Networks as Coherent Perfect Absorbers

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Statistical Properties of Resonances in Quantum Irregular Scattering

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(Received 2 May 1991)

The close relations between statistical properties of quantum dissipative systems and scattering systems is discussed. It is conjectured that for quantum chaotic scattering the distribution of the resonance poles of the S matrix is generic and follows the predictions of the Ginibre ensemble of random non-Hermitian matrices. This phenomenon has been demonstrated on a simple example of a single particle scattered by eight randomly distributed point obstacles in three dimensions.

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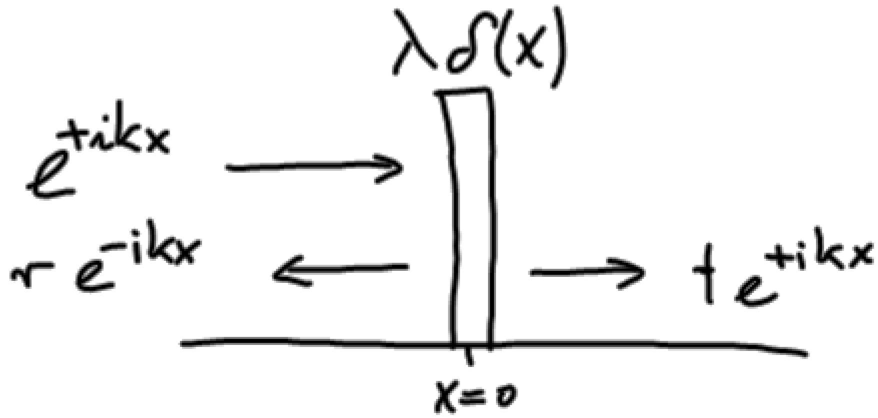
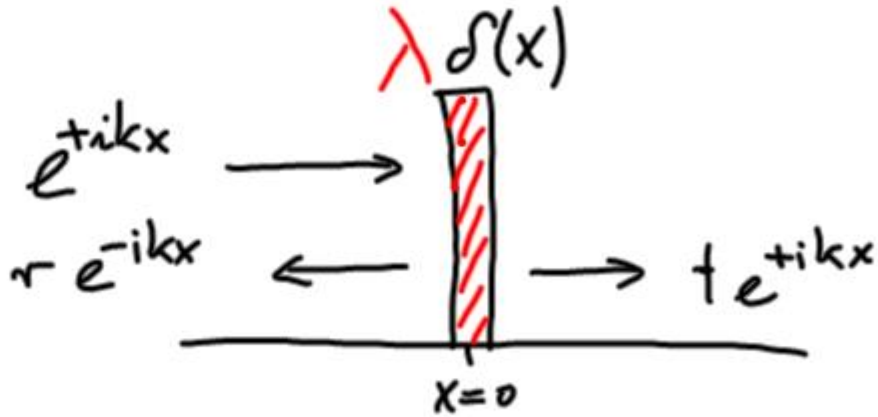
λδ(x)
x=0

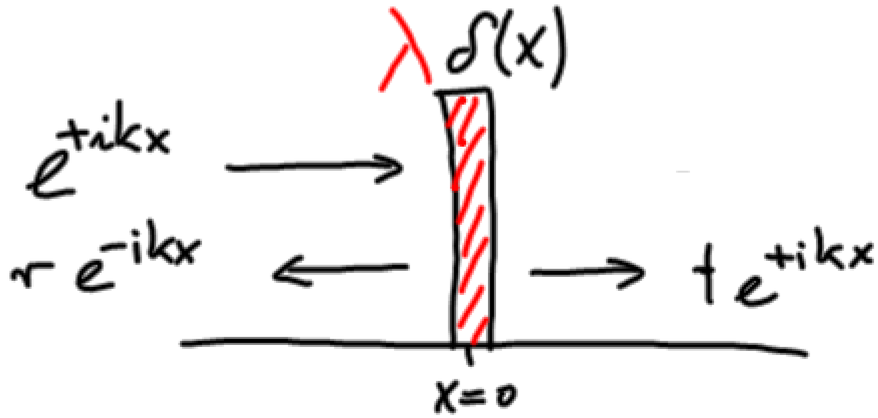
$$(\Delta + k^2)\, y(x) = \lambda \delta(x)\, y(x)$$



$$\left.\begin{aligned} t &= \frac{1}{1+i\lambda/2k} \\ r &= t-1 \end{aligned}\right\} \quad |t|^2 + |r|^2 = 1$$

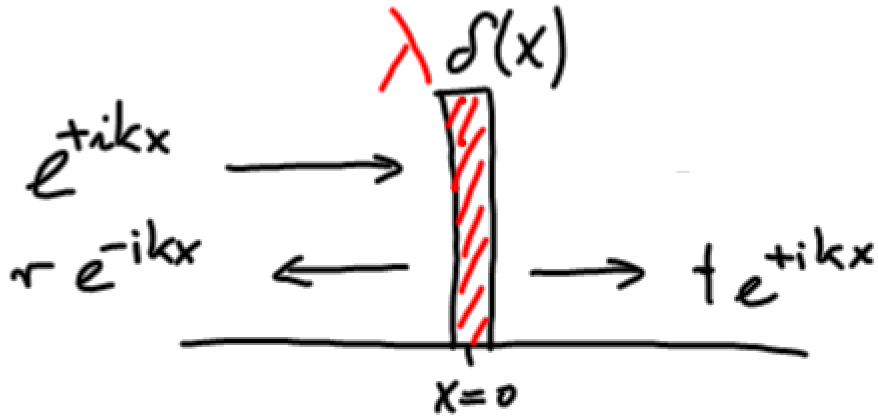


$$|t|^2+|r|^2=\frac{1}{1-\dfrac{\mathrm{Im}\,\lambda/k}{1+|\lambda/2k|^2}}$$



$$|t|^2+|r|^2=\frac{1}{1-\dfrac{\mathrm{Im}\,\lambda/k}{1+|\lambda/2k|^2}}$$

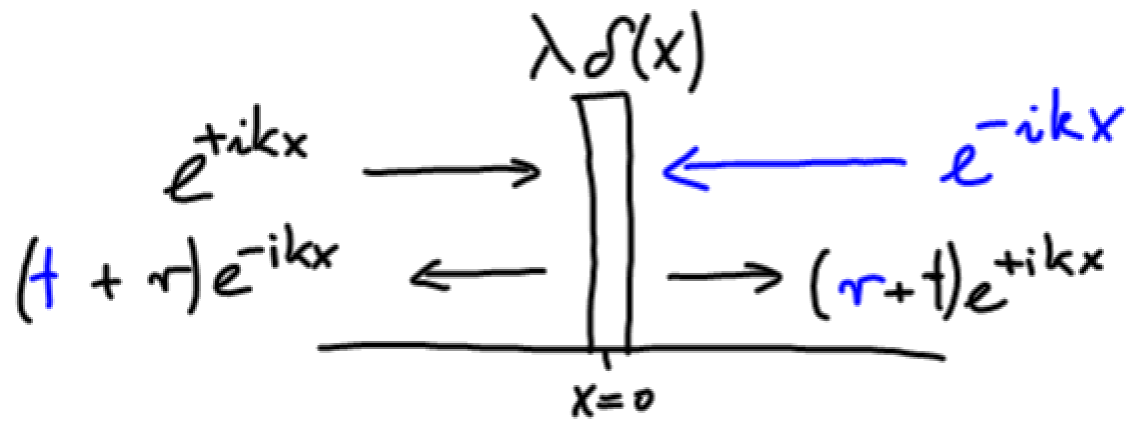
$\mathrm{Im}\,\lambda \lessgtr 0$: absorption (<) / gain (>)



