GYRO Simulations of Core Momentum Transport in DIII-D and JET Plasmas

R. Budny (PPPL), J. Candy (GA), R. Waltz (GA),

and contributors to the DIII-D and JET-EFDA work programs

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- New features in GYRO

1. multiple ion species
2. utility to generate input profiles using TRANSP
3. turbulent angular momentum transport
4. improved visualization

- Application to various plasma regimes

1. DIII-D L-mode ρ_* scan
2. JT-60U box ITB plasma
3. DIII-D and JET ELMy H-mode plasmas <= This poster

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Overview of the gyrokinetic code GYRO

- Comprehensive physics to simulate ITG/TEM modes
- Kinetic treatment of trapped and passing electrons
- Including Electromagnetic corrections
- $\boldsymbol{E} \times \boldsymbol{B}$ shear
- non-zero ρ_s
- real geometry (Miller local equilibria)
- ion-electron pitch-angle scattering
- Krook ion-ion collisions
- profile shear
- toroidal rotational shear (Kelvin-Helmholtz drive)
- experimental input profiles maintained by adaptive sources

Overview of this poster

- Studied two DIII-D and two JET ELMy H-mode plasmas
- TRANSP analysis to deduce transport from local conservation, measurements, and profiles of heating, torque, and fueling
- TRANSP to generate GYRO inputs
- Extensive nonlinear GYRO runs to simulate energy, momentum and species transport
- Varied $\nabla(T_i)$ drive and $\nabla(E_r)$ suppression to get energy flow in approximate agreement with experiment
- compared simulated momentum flow with energy flow and experiment

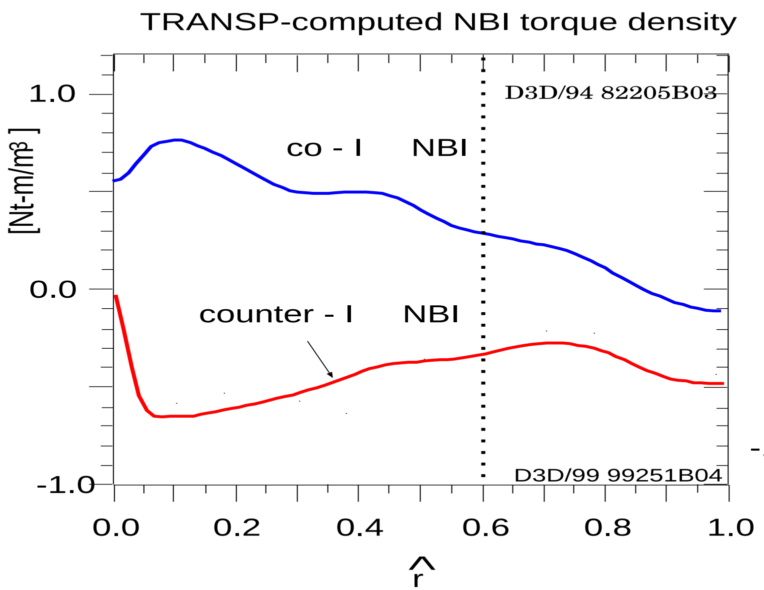
ELMy H-mode Plasmas Studied

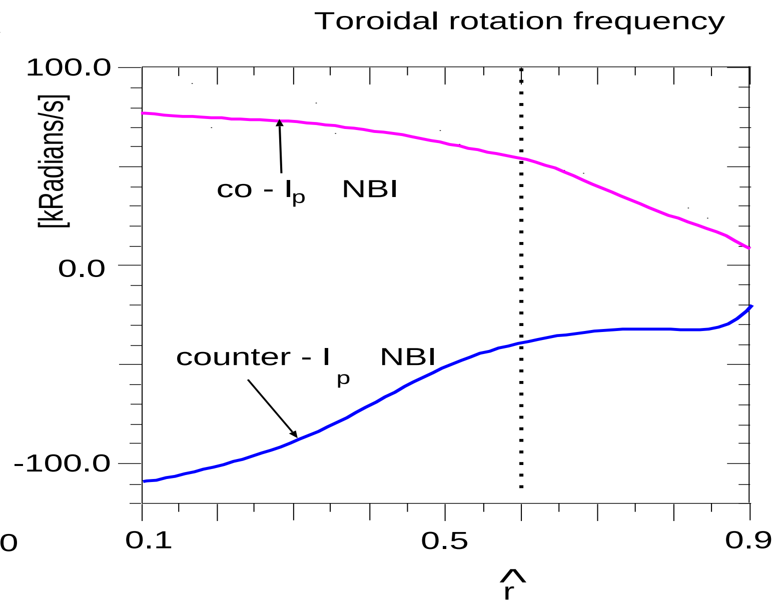
- Matched pair of DIII-D plasmas with co- and counter-I_p NBI
- High performance JET plasmas

