Emission Lines in Active Galaxies: New Methods and Techniques
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Disk Emission Lines

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Abstract. A thin disk illuminated by a central source will produce single-peaked broad emission lines if there is a wind emerging from the disk. The velocity gradient in the wind produces an anisotropic optical depth. For optically thick lines, the emission is strongest along directions perpendicular to the Keplerian velocity of the disk. The resulting line profiles are single peaked even though the emitting gas moves on essentially circular orbits. We argue that the broad emission lines seen in quasars, Seyferts, and luminous cataclysmic variables arise in disk winds.

Many luminous astrophysical objects are believed to be powered by disk accretion, including quasars, Seyfert galaxies, and cataclysmic variables. Quasars, Seyferts, and the most luminous cataclysmics, the nova-like variables, are all characterized by broad single-peaked optical and ultraviolet (UV) emission lines. A substantial fraction of objects in each of these classes also have blueshifted absorption in the UV resonance lines, indicating the presence of outflowing gas. It is possible that all such objects have outflowing gas, but that it does not cover the entire sky as seen from the center of the disk, so that only in some cases does it lie along our line of sight.

Cataclysmic variables reside in our galaxy, so they are the most easily studied among the objects mentioned. They are binary systems, consisting of a white dwarf accreting from a low-mass star that is overflowing its Roche lobe. In low-luminosity cataclysmics such as dwarf novae, both the ultraviolet (UV) and the optical emission lines are double peaked. In eclipsing systems, the lines are eclipsed along with the continuum, with the eclipse of the blue peak preceding that of the red peak, showing that the emission originates in the disk.

The single-peaked UV lines in nova-like variables are attributed to resonance scattering in an extended wind. However, the origin of the single-peaked optical lines, which are collisionally excited and hence cannot form in an extended low-density wind, has been problematic. Observations of eclipsing systems establish that the optical line emission comes from gas near the plane of the disk. The fact that the blue wing of the emission lines is eclipsed first, followed by the eclipse of the red wing, establishes that the emitting gas is rotating in the same sense as the binary.

The correlation between single-peaked lines and outflowing winds led us to propose that radiative transfer effects in the wind are responsible for the line profiles seen in nova-like variables (Murray & Chiang 1996). The emission comes from the region where the gas is accelerated away from the surface of the disk. This gas is rotating at the local Keplerian velocity, with a small radial velocity. However, the radial velocity gradient actually exceeds the gradient of the Keplerian velocity, and it is the velocity gradient that determines the line optical depth. The large radial velocity gradient allows photons to escape more easily along radial lines than along lines tangent to the velocity vector. Since photons traveling along radial lines have small projected velocity, the resulting line profiles are single peaked.

Because the line spectra of nova-like variables and those of AGN are similar, and because both classes of objects are believed to harbor accretion disks and outflowing winds, it is natural to suspect a similar line-emission mechanism. We and our colleagues have shown that line driven winds naturally arise from the disks of AGN (Murray et al. 1995). These winds cover about 10% of the sky as seen from the central source. When we observe such an object nearly edge on, we view it through the wind. The spectrum in that case shows broad absorption (out to 30,000 $\mathrm{km\,s^{-1}}$) on the blue wing of the UV resonance lines. At the same time, the soft X-rays from the central source are strongly absorbed. The gas at the transition between the disk proper and the wind, which emerges at radii ranging from $\sim 10^{16}$ cm to 10^{18} cm or farther in quasars, is heated by photoionization, resulting in line emission. Due to the radiative transfer effects described above, the line profiles are single peaked (Murray & Chiang 1997). The red and blue wings of the lines are formed at the same radii, but the red emission comes preferentially from the front of the disk, while the blue emission comes from the rear (Chiang & Murray 1996). This is consistent with the response of the C IV line seen in reverberation-mapping studies (e.g., Korista et al. 1995).

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