The physics of AGN: prospects from X-ray polarimetry

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Talk at the international COST meeting

Polarization & AGN

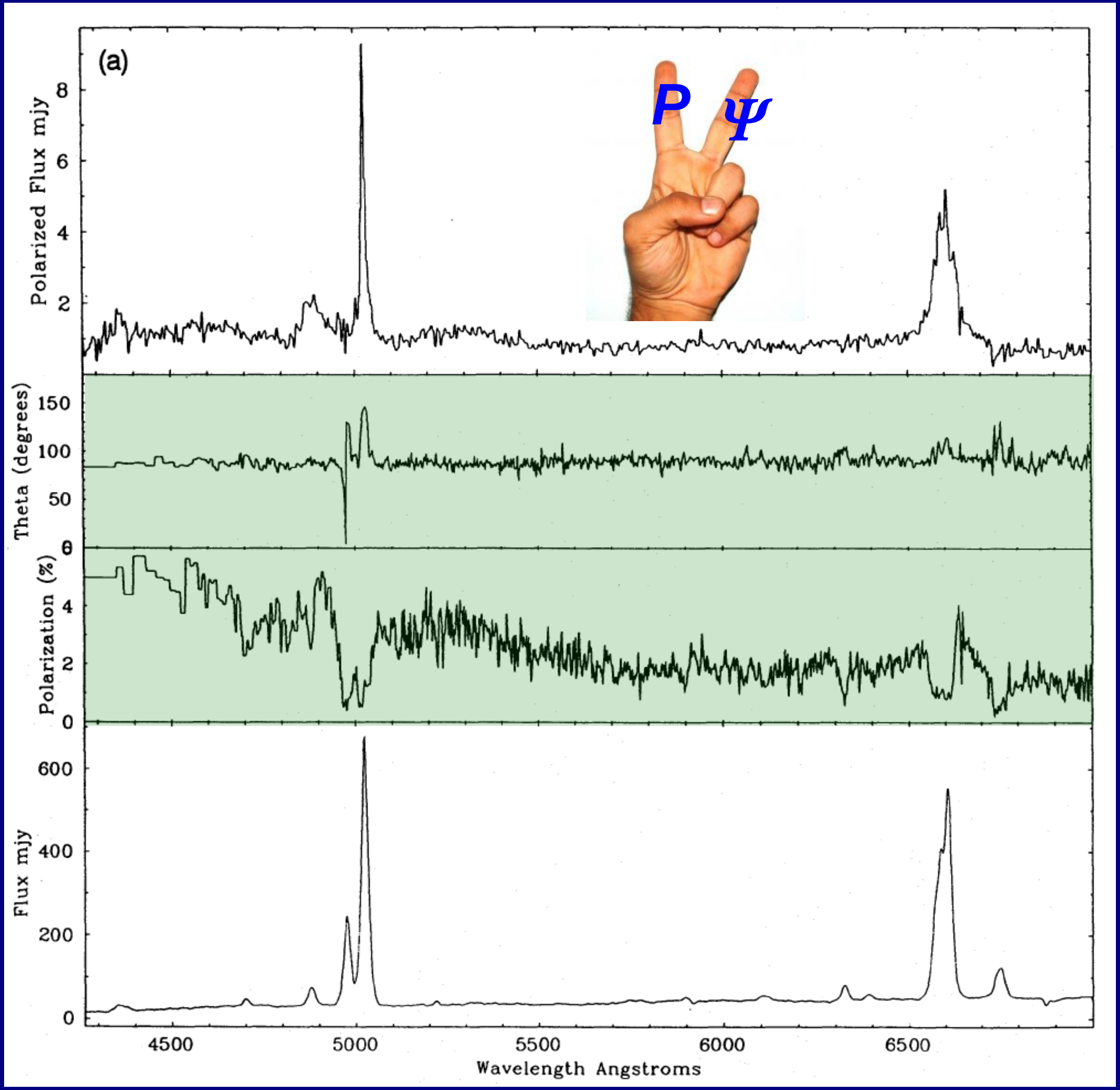
held at the Royal Observatory of Belgium

Brussels, 17th October 2012

Why should we care about X-ray polarization?

Note: almost any interaction of EM radiation with matter also modifies its polarization state!

ERGO: Considering the polarization state of light gives us a set of **two additional, independent observables** as a function of photon wavelength, time, and space.



Inglis et al. 1995

Processes producing (de-)polarization

Electron scattering

Dust (Mie) scattering

Resonant line scattering

Dichroic absorption

Faraday rotation

Dilution (by unpolarized radiation)

General Relativity

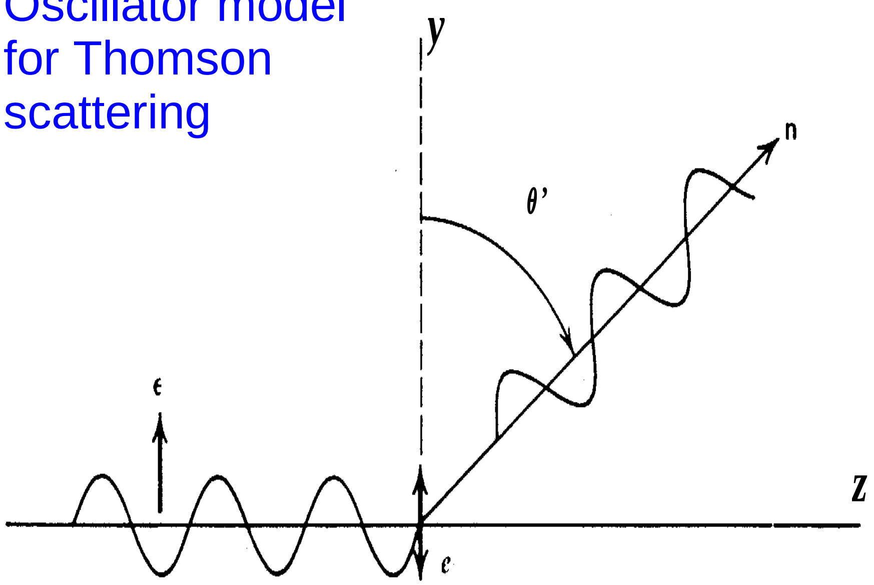
Synchrotron and SSC emission

Scattering

Strong polarization: $\Theta = 90°$ (Reflection)

Weak polarization: $\Theta = 0°$ (Transmission)

Oscillator model for Thomson scattering



$$\frac{\partial\sigma}{\partial\omega}(\alpha)_{tot} = \frac{1}{2} r_0 \left(1 + \cos^2\theta\right).$$

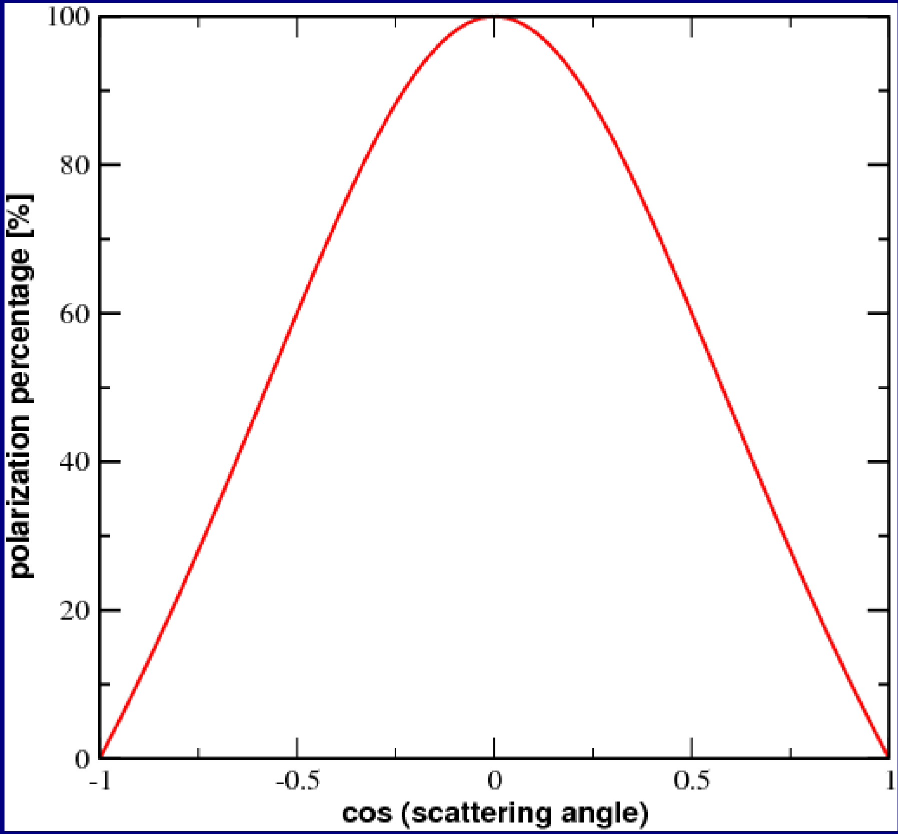
$$P = \frac{1 - \cos^2\theta}{1 + \cos^2\theta}.$$

