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Summary of the 11th Conference on Magnetic Confined Fusion Theory and Simulation

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Abstract

This conference report summarizes recent progress in plasma theory and simulation that was presented in contributed papers and discussions at the *11th Conference on Magnetic Confined Fusion Theory and Simulation* (CMCFTS) held in Chengdu, China, 27–30 October, 2023. Progress in various fields has been achieved. For example, results on zonal flow generation by mode coupling, simulations of the key physics of divertor detachment, energetic particle effects on magnetohydrodynamic (MHD) modes in addition to ion- and electron-scale turbulence, physics of edge coherent modes and edge-localized modes, and the optimization of ion heating schemes as well as confinement scenarios using advanced integrated modeling are presented at the conference. In this conference, the scientific research groups were organized into six categories: (a) edge and divertor physics; (b) impurity, heating, and current drive; (c) energetic particle physics; (d) turbulent transport; (e) MHD instability; and (f) integrated modeling and code development. A summary of the highlighted progress in these working groups is presented.

Keywords: magnetic confined fusion (MCF), theory and simulation, modeling, tokamak

(Some figures may appear in colour only in the online journal)

1. Introduction

The *11th Conference on Magnetic Confined Fusion Theory and Simulation* (CMCFTS) was held in Chengdu, 27–30 October, 2023. The conference has been successfully held ten times from 2013 to 2022. As the scale and influence of the conference gradually expanded, it has become an important event and academic exchange platform in the field of magnetic confined fusion (MCF).

The goal of the CMCFTS is to report the latest progress in theories and numerical simulations on magnetic confinement fusion and other plasma physics. It also discusses the latest developments in domestic and foreign magnetic confinement fusion investigations, which are needed for future fusion reactors. The conference topics include equilibrium and magnetohydrodynamic (MHD) instability, micro-instabilities and turbulent transport, heating and current drive, fast particle and alpha particle physics, boundary physics, impurity transport, plasma–wall interactions, fusion reactor physics and integrated modeling, deuterium–tritium plasma physics, new conceptual design, large-scale numeri-

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cal simulation and high-performance computing, and applications of artificial intelligence technology.

This year, the categories were similar to those of previous meetings. The presentations are divided into six topics as follows: (a) edge and divertor physics; (b) impurity, heating, and current drive; (c) energetic particle (EP) physics; (d) turbulent transport; (e) MHD instability; and (f) integrated modeling and code development. The reports focus on these six topics, including five plenary talks, 10 invited oral talks, 74 oral talks, and 96 posters. More than 300 people attended the conference. In the following sections, the main results and significant progress highlighted by these presentations are summarized.

2. Summary of plenary and invited talks

2.1. Summary of plenary reports

Zhong reported an overview of recent research activities on the newly built large-scale research facility: HL-3 tokamak. On HL-3, a milestone was achieved: a high-confinement mode (H-mode) with a plasma current exceeding 1 MA. High-performance discharges with advanced (e.g. snowflake) divertor configurations have been realized [1]. These breakthroughs represent recent significant improvements in the operational level of China's MCF device. Hu reported significant progress in various topics, including core confinement improvement and turbulence suppression, turbulence current drive, MHD and turbulence interaction, error field penetration, edge-localized mode (ELM) suppression and ELM-free regime investigation, transport barriers control and improvement, plasma–wall interaction, and RF-dominant heating noninductive plasmas on the EAST [2–4]. The key achievements of HL-3 and EAST provide important platforms and solid physics basis for solving key issues in MCF and supporting the ITER research plan.

