Spectroscopic Experiments and Diagnostics on Alcator C-Mod

ADAS Workshop

October 6th, 2009 at Ringberg Castle, Germany

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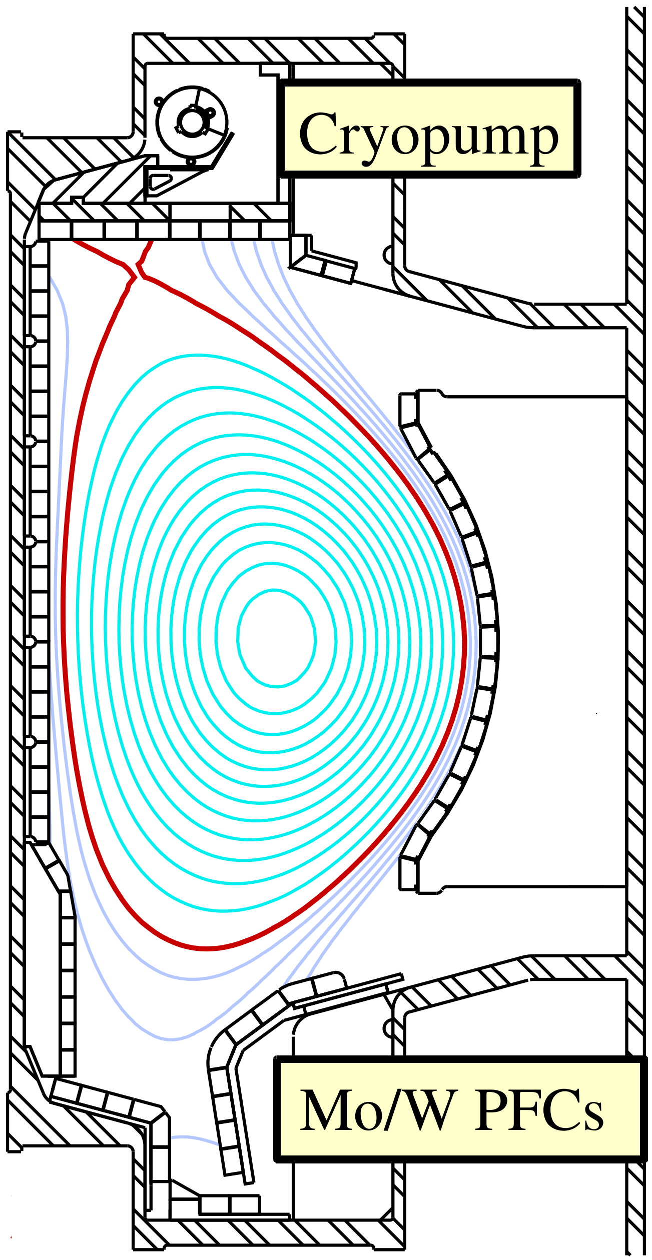
on behalf of

The Alcator C-Mod Team

- **Description of the Alcator C-Mod tokamak and its capabilities**
- **Spectroscopy tools and sample data**

