Coherent Intersubband Excitations on a Picosecond Time Scale

S. Hanna, A. Seilmeier
Institute of Physics, University of Bayreuth, Germany

E. Dupont, H. C. Liu
Institute for Microstructural Sciences, NRC, Ottawa, Canada

L. E. Vorobjev, V. Yu Panevin, D. A. Firsov, V. A. Shalygin
St. Petersburg State Polytechnic University, Russia

V. M. Ustinov, A. E. Zhukov
Ioffe Physico-Technical Institute, St. Petersburg, Russia

UNIVERSITÄT BAYREUTH

Outline

- Coherent intersubband excitations
- Electromagnetically induced transparency and absorption in a ladder system
- Quantum coherence beating on a picosecond time scale in a V-system
- Density matrix model for a 3-level system

Intersubband Excitation and Relaxation

Excitation intensity low ($\mu E/h \times \tau_2 < 1$):

- Incoherent regime
- Description by rate equations
- Occupation dynamics $\rho_{ii}(t)$

Excitation intensity high ($\mu E/h \times \tau_2 > 1$):

- Quantum coherence regime
- Description by the density matrix formalism

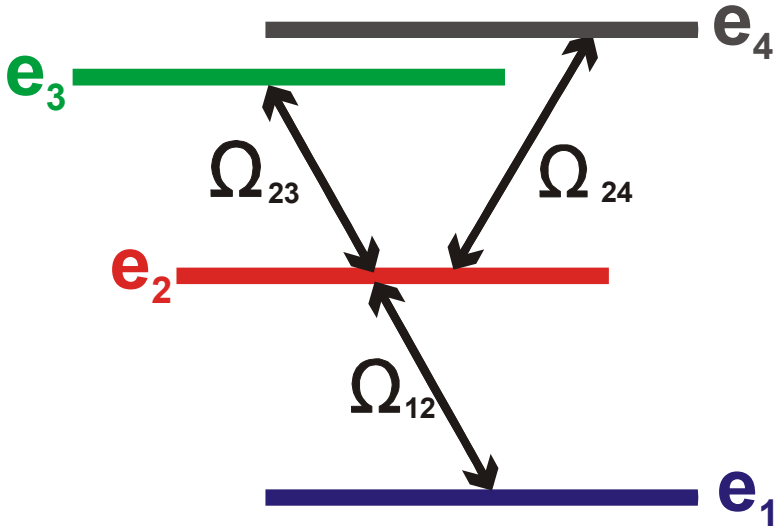
$$\dot{\rho}_{ij}(t) = -i/\hbar \left[H(t), \rho(t) \right]_{ij}$$

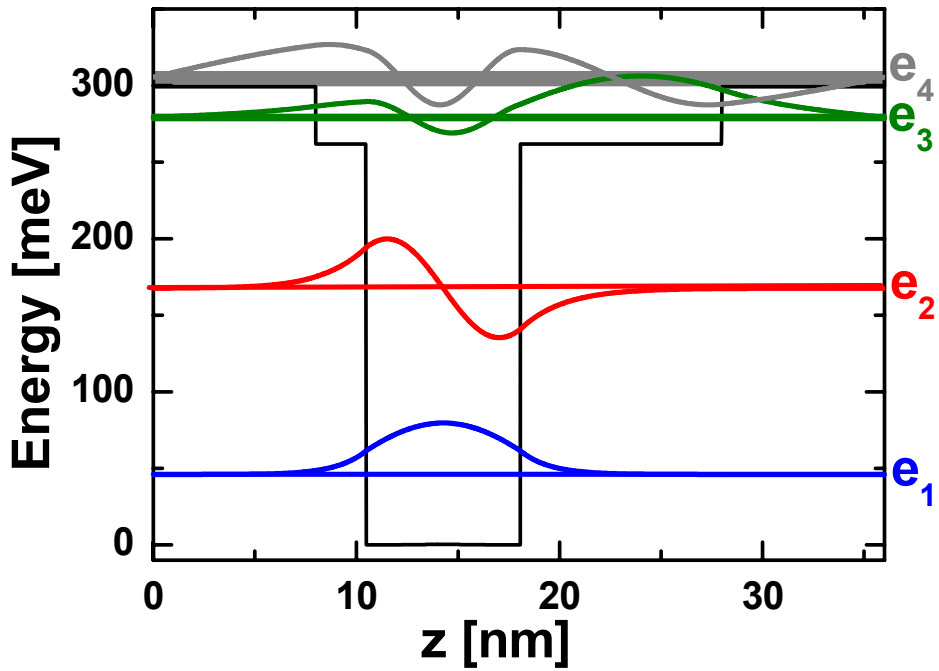
- Coherences $\rho_{ij}(t)$ play an important role

