

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

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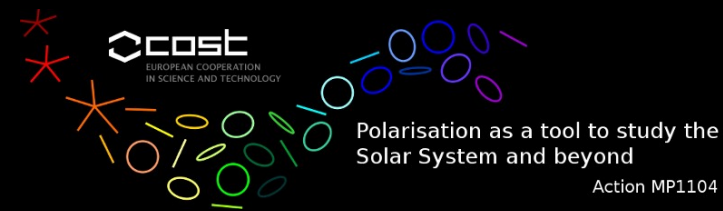
in collaboration with

Michal Dovčiak, C. Martin Gaskell, Nicolas Grosso, Vladimír Karas, Frédéric Marin, Giorgio Matt, Delphine Porquet, Francesco Tamborra

International conference

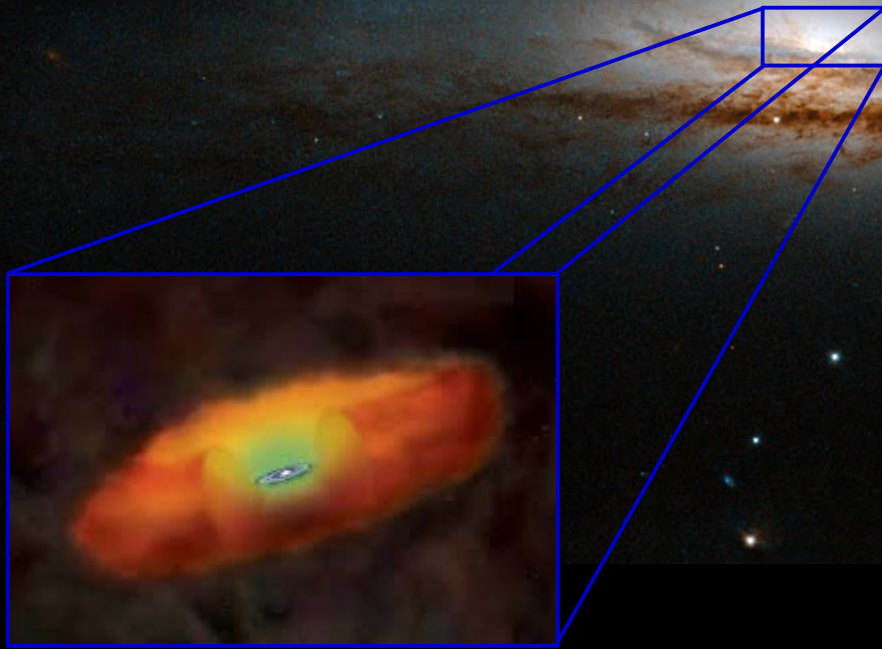
***X-ray polarization in astrophysics –  
a window about to be opened?***

