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**Introduction to the Hangzhou International Stellarator Workshop (HISW2018)**

* **Purpose**

This is first such stellarator meeting in China. Currently significant programs of stellarator research are being initiated in China. The University of South China is importing H1-N stellarator from Australian National University. The Southwest Jiaotong University in Chengdu is planning construction of a new quasi-symmetric stellarator. Zhejiang University in Hangzhou has started a stellarator theory program aiming for design and building of a new innovative stellarator. To help with all the initiatives, we are organizing a 3-day international workshop on stellarator/heliotron during March 26-28, 2018. The location will be in the city of Hangzhou where Zhejiang University is located. Hangzhou is well known for her scenic attractions and is only one hour away from Shanghai by high-speed trains. The purpose of the workshop is two folds: a) Provide a platform for discussion of current research and future direction of stellarator/heliotron both within China and abroad; b) Introduce stellarator physics and design to interested researchers in China.

* **Topics**

**The Hangzhou International Stellarator Workshop (HISW2018):**

1. Introduction to stellarator/heliotron configurations;
2. Latest theoretical and experimental results;
3. New stellarator programs in China;
4. Future direction of stellarator research;
5. Stellarator design and prospect for stellarator reactors.
* **Conference form**

Invited reports, Oral reports

* **Local Organization Committee**

Guoyong Fu, Xiaoyu Fu, Jianing Li, Zhengmao Sheng

* **Sponsor**

Institute for Fusion Theory and Simulation, Zhejiang University

* **Venue**

Hangzhou Liutong Hotel (referred to as conference hotel in the agenda, 杭州六通宾馆)

