X-ray Reflected Spectra from Accretion Disks: A Complete Grid of Ionized Reflection Calculations

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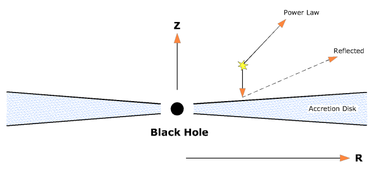
Abstract

We present a new and complete library of synthetic spectra for modeling the component of emission that is reflected from an illuminated accretion disk. The spectra were computed using an updated version of our code XILLVER that incorporates new routines and a richer atomic data base. We offer in the form of a table model an extensive grid of reflection models that cover a wide range of parameters. This library is intended for use when the thermal disk flux is faint compared to the incident power-law flux. The models are expected to provide an accurate description of the Fe K emission line, which is the crucial spectral feature used to measure black hole spin. A total of 720 reflection spectra are provided in a single FITS file† suitable for the analysis of X-ray observations via the `atable` model in XSPEC. Detailed comparisons with previous reflection models illustrate the improvements incorporated in this version of XILLVER.

†http://hea-www.cfa.harvard.edu/~javier/xillver/

Introduction

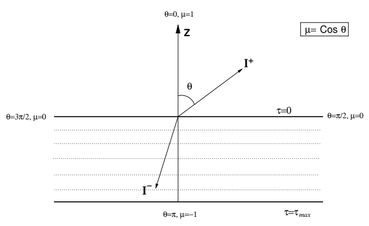
X-ray spectra from active galactic nuclei (AGN) and galactic black holes (GBHs) often show the effects of reflection.



Evidence for this includes the Fe K line emission, in the range 6.4-7 keV, which is observed from nearly all accreting compact sources. In addition, many sources show a Compton shoulder close to the Fe K line and a reflection bump, near 15-25 keV. These features indicate reprocessing in a large column density ($> 10^{24}$ cm^{-2}) of material, possibly in an accretion disk.

XILLVER: Model of Reflected Spectrum

To simulate the X-ray spectrum of reprocessed radiation emerging at the surface of an illuminated accretion disk, we consider a 1-dimensional gas, plane-parallel slab with a given composition of elemental abundances and constant number density. We then solve the radiation transfer equations using the Feautrier formalism and variable Eddington factors. The ionization balance is calculated by incorporating the latest XSTAR routines (Kallman & Bautista 2001), including the most recent atomic data for the K-shell of all the relevant astrophysical elements (e.g., Kallman et al. 2004, Garcia et al 2005, Witthoeft et al. 2011). Redistribution of photons due to Compton scattering is also included by means of a Gaussian approximation for the Compton kernel.

