Atomic and molecular collision physics at GANIL

L. Adoui, A. Cassimi, J.-Y. Chesnel, A. Domaracka, B. A. Huber, A. Méry, J.-C. Poully, J. Rangama, P. Rousseau, and V. Vizcaino

Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), 14000 Caen, France

in collaboration with groups from the following institutions:

Institute for Nuclear Research, Hungarian Academy of Sciences (Atomki), Debrecen, Hungary
CNR-Instituto di Struttura della Materia, Area della Ricerca di Roma 1, Monterotondo Scalo, Italy
Departamento de Química, Módulo 13, Universidad Autónoma de Madrid, Madrid, Spain
Department of Physics, Stockholm University, Stockholm, Sweden
Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
J. Heyrovský Institute of Physical Chemistry v.v.i., The Czech Academy of Sciences, Prague, Czech Republic
Faculty of Applied Physics and Mathematics, Gdansk University of Technology, Gdansk, Poland
Faculty of Sciences, Siedlce University of Natural Sciences and Humanities, Siedlce, Poland
Zernike Institute for Advanced Materials, Univ. of Groningen, 9747AG Groningen, Netherlands
Tokyo Metropolitan University, Tokyo, Japan
Institut für Kernphysik, Goethe Universität, Frankfurt, Germany
Inter-University Accelerator Center (IUAC), New Dehli, India
Instituto de Física - Universidade Federal do Rio de Janeiro, Cidade Universitária - Rio de Janeiro, Brazil

Since about 35 years, the community of atomic and molecular collision physics has widely used the GANIL facility for countless experiments performed within numerous national and international collaborations. Recent reviews of the advances achieved at GANIL in this field are available here: X. Fléchard et al JPCS 629 (2015) 012001 and H. Zettergren JPCS 629 (2015) 012003. These experiments have been focusing on the study of the interaction of ions with dilute matter ranging from isolated atoms and molecules to molecular clusters, as well as nanoparticles nowadays. Thanks to the wide range of projectile energies and species available on the different beam lines of the GANIL facility, elementary processes such as electron capture, ionization and excitation have been extensively studied. Since the last years, the relaxation processes of the collision partners after the collision have been another specific source of interest.

The community of atomic and collision physics aims to provide valuable upstream information relevant for both fundamental physics and societal issues. In the field of molecular collision physics, a major goal of the present and future short- and medium-term experiments at GANIL is the investigation of the stability and the fragmentation dynamics of multi-atomic systems after their excitation/ionization by ion impact at velocities ranging from a few tenths to several atomic units. These studies provide new insights into radiation damage processes by describing – at the molecular level – the early physical stages of ion-induced excitation and ionization of molecular systems and of their subsequent fragmentation. Another emerging foremost goal is the investigation of the formation of new molecular species in excited and ionized molecular clusters, in order to gain insights into the molecular growth occurring in the interaction between solar/stellar wind ions and the interstellar medium (ISM) and planetary atmospheres.

The uniqueness of the GANIL facility is that it offers complementary state-of-the-art beamlines producing a variety of ion species ranging from light ions (down to protons) to heavy ions (up to uranium) with a large range of charge states and with energies ranging from a few keV per charge unit at ARIBE to 0.25-1 MeV/u at IRRSUD and even up to 95 MeV/u at the high energy beamline dedicated to interdisciplinary research. This makes GANIL the most versatile facility in Europe, and possibly in the world. This versatility is a vital feature for the community of atomic and molecular collision physics as this research field requires systematic investigations as a function of the energy and/or of the charge

state of the incoming ion. For example, the balance between the energy transferred to the target electrons (electronic energy loss in soft collisions) and the energy transferred to the target nuclei (nuclear energy loss in hard binary collisions) depends on the ion velocity and to a certain extend on the initial charge state of the projectile.

