Constraining AGN corona size with Monk, a fully relativistic monte-carlo radiative transfer

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Introduction

Hard X-ray ($\gtrsim 2$ keV) spectra of active galactic nuclei (AGNs) are usually dominated a non-thermal component with high-energy cut-off at tens to hundreds of keV. The hard X-ray is generally believed to be dominated by radiation from corona, which contains hot optically-thin plasma that Comptonises soft UV/optical disc photons (e.g., Haardt & Maraschi, 1991). For thermal plasma Comptonising low-frequency thermal radiation, the electron temperature and optical depth of the corona can be constrained by analysing hard X-ray spectrum. However, the geometry of the corona, including the size and shape of the corona, is still not clear.

To date the the most promising constraints on AGN corona size come from analysis of strongly lensed quasars. Reis & Miller (2013) summarised the measurements and found the size in the range of ~ 1 to tens of gravitational radii. However, the paucity of strongly lensed quasars limits the application of this method.

Dovčiak & Done (2016, hereafter DD16) proposed a method to estimate the corona size with simultaneous UV/X-ray observations of AGNs. In this method one first obtains mass accretion rate with UV luminosity, and then estimate the X-ray flux in the corona frame. Together with the observed X-ray luminosity, constraint can be put on corona size.

DD16 method uses nthcomp, which assumes that the seed photons are illuminating the corona isotropically. Apparently this is not the case for AGN corona. Another limitation in DD16 method is that the calculation of Comptonised flux is made to a point-like, lamp-post corona, thus implicitly assuming that the spectra do not change much across the extended corona. This assumption may not hold for a large corona. To perform a more self-consistent modelling of emission from extended corona, we develop a general relativistic Monte Carlo code, Monk(Zhang et al., 2019), which is dedicated to calculating spectrum of disc-corona system in Kerr space-time. We assume Klein-Nishina cross section and take all general relativistic effects into account. We also implement polarised radiative transfer by taking into account both propagation of polarisation vector along null geodesic and change of polarisation due to scattering.

Procedure

1. Generate seed photons following the "superphoton" scheme (Dolence et al., 2009) to account for disc emissivity.
2. Ray-trace the photons along null geodesics.
3. If the photon is inside the corona, for each step we evaluate the scattering optical depth and subsequently scattering probability.
4. If the photon is scattered, we sample the Klein-Nishina differential cross section and calculate the energy, momentum, and polarisation properties of the photon after scattering.
5. Register photons arriving at infinity and re-construct energy and polarisation spectrum.

Results

We calculate spectra of disc-corona systems in which the optically-thick and geometrically-thin disc is located on the equatorial plane. Here we present the results for spherical stationary coronae. For more results, see Zhang et al. (2019).

Dependence on optical depth

As the optical depth increases, the thermal spectrum barely varies, while the non-thermal spectrum hardens and brightens as expected.

