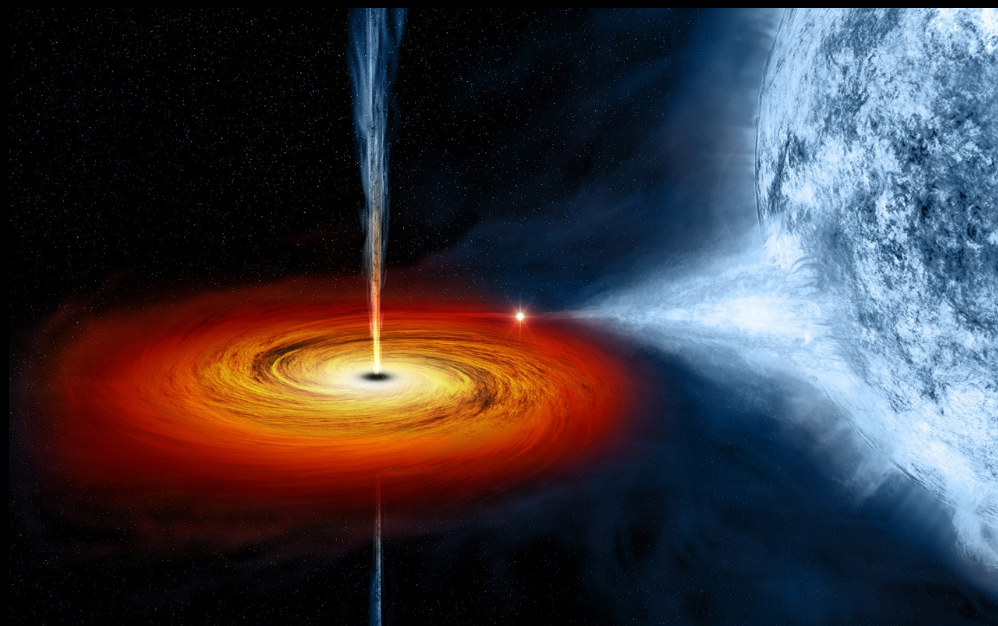
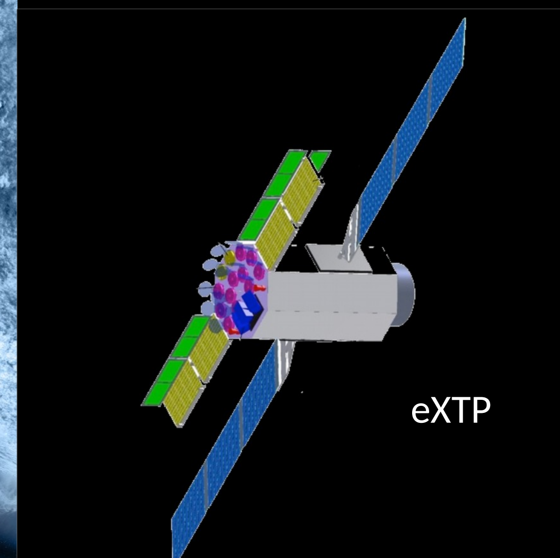
Studying microquasars with X-ray polarimetry





Andrea Marinucci

From quiescence to outburst: when microquasars go wild!

ROMA TRE UNIVERSITÀ DEGLI STUDI
SEVENTH FRAMEWORK PROGRAMME
STRONGGRAVITY
EU FP7-SPACE research project 312789 2013 - 2017

Ile de Porquerolles – 25 September 2017

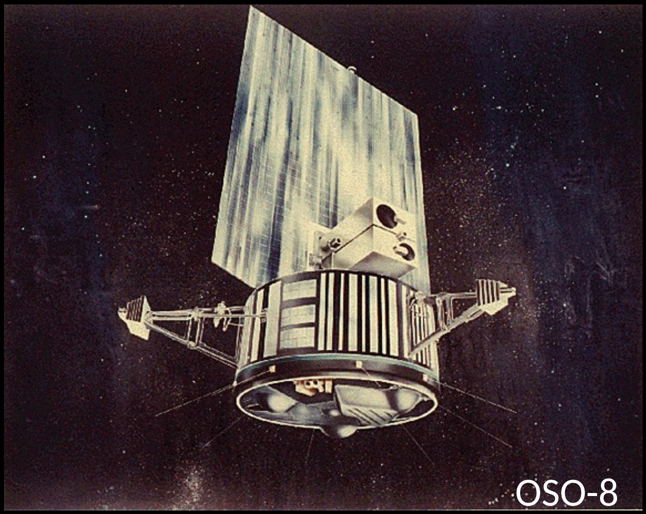
Outline

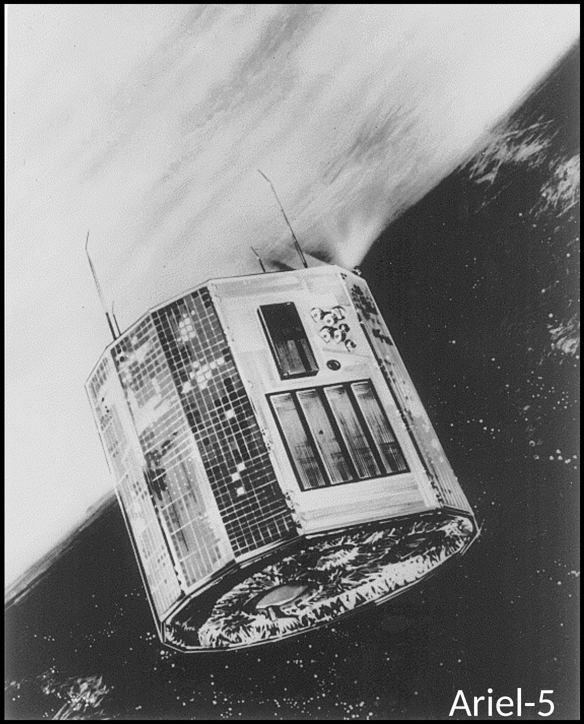
- Introduction

- Polarimetry and microquasars:
  - Coronal geometry
  - The role of the jet
  - The BH spin

- Future instruments

Introduction - polarization measurements





In the early days of X-ray astronomy, polarimeters were flown aboard rockets and aboard the OSO-8 and ARIEL-5 satellites.

With the advent of X-ray optics, polarimetry based on the classical techniques (Bragg diffraction and Thomson scattering) was left behind, with respect to imaging and spectroscopy.

In the last 15 years, with the development of sensors based on the photoelectric effect (Costa+01), polarimetry has been again considered as a realistic option, either for large telescopes with swappable instrumentation or for dedicated small missions.

Introduction - polarization measurements

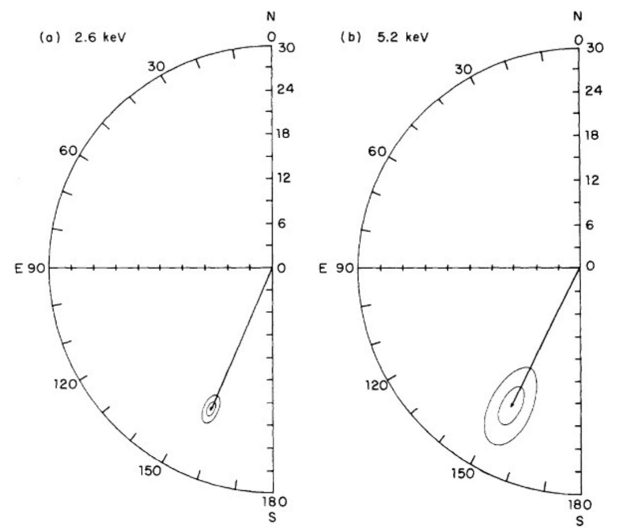
The only positive detection was the polarization of the Crab Nebula (Weisskopf+78) plus many other upper limits of modest significance (Sco X-1: Weisskopf+78; Hughes+84).

