Fundamental Physics: QED and Strong Gravity

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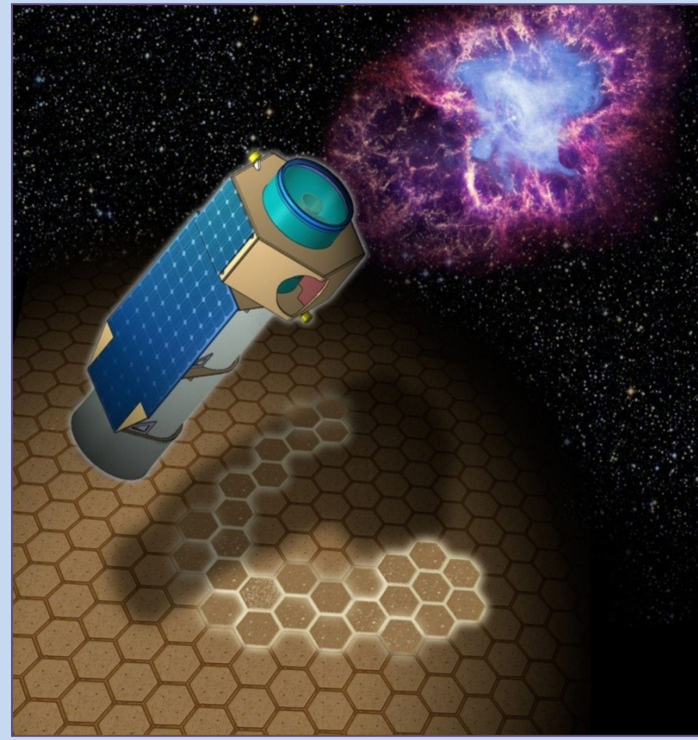
& WG 4.1 and 4.2



Picking the right direction

Xipe

www.isdc.unige.ch/xipe

SEVENTH FRAMEWORK PROGRAMME

STRONGGRAVITY

EU FP7-SPACE research project 312789

2013 - 2017

QED effects in magnetized compact objects

Neutron Stars

White Dwarfs

Strong gravity effects in accreting black holes

Galactic Black Hole Binaries

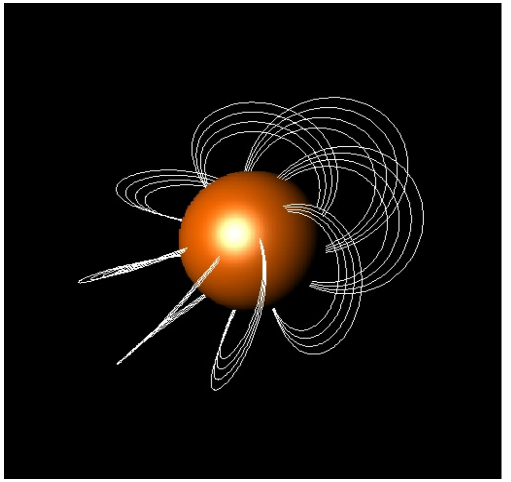
Active Galactic Nuclei

Disclaimer

QED effects have been already extensively discussed in Jeremy Heyl's review and by some speakers in session 2 (all of them infinitely more expert than me)

QED effects

Magnetars



Surface emission of NSs is highly polarized (due to different atmospheric opacities of O and X-mode photons)

X-ray polarimetry allows to probe QED effect: vacuum polarization induced by strong magnetic field (an effect predicted 80 years ago, Heisenberg & Euler 1936, yet to be verified)

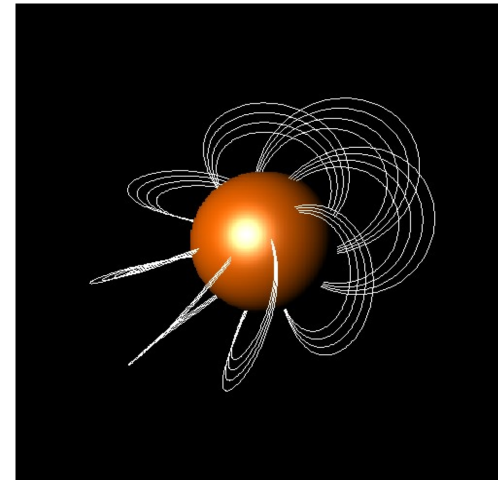
The presence of vacuum polarization has an imprint in both the degree of polarization and the polarization angle.

QED effects

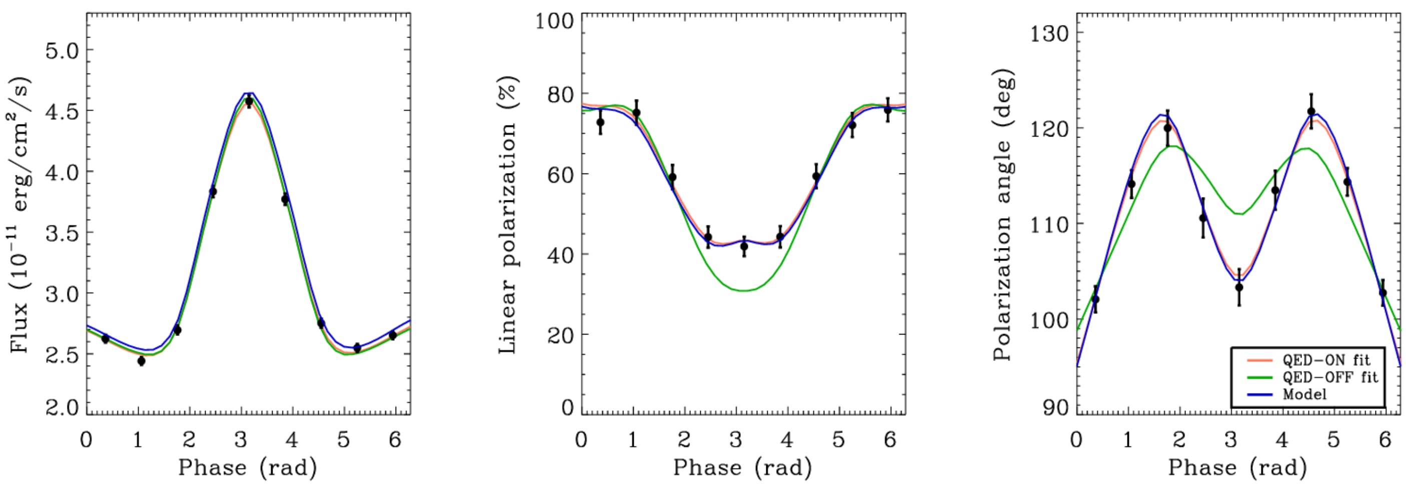
Magnetars

Magnetars are isolated neutron stars with likely a huge magnetic field (B up to 10^{15} Gauss).

