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Foreword

Laboratory Astrophysics and its challenges

The Universe offers a large variety of natural laboratories in which the evolution of matter can be studied in extreme physical conditions. A specificity of these environments is that we do not have any control on their composition and evolution as well as on the numerous processes that govern them, and the determination of the physical conditions relies solely on observations with large telescopes equipped with sensitive instruments, both spectral and photometric, using gas and dust properties as diagnosis. The interpretation of the data relies on theory and modelling with inputs for microphysics, chemical properties, and physical macroscopic processes, from laboratory experiments. Moreover, in order to reconstruct many phenomena arising in these objects, dedicated laboratory simulations are often necessary to approach and mimic at best some of the physical and chemical conditions that are inferred in these peculiar environments. By working from a bottom-up approach, this requires to develop dedicated and often sophisticated laboratory setups, in which the conditions are built-up, monitored and carefully controlled. None of these simulations can however provide a complete and therefore perfect view of the cosmic natural environments. However, it is the role and the experience of the scientist, in many different fields, to apply the laboratory results in given situations where at least part of the simulations are applicable and can be understood in terms of natural phenomena.

Because of the difficulty inherent to this approach, laboratory astrophysics (LA) is not well considered as a core activity in modern astrophysics where very often, manipulation of tools and large models hinders the underlying use and need for the LA bottom-up approach. For example, we may wonder how stellar astrophysics would have emerged in the first half of the XX$^{\text{th}}$ century without the decisive input of atomic physics and spectroscopy. The same situation applies nowadays to astrochemistry. However, this is expected to change in the near future because, with the advent of space observatories, space probes to planets and smaller bodies of the solar system, and many large ground-based telescopes, the flow and quality of data have dramatically increased in the last twenty years and will continue to do so in the near and even far future. With this flow of data it is now becoming close to possible to precisely reconstruct structures in three dimensions where microphysics, simulations and laboratory experiments are expected to play not an important role but actually a decisive one. Many examples can be

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found in this book of the first European Conference on Laboratory Astrophysics where the pluri- and interdisciplinary nature of the field is easy to apprehend.

There is still some need to work on the definition of LA. First, it must be fully recognized as a scientific field that is strongly coupled to astrophysics and not as a simple service to astrophysicists, observers and modellers. Secondly, four main types of LA activities can be recognized: (i) simulations in controlled laboratory conditions of the formation and evolution of molecules and dust particles; (ii) specific and dedicated experiments to study the spectroscopy and microphysics of matter under the extreme conditions of astrophysical environments; (iii) study of complex dynamical phenomena using scaling laws or approximate similarity; (iv) study of elementary complex processes like turbulence or magnetic reconnection. In most cases, a further step consists in a more global numerical modelling of the cosmic objects, which takes benefit from all experiments and theoretical calculations, including the role of large databases often directly fed by LA. This step allows for a direct comparison with actual observations but also provides strong guidelines for further laboratory studies as well as observational developments. Such an ambitious program cannot be matched without creating a community of interests in which LA is perceived as a wide multidisciplinary field at the core of the activities in astrophysics and planetary sciences. Finally, LA activities also benefit from the use of large physics facilities such as synchrotrons, Z-pinches and power lasers as well as of super calculators.

Laboratory simulations do imply the formation of interstellar dust analogues that include silicate dust, carbonaceous one, ices. Evolution of these analogues upon simulated irradiation processes (UV, X rays, cosmic rays) are of uttermost importance to understand the formation and evolution of the Solar nebula, as well as the gradual increase of complexity of matter in space environments, in particular for organic matter, a complexity which is a prerequisite to the problem of the origin of life. Besides, such analogues can be compared directly either to astronomical observations or they may also give clues about the processes that have been involved in the formation and the first step of the evolution of primitive materials such as carbonaceous chondrites. Simulations can also be applied to many dynamical processes such as radiative shocks, magneto-hydrodynamical jets and instabilities, turbulence, magnetic reconnection, structuration of the Universe from small scales (stars) to cosmological scales.

Spectroscopy is also a key feature from LA since it allows not only the identification of species but also a much more clear definition of the local physical conditions (T, n, P) in various environments. Opacities and radiative transfer modelling are of uttermost importance to interpret observations such as, for example in the vast and universal theme of star formation where the physical parameters of the collapsing clouds are still poorly known. Microphysical processes must be taken into account in reactivity involving gas-phase species, gas grain interactions, grain collisions and coagulation, which play a key role in the evolution of protoplanetary disks and the formation of planetesimals. Finally, one must not forget the frontiers with more fundamental physical and chemical processes including plasma physics, quantum electrodynamics and low temperature reactivity.

This book illustrates some of the studies performed in LA and their applications to objects and environments found in astrophysics and planetary sciences: compact objects, stars and Sun, stellar environments, Solar and planetary environments, extrasolar planets, and the interstellar medium. We are very grateful to the SOC members and other colleagues for their help in refereeing all the contributions.

After this first ECLA conference, the SOC meeting has debated over the general contents of this meeting and its political implications/significations. The format is good, mixing different subjects and communities in order to try to unify the community of scientists who are performing LA studies in the different fields. Invited reviews, presenting the astrophysical challenges, were very good. Effort should be kept so that lectures remain accessible to this broad community. Some communities e.g. astrochemistry, have already managed to develop a common interdisciplinary language and this approach should be extended to other communities. Whereas a general ECLA Conference may be held with a periodicity of 3 years it is therefore desirable that, in between, some smaller and more specialized workshops may take place with a co-sponsoring from ETFLA, the European Task Force for Laboratory Astrophysics whose mission is to render LA more visible in the general Astrophysics community where needs for, sometimes very specific, data are constantly taking a more important place.

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