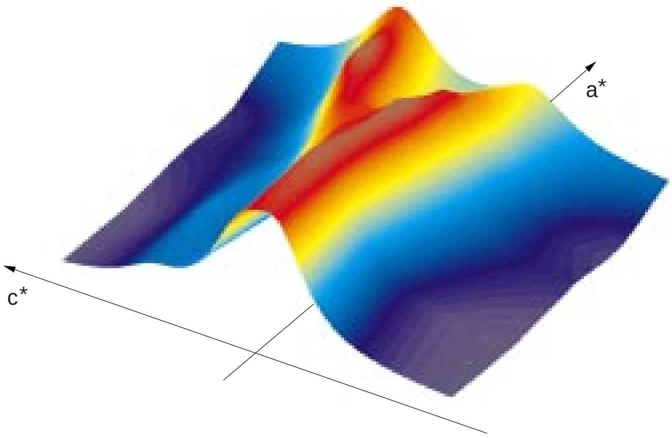
Fermi-liquid Instabilities in Correlated Metals (FERLIN)

An ESF scientific programme



The scientific programme Fermi-liquid Instabilities in Correlated Metals *(FERLIN) has been established in 1998 by ESF Member Organisations which contribute to the programme during a five-year period. The FERLIN programme offers different types of grants for both young and senior scientists to foster exchange and joint experiments, and organises workshops relevant to the programme.*

The Steering Committee guiding the programme is composed of expert scientists nominated by ESF Member Organisations which contribute to the programme.

The FERLIN programme addresses one of the key questions in solid-state physics:

What are the conditions under which a metal exhibits strong deviations from the standard behaviour of independent electrons that often holds even for interacting electrons described as a Fermi liquid?

These deviations, leading eventually to an instability of the Fermi liquid may have different microscopic origins.

The programme will investigate a variety of different materials with systematic combined research efforts including macroscopic and microscopic measurements, in order to better understand Fermi-liquid instabilities in correlated metals.

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

The standard model for metals: Fermi liquid

The standard model of conduction electrons in metals presumes that the interactions among electrons can be described by a few parameters, leading to effectively independent quasiparticles that can be treated within the framework of Fermi-liquid theory. Even heavy-fermion systems - metals with a high concentration of rare-earth or actinide elements such as Ce, Yb, or U - can be regarded as Fermi liquids. The strong interactions between electrons in these materials lead to a very large effective mass m* derived from the huge linear electronic specific-heat coefficient $\gamma = C/T$ and a correspondingly large Pauli susceptibility, with $\gamma \propto \chi$ = const at sufficiently low temperatures T.

