Nuclear Spectroscopic Telescope Array

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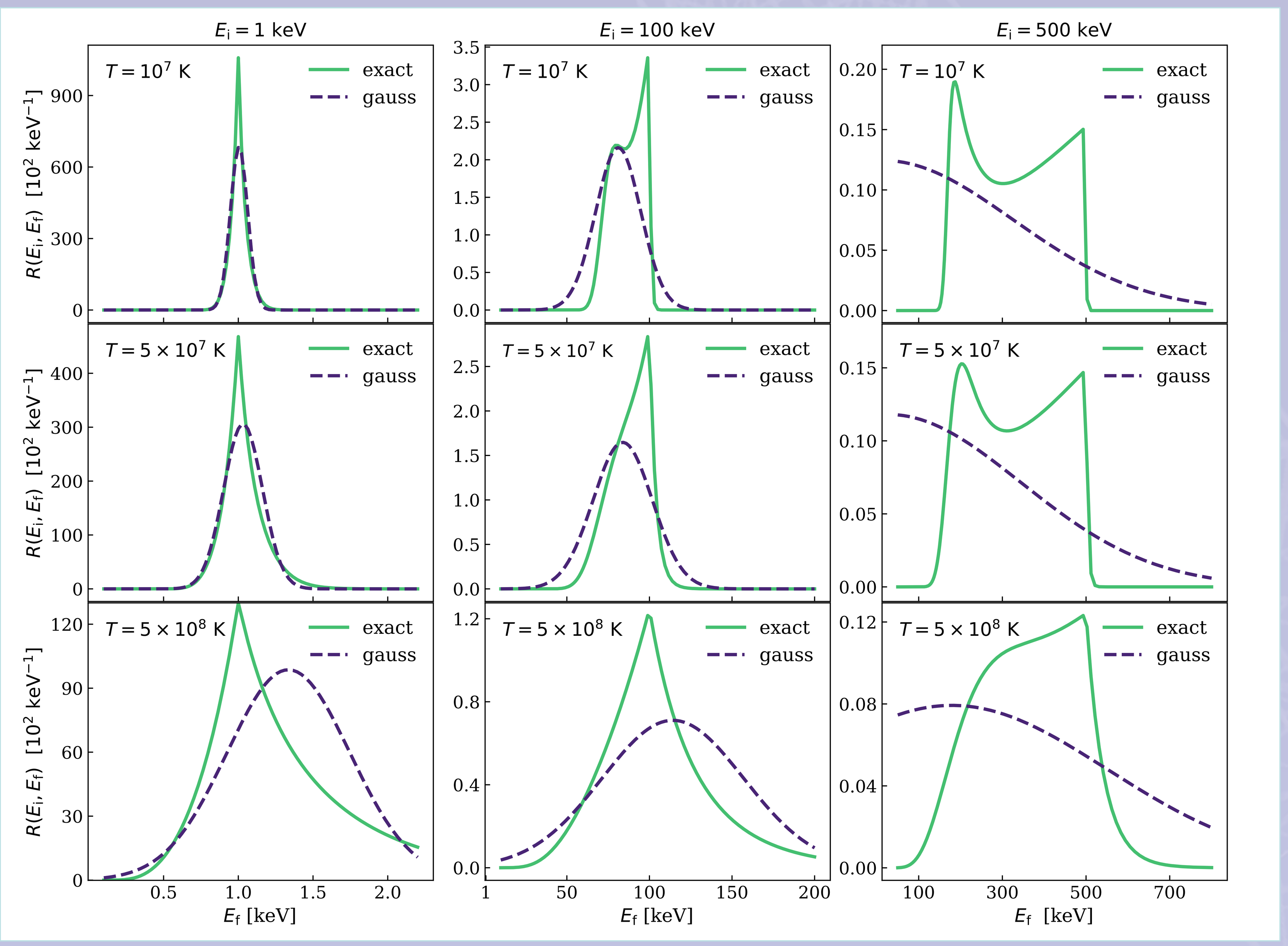
Accurate Treatment of Comptonization in X-ray Reflection Models

