A Willful Kick

Photoinduced Charge Order Enhancement

Hantao Lu

Yukawa Institute for Theoretical Physics, Kyoto University

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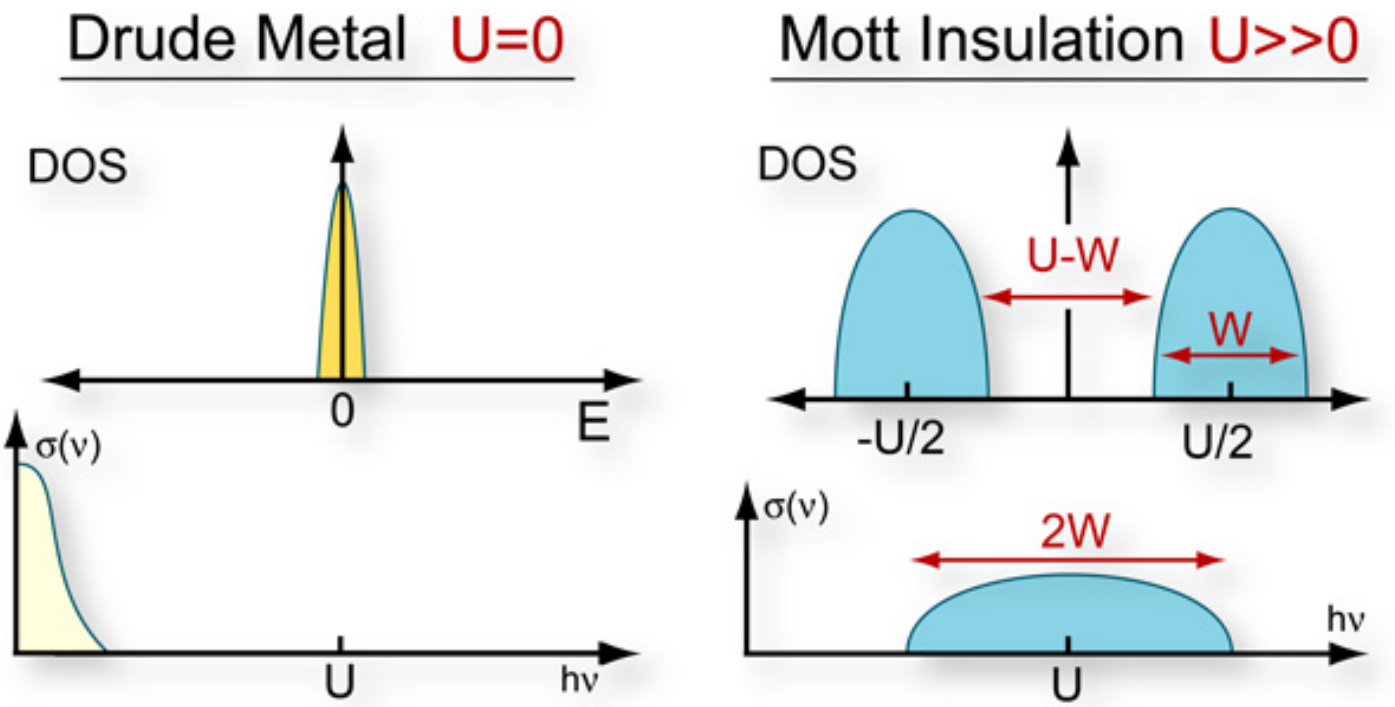
Hubbard Model and Mott Insulators

$$H_{\text{Hubbard}} = -t_h \sum_{<ij>,\sigma} \left(c^{\dagger}_{i,\sigma} c_{j,\sigma} + \text{H.c.} \right) + U \sum_i n_{i,\uparrow} n_{i,\downarrow}$$



