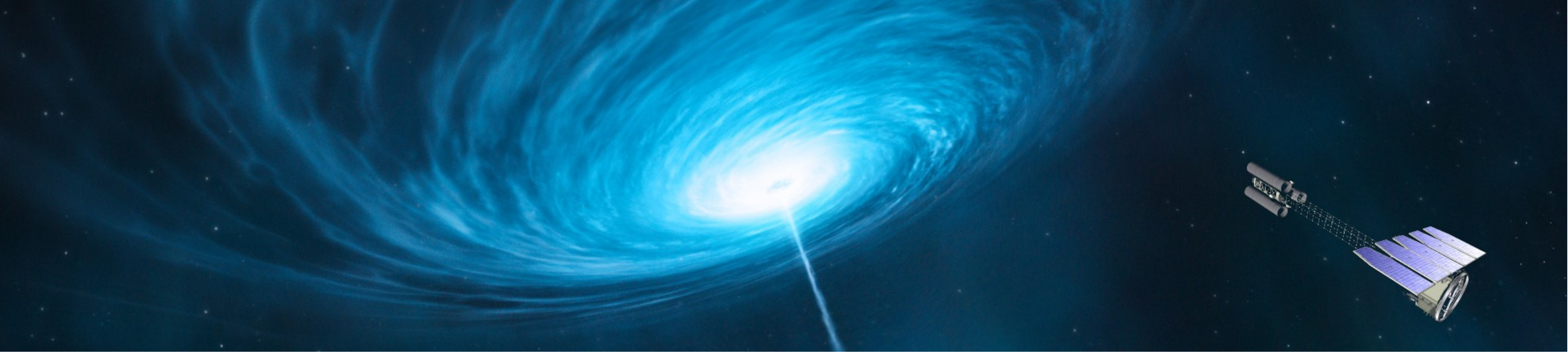


# What can X-ray polarization tell us about accreting black hole systems?

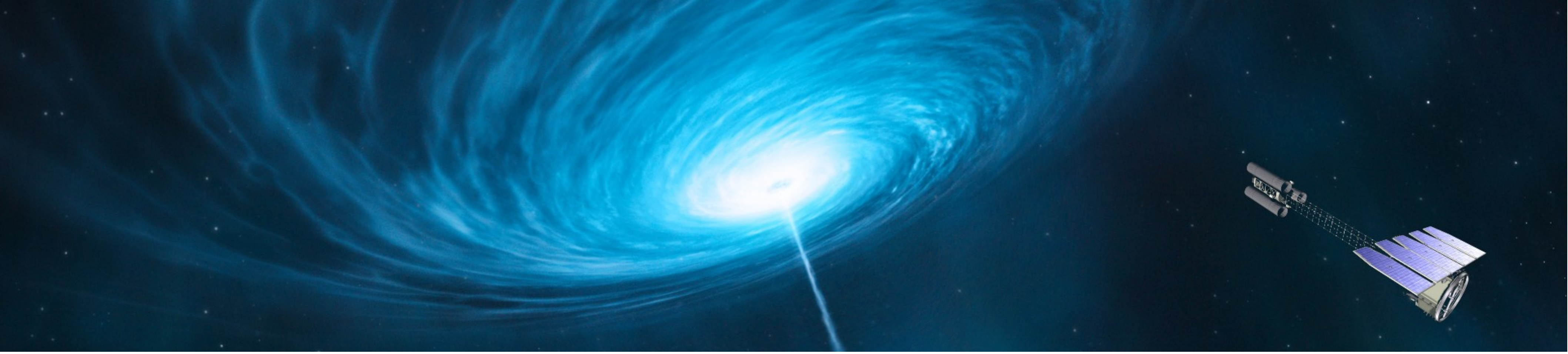
**Frédéric Marin**

Observatoire astronomique de Strasbourg

UNIVERSITÉ DE STRASBOURG

CNRS

X-ray Universe – Rome, Italy, 6 - 9 June 2017



**Presentation strongly IXPE-flavored**

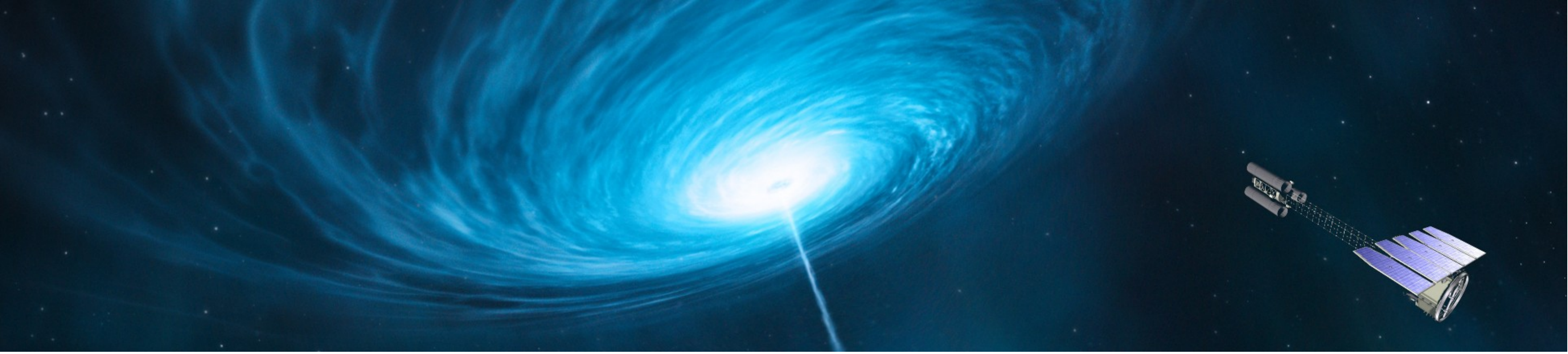
NASA SMEX mission to fly in 2020

- 40 years from the last positive measurement
- dramatic improvement in sensitivity:
  from one to hundred sources !!

