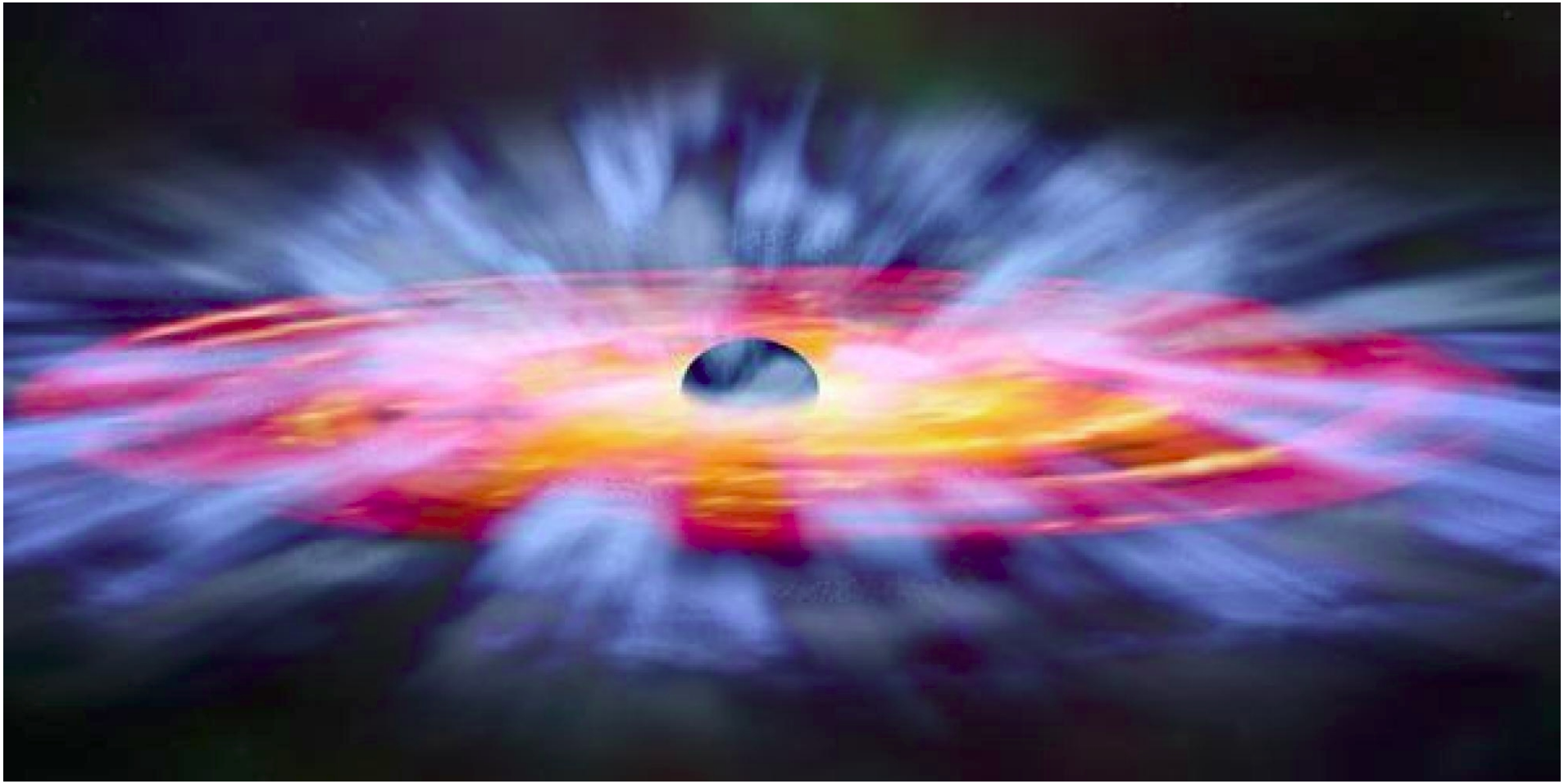
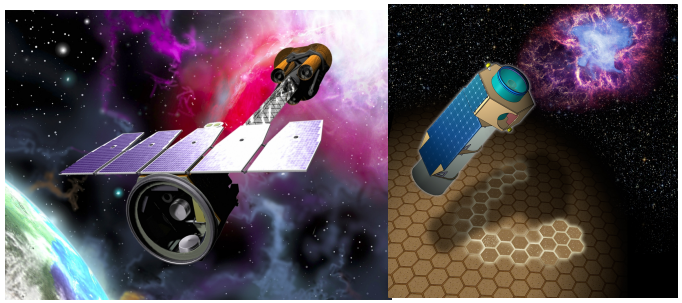
The X-ray polarization of reprocessed emission in black hole systems



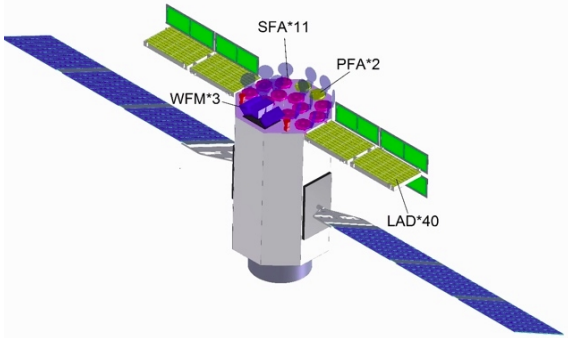
René W. Goosmann
Observatoire astronomique
de Strasbourg

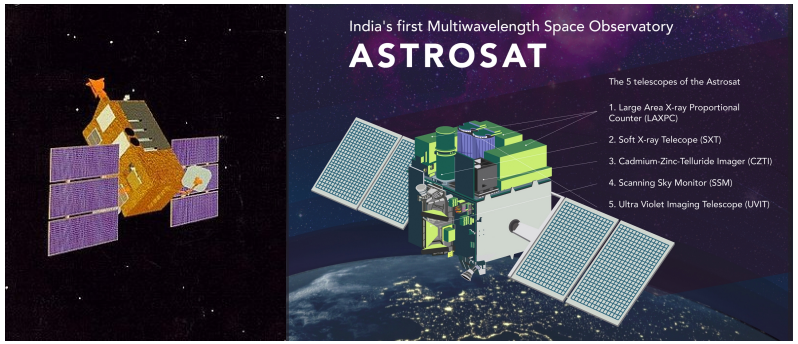
Observational challenges leading to an ambitious modeling effort...



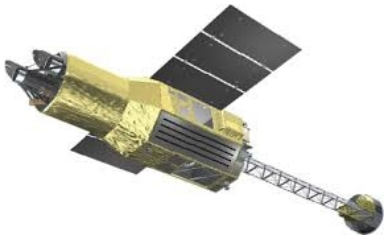
polarimetry

eXTP (2024)