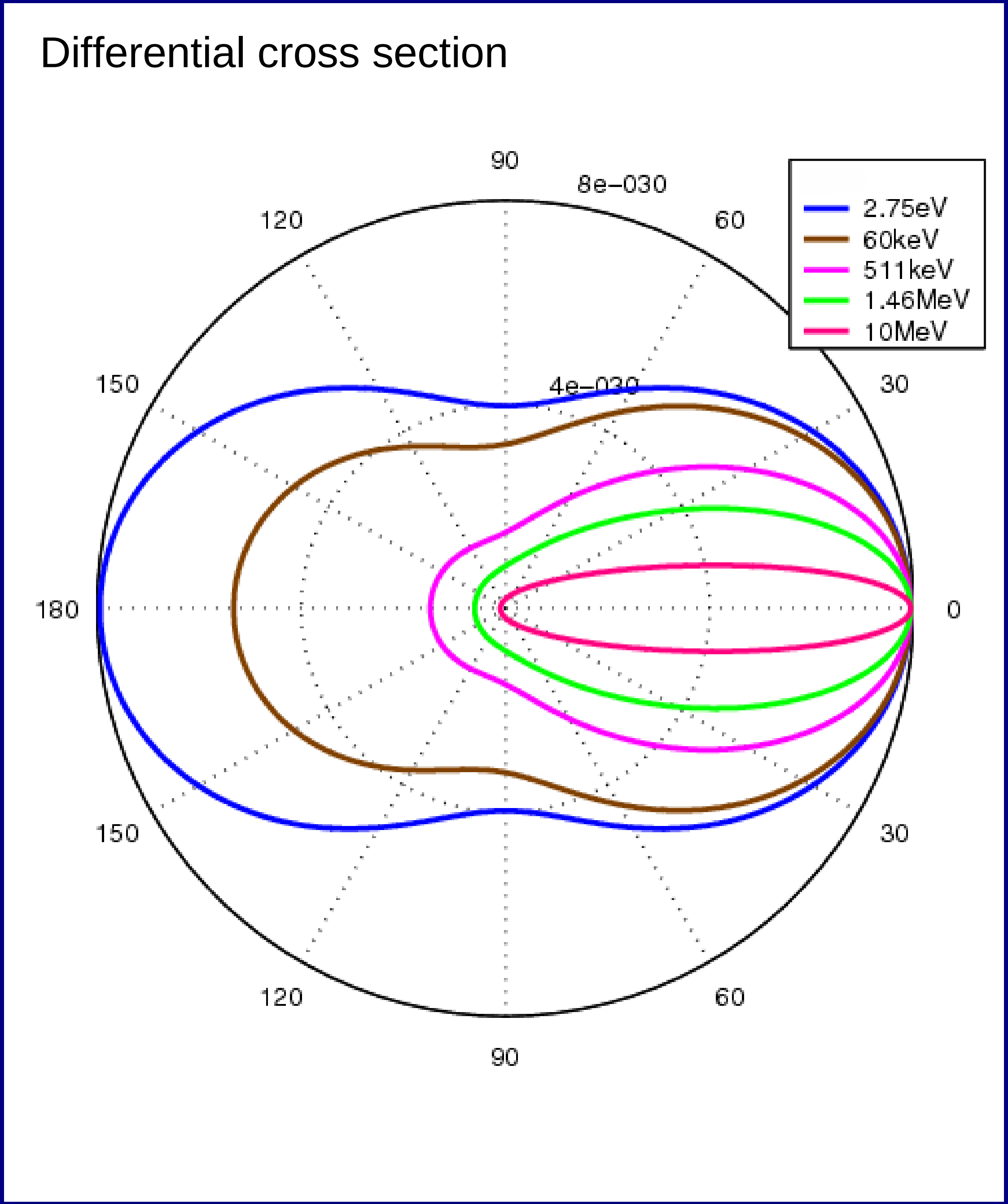
$$\sigma_T = \frac{8\pi}{3} r_0^2 = \frac{8\pi e^4}{3m^2c^4}.$$

Phase function for scattering-induced polarization

Electron scattering
(Thomson, Compton, Rayleigh scattering)

Polarization phase function:



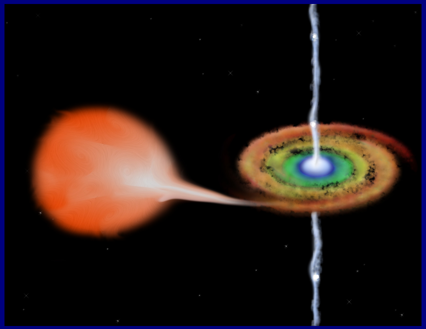


X-ray polarization in black hole X-ray binaries

Determining the local polarization (disk reference frame)

Intrinsically unpolarized radiation

Multiple Thomson scattering in a disk/corona



Early modeling work done by Angel (1969)

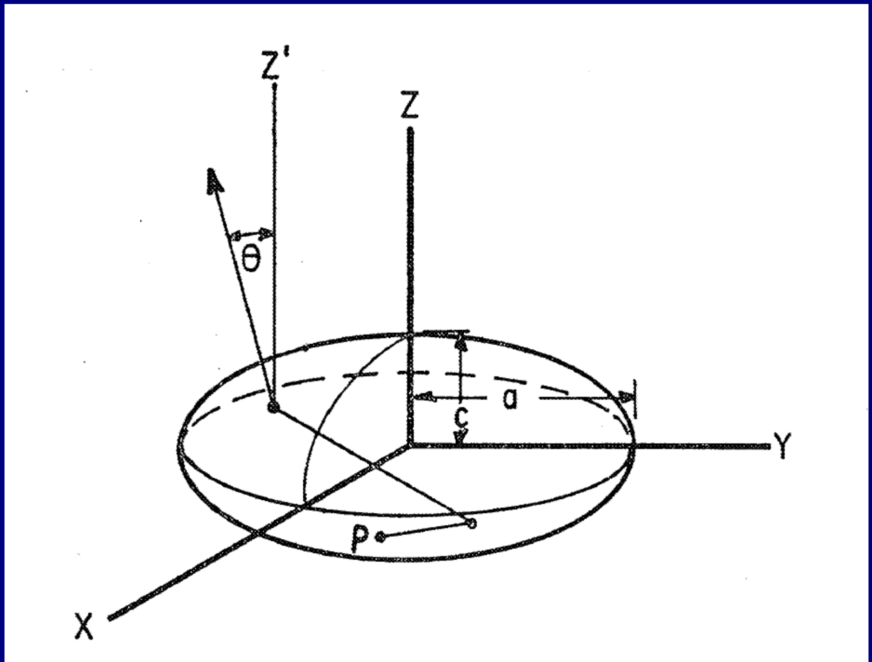
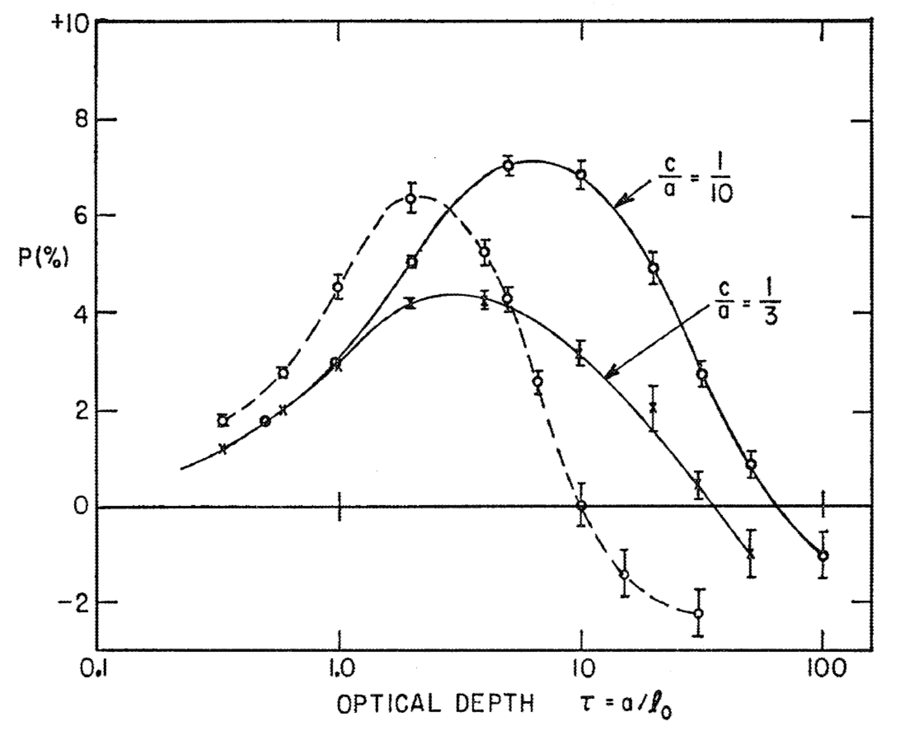


