# Comment on "Tuning low-energy scales in $YbRh_2Si_2$ by non-isoelectronic substitution and pressure"

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(Dated: October 10, 2019)

In Ref. 1, Schubert *et al.* [Phys. Rev. Research **1**, 032004 (2019)] reported measurements of the isothermal magnetoresistance of Fe- and Ni-substituted $YbRh_2Si_2$, based on which they raised questions about the Kondo destruction description for the magnetic field-induced quantum critical point (QCP) of pristine $YbRh_2Si_2$. Here we make three points. Firstly, as shown by studies on pristine $YbRh_2Si_2$ in Paschen *et al.* and Friedemann *et al.*, isothermal crossed-field and single-field Hall effect measurements are necessary to ascertain the evolution of the Fermi surface across this QCP. Because Schubert *et al.* did not carry out such measurements, their results on Fe- and Ni-substituted $YbRh_2Si_2$ cannot be used to assess the validity of the Kondo destruction picture neither for substituted nor for pristine $YbRh_2Si_2$. Secondly, when referring to the data of Friedemann *et al.* on the isothermal crossover of $YbRh_2Si_2$, they did not recognize the implications of the crossover width, quantified by the full width at half maximum (FWHM), being linear in temperature, with zero offset, over about 1.5 decades in temperature, from 30 mK to 1 K. Finally, in claiming deviations of Hall crossover FWHM data of Friedemann *et al.* from the above linear-in-$T$ dependence they neglected the error bars of these measurements and discarded some of the data points. The claims of Schubert *et al.* are thus not supported by data, neither previously published nor new (Ref. 1). As such they cannot invalidate the evidence that has been reported for Kondo destruction quantum criticality in $YbRh_2Si_2$.

Quantum criticality is a topic of considerable interest for a variety of strongly correlated electron systems, with antiferromagnetic heavy fermion systems representing a prototype. From extensive experimental measurements across QCPs of several heavy fermion metals, a variety of properties are found[2–16] to be inconsistent with spin-density-wave quantum criticality[17–19], which is based on Landau's framework of order-parameter fluctuations. Instead, they support Kondo destruction quantum criticality[20–22], which goes beyond the Landau framework through a critical destruction of the static Kondo entanglement. In particular, across the magnetic field-induced QCP in $YbRh_2Si_2$, the linear-response Hall coefficient determined from a crossed-field Hall measurement[3,5], along with single-field Hall effect[3,5], magnetoresistance[3,5], and thermodynamic properties[4], provided evidence for an extra energy scale, $T^*$, in the $T$–$B$ plane. This energy scale goes to zero as the QCP is approached from the non-magnetic side. Isothermal magnetotransport and thermodynamic properties undergo a rapid crossover across the $T^*$-line, which extrapolates to a jump in the $T = 0$ limit, across generations of $YbRh_2Si_2$ samples. These properties are in contrast with the polarization crossover scenario[1].

Recently, Schubert *et al.*[1] studied the magnetoresistance of Fe- and Ni-substituted $YbRh_2Si_2$. Primarily based on the isothermal behavior of the magnetoresistance in these doped materials, they questioned the Kondo destruction description for pristine $YbRh_2Si_2$. We have the following comments:

Firstly, the work of Paschen *et al.*[3], Gegenwart *et al.*[4], and Friedemann *et al.*[5], on pristine $YbRh_2Si_2$, is the combination of systematic studies in terms of magnetoresistance, thermodynamics and, most notably, single-field and crossed-field Hall measurements. *A priori,* only the latter can directly probe a Fermi surface jump, if also interference from anomalous Hall contributions can be ruled out. In $YbRh_2Si_2$, anomalous Hall contributions were shown to be extremely small[3]. It is also worth noting that the multiband nature was shown not to be relevant because a) the initial isothermal Hall resistivity $\rho_{xy}(B)$ is proportional to the probing magnetic field [Supporting Information (SI) of Ref. 5], implying that one of the multiple bands dominates the Hall coefficient; and b) on general grounds, a multiband effect *per se* is not relevant to any jump of the Hall coefficient at zero temperature: The scattering rate by itself has no way of creating a jump – only the carrier number can. An in-depth analysis of the magnetotransport data on the two sides of the QCP provided a good understanding of the Hall coefficients in terms of the renormalized bandstructure[23].

Schubert *et al.* took the unusual approach of assessing the Kondo destruction physics previously demonstrated for pristine $YbRh_2Si_2$[3–5,15] by investigating Fe- and Ni-substituted $YbRh_2Si_2$. Clearly, it is incumbent upon them to measure these materials with the same level of rigor previously used for pristine $YbRh_2Si_2$. Most notably, for a new set of samples, the equivalence of magnetoresistivity measurements and crossed-field Hall effect measurements, as well as the absence of an appreciable anomalous Hall contribution cannot be anticipated but must be explicitly demonstrated before drawing any conclusion on the Fermi-surface evolution across the QCP, which Schubert *et al.* have failed to do.

In addition, a more detailed analysis of the effects of disorder introduced by Fe- and Ni-substitution appears due. The studied substitutions not only introduce chemical pressure, but also extra carriers and an enhanced degree of disorder. This leads to rather pronounced changes of the overall magnetoresistance characteristics [*e.g.*, only positive magnetoresistance for $Yb(Rh_{0.9}Fe_{0.1})_2Si_2$ and an only tiny negative contribution for $Yb(Rh_{0.93}Fe_{0.07})_2Si_2$], which might indicate amplified effects of disorder as well as that another band gets populated by the extra charge carriers. Also Schubert *et al.*'s comparison of the residual resistivity values cannot add confidence, because the effect of substitutions cannot be captured by a change in the residual resistivity alone. In the absence of an understanding of such effects it appears particularly inappropriate to take crossover fits to such data as evidence against Kondo destruction quantum criticality not only in their samples, but even in pristine $YbRh_2Si_2$. Therefore, the data of Schubert *et al.* on Fe- and Ni-substituted $YbRh_2Si_2$, while interesting in their own right, can by no means invalidate stringent evidence for Kondo destruction quantum criticality in pristine $YbRh_2Si_2$.