<u>A large number of scientific topics:</u>
Acceleration phenomena, pulsar wind nebulae, SNR, jets, emission in strong magnetic fields, mCv, pulsars, magnetars, X-ray binaries, AGN, GC …

+ Fundamental Physics: QED effects, GR effects close to accreting BHs, quantum gravity

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



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Martin Weisskopf (P.I. IXPE)

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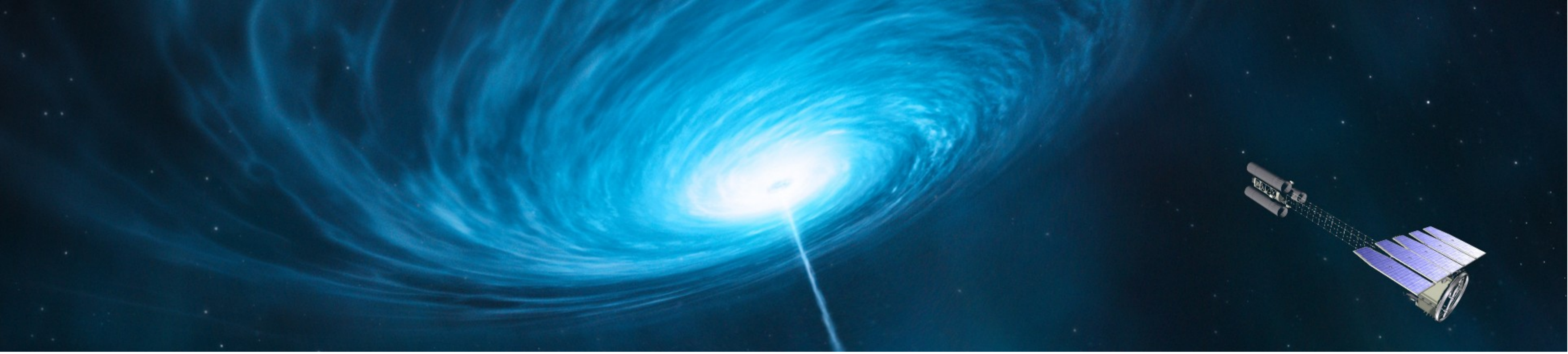


# Jets in radio-loud AGN

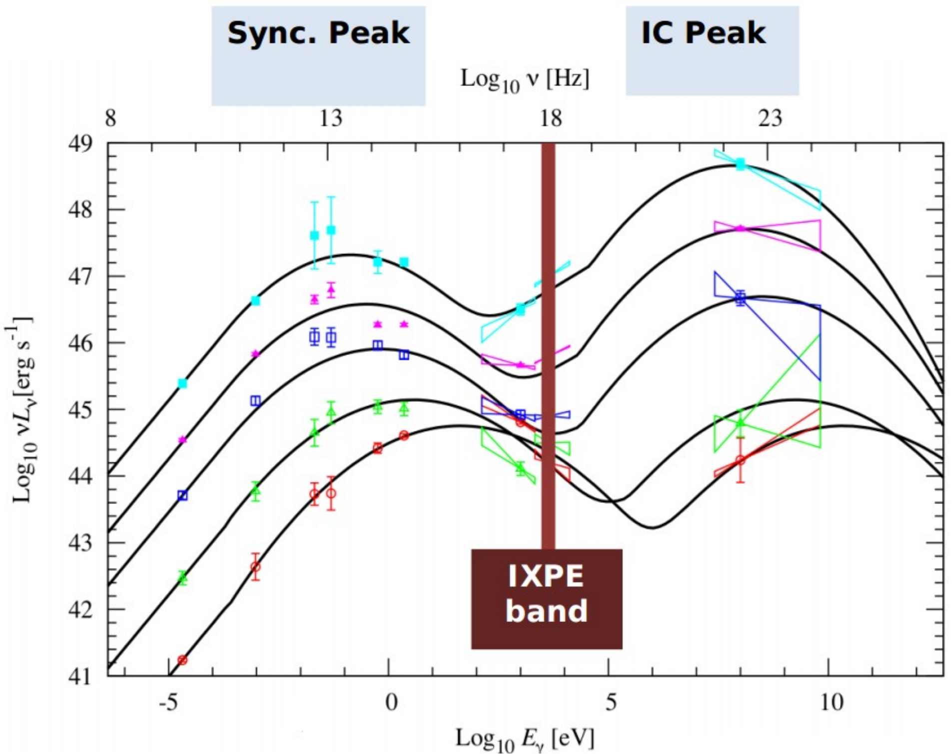
X-ray spectrum of BL Lac objects, OVV, steeper than optical spectrum

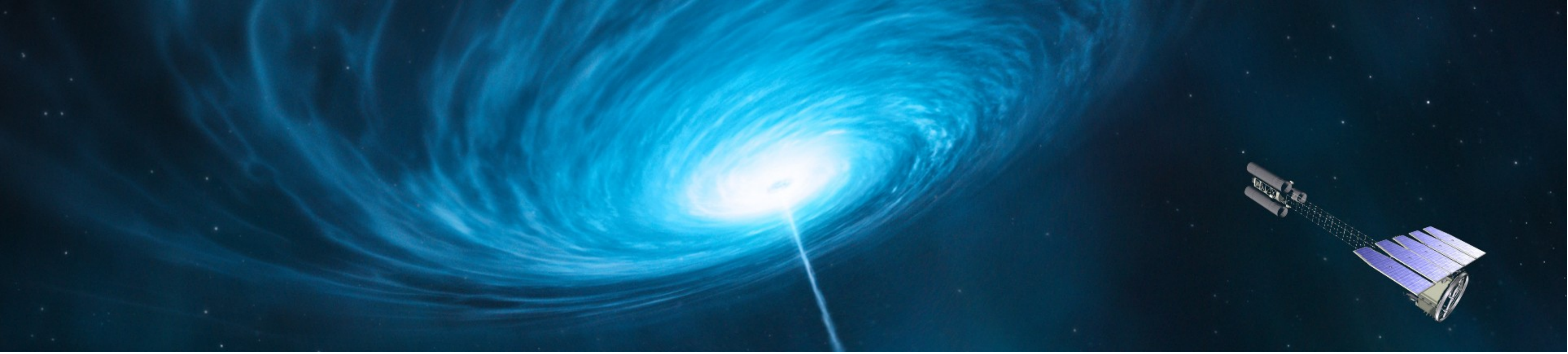
→ X-ray produced by accelerated, high energy $e^-$ in parsec-scale jets (base of the jet ? Shocks ?)

3 scenarios: disk/Compton, CMB or SSC ?

