Hinode-3: The 3rd Hinode Science Meeting
ASP Conference Series, Vol. 454
T. Sekii, T. Watanabe, and T. Sakurai eds.
©2012 Astronomical Society of the Pacific

Mass of Solar Prominences Estimated from Multi-Wavelength Data

P. Schwartz,[1] F. Fárník,[1] P. Heinzel,[1] P. Kotrč,[1] and U. Anzer[2]

[1]*Astronomical Institute, Academy of Sciences of the Czech Republic, Ondřejov, Czech Republic*

[2]*Max-Planck-Institut für Astrophysik, Garching, Germany*

Abstract. The mass of selected prominences was estimated using their multi-wavelength observations: in Hα by the HSFA2 spectrograph of the Ondřejov observatory, in EUV by SoHO/EIT and in the soft X-rays by Hinode XRT. The results are compared with values estimated by other authors.

1. Introduction

The total mass together with temperature, plasma density and structure of the magnetic field belongs to the important characteristics of the prominence. The total mass can be a crucial input parameter to the magneto-hydrostatic models of prominences to evaluate the strength of the magnetic field supporting the prominence plasma against its gravity. The total mass can be also used for estimating how much the prominence contributes to the mass ejected by a CME after a prominence eruption.

2. Observations

We use quasi-simultaneous observations of two prominences made by SoHO/EIT in EUV, by Hinode XRT in soft X-rays and in Hα by the HSFA2 multi-channel spectrograph (Kotrč 2009) situated at the Ondřejov Observatory. The two prominences were observed by EIT in the 304 Å, 195 Å and 171 Å channels (observations in the 171 Å channel look similar to those in 195 Å channel and therefore are not shown here). For identification of the Hα prominence in EUV the EIT images in the 304 Å channel were used. For co-alignment of EIT observations with XRT, EIT observations in the 284 Å channel (not shown in the figures) were used. Observations in the 304 Å channel were used also for fixing the prominence area. Observations in 195 Å and 171 Å channels together with X-ray observations are used for computations of the optical thickness in the resonance continua of hydrogen and helium (neutral and ionized) at 195 Å and 171 Å, respectively.

Observations of a small well visible prominence made on June 9, 2007 are shown in Fig. 1. The vertical black line in the Hα slit-jaw image (right lower panel) corresponds to the position of the spectrograph slit. The Hα profiles from the section of the slit crossing the prominence were used for estimations of the optical thickness $\tau_o(\mathrm{H}\alpha)$ of the Hα line centre.

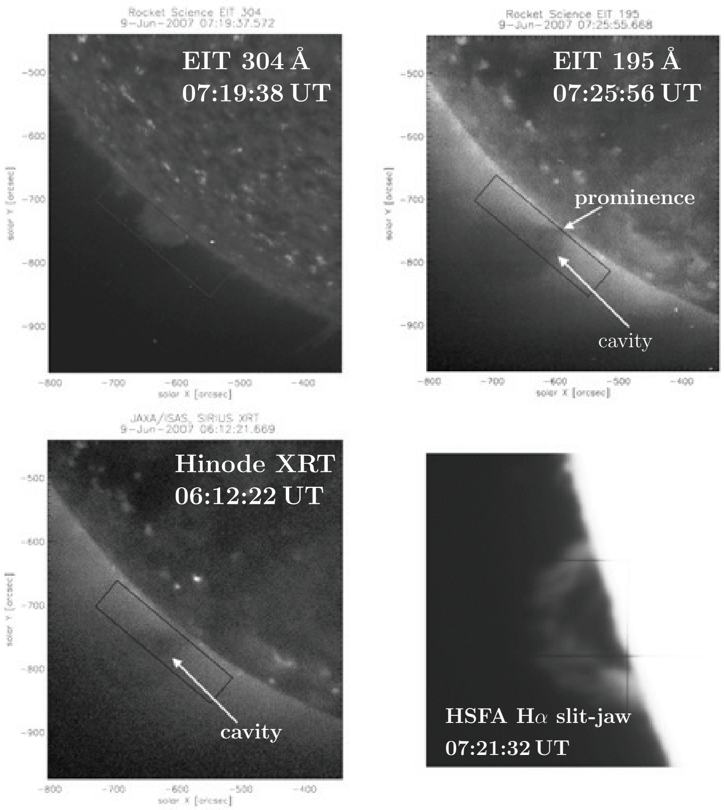

Figure 1. Multi-wavelength observations of the small and well visible prominence on the SE limb made on June the 9, 2007.

