Hund's rule induced spin-triplet pairing in the multiband Anderson lattice model

Patryk Kubiczek, Józef Spałek
patryk.kubiczek@student.uj.edu.pl
Jagiellonian University, Kraków, Poland

Introduction

The explanation of the nature of the superconducting phases coexistent with ferromagnetism, found in several heavy-fermion compounds, poses a challenge to theorists [1]. Recently, a satisfactory model of the magnetism in UGe_2 was proposed [2]. Previously, it was shown that Hund's exchange J can drive spin-triplet superconductivity in Hubbard-type multiband models [3]. Here we extend the model for UGe_2 by introducing doubly degenerate bands and J in order to investigate whether it admits spin-triplet orbital-singlet s-wave solutions for the superconducting gap.

Model and method

We investigate a doubly degenerate (2 conduction and 2 f-electron bands) extended periodic Anderson model on the 2D square lattice:

$$H = \sum_{\mathbf{ij}l\sigma} t_{\mathbf{ij}l} c^\dagger_{\mathbf{i}l\sigma} c_{\mathbf{j}l\sigma} + \epsilon^f \sum_{\mathbf{i}l\sigma} f^\dagger_{\mathbf{i}l\sigma} f_{\mathbf{i}l\sigma} + V \sum_{\mathbf{i}l\sigma} \left(f^\dagger_{\mathbf{i}l\sigma} c_{\mathbf{i}l\sigma} + c^\dagger_{\mathbf{i}l\sigma} f_{\mathbf{i}l\sigma} \right)$$
$$+ U \sum_{\mathbf{i}l} n^f_{\mathbf{i}l\uparrow} n^f_{\mathbf{i}l\downarrow} - 2J \sum_{\mathbf{i}} \left(\mathbf{S}^f_{\mathbf{i}1} \mathbf{S}^f_{\mathbf{i}2} + \frac{1}{4} n^f_{\mathbf{i}1} n^f_{\mathbf{i}2} \right).$$

We apply the usual Hartree-Fock-BCS procedure solving self-consistent equations for the following mean field parameters:

$$n^f = 2 \sum_\sigma \langle n^f_{\mathbf{i}l\sigma} \rangle, \qquad m^f = \frac{1}{2} \left(\langle n^f_{\mathbf{i}l\uparrow} \rangle - \langle n^f_{\mathbf{i}l\downarrow} \rangle \right),$$
$$\Delta_\sigma = J \,\mathrm{sgn}(l' - l) \,\langle f_{\mathbf{i}l\sigma} f_{\mathbf{i}l'\sigma} \rangle.$$

Simultaneously, we adjust the chemical potential to keep the total band-filling $n = \sum_{l\sigma} \langle n^f_{\mathbf{i}l\sigma} + n^c_{\mathbf{i}l\sigma} \rangle$ fixed.
We present the results as a function of V for the parameters:

t (n.n.)	t' (n.n.n.)	ϵ^f	U	J	n
-1	0.25	-3	3	1.5	3.2

Ground state results

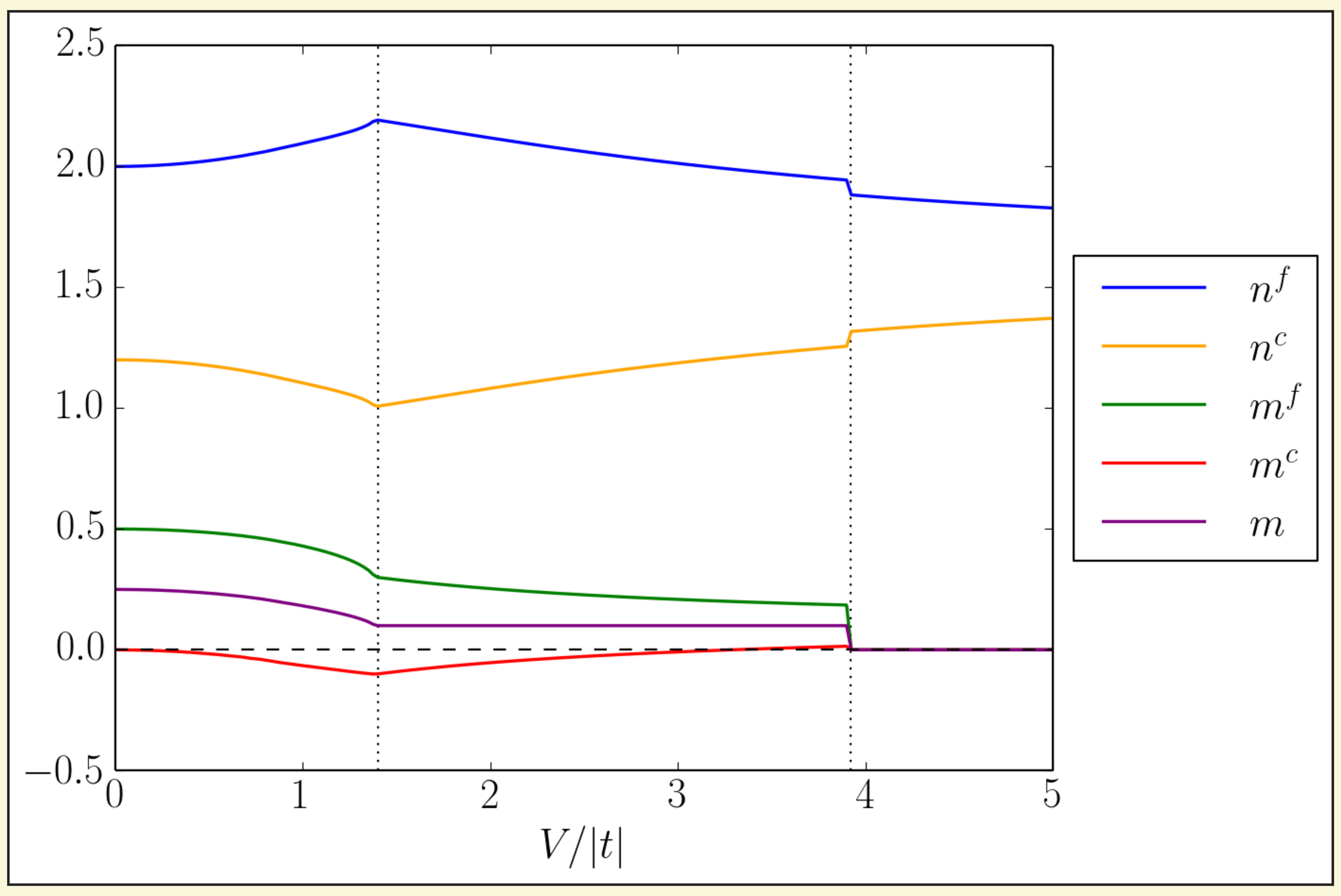

Figure 1: Band fillings: n^c and n^f, magnetizations (per band): m^c and m^f of conduction and f-electrons, and mean band magnetization m - all for $T = 0$

