Discovery of Newly Formed Broad Absorption Lines in a Radio-Loud Quasar

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ABSTRACT

We report a serendipitous discovery of broad absorption lines that were newly formed in the spectrum of the high-redshift, luminous radio-loud quasar TEX 1726+344, in a time interval of only 12 years. This is the first quasar showing a transition from narrow absorption lines to broad absorption lines. It also becomes one of the few radio-loud broad absorption line quasars. The gas cloud responsible for these broad absorption lines is derived to have parameters coinciding with those of the remnant of a tidally disrupted star.


1. Introduction

Approximately 10% of all quasars are “radio loud”, in the sense that they are more luminous at radio than at optical wavelengths. Also for some unknown reason, about 10% of radio-quiet quasars show broad absorption lines (BAL) in their spectra. Only recently have a handful of radio-loud BAL quasars been discovered (Becker et al. 1997; Brotherton et al. 1998), thus changing our view that BALs only appear in radio-quiet quasars. These quasars will serve as a link between radio-loud and radio-quiet quasars, and will aid in understanding the structure and kinematics of powerful outflows in these quasars. This may eventually lead to a breakthrough in understanding the origin of the radio loudness and the radio-loud/radio-quiet dichotomy.

2. Observations
In a spectroscopic survey of a sample of 62 radio-loud quasars, we searched for emission line variations on a time scale of ∼10 years (Ma & Wills 1998; Ma 2000; Ma & Wills 2001). A BAL system was serendipitously discovered in the radio-loud quasar TEX 1726+344, which showed only narrow absorption lines just 12 years ago. This quasar has a radio flux of 23.0 mJy or a luminosity of $10^{26.9}$ W Hz$^{-1}$ at 6 cm (Richards et al. 2001), a redshift of 2.43, and a V magnitude of 18.5 (Barthel, Tytler & Thomson 1990). The K-corrected ratio of radio-to-optical power $R^*$ (Sramek & Weedman 1980; Stocke et al. 1992; Brotherton et al. 1998), commonly used as a measure of radio loudness, is derived to be $10^{2.36}$ and is well above the criterion $R^* > 10$ for radio-loud quasars.

We observed TEX 1726+344 on 2000 June 4, using the 2.7-m telescope at McDonald Observatory. A 2-arcsecond slit was used for a total exposure of 5000 seconds. The resolution is about 0.7 nm. The spectrum was corrected with a short exposure using an 8-arcsecond slit. The corrected spectrum is denoted in the upper panel of Fig. 1 by a solid line. The historical spectrum taken by Barthel et al. (1990) in 1988, after scaled to the continuum level of the 2000 spectrum, is indicated by a dotted line. This historical spectrum was taken using the 5-m Hale telescope with a 1-arcsecond slit in a 3600-second exposure, and has a resolution of about 0.4 nm. The direct division spectrum and the fitting curve are shown in the lower panel.

The continuum and the emission lines match well, as in most of the 62 quasars observed in a time interval of about 10 years. However, historical spectra of TEX 1726+344 in 1988 (Barthel et al. 1990) and also in 1990 (Lanzetta et al. 1991, not shown here) show only narrow absorption lines. The BALs blueward the SiIV $\lambda 139.7$ and CIV $\lambda 154.9$ emission lines in the new spectrum are dramatic, especially in the direct division spectrum.

The SiIV and the CIV absorption lines both have a redshift of 2.36, as compared to a redshift of 2.43 in the emission lines. The difference in the peaks between the absorption and the emission lines suggests that the absorbing gas has an outflowing velocity of 6000 km/s. Both absorption features are significant with restframe equivalent widths of 0.3 nm and 0.2 nm, respectively. The full width at half maximum (FWHM) of these BALs are approximately 1 nm in the restframe, corresponding to a velocity dispersion over 2000 km/s.