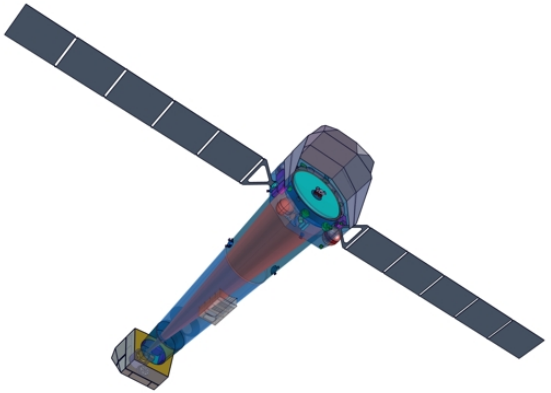




(fast-)timing



high-res. spectroscopy

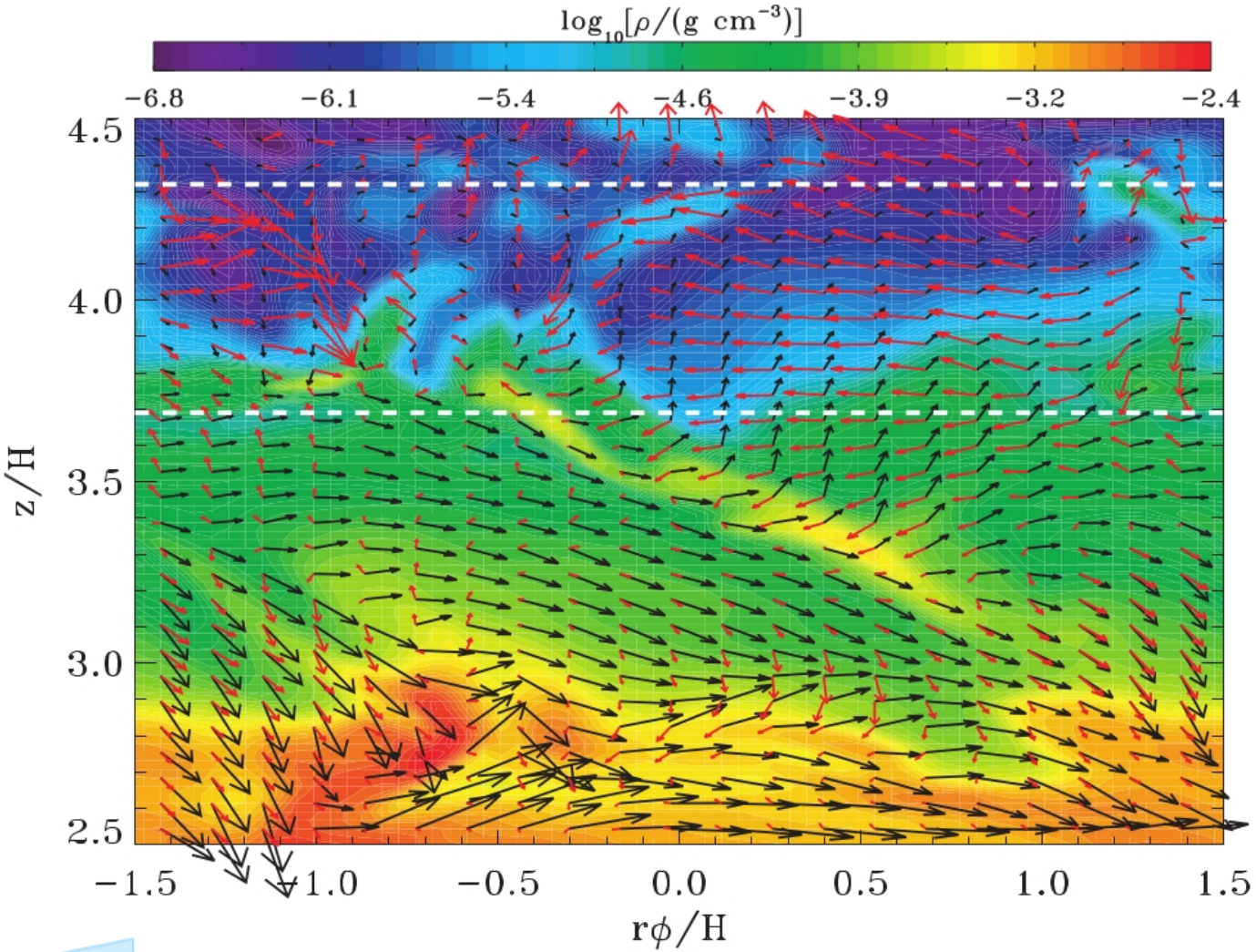


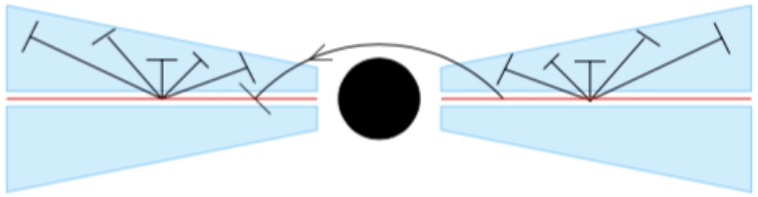
Athena

On the way to a full understanding of accretion – combining radiative transfer with (GR-)MHD

Missing element:

We need an on-the-spot reprocessing to be coupled to a Monte-Carlo radiative transfer method.



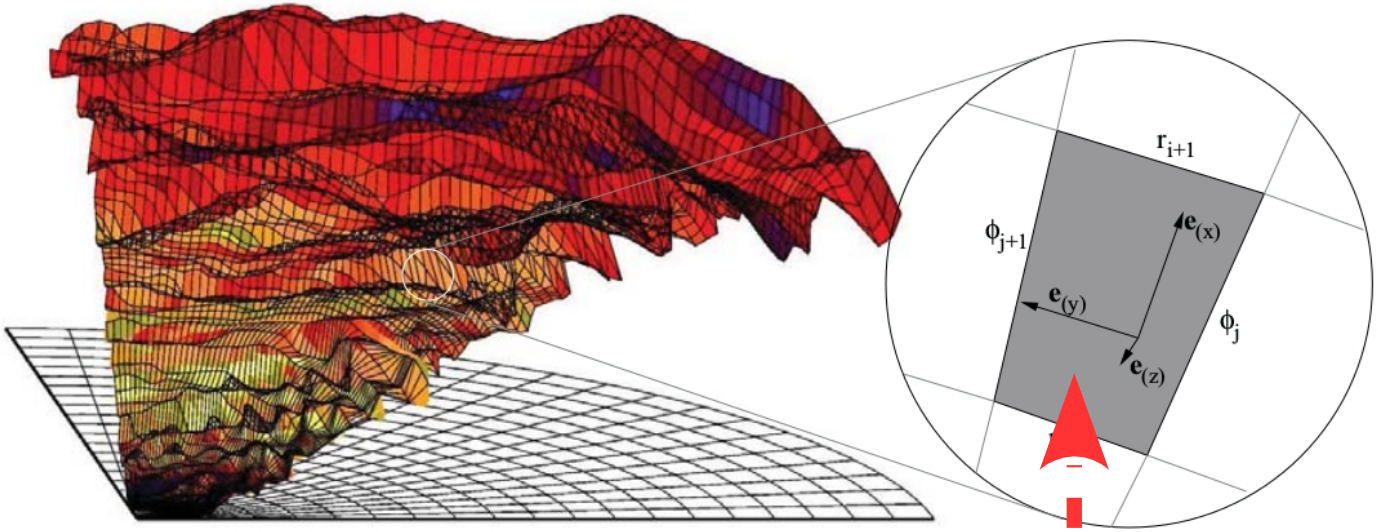


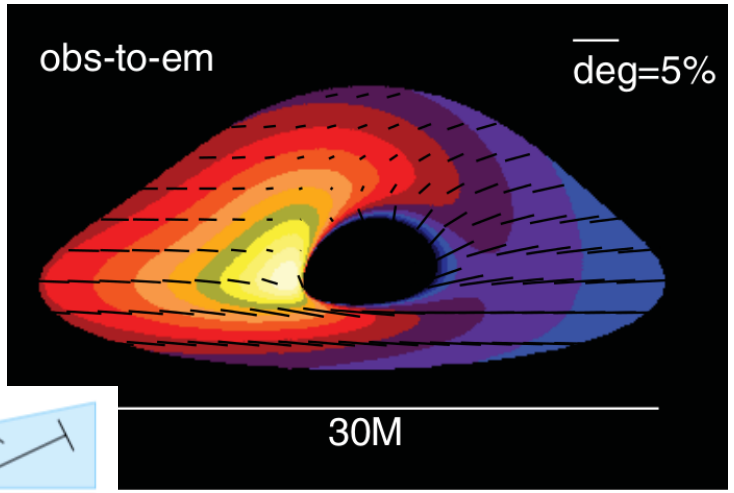
Blaes, Hirose & Krolik (2007),
Hirose, Krolik & Stone (2006)

On the way to a full understanding of accretion – combining radiative transfer with (GR-)MHD

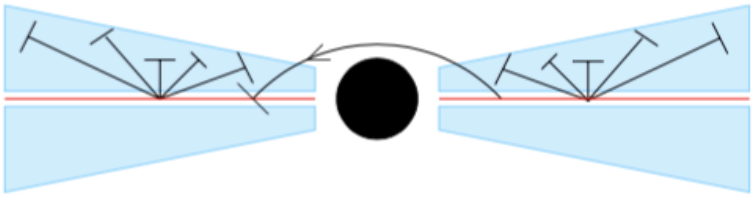
Missing element:

We need an on-the-spot reprocessing to be coupled to a Monte-Carlo radiative transfer method.





