ASTRONOMY 8300 – FALL 2024
Final Exam- Answers

Note: Please do not share the answers or questions from the final, midterm, project, or homework with the next generation of grad students.

1. Ionization parameter:

$$U = \frac{\int_{\nu_0}^{\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi r^2 c n_e} = \frac{\#\ \text{ionizing photons/vol}}{\#\ \text{electrons/vol}} \text{ at the incident face of cloud}$$

- U determines the ionization fractions of each element for a given SED:

e.g., $\frac{N(\text{H II})}{N(\text{H I})}$

2. Model input parameters needed:
- density (hydrogen or electron)
- spectral energy distribution (SED)
- incident ionizing flux (ionization parameter or luminosity plus radius)

additional parameters:
- abundances (default is normally solar)
- column density (default is usually optically thick – "radiation bounded")
- dust
- geometry (open, closed, etc.)
- filling factor

If fine-tuning doesn't work, try:
- multiple components (at different densities, ionization parameters, etc.)

3. Source of ionization for novae – initial ionization from thermonuclear runaway explosion of accreted hydrogen on a white dwarf; subsequent ionization from residual nuclear fusion on the white dwarf surface and, eventually, reformed accretion disk

The forbidden lines tend to be weak, compared to recombination. The temperature of the gas is low (< 5000 K), so the average free electron energy is low, and the collisional excitation rate of the levels responsible for the forbidden lines is therefore low.

4. Source of ionization for old supernova remnant (SNR) – collisional ionization from the shock front.

For the Crab nebula (a relatively young SNR), photoionization from synchrotron radiation is dominant (from electrons in the strong B field of the pulsar)

The temperature in collisionally ionized gas tends to be much higher than that in photoionized gas, so [O III] λ4363/ λ5007 is a good diagnostic.

5. BLR:
- Large range in ionization compared to a PN, due to X-rays and high column densities
- no forbidden lines: metastable levels are collisionally de-excited due to high densities. Strong collisionally excited permitted lines in the UV (C IV, N V)
- huge partially-ionized zone created by X-rays: very strong Fe II, Mg II, O I
- Lα/Hβ = 5 – 10, much lower than recombination: due to scattering of Lα photons, which populates the n=2 level. Subsequent collisional excitation leads to enhanced Hα and Hβ emission.

6. Short written explanation of the following terms (2 pts each):

a. "Blister" model: model for H II region formation, OB group ionizes face of a molecular cloud (blister), ionization front pushes into cloud to form new stars
b. Photodissociation region: zone between ionized and molecular gas in H II regions where the molecules have been dissociated by radiation
c. X, Y, Z: mass fraction of hydrogen, helium, and heavy elements, respectively
d. PAHs: polycyclic aromatic hydrocarbons; linked benzene rings (C and H)
e. Objective prism: Prism placed at the objective of a telescope (typically a Schmidt) to produce spectra of all of the sources in the field of view
f. WHIM: Warm/hot intergalactic medium
g. CGM: Circumgalactic medium
h. Lyman-alpha forest: photoionized gas in the IGM from recombination era
i. Classical nova: only one eruption observed, $10^3 - 10^5$ years between eruption, > 9 mag change
j. Polar: Cataclysmic variable in which a red M.S. star or subgiant transfers matter to a white dwarf with a strong magnetic field (B = 10 – 100 MGauss), allowing direct accretion onto the WD surface.
k. Nova shell ejection: discrete shell from initial blast, hot wind from continued H-burning on surface of WD
l. Type II supernova: H lines in spectrum of ejecta, collapse of massive star
m. Type I: no H lines in spectrum of ejecta, Ia: strong Si II, WD collapse in binary system, Ib: strong He I, Ic: no He I, weak or absent Si II, latter two likely from collapse of W-R stars
n. Shock front: compression wave that exceeds the sound speed in the gas ahead of it
o. AGN's optical/UV/Soft X-ray continuum from accretion disk around the SMBH
p. NLR: narrow-line region in AGN, ionized gas extending to ~1 kpc from the AGN
q. ULIRG: ultraluminous infrared galaxy, massive star formation
r. Blazar: AGN dominated by strong nonthermal continuum, high polarization, line of sight down the radio jet
s. Seyfert 2: AGN with strong narrow permitted and forbidden emission lines, Seyfert 1: adds broad permitted lines and strong nonstellar continuum
t. FR I vs. FR II: Radio galaxies with jets and lobes, FR Is have lower radio luminosities and are brighter in their centers
u. LINER: Low-ionization nuclear emission-line region; weak AGN
v. BPT: Separates starbursts, Seyferts, and LINERs as ionizing sources based on line ratios
w. PIZ: Partially-ionized zone: region behind classic H II region in an ionized cloud where X-rays penetrate to create partially-ionized H; N (H II)/N (H I) = 0.1 – 0.2
x. $L\alpha/H\beta = 5 - 10$ in BLRs, much lower than recombination values. Explained by resonance scattering of $L\alpha$ and collisionally excited $H\beta$ emission
y. Fe $K\alpha$ emission: transition from n = 2 to n = 1 in an Fe ion, often seen in X-ray spectra of AGN