

ODR Spectroscopy of IFQD's

C.J. Meining, M. Yasar, V.R. Whiteside, A. Petrou and B.D. McCombe
Department of Physics and CAPEM, University at Buffalo, SUNY, Buffalo, NY 14260, USA
J.G. Tischler, A.S. Bracker and D. Gammon
Naval Research Laboratory, Washington, D.C. 20375-5347, USA

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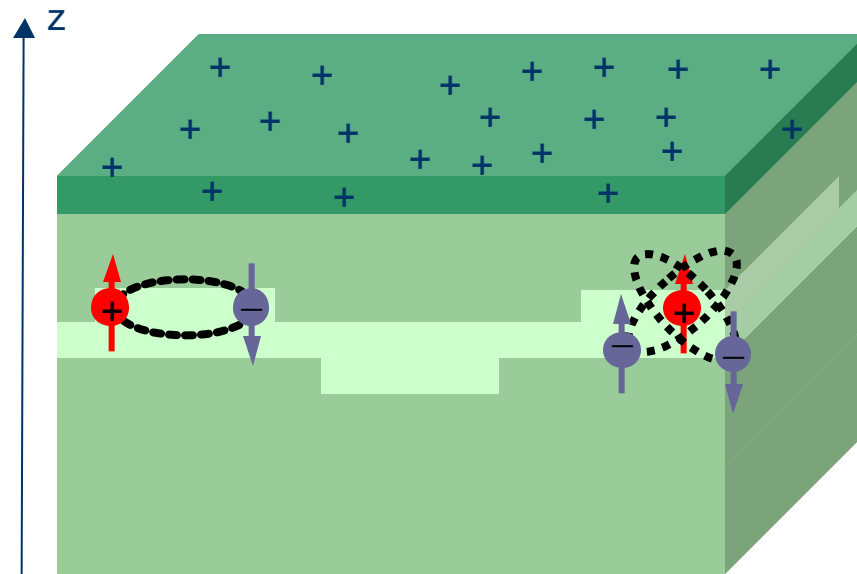


DMR # 0203560

Outline:

- Samples
- Experiment - ODR
- Ensemble and Single Dot PL
- Theory of trion transitions
- ODR results

Samples (NRL)



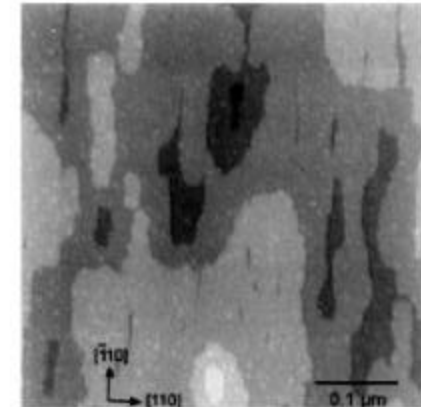
$\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}:\text{Si}$ @ $\sim 10^{17}\text{cm}^{-3}$