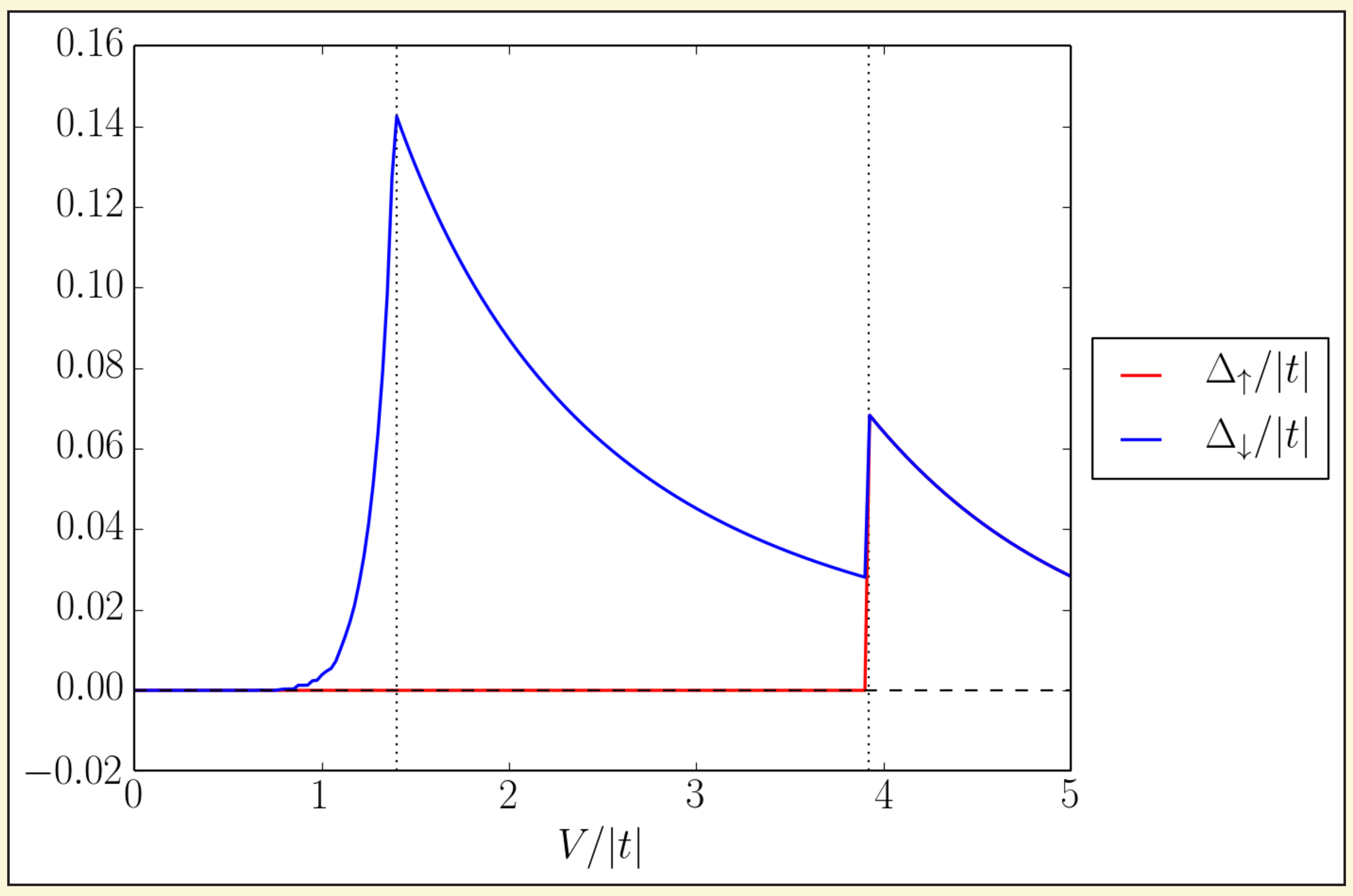

Figure 2: Superconducting gaps for $T = 0$

Phase diagram

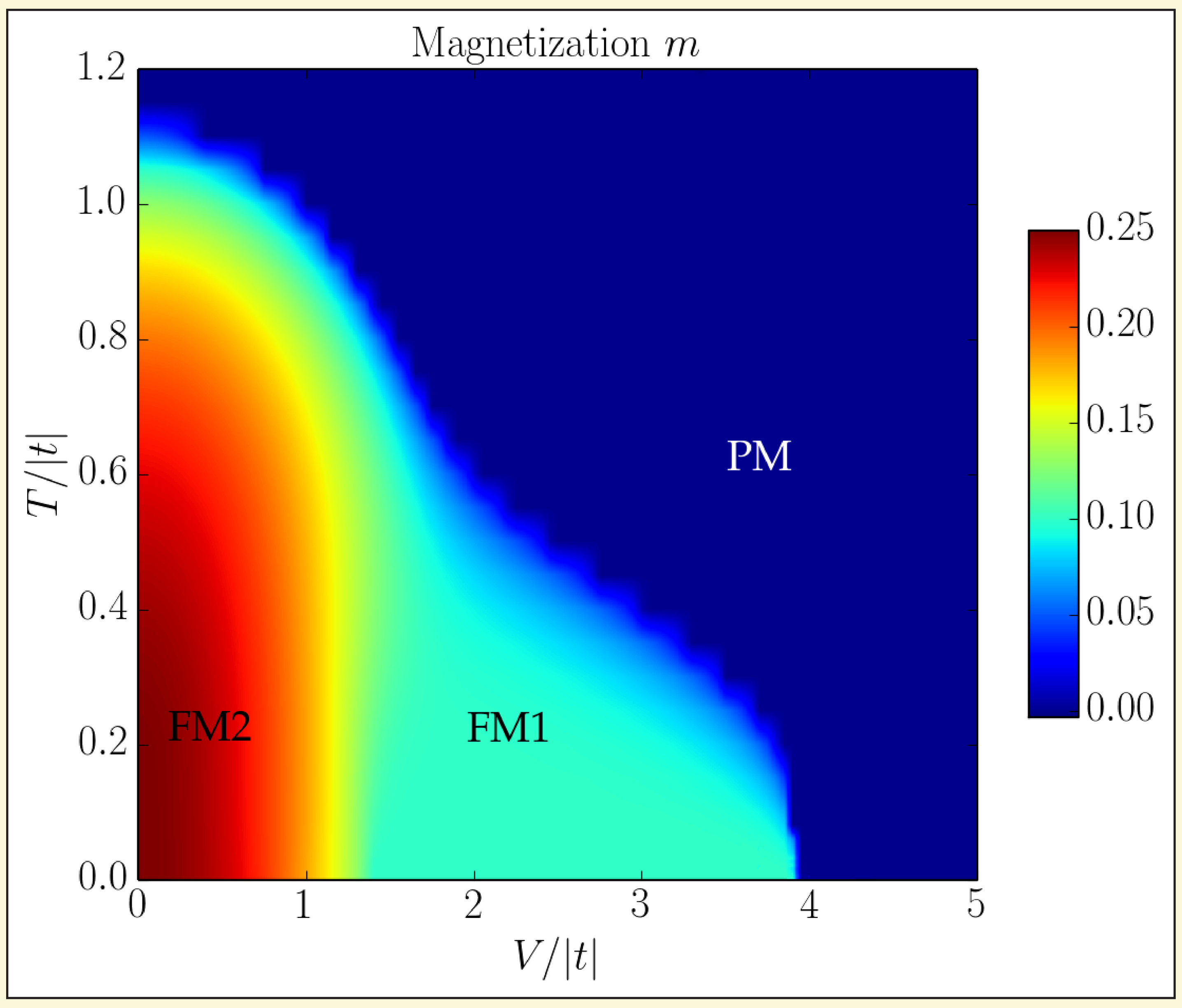

Figure 3: Mean magnetization m on hybridization V - temperature T plane. Strong (FM2) and weak (FM1) ferromagnetic, and paramagnetic (NS) phases are observed.

