

Atoms in Intense Fields

周祥顺

台湾海洋大学光电科学研究所

2013年7月8日 四川大学

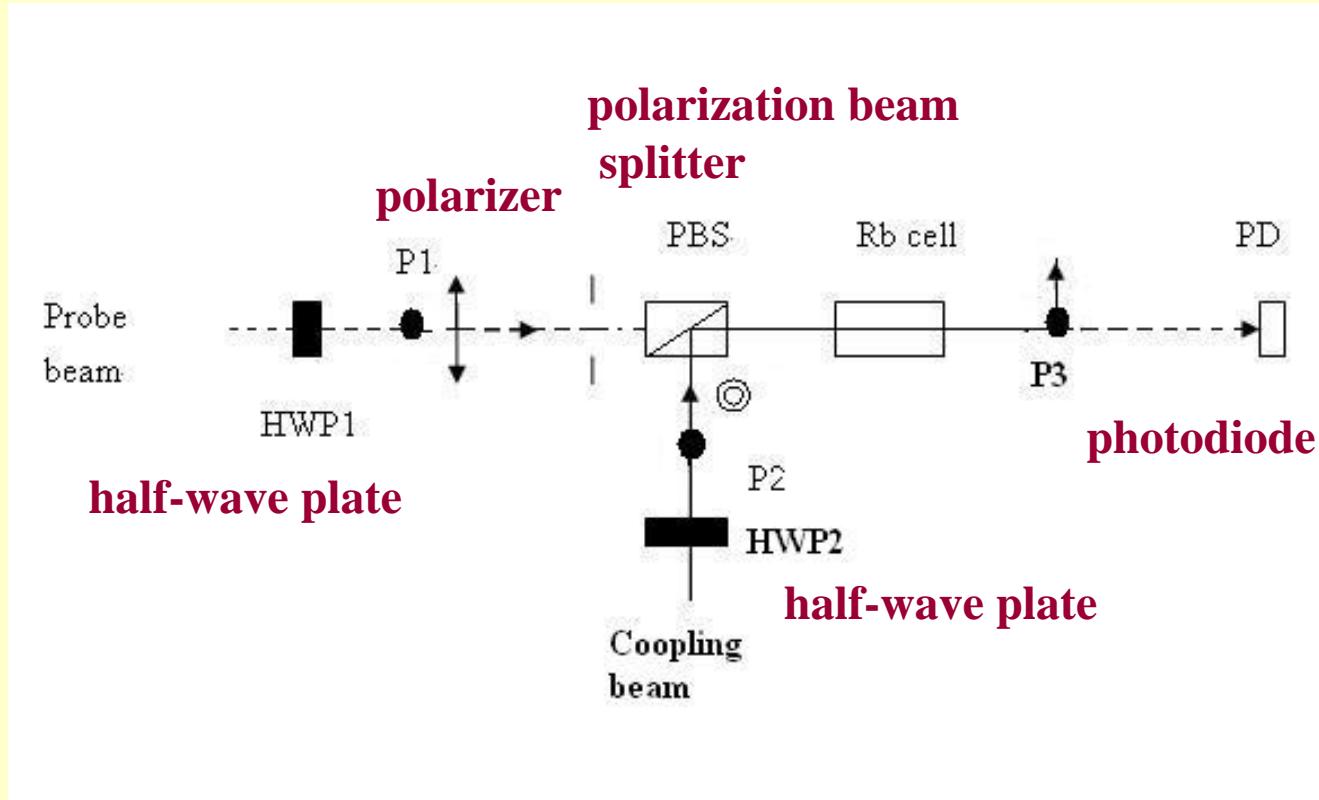
Contents

- **Introduction**
- **The dressed-atom approach**
- **The dressed-atom multiphoton spectroscopy**
- **Conclusions**
- **Outlook**

I. Introduction

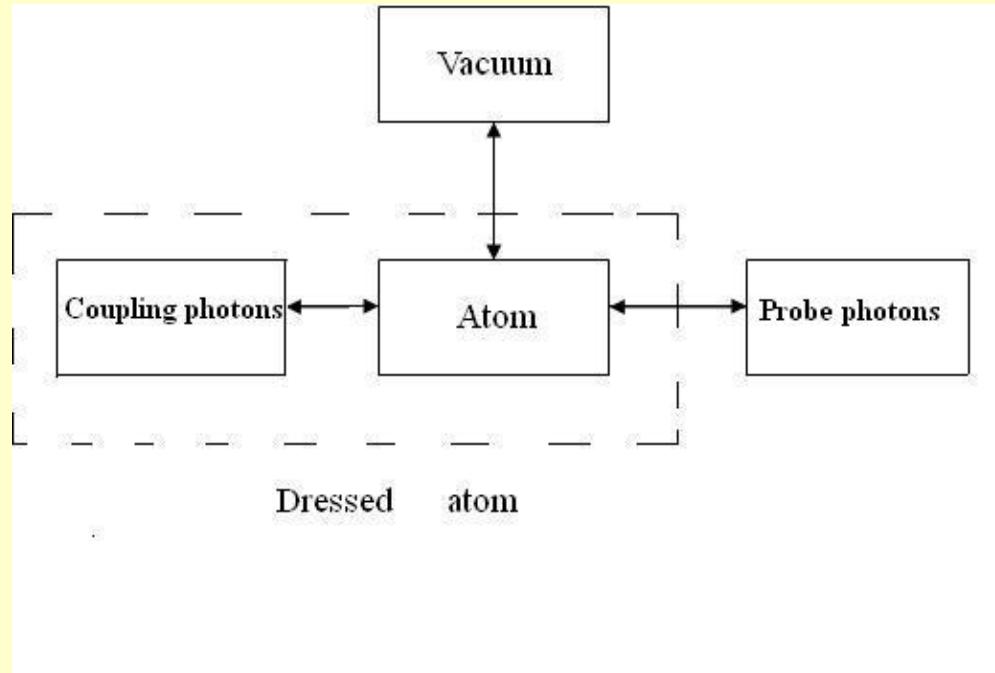
- **Subject:** The behaviors of atoms in intense laser fields.
- **Methods:** Dressed-atom approach
- **Example:** Pump-probe spectroscopy

Pump-probe spectroscopy



The modification of the absorption spectra of the probe beam due to the presence of the coupling beam.

