Boundary Physics Activities at W7-X

D. P. Stotler
NCSX Physics Meeting
June 22, 2000

Outline

1. PSI Highlights
2. BoRiS: 3-D SOL Fluid Code
   - Magnetic coordinates algorithm,
   - Prospects for coupling to DEGAS 2.
3. W7-X Divertor Engineering

PSI Highlights

Masuzaki "First Experimental Results of PSI Studies in the Large Helical Device"

- Bakeout limited to 95°C,
  $\Rightarrow$ doing wall conditioning without high temperatures.
- Still have $n_{\mathrm{div}} \propto \bar{n}_e$
  $\Rightarrow$ not reaching high recycling regime.
- Discharges up to 1 hr.
  - Temperatures stay low,
  - Walls not saturated.

Ghendrih "Control of Divertor Geometry and Performance with the Ergodic Divertor of Tore Supra"

- Nothing noteworthy from talk,
- Abstract notes:
  1. Maintain high I_p operation with ED,
  2. High cross-field transport in ED,
  3. Able to pump with vented target plates.

Eich "Transport Modelling of TEXTOR-DED Laminar Zone"

- Did not see the poster,
- Abstract talks about a 2-D finite element code to model $\perp$ transport on grid generated by field line tracing.

Stellaratortheory: Edge Physics Group

M. Borchardt, A. Mutzke, J. Riemann,
R. Schneider, (X. Bonnin)

IPP-Teilinstitut Greifswald, EURATOM Association, D-17489 Greifswald, Germany

(S. Weber)

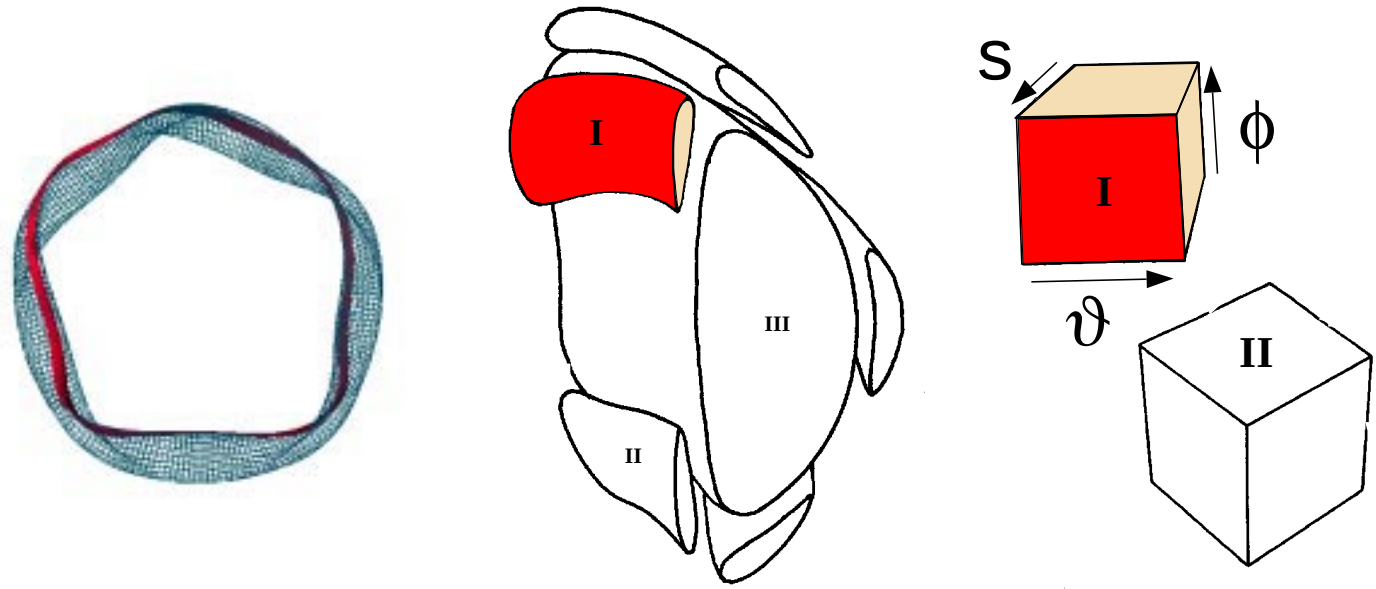
LULI, Ecole Polytechnique, F-91128 Palaiseau Cedex, France

