When loss destroys the Hilbert space: Purcell factors and strong coupling in plasmonic systems

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December 20, 2018

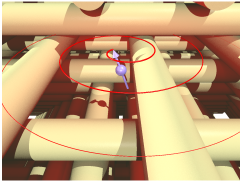
What to take from this talk

- Every band structure is complex
- Material dispersion and loss let conventional theory fail
- Ignoring imaginary parts (e.g. frequency or wave number) is dangerous

Emission from lossy/dispersive systems

Manipulating **emission dynamics** for:

- Single-photon sources



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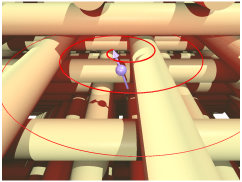

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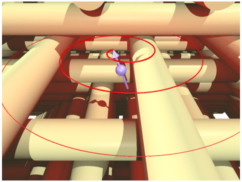

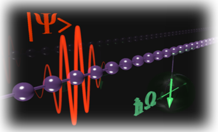

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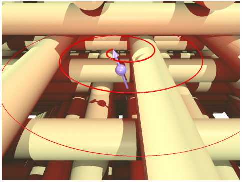

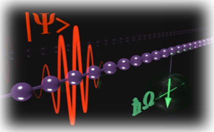

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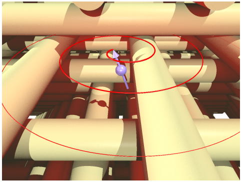

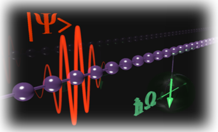

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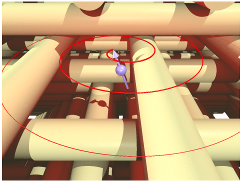

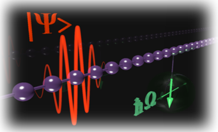

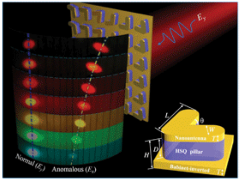

[Science Adv. **2,** e1501168 (2016)]

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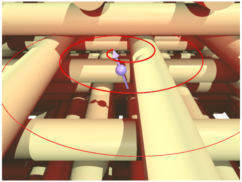

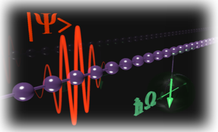

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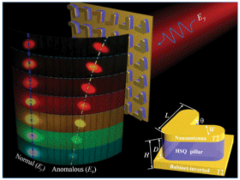

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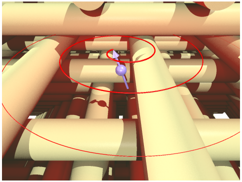

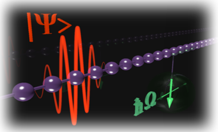

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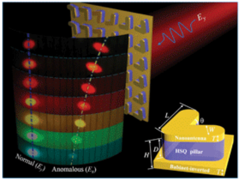
- Strongly coupled graphene or van-der-Waals materials



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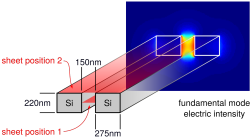

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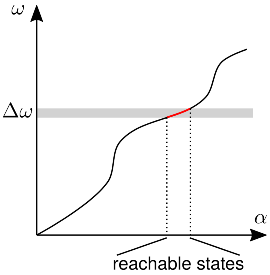

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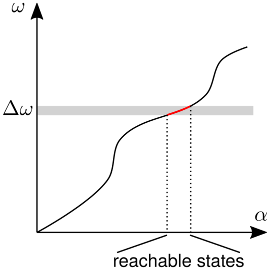

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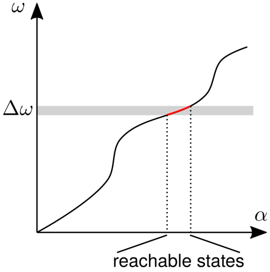

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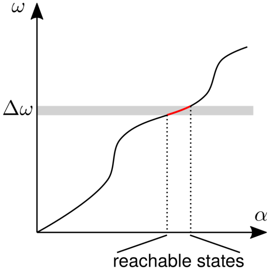

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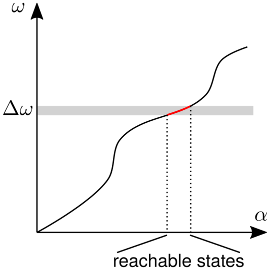

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- For continuous spectra: $\rho(\omega) \simeq \frac{\partial\alpha}{\partial\omega}$.