The polarization degree determines the electron temperature in the jet

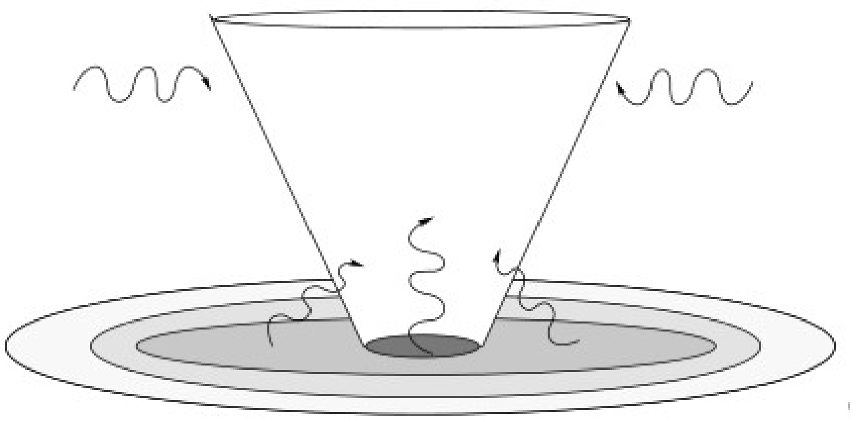
In synchrotron-dominated X-ray blazars, multi-wavelength polarimetry probes the structure of the magnetic field along the jet





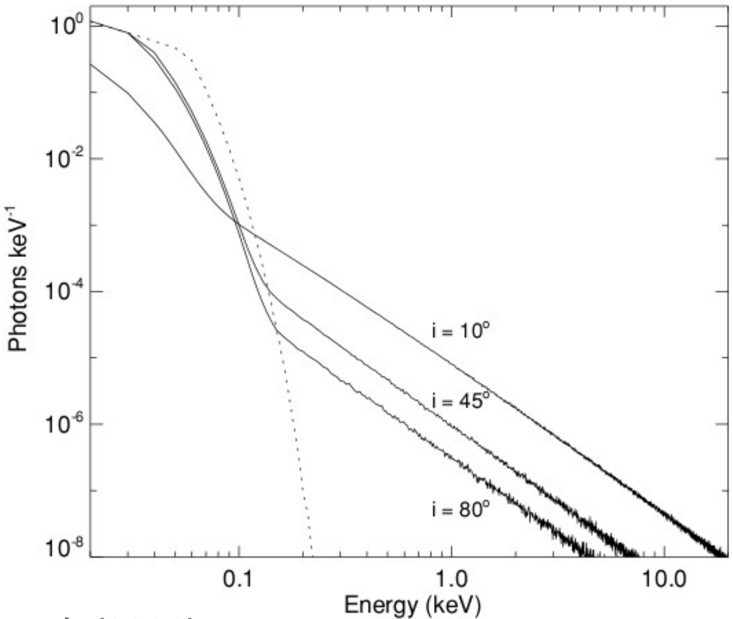
# Jets in radio-loud AGN

**Disk photons:**

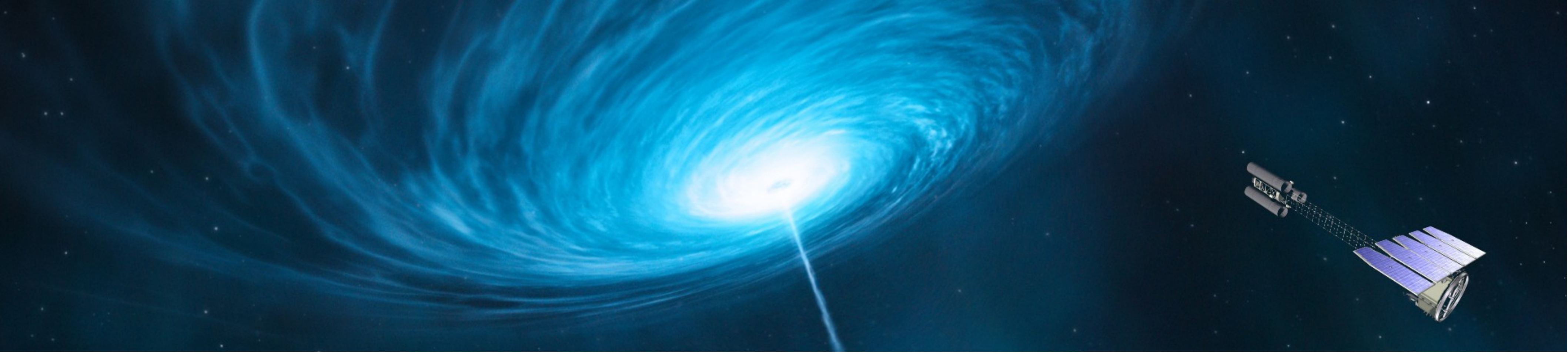



SMBH $10^8$ Msol, jet Lorentz factor = 5
jet opening angle 11°, accr. rate 0.1 Msol/yr
Z = 2, 50% conversion accr/jet

| $i$ | $P$ (per cent) ($E = 1$–$10$ keV ) | Average number of scatterings per photon |
|---|---|---|
| 10° | 3.2 | 3.0 |
| 45° | 14.0 | 2.8 |
| 80° | 20.6 | 2.8 |

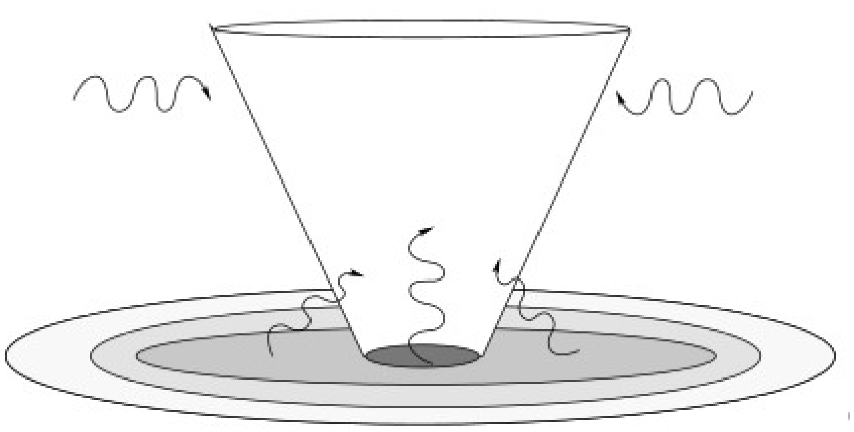



McNamara et al. (2009)



