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On the link between edge sheared flows and turbulence in fusion plasmas

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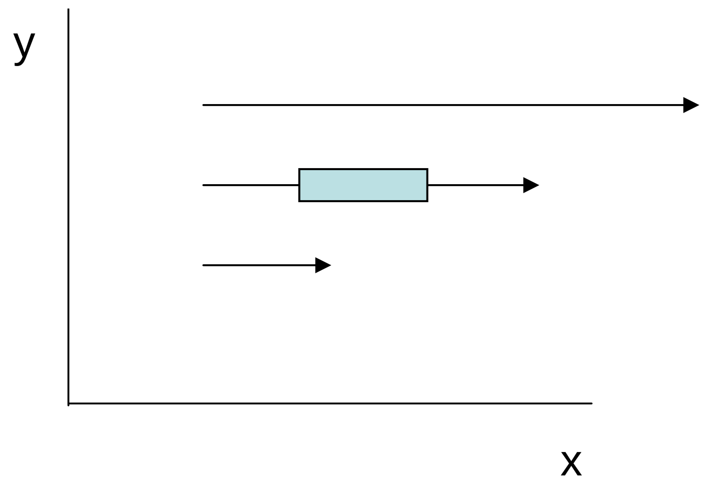
Outline:

- **The concept of negative viscosity and development of sheared flows.**
- **Edge sheared flows in fusion plasmas**
- **Energy transfer between flows and turbulence**
- **Conclusions**

Eddy (positive) viscosity

The resistance of fluids to shearing motion is a well known observation. The tendency of sheared motion to be reduced with the passage of time, if no other forces are at work to maintain it, leads to the concept of (positive) coefficient of viscosity

$$\tau = \mu \frac{\partial u}{\partial y}$$



The eddy momentum flux is directed from regions of larger values of mean flow toward regions of smaller values.

Negative viscosity

The eddy momentum flux is directed from regions of smaller values of mean flow toward regions of larger values.

This effect has a direct impact in the development of differential rotation

The subject of negative eddy viscosity has its origins from the calculation of Reynolds stresses from observed data mainly concerning earth's atmosphere.

Physics of negative viscosity phenomena

(with applications to earth and solar atmospheres, spiral galaxies, oceanic circulations)

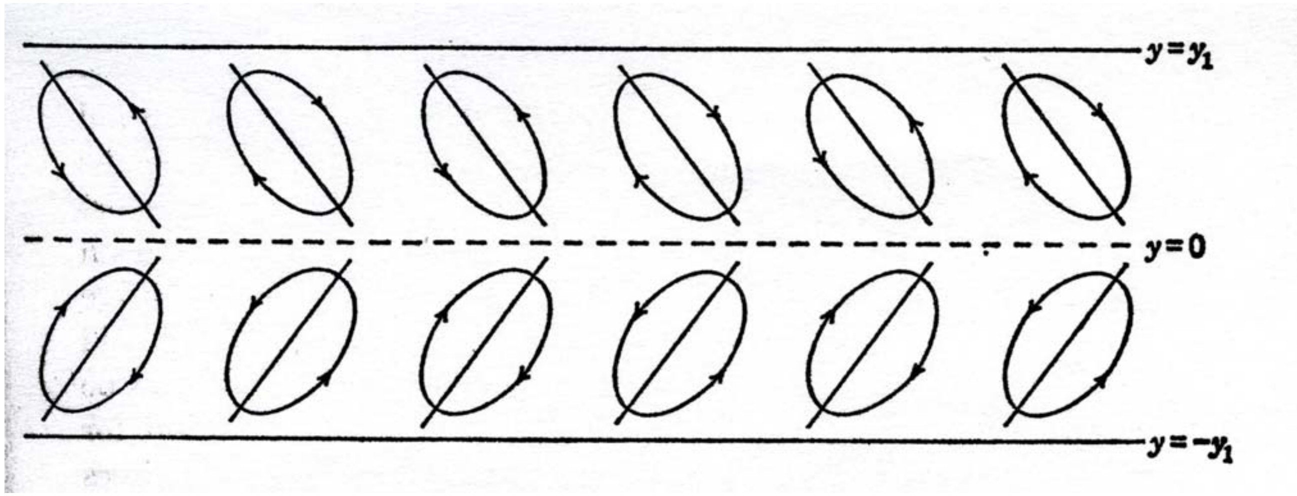
V. P. Starr , Earth and planetary science series, McGraw-Hill (1968).