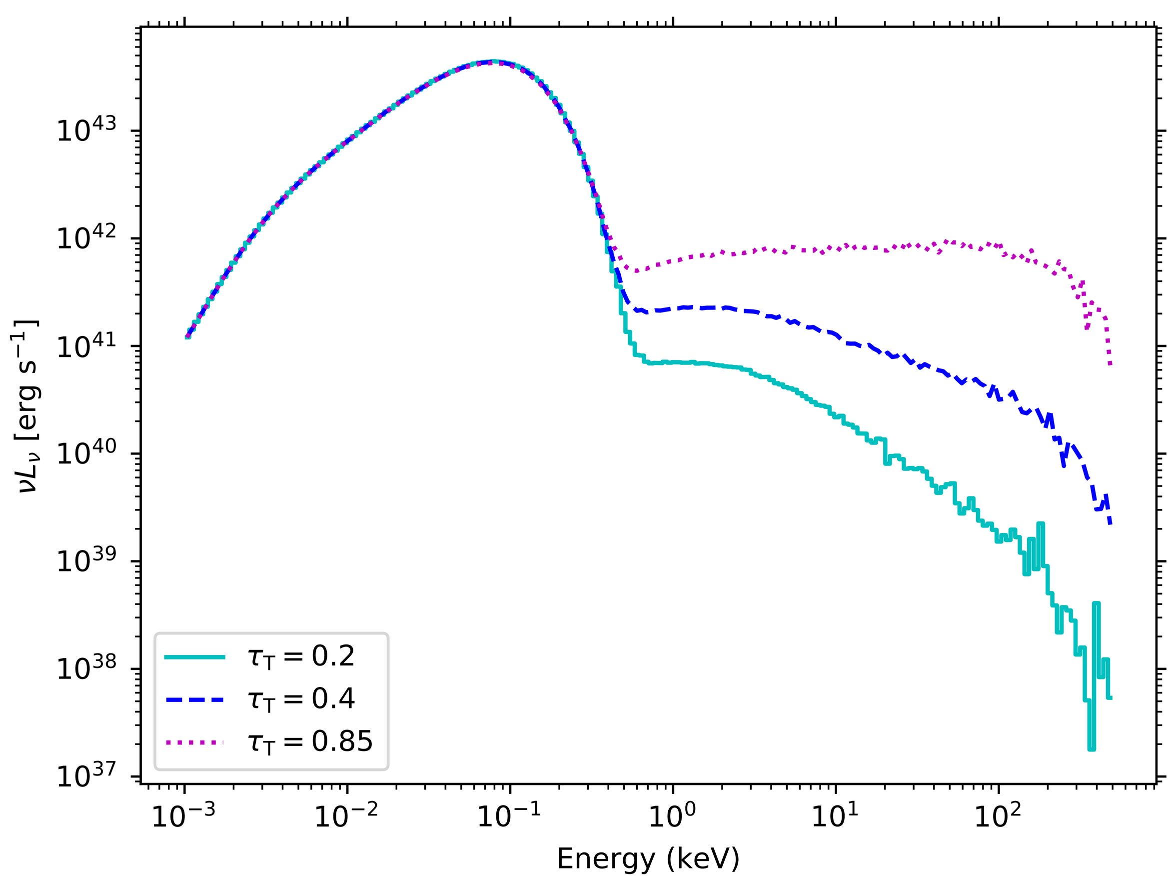

Figure 1: Spectra of disc-corona systems with various optical depths τ_T. The observer is located at an inclination of 30°. Results for different optical depths are plotted in different colors and line styles, as indicated in the plot. The spherical corona is located 10 GM/c^2 above the disc, and has radius of 4 GM/c^2 and electron temperature of 100 keV. The other parameters are: black hole spin $a = 0.998$, black hole mass $M = 10^7\,M_\odot$, mass accretion rate $\dot{M} = 4.32 \times 10^{23}$ g s^{-1} (10% Eddington rate if assuming radiative efficiency of 0.32), and color correction factor $f_{col} = 2.4$.

Dependence on observer's inclination

The spectra depend sensitively on the observer's inclination. The spectrum at inclination of 10° flattens towards low energy, and seems to be harder than that observed at larger inclinations below ~ 5 keV. We measure the photon indices between 2 and 10 keV by fitting the spectra with powerlaw model using least squares method. The photon indices are 2.68, 2.70, and 2.73 for inclinations of 10°, 60°, and 80°, respectively. The anisotropicity of corona emission is owing to the fact that for AGN corona the seed photons from the disc are not isotropic. For comparison in the isotropic case the expected spectrum is softer with photon index of ~ 2.9. One implication is that it may lead to inaccurate results in modelling and interpreting reflection spectrum by assuming an isotropic corona.

