Active Galaxies: Observations

‘Active galaxy’ is a general term which refers to any galaxy that produces significant emission in addition to that from its constituent stars, stellar remnants and interstellar medium. The characterization of such galaxies as ‘active’ is because the unusual emission characteristics are generally assumed to be associated with high-energy, eruptive phenomena. The earliest consistent user of the word ‘activity’ as applied to the nuclei of galaxies seems to have been V A Ambartsumian.

In most cases, this non-stellar emission appears to originate in the very center, or nucleus, of the galaxy, and these sources are known generically as ‘active galactic nuclei’ (AGN). A galaxy that harbors such a source is known as the AGN host. Historically, some other types of sources, such as STARBURST GALAXIES, that have some phenomenological similarities to AGN (e.g. strong near-UV emission) have also been known as active galaxies, though in these cases the activity might not be confined to the nuclear regions.

AGN are the most luminous long-lived sources in the universe. They emit strong radiation over the entire observable wavelength range, from x-rays and γ-rays through long-wavelength radio. A complete picture of the emission of an AGN can be obtained only by observing it at many wavelengths, preferably simultaneously over the entire spectrum because they are variable sources.

There are a number of different classes of AGN (see ACTIVE GALAXIES: OVERVIEW); SEYFERT GALAXIES constitute the low-luminosity end of the AGN phenomenon, i.e. their nuclear luminosities are roughly comparable with the total starlight from the host galaxy. Higher-luminosity AGN are known as ‘quasars’ or ‘quasi-stellar objects’ (QSOs) (see QUASISTELLAR OBJECTS: OVERVIEW) with the former being reserved (originally) for the stronger radio sources, and the latter weaker; in these cases the optical light from the AGN can exceed, sometimes by factors of more than 100, the stellar light from the host galaxy at all wavelengths. There are a wide variety of subclasses within these groups, based on the relative prominence of UV–optical emission lines, radio properties and polarization (see POLARIZATION IN ACTIVE GALAXIES). These will be mentioned below as necessary.

This section will discuss the current status of observations over the electromagnetic spectrum. We first discuss the continuous emission of AGN in terms of their ‘spectral energy distributions’ (SEDs), i.e. amount of energy emitted in various wavebands. We then focus on the prominent emission lines that are detected in the UV–optical (and, more recently, x-ray) spectra of most AGN and follow this with a brief description of absorption features in AGN spectra. Spatially resolved structures in AGN are also discussed.

Spectral energy distributions

The SEDs of normal stars (and galaxies) are well approximated as blackbodies in the temperature range 2000–50 000 K, and thus their emission is strongly concentrated in the ultraviolet (UV) through near-infrared (IR) parts of the spectrum. In contrast, AGN emit comparable energy (per unit logarithmic bandwidth) over most of the observable spectrum, as can be seen in figure 1.

Figure 1. The median radio–soft x-ray spectral energy distribution for radio-loud (dashed) and radio-quiet (solid) low-redshift quasars. Data from Elvis et al 1994 Astrophys. J. Suppl. 95 1.

The one exception is the radio region, in which ‘radio-loud’ (RL) AGN are some 3 orders of magnitude brighter than their ‘radio-quiet’ (RQ) counterparts. These RL AGN constitute ∼10% of the population. Figure 1 shows the low-redshift median SED for RL and RQ objects from a sample of more than 40 AGN. It is plotted as log(νLν) versus log ν, which shows the energy output in each waveband and also highlights the important structure in the SED.

Our knowledge of these SEDs is limited by current observational technology to fairly low-redshift, bright sources and includes (as is clear in figure 1) important gaps in various wavebands.

1. The absence of observations at high energies (γ-rays) is due to current technical limitations; higher-energy detectors are not sensitive enough to detect most AGN. Those that have been detected so far are generally core-dominated (CD) RL AGN, i.e. those whose emission is boosted by a relativistic flow along our line of sight (see ACTIVE GALAXIES: UNIFIED MODEL for more detail).

