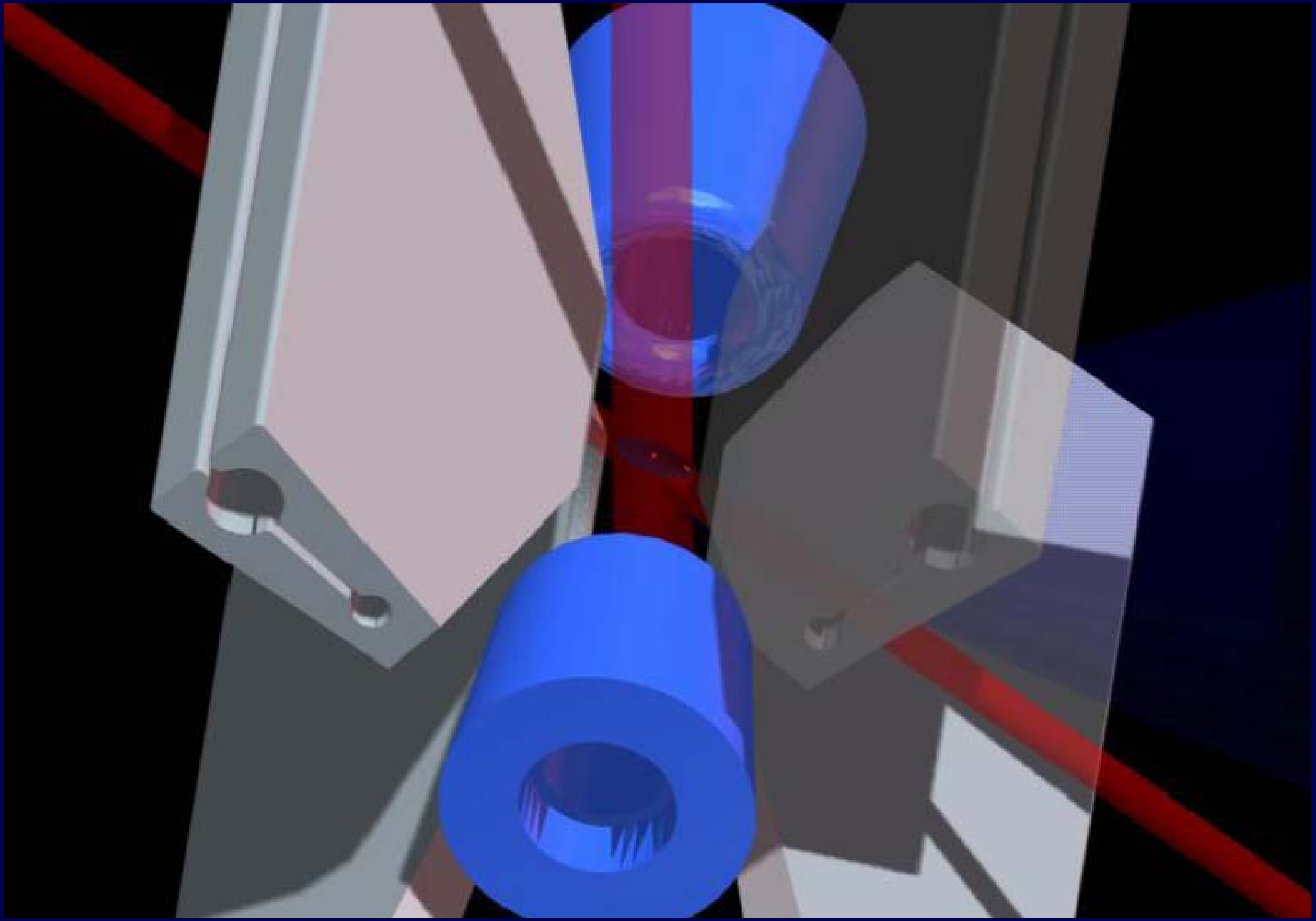
SFB/ TRR21

# Investigating three-body recombination in an ion trap

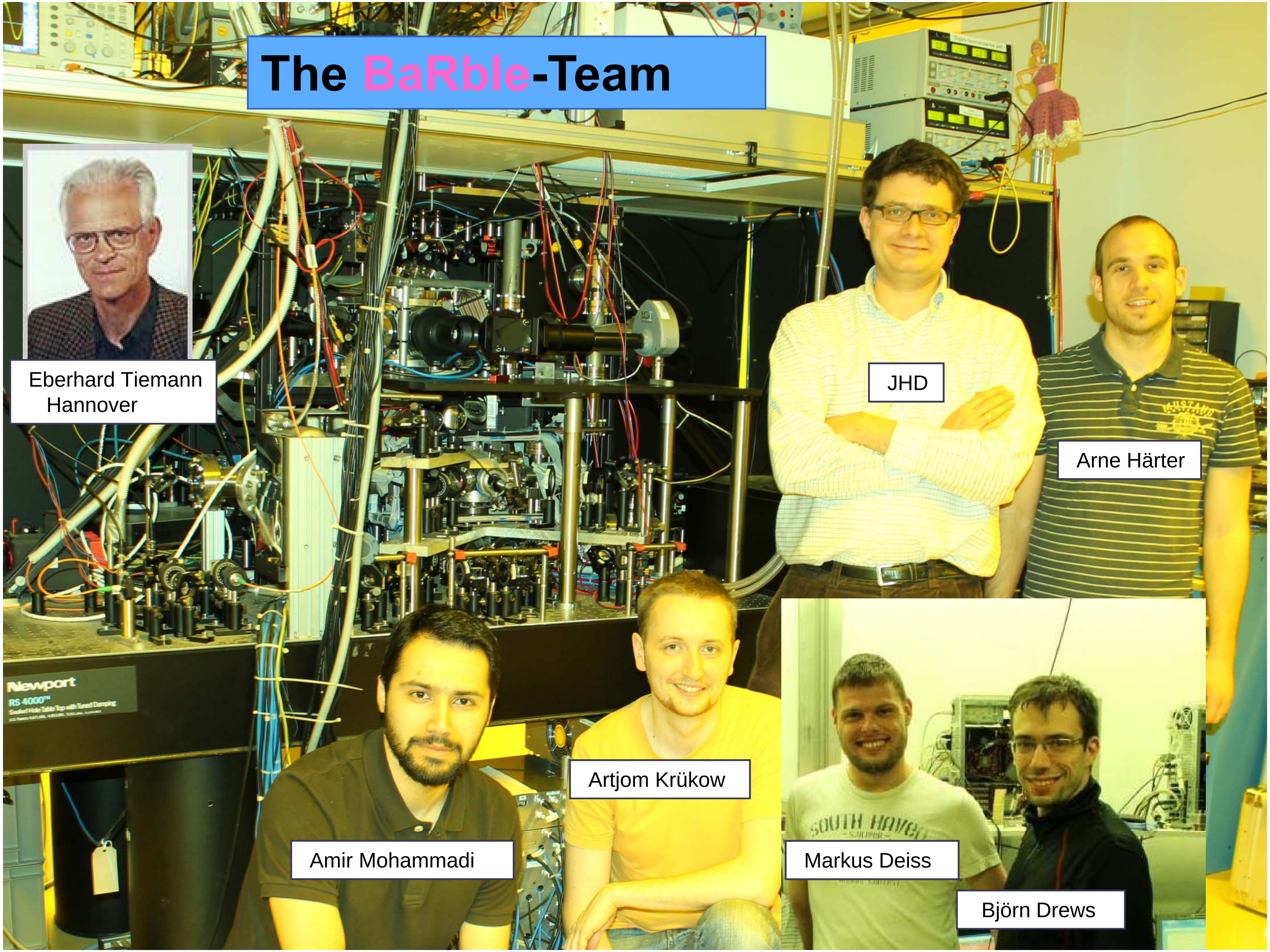


Johannes Hecker Denschlag

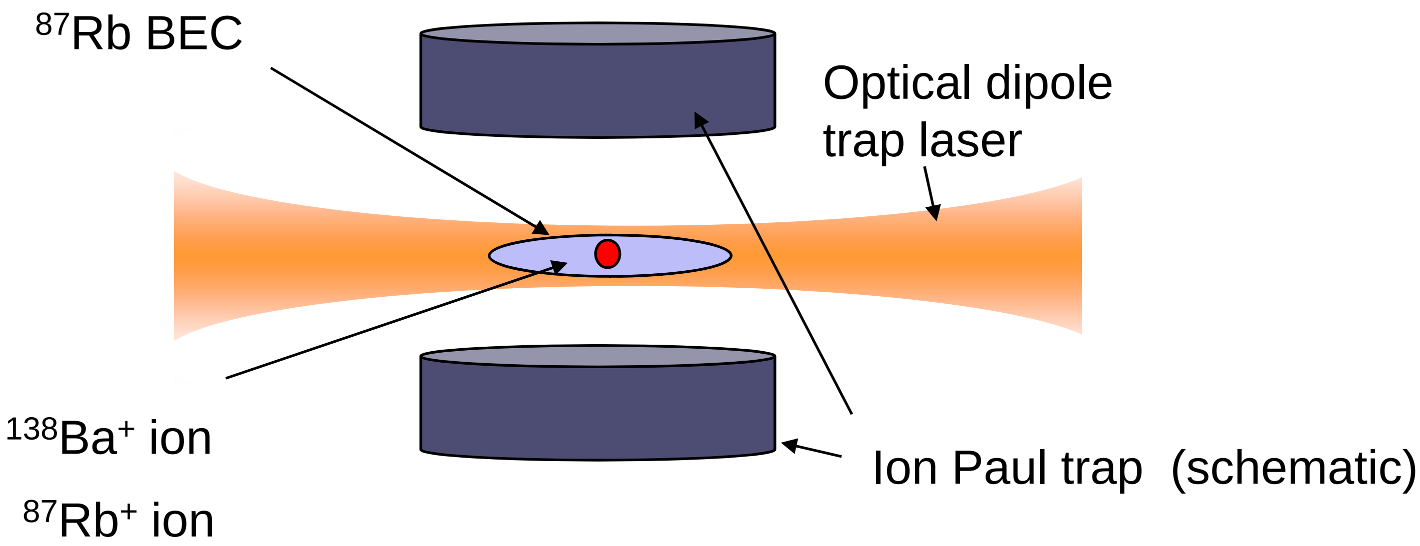
New Science with Ultracold Molecules, KITP, March 11, 2013

