Unknown Astronomy Major (Draft received a grade of B)

# Active Galactic Nuclei

A fascinating area of study in astronomy involves extremely small, compact nuclei of galaxies that emit extremely large amounts of radiation. These Active Galactic Nuclei, usually referred to as AGNs, have several basic characteristics. AGNs have unusually high luminosities, with a large contrast between the brightness of the nucleus and large-scale structures. The continuum emission of AGNs is nonthermal in origin, with more flux in the ultraviolet, infrared, radio, and x-ray regions of the electromagnetic spectrum than is found in normal galaxies. They contain a small region of at most a few lightyears across which undergoes rapid variability. AGNs often appear explosive or have jet-like protuberances. Finally, they often have broad emission lines. Although the basic types of Active Galactic Nuclei each have slightly different characteristics, astronomers believe that all AGNs are fueled by accretion of matter onto a supermassive black hole.

Seyfert galaxies, which are usually spiral galaxies, are characterized by lower luminosity, quasar-like nuclei, with the host galaxy clearly detectable. (Quasars, originally termed quasi-stellar objects, are intense, point-like sources of electromagnetic radiation.) Their nuclei are characterized by a high surface brightness. There are two subclasses of Seyferts: Type 1 and Type 2. Type 1 Seyferts have two sets of emission lines superimposed on each other. The first is characteristic of low-density ionized gas ($n_e \approx 10^3 - 10^6 \,\mathrm{cm}^{-3}$) and has widths on the order of several hundred kilometers per second, which is broader than the emission lines in normal galaxies. These are the ‘narrow lines’. The second set of emission lines are the ‘broad lines’, and consist of only permitted lines. Since there are no broad forbidden lines, the part of the AGN that emits the broad lines must have a high density so that the forbidden transitions are suppressed by collisions. Type 2 Seyferts have only narrow lines, and the AGN continuum is usually very weak and difficult to isolate from the stellar continuum.

Radio galaxies are strong radio sources generally found in giant elliptical galaxies. There are two types of radio galaxies that have optical spectra associated with AGN activity. These are termed broad-line radio galaxies and narrow-line radio galaxies, and are the radio-loud analogs to Type 1 and Type 2 Seyferts.

Quasars are the most luminous AGNs. They have small angular sizes, and many quasars are surrounded by a low surface brightness halo that appears to be the starlight of the host galaxy. They are very bright, very distant objects. A few have features such as optical jets. Quasar spectra are similar to Seyfert spectra, but the narrow lines are generally weaker relative to the broad lines.

Optically Violent Variables and BL Lacertae Objects, referred to collectively as ‘blazars’, are radio-loud AGNs with a strong relativistically beamed component of their emission close to our line of sight. They show abnormally large magnitude, short time-scale variations in their emission. For example, their emission may change by 0.1 magnitudes in the optical wavelengths on time scales as short as a day. Their emission is also polarized by as much as a few percent, while the emission of most AGNs is polarized by only one percent. BL Lac objects are also characterized by the absence of strong emission or absorption lines in their spectra.

Finally, narrow line x-ray galaxies have the same high excitation emission lines as Seyferts but lower luminosity. They are considered to be Seyfert galaxies whose optical spectra are heavily reddened and extinguished by dust in the galaxy.

The main question concerning astronomers is how the vast amount of energy detected from AGNs is produced. AGNs are all highly luminous, small sources that generate the light of up to several trillion stars in a volume significantly smaller than a cubic parsec. (Peterson, p.32) Astronomers believe that all of the different types of AGNs are powered by the same phenomenon: a ‘central engine’ that is made up of a hot accretion disk surrounding a supermassive black hole. Black holes are extremely massive, compact objects with escape speeds greater than the speed of light. As stars pass close to the black hole, they are tidally disrupted. The stellar material becomes part of the accretion disk, which radiates as it spirals into the black hole. Although no electromagnetic radiation can escape a black hole, the process of accreting material onto a black hole releases a large amount of energy. The fundamental process is the conversion of mass to energy with an efficiency $\eta$ ($E = \eta mc^2$). It can be shown that to the correct order of magnitude, $\eta \approx 0.1$. (Peterson, p. 34) The luminosity, which is the rate at which energy is emitted by the nucleus, is equal to the rate at which energy is supplied to the source by accretion, or

$$L = \frac{dE}{dt} = \eta \dot{M} c^2.$$

Even for relatively high luminosity sources, the rate of accretion only needs to be on the order of one solar mass of material per year to account for the radiation observed from AGNs. (Peterson, p. 34)

Since astronomers believe that the same underlying physical processes generate all types of AGNs, the type of AGN we observe may depend entirely on the orientation of the axis of the accretion disk to our line of sight and the amount of gas and dust near the nucleus of the galaxy. (Zeilik and Gregory, p. 483) This theory is supported by the fact that the properties of Seyferts and quasars show a slight overlap. The highest luminosity Seyferts are indistinguishable from quasars, forming a continuous sequence in luminosity. However, real physical differences depending on the luminosity of the central source may be found between the types of AGNs. (Peterson, p. 31) This is just one example of the many questions still left unanswered about AGNs. Even the driving mechanism is still in doubt. Although the theory that supermassive black holes form the central engine of AGNs is widely accepted and explains much of the observed data, it has not been satisfactorily proven. The wide acceptance of this theory is due in part to the absence of any other valid theories. (Peterson, p. 38) There is much information that remains unknown about AGNs, and only further research into the subject will give us a full understanding of this phenomenon.

References

Peterson, Bradley M., *An Introduction to Active Galactic Nuclei,* Cambridge University Press, 1997.

Zeilik, Michael, and Gregory, Stephen A., *Introductory Astronomy and Astrophysics*, 4th Edition, Saunders College Publishing, 1998.