1th DPP- APCPP

Summary of MC Plasma

Jiangang Li (ASIPP), Wulyu Zhong (SWIP)

on behalf of all contributors

18–22 Sept. 2017， Chengdu, China

Outline

– Highlight

– Major Progresses

- Major progresses for machines, H-mode physics, ELM physics and control, energetic particles, MHD, Transport, Steady-state, PWI, Negative triangularity, diagnostics, Control&scenario development.

– Future Challenges

– Summary

General Information

Plenary (9), OV (20), I (69), O(31), P(63)

Experiments （121）

Theory（28）

Simulation （43）

Total： 192， Largest contribution in 1st DPP-AAPPS

Highlight

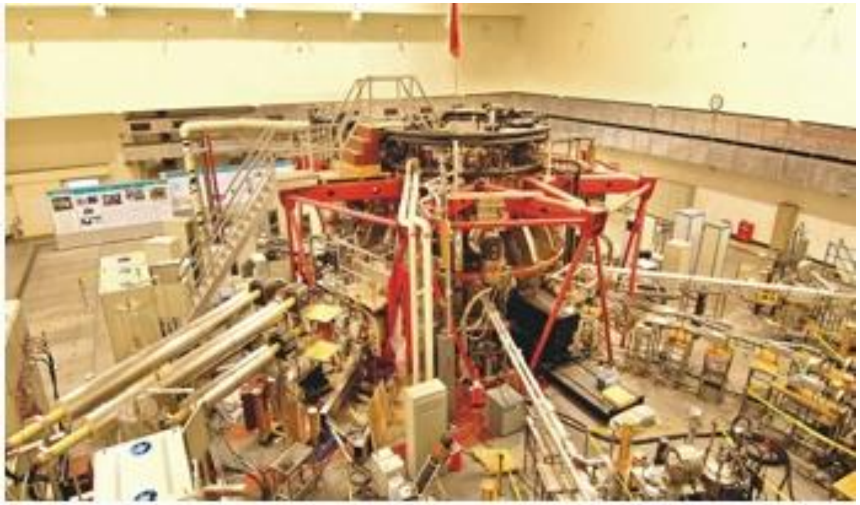
Significant progresses have been made
Efforts have been focus on physics understanding

- ITER on the right track, good progress for construction and preparation for operation
  (P4,OV11,OV16, I37)
- HL-2A explore robust ELM control methods(SMBI, RMP,LHCD, IM seeding, OV1)
- KSTAR strengthen the efforts for SS high beta plasma (OV2)
- LHD starts D operation (P25)
- EAST 100s H-mode (P11,OV6)
- Energetic particle remains the hot topic (20) and Nonlinear processes have been deeply addressed.
- Negative triangularity provide an alternative for power handling
- Small machines(15) make unique contributions for basic plasma science, physics understanding and training next generation plasma scientist.
- Theroy&Simulation (~40%) play a key role for understanding and future scenarios developments.

Outline

- Highlight
- **Major Progresses**
  - **Major progresses for machines, H-mode physics, ELM physics and control, energetic particles, MHD, Transport, Steady-state, PWI, Negative triangularity, diagnostics, Control&scenario development.**
- Future Challenges
- Summary

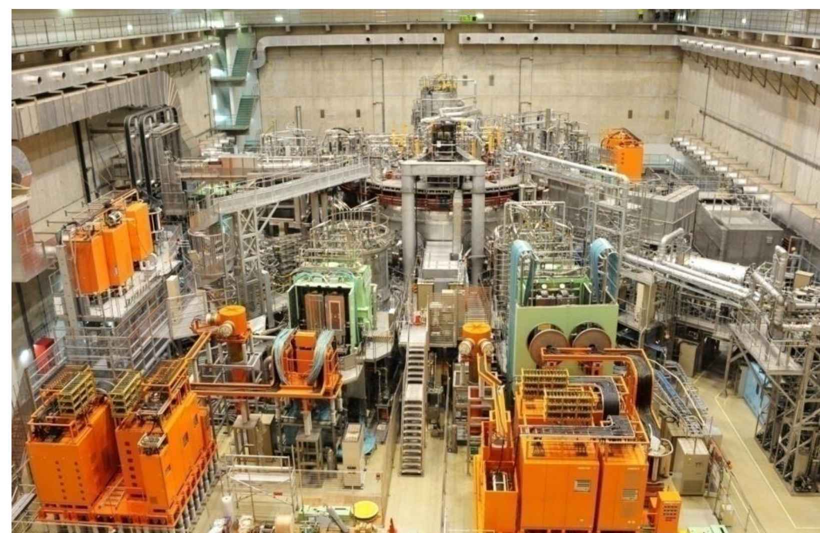
4 Asia leading devices provide major contributions



29 contributions

28 contributions

13 contributions

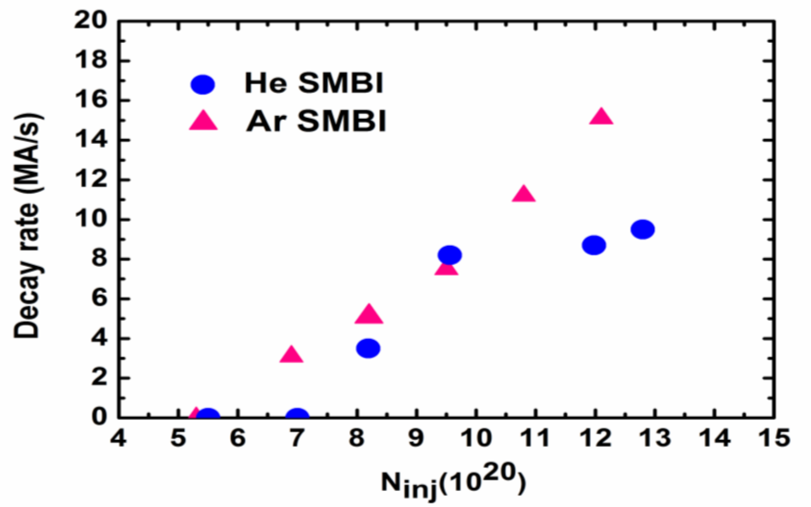


5 contributions

Efforts focus on plasma instability control and H-mode physics in HL-2A

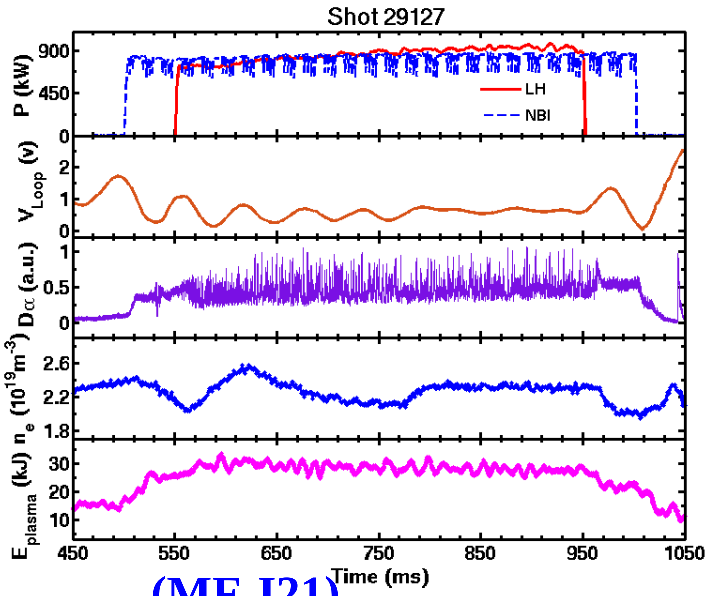
- **Plasma instability control**
  - explored robust ELM control methods (SMBI, RMP,LHCD, IM seeding)
  - MGI+ SMBI to mitigation run away current
  - real-time active control of NTM by ECRH launcher mirror steering
  - suppression of ion fishbone by ECRH

deliver low-Z gas for RE dissipation



- **H-mode physics**
  - Double critical gradients of electromagnetic turbulence in H-mode
  - mechanism of L-H transition
  - observed various pedestal instabilities

Using PAM launcher on H-mode plasmas

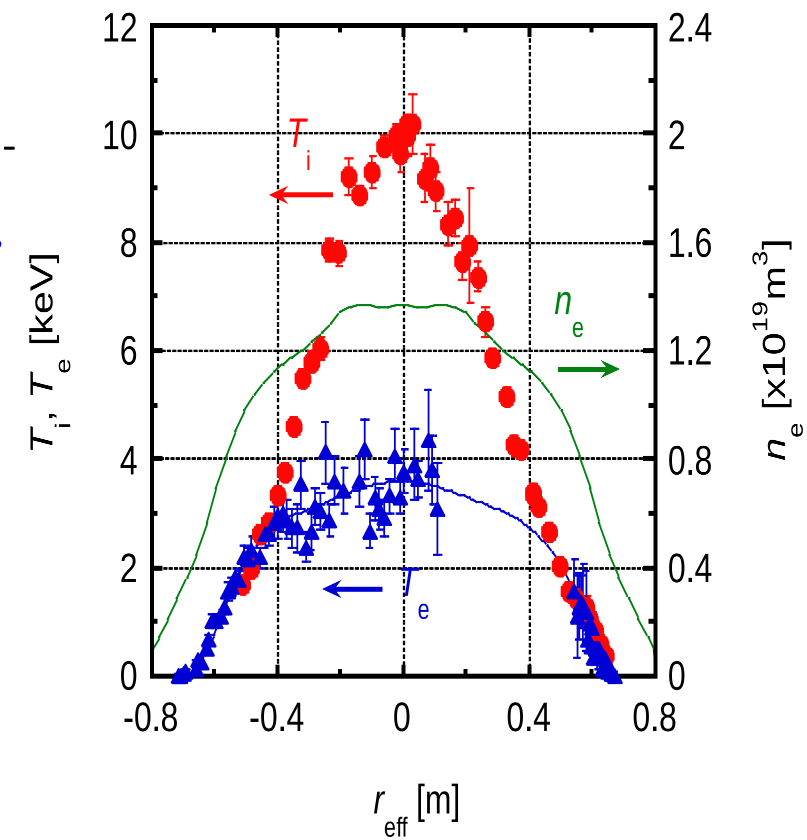


(MF-I21)

[P29] [MF-OV1] [MF-I3] [MF-O2] [MF-I29] [MF-05] [MF-I34] [MF-I36] [MF-I34] [MF-O20] [MF-I44] [MF-O26] [MF-O27] [MF-O30] [MF-I17] [MF-I19] [MF-O10] [MF-O12] +9 posters

The first deuterium experiment campaign was successfully finished on LHD

- **The preparation and the commissioning for D-XP are proceeded successfully.**
  - Calibration of Neutron diagnostic and Legal inspection completed, successfully.
  - Injection power of P-NBI is increased to 9MW. N-NBI decreases its injection power about a half due to the increase of co-extracted electron, i.e., isotope effect in negative-ion source.
- **The first D-operation on LHD was quite successful.**
  - **The ion temperature of 10keV was achieved in D.-exp.**
  - **Some indication of isotope effects, electron energy transport and impurity behavior, were observed.**
  - Neutron diagnostics accelerates useful EP confinement studies on helical machines.

