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A2_3 Observational evidence to support the existence of Broad Line Regions (BLR) in Active Galactic Nuclei (AGN).

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Abstract

Observational results of the integrated broad line flux, F_L, against ionising continuum flux, F_C, in AGN often show a tendency for F_L to plateau at significantly high values of F_C. We present a quantitative theory that, when combined with these observational results, gives a powerful argument for the existence of Broad Line Regions (BLR) in Active Galactic Nuclei (AGN).

Introduction

The spectral data from Active Galactic Nuclei (AGN) provide a powerful tool with which to investigate their basic structure and dynamics. Arguably the most important consequence of this data is its use in investigating the Broad Line Region (BLR). The BLR is spatially unresolved, and as a result its existence has only been inferred from the behaviour of AGN spectra.

The BLR is widely accepted as being a shell of small gas clouds, inside of which is embedded a source of ionising continuum flux, F_C. This gas is thought to be ionised by F_C, followed by electron-ion recombination a short time later ($t \approx$ 30secs) [1]. The superposed effect of these recombinations is thought to produce the broad line flux, F_L, observed in the UV and Optical spectra of most AGN (notably Quasars and Seyfert I types).

An effect often seen in plots of F_L against F_C is that of F_L levelling out toward a constant value at high enough values of F_C (this value changes between AGN) [2]. Basic photoionisation theory can be used to show that this is consistent with the existence of a BLR around the source of F_C.

The theoretical model

We start by assuming a spherical distribution of gravitationally-bound hydrogen gas clouds to surround a point source of continuum photons. The number of continuum photons capable of ionising hydrogen that are produced by the central source is given by

$$N = \int_{\nu_i}^{\infty} \frac{L_\nu}{h\nu} d\nu \qquad (1)$$

, where L_ν is the specific source luminosity, h is the Planck constant, and ν_i is the hydrogen ionising frequency. We assume the continuum source to emit radiation isotropically. Hence at a distance r from the continuum source, the 'surface density' of ionising photons is equivalent to dividing equation (1) by the spherical surface area defined at r,

$$n = \frac{1}{4\pi r^2} \int_{\nu_i}^{\infty} \frac{L_\nu}{h\nu} d\nu \qquad (2)$$

Multiplying equation (2) by the area of cloud that the photon flux is incident upon, A_C, gives the number of hydrogen ionising photons incident upon a cloud face per second as

$$N_S \equiv A_C n = \frac{A_C}{4\pi r^2}\int_{\nu_i}^{\infty} \frac{L_\nu}{h\nu} d\nu \quad (3)$$

The electron-ion recombination rate in the gas is given to be

$$N_R = \alpha n_i n_e V_i \quad (4)$$

, where n_i and n_e are the ion and electron volume number densities respectively (assumed uniform), α is the recombination coefficient (volume per unit time), and V_i is the volume of cloud that has been ionised [3]. Equation (4) arises because we expect each recombination in the cloud to be the result of an ionisation. Hence the rate of input of ionising photons into the cloud (N_S) should be equal to the rate of recombinations in the cloud (N_R). Equating (3) and (4), and dividing both sides by A_C gives

$$\frac{V_i}{A_C}\alpha n_e n_i = n \quad (5)$$

For constant α, n_e , and n_i , equation (5) can be expressed in terms of the surface density of continuum photons and the ionisation depth R_i , since $V_i = A_C R_i$. This leads to the powerful result of equation (6).

$$R_i \propto n \quad (6)$$

From equation (6), it can be seen that under the limiting assumptions of this model, the depth of ionisation should increase in proportion to the surface density of photons from the central source. There is a subtlety to this result. Imagine that when observing at some wavelength(s), an increase in F_C over some period of time is seen. This corresponds to an increase in source luminosity L_ν , and hence an increase in n by definition of equation (2). Increasing n increases R_i by definition of equation (6). As F_C increases further, R_i tends toward the cloud thickness, R_C. At a critical value of F_C (and hence n), the cloud is fully ionised ($R_i = R_C$). Any further increase in F_C will result in no further increase in F_L, since the recombination rate is limited by the amount of available material that can be ionised.

In conclusion, this result (despite simplifying assumptions) shows that observational results of F_L vs F_C for AGN are consistent with the existence of discrete gas clouds that reprocess the central continuum source into broad line photons, i.e. the conventional model for a BLR.

References

[1] "An introduction to active galactic nuclei", 1st Ed, B M Peterson. PG 82, equation (5.33)

[2] M.R Goad, K.T Korista, C.Knigge, Mon.Not.R.Astron.Soc, Issue 1, vol. **352**, pg 277-284, 2004 – See figure 4 for cited plot.

[3] "An introduction to active galactic nuclei", 1st Ed, B M Peterson. PG 72.