Spin Currents and Polarization Textures in Optically Generated Indirect Excitons

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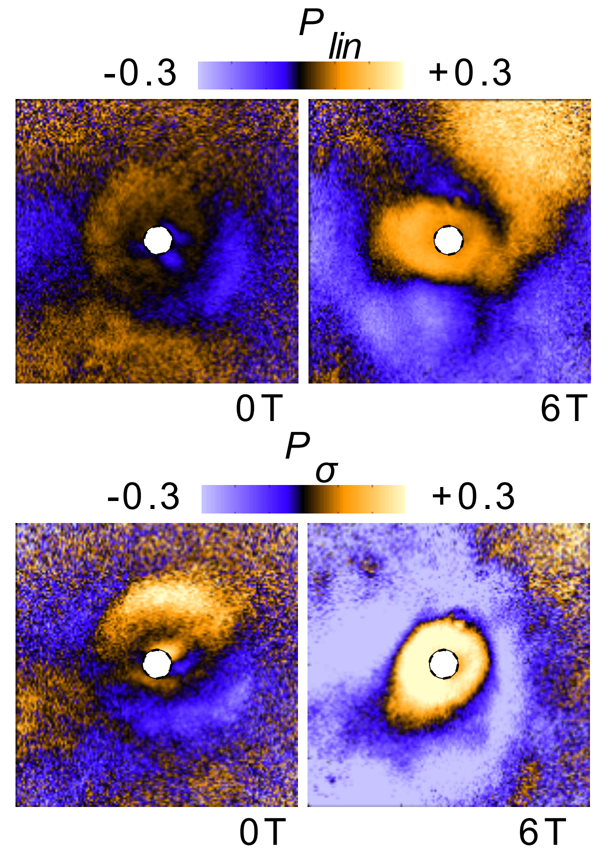
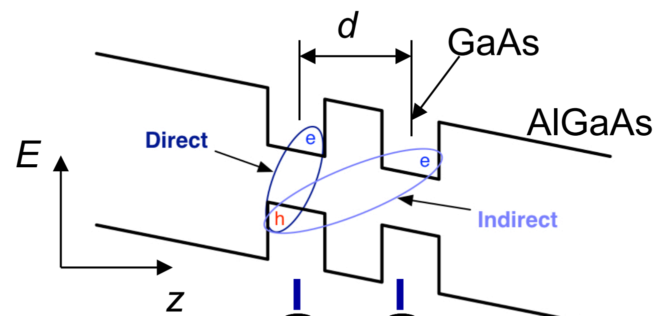


Indirect excitons



Exciton: bound electron-hole pair

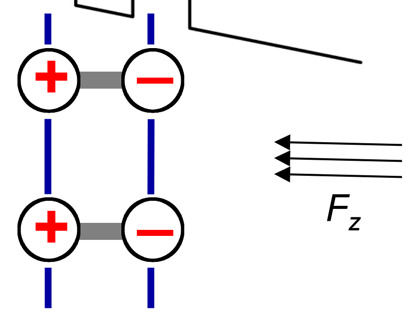
Properties of Indirect exciton: electron and hole are confined to spatially separated quantum well layers

Properties:

- bosons
- long and controllable lifetime

Cool to very low temperatures

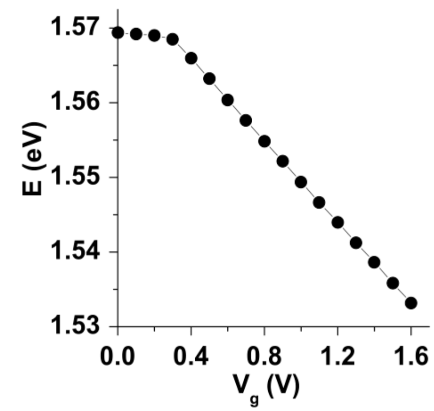
long-range exciton transport



- built-in dipole moment

excitons screen disorder

control of excitons by voltage:
$\delta E = edF_z$



These properties allow for

- basic studies: exciton transport, spin transport, interaction, kinetics, coherence, condensation, composite bosons in strong magnetic field regime
- development of excitonic devices: excitonic transistors, traps, ramps, lattices, conveyers (talk on excitonic devices tomorrow at 12:00 FM3B.5)

Excitons in high magnetic fields: Magnetoexcitons

Strong magnetic field regime for composite bosons:
$\hbar\omega_c \geq E_b$
cyclotron energy ≥ binding energy

This requires

- ~ 10^6 Tesla for atoms
- ~ 10 Tesla for excitons

due to large $\hbar\omega_c = \hbar eB/(\mu c)$
and small $E_b \approx (\mu e^4)/(2\varepsilon^4 \hbar^2)$

