B. Proposal Description and Role of Participants

1. OBJECTIVES AND ORIGINALITY OF PROJECT

1.1 Objectives and advances:

Highly **c**harged **i**ons (HCI) play an important role in different fields of science, e.g. in atomic physics, surface science, plasma physics, nuclear physics and astrophysics. Recent years have seen a breakthrough of the technological developments in the field of HCI research. The most advanced and most intense source of heavy HCI world-wide is the accelerator facility of the heavy-ion research institute GSI (see Fig. 1.1), where stable as well as radioactive heavy HCI can be investigated at MeV energies. The goal of the proposed HITRAP RTD network is the development of novel instrumentation for a broad spectrum of physics experiments with heavy HCI up to bare uranium (U^{92+}) at low energies (<1 eV/u) which can presently not be performed at any other institution using light or medium-heavy HCI or heavy HCI at MeV energies.

The new instrumentation will lead to new experimental possibilities in unique conditions:

- Ultimate accuracy due to cooling at cryogenic temperatures
- Highest sensitivity because of single-ion detection capability
- Highest electric fields up to 10^{16} V/cm in hydrogen-like uranium
- High atomic and nuclear polarization
- Clear theoretical situation in single-electron or few-electron ions

The novel instrumentation and prototypes to be developed include:

- Linear decelerator for deceleration of HCI from high energies (few MeV/u) down to rest
- Cooler Penning trap for capturing, cooling and accumulation of HCI at low energies (< eV/u)
- Experimental set-ups and detectors for investigation of the interaction of low-energy HCI with photons, atoms, molecules, clusters, surfaces, microstructures and solids

Within the proposed RTD network (Fig. 1.2), a linear decelerator will be installed at the Experimental Storage Ring ESR of GSI. At the GSI accelerator facility highly charged ions up to bare uranium (U^{92+}), produced by stripping an ion beam in a target foil, are injected into ESR and electron-cooled. After deceleration in the ESR, the HCI will be extracted from the ESR at an energy of 3 MeV/u and decelerated in the linear decelerator down to rest (Fig. 1.1).

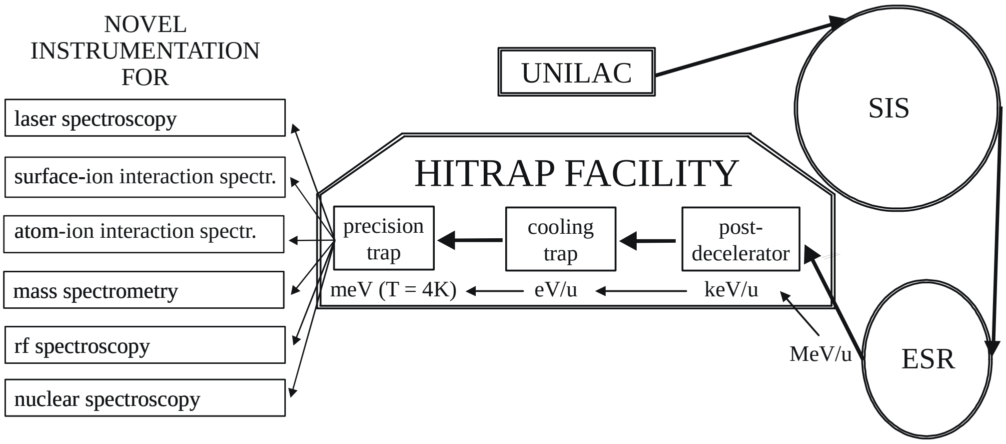

Fig. 1.1: Schematic of the GSI accelerator and the HITRAP facility with an overview of the novel instrumentation for the HITRAP physics programme. The HITRAP facility shown is an approved Midterm Project at GSI and is a follow-up of the related TMR network EUROTRAPS (ERBFMRX-CT97-0144) and of the RTD network EXOTRAPS (ERBFMGCET980099) focusing on experiments and instrumentation for trapped exotic species at accelerators.

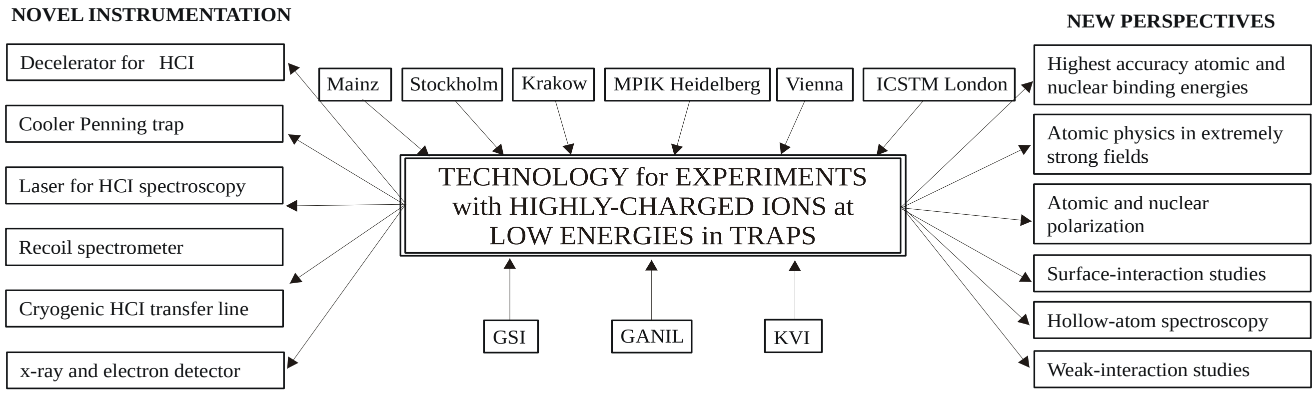

Fig. 1.2: The collaborative effort between the three Large Scale Facilities and European research institutes will lead to novel instrumentation for experiments with highly-charged heavy ions at rest in space or at low beam energies with small emittance. This will open up new perspectives for atomic, nuclear and surface physics.

The linear decelerator will represent an upgrade of the existing accelerator facility at GSI by extending the energy range of HCI from MeV/u down to very low energies (< eV/u). The technological know-how gained at the HITRAP Facility will be of importance for other European accelerator facilities, in particular for future radioactive ion beam (RIB) facilities, for example SPIRAL at GANIL.

Experiments with HCI at well-defined low energies (< eV/u) require accumulation and cooling of the decelerated ions which will be achieved in a cryogenic cooler Penning trap. The stored HCI can be investigated in the trap itself or can be extracted from the trap at energies up to about 10 keV/q. A prototype of such a cooler Penning trap operating at liquid-helium temperature will be designed, constructed and installed after the linear decelerator. Cooling of trapped ions is a key issue for experiments on HCI at low energies. Cooling of heavy HCI (like U^{92+}) will represent a substantial step forward in ion trap technology. Other teams of the collaboration will be able to exploit the experience in trap technology for improving the operation of their ion beam facilities.

With the novel techniques of deceleration and cooling of HCI which will be developed in context with the proposed RTD project, experimental studies on slow HCI up to U^{92+} interacting with photons, atoms, molecules, clusters, surfaces, microstructures and solids can be performed for the first time. For these collision studies with slow HCI an upgraded type of reaction microscope will be designed and constructed for detection of all reaction products (recoil ions, electrons, photons). The low emittance of the beam of slow heavy HCI extracted from the cooler Penning trap will make it possible to perform a new generation of collision experiments with substantially increased momentum resolution and kinematically complete detection of the reaction products. The formation of ”hollow atoms”, i.e. multiply excited states of HCI, which are created when HCI approach a surface at close distance or are injected into a microcapillary, is of particular interest. The encounter of a HCI with a surface leads to multiple emission of particles like electrons and photons. Because these particles are emitted virtually at the same time, the development of suitable fast particle detectors will give a push to present detector technology.