Photoexcitation and Nonequilibrium Process

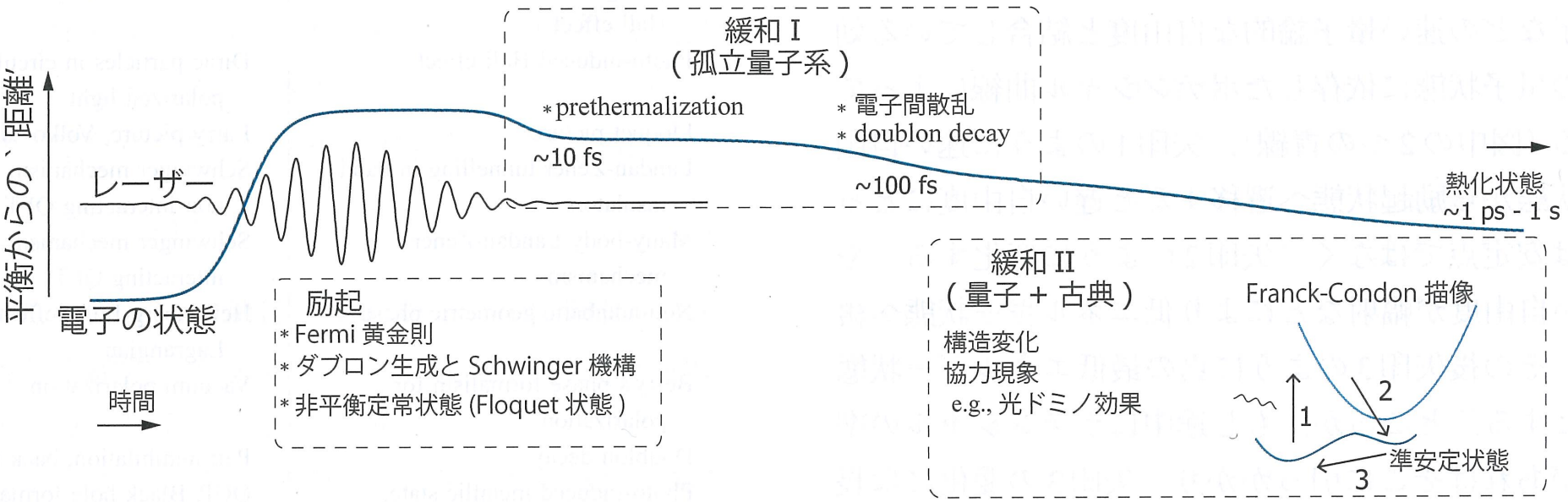
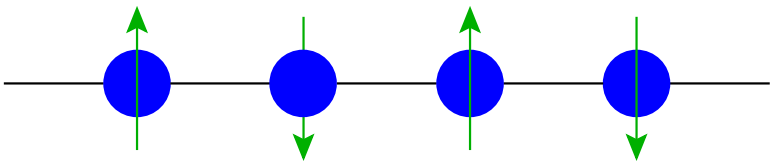
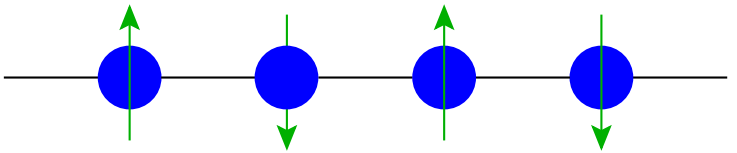


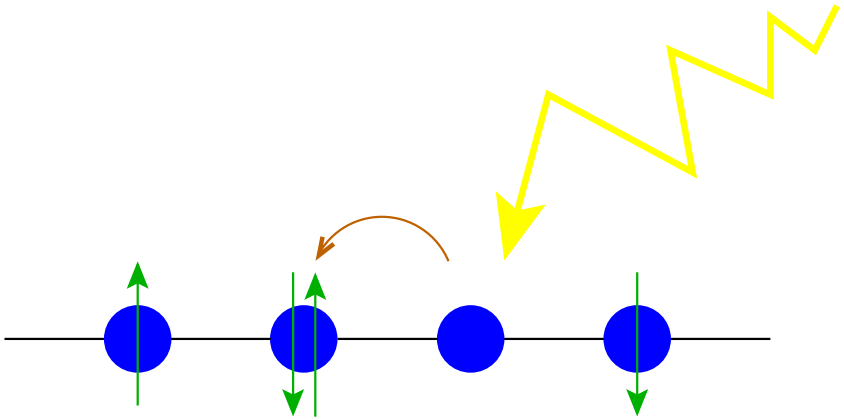
図2　ポンプ・プローブ実験における光誘起相転移と様々な物理的過程.　∗印はハバード模型のモット絶縁体相に関連深いもの.