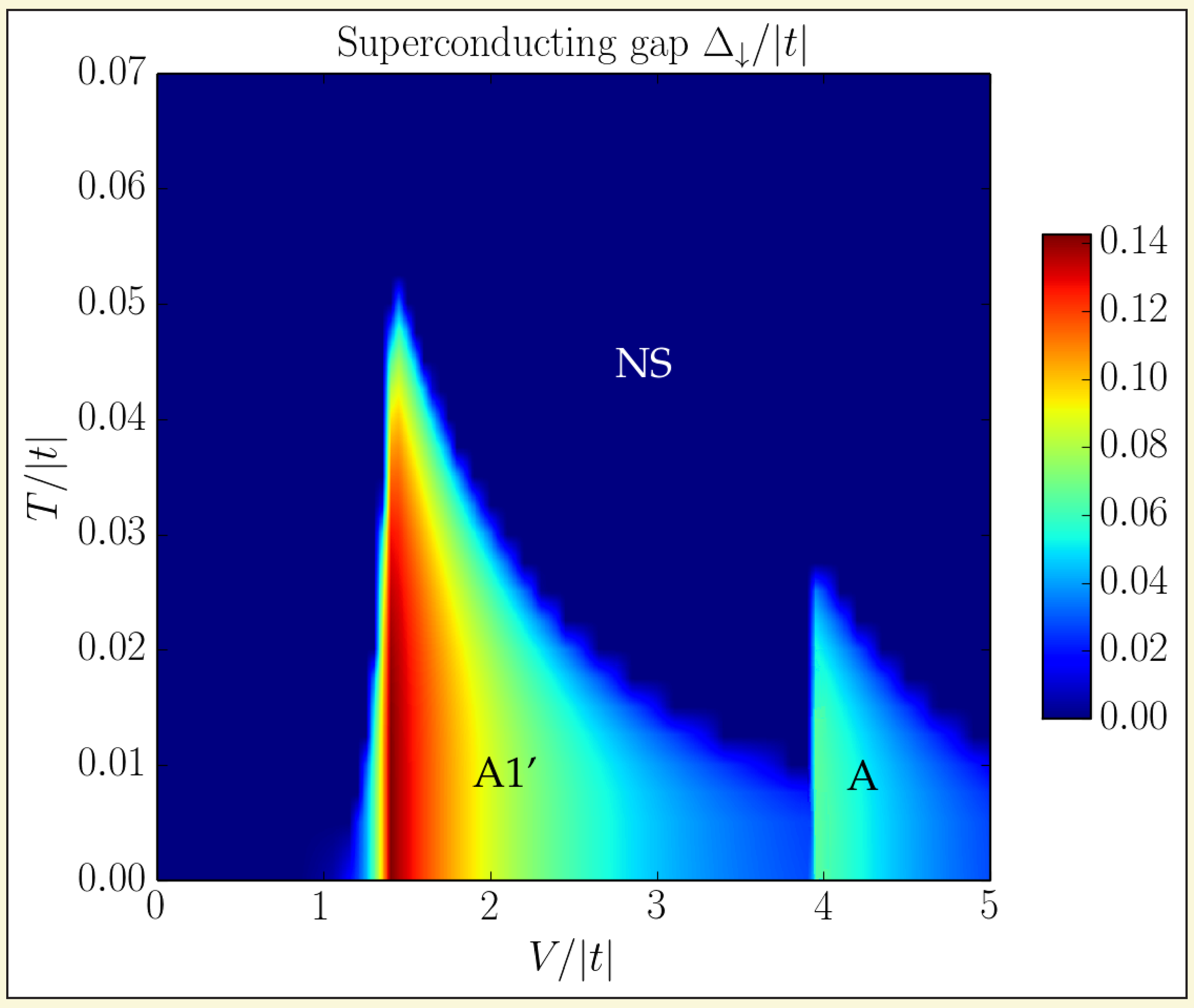

Figure 4: Superconducting gap $\Delta_\downarrow$ on V-T plane. A1' ($\Delta_\uparrow = 0$), A ($\Delta_\uparrow = \Delta_\downarrow$) and normal (NS) phases are observed.

Conclusions

- Our model exhibits a spin-triplet orbital-singlet s-wave pairing between the minority spin electrons at low temperatures (A1' phase).
- The highest transition temperature occurs at the transition point between the strong (FM2) and the weak ferromagnetic (FM1) phases.
- Further studies, presumably within the statistically-consistent Gutzwiller approximation (SGA), are planned to verify whether such a simple model can account for the superconductivity in UGe_2.

References

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