

ASDEX Upgrade LETTER



Max-Planck-Institut
für Plasmaphysik

No. 13 | May 2013

IN GARCHING FOR EUROPE – FUSION RESEARCH WITH GERMANY'S LARGEST TOKAMAK DEVICE



CAD DRAWING: IPP



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PHOTO: R. STORK

EDITORIAL

The European Fusion Research programme is presently in a transition period, moving from a relatively loosely coordinated organization based on bilateral Contracts of Association with EURATOM, to a much stronger coordinated consortium of European fusion laboratories. The ultimate goal of the consortium is to generate electricity from nuclear fusion before 2050. The European Fusion Roadmap that has recently been established to set out the path to reach that goal, is the key document to prioritize the European research and developments in the field of nuclear fusion. By far the most urgent and important topic in the Fusion Roadmap is the construction and subsequent exploitation of ITER. The ITER construction is coordinated in Europe by the European Domestic Agency Fusion for Energy (F4E). The European accompanying programme, which will be coordinated by the new consortium of European fusion laboratories, will have many elements that aim to improve the exploitation of ITER and also the subsequent realization of DEMO. The work in the accompanying programme is focussed on the eight missions of the Fusion Roadmap and will be carried out on a limited number of key research devices. More and more, the fusion programme will move from an organization where many laboratories exploit their own fusion devices to a tightly interacting consortium where the research is done on those devices that are best suited for the purpose. ASDEX Upgrade is one of these devices, as was already recognized in the Facility Review several years ago. This Newsletter regularly reports on work done by various European fusion laboratories carried out at ASDEX Upgrade, giving evidence that this device is already operated as a European device, fully in line with the spirit of joint collaboration.

TONY DONNÉ

Highlight from a recent ASDEX Upgrade experiment

High-accuracy radial electric field measurements

Learning more about the H-mode

The understanding of the physics relevant to the edge transport barrier (ETB) in an H-mode fusion plasma is of crucial importance as it leads to steep gradients at the plasma edge which implies a confinement gain at the boundary of the plasma. This improvement propagates into the plasma core, where a hot and dense plasma is

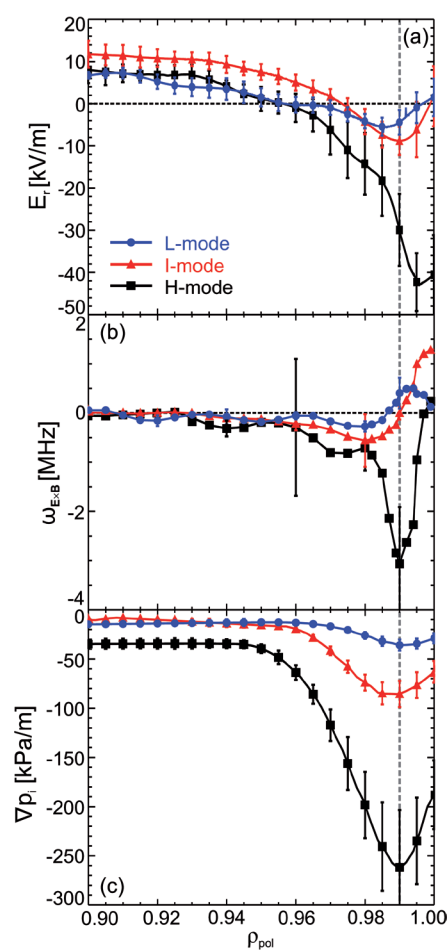
required for fusion. The ETB is thought to be caused by a sheared plasma flow perpendicular to the magnetic field which is equivalent to a sheared radial electric field E_r . Recently this mechanism has been confirmed as the location of the steepest ion pressure gradient ∇p_i was shown with unprecedented accuracy to match the position of the largest E_r shear.

The installation of a new edge charge exchange recombination spectroscopy (CXRS) diagnostic at ASDEX Upgrade enables high temporally and radially resolved measurements of the poloidal and toroidal rotation velocities, densities and temperatures of impurity ions. Thus, it provides all

measurements for deriving E_r from the radial force balance equation. The new CXRS measurements, combined with the unique edge diagnostic suite available at ASDEX Upgrade, allowed for the high-accuracy localization (2 to 3 mm) of the E_r profile based on an established alignment procedure. Using this technique in H-mode discharges it has been found that the maximum in the $E \times B$ shearing rate ($\omega_{E \times B}$) coincides with the steepest ∇p_i and lies inside the position of the minimum of the E_r well (black curves). This suggests that the negative shear region is the important region for the formation of the H-mode pedestal.