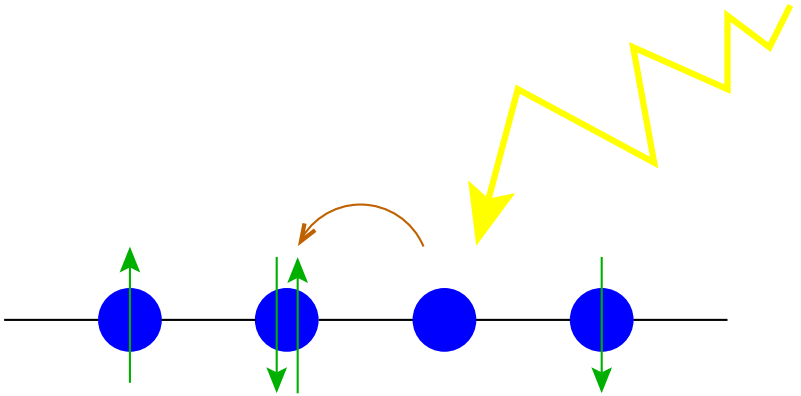
Figure: Source: T. Oka and H. Aoki, Butsuri **67** (4), 234 (2012).

Around Femtoseconds



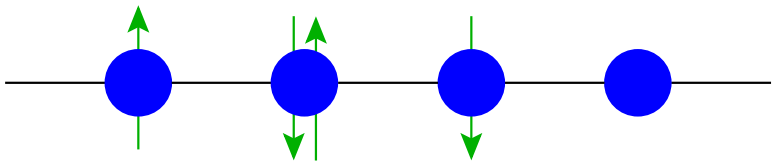


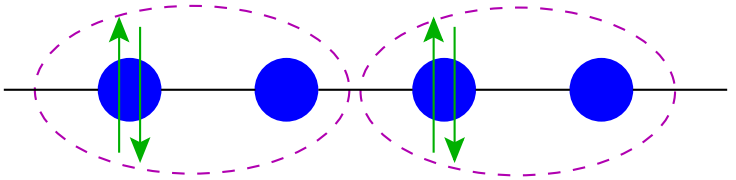




metallic state

bound state: exciton





Extended Hubbard Model

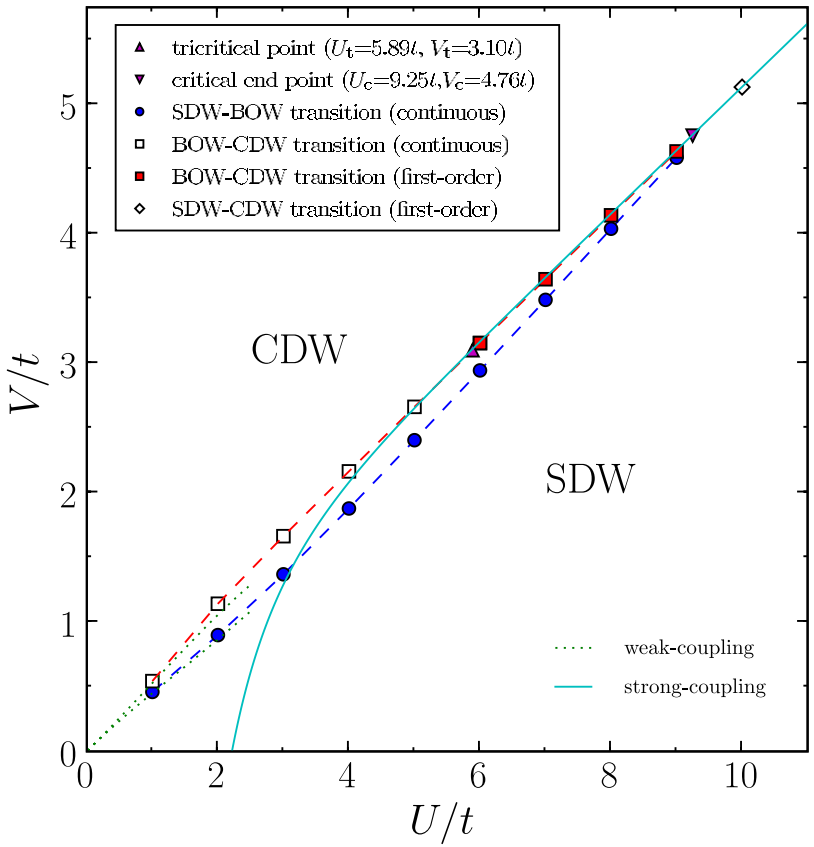


Figure: Phase diagram of the 1D half-filled EHM. Source: S. Ejima and S. Nishimoto, *Phys. Rev. Lett.* **99**, 216403 (2007).

$$
\begin{aligned}
H_{\mathrm{EHM}} &= -t_h \sum_{i,\sigma} \left(c^{\dagger}_{i,\sigma} c_{i+1,\sigma} + \mathrm{H.c.} \right) \\
