Spotting the misaligned outflows in NGC 1068 using X-ray polarimetry

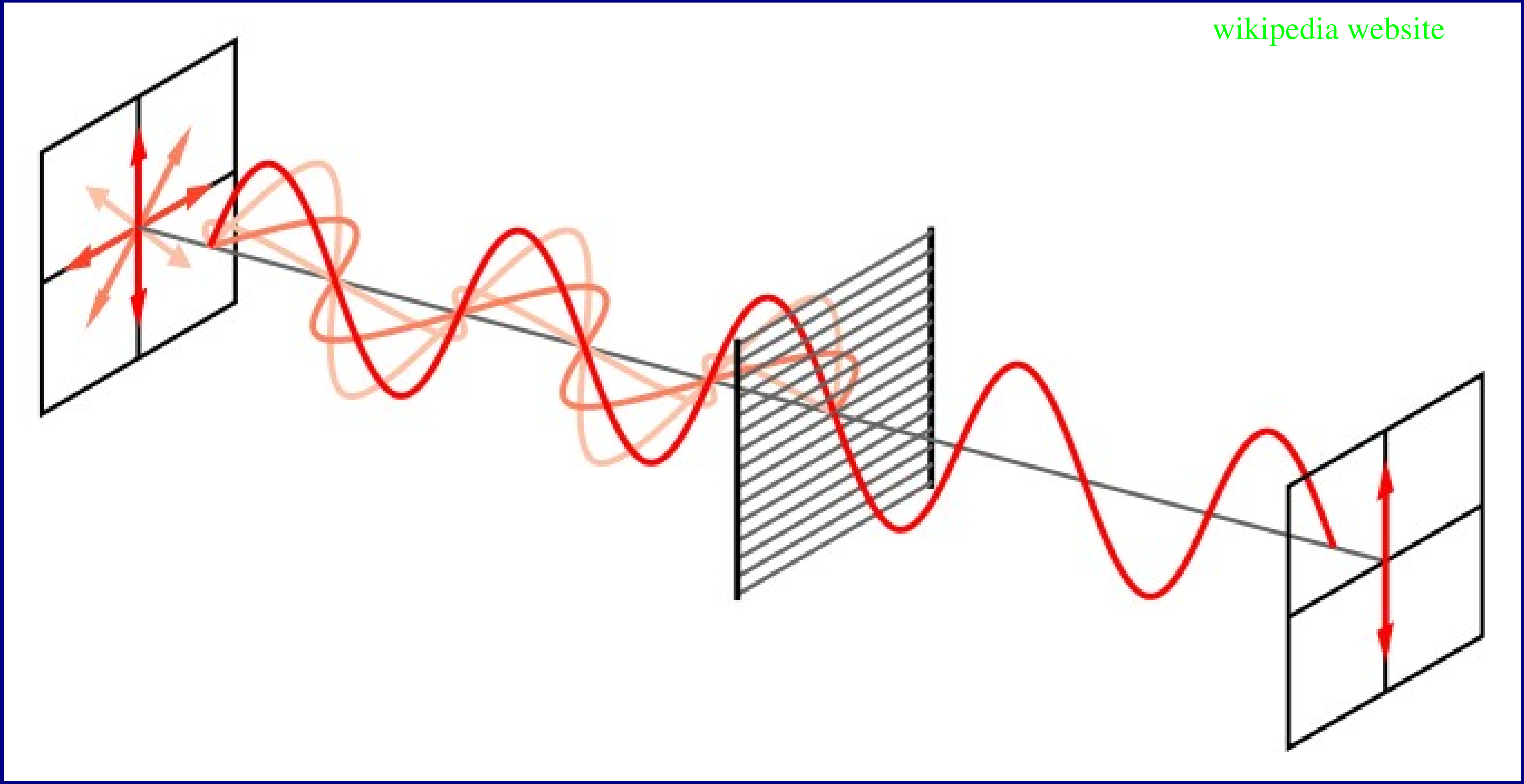
René W. Goosmann
Observatoire astronomique de Strasbourg, France

in collaboration with
Giorgio Matt, Frédéric Marin, and Martin Gaskell

International conference
The X-ray Universe 2011
Berlin, Germany, June 29th 2011

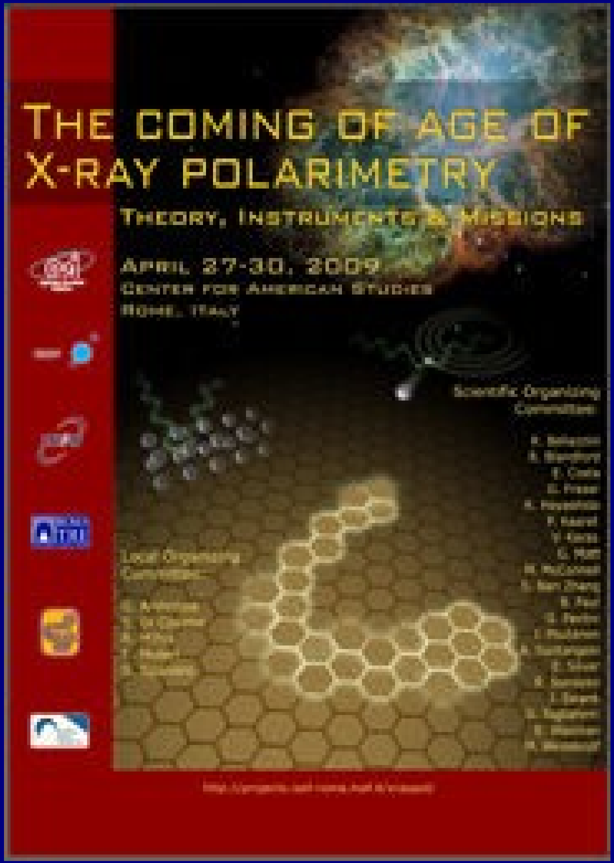
Linear polarization of light

The polarization state of an electromagnetic wave denotes the direction of the electric field vector (classical picture)



Observing multi-wavelength polarization

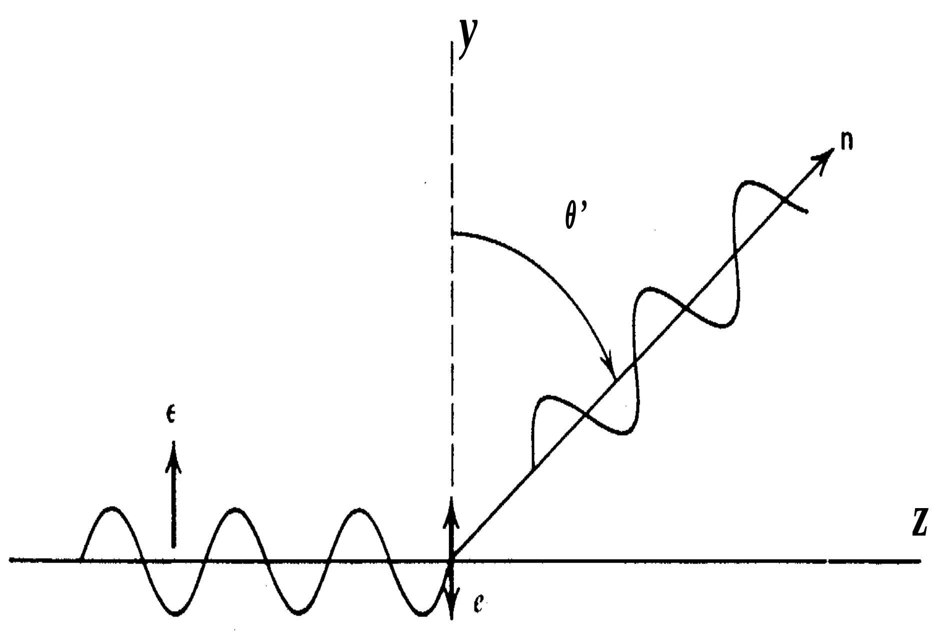
X-ray polarimetry relies on tracing ejected photoionization and Auger electrons



In the optical/UV, birefringent beam-splitters are used to separate the ordinary from the extra-ordinary beam

Scattering-induced polarization

- Electron scattering (Thomson, Compton, Rayleigh scattering)
- Dust (Mie) scattering
- Resonant line scattering



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

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

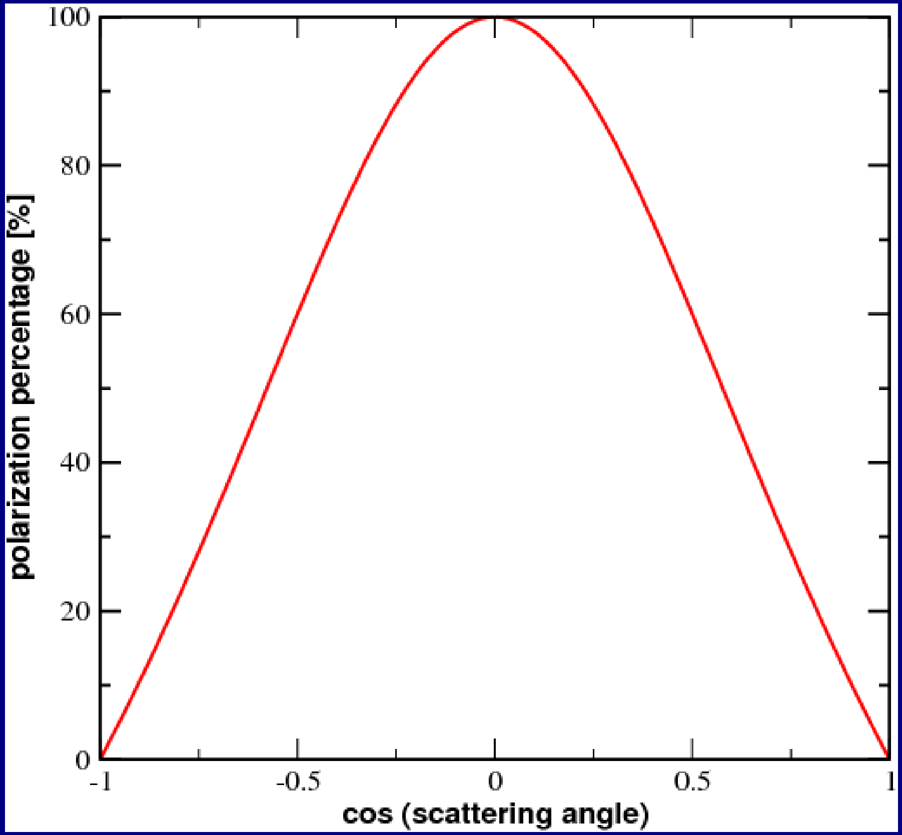
$$\sigma_T = \frac{8\pi}{3} r_0^2 = \frac{8\pi e^4}{3m^2c^4}.$$