FIG. 1.—Geometry of Monte Carlo calculations



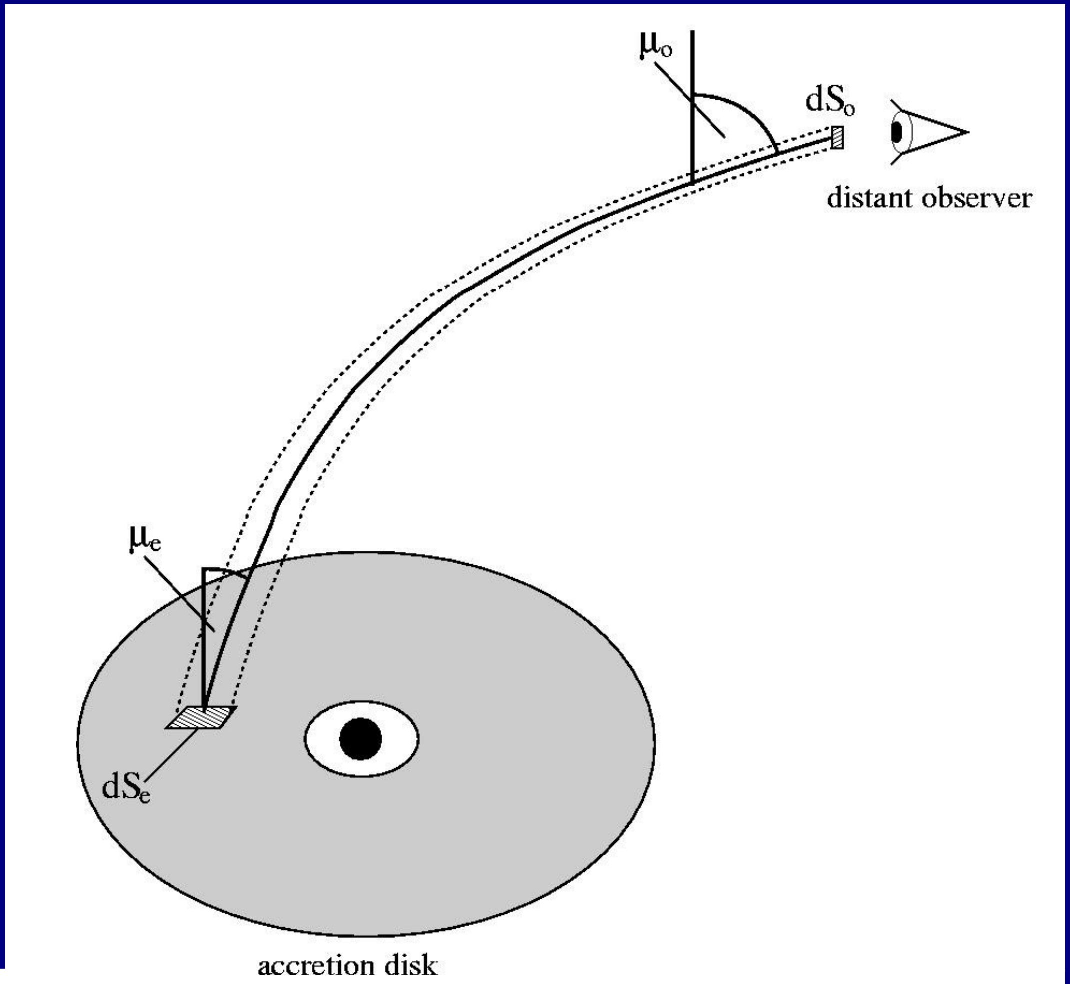
Including relativistic effects

- **Applying relativistic ray-tracing methods in Kerr metric**

- **Important to know the local polarization**

see e.g.
Connors, Piran, Stark (1980)
Dovčiak et al. 2004
Schnittman 2009

I, Q, U, V



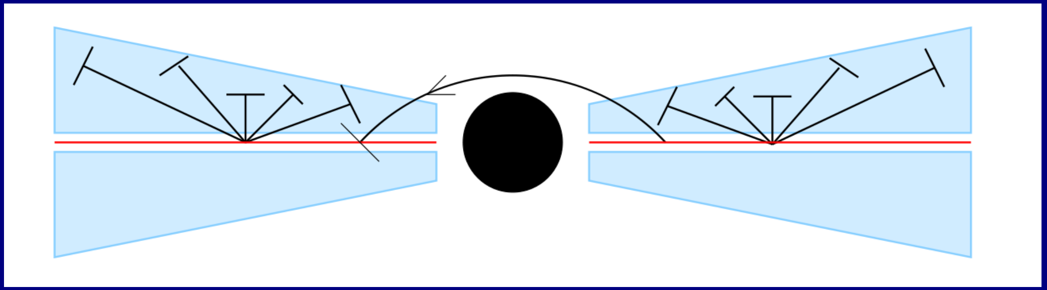
$$\Delta N_o^{\Omega_o}(E,\Delta E,t)=\int_{r_i}^{r_o} dr \int_{\phi}^{\phi+\Delta\phi} d\phi \int_{E/g}^{(E+\Delta E)/g} dE_l\, N_l(E_l,r,\phi,\mu_e,t-\Delta t)\, g^2 l\, \mu_e r\,.$$

observed photon flux | **disk integration** | **energy** | **local photon flux** | **transfer**

Light-bending and returning radiation

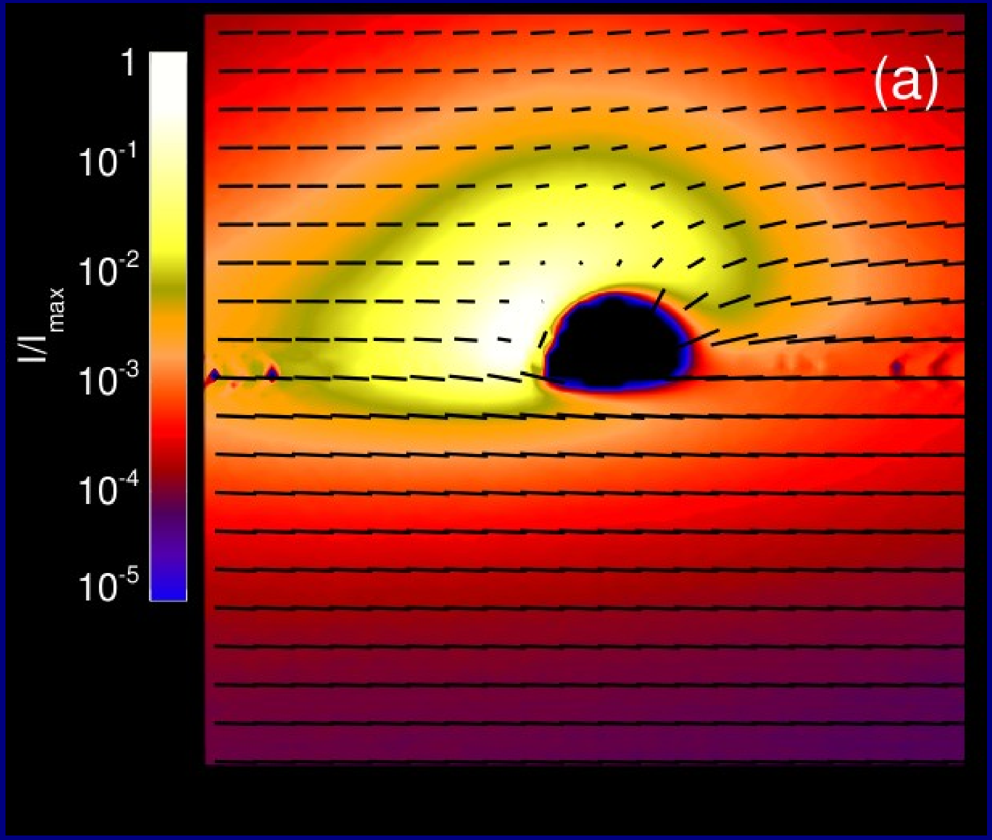
Schnittman & Krolik (2010)

