Magnetic Phases in Heavy Fermion Systems

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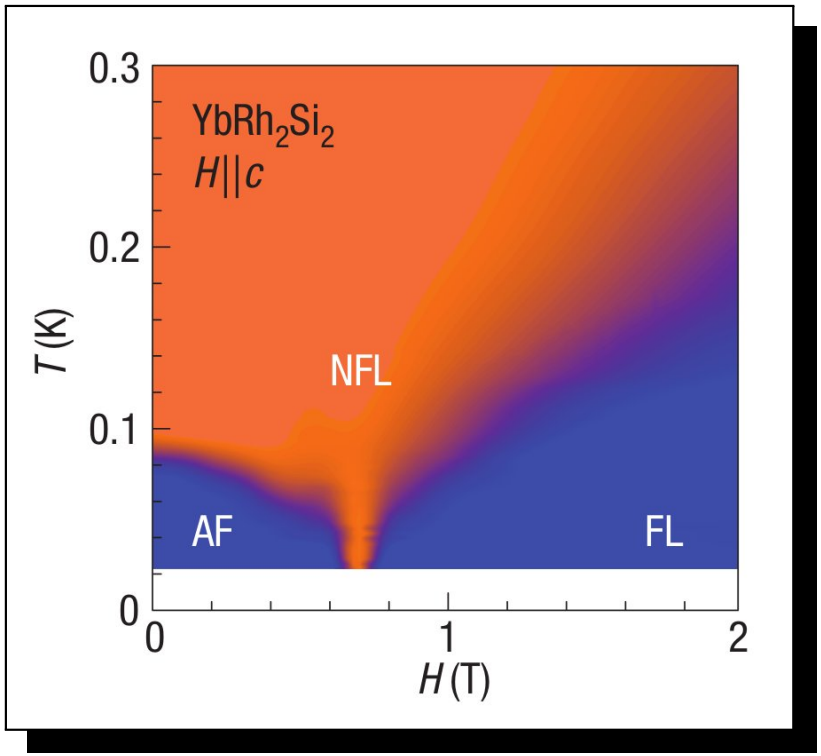
July 2014

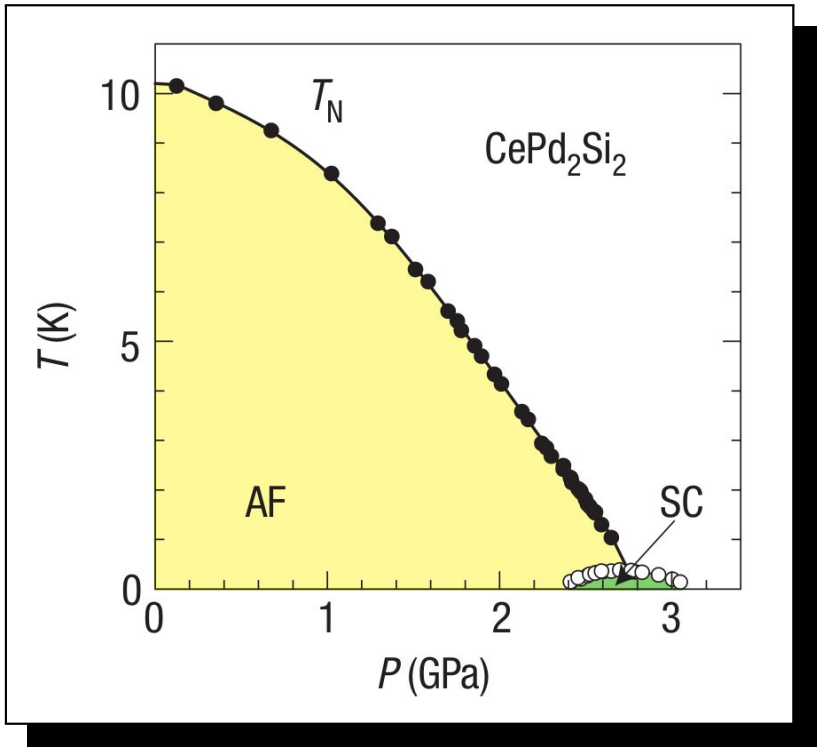
Outline

- Introduction: model and method
- the phase diagram of the Kondo lattice model
  - weak coupling: RKKY dominated phases
  - strong coupling: Kondo dominated phases

Heavy fermion systems

Due to the existence of strongly localized *f*-electrons, one can observe a variety of long-range ordered phases in *f*-electron systems.



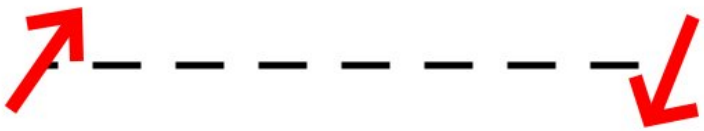


P. Gegenwart, Q. Si, F. Steglich: Nature Physics 2008

Heavy fermion systems

competing effects in f-electron materials

RKKY interaction

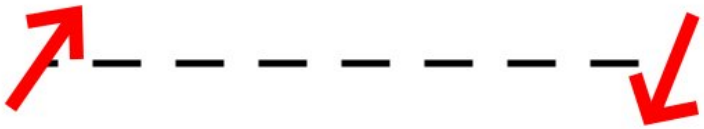


magnetic interaction between different magnetic moments

Heavy fermion systems

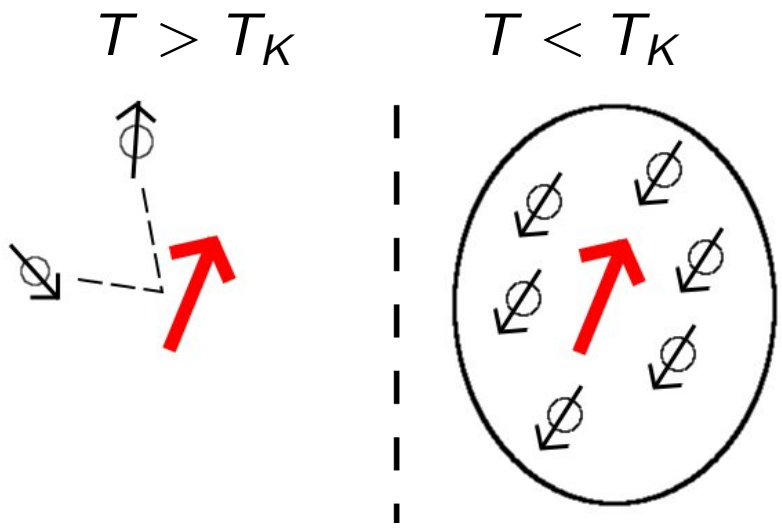
competing effects in f-electron materials

