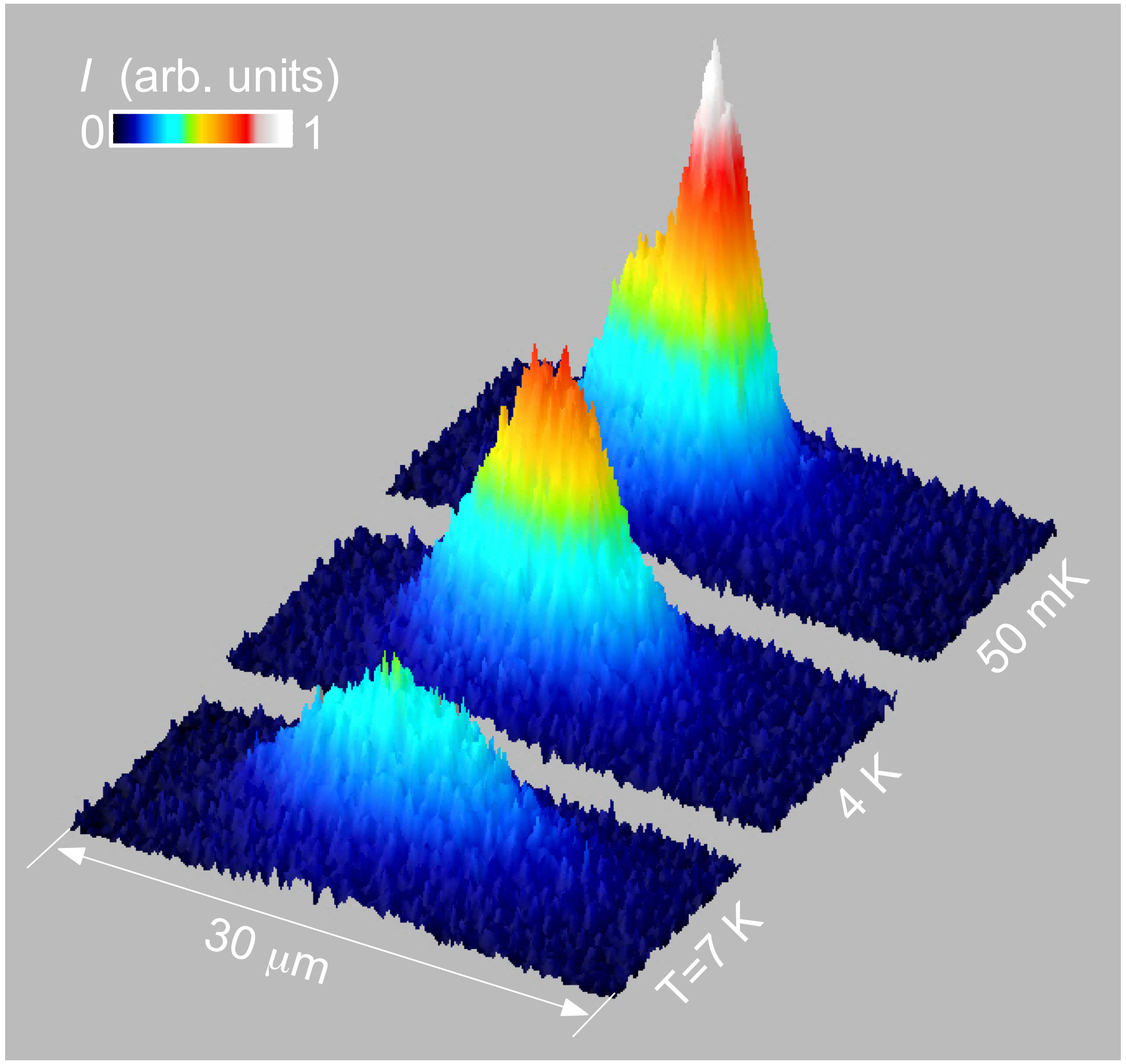
# Condensation of Excitons in a Trap





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*University of California at San Diego*

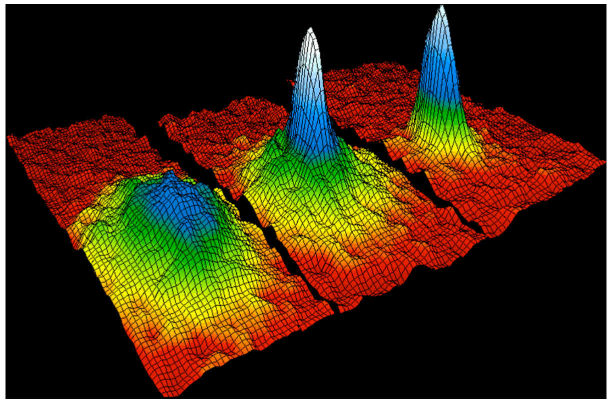
Micah Hanson & Art Gossard

*University of California at Santa Barbara*

# Traps in Low Temperature Physics

- Traps are critical for studies of atomic condensates

  → atomic BEC



MH Anderson, JR Ensher, MR Matthews, CE Wieman, EA Cornell, *Science* **269**, 198 (1995)

CC Bradley, CA Sackett, JJ Tollett, RG Hulet, *PRL* **75**, 1687 (1995)

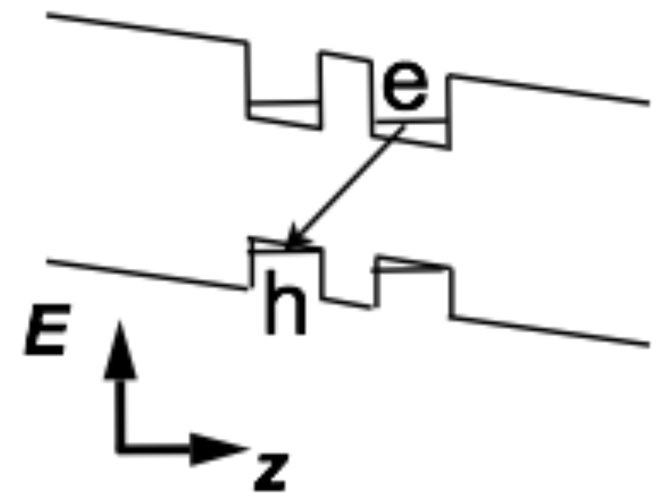
KB Davis, MO Mewes, MR Andrews, NJ van Druten, DS Durfee, DM Kurn, W. Ketterle, *PRL* **75**, 3969 (1995)

- Traps for excitons can be created through customized external potentials

  goal → exciton condensation in a trap

# An Introduction to Indirect Excitons

- An indirect exciton is composed of an electron and hole in separate quantum wells




Characteristics of indirect excitons

•long lifetime •bosons • electronically controllable

⟶ Model system for studies of physics of ultracold bosons in CM materials

QM1G.7: Yuliya Kuznetsova
*Transport of Indirect Excitons in a Potential Energy Gradient*
Monday, 9:45 AM

QM2G.7: Mikas Remeika
*Electrostatic Lattices for Indirect Excitons in Coupled Quantum Wells*
Monday, 12:15 PM

QTh4E.4: Alex High
*Spontaneous Coherence in a Cold Exciton Gas*
Thursday, 5:15 PM

# Onset of Quantum Degeneracy

- “Quantum gas” when thermal de Broglie wavelength comparable to separation between excitons

