Polarization effects of scattering in disk atmospheres

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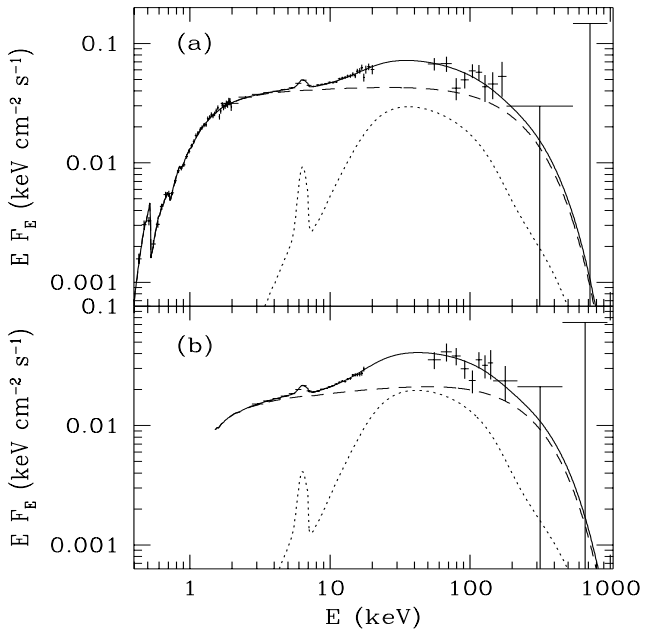
Plan:

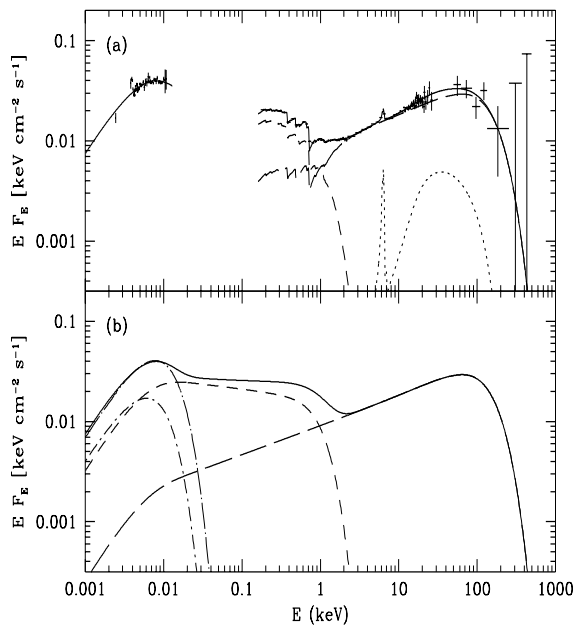
1. Spectra of black hole and neutron star sources
2. Polarization of the disk component
3. Polarization of Comptonized (corona) component
4. Bulk motion and impact on polarization
5. X-ray polarization of millisecond pulsars and X-ray bursters

