Polarimetry of AGN from the infrared to the X-ray range

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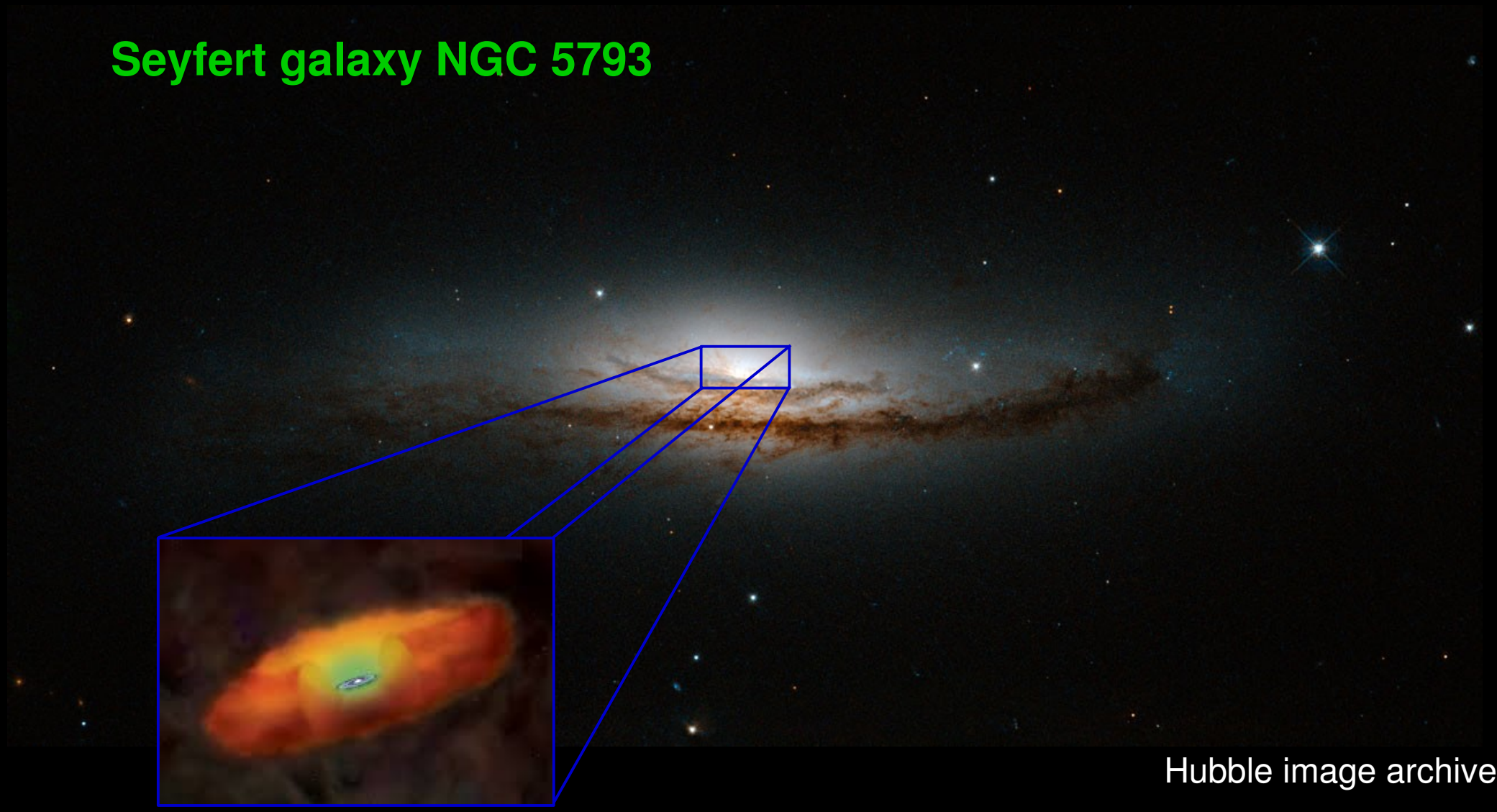
International conference
X-ray polarization in astrophysics – a window about to be opened?
Stockholm, Sweden, August 27th 2014

How to resolve the unresolvable?



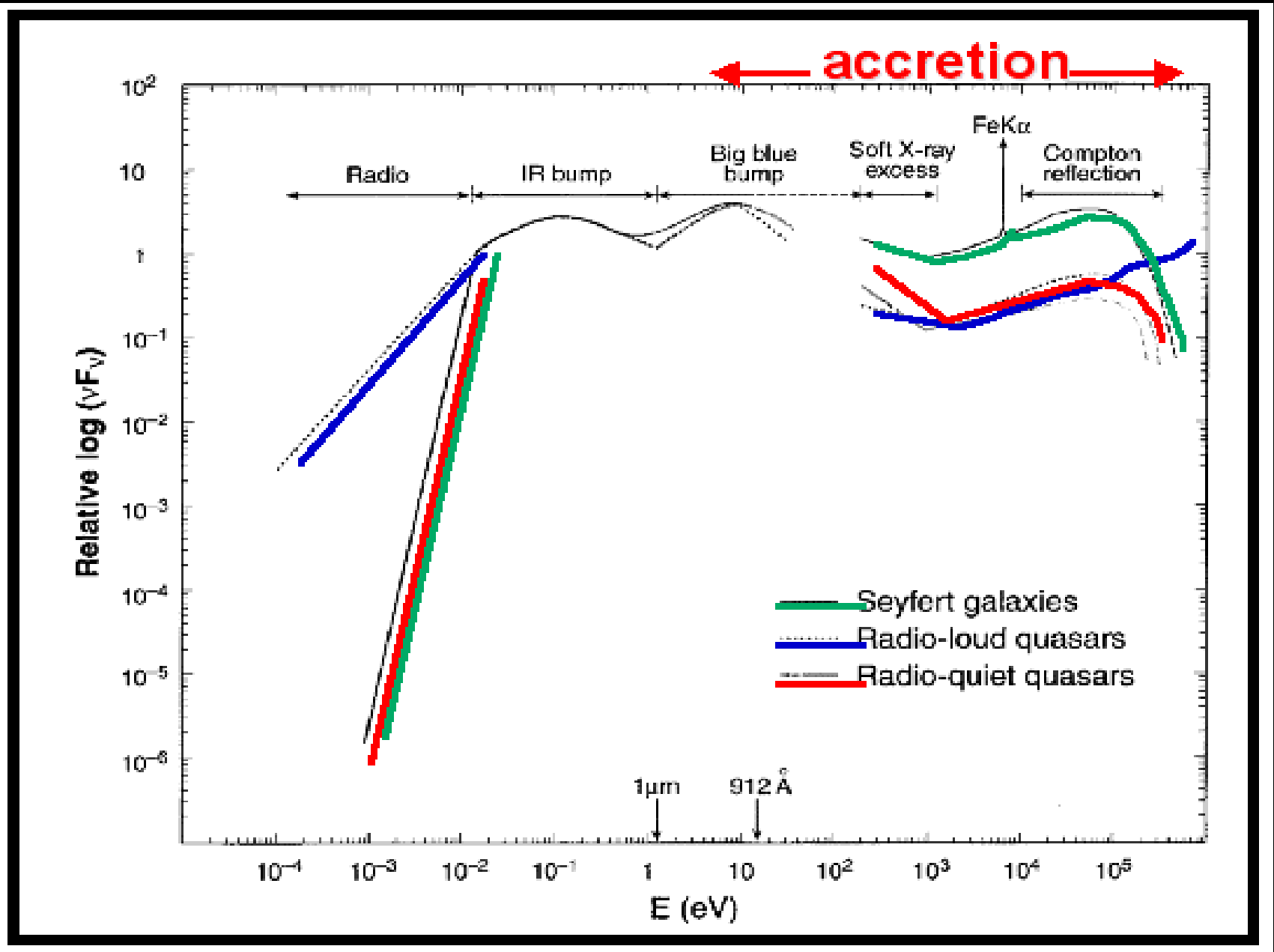
How to resolve the unresolvable?

Seyfert galaxy NGC 5793

MY ULTIMATE GOAL

Constrain the unresolved geometry and dynamics of AGN by using broad-band polarimetry as a complement to spectroscopy, imaging and timing...

