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DisruptionPy: An open-source physics-based scientific framework for disruption analysis of fusion plasmas

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Summary

Magnetically-confined fusion experiments routinely operate under a wide variety of engineering parameters in order to gain invaluable insight into fusion plasmas with the purpose of understanding and then harnessing their intrinsic power for energy production. Such exploration of a wide parameter space sometimes results in unexpected and rapid loss of confinement of the plasma discharge, events which are generically known as 'disruptions'. Disruptions represent a significant danger to both modern experimental machines and, above all, future reactor-relevant devices. Therefore preventing disruptions, detecting them, and avoiding them are features of paramount importance for any plasma control system. Given the sheer number of available diagnostic systems, and possible plasma modeling tools, artificial intelligence and machine learning (AI/ML) models are ideal candidates for heavy-duty numerical computation. Fast and agile numerical frameworks for database preparation and preprocessing are necessary for letting researchers focus on novel algorithms and benchmark different architectures and models.

Statement of need

`DisruptionPy` (Cristina Rea et al., 2024; Trevisan et al., 2024, 2026; Wei et al., 2024) is an open-source physics-based scientific framework for disruption analysis of fusion plasmas, designed with the explicit purpose of streamlining database preparation of experimental fusion data to allow efficient AI/ML workflows.

As the Fusion Community prepares for the upcoming burning plasma devices, the multiple existing data repositories already face numerous interoperability challenges. Previous community reporting (Humphreys et al., 2020) identified the need to improve several aspects of existing platforms, ranging from hardware and technology to software, including development of optimized ML-ready workflows for fusion scientific discovery. Therein, the authors highlighted the current different data access systems, the various data storage formats, and a lack of adequately-labeled data as main challenges that need to be addressed by the research community.

`DisruptionPy` originated as an institutional effort from the Plasma Science and Fusion Center within the Massachusetts Institute of Technology (MIT PSFC) to create a shared and validated set of feature-extraction routines, and evolved into an open-source scientific framework in order to aid disruption scientists everywhere. `DisruptionPy` natively supports efficiently extracting data from `MDSplus` (J. Stillerman et al., 2025; J. A. Stillerman et al., 1997), the leading open-source storage back-end for most fusion experiments, and enables scientists to carry out complicated Python-based computations at scale across entire experimental databases.

DisruptionPy also supports extracting data from the open FAIR MAST (Jackson et al., 2024, 2025) dataset, enabling researchers to easily access and analyze historical MAST data without connection to an institution. DisruptionPy relies on established numerical libraries, e.g. NumPy, SciPy, Pandas, Xarray, to allow effortless manipulation of either raw or pre-processed data into complicated feature-extraction workflows for database generation.

Additional example of similar frameworks for experimental data retrieval and database preparation are TokSearch (Sammuli et al., 2018) and DEFUSE (Pau et al., 2023). The TokSearch library (Sammuli et al., 2018) was developed to efficiently query, process, and analyze experimental data from DIII-D for ML applications. It leverages a distributed file format to increase throughput and a dedicated API to transfer data from MDSplus and export it in Parquet format. TokSearch appears to be established only for DIII-D workflows. DEFUSE (Pau et al., 2023), the Disruption and Event analysis framework for FUSion Experiments developed, implements an interface layer to access the data from different fusion experiments through MDSplus and HDF5. Source data, diagnostics, machine descriptions, and data-processing schemes are defined in interoperable data libraries in JSON format within a data abstraction layer. DEFUSE has been applied to several devices, however the framework has not been open-sourced yet.

The heterogeneous set of scripts from which DisruptionPy was developed led to several high-profile scientific publications (Hu et al., 2021; Keith et al., 2024; Maris et al., 2024; Montes et al., 2019; C. Rea et al., 2018, 2018; C. Rea et al., 2019, 2020; Spangher et al., 2025; Tinguely et al., 2019; J. Zhu et al., 2021; J. X. Zhu et al., 2020, 2023). DisruptionPy itself is now the basis for the scientific work of the entire Disruptions Group at MIT PSFC and will undoubtedly lead to further high-impact results in the near future.