Aspects of a new 3-D SOL code

- **applicability (2-D $\subset$ 3-D)**
  - $\Rightarrow$ benchmarking with 2-D situations
  - $\Rightarrow$ 3-D effects in tokamaks
  - $\Rightarrow$ stellarator SOL physics (non-ergodic)
- **modularity & compatibility**
- **flexibility**
  - $\Rightarrow$ local grid refinement
  - $\Rightarrow$ shape of computational cells
- **post-processing**
  - $\Rightarrow$ diagnostics and visualization

Magnetic coordinates

- **magnetic coordinates**
- **1 island flux tube**(x, y, z) $\longleftrightarrow$ **1 island flux cube** (s, θ, ϕ)
- **connection of flux tubes via boundary conditions**
- **use periodicity and symmetry**



Single island flux tube of W7-X

- **SOL** $= \cup$ **flux tubes** $+$ **contact with wall and core**

Magnetic Coordinates Algorithm

- Work being done by X. Bonnin,
- Have initial results, but need more testing.
- Spatial variables described in cylindrical coordinates (R, ϕ, z),
- BoRiS coordinates $\leftrightarrow$ Boozer coordinates (ψ, θ, ζ)
- Start with $\vec{B}$ in a box $\mathcal{B}$: $[R_{\min} \to R_{\max}, 0 \to 2\pi, z_{\min} \to z_{\max}]$,
- Map $\mathcal{B}$ to $m+1$ boxes in Boozer space,
  - m islands,
  - core & SOL regions.
- Compute:
  1. By field-line following, toroidal flux F_T & $\partial F_T / \partial R$,
  2. Ampere's law gives toroidal current J and poloidal current I,
  3. Clebsch vectors $\nabla\psi$ and $(\nabla\theta - \iota\nabla\zeta)$ obtained from "Nemov algorithm",
  4. $\iota(\psi)$ from ratio of poloidal to toroidal angles arising out of initial field line following,
  5. Boozer and BoRiS Jacobians computed from above quantities,
  6. Similarly, calculate other metric coefficients needed for BoRiS.

Anisotropic Laplace equation

$$\nabla \cdot \vec{q}_e = -\nabla \cdot \left(\kappa_\parallel \nabla_\parallel T_e + \kappa_\perp \nabla_\perp T_e\right) = 0$$

Heat flux in magnetic coordinates s, θ, ϕ:

$$\begin{aligned}
\vec{q}_e &= \vec{q}_{e,\parallel} + \vec{q}_{e,\perp_1} + \vec{q}_{e,\perp_2} \\
&= -\kappa_\parallel \frac{F_T'}{F_T' I + F_P' J} \vec{B} \left(\iota \partial_\vartheta + \partial_\phi\right) T_e \\
&\quad -\kappa_{\perp_1} \nabla s \left(\partial_s + \frac{g^{\vartheta s}}{g^{ss}} \partial_\vartheta + \frac{g^{\phi s}}{g^{ss}} \partial_\phi\right) T_e \\
&\quad +\kappa_{\perp_2} \frac{\nabla s \times \vec{B}}{(F_T' I + F_P' J) g^{ss}} \left(I \partial_\vartheta - J \partial_\phi\right) T_e
\end{aligned}$$

Anisotropy: $\frac{\kappa_\parallel}{\kappa_\perp} \approx 10^6$

$$\kappa_\parallel = \chi_\parallel^{class.} T_e^{5/2}, \qquad \kappa_\perp = \left(\chi_\perp^{anom.} + \chi_\perp^{class.}\right) n$$

Numerical aspects:

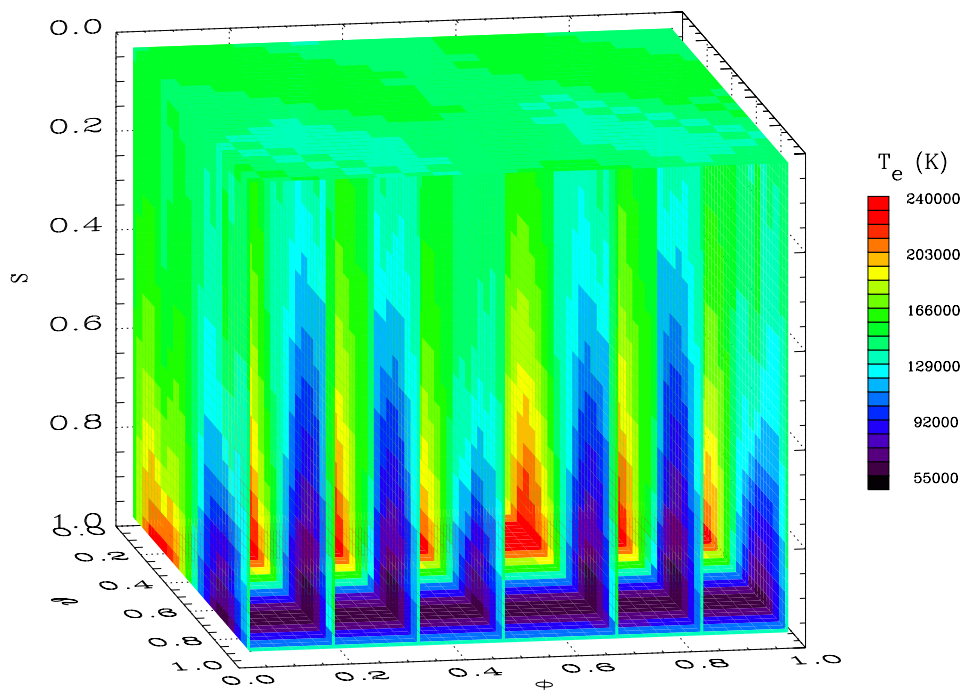
- **finite volume method**

$$\int_V \nabla \cdot \vec{q}_e \, \mathrm{dV} = \int_{\partial \mathrm{V}} \vec{\mathrm{q}}_\mathrm{e} \cdot \mathrm{d}\vec{\sigma} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \int_{\partial \mathrm{V}_\mathrm{i}} \vec{\mathrm{q}}_\mathrm{e} \cdot \mathrm{d}\vec{\sigma}_\mathrm{i} = 0$$

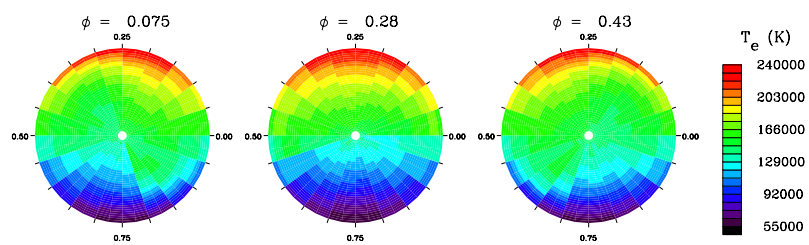
- **numerical solution via Newton method**
- **interpolation scheme enabling use of different computational molecules**

Result for a $20 \times 20 \times 20$ grid

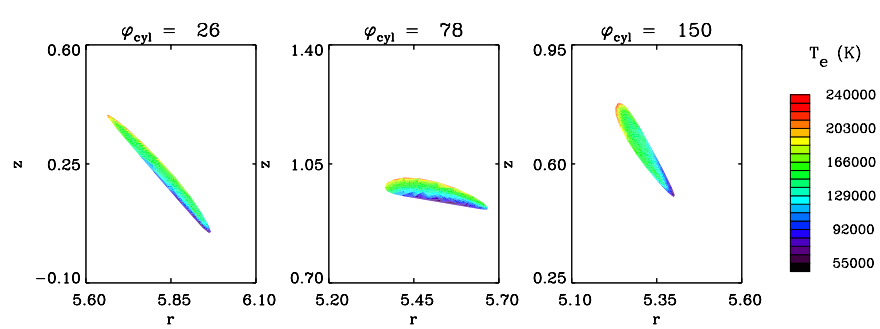
boundary conditions: $s = 0$**: no flux;** $s = 1$**:** $T \propto \sin[2\pi\theta]$**;** θ**,** ϕ **periodic**