TABLE 3

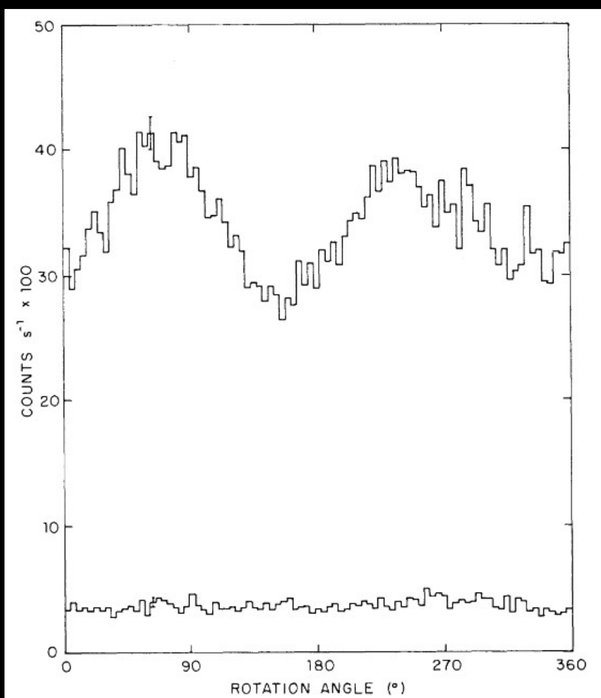
POLARIZATION RESULTS FOR TIME-AVERAGED 1976 AND 1977 OBSERVATIONS WITH AVERAGE EARTH-OCCULTED AND OFF-SOURCE BACKGROUNDS

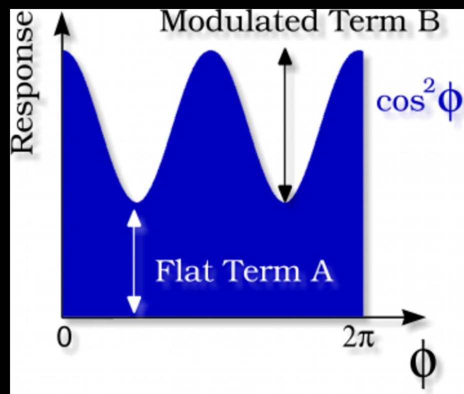
Parameter*	First Order (2.6 keV)	Second Order (5.2 keV)
$\bar{R}$ (Counts $s^{-1} \times 10^3$)	302.32 ± 1.29	53.13 ± 0.65
Q (%)	13.02 ± 0.65	11.24 ± 1.86
U (%)	−14.10 ± 0.65	−15.94 ± 1.86
P (%)	19.19 ± 0.97	19.50 ± 2.77
ϕ (degrees)	156.36 ± 1.44	152.59 ± 4.04

*See footnote to Table 2.



Weisskopf+78



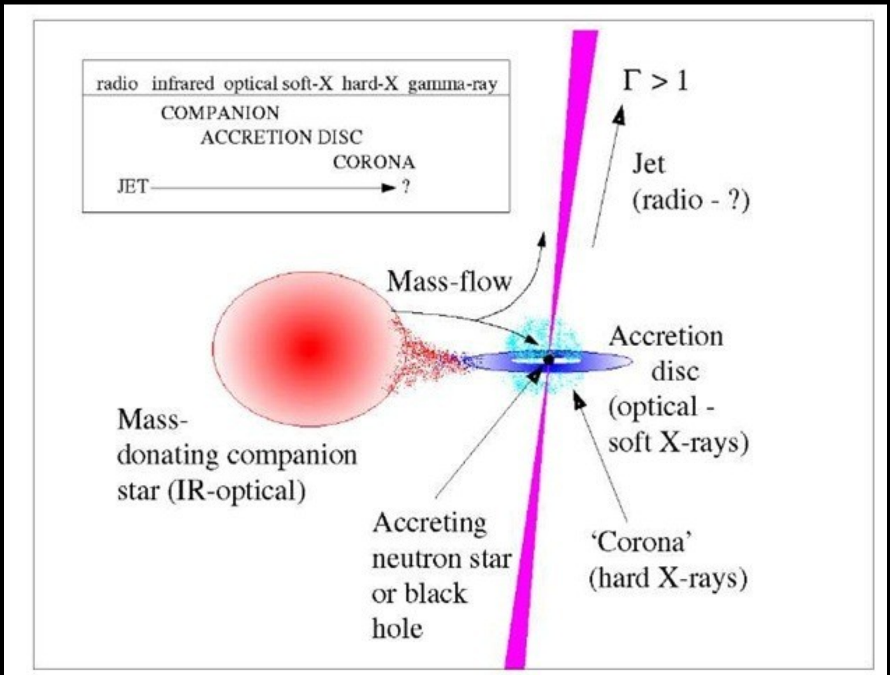


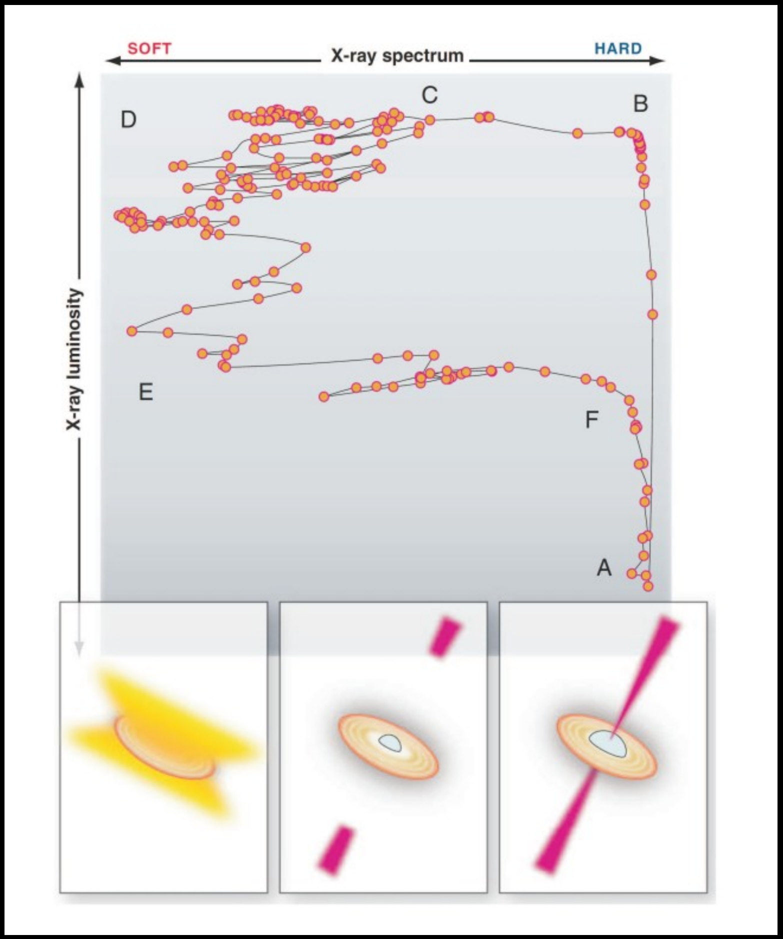
$$\mathcal{M}(\phi) = A + B\cos^2(\phi - \phi_0)$$

