9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Review of radio plasma physics for fusion science

T. Tokuzawa[1,2,3]

[1] National Institute for Fusion Science, National Institutes of Natural Sciences,
[2] Department of Fusion Science, The Graduate University for Advanced Study, SOKENDAI,
[3] Research Institute for Applied Mechanics, Kyushu University
e-mail (speaker): tokuzawa@nifs.ac.jp

The name "Radio Plasma Physics" may be unfamiliar to you, but it was named by the author, inspired by radio astronomy. In the world of astrophysics, which began with visual observations of stars, radio astronomy began to develop in earnest in the mid-20th century, followed by a series of major discoveries, including quasars, pulsars, and cosmic microwave background radiation (CMB), which have changed not only astronomy but also the human view of nature. This was accomplished through revolutionary advances in wireless communication technology, which came into peaceful use after two world wars. On the other hand, in the study of plasma physics, electromagnetic waves have been used for both plasma generation and observation since its dawn. Since the use of electromagnetic waves has been so routine that it has rarely been specifically classified or organized, I would like to introduce the characteristic results of plasma physics obtained by using radio waves as "Radio Plasma Physics". Note that due to the author's professional bias, there are many examples of magnetic fusion plasmas.

The biggest difference between the use of radio waves in plasma physics research and that in astronomy is that the plasma to be observed is within reach. That is, it is possible not only to make passive observations by receiving radio waves emitted by the plasma, but also to make active observations by emitting radio waves toward the plasma and studying its response. (It should be noted, of course, that astronomy and astrophysics also make active observations of relatively nearby objects, such as the Moon and the planets of our solar system.) Since not only passive but also active observation is possible, various observation methods have been developed and applied in laboratory plasma research. In the author's opinion, the most impactful use of electromagnetic waves was the confirmation of the 1 keV electron temperature plasma in the T-3 tokamak by incoherent Thomson scattering measurements. The fact that the reliability and reproducibility of this electromagnetic wave measurement technique was made known to the world was a major step toward the realization of a fusion reactor.

Active use of radio waves in plasmas has been widely used for plasma heating. However, instead of high-power heating, response function tests are also conducted in various plasmas to investigate plasma conditions and performance by exciting waves in the plasma and studying their absorption and propagation characteristics. This response function testing using radio waves has contributed to a wide range of plasma physics research topics, namely, wave-particle interaction. Recently, parametric decay characteristics associated with mixed-wave injection have been studied, and plasma heating based on these characteristics has also been proposed.

As an example of passive observation, the most widely used method is probably electron cyclotron emission (ECE). It is also used to monitor electron temperature, study instability characteristics, and control. In recent years, two-dimensional imaging measurements using arrays of receivers have also become popular. The ability to visualize and directly understand the complex dynamics of plasmas has allowed plasma physics to be discussed in a truly unprecedented dimension. Currently, higher resolution and three-dimensional observation system are being developed along with further miniaturization of equipment such as SOC (Surface on Chip) technology. Plasmas radiate not only continuous waves such as ECEs, but also sudden oscillations due to MHD instabilities and other phenomena. Asymmetric and localized plasma deformations called tongues have been observed at LHD, which produce bursty radio waves in a wide frequency range from DC to GHz. It has also been shown that velocity space distortions of ion occur at this time, and it is expected that such phase-space distortions will also be studied using radio waves in the future.

As for observation methods, not only traditional interferometry (heterodyne, dual wavelength, dispersion, etc.), but also scattering and absorption methods have been applied in the past, and highly stable, reliable, and high-performance instruments using the latest elements are still being developed and applied today. For example, Doppler radar and backward/forward scattering have been applied to observe microscopic turbulence, opening up the latest plasma physics. Recently, spectroscopic observations of collective scattering and higher harmonic ECE have begun to examine the possibility of knowing changes in the velocity space of electrons. Furthermore, there have been proposals to use the radio waves to observe the fuel ratio (hydrogen isotope ratio) inside the plasma, and the field of plasma research using these radio waves is becoming more and more active.

This study was supported in part by the Japan Society for the Promotion of Science KAKENHI (grant nos. 19H01880, 21H04973, 23H01161, and 23K25858), by a budgetary Grant-in-Aid from the National Institute for Fusion Science LHD project under the auspices of the NIFS Collaboration Research Program, and by the Collaborative Research Programs of the Research Institute for Applied Mechanics, Kyushu University. Additional support was provided by Japan/U.S. Cooperation in Fusion Research and Development.