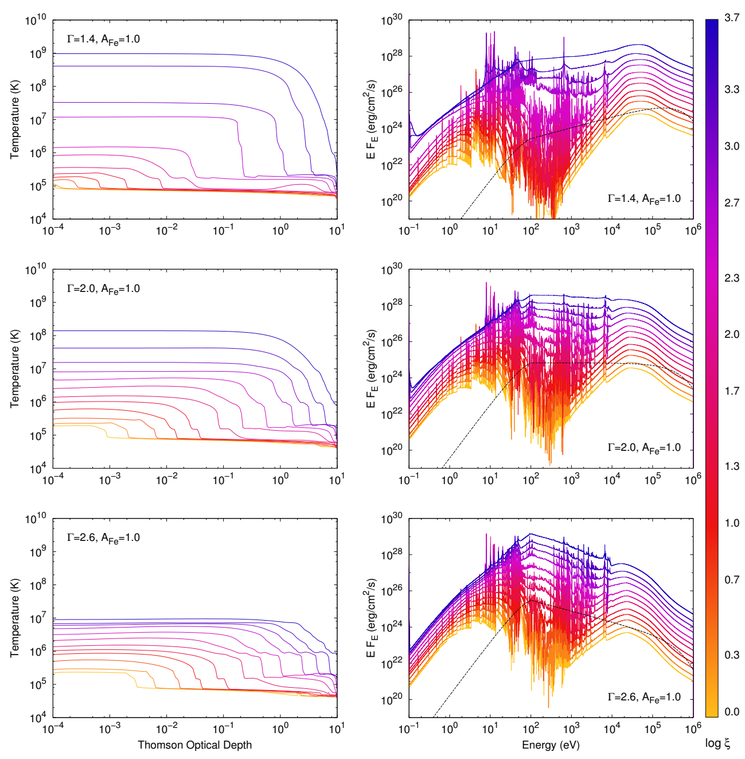


Model Parameters:

- Photon index $1.2 \leq \Gamma \leq 3.4$
- Ionization parameter $0 \leq \xi \leq 10^4$
- Fe abundance $0.5 \leq A_{\rm Fe} \leq 10$

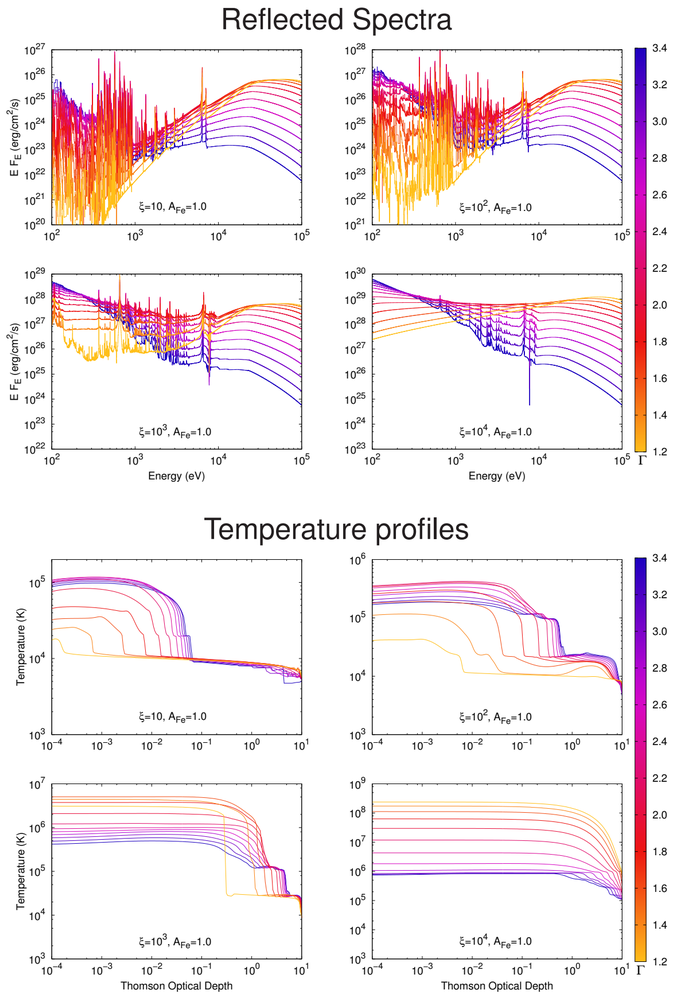
Variable Ionization Parameter ξ

Temperature profiles (left panels) and reflected spectra (right panels) showing the effects of the radiation incident on the accretion disk.



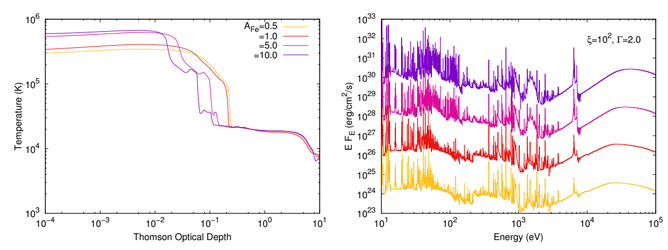
Variable Photon Index Γ

Effects of the shape of the illuminating radiation (assumed to be a power-law) on the reflected spectra and the resulting temperature of the slab for different degrees of ionization.