In addition to the collision experiments described above, high-accuracy atomic physics experiments on trapped HCI are part of the experimental programme of the proposed RTD project. The measurement of the g-factor of the bound electron in hydrogen-like ions is a stringent test of Quantum Electrodynamics (QED) calculations in extremely strong electromagnetic fields. The precision Penning trap (Fig. 1.1) has been developed within the highly successful TMR network EUROTRAPS (ERBFMRX-CT97-0144). First g-factor measurements on light hydrogen-like ions have been performed with an accuracy of 10^{-9} in the precision Penning trap. The potential of this set-up for high-accuracy mass measurements has been demonstrated with a resolving power of 10^9. At the HITRAP

Facility, such g-factor measurements can be performed up to the heaviest hydrogen-like ions where the product of proton number and fine structure constant ($Z\alpha$) approaches unity. Also atomic binding energies of HCI will be determined by measuring the masses of highly charged ions in different charge states with an accuracy of 10^{-10}. This represents a crucial test of QED calculations and atomic structure theories in extreme electromagnetic fields.

Finally, high-accuracy laser spectroscopic studies of trapped HCI are foreseen at the HITRAP Facility. The measurement of the hyperfine level Zeeman splitting in the ground state of hydrogen-like ions will yield nuclear g-factors with high accuracy. Measurements of the hyperfine splitting (HFS) in hydrogen-like ions in combination with the measured nuclear g-factor will give information about the distribution of the nuclear magnetization within the nucleus. The comparison of nuclear g-factors in hydrogen-like ions with the nuclear g-factors in neutral atoms will make it possible to test calculations of the diamagnetic shielding correction for the first time. Moreover, the manipulation of trapped radioactive ions with laser light opens possibilities to study questions of the Standard Model of fundamental interactions in a unique way at the HITRAP Facility. By optical pumping within the HFS levels of the ground state, the nuclear spins of radioactive nuclides can be polarized with high efficiency. The detection of the asymmetry of beta decay, for example, will allow one to explore the V-A-structure of the weak interaction and to set limits for the masses of heavy bosons which are not included in the Standard Model. These experiments will give exciting perspectives at the border-line between atomic and nuclear physics.

The physics programme of the HITRAP project was discussed on a workshop in 1997 (”New Prospects for Atomic Physics at GSI: HITRAP, Experiments with Highly Charged Ions at Rest or Low Energies”, 120 participants) and on the subsequent Joint Collaboration Meetings in 1998 – 2000 of the EUROTRAPS and EXOTRAPS networks.

1.2 ***Current international state-of-the-art***

Experimental studies of the interaction of slow highly charged ions with surfaces and solids have been performed in Europe only for moderately high charge states. Higher charge states have so far only been investigated at Lawrence Livermore National Laboratory, however, with very low intensity for the very heavy ions. With the proposed RTD project it will be possible for the first time to perform studies of slow heavy HCI with well-defined charge state and low emittance up to bare uranium (U^{92+}) interacting with surfaces where the kinetic energy at the surface due to the image acceleration strongly dominates over the incident kinetic energy. Also collisional studies of HCI with atoms, molecules and clusters have been performed only with medium-heavy HCI in the energy range up to about 100 keV/q where the HCI were delivered by ECR and EBIS sources.

High-accuracy mass measurements with an accuracy of $\delta m/m = 10^{-9}$ or even better on HCI up to $Z = 8$ have been performed by a group at the University of Washington. The SMILETRAP group in Stockholm recently measured the masses of moderately charged ions up to caesium ($^{133}Cs^{37+}$) in the frame of the related TMR network EUROTRAPS. The only g-factor measurements on highly charged ions ($Z = 6$ and $Z = 8$) were performed by the Mainz team. The RTD project will extend these measurements up to bare uranium (U^{92+}). Laser cooling and spectroscopy on singly charged ions in traps were performed at different places in the world (Heidelberg, Seattle, Garching, Boulder) and also at London and Mainz. Laser studies of heavy hydrogen-like ions (e.g. $^{209}Bi^{83+}$) have been performed only at the storage the ring ESR at GSI. However, the planned measurements of nuclear magnetic moments and weak-interaction studies with laser-polarized highly charged ions can only be carried out on stored and cooled ions in a Penning trap. A crucial test of the calculated diamagnetic correction factor has never been performed.

2. *INCREASED ACCESS TO INFRASTRUCTURES*

2.1 Improvement of access

All three participating European Large-Scale Facilities in Nuclear Physics have a very active research programs in atomic and nuclear physics at accelerators. The structure of highly charged ions, their properties and their interaction with photons, electrons, atoms, molecules, clusters, surfaces, microstructures and bulk material are investigated in close collaboration with groups from universities and research institutes.

The intended RTD project will - for the first time - provide the instrumentation required for experiments with highly charged ions (stable and radioactive ones) up to uranium which have defined charge states q = 1+ ... Z+ and are nearly at rest in space with 0.1 eV/q or are available as ion beams having very low and adjustable velocities (up to about 10 keV/q) and low emittance.

The Penning trap for radiofrequency spectroscopy of single ions, the set-up for laser spectroscopy, the apparatus for recoil ion momentum spectroscopy (RIMS) and the set-up for hollow-atom and surface studies will be designed in such a way that they will represent prototypes for use at the participating research infrastructures and other institutions providing highly charged ions, like the Max-Planck-Institute for Nuclear Physics in Heidelberg where an electron beam ion trap (EBIT) is being developed. The design will allow for a variety of experiments requiring different, sometimes specialised equipment. In this way new user groups will be able to test new ideas for advanced experiments with highly charged ions in a relatively short time and at low costs. The threshold for starting such experiments will be significantly decreased, especially for newcomers.

In the case of GSI, the HITRAP Facility will provide about 10^6 charges per second, i.e. about 10^4 ions/s in the case of U^{92+} or 10^6 U^{92+} ions in a single shot every 100 s. This will be a unique facility enabling novel experiments in many fields of physics which are until now impossible elsewhere in the world. Since the HITRAP Facility will only use 2% of the beam accelerated by the heavy-ion synchrotron SIS, operation of HITRAP in parallel to other experiments will not present any problem except in the case that the Experimental Storage Ring ESR itself is used for another experiment. Hence, there will be a considerable extension of the GSI access in quality and quantity which is essentially "free of charge". In this way an efficient use is guaranteed of the decelerator/cooler complex and of the provided instrumentation for experiments with highly charged ions nearly at rest in space or at low energies.

CIRIL/GANIL and KVI Groningen want to take advantage of this collaboration to acquire the knowledge and technology of Penning traps, of slowing down and cooling of singly and multiply-charged heavy ions and want to implement advanced instrumentation for *atomic physics* experiments behind their ECR sources. This would contribute to upgrade the infrastructures of GANIL and KVI Groningen and in this way increase the access to these large-scale facilities.

The decelerator and the cooler Penning trap represent a new technology for manipulation of highly charged ions the concept of which will be also useful for future Radioactive Ion Beam (RIB) facilities. The cooling and trapping technologies by use of Penning traps as well as simulation codes for the ion motion developed within the HITRAP project will be very useful for *nuclear physics* at the GANIL and KVI Groningen facilities. A cooler trap might be used at GANIL either for low-energy or high-energy radioactive beams. At KVI Groningen, a trap facility for radioactive nuclides is planned and a grant application has been approved recently by the national funding agency. These planned extensions will again increase the access.