The Alcator C-Mod Tokamak

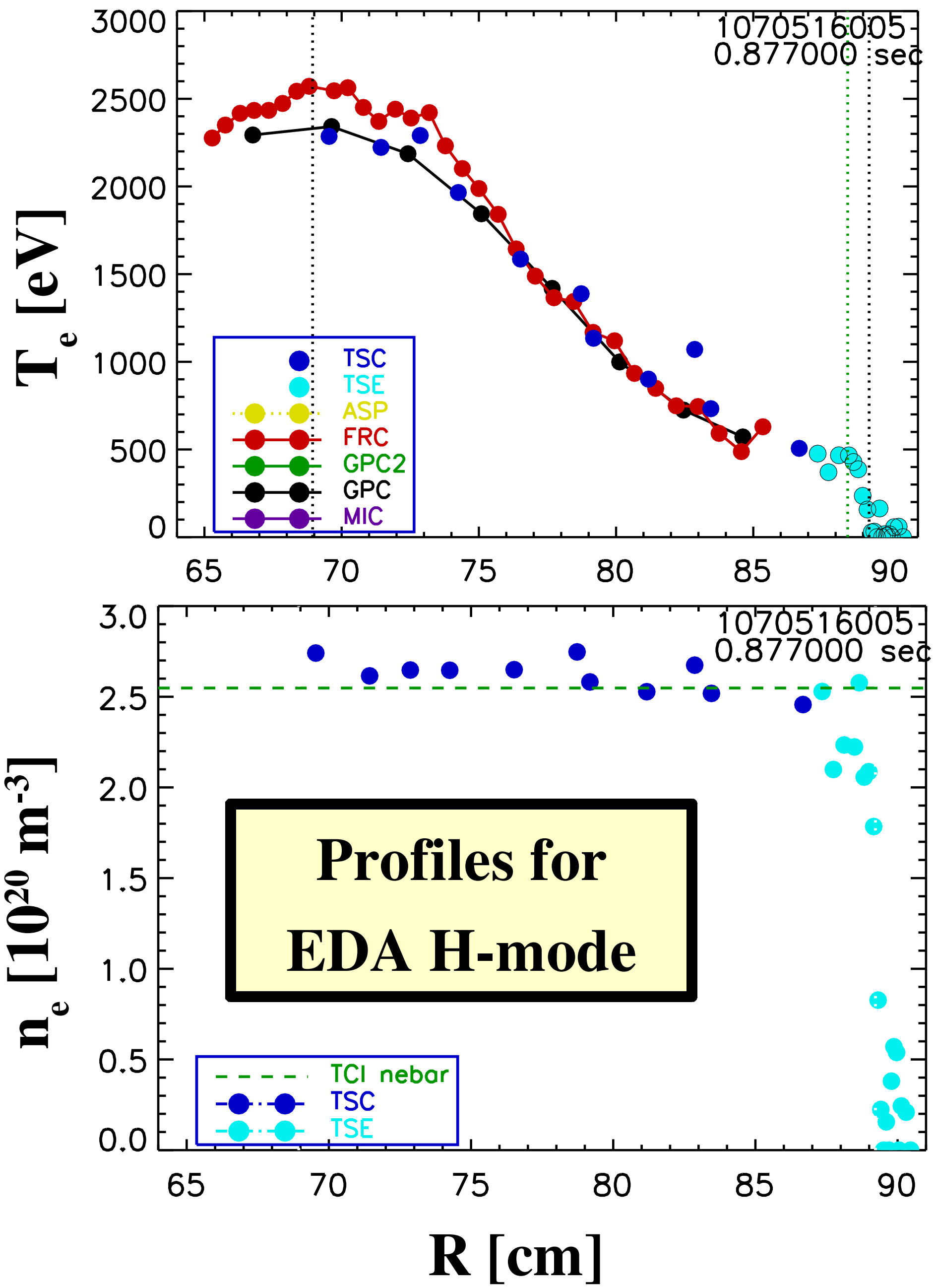


Alcator C-Mod[1] is a compact, high field tokamak capable of running at high density and temperature.

R_o~0.68 [m], a~0.21 [m]	$n_e < 6x10^{20}$ [m^{-3}]
B_T~5.4 [T] , V_p~1.0 [m^3]	T_e < 5-6 [keV]

- External heating via ICRF (6 MW)
  - heats hydrogen minority
  - effective in both D_2 and He plasmas
- Cryopump for particle control
- Impurity input via gas puffing and (**NEW**) laser blow-off injection

Well Characterized Electrons[2]



SOL

scanning probes: T_e, n_e

2 mm

EDGE

Thomson scattering: T_e, n_e

1 mm, .03-1.0 keV, 0.3-5e20 m^{-3}

CORE

Thomson scattering: T_e, n_e

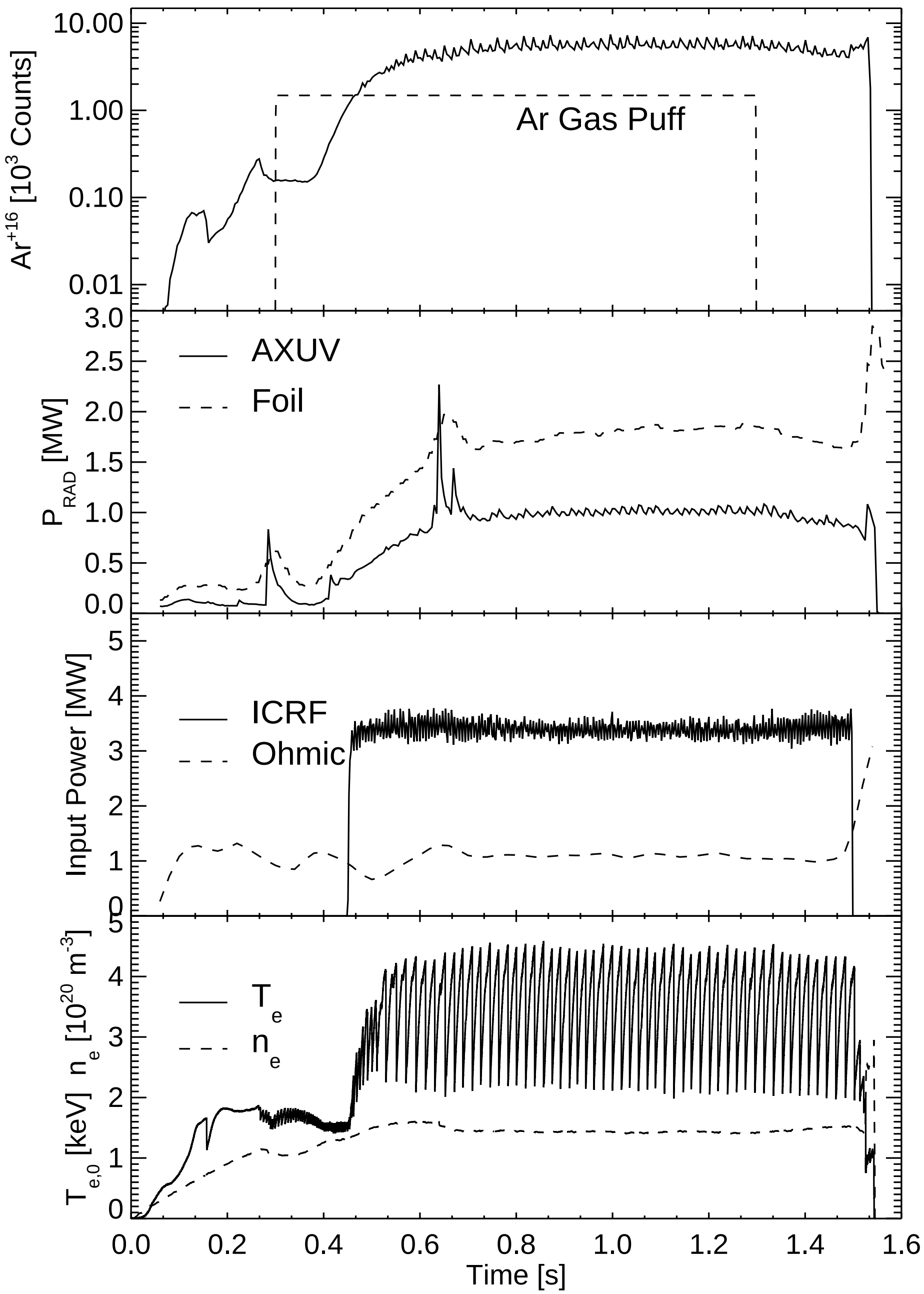
1 cm, < 10 keV, 3e21 m^{-3}, 60 Hz

10 ch interferometer: $\overline{n}_e$

e^- cyclotron emission: T_e

32 ch, 4 mm, 1 MHz

Noble Gas Infused Plasmas



- Continuous gas puff sets up puff/cryopump/plasma equilibrium
- Adjust input power/puff pressure to set T_e and absolute radiation level
- **<ε> ~ 3 MW/m^3 achieved (Kr)**
- Advantages over puffs or LBO
  - steady-state impurity transport
  - estimate n_z from P_{RAD}/SXR/Z_{eff}
  - typically weak transitions are easily observable

