Alcator C-Mod Highlights, Plans, and Budgets

FES FY2013 Budget Planning Video-Conference
March 28, 2011

Research supported by U.S. Department of Energy, Fusion Energy Sciences

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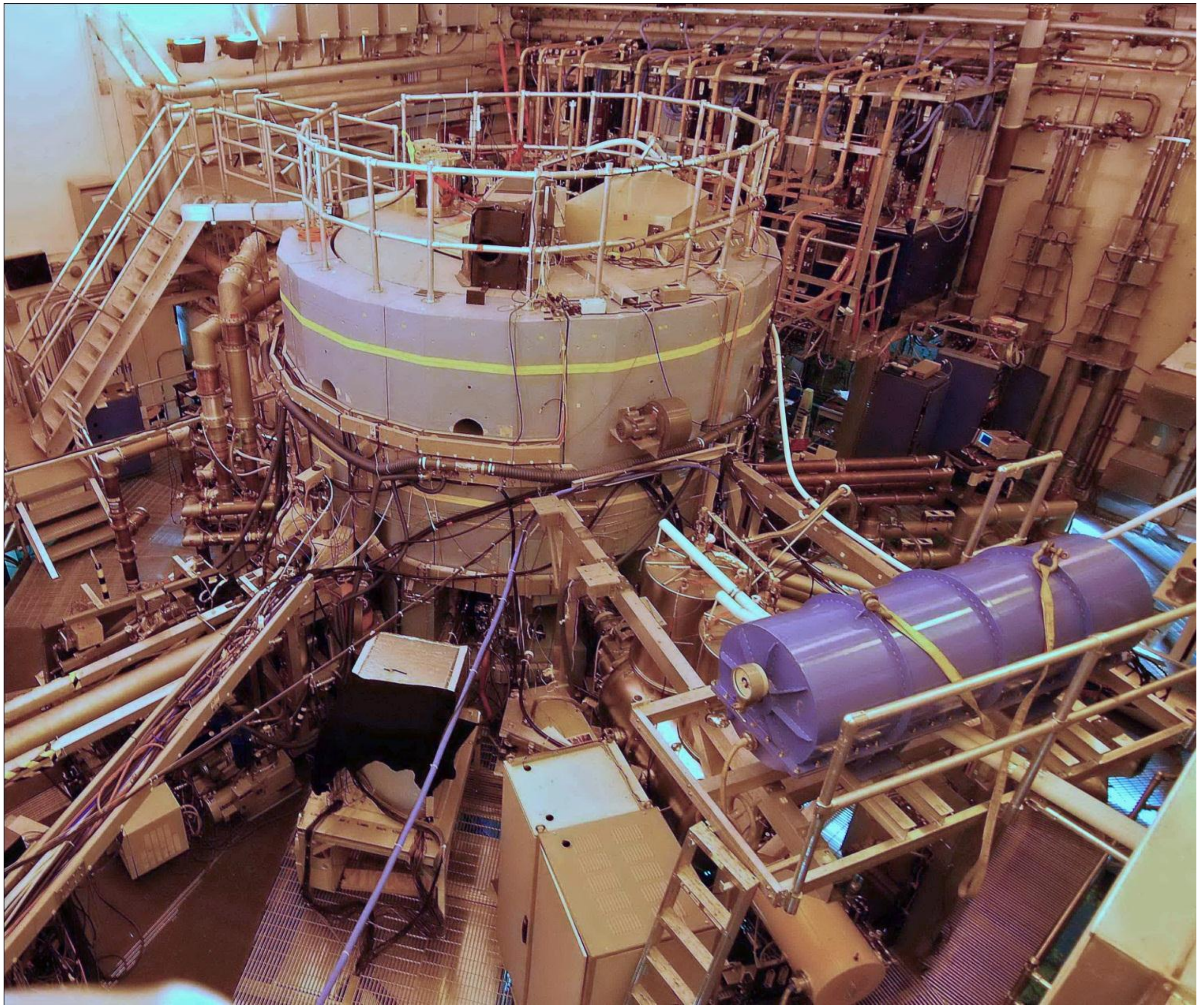
Alcator C-Mod



Compact high-performance divertor tokamak research to establish the plasma physics and engineering necessary for a burning plasma tokamak experiment and for attractive fusion reactors.

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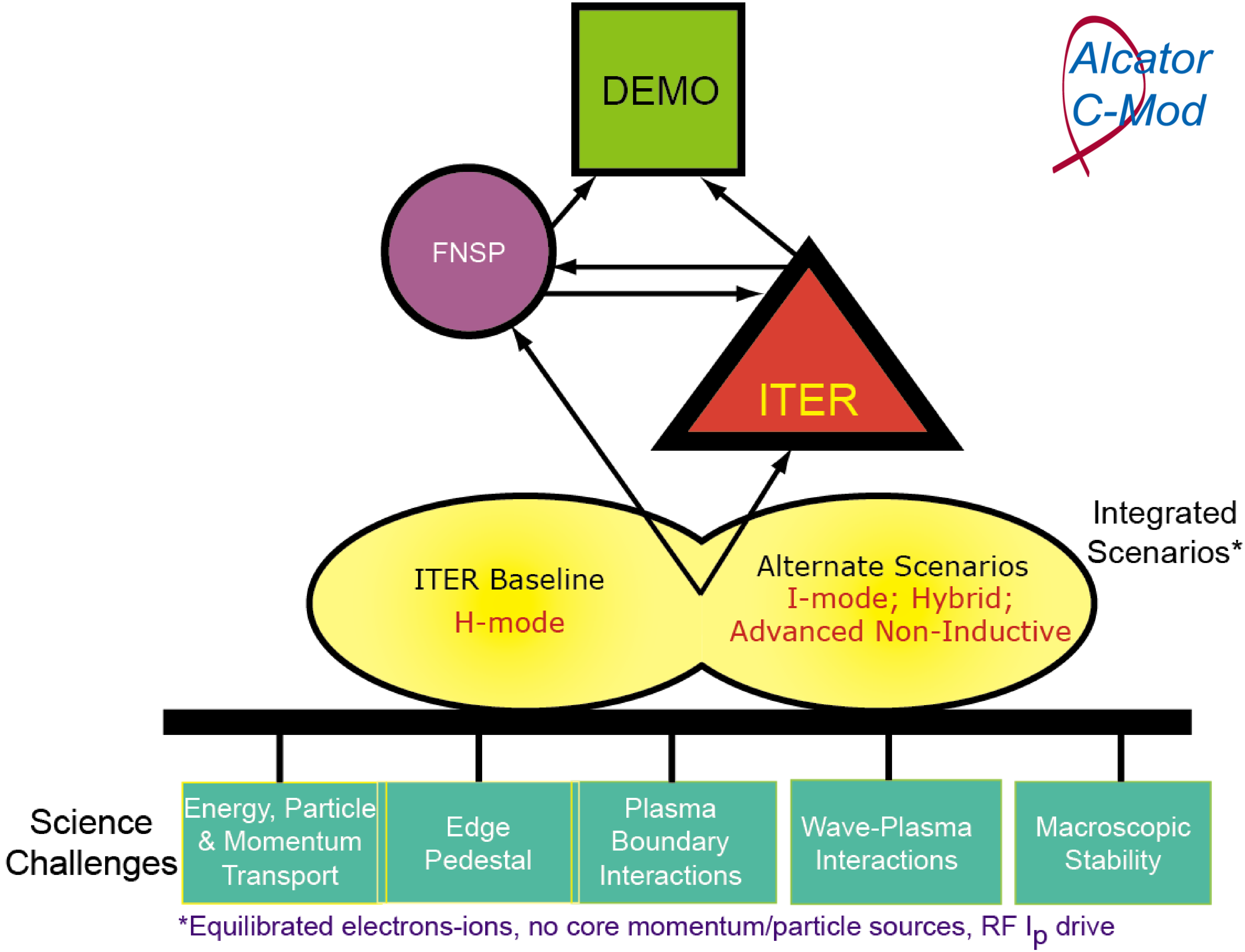
DEMO
FNSP
ITER
ITER Baseline
H-mode
Alternate Scenarios
I-mode; Hybrid;
Advanced Non-Inductive
Integrated Scenarios*
Science Challenges
Energy, Particle & Momentum Transport
Edge Pedestal
Plasma Boundary Interactions
Wave-Plasma Interactions
Macroscopic Stability
*Equilibrated electrons-ions, no core momentum/particle sources, RF I_p drive

C-Mod research program focuses on areas of unique capability, ITER relevance

Alcator C-Mod

- **Broad science campaign, with particular emphasis on ITER needs and requests.**
- **Experiments exploit key C-Mod features,** eg.
  - Solid metal walls; Mo, W: D retention and recovery
  - High divertor heat fluxes: Power handling, impurity generation.
  - High density and neutral opacity: Pedestals and n_e control.
  - ICRF and LHCD at ITER B_T, density: H&CD physics
  - Transport studies in electron dominated regimes: ITER and reactor relevant
  - High pressure (<P> up to 1.8 atm): Disruption mitigation
- **Tokamak Facility and Auxiliary Systems are operating at full performance, with high reliability**
  - Completed 21 research weeks in FY2010
  - So far, completed 12.2 (of 15 planned) research weeks in FY2011

C-Mod Plays Major Role in Education of Next Generation of Fusion Scientists

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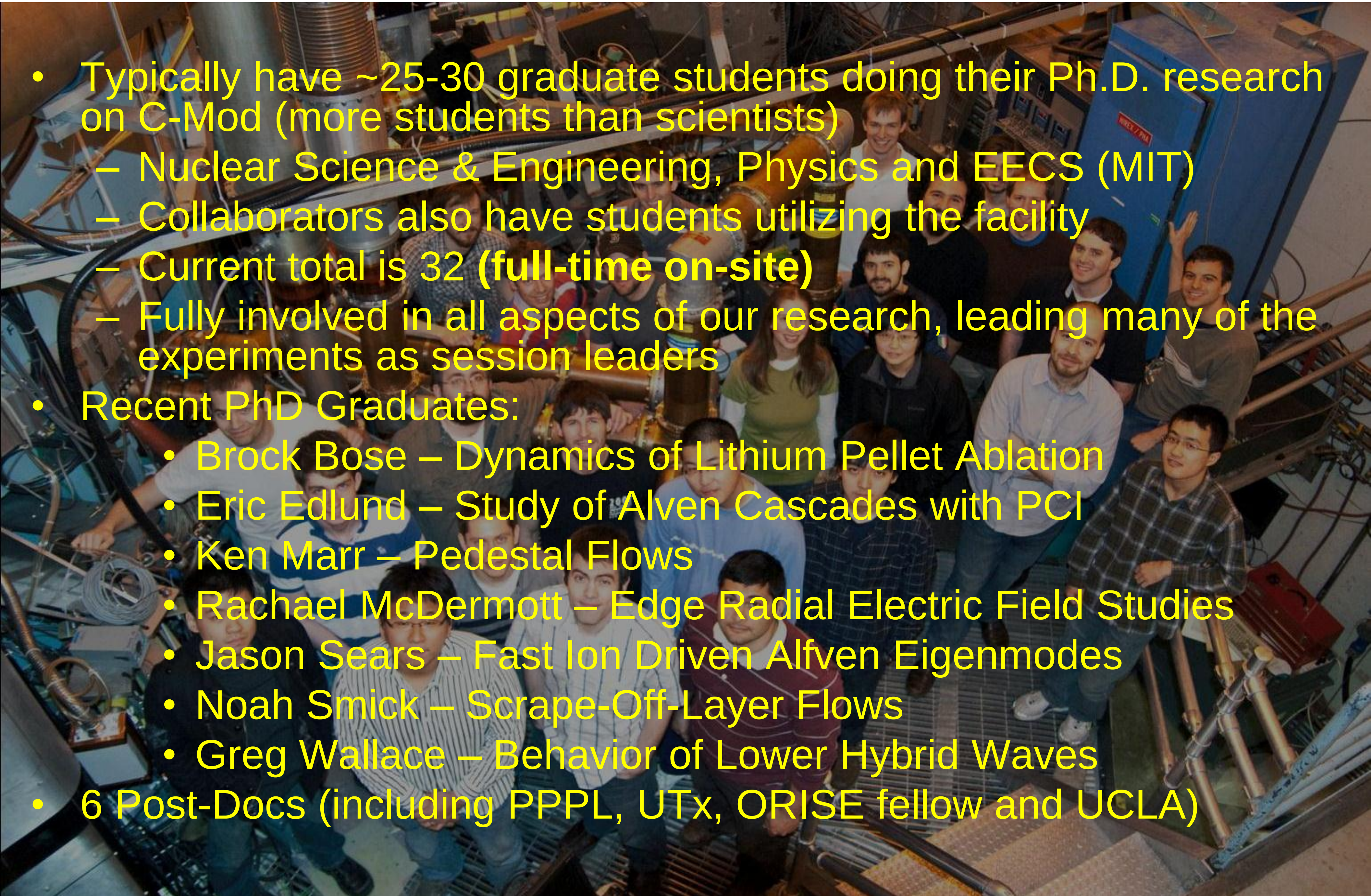

- Typically have ~25-30 graduate students doing their Ph.D. research on C-Mod (more students than scientists)
  - Nuclear Science & Engineering, Physics and EECS (MIT)
  - Collaborators also have students utilizing the facility
  - Current total is 32 **(full-time on-site)**
  - Fully involved in all aspects of our research, leading many of the experiments as session leaders
- Recent PhD Graduates:
    - Brock Bose – Dynamics of Lithium Pellet Ablation
    - Eric Edlund – Study of Alven Cascades with PCI
    - Ken Marr – Pedestal Flows
    - Rachael McDermott – Edge Radial Electric Field Studies
    - Jason Sears – Fast Ion Driven Alfven Eigenmodes
    - Noah Smick – Scrape-Off-Layer Flows
    - Greg Wallace – Behavior of Lower Hybrid Waves
- 6 Post-Docs (including PPPL, UTx, ORISE fellow and UCLA)

Collaborators are key participants in all aspects of the program

Alcator C-Mod

Domestic

Princeton Plasma Physics Lab
U. Texas FRC
UC-Davis
UC-Los Angeles
UC-San Diego
CompX
Dartmouth U.
General Atomics
LLNL
Lodestar
LANL
U. Maryland
MIT-PSFC Theory
NYU
ORNL
PPPL Theory
Purdue U.
SNLA
U. Texas IFS

International

ASIPP/EAST Hefei
C.E.A. Cadarache
C.R.P.P. Lausanne
Culham Centre for Fusion Energy
ENEA/Frascati
FOM Nieuwegein, Netherlands
IGI Padua
IPP Garching
IPP Greifswald
ITER Organization Cadarache
JET/EFDA
JT60-U, JAEA
KFA Jülich
KFKI-RMKI Budapest
KSTAR Korea
LHD/NIFS
Oxford U.
Politecnico di Torino
Royal Institute of Technology Stockholm
U. Tokyo
U. Toronto
U. Tromso Norway

Coordination: FFCC, USBPO, TTF, ITPA, IEA

Research: Major Themes
Science Challenges

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Overarching: model testing and code validation

- Core Transport
  - Particle and impurity transport; self-generated flows and momentum transport; internal transport barriers; gyrokinetic analysis of core turbulence and transport measurements
- ICRF
  - Flow drive; RF sheaths and impurities
- Lower Hybrid RF
  - Current drive at high density; shear reversal; pedestal modifications; flow drive; SOL interactions
- Pedestal physics
  - Thresholds/transition physics; relaxation (energy/particles); control
- Plasma boundary
  - Turbulence/transport; high-Z core compatibility; retention; material migration; ICRF and LHRF SOL interactions
- Macrostability
  - Disruption mitigation/gas jet dynamics/asymmetries/runaways; Alfvén eigenmodes/fast ion transport

