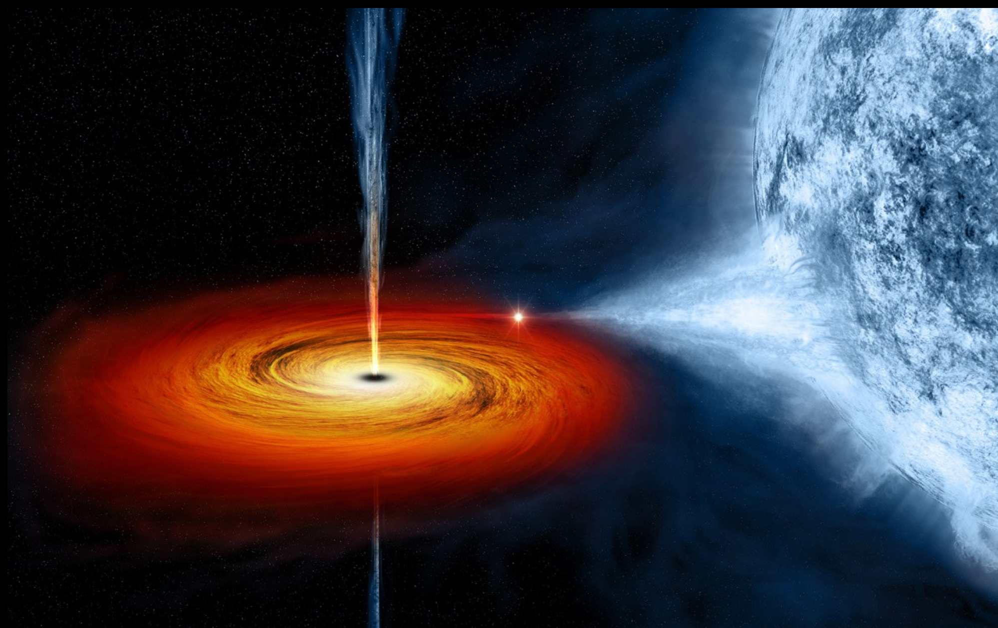
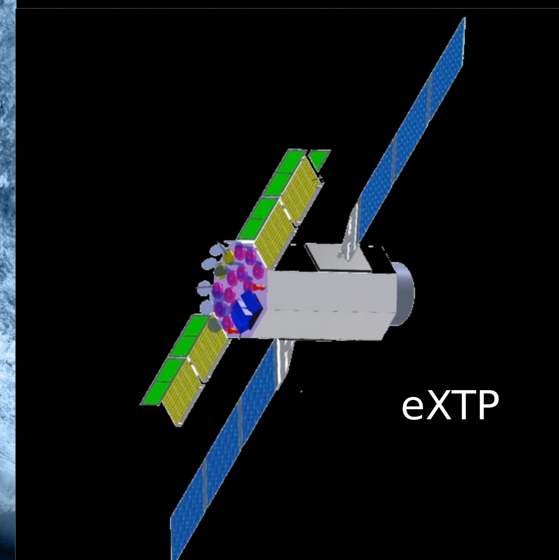
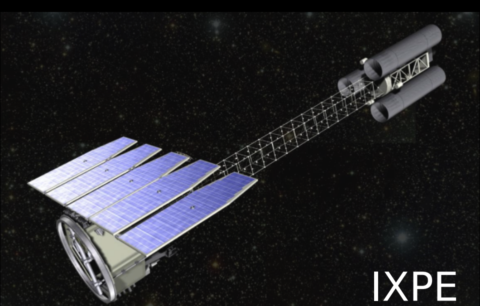
Studying microquasars with X-ray polarimetry







Andrea Marinucci

From quiescence to ouburst: 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

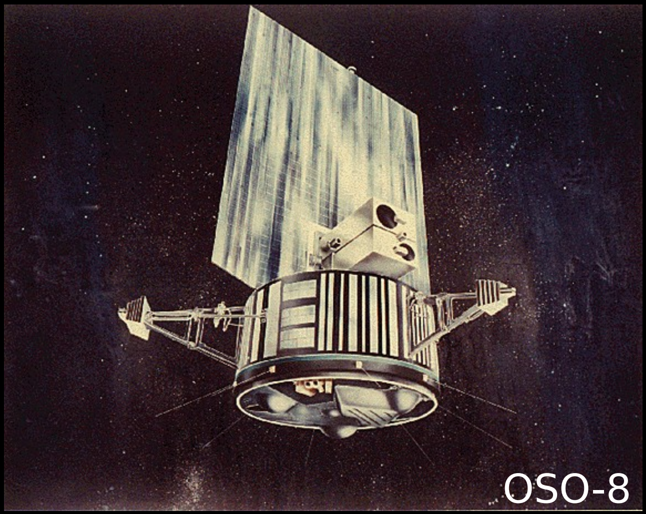
Outline

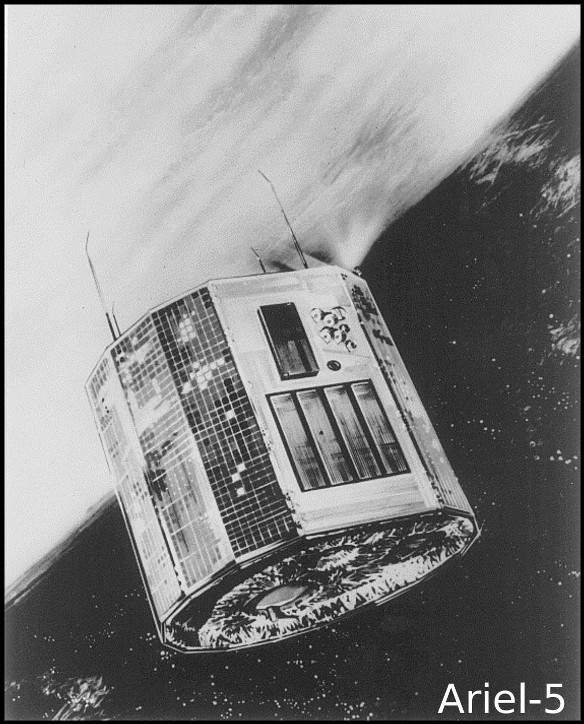
- Introduction

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

- Future instruments

Introduction - polarization measurements





At the beginning of X-ray astronomy, polarimeters were flown aboard rockets and aboard the OSO-8 and ARIEL-5 satellites.

The introduction of X-ray optics, while producing a dramatic improvement in sensitivity, removed the need to rotate the satellite. Therefore, polarimetry based on the classical techniques, Bragg diffraction and Thomson scattering (which require rotation), became seriously mismatched with imaging and spectroscopy.