Hard states of black holes and neutron stars

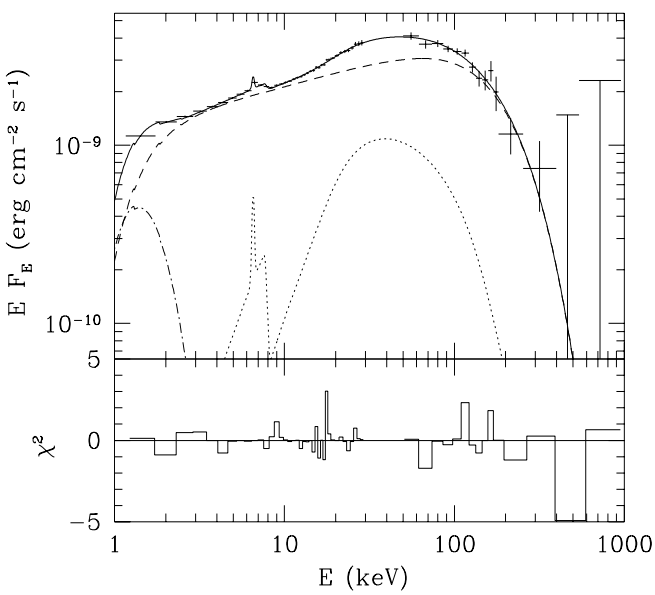
Seyfert 1 galaxy IC 4329A



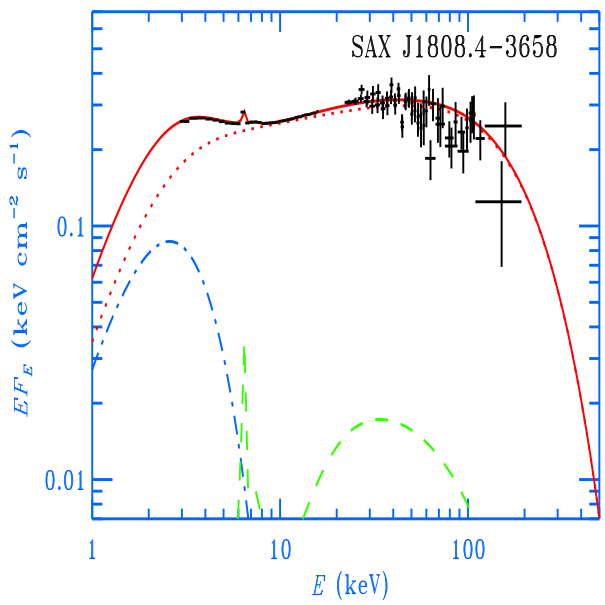
Seyfert 1 galaxy NGC 5548



Galactic black hole GX 339-4



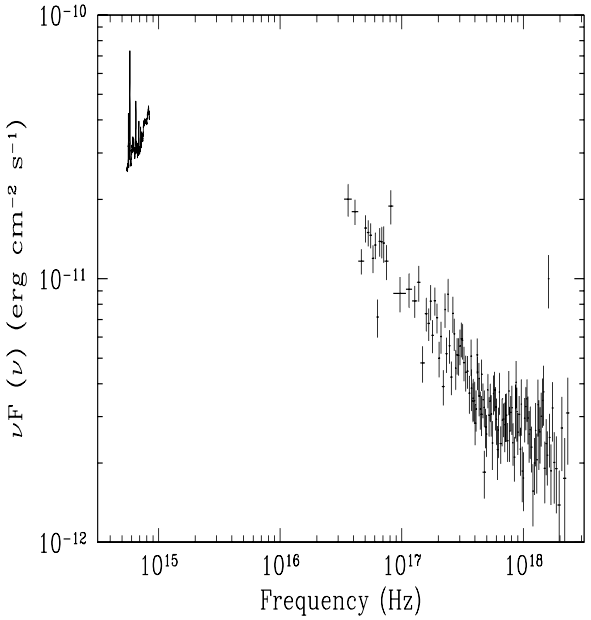
Accreting ms pulsar SAX J1808.4-3658



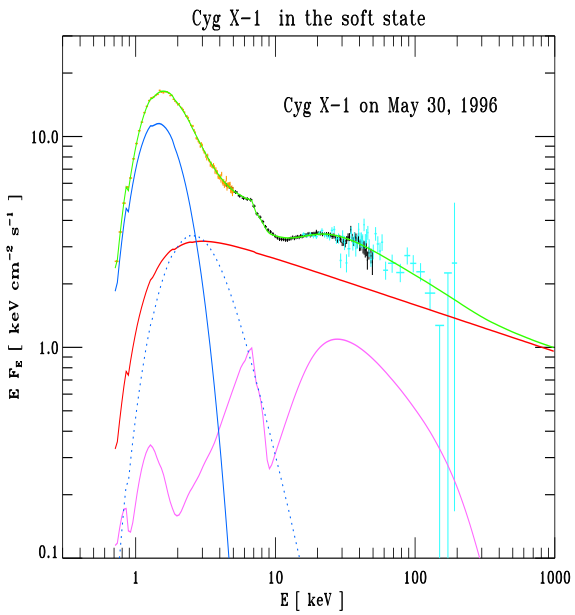
X-ray Polarimetry

Soft states of black holes

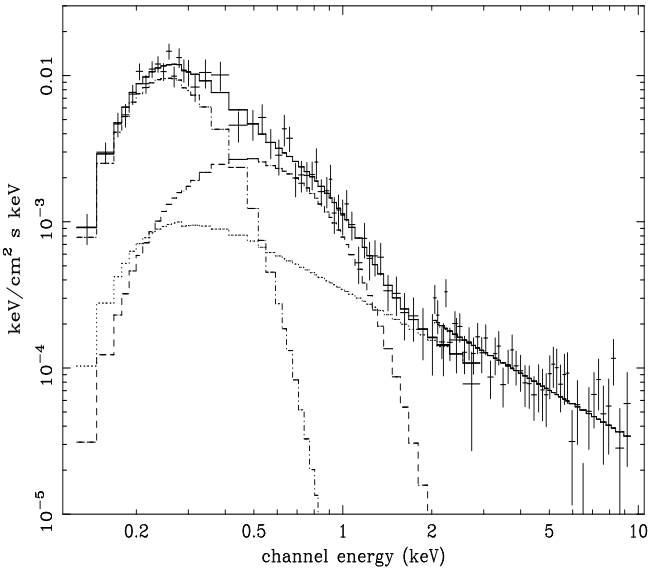
