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Progress in the Heating of Active Region Loops

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Abstract. Coronal heating is an important problem in solar physics. With the development of highly qualified instruments, such as TRACE, SOHO and Yohkoh, more and more observations about coronal loops have been obtained. The coronal loops' heating, being an important ingredient of coronal heating, has been paid particular attentions recently. But there are still some key issues about the structure and mechanism of the loops' heating unresolved. In this paper, after a brief review on the latest progress in both observations and modeling of coronal loops, we emphatically discuss the heating of hydrostatic loops and hydrodynamic loops based on the 1D model. The prospect of the subject is presented.

Keywords. Sun: corona

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1. Introduction

One of the main goals in observing the solar corona is to determine the coronal heating mechanism, a long-standing fundamental problem in solar and stellar physics. EUV and X-ray observations have shown that the building blocks in the solar atmosphere are loop-like structures that outline the coronal magnetic field. In this paper, we mainly discuss properties of nonflaring loops ($T > 10^6 K$) in the solar active regions, especially the heating of them. A lot of work has been done on the heating mechanism both in observation and theory, and one of the mechanisms named the nanoflare heating raised by Parker (1988) at first has been paid more and more attentions, but no definite conclusion has been made on it.

An important first step to understand the problem of coronal heating is to determine the magnitude, duration, and location of heating along a coronal loop. In §2 we present the general observations of the loops, and briefly describe the loop models. The heating of hydrostatic and hydrodynamic loops are discussed in §3. Finally, we will give some discussion about the study of coronal loops' heating.

2. Observations and models

Usually, the observations of coronal loops in EUV and soft X-ray wave bands can be classified into two types, images and spectra. EUV observations are carried out by TRACE, EIT and CDS, and among them TRACE has the highest resolution, while soft X-ray data can be acquired through SXT loaded on Yohkoh satellite.

Due to the limitations of loop observations, at present the heating structure of the loops can only be obtained by comparison between results of the 1-D models and observations. In the three hydrodynamic equations of models, the equation of energy reservation is the most important one, in which conductive loss, radiative loss and the supposed heating term are considered. The loops are evolved from the initial equilibrium state, with their boundaries located in the deep chromosphere.

3. Heating of hydrostatic and hydrodynamic loops

Early in the study of coronal loops, it is supposed that they were in hydrostatic state due to their long lifetime. So we should only consider their spatial distribution of heating. In the famous RTV model proposed by Rosner, Tucker and Vaiana (1978), coronal loops were thought to be uniformly heated. but Aschwanden *et al.* (2000) favored the footpoint heating, because such a nonuniform heating model was more consistent with the flat temperature distribution derived from TRACE data. However, it is still an open question. Different heating structures can be obtained from the same observation and different instruments often lead to different heating structures.

With the development of higher resolution instruments, more and more evidences indicate that majority of the loops are not hydrostatic but hydrodynamic. For example, in the coronal loops blobs exist moving from one footpoint to another; Pressure scale height of EUV loops is often several times of their hydrostatic scale height; And relative to hydrostatic loops, hotter and shorter loops are under-dense, while cooler and longer loops are over-dense.

When a loop is hydrodynamic, we should consider not only its spatial distribution but also its time structure. A representative diagnostic example of heating structure was the work done by Reale *et al.* (2000). (3.1) is a heating function adopted by Warren *et al.* (2003). The function g(t) is chosen to be a simple triangular pulse. What we shall do is to change the parameters in the heating functions to make the results of models more close to the observations.

$$E_H(s,t) = E_0 + g(t)E_F exp[-(s-s_0)^2/2\sigma^2] \tag{3.1}$$

To get more consistent results with the observations, the multi-thread models are included. They are useful to explain the flat temperature distribution and the long time scale of cooling. A kind of multi-thread model that must be mentioned, is the nanoflare-heated model raised by Cargill (1994), in which the main idea was one nanoflare event heated one thread and the nanoflares were distributed randomly in both time and space.

4. Summary and discussion

Recently, more and more efforts have been made to the study of coronal loops heating. But there are still some key issues unresolved both in theory and observation. Perhaps some imaging observations such as TRACE data of cooling loops do not provide adequate information to determine the heating parameters, hence observations must be made early in the evolution of a loop, or we shall depend more on the spectral data, so that to establish models more close to the observations.

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