&+ U \sum_{i} \left(n_{i,\uparrow} - \frac{1}{2} \right) \left(n_{i,\downarrow} - \frac{1}{2} \right) \\
&+ V \sum_{i} \left(n_i - 1 \right) \left(n_{i+1} - 1 \right)
\end{aligned}
$$

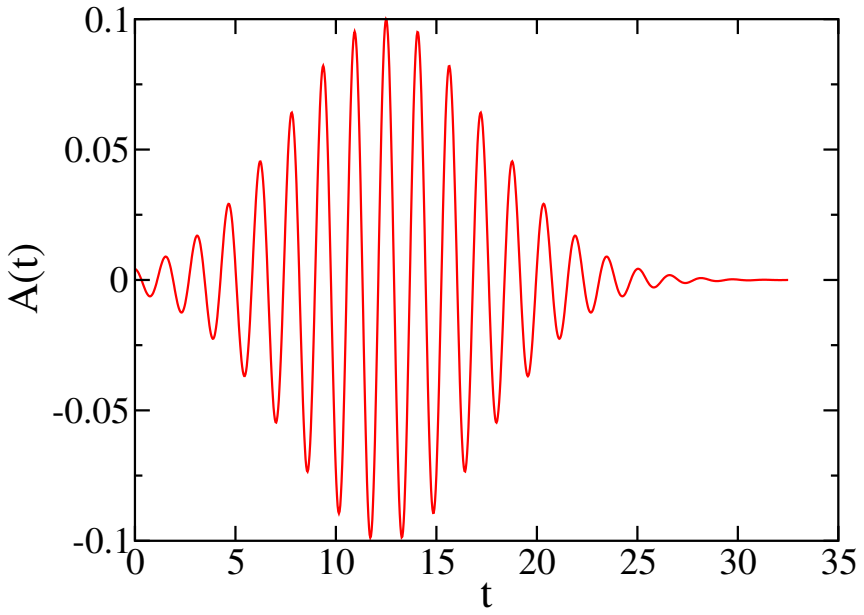
First order phase transition in equilibrium happens around $U \approx 2V$ between spin-density-wave (SDW) and charge-density-wave (CDW), driven by the competition between energy cost for doublon generation and energy reward due to the attraction between doublon-holon pairs.

