Influence of a polarized primary source on the X-ray polarization resulting from disc reflection in AGN

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Abstract: Theoretical computations showed that the reflection of X-ray radiation from the accretion disc in AGN should result in significant (detectable) polarization signals. Originating from a primary power-law coronal emission situated above the disc surface, X-ray photons are partially reprocessed by Compton scattering in the disc material and show a polarization level that heavily depends on geometry of scattering. In this contribution, we examine the polarization that can be obtained in the lamp-post geometry scenario, where a compact patch of corona is positioned on the axis above the black hole. The influence of differently polarized primary source is shown.

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The model components

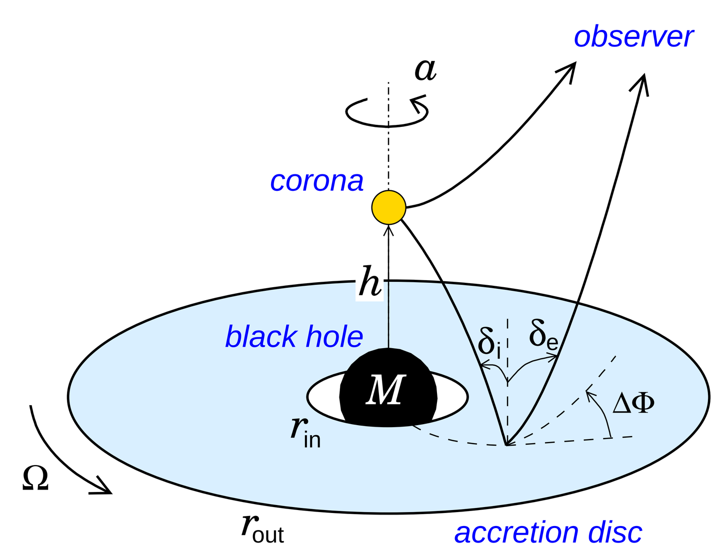
Black hole: Schwarzschild or maximally rotating Kerr metric for central gravitating body with mass M and spin $a = 0$ or $a = 1$ in the dimensionless geometrical units $G = c = M = 1$ is used.

Accretion disc: co-rotating, Keplerian, geometrically thin, optically thick, cold disc extending from the marginally stable orbit $r_{\rm in} = r_{\rm ms}$ ($r_{\rm in} = 6\,GM/c^2$, Schwarzschild BH or $r_{\rm in} = 1\,GM/c^2$, Kerr BH) up to the upper edge at $r_{\rm out} = 1000\,GM/c^2$.

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 $f = E^{-\Gamma}$ with the power-law index $\Gamma = 2$ for the specific photon number density flux. The coronal intrinsic polarisation is assumed to be $P_{\rm L} = 0\%$, 2% and 4% either parallel with ($\chi_{\rm L} = 0°$) or perpendicular to ($\chi_{\rm L} = 90°$) the system axis.

Observer: located at infinity, viewing the system with an inclination angle $\theta_{\rm o}$ with respect to the symmetry axis of the disc.

Figure 1: Sketch of the model



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 Kα and Kβ lines. Single scattering approximation is used for the local polarisation of the reflected continuum component, the line flux is supposed to be unpolarized. Both the reflected flux from the disc and its polarisation properties depend on the incident and emission angles $\delta_{\rm i}$, $\delta_{\rm e}$ and relative azimuthal angle $\Delta\Phi$ between incident and emitted light rays (see Figure 1). The polarisation of reflection depends on the polarisation degree and angle of the incident illumination, where the polarisation angle is rotated due do relativistic effects acting on photons between the source and the disc.