It heats the star crust and explains why the X-ray luminosity largely exceeds the spin down energy loss.



Flux **Pol. degree** **Pol. angle**



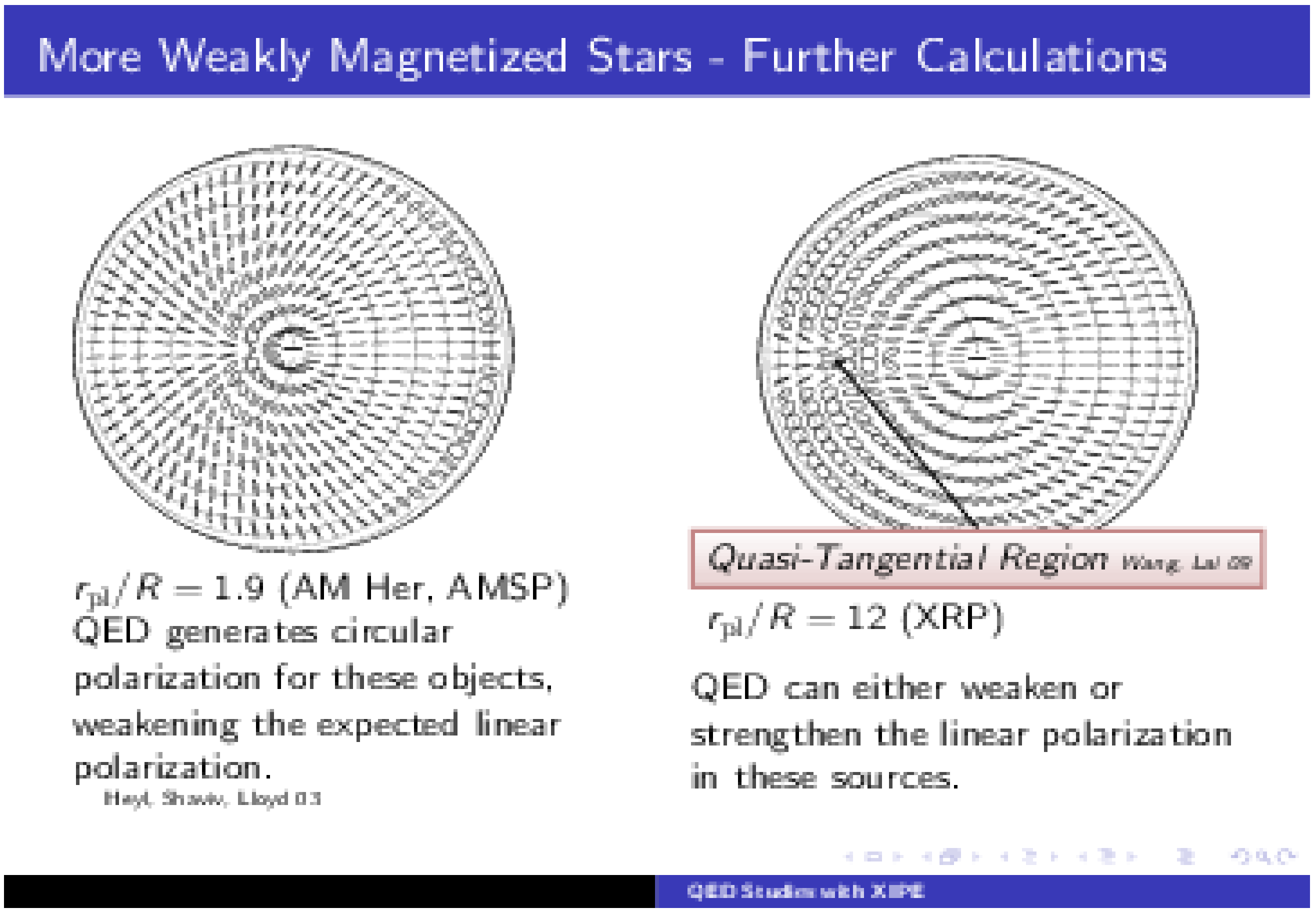
Taverna et al. 2014

Such an effect is **only** visible in the phase dependent polarization degree and angle.

QED effects

Weakly magnetized stars

QED effects are present also in more weakly magnetized stars, even in accreting magnetic White Dwarfs (Polars and Intermediate Polars)



Courtesy of Jeremy Heyl

Observing program:

Phase-dependent observations of a number of magnetic CVs, Accreting NSs and Magnetars, for a total observing time ~2 Ms