NLSy 1, Ton S180



Cyg X-1

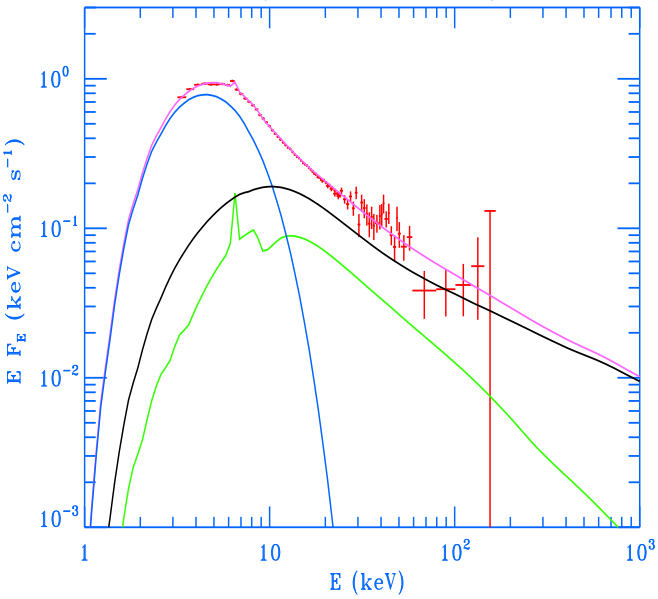


NLSy1, RE J1034+396



Microquasar GRS 1915+105

GRS 1915, May 26, 1997 and hybrid model



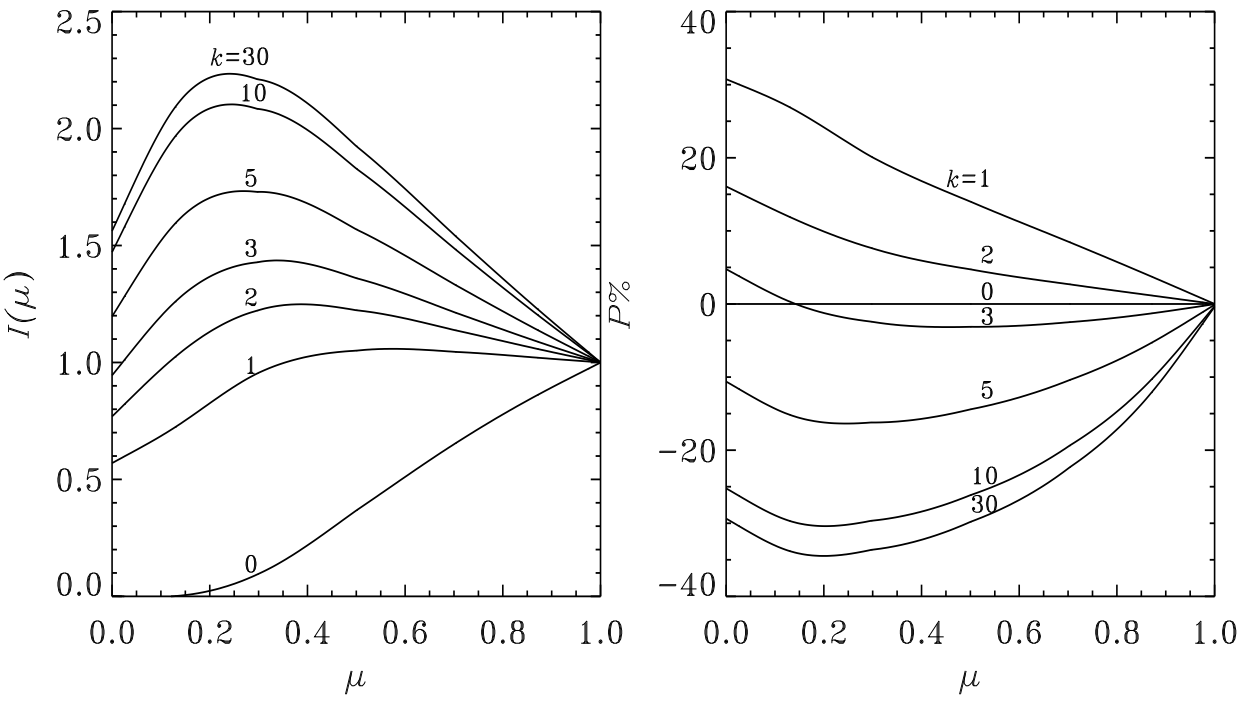
X-ray Polarimetry

Spectral components

1. Multicolor disk
2. Thermal comptonization (inner flow/corona/boundary layer?)
3. Non-thermal comptonization (corona/jet?)
4. Reflection from the disk

