HIGH ENERGY ASTROPHYSICS

Compulsary Home Exercises. Problem set 8.

Turn in Exercises by Wednesday, November 27, 2024.

Problems

8.1: The Imaging X-ray Polarimeter Explorer (IXPE) has observed the central part of the Milky Way (Marin et al. 2022), in particular a molecular cloud Sgr A, which is situated at a projected distance of 25 pc from Sgr A*. The detected X-rays are polarized, with the polarization degree $P = 31 \pm 11\%$ and the polarization angle perpendicular to the direction to Sgr A*. Polarization is likely produced as a result of single Thomson scattering of photons that originated from a short X-ray flare of Sgr A* some time ago. Estimate the time when this flare has occurred. *Hint:* The polarization degree for Thomson scattering is $P = 100\% \times (1-\mu^2)/(1+\mu^2)$, where $\mu = \cos\theta$ and θ is the scattering angle.

8.2: In Figure 1, the infrared SED of a distant quasar at $z = 5.34$ is shown. Assuming that the infrared bump at about 100 microns is produced by an optically and geometrically thick torus consisting of molecular gas and dust, estimate the parameters of the torus: its bolometric luminosity, size, and the range of temperatures in the reference frame of the quasar. What should the variability of the infrared component look like? Estimate the minimal possible variability time scale and the time lag with respect to the big blue bump emission component.

Hints: To estimate the luminosity, you can use any of the freely available cosmology calculators (note the cosmological parameters!) to convert the redshift to luminosity distance. Assume that the infrared emission is reprocessed ultraviolet emission.

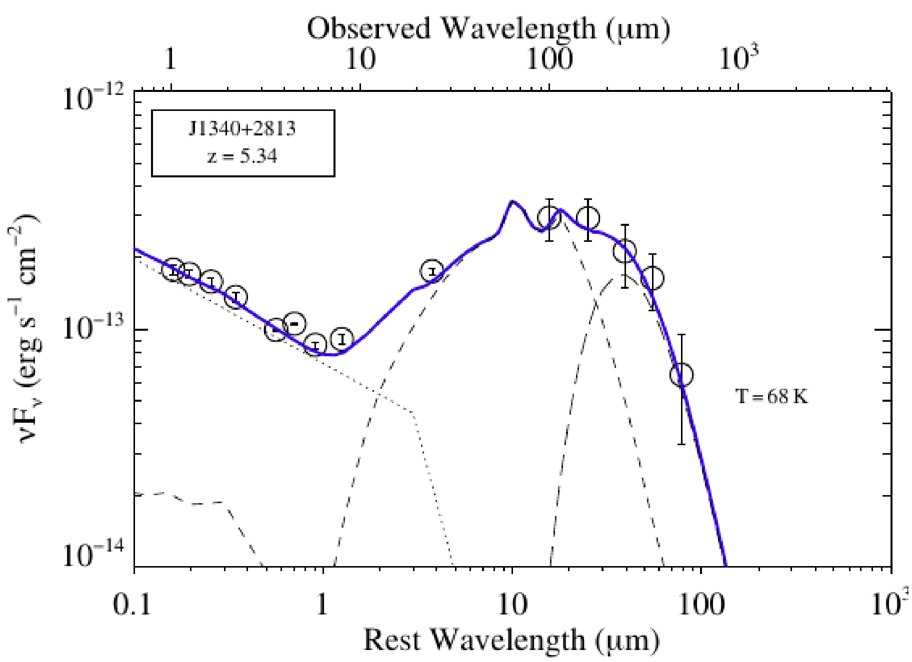

Figure 1: Spectral energy distribution of J1340+2813. Taken from Leipski et al. (2012).

8.3: The apparent velocity (in units of c) of a blob moving with relativistic velocity v is

$$\beta_{\rm app} = \frac{\beta \sin\theta}{1 - \beta\cos\theta}, \tag{1}$$

where $\beta = v/c$ and θ is the angle the velocity makes to the line of sight. Compute the maximum possible apparent velocity for a given β. Show that there is minimum velocity $\beta = \beta_{\rm min} = \beta_{\rm app}/\sqrt{1+\beta_{\rm app}^2}$ required to produce the apparent velocity $\beta_{\rm app}$. Show that this minimum corresponds to the angle between the blob velocity and the line of sight $\tan\theta_{\rm min} = 1/\beta_{\rm app}$.

8.4: The observed proper motion of approaching and receding blobs ejected from GRS 1915+105 are $\mu_a = 17.6$ mas day^{-1} and $\mu_r = 9.0$ mas day^{-1}, respectively. Assuming the distance to the source of $D = 12$ kpc, compute the velocity $\beta = v/c$ and the angle θ between line of sight and jet direction.

8.5: The jet in the nearby active galaxy M87 is probably inclined at 40° to the line of sight. Superluminal motion has been seen by radio astronomers within the core of the jet with $v_{\rm app} = 2.5c$. Estimate the velocity of the jet β, the bulk Lorentz factor of the jet Γ and the Doppler factor for each side of the jet. Note that even the approaching side has a Doppler factor smaller than 1; what is the physical reason for that?

8.6: (a) Show that an observer moving with respect to a black body field of temperature T will see black body radiation with a temperature that depends on the angle according to

$$T_{\rm obs} = \frac{T}{\Gamma(1 - \beta\cos\theta')}, \tag{2}$$

where θ' is the angle between direction of motion and observation in the observer's frame. (b) Cosmic microwave background radiation ($T = 2.7$ K) shows the anisotropy due to solar motion relative to that radiation. Estimate solar velocity if the anisotropy of radiation intensity at $\lambda = 3$ cm is

$$\frac{I_{\rm max} - I_{\rm min}}{I_{\rm max} + I_{\rm min}} \approx 10^{-3}. \tag{3}$$