

Supplementary information

Lightning at Jupiter pulsates with a similar rhythm as in-cloud lightning at Earth

Ivana Kolmašová^{1,2*}, Ondřej Santolík^{1,2}, Masafumi Imai³, William S. Kurth⁴, George B. Hospodarsky⁴, John E. P. Connerney⁵, Scott J. Bolton⁶, Radek Lán¹

¹Department of Upper Atmosphere, Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague, Czechia

²Faculty of Mathematics and Physics, Charles University, Prague, Czechia

³Department of Electrical Engineering and Information Science, National Institute of Technology (KOSEN), Niihama College, Niihama, Ehime, Japan

⁴Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa, USA

⁵NASA/Goddard Spaceflight Center, Greenbelt, Maryland, USA

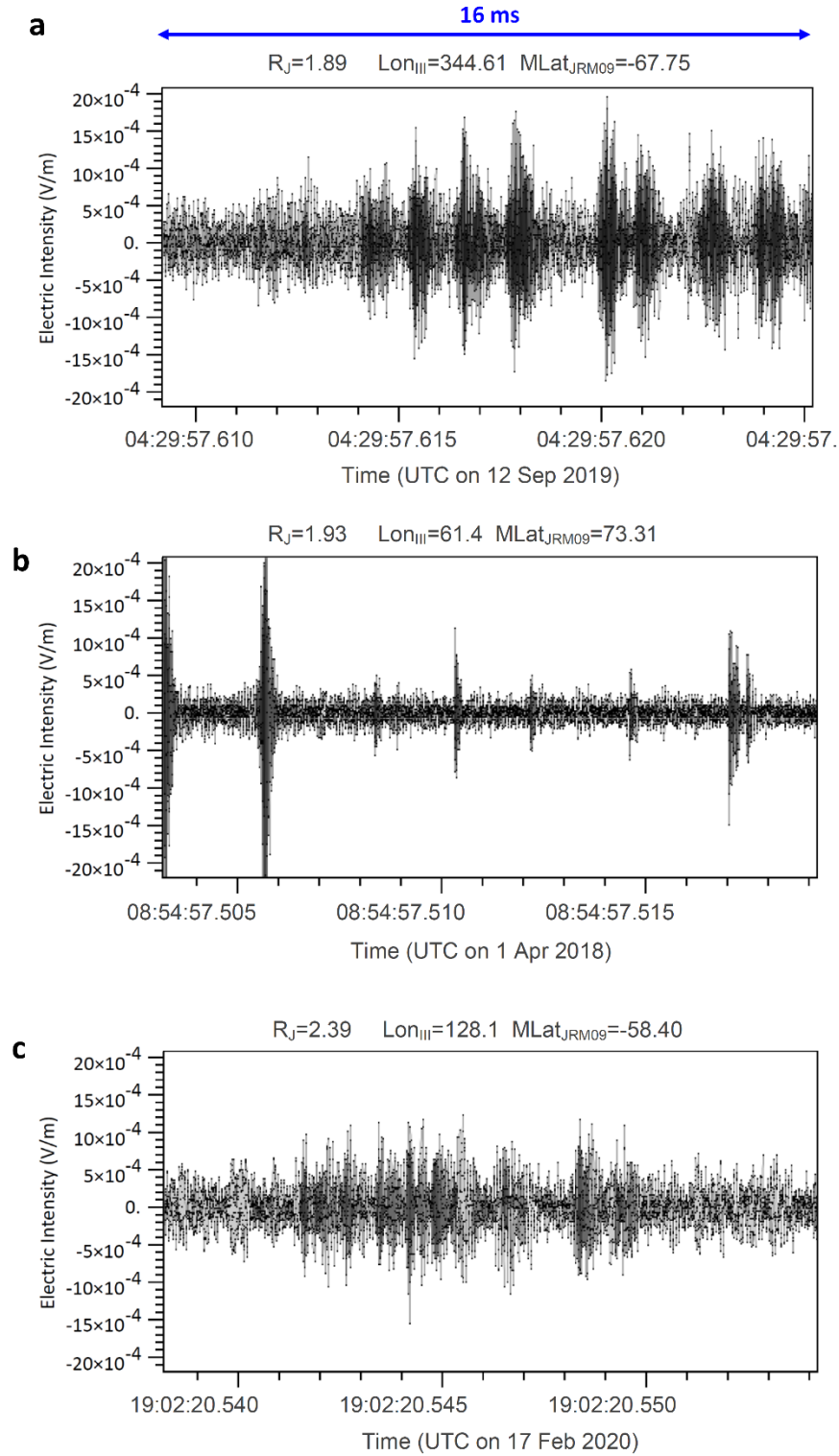
⁶Space Science Department, Southwest Research Institute, San Antonio, Texas, USA

