Overview of Alcator C-Mod: Pedestal Research and Capabilities

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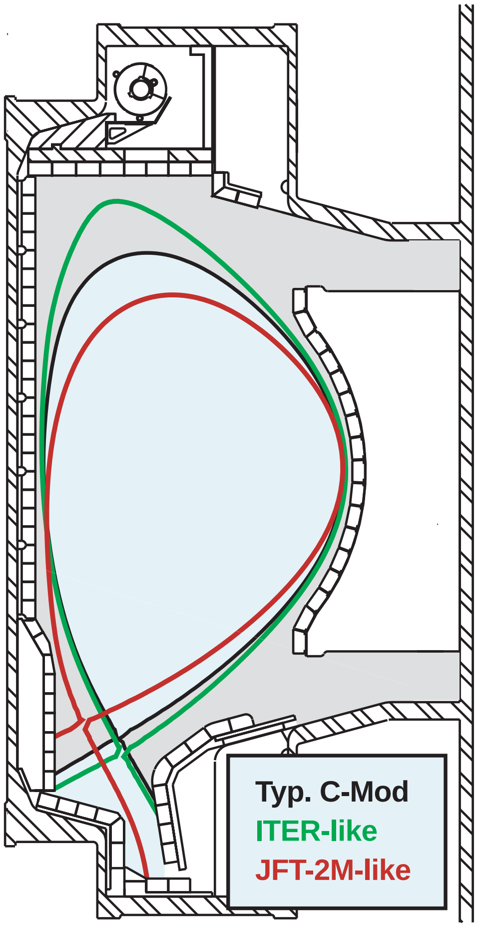
C-Mod/NSTX Pedestal Workshop

September 7—8, 2010

C-Mod: Compact, high field, diverted operation, at relatively high densities

- R=68cm, a=22cm
- B_T from ~2T to 8T
- I_P < 2 MA
- central $n_e < 1x10^{21}\ m^{-3}$
- T_i~T_e up to ~5 keV (T_e in excess of 8keV have been measured in some scenarios)
- Single null (lower or upper), double null or limited configurations
- Reversal of B_T and I_P direction possible
- Reasonable shaping flexibility available



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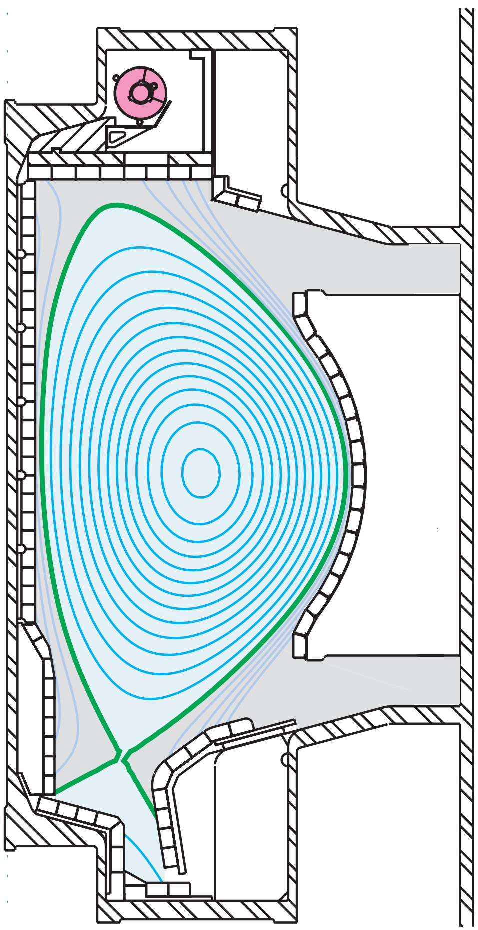
Alcator C-Mod

- Density control obtained with upper divertor cyropump (~10kL/s pumping speed)
- Heating predominately from ICRF
  - Routine net power up to ~5MW.
  - ~½ power has source freq. variable from 40 to 80MHz
  - ~½ power transmitted with real-time tuning
  - Current drive phasing available
- Lower Hybrid wave launcher with ~1MW power coupled to plasma
- Molybdenum PFCs generally require boronization for H-mode operation
  - currently a number of tiles have thick (0.1mm) boron layers pre-applied