$\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$

GaAs

$\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$

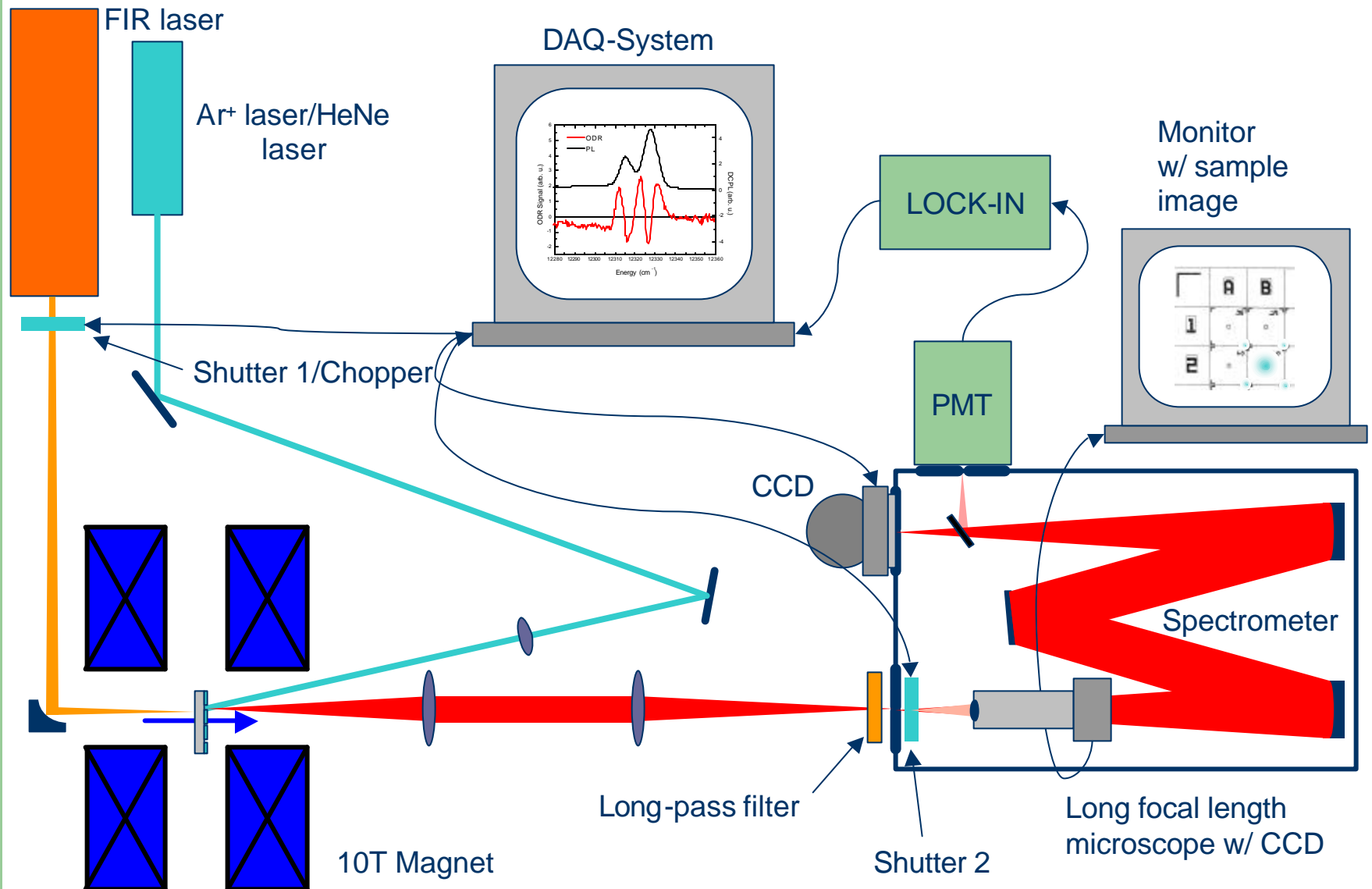
STM



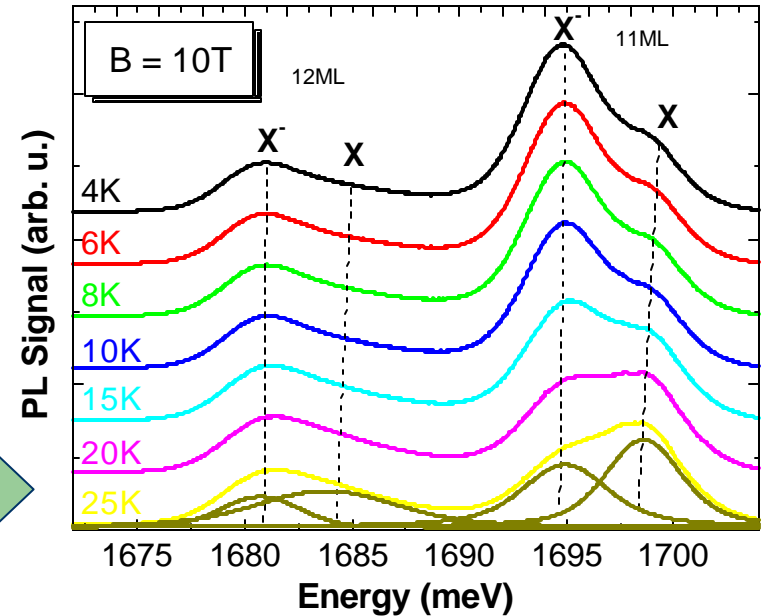
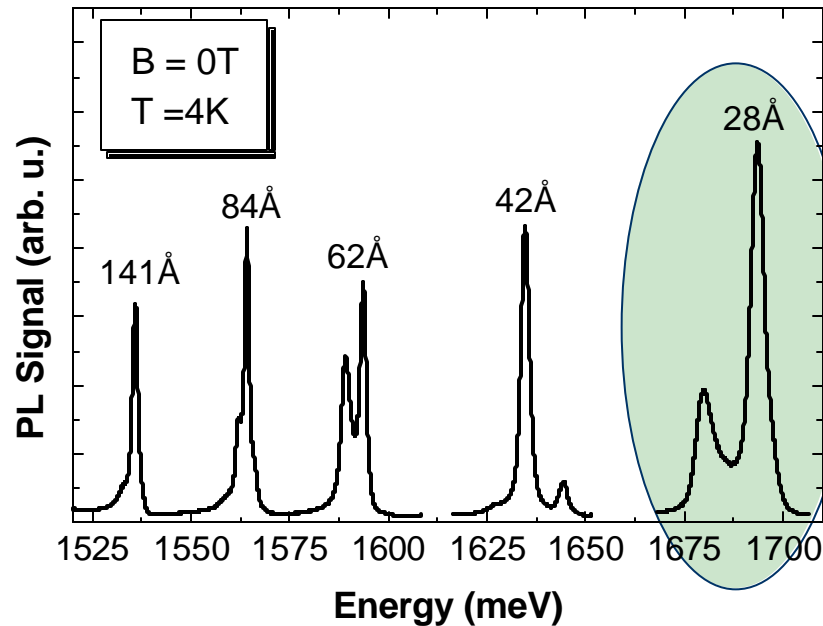
D. Gammon et al., PRL **76**, 1996

- Growth interrupted at interfaces
 - ⇒ monolayer high islands (30 – 100 nm)
 - ⇒ Interface Fluctuation Quantum Dots (IFQD's)
- Five quantum wells in one sample: **141Å**, **84Å**, 62Å, 42Å, 28Å
- Asymmetrically n-doped in barriers
 - ⇒ Recombination of free and *localized* neutral and charged excitons (X and X⁻)
- **Optically Detected Resonance**: Monitor ΔPL resonantly induced by FIR radiation
 - ⇒ Investigation of *intraband* transitions (internal structure of X and X⁻)

