Absorptionless Self-Phase Modulation in a Dark-State Electromagnetically Induced Transparency (DS-EIT) System

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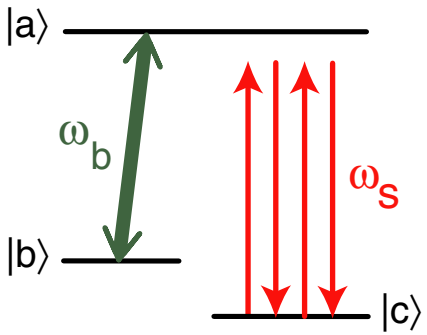
Mission Objectives:

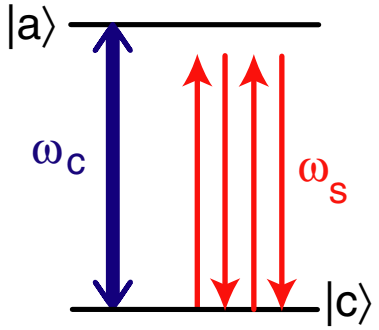
- *Large* nonlinearity in the *absence* of signal field absorption.
- *No* excited state population = *no* spontaneous emission noise.

Proposed System



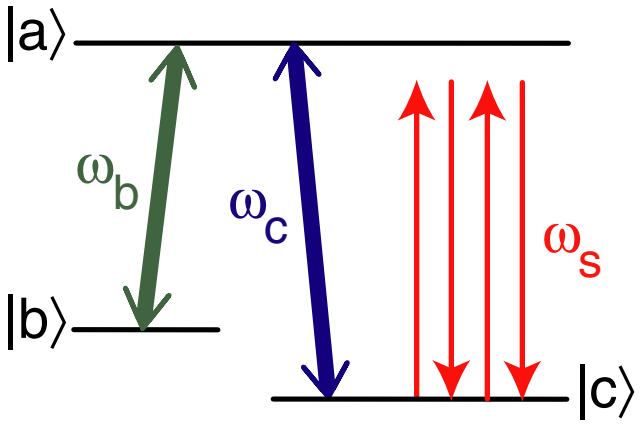
Dark State

+



EIT

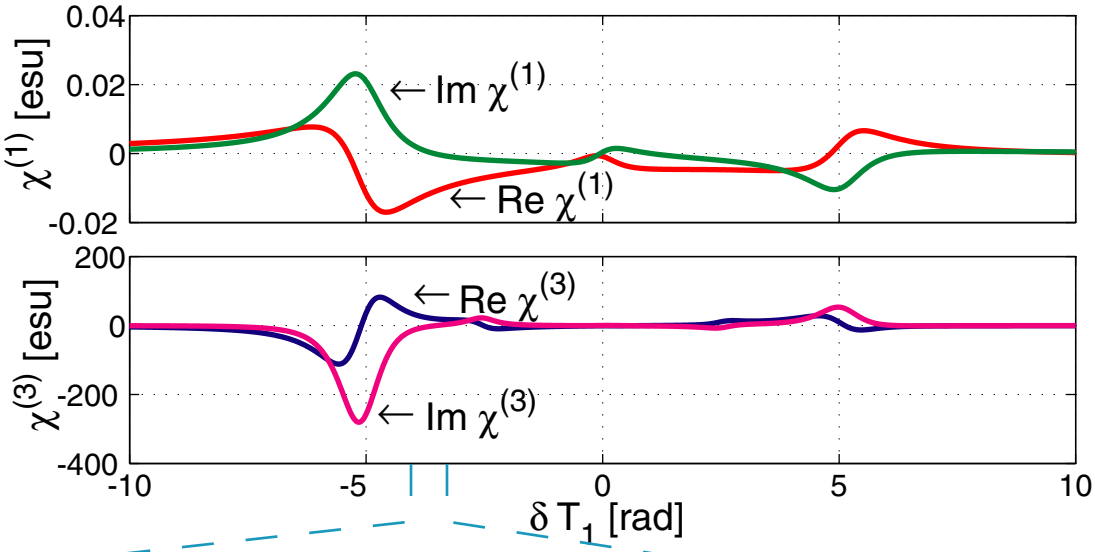
=

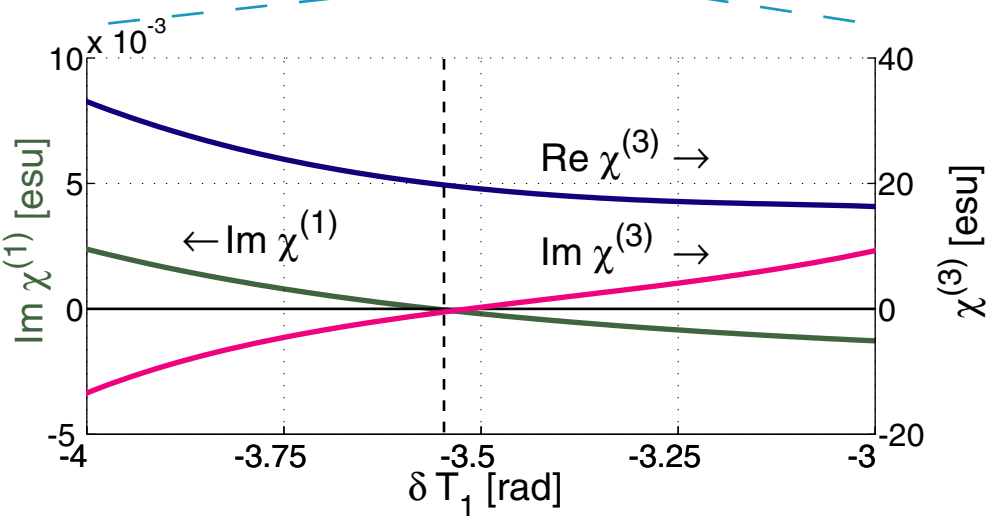


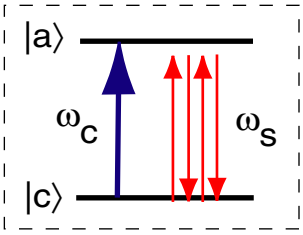
Dark-State EIT

EIT in the Two-Level Atom

Steady state linear and nonlinear response of the signal field in a strongly driven detuned two-level atom*.







$\gamma_b T_1 = 0,\ \gamma_c T_1 = 1,$
$\Delta_b T_1 = 0,\ \Delta_c T_1 = 1,$
$\Omega_b T_1 = 0.\ \Omega_c T_1 = 5.$

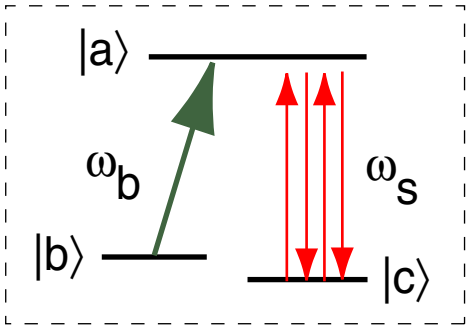
Goal Achieved:
- Strong Self-Phase Modulation with No Signal Field Absorption.

Goal Not Achieved:
- Pump Field is Absorbed Causing:
  - Large Excited State Population,
  - Shifted Transparency Window.

* Bennink et. al. Phys. Rev. A, **63**, 033804 (2001)