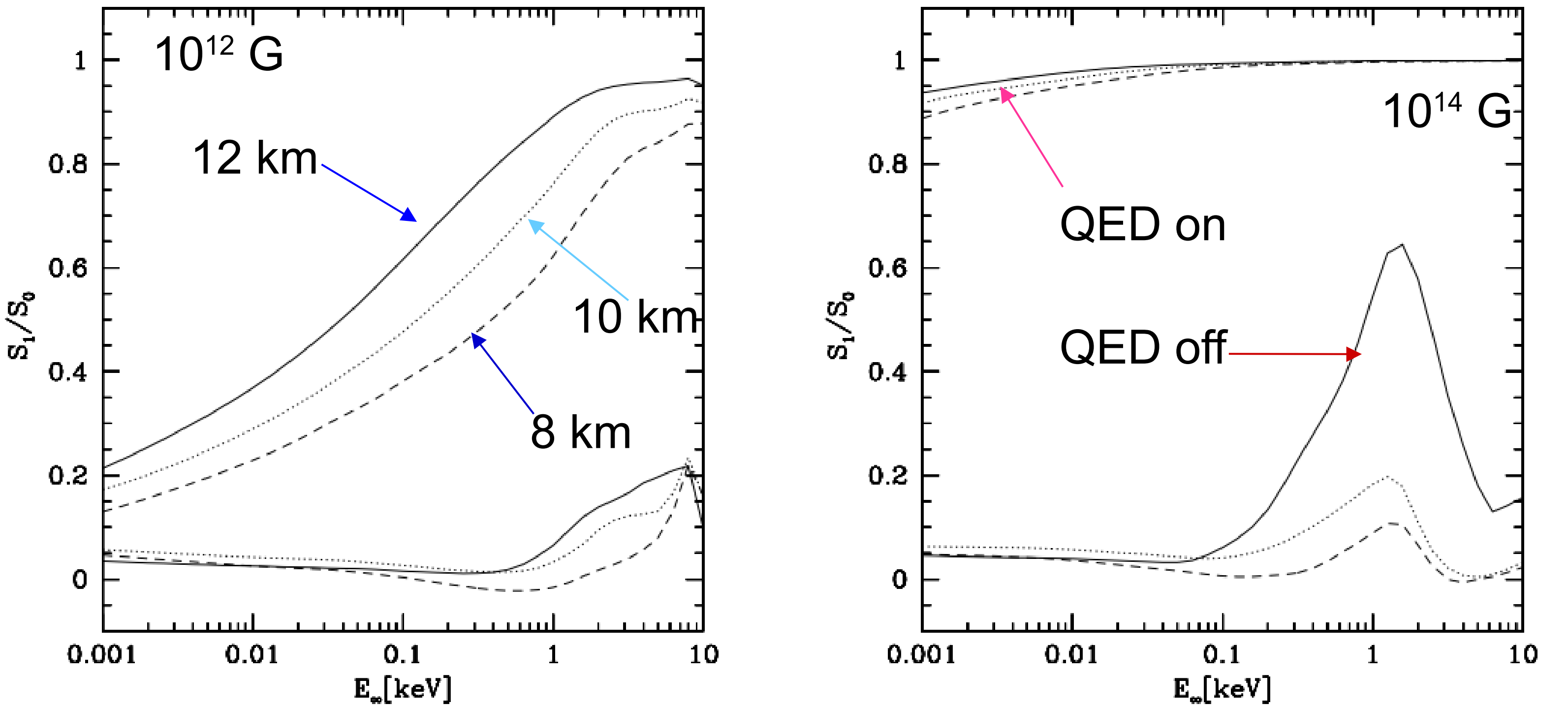
(synergies with WG 2.1-4)

QED effects

What next

Simulate QED effects from the thermal component of the atmosphere, and combine them with the non-thermal component

Linear polarization for hydrogen atmospheres with $T_{eff}=10^{6.5}$ K NS and magnetic moment 30 degrees from the line of sight



What next

Explore arbitrary magnetic field configurations and a variety of temperature distributions. Consider both the possibility of atmospheres as well as of bare surfaces.

Understand the level of covariance between QED effects on polarization and simply atmospheric/B-field geometry effects.

Determine the effect of QED on all classes of sources and how it affects the interpretation of the observed polarization.

Identify the best objects for this type of observations. We will need:

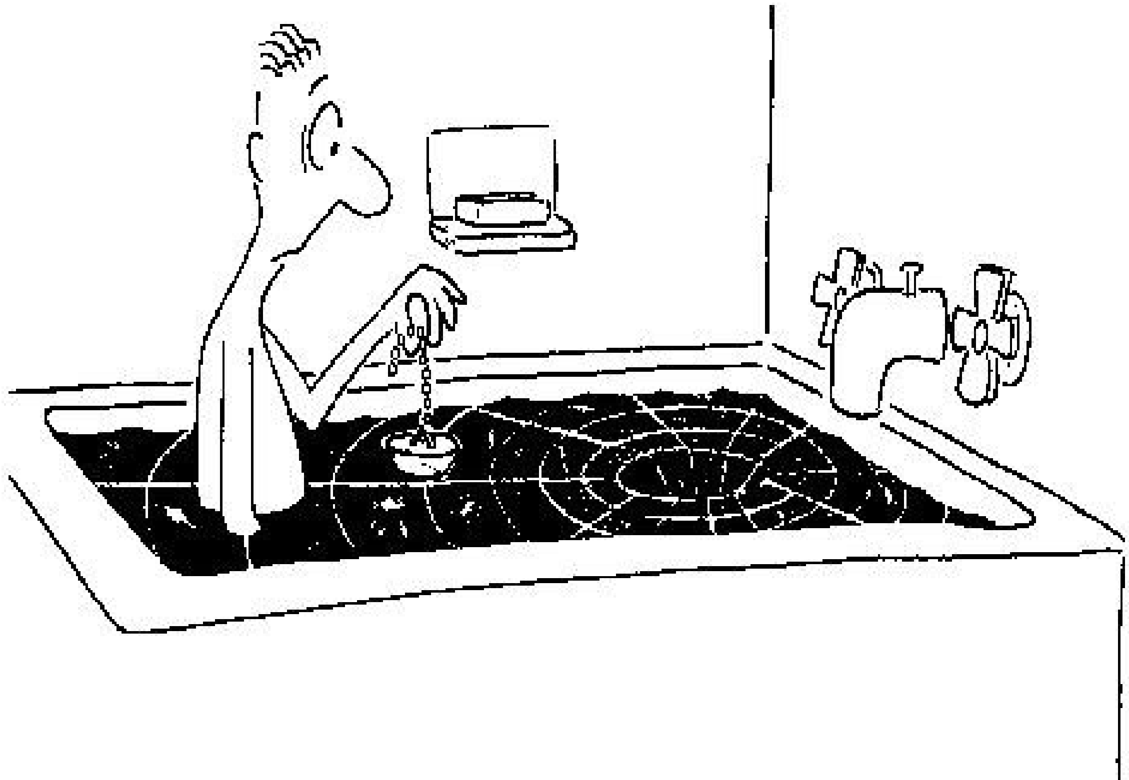
Hot object

Strong field

At least a fraction of the emission dominated by thermal surface radiation

Strong gravity

Black holes are fully characterized by their mass and angular momentum
(spin, $0 \leq a \leq 1$) (+Q)

