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Two-center resonant photoionization in slow atomic collisions & strong laser fields

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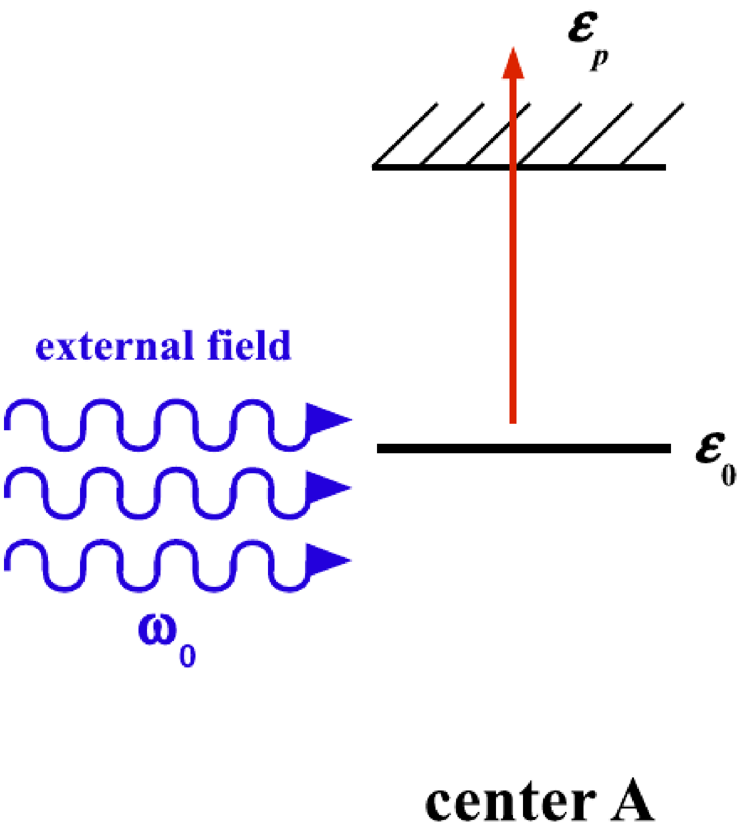
Two-center resonant photoionization:

Introduction

Scheme of the process



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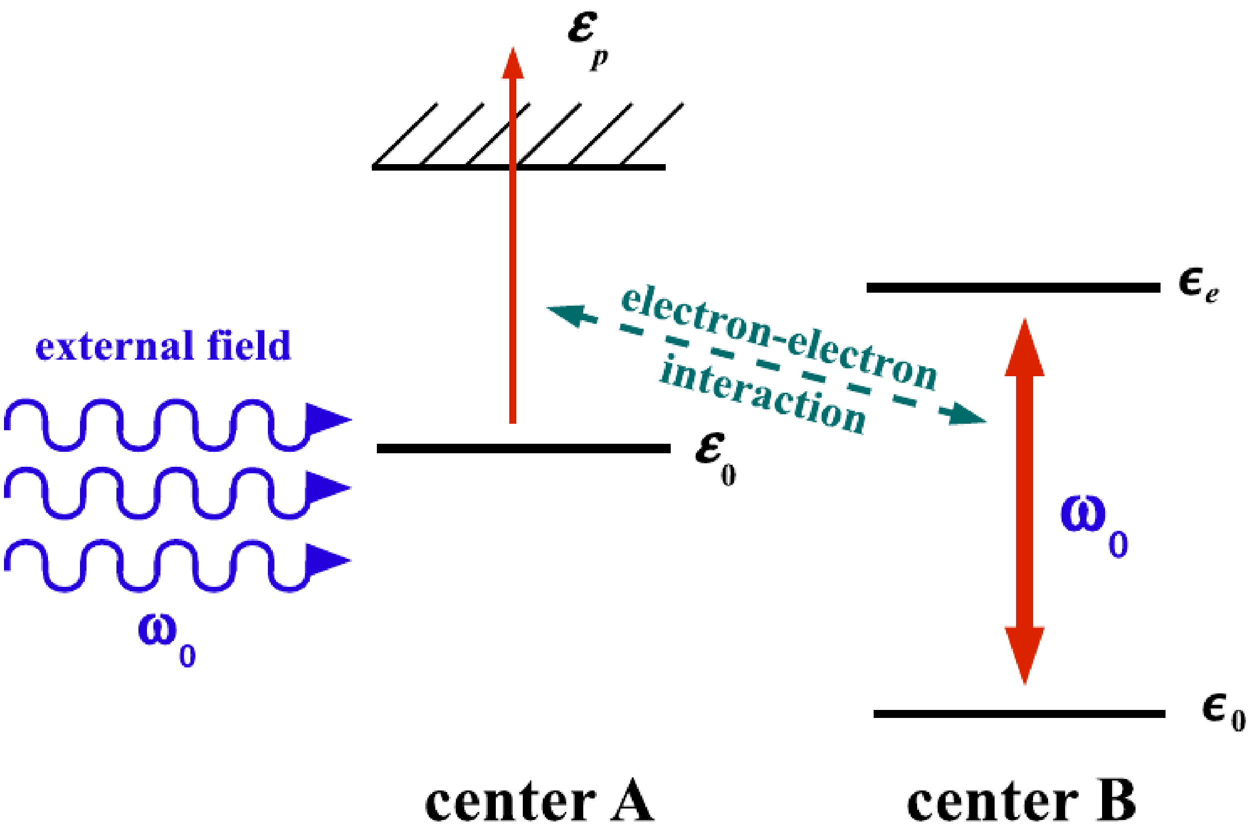

