Current carrying filaments in the L-mode, H-mode and ELMs in RFX-mod tokamak operation

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Introduction

The RFX-mod experiment is a fusion device designed to operate as a Reversed Field Pinch (RFP), with a major radius R= 2 m and a minor radius a = 0.459 m. Its high versatility recently allowed operating also as an ohmic tokamak allowing comparative studies between the two configurations in the same device. The device is equipped with a state of the art MHD mode feedback control system, providing a magnetic boundary effective control, by applying resonant or non-resonant magnetic perturbations (MP) both in RFP and in tokamak configurations. In the fusion community the application of MPs is widely studied as a promising tool to limit the impact of plasma filaments and ELMs on plasma facing components.

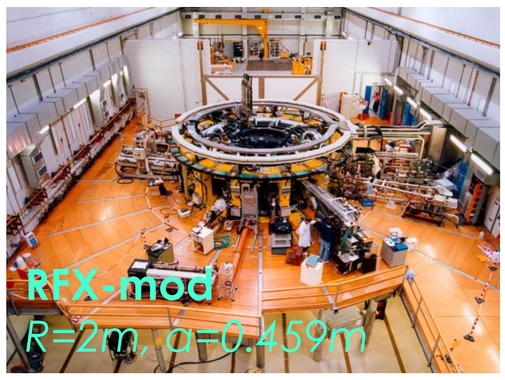
An important issue is envisaged in the exploitation of the RFX-mod active control system for ELM mitigation studies.

As a first step in this direction, this paper will focus on the most recent achievements in term of RFX-mod tokamak explored scenarios, which allowed the first investigation of the ohmic and edge **biasing induced H-mode**. Reproducible H-mode phases were obtained with insertable electrode negative biasing stimulation in shaped **Single Null** discharges, representing an unexplored scenario with this technique. Features of **current carrying filaments** in L-mode , H-mode and within ELM cycle are studied in details.

Experimental setup

ohmic tokamak operation

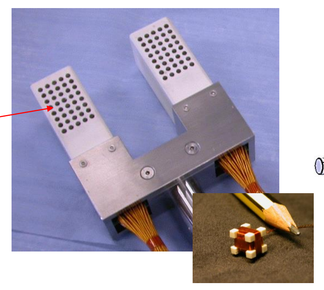
B_t = 0.55 T (up to 1 sec)

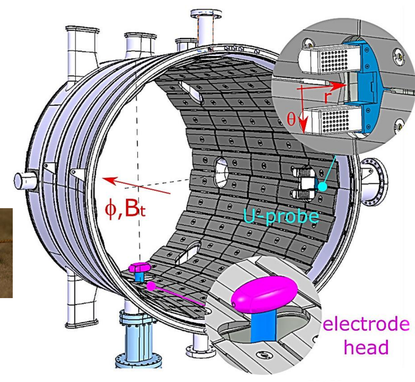


U-probe

Two 2D arrays of electrostatic pins:

Two arrays of 7 (B_r,B_θ,B_ϕ) magnetic probes:

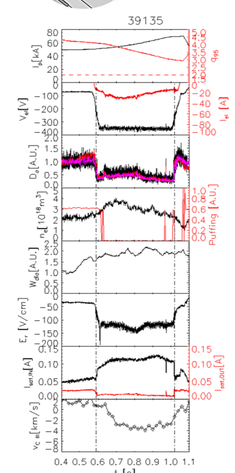




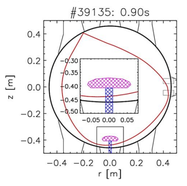
Transition to H-mode reproducibly achieved for negative biasing at:

- V_{el} ≥200-300V,
- average plasma density n_e ≥ 1-3 $10^{18}m^{-3}$ for I_p=70-80 kA

