13th International Workshop on Non-neutral Plasmas, 19 - 22 September 2022, University of Milano, Italy

Chaotic motion of positrons in a planned compact levitated dipole experiment

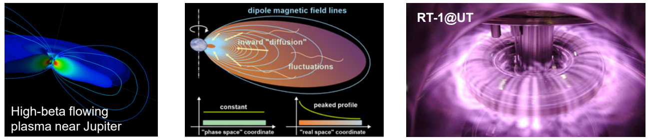
H. Saitoh and I. Tanioka, The University of Tokyo, Japan

Key words:
(towards) electron-positron plasmas, (levitated) dipole experiment, orbit chaos, High-temperature superconductor

The dipole magnetic field is planned to be used as one of trapping configurations for electron-positron plasmas [1]. We, the RT group of Japan, plan to develop a compact levitated dipole device toward the trapping of pulsed positron beam [2] and other plasma experiments. Although the dipole field is axisymmetric, the adiabaticity of trapped particle orbits in this geometry are not always conserved due to several reasons. Among these reasons, the coupling of gyro and bounce motions in the dipole field can break the first and second adiabatic invariants, resulting in chaotic orbits [3]. In the magnetic field configuration of RT-1, a fusion-oriented rather large-scale experiment, it has been shown that high-energy positrons (>10keV) shows chaotic orbits [4]. In this study we investigate the orbits of low-energy positrons in the planned levitated dipole experiment. Due to the lower field strength and effects of separatrix, positrons with K of the order of 10eV show chaotic motions in this geometry.

Dipole for NNP and beyond: past and ongoing experiments

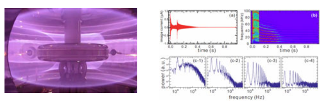
- Levitated dipole experiment, inspired by Jovian magnetosphere



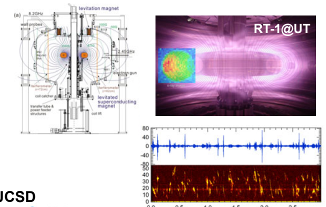
• Astrophysically relevant configuration, inward diffusion, self-organization, etc.

- Scientific applications of an artificial magnetosphere

• Non-neutral and e+/e- plasmas • Hot-electron plasmas

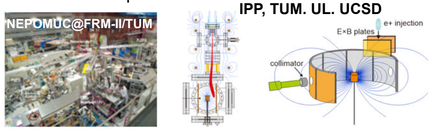


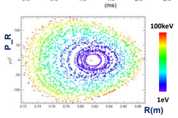
Stable confinement of toroidal electron plasma
Is realized after spontaneous turbulence decay



• Toroidal e+/e- plasmas

PAX/APEX [1], IPP, TUM. UL. UCSD





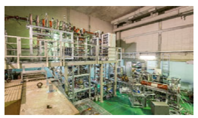
Very efficient (100%) injection and rather long time (~1s) trapping are realized in supported dipole

2018 Stenson+ Phys. Rev. Lett; 2018 Horn-Stanja Phys. Rev. Lett..

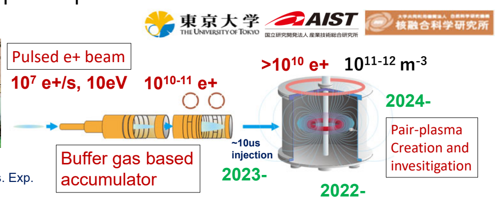
Acceleration of e-s by chorus mode (R-wave) whistler results in chaotic orbit in dipole field

Planned compact levitated dipole "RT-x" in Japan

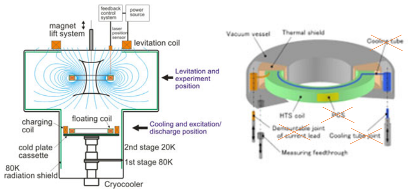
- Combination with pulsed positron beam



AIST Linac-based source
2020 Higaki Michishio+ Appl. Phys. Exp.



- Compact levitated dipole and planned parameters



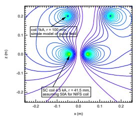
• Simplified structure
• R=7-12cm under consideration
• Vacuum and SI thermal shield region close to the SC winding
• Inductive charging
• Cooling with Solton multicontact

Injection into axisymmetric dipole configuration

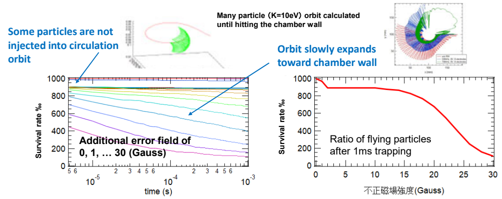
- Magnetic axisymmetry is essential for levitated dipole experiment

On stable coil levitation: Cf) Geomagnetic field (<1Gauss) is problematic at RT-1
• "Offset" injection method is not directly applicable
• Additional dummy injection port(s) can be a solution

On particle trapping:
• Error fields drastically shorten trapping times

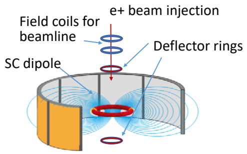


Possible "offset" injection for Dipole coil configuration

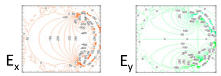


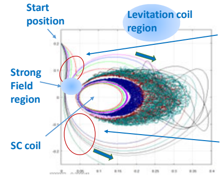
Error field of several Gauss is problematic even for single particle regime