2.2 Exploitation of Results

Deliverables at the end of the project

The following new instruments will have been developed at the end of the project:

- A decelerator for highly charged ions up to uranium, making use of an interdigital H-mode (IH) structure or a radiofrequency quadrupole (RFQ) structure.
- A cooler Penning trap at cryogenic temperatures for accumulation, cooling and storing of highly charged ions. The ions can be separated according to charge state as well as to mass and delivered as dc or pulsed beam with an energy up to about 10 keV/q.
- A precision Penning trap at cryogenic temperatures for radiofrequency spectroscopy of highly charged ions. This set-up is being developed in the frame of the TMR network EUROTRAPS. It will enable the measurement of the g-factor of the bound electron in hydrogen-like ions and high-accuracy determinations of atomic binding energies.
- A beamline for transfer of the highly charged ions between the cooler Penning trap and the different experimental set-ups which operates at ultra-high vacuum by using cryogenic temperatures and decouples the vacua of the cooler trap and the instrumental chambers by ion-optical bending.
- A prototype of a vacuum chamber with a set-up for recoil ion momentum spectroscopy with detection of the recoil ion in coincidence with at least ten electrons and photons. A gas jet target has to be incorporated with highly efficient differential pumping in order to maintain the required vacuum in the cooler Penning trap.
- A prototype of a vacuum chamber with a set-up for hollow-atoms/surface studies. This set-up will be optimised for electron, photon, and x-ray spectroscopy. It should be flexible in order to allow one to perform also characterisation of the surface modification due to heavy-ion impact by scanning tunnelling microscopy or by detecting the ions sputtered from the surface.
- A position-sensitive x-ray detector with multi-hit capability and excellent energy resolution including read-out electronics, computer control and data acquisition system.
- An experimental set-up for laser spectroscopic studies of trapped highly charged ions. This set-up will make it possible to polarize the nuclear spins of the trapped radioactive ions for weak interaction studies (physics beyond the Standard Model), to determine nuclear magnetic moments with high accuracy and to check the purely theoretical diamagnetic correction factor for the first time.
- For the first time completely stripped or few-electron ions nearly at rest in space or at very low beam energies will be available for experiments resulting in a unique potential for a variety of new experiments not listed above including, for example, x-ray spectroscopy of radioactive nuclides.

Expected users of the results, within and outside the partnership

The participating institutes and new groups will use the set-ups resulting from this RTD project for precision radiofrequency measurements (g-factor of the bound electron, binding energies), for laser spectroscopy on trapped highly charged ions, for investigating collision dynamics and for hollow-atom/ion-surface studies. There is a large community performing already studies of this kind either with light highly charged or heavy, moderately charged ions at low energies from ECR, EBIS or EBIT sources or, alternatively, with highly charged ions at high energies at accelerators. The instruments developed within the HITRAP project have the following advantages as compared to existing facilities: choice of element and charge state, extremely low energies, small emittance and control of the direction of the extracted beam, high intensity of highly charged heavy ions.

The strong interest in such facilities has been demonstrated by the participants of the series of three Euroconferences "Atomic Physics with Highly Charged Stored Ions" (Heidelberg, 1995; Stockholm, 1996; Ferrara, 1997), the "International Conference on Highly Charged Ions" (HCI-98, Bensheim, 1998), and the "International Conference on Trapped Charged Particles and Fundamental Physics", Monterey, 1998). A workshop on ”New Prospects for Atomic Physics at GSI: HITRAP, Experiments with Highly Charged Ions at Rest or Low Energies” taking place at GSI on 21 July 1997, attracted 120 scientists who expressed there strong interest in such a facility. A second series of Euroconferences focuses on the research field ”Atomic Physics at Accelerators” (Mainz 1999, Cargese 2000, Aarhus 2001). The next "International Conference on Trapped Charged Particles and Fundamental Physics" will take place in 2002 near Munich.

New applications will evolve like x-ray and laser spectroscopy of stored ions, use of polarized radioactive nuclei for weak interaction studies, surface microprobe analysis by sputtering, nanotechnology using the cooled highly charged ions or storage of radioactive ions as provided at the three participating infrastructures. Hence, it can be expected that new users are attracted by providing them clean beams of highly charged ions and instruments for experiments.

Partnership policy

Techniques developed in the framework of this project will be freely available to all the partners and will be published in the open literature.

Other measures of exploitation and dissemination

The results of the RTD project will be presented at international conferences, in users meetings of the participating research infrastructures and will be published in journals. The World-Wide Web pages of the participating institutes will be used to make the achievements known to potential users. A call for proposals will inform potential users once the HITRAP Facility is operational.

Assessment of risks

The ion trap technology, the laser technology for atomic spectroscopy on trapped ions, the recoil ion momentum spectroscopy, and the instrumentation for spectroscopy of hollow atoms and for surface-ion interaction studies have been developed during the last years by the participating institutes, the former SCIENCE and the ongoing EUROTRAPS and EXOTRAPS networks. Especially demanding are, however, the requirements on the quality of the vacuum which ask for extreme care in selecting the materials to be used for installation.

For the first time, a decelerator for heavy ions will be realised within the intended project. Within GSI, there is great expertise on IH structures since GSI has built such a linac for the CERN heavy-ion injector as well as one for GSI which is now installed for replacing the Wideröe part of the UNILAC at GSI. If detailed ion optical calculations indicate severe difficulties in using such structures for deceleration, the RFQ structure developed at CERN for the Antiproton Decelerator (AD) would be a back-up solution. The RFQ decelerator at CERN has already been commissioned and successfully tested at the end of 2000. Decelerating antiprotons imposes similar requirements on ultra-high vacuum as that of highly charged ions.

3. INTEREST SHOWN BY INFRASTRUCTURE OPERATORS AND USERS

3.1 Benefit for infrastructure operators:

The infrastructures of the project will be operated by the Large Scale Facilities GSI, GANIL and KVI Groningen. **For GSI** the new infrastructure will substantially enhance the scientific potential of the already existing heavy-ion research facility. It will stimulate and push the current research activities with highly charged ions to a highest scientific and technical level. This is guaranteed by the attractiveness of the project which will bring together and merge the activities of many research groups. The techniques for high-accuracy mass and g-factor measurements were developed in the TMR network EUROTRAPS (ERBFMRX-CT97-0144).

For GANIL, the deceleration and cooling techniques developed in the project will be of particular interest. The ion beams delivered by its ECR ion sources (stable or radioactive), decelerated to very low energies with a small momentum spread, would open a very large research field for any user of the facility. In addition, the deceleration and trapping technologies could be used to improve the beam emittance at SPIRAL, the Radioactive Ion Beam Facility in construction at GANIL. GSI and GANIL developed techniques for accumulation and cooling of singly-charged radioactive ions in the RTD network EXOTRAPS (ERBFMGCET980099).

The **KVI Groningen** group will benefit essentially by getting access to experiments with very heavy highly charged ions. Experiments of this group were supported within an earlier TMR network (Interaction of slow highly charged ions with solid surfaces: ERB-CHRX-CT93-0103) and can be extended by the new project to much higher charge states. Moreover, the KVI Groningen group will benefit from a strong cooperation within the HITRAP network, especially with the Stockholm group**.** This group will investigate ion-surface interaction with alternative ion scattering techniques. It will be a definite advantage to perform the various experiments under identical conditions in *one* apparatus, which will be designed and constructed in accordance to the needs of the users.

3.2 Potential benefits to research community:

The technological infrastructure to be implemented at the GSI HITRAP Facility will allow for unique experiments in various fields of physics dealing with highly charged ions. Classes of investigations become feasible far beyond those accessible at present ion sources, synchrotron radiation or intense laser facilities. At ultra-low velocities a correlated, intense flux of electrons from the target atoms, molecules, clusters or surfaces to the bare heavy ion occurs that can be investigated for the first time in kinematically complete experiments using advanced many-particle momentum imaging techniques (Reaction-Microscopes). Also electron transfer times can be precisely investigated over a hitherto unexplored range by varying the velocity of the ions from essentially zero to several atomic units. The phenomena of collective tunnelling and collective flux can be investigated in dependence of the potential barrier height between the target and the highly charged ion by measuring the collision impact parameter. In addition, many important and still unsolved questions, related to the modelling of laser-heated plasmas, can be addressed, for example, how the field energy is transferred to the target system or how effectively it is converted into kinetic energy, i.e. into thermal motion of the target constituents.

