First experiments in H-mode plasmas with the Passive-Active Multijunction (PAM) LHCD launcher in HL-2A and impact on pedestal instabilities

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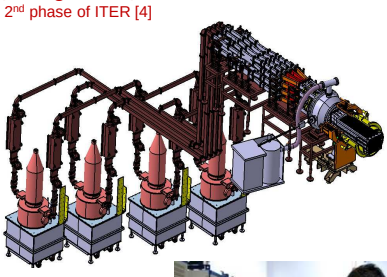
The 3.7 GHz LHCD system in HL-2A

Associated Laboratory CEA/IRFM – SWIP initiated in 2013, with Lower Hybrid Current Drive (LHCD) as one of the main activities.

- ✓ Four klystrons (3.7 GHz) installed and commissioned on HL-2A [1], as part of the collaboration.
- ✓ Passive Active Multijunction (PAM) antenna designed by SWIP, assisted by IRFM.
- ✓ Joint experiments on LHCD and LH coupling in H-mode carried out on HL-2A [2, 3].

Coupling of LH waves in H-mode, using a PAM, demonstrated for the first time.
PAM: LH launcher concept foreseen for the 2nd phase of ITER [4]



- ❖ 2014: Commissioning on plasma, L-mode
- ❖ 2015: First experiments in H-mode (~ 400 kW)
- ❖ 2016: 1 MW coupled power

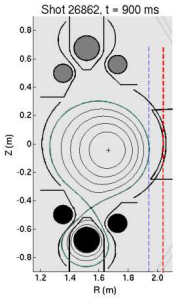
[1] X.Y. Bai et al., Proc. 42nd EPS Conf. (2015), paper P5.137.
[2] X.Y. Bai, A. Ekedahl et al., submitted to Nucl. Fusion.
[3] X.R. Duan et al., this conference, paper OV/4-4.
*[4] G.T. Hoang et al, Nucl. Fusion **49** (2009).*

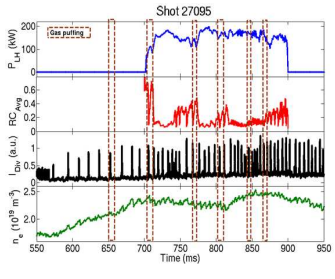
LH coupling experiments in H-mode

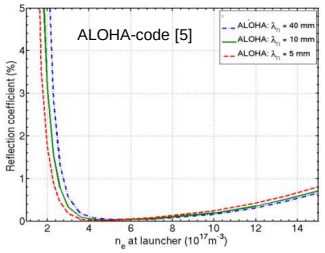
Local gas injection valves at three poloidal locations

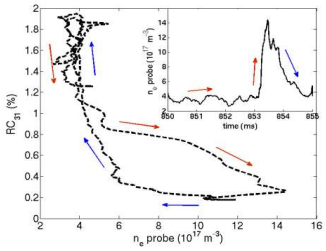
Eight Langmuir probes for T_e and n_e measurements at two radial locations

First H-mode experiments:
- ❖ Large plasma-launcher gap (~ 10 cm).
- ❖ Local gas injection needed to increase edge density and reduce reflected power.









*[5] J. Hillairet et al, Nucl. Fusion **50** (2010).*

Acknowledgments

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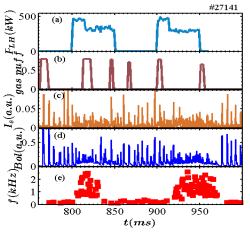
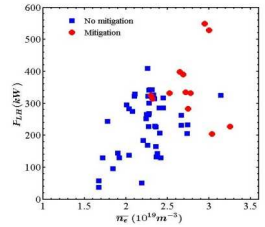
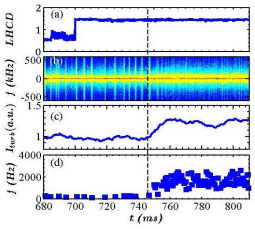
Effect on ELMs

- ➢ ELM-frequency ↗ and ELM-amplitude ↘ during LHCD.
- ➢ Observed for high LH power and high density.
- ➢ Mitigation effect is synchronized with an increase of the pedestal turbulence, measured by Doppler reflectometry ➔ Enhancement of the particle transport due to the pedestal turbulence may be the direct cause of the ELM mitigation.

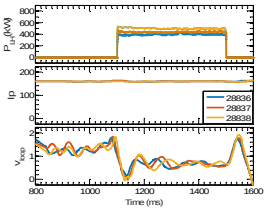


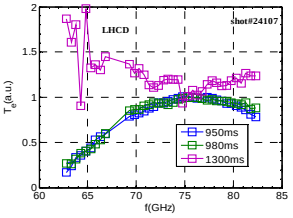




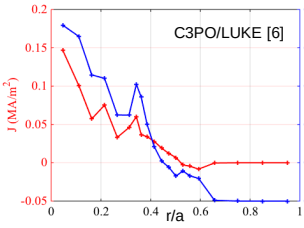
LH current drive observations

Current drive effect, i.e. loop voltage drop and non-thermal EC emission, observed in L-mode.





Modelling with RT/FP-codes C3PO/LUKE with "tail LH model" [6] suggests quite central LH power absorption. With standard model, the deposition is off-axis.

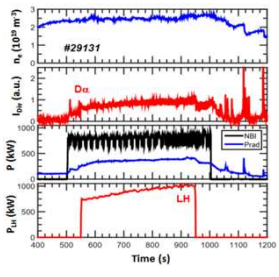


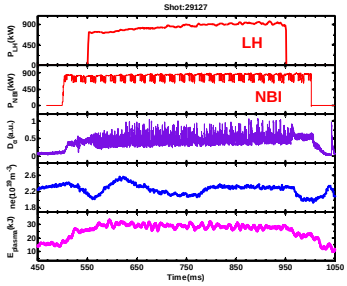
*[6] Y. Peysson et al., Plasma Phys. Control. Fusion **58** (2016).*

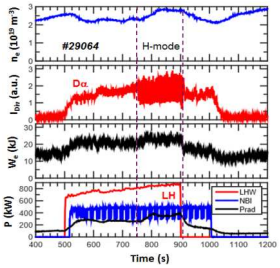
Latest results

Several improvements carried out before the 2016 campaign:
- ✓ Shortened waveguide lengths ➔ reduced transmission line losses.
- ✓ Improved control of plasma-launcher gap. Smaller gap ➔ higher density at LH grill mouth.
- ✓ Increased reliability of RF measurements.

1 MW reached in L-mode and 900 kW in H-mode [3].
LH power helps trigger and sustain H-mode.







Summary and outlook

The 3.7 GHz LHCD system in HL-2A has reached 1 MW coupled power in L-mode and 900 kW in H-mode.
- ❖ LHCD helps triggering and sustaining H-modes in HL-2A.
- ❖ Effect on ELM amplitude and ELM frequency observed in some conditions.

Plan for 2017: Install hard X-ray camera to investigate LH power deposition.