Green's functions for transmission of X-rays and γ-rays through cold media

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Abstract

Using a Monte Carlo method, we study Compton scattering and absorption of X-rays and γ-rays in cold media. We consider transmission of X/γ-rays through a shell of an arbitrary optical depth, for which we derive energy-dependent Green's functions. Fitting the Green functions with simple analytical formulae is in progress. We also present a simple treatment of the effect of absorption on Green's functions for Compton scattering, which allow to treat media with an arbitrary ionization state and chemical composition. Our transmission Green's functions allow to treat Thomson-thick absorbers, e.g. molecular tori of Seyfert 2s.

1. Introduction

We consider transmission of X/γ-rays through a slab assuming incident photons perpendicular to the slab, and integrate outgoing photons over all angles. This is equivalent to transmission through a geometrically thin but optically thick shell when neglecting effect of reflection. We calculate energy-dependent Green's functions taking into account fully relativistic Compton scattering as well as bound-free absorption. Green's functions are calculated using a Monte Carlo method of White, Lightman and Zdziarski (1988). An analytical formula fits the Green functions for Compton scattering and factorize impact of absorption.

2. Photon transmission through Compton-thick media

Fig. 1 presents the total Green functions and its decomposition on the first three scattering orders for various energies of incident photons and various Thomson thickness of the slab. For a low optical thickness, the second-order scattering is mostly due to photons propagating along the slab, which makes the second order Green function relatively flat in the range of Δy=1-3 and the third order function peaked at Δy=3 (cf. Fig. 1A). For a higher optical thickness, the second and third order Green function is peaked in the forward and backward direction due to photons propagating perpendicularly to the slab. The second and third order function on Fig. 1C exhibits corresponding peaks near $\Delta y \gtrsim 0$ and $\Delta y \lesssim 4$. For high energy incident photons, the Green functions are increasingly suppressed with increasing wavelength shift because the Klein-Nishina decline reduces the escape probability (cf. Fig. 1A and 1D). The high energy photons are moved quickly to lower energies by scattering, and thus attain diffusion limit after a first few scattering.

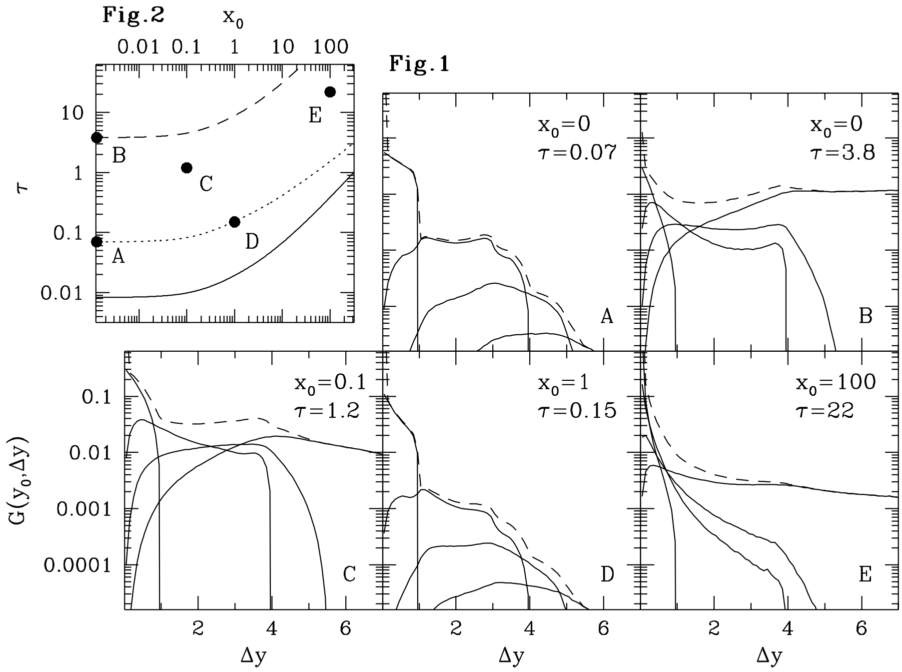

Fig. 1. The total Green functions (dashed line) in the points (A-E) marked on the Fig. 2. Solid lines mark contribution from subsequent orders Green's functions.

Fig. 2. Limits of the Thomson optical thickness for 1 per cent photons scattered by a geometrically thin shell (solid line), and 1 per cent photons scattered more than ones (dotted line). The dashed curve shows a limit of 1 per cent photons transmitted without scattering. The area above this curve corresponds to Compton scattering well-described by the diffusion approximation. x_0 is incident photon energy in units of electron rest mass.

3. The impact of absorption on Green's function

In solar composition matter, Compton scattering is accompanied by bound-free absorption, which gives important contribution up to energies of about 40 keV, where Compton cross-section is significantly relativistic, and no monochromatic approximation can be used. The Green function in the presence of absorption may be then written as:

$$G_{abs}(y, \Delta y) = \sum_{i=1}^{\infty} G_i(y, \Delta y) \prod_{k=1}^{i} \bar{\lambda}_k(y). \tag{1}$$

Here $\bar{\lambda}_k$ is an effective single scattering albedo over the distribution of photons after k scattering. Since the average wavelengh shift of photon distribution in k-th order appears at $\Delta y \approx k$ (relativistic effects shift the maximum to lower values of Δy), a sufficient approximation is $\bar{\lambda}_k(y) \approx \lambda(y + i - 1)$. This allows us to factorize Green's function as:

$$G_{abs}(y, \Delta y) \approx G(y, \Delta y) \exp\left(\int_0^{\Delta y - 1} \mathrm{d}k \ln\left(\lambda(y + k)\right) \right). \tag{2}$$

4. References

1. White, T. R., Lightman, A. P. and Zdziarski, A. A., 1988, *ApJ* **331**, 939.