Electron density gradients from linear D_α camera

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- Analytic model and computer simulation
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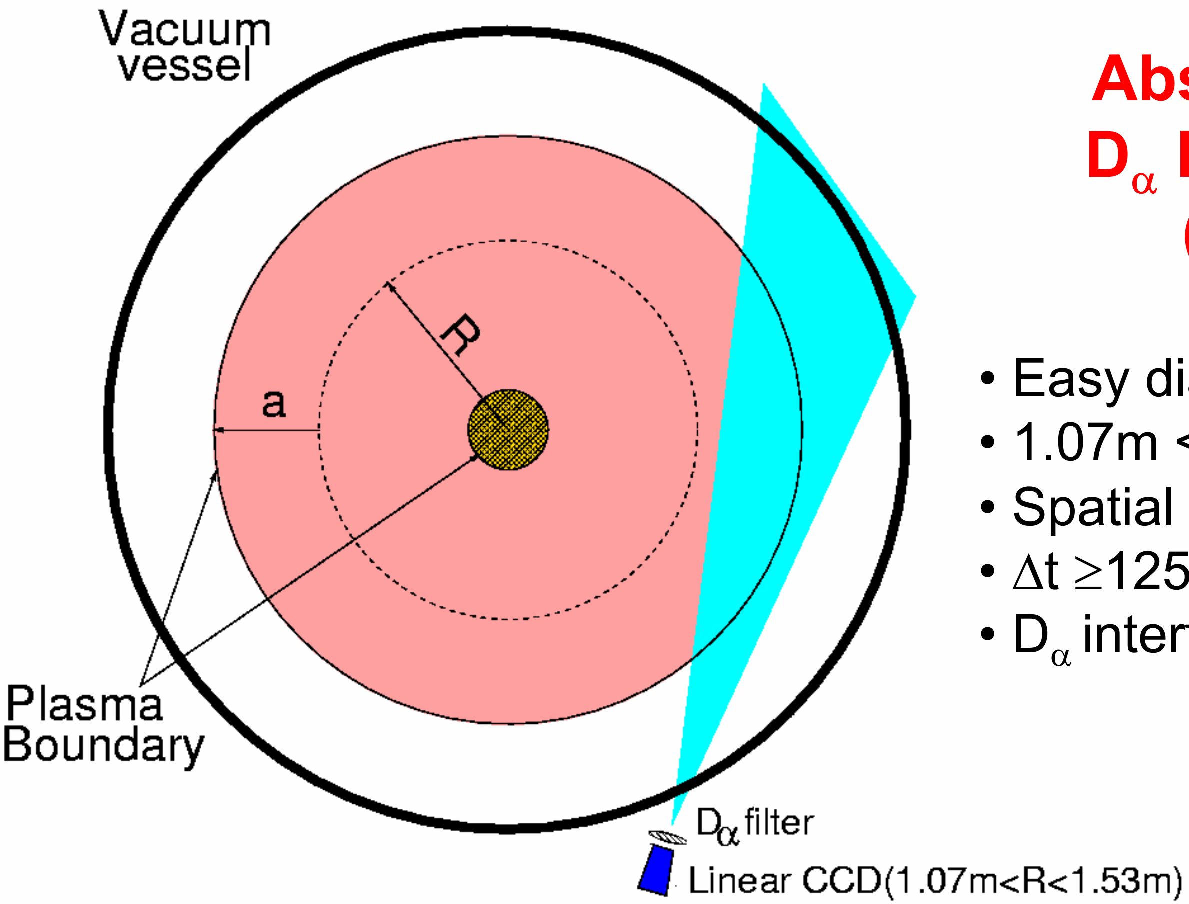
Instrumentation



Absolutely calibrated D_α linear CCD camera (256 elements):

- Easy diagnostic access
- 1.07m < R < 1.53m (Outboard)
- Spatial resolution $\Delta R \sim 2$mm
- $\Delta t \geq 125 \mu s$ (read out speed)
- D_α interference filter

