BOUT++ workshop 2015

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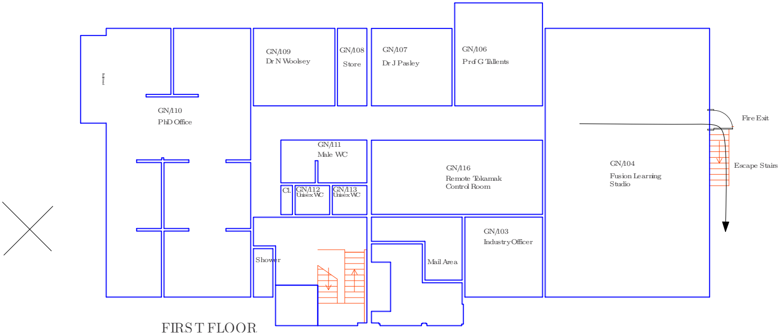
BOUT++ Workshop

14^{th} September 2015

Fire exits: first floor

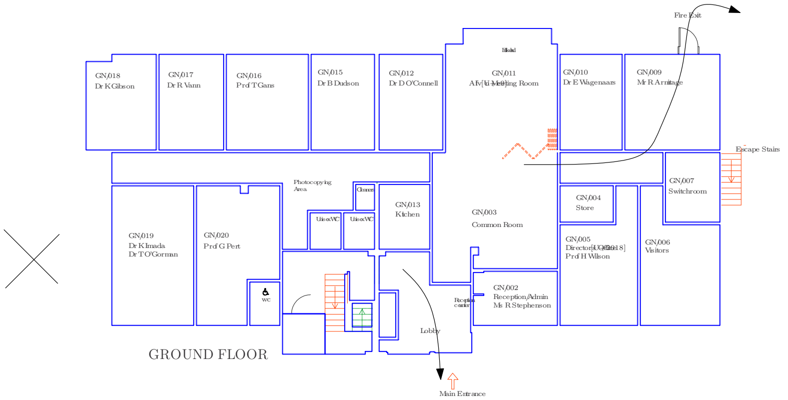
Fire exit from side of meeting room



Meet outside at the front of the building

Fire exits: ground floor

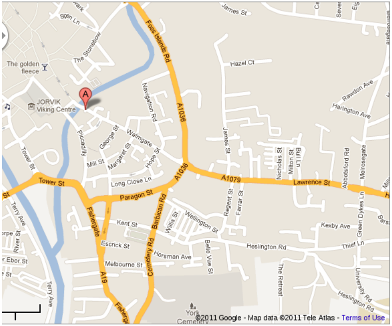
Two exits: the front, and the back right corner



Meet outside at the front of the building

Workshop events

- **Coffee**: Morning and afternoon coffee breaks
- **Lunches**: Buffet lunches with sandwiches, hot and cold drinks
- **Dinner**: The workshop dinner will be tonight in the Ale House on Walmgate, starting at 7:00pm. Please bring cash (around £20).



Miscellaneous

- **Taxis** The phone downstairs in the common area can call local numbers. Some taxi companies are
  - Ebor taxis: 641 441
  - Station taxis: 623 332
- **WiFi** internet access. If you need a guest account please see me. Connect to `eduroam` or `UoY Setup`.
- **Printing and Fax**. If you need anything printed, or faxed, please see Ben or Sharon
- Lecture room **not locked**. Please see Ben about storing valuables.

Welcome to York, and have a good meeting

Introduction to BOUT++

Background: Transport in the tokamak edge

- Plasma edge region critical to reactor design
  - Core performance
  - Heat fluxes to divertor
  - Particle fluxes to first wall
- Understanding of transport processes incomplete
- Leads to uncertainty in predictions for future devices