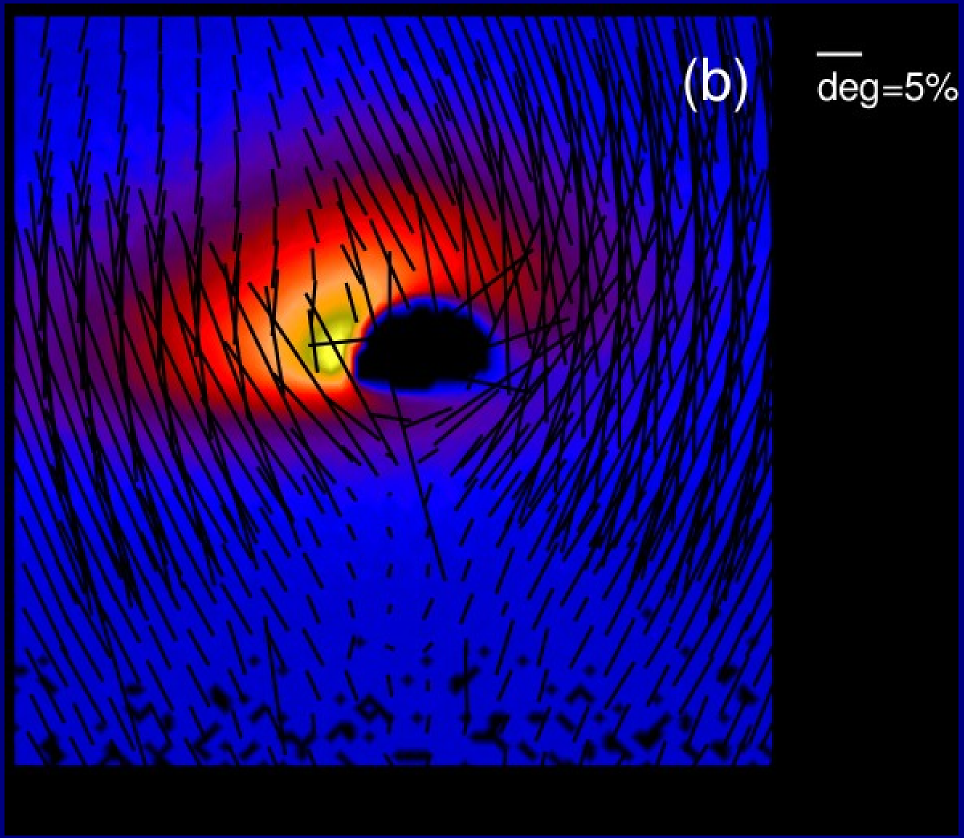
a/M = 0.9
H/R = 0.1
***i* = 75°**



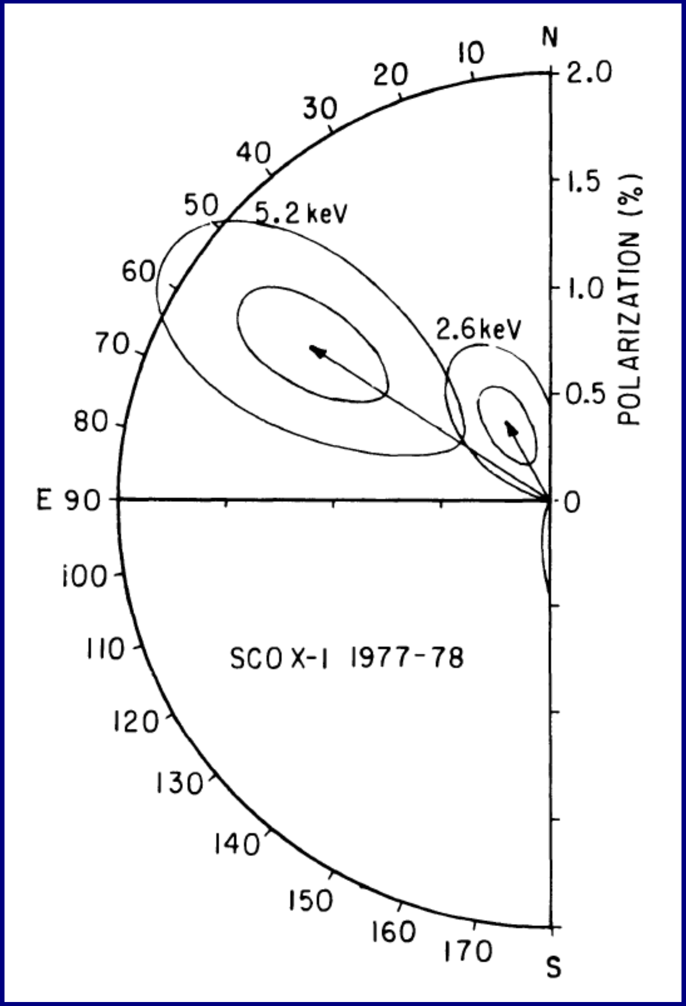
Disk and coronal emission without returning radiation

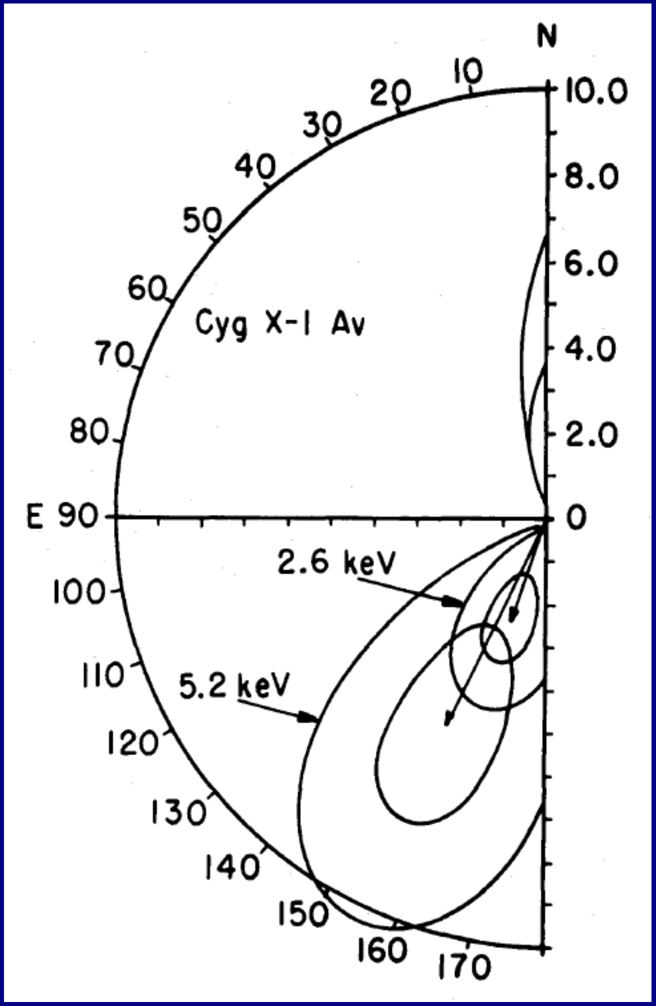
...and including returning radiation

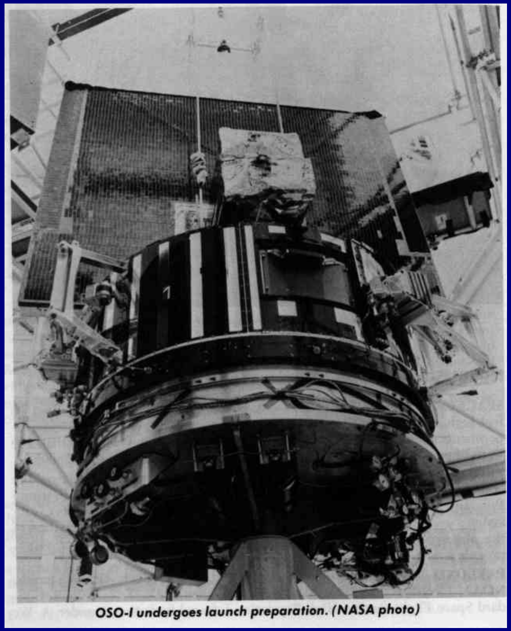


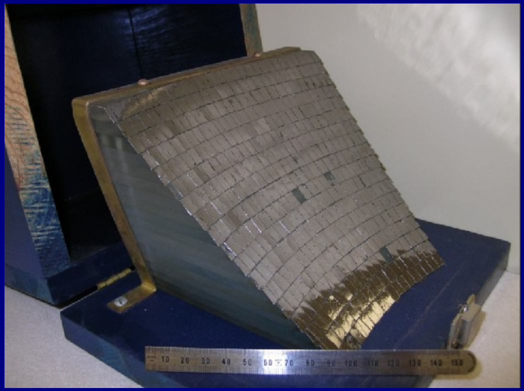


So-far X-ray polarization measurements









Sco-X1 and Cyg-X1 (OSO-8)

Long et al (1979, 1980)

Bragg-reflection polarimeter

Observational prospects – ready-to-fly technology

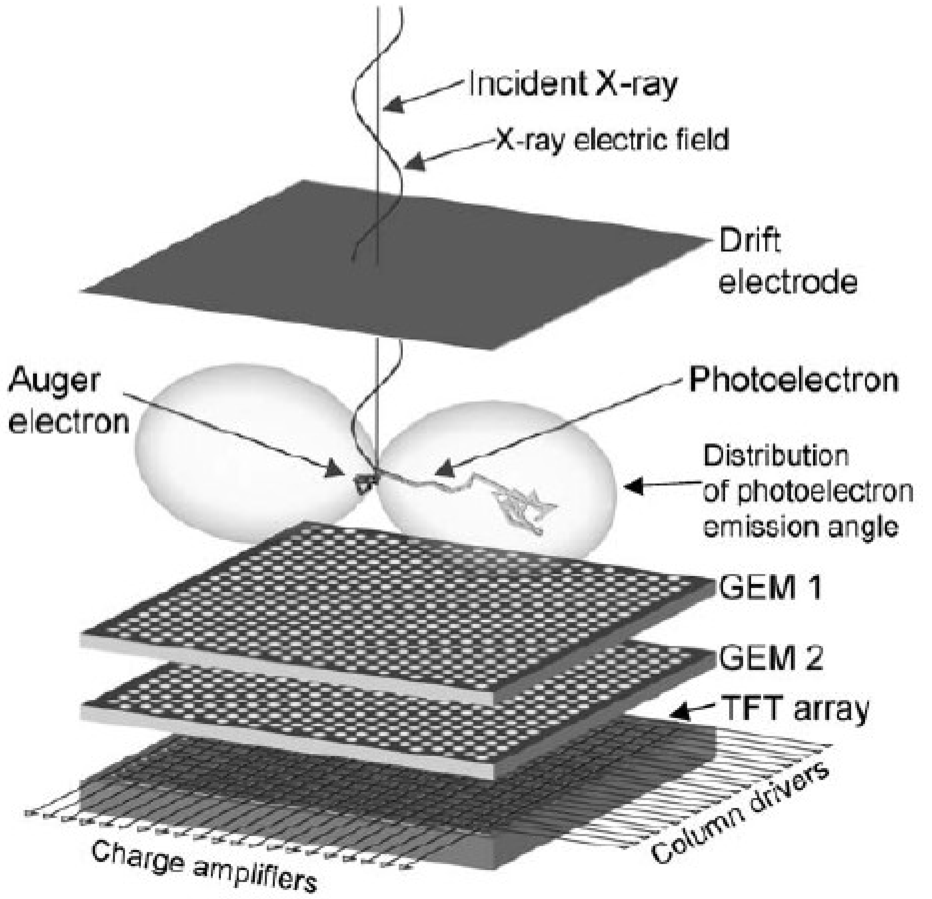


Fig. 1. Schematic diagram of detector geometry used in these measurements. The $\sin^2\theta\cos^2\phi$ distribution of photoelectron emission for normally incident X-rays is projected onto the detector plane and observed as $\cos^2\phi$.

