SUPPLEMENTAL MATERIALS

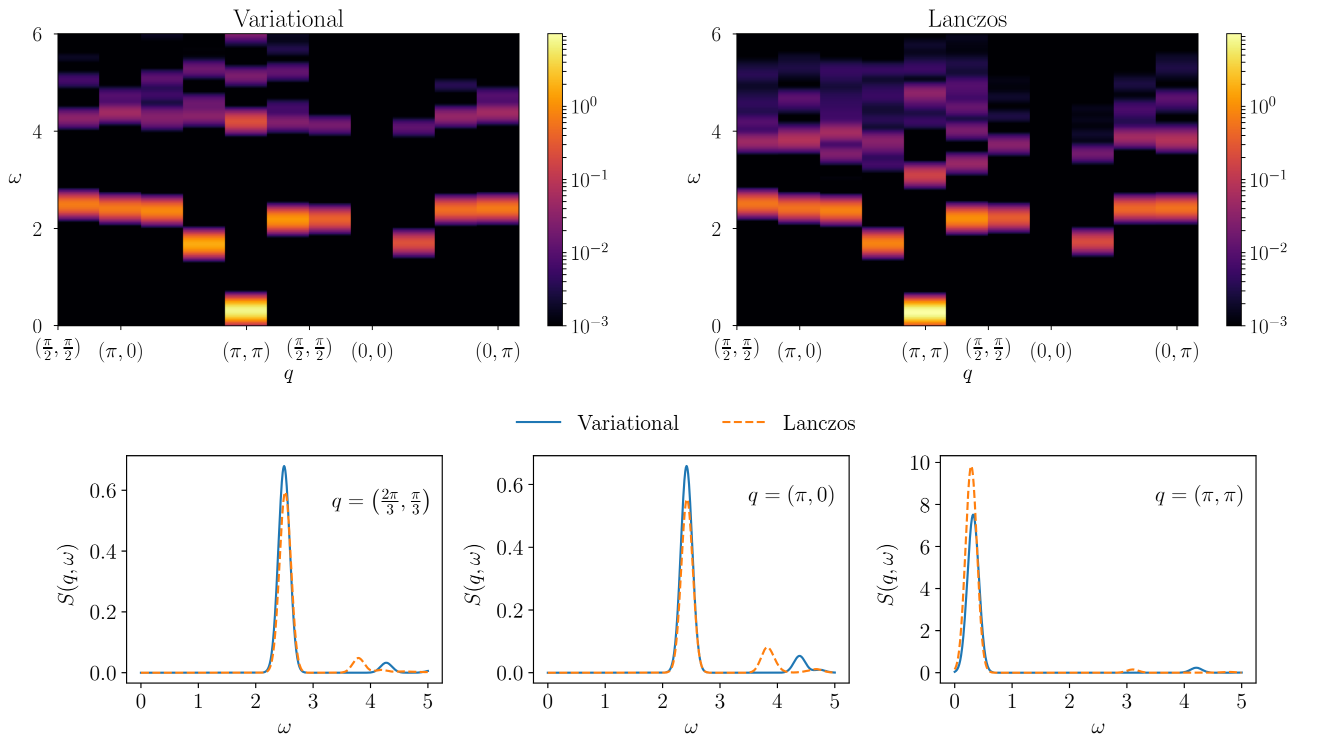

Figure 1: Dynamical spin structure factor of the unfrustrated Heisenberg model on the 6×6 square lattice. The results obtained with the variational approach are compared to the exact ones obtained by Lanczos diagonalization. The variational spectrum reported here corresponds to the transverse component of the dynamical structure factor, since the variational wave function explicitly breaks the $SU(2)$ symmetry of the Heisenberg model (due to the presence of a finite antiferromagnetic parameter $\Delta_{\rm AF}$). On the other hand, the spectrum obtained through Lanczos diagonalization is symmetric under $SU(2)$ rotations, since no spontaneous symmetry breaking is possible on finite clusters. **Upper panels:** Color maps of the dynamical structure factor along a given path in the Brillouin zone. **Lower panels:** Dynamical structure factor for three selected momenta.

