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Recent key contributions of ICRF heating in support of plasma scenario development and fast ion studies on JET and AUG

M.J. Mantsinen[1,2], R. Bilato[3], Vl. Bobkov[3], C. Challis[4], D. Gallart[1], M. Garcia-Muñoz[5], P. Jacquet[4], A. Kappatou[3], Ye.O. Kazakov[6], V. Kiptily[4], E. Lerche[6], P. Mantica[7], J. Manyer[1], M. Nocente[7,8], T. Pütterich[3], O. Sauter[9], M. Sertoli[4], G. Tardini[3], D. Taylor[4], D. Van Eester[6], S. Sharapov[4], M. Weiland[3], JET Contributors, EUROfusion MST1 Team and AUG Team

[1]Barcelona Supercomputing Center, Spain [2]ICREA, Barcelona, Spain [3]Max-Planck-Institut für Plasmaphysik, Garching, Germany [4]CCFE, Culham Science Centre, Abingdon, UK [5]Dept. of Atomic, Molecular and Nuclear Physics, Universidad de Sevilla, Sevilla, Spain [6]Laboratory for Plasma Physics, LPP-ERM/KMS, Brussels, Belgium [7]Institute for Plasma Science and Technology, National Research Council, Milan, Italy [8]Dipartimento di Fisica "G. Occhialini", Università di Milano-Bicocca, Milan, Italy [9]Swiss Plasma Center, EPFL-SPC, Switzerland

INTRODUCTION

We report on recent experiments carried out on JET and AUG tokamaks with high-Z plasma facing components to develop and investigate ICRF schemes and plasma scenarios with relevance to ITER.

Device	ICRF scheme	Plasma scenario
JET	^{3}He minority heating	High-performance hybrid
JET	Dual frequency ^{3}He minority +H minority heating	High-performance hybrid
AUG	^{3}He minority heating	H mode
AUG	2nd harmonic H+H minority heating	ITER baseline like
AUG	Third harmonic heating of D	H mode

^{3}HE MINORITY HEATING ON JET

^{3}He minority heating is an ICRF heating scheme to be used in ITER at full B_T

Here: JET 3.3T/2.2MA high-performance hybrid discharges with ^{3}He minority heating, compared to H minority heating.

Discharges with ^{3}He minority heating (Figs. 1-2):

- reach higher T and neutron rate R_{NT}
- maintain a lower plasma density

due to lower core W density (Fig. 3) through ^{3}He concentration scan of 1-9%.

Best R_{NT}, W_{DIA}, T_i and T_e obtained at low ^{3}He concentration of ≈2%.

ICRF modelling: stronger bulk ion heating and weaker W_{fast} with ^{3}He minority heating → changes to plasma transport (profiles, collisionality, impurity screening,..), leading to differences observed.

Our results are in line with computational multi-code work [Bilato et al., 2014, AIP Conference Proceedings 1580, 291] for ITER which suggests good ICRF absorption with ^{3}He concentration of ~3%.

Obtaining best performance at low ^{3}He concentration is advantageous for ITER because of lower operational costs..