Broadband Radiation Measurement

Alcator C-Mod

Resistive "foil" bolometers[3,4] for absolute P_{RAD}

- **20 midplane channels for core**
- **16 channels in divertor/x-point region**

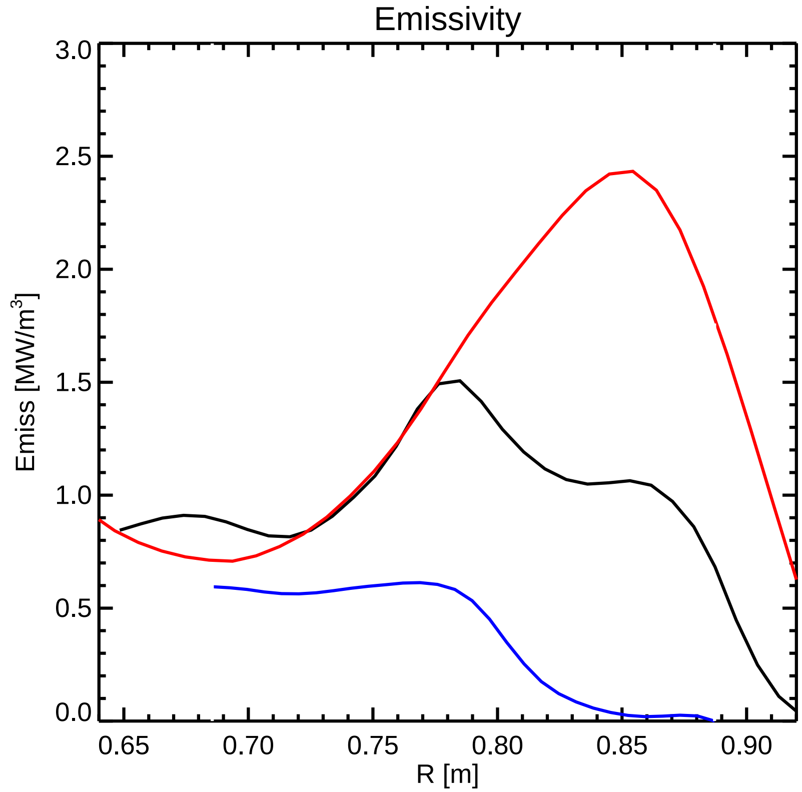
Absolute eXtreme UltraViolet (AXUV) diodes[4]

- **22-channel midplane arrays for core**
- **20 channels for divertor**

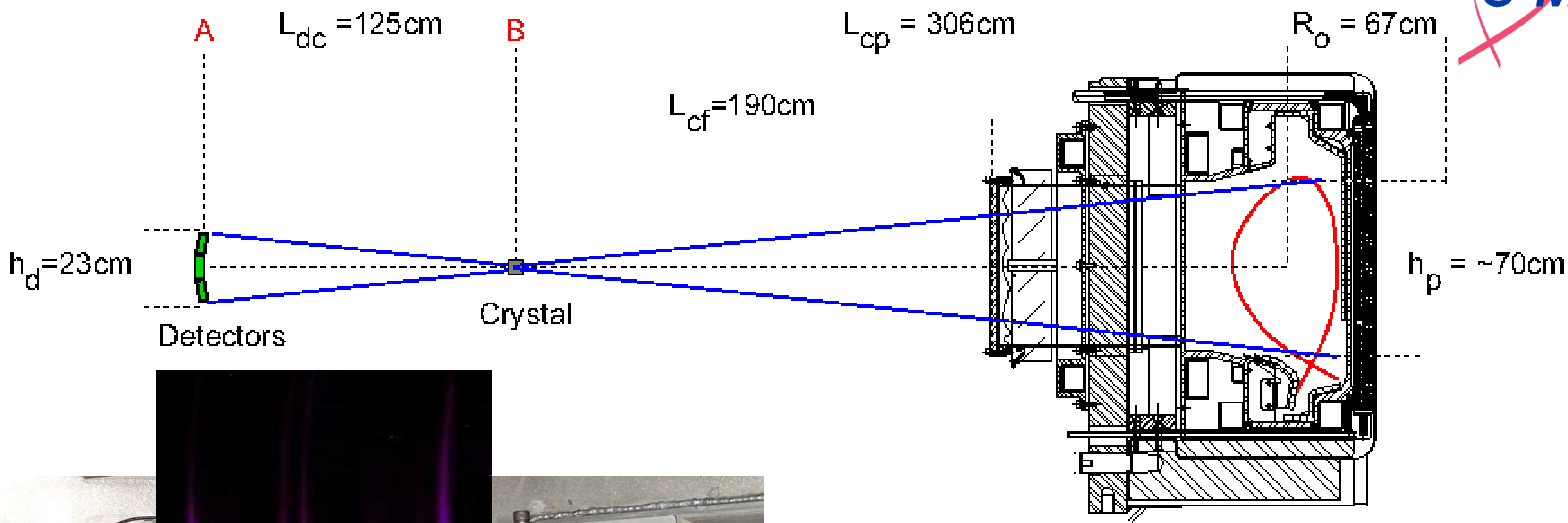
Soft X-Ray (SXR) diodes[2]