Stockholm, Sweden, August 27<sup>th</sup> 2014



# How to resolve the unresolvable?

Seyfert galaxy NGC 5793



Hubble image archive

# How to resolve the unresolvable?

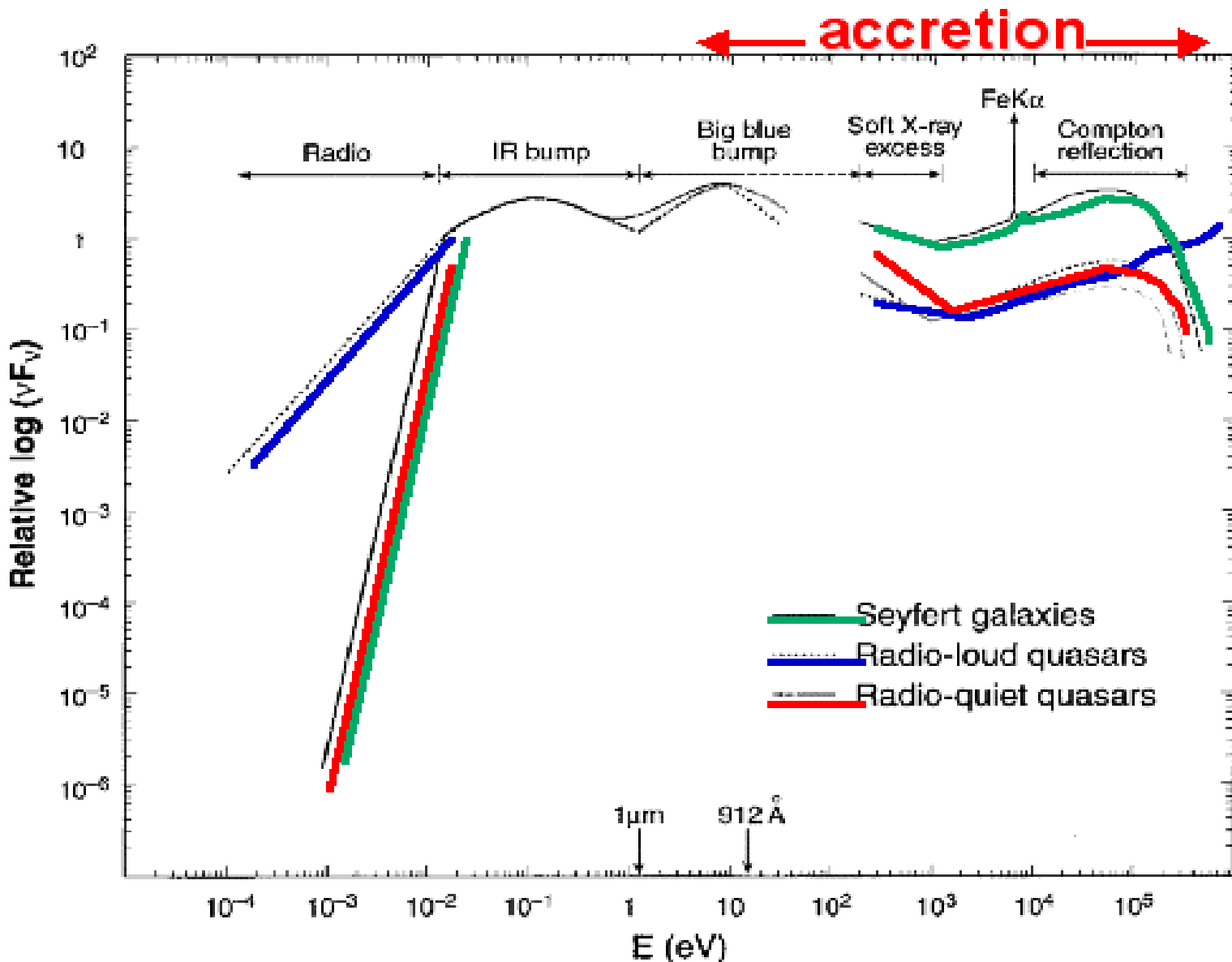
Seyfert galaxy NGC 5793



## MY ULTIMATE GOAL

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

# The broad spectrum of AGN

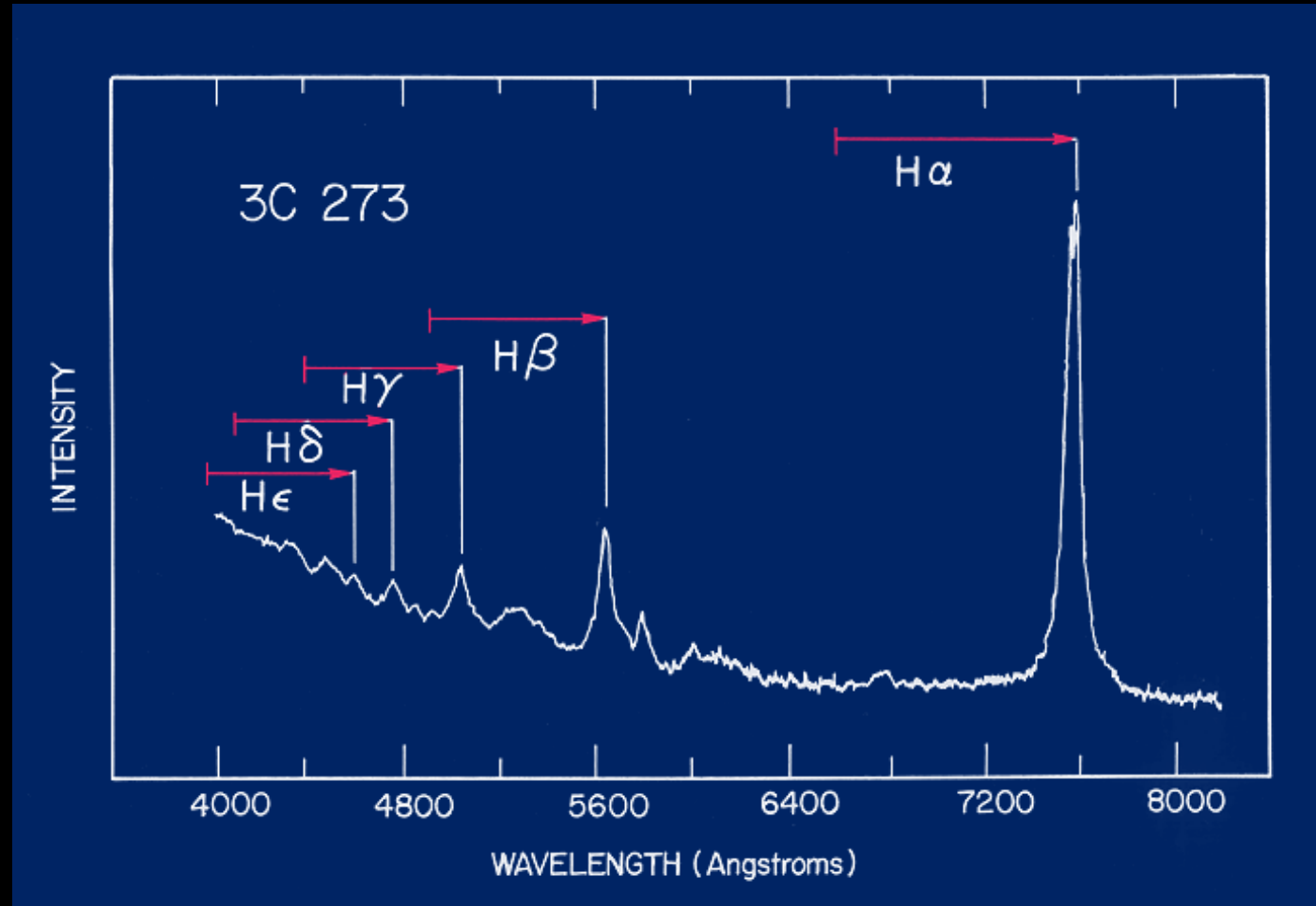


Collin (2001), Sanders et al. 1989

# The optical spectrum of AGN: 3C 273

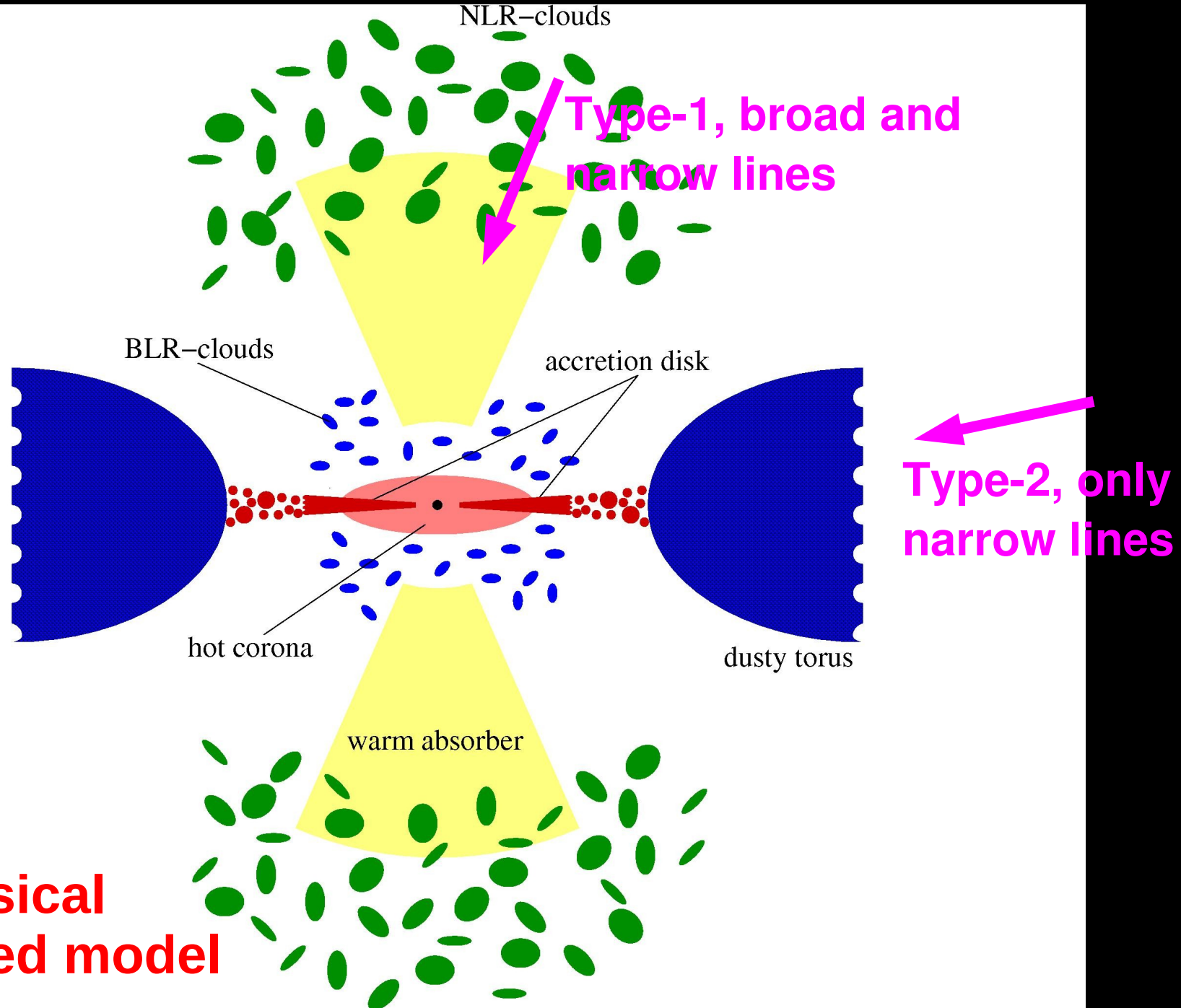
The optical spectrum of the quasar 3C 273 exhibits **broadened, redshifted Balmer emission lines**.

The broadening 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**

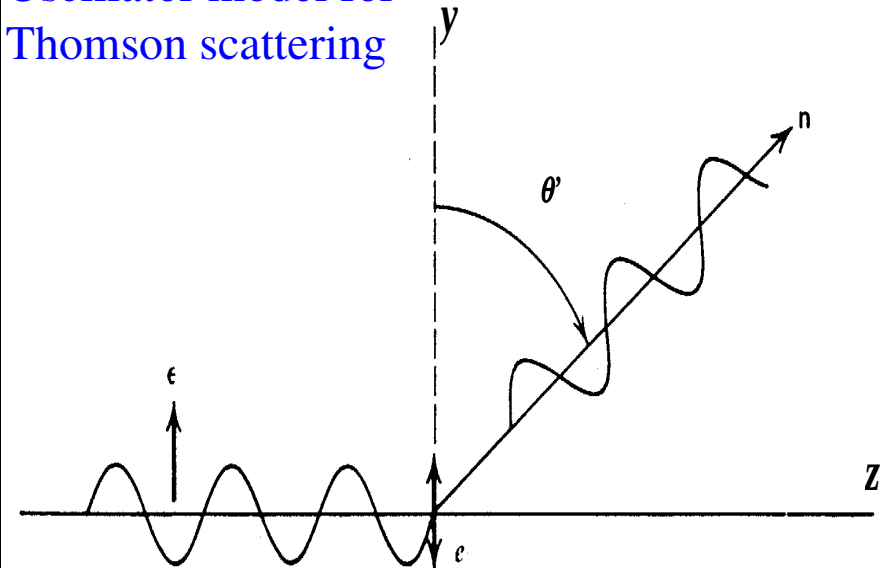
# Processes producing (de-)polarization in AGN

- Synchrotron emission
- Electron and Rayleigh scattering
- Dust (Mie) scattering
- Resonant line scattering
- Dichroic absorption
- Faraday rotation
- Dilution (by unpolarized radiation)
- General Relativity

## Scattering

- Strong polarization:**  $\Theta = 90^\circ$  (Reflection)
- Weak polarization:**  $\Theta = 0^\circ$  (Transmission)

