Wave packet simulation for 2D Hermitian Goldman model

The 2D Hermitian Goldman model is given by

$$\hat{H} = J\sum_{mn}(\hat{c}^{\dagger}_{m,n+1}e^{i\phi\sigma_y}\hat{c}_{m,n} + \hat{c}^{\dagger}_{m,n}e^{-i\phi\sigma_y}\hat{c}_{m,n+1} + \hat{c}^{\dagger}_{m+1,n}e^{i\theta\sigma_x}\hat{c}_{m,n} + \hat{c}^{\dagger}_{m,n}e^{-i\theta\sigma_x}\hat{c}_{m+1,n}) \tag{1}$$

The Hamiltonian in real space is given by

$$\hat{H} = \begin{pmatrix} U & T^{\dagger} & 0 & 0 & 0 & \cdots & 0 & 0 \\ T & U & T^{\dagger} & 0 & 0 & \cdots & 0 & 0 \\ 0 & T & U & T^{\dagger} & 0 & \cdots & 0 & 0 \\ 0 & 0 & T & U & T^{\dagger} & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \cdots & U & T^{\dagger} \\ 0 & 0 & 0 & 0 & 0 & \cdots & T & U \end{pmatrix} \tag{2}$$

where

$$U = \sum_{i=1}^{L_x-1}\left(|i\rangle\langle i+1| \otimes e^{-i\theta\sigma_x} + |i+1\rangle\langle i| \otimes e^{i\theta\sigma_x}\right) \tag{3}$$

and

$$T = e^{-i\phi\sigma_y} \oplus e^{-i\phi\sigma_y} \oplus \cdots \oplus e^{-i\phi\sigma_y}\,. \tag{4}$$

and

$$T^{\dagger} = e^{i\phi\sigma_y} \oplus e^{i\phi\sigma_y} \oplus \cdots \oplus e^{i\phi\sigma_y} \tag{5}$$

Therefore, the Hamiltonian corresponds to the x-direction hopping is defined by H_x,

$$H_x = U \otimes I = \bigoplus_{j=1}^{L_y-1} U\,, \tag{6}$$

where I is a 20×20 identity matrix. Also define the Hamiltonian that corresponds to the y-direction hopping as H_y

$$H_y = \sum_{j=1}^{L_y-1}\left(|j\rangle\langle j+1| \otimes T + |j+1\rangle\langle j| \otimes T^{\dagger}\right) \tag{7}$$

The full Hamiltonian is hence given by

$$H = H_x + H_y \tag{8}$$

Explicitly

$$
\begin{aligned}
H = & \bigoplus_{j=1}^{L_y-1} \sum_{i=1}^{L_x-1} \left(|i\rangle\langle i+1| \otimes e^{-i\theta\sigma_x} + |i+1\rangle\langle i| \otimes e^{i\theta\sigma_x} \right) \\
& + \sum_{j=1}^{L_y-1} \bigoplus_{i=1}^{L_x-1} \left(|j\rangle\langle j+1| \otimes e^{-i\phi\sigma_y} + |j+1\rangle\langle j| \otimes e^{i\phi\sigma_y} \right)
\end{aligned}
\tag{9}
$$

where the first line corresponds to H_x and the second line corresponds to H_y