In the last 10 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

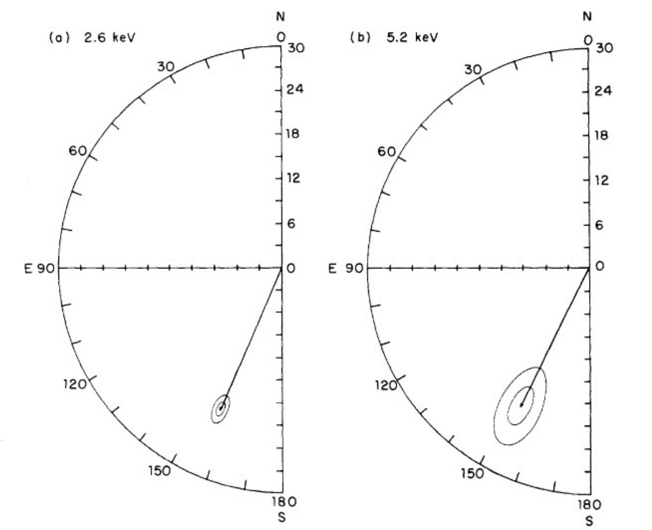
The only positive detection was the polarization of the Crab Nebula (Weisskopf+78) and
two significant upper limits were obtained on Cyg X-1 (Weisskopf+77) and
Sco X-1 (Weisskopf+78), plus many other upper limits of modest significance (Hughes+84).

TABLE 3

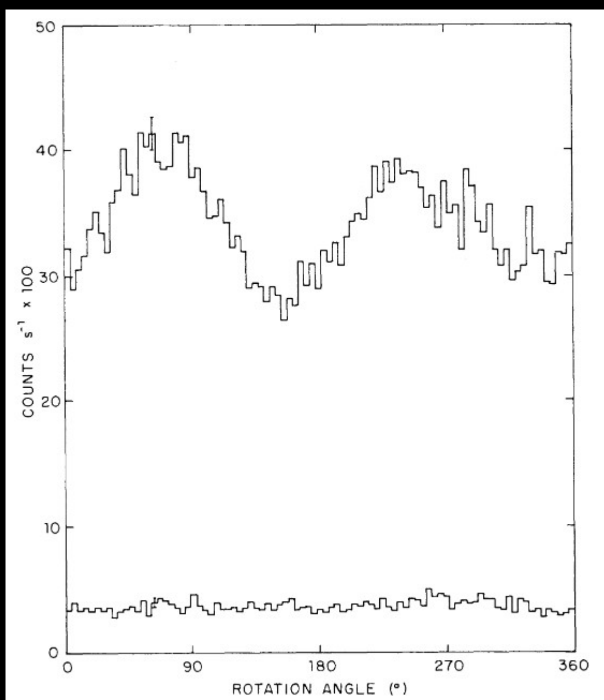
POLARIZATION RESULTS FOR TIME-AVERAGED 1976 AND 1977 OBSERVATIONS WITH AVERAGE EARTH-OCCULTED AND OFF-SOURCE BACKGROUNDS

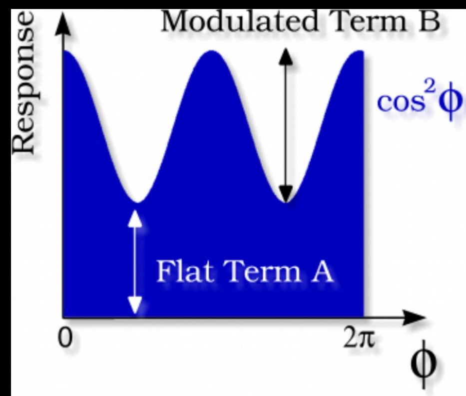
Parameter*	First Order (2.6 keV)	Second Order (5.2 keV)
$\bar{R}$ (Counts $s^{-1} \times 10^3$)	302.32 ± 1.29	53.13 ± 0.65
Q (%)	13.02 ± 0.65	11.24 ± 1.86
U (%)	−14.10 ± 0.65	−15.94 ± 1.86
P (%)	19.19 ± 0.97	19.50 ± 2.77
ϕ (degrees)	156.36 ± 1.44	152.59 ± 4.04

*See footnote to Table 2.



Weisskopf+78



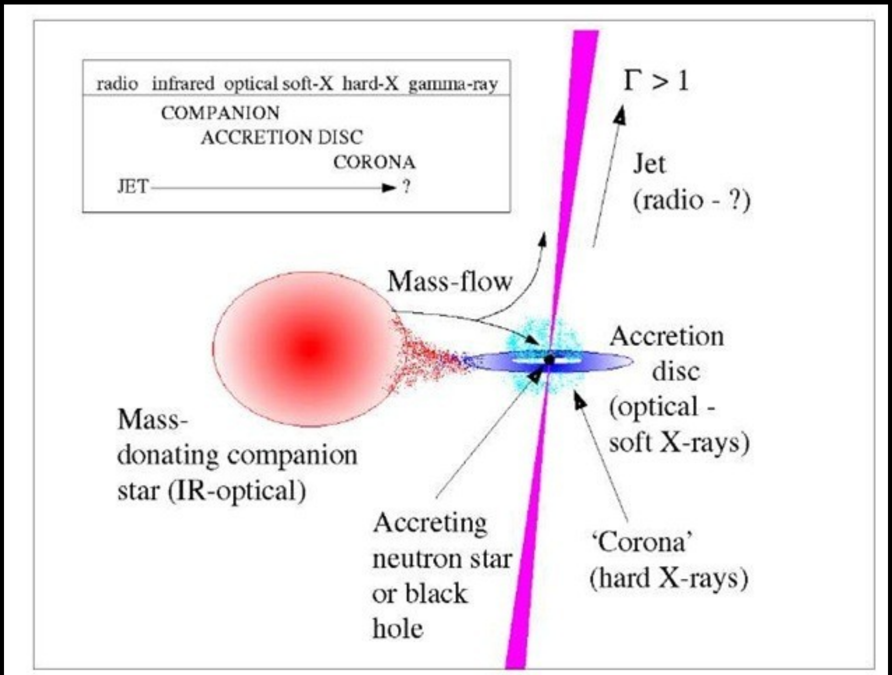


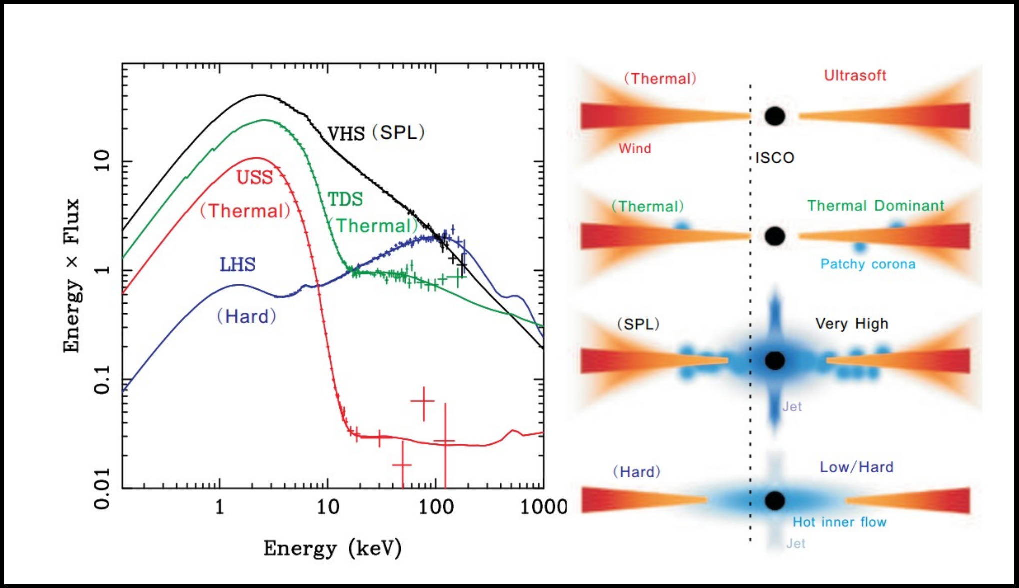
$$\mathcal{M}(\phi) = A + B\cos^2(\phi - \phi_0)$$

