X-ray polarization by reflection from accretion disc in AGN

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Scheme of the lamp-post geometry

- ▶ central black hole → mass, spin

- ▶ accretion disc
  - → Keplerian, geometrically thin, optically thick and neutral

- ▶ compact corona
  - → isotropic power-law emission
  - → static (or slow motion)
  - → height, photon index

- ▶ relativistic effects:
  - → Doppler and gravitational energy shift
  - → light bending (lensing)
  - → aberration (beaming)

- ▶ references:
  - → Matt (1993)
  - → Dovčiak, Muleri, Goosmann, Karas & Matt (2011)

Corona: P_p, χ_p

Disc: P_{loc}, χ_{loc}
  → Chandrasekhar (1960)

Relativistic effects: χ_o, χ_d, χ_{do}
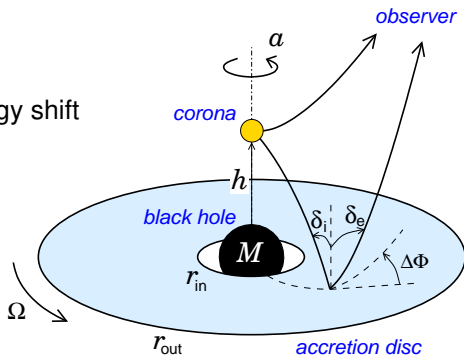
Stokes parameters at infinity

$$S(P_{\mathrm{p}}, \chi_{\mathrm{p}}) = S(0,-) + P_{\mathrm{p}} \left\{ [S(1,0) - S(0,-)] \cos 2\chi_{\mathrm{p}} + [S(1,\pi/4) - S(0,-)] \sin 2\chi_{\mathrm{p}} \right\}$$

$$I(E) = G_{\mathrm{p}} \, I_{\mathrm{p}}(E/g_{\mathrm{p}}) \qquad + \qquad \int_{\Sigma} \mathrm{d}S \, G \, I_{\mathrm{loc}}(E/g)$$

$$Q(E) = G_{\mathrm{p}} \, P_{\mathrm{p}}(E/g_{\mathrm{p}}) \, I_{\mathrm{p}}(E/g_{\mathrm{p}}) \, \cos 2[\chi_{\mathrm{p}}(E/g_{\mathrm{p}}) + \chi_{\mathrm{o}}] \quad +$$
$$\int_{\Sigma} \mathrm{d}S \, G \, P_{\mathrm{loc}}(E/g) \, I_{\mathrm{loc}}(E/g) \, \cos 2[\chi_{\mathrm{loc}}(E/g) + \chi_{\mathrm{do}}]$$

$$U(E) = G_{\mathrm{p}} \, P_{\mathrm{p}}(E/g_{\mathrm{p}}) \, I_{\mathrm{p}}(E/g_{\mathrm{p}}) \, \sin 2[\chi_{\mathrm{p}}(E/g_{\mathrm{p}}) + \chi_{\mathrm{o}}] \quad +$$
$$\int_{\Sigma} \mathrm{d}S \, G \, P_{\mathrm{loc}}(E/g) \, I_{\mathrm{loc}}(E/g) \, \sin 2[\chi_{\mathrm{loc}}(E/g) + \chi_{\mathrm{do}}]$$

I_{loc}, P_{loc} and χ_{loc} depend on:

▶ local geometry of scattering (μ_{i}, μ_{e}, $\Delta\varphi$)

▶ incident polarisation properties (P_{p}, χ_{p}, χ_{d})
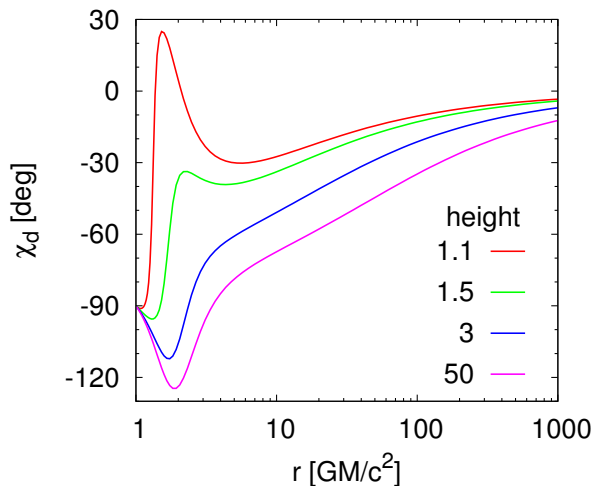
$$\tan \chi_o = a\,\frac{\beta - h\sin\theta_o}{a^2\sin\theta_o + \beta h}$$

relativistic change
of polarisation angle χ_o:

- ▶ is relatively small
  (and zero for
  non-rotating BH)
- ▶ has counter-clockwise
  direction
- ▶ increases with
  - → *inclination*
  - → *BH spin*
  - → *lower height*

Relativistic effects – lamp to disc

Relativistic change
of polarisation angle χ_d:

- is quite large (especially close to the BH)
- has mostly clockwise direction
- special relativistic effects important (aberration)
- for highly spinning BH and very low heights, gravitational dragging causes rotation in counter-clockwise direction

Change of polarization angle and transfer function

$\rightarrow$ important when integrating over the disc surface
$\rightarrow$ polarization angle changes due to aberration and light bending
$\rightarrow$ emission is amplified due to beaming and lensing
$\rightarrow$ depolarization around the critical point

Unpolarised primary radiation

$\rightarrow$ importance of the local polarization properties

$\rightarrow$ geometry of scattering (incident, emission and relative azimuthal angles)

$\rightarrow$ source height, observer inclination and black hole spin

$\rightarrow$ formation of additional depolarizing critical points

$\rightarrow$ illumination pattern depends on height of the source

Energy dependence
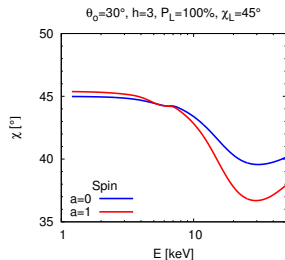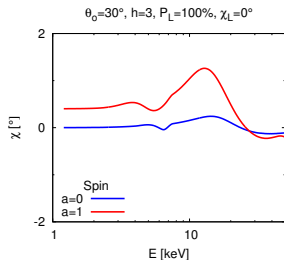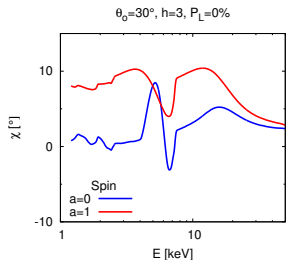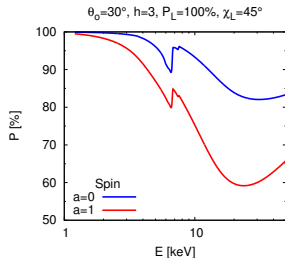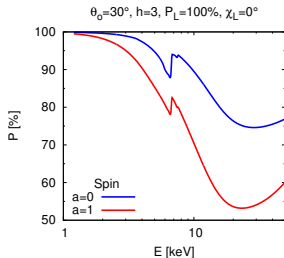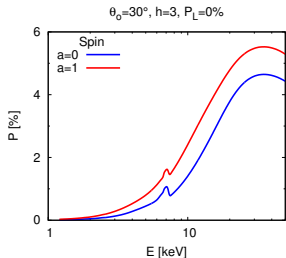
- ▶ polarisation changes with energy
  → primary power-law decrease and reflection Compton hump

- ▶ features at the energies of spectral lines and edges

Dependence on height
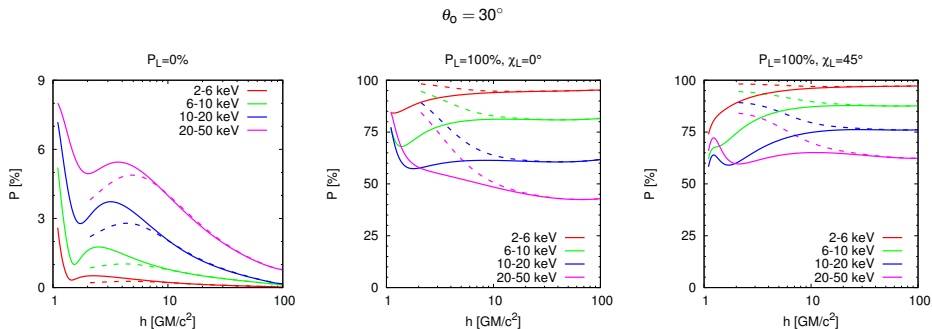
$\theta_o = 30°$

- ▶ larger changes in polarisation and de-polarisation for higher energies
- ▶ larger effect for higher spin
- ▶ largest polarisation for small heights ($h \lesssim 10$)
- ▶ significant de-polarisation for all heights

