Absorption on dust torus and point source for a $\mu_s \neq 1$ case

February 23, 2021

1 Variables

- r - gamma ray starts at the height r above the BH
- $\mu_s = \cos\theta_s$ - cos of the angle of the propagation of gamma ray to the z axis
- u - distance that the gamma ray moved along μ_s direction
- x - distance to the reprocessed material
- ϕ, μ - direction angles of the soft photon
- ϕ_e - azimuth angle of a piece of reprocessing material ($\phi_e = 0$ corresponds to the direction of gamma ray movement projected on XY plane
- Ψ - angle between the gamma ray and the soft photon
- R_{re} - distance of the reprocessing material from BH
- ν - frequency of the gamma ray (in the reference frame of the BH)
- L_{disk} - luminosity of the disk
- ξ_{dt} - fraction of the luminosity reprocessed in DT

2 Dust Torus

The vector of the soft photon (from the reprocessing material to the gamma ray position) is:

$$\vec{v}_\epsilon = \begin{bmatrix} v_{\epsilon,x} \\ v_{\epsilon,y} \\ v_{\epsilon,z} \end{bmatrix} = \begin{bmatrix} u\sin\theta_s - R_{re}\cos\phi_{re} \\ -R_{re}\sin\phi_{re} \\ r + u\mu_s \end{bmatrix} \tag{1}$$

from which you can compute the distance

$$x = |\vec{v}_\epsilon| = \sqrt{u^2 + R_{re}^2 + r^2 - 2uR_{re}\sin\theta_s\cos\phi_{re} + 2ru\mu_s} \tag{2}$$

and its direction angles:

$$\mu = v_{\epsilon,z}/x \tag{3}$$

$$\tan\phi = v_{\epsilon,y}/v_{\epsilon,x} \tag{4}$$

In order to compute the optical depth at we need to have a similar integral like Eq 133 in Finke'16 paper

$$\tau(\nu) = \frac{L_{disk}\xi_{dt}}{8\pi^2\epsilon_{dt}m_e c^3}\int_0^\infty du \int_0^{2\pi} d\phi_{re}\sigma_{\gamma\gamma}(s)\frac{1-\cos\Psi}{x^2}, \tag{5}$$

where $s = \epsilon_1\epsilon_{dt}(1-\cos\Psi)/2$, and Ψ is computed from Eq. 8 of Finke'16.

3 Point source

The calculations are the same as in Section 2. The distance is

$$x = |\vec{v}_\epsilon| = \sqrt{u^2 + r^2 + 2ru\mu_s} \tag{6}$$

Because of the definition of the gamma ray moving in XZ plane, the ϕ angle of the soft photon will be 0. The inclination angle to the Z axis can be computed as

$$\mu = (r + u\mu_s)/x \tag{7}$$

The angle between the two photons Ψ can be again computed from Eq. 8 of Finke'16, or simply as $\Psi = \theta - \theta_s$.

The formula for the optical depth is: In order to compute the optical depth at we need to have a similar integral like Eq 133 in Finke'16 paper

$$\tau(\nu) = \frac{L_0}{4\pi\epsilon_0 m_e c^3}\int_0^\infty du\sigma_{\gamma\gamma}(s)\frac{1-\cos\Psi}{x^2}, \tag{8}$$