X-ray polarimetry - a new window on black hole systems

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(on behalf of the XIPE collaboration)

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New Frontiers in Black Hole Astrophysics

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The X-ray Imaging Polarimetry Explorer under phase A study

Scientific objectives: what we want to observe and why

A **large** number of scientific topics and observable sources:

Astrophysics

- **Acceleration phenomena**
  - Pulsar wind nebulae
  - SNRs
  - Jets
- **Emission in strong magnetic fields**
  - Magnetic cataclysmic variables
  - Accreting millisecond pulsars
  - Accreting X-ray pulsars
  - Magnetars
- **Scattering in aspherical situations**
  - X-ray binaries and AGN
  - X-ray reflection nebulae

Fundamental Physics

- **Matter in Extreme Magnetic Fields:**
  - QED effects
- **Matter in Strong Gravity Fields:**
  - GR effects close to accreting BHs
- **Quantum Gravity**
- **Search for axion-like particles**

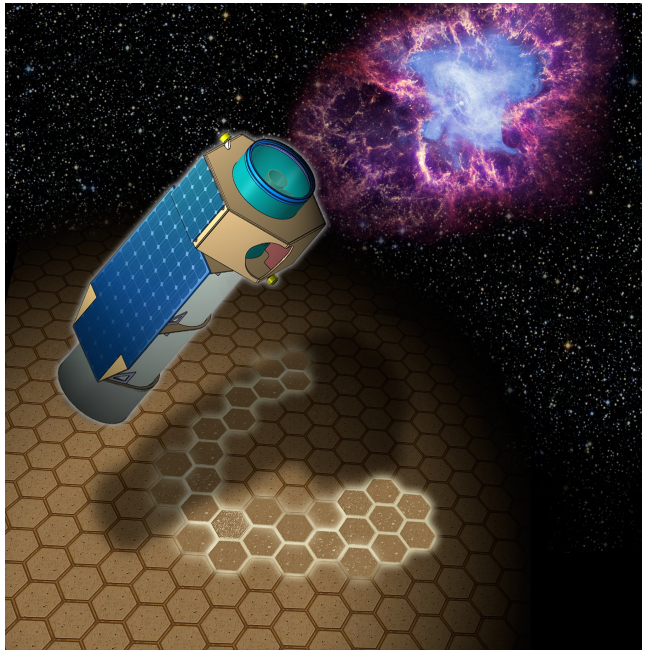
XIPE is going to observe **almost all classes of X-ray sources**.

After peer-review, ESA selected XIPE for a phase A study.

→ We have put a structure of scientific working groups in place

Goal: the Yellow Book for XIPE

→ More than **300 supporting scientists** signed up to participate in the working groups!



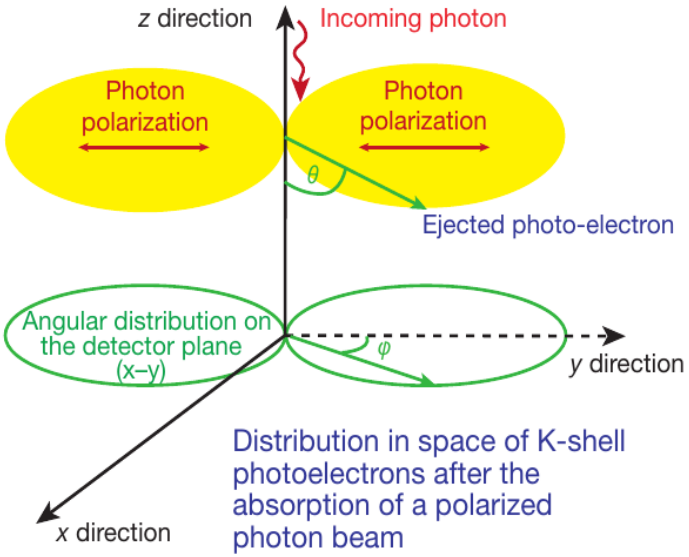
Why it is now possible to conduct X-ray polarimetry

The Gas Pixel Detector

We developed at this aim a polarization-sensitive instrument capable of imaging, timing and spectroscopy