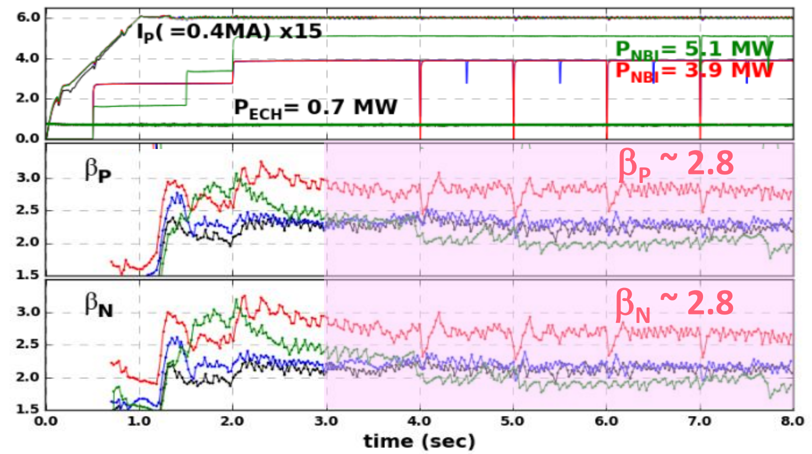


Triton burn-up rate over 0.4% was achieved. Comparable to tokomak.

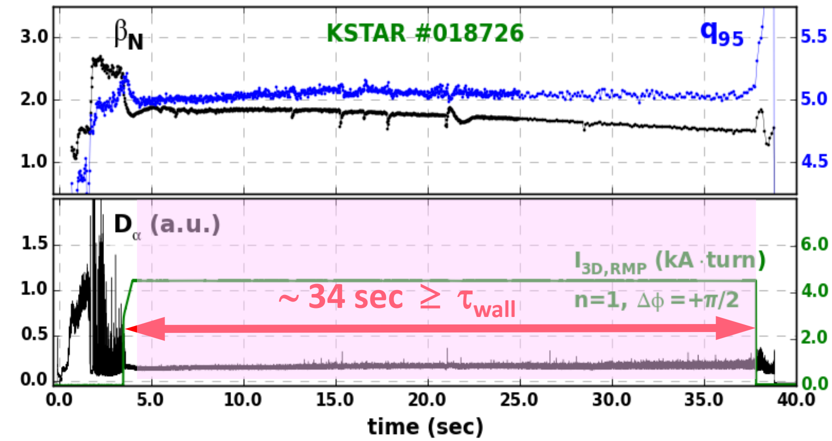
[P25] [MF-I4] [MF-I9] [MF-I59]

KSTAR made good progress in SS H-mode with high beta

- **Unique capabilities of KSTAR** : tokamak plasma symmetry, RMP coils, imaging diagnostics, and long pulse neutral beam.
- **Expanded operation regimes** : steady-state high beta operation (~ 72s) as well as alternative modes of high elongation (k >2) , IBS, ITB, hybrid (G >0.4) , high poloidal beta (β_P ~ 3), and low edge q.
- **ELM-crash suppression** : record long (~34s) ELM-crash suppression with n=1 RMP, and achieving suppression at ITER compatible low edge q (~3.4) with n=2 RMP.
- **Upgrade** : Plan is made which oriented to KDEMO



Stationary high beta discharge (β_N ~ β_N ~ 2.8) at 0.4 MA, 3.9 MW NBI and 0.7 MW ECH

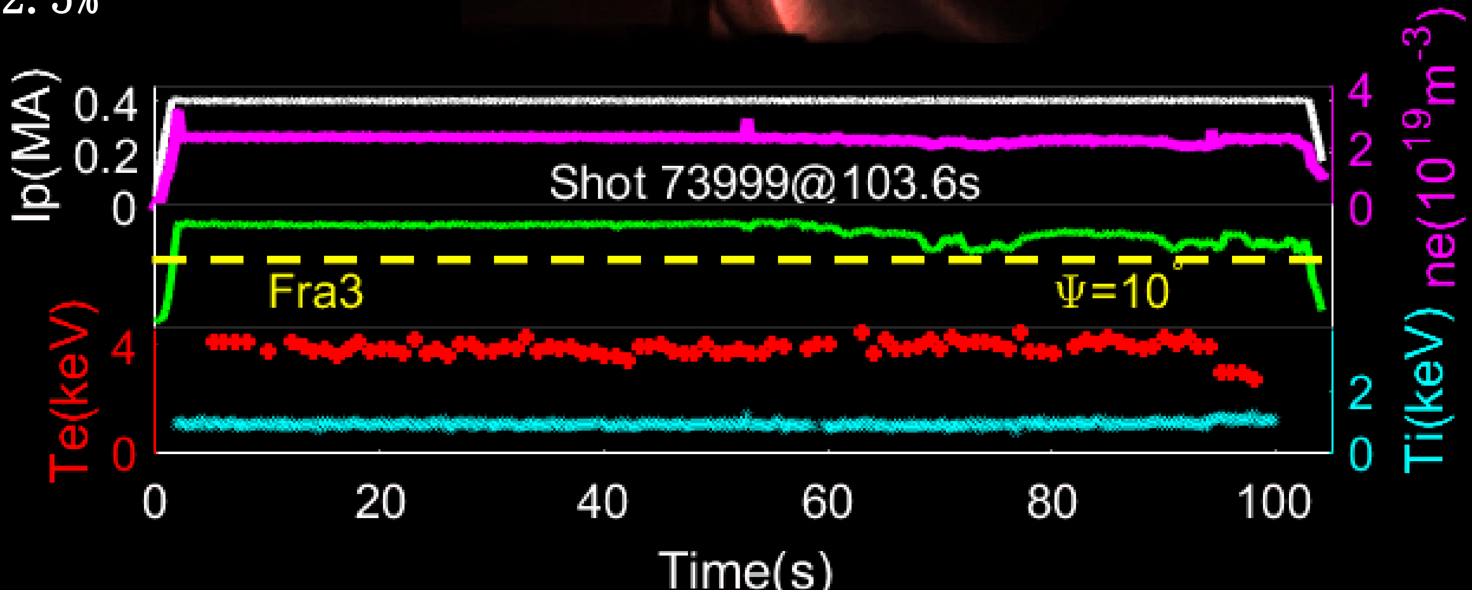


Record breaking long ELM-crash suppression (~ 34s)

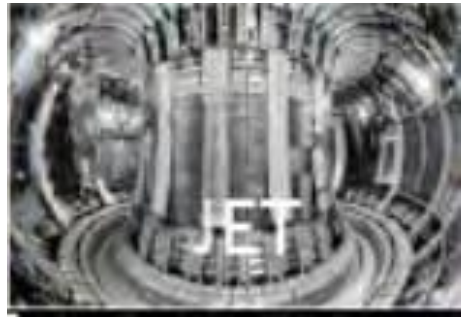
[P18] [MF-Ov2] [MF-I27] [MF-I30] [MF-I55] [MF-I58] [MF-I45] [MF-I47] [MF-I16] [MF-I18] [MF-I51] + 2 posters

100s Steady-state H-mode operation with W-Wall

- ~101.2 s H-mode, V_{loop}~0 V
- ~3 MW RF H&CD (LHW+ICRF+ECH)
- H_{98y2} ~1.1
- W-Divertor temperature was saturated after t=20s
- I_{LHCD}/I_p~76%
- f_{bs}~23%
- I_{ECCD}/I_p~2.5%



Unique contribution from different machines

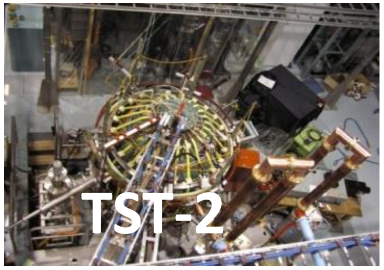


- **DIII-D** [Garofalo MF-OV12] [Marinoni MF-I54] [Humphreys MF-I35] [Tang MF-O25] [Xiao MF-I46] [Chen MF-O29]
  - Significant progress has been made in advancing the H-mode operating space and physics basis
  - QH-mode operation exceeds 80% of the Greenwald limit,
- **JET** [Romanelli MF-OV3]
  - Isotope experiments and scenario development: towards the DT phase
  - DD fusion yields have been extended to 2.9×10^{16} neutrons/s for 5s
- **ASDEX-U** [Stober MF-OV7]
  - 20 MW of NBI, 7 MW of ICRF and 6 MW of ECRH equipped
  - Developed integrated scenarios for ITER and DEMO

Unique contribution from different machines

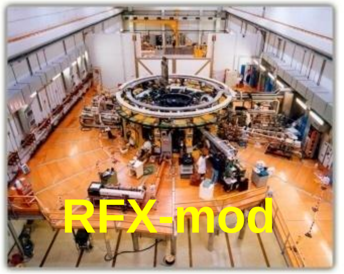
- **QUEST** [Hasegawa MF-OV10] [Onchi MF-I22] [Kuroda MF-I23]
  - Fully non-inductive plasma start-up, CHI
  - **1h55** min was successfully achieved, Control of hot wall
- **J-TEXT** [Yang MF-OV18]
  - RMP: an unique **fast rotating capability** (up to 6kHz)
  - Tearing mode control and disruption mitigation have been carried out
- **Heliotron-J** [Okada MF-OV14]
  - Using controllable five sets of coil systems to realizes **a wide range of configurations** by changing the coil-current ratios.

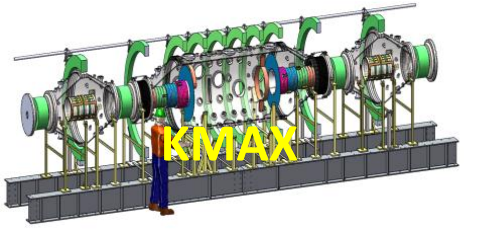
Unique contribution from different machines



- **TST-2** [Takase MF-OV4]
  - top-launch CCC antenna of lower hybrid wav alone demonstrated formation of an ST plasma
- **SUNIST** [Gao MF-OV19] [Tan MF-I69]
  - toroidal Alfven Eigen modes during minor disruptions have been found
  - Observed 3D structure of the eddy currents flowing in the split vacuum vessel
- **VEST** [Na MF-OV5]
  - Direct mode conversion of X-mode to Electron Bernstein Wave from the low field side is successfully utilized to enhance the ECH pre-ionization
- **TCV** [Porte MF-I53]
  - A significant improvement of the energy confinement time is observed in negative triangularity discharges

Unique contribution from different machines

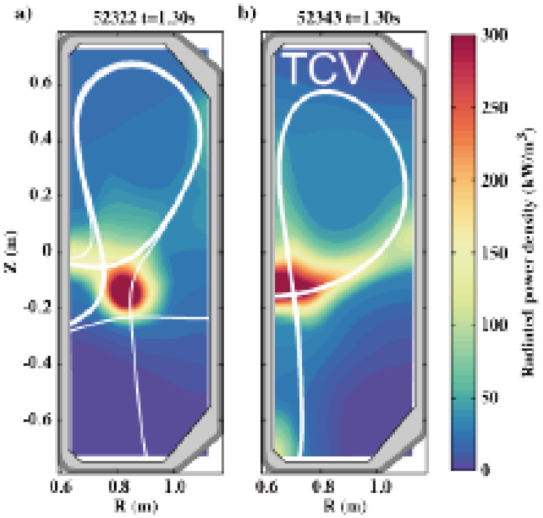




- **KTX** [Liu MF-OV17]
  - Low q tokamak discharges up to **200kA with advanced diagnostics**
- **RFX-mod** [Zuin MF-OV09]
  - **Spontaneous helical equilibria formation** associated to hot electron thermal structures
  - Energetic ion population self-generated in Ohmically heated RFP by magnetic reconnection
- **ADITYA/U** [Tanna MF-OV8]
  - **low loop voltage start-up** and current ramp-up experiments have been carried out using ECRH and ICRH
- **KMAX** [Sun MF-OV20]
  - A medium-sized washer gun is developed
  - **Two ICRF systems** can reliably deliver power ~100kW each