Oscillator model for Thomson scattering

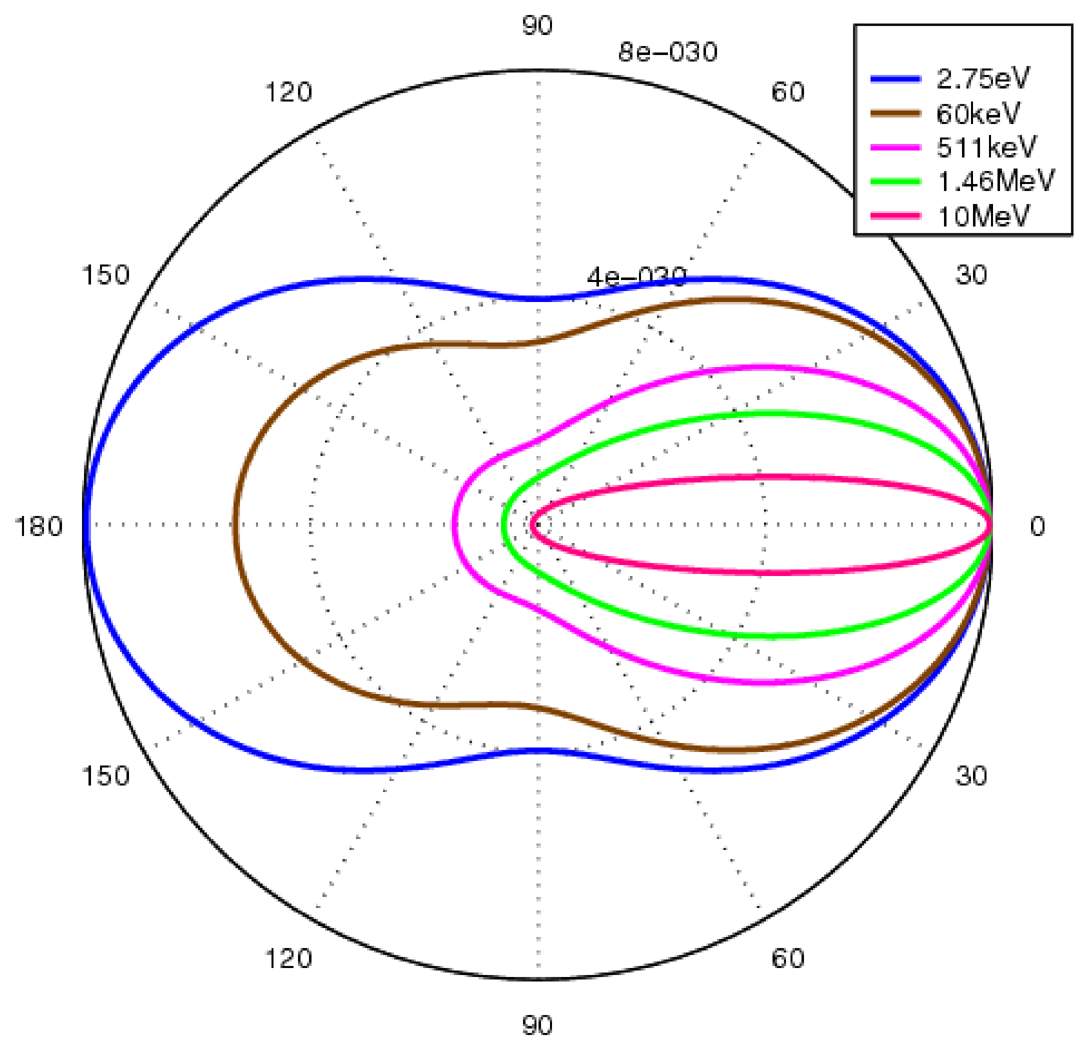
Scattering-induced polarization

- Electron scattering (Thomson, Compton, Rayleigh scattering)

Polarization phase function:



Differential cross section



wikipedia website

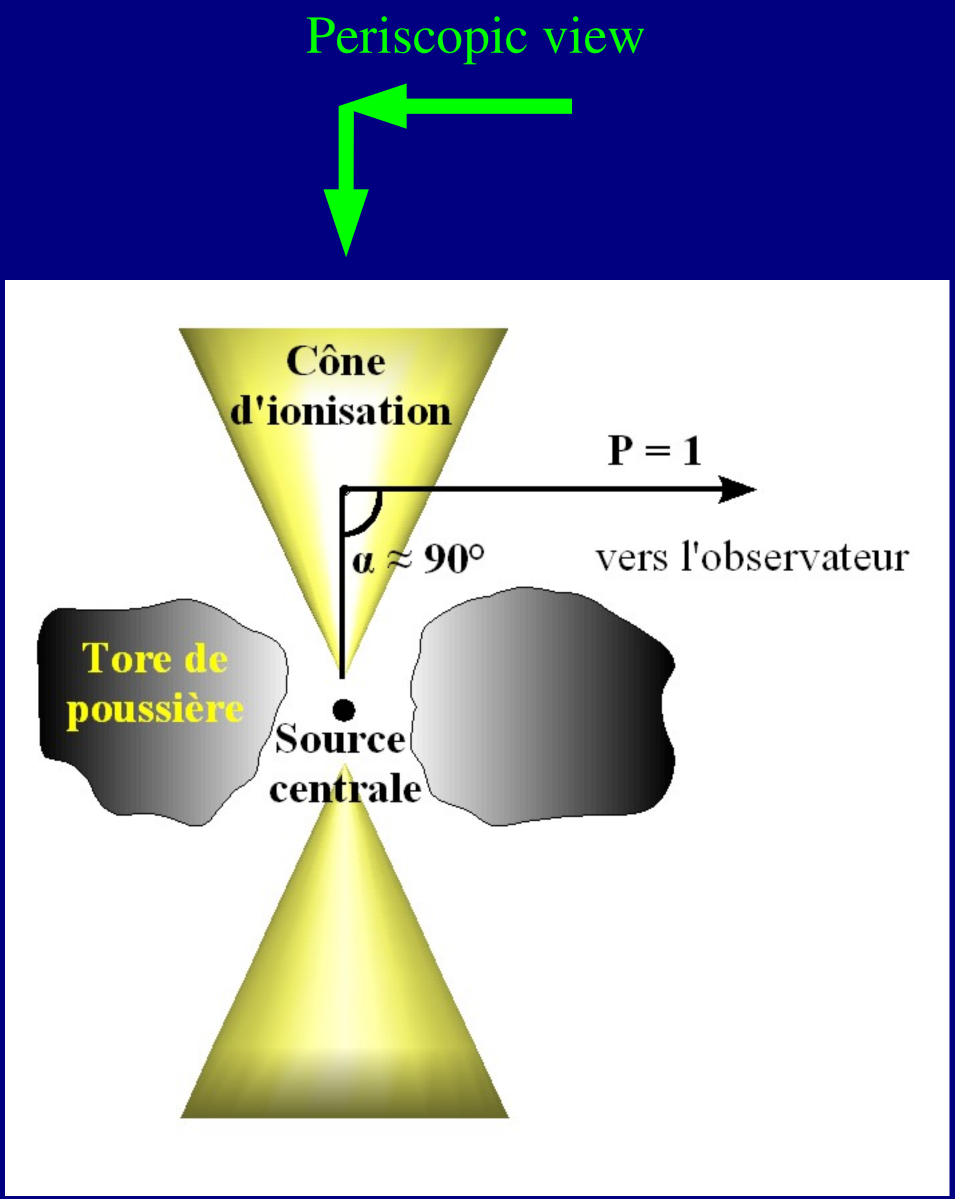
Photon – matter interactions causing (de-)polarization

Photon – particle:

- Electron scattering (Rayleigh, Thomson, and Compton)
- Resonant line scattering
- Dust scattering
- Dichroic absorption

Photon – magnetic field:

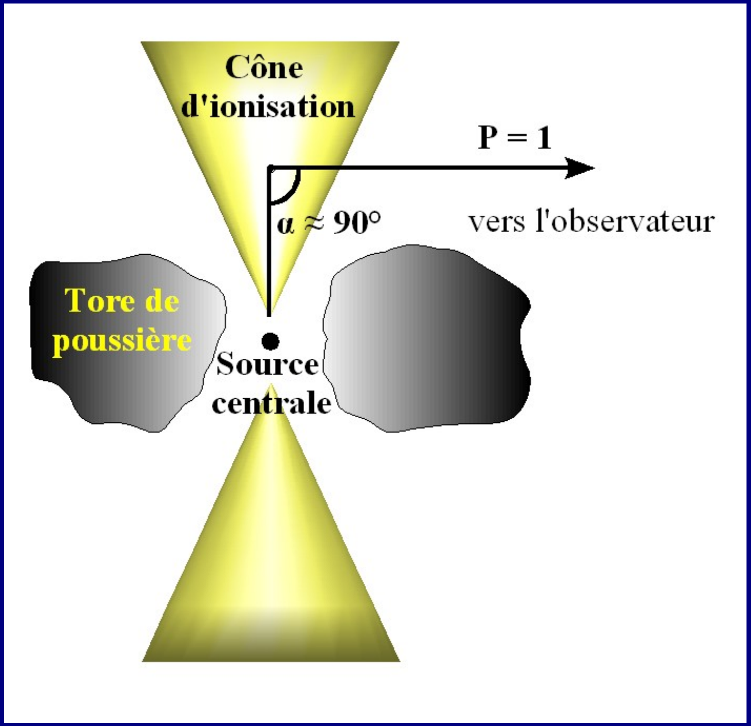
- Synchrotron emission
- Faraday depolarization