$$\mathcal{P} = \frac{M}{\mu} = \frac{1}{\mu}\frac{B}{B+2A}$$

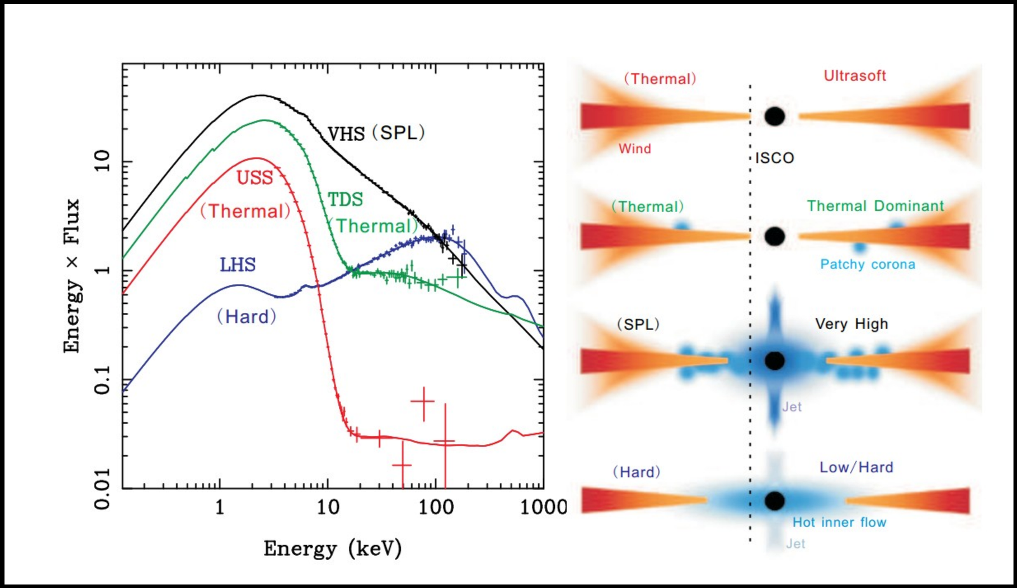
Modulation factor (instrument dependent)

Introduction - microquasars





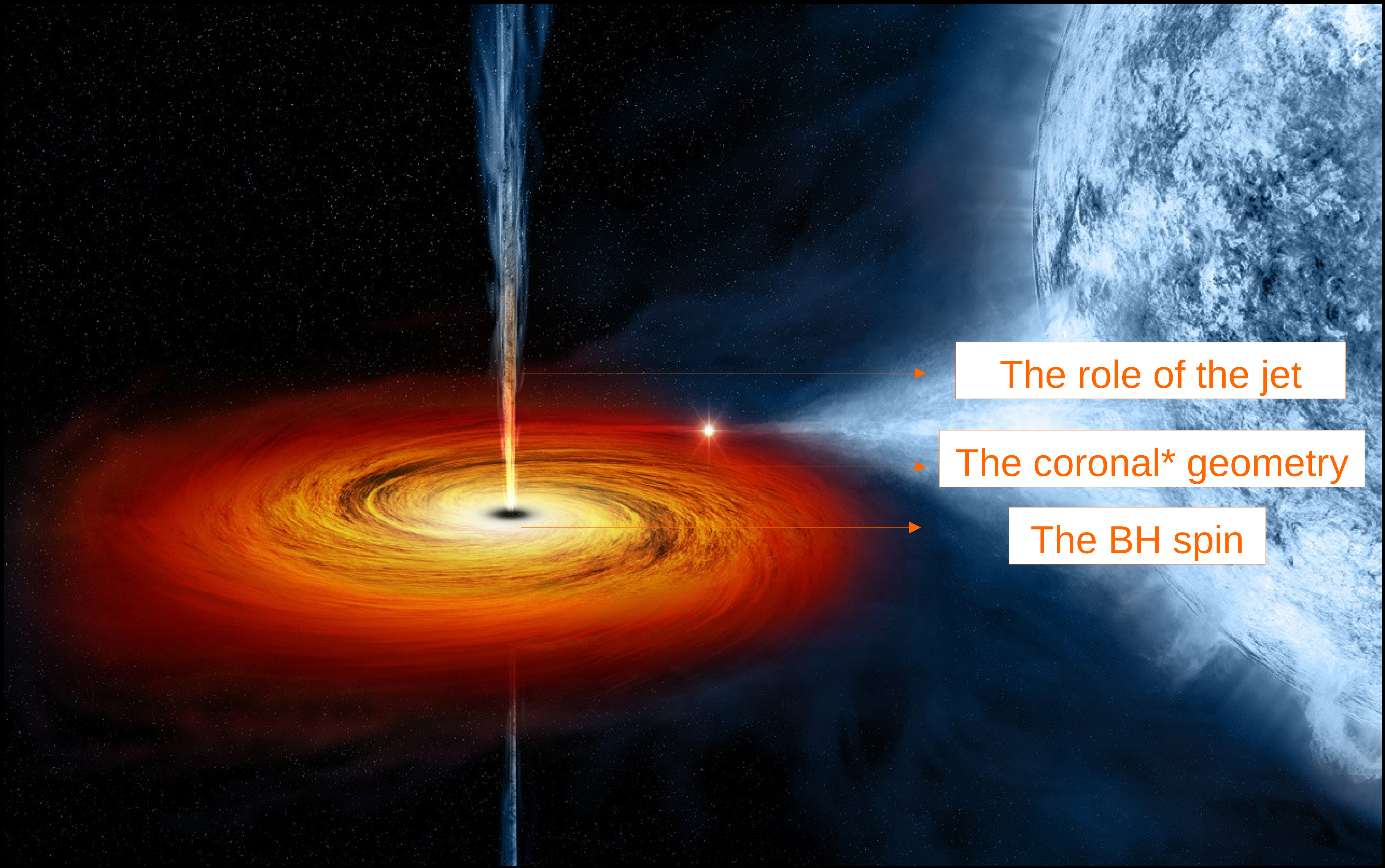
Fender&Belloni+12



Done+07

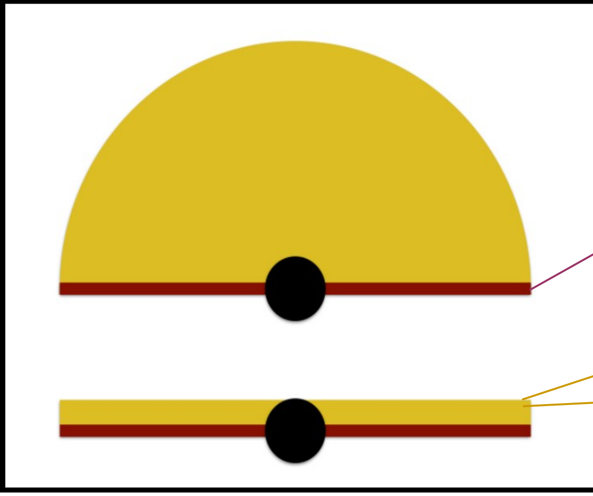
How can we use X-ray polarimetry to study such astrophysical systems?

