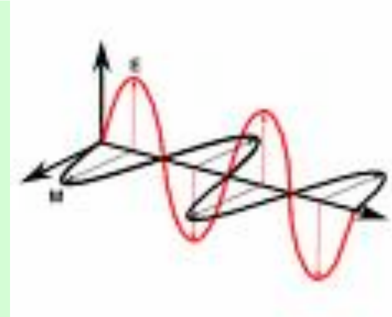

Polarimetry to test strong gravity

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(Dip. Fisica, Università Roma Tre, Italy)

Michal Dovciak, Vladimir Karas

(Academy of Science, Prague, Czech Rep.)

Plan of the talk

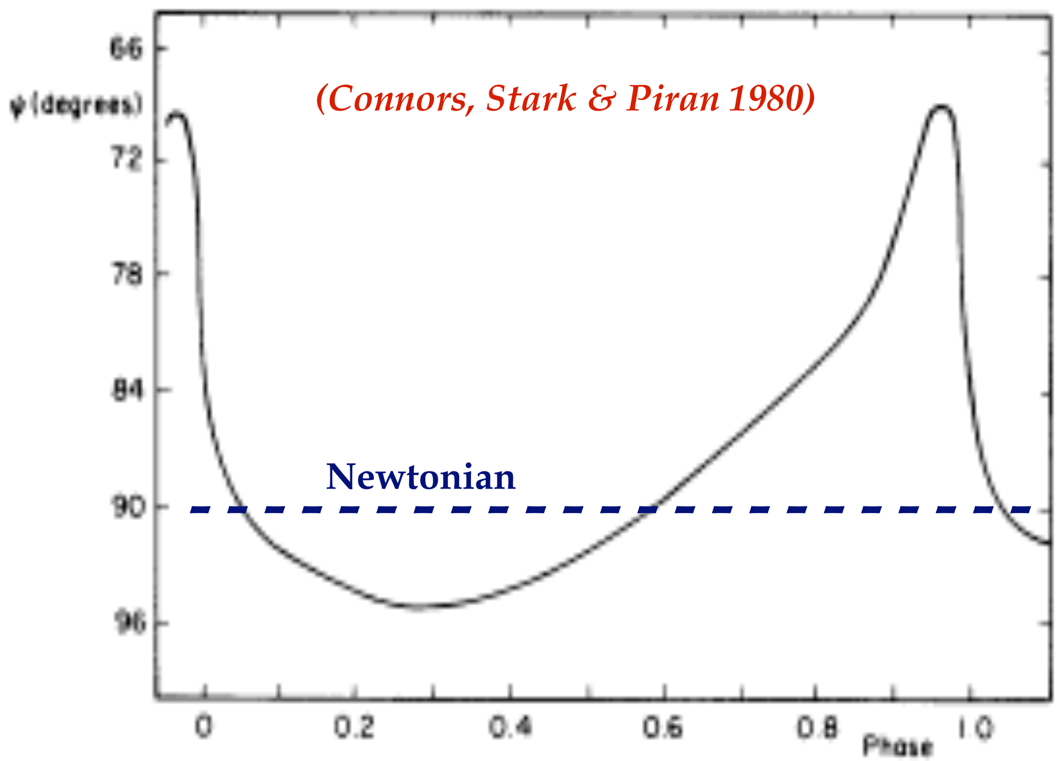
- **Effects of strong gravity on the polarization degree and angle**