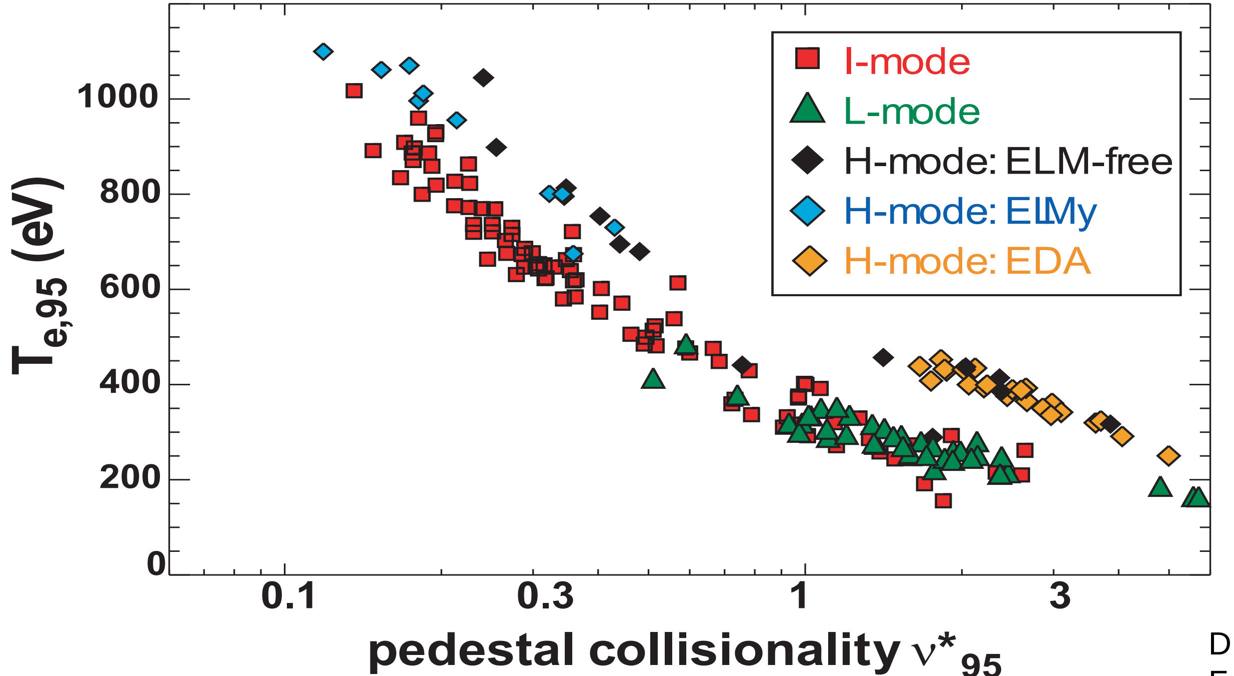
Pedestal research priorities on C-Mod

- Improving experimental diagnosis of *pedestal profiles, fluctuations, edge flows*
- Pedestal studies in an extended range of machine parameters, equilibrium configurations
- Seeking better understanding of transport, edge stability through modeling, simulation
- Collaboration with other facilities to develop multi-machine scalings
- Optimization and control of pedestal in various confinement regimes
- Support of integrated scenario development

- C-Mod occupies a unique parameter space that complements studies on other devices (large B/R, $n_e L$, range of pedestal collisionality)

Confinement regimes span a range of collisionality

- H-mode pedestals obtained over wide range of engineering parameters (*e.g.* B_T, I_P, n_e) and shaping variation
- ELMy regimes accessible and provide contact point to other devices
- Small/no-ELM regimes like EDA H-modes, I-modes are studied as well



