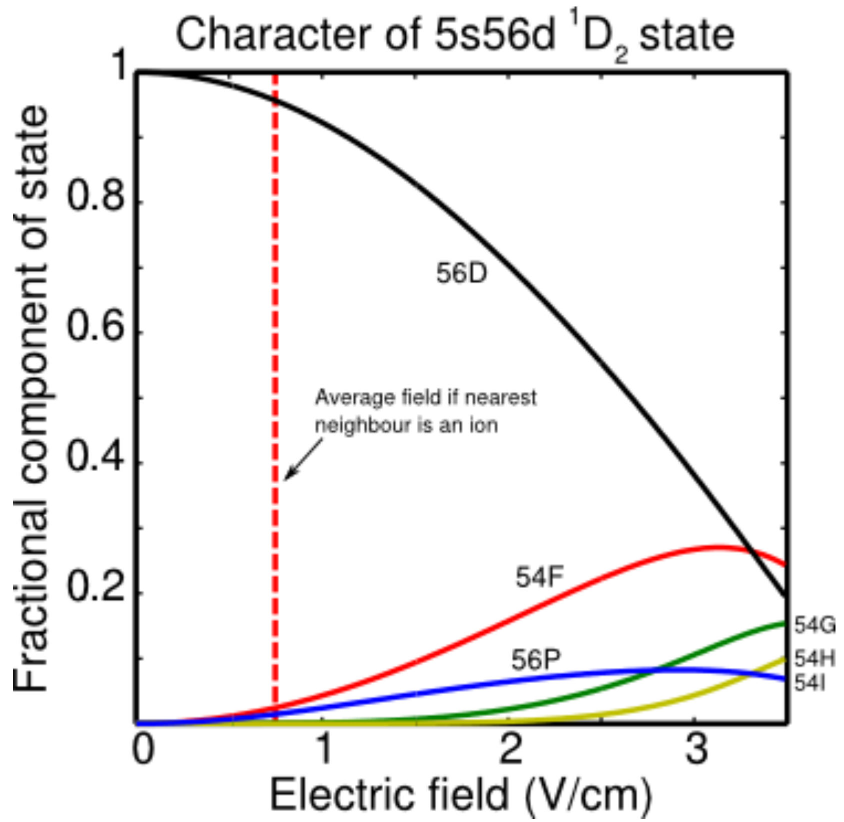


Calculations assume no singlet-triplet mixing

Stark mixing



Rydberg fraction ~10%

$$\Rightarrow \quad \bar{r}_{12} \sim 4.4\,\mu\mathrm{m}$$

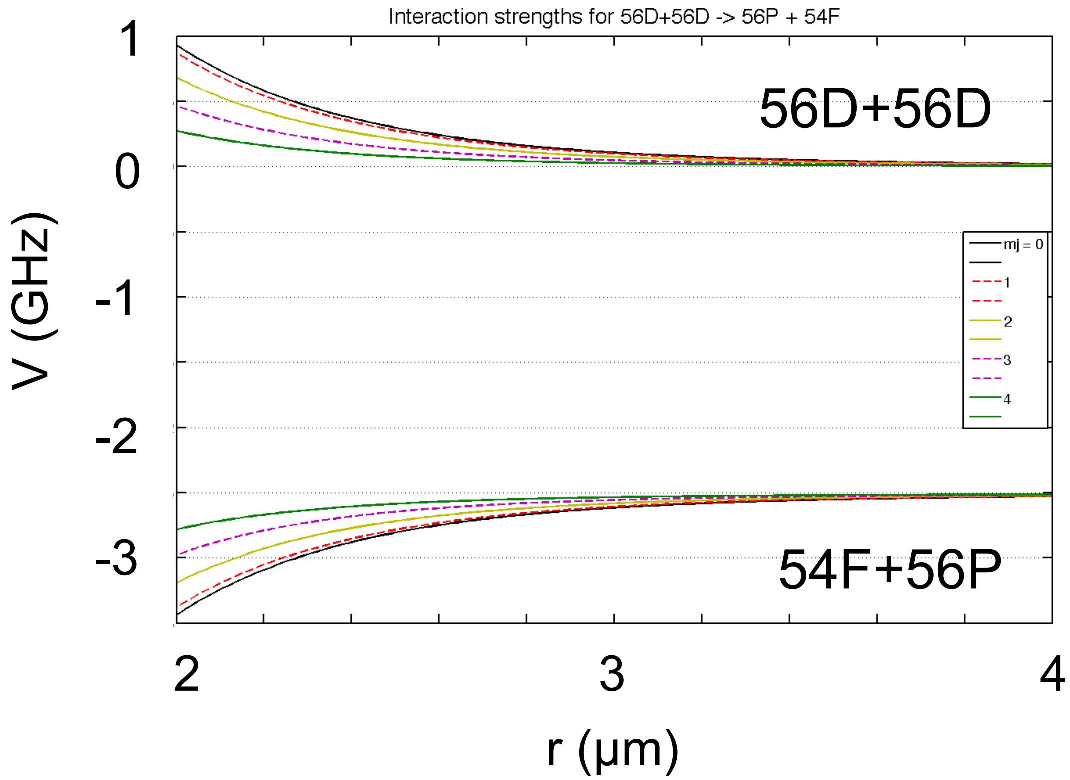
$$E\left(\bar{r}_{12}\right) \sim 0.7\,\mathrm{V cm}^{-1}$$