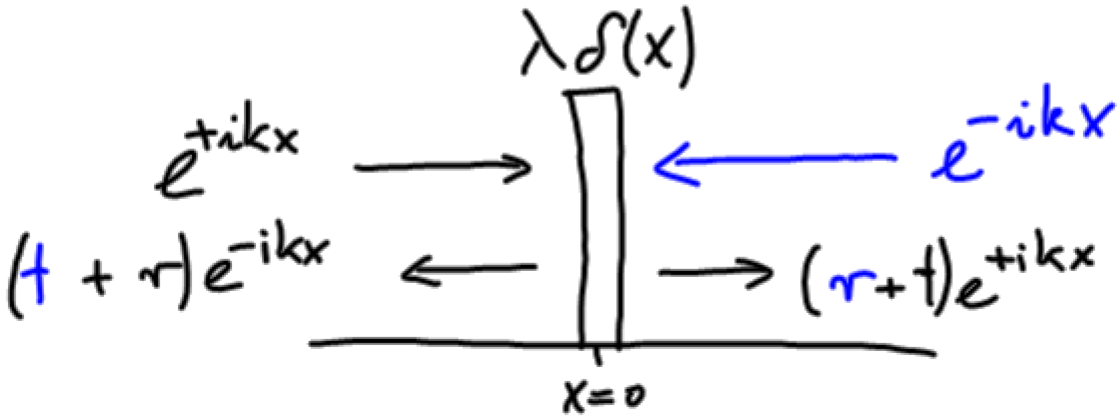
$$|t|^2 + |r|^2 = \frac{1}{1 - \frac{\mathrm{Im}\,\lambda / k}{1 + |\lambda/2k|^2}} \geq \frac{1}{2}$$

No perfect absorption!

$$\mathrm{Im}\,\lambda \lessgtr 0: \begin{matrix}\text{absorption}\\ \text{gain}\end{matrix}$$



$\lambda\delta(x)$
e^{+ikx}
e^{-ikx}
$(t + r)e^{-ikx}$
$(r + t)e^{+ikx}$
$x=0$

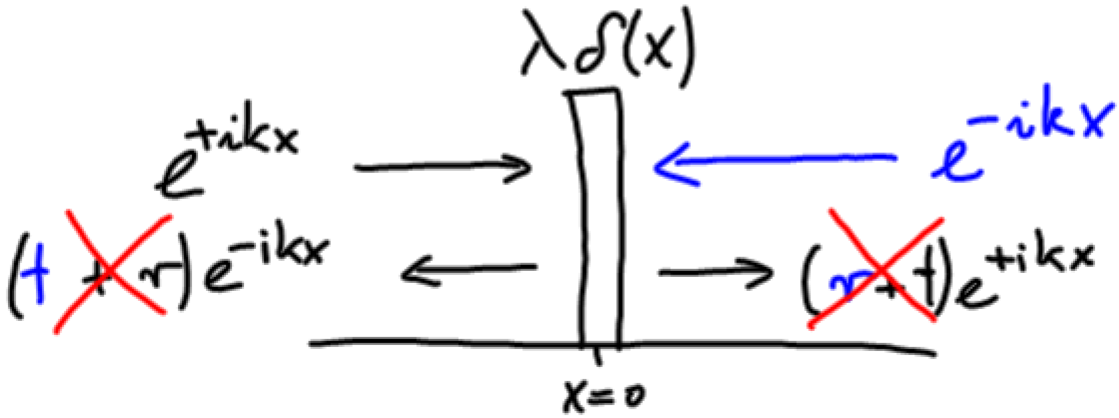


$$t = \frac{1}{1+i\lambda/2k}$$

$$r = t - 1$$

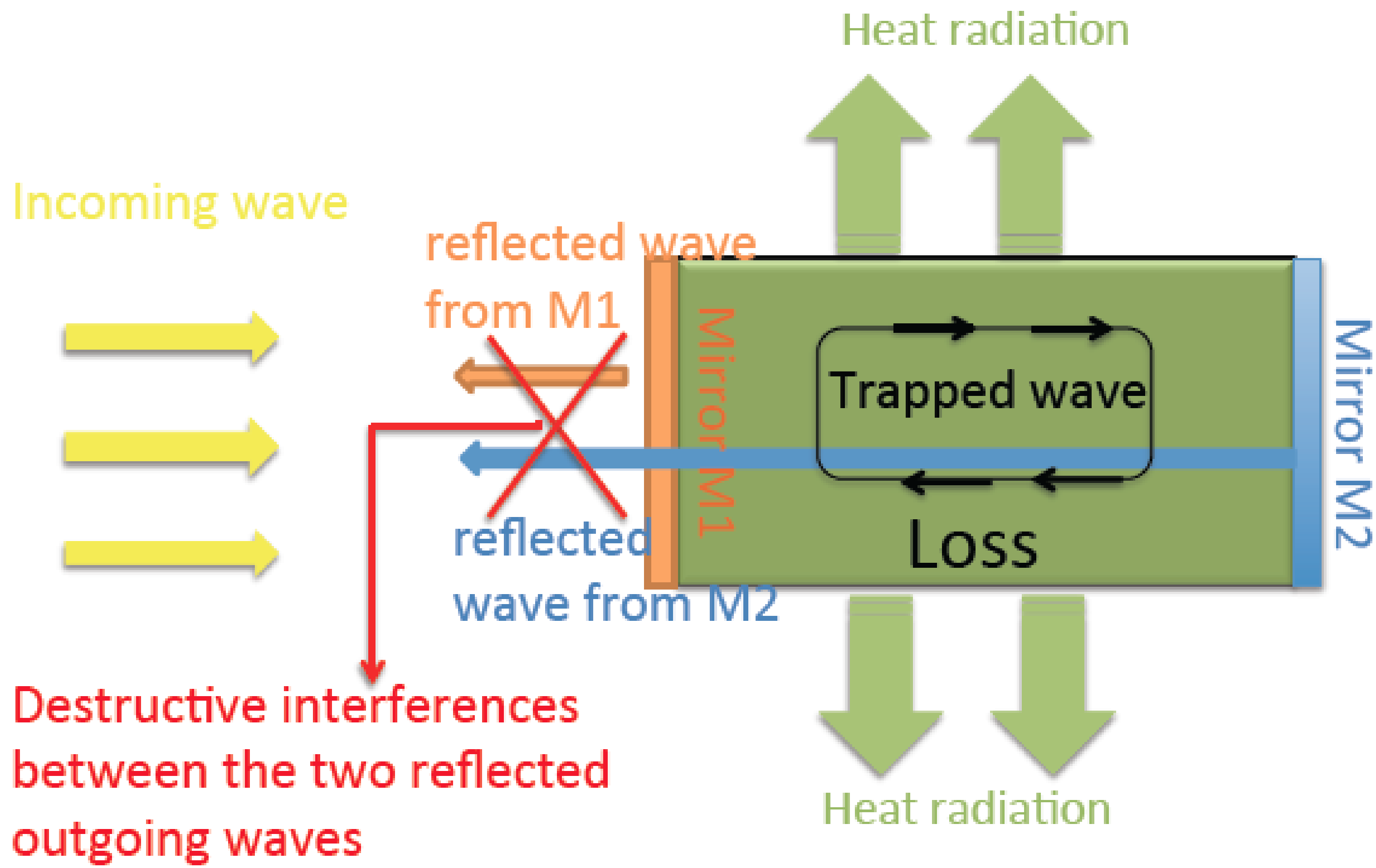
$$\lambda = -2ik \Rightarrow t = \frac{1}{2}$$