Laser Added

In the 1D extended Hubbard model with laser pulse applied, the external field is incorporated by means of the Peierls substitution:

$$c^{\dagger}_{i,\sigma} c_{i+1,\sigma} + \text{H.c.} \quad \rightarrow \quad e^{iA(t)} c^{\dagger}_{i,\sigma} c_{i+1,\sigma} + \text{H.c.}$$

$$A(t) = A_0 e^{-(t-t_0)^2/2t_d^2} \cos\left[\omega_{\text{pump}}\left(t - t_0\right)\right],$$

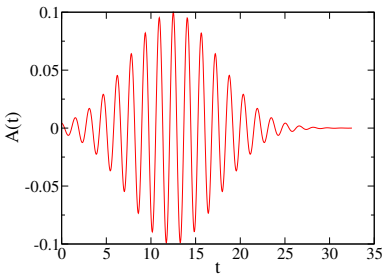


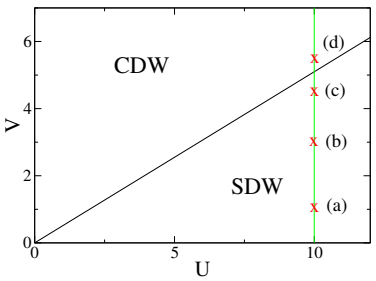
An illustration of the vector potential $A(t)$ with parameters as:

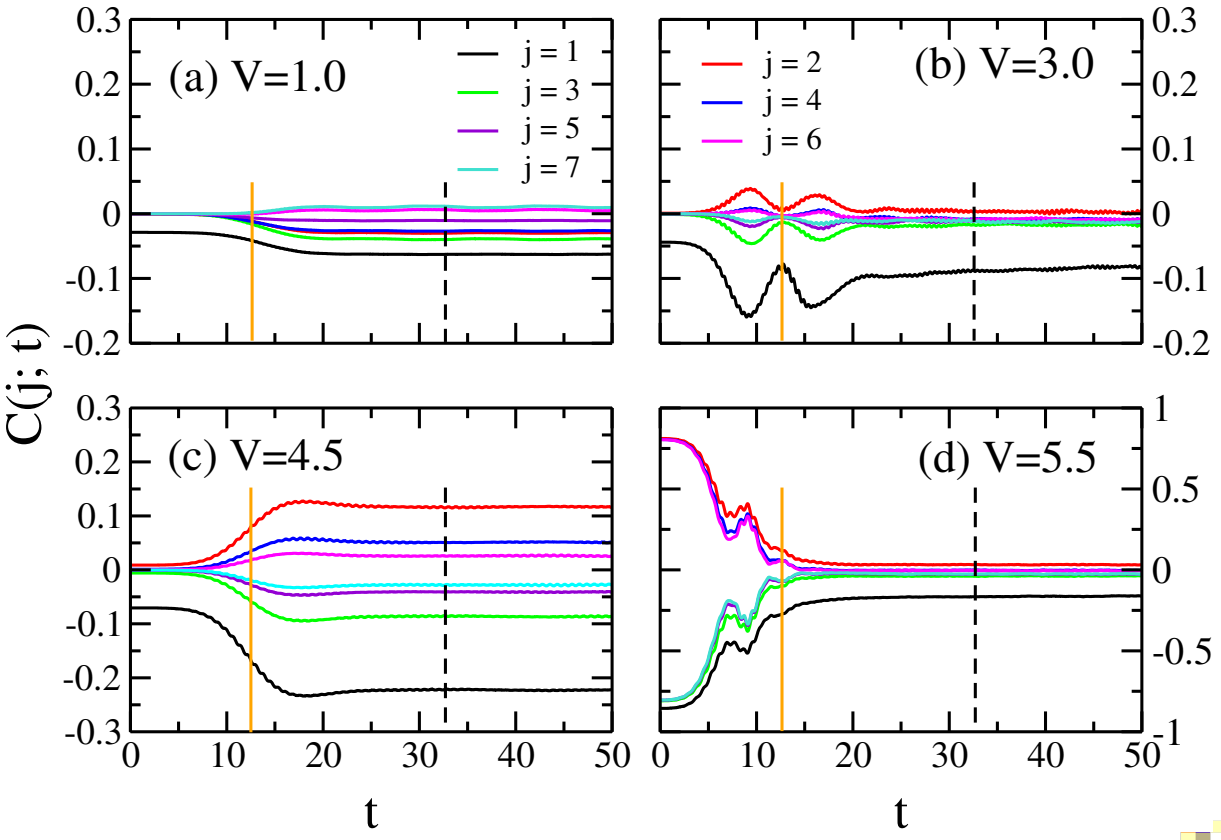
$$A_0 = 0.10, \quad \omega_{\text{pump}} = 4,$$
$$t_0 = 12.5, \quad t_d = 5$$