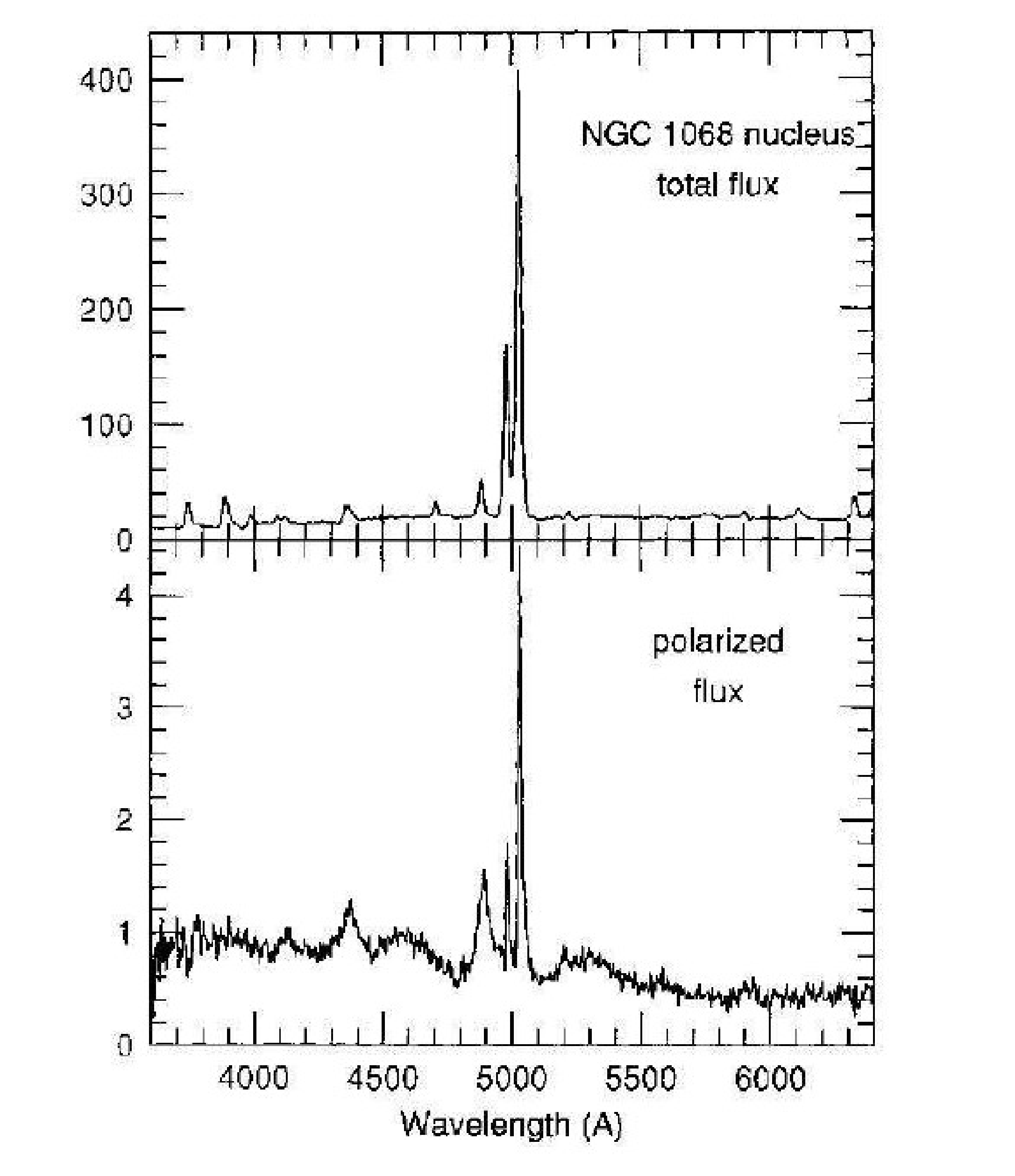


Radio-quiet objects Hidden type-1 AGN

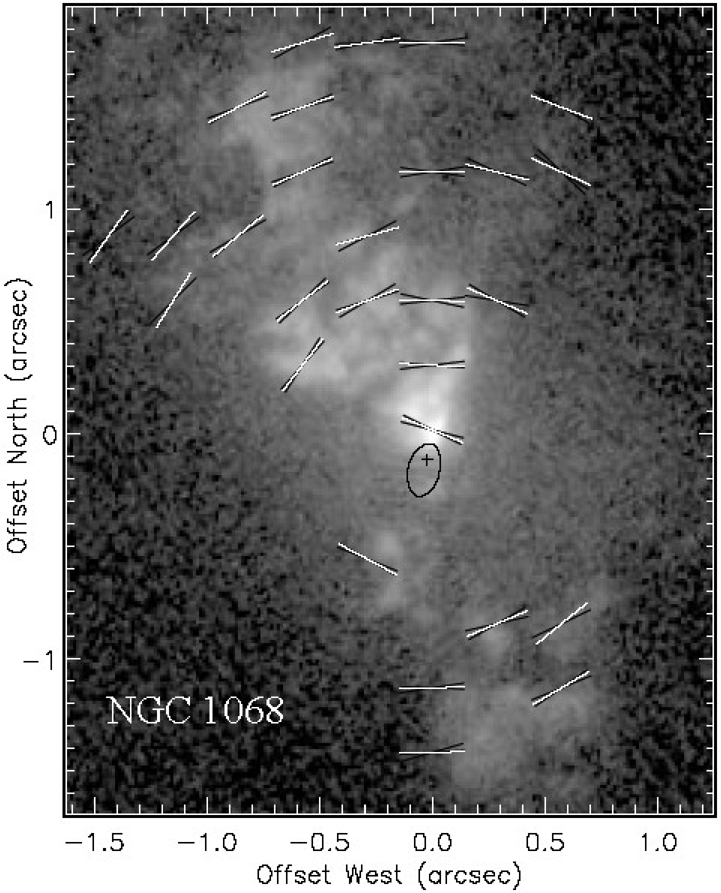
A major break-through for the unified model of NGC 1068 (Antonucci & Miller 1985)

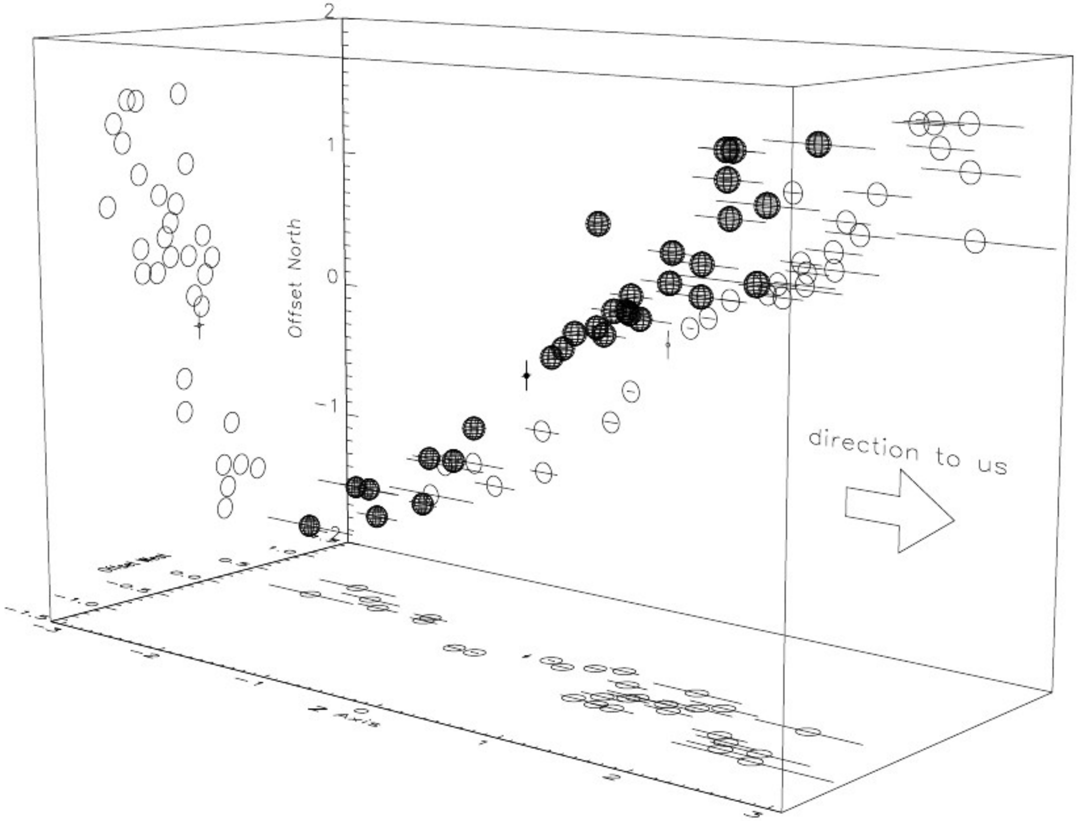
→ **periscope view of AGN in polarized flux**





A 3D image of the scattering clouds in NGC 1068





Capetti et al. 1995

Kishimoto et al. 1999

Phase function of Thomson scattering
Spatial distribution of polarized flux → **3D image of the scattering region!**
Assuming optically thin matter