The broad spectrum of AGN

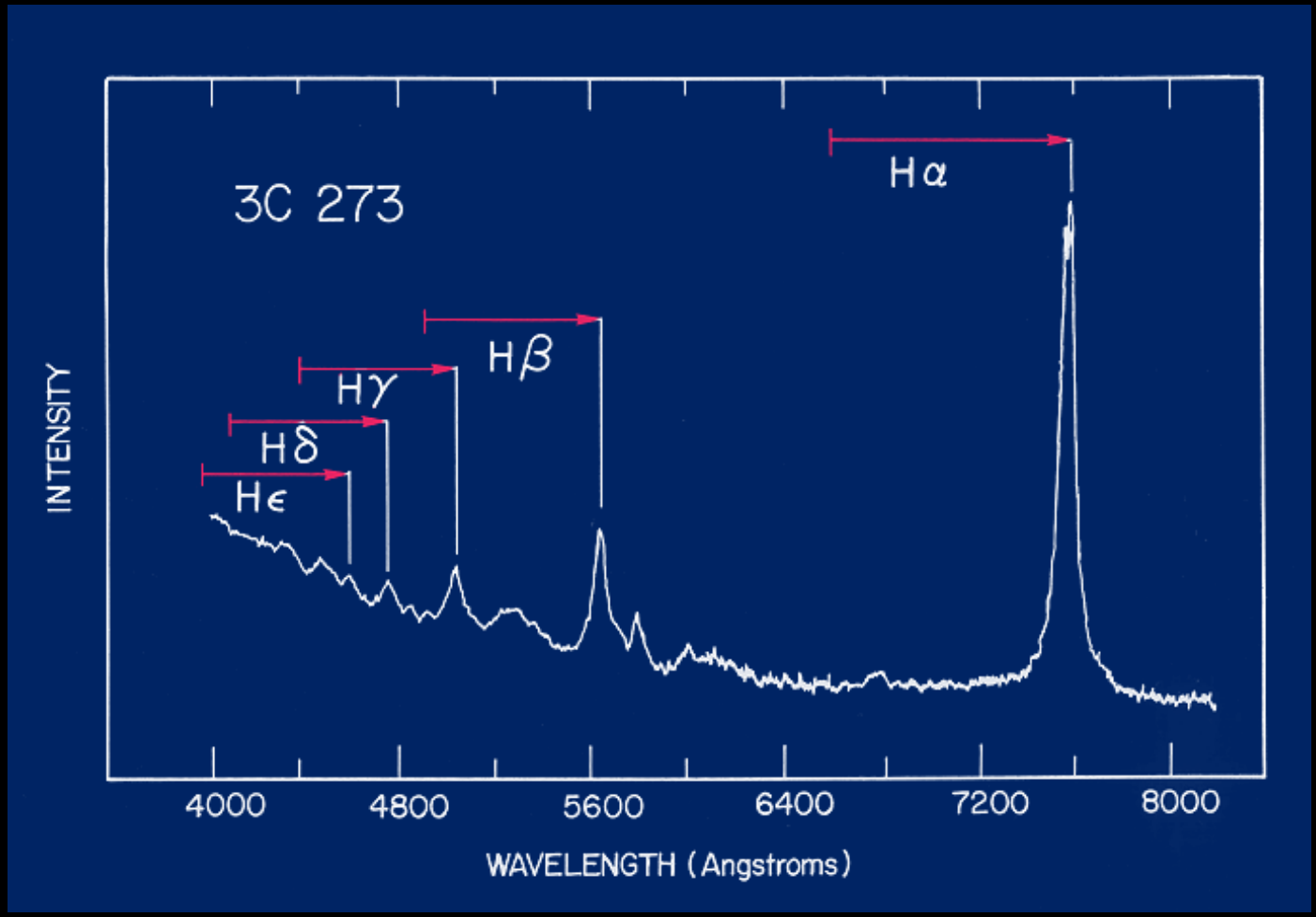


Collin (2001), Sanders et al. 1989

The optical spectrum of AGN: 3C 273

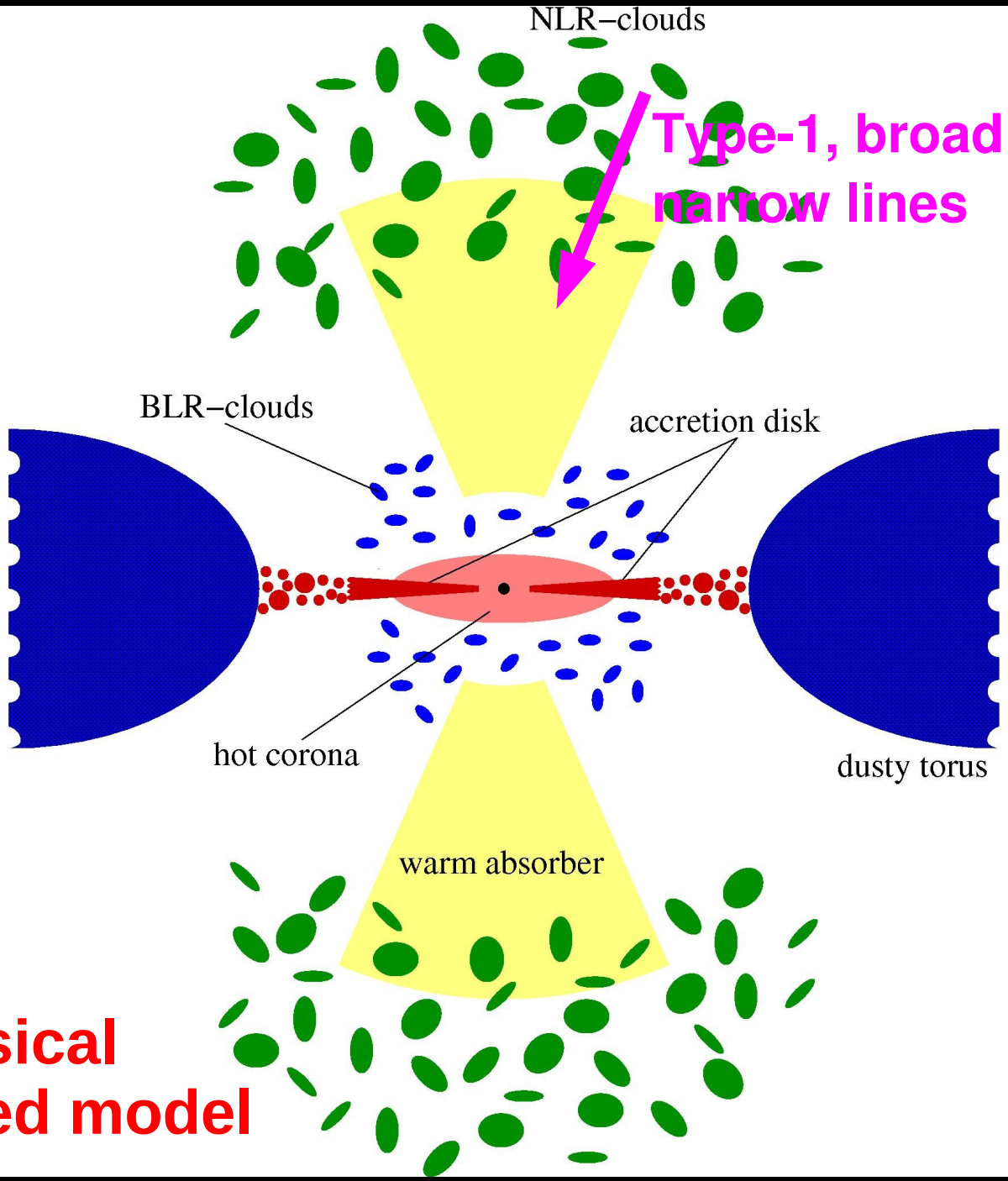
The optical spectrum of the quasar 3C 273 exhibits broadened, redshifted Balmer emission lines.

The brodening is due to a large differential velocity distribution of the reprocessing medium (several 1000 km/s).



Maarten Schmidt (1963)

Unifying broad and narrow line objects



Classical unified model

Processes producing (de-)polarization in AGN

Synchrotron emission

Electron and Rayleigh scattering

Dust (Mie) scattering

Resonant line scattering

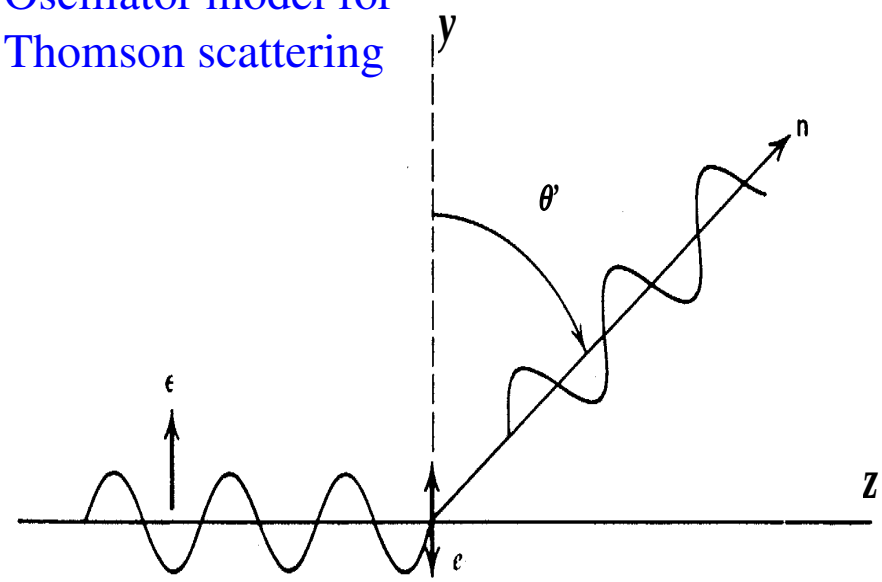
Dichroic absorption

Faraday rotation

Dilution (by unpolarized radiation)

General Relativity

Oscillator model for Thomson scattering



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

Scattering

Strong polarization: Θ = 90° (Reflection)

Weak polarization: Θ = 0° (Transmission)

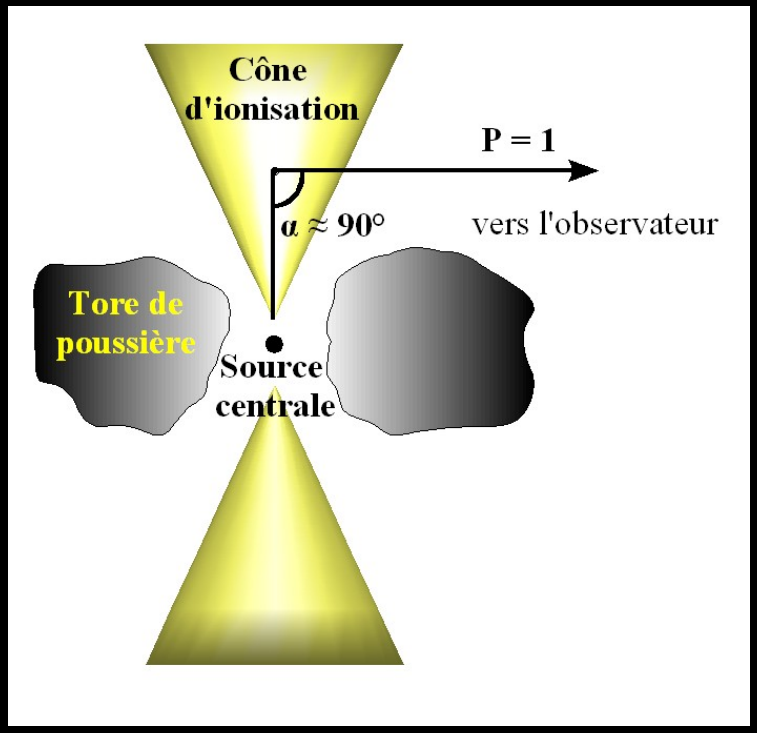
$$P = \frac{1-\cos^2\theta}{1+\cos^2\theta}.$$