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

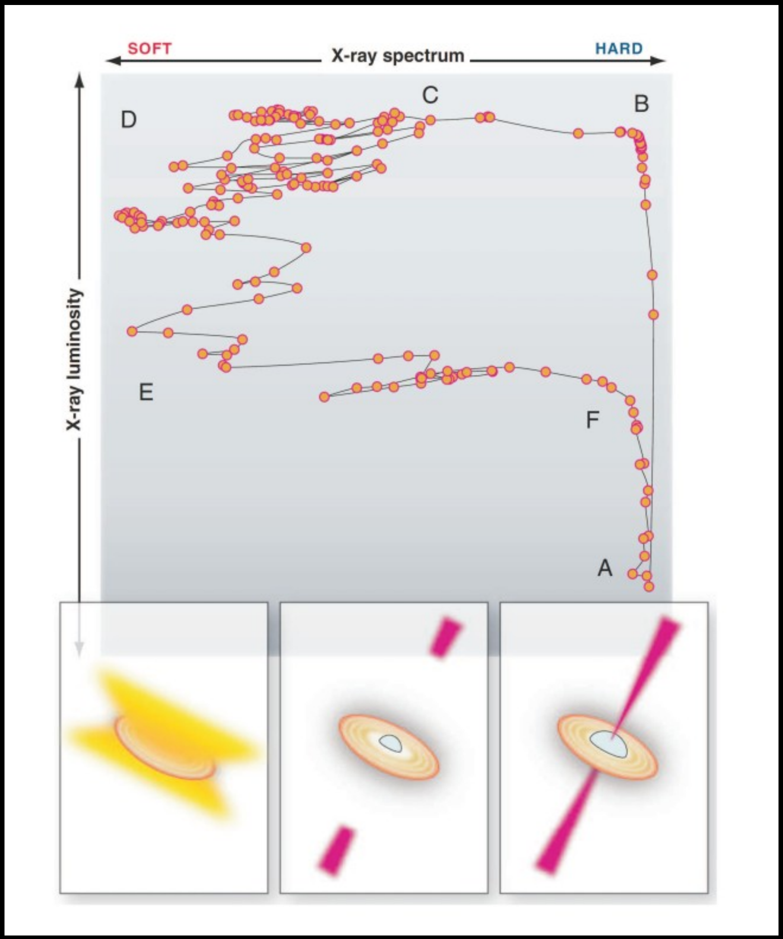
Instrument dependent

Introduction - microquasars





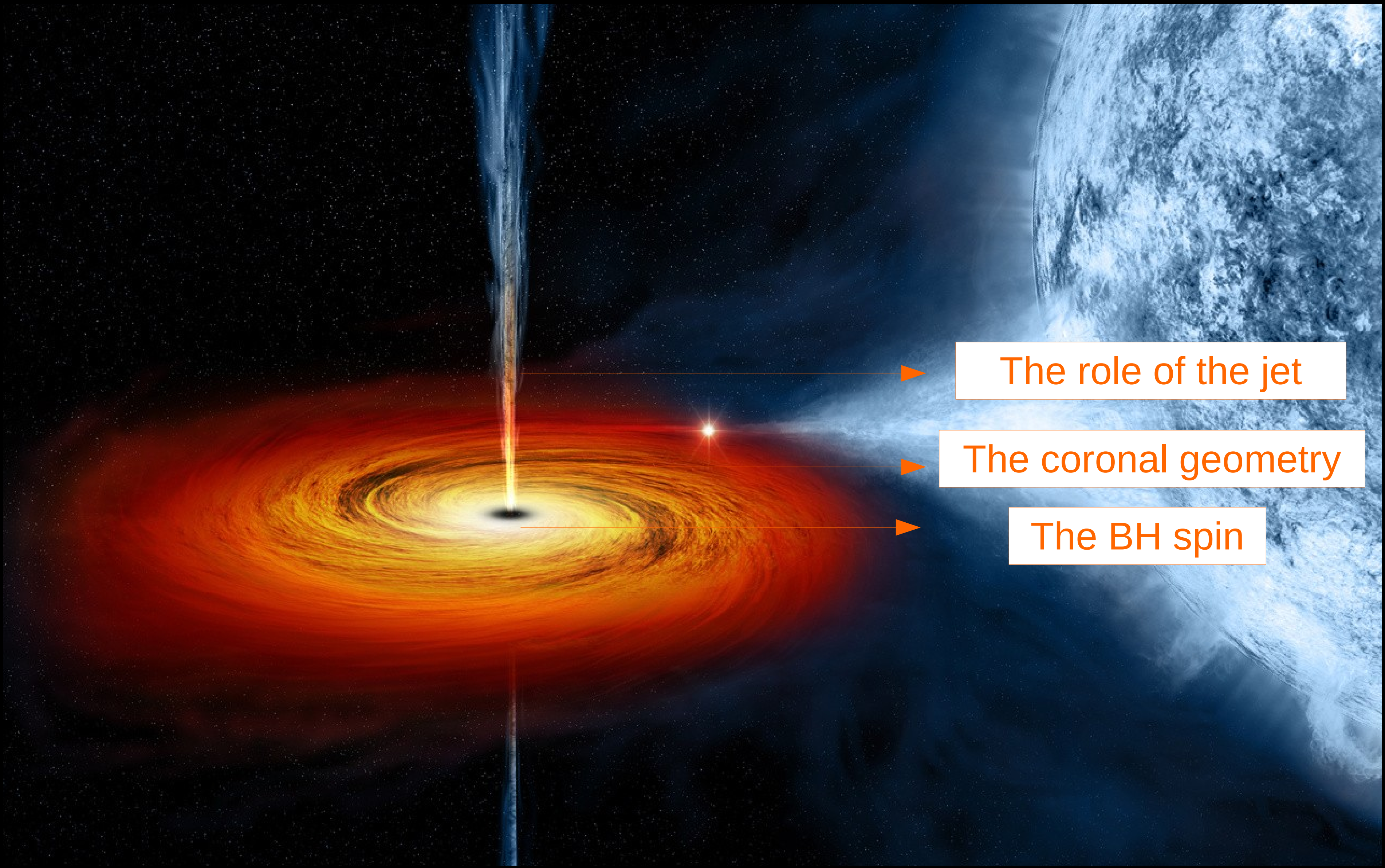
Done+07



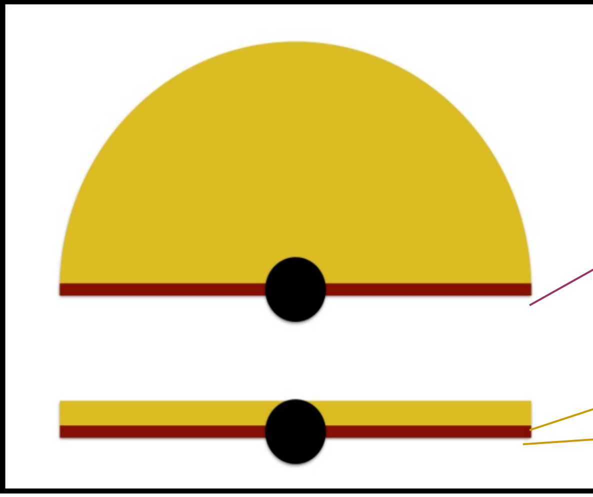
Zhang+13

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

Introduction - microquasars



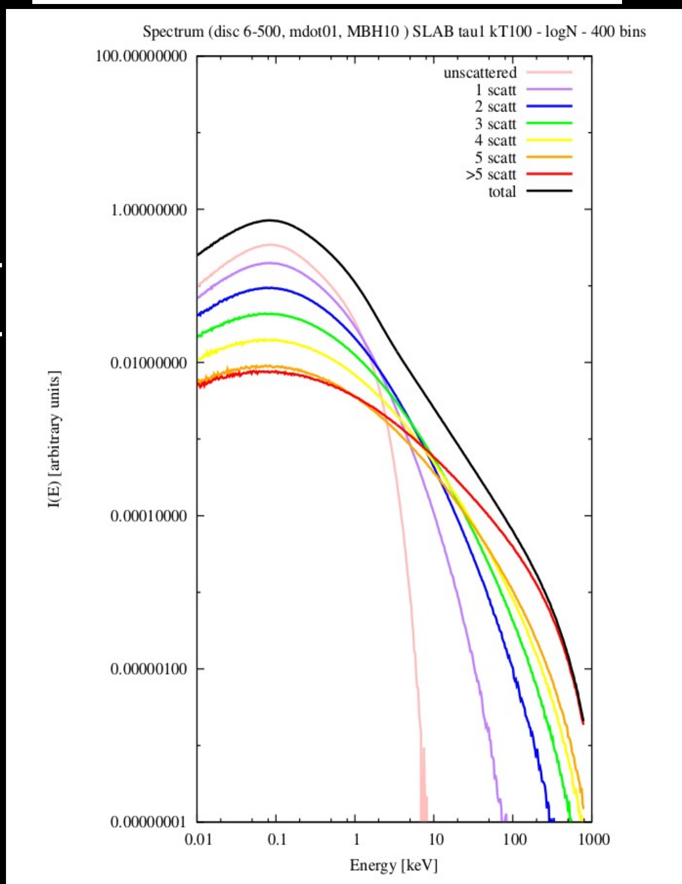
The coronal geometry (hard state)