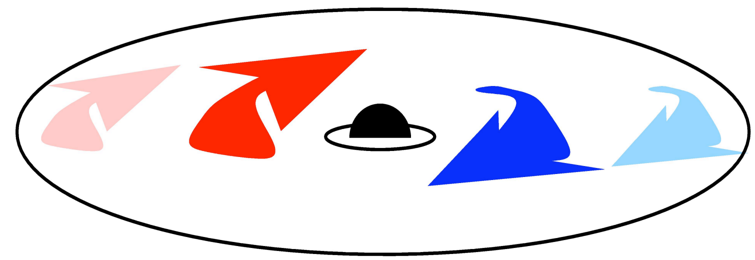
- **Applications to:**

  Galactic BH Binaries

  Active Galactic Nuclei

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



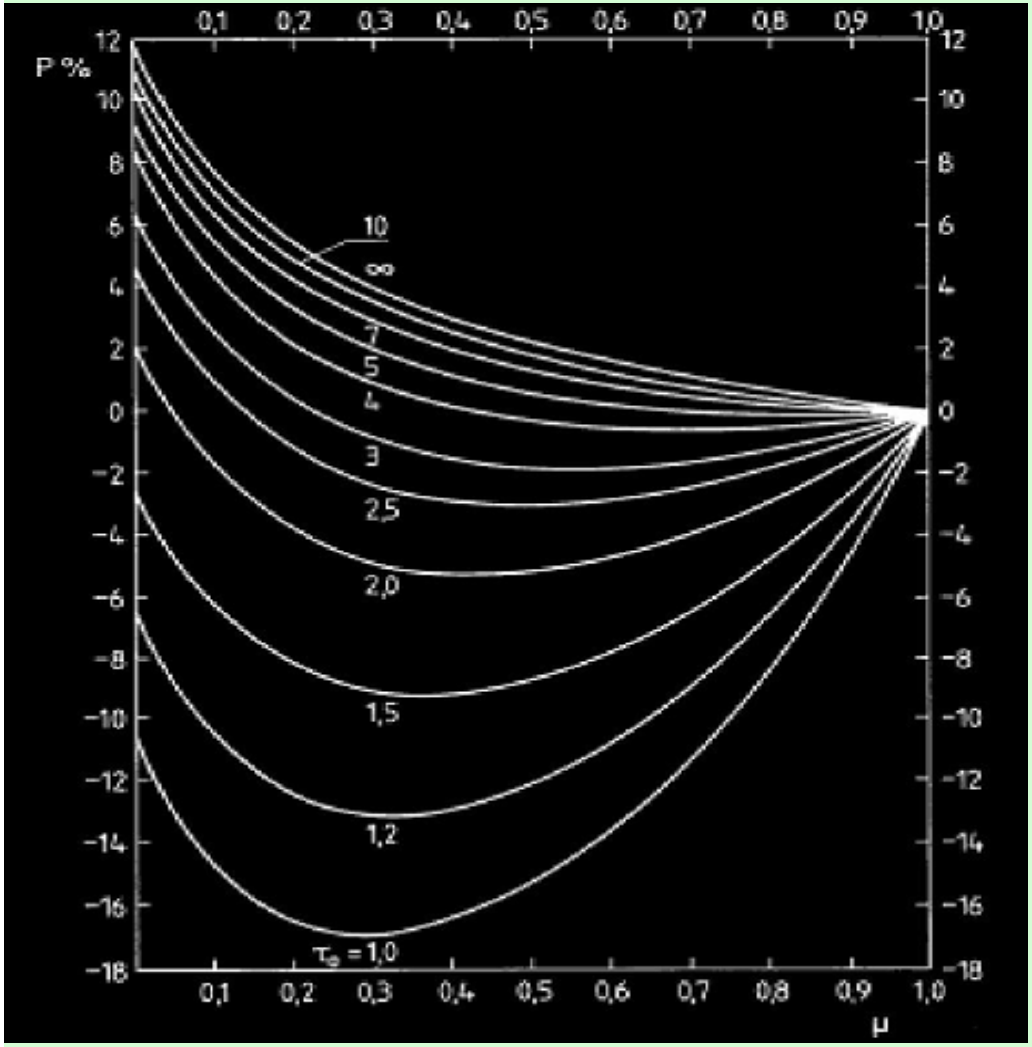


Orbiting spot with:
a=0.998; R=11.1 Rg
i=75.5 deg

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

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

Polarization of disc emission

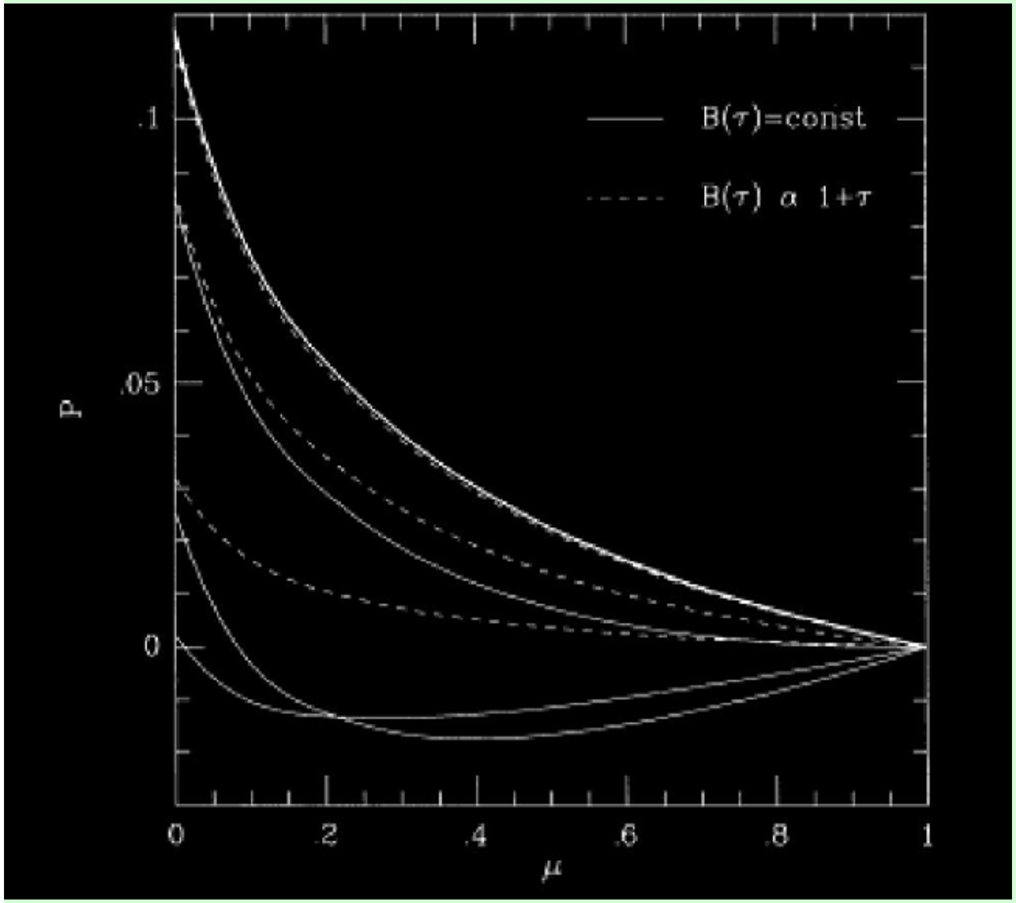


Sunyaev & Titarchuk (1985)

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

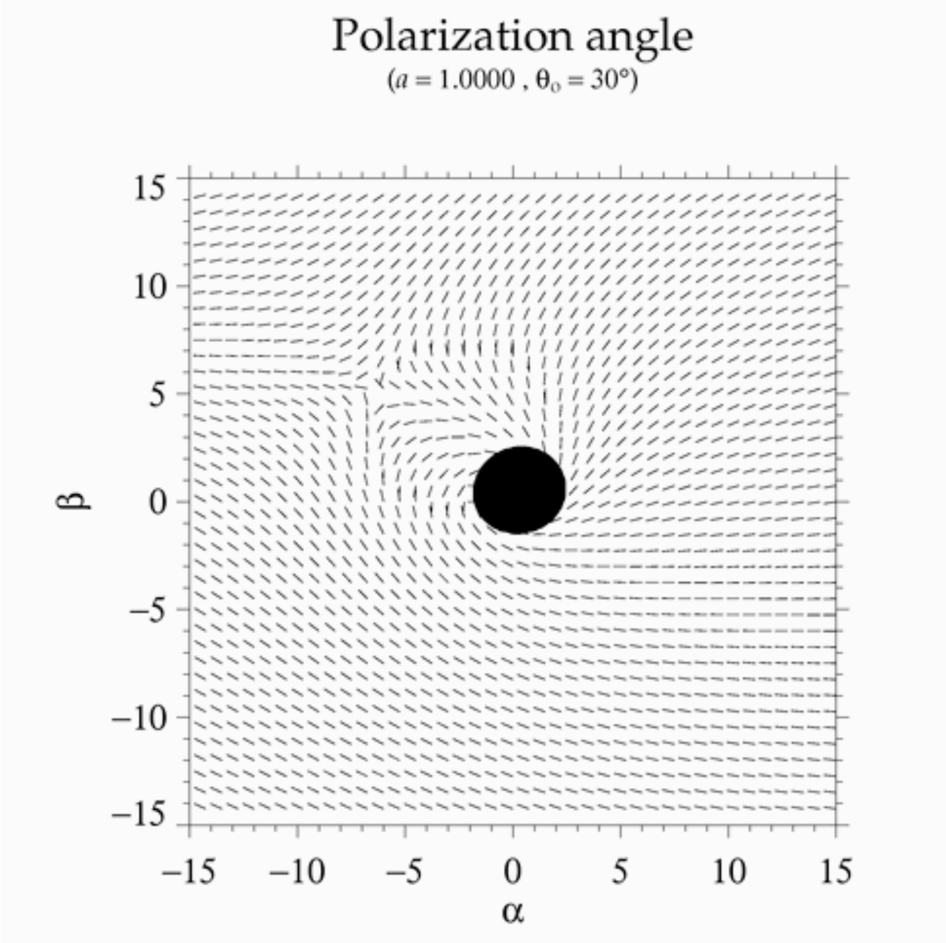


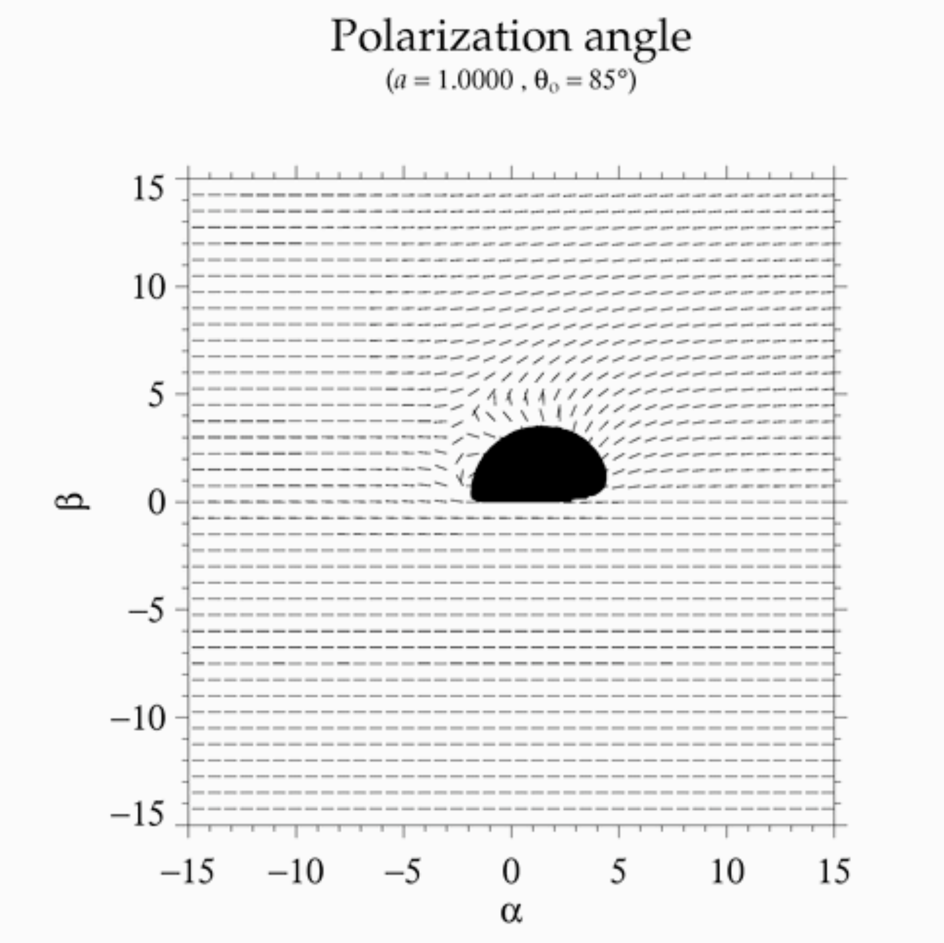
Matt et al. (1993)

A word of caution:

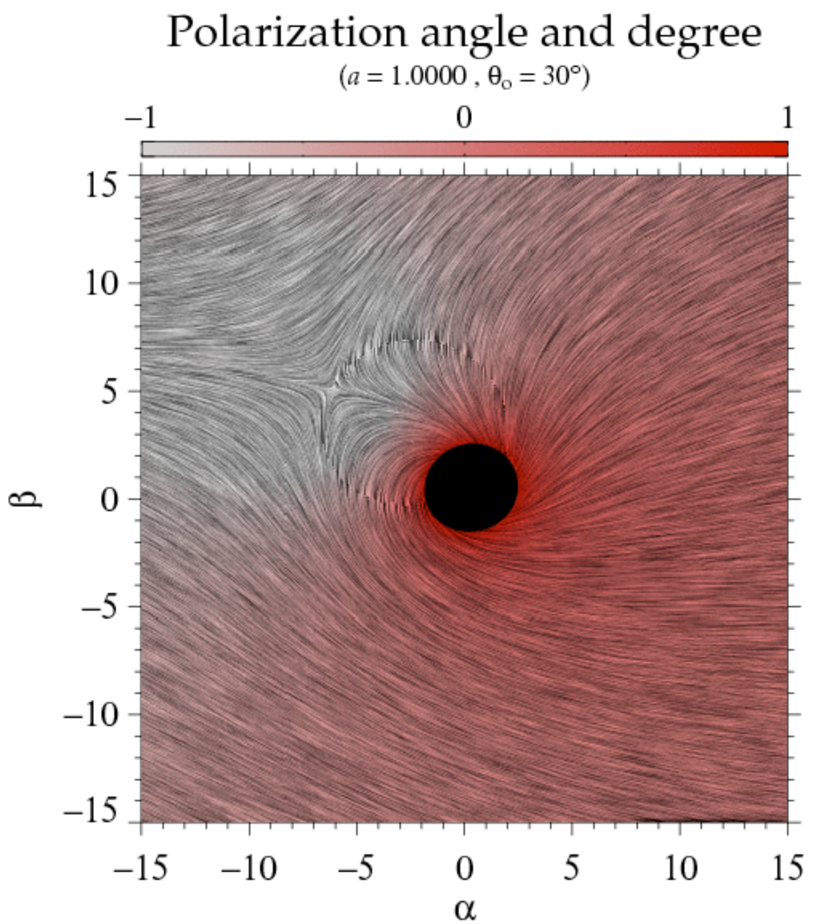
***P* decreases if there is significant absorption (e.g. Loskutov & Sobolev 1981; Laor et al. 1990; Matt et al. 1993)**