Nonlinear Optics of Coherent Population Trapping

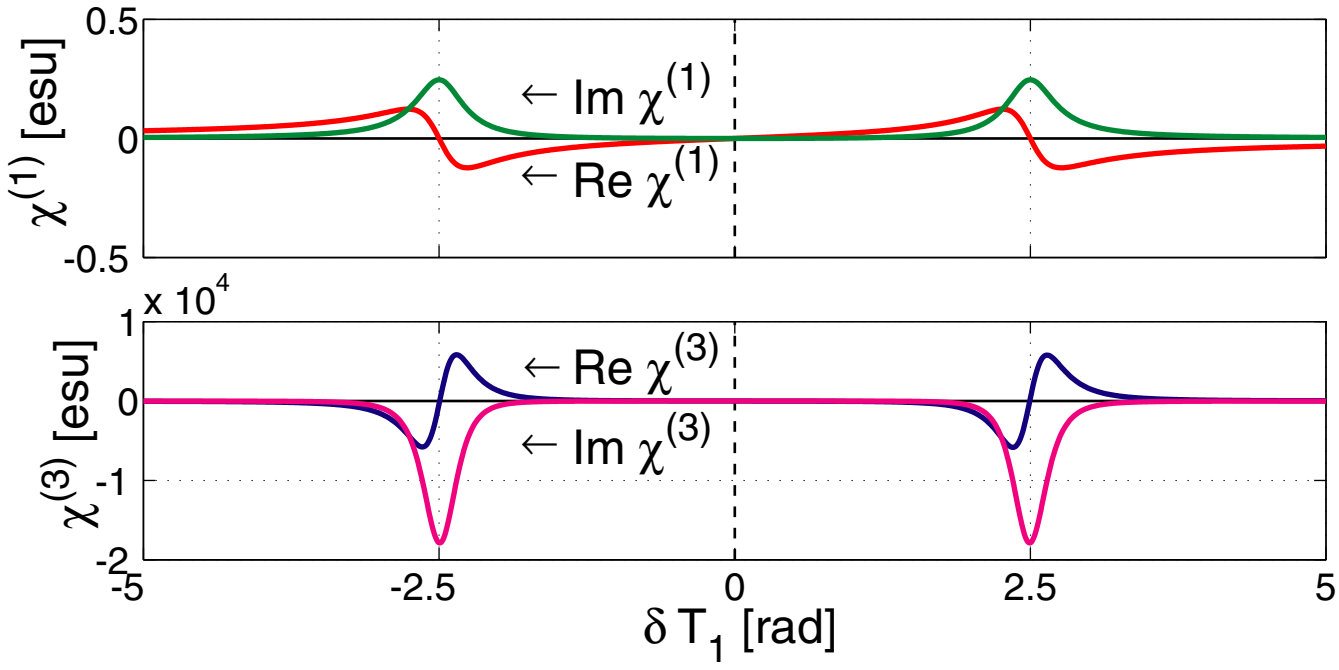
On resonance, linear and nonlinear response of the signal field in a dark state.



$\Delta_b T_1 = 0,$
$\Delta_c T_1 = 0,$
$\Omega_c T_1 = 0.$

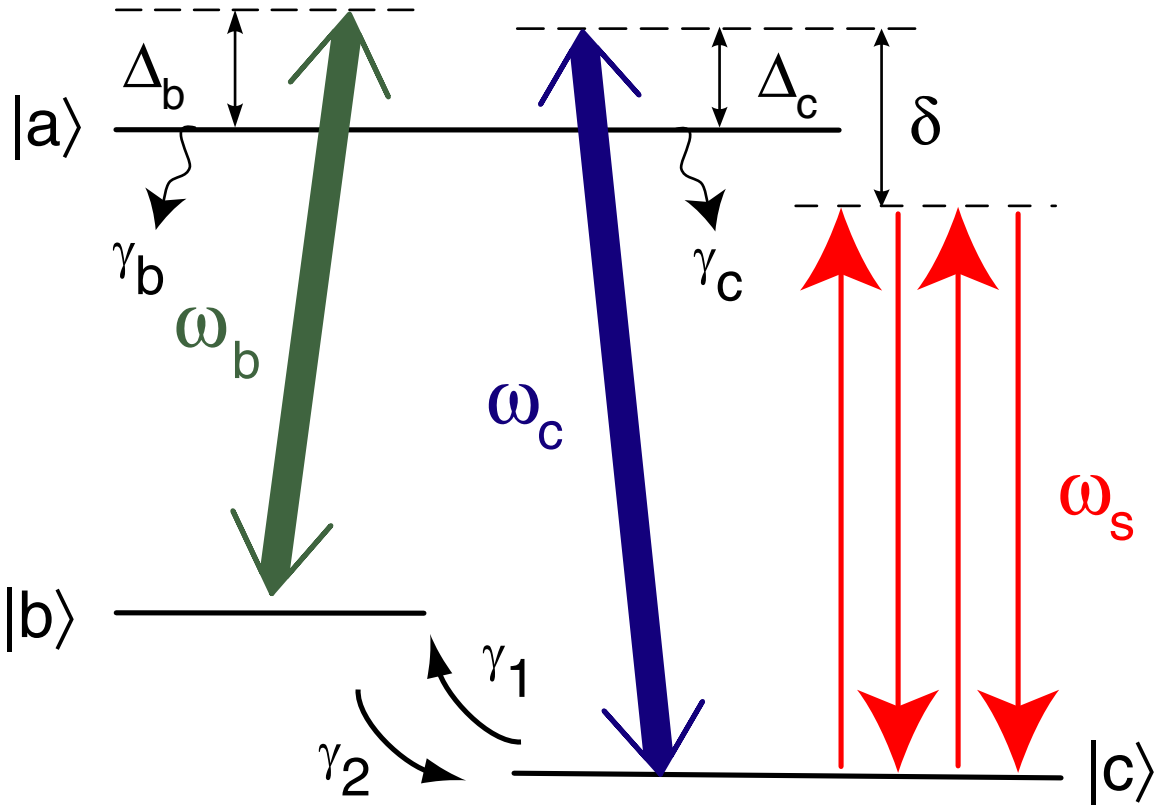
$\gamma_b T_1 = 3/8,$
$\gamma_c T_1 = 5/8,$
$\Omega_b T_1 = 5.$