Supplementary Figure 1: Time series of the electric field fluctuations corresponding to time-frequency spectrograms in Fig. 1 in the main paper.

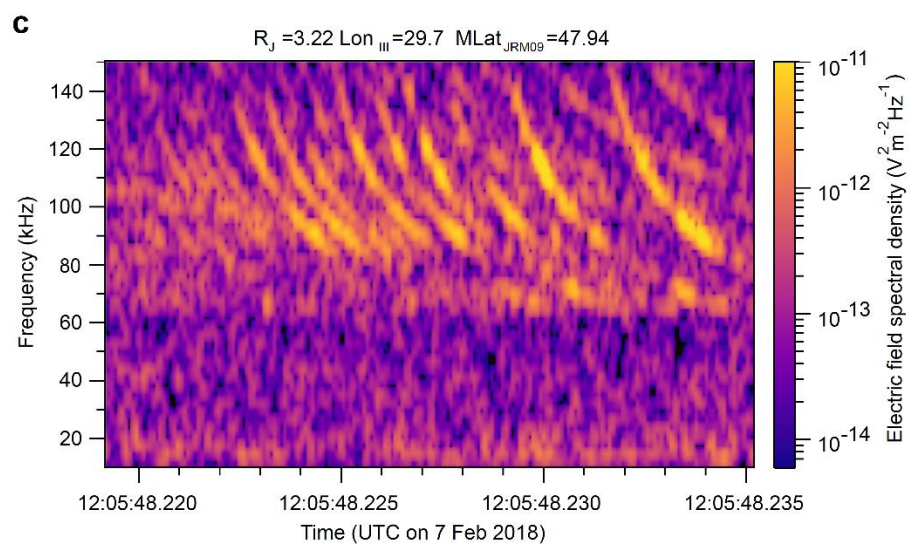
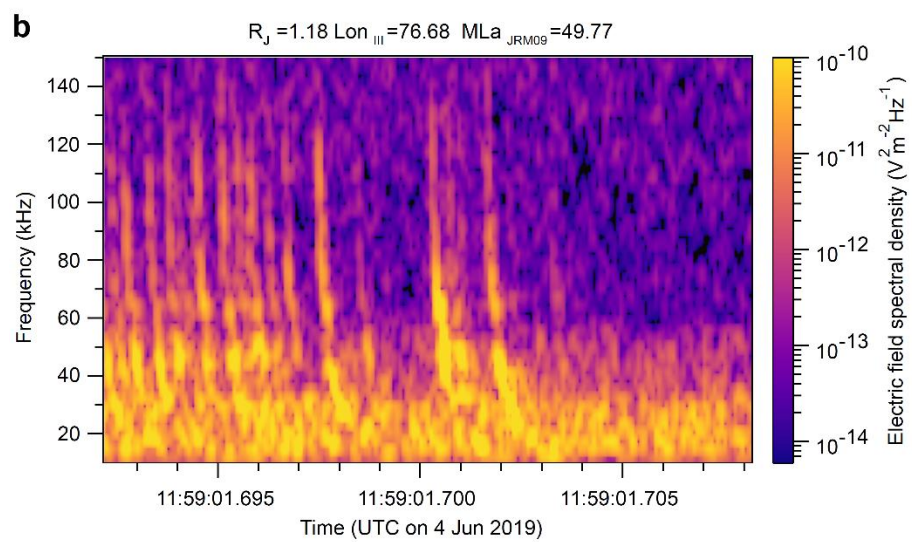
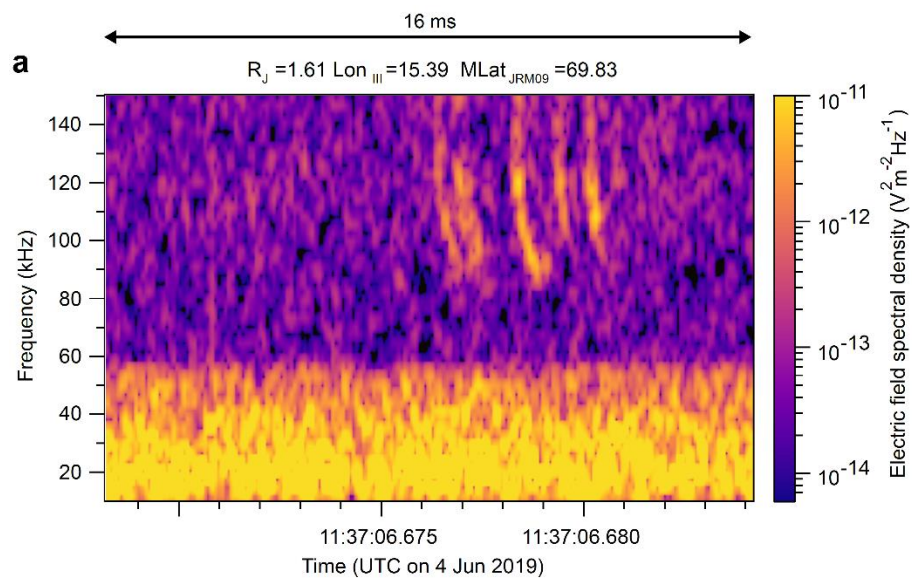
Supplementary Figure 2: Additional examples of groups of JDPs.