ulm university universität ulm

# The BaRble-Team



**Trapped Ions** **and** **Ultracold neutral Atoms**



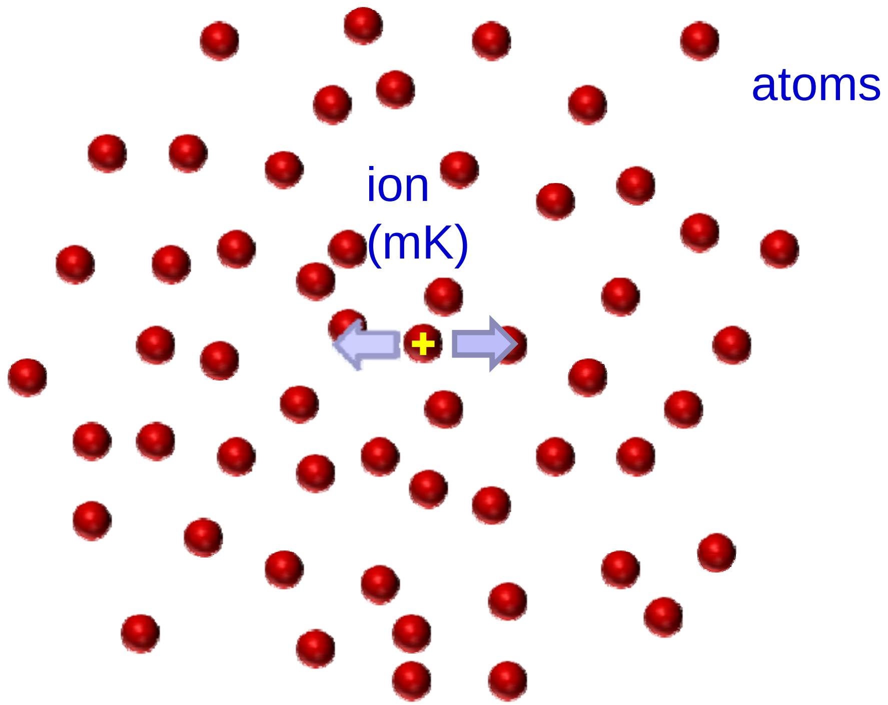

**Good compatibility of traps!**

# Two stories

1) An ion as a three-body reaction center

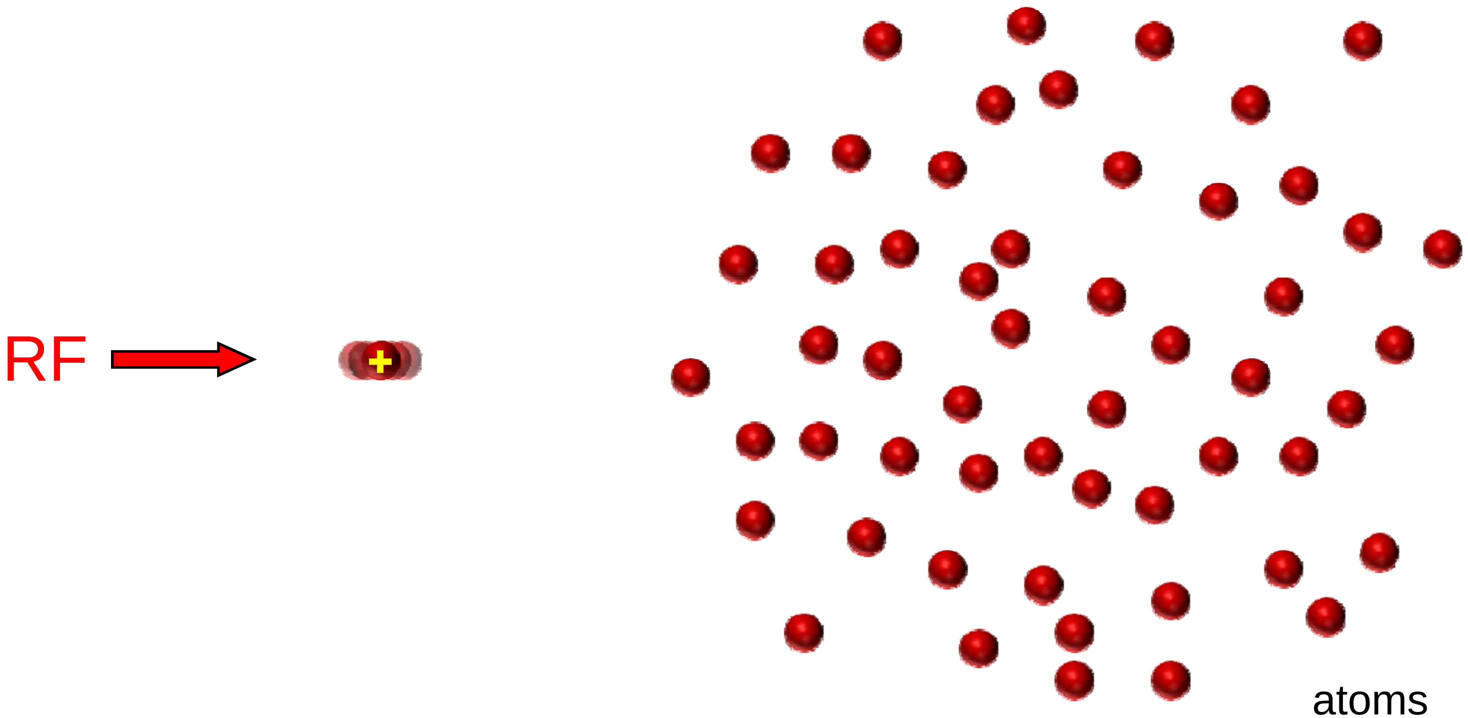
2) Three-body recombination of 3 Rb atoms
(revisited!!)

# An ion in a cloud of atoms, naive picture




- Thermalization of ion within a few collisions, sympathetic cooling
- Loss of a few Rb atoms
- no further dynamics afterwards….

# The role of excess micromotion

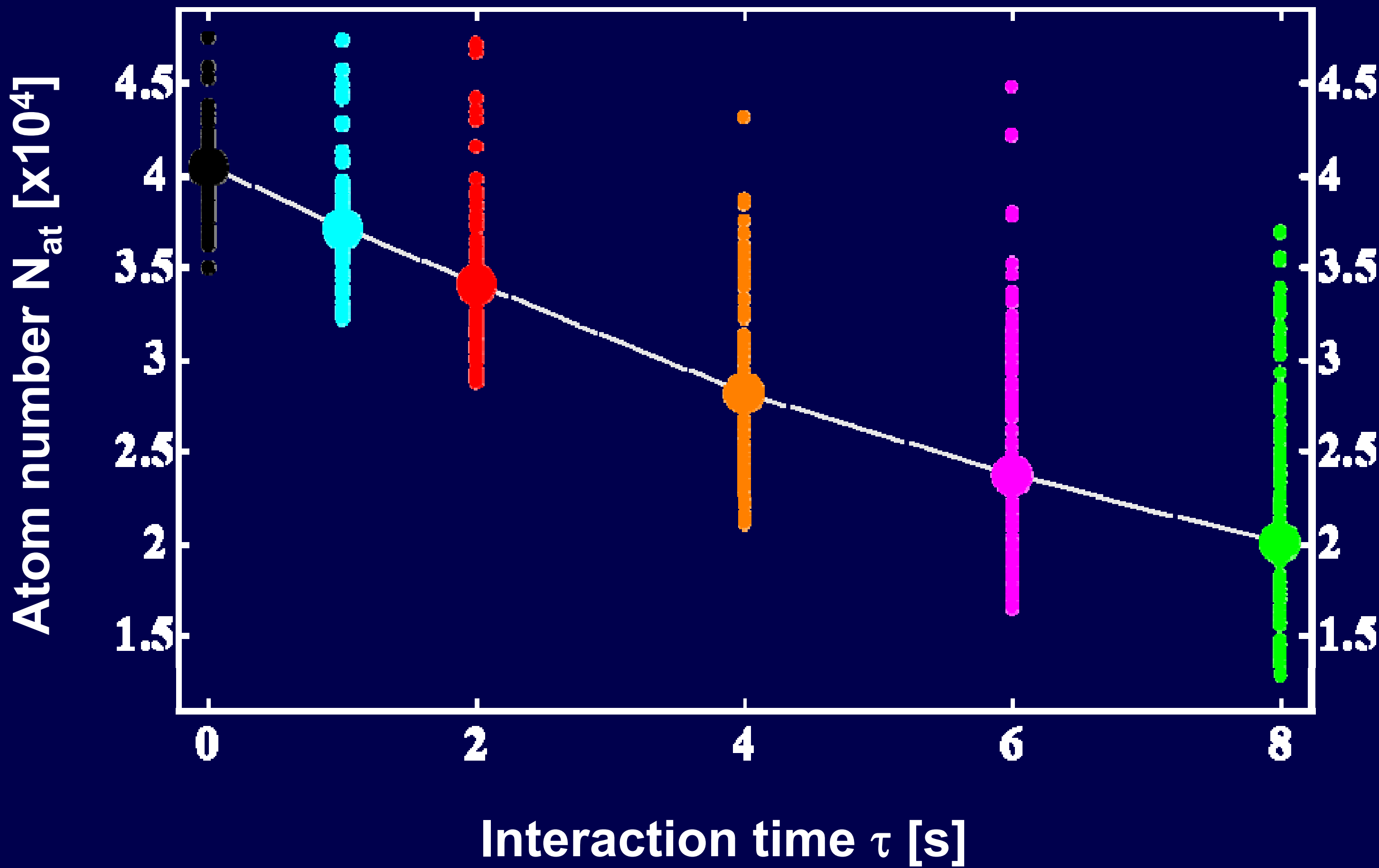



atoms $T \sim 1\,\mu\mathrm{K}$
confined by
shallow dipole trap
$U_{\mathrm{dip}} \sim 10\mu\mathrm{K}$

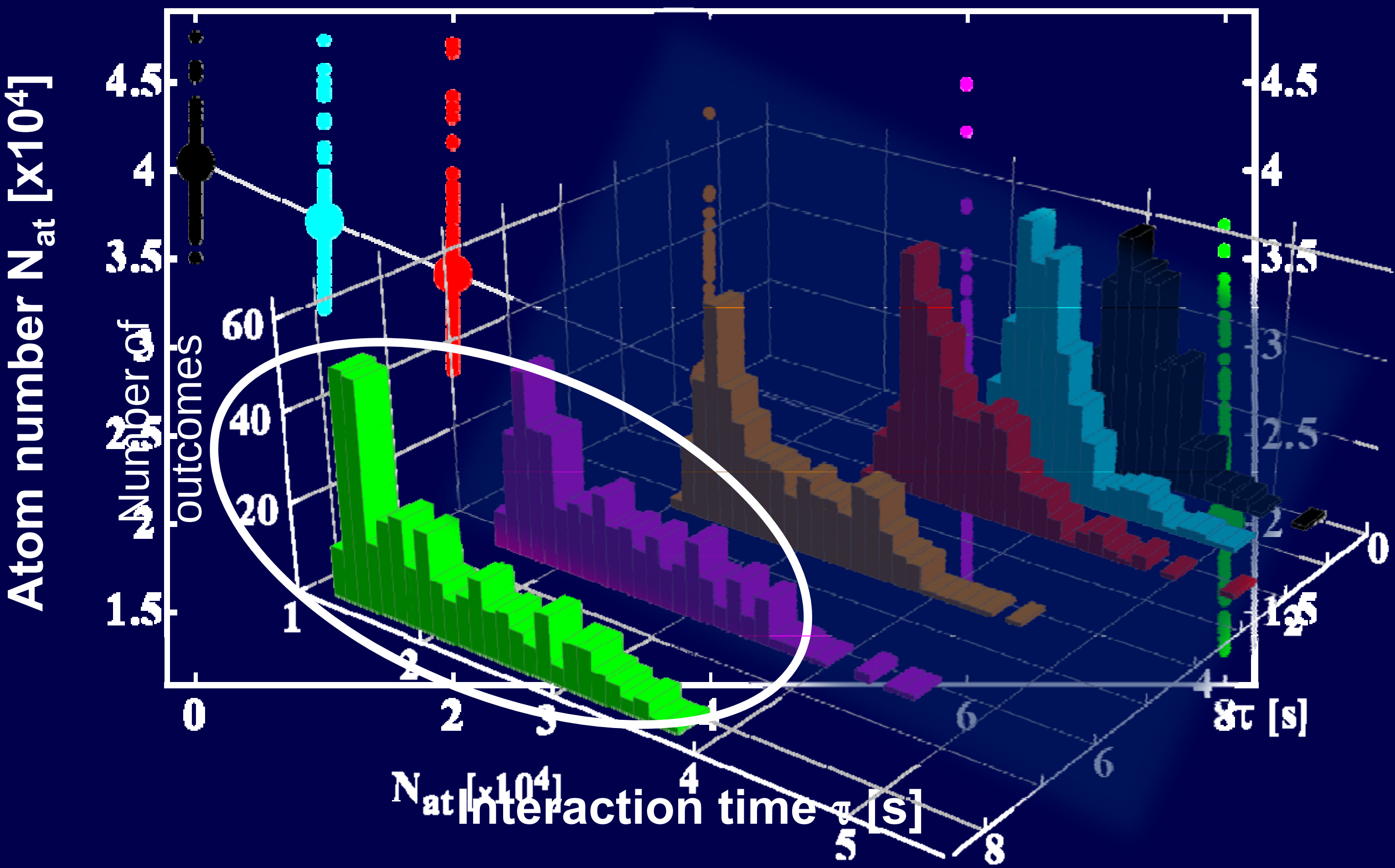
- coherent trap drive (5MHz) accelerates stopped ion again

