Cold molecular ion $RbBa^+$

Xiaodong Xing

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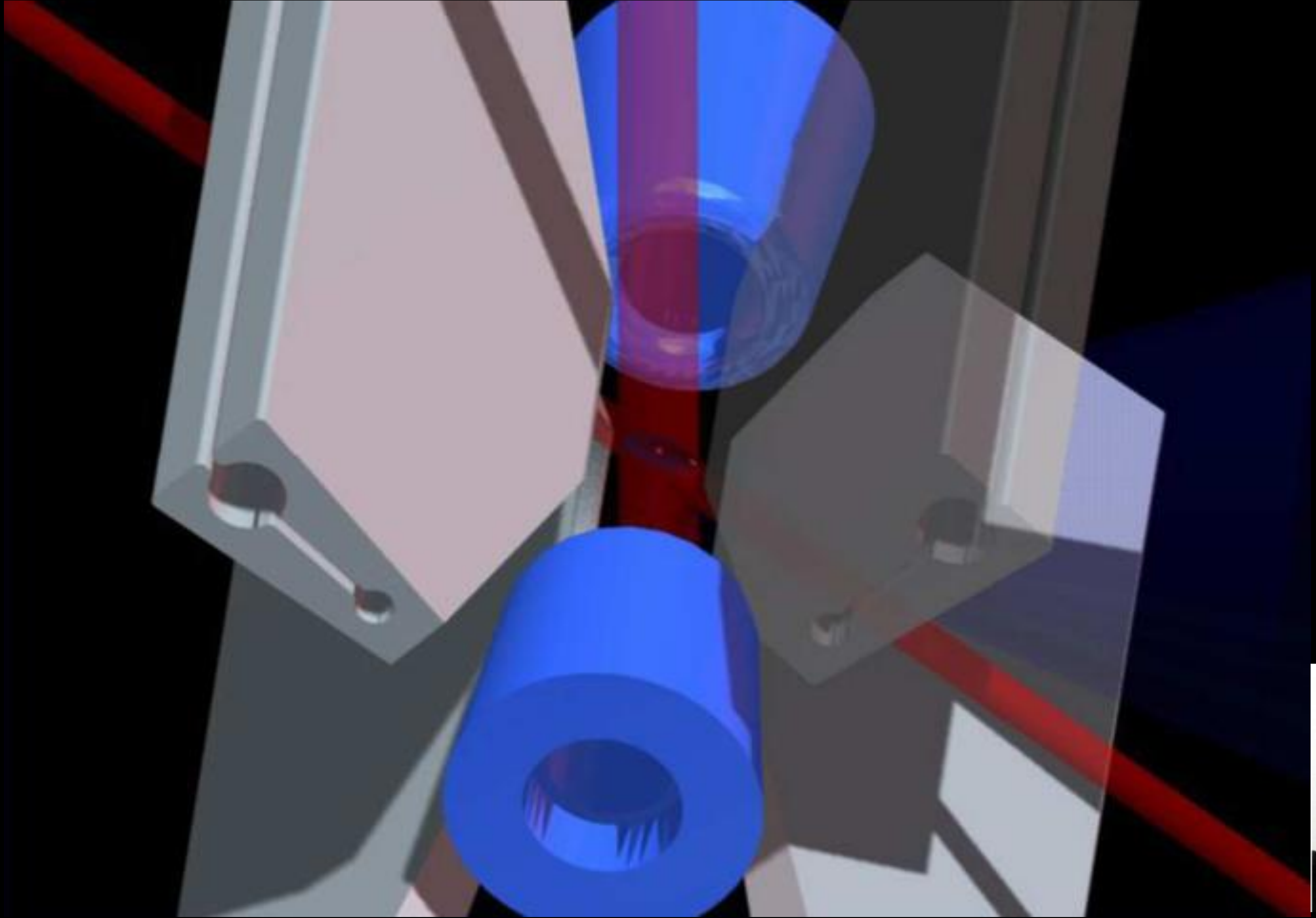

Doppler cooling of Ba+ ions: **493** nm, **685** nm and **986** nm lasers.
Dipole trap: 1064 nm laser.

J. H. Denschlag

Combining ultracold atoms and one cold ion

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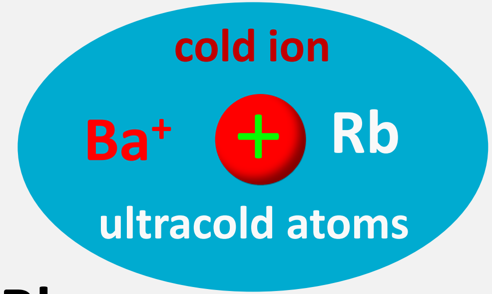
Combining ultracold atoms and one cold ion

$Rb + Ba^+ \rightarrow Ba + Rb^+$

$Rb + Ba^+ \rightarrow BaRb^+$



$Rb + Rb + Ba^+ \rightarrow BaRb^+ + Rb$

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Combining ultracold atoms and one cold ion

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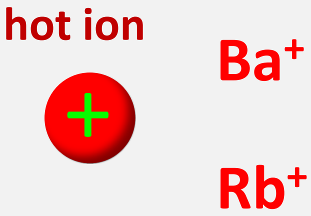

$Rb + Rb + Ba^+ \rightarrow BaRb^+ + Rb$

$BaRb^+ + h\nu \rightarrow Ba + Rb^+ / Rb + Ba^+$

$BaRb^+ + Rb \rightarrow Ba^+ + Rb_2 / Rb^+ + BaRb / Rb_2^+ + Ba$

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Combining ultracold atoms and one cold ion

$Rb + Ba^+ \rightarrow Ba + Rb^+$

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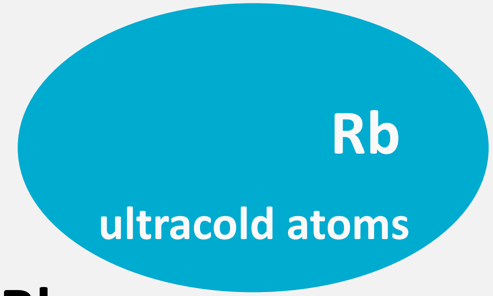

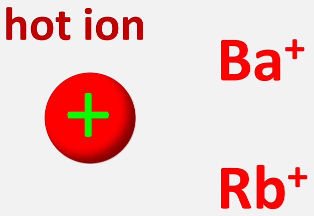

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J. H. Denschlag

Possible reactions

Two body collisions:

$Rb + Ba^{+} \rightarrow BaRb^{+}$

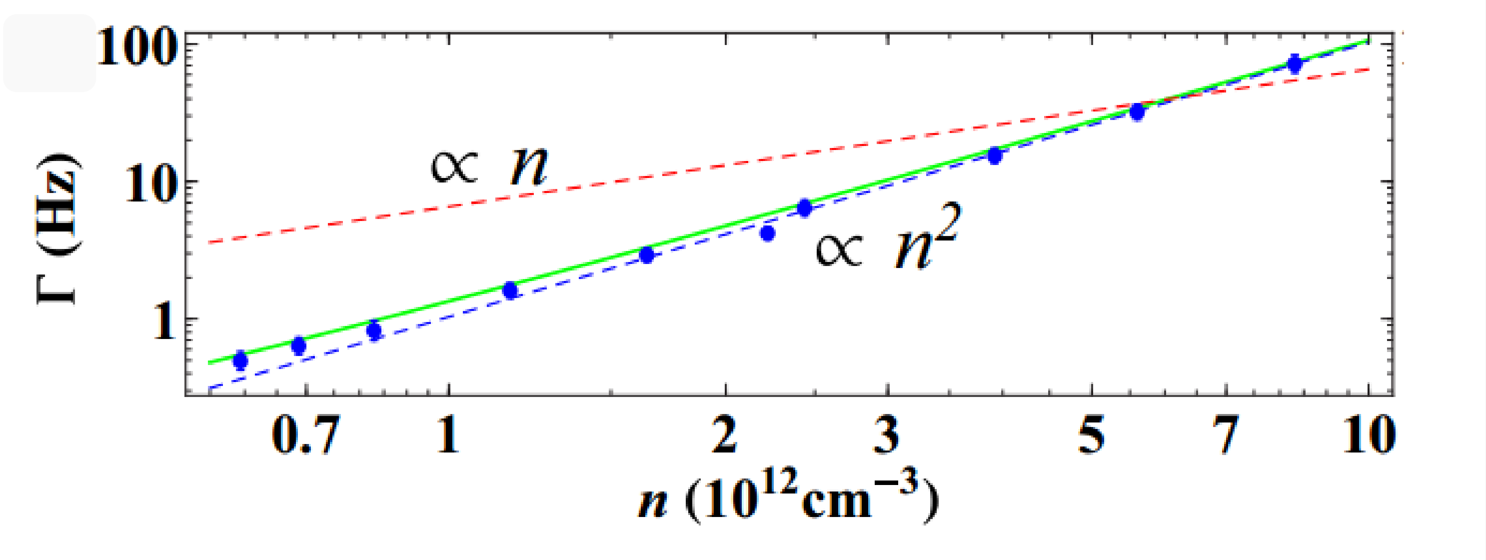
Three body collisions:

$Rb + Rb + Ba^{+} \rightarrow BaRb^{+} + Rb$

Photodissociation:

$BaRb^{+} + h\nu \rightarrow Ba + Rb^{+} / Rb + Ba^{+}$

Binary and Ternary reaction-rate constants



$$\Gamma = K_2 \times n_{atoms} + K_3 \times n_{atoms}^2$$

~ 10^{12} cm^{-3}

$$K_2 < 9\times10^{-14}\, cm^3 s^{-1} \quad K_3 = 1.02(1)\times10^{-24}\, cm^6 s^{-1}$$

A. Krukow, A. Mohammadi, A. Harter and J. H. Denschlag Phys. Rev. A **94,** 030701(R) (2016)

Possible reactions

Two body collisions:

$Rb + Ba^+ \rightarrow BaRb^+$

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Possible reactions

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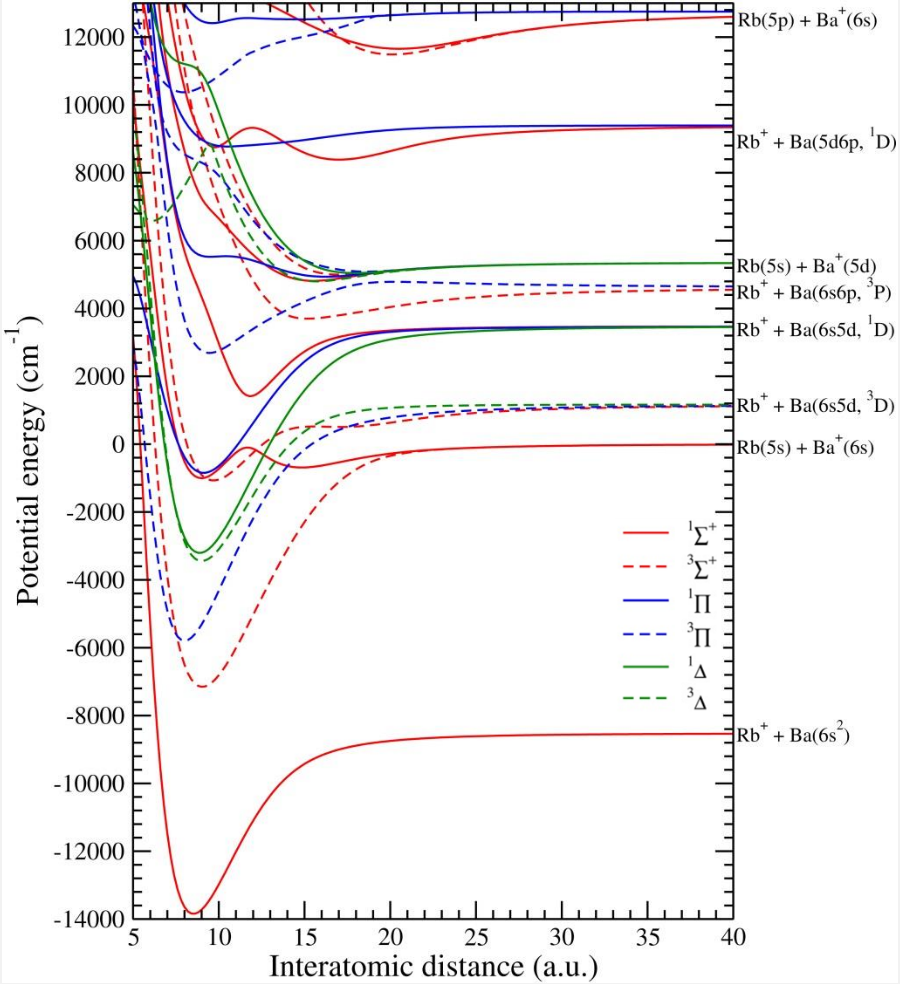
Hot Ba^+ in Hund's case a

Hot Ba^+ in Hund's case c

Hot Ba^+ in Hund's case a

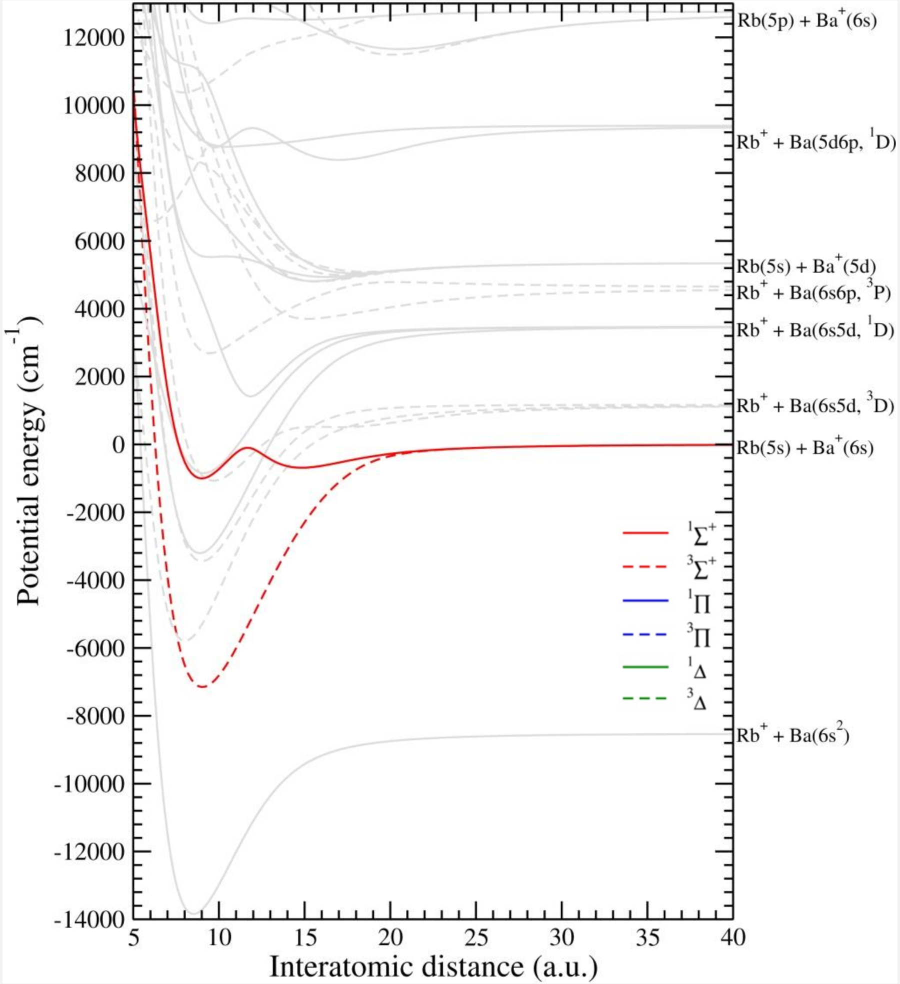
Hot Ba^+ in Hund's case c



Potential energy curves calculated by Romain Vexiau

[1] A. Krukow, A. Mohammadi, A. Harter and J. H. Denschlag Phys. Rev. A **94,** 030701(R) (2016)
[2] A. Krukow, A. Mohammadi, A. Harter and J. H. Denschlag Phys. Rev. Lett. **116,** 193201 (2016)

weakly-bound $BaRb^+$



Ion: 0.1 ~10 mk k_B atom:10 μk k_B

entrance channel

^{87}Rb(5s) + ^{87}Rb(5s) + ^{138}Ba$^+$(6s) collisions performed with Rb atomic densities of around 10^{12} cm^{-3} [1,2] , where $RbBa^+$ is **weakly-bound** on **$^1\Sigma^+$ or $^3\Sigma^+$**

