Highlights of Major US-PRC Collaborations over Last Five Years

by
H.Y. GUO
X.R. DUAN

Presented at the
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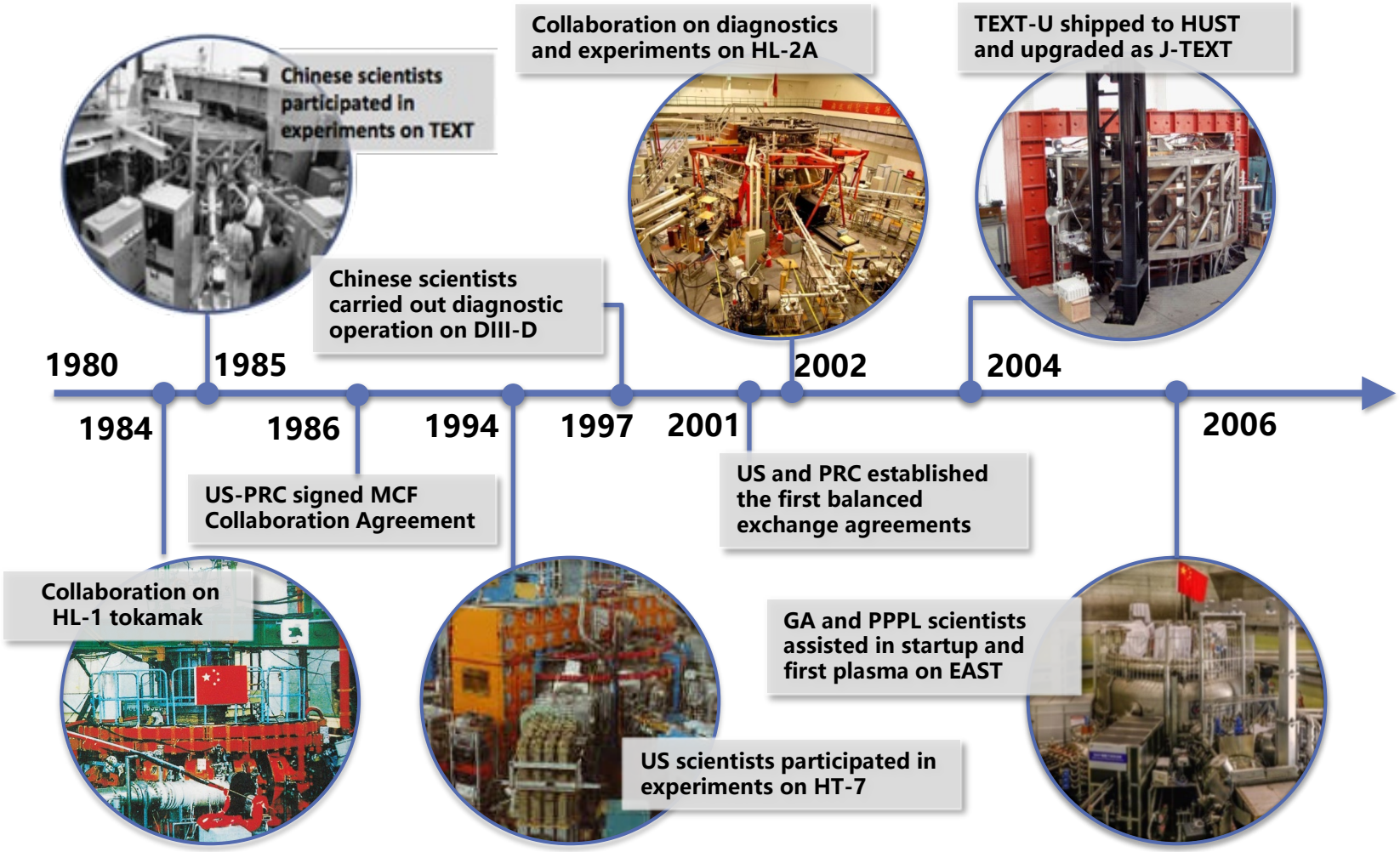
Virtual Workshop

March 22-26, 2021



Highlights of Major US-PRC Magnetic Fusion Collaborations over Last Five Years

1. **Major US → PRC Collaborations: (H. Guo)**

2. **Major PRC → US Collaborations (X. Duan)**

Highlights of Major Major US → PRC Collaborations

- International Collaboration for Tokamak Energy Development
- Scenario & Control for Long-Pulse High-Performance Operation in EAST
- US-China PMI Collaboration for Long pulse Operation
- Diagnostics Development

International Collaboration Center for Tokamak Energy Development

- **The center was established to accelerate fusion energy development**
  - Dedicated on April 10, 2015 at General Atomics
- **The new Center facilitates the Collaborations between EAST & DIII-D**
  - Exchange of scientific staff, hardware, data, computing software, …
  - Joint experiment planning, execution, analysis, publication
  - Joint design and simulation

Sharing of resources and focus on critical issues can mitigate challenges

Edmund Synakowski,
Associate Director of Science, FES

Jinghua Cao,
Deputy Director, Bureau of International Cooperation, CAS

Sharing of Resources to Advance Progress on Critical Issues for ITER and CFETR

Joint Publications and Shared Leadership:

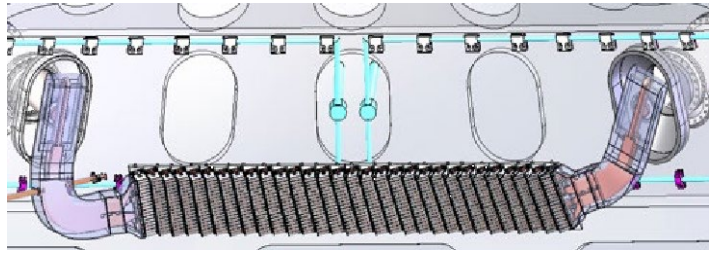
- 30 joint publications over past 5 years
- 24 invited/oral talks (APS, IAEA, AAPPS, PSI, EPS)

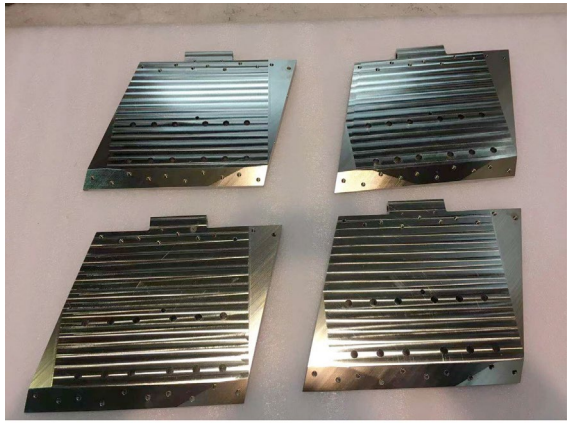
Hardware Exchange:

- 2016: New ASIPP Power Supply (16 kA of current at frequencies up to 1 kHz) transforming capabilities for ELM, stability, rotation, and shape control studies on DIII-D
- 2019: Helicon collaboration to evaluate efficient off-axis current drive for AT DEMO on DIII-D

Personnel Exchange:

- 1 ASIPP scientist working with post-doctoral appointment at DIII-D since 2018
- Many short-term visits of DIII-D scientist at EAST, and EAST scientists at DIIII-D





GENERAL ATOMICS

Major Active US Collaboration Teams for EAST Long Pulse Operation

1 LONG PULSE HIGH PERFORMANCE SCENARIOS AND CONTROL IN EAST

- High Performance Steady-State Scenarios
- Control for Long Pulse Sustainment
- Core-Edge Integration
- Simulations for Scenario Development and Control
- Modeling and Simulations for Scenario Development and Control
- Remote Collaboration and Third Shift Operation of EAST

GENERAL ATOMICS
LEHIGH UNIVERSITY
PPPL PRINCETON PLASMA PHYSICS LABORATORY
TEXAS The University of Texas at Austin
UCLA

2 CONTROL OF PLASMA-MATERIAL INTERFACE FOR LONG PULSE OPTIMIZATION IN EAST

- Evaluate Performance of W, Mo, and C PFCs, and Optimize Li Delivery
- Analyze Role of Li and Cryopump for Recycling Control
- PFC Tile Diagnosis
- Productivity: 49 refereed articles, 17 invited/selected orals (93 total)

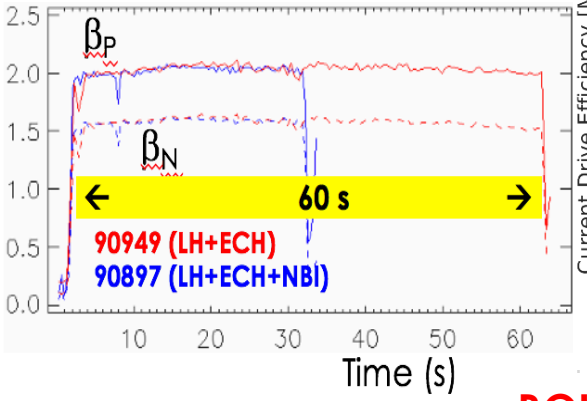
PPPL PRINCETON PLASMA PHYSICS LABORATORY
ILLINOIS
JOHNS HOPKINS UNIVERSITY
Los Alamos NATIONAL LABORATORY
OAK RIDGE National Laboratory
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Long Pulse Tokamak Project Advanced Key EAST/CFETR Scenarios, Control Capabilities, Understanding, and Diagnostics in 2019-2020

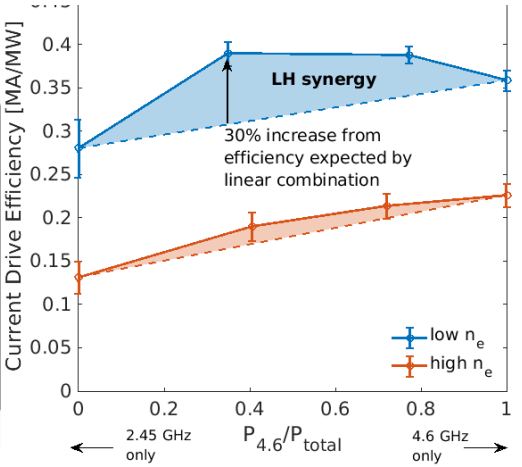
- **Experimental progress in last EAST campaign (Fall 2019 – early 2020):**
  - Key contributions to extension of DIII-D High-β_P scenario to 60 sec on EAST → SS Q>5 in CFETR
  - Control of 3-point q-profile with Ip + two LH frequencies
  - DPRF disruption predictor demonstrated experimentally
  - Ar equally effective for detachment control as Ne
  - Maximum robust controllable growth rate quantified

- **Analysis, simulation, and diagnostic advances:**
  - Major advance in usability of POINT constrained EFIT
  - TRANSP studies: 30% increase in CD efficiency from LH synergy
  - Advance in LH modeling + edge turbulence, wave scattering
  - BOUT++ simulations show different divertor heat flux widths between NBI/LHW
  - FMECE diagnostic tested at DIII-D, to deploy at EAST when travel possible

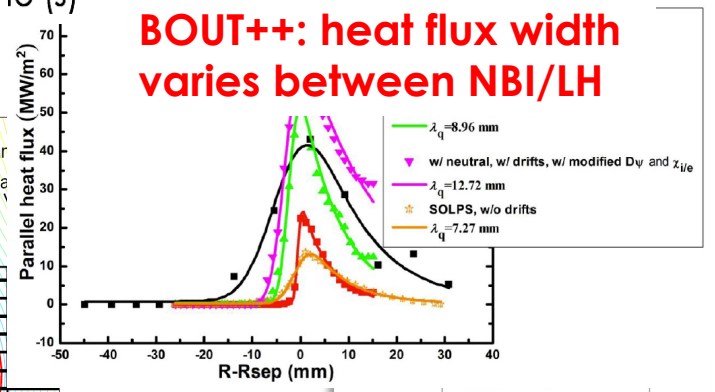
60 s Hi β_P Q>5 CFETR



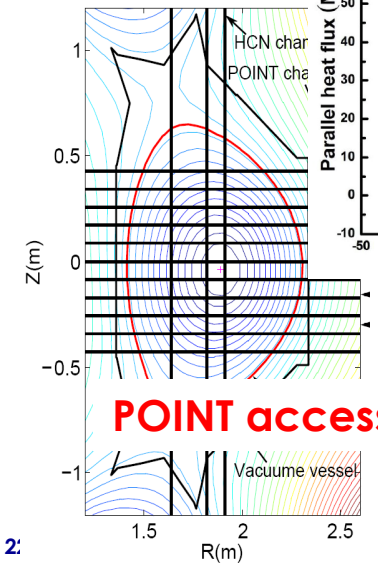
TRANSP: 30% Higher CD



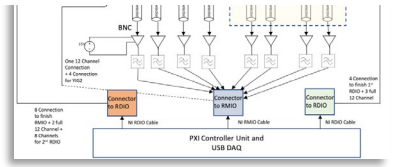
BOUT++: heat flux width varies between NBI/LH