- ion energy is set by excess micromotion $E_{\mathrm{ion}} \sim \mathrm{mK}\ \mathrm{k_B}$

# Ion-induced atom loss

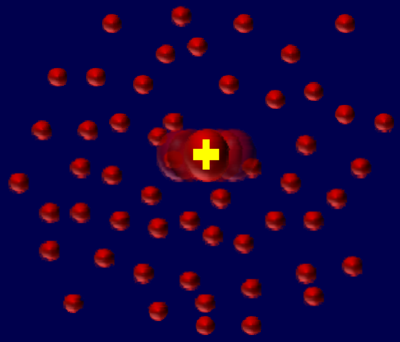


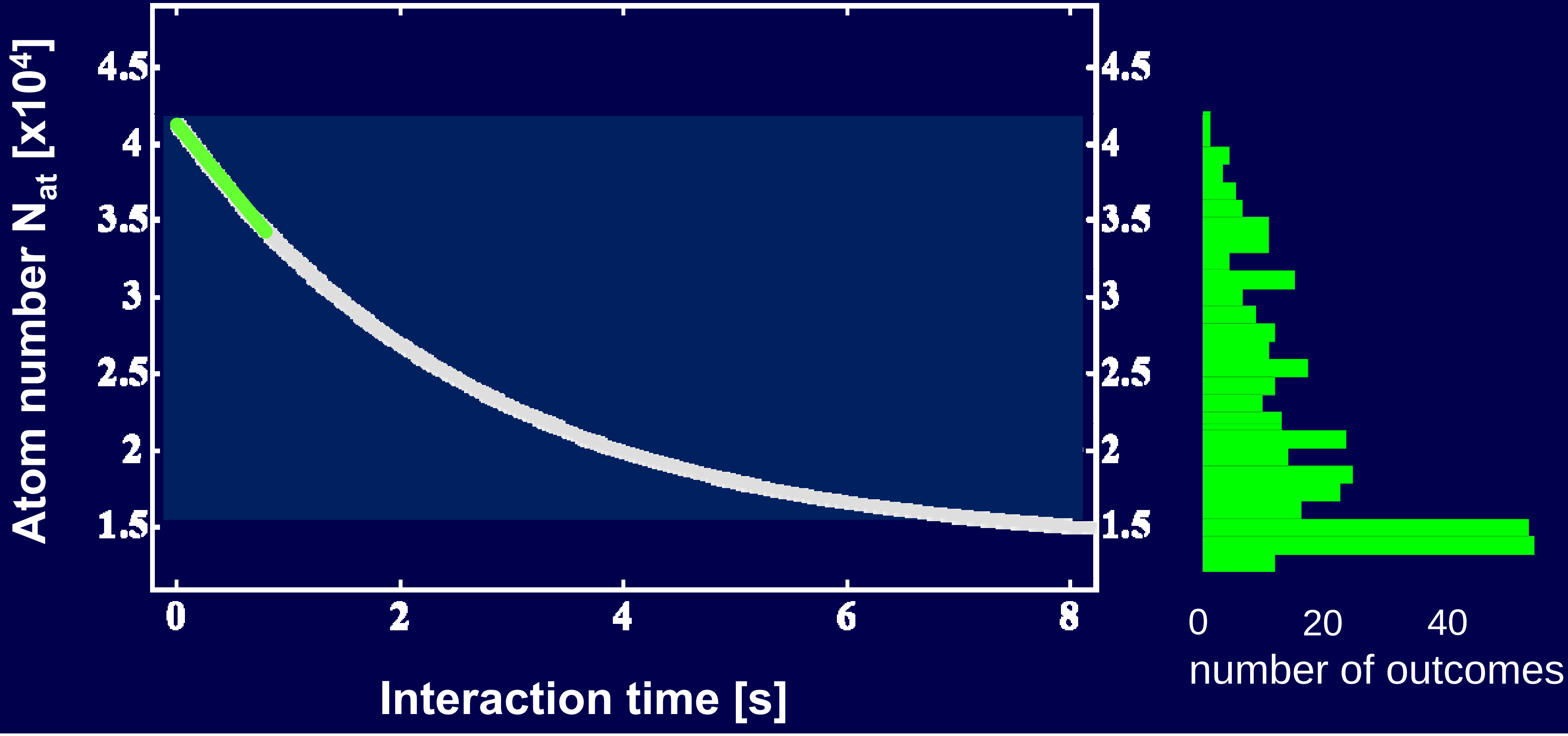
# Atom number distributions



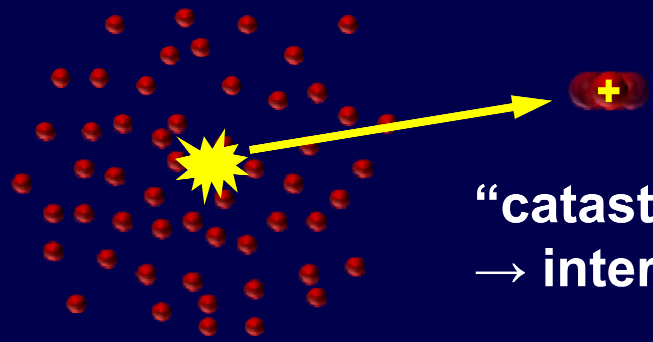

A. Härter et al. PRL 2012, in press

# Collision dynamics

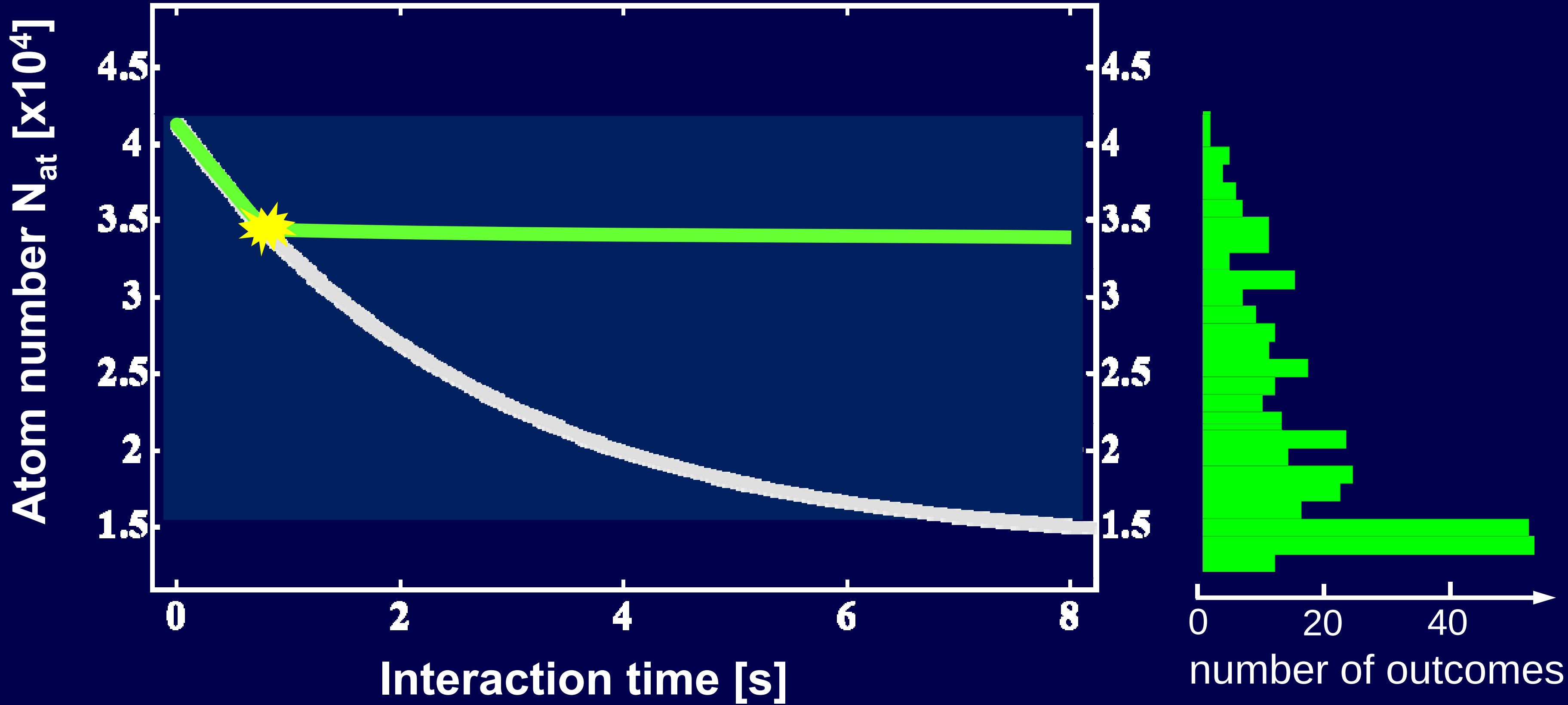




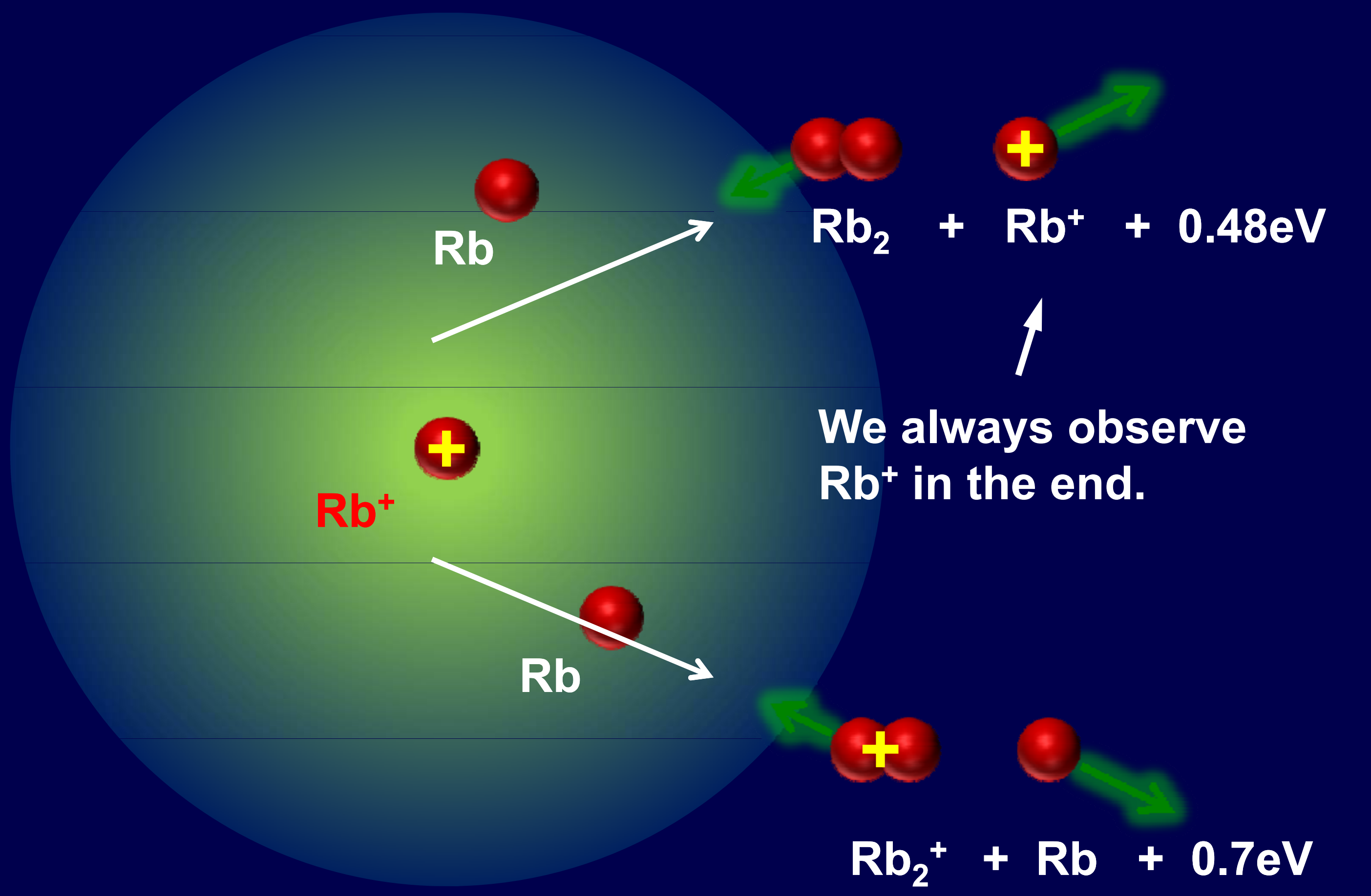
# Collision dynamics



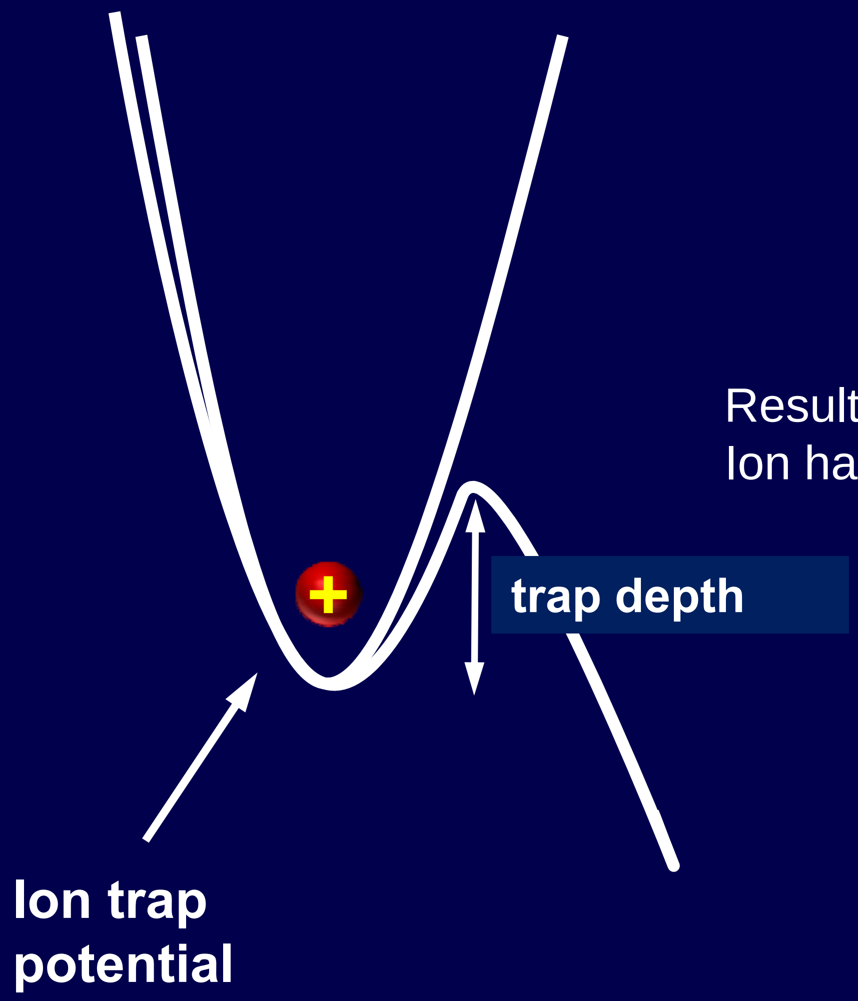