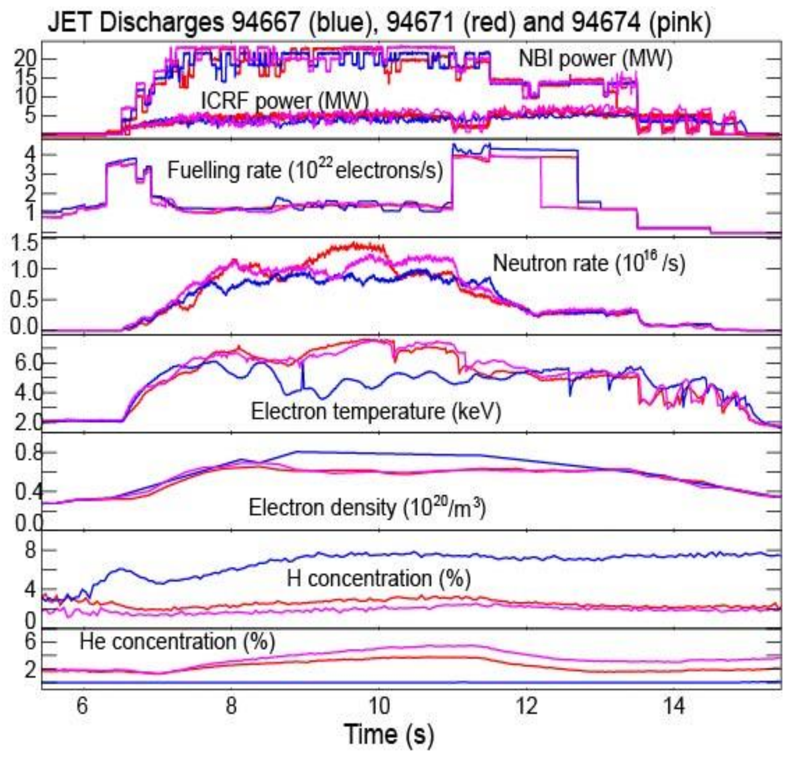

***Figure 1** Main plasma parameters in 3.3 T/ 2.2 MA discharges **94671** and **94674** with ^{3}He **minority heating** together with those in discharge **94667 with H minority heating**.*

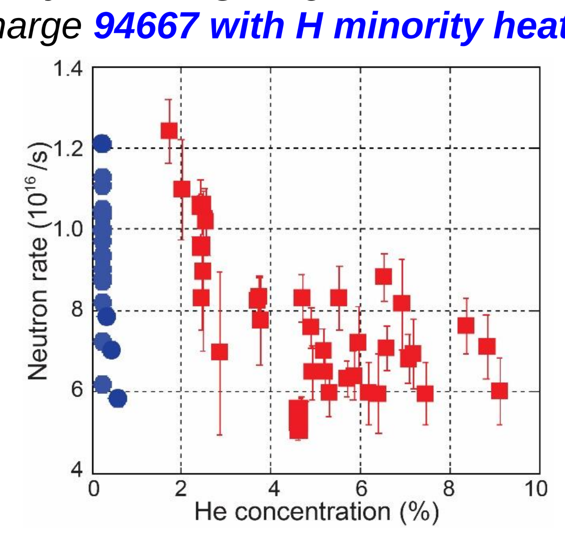

***Figure 2** Neutron rate as a function of ^{3}He minority concentration in discharges with ^{3}**He minority heating** and in discharges with **H minority heating**.*

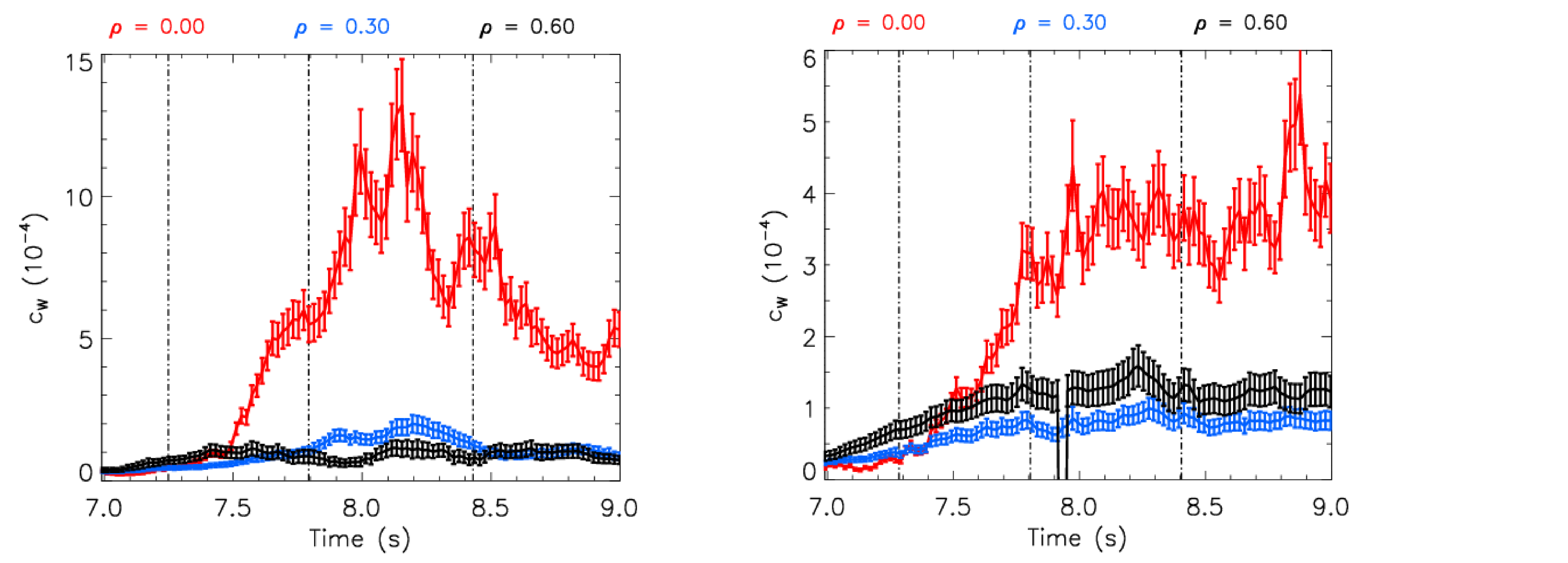

***Figure 3** Tungsten concentration at ρ = 0, 0.3 and 0.6 in discharge 94669 with H minority heating (left) and discharge 94672 with ^{3}He minority heating (right). Note the different vertical axes.*

