Gyrokinetic studies of edge ETG turbulence using GENE

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Many thanks to the ASDEX Upgrade Team and the rest of the GENE Development Team

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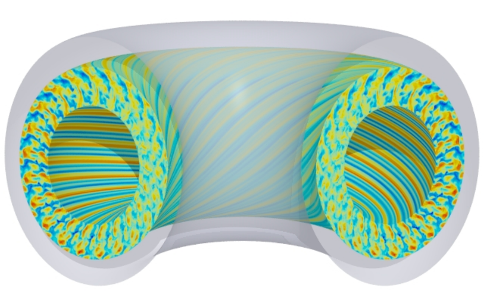

Gyrokinetics for ITER workshop, Vienna April 6th 2011

Outline

1. ETG turbulence studies in the plasma edge
2. First global ITB/ETB simulations using GENE

The GENE code – http://gene.rzg.mpg.de

Vlasov solver for delta-f gyrokinetic equations

Physics content:

- Local and global mode
- Arbitrary number of species (trapped/passing)
- Electromagnetic fluctuations (perp. + par.)
- Collisions (energy+pitch angle scattering)
- Realistic field geometry (interfaces to CHEASE, EFIT, TRACER, GIST)
- Sources for gradient-driven and flux-driven studies

Other features

- Python-based graphical launcher tool
- IDL-based diagnostics
- Optional HDF5 output
- Auto-parallelization, auto-optimization

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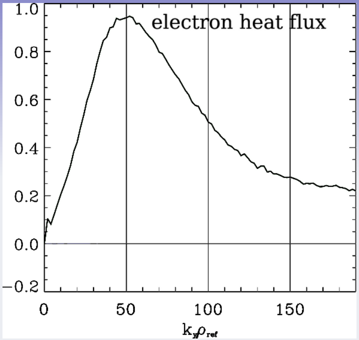
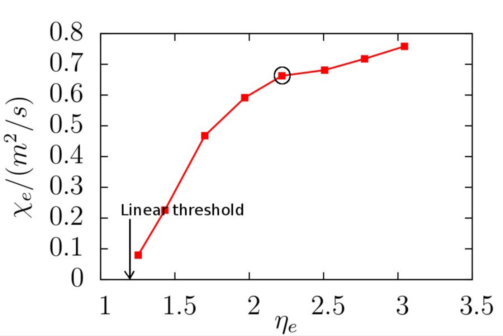
ETGs can explain edge electron heat flux

Told et al. 2008, Jenko et al., 2009





What causes residual electron heat flux in H-Modes?

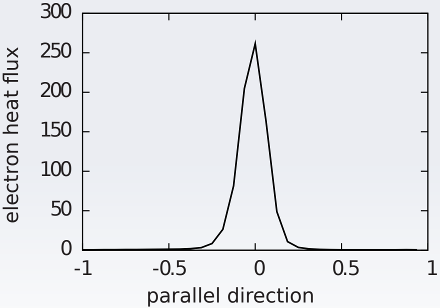
Simulations for AUG H-Mode #20431:

- Nominal profiles: Electron heat flux $Q_e \approx$ 8MW
  $\Rightarrow$ comparable to total input power
- Linear+nonlinear threshold $\eta_e \approx 1.2$
  $\Rightarrow$ ETGs should be unstable in most AUG edge plasmas (AUG: 1-3)

Large resolution requirements

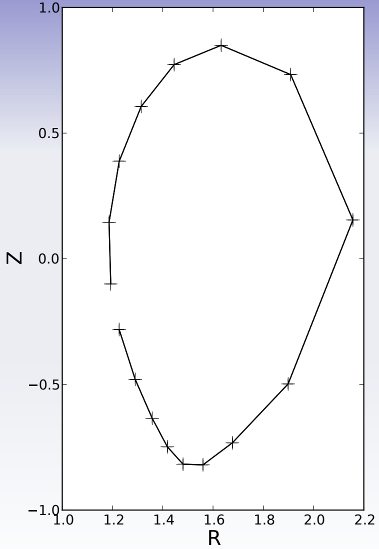
- Original simulations used $z = \phi/q \hat{=} \theta$ as parallel coordinate
- Shaping: Field lines concentrate on high field side
- But: edge ETG heat flux strongly localized around outboard midplane