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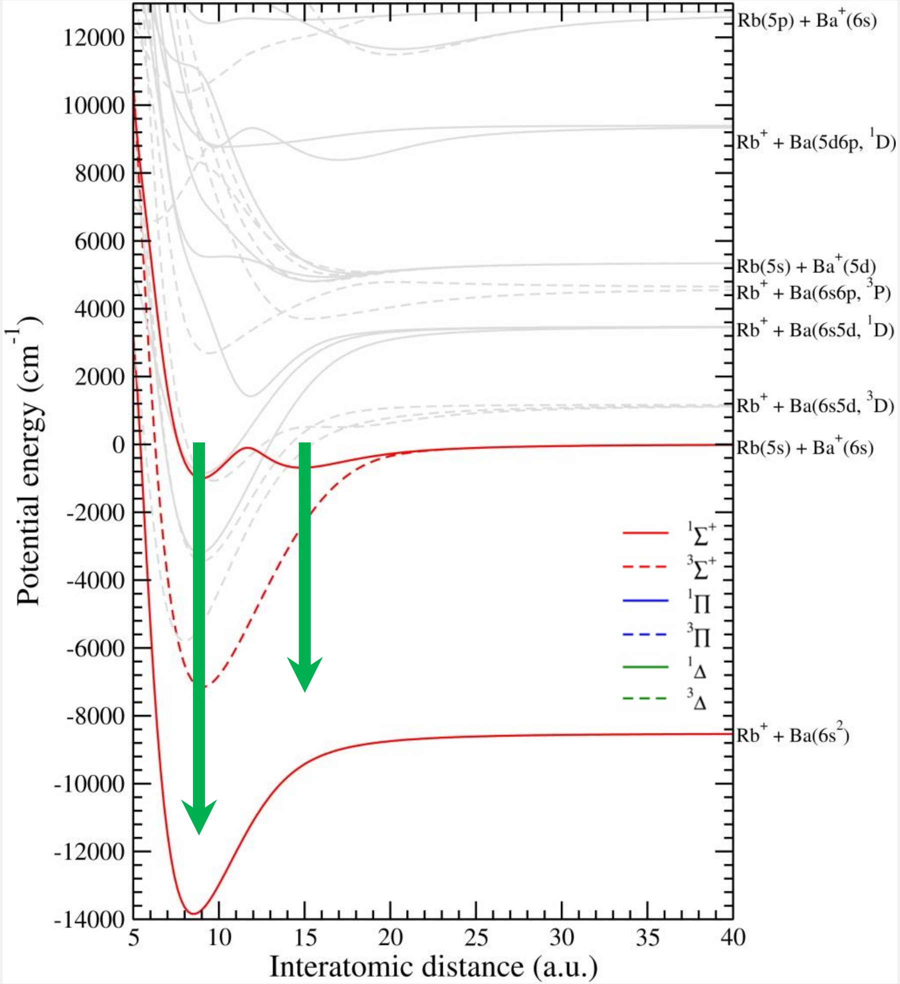

weakly-bound BaRb$^+$

Ion: 0.1 ~10 mk k_B atom:10 μk k_B

entrance channel

^{87}Rb(5s) + ^{87}Rb(5s) + ^{138}Ba$^+$(6s) collisions performed with Rb atomic densities of around 10^{12} cm^{-3} [1,2] , where RbBa$^+$ is **weakly-bound** on **$^1\Sigma^+$ or $^3\Sigma^+$**

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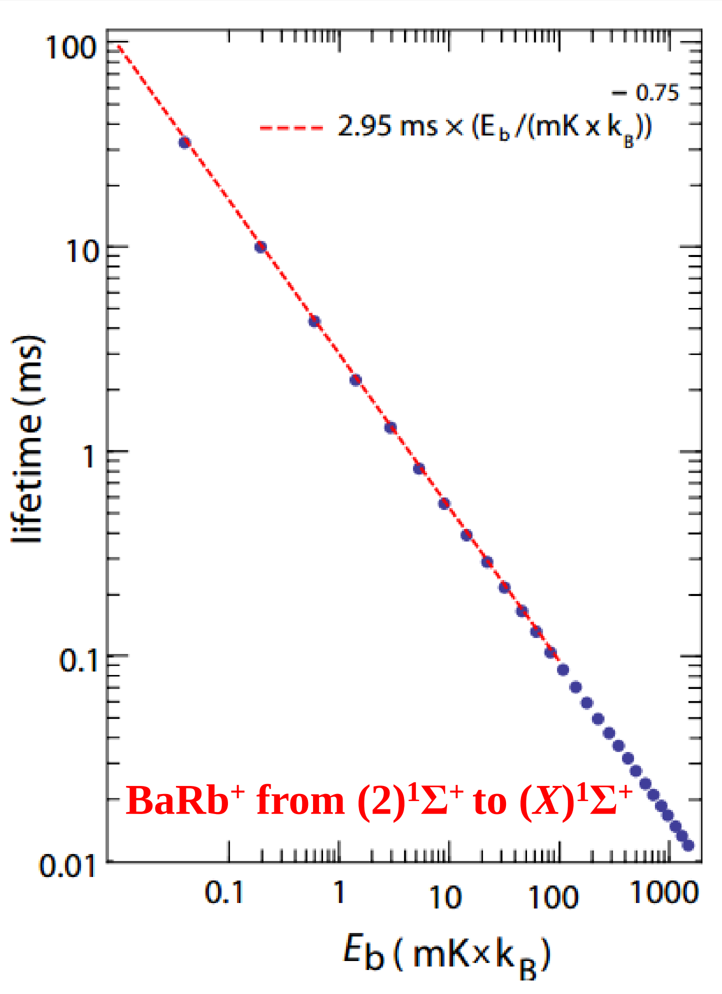
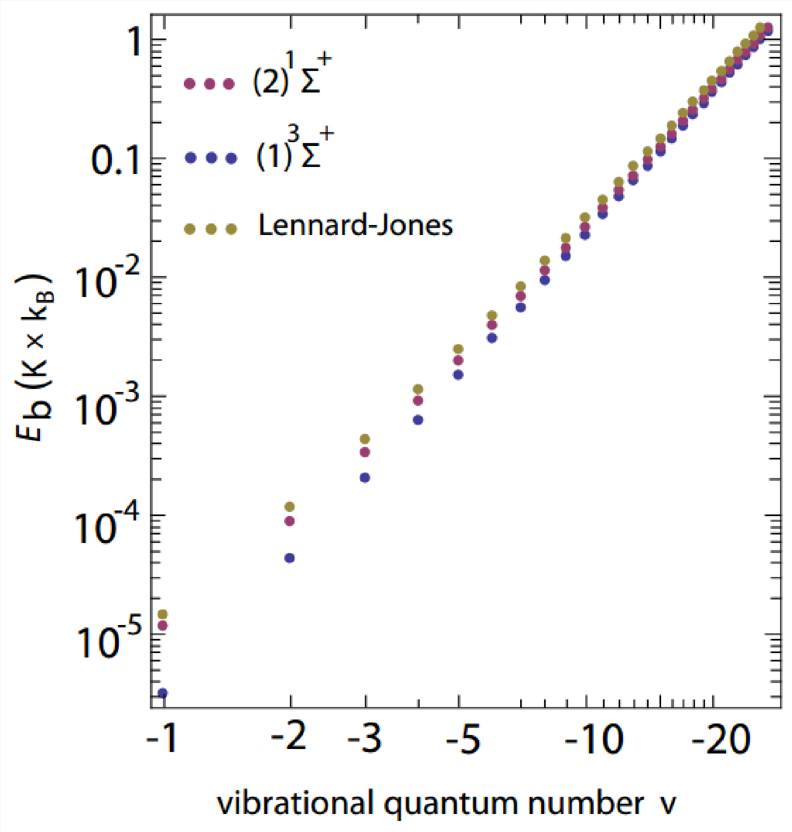
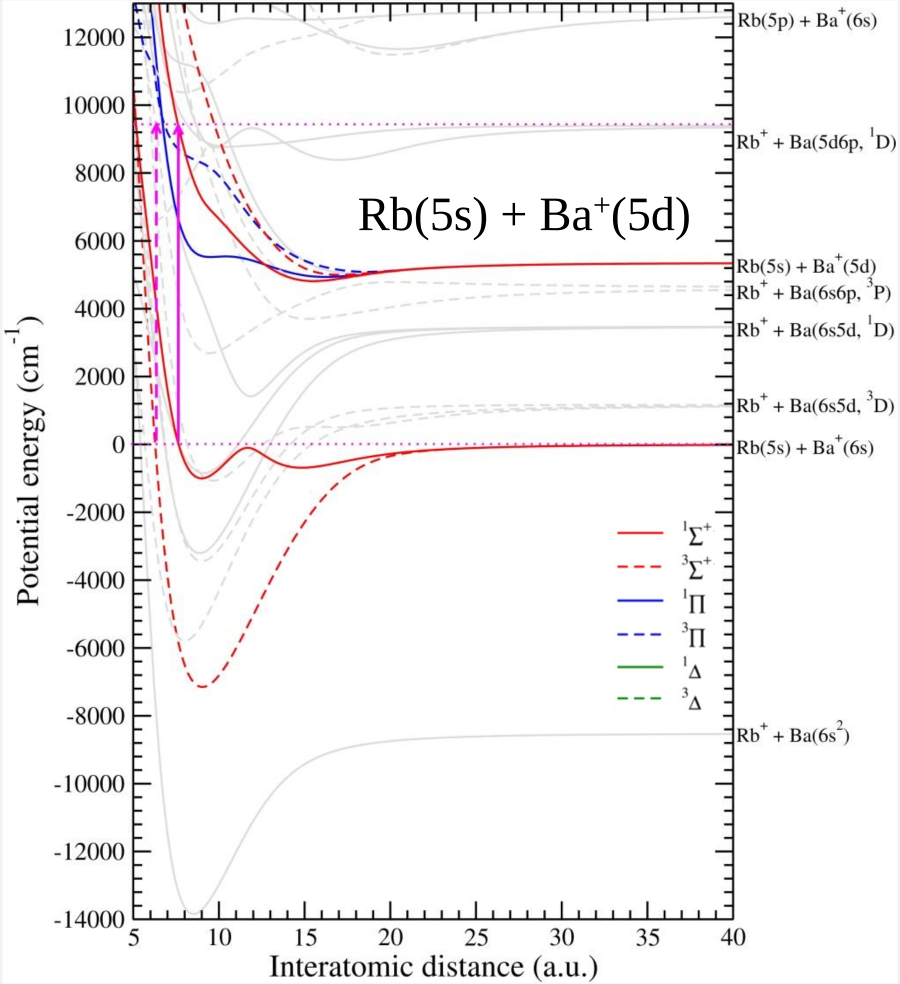
Radiative emission