Research: Major Themes
Integrated Scenarios

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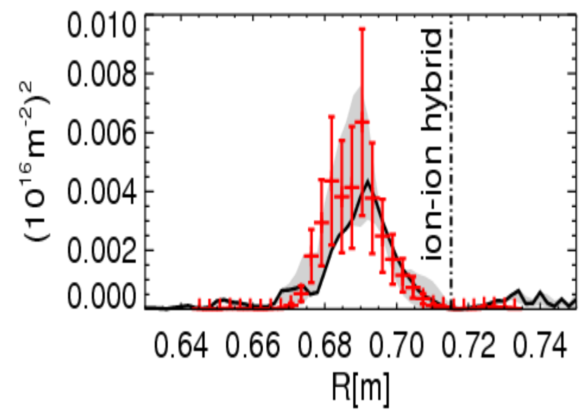
Overarching: model testing and code validation

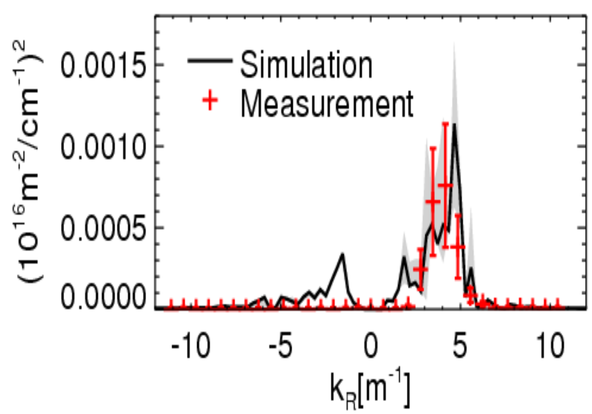
- ITER baseline scenarios
  - Demonstration/validation of ITER reference scenarios (including pre-nuclear)
  - H-mode access/performance
  - Particle/impurity control; power handling; impurity seeding
  - ELM/pedestal physics
  - Plasma control strategies
- Alternate tokamak scenarios
  - I-mode (energy barrier without strong particle barrier)
  - Core-edge compatible regimes with efficient LHCD, high power density and divertor solutions
  - Hybrid scenarios
  - Active current profile control, leading toward fully non-inductive regimes

Validation: Comparing State of the Art Code Results with C-Mod Data

- Pedestal, Edge and Boundary
  - XGC code being developed through SciDAC FSP Prototype Center
    - prediction of pedestal height and width
  - GEM, BOUT, ESEL, KN1D
  - ELITE for MHD stability of intermediate to high n ballooning modes
- Waves
  - (TORIC, AORSA, LHEAF) + (CQL3D, ORBIT RF, LSC) for minority tail evolution, ICH, LHCD, MCEH, MCCD, FWEH, FWCD, ICCD
    - Synthetic diagnostic comparisons with PCI, hard X-ray and CNPA measurements.
  - TOPICA + (TORIC) for comparisons with antenna loading and antenna electrical characteristics
  - TOPLHA and COMSOL for evaluating LH Launcher coupling and design.

Synthetic PCI Diagnostic using ICRF electric fields from coupled AORSA-CQL3D simulation reproduces experimental PCI signal for mode conversion in a plasma with n_H n_e = 8%.



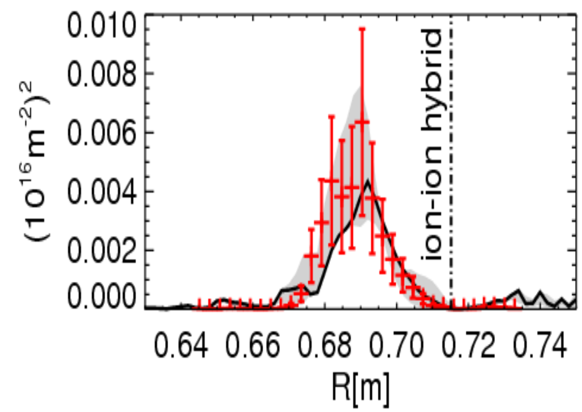


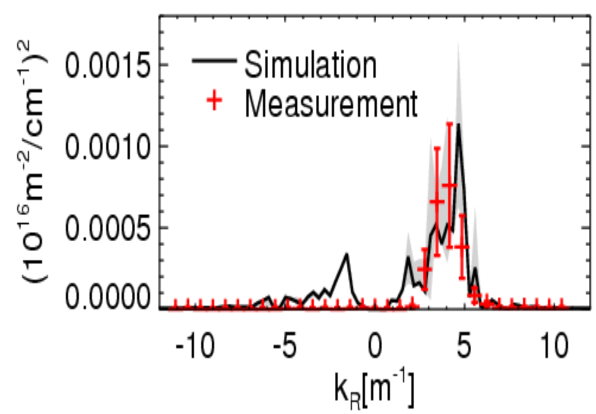
Validation: Comparing State of the Art Code Results with C-Mod Data

Alcator C-Mod

- Macroscopic Stability
  - NIMROD + KPRAD - simulate gas puffing to mitigate electron runaway production
  - M3D - sawtooth reconnection and NTM stabilization
  - NOVA-K to simulate Alfven cascades
    - Synthetic PCI diagnostic implemented
- Transport and Scenario Modeling
  - GS2, GYRO, TGLF – Transport, barrier simulations (internal and edge)
  - TSC-TRANSP, IPS simulations for AT scenario development
  - STRAHL for impurity transport

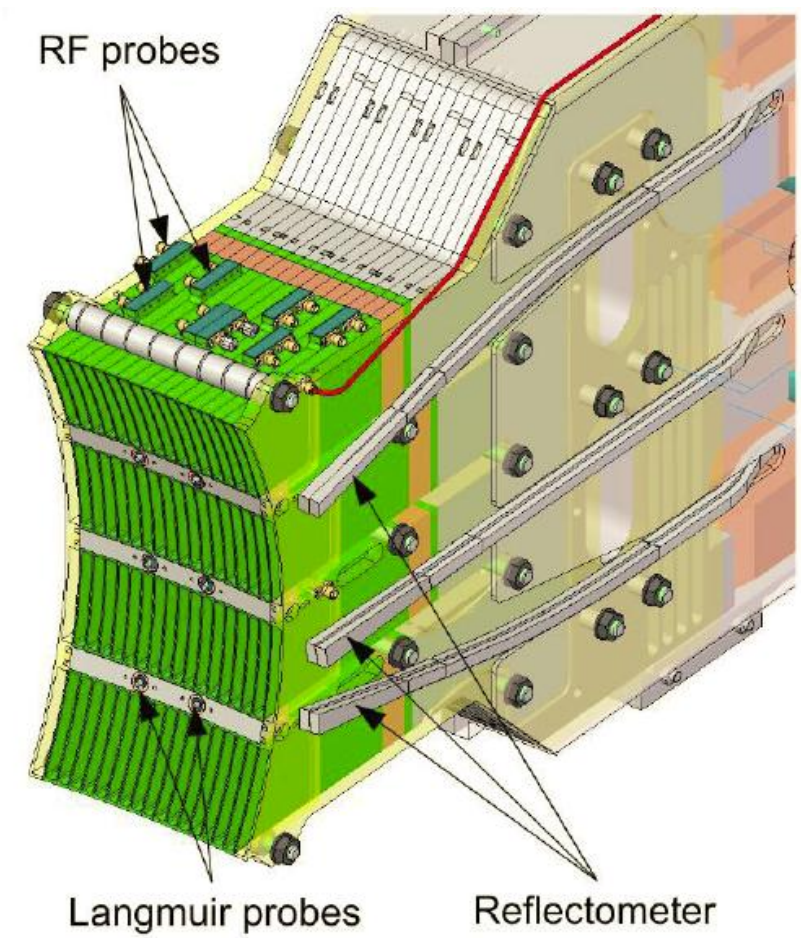
Synthetic PCI Diagnostic using ICRF electric fields from coupled AORSA-CQL3D simulation reproduces experimental PCI signal for mode conversion in a plasma with n_H n_e = 8%.

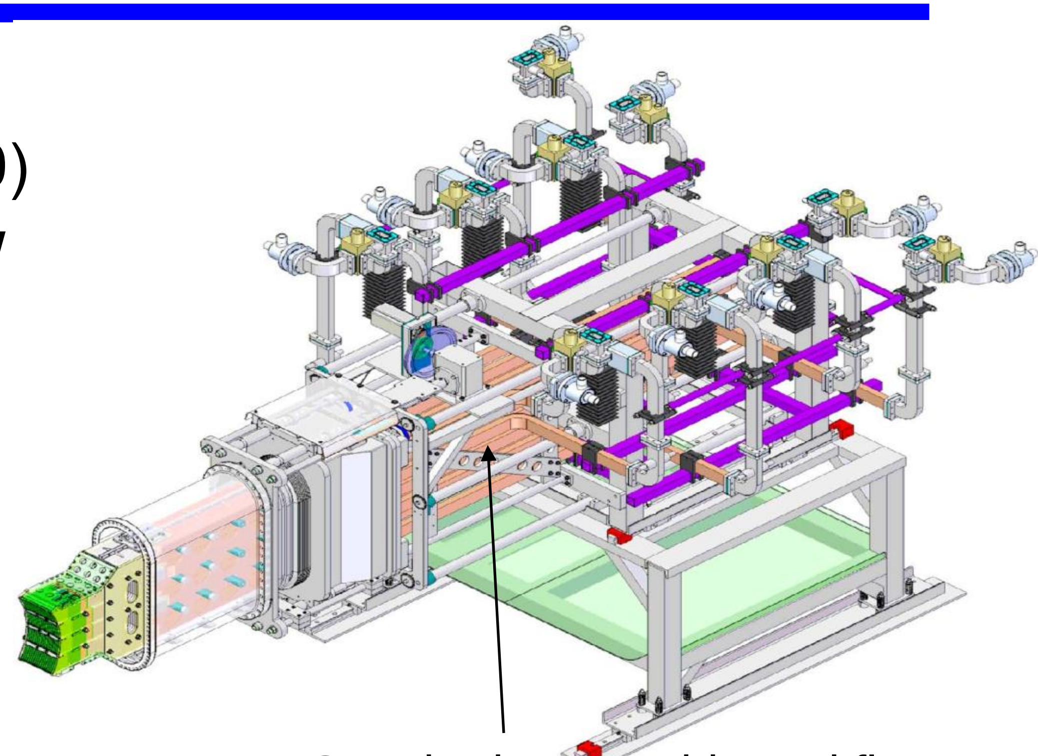




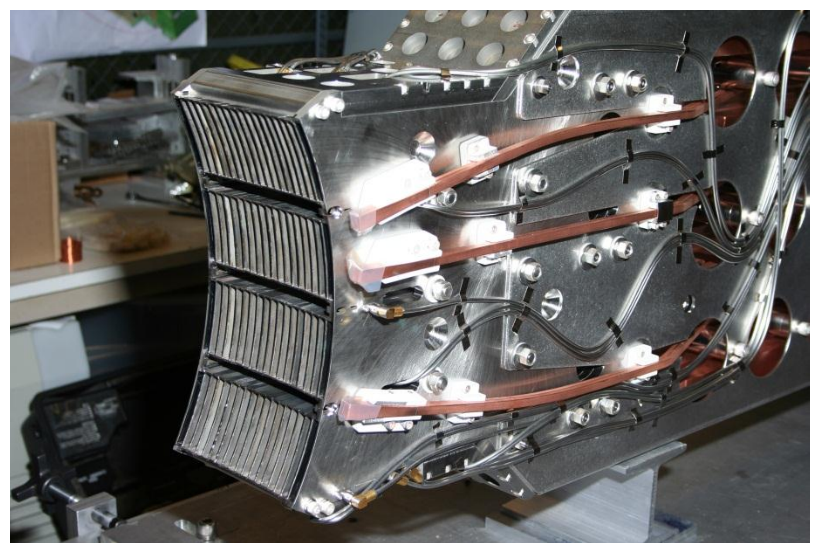
Facility Plans and Major Enhancements

- Lower Hybrid upgrades
  - 7 new klystrons @ 0.25 MW ('10)
  - Additional launcher and 4'th MW ('13)