II. The dressed-atom approach



- Step 1: Consider only the system “atom + coupling photons interacting together”.
- Step 2: Consider the coupling with the vacuum or the probe photons.

Total Hamiltonian: $H = H_A + H_L + H_{AL}$

H_A : **Atomic Hamiltonian**

H_L : **Laser Hamiltonian**

H_{AL} : **Interacting Hamiltonian**

Two-level systems

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

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

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

$$H_L |n\rangle = \omega_L \left(n + \frac{1}{2}\right) |n\rangle$$

ω : Atomic frequency ω_L : Laser frequency

Uncoupled states (bare states)

Uncoupled Hamiltonian : $H_0 = H_A + H_L$

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

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

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

$$E_F - E_I = \omega - \omega_L = \Delta \quad \text{:detuning}$$

As $\Delta = 0$, $E_F = E_I = (n - \frac{1}{2})\omega$

Coupled states (dressed states)

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

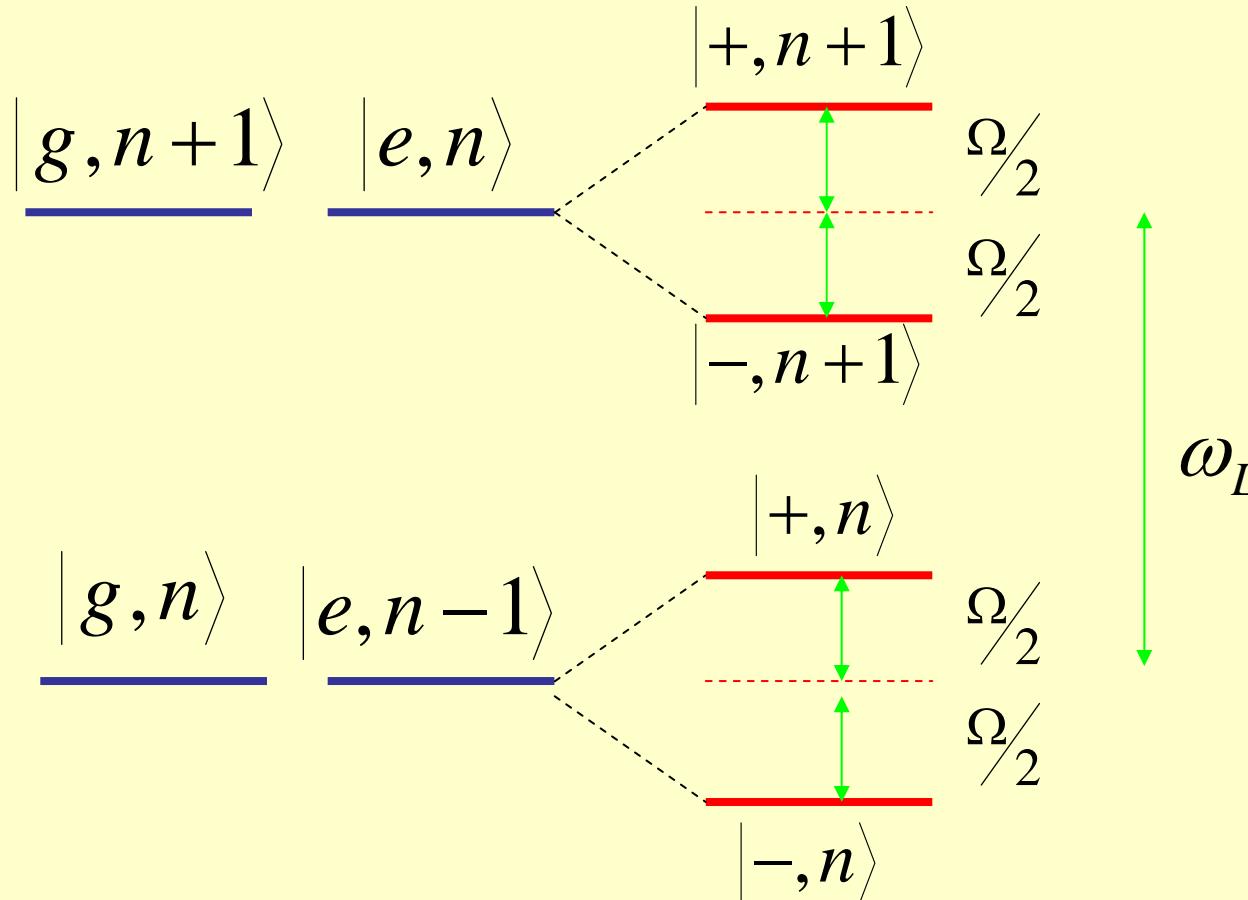
$$E_{\pm}(n) = (n - \frac{1}{2})\omega \pm \frac{1}{2}\Omega \quad (\Delta = 0)$$