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References

Hu, W. H., Rea, C., Yuan, Q. P., Erickson, K. G., Chen, D. L., Shen, B., Huang, Y., Xiao, J. Y., Chen, J. J., Duan, Y. M., Zhang, Y., Zhuang, H. D., Xu, J. C., Montes, K. J., Granetz, R. S., Zeng, L., Qian, J. P., Xiao, B. J., & Li, J. G. (2021). Real-time prediction of high-density EAST disruptions using random forest. *Nuclear Fusion*, *61*(6), 066034. https://doi.org/10.1088/1741-4326/abf74d

Humphreys, D., Kupresanin, A., Boyer, M. D., Canik, J., Chang, C. S., Cyr, E. C., Granetz, R., Hittinger, J., Kolemen, E., Lawrence, E., Pascucci, V., Patra, A., & Schissel, D. (2020). Advancing fusion with machine learning research needs workshop report. *Journal of Fusion Energy*, *39*(4), 123–155. https://doi.org/10.1007/s10894-020-00258-1

Jackson, S., Khan, S., Cummings, N., Hodson, J., Witt, S. de, Pamela, S., Akers, R., & Thiyagalingam, J. (2024). FAIR-MAST: A fusion device data management system. *SoftwareX*, *27*, 101869. https://doi.org/10.1016/j.softx.2024.101869

Jackson, S., Khan, S., Cummings, N., Hodson, J., Witt, S. de, Pamela, S., Akers, R., & Thiyagalingam, J. (2025). An open data service for supporting research in machine learning on tokamak data. *IEEE Transactions on Plasma Science*, *53*(9), 2440–2449. https://doi.org/10.1109/tps.2025.3583419

Keith, Z., Nagpal, C., Rea, C., & Tinguely, R. A. (2024). Risk-aware framework development for disruption prediction: Alcator c-mod and DIII-d survival analysis. *Journal of Fusion Energy*, *43*(1). https://doi.org/10.1007/s10894-024-00413-y

Maris, A. D., Rea, C., Pau, A., Hu, W., Xiao, B., Granetz, R., & Marmar, E. (2024). Correlation of the I-mode density limit with edge collisionality. *Nuclear Fusion*, *65*(1), 016051. https://doi.org/10.1088/1741-4326/ad90f0

Montes, K. J., Rea, C., Granetz, R. S., Tinguely, R. A., Eidietis, N., Meneghini, O. M., Chen, D. L., Shen, B., Xiao, B. J., Erickson, K., & Boyer, M. D. (2019). Machine learning for disruption warnings on alcator c-mod, DIII-d, and EAST. *Nuclear Fusion*, *59*(9), 096015. https://doi.org/10.1088/1741-4326/ab1df4

Pau, A., Sauter, O., Sommariva, C., Poels, Y., Venturini, C., Labit, B., Imbeaux, F., Litaudon, X., Falchetto, G., Joffrin, E., Pautasso, G., Gerasimov, S., Rimini, F., & De La Luna, E. (2023, October). *A modern framework to support disruption studies: The eurofusion disruption database*. https://infoscience.epfl.ch/handle/20.500.14299/250373

Rea, C., Granetz, R. S., Montes, K., Tinguely, R. A., Eidietis, N., Hanson, J. M., & Sammuli, B. (2018). Disruption prediction investigations using machine learning tools on DIII-d and alcator c-mod. *Plasma Physics and Controlled Fusion*, *60*(8), 084004. https://doi.org/10.1088/1361-6587/aac7fe

Rea, C., Montes, K. J., Erickson, K. G., Granetz, R. S., & Tinguely, R. A. (2019). A real-time machine learning-based disruption predictor in DIII-d. *Nuclear Fusion*, *59*(9), 096016. https://doi.org/10.1088/1741-4326/ab28bf

Rea, C., Montes, K. J., Pau, A., Granetz, R. S., & Sauter, O. (2020). Progress toward interpretable machine learning–based disruption predictors across tokamaks. *Fusion Science and Technology*, *76*(8), 912–924. https://doi.org/10.1080/15361055.2020.1798589