POINT access in EFIT



FMECE ready for EAST



Long Pulse Tokamak Project Continued to Pioneer Remote Operation on EAST and Helped Enable DIII-D to Operate Campaign in Pandemic

- **Remote 3rd Shift Experiments in EAST 2019-20 Campaign:**
  - Detachment control experiments
  - Extension of DIII-D High-β_P scenario to longer pulse in EAST
  - Current profile control experiments
  - Disruption prediction, prevention, avoidance experiments

- **EAST Remote Operation methods helped enable DIII-D to operate in pandemic conditions:**
  - DIII-D remote functions exploit procedures pioneered in EAST remote operation
  - Remote monitoring facilities imported from GA Remote Control Room (machine status, realtime traces, realtime boundary reconstruction, …)
  - Remote Physics Operations (plasma control system access and operation) modeled on EAST remote 3rd shift
  - Discord video gaming software use for EAST 3rd shift enables operations-physics team communication in DIII-D campaign

GA Remote Control Room Supports EAST 3rd Shift Experimental Operations

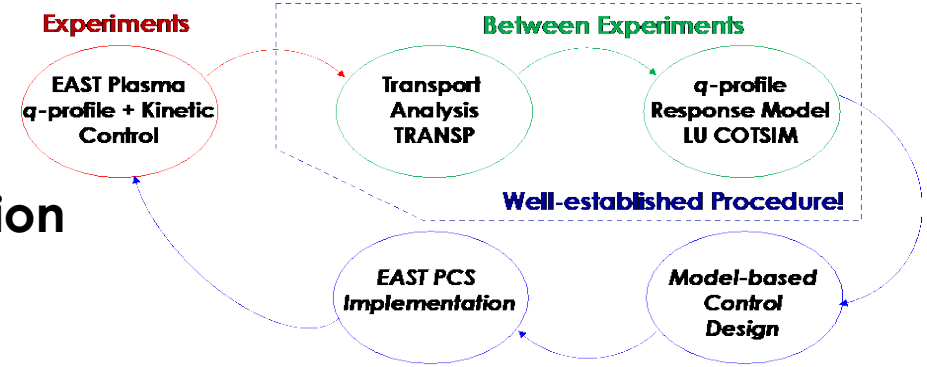
Discord Video Gaming Software for Remote Ops in 2020-21 DIII-D Campaign

GENERAL ATOMICS

Lehigh U: Integrated Model-based Plasma Control for Long-Pulse High-Performance Scenario Development in EAST

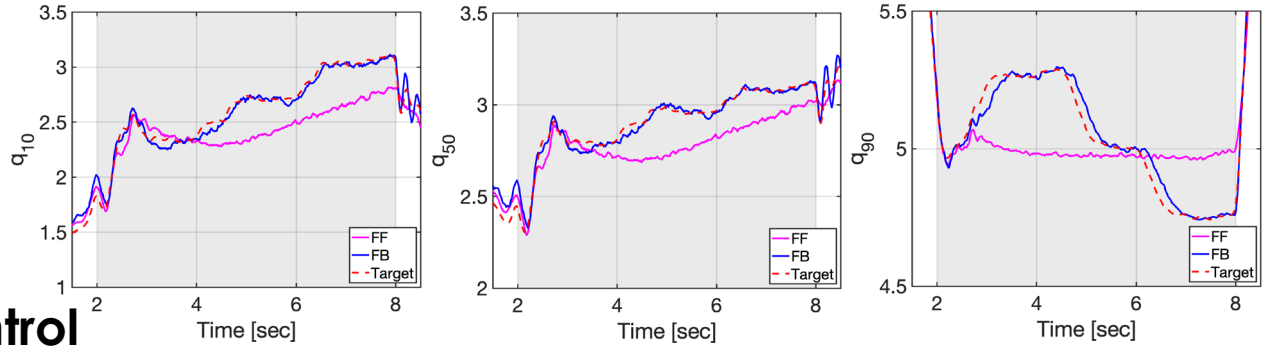
Mission:

- Adapt high-performance scenarios from DIII-D to EAST
- Develop control-physics understanding to enable adaptation
- Pioneer reactor-specific scenario and control solutions



Major Achievements:

- <u>High-performance steady state scenario</u>
- Control for long pulse sustainment
- Core-edge integration
- <u>Simulations for scenario development & control</u>
- Diagnostics for long pulse scenarios and control
- Remote collaboration and 3rd shift operation of EAST



Simultaneous feedback q-profile regulation at three spatial points was demonstrated for the first time in early 2020 by using two LH sources

Scientific Outputs:

- 1 PhD dissertation; 3 journal papers
- 5 conference presentations and 1 invited talk (EAST IAC)

LEHIGH UNIVERSITY

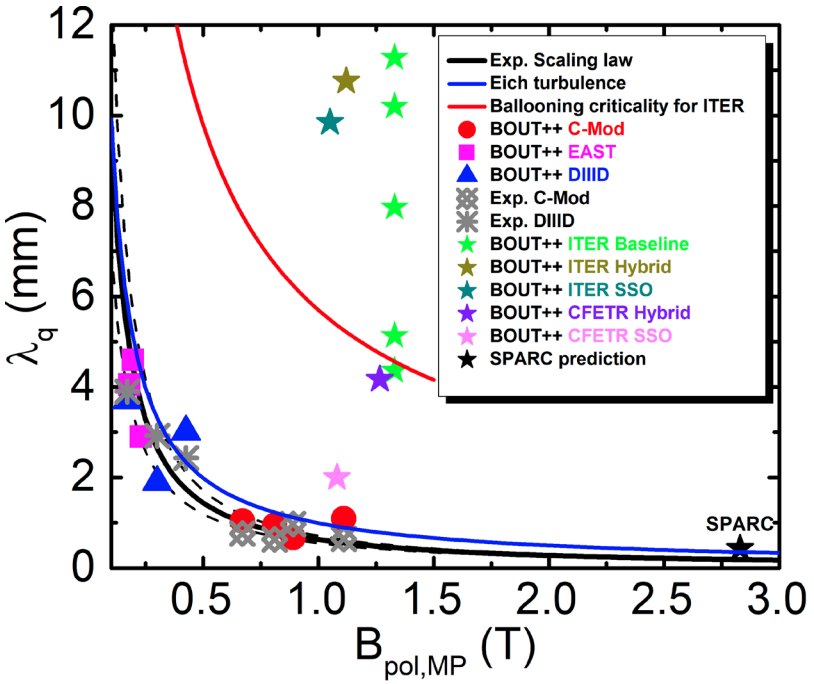
LLNL: Long Pulse High Performance Scenarios and Control in EAST

Key Collaboration Areas:

- Experimental steady-state scenario development & modeling of conditions for acceptable divertor heat flux in EAST, and projections to CFETR
- Theory and BOUT++ simulations on ELMs and boundary physics

Major Achievements:

- BOUT++ simulations predict that the CFETR & ITER scrape-off layer may be in a turbulence-dominant regime
- BOUT++ well reproduced EAST divertor heat flux width
- Development on higher $\rho(q_{min})$ & ITB for high performance steady State



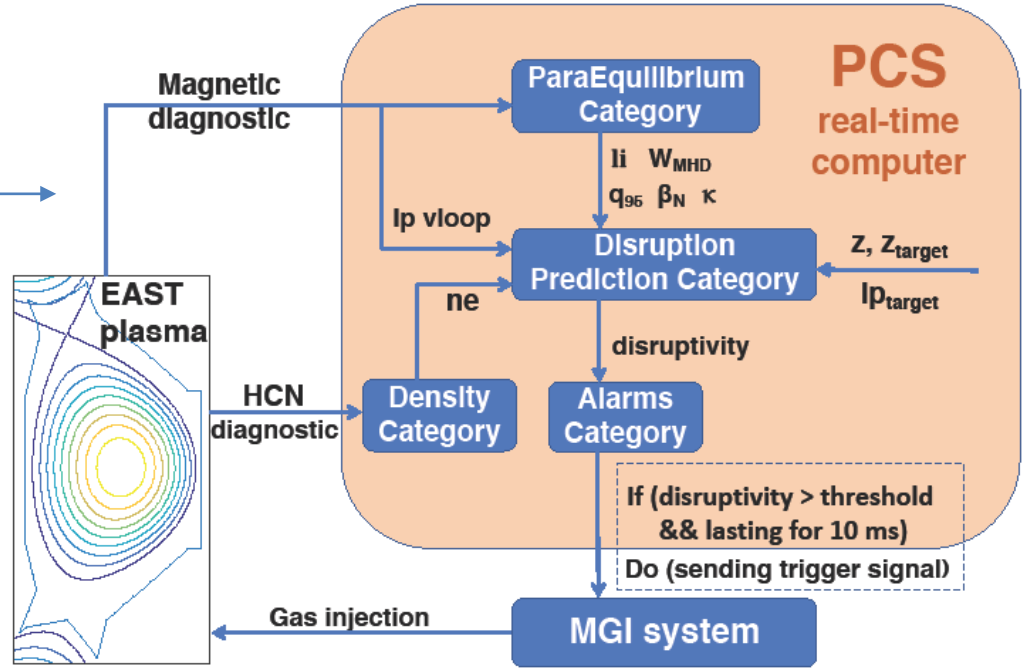
Publications & Scientific Exchange:

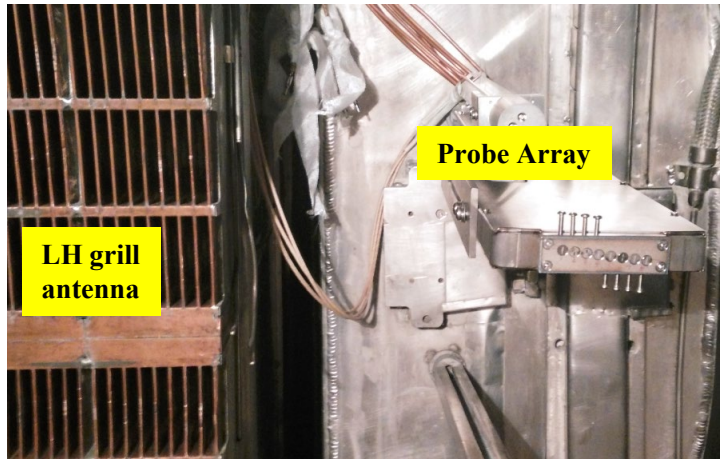
- 47 papers in peer-reviewed journals
- Hosted ~ 45 visitors, 2 BOUT++ workshops (2015, 2018) and the 10th US-PRC Fusion Collaboration Virtual Workshop in 2021 (this meeting)

MIT-PSFC: Long Pulse High Performance Scenarios and Control in EAST

Key Scientific Achievements:

- Machine learning-based real-time disruption predictor (DPRF) installed and running in the EAST PCS (2019-2020) for the first time
- Discovered that strong lithiation extends effective LHCD and heating to high density in EAST
- Elucidated potential role of turbulent scattering in LHCD on EAST
- Supported development of an 8 RF B-dot probe array installed next to the 4.6 GHz LH antenna
- Used HPC and advanced RF simulation models to study LHCD physics in EAST and CFETR