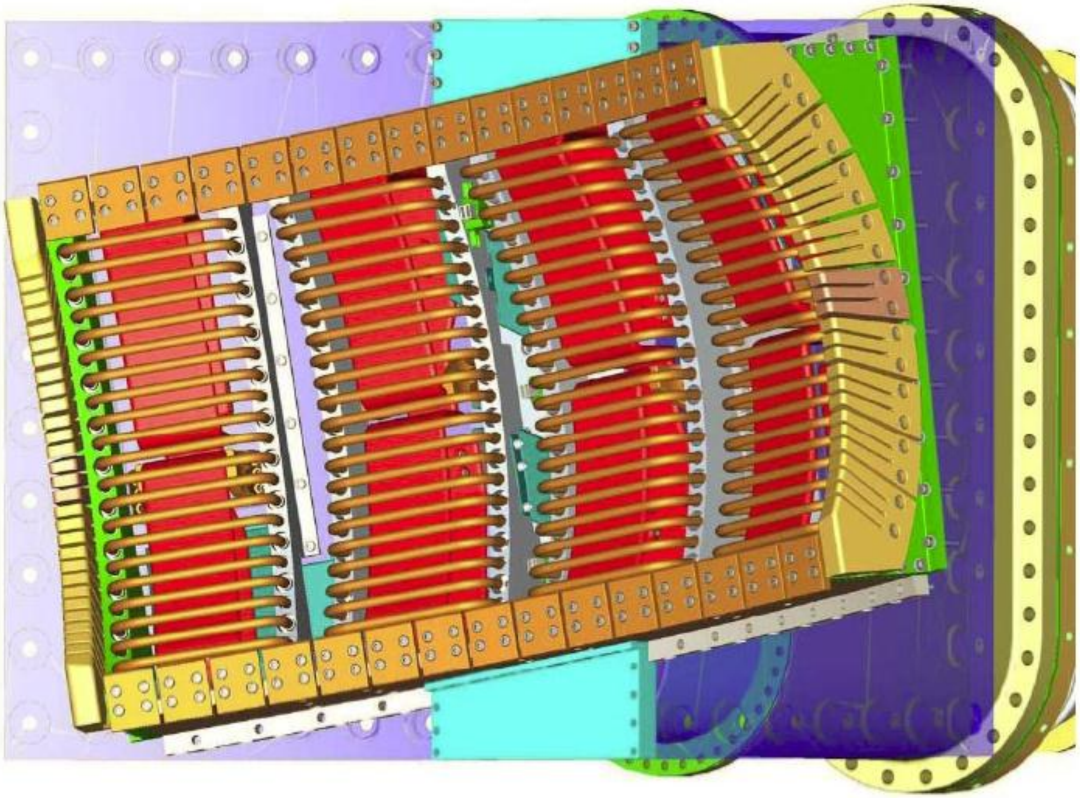
Standard waveguide and flanges



16x4 wave guide array

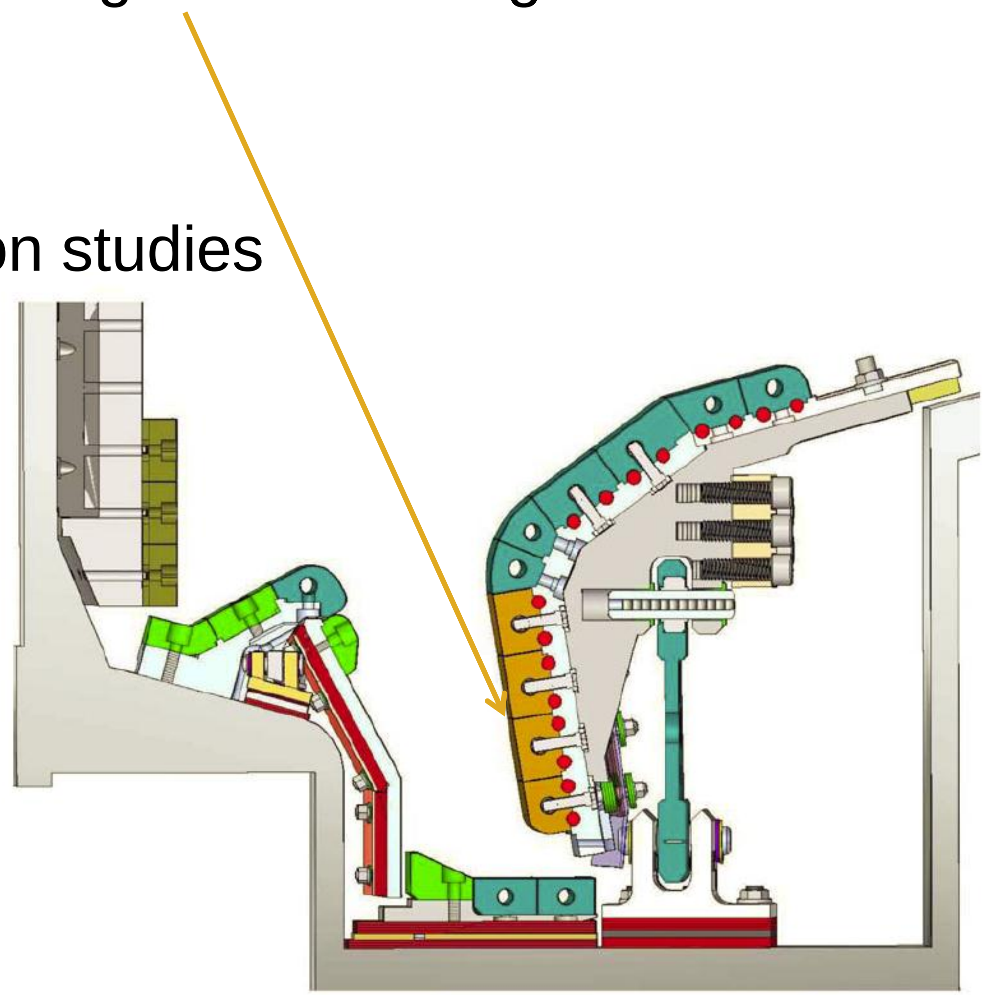
Facility Plans and Major Enhancements

- ICRF upgrades
  - New 4-strap antenna ('11)
    - Rotated/aligned with B
      - Reduce RF induced $E_{||}$ sheath, high-Z impurity sources
  - Fast-Ferrite Tuners for all 4 transmitters (real time adaptive tuning) ('11-'12)
  - Power supply + fast opening switch upgrade (with DTI SBIR) ('11)



Facility Plans and Major Enhancements (cont'd)

- Outer divertor upgrade – DEMO-like divertor ('13) (joint with PPPL)
  - Continuous vertical plate (higher power/energy handling, reduced EM loads)
  - Tungsten lamella plate tiles in high heat-flux region
  - High temperature (~ 600 ^{0}C)
    - Long pulse operations
    - Hydrogen isotope retention studies



Major Diagnostic Enhancements/Upgrades 2011-2013

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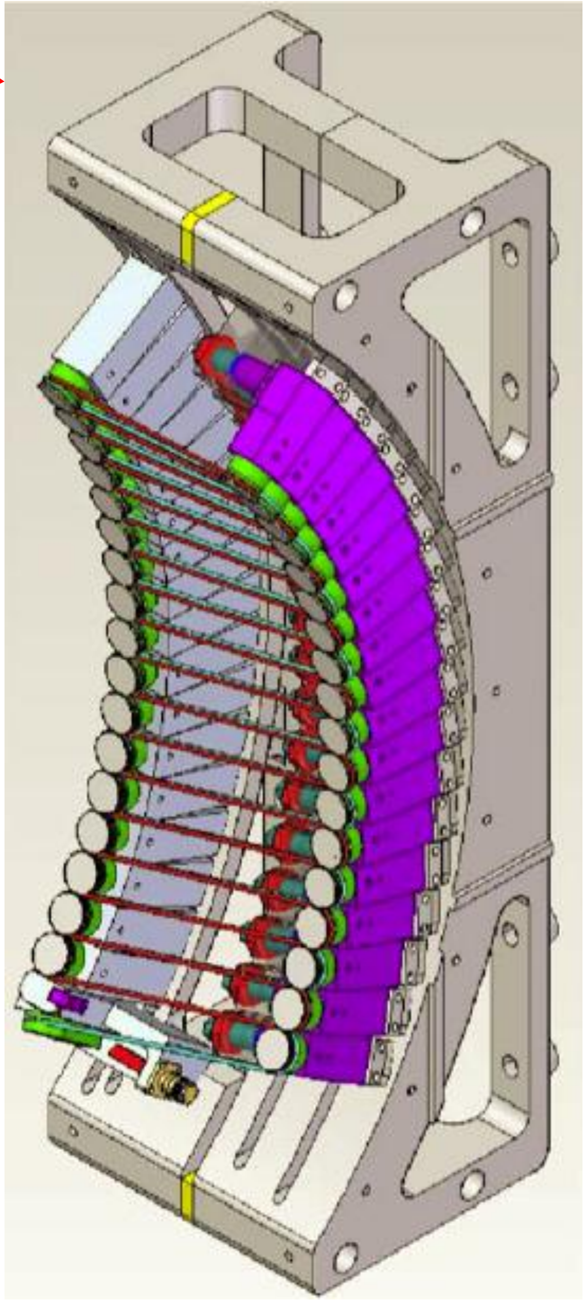
- QCM (*shoelace*) Antenna ('11)
- ICRF SOL Reflectometer (with ORNL) ('11)
- Correlation ECE (with UCLA) ('11)
- High Resolution X-ray Crystal upgrades (with PPPL) ('11)
- Bolometer upgrades (toroidal asymmetry in disruption mitigation) ('11)
- In-Situ Accelerator* [first wall analysis] ('11-'12)
- Fast Ion loss diagnostics ('11-'12)
- Charge eXchange Recomb. Spectr. upgrades (with U. Tx.) ('11-'12)
- Polarimetry (with UCLA) [j(r), n_e(r), magnetic fluctuations] ('11-'12)
- Ion Temperature Probes ('12)
- New Gas Puff Imaging views (with PPPL) ('12)
- Lyman-α poloidal array (LH power loss) ('12)
- SOL Thomson Scattering ('12-'13)
- Two Color Interferometer upgrades ('12-'13)
- Doppler Reflectometry ('13)
- Core Soft X-Ray Diode Imaging upgrade ('13)
- High Resolution X-Ray Spectroscopy upgrade (with PPPL) ('13)
- Lyman-α upgrade (CX power loss) ('13)

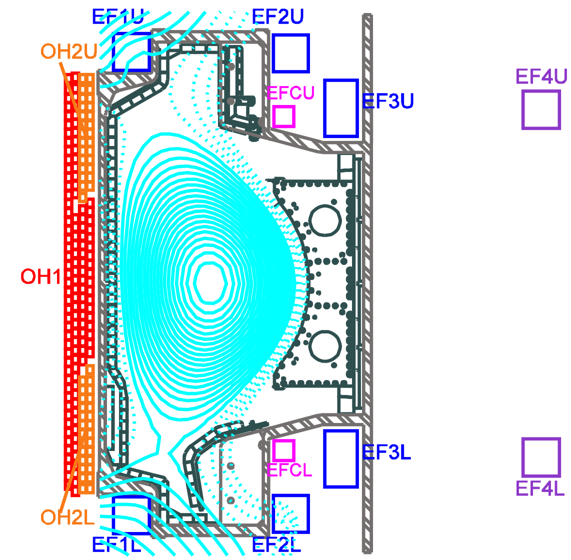


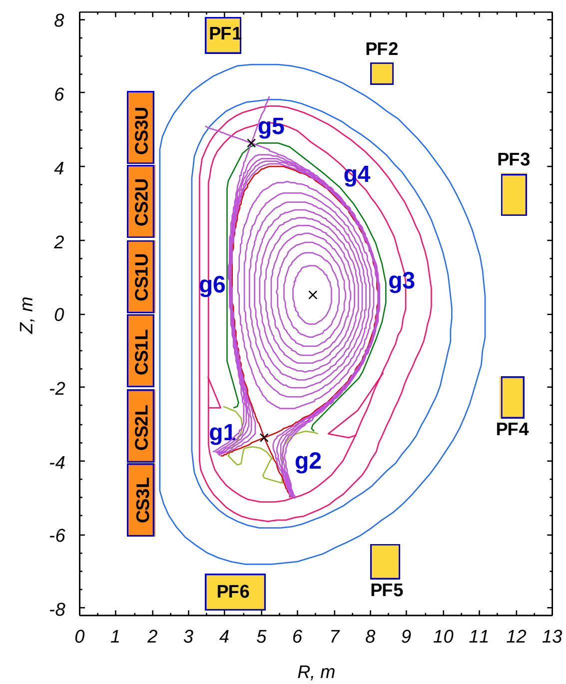
*Primarily funded through FES Diagnostic Initiative

C-Mod Addresses Critical Issues for ITER
>90% of Run Time in Support of ITER (FY10+FY11)

2011 PAC: *"The C-Mod team has been a high profile player in the demonstration of an integrated ITER H-mode baseline and is strongly coupled to the Integrated Operational Scenarios ITPA task effort."*

- Transport and confinement during transient phases
- Access conditions for high confinement regimes
- ELM control schemes
- Particle transport and fuelling
- H-mode pedestal characteristics
- Alternative ELM regimes, Small/No ELM regimes
- Momentum transport/intrinsic plasma rotation
- Disruption/runaway electron mitigation (including 3D modeling)
- Plasma control (initiation, startup, rampdown, I_p, position, shape)
- Tritium retention/removal (including all-metal walls and diagnostics)
- Plasma-facing materials (including operation with melt-damaged W)
- Plasma operations (H and D phases, hybrid/steady-state scenarios, H&CD performance and basis for upgrades)





Joint Experiments Coordinated through ITPA

Alcator C-Mod

- **Many issues (especially for ITER) studied in close coordination with other tokamak facilities**
- Current areas of emphasis on C-Mod (CY2011)
  - H-mode access/hysteresis/evolution/confinement (TC-2, TC-3*, TC-4, PEP-26*, PEP-27*, PEP-28, PEP-33)
  - Intrinsic rotation (TC-9*)
  - RF driven flows (TC-14*)
  - Momentum and particle pinch dependence on collisionality (TC-15)
  - ρ^* scaling of edge intrinsic torque (TC-17)
  - I-mode studies (TC-18, TC-19*, PEP-31*)
  - ITER demo discharges, model validation (TC-20*, IOS-1.1, IOS-1.2, IOS-6.3)
  - Divertor reattachment (DSOL-20)
  - PFC melt layers, material migration (DSOL-25, DSOL-26)
  - Disruption mitigation, database, runaways, avoidance (MDC-1, MDC-16*, DSOL-24)
  - Alfven Eigenmode/Fast Particle studies (EP-2, EP-3, EP-6)
  - Pedestal structure, gradients and ELM energy loss (PEP-2, PEP-6)
  - Pedestal control with RF (PEP-22)
  - ELM control (PEP-29)
  - Hybrid scenarios (IOS-4.1, IOS-6.1)
  - LHCD at high density (IOS-5.3*)
  - ICRF coupling (IOS-5.2)
  - Resolving discrepancy between ECE and TS at high T_e (DIAG-3)

*Led by C-Mod Spokesperson

Core Transport

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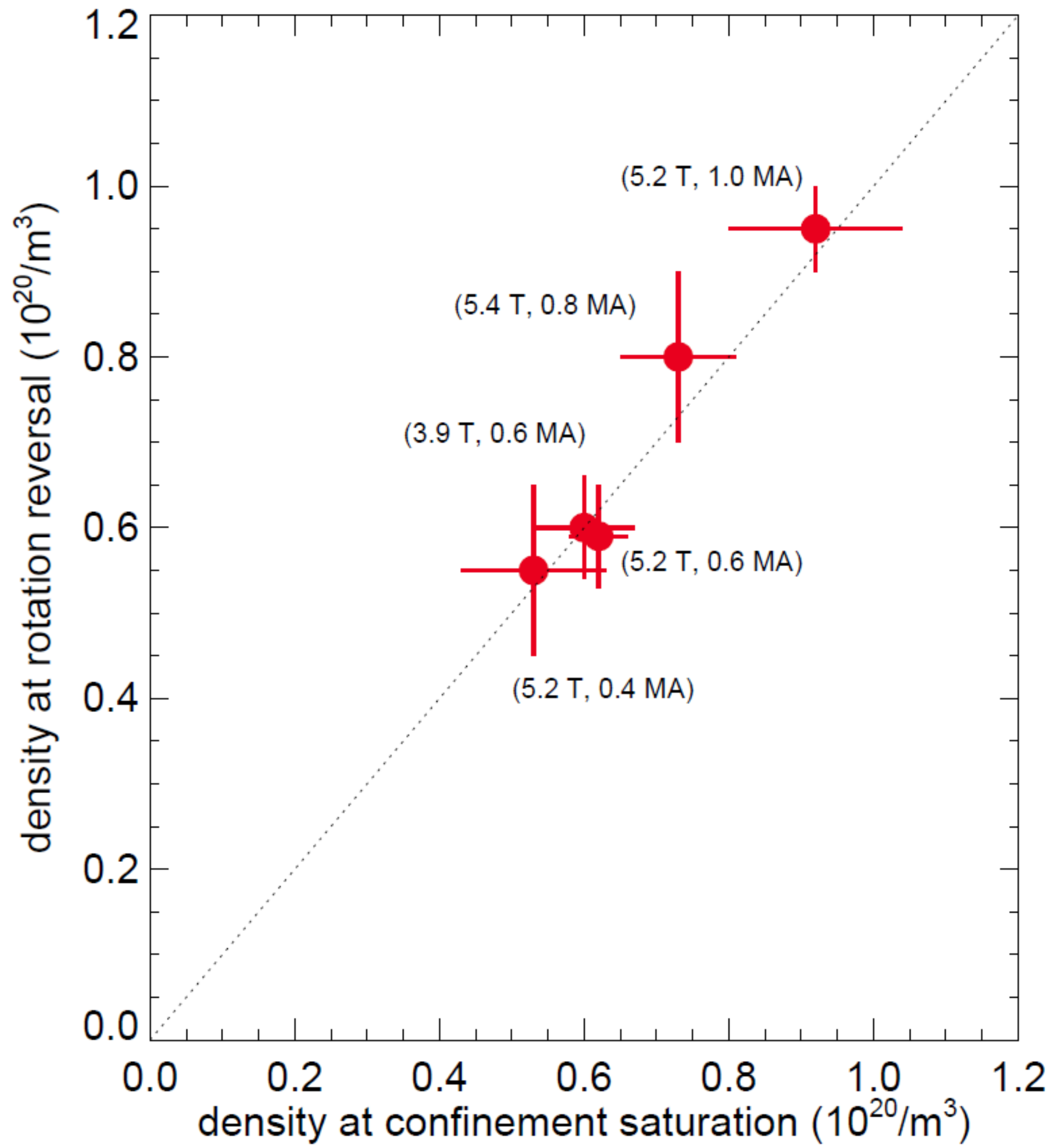
- FY2011 Accomplishments
  - Studies of self-generated flows*, turbulence and transport; esp. reversals at low density.
    - Suggests strong connection between reversal and transition between linear (electron dominated) and saturated (ion dominated) confinement regimes.
  - Impurity transport using new laser blow-off system and new crystal in HIREX to measure Ca+18 profile evolution
    - Analysis and error estimation with STRAHL atomic physics code
    - Comparison with linear and nonlinear gyrokinetic codes
  - Design, installation of Correlation ECE system
    - T_e fluctuations, correlation lengths for $k_\theta \rho_s < 0.5$
  - Electron transport barriers
    - Reversed shear with off-axis LHCD – apparently due to creation of flat or reversed magnetic shear by off-axis LHCD.



