TP6.00149

Ohm's Law in Gyrokinetic Magnetic Reconnection

Ryusuke NUMATA[1,*], Tomoya Tatsuno[1], William Dorland[1], Barret Rogers[2]
1) Center for Multiscale Plasma Dynamics, The University of Maryland
2) Department of Physics and Astronomy, Dartmouth College
*) Email: rnumata@umd.edu Web: http://www.glue.umd.edu/~rnumata/

Introduction

Magnetic reconnection is the phenomena which couples widely separated scales

Using gyrokinetics, we can seamlessly study different regimes in a strong guide field limit

Acknowledgements

The authors would like to thank N. F. Loureiro and A. A. Schekochihin for useful discussions.
This work is supported by DOE center for multiscale plasma dynamics.

Derivation of Ohm's law

Gyrokinetic equation

describes evolutions of distribution function *h* in gyrocenter coordinate (***R, V***) $\boldsymbol{R}=\boldsymbol{r}+\frac{\boldsymbol{v}\times\boldsymbol{b}_0}{\Omega}$

$$f_s=f_{0s}+q_s\phi T_{0s}+h(\boldsymbol{R})$$

$$\frac{\partial h_s}{\partial t}+V_\parallel\frac{\partial h_s}{\partial Z}+\frac{1}{B_0}\{\langle\chi\rangle_{\boldsymbol{R}_s},h_s\}=\frac{q f_{0s}}{T_{0s}}\frac{\partial\langle\chi\rangle_{\boldsymbol{R}_s}}{\partial t}+\langle C(h_s)\rangle_{\boldsymbol{R}_s},$$

$$\chi=\phi-\boldsymbol{v}\cdot\boldsymbol{A}.$$

Gyrokinetic field equations

relates between fields and moments in ***r***

$$\sum_s q_s\tilde{n}_s=0,\qquad \tilde{n}_s=\int\delta f_s\,\mathrm{d}\boldsymbol{v}=\int\langle h_s\rangle_{\boldsymbol{r}}\mathrm{d}\boldsymbol{v}-\frac{q_s n_{0s}}{T_{0s}}\phi$$

$$\nabla_\perp^2 A_\parallel=-\mu_0\sum_s q_s n_{0s}\tilde{u}_{\parallel,s},\qquad \tilde{u}_{\parallel,s}=\frac{1}{n_{0s}}\int\delta f_s v_\parallel\mathrm{d}\boldsymbol{v}=\frac{1}{n_{0s}}\int\langle h_s v_\parallel\rangle_{\boldsymbol{r}}\mathrm{d}\boldsymbol{v}$$

$$B_0\nabla_\perp\delta B_\parallel=-\mu_0\nabla_\perp\cdot\tilde{\mathsf{P}}_{\perp,s}\qquad \begin{aligned}\tilde{\mathsf{P}}_s&=\int m\boldsymbol{v}\boldsymbol{v}\,\delta f_s\,\mathrm{d}\boldsymbol{v}\\&=\int m v_\parallel^2\langle h_s\rangle_{\boldsymbol{r}}\mathrm{d}\boldsymbol{v}+\int\langle m\boldsymbol{v}_\perp\boldsymbol{v}_\perp h_s\rangle_{\boldsymbol{r}}\mathrm{d}\boldsymbol{v}-q_s n_{0s}\phi\,\mathrm{I}\\&=P_{\parallel\parallel,s}\boldsymbol{e}_\parallel\boldsymbol{e}_\parallel+P_{\perp\perp,s}\boldsymbol{e}_\perp\boldsymbol{e}_\perp+P_{\theta\theta,s}\boldsymbol{e}_\theta\boldsymbol{e}_\theta+P_{\theta\parallel,s}\boldsymbol{e}_\theta\boldsymbol{e}_\parallel\end{aligned}$$

Ohm's law

is derived by taking 1st order $v_\parallel$ moment in ***r***

$$m_e n_{0e}\frac{\partial\tilde{u}_{\parallel,e}}{\partial t}+\frac{1}{B_0}\Big(m_e n_{0e}G(\{\phi,\tilde{u}_{\parallel,e}\})-G(\{A_\parallel,(\tilde{P}_{\parallel\parallel,e}+n_{0e}q_e\phi)\})+G(\nabla^{-1}\{\delta B_\parallel,\tilde{P}_{\theta\parallel,e}\})\Big)+n_{0e}q_e\frac{\partial}{\partial t}\langle\langle A_\parallel\rangle_{\boldsymbol{R}}\rangle_{\boldsymbol{r}}=M_\parallel$$