**“catastrophic“ event**
**→ interaction stops!**



# Atom-atom-ion three-body recombination

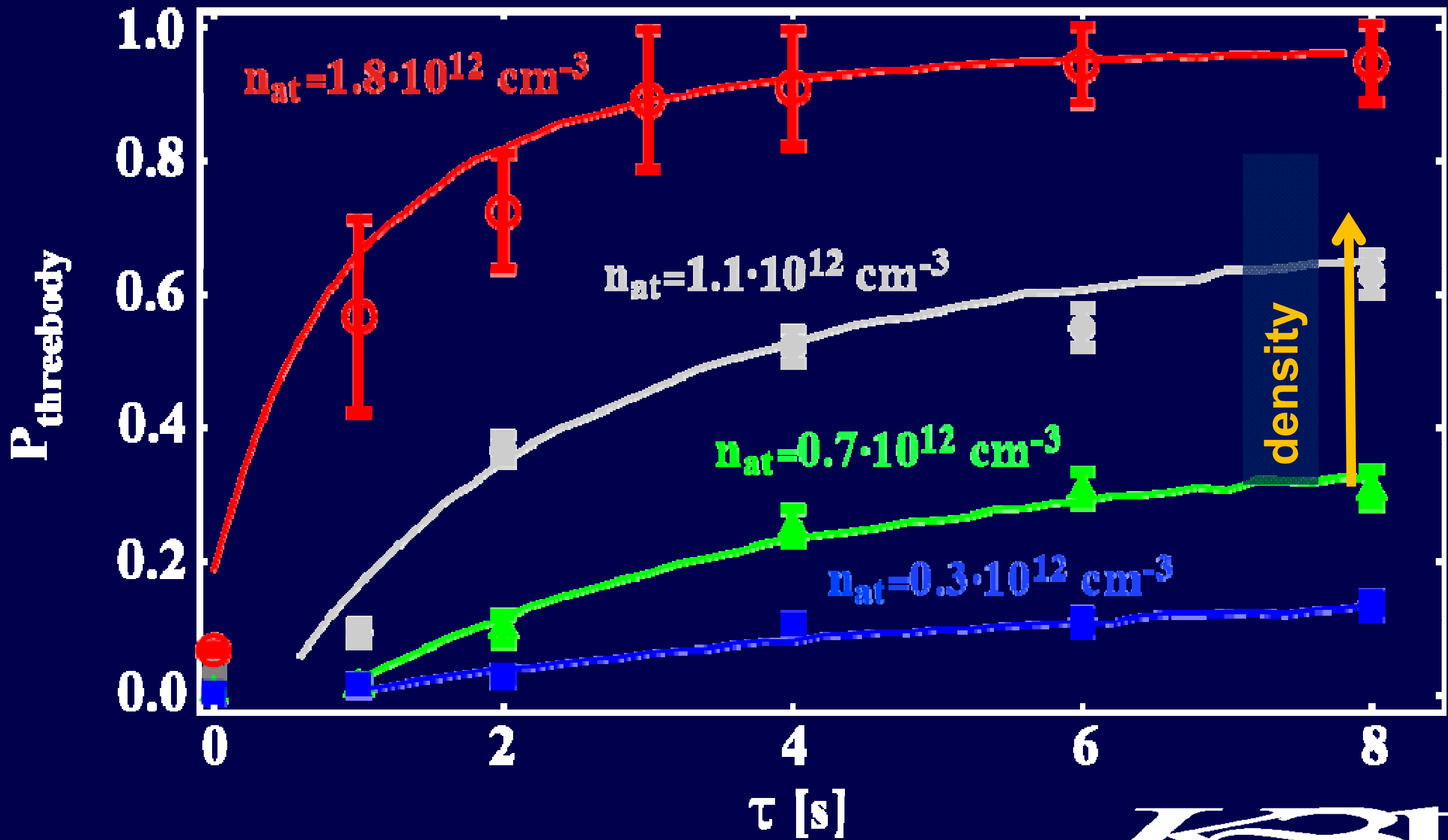


# Measurement of the reaction energy




Result:
Ion has typical energy of a few 0,1 eV.

# Data well described by three-body recombination dynamics




**quadratic density dependence → atom-atom-ion three-body coefficient**

A. Härter et al. PRL 2012

# Two stories

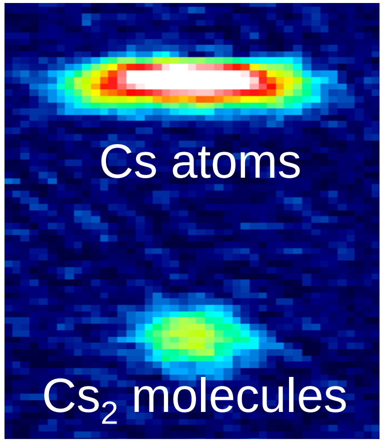
1) An ion as a three-body reaction center

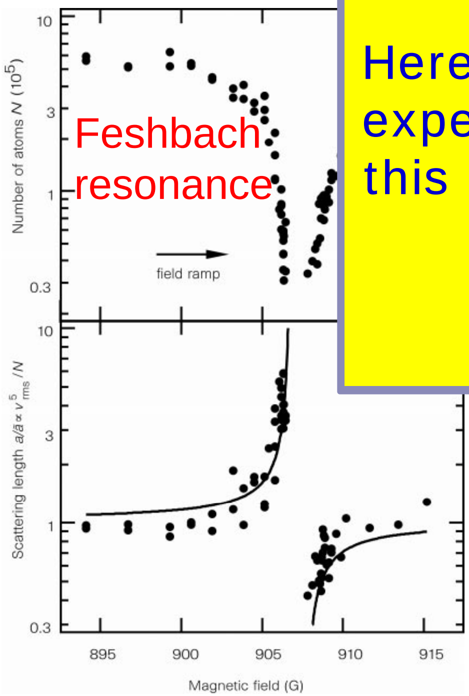
2) Three-body recombination of 3 Rb atoms
(revisited!!)