Supplementary Figure 3: Distribution of inter-pulse intervals – additional plots.

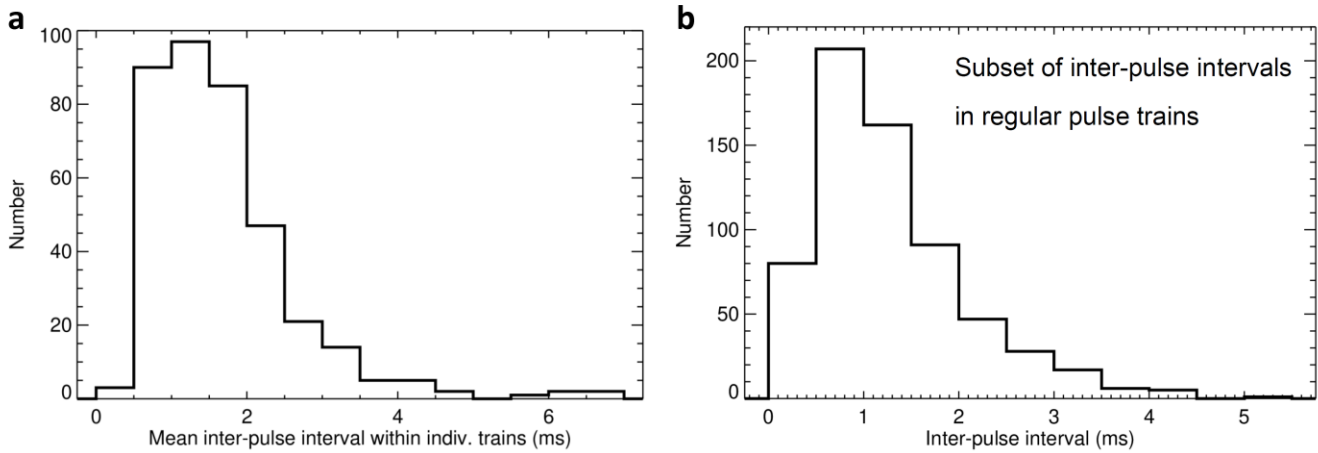
Supplementary Figure 4: Time series of magnetic field fluctuations



Supplementary Figure 1. Time series of the electric field fluctuations corresponding to time-frequency spectrograms in Fig. 1. a Snapshot recorded on 12 September 2017 after 04:29:57 UTC. **b** Snapshot recorded on 1 April 2018 after 08:54:57 UTC. **c** Snapshot recorded on 17 February 2020 after 19:22:20 UTC.

