ID: 644

Nonlinear equilibria and transport processes in burning plasmas

M. V. Falessi[1,2], S. Briguglio[2], L. Chen[3,4], Z. Qiu[3] and Fulvio Zonca[2,3]

[1] Consorzio CREATE, Via Claudio 21, Napoli, Italy

[2] C.R. ENEA Frascati, C.P. 65, 00044 Frascati, Rome, Italy

[3] Inst. for Fusion Theory and Simulation and Dept. of Physics, Zhejiang University, Hangzhou 310027, P.R.C.

[4] Dept. Physics and Astronomy, University of California, Irvine, CA 92697-4575, USA

matteo.falessi@mailbox.org

ABSTRACT

- We introduce a theoretical framework to describe transport in the phase space based of the theory of Phase Space Zonal Structures (PSZS) [1-5]
- we extend the usual definition of plasma equilibrium in the presence of a residual level of electromagnetic fluctuations, i.e. the Zonal State (ZS)
- governing equations are derived by means of Gyrokinetic transport theory
- as a simple application, we describe ZS evolution in the absence of symmetry breaking fluctuations
- we show the evolution of PSZS during an EPM simulation by means of HMGC [6]

BACKGROUND

- Predicting the dynamics of a burning plasma over long time scales, i.e. comparable with the energy confinement time or even longer, is essential to understand next generation fusion experiments
- most of the works for the study of core plasma transport are based on a systematic separation of scales between the reference equilibrium and fluctuations
- energetic particle (EP) transport in fusion devices is a spatiotemporal multi-scale process
- spatio-temporal mesoscales can be observed even in drift wave plasma turbulence simulations
- in a recent work [2] we have emphasized the fundamental importance of the self-consistency of the adopted description, including the determination of the characteristic spatiotemporal scales of the reference state

PHASE SPACES ZONAL STRUCTURES (PSZS)

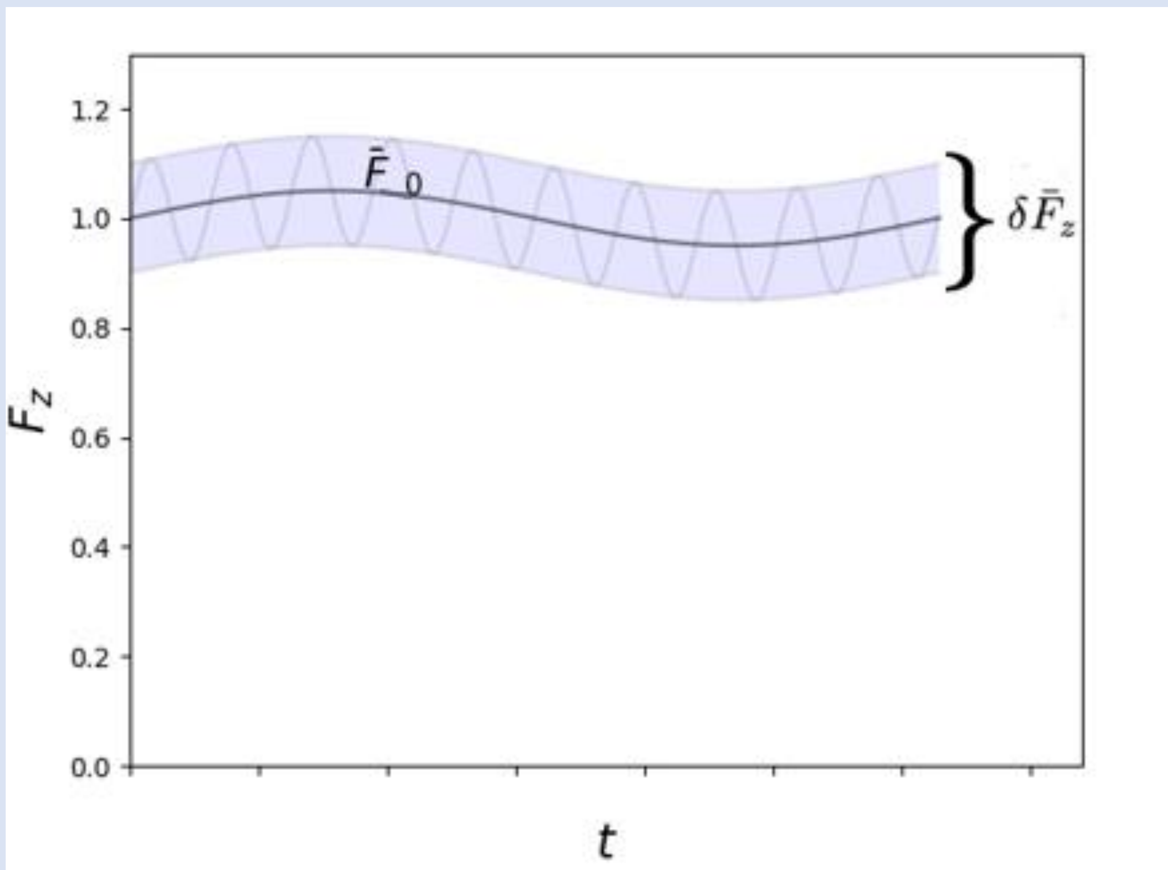
- PSZS equation is connected with the macro- meso-scopic component unperturbed orbit-averaged distribution function:

$$\frac{\partial}{\partial t}\overline{F_{z0}}+\frac{1}{\tau_b}\left[\frac{\partial}{\partial P_\phi}\overline{\left(\tau_b\delta\dot{P}_\phi\delta F\right)_z}+\frac{\partial}{\partial\mathcal{E}}\overline{\left(\tau_b\delta\dot{\mathcal{E}}\delta F\right)_z}\right]_S=\overline{\left(\sum_b C_b^g[F,F_b]+\mathcal{S}\right)_{zS}}$$

- we can decompose the toroidally symmetric distribution function

$$F_z=\overline{F_{z0}}+\overline{\delta F_z}+\delta\tilde{F}_z$$

- micro-scales are accounted by $\overline{\delta F_z}$ while macro- & meso-scales are described by PSZS



Equilibrium orbit averaged distribution

ZONAL STATE (ZS)

- Computing the ZS dynamics require equations for the zonal field structures (ZFS), i.e. the long lived component of toroidal symmetric fields
- assume, for simplicity, that ZS is characterized predominantly by the scalar potential $\delta\phi_z$
- we can study its self-consistent evolution in the absence of symmetry breaking fluctuations
- the scalar ZFS is obtained substituting the orbit averaged distribution function into the quasi neutrality condition:

$$\sum_s\left\langle\frac{e^2}{m}\frac{\partial F_{z0}}{\partial\mathcal{E}}\right\rangle_v\delta\phi_z+\sum_s\left\langle e\hat{I}_0\delta G_z\right\rangle_v=0$$

