Measuring the black hole spin with X-ray polarimetry

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Plan of the talk

- **Effects of strong gravity on the polarization degree and angle**

- **Measuring the BH spin in:**

Galactic BH Binaries

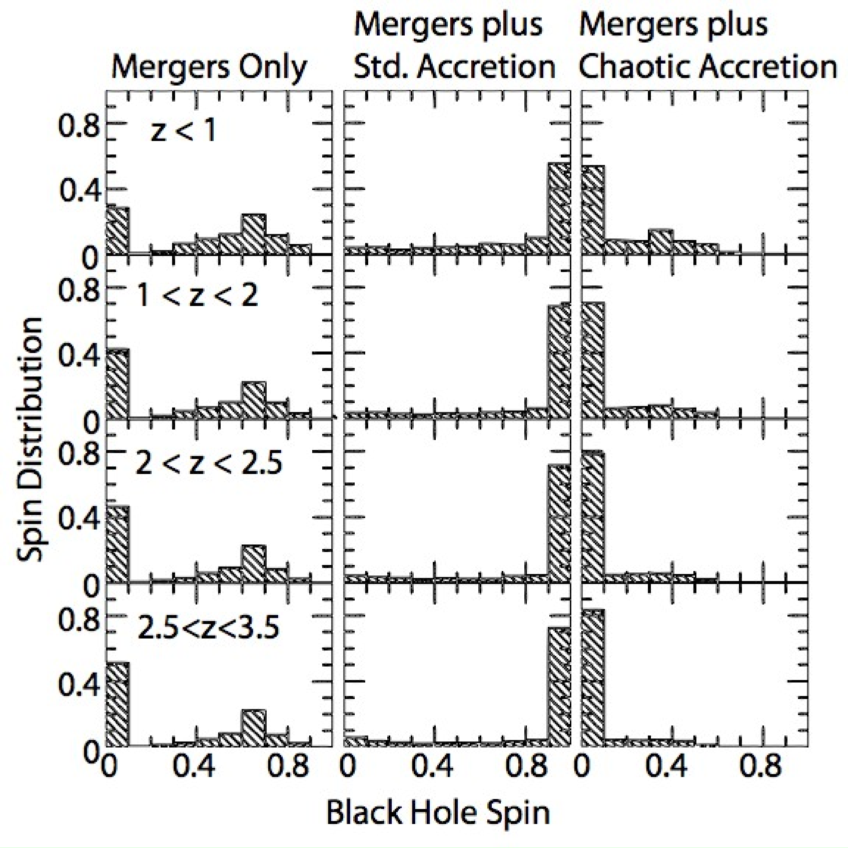
Active Galactic Nuclei

The importance of spin measurements

Why is important to know the BH spin?

In AGN, it can discriminate between different growth histories (spin is mainly acquired during the SMBH evolution)

In GBH, it tells us about the origin of the BH (spin is mainly pristine)



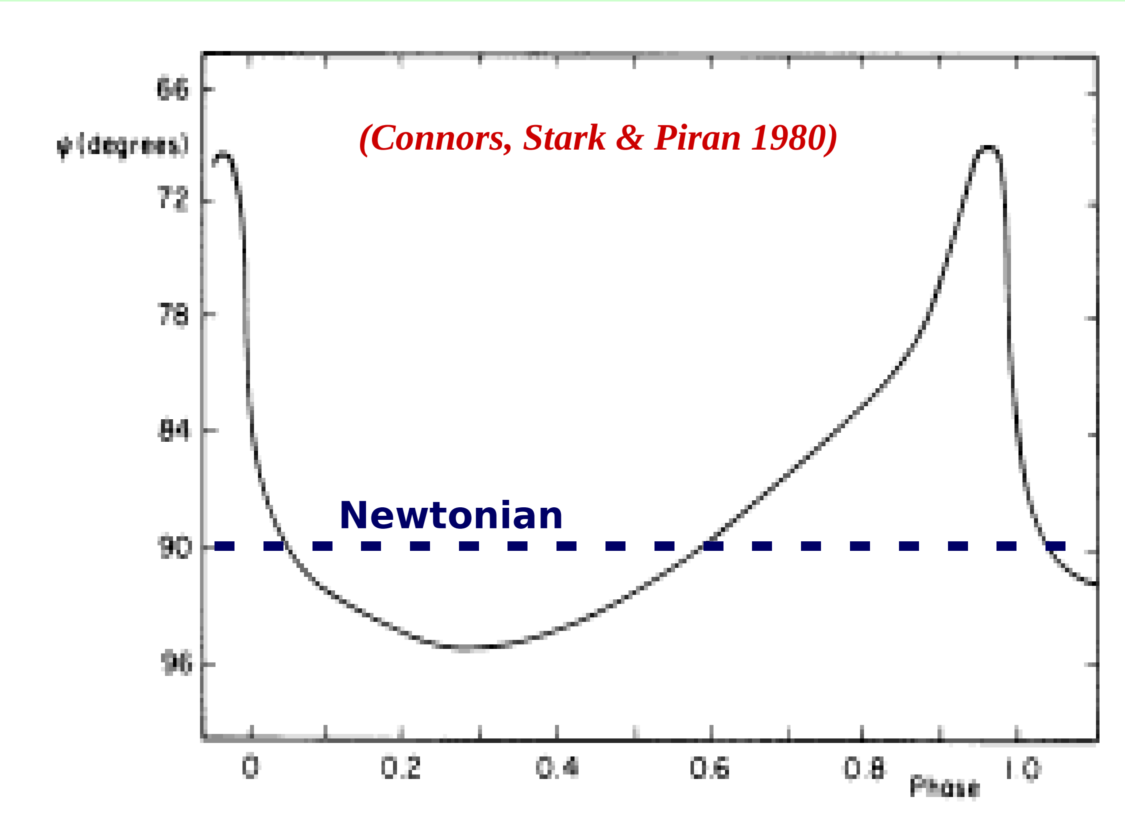
Berti & Volonteri 2008

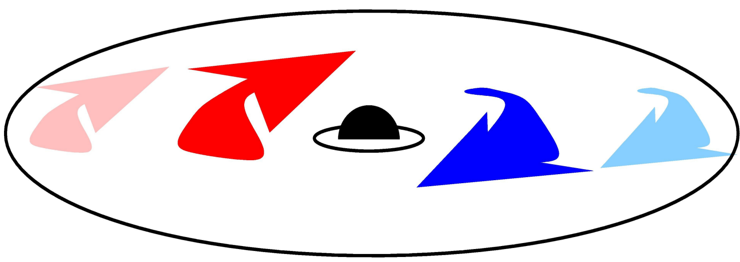
Techniques (electromagnetic)

- *Iron line and reflection spectroscopy (GBH, AGN)*
- *Disk continuum spectroscopy (GBH)*
- *QPO (GBH)*
- *Polarimetry (GBH, AGN)*

General and Special Relativity effects around a compact object (here-in-after collectively indicated as "strong gravity effects") significantly modifies the polarization properties of the radiation.

