

PRINCETON PLASMA PHYSICS LABORATORY

**WEEKLY** highlights



**The PPPL Highlights for the week ending July 17, 2015, are as follows:**

#### **U.S. ITER FABRICATION (D. JOHNSON):**

Work continues on developing Piping and Instrument Diagrams (P&ID) for US ITER diagnostics. To date, P&IDs have been started for all US ITER diagnostics except MSE. As building construction proceeds, an important follow-on activity is identifying building interfaces such as cable trays, penetrations, and cubicle space. "Single Line Diagrams" (SLDs) and preliminary cable lists are being requested by the IO on a floor-by-floor basis to support building design. Cabling information for tokamak complex floor level B1 was submitted in June.

Optical testing of the prototype retroreflector for the ITER TIP diagnostic began this week, using a visible laser with small mirrors glued to the aluminum facets. It was confirmed that the components could be repeatedly assembled with reproducible optical performance. Also demonstrated was optical 'tuning' of the assembly through removal of a small amount of aluminum from the contact pads at the component joints.

IO reviewer comments on the DRGA load spec were received this past week. New issues were raised that were not included in the previous submittal nor were listed as chits in the FDR-1 document.

#### **NSTX (M. ONO):**

The paper, "Coupling of Neutral-Beam-Driven Compressional Alfvén Eigenmodes to Kinetic Alfvén Waves in NSTX Tokamak and Energy Channeling" by E. V. Belova (PPPL) et al., was published in Phys. Rev. Lett. 115, 015001 (2015). An energy channeling mechanism is proposed to explain flattening of the electron temperature profiles at high beam power in beam-heated National Spherical Torus Experiment (NSTX). Results of first self-consistent simulations of neutral-beam-driven compressional Alfvén eigenmodes (CAEs) in NSTX demonstrate strong coupling of CAE to kinetic Alfvén wave (KAW) at the Alfvén resonance location. Three-dimensional, nonlinear hybrid MHD-particle simulations for the H-mode NSTX discharge (shot 141398) show unstable CAE modes for a range of toroidal mode numbers,  $n=4-9$ , and frequencies below the ion cyclotron frequency. It is found that the essential feature of CAE modes in the NSTX is their coupling to kinetic Alfvén wave (KAW) that occurs on the high-field side at the Alfvén resonance location. Nonlinear simulations demonstrate that CAE can channel significant fraction of the beam power, up to  $P=0.4\text{MW}$ , to the location of the resonant mode conversion at the edge of the beam density profile, modifying the energy deposition profile.

The paper, “Impact of ELM filaments on divertor heat flux dynamics in NSTX” by J-W. Ahn (ORNL) et al. was published in Journal of Nuclear Materials 463 (2015) 701 – 704 (<http://www.sciencedirect.com/science/article/pii/S002231151400926X>). This paper describes findings in the behavior of wetted area ( $A_{wet}$ ) and peak heat flux ( $q_{peak}$ ) of divertor heat flux, induced by naturally occurring ELMs in NSTX. More ELM filaments in the heat flux profile are found to lead to larger  $A_{wet}$  and lower  $q_{peak}$ . The typical number of filaments observed in NSTX is 0–9, while 10–15 are normally observed in other machines such as JET, and the ELM contracts heat flux profile when the number of filaments is less than 3–4 but broadens it with more of them. The smaller number of filaments in NSTX is attributed to the fact that NSTX ELMs are against kink/peeling boundary with lower toroidal mode number ( $n = 1-5$ ), while typical peeling–ballooning ELMs have higher mode number of  $n = 10-20$ . For ELMs with less filaments, relative  $A_{wet}$  change is rather constant and  $q_{peak}$  change rapidly increases with increasing ELM size (total power ejected by the ELM), while  $A_{wet}$  change slightly increases leading to a weaker increase of  $q_{peak}$  change for ELMs with more filaments.