shot	DIII-D 82205	DIII-D 99251	JET 42982	JET 53030
type	co-I_p NBI	ctr-I_p NBI	record Q_{DT}	Ar seeded
R_0, a [m]	1.76, 0.60	1.76, 0.60	2.99, 0.75	2.98, 0.70
I_p [MA], B [T]	1.35, 2.0	1.35, 2.0	3.8, 4.0	2.5, 2.5
P_{NBI} [MW]	4.8-7.2	9.0	21.5	12.4
time [s]	2.5	2.2	16.4	21.5
$\hat{r}$	0.60	0.60	0.75	0.70
$\rho_* \equiv \rho_s(\hat{r})/a$	0.0411	0.0403	0.0164	0.0168
$E_r(\hat{r})$ [kV/m]	40.8	-40.5	119.0	54.6
$\nabla(E_r)$ [kV/m^2]	-90.0	+52	-140	-138

Matched DIII-D plasmas with co-I_p NBI and counter-I_p NBI

- GyroBohm confi nement with co-I_p NBI, Bohm with counter-I_p NBI
- Similar plasma profi les and $|E_r|$, except for:
- different $|\nabla(E_r)|$ due to differing NBI torques





Methods

- Used TRANSP to extract transport and GYRO inputs from measurements

  1. E_r from measured v_{tor} and p_{carbon} and neoclassical v_{pol}

- Linear GYRO runs

  1. scan in $k_\theta \rho_s$ for maximum growth rate γ_{lin} and mode freqency ω_{lin}

- Nonlinear GYRO runs

  1. kinetic electrons, two ion species
  2. most runs with electrostatic approximation
  3. kept ion-electron, but ignored ion-ion collisions
  4. used 384 CPU's on an IBM SP RS/6000 (Seaborg), 128 on a dual AMD Opteron 248 cluster (Jacquard), and 64 on an IBM p690 system (Cheetah)

GYRO results depend sensitively on $\nabla(T_i)$ and $\nabla(E_r)$

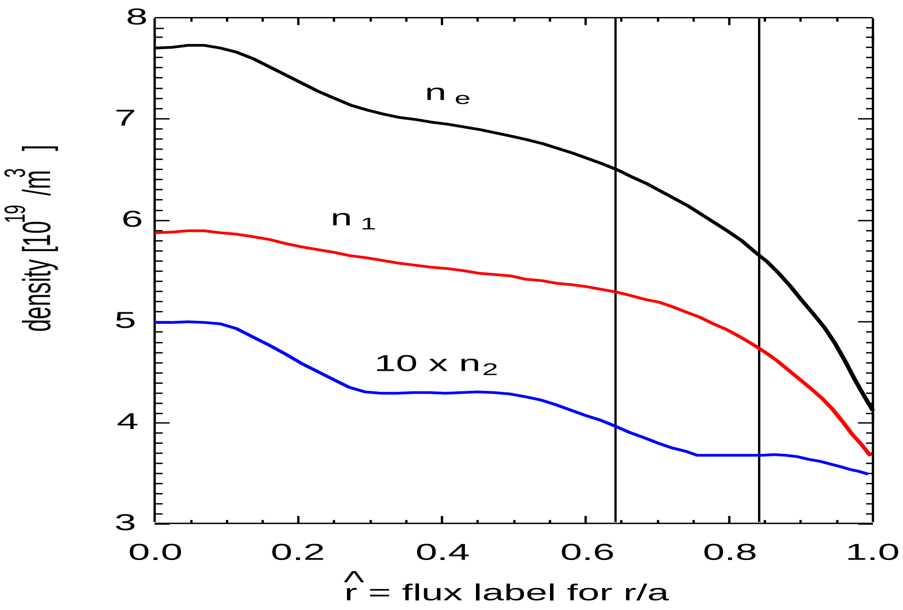
- Results with measured $\nabla(T_i)$ and $\nabla(E_r)$ (from TRANSP with NCLASS)
  1. simulated energy and momentum flows too high for DIII-D plasmas
  2. too low for JET plasmas
- Changing $\nabla(T_i)$ and/or $\nabla(E_r)$ $\leq$ 15 % gives approximate agreement for the simulated energy flows for 3 of the 4 plasmas studied
- $\Gamma_{mom}^{gyro}/\Gamma_{E}^{gyro} \sim$ OK for DIII-D, too high by $\simeq \times(2-4)$ for JET