In particular, the Polarization Angle (PA) as seen at infinity is rotated due to aberration (SR) and light bending (GR) effects (e.g. Connors & Stark 1977; Pineault 1977). The rotation is larger for smaller radii and higher inclination angles



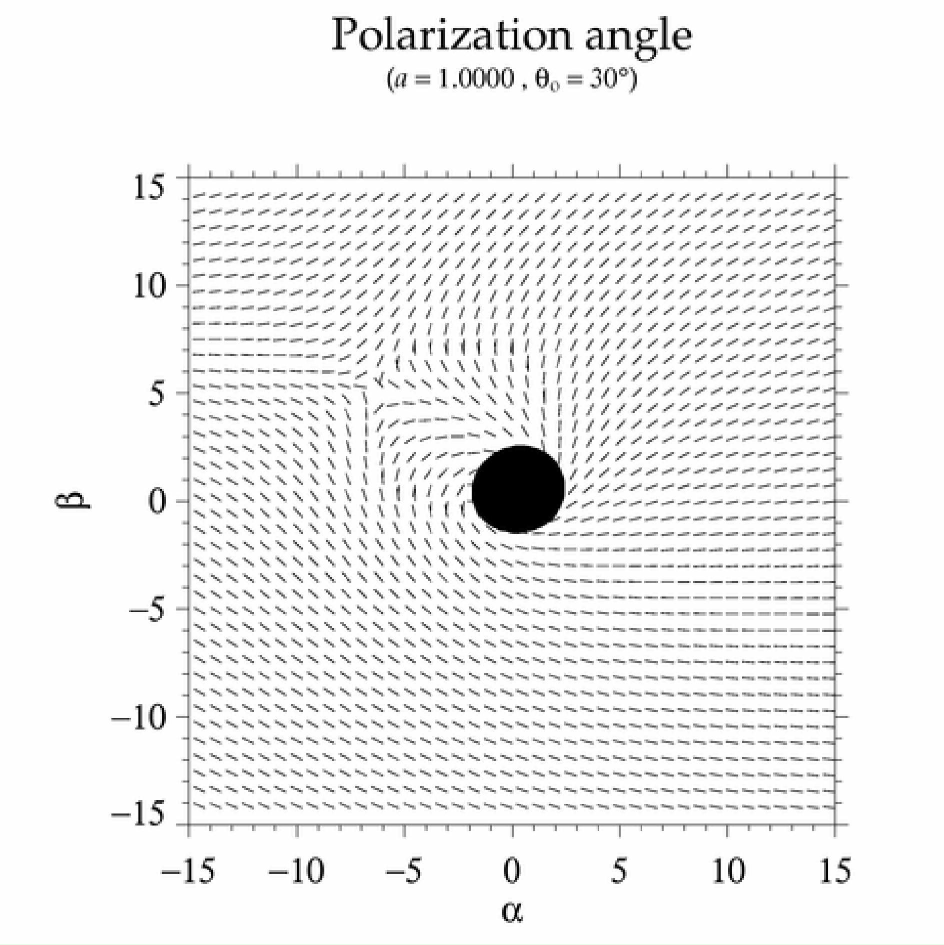


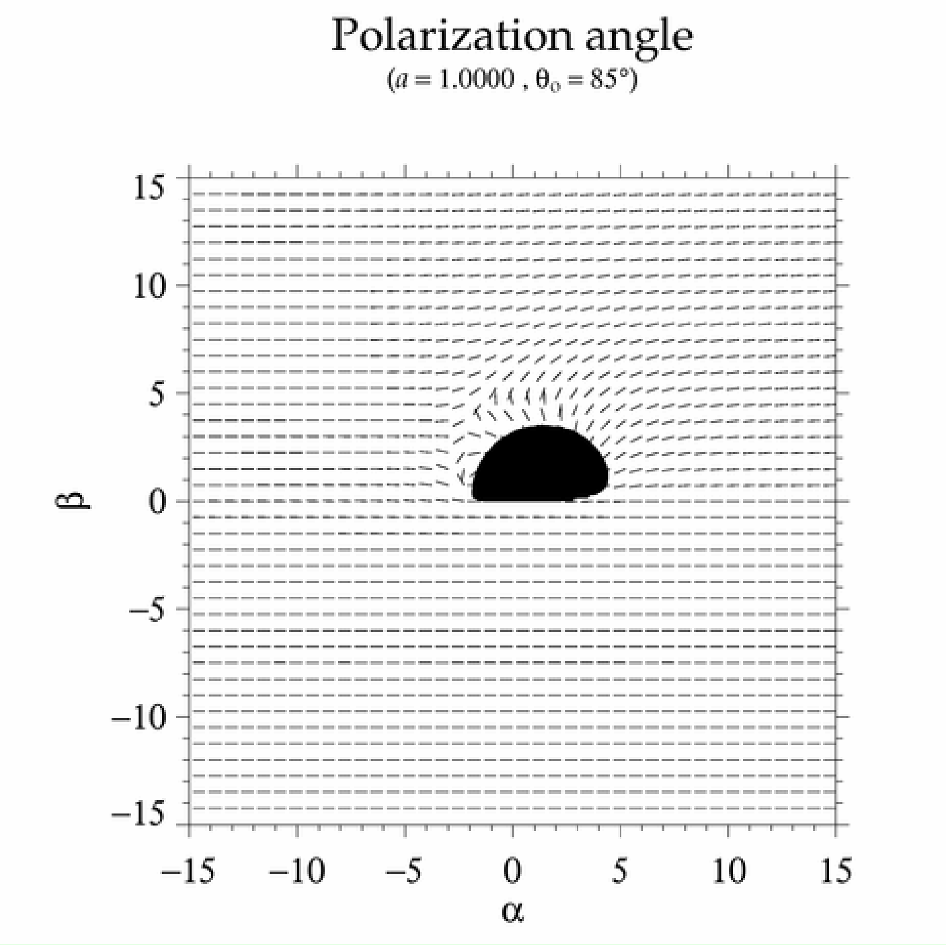
Orbiting spot with:
a=0.998; R=11.1 Rg
i=75.5 deg

(Phase=0 when the spot is behind the BH).

The PA of the net (i.e. phase-averaged) radiation is also rotated!