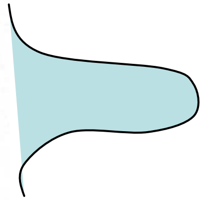
Properties of turbulent transport in fusion plasmas can not be understood without considering the coupling with sheared flows.

P. Diamond et al., Plasma Physics and Controlled Fusion 47 (2005) R35.

Negative viscosity: geometrical interpretation

Flow having a momentum transport into the central portion of the channel.



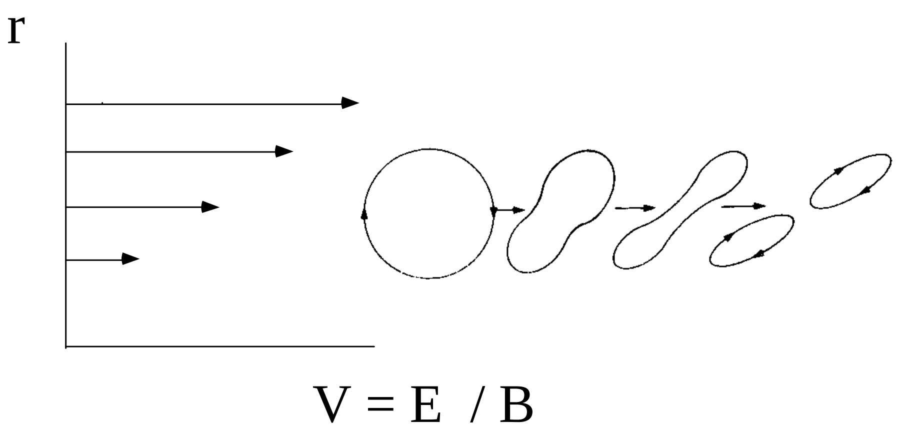


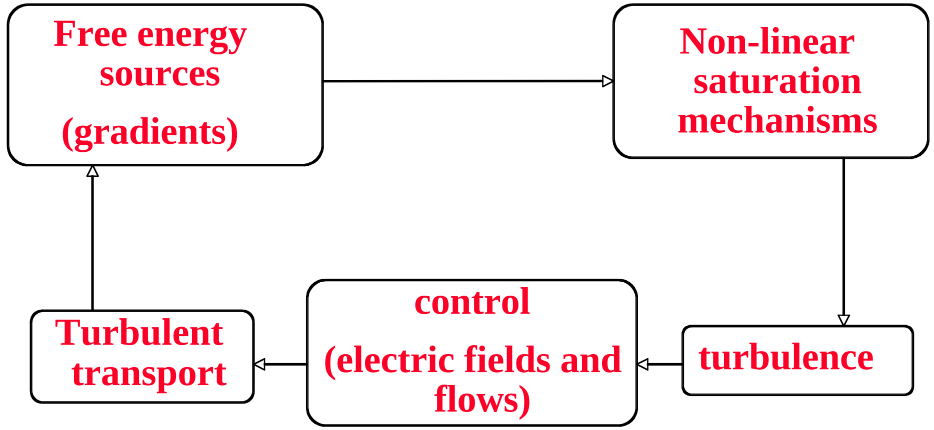
The essential features are the elliptical circulations and the systematic tilts of their major axes.

Physics of negative viscosity phenomena (with applications to earth and solar atmospheres, spiral galaxies, oceanic circulations)

V. P. Starr , Earth and planetary science series, McGraw-Hill (1968)

Sheared flows and transport in fusion plasmas





Sheared flows (electric fields) can damp the turbulence level, and the resulting transport can influence the gradients (the free energy source) themselves – giving rise to a feedback loop.

Negative viscosity physics

Key ingredients:

•The eddies which transport momentum contrary to the gradient of mean flow must have a supply of eddy kinetic energy.

