

**Authors' response to reviewer#3 comments on manuscript
Dynamics of He⁺⁺ ions at interplanetary shocks
by Sapunova et al.**

The authors are grateful to Reviewer for careful consideration of the manuscript and useful comments. Our reply is marked with initials OS and bold text.

Reviewer: This paper presents preliminary results using He⁺⁺ ion high time resolution measurements of the solar wind during the interplanetary shock front passage combined with magnetic field data. Either more information about the study performed should be included if this is to be an individual event study or else more events are needed if it is intended to be a statistical study. The English needs to be read/edited by somebody in the field. This may help to clarify some issues in the text. Below some suggestions for the authors to consider.

OS: We took into account the comments of the reviewer, revised the manuscript and improved the English.

Reviewer:

Abstract: It could be added that BMSW data has high time resolution and that He⁺⁺ measurements were compared with magnetic field data... At the end of the abstract 1-2 sentences presenting the main results would benefit the reader.

OS: The abstract was extended and now it includes information about data added from other satellites and main result obtained in the study.

Reviewer:

...and that 20 out of the 57 registered events were selected...

OS: These details were added to the text in section 3.3: "So, high temperature and high velocity are two main reasons why not all 57 IP shocks were suitable for He⁺⁺ parameters definition. Thus, 20 interplanetary shocks ... were selected..."

Reviewer:

Page 1: The background and the motivation behind the work performed should be elaborated in the introduction. At the end of the introduction shortly present the next sections of the paper.

OS: We expanded the introduction and methodology sections. We added links and explanations; also at the end of the introduction we shortly present the structure of the paper.

Reviewer:

Page 1: IT IS WRITTEN "Interplanetary shocks (IP) generated by solar flares and coronal mass ejections and propagated in the solar wind are one of the main agents transferring perturbations from the Sun to the Earth (e.g., Borrini et al., 1982; Volkmer and Neubauer, 1985; Borodkova, 1986)." The relevance of referring to both solar flares and coronal mass ejections as the origin of IPs needs to be explained in the context of the paper. (see for example Gopalswamy et al. 1998, <https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/97JA02634>).

OS: We corrected inaccuracy made in the IP description and added references:

"Interplanetary shocks (IP) (including generated by so-called High-speed streams from coronal holes and coronal mass ejections) propagating in the solar wind are one of the main agents transferring perturbations from the Sun to the Earth (e.g., Borrini et al., 1982; Volkmer and Neubauer, 1985; Borodkova, 1986; Yue et al., 2010; Ma et al., 2019). "

Reviewer:

PAGE 1: It would be useful if the references "(e.g., Scholer and Terasawa, 1990; Scholer, 1990; Trattner and Scholer, 1991)." could be separated between "...modeling (REF1, REF2) and by experimental data (REF 1, REF2). Which studies have compared outputs from both approaches?

OS: We added references and separated them:

"The study of the changes of He⁺⁺ ions on the IP shock fronts and their interaction was started by Gosling et al., (1978), after which this issue was investigated both by modeling (e.g. Scholer and Terasawa, 1990; e.g. Scholer, 1990; Trattner and Scholer, 1991) and by experimental (e.g., Borrini et al., 1982; Volkmer and Neubauer, 1985; Borodkova, 1986)."

Reviewer:

Page 2: IT IS WRITTEN "The aim of this brief article is to study variations of the density of the He⁺⁺ ions at the front of an interplanetary shock and to detect changes in the He⁺⁺ ions parameters directly next to the ramp with a precision high time resolution." Why is this important? What does it teach us? Does it provide us information about the origin of the IP event?

OS: We included discussion of these problem in the manuscript:

"Variations in the proton and He⁺⁺ ion parameters and the Na α /Np at large-scale distances > 10⁶ km are directly related to the properties of the Sun upper corona and the mechanisms of solar wind formation in it. Therefore, it is an important problem to determine the relative density of helium relative to the main (proton) component variations due to local physical processes at small-scale distance ~10³ km (e.g., Ogilvie and Wilkerson, 1969; Formisano et al., 1970; Borovsky, 2008; Kasper et al., 2012; Safrankova et al., 2013a; Yermolaev et al., 2020 and references therein)."

