THE POLARIZED SPECTRUM OF THE Fe II–RICH BROAD ABSORPTION LINE QSO IRAS 07598+6508

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ABSTRACT

We present IUE spectrophotometry and optical spectropolarimetry of the ultraluminous, extreme Fe II–emitting QSO IRAS 07598+6508. We find broad absorption troughs from high- and low-ionization species, showing that this object is a member of the class of rare low-ionization broad absorption line (BAL) QSOs. Compared with non-BAL QSOs, the spectral energy distribution is reddened by $E(B - V) \sim 0.12$, and the Hα/Hβ ratio is even more reddened with $E(B - V) \sim 0.45$. The broad emission lines are unpolarized. We see broad Na I λ5892 absorption in the unpolarized continuum, but not in the polarized continuum (at the 5–6 $\sigma$ level). The polarized continuum rises smoothly toward shorter wavelengths with $F_\lambda \propto \lambda^{-2}$. We argue that a normal QSO continuum is polarized by scattering from a region within, or very near, the broad emission line region (BELR). Thus there are at least three distinct light paths to the observer: a dusty path from the BELR; a direct path traced by the unpolarized continuum, passing through dust and low-ionization gas (Na I); and another relatively unobscured path followed by scattered continuum. This provides direct evidence that a BAL region and dust only partially cover the central QSO.

Ultraluminous active galactic nuclei, including IRAS 07598+6508, appear no more IR-luminous than non–IRAS-selected QSOs, and have normal $L_{6508}/L_{bol}$ ratios when the optical luminosities are corrected for reddening. BALs and reddening occur only along some sight lines, and the parent population of BAL QSOs appear to be “normal” QSOs.

Subject headings: quasars: absorption lines — quasars: emission lines — quasars: general — quasars: individual (IRAS 07598+6508) — polarization

1. INTRODUCTION

There are some very clear observational relationships among various properties of luminous active galactic nuclei (AGNs) that are important to investigate, because they bear on the interrelated themes of unification by orientation, by covering factors and amounts of cool and low-ionization material, and by the power of radio jets. The strongest relationships are the inverse correlation between optical Fe II and [O III] λ5007 strength (Boroson & Green 1992; Boroson & Meyers 1992), and the extremely strong Fe II (optical) emission and strong broad absorption lines (BALs) found only among radio-quiet QSOs (Stocke et al. 1992; Lipari, Terlevich, & Macchetto 1993).

Among radio-loud quasars, orientation unification supposes that lobe-dominant quasars represent objects whose central engine axis is highly inclined. Core-dominated blazars represent the low-inclination extreme. In the Fanaroff-Riley II (FR II) radio galaxies, the jet axes are closest to the sky plane, and the QSO is buried within a dusty torus whose axis is aligned with the central engine’s. In lobe-dominated sources, nonsynchrotron, optical polarization is often found aligned either parallel or perpendicular to the jets. In some well-studied cases this is attributed to central QSO emission scattered into the line of sight, and in some cases the scattering region is resolved: in continuum images it is seen aligned with the radio jets (di Serego Alighieri, Cimatti, & Fosbury 1993). The more lobe-dominated sources have weaker [O III] λ5007 emission—attributed to shadowing of the higher ionization narrow-line region (NLR) by a dusty torus aligned with the jet (Hes, Barthel, & Fosbury 1993). At least in some cases the continua and emission lines of lobe-dominated sources appear reddened. Also, associated absorption may be more common in lobe-dominated quasars (Wills et al. 1995; Aldcroft, Elvis, & Bechtold 1995).

Among radio-quiet QSOs, the following appear to be related: low-ionization BALs, superstrong Fe II emission, extremely weak [O III] λ5007 emission, reddened spectral energy distributions, and nonblazar linear polarization. Despite the above relations, the ultraviolet emission-line spectra of non-BAL and BAL QSOs are, overall, very similar, and so it was suggested that BAL differences might arise simply as a result of different viewing angles (Weymann et al. 1991; Hartig & Baldwin 1986); a disk geometry for the BAL region (BALR) was proposed (Turnshek 1988). Could some of the above similarities between lobe-dominated quasars and BAL QSOs be attributed to the same axisymmetric model for the inner few parsecs?

The discovery by Wills et al. (1992) of high, wavelength-dependent polarization in the first IRAS-discovered QSO, IRAS 13349+2438, led them directly to the now standard explanation: the observed spectrum is the combination of QSO light reddened by passage through a dusty torus, and less-reddened polarized light scattered from within the opening of the torus. At the time, BAL QSOs were the only QSOs showing significant nonblazar polarization (Stockman, Moore, & Angel 1984). Wills et al. (1992) therefore predicted that significant polarization and BALs might be found in other IRAS-selected QSOs, their model for IRAS 13348+2438 naturally leading to the idea that normal QSOs could appear as non-BAL or BAL QSOs depending on the viewing angle. Our subsequent polarization survey of the Low et al. (1988) sample of IRAS-selected QSOs, to investigate unification...
schemes and the role of dust, led to the discovery of significant polarization in most of the sample, including IRAS 07598+6508 (Wills & Hines 1995, see also Hines & Wills 1993). Our IUE spectrophotometry of IRAS 07598+6508 (Fig. 1) revealed the predicted BALs.