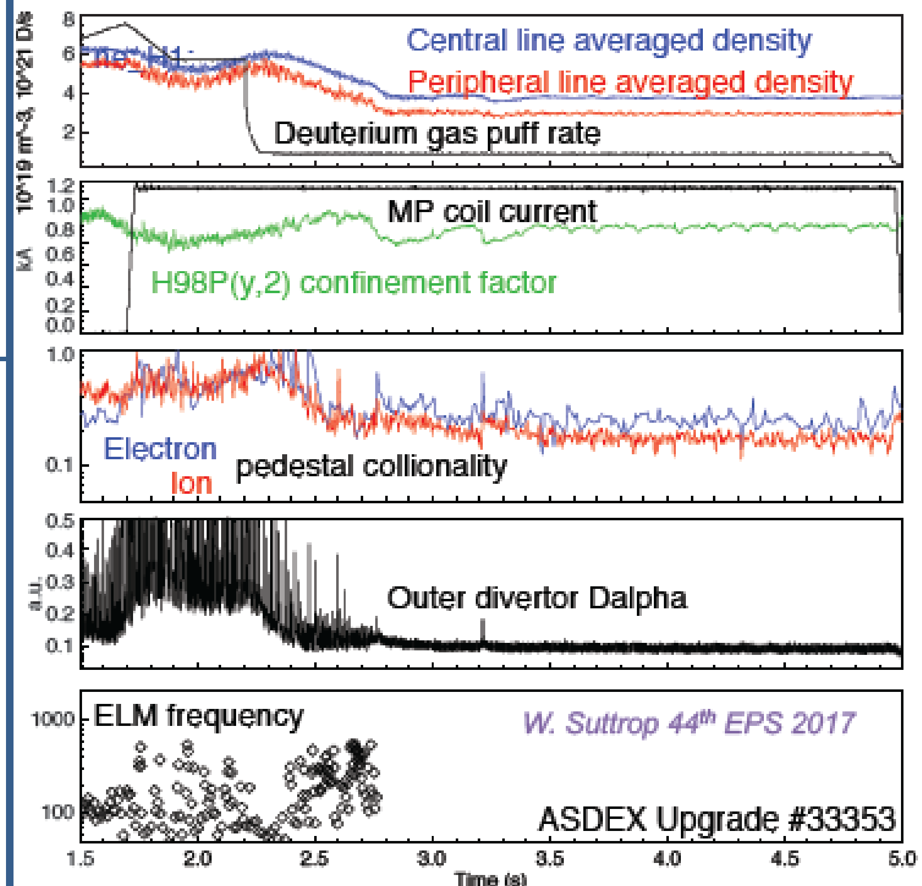
Coordinated EU research on medium sized tokamaks addresses critical ITER issues

H. Reimerdes NF(2017), IAEA FEC 2016

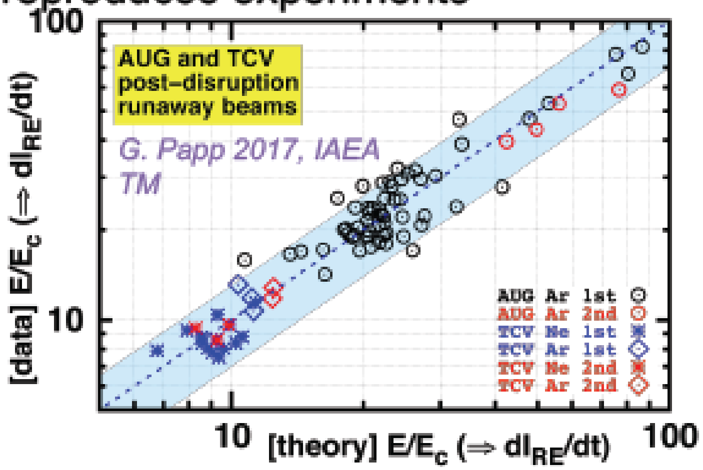


Alternative divertor configurations open operational window to solve the heat flux problem.

RMP ELM suppression on ASDEX Upgrade demonstrating high confinement achievable without ELMs in a W wall device.



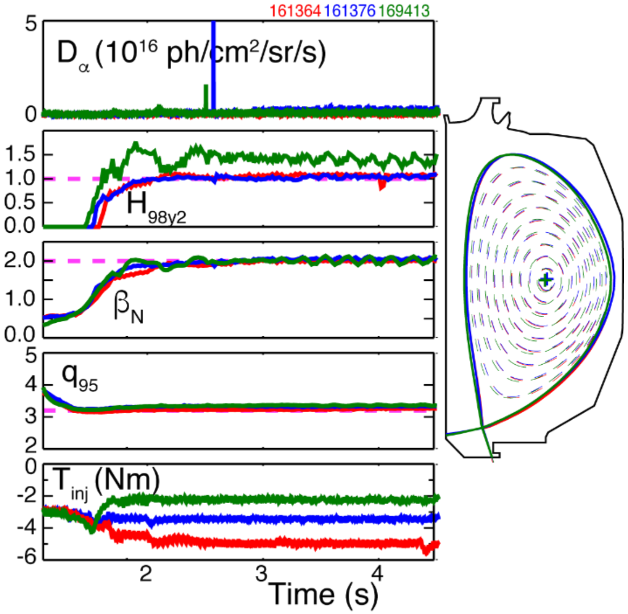
Modelling of runaway electron beam dissipation by high Z materials reproduces experiments

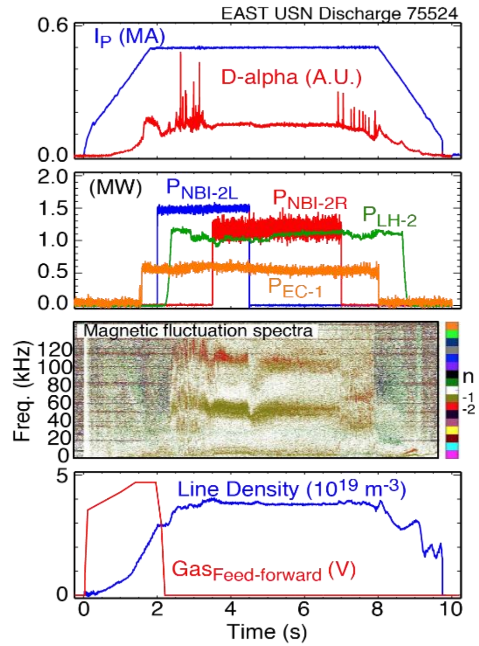


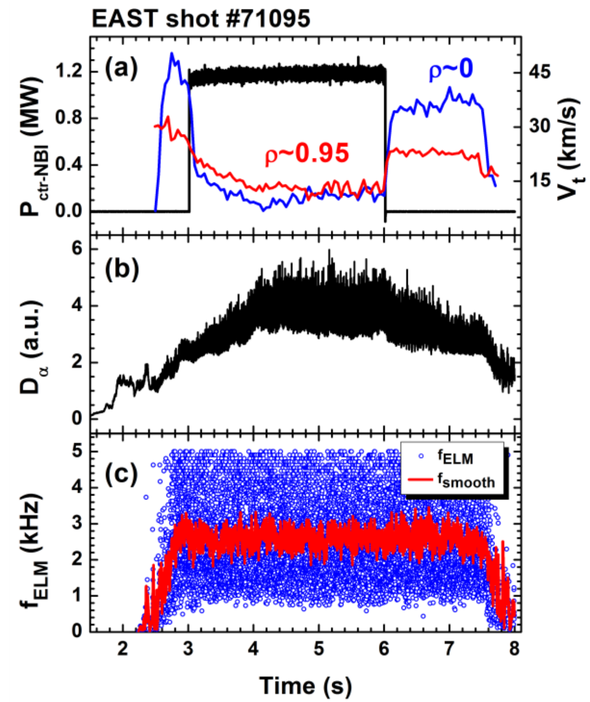
AAPPS should learn this from our EU colleagues

H-mode Physics

QH, Small-ELM H-- For ITER and beyond







[A.Garofalo, MF-OV12]
QH-mode at performance for Q=10 in ITER ,High density 80% of the Greenwald limit

MF-OV12 A type of QH-mode obtained on EAST using tungsten divertor

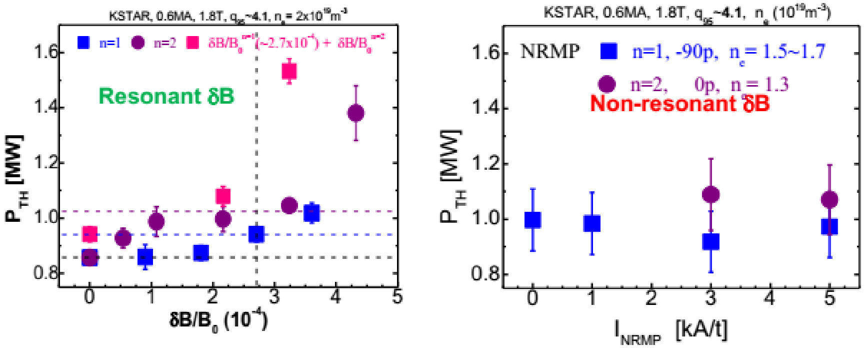
[G.S.Xu, MF-I6] Stationary small-ELM H-mode regime operations in EAST

[A. Ekedahl, MF-I21] LHCD PAM for small ELM HL-2A

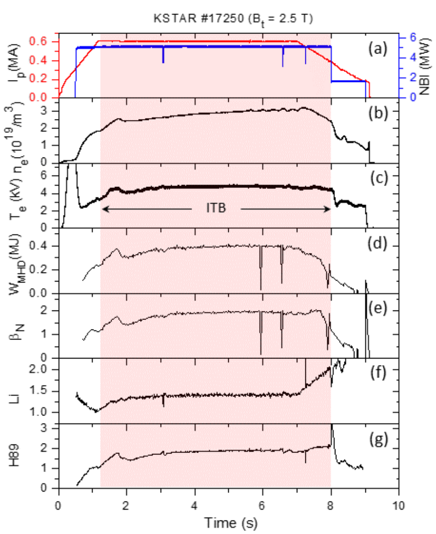
[L.M. Shao, MF-O11] The regime of small amplitude oscillations are consistent with the physical mode of zonal-flows and turbulence interaction at EAST.