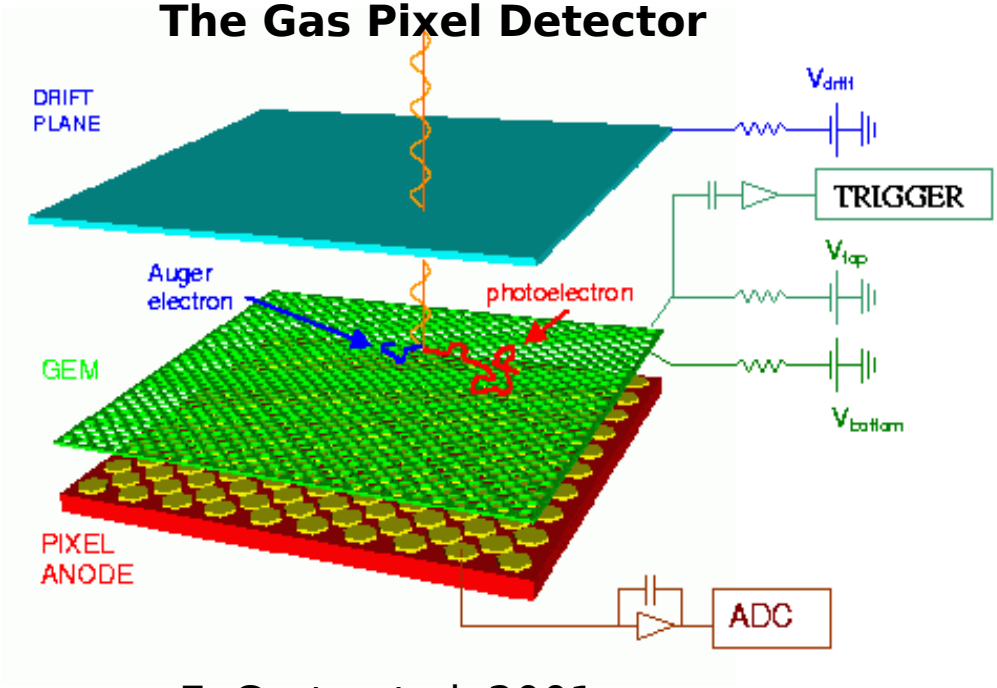
The photoelectric effect

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



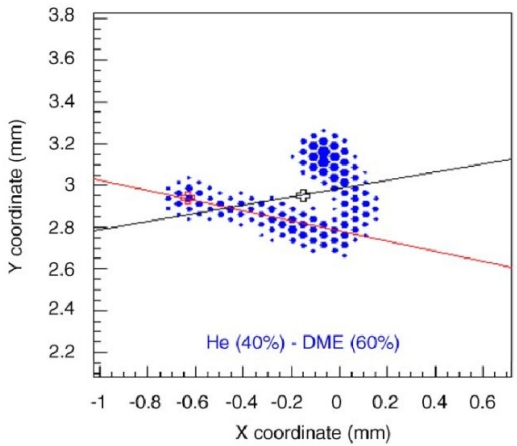
The direction of the ejected photo-electron is statistically related to the polarization of the absorbed photon.

