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Local structure and optical response

…a journey

Henry Schriemer

RECS lab

Research in Engineered Complex Systems laboratory

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School of Information Technology and Engineering
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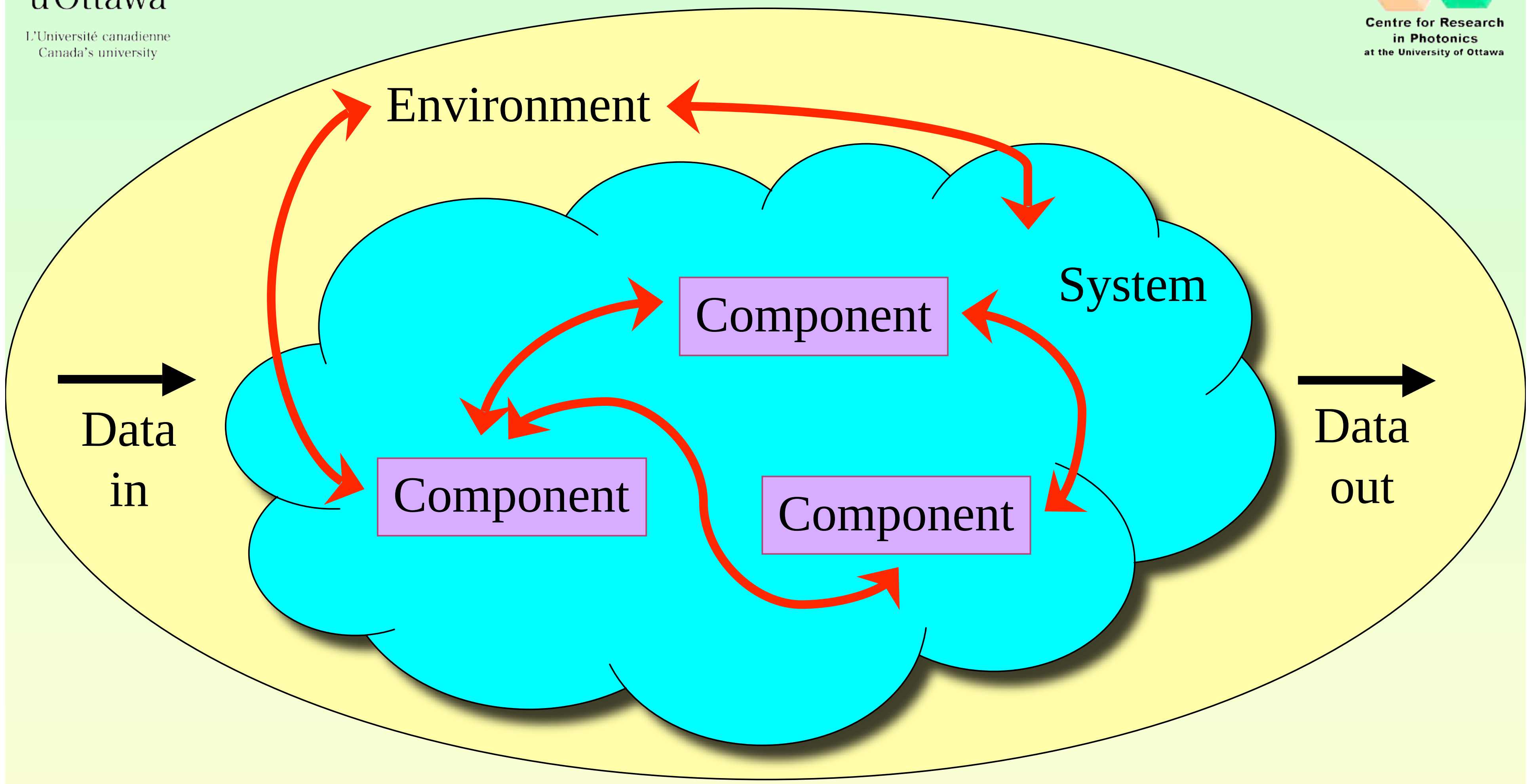
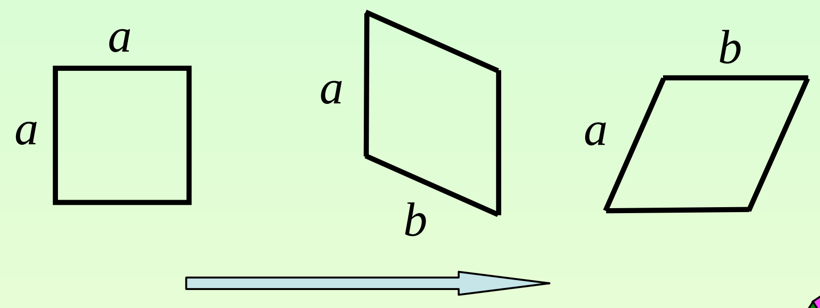
Complex Systems…



… a construct whose collective behaviour is predicated on the type and degree of **coupling** that exists between component parts, and with the global environment.

Structural Random Field Systems

Tetragonal | Orthorhombic



Lower temperature

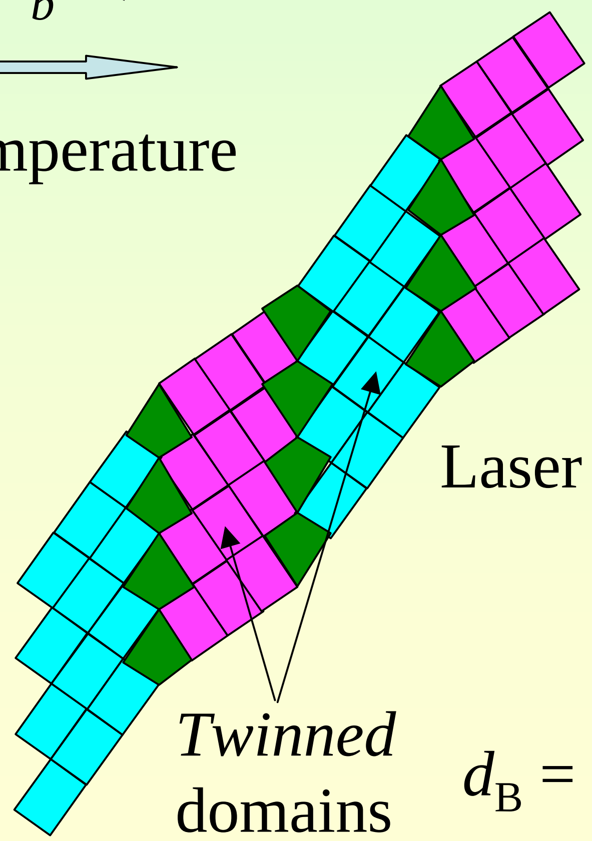
$TbVO_4 \Rightarrow TbAs_xV_{1-x}O4$

As/V size mismatch

Random strain fields

Roughen & pin domain walls

Elastic forces favour planes

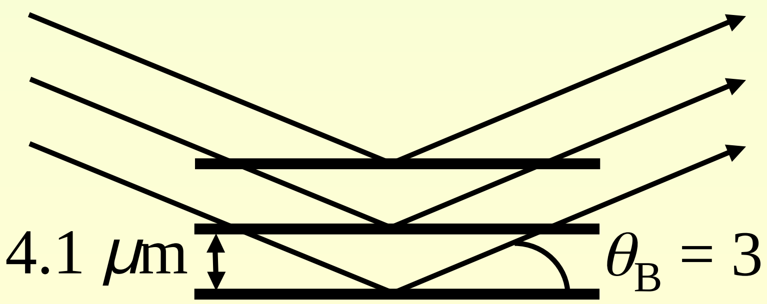


Optical Bragg diffraction:

$$2\, d_B \sin\theta_B = \lambda$$

Laser (λ = 543 nm)

Far-field detector (PMT)



Interfacial Roughness

"Specular" scattering from rough surface:

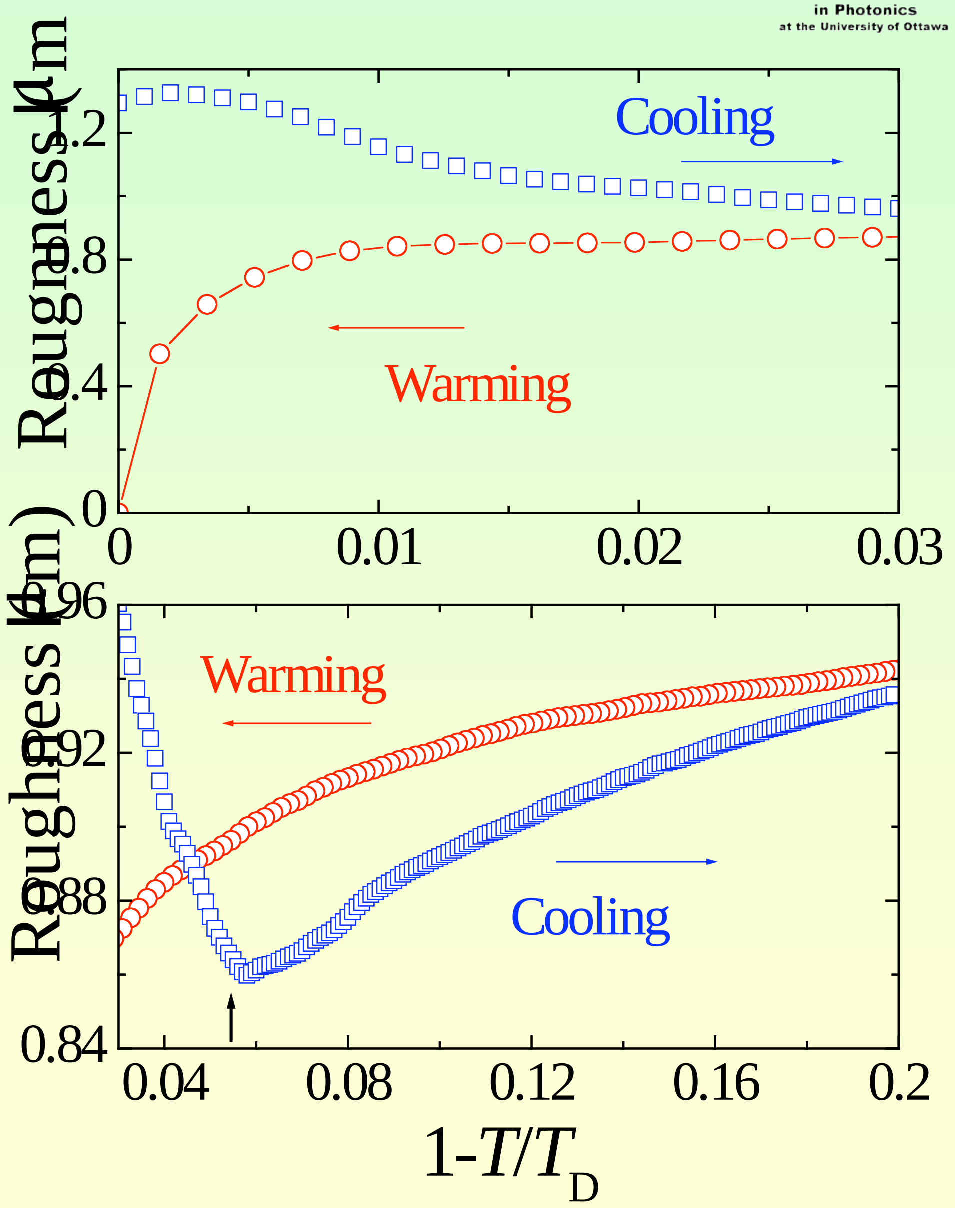
$$\langle I_{\text{mixed}} \rangle = \langle I_{\text{pure}} \rangle \exp\left(-\phi^2\right)$$