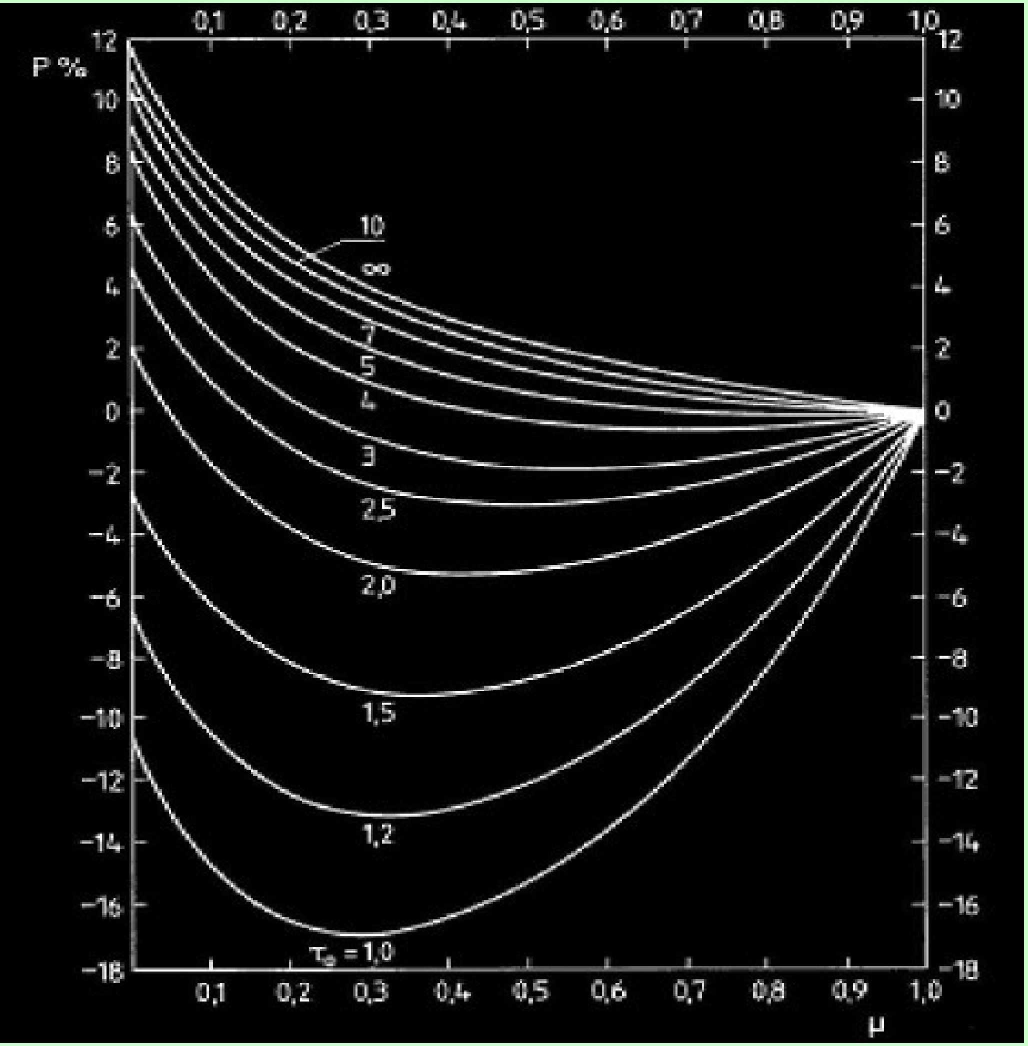
Strong gravity effects on polarization





Courtesy of Michal Dovciak

Polarization of disc emission

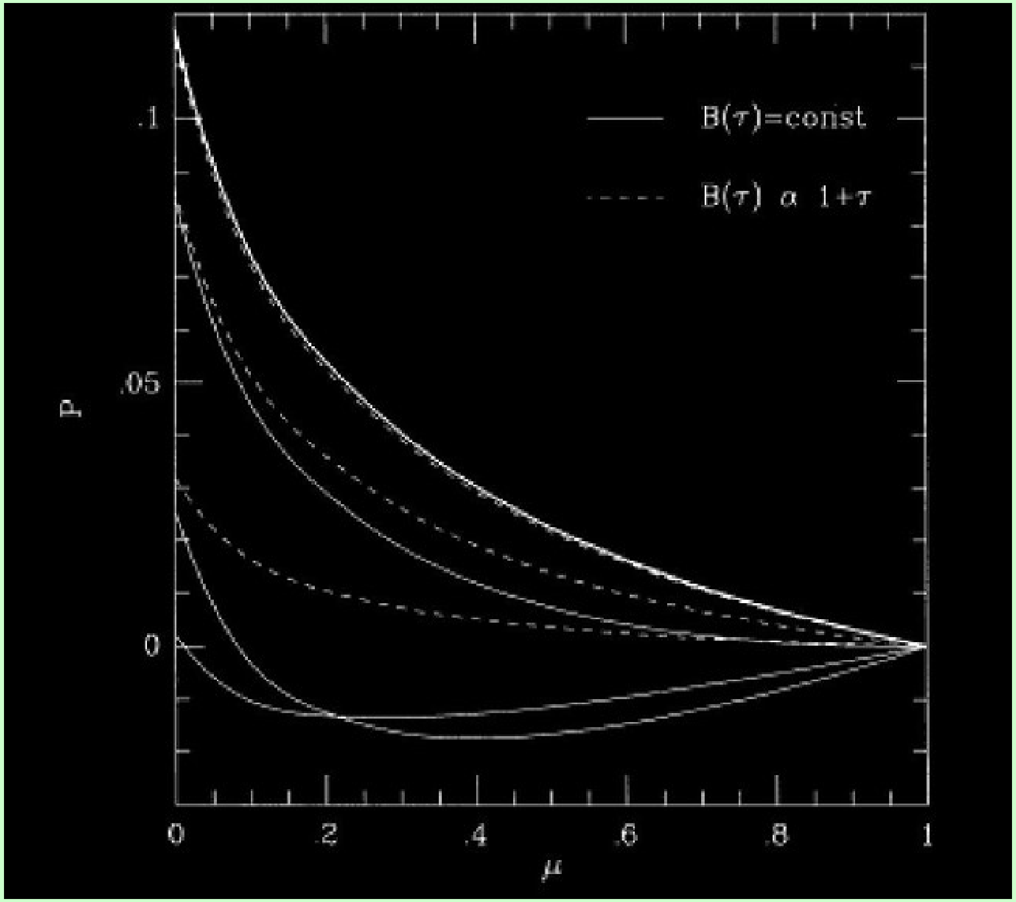


Sunyaev & Titarchuk (1985)

Thermal disc emission, in a pure scattering atmosphere, is polarized up to about 12% (Chandrasekhar 1960), even more if the scattering layer is optically thin (e.g. Sunyaev & Titarchuk 1985, Dovciak et al, 2008)

For symmetry reasons, the polarization is always either parallel or perpendicular to the disc axis.

Polarization of disc emission

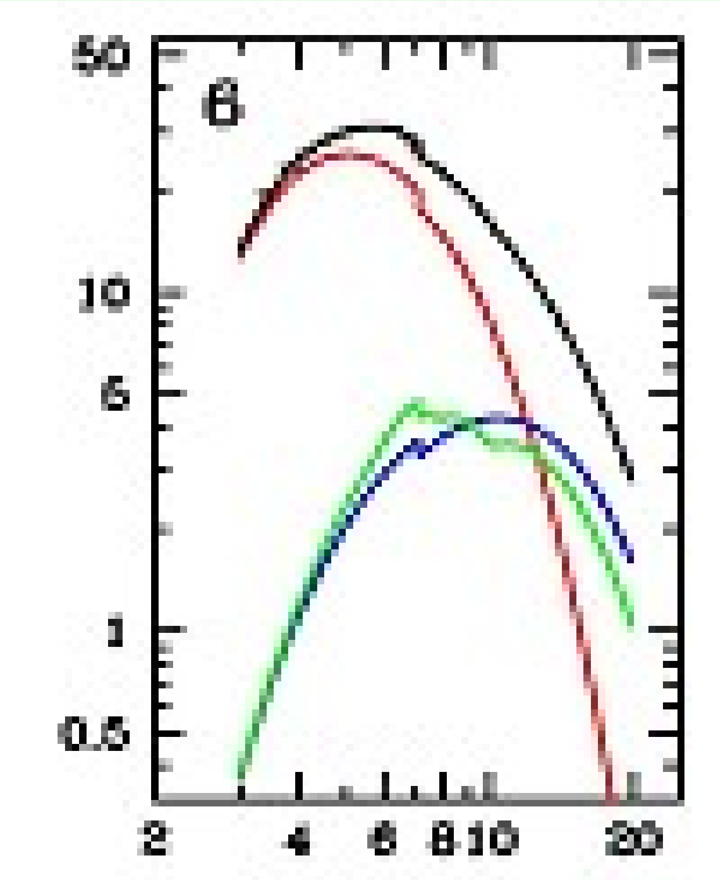


A word of caution:

P **decreases if there is significant absorption (e.g. Loskutov & Sobolev 1981; Laor et al. 1990; Matt et al. 1993)**

Matt et al. (1993)