Photodissociation

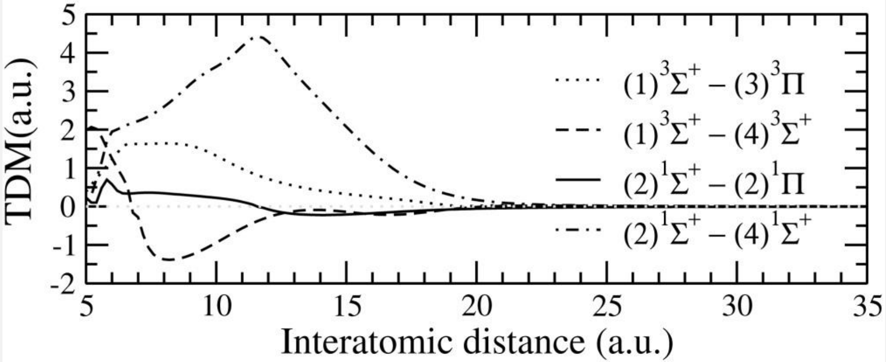
Hot Ba^+ ~ 4000 k

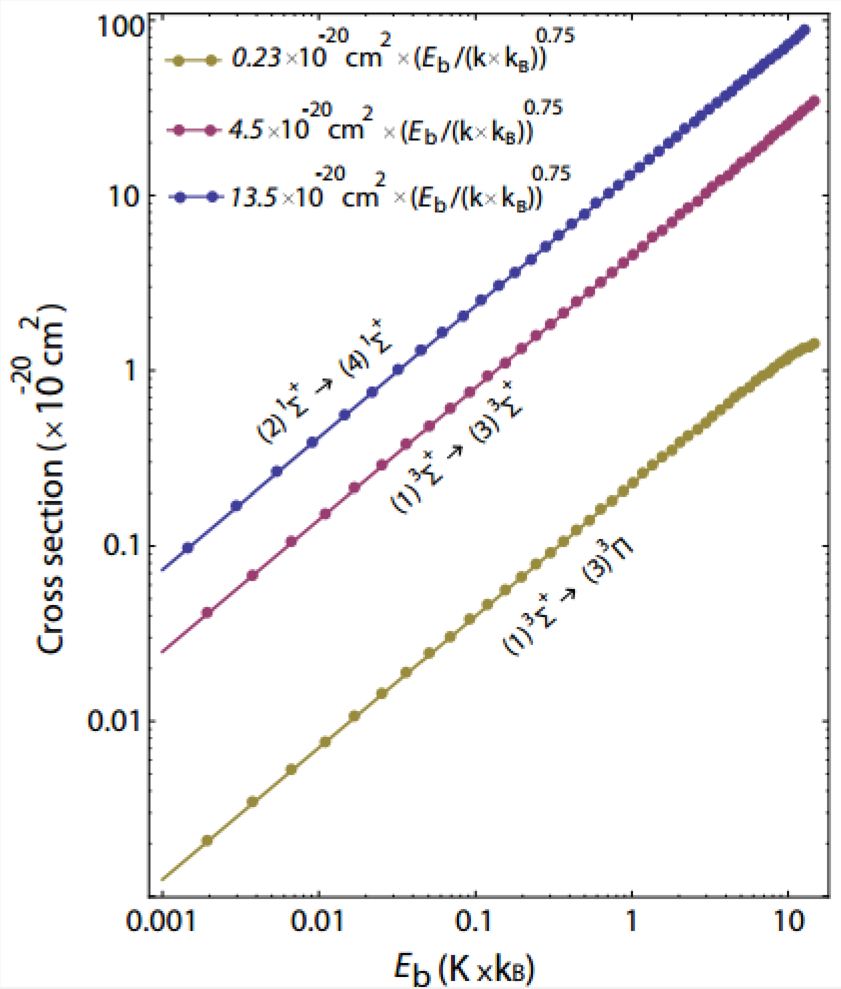


exit channel

entrance channel

Laser: $16 kW/cm^2$, 1064 nm, 9398.5 cm^{-1}





State-to-state absorbing cross section

$$\sigma_v = \frac{4\pi^2}{3C} h v \left| \langle \Lambda_f, E_{cont} \left| D \quad (r) \right| \Lambda_i, \mathrm{v} \rangle \right|^2$$

