Dressed-atom multiphoton spectroscopy：anomalous electromagnetically induced absorption

周祥順

國立台灣海洋大學光電科學研究所

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Introduction: the dressed-atom

Total Hamiltonian: $H = H_A + H_F + H_{AF}$

H_A **: Atomic Hamiltonian**

H_F **: Field Hamiltonian**

H_{AF} **: Interacting Hamiltonian**

Two-level systems

- **Two-level atoms in the presence of a single-mode radiation field**

$$H_A|g\rangle = -\frac{1}{2}\omega|g\rangle$$

$$H_A|e\rangle = \frac{1}{2}\omega|e\rangle$$

$$H_F|n\rangle = \omega_F(n + 1/2)|n\rangle$$

ω : **Atomic frequency** ω_F : **Field frequency**

Uncoupled states (bare states)

Uncoupled Hamiltonian： $H_0 = H_A + H_F$

Uncoupled states： $\left\{ \left|I\right\rangle = \left|g,n\right\rangle \text{，} \left|F\right\rangle = \left|e,n-1\right\rangle \right\}$

$$H_0\left|I\right\rangle = E_I\left|I\right\rangle \quad \text{with} \quad E_I = -\frac{1}{2}\omega + n\omega_F$$

$$H_0\left|F\right\rangle = E_F\left|F\right\rangle \quad \text{with} \quad E_F = \frac{1}{2}\omega + (n-1)\omega_F$$

$$E_F - E_I = (\omega - \omega_F) = \Delta$$

As $\Delta = 0$ ， $E_F = E_I = (n - {}^1\!/_2)\omega$

Coupled states (dressed states)

Dressed states： $H\left|\Psi\right\rangle = E\left|\Psi\right\rangle$

(I) $E = E_{+}(n) = (n - \tfrac{1}{2})\omega + \tfrac{1}{2}\Omega \qquad (\Delta = 0)$

$$\left|\Psi\right\rangle = \left|+,n\right\rangle = \frac{1}{\sqrt{2}}\left[e^{-i\phi_g}\left|g,n\right\rangle + \left|e,n-1\right\rangle\right]$$

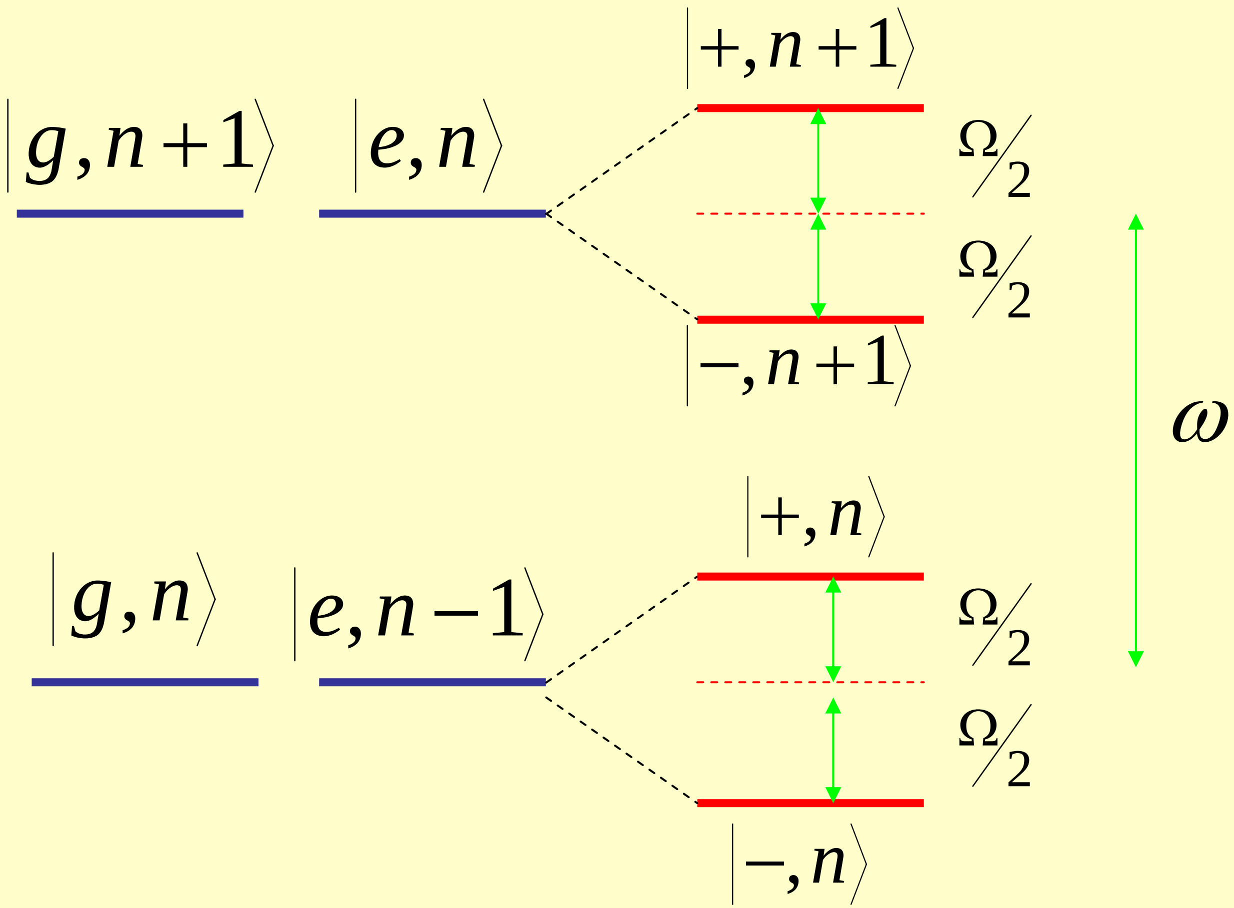
(II) $E = E_{-}(n) = (n - \tfrac{1}{2})\omega - \tfrac{1}{2}\Omega \qquad (\Delta = 0)$

$$\left|\Psi\right\rangle = \left|-,n\right\rangle = \frac{1}{\sqrt{2}}\left[\left|g,n\right\rangle - e^{i\phi_g}\left|e,n-1\right\rangle\right]$$

Rabi frequency : $\Omega = 2\left|q\right|\sqrt{n}$

with $\left\langle e,n-1\right|H_{AF}\left|g,n\right\rangle = q\sqrt{n} = \left|q\right|e^{i\phi_q}\sqrt{n}$