$\gamma_1 T_1 = 0,$
$\gamma_2 T_1 = 0.$



- No Absorption But Regrettably No Self-Phase Modulation Either.

The Dark-State EIT System



ω_b, ω_c are the pump fields,

ω_s is the signal field,

$\delta = \omega_s - \omega_c$ is the different in detuning between the signal field and pump C.

Density Matrix Equation of Motions

$$\dot{\rho}_{bb} - \gamma_b = -(\gamma_b + \gamma_2 + \tau_b)\rho_{bb} + (\gamma_1 - \gamma_b)\rho_{cc} + \frac{i}{2}\Omega_b^*\rho_{ab} - \frac{i}{2}\Omega_b\rho_{ba}$$

$$\dot{\rho}_{cc} - \gamma_c = -(\gamma_1 + \gamma_c)\rho_{bb} - (\gamma_c - \gamma_2 + \tau_c)\rho_{cc} + \frac{i}{2}\Omega_d^*\rho_{ac} - \frac{i}{2}\Omega_d\rho_{ca}$$

$$\dot{\rho}_{ab} + \frac{i}{2}\Omega_b = i\Omega_b\rho_{bb} + \frac{i}{2}\Omega_b\rho_{cc} - \Gamma_{ab}\rho_{ab} + \frac{i}{2}\Omega_d\rho_{cb}$$

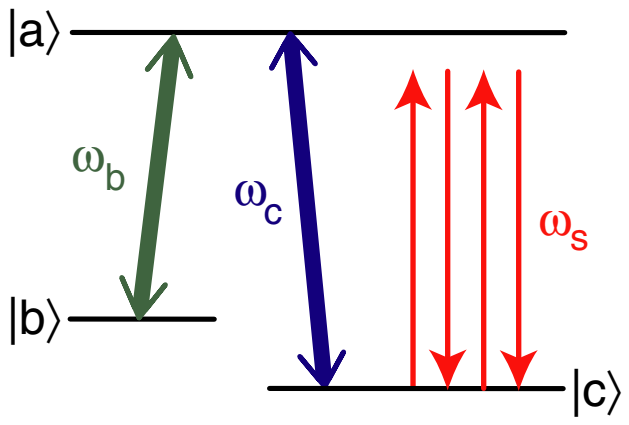
$$\dot{\rho}_{ac} + \frac{i}{2}\Omega_d = \frac{i}{2}\Omega_d\rho_{bb} + i\Omega_d\rho_{cc} - \Gamma_{ac}\rho_{ac} + \frac{i}{2}\Omega_b\rho_{bc}$$

$$\dot{\rho}_{bc} = -\frac{i}{2}\Omega_d\rho_{ba} + \frac{i}{2}\Omega_b^*\rho_{ac} - \Gamma_{bc}\rho_{bc}$$

$$\dot{\rho}_{ba} - \frac{i}{2}\Omega_b^* = -i\Omega_b^*\rho_{bb} - \frac{i}{2}\Omega_b^*\rho_{cc} - \Gamma_{ba}\rho_{ba} - \frac{i}{2}\Omega_d^*\rho_{bc}$$

