The Astrophysical Journal, **201**: 547–550, 1975 November 1

ANALYSIS OF GHOST SPECTRA WHICH SIMULATE THE ABSORPTION-LINE SPECTRUM OF 4C 05.34

Y. P. Varshni
Department of Physics, University of Ottawa, Ottawa, Ontario
Received 1974 September 16; revised 1974 November 12

ABSTRACT

Ten ghost spectra which simulate the absorption-line spectrum of the QSO 4C 05.34 are generated on a computer and analyzed according to the rules of Bahcall and Goldsmith. The results conclusively show that the number and properties of the absorption redshift systems proposed by Bahcall and Goldsmith are insignificantly different from those that would be expected from chance coincidences.

Subject headings: quasi-stellar sources or objects — redshifts

I. INTRODUCTION

The quasi-stellar object 4C 05.34 exhibits a rich absorption-line spectrum: a total of 93 lines have been measured by Lynds (1971) in the wavelength range 3497–6006 Å. The spectrum has been analyzed on the redshift interpretation by Lynds (1971) and by Bahcall and Goldsmith (1971; hereafter referred to as BG). The latter authors have used four well-defined rules and the condition that the maximum permissible wavelength discrepancy should be 2 Å in the observed frame. Lynds (1971) has proposed five absorption redshift systems; BG have dropped one of these and proposed four more. The eight absorption redshift systems of BG occur at $z = 1.7758, 1.8593, 2.1819, 2.4743, 2.5925, 2.7703, 2.8106$, and 2.8751, respectively. In order to determine how many of their eight redshift systems might be due to chance coincidences between standard and observed lines, BG have also analyzed 10 nonsense spectra. They find that for the "average" nonsense spectrum the number of acceptable redshifts is only 1.4, and the total number of lines identified is only 7. These results give the impression that most of the redshift systems proposed for 4C 05.34 by BG are "real" and not due to chance coincidences. On the other hand, statistical considerations (Varshni 1974) show that the distribution of absorption-line redshifts for 4C 05.34 is consistent with the hypothesis that the proposed systems are due to chance coincidences. It was felt that a detailed examination of the methods employed and the results obtained by BG was desirable, and in this paper we present the results of such an examination, and those of an independent analysis of 10 ghost spectra which simulate the absorption-line spectrum of 4C 05.34.

We define a ghost spectrum as a nonsense spectrum which simulates the real spectrum of an object in all its statistical characteristic features, but can be clearly distinguished from it. BG have used the term "nonsense spectrum." We prefer the term "ghost spectrum" because ghosts are supposed to be similar to human beings in appearance, but are not real.

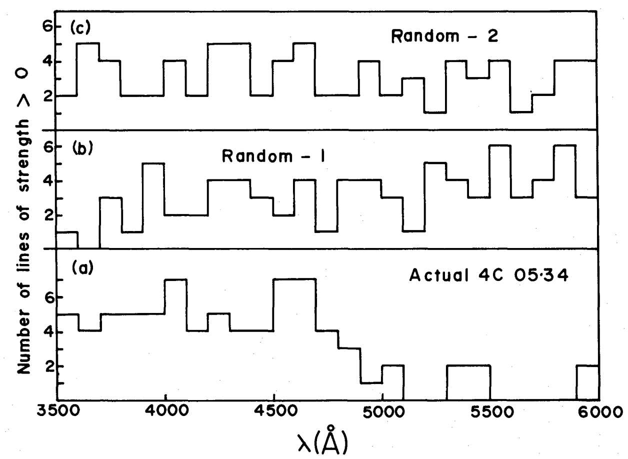

Fig. 1*a*–1*c*.—Number of lines (strength >0) in 100 Å intervals as a function of wavelength. Random-1 and Random-2 are two nonsense spectra for 4C 05.34 given by Bahcall *et al.* (1973).