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| **Agenda****The Hangzhou International Stellarator Workshop (HISW2018),** **March 26-28, 2018, Hangzhou, China** |
| **Sunday March 25th**  |
| 14:00-20:30 | Registration (Location: lobby of *Hangzhou Liutong Hotel*) |
| 17:30-19:30 | Reception with buffet dinner ( *Hangzhou Liutong Hotel*) |
| **Monday March 26th (first day of HISW) Venue: Jusi Hall of conference hotel, 2F, Bld. 3**  |
| 08:30-09:00 | Opening Ceremony |
|  | Overview session |
| **HISW sessionⅠ**(Chair: Liu Chen )  |
| 09:00-09:40 | **Allen Boozer** (Columbia University, USA), [IO]Stellarators |
| 09:40-:10:20 | **Thomas Sunn Pedersen** ( Max-Planck-Institute for Plasma Physics, Germany ), [IO]Overview on W7-X program |
| 10:20-10:50 | **Photo** session and coffee break |
| **HISW sessionⅡ** (Chair: Shoichi Okamura ) |
| 10:50-11:30 | **Tomohiro Morisaki** (National Institute for Fusion Science, Japan), [IO]First Deuterium Experiment in LHD over a Long History of the Heliotron Research in Japan |
| 11:30-12:10 | **David Thomas Anderson** ( University of Wisconsin, USA), [IO]Overview on HSX program |
| 12:10-13:30 | Buffet Lunch  **Venue: Tianfu Ju of conference hotel, 1F, Bld. 6** |
| **Afternoon session:** Towards Chinese Stellarator Program |
| **HISW session Ⅲ** (Chair: Thomas Pedersen ) |
| 13:30-14:00 | **Clive Michael** (Australian National University, Australia), [I]Research on the H-1 Heliac at the ANU in its differing operating phases |
| 14:00-14:30 | **Jinjia Cao** (University of South China, China ), [I]The progress of H1 stellarator relocation and the research plan in University of South China |
| 14:30-15:00 | **Guoyong Fu** ( Zhejiang University, China), [I]Design of quasi-axisymmetric stellarator and future plan |
| 15:00-15:30 | Coffee break |
| **HISW session Ⅳ**(Chair: David Anderson) |
| 15:30-16:00 | **[Shoichi Okamura](https://mail.zju.edu.cn/coremail/XT5/javascript%3Avoid%280%29)** ( National Institute for Fusion Science, Japan ), [I]History and scientific strategy from CHS experiment to CHS-qa program |
| 16:00-16:30 | **Yuhong Xu** ( Southwest Jiaotong University, China), [I]Progress on the design and construction of the joint project of the Chinese First Quasi-axisymmetric Stellarator (CFQS) |
| 16:30-17:00  | **Akihiro Shimizu** (National Institute for Fusion Science, Japan)Configuration design study of the Chinese First Quasi-axisymmetric Stellarator |
| 17:00-17:30  | **Haifeng Liu** ( Southwest Jiaotong University, China ), [I]Advanced Configuration and Coil System Design for Chinese First Quasi-axisymmetric Stellarator |
| 18:00 | **HISW banquet Venue: Tianfu Ju of conference hotel, 1F, Bld. 6** |
| **Tuesday March 27th (second day of HISW)** **Venue: Jusi Hall of conference hotel, 2F, Bld. 3** |
| **Morning session:** Stellartor design and optimization |
| **HISW sessionⅤ**(Chair: Guoyong Fu) |
| 08:30-09:00 | **David Gates** (Princeton Plasma Physics Laboratory, USA), [I]Recent Advances in Stellarator Optimization |
| 09:00-09:30 | **Michael Drevlak** (Max-Planck-Institut für Plasmaphysik (IPP),Germany), [I]Stellarator Optimisation: Equilibrium and Coils |
| 09:30-10:00 | **Stuart R. Hudson** ( Princeton Plasma Physics Laboratory, USA ), [I]Differentiating the coil geometry with respect to the plasma boundary |
| 10:00-10:30 | Coffee break |
| **HISW session Ⅵ**(Chair: Yuhong Xu) |
| 10:30-11:00 | **Donald A. Spong** ( Oak Ridge National Laboratory, USA ), [I]Energetic particle physics and optimization methods for stellarators |
| 11:00-11:30 | **Chris Hegna** ( University of Wisconsin-Madison, USA), [I]Identifying mechanisms to reduce ITG turbulent transport in stellarators |
| 11:30-12:00 | **Yasuhiro Suzuki** ( National Institute for Fusion Science, Japan ), [I]Design of new tokamak-stellarator hybrid |
| 12:00-13:30 | Buffet Lunch **Venue: Tianfu Ju of conference hotel, 1F, Bld. 6** |
| **Afternoon session:** Edge physics in stellarators and tokamaks |
| **HISW sessionⅦ** (Chair: David Gates) |
| 13:30-14:00 | **Yuhe Feng** (Max-Planck Institute for Plasma Physics, Germany), [I]Stellarator Edge Theory and Modeling |
| 14:00-14:30 | **Shuyu Dai** (Dalian University of Technology, China), [I]3D simulations of edge impurity flow obtained by the vacuum ultraviolet emission diagnostics in LHD with EMC3-EIRENE |
| 14:30-15:00 | **Allen Boozer** ( Columbia University, USA), [I]Stellarator Divertors |
| 15:00-15:30 | Coffee break |
| **HISW Session Ⅷ** Chair: Lu Wang |
| 15:30-16:00 | **Nengchao Wang** (Huazhong University of Science and Technology, China), [I]Preliminary research on the island divertor configuration by applying 3/1 RMP in J-TEXT |
| 16:00-16:30 | **Yonghua Ding** (Huazhong University of Science and Technology, China), [I]Recent RMP research in J-TEXT |
| 16:30-17:00 | **Tian Xie** (Dalian University of Technology, China), [I]EMC3-EIRENE numerical analysis of edge plasma and impurity emission in the liquid lithium limiter experiment on EAST |
| 17:00-17:30 | **Jie Huang** (ASIPP, China), [I]Magnetic field topology modeling under resonant magnetic perturbations on EAST |
| 17:30-19:30 | Buffet Dinner **Venue: Tianfu Ju of conference hotel, 1F, Bld. 6** |
| **Wednesday March 28th (third day of HISW) Venue: Jusi Hall of conference hotel, 2F, Bld. 3** |
| **Morning session**: stellarator experiment |
| **HISW session Ⅸ**(Chair: Xueyu Gong) |
| 08:30-09:00 | **Carlos Hidalgo** (CIEMAT, Spain), [I]On the interaction between neoclassical and turbulent transport in fusion plasmas |
| 09:00-09:30 | **Kazunobu Nagasaki** ( Institute of Advanced Energy, Kyoto University, Japan), [I]Recent Results from the Heliotron J Experiment |
| 09:30-10:00 | Coffee break |
| **HISW sessionⅩ**(Chair: Guoyong Fu) |
| 10:00-12:00 | Discussion on future direction of stellarator program in China and beyond |

**Introduction to Stellarators**

Supported by the U.S Department of Energy grant DE-FG02-01ER54624.

Allen H. Boozer

Columbia University

1. Why a poloidal field is required.
2. Ways the poloidal field can be produced.
3. Benefits of poloidal field production by external coils.
4. Poloidal field production.
5. Particle confinement in stellarators.
6. Important adiabatic invariants.
7. Controlling magnetic field strength to be quasi-symmetric. Controlling magnetic field strength to be quasi-isodynamic. Three types of stellarators that give enhanced particle confinement.

**Recent results and future plans for Wendelstein 7-X**

Thomas Sunn Pedersen1, for the W7-X Team.

Wendelstein 7-X (W7-X) went into operation in 2015 [1-4]. With a 30 cubic meter volume,

a superconducting coil system operating at 2.5 T, and steady-state heating capability of

eventually up to 10 MW, it was built to demonstrate the benefits of optimized stellarators at

parameters approaching those of a fusion power plant. Its most recent operation phase

(OP1.2a) featured the full complement of 10 divertor units, ECRH heating with up to 10

gyrotrons, more than 30 diagnostic systems, and a pellet fueling system. This talk will give

a general overview of the W7-X goals and capabilities, and describe some of the key

experimental results, eg. high density, (ne >1020 m-3), high ion temperatures (Ti=4 keV), long

pulse lengths (up to 26 seconds). These results will be put into a broader fusion perspective,

and an outlook towards the future operation phases OP1.2b and OP2 will be given.