Wang reported new results on the nonlinear gyrokinetic simulations [5]. The long-time nonlinear global simulations performed using the NLT code successfully revealed the formation dynamics of internal transport barrier (ITB) for the first time. They found that ITB is a kind of self-organized marginal structure. The initial formation of ITB near the magnetic axis was due to an inward propagated avalanche. The outward expansion of ITB is a catastrophe induced by an outward propagated avalanche. Ma presented progress in the mechanism and active control of plasma disruption [6]. The impurity injection is a useful control technique to mitigate heat deposition and halo current on the wall and reduce the amplitude of runaway current. In addition, combined with MHD instability control, CLT simulations have indicated that external fueling is an effective way to improve the operational density limit without disruption [7]. Chen reported the recent progress in the EP physics [8]. A zonal flow (ZF) can be generated by the nonlinear interaction between the Alfvén eigenmodes (AEs). EPs can affect the performance of edge plasma. For example, instabilities driven by EP play a role in triggering ELM, pedestal collapse, and nonlocal transport. It is suggested that the multiscale nonlinear interactions among different instabilities are essential for understanding complex plasma behaviors [9–12].

2.2. Summary of invited talks

Ten invited talks reported several important results regarding the theories and simulations of turbulent transport, ZF, three-dimensional (3D) physics in a stellarator, nonlinear MHD simulations, interactions between internal kink modes and EPs, neoclassical impurity transport, and ELM simulations. In this section, we summarize the key results of each invited talk.

Xiao reported global gyrokinetic GTC simulations of ion temperature gradient (ITG) turbulence transport and ZF physics [13] in a reversed magnetic shear configuration based on the designed equilibrium for CFETR [14]. A comparison revealed that magnetic shear can suppress ITG instability by controlling the distribution of density on a rational surface. This suppression effect persists in the absence of ZFs in nonlinear ITG turbulence and in the case of negative magnetic shear. Wang *et al* simulated MHD instabilities in the CFQS stellarator, which indicated that the bootstrap current led to the generation of low-order rational surfaces and magnetic islands, causing the breaking of some magnetic surfaces. When the plasma resistivity is high, resistive ballooning modes exist in the regions where the pressure gradient is large. However, fast ions have a stabilizing effect on the resistive ballooning mode [15].

Jian presented numerical results related to the recent DIII-D high-β_p experiment. It was found that the plasma achieved a high-performance regime due to the existence of ITB. However, the unstable kinetic ballooning mode (KBM) instabilities inside ITB [16] limited further increases in the plasma performance. Wang reported the results obtained by employing the global gyrokinetic code GKNET, which includes a heating source term. It was shown that the stability of the $\boldsymbol{E}\times\boldsymbol{B}$ staircase weakened with increasing heating power. Meanwhile, the outward propagation of avalanche structures was enhanced, and more intermittent turbulent bursts occurred [17].

Zhou *et al* simulated the sawtooth collapse phenomenon observed on the W7-X stellarator using M3D-C1. A small amount of near-axis electron cyclotron current drive led to two $l = 1$ resonance positions on the rotational transform profile, which resulted in the appearance of two $(n, m) = (1, 1)$ (where n and m are the toroidal and poloidal mode numbers, respectively) internal kink modes. A small collapse that occurred near the inner resonance position may be responsible for the sawtooth precursor, whereas a large collapse that occurred near the outer resonance qualitatively matched the experimental indicators, such as the temperature reversal minor radius [18]. Dong reported that the drift kinetic resonance of EPs had a stabilizing effect on the internal kink mode. The precession drift resonance of trapped particles played a dominant role [19].

Guo showed that the dilution effect of EPs reduces the real frequency of the density gradient-driven long-wavelength collisionless trapped electron mode (CTEM), thereby increasing the growth rate of CTEM. This is mainly because the smaller phase velocity of CTEM leads to more electron cyclotron resonance, which enhances the driving force of the CTEM instability [20, 21]. Su reported the newly developed Parametric Perturbation Instability Calculation code, which was used to systematically simulate the characteristics of parametric instability of low hybrid waves. Starting from the 'double-well structure' in the parametric instability equation, the decay channel for parametric instability has been clearly defined, which greatly improves the reliability of growth rate calculations [22].

Pan developed a theoretical model that was able to investigate the features of the asymmetrical distribution of impurity ion density in flux coordinates for various plasma shapes. The asymmetry of the poloidal magnetic field in a single-null divertor configuration can lead to an asymmetrical distribution of impurity ion density, which provides a new mechanism for neoclassical impurity transport [23]. Li presented a detailed analysis of the ELM suppression in the quasi-snowflake divertor discharges on the EAST and reported that local magnetic shear played an important role in controlling ELM dynamics. The change in the local magnetic shear altered the amplitude of the Reynolds stress, which in turn determined the redistribution of energy to the low-n mode and affected the ELM size [24−26].