RKKY interaction



magnetic interaction between different magnetic moments

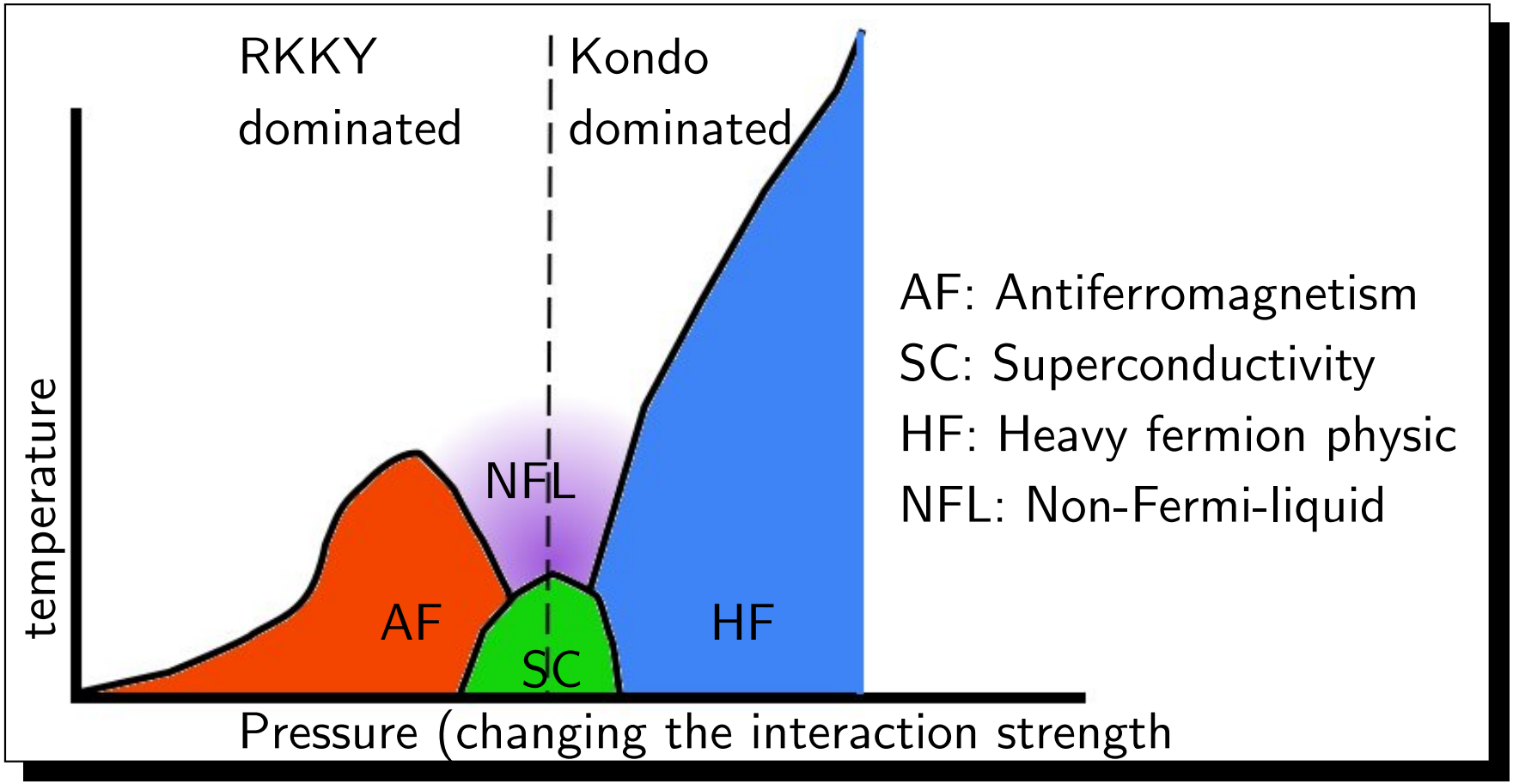
Kondo effect



Screening between magnetic moments and conduction electrons

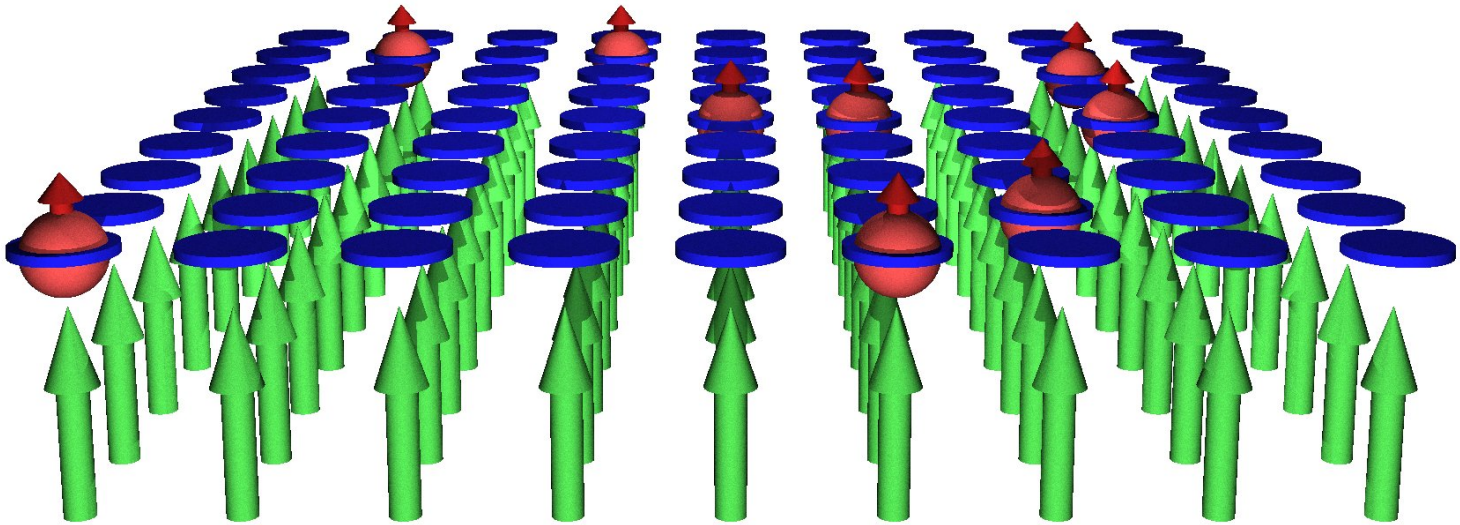
Heavy fermion systems

Doniach phase diagram



Magnetic phase diagram of heavy fermion systems

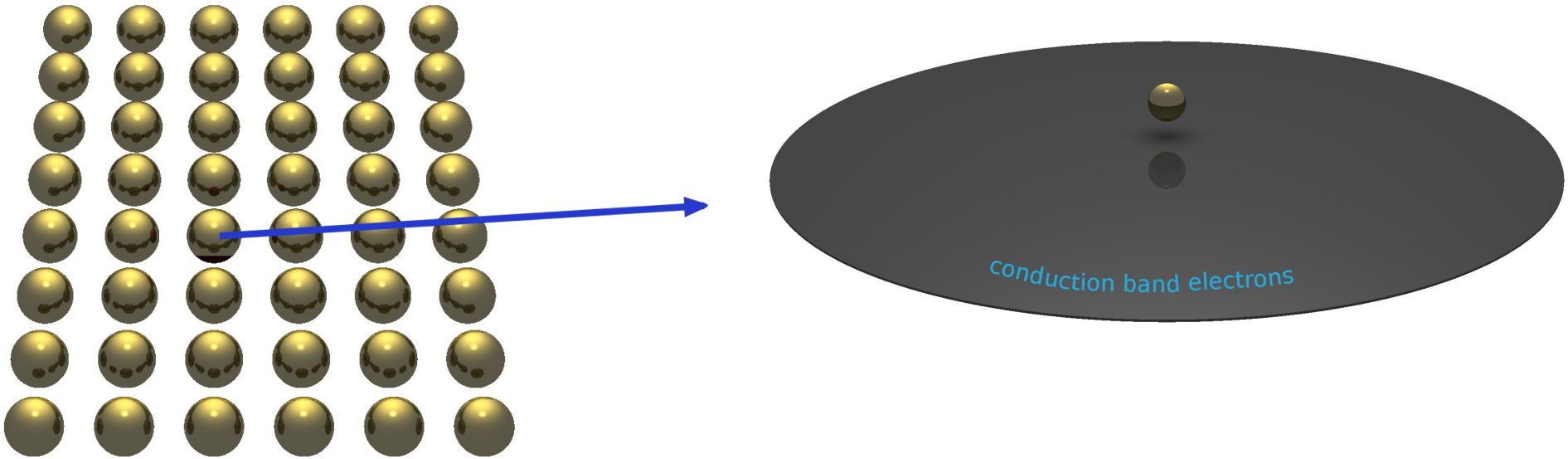
- lattice with conduction electrons
- lattice of magnetic moments
- local antiferromagnetically coupling between both



$$H = t \sum_{<i,j>,\sigma} c^{\dagger}_{i\sigma} c_{j\sigma} + J \sum_{i} \vec{s}_i \vec{S}_i$$

Dynamical mean field theory

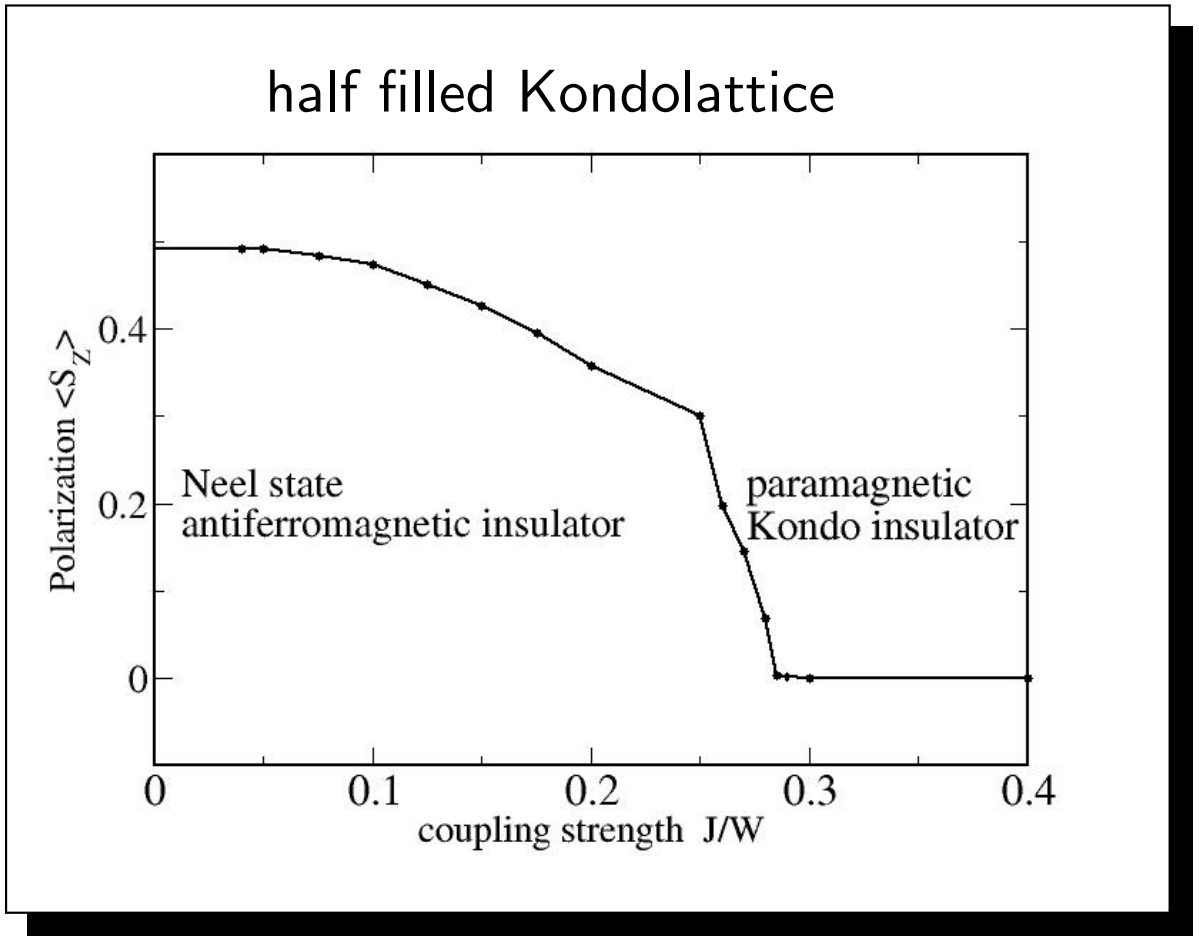
dynamical mean field theory (DMFT)



DMFT maps the lattice model onto a self-consistent impurity calculation

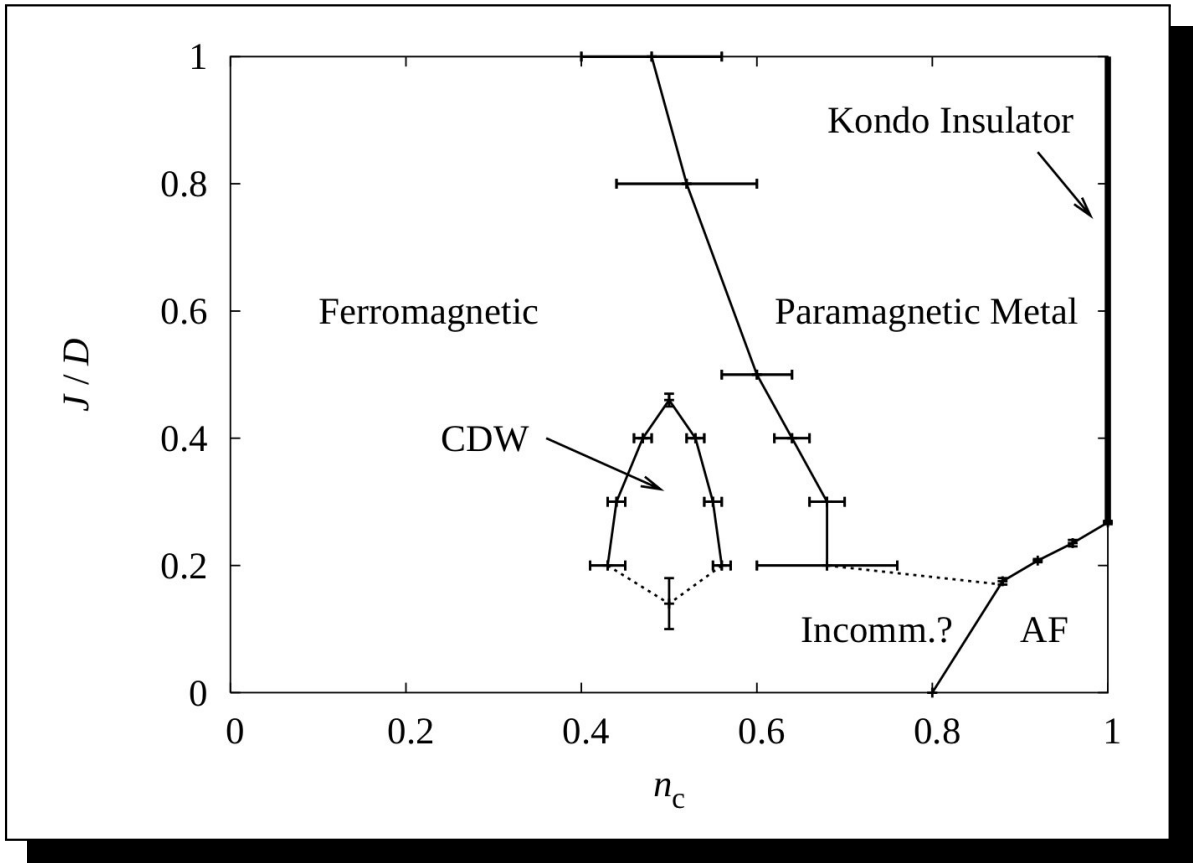
DMFT: PRL, W. Metzner and D. Vollhardt (1989); RMP, A. Georges et al. (1996)

Dynamical mean field theory



Dynamical mean field theory

phase diagram calculated by susceptibilities



Otsuki et al., J. Phys. Soc. Jpn. 78 (2009) 034719

Dynamical mean field theory

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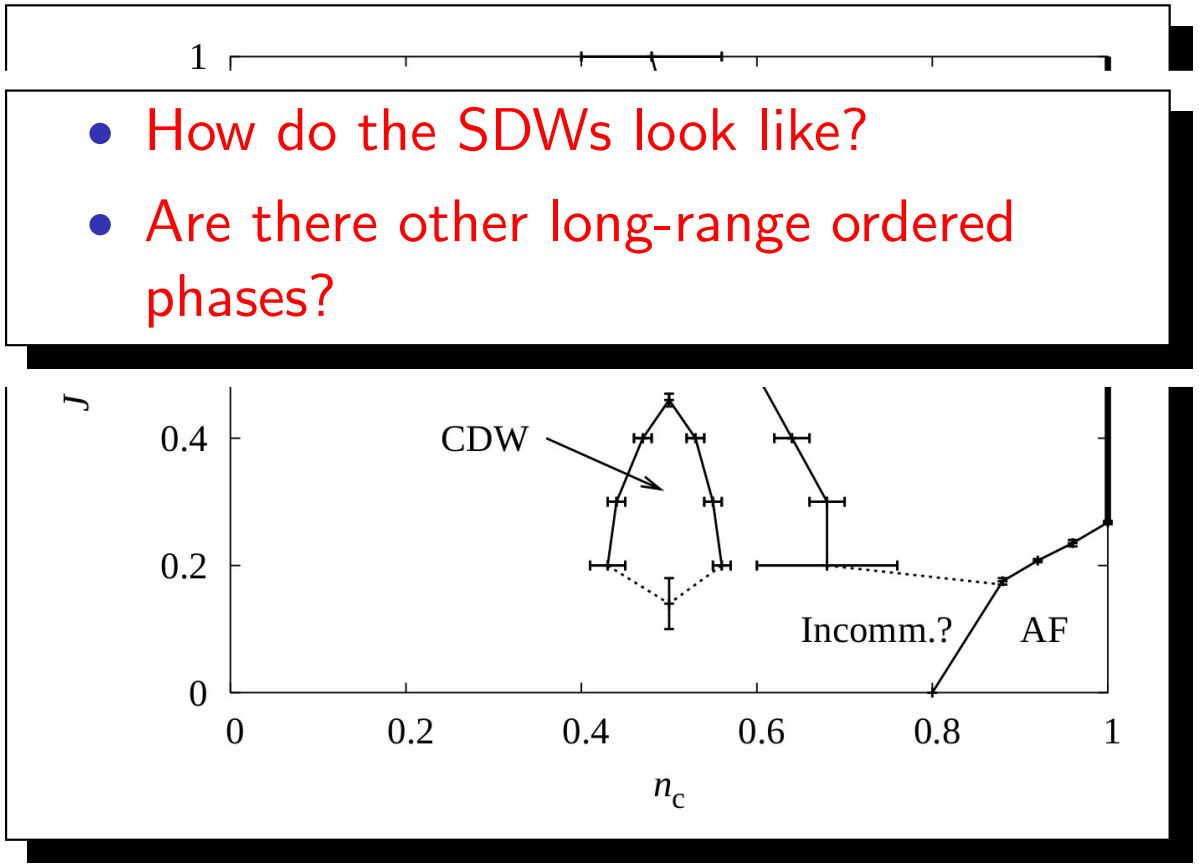


- How do the SDWs look like?
- Are there other long-range ordered phases?