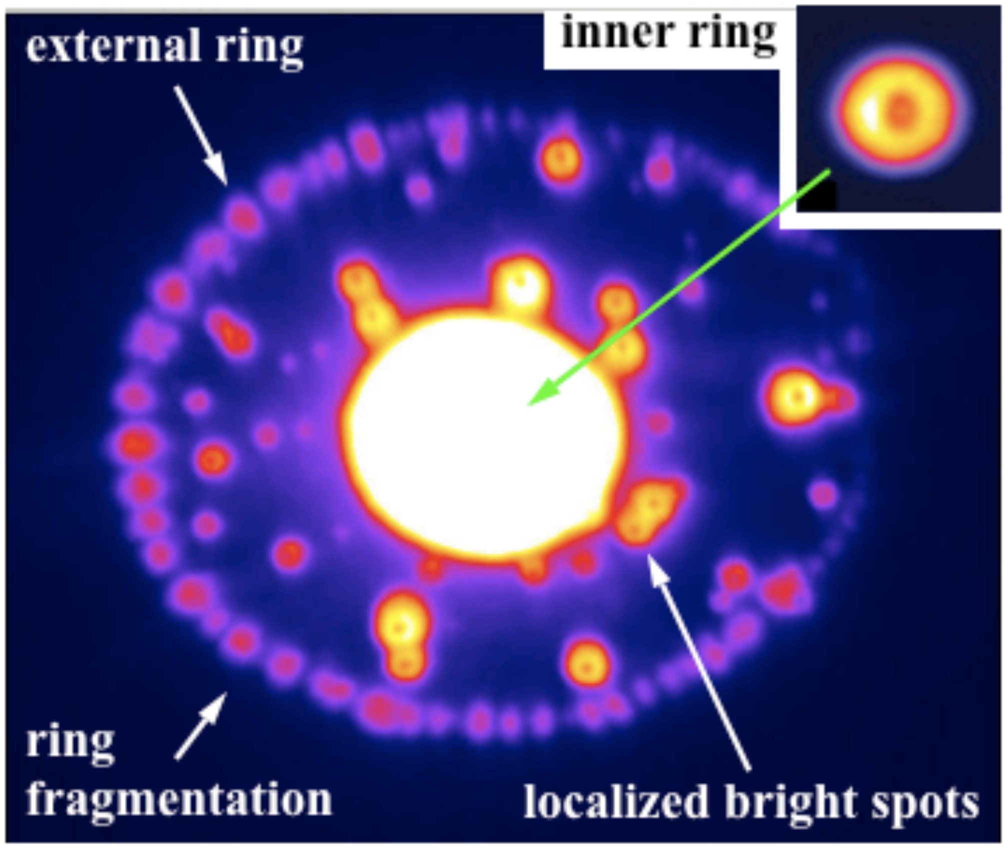
because of small mass and $\varepsilon > 1$
strong magnetic field regime for excitons is achieved in the lab

Talk tomorrow on magnetoexcitons at different Landau levels
(12:30 Dynamics in semiconductor QW)

UCSD Optical dilution refrigerator

- 40 mK bath temperature
- 16 Tesla magnetic fields

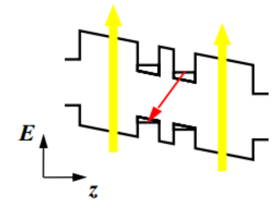
Exciton pattern formation



410 μm

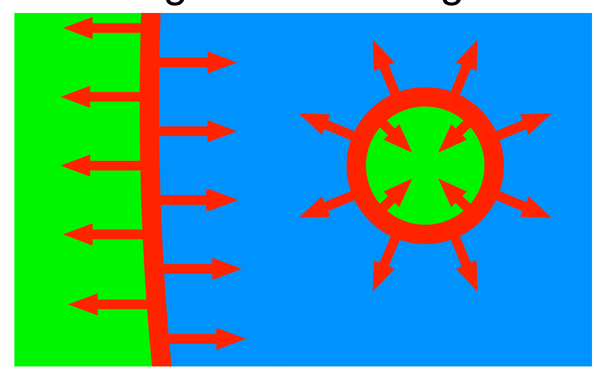
L.V. Butov, A.C. Gossard, D.S. Chemla, *Nature* **418**, 751 (2002)

above barrier laser excitation creates excitons + holes in CQW



external ring

LBS ring



electrons **excitons** **holes**

Excitons are created at the interface between electron rich regions and hole rich regions