[1] T. Klinger et al. Plasma Phys. Controlled Fusion 59(1) 014018 (2017)

[2] H.-S. Bosch et al., Nuclear Fusion 57, 116015 (2017)

[3] R. C. Wolf et al., Nuclear Fusion 57 102020 (2017)

[4] T. Sunn Pedersen et al., Physics of Plasmas 24 055503 (2017)

**First Deuterium Experiment in LHD over a Long History of the Heliotron Research in Japan**

Tomohiro Morisaki

National Institute for Fusion Science

Japan has a long history of the stellarator/heliotron research since 1950’s when the first heliotron was invented in Kyoto University. For more than half a century, the heliotron and its plasma performance have developed, aiming for the realization of the helical reactor. The LHD is an optimized heliotron succeeding to the traditional heliotron concepts, which explores the high performance steady-state plasma relevant to the burning plasma. Since last year, LHD has started the deuterium experiment to improve the plasma performance and explore the related physics, i.e., isotope effect, behavior of the high energy ions, etc..

In this conference, overview of the first deuterium experiment in LHD, together with the scientific history of the helical plasma research in Japan.

**Overview of the HSX Program**

David Anderson

HSX Plasma Laboratory, University of Wisconsin-Madison

HSX is the first experimental test of quasisymmetry employing a quasi-helically symmetric (QHS) field structure, and demonstrated many of the predicted benefits of quasisymmetry: reduced core neoclassical transport/improved particle heat and momentum transport, reduced direct orbit loss, lower drift of passing particles from magnetic surfaces, lower flow damping in the direction of symmetry and reduced Pfirsch-Schlüter and bootstrap currents, consistent with the high effective transform associated with quasi-helical symmetry. With suppressed neoclassical transport, turbulent transport is dominant in HSX. Experimental measurements are being compared to gyrokinetic calculations using the GENE code. The dominant contribution to transport comes from TEM turbulence, with heat flux comparable to calculations. A lack of stiffness in the profiles under the present operating conditions has been observed using the ECE system.

Work is underway to look at a possible follow on experiment for HSX. A key question is can we use shaping to lower ITG transport while maintaining good neoclassical properties? To focus on ion transport will require getting reduced charge exchange losses which will drive the experiment to higher densities and increased plasma radius. A QHS design will possess a moderate bootstrap current so the divertor design will need to be robust to variations in the rotational transform. The need for space for a divertor and to reduce high order ripple drives coils farther from the plasma. New codes are being employed to address this property.

**Research on the H-1 Heliac at the ANU in its differing operating phases**

Clive Michael

Australian National University

In this talk I will present a selection of the results obtained from H-1 over its 25 year operation at the ANU, focusing mainly, but not only, on my own contributions. This is with a view to seeding some discussion on the topics of future research based on H-1, both theoretically and experimentally, including in the commissioning phase of operation at USC before the full capability of magnetic field and heating power is realized. H-1 was originally heated with a magnetron source, then used extensively with Argon working gas with helicon heating at 7MHz and low field (0.1T), followed by H/He minority ion-cyclotron resonance heating at 0.5T, and each phase has revealed a different set of results. A rotatable array of wires crossing the plasma volume to detect and map electron beams has been invaluable in obtaining error fields and refining the coil filament model, and will be vital in first commissioning at USC to verify coil placement after transportation from Australia.

H-1 has the freedom for adjusting the iota profile. In Hydrogen discharges, Alfven waves are observed and identified by adjusting iota, and their dispersion relations and coupling to the sound-continuum will be discussed. The CAS3D code has been used to model these wave-modes and a few select theory/experiment comparisons have been made. The configuration flexibility has also been used to investigate the formation of static magnetic islands including the 4/3 near the edge, and 3/2 resonance at the plasma core. More broadly, plasma stability near rational surfaces can be investigated, exploiting a second configurational control over the magnetic well profile for varying the MHD stability. Moveable probe arrays have been used to characterize fluctuation-induced flux as well as the structure and dispersion of turbulence, including the so-called “long-range” correlations in potential representative of zonal flows. In Argon discharges, zonal flows were detected and their role was demonstrated in transport-barriers and L-H confinement transitions. Initial experiments on electrode biasing to drive flows were carried out. However, the use of LaB6 electron emitter would avoid impurity accumulation from ion sputtering and if successful would test neoclassical flow damping theory and investigate the influence of islands on flows. Research in RF-heating has focused on imaging propagating waves, revealing a surface wave characteristic of the slow wave. A new antenna design was also tested recently in collaboration with Kharkov Institute in Ukraine. Flux-surface asymmetries produced by localized heating have also recently been observed and their role on plasma stability investigated. Ion temperature and flows in Argon discharges were also measured using the so-called “coherence imaging” technique and revealed both cold charge-exchange neutral components as well as tails associated with RF heating, however such studies have not substantially been carried out in H/He discharges and would enable a detailed study of IRCH heating.