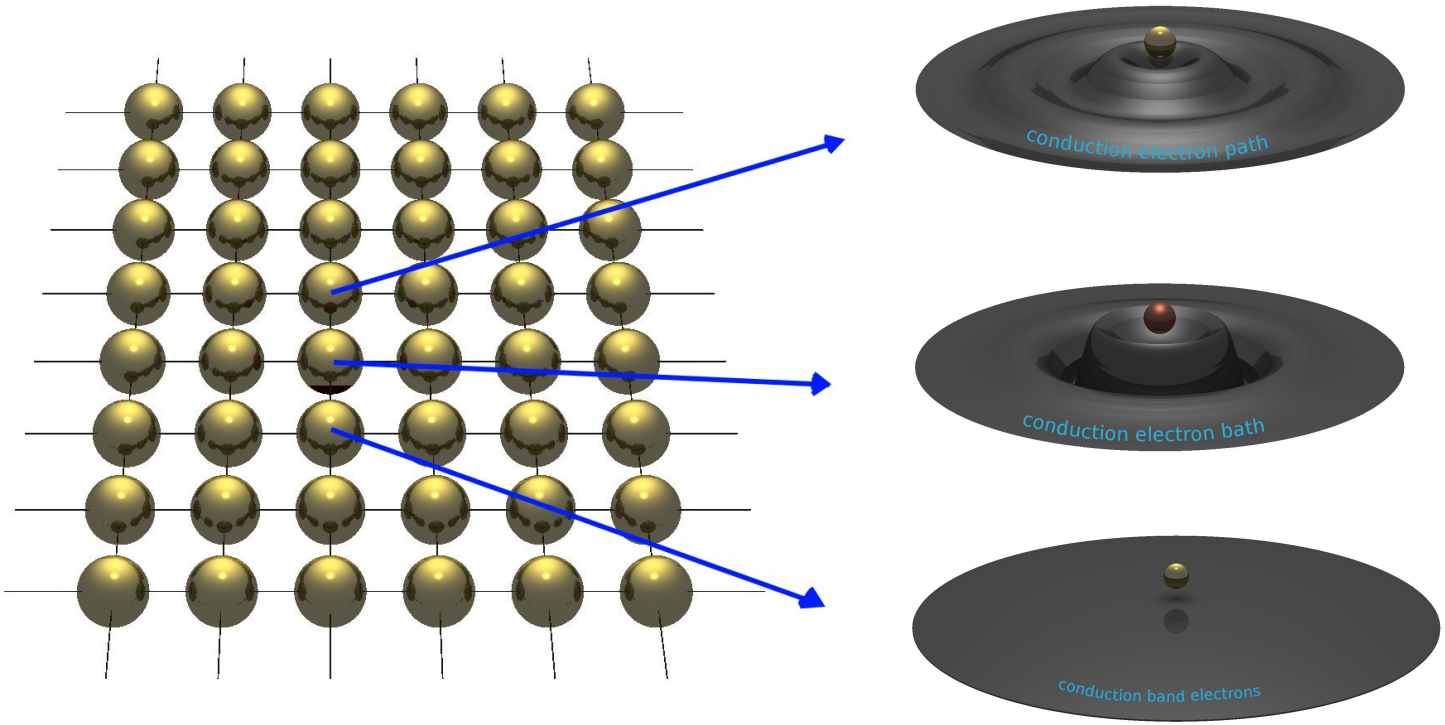
Otsuki et al., J. Phys. Soc. Jpn. 78 (2009) 034719

inhomogeneous DMFT

Inhomogeneous DMFT is the local approximation of the model, where each lattice site can have a different **local** self-energy.

It has been used to describe cold atoms in a trap, interfaces, superlattices, and surfaces. Furthermore, it can be used in situations where the lattice symmetry is broken spontaneously.

inhomogeneous DMFT

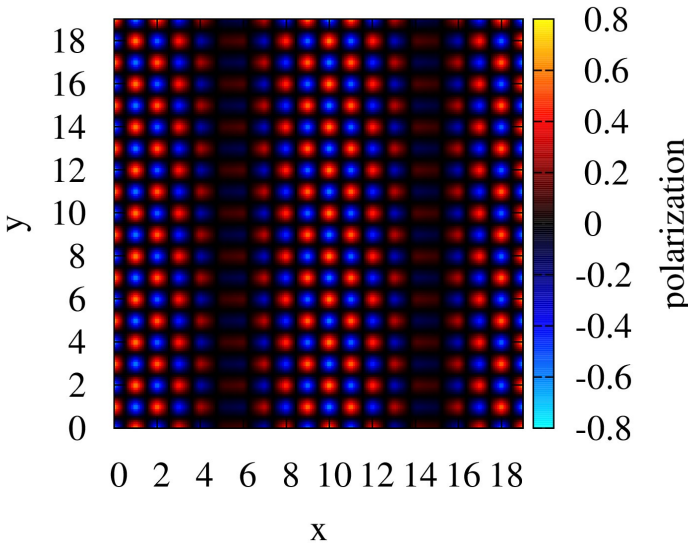


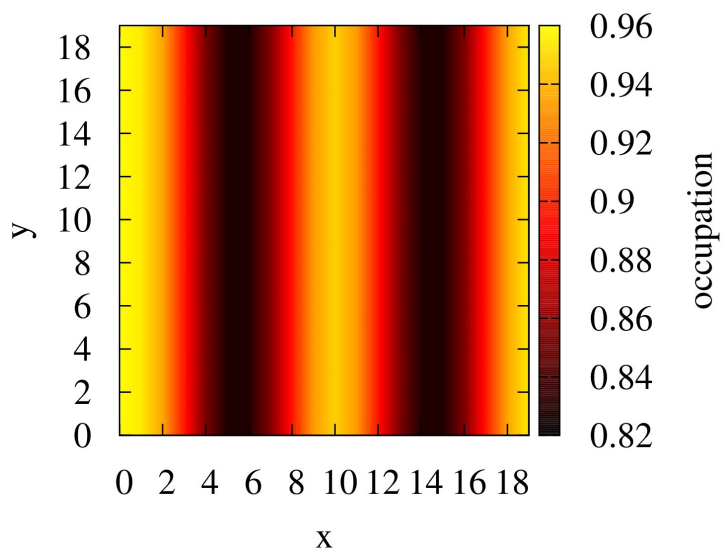
Each lattice site of a finite cluster is mapped onto its own impurity model, $G_{ij} = \left(\omega - H_{i'j'} - \Sigma_{i'j'}(\omega)\right)^{-1}_{ij}$

inhomogeneous DMFT

vertical SDW in the doped Hubbard model

$$H = t \sum_{<i,j>,\sigma} c^{\dagger}_{i\sigma} c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow}$$



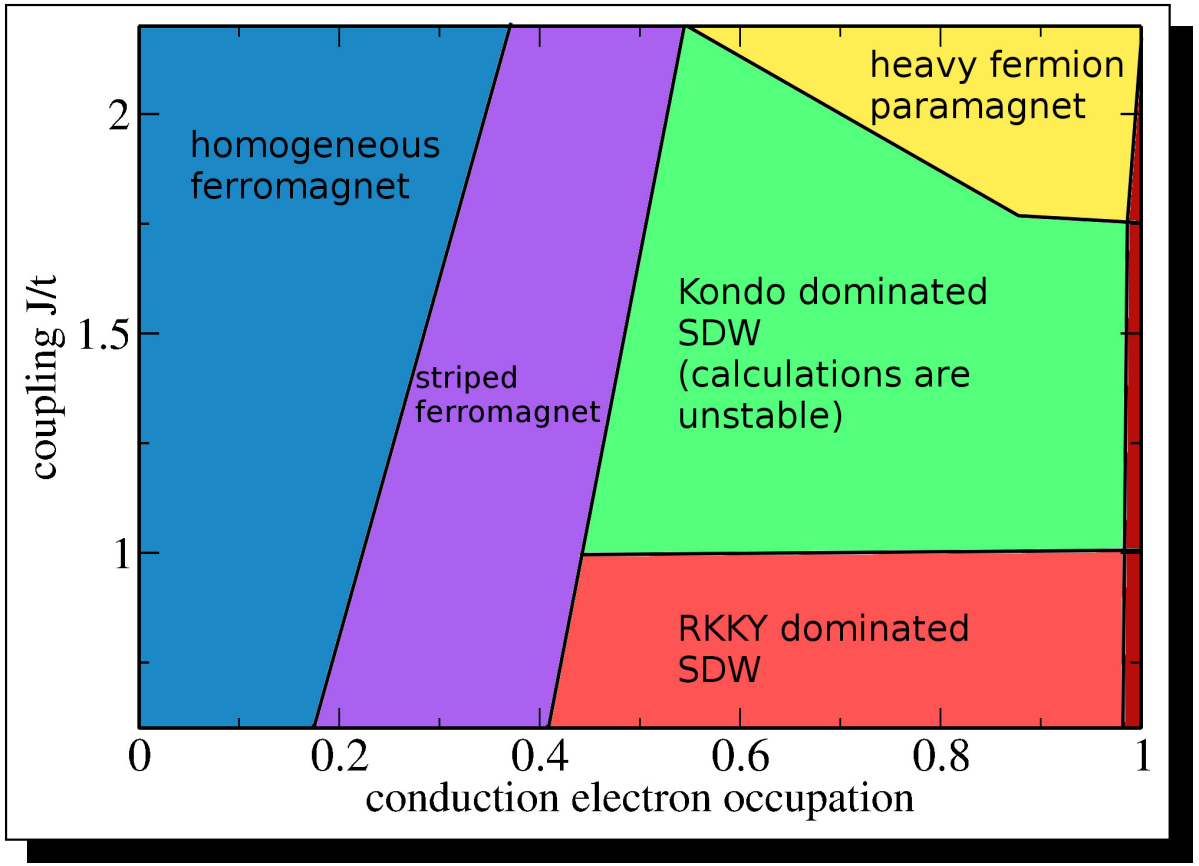


$$U = 8t, \ \langle n \rangle = 0.9$$

RP and N. Kawakami; PRB 2014

Magnetic phase diagram of heavy fermion systems

new iDMFT calculations, also stabilizing incommensurate SDW states



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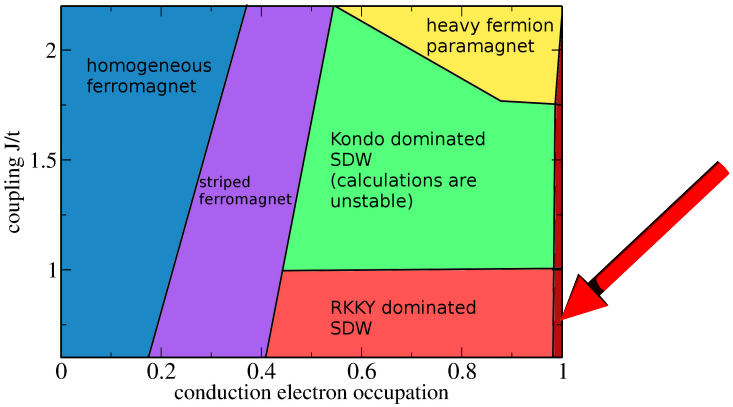
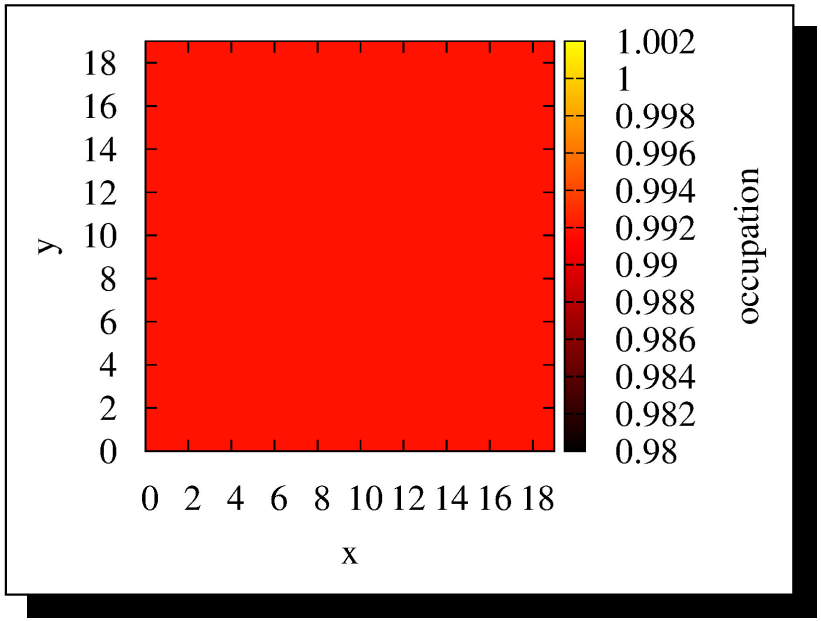
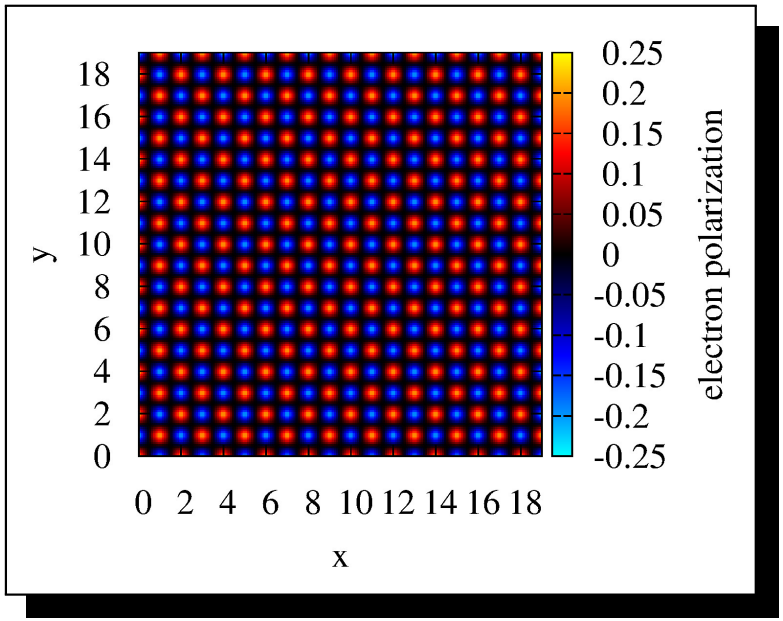