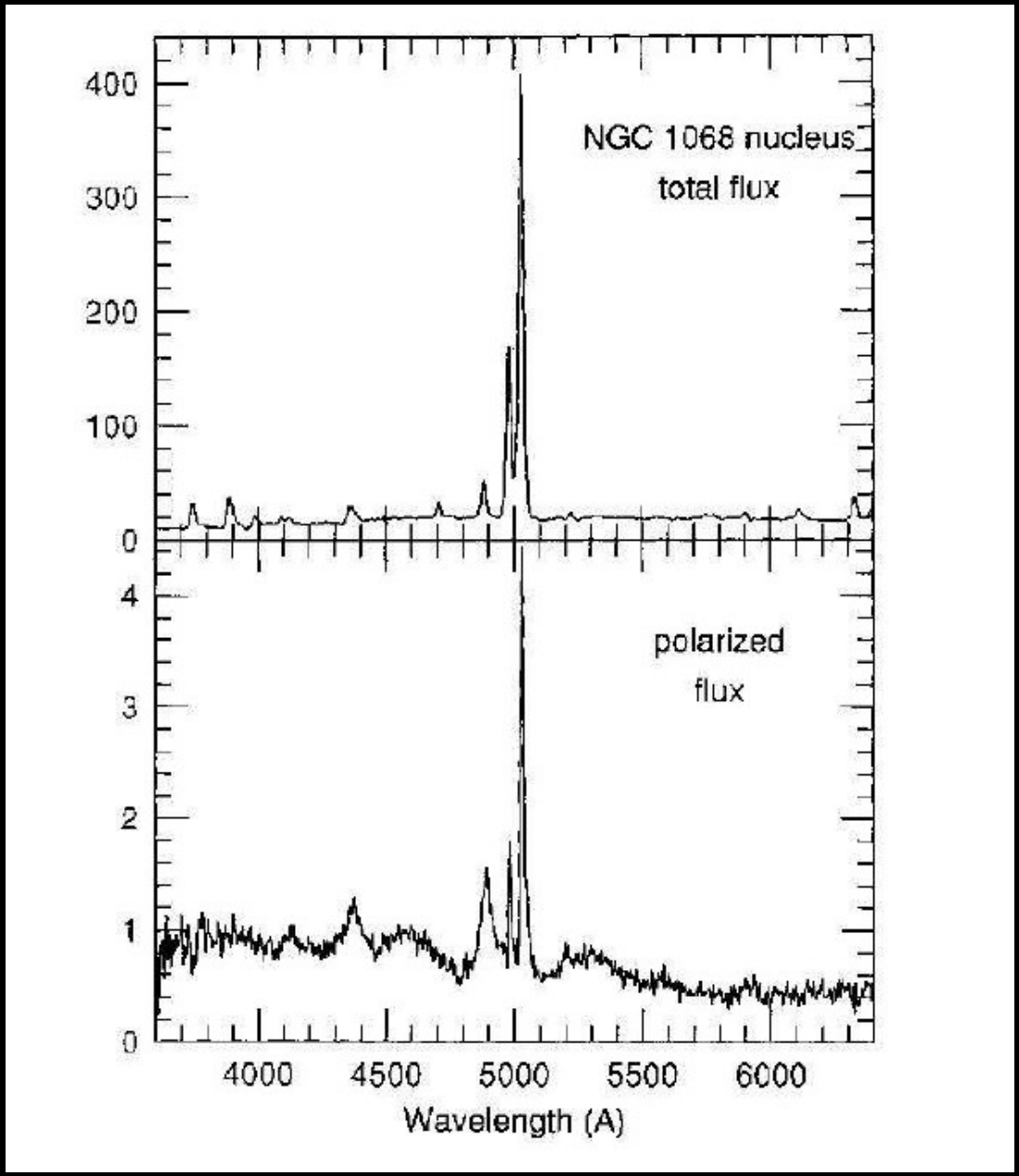
$$\sigma_T = \frac{8\pi}{3} r_0^2 = \frac{8\pi e^4}{3m^2c^4}.$$

Radio-quiet objects Hidden type-1 AGN

A major breakthrough for the unified model with NGC 1068 (Antonucci & Miller 1985)

→ periscope view of AGN in polarized flux

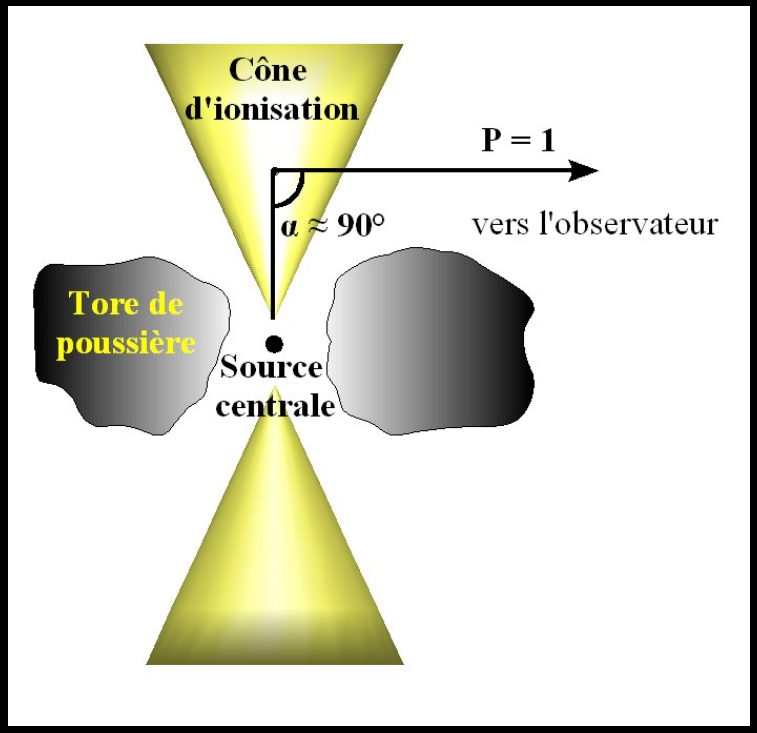


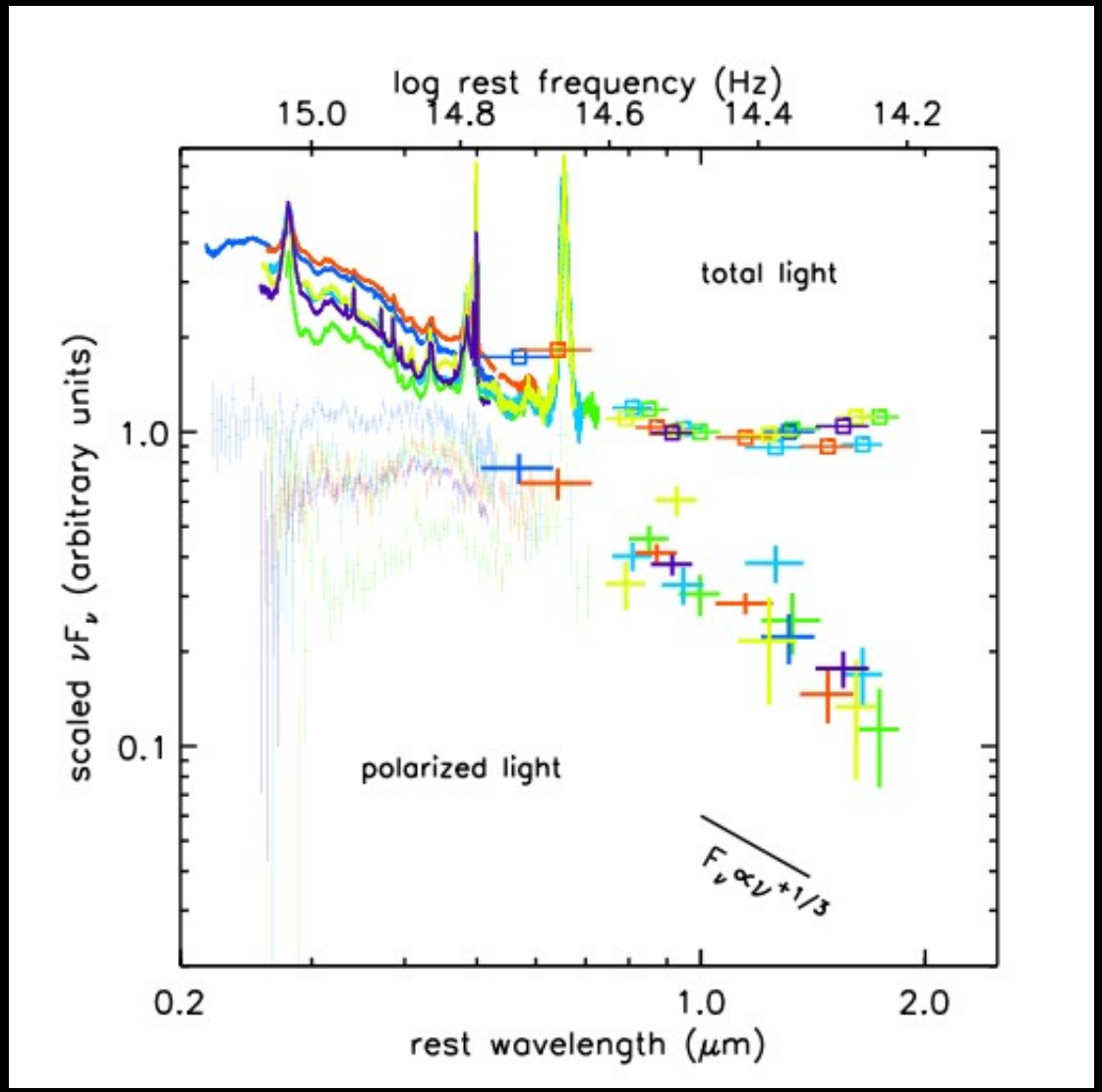


Recovering the hidden accretion disk spectrum

Looking through the periscope, the continuum spectrum of the disk can be recovered.

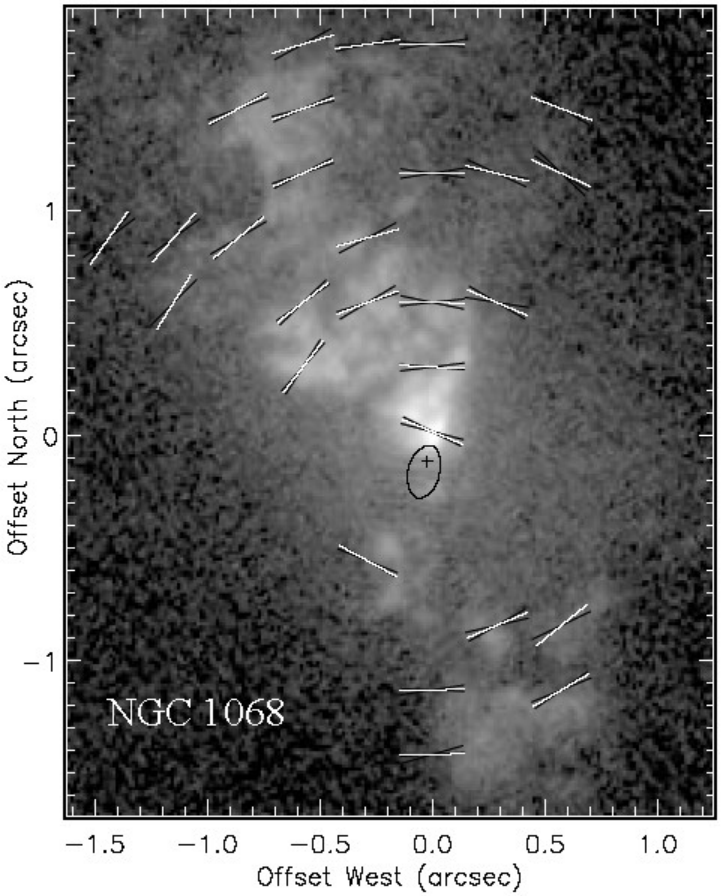
A multiple-blackbody shape with power-law slope of $n^{-1/3}$