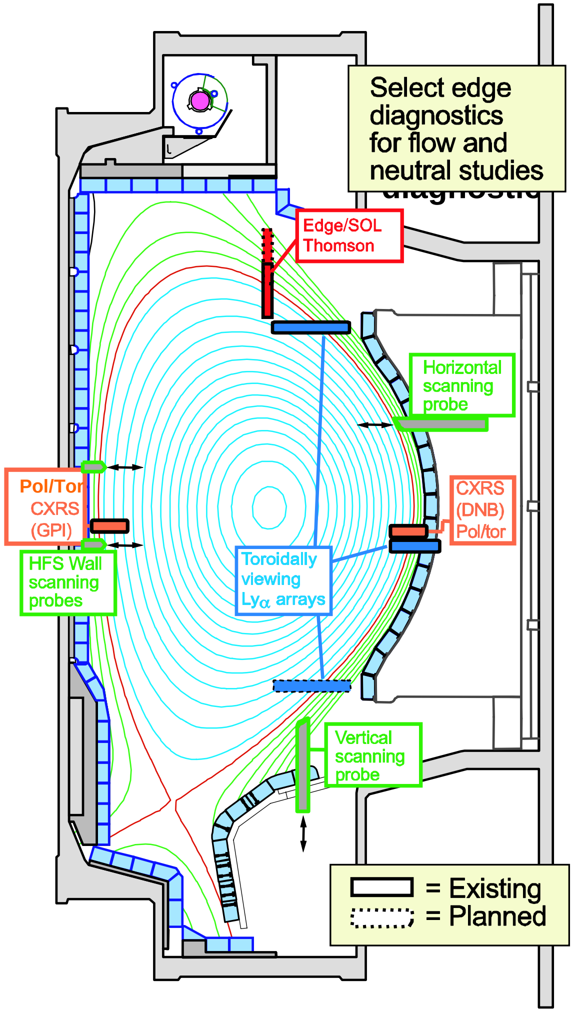
D.G. Whyte *et al*., Nucl. Fusion **50** (2010) 105005.

We are enabled by an extensive set of well-resolved edge diagnostics

Alcator C-Mod

Pedestal diagnostic set emphasizes ***millimeter-resolution*** profiles, fluctuations

- Thomson scattering (T_e, n_e)
- CXRS (T_I, $v_{I\theta}$, $v_{I\phi}$)
  - Inner wall toroidal views (passive and gas-puff assisted)
  - Pedestal beam-based CXRS (*toroidal* and *poloidal* views)
- Scanning Mach probes, HFS+LFS (T_e, n_e, v)
- Electron cyclotron emission (T_e)
- Visible bremsstrahlung ($n_e Z_{eff}^{1/2}$)
- Soft x-rays (n_I)
- Neutral emissivity measurements (passive, gas puff imaging)
- Reflectometer (n_e fluctuations)
- Phase-contrast imaging (n_e flucts.)
- 2D gas puff imaging (n_e flucts.)



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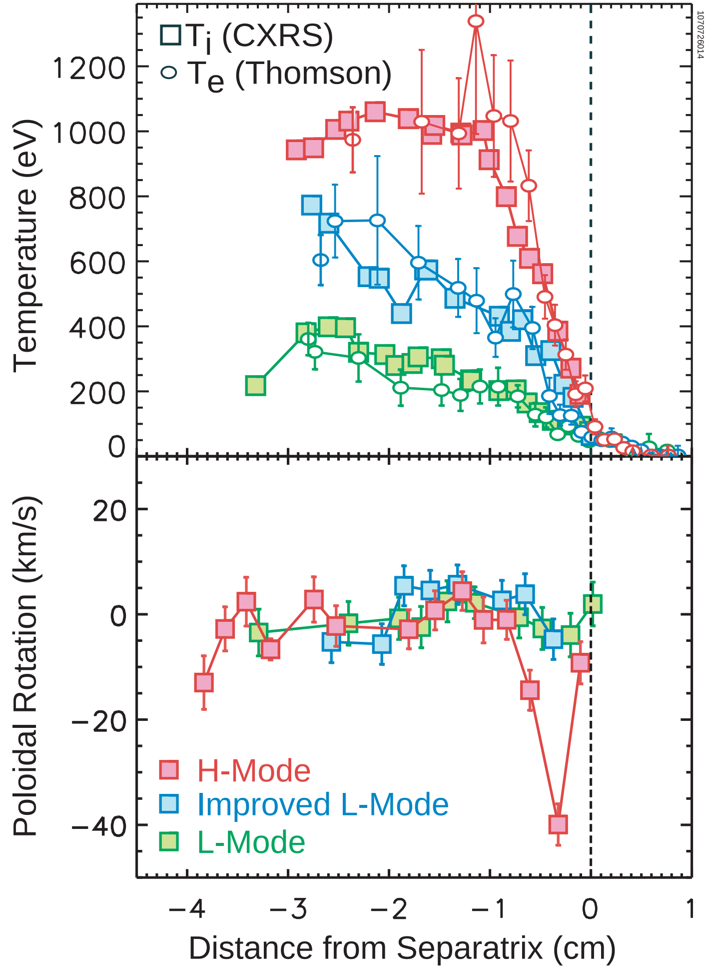