2. The EUV gap, between the far-UV and soft x-ray regions of the spectrum (i.e. between 912 Å and about 0.1 keV, spanning a factor of about 10 in photon energy), is due to the large opacity of the interstellar
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The most prominent feature of AGN SEDs is the strong peak in the UV spectrum. The feature, which is often known as the 'big blue bump' (BBB), begins in the near-IR and may extend all the way to soft x-ray energies. It is observed with a combination of low-resolution optical and UV spectroscopy and/or multicolor, optical photometry. It can be plausibly identified as arising in an accretion disk (AD) containing material with a wide range of temperatures and orbiting around a supermassive black hole. The BBB peaks in the extreme UV, which is consistent with the expected emission from an AD around a $\sim 10^8 M_\odot$ black hole that is accreting material at the Eddington rate.

The IR emission from RQ AGN is mainly observed via multicolor photometry, although IR spectroscopy is a rapidly expanding field. The IR spectrum is thought to be dominated by thermal emission from dust in the host galaxy or a molecular torus that surrounds the AGN. The most compelling evidence for this interpretation is as follows.

1. There is a local minimum in AGN SEDs at a wavelength of about 1 $\mu$m. This probably represents emission from the highest-temperature (about 1500 K) grains that can exist in the vicinity of an AGN; at higher temperatures, i.e. smaller distances from the central source, dust will sublimate.

2. In some AGN, the infrared continuum has been observed to vary, apparently in response to earlier, similar continuum variations in the UV-optical spectrum (see ACTIVE GALACTIC NUCLEI VARIABILITY). The light-travel time inferred is consistent with the maximum distance at which grains exposed to the AGN radiation field should sublimate.

3. The sharp break in the far-IR–submillimeter region of the SED in all but CD RL AGNs is generally too steep to be ascribable to optically thick synchrotron emission or to single-temperature blackbody emission, but is consistent with thermal emission from grains (depending somewhat on the unknown grain emissivity law).

In RL AGN, the IR is probably a mix of isotropic thermal and beamed non-thermal emission. The beamed emission dominates in the CD RL AGN as it is boosted by relativistic outflow along our line of sight. Strong evidence for this interpretation is provided by the coordinated variability observed in several of these sources, most notably 3C 273, which is the brightest nearby QSO and consequently has been extensively monitored. Preliminary results in the mid- and far-IR from the ESA satellite ISO show the progression from non-thermal to thermal emission in a small sample of CD and lobe-dominated RL AGN and RQ AGN, supporting this general picture.

While the UV–optical–IR emission from AGN appears to be predominantly thermal in origin, both the high- and low-energy extremes of the observable SEDs are thought to be produced by non-thermal processes. X-ray observations of AGN are largely confined to very low-resolution spectroscopy which yields the global continuum shape. The principal feature of RQ AGN hard x-ray spectra is a power-law continuum ($F_\gamma \propto \gamma^{-\alpha}$, with $\alpha \approx 0.9$) over the range $\sim$1–100 keV. The spectrum generally turns over at energies $\gtrsim$100 keV and is thought to arise through repeated Compton scattering of thermal or non-thermal photons.

RL AGN show a harder x-ray spectrum than their RQ counterparts (Figure 1). The relative strength of this hard component increases with the core dominance of the radio source, implying that the emission is beamed similarly to the radio and supporting an origin in Compton up-scattering of the radio synchrotron photons. CD RL AGN are, to date, the only AGN detected in the high-energy $\gamma$-rays, implying that beaming is a key factor. A few very high-energy observations have been made, including ground-based detection of Cerenkov showers that occur when TeV energy photons hit the Earth’s atmosphere. So far, the AGN detected by this method are all BL Lac objects (see BL LACERTAE OBJECTS). Similar to CD RL AGN, the observed emission from these sources is apparently dominated by a relativistic beam or jet (see ASTROPHYSICAL JETS) directed towards the observer.