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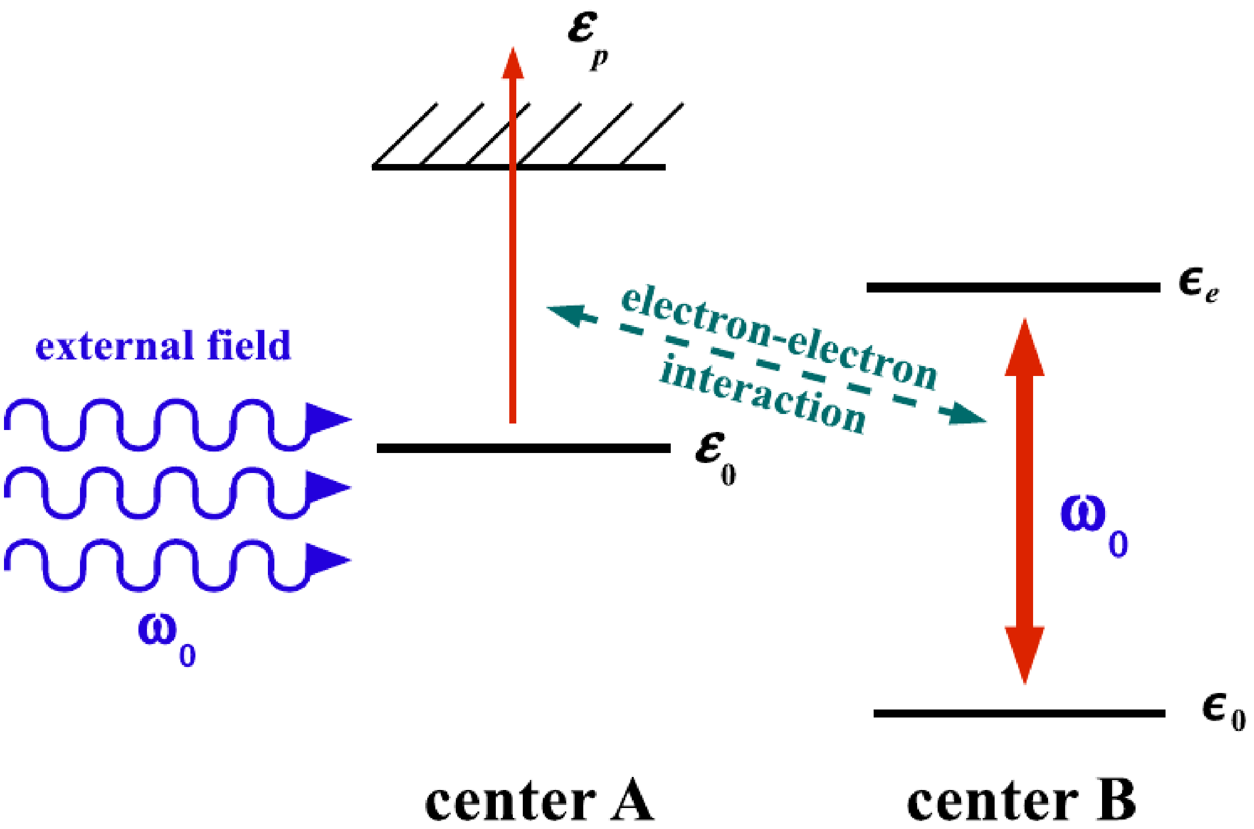


internuclear separation

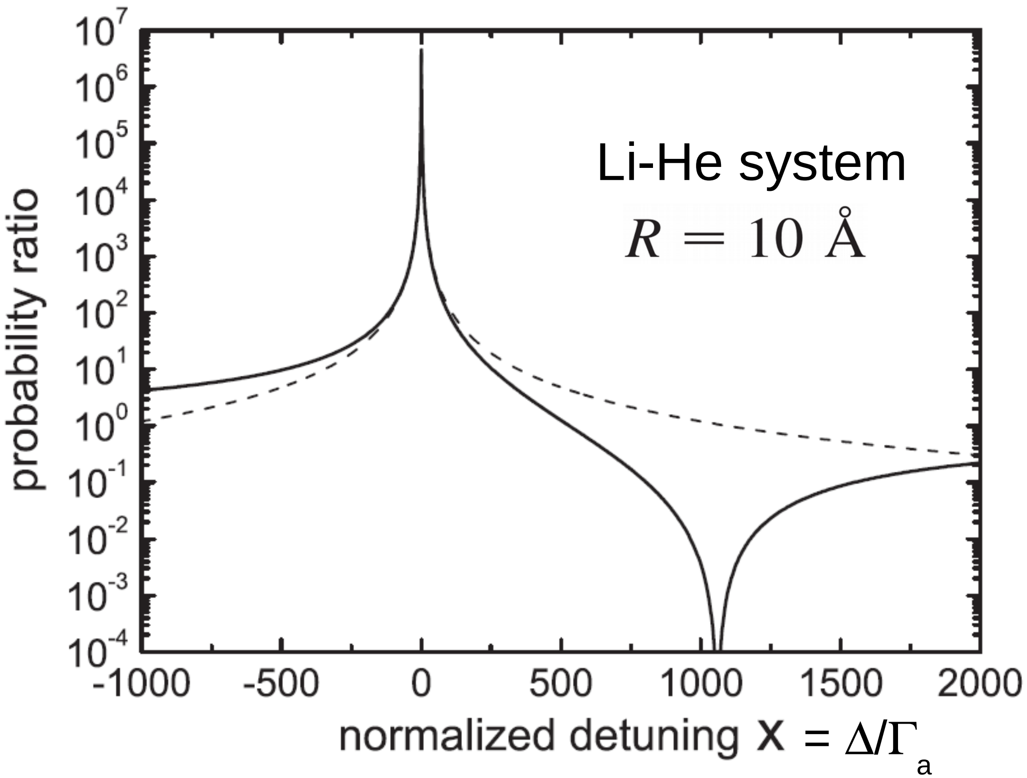
Dipole-dipole coupling:

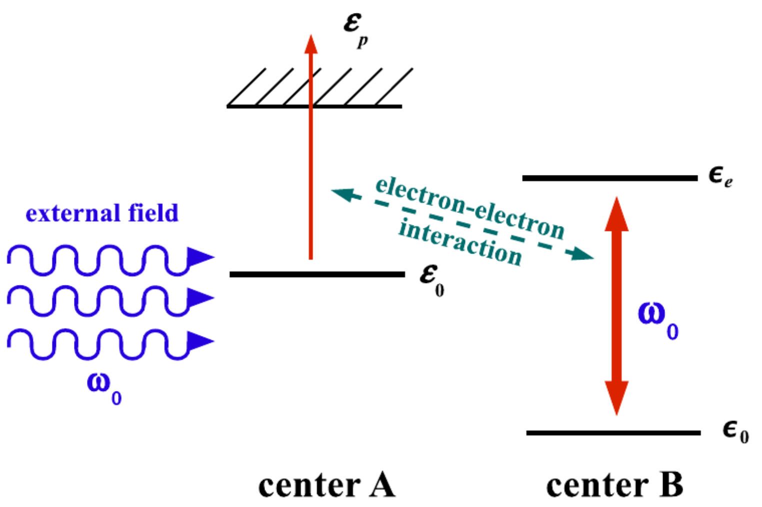
$$\hat{V}_{AB} = \frac{\mathbf{r}\cdot\boldsymbol{\xi}}{R^3} - \frac{3(\mathbf{r}\cdot\mathbf{R})(\boldsymbol{\xi}\cdot\mathbf{R})}{R^5}$$

Probability of the process

$$p^{2CPI} = \int d\Omega_{\mathbf{p}} \left| W^{A}_{\mathbf{p}_0,0} + \frac{V^{ee}_{\mathbf{p}_0,a}\ \tilde{W}^{B}_{e,0}}{\epsilon_0 + \omega_0 - \epsilon_e + i\overline{\Gamma}_a/2} \right|^2$$

direct channel   two-center channel





Theory by Najjari et al., PRL (2010)

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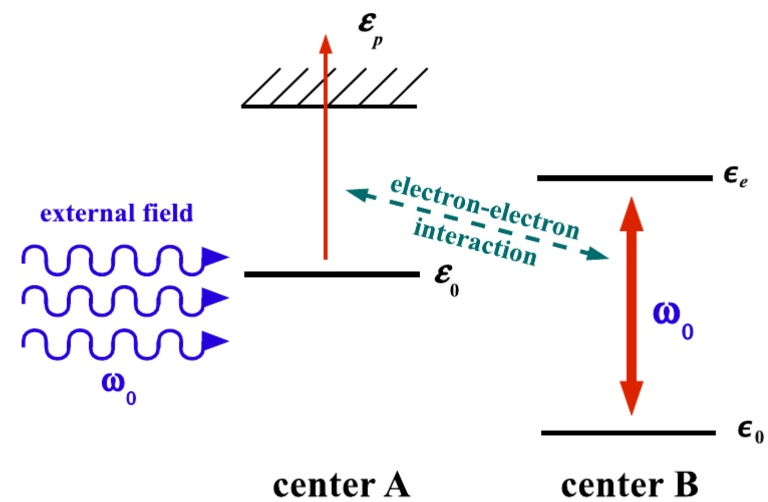
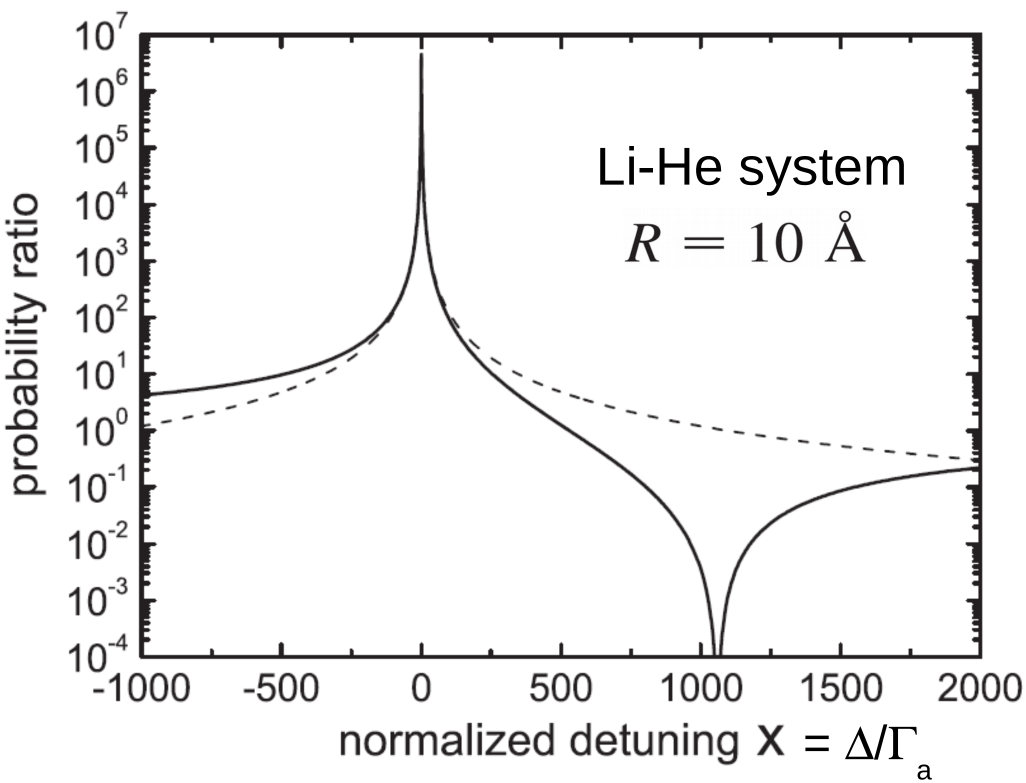