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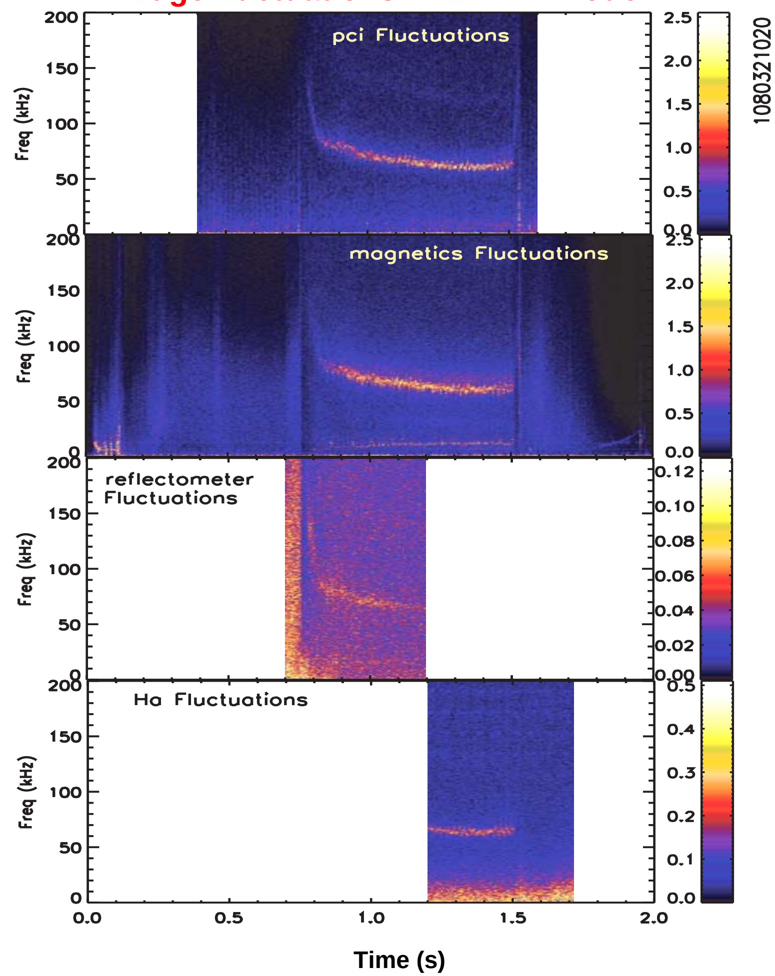
Edge fluctuations in EDA H-mode



