Fluid Codes and Heavy Impurities

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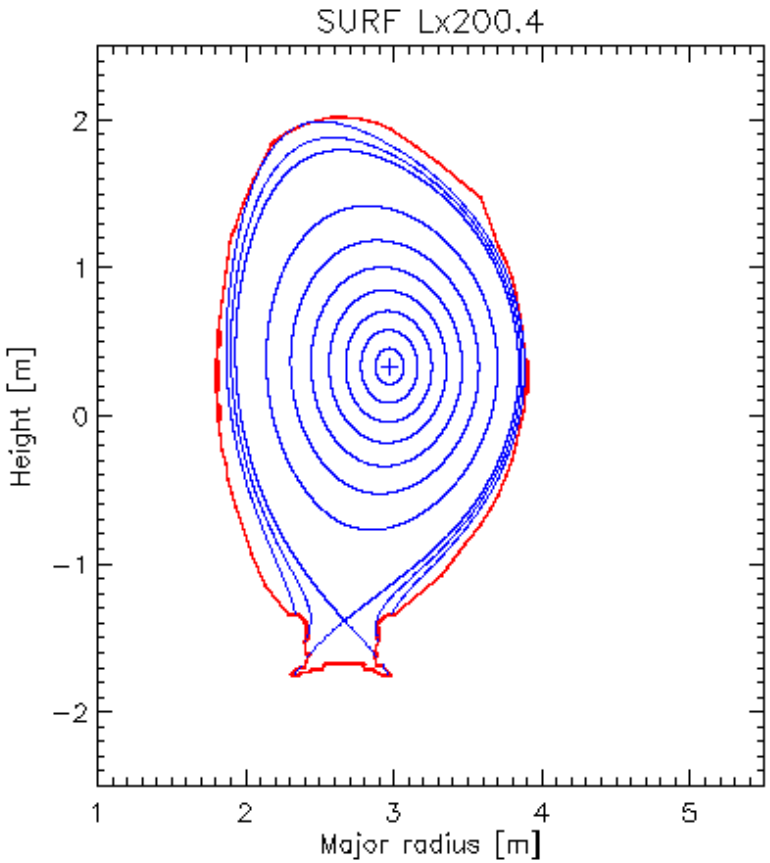
- Present status of impurity fluid codes available at JET
- Issues for inclusions of heavy species

1½-D Fluid Transport Codes

Assumptions:

- Axisymmetry
- The magnetic flux surfaces define the geometry
- Transport is analysed in the radial coordinate ρ, perpendicular to the FS
- The non-circularity is taken into account through “geometry factors” (V’, $\left\langle |\nabla\rho|^2 \right\rangle$)



1½-D Fluid Transport Codes

$$\frac{1}{V'}\frac{\partial}{\partial t}\left(n_{i,z}V'\right)+\frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\left\langle \Gamma_{i,z}^{\rho}\right\rangle\right)=Q_{i,z}-S_{i,z}$$

z=1,…,Z

Z coupled eq.ns

$\langle \ldots \rangle$ **represents the FS average of the flux**: $\Gamma_{i,z}=-D_{i,z}\nabla n_{i,z}+\mathrm{v}_{i,z}n_{i,z}$

$$\left\langle \Gamma_{i,z}^{\rho}\right\rangle=\left\langle \Gamma_{i,z}\cdot\nabla\rho\right\rangle=-D_{i,z}\left\langle \left|\nabla\rho\right|^{2}\right\rangle\frac{\partial n_{i,z}}{\partial\rho}+\mathrm{v}_{i,z}\left\langle \left|\nabla\rho\right|\right\rangle n_{i,z}$$

$Q_{i,z}$ **is the source term for each charge *z* of the impurity i due to ionisation from *z-1* and recombination from *z+1***

$S_{i,z}$ **is the sink term due to ionisation to *z+1* and recombination to *z-1***

The atomic physics in source and sink terms is from ADAS .