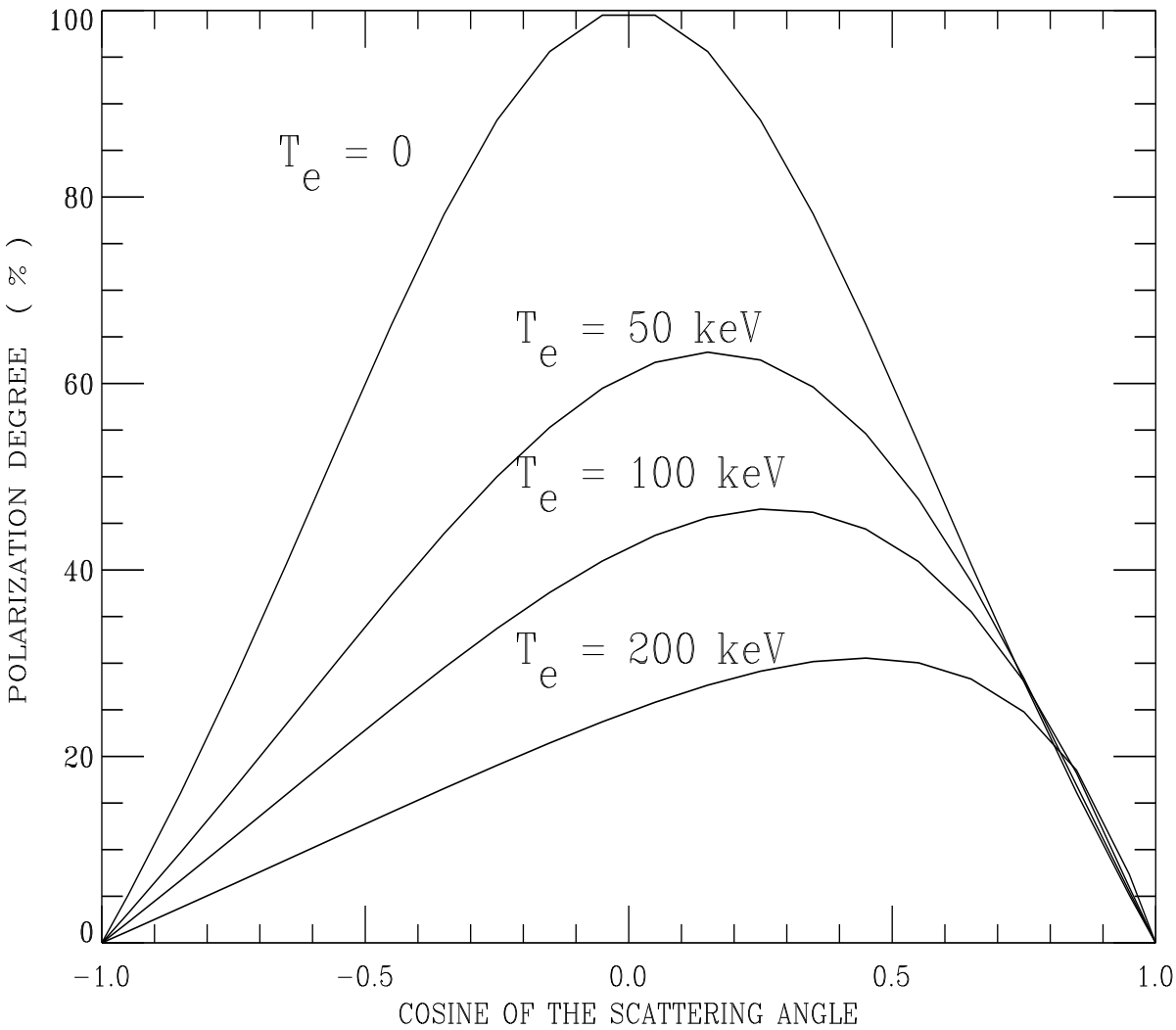
Polarization from the disk

1. Pure scattering atmosphere. Polarization perpendicular to the normal. Maximum $\sim 11\%$ (Sobolev 1949, Chandrasekhar 1960).
2. Depends on the ratio of the absorption-to-scattering opacity (Nagirner 1962; Loskutov & Sobolev 1982). Polarization edge at iron edge?
3. Warm fully ionized skin will affects polarization (Sunyaev & Titarchuk 1985; Beloborodov & Poutanen 1999).



