Overview of International Collaboration on “Control and Extension of ITER and Advanced Scenarios to Long Pulse in EAST and KSTAR”


FESAC Meeting, Bethesda, MD
13-14 January 2016
Outline

• Overview of Scenarios and Control International Collaboration

• Summaries of task elements:
  – Scenarios task
  – Control task
  – Diagnostics and Actuators task
  – Simulation and Modeling task
  – Remote Collaboration task

• Selected Lessons Learned to date

• Conclusions
Overview of Scenarios and Control International Collaboration
Scenarios and Control International Collaboration Includes Many Institutions from Across the US Fusion Program

- **US Team and PI’s:**
  - GA (PI’s: D. Humphreys/A. Garofalo)
  - MIT (PI: P. Bonoli)
  - PPPL (PI: W. Solomon)
  - Lehigh U. (PI: E. Schuster)
  - LLNL (PI: C. Holcomb)
  - ORNL (PI: J-M. Park)
  - UCLA (PI’s: E. Doyle/D. Brower)
  - U. Texas (PI’s: K. Gentle/W. Rowan)

- **International Collaboration Teams:**
  - ASIPP/EAST: GA/MIT/PPPL/Lehigh/LLNL/UCLA/UT
  - NFRI/KSTAR: GA/MIT/PPPL/ORNL

- **Project Scope:**
  - Long pulse scenarios/control physics studies on EAST and KSTAR
  - Period of Execution: Summer 2013 – Summer 2016
Scenarios/Control Project Consists of Five Closely-Interacting Research Areas

- **Scenarios Task:** (Principals: PPPL, LLNL, GA, MIT, ORNL)
  - Develop understanding of scenario physics in long pulse SC devices
  - Extend experimental scenarios from US devices to EAST and KSTAR: advanced, high performance and ITER fiducial

- **Control Task:** (Principals: GA, MIT, PPPL, Lehigh, LLNL)
  - Advance control science needed for long pulse in superconducting devices
  - Demonstrate and quantify solutions experimentally on EAST and KSTAR

- **Diagnostics/Actuators Task:** (Principals: UCLA, UT, MIT)
  - Implement diagnostics and improve actuator physics understanding
  - Enable new measurements and actuator use for scenarios and control studies in long pulse devices

- **Simulations and Modeling Task:** (Principals: PPPL, ORNL, GA, MIT, LLNL, Lehigh)
  - Perform simulations for scenario development and modeling for control science and design

- **Remote Collaboration Task:** (Principals: GA, MIT, PPPL, LLNL)
  - Develop tools and methods to maximize effectiveness of remote collaboration and experimental participation

_Humphreys/SCReview/January 2016_
Scenarios/Control Project Consists of Five Closely-Interacting Research Areas

- **Scenarios Task**: (Principals: PPPL, LLNL, GA, MIT, ORNL)
  - Develop understanding of scenario physics in long pulse SC devices
  - Extend experimental scenarios from US devices to EAST and KSTAR: advanced, high performance

- **Control Task**: (Principals: GA, MIT, PPPL, Lehigh, LLNL)
  - Advance control science needed for long pulse in superconducting devices
  - Demonstrate and quantify solutions experimentally on EAST and KSTAR

- **Diagnostics/Actuators Task**: (Principals: UCLA, UT, MIT)
  - Implement diagnostics and improve actuator physics
  - Enable new measurements and actuator use for scenarios and control studies in long pulse devices

- **Simulations and Modeling Task**: (Principals: PPPL, ORNL, GA, MIT, LLNL, Lehigh)
  - Perform simulations for scenario development and modeling for control science and design

- **Remote Collaboration Task**: (Principals: GA, MIT, PPPL, LLNL)
  - Develop tools and methods to maximize effectiveness of remote collaboration and experimental participation

Diversity of subtasks in project structure provides mitigation of uncertainties in machine availability or performance:

→ Progress can still be made if experimental time or plasma performance are limited…

→ Interacting tasks can adapt flexibly to varying machine conditions or experimental program constraints…
Scenarios/Control Collaboration Is Highly-Integrated

- **5 subtasks interact closely:**
  - **Task 1:** Scenarios
  - **Task 2:** Control
  - **Task 3:** Diagnostics/Actuators
  - **Task 4:** Simulations
  - **Task 5:** Remote Collaboration