Publications:

- 19 joint, with ~50:50 split (US, PRC) on first authorship

UCLA: Long Pulse High Performance Scenarios and Control in EAST

Primary Mission:

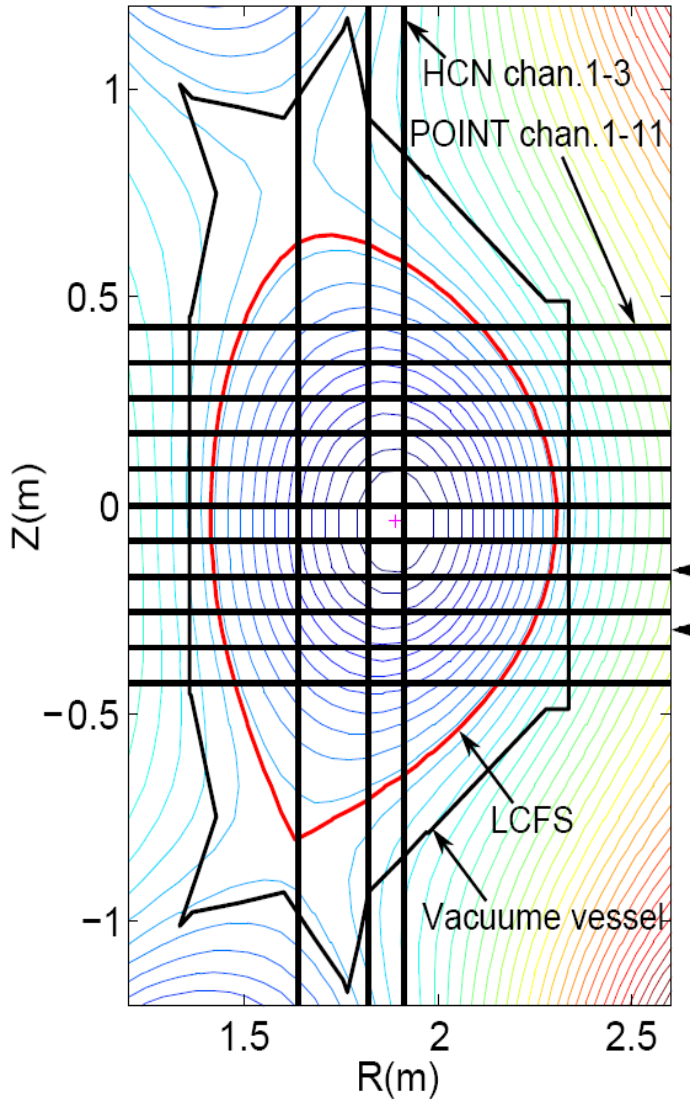
- **Provide density profile, q-profile, and internal constraints for EFIT**
- **support EAST-POINT operations for team experiments**

Major Achievements:

- **POINT Data used to constrain EFIT and determine q-profile in EAST**
  - Line-integrated spatial profiles using 11 POINT chords for 2 time slices
  - local profiles obtained using EFIT
  - EFIT is now being modified to better incorporate POINT data
- **Newly Developed Vertical Position Measurement Using POINT**

Publications:

- **3 papers from refereed journals including NF and RSI**

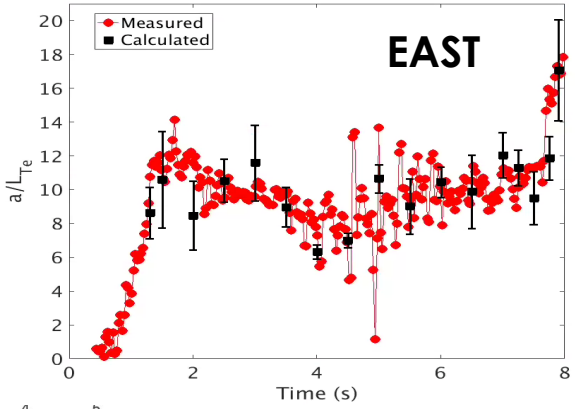


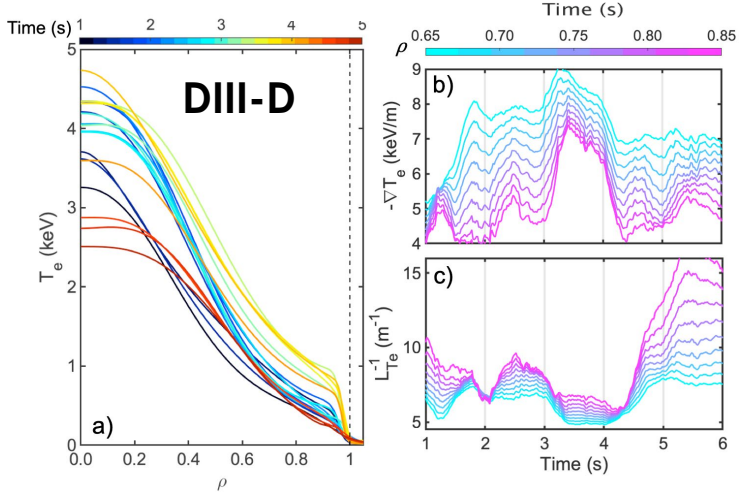
UCLA

UT: Long Pulse High Performance Scenarios and Control in EAST

Major Achievements:

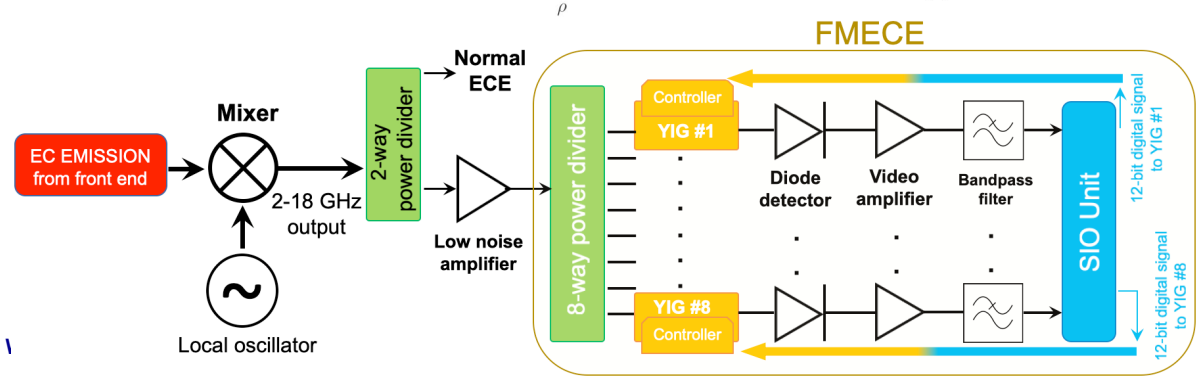
- Two variable frequency (YIG) Channels were integrated into the EAST's ECE radiometer; they successfully measured a/L_{Te} for an EAST discharge in June 2018
- A new FMECE diagnostic with variable-frequency (YIG) channels is designed and tested on DIII-D to measure ∇T_e & a/L_{Te} with high time & spatial resolutions





Publications & Scientific Exchange:

- 3 papers in peer-reviewed journals
- Hosted 1 ASIPP physicist to work on DIII-D completing 2 year visit to US
- Visit of UT physicists & engineer to ASIPP
  - Data analysis and support for ECE and MSE
  - Design and installation of FMECE on EAST



TEXAS
The University of Texas at Austin

PPPL and PRC collaborations have made excellent technical progress and have been mutually beneficial

Productive Collaborations in Multiple Areas:

- Plasma-materials interactions (PPPL-led domestic team; EAST/ASIPP)
- Scenario modeling and current drive (PPPL part of a team; EAST/ASIPP)
- Turbulence and transport (PPPL; ASIPP, SWIP, Zhejiang Univ.)
- Theory (PPPL; USTC)
- Resonant magnetic perturbations (PPPL; ASIPP, SWIP)
- CFETR design (PPPL; ASIPP) [completed a few years ago]

Hardware Exchange:

- Lithium powder dropper and granule injector
- Impurity powder dropper
- Guide plate substrates and heaters for flowing liquid Li limiter experiments (4 generations)

Personnel Exchange:

- 1-2 person years in travel from PPPL to PRC (frequent short trips) and from PRC to PPPL (longer term assignments/visits)

PPPL and PRC collaborations have made excellent technical progress and have been mutually beneficial

Key Scientific Achievements:

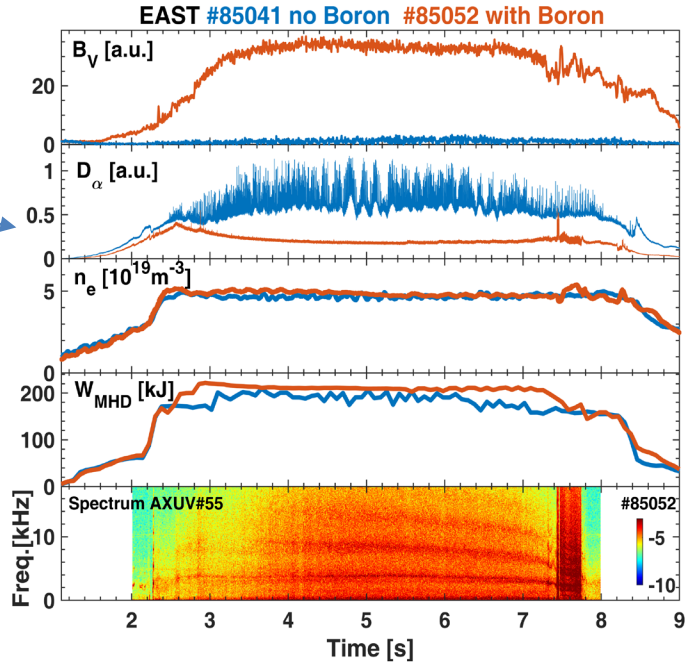
- Impurity (Li, B) injection for ELM suppression and mitigation in EAST
- Development of flowing liquid lithium plasma-facing components in EAST
- Lower hybrid current drive assessment and optimization in EAST
- Electron-scale turbulence comparison in NSTX and EAST

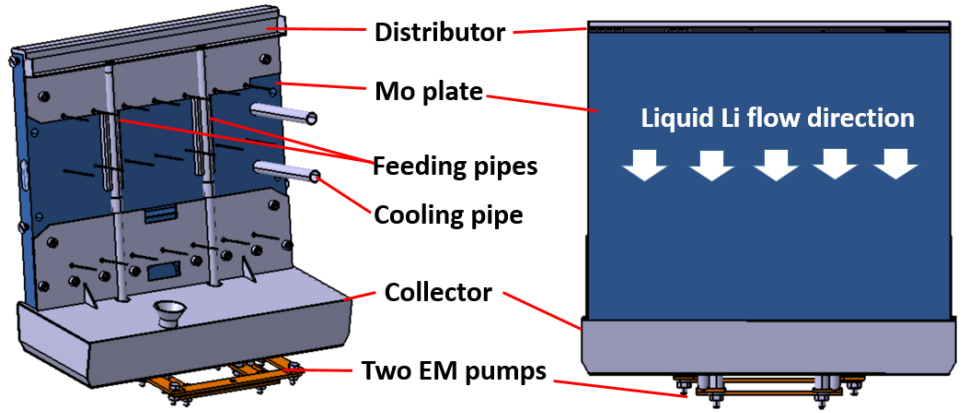
Refereed Publications:

- 51 joint, with a ~1:2 split (US, PRC) on first authorship

Invited talks and colloquia:

- 18 invited or selective orals, with a ~50-50 split (US, PRC) on speaker





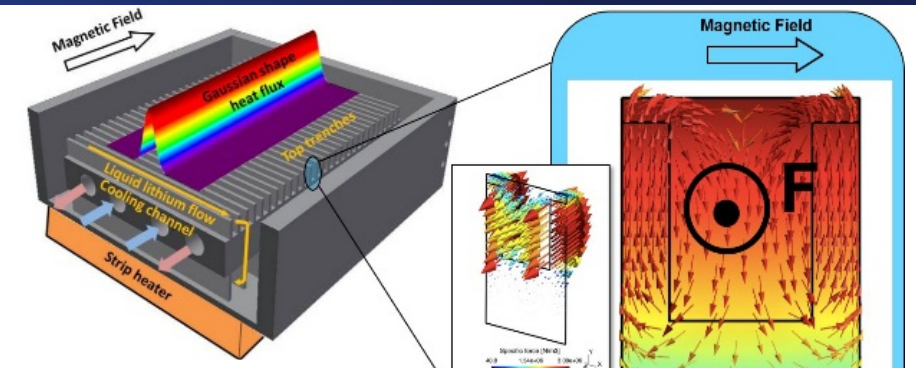
UIUC: Focusing on impurity and recycling control for long pulse optimization on EAST

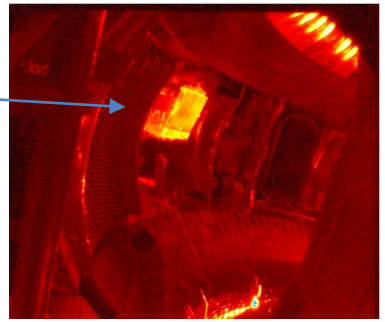
Goal:

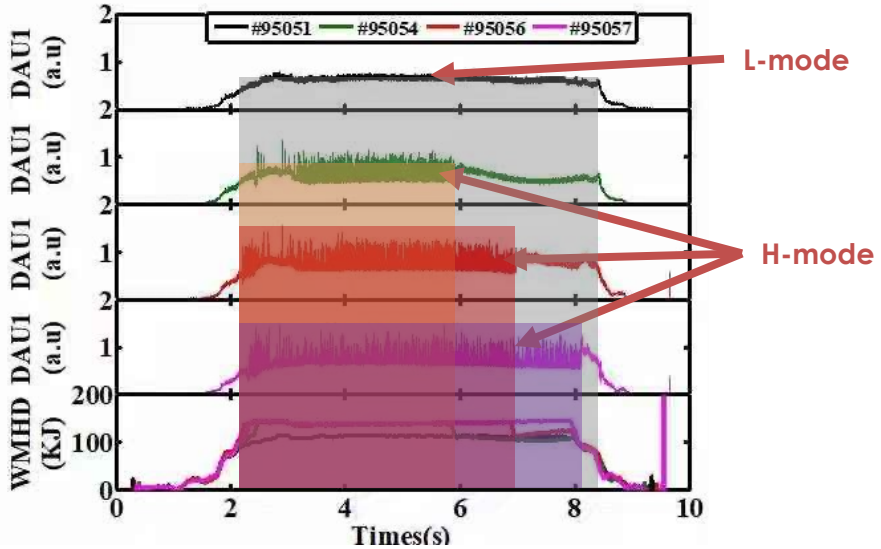
- **Evaluate the performance of the different PFC materials, which include tungsten, molybdenum, and graphite, and the role of Li wall conditioning**

Key Achievements:

- **Developed liquid metal infused trenches (LiMIT)**
  - Tested Generation 4 – LiMIT Tile on EAST
  - Demonstrated He cooling of LiMIT
- **Tested cycling and Li survivability in support of next generation FLiLI and LiMIT limiters and heaters for EAST**
  - Armored heaters used to survive the lithium environment
- **Achieved improved H-mode performance on EAST**
  - Increased lithium operation with LiMIT extended H-mode and reduce ELM frequency
- **Developing Mock-up Entry Module for EAST – MEME**
  - Large number and variety of flanges allowing for comprehensive observation and diagnostics of samples







ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UCD: Collaboration on EAST, HL-2A/2M, J-TEXT

Key Achievements:

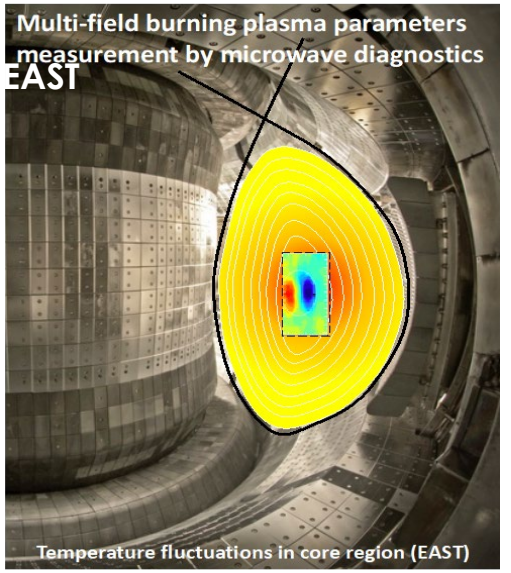
- Simultaneously and co-located n_e, T_e measurement by ECEI and Microwave Imaging Reflectometer on EAST
- Upgrade of ECEI for HL-2M
- Improved microwave diagnostics, developed 3D MHD structure measurement on J-TEXT for tearing mode and disruption studies

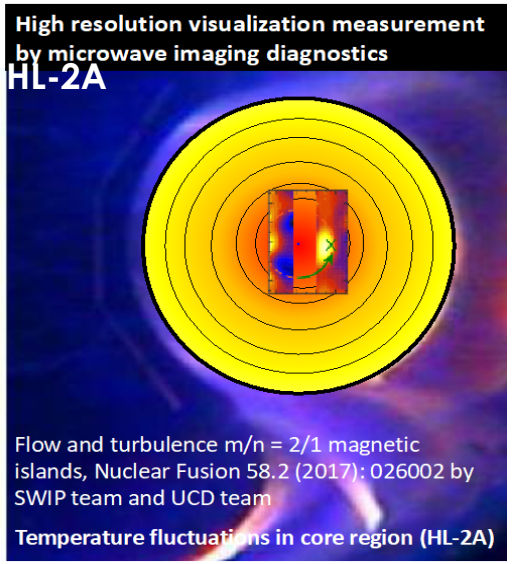
Hardware Exchange:

- EAST: Microwave Imaging Reflectometer; Ultra Short Pulse Reflectometer & Terahertz high-k collective scattering (under development)
- HL-2A and EAST: Prototype of System-on-Chip microwave diagnostics
- HL-2M: Electron Cyclotron Emission Imaging upgrade on HL-2M
- J-TEXT: Electron Cyclotron Emission Imaging

Personnel Exchange: 23 people in previous 5-years

Publications: 47 in previous 5-years





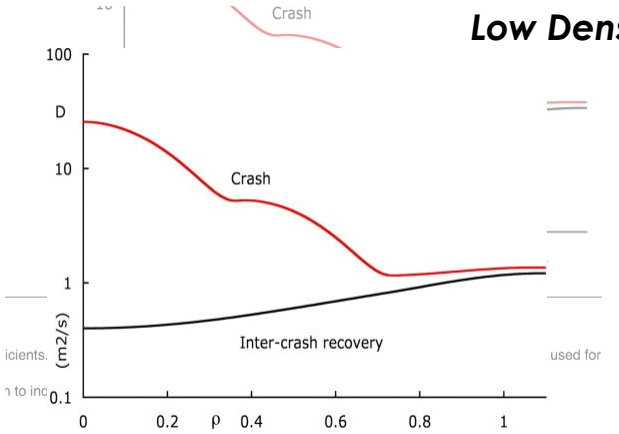
UT: Collaboration on J-TEXT

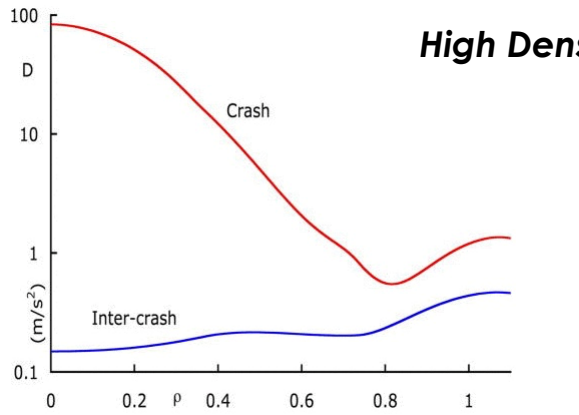
Major Collaboration Efforts:

- Ken Gentle – semi-annual visits to J-TEXT to participate in experiments and planning
- He Huang – Half-time in China each year to provide technical and engineering assistance to ASIPP and J-TEXT

Highlights of Key Scientific Results:

- Using the high-precision, multi-channel FIR interferometer on JTEXT, accurate measurements of the density profiles over the sawtooth cycle were made
- In addition to a core relaxation similar to the well-known temperature relaxation, a clear rapid density increase was seen from outside the inversion radius across most of the of the outer region → a large D (red) needed to explain the inter-crash recovery





Joint Publications:

- 7 papers in refereed journals, including NF (6), RSI (1)

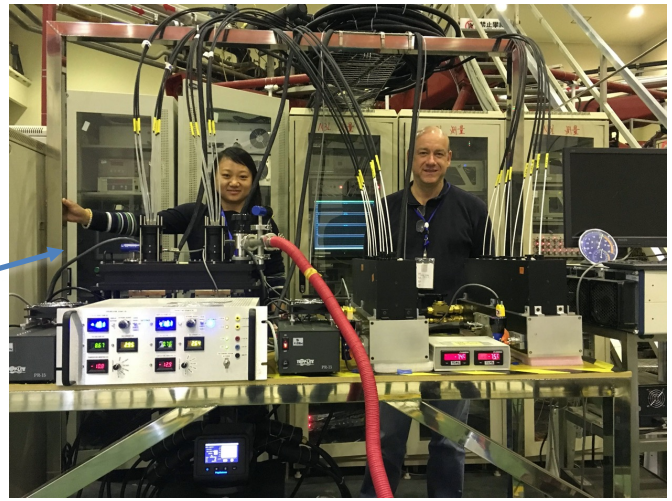
UW-M: Collaboration with SWIP

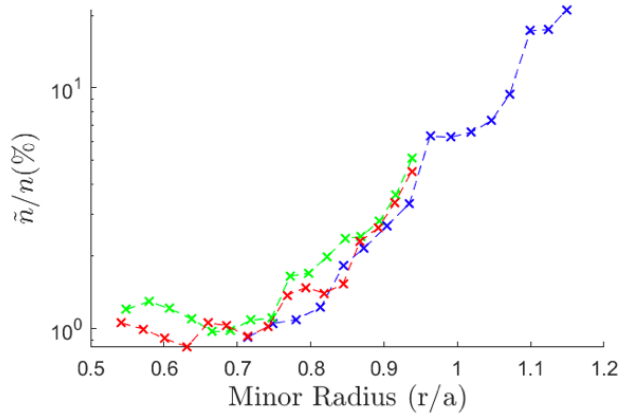
Goal:

- **Perform collaborative research on turbulence physics across multiple tokamaks through advanced measurements**

Key Achievements:

- **Diagnostics**
  - Installed a 16-channel Modular BES Diagnostic System
  - Installed a new 16-channel Integrated BES Diagnostic System
  - Loaned a 16-channel NSTX-U BES Diagnostic (~1 year: 2018-2019)
- **Experiments**
  - Led turbulence experiment on **ρ*** scaling of turbulence on HL-2A
  - Led experiment on L-H physics with applied magnetic perturbations
  - Supported experiment on ExB Staircase turbulence phenomena





*Density fluctuation amplitude, ñ/n scales with ρ**

Publications and Technical Presentations:

- **2 papers in refereed journals (POP and RSI)**
- **2 conference presentations and multiple on-site plasma physics seminars**

Highlights of Major US-PRC Magnetic Fusion Collaborations over Last Five Years

1. Major US → PRC Collaborations: (H. Guo)

2. Major PRC → US Collaborations (X. Duan)

Highlights of Recent PRC-US Fusion Collaboration

Dedicated collaboration between US and China has been very fruitful in numerous research fields: theory and simulation, fusion experiments, diagnostic development, tokamak construction and operation, reactor design, fusion materials, and ITER relevant technologies …