3. Edge and divertor physics

Xu reported the experimental results of detached divertor scenarios on the EAST. Under the conditions of low q_{95}, high density, and high-power heating, pure neon injection resulted in small ELMs on pedestal and divertor detachment. The density can approach the Greenwald density limit. At the same time, the ratio of radiation power to total heating power reached up to 50% [27, 28]. Du reported numerical results for the quantitative dependence of divertor detachment on particle recycling [29]. Mao *et al* developed a numerical suite to carry self-consistent simulation of transport and turbulence in tokamak edge plasma [30, 31]. The modeling results (e.g. ELM cycles) agreed with those of the EAST experiments.

Ou presented a fluid model to investigate the effect of the superthermal electrons on the heat flux through a magnetized sheath. It was revealed that the variation in the plasma density and sheath potential drop at the Debye sheath entrance with superthermal electrons and magnetic field modified the particle and heat fluxes across the Debye sheath to the material surface, and the sheath heat transmission coefficient can increase significantly even for a very small superthermal electron population [32]. Zhou *et al* numerically studied the effect of mixed impurity injection (40% D_2 + 60% N_2) on divertor detachment. They found that the radiation of nitrogen impurity played a dominant role on the realization of detachment for discharge HL-2A #38008 [33]. Zhang *et al* studied the influence of strike point position on the decay length of particle and heat fluxes on the divertor device using the SOLPS-ITER code. The results show that when the strike point was located on the horizontal target plate, the decay length was longer than that when it was located on the vertical target plate. The input parameters for the simulations were adopted based on the EAST discharge #98332 [34].

Ji applied a reduced fluid model to study the influence of multifield coupling effects on plasma stability in a scrape-off layer (SOL). The results indicate that multifield coupling may introduce new mechanisms of driving instabilities, which is beneficial for exciting turbulence and reducing the divertor heat load on the divertor target. Niu *et al* investigated the temporal evolution of ELM-induced heat flux on a monoblock (MB) surface and in the gap between MBs. The heat flux in the gap was even higher than that on the MB surface, which is beneficial for the design of an advanced divertor [35]. Wu *et al* studied the evolution of plasma and impurity radiation, profile redistribution, and turbulent transport before and after disruption. This revealed that the increase in density and core ion temperature and the decrease in edge turbulent transport were the main reasons for the enhanced core confinement after detachment [36].

Zou *et al* reported the experimental results on the interaction between turbulence and ZFs on HL-2A during tungsten impurity injection. This demonstrated that tungsten impurity can significantly enhance the ZF and almost does not affect its frequency. The nonlinear coupling between turbulences determined the variation in the ZF amplitude [37]. Deng *et al* developed a machine-learning regression model to quickly select the appropriate RMP coil phasing for controlling ELMs on the EAST. The effective rate of this model reached 88% [38, 39]. They developed a new method to reconstruct the plasma shape using a multiple spectral imaging system equipped on the HL-3 tokamak. The visible spectral image was used to identify the midplane plasma boundary with a temporal resolution of milliseconds, which is important for the real-time control of the plasma shape.

4. Impurity, heating, and current drive

Du applied the circuit/3DLHDAP code to optimize the conjugate-T circuit for an ion cyclotron resonance heating (ICRH) antenna system. The results show that the antenna system with a conjugate-T circuit maintains a lower reflection coefficient (< 0.4) without adjusting impedance matching when the plasma parameters vary over a wide range. Xu extended the DIVIMP impurity transport code to include the $\boldsymbol{E}\times\boldsymbol{B}$ drift effect. Combined with the SOLPS-ITER code, simulations showed that $\boldsymbol{E}\times\boldsymbol{B}$ drift played an important role in affecting tungsten impurity transport from the divertor region to the core plasma. Yin reported the numerical results on increasing the efficiency of heating ions by optimizing the parameters of the ICRH system (e.g. wave frequency and parallel wave number) and plasma density in SOL for the ITER device [40].

