

Summary of results obtained on the L-2M stellarator in 2022

The L-2M stellarator is at the Prokhorov General Physics Institute of the Russian Academy of Sciences in Moscow, Russia. Figure 1 shows a recent photograph of L-2M.

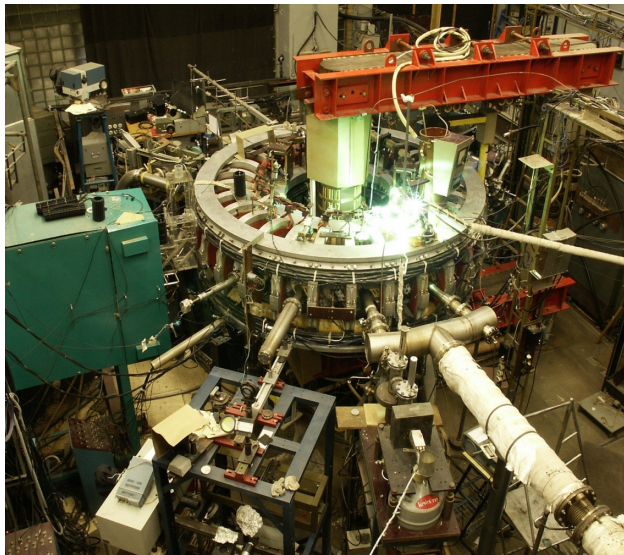


Fig. 1. The L-2M stellarator.

Experiments to search for the “X-ray pit” in soft X-ray spectra

The possible occurrence of the so-called “X-ray pit” in the spectrum of the L-2M stellarator plasma has been examined. This phenomenon was discovered at the T-11M tokamak [1]; the term “X-ray pit” denotes anomalously strong absorption of soft X-ray (SXR) radiation from plasma as it passes through 90- μm -thick or even thicker beryllium foils. To explain this phenomenon, an assumption was made concerning the “depletion” of the Maxwellian electron energy distribution due to the escape of electrons with energies several times higher than the thermal value one. Anomalous electron heat transport along the slightly perturbed toroidal magnetic field (the “magnetic flutter”

model [2]) has been proposed as a probable reason for this depletion. Such a process of depletion of the electron energy distribution function in a certain energy range must inevitably affect the shape of the SXR spectrum: starting from a certain critical energy, a dip should appear in the spectrum.

The L-2M stellarator plasma parameters are as follows: the major radius is $R = 1$ m, the plasma minor radius is $r_p = 0.115$ m, and the magnetic field is $B_0 = 1.35$ T. Three methods for plasma heating are used at L-2M: electron cyclotron resonance heating (ECRH, $f_{\text{ECRH}} = 75$ GHz, $P_{\text{ECRH}} = 1.0$ MW), ion cyclotron resonance heating (ICRH, $f_{\text{ICRH}} = 20$ MHz, $P_{\text{ICRH}} = 100$ kW), and ohmic heating (OH, $I_{\text{OH}} = 20$ kA, $P_{\text{OH}} = 50$ kW). The L-2M stellarator in the OH regime, is quite close to the T-11M tokamak in terms of such plasma parameters such as electron temperature and density [3]. In addition, L-2M is equipped with a set of SXR diagnostics, consisting of two SXR spectrometers and multichord SXR diagnostics. This had made it possible to perform direct spectral measurements

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Results from the past year at the L-2M stellarator (Prokhorov General Physics Institute of the Russian Academy of Sciences in Moscow, Russia) are presented. The so-called “X-ray pit” formation in the SXR spectrum of plasma does not occur. After several years of studying the problems of plasma self-organization, the formation of self-consistent pressure profiles can now be explained. The reasons for the formation of two-slope SXR spectra were also studied. 1

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The distribution for experimental proposals is presented, and decisions will be made soon. 4

and find out whether the “X-ray pit” formation in the SXR spectra is observed in the L-2M plasma.