Ladder of energy level

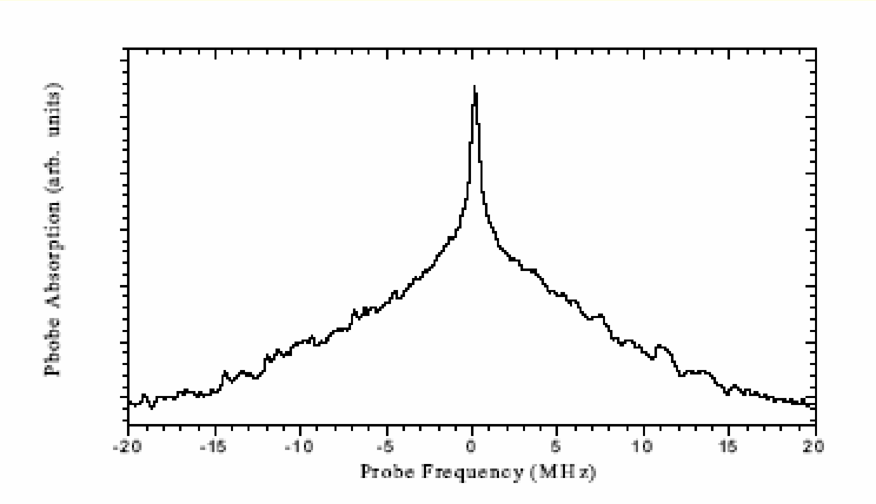


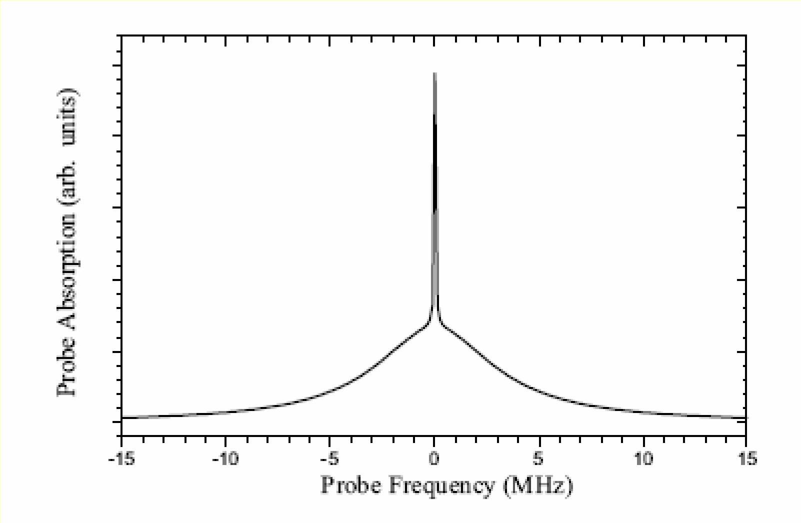
— : **Bare states** — : **Dressed states**

Dressed-atom multiphoton spectroscopy

- In the first step, the coupled system "atoms + coupling photons" is described by the dressed-state wave functions which describe the coupling field to all orders.
- In the second step, we use perturbation theory to treat the probe field.
- Quantum interference arises naturally in the dressed-atom multiphoton spectroscopy.

Electromagnetically induced absorption (EIA)





(1)Experiment

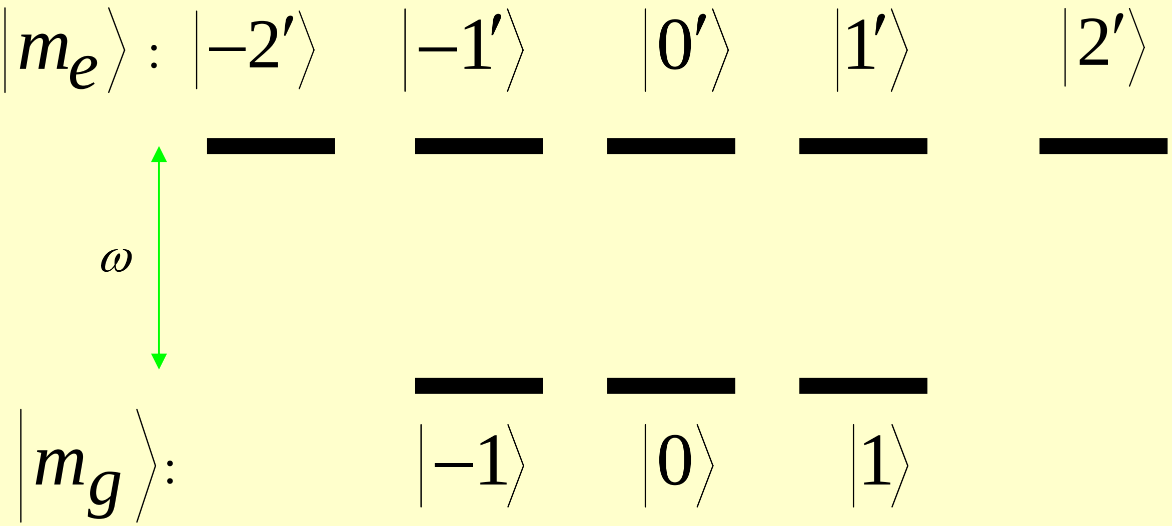
(2)Theory

The absorption of the probe beam is substantially enhanced when copropagating orthogonally polarized probe and coupling beams interact with a degenerate two-level system.

Ref. ：A. M. Akulshin *et al*, Phys. Rev. A57, 2996 (1998).

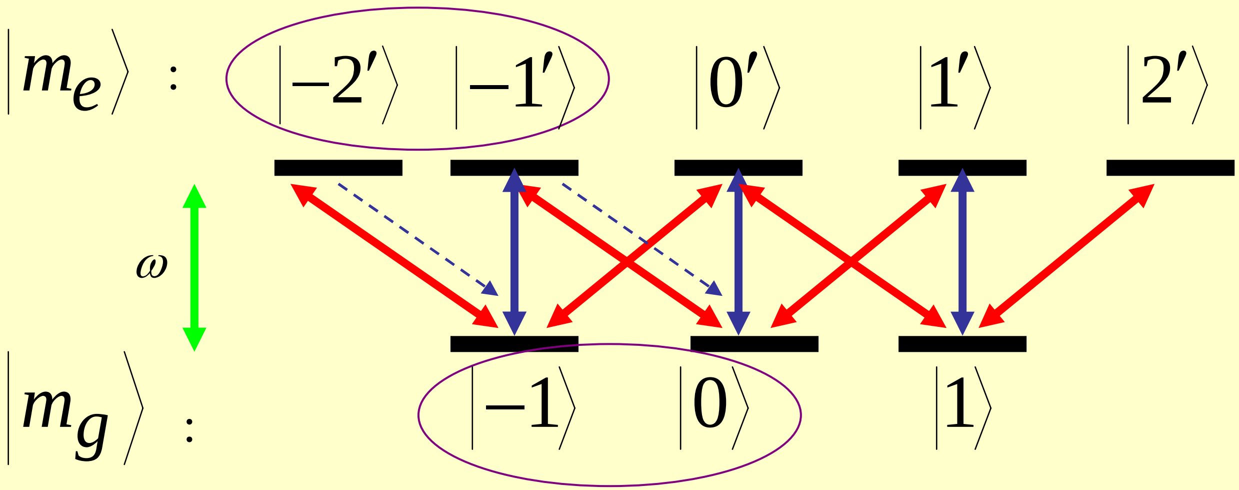
Lezama's condition for EIA

$$F_e = F_g + 1$$



Ref.：A. Lezama *et al*, Phys. Rev. A59, 4732 (1999).