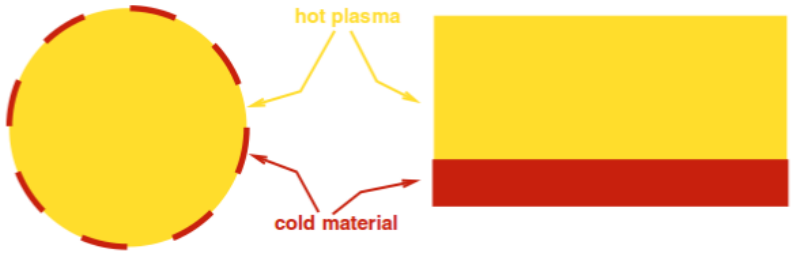
What is the reprocessed spectrum from this cell ?



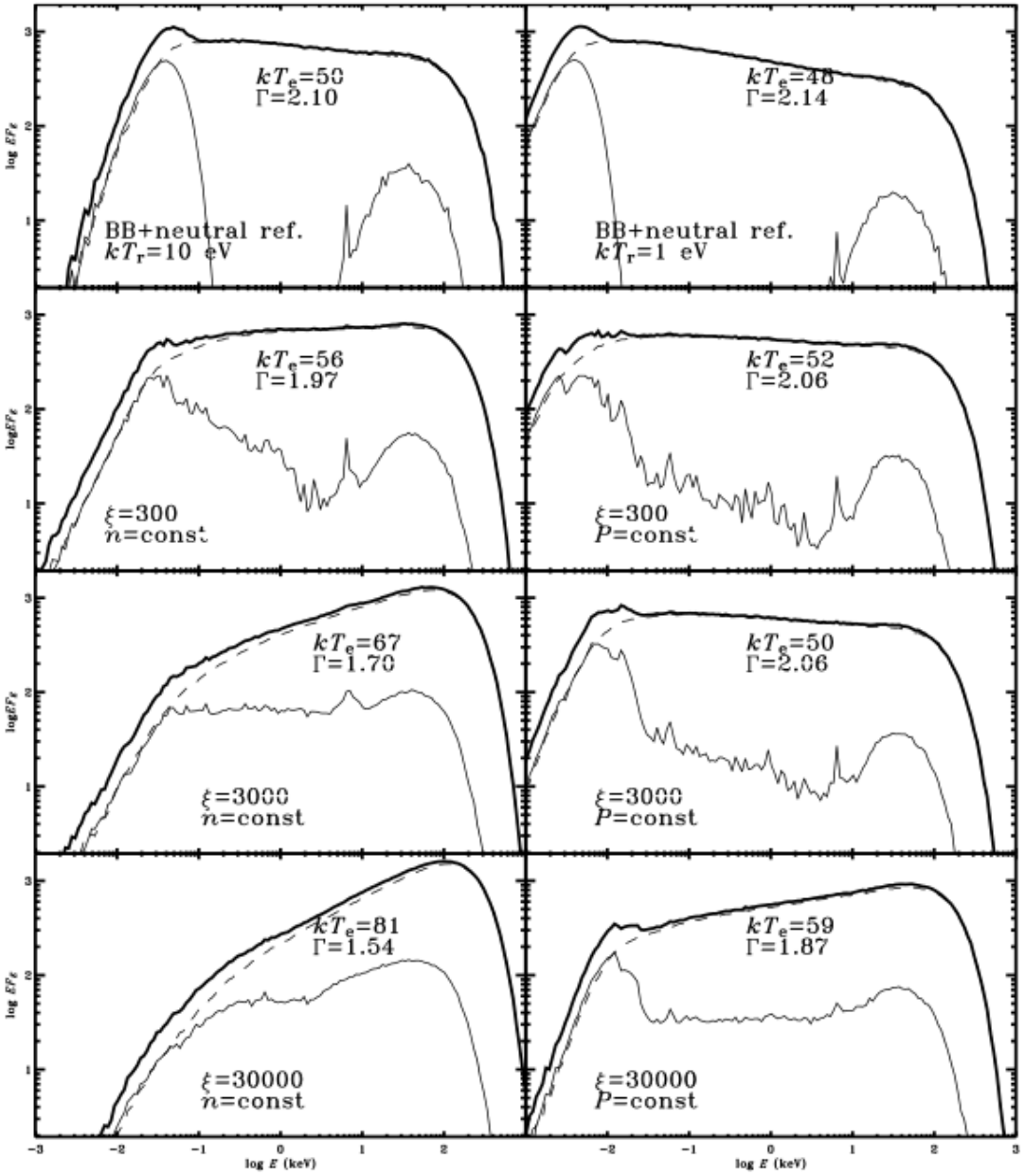
Schnittman & Krolik (2013)

Example: modeling the radiative coupling between the disk and the corona

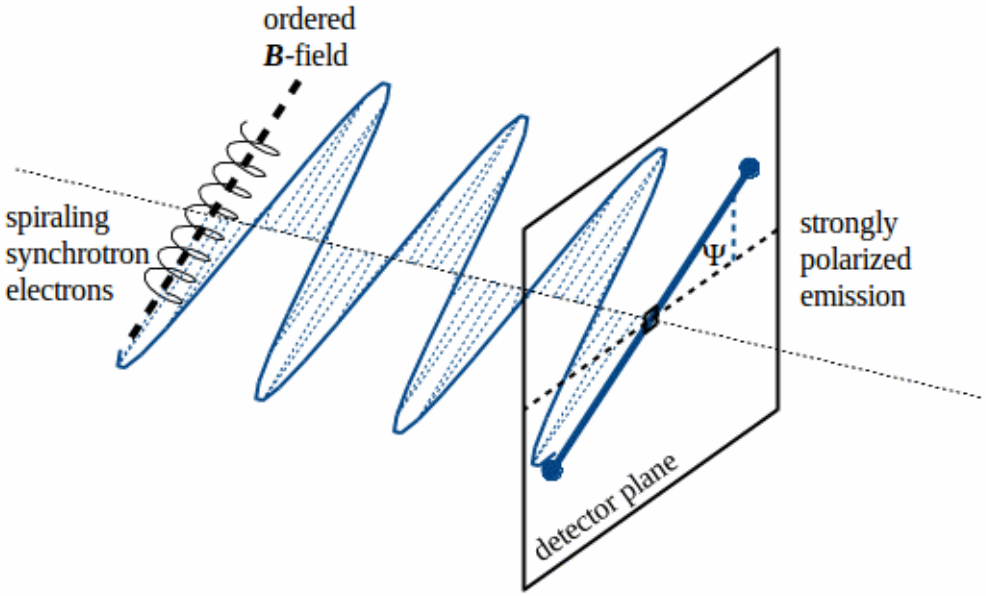
Inspiration by the work of Malzac, Dumont & Mouchet (2004) for AGN

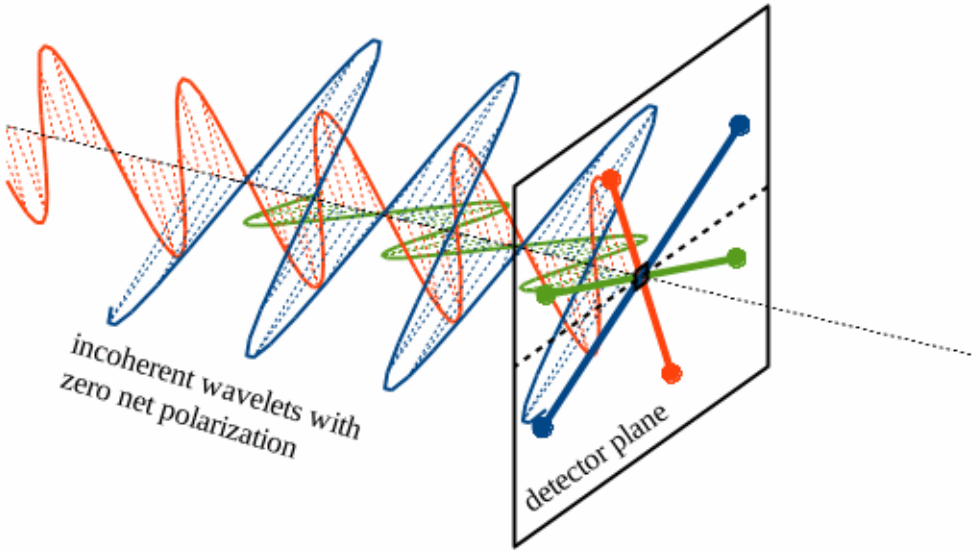


Inspired by this approach, can we construct a more general and versatile model?