- **Example institution research links**
  - MIT/GA/Lehigh/LLNL: RF modules in control & scenario simulations; validation in experiment
  - PPPL/ORNL/GA/LLNL/Lehigh: Multiple cross-cutting simulations develop scenarios/control
  - UCLA/UT/GA/PPPL: diagnostics in PCS for critical RT control
  - ALL: coordinated experimental participation on-site…
Scenarios
Task Summary
Scenario Understanding Has Been Advanced Through Simulation and Analysis of DIII-D and EAST Experiments

- Joint experiments on DIII-D developed fully non-inductive high-betap scenario under EAST-relevant conditions

- PTRANSP simulations reproduce high betap discharges on DIII-D, predict requirements for scenario on EAST

- Annual EAST/DIII-D Joint Planning Workshops enable coordination between programs
  - 2nd EAST/DIII-D Joint Planning Workshop held at General Atomics, April 6-9, 2015

- Participation in EAST campaigns has included experiments toward development of high betap long pulse and I-mode scenarios
Joint EAST/DIII-D Experiments on DIII-D Developed a Fully Non-inductive Scenario with Reactor-relevant Performance Under EAST-relevant Conditions (PROVIDED FOR CONTEXT: NOT UNDER GRANT FUNDING…)

- \( I_p \) ramp rate consistent with EAST (~0.2MA/s)
- \( I_p, B_T, P_{\text{inj}} \) consistent with upgraded EAST capabilities
- ITB at large minor radius for excellent confinement
- Normalized fusion performance comparable to ARIES ACT2 and ACT4 DEMO design studies

Results presented in invited talk at APS 2015 by Qilong Ren

Latest DIII-D experiments (December 2015) show robustness of large-radius ITB vs. rotation and \( q_{95} \)

- 164538: Very high confinement (\( H_{98y2} \leq 1.8 \)) maintained with strongly reduced rotation
Extension of the DIII-D High Bootstrap Scenario to Long Pulse on EAST Has Begun

- Loop Voltage Control algorithm successfully developed and deployed on EAST plasma control system

- Discharges terminated by impurity influxes
- Limited in the available power
- Upcoming experiments in 2016 (starting in January) will take advantage of improved wall conditions and at least double H&CD power
  - $6 \rightarrow 12$ MW
Two days of experiments conducted in July together with GA and LLNL collaborators to develop steady-state plasmas.

Used newly developed vloop controller to drive loop voltage to zero and let current evolve based on non-inductive sources. Even with vloop=0, TRANSP finds profiles are far from steady-state.

TRANSP simulations underway to simulate current evolution and predict fully relaxed solution.
Extension of the I-Mode Scenario to EAST

- A. Hubbard & S. Wolfe (MIT) and X. Gao, T. Zhang, Z. X. Liu, G. Q. Li, Y. Yang, D.F. Kong, X. Han, & C. Huang (EAST).

- EAST / KSTAR are opportunities to extend the range for I-Mode exploration from $B_0 \sim 5.4$-7.9T to lower field (~ 2T), long pulse discharges.

- Have successfully simulated I-mode experiments under EAST conditions on Alcator C-Mod [$B_t = 2.75T$, $I_p = 500$ kA, $n_e = (5-6) \times 10^{19}$ m$^{-3}$] using $2\Omega_{CH}$ ICRF heating.

- In July, 2015 conducted initial experiments for the proposal “Development and study of I-Mode on EAST”.
  - The needed USN configuration was not permitted at that time, but we obtained LSN L-H comparisons
  - USN was used in the final week of EAST operation. Discharges are being analyzed to bracket the power range for the P(L-H) transition
  - I-Mode experiments are being proposed again for 2016 campaigns
Increased EAST Collaboration on Operations Topics May Contribute to Enhanced Machine Availability/Productivity

• Challenges in machine availability impacted experimental collaborations on EAST and KSTAR 2013-15, and have motivated new collaborative focus on operations

• Visits to EAST in October 2015 focused on Neutral Beams, Plant Systems, and Operations Collaboration:
  – Two week visit to ASIPP/EAST by two DIII-D beam scientists (J.T. Scoville, B. Crowley), and DIII-D Tokamak Operations director (A. Kellman)
  – NB focus on ion source conditioning techniques and procedures, identification of opportunities for improvement of EAST beam operational performance
  – General operations focus on major hardware systems, operations procedures, identification of opportunities for operations improvement