Summary of TRANSP and GYRO transport

shot	DIII-D 82205	DIII-D 99251	JET 42982	JET 53030
$k_\theta \rho_s$ (max)	0.506	0.502	0.401	0.496
γ_{lin} $[c_s/a]$	0.190	0.227	0.109	0.164
$\gamma_{E\times B}$ $[c_s/a]$	0.068	-0.098	0.078	0.126
ω_{lin} $[c_s/a]$	-0.432	-0.284	-0.223	-0.311
$\lvert\nabla(T_i)^{used}\rvert/\lvert\nabla(T_i)^{transp}\rvert$	0.85	0.85	1.00	1.00
$\lvert\nabla(E_r)^{used}\rvert/\lvert\nabla(E_r)^{transp}\rvert$	1.00	1.00	0.90	0.25
$\chi^{gyro}_{E;\ ion-1,\ ion-2,\ el}$ $[(c_s/a)\rho_s^2]$	1.7,-0.1, 0.7	0.7, 0.3, 0.2	1.9, 3.6, 0.6	2.6, 2.2, 1.3
$\chi^{gyro}_{mom;\ ion-1,\ ion-2,\ el}$ $[(c_s/a)\rho_s^2]$	0.4, 0.1, 0.0	0.5,-0.1, 0.0	1.5,-0.0, 0.0	2.7,-0.0, 0.0
$D^{gyro}_{ion-1,\ ion-2,\ el}$ $[(c_s/a)\rho_s^2]$	0.7, 3.9, 0.3	0.3, 3.3, 0.1	0.2,-1.2, 0.2	0.8, 1.4, 0.7
Γ^{gyro}_E [MW]	8	4.2	16	8.5
Γ^{gyro}_{mom} [Nt-m]	6	-4.0	32	39
Γ^{gyro}_{el} [MW/keV]	-0.03	-0.01	0.02	0.0
Γ^{transp}_E [MW]	3.5-4.5	3.4-4.3	16.8	6.0
Γ^{transp}_{mom} [Nt-m]	2.8-4.8	-(3.3-4.1)	19.0	8.0
Γ^{transp}_{el} [MW/keV]	0.1	0.08	0.20	0.11

Example of density profi les input to GYRO

- Combine thermal deuterium and tritium as ion species 1
- Combine impurities and the deuterium and tritium beam ions as ion species 2