H-mode Physics (L-H transition, regimes)

L-H Transition Studies under Non-axisymmetric Magnetic Fields in KSTAR [Won-Ha Ko, MF-I30]



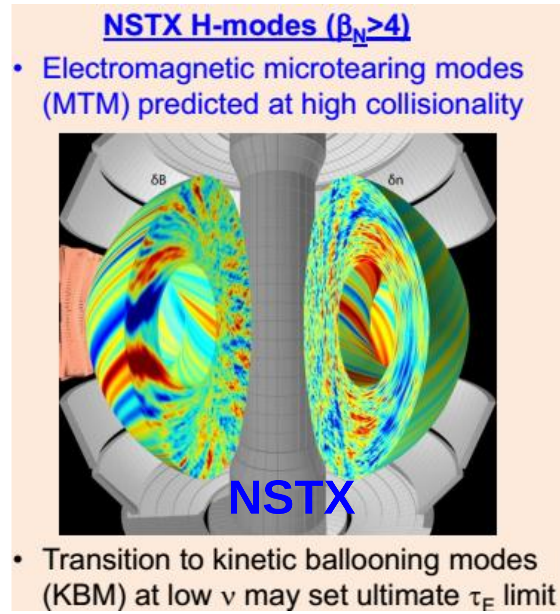
Sensitive dependence on resonant components and no dependence of non-resonant fields on L-H power threshold



[Chung MF-I55]

KSTAR 7s ITB discharge in a weakly reversed q-profile

Validating gyrokinetic predictions



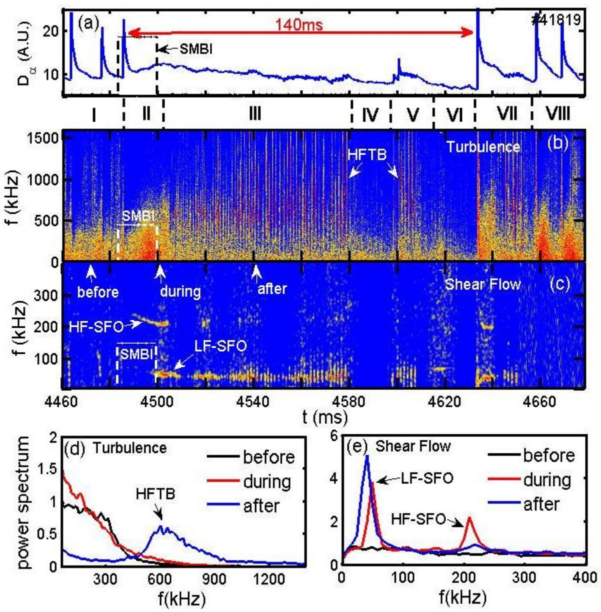
Understanding confinement scaling (t_E~1/ν) at low collisionality critical for future STs [W. Guttenfelder MF-I11]

[J.Weiland MF-I7] Zonal flows play a key role for L-H transition. The kinetic ballooning modes and peeling modes dominate on the H-mode barrier.

ELM physics and control

ELM Control: SMBI, RMP, Pellet, LHCD, LBO, Li granule, very good progress

EAST

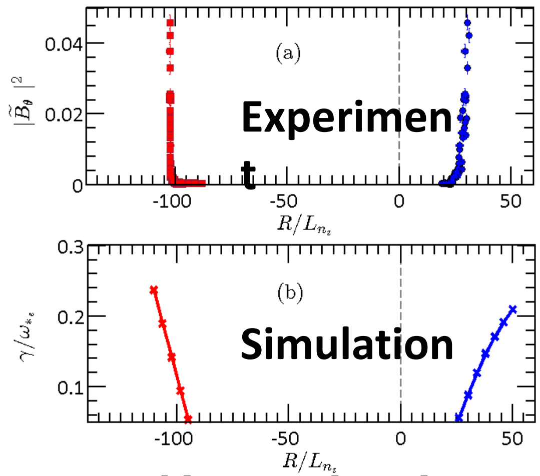


— New shear flow oscillation observed in the pedestal

— Shear flow oscillation and turbulence bursts are responsible for ELM mitigation and suppression.

[X.L. Zou MF-I21]

Physics understanding: good agreement between theory and experiments



HL-2A

[W.L. Zhong, MF-I29]

— Double critical gradients of electromagnetic turbulence observed and predicted

—Impurity seeding with mixture SMBI first performed in HL-2A

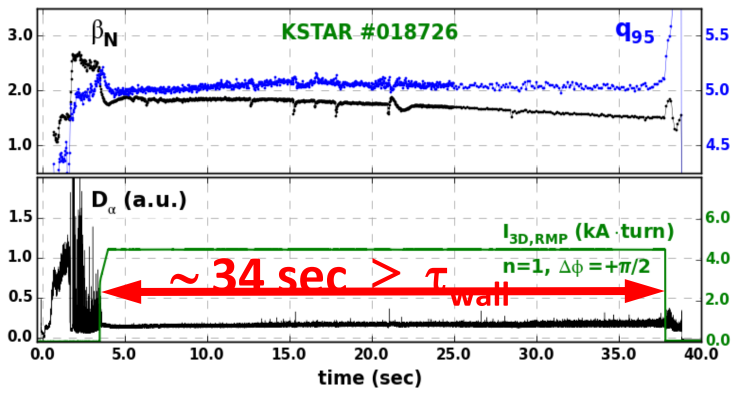
[Y.P. Zhang, MF-P6] ELM control by LBO-seeded impurity in HL-2A

[J.Q. Dong MF-I8] Impurity induced micro-electromagnetic instabilities

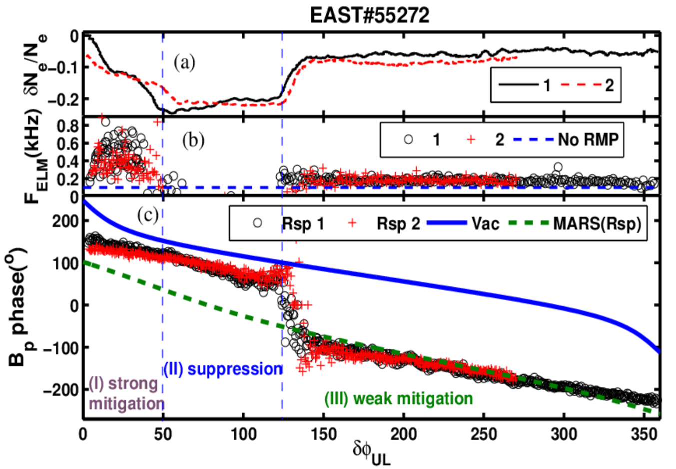
[P. Zhu MF-I49] Increasing pedestal resistivity due to lithium conditioning can fully stabilize low-n ELMs.

ELM control by RMP

Significant progresses have been made both on experiments and modeling



– Expanded operation boundary and capability of RMP-driven, ELM-crash-suppression [Y. In, MF-I16]



– **Magnetic topological change plays a key role in accessing final ELM suppression.** [Y.W. Sun, MF-I48]

[L.Li MF-I20] [M. Kim, MF-I18] modeling for understanding of ELM mitigation by RMP

[X.T. Yan MF-O12] **RMP helicity could be used as a new scheme for controlling NTV peak location.**

[S.Y. Liang MFP7] ELM mitigated by n=1 RMP in H-2A

[W.W. Xiao, MF-I46] Propagation Dynamics with Resonant Magnetic Perturbations Field in H-mode Plasmas

[J.-K. Park, MF-I45] **Optimization of Resonant and Non-resonant Magnetic Perturbations in KSTAR**

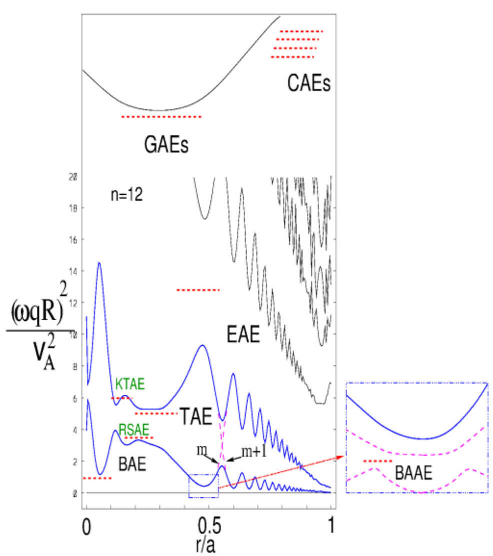
[J. Cheng, MF-I19] Observation of streamer as a trigger of ELM in HL-2A

Energetic particle remains the hot topic (20)

Potential directions for EP studies

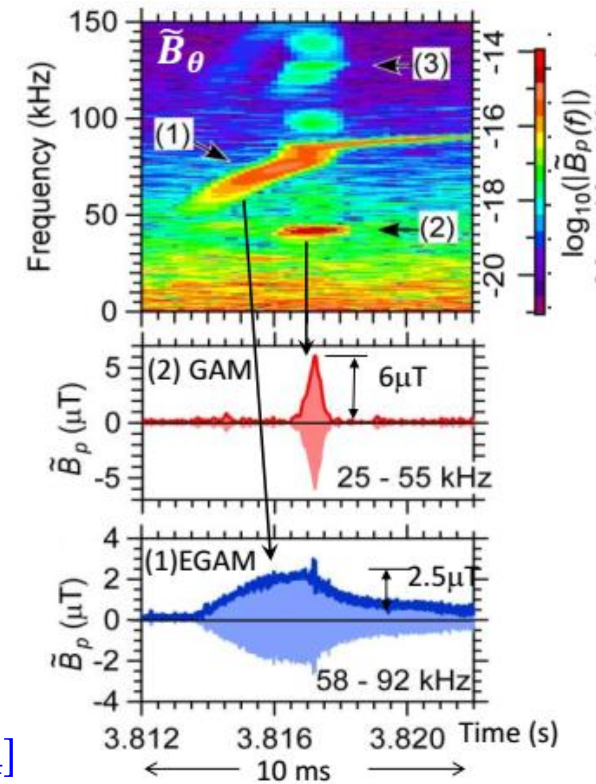
- **AE transport of fast ions**
  - Nonlinear regimes should be in focus both theoretically and experimentally
  - Initial value codes and reduced models are to be pursued
- Delterious effects on EP and thermal plasma confinement
- Ion Cyclotron Emission
   is important, partially (linearly) understood

[Gorelenkov ,MF-I1]

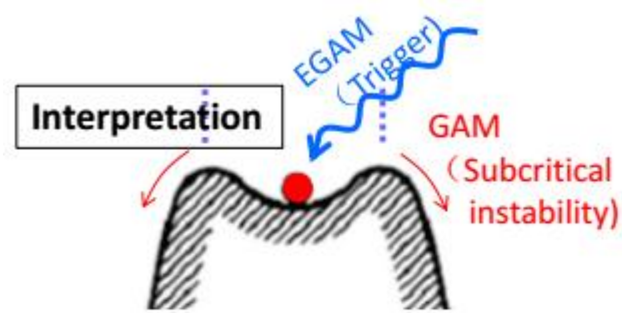


Subcritical instability of the GAM has been observed (parametric coupling and/or kinetic coupling)

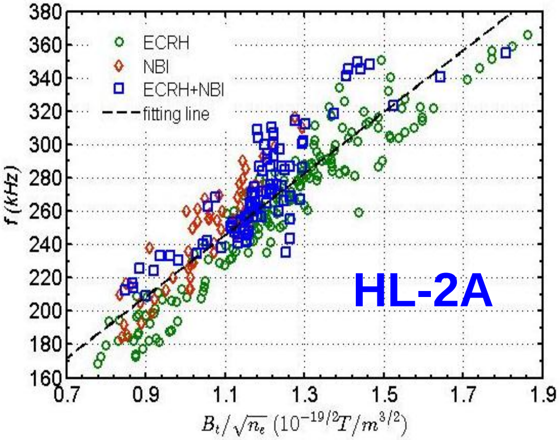
LHD



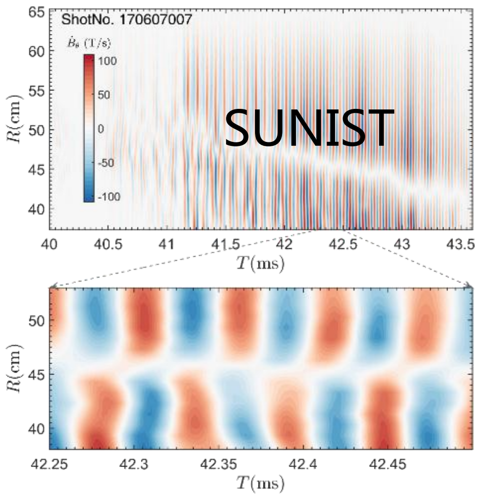
[T. Ido MF-I4]



