Comment on "Novel Superfluidity in a Trapped Gas of Fermi Atoms with Repulsive Interaction Loaded on an Optical Lattice"

In a recent Letter [1] (referred to as I below), Machida *et al.* made the exciting claim that in a *one-dimensional* (1D) trapped gas of fermions with repulsive interactions a superfluid phase appears around the Mott insulator (MI) at the center of the trap (COT). Their claim is based on a negative binding energy (E_b) and a large weight for a singlet formed by particles located at opposite sides of the MI. We show here that the observed effects are not related to superfluidity.

After a MI forms at large U, two particles with opposite spins added to the trap prefer to sit beyond the two ends of the MI phase in order to avoid double occupancy. Hence, the large weight of the singlet [Eq. (3)] in Fig. 4 of I can be understood to be a simple consequence of the density distribution and the antiferromagnetic character of the MI state; i.e., it does not signal superfluidity.

We then focus on the origin of the negative E_b observed in I. Most of the results in I exhibit a nonzero density at the borders of the trap; i.e., they depend on the boundary conditions. We thus recalculated two cases depicted in Fig. 1(a) of I, keeping the same curvature of the trap and increasing the system size to $N = 20$. This ensures zero density at the borders, as it should be for confined systems. We used quantum Monte Carlo (QMC) simulations [2,3], density-matrix renormalization group (DMRG) [4], and exact diagonalization (ED).

Figure 1 shows that a negative E_b appears for large values of U/t, at the point where the MI sets in the COT. Beyond this point, adding more particles to the system causes the MI to increase in size. This is in contrast to the systems without a trap, where adding more particles to the half-filled case causes the MI to disappear. Both negative and positive E_b arise in the latter doped case for different boundary conditions [5].

The dashed line in Fig. 1 corresponds to ED results of the 1D Hubbard model without trap, at half-filling, and open boundary conditions (OBC). Here E_b is calculated by adding a site when adding a particle, for OBC, in order to simulate the MI in the middle of the trap without the metallic wings. The results obtained are practically indistinguishable from the E_b obtained for trapped systems after the MI appears in the COT. Therefore, the negative E_b is due to the MI region and does not signal superfluidity in the wings of the MI. Moreover, in the inset in Fig. 1 we show that the negative E_b in the MI is due to an even-odd effect. There we have plotted the ground-state energy E_G for MI systems without the trap, and OBC, vs the number of particles (N_f). The even-odd effect is evident and becomes smaller with increasing system size. Additionally, consistent with the results above, we find that: (i) displacing the COT from the middle of two lattice points, as selected in I, leads to positive values of E_b. Results for the COT on a lattice point are also shown in Fig. 1. (ii) In the trap, similarly to the OBC case, the negative $E_b \to 0$ almost linearly with increasing system size; i.e., it is a finite size effect.

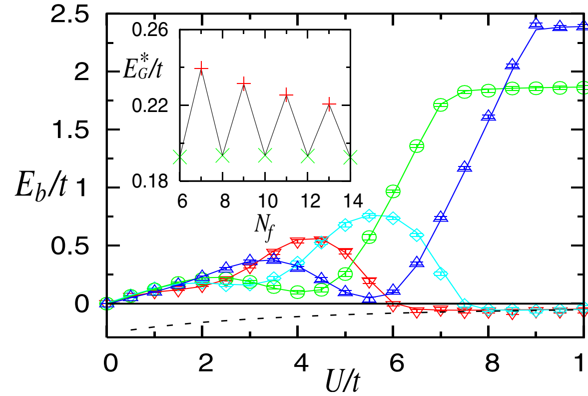

FIG. 1 (color online). QMC (points) and DMRG (continuous lines) results for $E_b(10) = E(5,5) + E(6,6) - 2E(5,6)$ vs U/t for: $V = 7.5t$ (red ▽, green ○) and $V = 9.5t$ (cyan ◇, blue △) (see I), when the center of the trap is located in the middle of two lattice points (red ▽, cyan ◇) and in a lattice point (green ○, blue △). The dashed line shows ED results for $E_b(10)$ in open MI systems (see text). The inset shows ED results for $E_G^* = E_G + AN_f$ vs N_f, in open MI systems with $U/t = 8$. Here we choose a nonzero value of $A = 0.327$ to stress the even(green ×)-odd(red +) effect, without affecting the actual value of $E_b < 0$ it causes.

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[1] M. Machida *et al.*, Phys. Rev. Lett. **93**, 200402 (2004).
[2] M. Rigol *et al.*, Phys. Rev. Lett. **91**, 130403 (2003).
[3] M. Rigol and A. Muramatsu, Phys. Rev. A **69**, 053612 (2004); Opt. Commun. **243**, 33 (2004).
[4] S. R. White, Phys. Rev. Lett. **69**, 2863 (1992); Phys. Rev. B **48**, 10 345 (1993).
[5] R. M. Fye *et al.*, Phys. Rev. B **42**, R6809 (1990).