Relative enhancement:

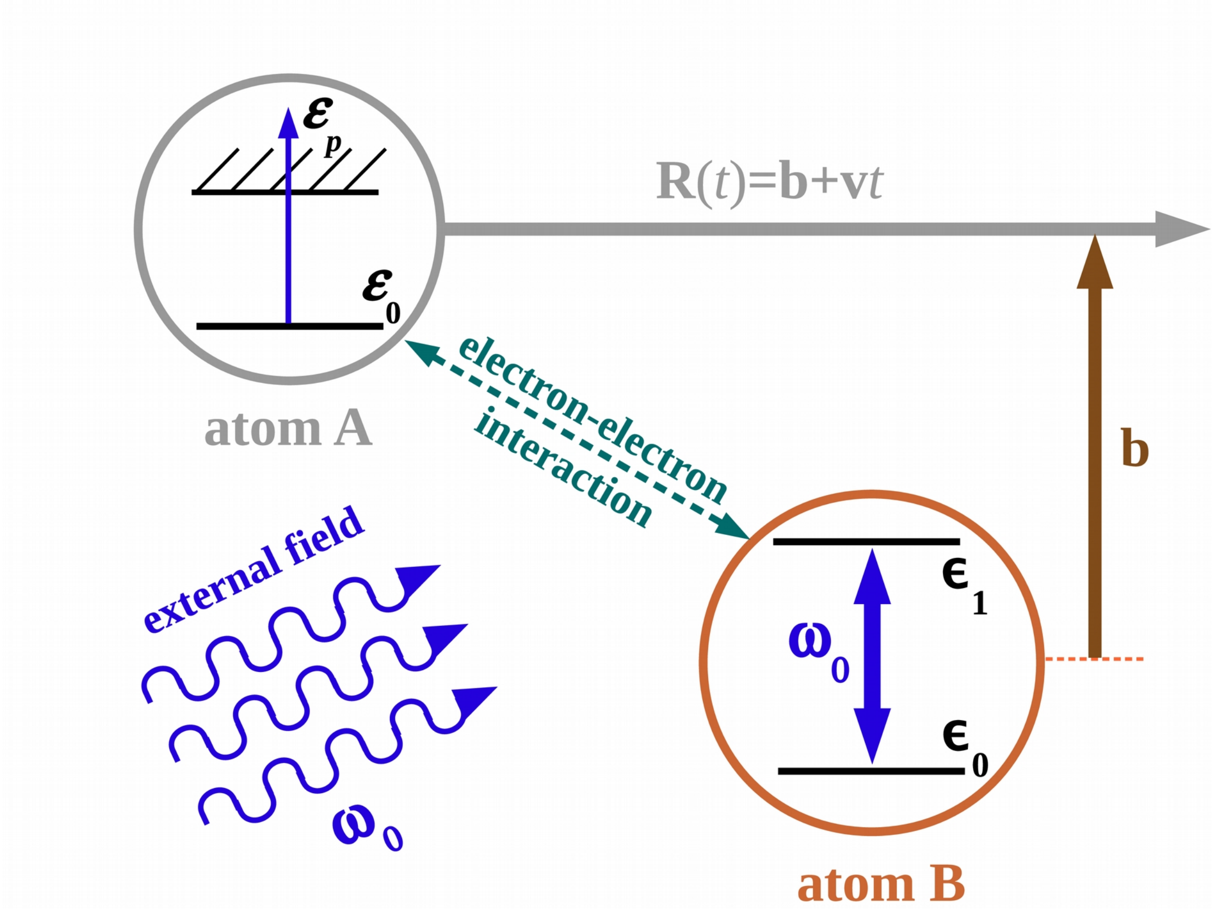
$$\eta \sim (c/R\omega_0)^6$$

Theory by Najjari et al., PRL (2010)