In the radial force balance of impurities the poloidal rotation contribution yields the dominant term in the evaluation of E_r at the plasma edge. For the main ions, the E_r minimum coincides with the maximum pressure gradient term $\nabla p_i / en_i$, supporting the hypothesis that the E_r well is created by the main ion species. The fact that $\nabla p_i / en_i$ matches E_r in the ETB is consistent with the main ion poloidal flow being at neoclassical levels. Quantitative comparisons between neoclassical predictions and measurements of both impurity and main ion poloidal rotation show that the sign and the magnitude are in remarkably good agreement.

E. VIEZZER



(a) E_r in L-, I- and H-mode and (b) resulting $E \times B$ shearing rate. For better clarity the uncertainties are only shown for distinct radial positions. (c) Main ion pressure gradient, ∇p_i , in different confinement regimes.

FIGURES: E. VIEZZER

Intrinsic plasma rotation

Shedding light on spontaneous spinning

The question of “intrinsic rotation”, or why tokamak plasmas spin in the absence of external torque, has presented the fusion community with an intriguing puzzle for decades. It is only recently, however, that this topic has received significant experimental and theoretical consideration, motivated, at least in part, by the idea that ITER will require a substantial level of rotation and/or rotation shear to improve confinement and provide stability. On ASDEX Upgrade, light has been shed on this topic through the formation of an intrinsic rotation database, which has enabled an unprecedented study of the dependencies of the intrinsic rotation profile on theoretically relevant plasma parameters.

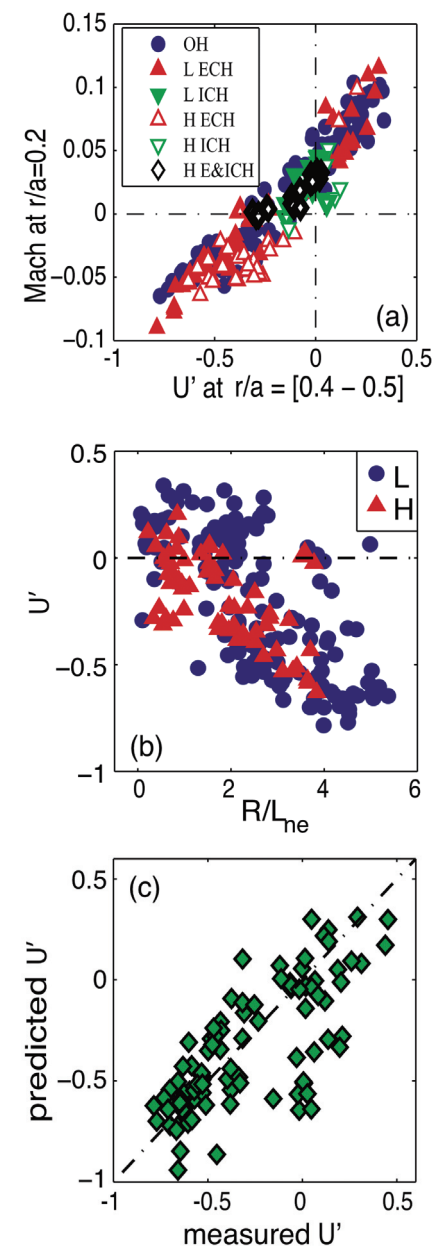
This study has shown that the Mach number in the center of the plasma appears to be determined, in large part, by the normalized gradient of the toroidal rotation at mid-radius, U' , which in turn exhibits the strongest correlation with the local logarithmic electron density gradient, see (a) and (b). Here, it is clear that the most hollow rotation profiles (negative U') coincide with the most peaked n_e profiles (high R/L_{ne}), while co-current rotation corresponds to low R/L_{ne} . The known relationship between R/L_{ne} and plasma turbulence suggests a connection between turbulence and intrinsic rotation behaviour as well.