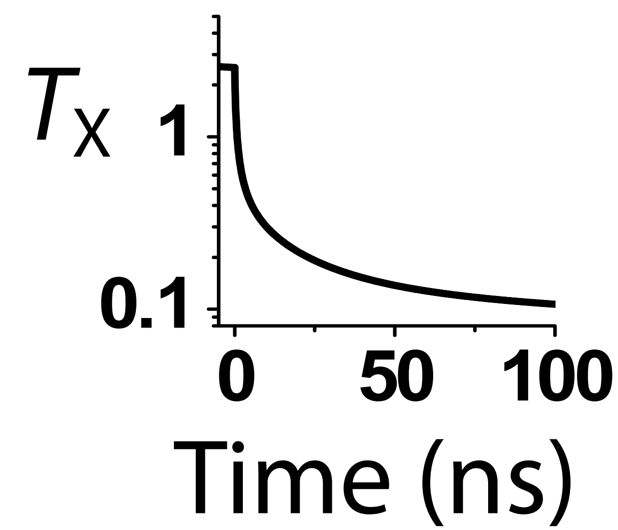
$$\lambda_{dB} = \left( \frac{2\pi\hbar^2}{mk_B T} \right)^{1/2}$$

$$\lambda_{dB} = n^{-1/2} \longrightarrow T_{dB} = \frac{2\pi\hbar^2}{mk_B} n$$

- Excitons in GaAs CQW: $n = 10^{10}$ cm$^{-2}$, $m_{exciton} = 0.2$ m$_0$

$$\longrightarrow T_{dB} \sim 3 \text{ K}$$

- Excitons can cool to 100mK within lifetime




L.V. Butov, A.L. Ivanov, A. Imamoglu, P.B. Littlewood, A.A. Shashkin, V.T. Dolgopolov, K.L. Campman, and A.C. Gossard, *PRL* **86**, 5608 (2001)

# Electronic Control of Excitons

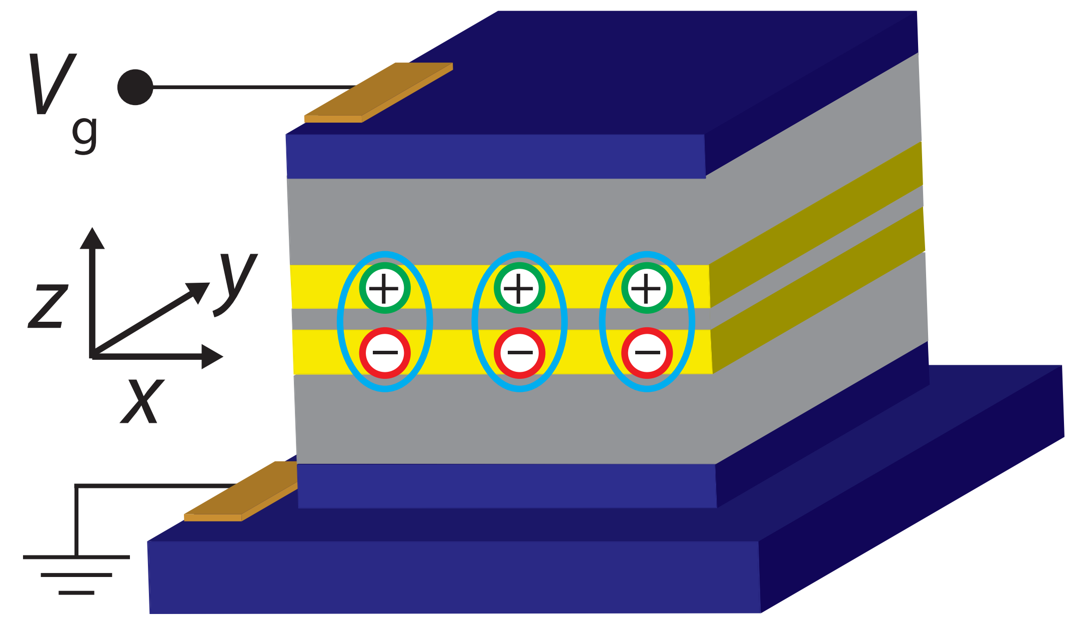
Indirect excitons are dipoles with energy controlled by electrode potential

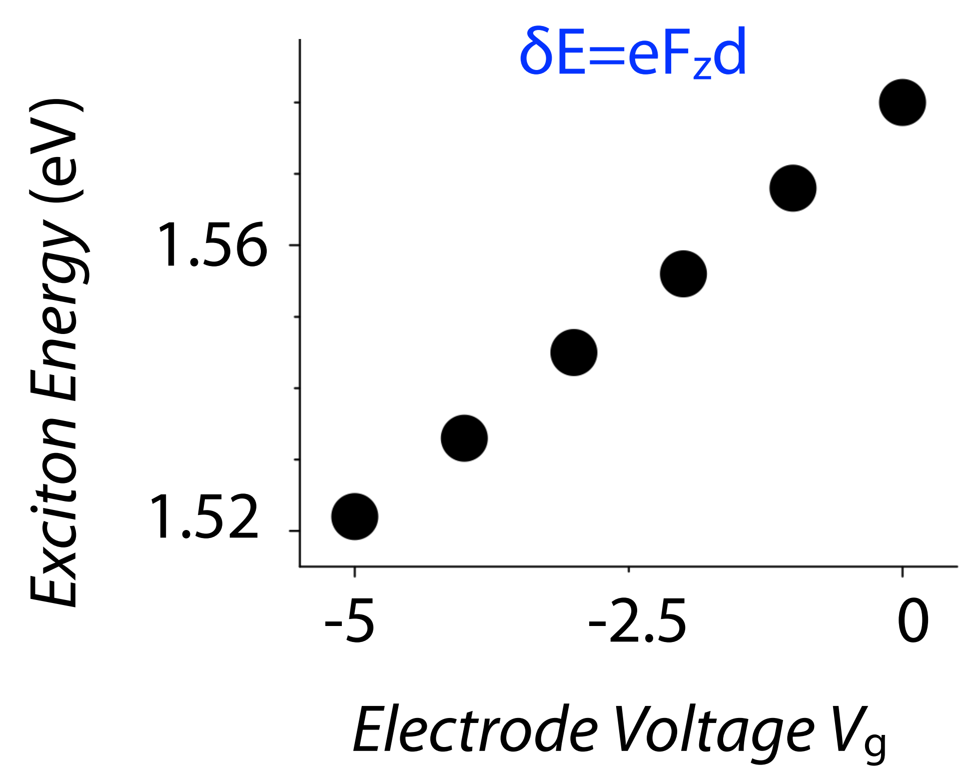
↓

Customized electrode design creates desired potential landscape

↓

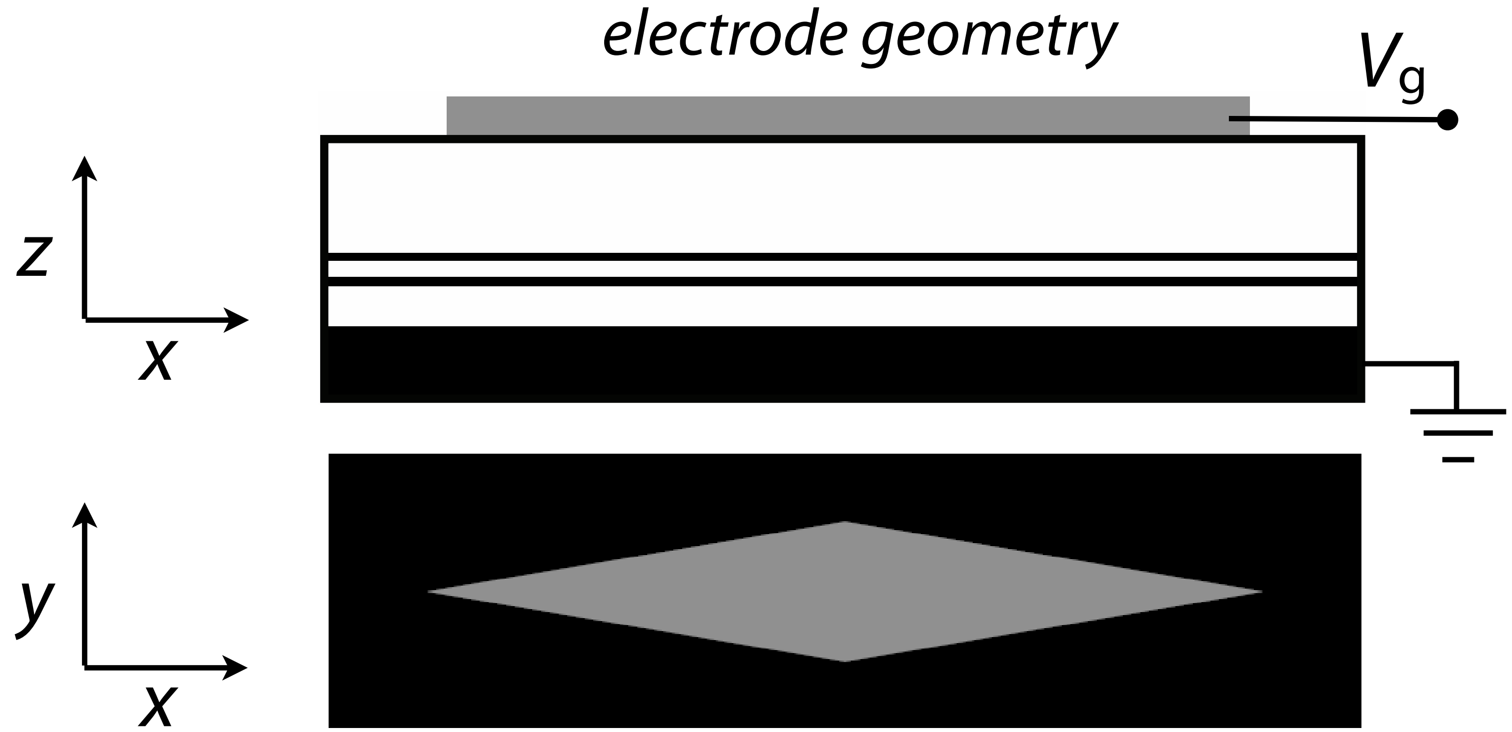
- conveyers
- lattices
- traps
- ramps
- transistors
- circuits