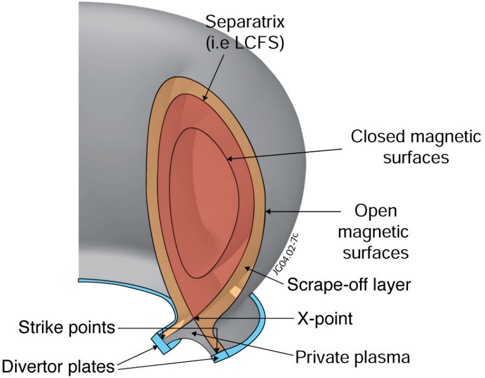


*Figure: www.euro-fusion.org/glossary/divertor/

Background: Tokamak divertor exhaust problem

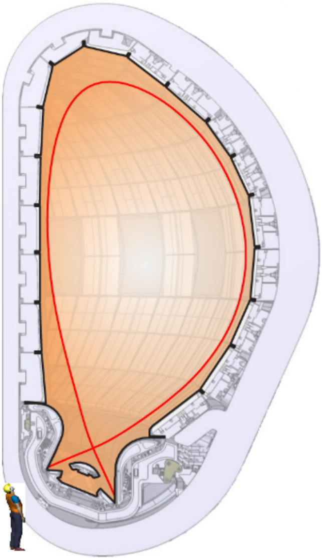
- ITER designed for 500MW fusion power for 50MW input
- Of this 500MW, 100MW goes into the plasma → 150MW must be exhausted from the plasma
- Area available to handle power

$$A \simeq 2\pi R\lambda_q / \sin\alpha$$

$$R \simeq 6\mathrm{m} \quad \alpha \simeq 2.5^o \quad \lambda \sim 2 - 20\mathrm{mm}$$

$$\rightarrow A \simeq 1.7\mathrm{m}^2$$

- Power fluxes could be
  $\sim 100\mathrm{MW/m}^2$
  $\sim 10\times$ technological limits!



Background: Tokamak divertor exhaust problem

IOP Publishing and International Atomic Energy Agency — Nuclear Fusion

Nucl. Fusion **53** (2013) 093031 (7pp) — doi:10.1088/0029-5515/53/9/093031

Scaling of the tokamak near the scrape-off layer H-mode power width and implications for ITER

T. Eich[1], A.W. Leonard[2], R.A. Pitts[3], W. Fundamenski[4], R.J. Goldston[5], T.K. Gray[6], A. Herrmann[1], A. Kirk[4], A. Kallenbach[1], O. Kardaun[1], A.S. Kukushkin[3], B. LaBombard[7], R. Maingi[5,6], M.A. Makowski[8], A. Scarabosio[1], B. Sieglin[1], J. Terry[7], A. Thornton[4] and ASDEX Upgrade Team and JET EFDA Contributors[a]

Background: Tokamak divertor exhaust problem

Abstract

A multi-machine database for the H-mode scrape-off layer power fall-off length, λ_q in JET, DIII-D, ASDEX Upgrade, C-Mod, NSTX and MAST has been assembled under the auspices of the International Tokamak Physics Activity. Regression inside the database finds that the most important scaling parameter is the poloidal magnetic field (or equivalently the plasma current), with λ_q decreasing linearly with increasing B_{pol}. For the conventional aspect ratio tokamaks, the regression finds $\lambda_q \propto B_{\mathrm{tor}}^{-0.8} \cdot q_{95}^{1.1} \cdot P_{\mathrm{SOL}}^{0.1} \cdot R_{\mathrm{geo}}^{0}$, yielding $\lambda_{q,\mathrm{ITER}} \cong 1$ mm for the baseline inductive H-mode burning plasma scenario at $I_{\mathrm{p}} = 15$ MA. The experimental divertor target heat flux profile data, from which λ_q is derived, also yield a divertor power spreading factor (S) which, together with λ_q, allows an integral power decay length on the target to be estimated. There are no differences in the λ_q scaling obtained from all-metal or carbon dominated machines and the inclusion of spherical tokamaks has no significant influence on the regression parameters. Comparison of the measured λ_q with the values expected from a recently published heuristic drift based model shows satisfactory agreement for all tokamaks.