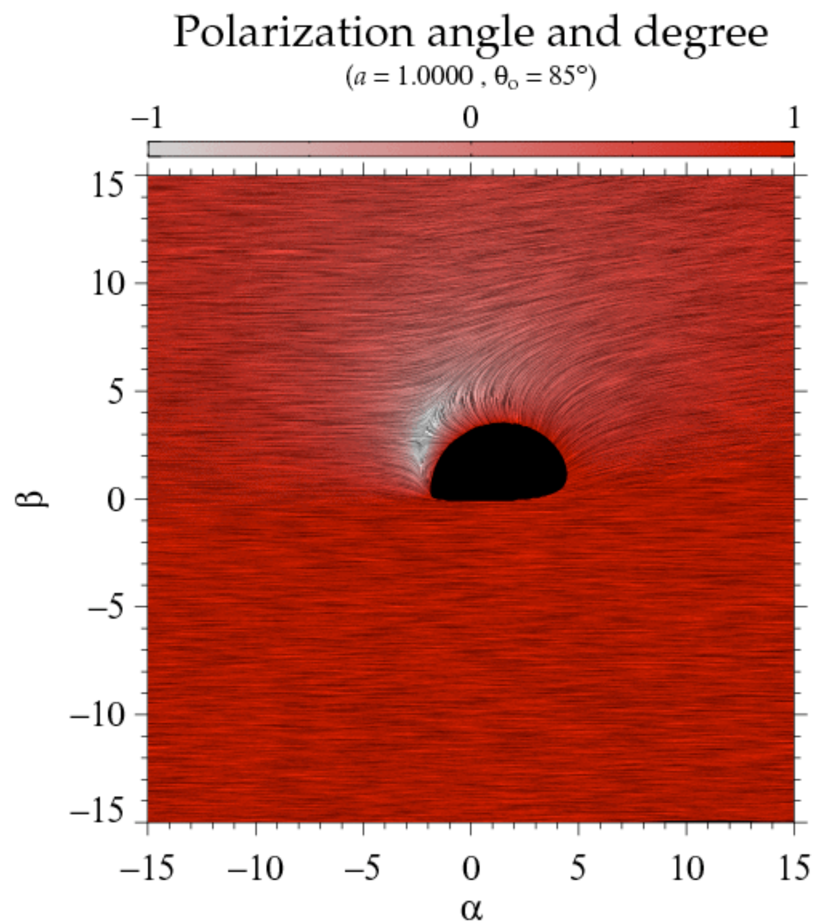
Strong gravity effects on polarization



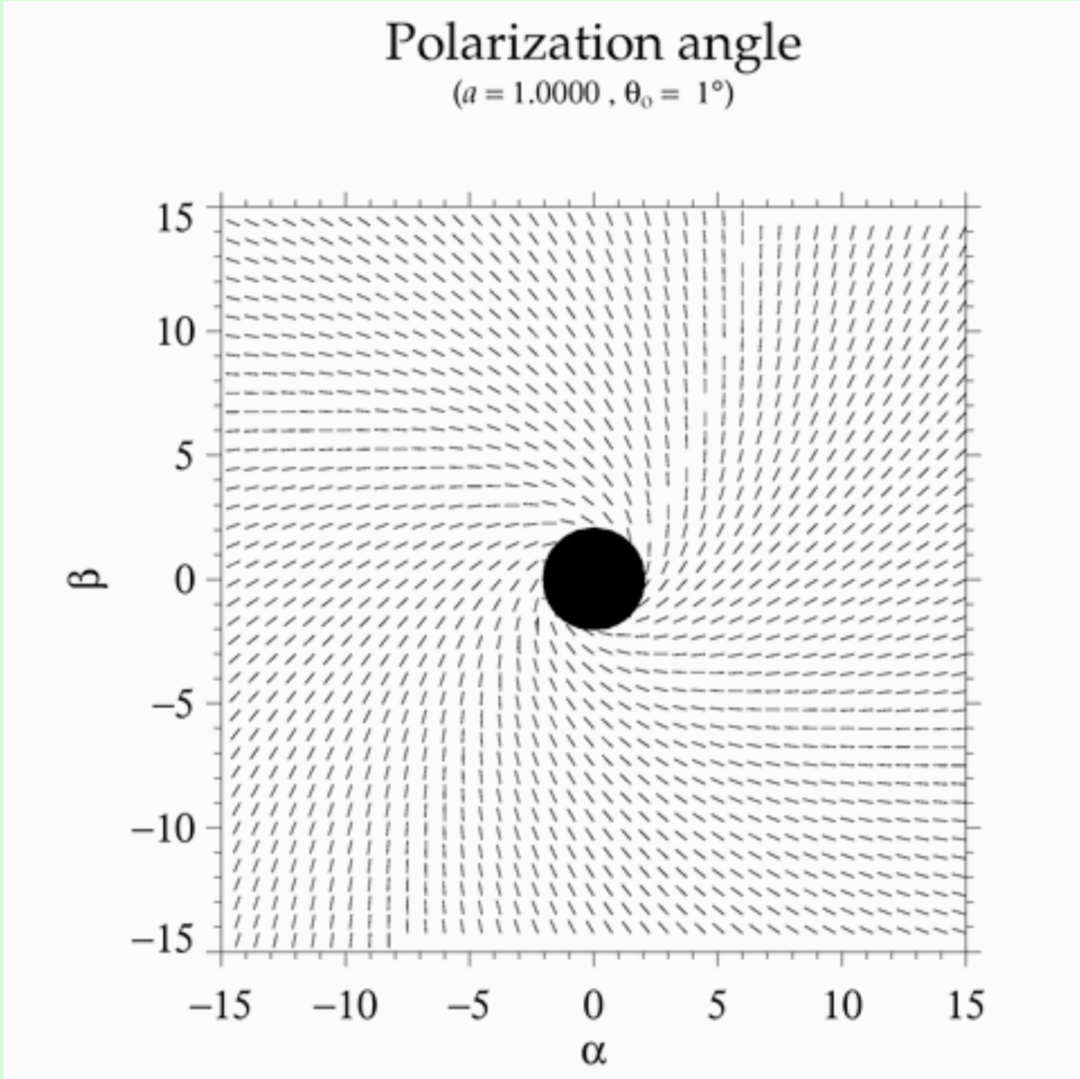


Strong gravity effects on polarization

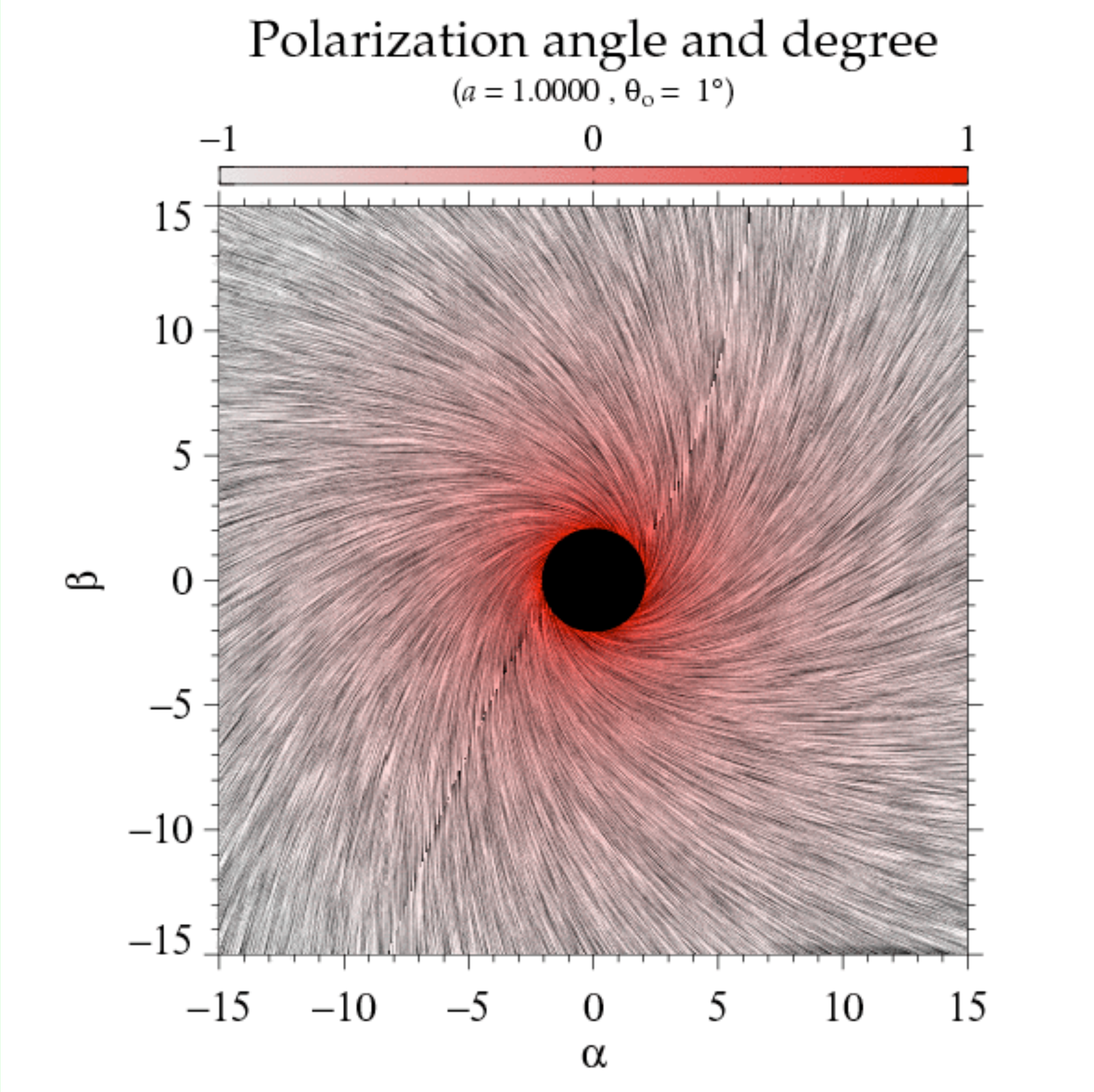




Strong gravity effects on polarization



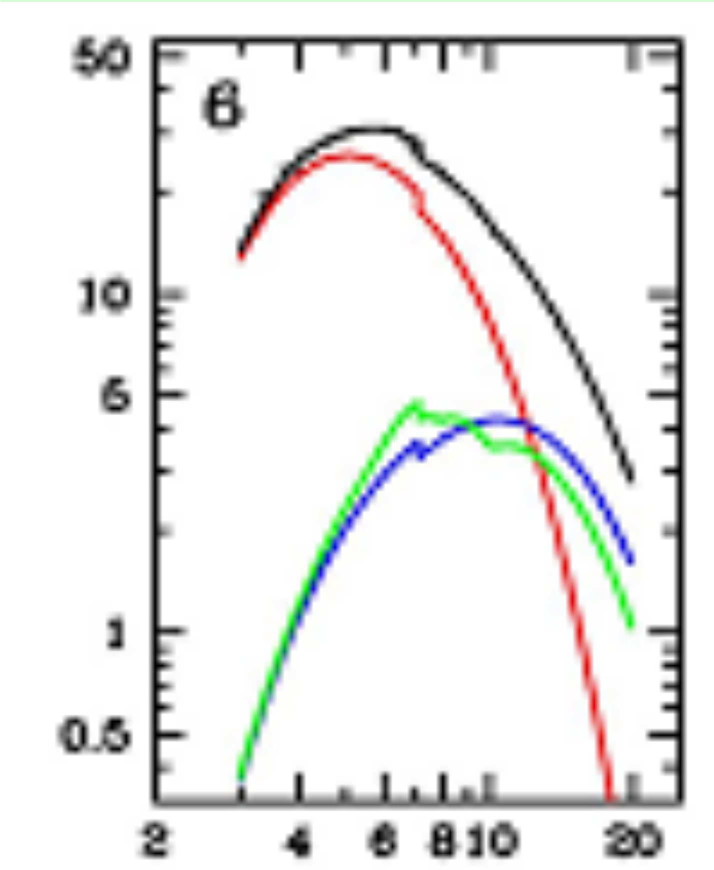
Strong gravity effects on polarization



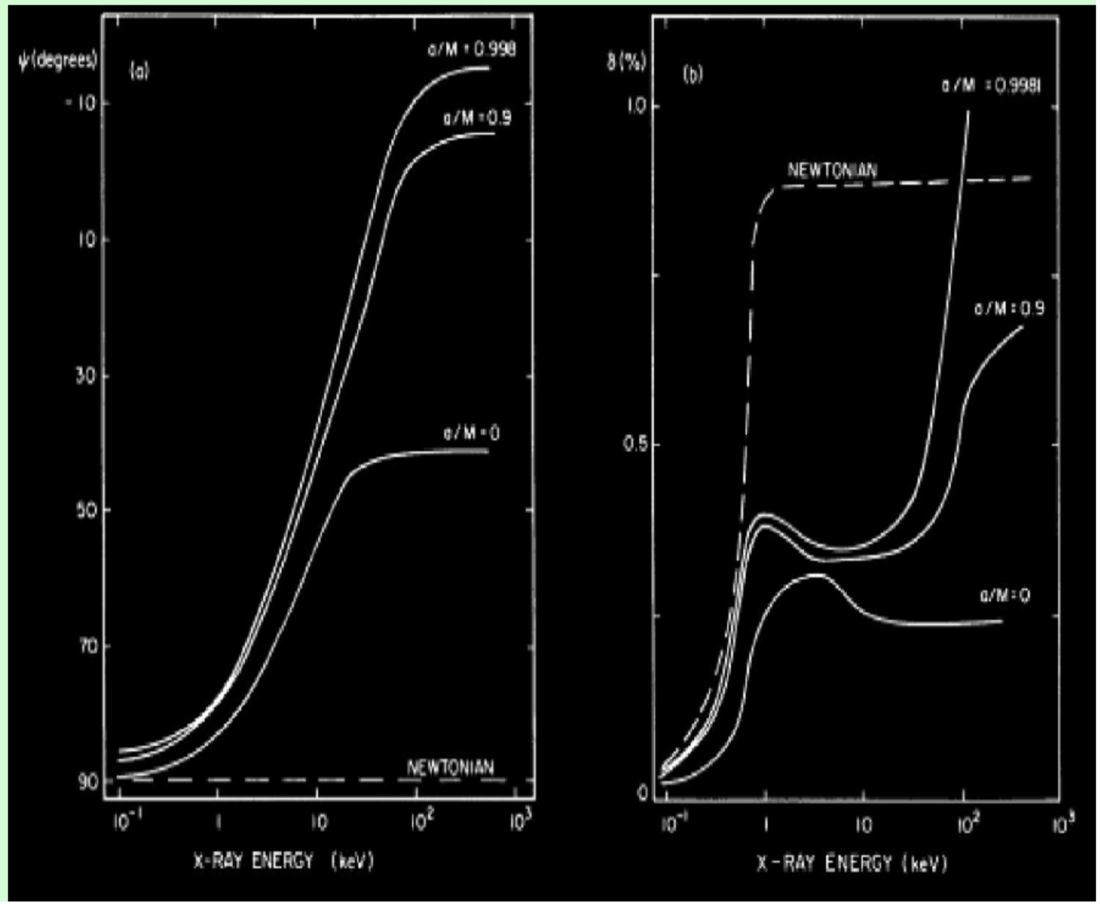
<u>Galactic BH binaries in high state</u>