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

kT_e

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



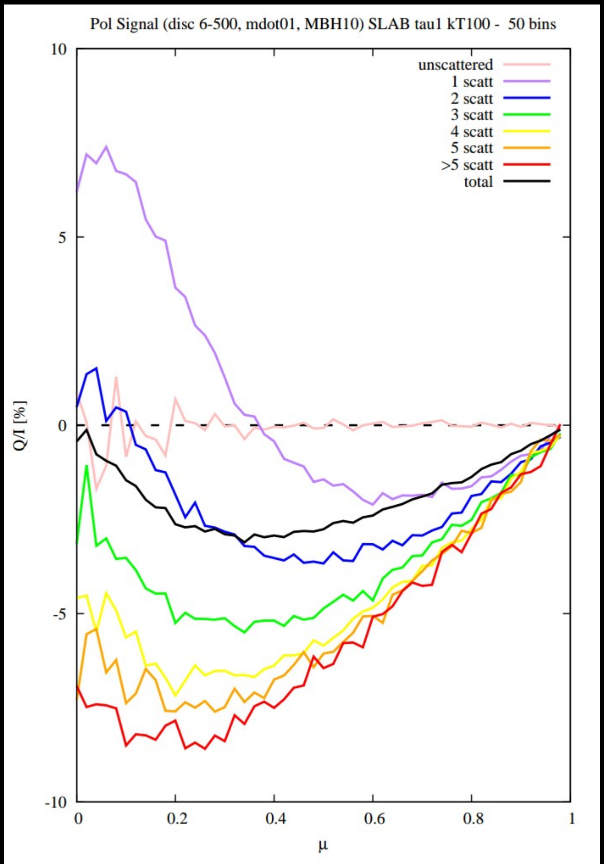
Tamborra+, in prep.

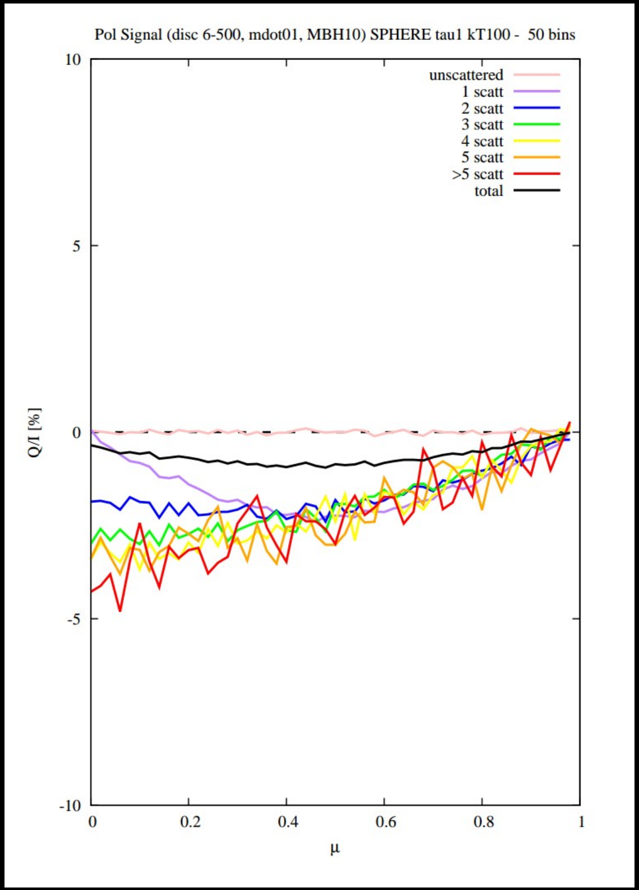
Assumptions and advantages:

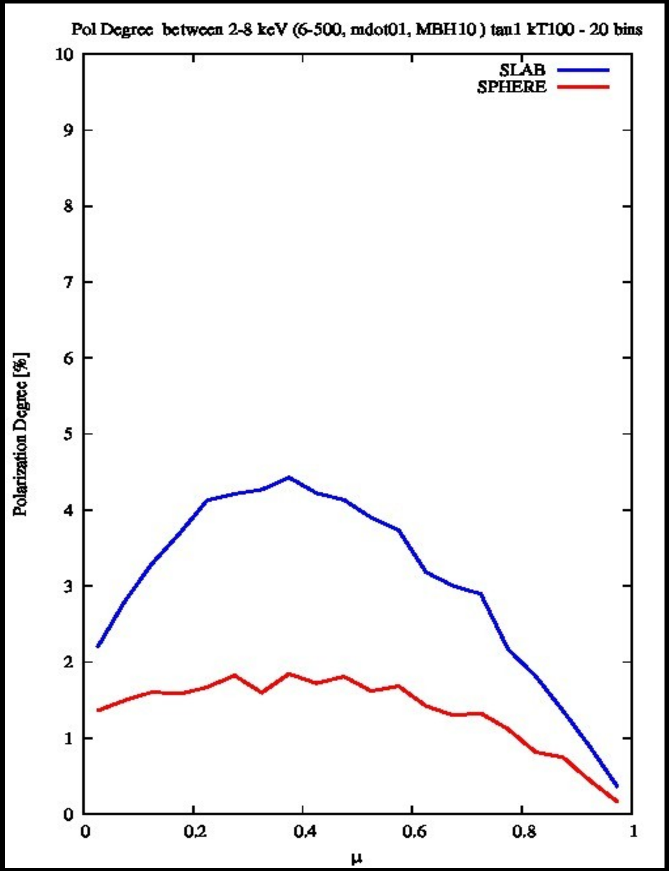
1. Shakura-Sunyaev neutral accretion disk
2. Extended coronae
3. Single photon approach
4. Full special relativity included
5. Polarization signal (!)