[1] T.Eich *et.al*Nucl. Fusion 53 (2013) 093031

Background: Tokamak divertor exhaust problem

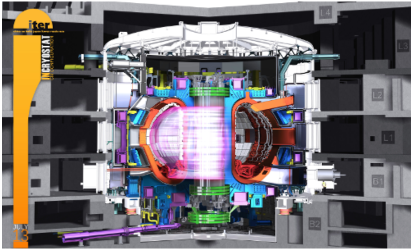
- A solution is thought to exist for ITER, even with $\lambda_q \sim 1$mm
- Beyond ITER, a demonstration power plant (DEMO) will need to handle even higher powers in order to be economical (Power increased $\times 5$)
- Machine cannot be much larger than ITER
- Heat flux becomes 500MW/m^2 rather than 100MW/m^2

"A reliable solution to the problem of heat exhaust is probably the main challenge towards the realisation of magnetic confinement fusion"

– EU-EFDA Report: Fusion Electricity A Roadmap to the realisation of fusion energy (2012)

Tokamak edge simulations

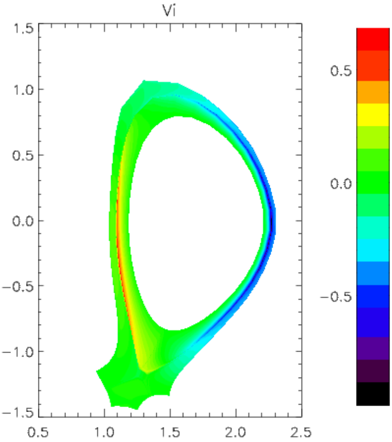
- Transition region between hot core and material surfaces
- Complex nonlinear physics: plasma turbulence, neutrals, impurities, material surfaces
- Complex geometry: X-points, shaped divertor surfaces, snowflake configurations,...



BOUT++ development aims to tackle these problems

BOUT++ has been designed (and re-designed) to handle this complicated physics

- Curvilinear coordinates and branch-cuts allow quite general geometries (*)
- Extendable code allows experimentation with numerical methods and physics models



BOUT++ overview

What BOUT++ is:

- A toolbox for solving PDEs on parallel computers. Aims to reduce duplication of effort, and allow quick development and testing of new models
- A collection of examples and test cases
- Focussed on flute-reduced plasma models in field-aligned coordinate systems, though has more general capabilities

And is not:

- A single plasma model or simulation
- A general library of numerical methods. Other libraries like PETSc are available for that
- Magic. Appropriate numerical methods depend on the problem, and must be chosen intelligently by the user

BOUT++: A toolbox for plasma simulations

- Collection of useful data types and associated routines. Occupies a middle ground between problem-specific codes and general libraries (e.g. PETSc, Trilinos, Overture, Chombo,...)
- Has its origins in the BOUT code[1][2][3]. Re-written and re-designed (at least once) in C++[4][5]
- Researchers can make use of a (mostly) well tested library of simulation code and input / output tools
- Greatly reduces the time needed to develop a new simulation

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[1] X.Q. Xu and R.H. Cohen, Contrib. Plasma Phys. 38, 158 (1998)
[2] Xu, Umansky, Dudson, Snyder, CiCP 4, 949-979 (2008)
[3] Umansky, Xu, Dudson et al. Comp. Phys. Comm. 180, 887-903 (2008)
[4] Dudson, Umansky, Xu et al. Comp. Phys. Comm 180, 1467 (2009)
[5] Dudson et al. J. Plasma Phys. (2014).
Preprint: `http://arxiv.org/abs/1405.7905`

Growing BOUT++ community

- Open source project, available on github

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http://boutproject.github.io
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- Users in labs and universities in UK, US, China, India, Japan, S.Korea, Denmark,...