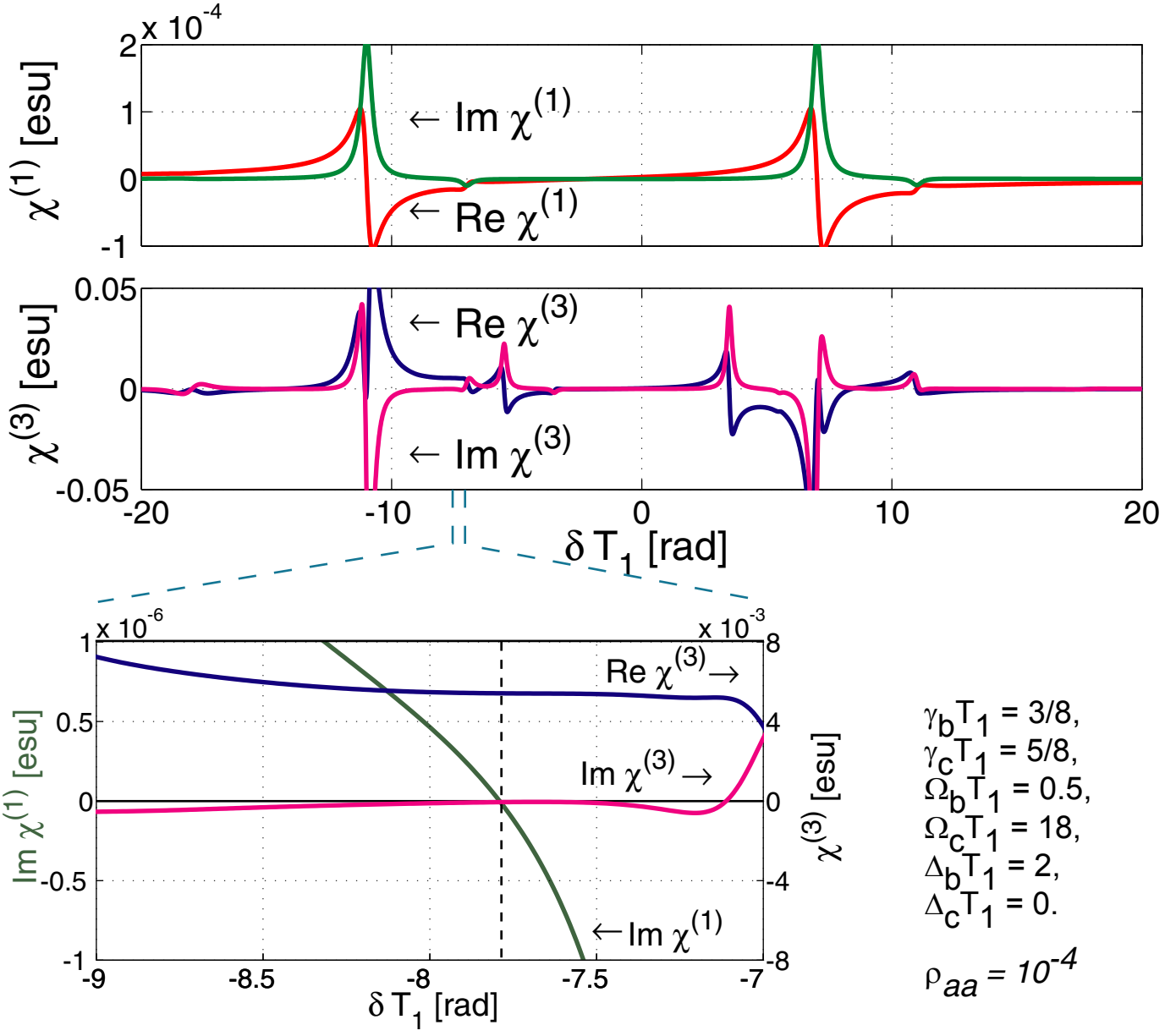
$$\dot{\rho}_{ca} - \frac{i}{2}\Omega_d^* = -\frac{i}{2}\Omega_d^*\rho_{bb} - i\Omega_d^*\rho_{cc} - \Gamma_{ca}\rho_{ca} - \frac{i}{2}\Omega_b^*\rho_{cb}$$