Additional diagnostics and operating features

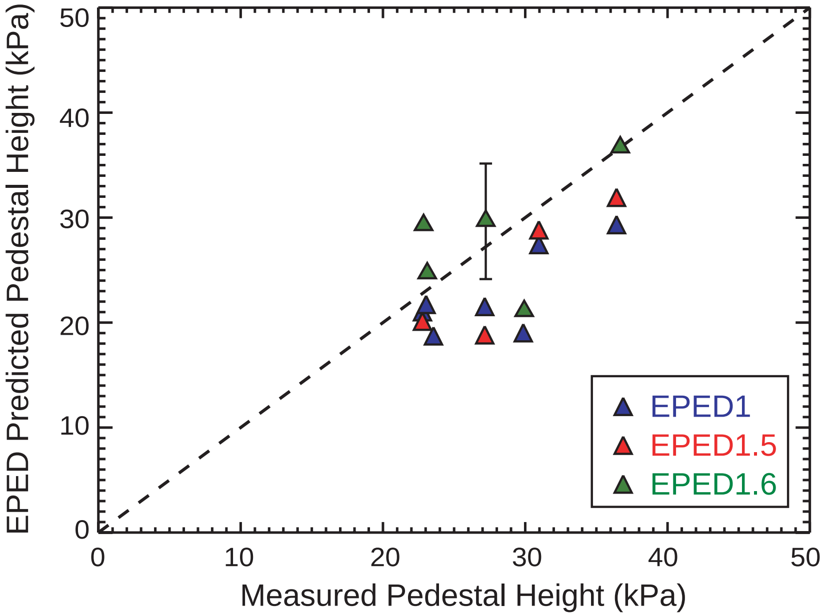
- Long-pulse diagnostic neutral beam (50kV, 6A)
- Fast magnetics behind PFC tiles
- Custom probe heads with radially spaced Langmuir probes, magnetic probes
- Core toroidal and poloidal rotation profiles via x-ray spectroscopy
- Core Ti v profile measurements via x-ray spectroscopy
- Central Ti from neutron rate
- Impurity measurements via spectroscopy (x-ray, VUV, EUV, visible)
- Core and edge bolometry
- Hard x-ray pinhole camera for fast electron measurements
- Compact neutral particle analyzer
- Divertor IR camera
- Extensive divertor tile probes, thermocouples
- External, off-midplane, correction coils (A-coils) for locked mode amelioration, non-axisymmetric field studies
- Active MHD antennas
- Digital plasma control system for flexible real-time feedback
- Massive impurity gas jet for disruption mitigation studies
- Laser blow-off impurity injection
- Impurity gas puff system for diagnostic D_2, He, Ar

Existing candidates for experimental run time in FY11

- Experimental tests of EPED in ELMy H-Mode (MP578)
- Pedestal and fluctuation evolution (MP589, others)
- Physics basis for I-mode (MP579, 615, others)
- Lower hybrid modification of the H-mode pedestal and edge relaxation mechanisms (MP614, others)
- Isotopic species effects on pedestal and ELMs (MP559, 580)
- Analysis of the Radial Impurity Transport at the Pedestal Region (MP595)
- Magnetic shear and pedestal width
- Core fueling from plasma transport vs. neutral penetration
- Isotope and I_P scaling of transport
- Radial width of edge EM modes

Collaborations with modelers

- Numerous edge modeling collaborations have been instituted
  - Already enhancing FY10 JRT
  - Ongoing work helps develop a starting point for FY11 JRT
- Examples of collaborations that have already begun
  - EPED validation (Snyder)
  - Simulations of the quasi-coherent mode with M3D (Sugiyama)
  - Neoclassical and anomalous pedestal width evaluated from XGC0 (Chang, Pankin)
  - I-mode simulations with XGC1 (Chang, Ku)
- What more should we do?



Schedule through FY11

- **Currently completing FY10 research operation** (campaign ends 9/10)
- **Oct—Dec '10: Begin FY11 research operation**
  - 7—8 run weeks of our 15 weeks guidance
- **Dec/Jan: *2011 C-Mod Ideas Forum* (date tbd)**
- **Jan—Mar '11: Up-to-air**
  - Installation of new 4-strap ICRF antenna
  - Other necessary maintenance, hardware installation
- **May—Aug '11: Complete FY11 research operation**
- **As always, we welcome participation from all our collaborators**