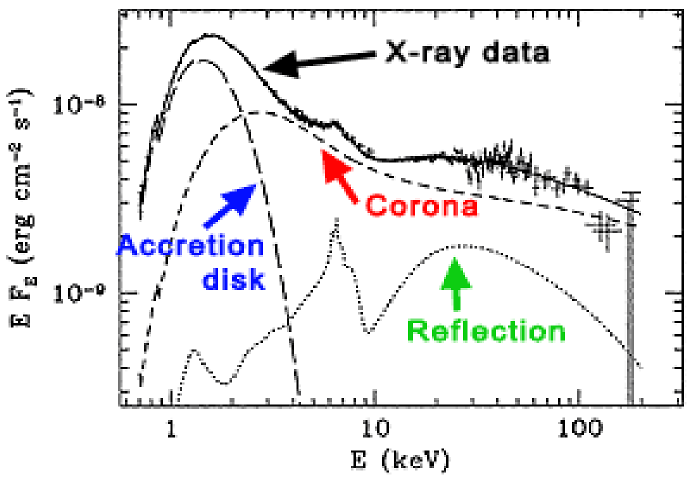


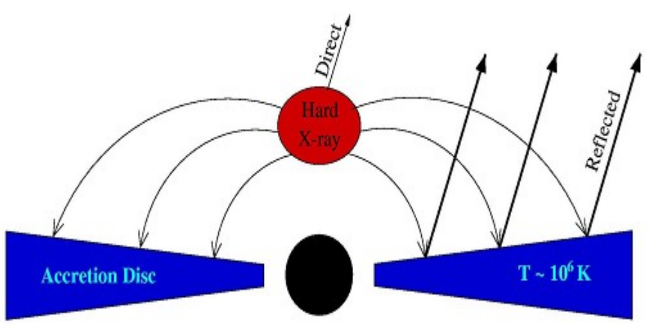
Knowledge of the spin tells us about the BH birth (in Galactic black holes) or the BH growth (in galaxies).

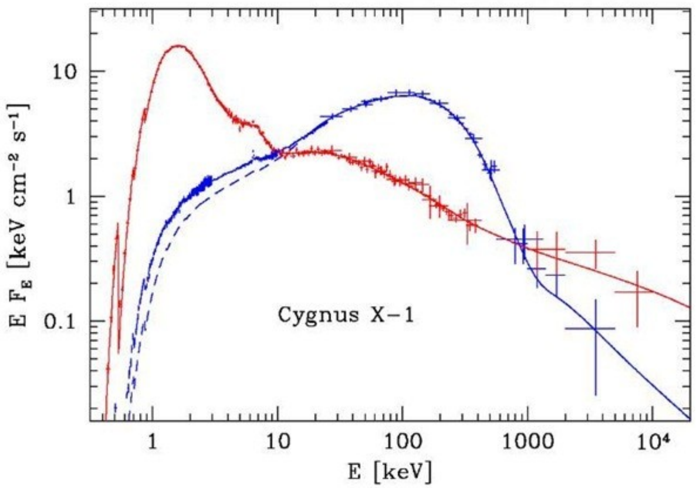
Galactic Black Hole Binaries

So far, three methods have been used to measure the BH spin in XRBs:

1. *Relativistic reflection*
2. *Continuum fitting*
3. *QPOs*



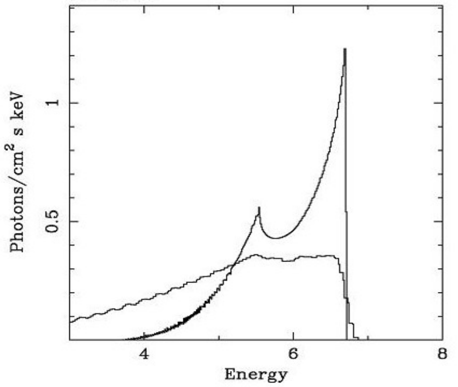




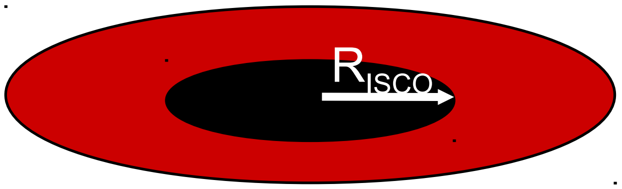
Strong gravity

Galactic Black Hole Binaries

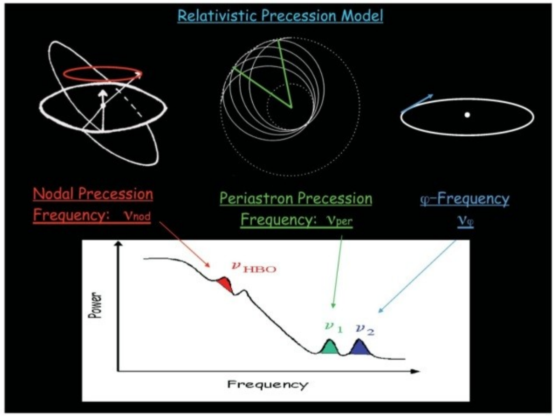
Relativistic reflection (still debated, requires accurate spectral decomposition)



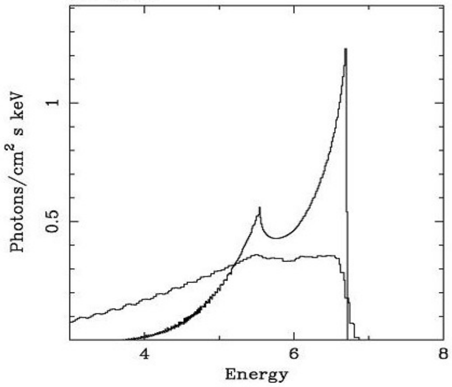
Continuum fitting (requires knowledge of the BH mass, distance and inclination)



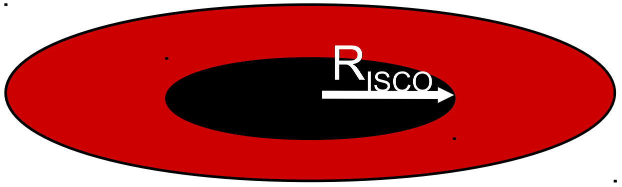
QPOs (all three QPOs required to completely determine the parameters, so far applied only to two sources)



Galactic Black Hole Binaries

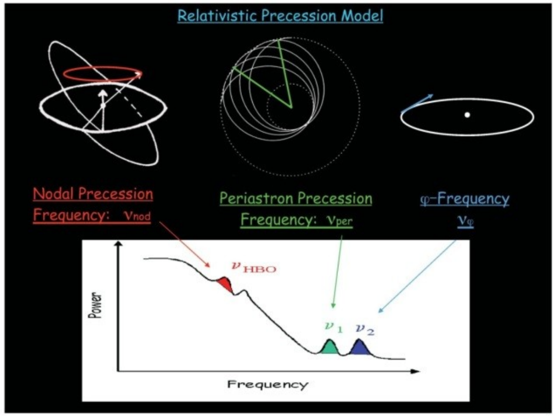


For a number of XRBs, the three methods do not agree!