Charge-Charge Correlations (14 sites)

$$C(j;t) = \frac{1}{L}\sum_{i=0}^{L-1}\langle\psi(t)|(n_{i+j}-1)(n_i-1)|\psi(t)\rangle$$

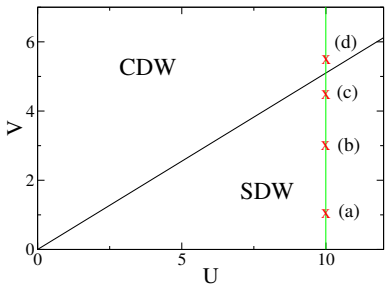




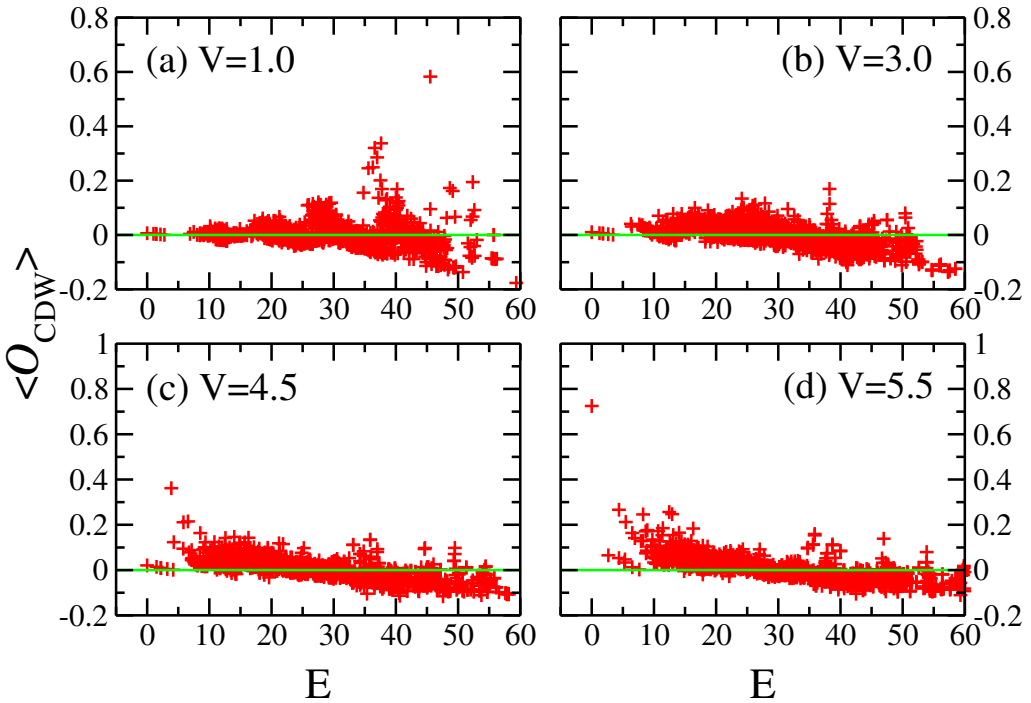


HTL, S. Sota, H. Matsueda, Janez Bonča, and T. Tohyama, arXiv:1204.1107

CDW Order Parameter (10 sites)