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

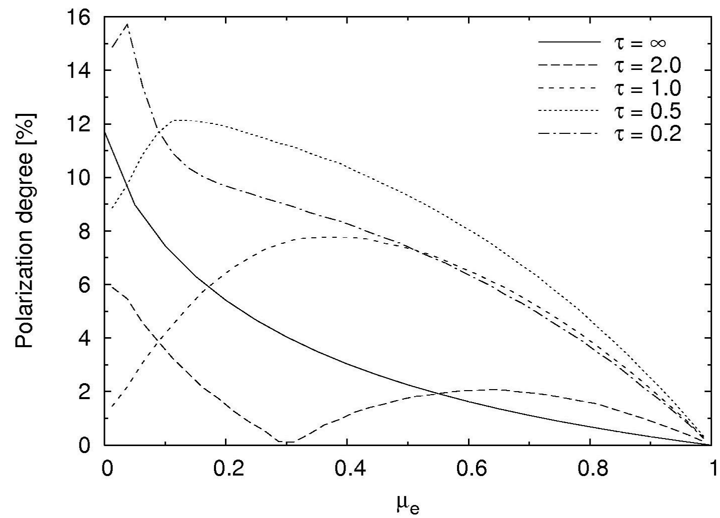
<u>A rotation of the polarization angle with energy is therefore expected.</u>



GRS 1915+105
(Done & Gierlinski 2004)

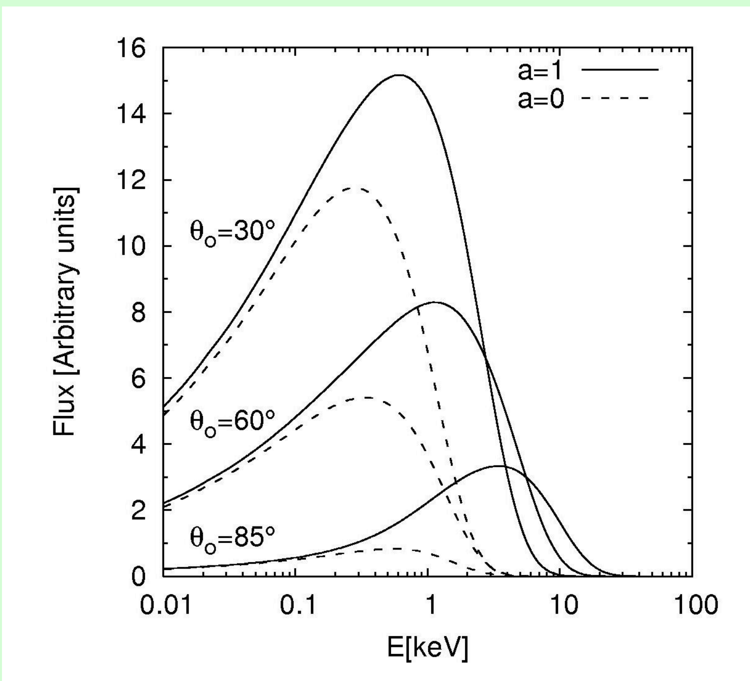


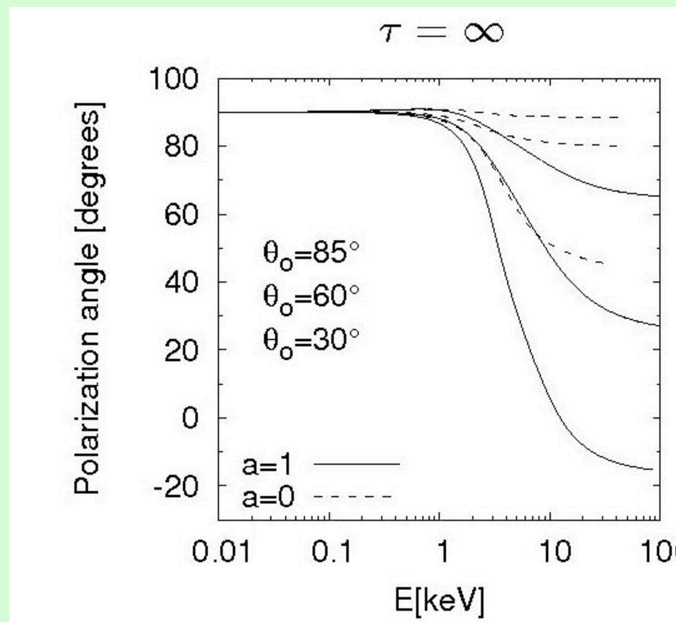
Connors & Stark (1977)

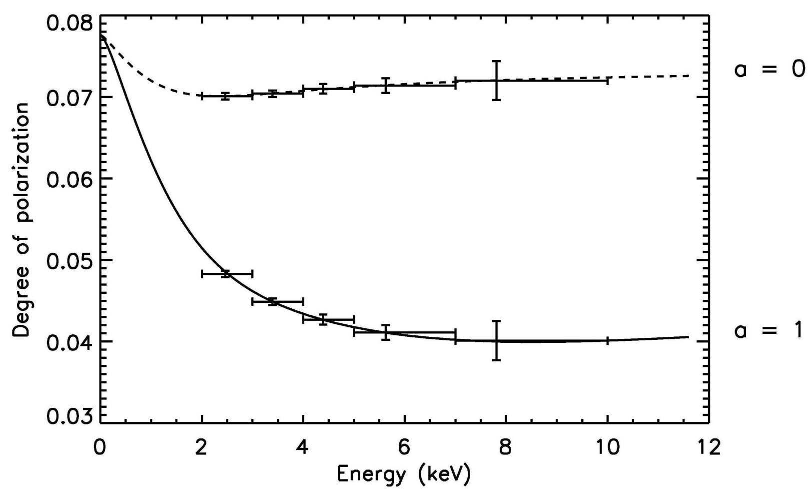


We (Dovciak et al. 2008) revisited and refined these calculations (see also Li et al. 2009).

Strongly dependent on the spin of the BH !!

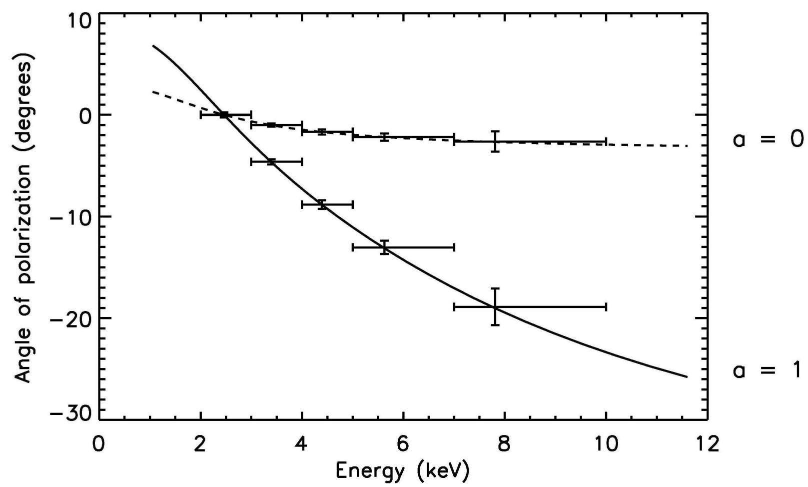






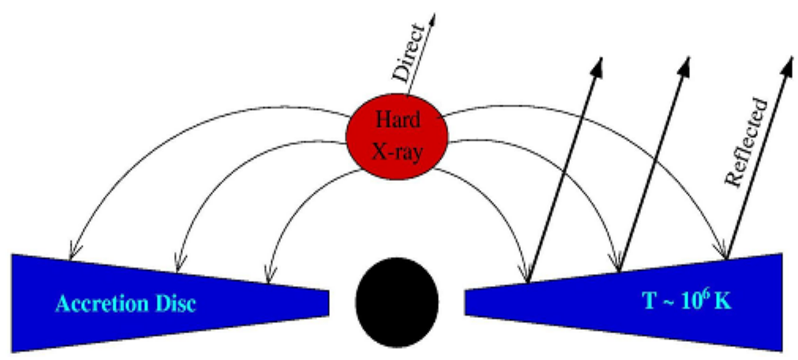
Observational perspectives with IXO

GRS 1915+105, 200 ks (courtesy F. Muleri)