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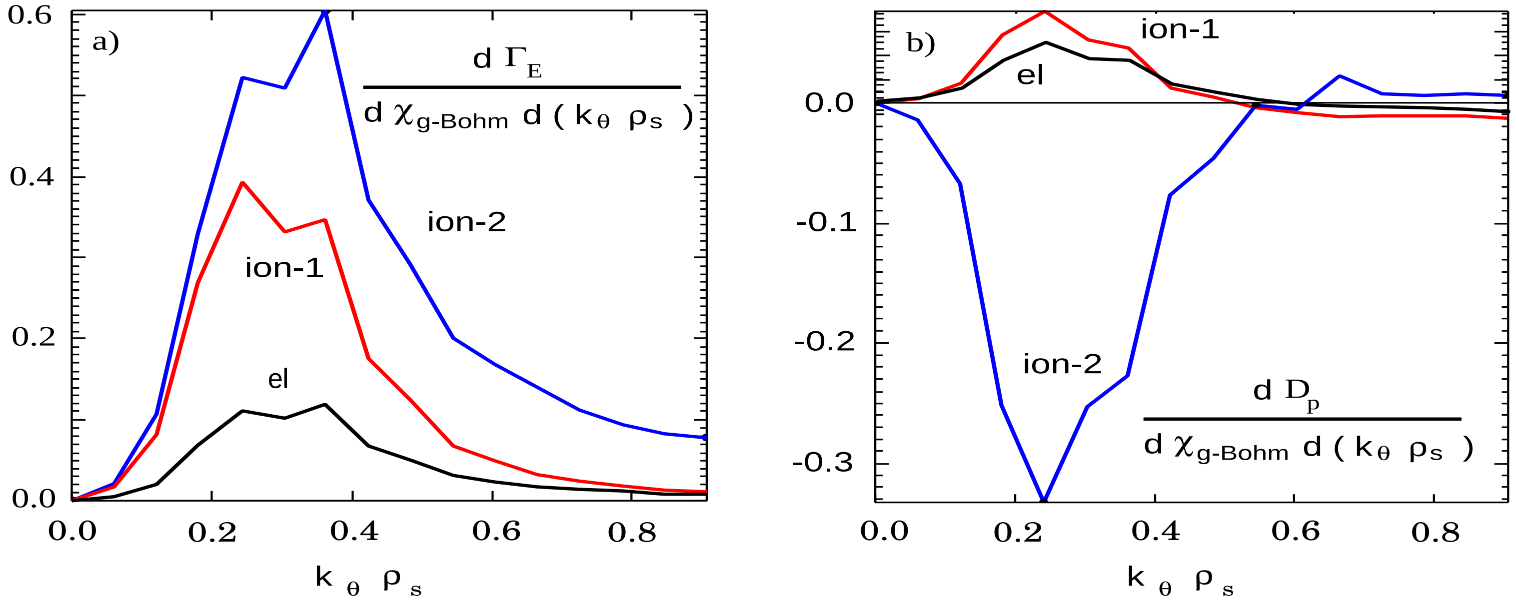
Spectra of energy and particle transport for JET 42982

- Complicated dependence on $k_\theta \rho_s$ $\Rightarrow$ kinetics needed to understand flows