At energies around 10 keV and above, RQ AGN spectra also have a 'hard tail' above the x-ray power law which is stronger in lower-luminosity sources. This is thought to arise through 'Compton reflection' (a combination of inelastic scattering of higher-energy photons and photoelectric absorption of lower-energy photons) of relatively cooler material. This feature is strong enough that the cooler material must cover about half of the sky as seen from the x-ray source itself, which has led to speculation that the reflecting body must be the AD itself, with the x-ray source located somewhere above it. An example of such a spectrum is shown in figure 2.

Spectral variability
One of the most remarkable characteristics of AGN is their strong flux variability. Indeed, the very existence of intraday continuum variability puts a severe upper limit (set by light travel time and source coherence arguments) on the size of the continuum source, and thus provides one of the strongest arguments for identifying an AD around a supermassive black hole as the source of continuum radiation. At a fundamental level, the cause of continuum
variability is not understood, although AD instabilities are sometimes invoked as a driving mechanism.

In general, the most rapid and highest-amplitude variations are seen at the highest photon energies. X-ray flux variations have been detected in Seyfert galaxies on time scales as short as several minutes. For phenomenological purposes, we can characterize the strength of the variations as a function of temporal frequency $f$ by their ‘power density spectra’, which are conventionally modeled as a power law, i.e. $P(f) \propto f^{-\alpha}$ where $\alpha$ is typically in the range 1–2 for most AGN. The case $\alpha = 0$ is ‘white noise’, i.e. the amplitude of variation is independent of time scale, and $\alpha = 1$ corresponds to variations that can be described as a random walk. Larger values of $\alpha$ correspond to increased amplitudes of variability over longer time scales (lower frequencies $f$). In some cases, e.g. NGC 4151 and 3C 390.3, the most prominent variations seem to occur quasi-simultaneously (i.e. simultaneous to within less than a day) from x-rays (or even $\gamma$-rays for NGC 4151) through to optical wavebands. The smaller-amplitude structures in the light curves differ across the spectrum, with lower amplitudes and less structure seen at lower photon energies. The near-simultaneity of the variations requires that the variations are driven by radiation rather than, for example, by propagation of disturbances through the AD on the much-longer viscous time scale. These observations, along with detection of the x-ray hard tail and the Fe Kα emission line, point to ‘reprocessing’ models, in which a variable x-ray source illuminates the AD from above, with the absorbed x-ray energy driving variations observed at lower photon energies.

In at least one case (the Seyfert galaxy NGC 7469), however, the x-ray variations do not correlate well with the UV–optical variations; variations of similar fractional amplitude are seen in both the x-ray and UV–optical regions, but there is no clear causal relationship between them.

It is in this same object, however, that a time delay between UV and optical variations has been detected. This is the only Seyfert galaxy that has been monitored sufficiently well for such wavelength-dependent continuum time delays to be detected. Relative to the variations in the shortest-wavelength UV, variations at longer wavelengths are delayed by an amount $\tau \propto \lambda^{-\alpha}$, which is precisely the wavelength dependence expected if the variations arise in a thin AD that is irradiated by a variable x-ray source. Of course, this interpretation fails utterly to account for the observed lack of correlation between the UV–optical and x-ray variations. At this time, NGC 7469 seems to present serious difficulties for reprocessing models, although no other explanation of the coupling (or lack of coupling) between the x-ray and UV–optical variations has been forthcoming.

Extreme flux variations are observed in BL Lac objects as well. In this case, however, the fundamental origin of the variations is probably related to the propagation of shocks through the relativistic jet. Unlike the Seyferts, while there is a close correspondence between the variations in different bands, a completely consistent relationship between time delay and wavelength has not yet emerged; the same source can apparently show different behavior at different times, and the reason for this is not understood.