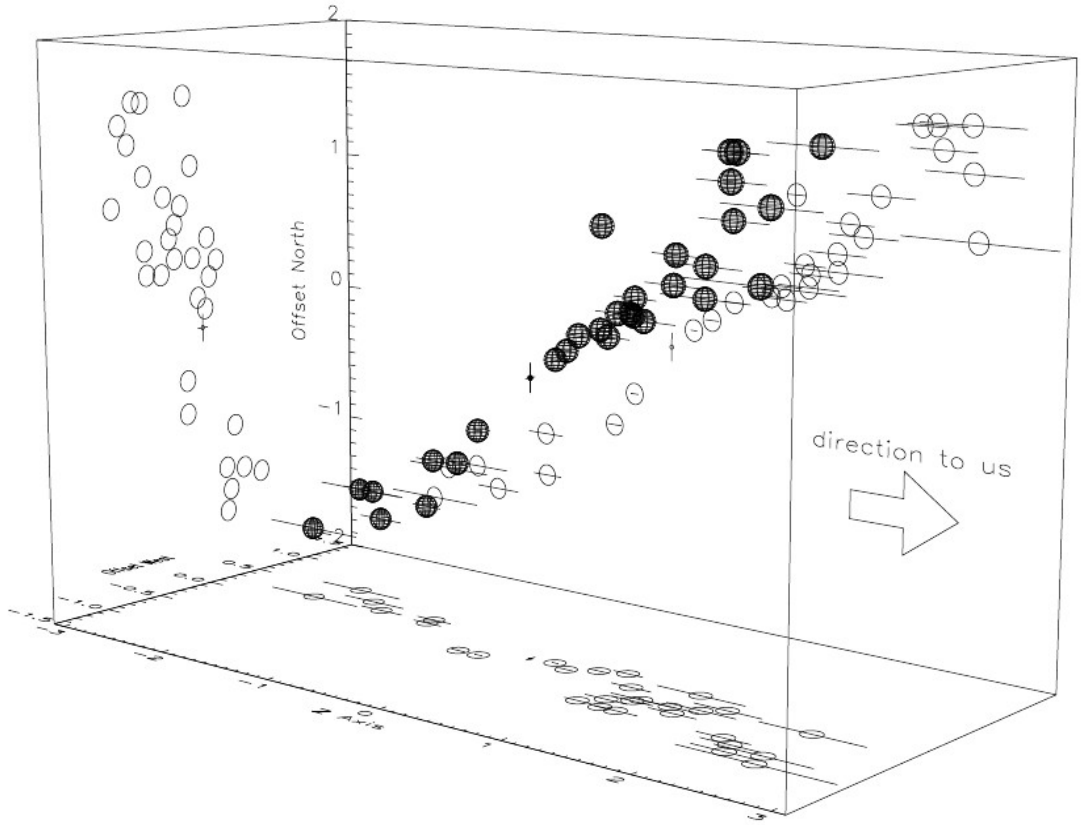




Kishimoto et al. 2008

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 clouds
Assuming optically thin matter

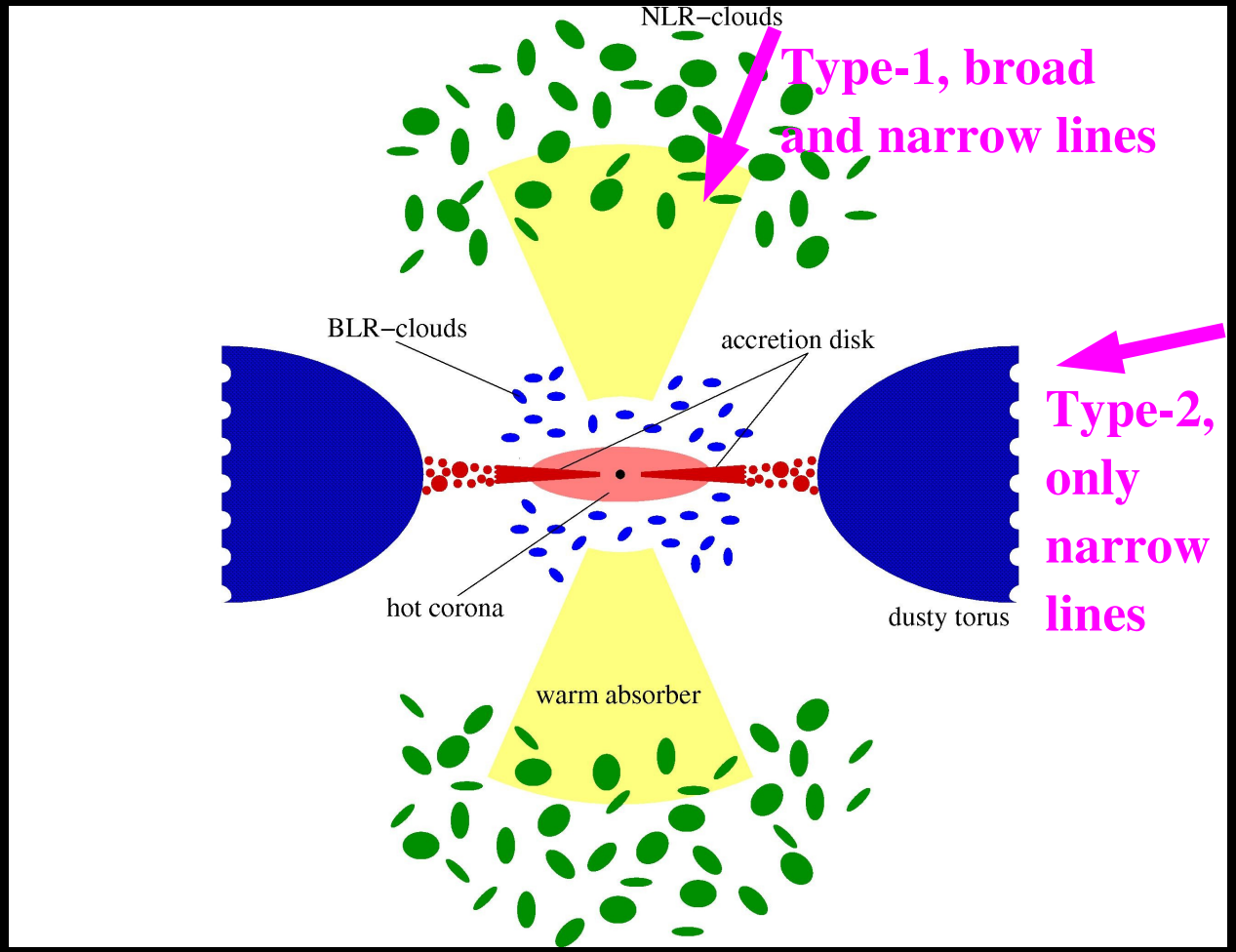
Hidden type-1 AGN and polarization dichotomy

The polarization dichotomy of AGN was established in the NIR/optical/UV:

Type-2 → *P.A.* ⊥ jet axis

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

See Antonucci (1993) and Smith et al. (2002) and references therein for an overview

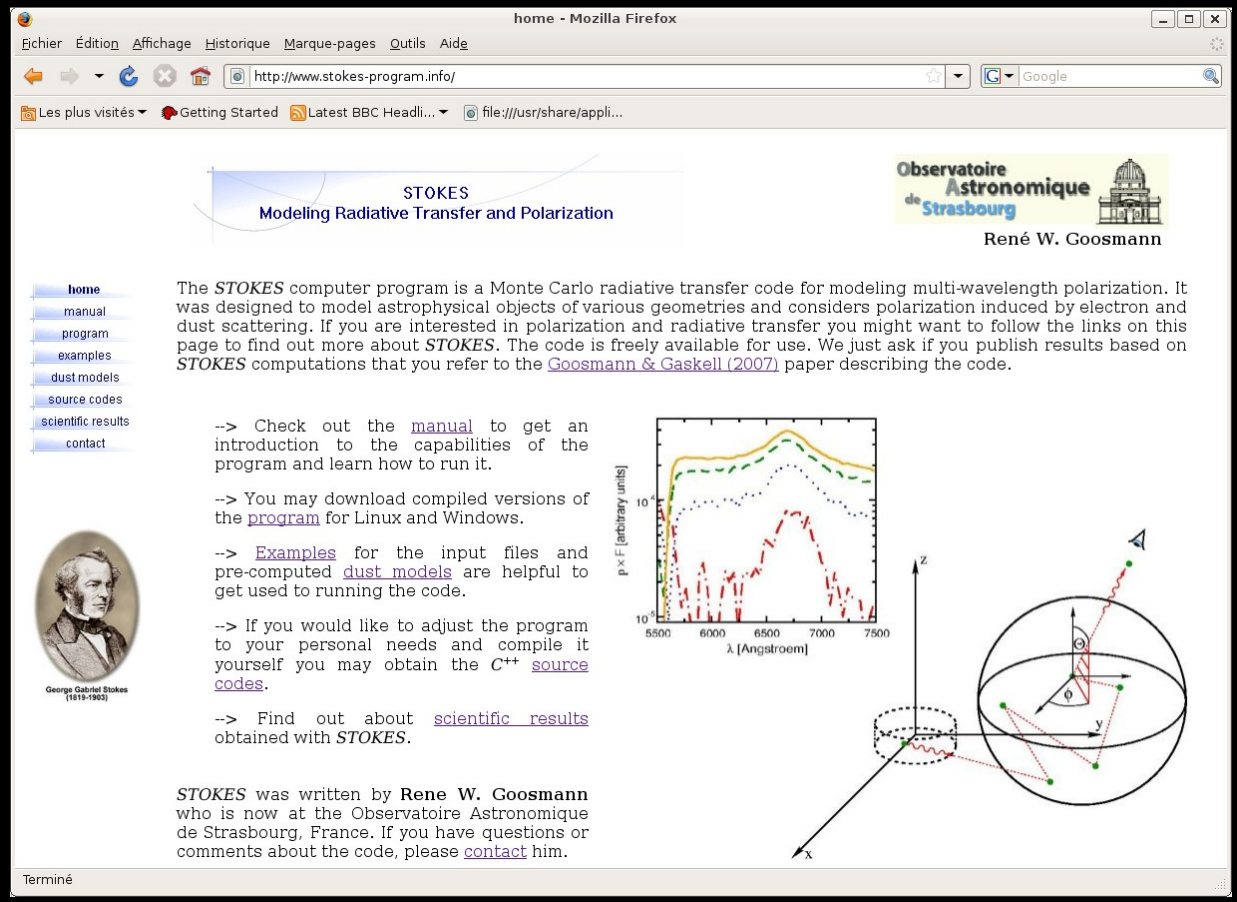


Modeling polarization with the STOKES code

- Monte-Carlo radiative transfer in 3D
- Various geometries for the emission / scattering regions
- polarization due to (multi-)electron scattering and dust (Mie-)scattering
- Resonant line scattering routines implemented
- Photo- and K-shell ionization / recombination
- variability and evolution of the incident spectrum
- Polarization imaging simulations

