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THE BRIGHT FUTURE OF THE ASTROPHYSICAL MAGNETIC FIELD RESEARCH

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Magnetic fields are ubiquitous in space and their role in affecting astrophysical processes is difficult to overestimate. For instance, they are known to be essential in the acceleration of cosmic rays, star formation, solar flares, gamma ray bursts, MHD heating of the interstellar medium, accretion disks, etc.

There are many questions that the existence of astrophysical magnetic fields raises. What is the largest scale for the coherent magnetic fields in the Universe? At what time of the Universe evolution magnetic fields have become essential? How and how fast are magnetic fields created at intergalactic and galactic scales? How do magnetic fields mediate the interstellar dynamics over an enormous range of scales, from 1000pc to 100km? How is magnetic energy transferred to particles and heating?

To understand cosmic fields, we must, first of all, understand their dynamics in turbulent plasma ("magnetic turbulence"), the dynamics of magnetic field amplification (usually called "dynamo") and topology change ("reconnection"). The complex interaction of magnetic fields with plasma and cosmic rays and the back-reaction of these processes to the magnetic field dynamics and structure make these processes difficult to describe quantitatively.

Recent years have been marked by substantial progress in observations of magnetic fields and theoretical understanding of their effects. In addition, a connection between laboratory studies and astrophysics has been fruitfully explored.

However, it would be wrong to feel completely satisfied with the progress. For instance, the recent tremendous advance in our ability to simulate magnetic fields should not hide the fact that numerical simulations are able to explore models which will be in any foreseeable future very limited in resolution. This presents serious challenges in connecting the astrophysical reality and model simulations, unless the fundamental properties of astrophysical magnetic fields are better understood. For instance, all numerical codes are diffusive enough to make the magnetic reconnection fast. Thus, magnetic fields in simulations easily change their topology. Is this also true for actual astrophysical media?

While recent years have been marked by a remarkable progress in simulating fast collisionless reconnection. this type of reconnection is restricted, however, to the situation when the length of the current sheet is not more than several times larger than the electron mean free path. Thus this type of reconnection is not applicable, for instance, to the interstellar gas, for which the reconnection is collisional. If collisionless reconnection is the only type of fast reconnection, this means that most of the interstellar MHD codes do not correctly represent astrophysical reality. If this is the case, this has catastrophic consequences not only for the simulations of galactic dynamo, but also invalidates the entire crop of simulations of interstellar medium dynamics, star formation, complex interaction of magnetic fields and cosmic rays, etc.

The latter is a very important example of the challenges that one has to overcome. As a rule, astrophysical environments are turbulent and astrophysical turbulence is characterized by enormously large Reynolds Re and magnetic Reynolds Rm numbers. The aforementioned Rm number, which characterizes the degree of frozenness of magnetic field within eddies, may differ in astrophysical environments and numerical simulations by a factor larger than 10^{10} factor, which, naturally, calls for caution while interpreting numerical results.

While there is no viable alternative to numerical modeling of the complex phenomena of astrophysical magnetic fields, it is essential to strive for understanding of the fundamental processes involving magnetic fields, i.e., magnetic reconnection, magnetic turbulence, ambipolar diffusion of magnetic fields, etc. Such studies should determine which of the phenomena are correctly represented by numerical simulations and may result in the emergence of completely new type of codes which successfully parameterize the processes not accessible through the brute force approach.

Theoretical studies should be tested against observations. In this respect we need not only better telescopes, but also new techniques to make use of

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existing and future observational data. We also need new ways of studying magnetic field.

The synergy advocated by many talks at the conference includes the traditional interplay between experiment, observations, and theory in developing a conceptual picture and understanding; the validation of numerical algorithms by appropriate comparison with laboratory and space experiments; and the application of validated codes to astrophysical phenomena. This approach should enable us to quantitatively study the magnetic fields in the Universe and predict confidently the outcomes of a wide range of astrophysical phenomena.

Let us finish by expressing the hope that at the next "Magnetic Fields in the Universe" conference we shall hear of many exciting advances in understanding this extremely enigmatic and extremely important subject.