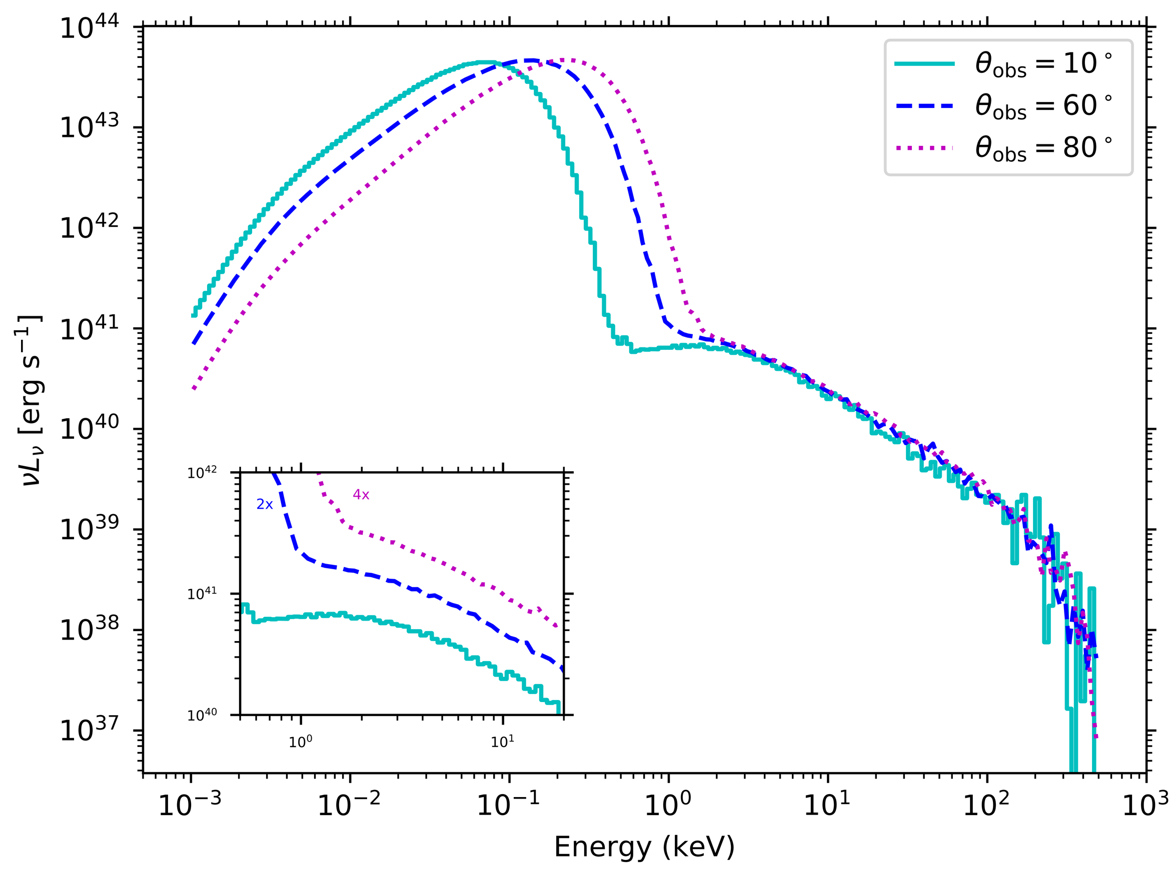

Figure 2: Same as Fig. 1, but for different observer's inclinations as indicated in the plot and $\tau_T = 0.2$. The inset shows the zoom-in plot of the spectra in the range of 0.5–20 keV, where the spectra for inclinations of 60° and 80° are shifted along the vertical direction for clarity.

Dependence on corona size

The hard X-ray radiation becomes brighter as R_c increases, where R_c is the corona radius. In the lower panel we show the spectra normalised by R_c^2. Apparently the non-thermal emission scales with R_c^2. We estimate the corona size with DD16 method. For corona sizes of 1, 2 and 4 GM c^{-2}, DD16 method gives estimate for corona sizes of 0.56, 1.17, and 2.29 GM c^{-2}, respectively, around half the assumed sizes. The reason is that in nthcomp the emergent spectrum is obtained under the assumption that the seed photons are isotropic. As shown above, for isotropic seed photons one needs an optical depth larger than assumed to explain the spectrum observed at low inclination, which subsequently leads to overestimate of X-ray flux and underestimate of size.

