Empirical model of fast-ion charge exchange emission in MAST

ADAS Workshop 2014
Warsaw

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Introduction

• Fast-Ion Deuterium Alpha (FIDA) spectroscopy provides a spatially, spectrally and temporally-resolved measurement of the energetic-ion population in fusion plasmas.

• Based on CX reaction between fast ions and injected beam neutrals:
  \[ \text{D}_f^+ + \text{D}_b^0 \rightarrow \text{D}_f^{0*} + \text{D}_f^+ \]

• System installed on the Mega-Amp Spherical Tokamak (MAST) has toroidal and vertical views, sensitive mostly to passing and trapped ions respectively.

• Useful for studies of energetic-particle transport by MHD instabilities (kink modes, Alfvén eigenmodes, magnetic reconnection).
Objective

- Map synthetic fast-ion distributions from the Monte Carlo NUBEAM module[1] of the TRANSP code[2] to synthetic FIDA spectra for comparison with measurements:


- The FIDAsim code[3], developed by Heidbrink et al. at UC Irvine/GA:
  - Takes plasma profiles, equilibrium, beam power and fast-ion distribution from TRANSP output.
  - Maps profiles, beam geometry and FIDA sightlines onto grid.
  - Solves collisional-radiative model internally to determine FIDA radiance per marker particle.
  - Sums radiance over marker particles to generate spectra for each viewing chord.

Motivation

- Using the Monte Carlo approach for \(\sim10^6\) fast ions + \(\sim10^5\) beam neutrals and solving the full collisional-radiative model for each marker is time consuming!
- ...although a recent re-write of FIDAsim from IDL to FORTRAN-90 by Benedikt Geiger at IPP Garching has delivered an order of magnitude speed-up\cite{B. Geiger, Ph.D. Thesis, Ludwig-Maximilians-Universitaet, Munich (2012)}.

- ADAS should provide the required *derived* rate coefficients in a usable format, obviating the need for an internal solver.
- Inspired by development of the NEBULA code for modelling of beam emission in MAST (S.H.).
Weight functions

- Sensitivity of FIDA measurements has a complicated dependence on velocity space coordinates of fast ions.
- In each view, the sensitivity is parametrised by LOS-beam angle, LOS-field angle and beam-field angle.
- Described most naturally in terms of weight functions in velocity space:

\[
I_\lambda = \int \int w_\lambda(v_\parallel, v_\perp; \bar{\theta}) f(v_\parallel, v_\perp) dv_\parallel dv_\perp
\]
Atomic physics

- Neutral density along beam path obtained after mapping plasma profiles \((n_e, T_e)\) onto path:
  - ADF21 files in /adas home directory interrogated directly by subroutine read_adf21.
  - Pure deuterium plasma (although inclusion of impurities should be straightforward, cf. NEBULA).

- Distribution of excited states (bundle-\(n\)) in beam determined from local plasma conditions:
  - ADF22 files, generated using ADAS312 and bundled with source code, interrogated directly by subroutine read_adf22.
  - Pure deuterium plasma (although inclusion of impurities should be straightforward).

- CX effective emission coefficient for Balmer alpha (656.1 nm) line:
  - ADF12 file interrogated using ADAS303 to provide look-up table.
  - \(n=2\) donor coefficient approximated as \(0.25*2s + 0.75*2p\) donor coefficients.
  - \(n=4\) donor coefficient approximated as \((0.25 * n=3\) donor coefficient).
  - Truncated at \(n=4\) due to negligible donor density above this level.

- Beam neutral – fast ion relative velocities averaged over narrow range of gyro-angles contributing to signal at each point in velocity space, at each radius.
FIDA emission

Typical injection energy

Possible missing ‘halo neutral’ contribution?
Ongoing work

• Including halo neutral contribution to FIDA CX emission:
  – beam stopping $\times$ (CX rate/ionization rate) gives birth rate of halo neutrals at each point along beam.
  – Diffusion of halo neutrals from source taken to reach steady state with ionization.
  – Solution given by sum of Bessel functions convolved with Gaussian beam profile.
  – Easier calculation for CX, since relative velocity = fast-ion velocity.

• Investigating discrepancy of radial profile with respect to data:
  – Modelled profiles shifted inward by approximately 7 cm compared to measurements.
  – Suspect faulty correction for FLR effects (in TRANSP output?).
  – Need to triple-check spatial calibration via beam emission redshift (in situ alignment data to be analysed).

Thank you for your attention!