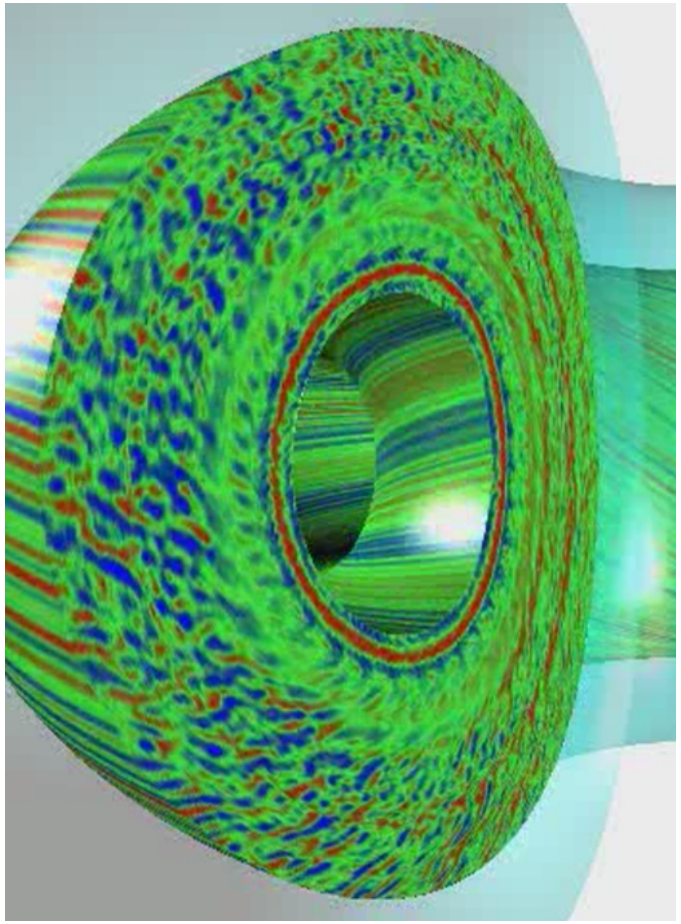
Uncoordinated Vorspiel Part 2:

Assorted Thoughts on Possible Gyrokinetic Research Topics

Greg Hammett, PPPL, March 19, 2012
Wolfgang Pauli Institute, Vienna, Gyrokinetics 2012



GYRO simulation, Candy & Waltz 2006

* Vienna etc. series of GK workshops very productive, significant insights and advances from past meetings: Very interactive, working meetings

* Fundamental theory, but also keep in mind final applications:

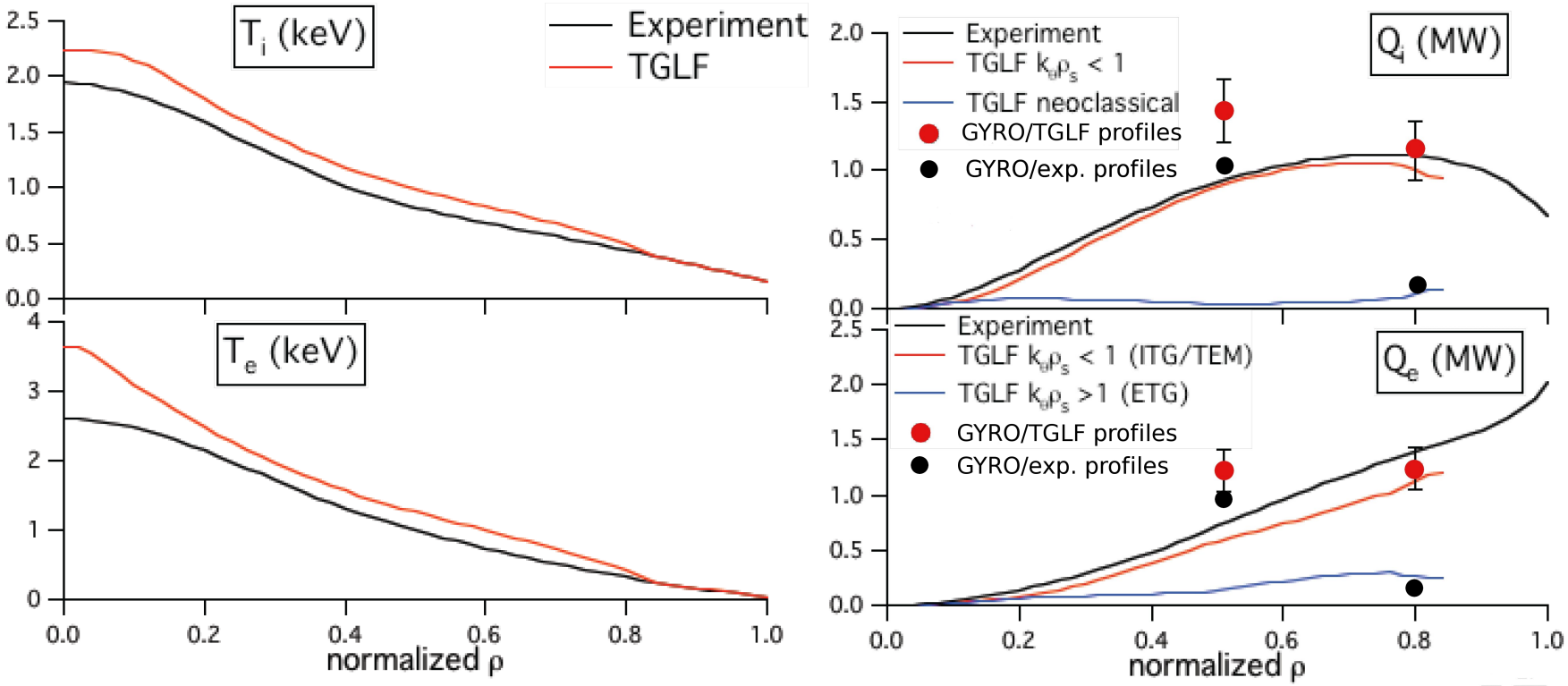
    * Need application of our codes to experiments for visibility, keeps us relevant and focussed on right things. Big opportunities using TGYRO+GYRO or TRINITY+GS2/GENE

    * Applications to ITER & future designs important. Ways to improve fusion energy concepts?

    * Fundamental theory and codes applied to other areas (plasma astrophysics, ...).

(these slides include feedback during talk from Dorland, et al.)

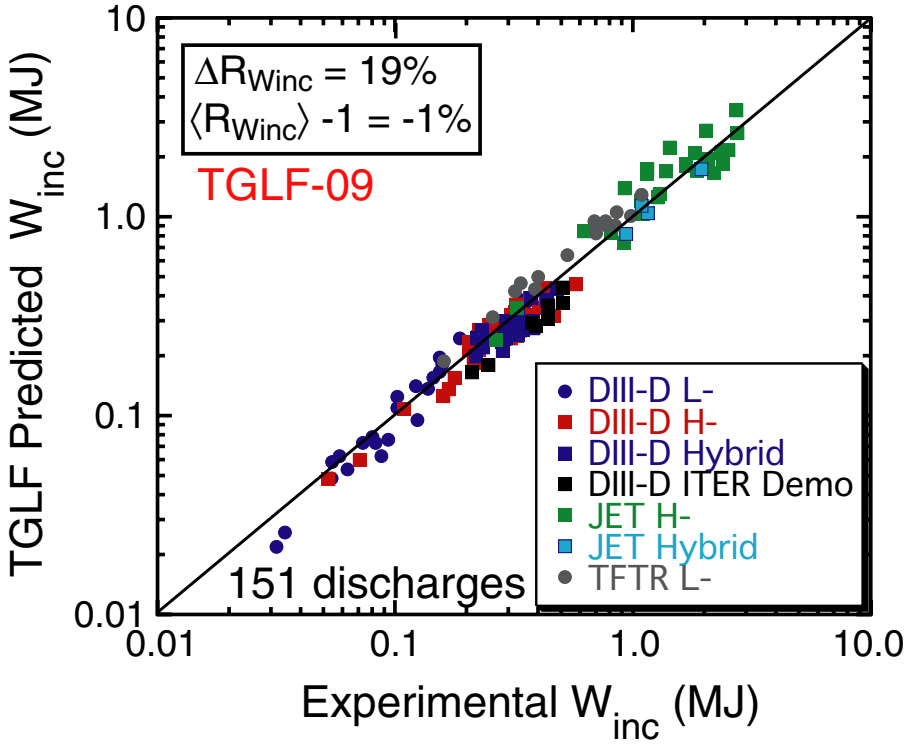
Need more tests of gyrokinetic codes against experiments



- Some apparent discrepancies between code/expt. can be explained by stiff transport, but not always. Typical breakdown somewhere near edge.
- Some recent progress explaining some disagreements, by fast ion dilution, finite beta, some turbulence spreading? (Holland, NF 12 subm.) Need to resolve remaining differences. Need larger boxes near edge at higher $q\ R/L_T$? (Barnes et al. PRL 107, 115003 (2011))

Figs. based on Holland TTF08, see also Holland PoP 09, A. White PoP 10 , ...