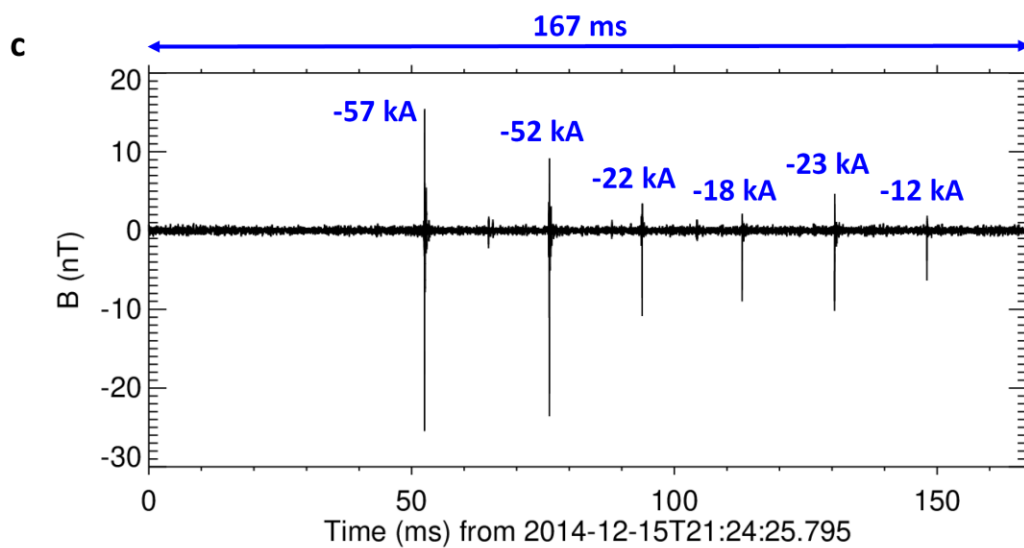
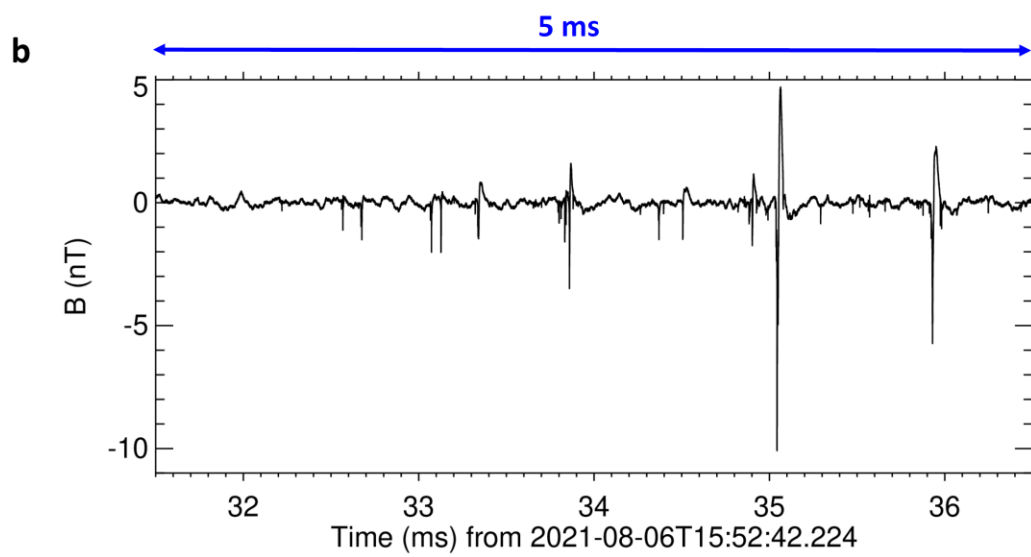
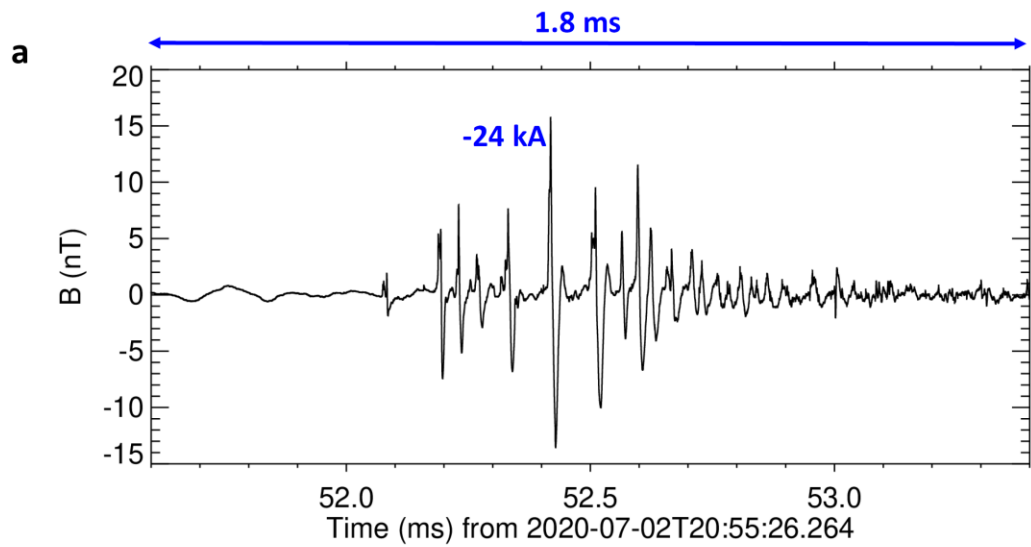