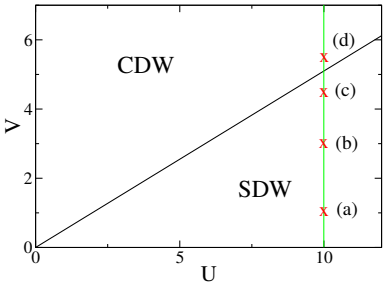


$$\mathcal{O}_{\mathrm{CDW}} := \frac{1}{L(L-1)} \sum_{i=0}^{L-1} \sum_{j \neq 0} (-1)^j \left(n_{i+j} - 1\right)\left(n_i - 1\right)$$



CDW order parameters of eigenstates

CDW Order Parameter (10 sites)



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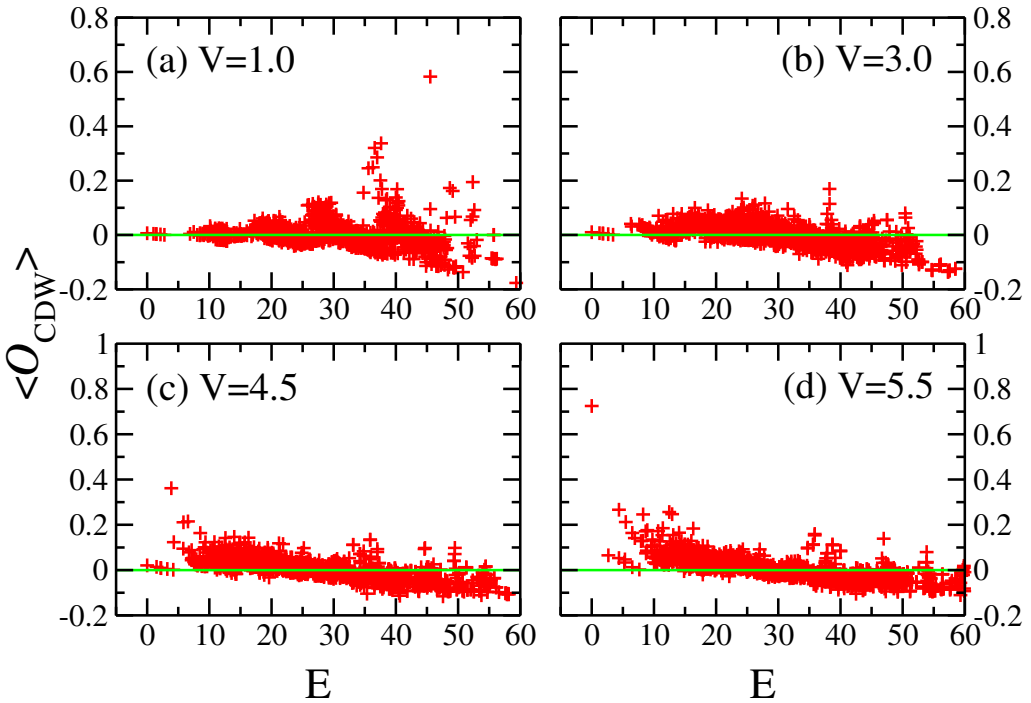
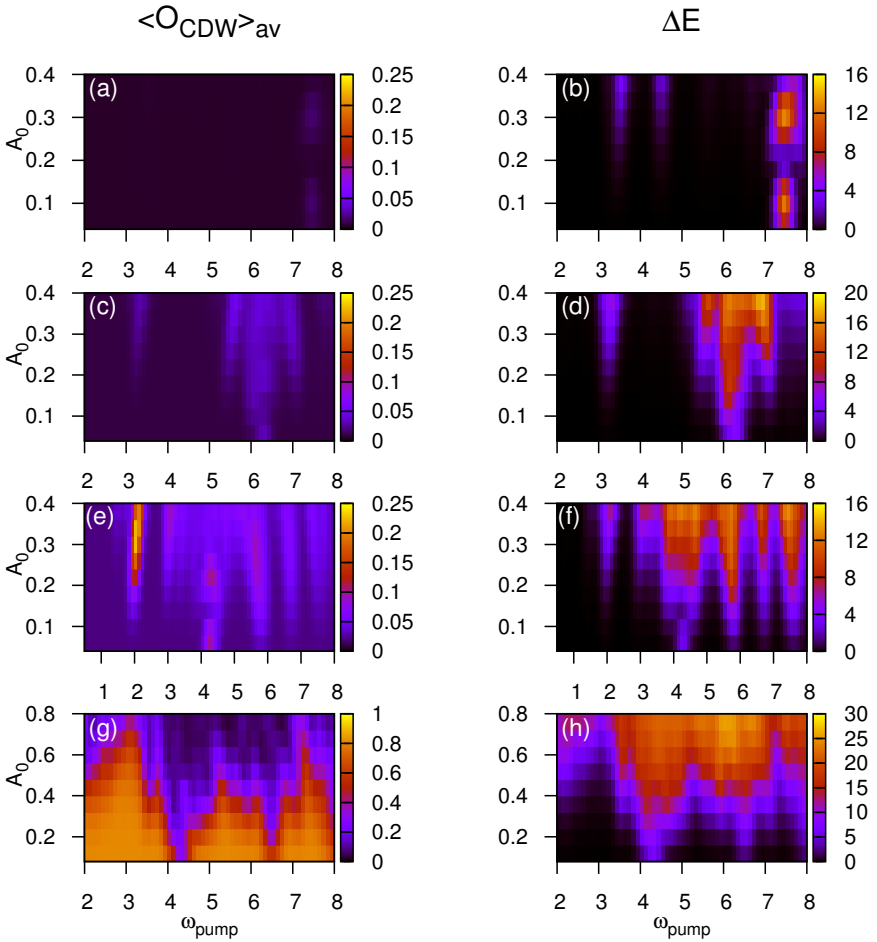