The polarization of reprocessed emission – basic notions





Coherent, strongly polarized emission as expected from synchrotron radiation produced in a highly-ordered magnetic field.

Incoherent, weakly polarized radiation produced by superposition of incoherent sources, such as turbulent magnetic fields emitting synchrotron emission.

Polarization mechanisms in the X-ray range – scattering-induced polarization

[Synchrotron emission]

Electron scattering

Dust (Mie) scattering

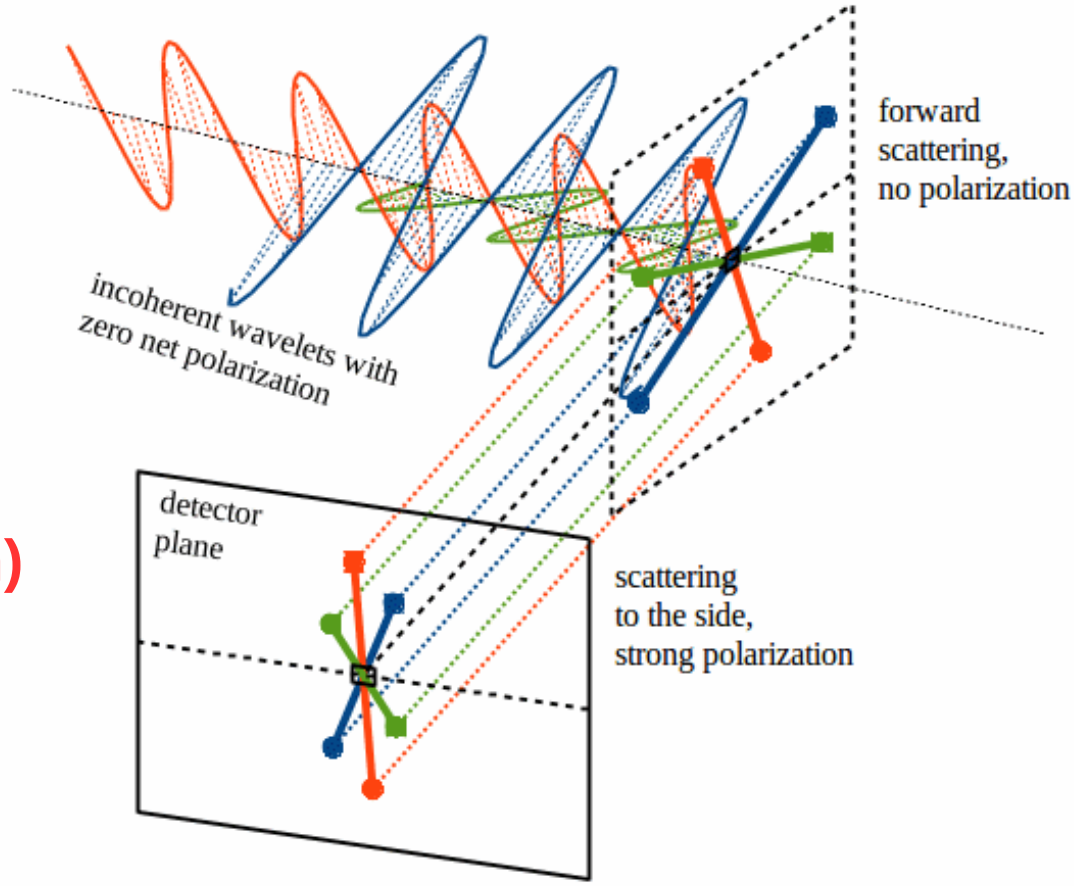
Resonant line scattering

Dichroic absorption

Dilution (by unpolarized radiation)

[General Relativity]

[Birefringence in strong *B*-fields]



Scattering

Strong polarization: Θ = 90° (Reflection)
Weak polarization: Θ = 0° (Transmission)

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

Oscillator model for Thomson scattering

Rotation of the polarization vector when transported through a strong gravity field.

Applying relativistic ray-tracing methods in Kerr metric. Again, it is important to quantify the local polarization.

see e.g.

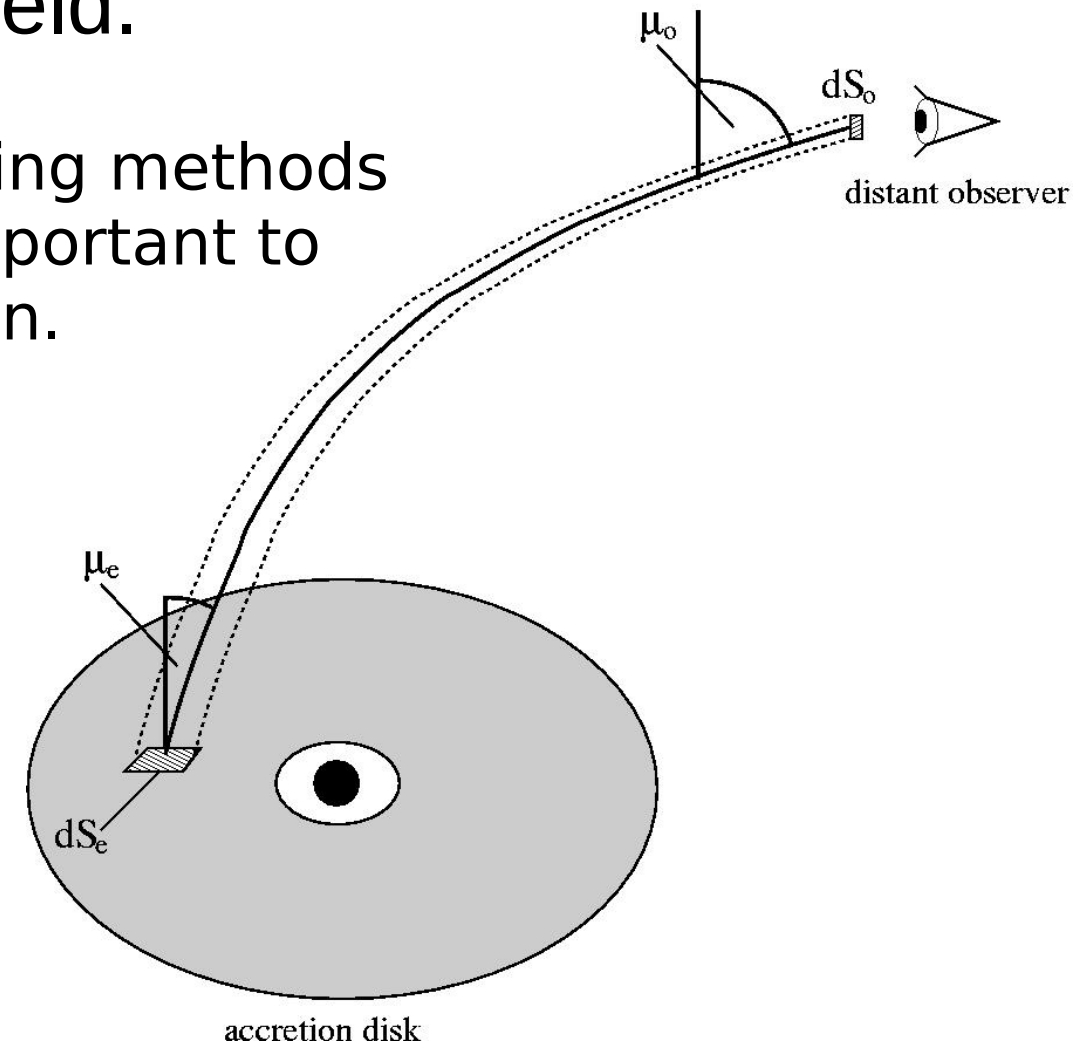
Connors, Piran, Stark (1980)

