Studying microquasars with X-ray polarimetry

Andrea Marinucci

From quiescence to outburst: when microquasars go wild!

Ile de Porquerolles – 25 September 2017
- 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.
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).

\[ M(\phi) = A + B \cos^2(\phi - \phi_0) \]
\[ P = \frac{M}{\mu} = \frac{1}{\mu} \frac{B}{B + 2A} \]
Introduction - microquasars

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

Zhang+13

Done+07

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Introduction - microquasars

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The role of the jet
The coronal geometry
The BH spin
The coronal geometry (hard state)

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)

Stokes parameters:

$I$ is proportional to the intensity of the polarized component  
$Q$ is related to the angle of polarization
If the emission is due to Comptonization of the disc thermal photons in a hot corona, polarimetry can constrain the geometry of the corona.
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:** \( a = J/J_{\text{max}} = 0.290 \pm 0.003 \)

**Continuum:** \( a = J/J_{\text{max}} = 0.7 \pm 0.1 \)

**Iron line:** \( a = J/J_{\text{max}} > 0.95 \)
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

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The BH spin (soft state)

Harder photons come 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 compact source.

Courtesy: Michal Dovciak

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The BH spin (soft state)

200 ks IXPE observation of GRS1915+105

Harder photons come 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 compact source.

(adapted from Dovciak+09)
Future instruments

The photoelectric polarimeter

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

Residual modulation for unpolarized photons.
## Future instruments - IXPE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarisation sensitivity</td>
<td>1.8 % MDP for $2 \times 10^{-10} \text{ erg/s cm}^2$ (10 mCrab) in 300 ks (CBE)</td>
</tr>
<tr>
<td>Spurious polarization</td>
<td>&lt;0.3 %</td>
</tr>
<tr>
<td>Number of Telescopes</td>
<td>3</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>28&quot; (CBE)</td>
</tr>
<tr>
<td>Field of View</td>
<td>12.9x12.9 arcmin$^2$</td>
</tr>
<tr>
<td>Focal Length</td>
<td>4 meters</td>
</tr>
<tr>
<td>Total Shell length</td>
<td>600 mm</td>
</tr>
<tr>
<td>Range Shell Diameter</td>
<td>24 shells, 272-162 mm</td>
</tr>
<tr>
<td>Range of thickness</td>
<td>0.16-0.26 mm</td>
</tr>
<tr>
<td>Effective area at 3 keV</td>
<td>854 cm$^2$ (three telescopes)</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>16% @ 5.9 keV (point source)</td>
</tr>
<tr>
<td>Timing</td>
<td>Resolution &lt;8 μs</td>
</tr>
<tr>
<td></td>
<td>Accuracy 150 μs</td>
</tr>
<tr>
<td>Operational phase</td>
<td>2 yr</td>
</tr>
<tr>
<td>Energy range</td>
<td>2-8 keV</td>
</tr>
<tr>
<td>Background (req)</td>
<td>$5 \times 10^{-3} \text{ c/s/cm}^2/\text{keV/det}$</td>
</tr>
<tr>
<td>Sky coverage, Orbit</td>
<td>50 %, 540 (0°)</td>
</tr>
</tbody>
</table>

**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!

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Future instruments - XIPE


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

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 cm² @2 keV (includes QE)