Energetic Particle Study--Experiments

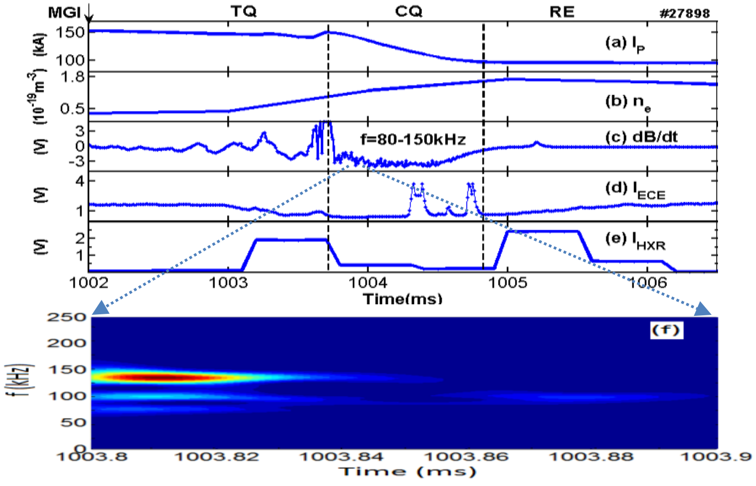


[L.M. Yu MF-I3] **TAE with frequency in the rang of 160-380 kHz** is observed in high-power ECRH

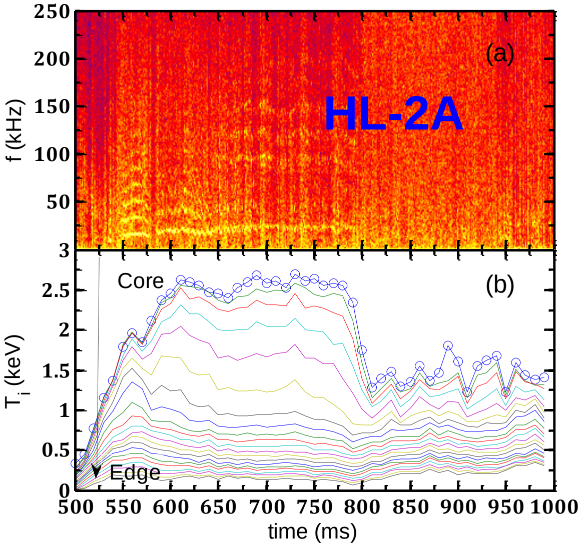


TAEs were found in ramp down phases during minor disruptions

[Y. Tan MF-I69]



[Y.B. Dong MF-I36] **(TAE) was observed during the disruption, , limiting the strength of runaway beam**



[W. Chen MF-I56] **AITG f=80-200 kHz (f_{BAE}<f<f_{TAE}) appears in the ITB plasmas with weak magnetic shear and high gradients of Ti;**

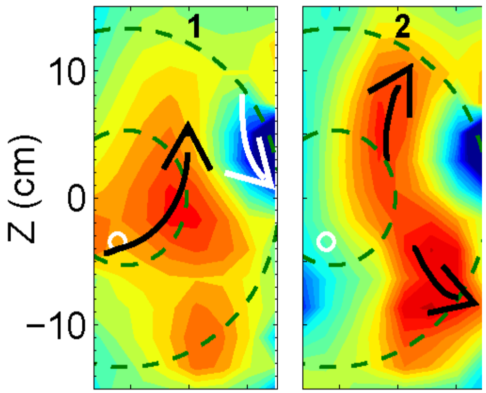
Energetic Particle Study--Modeling

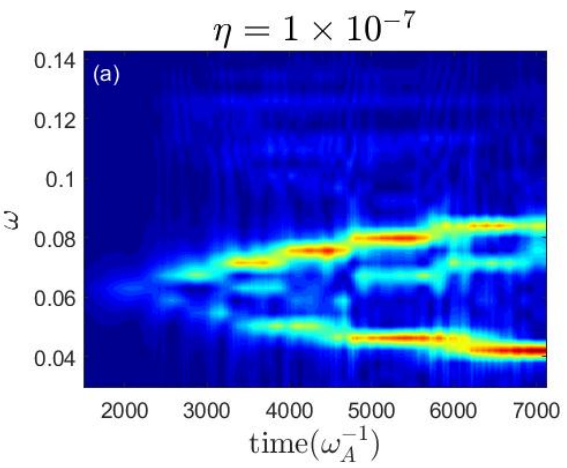
Nonlinear simulation of TAE

[Z. Qiu MF-I2] **Nonlinear processes and saturated spectrum of Alfvén eigenmodes**

Due to the typically radially localized TAE mode structures, the associated nonlinear processes also exhibit meso-scale; resulting in qualitative and quantitative modifications in the nonlinear processes of AEs

There are energy transport between double fishbones[J. Zhu MF-I66]





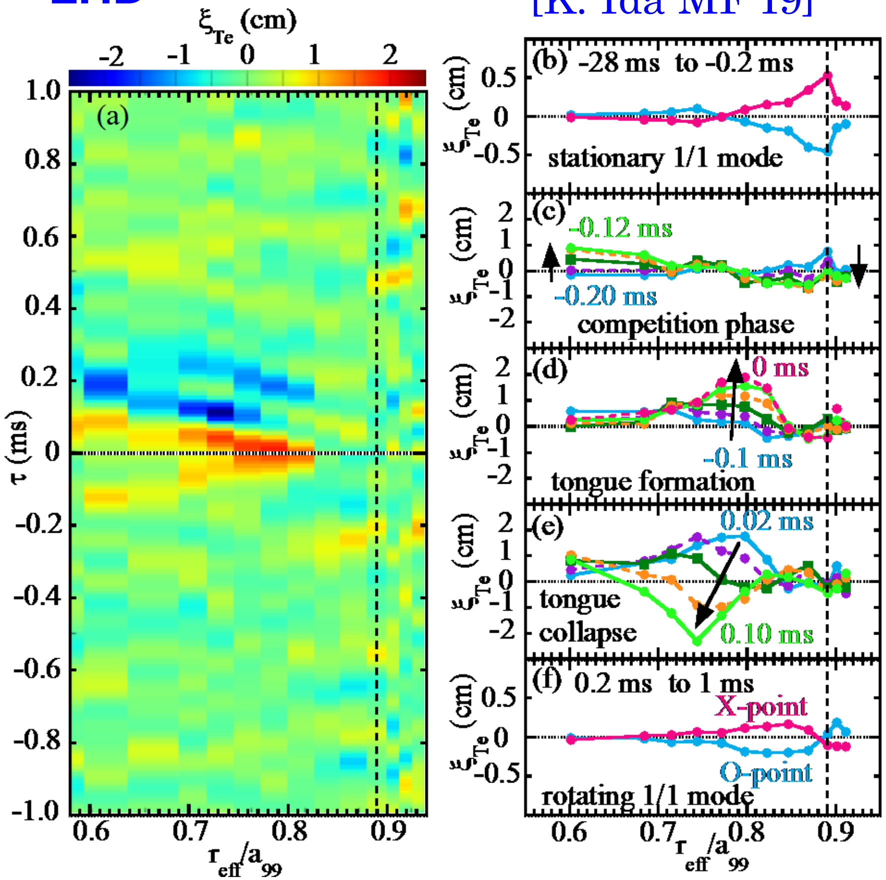
[H.S. Cai MF-I40]

- Possibility to use EP to suppress NTM for the steady state and hybrid scenarios with weak magnetic shear.
- Influence of energetic ions on stability criterion of tearing modes, *PRL* 106

MHD instabilities-New findings

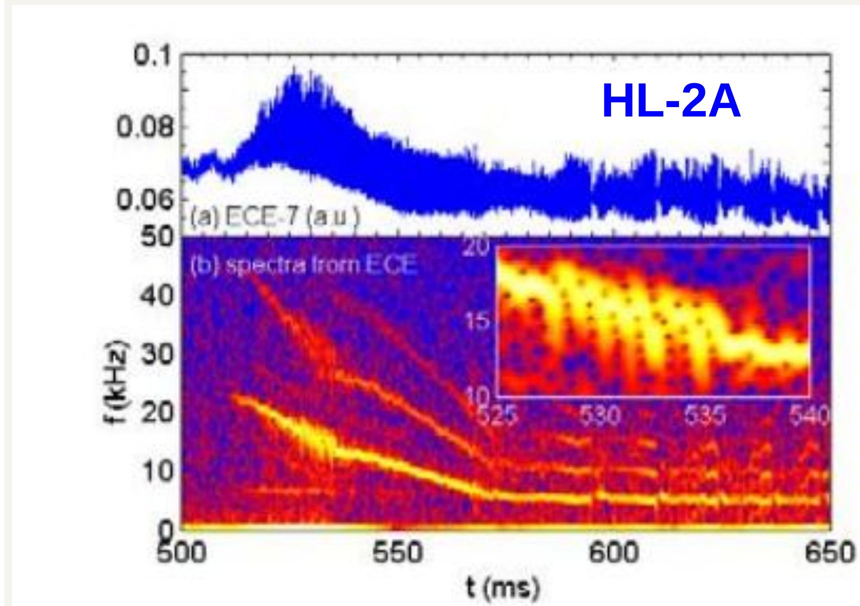
LHD

[K. Ida MF-I9]



— Tongue event triggers the minor plasma collapse

— A new trigger mechanism of MHD burst



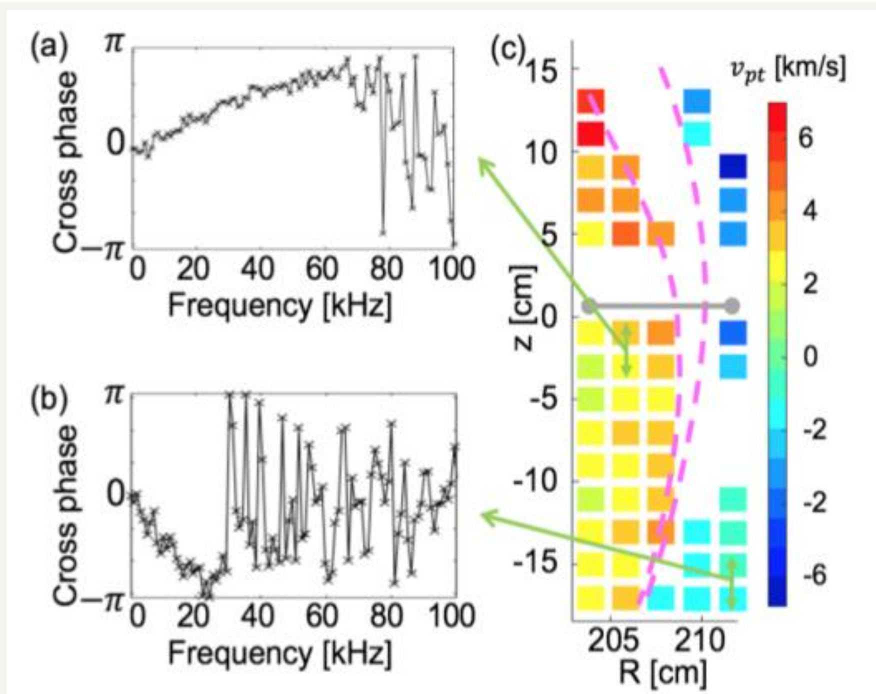
[L.M. Yu MF-I3] Various MHD modes have been observed in HL-2A

[Z.R. Wang MF-I41] Full toroidal computation of resistive MHD instabilities based on asymptotic matching approach

[Nornberg MF-I62] Using Integrated Data Analysis to optimize measurements critical to the validation of MHD simulations