Overview

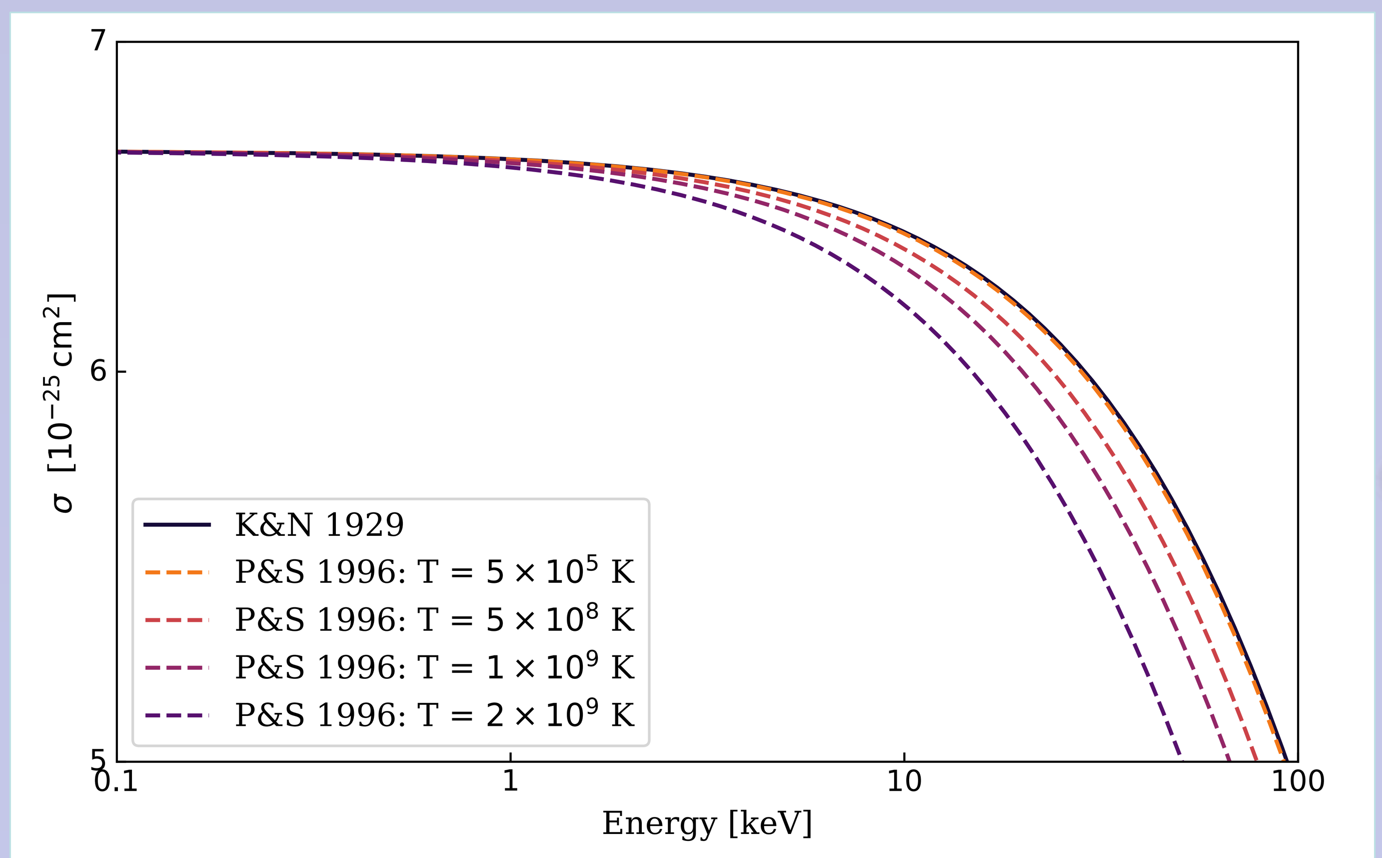
A large fraction of accreting black hole systems present clear evidence of the reprocessing of X-rays in the atmosphere of the accretion disk. The copious X-rays produced in the vicinity of a black hole illuminate the disk and produce a reflection spectrum which main hallmarks include fluorescent emission K-shell lines from iron (~6.4-6.9 keV), and a broad featureless component known as the "Compton hump" (~20-40 keV). The latter is produced by the scattering of high energy photons by the relatively colder electrons in the accretion disk, in combination with photo-electric absorption from iron. Until now, the treatment of this process in models of ionized X-ray reflection has been done in a very approximate manner using a Gaussian redistribution kernel. This approximation works sufficiently well up to ~100 keV, but it becomes largely inaccurate at higher energies and at relativistic temperatures. Here we report new calculations of X-ray reflection using a modified version of our model XILLVER, which now includes an accurate solution for Compton scattering of the reflected photons in the disk atmosphere. This solution takes into account quantum electrodynamic and relativistic effects allowing the correct treatment of high photon energies and electron temperatures. We present new reflection spectra computed with this model, and discuss the improvements achieved in the reproducing the correct shape of the Compton hump, as well as the effects of this new solution at softer energies.