Neel state at half filling

occupation



polarization



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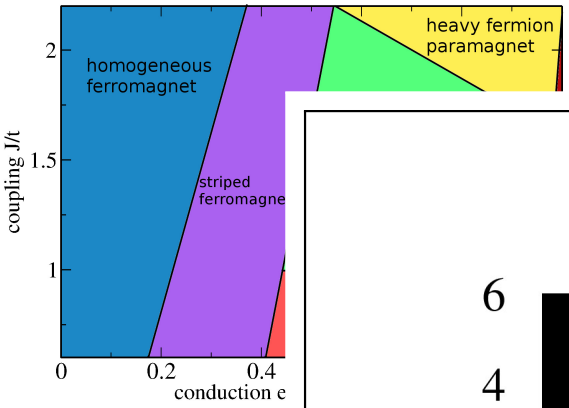

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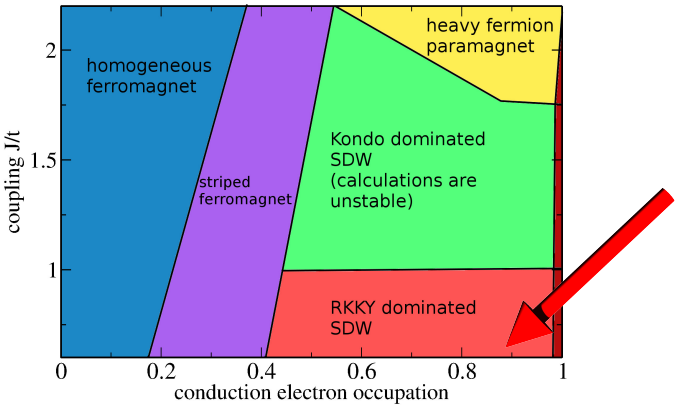
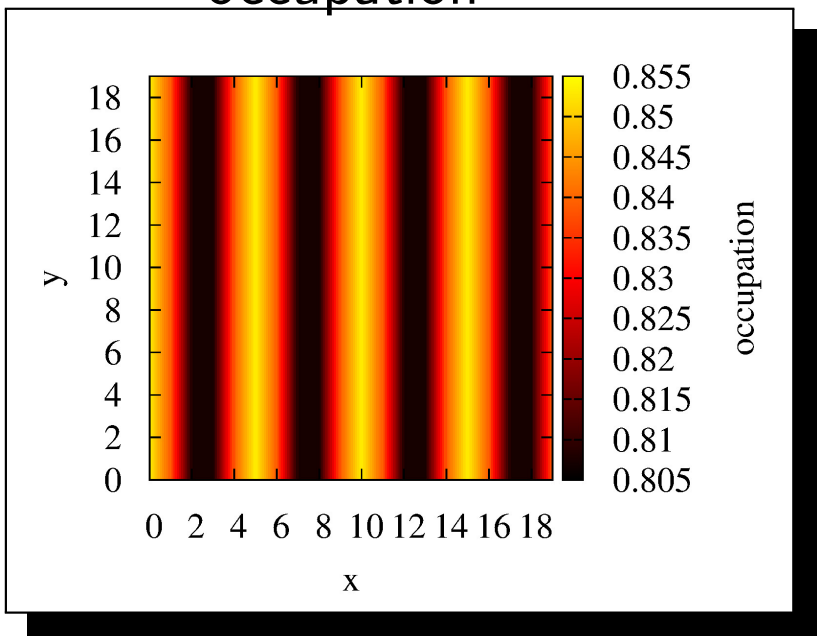


RKKY dominated SDW state

occupation



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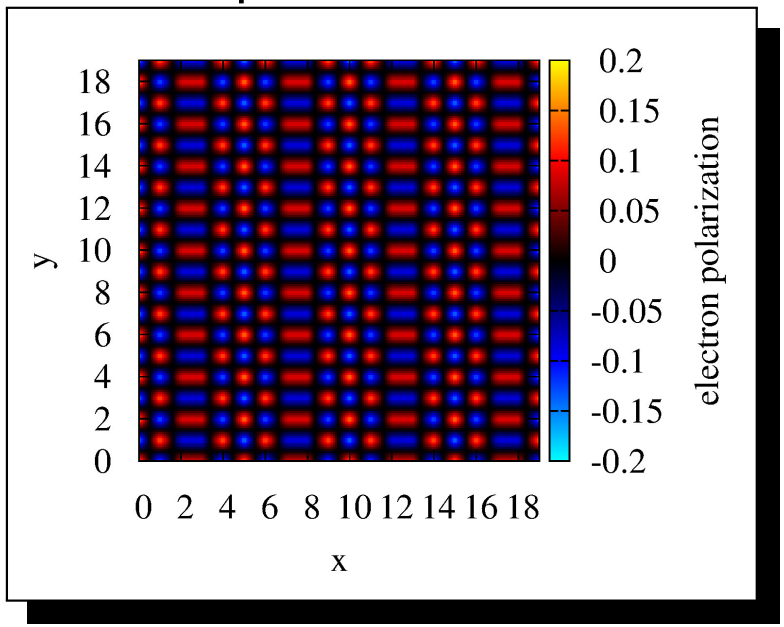

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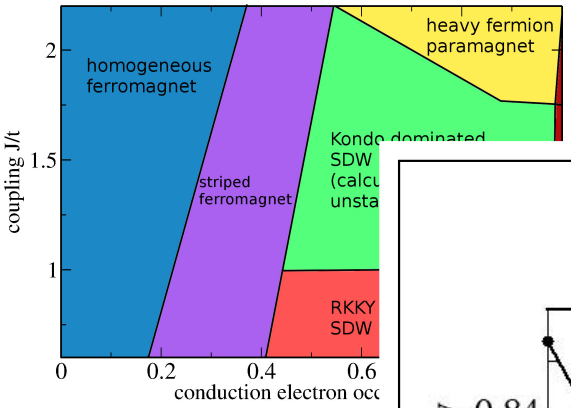

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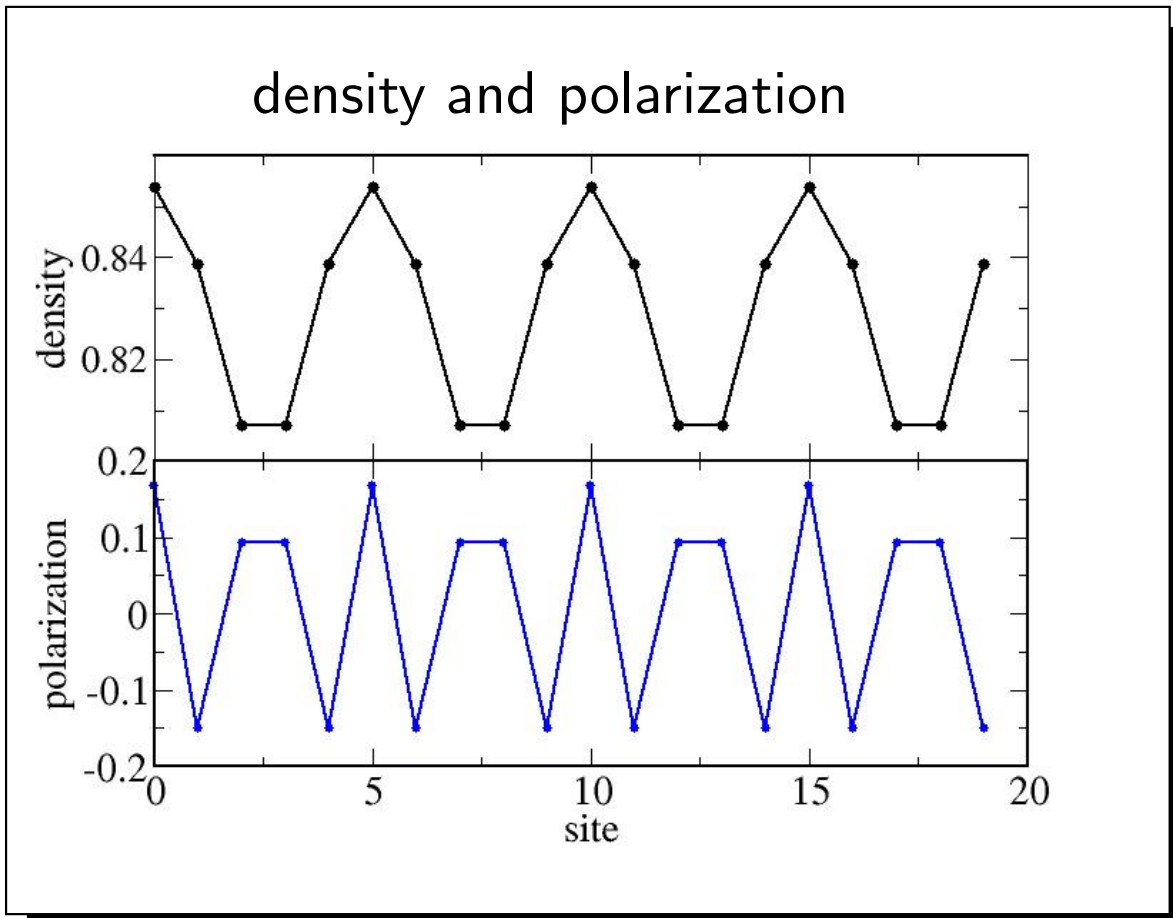

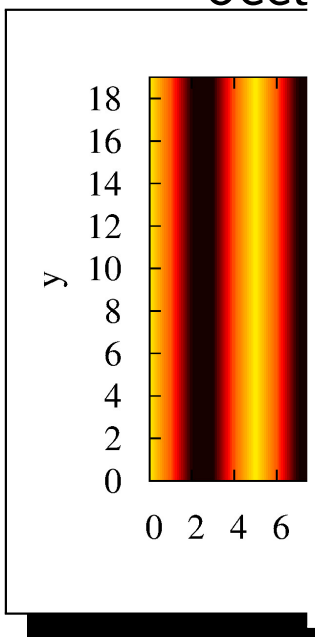

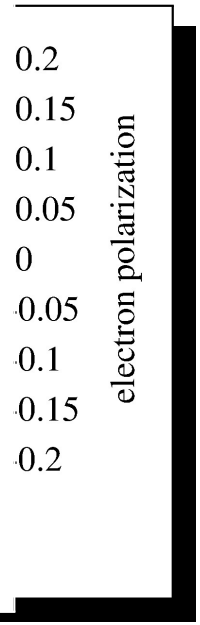

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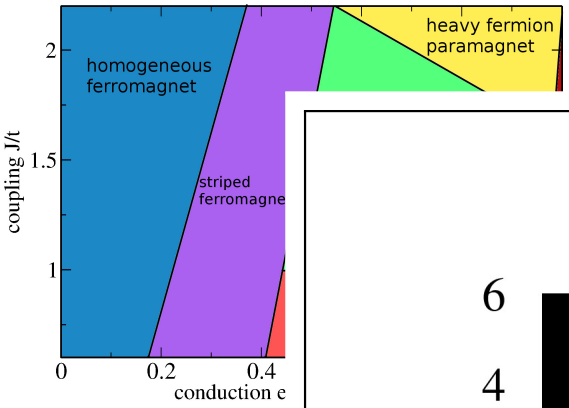