**Emission lines**

*Basic properties of UV–optical lines*

Strong broad emission lines are a defining characteristics of all types of AGN, except BL Lacertae objects in which the, presumably present, emission lines are swamped by the highly beamed continuum emission from the jet. In the UV–optical–IR part of the spectrum, the most prominent emission lines (those with equivalent widths$^1$ larger than some tens of Å) are usually $\text{Ly}\alpha\lambda 1215$, C IV $\lambda\lambda 1549$, C III $\lambda 1909$, Mg II $\lambda 2798$, Hβ $\lambda 4861$, Hα $\lambda 6563$ and Pa $\alpha\lambda 1849$ (figure 3). In most Seyferts and quasars, the observed emission arises in two physically distinct regions, a spatially compact ($10^{15}$–$10^{17}$ cm) ‘broad-line region’ (BLR) with relatively high particle densities ($n_e \approx 10^4$ cm$^{-3}$) and large velocity dispersions ($\sigma_{\text{FWHM}} \approx 1000$–$10,000$ km s$^{-1}$), and a spatially extended (100 pc–1 kpc) ‘narrow-line region’ (NLR) with relatively low particle densities ($n_e \approx 10^2$ cm$^{-3}$) and smaller velocity dispersions ($\sigma_{\text{FWHM}} < 1000$ km s$^{-1}$). Certain nebular ‘forbidden’ lines, such as [O III] $\lambda\lambda 4959, 5007$, are prominent features of narrow-line spectra but are not observed in broad-line spectra. In the low-density NLR, both the Balmer lines and the [O III] are in the low-density limit in which the emissivity is proportional to $n_e^2$. However, in the denser,

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$^1$ The equivalent width of an emission line can be thought of as the width (in wavelength units) of underlying continuum that would be required to produce the same emission-line flux.
but much lower-mass BLR, the Balmer lines are still in the low-density limit, but the [O III] lines are in the high-density limit in which the emissivity is proportional only to \( n_e \). The [O III] lines from the broad-line region are thus very weak relative to the Balmer lines, and the forbidden lines are often referred to as being ‘collisionally suppressed’.

Seyfert galaxies have traditionally been divided into two spectroscopic subclasses: type 1 Seyferts have both broad-line and narrow-line emission, whereas type 2 Seyferts have only narrow lines. In some and possibly all cases, the type 2 objects are those whose BLRs are obscured from our direct vision by dust. Spectra of quasars are always similar to those of type 1 Seyferts. The question of whether or not there are any bona fide ‘type 2 quasars’ remains open. Recent polarimetry has revealed broad lines in some ultraluminous infrared galaxies: spectroscopically these could sometimes be classified as the elusive type 2 quasars, but fundamentally these are still obscured type 1 quasars. Beyond semantics, the question is whether or not unified models explain all type 2 objects.

Emission-line variability
The broad components of AGN emission lines vary in flux in response to changes in the continuum flux, with time delays that are assumed to be due to light travel-time effects within the BLR. Indeed, measurement of the BLR size relies on measurement of the mean time delays (or ‘lags’) between continuum and emission-line variations. This process, known as ‘reverberation mapping’, has been carried out successfully for more than two dozen AGN. The BLR sizes in Seyfert galaxies are in the range of a few to around 100 light-days (i.e. \( r_{\text{BLR}} \approx 10^{15} - 10^{17} \text{ cm} \)), and scale with luminosity approximately as \( r_{\text{BLR}} \propto L^{1/2} \), consistent with the simplest theory. Different lines in a given AGN respond with different time delays, usually in the sense that higher-ionization lines respond faster than lower-ionization lines; this indicates that the BLR has a radially stratified ionization structure and that the maximum variability response of different lines occurs at different radii. The range of time responses is such that the outer edge of the BLR is at least 10 times larger than the inner edge.