# Three-body recombination in ultracold atomic gases (REVIEW!)

Considerable losses
at high densities!
e.g.
-Hydrogen BEC? (Hess, 1983)
-Cs BEC? (Grimm, 2002)

Feshbach molecule production
close to Feshbach resonance!
e.g.
- Li molecular BEC

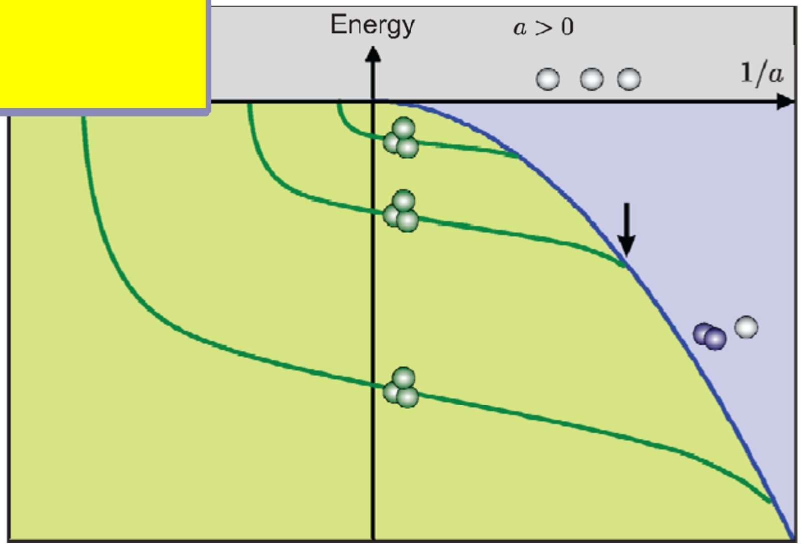



S. Inouye *et al.*, 392 Nature (1998)

Here are some first
experimental steps to address
this question....

...ction of Efimov states (2006+)
...o Feshbach resonance!



# Wait a minute: can‘t you just calculate it?

The calculation of the distribution of the final molecular states is difficult.

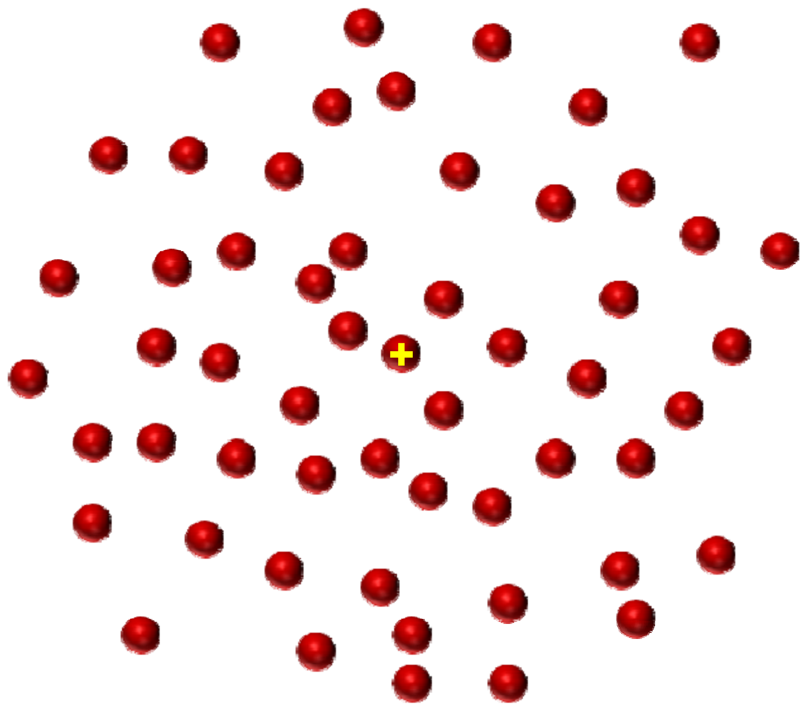
Theorists (e.g. Chris Greene, Brett Esry, Jose d‘Incao, Yujun Wang, ....) have been working on this problem for several years.

First results with relatively simple systems (e.g. single channel models) have been obtained. Even then the interpretation in terms of simple rules is not trivial.

# Let's start from the beginning...

$4 \times 10^4$ $^{87}Rb$ atoms
in an optical dipole trap
at 1064nm;
~1$\mu$K temperature;
density ~ $10^{13}$ $cm^{-3}$ ;

After a few seconds…
there is a $Rb_2^+$ ion
or a $Rb^+$ ion

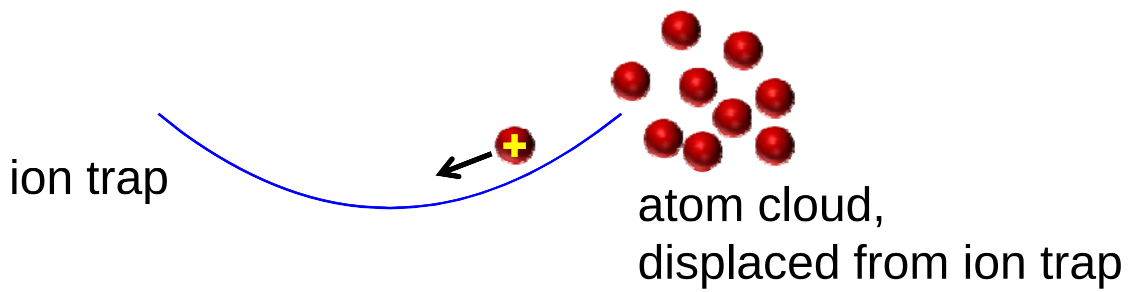


# Branching ratio between $Rb^+$ and $Rb_2^+$

What do we produce more of:
$Rb^+$ and $Rb_2^+$ ?

This depends!

If we extract the ion quickly from the atom cloud (~$\mu$s), then we get mostly $Rb_2^+$ (55%) otherwise mostly $Rb^+$ (~97%).




It seems like:

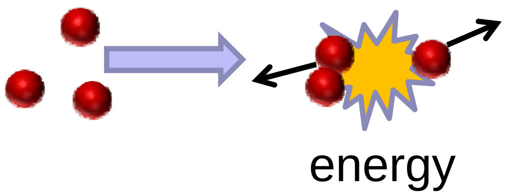
a) Ionization always produces $Rb_2^+$

~~b) Afterwards~~

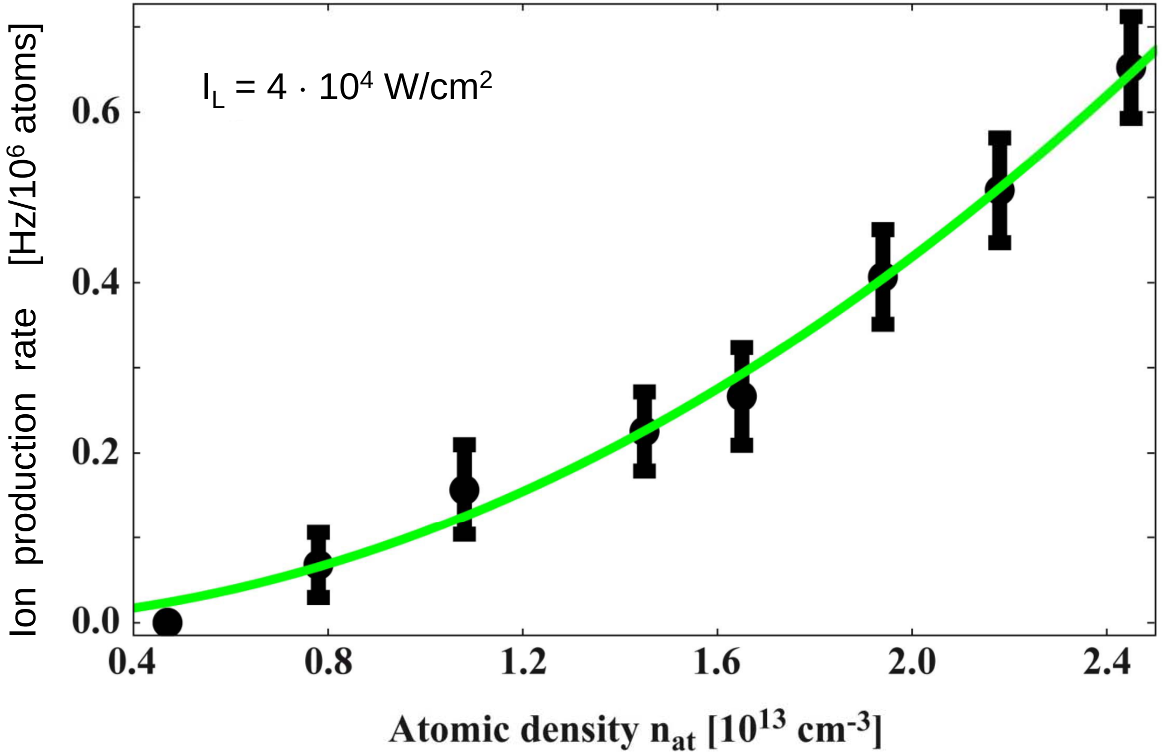
~~$Rb_2^+ + Rb + \gamma$ (?) → $Rb^+ + 2\,Rb$ (?)~~ Not of interest today!

# Not a background effect, i.e. no charge transfer collisions of hot ions!

Normalized ion production rate is quadratic in atomic density!
→ 3-body recombination process of Rb atoms!

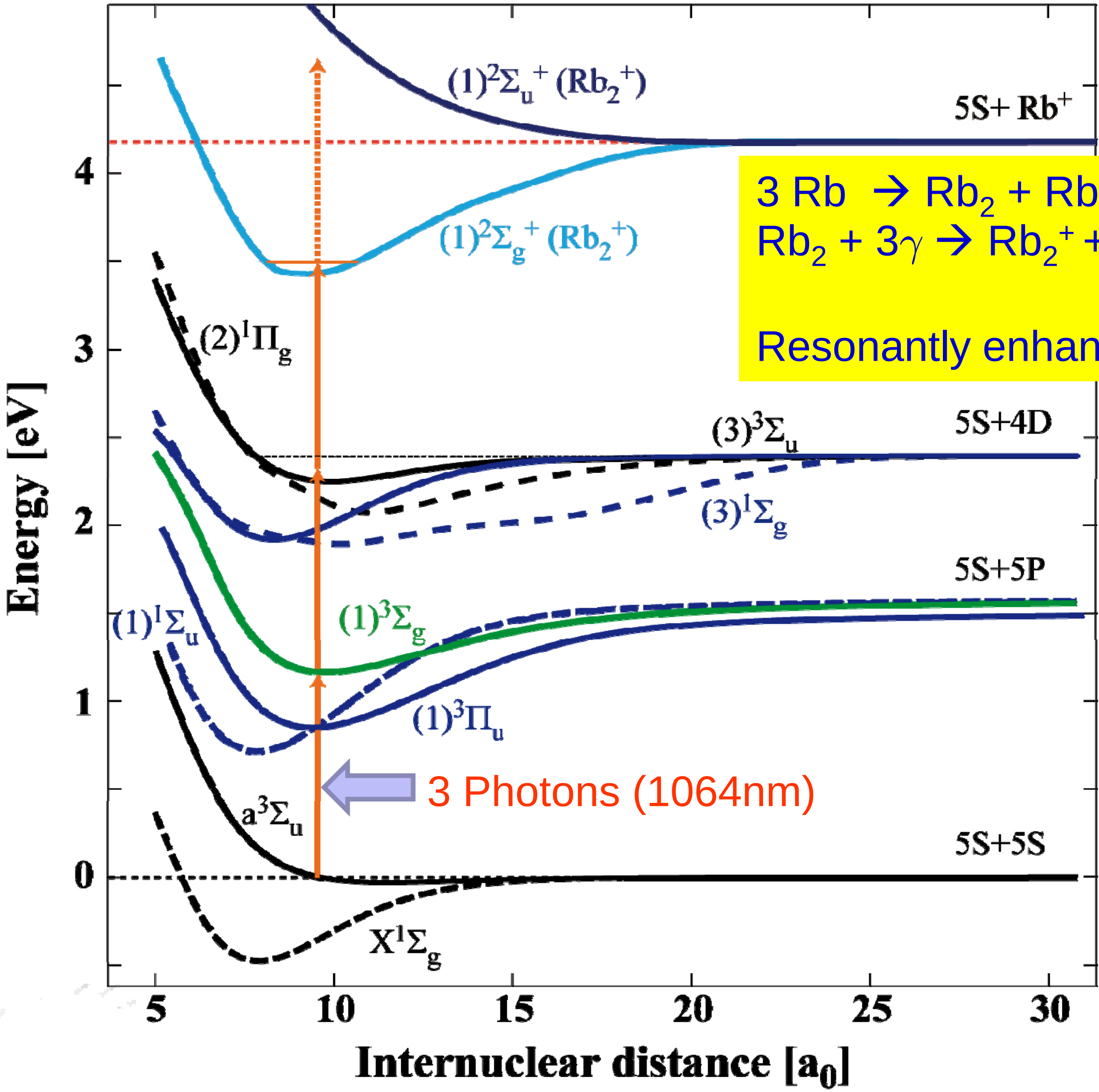



But that is not nearly enough energy to ionize Rb!!