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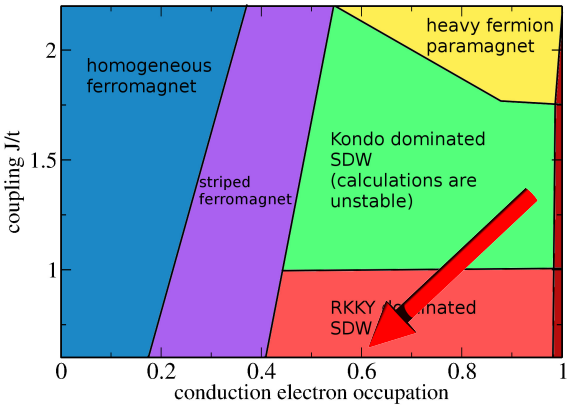

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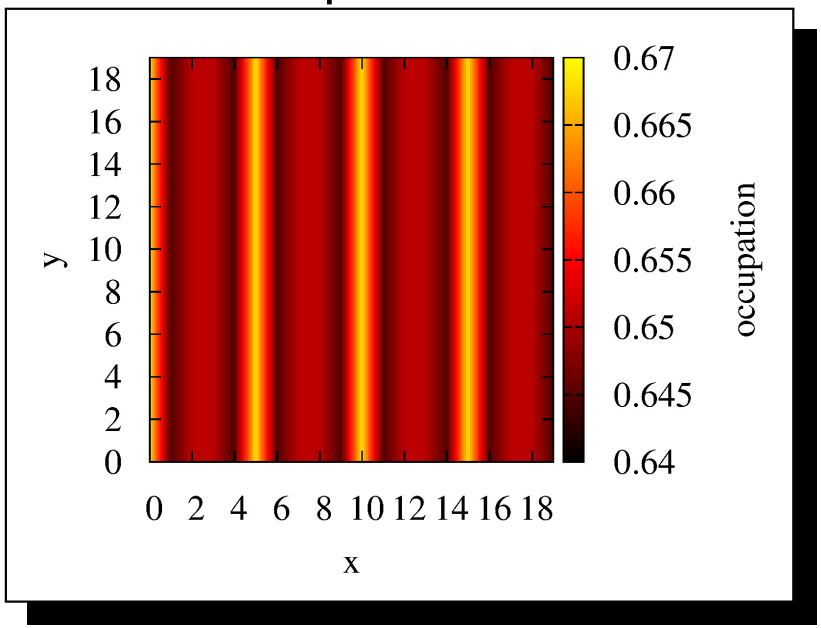
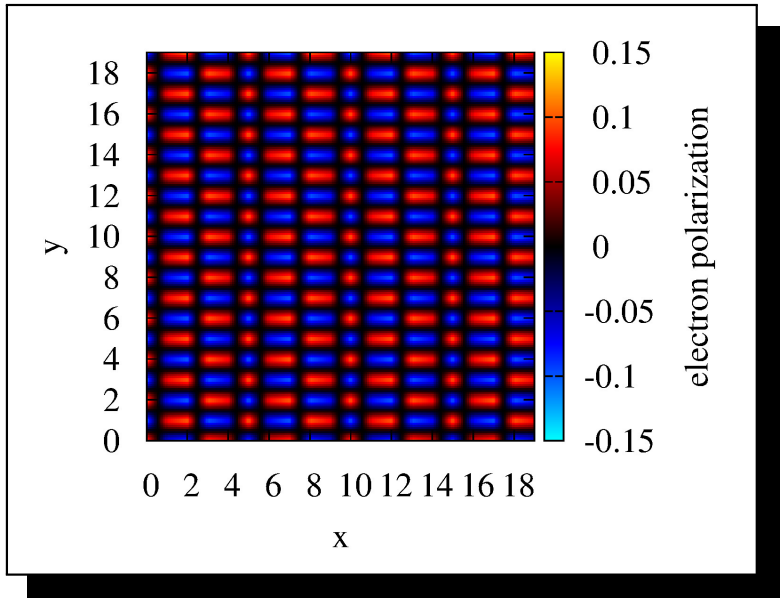


polarization



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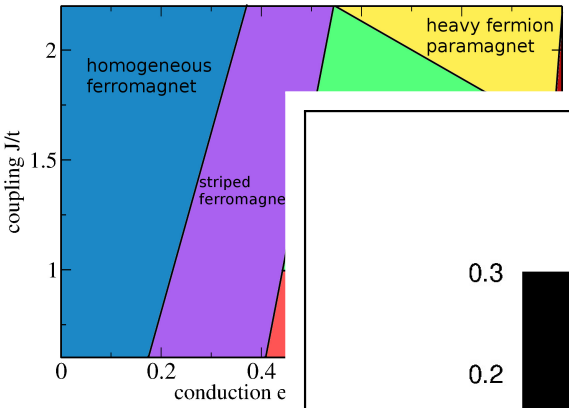

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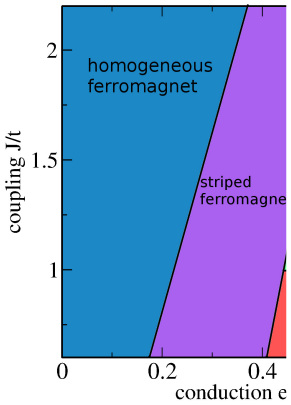

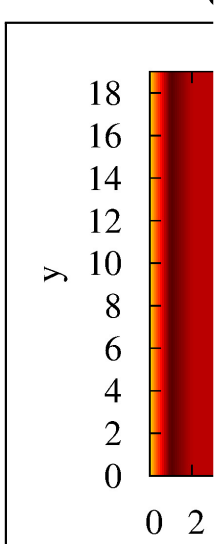

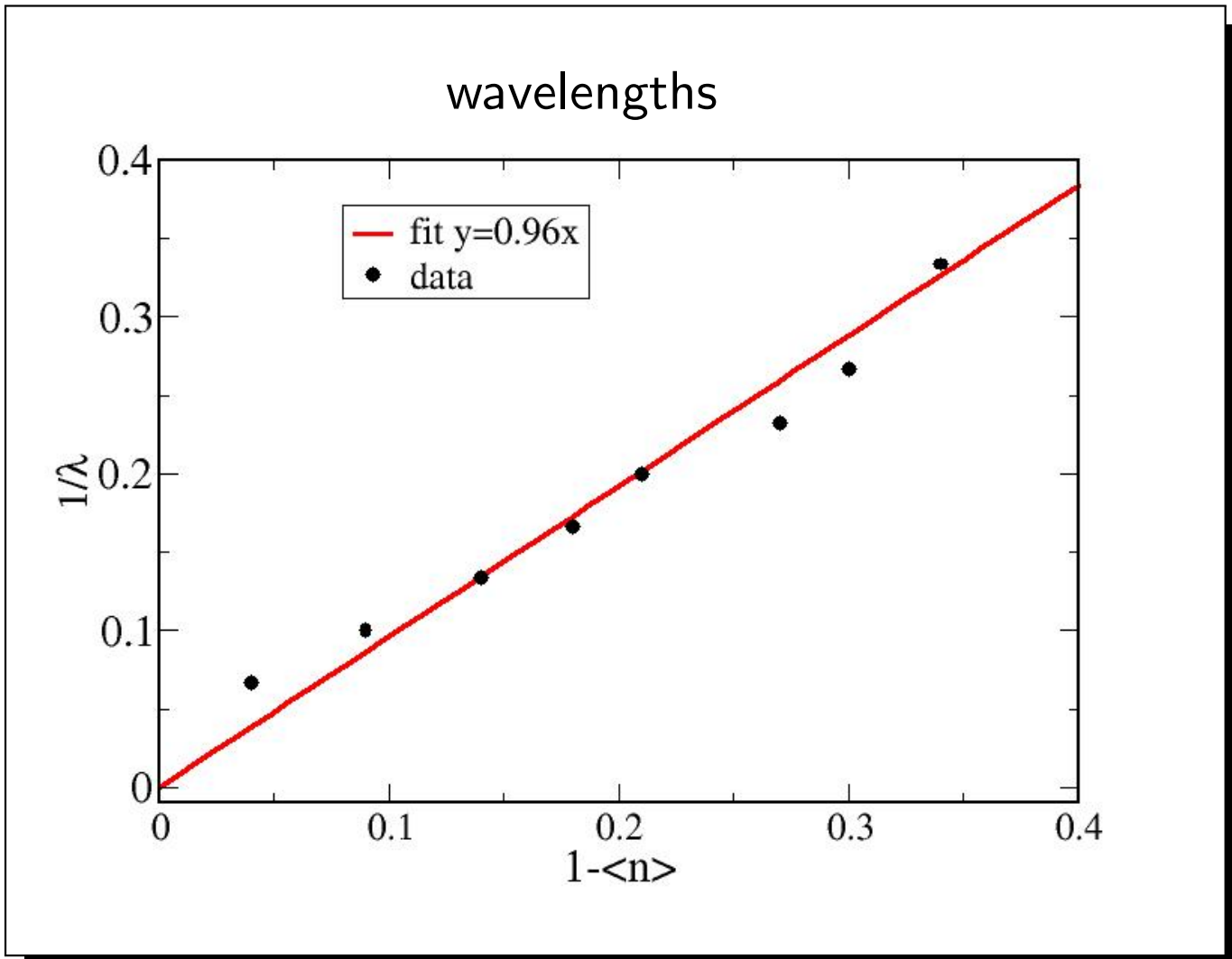

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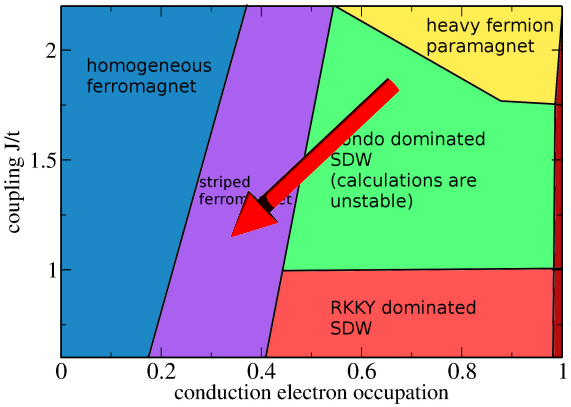
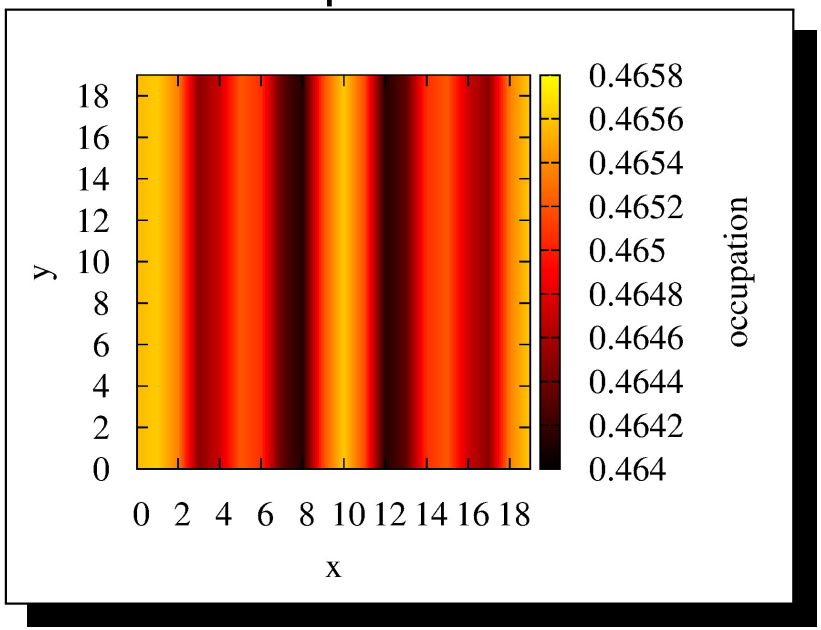
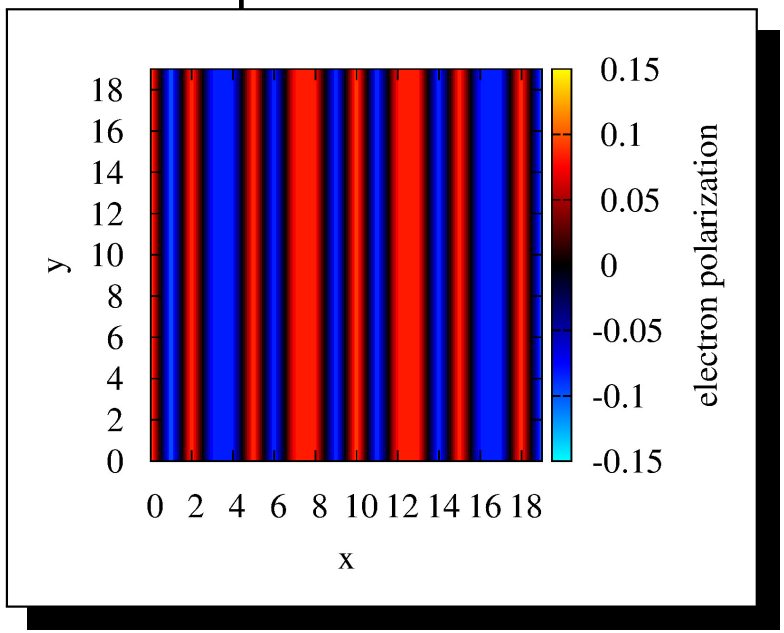