$(2)^1\Sigma^+$ - $(4)\ ^1\Sigma^+$ dominated

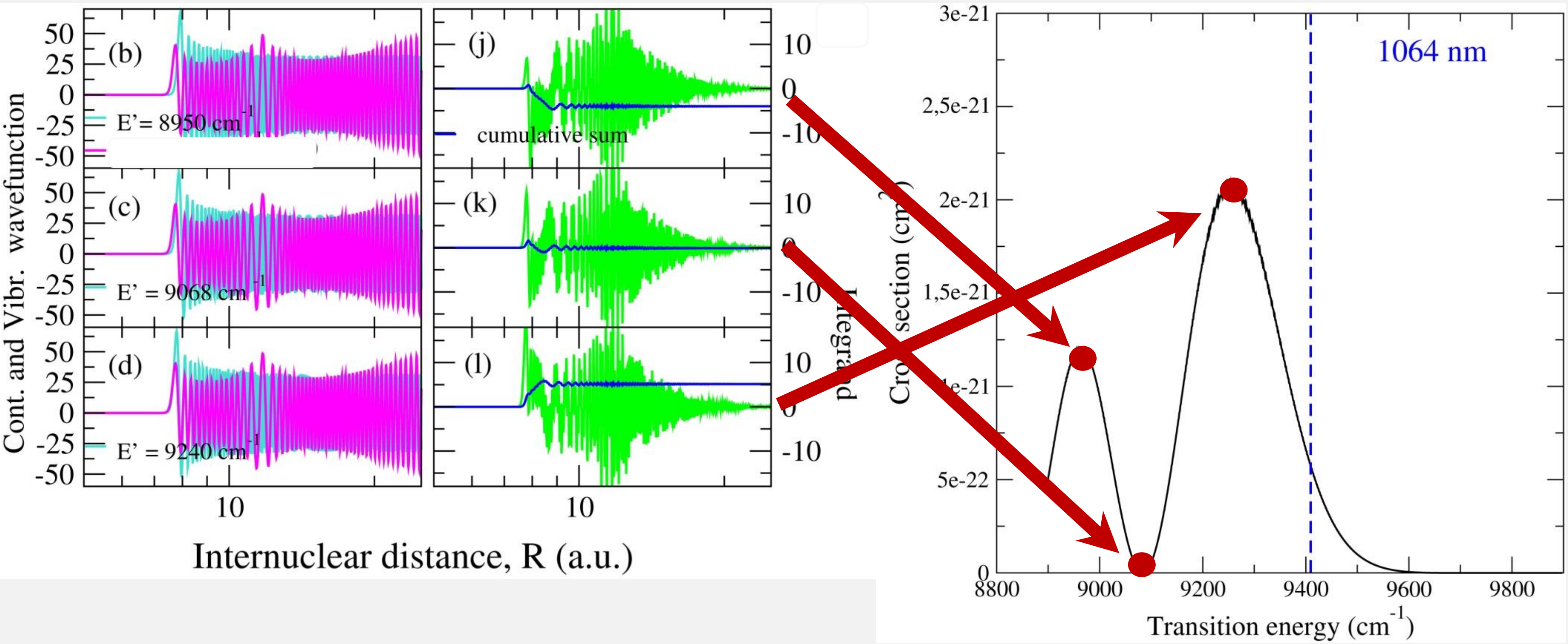
Theoretical data:
$13.5 \times 10^{-20}\ \mathrm{cm}^2 \times (E_b/(\mathrm{K} \times k_B))^{0.75}$

Experimental data:
$340 \times 10^{-20}\ \mathrm{cm}^2 \times (E_b/(\mathrm{K} \times k_B))^{0.75}$