Spontaneous coherence transfer (SCT)



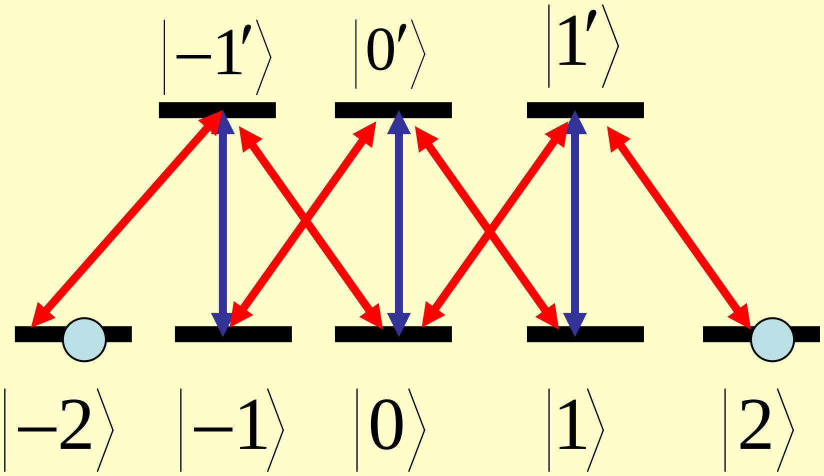
:coupling beam :probe beam :SCT

EIA is caused by the spontaneous transfer of the light-induced Zeeman coherence from the excited level to the ground level.

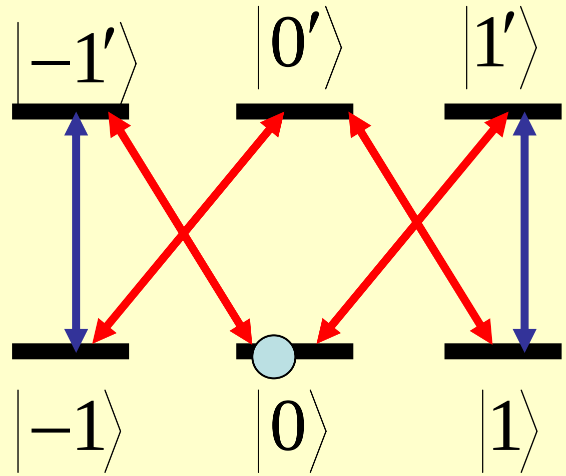
Ref.：A. V. Taichenachev *et al*, JETP Lett. 69 819 (1999).

Interpretations of Lezama's condition

(I): $F_e = F_g - 1$



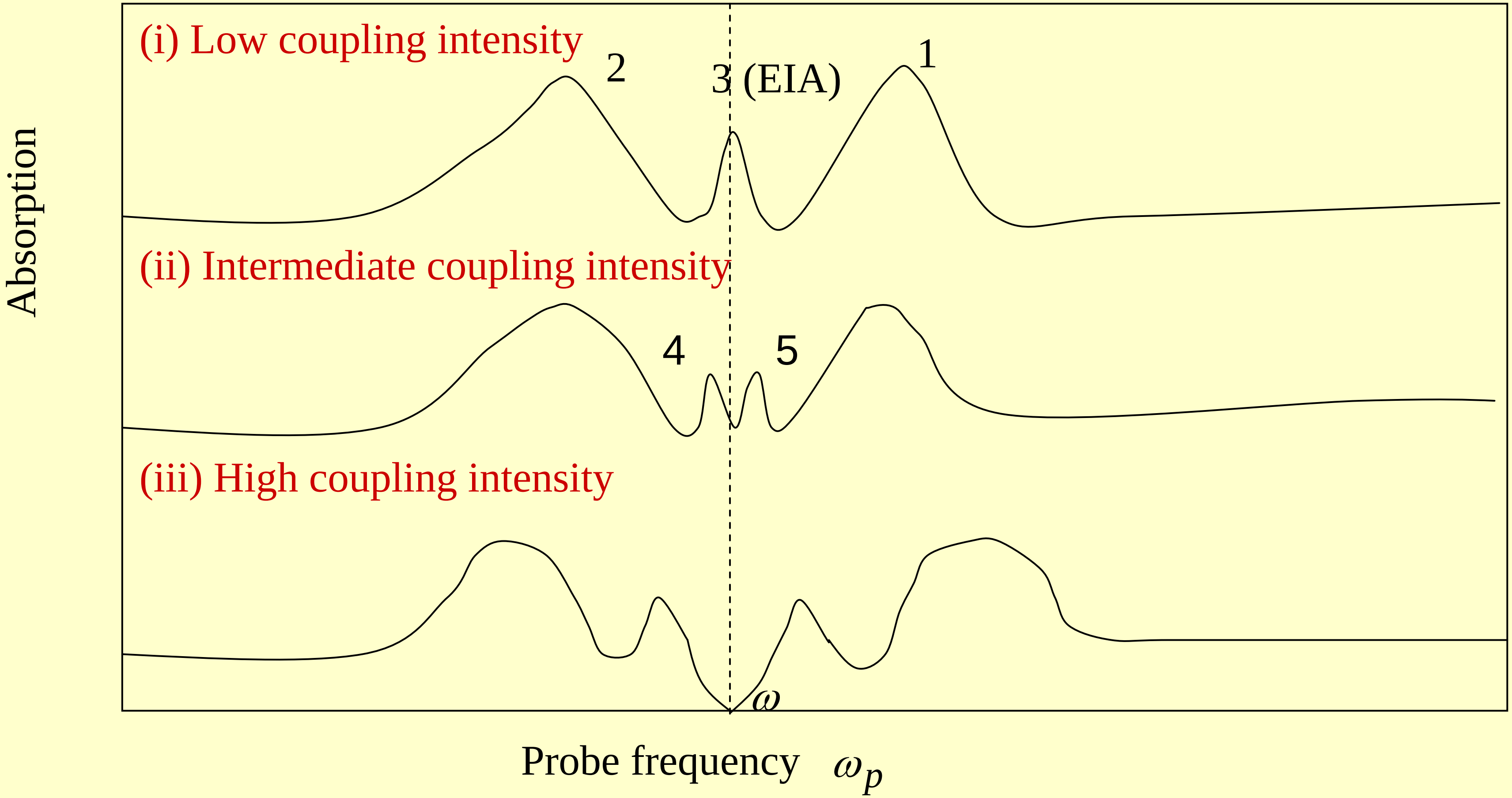
(II): $F_e = F_g$



The excited-state coherences are very small for systems with $F_e = F_g - 1$ and $F_e = F_g$,because the populations are trapped in the lower levels. SCT and EIA can not take place for such systems.

