Studies of RF discharge plasma behavior in the Uragan-3M and Uragan-2M torsatrons

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Uragan-3M torsatron

1. EXPERIMENTAL SETUP
2. TIME EVOLUTION OF RF DISCHARGE WITH H-TRANSITION
3. EDGE TURBULENT FLUX
4. A HIGHER E_r SHEAR FORMATION
5. CONCLUSIONS

Uragan-2M torsatron

1. EXPERIMENTAL SETUP
2. WALL CONDITIONING RF DISCHARGES
3. THE NEW FOUR STRAP ANTENNA
4. CONCLUSIONS

Uragan-3M torsatron

1. EXPERIMENTAL SETUP

l = 3, m = 9
R = 100 cm, $a \approx$ 12 cm
$\iota(a)/2\pi \approx$ 0.3, B_φ = 0.72 T

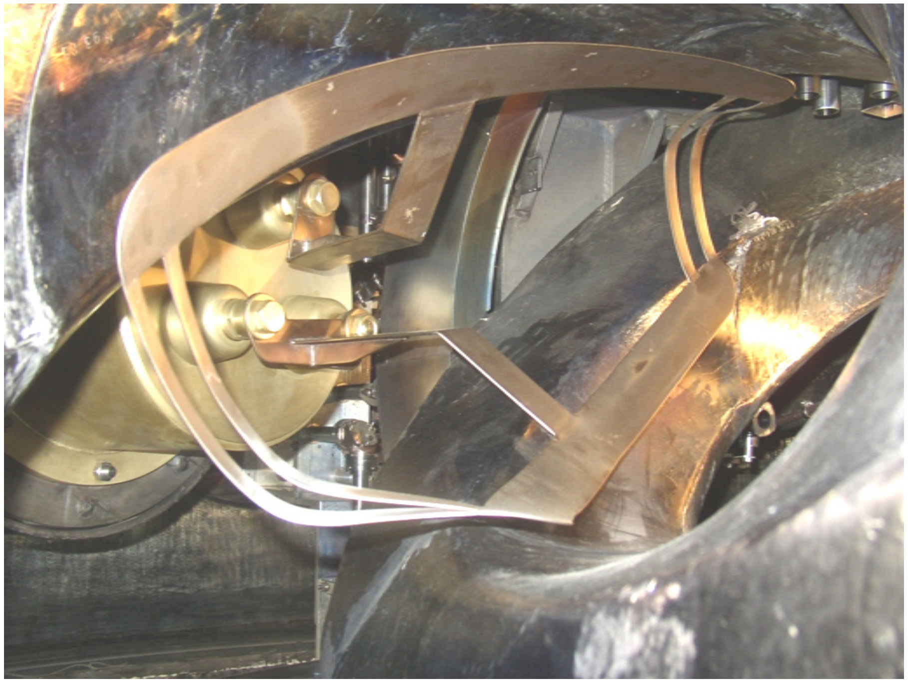
1. Magnetic system is enclosed into a large vacuum chamber.