3-D temperature profile



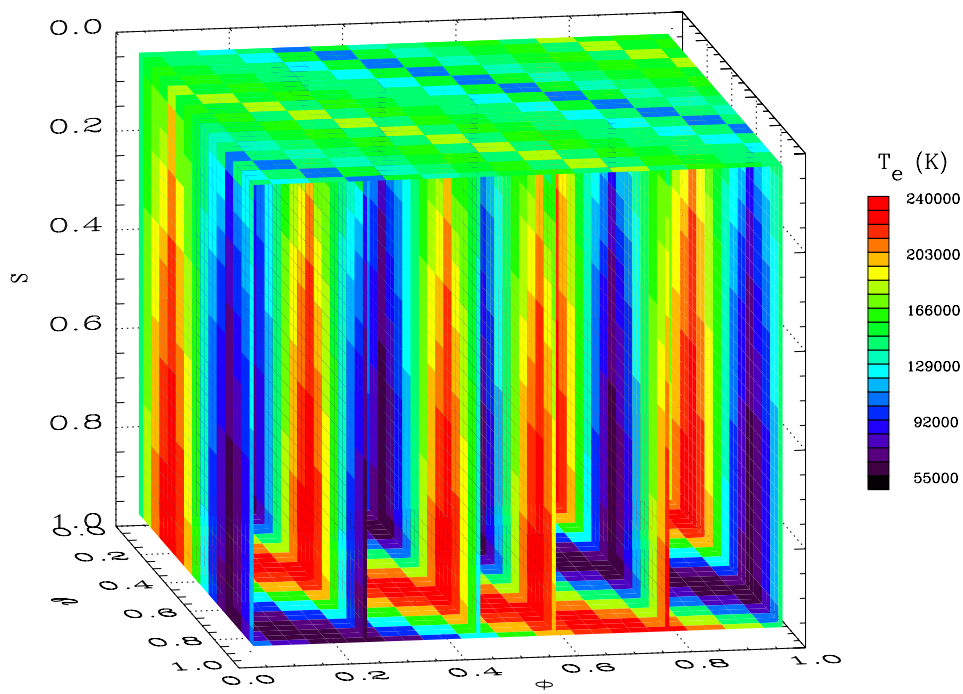
temperature (polar) profile for $\phi = const.$



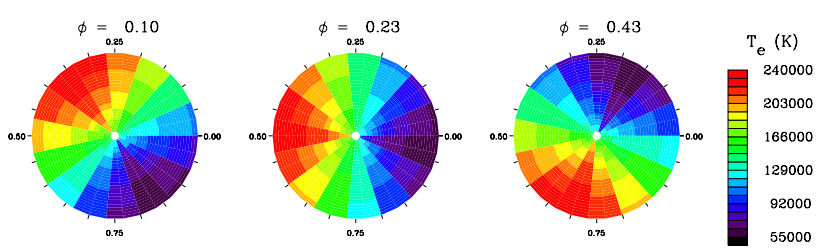
temperature profile (real) for $\varphi = const.$

Result for a $15 \times 15 \times 15$ grid

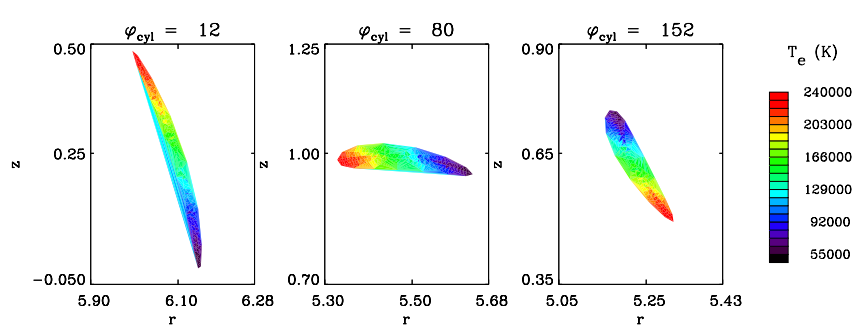
boundary conditions: $s = 0$**: no flux;** $s = 1$**:** $T \propto \sin[2\pi(\theta - \phi)]$**;** θ**,** ϕ **periodic**