$$r + t = 0$$



$$\boxed{\lambda = -2ik}$$

Coherent perfect absorption (CPA).



Yale Group, Phys. Rev. Lett. 2010, 2011; Longhi Phys. Rev. A 2011

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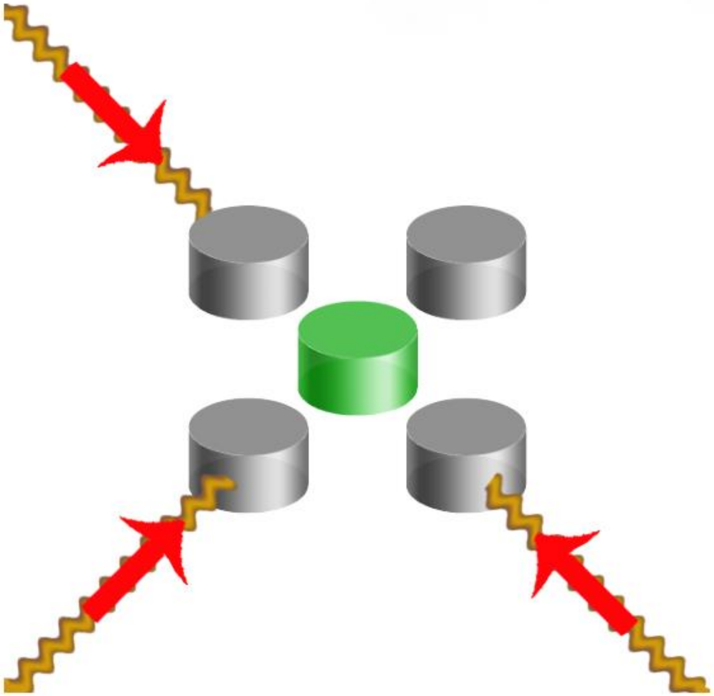
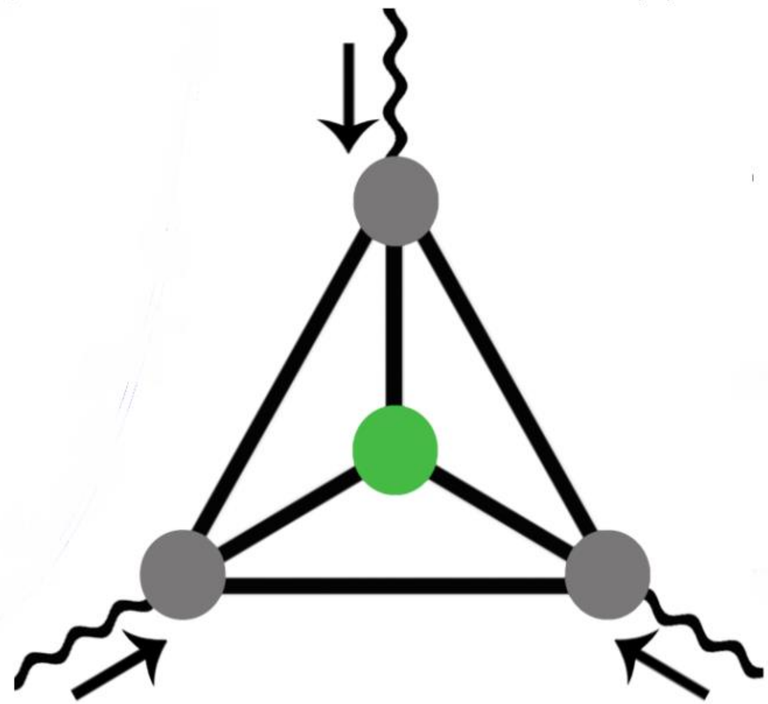
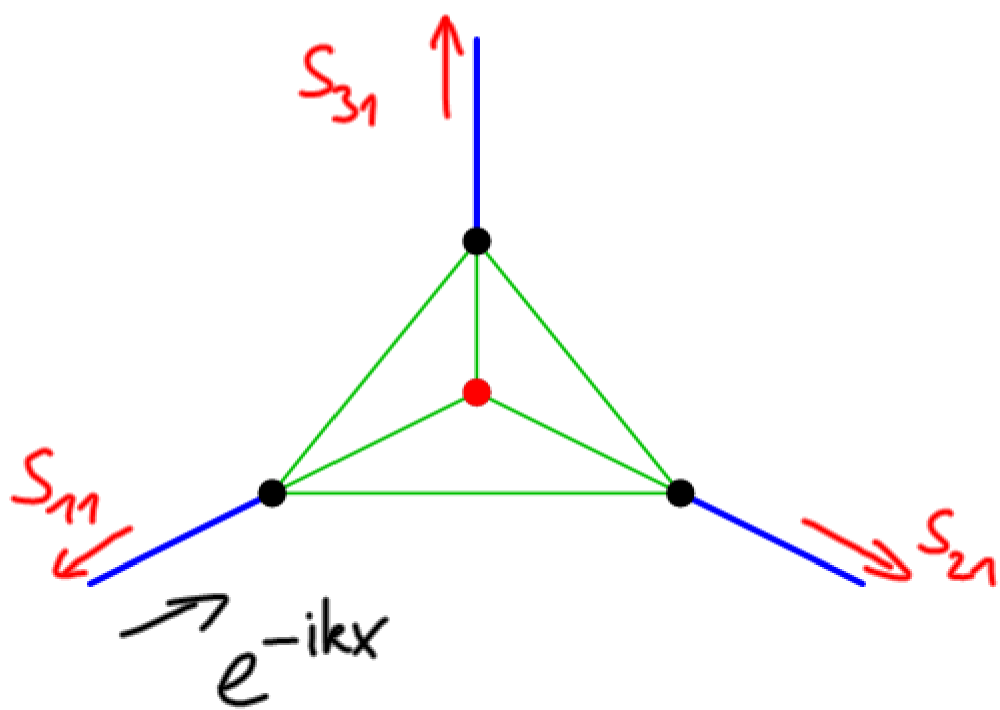
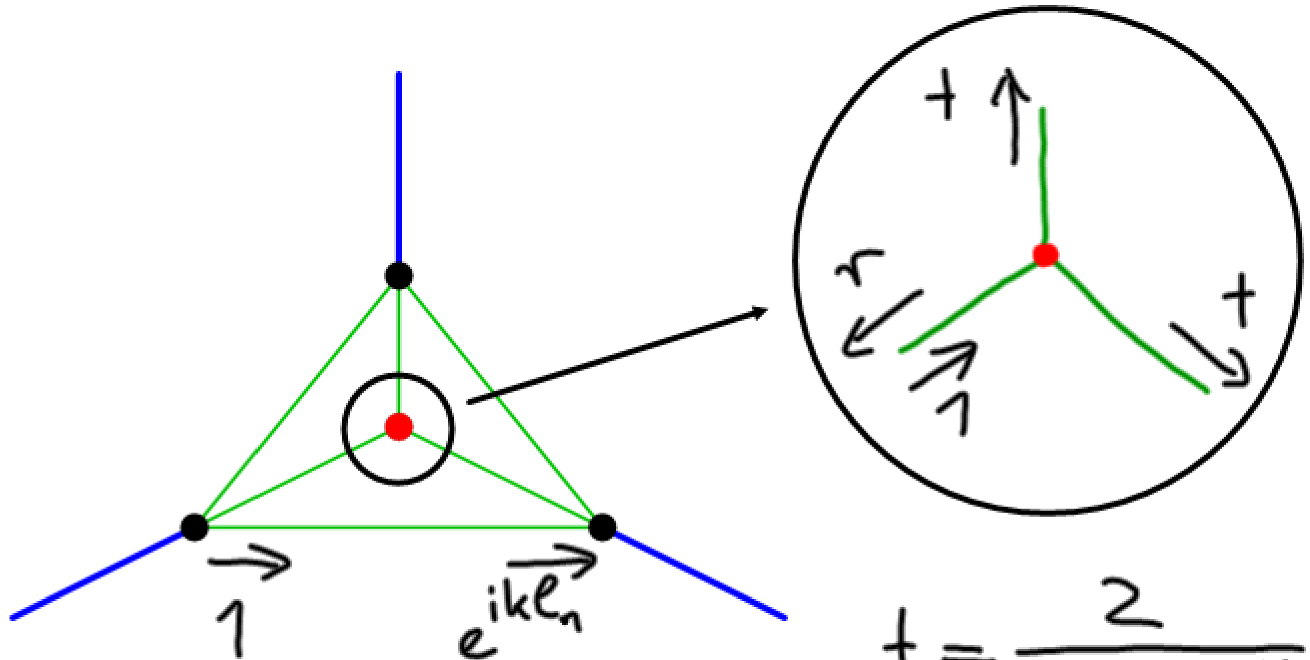




