

## Irreversibility of Landau damping

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Landau damping is one of the most important elementary process in the plasma kinetics and widely known to plasma physicists. However, its detailed understanding is somewhat controversial and several misconceptions are found in textbooks. One misconception found in most of textbooks is reversibility of collisionless plasmas. Explanation given there is that phenomena in collisionless plasmas are reversible since the Vlasov equation is time symmetric. Experiments on the plasma echo is often referred as an example of this reversibility, saying that the plasma holds the information of its initial state even after the wave dies out by Landau damping.

The plasma echo is, however, not reversible if we interpret the word "reversible" by its literal meaning, which is "the time reversal process actually takes place in the real world." There will never be a process in which the echo occurs first and then the system returns to its initial state. Landau damping is a time irreversible process when we view it from the point of view that tries to derive macroscopic irreversibility from reversible basic equations in statistical physics. In this point of view plasma echo can occur after the wave damped out because the dissipation takes place in velocity space in the same time scale as in real space. This interpretation can be generalized to phenomena in collisionless plasmas, and we can say they are essentially irreversible in the same sense as in ordinary dissipative matters.

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