Redistribution Function for Compton Scattering



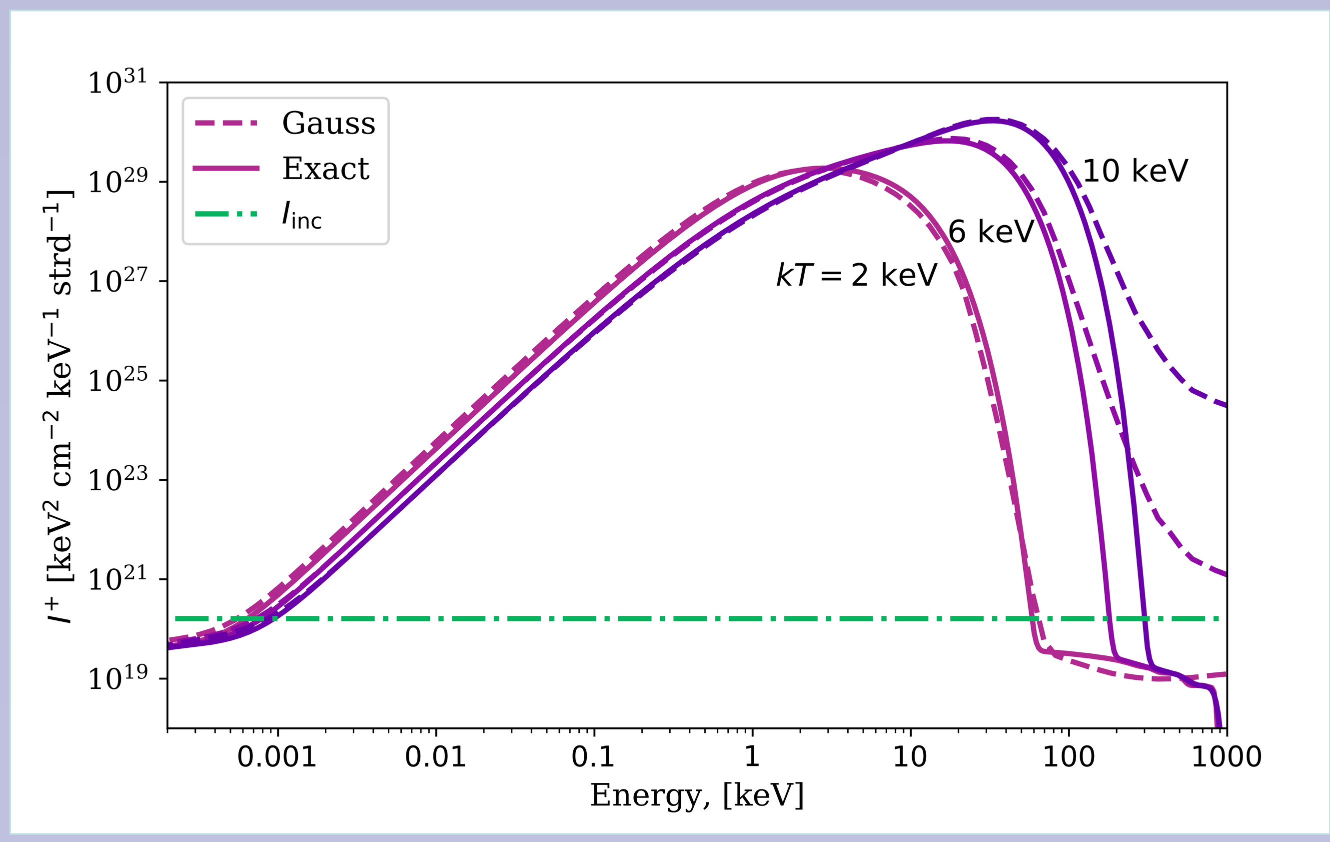
After a scattering event with an electron, an X-ray photon can gain or lose energy. The energy exchange depends on the initial photon energy, and on the electron temperature. The probability for a photon with energy E_i to had an energy E_f after the scattering is given by the Redistribution Function. The figure on top shows a comparison of the Gaussian approximation adopted in several reflection codes (e.g., reflionx, xillver), and the fully relativistic solution (exact) by Nagirner & Poutanen (1993). The strongest discrepancies are seen at high energies and electron temperatures.