Radio-quiet objects Hidden type-1 AGN

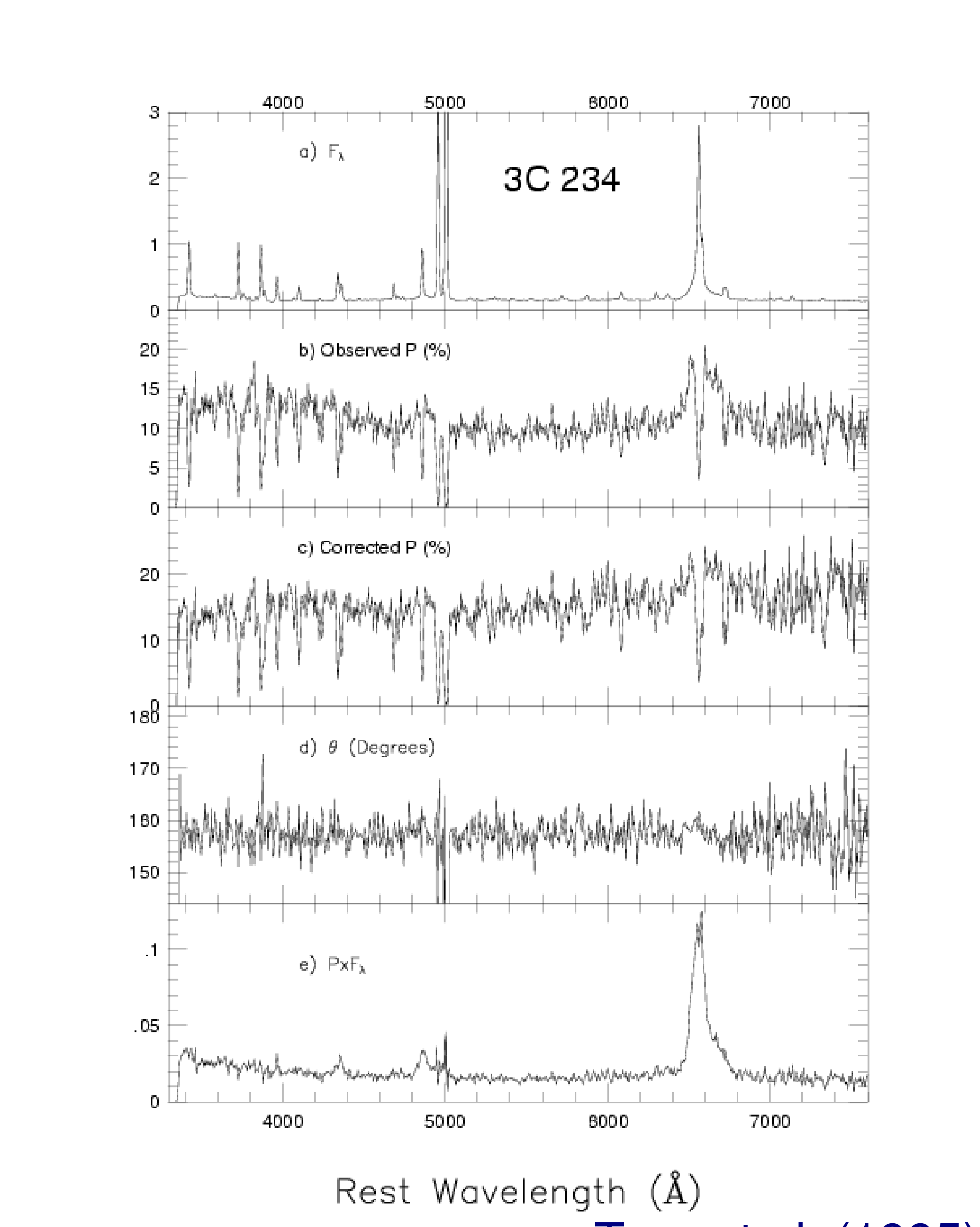
In the following, more and more hidden type-1 nuclei were found in Seyfert 2 galaxies.

The polarization dichotomy of AGN was established:

Type-2 → *P.A.* $\perp$ jet axis

Type-1 → *P.A.* $\parallel$ jet axis,
except for dominant polar scattering

See Antonucci (1993) and
Smith et al. (2002) and
references therein for a summary



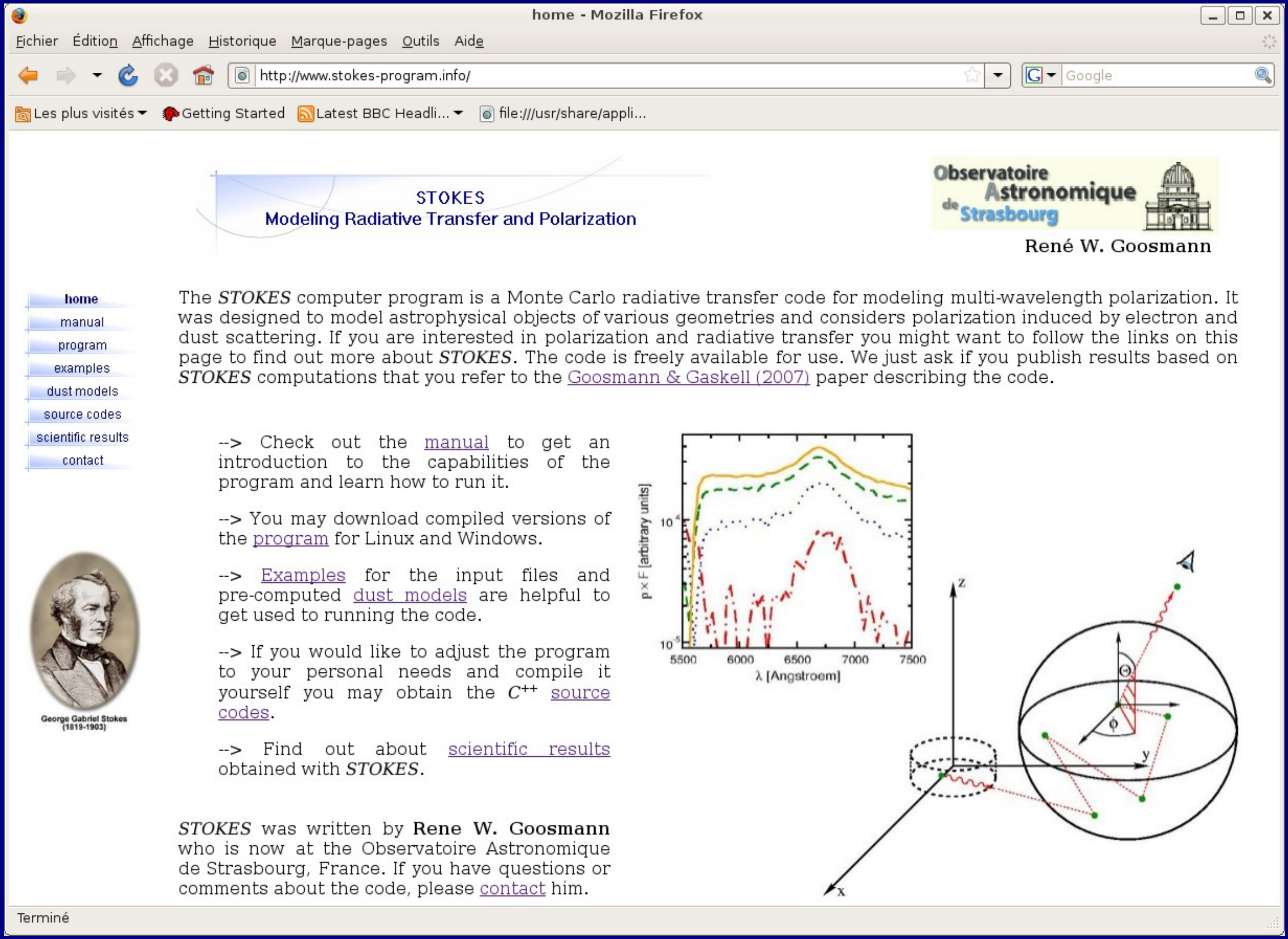
Tran et al. (1995)

Modeling polarization with STOKES

- Monte-Carlo radiative transfer in 3D
- Various geometries for the emission / scattering regions
- polarisation due to (multi-)electron scattering and dust (Mie-)scattering
- Resonant line scattering routines implemented
- Photo- and K-shell ionization
- variabiliy and evolution of the system