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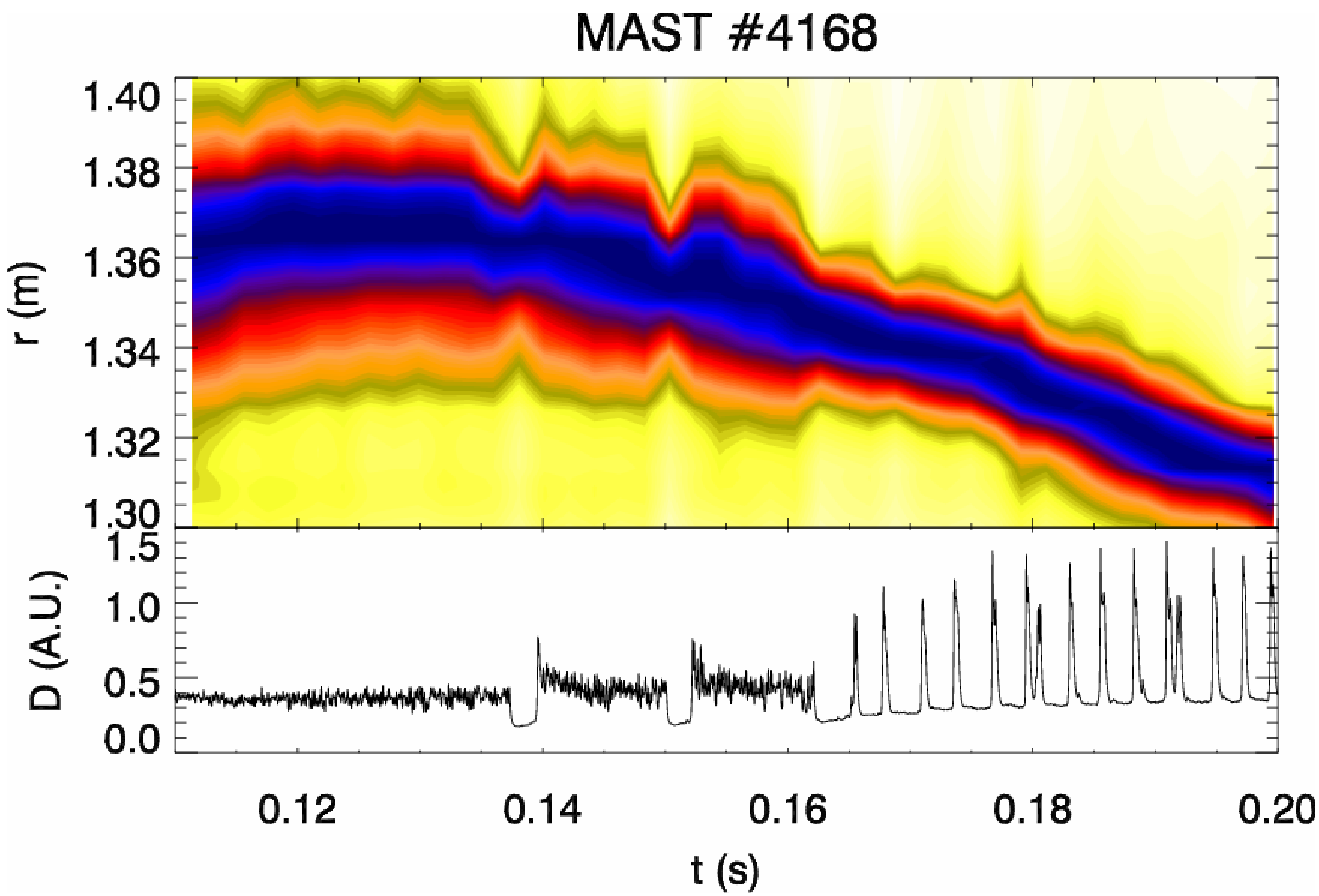
Experimental observations

