Control of ultracold molecular gases by optical shielding

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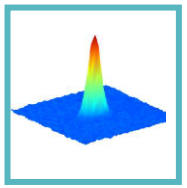
Goal :

Obtain a dense gas (10^{12} -10^{15} cm^{-3}) of ultracold molecules (<<1mK) in their absolute ground state.

Reach quantum degeneracy



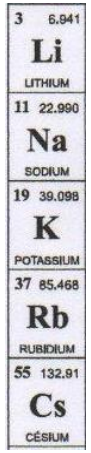
System :

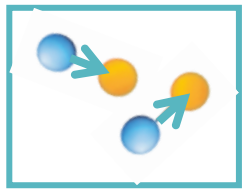
Bi-alkali-metal molecules…

Strong permanent electric dipole moment in ground state

→ Strong long-range interactions

+ Manipulation by external electric field.





Experimentally:

Ultracold samples of

NaRb (Hong-Kong)

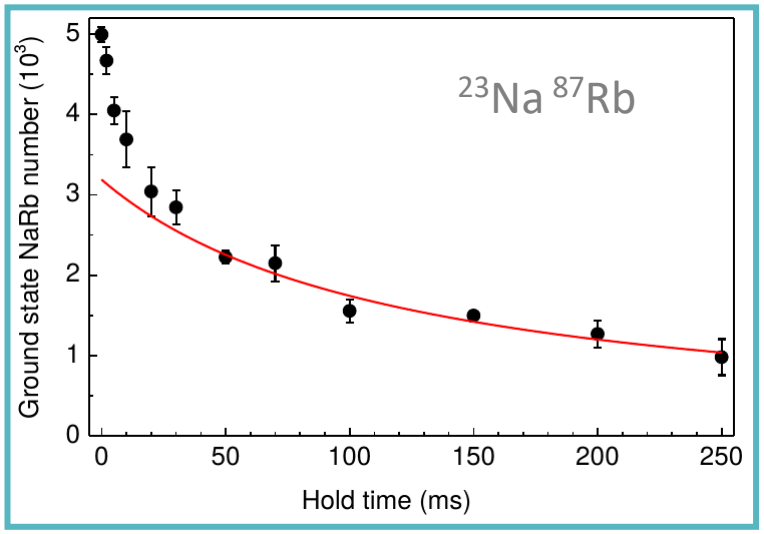
NaK (Hannover, Munich, Dalian, MIT)

RbCs (Durham, Innsbruck)

KRb (JILA, MIT)

LiNa (MIT)

Observed losses:



PRL **116**, 205303 (2016) – Collab: Theomol -Hong-Kong

Problem:

The number of ultracold molecules in the sample decreases for unknown reasons.

Causes are still unknown:

- Reactivity ?
- Sticky collisions?
- Photo-excitation of the tetramer complex by the trapping light?