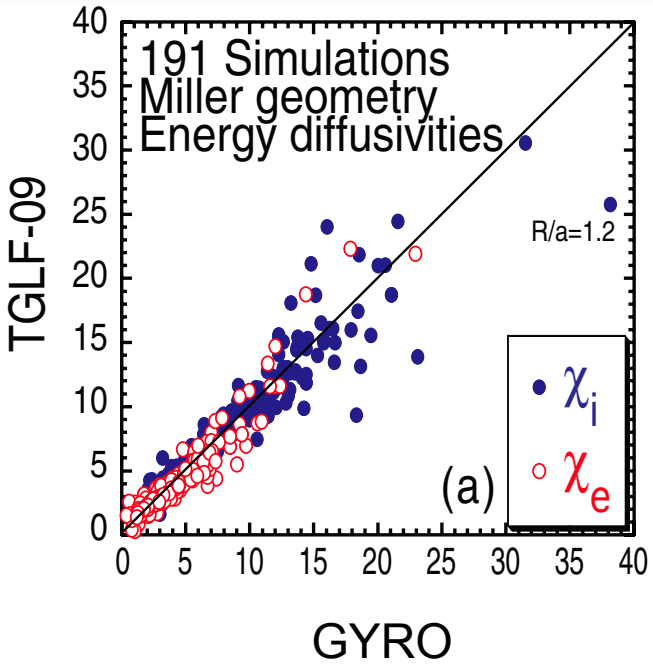
TGLF transport model compares with experiments fairly well in many regimes



TGLF is currently best available transport model, but needs improvement for some parameter regimes. Can we do better?

Kinsey et al. Nucl. Fus. 2011 http://stacks.iop.org/NF/51/083001

TGLF: a reduced transport model fit to full GYRO nonlinear turbulence simulations



TGLF is a reduced transport model (developed by Staebler et al.) based on quasilinear fluxes with saturation model that models zonal flow effects. There are a few adjustable parameters in the model, fit to full GYRO simulations.

Kinsey et al. Nucl. Fus. 2011 http://stacks.iop.org/NF/51/083001

Improving on TGLF Transport model

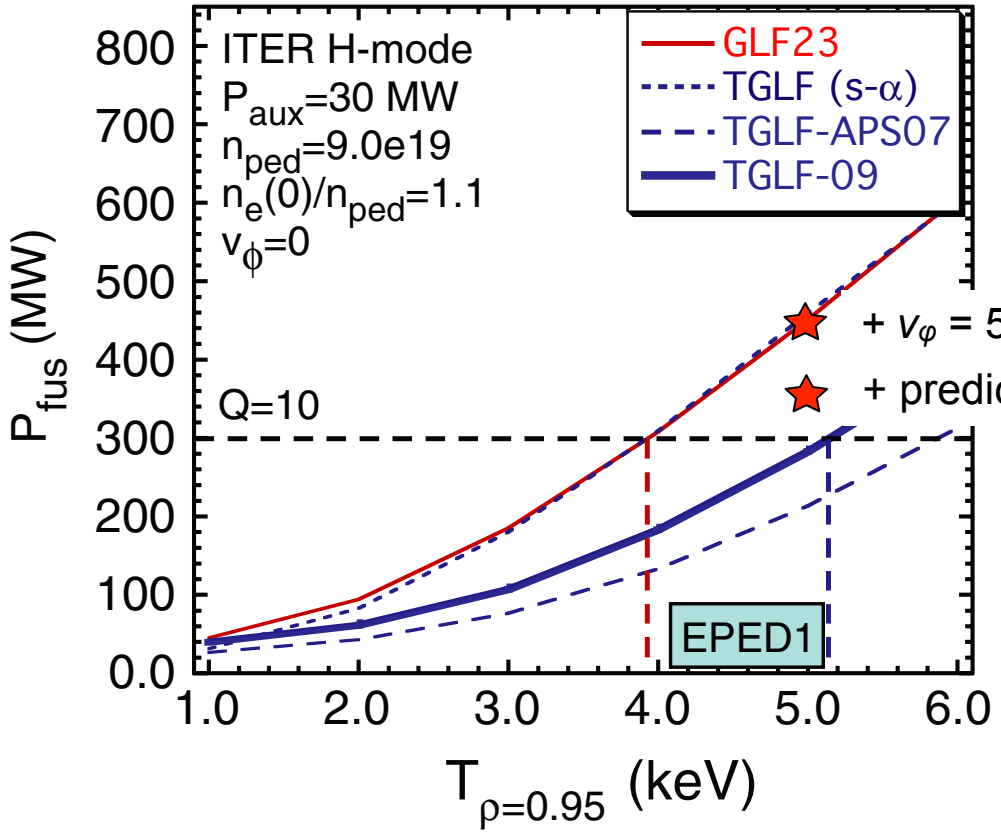
We know TGLF works less well in some regimes (such as when particular nonlinear effects become important):