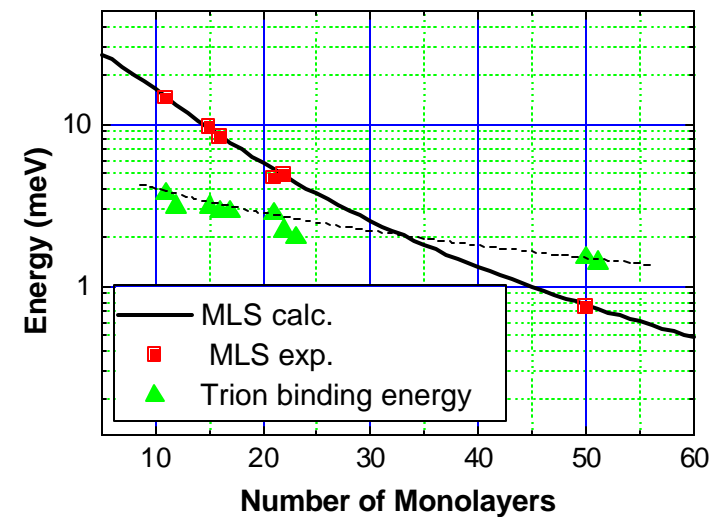
Experimental Setup



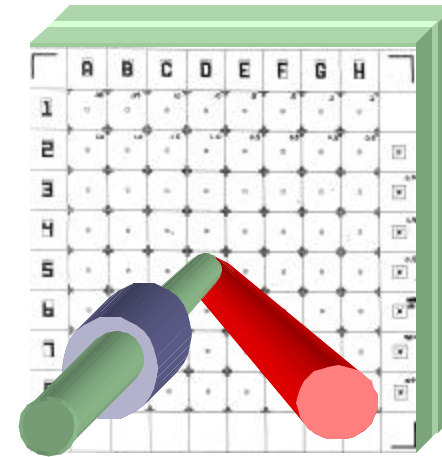
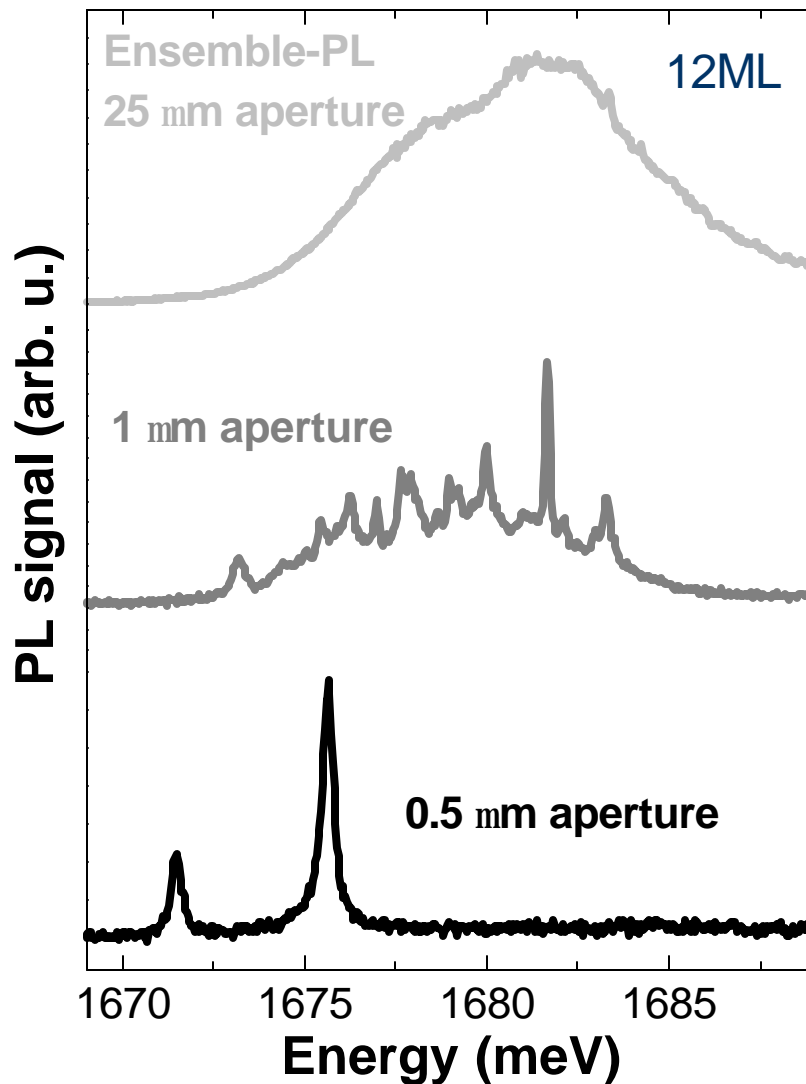
Ensemble PL



- Multiple features from each QW
- Temperature and excitation intensity study
 \Rightarrow Monolayer splitting (MLS), X and X'
- see also J.G. Tischler et al., PRB **66**, 2002