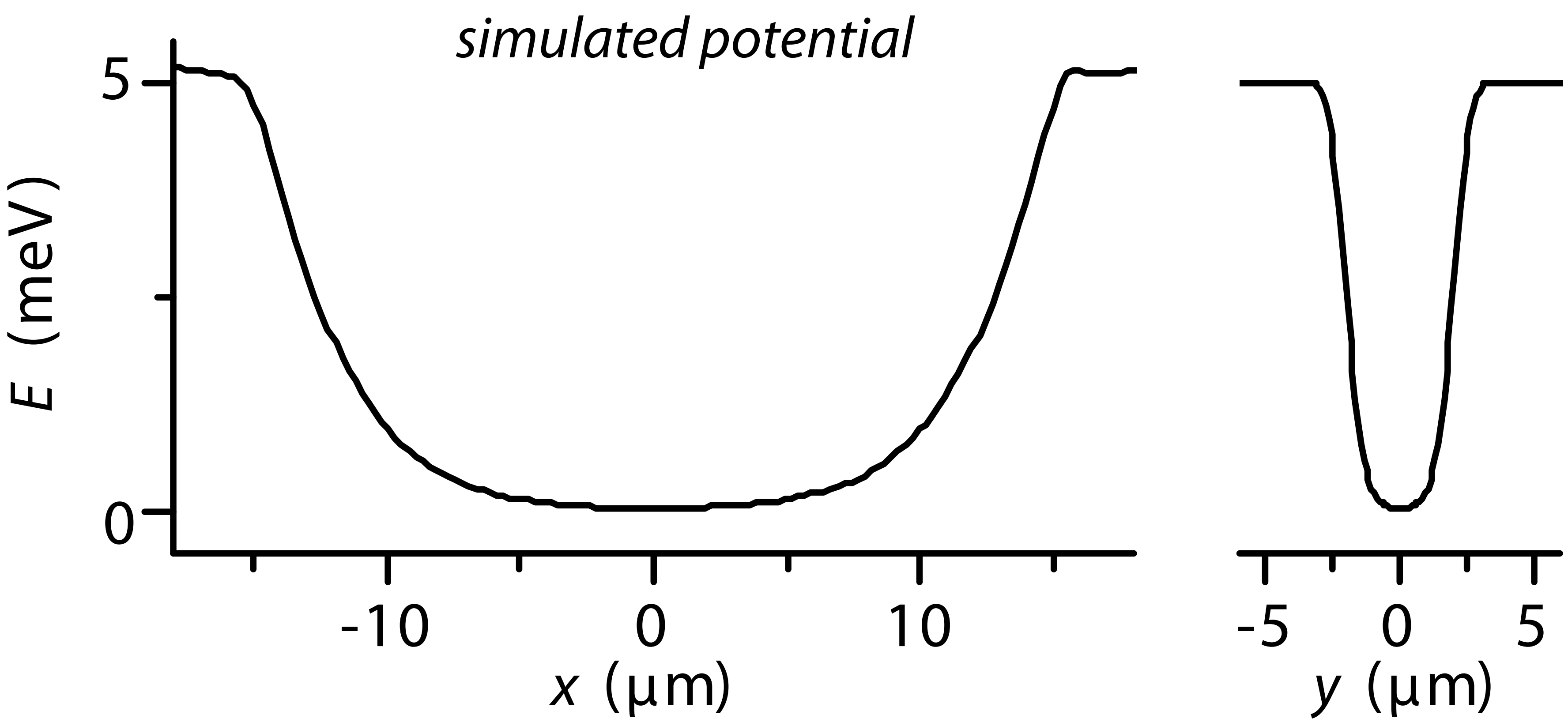




more info: physics.ucsd.edu/~lvbutov

# The Diamond Trap

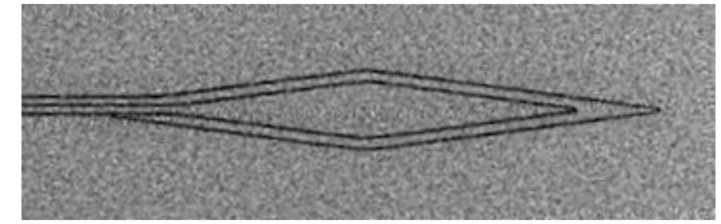


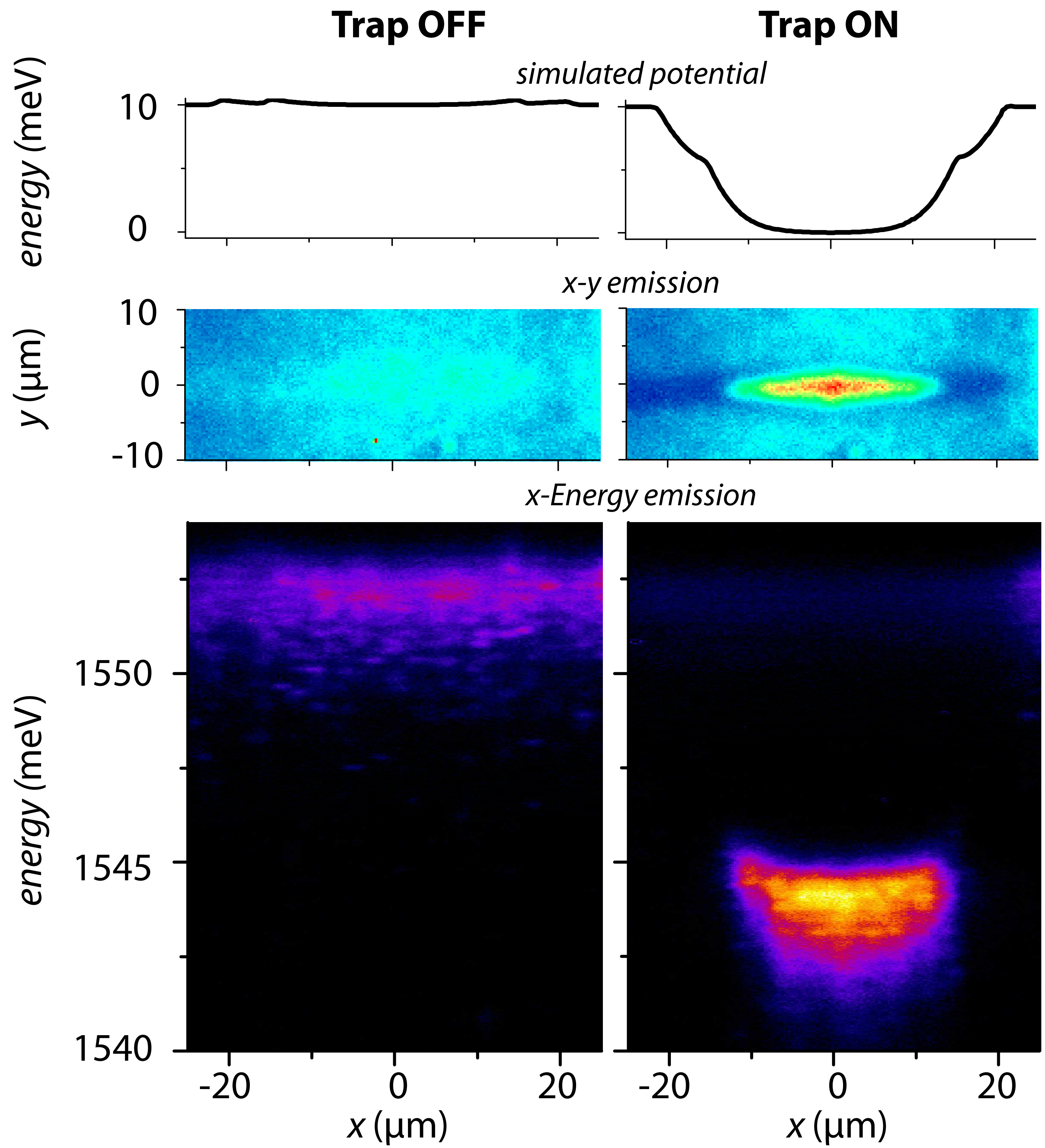

Parabolic-like potential along both *x*- and *y*-axis




A. A. High, A. K. Thomas, G. Grosso, M. Remeika, A. T. Hammack, A. D. Meyertholen, M. M. Fogler, L. V. Butov, M. Hanson, and A. C. Gossard, *PRL* **103**, 087403 (2009).

