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X-ray imaging and spectroscopy of space- and time-dependent phenomena in ECRISs to investigate fundamental plasma processes

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Within the INFN PANDORA project, a fully superconductive ECR plasma trap-based research facility is being developed to measure β-decays in magnetized plasmas. This infrastructure also enables fundamental and applied plasma physics studies through non-invasive multi-diagnostics systems, with implications for ion source R&D. X-ray diagnostics emerge a very powerful tool for monitoring plasma parameters, confinement dynamics, and stability in B-minimum ECR traps. While the full-scale PANDORA trap is under construction (expected completion by August 2026), several studies were conducted using the ATOMKI ECRIS.
In a recent experiment, a novel diagnostic setup –combining a 400 μm Pb pinhole, a 4 MP X-ray CCD camera (0.6-30 keV range), and a millisecond-resolution X-ray shutter - was deployed. Coupled with single photon counting algorithm and advanced trigger systems, this enabled energy-, space-, and time-resolved X-ray spectroscopy to study plasma transients, including ignition, afterglow decay, and turbulence.
The first relevant results include space-resolved gas mixing studies to investigate changes in plasma confinement structure (combining Ne, Kr, Ar, Xe) when compared to single-gas mode, shedding light on debated gas mixing effect. Further results concern time- and space-resolved plasma dynamics studies, where transient phenomena (plasma ignition and afterglow phases) were resolved for the first time with 100 μs temporal, 400 μm spatial, and 260 eV (@ 8 keV) energy resolution. Structural and temporal evolution of the plasma on ms timescales between different configurations were reveled using various trigger delays, and elucidated electron/ion deconfinement dynamics during afterglow decay. These evidences were also correlated with the main properties (intensity and ion charge state) of the extracted beam.
The obtained results highlight the broad potential of X-ray diagnostic techniques for applications in ECRIS operation and plasma physics research.

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