Inertia

Off-diagonal pressure

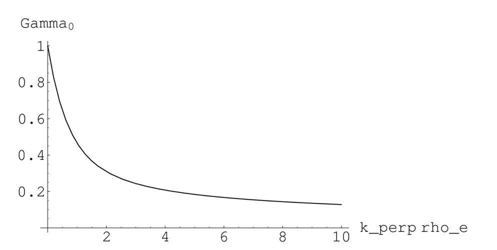
Where nonlinear terms cannot be simply given by fields and moments

$$G(\{\phi,\tilde{u}_{\parallel,e}\})=\sum_k e^{i\boldsymbol{k}\cdot\boldsymbol{r}}\sum_{\boldsymbol{k}'+\boldsymbol{k}''=\boldsymbol{k}}\left(-[\boldsymbol{k}',\boldsymbol{k}'']\phi_{\boldsymbol{k}'}\frac{1}{n_0}\int J_0(\alpha_e'+\alpha_e'')J_0(\alpha'_e)v_\parallel h_{e,\boldsymbol{k}''}\mathrm{d}\boldsymbol{v}\right)$$

$$G(\{A_\parallel,(\tilde{P}_{\parallel\parallel,e}+n_{0e}q_e\phi)\})=\sum_k e^{i\boldsymbol{k}\cdot\boldsymbol{r}}\sum_{\boldsymbol{k}'+\boldsymbol{k}''=\boldsymbol{k}}\left(-[\boldsymbol{k}',\boldsymbol{k}'']A_{\parallel,\boldsymbol{k}'}\int J_0(\alpha_e'+\alpha_e'')J_0(\alpha_e')mv_\parallel^2 h_{e,\boldsymbol{k}''}\mathrm{d}\boldsymbol{v}\right)$$

$$G(\nabla^{-1}\{\delta B_\parallel,\tilde{P}_{\theta\parallel,e}\})=\sum_k e^{i\boldsymbol{k}\cdot\boldsymbol{r}}\sum_{\boldsymbol{k}'+\boldsymbol{k}''=\boldsymbol{k}}\left(-[\boldsymbol{k}',\boldsymbol{k}'']\frac{\delta B_{\parallel,\boldsymbol{k}'}}{ik_\perp'}\int iJ_1(\alpha_e'+\alpha_e'')J_0(\alpha_e')mv_\perp v_\parallel h_{e,\boldsymbol{k}''}\mathrm{d}\boldsymbol{v}\right)$$

Electron feels $\langle\langle A_\parallel\rangle_{\boldsymbol{R}}\rangle_{\boldsymbol{r}}=\sum_k e^{i\boldsymbol{k}\cdot\boldsymbol{r}}A_{\parallel,\boldsymbol{k}}\Gamma_0\left(\frac{k_\perp^2\rho_e^2}{2}\right)$



Limiting cases

In $k_\perp\rho_e\ll1$ limit[1],

$$m_e n_{0e}\frac{\partial\tilde{u}_{\parallel,e}}{\partial t}+\frac{1}{B_0}\Big(m_e n_{0e}\{\phi,\tilde{u}_{\parallel,e}\}-\{A_\parallel,(\tilde{P}_{\parallel\parallel,e}+n_{0e}q_e\phi)\}+\{\nabla^{-1}\delta B_\parallel,\tilde{P}_{\theta\parallel,e}\}\Big)+n_{0e}q_e\frac{\partial}{\partial t}A_\parallel=M_\parallel$$

For perturbed maxwellian distribution

$$h_e=f_{0e}\left(\frac{\tilde{n}_e}{n_{0e}}+\frac{q_e\phi}{T_{0e}}+\left(\frac{v^2}{v_{th,e}^2}-\frac{3}{2}\right)\frac{\tilde{T}_e}{T_{0e}}+\frac{2v_\parallel}{v_{th,e}}\frac{\tilde{u}_\parallel}{v_{th,e}}\right)$$

$$P_{\parallel\parallel}=P_{\perp\perp}=P_{\theta\theta}=\tilde{n}_e T_{0e}+n_{0e}\tilde{T}_{0e},\ P_{\theta\parallel}=0$$