Lu introduced the progress of a newly developed code for studying the ICRH power coupling in the plasma boundary. This code includes the nonlinear effects related to the radio-frequency sheath and can be applied to design an ICRH antenna system and study impurity sputtering issues [41]. Wu *et al* calculated several ICRH schemes for the EHL-2 device using TORIC and found that the ratio of ion temperature to electron temperature strongly affects the efficiency of heating ions [42]. Zhou reported the simulations of tungsten impurity transport for the HL-3 tokamak by considering different divertor configurations and found that the tungsten impurity concentration in the core of the snowflake divertor was higher than that of a conventional divertor. Shi showed the progress of a solenoid-free current drive via ECRH on the EXL-50 device. The maximum ECRH-driven current reached up to 180 kA [43].

Wang presented the modeling results for divertor detachment with neon impurity seeding on the EAST and found that the inner divertor target was easier to detach than the outer divertor target in the case with a favorable toroidal magnetic field. Tao *et al* developed a numerical code for solving a one-dimensional (1D) gyrokinetic equation, which was applied to study the effect of impurity on the ITG mode. The decay length of the impurity played an important role in stabilizing ITG [44]. Li *et al* analyzed the sheath structure and energy flux to a divertor target in the presence of hot electrons under EAST parameters with particle-in-cell simulations, elaborated the effect of hot electrons on the temperature of the divertor target with ANSYS fluent calculation, and compared with the case of heat flux calculated with the classical sheath heat transmission coefficient [32, 45]. Liu applied the gyrofluid code ExFC to study the effect of carbon impurity on ITG turbulence. It was shown that ITG-induced turbulent transport strongly depends on the impurity density gradient. Yang *et al* developed a 3D Monte Carlo code SURO-FUZZ to study the formation and growing process of tungsten fuzz (e.g. porous nanostructure). The simulation results agreed well with the experiments on the devices (PISCES-A and NAGDIS-II) [46].

5. Energy particle physics

Xu discussed how fast ions affect turbulent transport in ITB based on HL-2A experiments. The results indicate that the enhancement of nonlinear electromagnetic stabilization effects caused by fast ions can significantly reduce the heat transport level [47]. Xie reported that nonthermal distribution can increase the fusion reaction rate by approximately 0.5–1 times for deuterium–tritium nuclei and by one to three times for hydrogen–boron fusion [48]. Liu reported the polarization characteristics of ion cyclotron instability (ICI) observed for the first time on the HL-2A device using the newly developed diagnostics. ICI can be used to infer the alpha particle distribution information in fusion reactors [49]. Gao identified a new resonant condition for the interaction between passing EPs and tearing mode (TM) using M3D-K simulation. The study revealed that the passing EPs can excite a 2/1 fishbone, which can interact strongly with TM, thus enhancing EP losses. Cao reported that a type of helical AE can be induced in magnetic islands in tokamak plasmas.

Zheng reported a new form of Hamiltonian in the wave–particle resonance coordinate. This theory simplifies the treatment of multiscale problems. Bao presented a brief overview of the MAS code. This code has been extended to include multicomponents of EPs and applied to study various AEs for tokamak devices [50]. Zhang carried out a linear simulation study of the $m/n = 1/1$ mode using the hybrid code CLT-K. They pointed out that the parallel inertia and δB response terms significantly affect the eigenvalues of kink instabilities. These two terms should be carefully treated in MHD–kinetic simulations. Chen *et al* investigated the influence of elongation on the dispersion relation of the EP-induced geodesic acoustic mode (EGAM) through gyrokinetic theory. This study revealed that the elongation had a weak effect on the frequency of EGAM but significantly reduced its growth rate. The theoretical results agreed well with GENE simulations [51]. Kong reported that the hydrogen–boron fusion reaction rate was increased for the slowing-down distribution of ions compared with the Maxwellian case [52].