Public access

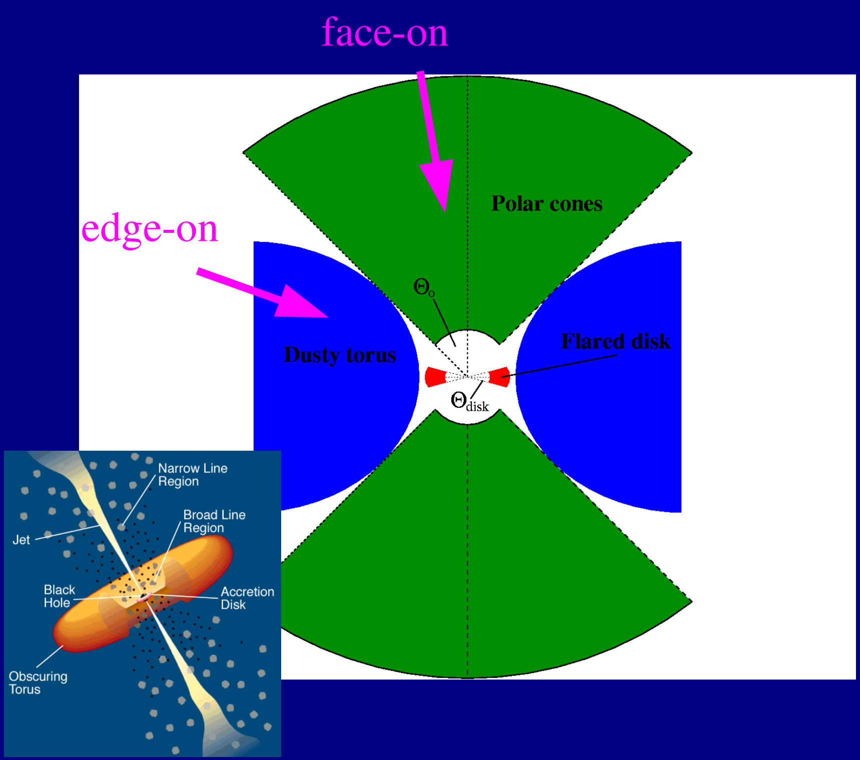
http://www.stokes-program.info/



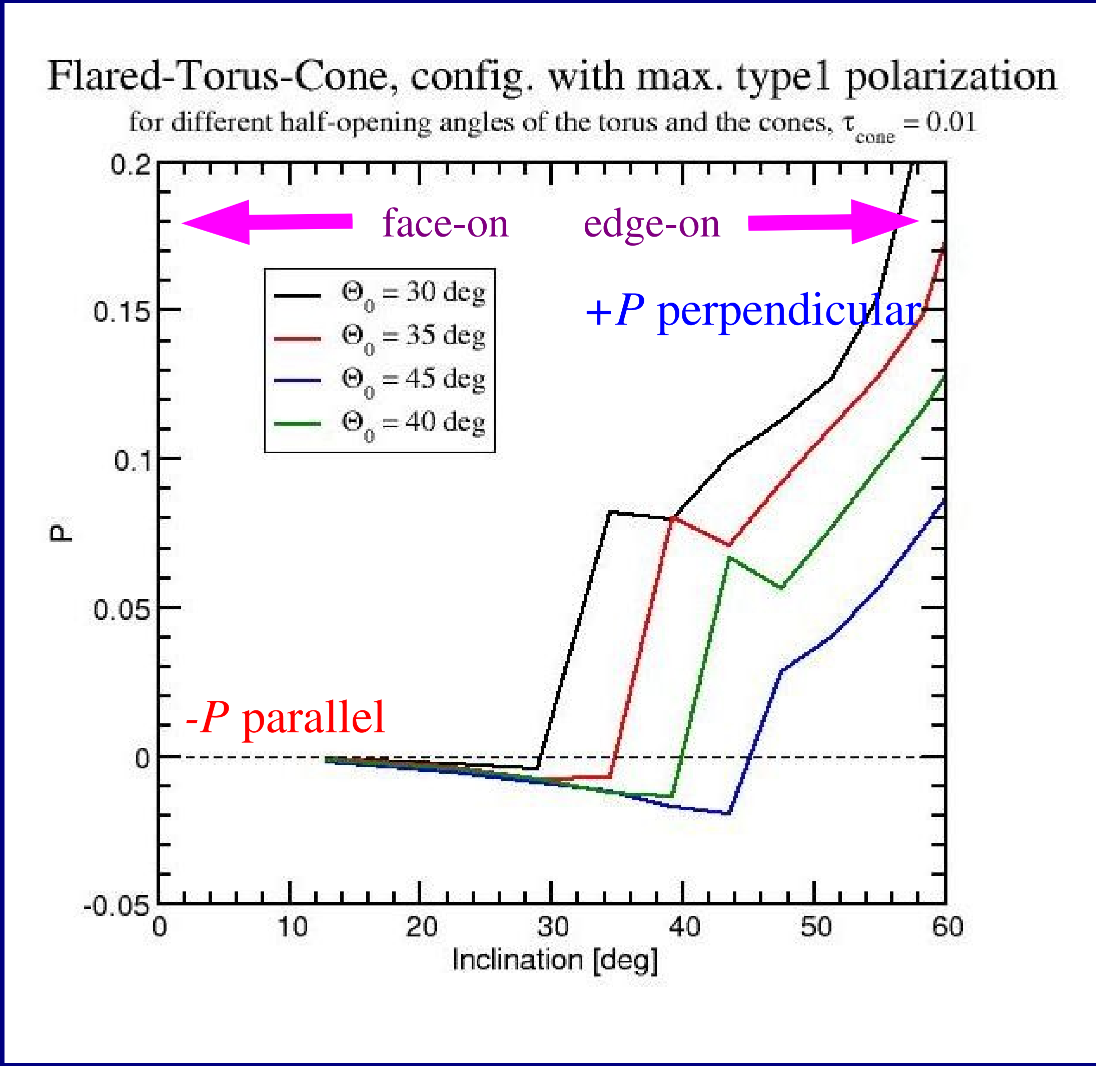
optical/UV

The polarization dichotomy of AGN

Modeling a composition of flared electron disk, dusty torus, and polar electron cones.



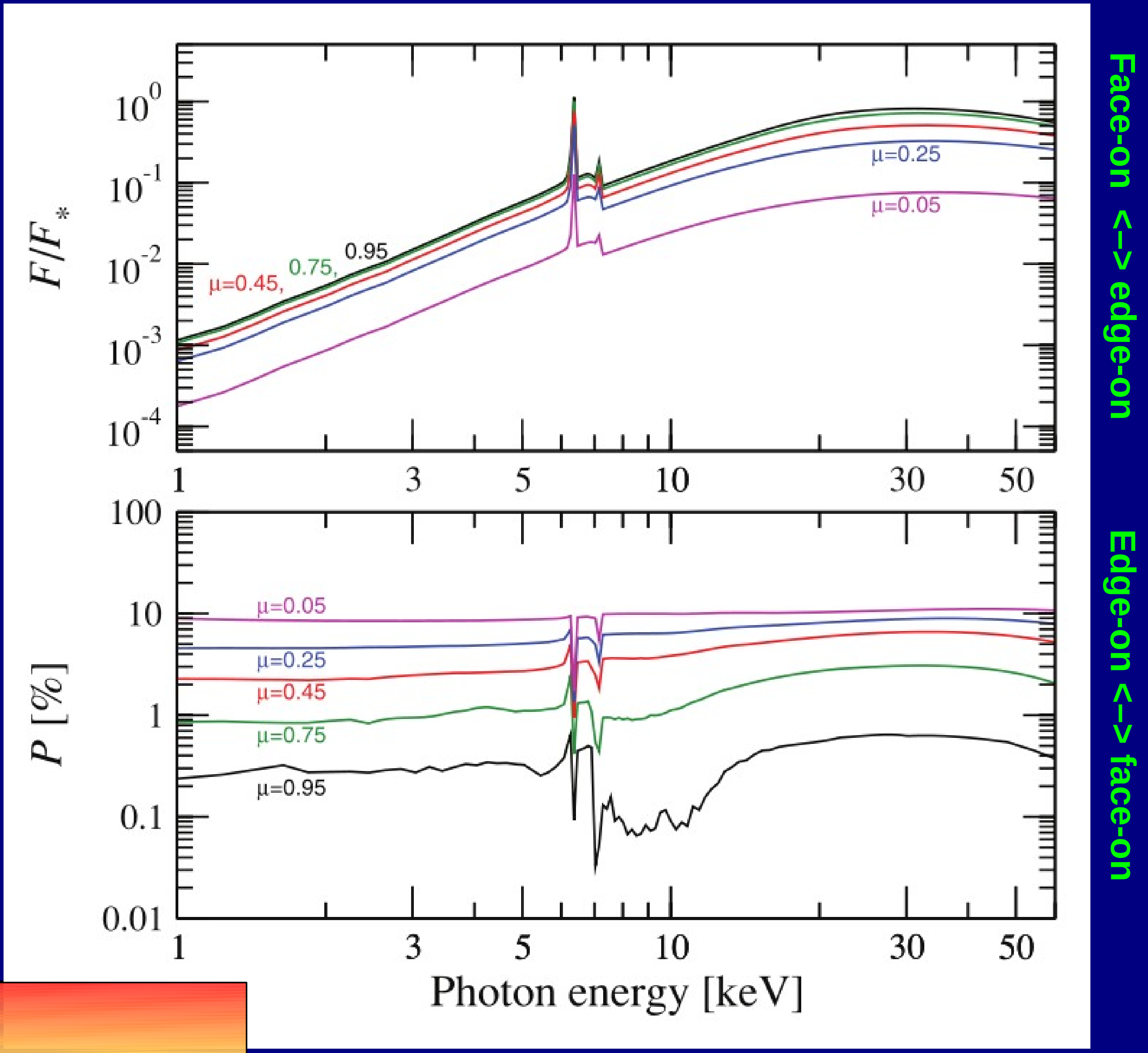
Urry & Padovani (1995)

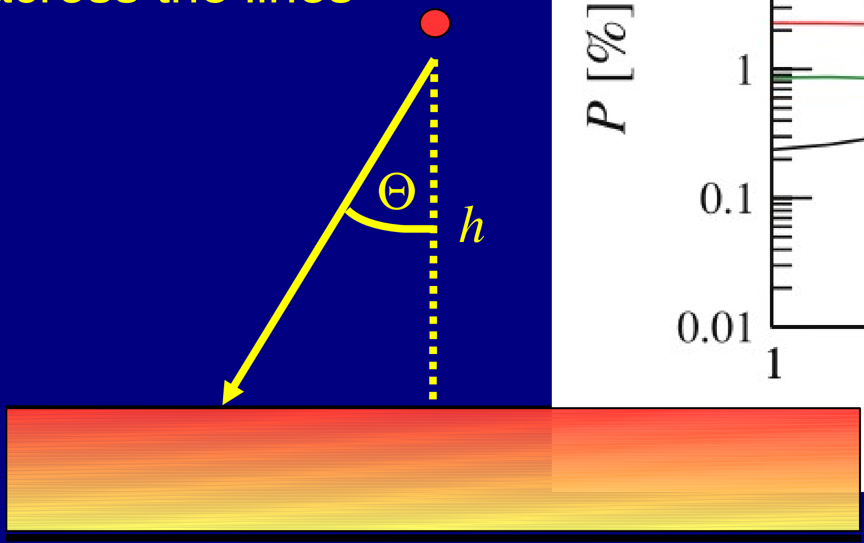


Goosmann et al. (2008)

The X-ray polarization of disk reprocessing

- Polarization is always parallel to the symmetry axis
- *P* rises with inclination
- The Compton hump is slightly more polarized than the soft continuum
- *P* drops steeply across the lines