electrically generated

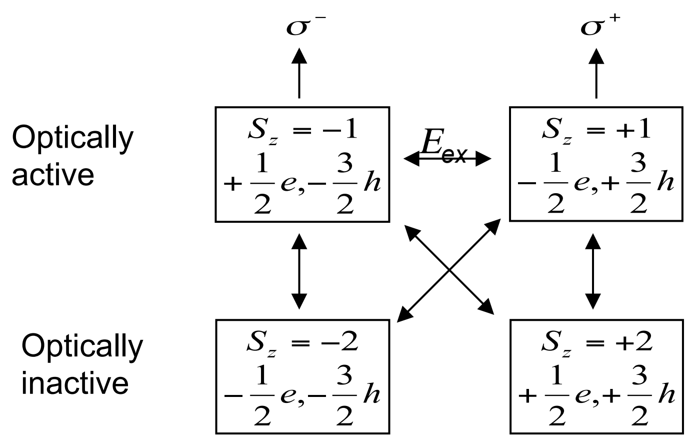
optically generated

Spin currents in a coherent exciton gas

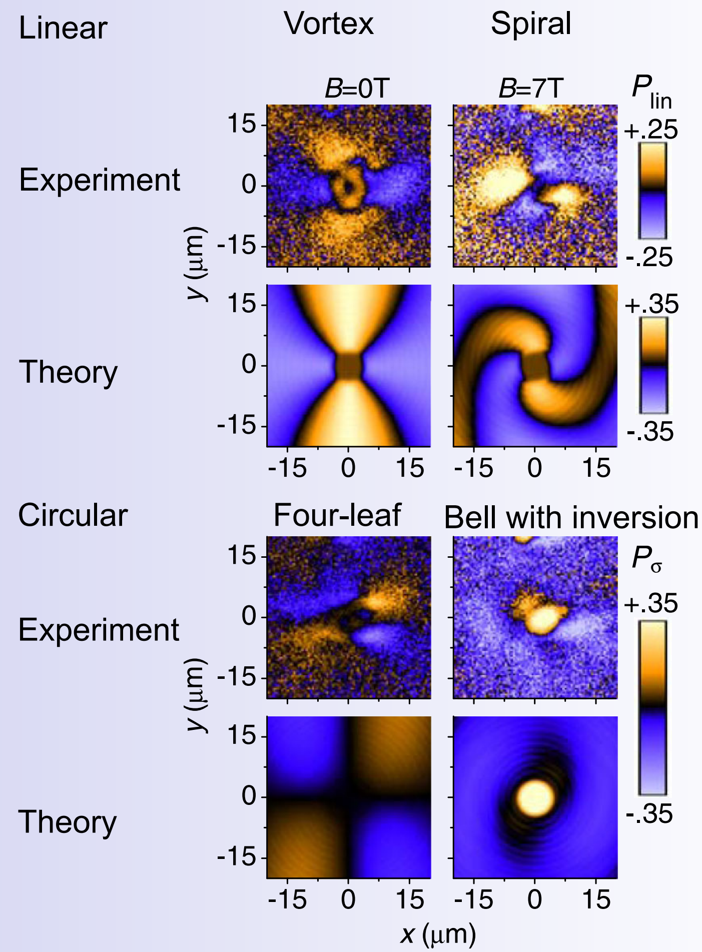
- Long range spin currents
- Ballistic exciton transport with coherent spin precession

Polarization textures

	B = 0	large B
Linear polarization	Vortex	Spiral
Circular polarization	Four-leaf	Bell-like with inversion

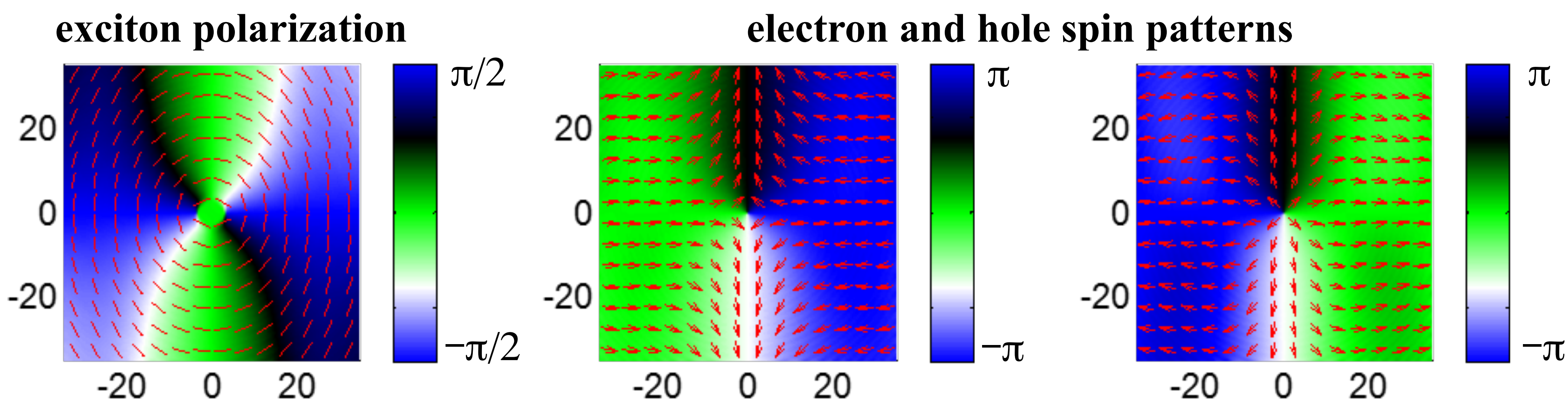


Polarization textures in LBS region



A.A. High *et al*, *Nature* 483, 584 (2012)
A.A. High *et al*, *PRL.* 110, 246403 (2013)