Wei *et al* developed an eigenvalue code to calculate the frequency and parallel mode structure of AEs in general geometry, which was applied to predict continuous spectrum and toroidal AE structure for a divertor tokamak test (DTT) facility that was built at the ENEA Research Center in Frascati, Italy [53–55]. You *et al* studied the formation of ambipolar radial electric fields in random magnetic fields by the gyrokinetic code NLT. Zheng showed that 3D perturbations (e.g. ripple fields and TM) have a synergetic influence on fast-ion losses. When the amplitude of TM exceeded a threshold, the fast-ion transport and losses were determined by TM [56].

6. Turbulent transport

Shen presented the results of gyrokinetic simulations of KBM and showed that impurity plays a stabilizing role in KBMs when the impurity density profile peaks in the same direction as those of the electron and main ion density profiles. There were clear thresholds for the first and second KBM stable regions in the electron density gradient. Hu developed a new gyrokinetic PIC code TEK, which was benchmarked with the GENE code for the case of the ITG mode. Tan numerically investigated the turbulence on the spherical tokamak EHL-2. In the high-β region, KBM was the dominant electromagnetic microinstability. Zhao *et al* performed a nonlinear simulation of KBM turbulence using the global gyrokinetic code NLT [57]. The results show that as β increased, the turbulence transport level first decreased and then increased, corresponding to the suppression of ITG by finite β and the enhanced turbulence transport caused by KBM excitation.

Xie *et al* simulated the edge coherent mode (ECM) on EAST with the global gyrokinetic code GEM, which showed that ECM is an electrostatic electron mode with a dominant toroidal mode number of n = 18 and drives significant outward particle and heat fluxes, thus greatly promoting the maintenance of the long-pulse H-mode [58]. Li presented a 1D simplified model of dynamic critical gradient for studying the dynamics of transport barriers. The self-consistently evolving critical gradient weakens the profile stiffness and promotes the generation of transport barriers, such as ITBs. Li *et al* studied the influence of magnetic island width on the interaction between islands and ITG turbulence. The results indicate that the increase in island width enhanced the helical flow at the island boundary, which is consistent with earlier experimental observations on HL-2A [59]. Kong *et al* used the gyrokinetic electron and fully kinetic ion model to study parametric decay instability (PDI) in uniformly magnetized plasmas. It was found that PDIs heat electrons and ions in parallel and perpendicular directions, respectively [60]. Wang *et al* used the particle orbit tracing code (PTC) [61] to study the dynamics of runaway electrons (REs). The avalanche process induced by large-angle collisions between runway electrons and background electrons was presented [62, 63].

Wang *et al* studied the nonlinear excitation of ZFs in toroidal plasmas using the NLT code [57]. In the quasilinear stage, the ZFs are initially excited by the self-interaction of the eigenmodes [64]. However, in the nonlinear saturation stage, both the self-interaction and modulated instabilities are important. Zhang *et al* carried out the self-consistent simulations on coherent vortex flows in the magnetic island using a five-field gyrofluid model. The coherent vortex flows exhibited different parities along the radial direction, which can be explained by a theoretical model of nonlinear parity instability [65]. Xie presented the nonlocal thermal transport phenomenon triggered by multiple SMBI on the J-TEXT device. As the density gradually increased, the nonlocal transport weakened. After SMBI, the temperature increased in the core region, and the heat pulse propagated outward. Sun pointed out the importance of injection time of pellets for increasing plasma density based on CLT simulations [7]. When a pellet was injected after the growing of double tearing mode (DTM), the radial flow generated by the reconnection brought the injected particles to the core region. As a result, the plasma density significantly increased and exceeded the Greenwald limit without disruption in the simulation.

7. MHD instability

Porcelli showed that vertical displacement oscillatory modes, with a characteristic frequency close to the poloidal Alfvén frequency, can interact resonantly with energetic ions, giving rise to a new type of fast-ion instability with mode number n = 0. Li reported that the neoclassical toroidal viscosity (NTV) torque dominated in the total net torque for an ITER baseline scenario. The resonant and nonresonant parts dominated at low and high toroidal rotations, respectively [66]. Lu *et al* discussed the complex dependence of explosively growing reconnection rate of 3/1 DTM on plasma resistivity in different parameter regions. The distance between two 3/1 rational surfaces appears to be a key parameter [67].

