# X-ray polarisation in the lamp-post model II: Non-smooth black-hole accretion discs 

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#### Abstract

According to theoretical computations, the X-ray continuum emission reprocessed by the accretion discs of Active Galactic Nuclei (AGN) is expected to be significantly polarised. In the reflection scenario, polarisation is mainly produced by Compton scattering of the primary, power-law, coronal radiation incident onto the disc. Polarisation being sensitive to the geometry of the scatterer, we decided to re-visit the lamp-post scheme, investigating how much the polarisation properties change if the geometry of scattering is not an ideal smooth disc. To do so, we assume that the disc surface has random irregularities, so that the final result is averaged over a range of scattering geometries.


The model components
Black hole: Schwarzschild or maximally rotating Kerr metric for central gravitating body with mass $M$ and spin $a=0$ or $a=1$ in the dimensionless geometrical units $G=c=M=1$ is used.
Accretion disc: co-rotating, Keplerian, geometrically thin, optically thick, cold disc extending from the marginally stable orbit $r_{\text {in }}=r_{\mathrm{ms}}\left(r_{\text {in }}=6 \mathrm{GM} / \mathrm{c}^{2}\right.$, Schwarzschild BH or $r_{\text {in }}=1 G M / c^{2}$, Kerr BH) up to the upper edge at $r_{\text {out }}=1000 G M / c^{2}$
Corona: hot point-like patch of plasma located on the rotation axis at the height $h$ above the centre and emitting isotropic power-law radiation $f=E^{-1}$ with the power-law index $\Gamma=2$ for the specific photon number density flux.
Observer: located at infinity, viewing the system with an inclination angle $\theta_{0}$ with respect to the symmetry axis of the disc.

Figure 1: Sketch of the model

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Methods and approximations
Light rays: Full relativistic ray-tracing code in vacuum is used for photon paths from the corona to the disc and to the observer and from the disc to the observer.
Reflection: Monte Carlo multi-scattering computations for the cold disc are used for the reflected flux including the Fe fluorescent $\mathrm{K} \alpha$ and $\mathrm{K} \beta$ lines. Single scattering approximation is used for the local polarisation of the reflected continuum component, the line flux and the primary radiation are supposed to be unpolarized. Both the reflected flux and the local polarisation depend on the incident and emission angles $\delta_{\mathrm{i}}, \delta_{\mathrm{e}}$ and relative azimuthal angle $\Delta \Phi$ between incident and emitted light rays.



$a=0, \theta_{0}=60^{\circ}, h=3$


$\underset{\mathrm{E}[\mathrm{keV}]}{10}$




Figure 2: The polarisation degree dependence on maximum deviation angle of irregular surface $\delta_{\max }=0^{\circ}, 10^{\circ}, 30^{\circ}$ and $60^{\circ}$ (black, red, green and blue graphs) in case of a Schwarzschild black hole. The region between the curves for the two cases of the probability distribution (increasing or decreasing with the deviation angle $\delta_{\text {max }}$ ) are filled with colour for convenience. The dependence for three heights of the primary source, $h=3,6$ and $15 G M / c^{2}$ (columns) and three inclination angles, $\theta_{0}=30^{\circ}, 60^{\circ}$ and $80^{\circ}$ (rows), is shown.








Figure 3: The polarisation degree dependence on maximum deviation angle of irregular surface $\delta_{\max }=0^{\circ}, 10^{\circ}, 30^{\circ}$ and $60^{\circ}$ (black, red, green and blue graphs) in case of an extreme Kerr black hole. The region between the curves for the two cases of the probability distribution (increasing or decreasing with the deviation angle $\delta_{\text {max }}$ ) are filled with colour for convenience. The dependence for three heights of the primary source, $h=3,6$ and $15 \mathrm{GM} / \mathrm{c}^{2}$ (columns) and three inclination angles, $\theta_{0}=30^{\circ}, 60^{\circ}$ and $80^{\circ}$ (rows), is shown.

Irregular disc surface: In our previous work, see Dovčiak et al. (2011), the geometry of scattering was precisely defined by the geometry of the system, i.e. by the height of the primary source, inclination of the observer and spin of the black hole. Here, we want to investigate how much the polarisation properties change if we relax the assumption on such a well defined scattering geometry. The physical motivation is that the surface of the disc is not perfectly smooth but irregular instead. We assume the irregularities have much smaller scale than the changes in relativistic effects and at the same time on much larger scale than the scale characterizing the radiative transfer. The irregularities in the surface are defined by the angle of the surface with respect to the equatorial
plane. We consider that this angle cannot be larger than the maximum angle $\delta_{\max }=10^{\circ}, 30^{\circ}$ and $60^{\circ}$. Two probability distributions are explored, the probability of surface angle either linearly decreases to zero for maximum allowed angle $\delta_{\max }$ or it linearly increases to be doubled for this angle.

Results
Our results for the polarisation degree are shown in Fig. 2 and 3 and for the polarisation angle in Fig. 4 and 5. One can see that the results are not changed much for small variations in the disc surface ( $\delta_{\max } \lesssim 30^{\circ}$ ). On the other hand, the polarisation degree is influenced by the disc
irregularities mainly for very low heights of the primary source, when the relativistic effects determining the local scattering geometry are the largest.

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## References

Dovčiak M., Muleri F., Goosmann R. W., Karas V., \& Matt G. (2011) ApJ, 731, 75