By revisiting old work and embarking on new directions, no doubt new results could be obtained and thereby train a new generation of Chinese scientists in Stellarator-specific issues of fusion science and engineering.

**The progress of H1 stellarator relocation and the research plan in University of South China**

X. Gong, J. Cao\*, X. Lu, D. Xiang, D. Du, P. Yang, X. Li and Fusion and Plasma Physics Innovation Team

*School of Nuclear Science and Technology, University of South China, Hengyang 421001, P. R. China*

 The H1-NF heliac [1] in the Australian National University (ANU) will be relocated to the University of South China (USC) this year. This will be the first stellarator in China. The buildings that accommodate the H1 and its auxiliary systems have been completed. The disassembly of H1 was completed in 2017 and the transport will start soon. This year the H1 will be reinstalled successfully and the first plasma will also be achieved. High power RF system with frequency range 4-22MHz will be equipped. A research plan is presented in the USC. At first, the relation between magnetic configuration and power supply needs to be investigated so as to optimize the magnetic field and upgrade the electric grid. The heating efficiency of ICRH and plasma confinement are the second aspect. Thirdly, the experiments on the plasma confinement, flow, and magnetic configuration control will be proceeded based on the research works of scientists in ANU. Turbulence transport, magnetic island induced transport and the Alfven-like instabilities will be important subjects. We will also perform some experiments and compare the results with those in tokamak. In the future, we will upgrade the H1 stellarator and design a new machine.

References

[1] S. M. Hamberger *et al.*, Fusion Technol. **17**, 123 (1990).

**Design of Quasi-Axisymmetric Stellarators: Recent Results and Future Plan**

G. Y. Fu1, Z. C. Feng1, D. A. Gates2, M. Landreman3, S. A. Lazerson2, N. Pomphrey2,

*1. Institute for Fusion Theory and Simulation, Zhejiang University, Hangzhou, China*

*2. Princeton Plasma Physics Laboratory, Princeton, NJ, 08540, USA*

*3. University of Maryland, College Park, Maryland, USA*

Quasi-symmetry is a powerful concept for improving neoclassical transport of stellarators. Here we report recent results of optimization of Quasi-Axisymmetric Stellarator (QAS) using STELLOPT code. Key parameter space is explored for existence of QAS configurations with good confinement and stability properties. Key shaping parameters include aspect ratio, elongation, external rotational transform, plasma beta and bootstrap current. A parameter scan of elongation for a 3 period QAS with A=6 aspect ratio shows the existence of good configurations with low neoclassical transport, good kink stability and self-consistent bootstrap current at finite beta. A scan of external iota shows the existence of good configurations with low to high external iota. Reasonable configurations are also possible with monotonically increasing iota profiles leading to enhanced tearing mode stability. Detailed numerical results of the parameter exploration as well as future stellarator research plan at IFTS will be presented.

**History and scientific strategy from CHS experiment to CHS-qa program**

Shoichi Okamura

National Institute for Fusion Science

CHS experiment started at 1988 as a satellite machine to the NIFS main experimental program of LHD. It was about ten years before the LHD experiment started. The main scientific target of designing CHS device was to confirm the plasma confinement performance in stellarator with very low aspect ratio. Another motivation of the program was to implement as many kinds of plasma diagnostics as possible for investigating their usefulness and power in stellarator experiments. After completing initial experimental achievements (high beta experiments, plasma flow and electric field measurements, transport studies with various heating schemes, etc.), a new design work for CHS-qa device started at 1996 in parallel to continue CHS experiments. The main emphasis of CHS-qa device design was to make the aspect ratio lower than CHS. The improvement of neoclassical transport was another important feature, which was not pursued in CHS device design. The spirit of CHS experiment to CHS-qa device design is now revives in NSJP joint project for CFQS device.

**Progress on the design and construction of the joint project of the Chinese First Quasi-axisymmetric Stellarator (CFQS)**

Yuhong Xu

Southwest Jiaotong University

The Chinese First Quasi-axisymmetric Stellarator (CFQS) is an internationally collaborative project, which will be jointly designed and constructed by Southwest Jiaotong University (SWJTU) in China and the National Institute for Fusion Science (NIFS) in Japan.

In this presentation, the scientific background and motivation as well as the scientific mission of the joint CFQS project will be generally explained. The current status on the progress of the design and manufacture of the CFQS, including the spec and major parameters of the device, will be presented. An estimated time schedule for the CFQS construction and initial operation will be given along with possible technical challenges and difficulties.