$$|\pm, n\rangle = \frac{1}{\sqrt{2}} [|g, n\rangle \pm |e, n-1\rangle]$$

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

with $\langle e, n-1 | H_{AL} | g, n \rangle = q\sqrt{n}$

Ladder of energy levels



— : Bare states

— : Dressed states

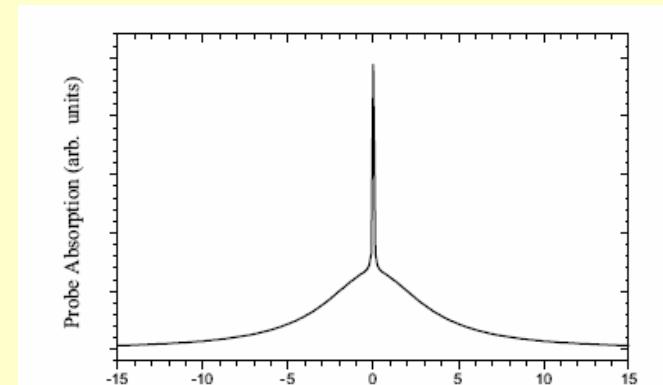
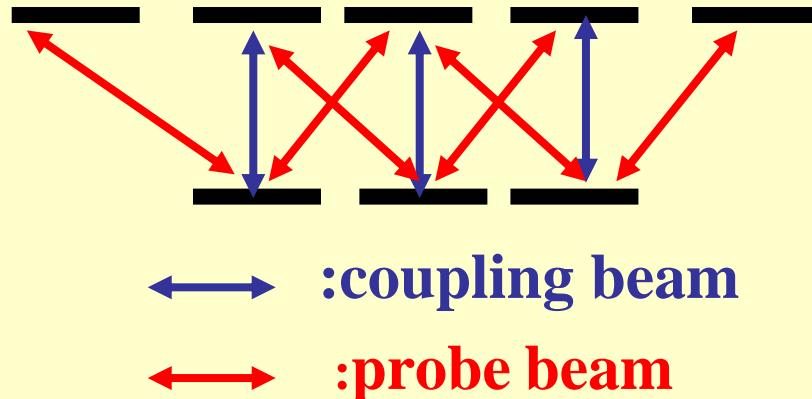
III. Dressed-atom multiphoton spectroscopy

- 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.

Ref. H. S. Chou and Jörg Evers, Phys. Rev. Lett. 213602 (2010).

Anomalous electromagnetically induced absorption (EIA)

- EIA

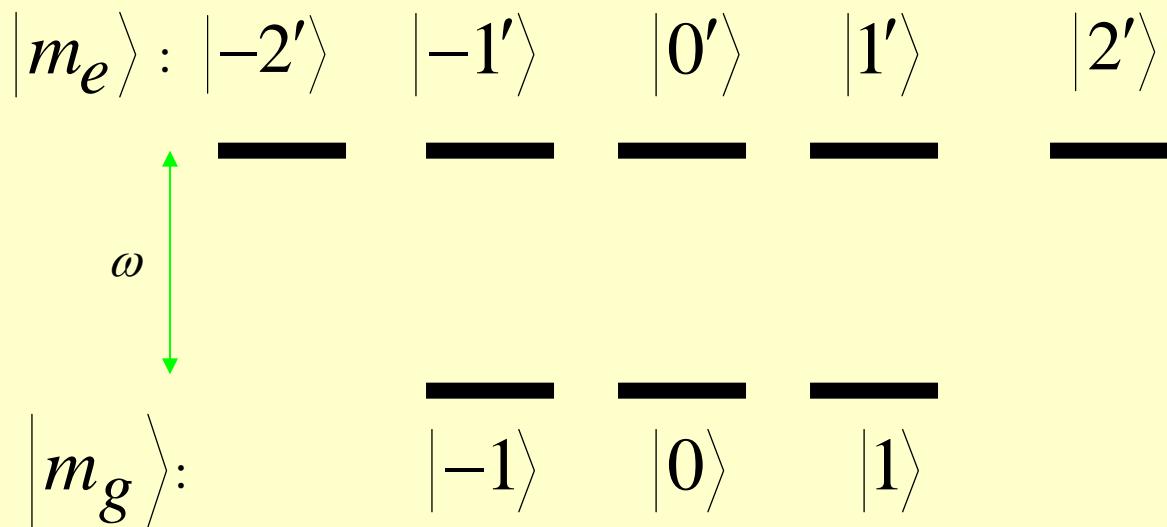


The absorption of the probe beam is substantially enhanced when copropagating orthogonally polarized probe and coupling beams interact with a degenerate two-level system.