# Jets in radio-loud AGN

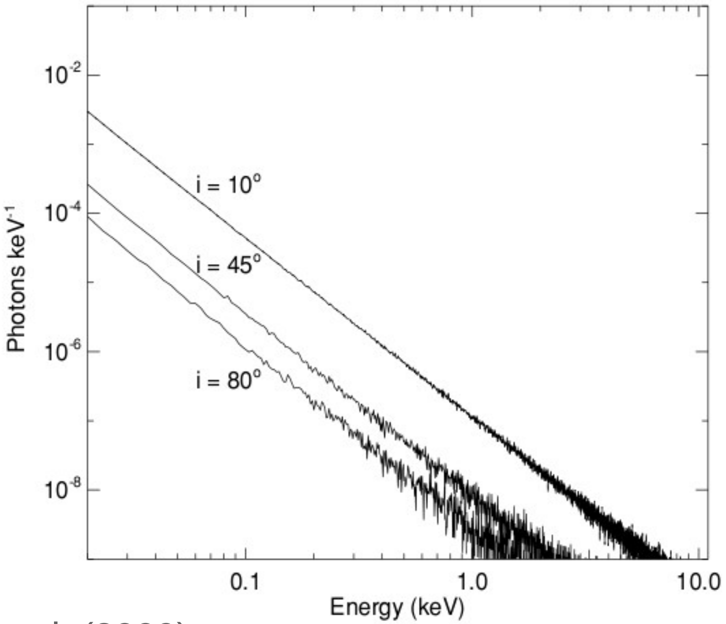
**CMB photons:**



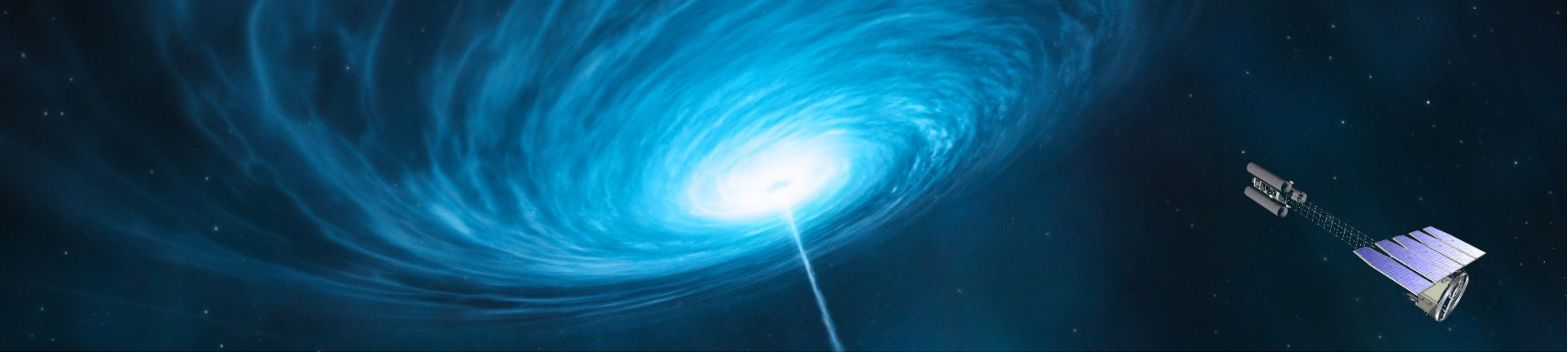

(a)

SMBH $10^8$ Msol, jet Lorentz factor = 5
jet opening angle 11°, accr. rate 0.1 Msol/yr
Z = 2, 50% conversion accr/jet

| $i$ | $P$(per cent) ($E$ = 1–10 keV) | Average number of scatterings per photon |
|---|---|---|
| 10° | 4.2 | 3.2 |
| 45° | 16.5 | 2.6 |
| 80° | 23.9 | 3.2 |

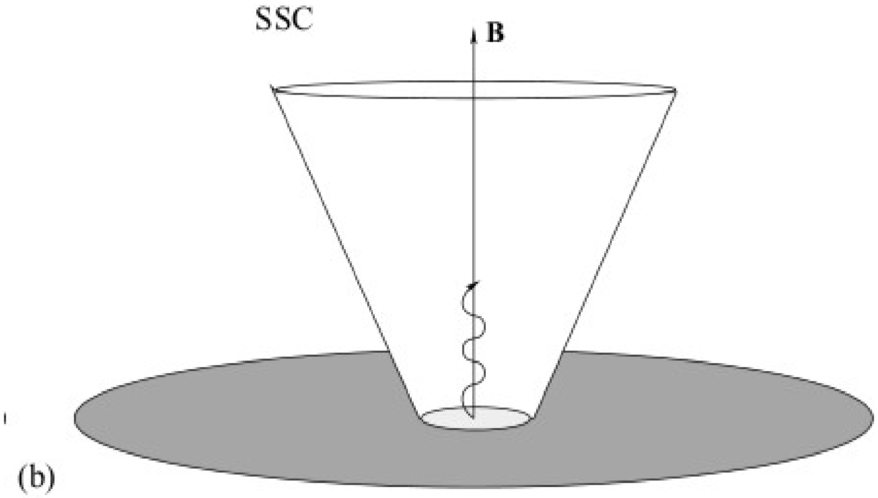



McNamara et al. (2009)



# Jets in radio-loud AGN

**SSC photons:**




Synchrotron seed photons are intrinsically polarized (depolarization ?)

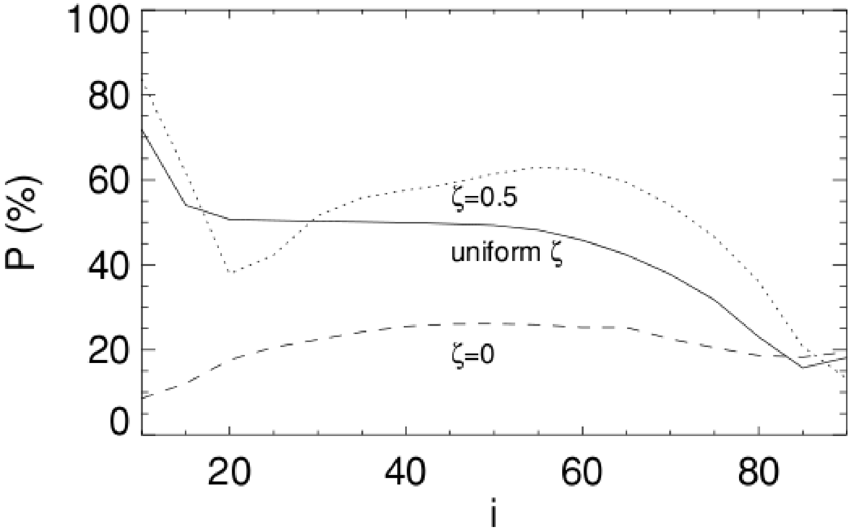
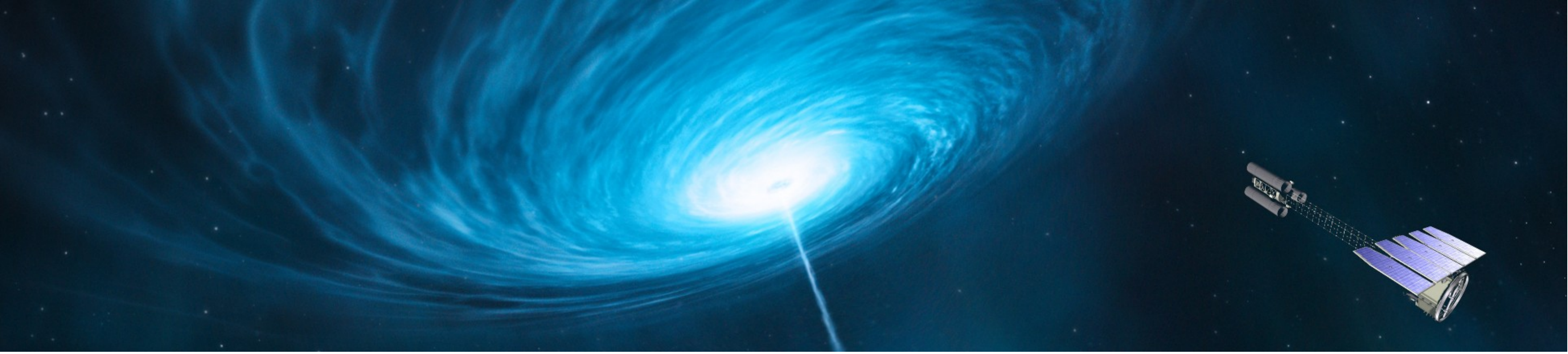