•Symmetry breaking (e.g. Eddy tilting…….)

•Turbulent "irregularities"

•The mean flow must be subject to some form of braking action so as not to increase without limit (e.g. positive viscosity). But, also this braking should be low enough to allow flow development.

Sustained negative viscosity effects are to be found in systems with great complexity (especially where eddy forcing takes place from the outside):

atmosphere, galaxies, stars,……fusion plasmas

Physics negative viscosity

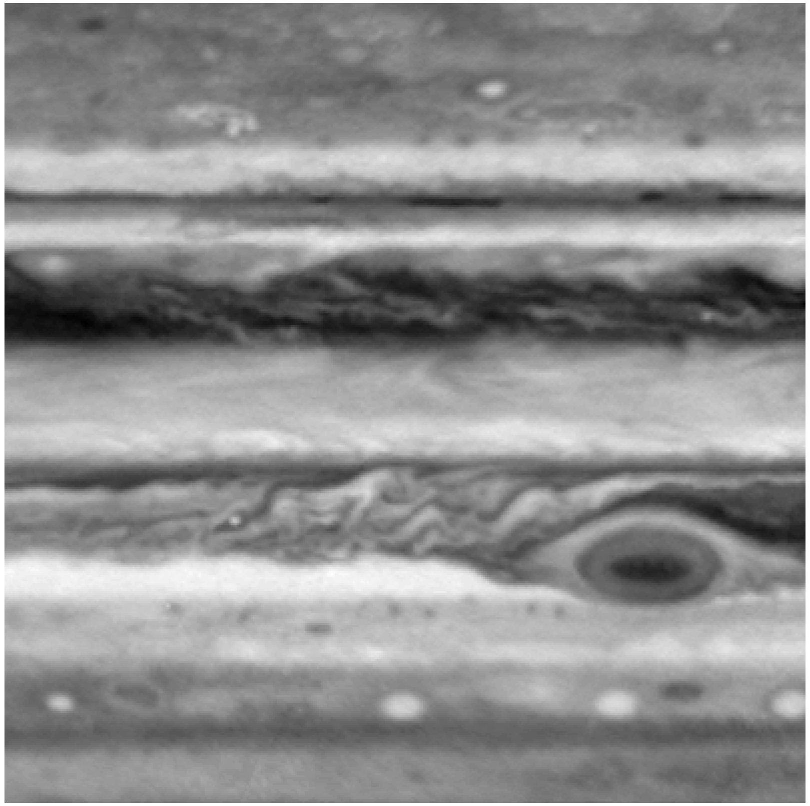
Turbulent anisotropy

Flujo DC

$$\frac{\partial \left\langle \tilde{v}_r \, \tilde{v}_\theta \right\rangle}{\partial r} = \mu V_\theta$$

Turbulent irregularities

Viscosidad positiva (e.g. Neoclásica,…)