The Gas Pixel Detector

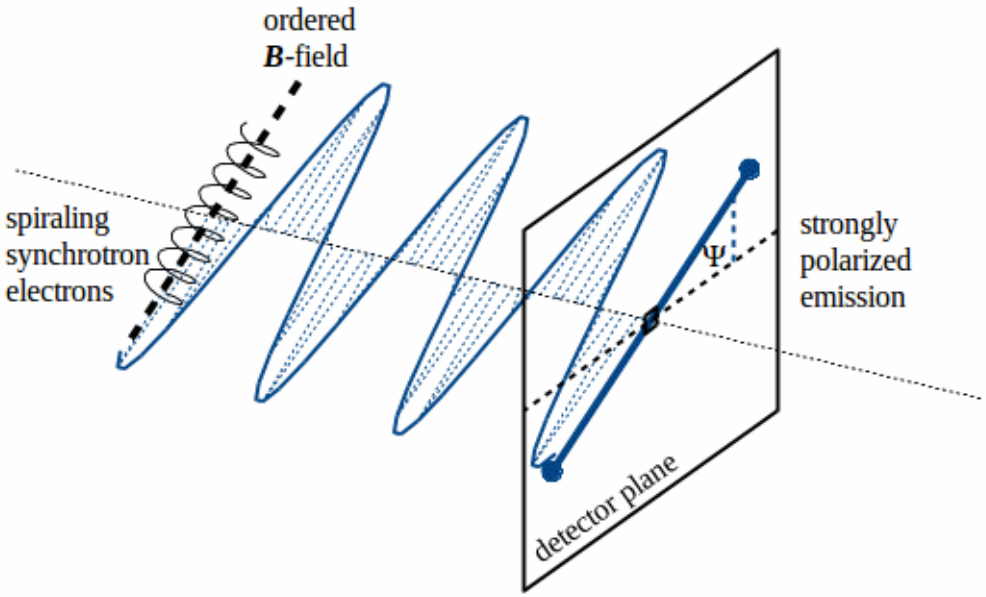


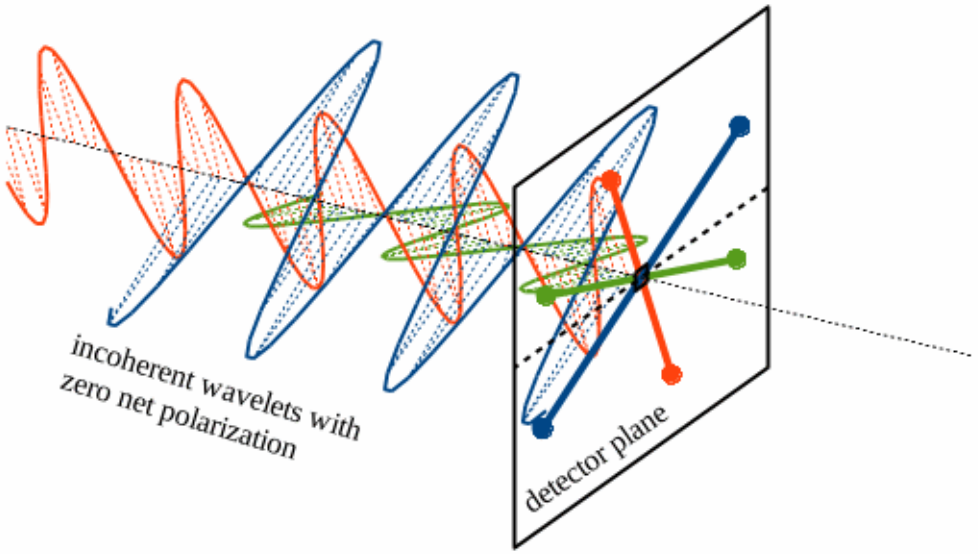
E. Costa et al. 2001

Image of a real photoelectron track. The use of the gas allows to resolve tracks in the X-ray energy band.



Linear polarization states of coherent and incoherent emission





Coherent, strongly polarized emission as expected from synchrotron radiation produced in a highly-ordered magnetic field.

Incoherent, weakly polarized radiation produced by a superposition of incoherent sources, such as turbulent magnetic fields emitting synchrotron emission.

Precesses producing X-ray polarization

Synchrotron emission

Electron scattering

Dust (Mie) scattering

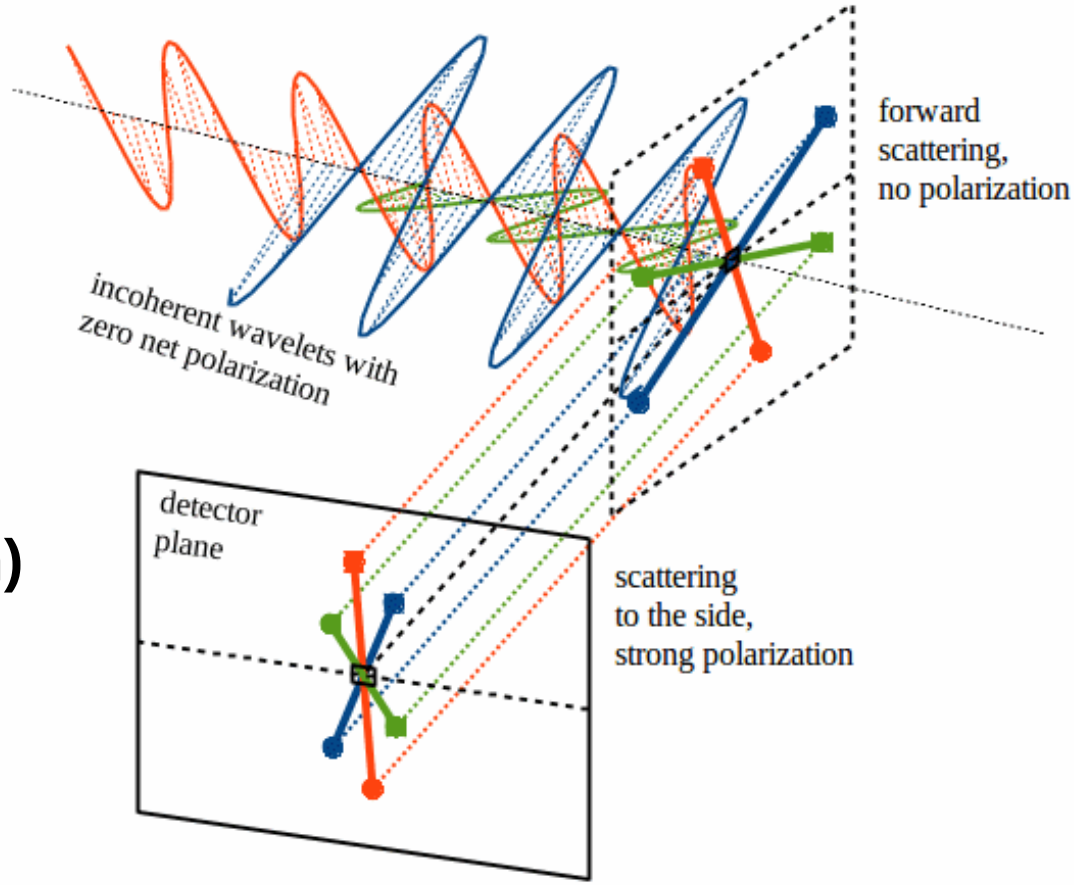
Resonant line scattering

Dichroic absorption

Dilution (by unpolarized radiation)