2. Open natural helical divertor.

3. Continuous hydrogen admission (10^{-6} - 10^{-4} Torr).

4. RF plasma production and heating by resonance absorption of Alfvén waves ($\omega \lesssim \omega_{ci}$).

5. Two-temperature ion energy distribution with a suprathermal tail.

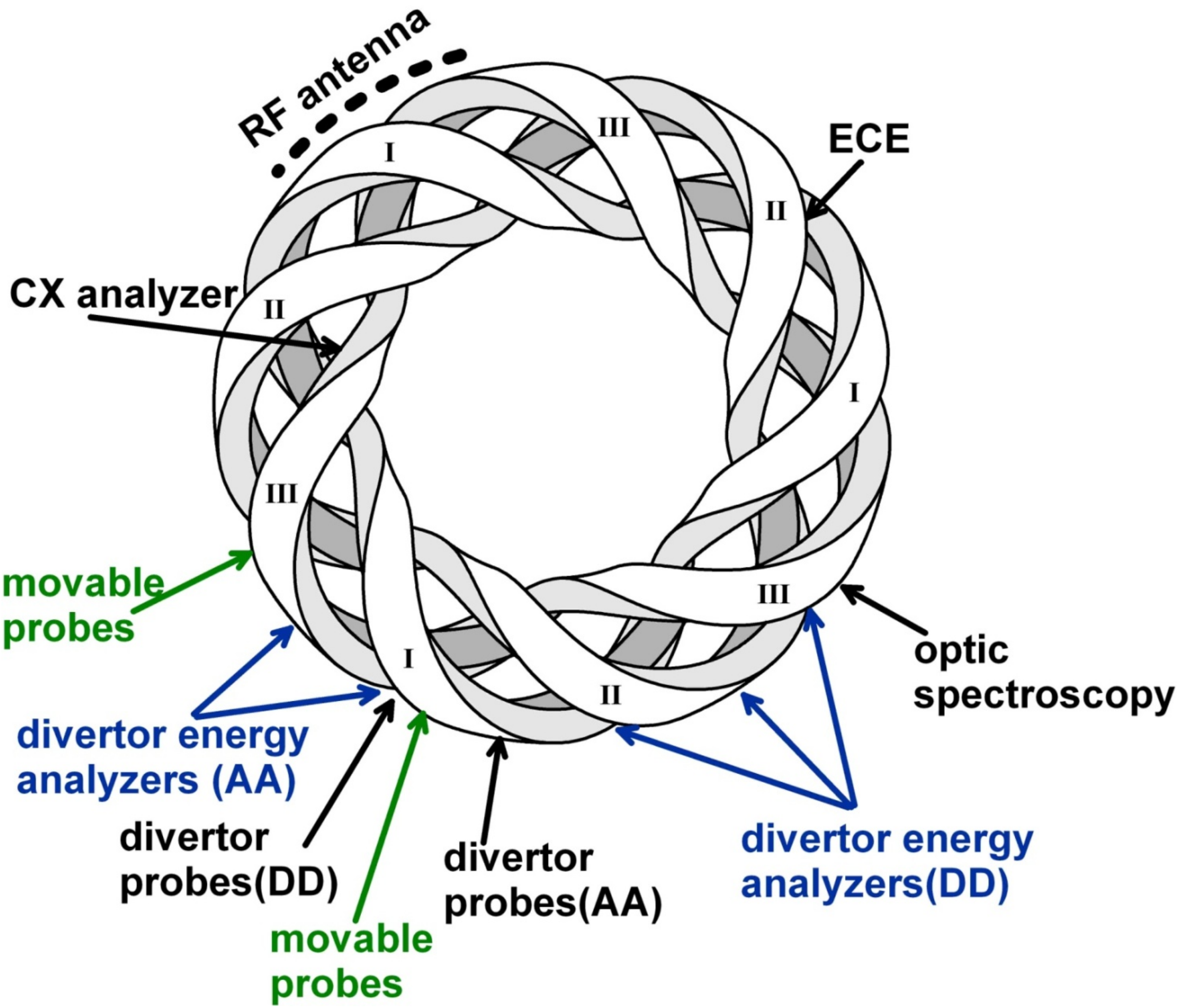


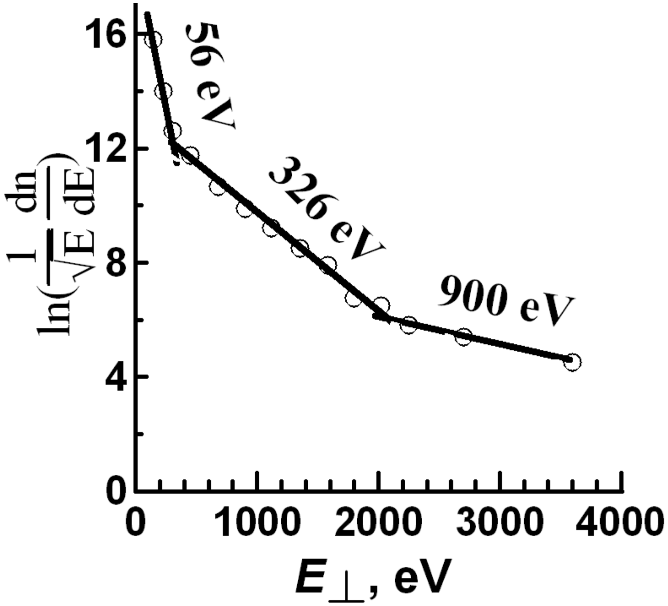
$P_{RF} \lesssim 200$ kW, $\tau = 50$ ms

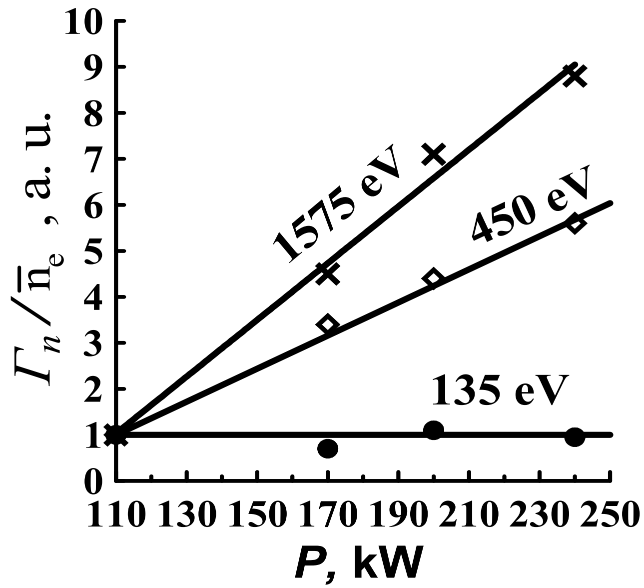
$\bar{n}_e \sim 10^{12}$ cm^{-3}

$T_e(0) \sim 500$ eV
(by 2nd harmonic ECE)

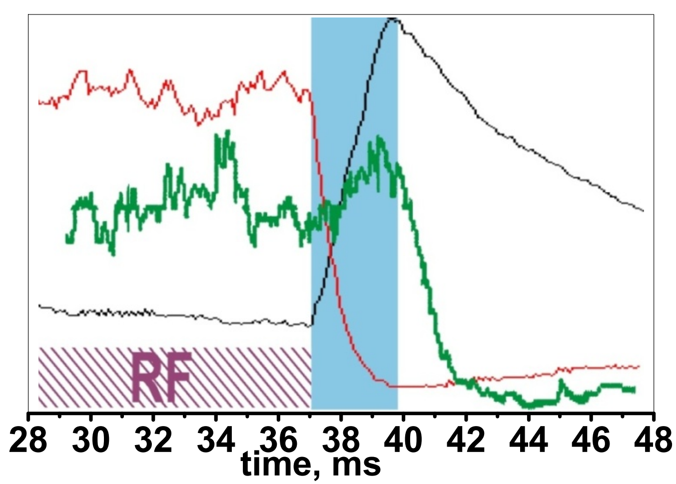
$T_e(a) \sim 50$ eV (ECE, probe)


RF antenna
I
III
ECE
II
CX analyzer
II
I
III
movable probes
III
optic spectroscopy
I
II
divertor energy analyzers (AA)
divertor probes(DD)
divertor probes(AA)
divertor energy analyzers(DD)
movable probes



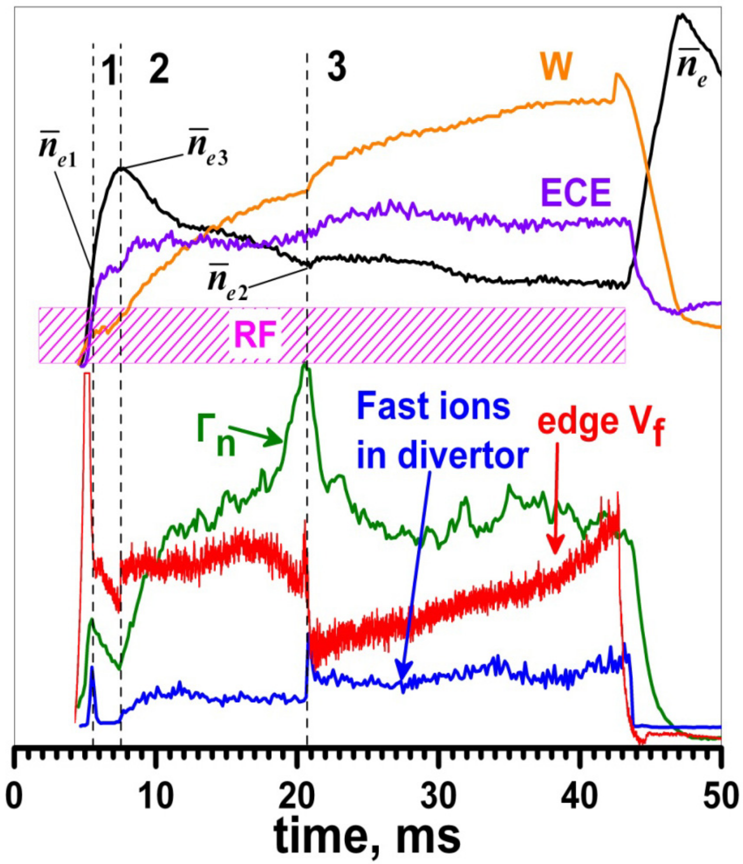


Two-temperature ion energy distribution with a suprathermal tail.
Perpendicular analyser at $P / \bar{n}_e = 300$ kW/10^{12} cm^{-3}.
The amount of fast ions rises with RF power.



The FI outflow to the divertor predominantly on the ion B×∇B drift side, thus indicating a substantial effect on FI loss of their trapping into toroidal and helical non-uniformities of the magnetic field.