Dovčiak et al. 2004

Schnittman, Krolik 2009

Dauser et al. 2013

I, Q, U, V



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

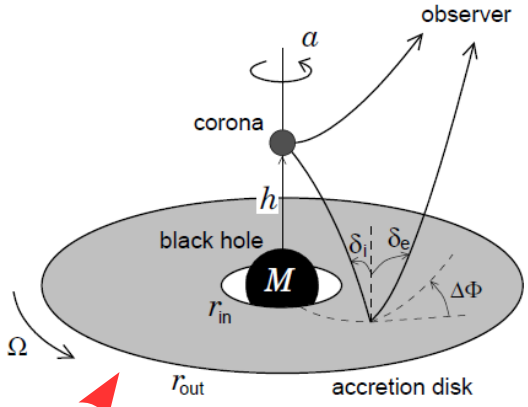
observed photon flux | **disk integration** | **energy** | **local photon flux** | **transfer**

What already nowadays and for sure(!) future observers would like theorists to do...

Constructing a self-consistent model that provides:

- high-resolution spectra (~very few eVs at 1 keV),
- timing information,
- (linear) polarization results

for the coupled radiative transfer between



- various emitting and reprocessing media
- of arbitrary geometry,
- taking into account all angular dependencies,
- covering a range of ionization strengths / temperatures.

Lorentz Center
International center for scientific workshops

STRONGGRAVITY
EU FP7-SPACE research project — 1/1/2013 - 31/12/2017

ANR

PNHE
Programme national hautes énergies

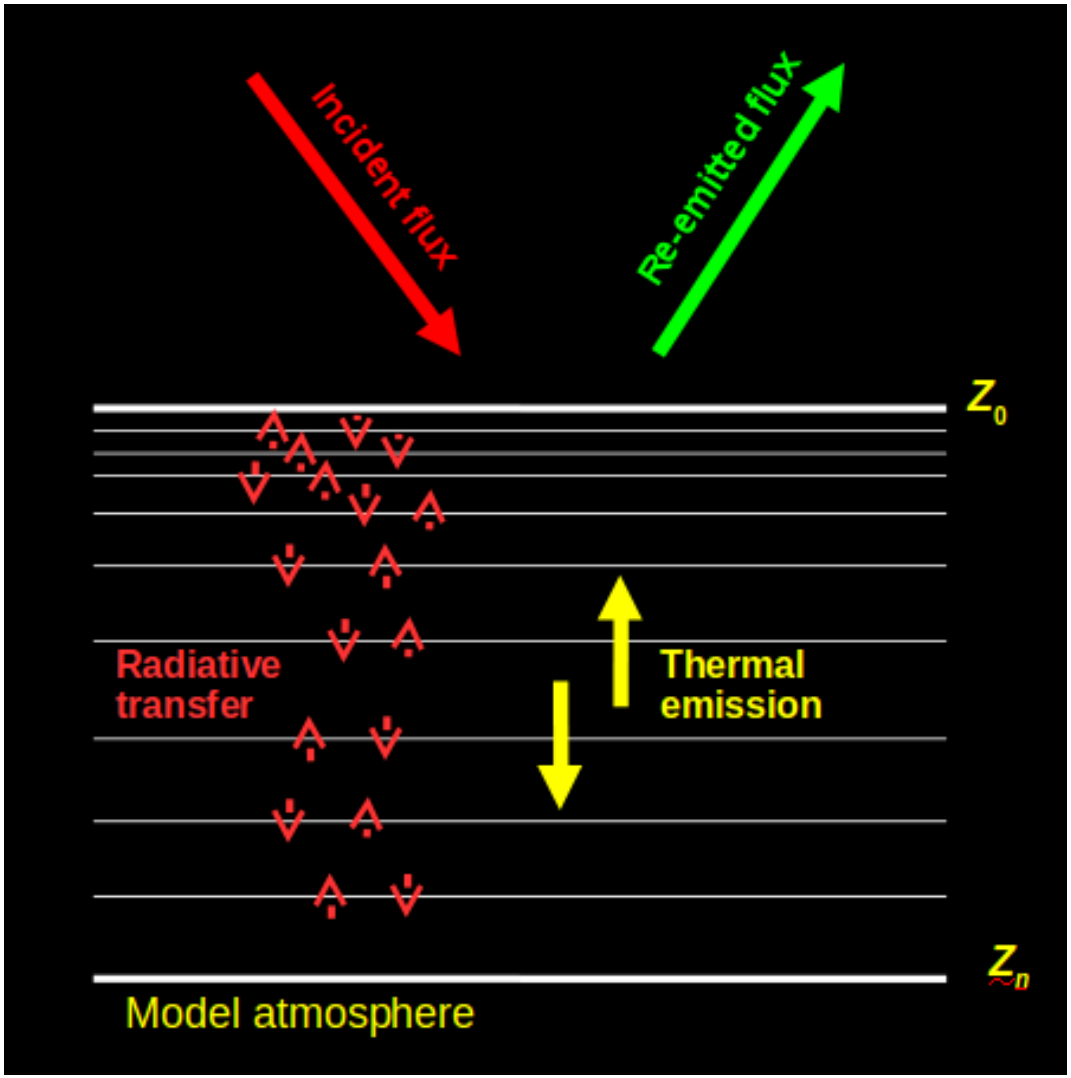
Applying two radiative transfer codes

Monte-Carlo radiative transfer method STOKES (Goosmann & Gaskell 2007, Marin et al. 2012)

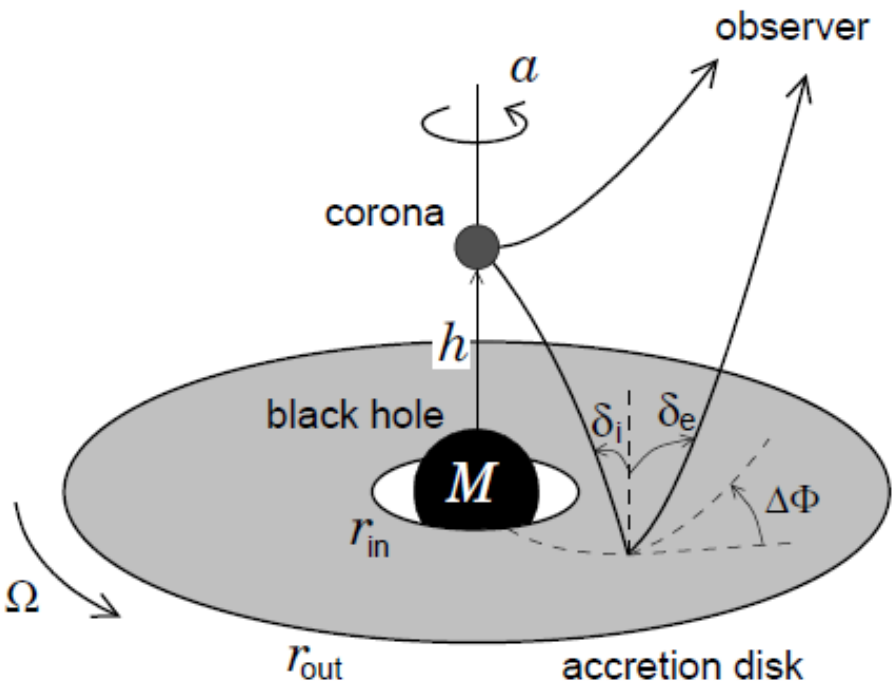
- reprocessed spectrum
- polarization spectrum
- time lag spectrum
- assuming a thin disk