Striped ferromagnet

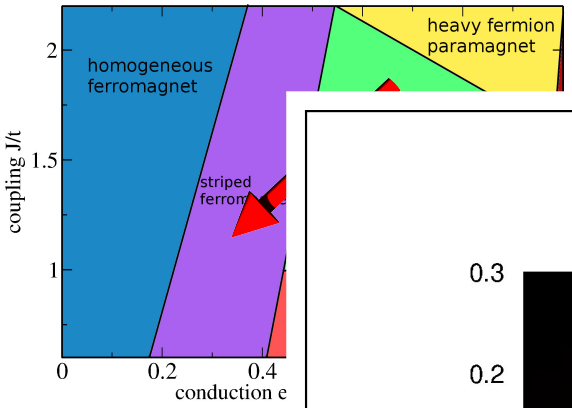
occupation



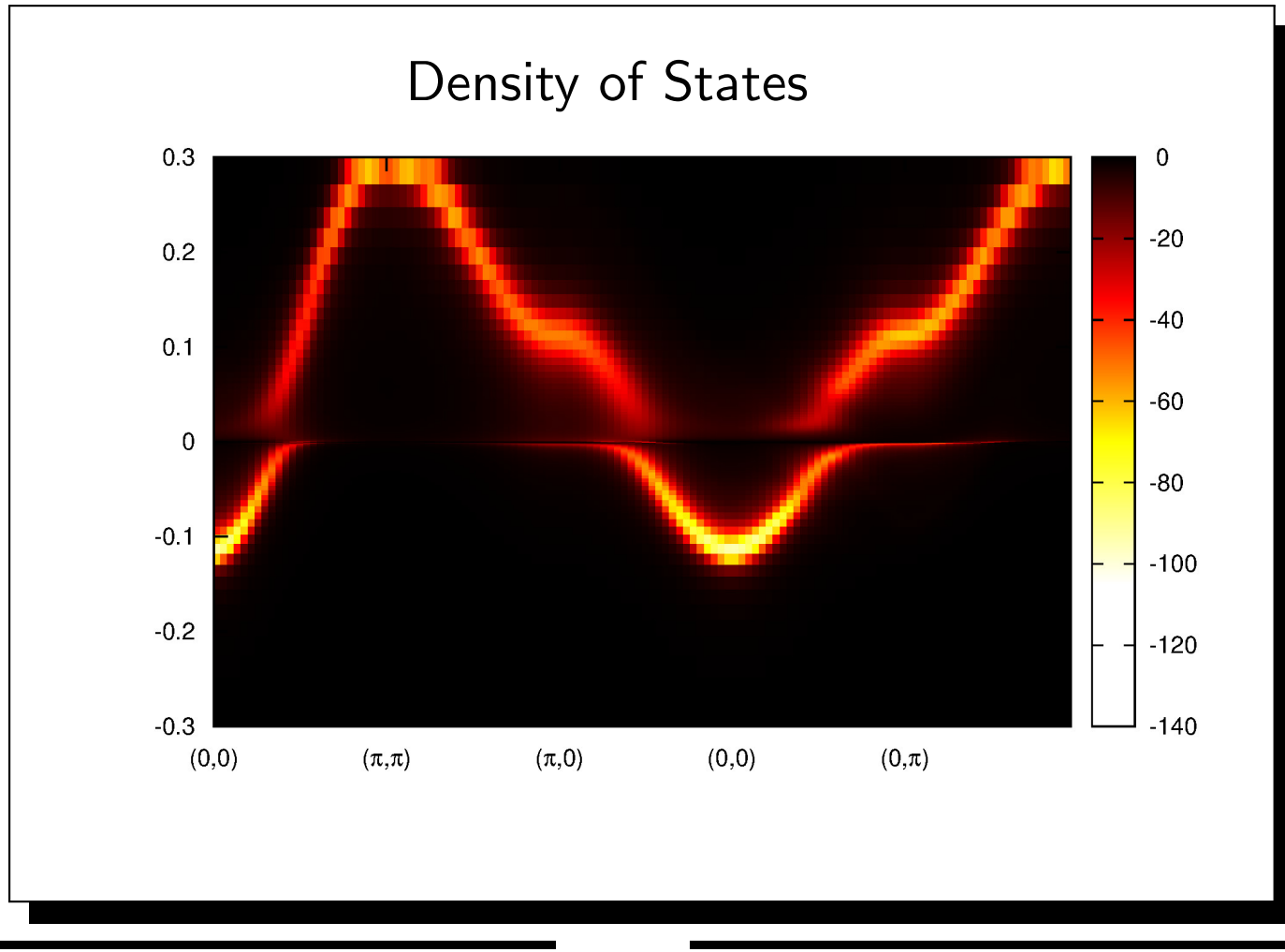
polarization

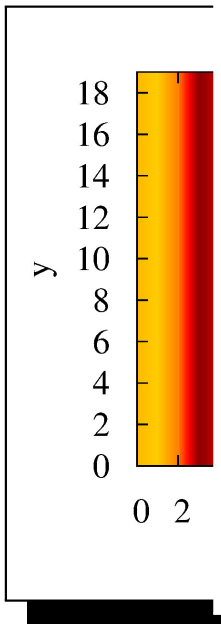


Magnetic phase diagram of heavy fermion systems



Striped ferromagnet





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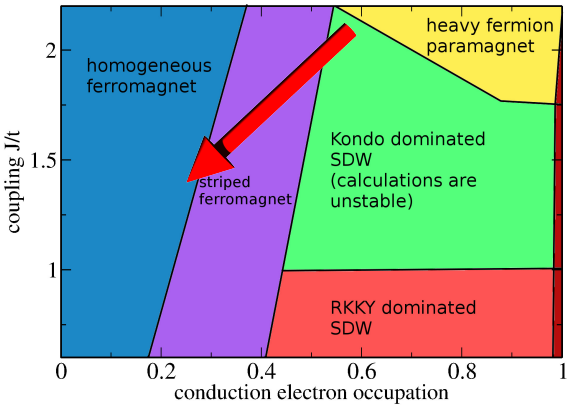
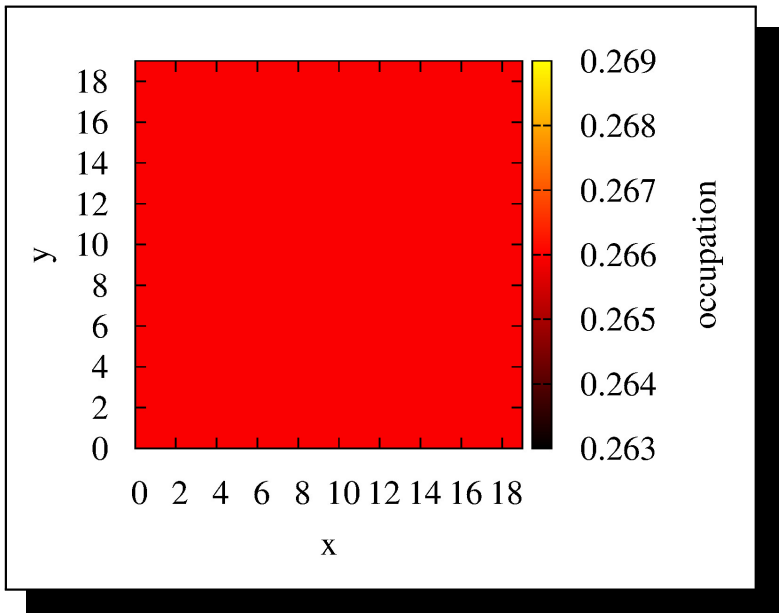


Ferromagnet

occupation



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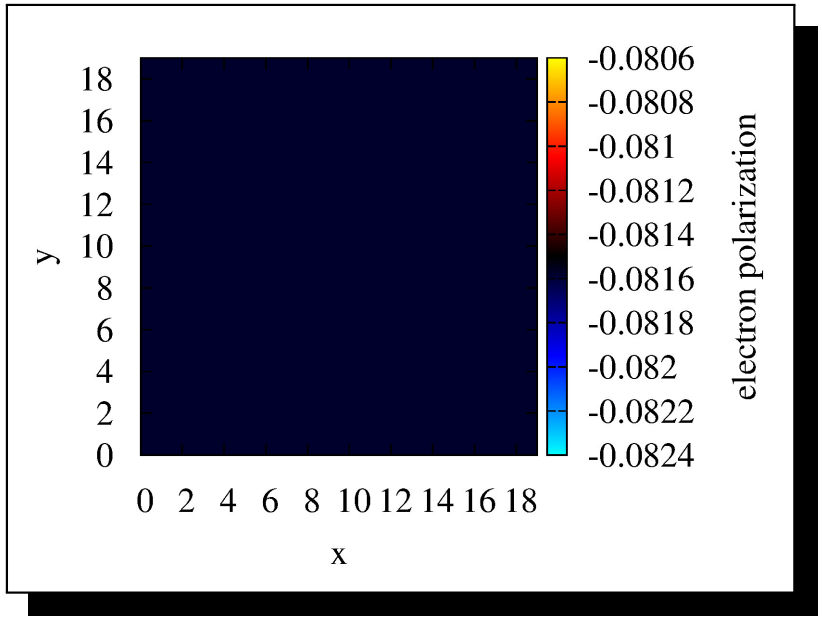

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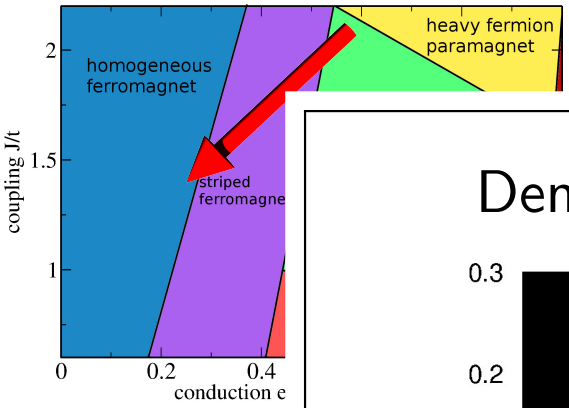
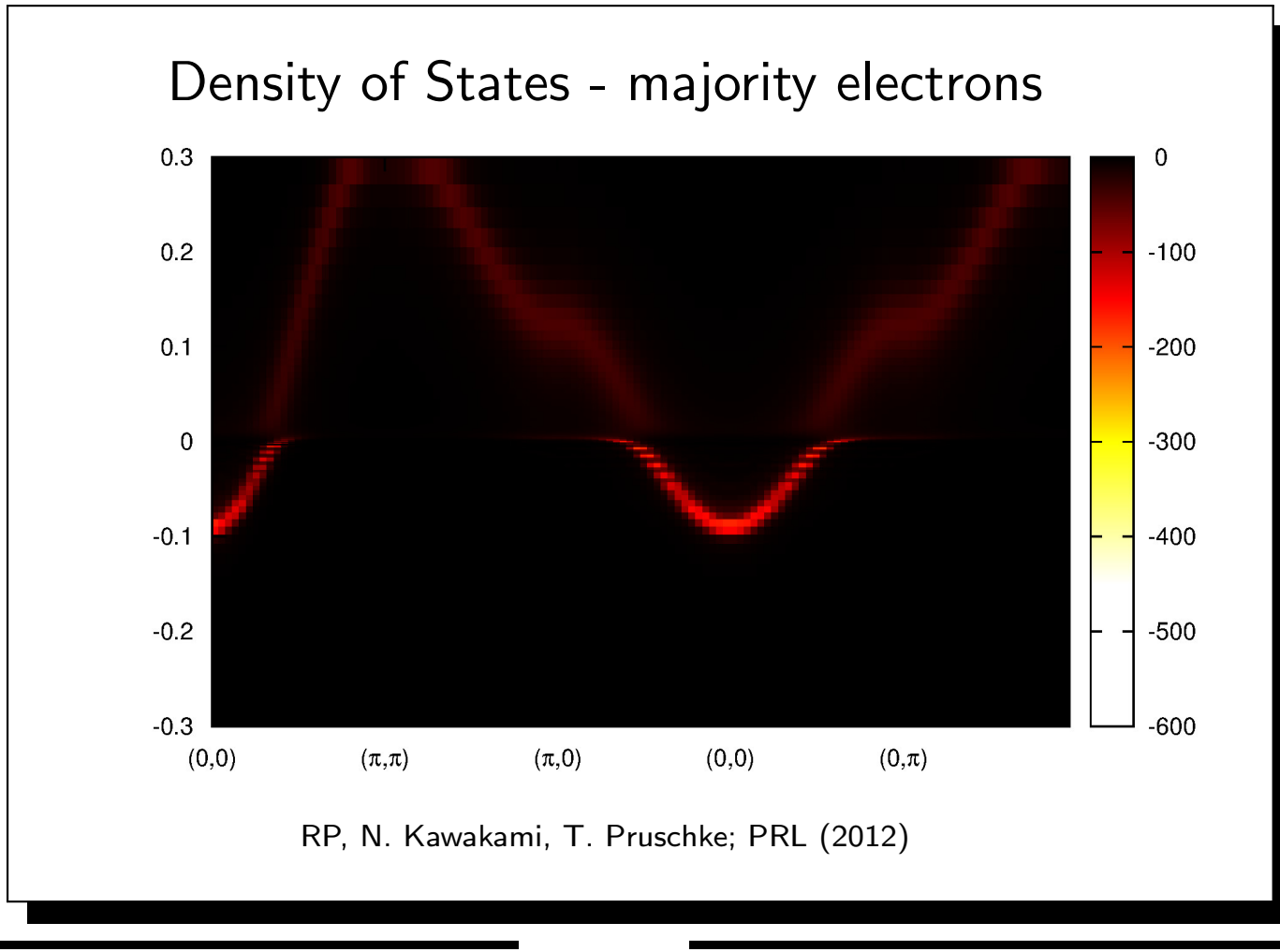


