§4. Observation of Asymmetric Velocity Distribution Functions of Neutral Particles in a Plasma

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In general, flow structures in magnetized plasmas are affected by E×B drift. On the other hand, vortex structures rotating to the counter direction of the E×B drift have been observed in a magnetized argon plasma in the HYPER-I device.[1] These anti-E×B vortices are considered to be caused by the momentum transfer from the neutral particles to the ions. Under the existence of the anti-E×B vortex, the neutral particles show a deeply concave structure of the density and flow toward the center of the vortex due to the density gradient. On the other hand, the ion density in the vortex is a few times higher than that in peripheral region, and the ions flow outward. The inward momentum corresponding to the relative velocity between the neutrals and the ions is transported to the ions through the charge exchange collisions, and the resultant force drives the anti-E×B drift. Thus, the neutrals have a potential to play an important role in the vortex formation. To experimentally clarify the effect of the neutrals on the vortex formation, we have developed a laser induced fluorescence (LIF) spectroscopy system.[2]

LIF technique is capable of measuring the velocity distribution function (VDF) of the arbitrary particles. To obtain information on the neutrals from its VDF, LIF measurement with high wavelength resolution is required. A diode laser we introduced to the system has the spectral width of 3 fm, which is sufficiently narrow compared to the Doppler broadening of the neutrals (typically 1.5 pm). The wavelength of the laser is tuned to 696.735 nm for excitation of the $4s[3/2]^o_2$ state of argon metastable atoms. The particles, which are excited to the upper energy level ($4p[1/2]_1$) by the laser, emit photons of the wavelength of 826.679 nm with the transition $4p[1/2]_1 - 4s[1/2]^o_1$.

The LIF photons are detected by a photomultiplier tube (PMT) with a collection optics, whose optical axis is perpendicular to that of the laser beam, and a lock-in amplifier. In the measurement of the anti-E×B vortex, the operation with high microwave power (5kW) and strong interaction between the neutrals and the plasma cause a reduction of the ratio of the LIF emission to the background emission (S/N ratio). To improve the S/N ratio, the laser beam is modulated to 100 kHz by an electro-optical modulator (EOM). Calibration of the laser oscillation frequency is performed with a Fabry-Perot interferometer (FPI).

The plasma was generated by electron cyclotron resonance (ECR) heating of argon gas with a pressure of 10 mTorr. In the presence of the anti-E×B vortex, the electron temperature and the electron density measured by a Langmuir probe were 5 eV and 2×10^{12} cm^{-3}, respectively.

We observed the radial velocity distribution functions (RVDFs) of the neutrals, as shown in Fig. 1. The RVDF at the center of the vortex (Fig. 1(a)) had symmetry with respect to the zero velocity; however, the RVDFs at other measurement positions had asymmetry (Fig.1 (b)). The RVDF was well expressed by two Maxwellians which have respectively inward and outward flow velocity. The magnitude of the asymmetry was evaluated as the skewness (Fig. 2). In the vortex region, the skewness increased linearly. At r > 2 cm, it gradually increased. We considered that this asymmetry was accompanied by the neutral density structure. On the other hand, the azimuthal velocity distribution function (AVDF) had less asymmetry compared to that of the RVDF.

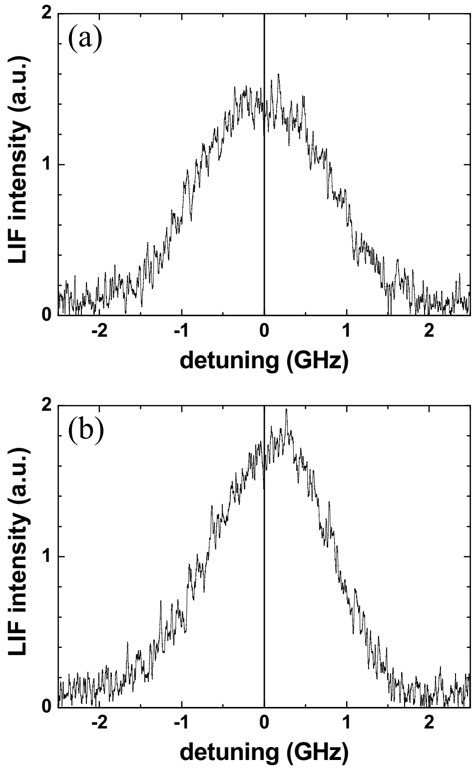

Fig. 1. LIF spectra of the argon metastable atoms in the anti-E×B vortex. (a) measured at r = 0. (b) measured at r = 5cm.

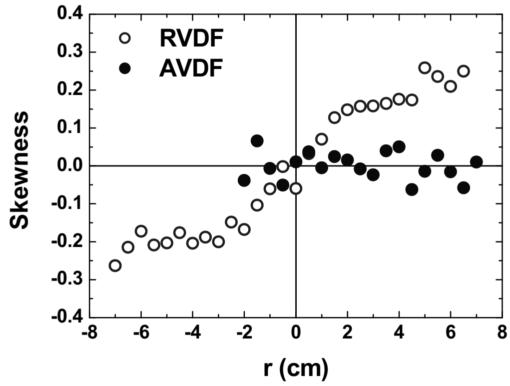

Fig. 2. Radial profiles of the skewness of the RVDF (○) and of the AVDF (●).

1) Okamoto, A., et al., Phys. Plasmas **10** (2003) 2211
2) Aramaki, M., et al., Rev. Sci. Instrum. **80** (2009) 053505