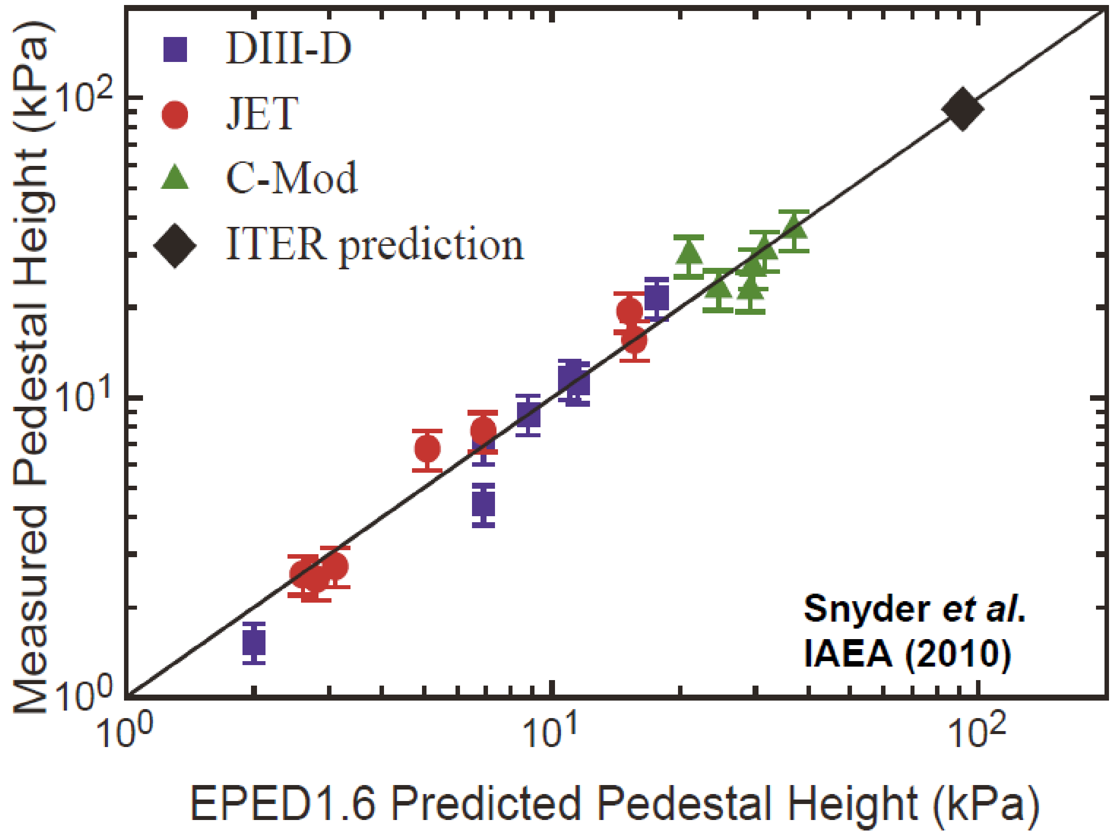
* **John Rice, 2010 Nuclear Fusion Journal prize**: "Inter-machine Comparison of Intrinsic Toroidal Rotation in Tokamaks", *Nucl. Fusion* **47**,(2007)1618

Core Transport Priorities

- FY2012 Plans
  - Joint Research Target
    - With DIIID, NSTX, expts aimed at testing gyrokinetic models (particle and energy transport)
  - Connection between reversal of self-generated flows, confinement regime bifurcation
    - Focus on changes in density fluctuations
  - Extended studies of particle transport, including low, medium and high Z impurities; electron particle and main ion transport
    - Emphasize ITER relevant regimes
- FY2013 Plans
  - Design and build second generation CECE; finalize Doppler backscatter system for density and velocity fluctuations
  - Origin and impact of self-generated rotation
  - RF tools to control transport – modified current and/or rotation profiles

Edge Pedestal

- FY2011 Accomplishments (including JRT)
  - Extended ELMY H-mode access
    - ELMy regime extended to typical shapes ($\kappa \sim 1.6$); tests of EPED model for ped. width/height over large range of I_p and B_t
  - Optimized access to I-mode, characterized profiles, transport, and fluctuations
  - L-H transition power threshold
    - 30% reduction for double null; correlation with outer divertor leg length; insensitive to deposition profile (r/a < 0.5); local edge analysis for low-density branch (dramatic P_{th} increase at low density)

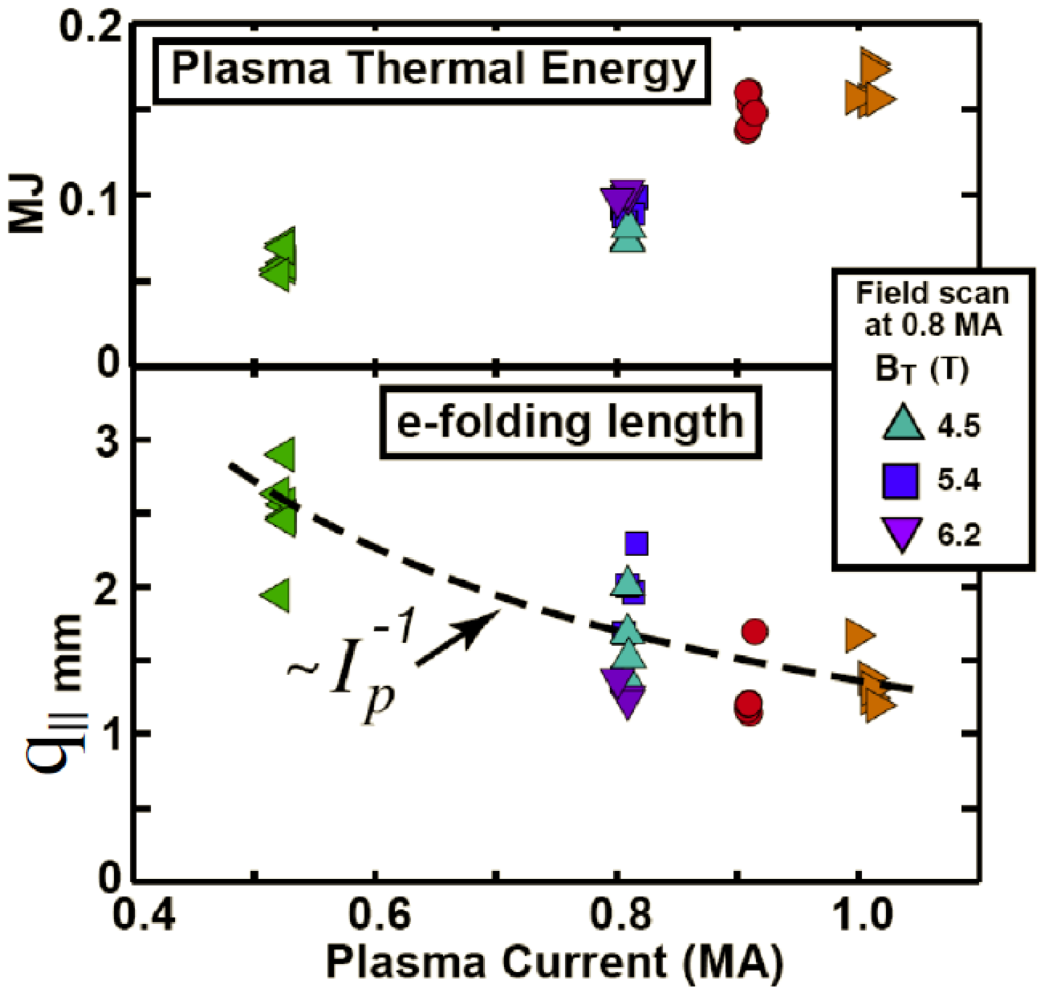


Edge Pedestal Priorities

- FY2012 Plans
  - H-mode transition
    - Role of SOL flows, rotation shear, E_r; Physics of H suppression in I-mode
  - Pedestal structure, transport; modeling comparisons
    - EPED 1.6 and follow-ons; Fluid turbulence codes in collisional H regimes
  - Stability boundaries and MHD growth rates
    - Peeling-ballooning boundary with ELITE, BOUT++ (both I- and H-modes)
    - Steady-state QCM analysis with SOLT, BOUT, M3D
    - Linear stability analysis (e.g. GS2, TGLF)
  - Pedestal and ELM modification by external means (ICRF, LHRF, shoelace antenna)
- FY2013 Plans
  - H-mode trigger
    - Density, flow profiles with increased time resolution
    - Analysis using multi-machine edge profile database
  - Comparisons with models
    - Tests of EPED2.0 with full calculation of KBM physics
    - Use extensions of gyrokinetic models to pedestal for mode stability
    - Comparisons with XGC1 full EM turbulence
    - B2-Eirene/OEDGE to understand impact of 2D ionization source
  - Enhanced neutral, impurity diagnostics to extend seeded H-mode studies

Plasma Boundary

- FY2011 Accomplishments
  - Determined size-scale for power going into edge turbulence ($k_{\perp}\rho_s$~0.1)
  - Dependence of divertor heat-flux footprint on plasma parameters: follows pressure profile of SOL plasma, connected to critical gradients
  - Confirmed theory prediction: density threshold for sheath enhancement
  - Delineated poloidal phase velocity of ICRF induced SOL turbulence: relation to RF induced E_r



Plasma Boundary Priorities

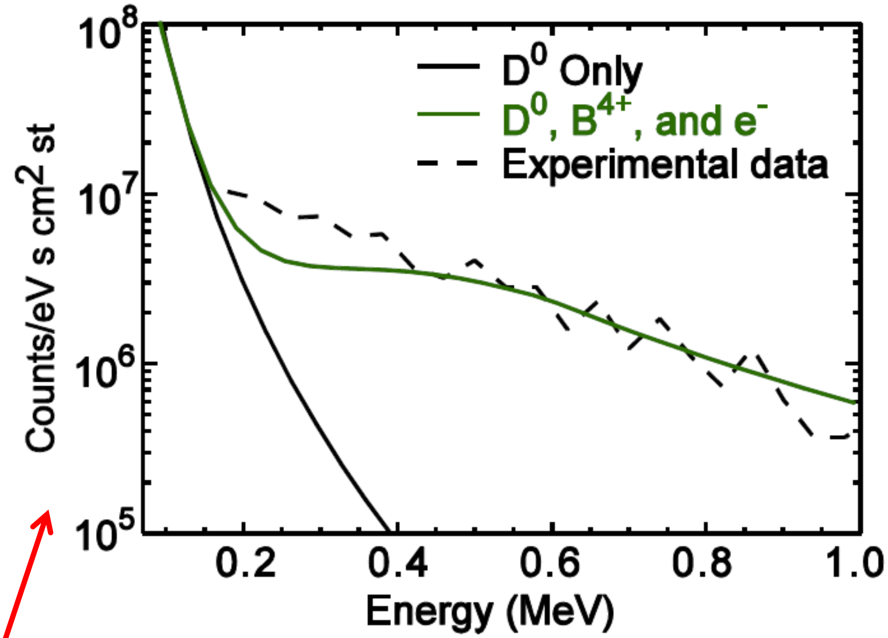
Alcator C-Mod

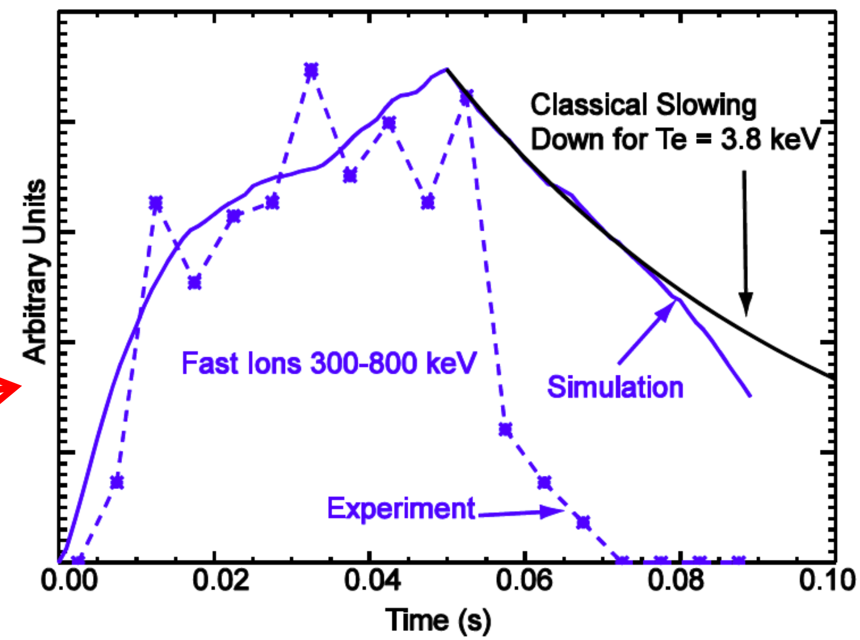
- FY2012 Plans
  - Contribute C-Mod data on heat-flux footprint to multi-machine database; plan follow-on expts.
  - Impurity seeding methods for H-mode optimization and ITER guidance
  - Modify boundary turbulence with shoelace antenna
  - Role of SOL in LHRF effects at high density
  - First ever between shot in-situ surface analysis using RFQ accelerator
  - Advanced probes for SOL profiles: T_i, potential, electron distr. fcn.
  - Finalize outer divertor design, begin construction
- FY2013 Plans
  - Manufacture/install advanced outer divertor
  - Full impurity seeding feedback development
  - Compare pedestal turbulence at high- and low-field sides
  - Explore roles of electron versus ion channel for boundary heat transport
  - Response of SOL electric fields, and electron and ion distribution fcns to ICRF and LHRF
  - Measure fluctuation-induced particle, heat and momentum transport (Reynolds stress) in boundary for intrinsic and externally excited turbulence

ICRF Research

Alcator C-Mod

- FY11 Accomplishments
  - Flow drive
    - MC ICW interaction with ^{3}He follows similar trend with ^{3}He fraction as driven rotation; RF momentum appears to make a direct contribution
      - Models suggest up-down asymmetry and $k_{||}$ upshift redistribute RF momentum
  - RF power deposition in SOL
    - Heat loads to limiters increase for low density, low I_p discharges
    - SOL flows significantly modified by ICRF: indication of cm scale convective cells
    - SOL density increases in near-SOL, decreases in far-SOL; stronger effect near top of antenna also consistent with convective cells (using new SOL reflectometer)
  - Model validation
    - Improved agreement between model and expt for lost fast ions due to charge exchange with boron
      - Good agreement during turn-on, model overpredicts decay time after turn-off
    - Good agreement for strong single pass absorption regime between PCI measurements of mode conversion density perturbation and synthetic diag. in full wave code; simulations suggest toroidal variation important