Polarization textures are associated with spin currents



Radial exciton polarization currents are associated with spin currents carried by electrons and holes bound into excitons

measured polarization pattern $\xrightarrow{\text{exciton spin density matrix}}$ spin currents carried by electrons and holes bound to excitons

electron and hole spin tend to align along the effective magnetic fields given by the Dresselhaus SO interaction

A.A. High, A.T. Hammack, J.R. Leonard, Sen Yang, L.V. Butov, T. Ostatnicky, M. Vladimirova, A.V. Kavokin, T.C.H. Liew, K.L. Campman, A.C. Gossard. Phys. Rev. Lett. 110, 246403 (2013)

Suppression of spin relaxation in exciton condensate

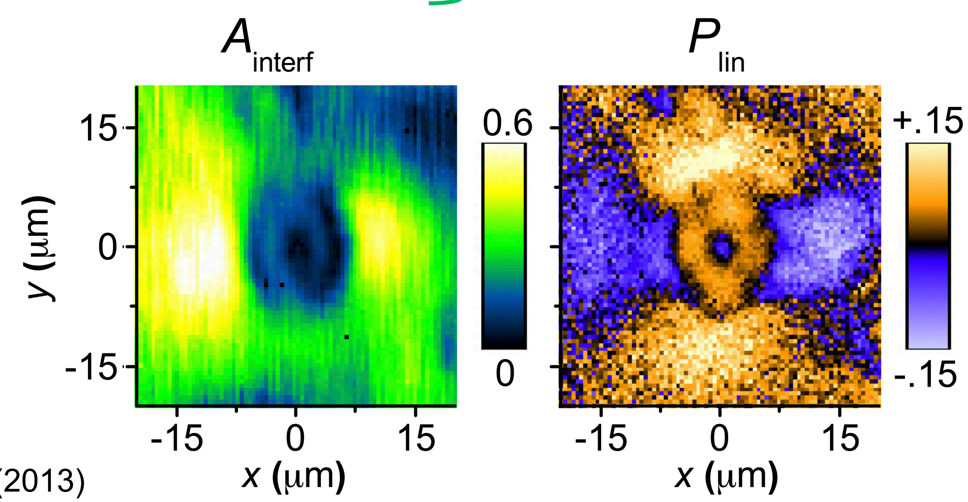
condensation of indirect excitons → suppression of exciton scattering → suppression of Dyakonov-Perel and Elliott-Yafet mechanisms of spin relaxation

exp: strong enhancement of coherence length

separation between electron and hole → suppression of Bir-Aronov-Pikus mechanism of spin relaxation for indirect excitons

strong enhancement of the spin relaxation time in a condensate of indirect excitons

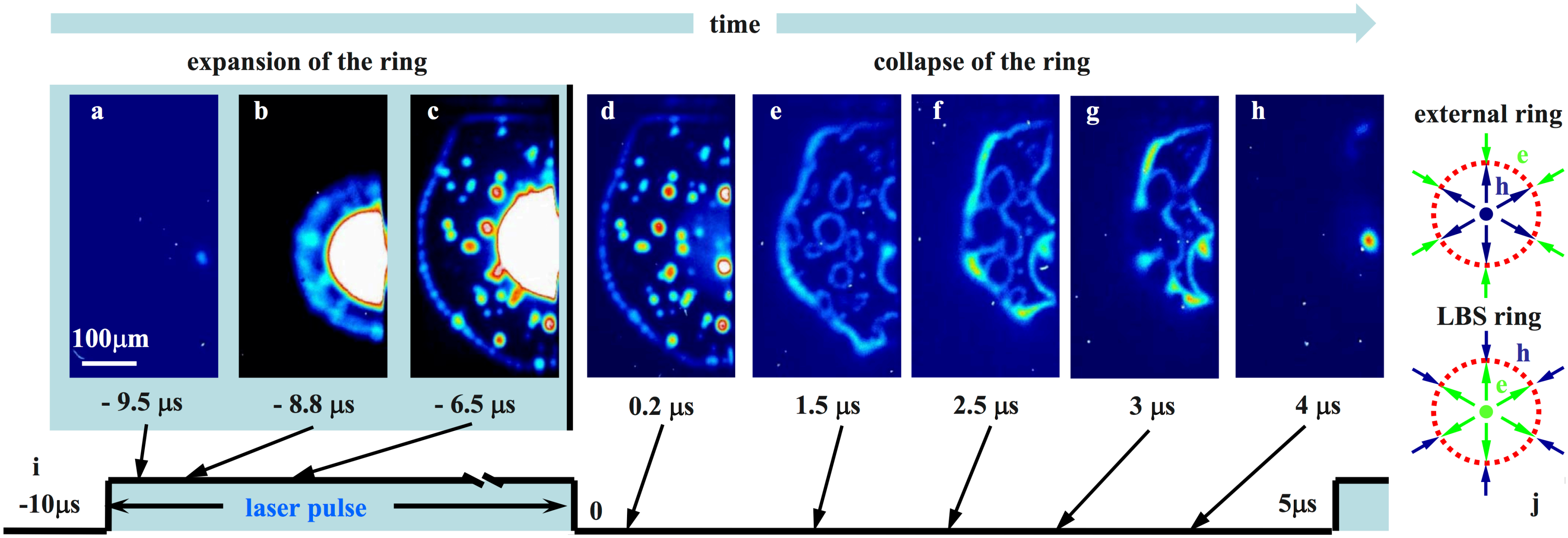
while the spin relaxation times of free electrons and holes can be short, the formation of a coherent gas of their bosonic pairs results in a strong enhancement of their spin relaxation times, facilitating long-range spin currents



