Research on the destabilization and eruption of prominences/filaments in solar active regions

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The topic of this work is focused on contemporary problems in the study of solar prominences. The thesis is divided into five chapters to which two appendices are added. Two parts with different concepts can be distinguished. The first one covers the first two chapters and includes a summary of the theory of filaments, a review of the unresolved problems, and comments on contemporary solutions. The second part demonstrates the main results of our research. Chapter 3 shows the variations in the velocity distribution of the prominence material during eruption, observed at altitudes up to 0.6 solar radii, as well as the results of promisence observations obtained during the total solar eclipse on 21 August 2017. Chapter 4 is dedicated to another poorly researched topic – the relation between prominences and solar energetic particles, based on the most complete sample of events presented to date. Finally, in Chapter 5 the main scientific contributions and the results of the thesis are summarized. The main results of this study are published in Tsvetkov and Petrov (2018), Tsvetkov et al. (2018), Tsvetkov and Petrov (2020).

The velocity distribution of the prominence material during eruption is studied using space-based solar observations from two observatories. To track the behavior of eruptive prominences (EPs) at heights <0.6 $R_\odot$, data from HeII 304 Å channel of Atmospheric Imaging Assembly (AIA) instrument onboard the Solar Dynamics Observatory (SDO) are used. In case the explored eruption continues after the prominence leaves the AIA field of view, data from Large Angle and Spectrometric Coronagraph/Solar & Heliospheric Observatory (LASCO/SOHO) are inspected. Two of the coronagraphs of LASCO instrument – C2 and C3 allow observations with fields of view from 2 to $6R_\odot$ and from 32 to 37 $R_\odot$, respectively.

Since EPs structures are complex and often there is no coherent leading edge, measurements of EPs kinematic properties require accurate determination of the highest part of the prominence, its position and its tracking during the eruption. For data analysis we obtained IDL procedure based on the SolarSoftware package.

We investigate the behavior during eruption of 41 prominences. Fluctuations of the velocity cannot be unambiguously identified in 7 cases. The kinematic profiles of other 14 EPs oscillations in velocity distribution are noted, but they occur once for the entire eruption and the interval between them cannot be established. There are 20 cases where fluctuations are observed more than once during the eruption and allow additional measurements. They include 3 active region prominences, 1 intermediate prominences, 10 quiescent prominences and 6 polar prominences.

Measured time intervals between the fluctuations do not show periodicity. The values lie in the range 31–244 minutes. For 2 of all 7 prominences that do not show velocity variations, the eruption lasts less than 31 minutes, which makes them inappropriate indicators of the presence of the explored variations. The heights at which they occur (where the local minimum of the speed is reached) also vary. The values lie in the range 55 000–296 000 km. There is strong correlation between the maximum reached height by the EPs and the heights at which fluctuations are registered.

Often the filament eruption continues after the loop leaves the field of view of AIA. Then the rising of the prominence up to $30R_{\odot}$ could be tracked using LASCO coronographs data. Our measurements show that EPs on higher altitudes do not show similar behavior as closer to the solar limb – oscillations similar to these observed by AIA cannot be noticed. The height-time dependence is close to linear for all 10 EPs observed by SOHO.

On the other hand, the current chapter summarizes observations obtained from Oregon, USA, during the total solar eclipse of 2017 August 21. Composite images of the corona are presented, as well as basic information about the registered prominences and their environment.

In Chapter 4 the association rate between solar energetic particles (protons) and filaments and/or filament eruptions (FEs) is investigated using the largest reported event sample. Proton events observed in the period 2010−2016, listed in SOHO/ERNE 20 MeV catalog by Miteva et al. (2017), are accompanied by filaments in 92% (143/156) of the cases. For the studied time period, more SEP events appeared in the northern solar hemisphere than in the southern - 86-to-66 out of 152 cases (57-to-43 %). The preferred solar hemisphere changes at the year of maximum of solar cycle 24 − in the years before April 2014 more SEP events are observed north of the solar equator, while the dependency changes in the second half of the period. Due to the lack of comprehensive catalog of all filaments, a catalog of FEs is used for the reversed association. Only 5% of FEs have in situ proton signatures with larger peak intensity, compared to the median of the entire proton sample. Other solar activity phenomena (flares and coronal mass ejections), related to the proton events show differences in their distributions compared to the respective FE-samples. The indication for a shock wave formation using the type II radio signatures is also considered and discussed.

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