**Figure 6.** Polarization degree $P$ of SSC photons with energies between 1 and 10 keV plotted as a function of the inclination angle $i$. The solid line is for the case where the seed photons are emitted uniformly throughout the jet (uniform $\zeta$). The dashed and dotted lines are for the cases where the seed photons are emitted at the jet base ($\zeta = 0$) and in the middle of the jet ($\zeta = 0.5$).

McNamara et al. (2009)



# Hot corona and strong gravity

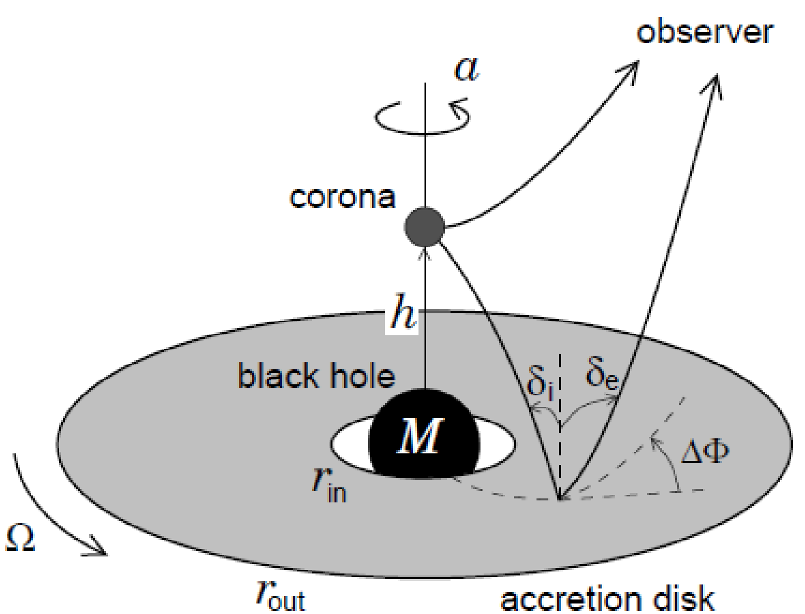
Dovciak et al. (2004)

Origin of jets not resolved, even in the X-ray band
Is the hot corona, responsible for the X-ray power-law spectrum in XRB and AGN, the base of the jets ?

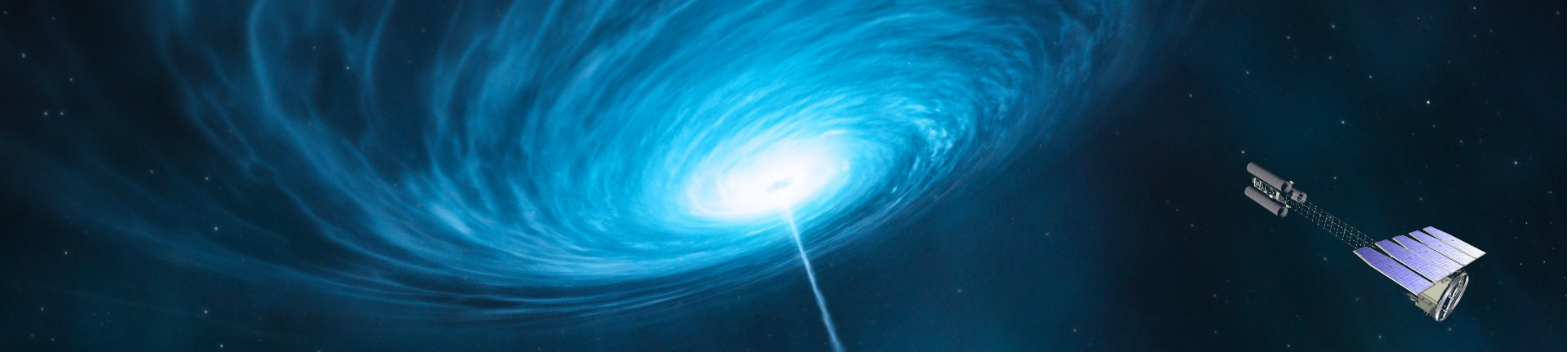
Disk illuminated by a hot corona (geom., temp., … ?)
→ soft X-rays: absorption + reemission
→ hard X-rays: Compton scattering

Scattering = polarization

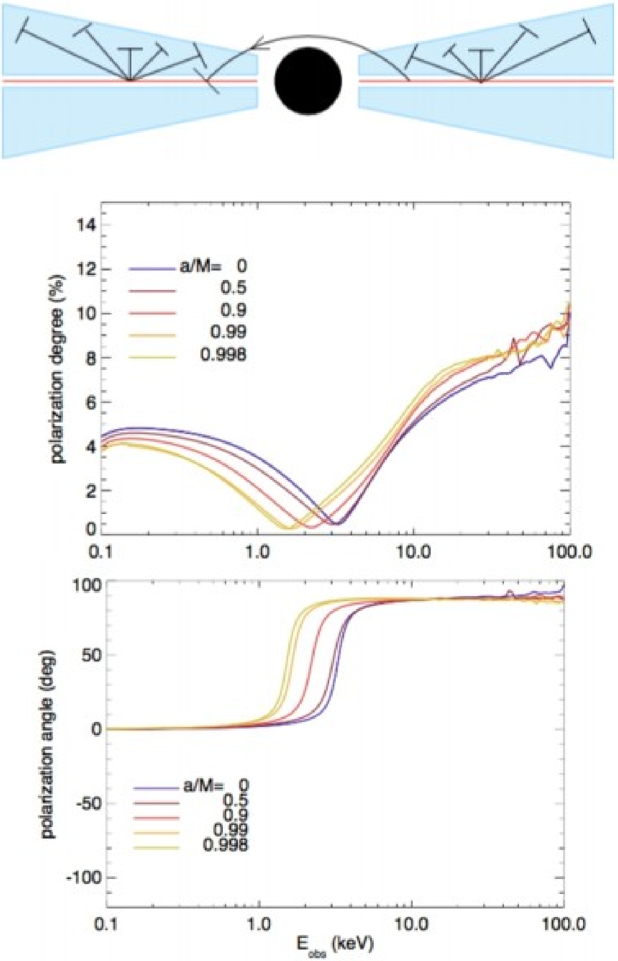
Strong gravity effects → parallel transport of P