# Diamond Trap Characterization

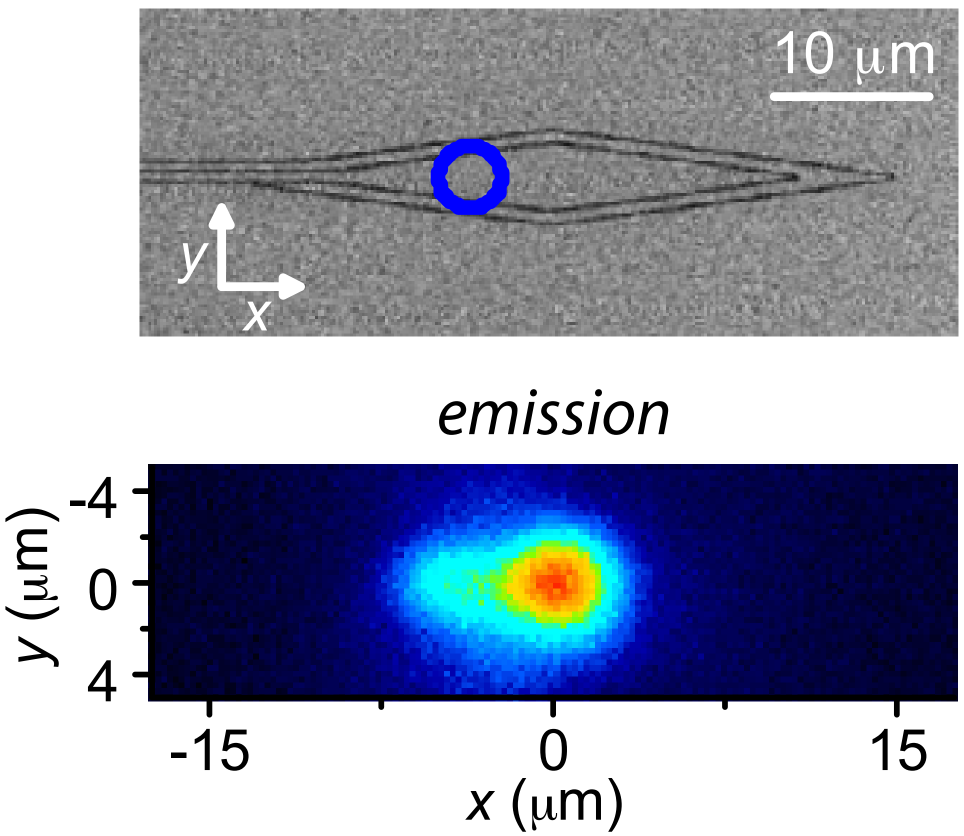




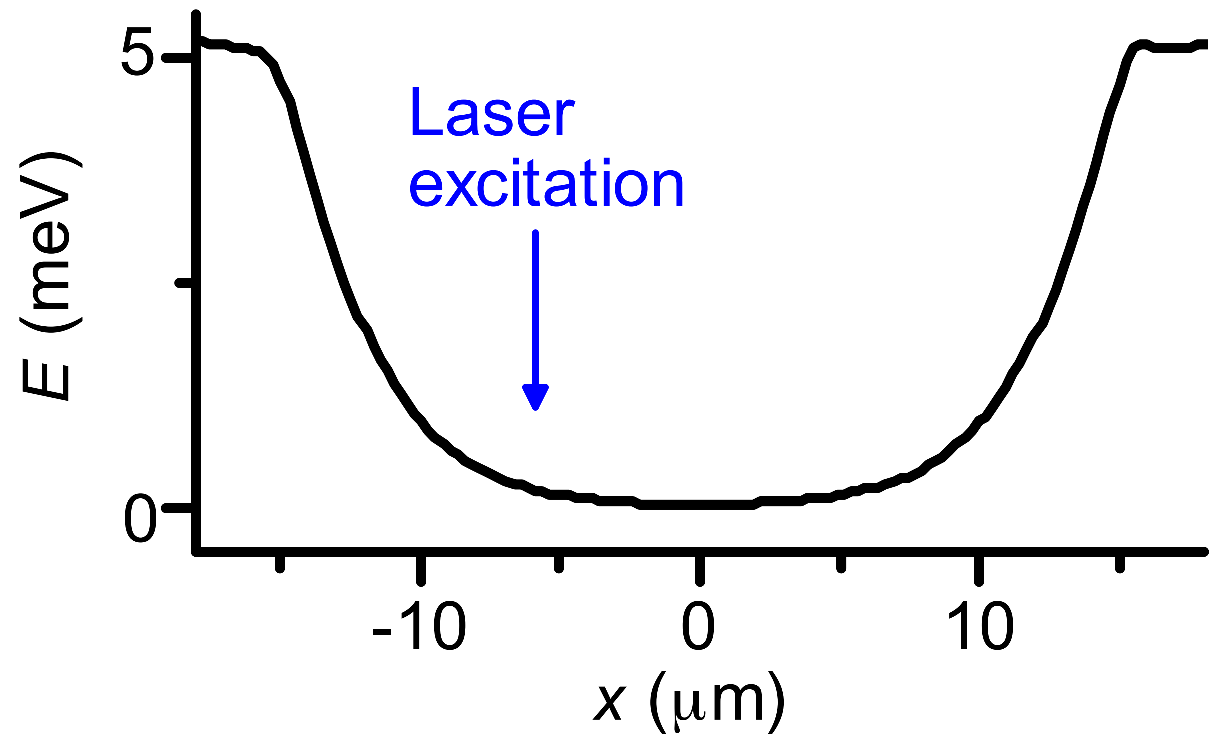

- *In situ* control
- Parabolic-like potential
- Collection to trap center

# Remote Excitation Schematic

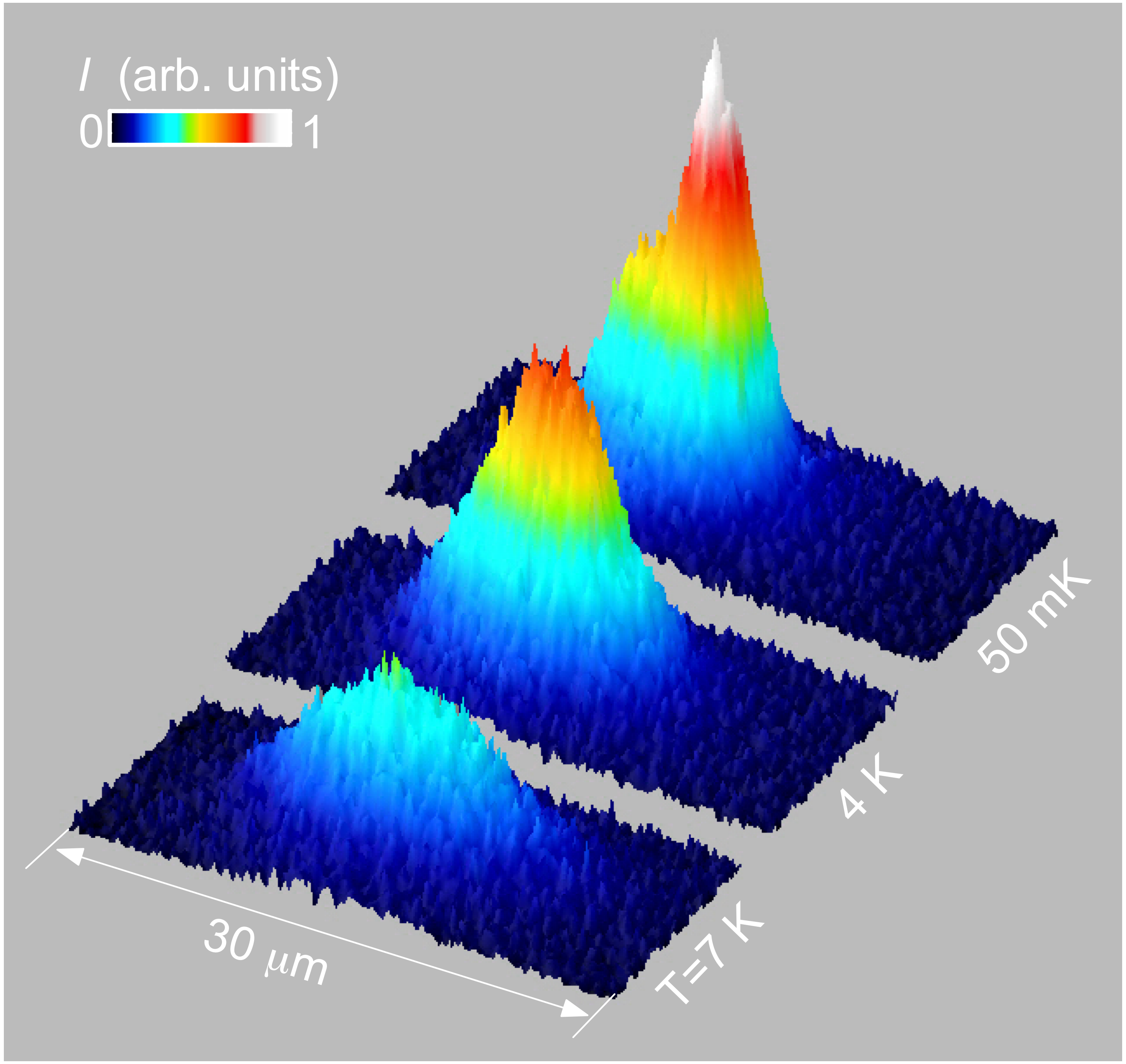
- Excitons are created 6μm from trap center




