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Opportunities and challenges of machine learning for astrophysics

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Machine learning (ML) is having a transformative impact on astrophysics. The field is starting to mature, where we are moving beyond the naive application of off-the-shelf, black-box ML models towards approaches where ML is an integral component in a larger, principled analysis methodology. Furthermore, not only are astrophysical analyses benefiting from the use of ML, but ML models themselves can be greatly enhanced by integrating knowledge of relevant physics. I will review three maturing areas where ML and astrophysics have already demonstrated some success, while still providing many further opportunities and challenges. (1) Physics-enhanced learning integrates knowledge of relevant physics into ML models, either through augmentation, encoding symmetries and invariances, encoding dynamics, or directly through physical models that are integrated into the ML model. (2) In statistical learning, ML and statistical models are tightly coupled to provide probabilistic frameworks, often in a Bayesian setting, that offer uncertainty quantification, generative models, accelerated inference, and data-driven priors. (3) For scientific analyses in particular, it is important that ML models are not opaque, black-boxes but are intelligible, ensuring truthfulness, explainability and interpretability. Throughout I will provide numerous examples of astrophysical studies where such approaches have or are being developed and applied, in the context of upcoming observations from the Euclid satellite, the Rubin Observatory Legacy Survey of Space and Time (LSST), and the Square Kilometre Array (SKA). Finally, I will highlight outstanding challenges and some thoughts on how these may be overcome.

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