Supplementary Figure 2. Additional examples of groups of JDPs. Frequency–time power spectrograms of the electric field fluctuations. **a** Snapshot recorded on 6 June 2019 after 11:37:06 UTC at a distance of 1.61 R_J . **b** Snapshot recorded on 6 June 2019 after 11:59:01 UTC at a distance of 1.18 R_J . **c** Snapshot recorded on 7 February 2018 after 12:05:48 UTC at a distance of 3.22 R_J .



Supplementary Figure 3. Distribution of inter-pulse intervals – additional plots. a

Distribution of average inter-pulse intervals calculated separately for each individual group of pulses. **b** Distribution of inter-pulse intervals in regular JDP groups (defined as groups with the standard deviation of their inter-pulse interval smaller than one-half of its mean value). Similar position of the main peak also resulted from preliminary analysis of a smaller subset of JDP intervals¹.



Supplementary Figure 4. Time series of magnetic field fluctuations. **a** 1.8 long ms waveform showing an initiation of an inverted IC flash starting by intense magnetic field IB pulses (-26 kA) occurring on 2 July 2020 at 20:55:26 UTC (detected at the Milešovka observatory, Czechia) - corresponds to the spectrogram in Fig. 4a in the main paper. **b** 5 ms long waveform showing an initiation of a normal IC flash occurring on 6 August 2021 at 15:52:42 UTC (detected at the Dlouhá Louka observatory, Czechia) - corresponds to the spectrogram in Fig.4b in the main paper. **c** 167ms long waveform of a multi-stroke negative cloud-to ground composed of 6 individual strokes (-57 kA, -52 kA, -22 kA, -18 kA, -24 kA, -12 kA) occurring on 15 December 2014 at 21:24:25 UTC in Southern France and detected at the external site of the LSBB laboratory in Rustrel, France. The peak current estimates were provided by the European Lightning location network EUCLID².

Supplementary references

1. Imai, M. *et al.* Evidence for low density holes in Jupiter's ionosphere. *Nat. Commun.* (2019) doi:10.1038/s41467-019-10708-w.
2. Poelman, D. , Schultz, W., Pedeboy, S. et al. Global ground strike point characteristics in negative downward lightning flashes – Part 1: Observations. *Nat. Hazards Earth Syst. Sci.* **21**, 1909–1919 (2021).