Active Galactic Nuclei

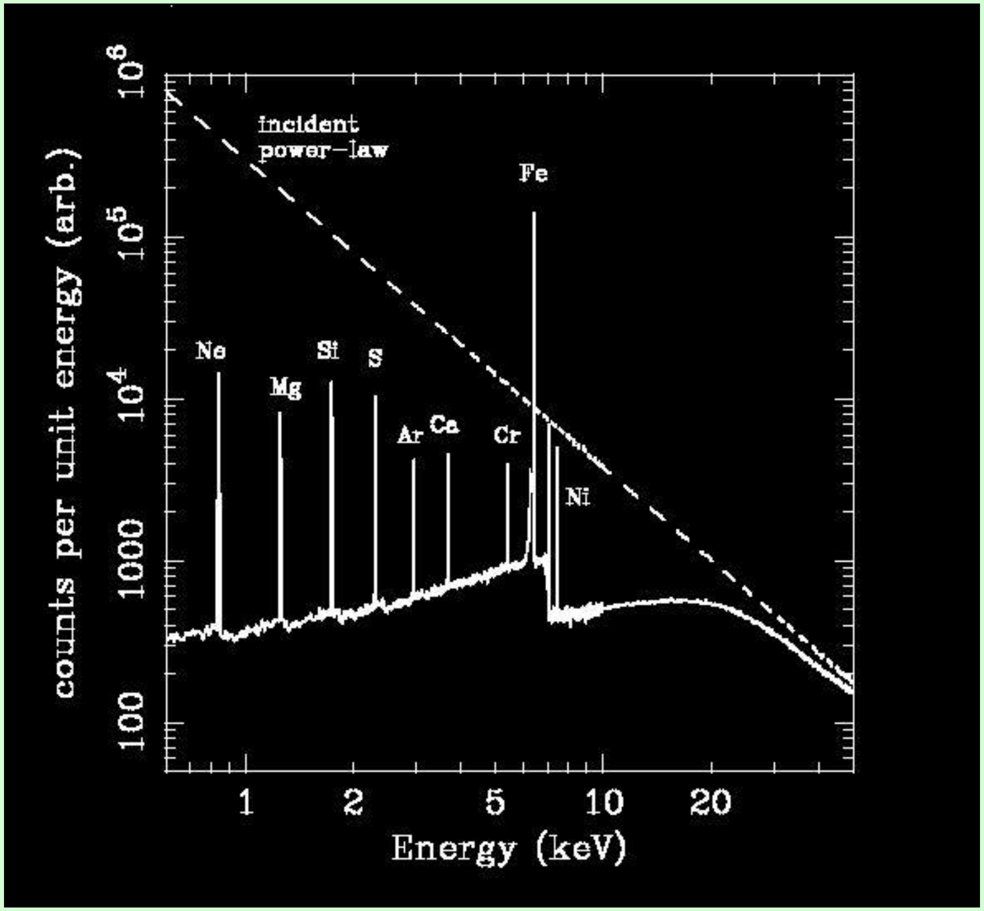
In Active Galactic Nuclei the primary X-ray emission is due to Inverse Compton by electrons in a hot Corona of the UV/Soft X-ray disc photons. It is likely to be significantly polarized (e.g. Haardt & Matt 1993, Poutanen & Vilhu 1993), because the system is unlikely to have a spherical symmetry.



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

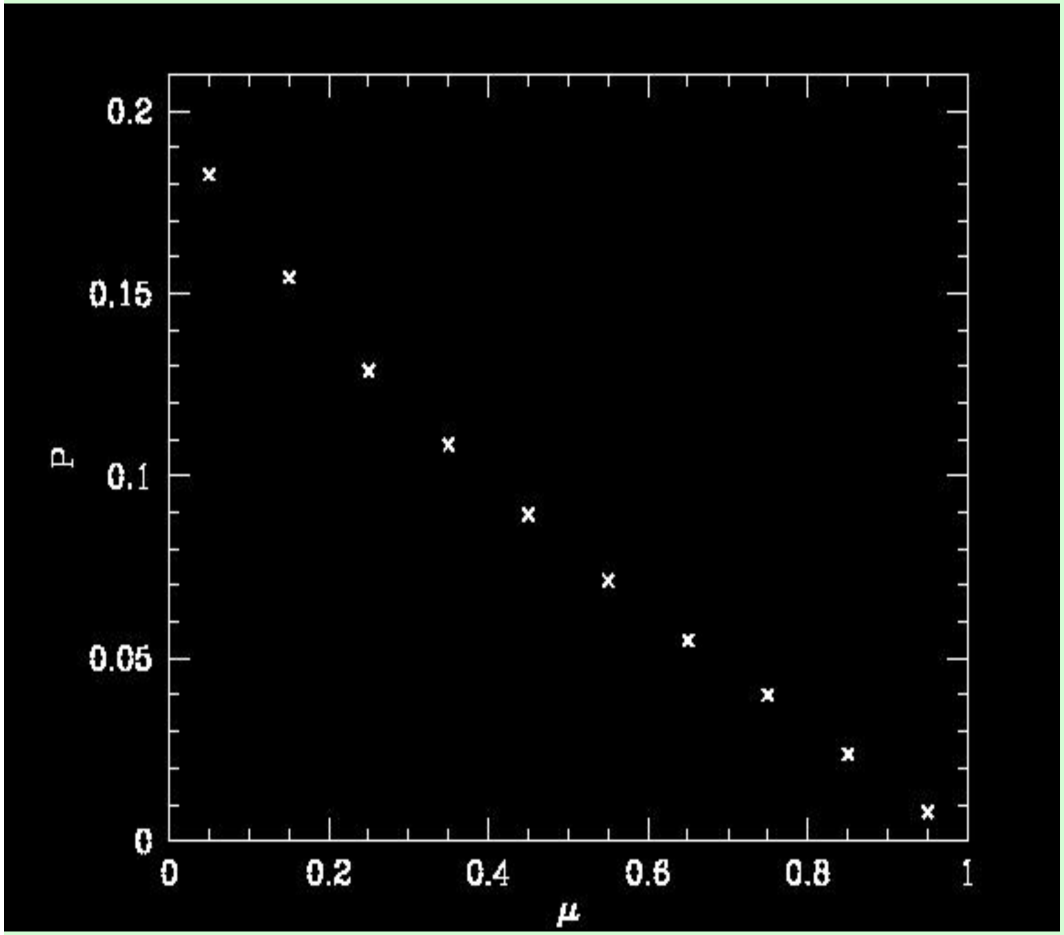
Reflection from cold matter

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)