Experiment on He-Ne dimers
by Trinter et al., PRL (2013)

Two-center resonant photoionization in slow atomic collisions

Scheme of the process



At target density n_B~ 10^{10} – 10^{13} cm^{-3} : mean interatomic distance $\bar{R}$ ~ 10^3 – 10^5 Å

➜ **Does the two-center channel become irrelevant ?**

Theoretical description

Classical trajectory: $\mathbf{R}(t) = \mathbf{b} + \mathbf{v}t$

Adiabatic condition: $\omega_0 a_0 / v \gg 1$

$\Big\}$ $50\ \text{eV/u} \lesssim E_{coll} \lesssim 1\ \text{keV/u}$

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Transition amplitude: $a_{0\to\mathbf{p}}^{2c,\pm} = i \int_{-\infty}^{+\infty} dt \exp(i(\varepsilon_p - \varepsilon_0)t) \langle \psi_\mathbf{p} \phi^\pm | \hat{V}_{AB} | \psi_0 \phi^+ \rangle$

Cross section: $$\frac{d\sigma^{2c,\pm}}{d^3\mathbf{p}} = \int_{b_{min}}^{+\infty} db\, b \int_0^{2\pi} d\varphi_\mathbf{b}\, |a_{0\to\mathbf{p}}^{2c,\pm}|^2$$

Theoretical description

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} 50 eV / u $\lesssim E_{coll} \lesssim$ 1 keV / u

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Relative enhancement:

$$\eta \sim \frac{n_B}{b^3_{min}} \left(\frac{c}{\omega}\right)^6$$

„effective“ distance :

$$R_{eff} \sim \sqrt{b_{min} / n_B^{1/3}}$$

Numerical examples

- H and He: ω_0 = 21.2 eV for $1s^2 \rightarrow 1s2p$ transition in helium
  $n_B \sim 10^{13}$ cm^{-3}, target size and photon mean free path ~ 0.1 mm,
  $\eta \geqslant 1$ (taking b_{min} = 5 Å)

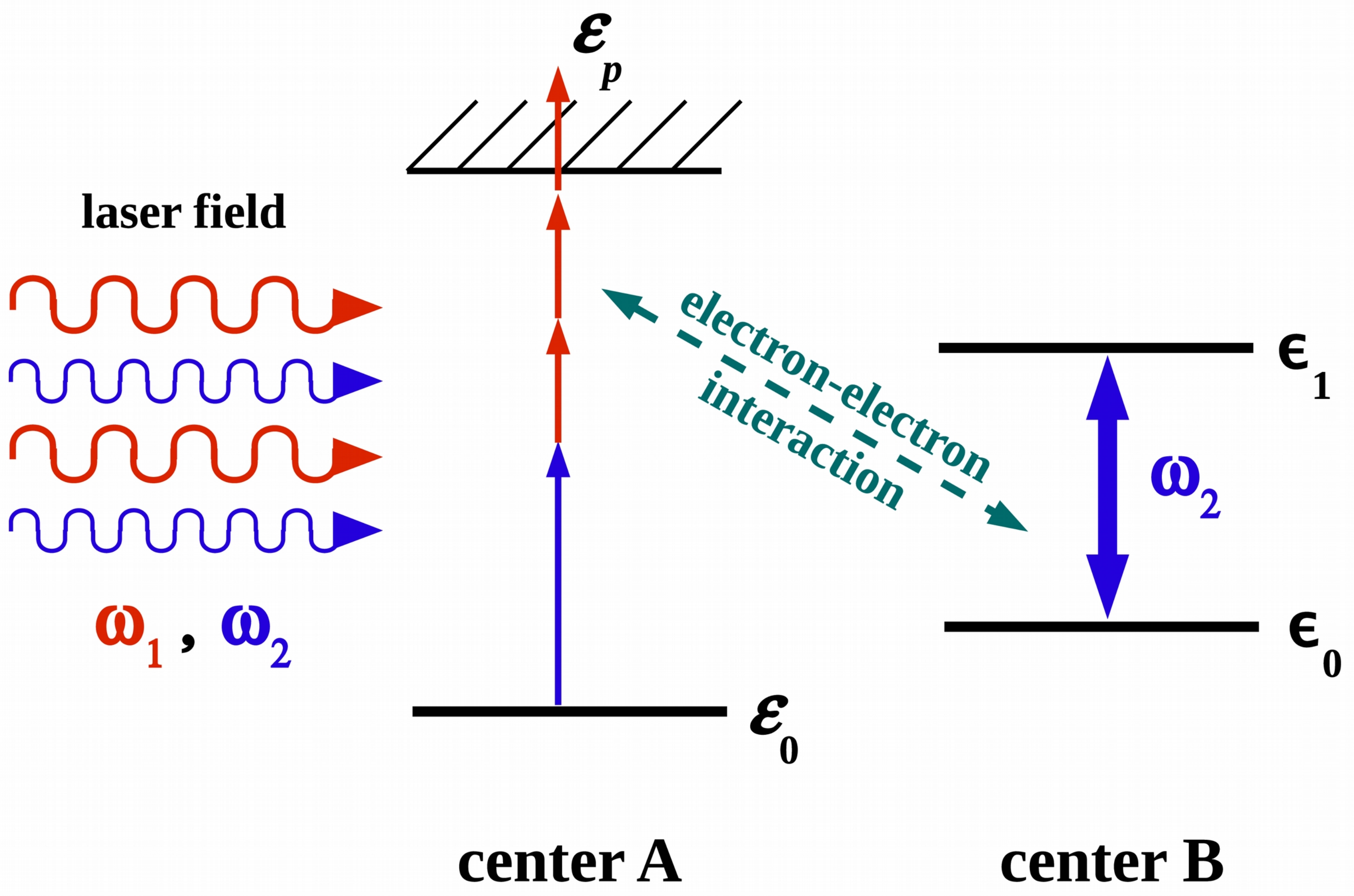
- Li and Mg: ω_0 = 6.1 eV for $3s^2 \rightarrow 3s4p$ transition in magnesium
  $n_B \sim 10^{10}$ cm^{-3}, target size and photon mean free path ~ 5 mm,
  $\eta \geqslant 1$ (taking b_{min} = 5 Å)