Ed Magee from Lawrence Livermore National Laboratory visited NSTX-U this week for the installation of LLNL extreme ultraviolet spectrometers. Two of the three spectrometers (XEUS, X-ray and Extreme Ultraviolet Spectrometer and MonaLisa, Metal Monitor and Lithium Spectrometer Assembly) have been installed. The third spectrometer (LoWEUS, Long Wavelength Extreme Ultraviolet Spectrometer) will be installed in the coming weeks. The LLNL on-site staff (Michael Weller and Vlad Soukhanovskii) assisted in installation. The three spectrometers provide simultaneous spectral coverage for low-Z, medium-Z and high-Z impurity studies and wall condition monitoring in NSTX-U.

Welding of the Divert or Tangential Imaging assembly is complete, and leak checking is in progress. Outer TF Rogowski coil supports are complete and have been successfully test fit to the Rogowski coil. G-10 and aluminum components for the Bay H IR Camera bracket are complete.

Alignments of the Multi-Pulse Thompson Scattering (MPTS) diagnostic flight paths continued, and details of the two respective Nd:YAG focii have been recorded via video. Fibers for the Beam Emission Spectroscopy (BES) diagnostic are being assembled in their holders.

OH system rework and machine reassembly activities continued this past week. Installation of upper and lower TF flex bus and potting of TF fingers continues along with the associated resistance checks. Joint resistance measurements are being compared to ANSI models as appropriate.

## **ITER & TOKAMAKS (R. HAWRYLUK):**

### **DIII-D (R. Nazikian):**

R. Nazikian visited ASDEX-U to collaborate with Wolfgang Suttrop and Andrew Kirk in a joint experiment with DIII-D on RMP ELM mitigation and suppression with rotating magnetic perturbations. He also presented a seminar on the physics of pedestal bifurcation driven by resonant magnetic fields on DIII-D.

Madeline Vorenkamp worked with W. Brown to begin fabrication for the second Neutral Beam Control System (NBLCS5). They have machined several panels and brackets, which have since been installed in the LCS cabinet. Wiring is set to begin the week of July 20.

### **C-Mod (R. Hawryluk):**

C. Kessel led an experiment on C-Mod to examine ELMy H-modes in He, as part of joint experiment in the ITPA IOS, in order to help inform ITER on their He H-mode operations. The discharges obtained highly regular ELMs utilizing the JFT-2M shape, varying the pre H-mode density from  $0.85\text{-}2.0 \times 10^{20} / \text{m}^3$ , and ICRF injected power from 1.5-4.0 MW. Density was found to be the most sensitive parameter in accessing long sustained ELMy phases, with high densities producing large isolated ELMs capable of H-L transitions, and low densities tending to smaller highly regular ELMs that could affect the ICRF but remained in H-mode. Tungsten laser blow off and N<sub>2</sub> seeding were done. The differences between these He and D ELMy H-modes will be identified.

The Lodestar collaboration seeks to understand the relationship between mean flow velocities and fluctuation (blob) velocities, and to understand the saturation mechanisms for the edge turbulence on Alcator C-Mod. A series of 2D SOLT turbulence code simulations have been compared with an L-mode discharge (#1120711021). Density and temperature profiles for the simulations were obtained by smoothly fitting Thomson scatter and mirror Langmuir probe (MLP) data from the shot. Simulations differing in turbulence intensity were obtained by varying a dissipation parameter. Density fluctuation amplitudes computed in a neighborhood of the separatrix were consistent with those measured by MLP in the experiment. Blob velocities in the simulations were determined from the correlation function for density fluctuations, as in the analysis of gas-puff-imaging (GPI) blobs in the experiment. A comparison of the blob velocities in the simulation with the measured GPI correlation velocities is in progress. We have also investigated the saturation mechanisms operative in the simulation of the discharge. There is evidence that profile modification (wave breaking) and stabilization by sheared ExB flow are both at work as saturation mechanisms, with wave-breaking increasingly important as the amplitude of turbulent fluctuations increases.