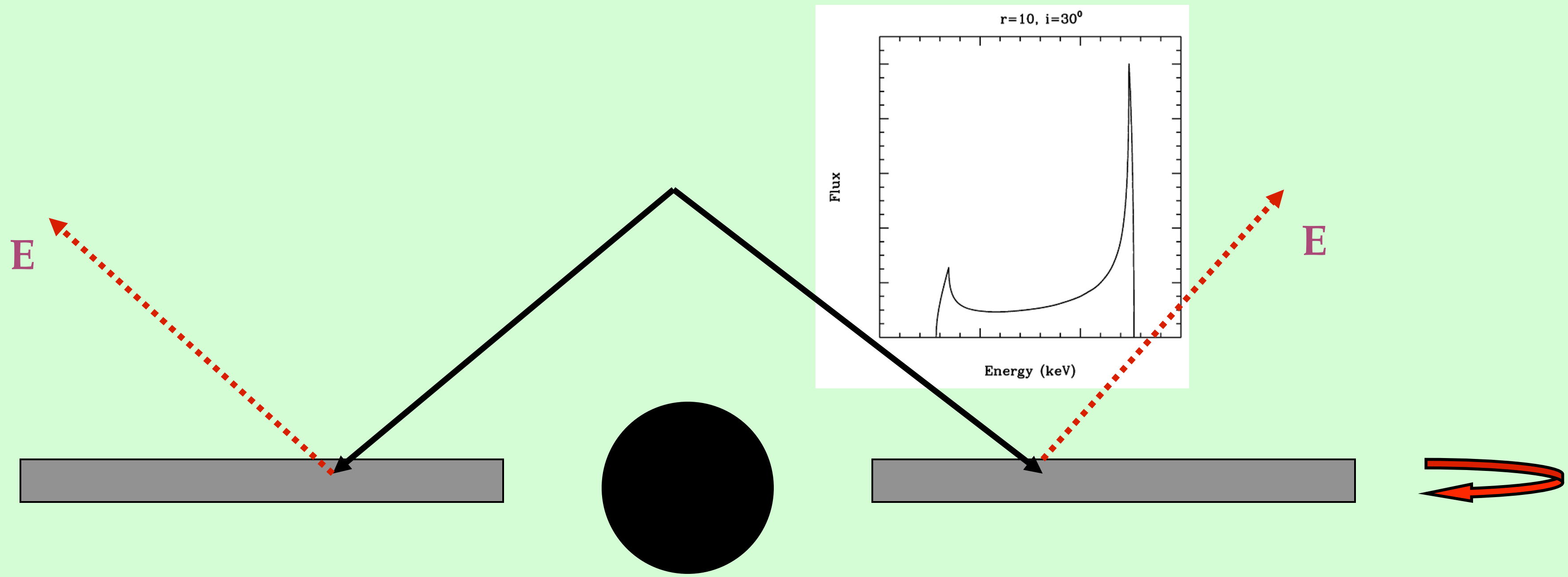
Polarization of reflected flux



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

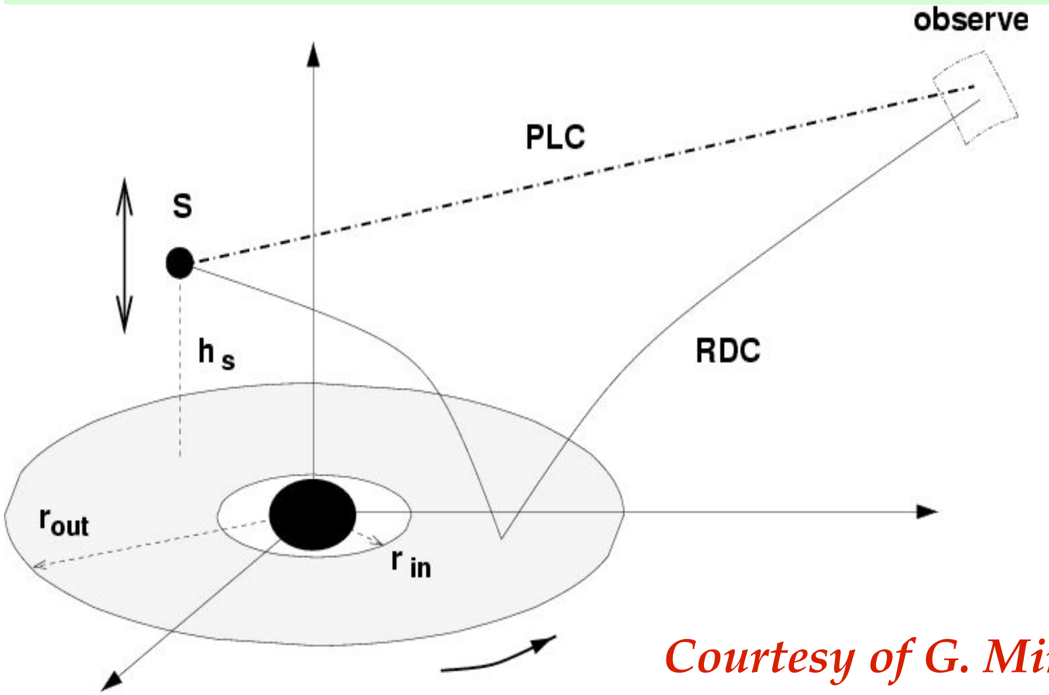
Reflection in Relativistic discs

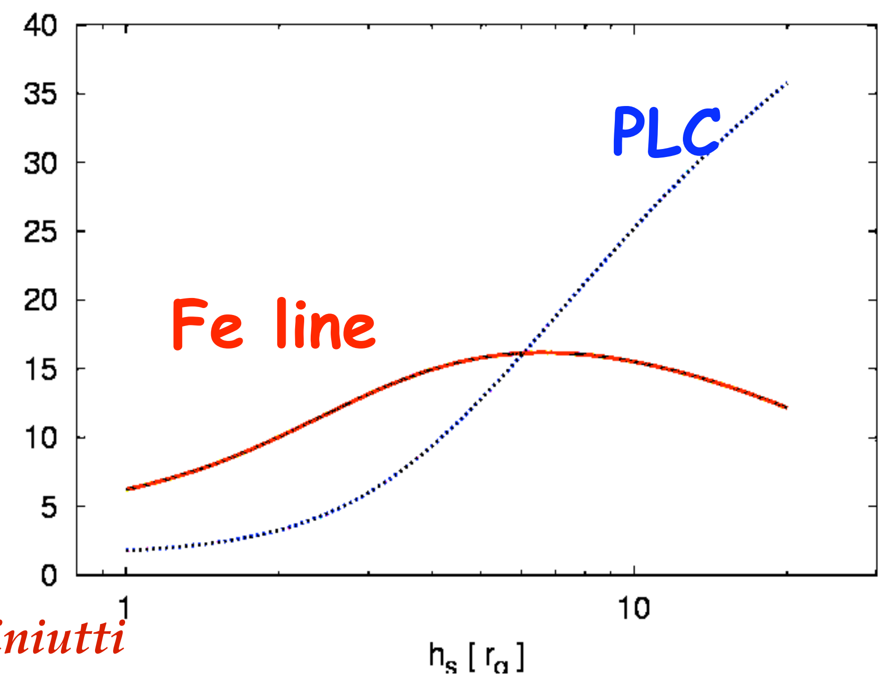


Breaking of the symmetry due to SR (Doppler boosting) adds to the effects already mentioned, causing the rotation of the PA with respect to the Newtonian case. Changes in the illumination properties (e.g. in the height of the lamp-post) will cause changes in the total PA, which is therefore likely to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

The case of MCG-6-30-15

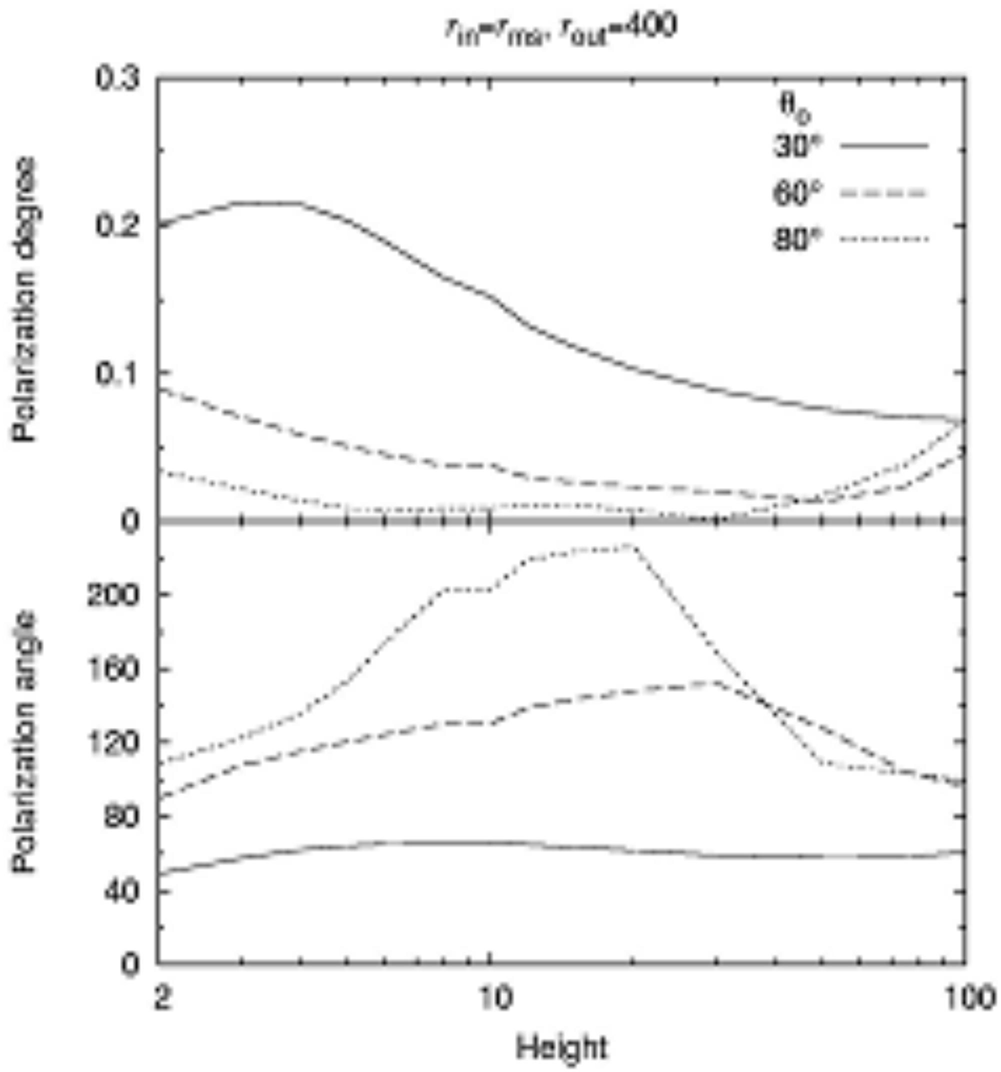
Variations of *h* have been suggested to be the cause of the puzzling temporal behaviour of the iron line in MCG-6-30-15 (Miniutti et al. 2003), where the line flux varies much less than the primary power law flux.