Using the perpendicular Ampere's law, we recover the Hall term from

AstroGK[2] (http://www.physics.uiowa.edu/~ghowes/astrogk/)

We are developing a slab gyrokinetics code AstroGK (a simplified version of GS2). Recently, we have implemented full electron-ion collision, which was missing in the previous work using GS2[3]

$$\langle C_{ei}(h)\rangle_{\boldsymbol{R}}=\sum_k e^{i\boldsymbol{k}\cdot\boldsymbol{R}}\nu_{ei}\left(\frac{v_{th,e}}{V}\right)^3\left(\frac{1}{2}\frac{\partial}{\partial\xi}(1-\xi^2)\frac{\partial h_{e,\boldsymbol{k}}}{\partial\xi}-\frac{k^2V^2}{4\Omega_{0e}}(1+\xi^2)h_{e,\boldsymbol{k}}+\frac{2J_0(\alpha_e)V_\parallel u_{\parallel,i}}{v_{th,e}^2}f_{0e}\right)$$

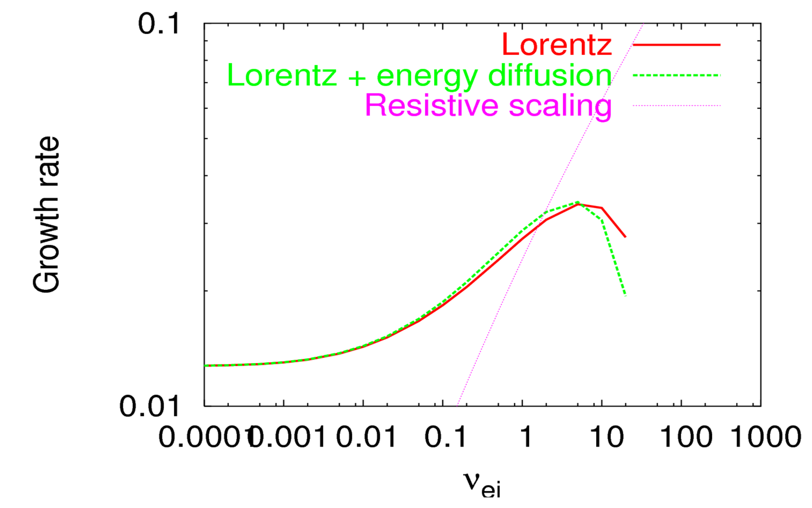
Numerical test of the e-i collision term using the classical Spitzer problem shows that the resistivity is given by

$$\eta=m_e/(1.98\tau_e n_e e^2)$$

where $\tau_e=3\sqrt{\pi}/4\nu_{ei}$ in $k_\perp\rho_i\ll1$ limit[4]

Tearing mode

Collisionless regime

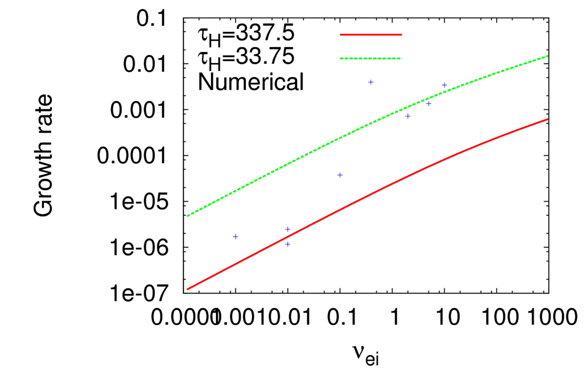


$\Delta'=23$

$\tau_H=3.375$

$\tau_R=\frac{1965}{\nu_{ei}}$

Collisional regime



Conclusions

We have derived ohm's law for gyrokinetic electrons.
Using recently implemented electron-ion collision in AstroGK, we have perfomed tearing mode simulations for collisionless and collisional regimes.

References

1) A.A. Schekochihin *et al*, submitted to Astrophys. J. (arXiv:0704.0044).
2) G.G. Howes *et al*, in preparation.
3) B.N. Rogers *et al*, Phys. Plasmas **14**, 092110 (2007).
4) M. Barnes *et al*, arXiv:0809.3945v2.
5) V.V. Mirnov, C.C. Hegna, S.C. Prager, Phys. Plasmas **11**, 4468 (2004).

UNIVERSITY OF MARYLAND

50th Annual Meeting of the Division of Plasma Physics
Dallas, Texas, November 17–21, 2008