* low R/a
* strong negative magnetic shear (doesn't have Cowley vs. Rogers secondary instability transition)
* Nonlinear Dimits shift might not be accurate in some regmes?
* Essentially no microtearing
* How accurate is ETG model?
* accuracy of momentum transport, particularly at low flow, or with nonlinearly-driven KH-like instabilities (Highcock, Barnes, et al.)?
* turbulence spreading? Becomes important near plasma edge where eddy size ~ L? Explains Bohm scaling in some regimes?

Can we run full transport codes with direct gyrokinetic codes (i.e., Barnes' TRINITY+GS2/GENE, Candy TGYRO+GYRO) more routinely? Better subgrid models to run gyrokinetic codes on coarser mesh? Broyden's method to reduce # of Jacobian calls? (first proposed by John Cary for FACETS) Better parallelization to larger number of processors on smaller problems?

Kinsey et al. Nucl. Fus. 2011 http://stacks.iop.org/NF/51/083001

Rotation, density peaking, $\delta B_\perp$ significant for ITER transport?



+ v_φ = 5x10^4 m/s (M~0.06) from NBI & $\chi_\varphi = \chi_i$

+ predicted n_{e0}/n_{ped}=1.3, $\delta B_\perp$

If Q=5 = recirculating power, this cut cost of electricity in half.

Need more experimental tests, multiple code simulations with more complete physics to enhance confidence.

Need comprehensive edge simulations...

Can we find operating regimes for ITER that perform better?

Is rotation going to be more important than realized? $\chi_\varphi < \chi_i$?

MeV beams challenging: because of marginal stability, can use lower voltage beams that don't penetrate as well and still get same profiles. Beam torque/power actually better at lower V. But is port space enough? NBI current drive?

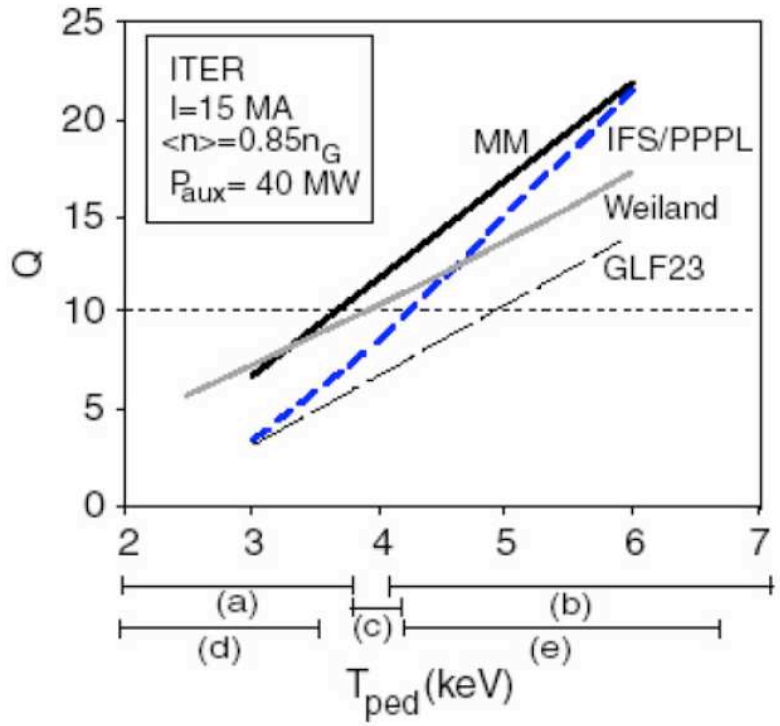
Hybrid mode with moderately reversed q to enhance confinement, but avoid beta limits of ITB?