Anomalous EIA $F_e = F_g - 1$

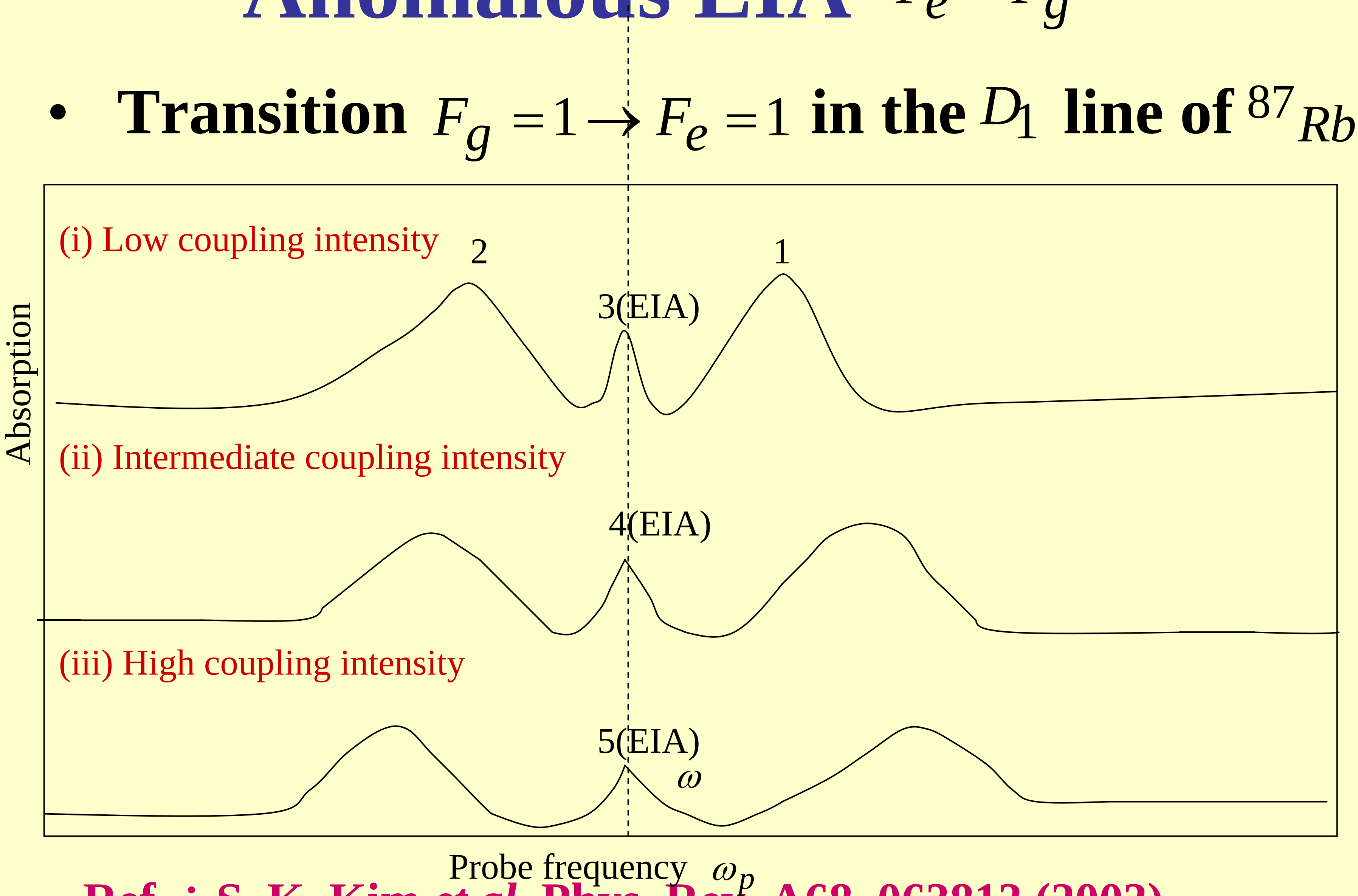
- **Transition** $F_g = 3 \rightarrow F_e = 2$ **in the** D_1 **line of** ^{85}Rb



Ref.：S. K. Kim *et al*, Phys. Rev. A68, 063813 (2003).

Anomalous EIA $F_e = F_g$

- **Transition** $F_g = 1 \rightarrow F_e = 1$ **in the** D_1 **line of** ^{87}Rb



Ref.：S. K. Kim *et al*, Phys. Rev. A68, 063813 (2003).