$$\phi \equiv \frac{4\pi}{\lambda} h \sin\theta_B$$

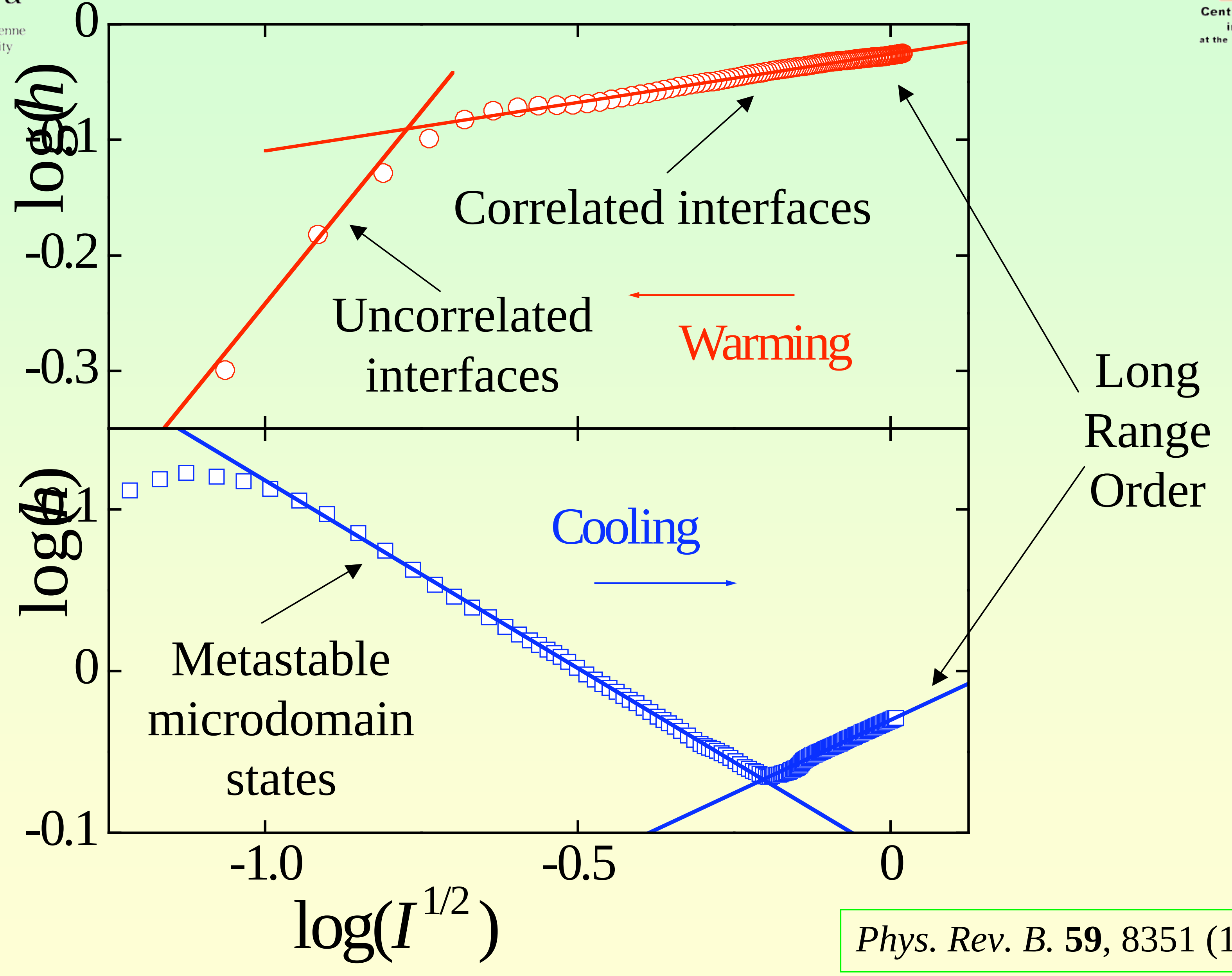
$h \rightarrow$ rms roughness

$\langle I_{\text{pure}} \rangle$ for $TbVO_4$

$\langle I_{\text{mixed}} \rangle$ for $TbAs_{0.15}V_{0.85}O_4$

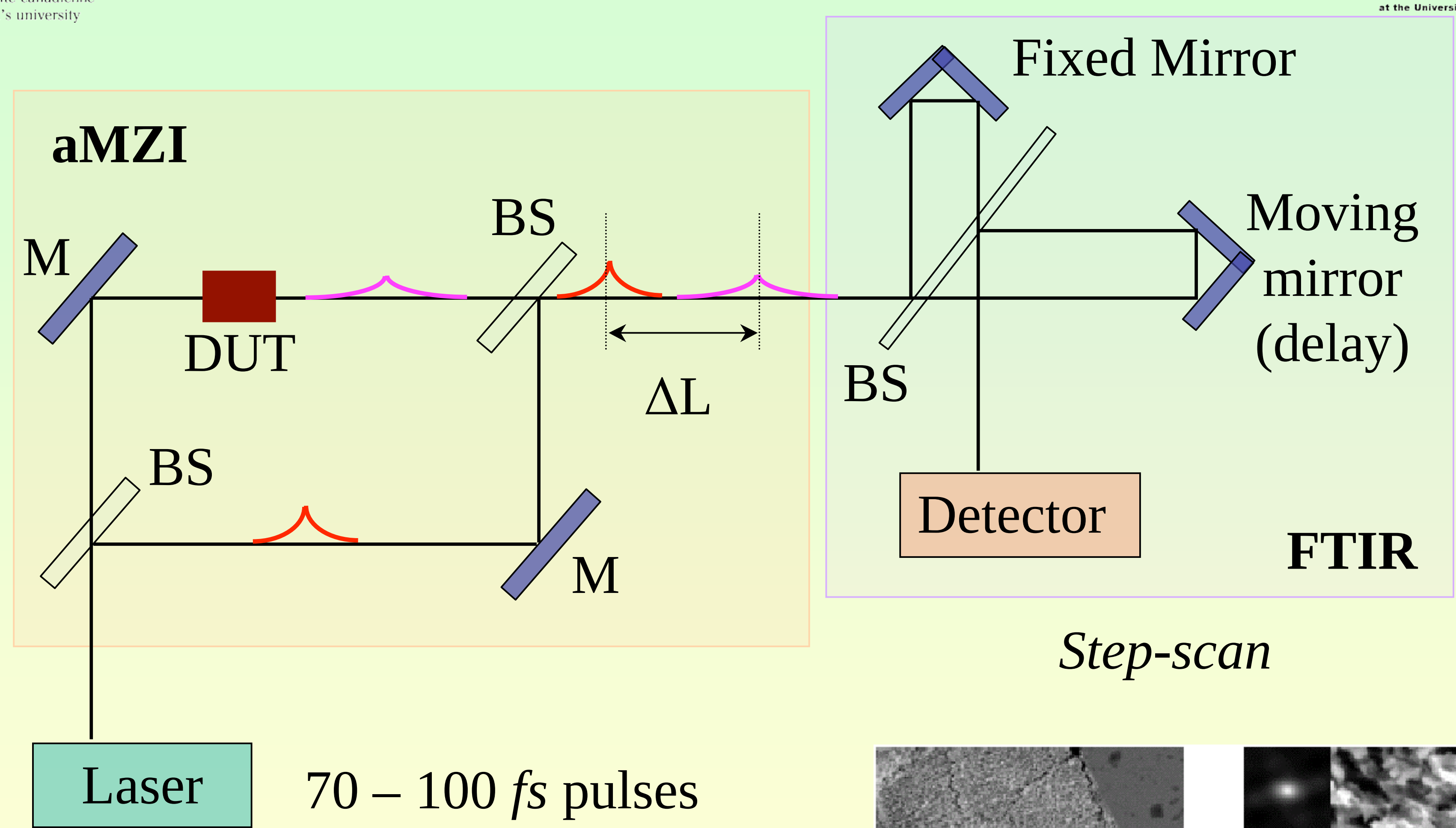


Scaling behaviour of (de)pinning



Phys. Rev. B. **59**, 8351 (1999).