H. Li, S. Suwunnarat, R. Fleischmann, HS and T. Kottos. Phys. Rev. Lett. 118 (2017) 044101.



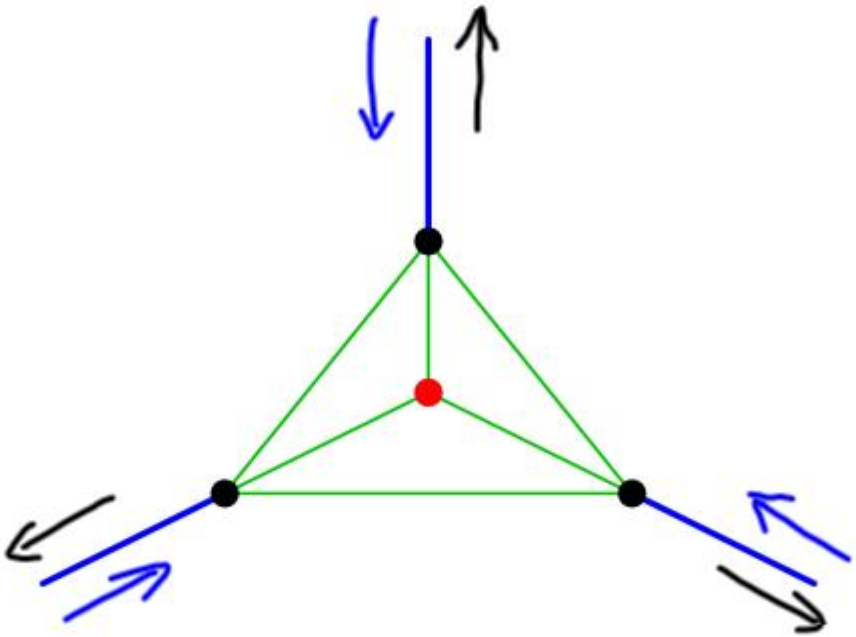
S_{31}
S_{11}
S_{21}
e^{-ikx}



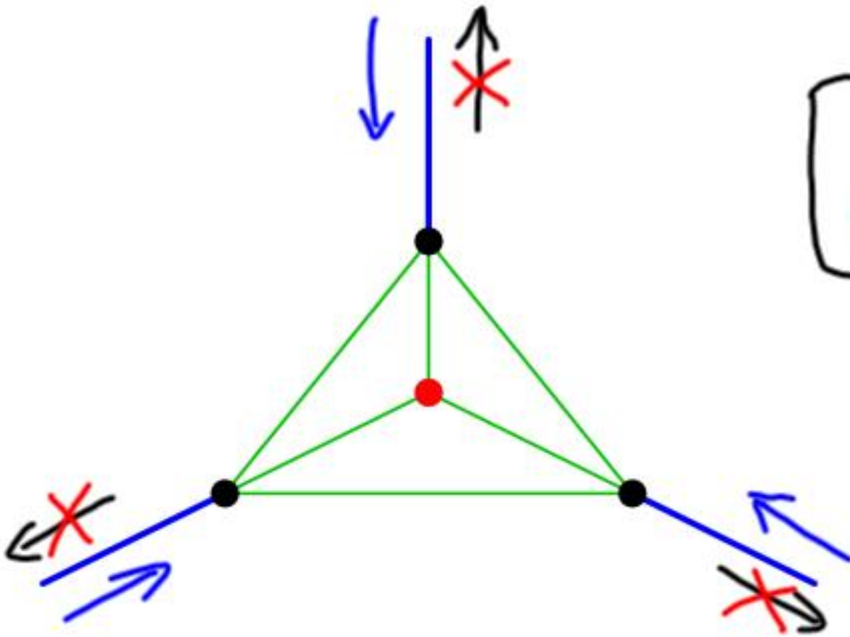
S_{BB}

$$t = \frac{2}{V + i\lambda/k}$$

$$r = t - 1$$



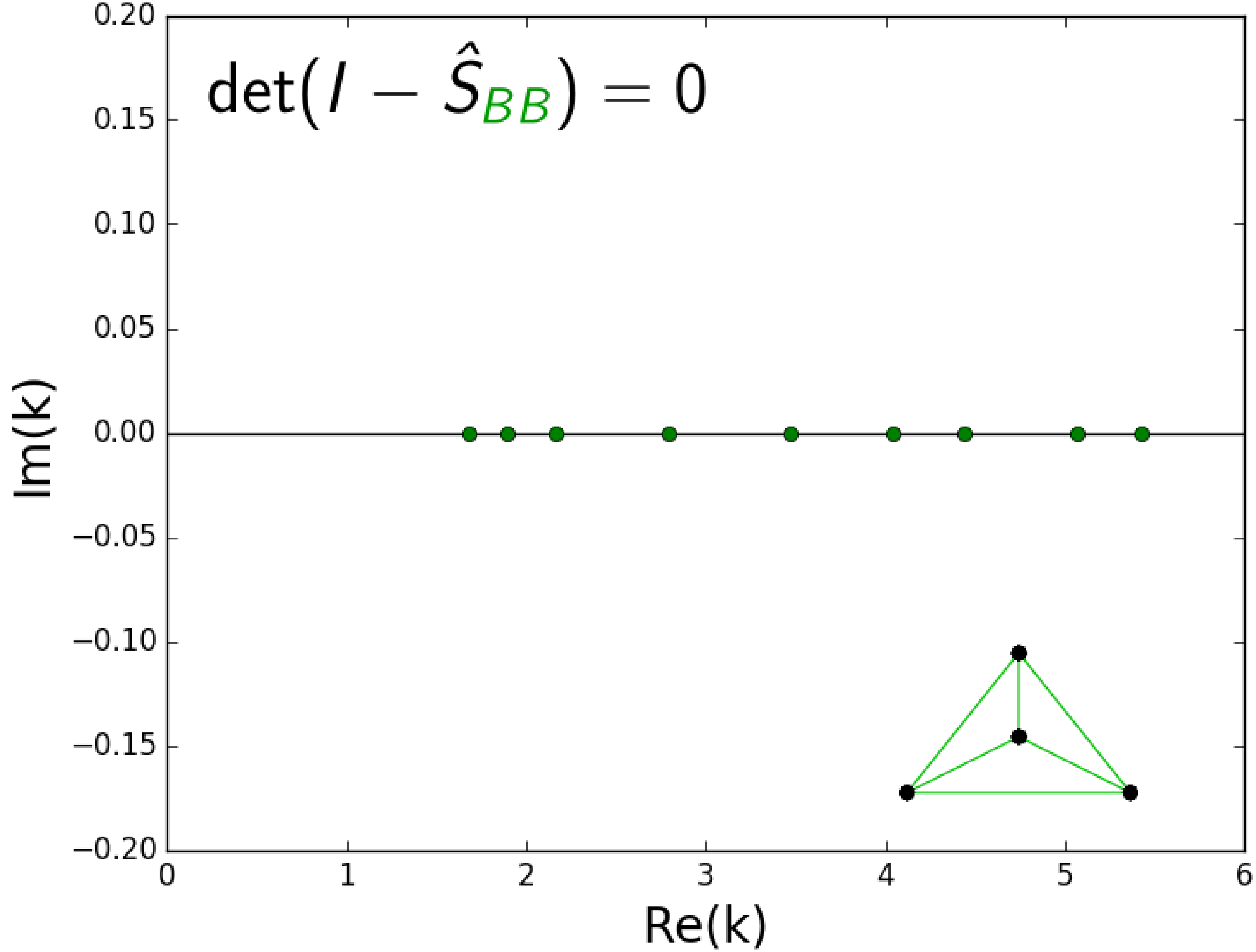
$$S = S_{LL} + S_{LB}\left(I - S_{BB}\right)^{-1} S_{BL}$$