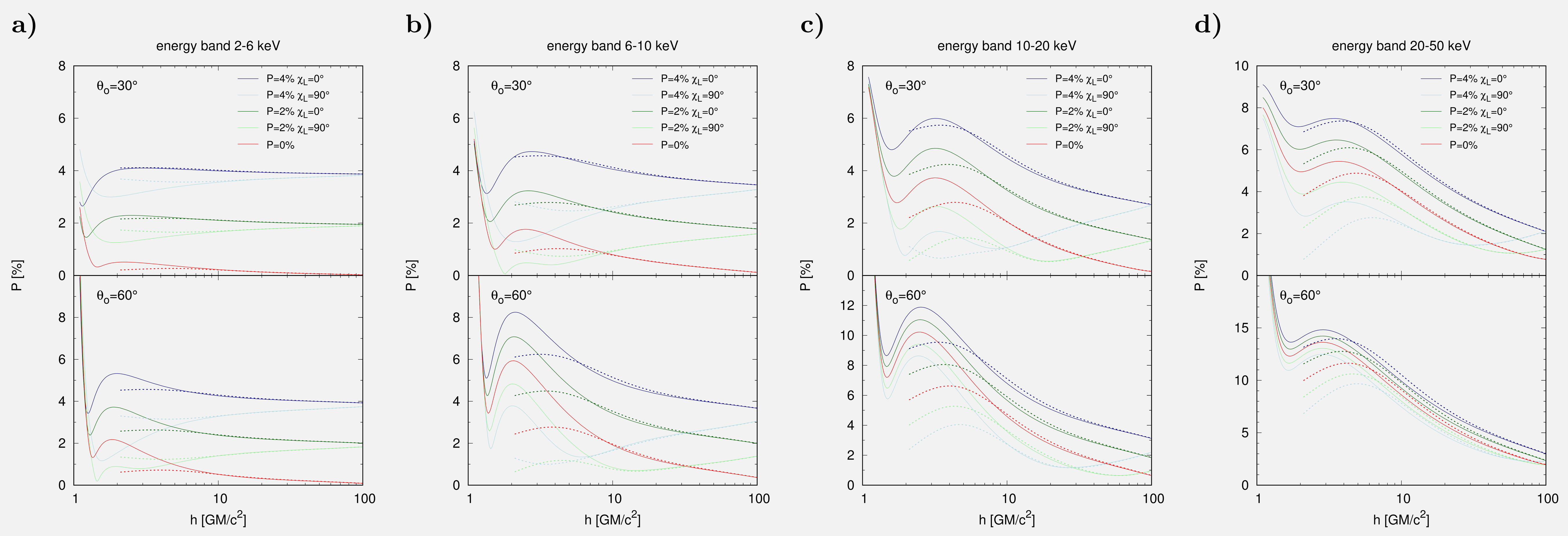


Figure 2: The dependence of the polarisation degree on height for differently polarised primary emission – unpolarised ($P_{\rm L} = 0\%$), polarised (with polarisation degree $P_{\rm L} = 2\%$ and 4%) in the direction parallel with the system axis ($\chi_{\rm L} = 0°$) and perpendicular to it ($\chi_{\rm L} = 90°$). The two cases for extremaly rotating Kerr black hole with the spin $a = 1$ (solid lines) and non-rotating Schwarzschild black hole with the spin $a = 0$ (dotted lines) are shown. The dependence for low inclination angle, $\theta_{\rm o} = 30°$ (top), and high inclination angle, $\theta_{\rm o} = 60°$ (bottom), is studied in four energy bands (left to right): $2-6$, $6-10$, $10-20$ and $20-50$ keV.