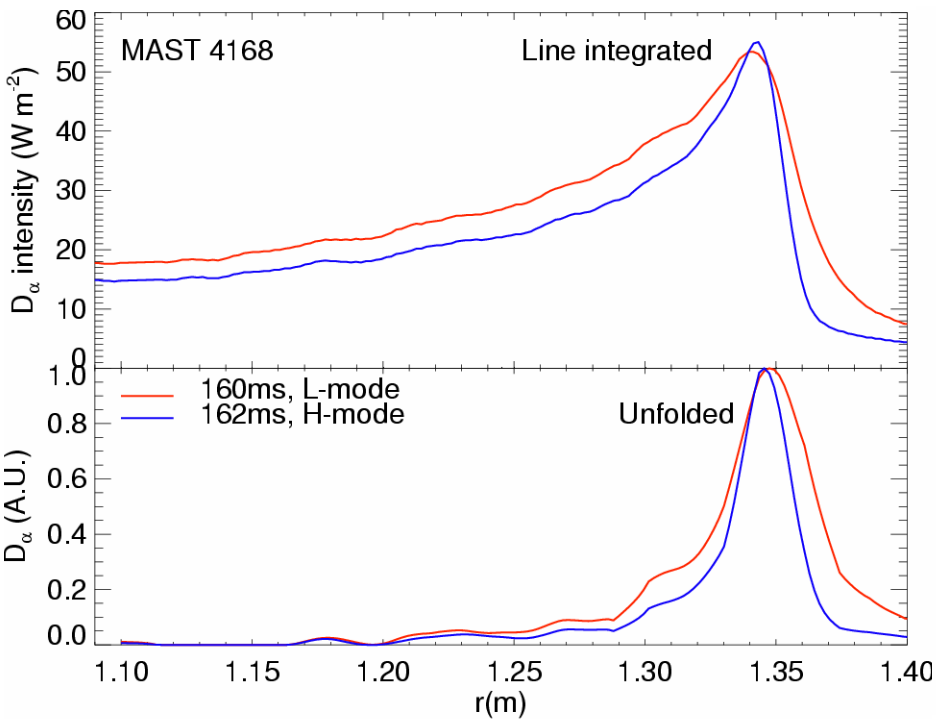


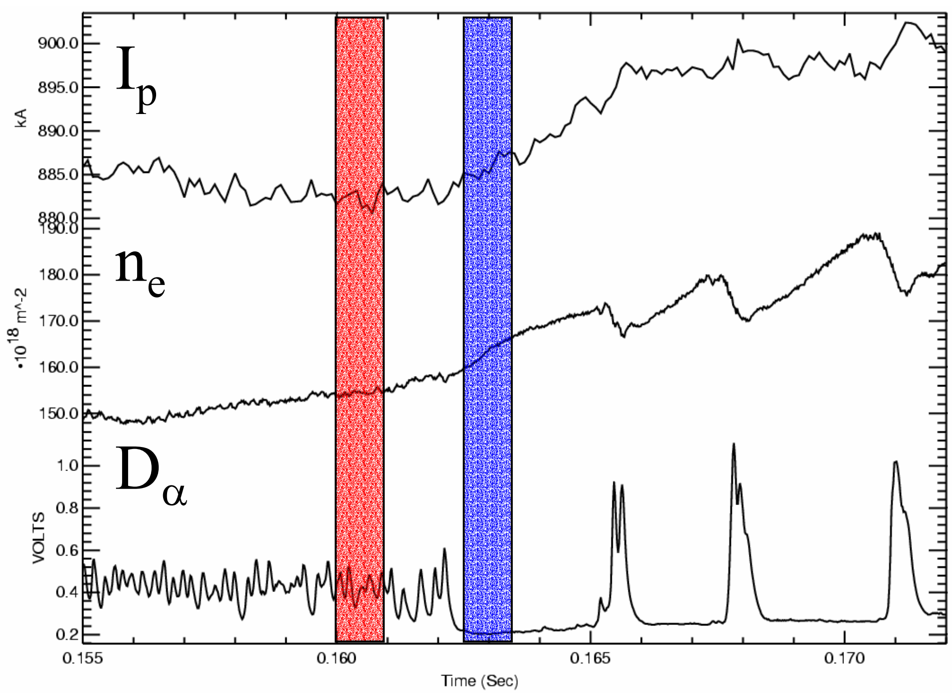
Contour graph
of unfolded D_α emission
(MAST #4168, 656nm)

Neutral density extraction
using TS on START/MAST
M. R. Tournianski et al.,
Nuclear Fusion
41(1) 77-89 (2001)

Unfolding the line-of-sight integrated intensities

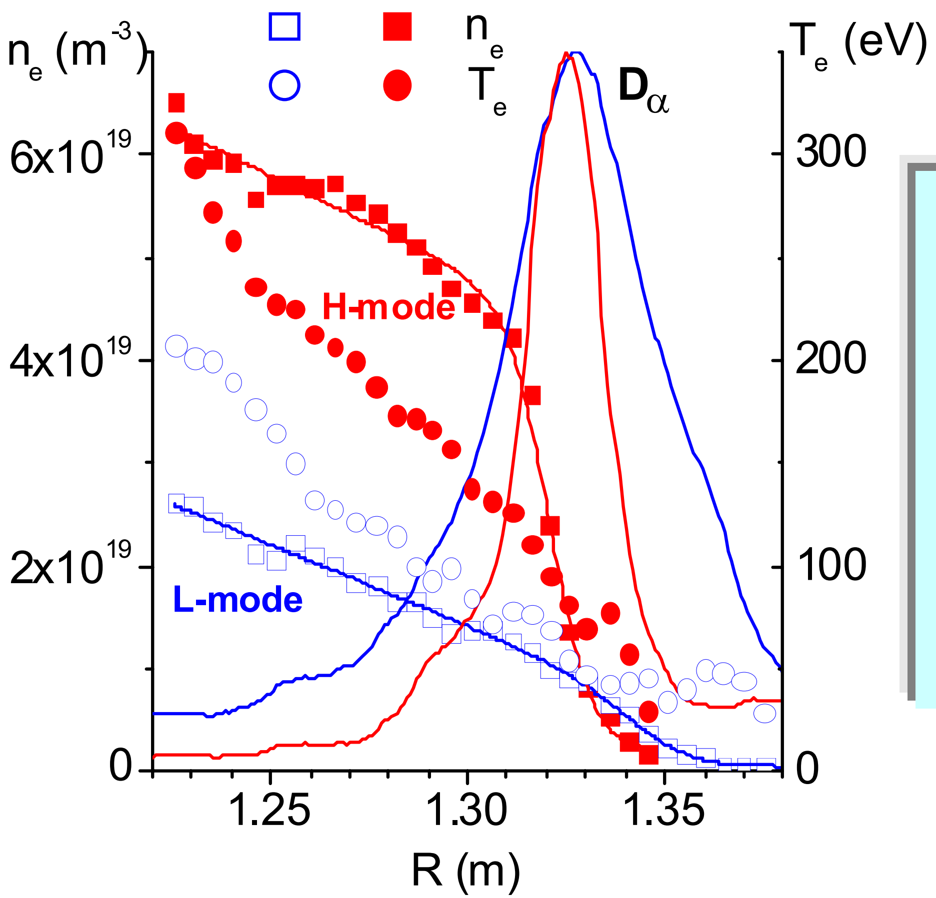
- Assume toroidal symmetry
- "Singular Value Decomposition"
- Radial smearing/finite CCD element size included





D_α emissivity narrows during L-H transition

D_α narrowing



- n_e profile accounts for D_α narrowing
- T_e>30eV in D_α range
- D_α peak at transport barrier
- Modified TANH least square fit position