- H^- and Rb: ω_0 = 1.59 eV for $5s_{1/2} \rightarrow 5p_{3/2}$ transition in rubidium
  $n_B \sim 10^{10}$ cm^{-3}, target size and photon mean free path ~ 1 mm,
  $\eta \sim 10^3$ (taking b_{min} = 5 Å)
  corresponding experiment planned at IMP, Lanzhou

Voitkiv et al., arXiv:1809.06526

Two-center resonant photoionization
in strong laser fields

Scheme of the process



Theoretical description

Bichromatic laser field: $$\mathcal{A}(t) = \mathcal{A}_1(t) + \mathcal{A}_2(t)$$

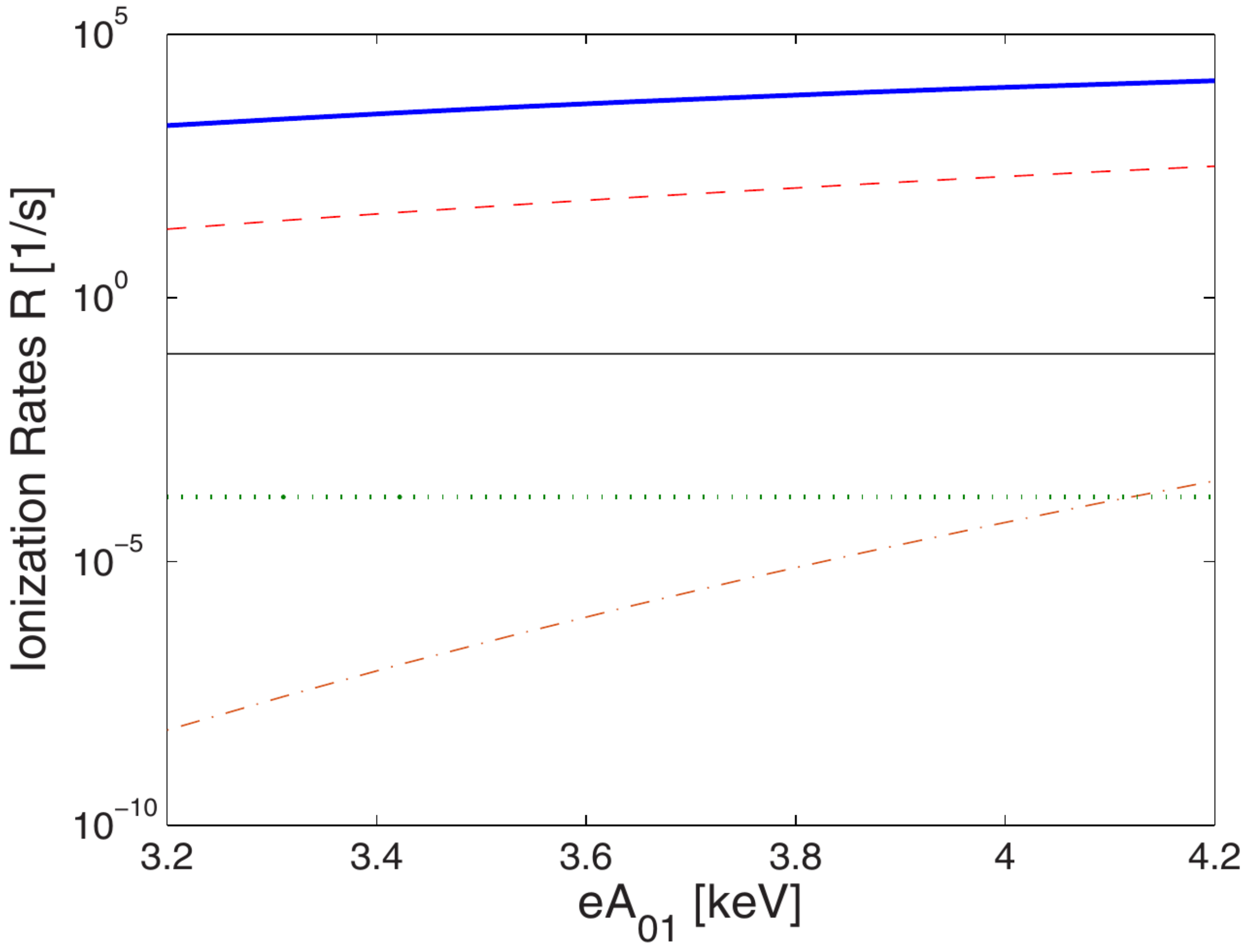
low frequency ω_1 — high (resonant) freq. ω_2