The coronal geometry (hard state)

Tamborra+, in prep.



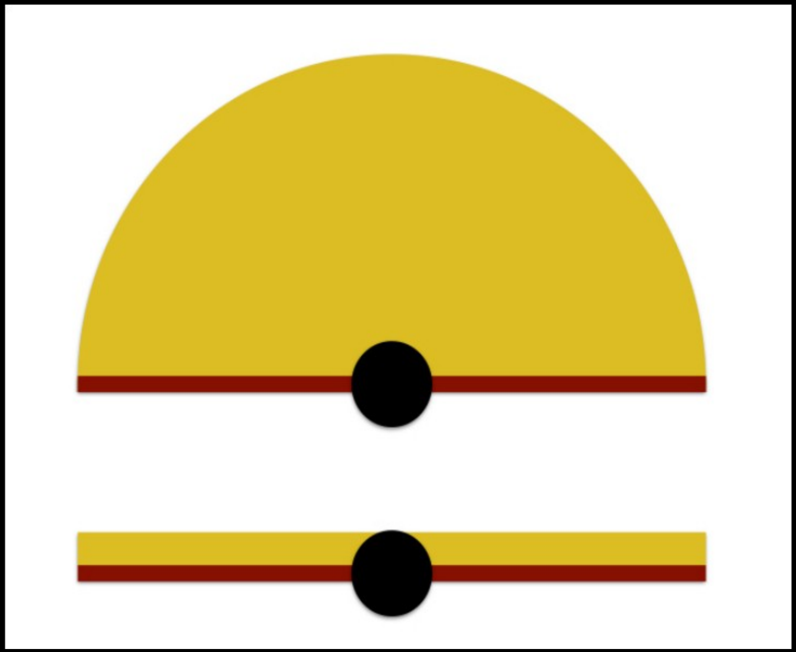


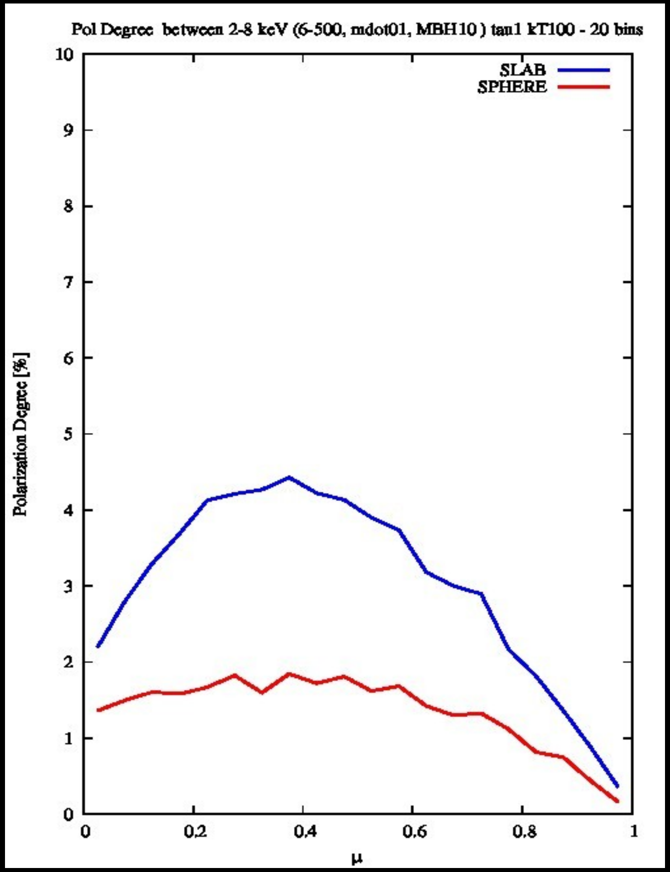


Stokes parameters:

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

The coronal geometry (hard state)

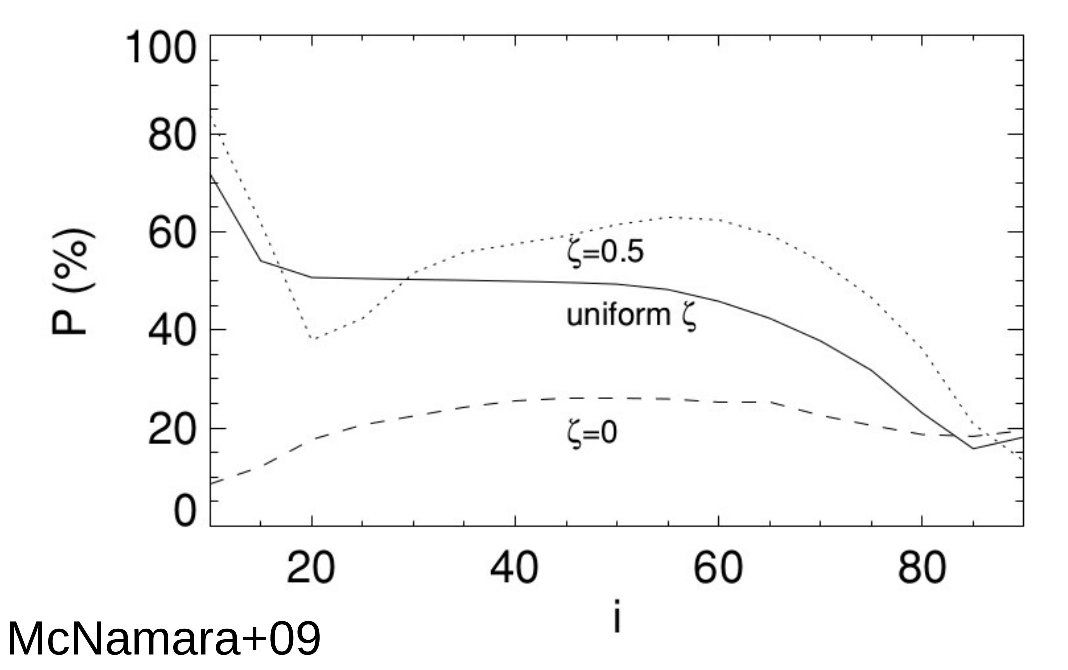


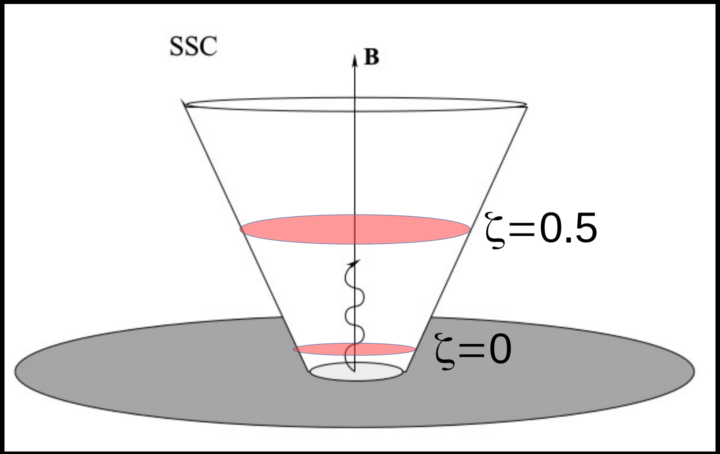


Tamborra+, in prep.