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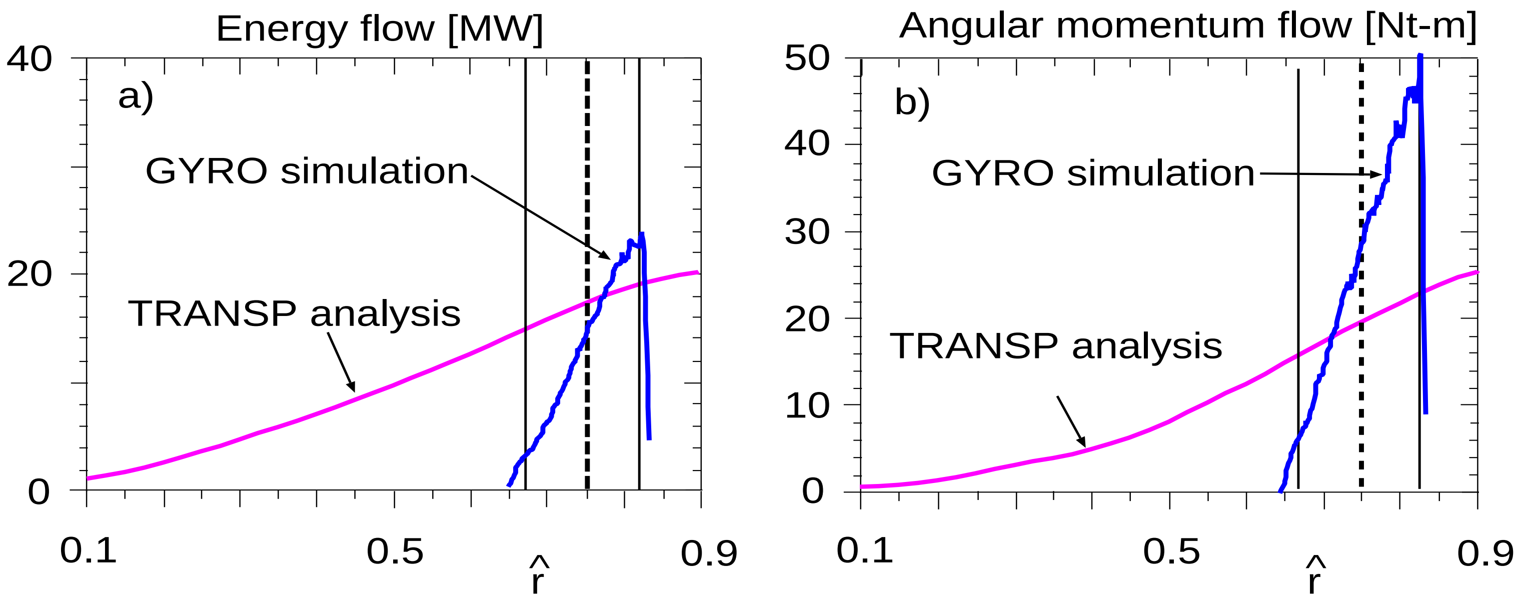
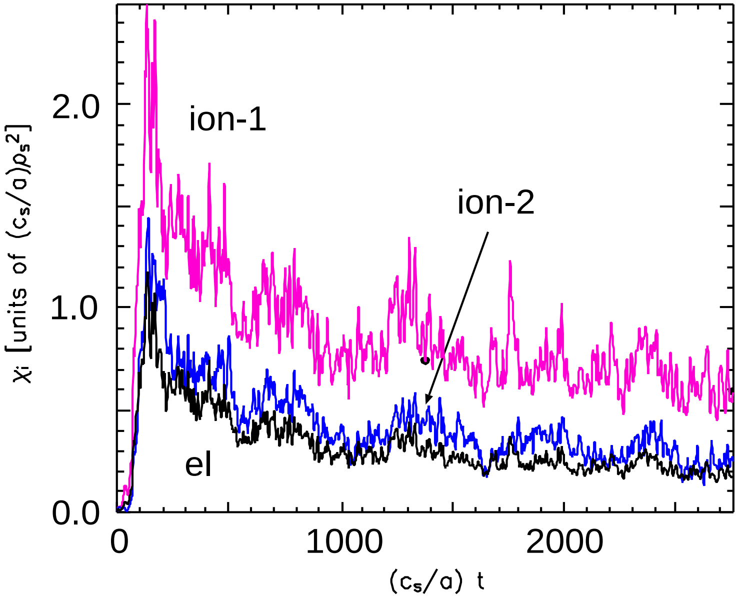
Energy and angular momentum flow from GYRO and TRANSP

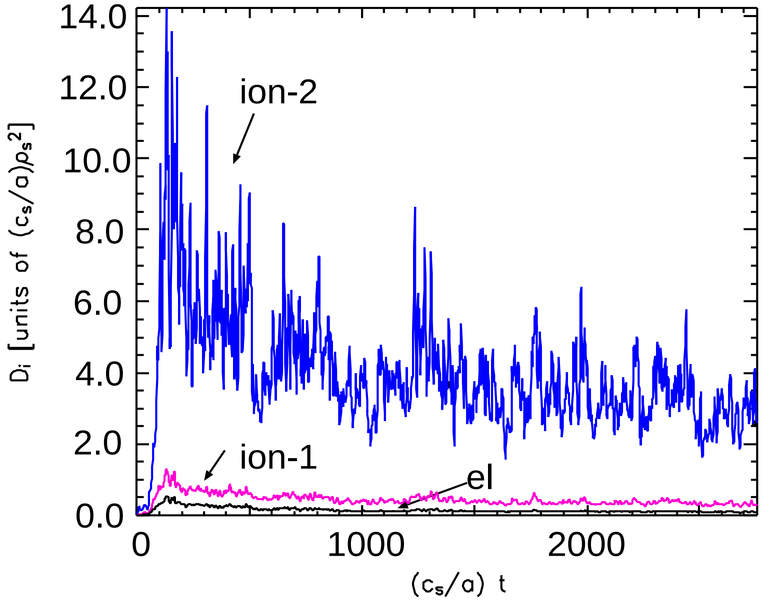
- Example of JET DT ITER prototype shot
- Simulated ion energy flow at $\hat{r} = 0.6$ close to measured with $|\nabla(E_r)|$ suppression reduced 10 %