Dependence on inclination
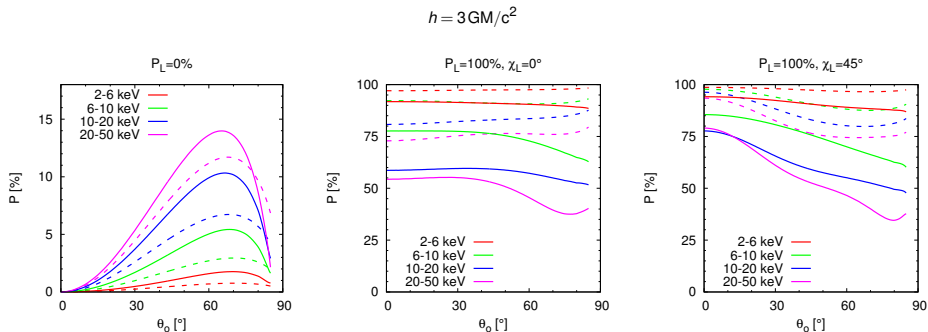
$h = 3\,GM/c^2$

- larger changes in polarisation and de-polarisation for higher energies
- larger effect for higher spin
- largest polarisation for inclinations $55° \lesssim \theta_o \lesssim 75°$
- usually significant de-polarisation for all inclinations

Reflection versus absorption – MCG-6-30-15
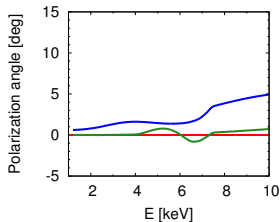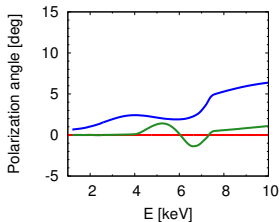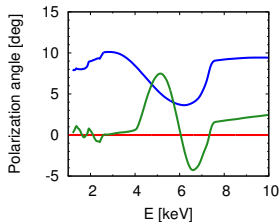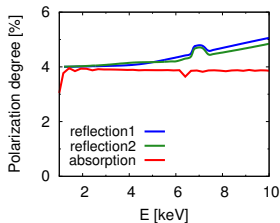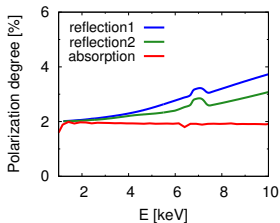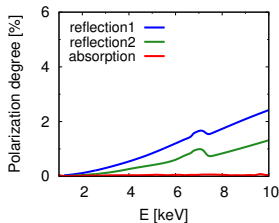
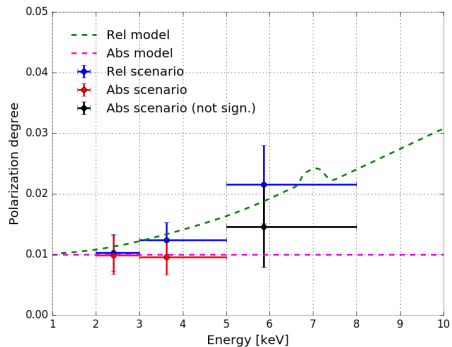| Inclination:	**30°**
Spin:	**a = 0, a = 1**
Photon index:	**Γ = 2**
Height:	**h = 2.5 GM/c²**
Primary pol. deg:	**P = 0.2, 4%**
Primary pol. ang:	**χ = 0°**