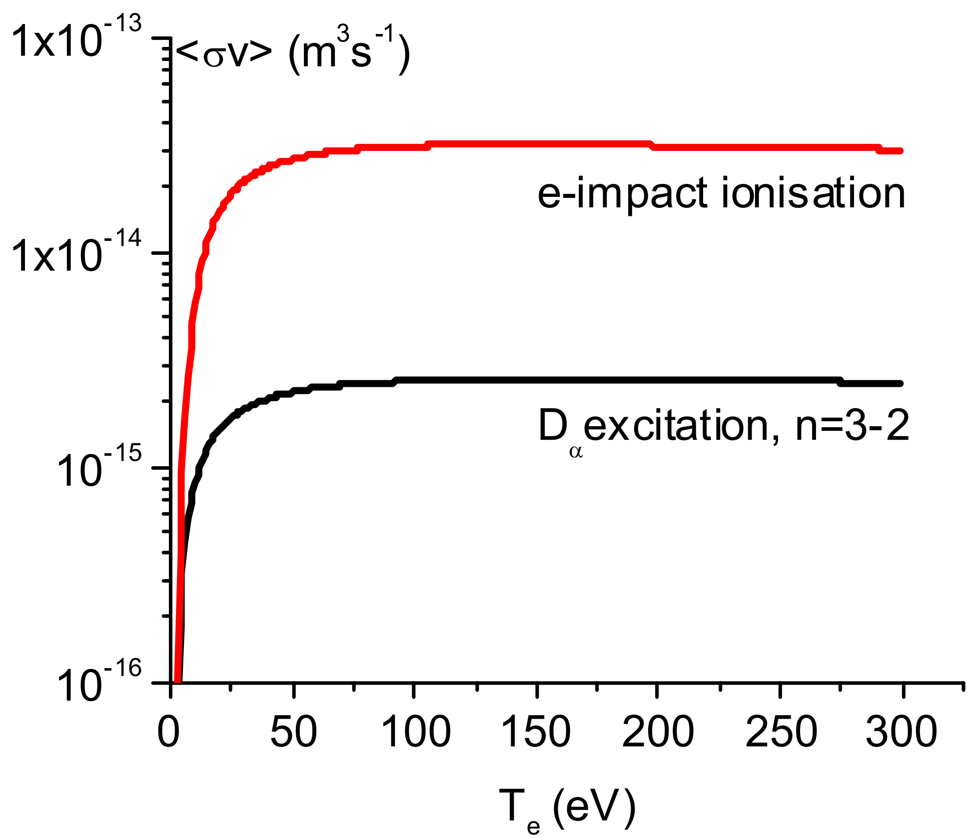
Motivation

Edge electron density profiles are important for H-mode studies

- To exploit physics of Hydrogen excitation
- Simple method to monitor edge density
- Limited TS time repetition rate
- Qualitative technique , 300 point TS system as yardstick
- Naturally limited in D_{α} range (transport barrier position)

Analytic model to understand main trends

Atomic physics helps !!!



$$D_\alpha = n_e n_o \langle \sigma v \rangle_{ex}$$

- T_e > 40eV in D_α range in MAST/START (probes)
- $<\sigma v>_{ex,ion}$ varies~15%, T_e=30eV-300eV (T_e >13.6eV)
- D_α narrowing due to T_e is much less important

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Simple model for D_α emissivity (analytical)

$$D_\alpha = n_e n_o \langle \sigma v \rangle_{ex}$$

- Linear approximation for n_e
- $<\sigma v>_{ion}$~const , $T_e > 40$eV

$$\left. \begin{aligned} n_e &= \frac{dn_e}{dr} \cdot r \\ \langle \sigma v \rangle_{ion} &\sim const \end{aligned} \right\} n_0 - ?$$

Basic n_0 from particle continuity

$$\frac{\partial n_o}{\partial t} + \vec{\nabla}\vec{\Gamma}_0 = -S$$

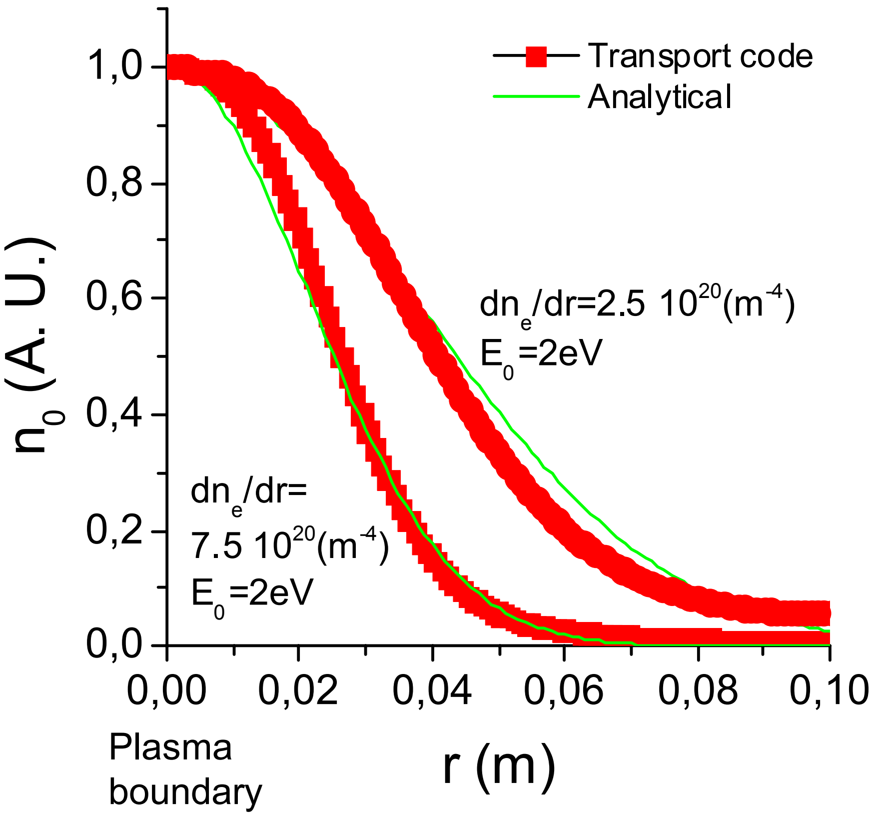
$$\vec{\Gamma}_0 = \vec{V}_0 \cdot n_0$$

$$\vec{V}_0 \cdot \vec{\nabla} n_0 + n_e n_0 \langle \sigma v \rangle_{ion} = 0$$