MHD instability VS turbulence

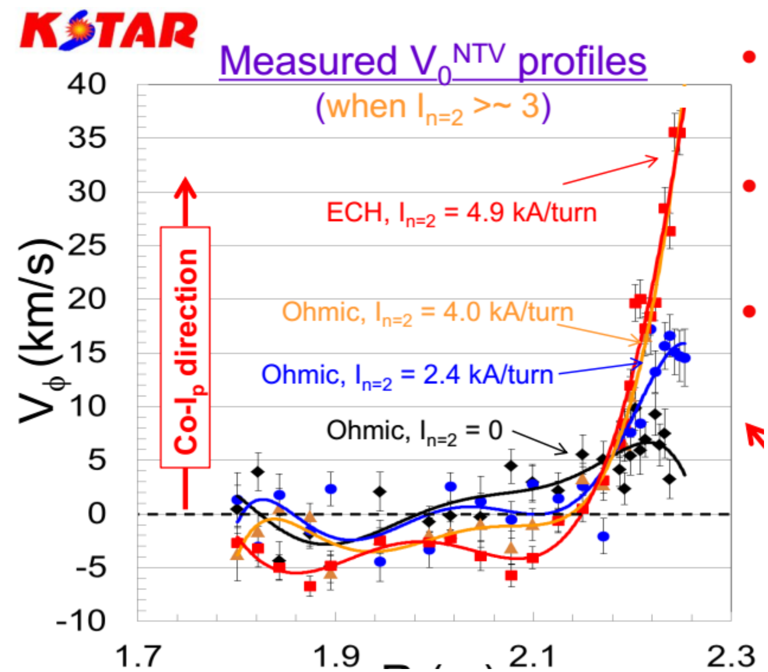
KSTAR



ECEI

— Multiscale nonlinear interaction between a large scale MHD instability and small scale turbulence
— Importance on the electron thermal transport

[M. J. Choi MF-I51]

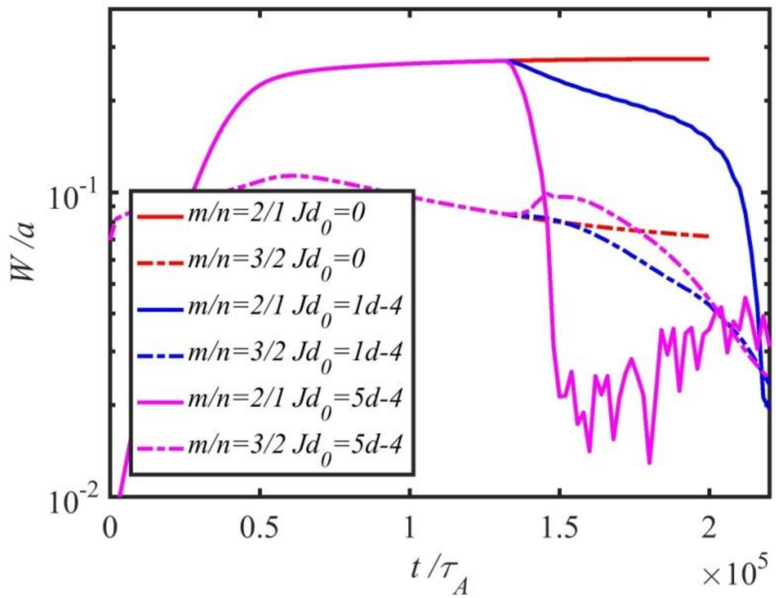


[S. Sabbagh MF-I47] Generalized Neoclassical Toroidal Viscosity (NTV) Offset rotation profile V_0^{NTV} measured in KSTAR, Potential aid for ITER.

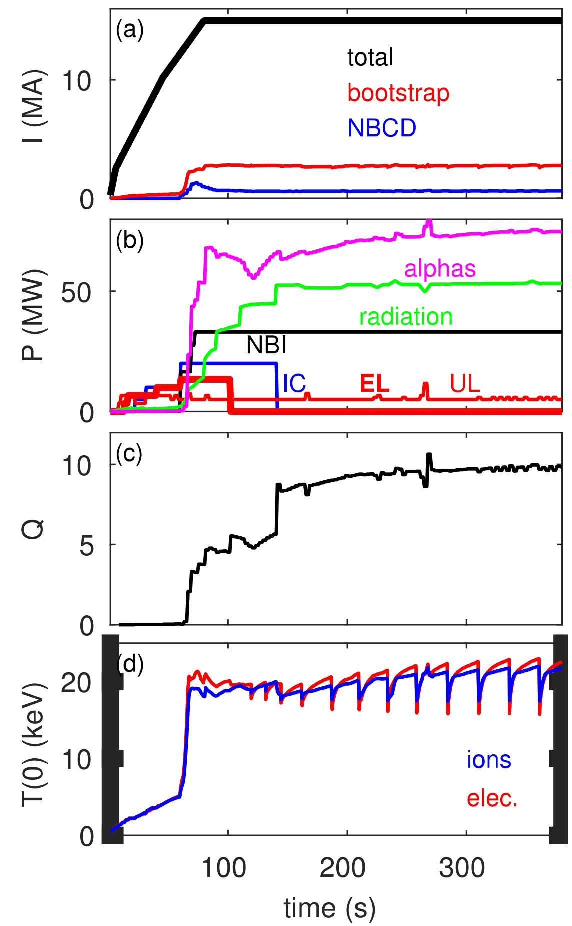
[M. Jiang MF-O20] Radial profiles of poloidal flow and density fluctuation around the magnetic island were firstly observed on HL-2A tokamak

MHD instability-NTM

[Z.X. Wang MF-I38] ECCD can effectively reduce 2/1 NTM island width. Deposition of ECCD at 2/1 surface can further stabilize 3/2 NTMs.



[F. Poli MF-I37] Simulations that evolve self-consistently NTM width and frequency and plasma profiles **help designing more robust control schemes for ITER**

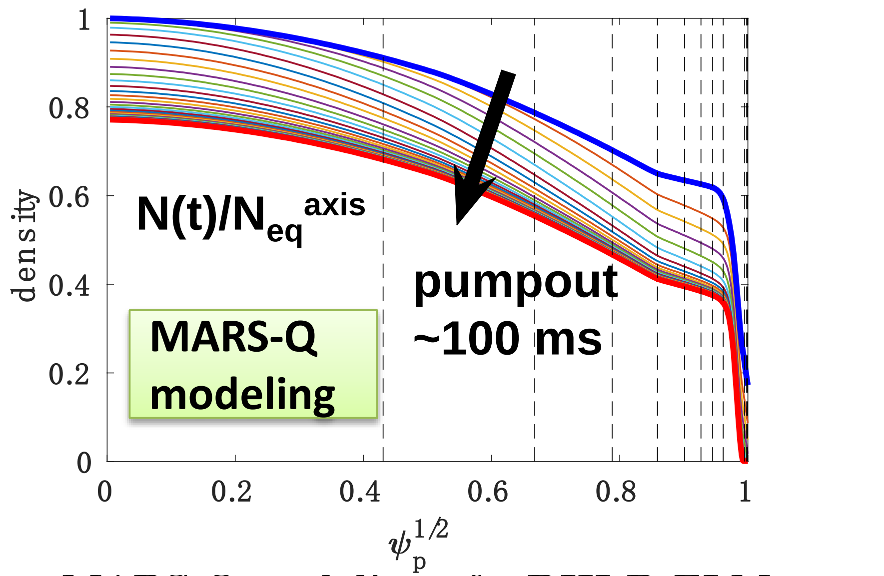


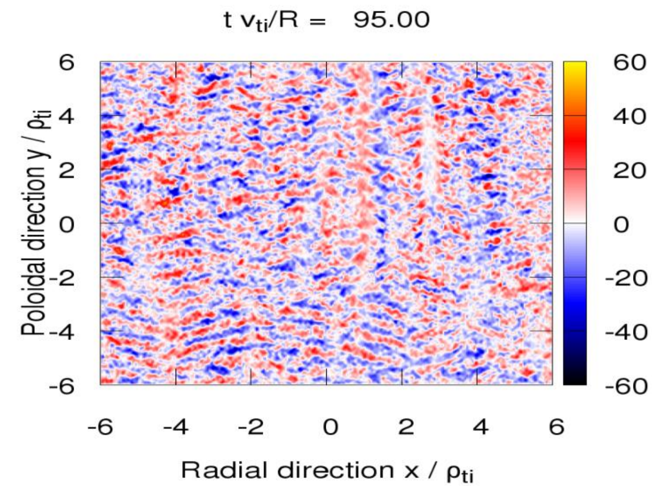
Stabilization of the 2/1 mode

[H.S. Cai MF-I40]Provide a possibility of using EP to suppress NTM for the steady state and hybrid scenarios with weak magnetic shear.

[H.P. Qu MF-I39] Magnetic islands and neoclassical currents

Turbulence and Transport





— MARS-Q modeling of a DIII-D ELM suppression **experiment re-produces large density pump out** [Y.Q. Liu MF-I33]

[D.Li MF-O18] Influence of strong magnetic field on plasma transport

[J. Weiland MF-I7] The role of zonal flows in reactive fluid closures

[Y. Ren MF-I15] GTS simulations demonstrate decent agreement in ion thermal transport

[SuminYi MF-I10] A gyrokinetic simulation study of Non-local Transport phenomenon

[Watanabe P5] MTM turbulence can be suppressed by ETGs through destruction of the current sheet structures

[Y. Xiao MF-I50] GTC simulation found the turbulent transport coefficient decreases with the applied gradient

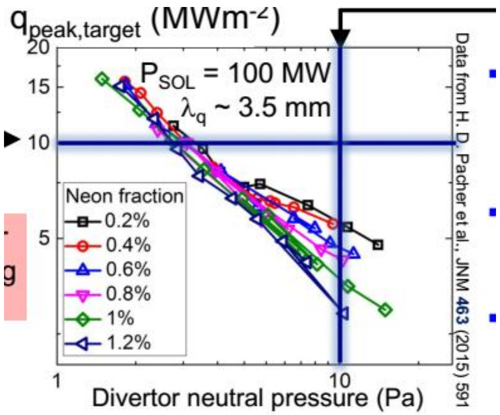
[S. Wang MF-I12 Nonlinear gyrokinetic simulation of ITG turbulence based on a numerical Lie-transform perturbation method

[J.Q. Dong MF-I8] Impurity induced micro-electromagnetic instabilities in toroidal plasmas

[S. Satake MF-I14] Global and Local Drift-Kinetic Simulation Models for Neoclassical Viscosities

DSOL Physics, Plasma Wall Interaction

Towards successful operation of ITER W divertor



[Pitts MF-OV11] Baseline is partially detached operation on full-W divertor using low Z seeding assist for dissipation of 50-70% P_{SOL}

[J.W. Coenen MF-I42] Risk of melt damage if plasma operation fails to keep surface heat flux below thermo-mechanical limits.