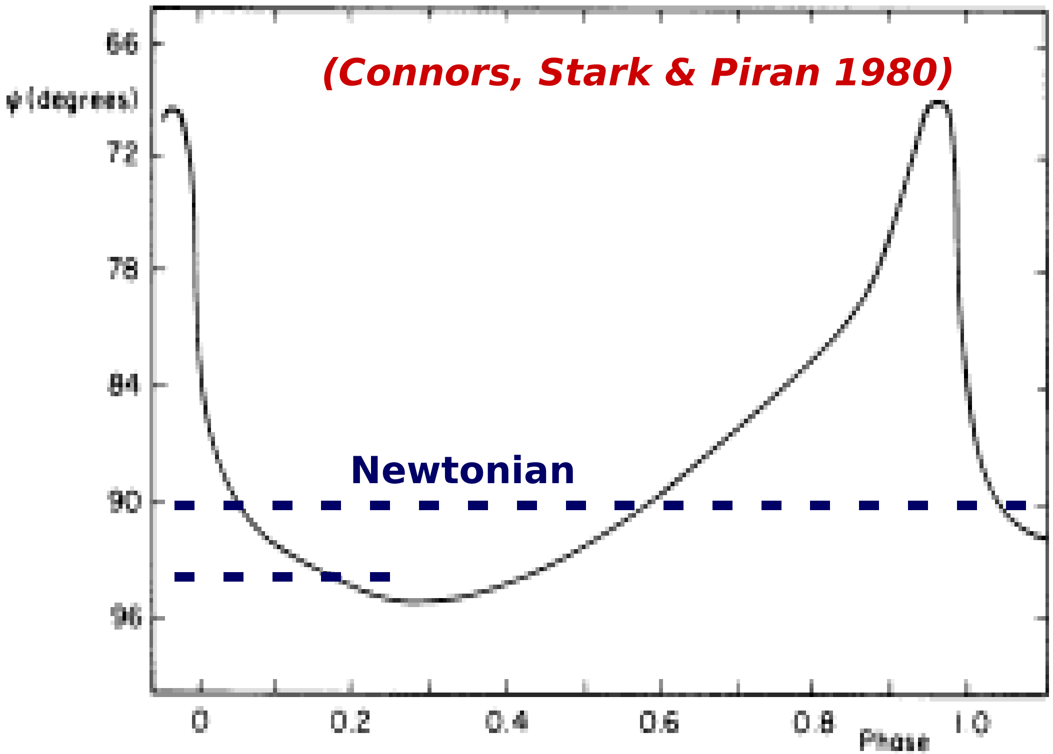


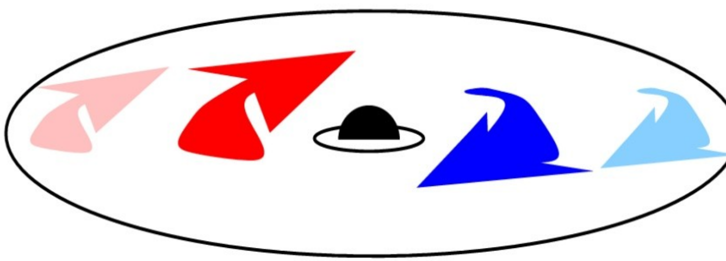
Example: J1655-40

QPO: a = 0.290±0.003
Continuum: a = 0.7±0.1
Iron line: a > 0.95



General and Special Relativity significantly modifies the polarization properties of the radiation. In particular, the Polarization Angle 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

