**A New Predictive Scaling Formula for ITER’s Divertor Heat-Load Width Informed by Gyrokinetic Simulation and AI/ML**

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**Introduction**

- Understanding the heat-flux width in attached divertor condition is essential since it sets the baseline for heat-load with in semi-detached/detached divertors.
- The edge gyrokinetic code XGC specializes in edge simulation across the separatrix to wall.
- Study non-equilibrium plasma (non-Maxwellian) profile.
- Heat, momentum and particle sources.
- Monte-Carlo neutral particle recycling with atomic data.
- Fully nonlinear Finite-Planck collision operator → AXM operator.
- Complicated edge geometry: unstructured triangular mesh.
- X-ray orbit loss is critically important for edge physics.
- XGC is a SciDAC + ECP code.
- In all three early-science programs: Frontier CAAR, Aurora ECP, Petrmutter NESAP.
- Now, electromagnetic (not a subject of this talk).

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**How different is a/p, between present-day tokamaks and full-current ITER, and how it affects ExB shearing rate across separatrix?**

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**Test: effect of the collisionless TEM (CTEM) turbulence on the edge stabilization.**

- Due to low T_e, it is difficult for today’s tokamaks to have CTEM turbulence across separatrix.
- Dissipative TEM (DTEM) turbulence is subject to ExB shearing suppression, which is present in today’s states a/p, tokamaks, while CTEM can be more robust against moderate/ExB shearing rate.
- Low aspect-ratio tokamaks can have a strong CTEM drive if the edge T_e is high enough.
- Most of the edge electrons are magnetically trapped & enhanced effective collisionality does not exist.
- XGC finds that the highest current (2MA) NSTX-U has a high enough edge T_e and yields \( \lambda_{XGC}^{\text{sim}} > 2.0 \times 10^{16} \) cm, while a lower current (1.5MA) NSTX-U shows \( \lambda_{XGC}^{\text{sim}} < 2.0 \times 10^{16} \).

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**XGC that predicted \( \lambda_{XGC} \) values in agreement with experiments in all three US tokamaks and JET also predicted \( \lambda_{XGC}^{\text{sim}} > 2.0 \times 10^{16} \) in full-current ITER plasma.**

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**The Al program Eureqa suggested simple formulas.**

**Which one should be taken?**

- \( \lambda_{XGC}^{\text{sim}} = 0.6 \times 10^{16} (T_e / 1.0 + 1.0 \times 10^{16}) \) (RMS error=18.7%)
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**We tested the formulas with more ITER simulations. The simplest formula works the best.**

**Formula No. | \( \lambda_{XGC}^{\text{sim}} \) from various formulas | Ratio to \( \lambda_{XGC}^{\text{sim}} = 2.6 \times 10^{16} \)**
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| Eq. (6) | 0.86 mm | 0.32 |
| Eq. (7) | 1.79 mm | 0.68 |
| Eq. (8) | 2.30 mm | 0.87 |
| Eq. (10) | 2.24 mm | 0.84 |

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**It turned out that blobs change to TEM streamers as a/p → 0 in 15MA ITER.**

**How could this be the new physics?**
- Is a/p really different between ITER and the present-day tokamaks and the ExB shearing rate really dependent on a/p? Yes.

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