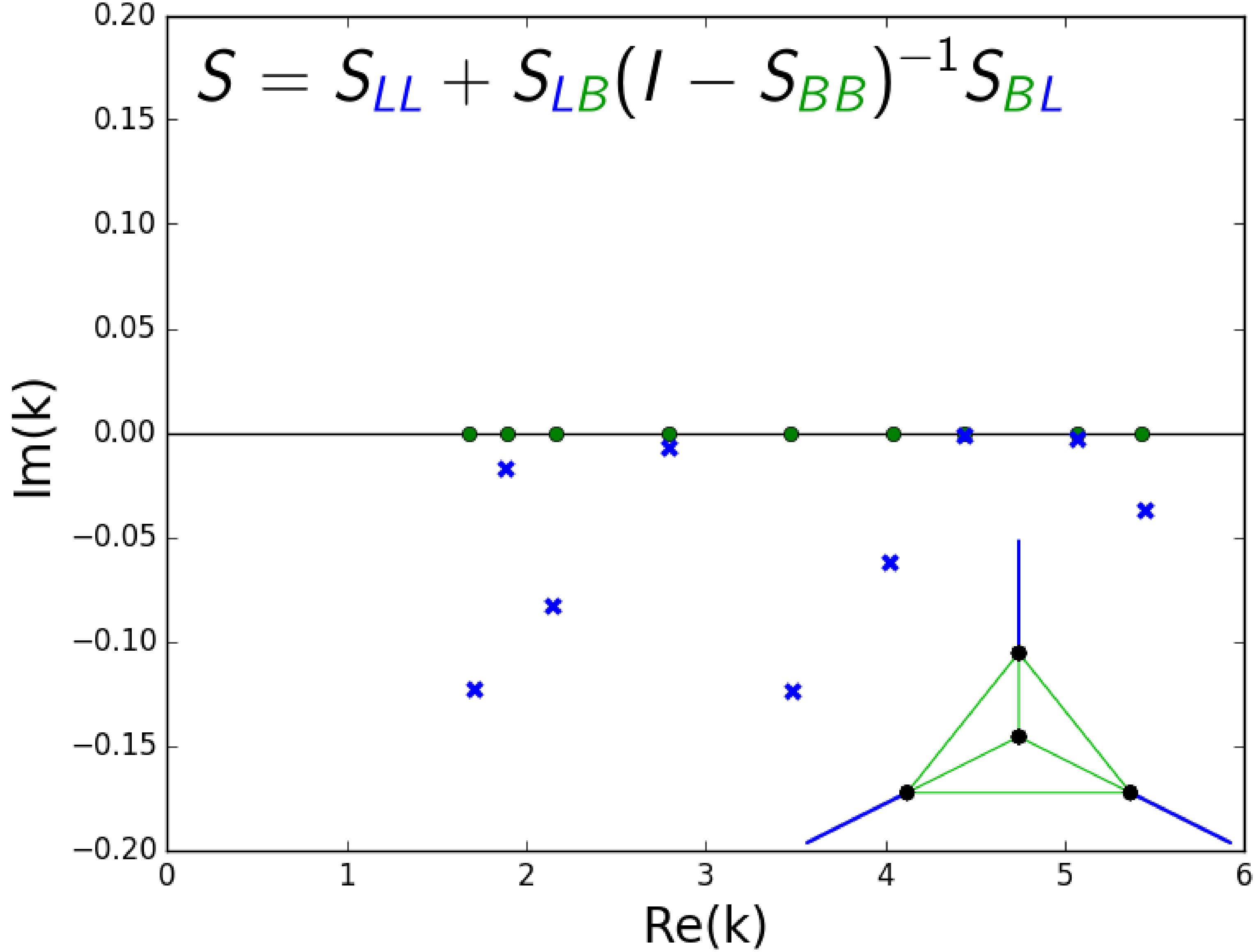
$$\det S = 0$$

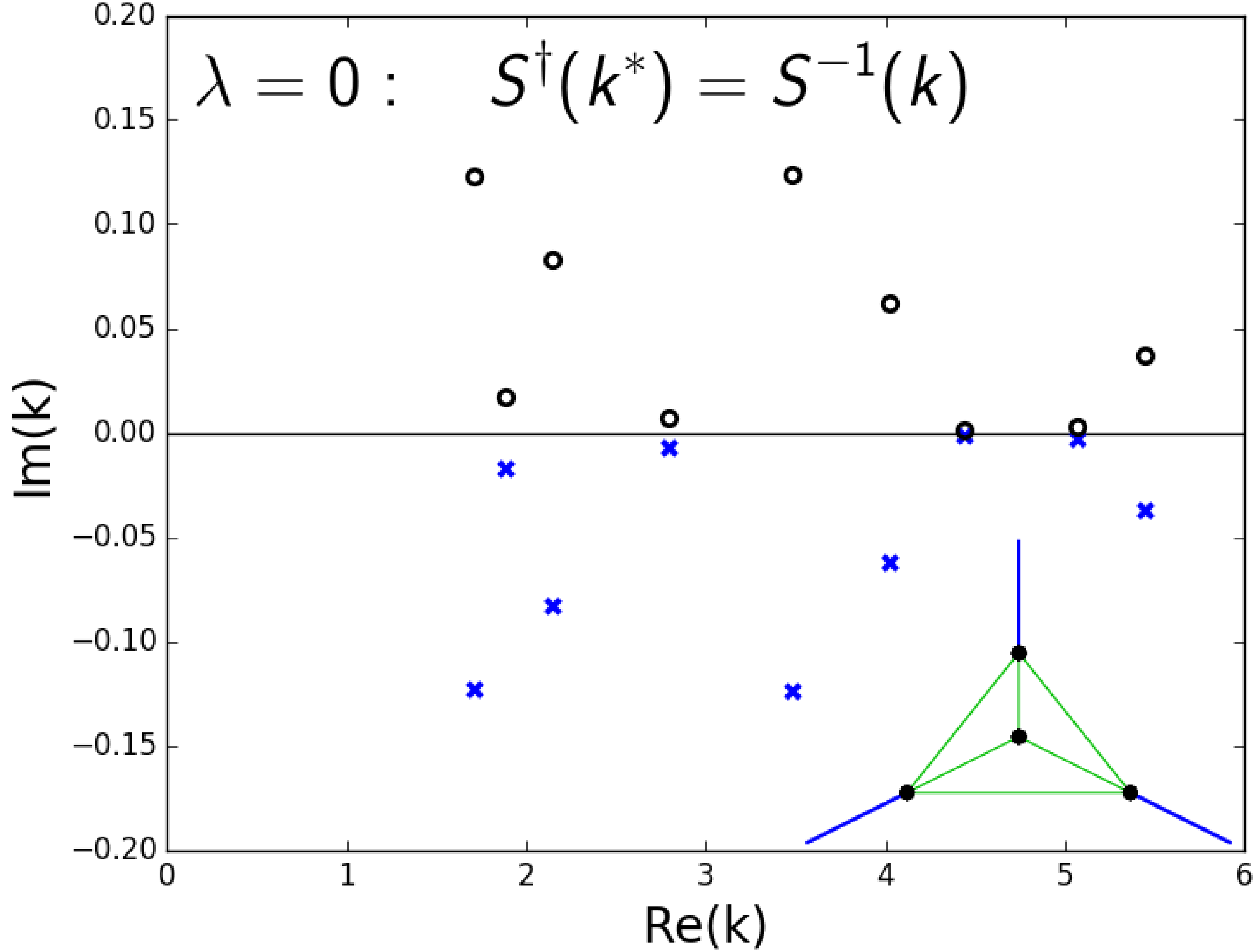
CPA

$$S = S_{LL} + S_{LB}\left(I - S_{BB}\right)^{-1} S_{BL}$$