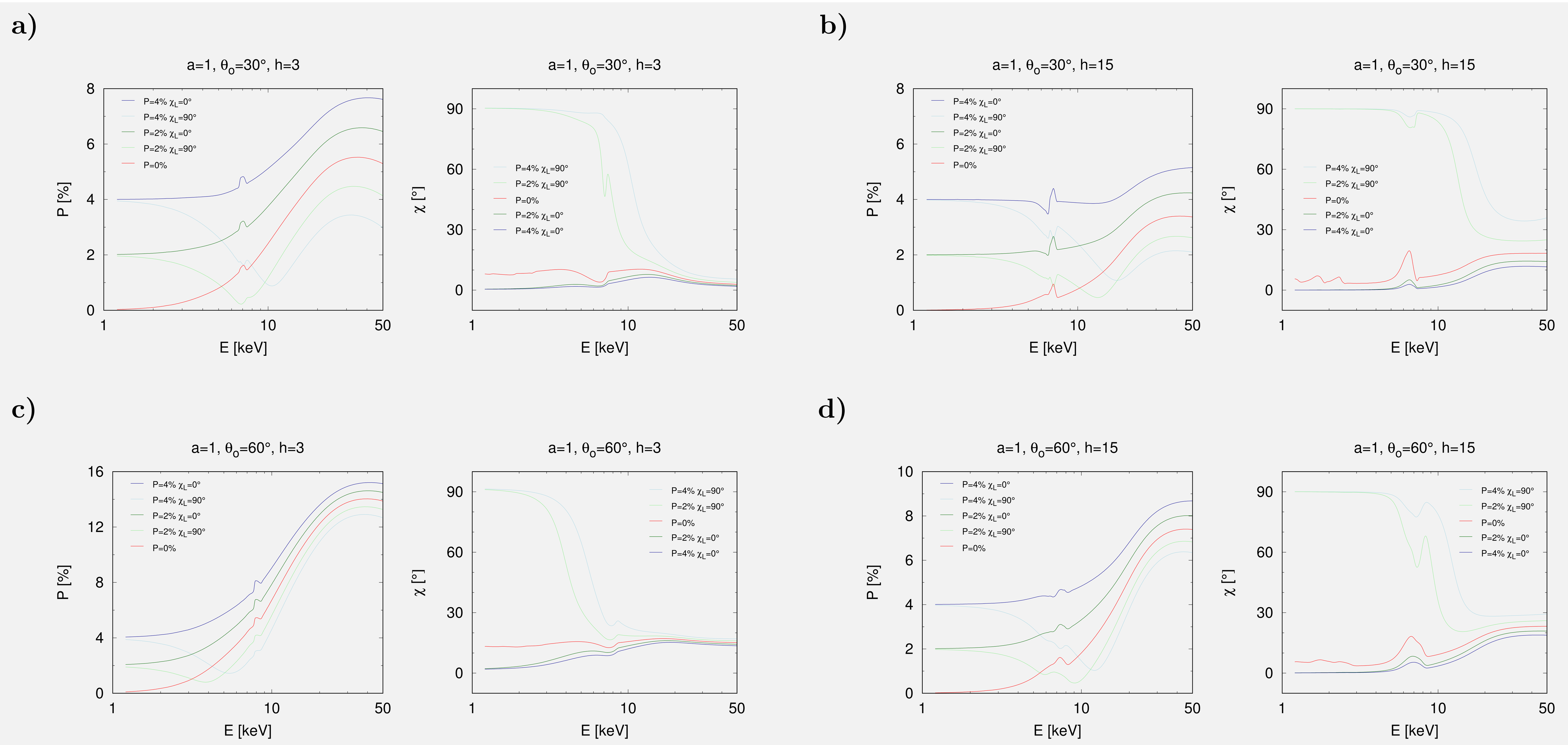


Figure 3: The energy dependence of the polarisation degree, $P[\%]$, and polarisation angle, $\chi[°]$, as it would be measured by the observer at infinity for differently polarised primary emission – unpolarised ($P_{\rm L} = 0\%$), polarised (with polarisation degree $P_{\rm L} = 2\%$ and 4%) in the direction parallel with the system axis ($\chi_{\rm L} = 0°$) and perpendicular to it ($\chi_{\rm L} = 90°$). The case for extremely spinning Kerr black hole with the spin $a = 1$ is shown for low, $\theta_{\rm o} = 30°$ (top panels), and high, $\theta_{\rm o} = 60°$ (bottom panels), system inclination, and for corona located at heights, $h = 3\,GM/c^2$ (left panels), and $h = 15\,GM/c^2$ (right panels).

The results

If the disc seed photons that scatter in corona are unpolarised, we expect that the polarisation from corona will be intrinsically either parallel with or perpendicular to the system axis due to symmetry. Since at lower heights the photons will arrive at corona mostly from sides while for large heights more from bottom, we expect parallel polarisation for low heights while perpendicular polarisation from corona located at higher position above the black hole. The results shown in the figures can be summarised in the following way:

- The reflected flux contributes to the parallel polarisation, while it depolarises the perpendicular primary polarisation.
- The largest effect of reflection on polarisation properties is at almost the lowest heights ($h \lesssim 10\,GM/c^2$).
- The reflection contribution to the polarisation increases with the energy, this is visible mainly in case of originally perpendicular polarisation that changes to “close to” parallel for high energies due to reflection.
- The effect of different black hole spin is visible only for low heights and the contribution to the overall polarisation is larger for higher spin.
- The reflection contribution to the polarisation increases with the inclination.
- In the reflection scenario we expect the polarisation properties that depend on energy.
- To distinguish between energy dependent polarisation and one that does not depend on energy with a medium-size polarimetric mission, such as XIPE, very long observation times are needed.

