Studying accreting compact objects with X-ray polarimetry

Giorgio Matt
(Università Roma Tre, Italy)

X-ray polarimetry so far

Polarimetry has proved very important in radio, IR and optical bands.

In X-rays, where non-thermal processes and aspherical geometries are likely to be more common than at lower energies, polarimetry is expected to be crucial to fully understand emitting sources.

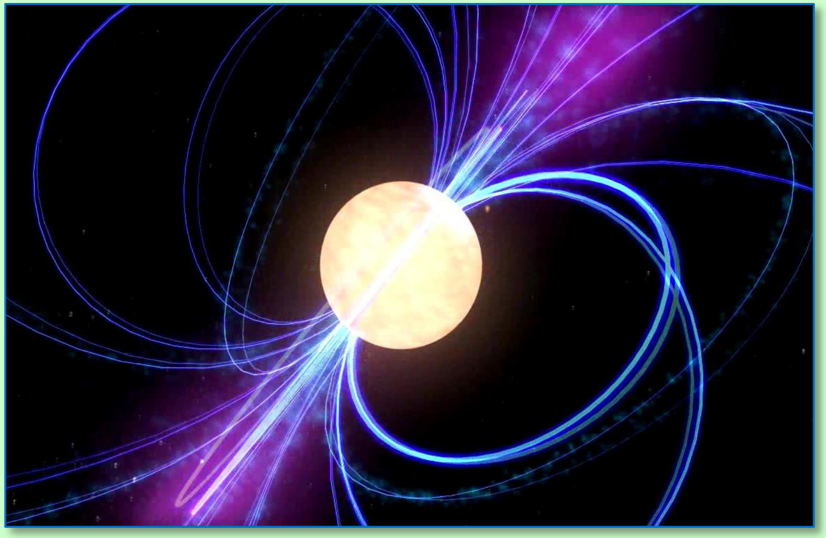
However, only one measurement (P=19% for the Crab Nebula) has been obtained so far, along with a tight upper limit to Sco X-1. These measurements date back to the 70s, for the two brightest sources in the X-ray sky.

The lack, for many decades, of significant technical improvements implied that no polarimeters were put on board of X-ray satellites. The situation has changed with the advent of polarimeters based on the photoelectric effect. Such detectors, coupled with a X-ray telescope, may provide astrophysically interesting measurements for hundreds of sources, belonging to all major classes of X-ray sources are now accessible!

Among them, accreting magnetized neutron stars and accreting black hole systems are among the most interesting