Extra slides on specific diagnostic capabilities

Edge CXRS, Reflectometry, PCI

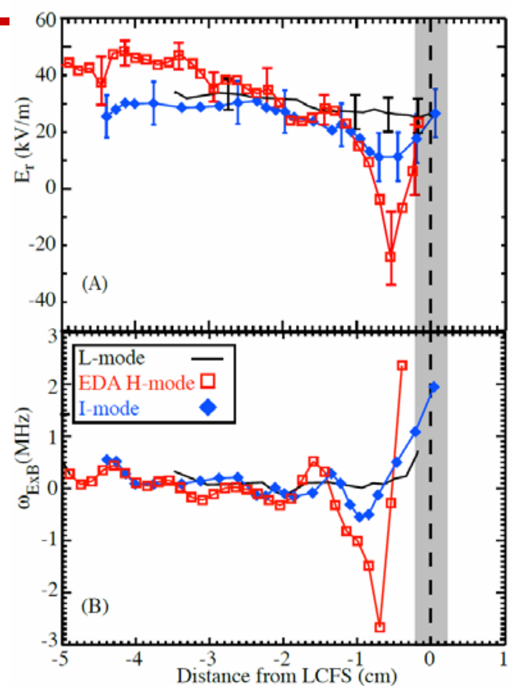
Edge CXRS capabilities

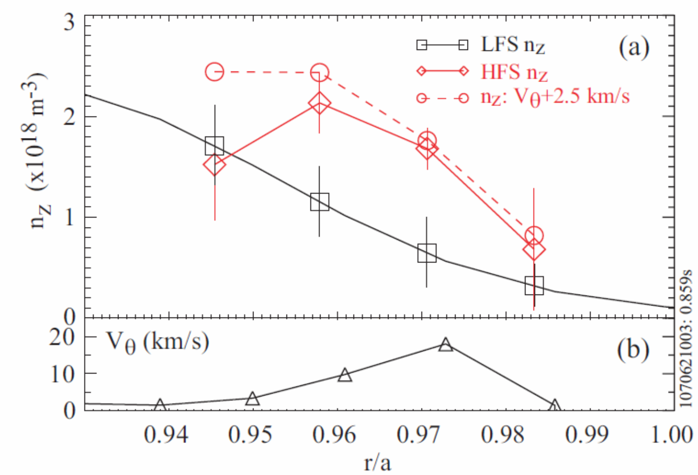
- Measures B^{5+} impurity ion $\mathrm{n}_I, V_{I\theta}, V_{I\phi}, T_I$
- Uses the BV *n=7-6* transition ($\lambda = 494.467\ \mathrm{nm}$)
- Two different neutral sources
  - 50 kV, 6 A, H^{0+} Diagnostic Neutral Beam (DNB)
  - 4 torr-L, 1 mm capillary, D_2 gas puff

Views	Neutral Source	Average ρ range	Line-of-sight angle with $\hat{\phi}$	Spot Size (mm)	Radial Resolution (mm)
Inner Wall Toroidal	Gas puff	0.92 – 1.03	-10°	3.8	4.0
Inner Wall Poloidal	Gas puff	0.92 – 1.03	+90°	3.8	4.0
Outer Wall Toroidal	DNB	0.77 – 1.03	+172.4°	2.2	2.7
Outer Wall Poloidal	DNB & Gas puff	0.76 – 1.03	-90°	2.0	2.4

Edge CXRS recent findings

- Radial Electric Field (E_r)[1]
  - H-Mode: Deep (-75kV/m) and narrow width (5mm) Er wells. Diamagnetic and poloidal velocity terms dominate; toroidal velocity an offset.//
  - I-Mode: Shallower (-20KV/m), still narrow width (5mm) Er wells. All three Er terms contribute, countercurrent toroidal velocity.