- Photoelectric ionization of and subsequent Auger effect
- Photo electron and Auger electron both <u>know about the initial polarization</u> of the incident photon

Active-matrix pixel prop. counter

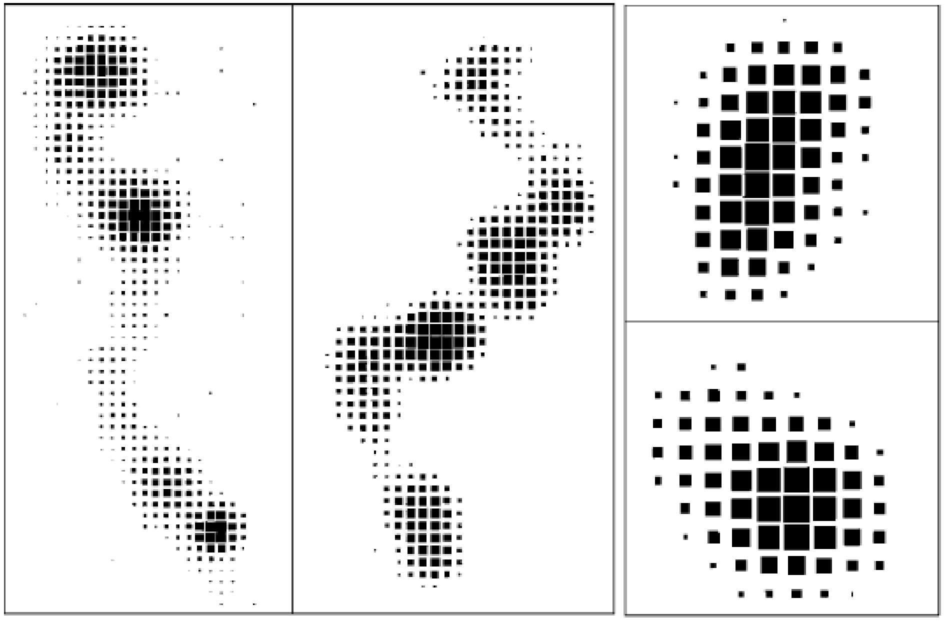
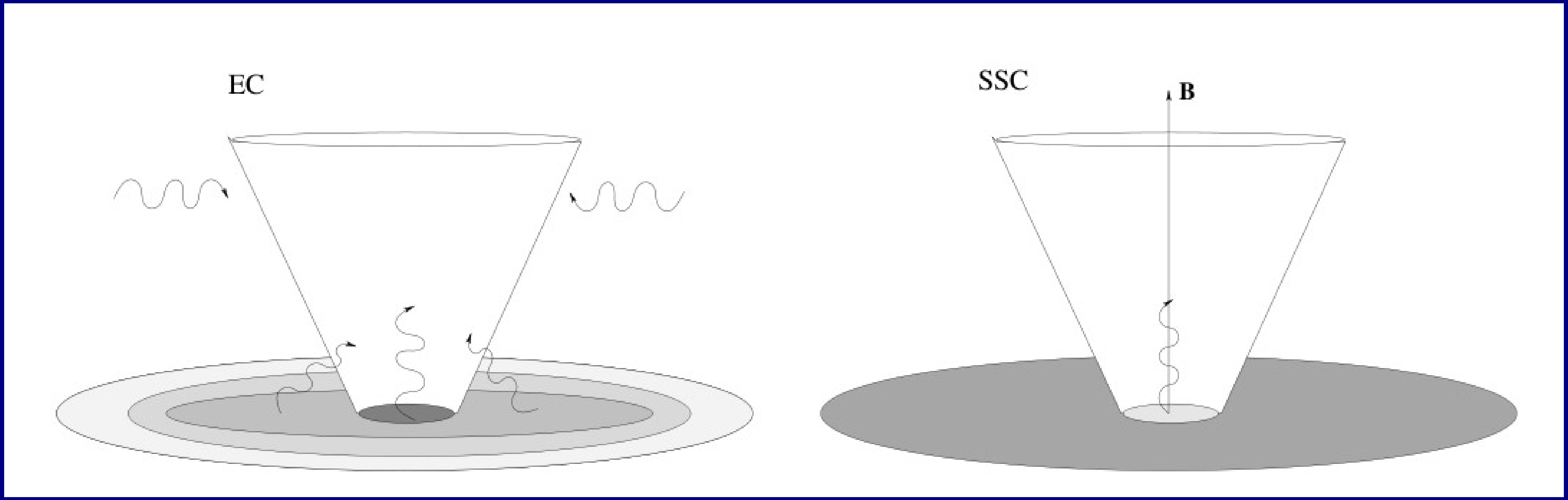


Fig. 3. Track images from 20 keV X-rays (left) and 4.5 keV X-rays (right).

Costa et al. (2001), Bellazzini et al.(2009), Muleri et al. (2009)

What causes the hard X-ray emission of jets?



McNamara, Kuncic & Wo (2009)

Two competing interpretations for leptonic models:

External Comtonization (EC)
Synchrotron-Self-Compton (SSC)

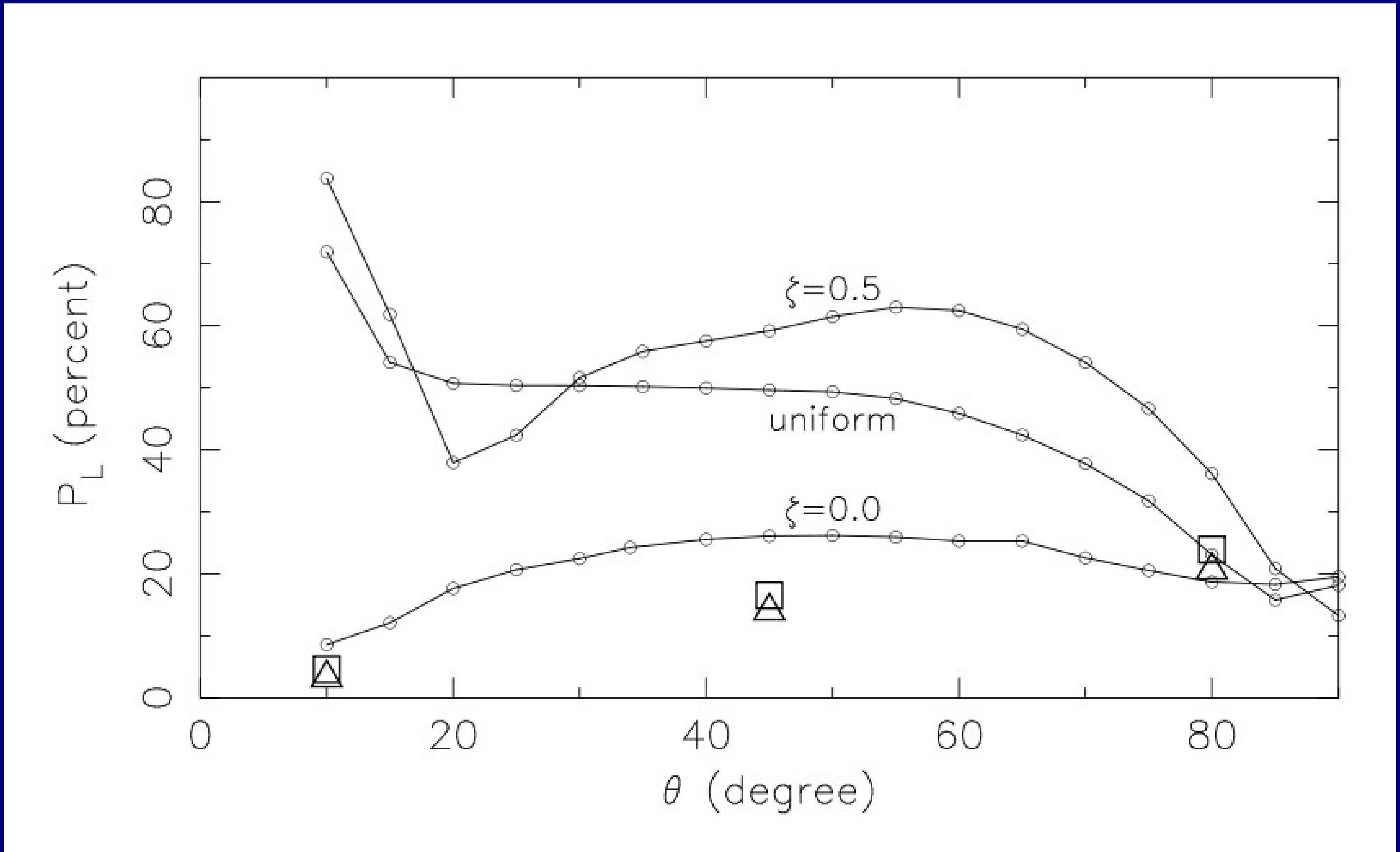
Differences in X-ray polarization are expected due to differences in geometry and polarization state of seat photons.

What causes the hard X-ray emission of jets?

Modeling:

Polarized synchrotron photons injected at different positions of the jet (SSC, ζ)

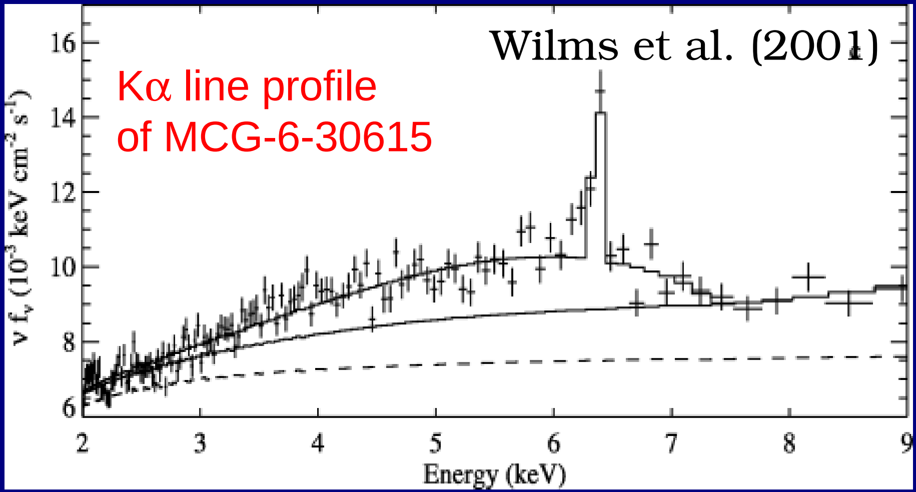
Unpolarized photons (EC) from a disk (square) or the CMB (triangles)



McNamara, Kuncic & Wo (2009)

See also:
Bjornssen & Blumenthal (1982)
Celotti & Matt (1994)

At a given viewing angle, there are characteristic differences in the polarization percentage between the two interpretations.