ICRF Research Priorities

- FY12 Plans
  - Compare rotated and standard antenna characteristics
    - Sheaths, impurity production, impact on SOL density and flows, role of seeding
    - Dependence on phasing
  - Investigate MCFD in I-mode (favorable low n_e, high T_e)
  - Characterize ICRF SOL modification as function of single pass absorption, phasing, confinement mode, n_e, I_p
    - Also assess effects on SOL n_e profiles
  - Characterize loading as function of plasma parameters, gaps, gas puffing
  - Assess response to transients: confinement transitions, ELMs
- FY13 Plans
  - Off-axis MC flow drive for rotation profile control
  - MCFD in low density H-modes, and in He and H majority plasmas
  - Use He FICX and CXRS for more precise characterization of D(^{3}He) minority heating
  - Heating effectiveness of ^{3}He minority in H majority (ITER non-active phase)
  - Develop analysis and simulation tools for impurity mitigation (collab. with RF SciDAC)
  - Characterize RF induced plasma potential changes with reciprocating probe
  - Assess gas puffing effectiveness for modifying SOL n_e profile
  - Using new FICX and lost ion diagnostics, revisit alpha channeling experiments
    - Minority heating to create proton tail, ^{3}He MC to establish channeling region; protons accelerated through high-Q resonance interaction

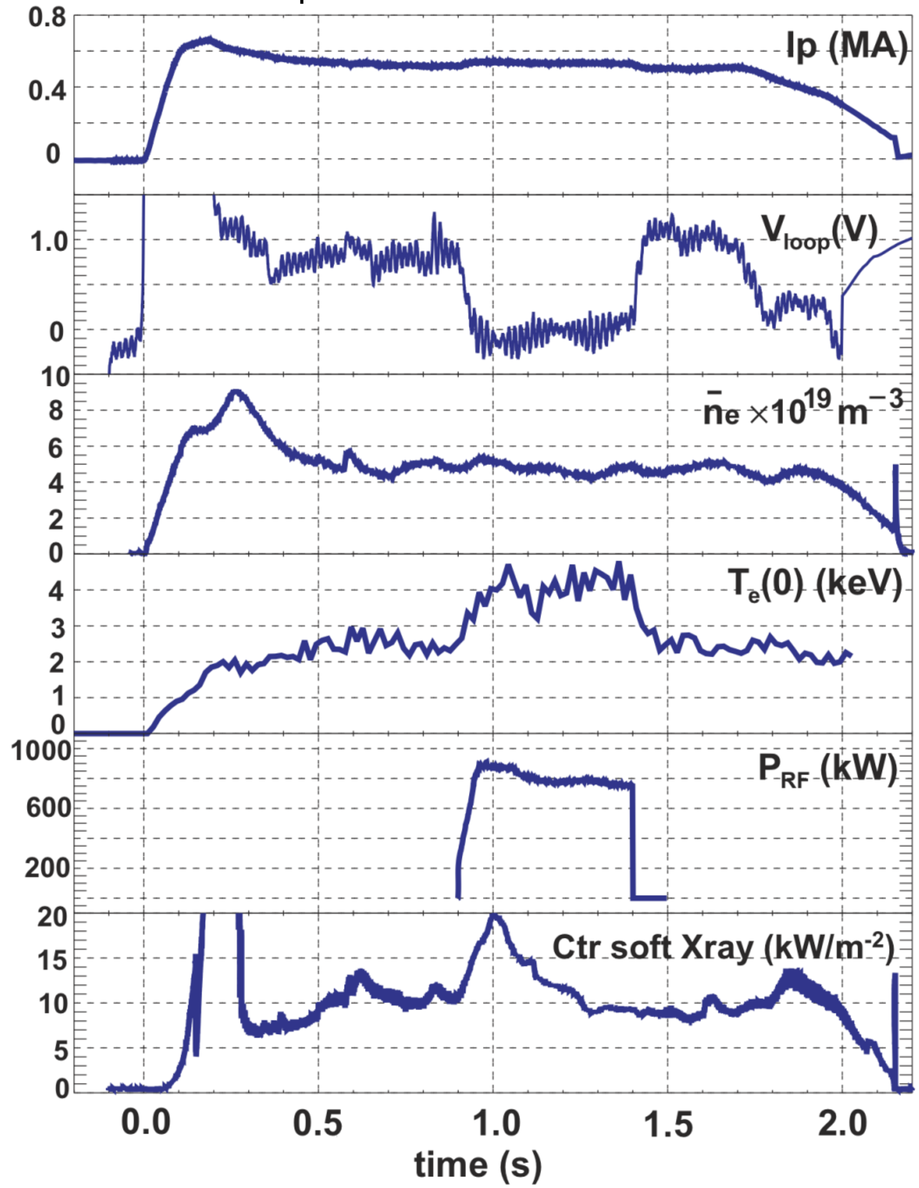
LH Research Program

Alcator C-Mod

- 2011 Accomplishments
  - Rapid deployment of new launcher to high power density
  - Fully non-inductive current drive for multiple skin times; MSE constrained EFIT shows weakly reversed shear, q_0~2; evidence of internal energy transport barriers triggered by LHCD shear modification
  - Modulation expts show good confinement of off-axis driven electrons
  - Improved understanding of "density limit", relation to changes in SOL
    - Supported by ray-tracing/Fokker-Planck and full-wave/Fokker-Planck simulations
  - I-mode discharges investigated as promising target for advanced scenarios

>0.5 MA sustained with 0 V_{loop} for $2\tau_{c.r.}$

$\eta \equiv n_e I_p R_0 / P_{LH} \sim 2\times10^{19}$ A/(Wm^2)



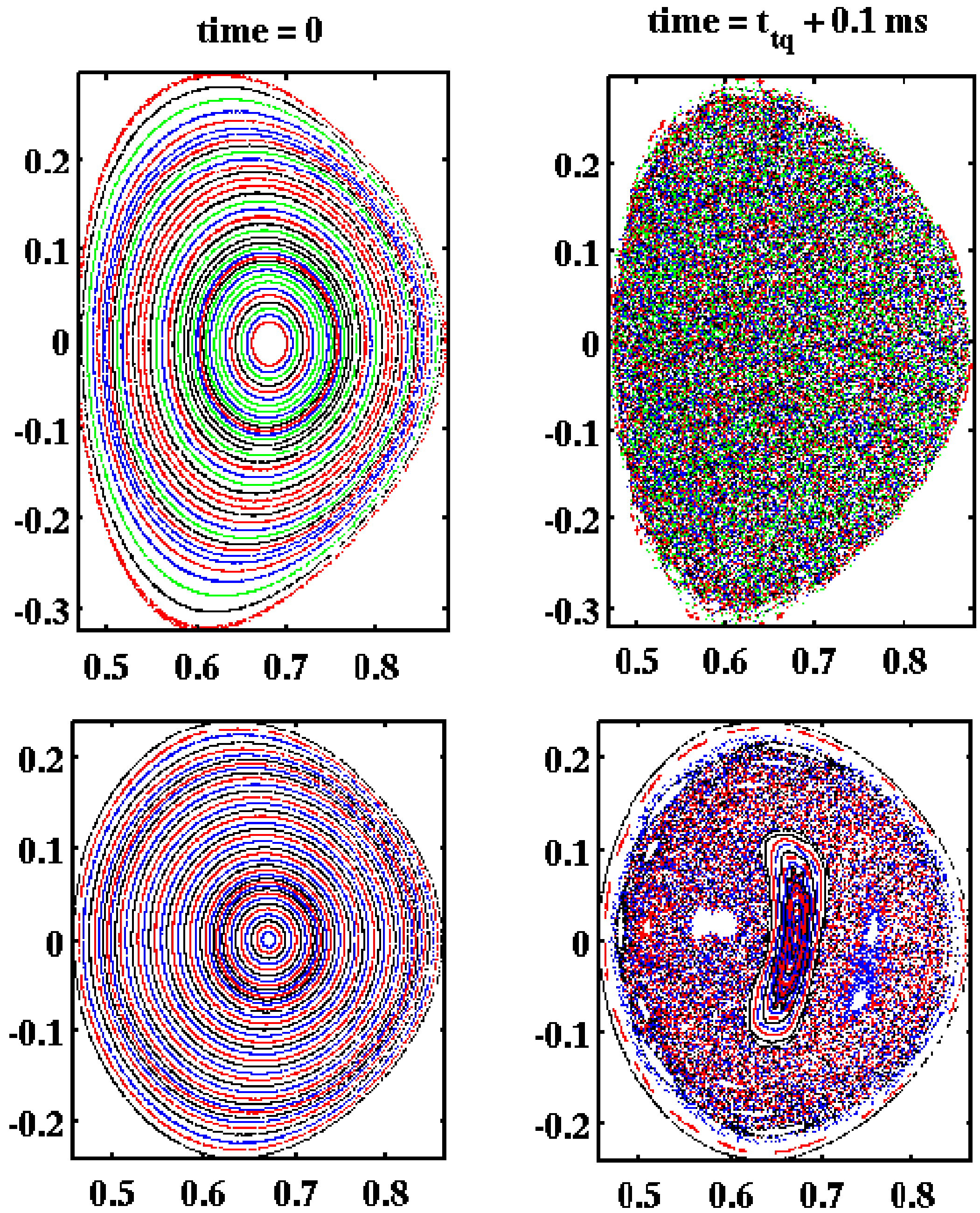
LH Research Program Priorities

- 2012 Plans
  - Validate density limit model, and determine CD efficiency in high single-pass absorption regimes (high temperature, higher $n_{||}$)
  - Investigate transport in non-inductive, flat/reversed shear plasmas with $q_0>1$
  - Fabricate 2nd LH launcher and complete fabrication of 4th klystron cart
- 2013 Plans
  - Install 2nd launcher, commission 4th cart (16 installed klystrons, 4 MW source, ≥2MW coupled
  - Fully non-inductive, reversed shear with I_p up to 1 MA
  - Extend transport, turbulence and rotation studies to these new regimes enabled by the increased CD power

Macrostability Research

- 2011 Accomplishments
  - Disruption Mitigation
    - Limited, low κ plasmas retain LHRF seeded suprathermal electrons through thermal quench, unlike diverted, high κ; during quench, fast electrons accelerated to relativistic energies
    - Growth rate of n=1 MHD modes during gas jet mitigation correlated with degree of radiated power asymmetry during thermal quench
  - Developed ICRF modulation at Alfven frequencies; used to study resonances and interactions with AE modes
  - Correlated AE mode induced fast particle losses with ICRF antenna phasing

NIMROD: Effects of κ on flux surfaces during quench



Macrostability Research Priorities

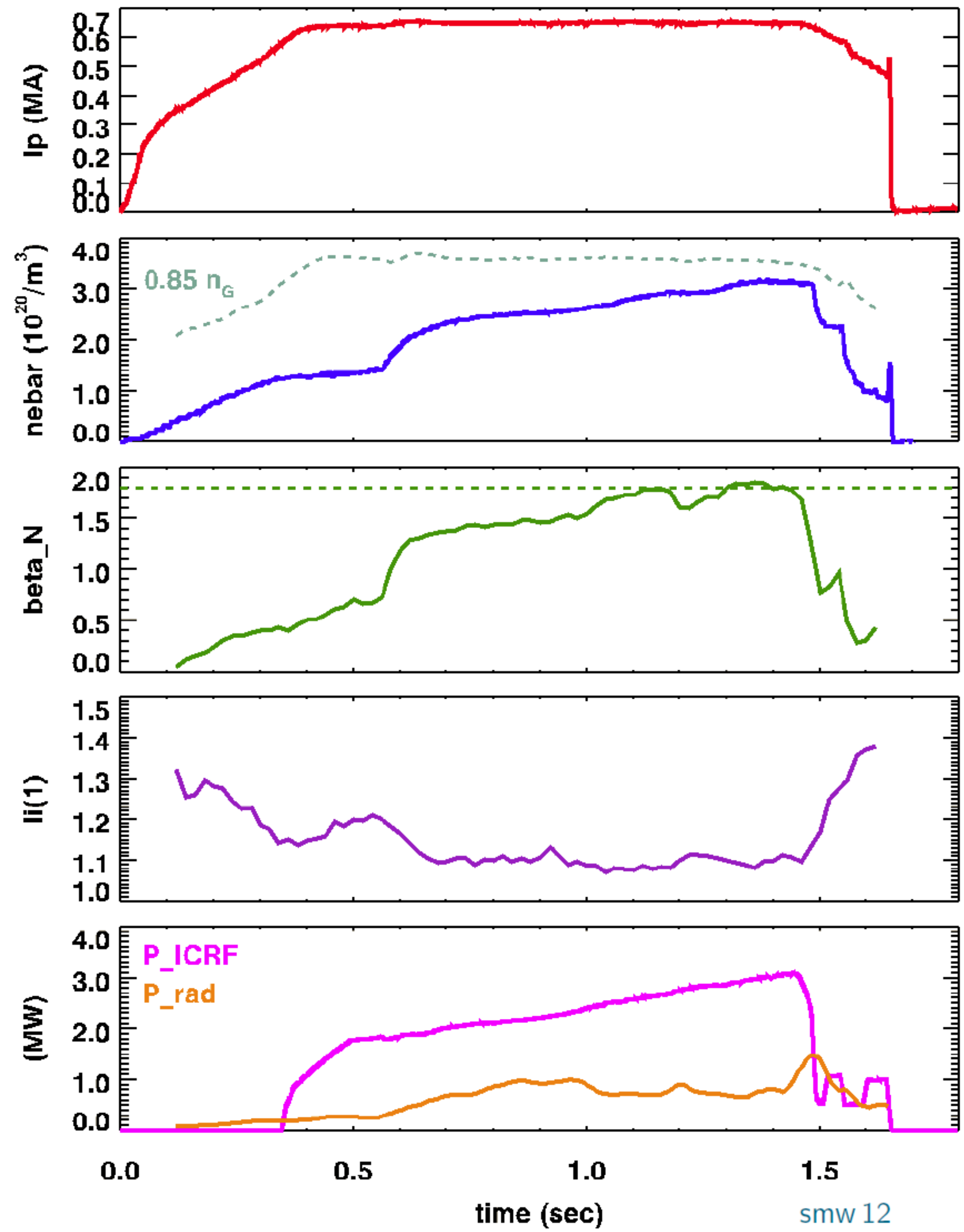
Alcator C-Mod

- 2012 Plans
  - Add 2nd gas jet and toroidally spaced bolometers to study radiation uniformity during mitigation
  - Use newly installed fast ion loss detectors and fast ion CX diagnostics to study AE/ICRF/fast particle interactions
  - Use upgraded IR and thermocouple instrumentation to study disruption heat footprint, comparing mitigated and unmitigated disruptions
  - Test proposed ITER grounding scheme (common bonding network)
- 2013 Plans
  - Test runaway electron position control, deceleration methods
  - Continue and extend NIMROD modeling of RE confinement
  - Compare fast particle loss and heating degradation with AE modeling from NOVA-K
  - Study NTMs during combined ICRF and LHRF heating
  - Real-time disruption prediction