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

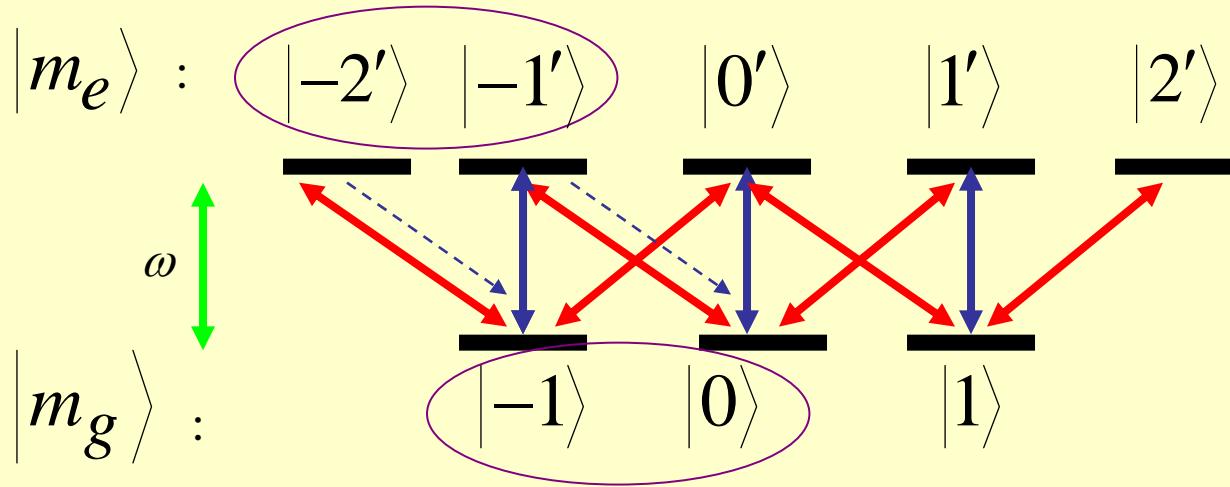
Lezama's condition for EIA

$$F_e = F_g + 1$$



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

Spontaneous coherence transfer (SCT)



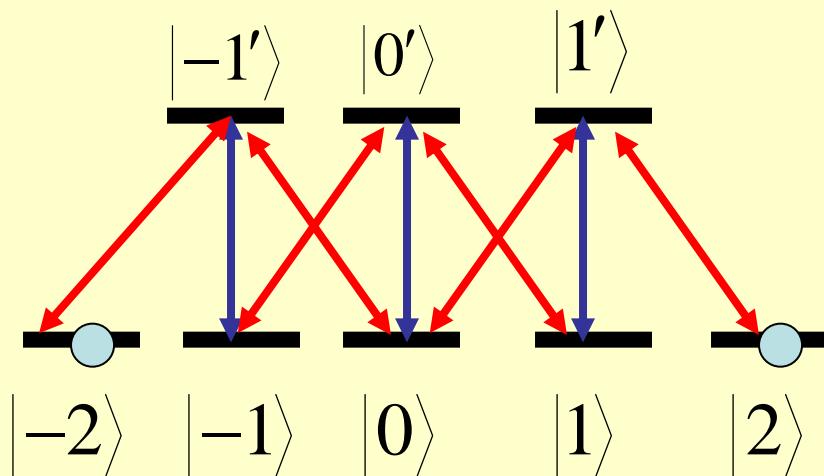
↔ :coupling beam ↔ :probe beam ⤵ :SCT

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

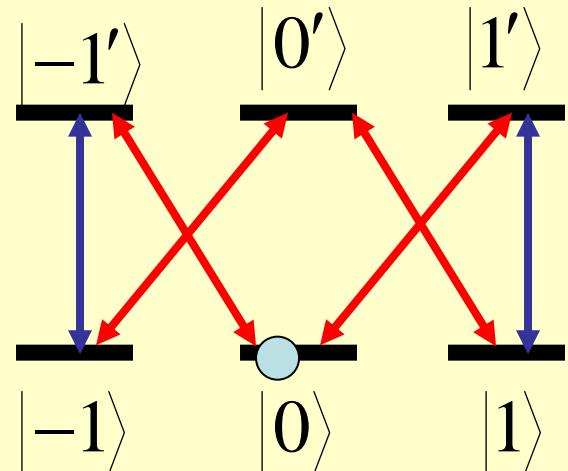
Ref. : A. V. Taichenachev *et al*, JETP Lett. 69 819 (1999).