2. TIME EVOLUTION OF RF DISCHARGE WITH H-TRANSITION

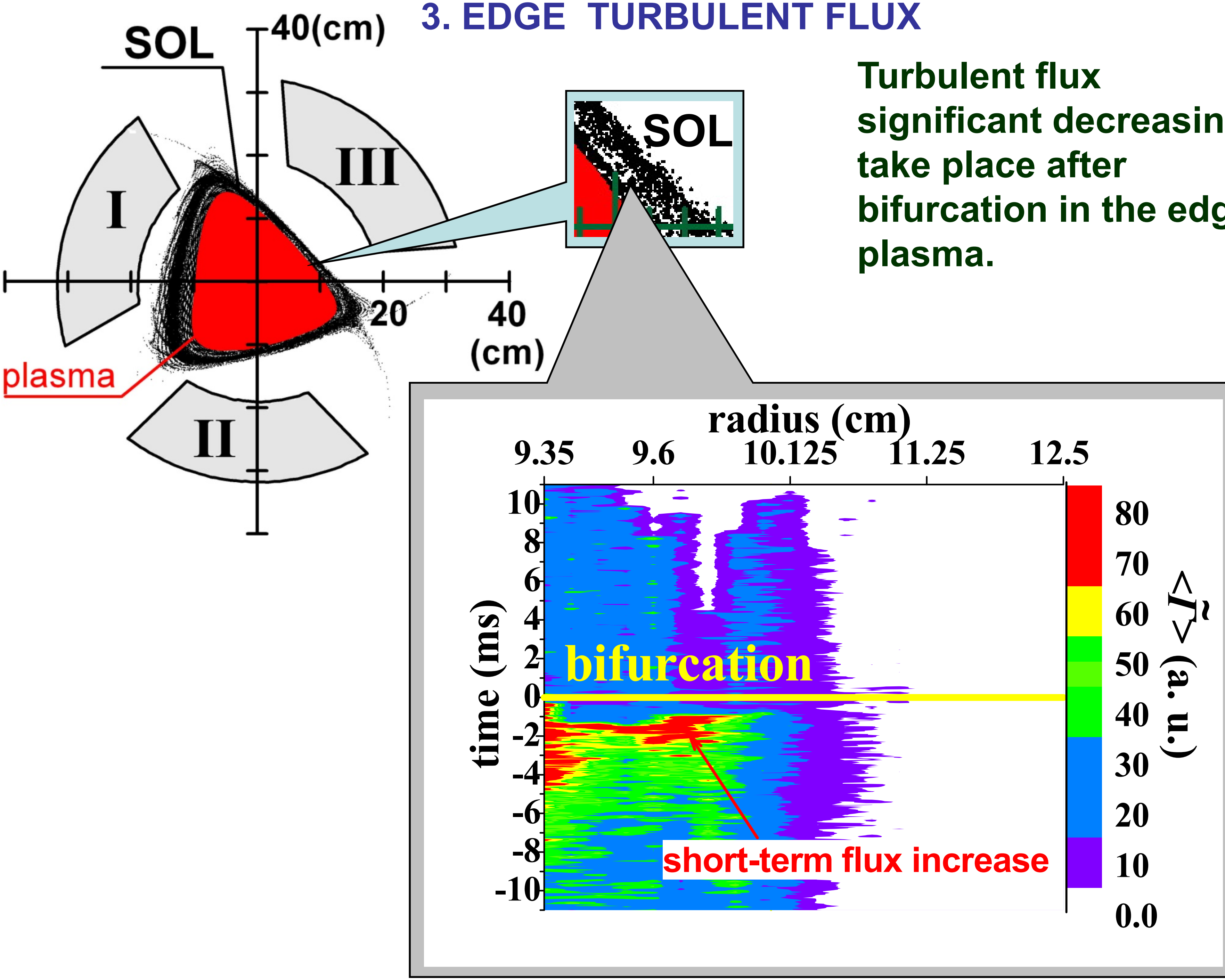


Phase 1. **Beginning from some threshold power $P \approx$ 170 kW at $\bar{n}_{e1} \approx 1.2\times10^{12}$ cm^{-3}, after burst of fast ions in divertor, a regime with reduced level of edge potential fluctuation arises. Ended by 1st V_f bifurcation at $\bar{n}_{e3}$.**

Phase 2. **Density decay after bifurcation. Enhanced fluctuation level. Ended by 2nd V_f bifurcation.**

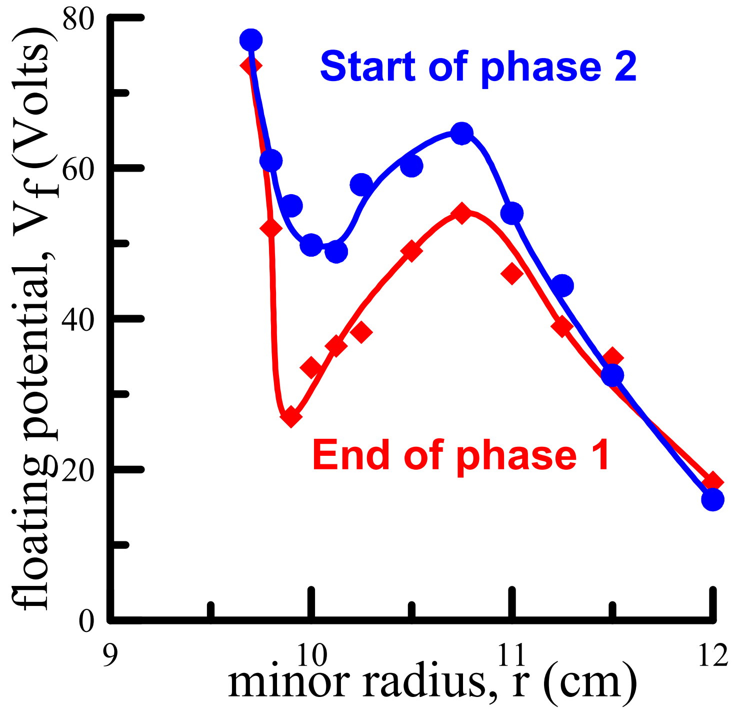
Phase 3. **At $\bar{n}_{e2} \approx 1.2\times10^{12}$ cm^{-3} the second burst of FI outflow to the divertor and an enhancement of high energy CX neutral flux Γ_n occur. The signals of diamagnetic energy content W and ECE increase, while the edge turbulent flux drops.**

3. EDGE TURBULENT FLUX

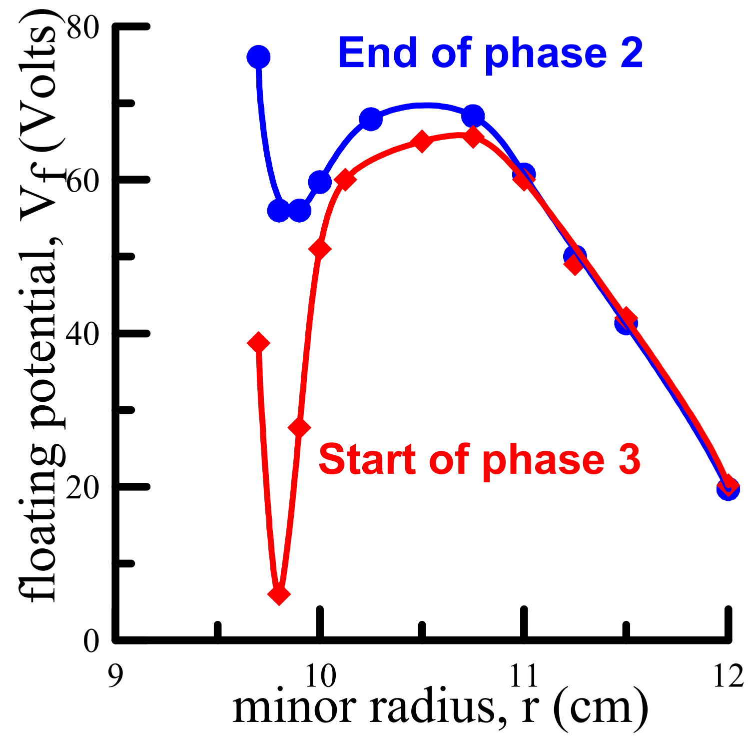


Turbulent flux significant decreasing take place after bifurcation in the edge plasma.