Ultrashort Pulse Interferometry



Step-scan

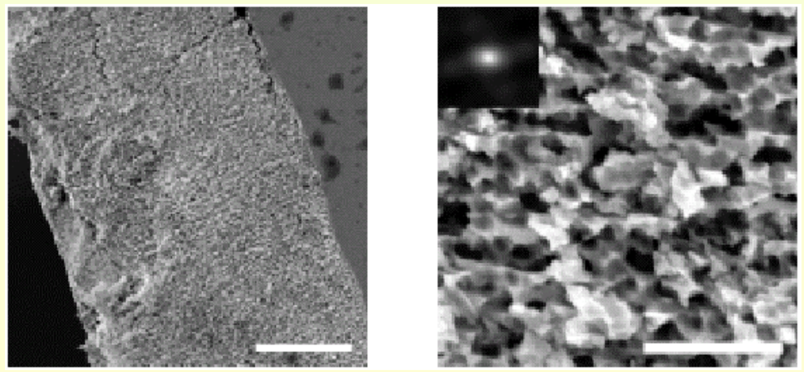
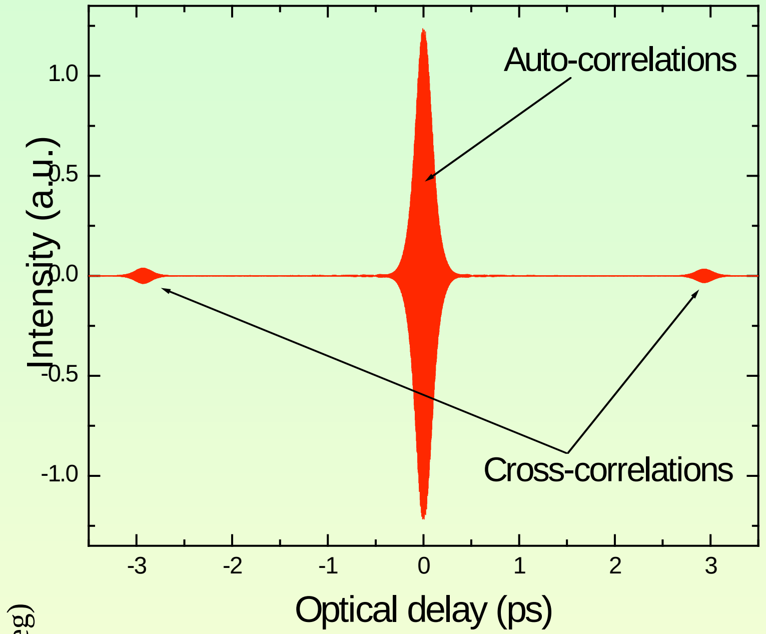
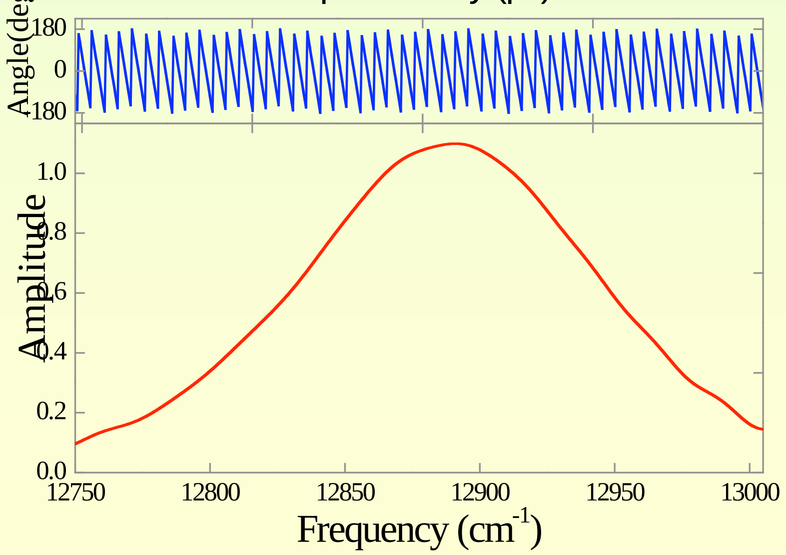
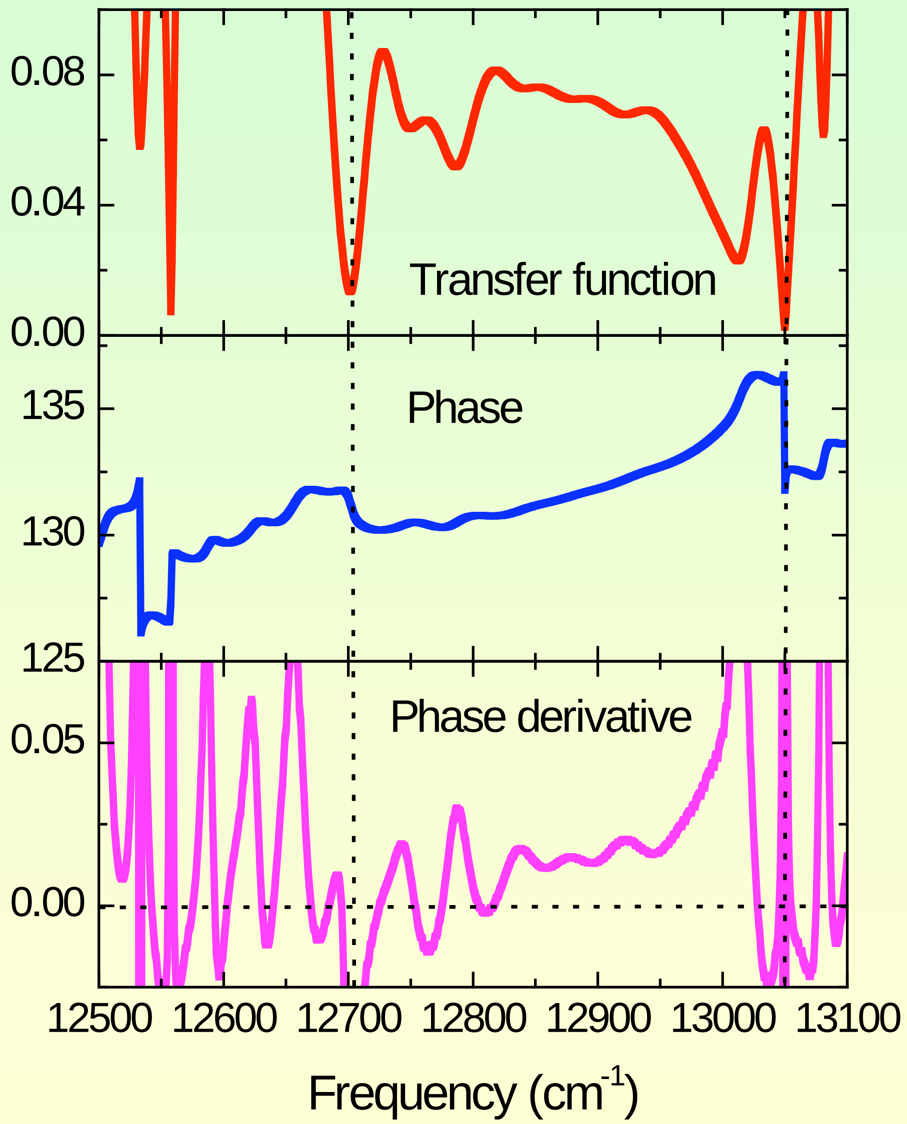


Photo-anodically etched macroporous GaP

Fast Fourier Transform of Cross-Correlation







Group Velocity – superluminal and negative!

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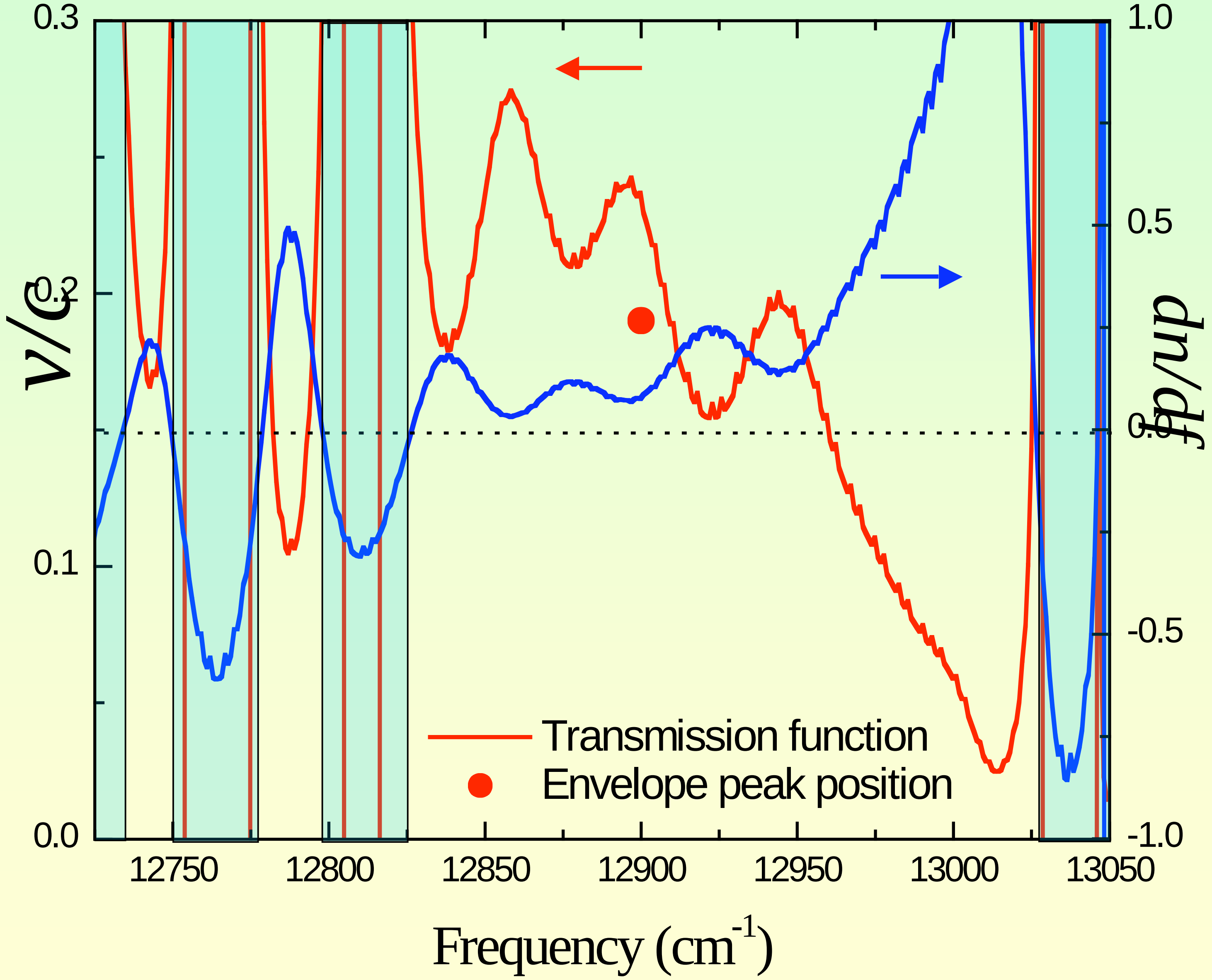

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Photonic Crystals

- Spontaneous emission...

  NOT an intrinsic property; control by modifying states of the radiation field.