3. Modeling

The outflowing velocity and velocity dispersion coincide with those of a stellar remnant tidally disrupted by a central massive black hole. It has been suggested that tidal disruptions may be responsible for quasar broad emission lines (Shields 1989; Roos 1992). A main sequence star, after being tidally disrupted by a $10^8 M_\odot$ black hole in the center of a quasar,
will be ejected at a high velocity. The head of the tidal debris will reach a distance of about $10^{17}$ cm in about 3 years, and the residual velocity will be 6000 km/s at this distance (Roos 1992). The thickness of the tidal debris is stretched at a velocity of $\sim$1000 km/s, and the density drops to $\sim 10^9$ cm$^{-3}$ at this point. The column density of the dense tidal stream is on the order of $10^{24}$ cm$^{-2}$ and is too dense to be responsible for the apparently un-saturated broad absorption lines in TEX 1726+344. However, as suggested by Ma (2000), the dense tidal stream is accompanied by faster-moving winds blown off of it due to radiation pressure. Both the density and the column density of the wind are two orders of magnitude smaller than those of the dense tidal stream.

A model of this piece of gas cloud with a density of $10^7$ cm$^{-3}$ and a column density of $10^{22}$ cm$^{-2}$, at a distance of $10^{17}$ cm to a central continuum source with a luminosity of $10^{39}$ W, can thus be studied. We have run a photoionization calculation using CLOUDY (Ferland 1996), and found that the ratio of CIV to total carbon is $6.3 \times 10^{-5}$. Assuming a solar abundance with C:H= $3.55 \times 10^{-4}$ (Grevesse & Anders 1989), we find that the column density of CIV of this piece of gas cloud is $2.2 \times 10^{14}$ cm$^{-2}$. This value coincides well with that derived from the equivalent width of the CIV broad absorption line.

Column densities for the CIV and SiIV absorbing ions can be estimated by (Wang et al. 1999)
\[
N = \frac{W_\lambda m_e c^2}{\lambda \pi e^2 g f},
\]
where $W_\lambda$ and $\lambda$ are the equivalent width and the wavelength, and $g$ and $f$ are the effective statistical weight and oscillator strength of the corresponding absorption lines, respectively. Following Wang et al. (1999) and taking the $g$ and $f$ values from Korista et al. (1991), we get the column density of CIV and SiIV to be $2.4 \times 10^{14}$ and $7.3 \times 10^{13}$ cm$^{-2}$, respectively.

4. Discussions

We note that absorption line variations with large magnitudes have been observed in the low-redshift radio-quiet quasar PG 1126−041 (Wang et al. 1999). Numerous studies on the absorption line variability of Seyfert galaxies also exist in the literature (Malizia et al. 1997; Risaliti, Elvis & Nicastro 2002; Akylas et al. 2002), and have been modeled with a single cloud moving through the line of sight (Akylas et al. 2002). Hamann, Barlow & Junkkarinen (1997) have identified variable intrinsic absorption lines (FWHM$\sim$400 km/s) in a radio-quiet quasar Q2343+125. BAL variability at a moderate level ($<40\%$) has been found in several radio-quiet quasars (Barlow 1993). In contrast to these previous studies,
TEX 1726+344, a high luminosity radio-loud quasar developing BALs in a time interval of 12 years, represents a new phenomenon.

The popular disk-wind model (Murray et al. 1995) for both broad emission and absorption lines has been challenged by Ma & Wills (2001) because some radio-loud quasars were discovered to have dramatic CIV emission line variability, speculated to be due to the illumination of the jet pointing to the polar region of the quasar. The tidally disrupted stars model now seems to be the best candidate. The broad absorption lines in TEX 1726+344 will disappear in just a few years, if they were indeed caused by a tidal disruption event.

The author wishes to thank Bev Wills for advice; Peter Barthel for making his data available in digital form; Gary Ferland for making his code CLOUDY available; and Angela Sinclair and Ariane Beck for help with the manuscript. This work makes uses of the NASA/IPAC Extragalactic Database (NED).

REFERENCES

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Fig. 1.— Comparison of observed spectra at two epochs. The continua at different epochs have been scaled to the same level. The solid line represents the new spectrum taken in 2000. The dotted line is the historical spectrum taken in 1988. The inset gives expanded spectra in the CIV region. The subtraction spectrum is plotted in the same panel. In the lower panel the direct division spectrum and the fitting curve are plotted together.