Reviewer:

Page 3: IT IS WRITTEN "Thus, 20 interplanetary shocks were selected, for which it was possible to isolate the flow of He⁺⁺ ions during the passage of the front." Could the origin of the IP events have anything to do with this selection? 20 out of 57 IP registered events is not a high ratio. Need to better explain why it was not always possible to isolate the flow of He⁺⁺ ions during the passage of the front. A table presenting and comparing the characteristics of the 20 IP events could be useful.

OS: This information was added to the text in section 3.3: "So, high temperature and high velocity are two main reasons why not all 57 IP shocks were suitable for He⁺⁺ parameters definition. Thus, 20 interplanetary shocks ... were selected..."

Also the new set of cases was added to the research to improve reliability of the results and a following table of main parameters was included:

Table 1 Parameters of IP shock and Earth's bow shock crossing.

IP shock crossings						Earth's bow shock crossings		
Date	V _{IP}	β_p	θ_{Bn}	M _{MS}	Na2(%) / Na1(%)	Date	θ_{Bn}	Na2(%) / Na1(%)
09.09.2011	412	3.0	26	3.0	0.6	23.03.2012	77±4	7.3
01.11.2011	403	0.4	74	1.5	0.95	28.03.2012	39±4	1.8
15.05.2012	428	1.5	86	1.0	0.94	05.04.2012	71±5	3.5
21.05.2012	406	1.4	80	2.6	0.71	23.04.2012	52±2	4.5
03.09.2012	457	0.5	35	2.7	0.82	28.05.2012	21±2	3.1
30.09.2012	302	1.8	65	1.8	0.83	07.08.2012	81±5	5.1
08.10.2012	409	0.3	84	1.7	0.91	08.08.2012	65±5	9.5
13.04.2013	472	0.5	47	3.0	0.87	24.08.2012	85±5	11.0
23.04.2013	312	1.5	63	1.6	0.84	16.09.2012	45±4	4.1
18.05.2013	502	0.2	75	1.3	0.99	12.10.2012	88±4	7.2
19.04.2014	520	0.2	62	1.0	0.87	30.10.2012	76±5	4.4
03.05.2014	225	4.0	89	1.2	0.97	02.11.2012	29±5	2.0
07.06.2014	438	0.3	89	2.5	0.92	14.11.2012	84±4	5.6
03.07.2014	309	2.2	55	1.0	0.91	17.11.2012	64±3	7.3

17.03.2015	562	0.3	65	2.3	0.87	24.11.2012	83±2	5.0
21.06.2015	327	2.2	83	5.7	1.12	09.03.2013	84±5	6.9
12.10.2016	431	0.5	21	2.3	0.48	11.03.2013	80±4	4.2
09.11.2016	354	0.6	87	1.6	1.05	11.03.2013	60±4	2.6
31.08.2017	398	0.9	53	1.4	0.92	14.03.2013	76±4	7.9
21.10.2017	395	0.6	76	1.4	0.97	16.05.2013	22±5	5.3
--	--	--	--	--	--	09.06.2013	48±4	3.8
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--	--	--	--	--	--	06.07.2013	32±6	2.5
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Reviewer:

Page 8: IT IS WRITTEN "The presented preliminary results were obtained with a small number of events and require further research." For example (data analysis, modelling)? Though the current study used high time resolution measurements it is not completely clear for me what the investigation has provided (the novelty of the results). This should be presented in the conclusion.

OS: The Conclusion part was also updated and, in particular, the following part was added:

"It was revealed that a correlation exists between $N\alpha/Np$ and the angle θ_{Bn} : the lower the value of the angle θ_{Bn} , the more the helium abundance $N\alpha/Np$ falls behind the IP shock front. For Earth's bow shock crossings it was shown a significant increase of the helium abundance $N\alpha/Np$ in quasi-perpendicular events. These results correspond with ones, showed by Ofman et al. (2019)."

Best regards,
Olga Sapunova