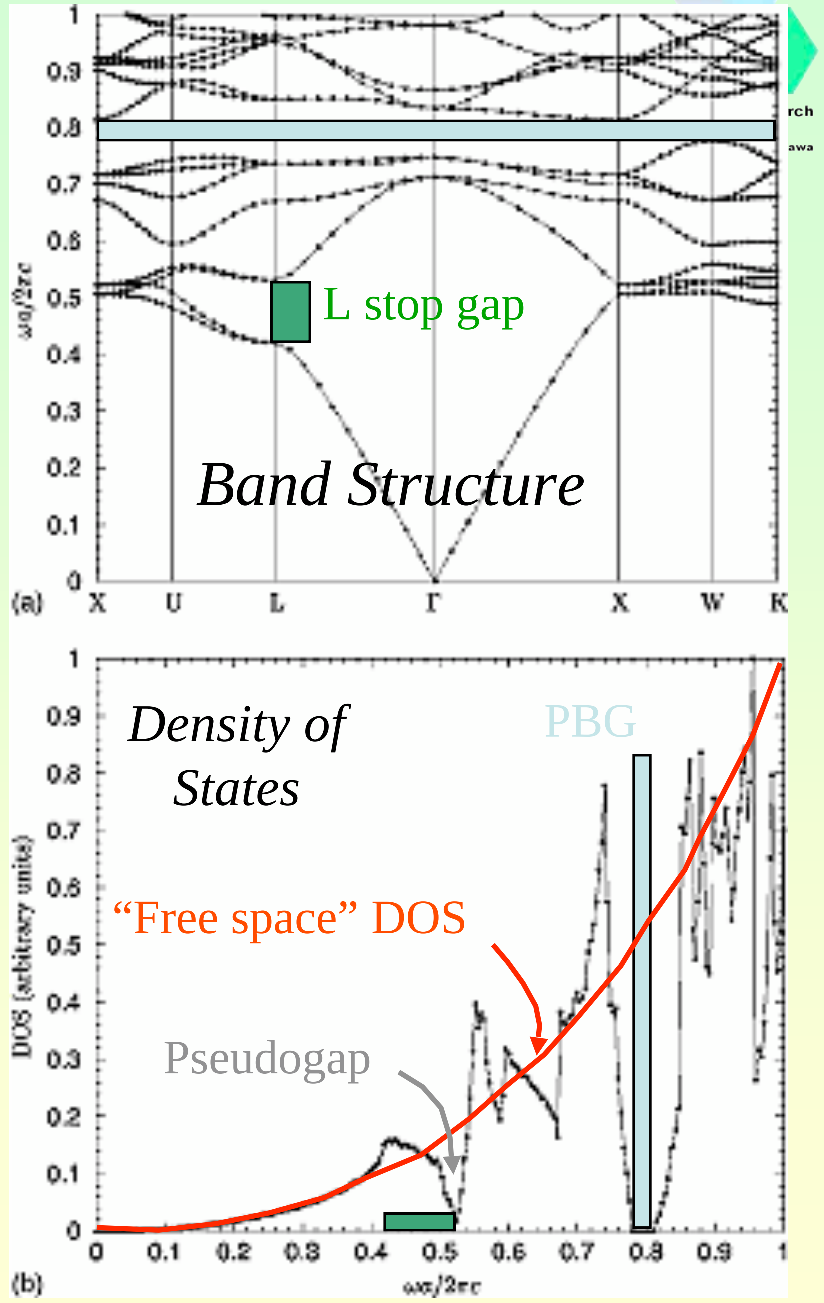
- Fermi's Golden Rule

  Rate ∝ DOS

  "Free space" DOS ∝ ω^2

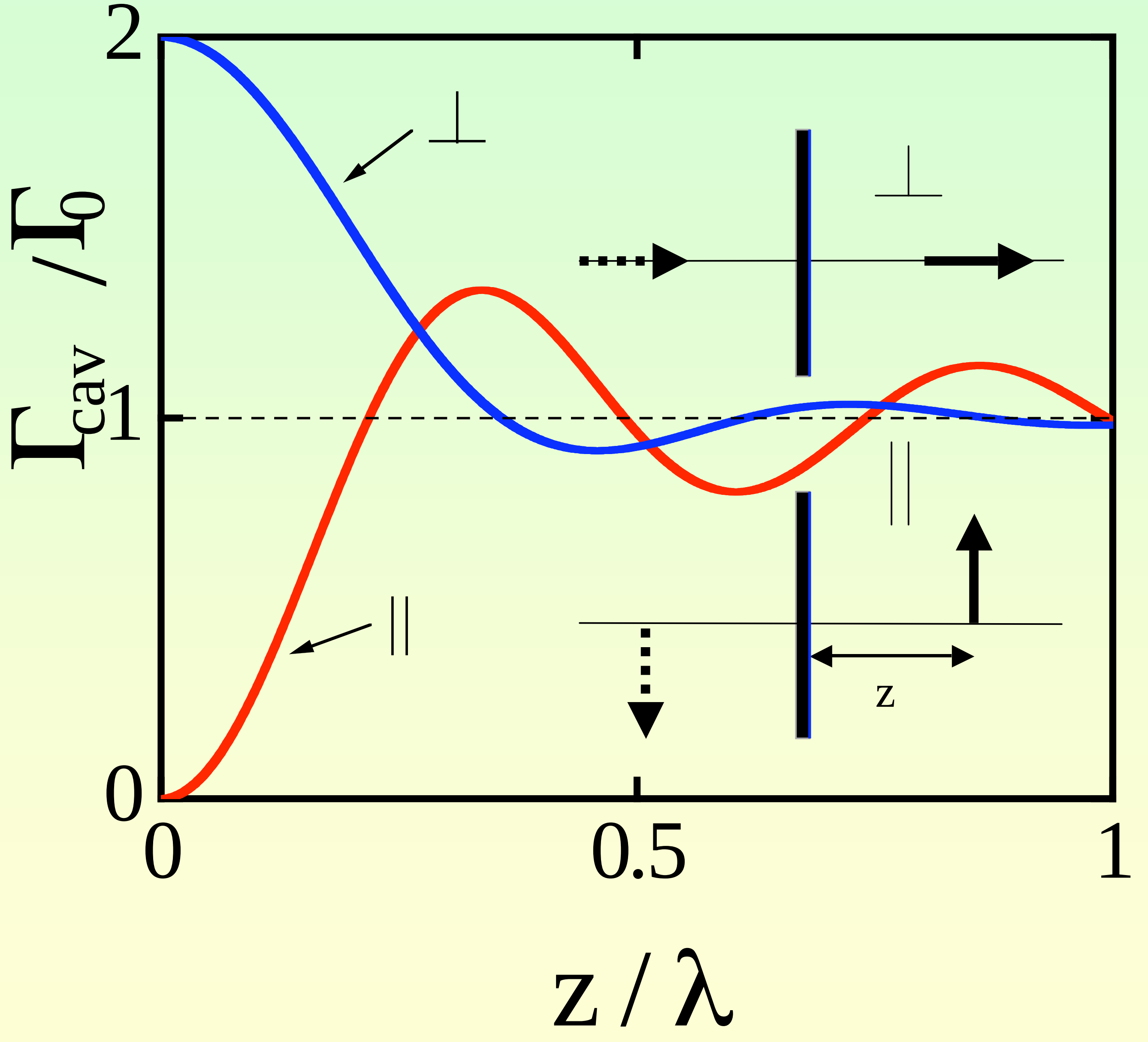
Close-packed *fcc* lattice of air spheres in silicon

*



*Adapted from: Fig. 8, Busch & John, *PRE* **58**, 3896 (1998)

Dipole near a mirror - QED



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Titania "Inverse Opal" Photonic Crystals