Single Dot PL

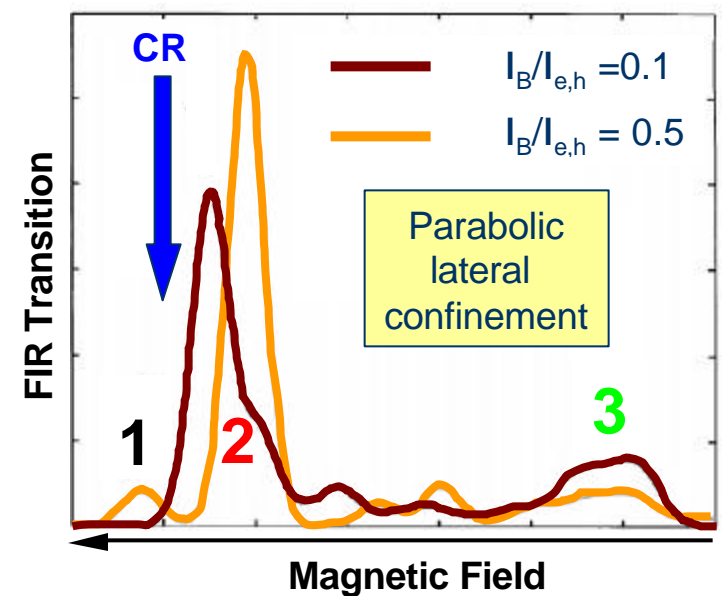
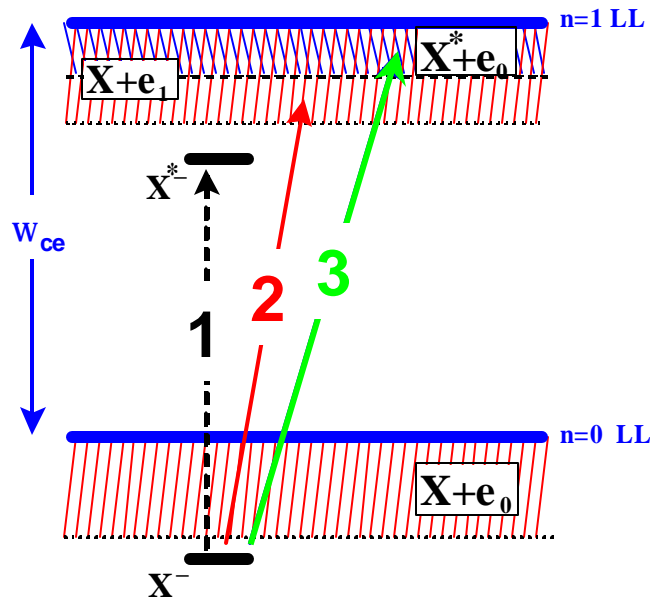


- Submicron apertures in Al mask by E-Beam lithography
- Ultra-narrow PL lines (small apertures) \Rightarrow X and X⁻ emission from single dots (cf. D. Gammon et al., PRL **76**, 1996)



Carrier localization in lateral interface fluctuations at low temperatures

Internal Transitions Translational Invariance



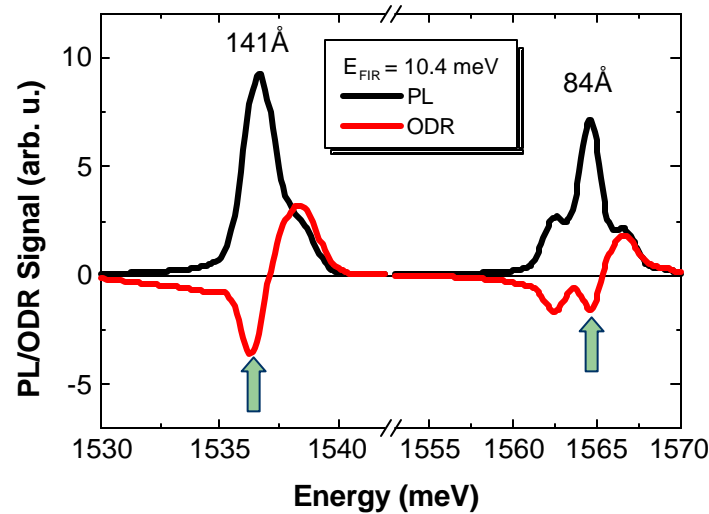
- Magnetic translational invariance for mobile X^-
 \Rightarrow only ionizing transitions allowed (2, 3)
- Bound-to-bound transition (1) strictly forbidden

- Localization of X^- breaks symmetry
 \Rightarrow finite oscillator strength of transition 1.
 \Rightarrow appears at $B > B_{e-CR}$

- Contrast to fixed negatively charged donor impurity D^-
 \Rightarrow bound-to-bound transitions dominate

Theory of X^- triplet states in the high B, ideal 2D limit
 (Dzyubenko et al., Physica E 6, 2000, PRL 84, 2000)

ODR of wide wells



- track X^- features of wide wells \uparrow
- FIR laser lines $\lambda_{\text{FIR}} = 118.8\mu\text{m}, 184.3\mu\text{m}$