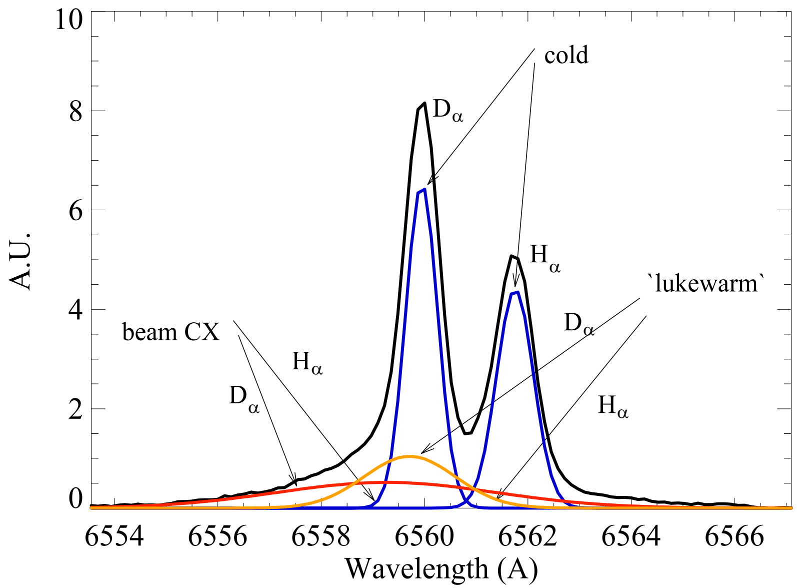
V_0- is neutral influx velocity

$$n_o = n_o(0) \exp\left(-\frac{\langle \sigma v \rangle_{ion}}{2V_0} \frac{dn_e}{dr} r^2 \right)$$

Edge neutral density



- n_0 analytical profiles compared with 1D Monte-Carlo neutral transport code
- Estimates of neutral influx velocity from D_α Doppler edge measurements (~1ev)



D_α emissivity (analytical)

$$\left.\begin{array}{l} n_e = \dfrac{dn_e}{dr} \cdot r \\ \langle \sigma v \rangle_{ion}, \langle \sigma v \rangle_{ex} \sim const \end{array}\right\} \Delta_\alpha \text{ of } D_\alpha - ?$$

$$D_\alpha = \frac{dn_e}{dr} n_e r \cdot n_o(0) \exp\left(-\frac{\langle \sigma v \rangle_{ion}}{2V_0} \frac{dn_e}{dr} r^2\right) \langle \sigma v \rangle_{ex}$$

Radial position at D_α -max

$$\frac{dD_\alpha}{dr} \Rightarrow r_\alpha = \sqrt{\frac{V_0}{\langle \sigma v \rangle_{ion} \, dn_e / dr}}$$

FWHM D_α emissivity (analytical)

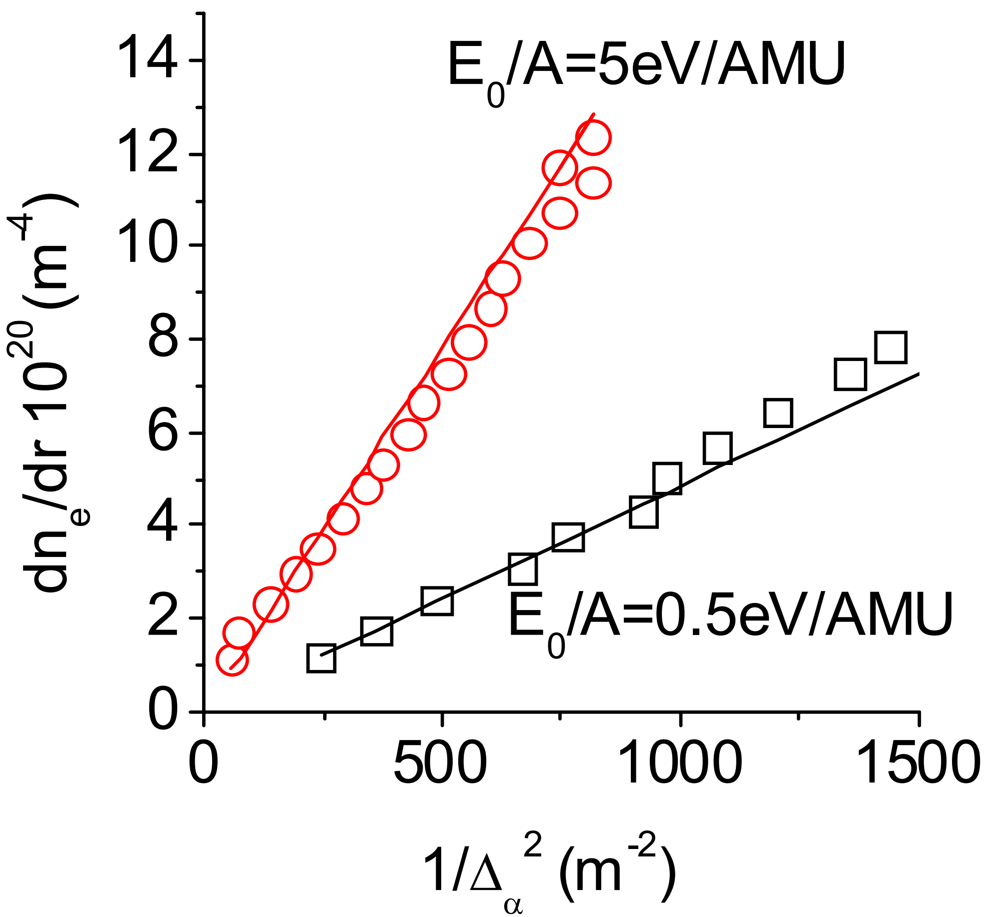
$$D_\alpha(r_\Delta) = \frac{D_\alpha(r_\alpha)}{2}$$ → r_Δ positions at D_α half max