Introduction - microquasars



*a.k.a. inner flow/PL emitting region

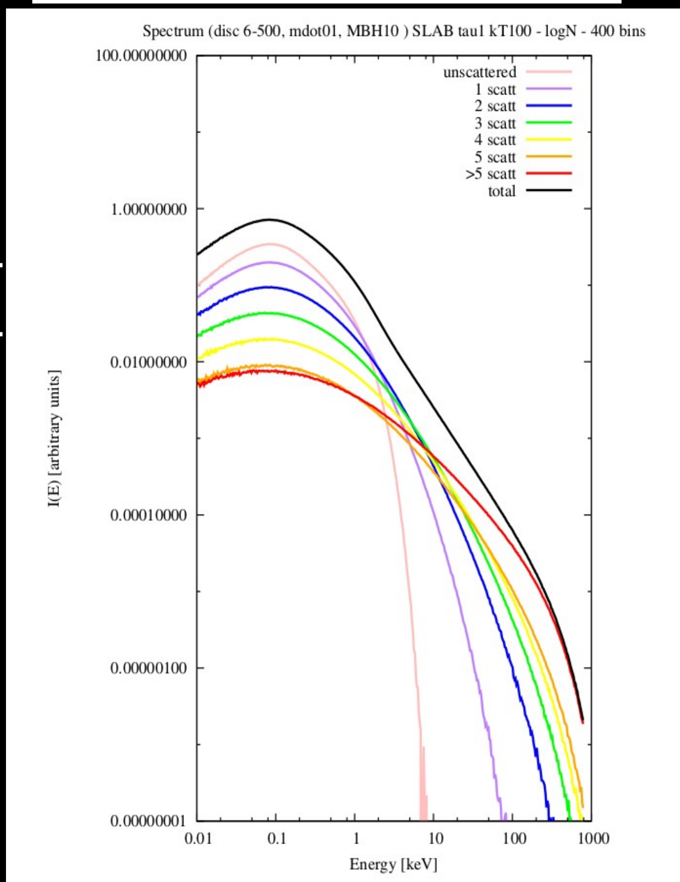
The coronal geometry (hard state)



$$T(R) = \left[\frac{3GM\dot{m}}{8\pi R^3 \sigma_{SB}}\left(1-\sqrt{\frac{R_{in}}{R}}\right)\right]^{\frac{1}{4}}$$

kT_e

$d\tau = n_e \sigma_{kn} dx$



Tamborra+, in prep.

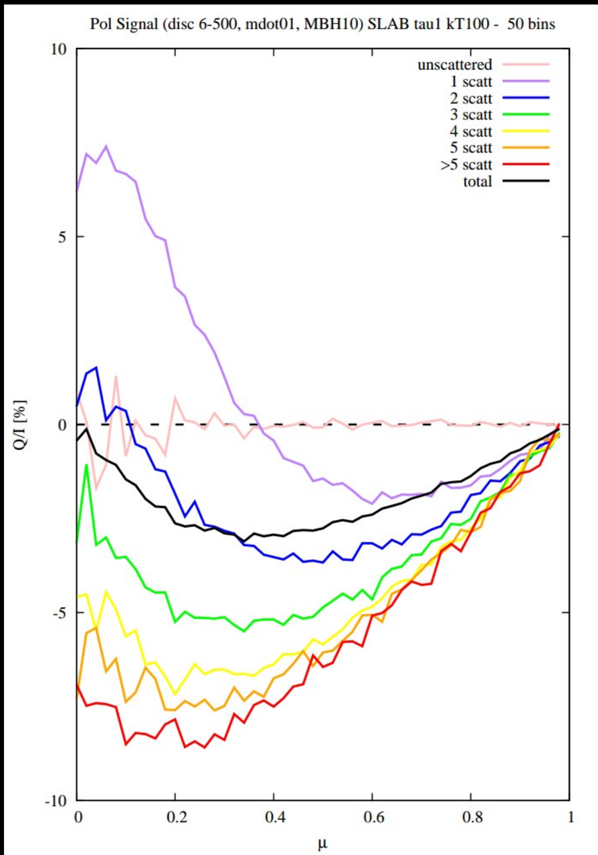
MoCA: Montecarlo Code for Accretion

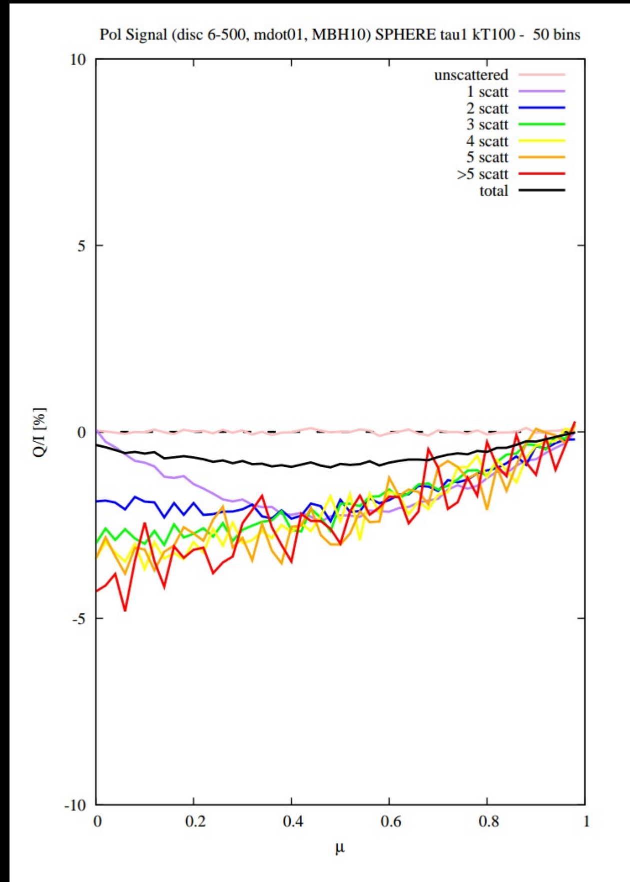
Assumptions and advantages:

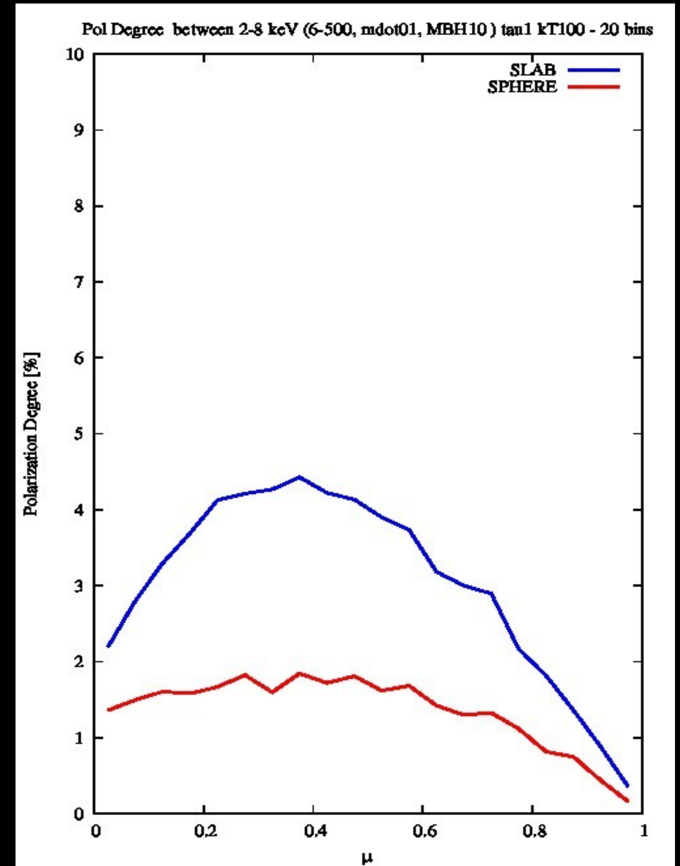
1. Shakura-Sunyaev neutral accretion disk
2. Extended coronae
3. Single photon approach
4. Full special relativity included
5. Polarization signal (!)

