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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Galina Chikunova

PhD Program: Engineering Systems

Title of Thesis: Coronal dimmings associated with coronal mass ejections: evolution, lifetime, and relation to the directivity

Supervisor: Associate Professor Tatiana Podladchikova

Name of the Reviewer: DSc Vladimir kalegaev

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 12-11-2023**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

- Brief evaluation of the thesis quality and overall structure of the dissertation.

Dissertation consists of 8 Chapters which give a good introduction to the field of knowledge and describe well the completed research and obtained results.

Chapters 1-3 are introduction part of thesis. It represents an overview of the Sun, including the main information on its interior and atmosphere, as well as on processes taking place around the Sun. Solar flares and coronal mass ejections are considered as a crucial element of solar dynamics. Coronal dimming phenomena is also introduced and their importance for better understanding the CME formation and propagation are discussed. In general, this part of dissertation gives a good introduction in the research.

Chapter 4 describes observational data that will be used in the next Chapters. The author declares importance of multipoint multi-satellite observations by SDO and STEREO space observatories. Data

preprocessing and calibration methods are described in the framework of IDL SolarSoft and SpacePy packages. Different algorithms of dimming detection are considered in detail.

Chapter 5 is about relationship between CME parameters and characteristics of dimming. As a result of statistical study based on SDO and STEREO observations, correlation between speed and mass of CME and dimming parameters is established.

Chapter 6 is devoted to recovery processes in solar atmosphere after eruption. Dimming lifetime is estimated for several events based on analysis of Sun EUV images.

Chapter 7 describes the concurrent evolution of the dimming region and CME during the early stage of eruption for event on 28 October, 2021. The main conclusion of this chapter is about the close relationship between CME and dimming, that allows to determine the CME direction based on dimming area evolution.

Chapter 8 contains the final discussion of the results and describe the possible future continuation of the research.

In general, this dissertation is the scientific research completed on actual topic, and prepared at high scientific level, when each chapter complements and develops the previous one.

- The relevance of the topic of dissertation work to its actual content

The dissertation is devoted to the relationship between coronal mass ejections and coronal dimmings. The author discussed in detail the nature of coronal dimmings, detection algorithms and methods for dimming analysis in conjunction with CME occurrence and propagation at early stage of evolution. The author proposed the methods allowing to estimate speed, mass and direction of CME based on comprehensive analysis of dimming parameters. The topic of dissertation fully corresponds to its actual content.

- The relevance of the methods used in the dissertation

Now, data coming from solar observatories, mostly, SDO images, SOHO/LASCO images, and Stereo-A images are of great importance for fundamental and applied (space weather) research. Such observations are the unique source of data in the chain “sun-solar wind-magnetosphere” allowing to better understand mechanisms of solar-terrestrial coupling. In addition, these observations give the only possibility to get reliable input for space weather forecasting services. The new approaches proposed in this dissertation allow to extract the “hidden” information on solar activity from the huge amount of satellite data.

The author uses the modern and community accepted software to analyze and calibrate the images (SunPy and SolarSoft), as well as Graduated Cylindrical Shell (GCS) model to reconstruct and analyze CME structure and direction.

The methods developed, data sets and software/models used in this research are completely relevant to the main theme of dissertation.

- The scientific significance of the results obtained and their compliance with the international level and current state of the art

The author developed the new comprehensive methods allowing to analyze the solar images obtained from satellite observations. They include calibration and preprocessing of the images based on the Python SunPy software widely used by scientific heliophysic community. The author developed the accurate methods and algorithms for determination of coronal dimming parameters like brightness, size, area and center of the mass. They are needed to reconstruct CME evolution at the early stages and to better understand the relationships between CME and dimmings.

The author completed statistical study of 43 dimming events based on multipoint SDO and Stereo satellite observations. Sun images processing and analysis show that CME characteristics correspond the dimming dynamics and there exists correlation between dimming parameters and CME speed and mass.

Dimming evolution, lifetime and recovery after eruption were investigated under detailed study of four events. Accurate analysis of long-term observations by SDO and STEREO satellites allows to determine evolution of dimming area and brightness, in comparison between SDO/AIA and STEREO/EUVI-A. The results obtained show a great variety in the dynamics of dimming parameters during the life cycle of this phenomena. Accurate analysis of the images allows to see the different behavior of core and secondary dimmings during corona recovery after eruption.

CME direction is most important parameter that cannot be determined based only on coronograph observations. Dimming characteristics and evolution can have a value for this task. In detailed study of 28/12/2021 dimming event the author shows that dimming grows direction corresponds to direction of CME inner part (magnetic flux rope) propagation in the low corona. This study demonstrates that coronal dimming evolution reproduces eruptive filament propagation and can be used for preliminary determination of the CME direction.

The obtained scientific results are at the high international level and correspond the current state of the art. Every chapter is started from literature overview. The author of dissertation discusses the other works related to this study and give enough references to the related publications. In the end of Section validation of results and extended comparison with the other studies is also provided.

- The relevance of the obtained results to applications (if applicable)

The obtained results have undoubted value for space applications. Space weather is needed firstly in Sun observations that give possibility for medium-term forecasting of space hazards. Approaches and methods developed in dissertation allows the intelligent processing of the observational data and consequent reconstruction of CME parameters and propagation direction, the crucial elements for magnetic storms prediction.

- The quality of publications

Dissertation includes results, obtained in 6 papers submitted in top level international journals.

Summary

Dissertation main objective is to create the new approaches to study the connections between coronal mass ejections and coronal dimmings. Author develop the comprehensive methods allowing to extract the “hidden” information from solar images obtained from SDO and STEREO observations. New results on relationships between dimming characteristics and CME parameters have been obtained. Dissertation is a complete scientific research carried out on an actual topic in the field of heliospheric physics.

I have only editorial comments that do not affect the overall appreciation of the work.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate’s thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*