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Validation of the plasma-wall self-organization model for density limit in ECRH-assisted start-up of Ohmic discharges on J-TEXT

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For decades, people used the empirical scaling law for the tokamak density limit n_G[m^{-3}] =I_p[MA]/(πa[m]^2)×10^{20}, where I_p is the plasma current and a is the minor radius. Recently, a power balance model considering radiation introduced a modified scaling for the density limit, $(I_pP/a^4)^{4/9}$, where P is the heating power [1]. This radiative scaling is in better agreement with the tokamak experimental databases as indicated in Fig. 4 of [1]. The primary factors influencing these power balance limits stem from impurity radiation, which is largely controlled by plasma-wall interactions [2]. This radiation affects the amount of heat reaching the limiter/divertor targets, subsequently determining the plasma temperature in the target region. The target region temperature also significantly impacts impurity production, which in turn influences impurity radiation. This feedback mechanism forms the foundation of the recently proposed plasma-wall self-organization(PWSO) model [2].

The PWSO model predicts a significantly enhanced density limit, which may be attainable in tokamaks with ECRH-assisted ohmic startup and sufficiently high initia neutral density. Experiments have been conducted on J-TEXT to validate such a density limit scenario based on this model. Although the wall conditions have some influence on the experiment due to the J-TEXT limiter material is mainly composed of carbon, the experimental results demonstrate that increasing the pre-filled gas pressure or ECRH power during the start-up phase can help enhance plasma purity and decrease the C_{III} radiation level as well as increase the target region plasma temparature. And this generally leads to a higher density limit at the flat-top, as shown in Fig. 1. Besides, the PWSO 0D and 1D model are applied to calculate the density limit of J-TEXT. Both 0D and 1D models predict the existence of a density-limit basin at higher plasma temparature around target and a desity-free basin at lower plasma temparature around target. As shown in Fig. 2, The J-TEXT experimental data quatitatively agree with the PWSO model's predictions under some papameter assumptions and are located in the density limit basin of the PWSO prediction.

In general, the density limits predicted from the 0D and 1D PWSO models are compared and validated with the J-TEXT experimental data, which are located in the density-limit basin and demonstrate quantitative agreement with the PWSO model predictions.

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References

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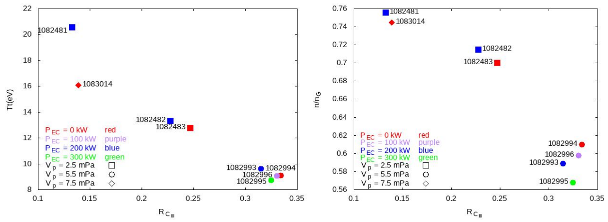

Figure 1. The relationship between (left) plasma temparature around limiter target as well as (right) density limit and the corresponding radiation power R_{CIII} measured from experiments for varying ECRH power and pre-filled gas pressure in the start-up phase.

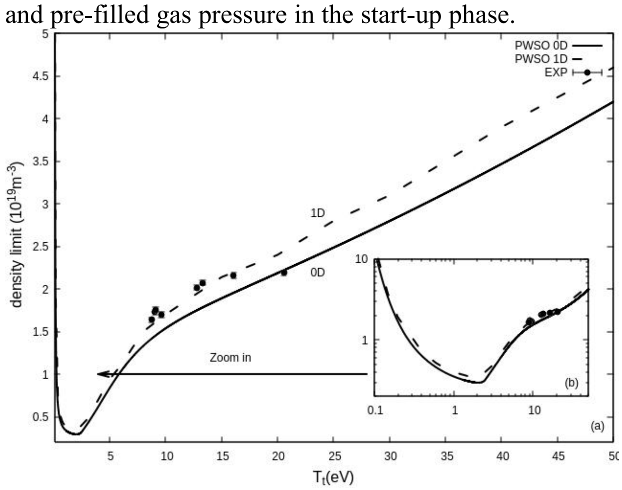

Figure 2. The density limits as functions of the target region plasma temperature Tt using (a): linear and (b): logarithmic coordinates as predicted from the PWSO 0D (solid line) and 1D (dashed line) models in comparison with the experimental data (circular symbol).