$$\xi \exp\left(-\frac{\xi^2}{2}\right) = \frac{1}{2}\exp\left(-\frac{1}{2}\right)$$ where $$\begin{cases} \xi - \text{dimensionless} \\ \xi = \sqrt{\dfrac{\langle \sigma v \rangle_{ion}}{V_0} \dfrac{dn_e}{dr}} \cdot r_\Delta \end{cases}$$

$$\Delta_\alpha \approx 1.62 \sqrt{\frac{V_0}{\langle \sigma v \rangle_{ion} \, dn_e / dr}} \Rightarrow \frac{dn_e}{dr} \approx \frac{V_0}{\langle \sigma v \rangle_{ion}} \left(\frac{1.62}{\Delta_\alpha}\right)^2$$

n_e gradient, dn_e/dr, is proportional to V_0/Δ_α^2

Modelling FWHM D_α

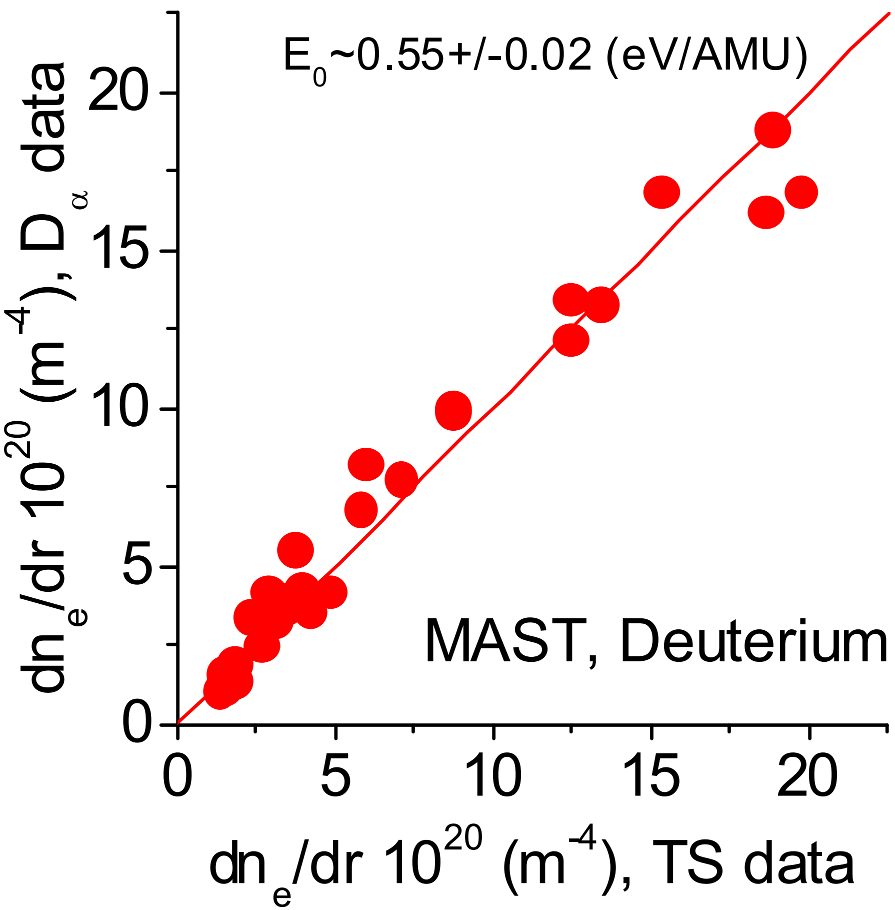


- Neutral transport code
- $<\sigma v>_{ex,ion}$ - from ADAS
- Various influx velocities
- Solid line - analytical model

n_e gradient almost proportional to $1/\Delta^2_{FWHM}$

$$\frac{dn_e}{dr} \propto \frac{V_0}{\Delta^2}$$

TS cross- correlation



- Taken at TS time
- Modified TANH fit
- dynamic range ~15
- 1.3 10^{20} m^{-4} < dn_e/dr < 2 10^{21} m^{-4}

- E_0~0.55±0.02 eV/AMU
- Initial error estimates

MAST data show almost linear dependence of n_e gradient on $1/\Delta^2_\alpha$

Source of Errors

Inversion makes accountability complicated

- inaccurate calibration
- other emission lines
- H impurity

10% H -> Δ_α (3%), dn_e/dr (5%)