The coronal geometry (hard state)

Tamborra+, in prep.



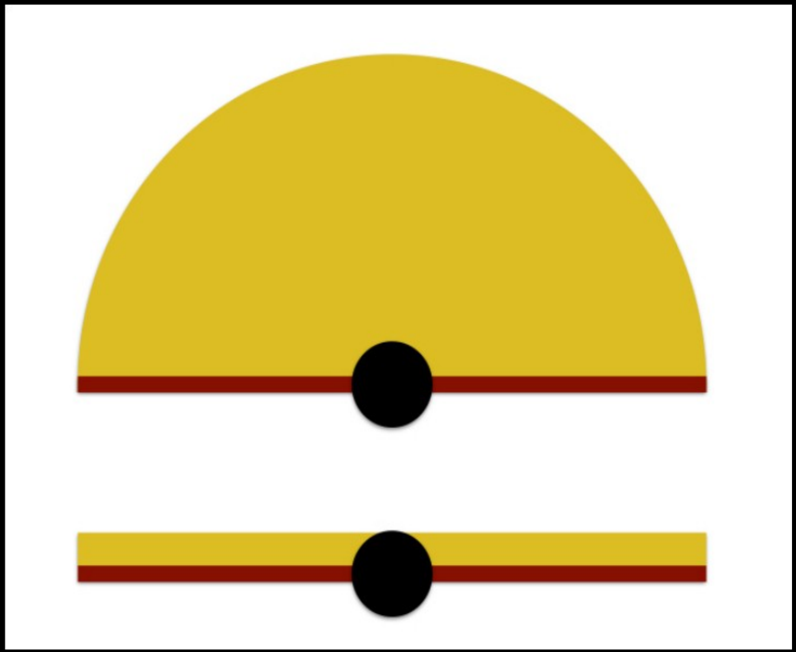


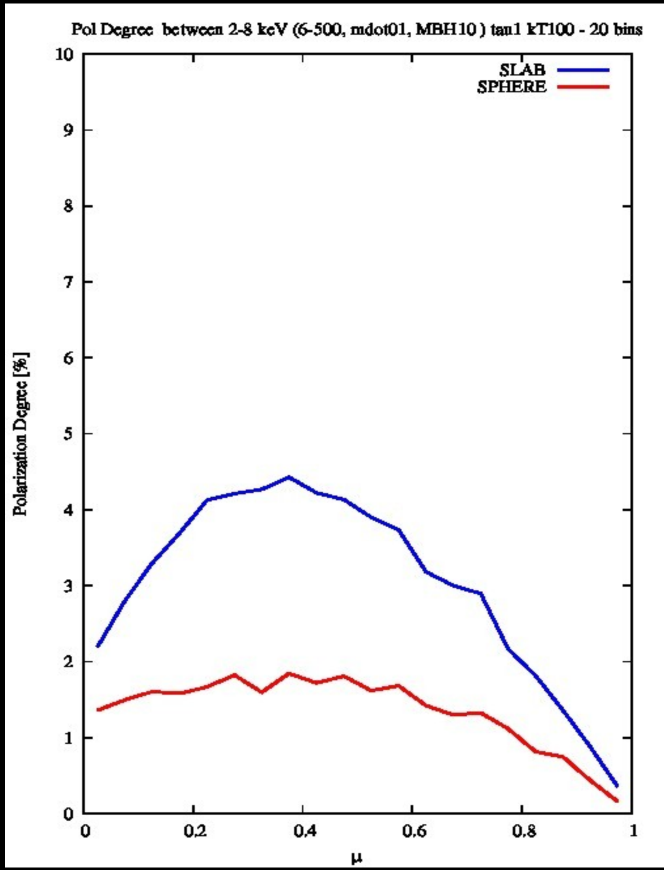


Stokes parameters:

I is proportional to the intensity of the polarized component
Q is related to the angle of polarization

The coronal geometry (hard state)

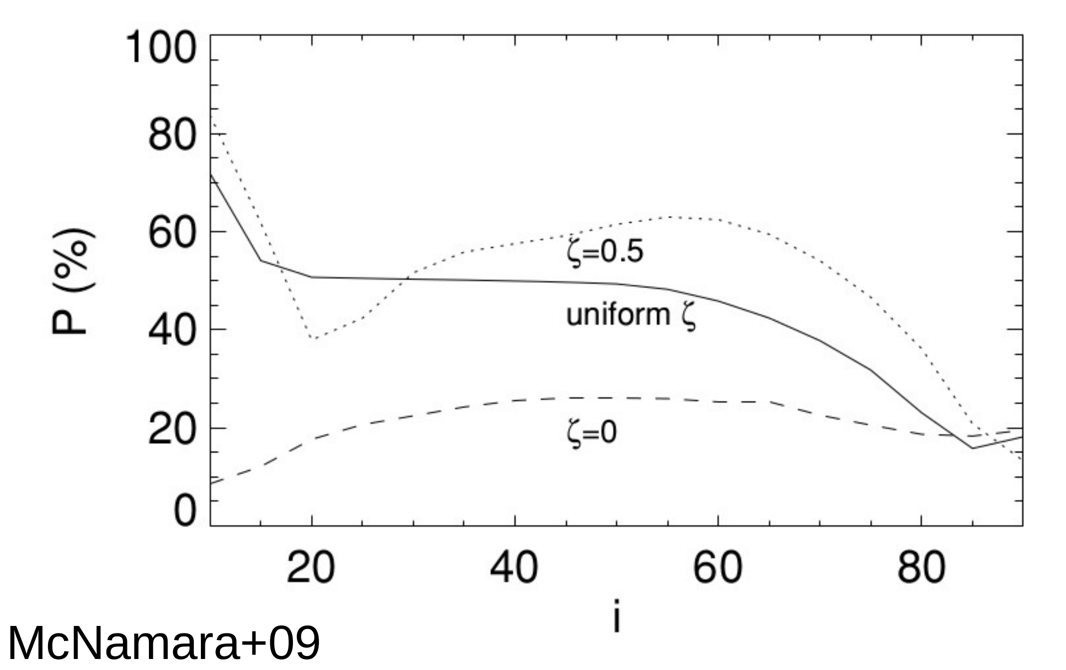


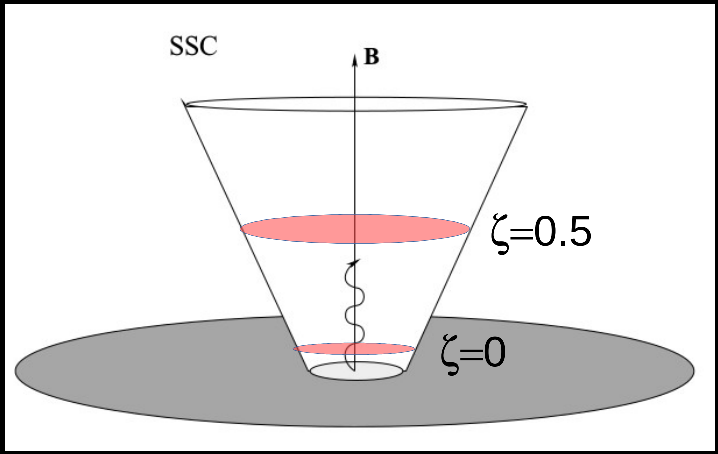


Tamborra+, in prep.