BUT: only 1% ionization

Mechanisms

- ~~Black body~~
- ~~Superradiance~~
- ~~Stark mixing~~ due to ions
- Dipole-dipole interactions
- l-changing electron-Rydberg collisions

$$5s56d\,^1D_2 + 5s56d\,^1D_2 \rightarrow 5s56p\,^1P_1 + 5s54f\,^1F_3$$



Förster defect = -2.5 GHz

$$c_6 = 85\ \mathrm{GHz}\,\mu\mathrm{m}^6$$

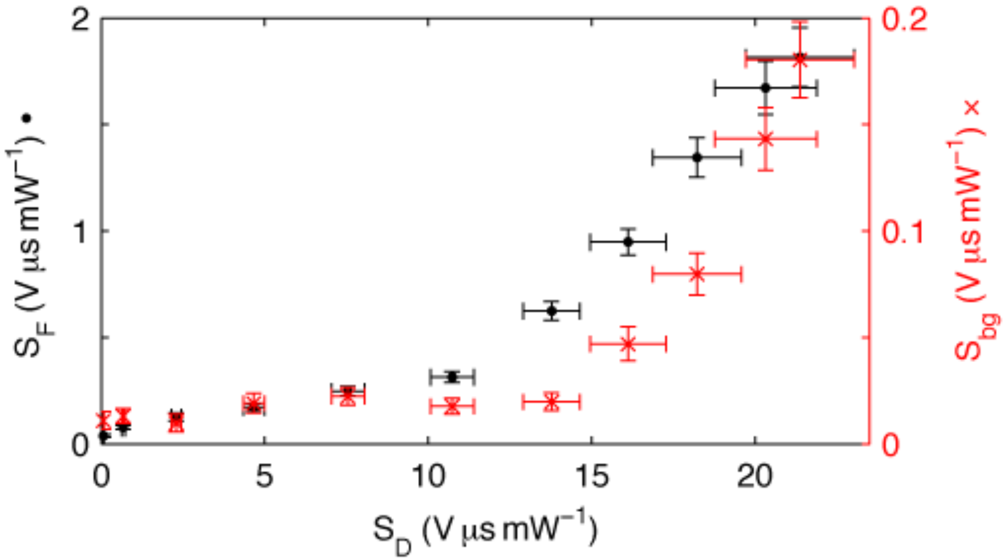
$$\bar{r} \sim 4.4\,\mu\mathrm{m}$$

Mechanisms

- ~~Black body~~
- ~~Superradiance~~
- ~~Stark mixing~~ due to ions
- ~~Dipole-dipole~~ interactions
- l-changing electron-Rydberg collisions

