THE ORIGIN OF ABSORPTION SPECTRA IN QUASI-STELLAR OBJECTS

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ABSTRACT

A classification scheme for QSO absorption line spectra is described which ascribes the origin of the lines to at least four mechanisms: (A) Explosive ejection of material at speeds up to 0.1 c. (B) Absorption by highly ionized material moving in a rich cluster in which the QSO is embedded. (C-1) Cosmologically distant intervening material with 'normal' abundances, probably associated with large galactic halos. (C-2) Cosmologically distant intervening material consisting of primordial uncondensed gas. Examples of each type of spectra are given and their ionization and other spectral characteristics discussed. The similarity between the development of novae spectra and a possible evolutionary sequence of the explosive ejecta of type A is striking and suggestive. Several difficulties and unsolved problems involving this scheme are noted. Finally, we speculate on the interpretation of two interesting objects (PKS 0237-23 and the 'twin quasars' 0957+56A,B) in the context of this scheme.

1. INTRODUCTION

Several years ago, Bahcall (1971) proposed a two-component classification scheme for absorption spectra in Quasi-Stellar Objects. On the basis of more recent work, briefly summarized below, it now seems possible to recognize at least four distinct origins for QSO absorption lines. Although a reasonable case can be made for such a scheme, we shall spend more time discussing the various weaknesses and unsolved problems this scheme presents than we shall justifying it.

2. BRIEF DESCRIPTION OF QSO ABSORPTION LINE CLASSIFICATION SCHEME

The scheme (modified slightly from the discussion of Weymann et. al. 1979, hereafter WWPT) is summarized in Table 1.

G.O. Abell and P. J. E. Peebles (eds.), Objects of High Redshift, 107–117.

TABLE 1

QSO ABSORPTION LINE SYSTEM CLASSIFICATION

TYPE	EXAMPLES	IONIZATION AND OTHER CHARACTERISTICS	CLOUDS ON HORIZON AND MAIN UNSOLVED PROBLEMS
A EXPLOSIVE EJECTION	PHL 5200 MCS 275 1303+308	High to Very High N V often >> Ly α Not ≡ Emission Line Region; Outside ELR	1. Why hardly ever strong radio source? 2. Total energetics? Total mass? 3. Ejection mechanism? 4. Evolutionary Sequence? 5. Is 0237-23 a member?
B INTRINSIC B-1 Intrinsic Galaxy	3C191	Broad Range Si II F.S. Present	1. No evidence this class exists! 2. Acceleration of disc material?
B-2 Intrinsic Cluster	0736-06 PKS 0119-04	High; Mg II << C IV NV often present	1. Velocity Dispersion ≃ rich cluster, but no low z QSOs in rich clusters. 2. Some examples of extreme velocity? 3. Parameters consistent with class C-1?
C INTERVENING C-1 Metal Enriched	Q1101-264 PHL 938	Moderate, but definitely higher than disk. CII F.S. usually, but not always << less than disk of our galaxy	1. OVV/Mg II absorption correlation? 2. Meaning of occasional F.S. lines? Disk of a galaxy? 3. Why galaxy → absorption but not absorption → galaxy so far?
C-2 Primordial	All high z QSOs shortward of Ly α	Unknown	1. Why lack of clustering? 2. Clear evidence of extreme metal deficiency? 3. Behavior at small z? 4. Helium abundance? (need knowledge of ionization).

The prototype of the first class, type A, PHL5200, was first discovered by Lynds (1967) during the early phase of spectroscopic studies of QSOs and for many years was considered to be almost unique. However it now appears that type A objects are fairly common and may comprise up to 10% of the optically selected QSOs with redshifts greater than about 1.6. The type is characterized by very broad absorption troughs with inferred ejection velocities up to 0.1 c. Although there is no direct proof that they in fact involve ejected material (it has been suggested that they could arise from intervening supernova remnants) the fact that (a) The absorption very frequently sets in just at the emission line redshift and (b) There are instances of multiple troughs well separated in velocity argues very strongly for ejection by the QSO. (See also discussion remarks by Wampler.) Two examples of this type of absorption are shown in Figure 1.