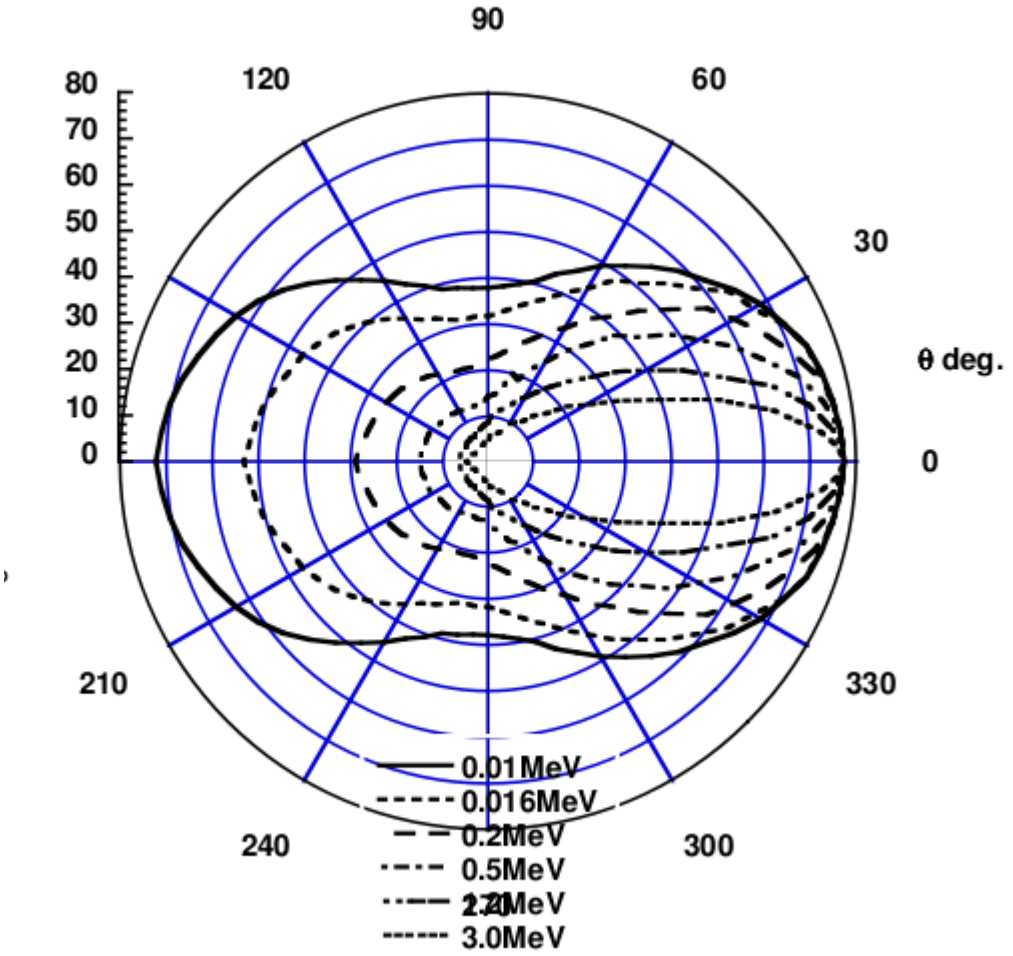
Radiative transfer code TITAN (Dumont 2000, 2003)

- constant density slab
- given ionization parameter $\xi = 4\pi F/n$
- solving radiative transfer, temperature and ionization profile using ALI method



Spot light on the azimuthal flux dependence of X-ray reprocessing

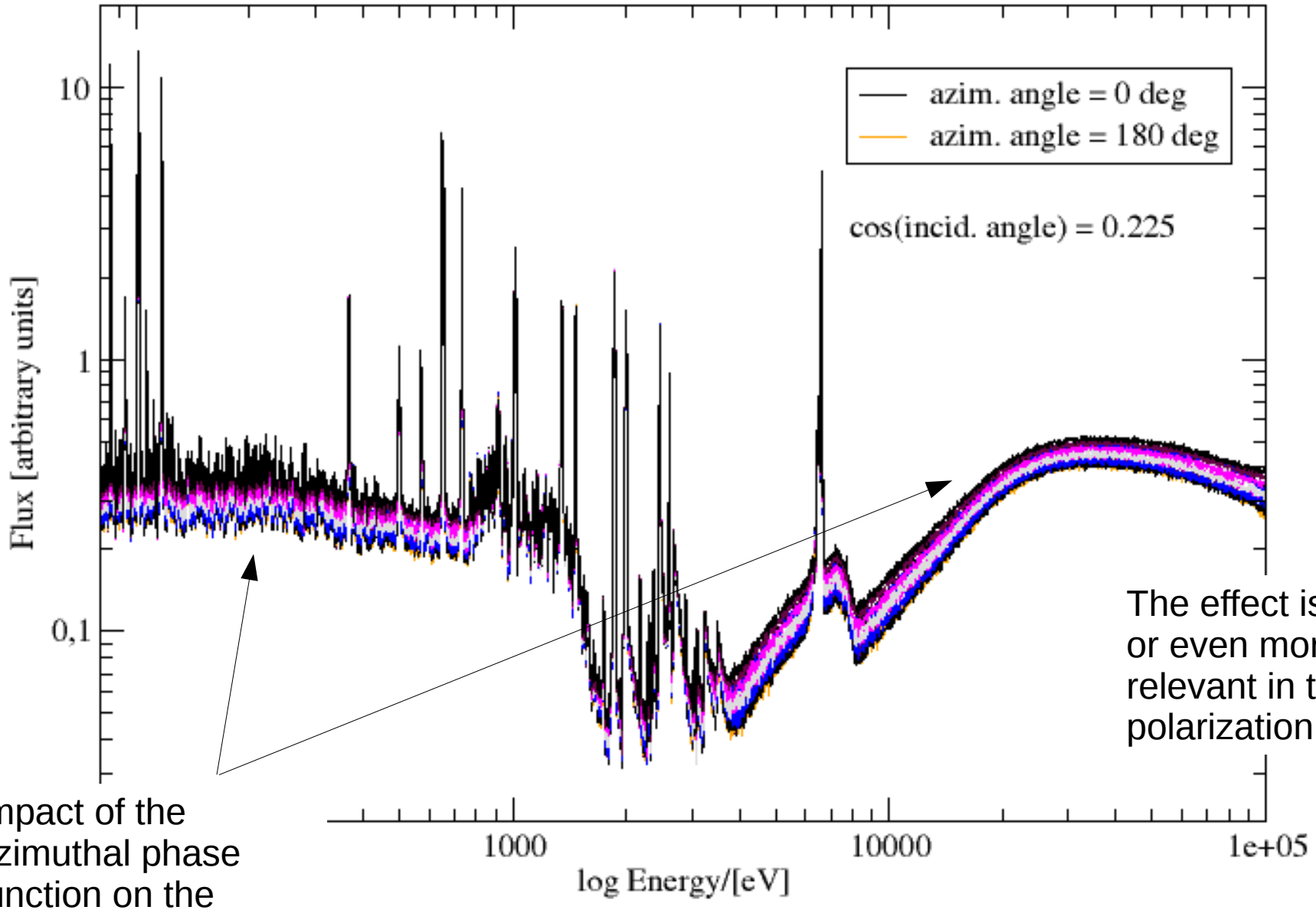




<u>State of the art models:</u> Garcia et al. (2013) [XILLVER]

<u>Next challenge:</u> correctly including **all** angular dependencies (see iron line diagnostics of Svoboda et al. 2010) as well as timing and polarization information