With the proposed facility interaction studies of very highly charged ions with surfaces and solids can be performed at low projectile energies in a systematic manner for the first time, comprising very high charge states up to bare uranium ions (U^{92+}). The interest of the research community in this field has been demonstrated by a recent review of the Livermore group (Schenkel et al.) on this subject which was published in "Progress in Surface Science". The new facilities to be installed at GSI are extremely interesting for studies of molecule production in collisions of heavy HCI with compound frozen gases which are of astrophysical relevance. The question concerning mechanisms for production of basic organic molecules in space, forming material for construction of biological cells, is still open. Heavy highly charged ions are expected to be very efficient producers of compound chemical radicals on the frozen surfaces of interstellar grains which form the material of comets and, finally, can be transported close to Earth. With the new infrastructure at GSI these astrophysical processes can be studied very effectively by means of mass spectrometry.

Moreover, precision spectroscopy of exotic atomic systems which enters deeply into the fundamental aspects of atomic structure should be performed, e.g. for He-like uranium ions. Investigations of such ions along the isoelectronic sequence probe uniquely our understanding of correlation, relativistic and quantum electrodynamical effects. It should be pointed out that for high-Z He-like systems, such information cannot be achieved at existing facilities. Strongly decelerated ions (keV/q – eV/q) will provide unique experimental conditions for almost Doppler-shift free spectroscopy. This advantage, combined with a new generation of position-sensitive solid-state detectors for x-ray radiation, warrants a considerable improvement of the currently reached precision in spectroscopy studies of high-Z ions. Construction of a new position-sensitive x-ray detector (for energy range 5-100 keV), as a part of the new infrastructure at GSI, is also crucial for precise estimation of lifetimes of exotic states in highly charged ions and for selection of particles in metastable states which, successively, can be applied in collision experiments relevant e.g. for surface physics. It may also be essential for identification of correlated many-electron processes in very slow adiabatic ion-atom collisions which go beyond the independent-particle approach.

Further on, questions of fundamental physics can be addressed by exploiting the potential of Penning traps which are widely used for precision measurements. We will improve the performance of Penning traps to increase the accuracy in the determination of atomic and nuclear magnetic moments as well as atomic masses and binding energies. For the first time, questions of the fundamental interactions of the Standard Model will be addressed by investigating radioactive ions in high charge states. The polarization of nuclear spins by laser excitation of the hyperfine transition in hydrogen-like radioactive ions is a novel method which will be an important enrichment for the active research field of fundamental-interaction studies. Present experiments in this field investigate neutral atoms or singly charged ions. Besides several recent workshops on these matters (Estoril, 1998; Leuven, 1998; London, 1999) the present status and future possibilities are documented in the proceedings of the conference ”Trapped Charged Particles and Fundamental Physics, Asilomar, 1998 (AIP Conference Proc. 457). The topics of other ongoing international workshops include: computer control, decelerators, cooling of trapped ions, rf quadrupole ion bunchers, gas control and impurities, weak-beam diagnostics, Penning traps, and simulation of ion optics.

Finally, the proposed instrumentation will offer unique experimental possibilities to the groups gathered in the TMR network EUROTRAPS (ERBFMRX-CT97-0144) and the RTD network EXOTRAPS (ERBFMGCET980099) which both will end at the end of 2001. In the frame of the EUROTRAPS network the performance of Penning traps is being improved for high-accuracy measurements on trapped HCI.

4. *STRUCTURE AND METHODOLOGY*

4.1 Research approach and technical programme:

The HITRAP Facility at GSI which will serve as a prototype for experiments on highly charged ions (HCI) at very low energies will employ a linear decelerator for deceleration of HCI extracted from the Experimental Storage Ring ESR at an energy of 3 MeV/u. Presently, the ESR is routinely operated at energies of about 500 MeV/u down to 25 MeV/u. During dedicated machine times in 1999 and 2000, the ESR machine parameters were tuned to decelerate the stored HCI in the ESR down to an energy of 9 MeV/u. The deceleration down to an energy of 3 MeV/u is planned for 2001.

Two types of linear decelerators are presently discussed: an interdigital H-mode (IH) structure and a radio-frequency quadrupole (RFQ) structure. A detailed design study of an IH structure for the HITRAP Facility has been completed in 1998 by U. Ratzinger, GSI (now University of Frankfurt), clearly showing the feasibility of such a decelerator. At CERN a RFQ for deceleration of antiprotons from 5 MeV down to rest is already operational since end of 2000. A similar RFQ could be used for the HITRAP Facility. The time for final design and construction of the decelerator is two years.

The methods of capturing, cooling and storage of HCI in a cooler Penning trap are key technologies of the proposed RTD project. Stored ions which are prepared in such a cooler trap can be extracted as an ion beam with very low emittance and well-defined time structure or can be, alternatively, used for experiments directly in the trap if the ions are to be investigated at extremely low energies (< 0.1 eV/q). Computer simulations done by the GSI team show that the application of these well-established trapping techniques to heavy HCI poses no serious difficulties. In close collaboration of the GSI, Mainz, Stockholm and GANIL teams the prototype cooler Penning trap will be built for the HITRAP Facility. First tests will be performed on light HCI injected into the cooler trap from an ion source. Later on, heavy HCI will be captured from the linear decelerator. After the first performance tests of the prototype cooler trap the GANIL team will decide on the question which ion trapping technique is most appropriate for the need of the GANIL accelerator facility.

The precision Penning trap at cryogenic temperatures for g-factor and binding-energy measurements has been developed and tested in the frame of the TMR network EUROTRAPS. It will be incorporated into the HITRAP facility and connected to the cooler trap by a cryogenic transfer line.

The availability of heavy HCI at low energies requires further development and refinement of the instrumentation techniques used to investigate the HCI and their reactions with neutral particles. Details of the reaction dynamics of HCI can be experimentally studied with the method of recoil ion momentum spectroscopy (RIMS). In a recoil-ion spectrometer the ion beam is crossed by well prepared target beams (atoms, molecules, clusters). Charged fragments, i.e. electrons and ions in different charge states, emerging from single collisions of ions with the target are projected onto large position- and time-sensitive detectors by means of electric and magnetic fields. From the hitting positions and the times-of-flight of the fragments their initial momenta, i.e. velocity as well as direction, can be calculated.

A prototype reaction microscope for recoil ion momentum spectroscopy of HCI will be built by the GANIL, Heidelberg and Krakow teams. This prototype will be designed and constructed with special consideration of the requirements of experiments with heavy HCI which is a challenge particularly with regard to the speed of the electronics. A special multi-hit detector for detection of many charged particles with extreme time resolution is a key feature of the prototype and will be developed and provided by the Heidelberg team. In addition to present designs, photon detectors for the optical and x-ray regime will be implemented. This will allow for the investigation of the decay channels of strongly inverted systems (”hollow atoms”) with unprecedented precision and completeness by detection of various photons in addition to the momenta of emerging ions and electrons. Fast multi-hit electron detectors (presently up to ten electrons from one reaction) will be further developed for the study of the dynamics of multi-electron transfer in collisions of HCI with neutral particles. The Krakow team will provide a position-sensitive, 200-fold segmented solid-state x-ray detector (built in co-operation with the FZ Jülich), including fast electronics, slits and collimators, for the detection of photons emitted during the reaction process (energy range 5-100 keV). The Vienna team will give theoretical guidance to the GANIL, Heidelberg and Krakow teams during the design phase of the prototype reaction microscope by simulations of the trajectories of the highly charged ions and the many-electron dynamics of the reaction. It will also help interpreting the experimental results. First tests of this apparatus will be performed at the GANIL ion beam facility on medium-heavy HCI. After completion of the HITRAP Facility, the RIMS spectrometer will be used at GSI for experiments on heavy HCI up to bare uranium ions (U^{92+}).