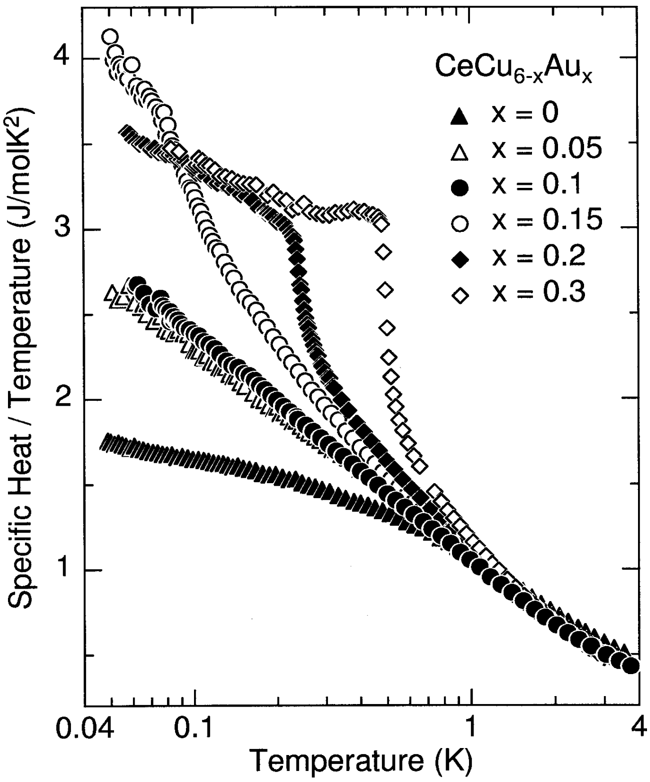
Fermi-liquid instabilities

Recently, striking deviations from Fermi-liquid behaviour have been found in several heavy-fermion systems, e.g. $\gamma \propto -\ln(T/T_0)$. In some cases, a linear T dependence for the electronic sepecific-heat coefficient of the electrical resistivity is found instead of the Fermi-liquid T^2 dependence. This non-Fermi-liquid (NFL) behaviour may have different microscopic origins such as the single-ion quadrupolar Kondo effect, a collective effect caused by the incipient antiferromagnetic order or simply a distribution of Kondo temperatures arising from disorder. The scenario of incipient magnetic order is exemplified in $CeCu_{6-x}Au_x$ where concentration and pressure tuning are employed to reach the quantum critical point where magnetic order is suppressed to absolute zero temperature. In other cases such as $CePd_2Si_2$ or $CeIn_3$ magnetism gives way to superconductivity upon approaching the critical point. 3*d* itinerant-electron systems such as MnSi and $ZrZn_2$, as well as some further heavy-fermion systems, follow a behaviour that can be explained in terms of spin fluctuations. U systems, on the other hand, are often described within single-ion models.

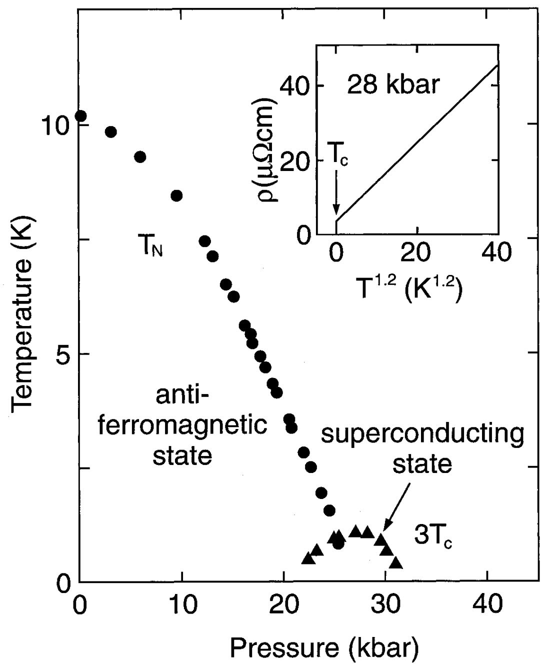
Scientific aims of FERLIN

The aim of the project is to delineate the similarities and differences of the different classes of metals with strong electronic correlations exhibiting Fermi-liquid instabilities by a variety of macroscopic (thermodynamic and transport) and microscopic (neutron scattering, μSR) measurements. This should allow us to make a definite assignment of the non-Fermi-liquid behaviour in a given system to one of the above scenarios and to shed light on the microscopic origin, in particular on the type of excitations that are responsible for NFL behaviour at the critical point.

Specific materials will be prepared - mostly in single-crystalline form - and investigated with the various techniques available by a collaborative effort of leading European laboratories. Microscopic probes such as neutron scattering are necessary in addition to detailed macroscopic measurements in order to identify the relevant magnetic fluctuations causing NFL behaviour. An interesting comparison between Ce compounds (one 4*f* electron) and Yb compounds (one 4*f* hole) is possible with pressure tuning. In Ce compounds a transition from magnetic to nonmagnetic state occurs with increasing pressure, while for Yb compounds this transition occurs with decreasing pressure.



Specific heat C of single-crystalline $CeCu_{6-x}Au_x$ divided by temperature T, plotted vs. T on a logarithmic scale. The onset of magnetic ordering for $x \geq 0.15$ is visible as a kink. For x = 0, C/T levels off towards a constant for low T. Near the critical concentration x = 0.1, C/T varies logarithmically with T, signalling non-Fermi-liquid behaviour (H. v. Löhneysen, J. Phys.: Cond. Matt. 8, 9689 (1996)).



Temperature-pressure phase diagram of a high-purity single crystal of $CePd_2Si_2$. Superconductivity appears below T_c in a narrow window where the Néel temperature T_N tends to absolute zero. For clarity, the values of T_c have been scaled by a factor of three, and the origin of the inset has been set below absolute zero (N. Mathur et al., Nature 394, 39 (1998)).

Another issue of considerable importance is the influence of disorder on the NFL properties. Disorder may play a role at two different levels: First, in a disordered alloy, a distribution of Kondo temperatures is possible due to different local environments. The incoherent superposition of local Fermi liquids may lead to NFL behaviour. Second, disorder is known to influence the critical behaviour of classical phase transitions. Its influence on quantum phase transitions is yet to be determined. We will address this problem by a comparison of NFL behaviour of stoichiometric compounds and alloys with substitution on magnetic and nonmagnetic sites.