**Configuration design study of**

**the Chinese First Quasi-axisymmetric Stellarator**

Akihiro Shimizu

National Institute for Fusion Science

The Chinese First Quasi-axisymmetric Stellarator (CFQS) is a future quasi-axisymetric (QA) stellarator device, which will be constructed in Southwest Jiaotong University (SWJTU) in China. This is the international joint project of National Institute of Fusion Science in Japan and SWJTU, and its design work has been continued jointly. A QA stellarator has mainly axisymmetric magnetic field components in the special magnetic coordinates (Boozer coordinates), which determine the guiding centre orbit, therefore, the neoclassical properties of the QA stellarator are similar to tokamak although inductive current is not required. About ten years ago, CHS-qa, has been designed as a post CHS device, which is a low aspect ratio (~3.2) QA stellarator. Based on this design, new configuration for the CFQS is obtained. The present parameters of the magnetic field strength, the major radius, the aspect ratio, and the toroidal periodic number are 1.0 T, 1.0 m, 4.0, and 2 respectively. The 16 modular coil system is optimized by the NESCOIL code for this configuration. By using this coil system, the free boundary equilibrium calculation by the VMEC is conducted, and the Shafranov shift and bootstrap current are estimated. The bootstrap current reaches 30 kA at ~1.5 %, and the QA characteristics and the good neoclassical transport properties are maintained up to this . For the flexibility of the magnetic field configuration, 3 pairs of poloidal field coils are considered. The Shafranov shift is suppressed by the vertical field produced by those coils.

**Advanced Configuration and Coil System Design for Chinese First Quasi-axisymmetric Stellarator**

Haifeng Liu

Southwest Jiaotong University

The quasi-axisymmetry is one type of omnigenous configurations, in which the radial guiding-center drift and neoclassical viscosity are significantly optimized. The Chinese First Quasi-axisymmetric Stellarator (CFQS) is an internationally collaborative project between Southwest Jiaotong University in China and National Institute for Fusion Science in Japan. The CFQS combines the advantageous features of optimized stellarators and advanced tokamaks. The candidate parameters of CFQS are that the major radius is 1.0 m, the toroidal magnetic field strength is 1.0 T, the toroidal periodic number is 2 and the aspect ratio is 4.0. The 16 modular coil system has been optimized and designed. With this optimized modular coil system, VMEC free boundary calculation is carried out to estimate the beta limit of MHD equilibrium. Mercier stability, ballooning stability and neoclassical transport are calculated to evaluate the property of CFQS configuration. The MHD equilibrium of configuration is almost stable up to beta = 1%. The neoclassical transport in the CFQS is less than that in the W7-X in 1/ regime.

**Recent Advances in Stellarator Optimization**

David Gates

Princeton Plasma Physics Laboratory

A multi-institutional study aimed at mapping the space of quasi-axisymmetric stellarators has begun. The goal is to gain improved understanding of the dependence of important physics and engineering parameters (e.g. bootstrap current, stability, coil complexity, etc.) on plasma shape (average elongation, aspect ratio, number of periods). In addition, the stellarator optimization code STELLOPT will be upgraded with new capabilities such as improved coil design algorithms such as COILOPT++ and REGCOIL, divertor optimization options, equilibria with islands using the SPEC code, and improved bootstrap current calculations with the SFINCS code. An effort is underway to develop metrics for divertor optimization. STELLOPT has also had numerous improvements to numerical algorithms and parallelization capabilities. Simultaneously, we also are pursuing the optimization of turbulent transport according to the method of proxy functions. Progress made to date includes an elongation scan on quasi-axisymmetric equilibria and an initial comparison between the SFINCS code and the BOOTSJ calculation of bootstrap current currently available in STELLOPT. Further progress on shape scans and subsequent physics analysis will be reported. The status of the STELLOPT upgrades will be described. The eventual goal of this exercise is to identify attractive configurations for future US experimental facilities..

**Stellarator Optimisation: Equilibrium and Coils**

M. Drevlak

Max-Planck-Institut für Plasmaphysik (IPP)

A viable stellarator reactor design must combine a range of properties, including good fast-particle confinement, acceptable neoclassical transport, high MHD stability limits and a potential for reasonably simple coils.

Designs of this type are commonly obtained in a two-stage approach, in which first an equilibrium featuring aforementioned properties is sought. Once such an equilibrium has been selected, coils are designed in the scope of a separate optimisation campaign.

The ROSE code was developed for optimising the equilibria of stellarators. It uses VMEC [1] and VM2MAG for calculating equilibria and the field in Boozer coordinates [2], and applies a range of different optimisers in order to optimise the plasma boundary.

Once a promising equilibrium has been identified, coils are designed using the ONSET suite of codes.

Optimisation results for quasi-axisymmetric, quasi-isodynamic and for quasi-helically symmetric configurations are presented.

**Differentiating the coil geometry with respect to the plasma boundary**

Stuart Hudson

Princeton Plasma Physics Lab.

The task of designing the geometry of a set of current-carrying coils that produce the magnetic field required to confine a given plasma equilibrium is expressed as a minimization principle, namely that the coils minimize a suitably defined error expressed as a surface integral, which is recognized as the quadratic-flux. A penalty on the coil length is included to avoid pathological solutions.