4. A HIGHER E_r SHEAR FORMATION

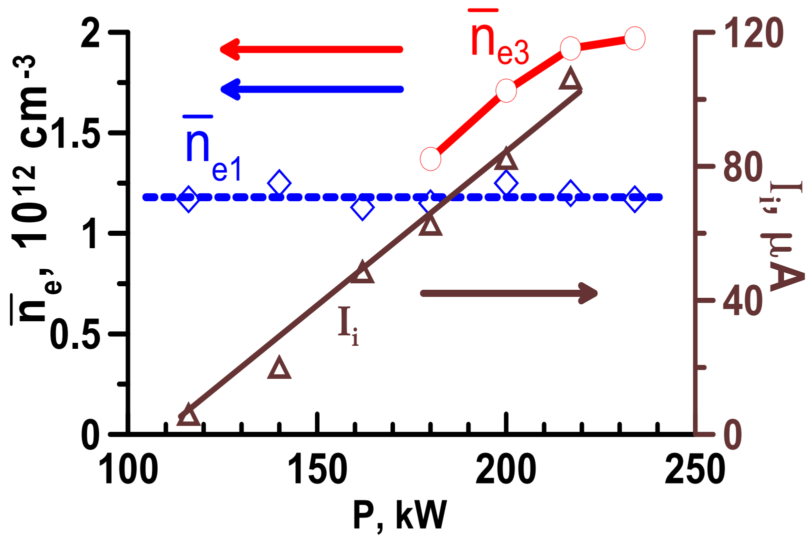


End of phase 1
$\nabla E_r \sim$ -520 V/cm^2
Start of phase 2
$\nabla E_r \sim$ -219 V/cm^2

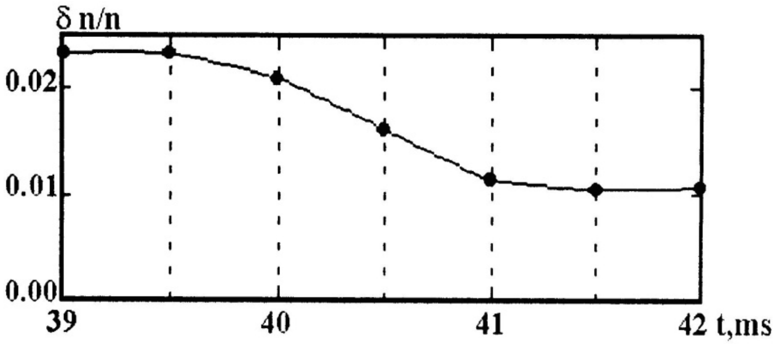


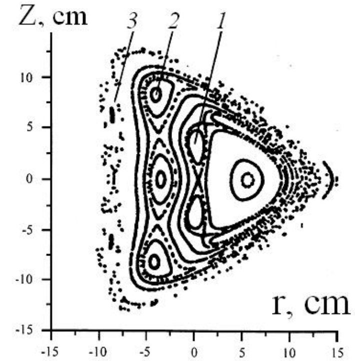
End of phase 2
$\nabla E_r \sim$ -490 V/cm^2
Start of phase 3
$\nabla E_r \sim$ -1820 V/cm^2

A higher E_r shear (and a higher E×B velocity shear) at the phases 1 and 3 results in suppression of edge turbulence and anomalous transport. An H-mode-like regime exists not only in phase 3 but in phase 1 too.

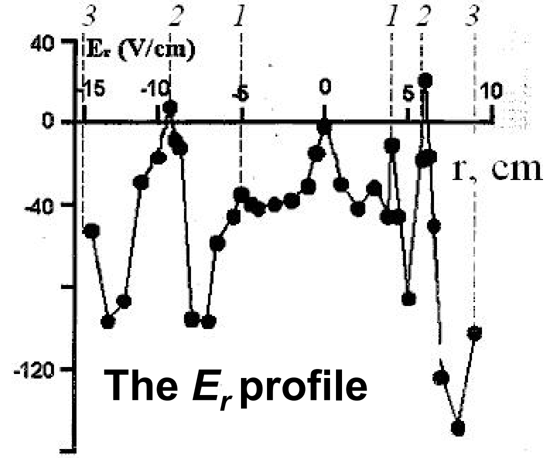


Values of $\overline{n}_{e1}, \overline{n}_{e3}$ and amplitude (I_i) of fast ions burst to the divertor, versus of RF power *P*. At the threshold power $\overline{n}_{e3}$ is close to $\overline{n}_{e1}$ and increases with further *P* increase.