Ferromagnet



RP, N. Kawakami, T. Pruschke; PRL (2012)

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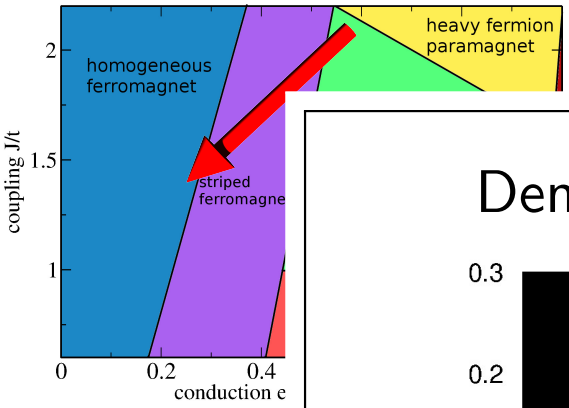

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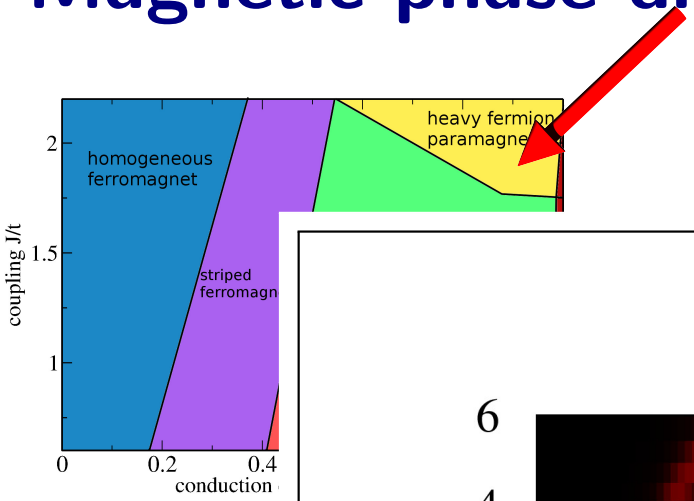
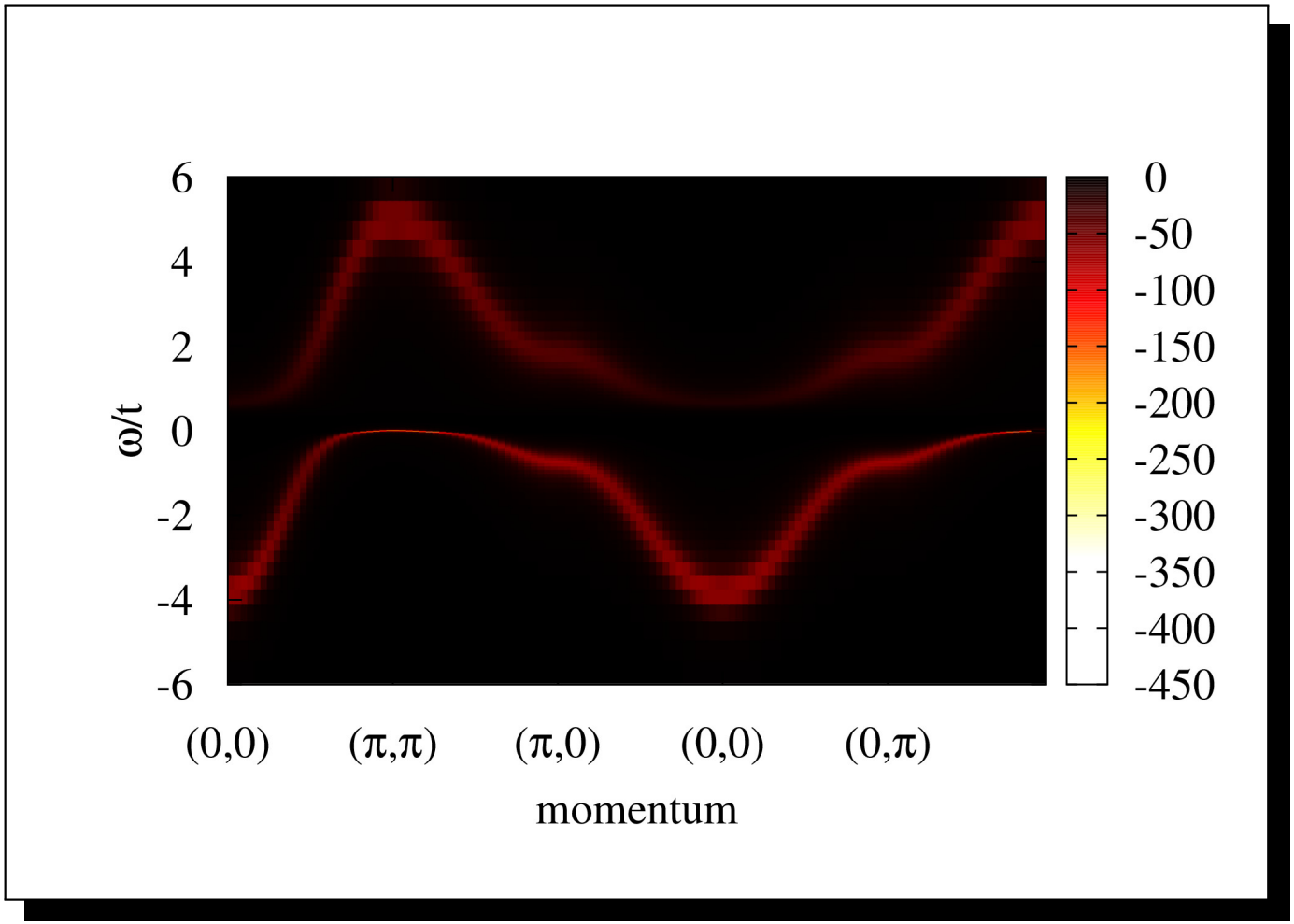


heavy fermion paramagnet



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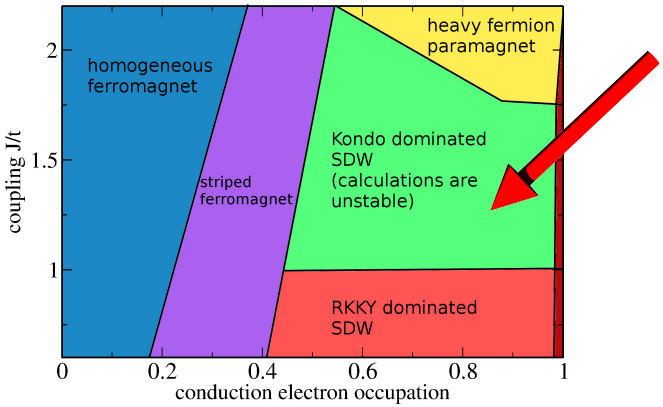
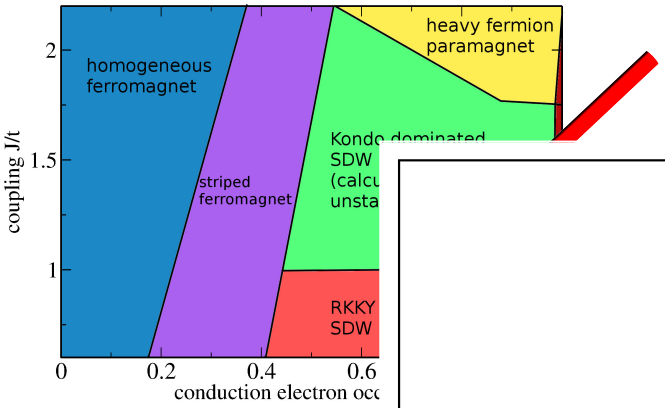


Kondo dominated SDW, close to QCP

NO CONVERGENCE

Magnetic phase diagram of heavy fermion systems



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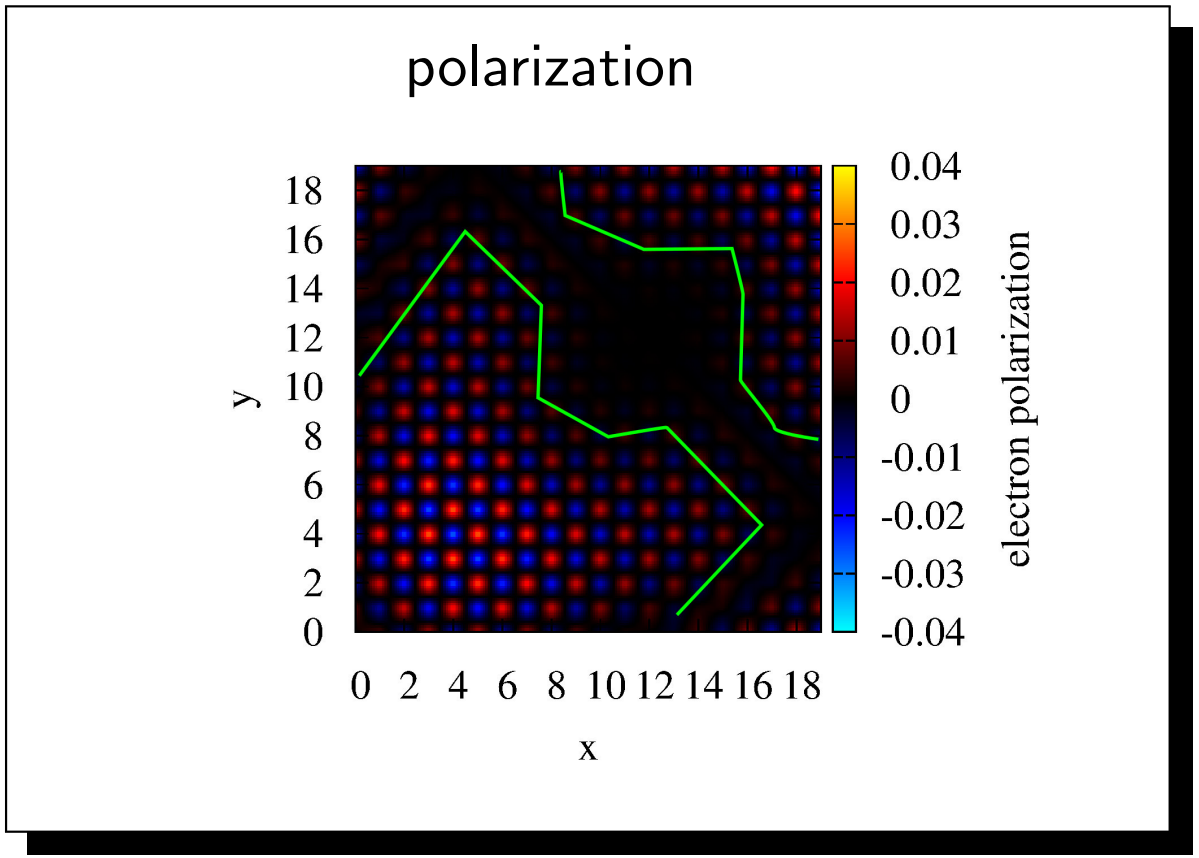