$$\dot{\rho}_{cb} = \frac{i}{2}\Omega_d^*\rho_{ab} - \frac{i}{2}\Omega_b\rho_{ca} - \Gamma_{cb}\rho_{cb}.$$



$$\Omega_d \quad \grave{\imath} \quad \Omega_c + \Omega_s e^{-i\delta t}$$

Radiatively Broadened



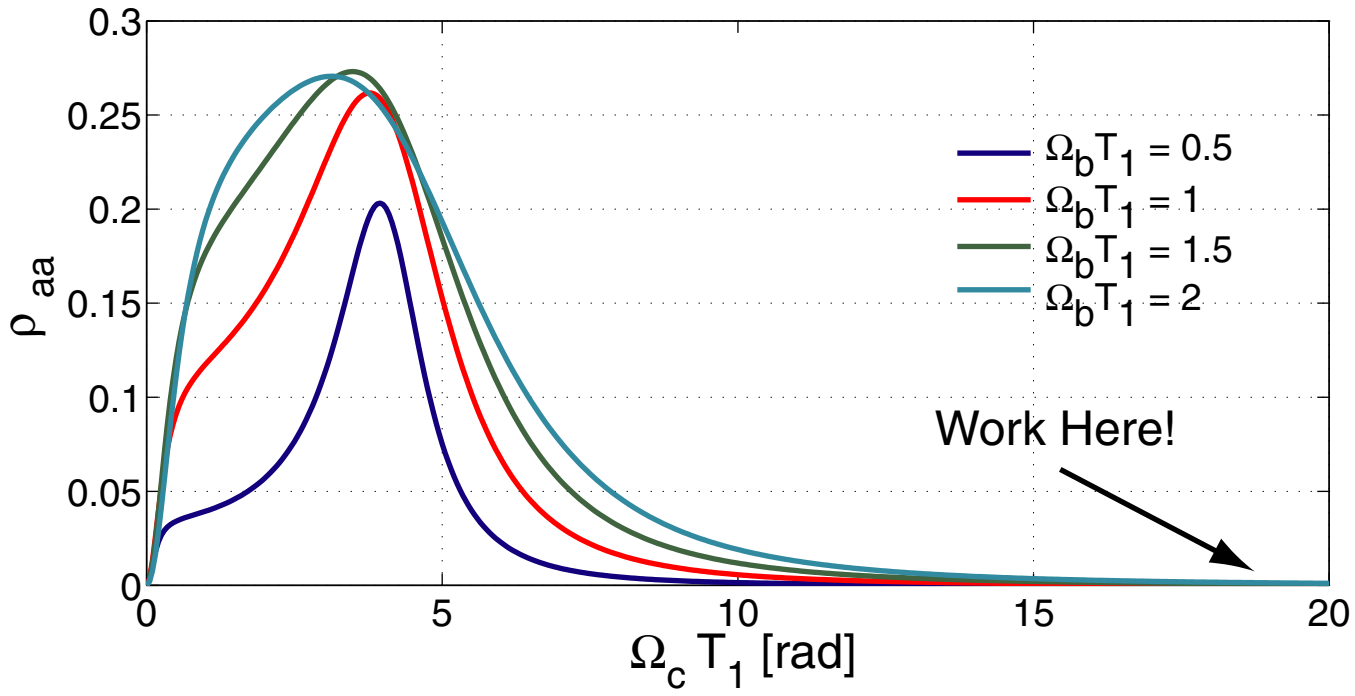
$\gamma_b T_1 = 3/8,$
$\gamma_c T_1 = 5/8,$
$\Omega_b T_1 = 0.5,$
$\Omega_c T_1 = 18,$
$\Delta_b T_1 = 2,$
$\Delta_c T_1 = 0.$