DUAL FREQUENCY ^{3}HE MINORITY AND H MINORITY HEATING ON JET

Dual frequency ICRF operation tested with combined H and ^{3}He heating in JET 3.3T/2.2 MA hybrid plasmas and compared with pure H and ^{3}He heating (Fig. 4).

Dual frequency ICRF operation maximized the coupled ICRF power.

R_{NT} in JET hybrid plasmas scales roughly linearly with input power→ input power is in key role in maximizing fusion performance at JET

Experiments will be expanded to D-T and pure T mixtures in the forthcoming JET campaigns.

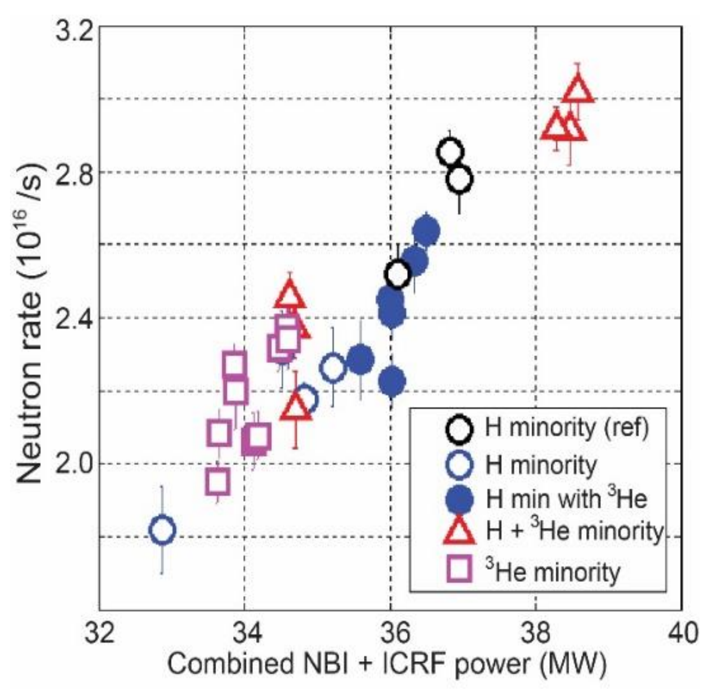

***Figure 4** Neutron rate as a function of ICRF+NBI power in discharges with different ICRF schemes*

^{3}HE MINORITY HEATING ON AUG

Earlier AUG experiments with ^{3}He minority heating: centrally strongly peaked T_i coincide with peaked x-ray emission profiles, indicating tungsten density peaking in the plasma core [Mantsinen et al., 2015, AIP Conference Proceedings 1689, 030005].

Here: study the role of radiation and impurity peaking in T_i peaking with new discharges prepared in the same way except for prior wall conditioning with boronization in order to reduce impurity sources.

Similar peaked T_i profiles were obtained (Fig. 5) while there was no soft x-ray radiation peaking (Fig. 6).

→ Radiation and impurity peaking do not play a major role in T_i peaking in these AUG discharges.

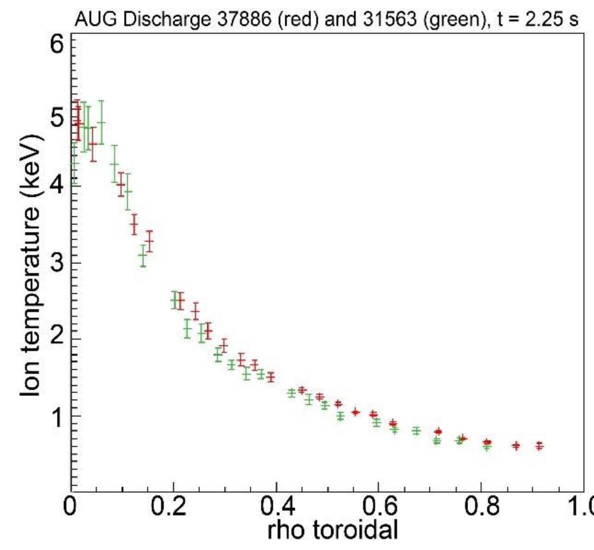

***Figure 5** Radial T_i profile for AUG discharges 37886 and 31563 with ^{3}He minority heating **with** and **without** prior wall-conditioning with **boronization**.*

