In this work, a self consistent Particle-in-Cell (PIC) model to describe the edge plasmas was developed for multi-component non-thermal plasmas with surface interaction. All relevant species (ions, electrons, neutrals) were treated kinetically, including collisions.

Application of this model to various systems obtained results in agreement with experiments. In addition, the code provides additional insight into the physics of such systems, because it gives access to information which is difficult (or impossible) to measure, e.g. exact temporally and spatially resolved distribution functions.

A first application of the model was done for low-temperature methane plasmas heated by electron cyclotron resonance in the PLATO device. In order to get insight into the complexity of the multi-species hydrocarbon plasma a simple zero dimensional rate equations model was used. In total 31 species were included in this model, participating in 169 reactions. In agreement with experiment a large number of higher hydrocarbons were formed. The PIC modeling of PLATO showed the dominance of kinetic effects in such plasmas. The electron energy distribution is highly non-isotropic due to the applied heating mechanism, which heats the electrons mainly in the perpendicular direction. The model reproduces the experimental observations: a rotating plasma hole due to the effect of strong spatial non-uniformity of the applied ECR heating on the electron density profile.

Ions are accelerated along the system in the longitudinal electric field of the pre-sheath and sheath regions, their longitudinal velocity following the profile of the potential. All ions have the same energy distribution, which shows that ion energy distribution at the target wall in our system is fully determined by the established ambipolar potential profile. All ion species at the wall have the same mean energy of random motion which is much less than the energy of directed motion. This is in agreement with experiment.

The next system, which was studied in collaboration with an experimental group at the University of Bochum, was a capacitively coupled radio-frequency (RF) discharge. We were able to follow the time and spatially resolved dynamics of the plasma particles. For the low pressure of the neutral gas the electron distribution is a sum of two Maxwellian distributions. The low temperature part corresponds to the static group of cold electrons in the bulk region, whereas the high-temperature component is contributed by the stochastically heated electrons, oscillating between sheaths. Similar bi-Maxwellian electron distributions were experimentally found in low-pressure capacitive RF discharges.
The effect of double hot electron layers observed in experiments with capacitive RF discharges as double emissive layers near the electrodes was reproduced in our simulations. Due to electric field reversal in the sheath region, electrons are heated in both half-periods of the RF cycle, which cause the two peaks in the intensity of electron-induced inelastic processes (ionization, excitation) near the electrodes.

The ion energy distribution (IED) at the wall position calculated within our model indicates a multi-peak structure due to ion modulation in the RF sheath, seen also in experiments.

The basic physics of dusty plasmas was studied using our PIC model. The dust particles are trapped in a capacitive RF discharge. In this case, the gravitational force acting on the particles can be equilibrated by the electrostatic force due to a strong repulsive electric field in the RF sheath. The trapped dust particles form a cloud levitating above the lower electrode.

Dust particles form vertical strings, in which negative particles are attracted due to polarization of the ion flow (wake-field effect). This agrees with stable vertically aligned dust strings observed in laboratory experiments.

A quasi 2 dimensional (simple hexagonal) structure is formed by the dust in which flat layers with hexagonal symmetry are vertically aligned due to the unidirectional strong ion background flow towards the electrode in the sheath. This is supported by the observation of a simple hexagonal dust structure in experiments.

In the case of zero-gravity conditions, our simulations showed void formation in the middle of the discharge which is in agreement with experiments onboard of the International Space Station (ISS). For this condition, the particle behavior is determined by forces which are usually unimportant in comparison with the gravitational force in laboratory experiments (ion drag force, thermophoretic force). In the PIC simulation we demonstrated that the ion-drag force alone is able to overcome the electrostatic force in the middle of the discharge and lead to the void formation.

Finally, we studied edge plasmas in magnetic fusion devices.

The results confirmed the dominant physical mechanisms. Neutral recycling leads to increased density close to the wall, and cooling down of electrons and ions by collisions with neutrals.

They provide the necessary boundary conditions for fluid models. In the case of strong collisions all ions tend to have a common drift velocity and temperature.

A special plasma phenomena is the occurrence of parasitic plasmas in areas far away from the SOL, such as below the divertor baffles. We proved the possibility of sustaining such low-temperature plasmas due to the emission of photoelectrons from surfaces or/and photoionization of neutral gas. The photon fluxes necessary within our kinetic PIC model are of the same order as experimental ones. Volumetric photoionization sources result in standard sheath conditions, whereas strong surface photoemission can lead to a double layer formation in agreement with analytical estimates.