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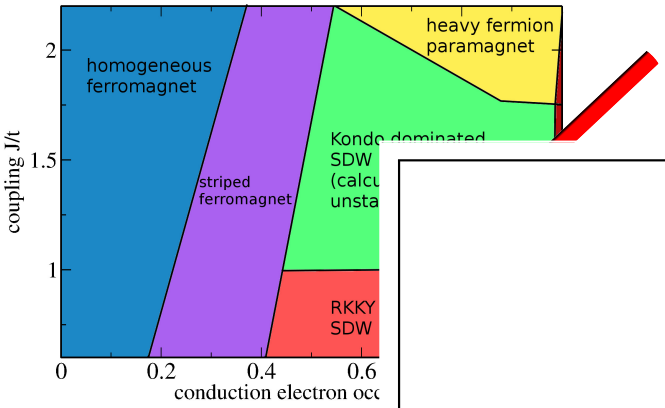

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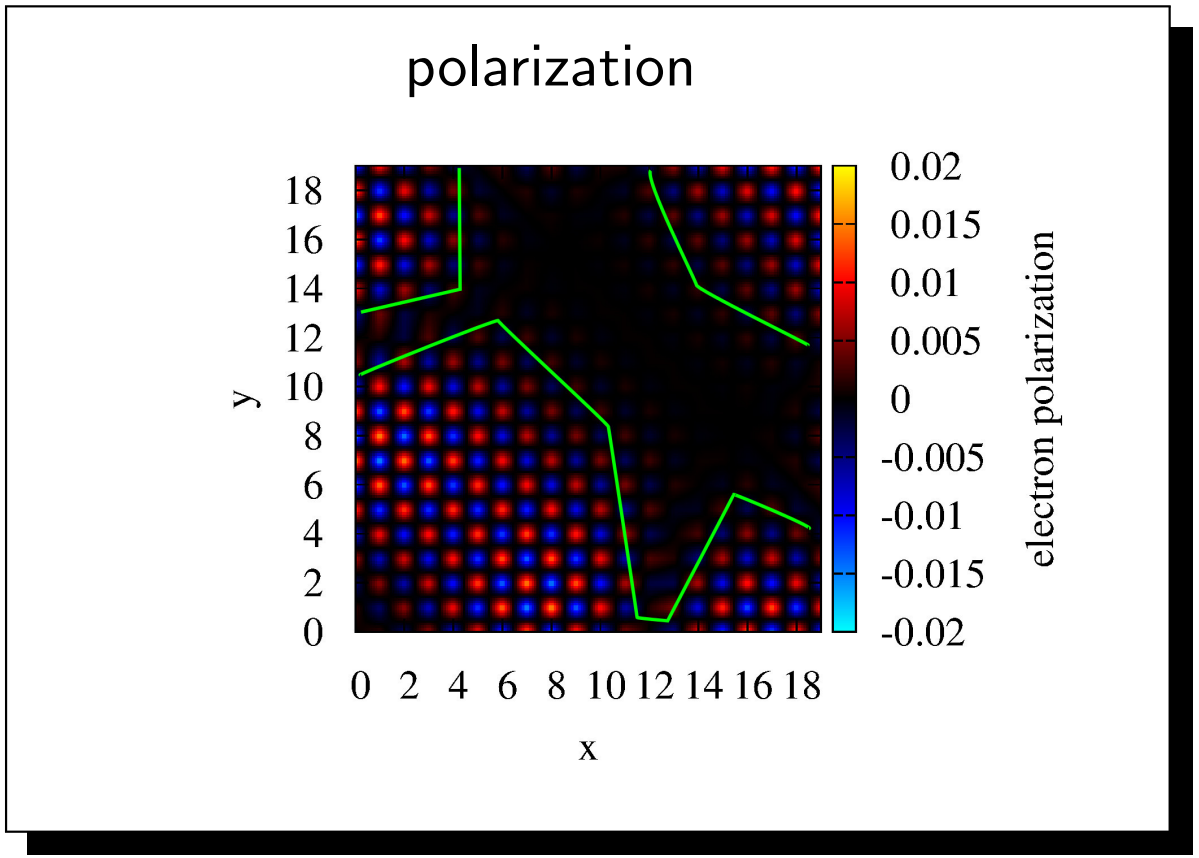

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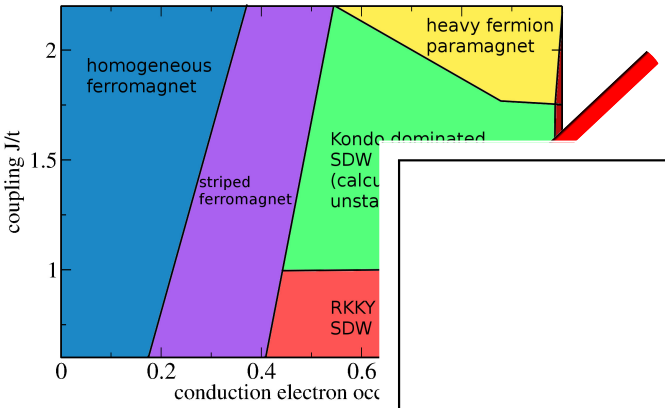
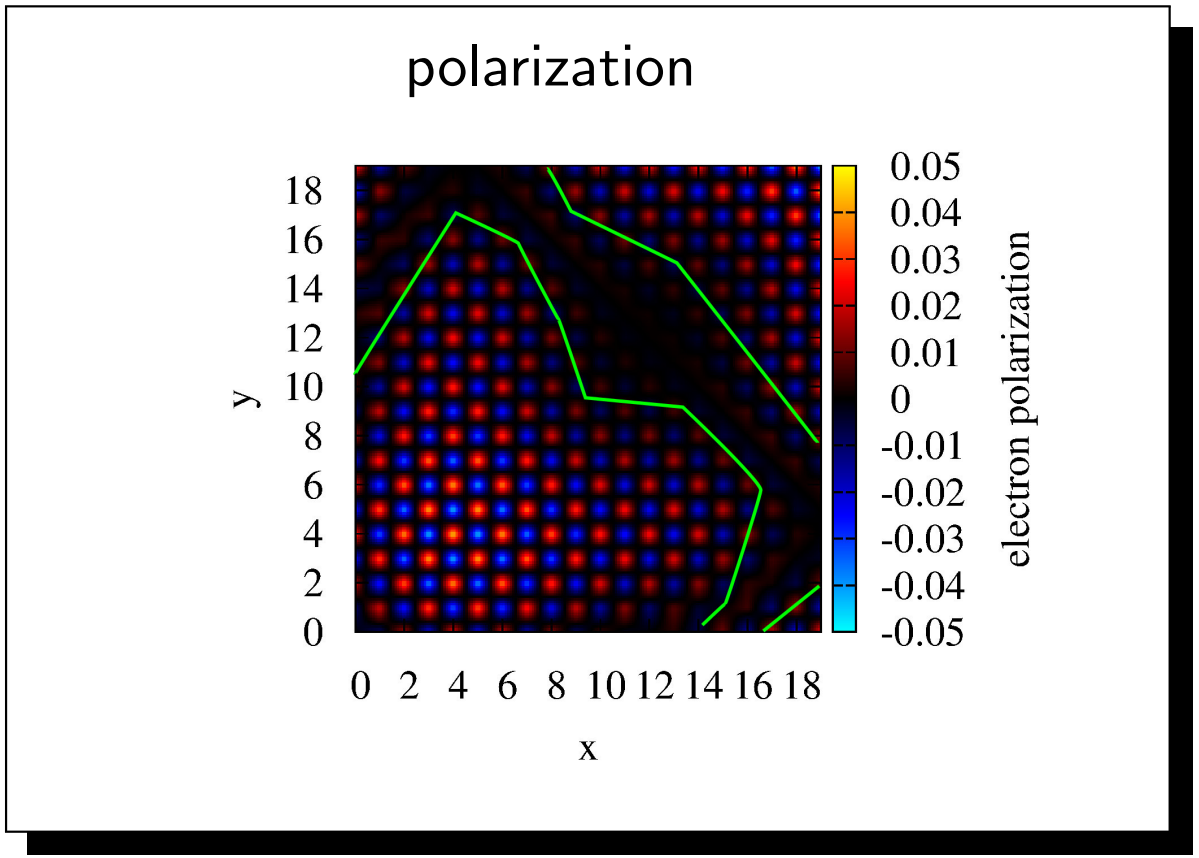
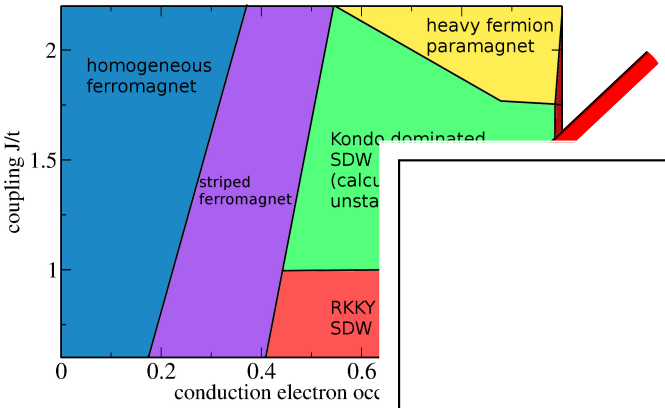


Kondo dominated SDW, close to QCP

NO CONVERGENCE



Magnetic phase diagram of heavy fermion systems



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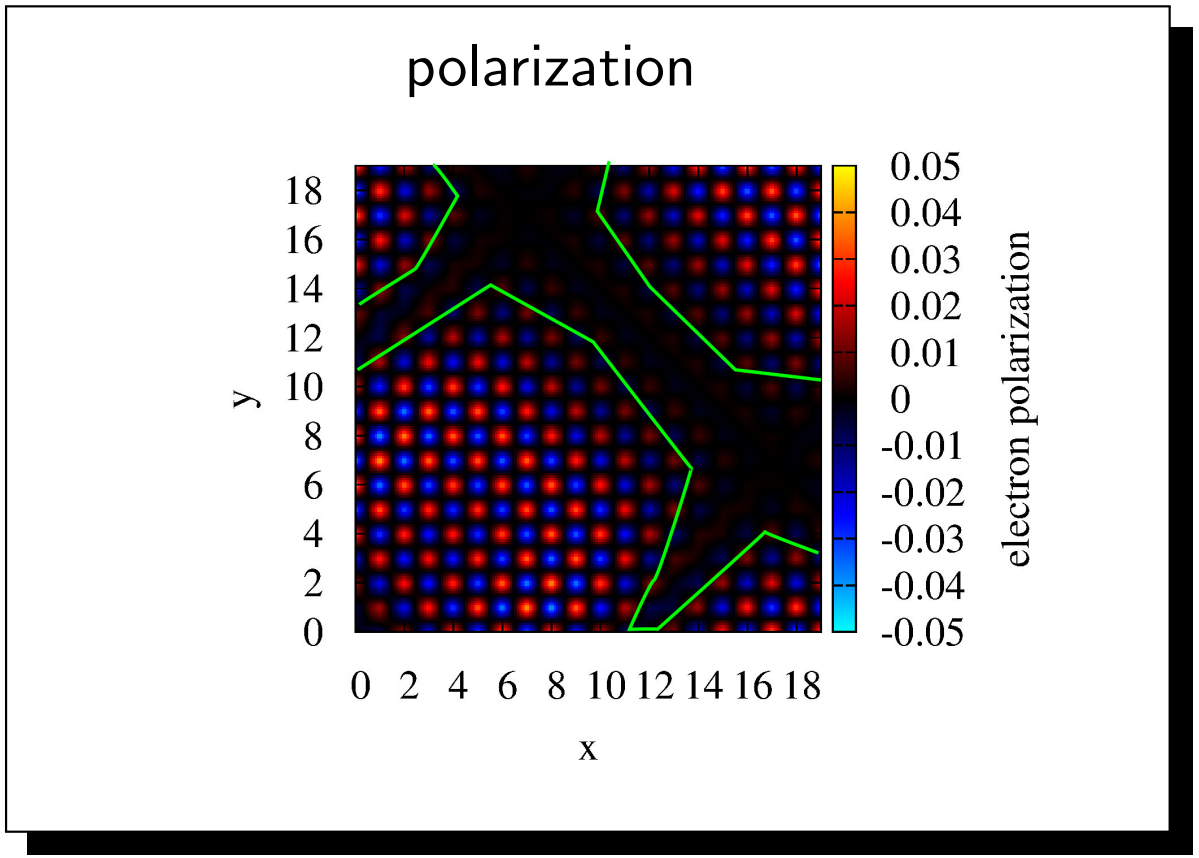

Summary

- By using the iDMFT, I have studied the magnetic phases of the Kondo lattice model
- There are several different types of SDW phases
- Such SDWs are a mixture of antiferromagnetic bonds and ferromagnetic bonds
- There are accompanied by a charge density wave.
- Close to the quantum critical transition, even iDMFT seems not to converge