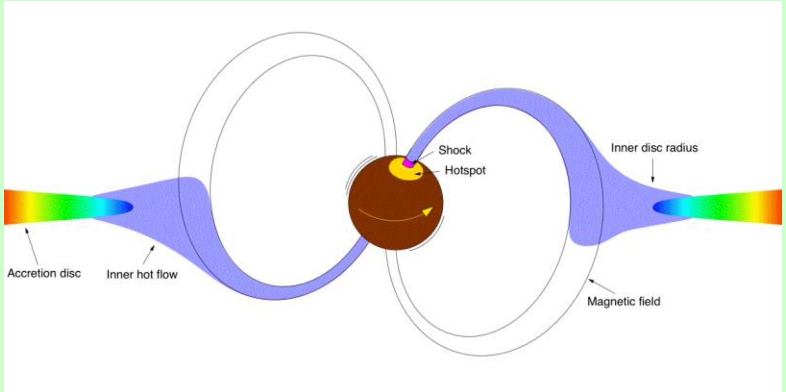
Accreting magnetized neutron stars

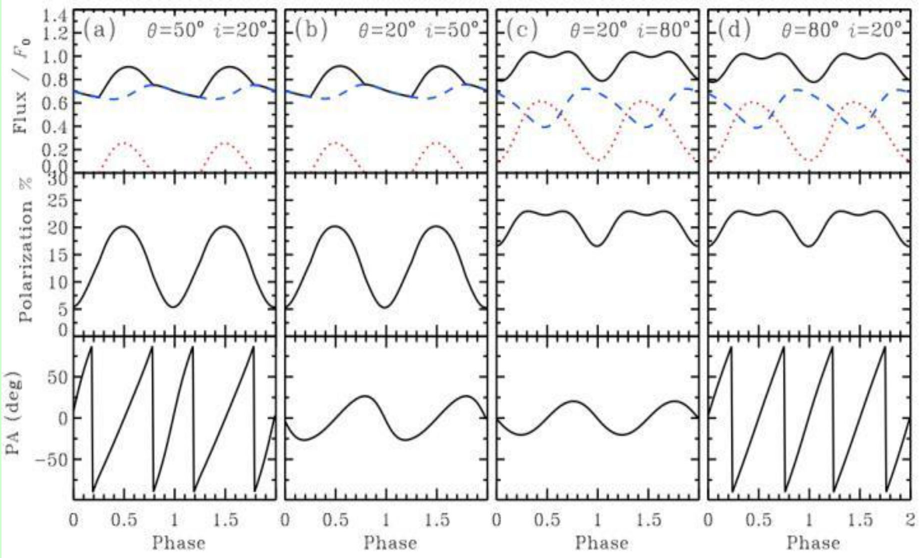
Millisecond pulsars



Accreting X-ray pulsars

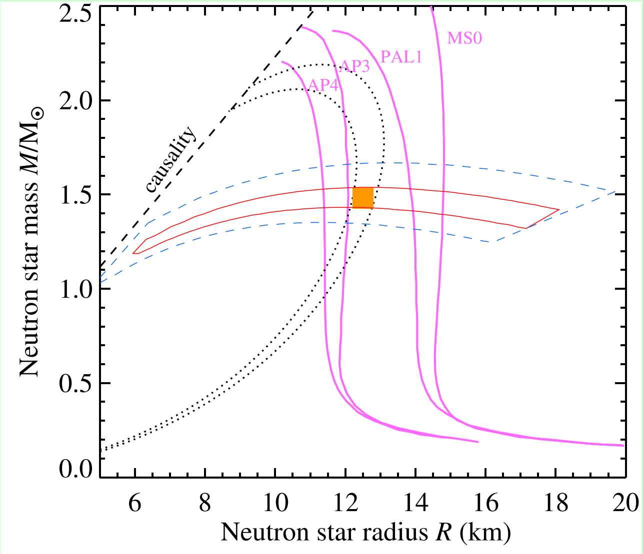
Millisecond Pulsars





Viironen & Poutanen 2004

Emission due to scattering in hot spots
⇒ Phase-dependent linear polarization



Polarization measurements contrain the geometrical parameters of the system. When combined with spectral and timing measurements from e.g. NICER and ATHENA, the EoS of the NS can be constrained

Accreting X-ray Pulsars

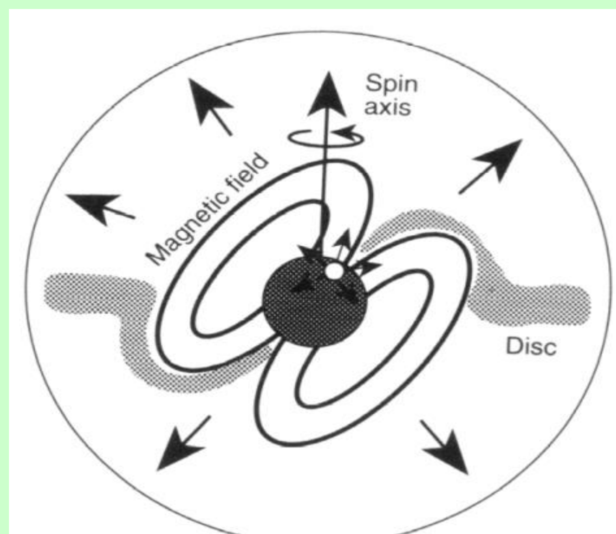
Opacity in highly magnetized plasma

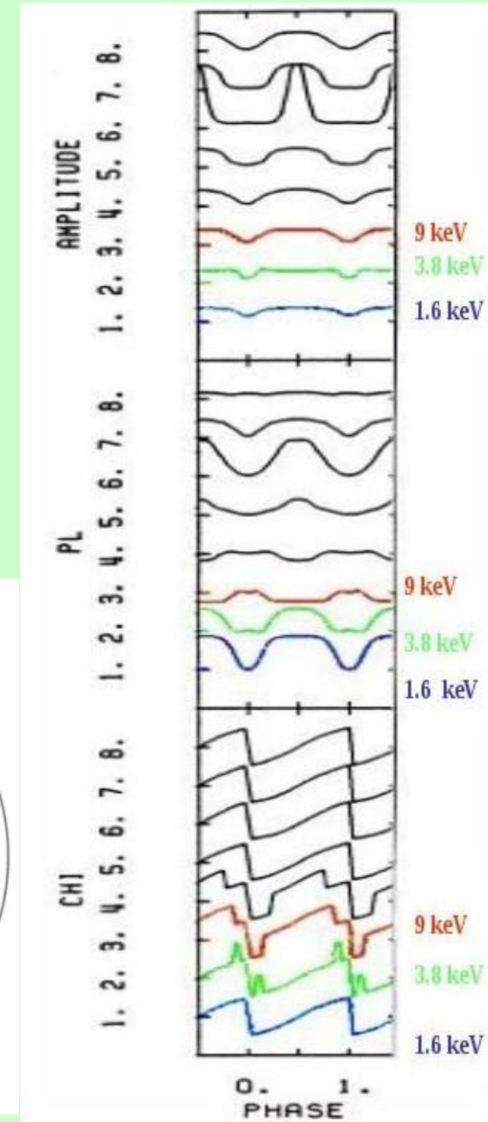
$\Rightarrow \quad k_\perp \neq k_\parallel$

Phase-dependent linear polarization

From the (phase-resolved) swing of the polarisation angle:

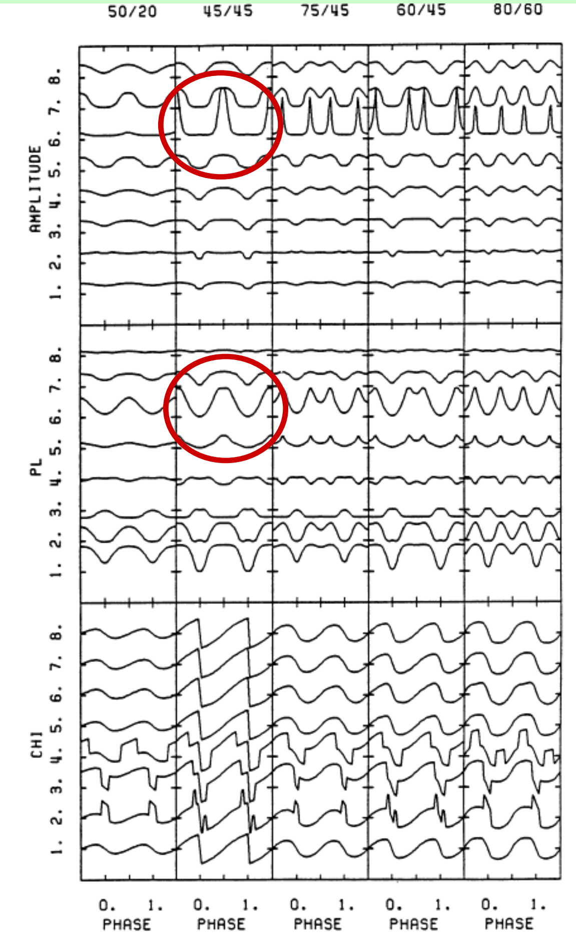
orientation of the rotation axis and inclination of the magnetic field (required for many purposes, e.g. measure of mass/radius relation)