In principle, reverberation mapping should be able to determine the velocity field of the BLR because the broad lines are resolved in line-of-sight (Doppler) velocity. For example, if the BLR clouds were traveling radially outwards from the central source, then an external observer would see the short-wavelength (relatively blueshifted) gas on the near side of the nucleus respond to continuum variations before seeing the long-wavelength (relatively redshifted) gas on the far side of the nucleus. The absence of such a strong signature indicates that the predominant gas motions are not radial. However, current observations are not extensive enough to determine whether the BLR gas is confined to a disk or has some different geometry.

Regardless of the details, if it is accepted that the BLR gas motions are primarily orbital around the central source, the mass of the central source (\( M_{\text{black hole}} \)) can be measured by combining measurements of the size of the region with emission-line width, i.e. to within some geometry-dependent factor of order unity, \( M_{\text{black hole}} \approx r_{\text{BLR}}^2 \Omega_{\text{eWM}} \). For the two dozen or so low-luminosity AGN for which this has been done, masses in the range (10^6–10^8)M\(_{\odot}\) have been inferred.

The narrow emission lines generally do not vary on time scales of years or less because the longer light-travel and recombination times tend to smear out the effects of any continuum variations. Reports of narrow-line variability are rare. Probably the best case for actual narrow-line variability is the case of the broad-line radio galaxy 3C 390.3, which seems to have an abnormally compact, high-density NLR.

Narrow-line widths seem to correlate well with the central masses of the AGN host galaxy on scales comparable with the size of the NLR (i.e. the interior galactic bulge mass), although there is also clear evidence that part of the narrow-line widths and asymmetries is due to interaction with jets.

The x-ray iron (Fe) Kα line
In the low-resolution spectra typically obtained in the x-ray region by satellites such as ASCA (Japan), SAX (Italy) and RXTE (USA), a fluorescent Fe Kα emission line is commonly observed. This emission line tends to be stronger in lower-luminosity sources. The energy at which the line is observed crudely indicates the ionization state of the emitting material. A wide range of behavior is seen from unresolved, cool lines (i.e. from low-ionization material), consistent with an origin in absorbing material along our line of sight through the quasar, e.g. the molecular torus, to hot, resolved lines with widths, \( \Gamma_{\text{FWHM}} \geq 10000 \text{ km s}^{-1} \), which imply material much closer to the central AGN than the UV and optical lines discussed above. In a few of these, most notably MCG-6-30-15,
complex line profiles are observed which suggest emission from very close to the central AGN. This interpretation is very attractive as the line then provides our only direct observation of the inner AD and is extremely important for diagnosing and constraining both AD and central-source models.

X-ray satellites, such as XMM (ESA) and the Chandra X-Ray Observatory (NASA), both launched in 1999, will be able to observe Fe Kα emission in a larger fraction of the AGN population. Their gratings will also provide extremely high spectral resolution \( E/\Delta E > 100–1000 \), allowing more detailed profile studies as well as the detection of more and weaker lines in bright, nearby AGN.

**Spatially resolved structures in AGN**

**The narrow-line region**

Whereas the size and structure of the BLR must be inferred indirectly by processes such as reverberation mapping, the NLR is sufficiently extended that, in the nearer AGN, it can be spatially resolved with the Hubble Space Telescope or, in some cases, even with ground-based observations. The NLR is typically approximately axisymmetric, with its long axis coinciding with the radio axis in those sources in which extended radio emission is detected. In some cases, there appear to be shock fronts at the interface between the radio-emitting plasma and the interstellar medium in the host galaxy. While the narrow-line emission is apparently driven primarily by photoionization by the central source, strong emission from post-shock cooling regions is also detected.

In some cases, narrow-line emission seems confined to wedge-shaped ‘ionization cones’ that emanate from the nucleus. The opening angles of these cones are typically 30′–100′. These cones are thought to be a result of anisotropy in the AGN radiation field that is introduced on much smaller scales by an obscuring torus that surrounds the central source.