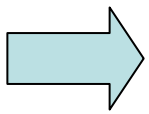
Impurity Experimental Data Available

- Spectroscopic lines : time evolution
- CX: fully stripped ion-profiles $n(\rho,t)$
  for low-Z impurities: (He), C, Ne, Ar
- Total Power (bolometry) and Filtered Power (SXR):
  multiple-lines-of-sight --> tomography

Impurity Transport Analysis

- Inputting $D_{i,z}(\rho)$ and $\mathrm{v}_{i,z}(\rho)$,

the coupled equations are advanced in time



$n_{i,z}(\rho,t)$ for each *z=1,…,Z*

All relevant quantities can be derived: l-o-s of spectroscopic lines, SXR, …, making use of ADAS data

Experimental and simulated data are compared

Impurity Analysis at JET (core)

- Fully Interpretive analysis: for low-Z impurities

Source-free : $0.1\text{–}0.2 \le \rho \le 0.6\text{–}0.8$

CX profiles of fully stripped He, C, Ne

Transients

At each ρ : $\Gamma_i / n_i = -D^* \nabla n_i / n_i + v^*$

Linear regression of Γ_i / n_i against $\nabla n_i / n_i$

get D*(ρ) & v*(ρ)

Impurity Analysis at JET (core)

- For heavier impurities and T:

  experimental $n_{i,z}(\rho,t)$ are **not** measured directly

BUT

- Multi-channel SXR (high-Z) or Neutron Yield (T) can be used

Injected trace impurity *i* produces an increase in SXR emissivity, simulated as:

$$\Delta\varepsilon_i(\rho,t) = n_e(\rho,t)\cdot\sum_z n_{i,z}\left((\rho,t),D,\mathrm{v}\right)\cdot P_{i,z}\left(T_e,n_e,\,filter\right)$$

D & v are optimised until best match between simulated and experimental data

Impurity Analysis at JET (core)

- Predictive-Interpretive analysis:
  - UTC

    version of SANCO stand-alone

    simulated data optimised against experimental data

    → optimization technique to get D & v

    mainly transient phenomena of traces (T, Ne, Ar, Ni)

  - STRAHL (Garching)
  - Mattioli (Cadarache & Padova)

    (atomic data collected by M. Mattioli)

Impurity Analysis at JET

- Fully Predictive analysis (modelling): JAMS

version of SANCO integrated in the code chain JAMS

D & v : from theoretical models

- neoclassical package NCLASS;
- Weiland model, with diagonal and off-diagonal elements of transport matrix;
- … (other models) …
- + combination of models

or

- predictive-interpretive mode (transport given from file)

Beyond the core into SOL

JAMS:

SANCO is integrated in the modular code **COCONUT**,

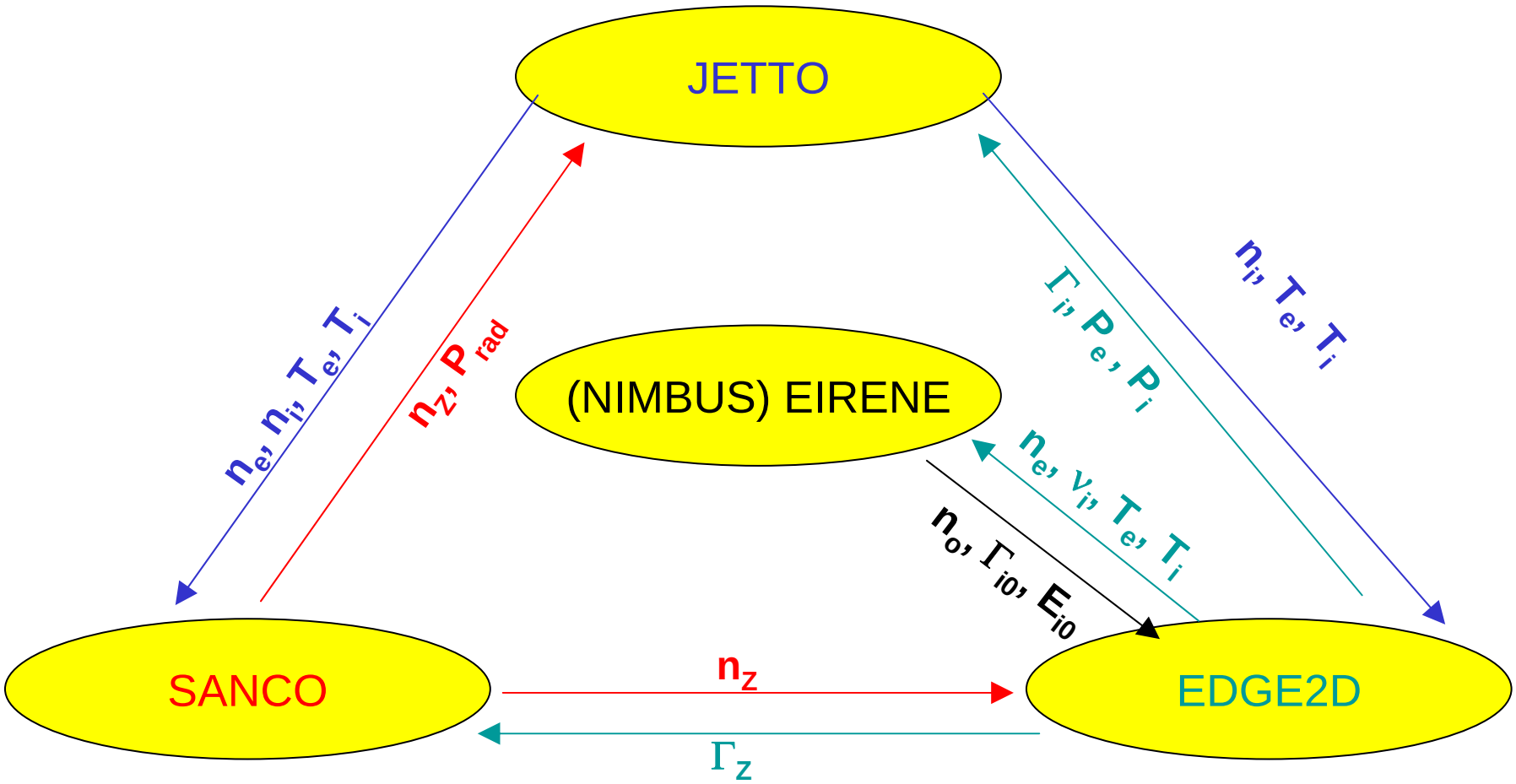
combining

- a Monte-Carlo code (NIMBUS -> EIRENE) for the neutral sources,
- the 2-D scrape-off layer code EDGE2D
- the core energy and particle transport code JETTO,

using SANCO for the impurities

The edge and the core are joined at the separatrix (or just inside)

JAMS: Integrated approach - COCONUT



In a COCONUT run, EDGE2D provides self-consistent b.c. for the core

JETTO-SANCO can be run without EDGE2D/NIMBUS

EDGE2D-(NIMBUS)EIRENE

- The conservation equations are written in the poloidal plane, with ρ labelling the FS and θ the poloidal coordinate (fully 2D)
- The MonteCarlo module (NIMBUS being replaced with EIRENE) is used to evaluate the density, temperature and velocity profiles of the neutral species
- Parallel transport (along θ) is classical (Braginskii/21-moment approx)
- 2 D → much longer CPU time

Heavy Impurities and Bundles

•Tungsten wall in ITER: simulations of W ingress from the wall into the SOL and then to the core

• CPU time needed increases with Z -> EDGE2D simulations with W are far too heavy in CPU and there are numerical stability issues (too many species with negligible density).

• BUNDLED STATES: from the numerical point of view the number of equations is greatly reduced and makes EDGE2D runs possible.

BUNDLED STATES: issues

- **Neutrals** are of different nature than ions: need to be kept separate → can**not** be bundled with low charged ion states

- 'Optimum' bundling scheme?
  - Likely to depend on: T_e, ne, ∇T_e , D, v,..
    region of the plasma (core, edge)

BUNDLED STATES: issues (cont'd)

- How to 'optimise' bundling scheme:
- SANCO: high-Z impurities (Ni, Mo, W)
  - full set of ionised states and compare with various numbers of bundles, various bundling schemes,

    Perform scans in Te, D and v

- Core-Edge: different bundling schemes?
- Figure of merit?