AA High, et al , PRL (2013)

LBS and external ring: limited control by light

Time-resolved measurements of LBS and external ring yield kinetics of front propagation rather than exciton kinetics

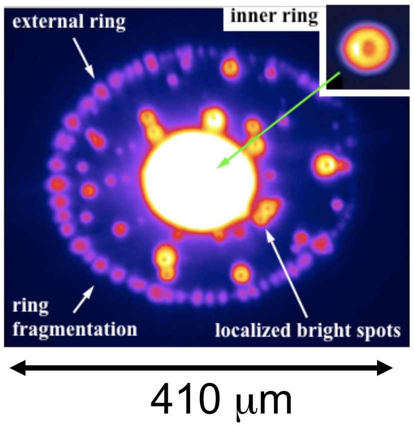


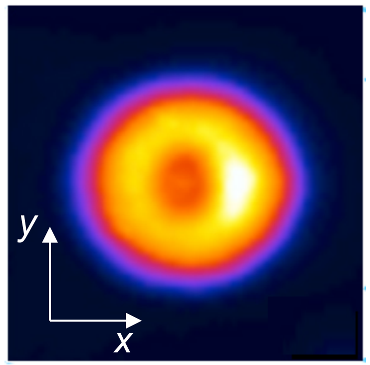
Sen Yang, L. V. Butov, L. S. Levitov, B. D. Simons, A. C. Gossard, Phys. Rev. B **81**, 115320 (2010)

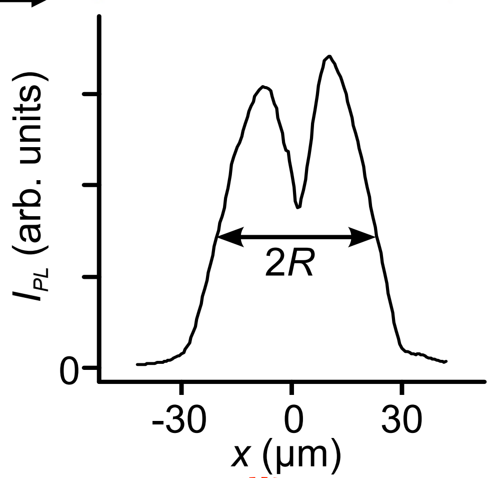
Measurements of spin current kinetics and optical control of spin currents require realization of spin currents generated by the optical excitation beam

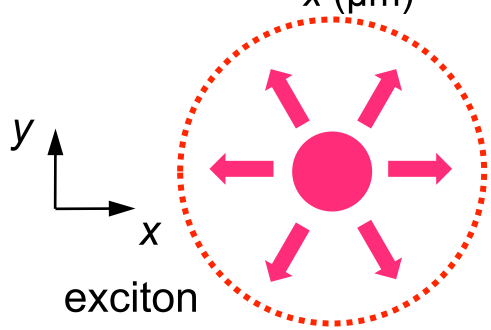
However, the optical excitation beam heats the exciton gas, so can we have cold optically created excitons?