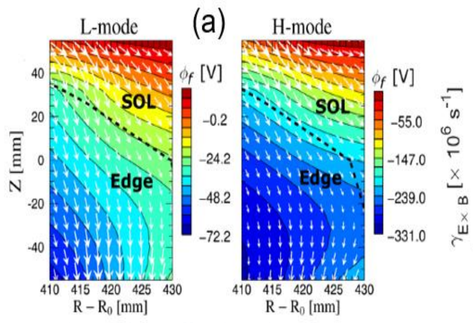
Single Null (r_p=36-39cm, I_p=45-75kA, q_{95}= 2.5-4.5, n_e<5 $10^{18}m^{-3}$)

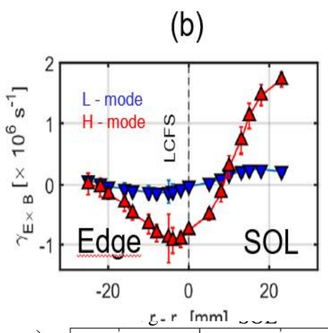


USN configuration



Filament properties in L and H-mode

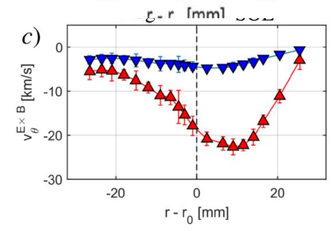


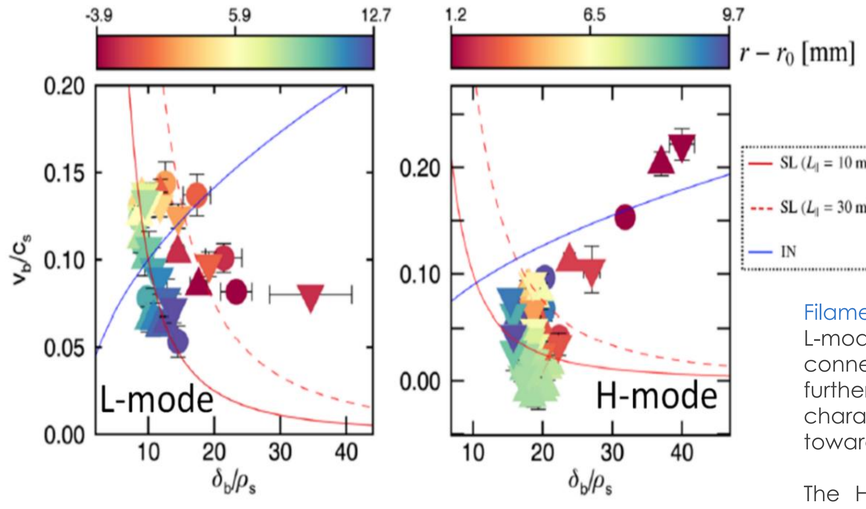


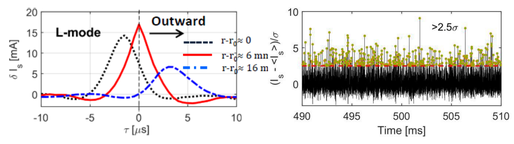
LH transition affects edge flow map

Strong ExB shear develops consistently with the LCFS position

change in the vorticity sign, with possible implication on the dynamics of filaments crossing this region



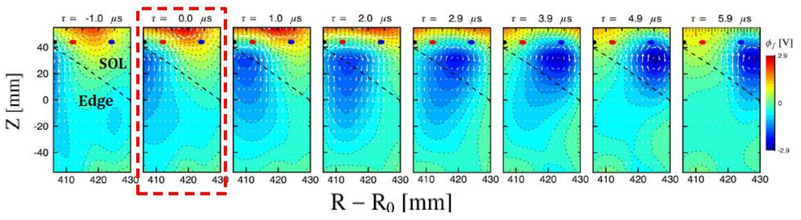




L-mode filament detection

filament tracking based on pattern recognition within the frame

2D correlation for the investigation of dynamics

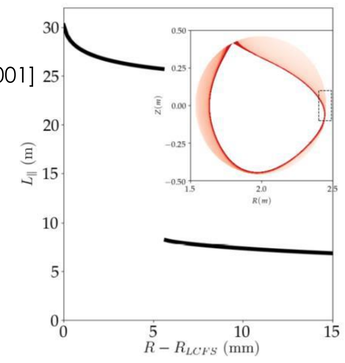


Sheath limitred [Krasheninnikov PLA 2001]

