Roles and Future Directions of Laboratory Plasma Astrophysics

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Introduction. Recent advances in astronomy and astrophysics have been enabled primarily by observatories, ground based and space-borne, and by large numerical computations. In the first half of the twentieth century, laboratory experiments led to astronomical spectroscopy and nuclear astrophysics, but since then experiment has been less influential than in other branches of science. Technological progress and maturing of plasma physics now presents new opportunities for astrophysically relevant experiments. Laboratory plasma astrophysics, though still developing, has become increasingly plausible and exciting. This contribution is intended to briefly summarize the possible roles and future directions of these laboratory plasma experiments in advancing astrophysics in the next decade.

Current Status. In the past decade, results obtained from laboratory plasma experiments have begun contributing to our understanding of the dynamics of astrophysical plasmas. Experiments have been designed to study specific plasma processes relevant to astrophysics. Promising experimental results to date include evidence for two-fluid effects and anomalous resistivity in collisionless magnetic reconnection [1]; dynamo action in forced turbulent flows [2]; upper limits on nonmagnetic, turbulent angular momentum transport in stably rotating flow [3]; and evidence of spatial structures in laser-induced collisionless shocks [4]. Some of the processes (e.g. reconnection) have application to controlled fusion and other fields of plasma physics, but others (e.g. angular-momentum transport due to magnetorotational instability) are specific to astrophysics and intended to provide insights that are otherwise unavailable. Another class of experiments has focused on the morphological comparisons between laboratory experiments and astrophysical observations [5] such as jet formation.

Roles of Laboratory Experiments. Like numerical experiments, laboratory experiments can provide both local measurements of key physical quantities simultaneously at numerous places and global morphologies as in the remote-sensing observations. While laboratory provides “ground truth” of the physical processes under investigation, we point out that the goal of these laboratory experiments is not to directly simulate astrophysical phenomena. This is because the laboratory and astrophysical plasmas are vastly different in spatial and temporal scales, and are often driven by different energy sources. By carefully matching the dimensionless parameters where possible, with appropriate initial and boundary conditions, some astrophysical processes can be studied on laboratory scales. This scalability of physical phenomena is fundamental to interpret laboratory results for astrophysical applications. However, we recognize that there exist large gaps in some of the dimensionless parameters, and these gaps will not likely disappear in the foreseeable future. This is most severe between laboratory or numerical systems and astrophysical phenomena. It is less severe but still problematic between laboratory experiments and numerical experiments. Here, analytic theory, guided by but not limited to the regimes accessible to the laboratory and to the computer, help to close the gap in parameters and unify our understanding. Although powerful, useful theories do not appear overnight. Often they are born from many failed attempts, and more importantly from the interplay between laboratory experiments, numerical experiments, and astronomical observations.

Future Directions. In the next decade, this emerging field of laboratory plasma astrophysics is expected to mature significantly, and thus to contribute more to our understanding of astrophysical phenomena in the following three respects. First, the scope of the physics topics studied in the laboratory and their parameter ranges will continue to broaden as technology advances and interests grow. Second, increasingly sophisticated diagnostics will elevate the data quality from these experiments. This will be especially important for experiments focusing on morphological comparisons to understand the underlying physics. Third, numerical and theoretical studies will play increasingly important roles in extracting physical insight from the laboratory and extrapolating to astrophysical regimes. The growing field of laboratory plasma astrophysics deserves more supports through a systematic funding strategy possibly involving multiple funding agencies due to its interdisciplinary nature.

References

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