Solution: Optical Shielding

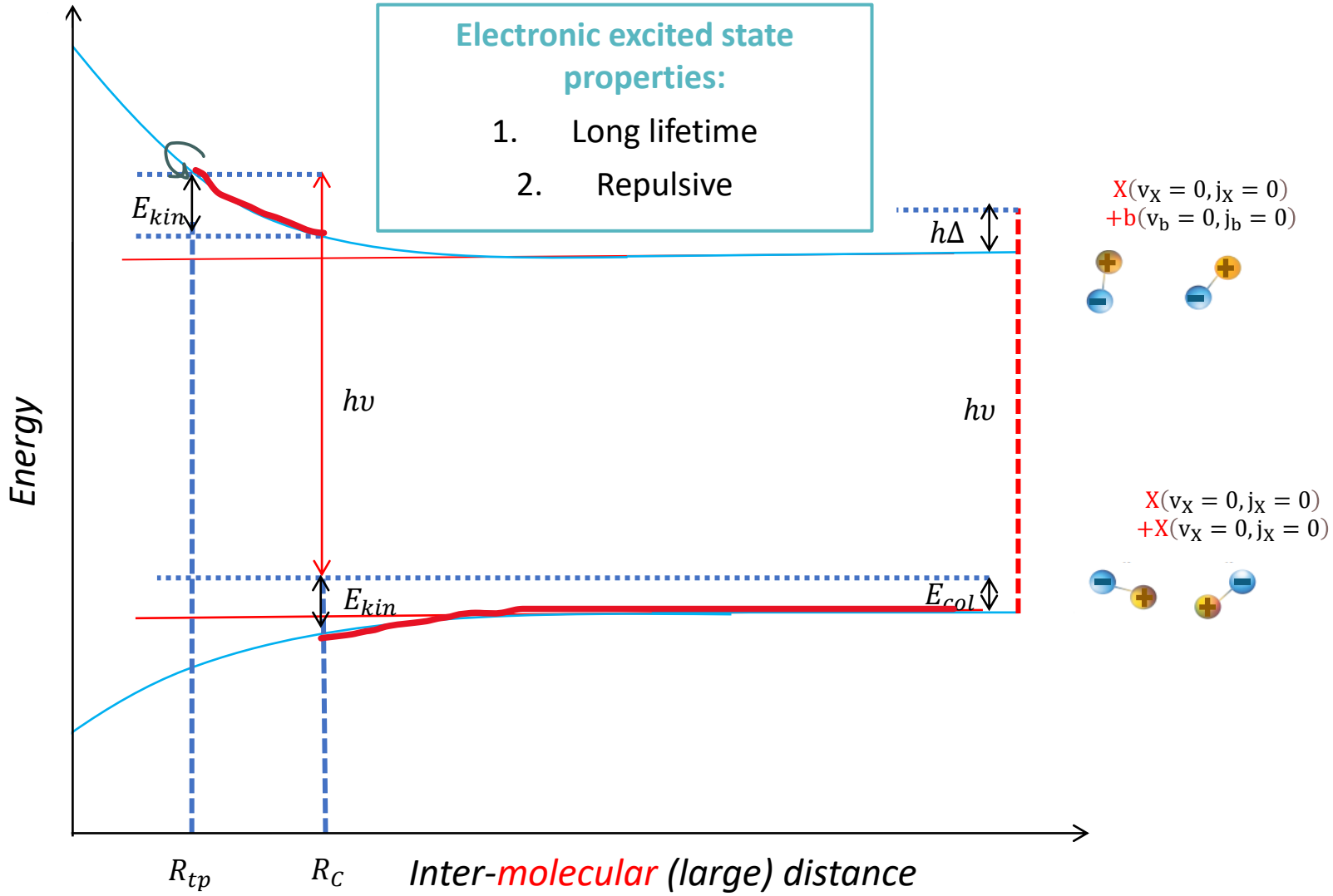
Control the collisions

By Optical Shielding

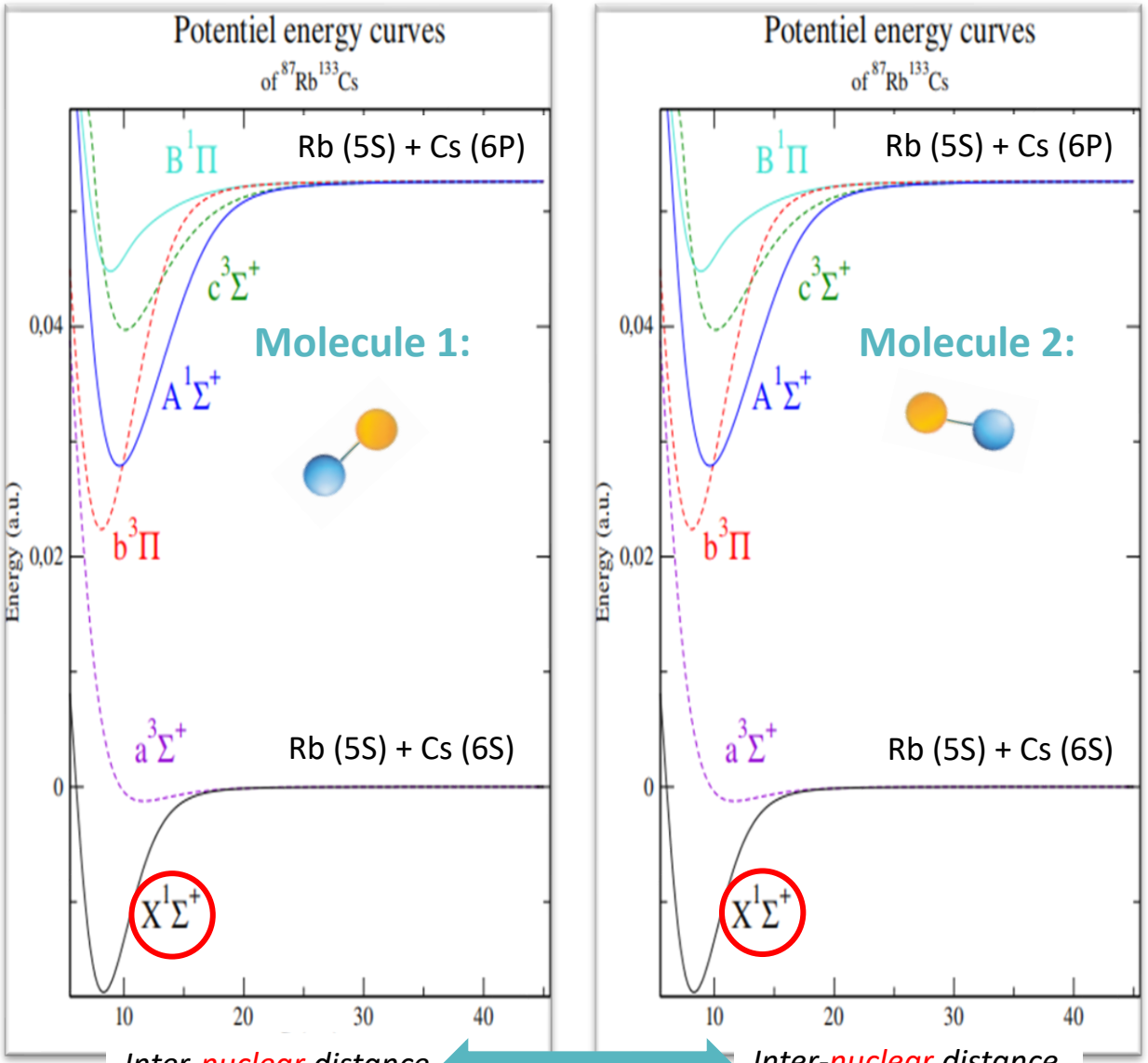
Engineering the long-range interactions between the molecules to prevent their collisions and suppress the losses.

How?

Optical field with a frequency blue-detuned by respect to a specific molecular transition

