THEORETICAL MODELS TO EXPLAIN THE VARIABLE 21 cm ABSORPTION SPECTRUM IN AO 0235+164

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The variability of the highly redshifted 21 cm absorption spectrum in AO 0235+164 presents us with two essential facts. First, rapid changes occur in the line depths of foreground clouds with redshift $z \simeq 0.524$. Second, the background radio source is among the most violently variable objects known. Thus it is reasonable to suppose that changes in the lines stem from activity in the background BL Lac object. The question is how?

We (F. H. Briggs, M. M. Davis, and I) have considered two alternatives. The intrinsic scenario assumes that activity in 0235 somehow alters the 21 cm opacity of absorbing HI within its neighborhood. Since the redshift of 0235 is $z>0.85$, we are confronted with the task of explaining how objects with redshifts differing by $\Delta Z \approx 0.3$ can by physically associated. In the extrinsic scenario we assume that activity in 0235 results in time-dependent changes of the brightness centroid of the 932 MHz radio source. When viewed through a non-uniform distribution of absorbing clouds the shifting light path brings about changes in line depth, without changes in opacity. In this case we assume that 0235 is cosmologically distant from the foreground HI.

Before comparing the data with the predictions of either model it is useful to reiterate some model-independent facts. First, the absence of significant variations of the 932 MHz continuum, VLB studies at 2.7 GHz (Cotton 1981), and synchrotron self-Compton considerations suggest that the background source contains a non-variable component with diameter $\theta_S \simeq 2.5$ to 3.0mas. Second, the shift in brightness centroid discussed in the previous talk is plausibly explained by relativistic bulk motion of a compact "knot" component. If the knot moves with the same type of rectilinear motion detected in known superluminal sources (Cohen and Unwin 1982), it must propagate through an angular displacement $\delta\theta > 2$mas in the 3.25y between previous VLB observations. Third, the appearance of the phase-shift spectrum implies that each absorption line forms in a multi-cloud configuration in which the diameter of each cloud $\theta_{CLOUD} < 0.3\theta_S$. As a result the

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source illuminates 4 or more multi-cloud regions having diameters of $\sim$ 25 pc.

In the extrinsic model, variations in line depth result from the projected motion of the knot across cloud boundaries. To estimate variations expected in observable quantities we have constructed a Monte Carlo model in which cloud parameters such as location, individual velocity, optical depth, and internal velocity dispersion are selected with a random-number generator. Single-dish and VLB spectra are calculated for a sequence of parameters until agreement with the initial (i.e., before 1978 August) spectra is obtained. We then displace the knot through its own diameter in a series of radial excursions to the boundary of the non-variable source. Each displacement results in variations in line depth and in the velocity centroids of the line profiles. We find that models adjusted to simulate the large changes in the line depth of feature D (see previous paper) also predict that the velocity centroid of this feature varies by more than 0.75 kms^{-1}, the 3-σ upper limit, in 2 out of 10 diameter displacements. In the 4.25y monitoring period there would have been $\simeq$ 10 such displacements, and so this model predicts at least two shifts in velocity centroid that are larger than observed. For this reason, we are currently investigating modifications in which the knot undergoes non-linear motions behind a single cloud of each configuration. In this case changes in line depth would be due to gradients in optical depth.

In the intrinsic scenario, we place 0235 within $\sim$15 kpc of the absorbing HI. We have not considered in any detail how this physical association came about, although ejection of 0235 from the nucleus of the galaxy containing the HI is a possibility. In any case the 21 cm continuum radiation will be so intense at the HI that radiative excitations will compete with collisions in determining the hyperfine level populations of the hydrogen 1s state. Variations of the continuum will then alter the level populations with a consequent variation in 21 cm optical depth. We have investigated these effects by solving the coupled, time-dependent transfer and population rate equations for a wide range of separation distances d, gas densities n, and fractional increases in continuum strength x. In order to reproduce the variations observed in the line depths of the 4 deepest features without introducing outbursts stronger than $x \approx 0.8$ we had to restrict d between 2.5 and 5.0 kpc, and n between 100 and 400 cm^{-3}. The resulting "light curves" for the line depths explain the synchronous behavior observed in these features between 1980 August and October quite naturally. Moreover, the absence of detectable fluctuations in velocity centroid is a natural consequence of this model. But, the lack of a continuum increase during those epochs when the line depth of feature D had decreased substantially is difficult to understand. With the increased sampling frequency of the current monitoring program we will be able to rule out this model if future decreases in line depth are not preceded by continuum outbursts.

In summary, comparison of the model predictions with the data leads to the following conclusions: 1) The lack of significant fluctuations in the velocity centroids of the line profiles indicates that the "knot" source has not propagated across the expected angular displacement, $\delta\theta > 2$mas. Rather, the motion of the knot is limited behind a single cloud of each of 4 configurations. The question for the extrinsic model is whether motions in which $\delta\theta \ll 2$mas can result in the changes observed in line depth and in VLB phase-shift.
2) An important distinction between the extrinsic and intrinsic models is that in the extrinsic case, changes in VLB phase-shift will probably be accompanied by changes in line depth, while in the intrinsic case no such correlations are expected.

References

Cohen, M H. and S. C. Unwin, 1982, this volume, p. 345.
Cotton, W., 1981, private communication.