$\rho_{aa} = 10^{-4}$

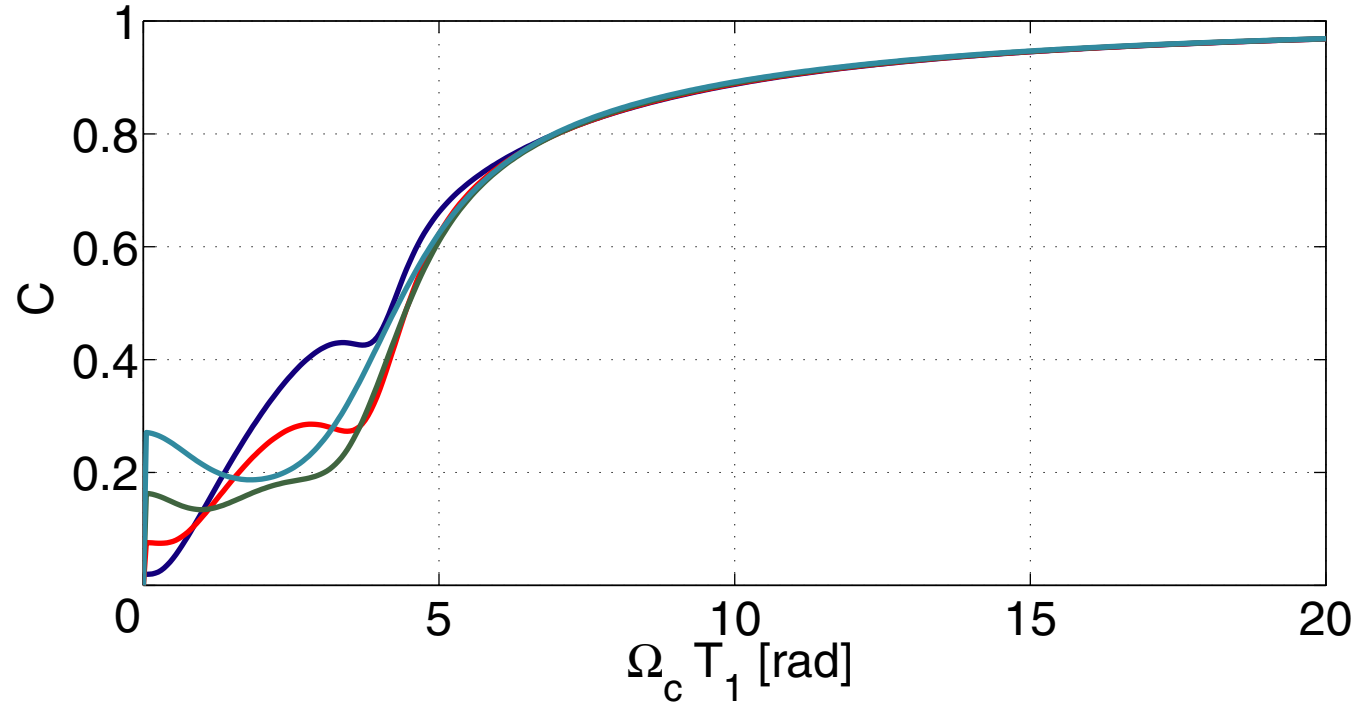
All Goals Achieved:

- Self-Phase Modulation with No Absorption.
- No Excited State Population.

