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Plasma profiles in the inner divertor of ASDEX Upgrade

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Abstract

On ASDEX Upgrade, the inner leg of the divertor is diagnosed by Langmuir probes, spectroscopy, and thermography. All of these observe a narrow peak near the strike point and a second, broad peak located 10–20 cm higher. The profile form in and between ELMs is very similar, so it is not the temporal superposition of two single peaks. Numerical modeling shows each of the peaks, depending on plasma conditions, but never both peaks at the same time, so an explanation based on axisymmetric physics appears unlikely. The observation in a discharge where the strike point is swept that the upper peak remains fixed in space while the lower peak follows the strike point favors a geometric origin, even though the observations by different diagnostics are similar and the probes were designed to be outside the shadows of the neighboring divertor tiles. Alternatively, toroidally asymmetric physics could produce such a profile. © 2001 Elsevier Science B.V. All rights reserved.

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1. Modeling

The inner leg of divertor tokamaks has not been studied as intensively as the outer leg. In the ASDEX Upgrade Divertor II the inner leg is relatively well measured by Langmuir probes, spectroscopy, and thermography. These diagnostics often indicate that the profiles of density, particle flux, and power flux have a double peak, which is not expected from modeling. Modeling with B2-Eirene [1,2] shown in Fig. 1, reproduces a narrow peak near the strike point at low density and high power. As the density is increased or the power lowered, the plasma begins to detach near the strike point and the profile becomes broader and moves upward. In this respect, either of the peaks observed can be reproduced by the simulations, but they have never been obtained simultaneously. Thus if the profiles are to be explained by axisymmetric physics, then there must be some effect that is not yet captured in the simulations. This seem unlikely, but some scenarios are conceivable. For example, if the scrape-off layer is hot enough and dense enough, neutrals coming from the walls or in-vessel components could be ionized outside of the separatrix, producing a local maximum in the parallel particle flux. These particles might then absorb a small fraction of the neutral beam or radio frequency heating power, not enough to be noticed in the power balance, but enough to produce a local maximum in the parallel heat flux. Alternatively, a 'second scrape-off layer' may be associated with recycling from the top of the divertor, where the poloidal field is almost normal to the divertor surface.

If such effects are not adequate to explain the profiles, another possibility is non-axisymmetric physics [3]. Imagine, for example, recycling concentrated at a point in space, such as the corner of an antenna or limiter. The particles would ionize and spread along the field to produce a helical structure. Particles that are a few centimeters outside the separatrix will be brought more or less directly to the divertor. Those very close to the separatrix, on the other hand, will experience the high local shear near the *X*-point and may be brought an entire additional revolution around the torus. The profile at one toroidal location may therefore consist of a peak high on the divertor plate and another near the strike point, while the particles on the flux surface in-between will land at a different toroidal position. A

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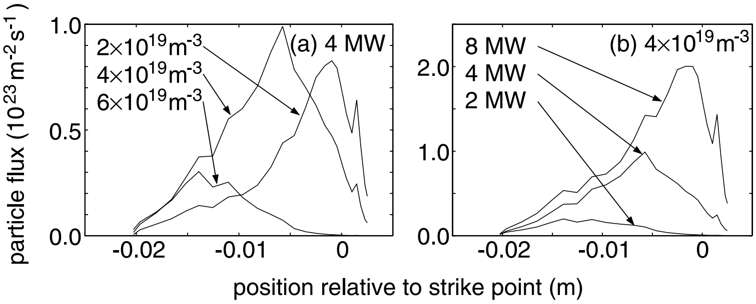

Fig. 1. Profiles of the particle flux to the inner divertor as calculated by B2-Eirene: (a) Three different densities at constant power; (b) three different powers at constant density.

similar effect could be caused by helically enhanced transport. There could be, for example, a mode on the $q = 3$ surface locked to field errors which enhances transport in a helical pattern.

2. Observations

The inner divertor plate contains an array of flush-mounted Langmuir probes with four electrodes at each of 11 poloidal locations (see Fig. 2), typically connected to form an asymmetric triple probe, allowing 30 μs time resolution with relative insensitivity to the value of the electron saturation current. The poloidal separation is typically 2 cm. Profiles of the ion saturation current in an H-mode discharge for several times during and between ELMs are shown in Fig. 3. In this example, as generally when a double peak is observed, the lower peak is narrow and localized near the strike point while the upper peak is generally of a similar magnitude but has a broad maximum on the transition module, 10–20 cm above the strike point. The valley between the peaks is often very deep, with a signal several times lower than the maximum on either side. The field angle is, by design, relatively constant over large portions of the divertor plates, so that the double-peaked profile is similar whether fluxes normal to the surface or parallel to the magnetic field are plotted. The electron temperature profile is relatively smooth, with no clear double peak, so quantities like the density, the pressure, and the power flux all show the double peak whenever the ion current shows it. The double peak appears in most discharges on ASDEX Upgrade, although it is weaker under low density conditions. We see from the time-resolved profiles in Fig. 3 that the double peak exists instantaneously and is a not superposition of two temporally independent peaks. The latter might have explained the double peak if, for example, the degree of

