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Evidence for Radiative Acceleration in Quasars

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Abstract. I give an overview of a promising signature for radiative acceleration in quasars "the ghost of Lyα," which is seen in the spectra of a few broad absorption line (BAL) QSOs. The ghost appears as an absorption hump in the C IV λ1549 BAL and is centered around 5,900 km s^{-1} to the blue of the corresponding broad emission line (BEL). This velocity separation is the same as the velocity separation between the N V λ1240 and Lyα lines. Thus, when the N V BAL and the C IV BAL are plotted as a function of velocity (where zero velocity corresponds to the peaks of these BELs), the hump in the C IV BAL appears at the same velocity as the Lyα BEL and qualitatively resembles it. The best examples and model fits are shown and the radiative dynamics explained.

1. Overview

Soon after the discovery of QSOs, it was noticed that a subset of these objects shows wide absorption troughs associated with prominent resonance lines such as C IV λ1549, Si IV λ1397, N V λ1240, and Lyα λ1215 (Lynds 1967; Burbidge 1970). These troughs are known as broad absorption lines (BALs) and are commonly attributed to a "spray" of absorbing cloudlets flowing toward the observer with velocities of up to $\sim 0.1c$, as evident by the width of the absorption (Weymann, Turnshek, & Christiansen 1985). Foltz et al. (1990) have shown that about 10% of all QSOs are BALQSOs and, combined with the assertion that the flow covers $\lesssim 0.2$ of the sky as viewed from the nucleus of the QSO (Hamann, Korista, & Morris 1993), it is plausible that all QSOs have BAL flows.

The nature of the acceleration mechanism for these flows is a fundamental question in BALQSO research. Considerable effort has been devoted in the last few years to developing theoretical models of radiative acceleration of the flows. Radiative acceleration via resonance line scattering of cloudlets embedded within a confining medium was investigated in Arav & Li (1994) and in Arav, Li, & Begelman (1994). Winds accelerated by radiation absorbed by dust (Scoville & Norman 1995), continuous winds accelerated by resonance line scattering (Murray et al. 1995), and radiation driven magnetic disk winds (de Kool & Begelman 1995) have also been explored.

A possible signature for the acceleration mechanism, the so-called double trough phenomenon, was observed by Weymann et al. (1991) and extensively studied by Korista et al. (1993). We developed a dynamical model (Arav & Begelman 1994; hereafter paper III) to explain the creation of such a signature.

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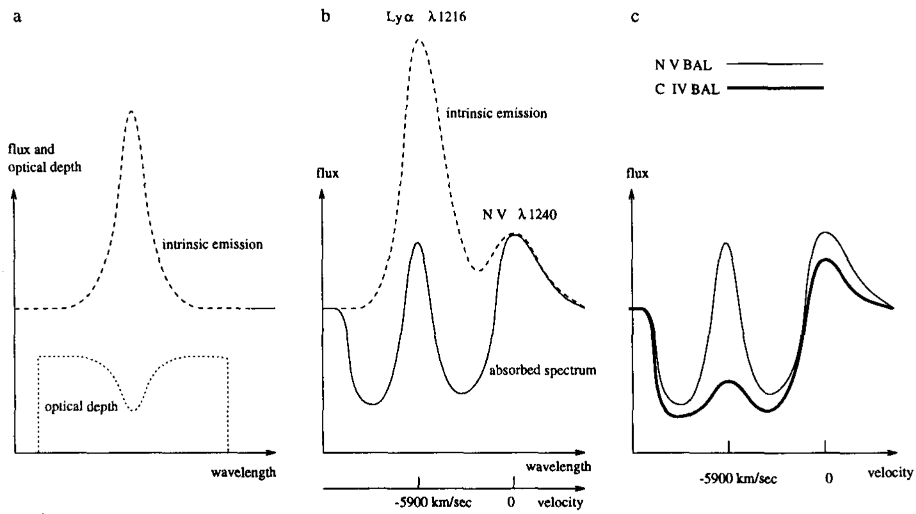

Figure 1. Schematic illustration for the creation of the ghost of Lyα signature. For a constant νL_ν (where ν is frequency and L_ν is the luminosity per unit frequency), pure radiative acceleration creates an absorption trough with a constant optical depth. When the accelerating ions sample an increasing flux, their acceleration, relative to the constant νL_ν case, increases, and as a result the optical depth of the wind decreases. In panel *a* we show the optical depth changes that result from the exposure of the accelerating ions to a strong emission line. A very similar situation is found in quasars, panel *b* shows the spectral regime around a quasar's strongest emission line, Lyα. The N V ions are exposed to the strong Lyα flux and in their rest frame the peak of Lyα occurs at a velocity of $-5{,}900$ km s^{-1}. Since we do not know the intrinsic Lyα emission spectrum it is impossible to determine from the absorbed spectrum whether the optical depth has changed at the appropriate velocity interval. However, the N V ions share their acceleration with the rest of the flow through Coulomb collisions or the presence of magnetic fields, and thus gives the optical depth modulation to all the absorbing ions. Therefore, as we show in panel *c* the C IV λ1549 BAL should show a lower optical depth around $-5{,}900$ km s^{-1} although there is no emission feature at the corresponding wavelength (1520 Å) in the quasar's rest frame. This hump in absorption around $-5{,}900$ km s^{-1} in the C IV BAL is what we termed "the ghost of Lyα."