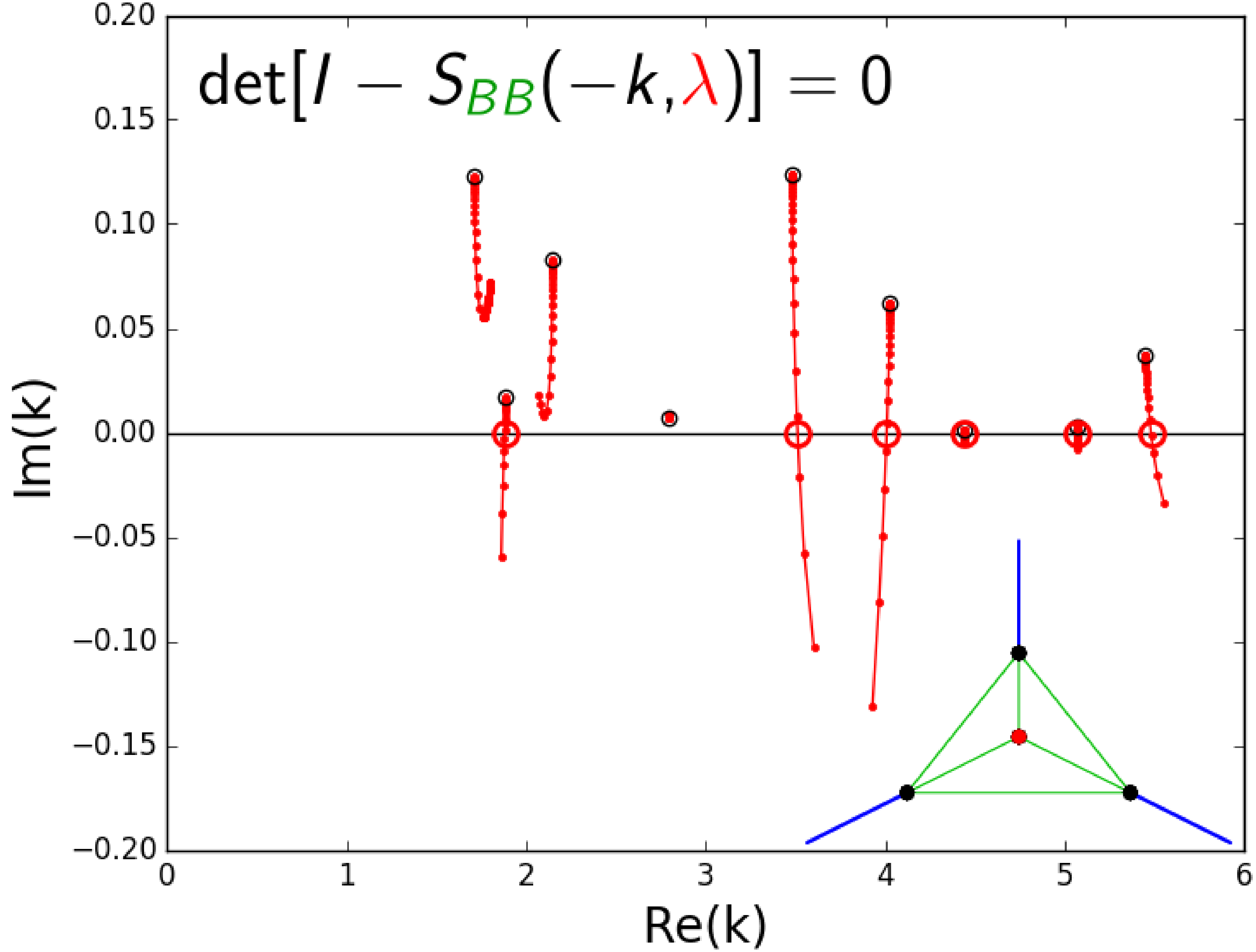


det(I − Ŝ_BB) = 0
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
Im(k)
0
1
2
3
4
5
6
Re(k)