GYRO time evolution of χ and D for DIII-D 99251

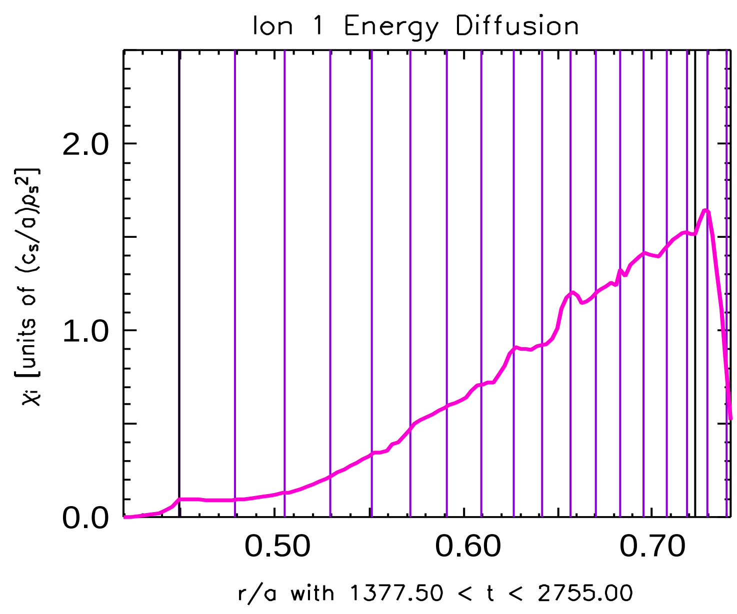
- Simulations of long durations needed to check for convergence to steady state