C-Mod ITER Baseline H-mode Scenarios

- 2011 Accomplishments
  - Validation of ITER reference startup
    - Effects of n_e variation in startup (ohmic, ICRF and LH rampups)
    - LH V-sec savings, internal inductance reduction confirmed
  - Rampdown starting from H-mode
    - Sustained H-mode late into ramp with ICRF; n_e decrease $\propto I_p$, n/n_g constant
    - Results applied to ITER simulations
  - ITER demonstration discharges at half field (ITPA IOS-1.1)
    - Very close match to ITER target, β_N~1.9, n/n_G~0.7, H_{98}~1
  - Evaluated power requirements for H_{98}~1 H-modes with seeding to reduce divertor heat load (successful with both neon and nitrogen, P_{div}/P_{loss}<0.1)
  - Access to ELMy H-mode in helium majority (needed for ELM mitigation studies in non-nuclear ITER phase)

ITER Half-Field (2.7 T)
Demonstration Discharges



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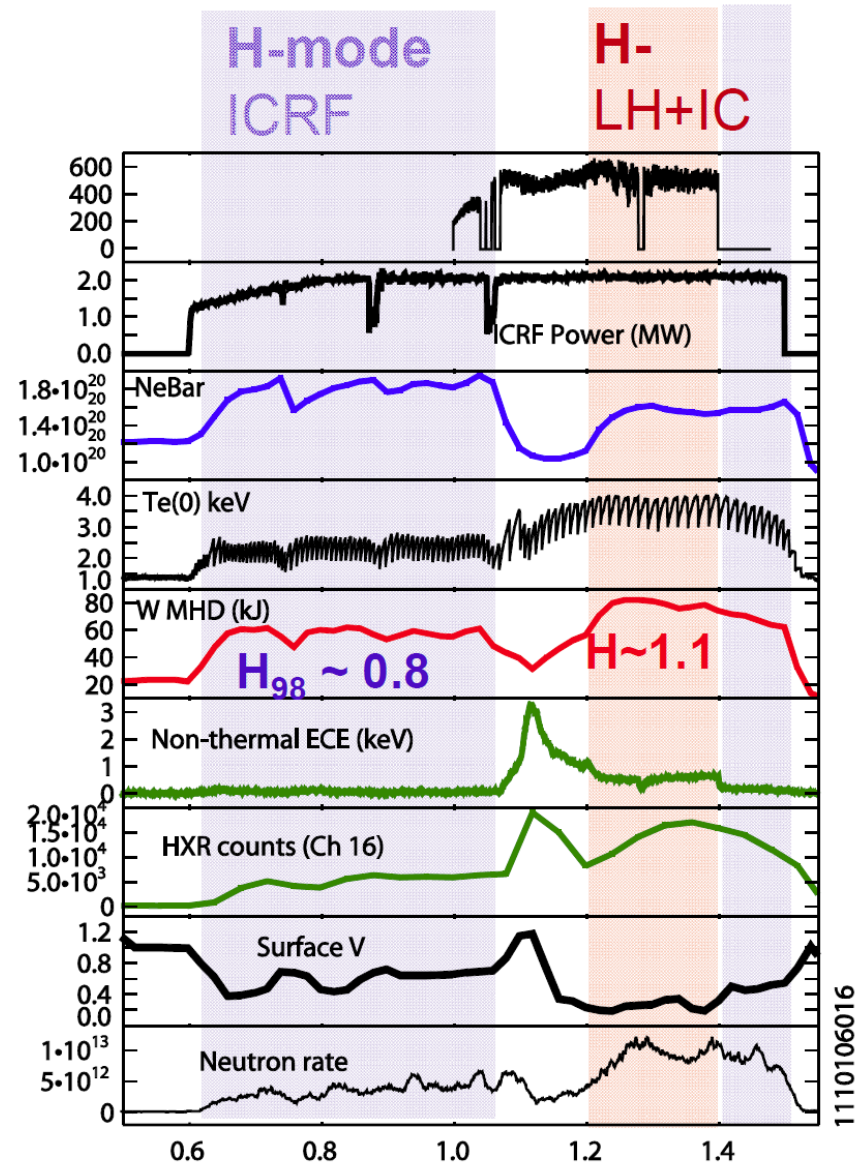
C-Mod ITER Baseline H-mode Scenarios Priorities

- 2012 Plans
  - Optimization of radiative H-modes at higher I_p
    - Divertor vs. main chamber seeding (IOS-1.2); feedback control
  - ITER demo conditions at full field (IOS-1.1)
  - Half-field helium demo discharge development
  - Extend I_p ramp-up scenarios with LHCD
  - H-mode access during current ramps
- 2013 Plans
  - Extend full field ITER demo conditions to lower ν^*, higher n/n_G
  - Burn control studies
  - Develop and test advanced plasma control, fault sensing and mitigation algorithms

Alternate Integrated Tokamak Scenarios

Alcator C-Mod

- 2011 Accomplishments
  - LHCD in I-mode and H-mode for $n_e > 10^{20}/m^3$
    - Non-thermal emission significantly higher than in L-mode; modeling indicates higher T_e target, with higher $n_{||}$ waves should be even better (ITPA IOS-5.3, with important implications for ITER LH upgrades
  - Reduced density H-modes developed at 450kA and 600 kA
    - Adding LHRF gives lower P_{rad}, higher confinement (H_{98}~1.2), substantial f_{boot}~50% (still being evaluated) (ITPA PEP-22)
  - Significant extension of I-mode parameter regime
    - $0.7 \le I_p \le 1.3$ MA, $3 \le B_T \le 6$ T, $0.86 \le n_e \le 2.05 \times 10^{20}$ m^{-3}, <P>=1.5 atm (close to C-Mod/world record of 1.8 atm)$_p$
    - 3 new ITPA joint experiments spawned
    - Steady I-mode accessed with favorable drift with shape normally conducive to ELMy H-mode, and L-I threshold lower than in unfavorable drift cases (might improve prospects for ITER access)



Alternate Integrated Tokamak Scenarios: Priorities

- 2012/2013 Plans
  - I-mode
    - Document/increase performance and robustness, assess applicability to ITER
    - Dependence on shape; compatibility with impurity seeding; divertor heat flux footprint assessments
  - Non-inductive scenarios with LHCD
    - Extend to higher T_e with ICRF Mode Conversion heating
    - Evaluate prospects for LHCD at intermediate densities (higher T_e, higher $N_{||}$, stronger single pass absorption)
    - Integrated scenario modeling (TRANSP, TSC) incorporating state of the art LH codes (GENRAY-CQL3D with SOL effects, TORIC-LH, LHEAF) for better predictions LHCD at intermediate density
    - Assess scenarios starting from L-, I- and H-mode targets, with P_{LH}~1 MW (FY12)
    - Most promising will be assessed at higher LH power (FY13)
  - Hybrid Scenarios
    - Complete recent experiments on LHCD j(r) modification, with sawtooth suppression, followed by ICRF induced H-mode
      - Key questions: can shear modification be sustained, and if so, is H-mode confinement improved
    - Further exploration of beneficial LHCD effects on energy and particle transport in H-mode; assess ITER application
    - Explore prospects of hybrid access in high β_N regime without LHCD, building on promising half-field ITER demo results

Milestones

Alcator C-Mod

- OFES Programmatic Joint Targets
  - FY11: Pedestal Physics
  - FY12: Core transport
- C-Mod Facility Targets (Plain English Goals)
  - FY11
    - ICRF sheath physics with advanced field-aligned antenna
    - Characterize H-mode pedestal
    - Hybrid scenarios
  - FY12
    - Lower Hybrid accessibility and current drive efficiency; relation to density limits
    - Low collisionality edge energy transport barriers (I-mode)
  - FY13 (proposed)
    - Core transport, turbulence and modeling
    - Pedestal modification via external means (ICRF, LHRF, active MHD)

Implications of -10% FY12 budget

- 30% reduction of research runtime (5 weeks)
  - Progress slowed across all science areas and integrated thrusts
  - Added backlog of high priority runs that don't get sufficient run time
  - Increased difficulty for graduate students to complete their data sets for thesis work
  - Significantly reduced impact in joint ITPA experiments
- Deferred upgrades
  - Outer divertor upgrade significantly slowed (at least 6 months)
  - ICRF Switchgear: impacts reliability of main auxiliary heating (1 year)
  - 1st replacement laser for Thomson scattering system (core and edge): reduced time resolution for key core profile diagnostic; risk of loss of one or both old, unmaintainable lasers
  - Two color interferometer (at least 1 year): lose core fluctuation upgrade capability
- Reduced travel budgets, impacting participation in national and international meetings, including ITPA

Implications of -10% FY13 budget
(assuming guidance in FY12)

- 33% reduction of research runtime (5 weeks)
  - Progress slowed across all science areas and integrated thrusts
  - Added backlog of high priority runs that don't get sufficient run time
  - Increased difficulty for graduate students to complete their data sets for thesis work
  - Significantly reduced impact in joint ITPA experiments
- Deferred upgrades (at least 1 year)
  - ICRF Switchgear: impacts reliability of main auxiliary heating
  - Replacement laser for Thomson scattering system (core and edge): reduced time resolution for key core profile diagnostic; risk of loss of old, unmaintainable laser, halving the available time resolution
  - Doppler reflectometer system: no core fluctuation propagation velocity; decreased impact of core transport studies

– Reduced travel budgets, impacting participation in national and international meetings, including ITPA

National Budget Profiles (k$)

Alcator C-Mod

Fin. Plan Guidance Base Increment -10%

Institution	FY11P	FY12	FY13A	FY13B	FY13D**
MIT	23,599	24,515	24,515	27,000	22,064
PPPL	3,441	3,525	3,525	3,878	3,173
U Texas	362	369	369	405	333
LANL	105	107	107	118	96
CompX	60	60	60	66	54
National Project Total (research run weeks)	27,567 (15)	28,576 (17)	28,576 (15)	31,467 (19)	25,720 (10)

**Reductions in Force:
FY13D: 2 Scientists, 2 Students, 1 Post-Doc, 3 Engineers, 2 Technicians

Incremental Funds for C-Mod in FY13 would Enable Significantly Extended Scientific Progress

Alcator C-Mod

- 26% increase of research runtime (4 weeks, to 19 total)
  - Progress extended across all science areas and integrated thrusts
  - Significant reduction of backlog of high priority runs that don't get sufficient run time
  - Graduate students able to complete their data sets for thesis work faster
  - Significantly increased impact in joint ITPA experiments
- Facility upgrades
  - Poloidal field power supply upgrades (EF2 and EFC)
    - Access to broader range of shapes (esp. at high I_p, longer pulses)
    - Significant improvement to error field/locked mode suppression
    - Faster implementation of ICRF switchgear upgrades
      - Improved reliability at high auxiliary power

Major Progress for Fusion Science and Fusion Energy

Alcator C-Mod

- Flexible, Capable Facility
- Excellent Tools and Diagnostics
- Key Upgrades to Facility and Diagnostics
- Premier Facility for Student Training

Unique and Complementary Contributions to Joint (National and International) Experiments

Model Validation across Broad Range of Dimensional and Dimensionless parameters

Key Contributions to solution of challenges for ITER and Beyond

Research supported by U.S. Department of Energy, Fusion Energy Sciences

Alcator C-Mod Program Detail in Bullet Form

FY11 Guidance: 15 weeks total research operations (1 week = 4 days, 8 hrs/day)

Areas of Research Emphasis

- Inductive H-mode scenarios (ITER baseline)
  - Validation of ITER reference startup
    - Density variation
    - Volt-second savings with Lower Hybrid
  - Rampdown in H-mode
    - H-mode sustainment, density evolution
    - Comparisons with ITER simulations
  - ITER demonstration discharges at half-field (2.6 Tesla)
    - Match to ITER target (β_N~1.9, n/n_g~0.7, H_{98}~1
  - Evaluate power requirements for H_{98}=1 in low z seeded H-mode
  - Access to ELMy H-mode in helium majority plasmas
- Alternate tokamak scenarios
  - LHCD in I-mode and H-mode with n_e>1e20m^{-3}
  - Develop reduced density H-mode target plasmas at intermediate I_p
    - Evaluate LHRF fast electron production and current drive
  - Extension of I-mode parameters (current, field, shaping, pressure, topology)
  - Hybrid scenario investigations with LHCD shear modification
- Core transport studies
  - Studies of self-generated flows
    - Flow reversals at low density and relation to turbulence and energy transport regimes
  - Impurity transport studies
    - Laser blow-off system; upgraded high resolution x-ray imaging
    - Analysis and error estimations, with STRAHL atomic physics model
    - Comparisons with linear and nonlinear gyrokinetic simulations
  - Design, installation of correlation ECE diagnostic
  - Electron transport barrier studies
    - Reversed shear with off-axis LHCD
- Pedestal studies
  - Joint research target (with NSTX, DIII-D)
  - Extend ELMy H-mode access
    - To higher elongation
    - Tests of EPED model for pedestal width/height over large range of I_p and B_t
  - Optimized access to I-mode
    - Characterize profiles, transport and fluctuations
  - L-H transition power threshold

        - Compare single-null/double null
        - Vary outer divertor leg length
        - Local edge analysis for low density branch (increased threshold)
- Plasma Boundary Physics and Technology
    - Determine size scale for power going into edge turbulence
    - Dependence of divertor heat-flux footprint on plasma parameters
        - SOL pressure profile; critical gradients
    - Test theory of density threshold for ICRF sheath enhancement
    - Study relationship between RF induced E_r and poloidal phase velocity of ICRF induced turbulence
- Wave-Plasma Interactions
    - Ion Cyclotron RF
        - Mode conversion flow drive
            - Evaluate direct momentum input from waves
            - Evaluate effects of up-down asymmetry in wave propagation
        - ICRF power deposition in the SOL
            - Parameterize heat loads to limiters as function of I_p, n_e, shape, topology
                - Measure and model lost fast ions
            - Effects of ICRF on SOL density profiles
    - Lower Hybrid RF
        - Fully non-inductive current drive for multiple skin times
            - Evaluate q-profile, shear modification
            - Evaluate effects on energy transport, formation of internal transport barriers
        - Measure and model confinement of LH-driven off-axis epithermal electrons
        - Investigate relationship between LHRF fast electron drive and SOL effects
            - Compare with models: ray-tracing or full wave, combined with Fokker-Planck
        - LHRF into I-mode targets
- Macroscopic Stability
    - Disruption mitigation
        - USE LHRF to seed plasma with non-thermal electrons prior to disruption
        - Compare runaway production, confinement in limited, circular with elongated, diverted plasmas
        - Model with NIMROD 3-d MHD simulations
    - Develop ICRF modulation at Alfven frequencies
        - Study resonances and interactions with AE modes
    - Correlate AE mode-induced fast particle losses with ICRF parameters, including antenna phasing

Plain English Goals

- Joint Research Target: H-mode pedestal

- Evaluate advanced rotated ICRF antenna
    - Sheaths, impurity production
- Investigate Hybrid scenario

Awards

- John Rice, Nuclear Fusion Prize for best paper

FY12D *10% below FY11A Guidance (*12 weeks research operations)

Plans

- Highest priority investigations will be carried out, particularly for ITER/ITPA needs and thesis research, including: Pedestal characterization (joint facility target); LHRF physics (density limits, current drive efficiency); advanced ICRF antenna (sheath reduction, impurity effects with high Z PFC's); disruption mitigation

Implications

- Personnel reductions: 2.5 scientists, 1 post-doc, 3 engineers, 2 technicians; do not replace 2 graduate students
- Reduced research runtime
    - Even fewer of high priority runs can be completed (to less than ¼)
- Delay DEMO-like divertor (~6 months)
- Delay second advanced LH launcher (1 year)
- Defer data acquisition and computing infrastructure upgrades
    - Hardware becomes obsolete on time scale of about 3 years
- Research areas with most significant negative impacts designated in next section in *green italics*