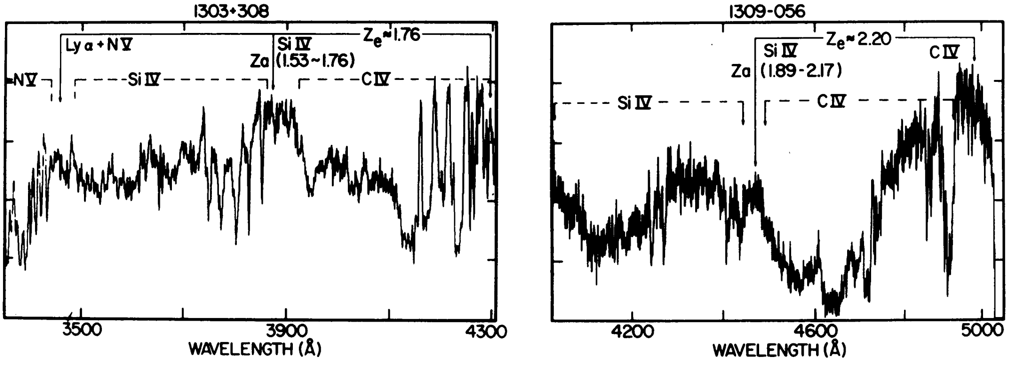

Fig. 1. Two broad-line QSOs in early (1309-056) and late (1303+308) stages of development. (1309 illustration courtesy Carswell and Smith)

When a histogram is made of the distribution of the (apparent) ejection velocities of the CIV doublet (Figure 1 of WWPT) one finds a pronounced maximum at zero velocity, but this peak extends to infalling material and has a characteristic dispersion of about 1000 km/sec. Such infalling material cannot be due to 'cosmologically distant' material, although it could be attributed to the gravitational potential of the QSO itself. However, arguments involving the CII fine structure line and applied to a single object (PHL1222, Williams and Weymann 1976) strongly suggest that the absorbing material is at a distance of several hundred kpc from the QSO. This scale and the velocity dispersion are characteristic of rich clusters of galaxies and this suggests that the zero velocity peak arises from gas moving within a rich cluster in which the QSO is itself moving.

https://doi.org/10.1017/S0074180900068406 Published online by Cambridge University Press

Very sharp absorption lines of the metals (especially CIV and MgII) in which the absorption redshift can be much less than the emission redshift are frequent in QSO spectra. In addition, shortward of Lyman α emission line in high redshift QSOs there are a large number of sharp absorption lines which are now recognized to be Lyman α. The prevailing opinion is that most of both these types of lines (class C-1 and C-2) are due to cosmologically distant intervening material, with the metal lines being associated with extended halos of galaxies. There are two lines of argument supporting this view. First, there has been direct detection of absorption lines in a QSO having the same redshift as a nearby galaxy, the best known example being 3C232, where 21 cm absorption was found by Haschick and Burke (1976) and the corresponding Ca II absorption lines subsequently found by Boksenberg and Sargent (1978). Second, there are indirect astrophysical arguments which place the absorbing material at such large distances from the QSO that the ejected masses and energies associated with the shell become exceedingly hard to explain. These arguments involve the failure to detect scattered Ly α radiation around certain QSOs (e.g. Sargent and Boroson 1979) together with the failure to detect the 1335 CII line arising from the fine structure level (e.g. Turnshek, Weymann and Williams 1979).

Until recently it has not been clear whether the large number of Ly α absorption lines shortward of the Ly α emission lines represented merely low column density counterparts to the metal line systems just described or in fact represented a different component of intervening material, perhaps uncondensed primordial gas. Sargent et. al. (1979) have now presented convincing evidence that the latter interpretation is correct. They find that the CIV lines and Ly α lines have different statistical properties, the former tending to clump in velocity space at a characteristic splitting of about 150 km/sec while the latter show no tendency to clump. These authors proceed to draw several important conclusions and inferences about the properties of these clouds and an inferred confining intergalactic medium.

3. PROBLEMS AND DIFFICULTIES

With this very brief outline of the proposed origins of various types of QSO absorption lines we now consider some of the major unsolved problems posed by this scheme.

3.1 Ejected Systems

Although we have described PHL5200 as the prototype of the ejection systems, in fact its very broad smooth troughs with relatively little structure differ significantly from those of other members of this class, some of which show more than one distinct trough, sometimes well separated from the emission line (MCS 275) while others show very complex and occasionally quite sharp components spread over several thousand km/sec (1303+308). All seem characterized by a very high level of ionization. In Turnshek et. al. (1979) it is speculated that this range in appearance represents an evolutionary sequence, with objects like PHL 5200 and 1309-056 representing a phase early in the ejection episode and objects like 1303+308 representing a much later phase when the ejecta have spread out and the column density has decreased. Then, only points in the profile where the material remains highly clumped in velocity space (or where such clumps develop due to instabilities) have high enough opacity to produce observable absorption. Very indirect support for this speculation is provided by the development of the absorption spectrum in some novae. This is illustrated in Figure 2 in a sequence of spectra of Nova Delphini obtained by Dr. L. Kuhi. One observes a stage in which there is more than one broad trough and the development of sharp components reminiscent of the sequence PHL 5200, MCS 275 and 1303+308.