Public access

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



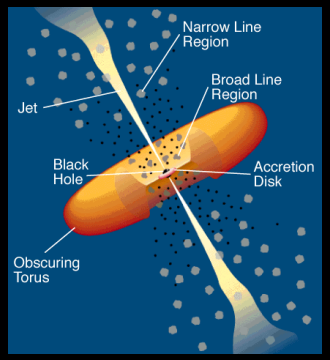
Goosmann & Gaskell (2007)
Marin et al. (2012)
Goosmann, Gaskell & Marin (2013)

Modeling the polarization dichotomy of AGN

AGN type-1 : view « face-on »
polarisation angle
parallel with respect to the axis

AGN type-2 : view « edge-on »
polarisation angle
perpendicular with respect to the axis

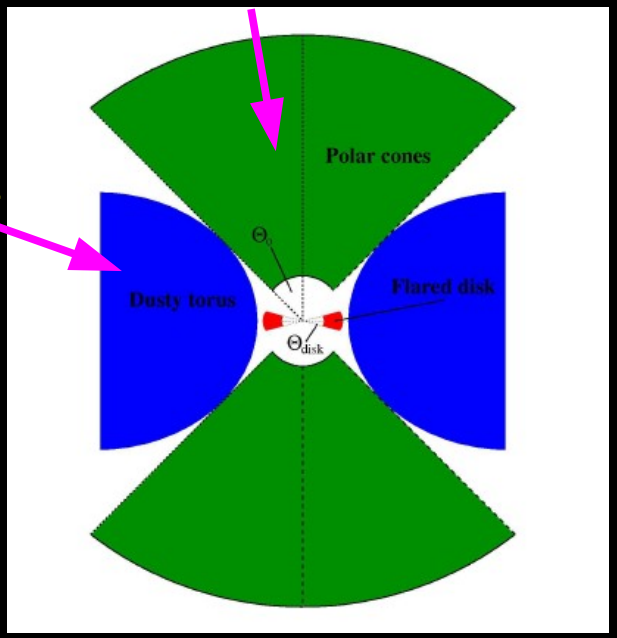
Modeling the unified scheme

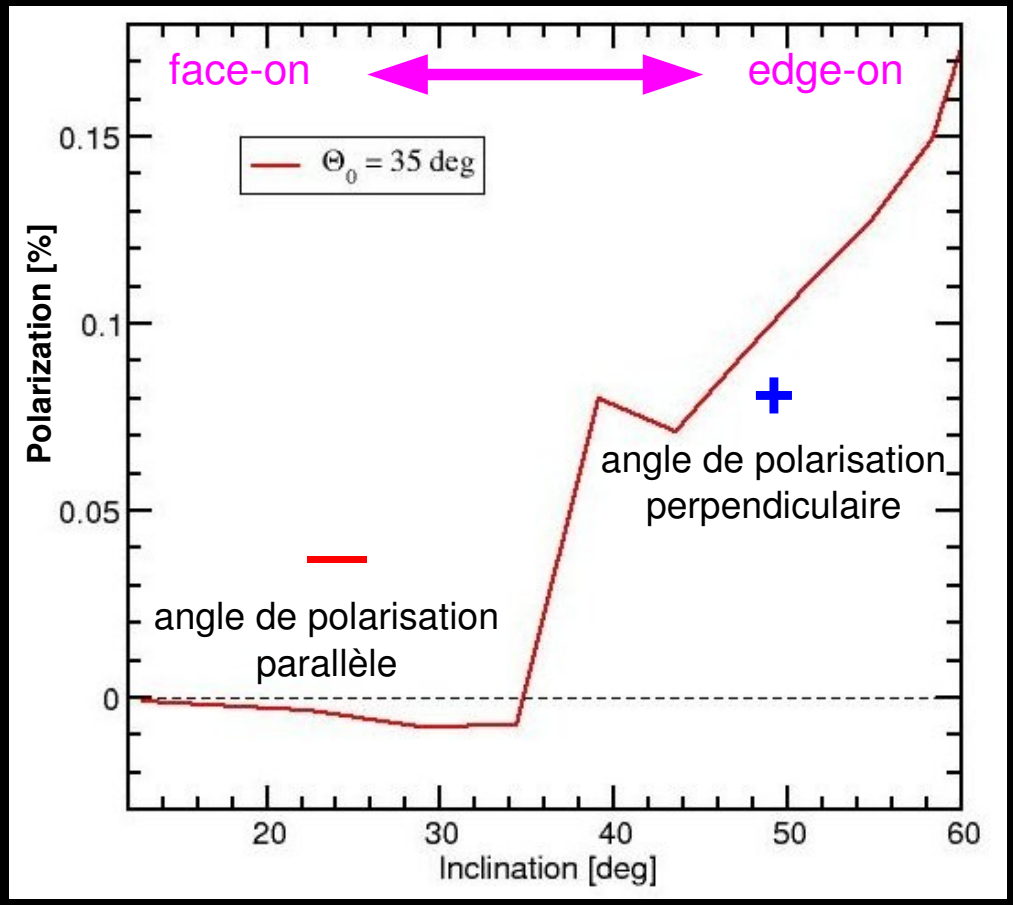


Urry & Padovani (1995)

face-on

edge-on





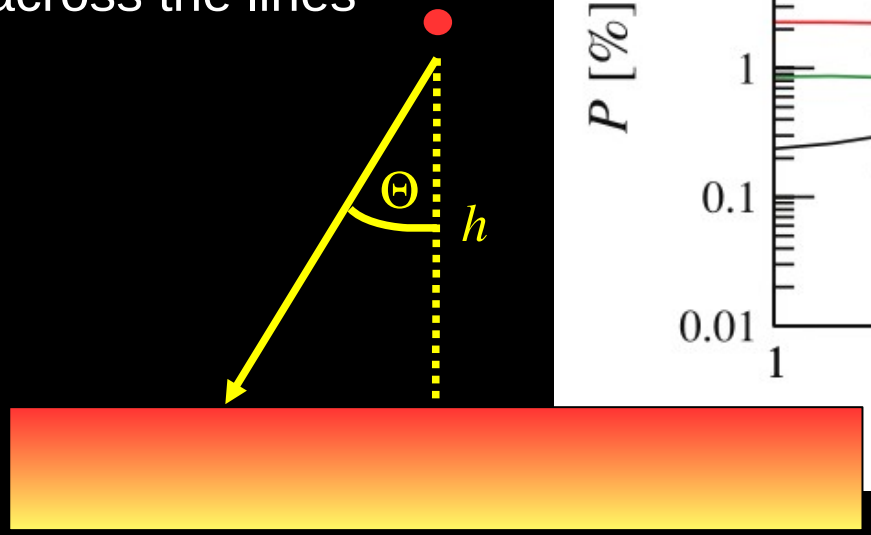
Goosmann et al. (2006)
Marin et al. (2012)