A simple expression for how the quadratic-flux and length vary as the coil geometry varies is derived, and an expression describing how this varies with variations in the surface geometry is derived. These expressions allow efficient coil-design algorithms to be implemented, and also enable efficient algorithms for varying the surface in order to simplify the coil geometry.

**Energetic particle physics and optimization methods for stellarators**

Donald A. Spong

Oak Ridge National Laboratory

In the design of future stellarators, energetic particle (EP) physics issues will be critical for the achievement of efficient heating, wall protection and, in the case of reactors, ignition margin. EP issues include: classical orbit confinement during slowing-down, EP-driven instabilities, EP transport, and wall loading. These topics can be addressed either in the initial device optimization, through various control actuators, or by the choice of plasma operational regime. While EP physics is crucial to the future success of stellarator reactors, it remains an area that has been insufficiently optimized in most existing devices. A variety of modeling tools and optimization target functions have been developed for 3D configurations. This talk will review these tools and the optimization approaches, describe the available methods for analyzing EP physics in stellarators, and suggest techniques for optimizing both the design and operational regimes of future devices for EP physics.

**Identifying mechanisms to reduce ITG turbulent transport in stellarators**

Chris Hegna

University of Wisconsin –Madison

A theory for turbulent saturation is developed for ion temperature gradient (IG) induced turbulent transport in stellarator configurations. The theory relies on the paradigm of nonlinear transfer of energy from unstable to damped modes at comparable wavelengths as the dominant saturation mechanism. The unstable-to-damped mode interaction is enable by a third mode that for dominant energy transfer channels primary serves as a regulator of the nonlinear energy transfer rate. Quantification of the nonlinear energy transfer physics is given by the product of a turbulent correlation lifetime and a geometric coupling coefficient, which are computed from properties of the linear eigenmodes. Larger turbulent correlation times denote larger levels of nonlinear energy transfer and correspondingly smaller turbulent transport. The theory provides a prediction for how 3D shaping can be used to lower turbulent transport.

**Design of new tokamak-stellarator hybrid**

Yasuhiro Suzuki

National Institute for Fusion Science

The tokamak is in principle the axisymmetric configuration, which has good confinement properties. However, since the plasma current is necessary, the current driven instability and the disruption are critical problems. In addition, for the H-mode, the edge localized mode (ELM) appears on the pedestal. The high-energy flux driven by the ELM damages the divertor and the operation to mitigate and suppress the ELM is widely studied in many tokamak experiments. On the other hand, the stellarator is intrinsically three-dimensional magnetic configuration. Because of the 3D magnetic field, the transport property is not good comparing with the tokamak. However, the stellarator has many advantages for the steady state operation, stable detachment, and so on. So, if we can design the new configuration, which has good properties of the tokamak and stellarator in both. In this talk, we will discuss a new tokamak-stellarator hybrid configuration. This configuration focuses the good core confinement based on the tokamak and also the 3D plasma boundary to make close flux surfaces from the stellarator field.

**Stellarator Edge Theory and Modeling**

Yuhe Feng

Max-Planck Institute for Plasma Physics

Plasma edge physics for stellarators is characterized by interplay of multiple physics processes of various spatial and temporal scales in a 3D setting, where magnetic fields and plasma-facing components usually exhibit complex structures, necessitating appropriate 3D numerical tools. The EMC3-Eirene code is one such tool, which was initially developed for the W7-AS island divertor and has become a work horse worldwide for 3D edge problems encountered not only in stellarators but also in tokamaks and even in linear devices. This paper presents a brief overview of EMC3-Eirene modeling activities on stellarators, major achievements, model limitations, code-development progress, and remaining challenges.

**3D simulations of edge impurity** **flow obtained by the vacuum** **ultraviolet emission diagnostics in LHD with EMC3-EIRENE**

Shuyu Dai

*Dalian University of Technology*

The edge impurity flow in the stochastic layer of the Large Helical Device (LHD) has been investigated with the three-dimensional (3D) edge transport code EMC3-EIRENE. The detailed analysis of the impurity flow directions obtained by the vacuum ultraviolet (VUV) spectrometer system has been performed by studying the 3D magnetic field structure and the parallel impurity flow velocity. The synthetic impurity flow profile obtained by EMC3-EIRENE shows a reasonable agreement with the VUV emission measurements for the present set of plasma parameter. The up-down asymmetry of the chord-integrated velocity of the impurity flow observed by the VUV spectroscopic measurements can be interpreted by the EMC3-EIRENE modelling. The transport behaviour of the edge impurity flow with different magnetic field structures is studied based on the recent development of computational grids. The horizontally outward shift of the magnetic axis position leads to a change of the distribution of the impurity flow velocity, which is induced by the variation of the edge plasma flow pattern under different magnetic field structures. Further, the impact of the plasma parameters on the edge impurity flow is studied, which shows that the impurity flow velocity is strongly affected by the force balance between thermal force and friction force.