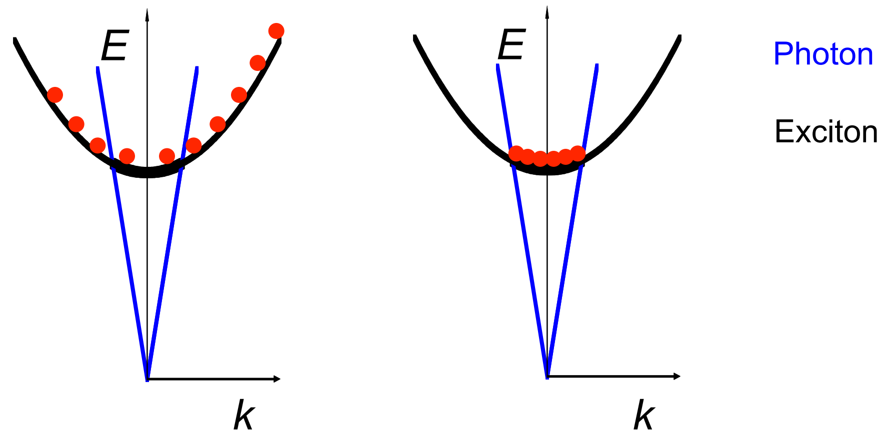
Cold exciton gas in the inner ring











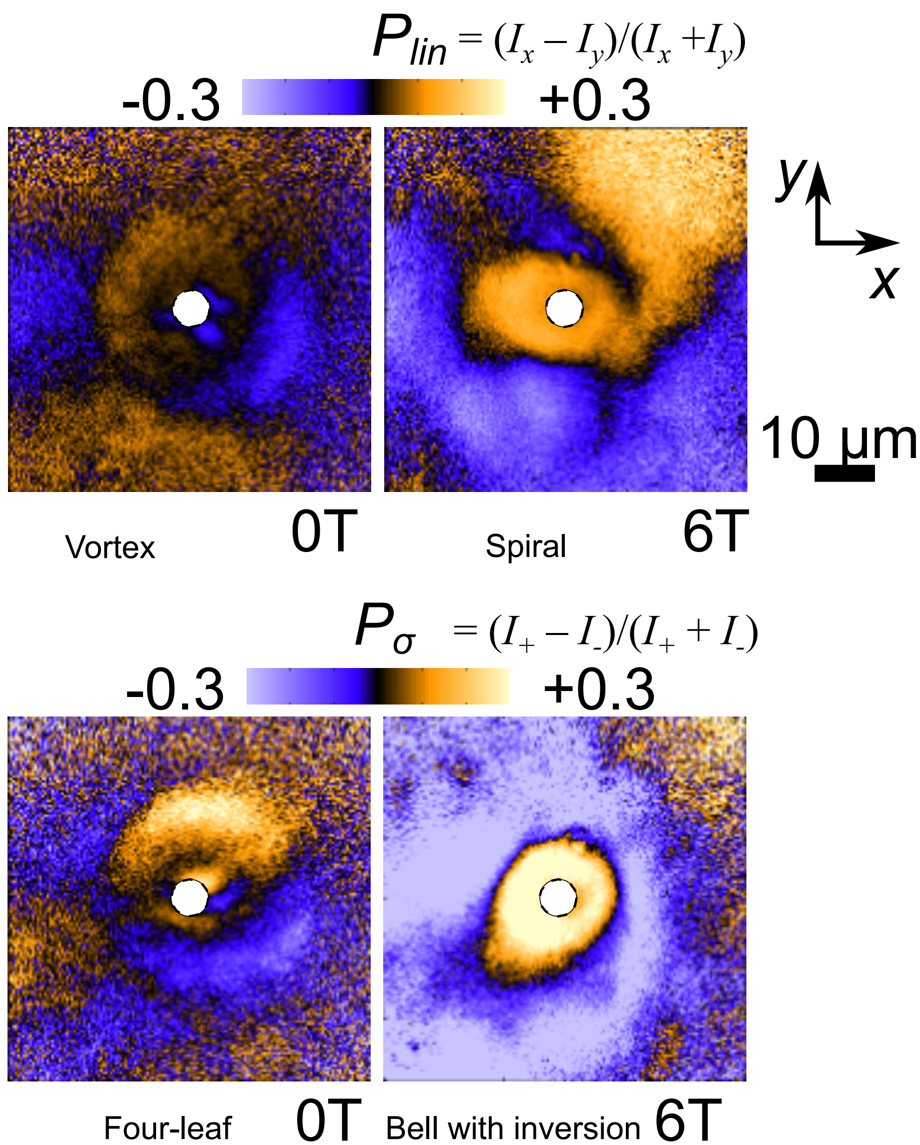
<u>excitation spot</u>
higher temperature
⬇
lower occupation
of radiative zone

<u>inner ring</u>
lower temperature
⬇
higher occupation
of radiative zone

excitons cool as they travel away from the excitation spot
→ increased occupation of radiative zone
→ enhancement of PL intensity
→ inner ring

L.V. Butov *et al*, *Nature* **418**, 751 (2002)
A.L. Ivanov *et al, EPL* **73**, 920 (2006)
A.T. Hammack *et al, PRB* **80**, 155331 (2009)
Y.Y. Kuznetsova *et al, PRB* **85**, 165452 (2012)

