3D Radiative Transfer of Lyman-series Lines with SKIRT

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High-resolution X-ray spectroscopy and polarimetry provided by XRISM and IXPE offer new diagnostics of the geometry and kinematics of photo-ionised plasmas around compact objects. Interpreting reprocessed X-ray emission in such systems requires full three-dimensional radiative transfer (3D RT) including photon-ion interactions.

We extended the Monte Carlo RT code SKIRT by implementing the Lyman-series lines of H-like ions, enabling self-consistent modelling of resonant scattering, radiative recombination, and polarisation of these lines in X-ray photo-ionised plasmas.

We implemented Lyman-series transitions (up to $n = 10$) for ions with $Z = 2 - 30$, including fine-structure splitting and linear polarisation in resonant scattering. We consider two production channels for Lyman lines: resonant scattering and radiative recombination. The microphysics (cross-sections, branching ratios, and redistribution functions) are validated against analytical solutions and compared with the 1D RT code Cloudy based on the two-stream solver. We further demonstrate the capabilities of the code using idealised setups and a 3D AGN geometry.

The implementation reproduces analytical expectations and shows good agreement with Cloudy. The SKIRT simulations naturally capture RT effects such as P Cygni profiles and line-profile distortion in optically thick media, which are inaccessible to the conventional 1D RT codes commonly used for X-ray modelling. In 3D geometries, we find that anisotropic illumination and velocity fields significantly modify the Lyman series line ratios and profiles, all of which are observable with XRISM.

The extended version of SKIRT provides a powerful framework for interpreting X-ray line spectra and polarisation from photo-ionised plasmas. It is particularly suited for constraining the geometry and velocity structure in the vicinity of compact objects in the XRISM and IXPE era.