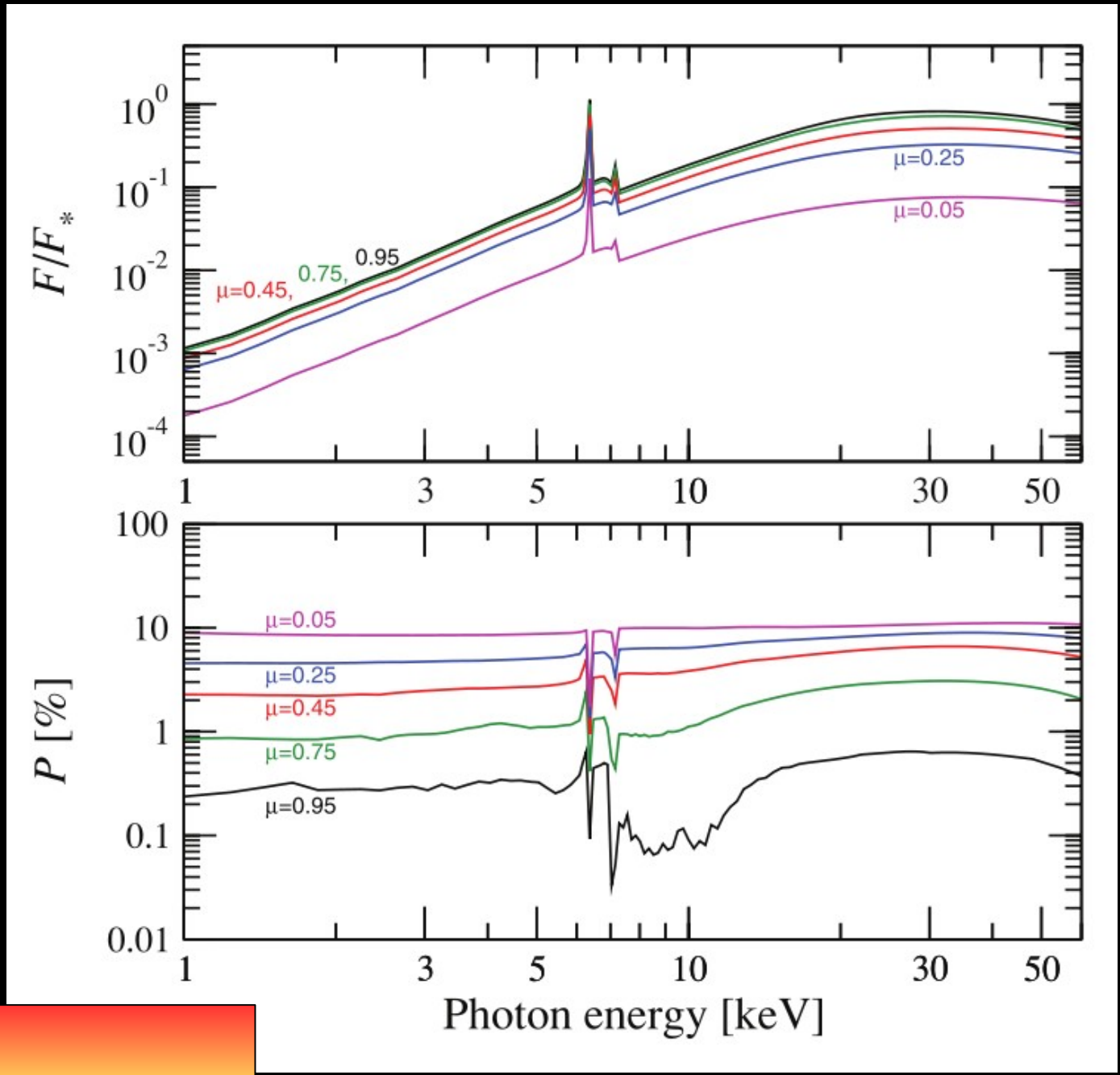
See also Smith et al. 2004, 2005

→ Reproduction of the observed polarization dichotomy in the opt/UV

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 strongly across the lines





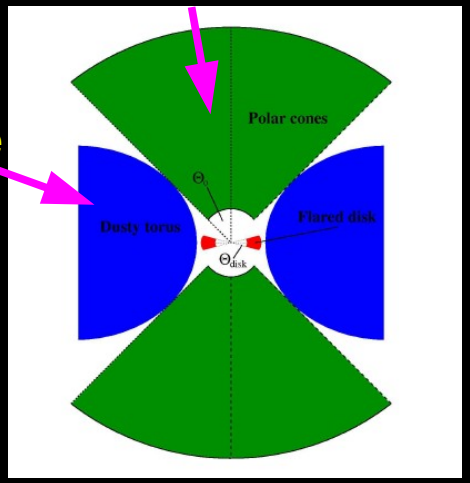
Face-on <–> edge-on

Edge-on <–> face-on

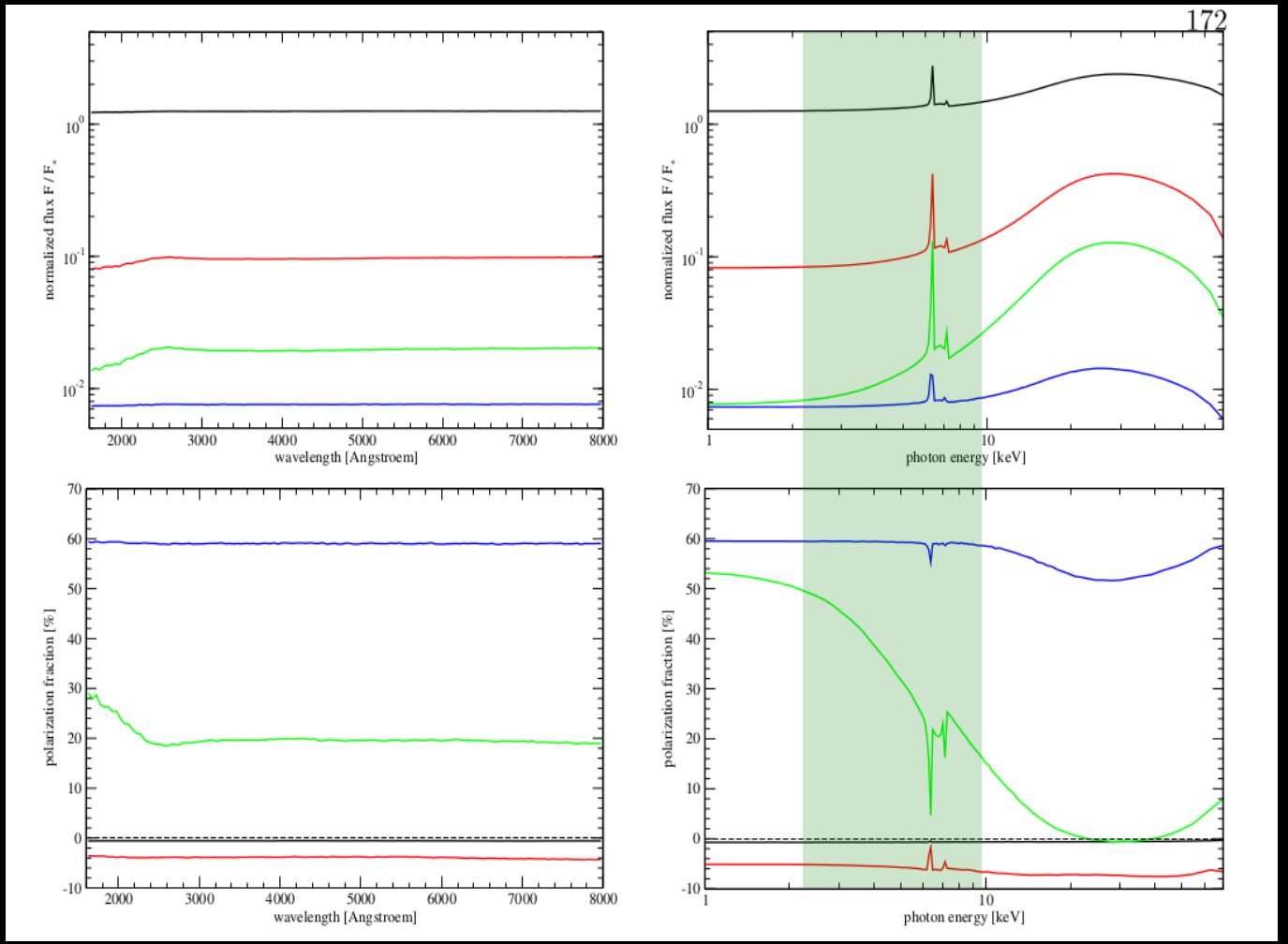
The X-ray polarization of disk reprocessing

face-on

edge
-on



soft X-pol



Face-on <–> edge-on Edge-on <–> face-on

Next steps:

- add clumpy structures
- explore the near and mid-infrared!

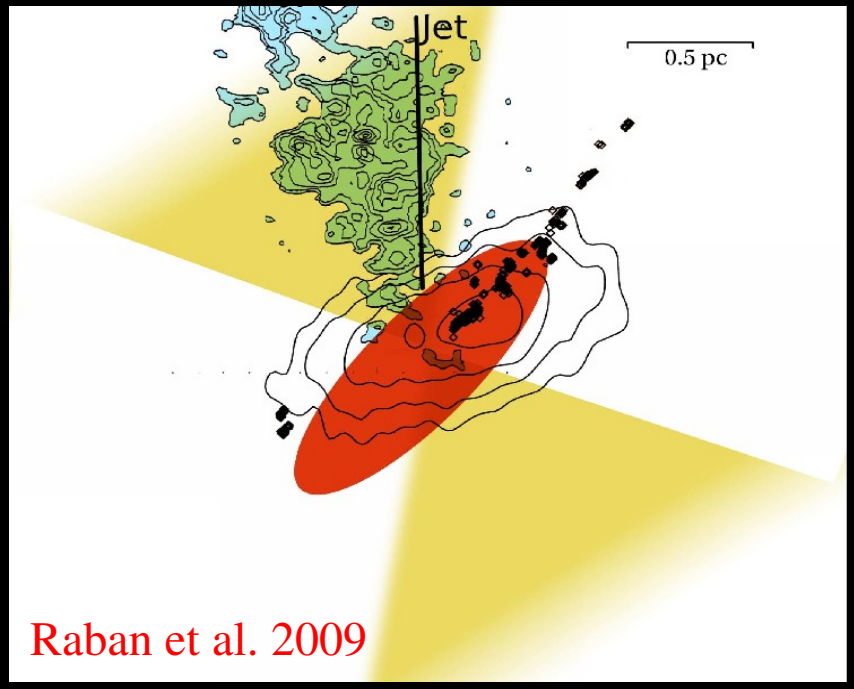
Marin & Goosmann (2011)

→ Prediction of a polarization dichotomy in the X-ray range *that evolves as a function of photon energy*