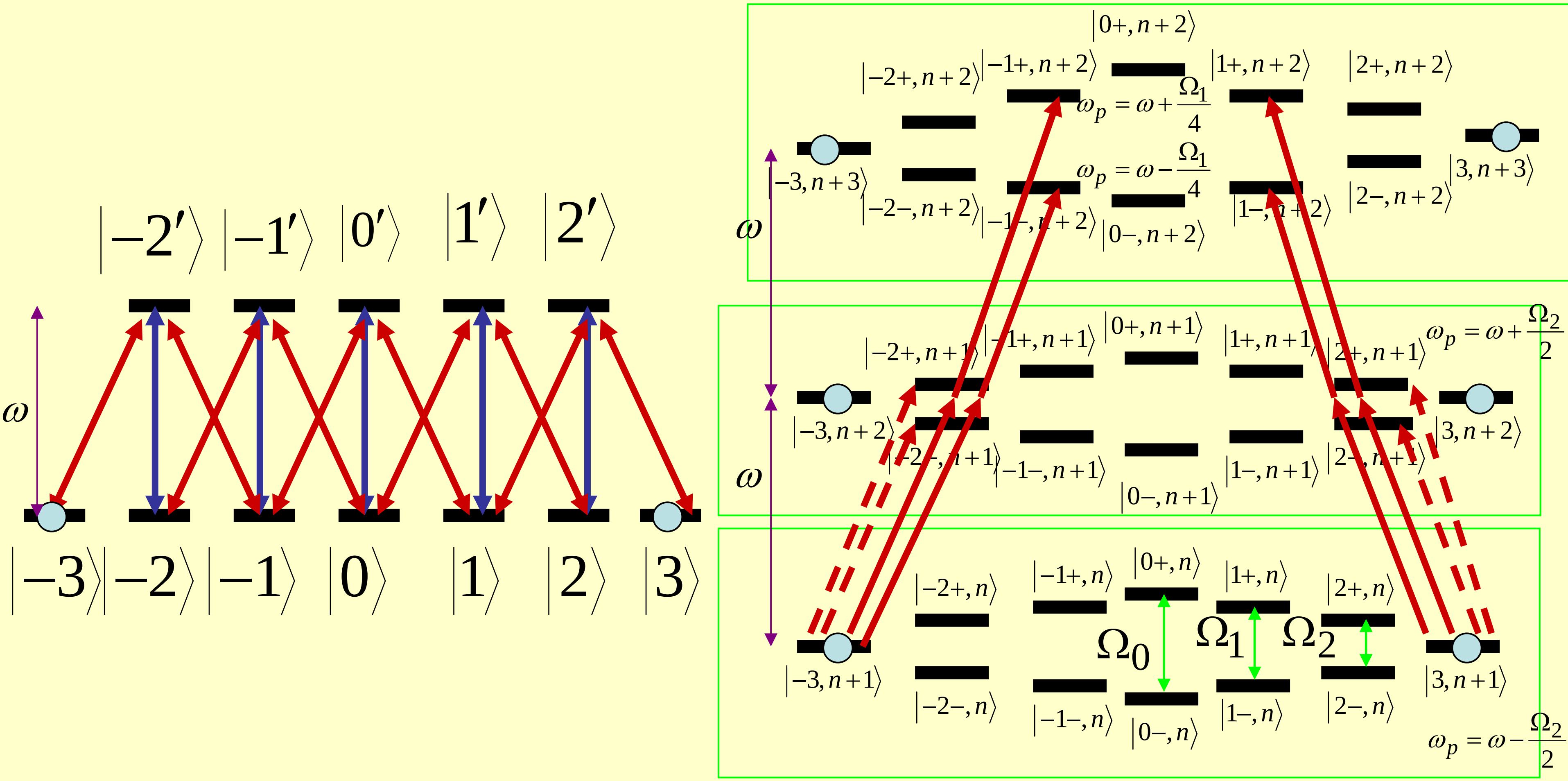
Anomalous EIA $F_e = F_g$

- **Transitions** $F_g = 2 \rightarrow F_e = 2$ **and** $F_g = 3 \rightarrow F_e = 3$ **in the** D_1 **line of** ^{87}Rb

The EIA peak breaks up again at intermediate coupling intensity.

Ref.：S. K. Kim *et al*, Phys. Rev. A68, 063813 (2003).

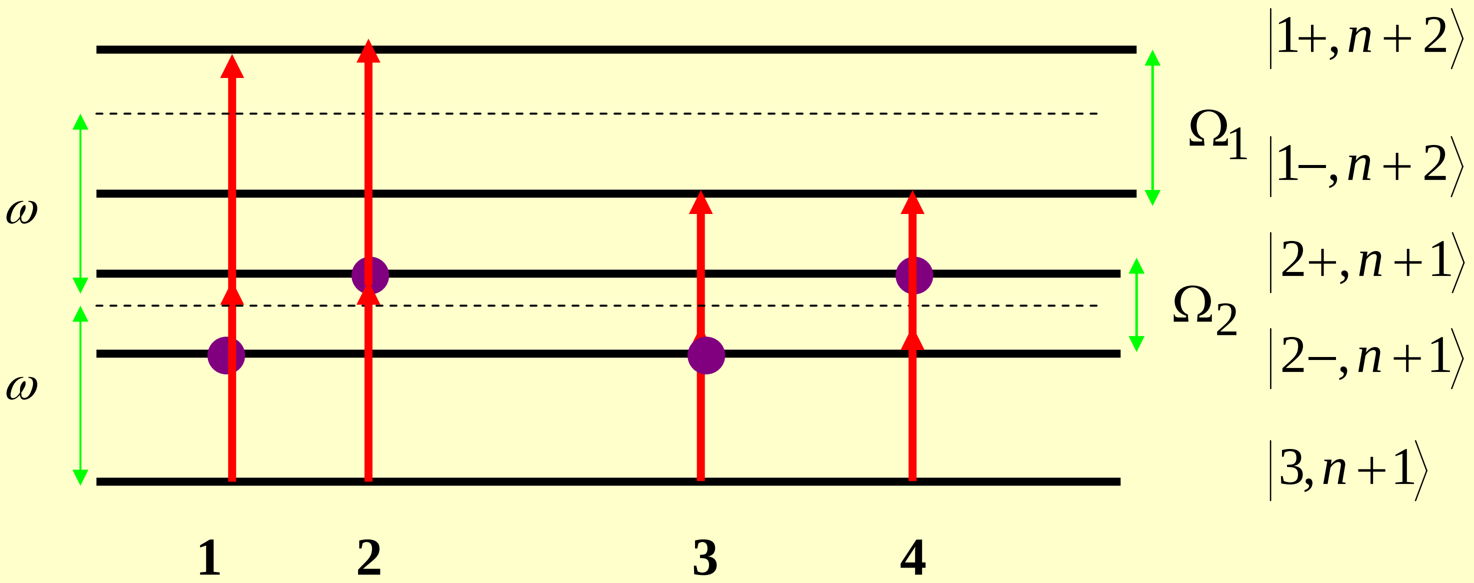
EIA in $F_g = 3 \rightarrow F_e = 2$ transition