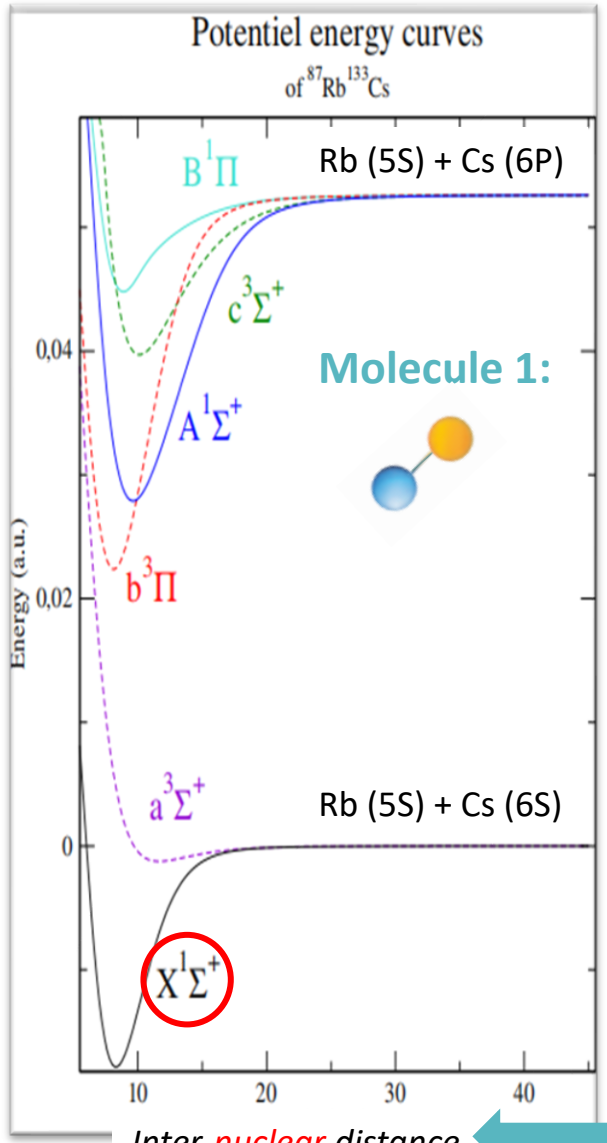


Case 1: two ground state molecules

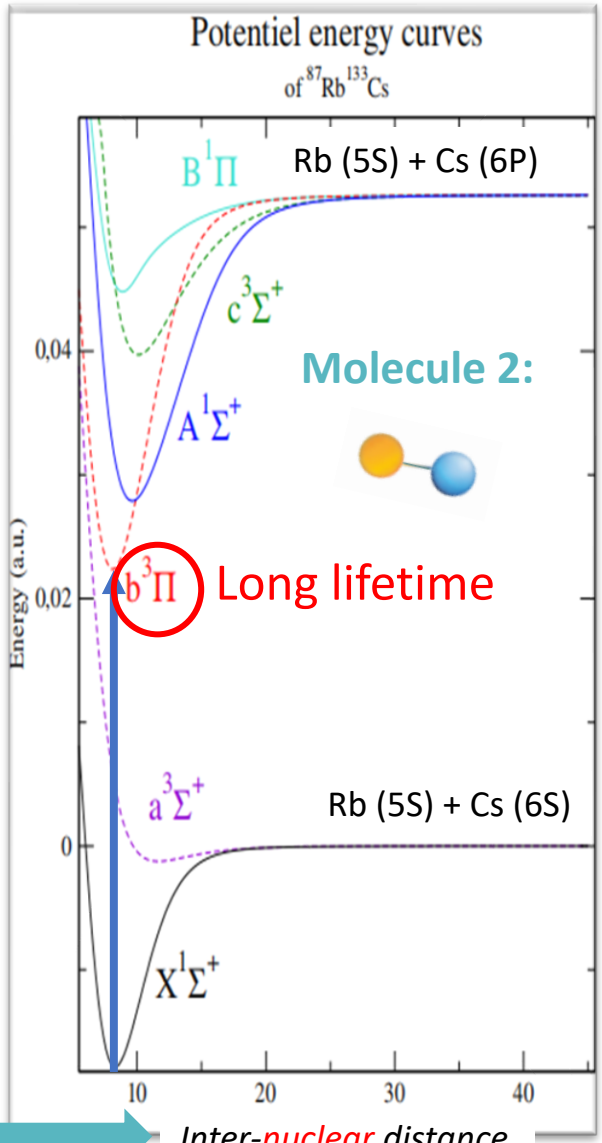


This interaction generates losses.

Case 2: one of the two molecules is electronically excited



What about the long-range interaction between them?



Could it generate a repulsive channel?

Long-range potential energy curves: (field-free)

Studied collision :

$X^1\Sigma^+ (v_X = 0, j_X) + X^1\Sigma^+(v_X = 0, j_X)$

$X^1\Sigma^+ (v_X = 0, j_X) + b^3\Pi(v_b = 0, j_b)$

Notations:

X = Ground electronic state.

b = Excited electronic state.

$v_{X/b}$ = Vibrational state.