General Relativity

Birefringence in strong magnetic fields



Scattering

Strong polarization: Θ = 90° (Reflection)
Weak polarization: Θ = 0° (Transmission)

$$P = \frac{1-\cos^2\theta}{1+\cos^2\theta}.$$

Oscillator model for Thomson scattering

Acceleration phenomena: Unresolved jets

The origin of the seed photons in extragalactic jets

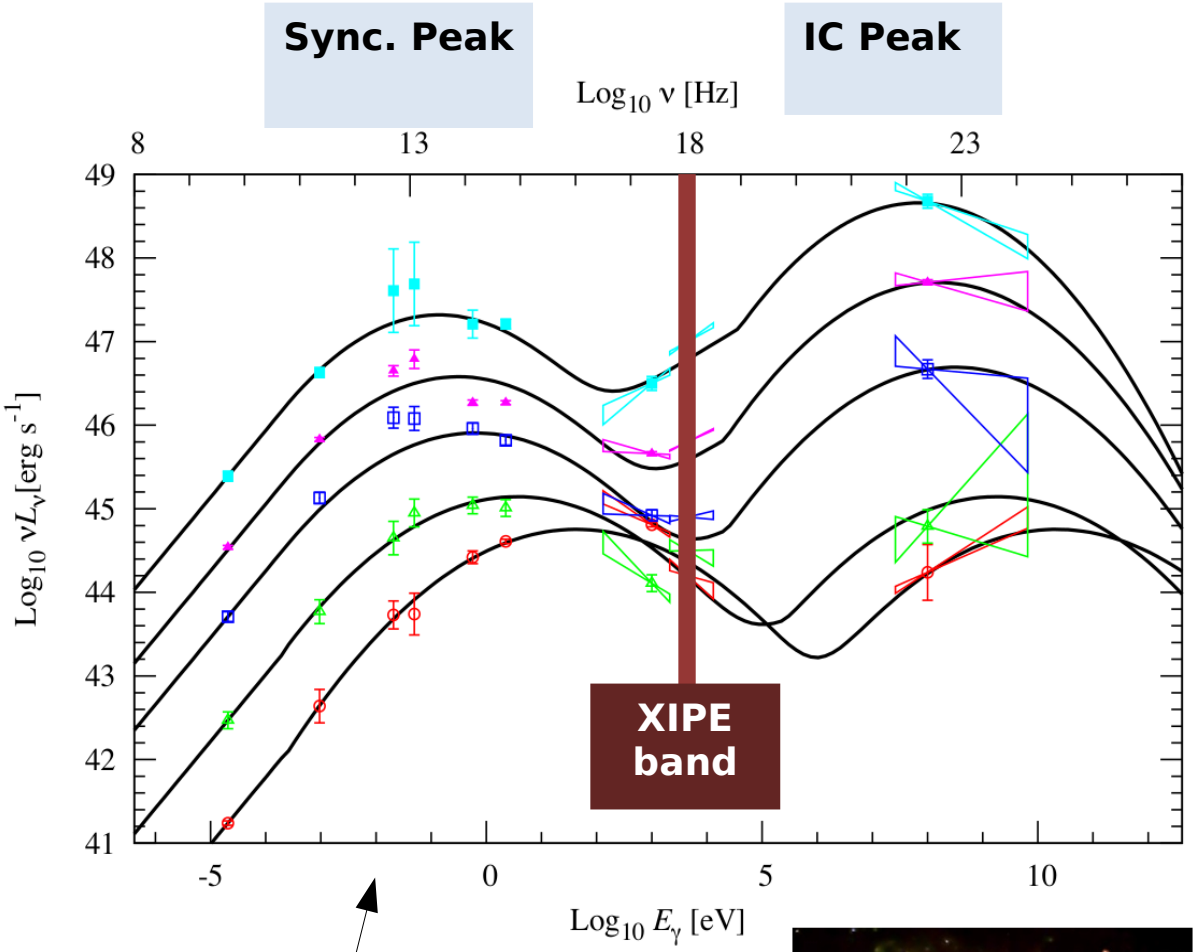
Blazars are extreme accelerators in the Universe, but the emission mechanism is far from being understood.