If the emission is due to Comptonization of the disc thermal photons in a hot corona, polarimetry can constrain the geometry of the corona

The role of the jet (hard state)





Coronal emission is predicted to be less than 10%

Much larger polarization degrees are expected for jet emission, independently of the details of the jet structure

The BH spin (soft state)

In accreting Galactic black hole systems, X-ray polarimetry can provide a technique to measure the spin of the black hole, in addition to the three methods employed so far

GRO J1655-40:

QPO: a = J/Jmax = 0.290±0.003

Continuum: a = J/Jmax = 0.7±0.1

Iron line: a = J/Jmax > 0.95

The BH spin (soft state)

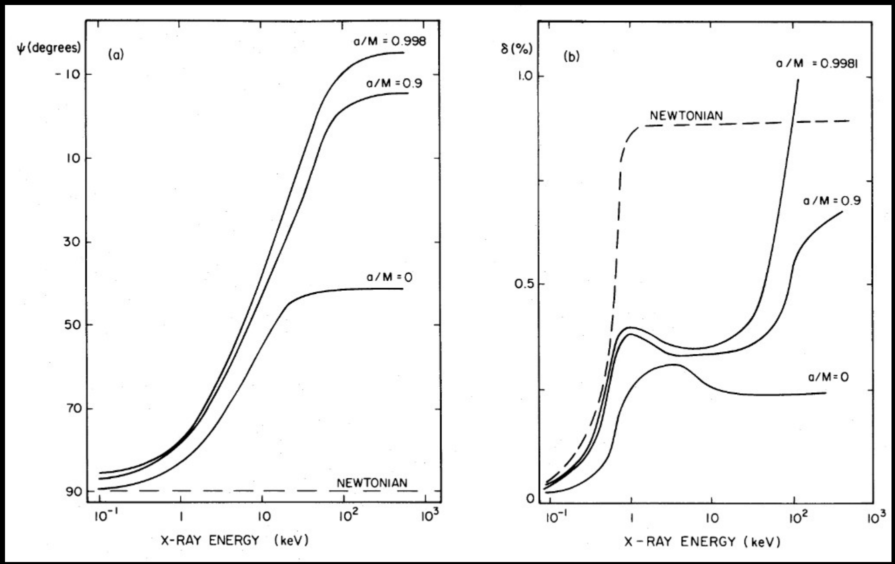
Gravitational bending modifies the light geodesics causing a rotation of the plane of polarization: the polarization angle rotates with respect to the Newtonian value

↓

The effect increases with decreasing radii, i.e. with increasing temperature, i.e. with increasing photon energy

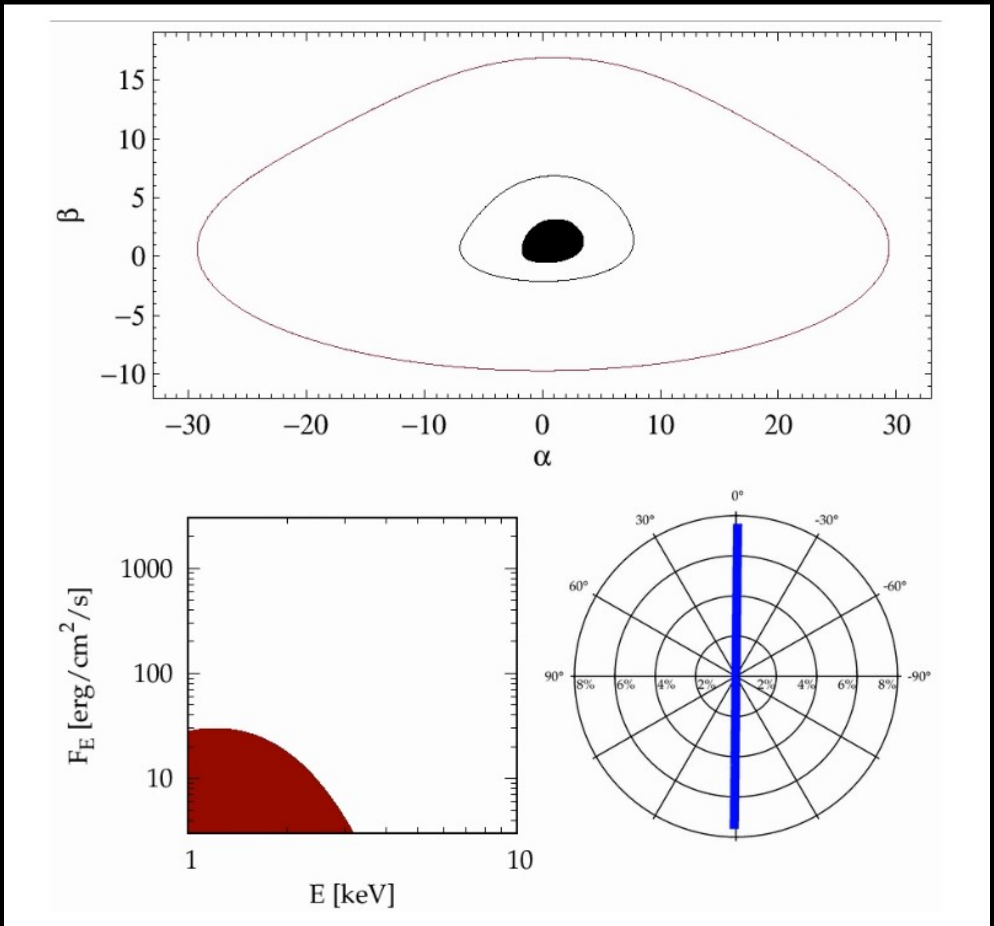
↓

rotation of the polarization angle with energy



Connors+80

The BH spin (soft state)



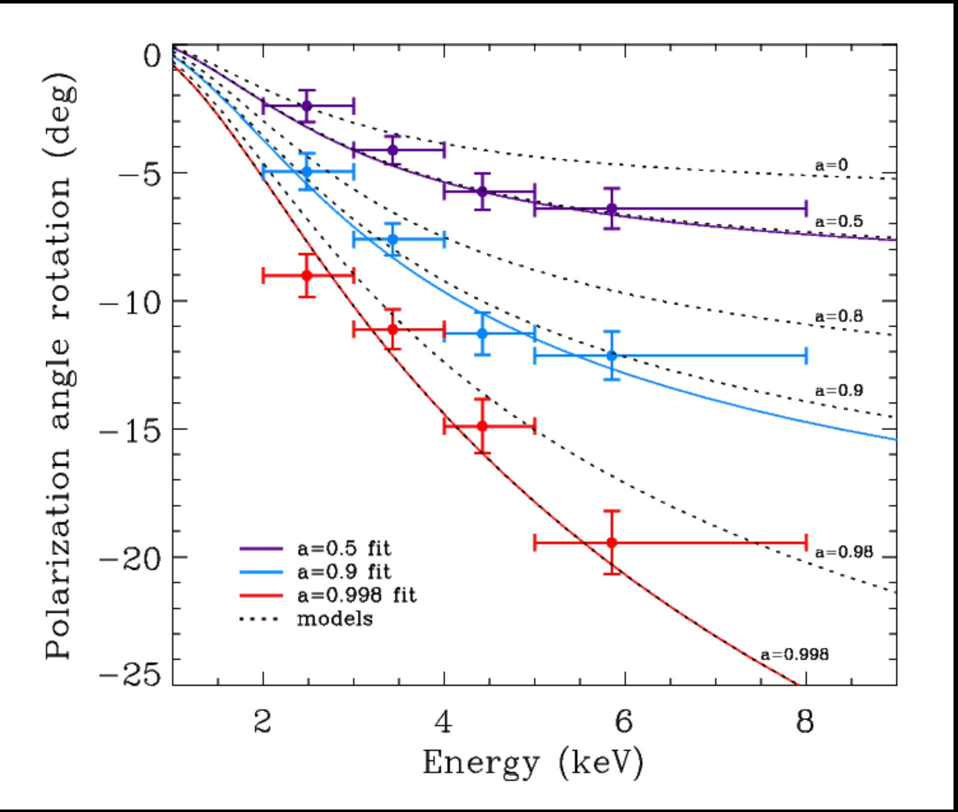
Courtesy: Michal Dovciak

Harder photons comes from the inner region of the accretion disk and then are more affected;