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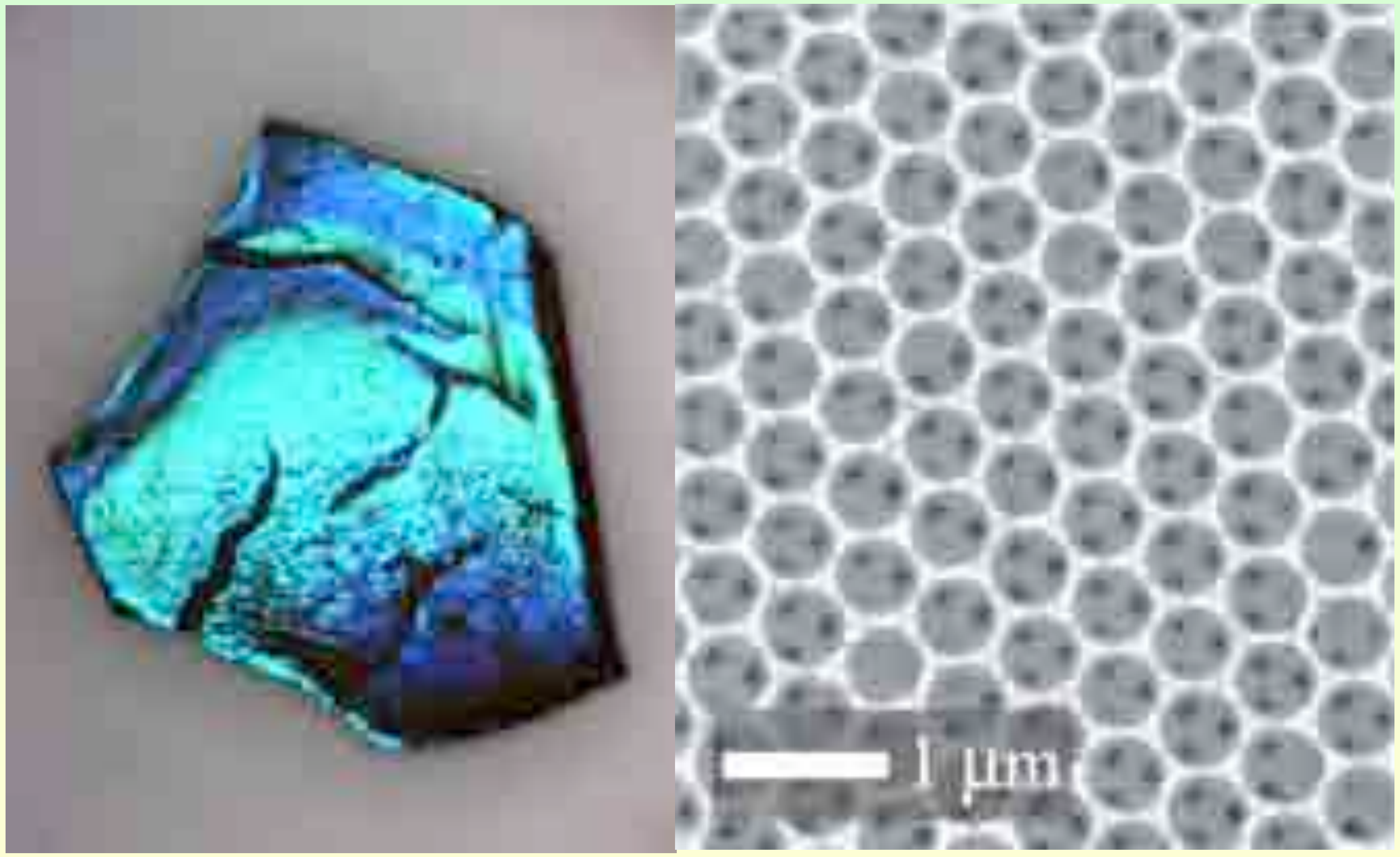
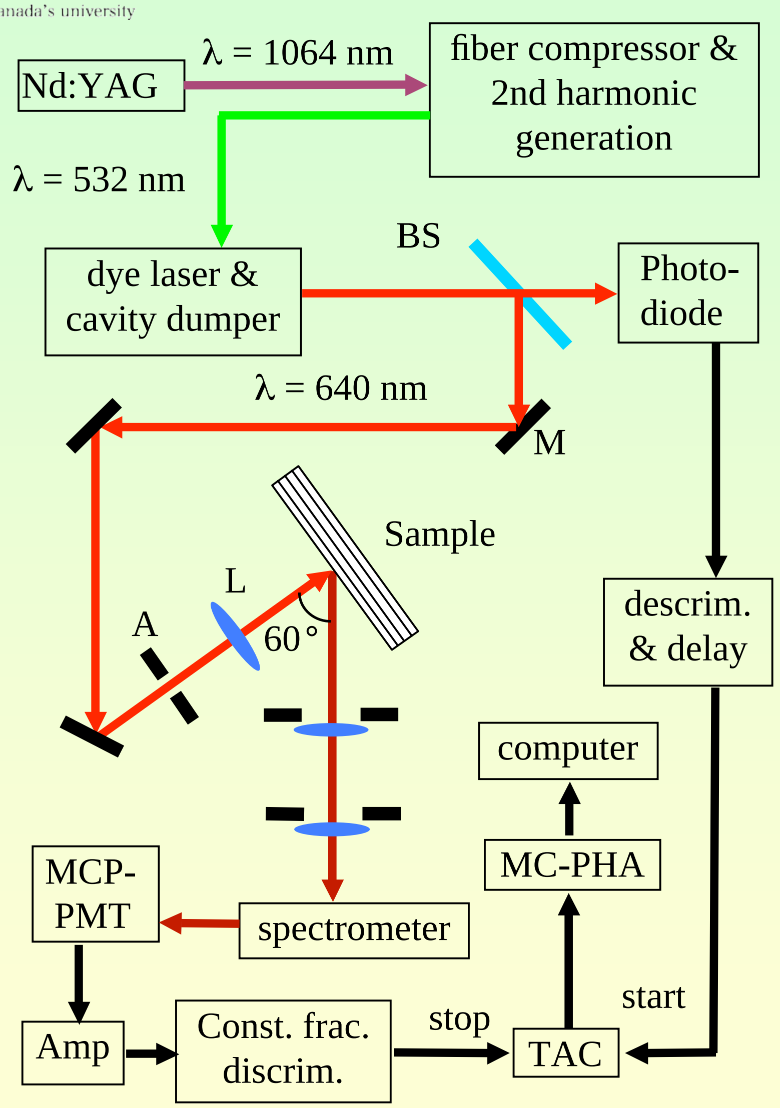
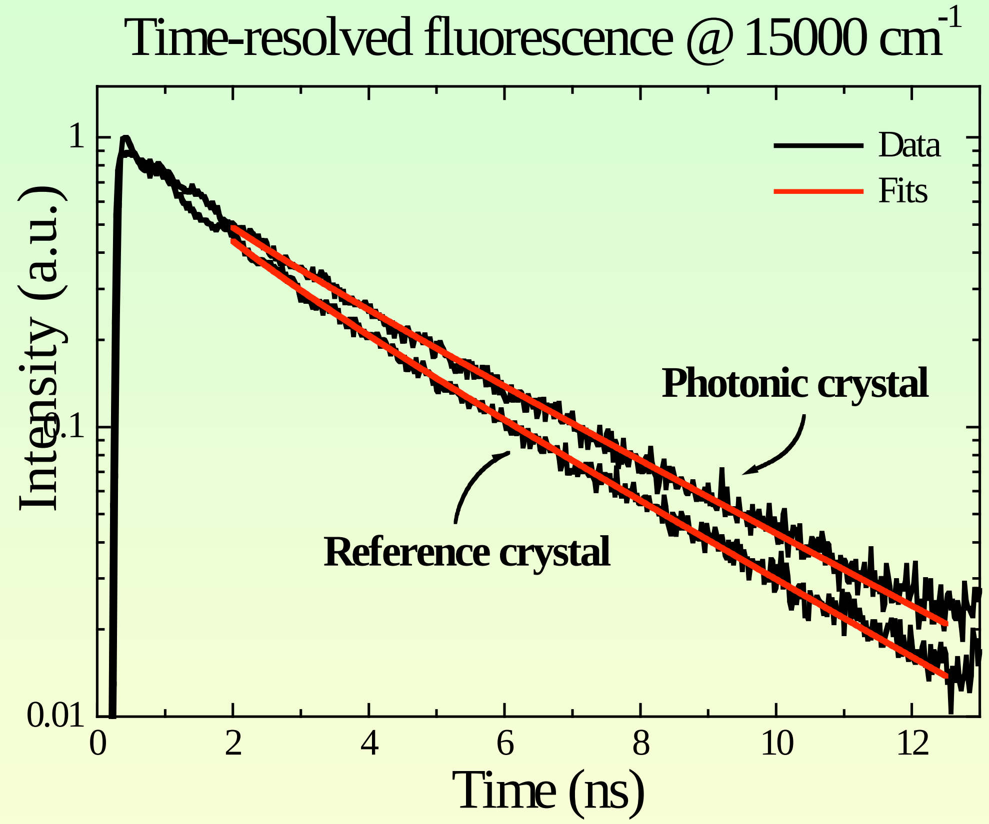


Time-correlated single photon counting





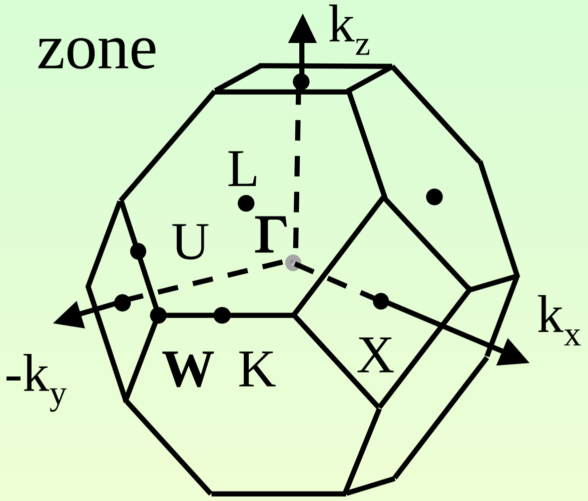
Dye on titania: low quantum efficiency

$$\gamma_{tot} = \gamma_{rad} + \gamma_{nonrad} \cong \gamma_{nonrad}$$

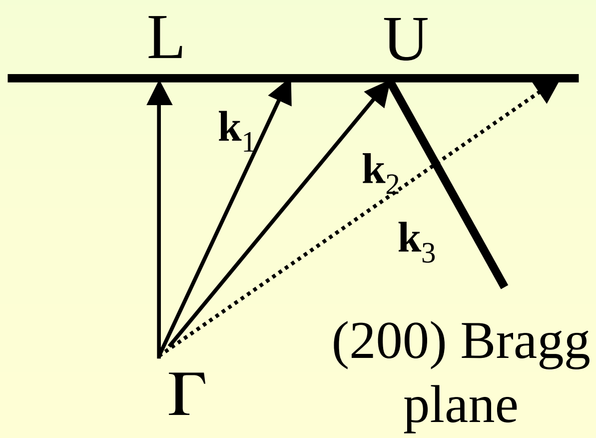
Lifetime determinations uncertain…

Emission from doped Ti "inverse opals"