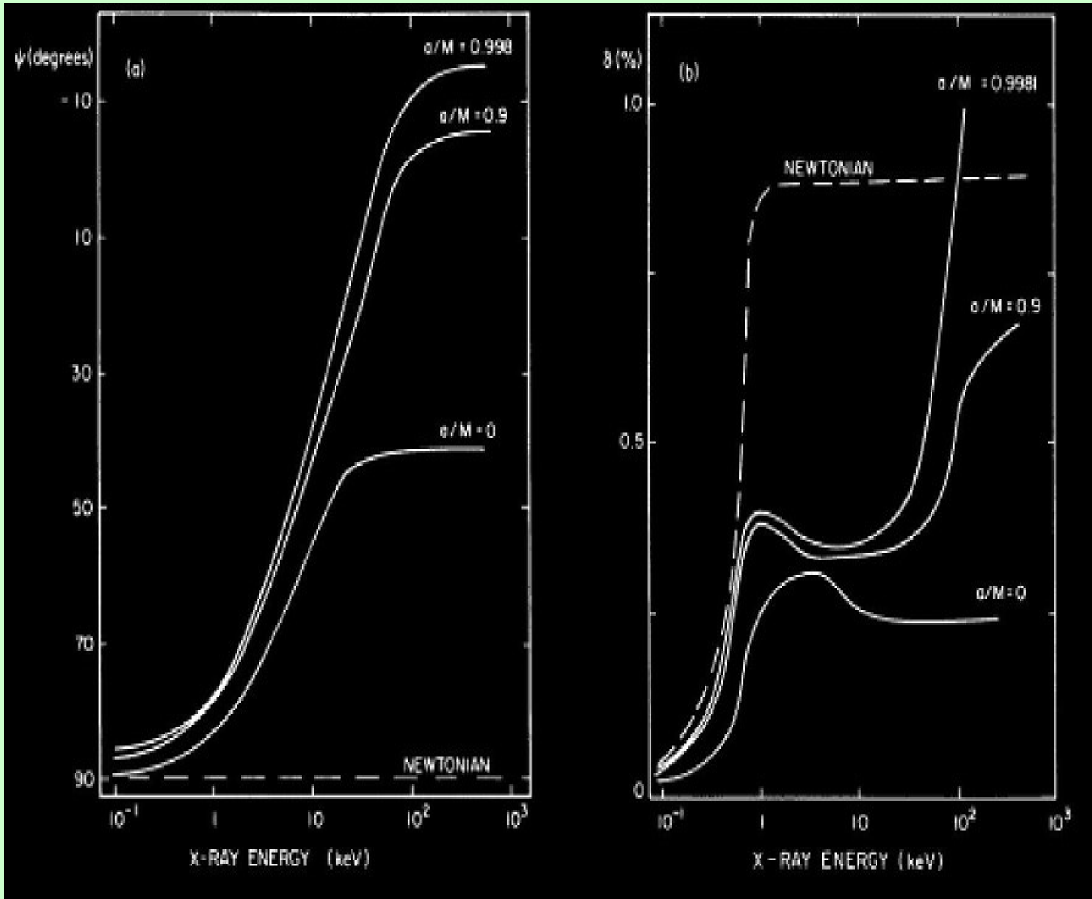
Galactic BH binaries in high state



GRS 1915+105
(Done & Gierlinski 2004)

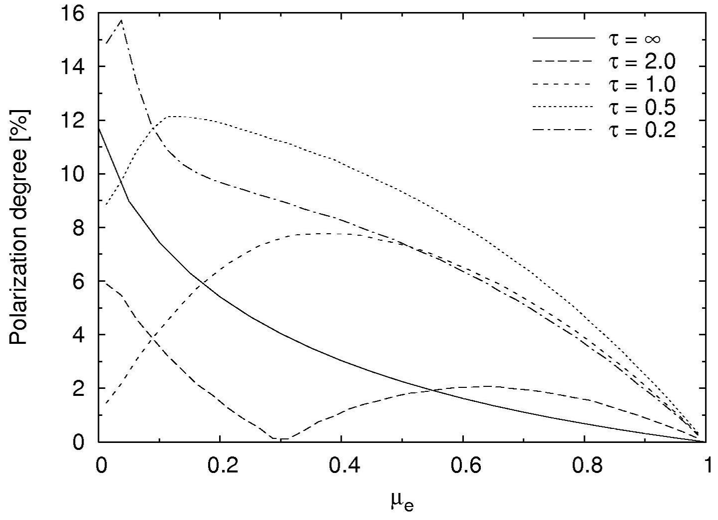
X-ray emission in Galactic BH binaries in soft states is dominated by disc thermal emission, with *T decreasing with radius.*

A rotation of the polarization angle with energy is therefore expected.

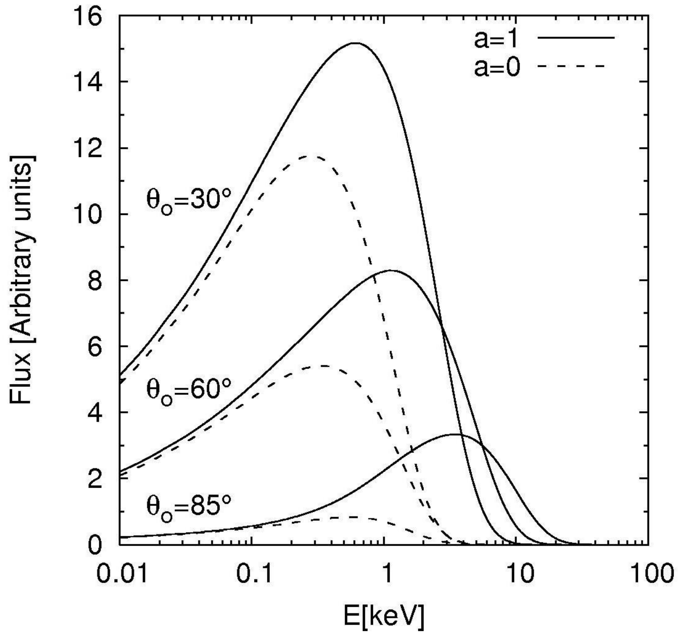


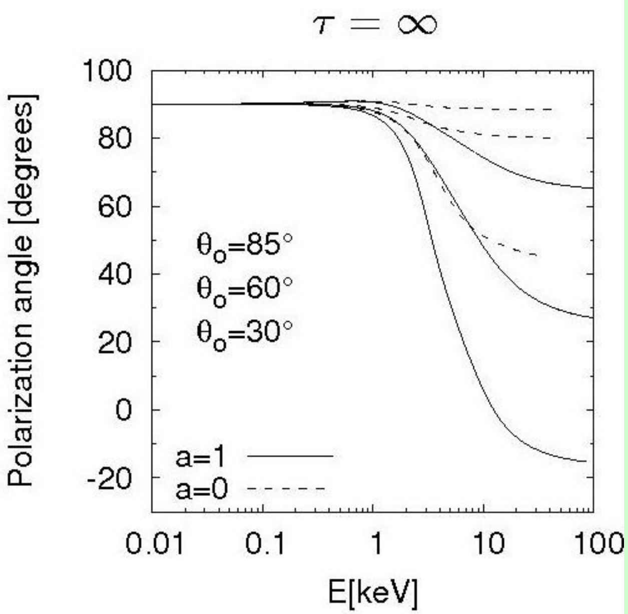
Connors & Stark (1977)

We (Dovciak et al. 2008) revisited and refined these calculations (see also Li et al. 2009).