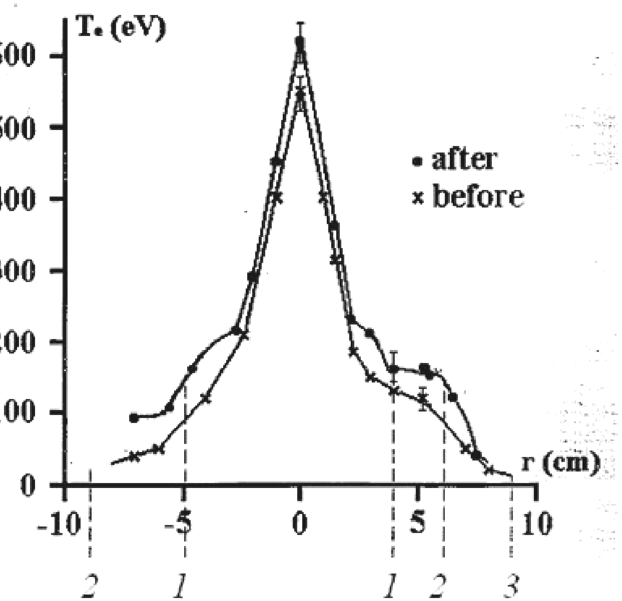


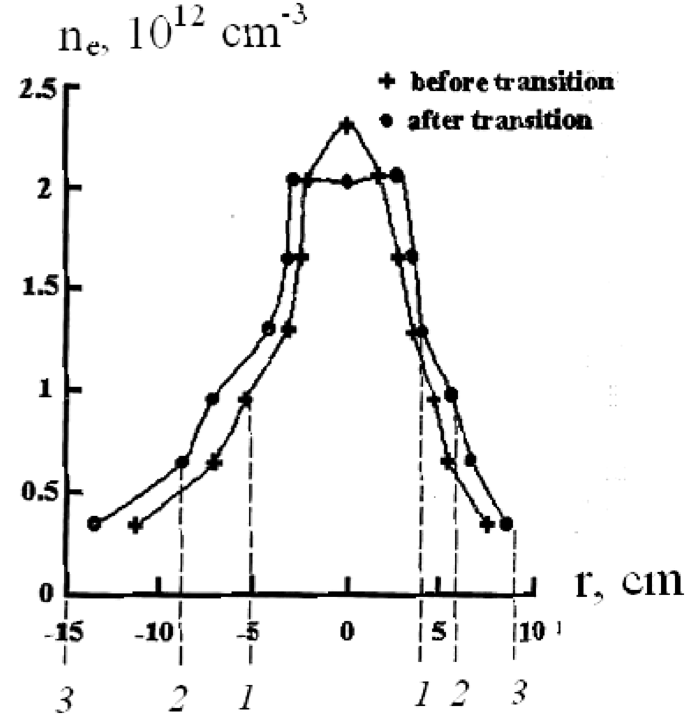


The behavior of the density fluctuations near the rational magnetic surface $\iota/2\pi = 1/4$ during the transition to regime of improved plasma confinement (f=10-40 kHz).



The E_r profile





Profiles of T_e and n_e before and after the transition to regime of improved plasma confinement. Microwave interferometry (2-8mm) and reflectometry (8-17 mm).

5. CONCLUSIONS

1. In Uragan-3M, beginning from some threshold RF power $P \approx 170$ kW, the time behavior of RF discharge can be divided into three phases.

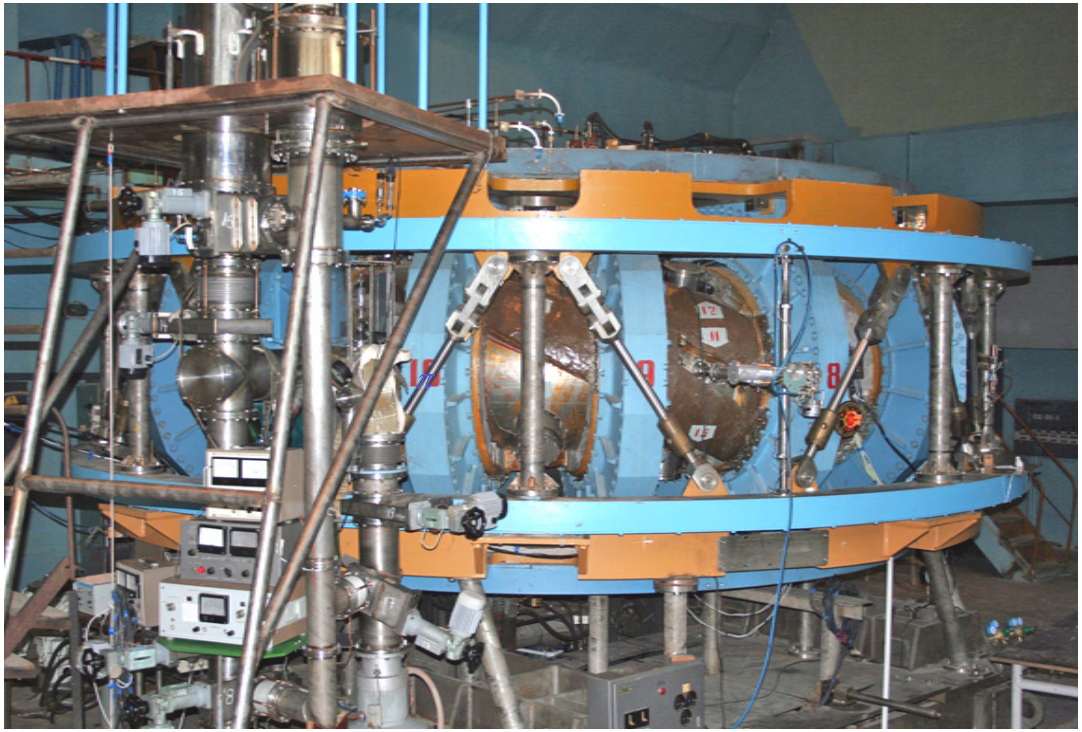
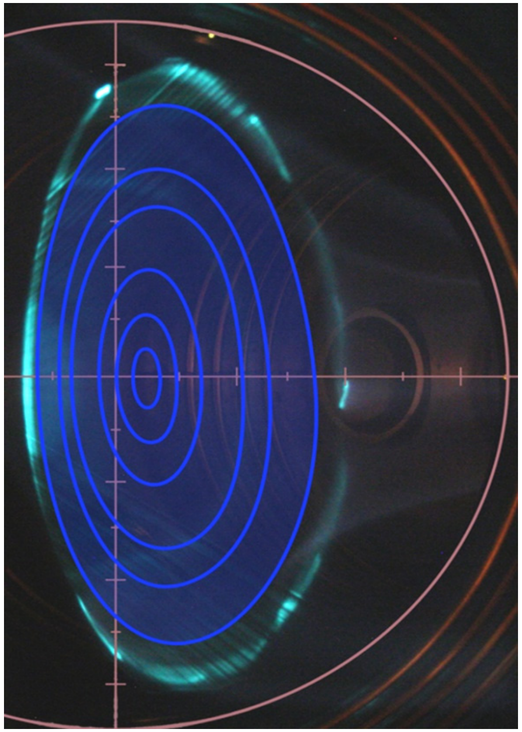
2. As a result of the burst of fast ions outflow, the radial electric field changes. A higher E_r shear (and a higher **E**×**B** velocity shear) at the phases 1 and 3 results in suppression of the edge turbulence and anomalous transport. H-mode-like regimes exist in phases 1 and 3. In phase 2 the L-like mode is observed.

1. V.V. Chechkin, L.I. Grigor'eva, Ye.L. Sorokovoy et al. Plasma Phys. Reports **35 (**2009) 852.
2. A. A. Beletskii, L. I. Grigor'eva, E. L. Sorokovoy et al. Plasma Phys. Reports **35 (**2009) 818.

Uragan-2M torsatron

1. EXPERIMENTAL SETUP

A small pitch angle of helical windings, additional toroidal field coils.

$l = 2$, $m = 4$, $R = 170$ cm, $a \approx 20$ cm

$\iota(0)/2\pi > 1/3$, $\iota(a)/2\pi < 1/2$,

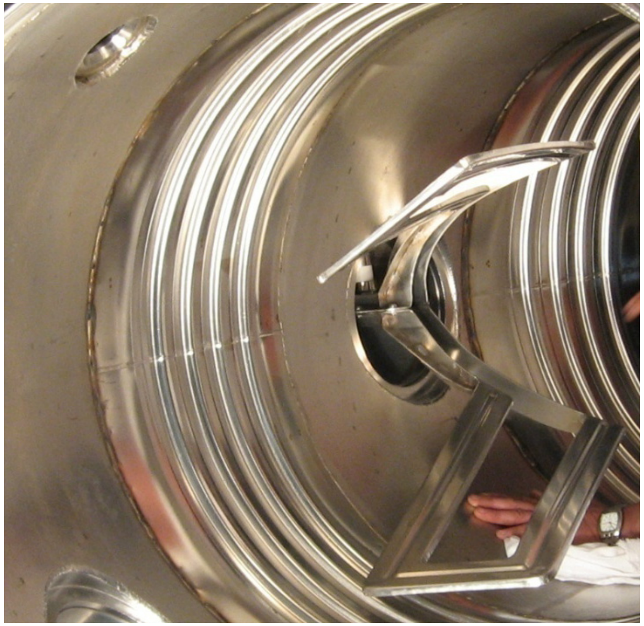
$B_\varphi = 2.4$ T ($B_\varphi = 0.6$ T)

U-2M is equipped with two compact RF frame antennas.