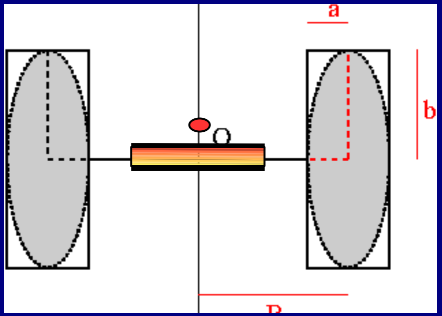


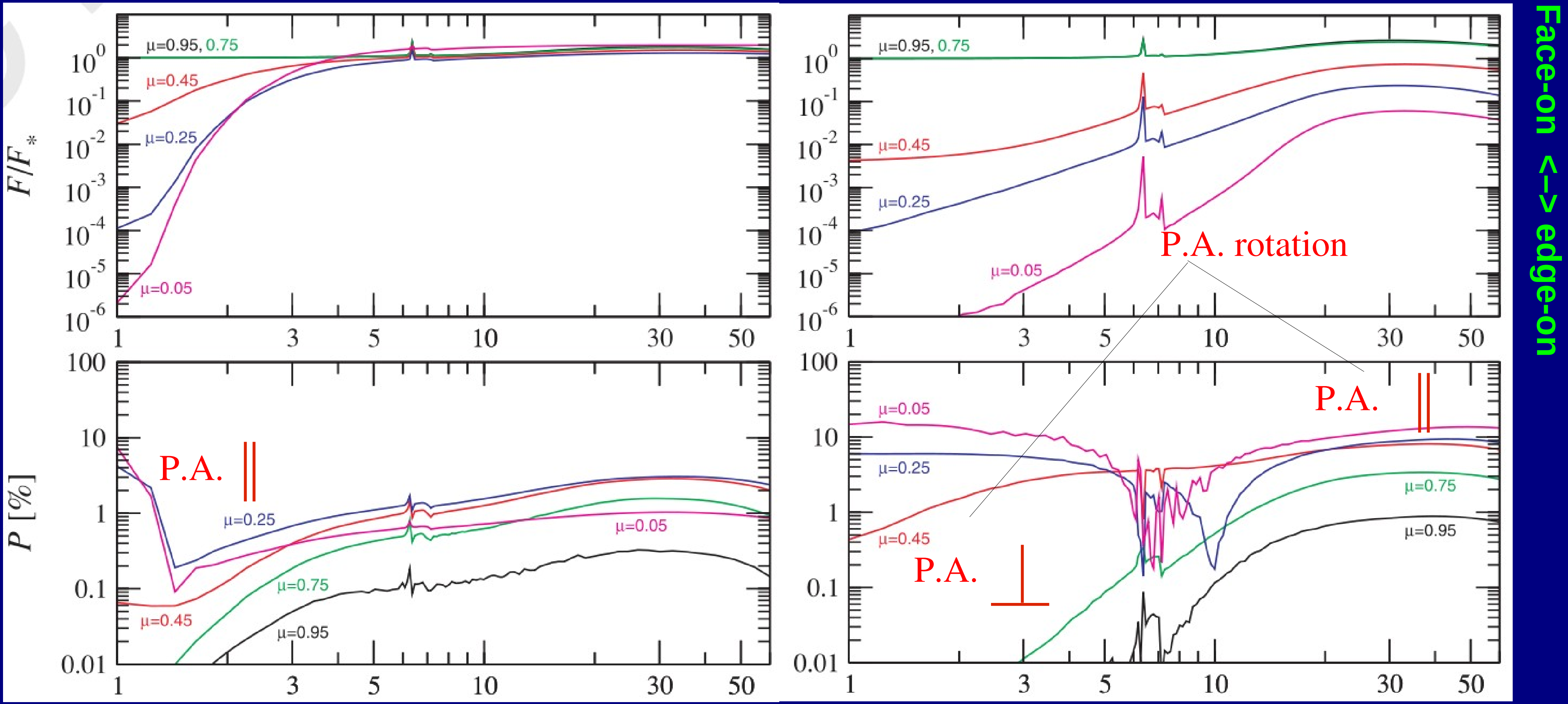


X-ray polarimetry from Compton thicker to thinner...

Modeling of an irradiated accretion disk at the center of a dusty torus with half-opening angle of Q=30°

Goosmann & Matt 2011





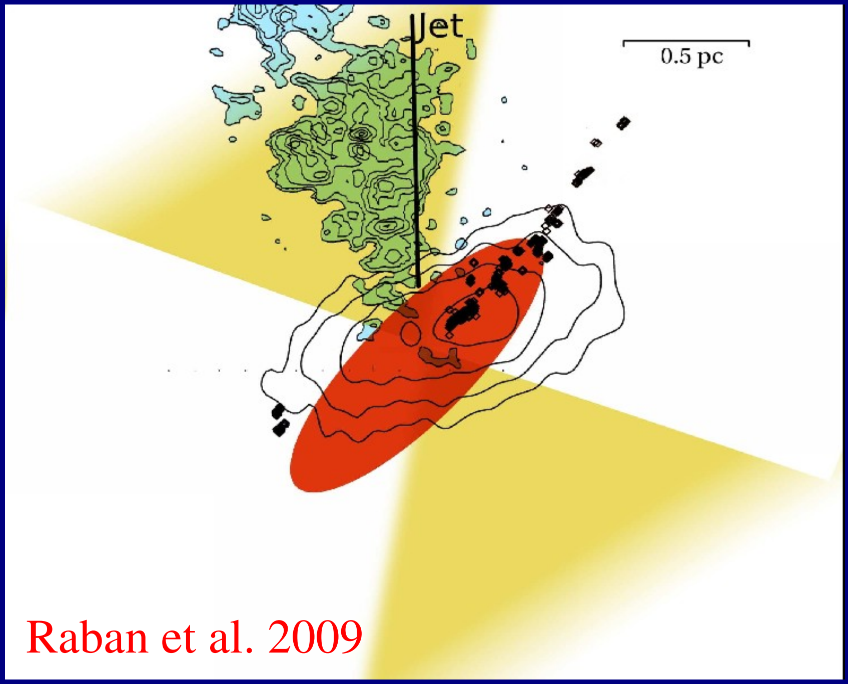
Compton thick

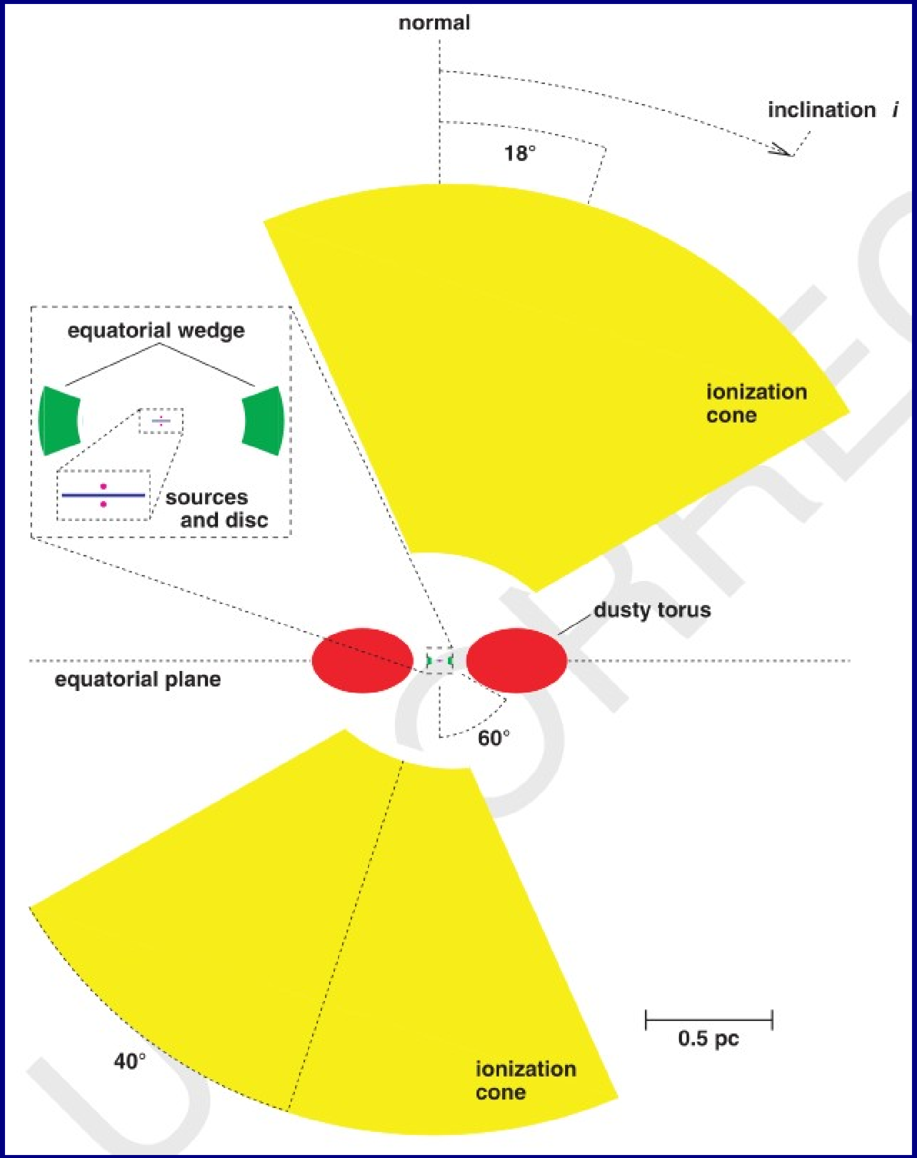
Compton thin

X-ray polarimetry of NGC 1068

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

Goosmann & Matt 2011



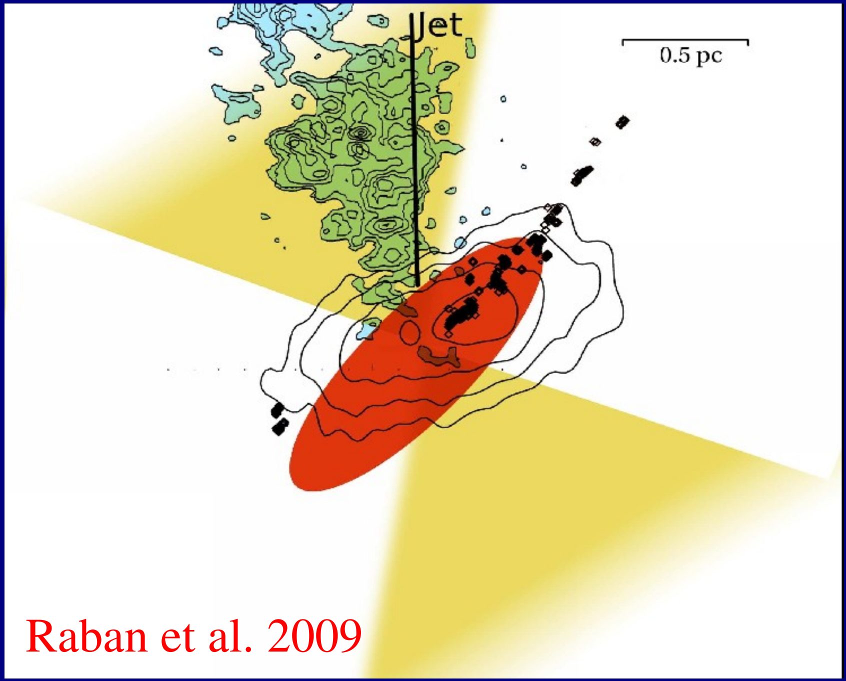


Possibility to measure the relative angle between torus and outflows by broad-band polarimetry!