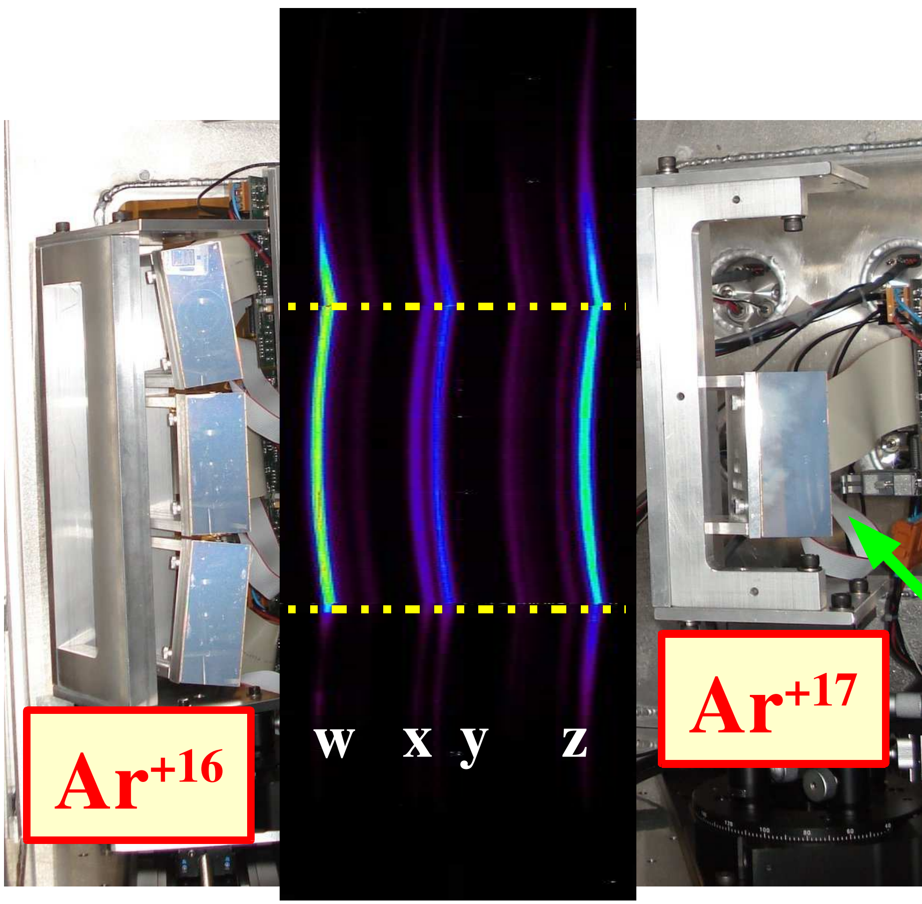
- **x2 38-channel arrays for core**
- **X2 38-channel arrays for edge**

1D emissivity profiles during Ar seeded L-mode



X-Ray Crystal Imaging Spectrometer





<u>Spherically-bent crystal optics</u>

- **high throughput**
- **spatial resolution**

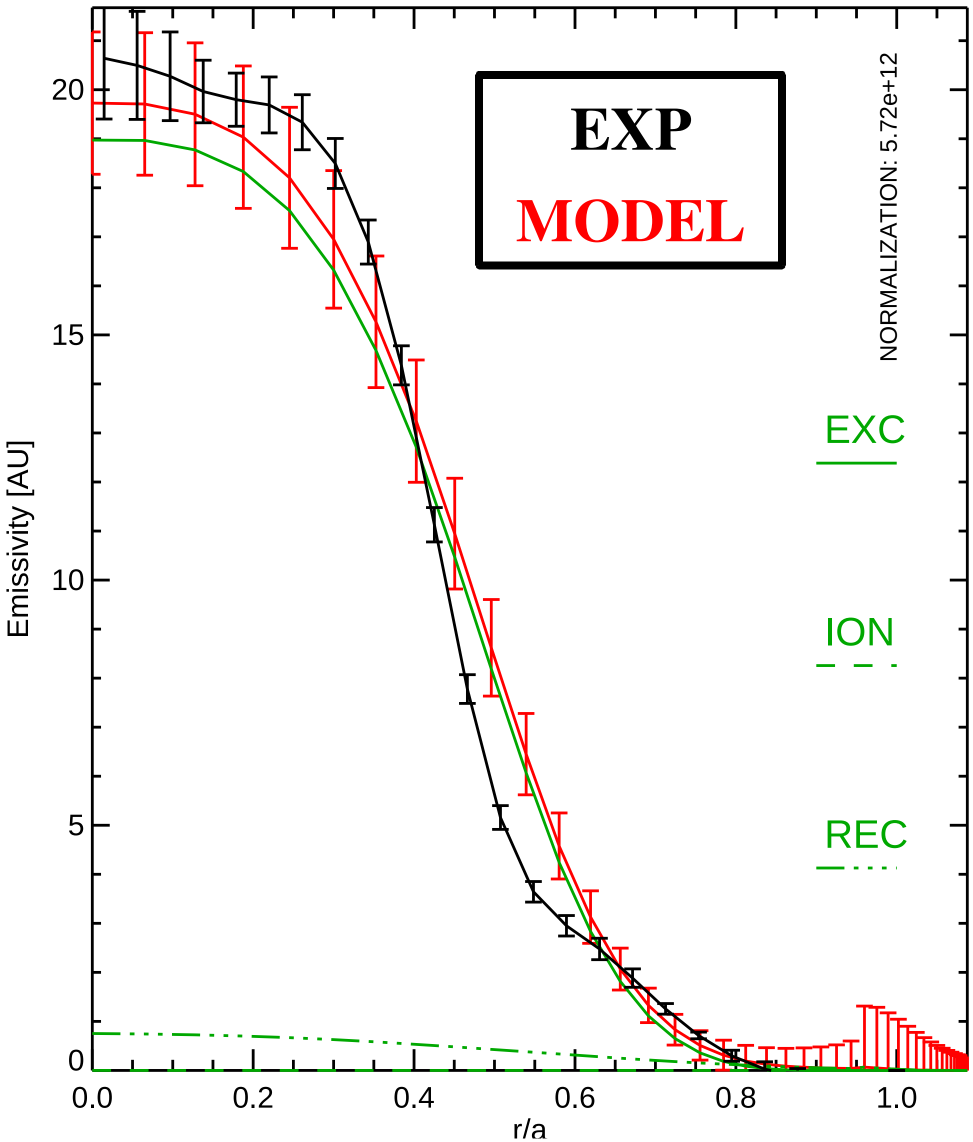
find local emissivity from line-integrated spectra