l-transfer associated with cold plasma formation

S. K. Dutta et al., PRL **86**, 3993 (2001)
A. Walz-Flannigan et al., **69**, 063405 (2004)



~1000 ions required for plasma to form

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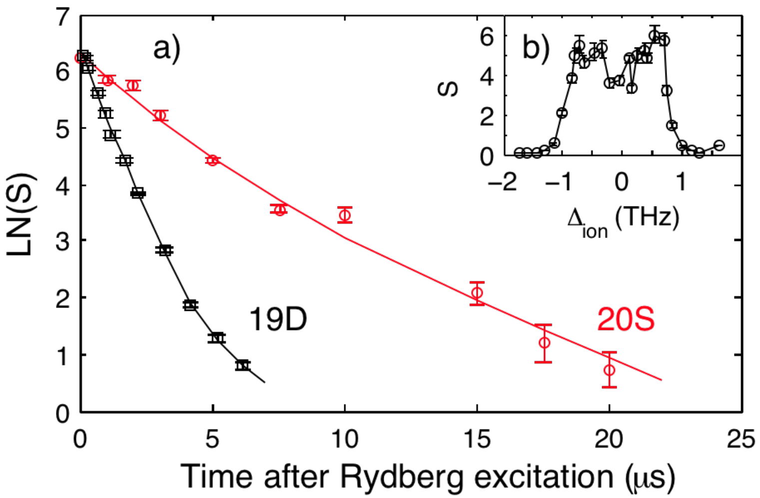
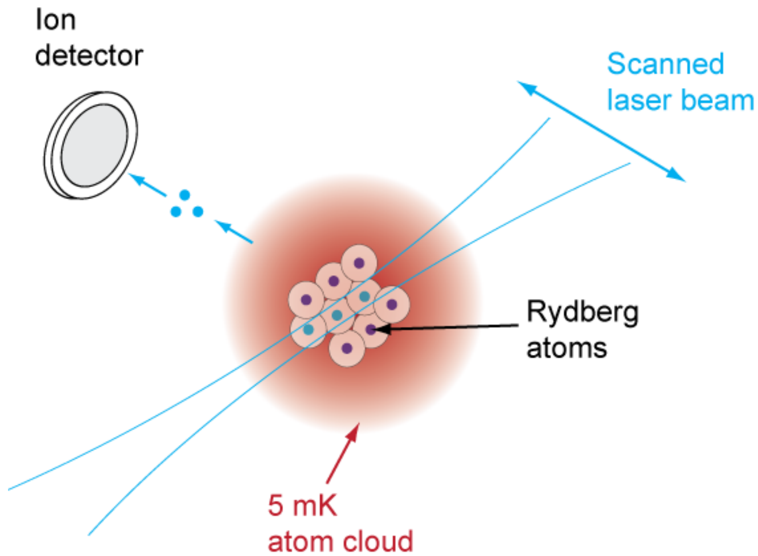
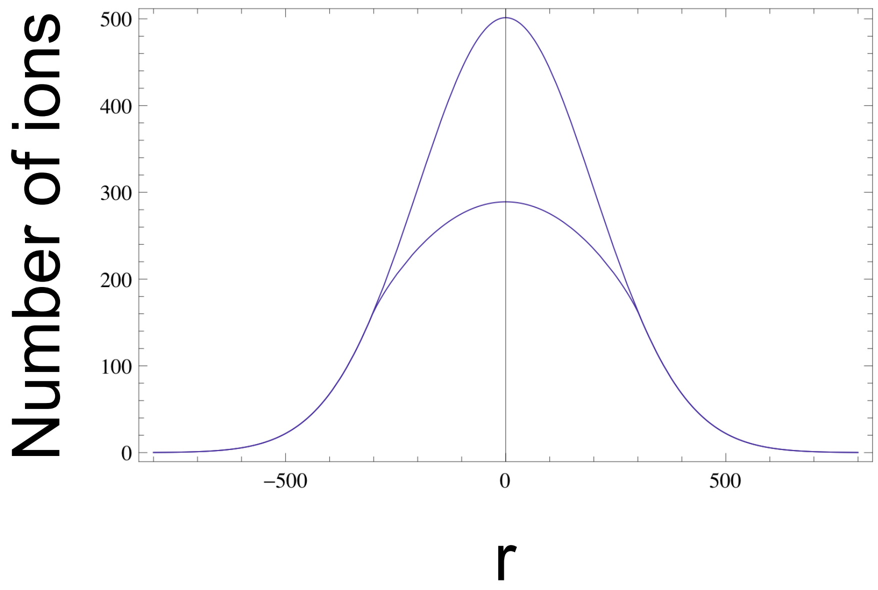
- State(s) populated mainly $5s54f\ ^1F_3$
- Amount of population transfer 13±3%
- Mechanism(s) mainly l-changing e^--Rydberg