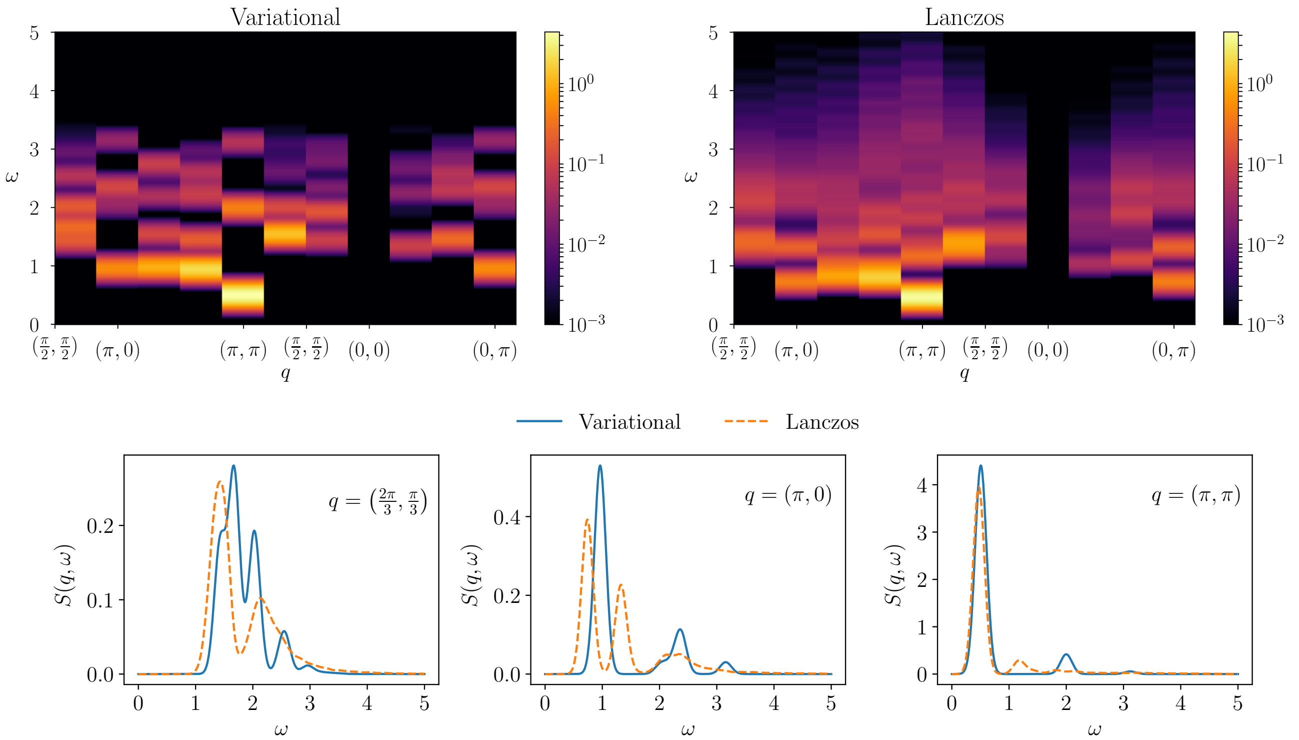

Figure 2: Dynamical spin structure factor of the $J_1 - J_2$ Heisenberg model with $J_2/J_1 = 0.5$ on the 6×6 square lattice. The results obtained with the variational approach are compared to the exact ones obtained by Lanczos diagonalization. **Upper panels:** Color maps of the dynamical structure factor along a given path in the Brillouin zone. **Lower panels:** Dynamical structure factor for three selected momenta.

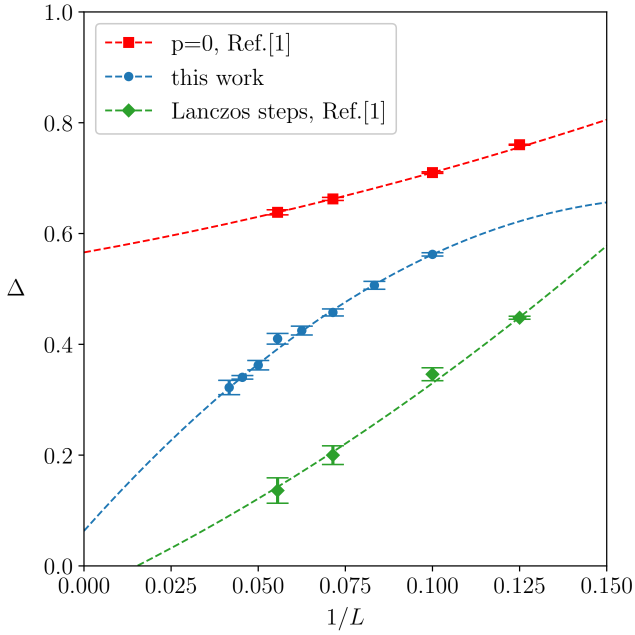

Figure 3: Finite-size scaling of the variational gap (Δ) at $q = (\pi, 0)$ within the spin-liquid phase ($J_2/J_1 = 0.55$). The results of Ref. [1] are also reported for comparison. For the latter ones, the lowest-energy excitation with momentum $(\pi, 0)$ is approximated by a single Gutzwiller-projected particle-hole excitation. The method employed in the present work makes use of a larger basis of excitations and, therefore, yields an improved finite-size scaling of the gap. The results obtained by a variance extrapolation with the Lanczos step procedure of Ref. [1] is also reported for completeness.

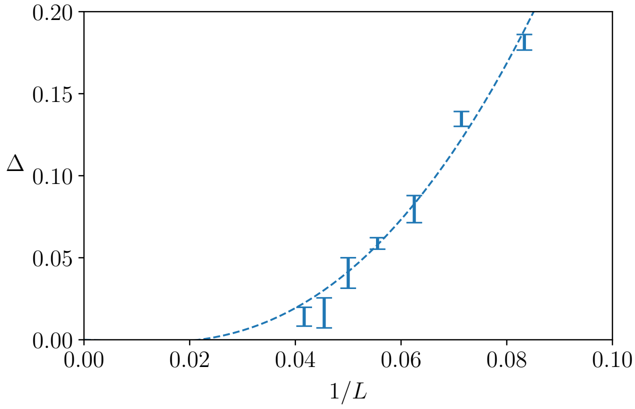

Figure 4: Finite-size scaling of the variational gap (Δ) at $q = (\pi, \pi)$ within the spin-liquid phase ($J_2/J_1 = 0.55$). The value of the gap is rapidly decreasing to zero, suggesting a vanishing value in the thermodynamic limit. The dashed line is a guide to the eye.

[1] W.-J. Hu, F. Becca, A. Parola, and S. Sorella, Phys. Rev. B **88**, 060402 (2013).