Spin currents in exciton inner ring

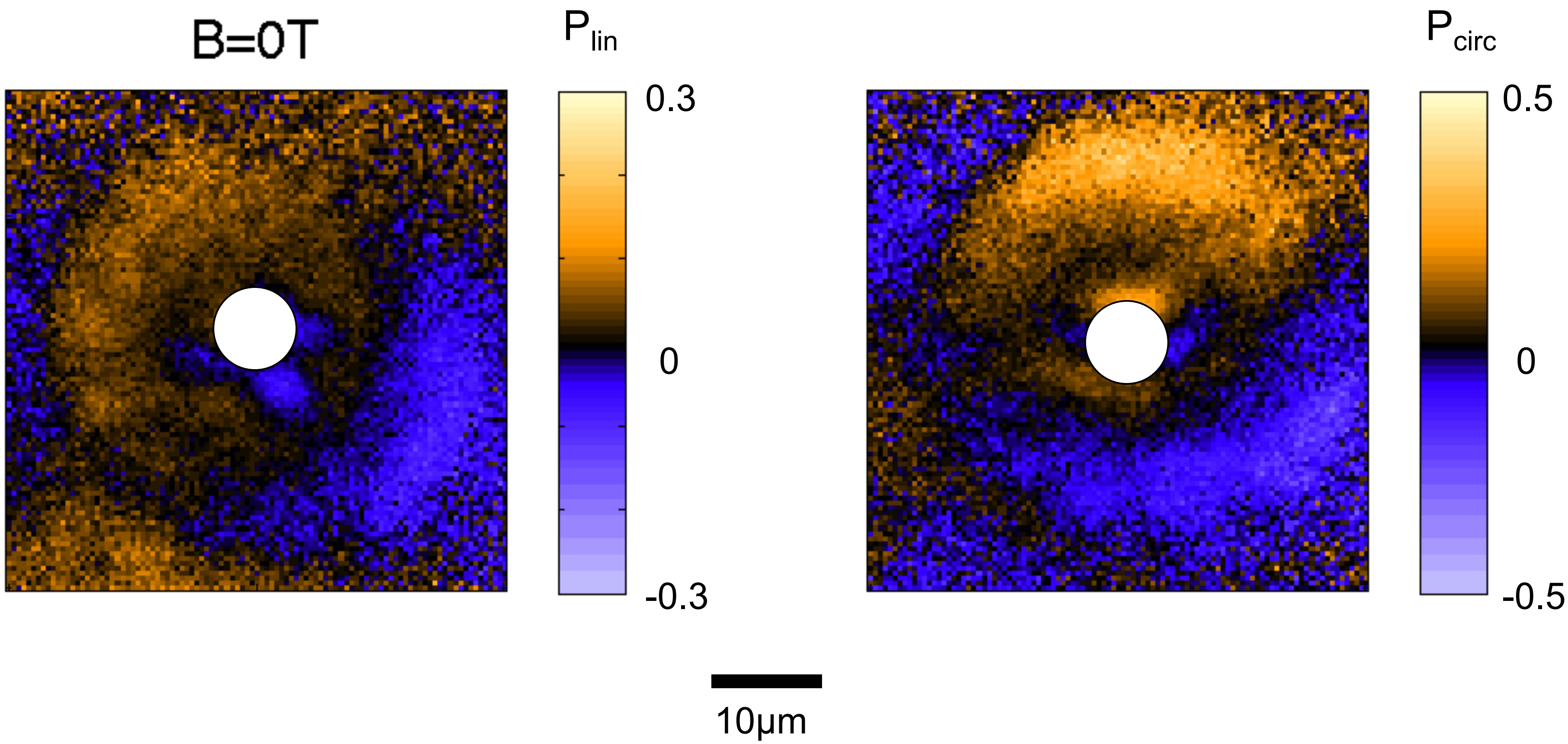


Inner ring Polarization Patterns

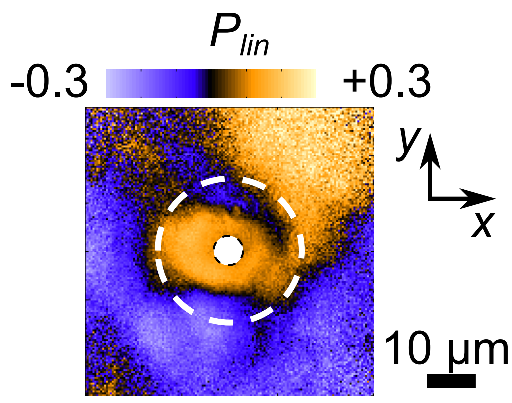
	B = 0	large B
Linear polarization	Vortex	Spiral
Circular polarization	Four-leaf	Bell-like with inversion

- Consistent with results for coherent spin currents in LBS region due to ballistic exciton propagation with coherent spin precession

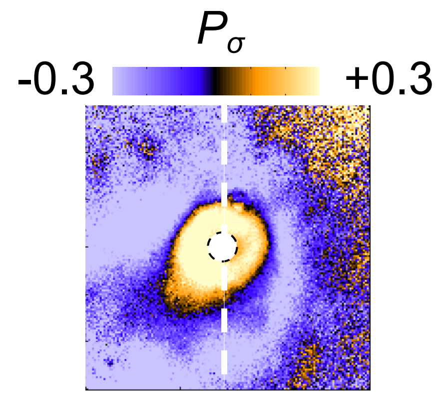
Spin currents in exciton inner ring vs B



