Gaussian Process Tomography of impurity radiation in the detached divertor plasmas of Wendelstein 7-X stellarator

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Wendelstein 7-X (W7-X) is an optimized stellarator with superconducting coils that started its first plasma operation in 2015. The first experimental campaign with uncooled divertors, conducted in 2017, has shown thermal detachment of the plasma from the target plates at the highest line-of-sight integrated electron densities of ~$3\text{-}6\times10^{19}$ m^{-2} accessible in this campaign without wall conditioning by boronization. In the last campaign (in 2018) much higher line-of-sight integrated electron densities of up to 1.6×10^{20} m^{-2} were reached as a result of strongly reduced impurity fluxes from the walls right after the first of three applied boronizations. At these high densities, the thermal detachment at the target plates was accompanied by high recycling of neutrals at the target plates and hence significantly higher neutral pressures in the divertor of up to 8×10^{-3} mbar, which allowed balancing the fuelled particles by gas pumping through the divertors. The optimum detachment working point was found at the radiation fraction of ~80%, as also predicted by EMC3-EIRENE simulations. In the significantly colder detached divertor plasmas the radiation of C^{1+} and C^{2+} ions detached from the target plates and moved towards the separatrix. The detached plasma conditions were also reached by impurity seeding at the divertor plates e.g. with nitrogen. The dynamics of the impurity line emission was studied using a comprehensive spectroscopic observation system at two divertors. At each divertor 27 lines of sight (LOS) were directed parallel to the horizontal target in addition to 27 perpendicular LOS. Several spectrometers with CCD cameras were utilized with a wide range of spectral resolution of 0.003-1 nm. Tomographic inversion of the measured line emission observed from both directions provides local 2D radiation profiles in the divertor. The inversion was done in the Bayesian modelling framework Minerva applying Gaussian Process Tomography (GPT) that allows non-parametric modelling the 2D radiation profiles with only the correlation length scales of the profiles provided as a-priori information to the Bayesian model. Occam's razor principle allows finding optimum length scales, which keep the model complexity at a minimum level necessary to satisfy the measurements within their error bars.