- Remote excitation reduces laser heating at the trap center

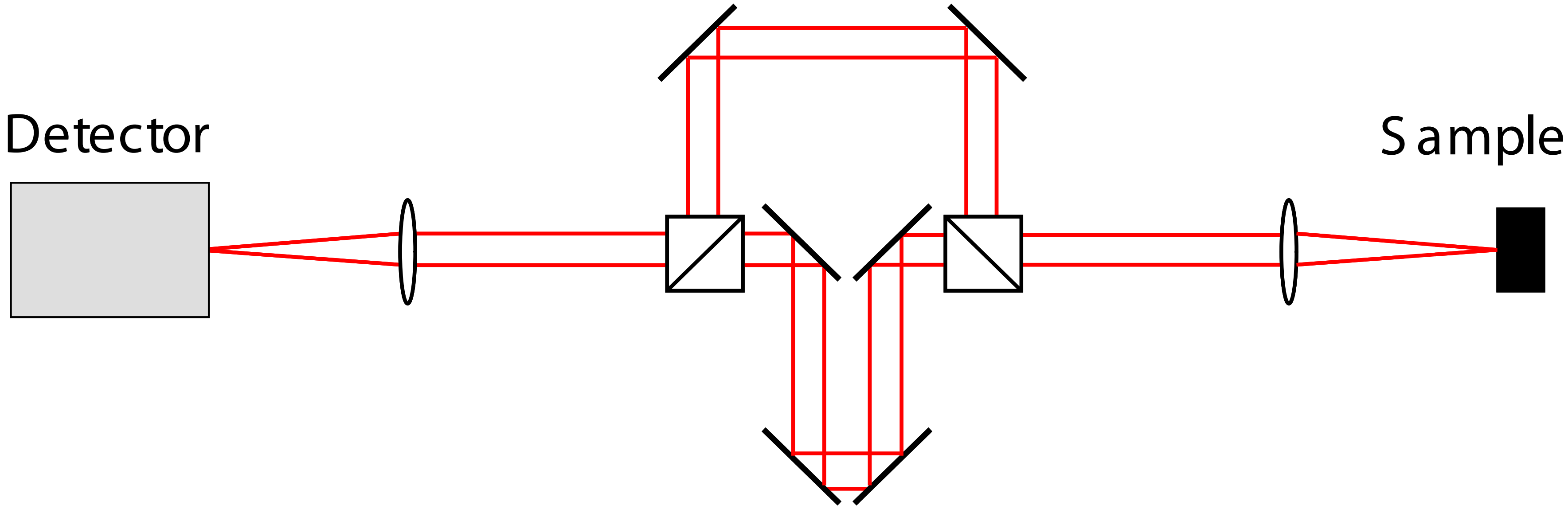


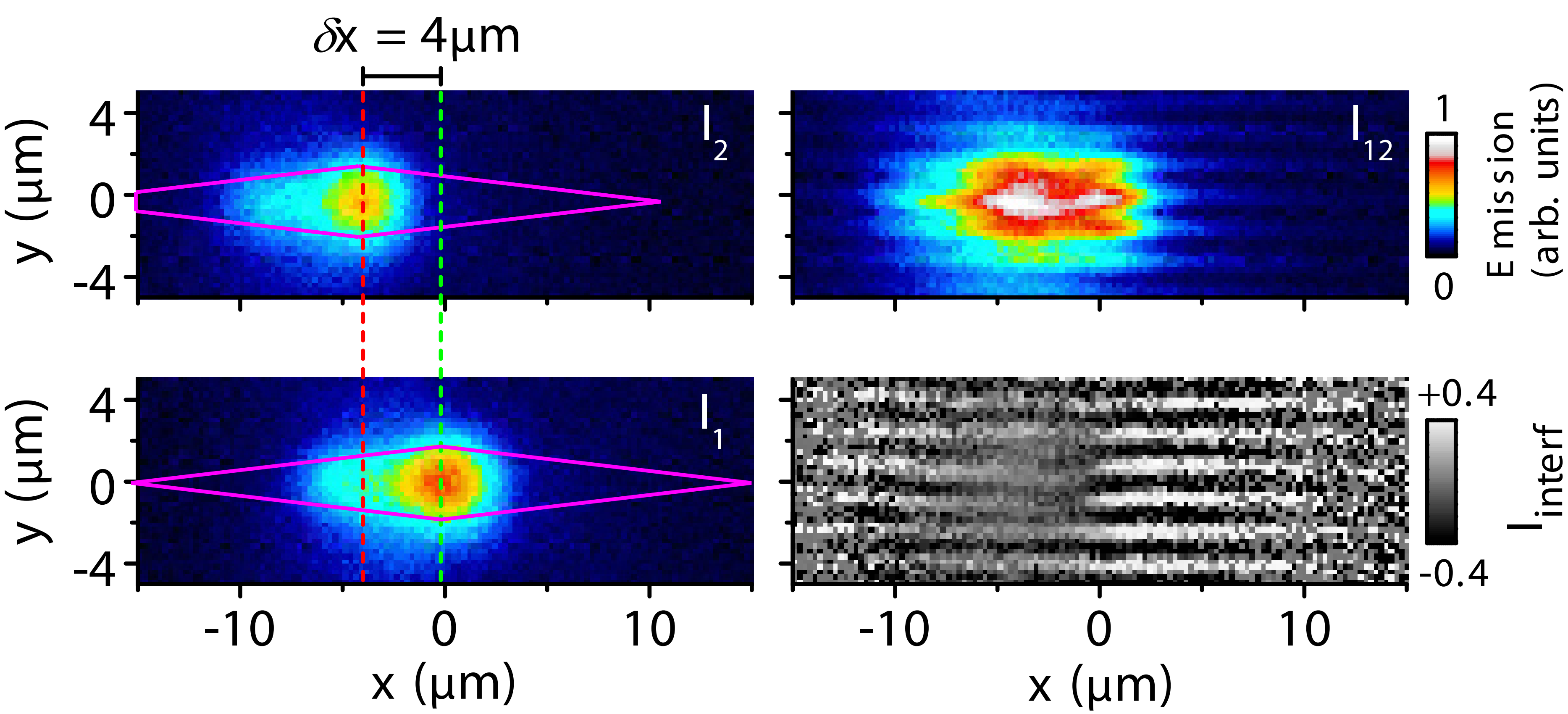
# Emission of Excitons in the Trap




Sharp peak at trap center emerges with decreasing temperature

