Collaboration on 3D MHD and Long Pulse Stability Physics and Control in KSTAR

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for the

KO-US Bilateral Collaboration on KSTAR Research

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International Collaboration Discussion Meeting

April 23rd, 2012
PPPL

Recent DOE Proposal Solicitation Defines Scope and Requirements

- "Collaborative Research in MFES on Int'l Facilities"
  - FESAC Report cited, one of the major scientific challenges identified: "Achieving high performance core plasma regimes for long-pulse"
  - Proposals from multi-institutional teams (2 or 3 teams to be chosen)
  - $6M total/yr (3 years) contested
    - Est. ~ 6 awards to national labs, ~ 8 universities and industry
- Specific topic areas: (from pages 4-5)
  - Transport
  - Long Pulse Control (incl. mode stability physics, ELMs, 3D aspects)
  - Plasma Wall Interaction
  - Magnetic Divertor Optimization
  - Auxiliary Systems
    - Topical area "Disruption PAM" (topic #5, pg 2)

Submission Schedule

May 14: Pre-proposals due

May 21: DOE 1st approval

Jun 21: Full proposals due

Some recent history preparing us for this task

- US collaborators have been actively working on KSTAR for more than 5 years
  - Columbia U., GA, ORNL, PPPL, UC Davis, UW, etc.
- Sabbagh appointed by H. Neilson as "PPPL KSTAR Physics Leader"
  - 22 years experience (post Ph.D.) as US collaborator, 5 years experience as funded KSTAR collaborator
    - Columbia U. group: 2 KSTAR papers, 2 IAEA FEC presentations, papers (aiming for 3rd IAEA FEC 2012, 3rd NF paper in prep.), 2 XPs run to date
    - Close ties with NFRI and POSTECH colleagues
  - SAS has established / is carrying out focused PPPL plan for FY2012 to best enable PPPL for KSTAR research
  - Appropriate connections to NFRI colleagues made
    - Consolidated at KSTAR Research Conference Feb 2012 (Muju, Korea)
    - 7 PPPL team physicists sent to Muju conference – largest US presence

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Collaboration on 3D MHD and Disruption Control of Steady-State Plasmas

- Addresses key KSTAR Milestones (including)
  - Long-pulse H-mode
  - ELM mitigation
  - Disruption avoidance and associated research (e.g. mode control)
  - Application of results to ITER
- Collaboration Approach
  - Coordinated partnership between institutions aiming at related physics goals
- Organization and Partnerships
  - Task agreement NFRI-PPPL: Columbia U., and POSTECH partners
  - Coupled, complementary research proposal by Columbia University
  - Key research/analysis and diagnostics by POSTECH

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KSTAR Goals/Capabilities 2012-16 (TENTATIVE)

Campaign	2012	2013	2014	2015	2016
Operation Time	'12. 7 ~'12. 12	'13. 3 ~'13. 9	'14.1 ~'14. 9	'15. 7 ~'15. 12	'16. 7 ~'16. 12
Experimental goals	• H-mode (10 s) • Isoflux control • ELM mitigation	• H-mode (20 s) • 3-D field physics (RMP)	• H-mode (50 s) • Hybrid scenario • Disruption	• Divertor Physics • AT Physics(Bootstrap) • Profile control • Metal(diverter) • RWM	• Divertor physics • Metal wall (PFC/diverter) • TBM simulation test
Operation Parameters	• B_T ~3.5 T • I_P > 1 MA • t_P > 10 s • Ti ~ 3 keV	• B_T ~ 3.5 T • I_P > 1 MA • t_P > 20 s • Ti ~ 3 keV	• B_T ~ 3.5 T • I_P > 1 MA • t_P > 50 s • Ti ~ 5 keV • β_N ~ 1 at 3T • f_{BS} ~ 0.3	• B_T ~ 3.5 T • I_P ~ 2 MA • t_P > 50 s • Ti > 5 keV • β_N ~ 1.65 at 3T • f_{BS} > 0.5	• B_T :~ 3.5 T • I_P ~ 2 MA • t_P > 50 s • Ti > 5 keV • β_N ~ 1.86 at 3T • f_{BS} > 0.5
Heating & Current Drive	• NBI : 3.5MW • ECH(84/110G):0.5MW • ECCD(170G): 1MW • ICRH : 1.5MW • LHCD(5G) : 0.3MW	• NBI : 3.5MW • ECH(84/110G):0.5MW • ECCD(170G): 1MW • ICRH : 1.5MW • LHCD : 0.5MW	• NBI : 4 MW • LHCD : 1 MW • ECH(84/110G):0.5MW • ECCD(170G): 1 MW • ICRH : 1.5MW	• NBI : 6 MW • LHCD : 2 MW • ECCD(170G): 2MW • ICRH : 1.5MW	• NBI : 8 MW • LHCD : 2 MW • ECCD(170G): 2MW • ICRH : 1.5MW
Diagnostics	• **MIR / 2nd ECE-I** • **Thomson (100Hz, 5J)** • **Reflecto. / FIR (1ch)** • **IRTV (Div.) / BES** • **Image Bolometer**	• **MSE** • Li-beam /DBS • Thomson(25ch)	• **CES (poloidal)** • **Thomson(40 ch)** • **XICS(upgrade)**	• **Thomson (Div.)** • **Bolometer (Div.)**	• **Neutron profile** • **VUV**
Magnetic Control	• **TF : 3.5T, PF : 6 Wb** • **IVC, RMP** • **Grid : 100 MVA**	• **TF : 3.5T, PF : 10 Wb** • **IVC, RMP,IRC** • **Grid+MG : 200 MVA**	• **TF : 3.5T, PF : 10 Wb** • **IVC, RMP,IRC** • **Grid+MG : 200 MVA**	• **TF : 3.5T, PF : 10 Wb** • **IVC, RMP,IRC, RWM** • **Grid+MG : 200 MVA**	• **TF : 3.5T, PF : 10 Wb** • **IVC, RMP,IRC, RWM** • **Grid+MG : 200 MVA**
PWI	• **Cryo pump(temperal)** • **PFC**	• **Cryo pump(normal)** • **PFC water cooling**		**+Diverter upgrade** **+Pellet injector** **+Radiative divertor**	Muju
Hardware		• **Cryo pump(기간)** • **PFC water cooling**	**+klystron(delivery)** **NB ion source**	**W-diverter** **NB PS**	**OFF axis NB(2MW)**