State-to-state absorbing cross section

$$(2)^1\Sigma^+ - (4)^1\Sigma^+$$

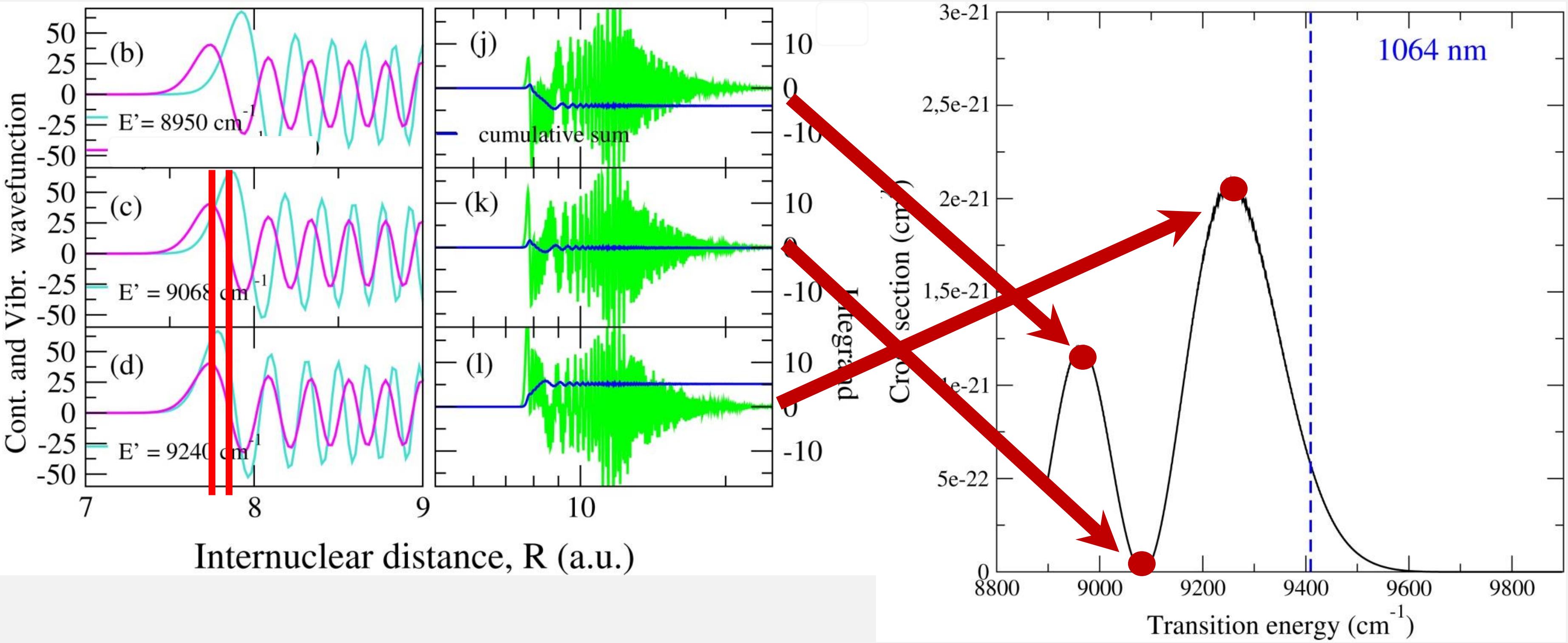
$V = -4$, $E_b = 0.86$ mk k_B



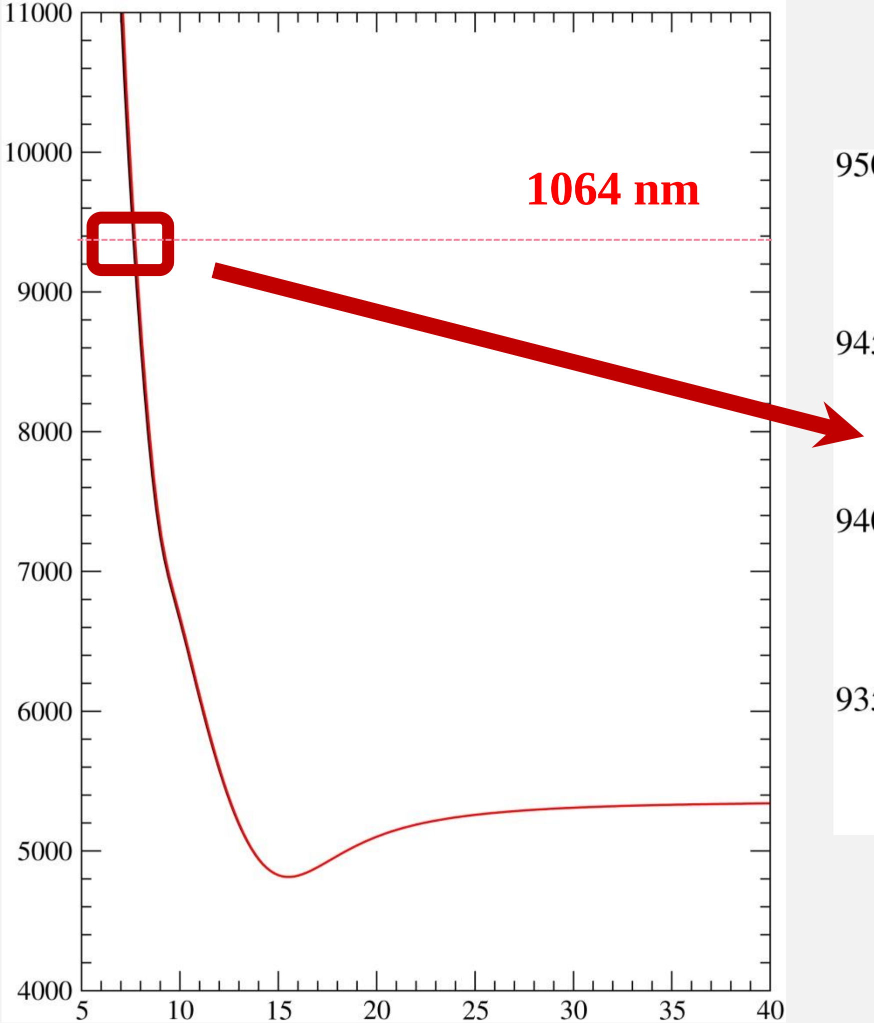
State-to-state absorbing cross section

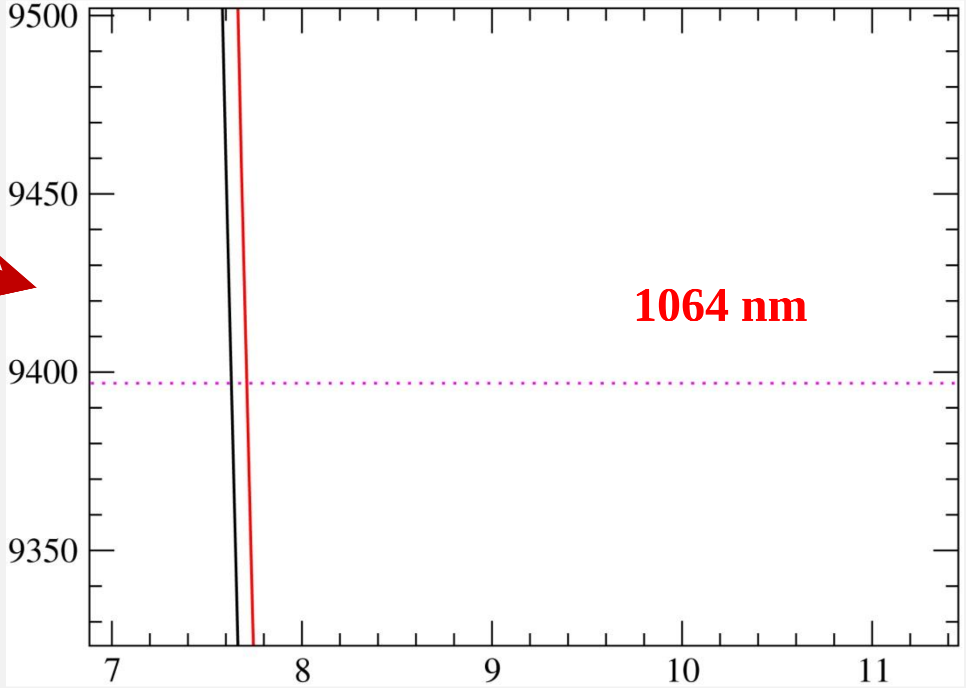
$$(2)^1\Sigma^+ - (4)^1\Sigma^+$$

V = -4, E_b = 0.86 mk k_B



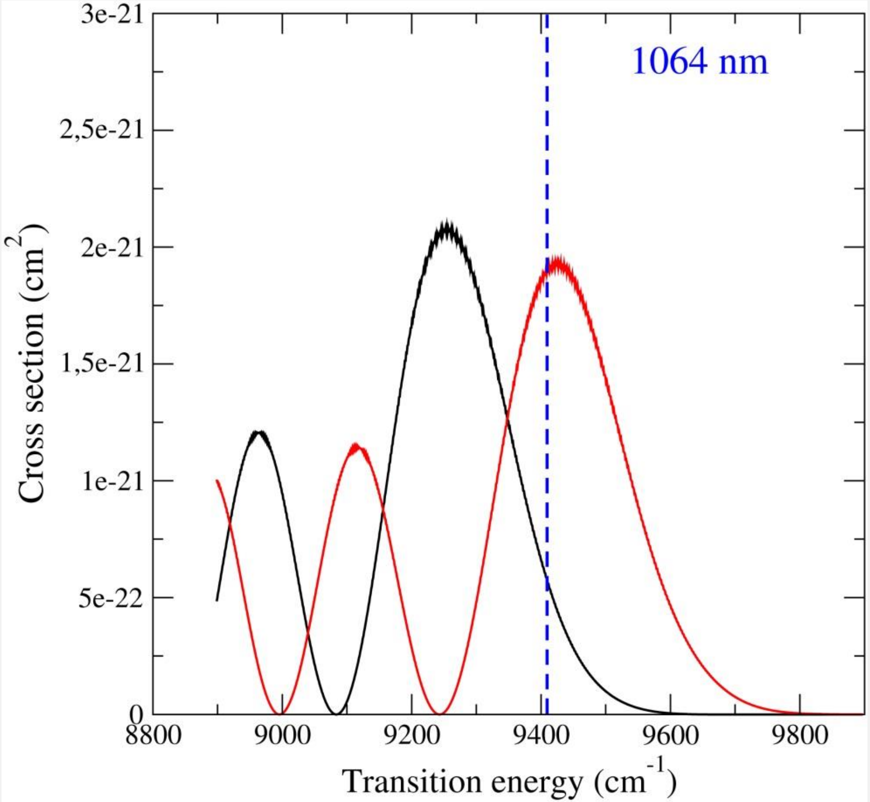
Artifical $(4)^1\Sigma^+$





~ 0.1 a.u.

State-to-state absorbing cross section for Artifical $(4)^1\Sigma^+$



Theoretical data:

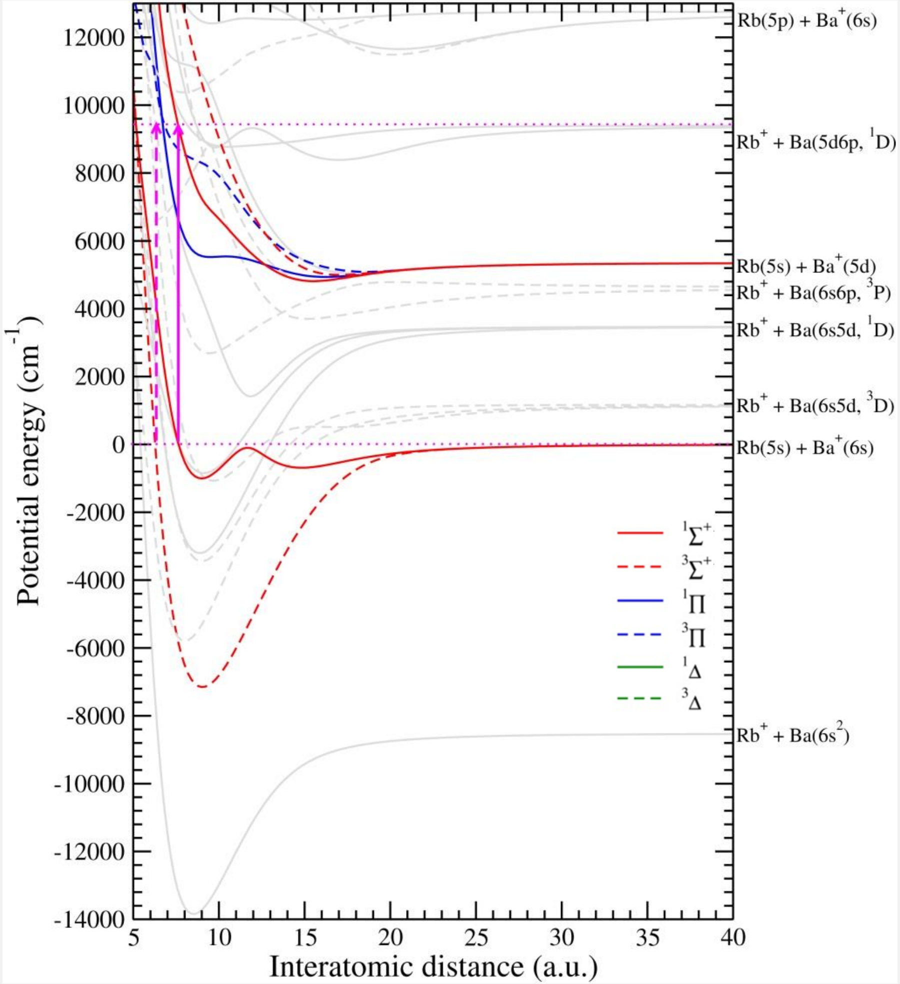
$135 \times 10^{-20}\ \mathrm{cm}^2 \times (E_b/(\mathrm{K} \times k_B))^{0.75}$