UNIVERSITÄT BAYREUTH

Electromagnetically Induced Transparency and Absorption

Ladder system



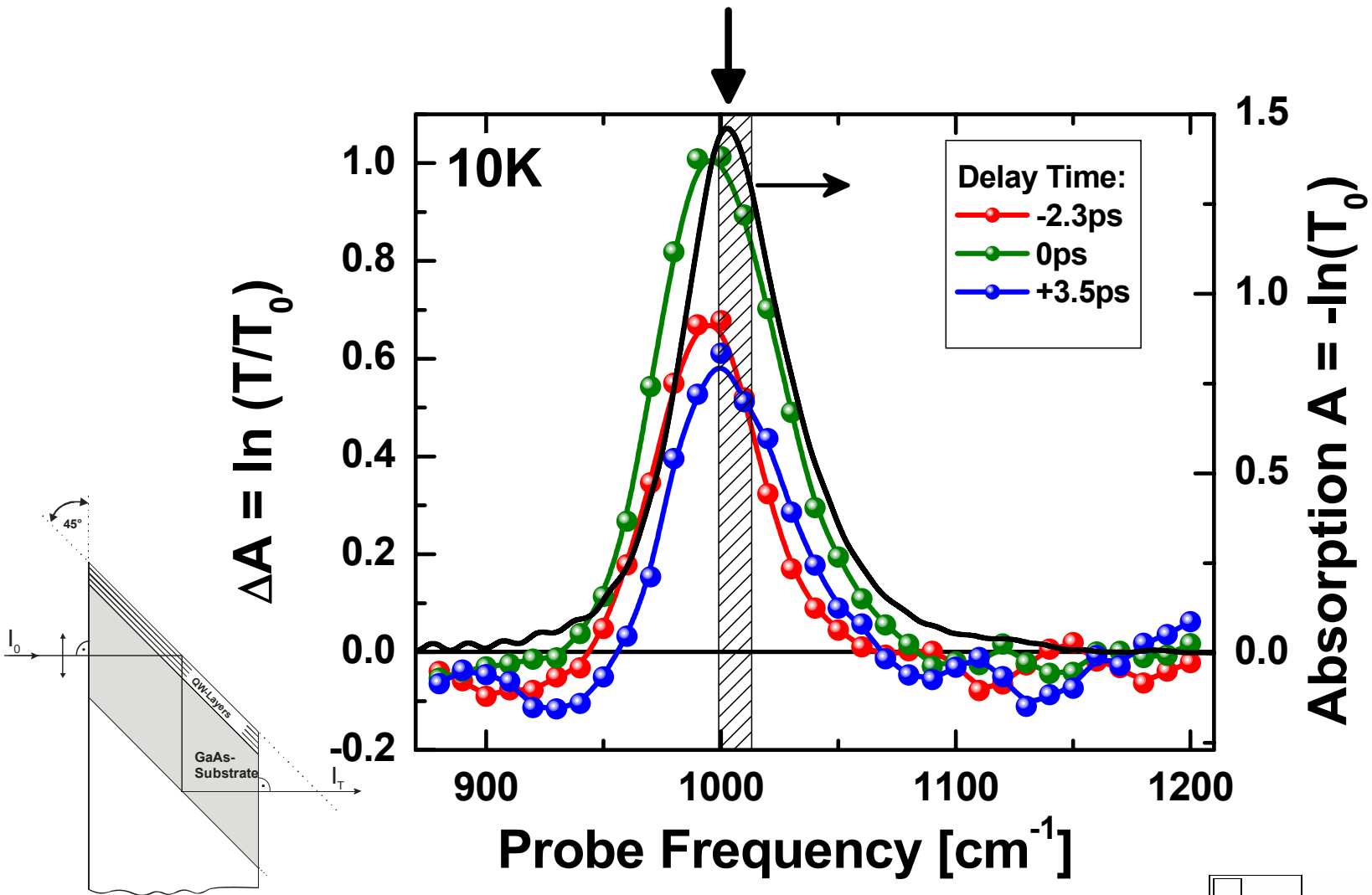


60 periods of

8nm $Al_{0.40}Ga_{0.60}As$
2.5nm $Al_{0.35}Ga_{0.65}As$
7.5nm n-GaAs ($3 \cdot 10^{17}$ cm^{-3})
9.9nm $Al_{0.35}Ga_{0.65}As$