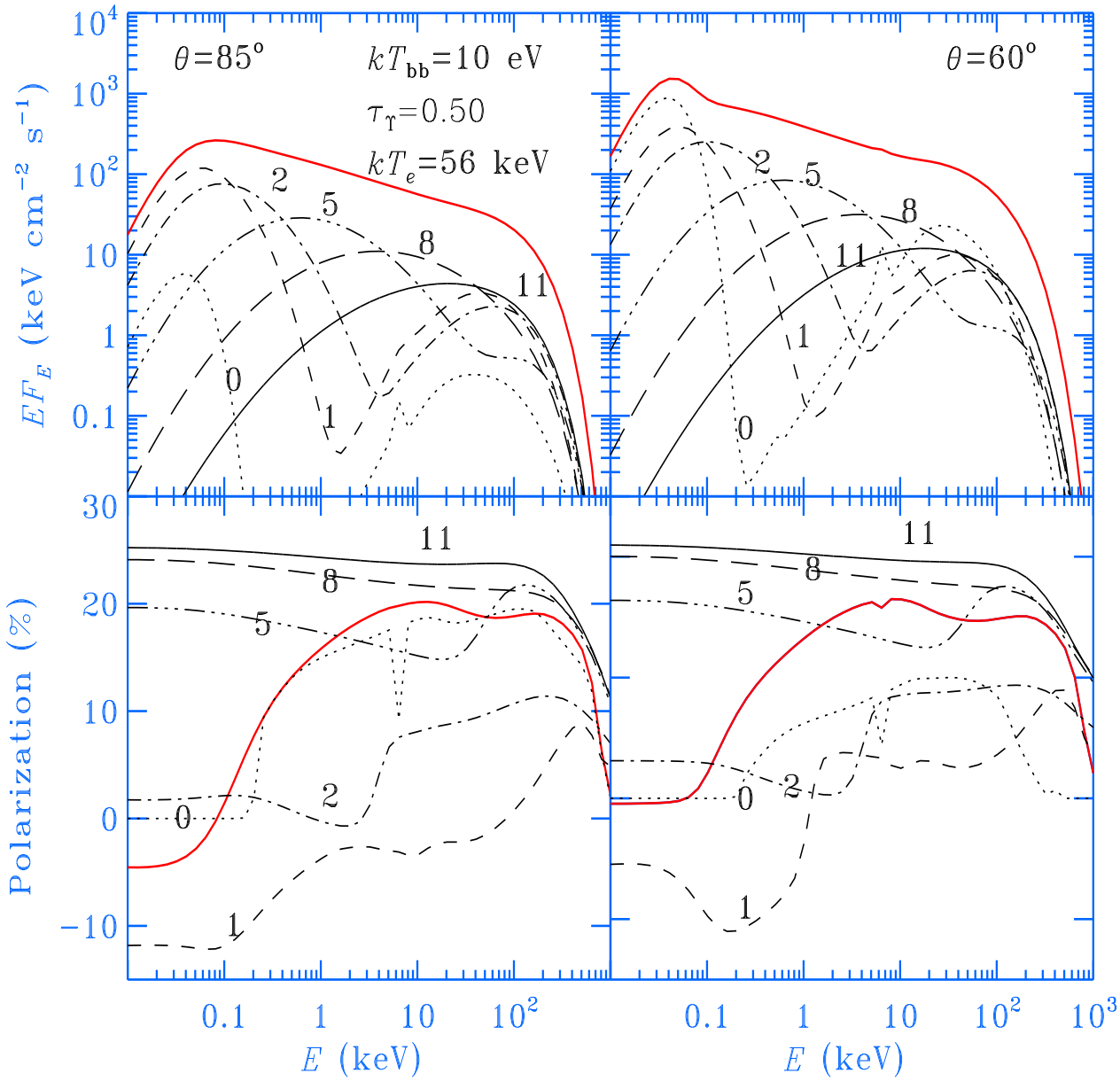
Intensity and polarization for different scattering orders k for Thomson optical depth $\tau_T = 1$. Incident photons from the bottom of the slab.

Polarization in Compton scattering / dependence on electron temperature



The degree of linear polarization as a function of electron temperature and scattering angle. Rayleigh /Thomson scattering gives $P = (1 - \mu^2)/(1 + \mu^2)$, where $\mu = \cos\Theta$ and Θ is the scattering angle. From Poutanen (1994).
Relativistic power-law isotropic electron distribution does not produce any polarization (Bonometto, Cazzola, Saggion 1970).

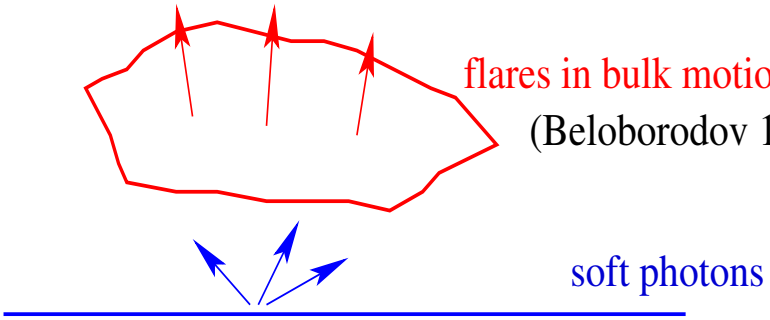
Polarization from the slab-corona



Intensity and polarization from the Comptonizing slab of Thomson optical depth $\tau_T = 0.5$ and electron temperature of 56 keV. Solid red curves - total intensity and polarization. Numbers mark the scattering orders. Incident radiation is unpolarized, first scattering order is polarized perpendicular to the slab normal, then polarization changes sign. From Poutanen & Svensson (1996).