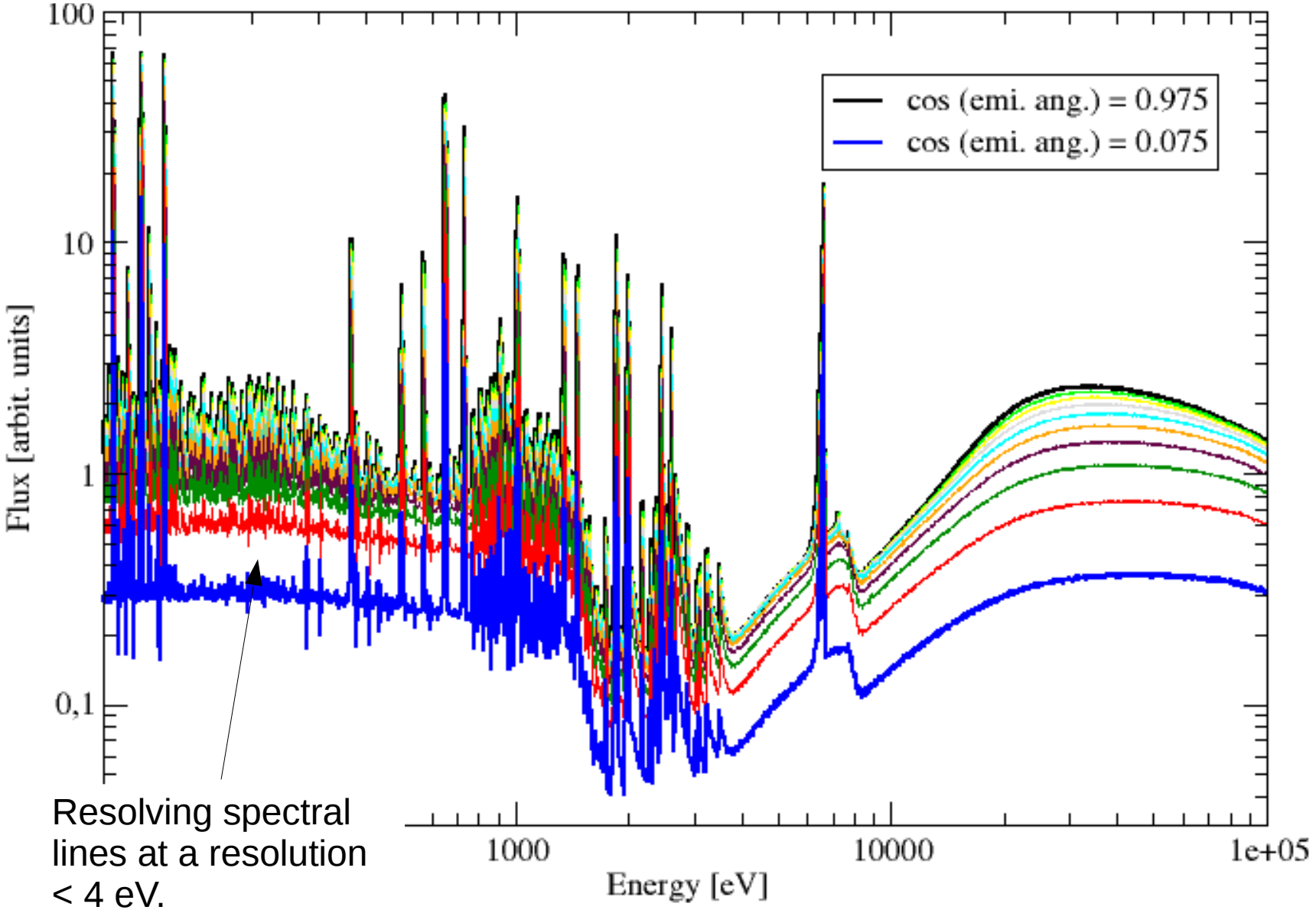
Results for an irradiated AGN accretion disk – the ***azimuthal*** dependence



The effect is equally or even more relevant in the polarization degree.

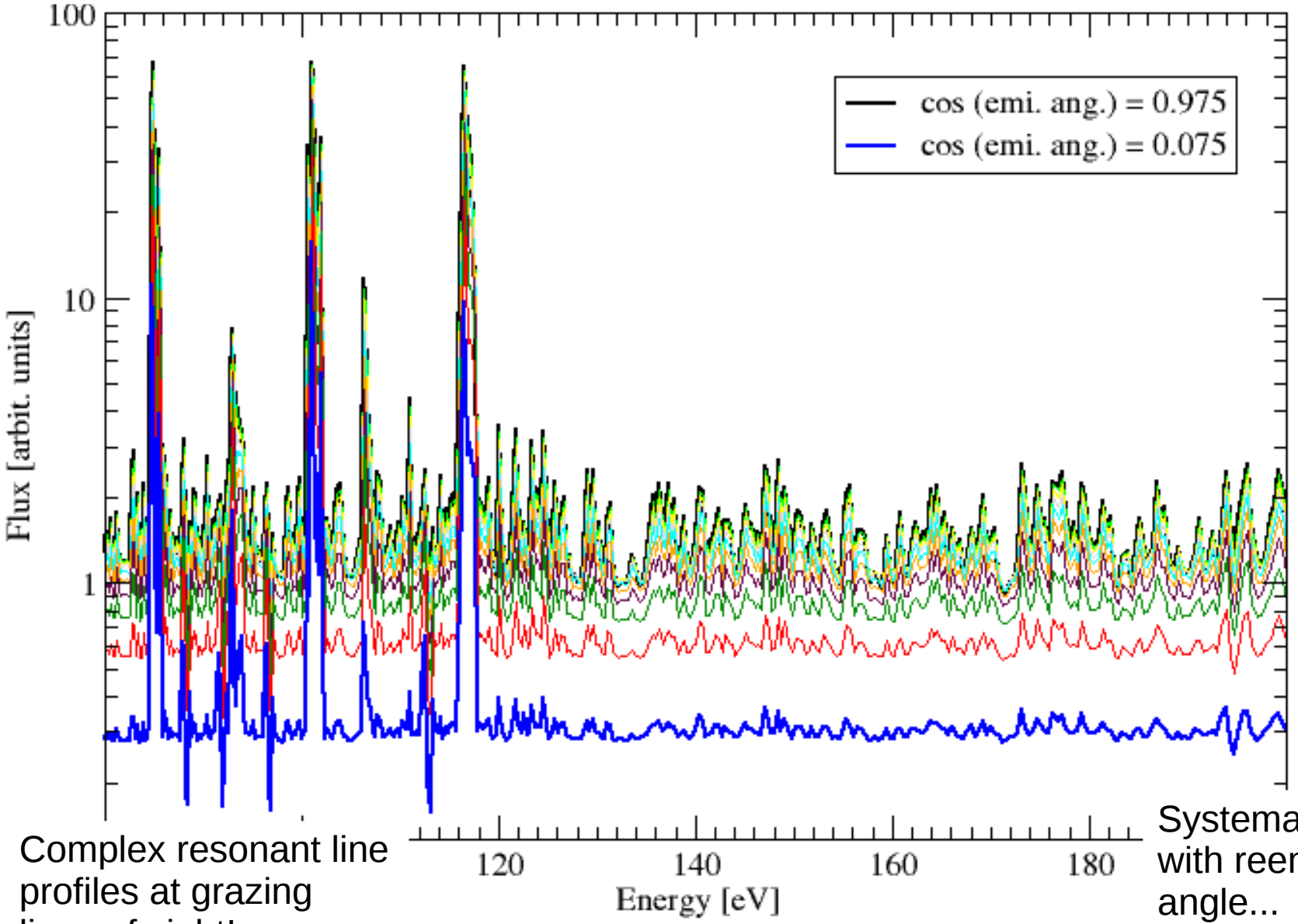
Impact of the azimuthal phase function on the reprocessed flux

Results for an irradiated AGN accretion disk – the ***polar*** dependence



Resolving spectral lines at a resolution < 4 eV.