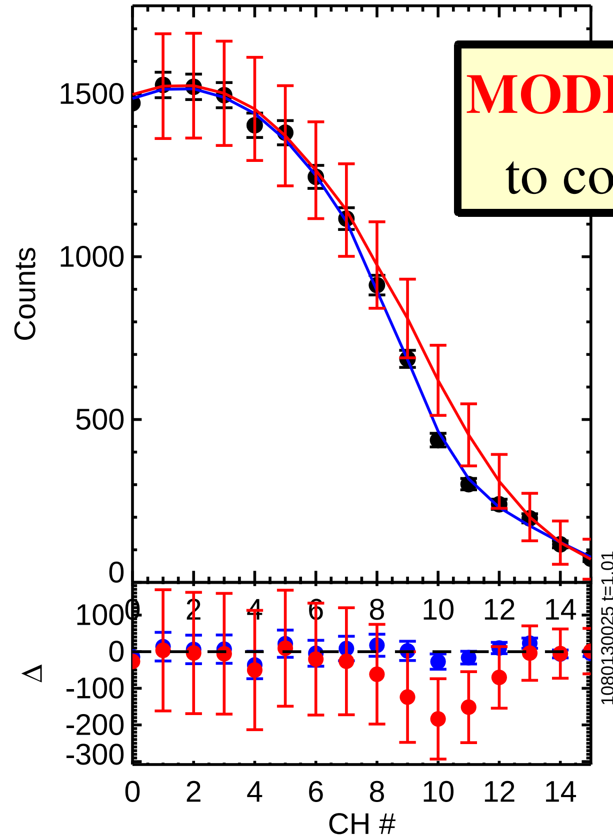
PILATUS II from Dectris

For XCIS diagnostic details see [5, 6]

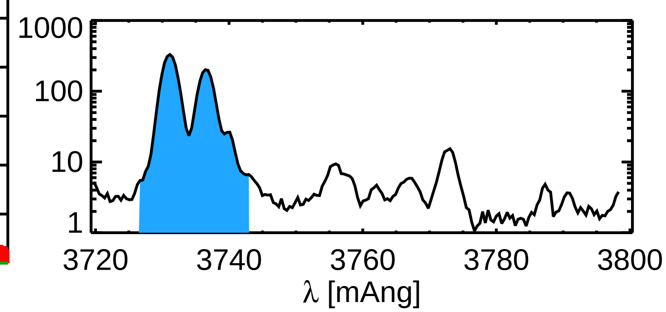
Good Agreement for Ar^{+17} Ly-α

Local emissivity found by inverting line brightness profile





MODEL normalized to core brightness



VUV Spectroscopy for Operations

Alcator C-Mod

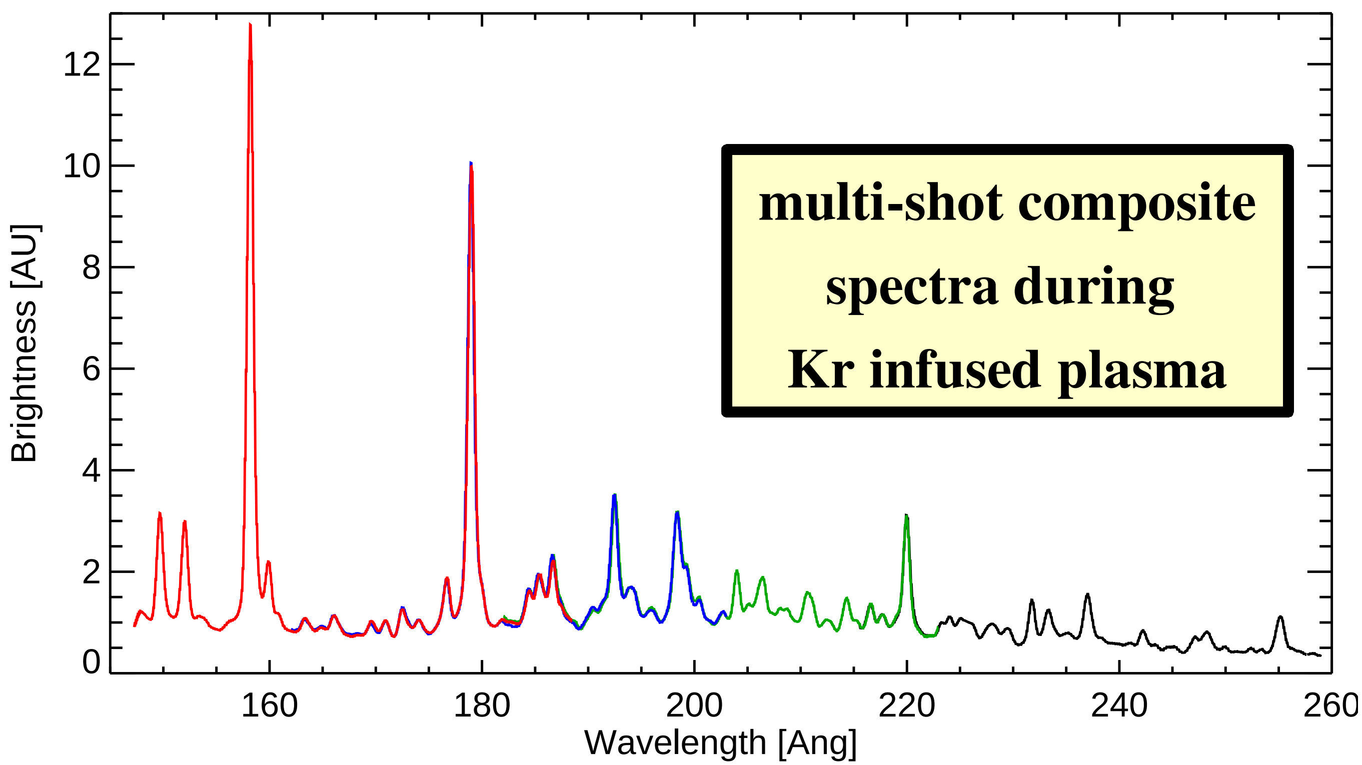
2.2 m Rowland circle spec for impurity monitoring