SL: $v_b^{SL} = 2c_s\left(\frac{\rho_s}{\delta_b}\right)^2\frac{L_\parallel}{R}$

Inertial regime [Garcia PoP2006]

IN: $v_b^{IN} = c_s\sqrt{\frac{2\delta_b}{R}}$



Filament velocity scaling

L-mode filaments better fit with the SL regime where filaments are electrically connected along the field lines through the sheath on the wall, the scaling is further structured accordingly to the two magnetic topology regions characterized by longer and shorter connection length moving in the SOL towards the wall.

The H-mode filaments are instead better described by the IN regime, however the effect of strong sheared background flows and electromagnetic effects can play a role

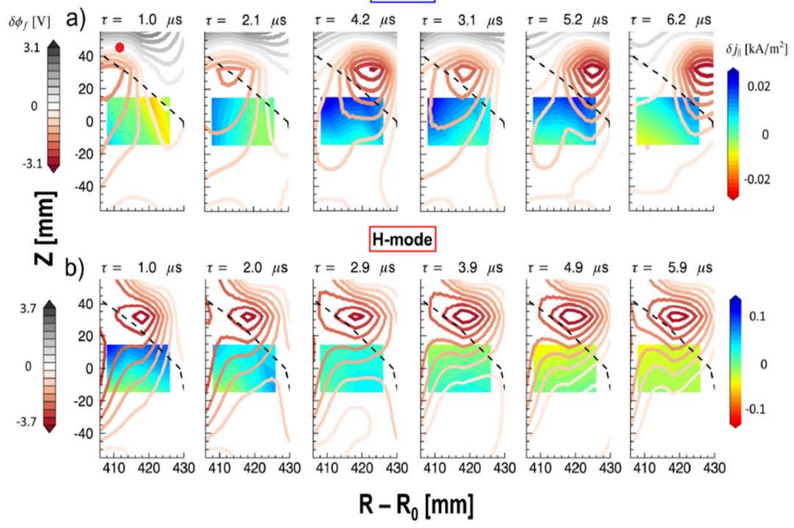
L-mode: dipolar structure clear propagation of the whole structure towards the wall is observed. Filaments travel almost freely,

H-mode, the potential structure monopolar and sticks on the SOL up to complete fading away. their motion is restricted to the near SOL.

the background shear decorrelation time becomes shorter than the filament convective time, favoring its suppression

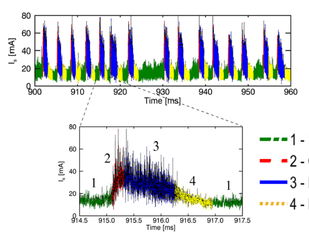
Parallel current density conditional structure results associated to the time evolving potential structure, so that the two quantities are roughly synchronized.

parallel current density conditionally averaged peaks are of the order of 0.02 kA/m² in the L-mode case while 5 times higher values are obtained in H-mode.