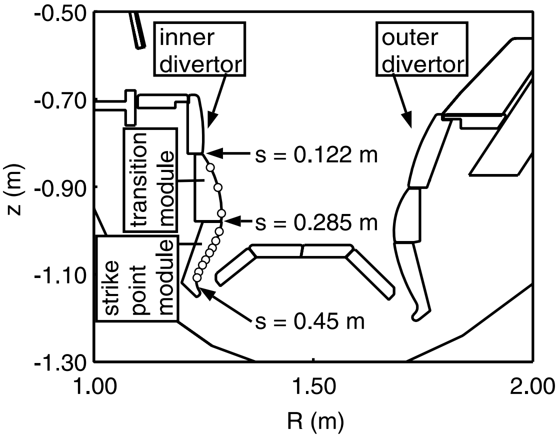

Fig. 2. A cross section of the ASDEX Upgrade Divertor II. The value of the s-coordinate at several poitions is indicated. The locations of fourfold Langmuir probes are marked with circles.

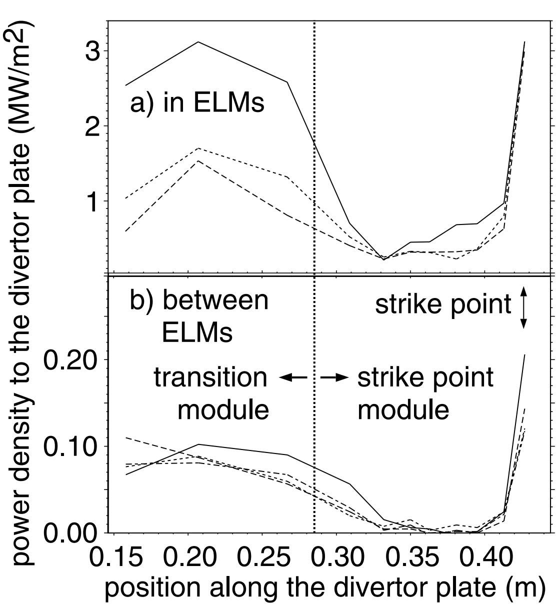

Fig. 3. Comparison of probe profiles in and between ELMs.

detachment changed ('burn-through') or the strike point shifted during ELMs. In fact, the profile form does not change greatly during ELMs, despite the factor of 20 difference in the amplitude. In addition, the double peak can be seen in ohmic and L-mode discharges.

The upper peak generally falls on the transition module, whose tiles and whose probes have a slightly different construction than those of the strike point module. In particular, the strike point module has a 'fish-scale' structure to eliminate leading edges. This raises the question whether there may be some subtle, systematic error, possibly related to misalignment or shadowing, giving rise to the double peak. Although not definitive, there are some observations which speak against this hypothesis. One is that a sort of double peak can also be seen in C-II spectroscopy and in thermography, although the agreement in detail is not overwhelming and certain types of shadowing might affect all of these methods. Fig. 4 compares the spectroscopy with the probes. Both diagnostics observe a double peak at roughly the same location and separation, and both show the lower peak to be initially somewhat stronger, with the relationship reversing over the course of about 0.8 s. The spatial resolution of the spectroscopy is about 0.06 m.

Another observation speaking against a geometrical explanation is that the probes do, on occasion, register a different profile form, e.g., with the peak near the top of the strike point module, as seen in a standard H-mode discharge at 4.25 s, Fig. 5. On the other hand, a closer look at this discharge in Fig. 6 provides strong evidence that the effect does in fact have a geometrical origin. As the strike point is swept up and down twice between 2 and 5 s, it is clear that the upper peak is not a fixed feature of the profile, but always has its maximum just below the joint between the strike point module and the transition module. When the strike point is raised to near that level, the features merge into a single peak. Further evidence of shadowing is provided by the fact that the strike point peak is much stronger when measured by the probes at the position of the upper peak. On the other hand, some of the physical explanations discussed above may also result in a feature which is fixed in relation to the vessel rather than in relation to the separatix.

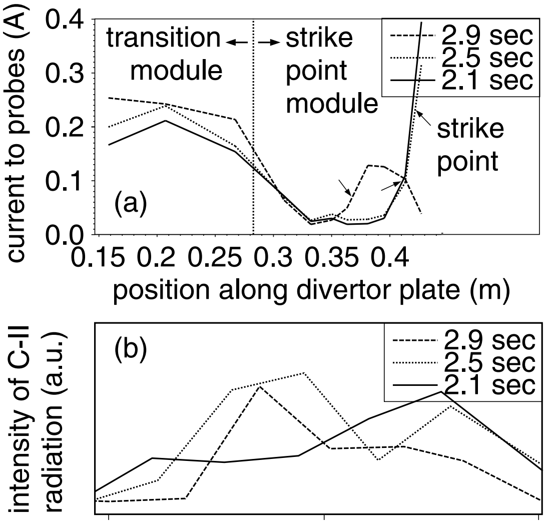

Fig. 4. Comparison of probes and spectroscopy. Profiles smoothed over ELMs of (a) the ion saturation current and (b) the C-II intensity are shown for three times in an H-mode discharge. The horizontal scales have been chosen so that the intersection of the line of sight with the divertor surface for the deflection angle in (b) corresponds to the *s* coordinate in (a).