In inverse Compton dominated Blazars, a XIPE observation can determine the origin of the seed photons:

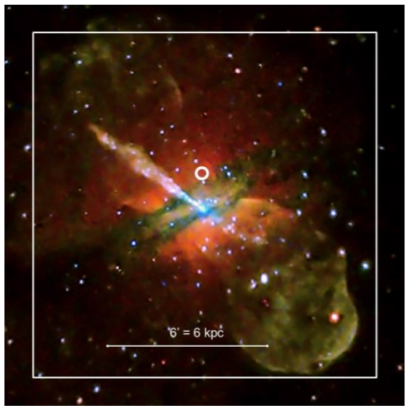
- Synchrotron-Self Compton (**SSC**)? The polarization angle is the same as for the synchrotron peak.
- External Compton (**EC**)? The polarization angle may be different.

The polarization degree determines the electron temperature in the jet.

In synchrotron-dominated X-ray blazars, multi-wavelength polarimetry probes the structure of the magnetic field along the jet.



XIPE (un-)resolved



Was Sgr A* a faint AGN in the past?

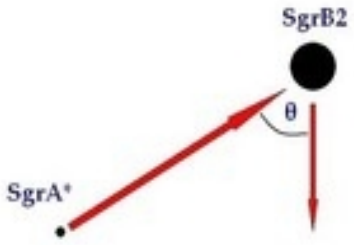
Unique contribution: what lightens up the molecular clouds in Sgr A*?

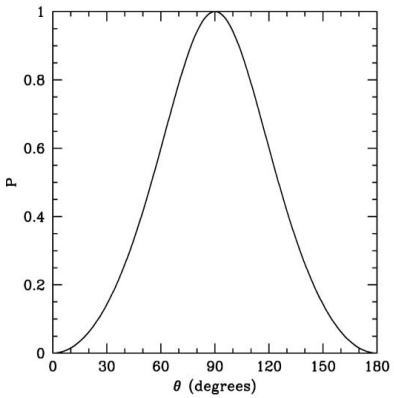
Cold molecular clouds around Sgr A* show a neutral iron line and a Compton bump → Reflection from an external source?

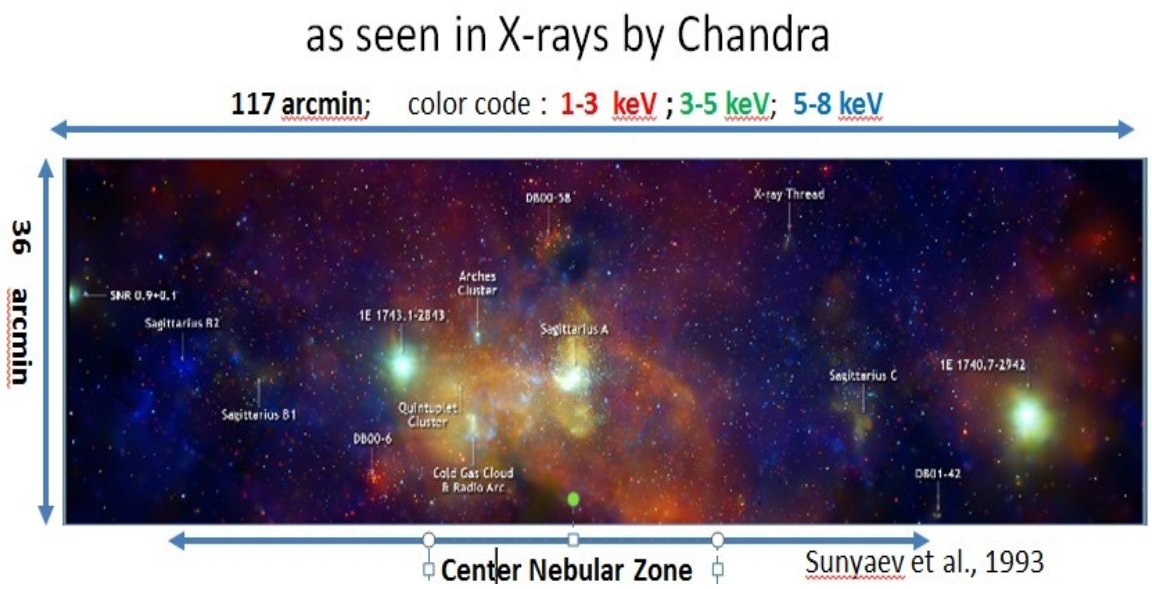
No bright source is there. Are they reflecting X-rays from Sgr A* when it was 10^6 times brighter?