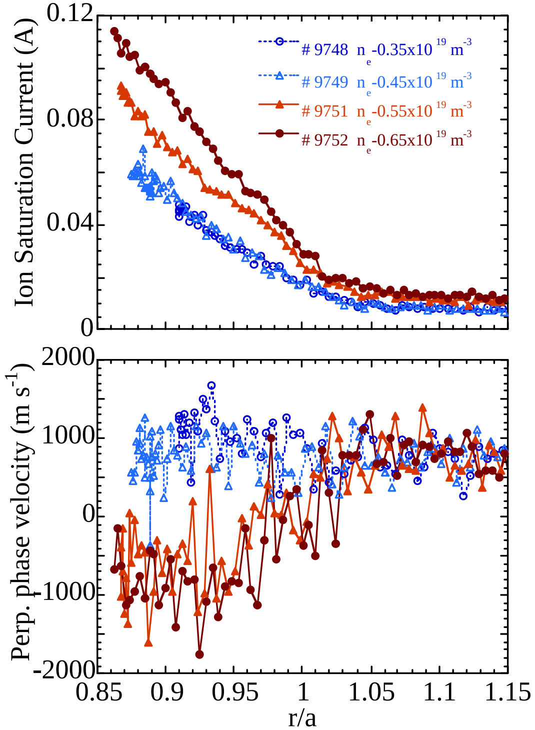


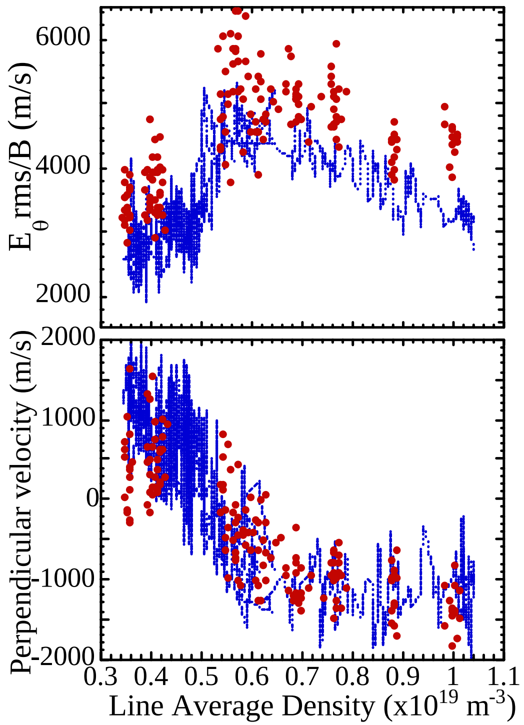
Jupiter (zonal flows): steady-state differential rotation

Edge momentum transport:

experiments in the TJ-II stellarator and the JET tokamak

Link between sheared flow development and turbulence (TJ-II)





•**There is a coupling between the onset of sheared flow development and the level of turbulence**

C. Hidalgo et al., Phys Rev-E 70 (2004) 067402.

Sheared flows and fluctuations in TJ-II appear to be organized near marginal stability. The universality of this property is easily understood assuming that edge sheared flows are controlled by turbulence.

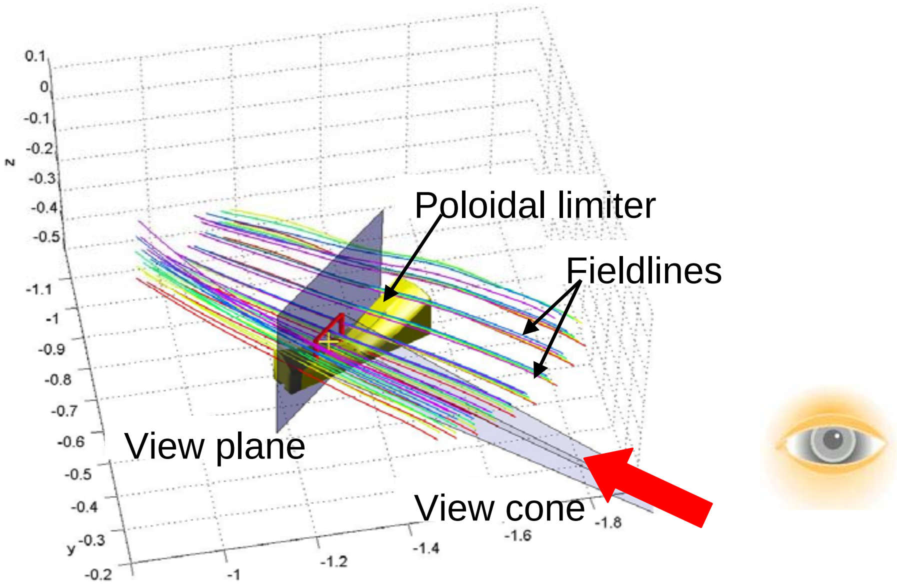
M.A. Pedrosa et al., PPCF 47 (2005) 777

2-D visualization of edge sheared flow development at a threshold density: sheared flows can be developed in a time scale of tens of microseconds