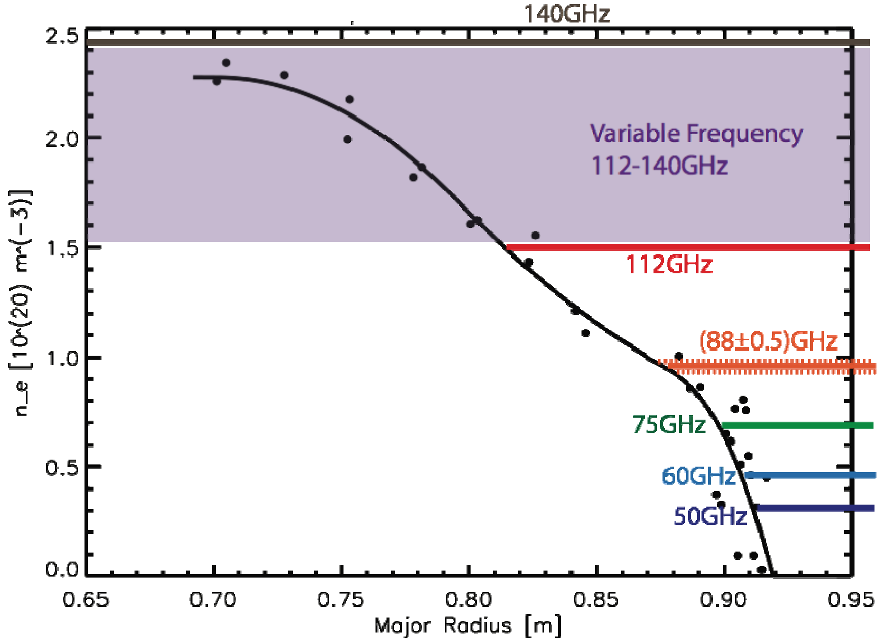


- Inferred Poloidal Density Asymmetry[2]
  - Discrepancy between measured and neoclassically calculated $V_{//}$ at high-field side. Possible explanation an in-out impurity density asymmetry (HFS 2-3 times higher than LFS)

1. **McDermott RM, Lipschultz B, Hughes JW, et al. *Physics of Plasmas*. 2009;16(5):056103**
2. **Marr KD, Lipschultz B, Catto PJ, et al. *Plasma Physics and Controlled Fusion*. 2010;52(5)**

O-Mode reflectometry for edge density fluctuation studies

- 5 fixed freq. channels at 50, 60, 75 and 88±0.5 GHz (corresponding to cutoff ne20=0.3-0.96)
- 2 fixed freq. channels at 112 and 140GHz (ne20=1.5—2.43) and a variable freq. channel covering the 112-140GHz range installed in collaboration with PPPL
- Radial positions of the cutoffs are interpolated from the Thomson Scattering density profiles.
- Routinely used to observe the presence of turbulent phenomena like the Quasi-Coherent Mode in EDA H-mode and the Weakly Coherent Mode in I-mode
- Typical radial resolution ~2mm
- Quantitative interpretation of the data (e.g. local ñ/n) requires fullwave modeling