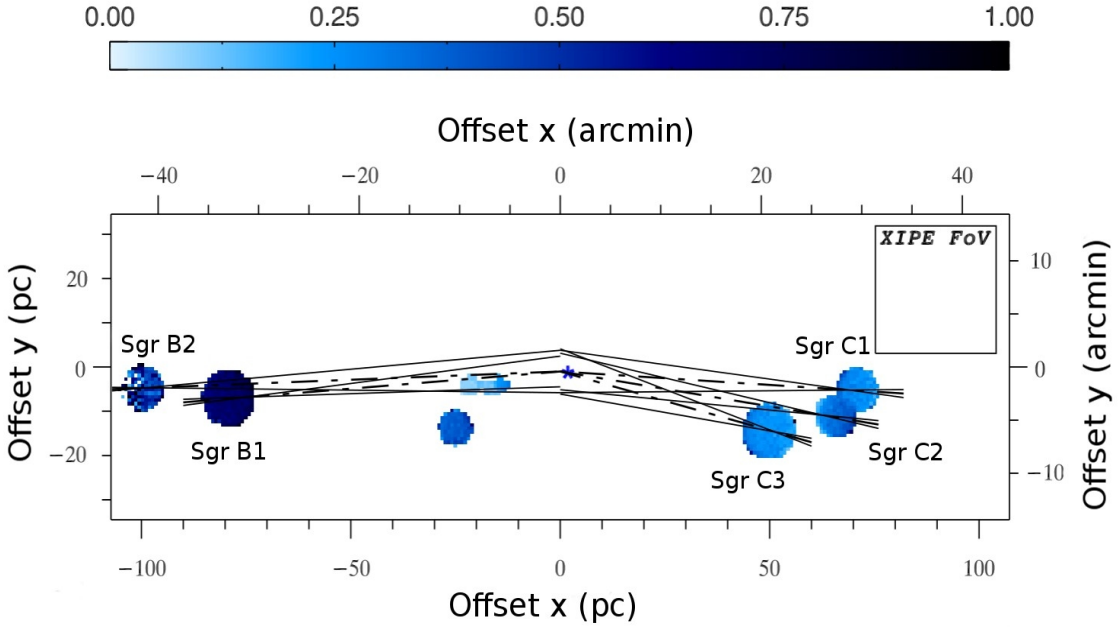
Polarization by scattering from Sgr B complex, Sgr C complex

- The angle of polarization pinpoints the source of X-rays (possibly SgrA*)
- The degree of polarization measures the scattering angle and determines the true distance of the clouds from Sgr A*.





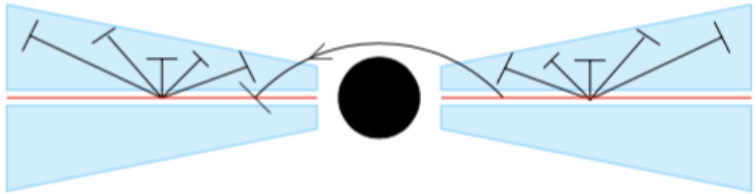


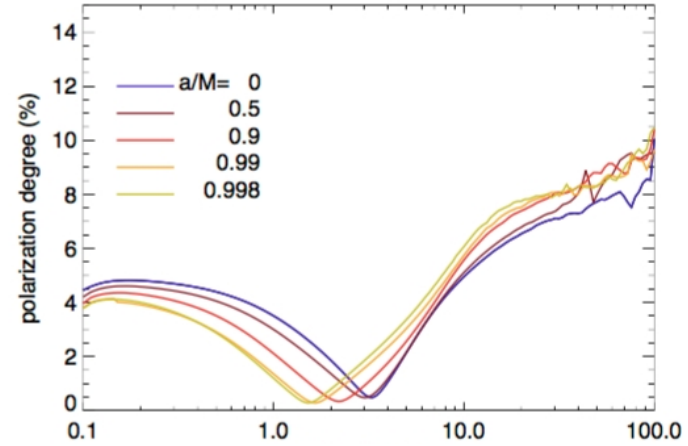


Disentangling the geometry of the hot corona

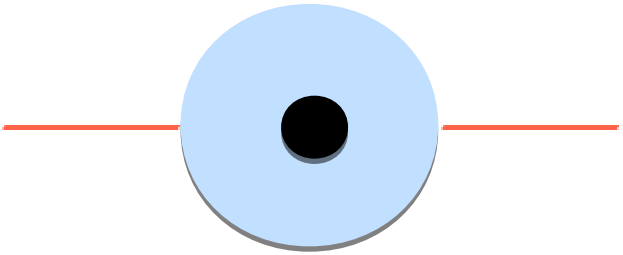
The perturbation by the effects of General Relativity