**Stellarator Divertors**

Work supported by the US DoE grants DE-FG02-95ER5433 to Columbia University and DE-FG02-01ER54624 and DE-FG02-04ER54793 to Hampton University. The research used NERSC resources, supported by the Office of Science under Contract DE-AC02-05CH11231.

Allen H. Boozer, Columbia University and Alkesh Punjabi, Hampton University

1. Divertors versus Limiters
2. Divertors defined by Catori
3. Perturbed Axisymmetric Divertors
4. Resonant Stellarator Divertors
5. Non-resonant Stellarator Divertors

**Preliminary research on the island divertor configuration by applying 3/1 RMP in J-TEXT**

Nengchao Wang

IFPP, HUST (International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, Huazhong University of Science and Technology)

Been proposed first in 1977 for tokamak, the island divertor configuration hasn’t been realized in a tokamak yet. Instead, successfully island divertor configurations have been established in various stellarators, such as, W7-AS, LHD and recently in W7-X, etc, leading to the impurity screening effect and the heat flux reduction on the target.

In the recent campaign of J-TEXT tokamak, an experimental attempt have been made to from an island divertor configuration. An edge 3/1 island has been excited by applying the resonant magnetic perturbation (RMP) with dominate m/n = 3/1 component to a plasma with edge safety factor qa >~ 3. The 2/1 component of external RMP fields was kept at a low level to avoid exciting large 2/1 locked mode. Once the 3/1 island has been excited, the radial and poloidal profiles of the floating potential, the intensity of CIII radiation, the edge toroidal rotation varied significantly. The poloidal profiles of the floating potential measured at the limiters, varied during the formation of 3/1 island, indicating the impact of the 3/1 island on the footprints.

In addition, the preliminary design for building a set of island divertor coils utilizing 4/1 island will also be discussed.

**Recent RMP research in J-TEXT**

Yonghua Ding

IFPP, HUST (International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, Huazhong University of Science and Technology)

**EMC3-EIRENE numerical analysis of edge plasma and impurity emission in the liquid lithium limiter experiment on EAST**

Tian Xie

*Dalian University of Technology*

The studies of the edge plasma and impurity transport in the liquid lithium limiter (LLL) experiment on EAST have been performed by the three-dimensional (3D) edge transport code EMC3-EIRENE. The transport behavior of the Li1+ and Li2+ ions shows a clear 3D effect in the toroidal direction while an axisymmetric distribution is obtained for the Li3+ ions. The detailed study of the Li distribution has been performed by the field line tracing technique, which indicates that Li ions with different charge states possess a different parallel transport in relation to the magnetic configuration. The 3D line-integrated lithium emission pattern shows a reasonable agreement with the experimental results of the Li-I (red spectrum) and Li-II (green spectrum) emission distributions, which are measured by the CCD camera on EAST. The distribution of the lithium impurity source eroded from the LLL is investigated to evaluate its influence on the 3D line-integrated lithium emission distribution. An unresolved question in the LLL experiment is that the species emitting the strong visible spectrum observed around the divertor regions cannot be distinguished by the current experimental diagnostics on EAST. The detailed numerical analysis of the carbon and deuterium emission has been carried out to resolve this issue. The simulated strong emission by deuterium is in good agreement with the experimental observation around the divertor regions, and hence, it can be speculated that the strong visible spectrum is mainly attributed to the deuterium emission.

**Magnetic field topology modeling under resonant magnetic perturbations on EAST**

Huang Jie

ASIPP

The standard tokamak H mode, characterized by the formation of transport barrier at the edge of the plasma, is foreseen as the baseline operating scenario of ITER and other future reactors. However, as another consequence, a steep plasma pressure gradient and associated increased current density at the edge pedestal could exceed a threshold value to drive edge localized mode (ELMs). The ELMs can release large amounts of particles and heat flux to the plasma facing components, which will damage the divertors and other plasma facing components. Therefore, the ELMs control becomes a key issue in tokamak fusion reactor research. The Resonant magnetic perturbations (RMPs), expected as one of the useful candidates for the control of ELMs size in H-mode plasma, have been installed for EAST in 2014. To understand physical mechanism, magnetic topology study in ELMs mitigation phase is a critical issue. In this talk, we developed a field line tracing code to model three-dimensional magnetic field topology under RMPs on EAST. During the application of n=1 RMP in ELMs H mode experiment, the stronger nonlinearity appears to mitigate ELMs on phase of RMP filed. The strong mitigation and suppression correlates to vacuum modeling, and the weak mitigation case correlates to screening effects of ideal plasma response modeling.

**On the interaction between neoclassical and turbulent transport**

**in fusion plasmas**

Carlos Hidalgo

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With the advent of neoclassically optimized stellarators, optimizing stellarators for turbulent transport is a key next step. It is now recognized that neoclassical and turbulent transport channels are not decoupled in magnetically confined plasmas, coupling that should be considered in the optimization criteria. This presentation is devoted to discuss the interplay between neoclassical and turbulent mechanism on the physics of zonal flows and turbulence spreading.