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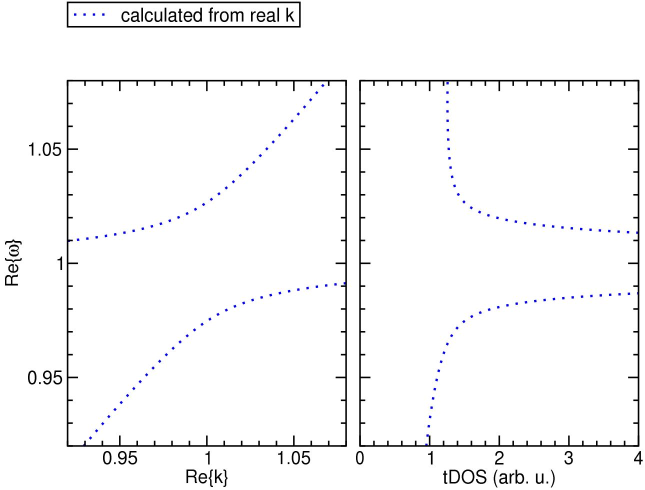

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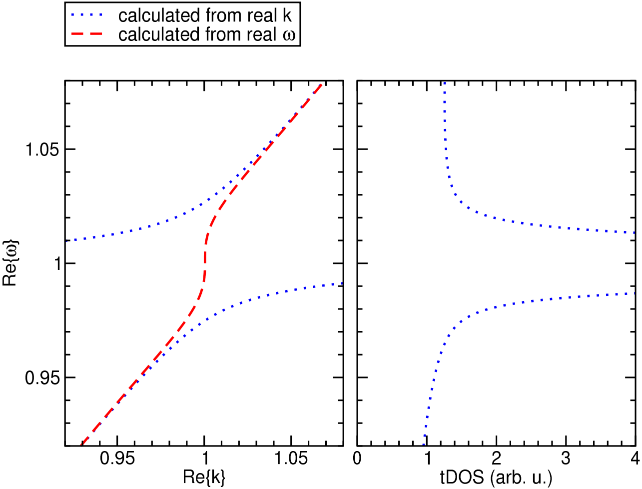

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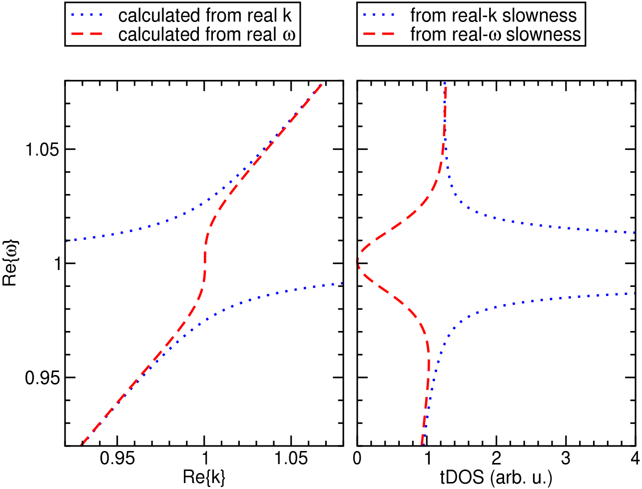

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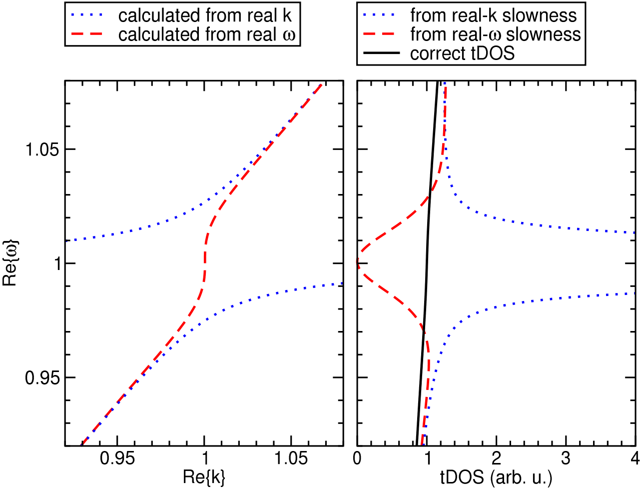

S. M. Barnett et al. J. Phys. B 29, 3763 (1996)

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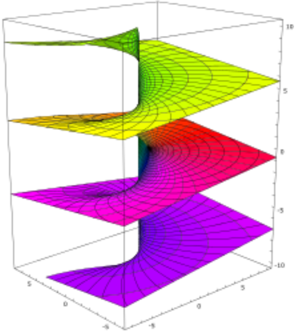

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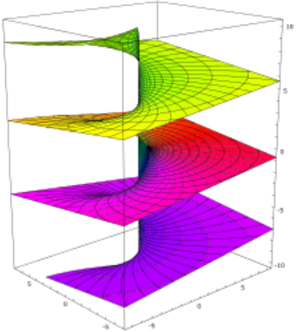