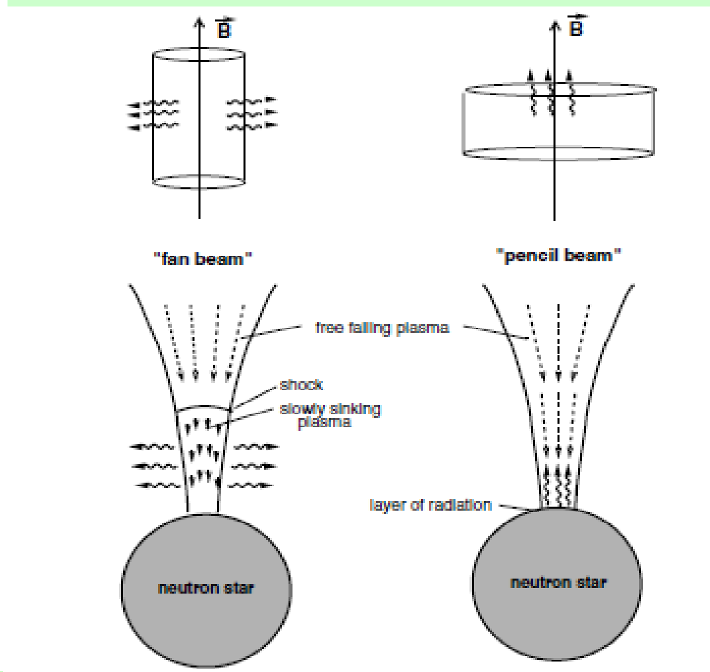


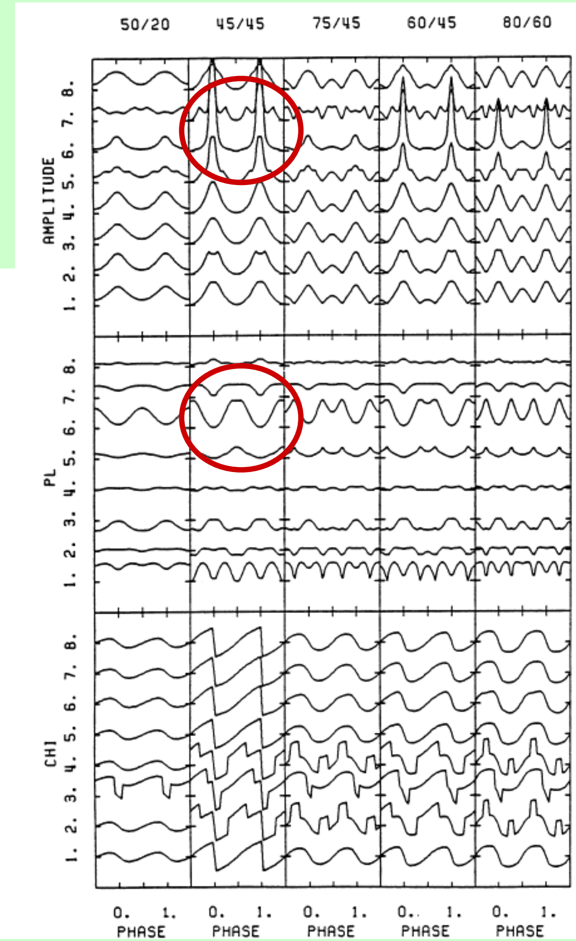


Meszaros et al. 1988

Accreting X-ray Pulsars



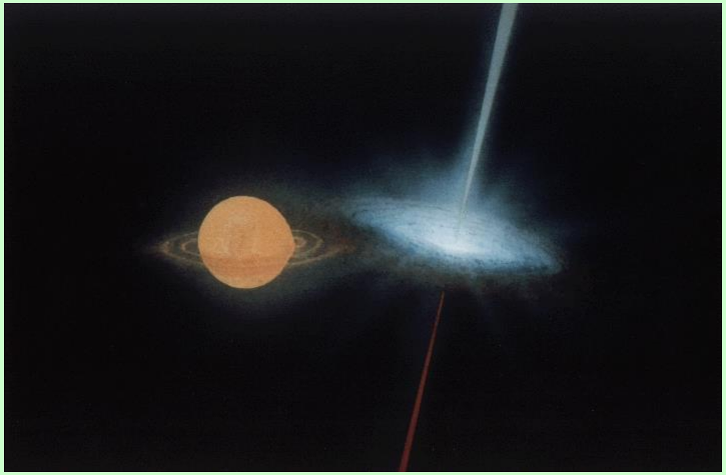


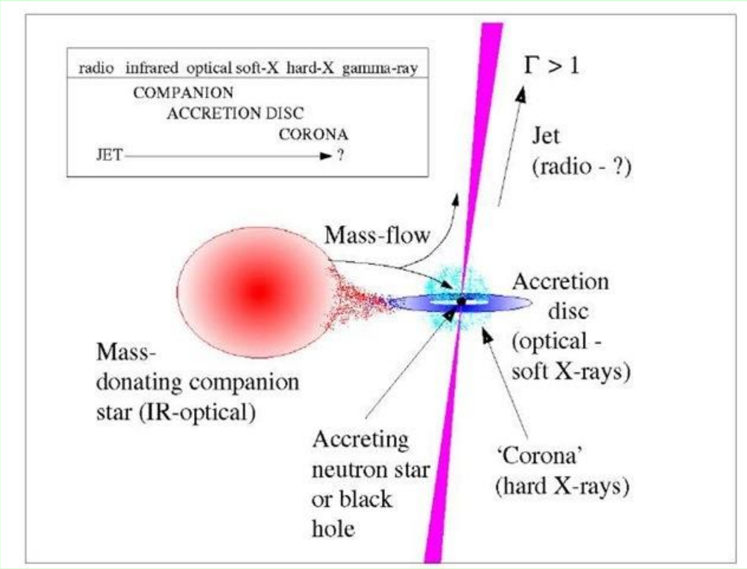


Meszaros et al. 1988