- **Participants from US**
  - GA, PPPL, LLNL, ORNL, INL, UCSD, UCLA, UC Davis, UCI, UW Madison, UT Austin, MIT, UIUC, JHU, Lehigh U…
- **Participants from China**
  - SWIP, ASIPP, USTC, HUST, INEST, DUT, CAEP, CIAE, HIT, PKU, Tsinghua U, ZJU, Beihang U, UCAS, SWJTU, USTB, BIT, SCU, SJTU, ITPCAS …

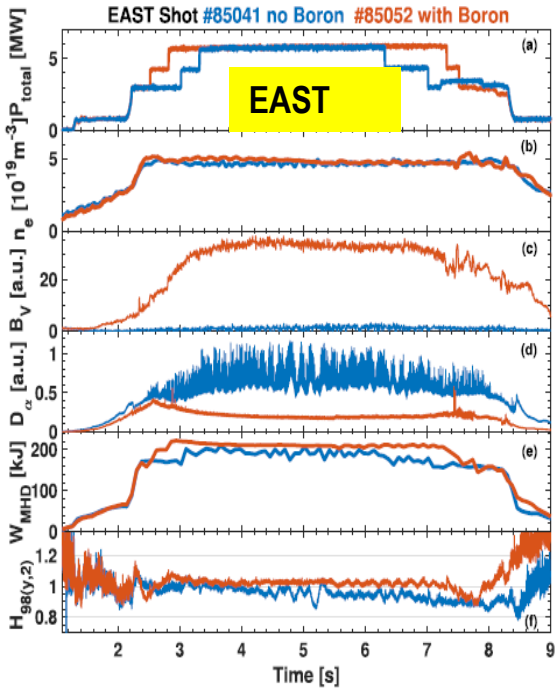
Highlights of Recent PRC-US Fusion Collaboration

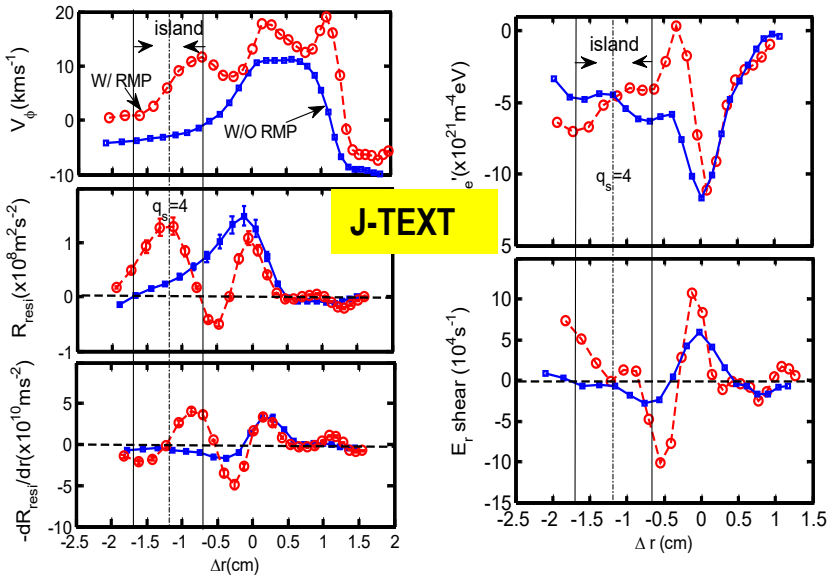
- **Plasma Physics**
  - Joint experiments on high-performance/steady-state/burning plasma physics (HL-2A, EAST and J-TEXT);
  - Theoretic studies and simulations
- **Fusion Technology and Engineering**
  - Advanced plasma diagnostics developments (ECEI, PCI, FCS, etc)
  - Scenario developments (Steady-state, high beta, high bootstrap current fraction)
  - Advanced divertor and control algorithms (snowflake, tripod configurations)
- **ITER-related Cooperation**
  - Blanket engineering technology research and ITER TBM design
- **Fusion-reactor and Nuclear Technologies**
  - Plasma-material interaction study

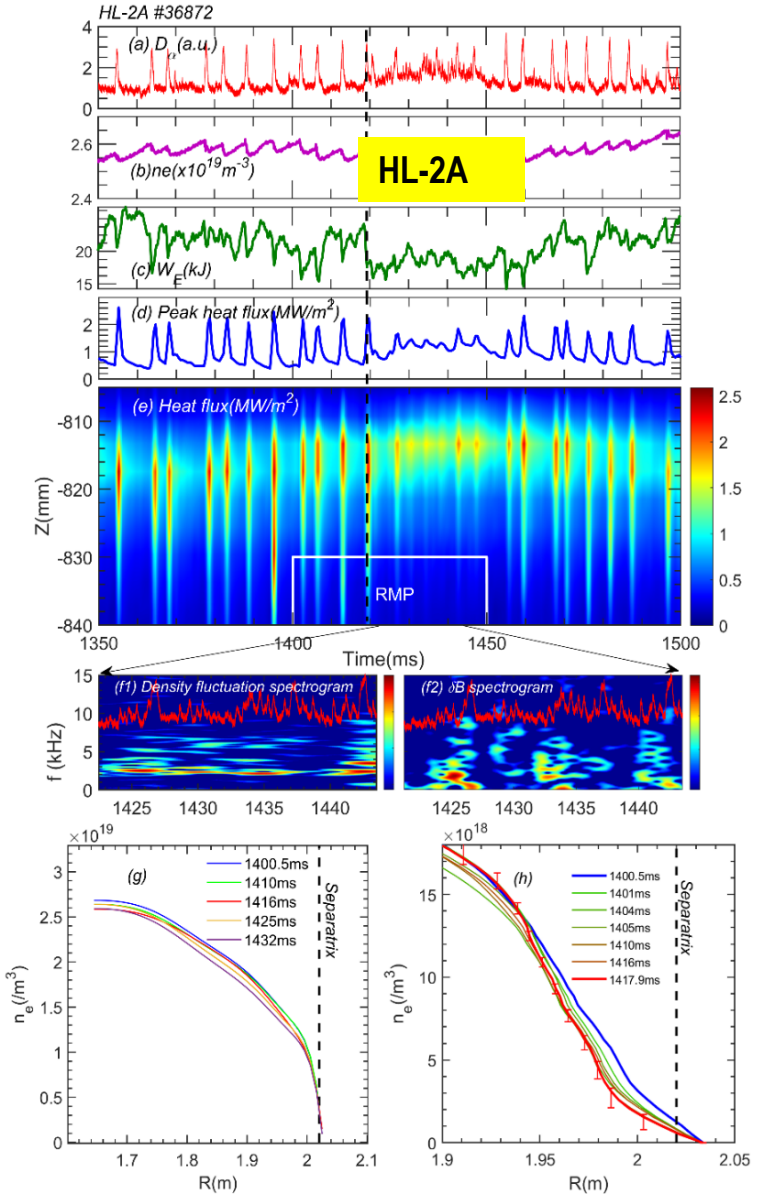
Joint Experiments on HL-2A, EAST and J-TEXT

Main joint experiments :

- Sheath potential coefficient and EEPF on HL-2A (with **UCSD**)
- Shear flow, intermittency and density limit (with **UCSD**)
- Turbulence and MHD instability on HL-2A (**with UCSD, UW-Madison, GA**)
- ELM control on EAST (with **PPPL, UIUC, JHU, GA, ORNL LLNL**)
- Flowing liquid Li limiters(FLiLis) on EAST (**with UIUC, PPPL**)
- Enhancement of residual stress by magnetic islands on J-TEXT (with **UCSD**)





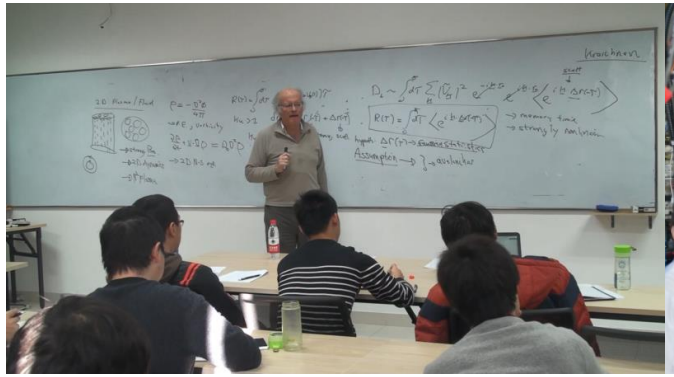


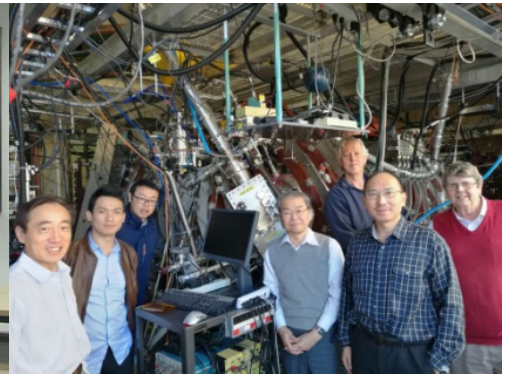
Collaboration on Advanced Fusion Theory

Collaboration b/w GA, PPPL, LLNL, MIT, UCSD, UW-Madison, UCI, U. Texas, … and SWIP, ASIPP, HUST, USTC, DUT, ZJU, SWJTU, PKU, HIT…

Goal: Promote the interaction between fusion theory and experiment; training the young generation of fusion theorists in the forms of directed research and seminars as well as lectures.

- **Research topics:**
  - SOL width and SOL fluctuations;
  - intrinsic rotation and momentum transport;
  - multi-scale interactions (turbulence, MHD, turbulence in presence RMP, ETG, ITG);
  - mesa-scale structures and non-locality;
  - q profile effect on transport;
  - H-L back transitions and hysteresis;
  - micro-macro connections with power threshold;
  - Generic theory of H-mode, and I-mode;
  - Physics of QH mode and ELMs;
  - Divertor plasma physics and code validation;
  - Discrete GAM in tokamak plasmas;
  - Non-resonant EPMs with weak and reversed shears.
  - High-temperature plasma dynamics and structure formation

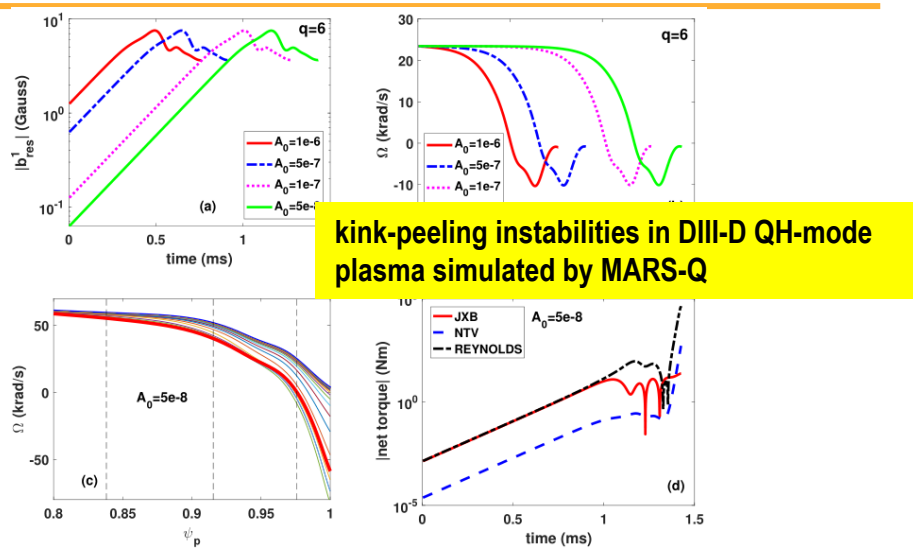




Collaboration on Theory Simulation

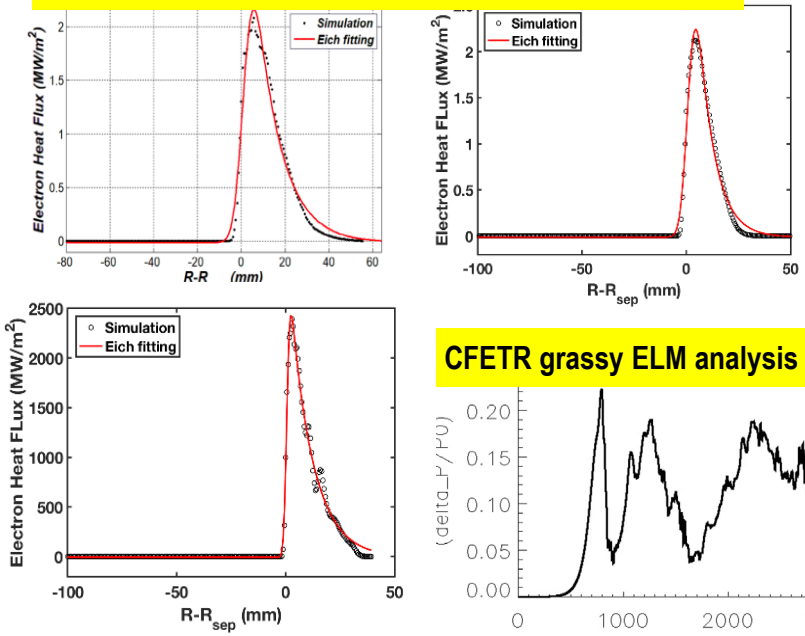
Participants from China: ASIPP, SWIP, DUT, ZJU, PKU, HUST …