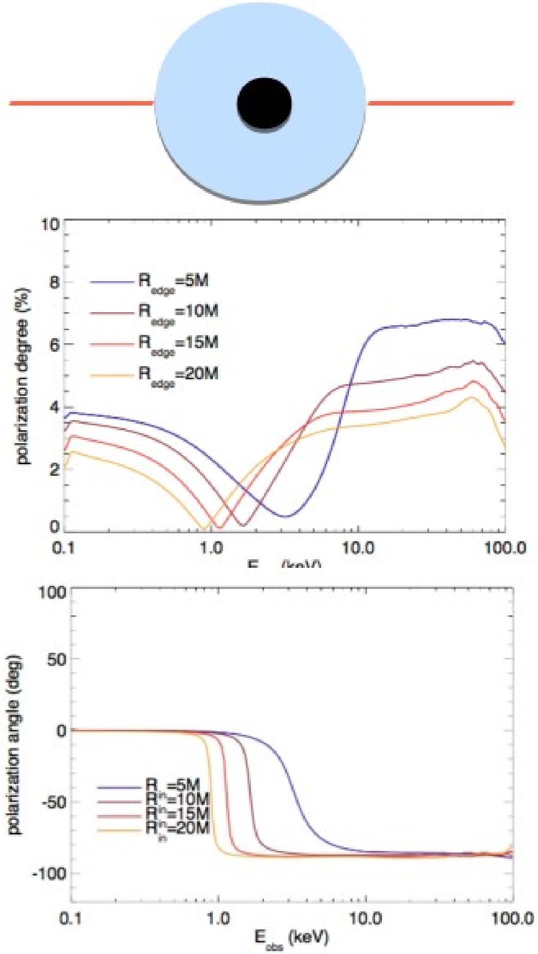

→ determining the composition of the corona
+ origin and orientation of jets at $r < 1000\ r_g$ with X-ray polarimetry



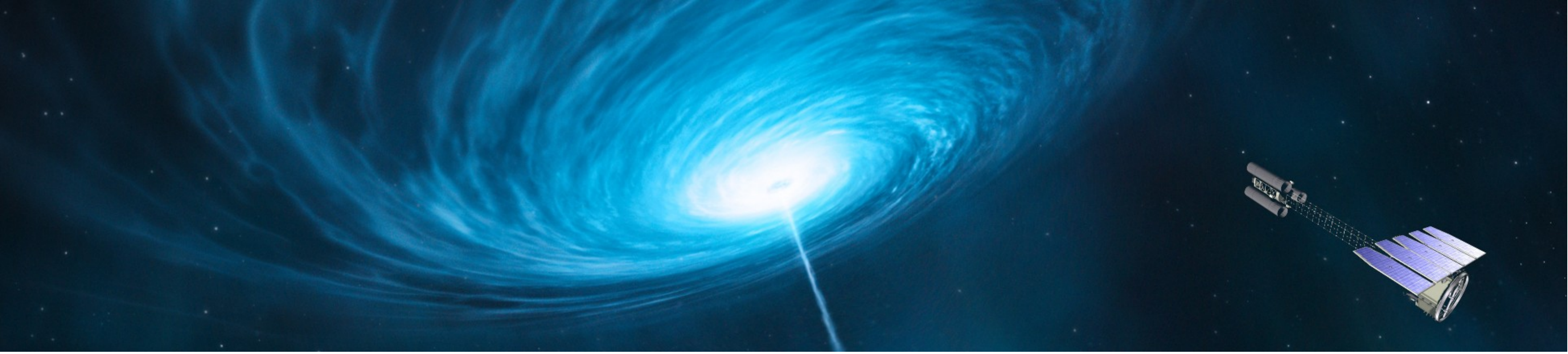
## Extended corona above disc




## Truncated disc + spherical corona




Schnittman & Krolik
(2009,2010,2013)



# Measuring BH spin

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

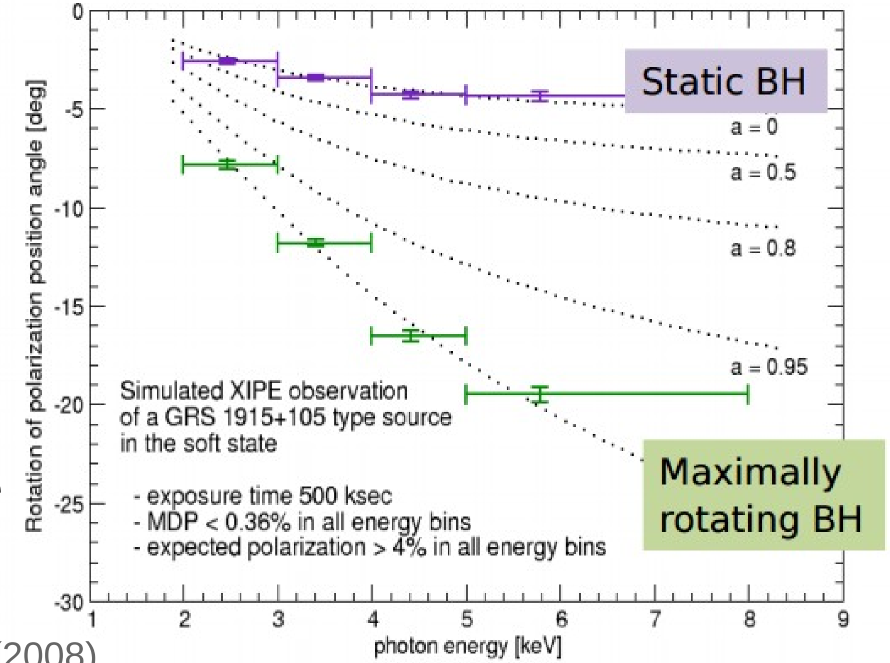
1. Relativistic reflection (still debated, requires accurate spectral decomposition)
2. Continuum fitting (requires knowledge of the BH mass, distance and inclination)
3. QPOs (all three QPOs required to completely determine the parameters)

Problem: the methods do not always agree!