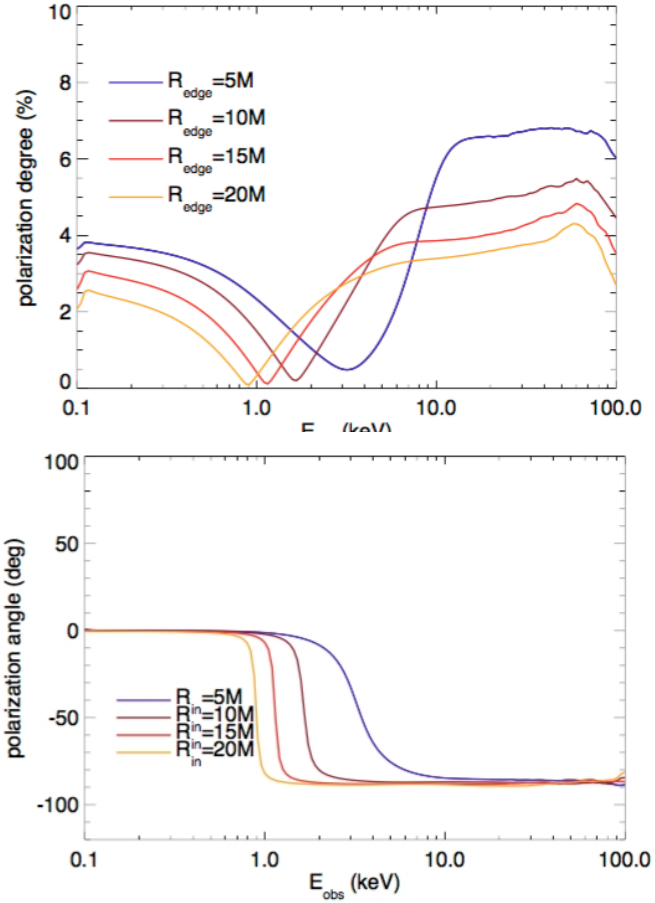
Extended corona above disc





Truncated disc + spherical corona

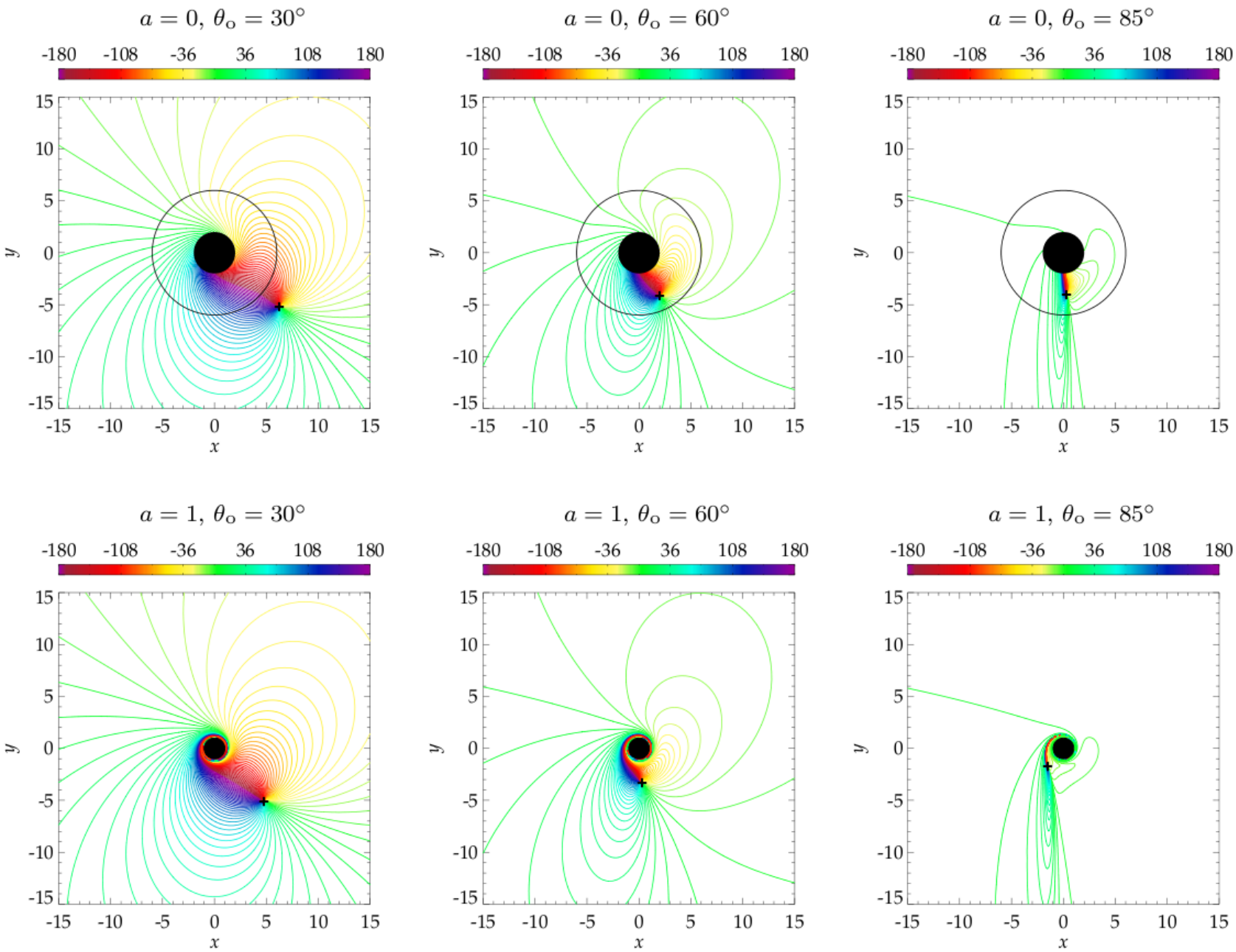




J. Schnittman & J. Krolik

Basic notions of polarization

Spot light on relativistic effects



The observed polarization at infinity is obtained by integrating the transferred local polarization.

This gives a vast range in polarization angle...

Dovčiak et al. (2008), see yesterday's talk by Pauli Pihajoki

Constraining black hole spin with XIPE

Supporting contributions: constraining black hole spin

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

1. Relativistic reflection (still debated, requires accurate spectral decomposition);
2. Continuum fitting (requires knowledge of the BH mass, distance and inclination);
3. QPOs (all three QPOs required to completely determine the parameters).