# Potential energy curves for $Rb_2$

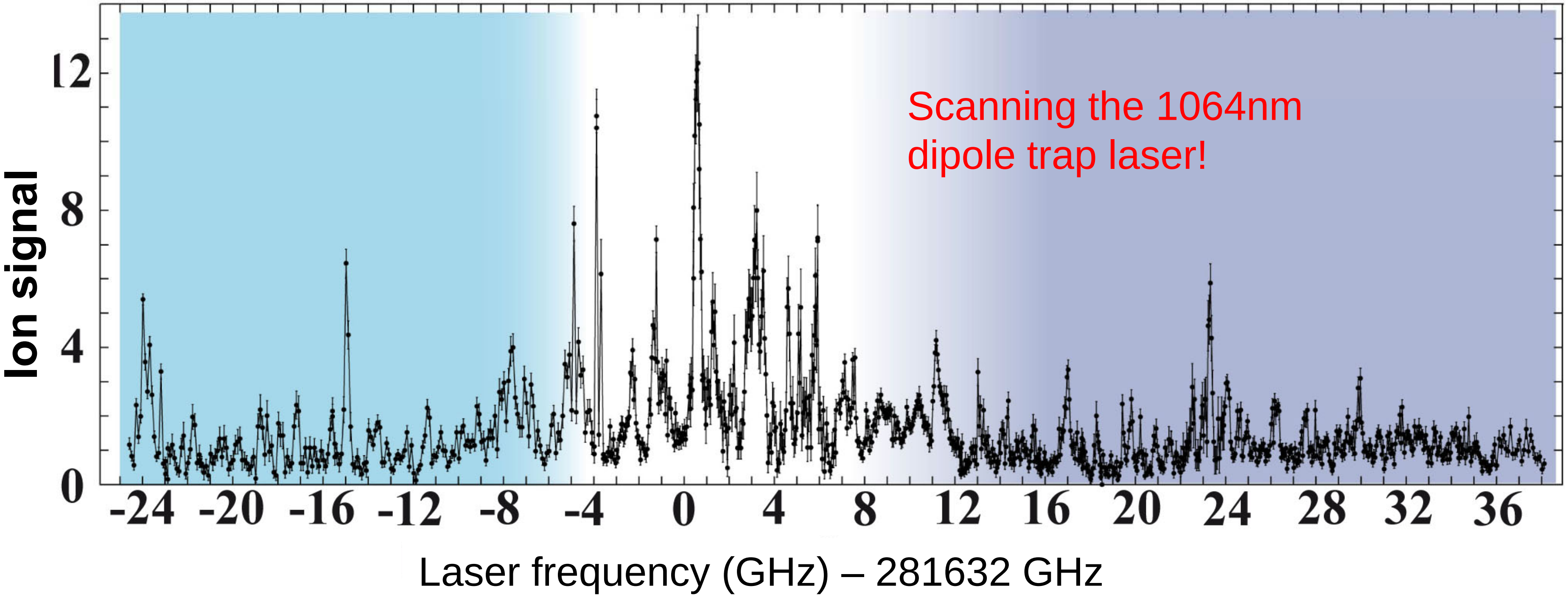
You need 3 or 4 1064nm photons!




3 Rb → $Rb_2$ + Rb
$Rb_2 + 3\gamma \rightarrow Rb_2^+ + e^-$

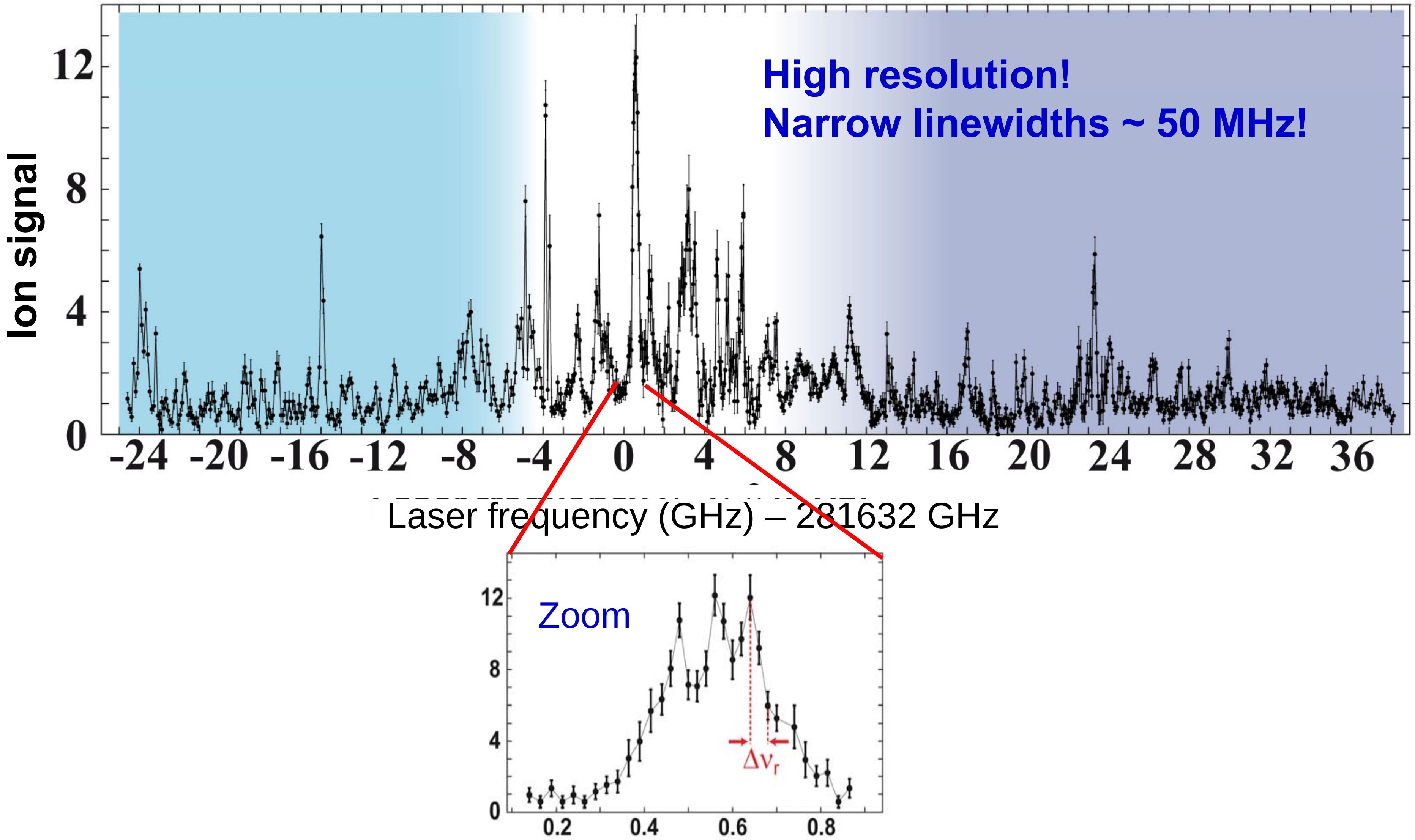
Resonantly enhanced?