Zonal flows and neoclassical radial electric fields. The influence of long-scale length radial electric field (Er) components on Zonal Flow-like structures (ZFs) has been reported in the TJ-II stellarator [1]. The mechanisms underlying the observed interplay between neoclassical radial electric fields and the amplification of low frequency zonal flow-like structures are at present under investigation, considering a) that sheared electric fields are efficient turbulence symmetry-breaking mechanism, amplifying the Reynolds stress drive of zonal flows, b) that radial electric fields give rise to Er x B drifts that prevent locally trapped particle orbits from drifting radially, reducing the effective damping of zonal flows. Recent simulations point out the synergetic role of electric fields driven by ion orbit losses and ZFs dynamics to trigger mechanisms of the L-H transition [2] which experimental validation is progress in TJ-II [3].

Turbulence spreading and sheared radial electric fields. Clarifying whether the Scrape-Off-Layer (SOL) width is dominated by local effects at the SOL region or/and by anomalous transport driven in the plasma edge is a relevant question. The influence of edge sheared radial electric fields, present in the proximity of the Last Closed Flux Surface in all fusion devices, on radial transport of turbulent energy has been investigated in the plasma boundary region of the TJ-II stellarator. Control modulation of edge sheared radial electric fields strongly impacts the level of turbulence spreading in the SOL. It is concluded that ErxB sheared flows, reaching shearing rates comparable to the inversed of the turbulence correlation time, can be an important tool not only to suppress turbulence but also to decouple the edge and SOL regions since it reduces the impact of nonlocal effects (turbulence spreading) [4].

[1] U. Losada et al., PPCF 58 (2016) 8

[2] C S Chang et al., PRL 118 (2017) 175001

[3] R. Gerrú et al., Master Thesis (2018)

[4] G. Grenfell et al., PRL (2018) to be submitted

**Recent Results from the Heliotron J Experiment**

Kazunobu Nagasaki

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The Heliotron J device is a medium-sized plasma experimental helical device based on the helical-axis heliotron concept, aiming at studying drift optimization by a combination of dominant magnetic Fourier harmonics including toroidicity, helicity and bumpiness in the Boozer coordinates. Particle confinement and neoclassical transport are reduced by using a bumpiness component, and the magnetic well is formed in the whole region. The main device parameters are the plasma major radius R = 1.2 m, the averaged minor radius a = 0.1–0.2 m, the rotational transform /2= 0.3–0.8 with weak magnetic shear, and the maximum magnetic field strength on the magnetic axis, B = 1.5 T. The coil system is composed of an L = 1, M = 4 helical coil, two types of toroidal coils A and B, and three pairs of vertical coils. Combination of these coils allows us to scan the magnetic configuration widely, making it possible to investigate the magnetic configuration effect. We will present experimental results on confinement, transport and MHD stability, especially confinement improvement, transport barrier, bootstrap current, toroidal rotation, confinement of energetic particles and electron cyclotron current drive.

**List of participants**

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* **Payment**

Registration fee can only be paid in ***Cash*** on-site.

Domestic Participants International Participants

Regular CNY ￥800 US$120

* **Transportation**

***Pudong International Airport***, Shanghai to ***Hangzhou Liutong Hotel*** (杭州六通宾馆), Hangzhou:

A. 1) Take **Metro Line 2**（地铁2号线）(recommended) or Airport Express Line 1（机场巴士1号快线）from **Pudong International Airport** to **Hongqiao Railway Station (**虹桥火车站**).** (1.5 -2 hrs）.

2) Take High-speed Rail（高铁）from **Hongqiao Railway Station** to **Hangzhou Railway Station**（杭州火车站）. (40 mins) Take a taxi from **Hangzhou Railway Station** to **Hangzhou Liutong Hotel**. (15 mins).

B. Take airport bus from **Pudong International Airport** to **Huanglong tourist distributing center** (黄龙旅游集散中心) (3.5 hr), and then take a taxi to **Hangzhou Liutong Hotel**. (15 mins).

***Xiaoshan International Airport***（萧山国际机场）, Hangzhou to ***Hangzhou Liutong Hotel****(*杭州六通宾馆):

Take a taxi to the hotel. (1hr).

***Hangzhou East Railway Station***(杭州火车东站) to ***Hangzhou Liutong Hotel****(*杭州六通宾馆):

Take Metro Line1(地铁1号线) from **Hangzhou East Railway Station** to **Longxiangqiao Station** (龙翔桥站)**.**（15 mins）Take a taxi from **Longxiangqiao Station** to **Hangzhou Liutong Hotel**. (20-30 mins)

* **Accommodation**

***Hangzhou Liutong Hotel*** (杭州六通宾馆)

Address：149 Santaishan Road, Westlake District, Hangzhou, Zhejiang, China (conference site) 杭州市西湖区三台山路149号(近高丽寺法相巷)

Price: ￥500 (~$78) per night (discounted) for Standard Room.

 ￥650 (~$101) per night (discounted) for Single Room.

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* **Map**

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