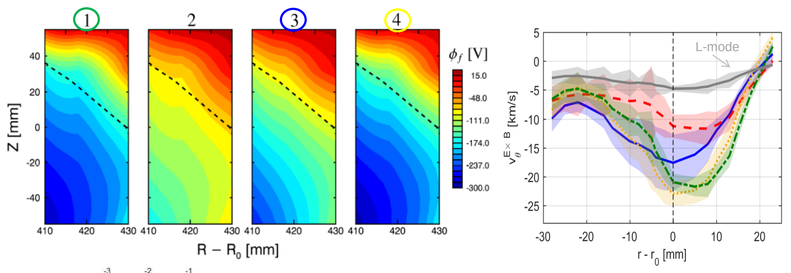


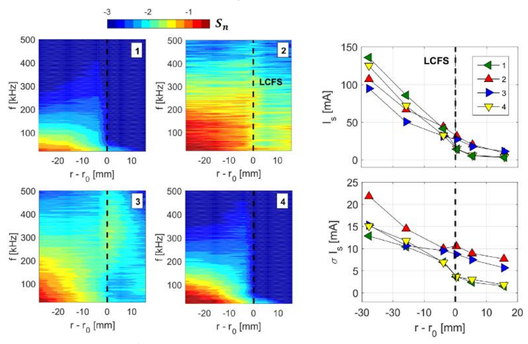
Current carrying ELM fine structure in the SOL

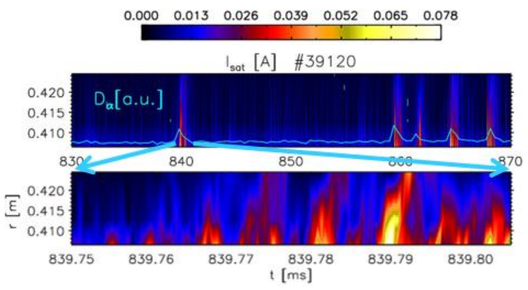
background ⟵ The ELM burst cycle ⟶ *filamentary structures*



- cyclic modifications in the edge parameter background are observed within the single ELM bunch
- four phases are identified for the statistical study



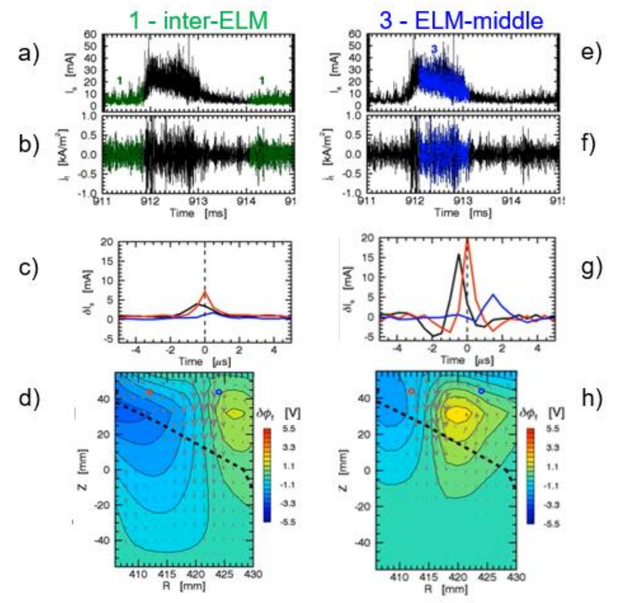


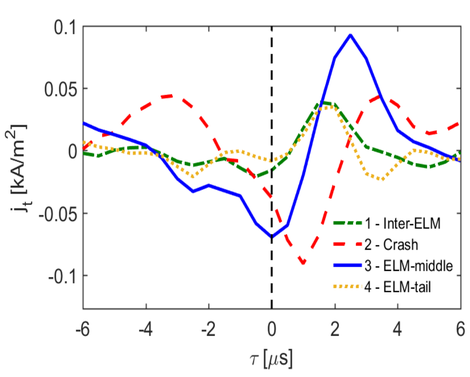


single burst: complex fragmented and radially extended structure composed by a bunch of events

- CA on events within each phase
- during crash and ELM-middle phases structures are more intense nearly dipolar and faster outward propagating

Intermittency within ELM cycle:
Size and velocity tracking on the 2D potential structures:
•Conditional average performed on different scales structures (wavelet analysis)
•Cross-field v and intensity larger on the ELM-middle phase wrt inter-ELM
•Size is nearly comparable in the two phases

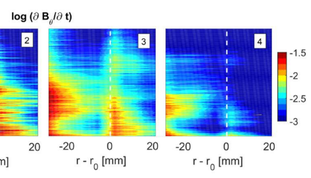




ELM cycle: parallel current $j_{||}$

ELMy phases present higher (x10) parallel current density events with respect to L-mode.