Interpretations of Lezama's condition

$$(I): F_e = F_g - 1$$



$$(II): F_e = F_g$$

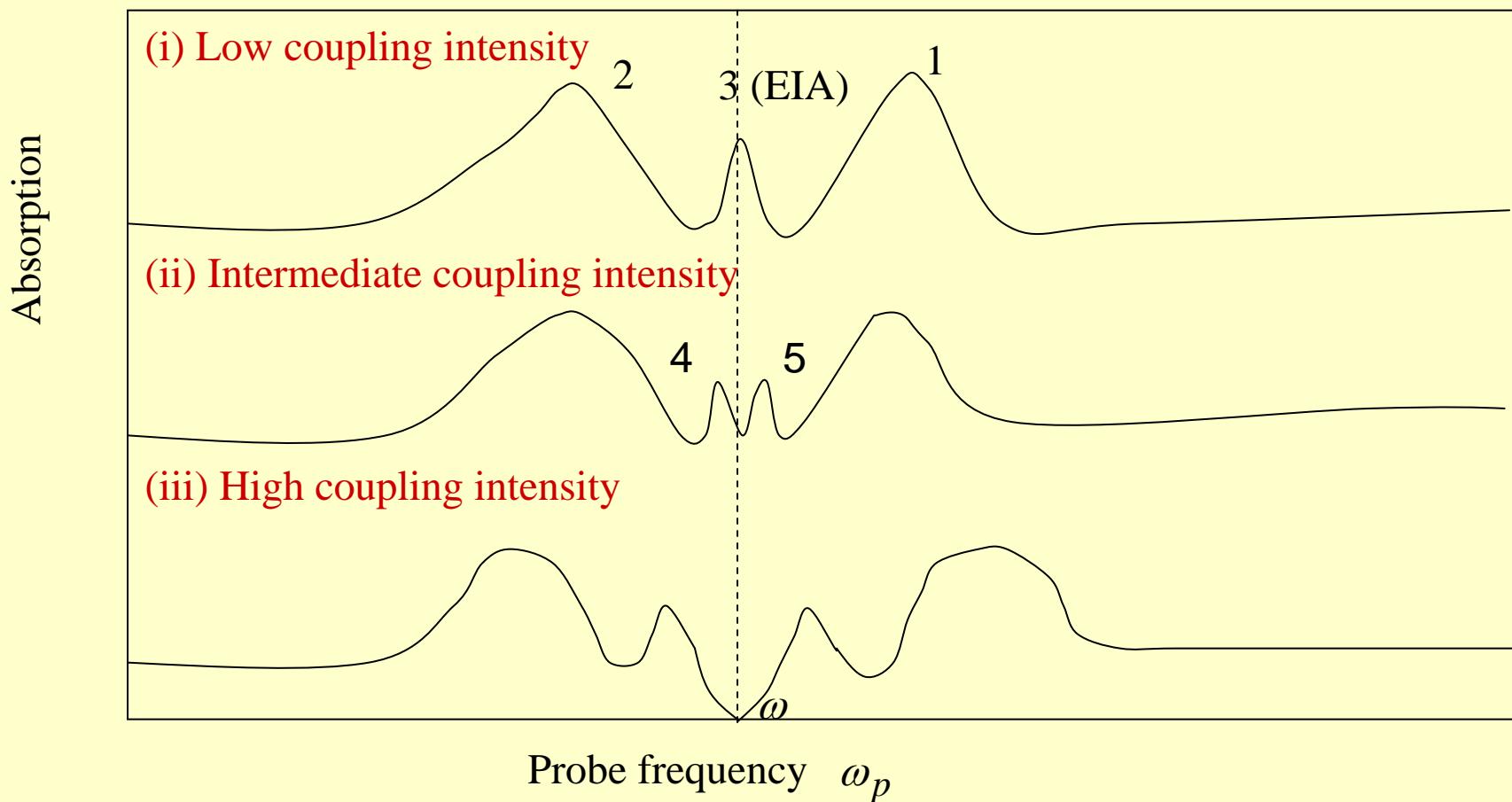


● : populations

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 $F_e = F_g - 1$

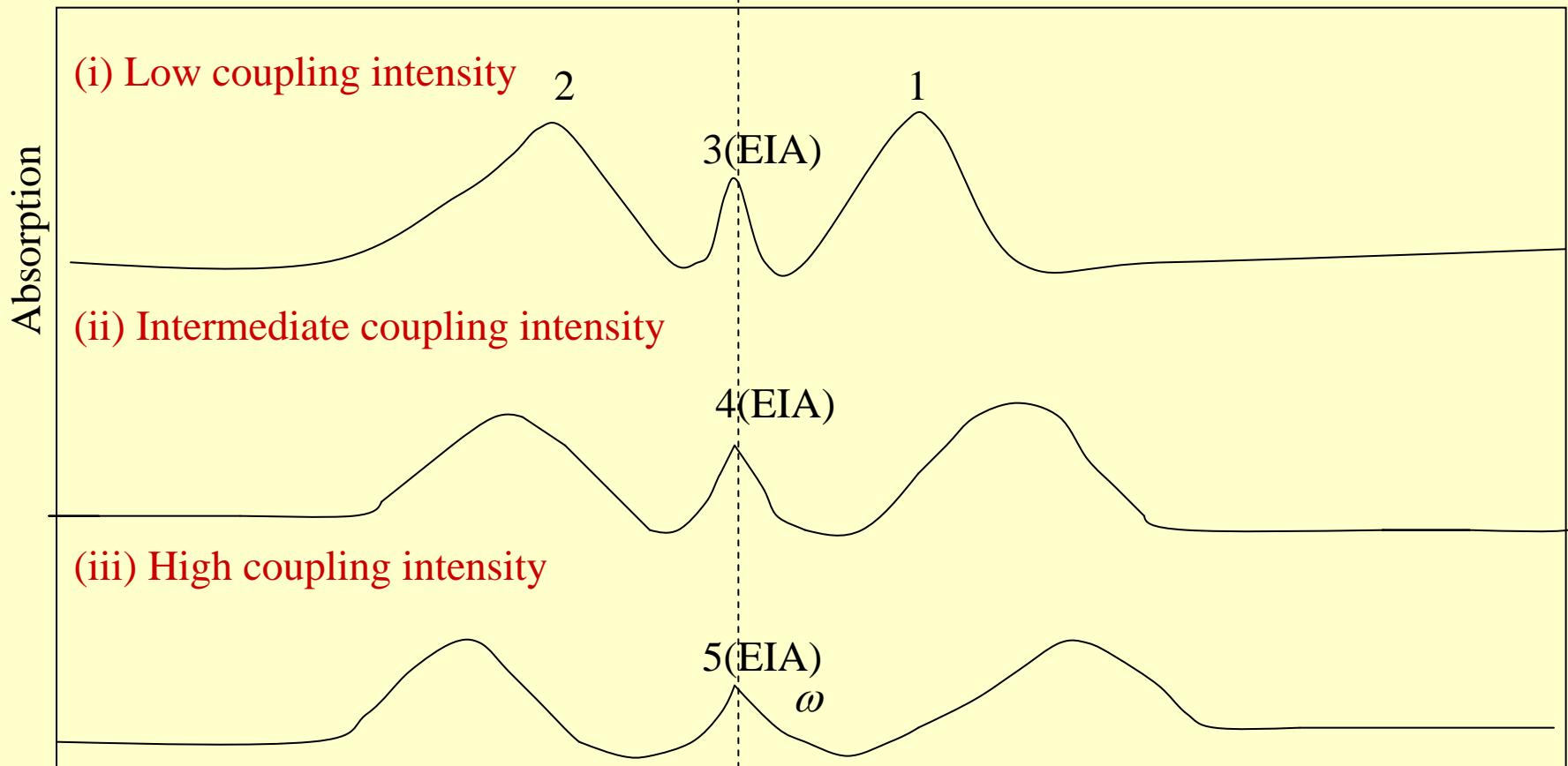
- Transition $F_g = 3 \rightarrow F_e = 2$ in the D_1 line of ^{85}Rb



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).