Ma *et al* studied the dynamics of resistive internal kink modes in the runaway plasma of HL-2A using the extended 3D MHD code M3D-C1 [68, 69]. The study revealed that REs can linearly affect the growth rate scaling of resistive internal kink modes on resistivity. In addition, the presence of the runaway current led to a significant suppression of sawtooth oscillations, resulting in the loss of REs outside the q = 1 surface, with minimal impact on the majority of REs well confined within it. Zu reported that impurity radiation caused a decrease in plasma temperature in the edge, which led to the shrinking of the temperature and current profiles. Finally, TM related to the density limit destabilized at the q = 2 rational surface. Chen *et al* studied the ELM collapse process through both simulations and experiments. The CLT simulation results indicate that the peeling–ballooning instability in the pedestal region can generate magnetic islands, which may lead to the formation of a stochastic field region at the edge, which in turn triggers ELM collapse [70]. Huang *et al* simulated the nonlinear dynamics of type III ELM in an EAST experiment using BOUT++ [71]. When the parallel current and electric field were included, the time to achieve nonlinear stage of ELM was delayed, and the stored energy loss was significantly enhanced. Huang studied the nonlinear evolution and saturation of NTM by CLT. The poloidal asymmetry of the bootstrap current reduced the saturation level of NTM. The effects of magnetic curvature and Hall term on NTM were also discussed in the presentation.

Wang reported that the relationship between the linear growth rate and toroidal mode number can be used to roughly distinguish ballooning, peeling, and coupled peeling–ballooning modes. When the pressure gradient was fixed, the mode transitioned from ballooning to peeling–ballooning and then to peeling-dominated mode as the edge current and magnetic shear varied. Zhang numerically studied the effect of RMP on neoclassical transport of impurity using the NTVTOK code. When the diamagnetic drift exceeded the $\boldsymbol{E}\times\boldsymbol{B}$ drift frequency, the impurity particle flux induced by NTV pointed inward and vice versa [72]. Li reported that the Kelvin–Helmholtz instability coexists with the DTM through nonlinear mode coupling in the weak reverse magnetic shear configuration. Meng and Guo showed that in Kelvin–Helmholtz instabilities, the dynamic system is pseudo-Hermitian and undergoes a PT symmetry-breaking bifurcation, which can be interpreted as the spatial coupling and phase locking of vorticity waves. The transient growth near marginal stability was explained as non-Hermitian critical dynamics near exceptional points, where the eigenvectors are nonorthogonal and lead to nonmodal phase-slip dynamics of vorticity waves [73].

8. Integrated modeling and code development

Sang reported the progress of the developed numerical framework, which provides an effective platform for the systematic study of boundary physics and plasma–wall interactions [74]. Wang developed a neural network (NN) code that realizes fast integration modeling to study the compatibility between heat flux control and plasma confinement. Feng developed a module for calculating the damage cross section related to the irradiations induced by fusion neutrons and deuterium nucleus, which allows the prediction of material displacement per atom under irradiation. Chen developed a zero-dimensional D-^{3}He fusion analysis code HED to investigate the D-T fusion assisted ignition process of D-^{3}He fusion in tokamak through PID feedback control of the D:T:^{3}He density ratio. METIS simulations show that under the same plasma current, the volt-seconds provided by the solenoid were able to trigger ignition of the D-T fusion.

Zhang *et al* developed the INTFLUK code based on a nonlocal model. The code can mimic the mode conversion process from fast wave to ion Bernstein wave during ICRH [40]. Liu presented the progress of the development of MHD–kinetic hybrid code GMEC. The first version of this code has been completed and benchmarked. GMEC has been used to simulate the AE driven by alpha particles for CFETR. Li introduced a flexible workflow for a supercomputing system. Yu discussed the possibility of improving core plasma confinement by optimizing the electron cyclotron heating power scheme for the HL-3 hybrid scenario, based on the METIS integrated modeling.

