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From MVPs to full models: a stepwise development of diagnostic forward models in constant support of diagnostic design, data analysis, instrument consistency and discharge modelling on the ST40 tokamak

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The characterization of magnetic-confined-fusion plasmas requires a comprehensive set of diagnostic systems measuring a wide range of parameters. New machines, such as the ST40 high-field spherical tokamak [1], typically start with a small subset and gradually increase the diagnostic suite to include more complex and comprehensive systems. To make the most of each plasma operation phase, forward models of various diagnostic systems have been developed to provide consistency-checks of the instruments being commissioned, aid diagnostic design, develop diagnostic analysis methods, as well as constrain higher-level parameters for discharge modelling.

Supporting the programmes at pace requires releasing approximate minimum-viable-product (MVP) models early and increasing their complexity in a stepwise manner. Even if limited in scope, including simple models in analysis and modelling chains can provide an extremely valuable contribution to inform decision-making and accelerate learning. Successive releases can then expand the boundary conditions for their application and provide a benchmark for previous versions, informing among other things what approximations can be retained and what complexity is necessary for an accurate (enough) characterization of the measurements.

This contribution discusses the philosophy behind the framework under development, giving details of the various forward models available to date, which include passive spectroscopy diagnostics [2], an X-ray crystal spectrometer (XRCS) measuring He-like of H-like argon [2, 3], charge-exchange recombination spectroscopy (CXRS) [4], interferometry, filtered visible diodes (e.g. for Bremsstrahlung measurements) [5], Thomson Scattering (TS), bolometric and SXR-filtered diode cameras. The different levels of complexity of the models are examined, analyzing their limitations when run stand-alone or integrated in complex analysis/modelling workflows. Examples of diagnostic design efforts will be presented, as well as results from recent high ion temperature (> 8.6 keV) ST40 plasma discharges reported in [1, 6, 7, 8].

[1] S.A.M. McNamara et al 2023 Nucl. Fusion 63 054002

[2] https://open.adas.ac.uk/

[3] O Marchuk et al 2006 Plasma Phys. Control. Fusion 48 1633

[4] J. Wood et al 2023 JINST 18 C03019

[5] S. Morita 1994 IPP III / 1999

[6] S. M. Kaye et al 2022 APS conference CP11.00016

[7] P. R. Thomas et al 2022 APS conference YI02.00005

[8] M. Sertoli et al 2022 APS conference CP11.00014

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