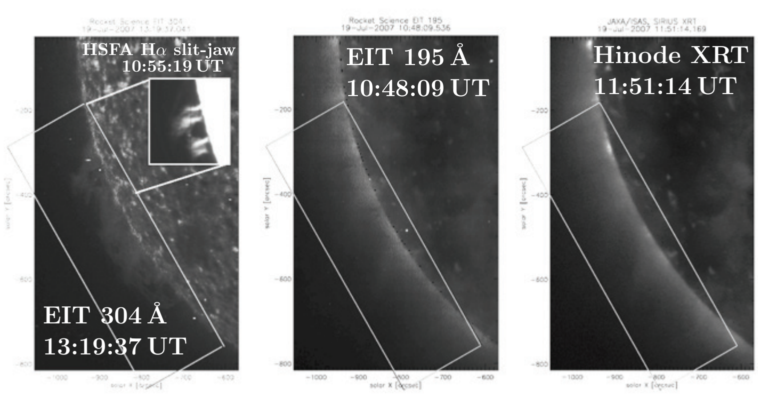

Figure 2. Multi-wavelength observations of the prominence on the SE limb made on July the 19, 2007. The prominence is faint and tangentially rather extended.

Observations of a faint and tangentially extended prominence made on July 19, 2007 are shown in Fig. 2. Inside the 304 Å image there is an example of the HSFA2 Hα slit-jaw showing schematically a part of the prominence observed by HSFA2. The prominence was observed at five slit positions by HSFA2. Eight Hα profiles from these slit positions were taken for estimations of the values of the optical thickness $\tau_o(\mathrm{H}\alpha)$.

3. Method

The value of optical thickness in resonance continua of hydrogen and helium at wavelengths in the EUV spectral range below 912 Å (head of the hydrogen Lyman continuum) can be computed by the following formula (Heinzel et al. 2008):

$$\tau = -\ln\left(1 + \frac{r' - 1}{\alpha}\right), \tag{1}$$

where r' is the ratio between intensities of EUV and X-ray radiation at the prominence position and α expresses the fraction of the X-ray coronal emissivity radiated from behind the prominence. This formula was derived taking into account two mechanisms responsible for a depression of the coronal radiation below 912 Å at the prominence location: absorption by the prominence plasma in hydrogen (H I) and helium (He I and He II) resonance continua and the so-called emissivity blocking which is the lack of coronal EUV emissivity in a volume occupied by the prominence itself and the surrounding cavity. For X-ray radiation there is only the blocking while the absorption is negligible (Anzer et al. 2007).

According to the theoretical work of Anzer & Heinzel (2005), the continuum optical thickness at wavelength λ below 227 Å can be calculated using the following formula:

$$\tau_\lambda = N(\mathrm{H})\ \{(1-i)\ \sigma_{\mathrm{H}}(\lambda) + r_{\mathrm{He}}\ [(1 - j_1 - j_2)\ \sigma_{\mathrm{HeI}}(\lambda) + j_1\ \sigma_{\mathrm{HeII}}(\lambda)]\}\ , \tag{2}$$