Total Compton Scattering Cross Section



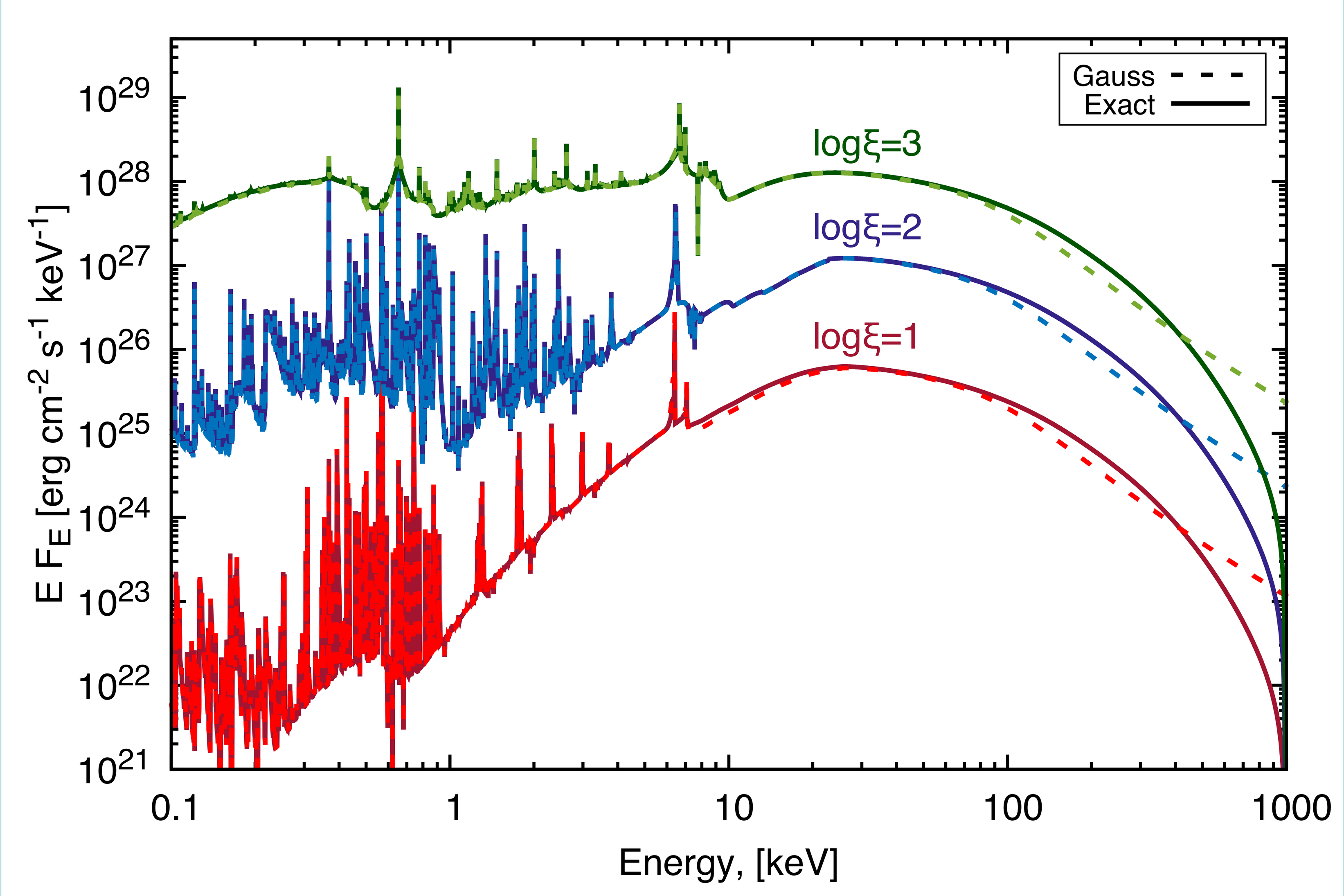
Comparison of the total quantum electrodynamic cross section for Compton scattering of photons off stationary electrons (Klein & Nishina, 1929), and the Klein-Nishina cross section convolved with a relativistic Maxwellian (Poutanen & Svensson, 1996). As expected, the largest departures occur at high electron temperatures.

Reflected Spectra: Pure Scattering Case



Radiative transfer calculations of X-ray reflection spectrum from a slab including only Compton scattering (i.e., no atomic contributions, no pair production). The slab is illuminated by a power-law at the top, and by strong thermal emission at the bottom. Shown are three cases for the disk temperature, comparing the exact solution with the previous Gaussian approximation.

Complete Reflection Calculations with XILLVER



Full calculations of reflected spectra with the XILLVER code, including all relevant atomic transitions, for a slab at constant density ($n_e=10^{15}$ cm^{-3}) for 3 different ionization parameter $\xi = 4\pi F_x/n_e$ = 10, 100, 1000 erg cm^2 s. Compton scattering inside the slab is calculated with the traditional Gaussian approximation for the energy redistribution of photons (dashed lines), and with the exact solution from Nagirner & Poutanen (1993).

While the largest differences are at high energies (above ~100 keV), there are secondary effects expected in the solution of the ionization balance due to the significant change in the energy budget of the reflected spectra. These effects are the subject of our work in progress.

Acknowledgements

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