### **International (R. Maingi):**

A. Diallo, Rajesh Maingi, and Dennis Mansfield visited ASDEX-Upgrade to collaborate on Lithium pellet injection experiments. In addition a seminar by A. Bortolon (presented by Maingi) was presented: 'First results with the Lithium Granule injector on DIII-D'. Also, Diallo presented a seminar: 'Pedestal Saturation and the Onset of the Quasi-Coherent Fluctuations on the C-Mod and DIII-D Tokamaks.'

### **ADVANCED PROJECTS (H. NEILSON):**

The Laboratory is preparing an X-ray imaging crystal spectrometer (XICS) that will be used to measure plasma temperature and velocity profiles with high resolution on the Wendelstein 7-X (W7-X) stellarator in Germany. The project is one of several activities within the framework of the U.S. W7-X collaboration program. This week, the final parts for the W7-X XICS diagnostic completed fabrication and were delivered to PPPL. Included were a large aperture Beryllium

window, acquisition electronics, and precision mounting hardware. This hardware will be shipped to Germany the week of July 20 and N. Pablant will travel to Germany later this month to complete the final installation. The XICS diagnostic was designed and built at PPPL and is expected to be ready for the first W7-X experimental campaign this fall.

D. Gates presented an invited talk at the Workshop on Theory and Simulation of Disruptions entitled, "The Tokamak Density Limit: a Thermoresistive Disruption Mechanism." The workshop is held annually at the Princeton Plasma Physics Laboratory. In the talk, Gates presented a simple model of the tokamak density limit based on a radiation driven island dynamic model that quantitatively reproduces the Greenwald limit with plausible assumptions for the impurity densities. The work is a collaborative effort with R. White, D. Brennan, L. Delgado-Aparicio, and Q. Teng.

### **PLASMA SCIENCE & TECHNOLOGY (P. EFTHIMION):**

I. Kaganovich, Y. Raitses and their collaborator, Professor Andrei Smolyakov of University Saskatchewan attended International Electric Propulsion Conference (IEPC) at Kobe, Japan (<http://www.ists.or.jp/2015/>). They presented six oral presentations on important issues of Hall thruster operation: anomalous electron transport and plasma-wall interaction.

### **THEORY (A. BHATTACHARJEE):**

On July 16, I. Dodin (PPPL) presented a theory seminar on variational methods in modeling plasma waves and recent developments. Variational methods are a standard tool of modern theoretical physics and can be extremely useful for studying plasma waves too. This applies both to radiofrequency (RF) waves and nonlinear waves such as those driven by energetic particles in tokamaks. The talk will overview results that have been obtained in this area since 2012, including, but not limited to, the quantumlike theory of classical waves, ponderomotive forces on photons, and the negative-mass instability of resonantly trapped particles. Yet the emphasis will be on the developments made in 2015, which are as follows. For RF waves, geometrical optics has been extended to include polarization effects. Corrections to ray tracing equations are proposed accordingly. More generally, the Lagrangian (particularly, multisymplectic) form of wave equations can be used to improve the robustness of full-wave simulations, which is a matter of future research. For nonlinear waves, a new variational theory is proposed that unifies the fluid and kinetic nonlinearities within a single formula. It is shown that the classic nonlinear shift that is bilinear in the amplitude (fluid nonlinearity) can be expressed simply through derivatives of the dielectric function. Also, an analytic comparison is reported with the exact solution for clump and hole modes, showing high accuracy of even the leading-order asymptotic Lagrangian model, which also enjoys the advantage of extreme simplicity. As a spinoff, the general wave theory also yields new insights to semiclassical formulations of plasma kinetics and hydrodynamics, as well as some long-standing quantum problems. For example, a first fully Lagrangian point-particle model of the Dirac electron is reported, which restates the famous BMT theory in a truly conservative form and, in addition, yields a fully relativistic ponderomotive Hamiltonian with spin effects included. Quantum corrections to ponderomotive forces on spinless particles are also discussed as a spinoff to research on classical plasma waves.

