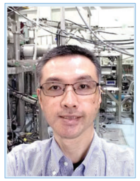
【Grant-in-Aid for Scientific Research (S)】

Creation and characterization of electron-positron plasma in an artificial magnetosphere as antimatter trap



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Project Information	Project Number : 22H04936　　Project Period (FY) : 2022-2026 Keywords : antimatter/electron-positron plasma, levitated dipole, SC magnet

Purpose and Background of the Research

●Outline of the Research

We plan to create and experimentally understand the properties of matter-antimatter electron-positron pair-plasma by using an intense pulsed positron source and an artificial magnetosphere created by a magnetically levitated superconducting magnet.

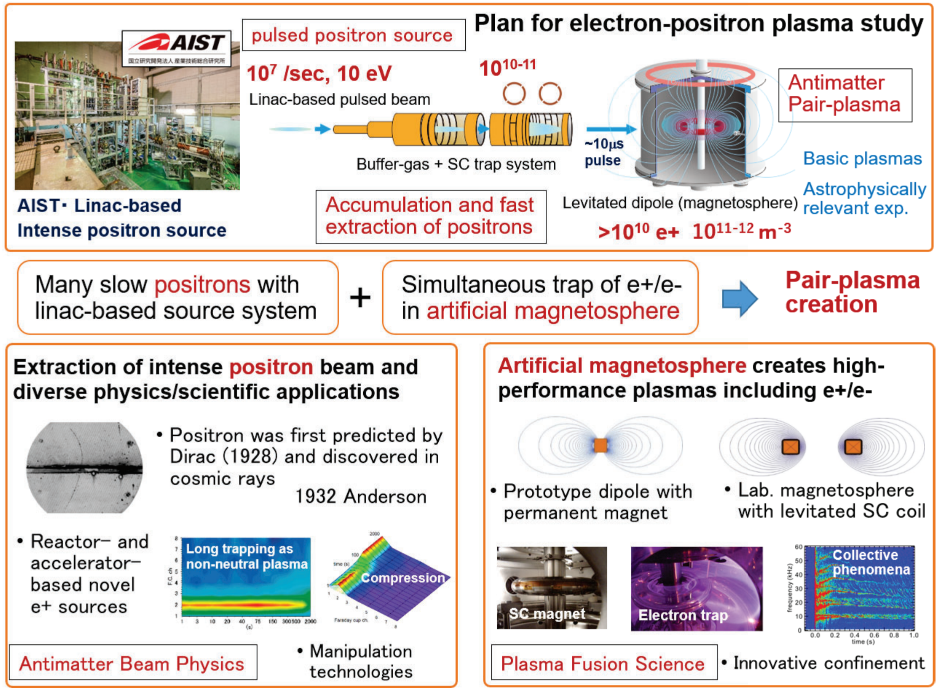

Figure 1. Electron-positron plasma investigation with pulsed positron source and levitated dipole

●Exotic pair-plasma of electrons and positrons

In contrast to ordinary ion-electron plasmas, where many properties are determined by their extremely large mass ratios, electron-positron plasma consists of equal mass particles and shows interesting properties as pair-plasmas. This type of plasma has been theoretically and numerically studied intensively as one of exotic plasmas especially in relation to astrophysical context. Experimentally, it is not easy to accumulate a large number of positrons and to capture them with electrons. Due to recent advances in the field of plasma fusion and beam physics, the time has come to create electron-positron pairs and conduct their experimental studies.

●Combination of plasma and antimatter sciences

High-performance plasma trap is realized in an "artificial magnetosphere" generated by a magnetically levitated superconducting coil. RT-1 (Fig.2) has realized long-time confinement of pure electron plasmas, which is also applied to positrons in principle. Recent progress in antimatter science realized intense antiparticle beams suitable for diverse scientific applications. In this project we combine these recent innovations in two research fields and realize electron-positron plasmas in a laboratory. Namely, we accumulate pulsed positron beams from a linac-based source of AIST, trap them with electrons in the compact artificial magnetosphere, and experimentally investigate their dispersion relations (wave properties), instabilities, and transport properties.

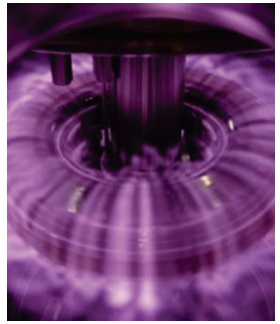

Figure 2. RT-1 levitated dipole

Expected Research Achievements

●Exotic pair-plasma of electrons and positrons

The first milestone of the project is to create electron-positron plasma. Based on the conditions for the emergence of collective phenomena, we set a goal to trap more than 10^{10} positrons and to generate electron-positron plasma with a density of 10^{11}-10^{12} m^{-3} and a temperature of 1eV. According to the evaluation of positron lifetimes (Fig. 3), trapping time of more than 100 seconds is expected with ultra-high vacuum environment of 10^{-8} Pa (ten-trillionth of the atmospheric pressure) and appropriate temperature control. As shown in Fig.1, positron beam with an average current of 1pA (10^7 positrons/sec) supplied from a linac-based source of AIST is accumulated using a buffer gas trap (BGT) and a superconducting trap (SCT) and confined with electrons in a levitated dipole device. After increasing the particles and determining the boundary to exhibit collective phenomenon, the dispersion relations of plasmas are studied by excitation and detection of waves in the plasma (Fig. 4). Focusing on the fluctuations and transport phenomena that are closely related to self-organization, we study the stability limit that regulates the density gradient using annihilation gamma rays.

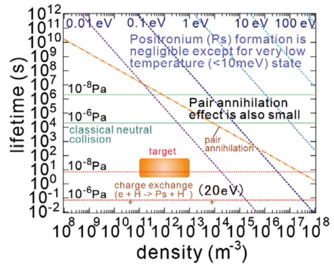

Figure 3. Positron life times

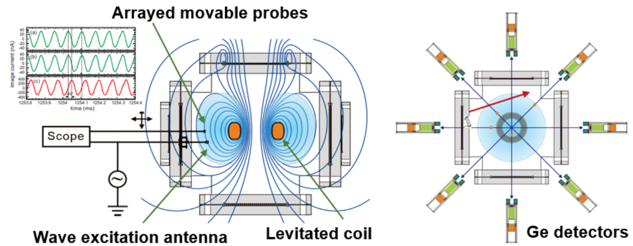

Figure 4. Measurement with waves and annihilation gamma-rays

●Study on antimatters as plasmas and its future plan

Today antimatters are used not only for physics research but also for diverse medical and industrial purposes. Combination of antimatter science and plasma fusion science enables novel study and application of collective phenomena of many particles and antiparticles. Based on the realization of electron-positron plasmas, we will broaden the scope of antimatter plasma physics toward space physics and material science.

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