Full reversed shear ITB but use ripple or RMP coils to control profiles and avoid beta limits?

Improved confinement can allow the plasma current to be lowered: reduces disruption forces, knock-on runaway electrons, current-drive needs, reactor machine size.

Can turbulent transport of energetic electrons during disruptions reduce the generation of relativistic runaways?

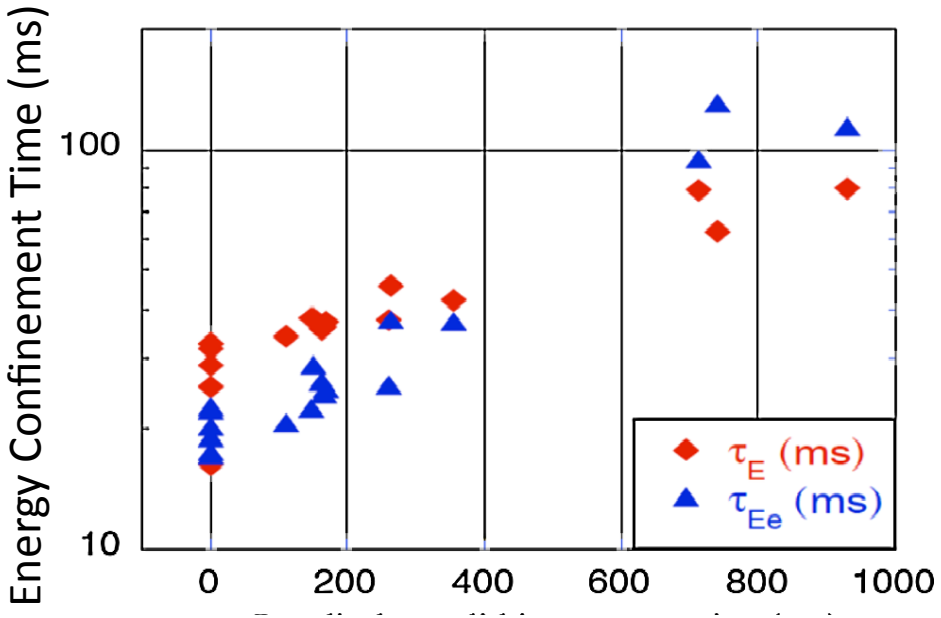
Performance of Tokamak Fusion Power Plants (like ITER) Depends Sensitively on Edge Physics



Predicted fusion gain Q from core transport models vs. assumed temperature at top of edge pedestal (T_{ped})

Fig. 5, "Progress in ITER Physics Basis", Nucl. Fus. 2007, http://www.iop.org/EJ/abstract/0029-5515/47/6/S01

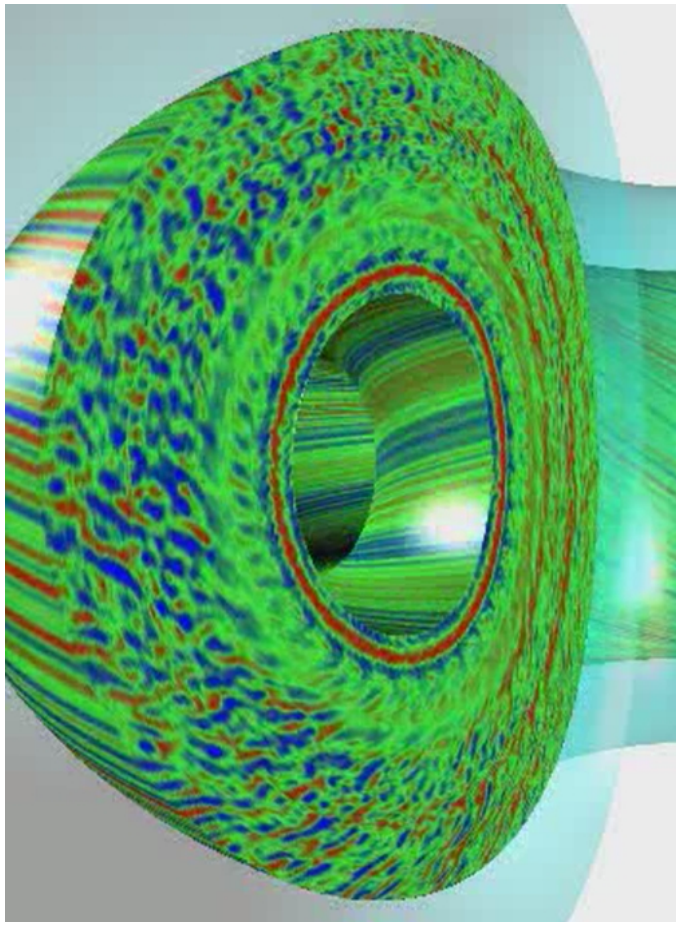
How much can lithium improve plasmas?