The intriguing observation that magnetism gives way to superconductivity approaching the critical point where magnetic order is suppressed may suggest that superconductivity is mediated by spin fluctuations instead of lattice vibrations in classical superconductors. A detailed study of the properties around the magnetic instability is required to lead to a microscopic understanding.

Ferlin activities

Workshops

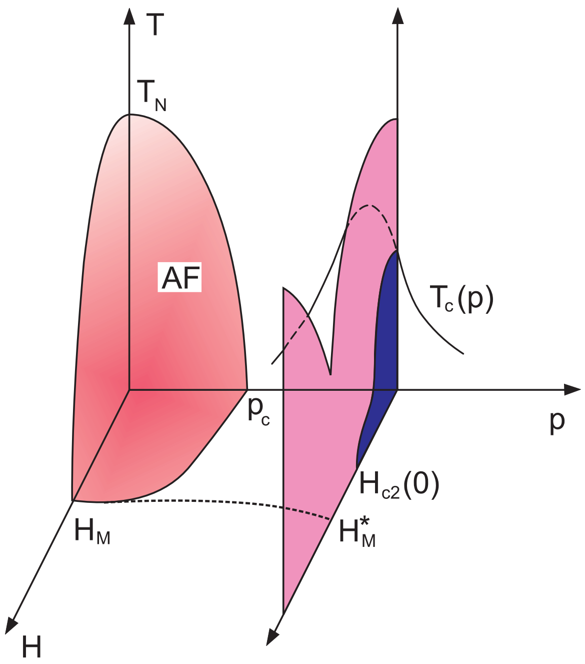
The Steering Committee organises International Meetings which will be held about once a year. The first International Meeting was held on September 23 - 25 1998 in Bad Herrenalb, Germany, with 55 participants from 11 countries. The next Meeting is planned to be held in January 2000 in Cambridge, England. In addition, workshops are organised on specific aspects of the FERLIN programme such as specific experimental techniques or theoretical models. The first workshop was devoted to high-pressure techniques. The Steering Committee invites proposals from potential organisers on topics with a clear connection to the scientific goals of the FERLIN programme.

Short-Term Fellowships

These are for qualified young scientists (normally under the age of 35), who need further training and expertise in other experimental methods for a fruitful continuation and broadening of their research scopes. Short-term fellowships are intended to facilitate the transfer of knowledge and techniques relevant to research from one laboratory within Europe to another (one contributing country should be involved). The grants are for a period of up to six months and the amount will be between 7000 and 9000 FF per month plus travel allowance. Selection rounds are March 1, June 1, September 1, and December 1 of each year. Applications should reach the ESF office prior to the corresponding date.

Short Scientific Visit Grants

These cover the costs of short visits (up to one month) of researchers working in the area of the FERLIN programme, in order to carry out joint experiments or theoretical work. Applications for short scientific visit grants are possible at any time and should at least involve one contributing country.



Generic temperature-pressure-magnetic field (T, p, H) phase diagram of an antiferromagnetic heavy-fermion compound. At H = 0, long range antiferromagnetism (AF) disappears above a critical pressure p_c leading to a magnetic quantum critical transition just near p_c.

Superconductivity with a pressure-dependent $T_c(p)$ occurs near p_c in several systems. Dark blue area indicates the superconducting region upon application of a magnetic field, limited by the upper critical field H_{c2}. Light blue area indicates temperatures and fields up to which magnetic correlations are observed.

In the case of heavy-fermion systems, the different phases can often be achieved with moderate magnetic field ($\mu_0 H \sim 10$ T) and pressure ($p < 100$ kbar). The experiments are performed at low temperatures extending down to 10 mK (J. Flouquet, private communication).

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For the latest information on this programme consult the FERLIN home page (http://www.esf.org/FERLIN)

Cover picture:
Contour map of the neutron scattering intensity in the a*c* reciprocal plane of $CeCu_{5.9}Au_{0.1}$ at an energy transfer of 0.1 meV measured at T = 70 mK. The anisotropic pattern with elongations along particular directions suggests quasi two-dimensional short-range fluctuations in real space, which would account for the logarithmic temperature dependence of the specific-heat coefficient [adapted from O. Stockert et al., Phys. Rev. Lett.80, 5627 (1998)].

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