where $N(\mathrm{H})$ is the column density of hydrogen, r_{He} is the helium solar abundance set to 0.1 . The ionization degrees of hydrogen and neutral and ionized helium are denoted as i, j_1 and j_2, respectively. Quantities $\sigma_{\mathrm{H}}(\lambda)$, $\sigma_{\mathrm{HeI}}(\lambda)$ and $\sigma_{\mathrm{HeII}}(\lambda)$ are the cross--sections of absorption in hydrogen and helium resonance continua at wavelength λ. Using Eq. (2) it is possible to calculate the ratio τ_{195}/τ_{171} that is independent of the column density of hydrogen $N(\mathrm{H})$. The ratio τ_{195}/τ_{171} is not very much dependent on the values of the ionization degrees i, j_1 and j_2 and it is approximately equal to 1.4 . Using Eq. (1) the ratio τ_{195}/τ_{171} can be estimated from EIT and XRT observations; for the correct value of α this observed ratio should be equal to the theoretical one 1.4 . In such a way values of α can be estimated for the whole area of the prominence. Then the maps of the continuum optical thickness at 195 Å can be computed using Eq. (1). From them, for known values of ionization degrees, the maps of the column density of hydrogen can be calculated using the formula simly derived from Eq. (2). The column mass m of the prominence plasma (consisting almost exclusively of hydrogen and helium) is calculated from the hydrogen column density using a simple formula:

$$m = N(\mathrm{H})\ (m_{\mathrm{H}} + r_{\mathrm{He}}\, m_{\mathrm{He}})\ , \tag{3}$$

where m_{H} and m_{He} are the masses of hydrogen and helium atoms, respectively. Finally, the total mass of the prominence is computed by integrating the column mass over the whole prominence area.

4. Results and discussion

For the prominence of June 9, 2007 an average value of $\tau_o(H\alpha)$=1.2 was estimated from the deviation of the Hα profiles from the Gaussian. According to Anzer & Heinzel (2005), it corresponds to $i \simeq 0.6$ at $T = 8000$ K. Then for $i = 0.6$, $j_1 = 0.5$ and $j_2 = 0$ the total mass of 2.3×10^{11} kg was calculated. For T from 6000 – 10000 K, i from 0.5 to 0.8 can be estimated. Then the mass can be lower by 2% or higher by 13%. Under typical conditions of the plasma of a quiescent prominence j_1 can range from 0.1 to 0.95 and j_2 is close to zero (Labrosse & Goutebroze 2004). Thus, for $i = 0.6$ the mass lower by 26% or higher by 37% could be obtained.

For the prominence observed on July 19, 2007 the average value 1.36 of $\tau_o(H\alpha)$ was estimated. This corresponds to $i \simeq 0.6$ at $T = 8000$ K. Then for $i = 0.6$, $j_1 = 0.5$ and $j_2 = 0$ the prominence total mass of 1.3×10^{12} kg was computed. For T ranging from 6000 to 10000 K, i from 0.5 to 0.8 can be estimated. Then the mass lower by 4% or higher by 18% could be calculated. For j_1 =0.1 – 0.95 and $j_2 \simeq 0$, the mass lower by 6% or higher by 34% can be obtained.

5. Conclusions

The values 2.3×10^{11} and 1.3×10^{12} kg of the total mass estimated in this work for the two studied prominences are comparable with the values of 7.4×10^{11} and 6×10^{11} kg for a different prominence given by Gilbert et al. (2005). They are also close to the values of $8.6 \times 10^{11} - 3 \times 10^{12}$ kg estimated for an EUV filament by Heinzel et al. (2003).

Acknowledgments. This work was supported by grants of the Grant Agency of the Czech Republic 205/07/1100 and 1QS300120506 and by the institutional project AV0Z10030501.

References

Anzer, U., & Heinzel, P. 2005, ApJ, 622, 714
Anzer, U., Heinzel, P., & Fárník, F. 2007, Solar Phys., 242, 43
Gilbert, H.R., Holtzer, T.E., & MacQueen, R.M. 2005, ApJ, 618, 524
Heinzel, P., et al. 2003, in Proc. ISCS 2003: Solar Variability as an Input to the Earth's Environment, ed. A. Wilson, ESA SP-535 (ESA Publication Division, Noordwijk), 447
Heinzel, P., et al. 2008, ApJ, 686, 1383
Kotrč, P. 2009, Cent. Eur. Astrophys. Bull., 33, 327
Labrosse, N., & Goutebroze, P. 2004, ApJ, 617, 614