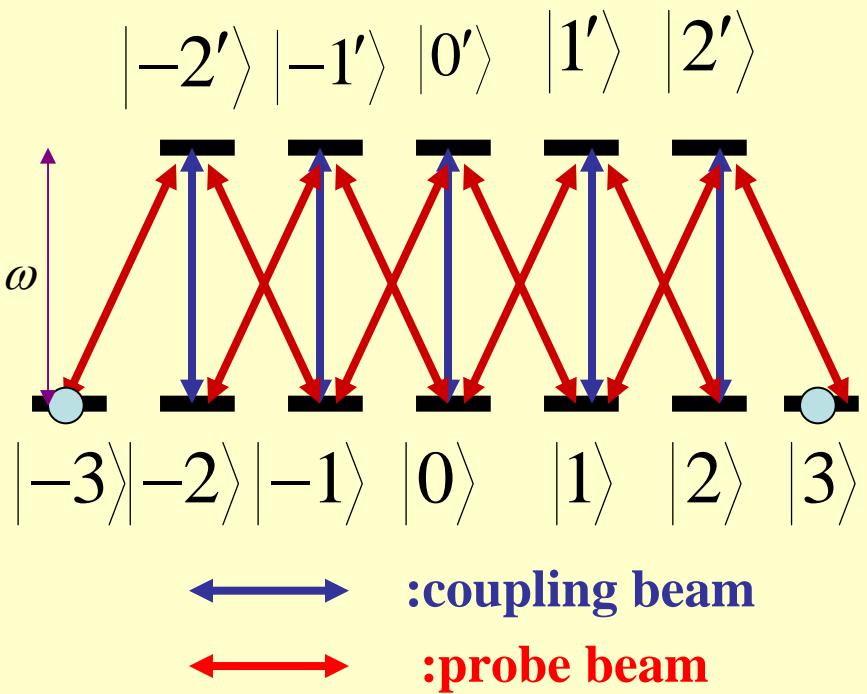
Anomalous EIA $F_e = F_g$

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

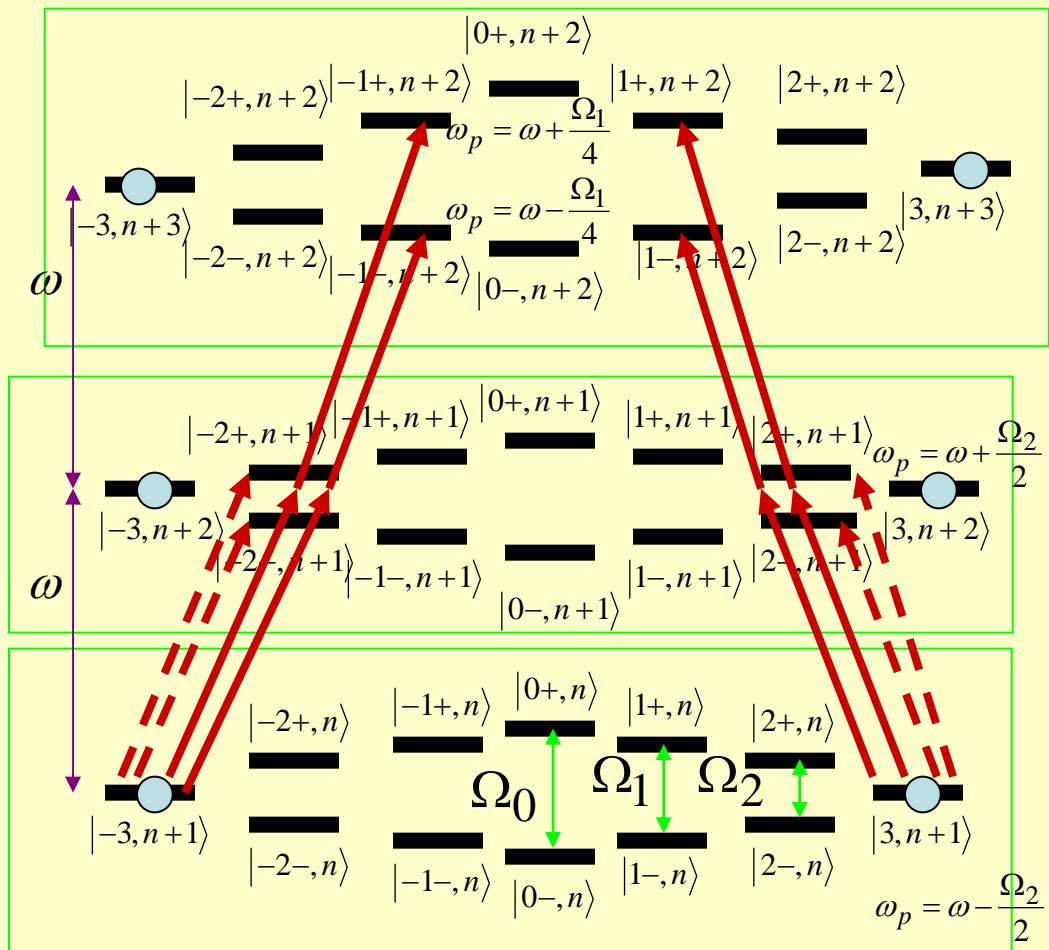
The anomalous EIA peak breaks up again at intermediate coupling intensity.