UNIVERSITÄT BAYREUTH

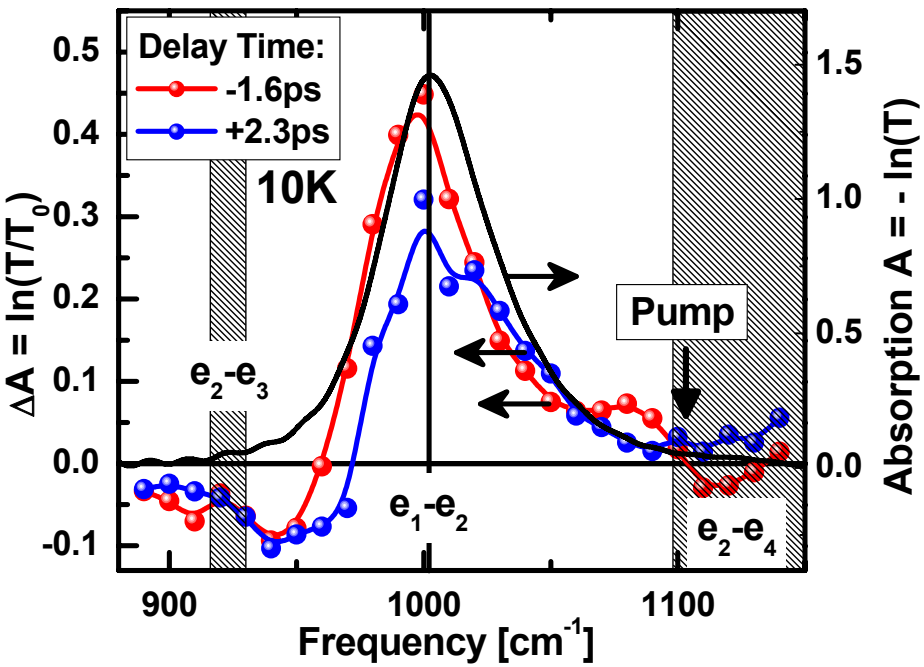
Absorption Spectrum / Absorption Change after Resonant Excitation

