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Relevant heating of the solar corona by quenching Alfvén waves : a result of adiabaticity breakdown

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Coronal heating is a long-standing problem in solar physics. Nowadays, it is broadly recognized that the source for this heating likely lies in a mixture between the energy released by magnetic reconnecting events and that delivered to ions by upwardly propagating MHD waves. Among them, Alfvén Waves (AWs) have since long been proposed as plausible candidates by virtue of their stability in the solar environment, and it has been argued that the measured energy flux carried by AWs may potentially account for the whole energy budget [1].

In the coronal environment, ions may be considered as collisionless test particles, which enables a Hamiltonian description of the wave-ion system. The corresponding Hamiltonian system is non-autonomous with a temporal variation parametrized by the ratio between AWs frequency ω and the ion cyclotron one Ω, which is extremely small: $\omega/\Omega << 1$. Within this regime, it is intuitive to argue that particle dynamics *is adiabatic* and that the irreversible transfer of energy, i.e. heating, from a single wave, is impossible [2,3].

However, it was first noticed experimentally and interpreted by McChesney *et al* [4] in the context of laboratory ion heating by drift-Alfvén waves, and then—numerically—by Chen *et al* [5], that ion motion can actually be chaotic even in the presence of a single low-frequency wave.

In this work we provide an analytical and numerical analysis of the non-autonomous single-particle Hamiltonian. We show that, despite the extremely large separation of frequency scales, ion motion in a spectrum of AWs is not adiabatic at all, because it involves one or several slowly pulsating separatrices in phase space, which force particles to cross them in a quasi-periodic way. Each separatrix crossing destroys adiabatic invariance, since the period is infinite there, yielding irreversible energy transfer from the wave, and thus particle heating (see the figure 1 and the video at the URL [6]. An extended discussion is available at [7]), without invoking any stochastic decorrelation. The only mandatory requisite is the presence of at least one separatrix, which translates into a minimum amplitude of the wave. This is a new aspect of neo-adiabatic theory (see [8] and references therein). This heating occurs no matter how narrow the wave spectrum, and contradicts the widespread belief that only decorrelation induced by a broadband spectrum can provide an efficiently heating [3,9]. The only benefit provided by a broadband spectrum is to slightly diminish the amplitude threshold to be imposed upon each individual wave. Third, self-organization is at work here. We show that the single-wave minimum amplitude required for the measured ion heating matches quite well the empirical estimates. The heating mechanism is so efficient that it quenches AWs, which may explain why their energy flux potentially accounts for the whole energy budget in the corona with its measured temperature [1], and not more.

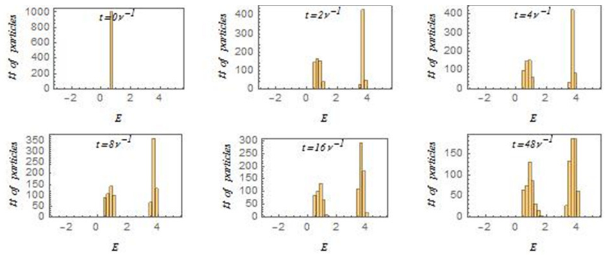

Fig. 1. Energy histogram for particles interacting with a single AW. An initially monoenergetic distribution of ions with otherwise random initial conditions at t = 0 spreads into two separated components after as few as two wave cycles.

References

[1] B. De Pontieu *et al*, Science **318**, 1574 (2007); S.W. McIntosh *et al*, Nature **475**, 477 (2011)

[2] R.M. Kulsrud, Phys. Rev. **106**, 205 (1957); A. Lenard, Ann. Phys. (N.Y.) **6**, 261 (1959)

[3] B.D.G. Chandran, *et al*, Astrophys. J. **720**, 503 (2010)

[4] J.M. McChesney, R.A. Stern and P.M. Bellan, Phys. Rev. Lett. **59**, 1436 (1987)

[5] L. Chen, Z. Lin and R. White, Phys. Plasmas **8**, 4713 (2001)

[6] https://tinyurl.com/y2cve5qn

[7] D.F. Escande, V. Gondret, F. Sattin, https://hal.archives-ouvertes.fr/hal-01929112.

[8] D.L. Bruhwiler and J.R. Cary, Physica D **40**, 265 (1989); Y. Elskens and D.F. Escande, Nonlinearity **4**, 615 (1991); Y. Elskens and D.F. Escande, Physica D **62**, 66 (1993); A.J. Lieberman and M.A. Lichtenberg, *Regular and Stochastic Motion*, chap. 5.7 (Springer, second edition, 1992); A. Bazzani, Il Nuovo Cimento A **112**, 437 (1999)

[9] O.Ya. Kolesnichenko, V.V. Lutsenko and R.B. White, Phys. Plasmas **12**, 102101 (2005); C.B. Wang, C.S. Wu and P.H. Yoon, Phys. Rev. Lett. **96**, 125001 (2006); S. Bourouaine, E. Marsch. and C. Vocks, Astrophys. J. **684**, L119 (2008); C.S. Wu and P.H. Yoon, Phys. Rev. Lett. **99**, 075001 (2007)