The interaction of heavy HCI with surfaces, solids and microstructures will be experimentally studied with an apparatus to be built by the KVI Groningen and Stockholm teams. The UHV apparatus for these measurements will be provided by the KVI Groningen team. It will be versatile to allow for a broad range of experiments, using a large variety of different targets (metals, semiconductors, insulators, thin-film covered targets and microstructures like micro-capillaries). It will be important to find a design with high flexibility to guarantee easy access for other users. For example, in view of the extremely good vacuum necessary for experiments with ions in high charge states it will be important to include a valve system which allows target exchange without breaking the vacuum. A similar apparatus has been built by the KVI Groningen team for experiments on medium-heavy HCI. The instrumentation for the measurement of the angular distribution of the HCI after the scattering process will be supplied by the Stockholm team. The analysis of the angular distribution is crucial for the investigation of the effect of image-charge acceleration of HCI close to a surface. The Vienna team will support these experimental teams in the lay-out of the scattering chamber by calculations of the expected scattering parameters, in the optimisation of the instrumentation and in the interpretation of the experimental results with theoretical simulations of the scattering dynamics of HCI and the decay of hollow atoms. The ion-surface experiments of the KVI Groningen and Stockholm teams will be complemented by the material research department of GSI which will perform off-line surfaces analysis via scanning probe microscopy like, e.g., atomic force and scanning tunnelling microscopy. With these methods the imaging of defect creation on surfaces and of ion tracks is possible.

An experimental set-up for high-accuracy laser spectroscopic studies of trapped highly charged ions will be developed by the London team. The planned measurements of the hyperfine splitting (HFS) and the Zeeman splitting of hydrogen-like ions in a Penning trap pose stringent requirements on the photon detection sensitivity, since the rate of the M1-transition between the hyperfine levels is much lower than in the case of electric-dipole allowed transitions in singly charged ions. Therefore, the London team will construct an optical detection system which is optimised with respect to large solid angle and which includes a single-photon counting camera for spatial discrimination of background photons. The laser system will be laid out in such a way that several candidates of hydrogen-like ions, which are interesting for HFS and weak interaction studies, can be investigated. The London team will do performance tests of the laser and photon detection system on singly charged stable ions in co-operation with the Mainz team. The degree of atomic and nuclear polarisation achieved by optical pumping will be determined. In this way, the feasibility of weak interaction studies will be investigated.

Technical programme: work packages

Table 4.1: Technical work tasks of the teams.

Responsible partner *(other principal partners)*	***Task***	***Technical objectives***	***Technical work***
GSI (GANIL, Mainz)	Supply of linear decelerator for HITRAP Facility, beamline for extracted slow HCI	Deceleration of HCI from 3 MeV/u, transfer of HCI to experimental set-ups	Design studies, construction and test of linear decelerator, setting up a beamline for low-energy HCI
Mainz (GSI, GANIL, Stockholm)	Provision of Penning trap for capture of HCI	Capture and detection of HCI in cooler Penning trap, improvement of performance of Penning traps	Design and construction of trap electrodes and UHV-chamber, study of systematic uncertainties of high-accuracy experiments
GANIL (Heidelberg)	Development of apparatus for RIMS (recoil ion momentum spectroscopy)	Kinematically complete investigation of collisions of highly charged ions	Set-up of recoil-ion and electron spectrometer
Heidelberg (GANIL)	Development of reaction microscope as multi-user instrument	Investigation of collisions of HCI with atoms, molecules and clusters	Multi-electron recoil-ion spectrometer, supersonic atomic beam, implementation of photon detectors
KVI Groningen (GANIL, Krakow)	Development of spectrometer for ion-surface interaction studies	Focusing slow ions onto solid-state target, versatile electron energy spectrometer	Construction of versatile UHV-scattering chamber for surface experiments; ion optics for ion beam handling
Stockholm (Mainz, GSI, KVI Groningen, Vienna)	Investigation of ion-ion and electron-ion cooling in Penning traps, development of ion diagnostics and spectrometer for HCI surface scattering	Diagnostics for ion cooling, determination and optimization of detection efficiency, position-sensitive time-of-flight spectrometer	Installation of nested trap in SMILETRAP magnet, engneering of stable high-voltage supplies for switching and manipulation of electrons and ions
Krakow (KVI Groningen, Heidelberg, GSI)	Providing position-sensitive x-ray detector for energy range 5-100 keV	Fast signal processing for 200-fold segmented x-ray detector, collimation of emitted x-ray radiation	Design, manufacture and performance test of electronic circuits, design and manufacture of collimators and slits
Vienna (KVI Groningen, GANIL, Heidelberg)	Development of simulation codes for calculation of interaction of HCI with surfaces, clusters and micro-structures	Calculation of ion trajectories, image-charge acceleration, determination of charge state and angular distribution of scattered ions	Calculation of atomic and surface-specific transition rates, development of simu-lation code, theor. study of electronic surface response due to the Coulomb fields
ICSTM London (Mainz, GANIL, Heidelberg)	Development of experiments to investigate hyperfine structure in HCI	Measurement of hyperfine structure splittings by laser spectroscopy, establishment of nuclear polarization	Survey of suitable HCI isotopes for laser spectroscopy, calculation of transition rates, experimental design and tests

4.3 Project milestones and technical deliverables:

Table 4.2 Work plan of the teams (in months from start of contract, milestones indicated by X).

Tasks	**1 - 12**				**13 - 24**				**25 - 36**				**37 - 48**			
Design and construction of linear decelerator for HITRAP Facility *GSI / GANIL* MILESTONE: test of decelerator at GSI accelerator facility	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	X				
HITRAP: transfer line from cooler trap to experimental set-ups *GSI / Mainz / GANIL / Stockholm*									▨	▨	▨	▨				
Design and construction of cooler Penning trap *Mainz / GSI / GANIL / Stockholm* MILESTONE: single HCI detection in trap	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	X					
Installation and test of cooler Penning trap at HITRAP Facility *Mainz / GSI / GANIL / Stockholm* MILESTONE: test of cooler trap with heavy HCI extracted from storage ring												▨	▨	X	▨	▨
Reaction microscope as multi-user instrument *Heidelberg / GANIL / Krakow* MILESTONE: tests on light HCI	▨	▨	▨	▨	▨	X										
Spectrometer for recoil ion momentum spectroscopy (RIMS) *GANIL / Heidelberg / Krakow*	▨	▨	▨	▨	▨	▨										
Implementation of reaction microscope in RIMS spectrometer *GANIL / Heidelberg / Krakow* MILESTONE: test of full RIMS spectrometer at GANIL ion beam facility							▨	▨	▨	▨	▨	▨	X			
Installation of RIMS spectrometer at HITRAP Facility *GANIL / Heidelberg / Krakow/ GSI* MILESTONE: test of RIMS spectrometer on heavy HCI at HITRAP Facility														▨	X	▨
Set-up for laser spectroscopy of trapped ions *London / Mainz* MILESTONE: test of laser set-up with singly charged ions	▨	▨	▨	▨	▨	▨	▨	X								
Laser spectroscopy of HCI *London / Mainz* MILESTONE: measurement of HFS of trapped HCI								▨	▨	▨	▨	▨	▨	X	▨	▨
UHV chamber for ion-surface interaction studies *KVI Groningen* MILESTONE: UHV test at 10^{-10} mbar	▨	▨	▨	X	▨	▨	▨									
Position-sensitive solid-state x-ray detector *Krakow / KVI Groningen / Heidelberg / GSI* MILESTONE: test of spatial resolution of detector	▨	▨	▨	▨	▨	▨	X									
Spectrometer for ion-surface interaction studies *KVI Groningen / Krakow* MILESTONE: test of completed scattering spectrometer at Groningen facility								▨	▨	▨	▨	X	▨	▨		
Installation of spectrometer for ion-surface studies at HITRAP Facility *KVI Groningen / Heidelberg / Krakow / GSI* MILESTONE: test of completed scattering spectrometer at HITRAP Facility															▨	X
Monte-Carlo calculation of ion trajectories for design of scattering chamber *Vienna / KVI Groningen / GANIL / Heidelberg* MILESTONE: deliver design parameter for experimental groups	▨	▨	▨	X												
Simulation codes for calculation of ion trajectories and transition rates *Vienna / KVI Groningen / GANIL / Heidelberg* MILESTONE: calculations for interpretation of experimental results on heavy HCI					▨	▨	▨	▨	▨	▨	▨	X	▨	▨	▨	▨
Modification of high-accuracy Penning trap for heavy HCI *Mainz / GSI* MILESTONE: mass measurements and g-factor measurements on moderately charged ions	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	X				
Installation of high-accuracy Penning trap at HITRAP Facility *Mainz / GSI* MILESTONE: High-accuracy experiments on heavy HCI													▨	▨	X	▨