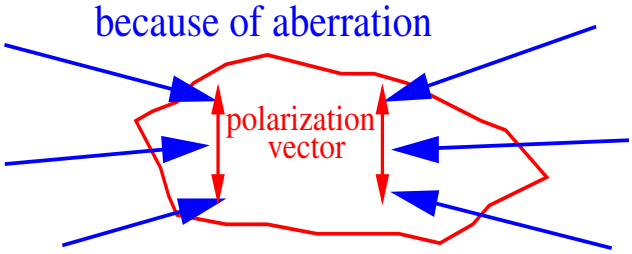
Atmospheres in bulk motion

HOT ATMOSPHERES IN BULK MOTION



IN THE COMOVING FRAME

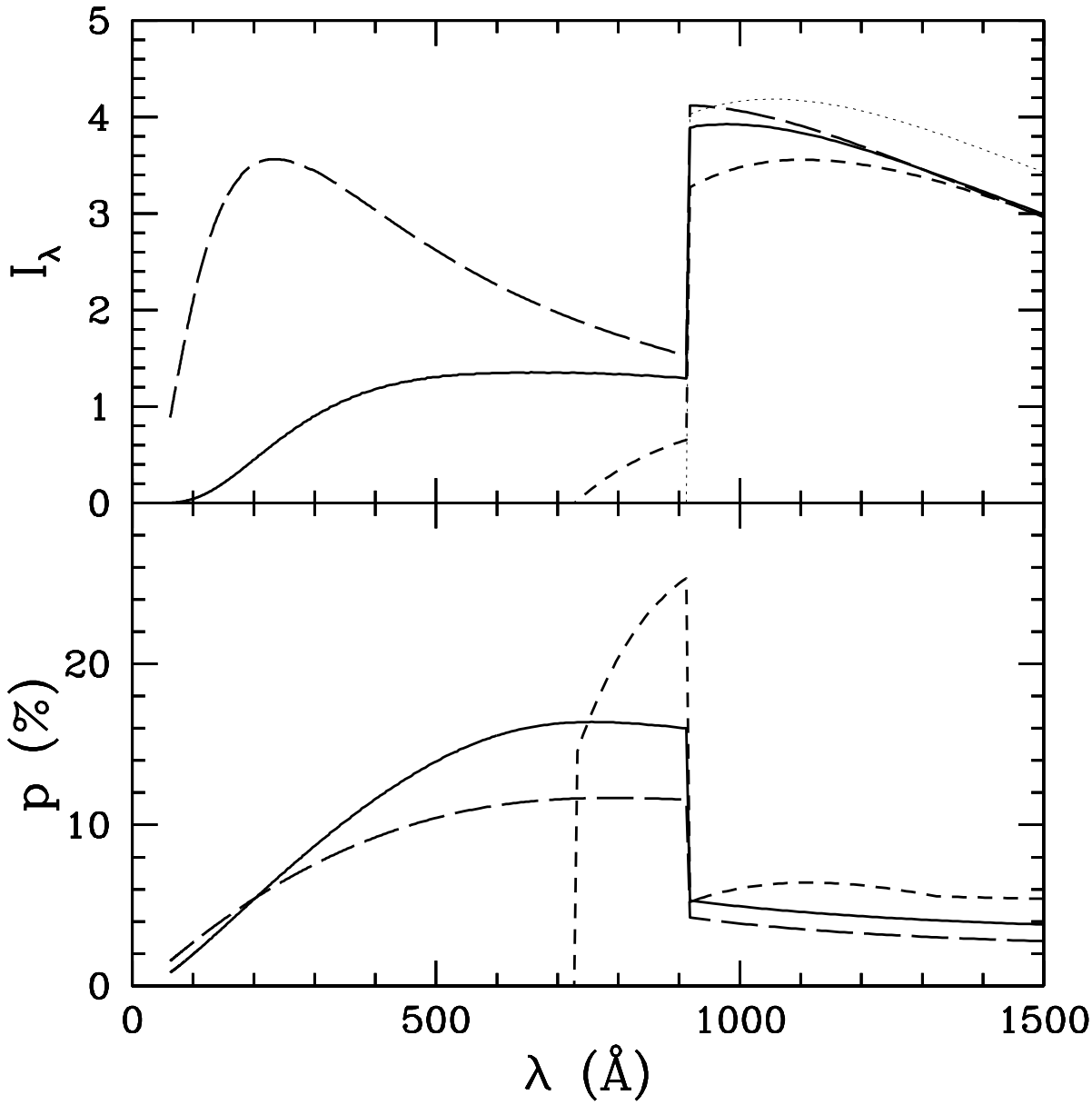
incident photons are coming from the sides
because of aberration