Brillouin
zone

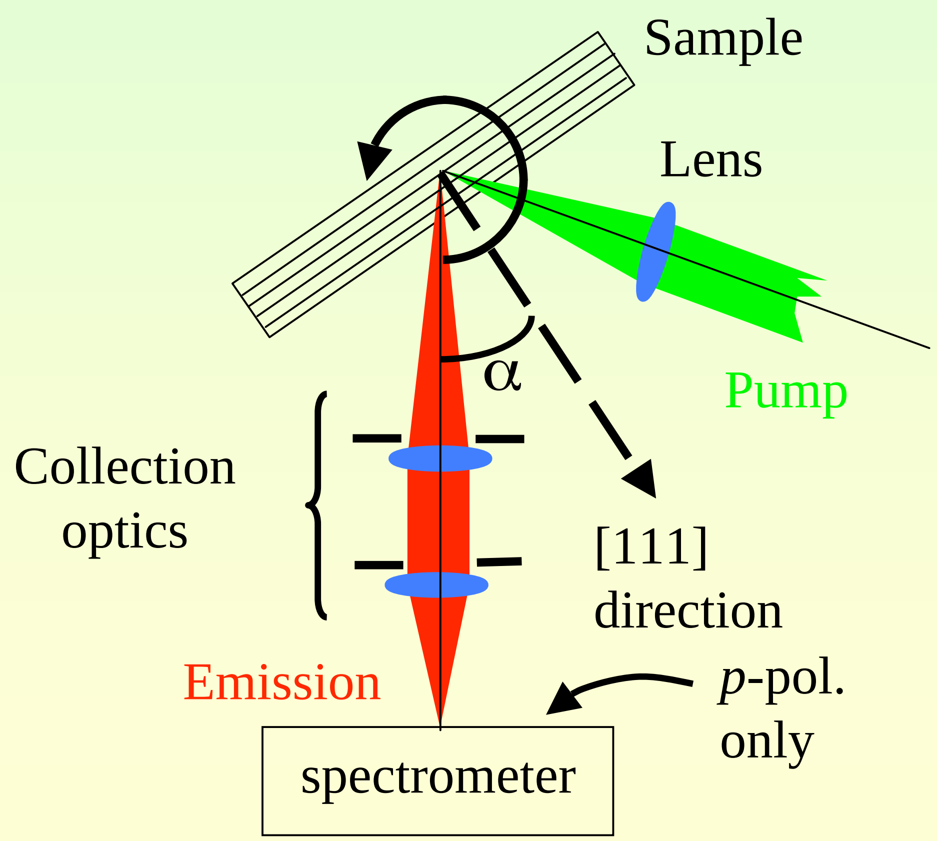


(111) Bragg plane



Adsorbed R6G or Nile Blue

Linewidths: small homogeneous,
large inhomogeneous



Inhibition rates via emission spectra

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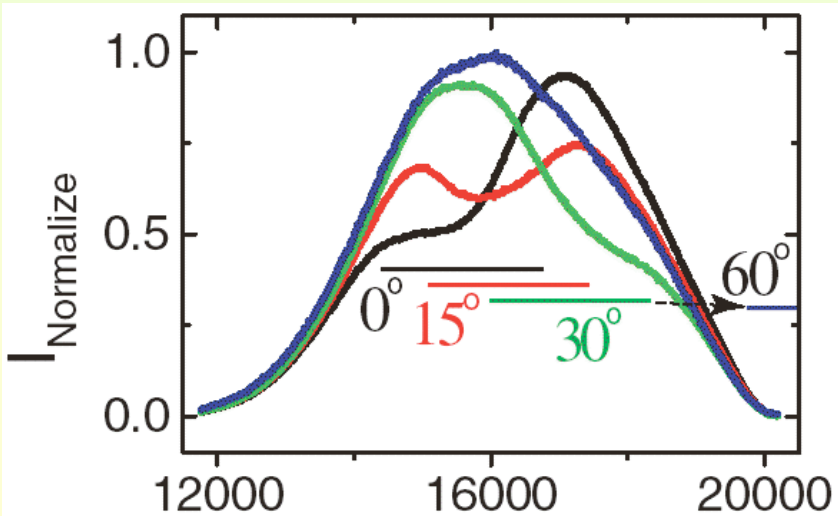
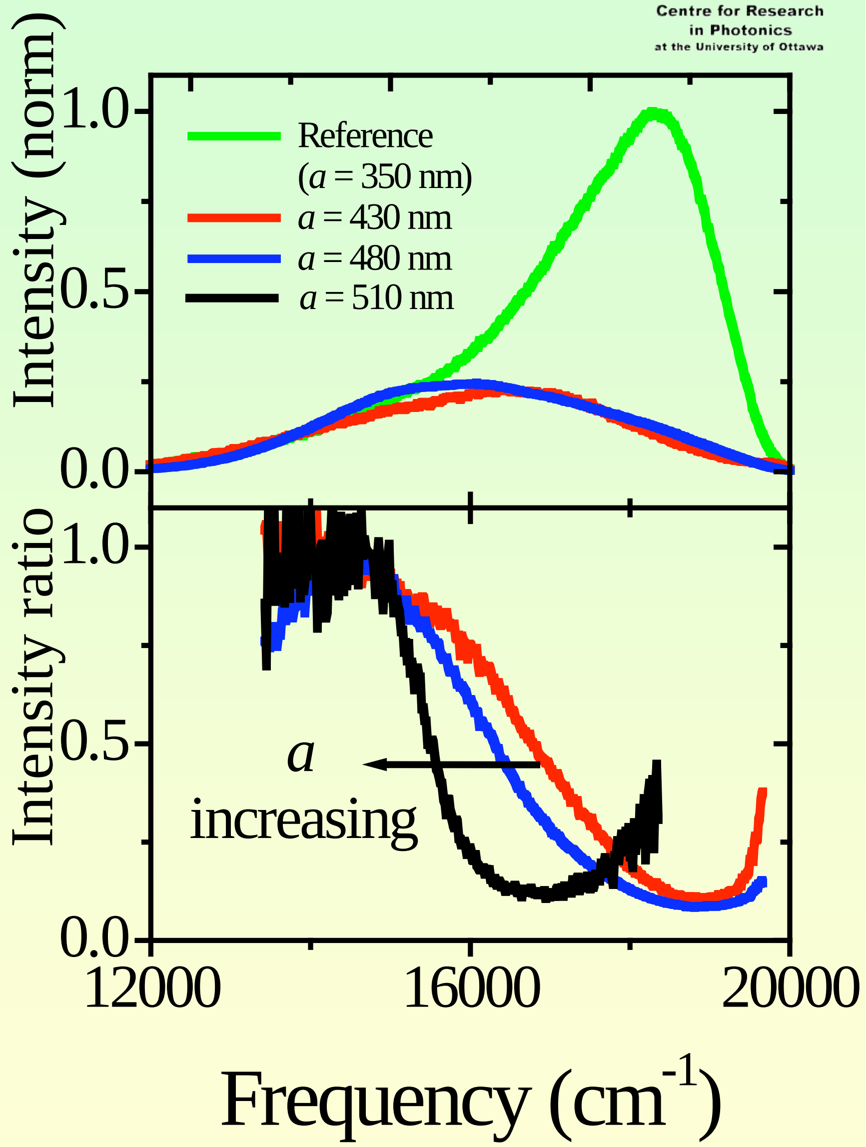
Population of excited state: W / γ_{tot}

Photon emission rate: $\gamma_{rad} \left(W / \gamma_{tot} \right)$

$\therefore$ Emitted power $\propto \gamma_{rad}$

Angular dependence





Phys. Rev. Lett. **88**, 143903 (2002)

Symmetry of Photonic Crystals

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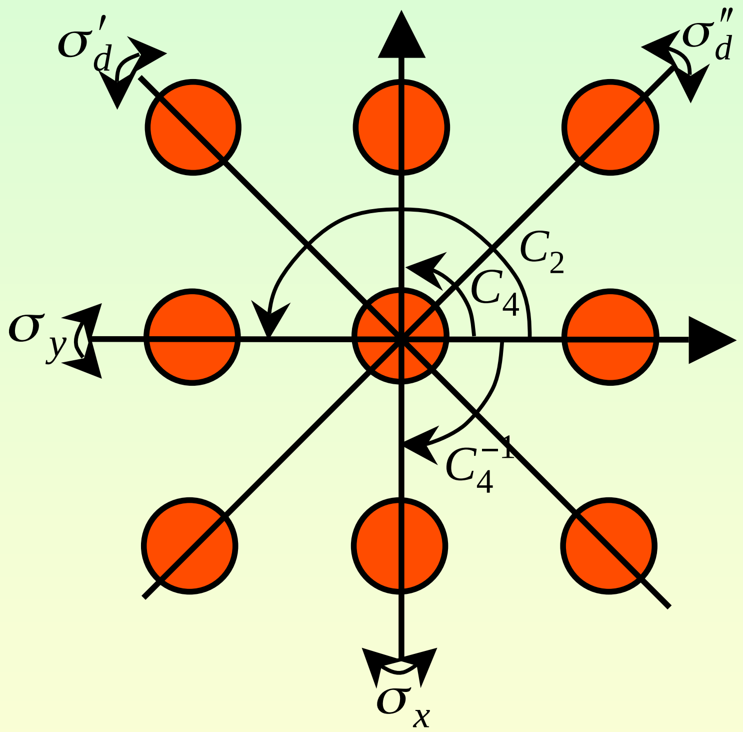
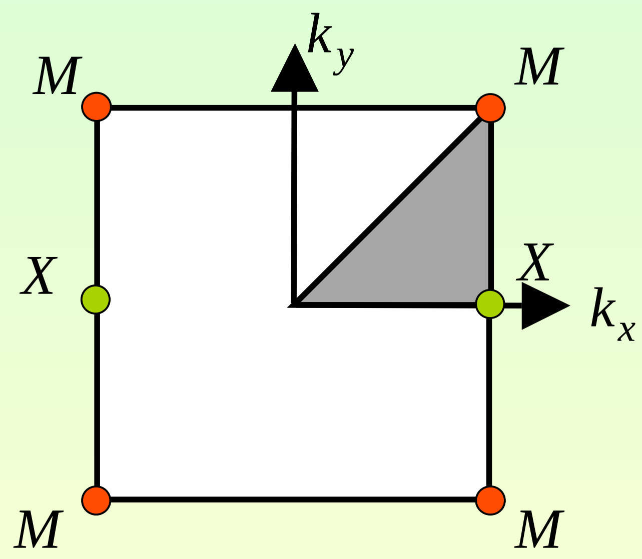
Real Space



$$\varepsilon\left(R^{-1}\mathbf{r}\right)=\varepsilon\left(\mathbf{r}\right)$$

Reciprocal Space



$$R\mathbf{k}=\mathbf{k}-\mathbf{G}$$

$$C_{4v}=\left\{E,C_4,C_4^{-1},C_2,\sigma_x,\sigma_y,\sigma_d',\sigma_d''\right\}$$

Real Space + Reciprocal Space → Overall Symmetry

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Characterizing the symmetry

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Bloch operator determines the symmetry group…

$$\Theta\left[\varepsilon\left(\mathbf{r}\right),\mathbf{k}\right]\psi\left(\mathbf{r}\right)=\lambda\psi\left(\mathbf{r}\right)$$

…set of all symmetry operators *R* that leave it invariant

A	Symmetry Operators R			
	E	C_2	σ_y	σ_x
A_1	1	1	1	1
A_2	1	1	-1	-1
B_1	1	-1	1	-1
B_2	1	-1	-1	1

C_{2v} Character Table

$$R\Theta\left[\varepsilon\left(\mathbf{r}\right),\mathbf{k}\right]R^{-1}=\Theta\left[\varepsilon\left(\mathbf{r}\right),\mathbf{k}\right]$$

Symmetry transformation properties are characterized by…

$$\chi_{RA}=Tr\left[D_A\left(R\right)\right]=\sum_i^l D_{Aii}\left(R\right)$$

where

$$R\psi_{Ai}\left(\mathbf{r}\right)=\sum_i^l D_{Aij}\left(R\right)\psi_{Aj}\left(\mathbf{r}\right)$$

