2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Kinetic Instabilities and Collisional Processes in the Solar Wind

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The solar wind research has entered a new era in view of the historical return to the inner heliosphere via NASA's artificial satellite missions, the Parker Solar Probe (PSP) mission, and ESA's Solar Orbiter (SO) mission. In view of this, it is timely to review the current status of solar wind research. Solar coronal heating and the solar wind acceleration [see *Schwenn & Marsch*, 1991, for overview of an earlier inner heliospheric mission HELIOS] are two mutually related topics, and these coupled problems are intimately related to the physical processes that take place close to the Sun. In contrast, the subject of this review pertains to physical processes occurring near 1 AU (i.e., the earth orbit) and beyond. Of various physical processes, kinetic instabilities driven by the temperature anisotropies of various charged particle species, which are spontaneously generated in the expanding solar wind, are of primary interest [*Yoon*, 2017]. As the solar wind expands out into the interplanetary space, the conservation of adiabatic moments automatically generates temperature, or more precisely, pressure anisotropy. Observations show that the actual solar wind is much more close to being isotropic than predicted by the simple (double) adiabatic theory. This implies that kinetic instabilities driven by the temperature anisotropy, such as the fire-hose, mirror, and cyclotron instabilities may be operative in order to bring the local solar wind close to the marginally unstable state. For excessive perpendicular temperature anisotropy ion cyclotron and mirror instabilities are operative, while for excessive parallel temperature anisotropy, parallel and oblique fire-hose instabilities are excited. If there exists significant heat flux, then various heat flux instabilities are also excited [for discussion of various space plasma instabilities, see *Gary*, 1993]. However, if the instabilities were the only process regulating the temperature anisotropy upper bound, then the solar wind near 1 AU should invariably be close to the marginal state of one instability or another. Instead, the actually observed solar wind near 1 AU is more likely to be in quasi-isotropic state, sufficiently removed from the marginal stability state. This is the "solar wind *isotropy* problem." In other words, there must be some processes that are operative in addition to kinetic instability processes in order to further isotropize the solar wind. The collisional processes are a natural candidate. Even though the solar wind is largely collisionless, the cumulative effect of collisional processes over the solar wind's evolutionary path is known as the collisional age effect, and it was shown that such an effect is not insignificant. Consequently, the collisional age effect may contribute toward the observed isotropic state of the solar wind. Moreover, coupling between the electrons and ions via kinetic instability processes may also contribute toward the isotropization of the solar wind [*Yoon & Sarfraz*, 2017]. To account for the collisional age and coupled kinetic instability effects, the present speaker generalized the standard collisional transport theory available in the literature, which is applicable for unmagnetized plasma, in order to account for the presence of ambient magnetic field [*Yoon*, 2016]. The present speaker also developed quasilinear kinetic theory of various instabilities in order to investigate the nonlinear saturation behavior of plasma subject to various instabilities [*Yoon & Seough*, 2014]. By combining the large-scale expansion effect, local kinetic instability effect via quasilinear scheme, and the collisional age effect, it is possible to develop a global-kinetic (or macro-micro) model of the solar wind. Such a model may be utilized in order to analyze the data from PSP and SO missions, as well as to reinterpret the historical data taken from the Helios mission (in the 1970s) and Ulysses mission (1990s). The theoretical model may also be compared against the expanding box hybrid simulation models [e.g., *Matteini et al.*, 2012]. In order to test the validity of the quasilinear scheme based upon the assumption of bi-Maxwellian plasma distribution function, a number of detailed comparative tests are also carried out against particle-in-cell simulations [*Seough et al*., 2014, 2015a,b, *Yoon et al*., 2015, 2017, *Stockem Novo et al*., 2015, *Kim et al*., 2017, *Lazar et al*., 2018, *Lee et al*., 2018]. The present talk will overview the current status of the solar wind research for processes taking place near 1 AU and beyond, and also discuss how the model can be improved for future purposes.

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