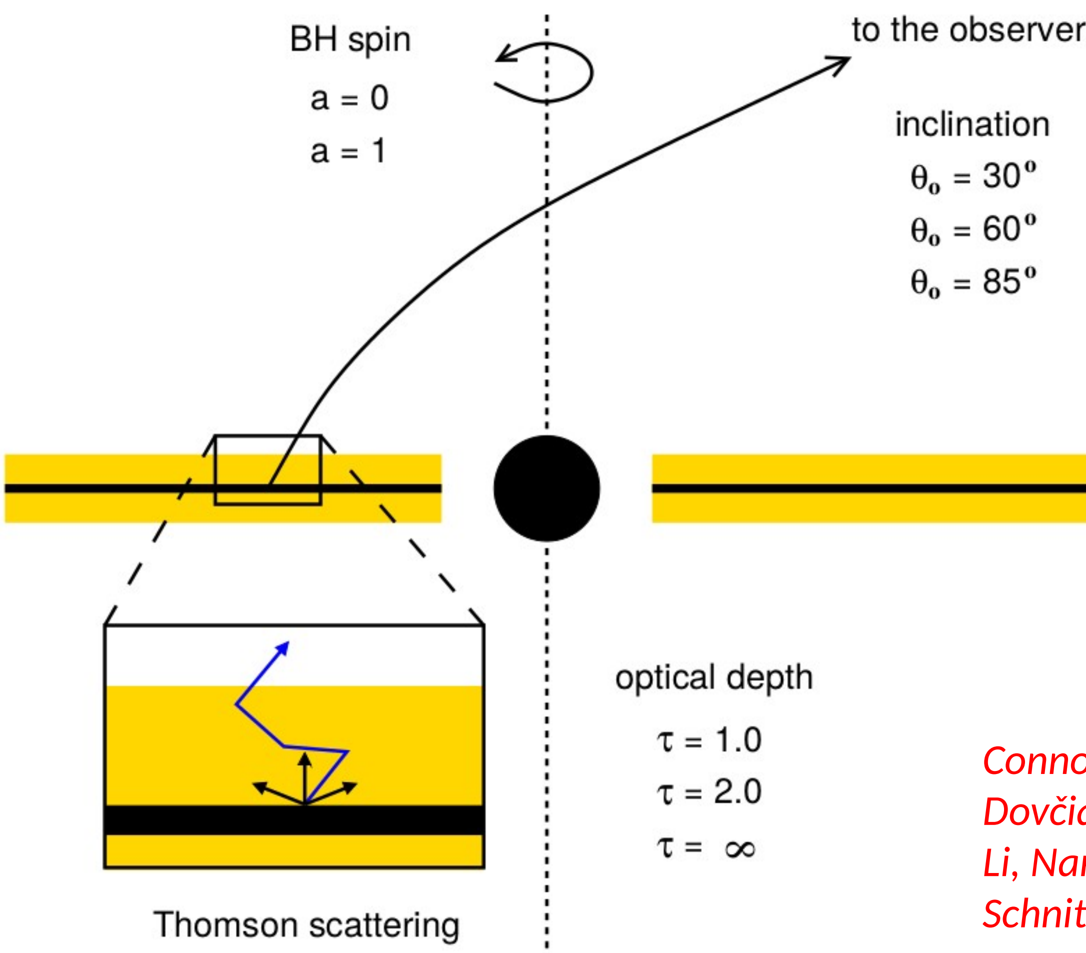


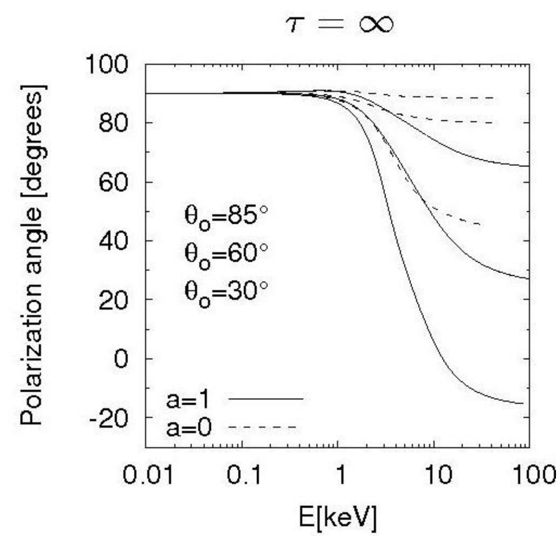


Orbiting spot with:
a=0.998;
R=11.1 Rg
i=75.5 deg

Strong gravity

Galactic Black Hole Binaries

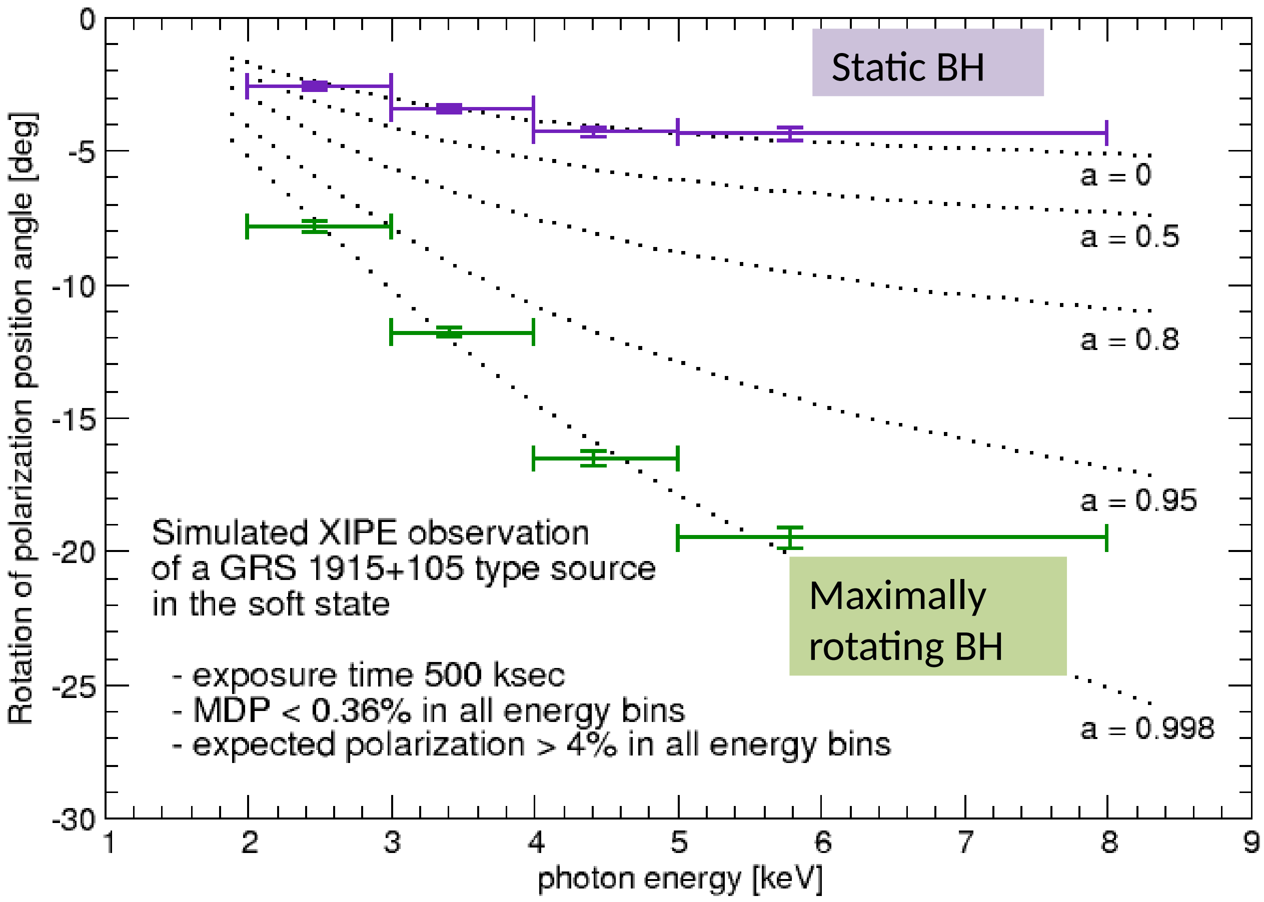




Connors & Stark (1977)
Dovčiak et al. (2008)
Li, Narayan & McClintock (2009)
Schnittman & Krolik (2009)