5. PROJECT MANAGEMENT AND COMPETENCE OF THE PARTNERS

5.1 Management structure

The proposed RTD network will be co-ordinated by H.-Jürgen Kluge who is Research Director at the heavy-ion accelerator facility GSI, the Head of the Atomic Physics Division at GSI and Professor of Physics at the University of Heidelberg. He has extensive experience in directing research teams, in grant applications, work in committees, conference organisation, and in project management. The infrastructure of the Atomic Physics Division as well as that of GSI is well suited for the HITRAP project management. The management of the proposed RTD project will be done in a way very similar to the one successfully applied in the former SCIENCE and the present TMR EUROTRAPS Networks (ERBFMRX-CT97-0144) which is also co-ordinated by H.-J. Kluge and will end on 31. Dec. 2001:

- Annual Project Meetings organised year by year by different partners in the RTD project. If the present Euroconferences series on "ATOMIC PHYSICS AT ACCELERATORS" (ERBFMMACT 980469, co-ordinated by H.-J. Kluge) will be extended, the meetings will be held in connection with those conferences.
- Two Business Meetings of the leaders of the different participating teams per year in order to establish a work plan and to follow-up its realisation or eventual delays, to discuss and decide on distribution of tasks and financial resources, to co-ordinate publications, conference attendance, etc. One of the two annual meetings will take place during the Project Meeting. Working Groups will be set up for the different parts of the project according to the actual needs. Seven Working Groups are presently obvious and listed in Tab. 5.1. These Working Groups will meet on a regular basis. They will also call experts from outside the partnership if appropriate.
- Regular exchange of information sent by the different participating teams to the other teams and the co-ordinator by electronic mail.
- Every six months written reports on the progress of the project work as well as of the Working Groups prior to the Business Meeting. The progress reports will be evaluated and discussed in the Project and Business Meetings.

The World-Wide Web will be used for information on the RTD project, the Working Groups and the progress in each participating institute.

Table 5.1: Working Groups in the HITRAP project

#	Task	Co-ordination by
1.	Deceleration, Storing and Cooling of Ions	GSI
2.	Recoil Ion Momentum Spectroscopy Instrumentation	GANIL
3.	Hollow-Atoms and Surface Studies Instrumentation	KVI Groningen
4.	Instrumentation for Laser Spectroscopy of Trapped Ions	London
5.	Penning Trap Technology	Mainz
6.	X-ray Detector, Electronics, Computer Control, Data Acquisition	GSI
7.	Theoretical Aspects of HITRAP	Vienna

5.2 Competence of the partners

The proposed Network gathers high-level scientists with profound expertise in performing experiments at accelerators or in setting up new instrumentation. They have served as members or chairpersons in several national or international advisory committees, peer reviews and are experienced in working efficiently in international collaborations. The individual competence of the partners is compiled in Table 5.2 and the research effort and expertise of principal research staff in Tab. 5.3.

Table 5.2: Competence of the partners

Team Team Leader	**Qualification and Expertise**
GSI H.-J. Kluge	GSI operates a unique accelerator complex for heavy-ion research which covers a broad spectrum. The Atomic Physics Division performs a wide range of experiments by use of beams of relatively low energy (10 MeV/u) at the UNILAC, by use of high-energy beams (1 GeV/u) at the heavy-ion synchrotron SIS, with cooled ions in the Experimental Storage Ring ESR, and with radioactive beams by use of the Penning triple-trap mass spectrometer ISOLTRAP at ISOLDE/CERN. GSI offers excellent support in accelerator design, detector development, electronics and computing. There is extensive expertise in ion trap technology (first on-line ion trap) and single-ion detection.
GANIL J.-P. Grandin	GANIL has a recognised experience in production and handling of ion beams (ion sources, ion optics, ion acceleration,...). With the SPIRAL facility, GANIL has proven its qualification and knowledge in ion beam technology. CIRIL is involved in recoil ion detection since more than 10 years. The laboratory is among the three pioneer laboratories, the work of which has led to the present state-of-the-art of recoil ion momentum spectroscopy (RIMS). Its main technical contribution has been to introduce a supersonic gas jet as the target which was the major step towards the achieved momentum resolution. CIRIL has used this technique either at high collision energy (10-50 MeV/u) or at low collision energy (5 keV/u).
KVI Groningen R. Morgenstern	The KVI Groningen group has extensive experience in hollow-atom spectroscopy as well as in investigating ion-surface interactions for projectile charges up to a charge state of q=12 and for a variety of surfaces (metals, semiconductors, insulators as well as thin-film covered surfaces). The KVI Groningen group has used ion-deceleration techniques in order to study collisions at low kinetic energies such that the potential energy of the projectile is higher than its kinetic energy. KVI Groningen offers excellent infrastructure for design and construction of the instrumentation for hollow-atom spectroscopy and ion-surface interaction studies.
Mainz G. Werth	The Mainz team has extended experience in trapping and cooling charged particles in various types of traps, in the detection of single trapped ions, in the handling of ultrahigh vacuum apparatus as well as superconducting magnets. Precise mass measurements have been carried out in the past on singly charged heavy ions, electronic and nuclear g-factors of heavy atomic ions have been obtained with great accuracy and precision g-factors of hydrogenic light ions have been determined. Transfer of single ions between different traps has been performed successfully and cryogenic electronics for single particle detection has been developed.

Team Team Leader	**Qualification and Expertise**
Krakow A. Warczak	The Krakow team performs atomic physics experiments at ion accelerators since more than twenty years. The Krakow team constructed and manufactured experimental equipment successfully used in many accelerator experiments (target chambers, collimators, particle and x-ray detectors, remote control systems). Within the present network the group will be responsible for construction and manufacture of electronic circuits for the position sensitive x-ray detector as well as for special collimators and slits. The group is interested in future experiments on ion-atom and ion–surface collision and may provide its experience and skills for development and construction of vacuum equipment, especially for the investigation of ion-surface collisions.
Stockholm R. Schuch	The Stockholm team was first in developing trapping of highly charged ions in a Penning trap for precise mass measurements. In the past, successful measurements of light ion masses have been carried out with very high precision (≈10-10), and for medium heavy ions a good precision (≈10-9) was reached. The theory group of Dr. E. Lindroth, which is part of the Stockholm team, provides valuable theoretical support for the experimental groups. This team has excellent experience in production and handling of highly charged ion beams and of magnetized electron beams. Ion sources (EBIS, ECR) for medium to highly-charged heavy ions are available for tests. The Stockholm team has started to develop a while ago the technique of ion-surface scattering spectroscopy with highly charged ions up to a charge state of q=15. Extensive experience on x-ray spectroscopy for the investigation of highly-charged ion-surface interactions has been documented by this group.
Heidelberg J. Ullrich	The Heidelberg group has been involved over 10 years in the development of many-particle detection systems. The group developed the first Reaction Microscope that allowed for the simultaneous detection of the full momentum vectors of up to ten electrons and of the target recoil ion (group members hold two patents: one on the ”attosecond microscope” and the other on many-electron – ion detection from surfaces for surface analysis). There is sound experience in position-sensitive multiple-electron or ion detection, multi-parameter data taking and evaluation, high-resolution electron spectroscopy, differentially pumped supersonic beams. Through the continuous work at heavy-ion accelerators and the present development of a trap and source for highly charged ions (EBIT, EBIS) in Heidelberg the group has firm knowledge on ion-beam handling, operation of experiments at storage rings as well as on the production and trapping of highly charged ions.
Vienna J. Burgdörfer	This research team has many years of research experience in the field of ion-surface interactions, both for fast and slow collisions and for low and high charge states. This group originally developed the COB model for ion-surface interaction now widely used for describing ion-surface charge transfer processes. Recently, they have developed the first theoretical model for the interaction of highly charged ions with microstructures. In addition, Dr. Lemell has experience in both theoretical and experimental aspects of ion-surface interactions and is therefore well qualified as a ”liaison” between the theoretical and experimental groups involved with the HITRAP project.
ICSTM London: R. Thompson	This team has been working on laser spectroscopy and laser cooling of trapped ions for many years, especially in Penning traps. The team has developed spectroscopic techniques for measuring the oscillation frequencies and studying the dynamics of trapped ions. Studies have also been made of the combined trap. Recent experimental work includes studies on single ions. Theoretical and computational studies of laser cooling in the Penning trap have been made. The team has experience of laser spectroscopy of the hyperfine structure of stable and unstable atoms.