scattered photons are polarized
parallel to the outflow velocity

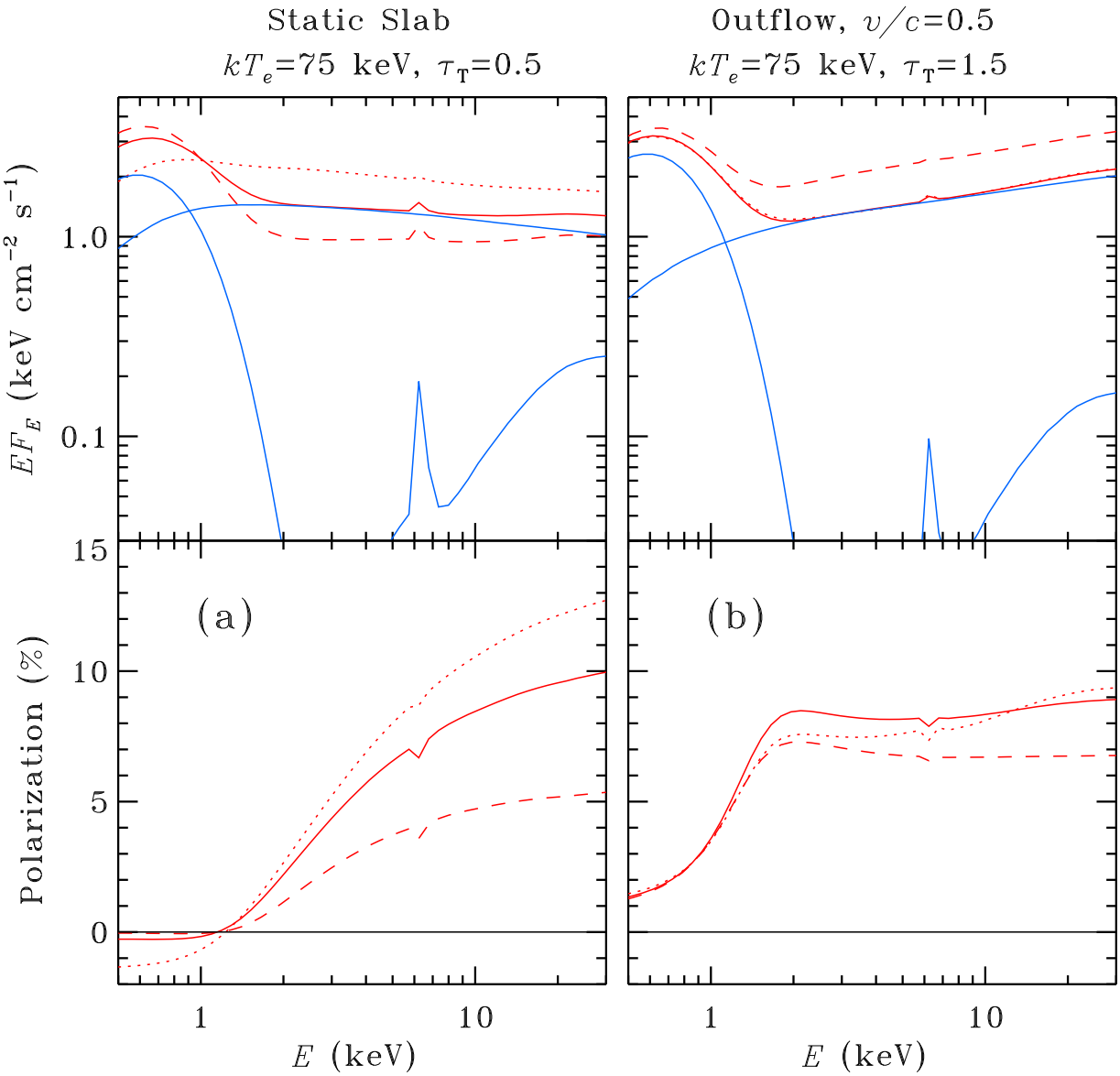
MODEL EXPLAINS: (1) reflection−spectral index correlations in GBHs and AGNs
(2) polarization parallel to the jet axis in Seyfert 1s
(3) steep rises of polarization at Ly edge in quasars

Atmospheres in bulk motion



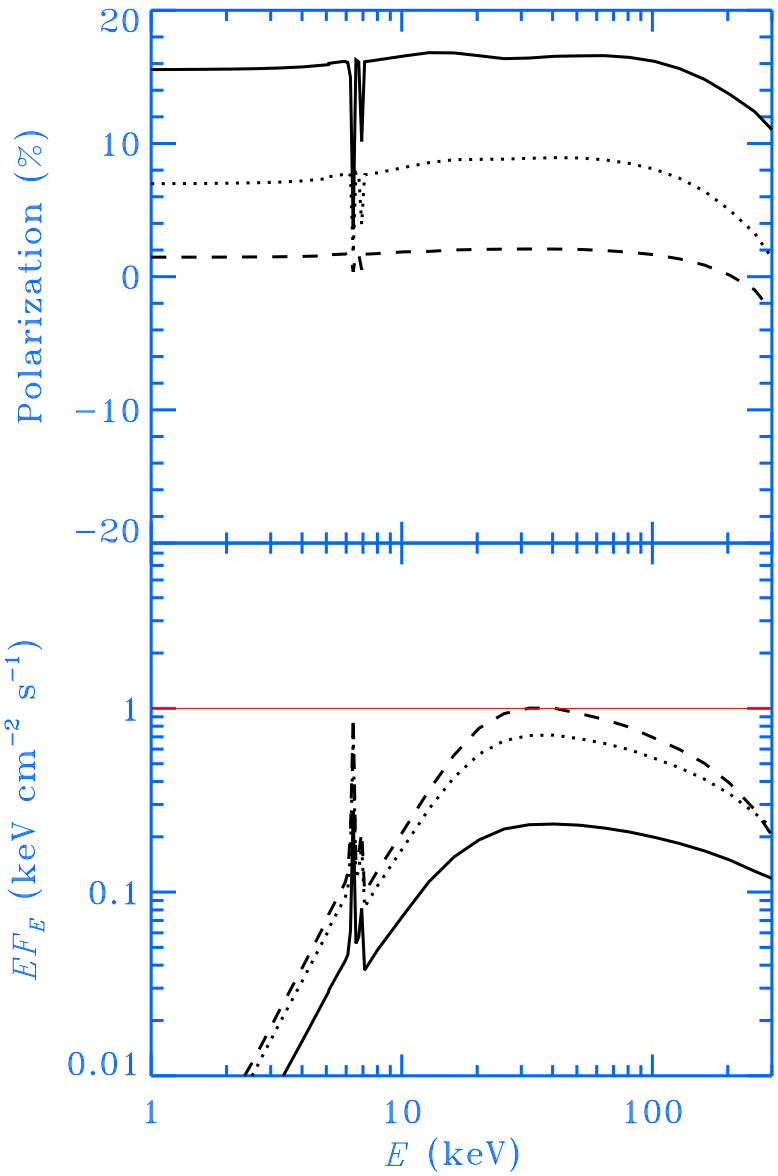
Disk radiation after passing through an outflow with $\beta = v/c = 0.45$ and column density $N_c = 0.2\sigma_T^{-1}$, as viewed at $\mu = \beta$. $I_\lambda = I\nu^2/c$ is plotted in arbitrary units. The sign of p is chosen so that $p > 0$ corresponds to the parallel polarization. The disk radiation is assumed to be a black body (unpolarized) with a sharp edge. The dashed, solid, and long-dashed curves represent the observed radiation (in the single-scattering approximation) for outflow temperatures $kT = 0$, 50, and 100 keV, respectively. From Beloborodov & Poutanen (1999).