In this Letter we present spectroscopy and spectropolarimetry of IRAS 07598+6508 and use these results to constrain an anisotropic geometry for the scattering and absorbing regions. IRAS 07598+6508 is the only QSO we know of that embodies all the above radio-quiet characteristics in an extreme way, and our new results show how this QSO may provide an important link between apparently different observational classes of QSOs.

2. RESULTS

We used the International Ultraviolet Explorer (IUE) to obtain two SWP and two LWP spectra, taking particular care in centering in the 20° aperture to obtain reliable wavelength calibration and spectrophotometry. Reduction was by NEW-SIPS with optimal extraction techniques, using the duplicate observations to remove cosmic-ray “hits” and improve the signal-to-noise ratio. The same data have been discussed by Lipari (1994). The ground-based data were obtained and reduced as described by Hines & Wills (1993).

Figure 1 presents the UV-optical spectrophotometry of IRAS 07598+6508. Note the rich Fe II spectrum originally found by Lawrence et al. (1988) and the absence of significant NLR emission. (The optical spectrum has been discussed by Boroson & Meyers 1992, who were the first to recognize the broad Na i λ5892 absorption trough in their higher resolution spectrum; Lipari 1994). The low-ionization BALs are among the strongest known, with EW(Mg II λ2798) = 62 Å, but show trends seen in other low-ionization BAL QSOs (Voit et al. 1993). Using the peak of the broad Hα emission line to define the rest frame, the BAL troughs extend between blueshifts of 5200 and 22,000 km s⁻¹, as shown by the horizontal lines on the figure. As in other BAL QSOs, the peaks of the high-ionization UV lines are blueshifted with respect to Hα, but in IRAS 07598+6508 this shift is especially large: 3000 km s⁻¹ relative to the Balmer line and Na i λ5892 emission peaks. The Hα/Hβ intensity ratio of 6.2 ± 0.8, when compared with typical values for UV-selected QSOs (3.3; Thompson 1992), indicates broad emission line reddening, E(B − V) = 0.45. As in other low-ionization BAL QSOs, the Balmer line EWs are low, with EW(Hα) ~ 275 Å. The spectral energy distribution is less reddened and matches that of a typical QSO, if a Small Magellanic Cloud reddening curve is adopted with E(B − V) = 0.12; this value is typical for the UV spectra of other low-ionization BAL QSOs (Sprayberry & Foltz 1992).

The spectropolarimetry results are shown in Figure 2. The percentage polarization (represented by a Stokes parameter rotated to the wavelength-independent position angle of 116° shown in the bottom panel) decreases in regions of line emission and increases to about 3.5% in the region of the Na i λ5892 BAL. The third panel shows the corresponding polarized flux density spectrum. This is well fitted by F_p ∝ λ^-2, showing no significant features, even in the region of the Na i
BAL. Blended Fe II emission contributes increasingly at the shorter wavelengths, resulting in the decline of percentage polarizations shortward of 4500 Å. The polarization in the broad emission lines was derived by subtracting a smoothed continuum from each Stokes flux density spectrum ($Q_l$ and $U_l$), using the regions of minimum line contribution, to yield $Q_l$ and $U_l$ for the emission lines alone. By integrating $Q_l$ and $U_l$ over the emission lines and dividing by the observed total line intensities, we derive an emission-line polarization of $0.16\% H_0.04\%$ and position angle $u_5^150^8$. This is less than the maximum expected 0.5% Galactic interstellar polarization.

In order to investigate the continuum polarization, we have subtracted the Fe II blends and other broad emission lines, using the method and I Zw 1 template of Boroson & Green (1992) (for $\lambda > 4300$ Å; Fig. 3, upper panel). The lower panel of Figure 3 shows the polarization spectrum after subtracting the unpolarized emission lines. Between 6800 and 4300 Å the polarization rises from 2% to 3%, except in the region of the Na I BAL where it rises to 3.5% ± 0.3%. This peak is entirely accounted for by absorption in the unpolarized continuum. Such absorption is absent from the polarized flux density spectrum at a significance level of 5–6 $\sigma$. The maximum intrinsic polarization of the polarized continuum must be at least 3.5% ± 0.3%.

3. THE GEOMETRY AND POLARIZATION MECHANISM

The spectropolarimetry shows that there are at least three spectral components: (i) light from the broad emission line region (BELR) that is unpolarized and reddened with $E(B - V) \sim 0.45$; (ii) unpolarized continuum that passes through a low-ionization BALR, and also suffers significant reddening, $E(B - V) > 0.12$; and (iii) polarized continuum that is much less reddened than component (ii) and does not pass through significant Na I BAL material. We adapt a standard QSO geometry in which the BELR lies at $\sim0.1$–1 pc from, and partially covers, a central continuum source.