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Collaboration to address these topics

Focus on MHD stability and transport aspects to help fulfill KSTAR milestones

- Overview of Research
  - Characterize beta and pulse-limiting instabilities impeding long pulse H-mode
    - Assess error field and optimize correction for long-pulse
    - Evaluation of NTM, RWM, and kink/ballooning modes at high β_N, long pulse
    - Plasma startup/control improvements and NBI support enabling pulse extension
  - Assess ELM mitigation including plasma response in long pulse H-mode
  - Alter plasma rotation by 3D fields and assess access to ITER-relevant regime
  - Assess approach to mode stability boundaries and active mode control under long-pulse profile evolution
  - Generate transport analysis to understand profile evolution/influence of 3D field

- Comments
  - KSTAR/NSTX synergy: large difference in aspect ratio gives best opportunity to understand and test underlying physics by comparing results
  - Near-term program plan tasks (FY12-13) need completion to ensure basic operational, diagnostic, analysis capabilities to support longer-term goals

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Multi-staged approach: First establish modes/profiles; then move to mode avoidance/control research

- Diagnostic/analysis support, etc. (2012-13)
  - Thomson scattering (LeBlanc): Connection made to Jonga Lee
  - CXS (Grierson): Connection made to Wonha Ko
  - TRANSP (Budny/Sabbagh): Connection to Jinyong Kim / L. Terzolo
  - Efficient data transfer/access (Carroll): Connection made to M. Park
  - XRC (Hill/Bitter): Existing connection with Sang Gon Lee
  - NBI (Grisham): Existing connection with Y.S. Bae
  - PPPL Theory: (CS Chang): Existing connection with G.Y. Park
- Further support/upgrades/needs identified (2012-13)
  - Power systems (Ramakrishnam)
    - Control power supplies/design: Connection to be made to H.L. Yang, J.H. Choi starting 2012 (suggested by Y.K. Oh)
  - Magnetic diagnostics (Sabbagh)
    - Upgraded error field/control sensors: Connection made to J.G. Bak

starting now

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Multi-staged approach: First establish modes/profiles; then move to mode avoidance/control research

- Mode Characterization / analysis / control needs (2012-2014)
  - Startup/equilibrium control (Mueller/Kolemen)
    - Optimization of real-time plasma control and startup, isoflux control
  - Definition of needs for control (Sabbagh/HK Park/JK Park/YS Park/Kolemen)
    - Design / support implementation of diagnostic upgrades needed for control
  - Rotation alteration (ITER relevance/stability): (Sabbagh/YS Park)
  - Scenario / transport modeling: (J Menard, C.S. Chang, et al.)
- ELM Mitigation (2012-)
  - ELM mitigation and intensification analysis vs. applied field configuration, phase; examination of threshold conditions (JK Park)
  - ELM control analysis by theoretically optimizing magnetic configurations (enabled by patch panel) and available profile modification (JK Park)
- Mode and Error field Control (2013-2016)
  - Definition of dynamic error field spectrum and methods to minimize (JK Park)
  - Mode stabilization and control (Sabbagh/YS Park/Hosea/Ellis)
- Associated experiments: JK Park, YS Park, Sabbagh, Mueller