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)

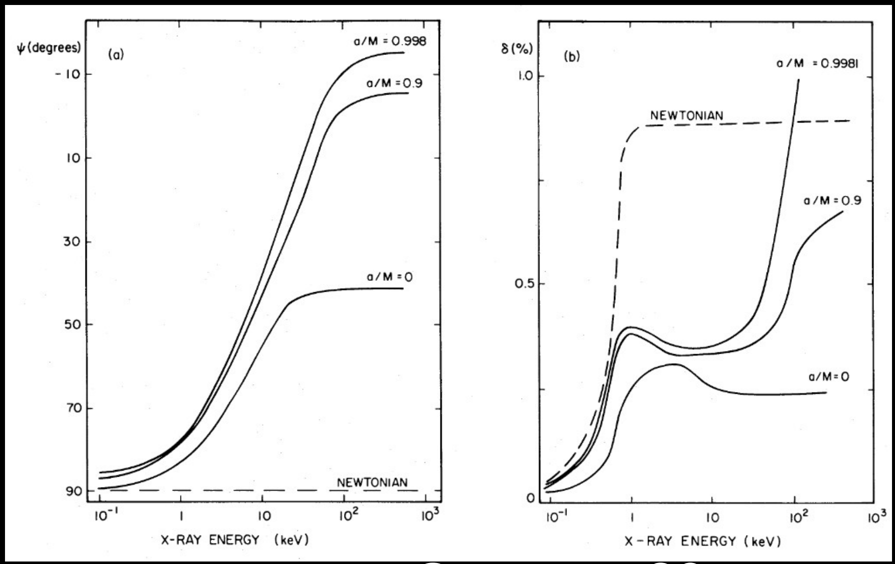
Gravitational bending modifies the light geodesics causing a rotation of the plane of polarization, stronger the field larger the rotation: the polarization angle rotates with respect to the Newtonian value

↓

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

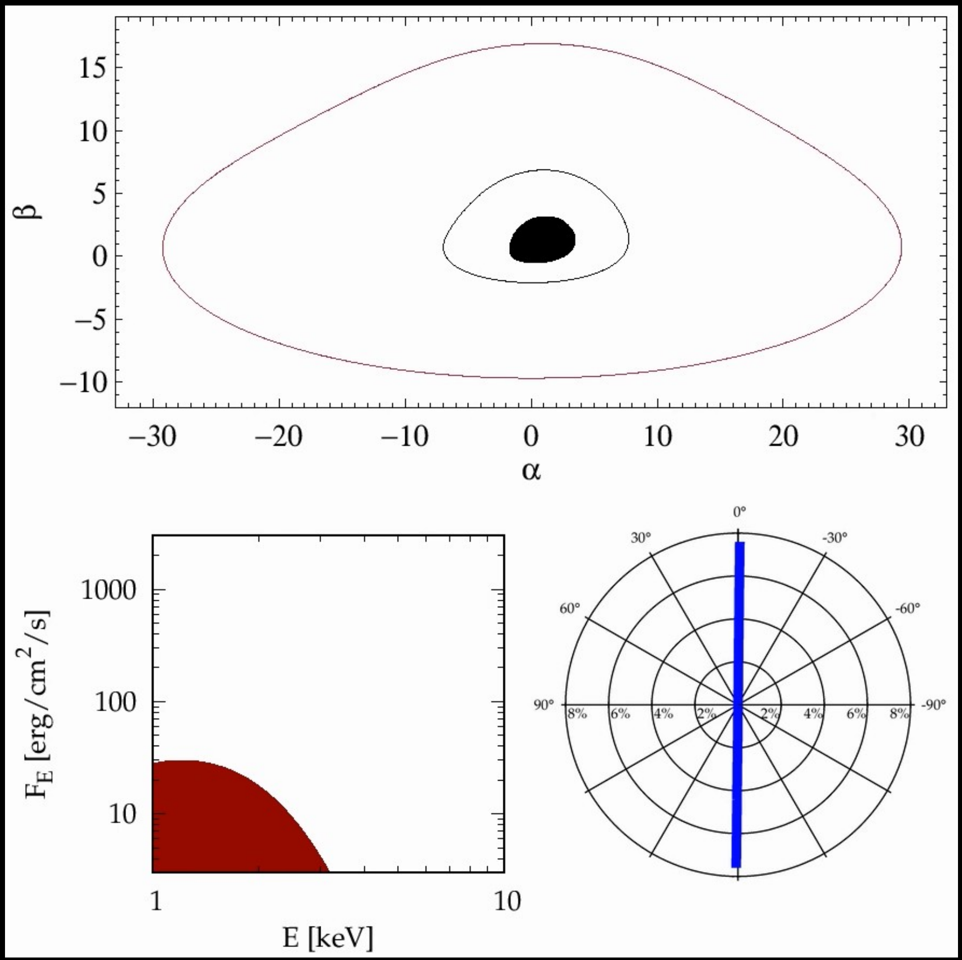
↓

rotation of the polarization angle with energy



Connors+80

The BH spin (soft state)



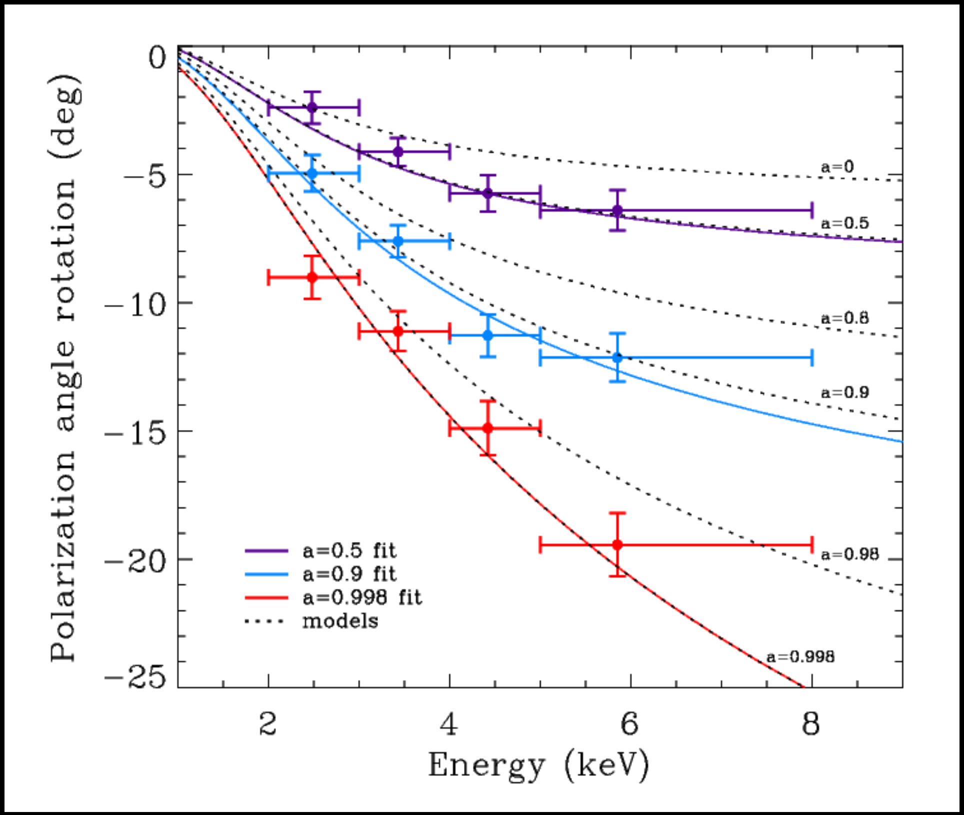
Courtesy: Michal Dovciak

Harder photons comes from 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 compact source