- 90 Å < λ < 1050 Å w/ 40-100 Å observation window
- single chord, scanning shot-to-shot poloidally for radial transport[7]
- generally sits at 110 Å -140 Å for Mo XXXI, XXXII

observed:

Mo, Fe, Ni, Cu, Ti, Cr, W, Zr, Mn

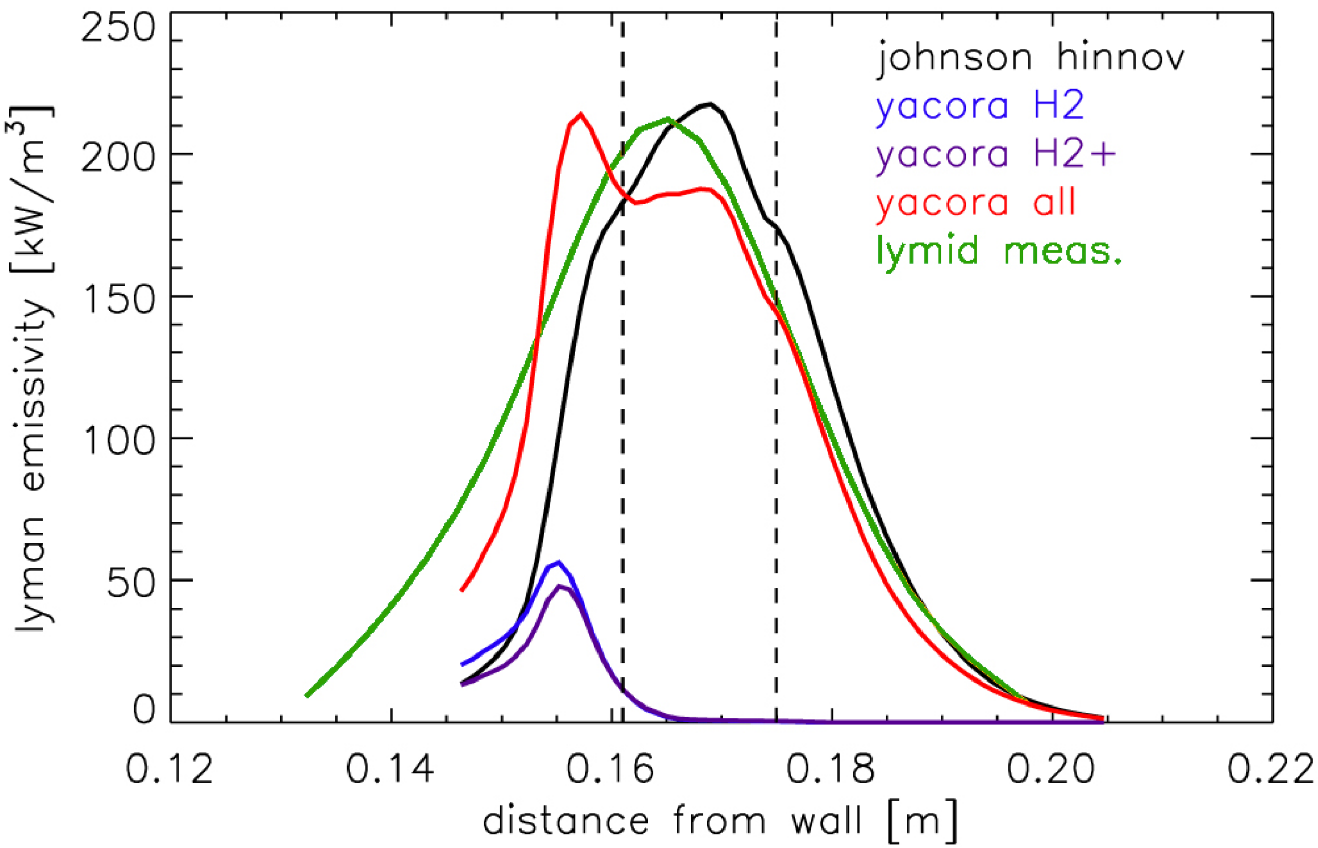
w/ LLNL deploying a flat-field imaging spectrometer for radial profiles of VUV emission.