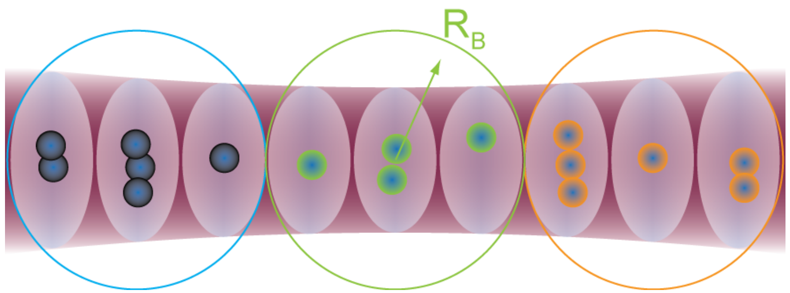




Temporal resolution

Spatial resolution





Spatial distribution
Correlations

Trapped Rydberg lattices

The End

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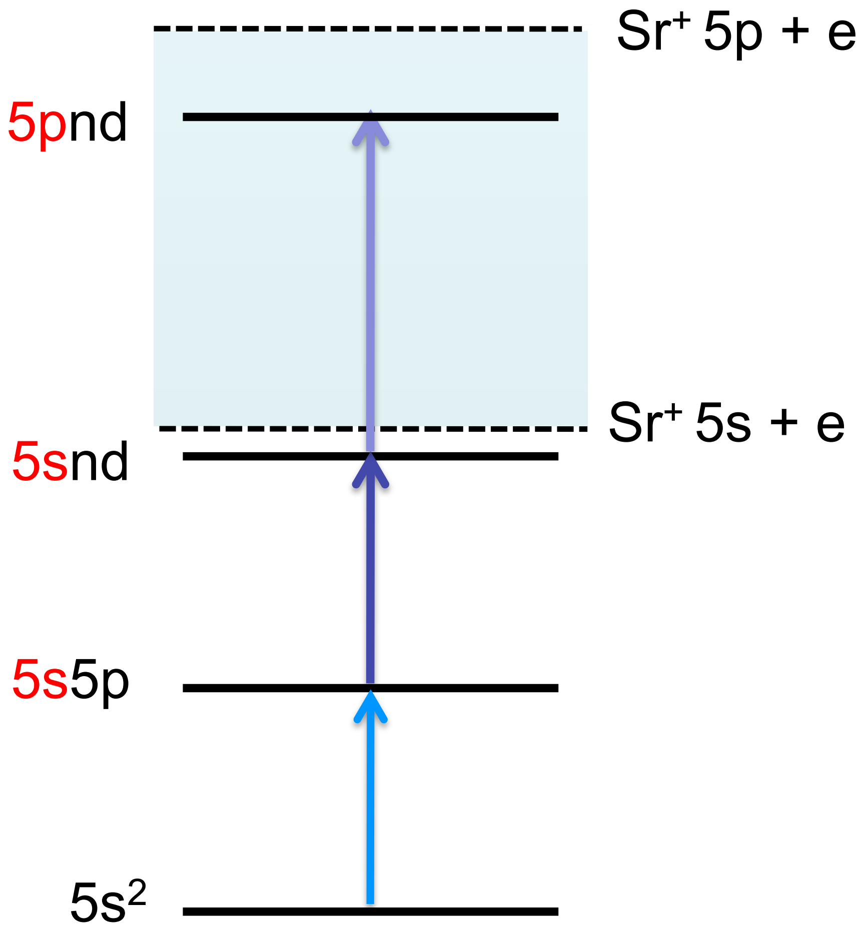
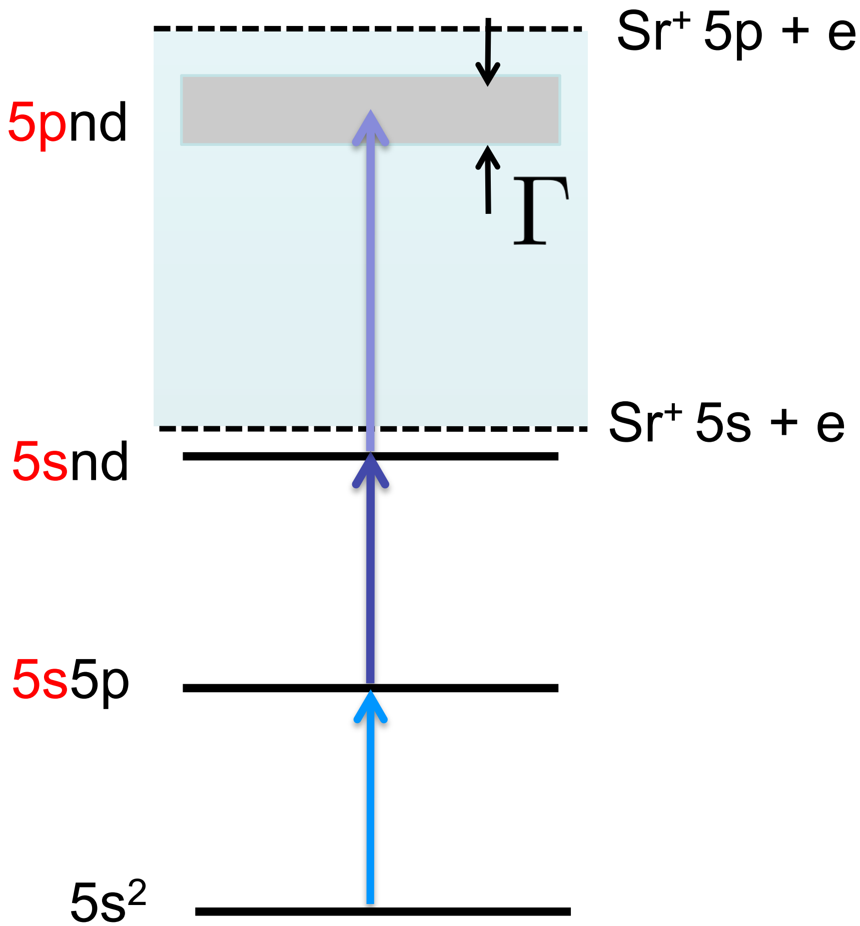


$$H' = \frac{1}{r_{12}}$$

couples to continuum

Isolated core excitation



$$H' = \frac{1}{r_{12}}$$

couples to continuum