Experimental data:

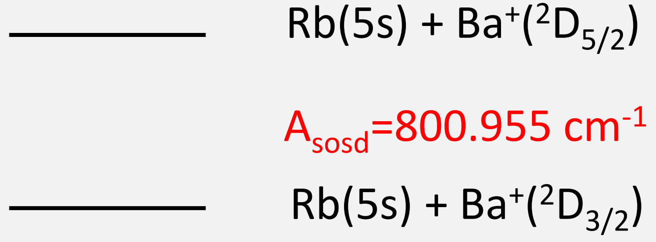
$340 \times 10^{-20}\ \mathrm{cm}^2 \times (E_b/(\mathrm{K} \times k_B))^{0.75}$

Hot Ba^+ in Hund's case a

Hot Ba^+ in Hund's case c



Potential energy (cm^{-1})
Interatomic distance (a.u.)
Rb(5p) + Ba^{+}(6s)
Rb^{+} + Ba(5d6p, ^{1}D)
Rb(5s) + Ba^{+}(5d)
Rb^{+} + Ba(6s6p, ^{3}P)
Rb^{+} + Ba(6s5d, ^{1}D)
Rb^{+} + Ba(6s5d, ^{3}D)
Rb(5s) + Ba^{+}(6s)
Rb^{+} + Ba(6s^{2})
$^{1}\Sigma^{+}$
$^{3}\Sigma^{+}$
$^{1}\Pi$
$^{3}\Pi$
$^{1}\Delta$
$^{3}\Delta$



Rb(5s) + Ba^{+}($^{2}D_{5/2}$)
A_{sosd}=800.955 cm^{-1}
Rb(5s) + Ba^{+}($^{2}D_{3/2}$)

$\Omega = 3$ $H = (A + V(^3\Delta_u))$

Constant A = 2/5A_{sosd}=320.382 cm^{-1}

$\Omega = 2$ $$H = \begin{pmatrix} V(^3\Delta_u) & A & \frac{A}{\sqrt{2}} \\ A & V(^1\Delta_u) & -\frac{A}{\sqrt{2}} \\ \frac{A}{\sqrt{2}} & -\frac{A}{\sqrt{2}} & V(^3\Pi_u)+\frac{A}{2} \end{pmatrix}$$

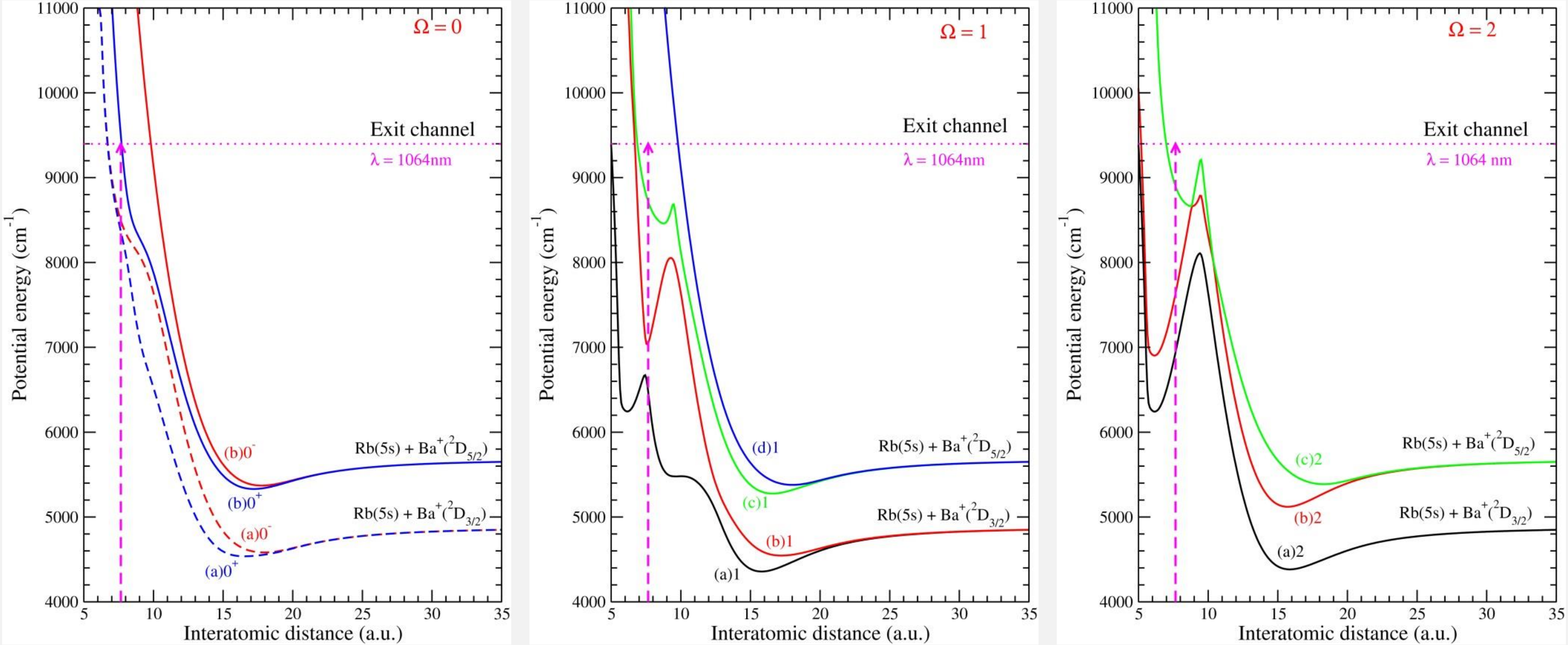
$\Omega = 1$ $$H = \begin{pmatrix} V(^3\Delta_u)-A & \frac{A}{\sqrt{2}} & \frac{A}{\sqrt{2}} & 0 \\ \frac{A}{\sqrt{2}} & V(^3\Pi_u) & \frac{A}{2} & \frac{\sqrt{3}A}{2} \\ \frac{A}{\sqrt{2}} & \frac{A}{2} & V(^1\Pi_u) & -\frac{\sqrt{3}A}{2} \\ 0 & \frac{\sqrt{3}A}{2} & -\frac{\sqrt{3}A}{2} & V(^3\Sigma_u^+) \end{pmatrix}$$

$\Omega = 0^+$ $$H = \begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^1\Sigma_u^+) \end{pmatrix}$$

$\Omega = 0^-$ $$H = \begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^3\Sigma_u^+) \end{pmatrix}$$