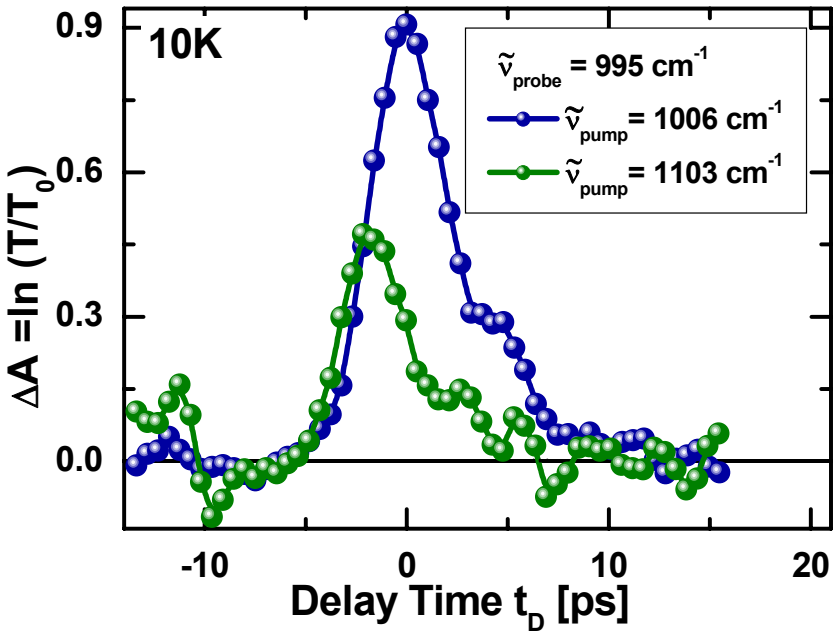


UNIVERSITÄT BAYREUTH

Electromagnetically Induced Transparency and Absorption

Rabi frequency of excitation pulse Ω_{24}~ 6meV



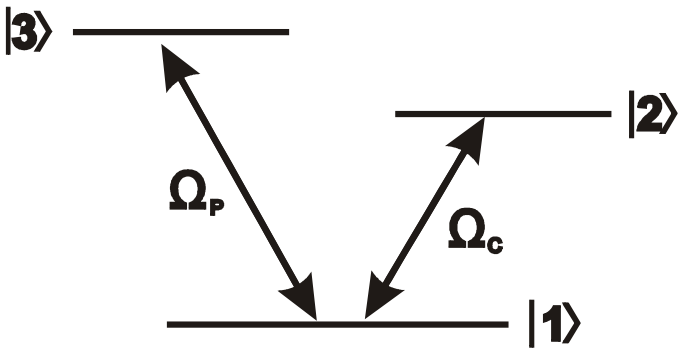


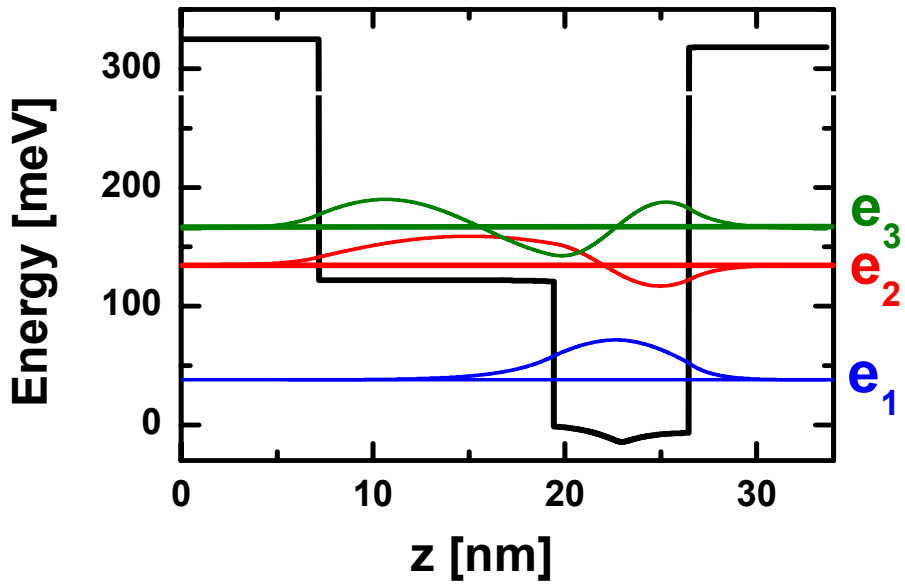
Transmission increase is 7 times larger than estimated from population numbers ⇨ electromagnetically induced transparency

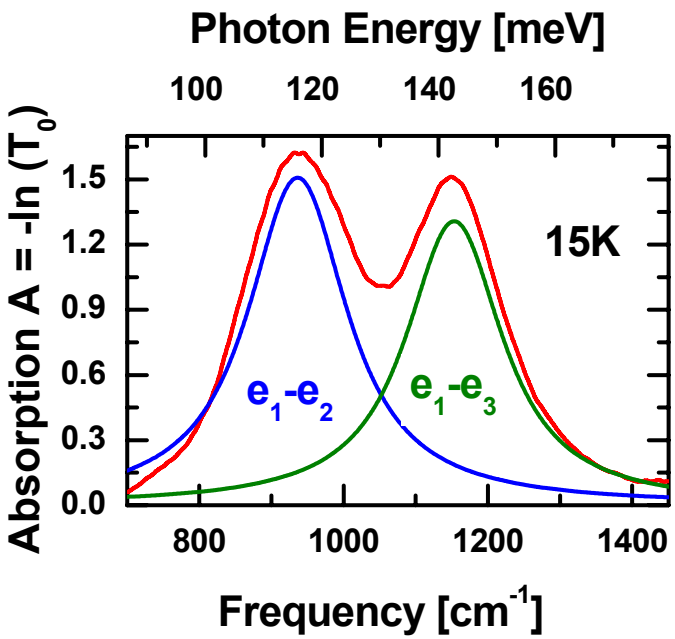
UNIVERSITÄT BAYREUTH

Quantum Oscillations on a ps-Time-Scale

V-type level system:





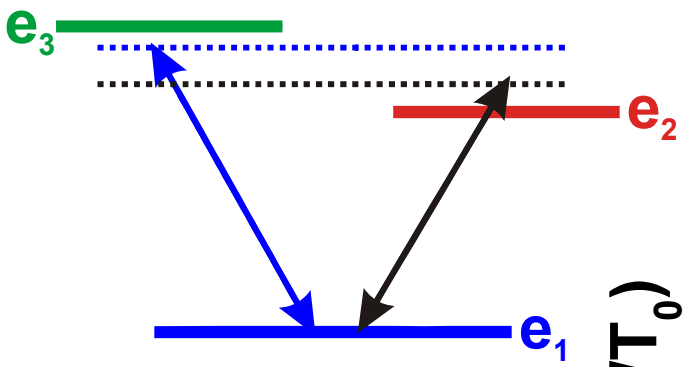


100 periods:

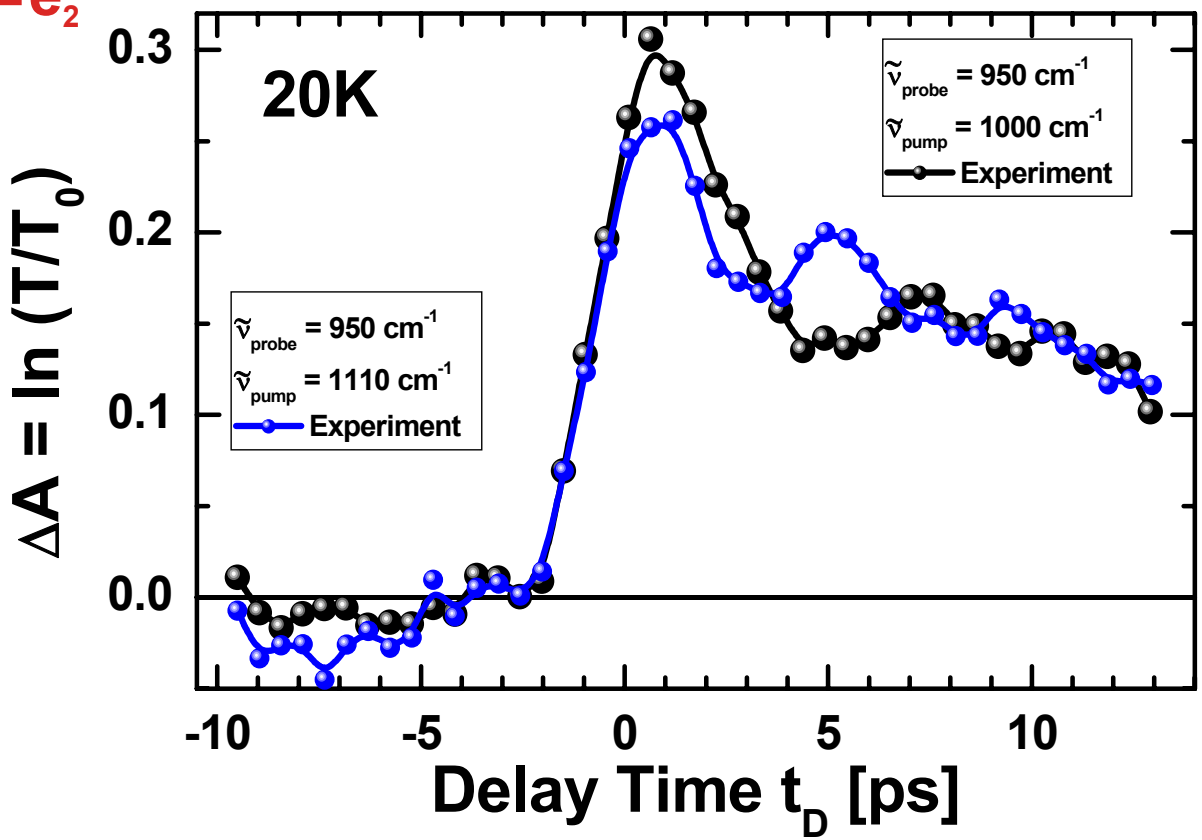
12.2 nm $Al_{0.16}Ga_{0.84}As$
7.0 nm n-GaAs (δ-doped 10^{12} cm^{-2})
7.2 nm $Al_{0.43}Ga_{0.57}As$

UNIVERSITÄT BAYREUTH

Excitation at Frequencies between the Two Transitions



Estimated Rabi frequencies: 3….5 meV



UNIVERSITÄT BAYREUTH

The Model

$$\dot{\rho}_{nm}(t) = \left(-\frac{1}{\tau_{nm}} - i\omega_{nm} \right) \rho_{nm}(t) + i\Omega_{nm}(t)\left[\rho_{mm}(t) - \rho_{nn}(t)\right] + i\left[\Omega_{nl}(t)\rho_{lm}(t) - \rho_{nl}(t)\Omega_{lm}(t)\right]$$