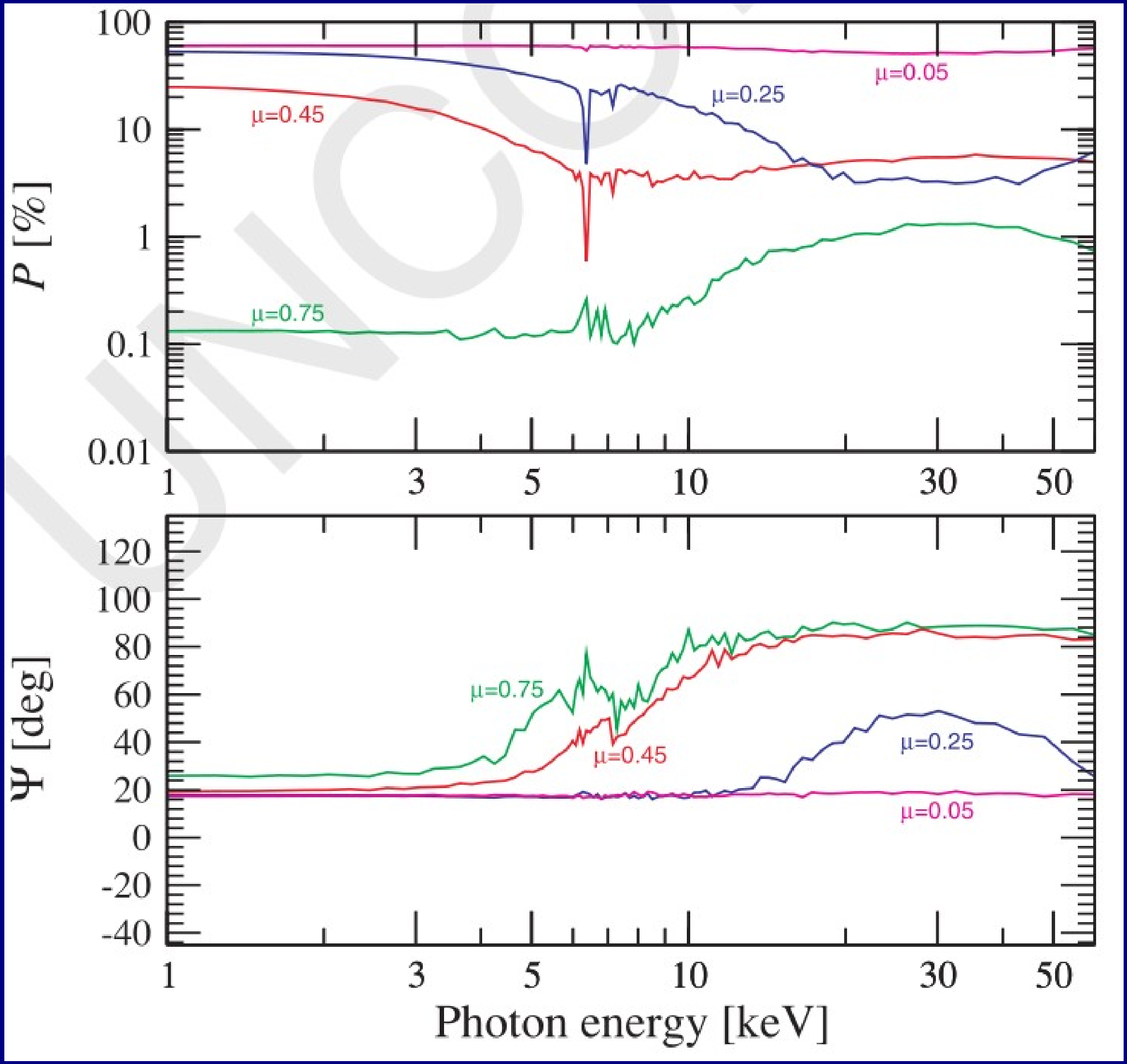
X-ray polarimetry of NGC 1068

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

Goosmann & Matt 2011



Raban et al. 2009



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

X-ray polarimetry of NGC 1068

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

Table 2. Rotation $\Delta\psi = \psi(20\,\mathrm{keV}) - \psi(2\,\mathrm{keV})$ of the polarization angle and range of the polarization percentage P between 20 and 2 keV for the two values of τ_{cone} examined in Section 4.3 (columns 1 and 2) and Section 4.4 (columns 3 and 4).

Viewing angle i	$\tau_{\mathrm{cone}} = 0.03$ $\Delta\psi$ (°), ΔP (per cent)	$\tau_{\mathrm{cone}} = 0.3$ $\Delta\psi$ (°), ΔP (per cent)
$\cos i = 0.45$, $i \approx 63°$	$84.9 - 20.0 = 64.9$ 4.8–21.3	$32.9 - 19.3 = 13.6$ 6.8–36.7
$\cos i = 0.35$, $i \approx 70°$	$74.6 - 18.3 = 56.3$ 2.8–41.3	$23.4 - 18.4 = 5.0$ 13.6–45.6
$\cos i = 0.25$, $i \approx 76°$	$40.6 - 17.8 = 22.8$ 4.0–50.3	$20.3 - 17.9 = 2.4$ 25.8–51.0
$\cos i = 0.15$, $i \approx 81°$	$23.4 - 17.5 = 5.9$ 16.6–56.9	$18.6 - 17.6 = 1.0$ 43.5–55.1
$\cos i = 0.05$, $i \approx 87°$	$18.7 - 17.5 = 1.2$ 52.7–60.2	$17.9 - 17.3 = 0.6$ 55.3–57.7

Viewing a…	…	…$_{\mathrm{e}} = 0.3$ (equat. wedge) (°), ΔP (per cent)
$\cos i = 0.$…	…	… $- 27.3 = 12.6$ …15.9
$\cos i = 0.$…	…	… $- 20.0 = 4.7$ …44.6
$\cos i = 0.$…	…	… $- 19.4 = 1.5$ …49.6
$\cos i = 0.$…	…	… $- 18.9 = 0.3$ …53.7
$\cos i = 0.$…	…	… $- 18.6 = -0.2$ …56.4

Intermediate view <–> edge-on

Matt 2011

X-ray polarimetry of NGC 1068

Modeling of an irradiated accretion disk, a dusty torus with $\Theta = 60°$, inclined outflows as suggested by Raban et al. (2009).
including an equatorial scattering wedge

Table 2. Rotation $\Delta\psi = \psi(20\,\mathrm{keV}) - \psi(2\,\mathrm{keV})$ of the polarization angle and range of the polarization percentage P between 20 and 2 keV for the two values of τ_{cone} examined in Section 4.3 (columns 1 and 2) and Section 4.4 (columns 3 and 4).

Viewing angle i	$\tau_{\mathrm{cone}} = 0.03$ (equat. wedge) $\Delta\psi$ (°), ΔP (per cent)	$\tau_{\mathrm{cone}} = 0.3$ (equat. wedge) $\Delta\psi$ (°), ΔP (per cent)
$\cos i = 0.45$, $i \approx 63°$	$85.9 - 78.4 = 7.5$ 7.7–6.9	$39.9 - 27.3 = 12.6$ 7.2–15.9
$\cos i = 0.35$, $i \approx 70°$	$75.8 - 20.1 = 55.7$ 4.5–41.3	$24.7 - 20.0 = 4.7$ 15.8–44.6
$\cos i = 0.25$, $i \approx 76°$	$47.8 - 19.3 = 28.5$ 4.4–48.8	$20.9 - 19.4 = 1.5$ 26.4–49.6
$\cos i = 0.15$, $i \approx 81°$	$24.8 - 18.8 = 6.0$ 17.0–55.2	$19.2 - 18.9 = 0.3$ 43.8–53.7
$\cos i = 0.05$, $i \approx 87°$	$18.8 - 18.5 = 0.3$ 53.1–58.8	$18.4 - 18.6 = -0.2$ 55.3–56.4