$\Rightarrow$ inefficient parallel grid



here: $n_z = 32$

Flux surface at $\varrho_{tor} \approx 0.96$ ($n_z = 16$):

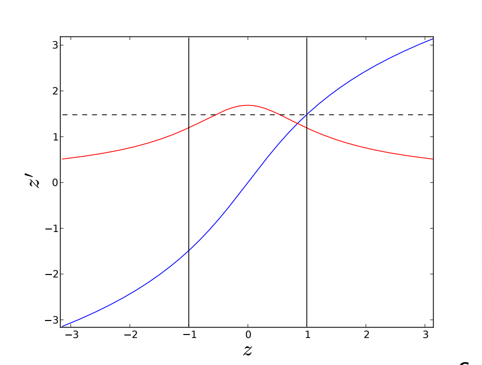


Optimized parallel grid:

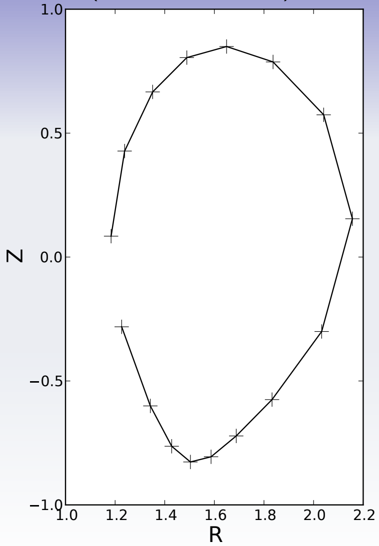
- Define parallel coordinate that runs more slowly through the low-field side:

$$z' = \operatorname{arsinh} kz \cdot \frac{\pi}{\operatorname{arsinh} k\pi}$$

- Transform parallel metric components via chain rule
- Interpolate to equidistant-z' grid



Flux surface at $\varrho_{tor} \approx 0.96$:
(figures for $k = 1$)



IPP

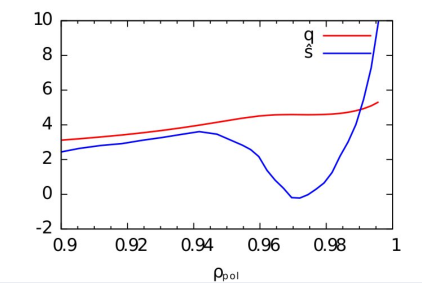
What about perpendicular resolution?

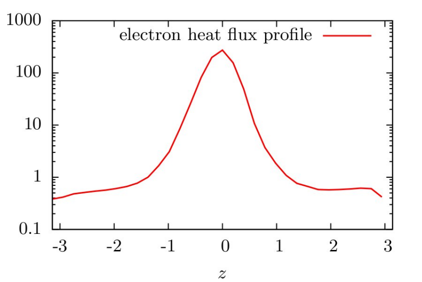
Properties:

- Edge characterized by large magnetic shear
  $\Rightarrow$ can lead to spurious ballooning of heat flux (Scott, 2001)
- Strong ballooning of ETG heat flux observed
  $\Rightarrow$ real or artificial?

Use shifted metric treatment:

- Shift y coordinate:
  $y_k = y - x \cdot g^{xy}/g^{xx} \Rightarrow$
  orthogonalization of field-aligned coordinates
- Requires use of nonlocal GENE (no Fourier treatment of radial direction possible)





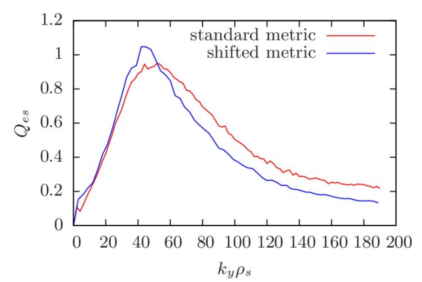
Agreement between shifted/standard metric