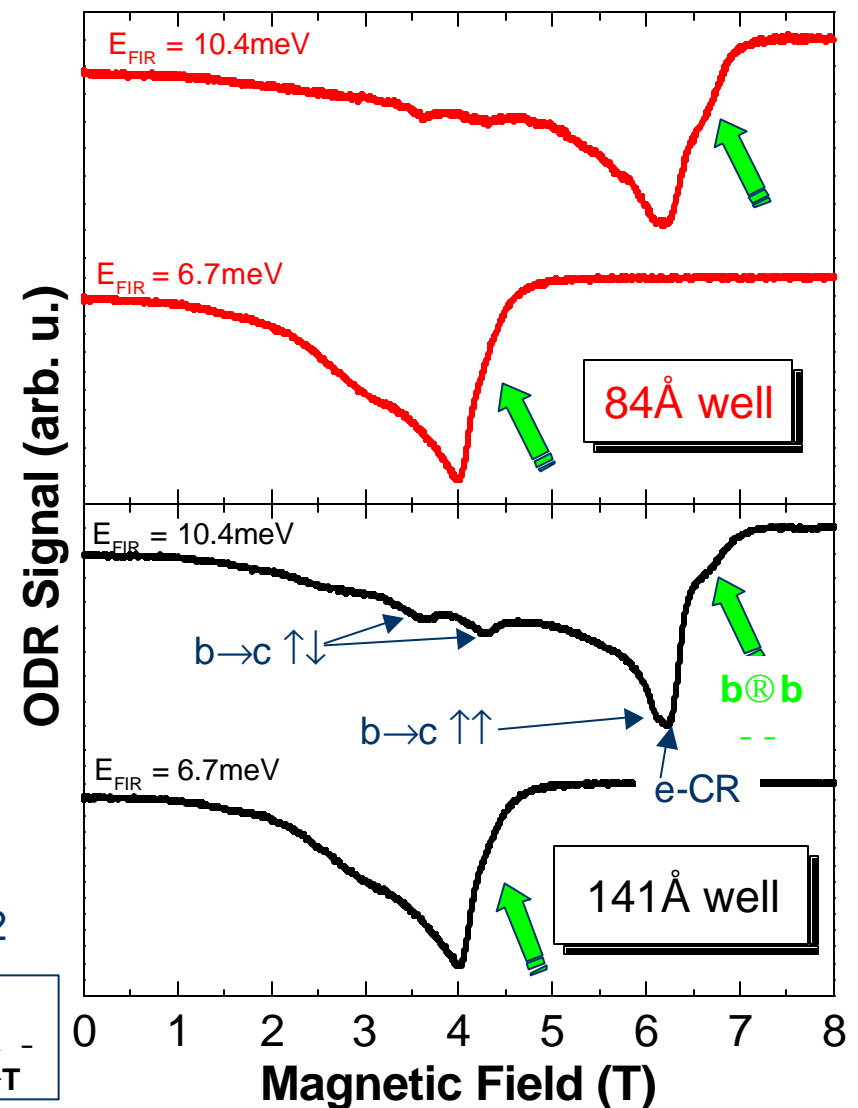
Features observed in addition to e-CR:

Low-field side

- bound \rightarrow continuum of free X_S^-
 - bound \rightarrow continuum of free X_T^-
- \Rightarrow see A.H. Nickel et al., PRL **88**, 2002

High-field side

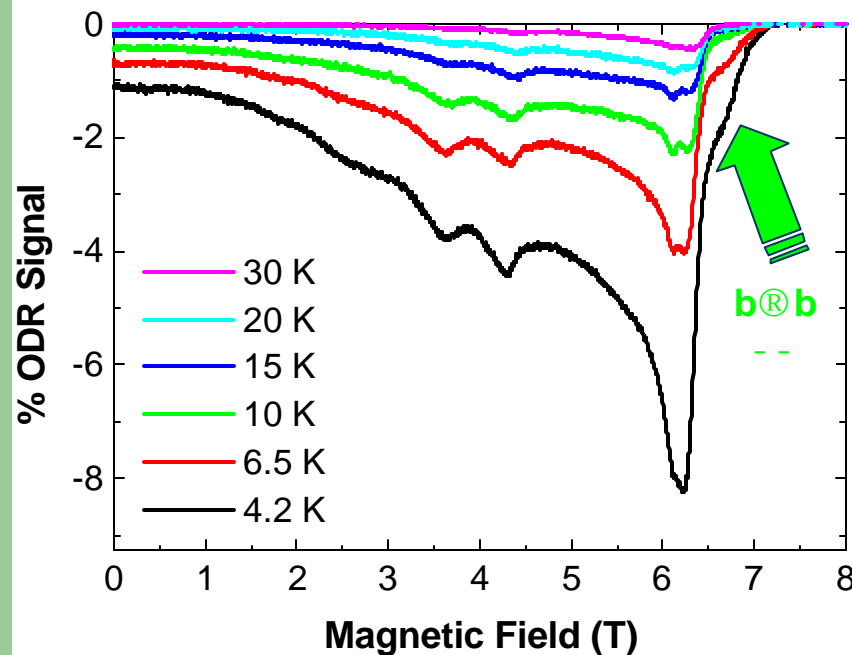
bound \textcircled{R} bound transition of localized X_T^-



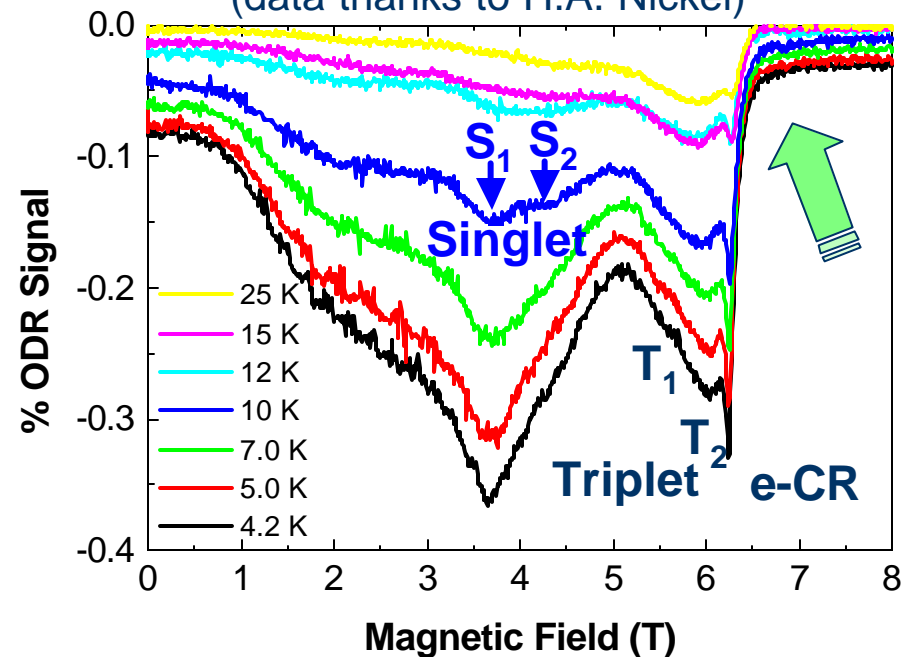
Temperature Study

$E_{\text{FIR}} = 10.43\text{meV}$

141Å QW with **interface fluctuations**
(asymmetric doping $\sim 3 \times 10^{10}\text{cm}^{-2}$)