Oscillator model for Thomson scattering



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

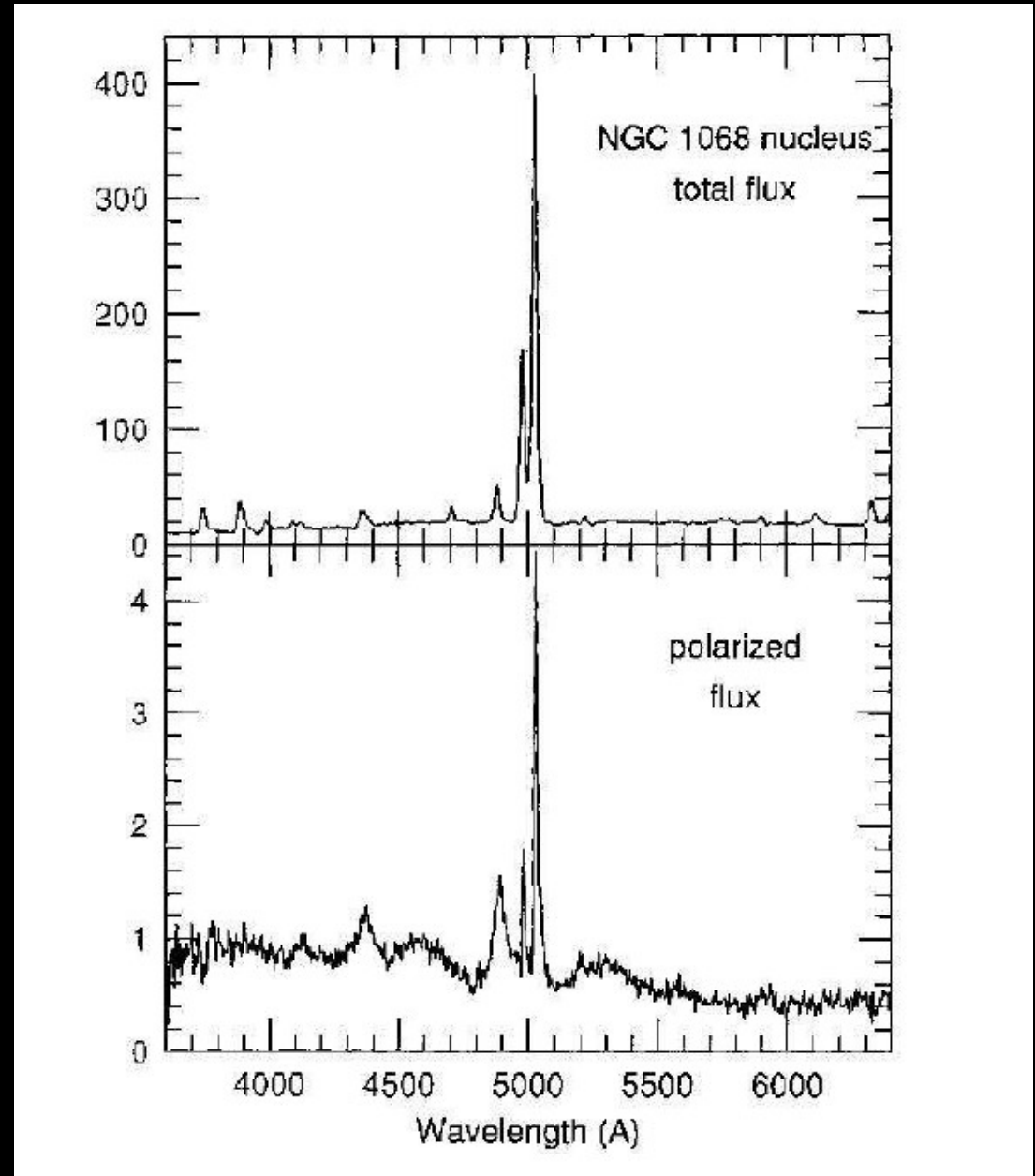
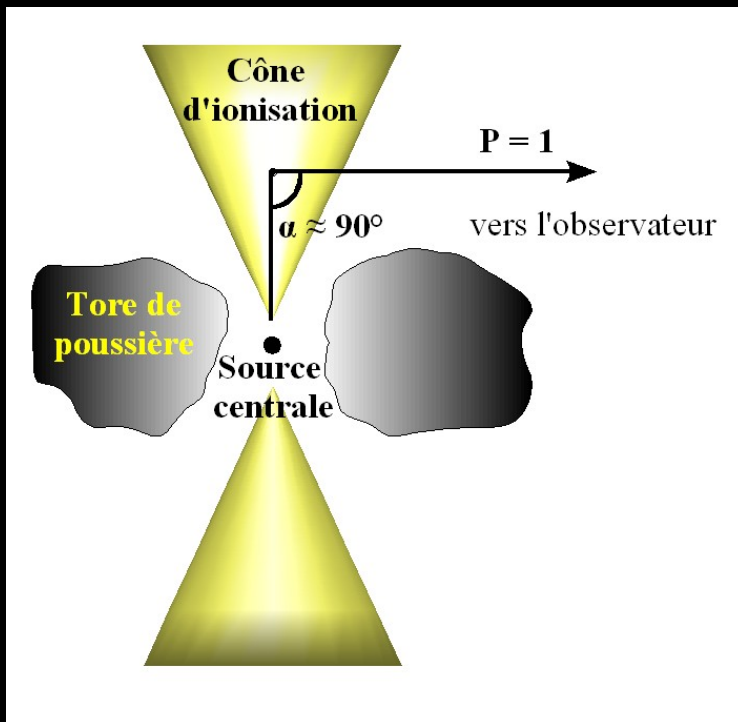
$$P = \frac{1 - \cos^2 \theta}{1 + \cos^2 \theta}.$$

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

# 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**

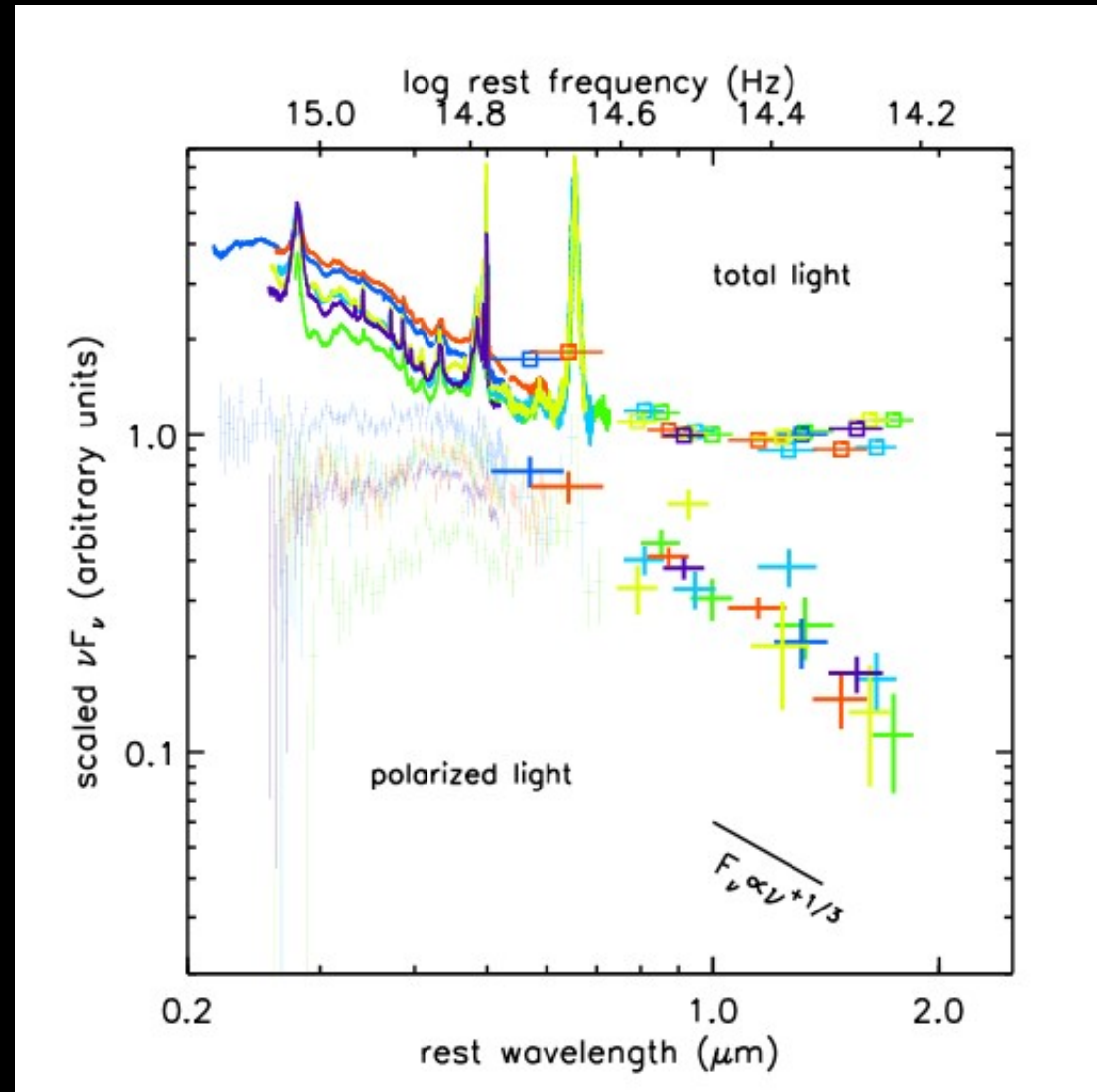
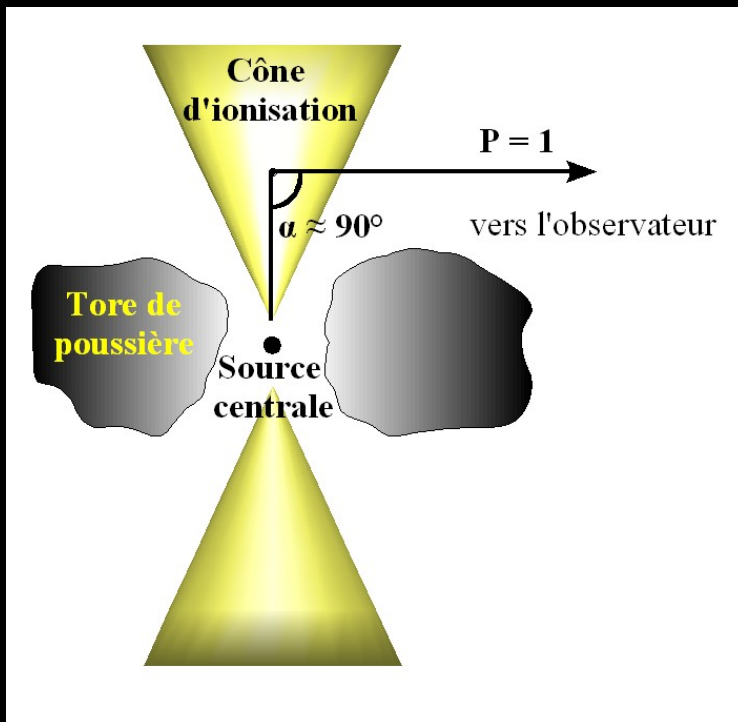