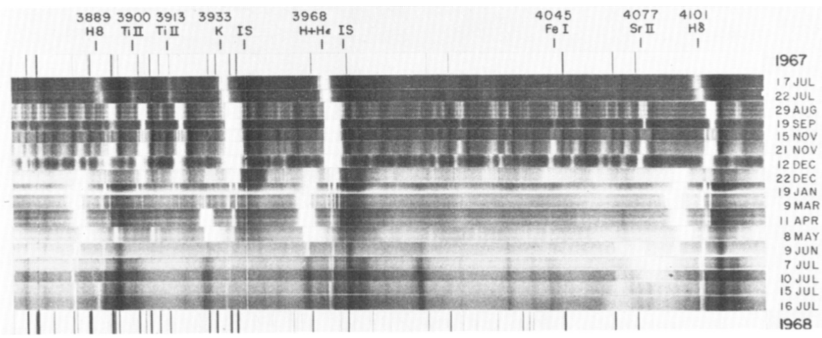

Fig. 2. Nova Delphini (Courtesy L. Kuhi).

The widespread belief that both pre-novae and QSO nuclei involve accretion discs adds interest to the analogy but before it can be seriously pursued some fundamental questions about these objects must be answered. What are the masses and energies involved in the ejecta? What is the duration of the ejection? What is the true incidence of this phenomonon among all QSOs? PHL 5200 has been observed for over a decade and no clear evidence for a change in the absorption structure has been observed. This suggests that a quasi-steady wind lasting $\gtrsim$ 10 years is involved or that the scale of the flow is larger than a few tenths of a parsec. Photoionization models generally require material in the emission line region to be at distances of 1 to 10 parsecs from the continuum source. The residual intensity and shape of the profiles in some of these objects, together with an apparent difference in the ionization level between the emitting and absorbing regions (e.g. the MgII/CIV ratio) seems to require that the absorbing material be separate from, outside of, and cover most of the emission line region. In a recently studied sample of QSOs (Turnshek et. al. 1979) discovered with objective prism techniques by the University of Michigan group (McAlpine and Lewis, 1978) 3 out of 15 objects were members of this class. Though this summer is very small and selection effects may be important it appears that the covering factor for absorbing material in this sample must be at least 0.1. These considerations suggest ejecta masses of 10 solar masses or more and energies of at least 10^{53} ergs. Some violent outbursts in QSOs (Eachus and Liller 1975) have released about this amount of energy in visible radiation. Photons, relativistic gas or hot thermal gas may all play an important role in the acceleration process.

An important clue to the nature of these outbursts is surely contained in the fact that with one or possibly two borderline exceptions these objects are not strong radio sources, but we have no idea which is cause and which is effect in this correlation. Perhaps strong radio sources establish a clean channel through which relativistic plasma and hot gas flows before radiative cooling occurs in the thermal gas. Perhaps geometrical orientation is crucial.

3.2 Intrinsic Intervening Systems

Many examples are known in which absorbing material is apparently falling in towards the QSO with speeds up to about 3000 km/sec. (Note that such infalling material is not confined to QSOs: NGC 1275 also shows the same phenomenon.) As mentioned previously, largely on the strength of the lack of the λ1335 CII line in a single object, PHL 1222, it has been argued (Weymann et. al. 1977; WWPT) that these systems arise in rich clusters where both the extremes in velocity differences and the mean dispersion in velocity are adequate to explain the phenomenon. However, as emphasized by Perry, Burbidge and Burbidge (1978), this model runs into the difficulty that QSOs of low enough redshift such that rich clusters in which the QSO is embedded could be detected avoid such clusters. Instead, such QSOs seem to be frequently associated with small groups having very much smaller velocity dispersions. (Stockton 1978; note that Stockton's data also seem to rule out both systematic and random differences between the measured emission redshift and the true redshift of the QSO large enough to avoid the difficulty.) Since the redshift required to detect such CIV systems (comparable Mg II lines are rarely seen) from the ground is at least 1.2, it is still conceivable that there are evolutionary effects giving rise to differences in rich cluster-QSO associations between low and high redshift QSOs. Observations with Space Telescope would settle this. If this alternative is eliminated we may have to explore the possibility that the presence of a QSO in a large volume of gas having the dispersion of rich clusters suppresses the formation of normal galaxies. If it is true that QSOs are frequently found in the nuclei of otherwise normal spiral galaxies, then we should occasionally see absorption lines (possibly shocked and mildly accelerated) arising from this gas. The high densities and moderate distances in 3C191 (Williams et. al. 1975) may be an example of such a situation. The small outflow velocity may be the result of a QSO wind as discussed recently by Dyson, Falle and Perry (1979).