3-D temperature profile



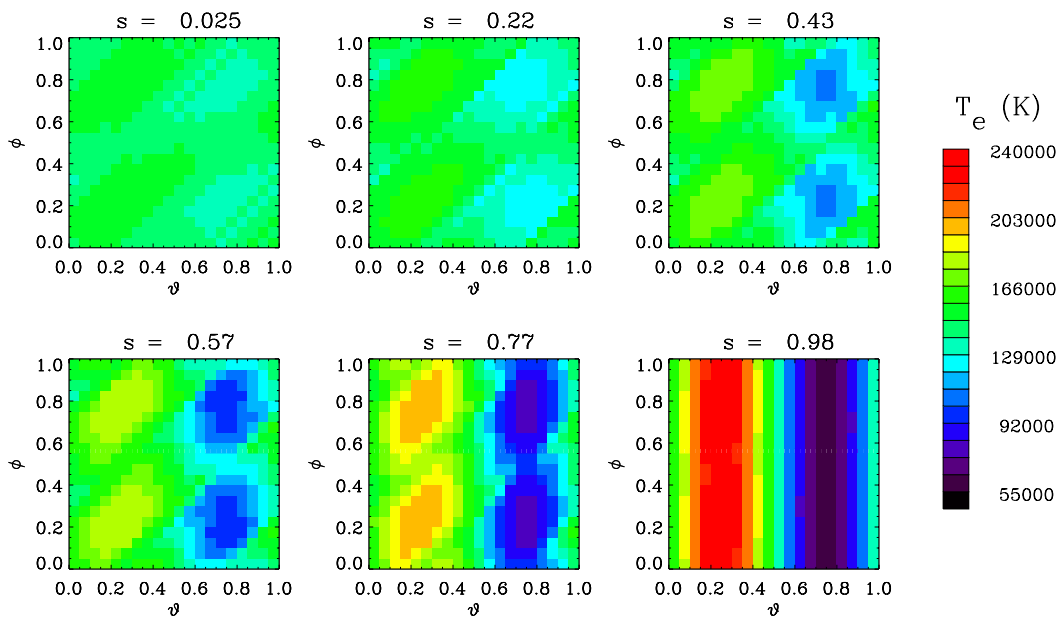
temperature (polar) profile for $\phi = const.$



temperature profile (real) for $\varphi = const.$

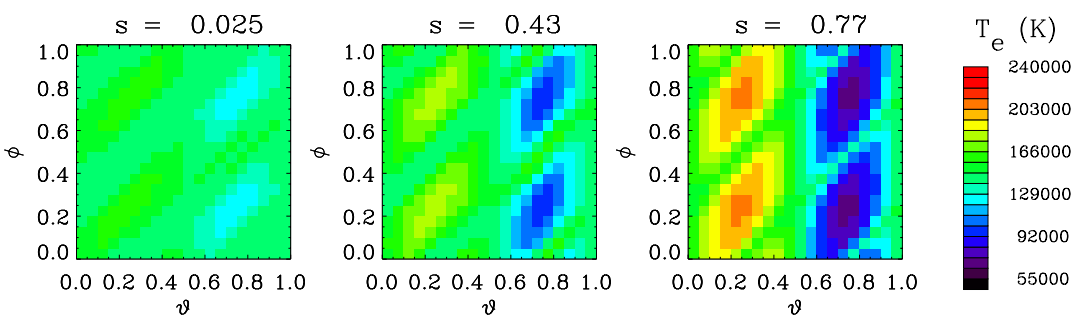
Effect of 3-D metrics

boundary conditions: $s = 0$**: no flux;** $s = 1$**:** $T \propto \sin[2\pi\theta]$**;** θ**,** ϕ **periodic**