NSTX (APS 2011) finds more lithium is still good. Can we raise edge temperature to ~4 keV or higher? (NSTX global τ_E went up as pedestal broadened and ELMs were suppressed, but T_{SOL} didn't rise? Unlike TFTR, where T_{SOL} ~ 2 keV.)

Lithium on wall absorbs hydrogen, reduce recycling of hydrogen as cold neutrals that cool the edge, raises edge temperature. Liquid lithium coating protects wall, avoid melting divertor plates by ELMS? avoid melting wall in disuption? Potentially dramatic effect.

Can we design tokamaks or stellarators so they spontaneously spin at significant rates?



GYRO simulation, Candy & Waltz 2006

General theory of why intrinsic torques vanish in standard low-flow ordering in up-down symmetry:
Parra et al. PoP, 18, 062501 (2011)

Expt. demo of driving flows by breaking up-down symmetry:
Camenen et al., PRL 2010

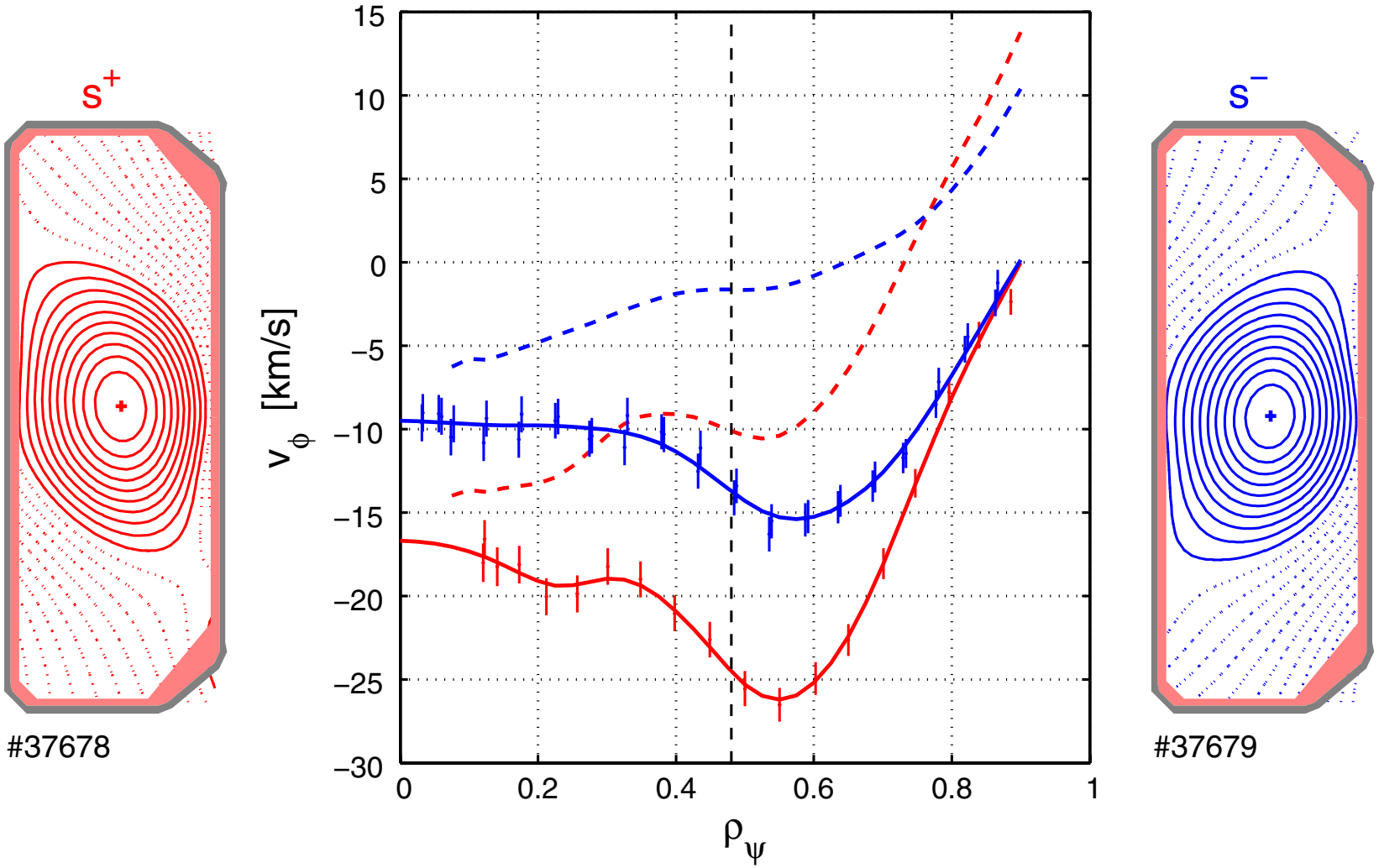
Simple picture of how breaking up-down symmetry can drive net Reynold's stress $\langle v_\theta v_r \rangle$ ... (show on blackboard)