J. Lozeille, A. Fioretti, C. Gabbanini, Y. Huang, O. Dulieu *et al*. Eur. Phys. J. D. **39**, 261-269 (2006)

Hund's case C Potential Energy Curves



Ω = 3 $H=(A+V(^3\Delta_u))$

Constant A = 2/5A$_{sosd}$=320.382 cm^{-1}

Ω = 2 $$H=\begin{pmatrix} V(^3\Delta_u) & A & \frac{A}{\sqrt{2}} \\ A & V(^1\Delta_u) & -\frac{A}{\sqrt{2}} \\ \frac{A}{\sqrt{2}} & -\frac{A}{\sqrt{2}} & V(^3\Pi_u)+\frac{A}{2} \end{pmatrix}$$

Ω = 1 $$H=\begin{pmatrix} V(^3\Delta_u)-A & \frac{A}{\sqrt{2}} & \frac{A}{\sqrt{2}} & 0 \\ \frac{A}{\sqrt{2}} & V(^3\Pi_u) & \frac{A}{2} & \frac{\sqrt{3}A}{2} \\ \frac{A}{\sqrt{2}} & \frac{A}{2} & V(^1\Pi_u) & -\frac{\sqrt{3}A}{2} \\ 0 & \frac{\sqrt{3}A}{2} & -\frac{\sqrt{3}A}{2} & V(^3\Sigma_u^+) \end{pmatrix}$$

Ω = 0$^+$ $$H=\begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^1\Sigma_u^+) \end{pmatrix}$$

Ω = 0$^-$ $$H=\begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^3\Sigma_u^+) \end{pmatrix}$$

J. Lozeille, A. Fioretti, C. Gabbanini, Y. Huang, O. Dulieu *et al*. Eur. Phys. J. D. **39**, 261-269 (2006)

Ω = 3 $H = (A + V(^3\Delta_u))$

entrance $^1\Sigma^+$

Constant A = 2/5A_{sosd}=320.382 cm^{-1}

Ω = 2 $$H = \begin{pmatrix} V(^3\Delta_u) & A & \frac{A}{\sqrt{2}} \\ A & V(^1\Delta_u) & -\frac{A}{\sqrt{2}} \\ \frac{A}{\sqrt{2}} & -\frac{A}{\sqrt{2}} & V(^3\Pi_u)+\frac{A}{2} \end{pmatrix}$$

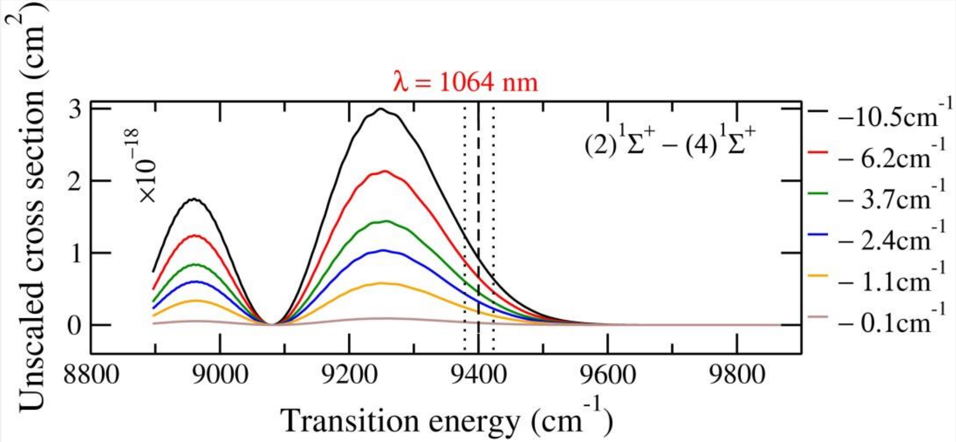
Ω = 1 $$H = \begin{pmatrix} V(^3\Delta_u)-A & \frac{A}{\sqrt{2}} & \frac{A}{\sqrt{2}} & 0 \\ \frac{A}{\sqrt{2}} & V(^3\Pi_u) & \frac{A}{2} & \frac{\sqrt{3}A}{2} \\ \frac{A}{\sqrt{2}} & \frac{A}{2} & V(^1\Pi_u) & -\frac{\sqrt{3}A}{2} \\ 0 & \frac{\sqrt{3}A}{2} & -\frac{\sqrt{3}A}{2} & V(^3\Sigma_u) \end{pmatrix}$$

Ω = 0^+ $$H = \begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^1\Sigma_u^+) \end{pmatrix}$$

Ω = 0^- $$H = \begin{pmatrix} V(^3\Pi_u)-\frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^3\Sigma_u^+) \end{pmatrix}$$

J. Lozeille, A. Fioretti, C. Gabbanini, Y. Huang, O. Dulieu *et al*. Eur. Phys. J. D. **39**, 261-269 (2006)

$$(2)^1\Sigma^+ - (4)^1\Sigma^+$$



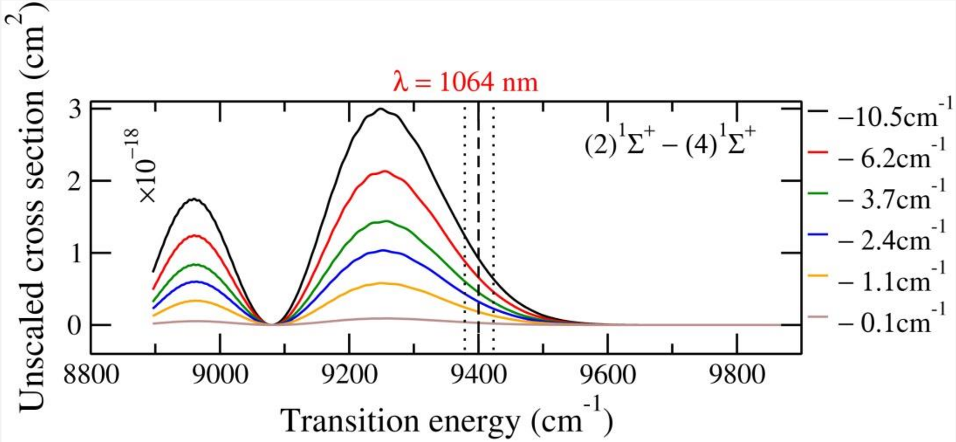
Hund's case A

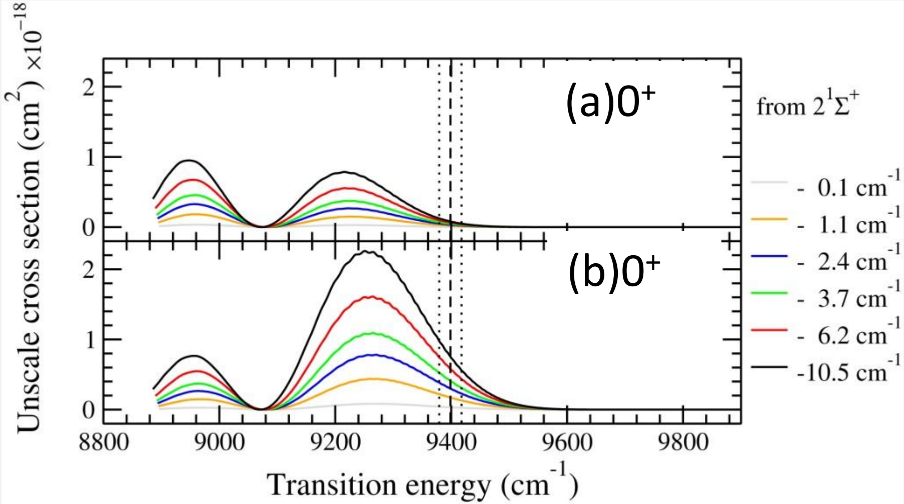
Conclusion and outlook

$$(2)^1\Sigma^+ - (4)^1\Sigma^+$$

For $\Omega = 0^+$

$$H = \begin{pmatrix} V(^3\Pi_u) - \frac{A}{2} & A\sqrt{\frac{3}{2}} \\ A\sqrt{\frac{3}{2}} & V(^1\Sigma_u^+) \end{pmatrix}$$





Hund's case A → **Hund's case C**

Thanks