A study based on local linear gyrokinetic calculations predicts the same dependence of the turbulence induced rotation gradient U' versus the logarithmic density gradient as observed in the experiments, when an appropriate finite constant tilting is imposed on the turbulence mode structure, see (c). Although the dominant physical mechanisms which are responsible for the tilt of the turbulent eddies are still under investigation, the agreement observed between the theoretical calculations and the observations suggests that at least some of the main dependencies of the intrinsic rotation can be captured by relatively simple local models which describe the turbulent transport. A detailed comparison of the ASDEX Upgrade results with those of other devices can be expected to provide a more reliable basis for the extrapolation of intrinsic rotation to future devices.

R. MCDERMOTT

(a) Mach number at $r/a=0.2$ versus the normalized rotation gradient, U' , at $r/a=0.45$ in L- and H-modes with ohmic heating (OH) and with auxiliary ion (ICH) and electron cyclotron heating (ECH) (b) U' versus the logarithmic electron density gradient, R/L_{ne} and (c) predicted values of U' (assuming a tilt angle of -0.3 degrees of the turbulent eddies) versus the measured values of U' in the TEM domain.

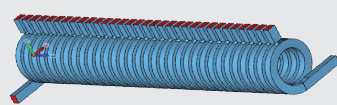
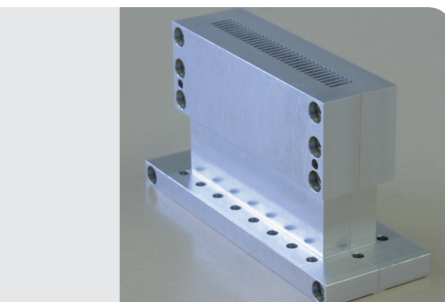
FIGURES: C. ANGIONI



Turbulence diagnostics advance

In autumn 2012 IPP became the host for a new »Virtual Institute on Plasma Dynamics and Turbulence using Advanced Microwave Diagnostics« funded to the tune of 2.4 million euro by the German Helmholtz Association. Together with German university and European fusion lab partners, the virtual institute aims to advance, over the next five years, the understanding of turbulent transport using a series of novel microwave diagnostic developments. These are centred on PhD projects and include reflectometer beam steering via phased array antennas, multi-beam probing via frequency diplexed comb-reflectometers, 3D turbulence imaging systems, antenna clusters for turbulence correlation studies plus many others.

G.D. CONWAY



Leaky-wave phased array antenna under construction at IGVP Stuttgart. Top: antenna, bottom: feeder.
PHOTO/CAD DRAWING: IGVP Stuttgart

New Helmholtz Young Investigators Group at ASDEX Upgrade

Rachael McDermott, from the IPP's Plasma Edge and Wall division, was one of 14 scientists out of 244 candidates selected by the Helmholtz-Gemeinschaft to lead a Helmholtz Young Investigators Group. The new group, entitled »Macroscopic Effects of Micro-turbulence Investigated in Fusion Plasmas« will be based at the ASDEX Upgrade tokamak and will be supported by an annual endowment of 250.000 € for five years. The group, which will consist of up to five persons, will build new, innovative



diagnostics in ASDEX Upgrade to investigate the poloidal asymmetries in the plasma rotation and impurity densities as a function of plasma parameters and turbulence regimes. This information will provide a better fundamental understanding of the interactions between the different turbulent transport channels, which is essential for accurate prediction of the energy, momentum, and particle transport in future devices.

R. McDermott

PHOTO: KARL-HEINZ WAGNER

New diagnostics for ASDEX Upgrade

The fusion research programme of the FOM Institute DIFFER (Dutch Institute for Fundamental Energy Research) is focused on two main topics that align with the first two missions in the EFDA Fusion Roadmap: plasma surface interactions – concentrated on the MAGNUM-PSI and Pilot-PSI facilities in The Netherlands – and advanced control of MHD modes in burning plasmas – largely concentrated on ASDEX Upgrade. An important aspect is how fast particles, that will be present in copious amounts in burning plasma, interact with the various MHD modes in the plasma.

