Discipline of Astronomy, Astrophysics and Space Engineering

INDIAN INSTITUTE OF TECHNOLOGY INDORE

Spring Semester	**Academic Year 2020-21**
End Semester Exam	**Course Code : AA 472N/672N**
Date: **08 March 2021** Max. Time Duration : **3 Hr (from 10:00 am)**	Max Marks : **100**
Number of Questions : 5	Number of pages in the Question Paper: 2

Instructions:

- The **exam starts at 10:00 am and will be of 3 hrs. Additional 30 minutes will be given to upload the answer sheet**.
- Write your **Roll number and name on each page of the answer sheet** that you will scan and upload as a PDF file.
- All Questions are compulsory and should be answered in the same order. Further **insert page numbers on all pages**. The sub-questions within each question should also be answered in order.
- All questions are clear and in case if you feel that there is something missing and need to assume then go ahead and state the assumption and justification.
- *Undertaking :* Every student is requested to copy this undertaking and fill up with their name, roll-number, signature and date on the first page of their answer-sheet.
  Without this undertaking, answer sheet will not be considered as a valid one:
  *I, ———(write your name and roll number) ————————- hereby declare that during the course of this exam, have **NOT USED** any means of communication through phone, chat or any messaging, VoIP or social media app to discuss regarding this exam with any human or any bot. (your signature and date)*

1. *Magnitude, extinction and scaling relations*

   (a) A source is dimmed by an amount $e^{-\tau_\lambda}$. Show that its apparent magnitude increases by an amount $A_\lambda = 1.086\ \tau_\lambda$, where A_λ is extinction at wavelength λ.*[6 marks]*

   (b) An edge-on disk galaxy is observed to have the HI line profile with equivalent width $W \sim 70 km\, s^{-1}$ and an H-band flux of $m_H = 15.1$. Assume the empirical relation between the equivalent width and absolute magnitude of HI band as

   $$M_{\rm H} \approx -9.50(\log_{10} W - 2.5) - 21.67.$$

   Use the Tully-Fisher relation to estimate the distance to this object for the case with $A_\lambda = 0.0$. Discuss how will the distance estimate be affected for a non-zero extinction. *[10 marks]*

   (c) Discuss the fundamental plane for elliptical galaxies and write its equation. *[4 marks]*

2. *Galaxy Clusters : Coma Cluster*

   (a) The Coma cluster has a radial velocity of 6750 km/s, an effective radius of $50'$ and a 3-dimensional velocity dispersion of 900 km/s. Estimate the total mass of the galaxy cluster, assuming the gravitational radius to be 2.5 times larger than the effective radius. *[6 marks]*

   (b) Estimate the mass of the ionized gas in the Coma cluster, using the information that the central gas number density (atomic nuclei per volume) is 2×10^{-3} cm^{-3} and that the density distribution of ionized gas may be approximated by the relation:

   $$\rho = \rho_0 \left[1 + (r/a)^2\right]^{-3/2}$$

   where a = 0.5 Mpc. You may furthermore assume that neither the ratio of X-ray to bolometric luminosity nor the M/L-ratio of the X-ray gas change with radius. *[8 marks]*

   (c) Estimate how long a Galaxy in the Coma cluster would take to travel from one side of the cluster to the other. Assume that the galaxy moves with a constant speed equal to the cluster?s radial velocity dispersion σ_r=977 km/s. How does this time compare to the Hubble time? What can you conclude about whether the galaxies in the Coma cluster are gravitationally bound? *[6 marks]*

3. *Chemical Evolution of Galaxies*

   (a) Discuss the bimodal nature of galaxies explaining the red and blue sequence. *[4 marks]*

   (b) Define G-dwarf problem and explain the same using the closed box model of chemical evolution of galaxy. Clearly describe all the assumptions involved *[10 marks]*

(c) If the disk gas had Z = 0.15 $Z_\odot$ at t = 0 when stars first began to form, while $Z(now) \approx Z_\odot$, and ratio of gas mass $M_g(t=0)/M_g(t) = 50/13$. Estimate the value of yield p and show that about 20% of low-mass stars should have $Z < Z_\odot/4$ today. *[6 marks]*

4. *Active Galactic Nuclei - I*

- An electron with random Lorentz factor γ=10^6 produces a synchrotron photon of energy 7 keV in a blazar jet, find out the magnetic field present in the jet. If the emitted synchrotron photon goes under an Inverse Compton scattering with the same electron, find out the energy of the Inverse Compted photon? *[4 Marks]*
- A plasma blob moves with a Lorentz factor 20 in blazar jet and blob has a random magnetic field $\boldsymbol{B}$=5 G. Find out the synchrotron cooling time scale for an electron having random Lorentz factor γ=10^6 in the jet frame and in the observer frame. The angle between the blazar jet and the Earth is 3°. *[8 Marks]*
- A quasar shows the variability of the order of 3 min time scale at the TeV energies in the observer frame. Can a 100 TeV photon be produced inside this emission zone through Photo-Hadronic (P-γ) process? Consider the random magnetic field at the emission site is 5 G, and the Doppler factor of the jet is 10. *[5 Marks]*
- Prove that the observed maximum value of linear polarization for a power-law distribution of electrons, emitting synchrotron radiation is 70%. *[7 Marks]*

5. *Active Galactic Nuclei - II*
Write brief notes on: *[16 Marks]*

(a) FR II galaxies and Radio-loud AGN

(b) Superluminal motion

(c) Flat spectrum radio quasars and Narrow-line Seyfert 1 (NLS1)

(d) Explain the cause of the ring-like structure of the M 87 black hole image.