# Yes, plenty of resonances!

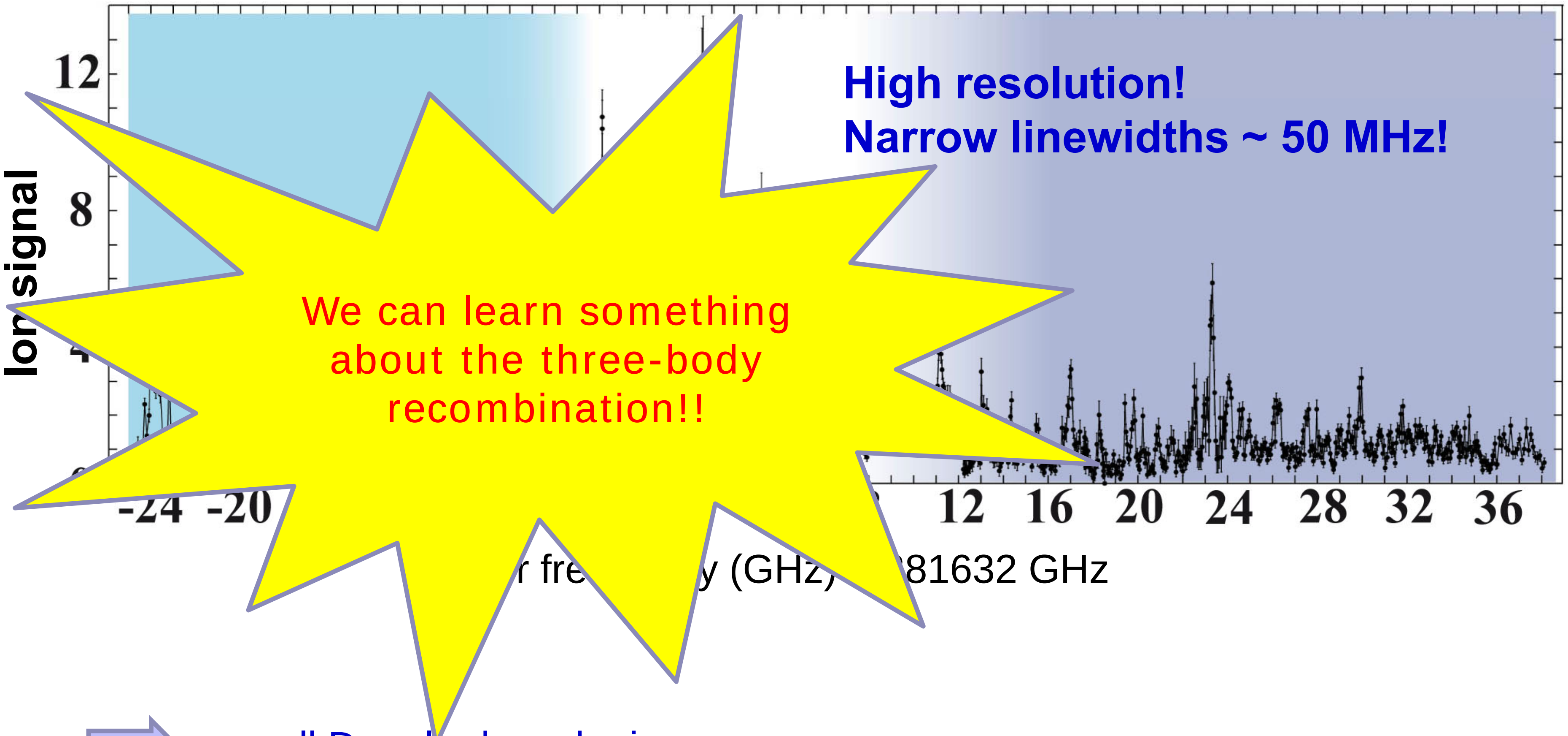



A. Härter, A. Krükow, M. Deiß, B. Drews, E. Tiemann,
and J. Hecker Denschlag **arXiv:1301.5518 (2013)**

# Yes, plenty of resonances!

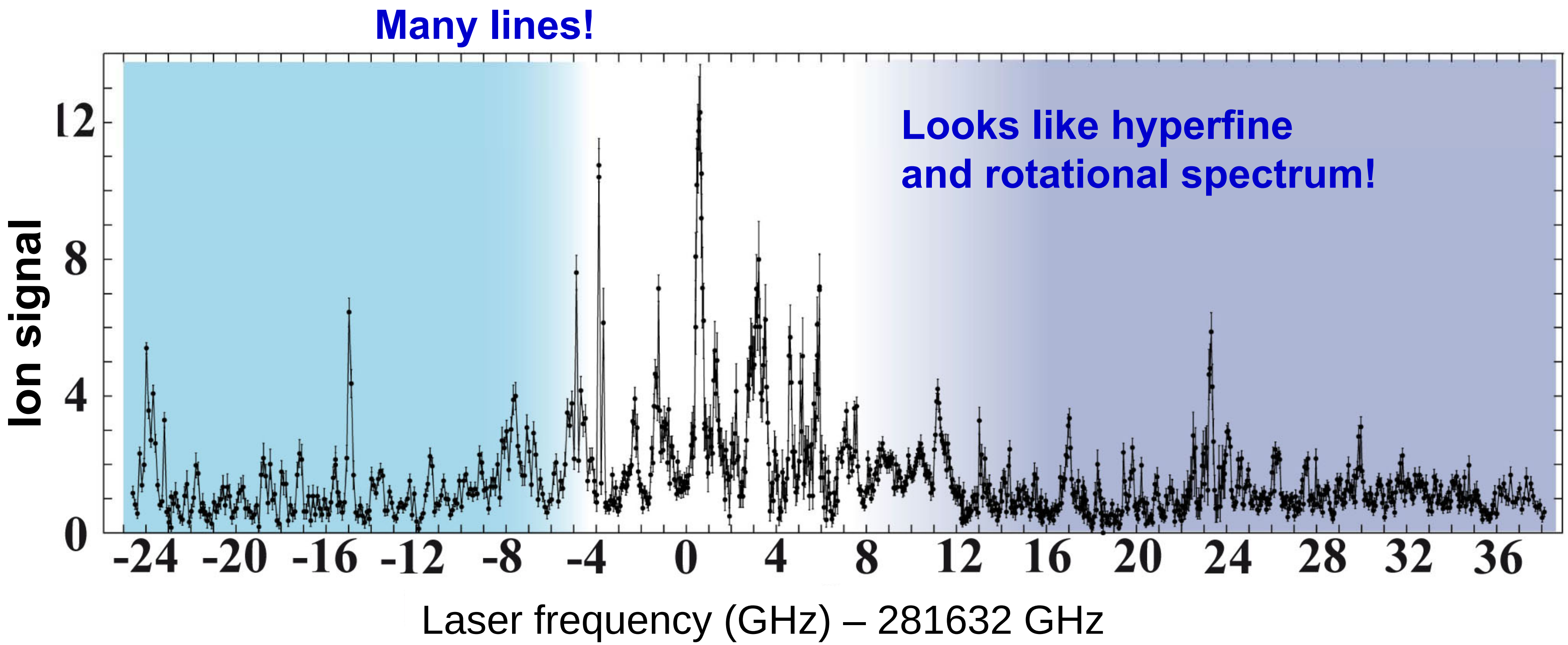


# Yes, plenty of resonances!




- small Doppler broadening
- $Rb_2$ molecules slow after three-body recombination
- energy released in three body-recombination is not large (< 0.01 eV)

# What are all these lines?




Can we understand the spectrum? Perhaps part of it!

Spectroscopic expertise: E. Tiemann (Hannover)

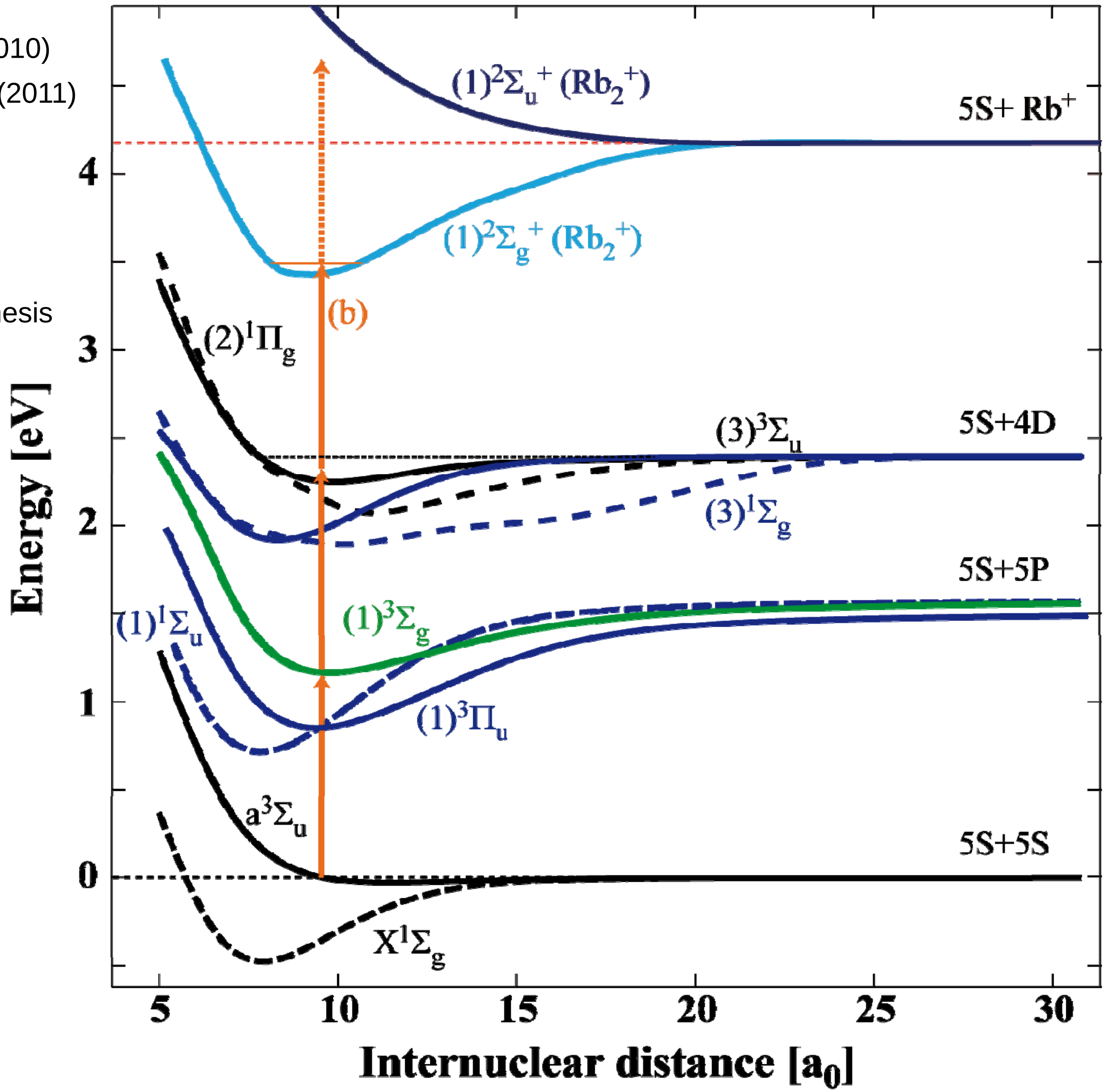
From recent spectroscopy we know several spectra quite well!! (~300 MHz precision!)

Strauss et al., PRA (2010)

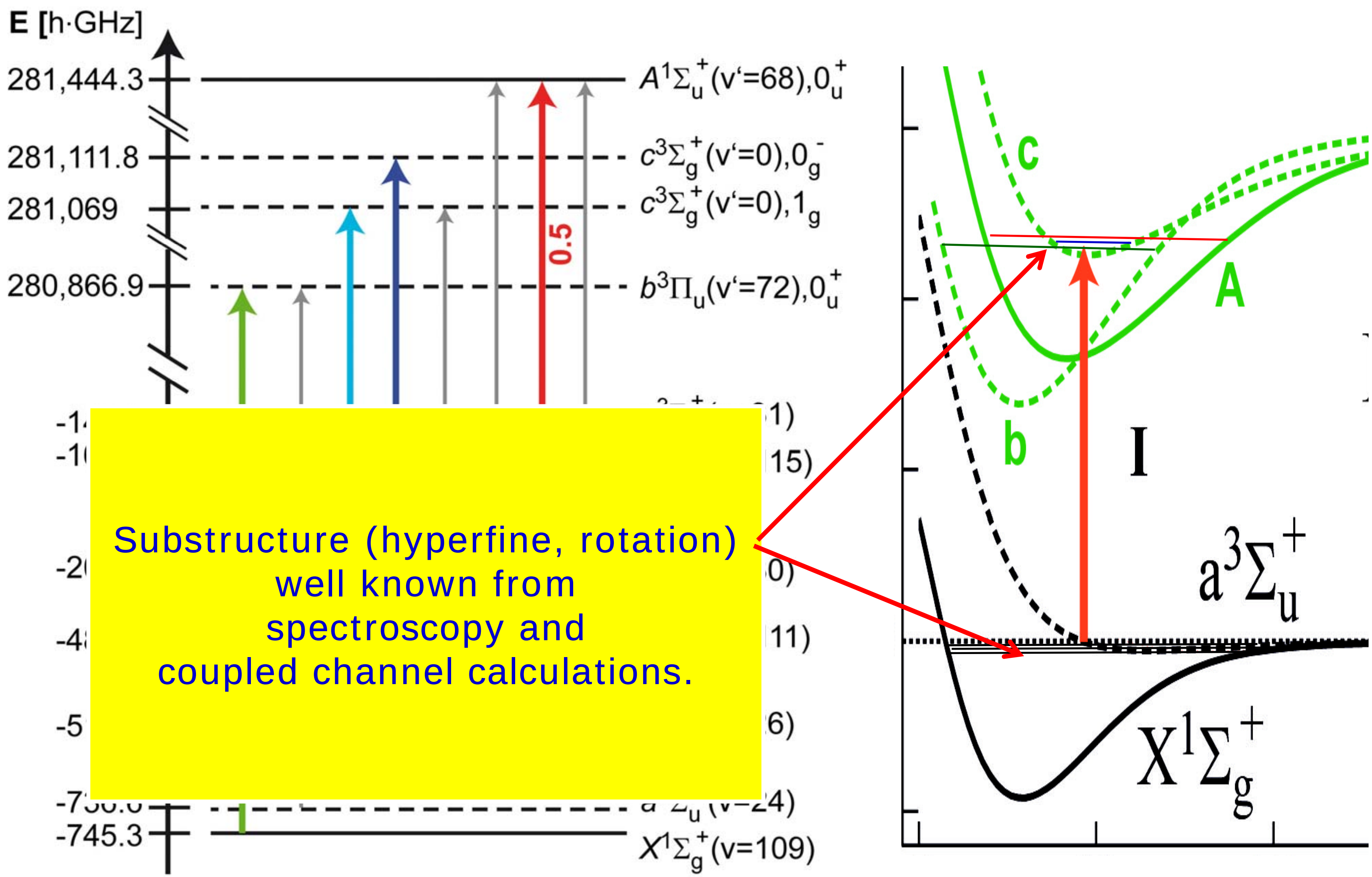
Takekoshi et al., PRA (2011)