• Future Plans for EAST/DIII-D Neutral Beam and Operations Collaborations:
  – Operational assistance from DIII-D NB and ECH groups on optimizing performance, reliability, and safety; participation in beam spectroscopy studies...
  – DIII-D support on current operations challenges: divertor performance, Li removal, graphite tile analysis and potential exchange
  – Joint work on divertor development (~2-year time frame)
  – Collaborative development of negative ion source
Control
Task Summary
Control Research Task Studies EAST Controllability and Develops Algorithms to Support Scenario Goals

- EAST model/simulation development for control analysis:
  - Updated EAST conductor/structure models
  - Validation experiments
  - Control simulation development with new H/CD modules

- Specialized control algorithms for scenarios:
  - Vertical control optimization
  - Off-normal/fault response algorithms to prevent VDE
  - Loop voltage control for non-inductive scenarios

- Control research and novel configuration studies:
  - ITPA MHD joint experiment controllability research: experiment done during EAST 3rd shift
  - Disruption simulation, RE mitigation and control
  - Development of disruption-free rampdown control

Updated EAST system model 2015

Simulated EAST VDE Experiment

Experimental growth rates agree with model for L-mode but not for H-mode
Control-oriented Transport Model for Current-profile Control Design (Fast Simulation and Model-based Synthesis) in EAST

- **Control-oriented Transport Code for Fast Plasma-Profile Prediction in EAST**
  - EAST’s magnetic geometry integrated in magnetic diffusion equation (MDE) solver
  - NB and LH H&CD models tailored to TRANSP simulations
  - Integration of MIT’s LH current drive & heating source models
  - Development of heat transport equation solver

- **Optimization Codes for Systematic Scenario Planning**
  - Nonlinear optimization algorithm coupled with control-oriented transport code
  - Systematic model-based approach to scenario planning in EAST

- **Model-based Feedback Control Design for Current Profile Regulation**
  - Model Predictive Control (MPC) approach enables real-time optimization
  - Observer exploits model to filter measurement “noise” not consistent with physics
Snowflake Divertor (SFD) Control Algorithm Installed and Tested on the EAST Plasma Control System

- Feedback system uses fast real-time snowflake identification algorithm based on local expansion of the Grad-Shafranov equation to locate the two X-points
  - Sensitivity of SFD formation on Poloidal Field (PF) coil is calculated
  - PF coil currents needed for desired SFD configuration are calculated based on sensitivity

- Simulation of controller performed
  - Initially, angle of the SFD formation ($\theta$) $\sim$20° and control asked to adjust to 0° while keeping separation roughly constant
  - Currents at the PF coils that are closest to the divertor region are updated continuously to achieve the final state

New SFD controller can maintain target geometry, overcoming non-stationarity observed in feedforward implementations
Control for Long Pulse Disruption-Free Operation in EAST

- R. Granetz & A. Tinguely (MIT) and Wang Bo (USTC)
- Primary activity has been the installment of a disruption database on EAST, which is now fully functional and automatically populated with new disruptions:
  - This disruption database was the first SQL database of any kind at EAST.
  - Has involved regular visits to EAST by R. Granetz (3 per year).
- Developed disruption warning databases for all C-Mod and EAST discharges in 2015:
  - Database is modelled after S. Gerhardt NF 53, 063021 (2013).

44% of all disruptions have Ip_error ≤ -30 kA
Studies with KSTAR Have Quantified Controllability and Implemented Algorithms to Support Scenario Goals

- Specialized control algorithms developed for ITER Baseline scenario:
  - New isoflux control scheme for ITER shape
  - Decoupled fast/slow vertical control loops
  - Model-based multivariable shape/x-point control
  - Model-based realtime feedforward coil current trajectory calculation

- Controllability studies extended:
  - New “Release and Catch” experiments updated controllability scaling for 2015 passive plate system
  - 2013: $\Delta Z_{\text{MAX}} \sim 1.80 \pm 0.80 \text{ cm} \sim (185 \pm 80)/\gamma z$
  - 2015: $\Delta Z_{\text{MAX}} \sim 2.47 \pm 0.94 \text{ cm} \sim (274 \pm 104)/\gamma z$

Disabling and Restoring Vertical Control Directly Measures Maximum Controllable Displacement $\Delta Z_{\text{MAX}}$