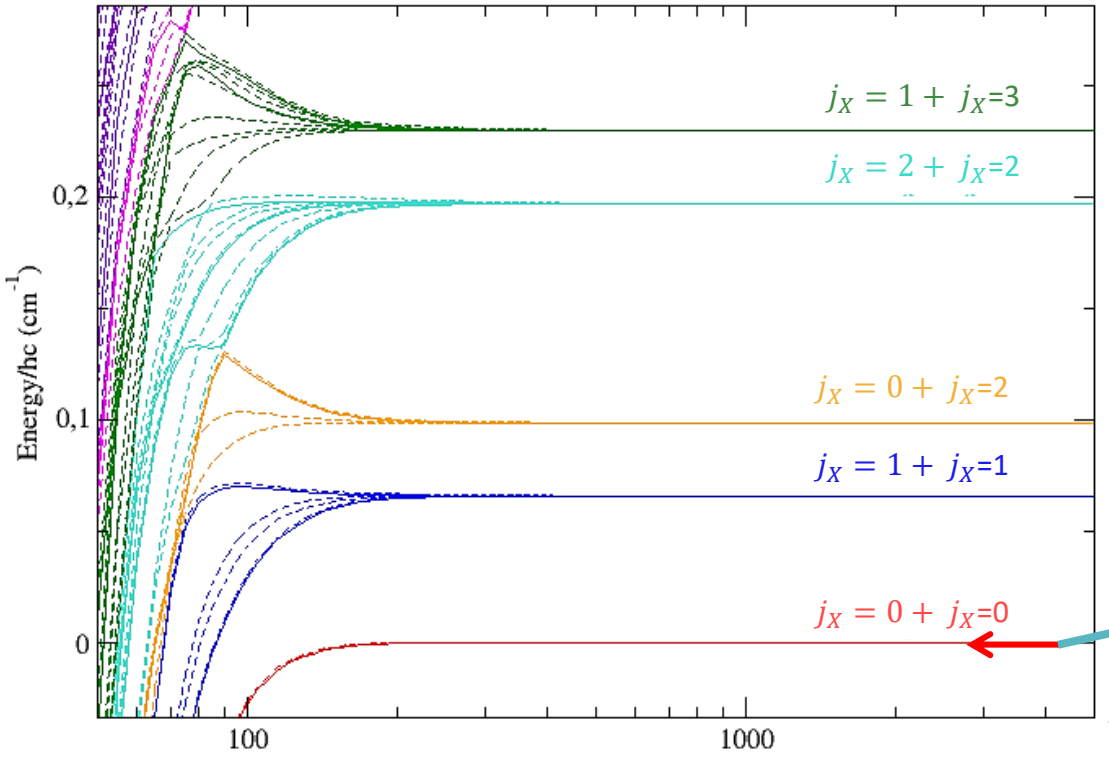
$j_{X/b}$ = Rotational state.

J = Total angular momentum of the system.

Adiabatic Long-range PECs

$X(v_X = 0, j_X) + X(v_X = 0, j_X)$

For J=0 J=2



Inter-molecular distance (a.u.)

