Erratum: algebraic spin liquid as the mother of many competing orders

Michael Hermele, T. Senthil, and Matthew P. A. Fisher

1Department of Physics, University of Colorado, Boulder, Colorado 80309, USA
2Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
3Microsoft Research, Station Q, University of California, Santa Barbara, California 93106, USA
4Physics Department, University of California, Santa Barbara, California 93106, USA

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We correct an error in our paper Phys. Rev. B 72, 104404 (2005) [cond-mat/0502215]. We show that a particular fermion bilinear is not related to the other “competing orders” of the algebraic spin liquid, and does not possess their slowly decaying correlations. For the square lattice staggered flux spin liquid (equivalently, d-wave RVB state), this observable corresponds to the uniform spin chirality.

In a recent paper we studied the staggered flux algebraic spin liquid state of the square lattice $S = 1/2$ Heisenberg antiferromagnet. We emphasized the presence of an SU(4) emergent symmetry present at low energy in this state, and showed that it leads to a striking unification of several seemingly unrelated “competing orders,” including order parameters for the Neel and valence bond solid states. In the field theory of the algebraic spin liquid, which consists of valence bond solid states. In the field theory of the emergent orders,” including order parameters for the Neel and

In Ref. 1, we claimed that the SU(4) singlet $M = \Psi \bar{\Psi}$ has the same power law decay as $N^\alpha$, that is $\langle M(r)M(0) \rangle \sim 1/|r|^{2\Delta_M}$, where $\Delta_M = \Delta_N$ to all orders in the $1/N_f$ expansion. However, our argument in Appendix D of Ref. 1 missed an important class of diagrams, and as a result this statement is not correct. In fact, $\Delta_M$ and $\Delta_N$ differ at order $1/N_f$. Here, we outline the calculation of $\Delta_M$ to this order. The result is $\Delta_M = 2 + 128/(3\pi^2 N_f) + O(1/N_f^2)$. Next, we discuss this result in the context of the physical picture of gauge binding given above.

We calculate $\Delta_M$ by adding $mM$ as a perturbation to the action, and examining its leading order contribution to the fermion Green’s function: this is along the same lines as the calculation of the scaling dimension of velocity anisotropy in Appendix C of Ref. 1. The vertex corresponding to insertion of $M$ is denoted by \[ \text{vertex} = im. \] (1)

We consider the term in the fermion self-energy of first order in both $1/N_f$ and in $m$, denoted $\Sigma(k) = \sum_{i=1}^{3} \Sigma_i(k)$. We have

$$ \Sigma_1(k) = \begin{array}{c} \text{diagram 1} \end{array}, $$ (2)

$$ \Sigma_2(k) = \begin{array}{c} \text{diagram 2} \end{array}, $$ (3)

and

$$ \Sigma_3(k) = \begin{array}{c} \text{diagram 3} \end{array}. $$ (4)

These diagrams, which were missed by us in Ref. 1, only contribute to $\Delta_M$; the corresponding diagrams for $N^\alpha$ vanish because the fermion loop involves a trace over a single SU(4) generator.

These diagrams can be evaluated using dimensional regularization, as in Appendix C of Ref. 1. Keeping only the logarithmically divergent parts, we have

$$ \Sigma_1(k) = -\frac{24}{\pi^2 N_f} (im) \ln \left( \frac{|k|}{\mu} \right) $$ (5)

$$ \Sigma_2(k) = \Sigma_3(k) = \frac{32}{\pi^2 N_f} (im) \ln \left( \frac{|k|}{\mu} \right). $$ (6)

Applying the Callan-Symanzik equation as described in Ref. 1, we find

$$ \Delta_M = 2 + \frac{128}{3\pi^2 N_f} + O(1/N_f^2). $$ (7)

It is perhaps surprising that $\Delta_M$ has increased above its $N_f \to \infty$ value, because this seems to call into question the validity of the physical picture that gauge binding should lower the scaling dimension. However, there is
an important difference between the $N^a$ and $M$ fermion bilinears. The $M$ fermion bilinear can decay into photons, as represented by the diagram

\[ \text{Diagram representing decay into photons} \] \hspace{1cm} (8)

This is impossible for $N^a$, because it carries the SU(4) flavor quantum number. Such decay processes will reduce the ability of the mode created by $\Psi^\dagger \tau^3 \Psi$ to propagate as a single particle-like object, and thus compete against the binding due to the gauge force. Evidently, at least at large-$N_f$ the decay processes win out over the gauge binding, and $\Delta_M$ is increased above the value for noninteracting fermions. Because no similar decay process is allowed for $N^a$, we still expect $\Delta_N < 2$ for all values of $N_f$.

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1 M. Hermele, T. Senthil, and M. P. A. Fisher, Phys. Rev. B 72, 104404 (2005).
2 W. Rantner and X.-G. Wen, Phys. Rev. B 66, 144501 (2002).