New Isoflux Control Scheme for ITER Baseline in KSTAR
• Slow z motion (t~100 ms) due to shape control using superconducting coils can cause the IVC coil to saturate
  – Lose ability to perform fast control
• Avoided by employing a high-pass filter (2 Hz) on the fast z error
• Use of existing flux loops in fast z estimator limited by passive filtering; improve if instrument flux loops to measure relative flux

Improved z-control achieved, aiding in realization of ITER baseline shape. Further improvements possible with new signals.
Diagnostics and Actuators
Task Summary
Diagnostic Development on EAST: UCLA Faraday-Effect Polarimetry-Interferometer Diagnostic

- **POINT: POlarimeter-INTerferometer system**
  - time resolved $J(r)$ and $n_e(r)$ profiles throughout discharge for all EAST operation scenarios
  - 2015: upgraded from 5 to 11 chords
  - 2016: polarimeter calibration optimization
  - 2016: provide constraints for EFIT and integrate realtime current density profile data into PCS

*Fast profile changes at L-H transition*

11 chord: horizontal view

POINT provides realtime measure of current and q profile evolution during long-pulse, high-performance EAST plasma operation
Diagnostic Development on EAST: UCLA-USTC Microwave Reflectometer

- **Profile reflectometer** covers 33-75 GHz, with density range of ~0-6.5x10^{19} m^{-3}
  - Also 50-75 GHz 8-channel Doppler backscattering (DBS) system for turbulence studies
- **System is collaboration** between the University of Science and Technology of China (USTC) and UCLA
  - China funded hardware and construction
  - UCLA designed, constructed and tested new microwave front-end, and provided 8-channel source/receiver system for DBS
- **New microwave front-end** installed on EAST in May 2014
- **New US-supplied** microwave transmission line, source/receiver electronics installed on EAST over summer/fall 2014
- **System commissioning** and plasma data in 2015 – first profiles
Diagnostic Development on EAST: UT CXRS

- Providing neutral beam modeling for CXRS and MSE using the ALCBEAM code
  - Used for diagnostic design
- Optical system developed for CXRS calibration
  - Accept light from one plasma chord
  - Split into CXRS spectrum and BES spectrum
  - Send to appropriate spectrometer for analysis
- Spin off: spectral MSE measurements are alternate application of spectrum used for CX calibration
  - UT team providing analysis and design
- EAST MSE synthetic diagnostic developed
  - Uses fully 3D model of beam and view geometry
  - Spectral MSE performance analyzed
  - Applications to polarization MSE filter design
- Collaboration-Exchange
  - ASIPP scientist will visit to acquaint with synthetic diagnostic and C-Mod spectral MSE system
- ITER JEX9 activity
  - Experiments to compare spectral MSE and polarization MSE on EAST in 2016
Diagnostic Development on EAST: ECE

- **Instrument for calibration of ECE**
  - In-situ calibration source for ECE
  - Spin-off from our development of sources for ITER ECE

- **Specially designed in-vessel optics to allow use of calibration source**
  - UT-IFS conceptual design; ASIPP, mechanical design

- **Calibration yields measurement of $T_e$ independent of other diagnostics**
  - Results presented: Chinese Physical Society Fall Meeting

- **PID controller recently developed for automated control of calibration**

- **Active Collaboration**
  - Dr. Liu Yong, Mr. Ang Ti

- **Collaboration Exchange**
  - Postdoc from EAST ECE program will visit for one year to collaborate on common thermal transport experiments

- **On-site at EAST**
  - UT-IFS Engineer, March - June
  - Two UT-IFS Physicists in April

**In-Situ Calibration Instrument**

**Typical Calibration Data**
EAST: LHCD Efficiency at 2.45 GHz Decreases Rapidly Above Densities Needed for High Performance Regimes and Physical Mechanisms are Under Study

- Ray tracing / Fokker Planck simulations with GENRAY / CQL3D indicate that collisional losses of LH power in the SOL can be significant:
  - C. Yang et al, PPCF (2014) and B. Ding et al., accepted for publication in NF (2015).
- LHRF power deposition is sensitive to details in the structure of the coupled wave spectrum:
- Have worked with EAST Team to locate RF probes inside the EAST vacuum vessel to detect PDI spectra and to compute PDI growth rates and decay spectra:
  - Indicates significant pump wave depletion at 2.45 GHz in discharges with poor lithiation.