$n < n_{th}$

$n \approx n_{th}$

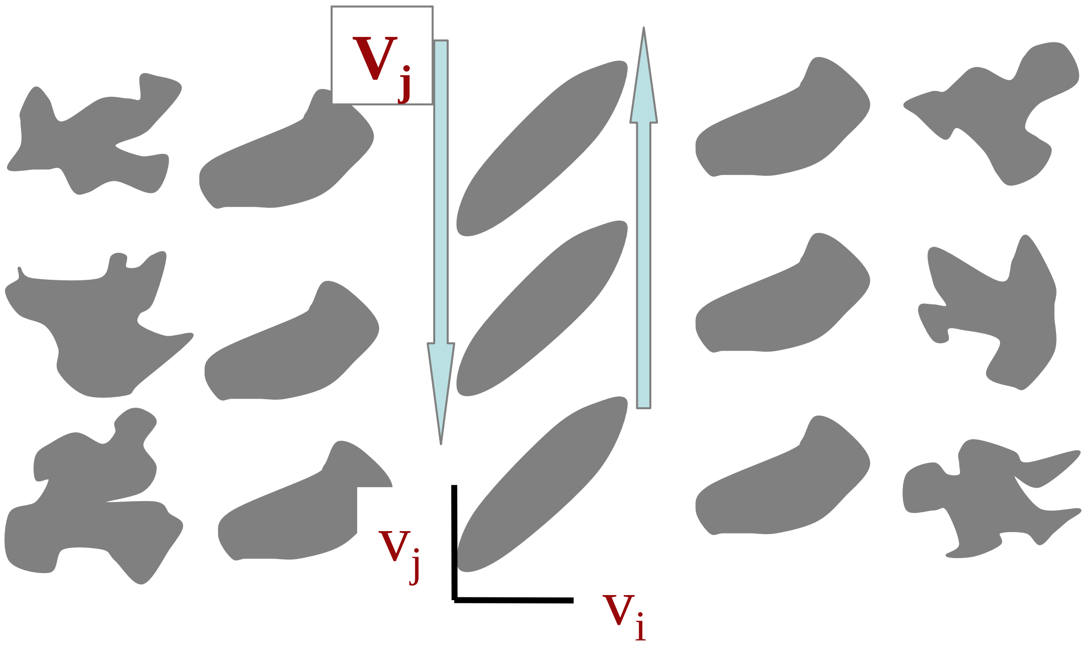
$n > n_{th}$

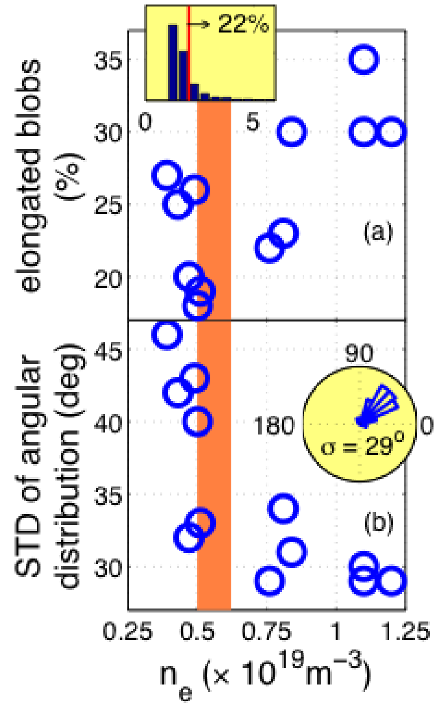


Alonso et al.,

PPCF 48 (2006) B465

Is there any evidence of changes in the degree of turbulence anisotropy during sheared flow development?