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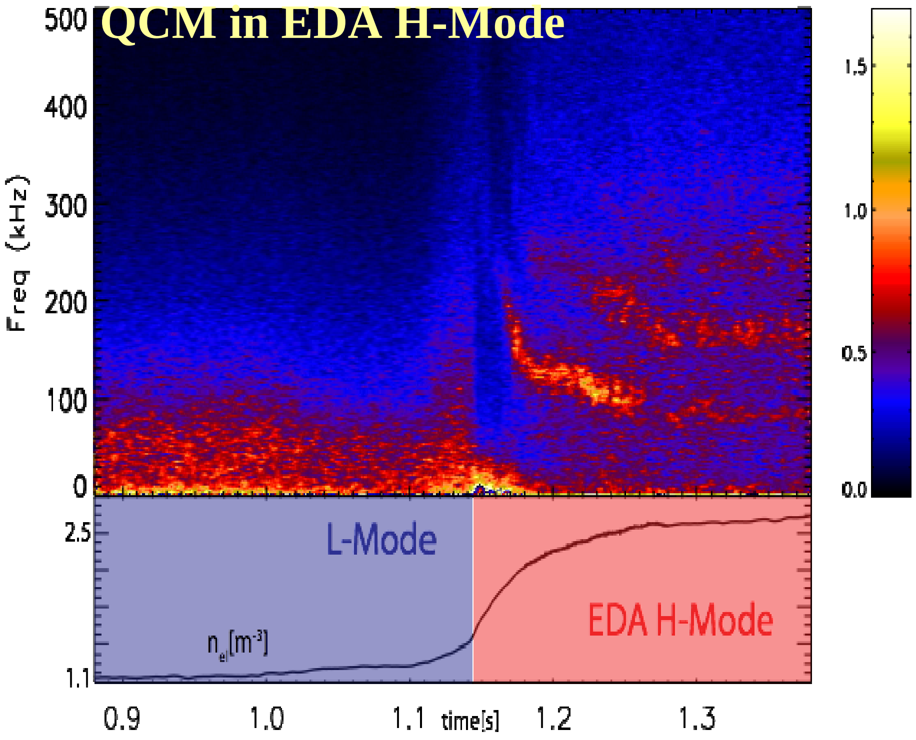
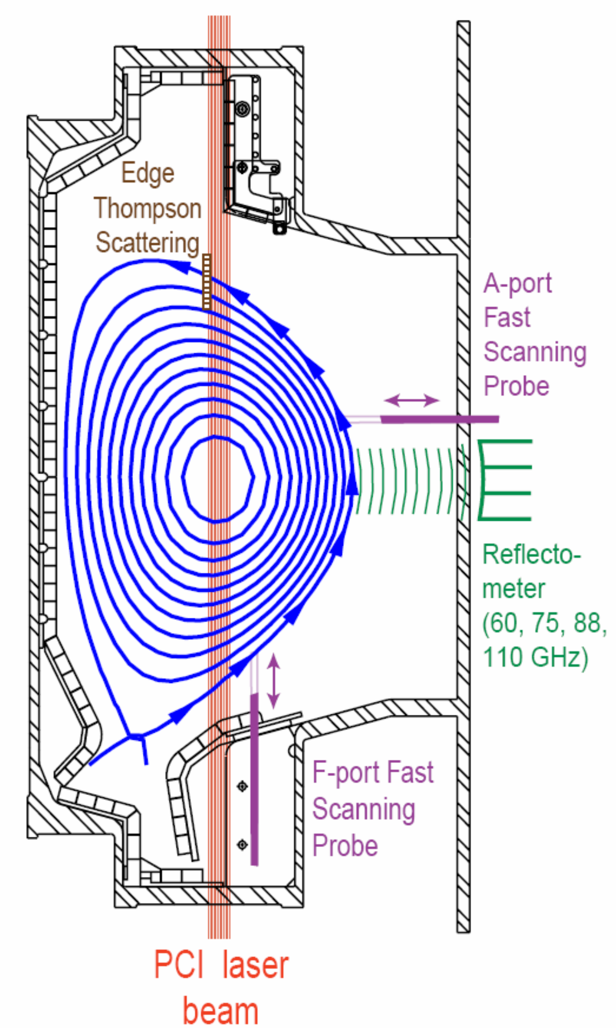
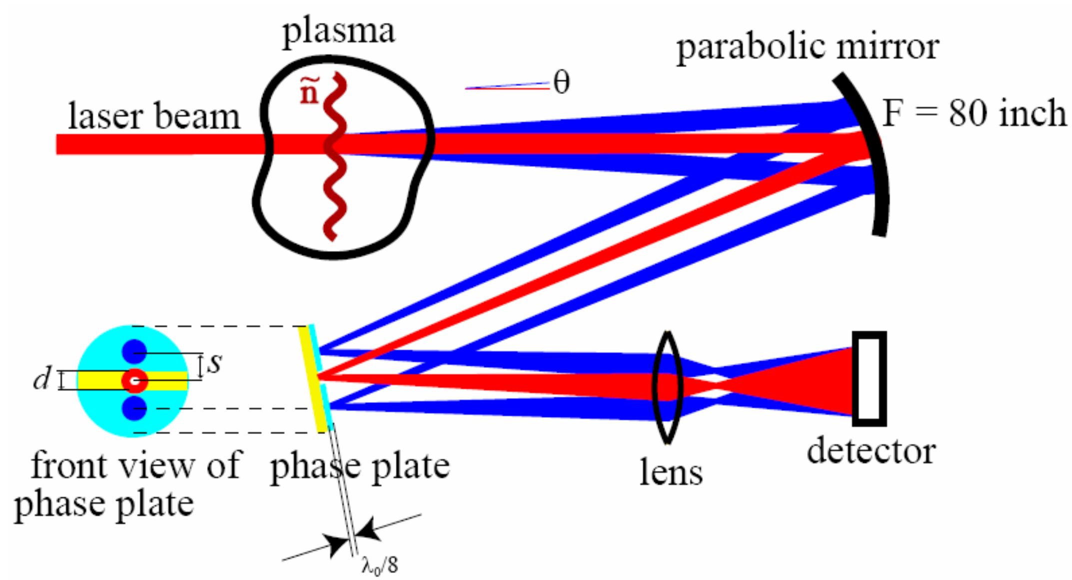


Phase Contrast Imaging



- k_R = 1-15 cm^{-1}
- R = 64-74 cm
- 5 MHz band width
- Sensitivity ~$(10^{13}\ m^{-2})^2$/kHz



PCI Vertical Localization