Selection of Homework Questions

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Topic 15: AGNs & Quasars

(1) Narrow Line Region (NLR) Gas Properties

Let's follow a path from typical spectroscopic observations of an AGN to deducing a number of physical properties of its NLR.

Spectra taken through a 2 arcsec circular aperture show an Hβ flux of 1.0×10^{-14} erg s^{-1} cm^{-2}. The [OIII]5007 emission line has a central wavelength of 5200A and a width (FWHM) of 10A. The following flux ratios are measured : [OIII]5007/[OIII]4363 = 100 ; [SII]6716/[SII]6731 = 0.6. UV observations show a nuclear ionizing flux of $N_i = 3.8$ photons/s/cm^2 at the Earth. Assume the ionized gas has a single temperature and density, and fills the aperture as a spherical region.

a. What is the approximate electron density and temperature.
b. What is the total volume and mass of ionized hydrogen.
c. Use the redshift and aperture size to calculate the emission region diameter (use $H_o = 75$ km s^{-1} Mpc^{-1}) and hence the filling factor for the ionized gas. Hopefully, you will find a small filling factor and hence confirm the general view that the NLR is cloudy.
d. We can estimate the number of clouds if we know the size of each cloud, which we can estimate assuming the clouds are ionized just down to their Stromgren depth (a somewhat risky assumption). First evaluate the number of ionizing photons striking unit area of the cloud surface, assuming a typical cloud to be at a distance of half the aperture radius from the nucleus. Next evaluate the Stromgren depth, S_d, by equating this ionizing flux to the total number of recombinations in a column of depth S_d (ie $N_i = \alpha_B N_e N_p S_d$). Taking this depth to be the diameter of a typical cloud calculate the volume of one cloud, and hence the total number of clouds.
e. Assuming no clouds overlap and all are at the same distance from the nucleus (half the aperture radius), what is the covering factor that the clouds present to the nuclear radiation field --- ie what fraction of the nuclear radiation do they intercept.
f. Assuming that the velocity field is basically gravitational in origin, estimate the total gravitating mass within the region. Compare this with an estimate of the Black Hole mass assuming it is radiating at 10% of the Eddington luminosity (assume all ionizing photons have an energy of a photon at the Lyman edge, and that this constitutes the entire nuclear luminosity). Is it likely that NLR kinematics are influenced by the mass of the central black hole ?

(2) Anisotropic emission in AGN

Continuing with the path from observations to inferred properties, let's look at evidence for anisotropic nuclear radiation field. The method makes use of extended emission line regions. These off-nuclear regions have a different sight line down to the nucleus that our own sight line. Spectra from the off-nuclear regions allow us to calculate the nuclear luminosity emerging in their direction, and this is often found to be different from the nuclear luminosity emerging in our own direction --- i.e. the nuclear luminosity emerges **anisotropically**.

A typical example might be the following: An active galaxy at redshift 5000 km/s is observed using an aperture placed 10 arcseconds away from the nucleus. The following line ratios are found: [SII]6716 / [SII]6731 = 0.9 ; [OIII]5007 / Hβ = 18.0 ; [OI]6300 / Hα = 0.30 ; [NII]6584 / Hα = 0.63 ; [OII]3727 / [OIII]5007 = 0.18. An aperture placed over the nucleus shows a power law non-stellar continuum the form $F_\nu \propto \nu^{-1.5}$ with $F_\nu = 6.8 \times 10^{-25}$ erg/s/cm^2/Hz at 5000A.

a. Plot the off-nuclear line ratios on the diagnostic diagrams shown here to show that the regions are likely to be photoionized by the central source (and are not star forming HII regions, for example). Hand in printed versions of these figures.

b. Use these diagrams to estimate the radiation parameter for the off-nuclear gas, assuming solar abundances.

c. Use the [SII] line ratio to estimate the electron density, and the redshift (H_o = 75) to estimate the distance from the off-nuclear region to the nucleus. Hence, using the standard equation which defines the radiation parameter (eg 15.6 in the notes), estimate the nuclear ionizing photon rate, Q_i (the answer will be in number of ionizing photons per second). This value is the one appropriate for a line of sight towards the off-nuclear gas.

d. Now we need to compare this with the ionizing photon rate **we infer** from our line of sight. First convert F_ν at 5000A to L_ν at 5000A (ignore K corrections and use H_o=75, and remember L_ν has units of erg/s/Hz) --- to do this, of course, you will be assuming that the source radiates isotropically (ie you multiply by $4\pi\, d^2$ --- precisely the assumption we will ultimately be testing). Next, derive the constant in $L_\nu = k\, \nu^{-1.5}$ using L_ν at 5000A (dont forget to convert 5000A to Hz !). Now derive the ionizing photon rate by integrating $L_\nu / h\nu$ from the Lyman edge (912A in Hz) to ∞. This is the value appropriate for our line of sight to the nucleus.

e. Compare the ionizing luminosities estimated in `c' and `d' above --- `d' should be about a factor 10 less (depending on exactly what radiation parameter and electron dentity you estimated). Thus, the off-nuclear ionized region is seeing a nuclear source which is about 10 times brighter than the one we see. Hence our conclusion that the nuclear ionizing radiaton emerges anisotropically.

f. A second test of this picture is to see if the blocked radiation does ultimately emerge in our direction but in another waveband --- the IR, for example, since our model places a dusty torus around the central source. Continuing with our example : assume all radiation below 1 micron is absorbed and re-radiated as a single black body of T = 50K, what is the expected flux, in Jy, at 60 μm (one of the IRAS bands).

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