(I) Bare-atom picture **(II) Dressed-atom picture**

:coupling beam **:probe beam**

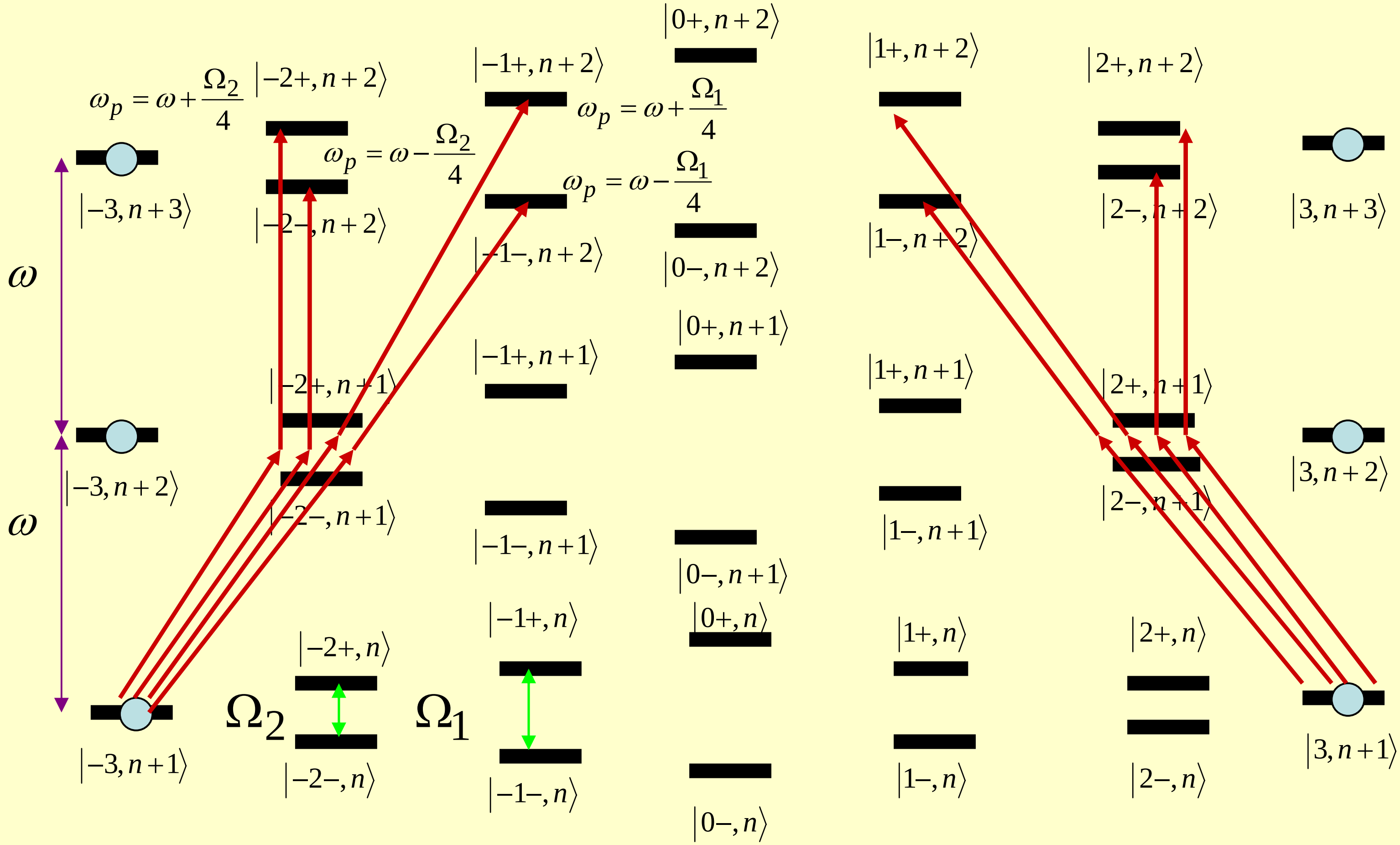
Two-photon processes



● : **intermediate states**

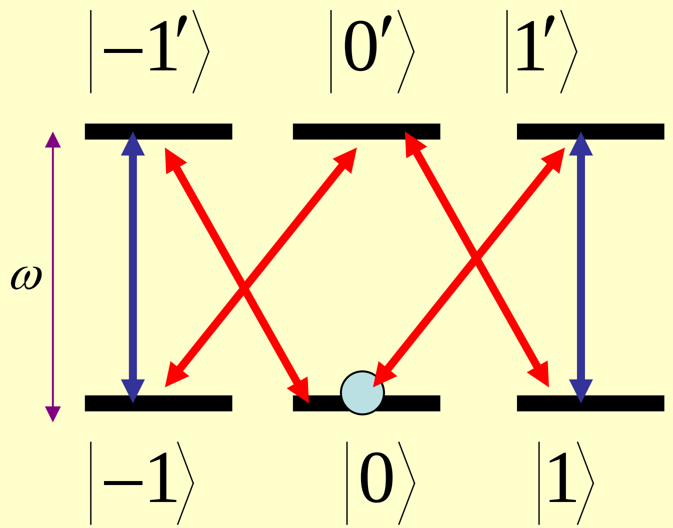
- **Positions of 1,2** : $\omega_p = \omega + \frac{\Omega_1}{4}$, **Positions of 3,4** : $\omega_p = \omega - \frac{\Omega_1}{4}$
- **Constructive interferences between 1,2(3,4) lead to two peaks.**
- **At low coupling intensity, the two peaks overlap at** $\omega_p = \omega$ **and produce an EIA peak. At intermediate intensity, the peak splits.**