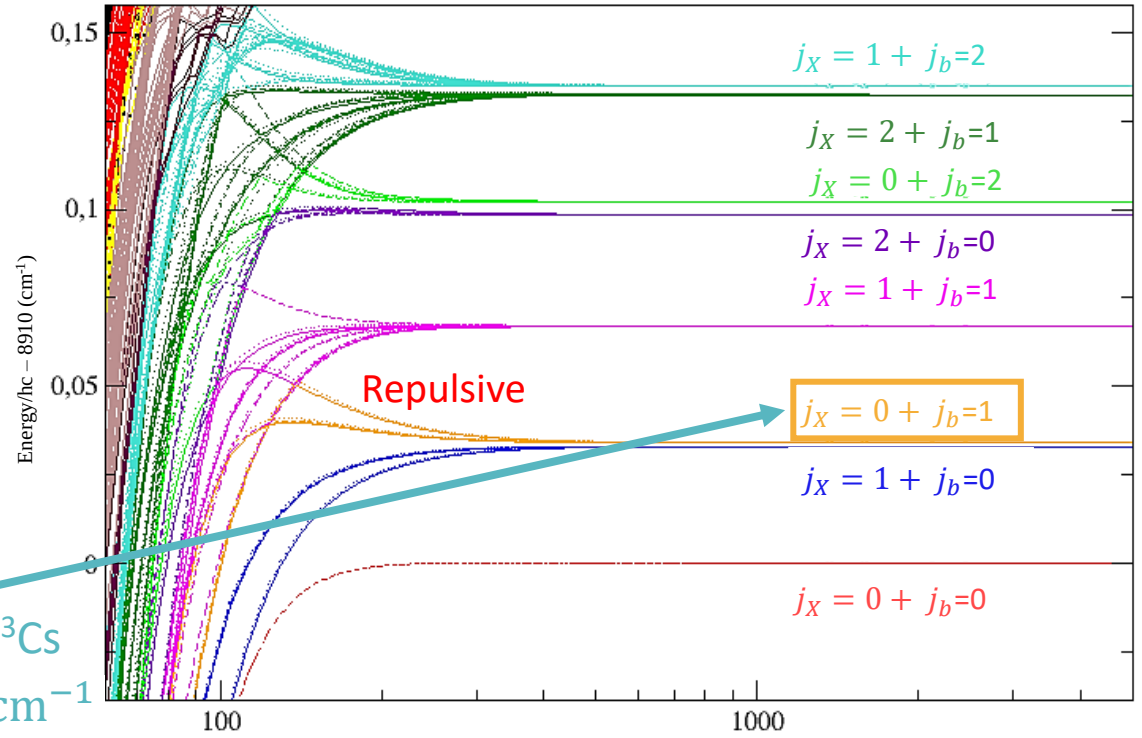
^{87}Rb ^{133}Cs

$\sim 8910\ cm^{-1}$

Adiabatic Long-range PECs

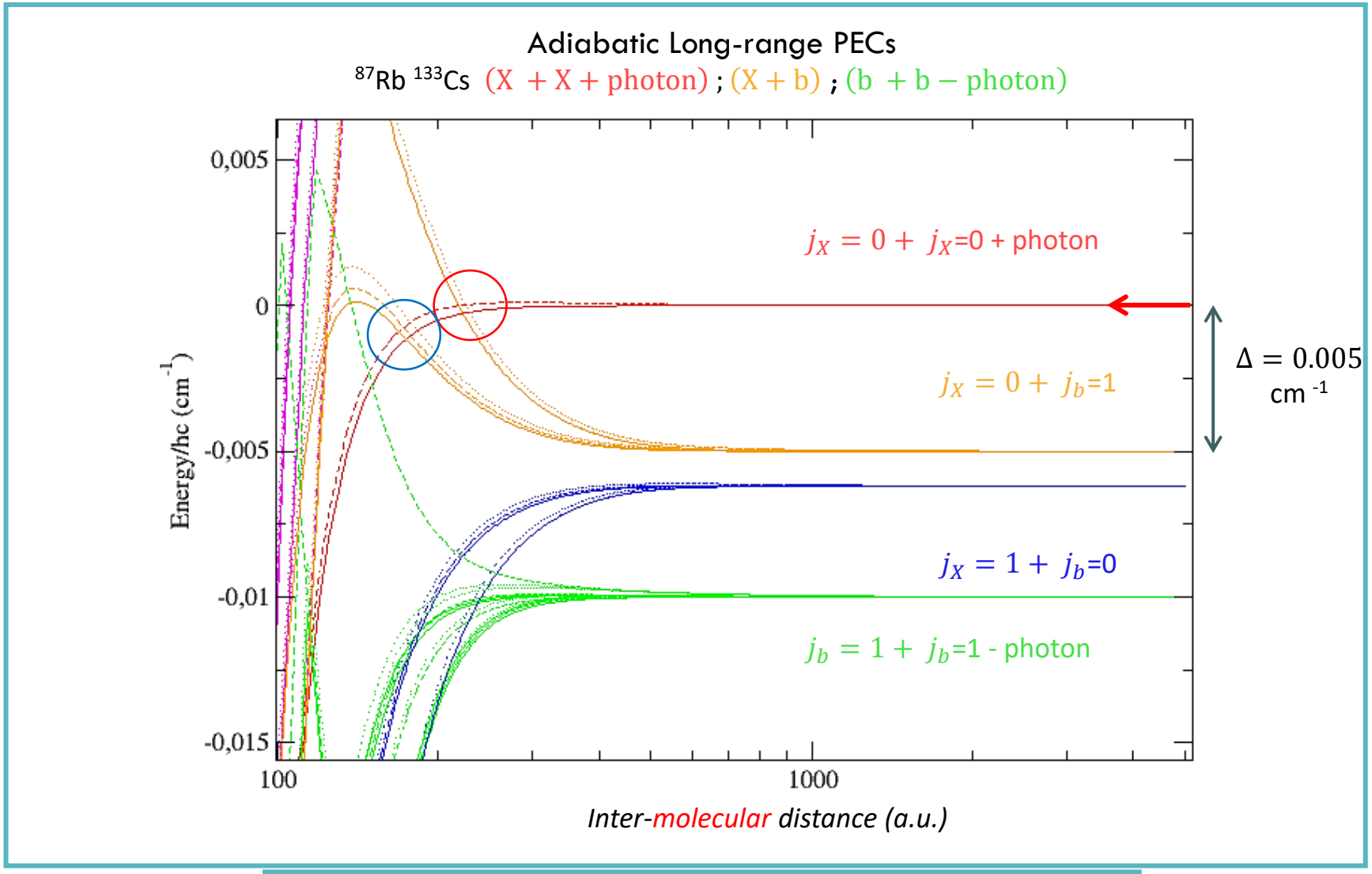
$X(v_X = 0, j_X) + b(v_b = 0, j_b)$

For J=1 J=2 J=3



Inter-molecular distance (a.u.)

The representation in the basis of molecular states dressed by light: Adding the energy of the photon



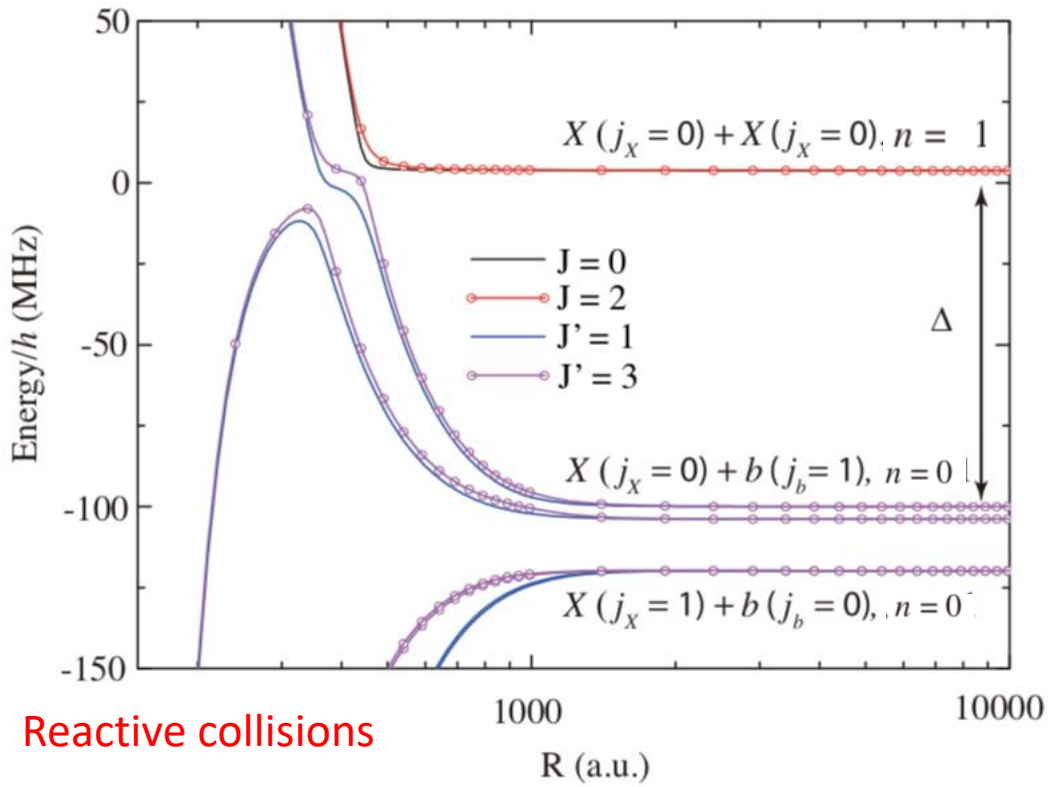
X + (X + Photon) ; X + b

X + (X + Photon) ; b + (b − Photon)

The representation in the basis of molecular states dressed by light: Adding interaction with the photon

Previously calculated for ^{23}Na ^{87}Rb

Phys. Rev. Lett. 125 (2020) T. Xie, M. Lepers, R. Vexiau, A. Orbán, O. Dulieu, N. Bouloufa-Maafa



Elastic collisions

Inelastic collisions

Reactive collisions

Calculation of rates:

- Elastic collisions k_{el}.
- Inelastic collisions k_{in}.
- Reactive collisions k_{re}.

Efficiency of the shielding

$k_{el} >> k_{in}, k_{re}$