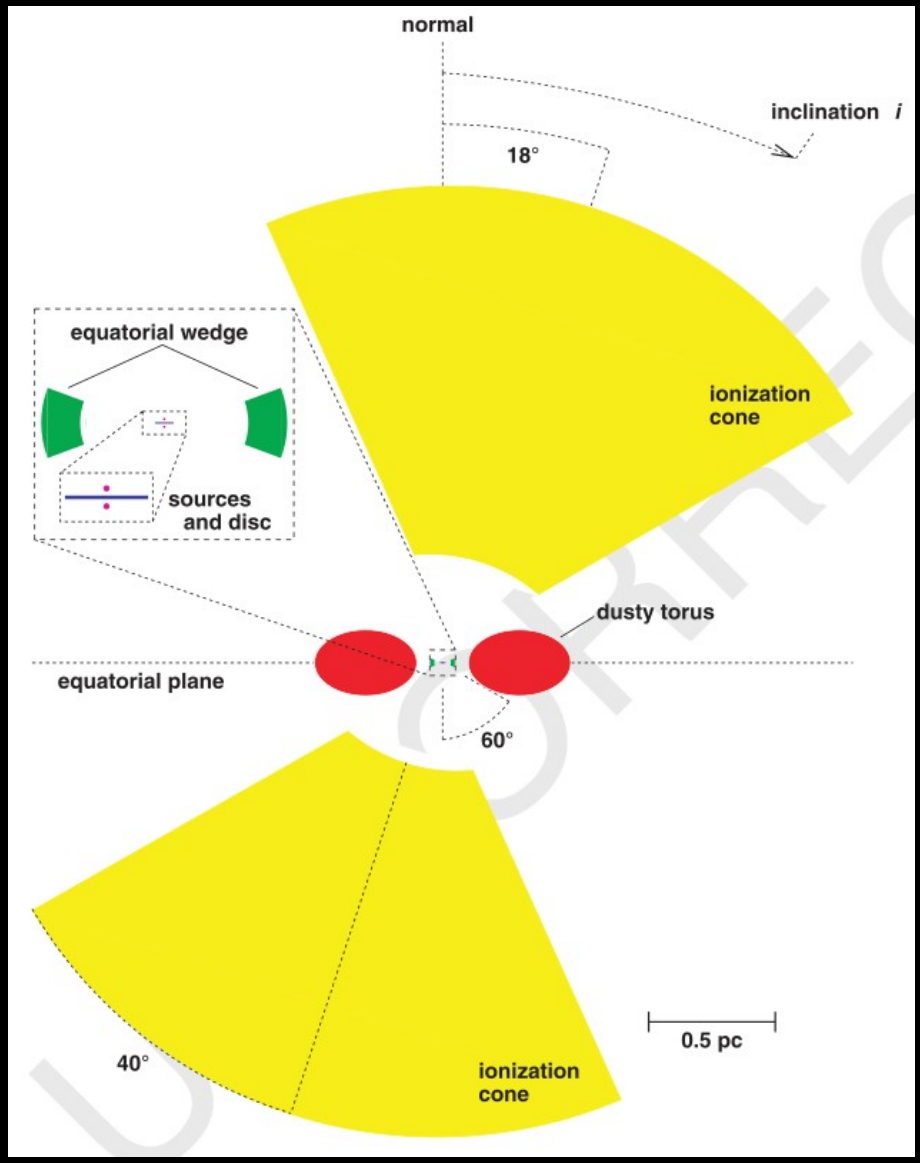
X-ray polarimetry of NGC 1068

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

Goosmann & Matt 2011



Raban et al. 2009



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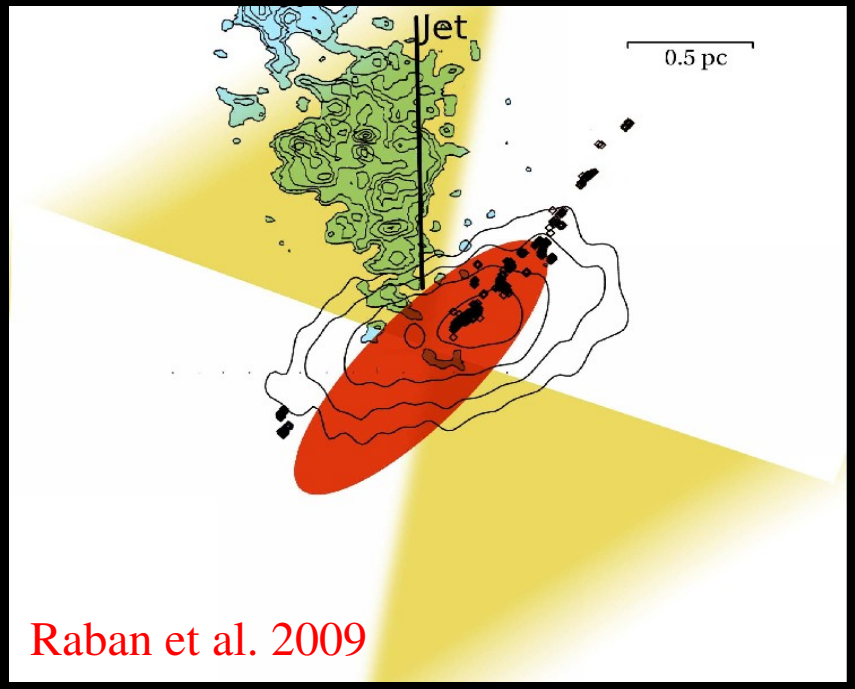
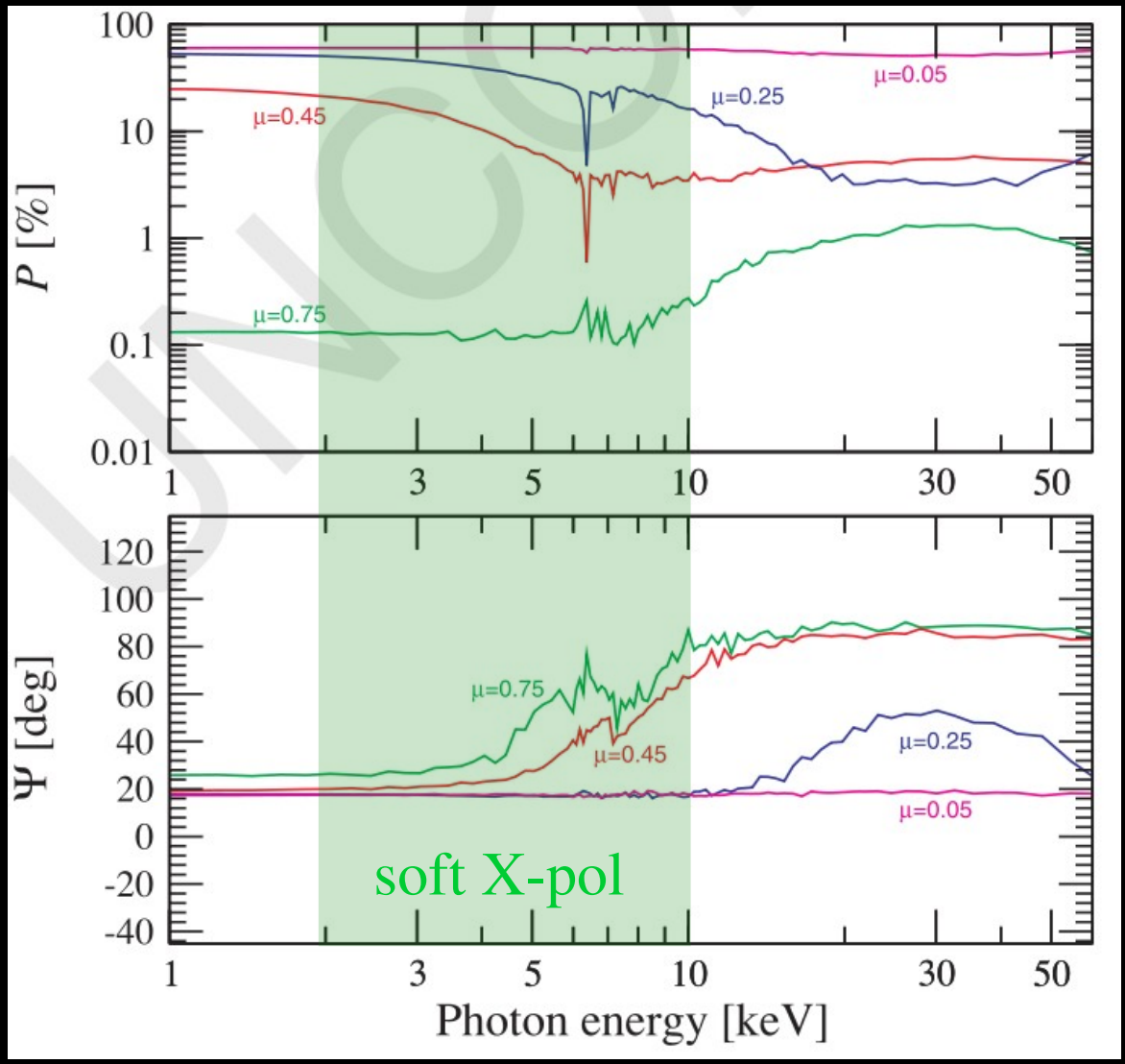
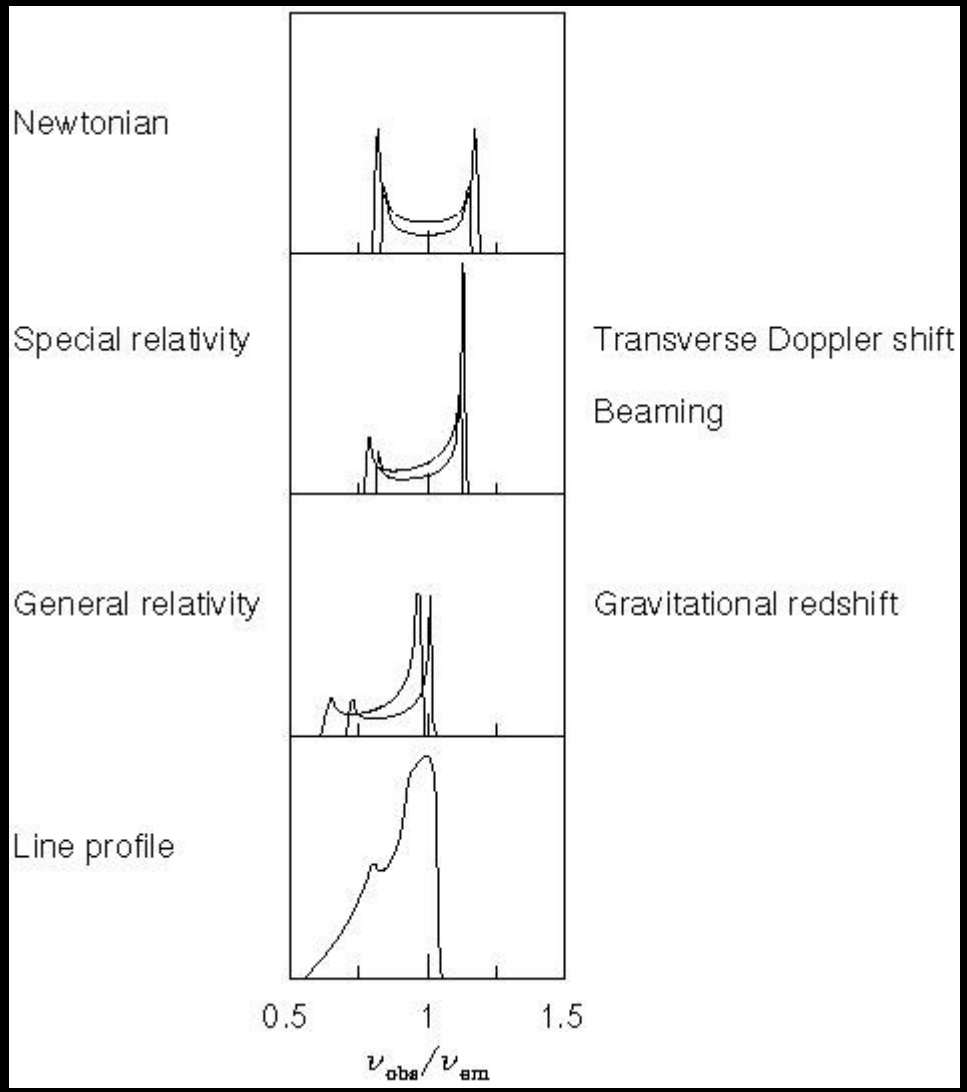


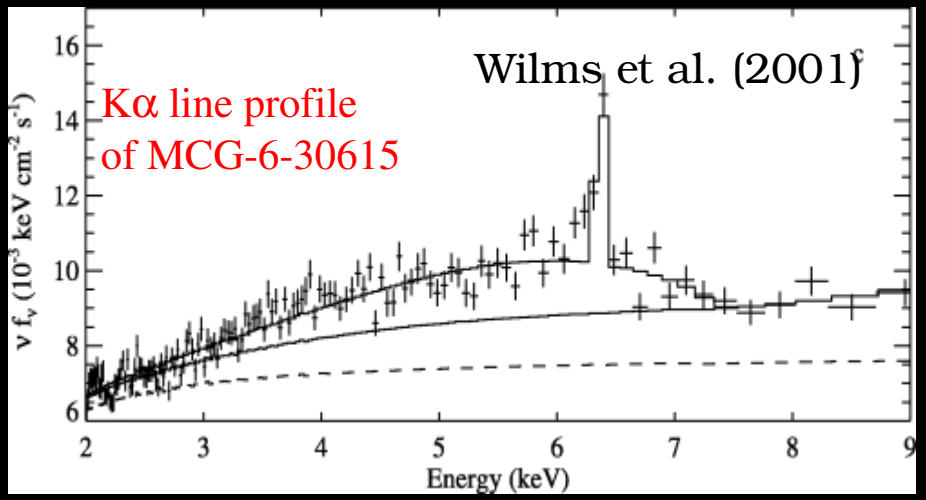


Possibility to measure the relative angle between torus and outflows by broad-band polarimetry!