Courtesy of G. Miniutti

Polarization of reflected radiation

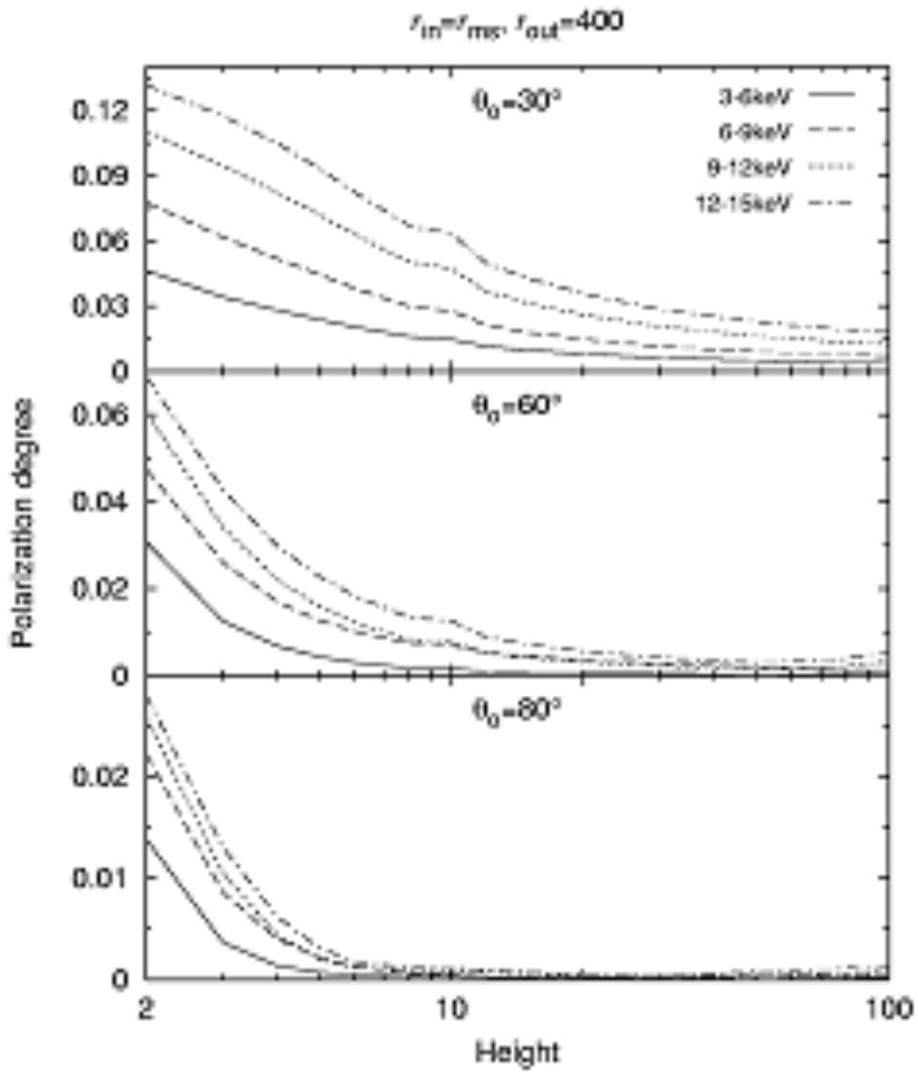


(Dovciak, Karas & Matt 2004)

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

Net polarization



(Dovciak, Karas & Matt 2004)

If the primary emission (supposed unpolarized) is included, the net polarization degree of course decreases, but it is still significant especially for low heigths, where light bending strongly enhances the relative amount of reflection.

Polarization measurements will provide an independent test of the light bending model

Back to primary emission ...

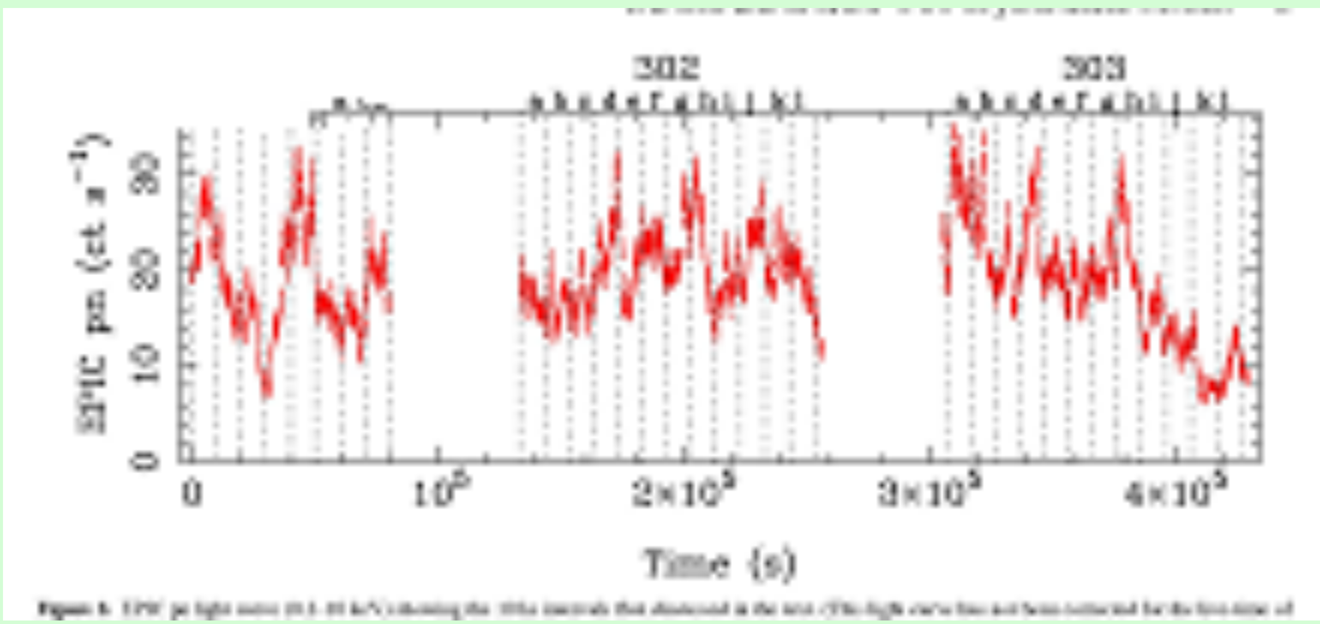
Of course, the primary emission is likely to be polarized, as it is due to IC in a likely non-spherical geometry. This of course can significantly increase the polarization degree of the total radiation.

Again, a variation of the size and shape of the emitting region results in a variation of the polarization angle. Detailed modeling of the polarization properties for different scenarios (e.g. disc coronae vs. aborted jets) is necessary to make quantitative predictions (future work)

In any case, it is hard to imagine a plausible scenario in which the PA would vary with time on short time scales without strong gravity effects

Observational perspectives with IXO

IXO can measure polarization degrees down to about 1.5% in 100 ks in MCG-6-30-15, and polarization angles with a precision of about 3 degrees, allowing for a test of the light bending model.



Fabian & Vaughan 2004

Summary: Pros and Cons

- **GBHB**

Pros: A very clean method, based on a known geometry. Very bright sources

Cons: Intrinsic polarization degree poorly known

- **AGN**

Pros: Polarization degree easy to calculate

Cons: Poorly known geometry of the illuminating region. Fainter sources (mCrab)

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

Energy- (Time-) dependence of the polarization angle in GBH (AGN) would provide unambiguous evidence for strong gravity effects.

X-ray polarization measurements will provide valuable information on the physical conditions and the geometry of the emitting regions.

The coming of age of X-ray polarimetry

Roma, April 27th - 30th, 2009

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