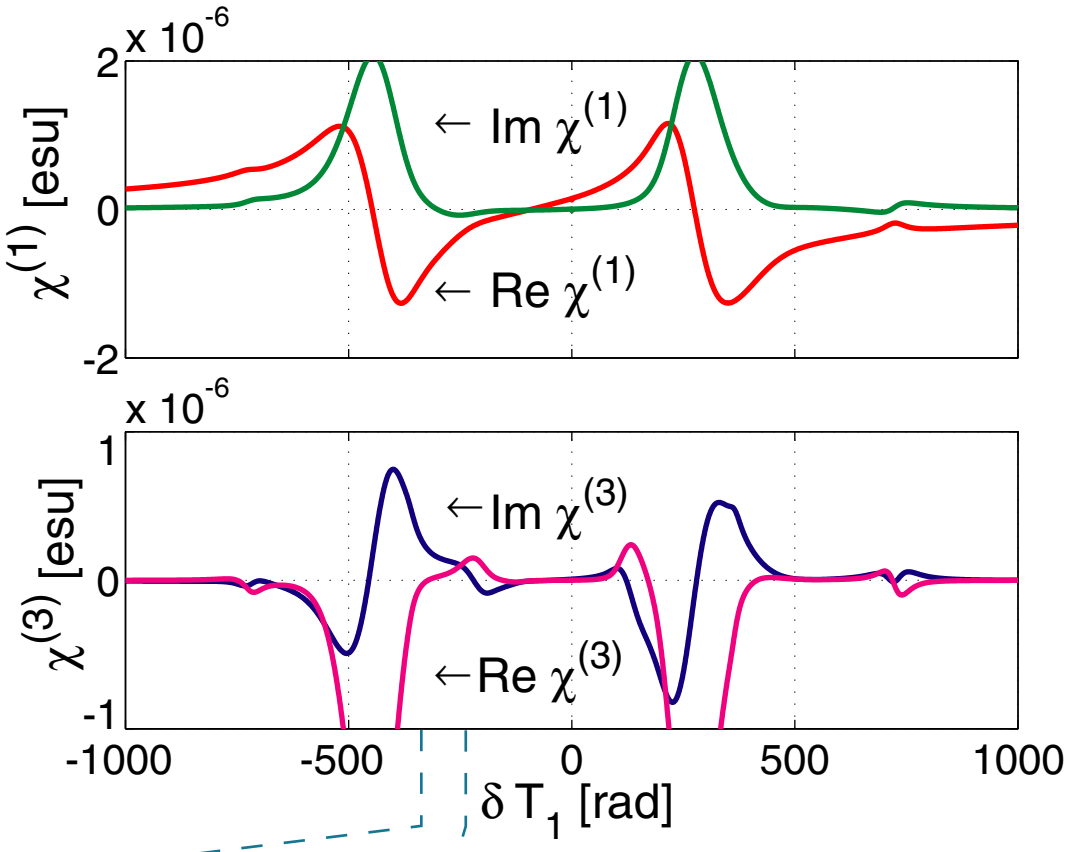
Excited State Population

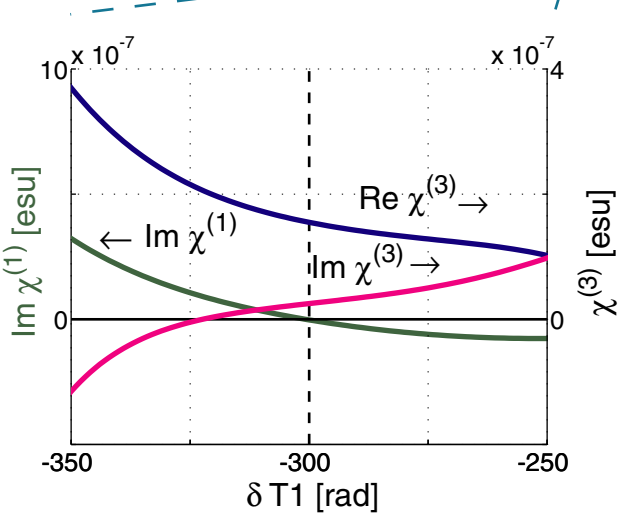


Degree of Coherence $C = \rho_{bc} / \sqrt{\rho_{bb}\,\rho_{cc}}$



Effect Persists Even Under Laboratory Condition.





@ w_o = 100 μm,
$Z_o = L_{cell}$ =10 cm.

Cell Temp = 300 ^oC,
Doppler HWHM = 0.9GHz,
Collisional HW = 0.6GHz.

I_b = 5.08 W/cm^2,
I_c = 6.58 KW/cm^2,
I_s = 0.66 KW/cm^2,
Δ_b = 0.8 GHz,
Δ_s = 3.07 GHz.

$\phi_{NL} = 4.7$ *rad.*

Conclusion

Goals:

To find a sytem that is suitable for quantum optics applications such as squeezed light generation.

- *No* signal field absorption but with *large* self-phase modulation.
- *No* excited state population.

Explored two-level and three-level atoms.

Both can't satisfy all the goals independently.

Combine them to create a dark-state electromagnetically induce transparency (DS-EIT) system.

Near perfect dark state is created.

Nonlinearity still present.

Experiment effort is underway to verify these predictions.