SIMULATION OF STOCHASTIC TRANSPORT AND DEPOSITION OF SEED RUNAWAY ELECTRONS DURING ITER SPI

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ABSTRACT

- Using the PTC code based on fluid fields produced by JOREK simulations with a conservative higher-order magnetic moment, to investigates the relativistic seed REs transport behavior.
- Self-similar density profile and exponential decay of seed REs are found for case with sufficiently stochastic magnetic field.
- The diffusion transport coefficient of REs obtained by simulation is well match with the theoretical prediction.
- The timescale of seed REs loss is much shorter than the avalanche time.
- Diffusion alone is a good enough description of the RE transport, at least in cases with sufficiently stochastic magnetic field.

BACKGROUND

- During plasma disruptions, Runaway electrons (REs) can be generated and multiply via the avalanche mechanism, potentially causing severe damage to plasma facing components once they deposit on the first wall.
- One way of preventing such an RE avalanche is to induce enhanced RE transport. An especially interesting scenario of such enhanced loss is the RE transport during the Thermal Quench or its mitigation via disruption mitigation systems such as Shattered Pellet Injection (SPI).
- To avoid the *high computational cost* of full-orbit simulations, and the *low precision* of standard guiding center theory, we take advantage of the high-order conservative magnetic moment.

NUMERICAL METHODS AND SETTINGS

This work is mainly based on a test particle tracing code named PTC, which is capable of both full orbit and drift orbit solvers [2]. 1×10^5particles with a 5 MeV energy are initialized in the plasma region, and the pitch angle $(p_\parallel/p_{total})$ is set to 0.9.

HIGH ORDER CONSERVATIVE MAGNETIC MOMENT

The guiding-center solver is used in this work for its efficiency over the full orbit solver. Traditional guiding-center theory assumes the conservation of the magnetic moment ($\mu = p_\perp^2/2mB$), but full-orbit simulations have shown that this assumption breaks down for REs with higher energy, depending on the pitch angle. Liu et al [2] has addressed this issue by deriving a higher order expression for the magnetic moment.

$$\mu = \frac{\left|p_\perp + p_\parallel^2 \boldsymbol{\kappa}\times\boldsymbol{b}/(qB)\right|^2}{2m_0 B} = \mu_0 + \mu_1 + \mu_2$$

STOCHASTIC BACKGROUND FIELD

Particle simulations are carried out based on static fluid fields produced in previous JOREK [3] mitigated TQ simulations for ITER. Fig.1 shows the (a) perturbed magnetic energies and (b) Poincare of the chosen field.