- **Main achievements:**
- Effect of turbulence and core MHD instability on particle transport (with **GA**)
- The dependence of turbulence characteristics on ρ* (with **UW-Madison**)
- Turbulence Spreading and Explicit Nonlocality (with **UCSD**)
- A Mean Field Model in a stochastic B field (with **UCSD**)
- Physics of turbulence and impurity transport (with **U. Texas**)
- Explanation for EHO accompanied with QH-mode (with **GA**)
- kink-peeling instabilities in QH-mode plasma (with **GA**)
- Influence of plasma resistivity on fishbone mode (with **GA**)
- Fishbone-like mode (FLM) excitation by trapped thermal ions (TTIs) (with **GA**)
- Effects of anisotropic thermal transport on plasma response and MHD instabilities (with **GA**)
- Integrated simulation of ELM and transport on OMFIT platform (with **LLNL, GA**)
- Time-dependent simulation of two frequencies of lower hybrid power (with **PPPL, MIT**)
- CFETR Hybrid regime compatible with the Grassy ELM (with **LLNL**)
- Effect of Various types of ELM on ITER divertor heat flux width (with **LLNL**)
- Removal of helium ash and transport of D-T ions (with **UCSD**)
- Vortex wave interaction theory of ELM-free H-mode (with **UCSD**)



kink-peeling instabilities in DIII-D QH-mode plasma simulated by MARS-Q

ITER divertor electron heat flux analyzed by BOUT++



CFETR grassy ELM analysis by BOUT++

Highlights of Recent PRC-US Fusion Collaboration

❒ Plasma Physics

- Joint experiments on high-performance/steady-state/burning plasma physics (HL-2A, EAST and J-TEXT);
- Theoretic studies and simulations

❒ **Fusion Technology and Engineering**

- Advanced plasma diagnostics developments (ECEI,PCI, FCS, etc)
- Scenario developments (Steady-state, high beta, high bootstrap current fraction)
- Advanced divertor and control algorithms (snowflake, tripod configurations)

❒ ITER-related Cooperation

- Blanket engineering technology research and ITER TBM design

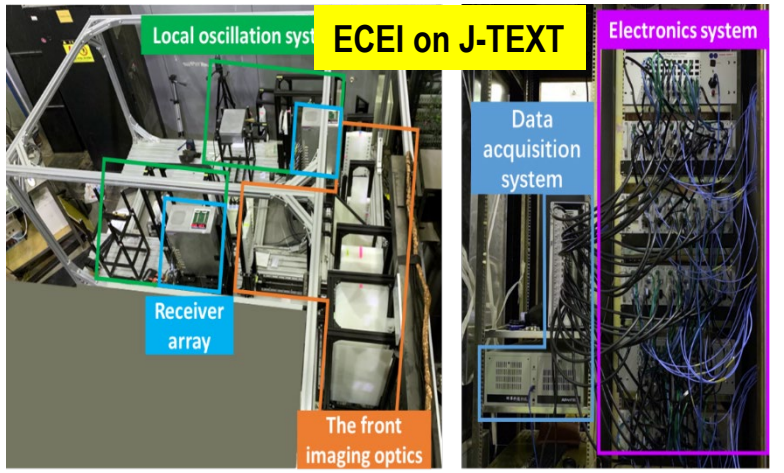
❒ Fusion-reactor and Nuclear Technologies

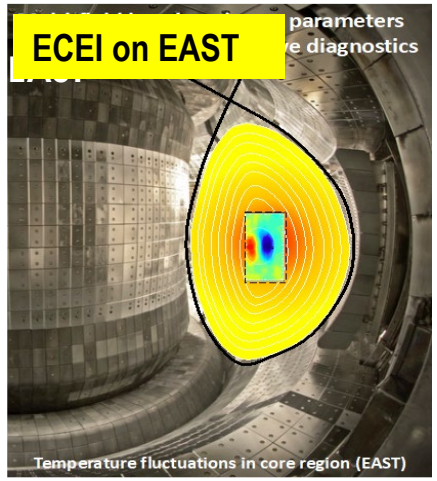
- Plasma-material interaction study

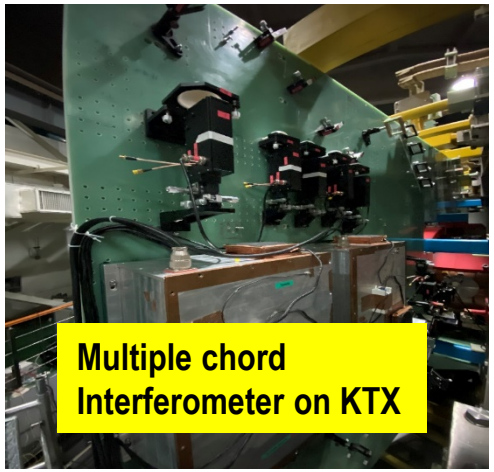
Advanced Plasma Diagnostics Developments

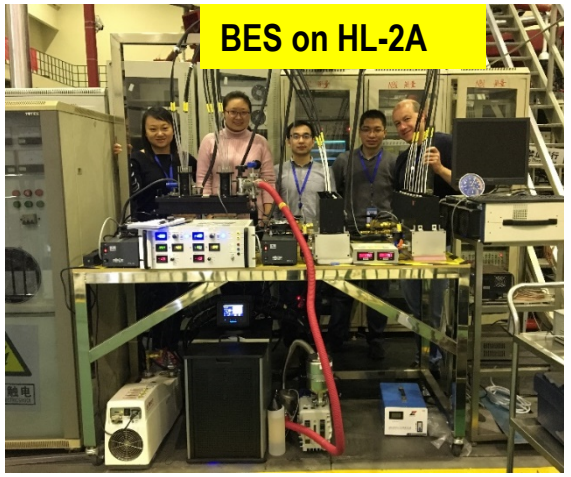
Collaboration b/w UCLA, UW Madison, UC Davis, MIT, … and SWIP, ASIPP, HUST, USTC …

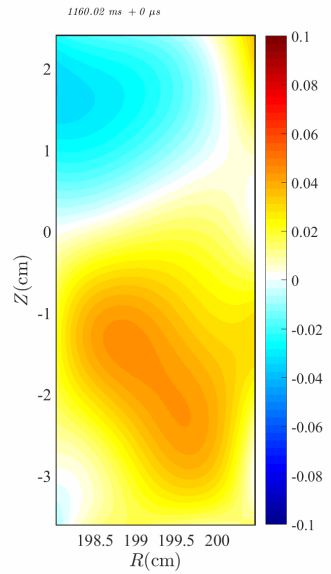
- **Main diagnostics / actuators:**
- Microwave Imaging Reflectometer on EAST;
- Ultra Short Pulse Reflectometer on EAST;
- Terahertz high-k collective scattering on EAST;
- Beam Emission Spectroscopy (BES) on HL-2A
- Electron cyclotron emission imaging (ECEI) on HL-2A
- Phase Contrast Imaging (PCI) on HL-2A
- Fast ion Dα diagnostic (FIDA) on HL-2A
- Electron cyclotron emission imaging (ECEI) system on J-TEXT
- Interferometer system on KTX
- …









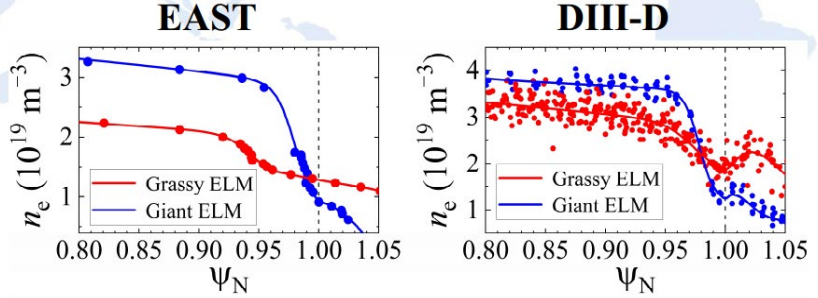


EAST/DIII-D Joint Experiments for Scenarios Development

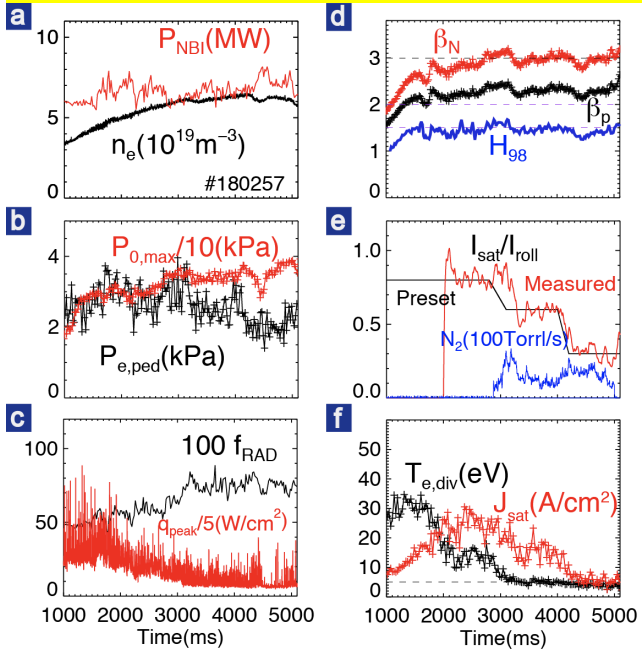
Main joint experiments:

- Full divertor detachment with improved core confinement on DIII-D;
- Grassy ELM regime on DIII-D;
- High confinement, high β_p on DIII-D;
- Long-pulse full non-inductive regime on EAST;