BOUT++ workshop

Aims of this workshop are to:

- Get new users started with using BOUT++
- Share experience and expertise in plasma edge modelling and tools
- Discuss problems and future work

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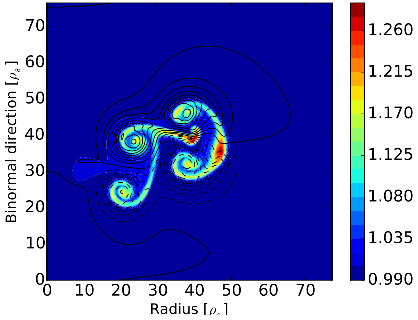
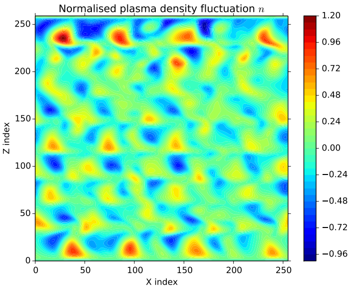
Outline

- Getting started (This afternoon, Tuesday afternoon)
- Recent work and developments (This morning, uesday morning)
- More advanced uses (Tuesday afternoon)
- Divertor modelling activities (Wednesday morning)

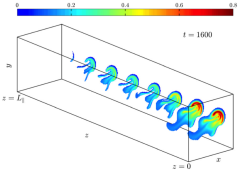
- Getting started, running some “simple” test cases
  - Heat conduction, turbulence, plasma blobs
  - Reading data into Python. Also possible in IDL, Mathematica, Matlab, Octave,...
  - Some new tools for running simulations and visualising outputs
- Introduction to where the important bits of the code are
  - Data handling, PDE solvers, integration
  - Anatomy of a physics model

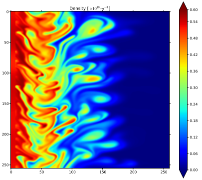


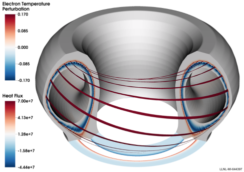


Applications in tokamak physics

- Filaments / blobs
  - Transport of heat and particles in SOL
  - 2D examples run on a laptop
- Edge turbulence
  - Formation of blobs
  - Near SOL heat transport (λ_q)
- Divertor simulations
  - Spreading of particle and power fluxes to surfaces
  - Interaction with neutral gas and detachment
- Pedestal physics and ELMs
  - Gyro-fluid models to capture FLR, Landau damping, and drift resonance effects
  - L-H transition physics
  - Stability and nonlinear dynamics





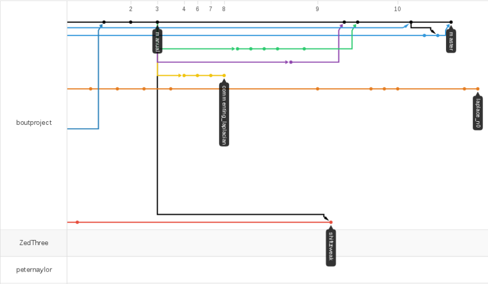


Recent developments

Many people contributing fixes, features and improvements: George Breyiannis, David Dickinson, Luke Easy, Erik Grinaker, Joe Henderson, Peter Hill, Jarrod Leddy, Michael Loiten, Peter Naylor, Jens Madsen, John Omotani, Kevin Savage, David Schwoerer, Luke Townley, Nick Walkden (apologies for omissions)

In the last year
`(git diff --stat)`

- 534 files changed
- 22674 insertions(+)
- 47251 deletions(-)



Recent developments

Some of the new features at this workshop are:

- Implementation of the Flux Coordinate Independent (FCI) scheme (P.Hill, B.Shanahan)
- Implicit-Explicit (IMEX) schemes for time integration (N.Walkden, B.Dudson, D.Dickinson)
- Non-orthogonal meshes for realistic tokamak geometries (J.Leddy, N.Walkden)
- Interaction with neutral gas (S.Mekkaoui, J.Leddy, B.Dudson)
- Finding eigenvector/eigenvalues using SLEPc (D.Dickinson, B.Dudson)

Issues and future work

- Increasing time-step size: Often limited by fast electron parallel dynamics to $\delta t < 1/\Omega_{ci}$
- Calculating the potential ϕ from vorticity efficiently and robustly
- Inclusion of impurities
- Development of neutral gas models and divertor turbulence studies
- ...

Lots of things to discuss!