Transition amplitude: $$S_{2\pm} = i \int_{-\infty}^{\infty} dt \, \langle \psi_{\mathbf{p}}^{(\mathcal{A}_1)} \Phi_{\pm} | \hat{V}_{AB} | \varphi_0 \Phi_+ \rangle \, e^{-i\varepsilon_0 t}$$

Volkov state — dressed states

Ionization rate: $$\mathcal{R}_{2+}^{(\mathrm{bi})} = \frac{A_{02}^2 (\Delta - \Omega_B)^2}{R^6[(\Delta - \Omega_B)^2 + 4|W_{10}|^2]^2} \sum_{n \geqslant n_0}^{\infty} \mathcal{G}_n$$

Photoionization in a “He-Ne” system



bichromatic 2CPI

ω_1 = 0.85 eV, ω_2 = 16.85 eV, $I_1 \sim 10^{13}$ W/cm^2, $I_2 \sim 10^6$ W/cm^2, R = 5 Å

Fedyk et al., PRA 98, 033418 (2018)

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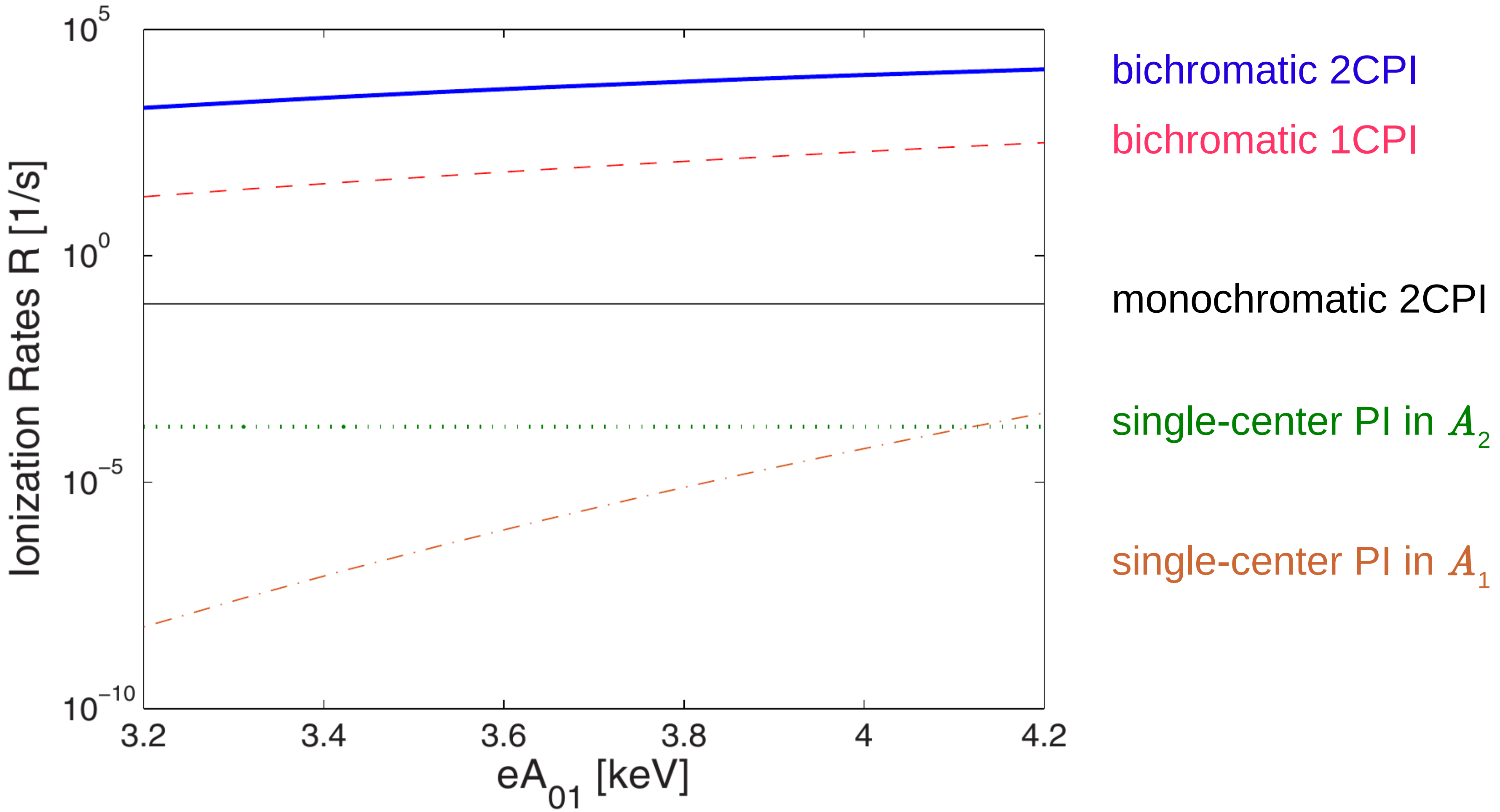

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Conclusion

- Two-center resonant photoionization was generalized to (slow) atomic collisions and relatively strong laser fields.
- Despite the R^{-6} scaling, 2CPI can lead to substantial enhancement of ionization also in collisions; experimental verification planned in H^- - Rb collisions.
- Enhanced ionization occurs in bichromatic fields as well; might be tested with He-Ne dimers in weak soft-xuv beam (resonant) + moderately strong near-optical laser field.