On July 17, Katy Ghantous (Ecole Polytechnique) presented a theory seminar on a hierarchical tree model for inhomogeneous turbulence: Turbulence in fusion plasmas is a major deterrent to having a successful power plant. The problem of anomalous transport due to turbulence is addressed by the community using advanced numerical simulations often run on supercomputers. In this talk, however, she presented some basics from classical turbulence theory and a brief history of our phenomenological understanding of turbulence. She then presented a spectral approach to modeling turbulence that is anisotropic and/or inhomogeneous. While spectral approaches have their limitations and caveats, they can be of interest for validation or finding relations that are not easily captured with full codes. Using dimensional analysis, they found a new scaling law for large  $k$  for certain regimes of drift wave turbulence. The scaling law is verified using an anisotropic spectral model (shell model) developed for the coupled Hasegawa-Wakatani equations. She then demonstrated a modified hierarchical tree mode that is an extension of the shell model to account for spatial as well as spectral signatures. This model is a multi-scale multi-resolution model that attempts to capture inhomogeneities in turbulence. She showed some preliminary results of the model applied on Navier-Stokes Equations.

A paper on gyrokinetic studies of Alfvén turbulence has just been published in Physical Review Letters, by D. Told, F. Jenko (UCLA), J. M. Tenborge (U. Maryland), G.G. Howes (U. Iowa), and G.W. Hammett (PPPL), on "Multiscale Nature of the Dissipation Range in Gyrokinetic Simulations of Alfvénic Turbulence" (<http://dx.doi.org/10.1103/PhysRevLett.115.025003>). This collaboration is part of the Max-Planck/Princeton Center for Plasma Physics. This work used the gyrokinetic code GENE, originally developed for fusion research, to study a problem of interest in the solar wind and other astrophysical plasmas (building on earlier work with the GS2 code). These simulations looked at a high beta regime ( $\beta=200\%$ ), and were the largest gyrokinetic simulations of Alfvén wave turbulence to date, spanning from the tail of the MHD range to the electron gyroradius scale.

## **ENGINEERING AND INFRASTRUCTURE (M. WILLIAMS):**

### **Facilities and Site Services (M. Donohue):**

The PPPL Facilities Information Management System (FIMS) five-year Data Validation Review was held at PPPL on July 14-15. FIMS is DOE's official repository of real property data. Maintaining accurate and credible data in FIMS is critical to efficient operations and resource planning and DOE is required to certify the accuracy of the data. All but one of the 57 data elements that were validated received a green score on the validation scorecard. One red score was received regarding a legacy issue of how maintenance costs are captured, and a corrective action plan will be developed to resolve this issue.

## **OFFICE OF COMMUNICATIONS (C. CANE):**

On July 13, the Office of Communications sent out a news release about C. Kessel's winning the 2015 Fusion Technology Award.

## **DIRECTOR'S OFFICE (C. AUSTIN):**

Laboratory Management hosted the quarterly Laboratory Management Review (LMR) on July 17. This was a self-evaluation against each of the eight Performance Evaluation Management Plan (PEMP) goals.

## **PUBLICATIONS:**

Belova, E.V.; Gorelenkov, N.N.; Fredrickson, E.D.; Tritz, K.; and Crocker, N.A., "Coupling of Neutral-Beam-Driven Compressional Alfvén Eigenmodes to Kinetic Alfvén Waves in NSTX Tokamak and Energy Channeling," *Physical Review Letters* 115, 015001 (2015)

Ahn\*, J-W.; Maingi, R.; Canik, J.M.; Gan, K.F.; Gray, T.K.; McLean, A.G., "Impact of ELM Filaments On Divertor Heat Flux Dynamics In NSTX," *Journal of Nuclear Materials* 463 (2015) 701 – 704 (<http://www.sciencedirect.com/science/article/pii/S002231151400926X>)

Told, D.; Jenko, F.; Tenborge, J.M.; Howes, G.G.; and Hammett, G.W., "Multiscale Nature of the Dissipation Range in Gyrokinetic Simulations of Alfvénic Turbulence" *Physical Review Letters* 115, 025003, July 2015 (<http://dx.doi.org/10.1103/PhysRevLett.115.025003>)

This report is also available on the following web site:  
<http://www.pppl.gov/publication-type/weekly-highlights>