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

Anomalous EIA $F_g = 3 \rightarrow F_e = 2$

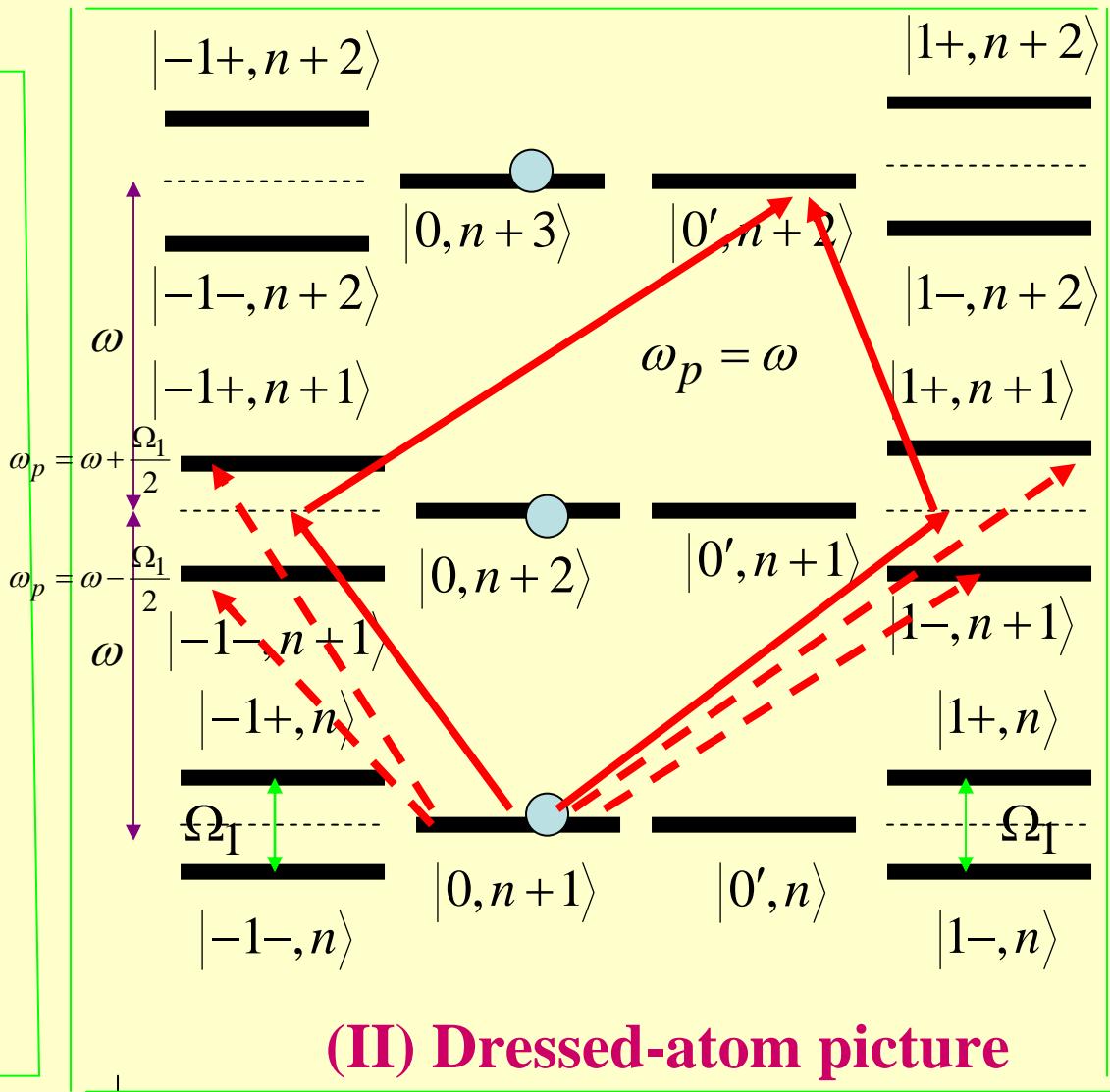
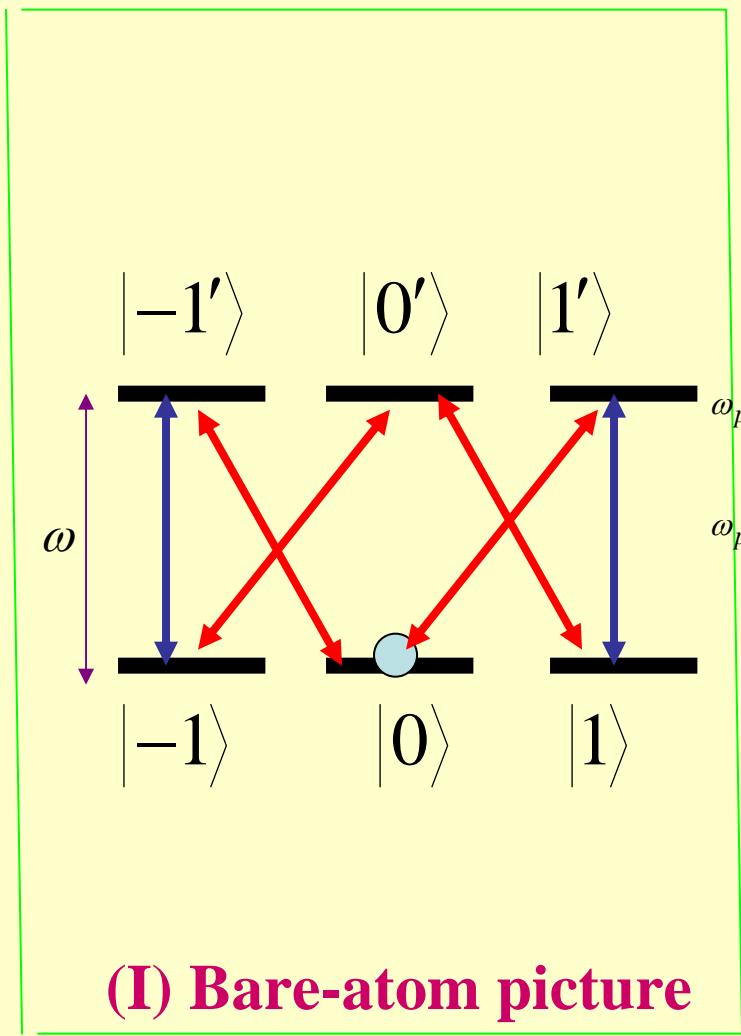