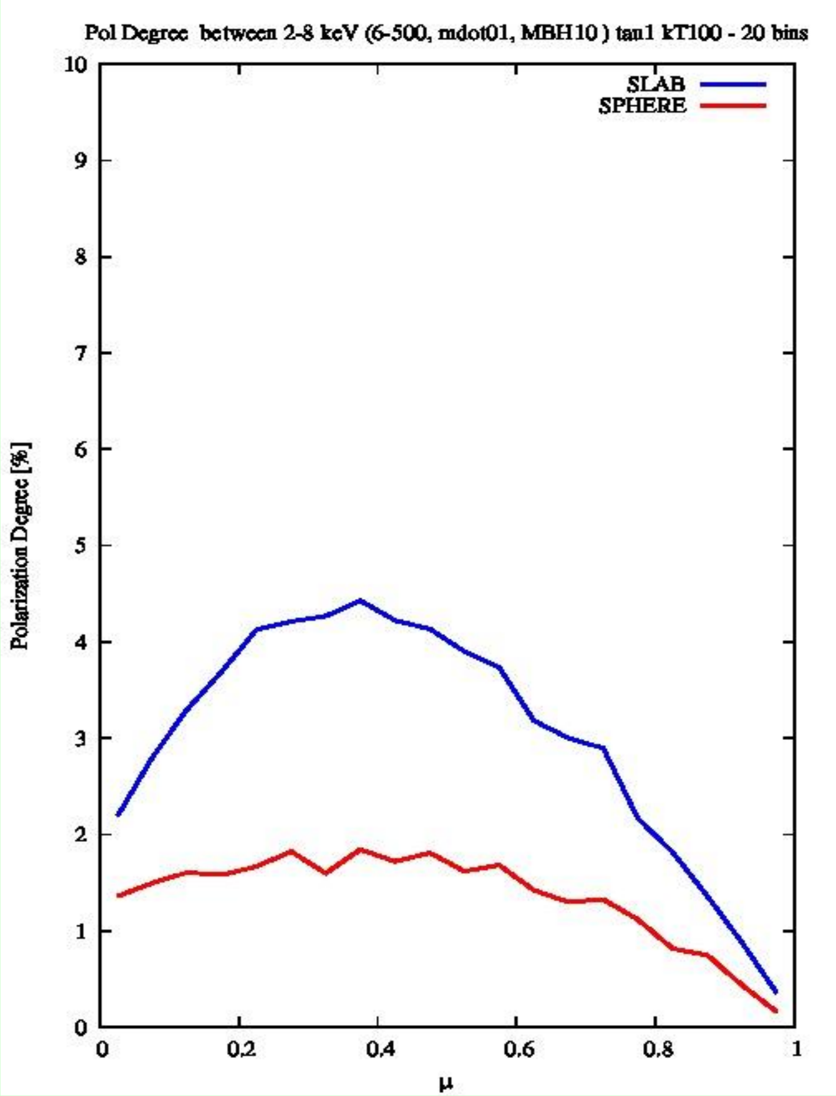
Accreting black hole systems

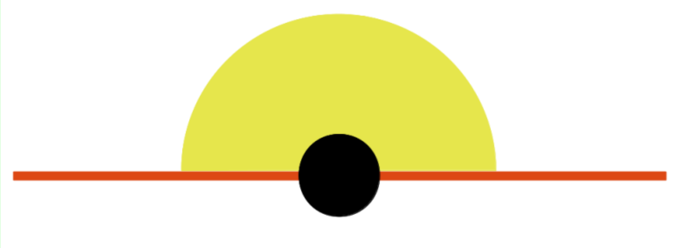
- The geometry of the corona
- The role of the jet
- The spin of the black hole





The geometry of the corona (hard state)