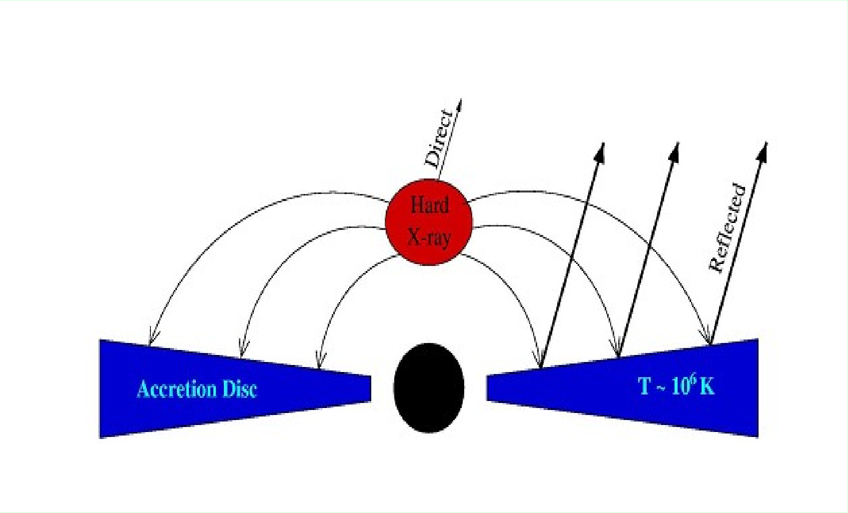
Strongly dependent on the spin of the BH !!

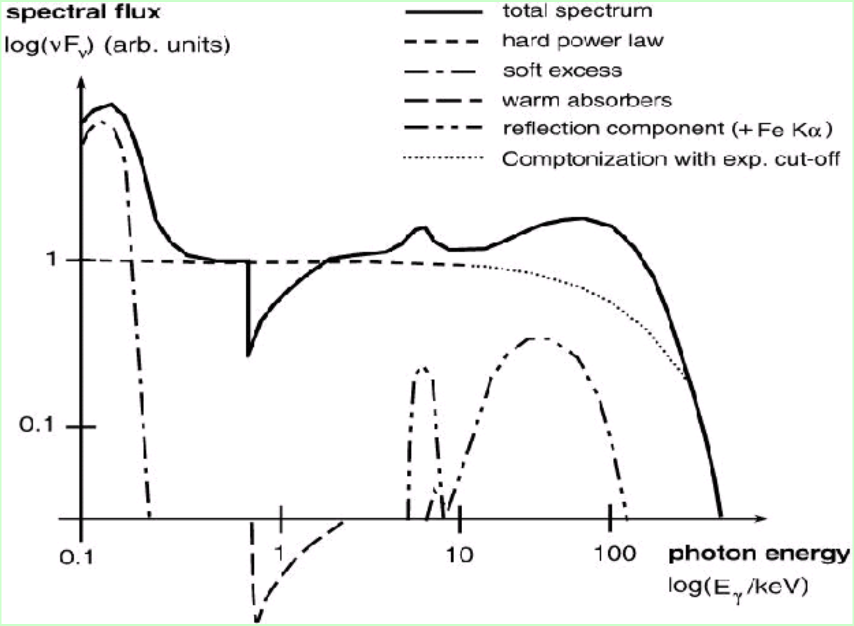




Active Galactic Nuclei

In AGN the primary X-ray emission is due to Inverse Compton by electrons in a hot Corona of the UV/Soft X-ray disc photons. It is likely to be significantly polarized (e.g. Haardt & Matt 1993, Poutanen & Vilhu 1993, Schnittman & Krolik 2010, Tamborra et al., submitted).

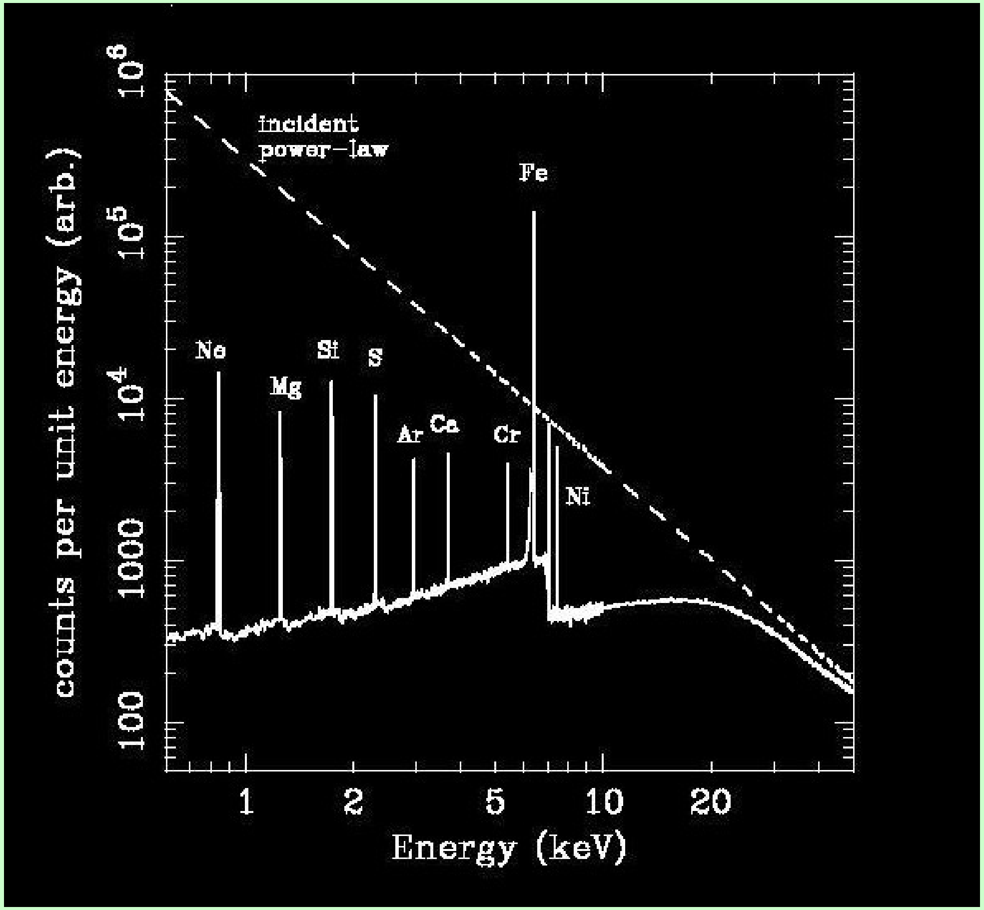




Part of the primary emission illuminates the disc and is reflected (and polarized) via Compton Scattering