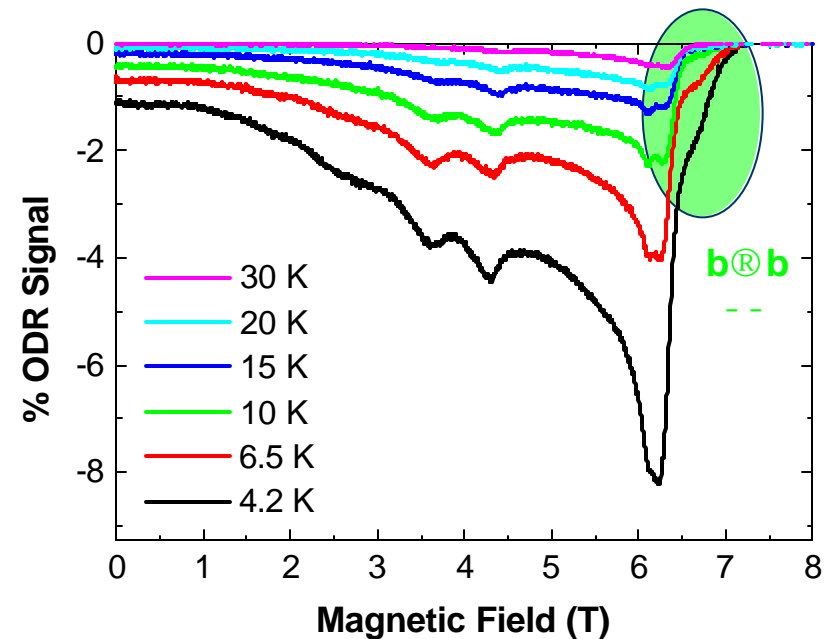
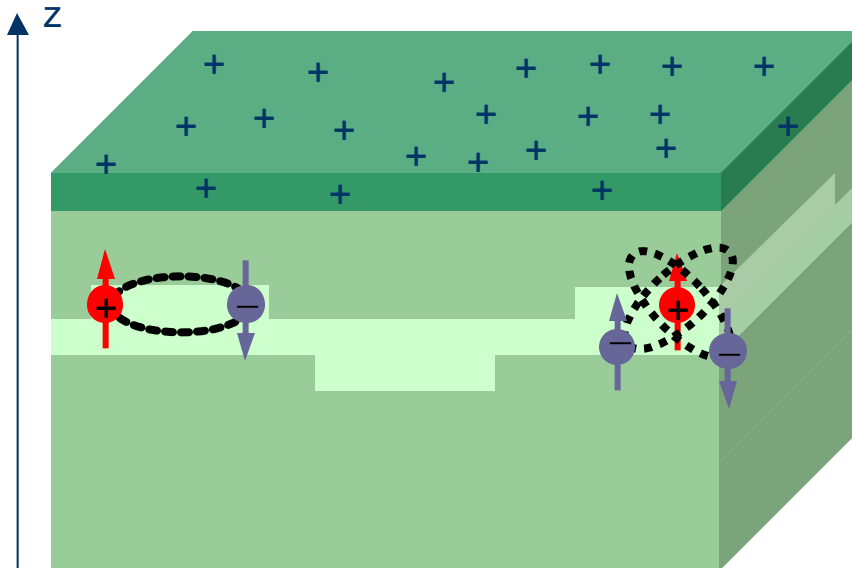


200Å QW with **smooth interfaces**
(symmetric doping $\sim 2 \times 10^{10}\text{cm}^{-2}$)
(data thanks to H.A. Nickel)



- QW w/ smooth interfaces: **only** bound \rightarrow continuum transitions of **free** X_S^- / X_T^-
 \Rightarrow both types of $b \rightarrow c$ transitions are resolved and identified (T_1, T_2, S_1, S_2)
- QW with IFQD's **also** show **$b \otimes b$ transition of localized X_T^- above CR**
 \Rightarrow **$b \otimes b$** - - transition vanishes quickly with increasing temperature