Energy dependent rotation of the X-ray polarisation plane

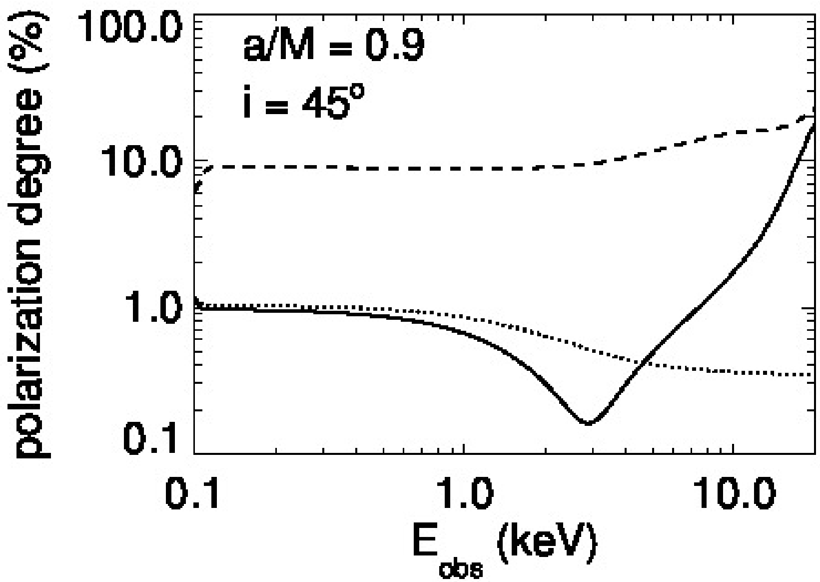
- Two observables: polarisation degree & angle
- Two parameters: disc inclination & black hole spin



$\tau=1$
$\theta_o=70°$

Warning: the above calculations do not include returning radiation

Schnittman & Krolik 2009



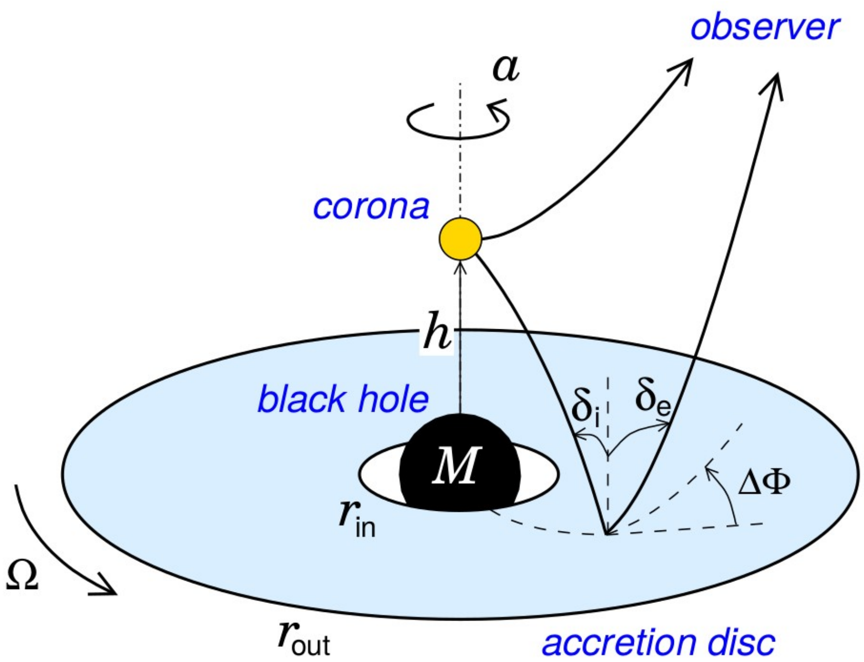
Observing program:

- GRS 1915+105
- Cyg X-1 (soft state)
- transients in outburst (GX 339-4, J1655-40 in soft states)

Texp ~ 500 ks each

(synergies with WG 1.4 & 3.1)

Active Galactic Nuclei



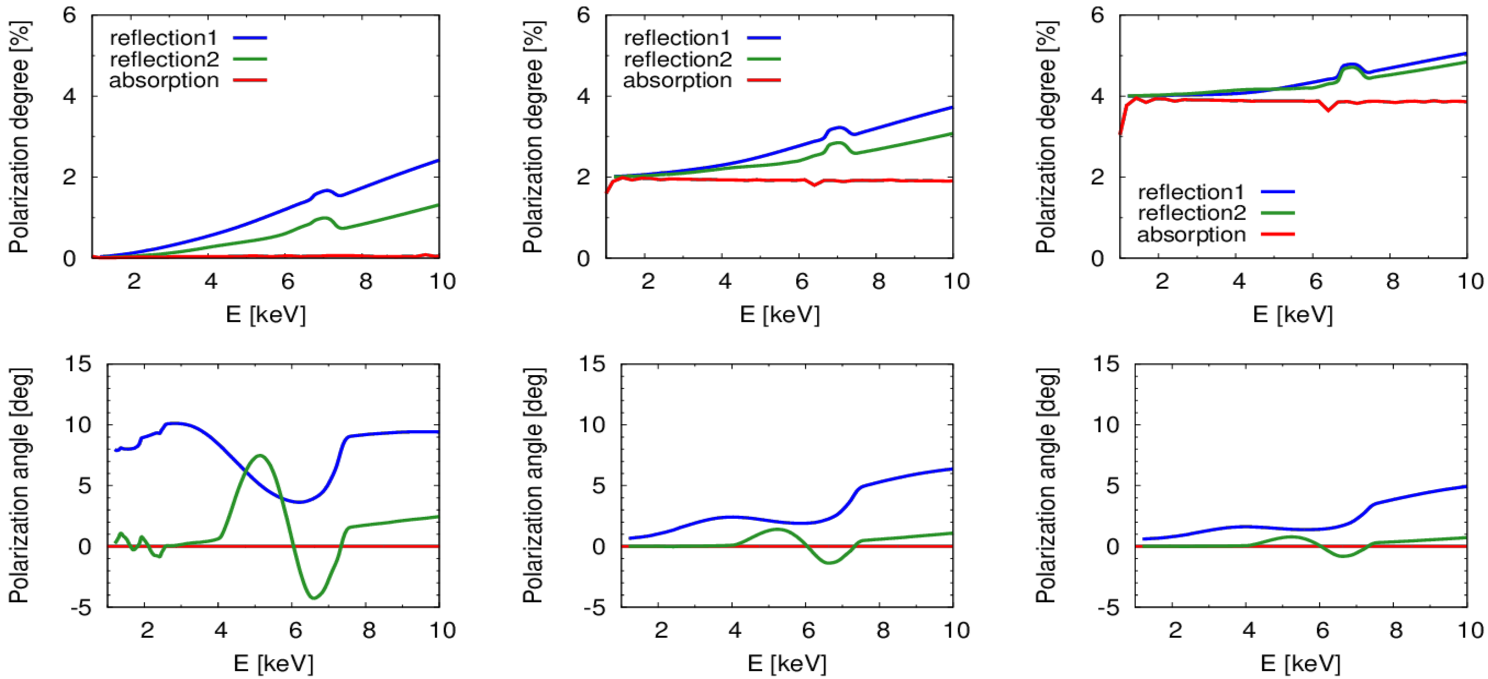
The reflection component is strongly polarized. If the corona moves up and down, the polarization degree and angle change in a spin-dependent way.