# Recovering the hidden accretion disk spectrum

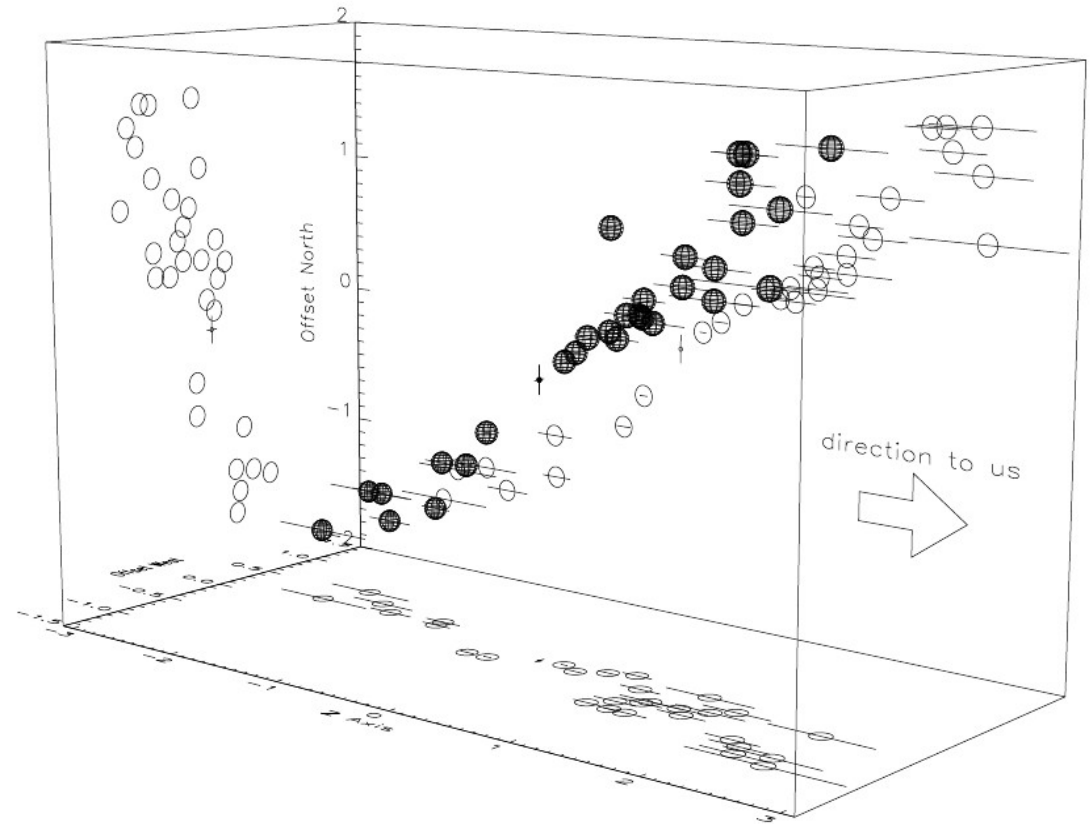
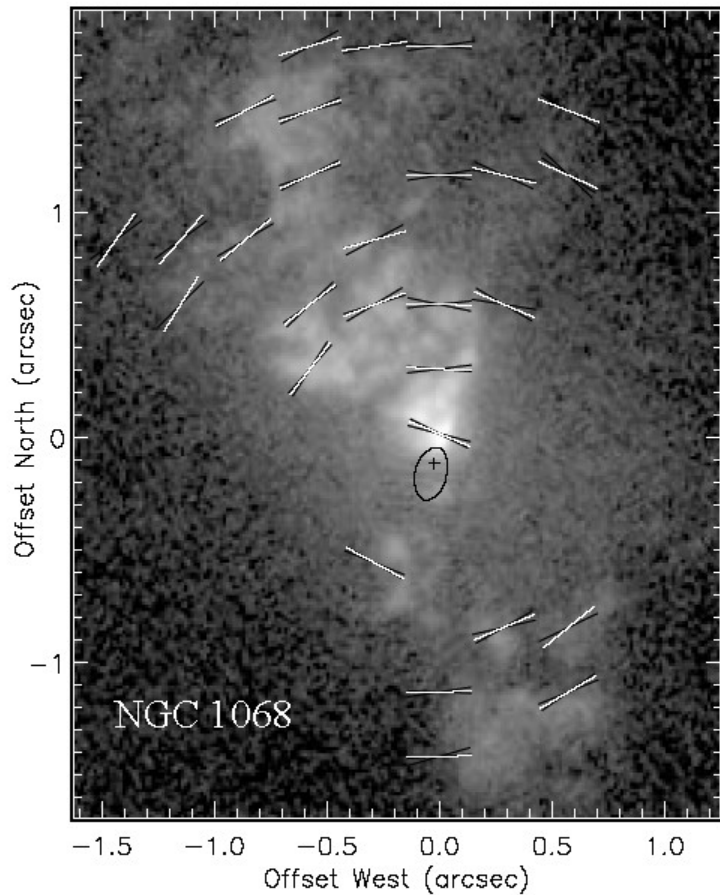
Looking through the periscope, the continuum spectrum of the disk can be recovered.

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

Assuming optically thin matter

→ 3D image of the scattering clouds

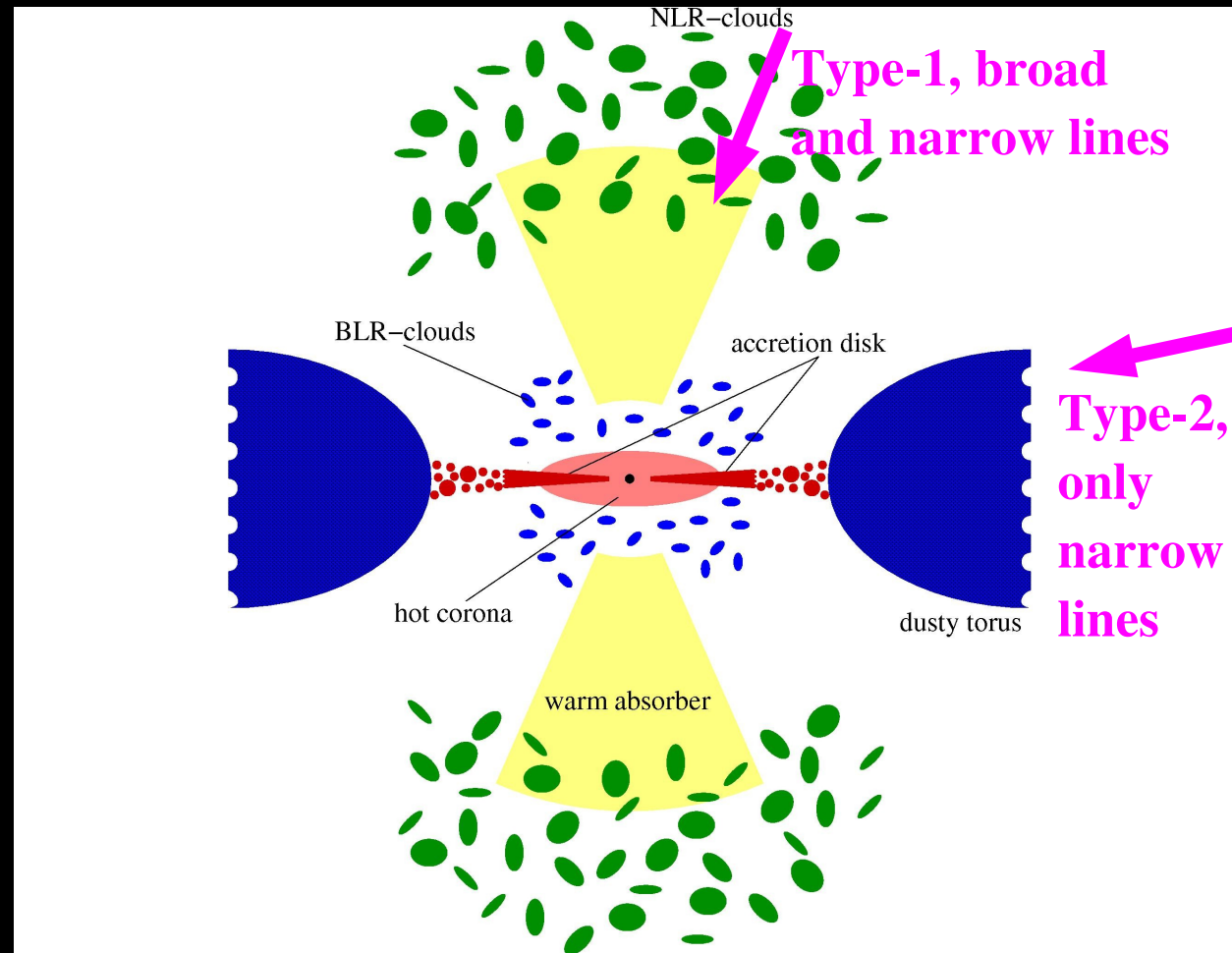
# Hidden type-1 AGN and polarization dichotomy

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

**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 an overview



# Modeling polarization with the STOKES code

Public access

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

- 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

home - Mozilla Firefox

STOKES  
Modeling Radiative Transfer and Polarization

Observatoire  
Astronomique  
de Strasbourg  
René W. Goosmann

The *STOKES* computer program is a Monte Carlo radiative transfer code for modeling multi-wavelength polarization. It was designed to model astrophysical objects of various geometries and considers polarization induced by electron and dust scattering. If you are interested in polarization and radiative transfer you might want to follow the links on this page to find out more about *STOKES*. The code is freely available for use. We just ask if you publish results based on *STOKES* computations that you refer to the [Goosmann & Gaskell \(2007\)](#) paper describing the code.

--> Check out the [manual](#) to get an introduction to the capabilities of the program and learn how to run it.

--> You may download compiled versions of the [program](#) for Linux and Windows.

--> [Examples](#) for the input files and pre-computed [dust models](#) are helpful to get used to running the code.

--> If you would like to adjust the program to your personal needs and compile it yourself you may obtain the C++ [source codes](#).

--> Find out about [scientific results](#) obtained with *STOKES*.

*STOKES* was written by René W. Goosmann who is now at the Observatoire Astronomique de Strasbourg, France. If you have questions or comments about the code, please [contact](#) him.