Better understanding via modelling

[A. Kirschne, MF-I57] Modelling of layer deposition and accompanying tritium retention. Evaluation of erosion yields. Estimation of lifetime of ITER wall components

[T.Y. Xia, MF-O24] Simulation of **SOL width** with helical current filaments

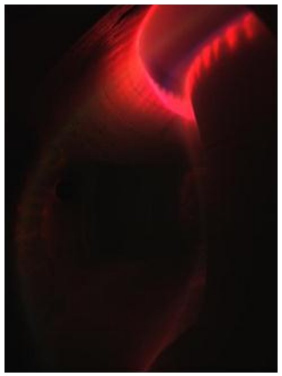
[C.F. Sang MF-I65] The closure of divertor also has great impact on the upstream plasma condition

[T. Wu MF-O23] Coupling of SOL density profiles with edge plasma parameters

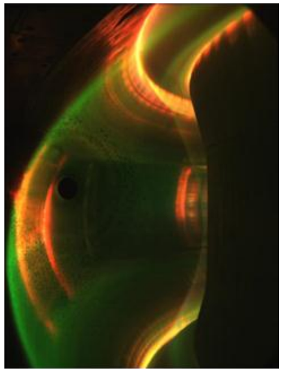
[C.S. Corr MF-O19] High power, steady state MAGPIE II linear plasma device is under construction

DSOL Physics, Plasma Wall Interaction

Control particle and heat fluxes in long pulse by integrated way

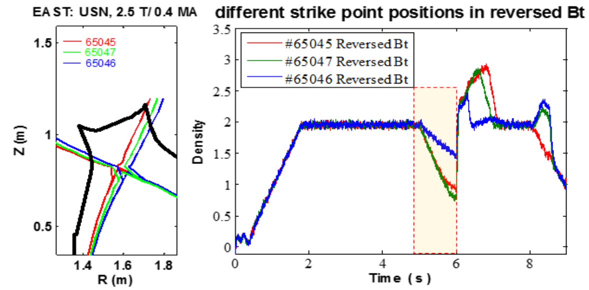


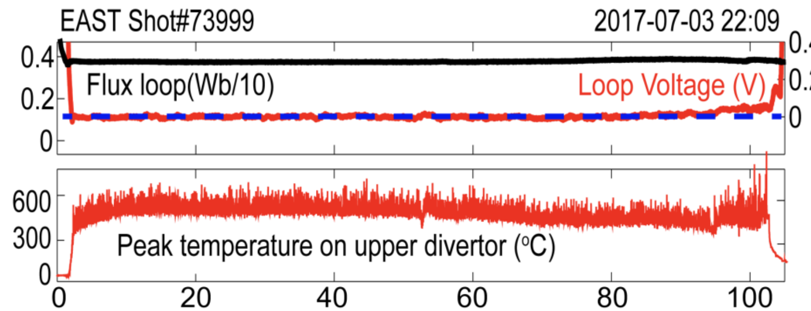
Without FLiLi



With FLiLi

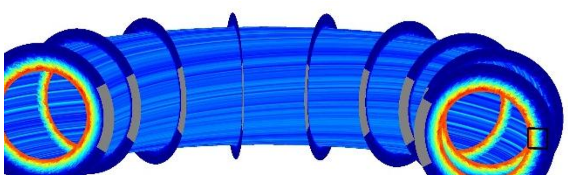
EAST





[J.S. Hu MF-I63] Li Experiments : effectively suppress W impurity

[L.Zakharov MF-I64] Plasma boundary play a key factor. FLiW is important for confinement and particle control.



(a)

[M.Francisquez MF-I31] Global 3D two-fluid tokamak edge simulations

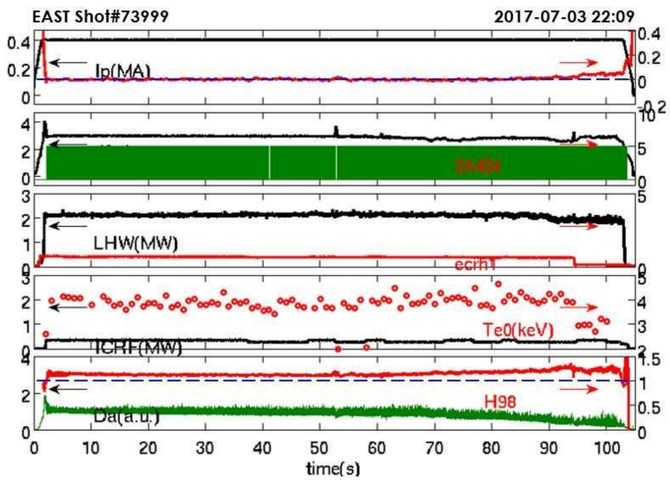
[L. Wang MF-I43] Active handling of heat flux and impurity accumulation by utilization of in-out divertor asymmetry and optimization of configuration & strike point

[G.Y. Zheng MF-I44] Modeling of heat load and impurity for snowflake, tripod configurations

K.Wu MF-O16] Active feedback control of radiation for power exhaust in EAST long-pulse operations

Efforts for steady state high performance

EAST [Y.F.Liang, MF-OV6]

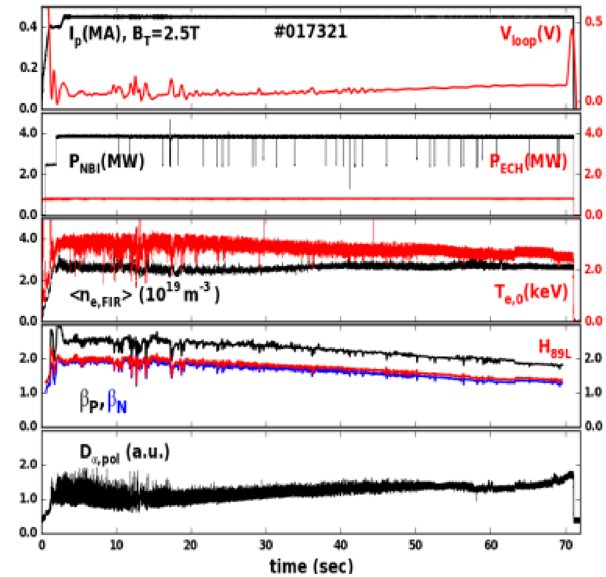


Ip=0.4MA, <ne>~3.0X10[19]/m[3] ,P_{RF}~3.0MW, H_{98y2}~1.1,USN,Te(0)~4.0keV

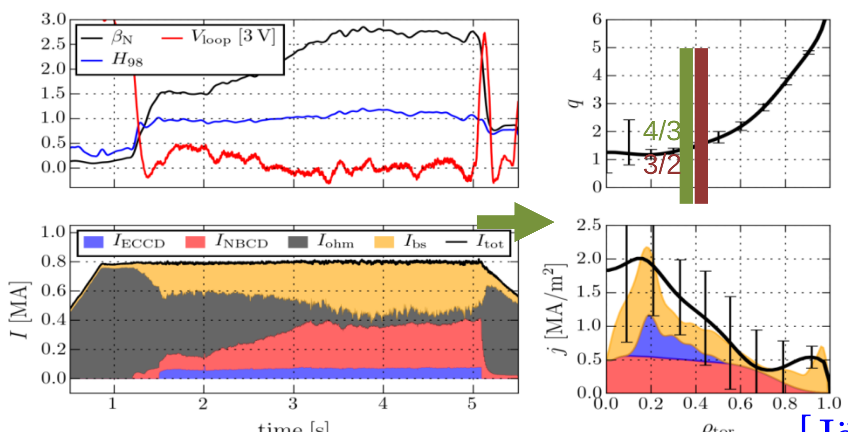
All actively cooled PFC & Diagnostics, CW H&CD

KSTAR [Y.K. Oh , MF-OV2]

0.45 MA, 70s



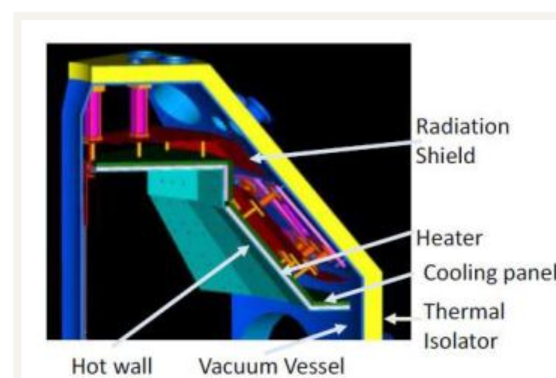
ASDEX-U full-W environment



Fully non-inductive operation at I_p= 0.8 MA, q_{95}=5.3

[Jörg Stober, MF-OV7]

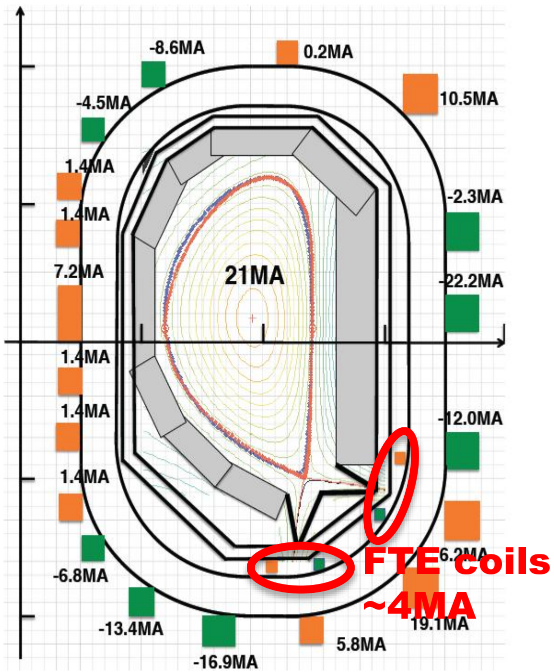
QUEST [M. Hasegawa, MF-OV10]



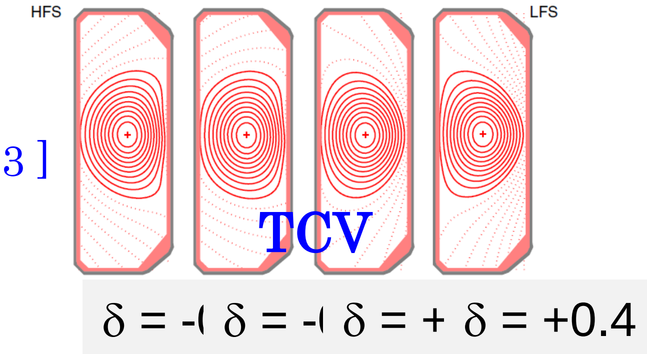
non-inductive 1h55min

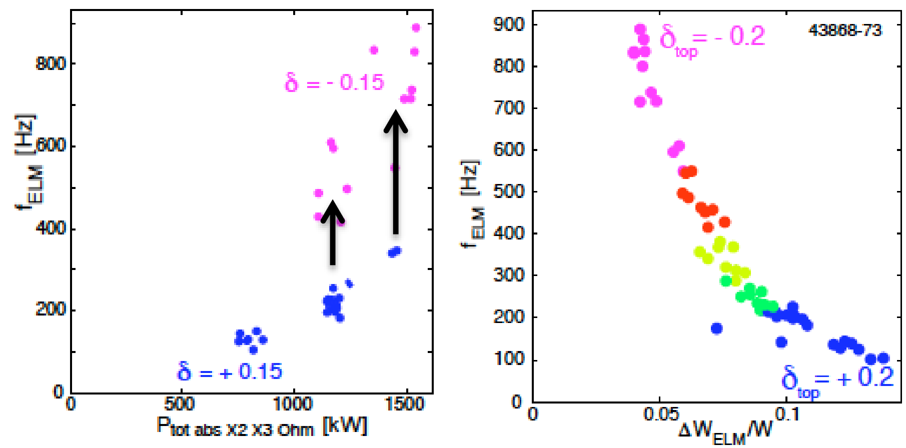
Negative triangularity

[M. Kikuchi MF-013]



[L. Porte MF-I53]





- NTT reduce power load geometrically
- NTT stabilize TEM and can have HH~1.2 with L-mode edge

Pedestal in negative δ H-mode is smaller than in positive δ

[L.Xue, MF-O14]VDEs investigation of the negative triangularity plasmas

[A. Marinoni, MF-I54]