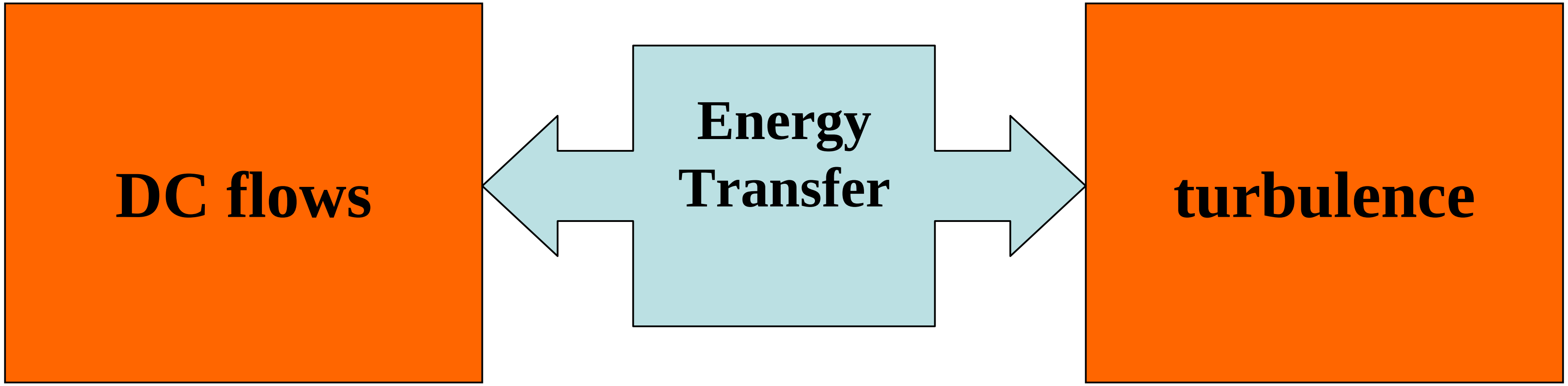




ALONSO, A et al., Plasma Phys. Control. Fusion 48 (2006) B465

•DC flows can be coupled with the degree of turbulent anysotropy ($<v_i v_j>$, momentum transport) .

Quantifying the link between global flows and turbulence: **energy transfer**



B. Gonçalves, C. Hidalgo, M.A. Pedrosa et al.,

Phys. Rev. Lett. 96 (2006) 145001.

Energy transfer computation

Equations for the mean flow (E) and turbulence (k) kinetic energy evolution

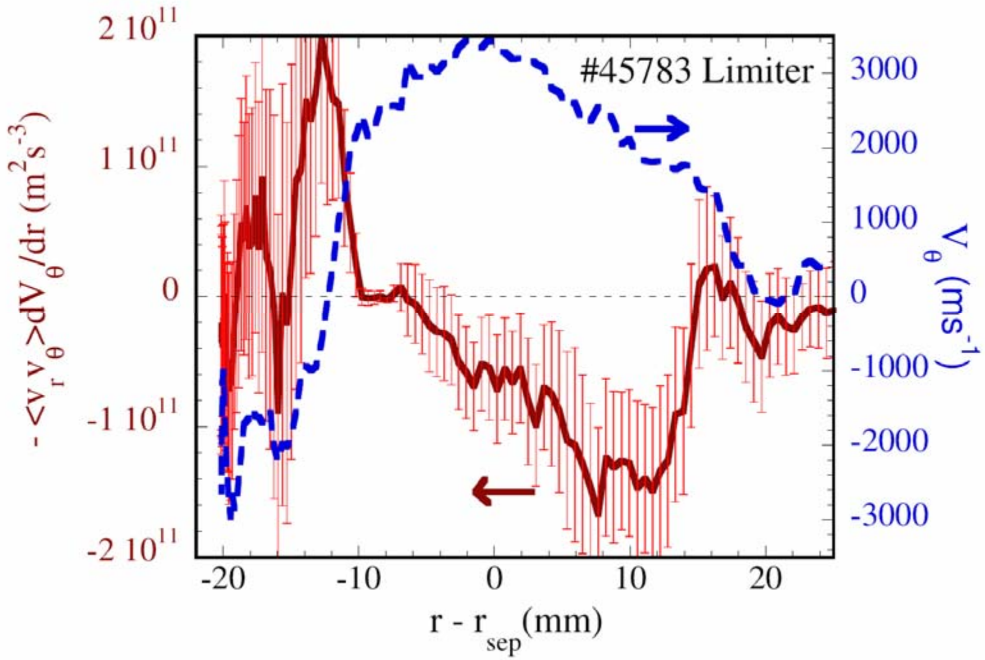
$$\left.\begin{aligned}\frac{dE}{dt}+\nabla\bar{\bar{T}} &= -P-\bar{\varepsilon}\\ \frac{dk}{dt}+\nabla T' &= P-\varepsilon\end{aligned}\right\}$$

$$P \equiv -<v_i v_j> \frac{\partial <V_i>}{\partial x_j}$$

There are four terms in the k equation: the mean flow convection (dk/dt), the turbulent transport, the dissipation (ε) and the production (P).