The first antenna has a broad $k_{||}$ spectrum and is used for plasma production. The second one with narrower $k_{||}$ spectrum heats plasma in the Alfvén range of frequencies. Two generators with RF power 0.5 MW and frequency in the range of 10 MHz are used.

The antenna with the broad $k_{||}$ spectrum provides reliable gas break-down in the pressure range of $(3\times10^{-6} - 8\times10^{-5})$ Torr and produces plasma with the density $(1\text{-}2)\times10^{12}$ cm^{-3}. Combined use of two antennas with RF power P ~100 kW (after preliminary short time wall conditioning) results in increase of the plasma density up to 6×10^{12} cm^{-3}. The increase of the carbon line intensity with time indicates that to improve plasma parameters, a careful wall conditioning is needed.

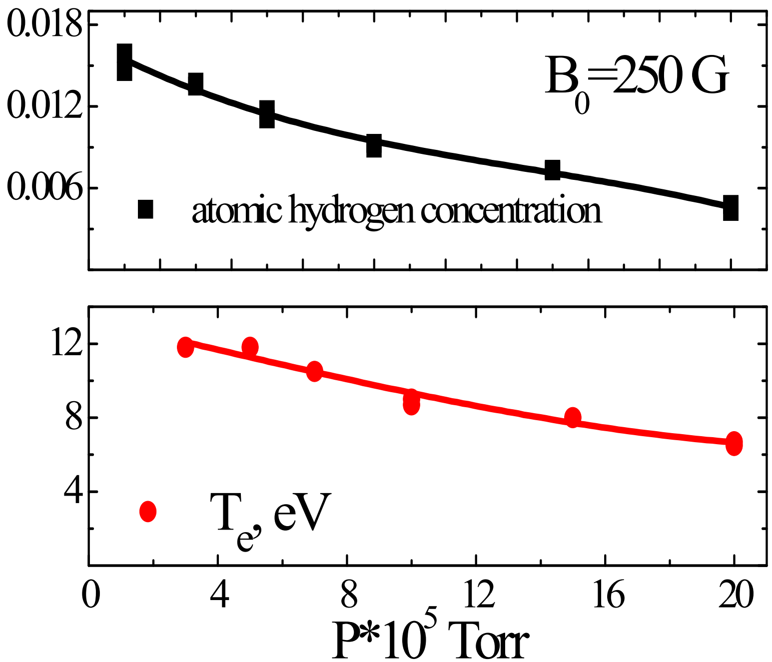
2. WALL CONDITIONING RF DISCHARGES



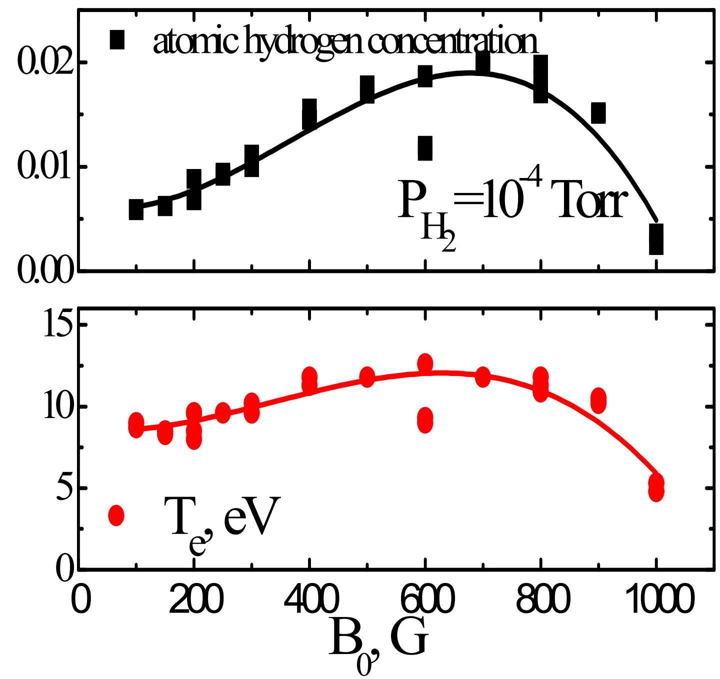
The cleaning is associated with the chemical reactivity of the atomic hydrogen capable to create volatile substances. The cleaning agents are the hydrogen atoms (3 eV) resulting from the dissociation of the hydrogen molecules (T_e= 4 -10eV, the dissociation rate is higher than the ionization one).

Continuous RF discharges are sustained by the 1 kW RF oscillator in the frequency range 4.5-8.8 MHz. The power is coupled to plasma by double frame antenna. The maximum density is $n_e = 8\times10^9$ cm^{-3}, B_0=250 G.

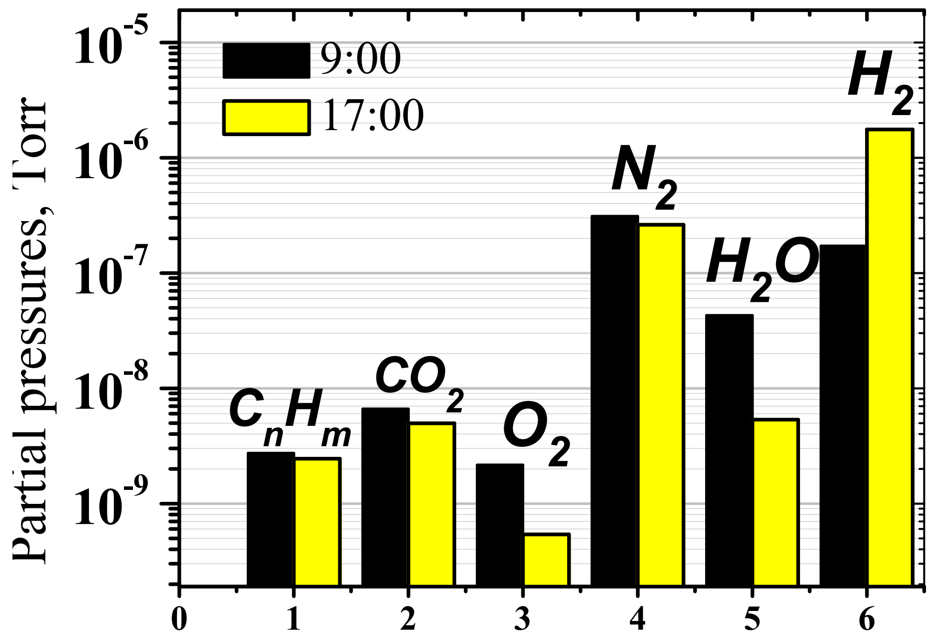
V.E. Moiseenko, P.A. Burchenko, V.V. Chechkin et al. Wall Conditioning RF Discharges in Uragan-2M Torsatron, 36th EPS Conference on Plasma Physics (2009, Sofia, Bulgaria) P5.199.