H-mode-like confinement with L-mode edge in negative triangularity plasmas on DIII-D

Plasma Diagnostics

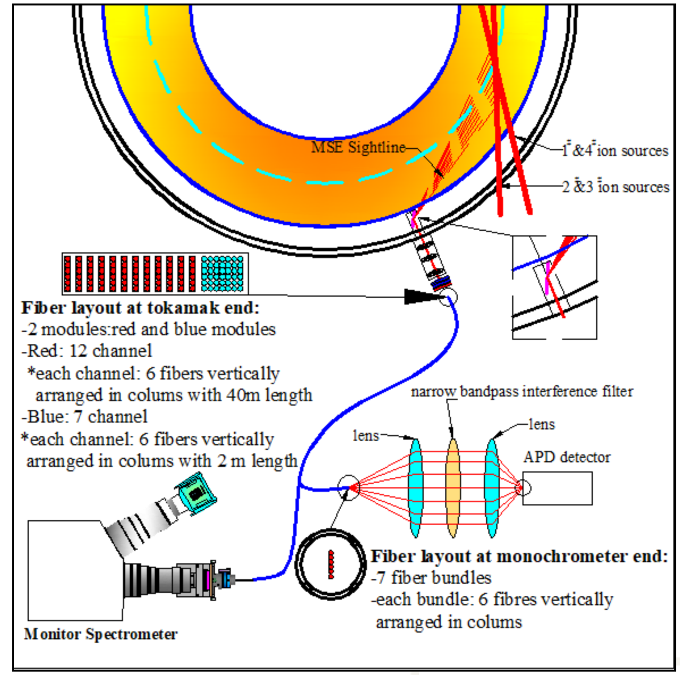
ITER diagnostics [Michael Walsh, MF-I60]

- About 50 large scale diagnostic systems are foreseen:
  - Diagnostics required for protection, control and physics studies
  - Measurements from DC to γ-rays, neutrons, α-particles, plasma species
  - Diagnostic Neutral Beam for active spectroscopy (CXRS, MSE ….)

EAST: [Liu MF-I61] Reliable all key profiles diagnostics for exploring high performance long pulse scenarios

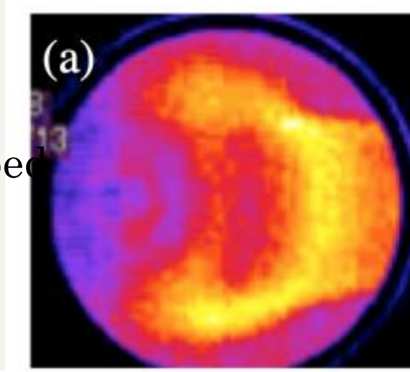
HL-2A : [Yuan MF-O10] [Liu MF-O26]
—A new gas-puff imaging (GPI) diagnostic system has been developed to study two-dimensional (2-D) plasma turbulence
—Zeff measurement by visible bremsstrahlung diagnostic

HL-2A: 7-channel MSE diagnostics based on dual PEMs [Chen MF-O27]



RELAX: high-speed tangential SXR imaging diagnostics were developed to identify the emission structures

[A. Sanpei MF-O7]

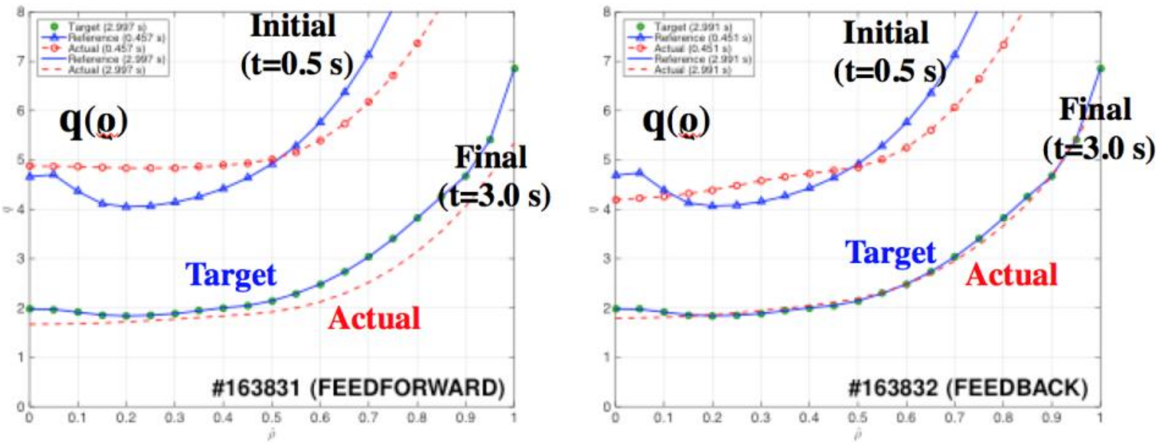


Operation control and scenarios development

[D.A. Humphreys MF-I35]

DIII-D, EAST, KSTAR are advancing integrated plasma control toward disruption-free operation

q-profile regulated in DIII-D with Model Predictive Control



[S.Ding MF-I28]

DIII-D-EAST to CFETR

High confinement compatible with low rotation and medium q_{95}

Large radius ITB (@$r \geq 0.7$) is key to excellent confinement.

[X.Q. Ji MF-I34] Plasma Scenario Development for the HL-2M tokamak

Addressing Physics issues in operation conditions expected on ITER, CFETR. High b_N, Ti ~Te, and vanishing loop voltage simultaneously

KSTAR upgrade [Si-Woo Yoo MF-I27]

off-axis NBI ~ 6 MW (2019) and ECH ~6 MW & in-vessel components to address critical issues at high beta steady-state operation for k-DEMO realization (β_N ~4.0 , f_{BS} ~0.7, f_{GW} ~ 1 with long-pulse steady-state conditions)

[Joerg Stober MF-OV07] Development of integrated scenarios for ITER and DEMO on ASDEX Upgrade

[M. Romanelli MF-I26] Integrated Modelling preparing for high-beta Scenarios on JT-60SA

Outline

- Highlight
- Major Progresses
  - Major progresses for machines, H-mode physics, ELM physics and control, energetic particles, MHD, Transport, Steady-state, PWI, Negative triangularity, diagnostics, Control&scenario development.
- **Future Challenges**
- Summary

Future Challenges

Outstanding Issues with Gaps beyond ITER

Steady-state H operation(weeks)

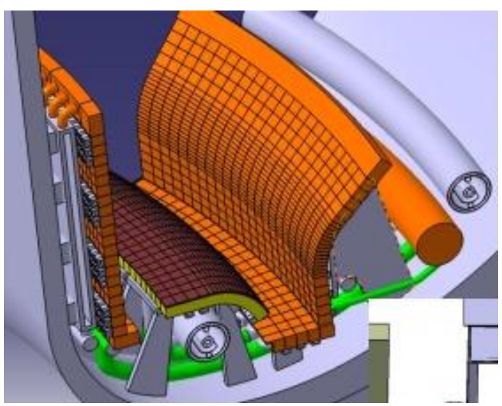
most novel part of DEMO

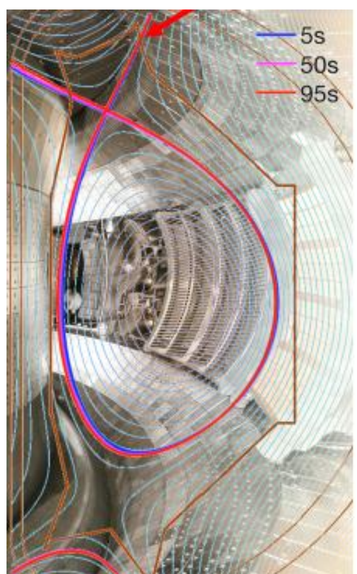
Core

Efficient non-inductive CD in H-mode
High bootstrap current fraction
Low impurity concentration

Edge

Controllable PSI for lowering impurity generation and particle recycling in W divertor
Low peak heat load Tolerable transient heat shock (small/no ELMs)
erosion free



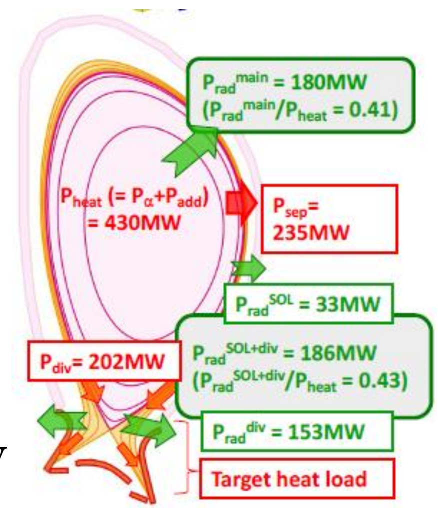


[B.N Wan, P11]

Power Exhaust

Peak heat fluxes near technological limits (>20 MW/m^2)
ITER solution may be marginal for DEMO
Integration of DEMO working condition is very challenging

Need both new physical (advanced divertor +impurity seeding) and technical (new robust DEMO 20MW/m^2 target) solutions
NTT reduce power load geometrically by factor of 7 ?
Validation on long pulse tokamak experiments.

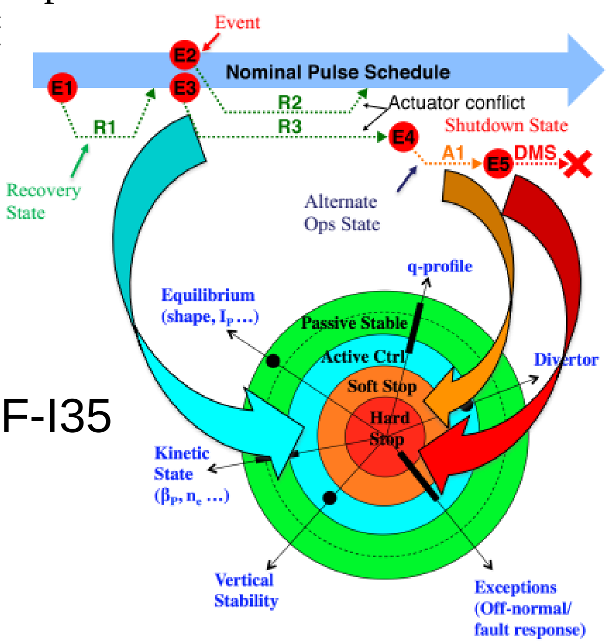


Future Challenges

Outstanding Issues with Gaps beyond ITER

Off normal events

- Exits for nearly 50 years and not solved yet.
- Efforts for theory& modeling and technology for advanced integrated control to a Robust, Disruption-Free Operation
- Experimental validation to 100% c



MF-I35

Burning Plasma

- Confinement&transport for alpha particle heating dominated plasma in the presence of AE driven by superthermal fast ions (MF-I1)
- Significant loss of Alpha/fast ions degrades plasma H&CD efficiency , may quench DT burning (P2-2)
- Robust, simple burning plasma diagnostics. Lesson learned from ITER (MF-I60)

Summary

- Significant progresses have been made in DPP-AAPPS. Efforts have been which focus on physics understanding
- Understanding of H-mode & ELMs, and effective control scenarios have been progressed.
- Transport / turbulence / instabilities are reproduced well by simulations
- Energetic particles and advanced SSO remain challenging and efforts should made for near future.
- Fusion is a century project which involves science, technology and engineering. Scientifically, we have to make targets more simple rather than more complicated. Technically, we have to make every component and system robust and reliable towards our final goal. Lets work on it.
- Training excellent young talent is very important. Please bring more students to next DPP meeting.

See you in Japan