Multiwavelength Observations of Solar Prominences

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Abstract. We briefly review the multiwavelength observations of solar prominences and filaments ranging from the infrared up to soft X-rays. We give several examples of current observations and mention those specific to the total solar eclipses. Our particular focus is on the ultraviolet (UV) and extreme-UV images taken in various lines of different species.

1. Introduction

Solar prominences are the plasma structures located inside the solar corona, typically at heights ranging from a few thousands km up to several tens or even hundreds thousands km. They are relatively cool, surrounded by the hot corona. Typical temperatures of central cool parts are between 6000 – 8500 K. Outside the central regions the temperature rapidly increases up to coronal values exceeding one million degrees. This particular region is called the Prominence-Corona Transition Region (PCTR). The plasma density in the central coolest parts is about two orders of magnitude larger than that in the corona and thus the presence of the magnetic field is also crucial for the prominence support and stability. The coronal magnetic field penetrates the whole prominence and keeps it in a quasi-static state, supporting its dense plasma against the solar gravity. The intensity of this field is not very large, according to current determinations it ranges from a few Gauss to few tens of Gauss. However, at this point we have to distinguish between the so-called quiescent and active prominences. Quiescent prominences usually last in the corona for many days and even weeks (finally they may be activated and disappear), while active prominences are usually very dynamic phenomena with rather short life-time (minutes or hours). Also the magnetic field in active prominences is typically stronger, its intensity reaches tens of Gauss or even more. Characteristic conditions prevailing in quiescent prominences are summarised in the so-called ‘Hvar Reference Atmosphere of Quiescent Prominences’ (Engvold et al. 1990). The physics of solar prominences is treated in the textbook by Tandberg-Hanssen (1995).

The prominences are tightly connected with the presence of magnetic fields and are, to a certain degree, also related to active regions on the Sun. This is why they are more numerous around the solar maximum. The prominences are very well visible above the solar limb, projected against the dark sky. The best contrast can be reached using the coronagraph equipped with an Hα filter. Due to solar rotation, prominences visible on the east limb move across the solar disk toward the west limb and during this period we can observe them in projection against the solar disk as dark features called filaments. Both
prominences and filaments represent the same kind of an active solar structure, but seen in different projections. This also makes a significant difference in their emitted radiation and thus visibility (contrast).

Solar prominences represent a subject of wide interest for solar physicists. This is mainly due to recent development of various observing techniques. With the help of the largest solar telescopes (located e.g. on Canary Islands) one can resolve prominences or filaments on spatial scales reaching tens of km. Moreover, using the space instruments (telescopes, coronagraphs, spectrographs) it is possible to observe them also in ultraviolet (UV) or extreme-UV (EUV), the wavelength range not accessible from the ground. UV and EUV data provide us with a rich diagnostic information. However, any quantitative analysis of these modern prominence observations requires the development of appropriate numerical models based on an adequate theory of the plasma in a magnetic field and the theory of its interaction with radiation (under non-LTE conditions where the scattering of radiation plays a dominant role).

2. Optical and Infrared (IR) Observations

Solar prominences are most frequently observed in optical lines where they appear in emission above the limb (i.e. against much darker corona) and in absorption as dark filaments on the disk. The reason why we see Hα prominences on the limb in emission and filaments on the disk in absorption is the following: Cool prominence plasma absorbs the radiation coming from the solar disk and scatters it in all directions. Because there is no coronal background in Hα, we see on the limb only the scattered radiation and the Hα line is thus in emission. On the other hand, the chromospheric background of the filament is represented by the Hα absorption-line radiation. Part of this radiation scattered by the filament in the direction toward the observer represents only a fraction of the absorbed one and thus cannot compensate for the absorption. We thus see filaments darker than the background chromosphere in Hα. For more details concerning the non-LTE line formation theory in prominences see Heinzel & Anzer (2005).

Most prominence and filament observations have been acquired in the hydrogen Hα line, using the narrow-band filters. A pictorial atlas of solar prominences can be found at http://www.astro.uni.wroc.pl/prominatlas.html. Hα and calcium Ca II H and K lines are also detected using the spectroheliographs, like the one in Meudon (France) and its twin in Coimbra (Portugal) (see the respective www sites of these observatories for solar images). A unique technique is used in the so-called MSDP instrument, which is capable of getting a 2D field-of-view image in which the spectral line profiles are obtained simultaneously at each spatial pixel. These data, obtained namely in Hα and IR Ca II lines were extensively used to derive the temperatures, densities and line-of-sight velocities in filaments (e.g. Tziotziou et al., 2001).

Recent high-resolution Hα images of prominences and filaments obtained with large solar telescopes on the Canary Islands open new windows for our understanding of the prominence fine structures and their relation to the magnetic field. An example of the fine structures within the disk filament is shown in Fig. 1. As discussed by Heinzel & Anzer (2006), the shape and the nature
of such fine structures will strongly depend on the ratio of the gas-to-magnetic pressure (the so-called plasma beta parameter). When this is close to unity, the fine structures are located in the dipped magnetic field which keeps them in the corona against the solar gravity.