Dependence of atomic hydrogen concentration and electron temperature on hydrogen pressure.



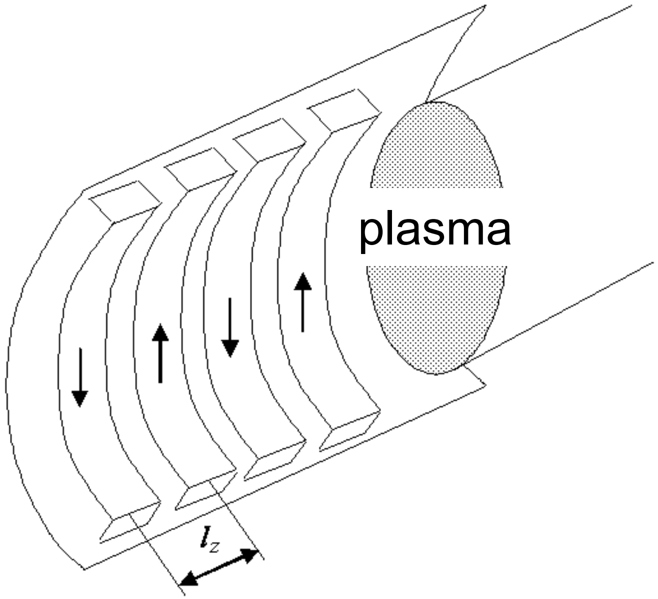
Dependence of atomic hydrogen concentration and electron temperature on axial magnetic field.



Mass-spectrometer measurements of partial pressures before and after 6-hour RF discharge.

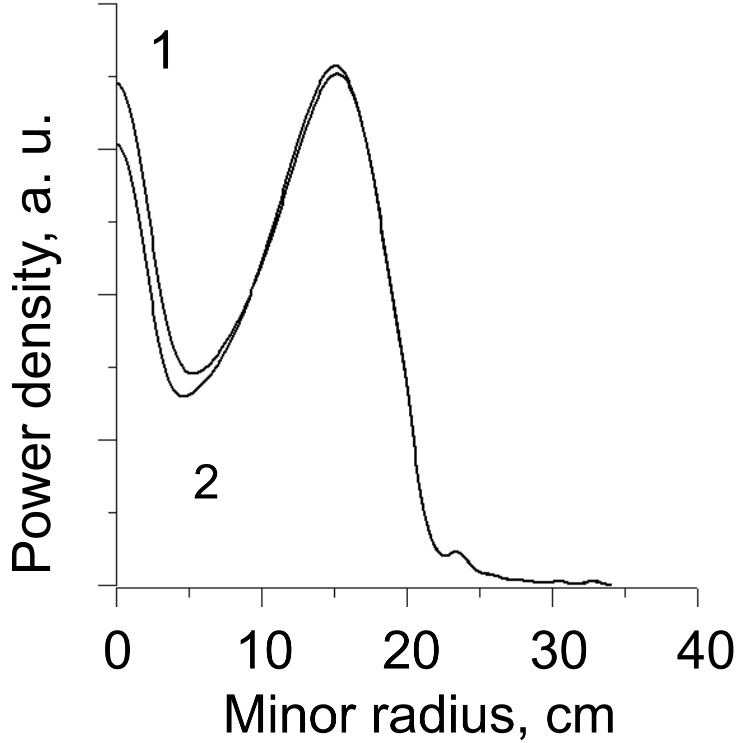
The continuous discharge is also combined with a pulse discharge with power of 50-100 kW, 5.6 MHz, the pulse length is 10-20 ms and the repetition rate is 2- 5 pulses per minute. In combined discharge the time of wall conditioning shortens.

3. THE NEW FOUR STRAP ANTENNA



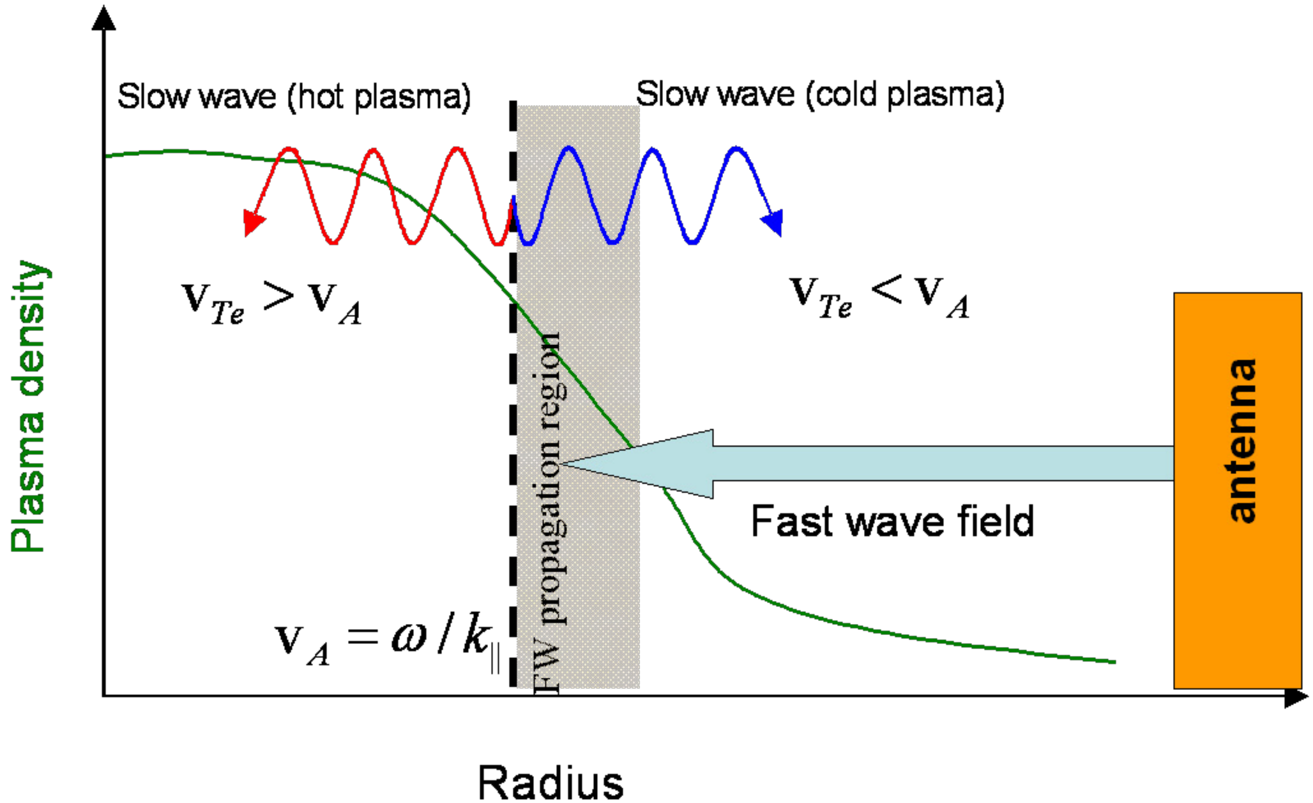
Sketch of four-strap antenna

The strap width is 10 cm and the distance between the central lines of neighboring straps is the same and equals 20 cm. The poloidal strap length is 40 cm, $\langle k_{||} \rangle \approx 0.17$ cm^{-1}.