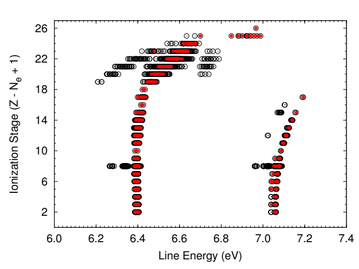
Variable Iron Abundance $A_{\rm Fe}$

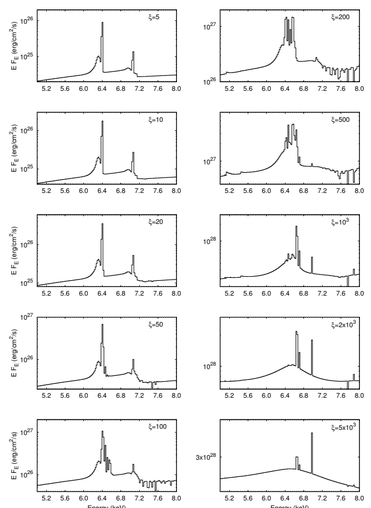
Influence of the Fe abundance (with respect to the solar value) on the temperature (left panel) and reflected spectra (right) panel in a slab with $\xi = 10^2$ and $\Gamma = 2$. The Fe emission features are enhanced when $A_{\rm Fe}$ is increased, but the continuum is also more absorbed due to the photoelectric opacity.



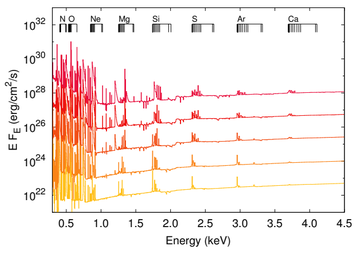
The Fe K Emission Complex

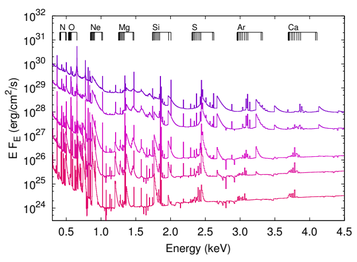
Emission lines from all the Fe ions in the $6 - 10$ keV energy range.
Red circles: Transitions with $A_r > 10^{13}$ s^{-1}.

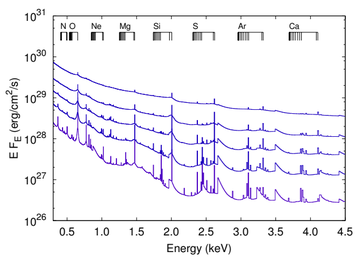




Lower-Z Elements



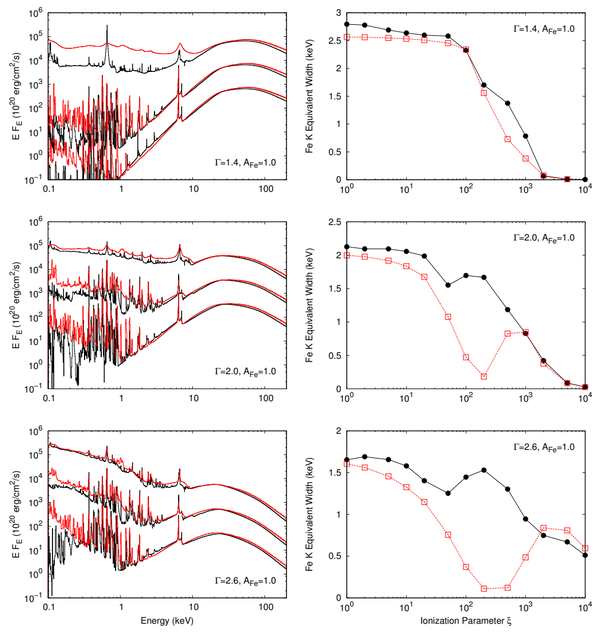




- XILLVER spectra for $\Gamma = 3$ and solar abundances showing the soft-energy band.
- The strongest Kα emission lines are indicated for each ion considered in the calculation.
- Ionization increases upward in each figure.