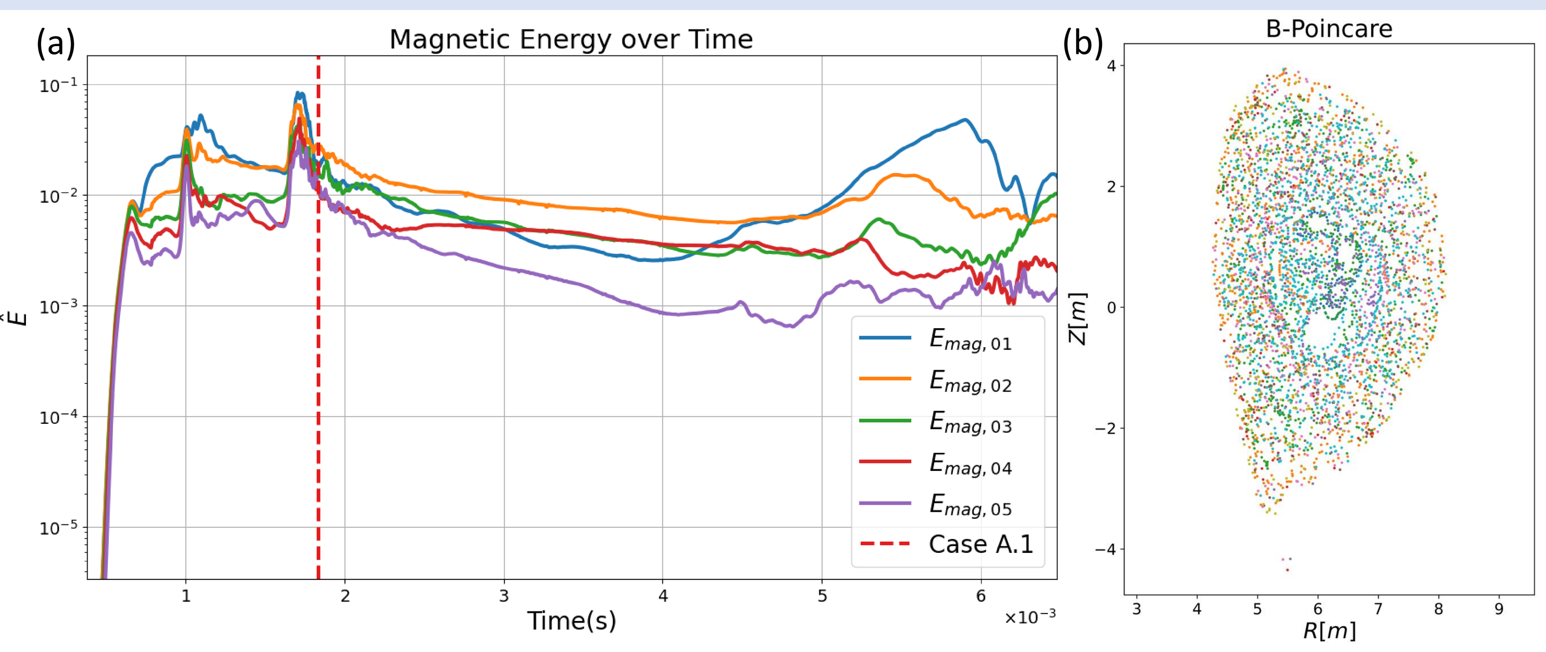

FIG. 1. Magnetic energy and Poincare of the background fluid field

OUTCOME

SELF-SIMILAR RE DENSITY PROFILE

The normalized density profiles of REs in stochastic fields exhibit self-similarity regardless of initial distribution, as shown in FIG. 2.

- Two schemes converge to the same self-similar density profile within $50\ \mu\mathrm{s}$, much shorter than background field evolves timescale (FIG. 1 (a)).
- The green dash line is the normalized first-order eigenmode density n solved from radial diffusion equation, which is in good agreement with the self-similar profile. This suggests an eigen-solution for the RE transport.

LOST TIMESCALE AND HEATMAP OF ENERGY DEPOSITION

- FIG. 3 shows the distribution of lost particles over time. The red solid line is the exponential fitting of the lost particles, and matches the lost counts well. This gives a characteristic lost time τ as 6.63×10^{-5} s and shorter enough to overcome the avalanche process of REs.
- FIG. 4 presents the heat map of the cumulative energy deposited on the wall by lost REs and unwrapped toroidally. This pattern shows a special dominant n=1 mode and higher-order harmonics.

COMPARISON OF PARTICLE FLUX AND DIFFUSIVE FLUX

The real particle flux Γ and diffusive flux $-D\nabla n$ exhibit similar magnitudes and tendencies, as shown in FIG. 5. Such agreement suggests that diffusion alone is already a good enough description of the RE transport.