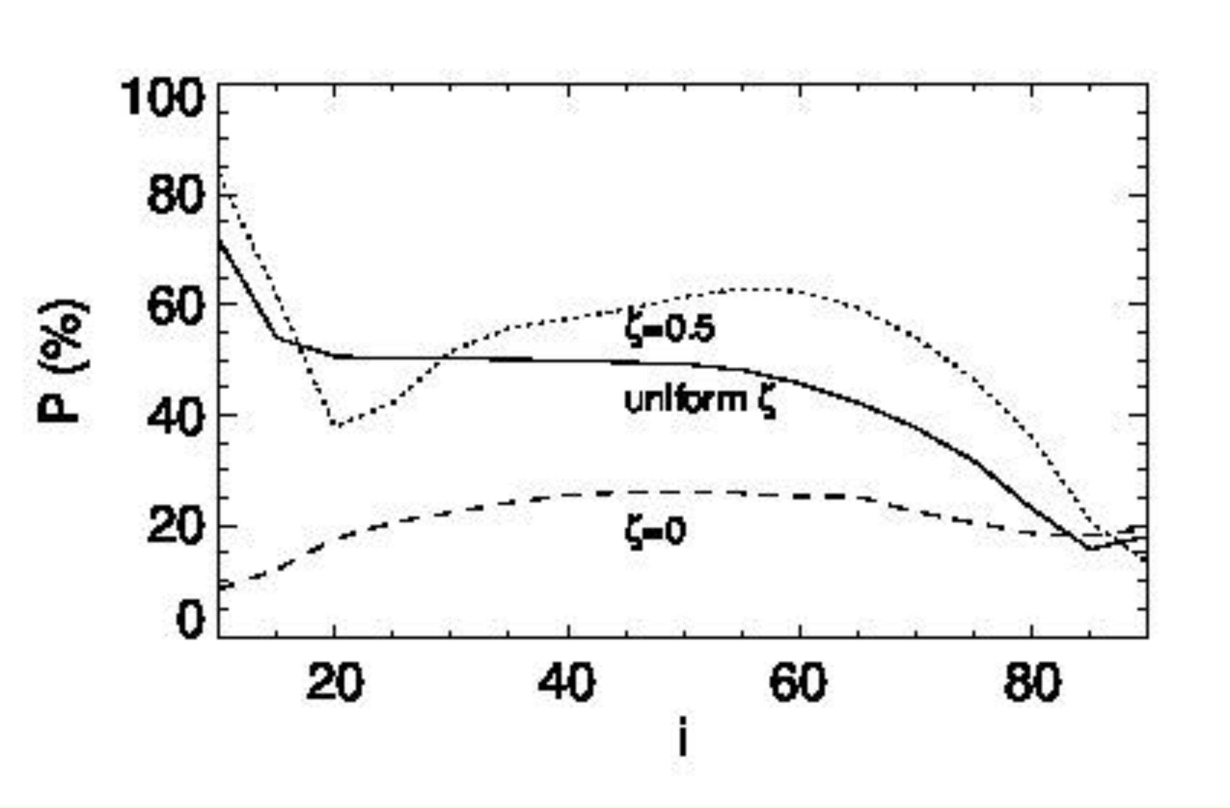




If the emission is due to Comptonization of the disc thermal photons in a hot corona, polarimetry can constrain the geometry of the corona

Courtesy: Francesco Tamborra

The role of the jet (hard state)