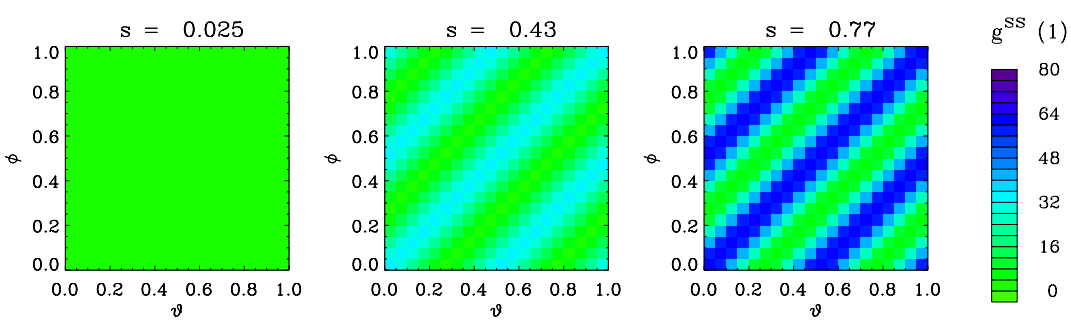


3-D temperature profile for $s = const.$

- $g_{\theta s} \to 0$ **: radial heat flow pattern governed by** g^{ss}



3-D temperature profile for $s = const.$



Metric coefficient g^{ss} **for** $s = const.$

Collaborations

- B. Braams (Courant Institute, USA),
  H. Bürbaumer (TU Wien), D. Coster:
  non-staggered parallel momentum equation
- V. Rozhansky, S. Voskoboynikov
  (TU St. Petersburg):
  SOL equations
- P. Lalousis (IESL Forth, Crete),
  A. Ushakov, I. Veselova (TU St. Petersburg):
  pellet modelling
- D. Reiter, A. Runov (U Düsseldorf):
  ergodic configurations

Outlook

- **link to experiment:**
  design W7-X, ASDEX Upgrade, JET, LHD
- **complete set of equations (Physics)**
- **generalized grid generation (Physics/Numerics)**
- **matrix free solvers, parallelization (Numerics)**

Prospects for Coupling to DEGAS 2

- W7-X engineers need neutrals code within 1 year:
  - EIRENE,
    - Need Monte Carlo for physics & geometry details.
    - Being used for W7-AS,
    - Geometry setup procedure may be too inflexible,
    - May lead to too large meshes.
  - Fluid neutral model,
    - Primarily for code development and testing,
    - Expect neutrals in W7-X to be kinetic.
  - Stacey's GTNEUT code?
    - Keeping track of all possibilities.
- *Or, could use DEGAS 2:*
  - Geometry approach flexible
    $\Rightarrow$ can be made compatible with BoRiS.
  - Modern code design features are attractive:
    1. Designed to be run on parallel machines,
    2. Cross platform compatibility,
    3. Modular interfaces.

- A significant opportunity to expand usage of DEGAS 2:
  - Envision a nearly full time person at PPPL,
    - First learning DEGAS 2 thoroughly,
    - Then, work with W7-X group on specifying geometry for DEGAS 2.
  - IPP would fully support extended trips to Greifswald,
    - Learning about BoRiS during these visits.
  - $\Rightarrow$ collaborative design of BoRiS-DEGAS 2 code,
    - With a PPPL employee able to run it for NCSX.

W7-X Divertor - Discussion with H. Renner

- Target shape optimized according to:
  - Field-line following calculations (Strumberger),
  - & Orbit losses.
  - Took into account β values up to 4%,
  - Deposition pattern doesn't change much.
- Plasma facing components divided into 3 groups:
  1. **Target** (10 MW/m^2)
     - CFC brazed onto "TZM" (Mo/Zr/Ti),
     - Actively cooled,
     - Planar elements oriented & shaped to match plasma, remove leading edges.
     - Tradeoff between thinner CFC for lower CFC temps & future flexibility for thicker CFC,
     - Currently at 6 mm.
  2. **Baffle** (0.5 MW/m^2)
     - CFC bolted onto Cu,
     - Water cooled.
  3. **1st wall** (0.2 MW/m^2)
     - SS panels sprayed with B_4C or Li,
     - Two layers; outer is inner cryostat,
     - Water cooled to exhaust up to 10 MW (e.g., 100% radiation).
     - Bakeout only up to 150°C.