Unfortunately, this dependence is not very strong, and the disc reflection component is usually small in the XIPE band.

An observing time of ~ 1 Ms is required to search for this effect in MCG-6-30-15

However, not everybody believes that we are really seeing relativistic reflection in AGN. Complex ionized absorption?

Polarimetry can tell! (Marin et al. 2012, 2013)



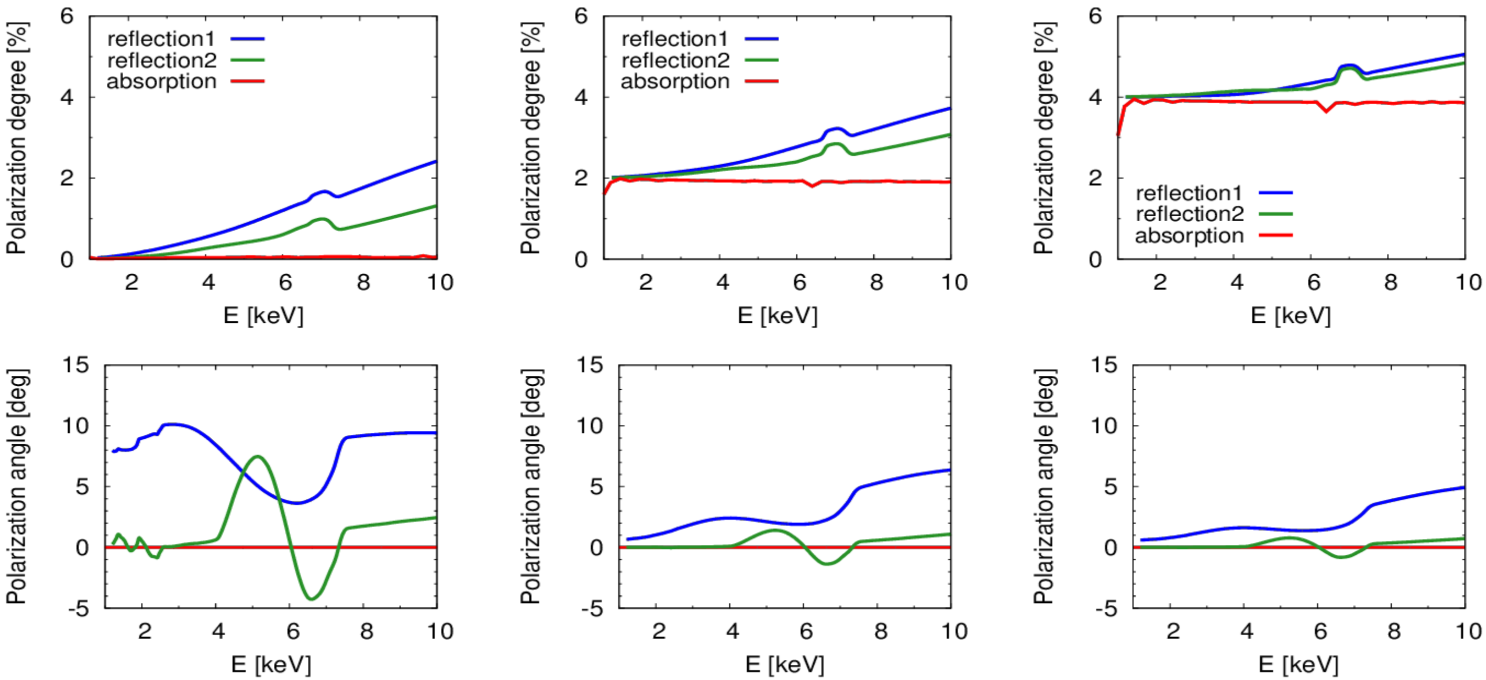
Courtesy of M. Dovciak and F. Marin

Inclination: **30°**
Spin: **a = 1**, **a = 0**
Photon index: **Γ = 2**
Height: **h = 2.5 GM/c²**
Primary pol. Deg: **P = 0, 2, 4 %**
Primary pol. Ang: **χ = 0°**

<u>Absorption scenario</u> – *clumpy wind*:
→ **constant** polarisation degree and angle

<u>Reflection scenario</u>:
→ **energy dependent** polarisation degree and angle

Active Galactic Nuclei



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Inclination: **30°**
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Photon index: **Γ = 2**
Height: **h = 2.5 GM/c^2**
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

Observing program: MCG -6-30-15, Texp=600 ks for MDP=2%

other bright AGN with relativistic reflection reported in the past (NGC 4151, Ark 120, NGC 3783, NGC 1365, NGC 3227, Mrk 766, Fairall 51, Ark 564, …) *(synergies with WG 3.2)*

What next

- X-ray binaries
  - include returning radiation in our modelling

- AGN
  - reflection vs. absorption scenario:
    polarised primary emission (work in progress)
  - include more geometries of the corona (i.e. extended corona)?
    → different illumination pattern and covering of the disc

- perform detailed simulations with XIMPOL

Conclusions

Clear and strong cases (at least QED and SG in GBHB)

More work to refine expectations and explore more situations

Affordable exposure times