

# Intensity and polarization light-curves from radiatively-driven clouds

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**Abstract.** We study linear polarization from the Thomson scattering of light on a cloud of relativistic electrons. At first we derive simple and general analytical formulae for the Stokes parameters. These formulae are then used in calculations of the temporal evolution of the observed signal from a cloud moving under the combined influence of the radiation and gravitational fields in near an accreting black hole. We find that higher-order images can significantly enhance the observed intensity. Possible targets when the effect should be searched are accreting super-massive black holes and Galactic microquasars exhibiting episodic accretion/ejection events.

**Keywords.** Polarization, Thomson scattering, Radiative acceleration, Gravitational lensing

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## Model

We consider a cloud of particles moving through the radiation field of a standard thin accretion disc. Primary photons from the disc are scattered by electrons in the cloud, they are beamed in the direction of the cloud motion, and polarized by Thomson mechanism. We adopt the first-scattering approximation and we restrict the cloud motion to the symmetry axis. The cloud moves in the radiation field of the disk that acts on the cloud together with gravity of the central black hole. The light rays of primary and scattered photons are also influenced. Direct and indirect (retro-lensed) light rays exhibit different degree of linear polarization and they experience different amplification and the Doppler boosting. The indirect photons contribute most intensely to the total signal if the cloud moves toward the black hole and the observer inclination  $i$  is small.

## Local intensity and polarization

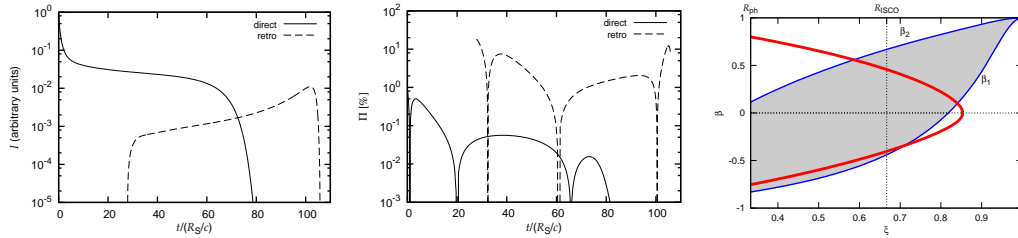
The electron distribution is considered isotropic in the cloud comoving frame. We derived simple formulae for frequency-integrated Stokes parameters  $I$ ,  $Q$  and  $U$  of the scattered radiation (Horák & Karas 2006a,b):

$$\begin{aligned} I &= A [(1 + \mathcal{A})(T^{tt} + T^{ZZ}) + \mathcal{B}(T^{tt} - 3T^{ZZ}) - 2\mathcal{A}T^{tZ}], \\ Q &= A (T^{YY} - T^{XX}), \\ U &= -2 A T^{XY}, \end{aligned}$$

where

$$\mathcal{A} \equiv (4/3)\langle\gamma_e^2\beta_e^2\rangle, \quad \mathcal{B} \equiv 1 - \langle\ln[\gamma_e(1 + \beta_e)]/(\beta_e\gamma_e^2)\rangle;$$

$A$  is a constant factor proportional to the cloud optical depth,  $\beta_e$ ,  $\gamma_e$  are electron individual velocity and the Lorentz factor,  $\langle\dots\rangle$  denotes the averaging over the particle distribution in the cloud comoving frame. The fourth parameter  $V$  vanishes (the resulting polarization is linear). The Stokes parameters are evaluated in the polarization frame



**Figure 1.** Examples of intensity (left panel) and polarization (middle panel) lightcurves. Contributions of the retro-lensing images have been summed together and plotted (by a dashed line); they are clearly distinguished from the signal produced by the direct-image photons (solid line). Polarization vanishes at the moment when the cloud crosses one of the critical velocities  $\beta_1(\xi)$ ,  $\beta_2(\xi)$ . In both cases the view angle was  $i = 5$  deg.

comoving with the cloud, whose one basis vector is pointed along the direction of the scattered radiation and the two other basis vectors lie in the perpendicular observation plane. The incident unpolarized radiation comes into the formulae as components of the stress-energy tensor  $T^{\alpha\beta}$  with respect to this reference frame.

The total four-force acting on the cloud is a superposition of the radiation and inertial terms. The equation of motion is solved in the spacetime of a static black hole. (Schwarzschild radius  $R_S$ ). The radiation field influences both, the bulk motion of the cloud and the electron distribution in the cloud comoving frame. For polarization we obtain two critical velocities at which the polarization vector changes its orientation between transversal and longitudinal one. Similar effect of polarization direction changing with velocity of the scattering medium was studied by Beloborodov (1998).

## Retro-lensing lightcurves and polarization

When determining the temporal evolution of observed intensity and polarization we consider the first three images of the observed radiation – the direct one and two retro-lensed images. The latter are formed by rays making a single round about the black hole by the angle  $2\pi \pm i$ . For small inclinations these images take the form of Einstein arcs. The retro-lensed photons give rise to peaks in the observed signal occurring with a characteristic mutual time lag after the direct-image photons. Duration of these features is very short and comparable to the light crossing time.

## Conclusions

Our calculation is self-consistent in the sense that the motion of the blob and of photons, and the resulting polarization are mutually connected. We concentrated ourselves on gravitational effects and compared the polarization magnitudes of direct and retrolensing images. We have noticed the mutual delay between the signal peaks formed by photons of different orders. The delay is characteristic to the effect and has a value proportional to the black hole mass.

## References

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