dipolar current density structures characterize the crash and ELM-middle phases consistently with the corresponding dipolar potential structures
Current structure in agreement with the equivalent circuit model for current carrying filaments proposed by S. Krasheninnikov (2001)



Ion saturation current fluctuation in the edge and SOL: Higher fluctuations during ELMs with relaxed mean profile

Quasicoherent magnetic fluctuation in the edge before, during, and after ELM;

Conclusions

- These discharges provided the opportunity to be explored with an advanced system of an insertable probe to get information on 2D cross-field features of current carrying filaments.
- In L-mode dipolar structures fast propagating toward the wall were observed, while during the H-mode they appear mostly as monopolar structures turning around without evident propagation until their complete fading.
- A noticeable shear detected the H-mode affects filament stretching and decorrelation and vorticity selection , the latter bringing dipolar potential structure to become monopole.
- A better description for the L-mode filaments was found in the SL regime, structured accordingly to the magnetic topology. The H-mode filaments are instead better described by the IN regime, however the effect of strong sheared background flows and electromagnetic effects can play a role.
- Complex fragmented and radially extended filamentary structure within a single ELM. strong peaks in parallel current density J_{tor} are observed to characterize the ELM bunch.
- Time evolution of near-SOL cyclical establishment of strong edge gradients followed by the ejection of clusters of filamentary fragments (ELMs) with electromagnetic features. This behavior is confirmed by the 2D potential map reconstruction with vorticity peaks associaterd to density bursts
- Within the ELM burst cycle the ejection phases were identified with the "crash" and "middle phase" where radial propagation of e.m. filaments recovers transiently the L-mode turbulent filament features.

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References

Piovesan P, et al. 2013 Physics of Plasmas 20 056112
Zanca P et al., Plasma Physics and Controlled Fusion 54 094004
Spolaore M, et al., Nucl. Fusion 55 (2015) 063041
[Vianello N. et al. 2015 Plasma Phys. Control. Fusion57 014027
Kirk A et al. 2013 Plasma Physics and Controlled Fusion 55 015006
Zuin, M., et al. Nuclear Fusion 57.10 (2017): 102012.
L Marrelli, L., et al. Nuclear Fusion 59.7 (2019): 076027
G. Grenfell, PhD thesis (2020), Padova University Electromagnetic turbulence in the edge of fusion plasmas: spontaneous and actively modulated features, http://paduaresearch.cab.unipd.it/12892/
Grenfell, G., et al. "Turbulent filament properties in L and H-mode regime in the RFX-mod operating as a tokamak." Nuclear Fusion 60.12 (2020): 126006.
[Spolaore M. et al., Nuclear Fusion 57.11 (2017): 116039.
Spolaore, M., et al. Physical review letters 102.16 (2009): 165001.
Krasheninnikov S.I. 2001 On scrape off layer plasma transport Phys. Lett. 283 368–70
Garcia O.E., Bian N.H. and Fundamenski W. 2006 Phys. Plasmas 13
D'Ippolito, D. A., J. R. Myra, and S. J. Zweben Physics of Plasmas 18.6 (2011): 060501.
[M. Spolaore et al. 3rd Asia-Pacific Conference on Plasma Physics, November 4-8, 2019, Hefei, China, MF-I31, invited.
Furno I., et al. 2011 Phys. Rev. Lett. 106 245001
[Krasheninnikov S.I., D'ippolito D.A. and Myra J.R. 2008 J. Plasma Phys.74 679–717
Burrell K.H. 1997 Phys. Plasmas 4 1499–1518
[Bisai N. et al. 2005 Phys.Plasmas 12 072520
[Marcus P.S., Kundu T. and Lee C. 2000 Phys. Plasmas 7 1630–40; Spolaore M., et al 2002 Phys. Plasmas 9 4110–13
[Manz, P., et al. Physics of Plasmas 20.10 (2013): 102307.
[Marrelli, L., at al. (2019). Nuclear Fusion, 59(7), 076027.