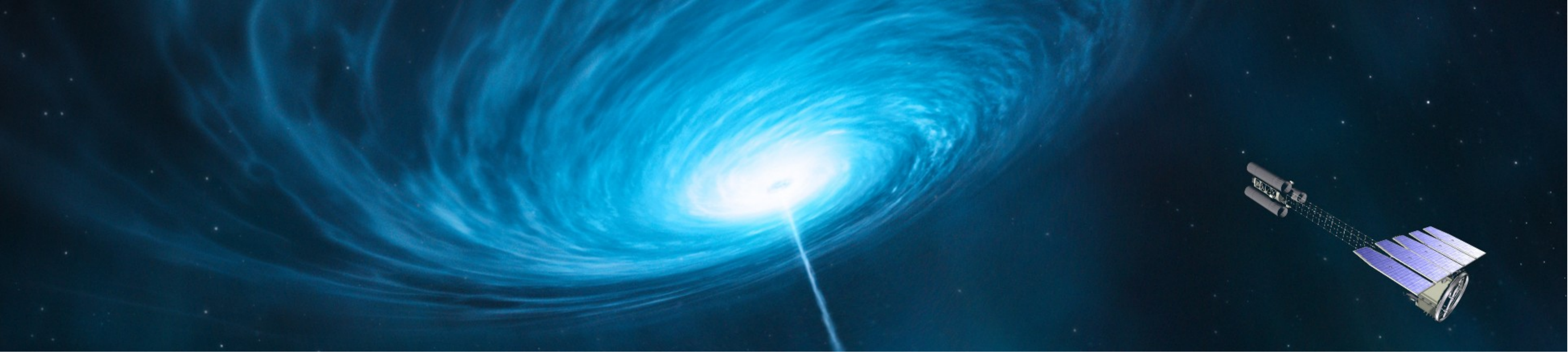
For GRO J1655-40: QPO: $a = 0.290 \pm 0.003$
Continuum: $a = 0.7 \pm 0.1$
Iron line: $a > 0.95$

X-ray polarization → energy dependent rotation of the X-ray polarization plane

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



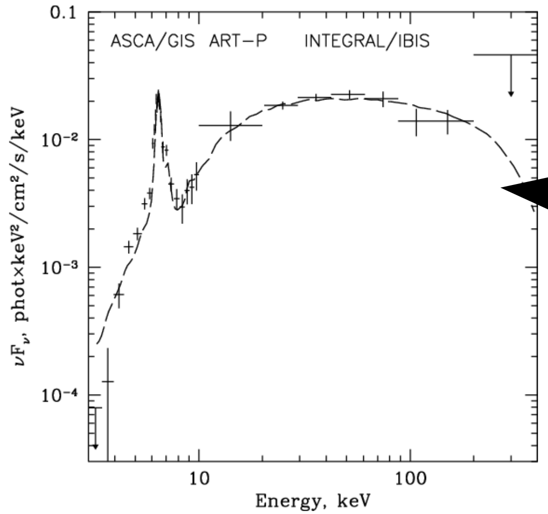

Adapted from Dovciak et al. (2008)



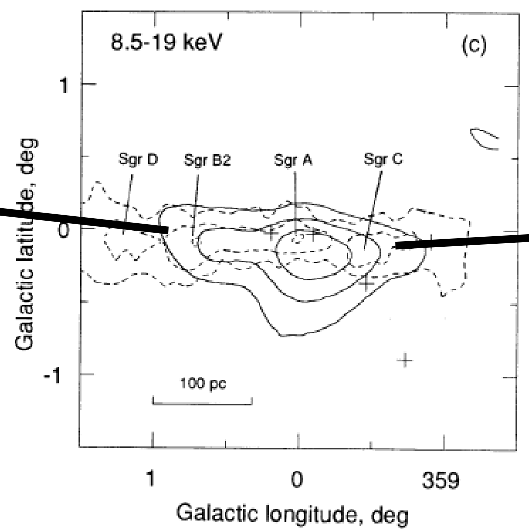
# Revealing the history of Sgr A*

Sgr A* has a very low accretion rate ~ $10^{-8}$ $M_{sol}$ $y^{-1}$ near the event horizon (Baganoff et al. 2003)

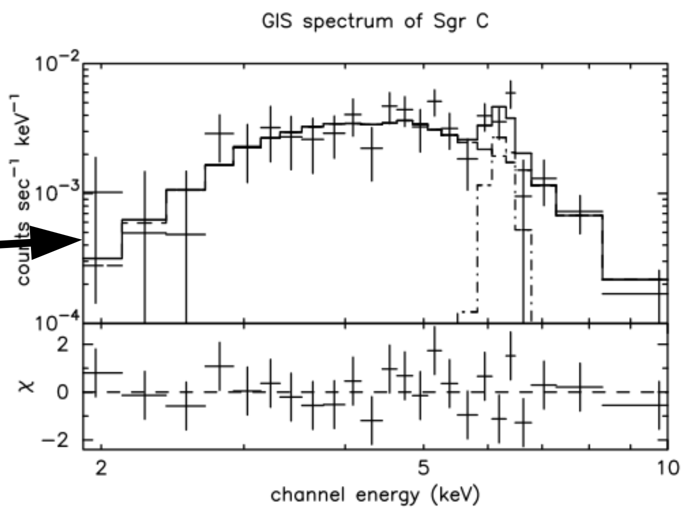
→ X-ray luminosity of the order $2 \times 10^{33}$ erg $s^{-1}$ (Baganoff et al. 2001; Quataert 2002)




Koyama et al. (1996) / Terrier et al. (2010)

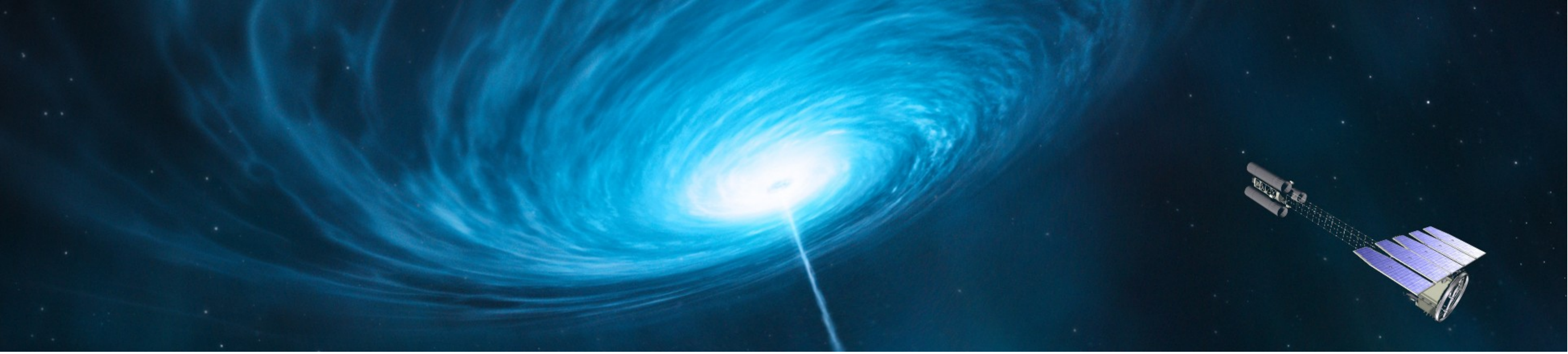



Sunyaev et al. (1993)