Bulk motion vs static



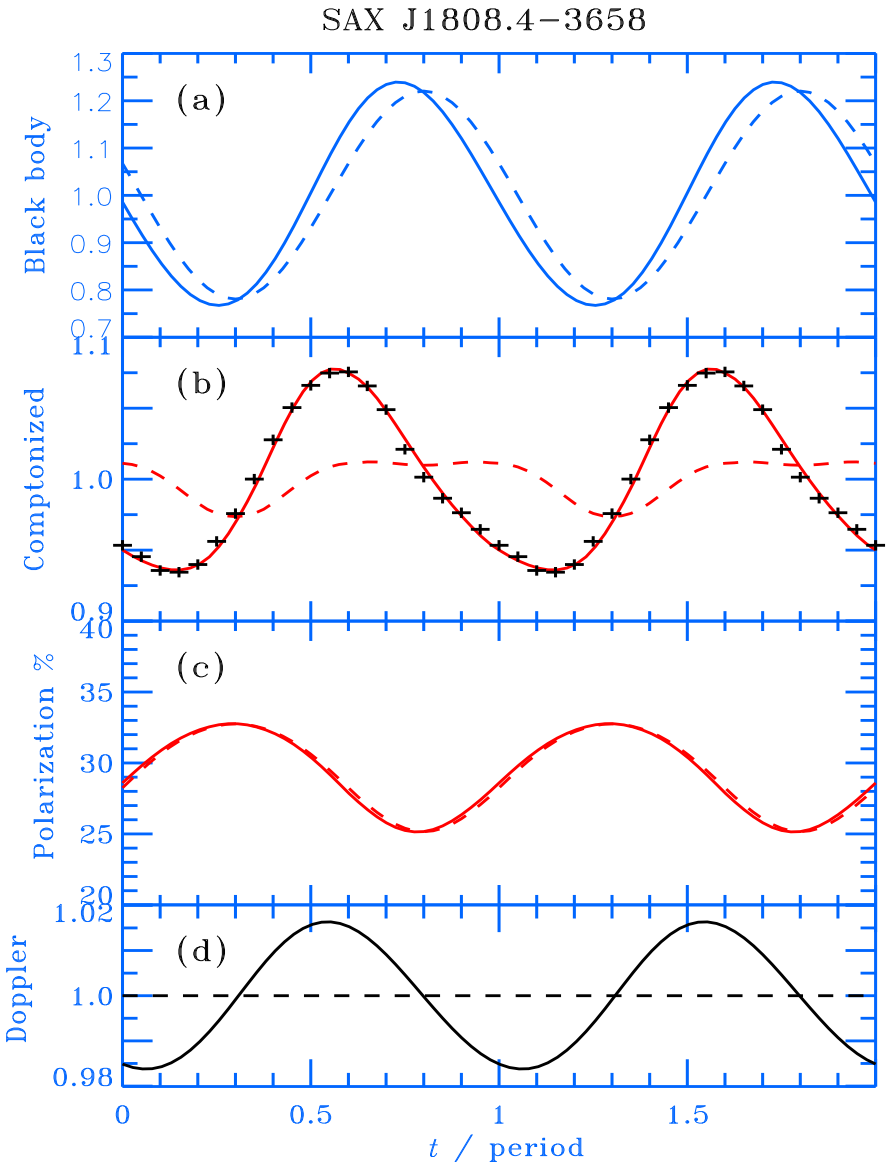
Intensity and polarization of X-ray radiation expected from static slab and outflowing corona for different viewing angles.

Polarized reflection



Polarization of Compton reflection for an isotropic source above a disk. From Poutanen, Nagendra, & Svensson (1996).

Prediction of X-ray polarization from SAX J1808.4−3658: the First Accreting Millisecond Pulsar



Light curves from SAX J1808.4-3658 folded with the 2.5 ms period. (a) Black body flux; (b) Comptonized flux; (c) predicted linear polarization in % for a slab geometry of the emitting region; (d) variations of the Doppler factor. Dashed curves correspond to a slowly rotating pulsar.