(I) Bare-atom picture

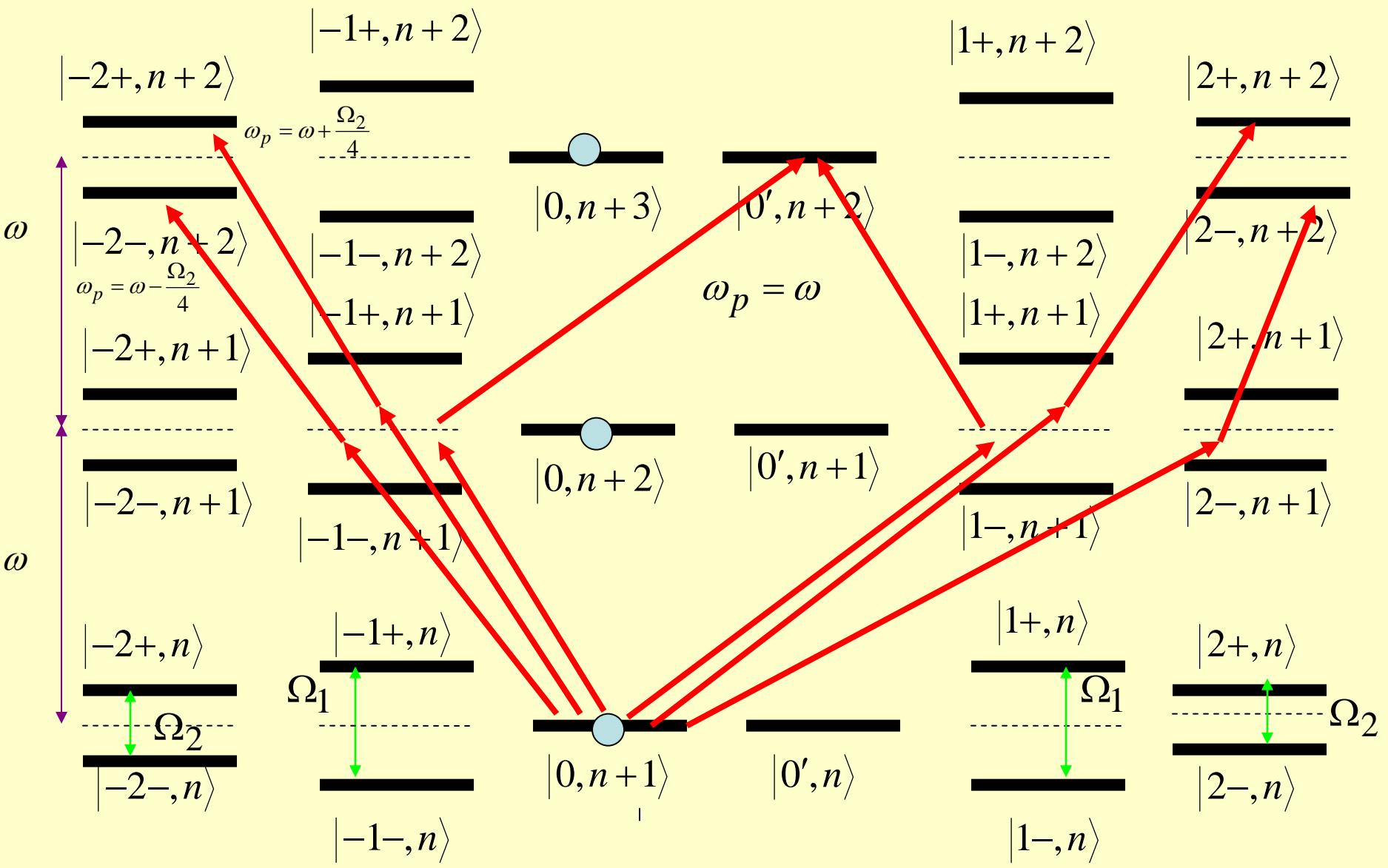


(II) Dressed-atom picture

Anomalous EIA $F_g = 1 \rightarrow F_e = 1$



Anomalous EIA $F_g = 2 \rightarrow F_e = 2$



IV. Conclusions

- We propose the **dressed-atom multiphoton spectroscopy (DAMS)** to interpret the nonlinear pump-probe spectra.
- We apply the DAMS to provide a clear physical interpretation for the anomalous EIA.

V. Outlook

- Nonlinear pump-probe spectroscopy.
- Quantum control via interference and coherence
- Relativistic many-body theory of laser-dressed atoms

Thank you for your attention.