Vanishing Contrast Approach

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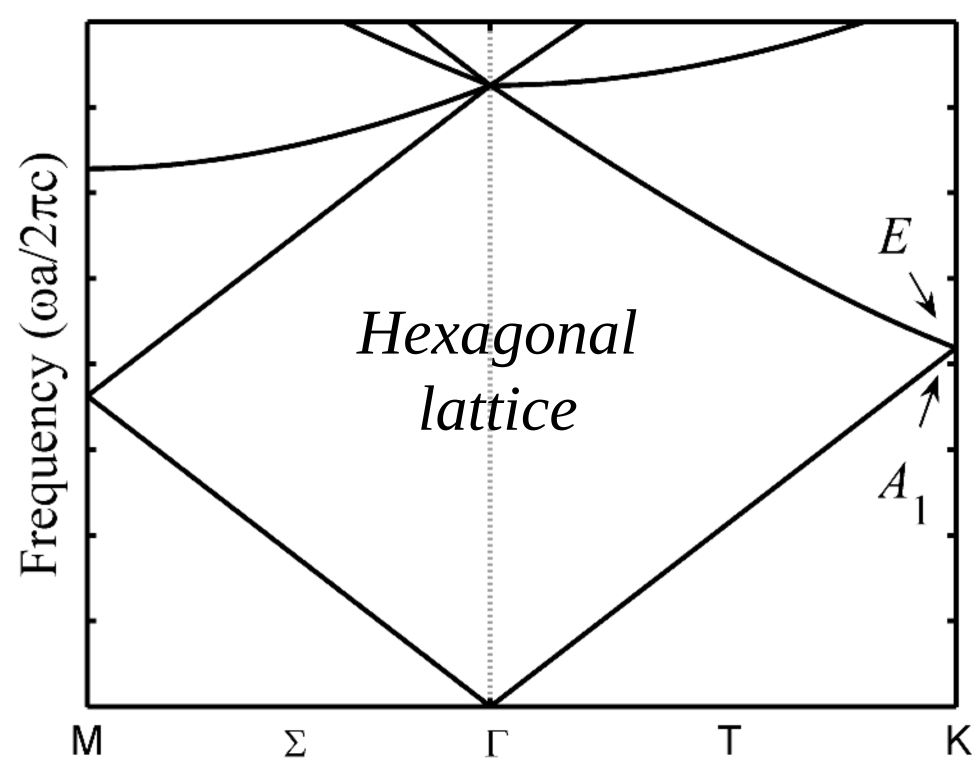
Bloch mode:

$$\psi_{\mathbf{k}}(\mathbf{r}) = \sum_{\mathbf{G}'} U(\mathbf{k}-\mathbf{G}')e^{i(\mathbf{k}-\mathbf{G}')\cdot\mathbf{r}}$$



Coefficients depend on system symmetry…

Approximate as sum of plane waves:

$$\psi_{\mathbf{k}}(\mathbf{r}) \approx U(\mathbf{k}-\mathbf{G})e^{i(\mathbf{k}-\mathbf{G})\cdot\mathbf{r}} + U(\mathbf{k}-\mathbf{G}')e^{i(\mathbf{k}-\mathbf{G}')\cdot\mathbf{r}} + U(\mathbf{k}-\mathbf{G}'')e^{i(\mathbf{k}-\mathbf{G}'')\cdot\mathbf{r}} + \ldots$$

Take vanishing contrast limit → use character table to find coefficients

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Bloch Modes and the Vortex State

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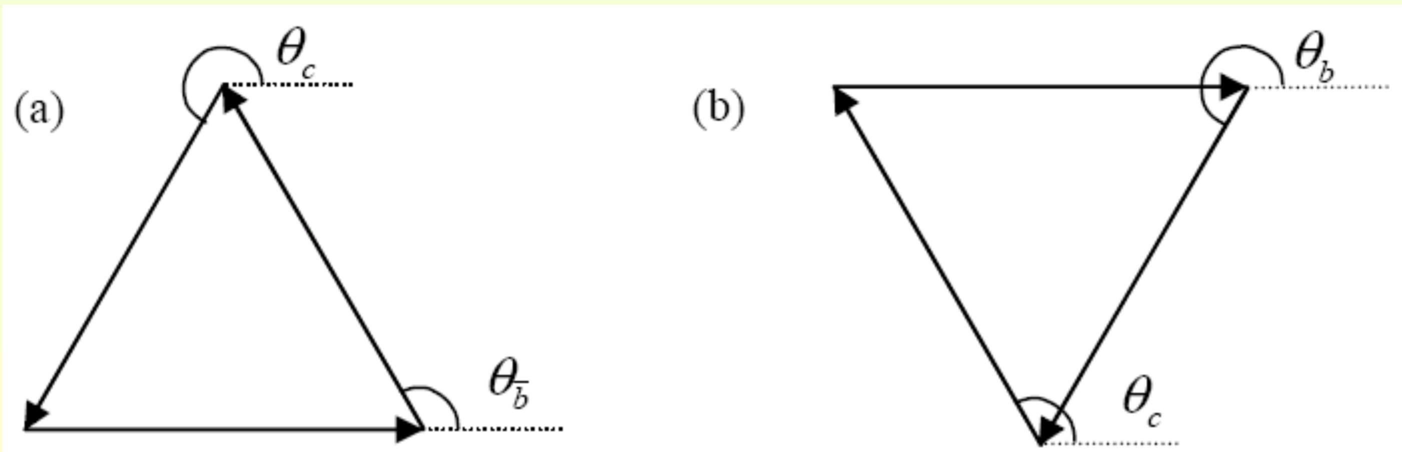
$$\{A_1\}: \quad \psi_{1,\mathbf{k}}(\mathbf{r}) = U(\mathbf{k}-0)\left(1 + e^{-i2\pi\left(x/a - y/(\sqrt{3}a)\right)} + e^{-i2\pi\left(x/a + y/(\sqrt{3}a)\right)}\right)e^{ix(4\pi/3a)}$$

$$\{E\}: \quad \psi_{2,\mathbf{k}}(\mathbf{r}) = U(\mathbf{k}-0)\left(2 - e^{-i2\pi\left(x/a - y/(\sqrt{3}a)\right)} - e^{-i2\pi\left(x/a + y/(\sqrt{3}a)\right)}\right)e^{ix(4\pi/3a)}$$

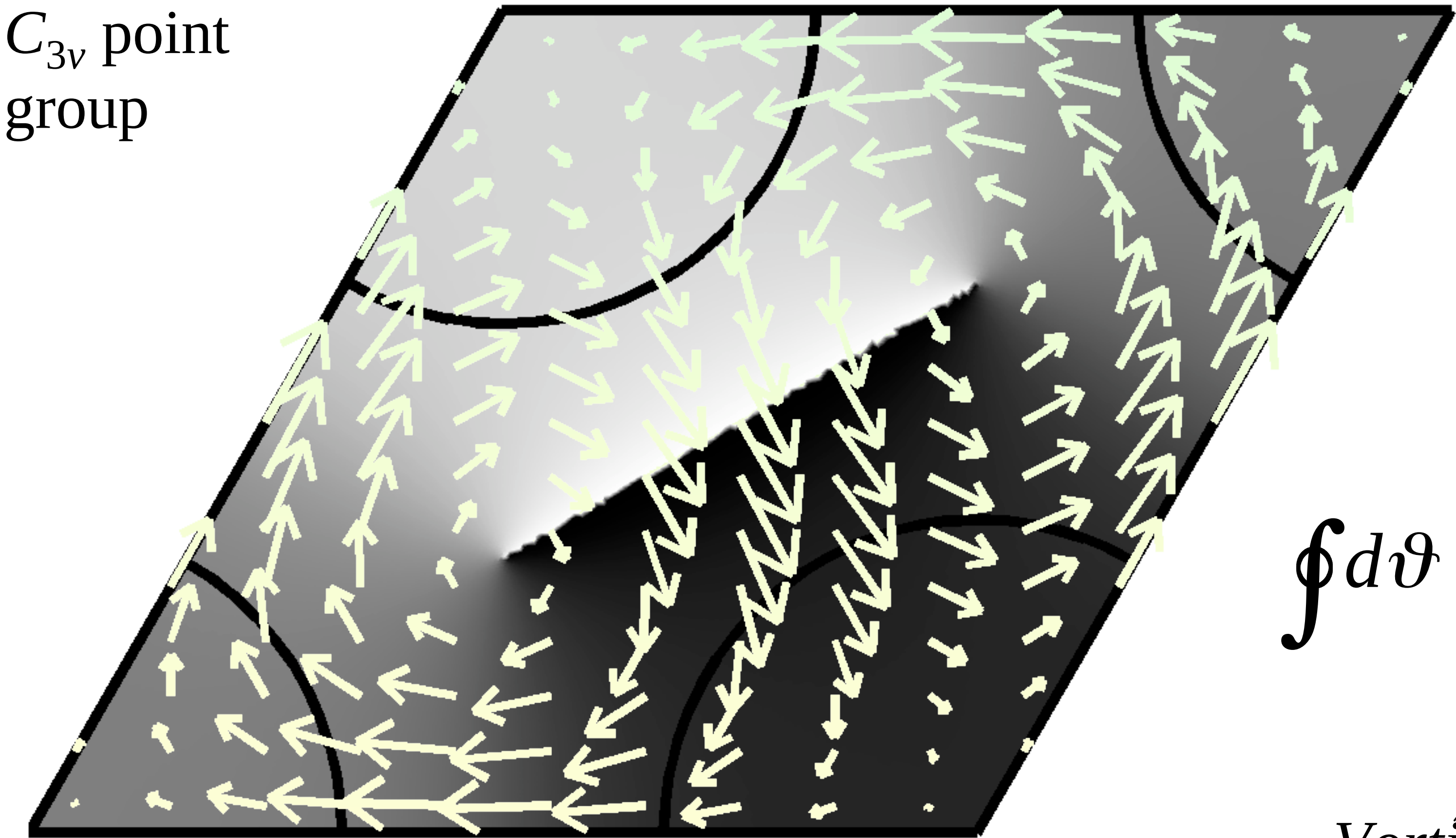
$$\{E\}: \quad \psi_{3,\mathbf{k}}(\mathbf{r}) = U(\mathbf{k}-0)\sqrt{3}\left(-e^{-i2\pi\left(x/a - y/(\sqrt{3}a)\right)} + e^{-i2\pi\left(x/a + y/(\sqrt{3}a)\right)}\right)e^{ix(4\pi/3a)}$$