The SXR spectra were measured at the L-2M stellarator in the OH [4] and ECRH [5] regimes of plasma heating. Simulations were performed that suggested that in both OH and ECRH regimes, an “X-ray pit” could be observed in the energy range of $E = (5-7)T_e$. In the OH regime, the typical plasma parameters were close to the corresponding parameters of the T11-M tokamak: $T_e = 250-350$ eV, $n_e = (0.8-2.5) \times 10^{19} \text{ m}^{-3}$. In the measured SXR spectra, in the energy range of $E = (5-7)T_e$, no drop was observed in the radiation intensity. In the ECRH regime ($P_{\text{ECRH}} = 250$ kW), the plasma parameters were as follows: $n_e = 1.7 \times 10^{19} \text{ m}^{-3}$ and $T_e = 750$ eV. In the energy range of $E = (5-7)T_e$, no decrease in the radiation intensity of the SXR spectrum was detected as well. Thus, at the L-2M stellarator, the “X-ray pit” effect was not observed either in the OH regime, or in the ECRH regime.

Self-consistency of the profiles of electron temperature and pressure of the electron component in the ECRH Regime

In the ECRH regime, experiments were performed to determine whether the profiles of electron temperature $T_e(r)$ and pressure of the plasma electron component $p_e(r)$ are self-consistent [6, 7].

In the on-axis ECRH regime, electron temperature profiles were measured in working shots differing in plasma density ($1.5 < n_e < 2.8 \times 10^{19} \text{ m}^{-3}$) and microwave power introduced into the plasma ($190 < P_{\text{ECRH}} < 600$ kW). The resulting electron temperature profiles, normalized to the corresponding temperatures at the plasma axis, are shown in Fig. 2. At ECRH powers in the range of $190 < P_{\text{ECRH}} < 250$ kW, all profiles have the same bell-shaped form (curve 1): the temperature monotonically decreases from the axis to the plasma edge.

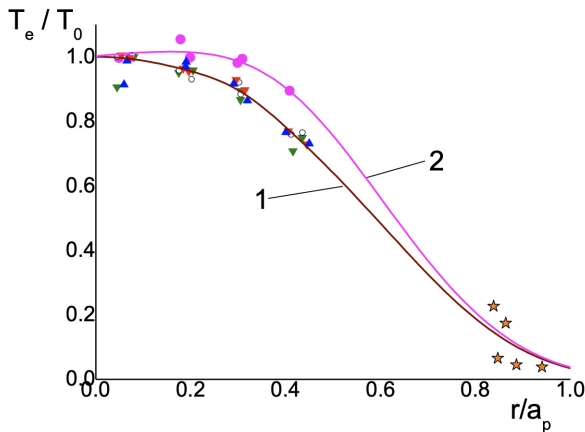


Fig. 2. Normalized profiles of electron temperature.

The normalized temperature profile measured at $P_{\text{ECRH}} = 600$ kW is also shown in Fig. 1 (curve 2). It can be seen that in this case, the shape of the electron temperature profile is different. At ECRH powers higher than 250 kW, the electron temperature profiles in the L-2M stellarator become flat in the central part of the plasma column.

The pressure profiles of the plasma electron component were calculated using data from diagnostics that perform chord-averaged measurements: the HCN laser interferometer and the multichord diagnostics of SXR. It was shown that at relatively low ECRH powers, $190 < P_{\text{ECRH}} < 250$ kW, the pressure profiles of the electron component have similar shapes that can be approximated by the canonical pressure profile calculated for stellarators in Ref. [7]:

$$p_c(\rho) = p_0 \exp\left(-2\left[\left(\ln\left(\frac{p_0}{p_a}\right)\right) \left(1 + \frac{\mu_a}{\mu_0}\right)\right] \cdot \rho^2 \left(1 + \left(\frac{\mu_a}{\mu_0} - 1\right) \frac{\rho^2}{2}\right)\right)$$

Here, p_0 and p_a are the pressures of electron component at the axis and edge of the plasma (the plasma boundary is determined by the separatrix of the L-2M magnetic system, $r_a = 0,115$ m), respectively; μ_0 and μ_a are the corresponding rotational transformation angles.