George Gabriel Stokes (1819-1902)

$p \times F$  [arbitrary units]

$\lambda$  [Angstrom]

x, y, z coordinate system and polarization vectors diagram

Terminé

Goosmann & Gaskell (2007)

Marin et al. (2012)

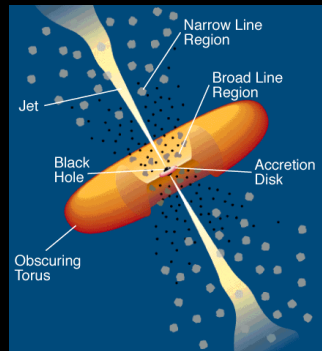
Goosmann, Gaskell & Marin (2013)

# Modeling the polarization dichotomy of AGN

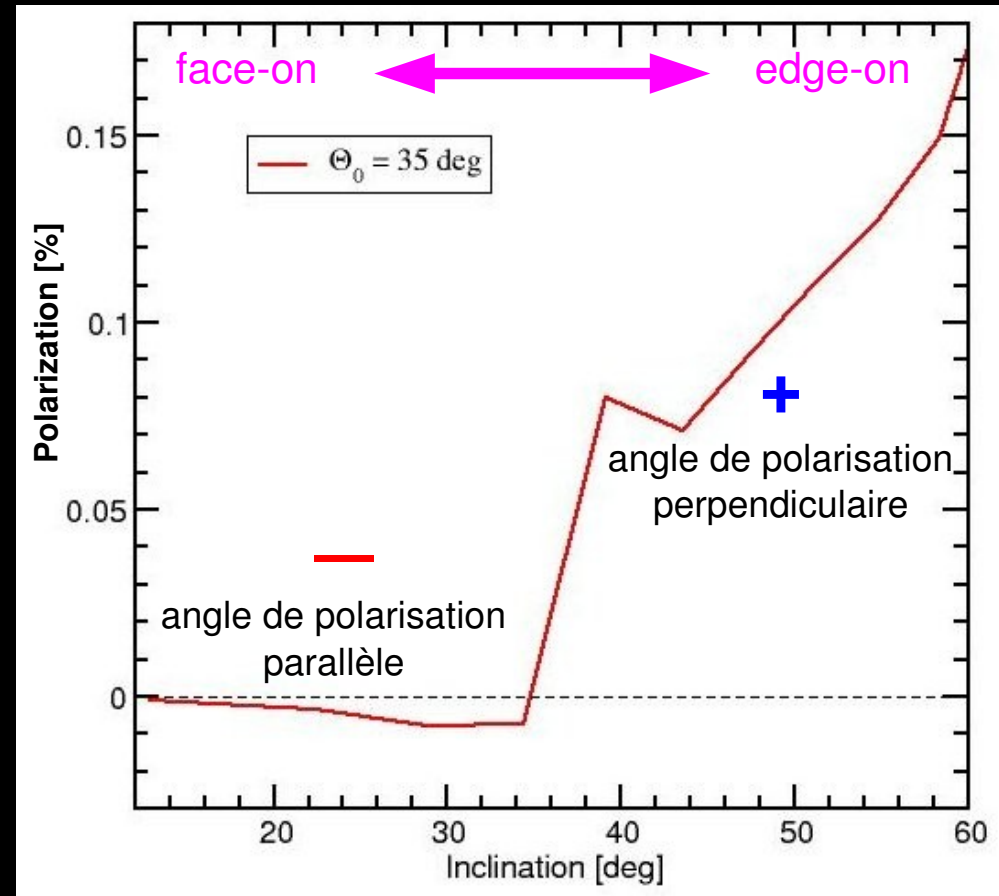
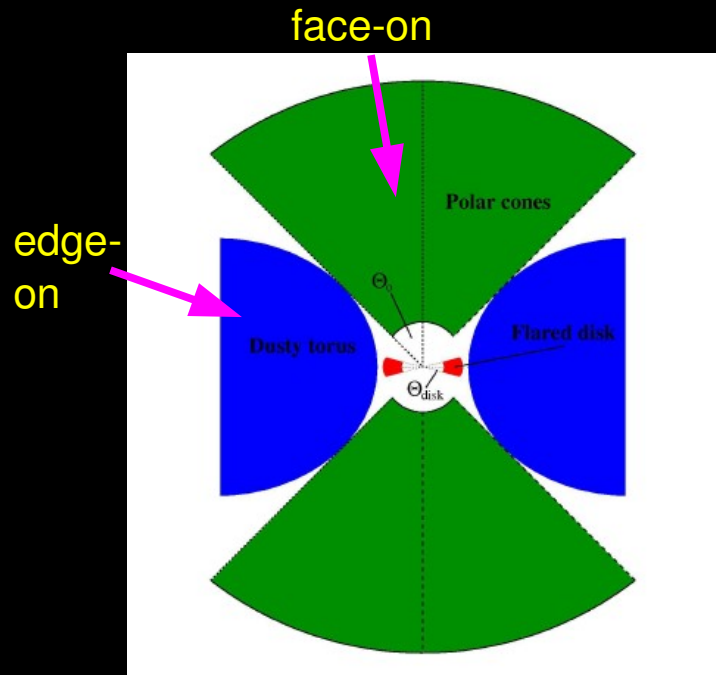
AGN type-1 : view « face-on »  
 polarisation angle  
 parallel with respect to the axis

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

## Modeling the unified scheme



Urry & Padovani (1995)



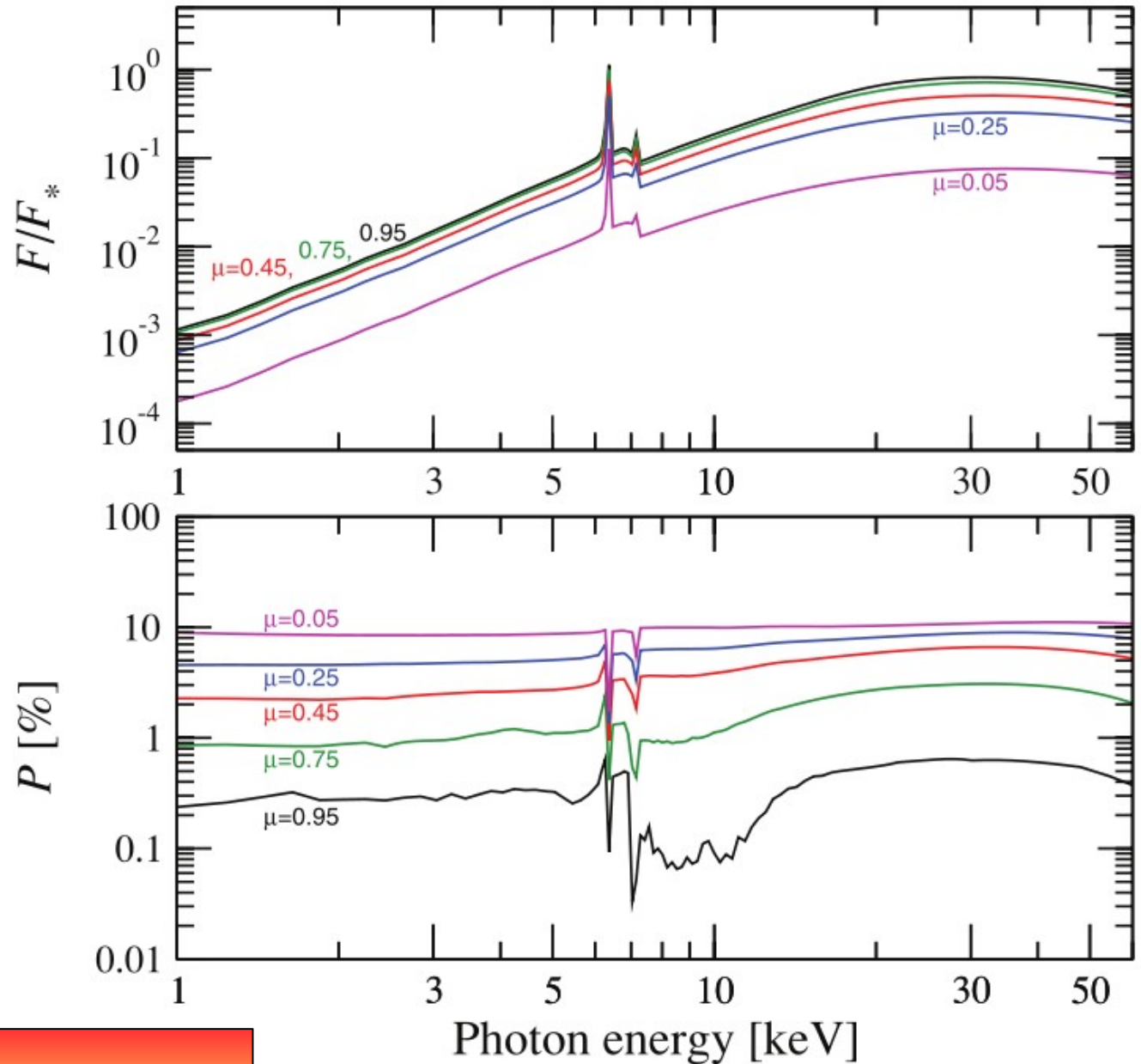
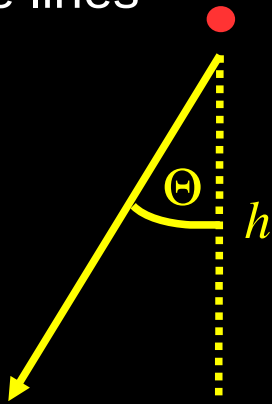
Goosmann et al. (2006)  
 Marin et al. (2012)

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



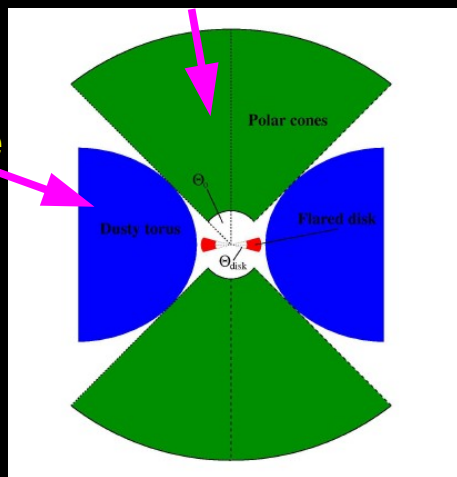
Face-on  $\leftarrow \rightarrow$  edge-on

