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Bayesian analysis of magnetic island dynamics of tearing modes in ASDEX Upgrade

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1 Introduction

The dynamics of neoclassical tearing modes (NTM) is theoretically described by the generalized Rutherford equation for the magnetic island width [1, 2]:

$$\begin{aligned}\frac{\tau_R}{r_{res}}\frac{dW}{dt} = r_{res}\Delta'(W) + r_{res}\beta_p \Bigg\{ & a_{BS}\sqrt{\varepsilon}\frac{L_q}{L_p}\frac{W}{W^2+W_0^2} \\ & -a_{GGJ}\frac{r_{res}}{R_0^2}\frac{L_q^2}{L_p}\frac{1}{W} - a_{Pol}\left(\rho_p\frac{L_q}{L_p}\right)^2 g(\varepsilon)\frac{1}{W^3}\Bigg\} \quad ,\end{aligned} \tag{1}$$

where $\tau_R = \mu_0 r_{res}^2/1.22\eta$ is the resistive time scale with plasma conductivity η, resonant surface at r_{res}, inverse aspect ratio of the resonant surface $\varepsilon = r_{res}/R_0$, decay length of shear $L_q = q/q'$ and pressure $L_p = p/p'$, $\beta_p = 2\mu_0 p/B_p^2$ with the poloidal field B_p and poloidal Larmor radius $\rho_p = \sqrt{2m_iT_i}/\sqrt{e}B_p$. The nonlinear stability parameter $\Delta'(W)$ describes the stability of the equilibrium current profile against the tearing mode instability [3]. The above equation contains three free parameters which are assigned to three terms describing stabilizing and destabilizing effects to the magnetic island. The first term is due to the destabilizing bootstrap effect (a_{bs}). It includes the stabilizing effect of the incomplete pressure profile flattening in small islands due to the finite heat conductivities χ across the island by $W_0 = 5.1\sqrt{R_0L_q/2}(\chi_\perp/\chi\|)^{1/4}$ =1.8cm [4]. The next term describes the stabilizing effects of shaping and toroidicity (Glasser-Greene-Johnson effect, a_{GGJ}) [5, 6]. Finally the polarization currents induced by the motion of the island through the plasma are comprised by the stabilizing last term (a_{pol}), where due to the low plasma collisionality in the considered discharges we can use $g(\varepsilon) = \varepsilon^{3/2}$. The knowledge of the parameters a_{BS}, a_{GGJ} and a_{pol} is of crucial importance for the determination of the NTM onset and for the microwave power in order to perform electron cyclotron current drive stabilization of tearing modes. In this work the dynamics of (3,2)-NTMs in ASDEX Upgrade

discharge	t_{ECE} (s)	W_{ECE} (cm)
#10075	3.02	12.0 ± 2.5
#11079	3.75	11.3 ± 2.5
#12238	4.5	7.0 ± 1.0

Table 1: Estimation of the island with from ECE diagnostic

has been experimentally observed for three β–limit discharges. In order to infer the free parameters of Eq. 1 from the data, we employ Bayesian probability theory [7] which provides a consistent frame for combining experimental data and further information.

2 Determination of the Rutherford equation

The dynamical behavior is obtained from the time evolution of the amplitude of the Mirnov coil signal dB_p^W/dt. For this purpose perturbing events like ELMs have to be removed from the signal which is done by looking for the ELM peaks in a smoothed signal and then employing fast Fourier transformation with time integration for that part of the original signal which lies in between two ELMs. Since the amplitude B_p^W is proportional to the island width we get

$$W = \sqrt{\frac{B_p^W - B_p^0}{b}} \tag{2}$$

where B_p^0 is the offset and b a proportionality constant. Information about the absolute size of the magnetic island for a certain time comes from the ECE diagnostic 1. Finally some estimates for $a_{BS} = 1.7$ and $a_{GGJ} = 6 * 5/9$ are provided by literature [2] and used as prior information. Then the posterior estimates for the a_{BS}, a_{GGJ} and a_{pol} were calculated together with the estimation

3 Results

Fig. 1 depicts the dynamics of the magnetic island width for the discharge #10075, #11079 and #12238. The thin line is the width obtained from the magnetic signal B_p^W employing Eq. 2 with

	#10075	#11079	#12238
$B_p^0[10^{-4}]$	1.63±0.20	4.60±0.88	2.88±0.34
${B_p^0}^{all}[10^{-4}]$	1.64±0.19	4.70±0.93	3.05±0.36
$b[10^{-2}]$	4.10±0.81	6.75±0.46	11.13±0.07
$b^{all}[10^{-2}]$	4.31±0.03	7.62±0.11	11.11±0.07

Table 2: Expectation values for the magnetic offset and the linear factor b.