# Coherence Measurements with M-Z interferometer

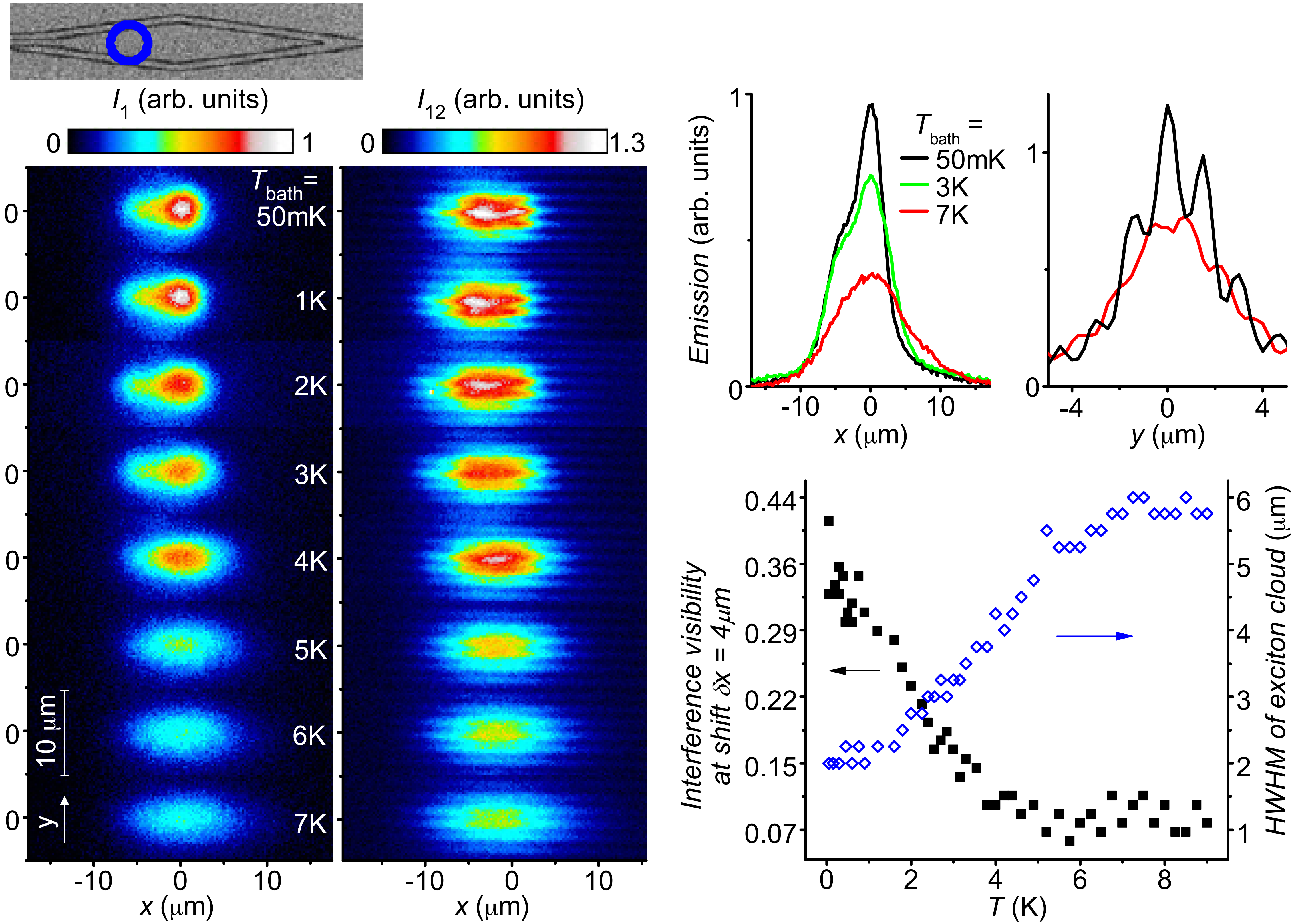



Shift interferometry measures the first-order spatial coherence function

$$I_{\mathrm{interf}} \text{ vs. } \delta x \rightarrow g_1(x)$$

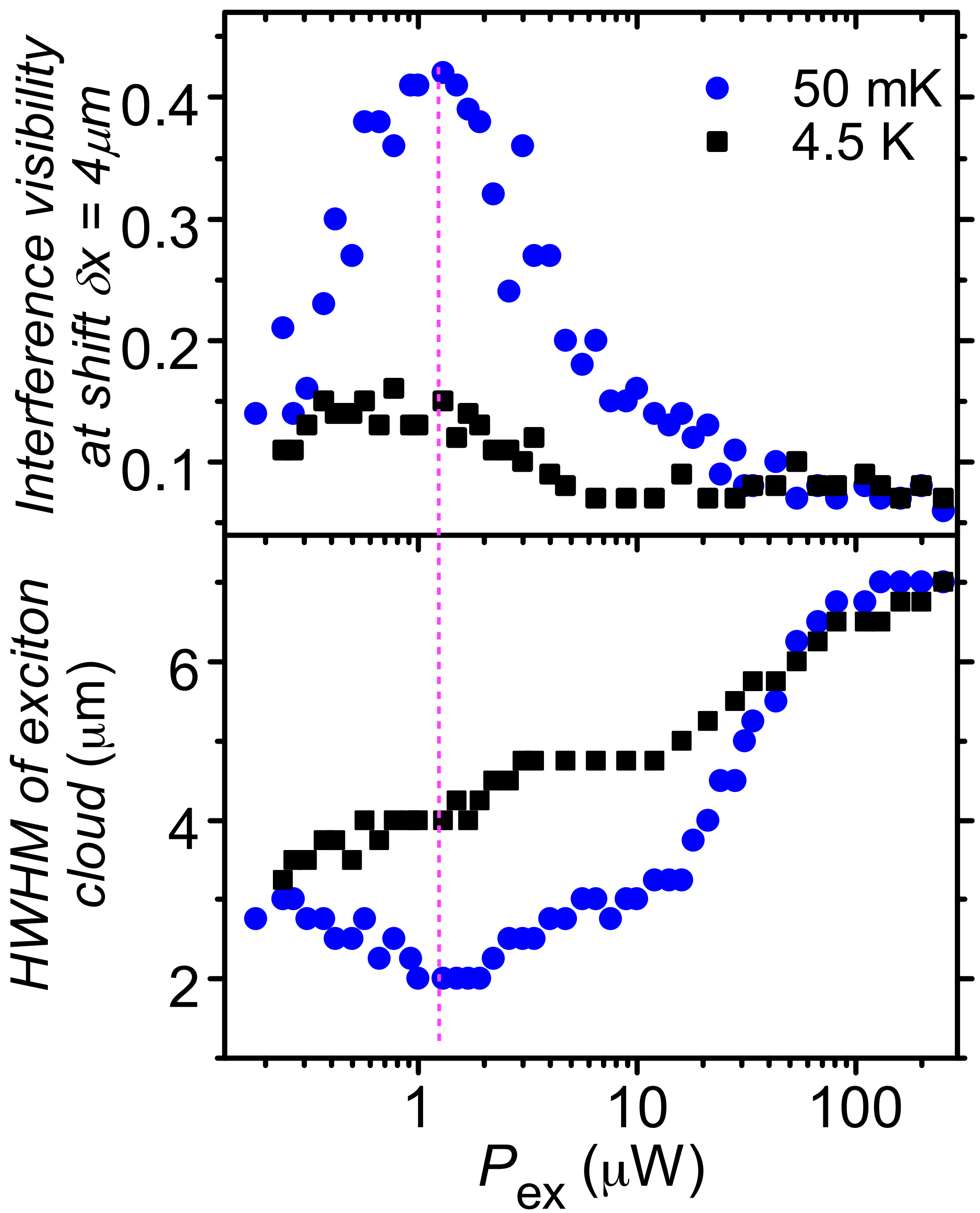
# Coherence Measurements: Temperature Dependence



