Extragalactic Astronomy 2
Assignment 2

Due: 1700 hours, July 2nd, 2021 (*Total: 300 Points, Weightage : 30%*)

General Instructions

(1) You should obtain solutions to these questions by yourself. Any suspicion of plagiarism will warrant deduction of points (2) The deadline for submission of the answers is fixed. No credit for late submissions. Having said this, given the pandemic situation, if there is a genuine issue that prevents on-time submission, please email me. (3) The number of points allotted for each question are given in square brackets at the end of the question. (4) A few of these questions involve making plots. Please attach a print-out of the most relevant plot(s) and the code you used to make the plot(s). Make sure all plots are clearly labeled and use sensible units. (5) I hope that the pandemic situation will improve further by the submission date, so that you can submit the assignment in person at NCRA. I will give you separate instructions on submission closer to the submission date.

1. Assuming an efficiency of energy conversion $\epsilon = 0.1$, compute the mass accretion rate to sustain a quasar with a bolometric luminosity of 10^{46} erg s^{-1} in units of $M_\odot$ yr^{-1} [10 points]

2. On the website I have placed a FITS format image of the quasar 3C 273 obtained at 1.4 GHz with the VLA. Open the image with a suitable viewer like *ds9* or *Aladin*. You should see the core emission (circular in shape) as well as emission from one lobe (somewhat elongated). Additional information needed to answer the questions is to be found in the FITS header of the image.

   - Using the standard concordance cosmology, calculate the projected distance between core and the lobe in kpc. Redshift of 3C 273 is $z = 0.16$ [20 points]
   - Assuming that the emission from the core is unresolved, measure the flux density of the source in Jansky. Compare your value to the value published in the literature at this frequency. [20 points]
   - Calculate the luminosity of the core of 3C273 at 1.4 GHz assuming that the radio spectral index is $\alpha = 0.5$ [10 points]

3. Show that a star of mass M_* and radius R_* can be disrupted by a SMBH only if the black hole mass M_{BH} is not too large. Calculate this limiting mass for a star with the same mass and radius as the Sun. [30 points]

4. Assume that the SMBH mass in an AGN host galaxy is 10^{-3} times the stellar mass of its spheroidal component, as has been found for nearby galaxies. Furthermore, assume that the spheroidal component contains a fraction f_{sph} of the total stellar mass of the galaxy. Let the AGN radiate with an Eddington ratio L/L_{edd}, and assume that 10% of the radiation comes out in the optical waveband.

   - Calculate the ratio of the optical AGN luminosity and the stellar luminosity, as a function of Eddington ratio, mass-to-light ratio of the stellar population, and the spheroidal fraction f_{sph}. [30 points]
   - Using this result, explain why it is difficult to AGN in late-type galaxies, assuming $L \sim 0.1 L_{edd}$ and a typical mass-to-light ratio $M/L = 3$. [20 points]

5. Assume that the broad line region (BLR) is a spherical shell with characteristic radius r and thickness $\delta r \approx r$. Also, assume that it consists of N_c clouds of radius r_c and electron number density n_e.

   - What is the covering factor of the BLR clouds as seen from the continuum source, i.e., what fraction of lines- of-sight from the center of the BLR intersect a cloud, in terms of the model parameters? [10 points]
   - Calculate the filling factor, i.e., the volume fraction of the BLR that is filled with clouds. [10 points]
   - Assume that the covering factor is 0.1, and that the filling factor is 10^{-6} . For a BLR radius of $r = 10^{16}$ cm and $n_e = 10^{10}$ cm^{-3}, determine r_c and N_c . What is the total mass of the gas in the clouds in the BLR? Comment on whether this mass is very small or very large. [30 points]

   Given that this estimate is subject to many uncertainties, you may neglect factors of order unity in the calculation.

6. Suppose that the SMBH at some initial time $t = 0$ has mass $M_{BH}(0)$, and then accretes at constant efficiency ϵ at a fixed Eddington ratio L/L_{edd}.

   - Show that its mass after some time t has grown to

   $$M_{BH}(t) = M_{BH}(0)\exp\left(\frac{1-\epsilon}{\epsilon}\frac{L}{L_{edd}}\frac{t}{t_{gr}}\right)$$

   where $t_{gr} = M_{BH}c^2/L_{edd} \approx 5 \times 10^8$ yr, independent of M_{BH} . [30 points]
   - Suppose the initial (seed) mass is $M_{BH}(0) = 10M_\odot$. If the efficiency is $\epsilon = 0.1$, and the accretion occurs with Eddington luminosity, what is the black hole mass after 10^9 yr? [10 points]

7. A distant quasar with $z = 1.26$ has a compact radio component that moves at an angular speed of 0.15 milliarcsec/year. What is that apparent velocity of the component as a fraction of c? [20 points]

8. For this question, use the SDSS data on 2000 quasars with model magnitudes in the 5 SDSS filters and the redshift, which I have put on the website as a table in FITS format.

   - Make a graph with $u - g$ on the X-axis and $g - r$ on the Y-axis. Make a second plot with $g - r$ on the X-axis and $r - i$ on the Y-axis. Make a third plot with $r - i$ on the X-axis and $i - z$ on the Y-axis. In each plot, color the datapoints by redshift. [30 points]
   - Suggest color-cuts for identifying quasars with $z > 2$. [10 points]
   - Suggest color-cuts for identifying quasars with $z < 1$ [10 points]

   You may want to compare your plots and suggested color cuts with SDSS quasar selection criteria e.g. Richards et al. 2002, AJ, 123, 2945.