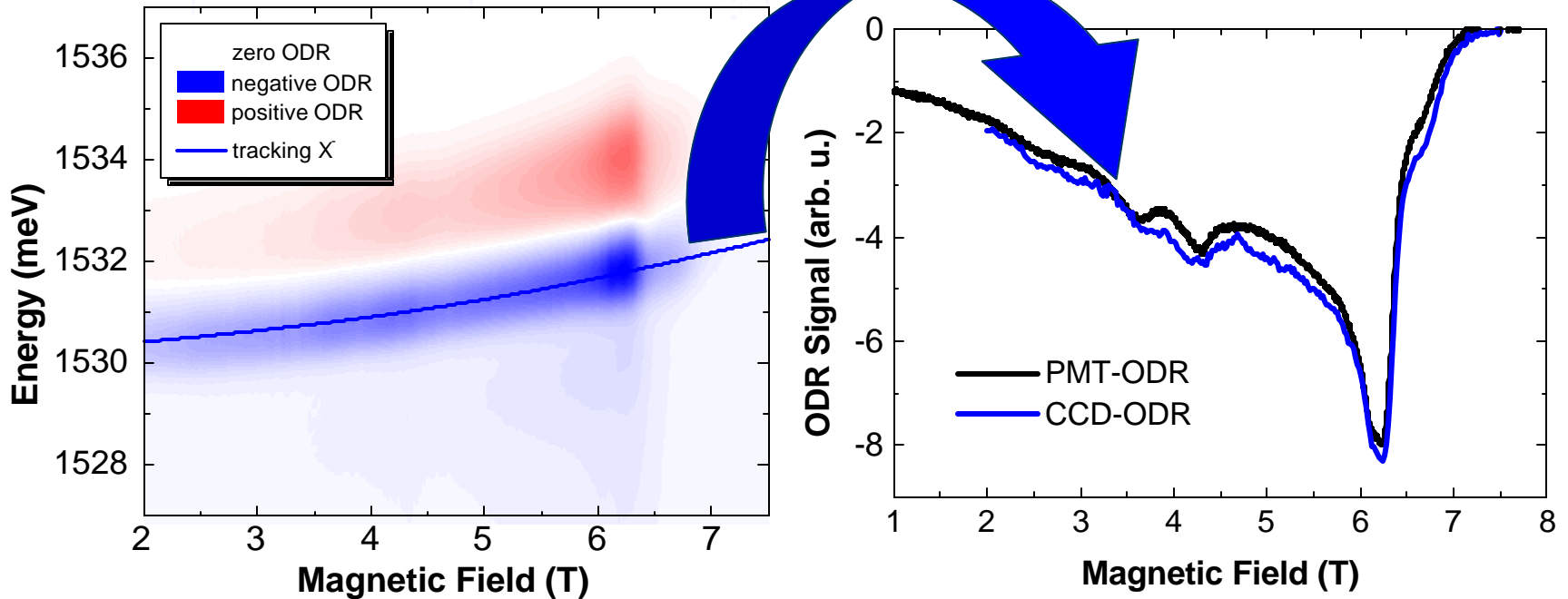
Summary



- ⇒ Ensemble and single dot PL of interface fluctuation quantum dots (IFQD's)
- ⇒ Optically detected resonance (ODR) spectroscopy on ensemble PL
- ⇒ Breaking of magnetic translational invariance leads to observation of otherwise forbidden bound-to-bound triplet transition at $B > B_{e-CR}$