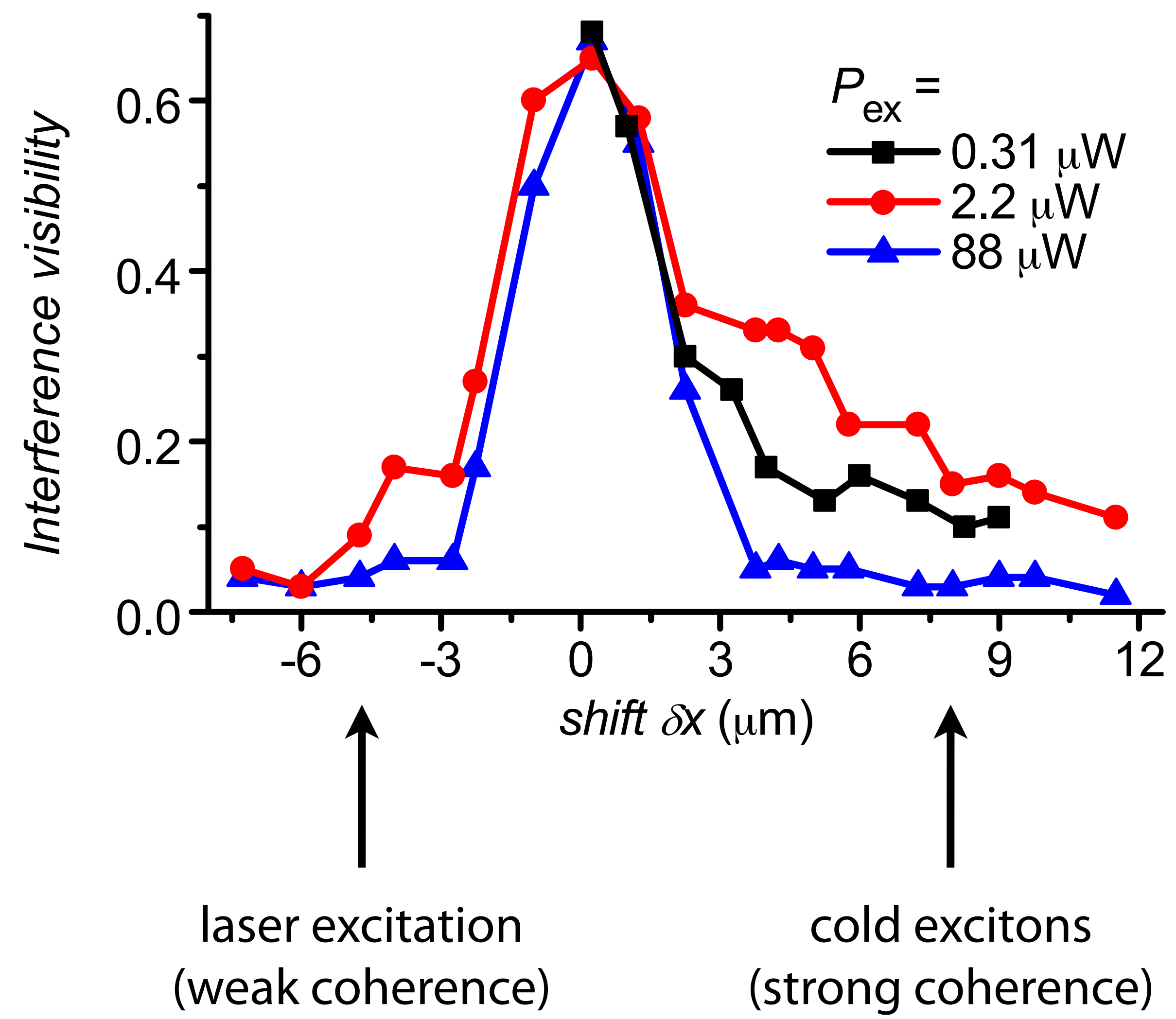

- Excitons condense at the trap bottom
- Exciton spontaneous coherence emerges with lowering temperature

