Ikeda and Ohashi reply: In our previous letter [1], we have proposed an unconventional spin density wave state as a possible mechanism of the micromagnetism in URu$_2$Si$_2$. As an example, we have studied the $d$-wave SDW ($d$SDW). This novel SDW can explain various experimental results. Kiselev and Bouis (KB) have pointed out that the ferromagnetic (FM) state should be considered in the phase diagram (Fig.1 in [1]), and the dSDW cannot be realized for the most physically reasonable limits.

In [1], we analyzed the simplest model for the dSDW (Eq.(1) in [1]) within the mean field theory. It was implicitly assumed that the antiferromagnetic state in URu$_2$Si$_2$ originates from the nesting in the heavy fermion state $Q$. Then, among the possible orderings, we examined only states with the nesting vector $Q$ ($Q$-group). The states in this group are expected to always compete with one another irrespective of the detail of models whenever the nesting works relevantly. On the other hand, since the exchange term $J$ favours the FM state, Fig.1 in [1] is modified as pointed out by KB (See Fig.1.) when possibility of the FM state is included. We, however, note that this FM instability mainly comes from the peculiarity of our simple model besides the presence of $J$, i.e., the divergence of the density of states (DOS) at $E=0$. Actually, no precursor of the FM instability has been observed experimentally in pure URu$_2$Si$_2$ [3,4]. In this regard, our model in [1] is too simple to correctly describe this feature in real URu$_2$Si$_2$, although it is enough to grasp the essence of the dSDW. In a more realistic model [5], the FM instability is expected to be less dominant compared with the simple one.

Next, we discuss the stable region of the dSDW within Eq.(1) in [1]. As noted in [1], the micromagnetism occurs after the formation of the heavy fermion state. Eq.(1) in [1] should be regarded as the effective Hamiltonian for, not the bare electrons, but the quasiparticles with the renormalized interactions, $U$, $V$, $J$. We can expect that $U$ is renormalized to be the order of the quasiparticle bandwidth and $V,J < U$ [5]. Then, there exists a stable dSDW-region as shown in Fig.1, even if the possibility of the FM state is included.

In conclusion, the possibility of the FM state modifies the phase diagram in [1]. Since this strong FM enhancement is peculiar to our model, further careful analyses may be necessary in constructing more realistic models for URu$_2$Si$_2$. However, the physical properties of the dSDW obtained in [1] themselves are not altered at all by the presence of the FM state, so that the unconventional SDW is still a candidate for the curious magnetism in URu$_2$Si$_2$.

Hiroaki Ikeda
Department of Physics,
Kyoto University,
Kyoto, 606-8502, Japan
Yoji Ohashi

Institute of Physics,
University of Tsukuba,
Ibaraki 305, Japan

PACS numbers: 71.27.+a, 75.50.Ee

[1] H. Ikeda and Y. Ohashi, Phys. Rev. Lett. 81, 3723 (1998).
[2] Since there should exist many Fermi surfaces in URu$_2$Si$_2$, the interband nesting is expected in real system as in the case of Cr. Indeed, in the band calculation, the presence of two electron surfaces around the $\Gamma$ point and two hole surfaces around the $Z$ point is reported; G. J. Rozing, et al., Phys. Rev. B43, 9515 (1991). These Fermi surfaces seem to be nested with each other.
[3] M. B. Maple, et al., Phys. Rev. Lett. 56, 185 (1986).
[4] The FM state is observed in the impure system URu$_2$-xRe$_x$Si$_2$; M. S. Torikachvili, et al., Phys. Rev. B45, 2262 (1992). This implies that the $J$-term exists to some extent.
[5] For instance, in an extended 2-band Lomar model which is well-known as a realistic model for the SDW in Cr (See, E. Fawcett, Rev. Mod. Phys. 60, 209 (1988)), the FM state becomes less important in compared with the case of the single band model because of the absence of singularity in DOS. In this case, the $Q$-group can be favorable unless we choose extremely large $J$.

FIG. 1. (a) $U-V$ phase diagram at $J/t = 0.2$. The FM is stable in small $U$ and $V$. (b) $J-V$ phase diagram at $U/t = 1$. 