Availability of both 2.45 GHz and 4.6 GHz LHRF systems on EAST provides a unique opportunity to study the frequency dependence of LHCD as the density is increased.

Humphreys/SCReview/January 2016
Analysis of LHRF Actuator for KSTAR Indicates Off-Midplane Launcher Will Provide Improved Access to High Performance H-mode Plasmas Relative to Equatorial Launcher

- S. Shiraiwa, P. T. Bonoli, J. C. Wright, R. Parker, and G. Wallace (MIT) and Y. S. Bae (KSTAR)
- Detailed analysis carried out for with GENRAY / CQL3D to assess LH wave launch in KSTAR from the top position near the upper X-point:

\[ n_e(0) = 5 \times 10^{19} \text{ m}^{-3}, \quad T_e(0) = 5 \text{ keV}, \quad B_t = 2 \text{ T} \]
\[ f_0 = 5 \text{ GHz}, \quad n_{//} = 2.3 - 2.7 \]
\[ \eta_{CD} = 0.12 - 0.18 \left(10^{20} \text{ A/W/m}^2\right) \]

Simulation/Modeling
Task Summary
CORSICA Progress:

- Identified ~half dozen EAST discharges from July 2015 with various heating and current that will be used for benchmarking CORSICA.
- Fixed boundary EAST simulations started based on modification of functioning ITER cases.
- More debugging needed: finding and removing ITER-specific items.
- Developed new 64-bit version of CORSICA required for high-resolution equilibria.
- Preparations underway for presenting a class on the use of Corsica at EAST, January 2016.
  - Lectures and hands-on.
  - Tom Casper participating, including lectures on using Corsica for his ITER studies.
Development of Control-Level LHRF Model for EAST H/CD Control Design and Analysis

- S. Shiraiwa, P. T. Bonoli (MIT), M. Walker, D. Humphreys (GA), and E. Schuster (Lehigh)
- Established a first of its kind profile database for LHCD in EAST based on 880 ray tracing / Fokker simulations:
  - To be used in scenario simulation and control studies by GA (TokSys) and Lehigh.
  - GENRAY / CQL3D simulations run on the python-based πScope widget at MIT.
  - Simulations scan a parameter space in $T_e(0)$, $n_e(0)$, and $I_p$, at fixed $B_0$ and $n_{//}$.
  - Will produce a similar database for C-Mod and test against experiment.

$B_0 = 2.24\, \text{T}$

$f_0 = 2.45\, \text{GHz}$

$n_{//} = 2.1$

$I_p = 0.48\, \text{MA}$

$n_e(0) = 5 \times 10^{19}\, \text{m}^{-3}$
ICRF Actuator Model Development for EAST – crosscutting with Int. Collab. on Development of Long-Pulse RF (Wukitch)

- E. Edlund, P. T. Bonoli, M. Porkolab, S. Wukitch (MIT) and X. Zhang (EAST)

- Original goal: build a control level actuator model from parameter scans in the TORIC solver:
  - Total coupled power & profiles
  - Scan density, plasma composition, antenna frequency and phasing, SOL width and scale length

- Theoretical analysis suggests good single pass absorption for ICRF power.

- However, full-wave simulations indicate poor ICRF wave coupling, especially for larger \( n_\phi \) and lower density where the ICRF wave accessibility condition is not well-satisfied:
  - Evidenced by eigenmode behavior in loading as density is varied.

- Points to a fundamental problem with the original ICRF antenna design → coupled \( k_{//} \sim (n_\phi / R) \) is too high.

\[
\begin{align*}
\text{Loading (Ohm)} & \quad \text{Loading (Ohm)} \\
n_e & = 0.3 \times 10^{20} \text{ m}^{-3} \quad \text{(typ. EAST)} \\
n_e & = 1.2 \times 10^{20} \text{ m}^{-3} \quad \text{(C-Mod like)}
\end{align*}
\]
Simulations of Advanced Scenarios Accelerate KSTAR Research Program

- **KSTAR scenario modeling**
- **Optimize KSTAR H/CD upgrade choice**
  - FASTRAN/IPS predicts off-axis NBCD is crucial to achieving high $\beta$ Steady State scenario at KSTAR

**Extend DIII-D Steady State scenarios to KSTAR long pulse**

- Export *DIII-D high li scenario* to KSTAR
- High $\beta_N \sim 3$ operation demonstrated at $li \sim 1.5$, but transiently