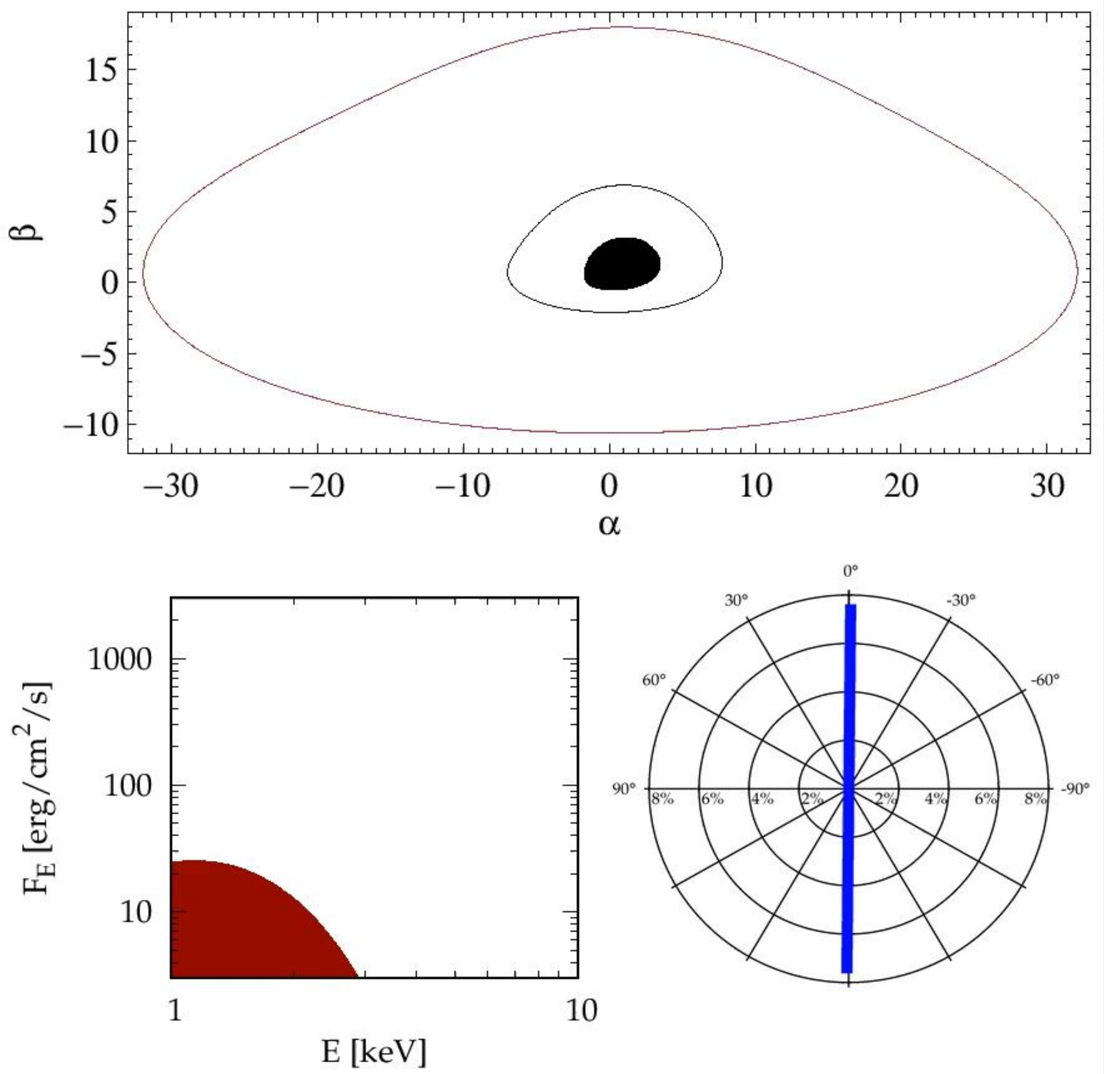


Corona emission is predicted to be less than 10%.

Much larger polarization degrees are expected for jet emission

McNamara et al. 2009

The spin of the black hole (soft state)



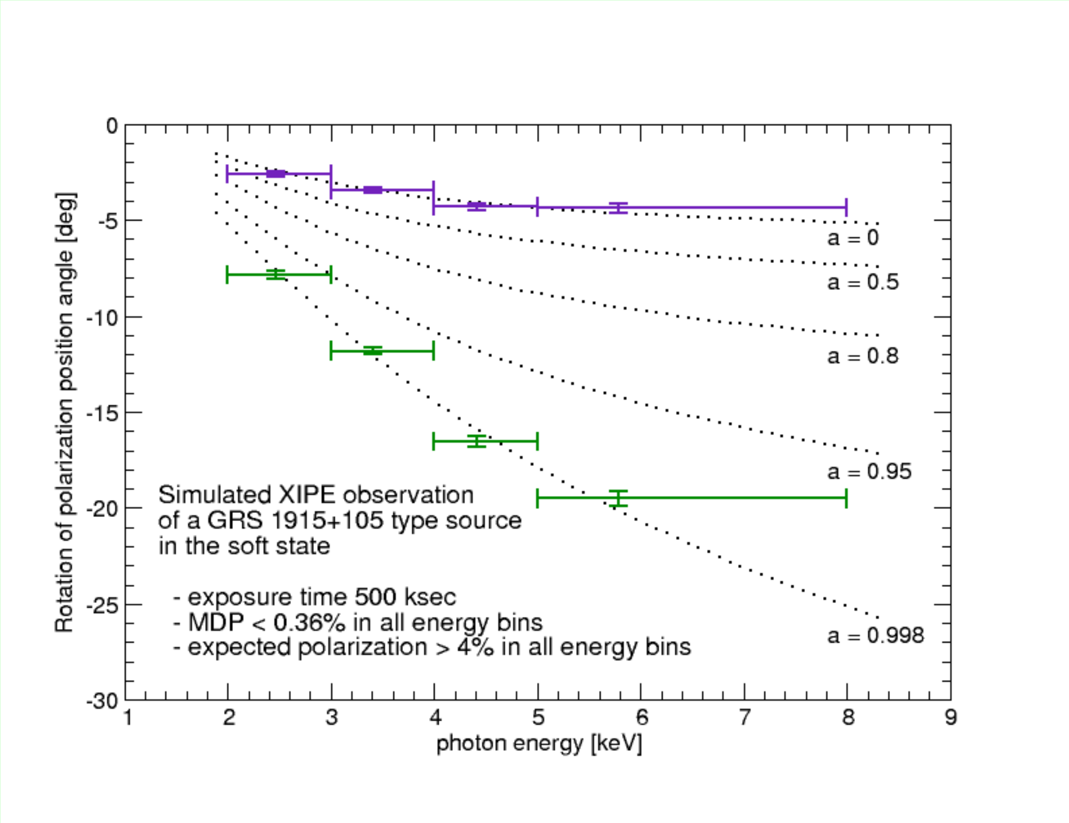
General Relativity modifies the polarization properties of the radiation emitted close to the black hole. In particular, the polarization angle rotates with respect to the Newtonian value.

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

→ rotation of the polarization angle with energy

Courtesy: Michal Dovciak

Accreting black hole systems



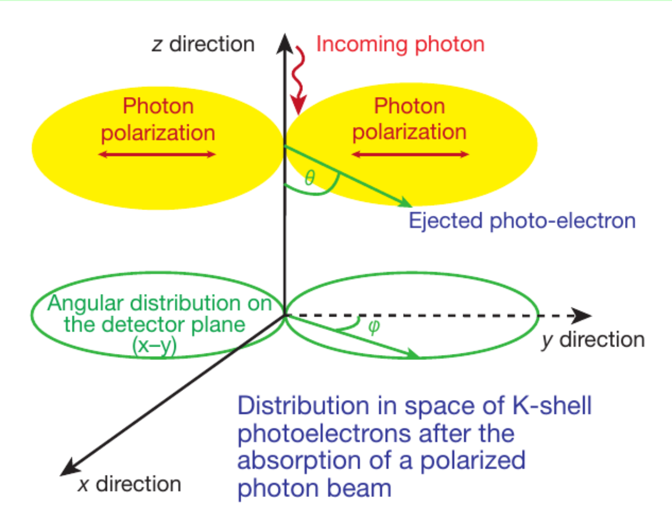
e.g. Dovciak et al. 2009

General Relativity modifies the polarization properties of the radiation emitted close to the black hole. In particular, the polarization angle rotates with respect to the Newtonian value.