Rea, Cristina, Trevisan, G. L., Stillerman, J. A., Wei, Y., Lane-Walsh, S., Winkel, M., Jelenak, A., Mordijck, S., Kostadinova, E. G., Diem, S. J., Cummings, N., Hollocombe, J., Murphy, N. A., Pau, A., & MIT PSFC Disruption Studies Group. (2024). Open and FAIR fusion for machine learning applications. *Proceedings of the 2024 APS Division of Plasma Physics Meeting*. https://meetings.aps.org/Meeting/DPP24/Session/PP12.27

Sammuli, B. S., Barr, J. L., Eidietis, N. W., Olofsson, K. E. J., Flanagan, S. M., Kostuk, M., & Humphreys, D. A. (2018). TokSearch: A search engine for fusion experimental data. *Fusion Engineering and Design*, *129*, 12–15. https://doi.org/10.1016/j.fusengdes.2018.02.003

Spangher, L., Bonotto, M., Arnold, W., Chayapathy, D., Gallingani, T., Spangher, A., Cannarile, F., Bigoni, D., Marchi, E. de, & Rea, C. (2025). DisruptionBench and complimentary new models: Two advancements in machine learning driven disruption prediction. *Journal of Fusion Energy*, *44*(1). https://doi.org/10.1007/s10894-025-00495-2

Stillerman, J. A., Fredian, T. W., Klare, K. A., & Manduchi, G. (1997). <Scp>MDS</scp>plus data acquisition system. *Review of Scientific Instruments*, *68*(1), 939–942. https://doi.org/10.1063/1.1147719

Stillerman, J., Lane-Walsh, S., Winkel, M., Rea, C., Trevisan, G. L., Jelenak, A., & Readey, J. (2025). MDSplusML – optimizations for data access to facilitate machine learning pipelines. *Fusion Engineering and Design*, *211*, 114770. https://doi.org/10.1016/j.fusengdes.2024.114770

Tinguely, R. A., Montes, K. J., Rea, C., Sweeney, R., & Granetz, R. S. (2019). An application of survival analysis to disruption prediction via random forests. *Plasma Physics and Controlled Fusion*, *61*(9), 095009. https://doi.org/10.1088/1361-6587/ab32fc

Trevisan, G. L., Rea, C., Lorincz, J. A., Wei, Y., Saperstein, A. R., Decker, A., Granetz, R. S., & MIT PSFC Disruption Studies Group. (2024). Functional improvements and technical developments of a community-driven and physics-informed numerical library for disruption studies. *Proceedings of the 2024 APS Division of Plasma Physics Meeting*. https://meetings.aps.org/Meeting/DPP24/Session/PP12.9

Trevisan, G. L., Rea, C., & MIT PSFC Disruption Studies Group. (2026). *DisruptionPy: An open-source physics-based scientific framework for disruption analysis of fusion plasmas* (Version 0.13.0). Zenodo. https://doi.org/10.5281/zenodo.13935223

Wei, Y., Trevisan, G. L., Rea, C., Lorincz, J. A., Saperstein, A. R., Decker, A., Granetz, R. S., & MIT PSFC Disruption Studies Group. (2024). Physics validation of parameter methods in DisruptionPy. *Proceedings of the 2024 APS Division of Plasma Physics Meeting*. https://meetings.aps.org/Meeting/DPP24/Session/PP12.10

Zhu, J. X., Rea, C., Granetz, R. S., Marmar, E. S., Sweeney, R., Montes, K., & Tinguely, R. A. (2023). Integrated deep learning framework for unstable event identification and disruption prediction of tokamak plasmas. *Nuclear Fusion*, *63*(4), 046009. https://doi.org/10.1088/1741-4326/acb803

Zhu, J. X., Rea, C., Montes, K., Granetz, R. S., Sweeney, R., & Tinguely, R. A. (2020). Hybrid deep-learning architecture for general disruption prediction across multiple tokamaks. *Nuclear Fusion*, *61*(2), 026007. https://doi.org/10.1088/1741-4326/abc664

Zhu, J., Rea, C., Granetz, R. S., Marmar, E. S., Montes, K. J., Sweeney, R., Tinguely, R. A., Chen, D. L., Shen, B., Xiao, B. J., Humphreys, D., Barr, J., & Meneghini, O. (2021). Scenario adaptive disruption prediction study for next generation burning-plasma tokamaks. *Nuclear Fusion*, *61*(11), 114005. https://doi.org/10.1088/1741-4326/ac28ae