The BH spin (soft state)

200 ks IXPE observation of GRS1915+105



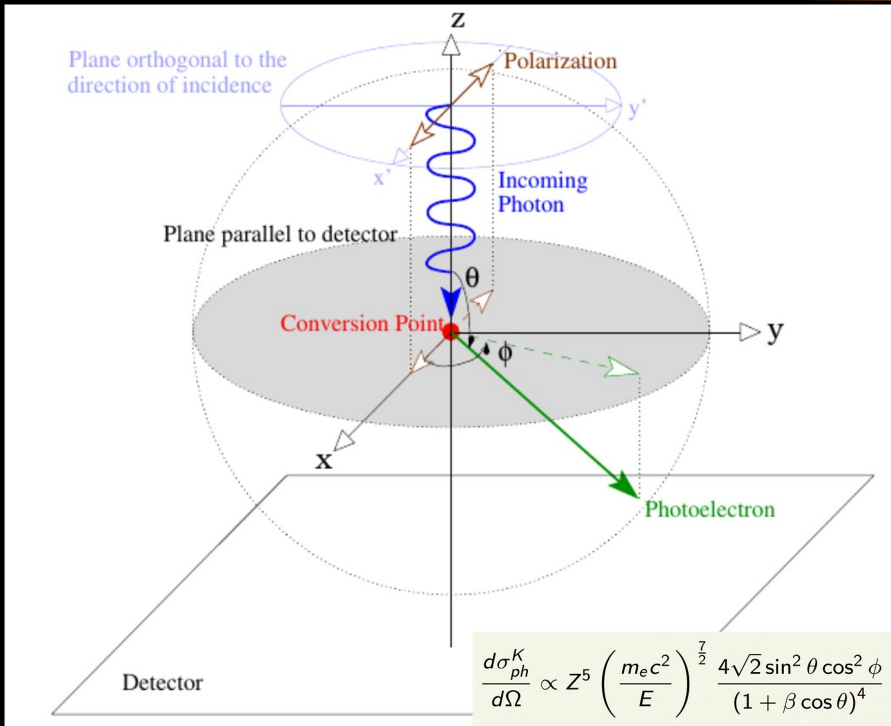
(adapted from Dovciak+09)

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

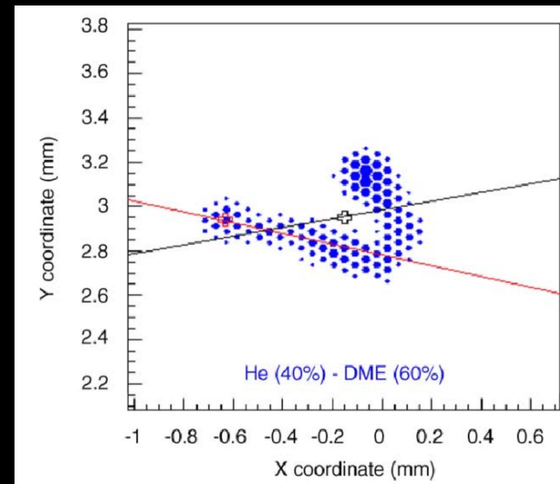
The effect is stronger for a Kerr BH, because the disk gets closer to the compact source

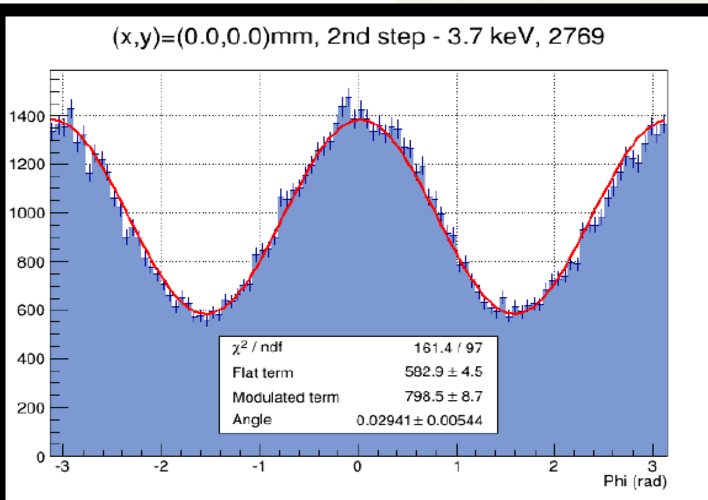
Future instruments

The photoelectric polarimeter

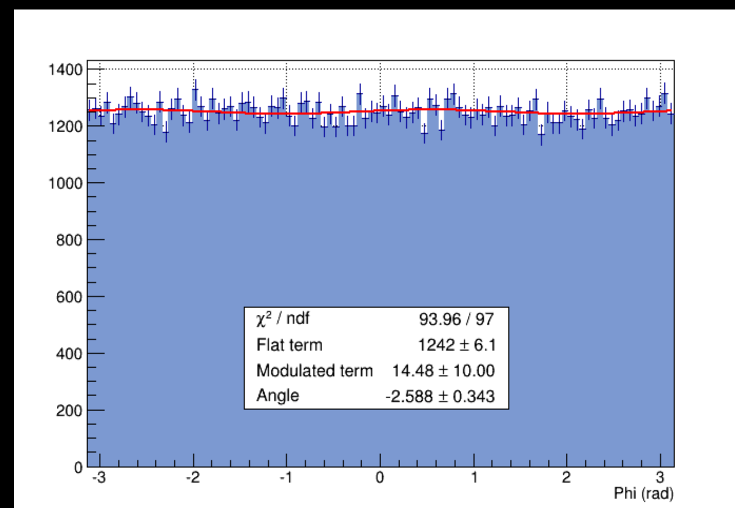


$$\frac{d\sigma_{ph}^{K}}{d\Omega} \propto Z^5 \left(\frac{m_e c^2}{E}\right)^{\frac{7}{2}} \frac{4\sqrt{2}\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$





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



Residual modulation for unpolarized photons.