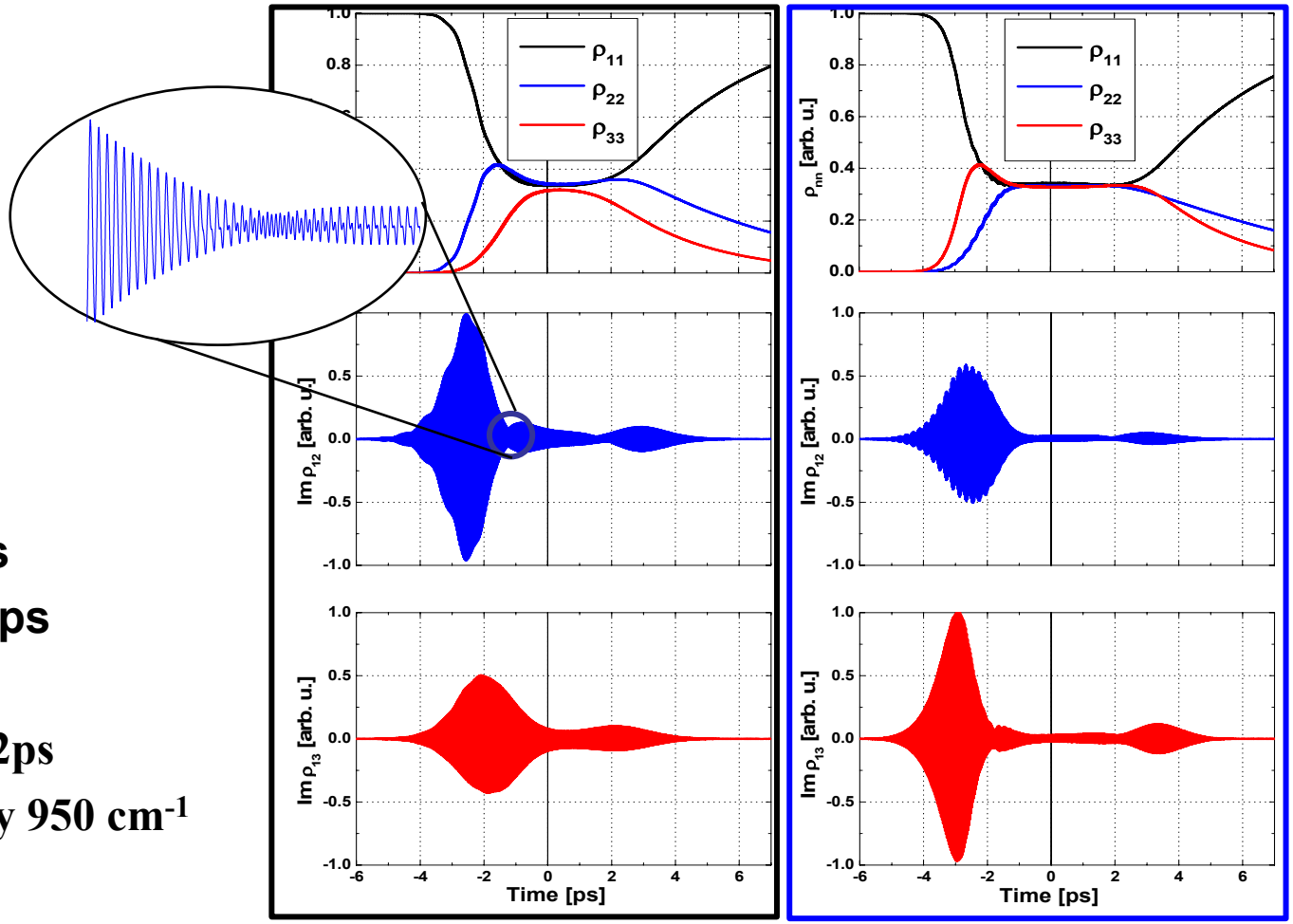
$$\dot{\rho}_{nn}(t) = i\left[\Omega_{nl}(t)\rho_{\mathrm{ln}}(t) - \rho_{nl}(t)\Omega_{\mathrm{ln}}(t)\right] + \sum_{E_m > E_n} \frac{\rho_{mm}(t)}{T_{nm}} - \sum_{E_m < E_n} \frac{\rho_{nn}(t)}{T_{mn}}$$

and

the field equations for optical pulse propagation

UNIVERSITÄT BAYREUTH

Simulation of Populations and Coherences



Parameters:

$\tau_{dephasing}$ = 300fs

$T_{depopulation}$ = 4 ps

Pulse duration 2ps

Probe frequency 950 cm^{-1}

Rabi-frequencies:

Excitation: $\tilde{\nu}_{exc}$ =1000cm^{-1}

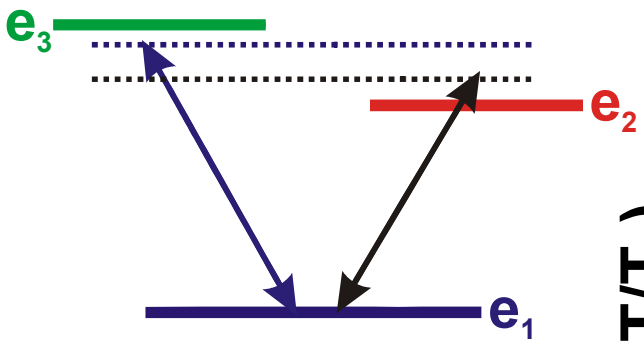
$\Omega_{31}=\Omega_{21}$ =20 meV

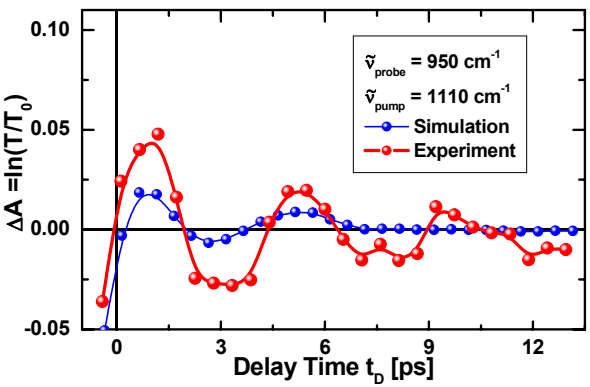
Excitation: $\tilde{\nu}_{exc}$ =1110cm^{-1}