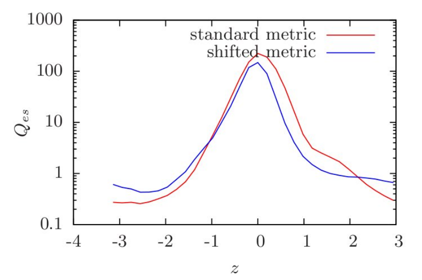
Numerical approach

- Use nonlocal code with 'local' profiles
- Shifted metric incompatible with periodic radial boundaries
  $\Rightarrow$ use Dirichlet boundary with damping zones + Krook-type heat source (see later)

Results of comparison:

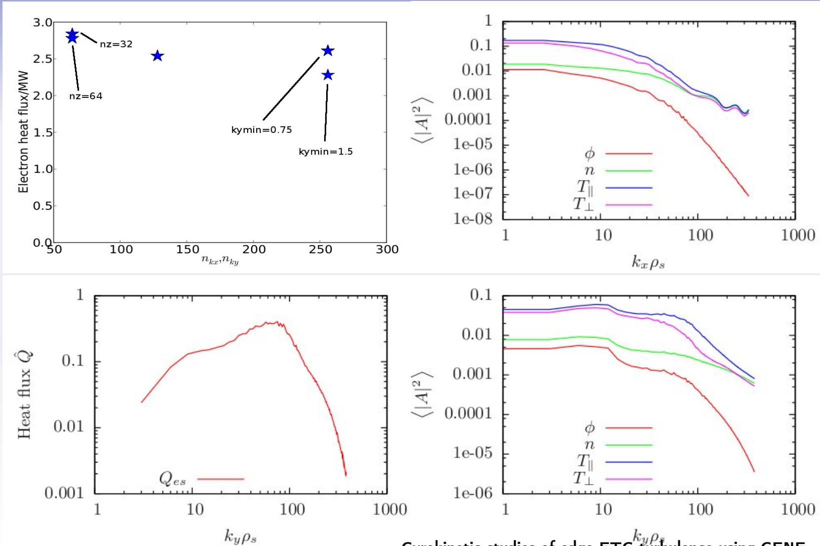
- Heat flux spectrum very similar
- Parallel localization appears in both geometry descriptions
- Average heat flux (including damping zones) $\sim$ 20% lower





Local convergence tests

- Heat flux robust with respect to perpendicular resolution
- Strong shaping: *n* and *T* fluctuations show only weak decay



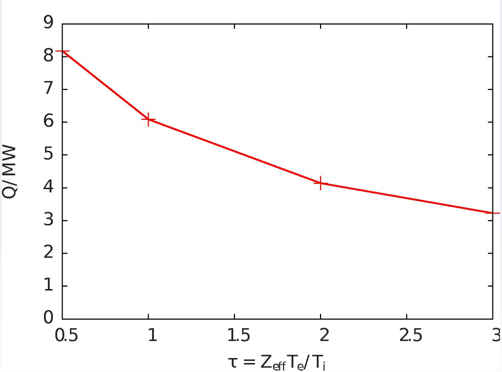
Influence of impurities and temperature ratio

Adiabatic ion response:

- $\tilde{n}_i / n_{i0} = -\tau (e\tilde{\phi} / T_e)$ with $\tau = Z_{\text{eff}} T_e / T_i$ (for equal T_i's)
- Expectation: no dependence of $R/L_{Te,\text{crit}}$ on τ due to large density gradient (Jenko et al. '01)
- Reaction of heat flux to this parameter?

Nonlinear scan over τ:

- Simulations for $\varrho_{\text{pol}} = 0.98$, varying τ
- Result: moderate dependence of Q_e on τ, roughly $Q \propto \tau^{-0.5}$
- AUG edge: $Z_{\text{eff}} \sim 2-3$, but often $T_e < T_i \Rightarrow Q_e$ relatively flat



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Sources for gradient-driven global simulations

Sources already present in GENE

- Krook-type heat source (McMillan PoP 2008, Lapillonne PoP 2010)

$$S_H = -\kappa_H \left(\langle \delta f \rangle - \frac{\langle \int \langle \delta f \rangle dv \rangle}{\langle \int \langle F_M \rangle dv \rangle} \langle F_M \rangle \right)$$