CDW order parameters of eigenstates

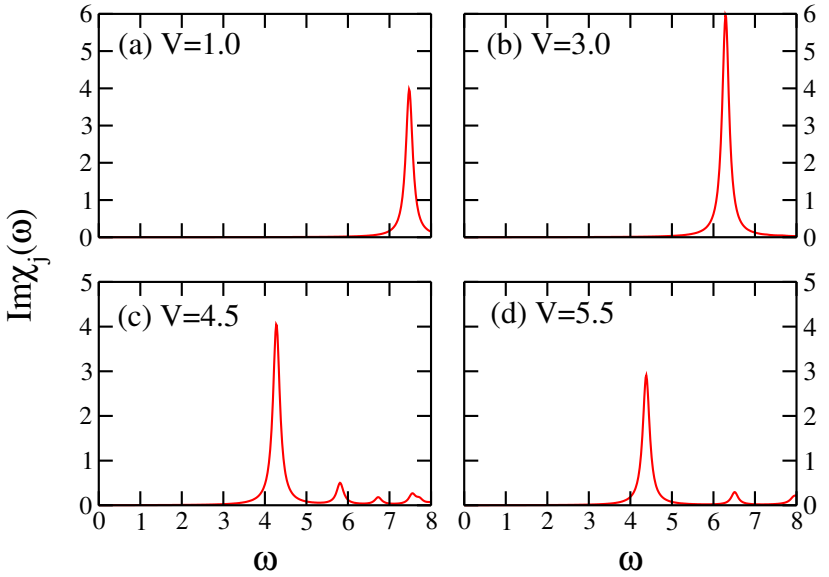
Observations

With increase of V, the states with prominent CDW order move to lower energy regime.

Parameter Sweeping (10 sites)



(I) CDW order *vs.* A_0 & ω_{pump} at $V = 1.0$, 3.0, 4.5 and 5.5.



(II) Optical spectra, obtained from the imaginary part of the dynamical current-current correlation functions.