Do we basically want an elongated tokamak tilted 45 degrees? Something fancier?

Stellarator equivalent of up-down tokamak symmetry is "stellarator symmetry". Only for convenience? (Weitzner?)
Do we want to make a non-stellarator-symmetric stellarator that has quasi-symmetry?

Useful status report on rotation:
Peeters et al. Nucl. Fusion, 51, 094027 (2011)

TCV Tokamak verified that toroidal rotation can be affected by up-down asymmetry

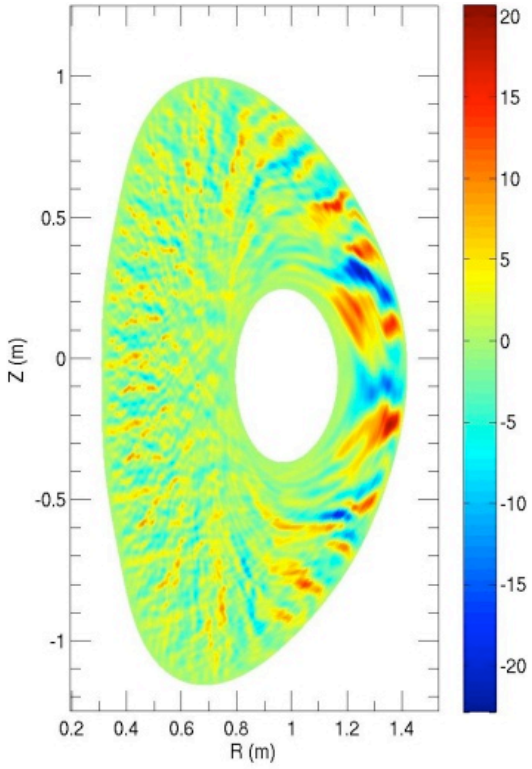


Rotation of carbon (solid lines) & main ions (dashed)

Camenen et al., PRL 2010

Interesting work on magnetic fluctuations in ITG/TEM, and Micro-tearing

Magnetic turbulence matters



More from many others this week & next.

Can microtearing or magnetic component of ITG/TEM/KBM explain discrepancies between GYRO and experiments in some cases, such as the outer region of colder L-mode plasmas?

GYRO simulation (Guttenfelder et al.) of microtearing in NSTX, agrees with experiment, predicts confinement improves with temperature (NSTX-U / MAST upgrades better?)

Fundamental plasma theory: fusion & beyond

Random questions about interesting recent work:

* Ben Chandran & Eliot Quataert et al.: breaking of μ invariance with sub-cyclotron frequency fluctuations. Heating mechanism? How related to entropy cascade in gyrokinetics?

* Most astrophysics code for large scale phenomena can't resolve reconnection layers. Is it possible to develop a subgrid model for such applications? Can there be a general theory of turbulence-enhanced reconnection? Dynamo? Prandtl # dependence?

* Related: Can one develop a subgrid model of magnetic fluctuations for fusion applications, since we often don't resolve the c/ω_{pe} or resistive scale where final field-line breaking occurs