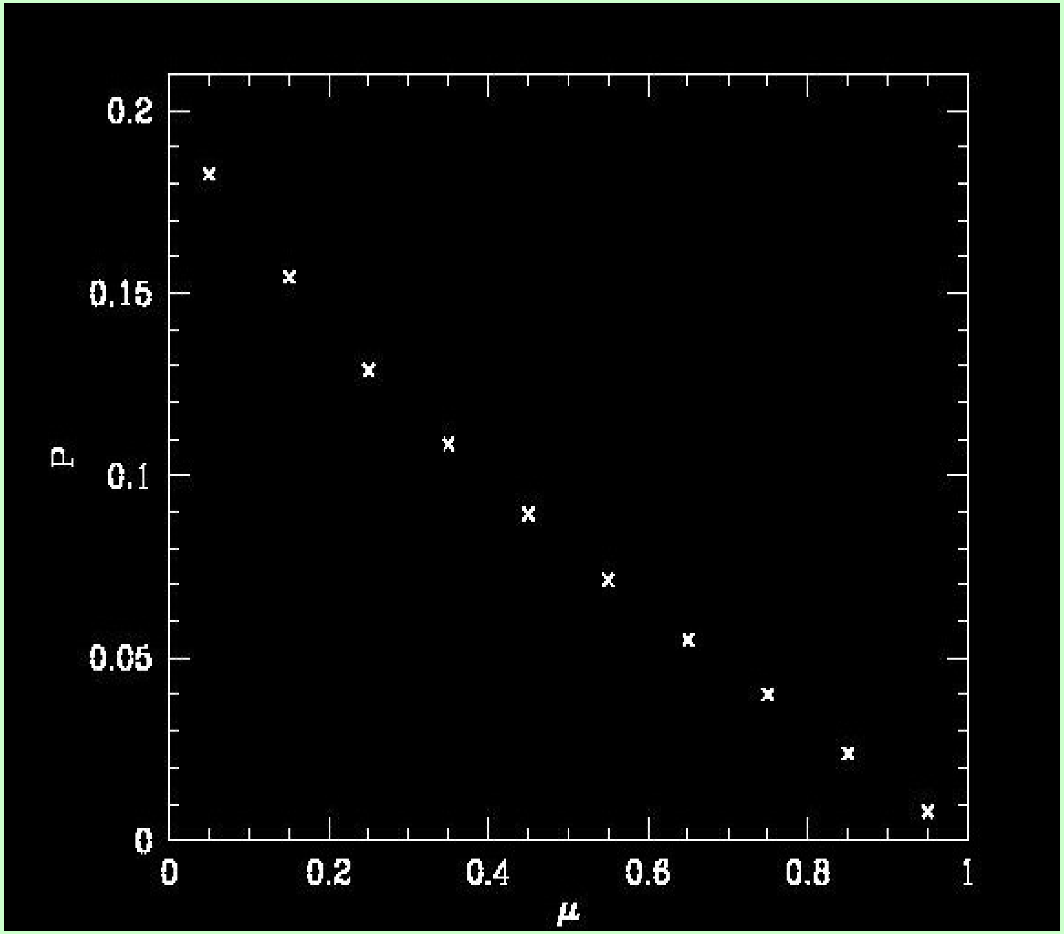
Reflection from cold matter

Reflection from cold matter produces a continuum peaking around 20 keV, due to the combined effects of photoelectric absorption and Compton scattering (plus several fluorescent lines, most prominent of them the Fe Kα line at 6.4 keV).



Reynolds et al. (1995)

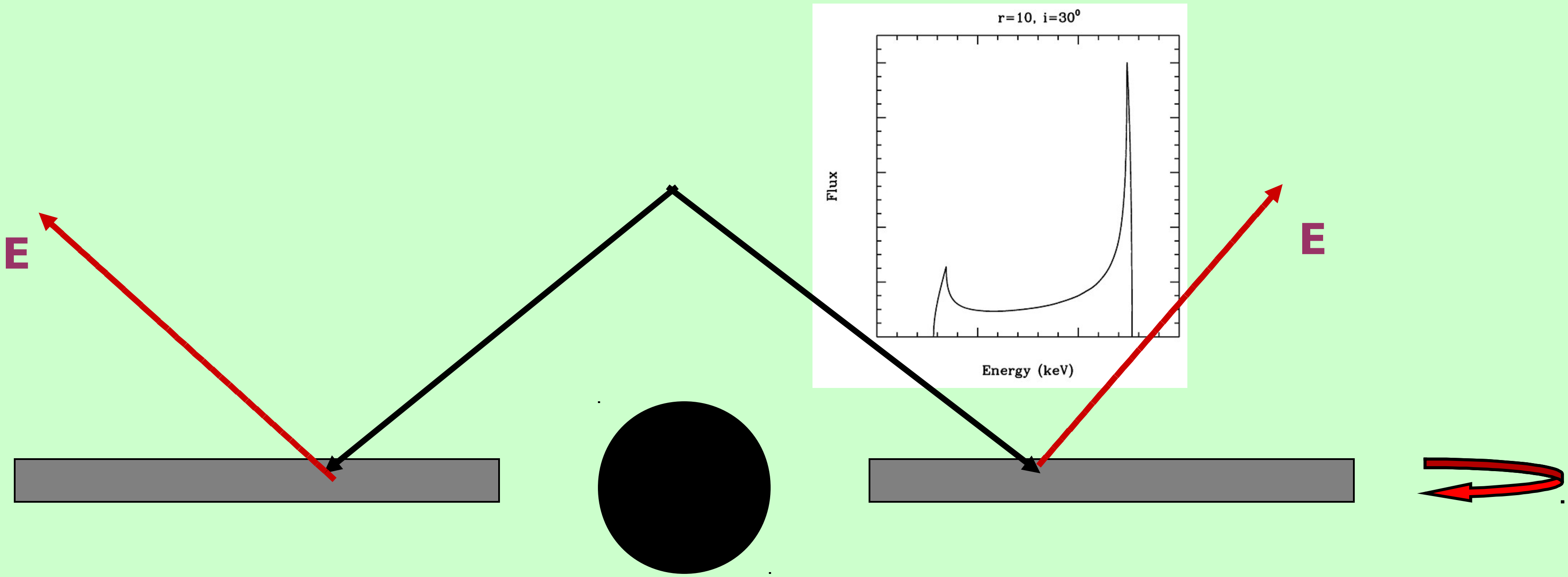
Polarization of reflected flux



Polarization of reflected (continuum) radiation is large. For instance, it is up to 20% (Matt et al. 1989) assuming isotropic illumination, a plane-parallel reflecting slab and unpolarized illuminating radiation.

The exact values depend on the actual geometry of the system and on the polarization degree of the primary radiation