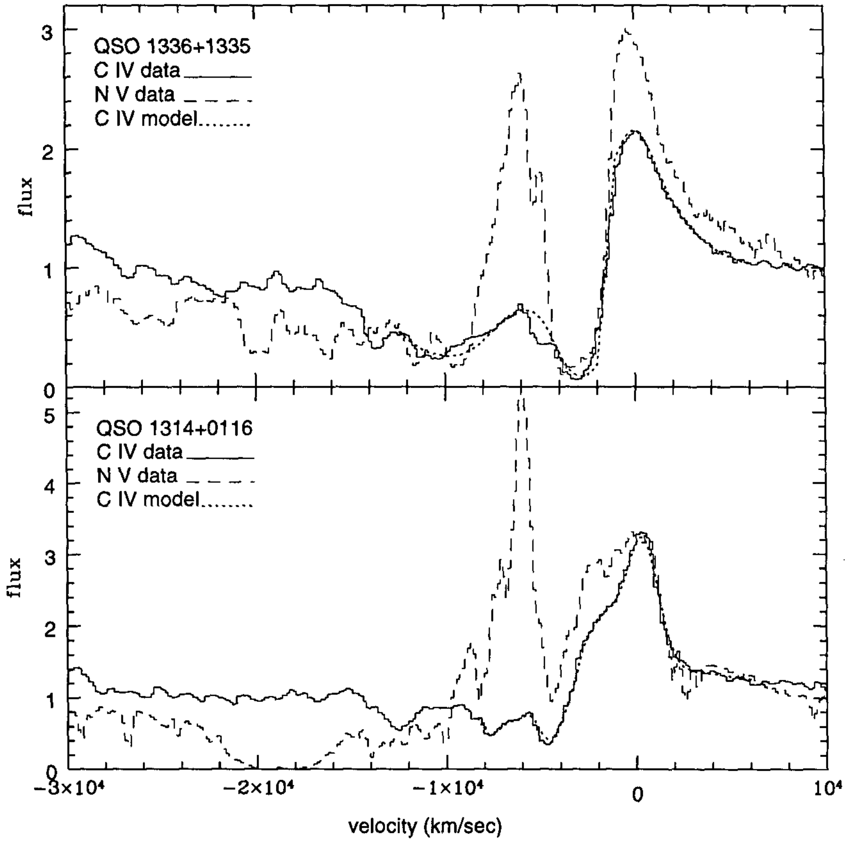

Figure 2. The two best examples for the ghost of Lyα phenomenon. Data are plotted as flux vs. velocity relative to the quasar rest frame. The solid histogram shows the data for the C IV region where zero velocity corresponds to 1549 Å. The dashed histogram shows the N V–Lyα data where zero velocity corresponds to the rest wavelength of the N V line (1240 Å). The dotted lines show the model fits across the extent of the dynamical signature. Absorption structures at higher velocities are unrelated to the ghost signature and might be explained by other means (see Arav 1996, Fig. 3).

After acquiring the Korista et al. (1993) data, we identified what appears to be a clear signature of radiative acceleration — "the ghost of Lyα" (Arav et al. 1995, hereafter paper IV) — which is related to the double trough phenomenon. The full details of the dynamical model and of each observed signature is given in Arav (1996, hereafter paper V). In figure 1 we illustrate (and give a brief explanation for) the dynamical scenario that creates the ghost signature and sketch its expected appearance based on our results from papers III and V. Figure 2 shows the data and model fits for the best cases of a ghost signature we have identified so far. In papers IV and V we 1) presented model fits for "ghosts" in individual objects, 2) demonstrated the ability of our dynamical selection criteria to predict which object would show the signature, and 3) estimated that the probability for chance occurrence of the ghosts is $\lesssim 10^{-3}$. Each of these three lines of reasoning gives independent support for our dynamical scenario, and combined they make the strongest case yet for the nature of the acceleration mechanism of BALQSO flows: radiative acceleration via resonance line scattering.

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References

Arav, N., & Li, Z. Y. 1994, ApJ, 427, 700

Arav, N., Li, Z. Y., & Begelman, M. C. 1994, ApJ, 432, 62

Arav, N., & Begelman, M. C. 1994, ApJ, 434, 479 (paper III)

Arav, N., Korista, T. K., Barlow, T. A., & Begelman, M. C. 1995, Nature, 376, 576 (paper IV)

Arav, N. 1996, ApJ, 465, 717 (paper V)

Burbidge, E. M. 1970, ApJ, 160, L33

de Kool, M., & Begelman, M. C. 1995, ApJ, 455, 488

Foltz, C. B., Chafee, F. H., Hewett, P. C., Weymann, R. J., & Morris, S. L. 1990, BAAS, 2, 806

Hamann, F., Korista, T. K., & Morris, S. L. 1993, ApJ, 415, 541

Korista, T. K., Voit, G. M., Morris, S. L., & Weymann, R. J. 1993, ApJS, 88, 357

Lynds, C. R. 1967, ApJ, 147, 396

Murray, N., Chiang, J., Grossman, S., & Voit, G. M. 1995, ApJ, 451, 498

Scoville, N., & Norman, C. 1995, ApJ, 451, 510

Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23

Weymann, R. J., Turnshek, D. A., & Christiansen, W. A. 1985, in Astrophysics of Active Galaxies and Quasi-stellar Objects, ed. J. Miller (Oxford: Oxford Univ. Press), 333

Discussion

G. Schmidt: Assuming that the BAL clouds are radiatively accelerated as you describe, can you place a constraint on their location relative to the source of driving flux?

N. Arav: Yes, radiative acceleration operating on material with solar metalicity will not be capable to accelerate the observed flow beyond a few parsecs. Therefore the BAL region is constrained to be between the broad emission line region (0.1 parsec) to about a few parsecs.

R. Sutherland: Does your model use only single scattering for momentum transfer or is multiple scattering used/needed?

N. Arav: Only single scattering is used since it is a very good approximation for the actual situation. The reason for that is that adjacent to the BALs there is no absorption so one scattering is enough to move the photon to a frequency in which there is no absorption.

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