3.3 Cosmologically Distant Intervening Material

The hypothesis that essentially all of the sharp, highly displaced metal lines are due to cosmologically distant material implies that associated with many galaxies are clouds with approximately solar abundances extending to many Holmberg radii. 'Effective cross sections' implying radii for halos of about 100 kpc for galaxies like our own are required, but this number depends upon assumptions concerning the Hubble constant, galaxy luminosity function normalization, and whether all classes of galaxies contribute to such absorption. Moreover, since the material is certainly patchy, the actual radii out to which absorbing clouds are found must be substantially larger than this. The clouds responsible for most of these displaced systems are not typical of those responsible for interstellar lines in the disc of our galaxy. In the QSO lines the ionization is in general higher than it is in the disc. Recent observations of stars in the Magellanic Clouds by Savage and deBoer (1979) in which the line of sight passes through our halo suggest there is a substantial column density of CIV well above the disc. Occasionally, however CII fine structure lines are apparently seen in highly displaced QSO absorption systems. Does this represent a chance passage of the line of sight through a galaxy disc? The fact that the absorbing material is usually associated with highly ionized gas may explain two recent results of Wolfe (1979). Wolfe found that observable 21 cm absorption was detected in only 1 of 16 QSOs showing FeII or MgII absorption and, that the results of a search for 21 cm emission were incompatible with the incidence of MgII absorption by halos of intervening galaxies unless the properties of the galaxies in the 21 cm survey were different from the hypothetical intervening ones or that the gas in the halos of the galaxies was more than 90% ionized.

In any event some basic problems concerning the generation and/or confinement of such metal-containing clouds at distances of at least 100 kpc from the galaxy nucleus remain to be understood.

At least one potential observational inconsistancy remains in this picture: The incidence of MgII absorption in optically violent variables (Miller 1979) and in some QSOs which are compact radio sources (Burbidge 1979) seems much higher than expected on the basis of the survey of WWPT. This point needs to be settled by examination of a control group with data of exactly the same quality and coverage as used in the OVVs and compact sources.

As noted earlier, the discovery by Sargent et. al. (1979) that the Ly α lines are distributed uniformly in redshift with no tendency to bunch in velocity space, and with properties which are independent of the particular QSOs examined argues strongly for cosmologically distant intervening material of a character different from the metal-containing clouds described above. These authors discuss the properties of the clouds and infer that they must be confined by a warm intergalactic medium which ought to be detectable by a general depression in the continuum of all QSOs shortward of HeII Ly α. It will be of great interest to see if the approximately constant density of Ly α lines with redshift holds right down to the present epoch. In addition, if these clouds really represent primordial material they should be nearly pure hydrogen and helium. With space telescope one ought to be able to observe oxygen in its most abundant ionization state and detect lines in some of the larger clouds even if the abundance is down by a factor of 1000 from solar abundance.

4. TWO SPECIAL OBJECTS

4.1 The Twin Quasars

There are two objects which pose especially interesting problems for the scheme described above. One is the pair of nearly identical quasars 0957+561A,B (Walsh et. al. 1979). At present, the various radio, spectroscopic, X-ray and direct photographic evidence does not conclusively rule out the gravitational lens hypothesis, although substantial difficulties are posed by it. Suppose the lens hypothesis is eliminated. Then, as noted by Walsh et. al. and Weymann et. al. (1979) the explanation for the velocity difference of less than 15 km/sec between the absorption systems in the two objects involves some unlikely coincidences. If the velocity difference of about 2000 km/sec between the emission line and absorption line redshifts is used to classify the lines as of type B-2, then agreement to within 15 km/sec of two clouds chosen at random out of a sample with a dispersion of 750 km/sec is unlikely, especially when coupled with the fact that very low ionization systems such as the ones in 0957+561 are very rare in type B-2 systems. Alternatively, we could consider the clouds to be an intervening halo (type C-1). Since the characteristic velocity dispersion within a halo is very much smaller, the agreement in velocity between A and B is less unlikely, but this advantage is offset by the a priori improbability that an intervening system would occur only 2000 km/sec to the blue of the emission line redshift.