To aid the work in the field of MHD control, the FOM-DIFFER team has, in recent years, largely concentrated on the installation of new diagnostics on ASDEX Upgrade:

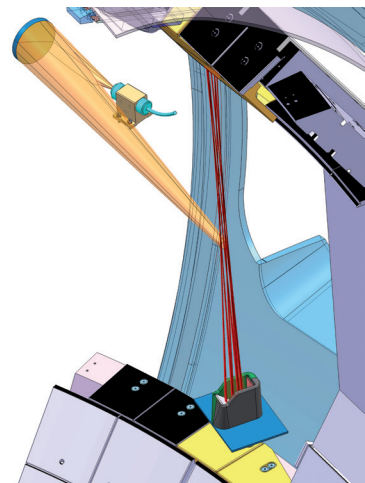
- A novel spectrometer with high optical throughput has been installed for charge exchange recombination spectroscopy. The spectrometer, which was developed by ITER-NL, can measure simultaneously carbon, helium and deuterium lines and is specifically suited to the study of the fast ion population (e.g. the slowing down of fast minority-heated helium ions). Ultimately, it is the aim to study the effect fast ions have on the stabilization and/or suppression of MHD modes in ASDEX Upgrade.
- The Electron Cyclotron Emission Imaging system is in operation for a number of years. The system, which was jointly developed with UC Davis, features 128 channels and measures the 2-D electron temperature with high spatial and temporal resolution, enabling accurate determination of the mode structure and dynamics of MHD modes. Amongst others, it has been used to study Alfvén eigenmodes and edge localized modes (ELMs). The system is proposed to be upgraded with a second view at a slightly different toroidal location to investigate the 3-D nature of MHD modes.
- In close collaboration with IPF Stuttgart the tuneable mm-wave cavity, the Fast Diplexer Switch FADIS, is used to enable Electron Cyclotron Emission measurements along the same line as one of the ASDEX Upgrade Electron

Cyclotron Current Drive (ECCD) beams. In this way it is possible to directly observe the response of MHD modes in the plasma to ECCD without the need to use any magnetic equilibrium calculations. A direct digitizing radiometer observes back-scattered waves, while a six-channel radiometer is installed to determine the radial location and phase of tearing modes for control. With a similar (but quasi-optical) system on TEXTOR, it was demonstrated that the in-line ECE signal can be used for feedback control on the gyrotron and launcher mirror. In 2012 first measurements were successfully done on ASDEX Upgrade in a collaboration between IPF Stuttgart, IPP, FOM-DIFFER and TNO. The latter organization developed the new mechanical control of the launcher mirrors.

- A multi-pass Thomson scattering system is presently in the implementation phase. It will be used to monitor a vertical plasma chord that is just inside the edge pedestal. Thanks to the very high effective laser power that is achieved in a multi-pass cavity, the system is suitable for measurement of the local edge current density in addition to the more standard electron temperature and density measurements.

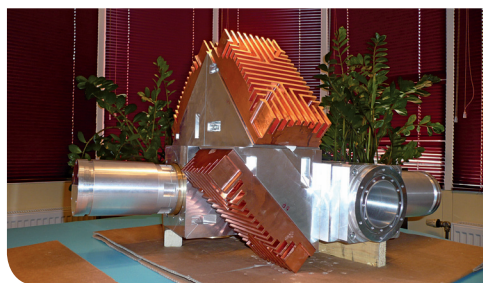
Design drawing of the multi-pulse Thomson scattering system. The laser beam (red) is reflected back and forth between a mirror at the top (not visible) and a mirror, protected by a Brewster window, in the green holder at the bottom. The collection mirror and the fibre optic head (light blue) are shown near the top left of the picture.

CAD DRAWING: DIFFER



The edge current density is deduced from measurement of the small wavelength shift (a few nm) of the scattering distribution, which is much wider (~100 nm). The multi-pass cavity features in-vessel mirrors and piezo-driven shutters. The expectation from assessment studies is that the multi-pass cavity will remain stable for the majority of operating scenarios, while having a good overall long-term stability.

T. DONNÉ



The Mach-Zehnder interferometer is used in conjunction with the Fast Diplexer Switch to separate the low-power ECE signal emitted by the plasma from the high-power ECRH/ECCD radiation launched into the plasma via the same transmission line.

PHOTO: DIFFER