"Monte Carlo" technique

- Noise errors

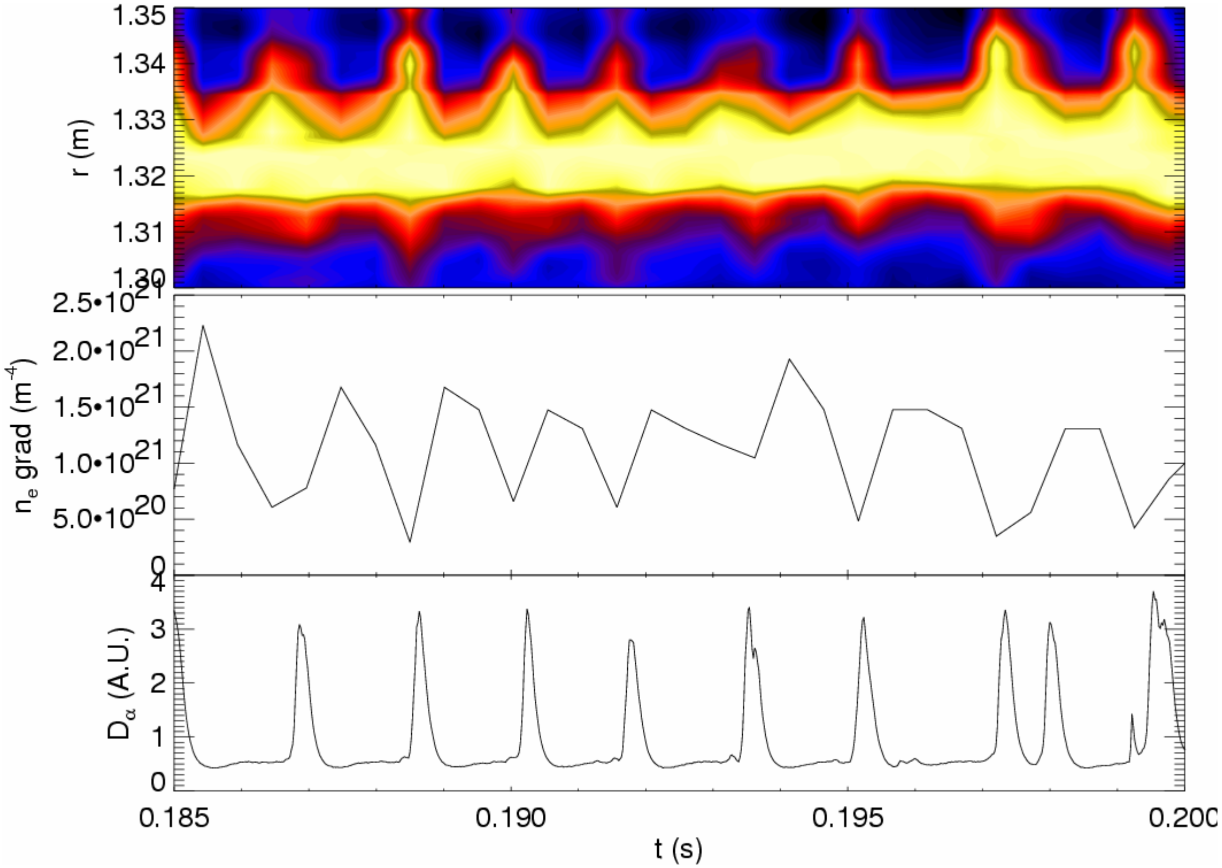
ideal spectra + Poisson (photon/statistical noise)
+ Normal (read-out noise)

Δ_α (5%) —> dn_e/dr (10%)

- Systematic errors (10%)