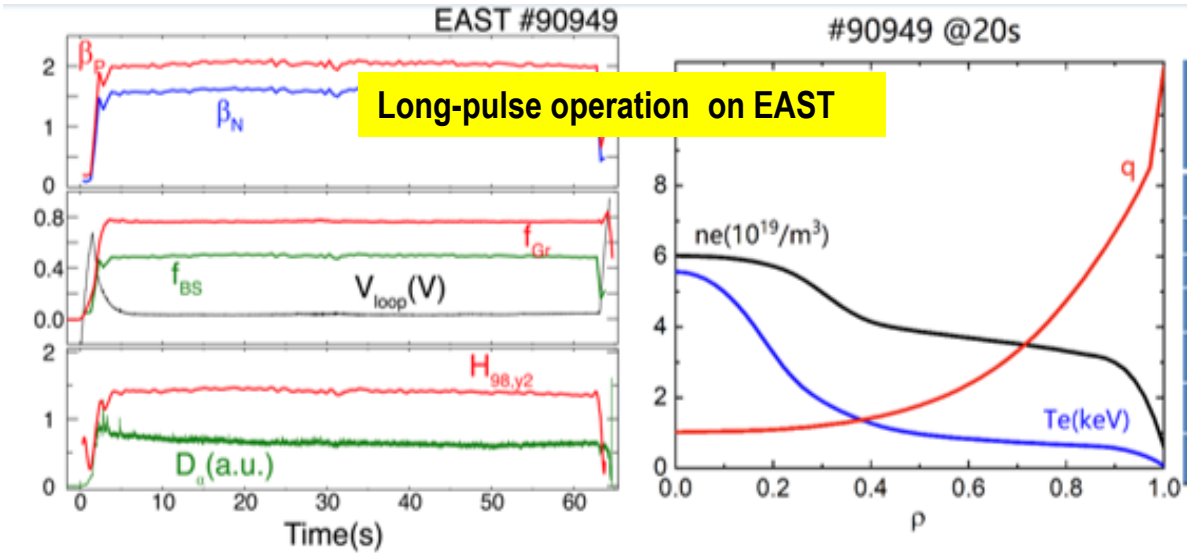
Grassy ELM regime on DIII-D



Full divertor detachment regime with improved core confinement on DIII-D



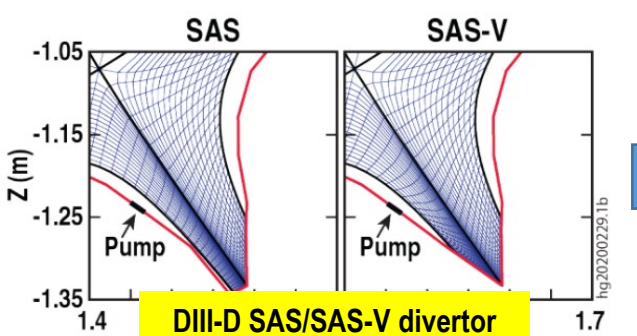
Long-pulse operation on EAST



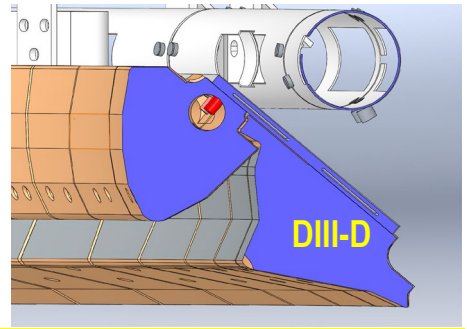
HL-2M/DIII-D Collaboration on Divertor

Main achievements:

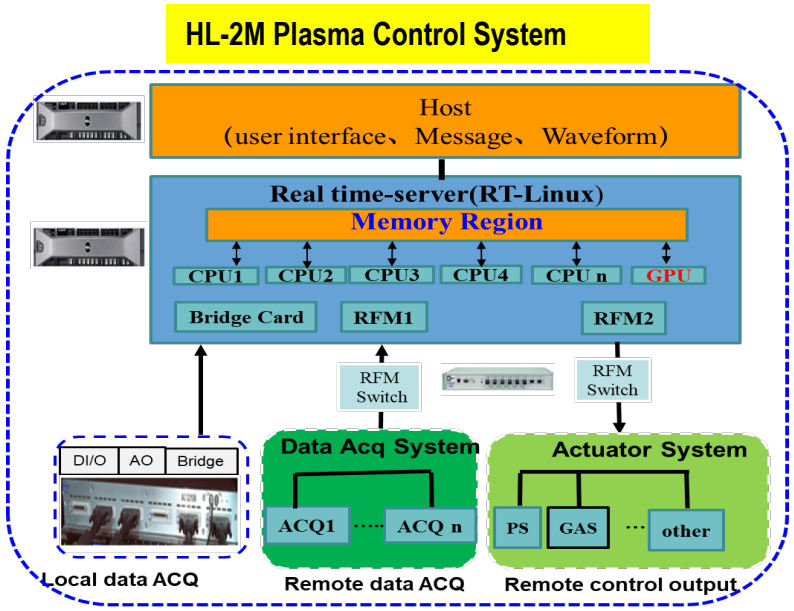
- Physical mechanism of detachment Cliff on DIII-D
- Adding extra particle reflecting to improve divertor design for HL-2M
- PUMP with Puff to screen impurity and control Z_{eff}
- Effect of drift HL-2M V Divertor
- Controlling target Heat loading and Core Zeff
- E× B drifts effect on HL-2M SF- controlling target Heat loading
- Consulting and control design support for deployment of HL-2M PCS
- Plasma equilibrium and discharge and forward discharge waveform Design Tools
- Advanced divertor configuration control

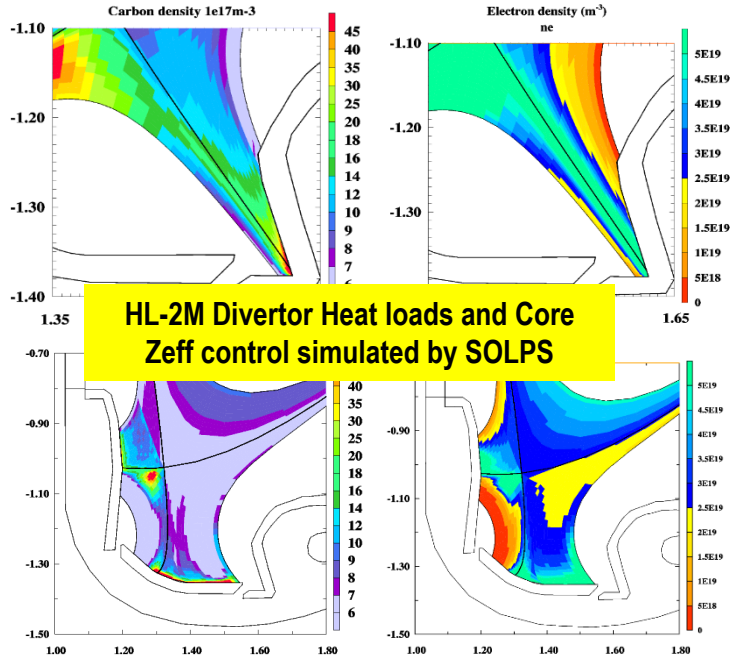


DIII-D SAS/SAS-V divertor simulated by SOLPS-ITER

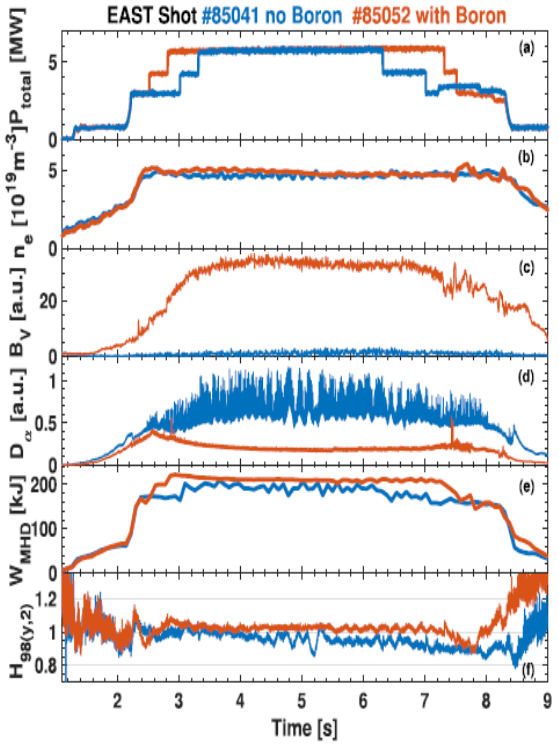


To be tested on DIII-D in Fall 2021





HL-2M Divertor Heat loads and Core Zeff control simulated by SOLPS

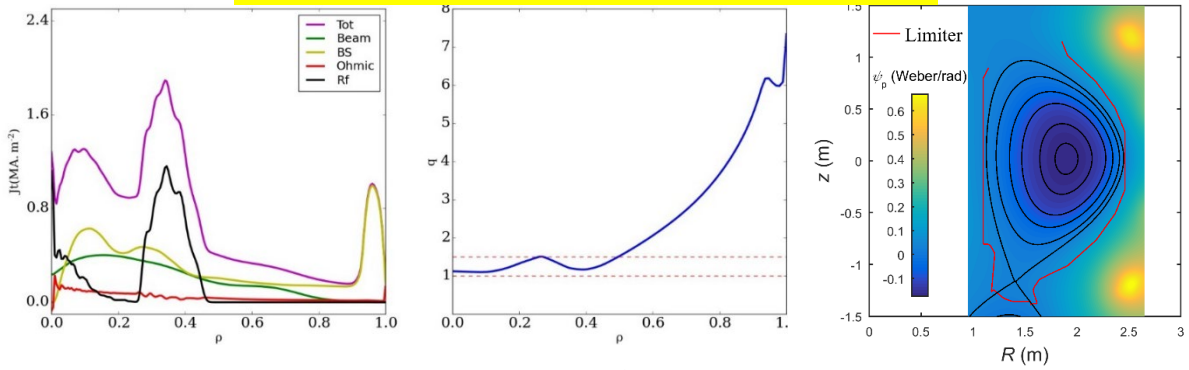


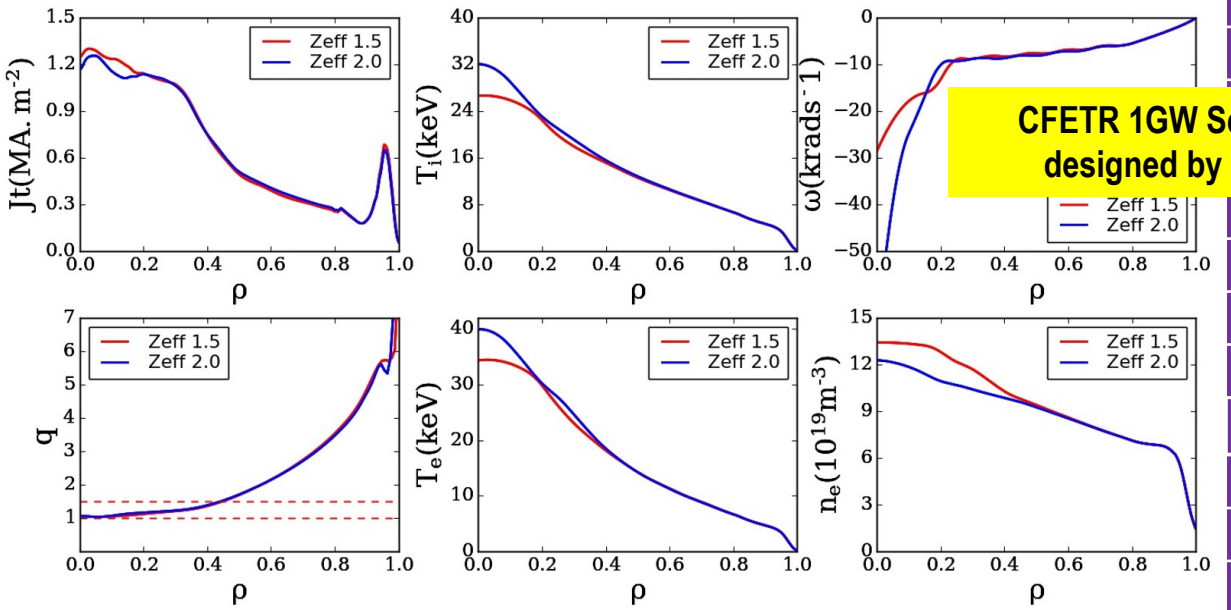
Integrated Modelling Preparation for CFETR/ EAST/HL-2A/ HL-2M Scenarios

Main achievements □

- Design of CFETR 1GW scenario by OMFIT **(with GA):**
- Design of HL-2M scenarios by kinetic-EFIT and OMFIT **(with GA):**
- Preliminary kinetic analysis of HL-2A experiment by kinetic-EFIT **(with GA):**
- Time-dependent simulation of the lower hybrid wave (LHW) with two frequencies on EAST **(with PPPL, MIT):**