5.3 Research effort, principal research staff and expertise

Table 5.1: Manpower provided by principal research staff and their expertis. The manpower provided by graduate students is not counted.

Team	Manpower provided by principal research staff [personmonths]	Principal Research Staff	Partici-- pation [%]	Expertise/graduate students
GSI	240	Prof. H.-J. Kluge Dr. W. Quint Dr. Th. Stöhlker Prof. P. Mokler Dr. C. Kozhuharov Dr. T. Kühl Dr. F. Bosch Dr. A. Bräuning-D. Dr. G. Marx Dr. R. Mann Dr. R. Neumann Dr. B. Schlitt Dr. M. Steck	30 90 50 20 20 20 20 60 10 100 30 25 25	Atomic and nuclear physics, ion traps Ion traps, cryogenics, precision experiments X-ray detectors and spectroscopy, highly charged ions Atomic physics with highly charged ions Data acquisition, electronics Laser spectroscopy Atomic and nuclear physics at ion accelerators Recoil ion momentum spectroscopy RF spectroscopy in ion traps, UHV technology Recoil ion spectroscopy Material science, scanning probe microscopy Accelerator physics and mass measurements Accelerator physics, storage rings 3 graduate students
CIRIL/ GANIL	48	Prof. J.-P. Grandin Dr. B. Ban-d’Etat Dr. A. Cassimi Dr. J.-Y. Chesnel Dr. D. Hennecart	10 20 30 20 20	Atomic Physics at ion accelerators Slow ion-surface interaction Recoil Ion Momentum Spectroscopy Ion beam deceleration Recoil Ion Momentum Spectroscopy 1 graduate student
KVI Groningen	48	Prof. R. Morgenstern Dr. ir. R. Hoekstra Dr. Th. Schlathölter	25 25 50	Atomic physics at ion accelerators Hollow-atom spectrometer and spectroscopy Atomic spectroscopy of highly charged ions 1 graduate student
Mainz	34	Prof. G. Werth Dr. R. Ley	20 50	Atomic physics, ion traps Magnet technology 3 graduate students
Krakow	38	Prof. A. Warczak Dr. Z. Stachura Dr. R. Pedrys Eng. S. Samek	20 10 10 40	Atomic physics at ion accelerators Atomic collision physics with heavy ions Mass spectrometry of sputtered surfaces Detector electronics, remote control systems 2 graduate students
Stockholm	43	Prof. R. Schuch Dr. G. Vikor Prof.em. I. Bergström	30 40 20	Atomic physics at accelerators Ion sources, diagnostics, and manipulations Mass measurement of highly charged ions 2 graduate students
Heidelberg	58	Prof. J. Ullrich Dr. R. Moshammer Dr. J. Crespo Dr. A. Dorn Dr. B. Feuerstein	10 30 10 20 50	Atomic collisions, Reaction Microscopes recoil-ion spectroscopy, multi-electron spectroscopy ion source and trap (EBIT) optical spectroscopy polarised electron beams 2 graduate students
Vienna	62	Prof. J. Burgdörfer Dr. C. Lemell Dr. K. Tökesi Dr. S. Yoshida	20 30 50 30	Theory of ion-surface and ion-solid interaction Simulation of HCI-surface interactions Simulation of ion trajectories in microstructures Theory of HCI 1 graduate student
London	38	Dr. R. C. Thompson Dr. D. M. Segal	40 40	Laser spectroscopy, laser cooling, ion traps, HFS Laser spectroscopy, laser cooling, ion traps 1 graduate student
Sum	**619**			

5.4 Publications

Recent publications of the HITRAP teams are listed in Tab. 5.4.

Table 5.4: Publications of the teams relevant for the proposed RTD network

GSI team:

1. Th. Stöhlker, X. Ma, T. Ludziejewski, H.F. Beyer, F. Bosch, O. Brinzanescu, R.W. Dunford, J. Eichler, S. Hagmann, A. Ichihara, C. Kozhuharov, A. Krämer, D. Liesen, P.H. Mokler, Z. Stachura, P. Swiat, and A. Warczak
   Near-Threshold Photoionization of Hydrogenlike Uranium Studied in Ion-Atom Collisions via the Time-Reversed Process
   Phys. Rev. Lett. 86 (2001) 983
2. H. Bräuning, P. H. Mokler, D. Liesen, F. Bosch, B. Franzke, A. Krämer, C. Kozhuharov, T. Ludziejewski, X. Ma, F. Nolden, M. Steck, Th. Stöhlker, R. W. Dunford, E. P. Kanter, G. Bednarz, A. Warczak, Z. Stachura, L. Tribedi, T. Kambara, D. Dauvergne, R. Kirsch, and C. Cohen
   Observing a Single Hydrogen-like Ion in a Penning Trap at T = 4 K Strong Evidence for Enhanced Multiple Electron Capture from Surfaces in 46 MeV/*u* Pb^{81+} Collisions with Thin Carbon Foils
   Phys. Rev. Lett. 86 (2001) 991
3. Häffner, N. Hermanspahn, H.-J. Kluge, W. Quint, S. Stahl, J. Verdu, G. Werth
   High-Accuracy Measurement of the Magnetic Moment Anomaly of the Bound Electron in a Hydrogen-like Ion
   Phys. Rev. Lett. 85 (2000) 5308
4. M. Diederich, H. Häffner, N. Hermanspahn, M. Immel, H.-J. Kluge, R. Ley, R. Mann, W. Quint, S. Stahl and G. Werth:
   Observing a Single Hydrogen-like Ion in a Penning Trap at T = 4 K
   Hyperf. Int. 115 (1998) 185
5. Seelig, P., S. Borneis, A. Dax, T. Engel, S. Faber, M. Gerlach, C. Holbrow, G. Huber, T. Kühl, D. Marx, K. Meier, P. Merz, W. Quint, F. Schmitt, M. Tomaselli, L. Völker, H. Winter, M. Würtz, K. Beckert, B. Franzke, F. Nolden, H. Reich, M. Steck and T. Winkler:
   Ground State Hyperfine Splitting of Hydrogenlike ^{207}Pb^{81+} by Laser Excitation of a Bunched Ion Beam in the GSI Experimental Storage Ring
   Phys. Rev. Lett. 81 (1998) 4824

GANIL team:

1. Cassimi, S. Duponchel, X. Flechard, P. Jardin, P. Sortais, D. Hennecart, R. E. Olson
   State Selective electron capture in low velocity multiply charged ion Helium collision
   Phys. Rev. Lett. 76 (1996) 3679
2. X.Flechard, S.Duponchel, L.Adoui, A.Cassimi, P.Roncin, D.Hennecart
   State-selective double electron capture in low-velocity Ne10+ He collisions studied by recoil-ion momentum spectroscopy
   J.Phys. B: At. Mol. Opt. Phys. 30 (1997) 3697-3708
3. **The Spiral project at GANIL and future opportunities**
   Phys G Nucl. Part. Phys. 24 (1998) 1331-1339
4. A.Cassimi
   Recoil ion momentum spectroscopy : a microscope for HCI-atom or molecule collisions.
   Phys. Scr., T80 (1999) 98-105
5. M.Tarisien, L.Adoui, F.Fremont, D.Lelievre, L.Guillaume, J.Y.Chesnel, H.Zhang, A.Dubois, D.Mathur, S.Kumar, M.Krishnamurthy, A.Cassimi
   Ion-induced molecular fragmentation : beyond the Coulomb explosion picture.
   J. Phys. B : At. Mol. Opt. Phys.,33 (2000) L11-L20