FY12A Guidance Budgets: 17 weeks research operations

Prioritized increments:

- Add 5 weeks research operation (to 17 total), and restore personnel cuts
    - Increased productivity across all topical areas
        - Particularly important to take advantage of new tools (LH, ICRF, diagnostics) developed in FY10
- Student training maintained
- Second ICRF antenna on schedule (reduced impurity generation at full power, operation in FY13)
- Second LHRF launcher on schedule (installation in FY12, operation in FY13)
- Advanced DEMO-like divertor scheduled maintained (for FY13 installation)
- Data acquisition upgrade pace maintained
    - Improving reliability and productivity

Areas of Research Emphasis and Principal Upgrades (areas benefitting most from increment, relative to -10% budgets, shown in *green italics*)

- Inductive H-mode scenarios (ITER baseline)
    - Optimization of radiative H-modes at higher I_p
        - *Divertor vs. main chamber seeding, feedback control*

- ITER demo conditions at full field (5.3 tesla)
- *Helium majority demonstration discharges at half-field (2.6 tesla)*
- Extend I_p rampup experiments with LHCD
- H-mode access during current rampup

- Alternate tokamak scenarios
  - I-mode
    - Document/increase performance and robustness
    - Assess applicability to ITER
    - *Dependence on shape*, compatibility with impurity seeding
  - Non-inductive scenarios with LHCD
    - Extend to high T_e (with ICRF mode conversion heating)
    - Evaluate LHCD at intermediate densities
    - *Evaluate LHCD into I-mode*
  - Hybrid scenarios
    - Complete recent experiments on LHCD j(r) modification, with sawtooth suppression
  - *Further exploration of beneficial LHCD effects on energy and particle transport, pedestal modifications*
    - *Assess ITER application*
- Core transport studies
  - Joint research target
    - With DIII-D, NSTX, experiments aimed at testing gyrokinetic models (particle and energy transport)
  - Connections between reversal of self-generated flows, confinement regime bifurcation
    - Focus on changes in density fluctuations
  - Extend studies of particle transport emphasizing ITER relevant regimes
    - Low, medium and high Z impurities
    - Electron particle transport
    - *Main ion transport*
- Pedestal studies
  - H-mode transition
    - Role of SOL flows, rotation shear, E_r
    - physics of H suppression in I-mode
  - Pedestal structure, transport – modeling comparisons
    - EPED 1.6 and follow-ons
    - *Fluid turbulence codes in collisional H regimes*
  - Stability boundaries and MHD growth rates
    - Peeling-ballooning boundary with ELITE, BOUT++ (I- and H-modes)
    - *Steady-state QCM analysis with SOLT, BOUT, M3D*
    - Linear stability analysis (e.g. GS2, TGLF)
  - Pedestal and ELM modification by external means
    - ICRF, LHRF, shoelace antenna
- Plasma Boundary Physics and Technology
  - Impurity seeding methods for H-mode optimization and ITER guidance

- Modify boundary turbulence with shoelace antenna
- First ever between shot in-situ surface analysis using Radio Frequency Quadrupole accelerator
- Contribute C-Mod data on heat-flux footprint to multi-machine ITPA database
    - Plan follow-on experiments
- Investigate role of SOL in LHRF effects at intermediate density
- Deploy advanced probes for SOL profiles
    - T_i, potential, electron distribution function
- *Finalize outer divertor design, begin construction*

- Wave-Plasma Interactions
    - Ion Cyclotron RF
        - Compare rotated and standard antenna characteristics
            - Sheaths, impurity production, impact on SOL density and flows, role of seeding
            - Dependence on phasing
        - *Investigate Mode Conversion Flow Drive in I-mode*
        - Characterize ICRF SOL modification as function of single pass absorption, phasing, confinement mode, n_e, I_p
            - Also assess effects on SOL n_e profiles
        - Characterize loading as function of plasma parameters, gaps, gas puffing
        - Assess response to transients
            - Confinement transitions, *ELMs*
    - Lower Hybrid RF
        - Validate density limit model and determine CD efficiency in high single-pass absorption regimes
        - Investigate transport in non-inductive, flat/reversed shear plasmas with $q_0>1$
        - *Fabricate 2nd LH launcher and complete fabrication of 4th klystron cart*
- Macroscopic Stability
        - Study radiation uniformity during disruption mitigation
            - utilize 2nd gas jet and toroidally spaced bolometers
        - *AE/ICRF/fast particle interaction studies*
            - Utilize newly installed fast ion loss detectors, fast ion CX (FICX)
        - Test proposed ITER grounding scheme (common bonding network)

Plain English Goals
- Lower Hybrid accessibility and current drive efficiency; relation to density limits
- Low collisionality edge energy transport barriers (I-mode)

FY12B Incremental budget: 21 weeks research operation

Prioritized increments:

- Add 4 weeks of research operation
- Earlier implementation of ICRF power supply upgrades
  - Increased reliability, increase of total available source power
- Diagnostic upgrades (core fluctuations)

Research Highlights

- Substantial increased progress across all topical science areas and integrated thrusts, with particular emphasis on high priority ITER R&D and ITPA joint research, both in FY12 and subsequent years

FY13D: 10% Decrement from FY11A (10 weeks research operation)

Plans

- Continue highest priority studies, but at significantly reduced pace

Implications (assuming guidance budget in FY12):

- Personnel reductions: 2 scientists, 3 engineers, 1 Post-Doc, 2 technicians; do not replace 2 graduate students
- Reduced runtime (5 weeks)
  - Even fewer of priority runs can be completed (to less than ¼)
  - Increased pressure on graduate students to complete data sets for thesis work
  - Significantly reduced impact in joint ITPA experiments
- Delay (1 year) installation of ICRF switchgear
- Delay (1 year) replacement of Thomson laser: reduced time resolution; risk of loss of old, unmaintainable laser, halving available time resolution
- Delay (1.5 years) installation of Doppler reflectometer system: no core fluctuation propagation measurements; reduced impact of core transport studies
- Reduced travel budgets: decreased participation in, impact at national and international conferences/workshops, including ITPA
- Research areas with most significant negative impacts designated in next section in *green italics*

FY13A Guidance Budgets (flat from FY12A): 15 weeks research operation

Prioritized increments:

- Add 5 weeks research operation and restore personnel cuts

Areas of Research Emphasis and Principal Upgrades (areas benefitting most from increment, relative to -10% budgets, shown in *green italics*)

- Inductive H-mode scenarios (ITER baseline)

- Extend full field (5.3 Tesla) ITER demonstration conditions to lower ν*, higher n/n_G
- *Burn control studies*
- Develop and test advanced plasma control, fault sensing and mitigation algorithms

- Alternate tokamak scenarios
  - I-mode
    - Divertor heat-flux footprint assessments, with and without seeding
  - Non-inductive scenarios with LHCD
    - Integrated scenario modeling incorporating state-of-the-art LH codes
    - Assess scenarios starting from L-, I-, and H-mode targets, with P_{LH}~2 MW
  - Hybrid scenarios
    - ICRF induced H-mode with LHCD hybrid target
      - Can shear modification be sustained for multiple skin times, and if so, is H-mode confinement improved?
    - *Assess ITER applications of beneficial LHCD effects on energy and particle transport*
    - Explore prospects of hybrid access in high β_N regime without LHCD, building on promising half-field (2.6 Tesla) ITER demo results
- Core transport studies
  - Origin and impact of self-generated rotation
  - RF tools to control transport
    - Modified current density and/or rotation profiles
  - Design and build second generation CECE
  - *Finalize Doppler backscatter system for density and velocity fluctuations*
- Pedestal studies
  - H-mode trigger
    - Density, flow profiles with increased time resolution
    - Analysis using multi-machine edge profile database
  - Comparisons with models
    - Tests of EPEC2.0 with full calculation of KBM physics
    - *Use extensions of gyrokinetic models for mode stability in the pedestal*
    - Comparisons with XGC1 full EM turbulence
    - B2-Eirene/OEDGE to understand impact of 2D ionization source
  - *Enhanced neutral*, impurity diagnostics to extend seeded H-mode studies
- Plasma Boundary Physics and Technology
  - Full impurity seeding feedback development
  - Compare pedestal turbulence at high- and low-field sides
  - Explore roles of electron versus ion channel for boundary heat transport
  - Response of SOL electric fields, and electron and ion distribution functions to *ICRF* and LHRF

  - Measure fluctuation-induced particle, heat and momentum transport (Reynolds stress) in boundary for intrinsic and externally excited turbulence
  - *Manufacture/install advanced outer divertor*
- Wave-Plasma Interactions
  - Ion Cyclotron RF
    - Off-axis MC flow drive for rotation profile control
    - *MDFD in low density H-modes, and in He and H majority plasmas*
    - Characterization of $D(^3He)$ minority heating
      - Use new/upgraded FICX and CHRS diagnostics
    - ^3He minority heating in H majority (ITER non-active phase)
    - Develop analysis and simulation tools for impurity mitigation
      - Collab. with RF SciDAC
    - Characterize RF induced plasma potential changes with reciprocating probe
    - Assess gas puffing effectiveness for modifying SOL n_e profile
    - *Revisit alpha channeling*
      - Minority heating to create proton tail, ^3He MC to establish channeling region
  - Lower Hybrid RF
    - *Install 2nd launcher, commission 4th cart*
      - *16 installed klystrons, 4 MW source, ≥2 MW coupled*
      - *Fully non-inductive, reversed shear with I_p up to 1 MA*
      - *Extend transport, turbulence and rotation studies to these new regimes enabled by increased CD power*
- Macroscopic Stability
  - Disruption mitigation
    - *D_2 opacity studies*
    - Runaway electron position control and deceleration
    - NIMROD modeling

Plain English Goals (proposed)

- Core transport, turbulence and modeling
- Pedestal modification via external means (ICRF, LHRF, active MHD)

FY13B Incremental budget (10% above FY11A): 19 weeks research operation (assuming guidance budget in FY12)

Prioritized increments:

- 4 weeks additional research operation, to 19 weeks
- Upgrade to fast vertical control power systems for improved stability at high elongation
- Upgrade to correction coil power supplies for increased capabilities to study effects of applied non-axisymmetric fields

Research Highlights

- Substantial increased progress across all topical science areas and integrated thrusts, with particular emphasis on high priority ITER R&D and ITPA joint research
- Significant reduction of backlog of high priority runs
- Graduate students able to complete their data sets for thesis work sooner and in greater depth
- Increased participation in, impact at national and international conferences/meetings, including ITPA

Alcator C-Mod Publications –2010 to present

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Wallace, G. M., Parker, R.R., Bonoli, P.T., et al., "Absorption of Lower Hybrid Waves in the Scrape Off Layer of a Diverted Tokamak", *Phys Plasmas* **17** p. 082508, 2010.

Xu, P., Irby, J.H., Bergerson, W.F., et al., "Preliminary Results from the Alcator C-Mod Polarimeter". *Rev Sci Instrum* **81** p. 10D507, 2010.

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Bakhtiari, M., et al., "Using Mixed Gases for Massive Gas Injection Disruption Mitigation on Alcator C-Mod", submitted to *Nucl Fusion*.

Brunner, D., LaBombard, B., Payne, J., et al., "Comparison of Heat Flux Measurements by IR Thermography and Probes in the Alcator C-Mod Divertor", to be published in *J Nucl Mater* 2011.

Howard, N., et al., "Characterization of Impurity Confinement on Alcator C-Mod Using a Multi-Pulse Laser Blow-Off System", to be published in *Rev Sci Instrum* 2011.

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Meneghini, O., Shiraiwa, S., Faust, I., et al., "Fullwave Simulations of Lower Hybrid Waves Coupled to 3D Fokker Planck Solver: Comparison with Alcator C-Mod Experiments," submitted to *Fus Sci and Tech*.

Neilson, G., Bromberg, L., Brown, T., … Meneghini, O., et al., "Progress Toward Attractive Stellerators", submitted to *Nucl Fusion.*

Ochoukov, R., Whyte, D.G., Lipschultz, B., et al., "Interpretation and Implementation of an Ion Sensitive Probe as a Plasma Potential Diagnostic on Alcator C-Mod", to be published in *J of Nucl Mater*.

Reinke, M.L., Hughes, J.W., Loarte, A., et al., "Effect of N2, Ne and Ar Seeding on Alcator C-Mod H-Mode Confinement", to be published in *J Nucl Mater* 2011.

Rice, J.E., Reinke, M.L., Ashboum, J.M.A., et al., "The Ar17+ Lya 2/Lya1 Ratio in Alcator C-Mod Tokamak Plasmas", submitted to *J Phys B.*

Rice, J.E., Hughes, J.W., Diamond, P.H., et al., "The Edge Temperature Gradient as Intrinsic Rotation Drive in Alcator C-Mod Tokamak Plasmas", submitted to *Phys Rev Lett.*

Schmidt, A.E., Bonoli, P.T., Harvey, R.W., et al., “Investigation of Lower Hybrid Physics Through Power Modulation Experiments on Alcator C-Mod”, submitted to *Phys of Plasmas.*

Shiraiwa, S., Meneghini, O., Beck, W., et al., “Design and Commissioning of a Novel LHCD Launcher on Alcator C-Mod”, submitted to *Nucl Fusion.*

Takase, Y., Kakuda, H., Wakatsuki, T., Bonoli, P.T., et al., “Development of a Plasma Current Ramp-Up Technique for Spherical Tokamaks by the Lower-Hybrid Wave”, submitted to *Nucl Fusion.*

Wallace, G.M., Hubbard, A.E., Bonoli, P.T., et al., “Lower Hybrid Current Drive at High Density in Alcator C-Mod”, submitted to *Nucl Fusion.*

Conferences:

23rd IAEA Fusion Energy Confernece, Daejon, South Korea, October 2010.

Talks

Catto, P., “Radial Electric Field Evaluation and Effects in the Core and Pedestal”.

Izzo, V., “Runaway Electron Confinement Modeling for DIII-D, Alcator C-Mod and ITER”.

Lin, Y., “ICRF Mode Conversion Flow Drive on Alcator C-Mod”.

Marmar, E., “Overview of Recent Results from Alcator C-Mod Including Applications to ITER Scenarios”.

Rice, J., “Progress Towards a Physics Based Phenomenology of Intrinsic Rotation in H-Mode and I-Mode”.

Whyte, D., “I-Mode: An H-Mode Energy Confinement Regime with L-Mode Particle Transport in Alcator C-Mod”.

Posters

Bonoli, P., “Validation of Simulation Capability for RF Wave Propagation and Absorption in the Ion Cyclotron Range of Frequencies on Alcator C-Mod”.

Hughes, J., “Power Requirements for Superior H-Mode Confinement on Alcator C-Mod: Experiments in Support of ITER”.

Meneghini, O., “Fullwave Simulations of Lower Hybrid Waves Coupled to 3D Fokker Planck Solver: Comparison with Alcator C-Mod Experiments”, presented at the 1st International Youth Cnference on Fusion Energy, in conjunction with the 23rd IAEA Fusion Energy Conference.

Shiraiwa, S., “Design and Commissioning of a Novel LHCD Launcher on Alcator C-Mod”.

Takase, Y., Kakuda, H., Wakatsuki, T., Bonoli, P., et al., “Development of a Plasma Current Ramp-Up Technique for Spherical Tokamaks by the Lower-Hybrid Wave.”

Wallace, G., “Lower Hybrid Current Drive at High Density in Alcator C-Mod”.