Edge-on  $\leftarrow \rightarrow$  face-on

# The X-ray polarization of disk reprocessing

face-on

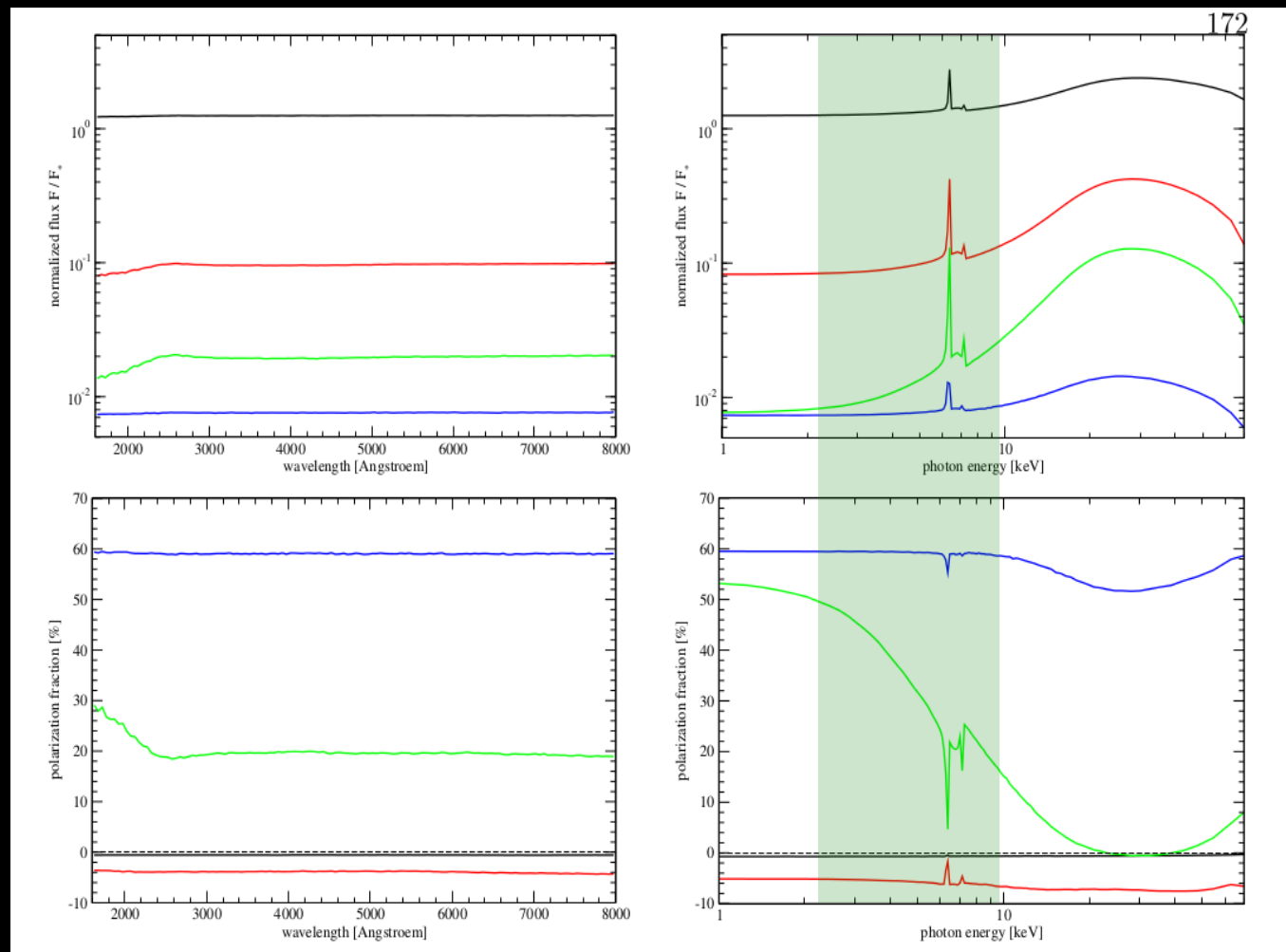
edge-on



Next steps:

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

Marin & Goosmann (2011)



Face-on  $\leftrightarrow$  edge-on

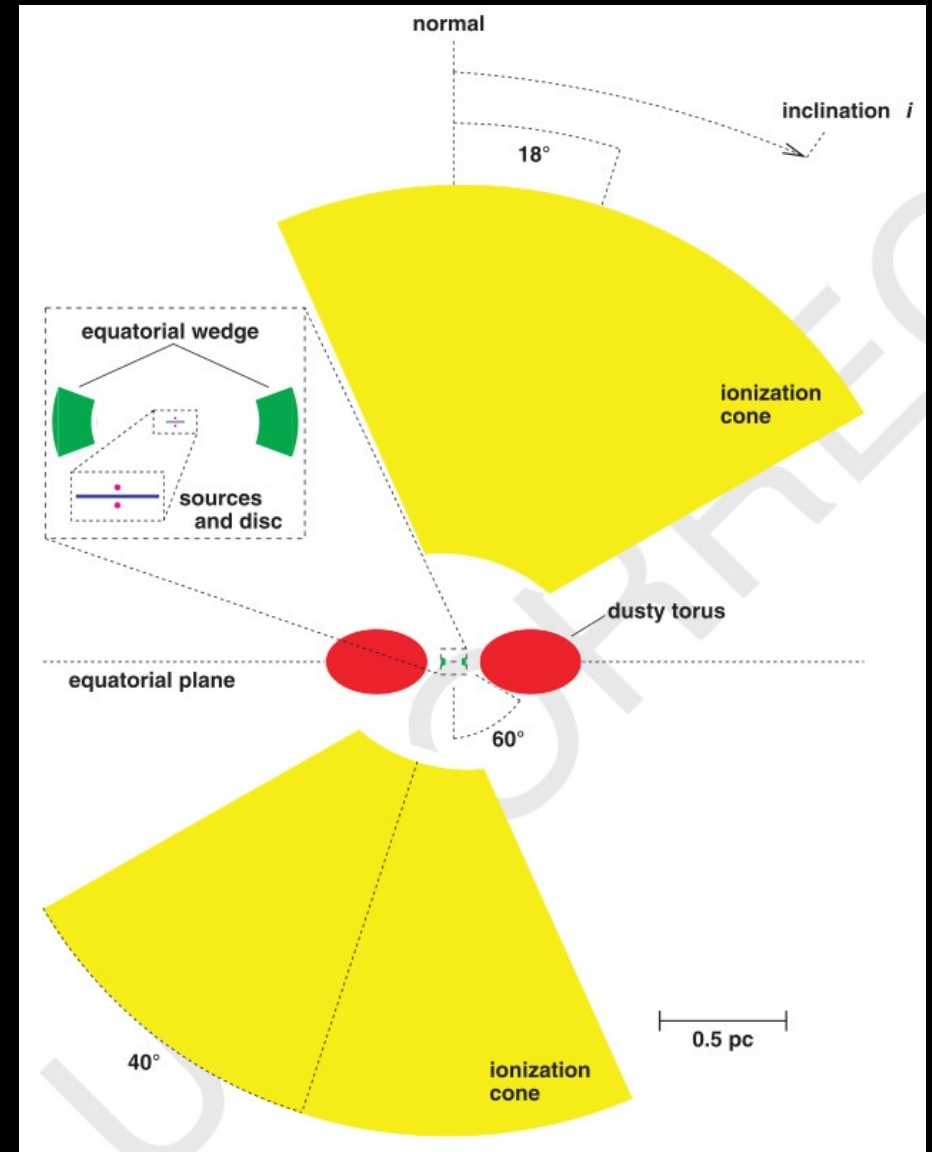
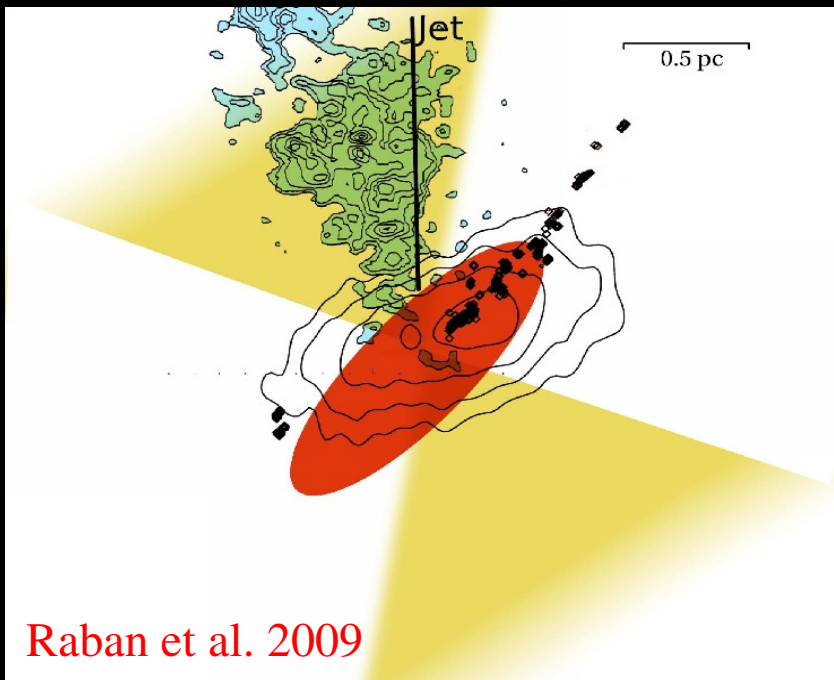
Edge-on  $\leftrightarrow$  face-on

→ 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  $\Theta=60^\circ$ , and inclined outflows as suggested by Raban et al. (2009).