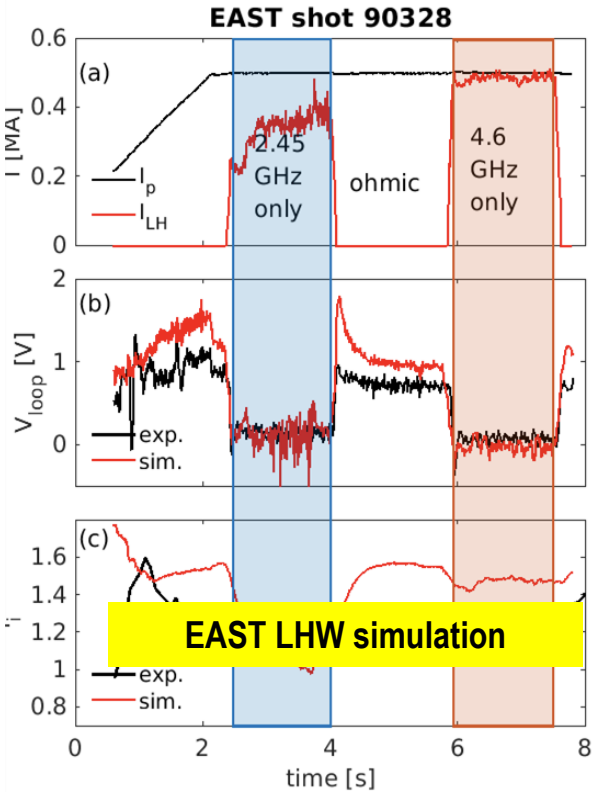
HL-2M hybrid scenario designed by OMFIT





CFETR 1GW Scenarios designed by OMFIT

Z_{eff}	1.5	1.75
P_{fus}(MW)	1110	1055
Q	11.6	11.0
P_{RF}(MW)	38	38
P_{NB}(MW)	54	54
	69	79.3
	13.0	13.0
$n_{e\text{-}ave}$	9.46	9.37
Te_0/ Ti_0	34.4/26.6	34.5/27.1
$H_{98,y2}$	1.00	1.01
β_N	2.35	2.28
τ_e	2.54	2.71
f_{bs}/f_{ohm} (%)	46.4/26.3	45.3/28.2
f_{NB}/f_{EC} (%)	18.9/8.4	18.7/7.9
q_0/q_{95}	1.1/5.5	1.2/5.4



EAST LHW simulation

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- Scenario developments (Steady-state, high beta, high bootstrap current fraction)
- Advanced divertor and control algorithms (snowflake, tripod configurations)

❒ **ITER-related Cooperation**

- Blanket engineering technology research and ITER TBM design

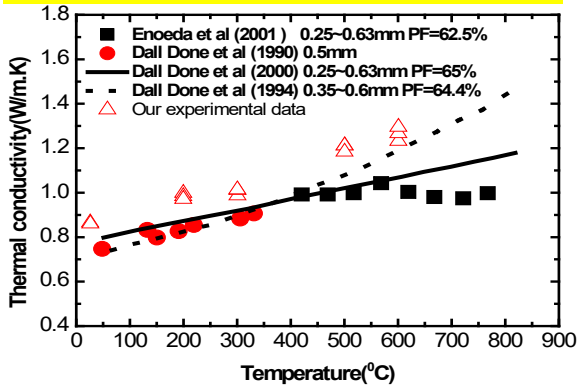
❒ Fusion-reactor and Nuclear Technologies

- Plasma-material interaction study

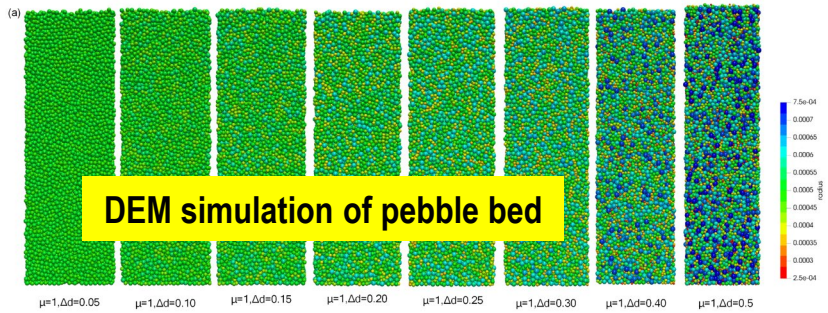
Collaboration on HCCB TBS and DCLL Blanket

- **R&D of Advanced tritium breeder (with UCLA)**
  - Composite Li_4SiO_4-Li_2TiO_3 pebble
  - New cellular solid breeder
- **Pebble bed technology (Experimental measurement and numerical simulation) (with UCLA)**
  - Thermo-mechanical properties: thermal mechanical, thermal expansion and creep, deformation modulus, crushed load and crush characteristics, etc.
  - Heat transfer performance: effective thermal conductivity, interface conductance, etc.
  - Flow characteristics of purge gas: Pressure drop, velocity distribution, etc.
- **Safety analysis (with INL)**
  - Benchmark of RELAP and MELCOR
  - Accident analysis cooperation for CN HCCB TBS
- **Tritium simulation technology (with INL)**
  - TMAP workshop for tritium simulation technology exchange
  - Tritium simulation benchmark
- **Modeling for DCLL blanket at Ha~104 (with UCLA)**
  - Based on the algorithm and platform developed at UCAS by Chen & Ni, a great achievement in direct numerical simulation of MHD flows in a whole DCLL blanket module under the fusion magnetic field with Ha~ 104 is performed.

Effective thermal conductivity



Thermal mechanical measurement



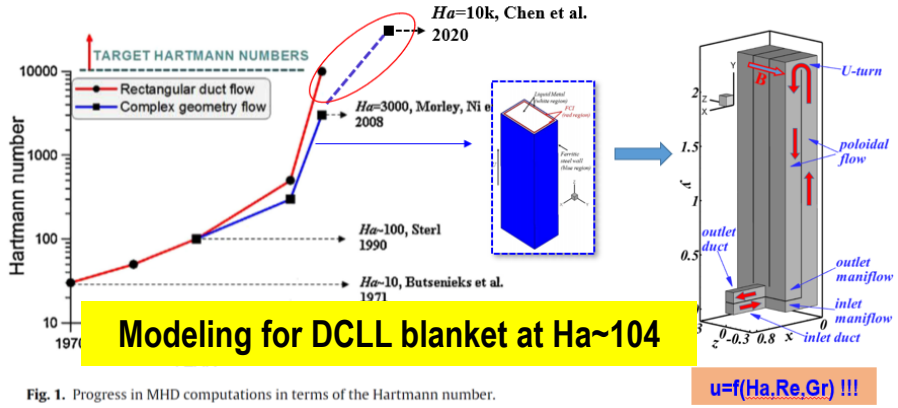


Fig. 1. Progress in MHD computations in terms of the Hartmann number.

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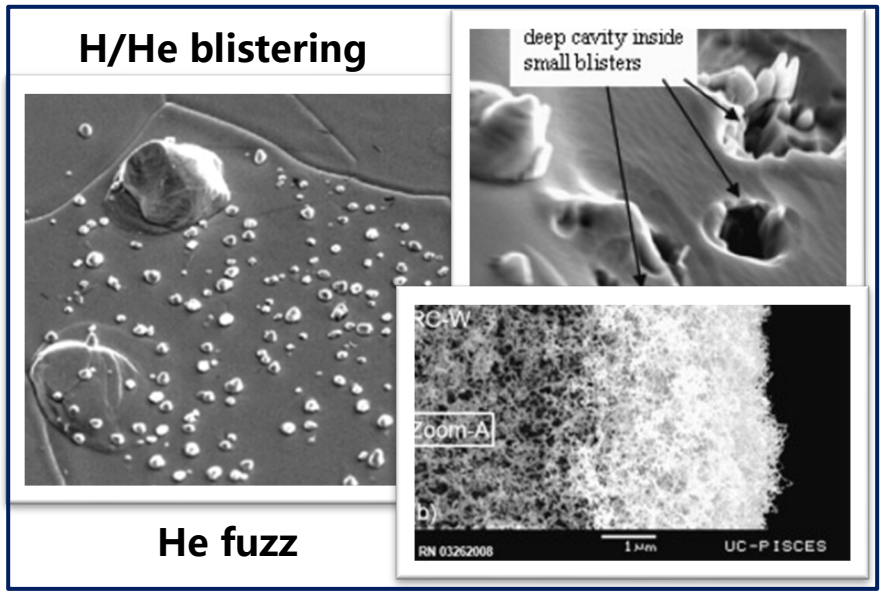
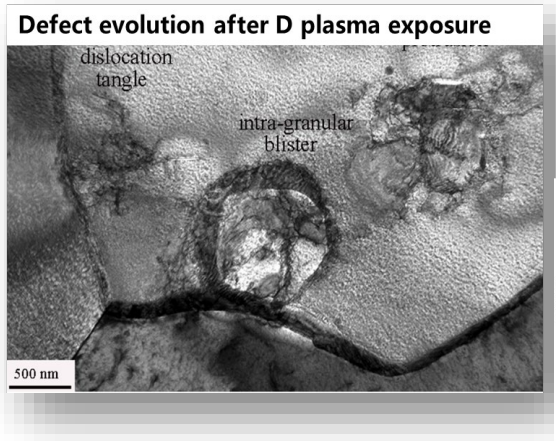
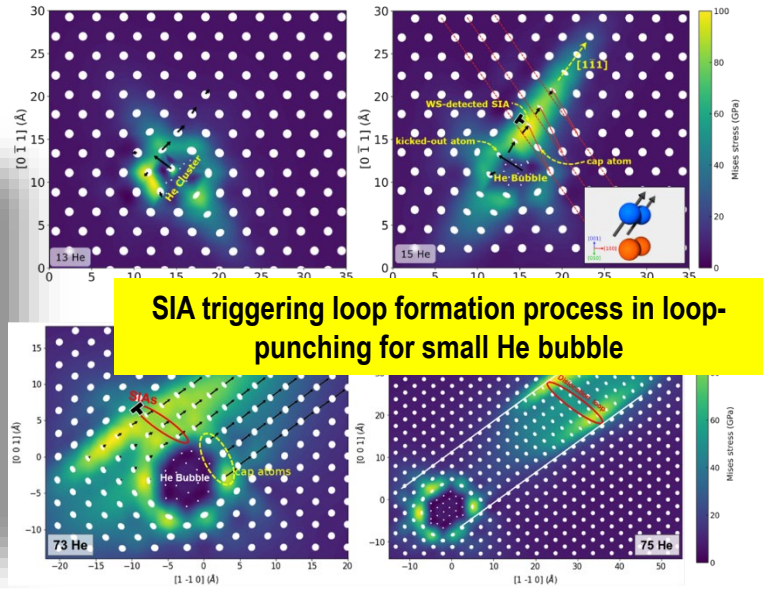
Collaboration on Plasma-Material Interaction

Participants from China: USTC, Beihang U, INEST, ASIPP, SWIP …



- **Deuterium Transport and Retention Behaviors in Advanced RAFM Steels (with UTK, ORNL)**
  - Gas-driven permeation (GDP) and thermal desorption spectroscopy (TDS) :
    - **Permeability:** 7 materials are with a narrow range.
    - **Diffusivity:** More scattering; Transition temperature representing for trapping effect; Abnormal diffusivity of FTa1 at 450° C.
    - **Solubility:** ODS show higher solubility than RAFM and CNA.
    - **Retention**: Positive relationship between deuterium retention and sink strength.
- **Energetics and dynamic behaviors of radiation defects in bcc metals (with U. Utah, U. Michigan, U. Tennessee)**
  - Electrophobic interaction, H-governed dislocation mobility
  - MD studies on He bubble growth in W
  - Helium-Defect interplay
  - Re ductilizing vs Re hardening
- **Developed liquid metal infused trenches (LiMIT) (with UIUC)**
- **PMI science research to enable a credible design for the future fusion energy systems.(with UCSD)**





SIA triggering loop formation process in loop-punching for small He bubble

Thank you very much!