# Average flows and stochastic islands in the magnetic field line random walk

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The nonlinear effects that appear in the field line random walk (FLRW) in magnetic turbulence are discussed. The magnetic lines show both random and quasi-coherent aspects. The random motion leads to diffusive transport while the coherent motion is associated with trapping or eddying in the structure of the stochastic field. The strength of each of these aspects depends on the parameters of the turbulence reflected in the magnetic Kubo number $R = L_{II}\beta/L_{\perp}B_0$, where $\beta$ is the amplitude of the stochastic magnetic field **b**, $B_0$ is the average magnetic field, $L_{II}, L_{\perp}$ are the correlation lengths of **b** along and perpendicular to $\mathbf{B}_0$, respectively. Trapping is negligible for R < 1, and it is statistically relevant for R > 1, with effects that become stronger as R increases. At large R the field line statistics is a mixture of random and quasi-coherent behaviour, with diffusive spreading combined with the generation of stochastic islands. In the limit R $\to\infty$, the transport is subdiffusive.

In special conditions, orientated steps of the field lines can appear even if the average of **b** is zero. They lead to quasi-coherent flows of the magnetic lines. We identify and analyse two sources of flows in FLRW, the large scale variation of the amplitude $\beta$ and of $B_0$.

We have shown that the gradient of $\beta$ determines a quasi-coherent flow along its direction. The average velocity $V_f$ is an increasing function of R at R<1, it reaches a maximum around R=1 and eventually decreases. The decrease is determined by the stochastic magnetic islands, which yield an average velocity in the opposite direction. This process determines the tendency of field line accumulation on the maxima of the amplitude $\beta$.

The gradient of $B_0$ also determines a flow, but with different properties and physical reasons. It is similar to a process found in confined plasmas [3].

The transport coefficients, the average size of the stochastic magnetic islands and the average flows of the magnetic lines are determined. Our instrument, the decorrelation trajectory method [4] is essentially analytical.

[1] Vlad M and Spineanu F 2014 *Astrophys. J.* **791** 56

[2] Vlad M, Spineanu F and Croitoru A 2015 *Astrophys. J.* **815** 11

[3] Vlad M, Spineanu F and Benkadda S 2006 *Phys. Rev. Lett.* **96** 085001

[4] Vlad M, Spineanu F, Misguich J H and Balescu R 1998 Phys. Rev. E 58 7359