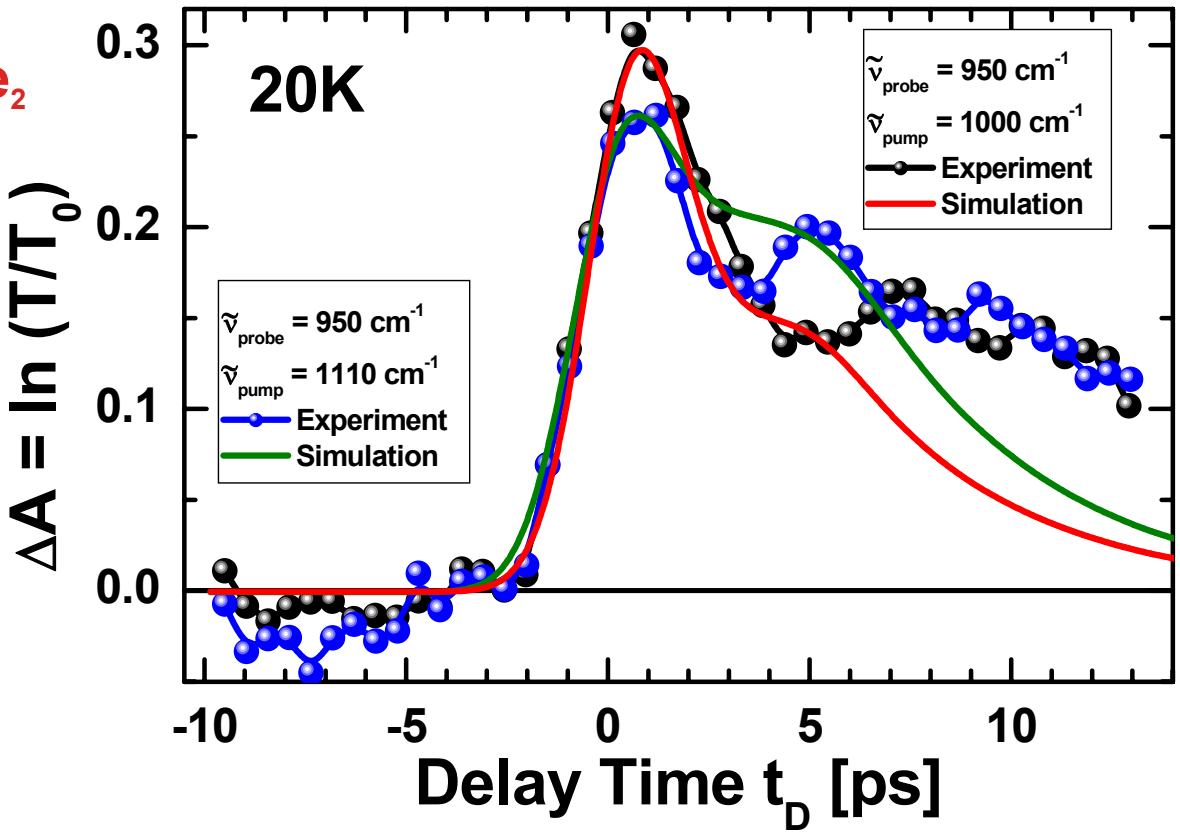
$\Omega_{31}=\Omega_{21}$ =40 meV

UNIVERSITÄT BAYREUTH

Experimental Results and Simulation



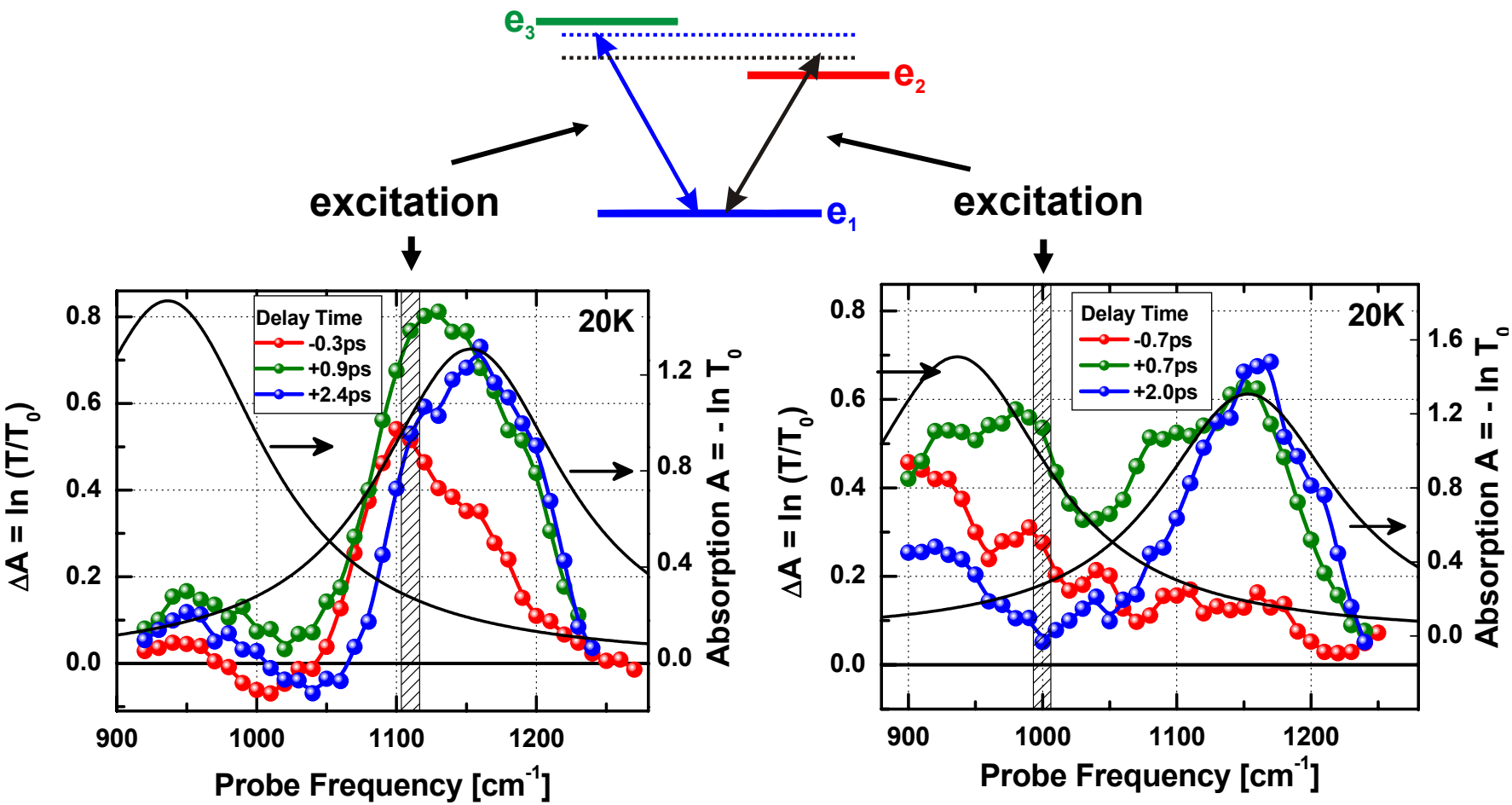




↳Oscillations due to beating of coherences

UNIVERSITÄT BAYREUTH

Transient Spectra due to Coherent Excitation



Transmission increase at the excited transition e_1-e_3

Transmission increase at the not excited transition e_1-e_3

UNIVERSITÄT BAYREUTH

Summary

- Coherent intersubband excitations are observed on a ps time scale
- Electromagnetically induced transparency and absorption are found in a ladder system
- Time resolved experiments in a V-system show beating of quantum coherences on a ps time scale
- The beating period is in agreement with simulations of the corresponding 3-level system