Goosmann & Matt 2011

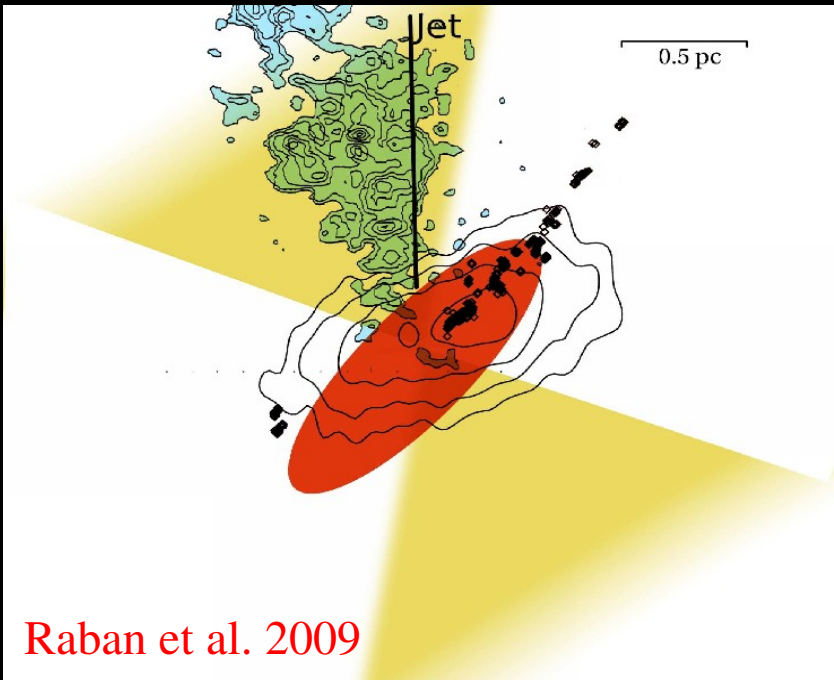




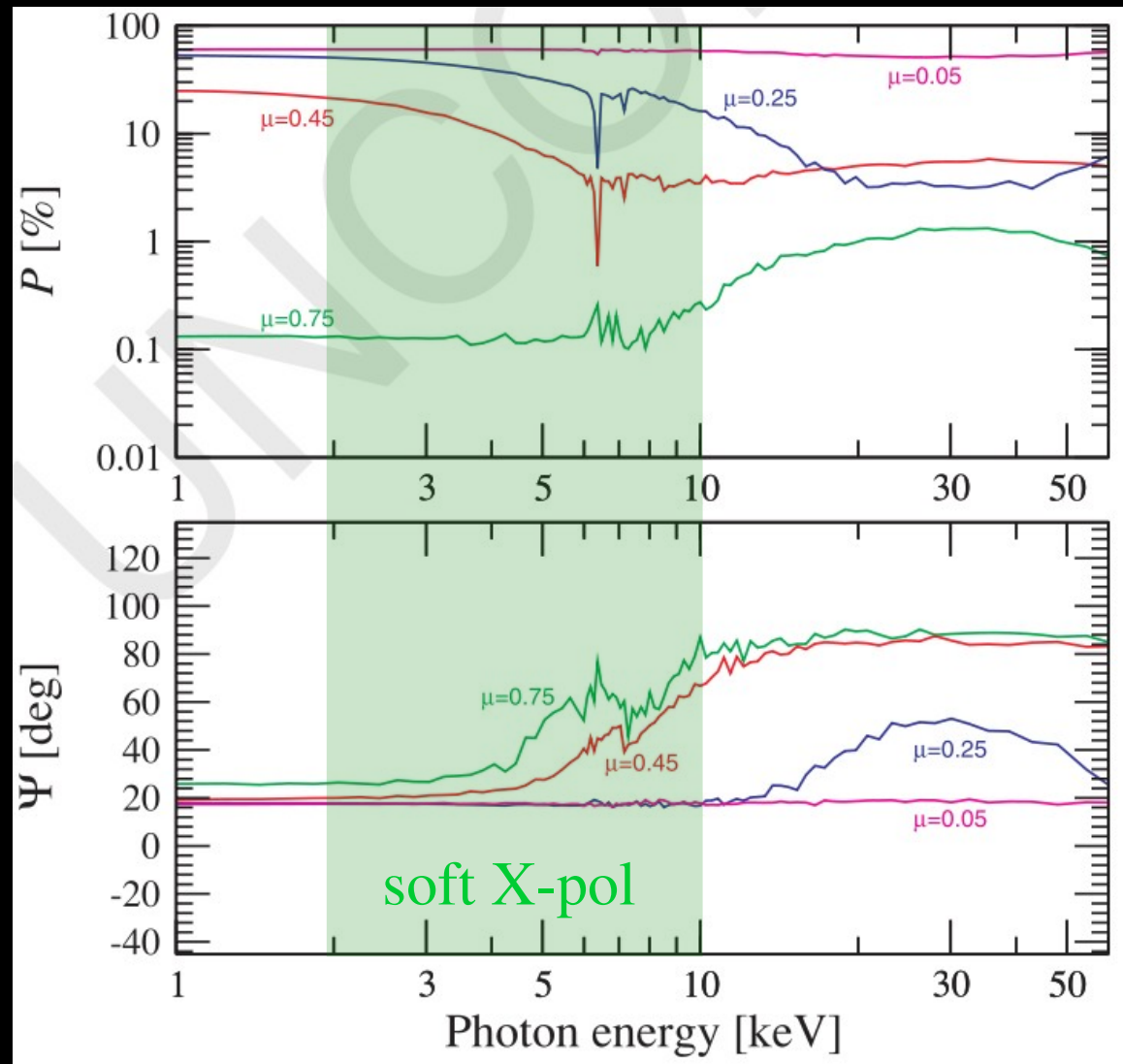
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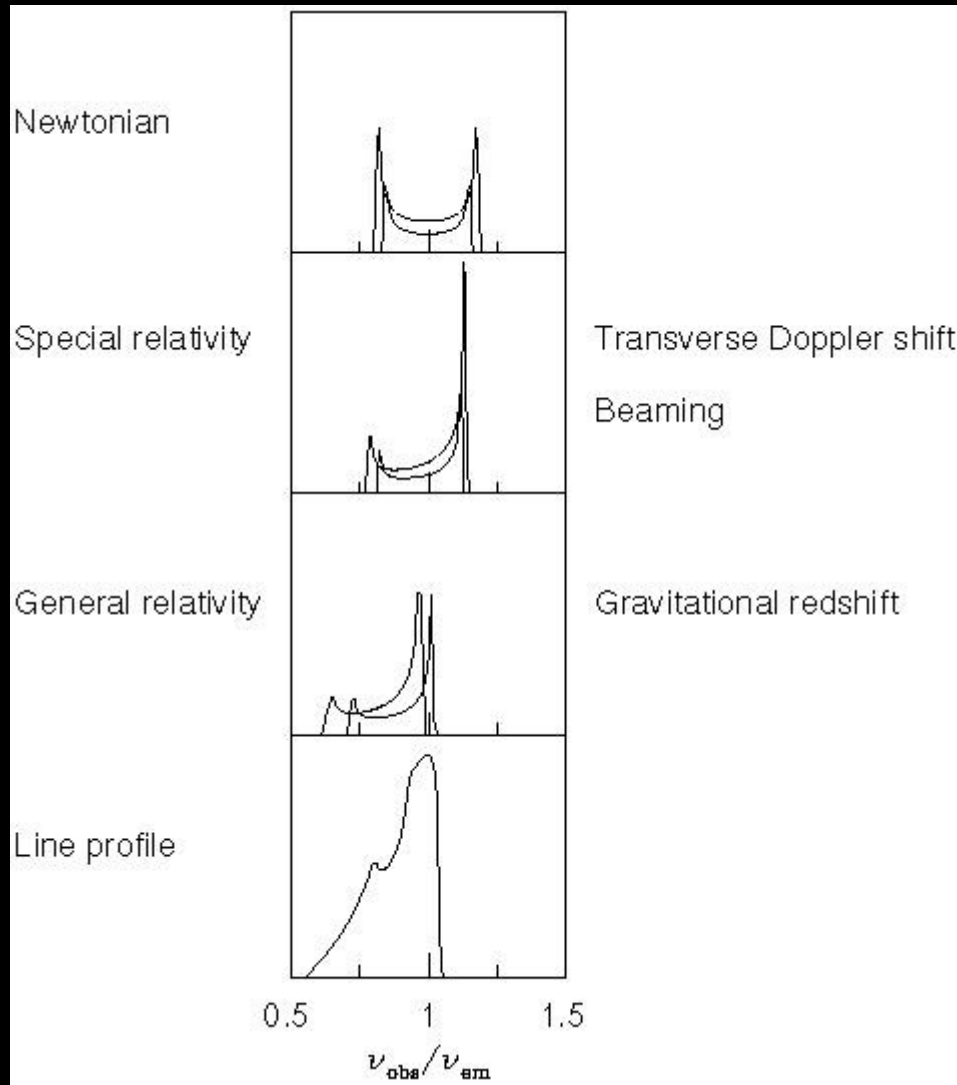
Goosmann & Matt 2011



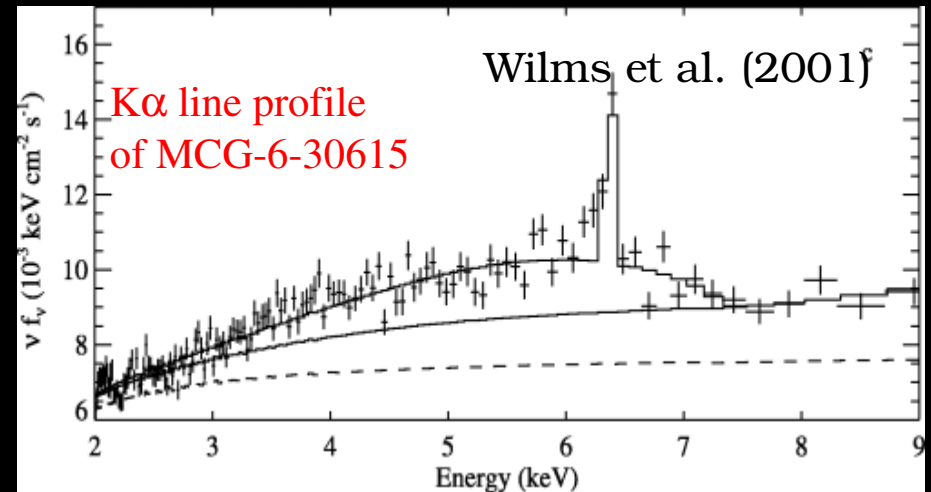
Possibility to measure the relative angle between torus and outflows by broad-band polarimetry!