SXR spectra in operating regimes with high-power ECRH

It has been experimentally observed at many facilities that in high-power ECRH experiments in toroidal magnetic traps, non-Maxwellian SXR spectra are formed [8, 9, 10]. These spectra have a characteristic two-slope shape when plotted in semilogarithmic coordinates, $\ln(I/I_0) = f(E)$. In these experiments, the SXR spectra were measured along the central plasma chord. We succeeded in finding the reasons for the appearance of a suprathermal tail in these spectra. In the on-axis ECRH operating regime of the L-2M stellarator ($P_{\text{ECRH}} \sim 240$ kW, $n_e \sim 1.9 \times 10^{19} \text{ m}^{-3}$), the SXR spectra were measured along the chords passing through the plasma center and the heating region (Fig. 3).

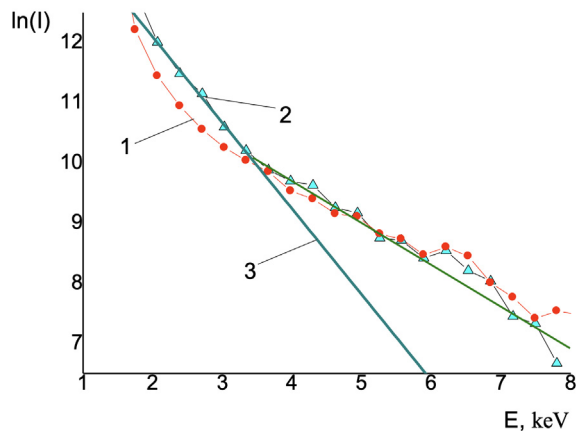


Fig. 3. SXR spectra measured along (1) the chord passing through the heating region located in the region with the inverse density gradients, and (2) the central chord. Straight line (3) corresponds to the Maxwellian spectrum.

It was ascertained that at the L-2M stellarator, in operating regimes with on-axis high-power ECRH, a considerable part of the ECRH power is not absorbed in the axial plasma region. Due to the pump-out effect, regions with inverse gradients in the electron density profile are formed in plasma. The region of heating power absorption shifts to these regions with the inverse density gradients, in which absorption occurs due to many-stage decay processes of microwaves heating the plasma [11]. Thus, the two-slope shape of the spectra arises because, during the time when measurements performed along the central chord, both the radiation coming from the central plasma region and the radiation from the heating region, located in the region with the inverse density gradients, fall into the field of view of the spectrometer. In this case, the spectrometer records the total spectrum, which turns out to have the two-slope shape.

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Wendelstein 7-X Program Workshop for upcoming operation phases

After the rather long period of the Wendelstein-7X (W7-X) completion phase without plasma operation, the scientific program for the upcoming operation campaigns OP 2.1 (starting in October 2022) and OP 2.2 (scheduled for early 2024) was discussed in the framework of the W7-X program workshop, which was held 5–6 September 2022 at IPP Greifswald as a hybrid workshop with on-site and remote participants.

The workshop marked the final step of the programmatic scientific planning for the upcoming two campaigns, which was prepared in the framework of topical task forces. The task force structure was revised from that of previous operation campaigns to account for the main objectives of the upcoming campaigns. Three task forces, Core scenario development, Edge scenario development, and W7-X optimization, all with new task force leaders were already established in September 2021.

The task force leaders have defined the key programmatic research goals and associated deliverables to foster the proposal discussion.

Those goals stem from four main sources: (i) Scientific results of the last operation campaign, highlighting the successful neoclassical optimization and the role of turbulence in heat and impurity transport; (ii) strategic development of W7-X, particularly progressing with the neutral beam heating system as part of the necessity to considerably increase the plasma heating power; (iii) W7-X project goals as, e.g., long-pulse operation with control of the heat loads on the high-heat flux divertor; (iv) the exploitation of new and enhanced functionalities, as, e.g., the steady-state pellet injector as a tool for central fueling and profile control.