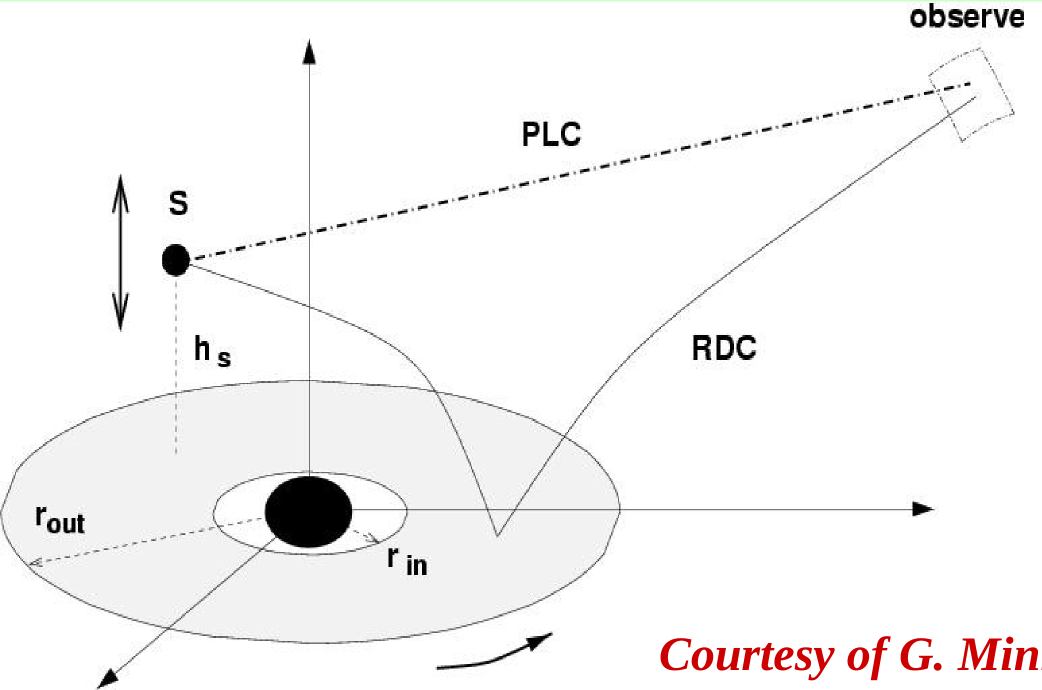
Reflection in Relativistic discs

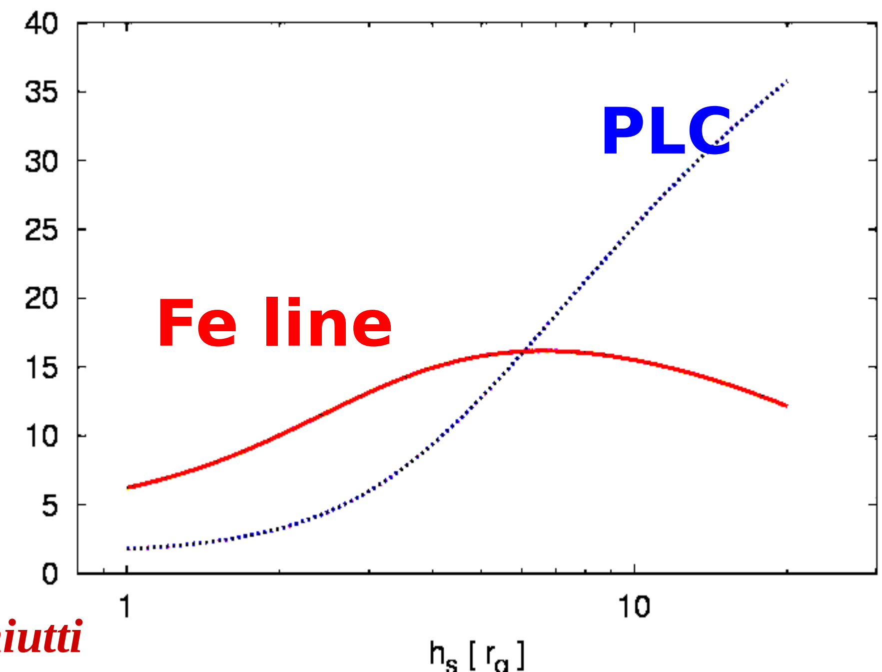


Breaking of the symmetry due to SR (Doppler boosting) adds to the effects already mentioned, causing the rotation of the PA with respect to the Newtonian case. Changes in the illumination properties (e.g. in the height of the lamp-post) will cause changes in the total PA, which is therefore likely to be time dependent (relevant for AGN, timescales too short for GBH).

Light bending model

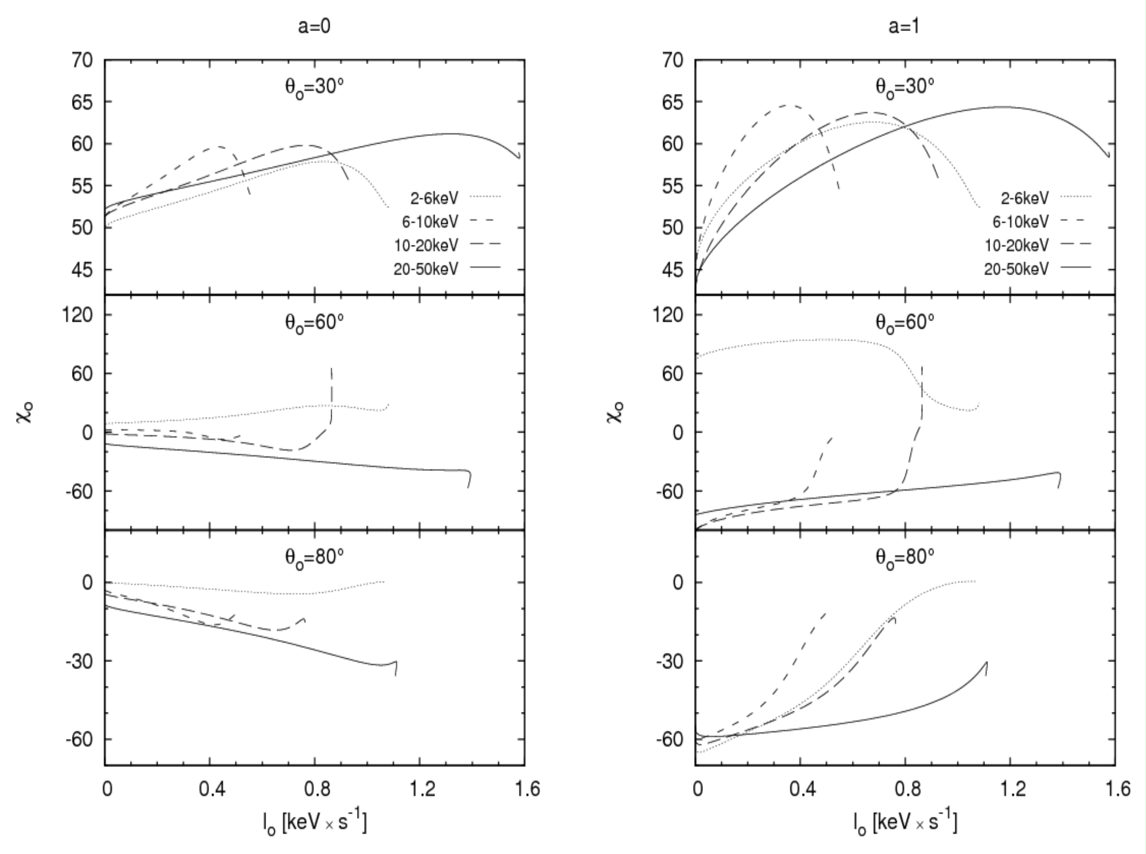
Variations of *h* have been suggested to be the cause of the puzzling temporal behaviour of the iron line in MCG-6-30-15 (Miniutti et al. 2003), where the line flux varies much less than the primary power law flux. Similar effects observed also in other sources (both AGN and GBH in hard state)





Courtesy of G. Miniutti

Polarization of reflected radiation



Dovciak et al. 2011

The polarization degree and angle depend on both *h* and the incl. angle (the latter may be estimated from the line profile; for MCG-6-30-15 is about 30 degrees, Tanaka et al. 1995)

Variation of h with time
implies a time variation of the degree and angle of polarization

Pros and Cons

GBH

Pros: A very clean method, based on a simple geometry. Sources may be very bright