# 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)
- Wilkins & Fabian (2011)

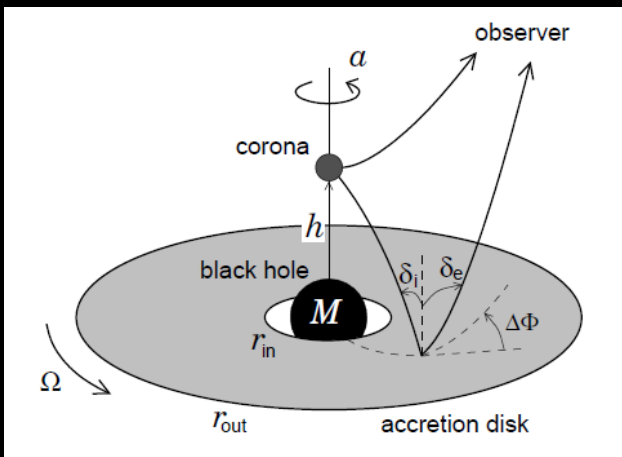
...

# Unravel the nature of broad iron $K\alpha$ lines

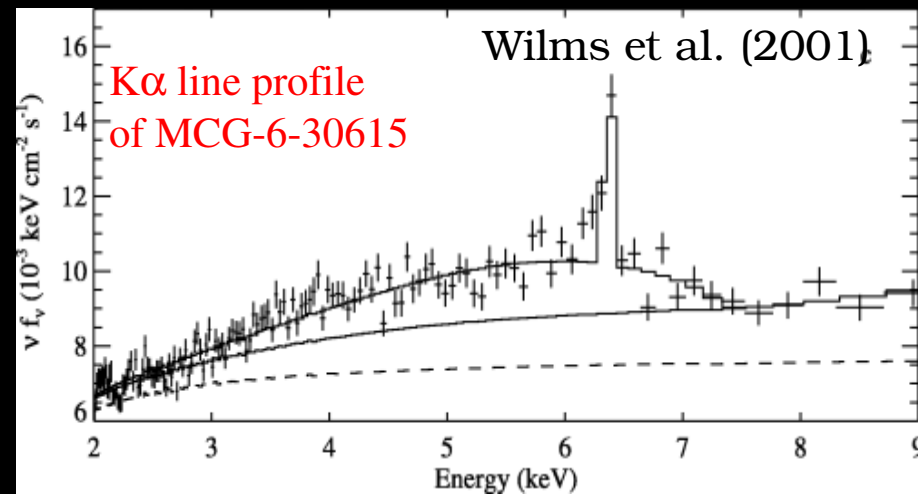
Marin et al. (2012)

## Relativistic case

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

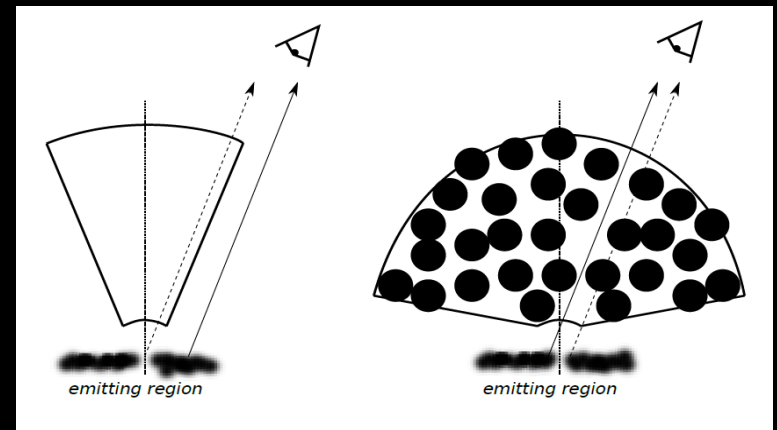


$h = 2.5GM/c^2$   
 $a = 1$  (Kerr)  
 (Miniutti & Fabian 2004)

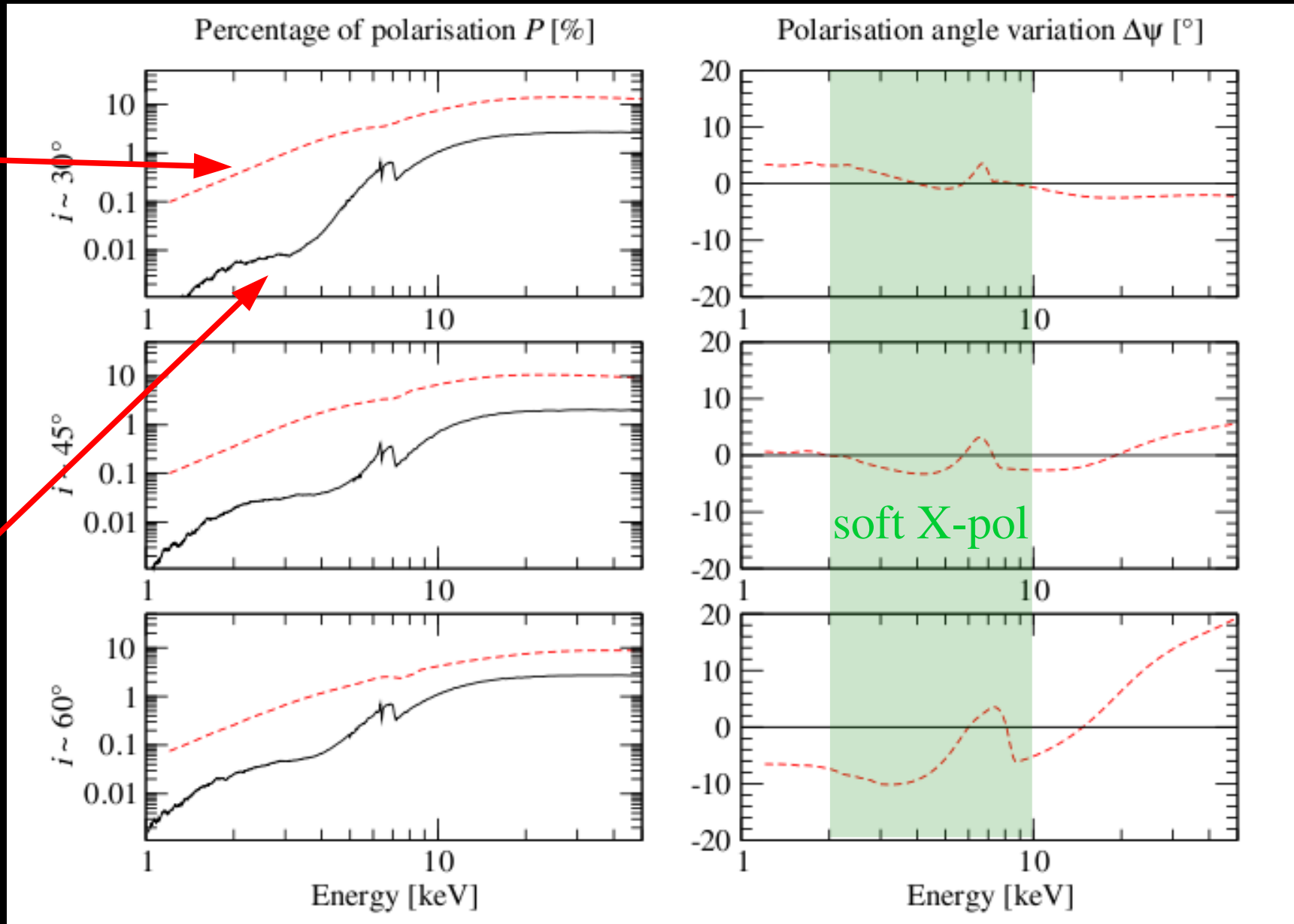
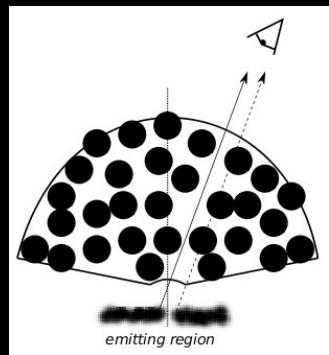
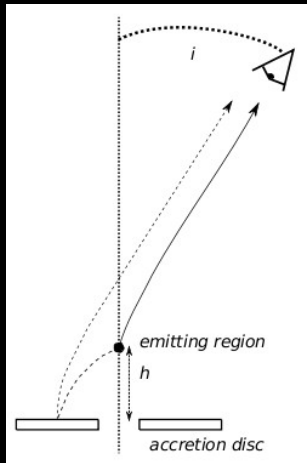


## Absorption case

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



# Unravel the nature of broad iron $K\alpha$ 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!**