Wilson, R., Kessel, C., Wolfe., S., et al., “Experiments and Simulations of ITER-like Plasmas in Alcator C-Mod”.

Wukitch, S., “ICRF Impurity Behavior with Boron Coated Molybdenum Tiles in Alcator C-Mod”.

18th Topical Conference on High Temperature Plasma Diagnostics, Wildwood, NJ, USA, May 2010

Arai, K., “Detection of Lower Hybrid Waves on Alcator C-Mod with Phase Contrast Imaging Using Electro-Optic Modulators”.

Bespamyatnov, I., “An Integrated CXRS/BES Diagnostic for Alcator C-Mod Tokamak”.

Hartwig, Z., “Simulated PFC Surface Composition Measurements for an In-Situ Accelerator-Based Surface Diagnostic on Alcator C-Mod”.

Lau, C., “SOL Reflectometer”.

Mumgaard, R., “Design Considerations for Real-Time MSE Background Subtraction for Alcator C-Mod”.

Ochoukov, R., “Interpretation and Implementation of an Ion Sensitive Probe (ISP) as a Plasma Potential Diagnostic in Magnetized Plasmas”.

Reinke, M., “VUV Impurity Spectroscopy on the Alcator C-Mod Tokamak”.

Shiraiwa, S., Baek, S.G., “LH Reflectometer: Direct Detection of Lower Hybrid Wave Using Reflectometer on Alcator C-Mod”.

Terry, J., “IR Thermography on Alcator C-Mod”.

Xu, P., “Preliminary Results from the Alcator C-Mod Polarimeter”.

23rd US Transport Task Force Workshop, Annapolis, MD, USA, April 2010

Talks

Fiore, C., “The Role of Rotation in C-Mod ITB Plasma Transport”.

Greenwald, M., “FSP: Validation Program Planning”.

Howard, N., “Impurity Transport Studies on Alcator C-Mod L-Mode Plasmas”.

Hubbard, A., “Investigation of a Regime with an Edge Energy Transport Barrier but No Particle Barrier in Alcator C-Mod”.

Hughes, J., “Edge Transport Barrier Structure and Dynamics: Highlights of Recent Research”.

Posters

Dominguez, A., “Study of Edge Fluctuations in I-Mode Plasmas on C-Mod”.

Hughes, J., “Edge Profile and Fluctuation Evolution During H-Mode Pedestal Formation on Alcator C-Mod”.

37th European Physical Society Conference on Plasma Physics, Dublin, Ireland, June 2010

Poster

Hughes, J., “Power Requirements for High Performance H-Modes in Alcator C-Mod”.

Lin, Y., “ICRF Mode Conversion Flow Drive in JET (He3) Plasmas and Comparison with Alcator C-Mod”.

Marmar, E., “I-Mode: An H-Mode Energy Confinement Regime with L-Mode Particle Transport in Alcator C-Mod”.

Meneghini, O., “Microwave Probe Diagnostics for the Lower Hybrid Four-Way-Splitter Antenna on Alcator C-Mod”.

Rice, J., “Parameter Scalings of ICRF Mode Conversion Flow Drive in Alcator C-Mod Plasmas”.

Shiraiwa, S., Meneghini, O., Garrett, M., et al., “Recent Progress in Core/Edge Integrated Plasma Wave Modeling Based on FEM”.

Wallace, G., Parker, R., Bonoli, P., et al., “Modification of the Scrape-Off Layer by Lower Hybrid Waves in the Alcator C-Mod Tokamak”.

Wukitch, S., “Evaluation of ICRF Heated Discharges with Boron Coated Molybdenum Tiles”.

52nd Annual Meeting of the APS Division of Plasma Physics, Chicago, IL, USA, Nov. 2010

Invited Talks

Hubbard, A., “I-Mode Regime with an Edge Energy Transport Barrier but not Particle Barrier in Alcator C-Mod”.

LaBombard, B., “Scaling of the Power Exhaust Channel in Alcator C-Mod”.

Loarte, A., “High Confinement/High Radiated Power H-Mode Experiments in Alcator C-Mod and Consequences for IER Qdt=10 Operation”.

Schmidt, A., “Investigation of LH Physics Through Power Modulation Experiments on Alcator C-Mod”.

Contributed Orals

Bader, A., “Investigating Highly Energetic Ions in the Alcator C-Mod Tokamak”.

Ernst, D., “Using Modulated On-Axis ICRH to Control Fluctuations in an Internal Transport Barrier”.

Fiore, C., “The Role of Rotation in C-Mod Internal Transport Barriers”.

Granetz, R., “Effect of Plasma Configuration on Disruption Runaway Electrons”.

Howard, N., “Experimental and Gyrokinetic Investigations of Impurity Transport on Alcator C-Mod”.

Kessel, C., Wolfe, S., Hutchinson, I.H., et al., “Time-Dependent Imulations of Alcator C-Mod ITER-Like Discharges”.

Marmar, E., “Alcator C-Mod Research Highlights”.

Meneghini, O., “Coupling of LH Waves with Four-Way-Splitter Antenna on Alcator C-Mod”.

Reinke, M., “Poloidal Variation of AR17+ Impurity Density in Alcator C-Mod”.

Sears, J., “Recent Measurement and Interpretation of Stable and Unstable Alfvén Eigenmodes in the Presence of Fast Ions in Alcator C-Mod”.

Terry, J., “Measurements of Heat-Flux on the Divertor Target of Alcator C-Mod”.

Tsujii, N., “Measurement of ICRF Mode Conversion and Minority Ion Tail Influence on the Wave Absorption”.

Wilson, R., “Experiments on the Alcator C-Mod Tokamak Utilizing a Novel Lower Hybrid Wave Launcher”.

Wright, G., “Tungsten Migration in the Alcator C-Mod Divertor”.

Posters

Baek, S., “The Development of LH Reflectometer in Alcator C-Mod”.

Bespamyatnov, I., “Detection and Application of Doppler and Motional Stark Features in the DNB Emission Spectrum in the High Magnetic Field of the Alcator C-Mod Tokamak”.

Bonoli, P., “Analysis of Lower Hybrid Current Drive Modification of Sawteeth in Alcator C-Mod”.

Brunner, D., “Measurements of Sheath Heat Flux in the Alcator C-Mod Divertor”.

Burns, C., “Analysis Tools for Turbulence Studies at Alcator C-Mod”.

Churchill, M., “Inner-Wall B5+ Impurity Density Measurements Using CXRS”.

Delgado-Aparacio, L., “In-Situ Wavelength Calibration and Temperature Control for the C-Mod High-Resolution X-Ray Crystal Imaging Spectrometer”.

Dominguez, A., “Correlation Reflectrometry Experiment and Simulation on Alcator C-Mod”.

Faust, I., “High Density Scrape-off Layer Absorption of Lower Hybrid Waves on the Alcator C-Mod Tokamak”

Garrett, M., “ICRF Antenna Optimization for Alcator C-Mod”.

Golfinopoulos, T., “Active Simulation of MHD Modes in Alcator C-Mod”.

Hughes, J., “Developing Predictive Capability for the H-Mode Pedestal: Experimental Contributions from Alcator C-Mod”.

Kohno, H., “A Numerical Analysis of the RF Wave Propagation Under the Sheath Boundary Condition in the Ion Cyclotron Range of Frequencies”.

Liao, K., “CXRS-Based Diagnostic for Fast Ion Detection in the Core of the Alcator C-Mod Tokamak”.

Lau, C., “Current Status of SOL Reflectometry”.

Lee, J., “C-Mod Experimental Toroidal Rotation Results”.

Lin, Y., “ICRF Mode Conversion Flow Drive on Alcator C-Mod”.

Ma, Y., “Plasma Density Dependence of L-Mode Confinement and L-H Transition on Alcator C-Mod”.

Mikkelson, D., “Low-Collisionality Density-Peaking in GYRO Simulations of C-Mod Plasmas”.

Mumgaard, R., “Design Considerations for Real-Time MSE Background Subtraction on Alcator C-Mod”.

Ochoukov, R., “Quantitative Assessment of RF Sheath Rectification in Alcator C-Mod with Emissive, b-dot, and Ion Sensitive Probes”.

Olynyk, G., “MHD Activity During the Pre-TQ Phase of Gas Jet Mitigated Disruptions on Alcator C-Mod”.

Parker, R., “Recent Results from Lower Hybrid Current Drive Experiments on Alcator C-Mod”.

Podpaly, Y., “Momentum Transport Calculations on Alcator C-Mod in the L-H Mode Transition”.

Porkolab, M., et al., “Electron Transport Dominated Regimes in Alcator C-Mod”.

Rowan, W., “Comparison of Impurity Transport in Alcator C-Mod with Predictions of Fluid Models of Drift Wave Turbulence”.

Scott, S., “Status and Recent MSE Results on Alcator C-Mod”.

Shiraiwa, S., “Full Wave Modeling of Off-axis LHCD using the LHEAF Code on Alcator C-Mod”.

Tsujii, N., Porkolab, M., et al., “Measurement of ICRF Mode Conversion and Minority Ion Tail Influence on Wave Absorption”.

Wallace, G., “Absorption of Lower Hybrid Waves in the Scrape Off Layer of a Diverted Tokamak”.

White, A., “Correlation Electron Cyclotron Emission Diagnostic for Alcator C-Mod”.

Woller, K., “Depth Profiles of Helium and Deuterium in Tungsten “Fuzz” using Elastic Recoil Detection”.

Wright, J., “Self-Consistent Full Wave Analysis of Lower Hybrid Current Drive in Weak and Strong Absorption Regimes on Alcator C-Mod”.

Wukitch, S., “Impurities Associated with ICRF on C-Mod”.

Xu, P., “Progress on the C-Mod FIR Polarimeter System”.

19th International Conference Plasma Surface Interactions, San Diego, CA, USA, May 2010

Talks

Cziegler, I., “Connections Between Particle Transport and Turbulence Structures in the Edge and SOL of Alcator C-Mod”.

Smick, N., “Drift-Driven and Transport-Driven Plasma Flow Components in the Alcator C-Mod Boundary Layer”.

Posters

Brunner, D., LaBombard, B., Payne, J., et al., “Comparison of Heat Flux Measurements by IR Thermography and Probes in the Alcator C-Mod Divertor”.

LaBombard, B., “Divertor Heat Flux Footprints in Alcator C-Mod”.

Hartwig, Z., “Simulated PFC Surface Composition Measurements for an In-Situ Accelerator-Based Surface Diagnostic on Alcator C-Mod”.

Ochoukov, R., “Interpretation and Implementation of an Ion Sensitive Probe as a Plasma Potential Diagnostic on Alcator C-Mod”.

Reinke, M., “Effect of N2 and Ar Seeding on Alcator C-Mod H-Mode Confinement”.

Wukitch, S., “Evaluation of ICRF Heated Discharges with Boron-Coated Molybdenum Tiles”.

RF SciDAC Workshop, PPPL, Princeton, NJ, USA, September 2010.

Bonoli, P., “Some Progress on Edge Coupling Simulations in the Lower Hybrid Range of Frequencies”.

Kohno, H., “A Numerical Analysis of the RF Wave Propagation Under the Sheath Boundary Condition in the Ion Cyclotron Range of Frequencies”.

Lee, J., “Theoretical Studies of Toroidal Rotation Induced by Lower Hybrid Wave Fields”.

Wright, J., “Improvements to Wave Codes”.

C-Mod/NSTX Pedestal Workshop, PPPL, Princeton, NJ, USA, September 2010.

Cziegler, I, "Gas-Puff-Imaging on Alcator C-Mod".

Golfinopulos, T., "External Stimulation of Edge Modes".

Hughes, J., "Overview of Alcator C-Mod Pedestal Research and Capabilities"

Hughes, J., "Pedestal Modification via Lower Hybrid Waves".

Hughes, J., "ELMs on C-Mod".

Hubbard, A., "Barriers in Different Transport Channels (e- and i-thermal, particle) and Relation to Pedestal Structure".

Fusion Power Associates Annual Meeting, Washington, DC, December 2010

Porkolab, M., "Continued Research Through the Next Decade on Existing Tokamaks is Critical to Make Magnetic Fusion a Viable Energy Source".

Other Invited Talks

Podpaly, Y., "Tungsten Measurement on Alcator C-Mod and EBIT for Future Fusion Reactors, presented at the Atomic Spectroscopy and Oscillator Strength in Laboratory and Astrophysical Plasmas (ASOS), University of California Berkeley, CA, August 2010.

Porkolab, M., "Alfvén Eigen Mode and Energetic Particle Studies in Alcator C-Mod", presented at the GSEP Workshop, General Atomics, San Diego, CA, August 2010

C-Mod Related Science Talks, Presented to Audiences Primarily Composed of Fusion Science Researchers

Bonoli, P.T., "Integrated Simulations within the RF SciDAC Center", presented at the US-Japan Workshop on Integrated Modeling and Simulation of Toroidal Plasmas, MIT, Cambridge, MA, February 2010.

Bonoli, P.T., Berk, H.L., "Nazikian, R., et al., "Design of the Wave-Particle Science Driver", presented at the Fusion Simulation Planning Workshop, Boulder, CO, March 2010.

Bonoli, P.T., Berk. H.L., Chan, V.S., et al., "Disruptions and Wave-Particle Science Drivers: Components, Gaps Analysis, and Common Components", presented at the Fusion Simulation Planning Workshop, Boulder, CO, March 2010.

Bonoli, P.T., (on behalf of Berry, L.A., Bader, A, Harvey, R.W., et al.), "Time Dependent Minority Ion Tail Dynamics Study in Alcator C-Mod", Annual Workshop of the SWIM Proto-type Fusion Simulation Project", Boulder, CO, October 2010.

Bonoli, P.T., Harvey, R.W. , Batchelor, D.B., "Lower Hybrid Current Drive (LHCD) Control Studies in Alcator C-Mod", Annual Workshop of the SWIM Proto-type Fusion Simulation Project, Boulder, CO, October 2010.

Lin, Y., ICRF Physics and Applications on Tokamaks", presented at lecture series in Chinese Summer School on Plasma Physics, Shanghai, August 2010.

Porkolab, M., et al., "Studies of Waves and Turbulence in Tokamak Plasmas with Phase Contrast Imaging and Comparisons with Code Predictions by Synthetic Diagnostics", presented at the 40th Annual Anomalous Absorption Conference, Snowmass, CO, 2010.

Porkolab, M., "Comments on Core Turbulence, Transport and Gyrokinetics in Tokamaks: What is Missing"? presented at the Workshop on Electric Fields, Structures and Self-Organization in Magnetized Plasmas, Dublin, Ireland, 2010.

Porkolab, M., "Turbulence and Transport Studies in Alcator C-Mod Using Phase Contrast Imaging (PCI) Diagnostics and Comparison with TRANSP and Nonlinear Global GYRO", presented at EFTSOMP2010, Dublin, Ireland, June 2010.

Wallace, G.M., et al., "Lower Hybrid Current Drive Studies on Alcator C-Mod", presented at IAEA Steady State Operations Meeting, Vienna Austria, December 2010.

MIT IAP Talks, **MIT Plasma Science and Fusion Center, January 2011.**

Parker, R.R., "An Alcator Chronicle, or What Happened to Alcator B"?

White, A., "Diagnosing Plasma Turbulence in Tokamaks".

Awards and Prizes

Rice, J.E., "Inter-machine Comparison of Intrinsic Toroidal Rotation in Tokamaks", *Nucl Fusion* **47**, p. 1618, 2007, received the 2010 Nuclear Fusion Journal prize.