To elucidate our second point, we show the stringent $T$-linear FWHM of $YbRh_2Si_2$ in an extended temperature range (Fig. 1a, from Ref. 5). Over 1.5 decades in temperature – from 30 mK to 1 K – the FWHM is linear in $T$ and extrapolates to zero in the zero-temperature limit. Along with the finding that for all samples and all physical quantities studied the jump size is finite[5], this makes a clear-cut case that the quantum critical physics within this extended temperature window is controlled by an underlying QCP for which the Fermi surface jumps.

To underpin our third point, in Fig. 1b we zoom into the lowest temperature range of Fig. 1a. Schubert *et al.* argued that, at the very lowest measured temperatures ($18\,\text{mK} \le T < 30\,\text{mK}$), the FWHM deviates from the linear fit (red line). Yet, within the error bars, this is not the case. It is clear that extracting the crossover characteristics at these very low temperatures is complicated by the vicinity to the antiferromagnetically ordered phase. Classical critical fluctuations associated with the phase transition will lead to scattering, which will in particular affect the magnetoresistance. In addition, as pointed out in the SI of Ref. 5, the single-field measurements (including the blue open circles in Fig. 1b) are obtained with magnetic fields along the hard magnetic axis (along $c$); magnetic fields in the crossover range are thus larger than for the other measurements, which facilitates the accurate determination of the crossover width (in agreement with the smaller error bars). Thus, there is no point to selectively discard the single-field Hall effect data of sample 2 (blue open circles) as Schubert *et al.* did. Taken together, there is very solid evidence that the FWHM of the Hall crossover of $YbRh_2Si_2$ in the entire measured temperature range extrapolates to zero in the zero-temperature limit.

Beyond these main points, it is important to note on the results of spectroscopic studies of pristine $YbRh_2Si_2$. STM measurements[24] do detect a signature at $T^*$ consistent with a critical slowing down (when there is no $T_N$ whatsoever, at $T = 0.3\,\text{K}$), contrary to the statement of Schubert *et al.* Equally important, the optical conductivity measured by THz spectroscopy in pristine $YbRh_2Si_2$ has shown $\omega/T$-scaling in the charge response[15], which

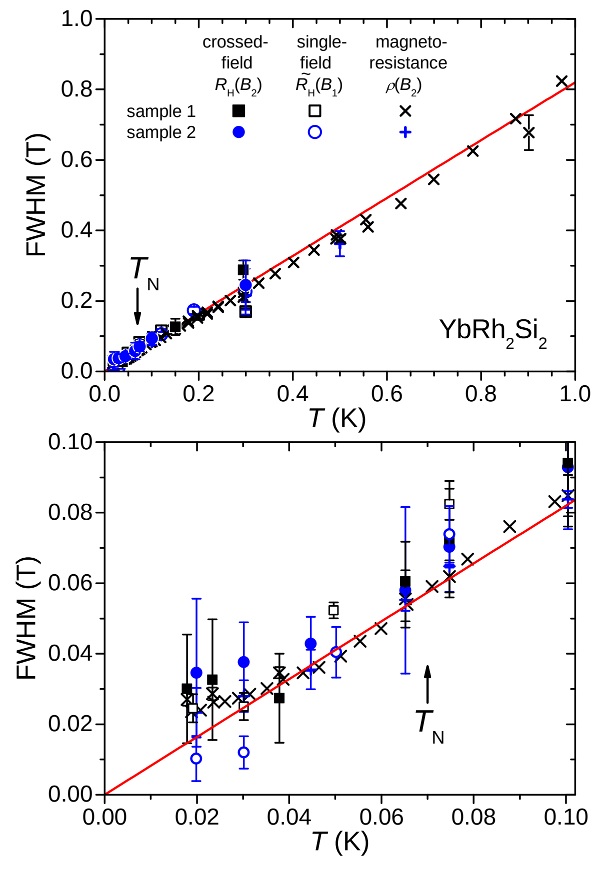


FIG. 1. (a) FWHM *vs.* $T$ over an extended temperature range; (b) FWHM *vs.* $T$ at the lowest measured temperatures. $T_N$ indicates the Néel temperature. Adapted from Ref. 5.

is expected in the Kondo destruction picture.

Finally, $YbRh_2Si_2$ is not alone in displaying evidence for Kondo destruction quantum criticality. Other examples are the anomalous dynamical scaling observed over an extended wavevector range in the Brillouin zone of $CeCu_{5.9}Au_{0.1}$ by inelastic neutron scattering measurements[2], and evidence for Fermi surface jumps in $CeRnIn_5$ by dHvA measurements across its pressure-induced QCP[12], in $Ce_3Pd_{20}Si_6$ based on Hall measurements across its two field-induced QCPs[13,14], and in CePdAl from Hall measurements across its line of QCPs in the pressure-magnetic field phase diagram[16].


## ACKNOWLEDGMENT

The work was in part supported by the DFG Research Unit 960 ‘Quantum Phase Transitions’ (S.W. and F.S.), the Austrian Science Fund (FWF project P29296-N27) and the European Union’s Horizon 2020 Research and Innovation Programme, under Grant Agreement no EMP-824109 (S.P.), and by the NSF grant DMR-1920740 and the Robert A. Welch Foundation grant C-1411 (Q.S.).



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