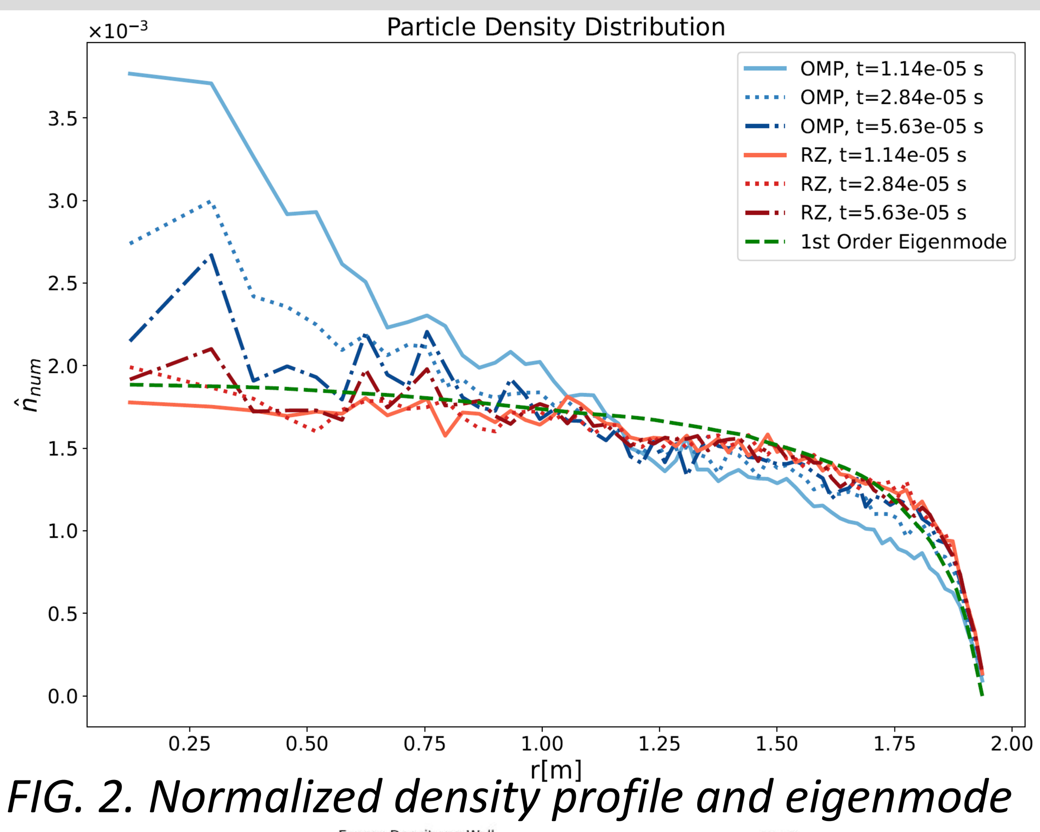

FIG. 2. Normalized density profile and eigenmode

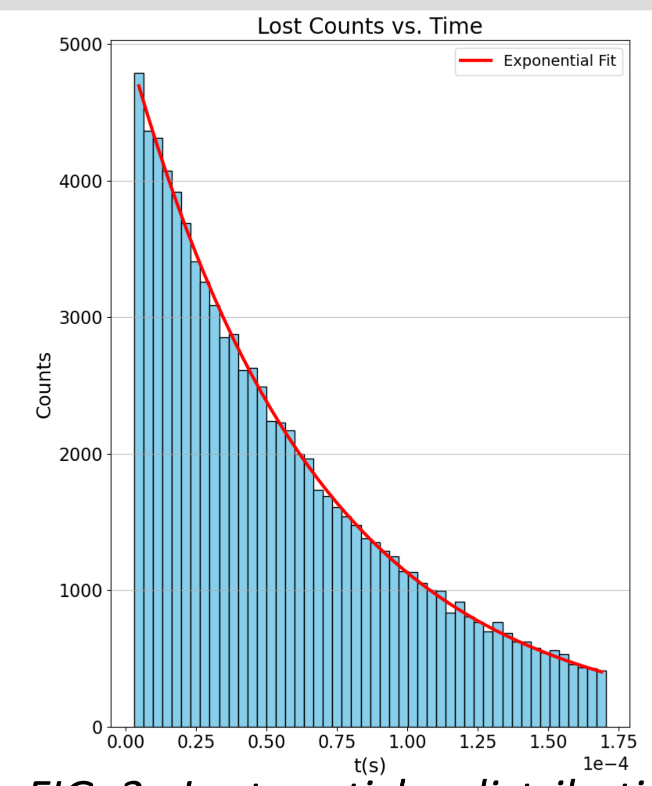

FIG. 3. Lost particles distribution

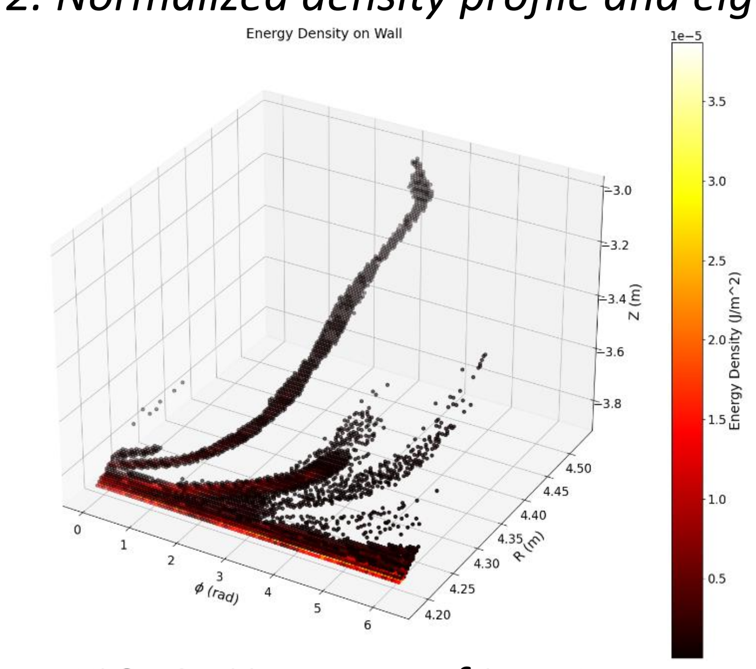

FIG. 4. Heatmap of Lost Energy

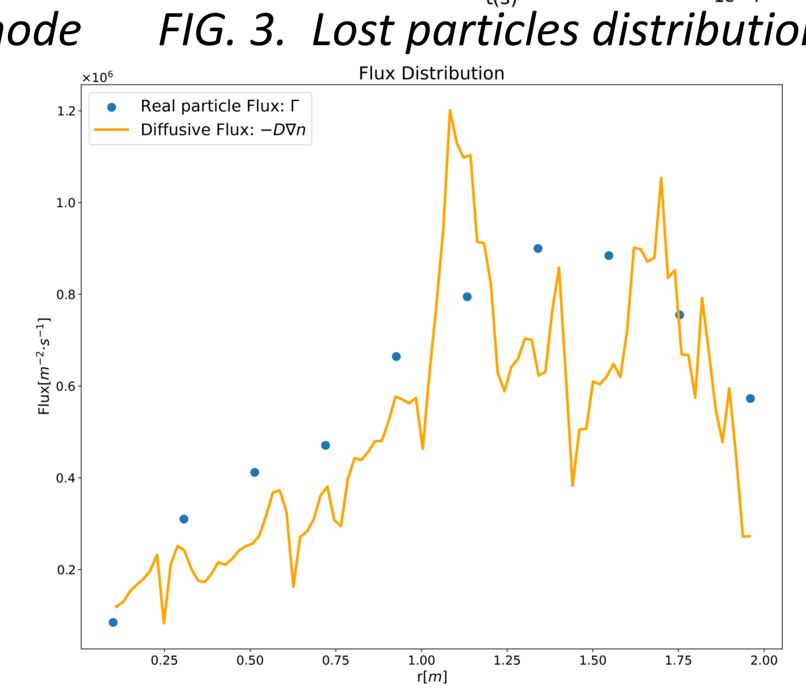

FIG. 5. Comparison of flux

CONCLUSION

- Utilizing the high-order conservative magnetic moment, we have performed guiding-center simulations of relativistic seed REs in stochastic magnetic fields after SPI injection with high precision.
- The results—**self-similar normalized density profiles, exponential loss time distributions, heatmap of REs energy, and consistency between diffusive and real particle fluxes**—provide new insights into the transport and deposition behavior of seed REs.

REFERENCES

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