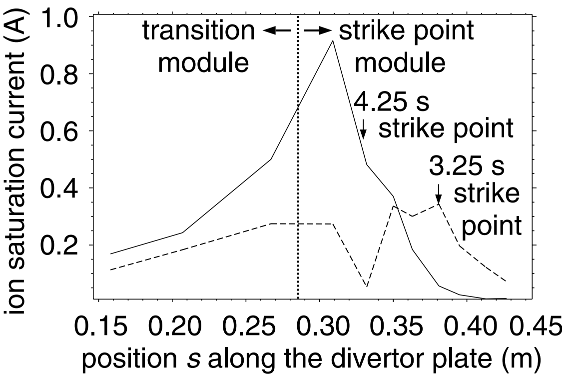

Fig. 5. Profiles of the ion saturation current at two times during a standard H-mode discharge. A profile like that at 3.25 s is observed in many discharges. Single peaked profiles like that at 4.25 s are rare.

3. Conclusions

In conclusion, we have presented observations of a double peak in the profiles of plasma parameters at the inner divertor plate in ASDEX Upgrade. We have ruled out time-dependent effects and simple effects of variations in the angle of incidence of the magnetic field. At the present time, the most likely explanation seems to be a shadowing effect that is not yet understood, the strongest evidence for this being the immobility of the upper peak during strike point sweeps. We will pursue this hypothesis by reviewing the mechanical and magnetic geometry and tolerances. Though it has not been completely ruled out, it seems unlikely that the feature can be explained by any axisymmetric plasma physics. A more likely candidate may be non-axisymmetric effects. This hypothesis will be pursued by examining

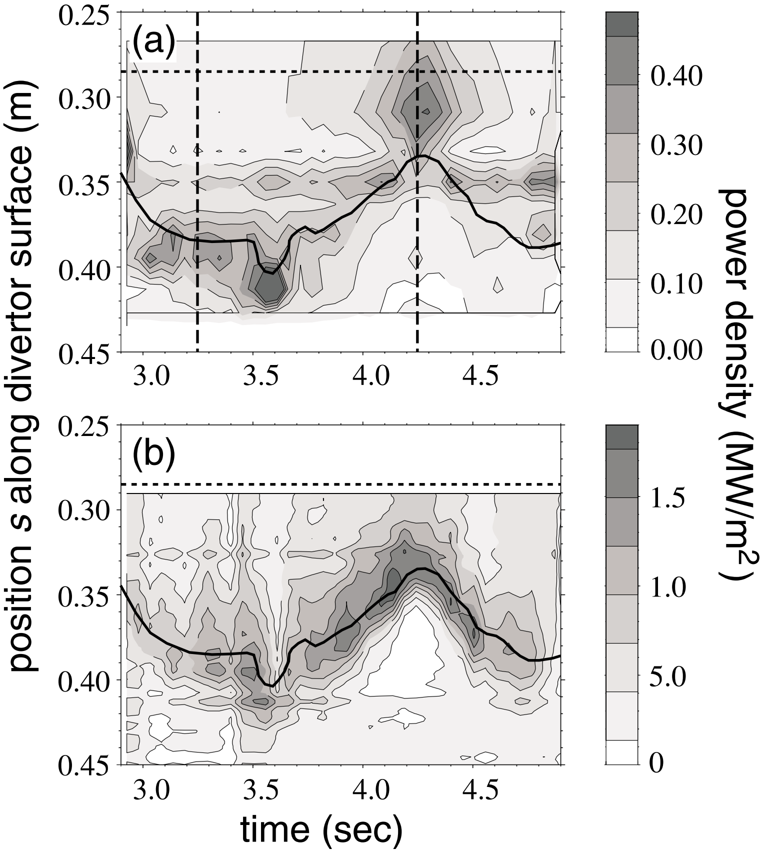

Fig. 6. Profiles of the heat flux to the divertor plate over 2 s of the same standard H-mode discharge as shown in Fig. 5, as measured by (a) the Langmuir probes and (b) thermography. The solid curve running from left to right shows the position of the strike point. The dotted horizontal line is the joint between the strike point module and the transition module. The dashed vertical lines are the times plotted in Fig. 5.

the connection between the inner divertor profiles and plasma conditions elsewhere on the same flux surface, using for example the reciprocating *X*-point probe, the reciprocating mid-plane probe, the probes mounted in the outer divertor, other spectroscopic lines, and other diagnostics of the mid-plane scrape-off-layer profiles.

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