ARIBE and IRRSUD are currently the most widely used beamlines for the experiments carried out at GANIL in the field of atomic and molecular collision physics. Indeed, both ARIBE and IRRSUD provide a large variety of ion species with charge states and energies that are of astrophysical and atmospheric interest, as they are relevant to mimic ions of stellar winds and cosmic rays in interaction with ISM and planetary atmospheres. In addition to protons and alpha particles, stellar winds contain trace amounts of heavy ions and atomic nuclei (such as C, N, O, Ne, Mg, Si, S, and Fe). Only quite recently, it has been shown that such heavy ions can play a key role in the chemistry of planetary atmospheres and ISM medium and up to now their role was in general neglected in astrophysical models. Based on GANIL know-hows on the production of metallic ion beams, the implantation of the associated methods on the ion source of ARIBE will offer an extended range of heavy ions of interest for stellar winds (e.g., Fe). Ion beams of ARIBE and IRRSUD are also of major interest for radiobiology since they are relevant for hadrontherapy and radiation damage, especially ion energies at IRRSUD are in the range of Bragg-peak energies (e.g., 1 MeV/u carbon ions) and those at ARIBE are useful to mimic “post-Bragg-peak” ions at the end of their path in matter. The wide relevance and versatility of these beamlines makes the GANIL installation very attractive for our community. This attractiveness results in the fact that each call for proposals issued by iPAC leads to numerous proposals for experiments in our field, a majority of them coming from external and often foreign teams. In view of the success of the calls for proposals, a general increase of the beam time allowance at GANIL would be very welcome.

An emerging topic is the time-resolved investigation of collision-induced molecular fragmentation dynamics. While high harmonic generation sources (HHG) and free electron lasers (FEL) provide short temporal resolutions, ion storage devices give access to relaxation processes over very long time scales (up to seconds). Moreover it is possible to prepare well-defined target states with laser excitation and in a more general way to perform laser spectroscopy on ions. It is noteworthy that such laser spectroscopy in an electrostatic linear ion trap is under development as well in nuclear physics (MIRACLS project at CERN) and is foreseen for DESIR. Thus to extend the possibilities offered by the ARIBE facility, one can consider to convert the so-called “banc 2” into a molecular-ion beamline equipped with a linear electrostatic trap. This beamline is already coupled to a laser beamline and the existing laser lab can be upgraded with additional lasers. Thanks to the complementary skills of the CIMAP and GANIL researchers and engineers, we expect that the implementation of the linear trap at ARIBE can be carried out in the framework of an efficient cooperation offering new perspectives in molecular physics at GANIL and a sandbox to develop new instrumentation for nuclear physics.

As a last recommendation, we would like to emphasize that the construction of a Very Low Energy (range of a few eV) beamline at ARIBE would allow GANIL to reach the completeness of the range of energies that are relevant for experiments dedicated to stellar wind ions. We anticipate that this Very Low Energy beamline would open the way for new series of systematic studies of astrophysical and atmospheric interest, as well as of radiobiological interest.

The current projects in atomic and molecular collision physics are largely supported at regional, national and international scales. For example, in the local context in Caen, several projects leaded by CIMAP researchers are currently under progress at GANIL thanks to the financial support from the ANR, the CNRS and the Normandy Region: ANR IMAGERI, ANR FRAPA, RIN Emergence MAGIC and CNRS International Associated Laboratory LIA DYNAMO (CIMAP-Stockholm University-Universidad Autonoma de Madrid). Moreover, a large majority (> 80%) of the experiments performed at GANIL in

atomic and molecular collision physics take place within the framework of international collaborations that are supported by various cooperation contracts between CNRS and foreign institutions. This strong support is encouraged by the large number of publications in peer review journals with high impact factor (> 20/year) and invited talks in international conferences like ICPEAC, HCI, ECAMP, etc, (> 10/year) reporting on our works carried out at GANIL. As shown by the success of the recent calls for proposals dedicated to interdisciplinary research, the GANIL facility is very attractive and it is essential to tackle urgent questions to understand the evolution of dilute matter exposed to ion impact in the context of e.g. astrophysics, atmospheric sciences, and radiation damage.