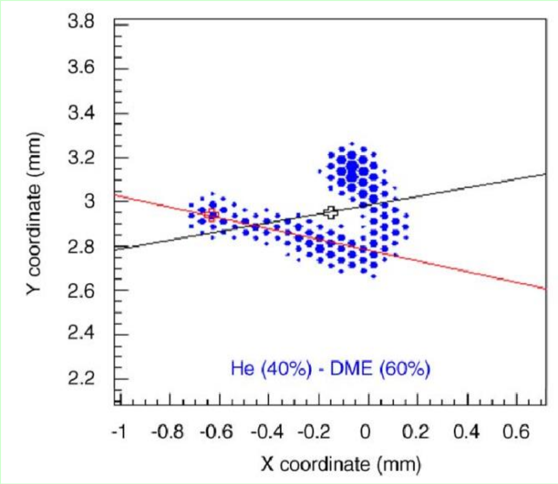
The effect increases with decreasing radii, i.e. with increasing temperature, i.e. with increasing photon energy

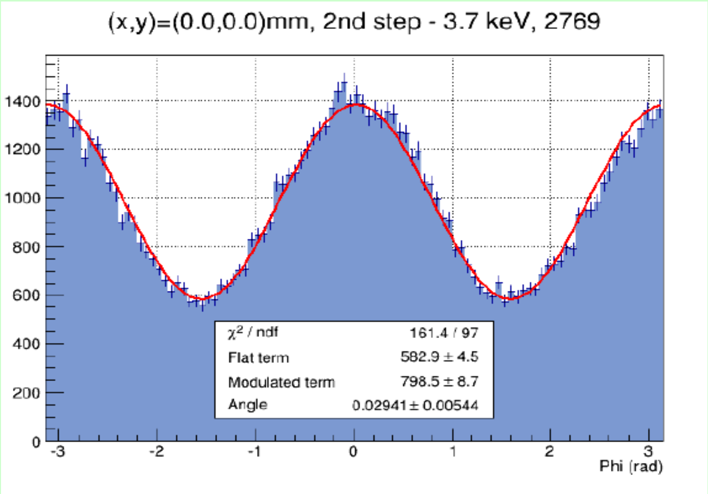
→ rotation of the polarization angle with energy.

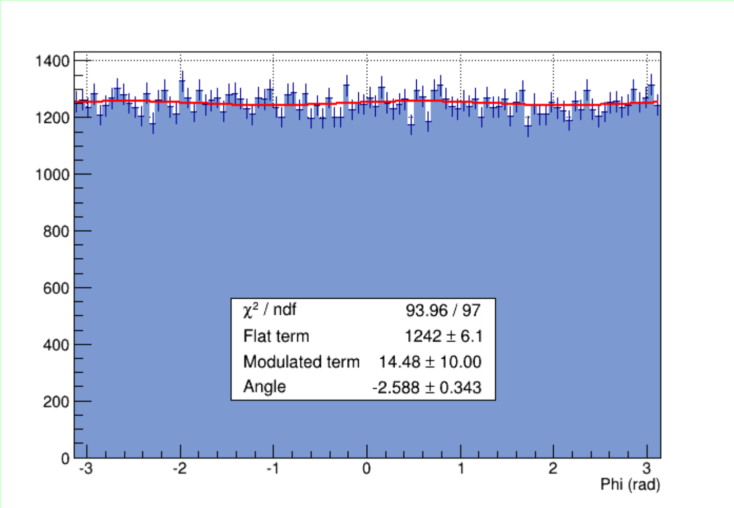
The photoelectric polarimeter



$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$







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

Residual modulation for unpolarized photons.

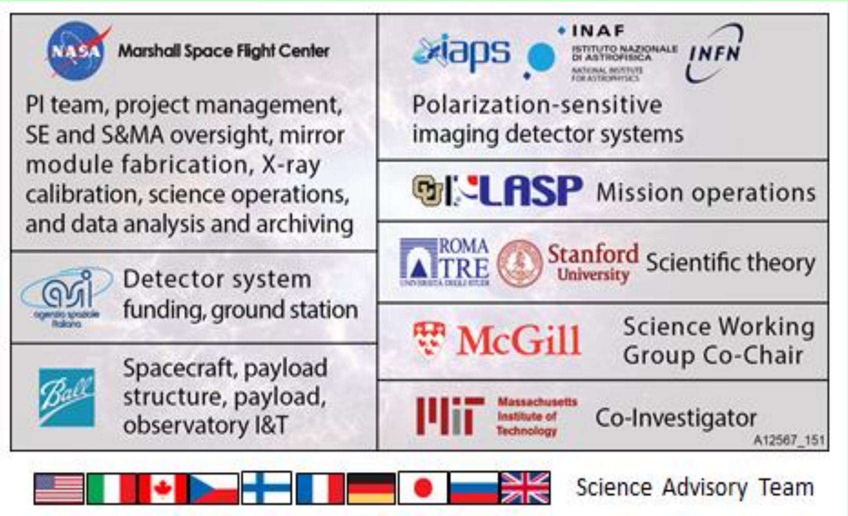
IXPE

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!