Future instruments - IXPE

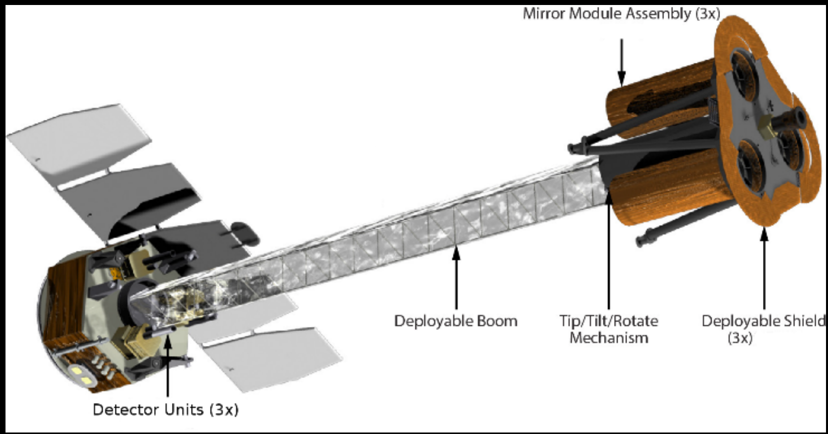
Polarisation sensitivity	1.8 % MDP for $2x10^{-10}$ erg/s cm^2 (10 mCrab) in 300 ks (CBE)
Spurious polarization	<0.3 %
Number of Telescopes	3
Angular resolution	28'' (CBE)
Field of View	12.9x12.9 $arcmin^2$
Focal Length	4 meters
Total Shell length	600 mm
Range Shell Diameter	24 shells, 272-162 mm
Range 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
	Accuracy 150 μs
Operational phase	2 yr
Energy range	2-8 keV
Background (req)	$5x10^{-3}$ c/s/cm2/keV/det
Sky coverage, Orbit	50 %, 540 (0^o)

IXPE
(Imaging X-ray Polarimetry Explorer)

Selected by NASA (SMEX) for a launch in Nov. 2020

P.I.: Martin Weisskopf (MSFC)

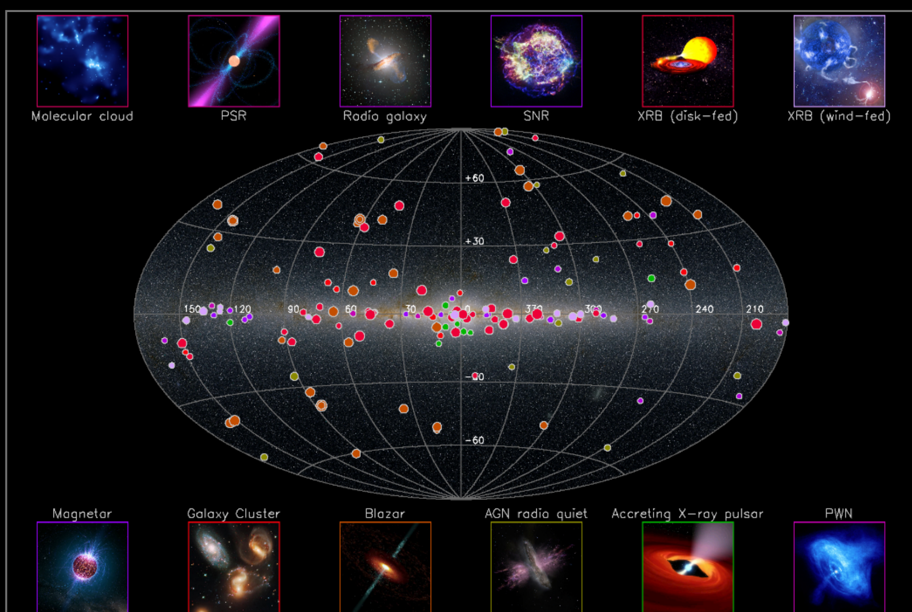
It will re-open the X-ray polarimetry window!

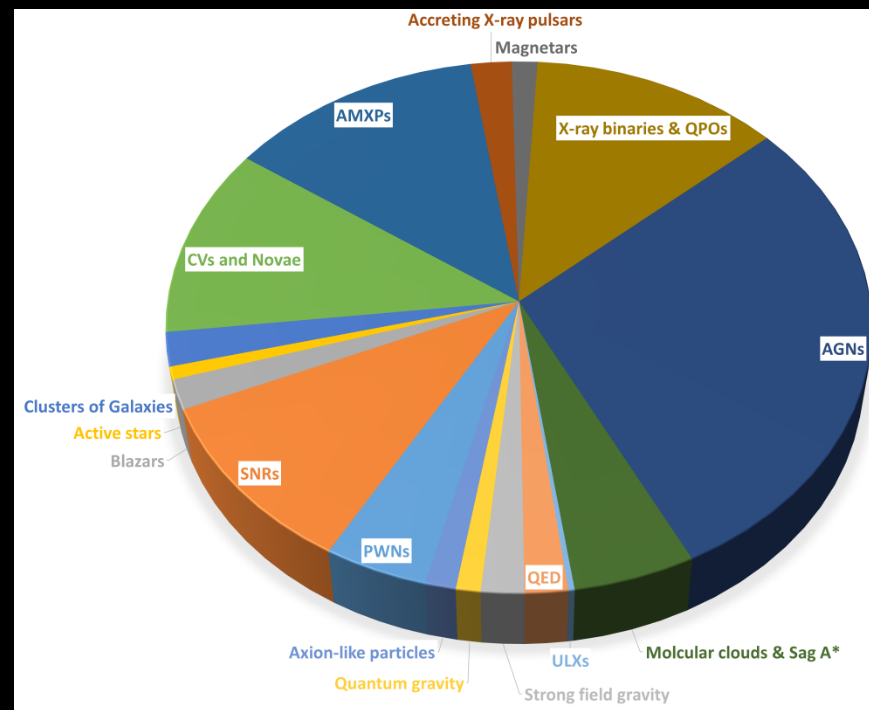


Future instruments - XIPE

XIPE (X-ray Imaging Polarimetry Explorer). ***Selected by ESA (M4) for phase A study. Final selection: July 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

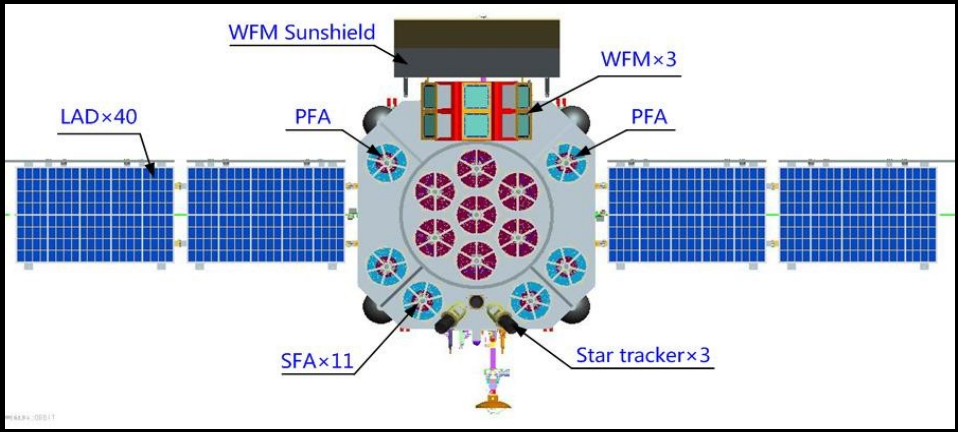




Future instruments - eXTP

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)