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POSTECH Program (from H.K. Park)

- New/advanced approach for understanding H-mode physics and ELM dynamics
  - New approach to understand H-mode related transport physics – 2-D MIR/3-D ECEI/ 2-D BES
    - Role of recycling and contact points of divertor/limiter in L-H transition
    - Role of in-out flux of energy flux and particles in confinement
  - New approach to understand ELM physics and study first principle based mitigation/suppression methods using 3-D visualization and 2-D active control
    - Coupling to PPPL/Columbia U. work on mode stability/control
- Present KSTAR results/analysis motivate our plan
  - Recent visualization of ELM structures – growth rate, saturation and burst
  - Recent visualization of the RMP assisted suppression and mitigation of ELMs – mode structure change, etc.

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Analysis begins with existing data, reconstructions, models; advances to long-pulse, high β_N experiments

- 3D Physics and Stability
  - IPEC (JK Park): ELM mitigation, error field with plasma response
  - TRIP3D, SURFMN (YS Park): ELM mitigation
  - MISK/DCON (Berkery/Sabbagh): Kinetic RWM stability analysis
  - NTM analysis (YS Park/Sabbagh)
  - NTV analysis (Sabbagh/JK Park/YS Park)
  - KSTAR EFIT reconstructions/development (Sabbagh/YS Park)
  - XGC/M3D-C1: 3D field penetration and ELM analysis (CS Chang/Jardin)
- Scenarios and Transport
  - TRANSP (Budny, et al.): Shot modeling and development
  - TSC/TRANSP (Menard, et al.): Scenario development, including fully non-inductive, with comparison to NSTX-U
  - XGC codes (C.S. Chang): Kinetic G.C. / turbulence transport (3D field effects)
- Control
  - VALEN (Bialek/YS Park): RWM / dynamic error field control analysis
  - IPEC (JK Park): Dynamic error field reduction
  - RWMSC (Sabbagh/YS Park): State-space RWM analysis / feedback control
  - Startup/equilibrium control analysis, rtEFIT (Kolemen/Mueller)

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The PPPL/Columbia/POSTECH Collaboration on KSTAR aims to address/support several key device milestones

- Addresses key KSTAR Milestones (including)
  - Long-pulse H-mode
  - ELM mitigation
  - Disruption avoidance and associated research (e.g. mode control)
  - Application of results to ITER
- US components of this plan are dependent on funding
  - Good publication progress: two published Nuclear Fusion papers, three IAEA FEC presentations, one PRL, one co-authored PRL submission, one APS invited, eight RSI/JINST (POSTECH)
- NFRI support is critical for this funding to be maintained
  - Continued, close discussion with NFRI management is needed to create the best research for KSTAR and to meet collaborative goals
    - Favorable response by NFRI to date
  - US funding will be strongly related to fulfillment of DOE fusion goals

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Proposal: physics research list and team building

- Approach
  - Maintain strong coupling to US facility: NSTX (+DIII-D if GA joins)
  - Address hosts' needs: NFRI has endorsed the present program
- Research (3D physics and long pulse control) — Incl new PPPL PD/hire
  - Stability physics of long pulse H-mode
    - TM, RWM, +internal mode, ECEI, future control
  - ELM mitigation / control ← Couple ORNL? (Wed 2pm meeting scheduled) Couple GA 3D (Evans)? (contacted)
  - Long pulse scenario modeling
  - Stability control of long pulse H-mode ← Couple GA control ? (contacted)
  - Disruption avoidance
  - Rotation alteration physics (NTV, ECH, etc.) ← Couple theory outside PPPL (UT Austin) MHD, ECH induced V_ϕ, etc.
  - Rotation control
    - ECH/NTV actuators, NFRI endorsed, incl. new CU PD (contact made)
- Present budget est: $1.7M/yr for this activity w/o GA, ORNL
  - Expands originally planned PPPL FY13-14 program
  - Includes ECH support ~$200k but not SS ECH launcher ($1.7M)

Further Research Ideas - Discussion

- Some Potential Research Additions / Expansion
  - Transport
    - US collaboration/leadership opportunities in diagnostics and theory
      - Fast ion diagnostics a possible niche
    - PPPL has strong transport research presence (NSTX)
      - Interest from Diallo? Other NSTX contributors?
    - G. McKee (UW) expressed KSTAR BES plans at Muju
  - Disruption mitigation
    - KSTAR will need new capabilities to address this, but might do so in out years
  - Auxiliary systems (actually, included as present research)
    - PPPL strong here (e.g. proposed steady-state launchers) – present thought is that this funding falls under separate proposal w/MIT
    - Continue to ramp-up coordinated physics program utilizing this hardware
- Continue further discussion, send suggested ideas
  - But quickly – time is tight. Contact: sabbagh@pppl.gov