3. Prominences Observed During Total Solar Eclipses

Solar prominences, and in particular the quiescent ones, are frequently seen during total solar eclipses. These observations are usually made in the white-light and the prominences typically appear brighter than the surrounding corona. When their image is taken in color, they mostly show-up as red or pink structures on the white background of the corona. At lower heights, the white-light corona is dominated by its K-component (the so-called K-corona) which is due to the Thomson scattering on free coronal electrons. On the other hand, the pink color of prominences can be explained by their dominant emission in the hydrogen Hα line, mixed with the white-light emission of the prominence itself - for details see a recent work by Jejič & Heinzel (2006).

4. Ultraviolet Spectra and Images

Ultraviolet (UV) observations of solar prominences and filaments have been obtained on Skylab ATM and then by various space observatories like OSO (Orbiting Solar Observatory), SMM (Solar Maximum Mission) and recently by SOHO (SOlar and Heliospheric Observatory). Both spectra, as well as images (rasters), were used to study the properties of cool parts of prominences and the PCTR. On SOHO, the UV spectrograph is called SUMER (Solar Ultraviolet Measurements of Emitted Radiation, see Fleck et al. (1995)). This UV and EUV spectrograph is capable of detecting the solar spectrum in the range from about 500 Å to 1600 Å. This covers also the whole Lyman spectrum of hydrogen, i.e. all lines from the Lα at 1215 Å till the series limit plus the hydrogen Lyman continuum which starts at 912 Å. Such spectra were analysed using sophisticated non-LTE radiative transfer codes which compute the synthetic profiles of the Lyman lines and the continuum intensities for various 1D or 2D models (Heinzel et al. 2001, Heinzel & Anzer 2001). Heinzel et al. (2001) show the profiles of the
5. Extreme UV - Surprising Appearance of Prominences

With the recent generation of satellites the prominences are now also observed in the extreme UV (EUV) range of the spectrum. Both PCTR lines and coronal lines have been studied in this context. New particularly interesting observations come from the *Extreme Ultraviolet Imaging Telescope* EIT on board of SOHO (Fleck et al. 1995) and from the *Transition Region and Coronal Explorer* TRACE. These instruments observe the iron lines of Fe IX at 171 Å, of Fe XII at 195 Å and of Fe XV at 284 Å. The formation temperatures of these coronal lines peak at 1.3, 1.6 and 2.0 $10^6$ K, respectively. EIT observations also include the PCTR line of He II at 304 Å, corresponding to a temperature of about 50000 K. In addition to the EIT and TRACE iron lines, some other coronal EUV lines
have been detected by the Coronal Diagnostic Spectrometer CDS instrument on SOHO (Fleck et al. 1995) with its grazing incidence spectrograph.

Contrary to optical and most UV lines emitted by the cool parts and by PCTR, the prominences observed in hot coronal lines appear dark relative to the bright coronal background (Kucera et al., 1998) - see Fig. 2. This is rather surprising for the first sight and can be explained as follows. Coronal radiation of EUV lines which lie below the head of the hydrogen Lyman continuum (at 912 Å) can be absorbed by neutral hydrogen which is abundant in cool prominence structures. For even shorter wavelengths an additional absorption by neutral helium can occur below 504 Å and for very short wavelengths below 228 Å also singly ionized helium will contribute under specific conditions. All cool structures (typically below 20000 K) which extend into the hot solar corona can have essentially two effects on the radiation which is detected in the coronal EUV lines. If the lines considered have wavelengths below 912 Å then the radiation is absorbed by hydrogen and helium resonance continua as it passes through the cool material. The second effect which can be present is the volume blocking by cool material. In the case that the cool structures are sufficiently extended along the line of sight the part of the coronal volume occupied by cool plasma does not contribute to the emission in coronal lines and therefore the total radiative output will be correspondingly reduced. For a detailed discussion of these effects see Anzer & Heinzel (2005).

6. Some Comments on Visibility in Soft X-rays

In soft X-rays (SXR), a brightness depression of the SXR corona was noticed by Batchelor & Schmahl (1994), who show several examples of coronal SXR darkenings detected by the SXR telescope (SXT) onboard Yohkoh. Although these examples are not very convincing (the SXR corona is very inhomogeneous anyway), they deferred the authors’ attention. These dark features were then interpreted as due to the continuum absorption in the X-ray region.

Heinzel et al. (2006) studied the region around a prominence observed on 5 September 1996 which was also detected by SXT on Yohkoh. This makes possible to compare the SXR features with the above-mentioned UV and EUV structures seen by SOHO. In Fig. 3 from Heinzel et al. (2006) we show the SOHO/EIT image in the HeII 304 Å line, which can be compared with an SXT image taken in the Al.1 filter more than one hour later. We see clearly an extended dark feature in SXR, but it resembles more the brightness depression some times seen in hot EIT coronal lines, rather than narrower cool structure.

The question arises whether the dark SXR structure indeed results from an absorption of the background coronal radiation. Our answer is no and this is supported by quantitative estimates based on the multiwavelength observations. For further discussion see Heinzel et al. (2006).

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Figure 3. SOHO/EIT image of the prominence in the HeII 304 Å line (left) and the Yohkoh/SXT image of the same region (both images here are negative).

References