The simplest explanation for the polarized continuum would be synchrotron emission, e.g., from the inner regions of a stable jet (our broadband polarization observations over 3 years show no signs of variability). However, the observed rise of the polarized flux density spectrum toward shorter wavelengths has never been seen in spectra attributed to synchrotron radiation. Also, it would be barely possible to explain the strength of the optical polarized flux density given IRAS 07598+6508’s weak 11.7 mJy radio source (Neff & Hutchings 1992) and the flattest observed radio-optical synchrotron spectrum (as in X-ray–selected BL Lac samples).

If dichroic transmission were the explanation, aligned grains would have to be within BELR distances of the nucleus or between BELR clouds so that line radiation would not pass through aligned grains. The grain properties would be totally unlike those in our Galaxy, with polarization increasing into the UV ($p > 4\%$).

Thus, we prefer a scattering explanation, and a possible geometry for the two continuum light paths is shown in Figure 4. Note that scattering close to an accretion disk is excluded because we must account for unscattered continuum that passes through the BALR. Any scattered line emission would tend to be unpolarized because of the almost symmetric BELR scattering geometry and dilution by direct line emission. Figure 1 shows a plausible decomposition of the observed continuum into a scattered component and a direct reddened component, corresponding to paths “a” and “b” in Figure 4. With a wavelength-independent polarization of 5% for the scattered component and a reddening for light path “b” equal to the Balmer line reddening, we can account for the observed wavelength dependence of polarization and the total spectral energy distribution.
4. DISCUSSION

Regardless of the details of the “model” (Fig. 4), different light paths exist, and some continuum escapes without passing through the dust and Na I BALR. Thus IRAS 07598+6508 may be a non-BAL QSO when viewed from some directions. Observational characteristics such as polarization, reddening, extinction, and obscuration are expected to be aspect-dependent as well. In FR II narrow-line radio galaxies, where it has been suggested that an obscuring torus is observed close to edge-on, Hes et al. (1993) suggest that [O III] λ5007 may be partially hidden. If this is the entire explanation for the weakness of [O III] in BAL QSOs, then the strong Fe II emission is dependent on viewing angle, even more so than other broad emission lines.

It might be expected that QSOs selected by \( IRAS \) flux density would be biased toward those with especially high \( L_{IR} \), so that the existence of reddening and BALs among the \( IRAS \) QSOs could be attributed to larger covering by dust and low-ionization gas rather than to orientation. This does not seem to be the case. If we correct the ratio of infrared to optical luminosity for reddening (Hines & Wills 1995), we find that the \( IRAS \)-discovered QSOs, including IRAS 07598+6508, are indistinguishable from the Palomar-Green (PG) QSOs in an \( L_{IR}/L_{opt} \) versus \( L_{bol} \) diagram (Fig. 2 in Low et al. 1989; Fig. 4 in Cutri et al. 1994). The \( IRAS \)-discovered QSOs were not known previously, almost certainly because their UV-optical spectra are too red to be selected by UV excess (Hines & Wills 1995; Wills et al. 1992). The similarity in \( L_{IR} \), combined with the fact that the dereddened continuum and Balmer line ratios and the scattered spectra resemble those of typical PG QSOs, strongly supports the suggestion that all QSOs harbor a BALR, but some are viewed from a direction that intercepts the BAL clouds.

We have no information concerning any fundamental axis in IRAS 07598+6508, although faint optical extensions have been observed, suggesting tidal interaction (D. B. Sanders 1992, private communication). The strongest support that we can muster for an axisymmetric model is by analogy with the ionization and scattering cones and jet directions observed for some lower luminosity polarized AGNs. IRAS 07598+6508 has been selected by its 60 \( \mu \)m flux density and “warm” \( IRAS \) colors in a way similar to other polarized \( IRAS \) QSOs, and at least in the case of IRAS 13348+2408, where a similar scattering model has been proposed, the polarization position angle is aligned with the host galaxy’s major axis.

An important difference between IRAS 07598+6508 and other polarized AGNs is the lack of significant polarization of the emission lines. Glenn, Schmidt, & Foltz (1994) find the same for the BAL QSO CSO 755 (see also PHL 5200; Stockman, Angel, & Hier 1981; Goodrich & Miller 1995; Cohen et al. 1995). (Note that neither of these objects was selected by a bright, UV excess continuum.) Perhaps this difference could be attributed to orientation by means of angular dependence of optical depth and the grain scattering function. Antonucci (1988) reports this phenomenon in three low-polarization nonblazar radio-loud quasars, suggesting that the “model” for IRAS 07598+6508 may be applicable to radio-loud quasars.

If the polarized continuum in IRAS 07598+6508 does arise from scattering, the scattering region is within or near the BELR, suggesting that photoionization models for the BELR should take into account these scattered continuum photons either within the BELR or by external illumination (Kallman & Krolik 1986).

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