4.2 PKS 0237-23

The absorption spectrum of this object has defied a convincing interpretation despite many years effort and some excellent data. Boroson et. al. (1978) proposed that the concentration of CIV doublets represents an intervening supercluster. The discovery of several type A objects with complex troughs extending to at least 0.1 c suggests the possibility that the CIV complexes in this object represent a more extreme and later phase of the same phenomenon. There is still some dispute about the presence of the SiII fine structure lines and it is important to resolve this point (cf. Roberts 1978). If the ejection occuring in the type A objects is accompanied by some kind of collimating process than very late stages in this type may have rather small covering factors and the energetics of an object like 0237-23 with marginally present SiII fine structure lines may not be insuperable.

https://doi.org/10.1017/S0074180900068406 Published online by Cambridge University Press

Even if this interpretation is correct, the extremely high velocities together with the fact that PKS 0237-23 is such a strong radio source makes it a unique object.

I wish to thank Drs. J. Bahcall, E.M. Burbidge, R.F. Carswell, W.L.W. Sargent, M.G. Smith, A. Wolfe, and A. Wright for the use of both published and unpublished material in preparing this review and for several helpful discussions. Much of the work summarized here was done in collaboration with colleagues at the Steward Observatory and I wish to acknowledge their contributions, especially H. Stockman, P. Strittmatter, D. Turnshek, B. Peterson, J. Scott and R. Williams.

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DISCUSSION

Aller: You mentioned the metallic absorption lines attributed to absorption by halos of intervening galaxies. Can we draw any firm conclusions about gas kinetic temperatures, densities, and levels of excitation in these halos?

Weymann: The level of ionization seems definitely higher in QSO spectra than in our disc. Likewise, the ratio of strengths of the fine structure CII line λ1335 to the ground state line λ1334 is generally lower in QSO spectra than in interstellar lines, implying that the electron density is lower in the halo (which would explain the higher ionization). Note that the CIV at zero redshift seen in 3C 273 is consistent with this picture.

Wampler: I would like to comment about the suggestion that the strong absorption seen in PHL 5200 is due to an intervening supernova explosion. In the PHL 5200 system one does see a nearby symmetric Lyα emission feature in the absorption trough of NV. Now, as you pointed out, MgII λ2800 does not show as strong absorption features. This can be understood if Mg^+ is in a cloud in front of the region producing the strong absorption. In that case the Lyα is easily explained as emission coming from the Mg^+ region, too. But if the absorption is produced by an intervening supernova, the Lyα line in the QSO should be absorbed by the NV feature in the SN and then the Lyα line from the SN shell at $z \approx 2$ should be too weak to detect.

Weymann: No comment except to note that the suggestion has been made by others, not by me.

Rees: The blanketing of the continuum by the "Lyman-α forest" increases with redshift as $(1 + z)^2 (1 + \Omega z)^{-1/2}$ x (a factor allowing for the z-dependence of cloud properties). Maybe the effect could frustrate the attempts by Dr. Osmer to discover quasars with $z > 4$.

Weymann: I doubt it. The forest shouldn't eat into the red wing of Lyα, so Lyα emission detection techniques should work.

Chaffee: Do you have any evidence for the existence of H_2 absorption toward any QSO?

Weymann: H_2 has been looked for in the spectra of a number of high redshift QSOs and has not been found. It would not be expected in either highly ionized galactic halos or in the hydrogen bubbles of Sargent et al.

G. Burbidge: What is your opinion concerning line locking? If the ratio 1.11 is real, will this give you a problem in terms of your various scenarios for absorption line production?

Weymann: If the 1.11 line locking ratio were to be demonstrated to be a statistically significant phenomenon in a certain subclass of absorption systems, we would certainly be forced to the conclusion that they presented ejecta at 0.1c, possibly the remnants of what I have called "class A" systems, which apparently eject material at $\lesssim$ 0.1c. My own opinion, however, is that the most persuasive cases for line locking may be found in CIV doublet overlapping and SiIV doublet overlapping. This still implies ejection, and is much easier to understand theoretically.