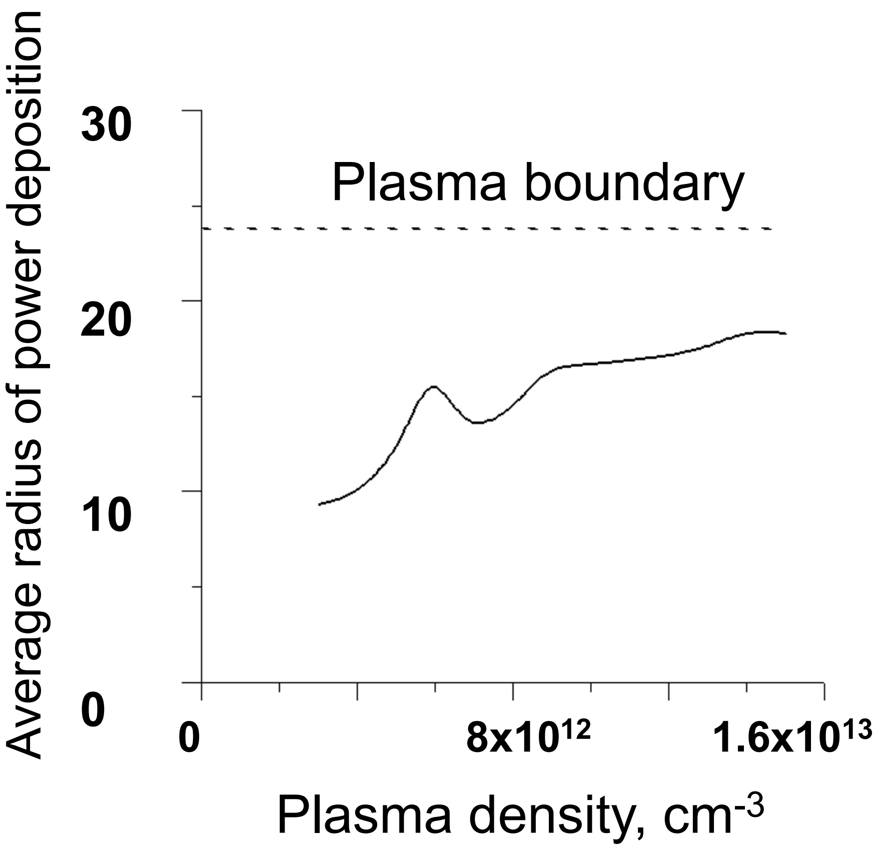
Power deposition profile

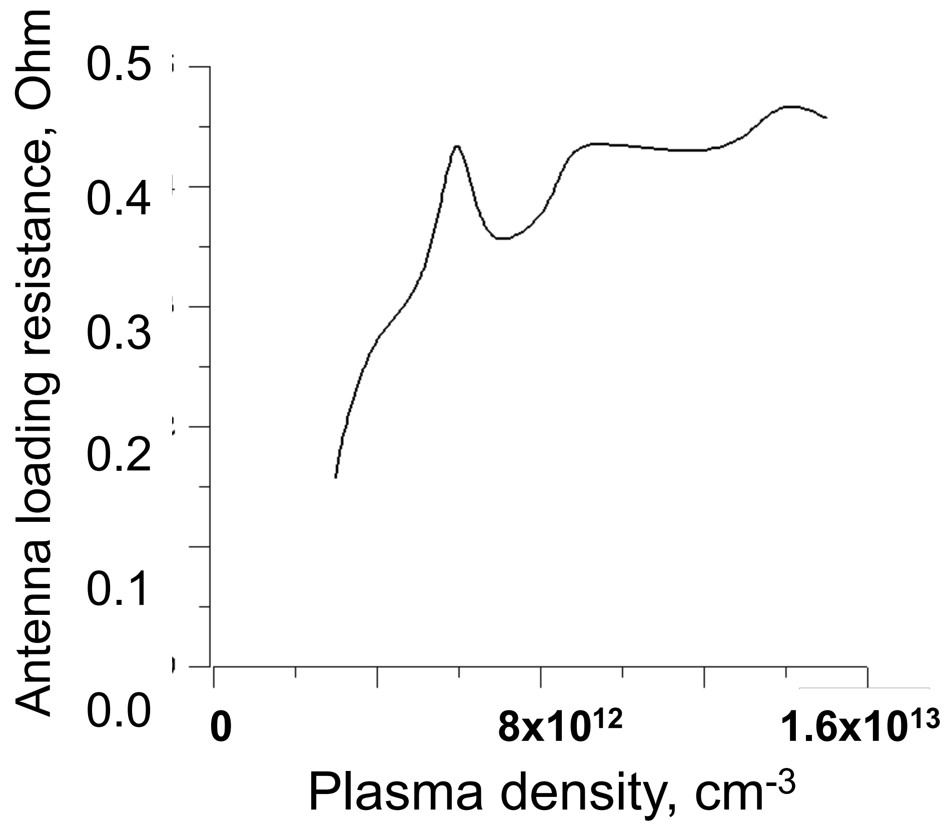
Landau damping and ion cyclotron wave damping (the fundamental cyclotron harmonic); parabolic profiles: $T_e(0)$=500eV and $T_i=0$ (curve 1); $T_e(0)$=500eV and $T_i(0)$=200eV (curve 2). B_0=0.5 T, $n(0)=8\times10^{12}$ cm^{-3}, $\omega=0.82\omega_{ci}$, $\omega=4.2\times10^7$ c^{-1}.



Scheme of Alfvén resonance heating

The mode conversion scheme with high value of $k_{||}$ will be used in Uragan-2M for plasma production and heating by RF methods from low plasma density values up to 1.6×10^{13} cm^{-3}.





Average radius of power deposition as a function of plasma density.

Antenna loading resistance as a function of plasma density.

V. E. Moiseenko, Ye. D. Volkov, V. I. Tereshin, Yu. S. Stadnik Alfvén Resonance Heating in Uragan-2M Torsatron 2009 Plasma Phys. Reports **35** (in press)**.**

4. CONCLUSIONS

1. The physical features of the low-power discharges producing hydrogen atoms are studied in a very wide range of the neutral gas pressures and magnetic field values.

2. The continuous discharge and continuous discharge combined with a pulse discharge are investigated for wall conditioning. Both discharges look to be suitable for wall conditioning and, after certain improvements, have a prospect for use in superconducting devices.

3. Compact antenna is proposed:
    - suppressed periphery plasma heating;
    - both low and high density plasma heating are possible;
    - no sensitive dependence on the plasma parameters;
    - the same antenna could be used for ICRH.