Plasma Fueling from Deuterium Ly-α

Alcator C-Mod

20-ch AXUV array w/ 10 nm bandpass filter @ 121.5 nm[8]



Modeling using 1-D neutral transport code (KN1D[9]) w/ measured T_e, n_e and neutral pressure

excellent absolute agreement w/o any 'fudge-factor'

Balmer-α emission from molecules much greater than Lyman-α and comparison will provide a good check for codes like Yacora

Collaboration with D. Wüderlich at IPP using Yacora.

Charge Exchange Spectroscopy

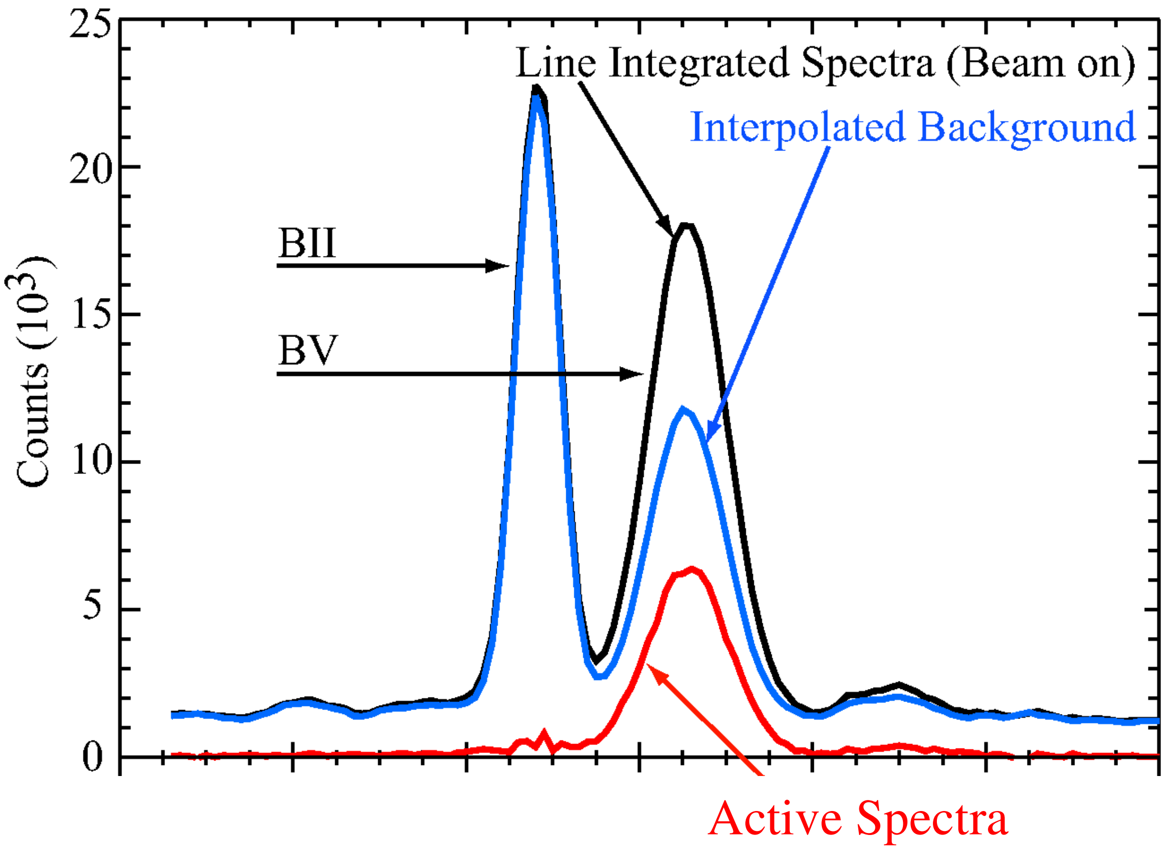
Alcator C-Mod

B V n=6-7 transition for v_ϕ, v_θ, T_z and n_z

Large array of LFS and HFS fiber views, both poloidal and toroidal[10,11]