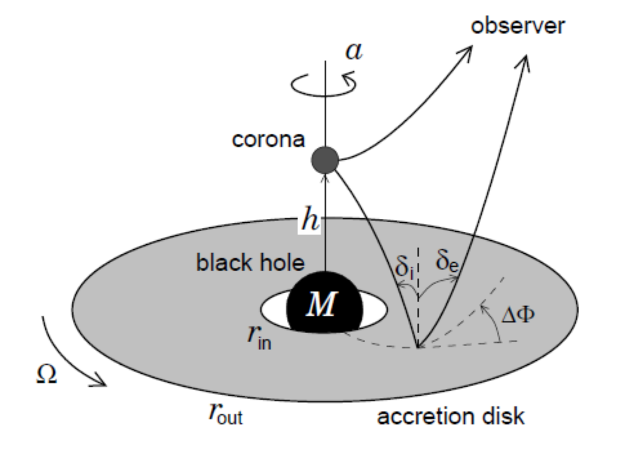


Disentangling the nature of broad iron Kα lines

Marin et al. (2012)

Relativistic case

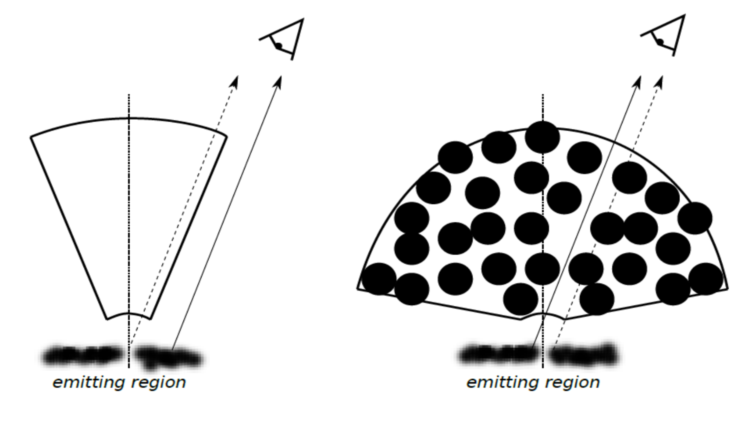
Re-emitted radiation from a rotating accretion disc and relativistic ray-tracing



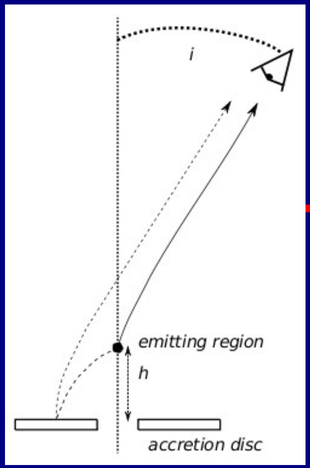
$h = 2.5GM/c^2$
$a = 1$ (Kerr)
(Miniutti & Fabian 2004)

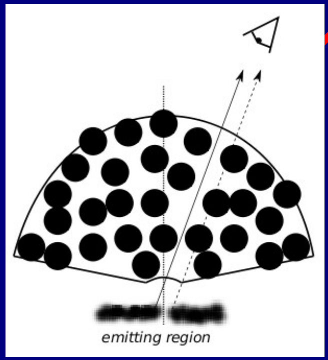
Absorption case

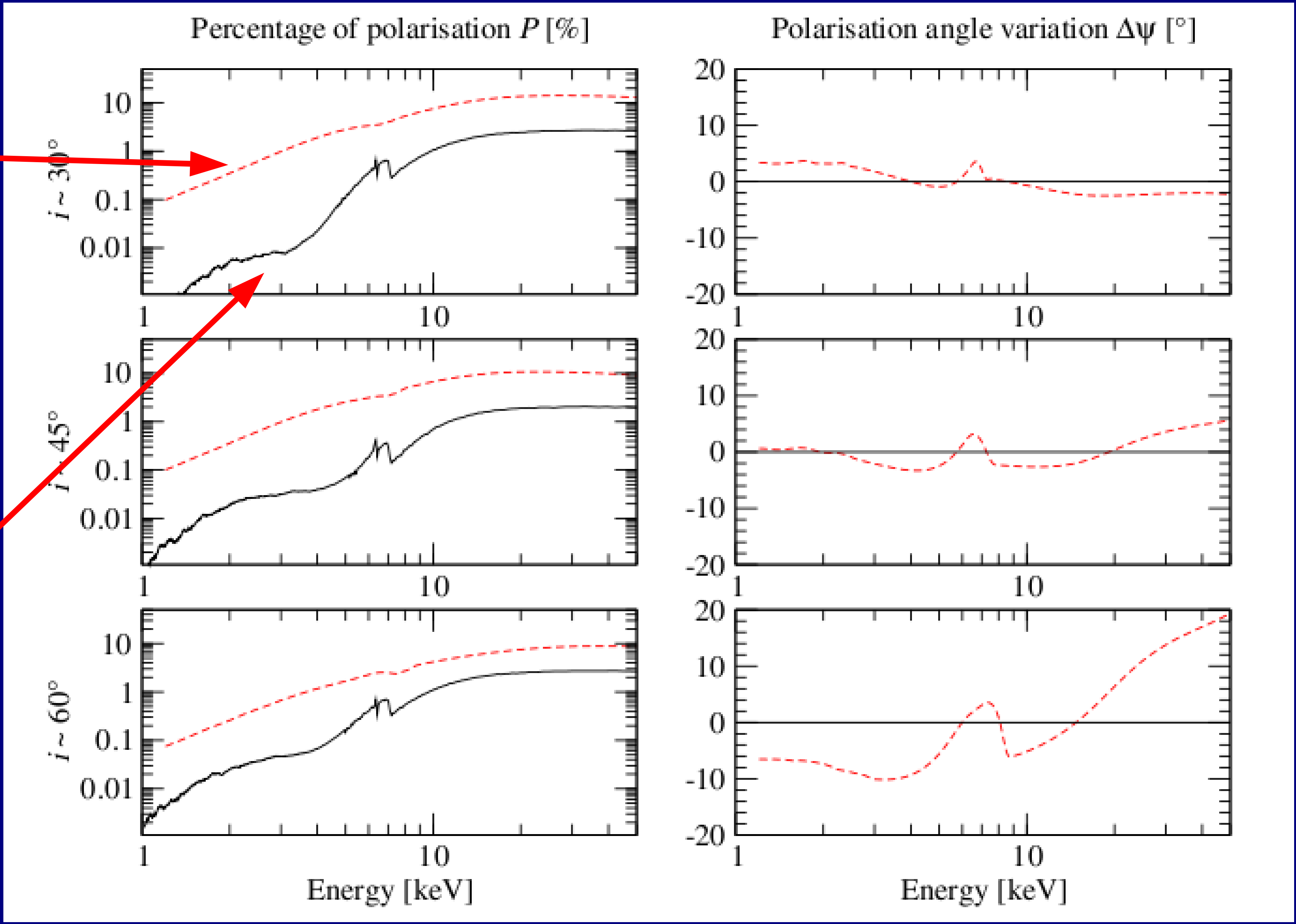
Optically thick, low ionized absorber partially covering the emission region (Miller et al. 2008/2009)



Unravel the nature of broad iron Kα lines







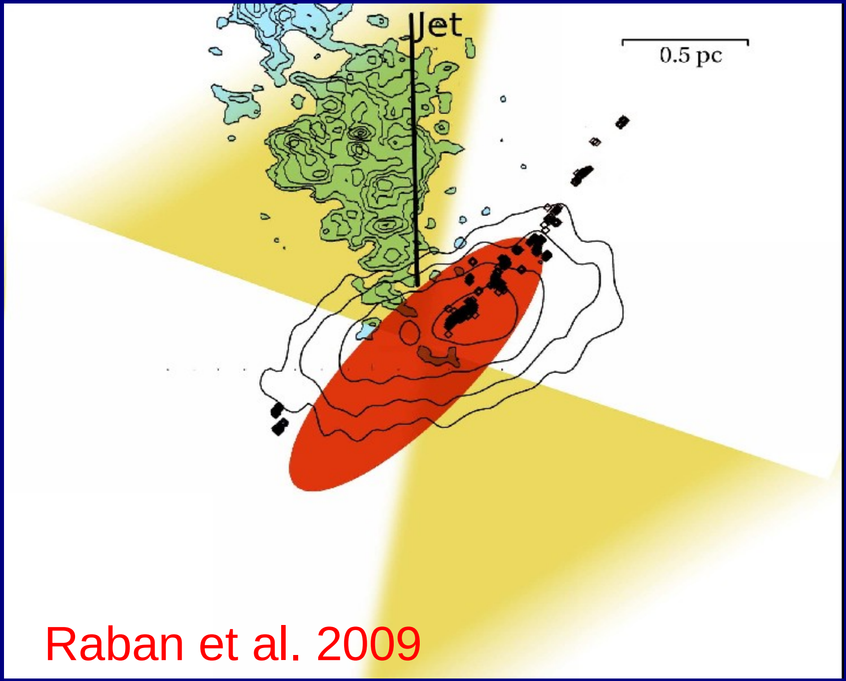
Marin et al. (2012)