Absorption scenario – *clumpy wind*:
→ constant polarisation degree and angle

Reflection scenario:
→energy dependent polarisation degree and angle

see Marin et al. (2012) MNRAS, 426, L101
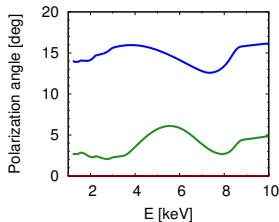
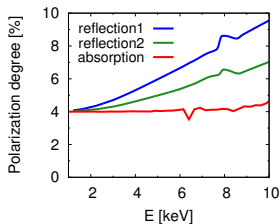# Simulation of the reflection in MCG-6-30-15
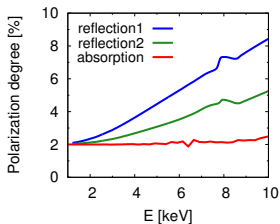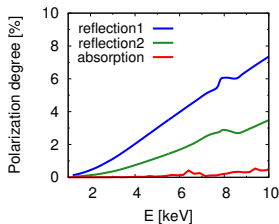

Polarization degree MCG_6_30_15 5 Ms

Polarization angle MCG_6_30_15 5 Ms
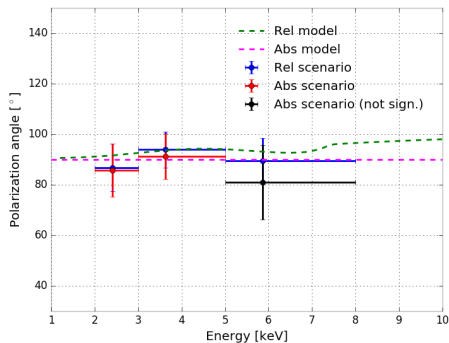
Reflection versus absorption – NGC-1365
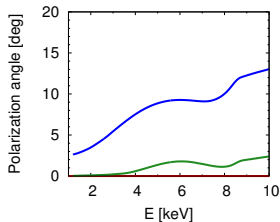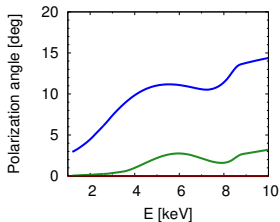
| Inclination: | **60°** |
Spin:	**a = 0**, **a = 1**
Photon index:	**Γ = 2**
Height:	**h = 2.5 GM/c²**
Primary pol. deg:	**P = 0, 2, 4%**
Primary pol. ang:	**χ = 0°**

Absorption scenario – *obscuring circumnuclear clouds*:
→ constant polarisation degree and angle
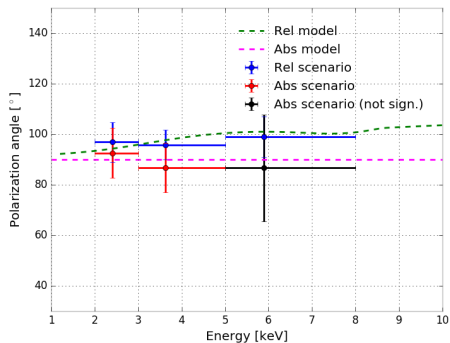
Reflection scenario:
→ energy dependent polarisation degree and angle

see Marin et al. (2013) MNRAS, 436, 1615

Simulation of the reflection in NGC-1365

Polarization degree NCG 1365 4 Ms
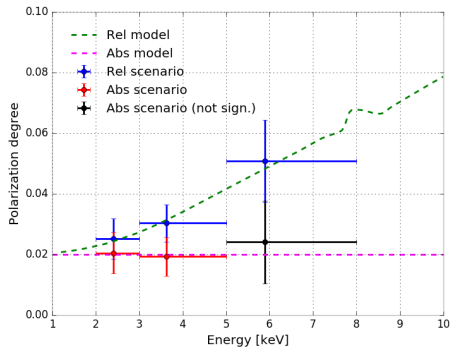
Polarization degree NCG 1365 4 Ms

Summary of results

- relativistic effects from the lamp to the observer are small

- relativistic effects from the lamp to the disc are large even for high heights and large radii

- largest polarisation degree for high spin, low heights, inclinations of $55° − 75°$ and high energy

- expected variation of polarisation angle with energy is $\Delta\chi \lesssim 10°$

- polarisation by reflection in AGN will probably not be observable with near future polarimetry missions such as IXPE or eXTP

Advertisement:

Codes KYNBB and KYNLPCR usable inside XSPEC with polarisation computations included are available at

https://projects.asu.cas.cz/stronggravity/kyn