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Improved understanding of plasma exhaust and spherical tokamaks from initial physics operations on MAST Upgrade

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MAST Upgrade is a low aspect ratio device (R/a = 0.85/0.65 ~ 1.3) based on the MAST tokamak that started plasma operations in October 2020. It has substantial new capabilities compared with the original MAST device [1] as a result of 19 new poloidal field coils (shown in Figure 1, 14 of which are within the vacuum vessel); new, closed, up-down symmetric divertors with Super-X capability fitted with cryopumps; 50% higher toroidal field. MAST-U is designed to operate at higher toroidal field (0.585 T to 0.85 T at full current), the new solenoid nearly doubles the inductive flux from 0.9Vs to 1.7Vs, allowing for the maximum plasma current and pulse length to be 2MA and 5s respectively and a combination of on and off-axis neutral beam heating and current drive. In the first physics campaign the operational envelope is slightly reduced compared to the full design with pulses at up to 1 MA for 2 seconds duration, 0.65 T toroidal field at R=0.8 m, but with the full on and off axis beam power at 2.5 MW per beam line, for a total of 5 MW of injected power.

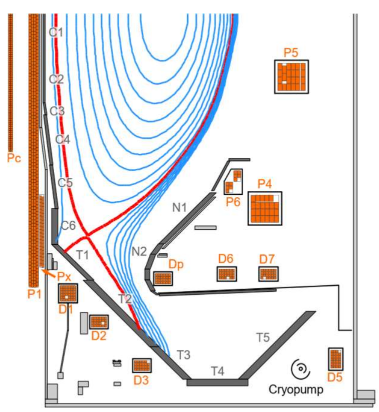

Figure 1: Poloidal cross-section of MAST Upgrade

The physics programme has a strong emphasis on addressing key ITER physics issues, such as controlling ELMs with 3D fields and power exhaust in future reactors. The uniquely flexible divertors, combined with high resolution diagnostics in the main chamber and divertor, makes MAST Upgrade an excellent facility to understand plasma exhaust and identifying the key mechanisms and divertor properties that govern power and particle dissipation [2]. The tightly closed divertors and considerable flexibility to vary the magnetic geometry in the divertors, enabling detailed studies of a wide range of alternative and conventional divertor configurations in a single device.

Moreover, MAST Upgrade explores the physics of spherical tokamaks, including but not limited to improved confinement at low collisionality, spanning broad energetic particle phase space and strong gradients in magnetic field amplitude across the divertors that is predicted to reduce the sensitivity of detachment to changes in upstream plasma conditions [3].

The physics highlights from the first MAST Upgrade campaign will be presented, including detailed characterisation of the Super-X divertor configuration and comparison with a conventional divertor. where initial results indicate the increased connection length from the outer mid-plane to the divertor target significantly facilitates access to detachment in the Super-X configuration. These observations are in qualitative agreement with predictive modelling with SOLPS [4, 5, 6] that indicated a reduction in the upstream density required to detach the outer divertor in the Super-X configuration due to a combination of increased divertor volume, increased parallel connection length and the tightly baffled divertor chambers.

On and off-axis neutral beam injection is used to explore the benefits of off axis injection on accessing favourable equilibrium safety factor profiles for improved stability and fast particle confinement. The impact of the new divertors on confinement in the core and pedestal will also be reported. Experimental results will be compared with modelling where possible to elucidate the underlying physical mechanisms.

References

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