It should be noted that the production term (P) appears with different sign both in the mean-kinetic-energy equation and turbulent-kinetic-energy equation

Energy transfer in tokamak (JET): radial –perpendicular component



$$P = < \tilde{v}_{\perp} \tilde{v}_r > \frac{\partial V_{\perp}}{\partial r}$$

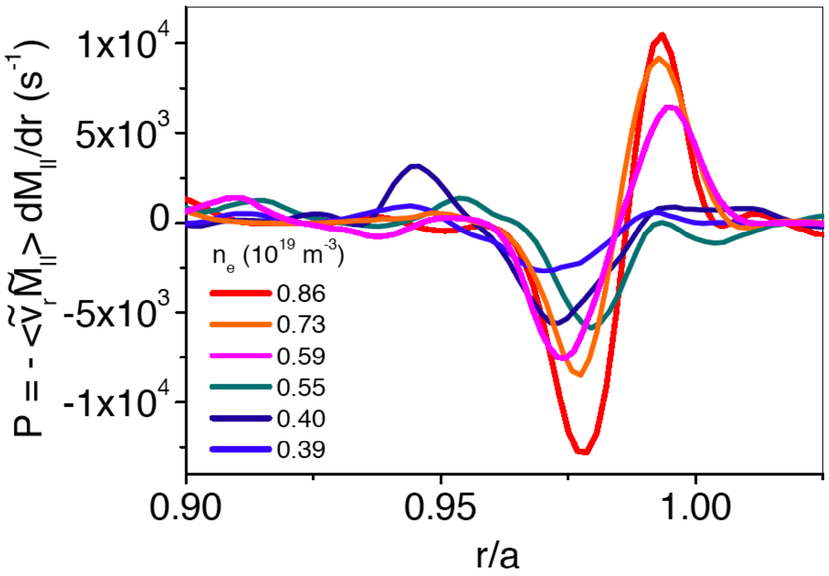
It has been found that the energy transfer from DC flows to turbulence can be both positive and negative in the proximity of sheared flows.

Furthermore, the energy transfer rate is comparable with the mean flow kinetic energy normalized to the correlation time of turbulence, implying that this energy transfer is significant.

These results show that turbulence can act as an energy sink and energy source for the mean flow near the shear layer.

E. Sánchez et al., J. of Nuclear Materials 337 (2005) 296.

Energy transfer in stellarator (TJ-II): parallel-perpendicular component



$$P \approx - < v_{\parallel} v_r > \frac{\partial V_{\parallel}}{\partial r}$$

Evidence of existence of significant energy transfer between turbulence and parallel flows at the on-set of sheared flows in TJ-II stellarator.

B. Gonçalves, C. Hidalgo, M.A. Pedrosa et al., Phys. Rev. Lett. 96 (2006) 145001

Zonal flows: 2-D or 3-D physics ?

ENERGY (DC flows) ⟷ **Energy Transfer** ⟷ **ENERGY turbulence**

2-D $$P \approx -< v_{\perp} v_r > \frac{\partial V_{\perp}}{\partial r}$$

3-D $$P \approx -< v_{\parallel} v_r > \frac{\partial V_{\parallel}}{\partial r} - < v_{\perp} v_r > \frac{\partial V_{\perp}}{\partial r}$$

Conclusions

- Identifying the underlying physics of negative viscosity effects on fusion plasmas is a key research issue. This topic opens many possibilities for interdisciplinary research (e.g. astrophysics, planetary and fusion science).
- It is now clear that intermittent transport cannot be understood without considering the coupling with plasma (sheared) flows in fusion plasmas.
- Shear flow physics involves 3-D physics phenomena in which both perpendicular and parallel dynamics are involved.
- Experimental results show that turbulence can act as an energy sink and energy source for the mean flow near the shear layer.