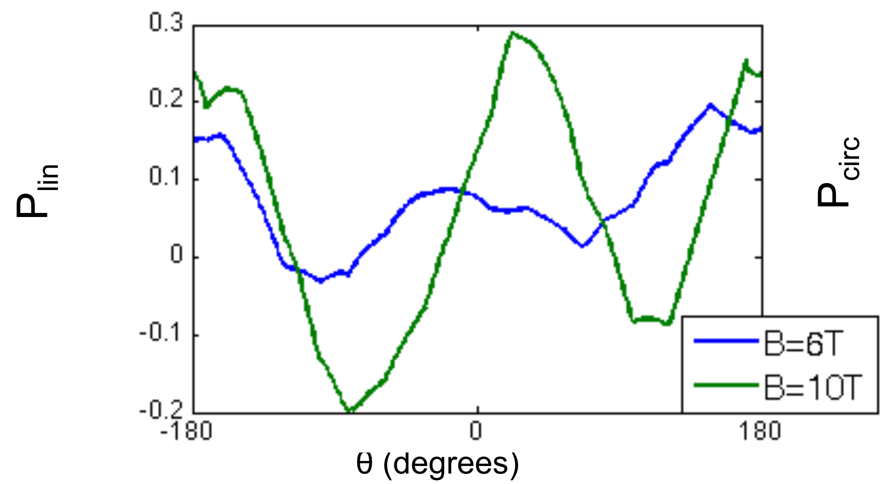
Spin currents in exciton inner ring



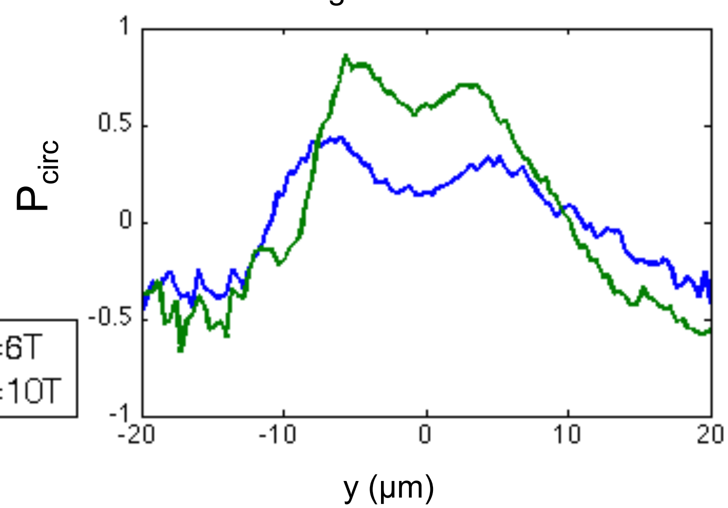
B = 6T



Linear polarization:
function of angle at r = 12 µm



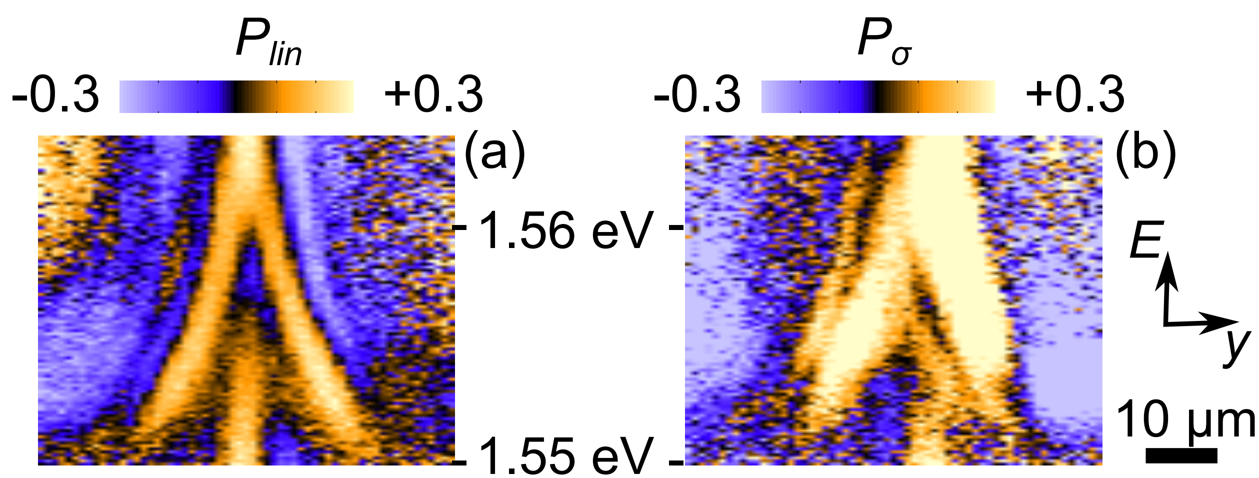
Circular polarization:
cut through the center at x = 0



Work in Progress

Coherence measurements: are spin textures correlated with coherence as in LBS region?

Energy-resolved spin patterns
Preliminary results:



Outlook

Potential for optical control and kinetics measurement of spin currents

Conclusion

- Observed long range spin currents in optically generated indirect excitons
- Observed vortex, spiral, four-leaf, and bell-like with inversion polarization textures