---

**Preliminary design of KSTAR off-axis NBI**

**2015 KSTAR high li SS discharge**

- $\beta_N = 3$
- $\ell_i = 1.5$
Remote Collaboration
Task Summary

**GA Remote Control Room:**
- Display hardware and software to provide control room experience remotely
- Accommodates 8 scientists and remote communication support staff
- Audio/video connection to EAST control room, headphone links to key individuals

**Operations and physics data display resources:**
- Shot cycle, countdown clock display
- Realtime in-vessel view video image from EAST
- Pseudo-realtime signal traces and plasma boundary evolution displayed during shot (~100 ms delay)

**GA Science Collaboration Zone:**
- Utilizes 80% of a 1 GB/s network between GA and ASIPP through specialized tools
- Maximum network utilization allows between-shot transfer of EAST data
- Data mirror at GA serves all US collaborators

General Atomics Remote Control Room Supports 3rd Shift Operation of EAST by US Scientists

Between-shot data display
Shot & data Status info
Realtime displays (during shot)

Zoom & H.323 communication between control rooms

GA EAST Data Repository
Remote 3rd Shift Experimental Operation Successfully Demonstrated for Two Consecutive EAST Nights in 2015

- **Remote operation is a research activity itself:**
  - Experimenting with approaches to running remote experimental physics sessions...
  - What are performance specs needed for data display infrastructure?
  - How to best communicate and do science?

- **Some lessons learned to date:**
  - Higher refresh rate needed in boundary display to correlate with realtime video camera
  - Communication between remote/on-site physics operators (PO) requires sound isolation
  - Remote programming of EAST Plasma Control System with confirmation check by EAST PO is very efficient

- **3rd Shift Vertical Controllability Experiment 2015:**
  - Triggered VDE’s to assess vertical growth rate, nonlinear evolution
  - Plasma vertical Release & Catch to directly assess maximum controllable displacement
  - EAST superconducting PF, Cu in-vessel coils provide unique environment for controllability
Lessons Learned, Scientific Output, and Conclusions
Many Important Lessons Have Been Learned in Scenarios/Control International Collaboration

- US collaborative role has been highly beneficial to EAST and KSTAR programs, enhancing productivity and providing focused results of specific importance to US

- Effectiveness of EAST/KSTAR collaborations depends significantly on sufficient planning and preparation for visits and remote experiments

- Machine availability and performance have been challenges for experimental studies on both EAST and KSTAR in the project period 2013-15, however:
  - Diverse project structure (i.e. beyond experimental participation) enables progress even when machine availability/performance are limited
  - Increased US involvement in operations on EAST may contribute to improved productivity

- Development of methods and policies for multi-institution, international coordination of data ownership and publication responsibilities have been key to collaboration

- Long-term travel to China and Korea remains challenging, but multiple ~2 week visits per year are optimal for most US scientist collaborations on-site at EAST and KSTAR
  - Diagnostics collaborations have tended to require longer, sustained visits
  - Remote collaboration tools have dramatically increased US impact when scientists are off-site
Rich Scientific Output is Resulting from Collaboration: Publications and Presentations (1)

- X. Gong, “Development of fully non-inductive scenario at high bootstrap current fraction for steady state tokamak operation on DIII-D and EAST,” IAEA FEC 2014, EX/P2-39
Rich Scientific Output is Resulting from Collaboration: Publications and Presentations (2)


Rich Scientific Output is Resulting from Collaboration: Publications and Presentations (3)

- D. Mueller et al, “Improvements in the fast vertical control systems in KSTAR, EAST, NSTX and NSTX-U”, PPC/P8-17, IAEA (2014)
Conclusions: Scenarios and Control Collaboration Has Been Very Successful

- Scenario understanding is advancing through transfer from US devices to EAST/KSTAR, enabled by simulations and analysis

- Control science understanding has advanced through EAST/KSTAR algorithm development and experiments

- Diagnostics development on EAST are enabling measurements critical to scenarios and control physics

- Actuator modeling is contributing to improved utilization on EAST and high-fidelity model-based control development for both EAST and KSTAR

- Simulations of advanced scenarios are accelerating EAST and KSTAR research programs

- Remote collaboration research and development is on track to enable access by US scientists to entire EAST 3rd shift