discharge	a_{BS}	a_{GGJ}	a_{pol}
#10075	0.83±0.14	1.6±1.4	0.12±0.12
#11079	0.76±0.04	0.59±0.53	0.17±0.13
#12238	0.84±0.05	2.10±0.51	0.041±0.032
all three	0.79±0.03	1.55±0.33	0.024±0.021

Table 3: Expectation values with error margin for the three parameters of the Rutherford equation.

the expectation values of B_p^0 and b from the analysis (see table 2). Only that time intervall of the complete signal is examined which comprises the island after is has stabilized untill the temperature signal shows decoupling from the behavior of the collapsing island. The comparison with the experimental data (thin line) gives a very good agreement. The accompanying parameters are given in table 3. They agree very well within their error margins. Using all three discharges as a common data set yields the parameters in the last line of table 3. Notice that the error margin of the common parameter set is smaller than each of the above discharges. Finally an investigation of the correlation coefficients of the parameters for the common analysis shows that a_{BS} and a_{GGJ} are highly correlated. Therefore the boot strap term is already sufficient to describe the dynamics and there is no relevance in the data for an additional Glasser-Greene-Johnson term in the present data set.

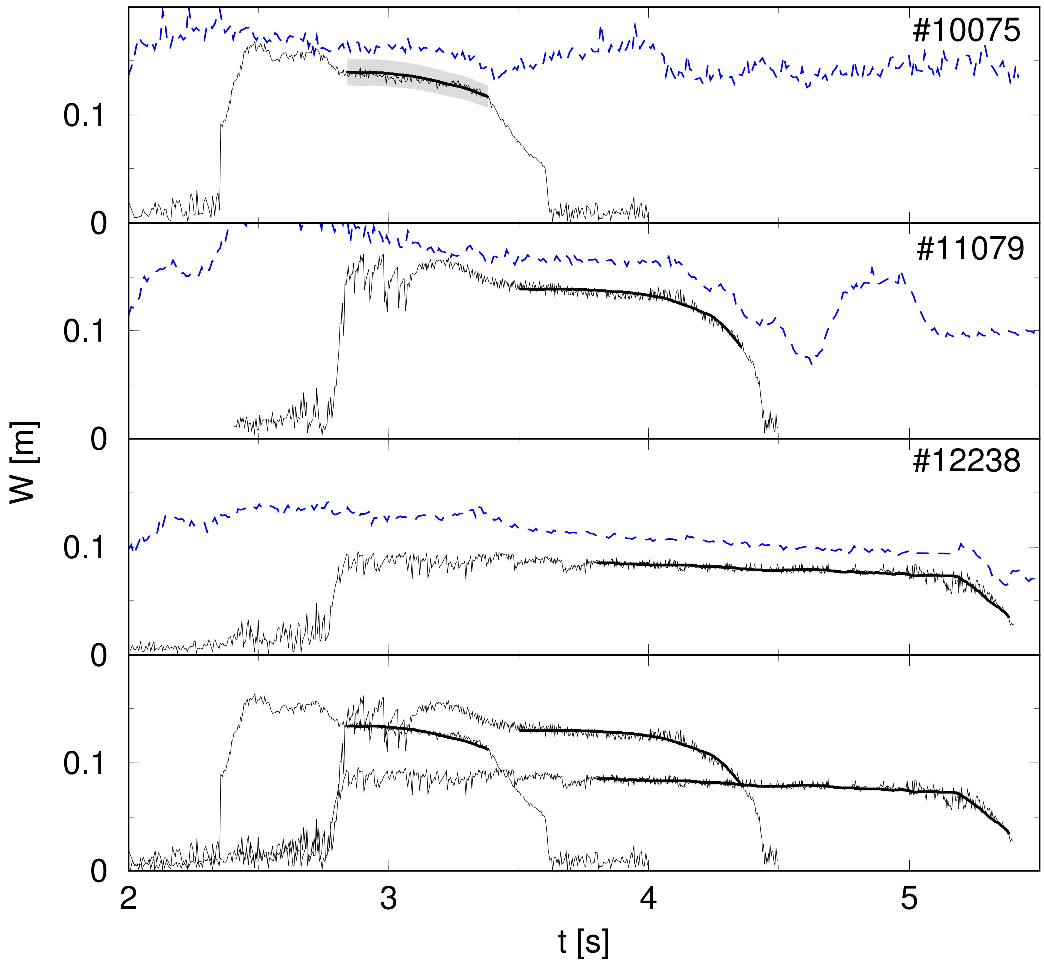

Figure 1: Magnetic island width for the discharges #10075, #11079 and #12238 of ASDEX-Upgrade. The thick line is the expectation value of the width with the gray shaded area as its error margin. The lowest graph depicts the result from the common analysis of all three discharges. As can be seen the island width is strongly connected to the temperature (dotted line).

References

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