After the call for proposals in February 2022, proposals were collected in April 2022. Approximately 600 proposals were submitted, providing broad coverage of the defined research goals of the task forces, c.f. Figure 1.

Out of all proposals, about 50% were selected as highest priority proposals. The scientific program as it emerges out of the high-priority proposals was discussed at the W7-X program workshop and finally approved by the international program committee. The workshop was well attended with a total number of over 200 participants. The next step of the planning is to schedule the conduction of the individual proposals, which is currently ongoing and expected to be finalized in the beginning of October.

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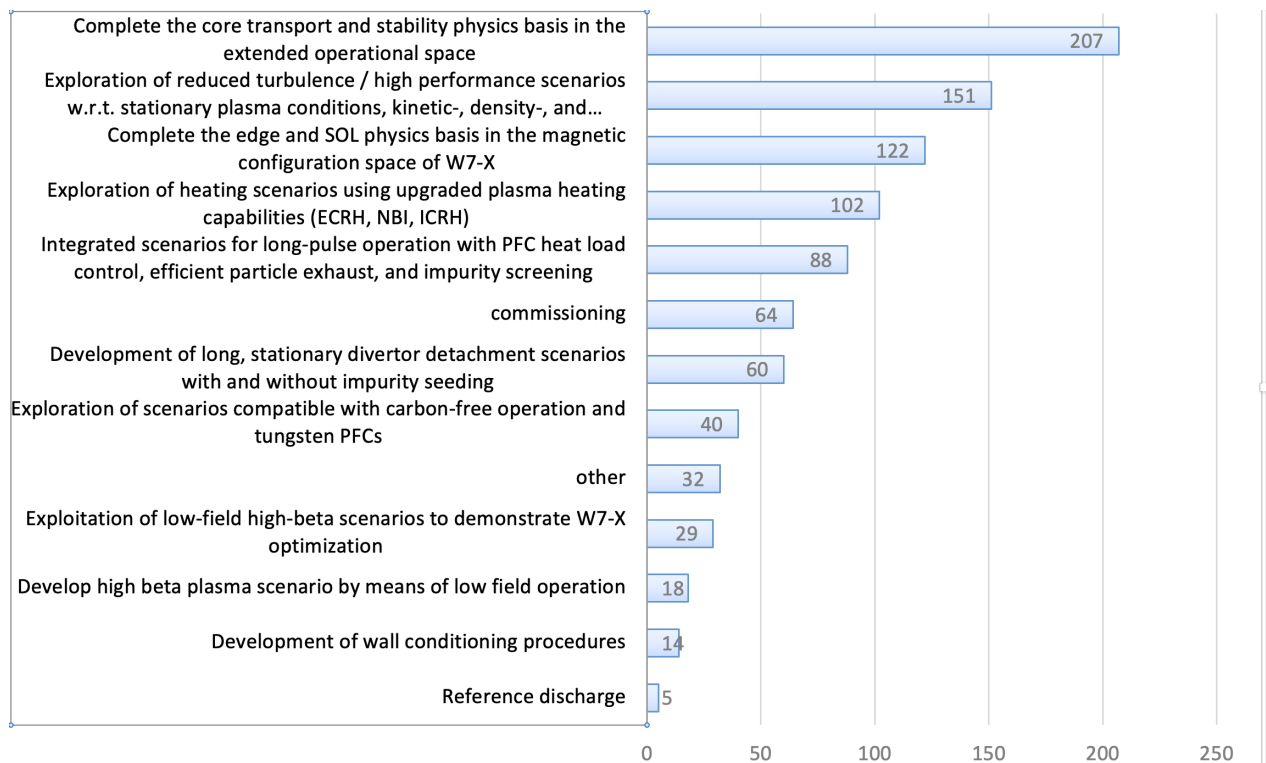


Fig. 1. Distribution of submitted proposals over the main research goals.