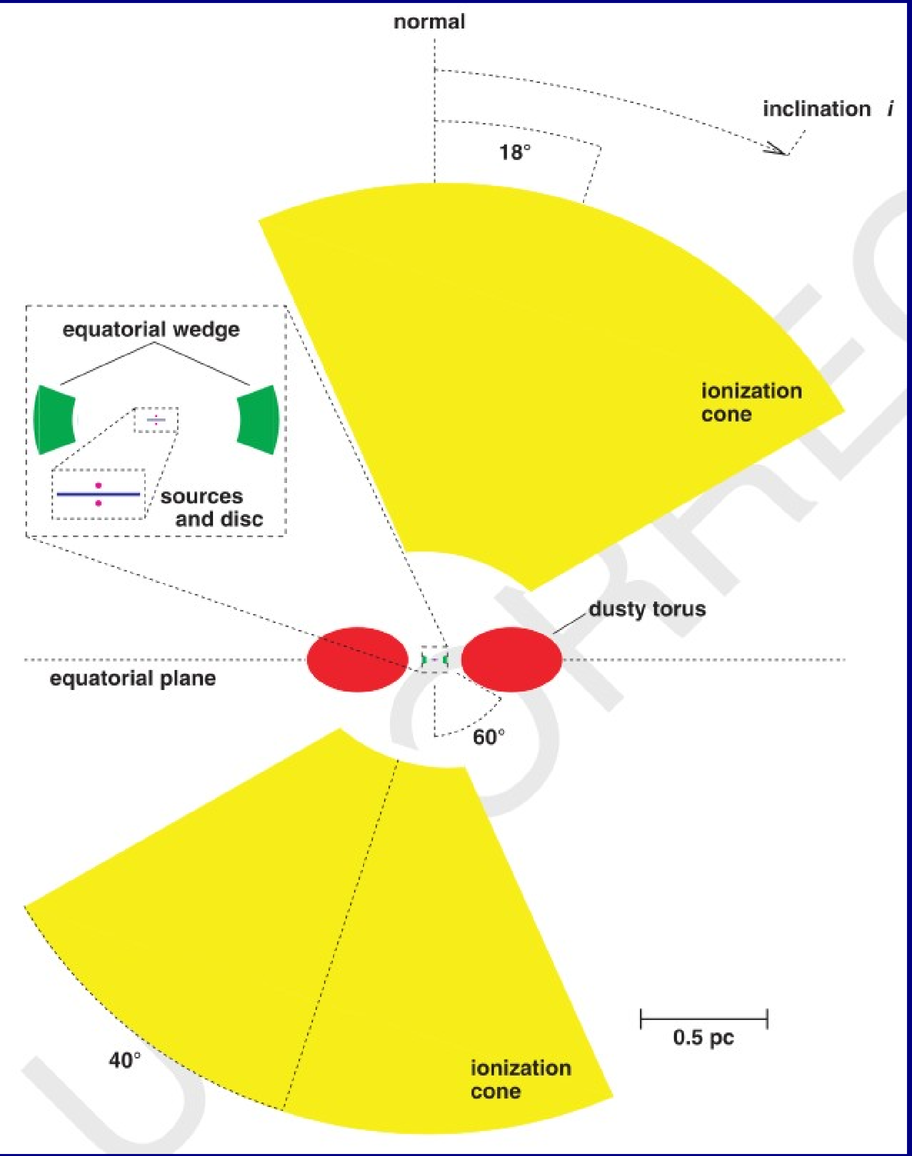
X-ray polarization modeling of NGC 1068

Modeling of an irradiated accretion disk, a dusty torus with Θ=60°, and inclined outflows as suggested by Raban et al. (2009).

Goosmann & Matt 2011

Marin, Goosmann & Dovciak (2012)





Possibility to constrain the relative angle between torus and outflows by broad-band polarimetry!

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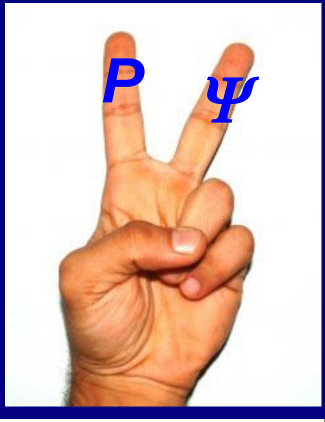

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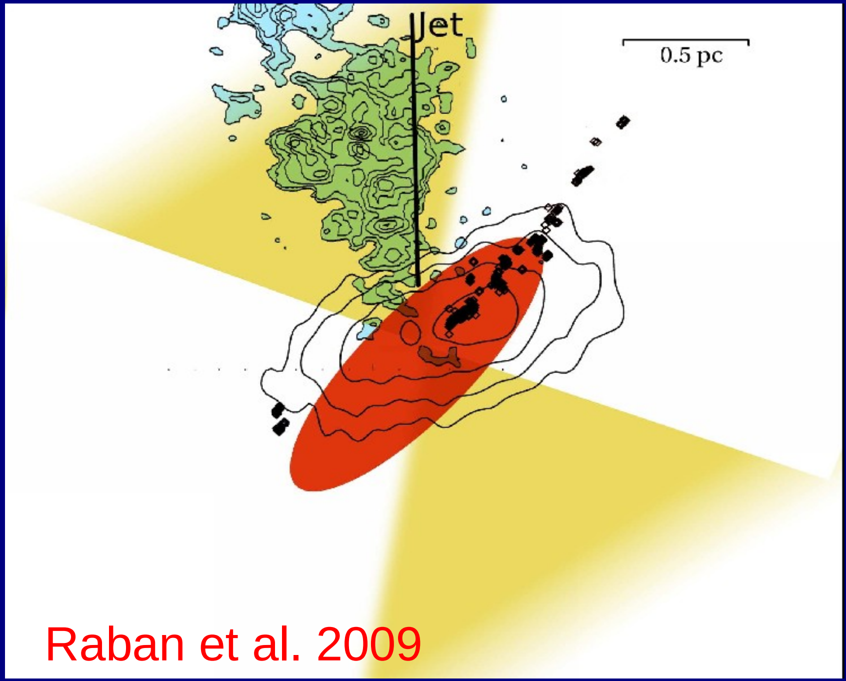
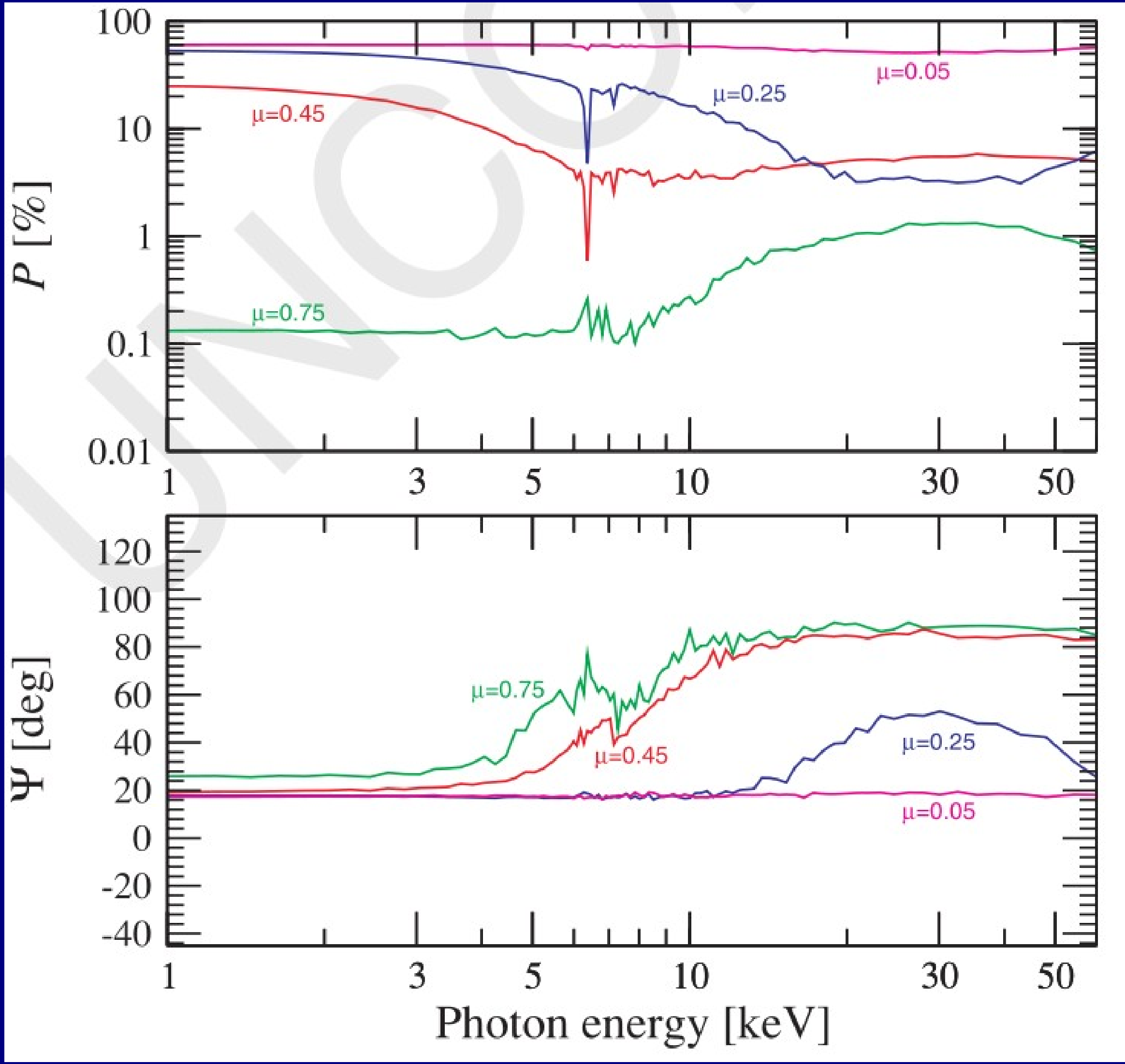
Goosmann & Matt 2011, Marin, Goosmann & Dovciak (2012)