- Axisymmetric injection route consideration



Example of E_x and E_y generated by Segmented electrodes





Two typical injection trajectories from dipole axis to confinement region. e+ of V_{para}=3eV and V_{perp}=1eV, 500-1400V/m E_{perp} in this calculation

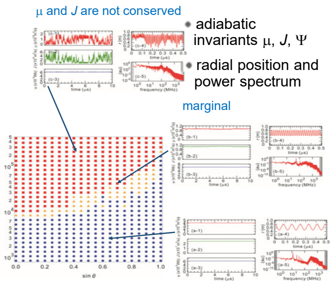
Route 1. Relatively strong bias; Mirror reflection by increased V_{perp}, "northbound" injection into trapping region
Quantitatively similar to the orbit in permanent magnet injection experiment

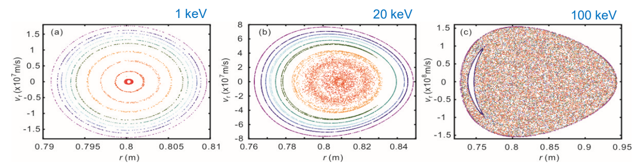
Route 2.Relatively weak bias: moderate V_{perp} increase without reflection, "southbound" injection
Orbit does not interfere the region close to the levitation coil position

Chaos of high-energy positron orbit in RT-1 (review)

- Periodic and random behaviors

• Temporal evolutions of adiabatic invariants and radial position for various E_k and θ
• Ψ is always conserved due to symmetry
• Above E_k = 20keV, coupling between gyro and bounce motions results in the breakdown of μ and J conservation
• Two degree of freedom means non-integrable chaotic system (Liouville-Arnold theorem)

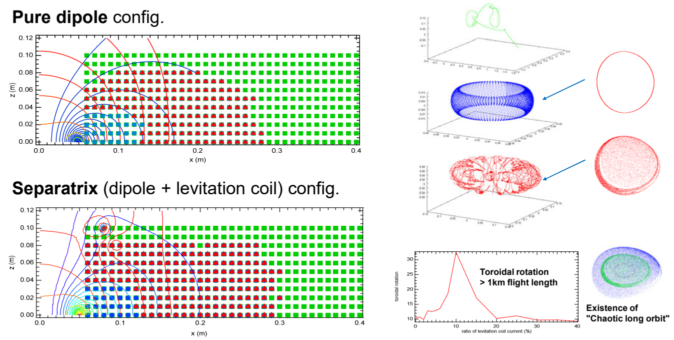




- Poincaré plot confirms chaos, implying long orbit lengths before annihilation

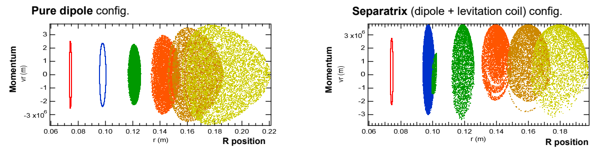
Chaos of low-energy e+ in a compact dipole trap

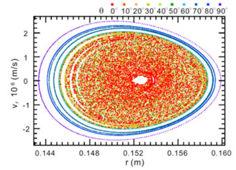
- Classification of low energy e+ orbit type in a weak dipole field



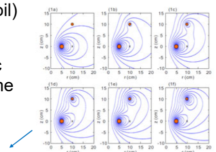
Broad "chaotic orbit" region exists between "regular" and "untrapped" orbit regions, depending on injection parameters and coil configurations.

- Poincaré plot for various injection conditions

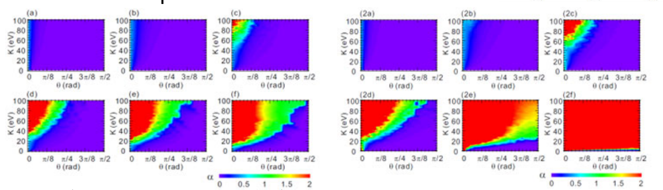




• Even low energy e+ (~10eV) orbit can be chaotic
• Effects of separatrix (L coil) enhance chaotic orbit
• Some particles in chaotic orbit exhibit long flight time



- Parameter dependence



Orbit type (blue: regular, green: marginal, red: chaos) for different kinetic energy and pitch angle, when the dipole field coil radius is a:7.5, b:10, c:12.5, d:15, e:17.5, f: 20cm.

Effects of separateix, by adding a:0%, b:10%, c:15%, d:20%, e:25%, f:30% of floating coil current to the levitation coil current. (color contour is similar to (a)).

References

[1] M.R. Stoneking *et al.* (PAX/APEX team), J. Plasma Phys. **86**, 155860601 (2020).
[2] H. Higaki, K. Michishio *et al.*, Appl. Phys. Express **13**, 066003 (2020).
[3] S. Murakami, T. Sato and A. Hasegawa, Phys. Fluids B **2**, 715 (1990).
[4] H. Saitoh, Z. Yoshida, T. Sunn. Pedersen *et al.*, Phys. Rev. E **94**, 043203 (2016).
[5] H. Saitoh and I. Tanioka, Plasma Fusion Res. **17**, 2401026 (2022).