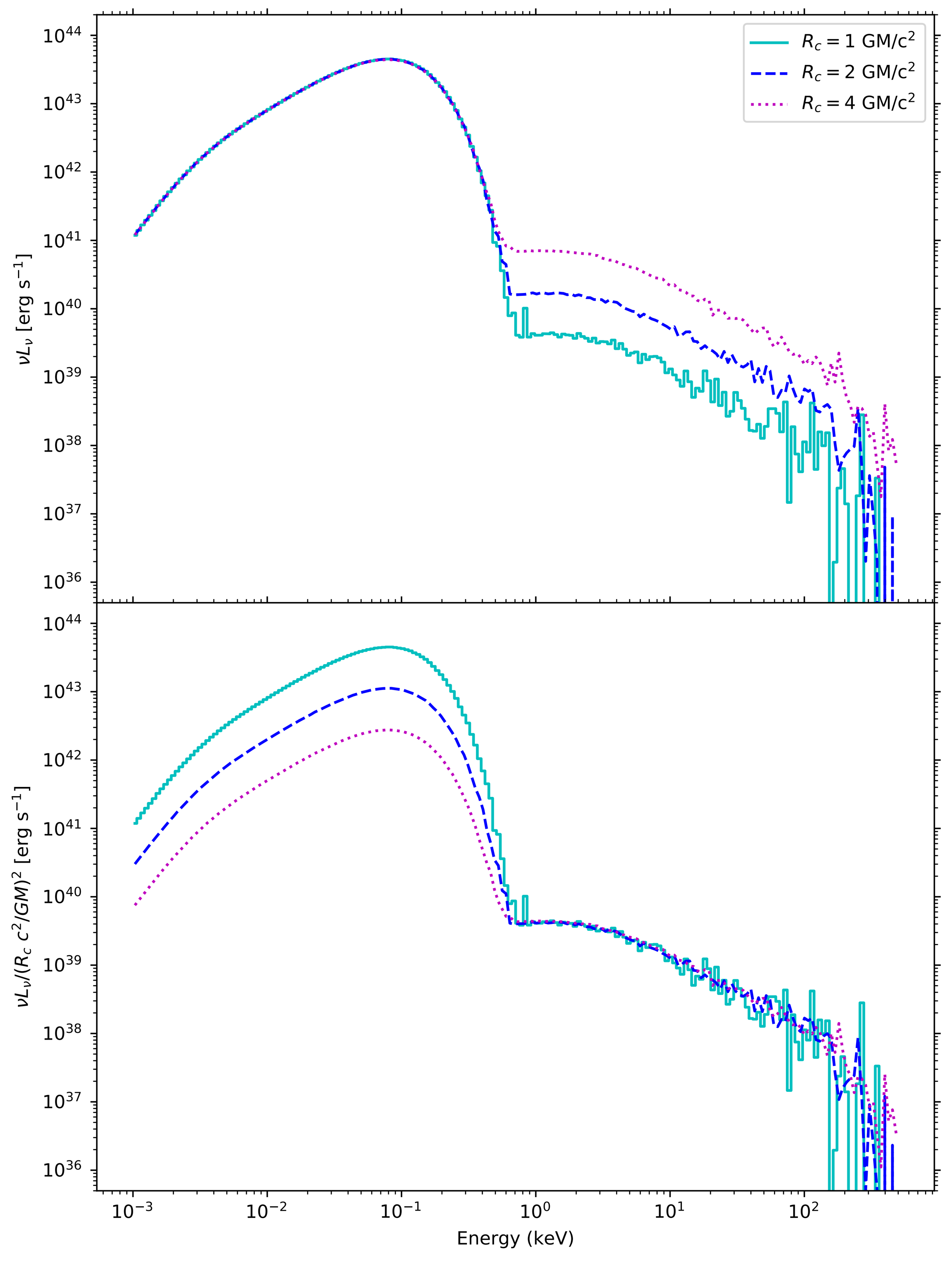

Figure 3: Upper panel: same as Fig. 1, but for different corona radii as indicated in the plot and assuming $\tau_T = 0.2$. Lower panel: spectra normalised by R_c^2, where R_c is the corona radius in GM c^{-2}.

Summary

- To calculate the spectra of extended coronae in AGNs, we develop a general relativistic Monte Carlo code dedicated for Comptonisation process in Kerr space-time. We include all general relativistic effects and assume Klein-Nishina scattering cross section.
- For stationary spherical corona above the disc, we find that the corona emission is not isotropic in the corona rest frame.
- The size estimated by DD16 method is around half the assumed size, mainly due to the anisotropicity of the corona emission.

References

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