REPLY TO STUCHLÍK ET AL.:

# The Younger Dryas onset at 12.87 ky B.P. is still justified if the Laacher See eruption is considered

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We thank Stuchlík et al. for their comments (1) on our paper (2). First, for the sake of clarity, we note that Stuchlík et al. may have inadvertently stated "$\delta^{18}O$ records in several ice cores from Greenland and Antarctica that were originally dated by the radiocarbon method." This is obviously incorrect, as ice-core $\delta^{18}O$ series are not radiocarbon-dated. We are also intrigued by their comment that "the authors refer to several papers dealing with the Laacher See volcanic eruption (LSVE)" (1), because we neither discussed the LSVE nor cited any papers related to the LSVE (2). We stress that one of the key issues discussed in our paper was evaluating the extraterrestrial impact (3), rather than the LSVE, as an immediate trigger of the Younger Dryas (YD) event. As discussed in previous publications, the extraterrestrial impact has been considered the source of a ~20-y-long Pt anomaly in the Greenland Ice Sheet Project (GISP2) ice core (4) at a depth of 1,712.375 to 1,712.000 m. We suggested that "a possible extraterrestrial impact event at ~12,820 B.P. inferred by Pt-anomaly in the GISP2 ice core appears to lag the initial onset of the YD by ~50 y without apparent disruption on the hydroclimate trend, suggesting that this event might not be the trigger for the YD onset" (2). As we noted in the paper, "the data presented here provide a precise timing framework for further research in the area" (2), including testing the LSVE hypothesis (5).

In response, Stuchlík et al. (1) contest that we mistakenly associated the "first drop in $\delta^{18}O$" with the onset of the YD, rather than climatic reversal of the warm period in which the LSVE tephra is found. However, one can test the causal link of the volcanic sulfate spike (possibly indicating the LSVE) at ~12.9 ky B.P. in the GISP2 to the YD onset by evaluating the occurrence of the sulfate spike in relative to changes in multiple proxies (e.g., $\delta^{18}O$) from the same core without the restraint of age uncertainties (5, 6). A closer look suggests that the immediate hydroclimatic impact (presumably from the LSVE, inferred from the sulfate spike in the GISP2 record), if any, was likely minor, as inferred from the $\delta^{18}O$ record in the same ice core (5). While the volcanogenic sulfate aerosols typically settle out of the atmosphere within 1 to 3 y, the GISP2 $\delta^{18}O$ values were virtually unchanged for more than 30 y after the presumed LSVE sulfate spike in the same ice core (5, 6).

In summary, the main criticism from Stuchlík et al. (1) rests on the potential influence of the LSVE on abrupt cooling at ~12,870 B.P.—an issue not discussed in our paper, but which has been disputed elsewhere—and identification of the YD onset later within the negative $\delta^{18}O$ trend. Nevertheless, our data (2) indeed provide a precise chronological framework for subsequent research in the field, including the LSVE.

We thank the editors for giving us the opportunity to provide a reply to the comments.

## Acknowledgments

This work was supported by grants from National Natural Science Foundation of China (NSFC 41888101 and 41731174 to H.C.).

1 E. Stuchlík *et al.*, Identification of the Younger Dryas onset was confused by the Laacher See volcanic eruption. *Proc. Natl. Acad. Sci. U.S.A.*, 10.1073/pnas.2022485118 (2021).

2 H. Cheng *et al.*, Timing and structure of the Younger Dryas event and its underlying climate dynamics. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 23408–23417 (2020).

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The authors declare no competing interest.



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Published January 18, 2021.

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