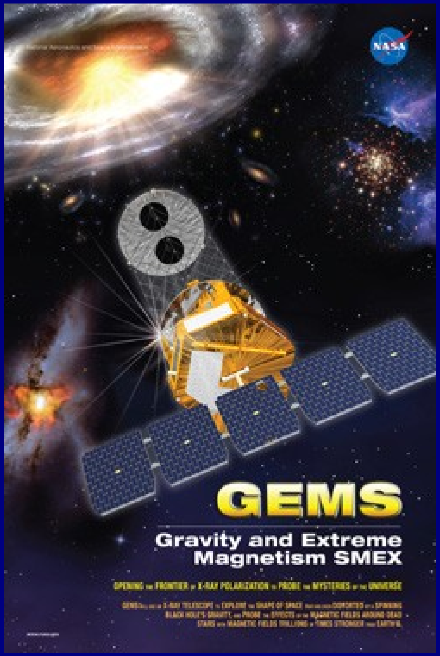
Intermediate view <-> edge-on

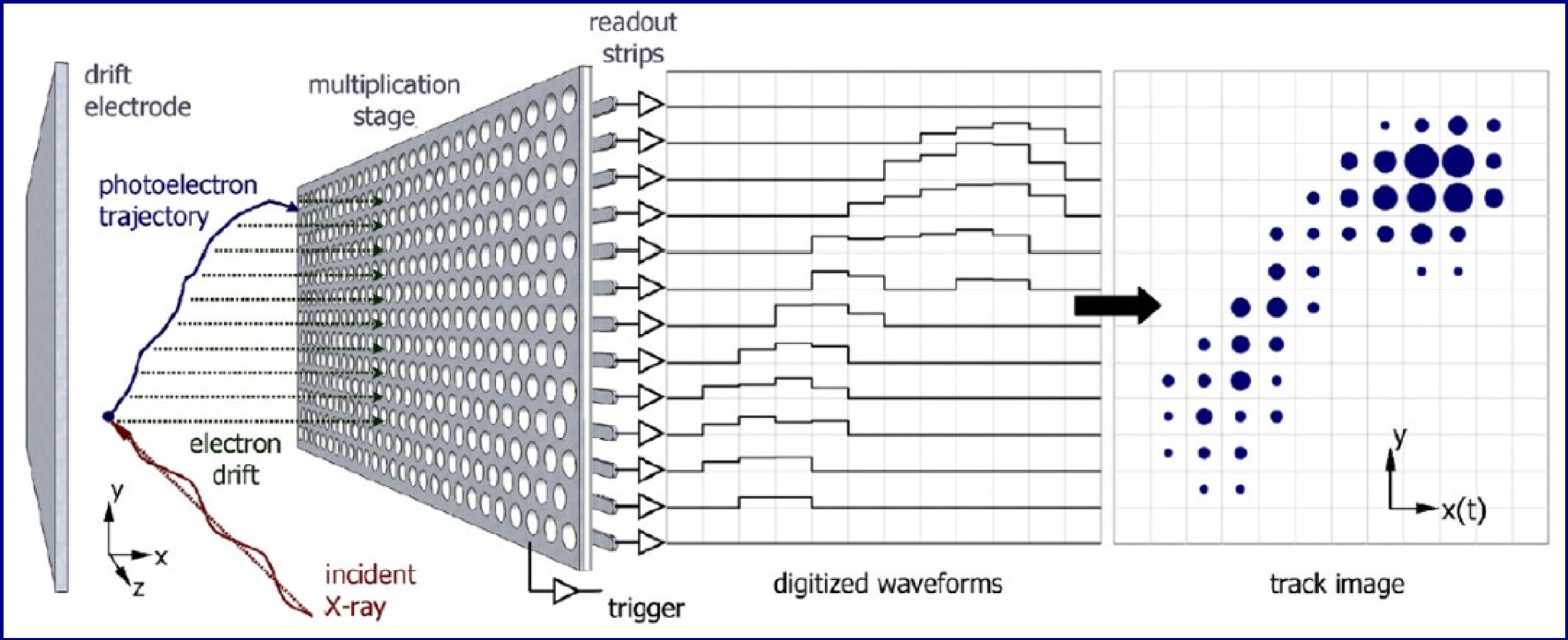
Matt 2011

Observational prospects

Gravity and Extreme Magnetism SMEX (2014)

- NASA small explorer mission explicitly dedicated to X-ray polarimetry
- Stereo focusing telescope connected to the X-ray Polarimeter Instrument (XPI) operating at



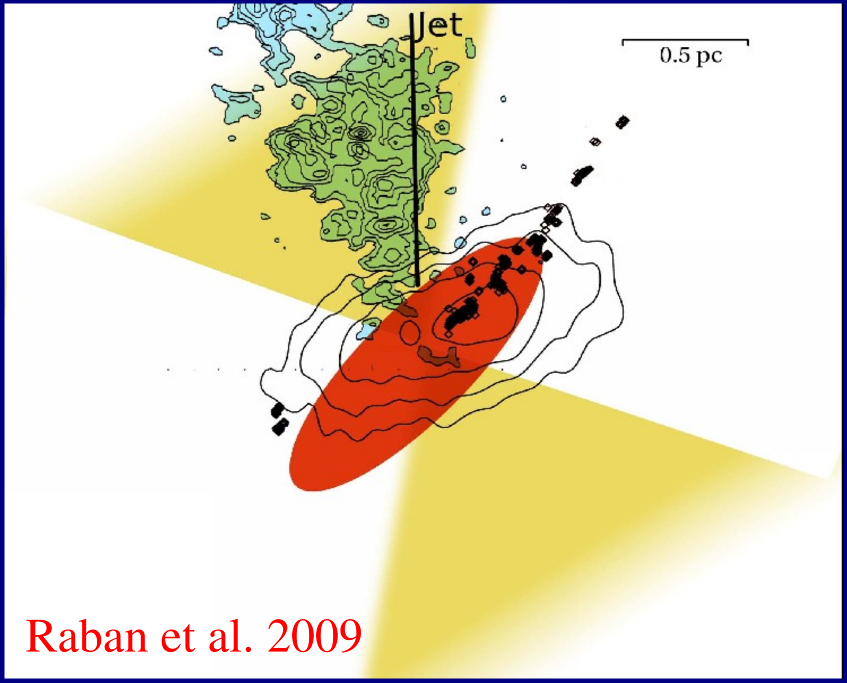


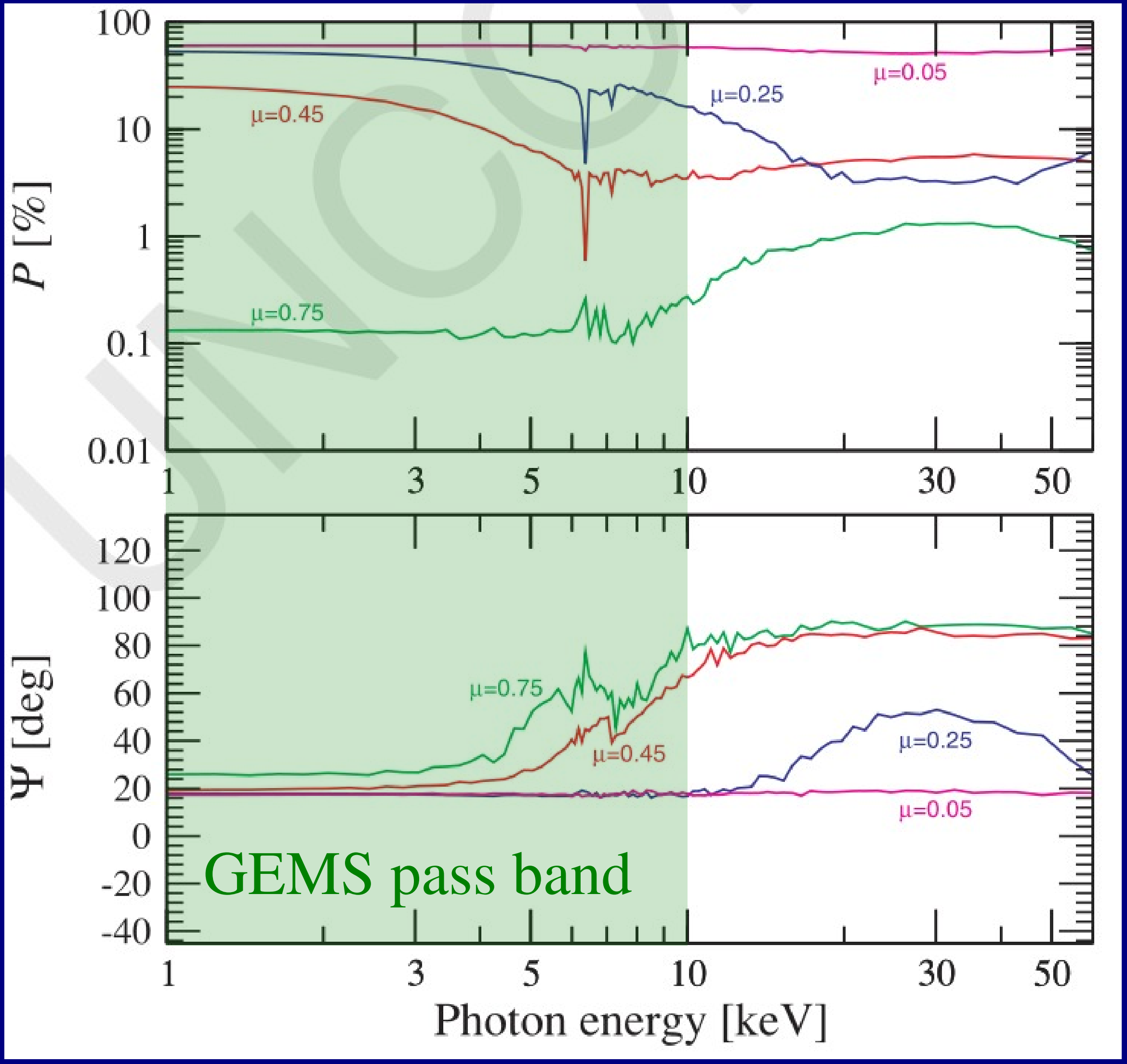
Black et al. 2007

X-ray polarimetry of NGC 1068

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

Goosmann & Matt 2011





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

Conclusions

• Polarization gives <u>two additional observables</u> (besides the spectral intensity) as a function of wavelength and time.

• In order to understand the polarization signal of complex X-ray sources, coherent modeling is necessary including all photon-matter interactions.

• X-ray polarimetry of NGC 1068 will unambiguously measure the P. A. of the ionization cones close to the nucleus (GEMS).

• Broad-band X-ray polarimetry up to 25 keV is technologically feasible (see NHXM proposal, Tagliaferri et al. 2011) and could even constrain the amount of a misalignment between the outflows and the torus in NGC 1068.

THANK YOU FOR YOUR ATTENTION!