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The Role of Toroidal Rotation in the Very High Energy Confinement Observed in Super H-mode Experiments on DIII-D[1]

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Experimental analysis and modeling of recent super H-mode experiments on DIII-D show that driven high toroidal rotation, not high pedestal pressure, plays an essential role in achieving very high energy confinement $H_{98y2} > 1.5$. Understanding the mechanisms leading to improved confinement in the super H-mode experiments is essential to the ability to extrapolate to a future reactor. For fixed plasma shape and rotation, the energy confinement time for discharges analyzed here with different plasma current, density, injected power, is proportional to the $\tau_{E,98y2}$ scaling, i.e. the energy confinement quality H_{98y2} is constant, despite different pedestal pressure (up to $\times 2$), and plasma stored energies. For fixed plasma shape but different toroidal rotation, which varies according to injected neutral beam torque per particle, H_{98y2} varies linearly with rotation, independent of pedestal pressure. A transient phase of very high confinement quality, $H_{98y2} \sim 2$ (well above standard H-mode, $H_{98y2} \sim 1$), is only achieved at very high level of core rotation, e.g. 400 km/s at $\rho=0.4$, and is independent of the pedestal pressure. At moderate rotation on DIII-D (similar to levels expected in ITER) very high super H-mode pedestal pressure yields a lower confinement quality improvement ($H_{98y2} \leq 1.2$) if no core MHD modes are present. Linear gyrofluid and nonlinear gyrokinetic transport modeling confirms that rotation-driven E$\times$B shear is responsible for confinement quality significantly above standard H-mode, and that E$\times$B shear turbulence stabilization is far stronger than EM stabilization, so-called hot-ion stabilization (T_i/T_e), or fast ions effects. Gyrokinetic simulations also show a potential approach to improve confinement at low rotation: higher impurity (carbon) gradient in the plasma core can efficiently suppress ITG turbulence, and improve confinement in the super H-mode scenario.

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