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Innovative And Efficient Plasma Magnetic Confinement Method Based On An Overlooked Historical Discovery

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ABSTRACT

- An **alternative method of magnetic confinement** of plasma was demonstrated theoretically and published by Owen Storey and Laurent Cairó in the late 1970s, inspired by an earlier discovery by Eugene Parker.
- They proposed a conceptual device, which has the potential to be **simple**, **inherently stable**, **energetically efficient**, and **to operate continuously**.
- This work is now revisited, initially **aiming to demonstrate the theoretical concept in practice** by numerical simulation and laboratory experiments.
- This is on-going. Preliminary results and the roadmap are presented here.

BACKGROUND

- Parker discovered, while studying a simplified model of the Earth magnetosphere, that when field-free plasma flows around and parallel to a plasma-free magnetic field, a new magnetic field emerges in certain circumstances, causing the boundary layer between field and plasma to disintegrate [1].
- Storey and Cairó showed that if the magnetic field surrounds the flowing plasma, then the emergent magnetic field ("Parker's effect") can reinforce the confinement, in certain circumstances, while the bulk plasma remains field-free and current-free [2].
- They proposed a simple device based on a modification of James Tuck's picket fence [3], in a toroidal geometry (Fig. 1). They called it the Plasma Storage Ring (PSR) and showed that its confinement would be effective, inherently stable, and could be, with Parker's effect, particularly efficient. Fig. 2 shows that the global beta increases (i.e. the external magnetic field required decreases) with plasma flow velocity, up to a point.

FIG. 1 – PSR concept

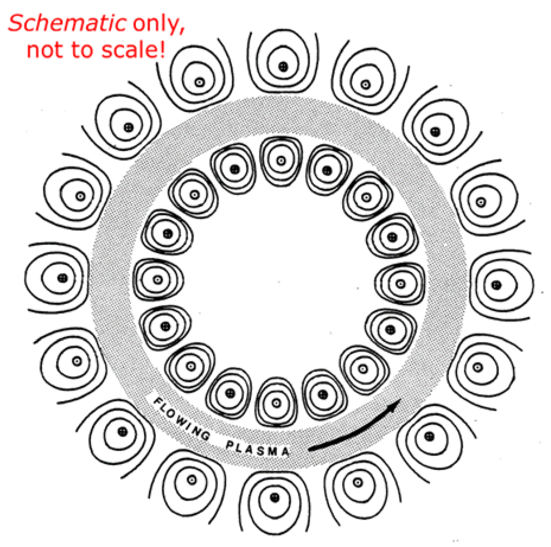
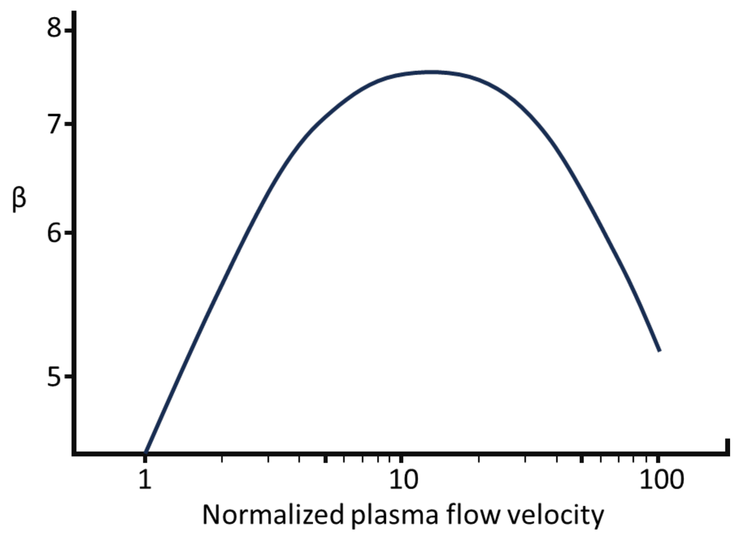


FIG. 2 – Global beta vs. flow velocity



CHALLENGES

PROOF BUT NO DEMONSTRATION

- The theoretical work suggests stable plasma confinement at substantially reduced field strength, but to date, Parker's effect has not been observed or demonstrated computationally or experimentally.
- Capturing Parker's effect requires a fully kinetic model, a multi-scale spatial domain, and time integration that reaches ion times while remaining stable to electron dynamics.
- The qualitative behavior of the boundary layer is understood, but its evolution with time as Parker's effect emerges is not.

METHODS, IMPLEMENTATION AND OUTCOMES

NUMERICAL MODELING

- An initial **simplified simulation** has shown that the confinement becomes excellent at flow speeds of ion-thermal Mach 5 (Fig. 3).
- A **full kinetic simulation** to observe the transition to steady state and the emergence of Parker's effect has been attempted using the Gkeyll software framework [4] but was inconclusive (Fig. 4). We are now starting over using an energy-conserving semi-implicit particle-in-cell framework.

METHODS, IMPLEMENTATION AND OUTCOMES (Cont'd)

- A **full kinetic simulation** of a plasma beam flowing through a current-carrying ring is defined to demonstrate Parker's effect and support the bench-top experiment (Fig. 5).

BENCH-TOP EXPERIMENTS

Two small-scale laboratory experiments have been specified: the first is only to observe and characterize the emergence of Parker's effect as per Fig. 4. The second is to observe both the confinement and the efficiency gain due to Parker's effect in a linear PSR section, as per Fig. 5.