Polarizations are not perpendicular

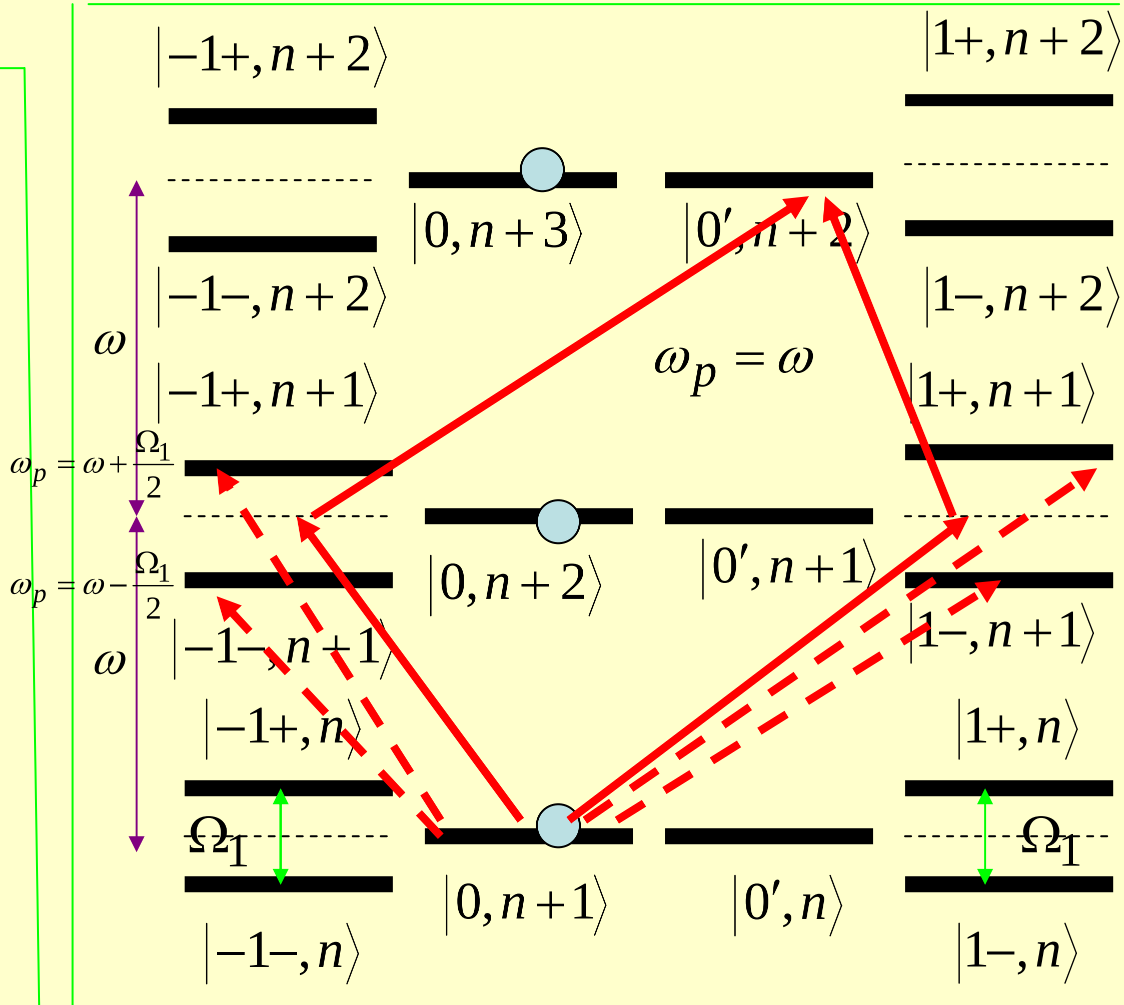


The EIA peak splits into four peaks as the coupling intensity increases.