The effect is stronger for a Kerr BH, because the disk gets closer to the BH

The BH spin (soft state)

200 ks IXPE observation of GRS1915+105



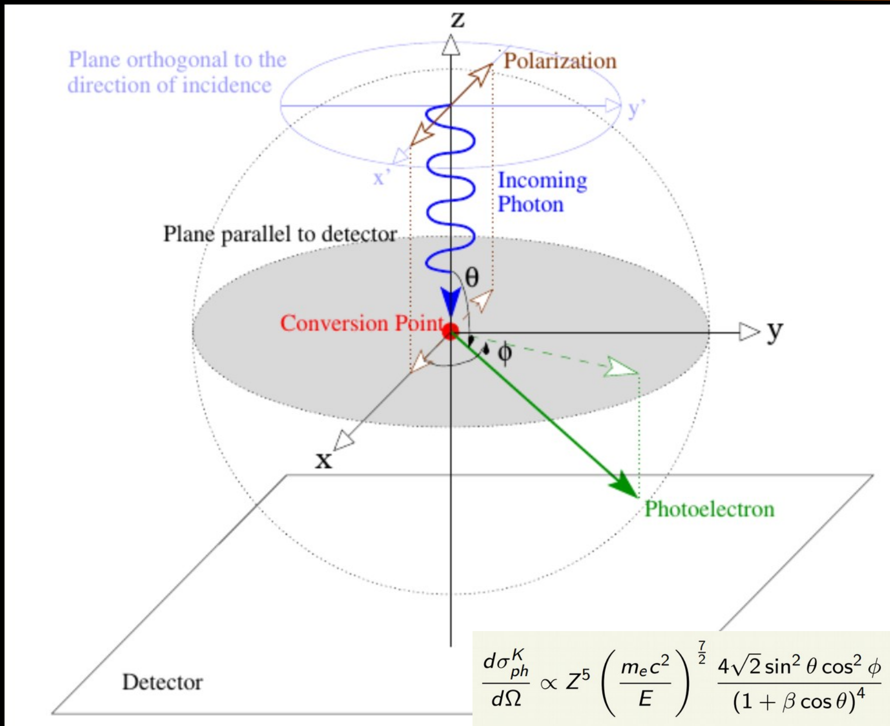
(adapted from Dovciak+09)

Harder photons comes from the inner region of the accretion disk and then are more affected;

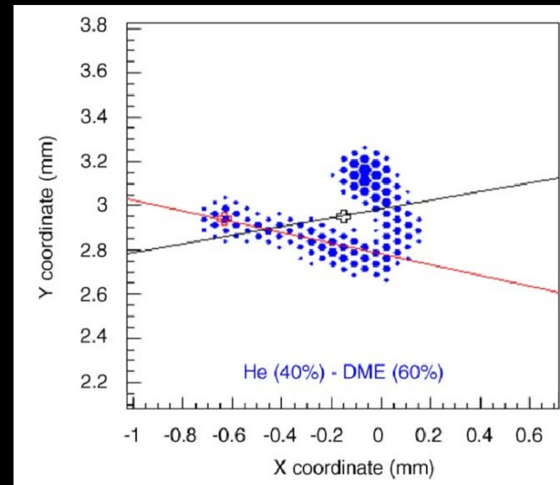
The effect is stronger for a Kerr BH, because the disk gets closer to the BH

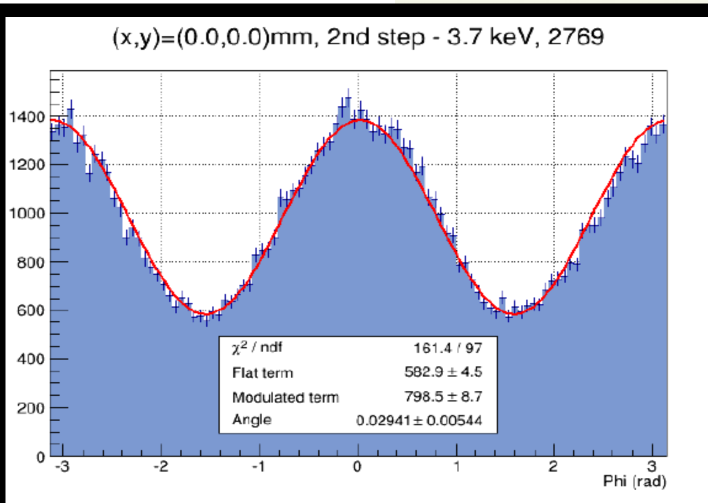
Future instruments

The photoelectric polarimeter

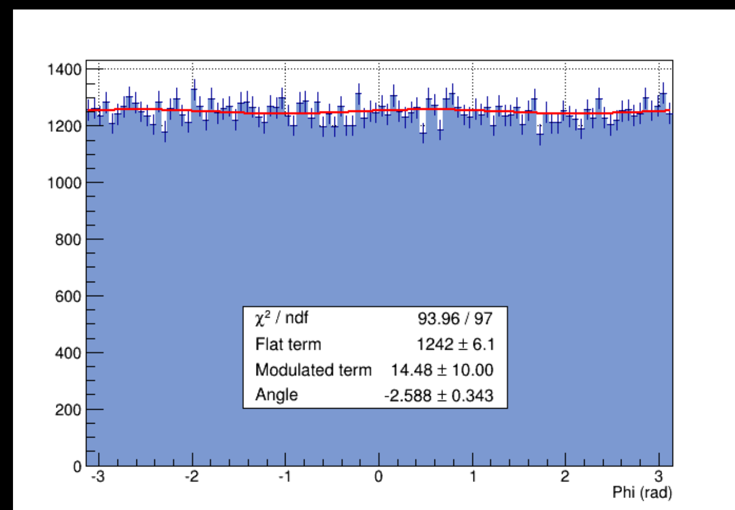


$$\frac{d\sigma^K_{ph}}{d\Omega} \propto Z^5 \left(\frac{m_e c^2}{E}\right)^{\frac{7}{2}} \frac{4\sqrt{2}\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$





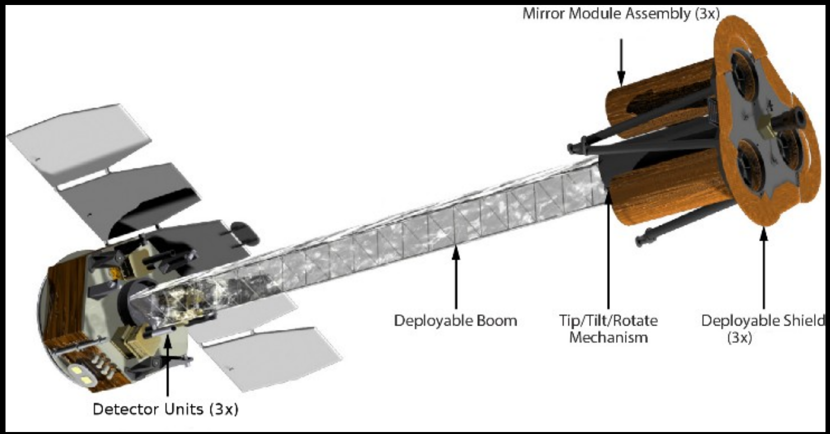
Real modulation curve derived from the measurement of the emission direction of the photoelectron.