FIG. 3 – Preliminary results

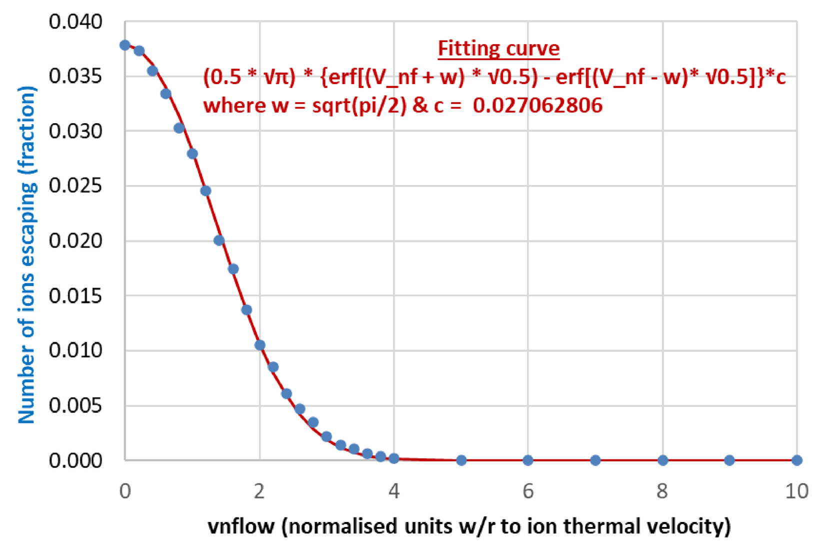
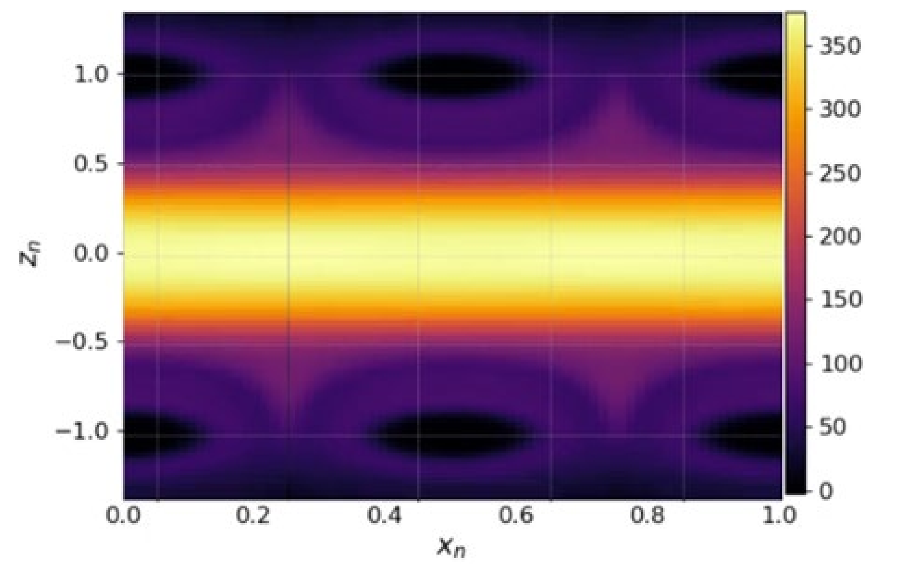


FIG. 4 - Electron density in spatial domain



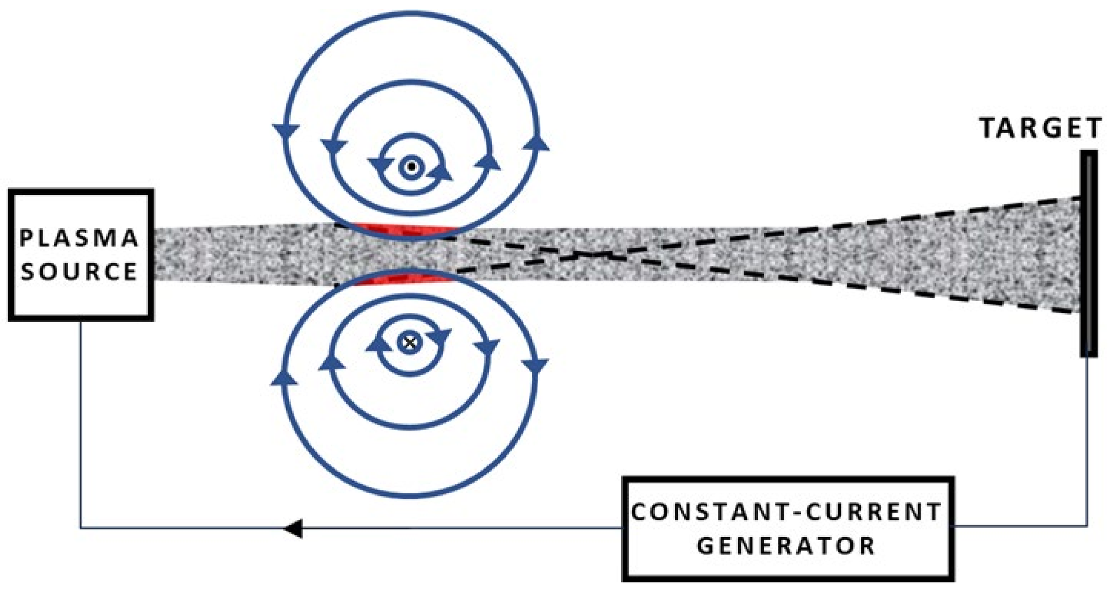


FIG. 5
Setup for plasma jet in current-carrying ring

CONCLUSIONS

- A **roadmap** has been specified to demonstrate in practice and characterize a possible new method of magnetic confinement of plasma that is simpler and more efficient that the mainstream methods.
- **Preliminary results** are encouraging and work to confirm the concept indisputably is on-going, with collaborations sought for **acceleration**.
- Confirmation of the theoretical results could open a new pathway to the realisation of fusion energy with reduced complexity and cost.

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