- **50 kV, 7 A DNB for edge -> core**
- **thermal D_2 puff for LFS/HFS edge**

Weak beam enhancement makes CXRS challenging

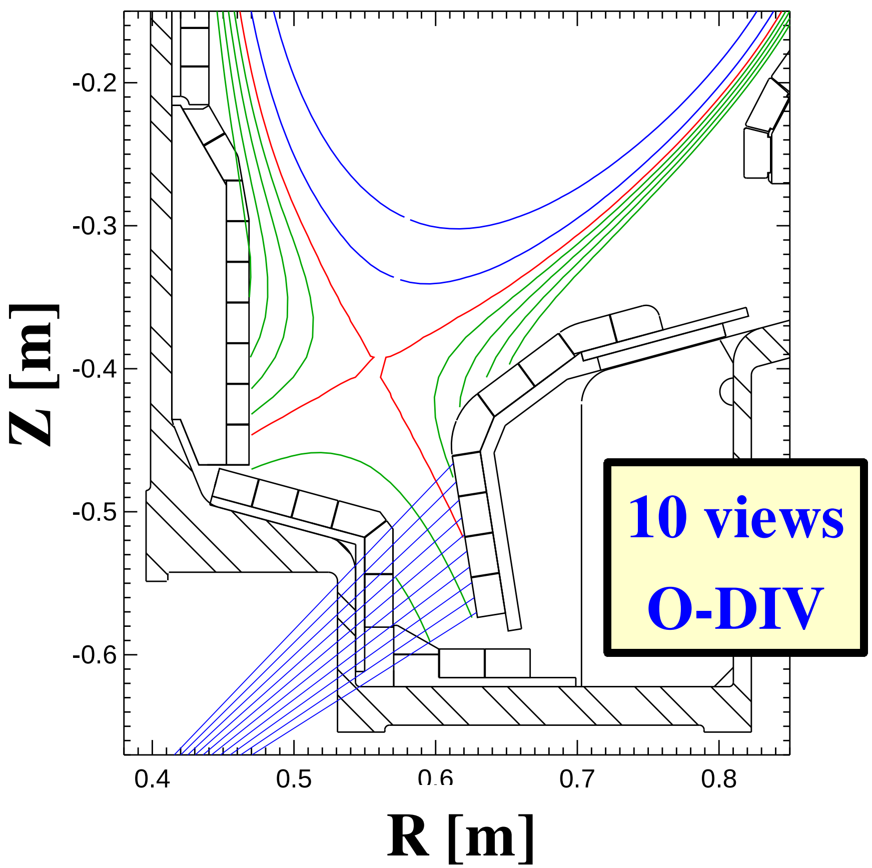


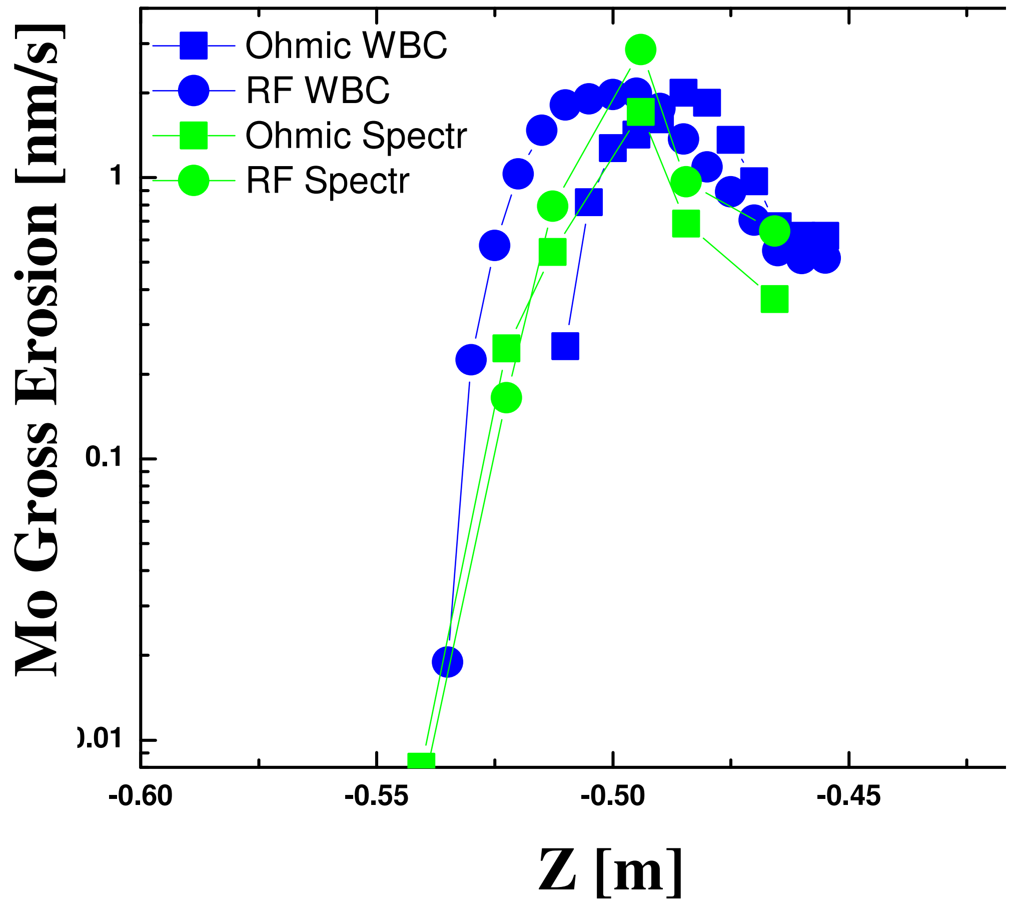
Working with Loch & Ballance at Auburn to look at e^- impact excitation of high-n and Guzman w/ ADAS to understand thermal C-X

Visible Spectroscopy for Impurity Influx

- Over 50 fiber views of the divertor and limiter
- Sub-set coupled to an imaging spectrograph

Use Mo I (386.4 nm) emission for erosion studies using S/XB[12]





Conclusions

Alcator C-Mod's high density, high-temperature plasmas, combined with an excellent set of diagnostics make it a unique facility to challenge and extend the understanding of atomic processes in plasmas

Open to discussions/collaborations on:

- SXR/VUV spectroscopy and radiation modeling
- charge exchange spectroscopy (beam-based & thermal)
- impurity transport
- impurity influx (S/XB)
- neutral and molecular emission

References

[1] Marmar, E. S. Fusion Science and Techology. **51** 261 (2007)

[2] Basse, N. P. *et al*. Fusion Science and Techology. **51** 476 (2007)

[3] Mast, K. F. *et al*. Rev. Sci. Instrum. **62** 744 (1991)

[4] Reinke, M. L. *et al.* Rev. Sci. Instrum. **79** 10F306 (2008)

[5] Ince-Cushman, A. *et al*. Rev. Sci. Instrum. **79** 10E302 (2008)

[6] Ince-Cushman, A. PhD Thesis. Department of Nuclear Science and Engineering, Massachusetts Institute of Techology (2008)

[7] Rice, J. E. *et al*. J. Phys. B: At. Mol. Opt. Phys. **29** 2191 (1996)

[8] Boivin, R. L. *et al*. Rev. Sci. Instrum. **72** 961 (2001)

[9] LaBombard, B. PSFC Research Report, **PSFC/RR-01-03** (2001)

[10] McDermott, R. M. *et al.* Phys. Plasmas. **16** 056103 (2009)

[11] Rowan, W. L. *et al.* Rev. Sci. Instrum. **70** 882 (1999)

[12] Lipschultz, B. *et al*. Nucl. Fusion. **41** 585 (2001).