Thank you for your attention!

Semiclassical approximation

Applicability conditions:

- Large incident momentum $P_i \gg 1$ a.u.
- $P_i \approx P_f \gg (2\mu \Delta E)^{1/2}$ with reduced mass μ and inelasticity ΔE
- Small scattering angle $\theta_s \ll 1$

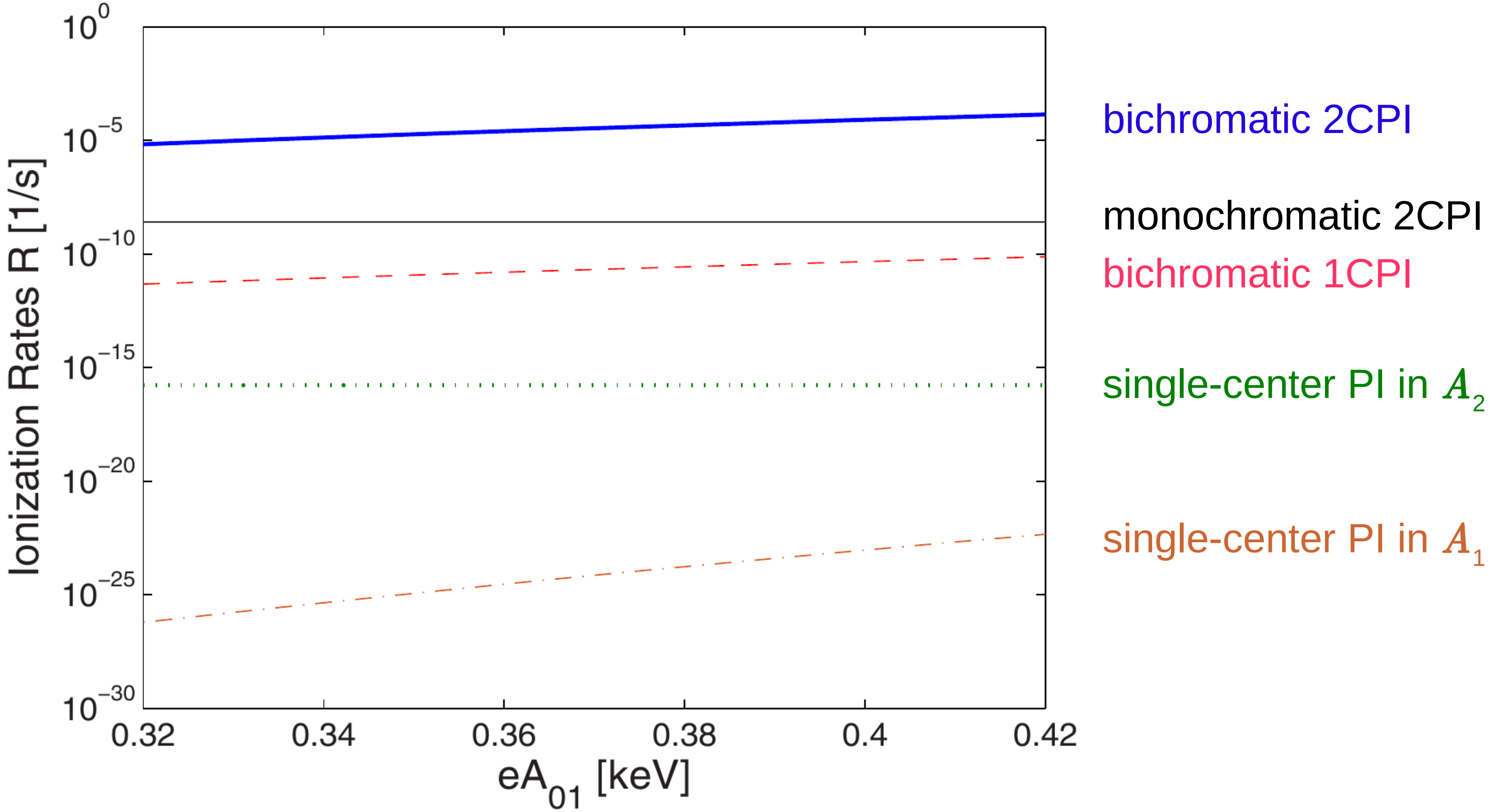
In our case:

- $P_i \sim 100$ a.u. , $\Delta E \approx 0$ due to resonant character of the process
- $\theta_s \sim P_\perp / P_i \ll 1$ with $P_\perp \sim 1/(bv) \sim 1$ a.u

  since $b_{min} \sim 10$ a.u. and $v \sim 0.1$ a.u.

See, e.g., McDowell & Colemann, Introduction to the Theory of Ion-Atom Collisions

Photoionization in a "He-Ne" system



ω_1 = 1.7 eV, ω_2 = 16.85 eV, $I_1 \sim 10^{12}$ W/cm^2, $I_2 \sim 1$ W/cm^2, R = 5 Å

Fedyk et al., PRA 98, 033418 (2018)