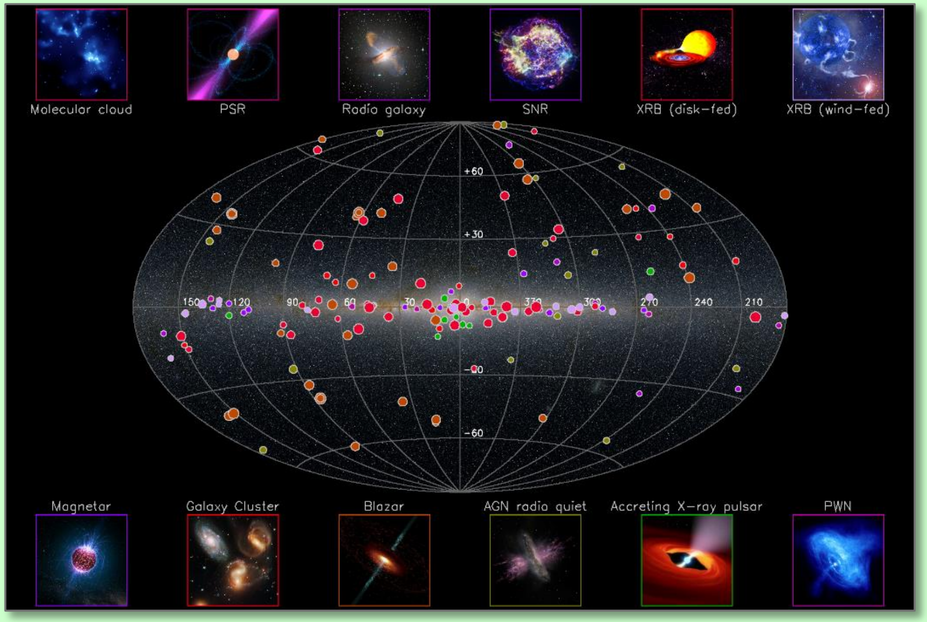


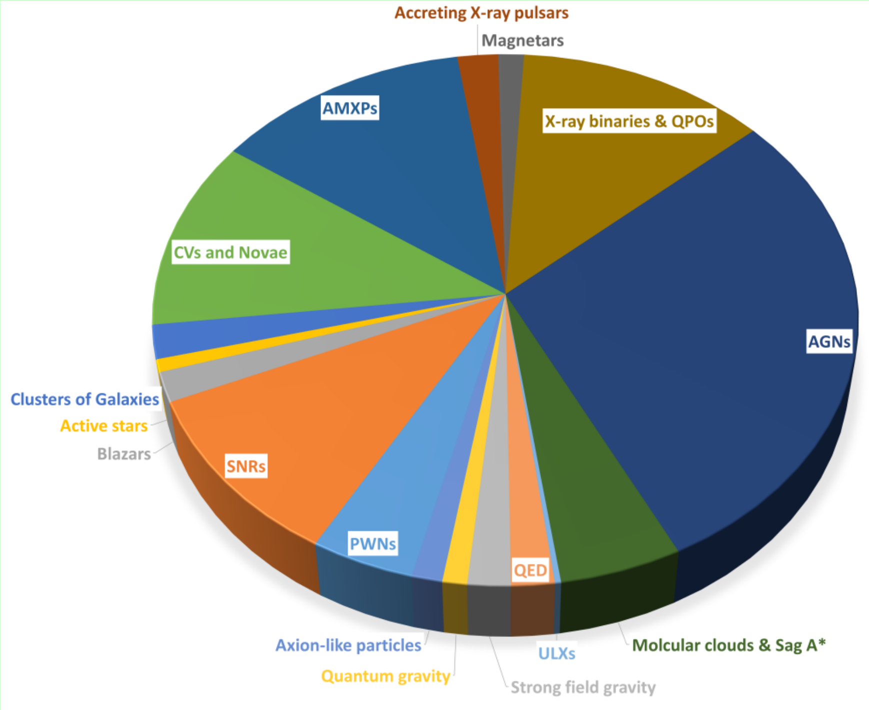
Polarisation sensitivity	1.8 % MDP for $2x10^{-10}$ erg/s cm^2 (10 mCrab) in 300 ks (CBE)
Spurious polarization	<0.3 %
Number of Telescopes	3
Angular resolution	28” (CBE)
Field of View	12.9x12.9 $arcmin^2$
Focal Length	4 meters
Total Shell length	600 mm
Range Shell Diameter	24 shells, 272-162 mm
Range 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)

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

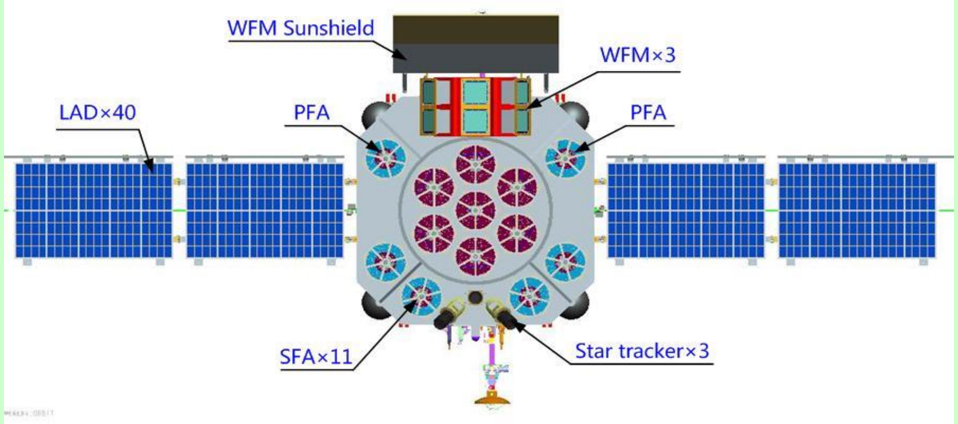




eXTP

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