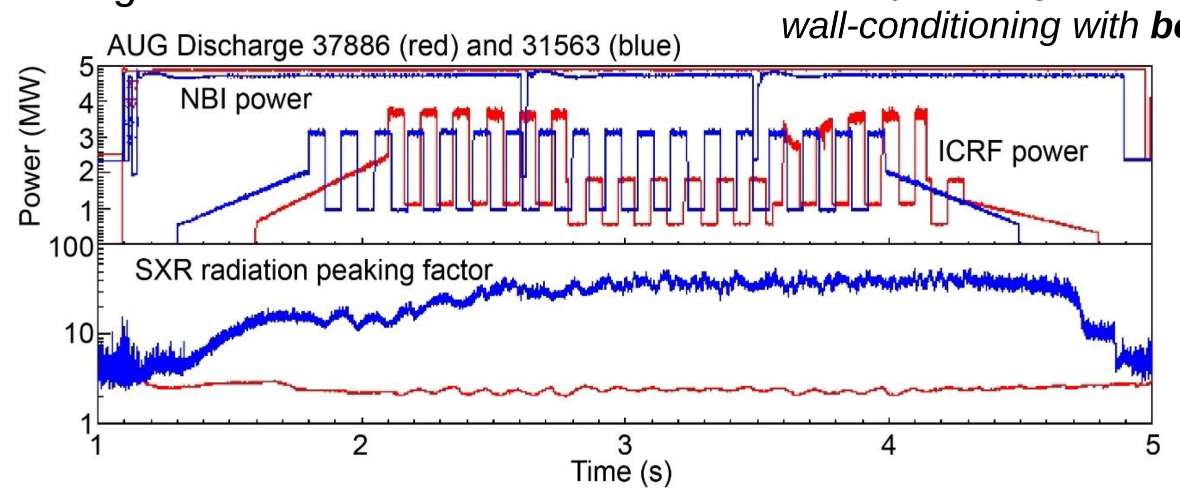

***Figure 6** NBI and ICRF power and radiation peaking factor deduced from soft X-ray (SXR) measurements for discharges 37886 and 31563 with ^{3}He minority heating and **with** and **without** prior wall conditioning with **boronization**, respectively.*

SECOND HARMONIC HEATING OF HYDROGEN ON AUG

Central 2nd harmonic H minority heating has been applied for the first time in AUG ITER baseline like plasmas, both alone and in combination of off-axis H minority heating, and compared with pure off-axis H minority heating (Fig. 7).

It results in higher T_e, β_N and R_{NT} as compared to other schemes studied.

It allows ICRF heating in ITER relevant plasma scenario studies on AUG at lower B_T than would be otherwise possible.