Probing general relativity close to the black hole



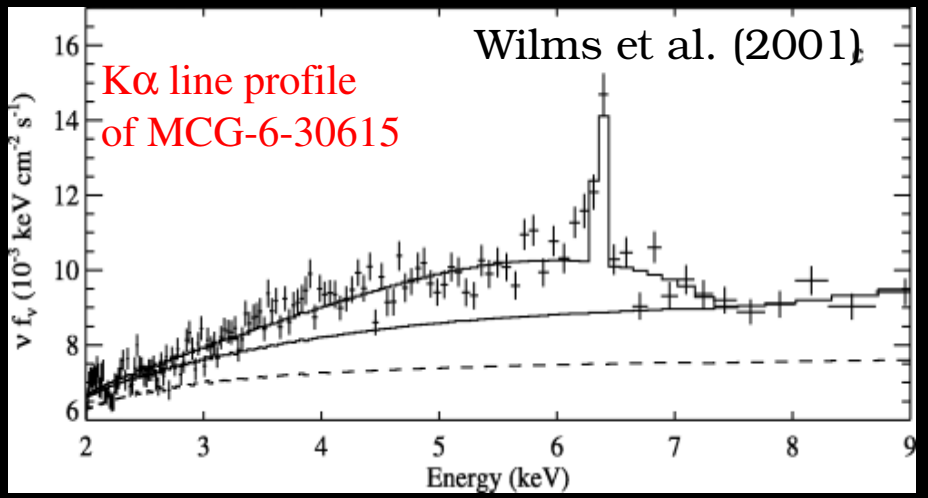
Fabian (2000)



Doppler and general relativistic effects produce a very broad red wing of the reprocessed iron line emission.

Martocchia & Matt (1996)
Kazanas & Nayakshin (2001)
Dovciak et al. (2004)
Miniutti & Fabian (2004)
Dauser et al. (2010)
Wilkens & Fabian (2011)
...

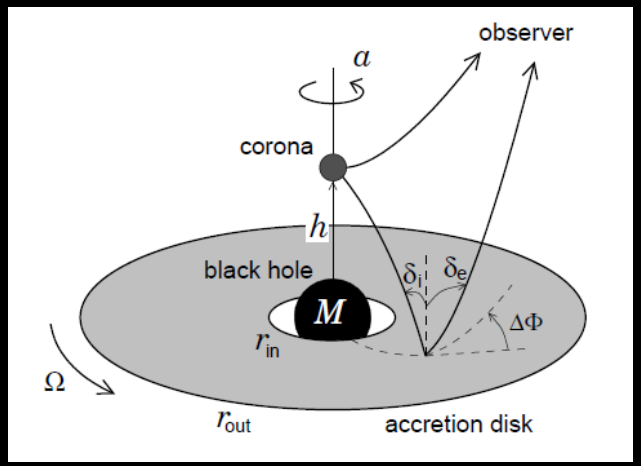
Unravel the nature of broad iron Kα lines



Marin et al. (2012)

Relativistic case

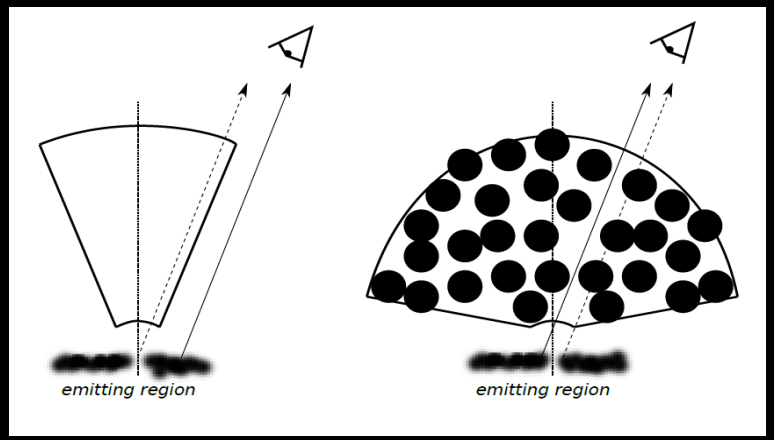
Re-emitted radiation from a rotating accretion disc and relativistic ray-tracing



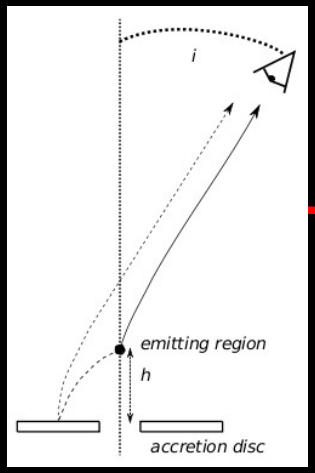
h = 2.5GM/c²
a = 1 (Kerr)
(Miniutti & Fabian 2004)

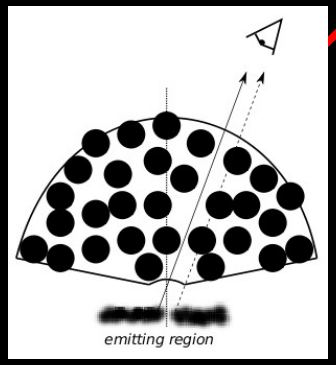
Absorption case

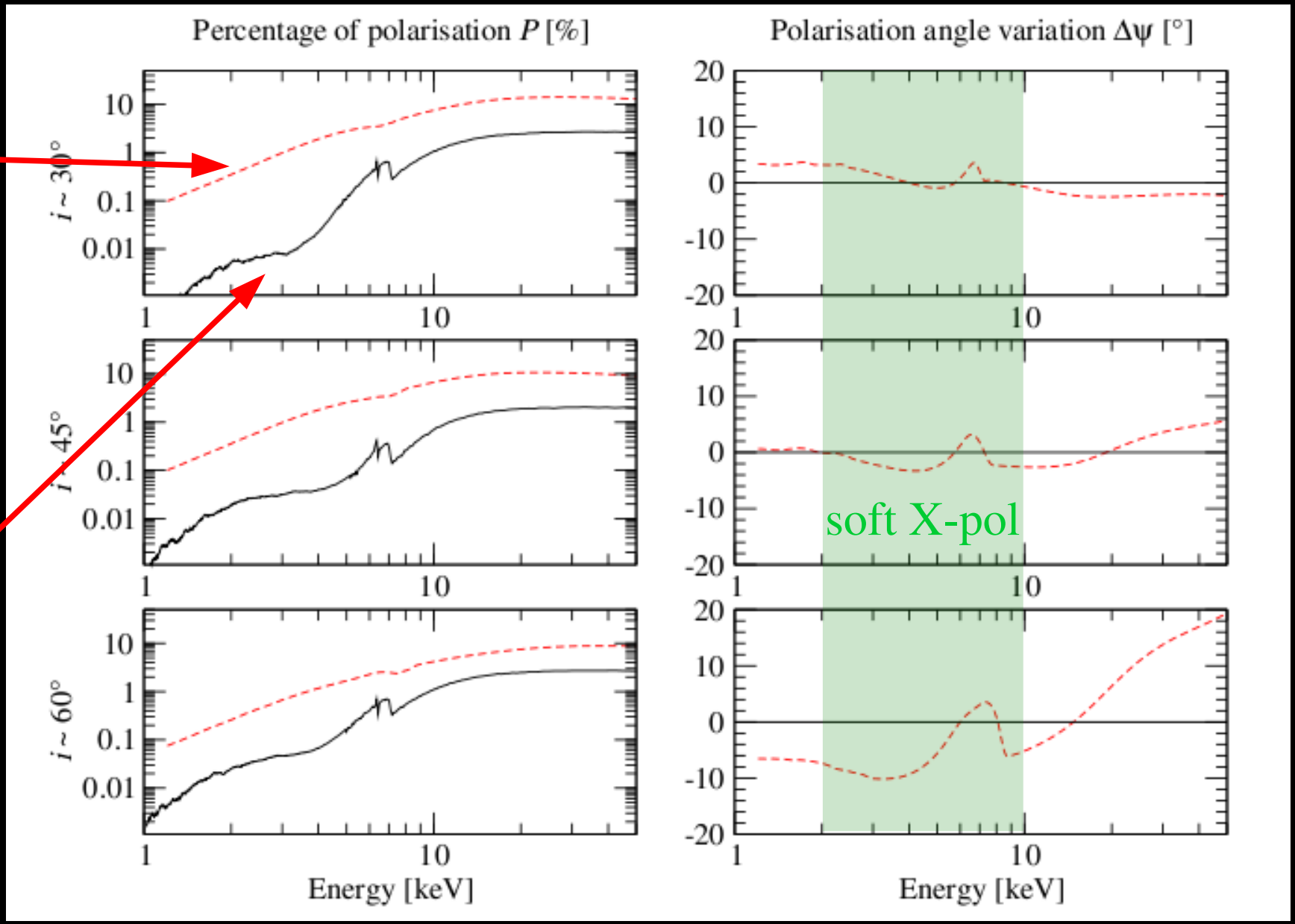
Optically thick, low ionized absorber partially covering the emission region (Miller et al. 2008/2009)



Unravel the nature of broad iron Kα lines







Marin et al. (2012)

Summary and conclusions

- X-ray polarimetry is challenging – and so is the modeling!

- X-ray polarimetry complements polarization studies of AGN at other wavebands, because the polarization mechanisms are connected.

- So far, we can predict for AGN that:

  – a polarization dichotomy known from the NIR/optical/UV occurs also in the X-ray range but is energy-dependent,

  – a misalignment of the outflows in NGC 1068 induces a rotation of the X-ray polarization position angle with energy,

  – the signature of X-ray polarization discriminates between relativistic reflection and complex absorption models.

- Next steps: exploring clumpy structures and the full infrared range...

THANK YOU FOR YOUR ATTENTION!