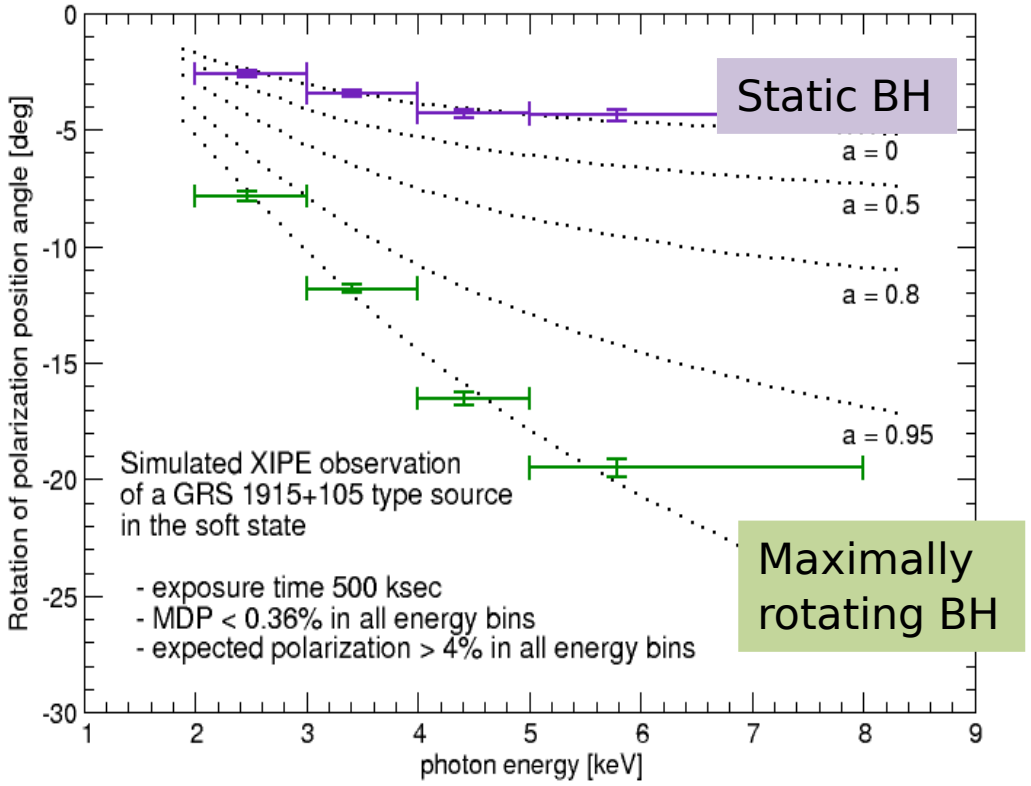
Problem: for a number of XRBs, the methods do not agree!

For GRO J1655-40:

QPO:	$a = J/J_{max} = 0.290 \pm 0.003$
Continuum:	$a = J/J_{max} = 0.7 \pm 0.1$
Iron line:	$a = J/J_{max} > 0.95$

Energy dependent rotation of the X-ray polarization plane

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



Conclusions and reaching out to the (pan-)scientific community

I hope I was able to show that...

- X-ray polarimetry is going to make important unique and supporting contributions to astrophysics and also fundamental physics

- X-ray polarimetry is going to serve a large scientific community involving almost all source types in the high energy domain

If you are interested, do not hesitate to join the mission project of XIPE!

More information can be found here:

http://www.isdc.unige.ch/xipe/