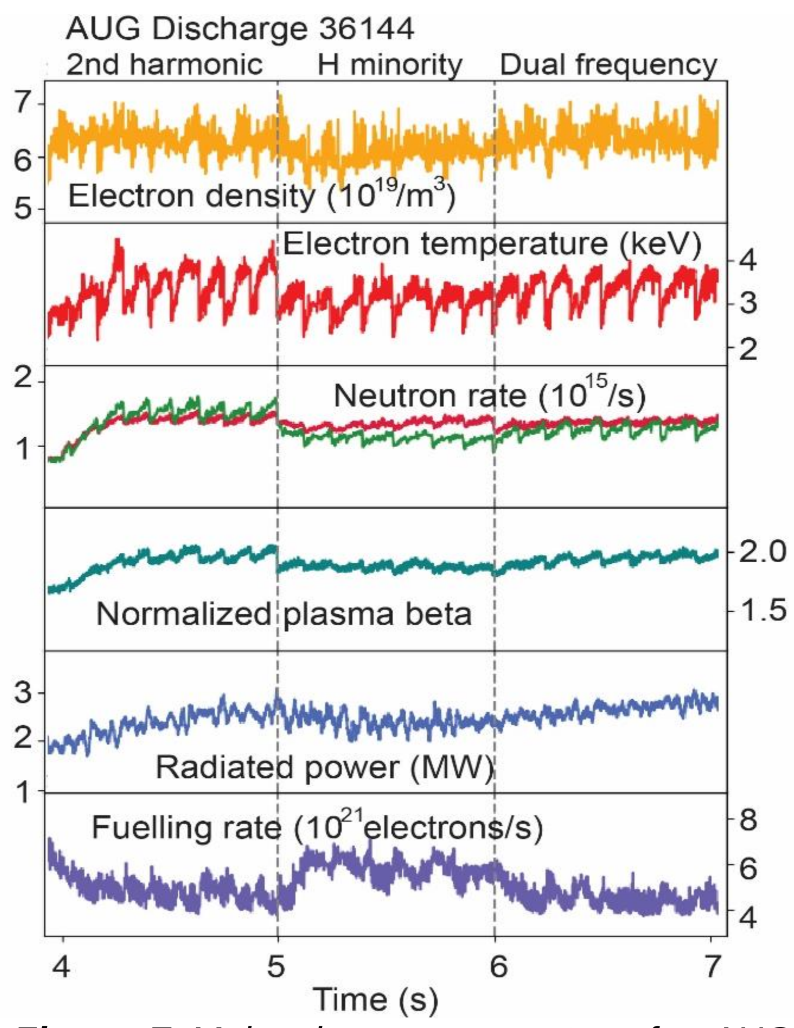

***Figure 7** Main plasma parameters for AUG 1.8T / 1.1 MA discharge 36144 during **three different phases of ICRF heating**.*

THIRD HARMONIC HEATING OF DEUTERIUM ON AUG

We have extended our earlier work with 3rd harmonic heating of D NBI ions on AUG [Mantsinen et al. , EPS2016] to more robust plasmas with central ECRF heating at B_T around 2.5 T.

Controlled variations of the fast D distribution have been obtained in response to variations in several physical parameters such as NBI, ICRF power, T_e, and ICRF resonance location, in line with theoretical predictions.

Figure 8 shows an example with more than two-fold increase of R_{NT} as well as lengthening of the sawtooth period due to ICRF-accelerated deuterons.

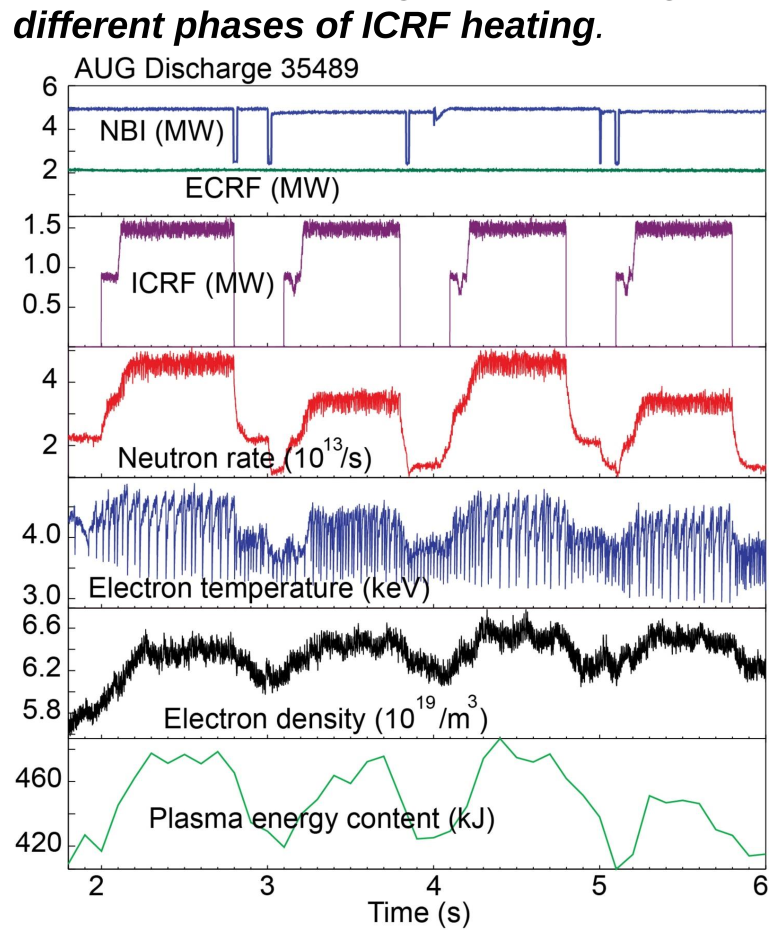

***Figure 8** Plasma parameters for AUG discharge 35489 with 3rd harmonic ICRF heating of D with synergy with D NBI. Different NBI injectors were used for each ICRF phase.*

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.