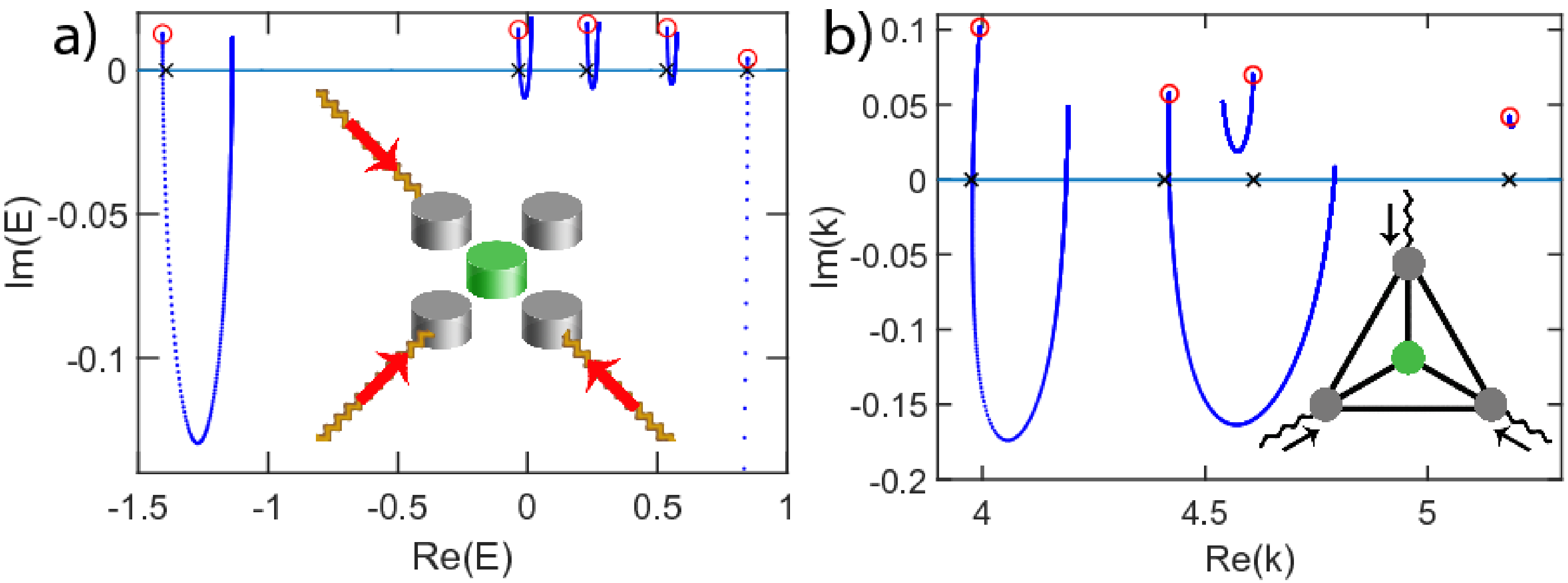

$S = S_{LL} + S_{LB}(I - S_{BB})^{-1}S_{BL}$
Im(k)
Re(k)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
1
2
3
4
5
6



$\lambda = 0: \quad S^\dagger(k^*) = S^{-1}(k)$
Im(k)
Re(k)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
1
2
3
4
5
6



$\det[I - S_{BB}(-k,\lambda)] = 0$
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
Im(k)
0
1
2
3
4
5
6
Re(k)


a)
0
-0.05
-0.1
Im(E)
-1.5
-1
-0.5
0
0.5
1
Re(E)
b)
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Im(k)
4
4.5
5
Re(k)

$$H = H_0 - i\Gamma \qquad \Gamma = \sum_\mu \gamma_\mu \left|e_\mu\right\rangle \left\langle e_\mu\right|$$

$$S\left(k,\gamma\right) = -\hat{I} + 2i\,\frac{\sin k}{t_L} W^T \frac{\hat{I}}{H_{\mathrm{eff}}(k,\gamma) - E\left(k\right)} W$$

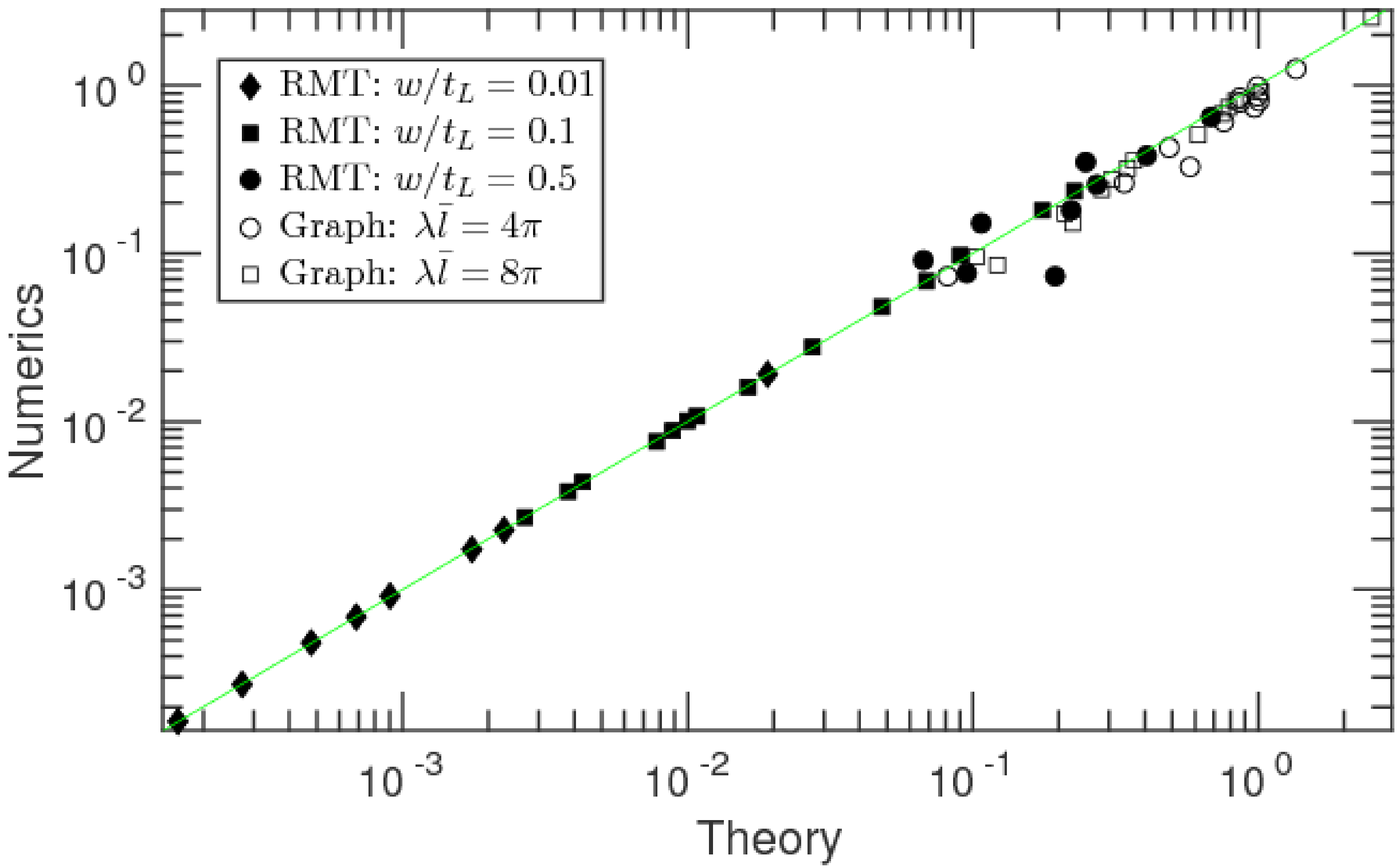
$$H_{\mathrm{eff}}\left(k,\gamma\right) = H(\gamma) + \frac{e^{ik}}{t_L} W W^T$$