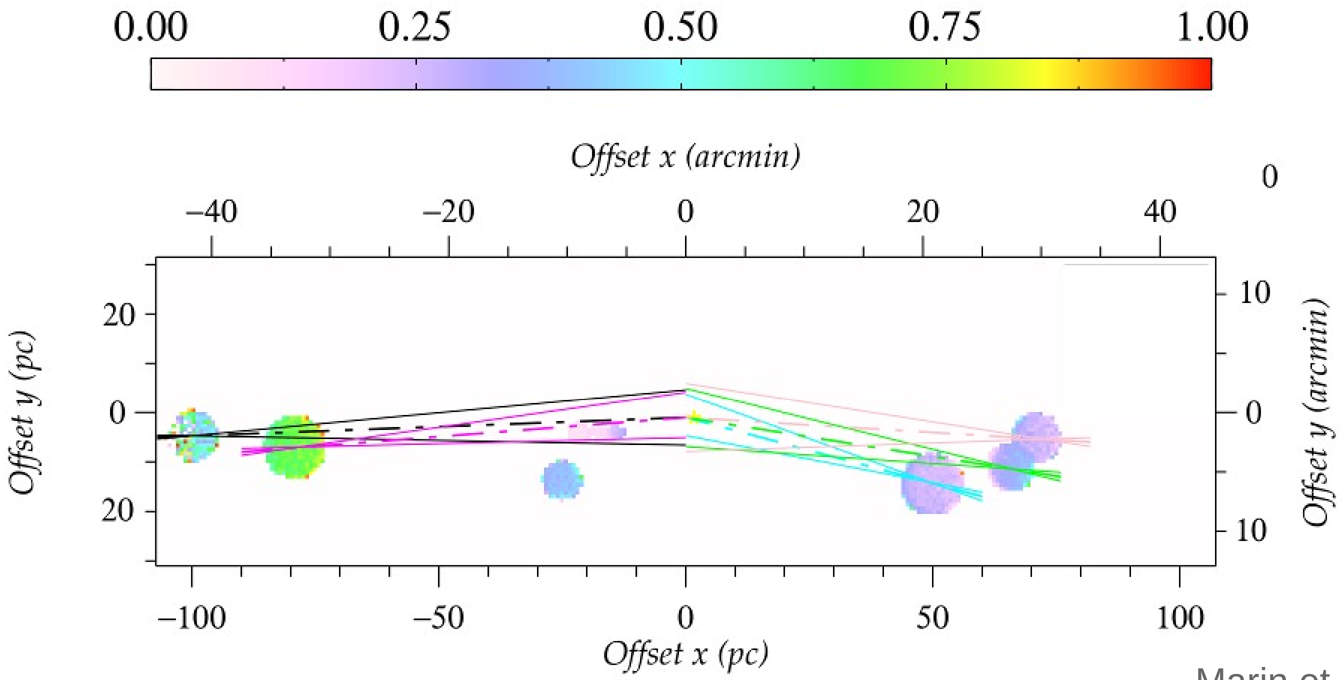

Murakami et al. (2001)

Pure reflection spectra ($L_X$ ~ $10^{35}$ erg $s^{-1}$) … but no nearby sources bright enough!

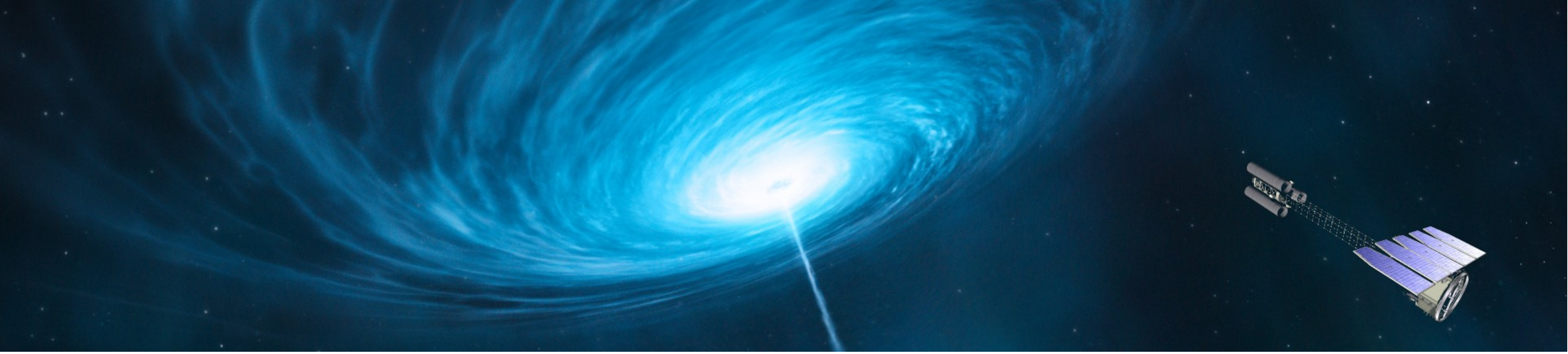


# Revealing the history of Sgr A*

If molecular clouds are echoing a past flare of Sgr A* → high soft X-ray polarization is expected with electric vector perpendicular to the line connecting the two sources




Marin et al. (2014,2015,2016)



# Conclusions

X-ray polarimetry will open a new observational window, adding the two missing observables in X-rays. X-ray polarimetry is going to make important unique and supporting contributions to astrophysics and also fundamental physics

Many X-ray sources are aspherical and/or nonthermal emitters, so radiation must be highly polarized → more than a hundred sources to be observed with IXPE

Look a the posters:
- **M. Dovciak**: Influence of a polarized primary source on the X-ray polarization resulting from disc reflection in AGN
- **F. Tamborra**: MoCA: A Monte Carlo code for Comptonization in Astrophysics
- **F. Marin**: Transmitted and polarized scattered fluxes by the exoplanet HD 189733b in X-rays

Alsatian Workshop on X-ray Polarimetry (Strasbourg, November 13th – 15th)
→ http://awoxpol.u-strasbg.fr/