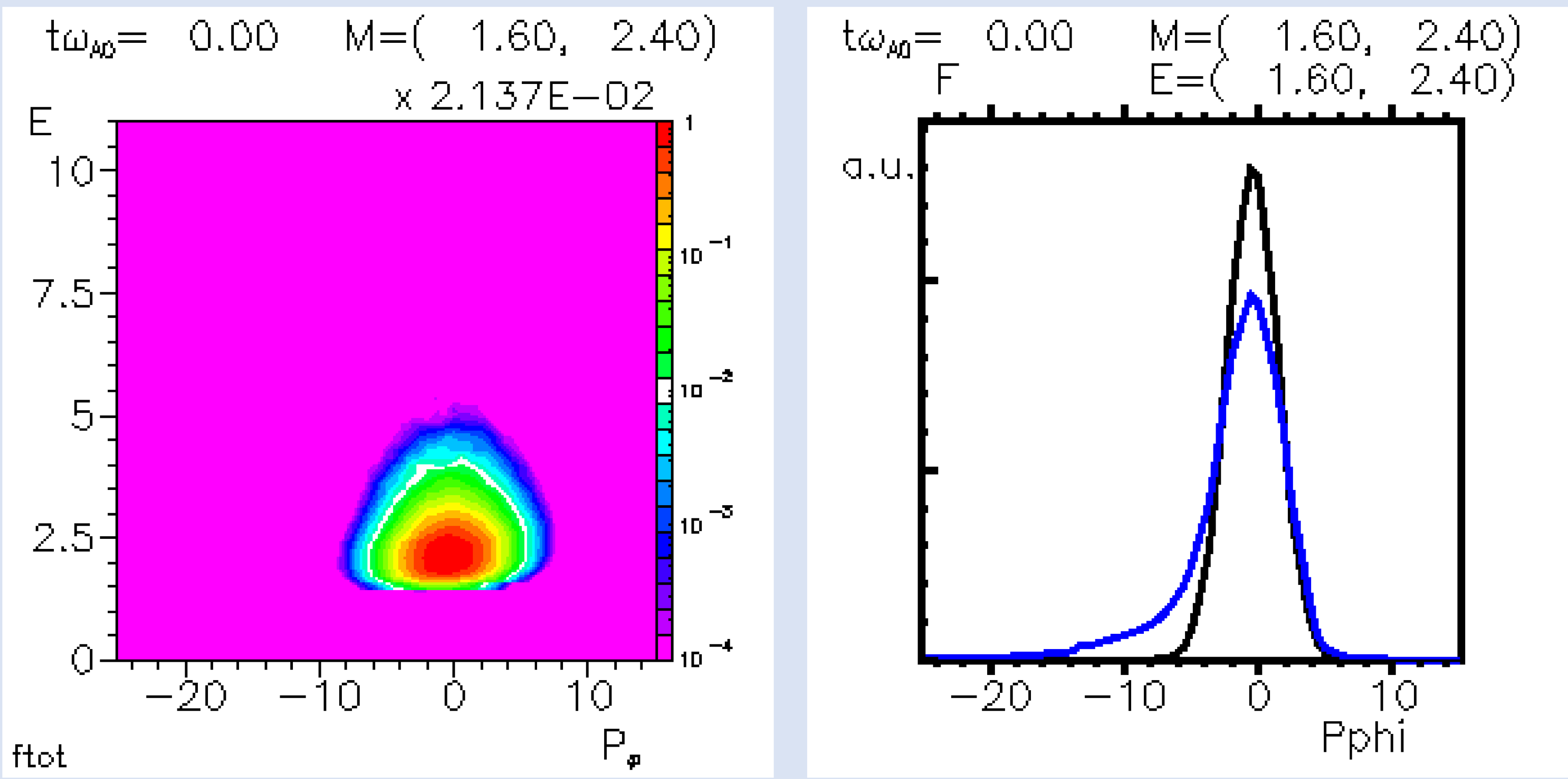
$$(\partial_t+\omega_b\partial_{\vartheta c})\delta G_B=-e^{-iQ_z}\left[\frac{e}{m}\frac{\partial F_{z0}}{\partial\mathcal{E}}\hat{I}_0\partial_t\delta\phi_z+NL\right]$$

- substituting the $l=0$ component into the flux surface averaged QN:

$$\sum_s\frac{V'_\psi}{4\pi^2}\frac{e^2}{m_s^2}\left\langle\left\langle\frac{\partial F_{z0}}{\partial\mathcal{E}}\delta\phi_z-e^{-iQ_z}\overline{\hat{I}_0e^{iQ_z}\hat{I}_0\frac{\partial F_{z0}}{\partial\mathcal{E}}\delta\phi_z}\right\rangle_v\right\rangle_\psi=$$

$$\sum_s\sum_\sigma\int d\mathcal{E}d\mu\tau_B e\frac{i}{\omega}\overline{e^{iQ_z}\overline{\hat{I}_0e^{iQ_z}NL}}$$

- F_{z0} is an arbitrary (renormalized) anisotropic distribution function;
- neglecting the non linear term we can study the polarizability in arbitrary geometry and realistic F_{z0};
- results known in literature, e.g. Wang and Hahm 2009 ; Lu et al. 2019 , are recovered in the proper limits;
- GAM/EGAM dispersion relations retaining finite Larmor radius and finite orbit width effects can be derived according to this expression;



PZSZ evolution during an EPM simulation by HMGC [6]

CONCLUSION

- we have introduced the concept of zonal state to describe the evolution of the plasma between neighboring nonlinear equilibria;
- governing equations for all the components of the ZS have been derived;
- the system is closed by the governing equations for em potentials.

ACKNOWLEDGEMENTS / REFERENCES

[1] L. Chen and F. Zonca, Reviews of Modern Physics 88.1 (2016), [2] Falessi M V and Zonca F 2019 Physics of Plasmas 26.2, [3] Zonca F, Chen L, Falessi M and Qiu Z 2021 Journal of Physics: Conference Series 1785 [4] F. Zonca et al. New Journal of Physics 17.1 (2015), [5] Falessi M V Chen L, Qiu Z and Zonca F 2021 to be submitted to New Journal of Physics, [6] Briguglio S et al. Physics of Plasmas 2.10

This work has been carried out within the framework of the EUROfusion Consortiumand has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed therein do not necessarily reflect those of the European Commission