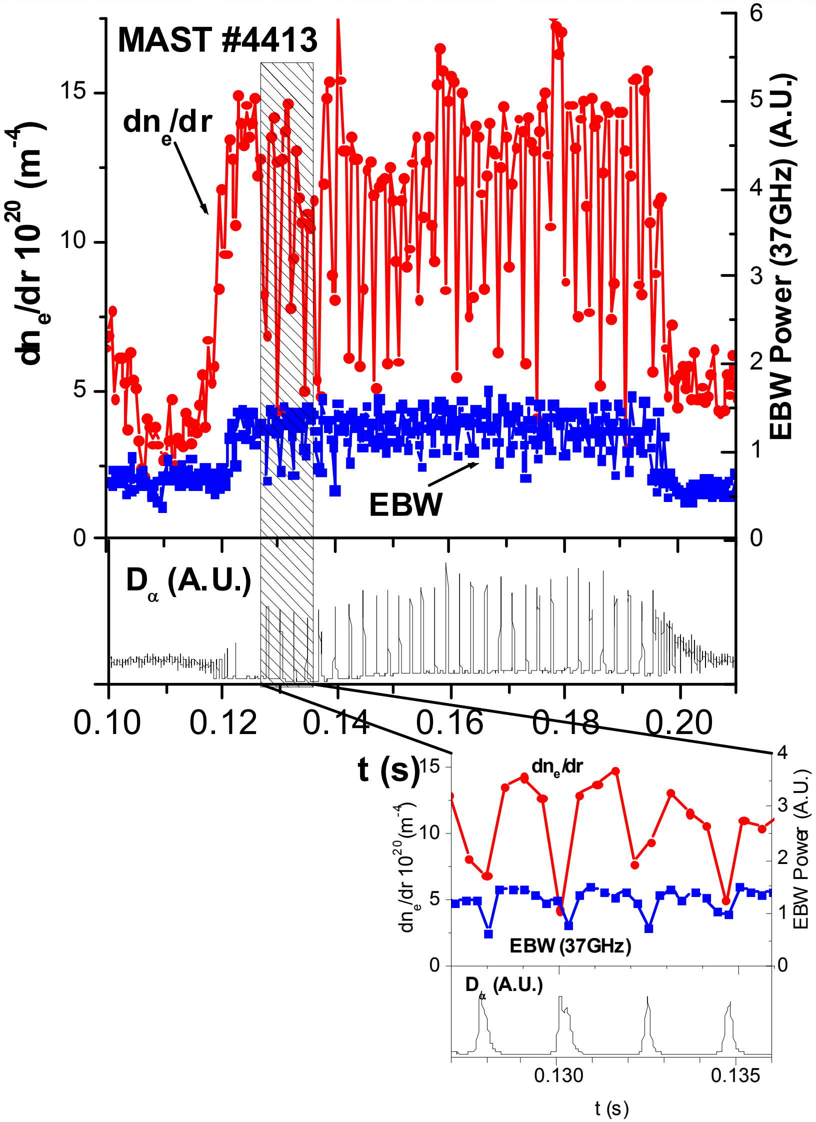
H-mode studies

MAST #4415



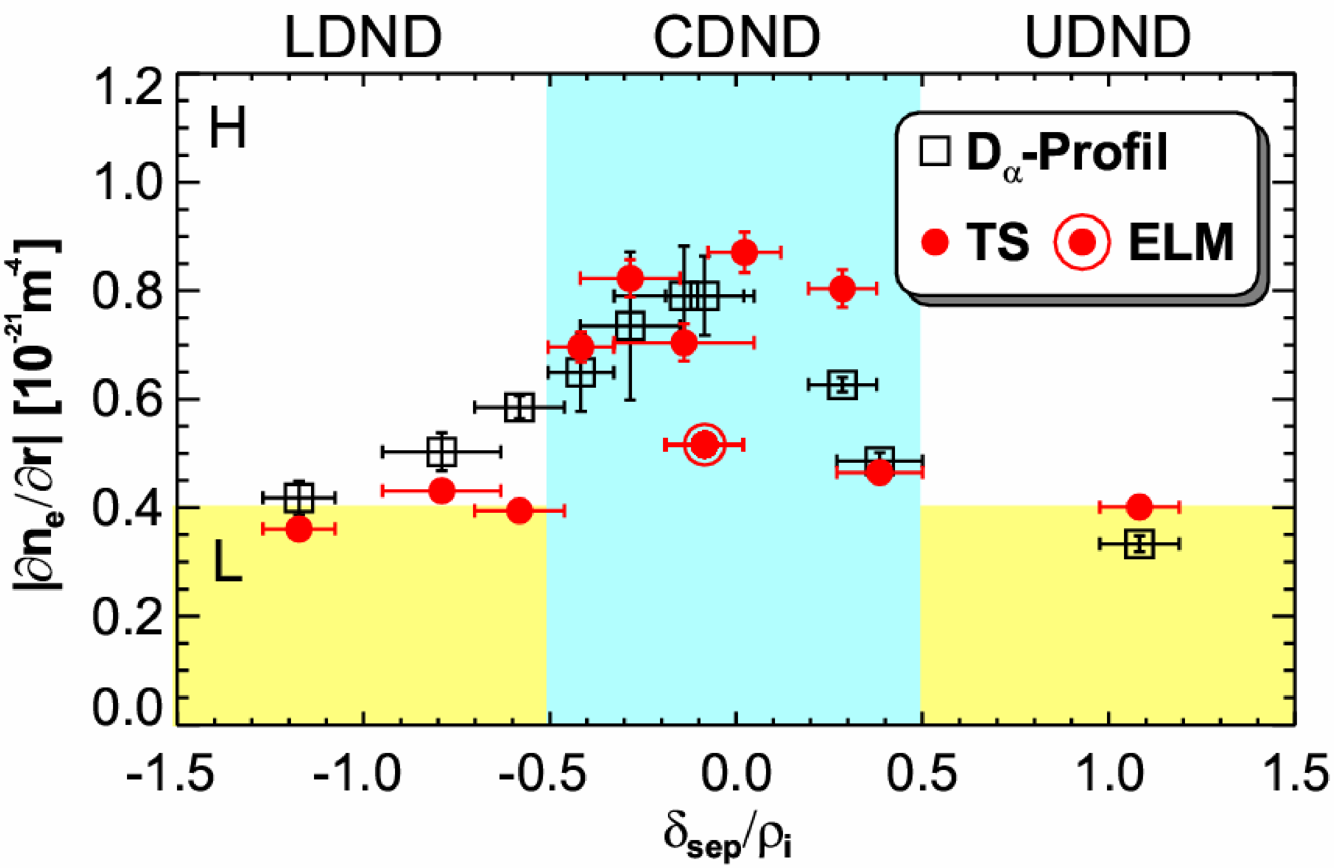
MAST data show rise n_e gradient during inter ELM period

EBW correlates well with n_e gradient



- n_e gradient increases during ELM-free period
- EBW emission correlates well with n_e gradient changes

H-mode study



Magnetic configuration study in MAST H-mode plasmas

Conclusions

Method

- simple, exploiting atomic physics, no extra cost
- higher repetition rate than TS
- n_e gradient is an importance for H-mode studies
- extracting neutral influx energy
- cross calibration of diagnostics

Anticipated development

- real time plasma control for plasma feedback
  - Pick-up coils remote from plasma
  - Quasi continuous (ITER)
- use fast camera, - x-point region,total particle influx
- monitoring D_α, D_β and D_γ emissions to yield edge n_e and T_e

Magnetic configuration study