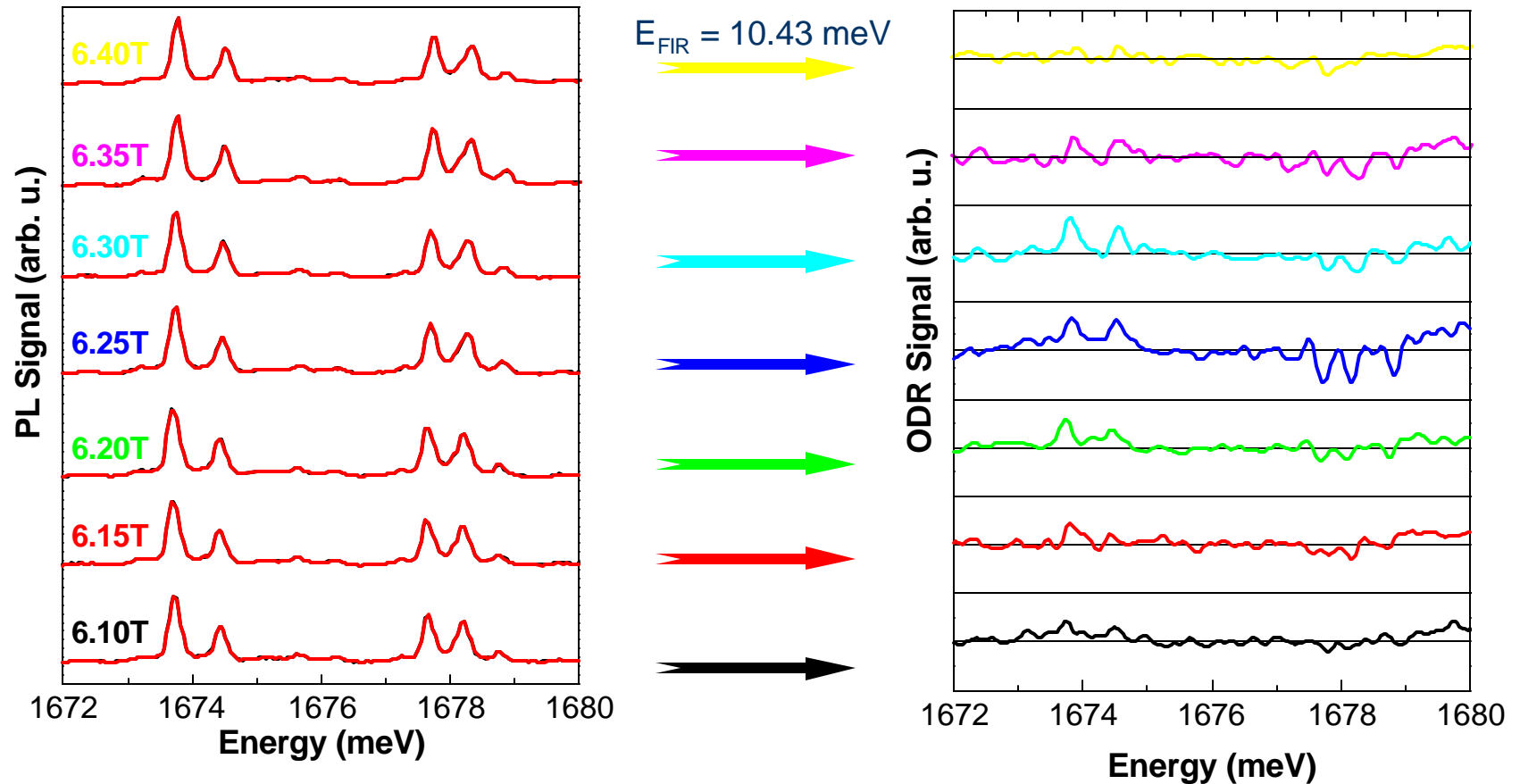
Special thanks to A.B. Dzyubenko

CCD ODR - 141Å well



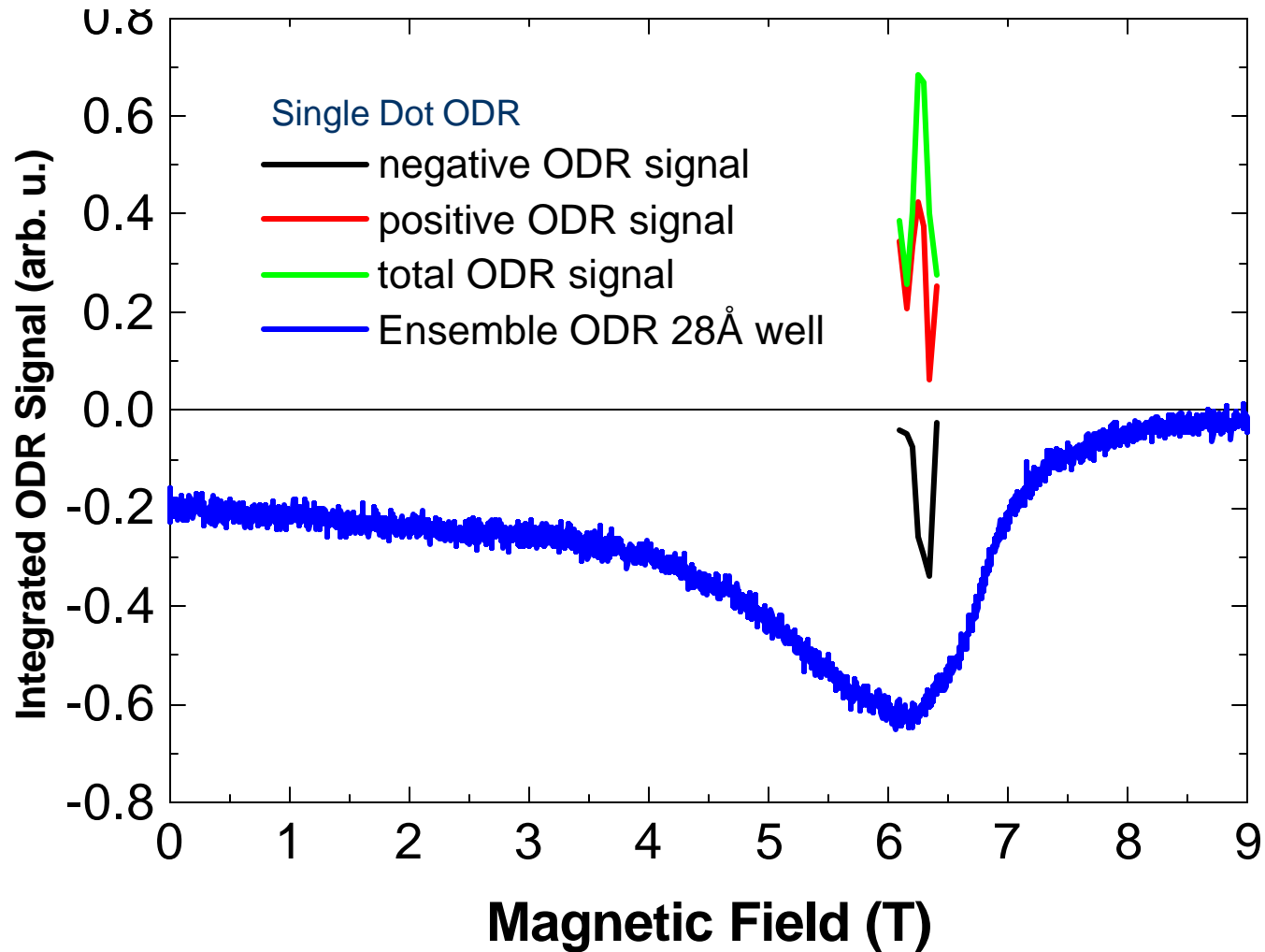
- Full spectrum ODR with silicon CCD: $ODR = PL_{FIR\ on} - PL_{FIR\ off}$
 - Field cuts along arbitrary paths possible
 - Here $\Delta B = 0.02T$ steps for CCD-ODR, following X^- feature shift with B
⇒ all features reproduce
- ⇒ **CCD-ODR favorable for low-intensity PL features (Single Dot ODR)**

Single Dot ODR ???



- Zeeman splitting of single dot features resolved; origin (X or X^-) unclear
- positive and negative ODR signals observed for different single dot features

Single Dot ODR ???



D⁻ internal transitions