Residual modulation for unpolarized photons.

Future instruments - IXPE

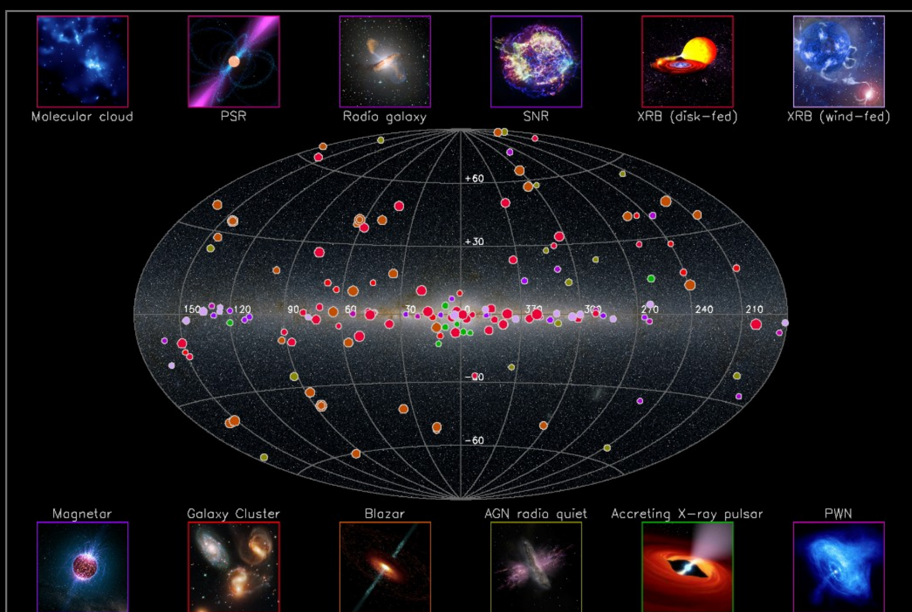
Polarisation sensitivity	1.8 % MDP for $2x10^{-10}$ erg/s cm^2 (10 mCrab) in 300 ks (CBE)
Spurious polarization	<0.3 %
Number of Telescopes	3
Angular resolution	28'' (CBE)
Field of View	12.9x12.9 $arcmin^2$
Focal Length	4 meters
Total Shell length	600 mm
Range Shell Diameter	24 shells, 272-162 mm
Range of thickness	0.16-0.26 mm
Effective area at 3 keV	854 cm^2 (three telescopes)
Spectral resolution	16% @ 5.9 keV (point source)
Timing	Resolution <8 μs

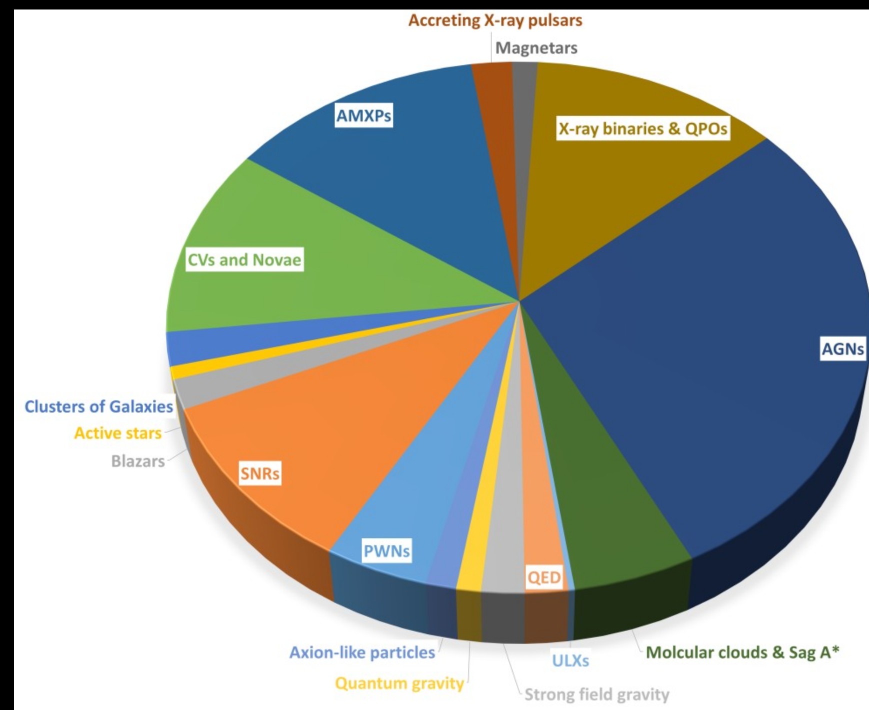


Future instruments - XIPE

XIPE (X-ray Imaging Polarimetry Explorer). Selected by ESA (M4) for phase A study. Final selection: November 2017 – Launch: 2025.
Lead Scientist: Paolo Soffitta (IAPS/INAF, Italy)

A scaled-up version of IXPE (larger area, longer duration, more flexible operations). From the exploratory to the mature phase

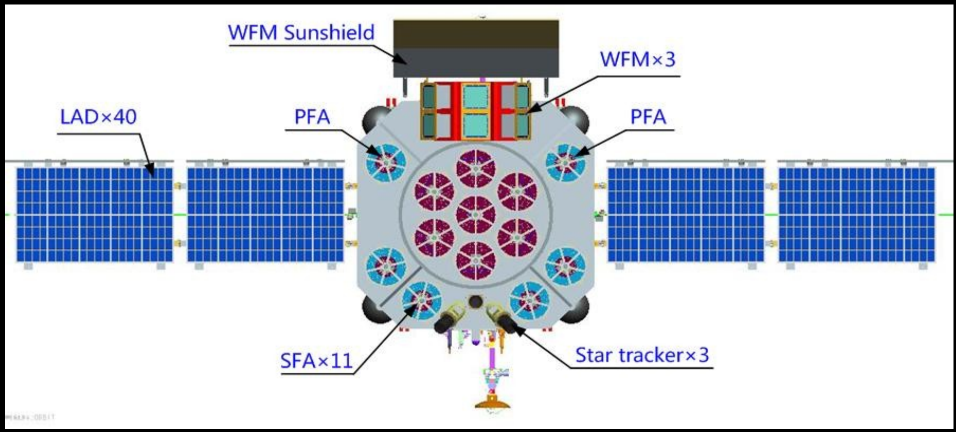




Future instruments - eXTP

eXTP (enhanced X-ray Timing and Polarimetry Mission). Proposed to CAS; selected in 2011 as one of 8 “background missions”. Phase A study in 2011-14.
P.I: Shuang-Nan Zhang (Tsinghua Univ.). An international consortium (China + many european countries). Launch: 2025 ?

Simultaneous spectroscopic,
timing and
polarimetric observations



Focal plane imaging polarimeter: 4 optics with 5.25m FL
Imaging, PSF 20 arcsec HPD
Gas Pixel Detector: single photon, <100µs
Energy band: 2-10 keV
Energy resolution: 20% FWHM @6 keV
Total effective area: 900 cm^2 @2 keV (includes QE)

Thank you for the attention!