collaboration with E. Tiemann

A. Drozdova, PhD Thesis



# Only three excited levels accessible!
# (due to long wavelength of 1064nm)

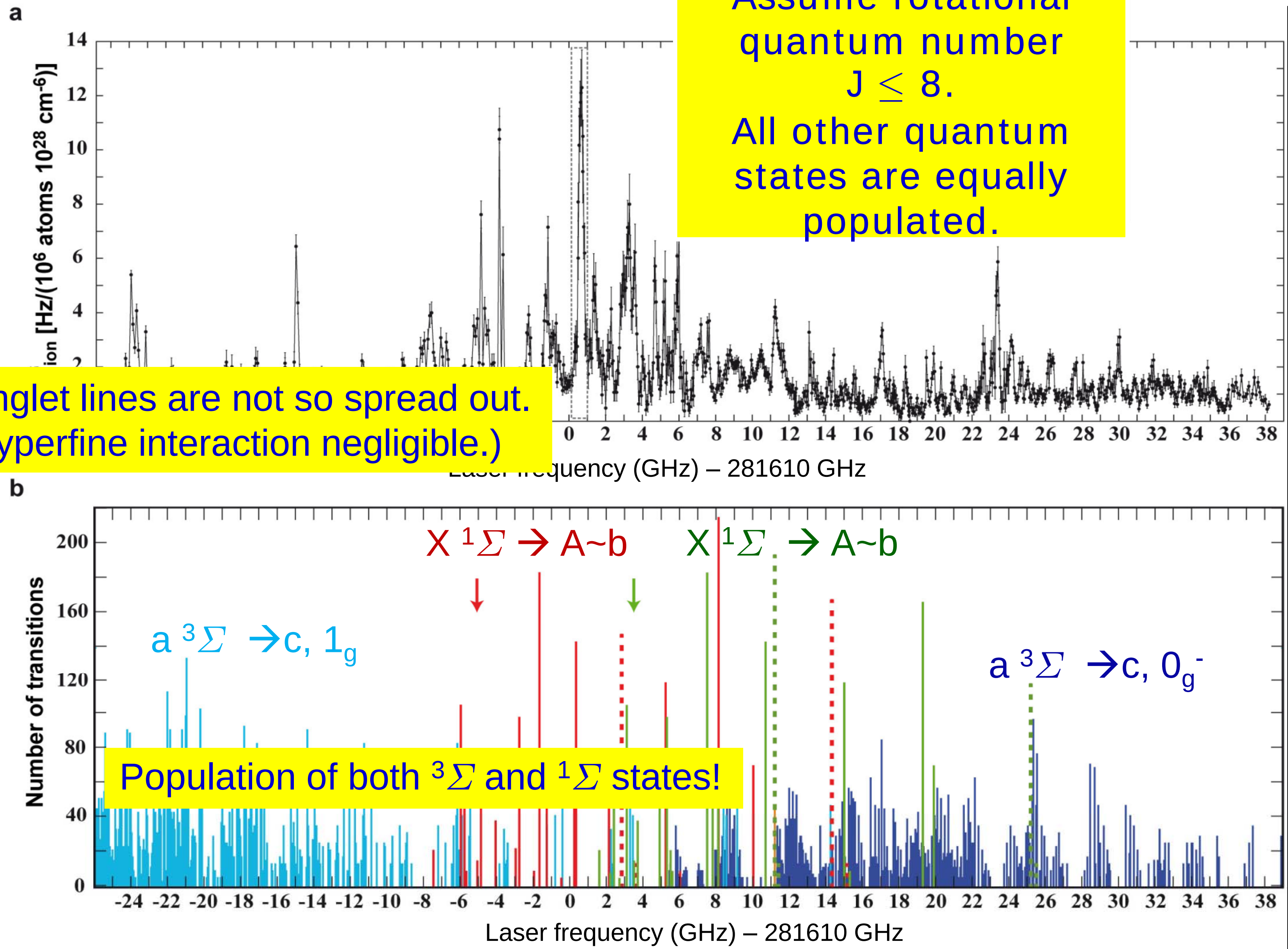



Substructure (hyperfine, rotation) well known from spectroscopy and coupled channel calculations.

# Theoretical estimate of distribution of lines

Assume rotational quantum number $J \leq 8$.
All other quantum states are equally populated.

Singlet lines are not so spread out.
(Hyperfine interaction negligible.)




Population of both $^3\Sigma$ and $^1\Sigma$ states!

# First assignment of rotational line spectrum

Broad distribution!

Population of
Total nuclear spin
I = (0), 1 , 2, 3

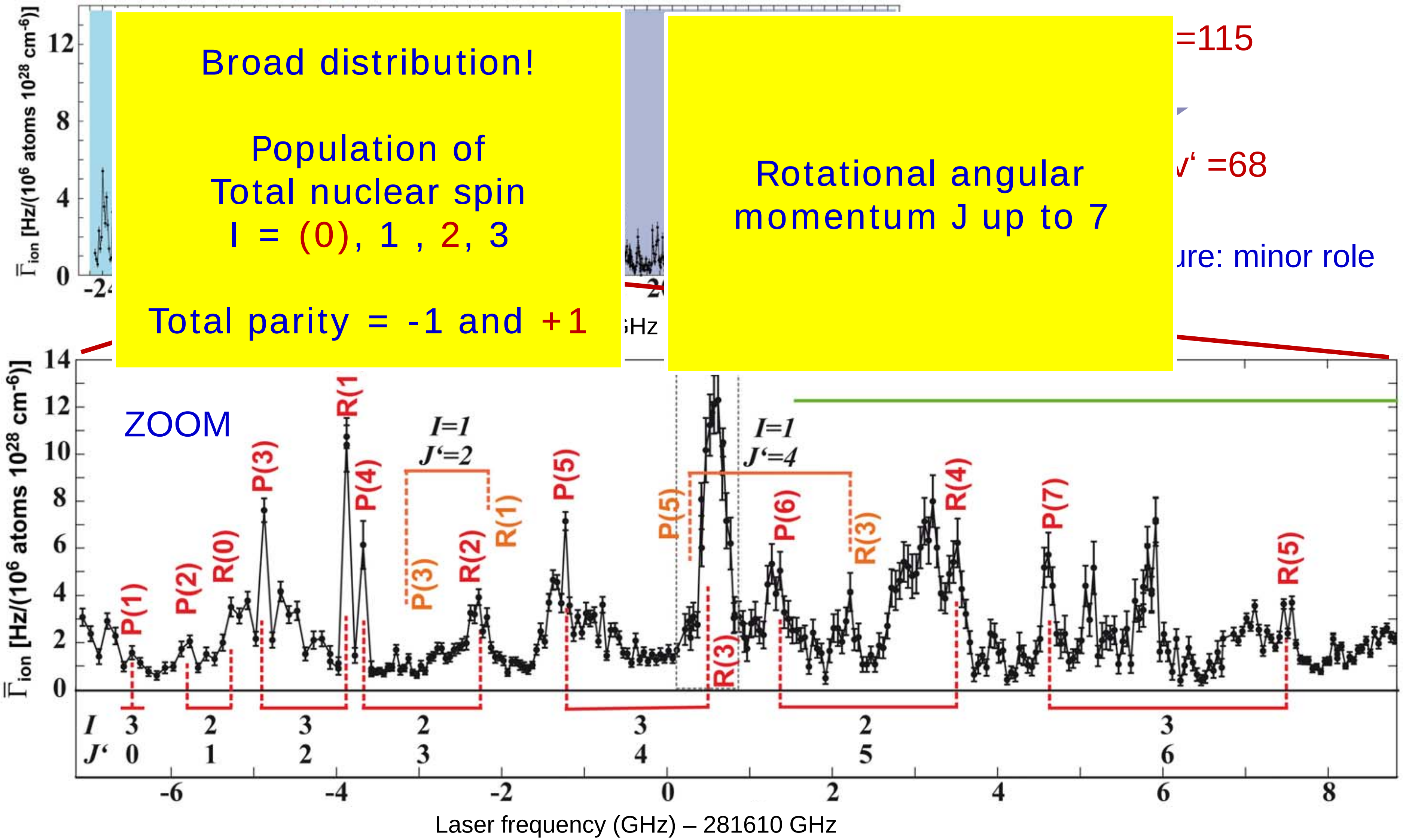
Total parity = -1 and +1

Rotational angular
momentum J up to 7

=115

v' =68

ure: minor role




P, R branches

P(J): J → J -1

R(J): J → J +1

# What have we learned so far?

- First detailed insights into 3-body recombination away from Feshbach resonance!
  (There we produce dominantly Feshbach molecules, Efimov states,....)

- We identified $Rb_2$ molecules with binding energy up to 0.750 THz.
  (This is about 30 vibrational levels below the asymptote).

- A good fraction (> 30) of all vibrational levels (169) are populated.

- Broad population of electronic ($^3\Sigma$ , $^1\Sigma$) and nuclear spin states (I = 0, 1, 2, 3) with total parity = +/- 1 are populated.

- Rotational quantum numbers up to J < 8 occur.

A. Härter, A. Krükow, M. Deiß, B. Drews, E. Tiemann,
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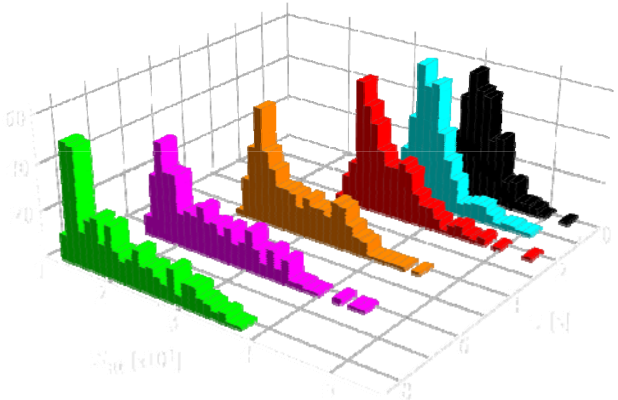
# Two stories

1) An ion as a three-body reaction center

$Rb^+ + 2Rb \rightarrow Rb^+ + \text{energy} + (2Rb)$



2) Gained insight into three-body recombination

$3\,Rb + 3\gamma \rightarrow Rb_2^+ + e^- + Rb$