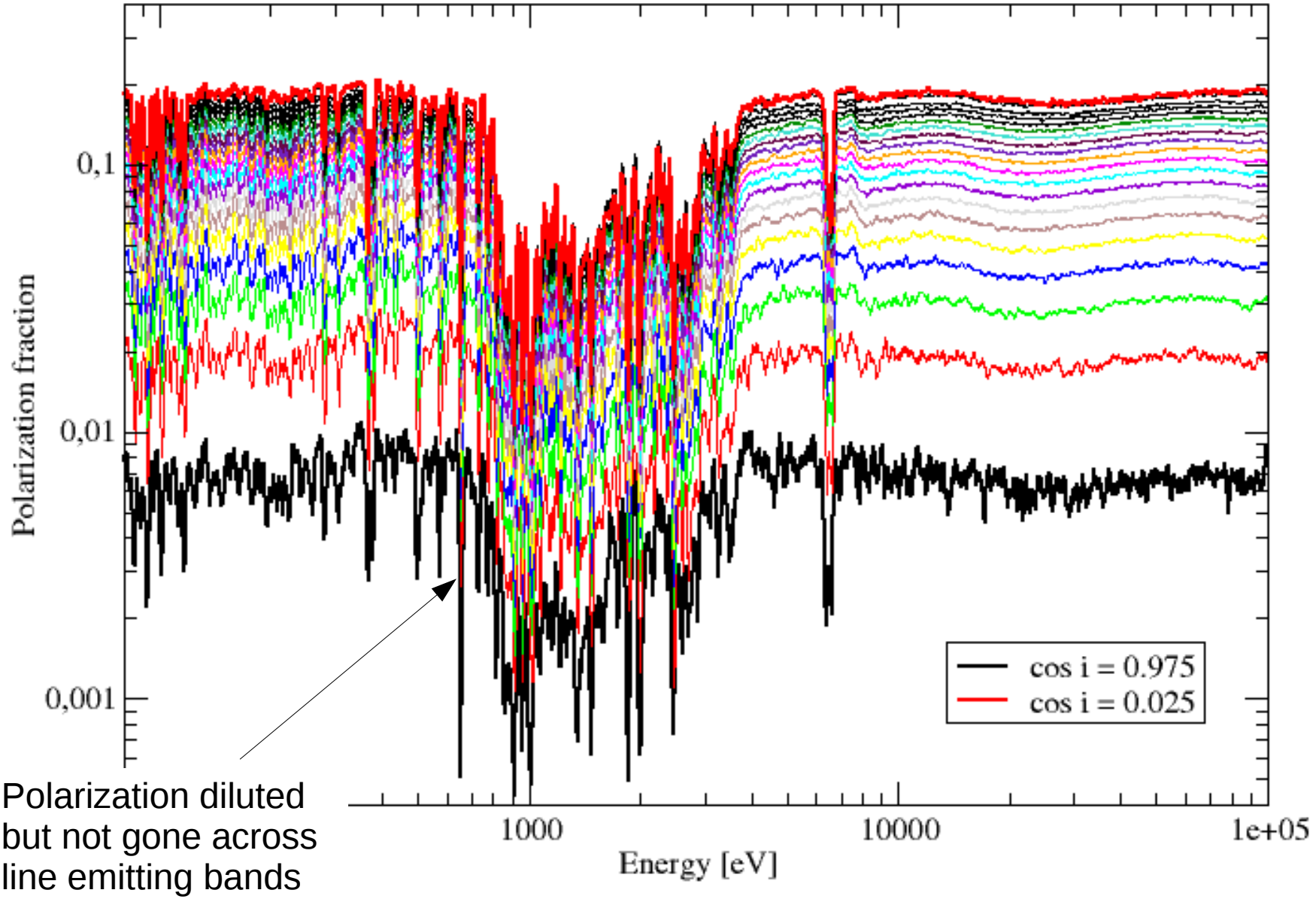
Results for an irradiated AGN accretion disk – the ***polar*** dependence



Complex resonant line profiles at grazing lines of sight!

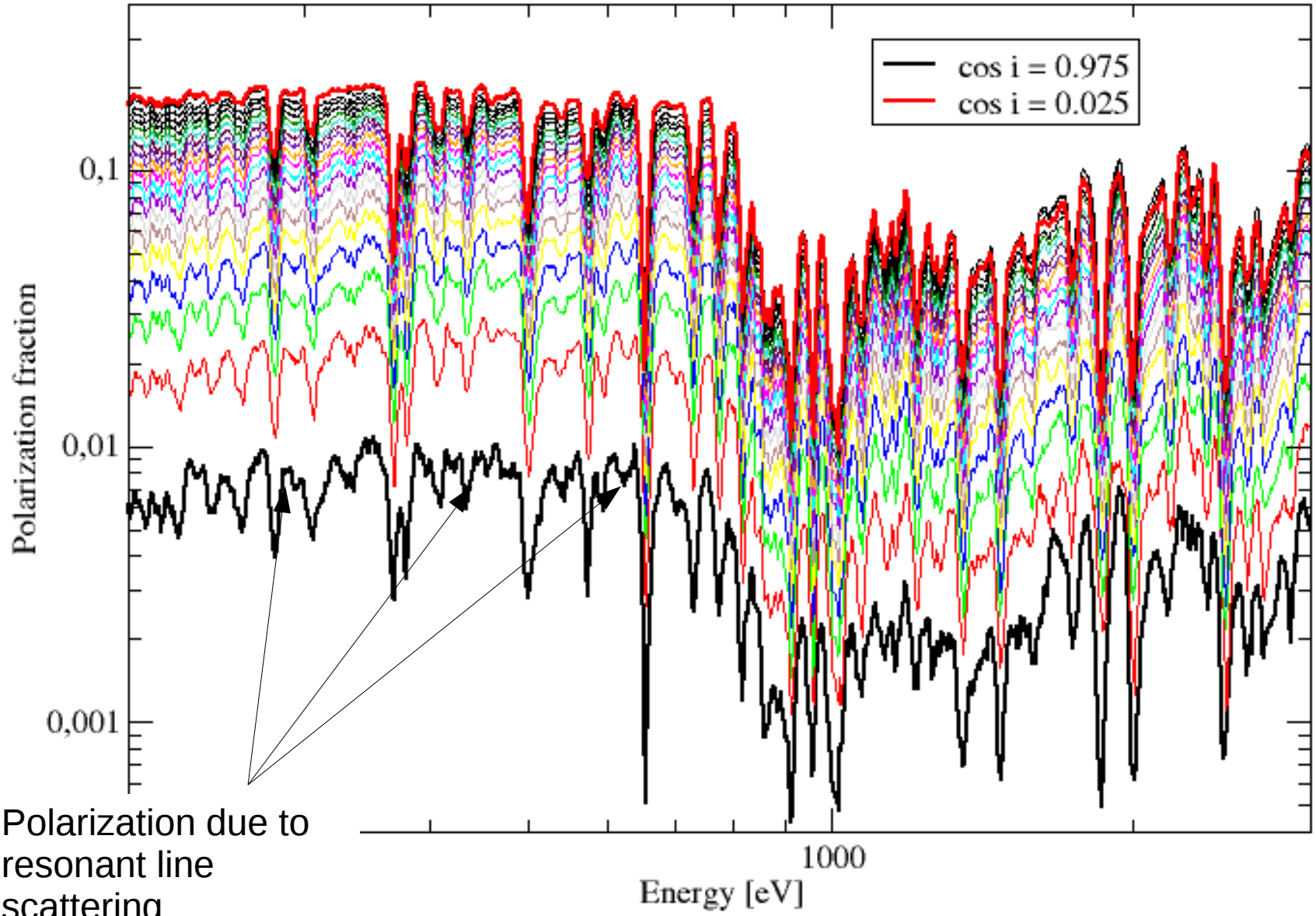
Systematic behavior with reemission angle...

Extracting polarization information – factor of 20 in polarization degree between face-on and edge-on



Polarization diluted but not gone across line emitting bands

Extracting polarization information – factor of 20 in polarization degree between face-on and edge-on



Polarization due to resonant line scattering

Where we stand and where we still want to go...

An ambitious model grid for disk reprocessing in AGN and X-ray binaries (for the latter with underlying disk heating included):

Parameter space to be cover:

- Ionization parameter: 50 erg cm/s < ξ 5000 erg cm/s
- Spectral slope: 1.0 < Γ < 3.0
- Disk temperatures in X-ray binaries (0.2 – 2 keV)
- Element (iron) abundance 0.1 < A < 10 solar
- 40 incident and 72 local emission angles included

Grid completed for solar abundances: evaluation ongoing for timing and polarization.

Analysis of the reprocessing time currently underway!

Question: what else do you need?