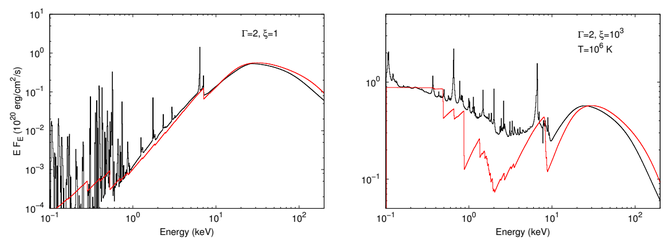
Comparison with Other Models I

Comparison of the reflected spectra (left panels) and the Fe K equivalent widths (right panels) calculated with the XILLVER and with REFLIONX models (Ross & Fabian 2005), for the same input parameters. Discrepancies are mostly due to the lack of K emission from L-shell Fe ions.



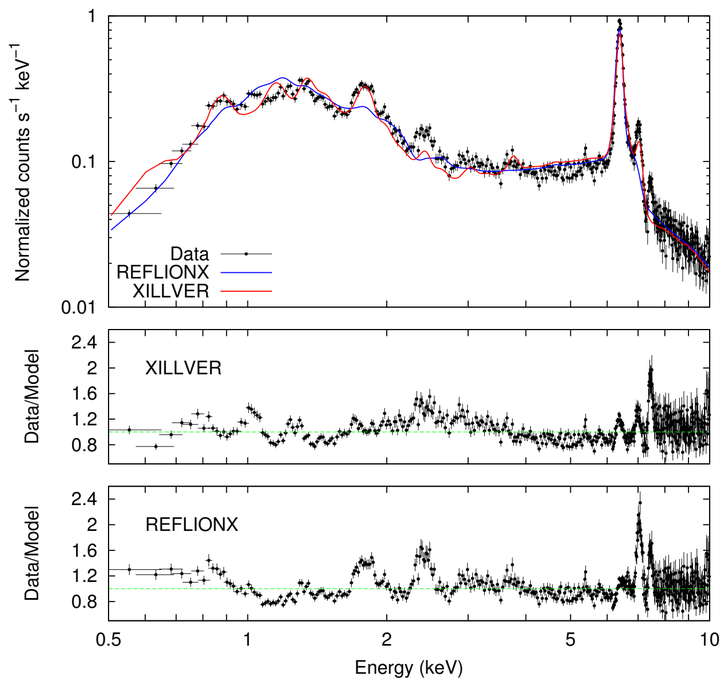
Comparison with Other Models II

Comparison of the XILLVER reflected spectra with Magdziarz & Zdziarski (1995) models PEXRAV (neutral gas, left panel) and PEXRIV (ionized slab, right panel). For all the models, $\Gamma = 2$, the high-energy cutoff is at 300 keV, and solar abundances are used.



Test Case: The Circinus Galaxy

Comparison of best-fits to *XMM-Newton* EPIC-pn spectrum of the Circinus galaxy: XILLVER vs. REFLIONX. The lower panels show the data to model ratio for each case. Our model XILLVER is able to reproduce the Fe Kβ at ~ 7.2 keV and many other features at low-energies.



Summary

- A new and complete library of synthetic spectra for modeling an X-ray spectrum reflected from an accretion disk is now available for use with standard spectral analysis packages such as XSPEC and ISIS.
- This new version of XILLVER features both a richer collection of atomic data and improvements in the computational methods employed.
- The parameters span wide ranges making the models applicable to different classes of sources and a variety of conditions.
- Presently, XILLVER is intended for modeling spectra with a dominant power-law component, such as AGN and GBHs in the hard state. A version of XILLVER incorporating a strong thermal component is under development.

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