EIA in $F_g = 1 \rightarrow F_e = 1$ transition

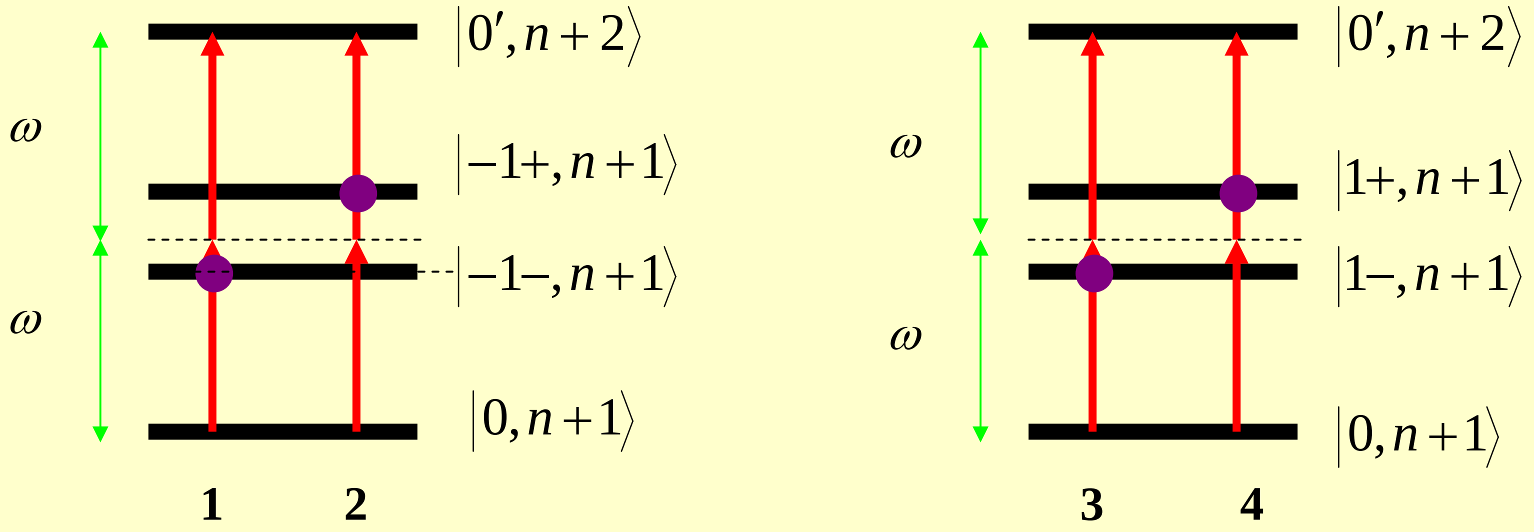


(I) Bare-atom picture



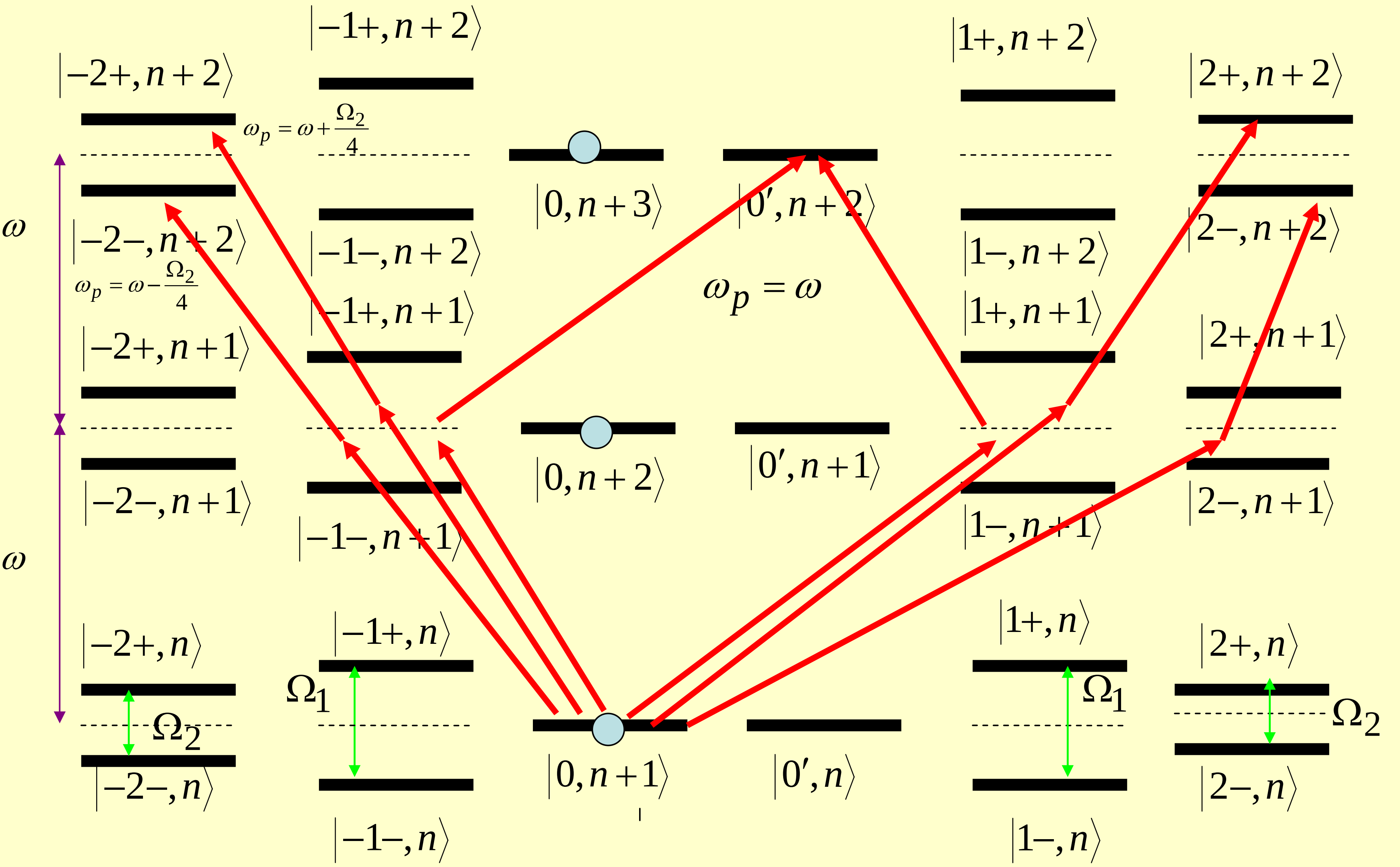
(II) Dressed-atom picture

Two-photon processes

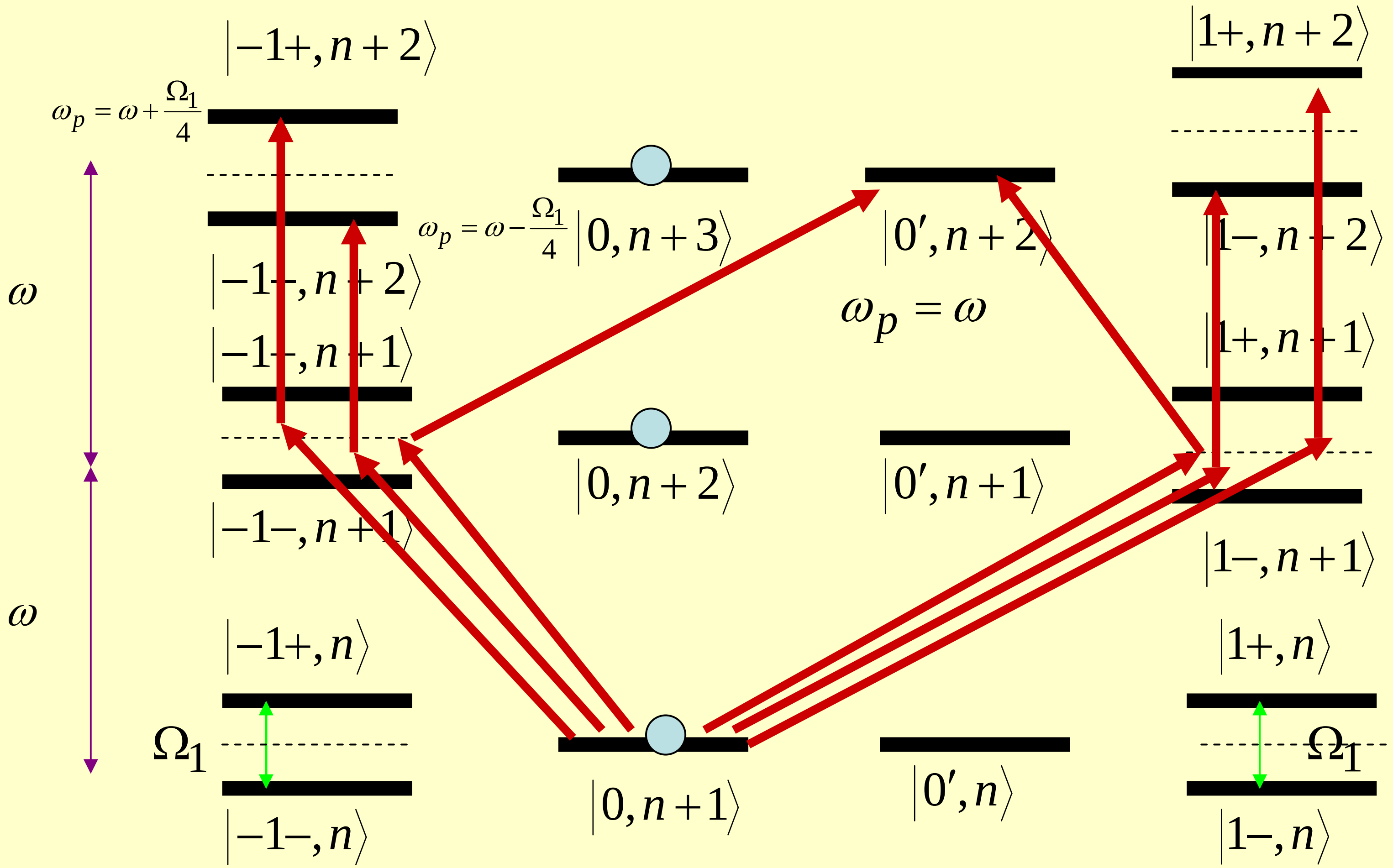


- **Positions of 1,2,3,4：** $\omega_p = \omega$
- **Transition amplitudes：** $T^{(1)} = T^{(2)} = T^{(3)} = T^{(4)}$
- **Constructive interferences among 1,2,3,4 lead to an EIA peak at** $\omega_p = \omega$ **.**

EIA in $F_g = 2 \rightarrow F_e = 2$ transition



Polarizations are not perpendicular



The EIA peak splits into three peaks as the coupling intensity increases.

Summaries

- We propose a new method-dressed atom multiphoton spectroscopy (DAMS) to interpret probe spectra of driven degenerate atomic systems.
- We apply the DAMS to provide a clear interpretation for the anomalous EIA.

Future perspectives

- **We have applied the DAMS to unveil the underlying mechanism of the central dispersion-like resonances in cold atoms. The DAMS can not only interpret the lineshape of the central resonances, but also predicts precisely the positions of the resonances.**
- **We will apply the DAMS to shed new light on higher-order processes in other probe spectroscopy setup.**

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