Cons: Intrinsic polarization degree may be low

AGN

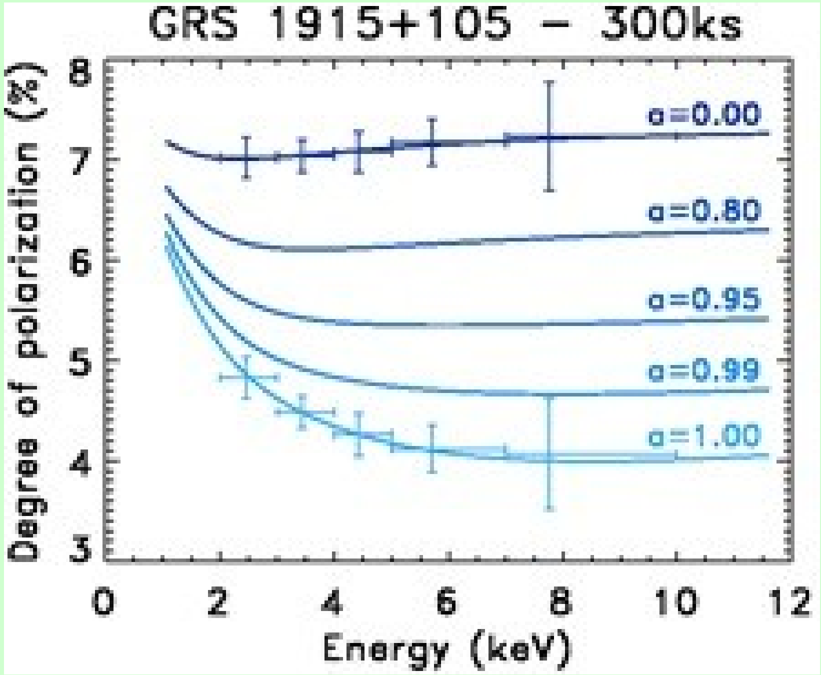
Pros: High polarization degree

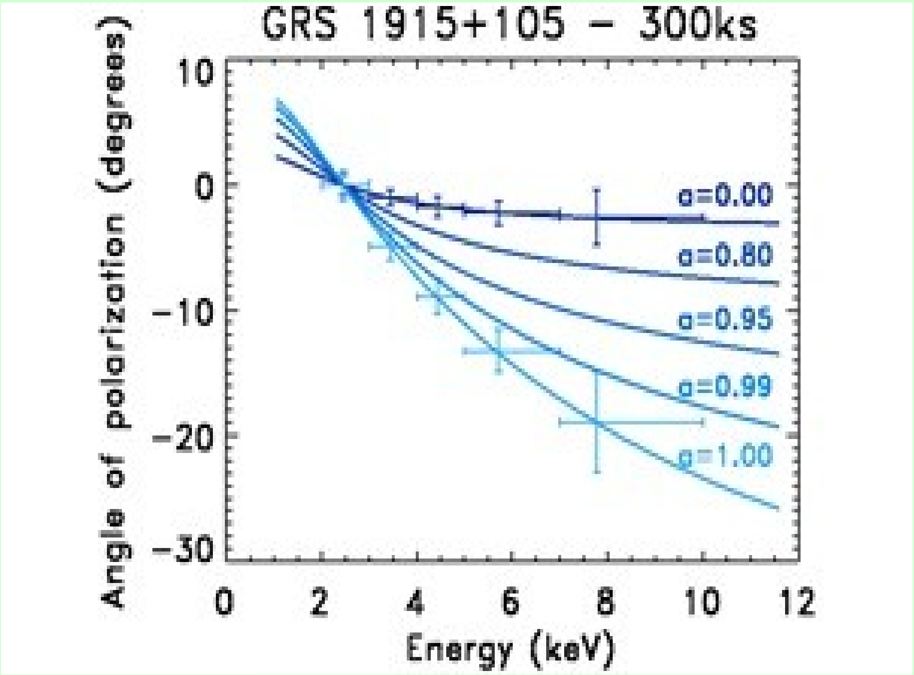
Cons: Poorly known geometry of the illuminating region. Dilution by a strong (and possibly highly polarized) primary emission. Fainter sources (a few mCrab at most)

In both cases, the main information is provided by the variations of the polarization properties (and in particular of the angle), which are unique strong gravity effects

Observational perspectives I. GBH

The Black Hole spin can be measured in bright GBH like GRS 1915+105 with a small mission

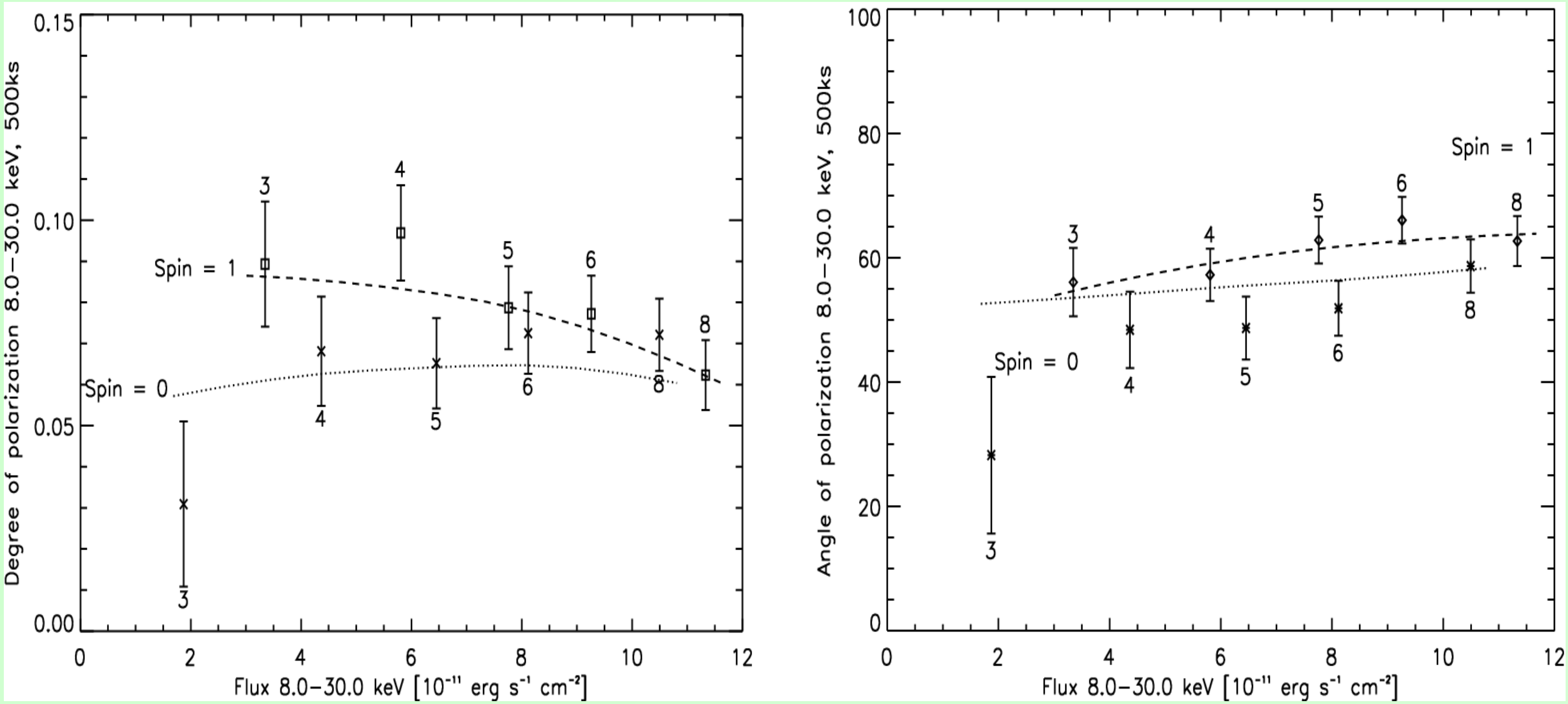




XIPE (Soffitta et al. 2013)

Observational perspectives II. AGN

The Black Hole spin can be measured in bright AGN like MCG-6-30-15 with a small mission (but assuming an unpolarized primary emission)



NHXM (Dovciak et al. 2011)

Energy- (Time-) dependence of the polarization angle in GBH (AGN) can provide a new and independent method to measure the black hole spin.

A small mission should suffice to measure the spin in bright GBH, and at least to make an attempt at AGN.