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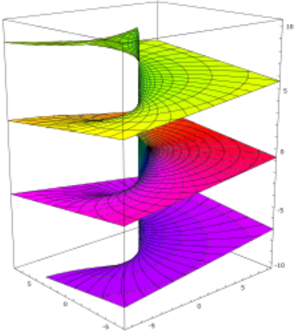

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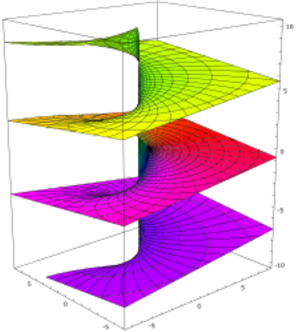

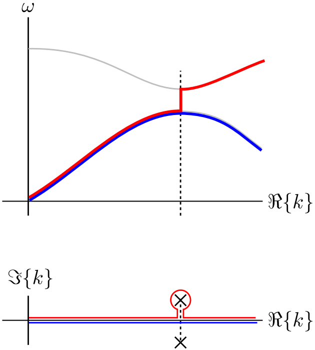

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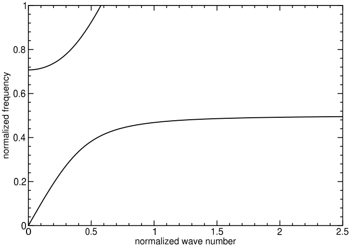

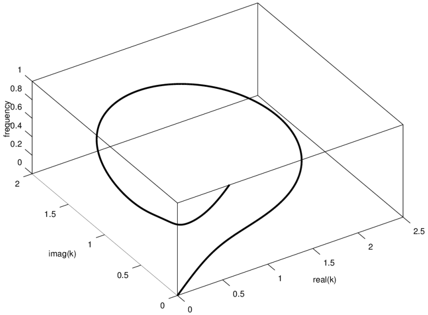

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Group velocity and DOS

- Group velocity along $\hat{z}$:

$$v_z = \frac{\int_{\mathrm{WSC}} \mathrm{d}^3 r \; \hat{z} \cdot (\vec{E}^{\ddagger} \times \vec{H} + \vec{E} \times \vec{H}^{\ddagger})}{\int_{\mathrm{WSC}} \mathrm{d}^3 r \; (\vec{E}^{\ddagger} \frac{\partial(\omega\varepsilon)}{\partial\omega} \vec{E} + \vec{H}^{\ddagger} \frac{\partial(\omega\mu)}{\partial\omega} \vec{H})}.$$

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- With dispersion: Maxwell's equations form nonlinear eigenvalue problem:

$$\mathcal{L}(\omega)\Psi(\vec{r}) = \omega\Psi(\vec{r}).$$

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- Green function without material dispersion:

$$\mathcal{G}(\vec{r}, \vec{r}', \omega) = \frac{1}{V_{\mathrm{BZ}}} \sum_n \int_{\mathrm{BZ}} \mathrm{d}^3 k \ \frac{\Psi_{n\vec{k}}(\vec{r}) \otimes \Psi^{\ddagger}_{n\vec{k}}(\vec{r}')}{\omega - \omega_{n\vec{k}}}$$

- Fix: Auxiliary frequency-like eigenvalue λ:

$$\mathcal{L}(\omega)\Psi_\omega(\vec{r}) = \lambda_\omega \Psi_\omega(\vec{r}).$$

Group velocity and DOS

- Group velocity along $\hat{z}$:

$$v_z = \frac{\int_{\mathrm{WSC}} \mathrm{d}^3 r \;\, \hat{z} \cdot (\vec{E}^{\ddagger} \times \vec{H} + \vec{E} \times \vec{H}^{\ddagger})}{\int_{\mathrm{WSC}} \mathrm{d}^3 r \;\, (\vec{E}^{\ddagger} \frac{\partial(\omega\varepsilon)}{\partial\omega} \vec{E} + \vec{H}^{\ddagger} \frac{\partial(\omega\mu)}{\partial\omega} \vec{H})}.$$

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- Generalized Green function with dispersion (ω fixed):

$$\mathcal{G}_\omega(\vec{r}, \vec{r}', \lambda) = \frac{1}{V_{\mathrm{BZ}}} \sum_n \int_{\mathrm{BZ}} \mathrm{d}^3 k \;\, \frac{\Psi_{n,\vec{k},\omega}(\vec{r}) \otimes \Psi^{\ddagger}_{n,\vec{k},\omega}(\vec{r}')}{\lambda - \lambda_{n,\vec{k},\omega}}$$