Acknowledgments

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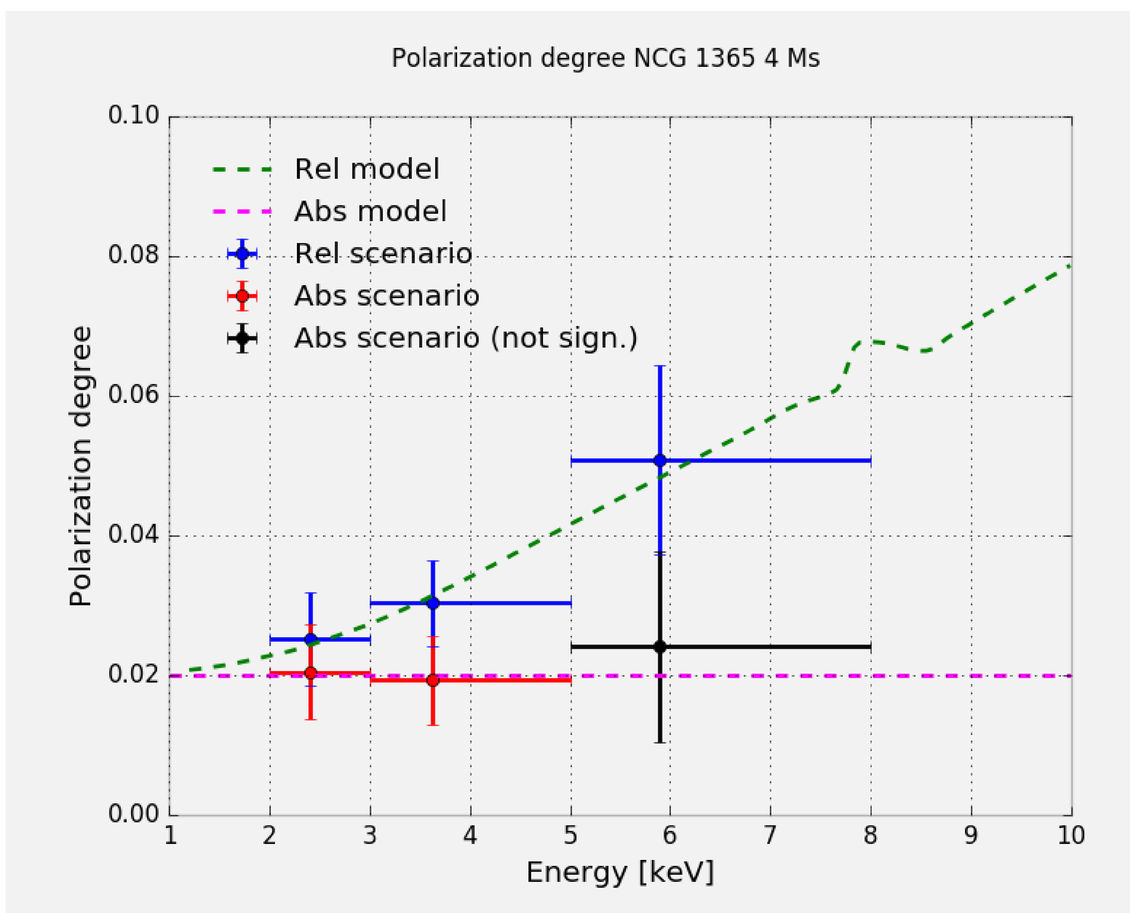

Figure 4: The simulated 4Ms observation of the polarisation degree for the source NGC 1365 with the gas pixel detector on-board XIPE mission (proposed as medium M4 ESA mission). Two cases are compared, the relativistic reflection model with the X-ray absorption model. In the former case the energy dependence of the polarisation degree is expected as opposed to the latter case. Here, the system inclination $\theta_{\rm o} = 60°$, corona at height $h = 3\,GM/c^2$, black hole spin $a = 1$, and parallel ($\chi_{\rm L} = 0°$) primary source polarisation with the polarisation degree $P_{\rm L} = 2\%$ was assumed.

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