**AGN host galaxies**

In the present-day universe, AGN constitute fewer than 5–10% of all bright galaxies. Why are some galaxies ‘active’, whereas others are not? Does the AGN phenomenon represent a transient phase in galaxy evolution (noting that there were far more AGN in the distant past than there are today?) Attempts to address these problems have led to studies of the ‘host galaxies’ of AGN. This is often a difficult undertaking, since AGN are typically at large distances, so the host galaxies are faint and have small angular sizes, and, in the case of quasars in particular, much of the host-galaxy light is simply lost in the glare of the quasar.

Carl Seyfert’s original list of high-surface-brightness emission-line galaxies was composed almost entirely of spiral galaxies. Over time, the definition of ‘AGN’ has become primarily spectroscopic (based on the presence of strong emission lines, except in the case of BL Lac objects). High-luminosity AGN are found in both elliptical and spiral galaxies, although at low redshift RL AGN are found preferentially in ellipticals.

Until relatively recently, it was generally believed that there is a correlation between AGN and host-galaxy luminosity: more luminous AGN reside in more luminous galaxies. There are, however, strong selection effects that can lead to such a conclusion. Recent observations of quasars with the Hubble Space Telescope (to aid detection of faint host galaxies with high-luminosity AGN) and more through survey work on nearby galaxies (to find weak AGN in luminous hosts) have not supported the existence of a strong correlation between AGN and host-galaxy luminosities. Faint AGN are found in both low- and high-luminosity host galaxies, whereas high-luminosity AGN are found only in more luminous hosts.

As a result in a large part of observations with the Hubble Space Telescope, it now seems that virtually all galaxies harbor supermassive black holes in their nuclei (see SUPERMASSIVE BLACK HOLES IN AGN). Identification of supermassive objects requires measurement of high velocity dispersions on small spatial scales (thus requiring the high angular resolution obtainable with space-based imaging), leading to virial mass measurements. The most interesting question now seems to be shifting from ‘do supermassive black holes exist?’ to ‘why are some supermassive black holes accreting mass (AGN) whereas others are not (normal galaxies)?’ Whether or not the nucleus is fueled may be related to how easy it is to drive gas into the galaxy nucleus, and this may in turn depend on host-galaxy characteristics.

**Extended x-ray emission**

The high (for the x-ray) spatial resolution of the High Resolution Imager on the ROSAT x-ray satellite (∼5″) facilitated imaging of bright, nearby Seyfert galaxies such as NGC 1068 and NGC 4151. X-ray imaging shows that a significant fraction (up to ∼50%) of the x-ray emission can originate in an extended region around the central AGN. In a few sources, this x-ray emission is spatially correlated with the NLR. The origin of the extended x-ray emission could be due to electron scattering of the central x-ray emission or to x-ray emission from a hot, outflowing wind. The Chandra X-Ray Observatory (NASA) with its unprecedented spatial resolution (∼0.5″) will allow many more of these spatial studies to be made.

**Megamaser emission**

Among the most exciting observations of AGN in recent years are those of water maser emission in the radio regime. Radio observations, because of the long wavelengths and correspondingly larger telescopes that can be built or synthesized, are currently unsurpassed.
Absorption lines

Optical and UV

The optical and UV spectra of AGN contain absorption features due to material along the line of sight between us and the optical–UV continuum source both within the AGN itself and in intervening space.

The intervening absorbers, whose redshifts are always lower than those of the background QSO, are most numerous in high-redshift QSOs with their correspondingly longer line of sight. They are dominated by lines from the fundamental transition of neutral hydrogen, Lyα $\lambda$ 1215. Known as the ‘Lyman α forest’, these lines provide a wealth of information concerning the distribution of cold material in the universe. The range of column densities in these absorbing systems is wide, $N_{\text{H}} \approx 10^{17} - 10^{21}$ cm$^{-2}$, so that metal features, Mg II $\lambda$ 2798, C IV $\lambda$ 1549, and Lyman limit break are observed in a subset. At high redshift, where only the brightest sources, mostly QSOs, are visible to us, the Lyman α forest provides our only view of the cold material and so is a very important window on the early universe for cosmological studies (see QUASISTELLAR OBJECTS: INTERVENING ABSORPTION LINES).