Guo introduced an MHD-accurate particle hybrid code MAP, in which a structure-preserving algorithm was used to describe the dynamics of particles. Chen merged the PTC code into the OMFIT framework, which allows the modeling of neutral beam injection. The results from the integrated simulations were in good agreement with the workflow calculations using NUBEAM under the core plasma conditions for CFETR. Lu constructed and trained a deep NN for the predictions of equilibrium on EAST. The NN predictions showed good agreement with the results provided by EFIT [75]. Shi analyzed two different high-β_N discharges on HL-2A using the METIS code. The key quantity profiles (e.g. temperature and density) obtained from modeling agreed with the experimental measurements [76].

9. Poster section

In this section, 96 posters are presented to report the achievements in many topics in MCF. Several highlights are reported as follows. Hu *et al* developed the ATEC code to investigate the equilibrium with reversal current for advanced tokamak discharge. ATEC is a useful tool for the optimization of the equilibrium control coil current, design of divertor plates, MHD stability analysis, and transport studies [77]. Chen *et al* extended the CLT-EQ code to study the self-consistent equilibrium, including plasma toroidal rotation. It was shown that the Shafranov shift increased by ~$0.1a_0$ when the Mach number at the magnetic axis reached 0.2, where a_0 represents the minor radius of the plasma [78]. Lan *et al* designed and constructed a novel electromagnetic probe array (EMPA). Compared with the regular magnetic probe, EMPA strongly improved the measurement ability of the toroidal mode number n (up to $|n| \leqslant 112$) for magnetic fluctuation [79]. Yang *et al* investigated the effect of internal kink on beam fast-ion transport and loss for the 15 MA scenario of ITER. The internal kink mainly induced the redistribution of fast ions in the core region, but it almost did not lead to fast-ion loss (loss rate $< 0.1\%$) [80].

10. Conclusions

Significant progress has been made in several areas since the 10th CMCFTS [81]. Nonlinear gyrokinetic simulations have revealed the important role of ZFs in the formation of transport barriers and the impact of electromagnetic turbulence on confinement performance. A scheme for impurity injection and fueling with control of disruption was proposed. Many hybrid simulations have shown that the interactions between EPs and MHD instabilities may be important for fast-ion loss in future fusion devices. A considerable advance has been made in simulations of core–edge coupling, particularly for divertor detachment. Various fluid simulations have led to a deeper understanding of the physics of ELM control. Several advanced simulation codes have been developed and extended, including NLT, ExFC, CLT/CLT-K, TEK, PTC, MAS, and ATEC. These codes provide useful tools for exploring the frontier of plasma physics, with the goal of accelerating the realization of fusion energy. More presentations related to burning plasmas are expected at the next CMCFTS conference.

The 12th CMCFTS was held in Beijing on 24–27 May 2024, and the organizer was the School of Physics at Peking University.

Acknowledgments

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Data availability

The Chinese abstracts summarized in this conference report are available from the corresponding authors upon reasonable request.

Appendix. Organizing committee of the 11th Conference on Magnetic Confined Fusion Theory and Simulation

Co-executive chairmen

Guangzhou Hao, Youwen Sun, and Zhibin Guo

Organizing committee

Baonian Wan, Zhiwei Ma, Xiaogang Wang, Shaojie Wang, Zhengxiong Wang, Zhiyong Qiu, Lu Wang, Ge Zhuang, Youwen Sun, Qilong Ren, Ping Zhu, Ding Li, Jiquan Li, Jiangfeng Song, Wei Chen, Wenlu Zhang, Chijie Xiao, Yong Xiao, Zhihong Lin, Xuru Duan, Xiwei Hu, Nong Xiang, Guangzhou Hao, Xueqiao Xu, Zhe Gao, Tianyang Xia, Jiaqi Dong, and Guoyong Fu

Local committee

Xuru Duan, Wulyu Zhong, Shuo Wang, Linzi Liu, Ji He, and Fan Wu

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