KVI Groningen team:

1. T. Schlathölter, A. Närmann, A. Robin, D.F.A. Winters, S. Marini, R. Morgenstern, R. Hoekstra,
   Sputtering of hollow atoms from carbon surfaces
   Phys.Rev. A 62 042901 (2000) 1-7
2. H. Khemliche, T. Schlathölter, R. Hoekstra, R. Morgenstern, S. Schippers
   Hollow atom dynamics on LiF covered Au(111): role of surface electronic structure
   Phys. Rev. Lett. 81 (1998) 1219
3. A. Arnau, F. Aumayr, P.M. Echenique, M. Grether, W. Heiland, J. Limburg, R. Morgenstern, P. Roncin, S. Schippers, R Schuch, N. Stolterfoht, P. Varga, T.J.M. Zouros, H. Winter
   Interaction of slow multicharged ions with solid surfaces
   Surf. Sci. Reports 27 (1997) 113-240
4. J. Limburg, S. Schippers, R. Hoekstra, R. Morgenstern, H. Kurz, F. Aumayr, H. Winter
   Do hollow atoms exist in front of an insulating LiF(100) surface?
   Phys.Rev.Lett. 75 (1995) 217 -220
5. J. Limburg, J. Das, S. Schippers, R. Hoekstra, R. Morgenstern
   Coster-Kronig transitions in hollow atoms created during highly charged ion-surface interactions
   Phys.Rev.Lett. 73 (1994) 786-789

Mainz team:

1. R. Ley, W. Quint, S. Stahl, G. Werth
   Concept of a 6-T Penning trap at liquid-He temperature for the accumulation of positrons
   Hyperfine Interactions 115 (1998) 181
2. G. Marx, G. Tommaseo, G. Werth
   Precise g-factor measurements on Ba+ isotopes
   Europhys. Journ. D4 (1998) 279
3. G. Savard, G. Werth
   Precision Nuclear Measurements with Ion Traps
   Annu.Rev.Nucl. Part. Sci.50 (2000) 119
4. M. Block, A. Drakoudis, H. Leuthner, P. Seibert, G. Werth
   Crystalline ion structures in a Paul trap
   J. Phys. B33 (2000) L375
5. N. Hermanspahn, H. Häffner, H.-J. Kluge, W. Quint, S. Stahl, J. Verdu, G. Werth
   Observation of the Continuous Stern-Gerlach Effect on an Electron Bound in an Atomic Ion
   Phys. Rev. Lett. 84 (2000) 427

Krakow team:

1. R. Pedrys, B. Warczak, J. Schou, B. Stenum, O. Ellegaard
   Ejection of molecules from solid deuterium excited by electrons
   Phys. Rev. Lett. 79, 3070 (1997)
2. L. Dutkiewicz, R. Pedrys, R.E. Johnson
   Desorption of solid O2 induced by vibrational excitations
   J. Low Temp. Phys. 111, 747 (1998)
3. Bednarz, A. Warczak, H. Tawara, T. Azuma, K. Komaki, and E. Takada
   Radiative electron capture into continuum in relativistic collisions of bare C ions with solid matter
4. P. Swiat, A. Warczak, Th. Stoehlker, F. Bosch, C. Kozhuharov, P. H. Mokler, H. Reich, R. W. Dunford, P. Rymuza, T.Ludziejewski, Z. Stachura
   Monte Carlo simulations of atomic processes at the gas jet target of the ESR storage ring
   Physica Scripta T80, 326 (1999)
5. T. Ludziejewski, Th. Stoehlker, D.C. Ionescu, P. Rymuza, H.F. Beyer, F. Bosch, C. Kozhuharov, A. Kraemer, D.Liesen, P.H. Mokler, Z. Stachura, P. Swiat, A. Warczak, R.W. Dunford
   Simultaneous excitation and ionization of He-like uranium ions in relativistic collisions with gaseous targets
   Phys. Rev. A 61, 052706 (2000)

Stockholm team:

1. Huang Weiping, H. Lebius, R. Schuch, M. Grether, and N. Stolterfoht
   Energy loss in large-angle scattering of slow highly charged Ar ions from a Au surface
   Phys. Rev. A58, 2962 (1998)
2. C. Carlberg, T. Fritioff, G. Douysset, and I. Bergström,
   Determination of the Cs mass in a Penning trap
   Phys. Rev. Letters 83, 4506 (1999)
3. R. Schuch, S. Madzunkov, E. Lindroth, D. Fry
   Unexpected x-ray emission due to formation of bound doubly-excited states
   Phys. Rev. Letters 85, 5559 (2000)
4. T. Fritioff, C. Carlberg, G. Douysset, I. Bergström, and R. Schuch,
   A new determination of the ^{4}He and ^{3}He masses in a Penning trap
   Eur. Phys. Letters, to be publ.
5. ***G. Douysset, T. Fritioff, C. Carlberg, I. Bergström***
   Determination of the ^{76}Ge double beta-decay Q value
   submitted to Phys. Rev. Letters

Heidelberg team:

1. **Vielelektronen – Rückstoßionen – Spektrometer und Verfahren zur Vermessung korrelierter Elektronen-impulse**
   Deutsches Patent Nr. 196 132 81
2. Dorn, A. Kheifets, C. D. Schröter, C. Höhr, G. Sakhelashvili, B. Najjari, R. Moshammer, J. Ullrich
   Double Ionization of Helium by Electron Impact: Complete Pictures of the Four-body Break-up Dynamics
   Phys. Rev. Lett. (2001) (accepted)
3. R. Moshammer, B. Feuerstein, W. Schmitt, A. Dorn, C.D. Schröter, J. Ullrich, H. Rottke, C. Trump, M. Wittmann, G. Korn, K. Hoffmann, W. Sandner
   Momentum Distributions of Ne^{n+} Ions Created by an Intense Ultra-short Laser Pulse
   Phys. Rev. Lett. 84 (2000) 447
4. M. Schulz, R. Moshammer, W. Schmitt, H. Kollmus, B. Feuerstein, R. Mann, S. Hagmann, J. Ullrich
   Electron Correlation Observed through Intensity Interferometry
   Phys. Rev. Lett. 84 (2000) 863
5. J.R. Crespo López-Urrutia, B. Bapat, B. Feuerstein, A. Werdich, J. Ullrich
   First Results from the Freiburg Electron Beam Ion Trap FreEBIT
   Hyperfine Interactions 127 (2000) 497
6. R. Moshammer, P.D. Fainstein, M. Schulz, W. Schmitt, H. Kollmus, R. Mann, S. Hagmann, J. Ullrich,
   Initial State Dependence of Low-Energy Electron Emission in Fast Ion Atom Collisions
   Phys. Rev. Lett. 83 (1999) 4721

***Vienna team*:**

1. D. Arbó, C. Reinhold, P. Kürpick, S. Yoshida, and J. Burgdörfer
   Quantum Theory for Atomic States Through Solids
   Phys. Rev. **60** (1999) 1091
2. G. Hayderer, M. Schmid, P. Varga, HP. Winter, F. Aumayr, L. Wirtz, C. Lemell, J. Burgdörfer, L. Hägg, and C. Reinhold
   Threshold for Potential Sputtering of LiF
   Phys. Rev. Lett. **83** (1999) 3948
3. K. Tökesi and J. Burgdörfer
   Energy Loss of Highly Charged Ions in Distant Collisions with Microcapillary Surfaces
   Surface Science **454-456** (2000) 2038C. Reinhold, D. Arbó, J. Burgdörfer, B. Gervais, E. Lamour, D. Vernhet, and J. Rozet
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