  Conserves density and parallel momentum (δf symmetrized in $v_{\|}$)
- Allows steady-state simulations close to initial profiles

Necessary addition for kinetic electron runs:

- Density profiles evolve; require particle source for steady state

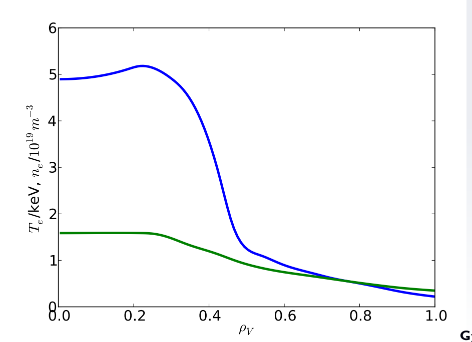
$$S_P = -\kappa_P \left(\langle \delta f \rangle - \frac{\sum_{\text{spec}} q \langle \int \langle \delta f \rangle dv \rangle}{q n_{\text{spec}} \langle \int \langle F_M \rangle dv \rangle} \langle F_M \rangle \right)$$

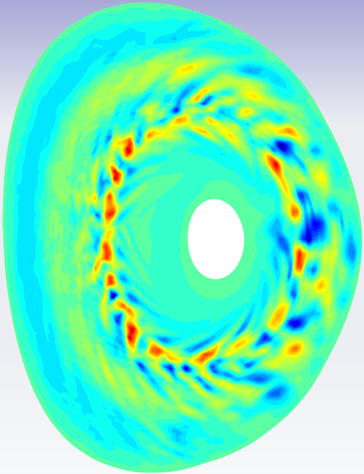
- Conserves parallel momentum; correction term ensures quasineutrality
- Heat contribution can be compensated by adapting the heat source

First steps: ITB simulations for TCV

What causes electron ITBs in TCV?

- Experiment: Slight changes in current profile strongly change ITB strength (Sauter PRL 2005)
- Strongly varying temperature requires large velocity space resolutions (example: $128 \times 24 \times 24 \times 96 \times 64$)

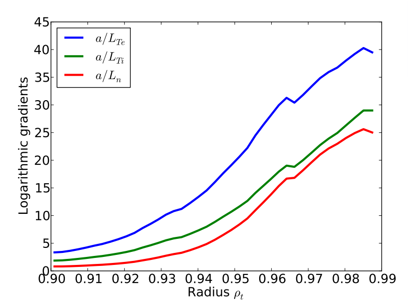


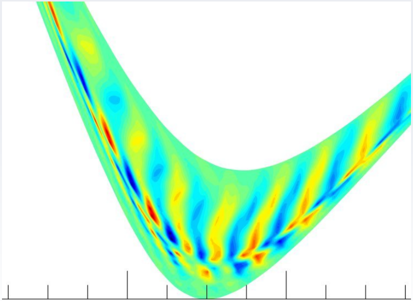


First tests for global AUG edge simulations

Linear study

- Box size $\varrho_t \in [0.91, 0.99]$ $(L_x = 30\varrho_{s,0.95})$
- Linear runs already expensive (need $\sim 80 \times 48$ v-space points)
- Low-k growth rates are much decreased compared to local runs
- Require buffer zones at the boundaries: should move this out of the pedestal
  $\Rightarrow$ simulations must include some SOL region





Thank you for your attention!

- [Jenko, 2001] F. Jenko et al.,
  Phys. Plasmas 8, 4096 (2001)
- [Jenko, 2009] F. Jenko et al.,
  Phys. Plasmas 16, 055901 (2009)
- [Lapillonne, 2010] X. Lapillonne et al.,
  Phys. Plasmas 17, 112321 (2010)
- [McMillan, 2008] B. F. McMillan et al.,
  Phys. Plasmas 15, 052308 (2008)
- [Sauter, 2005] O. Sauter et al.,
  Phys. Rev. Lett. 94, 105002 (2005)
- [Scott, 2001] B. Scott,
  Phys. Plasmas 8, 447 (2001)
- [Told, 2008] D. Told et al.,
  Phys. Plasmas 15, 102306 (2008)