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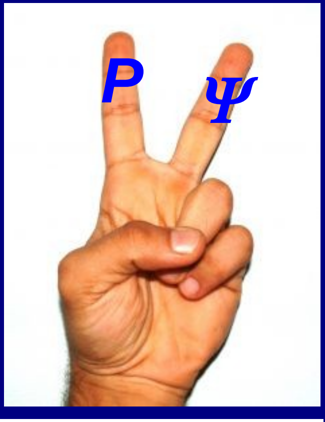

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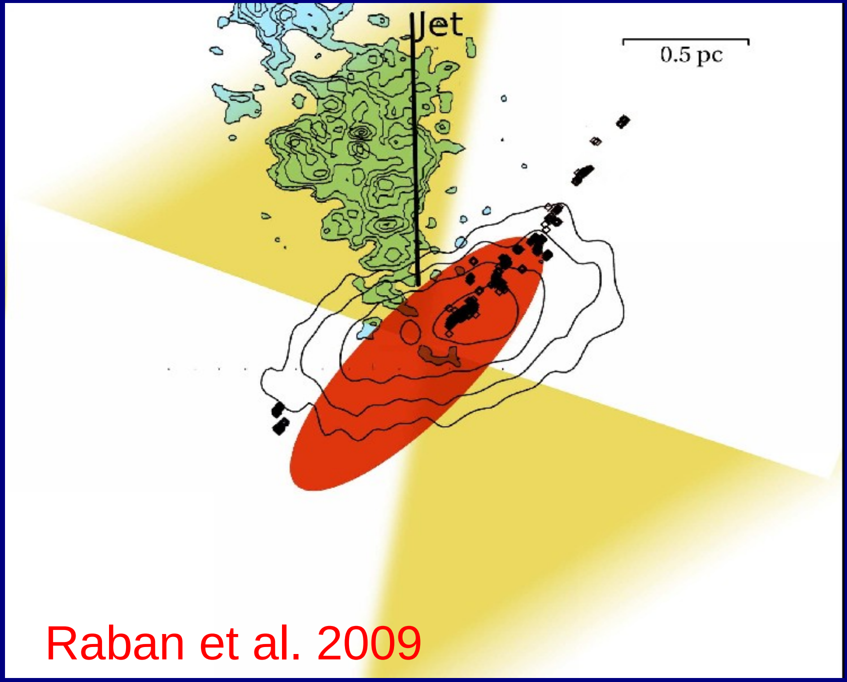

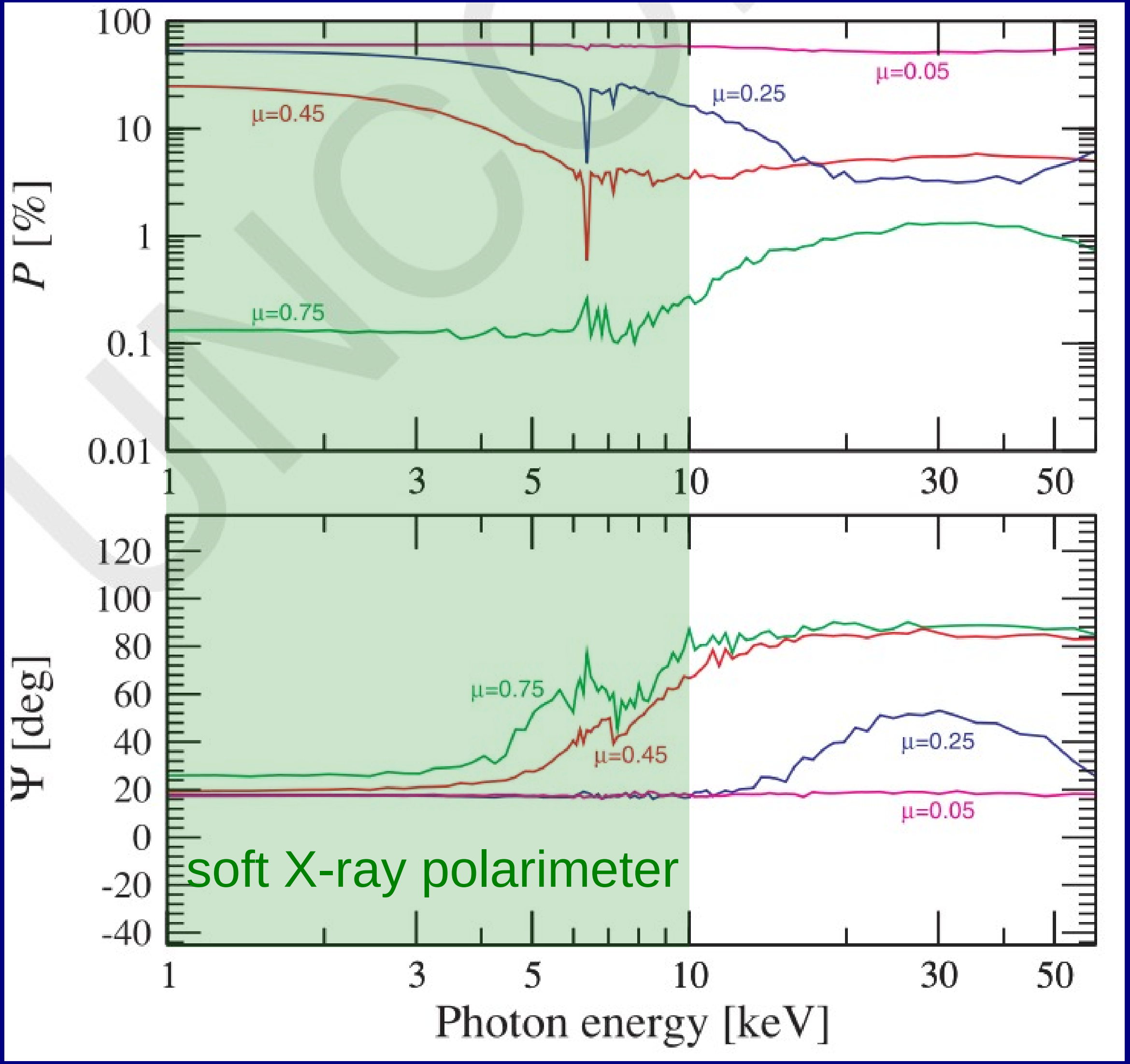

Possibility to constrain the relative angle between torus and outflows by broad-band polarimetry!

WHAT I NEGLECTED...

This talk did not cover all important aspects of X-ray polarimetry. I focused on the effects that do not involve strong magnetic fields.

Here are two references to theoretical work on X-ray polarization in magnetized plasma and outflows (+references therein):

Davis et al. (2009) – effects of magnetic fields on the X-ray polarization from an accretion disk

Dordnitsin & Kallman (2011) – X-ray polarization induced by resonant scattering inside MHD winds

Comprehensive overviews for broad-band X-ray polarimetry and its science drivers can be found in Krawczynski et al. (2011) and Tagliaferri et al. (2011).

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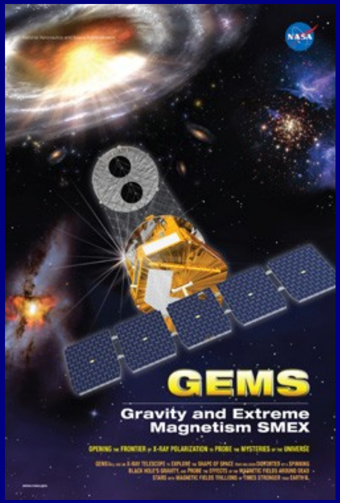
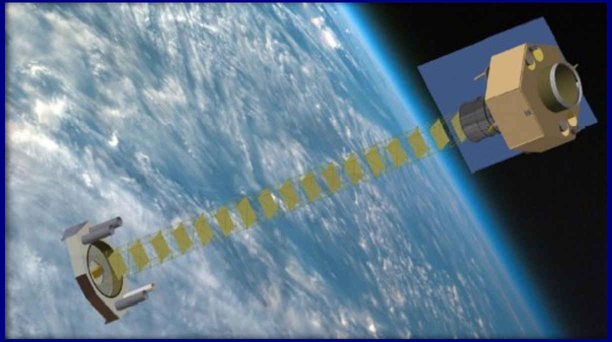
Our dilemma : the so-far missing observational perspective

IXO+XPOL (†2011)



GEM SMEX (†2012)

→ ?



NHXM (†2012)

XIPE (†2012)

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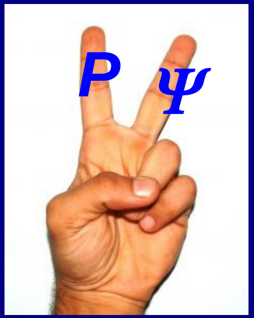
A FEW CONCLUSIONS



• X-ray polarimetry is going to reveal details of the accretion and ejection geometry and the metric around the black hole.

• X-ray polarimetry may discriminate reflection from absorption scenarios in AGN with broad iron Kα lines.

• We need more simulated data for the expected X-ray polarization from a magnetized jet (based on the existing theoretical work).

• Extension to harder X-ray polarimetry (10-35 keV) would be a very useful, following step. The technology is already available.

• **However, most importantly we need a mission project to open this new observational window!**

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