Locating the vortex: the phasor picture



Optical Singularities

Phase singularities and flux vortices

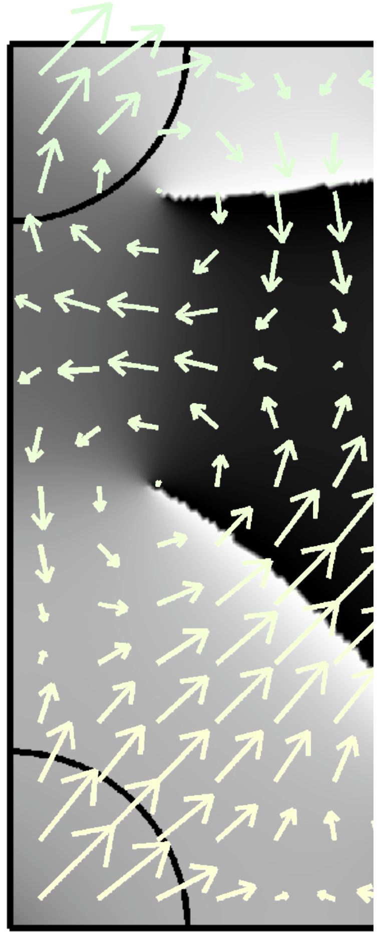


$$\oint d\vartheta = 2\pi\upsilon$$

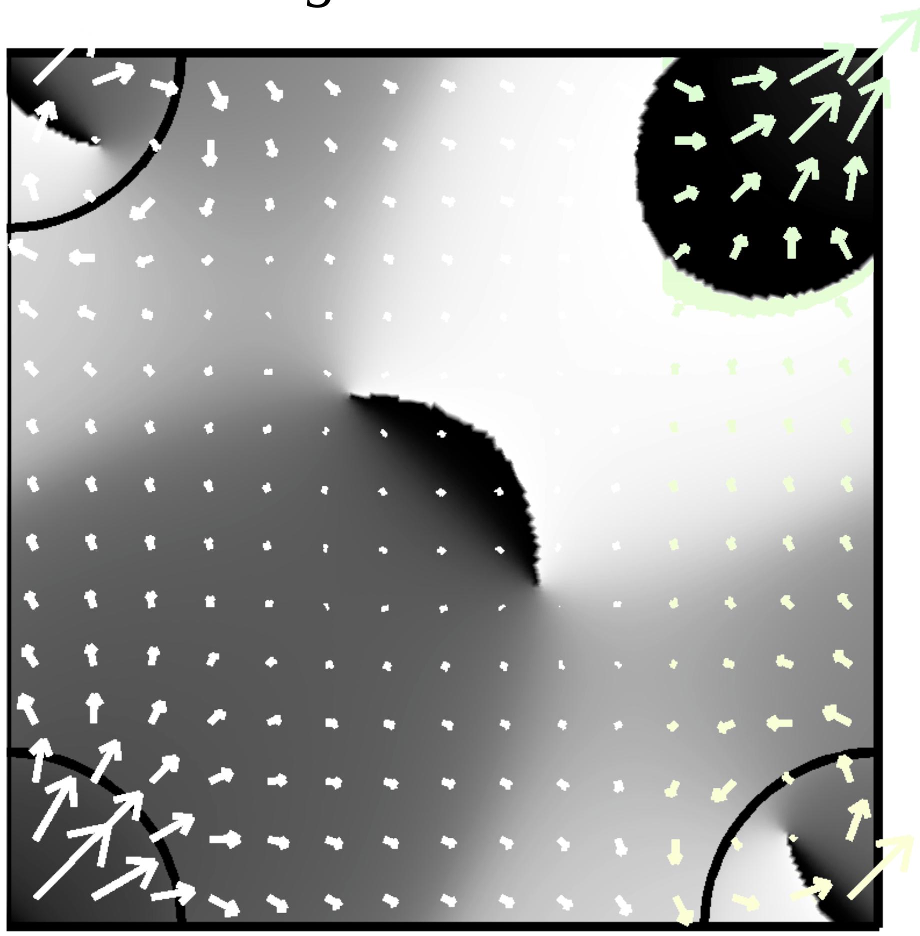
Vorticity

“Accidental” Singularities

“Vanishing” contrast

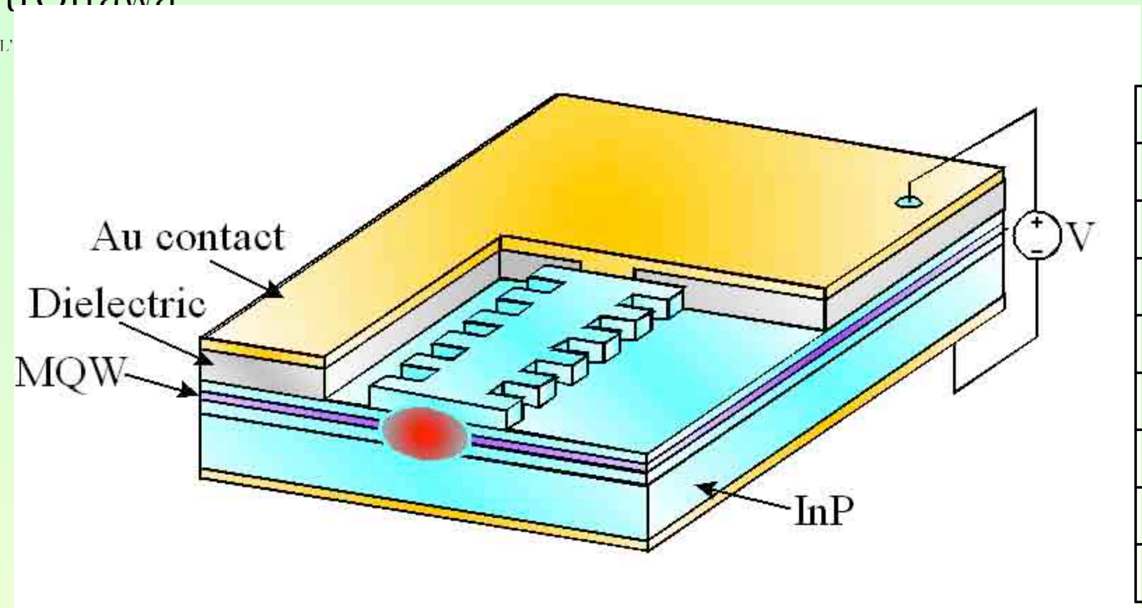


High contrast

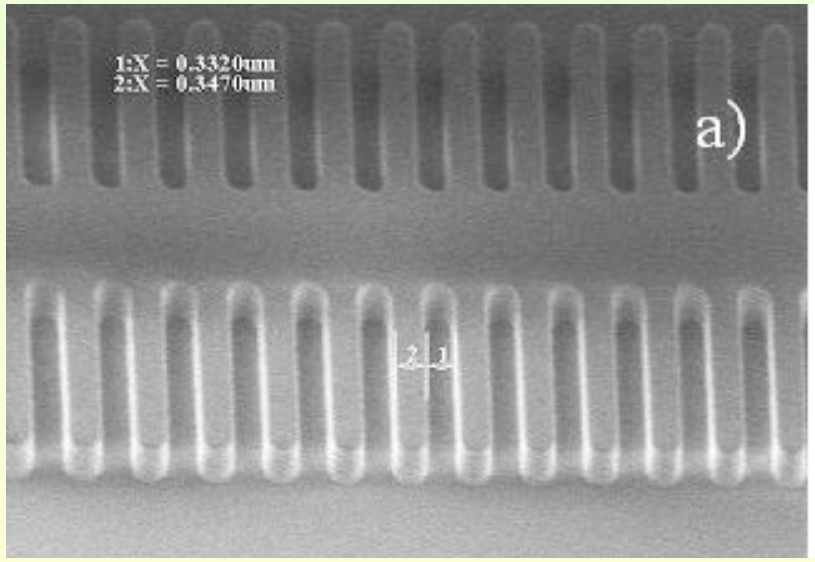


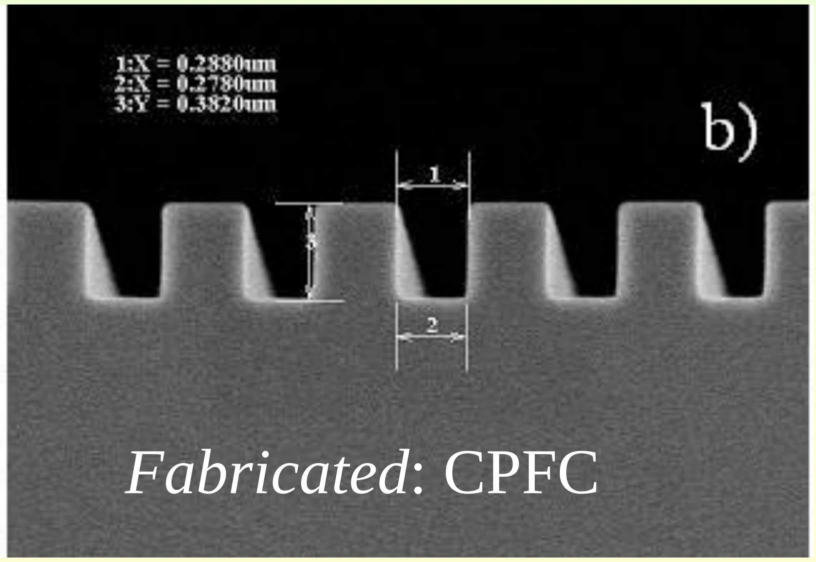
Wheeldon *et al*, Optics Express 15, 3531 (2007)

Laterally-Coupled DFB Laser …



P cap	InGaAs
Upper cladding 2	InP
Buffer	$In_{0.929}Ga_{0.071}As_{0.156}P_{0.844}$
Upper cladding	$In_{0.795}Ga_{0.205}As_{0.415}P_{0.585}$
MQW	InGaAsP
Lower cladding	$In_{0.795}Ga_{0.205}As_{0.415}P_{0.585}$
Buffer	$In_{0.929}Ga_{0.071}As_{0.156}P_{0.844}$
Buffer	InP
Substrate	InP





…Modified Coupled Mode Theory

Higher-order gratings

Streifer approach for a 2D waveguide:
Partial wave expansion
← "Leaky modes"

Finite element analysis
→ absorbing boundary layer treatment

Complex coupling coefficients…

Full tolerance analysis

Millett *et al*, submitted JQE (2008)

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The future – Spectroscopic NSOM

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Near Field Modes (NSOM):

- ***Reflection***
- ***Transmission***
- ***Collection***
- ***Fluorescence***
- ***Photo-Luminescence***
- ***Raman***