# Coherence Measurements: Density Dependence

- Peak in coherence corresponds to minimum exciton cloud width

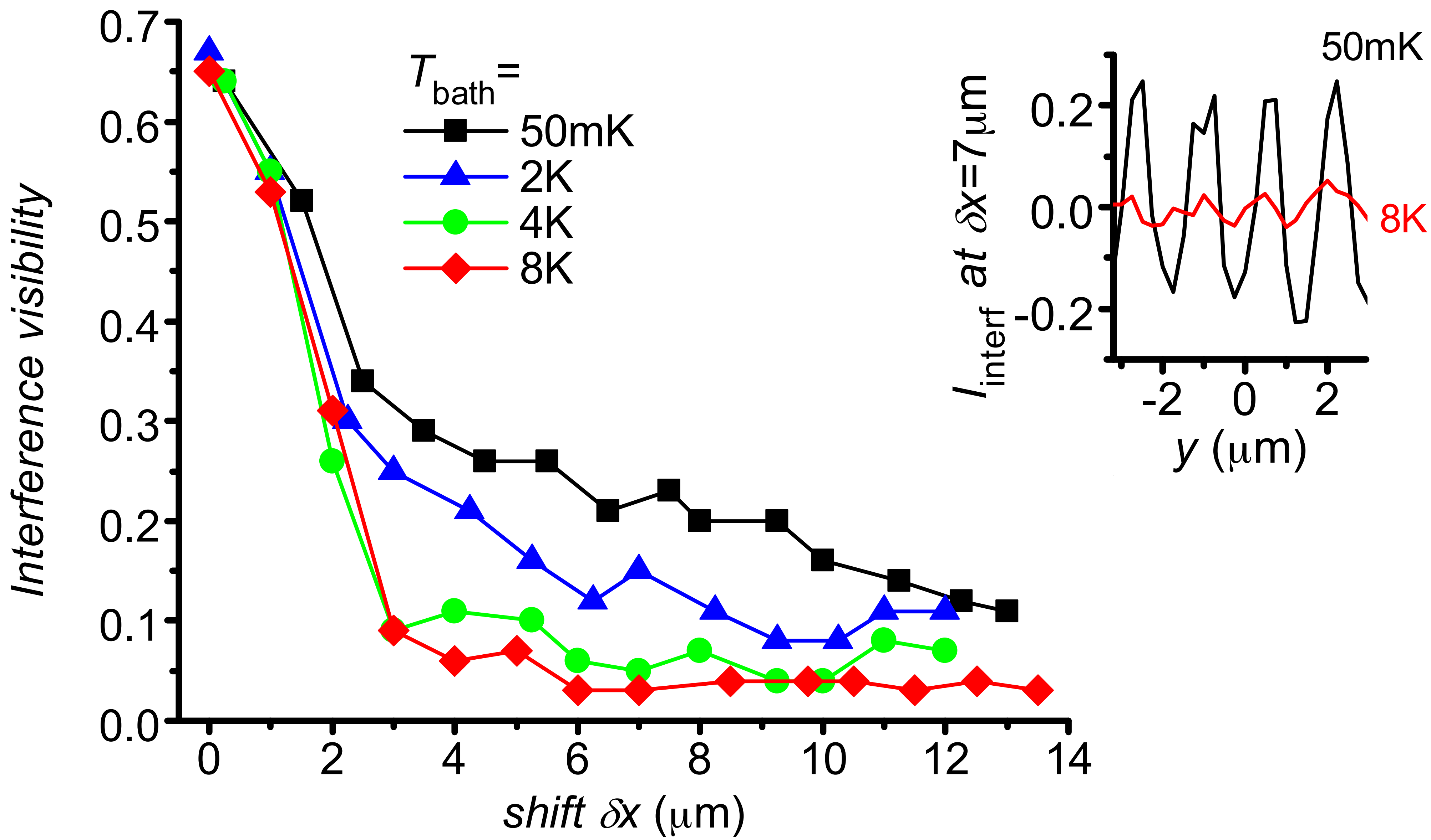



- Asymmetry in coherence due to laser heating



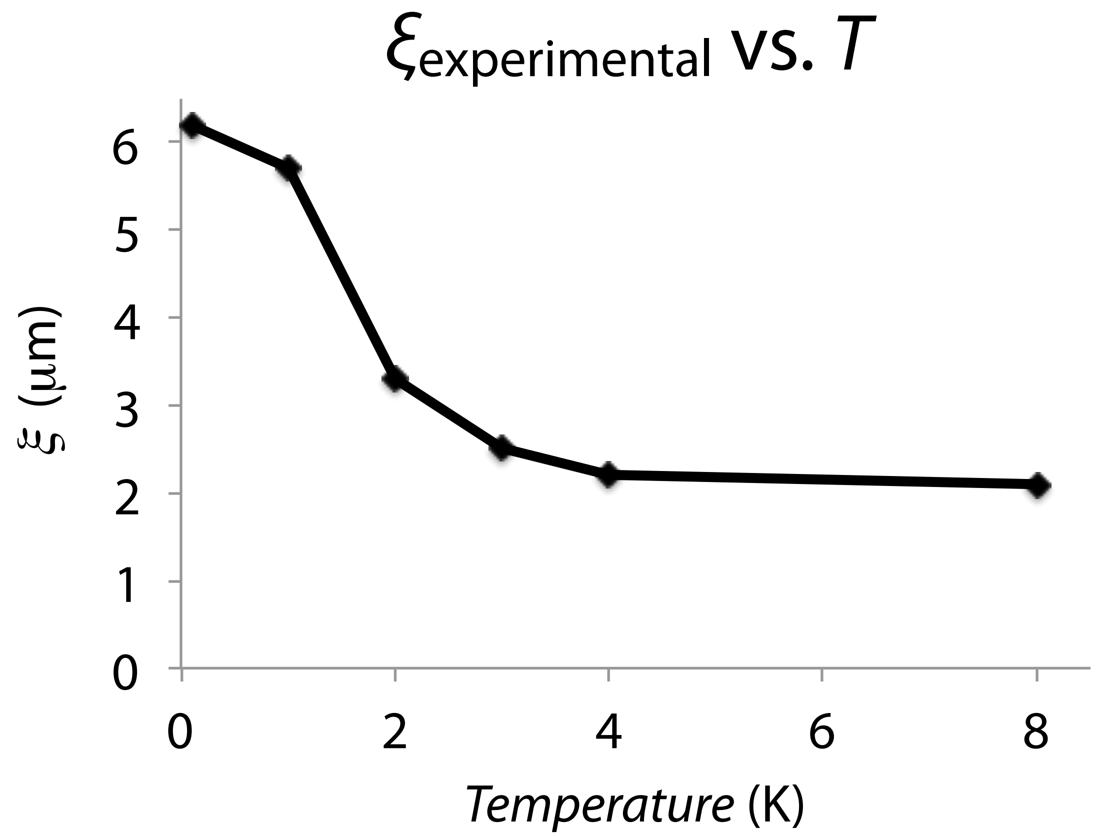

- Non-monotonic dependence on density at 50mK

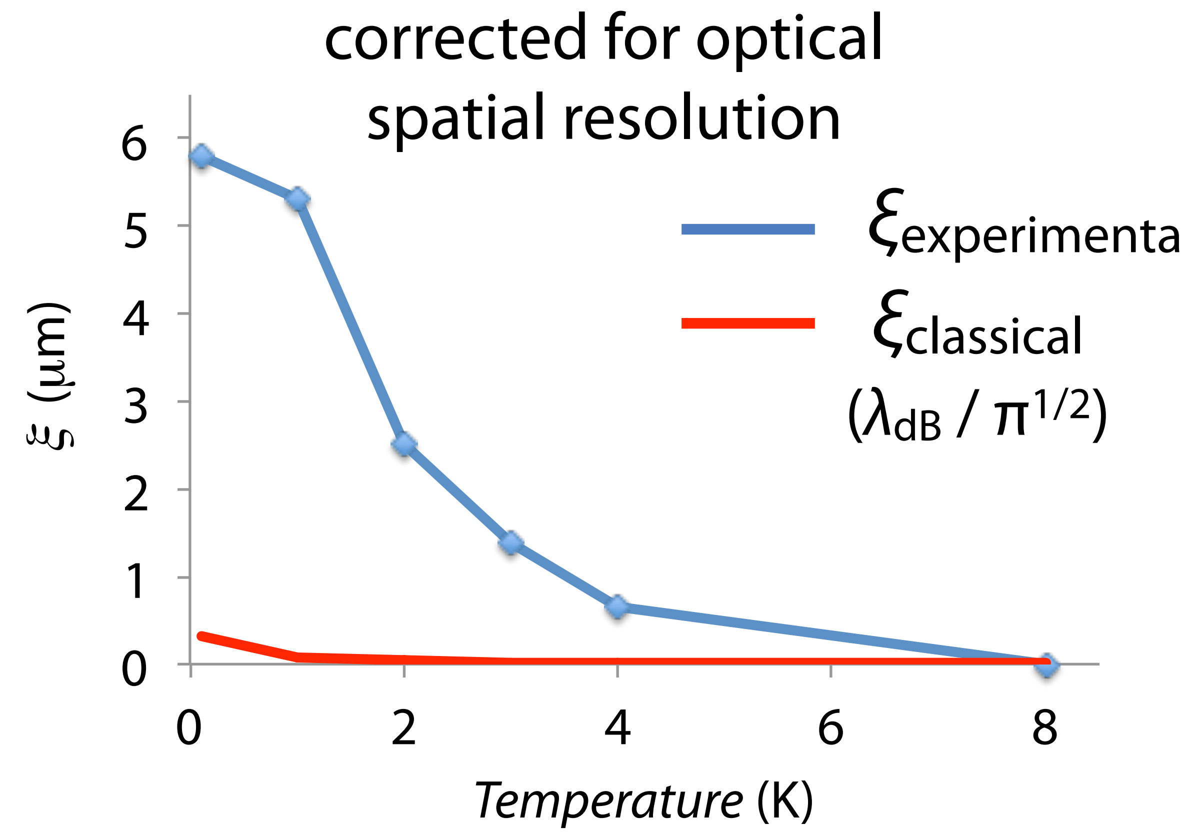
# Coherence Measurements: $g_1(x)$ vs. T




Coherence extends over entire cloud at $T_{bath}$=50mK

# Coherence Length vs. T




## Estimate of transition temperature

BEC temperature in a 2-D harmonic trap: $T_c = \frac{6^{1/2}}{\pi} \hbar\omega_{2D} \left(\frac{N}{g}\right)^{1/2}$ $\omega_{2D} = (\omega_x \, \omega_y)^{1/2}$

F. Dalfovo, S. Giorgini, L.P. Pitaevskii, S. Stringari, *Rev. Mod. Phys.* **71**, 463 (1999)

*Trap Frequency:* $\omega_x \sim 4 \times 10^9$ s$^{-1}$ $\omega_y \sim 3 \times 10^{10}$ s$^{-1}$

*Number of Excitons:* $\Delta E = 1.3$meV $\rightarrow N = 3000$

$\longrightarrow$ $T_c \approx 2$K

M. Remeika, J.C. Graves, A.T. Hammack, A.D. Meyertholen, M.M. Fogler, L.V. Butov, M. Hanson, A.C. Gossard, *PRL* **102**, 186803 (2009)

# Conclusions

Observed condensation of excitons in a trap

- Excitons condense at the trap bottom
- Exciton spontaneous coherence emerges with lowering temperature
- Below a temperature of about 1 K coherence extends over the entire trapped cloud

A. A. High, J. R. Leonard, M. Remeika, L. V. Butov, M. Hanson, A. C. Gossard, Condensation of Excitons in a Trap, arXiv:1110.1337, Nano Lett. DOI: 10.1021/nl300983n (17 April 2012)