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$$\rho(\omega) = \frac{4\omega}{c^2} \int_{\mathcal{I}_{\omega}} \Re \left\{ \frac{\int_{\mathrm{WSC}} \mathrm{d}^3 r \ (\vec{E}^{\ddagger} \varepsilon \vec{E} + \vec{H}^{\ddagger} \mu \vec{H})}{\int_{\mathrm{WSC}} \mathrm{d}^3 r \ \hat{z} \cdot (\vec{E}^{\ddagger} \times \vec{H} + \vec{E} \times \vec{H}^{\ddagger})} \right\}$$

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Analytical example: Strong coupling with band edge

- Idealized problem: Isotropic band edge & single resonance pole

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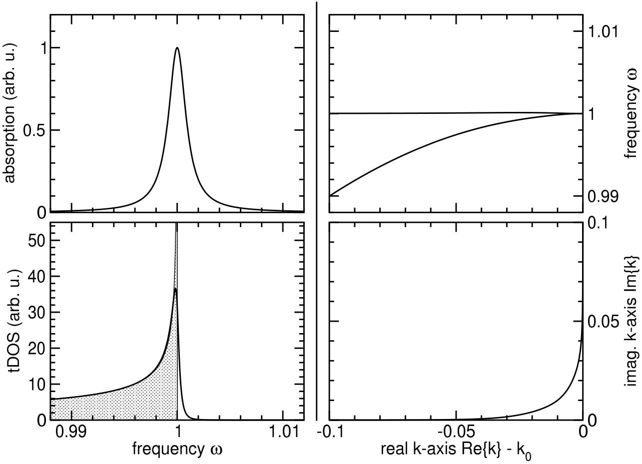

Analytical example: Strong coupling with band edge

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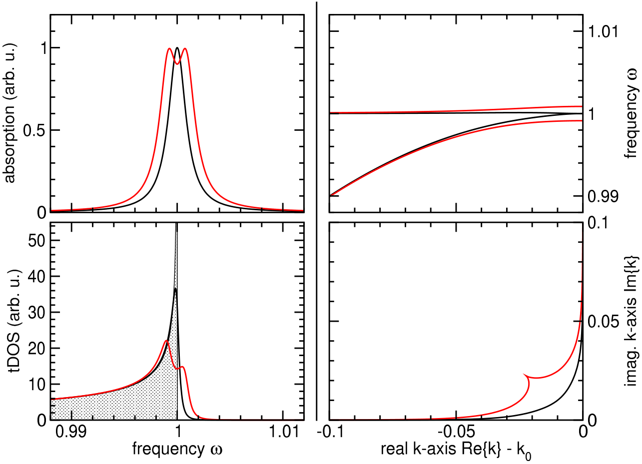

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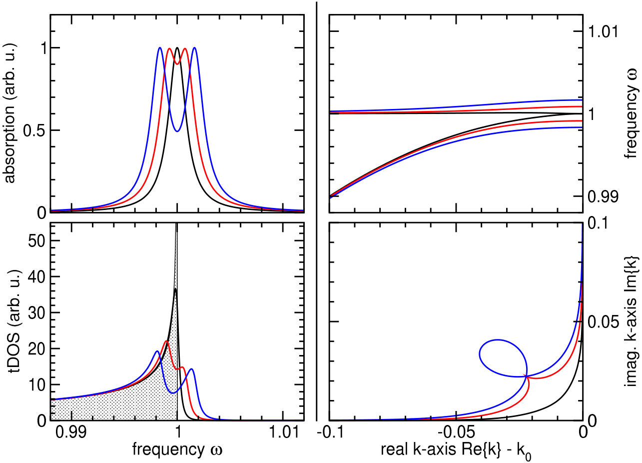

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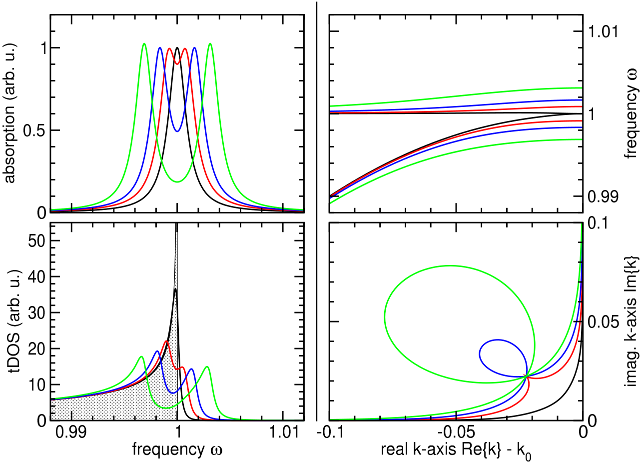

Summary

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- Ignoring imaginary parts (e.g. frequency or wave number) is dangerous

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[Wolff *et al.*, Phys. Rev. B **97**, 104203 (2018)]