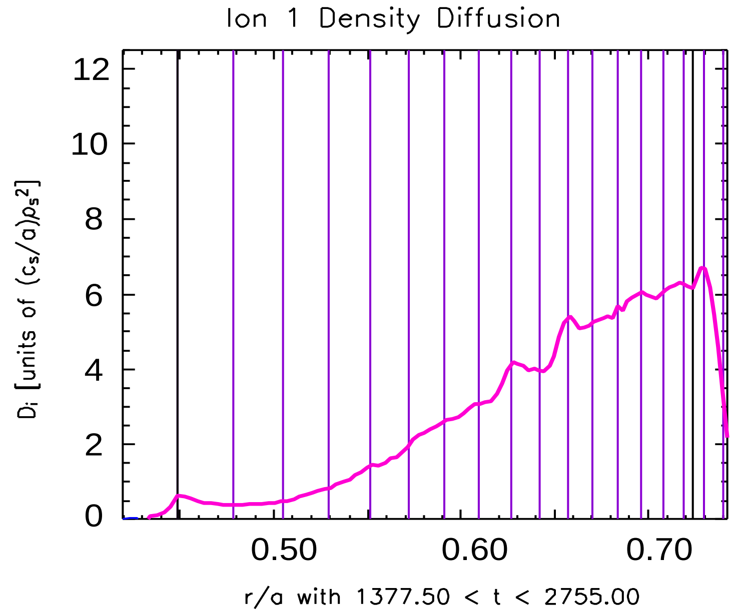




Structures in transport coeffi cients at mode-rational surfaces

- Examples in bulk ion energy and transport





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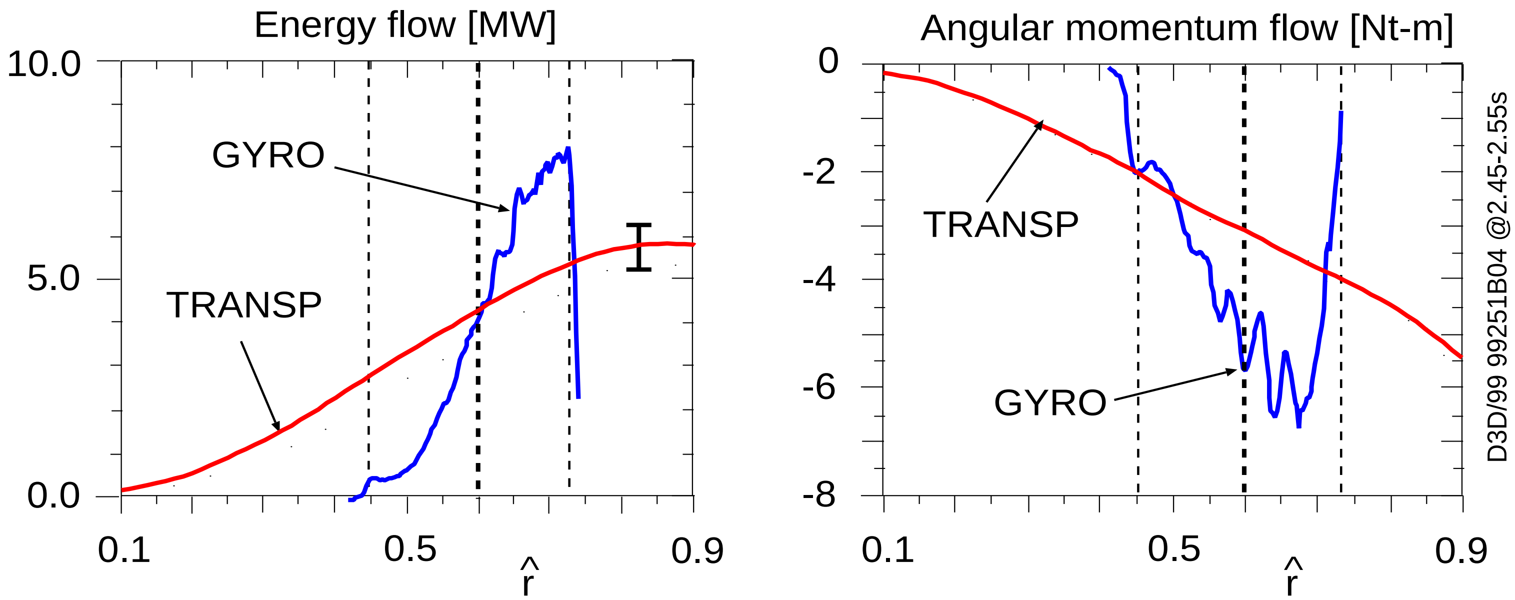
Compare simulated and measured flows in DIII-D

- DIII-D shot with ctr-I_p-NBI
- Simulated energy flow close to measured with $|\nabla(T_i)|$ drive reduced 15 %
- Magnitude of simulated angular momentum flows agree to within 60 % at $\hat{r}$



Summary

- GYRO simulations of energy, angular momentum, and particle flows were compared with measurements analyzed with TRANSP
- Strong sensitivity to drive $\nabla(T_i)$ and damping $\nabla(E_r)$
- DIII-D: GRYO transport too high with nominal $\nabla(T_i)$ and $\nabla(E_r)$
  1. reducing $|\nabla(T_i)|$ by 15 % gives approximate agreement for energy and momentum flow
- JET: GRYO transport too low with nominal $\nabla(T_i)$ and $\nabla(E_r)$
  1. reducing $|\nabla(E_r)|$ by 10 % gives approximate agreement for energy flow in DT plasma
  2. reducing $|\nabla(E_r)|$ by a factor of 4 needed for Ar injection plasma
  3. both JET plasmas have $\Gamma_{mom}^{gyro}/\Gamma_{E}^{gyro} \simeq (2-4)\times$ measured value
- Simulated electron species transport near zero, as inferred from measurements

Discussion

- Why don't simulated and measured flows agree at nominal $\nabla(T_i)$ and $\nabla(E_r)$?
  1. incorrect $\nabla(E_r)$ due to lack of measured v_{pol} or E_r?
  2. profile shearing effects or turbulence spreading?
  3. need better treatment of impurities (ex separate from beam ions)?
- Why is $\Gamma^{gyro}_{mom}/\Gamma^{gyro}_{E} \sim$ OK for DIII-D, but high for JET?
  1. a more accurate treatment of the angular momentum of each species is needed
  2. use v^{bulk}_{tor} for the bulk ions from neoclassical theory