The most interesting class of absorbers, in terms of QSO studies, is that of associated–intrinsic absorbers. These are high column density, metal line systems which occur in more than 50% of all AGN and whose redshift is close to and sometimes even slightly in excess of that of the background QSO. In UV–optical spectra with sufficiently high resolution ($\lesssim 5$ Å), the lines are often visible within the broad emission-line profiles. This makes them difficult to study as neither their profiles, which often include multiple components, nor those of the emission lines they absorb are known. High-resolution and signal-to-noise data are required and, even then, the uncertainties tend to be high. The absorption is thought to originate in material close to the nucleus of the QSO and moving relative to it, usually in an outward direction. They show a range of ionization from low, where Mg II is the dominant line, to high, where C IV or even O VI $\lambda$ 1034 predominate. These high-ionization absorbers are thought to also be responsible for the x-ray warm absorbers discussed below.

X-ray warm absorbers

The soft x-ray spectral region is strongly affected by atomic absorption due to any material along the line of sight between us and the x-ray source within the AGN itself. Our Galaxy has a significant column density of neutral (cold) material whose signature is present in AGN soft x-ray spectra (in the range 0.1–5 keV). The host galaxy of the AGN produces a similar signature. In addition to this cold absorption, absorption by ionized (warm) material is often observed in the soft x-ray spectra. This is generally evidenced by the presence of strong absorption at the edge(s) of highly-ionized oxygen (O VII or O VIII) or, in lower-resolution data, a ‘leakage’ of soft photons above the expectations of cold absorption since the low-energy opacity decreases as the ionization increases.

Indications are that all or nearly all QSOs showing x-ray warm absorption also have associated absorption lines in the UV which include high-ionization lines such as O VI and N V $\lambda$ 1240. Recent work has shown that high-column-density, outflowing material can produce both the x-ray and the UV features of such absorbers. The resulting combination of UV and x-ray constraints on the absorbing material has provided us with unprecedentedly strong diagnostics for the absorber. It appears to be high-column-density ($N_{\text{H}} \approx 10^{20–22}$ cm$^{-2}$) material, outflowing from the central regions at velocities $\sim 100$–1000 km s$^{-1}$, located between the BLR and NLR at $\approx 10^{17}$ cm and often including several distinct components within an individual system.

The most dramatic absorption features seen in the UV–optical spectra of QSOs are the broad absorption lines (BALs) (figure 4). These are high-column-density ($N_{\text{H}} \approx 10^{20–21}$ cm$^{-2}$) intrinsic absorbers outflowing from the QSO nucleus. They have a range of ionization (hence C IV or Mg II BALs) and a wide range of velocities sometimes approaching $\sim 10\%$ of the speed of light. The absorption generally contains a great deal of structure although a...
small subset have smooth P-Cygni-type profiles indicating a smooth, spherical outflow. Since they absorb out so much of the QSO continuum and line emission, it is very hard to study them quantitatively. High-resolution and high-signal-to-noise spectra are essential along with detailed modeling of both emission and absorption features in order to build up information on the column densities as a function of velocity for this material. Interpretation is generally in terms of a turbulent, outflowing wind close to the QSO nucleus and covering a significant fraction of the central continuum source and the BLR. These sources are universally weak x-ray emitters, mostly undetected down to limits well below those of other QSOs. The strong absorption seen in those few detected to date leads to an interpretation in terms of absorption of the x-ray emission by the same, outflowing wind and suggests that the column densities is at the high end of the quoted range.

Bibliography

Blandford R D, Netzer H and Woltjer R 1990 Active Galactic Nuclei (Berlin: Springer)
Osterbrock D E 1989 Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (Mill Valley: University Science Books)
Peterson B M 1997 An Introduction to Active Galactic Nuclei (Cambridge: Cambridge University Press)

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