$$E(k) = 2t_L \cos(k)$$

$$E_{w,\gamma} \approx E(k_0) + \Delta E_{w,\gamma}$$
$$\mathrm{Im}\Delta E_{w,\gamma} = 0$$

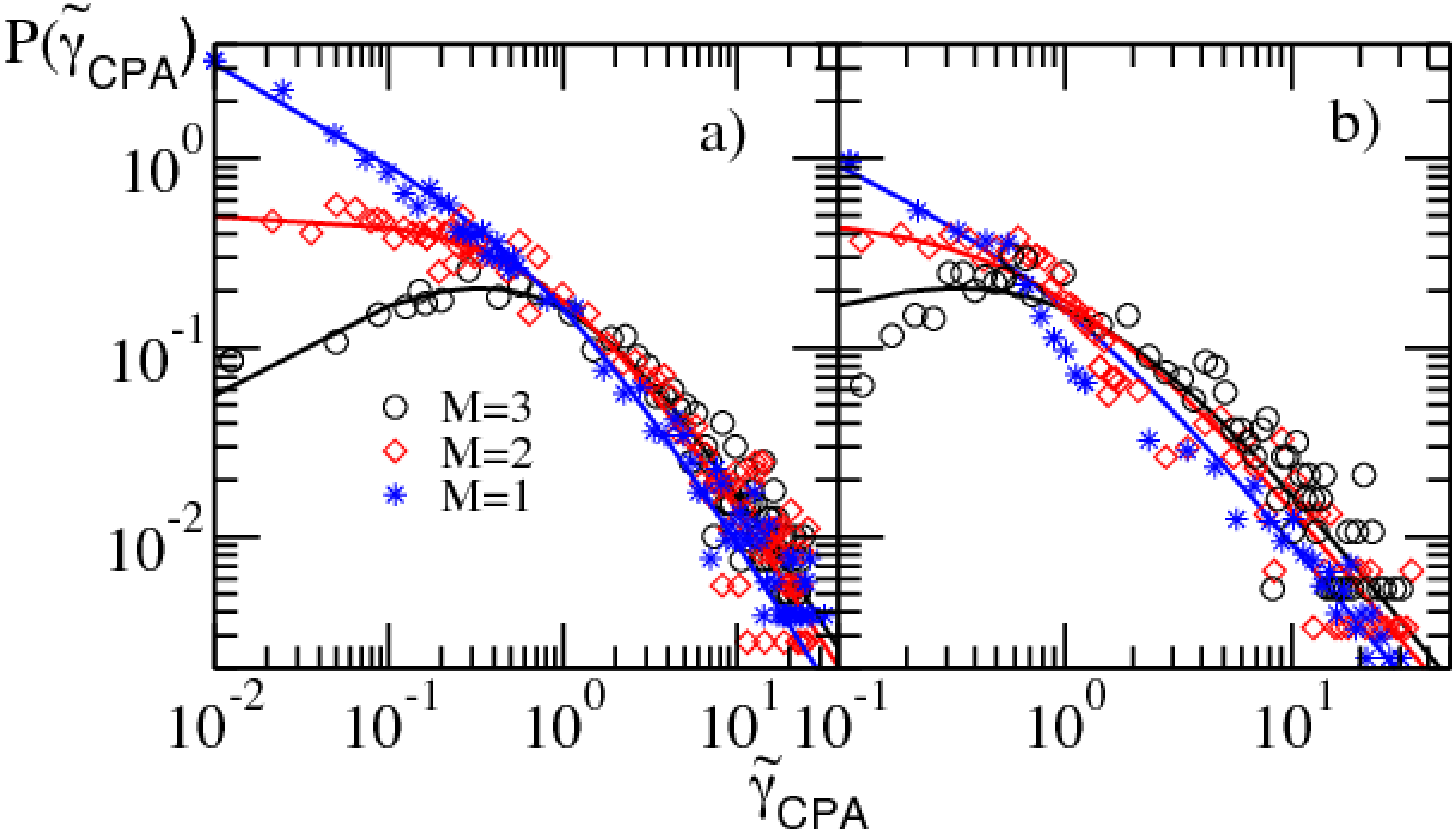
$$\Delta E = \frac{E(k_0)}{2}\left(\frac{w}{t_L}\right)^2 \sum_{\ell}\left|\Psi_{\ell}^{(0)}\right|^2$$
$$\gamma_{\mathrm{CPA}} = \frac{E'(k_0)}{2}\left(\frac{w}{t_L}\right)^2 \frac{\left|\Psi_{\ell}^{(0)}\right|^2}{\left|\Psi_{\alpha}^{(0)}\right|^2}$$

$$|a\rangle = W^T \frac{1}{H_{eff}^{\dagger} - E(k)} |e_{\alpha}\rangle$$



Numerics
Theory
10^0
10^-1
10^-2
10^-3
RMT: $w/t_L = 0.01$
RMT: $w/t_L = 0.1$
RMT: $w/t_L = 0.5$
Graph: $\lambda\bar{l} = 4\pi$
Graph: $\lambda\bar{l} = 8\pi$

$$\mathcal{P}_\beta(\tilde{\gamma}_{\mathsf{CPA}}) = \mathcal{N}_\beta \frac{\tilde{\gamma}_{\mathsf{CPA}}^{\beta\frac{M}{2}-1}}{(1+\tilde{\gamma}_{\mathsf{CPA}})^{\beta\frac{M+1}{2}}}$$



$$\alpha(k_{\mathrm{CPA}};\gamma) = \frac{4\gamma/\gamma_{CPA}}{(1+\gamma/\gamma_{CPA})^2}$$