We find that BG have missed a vital factor, namely the density distribution of lines, in generating their nonsense spectra. This can be readily explained by referring to Figure 1, where we show histograms of the number of lines in 100 Å intervals as a function of the wavelength. Lines having strength 0 play an insignificant role in the analysis procedure of BG, and have not been included in Figure 1. Figure 1*a* shows the distribution of lines in 4C 05.34; Figures 1*b* and 1*c* show two typical nonsense spectra for 4C 05.34 used by Bahcall and co-workers (Bahcall *et al.* 1973). It will be noticed that in the actual spectrum, most of the lines are in the range 3500–4900 Å and very few are beyond it; while in the nonsense spectra, lines are distributed more or less uniformly over the whole interval. Exact figures will help to make the point clearer. In the observed spectrum, there are 69 lines (strength >0) in the interval 3495–4850 Å (density: 5.09 lines per 100 Å), but only nine lines in the

TABLE 1

DIVISION OF THE ABSORPTION-LINE SPECTRUM OF 4C 05.34 IN SIX INTERVALS

Wavelength Interval (Å)	Number of Lines Having Strength > 0	Total Number of Lines
3497–4850	69	78
4850–5050	3	4
5050–5370	0	2
5370–5460	4	5
5460–5900	0	2
5900–6006	2	2

remaining interval of 4850–6006 Å (density: 0.78 lines per 100 Å). The density of lines plays a very important role in determining chance coincidences (Russell and Bowen 1929; Russell *et al.* 1944); this difference in the density of lines in the different regions of the spectrum of 4C 05.34 must also appear in any ghost spectrum for this quasar, but is missing in the nonsense spectra investigated by Bahcall and his co-workers.

A detailed examination of the data of Lynds (1971) shows that the absorption-line spectrum of 4C 05.34 can be conveniently divided into six intervals according to the density of lines having strength > 0. These intervals are identified in Table 1, which also shows the number of lines with strength > 0, and the total number of lines in each of these intervals.

We have generated ghost spectra for 4C 05.34 on a computer (IBM 360/65). The six intervals were considered separately; inside an interval, the ghost wavelengths were generated by the same formula as that used by Bahcall:

$$\lambda_i(\text{ghost}) = \lambda_{\min} + R_i(\lambda_{\max} - \lambda_{\min}) ,$$

where $\lambda_{\min}$ and $\lambda_{\max}$ represent the lower and upper limits, respectively, of the interval, and R_i is a uniformly distributed random number between zero and one (generated using the RANDU subroutine of IBM's Scientific Subroutine Package). It was constrained that the minimum separation between two wavelengths was 6 Å. The strength, width, etc., of the ith observed line was assigned to λ_i(ghost). Thus, in any given interval in Table 1, a ghost spectrum has the same number of lines of various strengths as in the observed spectrum. Ten ghost spectra were generated. The initiating numbers used for the RANDU subroutine for generating these ghost spectra are as follows: 37313, 9003, 32279, 78625, 765231, 7555, 11179, 334447, 1337, and 8641.

II. IDENTIFICATION PROBLEMS AND RESULTS

Before coming to the results, we wish to comment on certain problems that one faces in analyzing any spectrum on the redshift hypothesis and the procedures adopted by us, especially because BG have not discussed these. We used the same four rules as those used by BG and the constraint that the maximum permissible wavelength discrepancy was 2 Å in the observed frame. The search lines employed were the same as those used as BG. As a prelude to the analysis of ghost spectra, we first analyzed the absorption-line spectrum of 4C 05.34, and we shall illustrate the above-mentioned problems with reference to this spectrum. The first problem is of certain "awkward" identifications, i.e., certain identifications appear rather unacceptable in a redshift system. The second problem is of multiple identifications, i.e., an observed line can be identified with different search lines in two or more redshift systems. In some cases, the two problems are interrelated. Thirteen cases of multiple identifications occur in the eight redshift systems of BG, and these are listed in Table 2. We note here that BG have not even mentioned this problem in their paper. Subsequent authors (e.g., Lowrance *et al.* 1972) have taken cognizance of this problem. In case of multiple identifications, how is the strength of a line to be apportioned in different redshift systems? Redshift proponents have no answer to this question. The credibility of a redshift system is a function of the relative strengths of lines in a multiplet; without knowing the strength how can we judge the credibility? It must also be remembered that the eight systems of BG identify only about half the number of observed lines. On the redshift interpretation, presumably the remaining lines are due to unknown search lines and/or as yet undiscovered redshift systems. In either case, there would be further multiple identifications in addition to those listed in Table 2. BG have disregarded all these problems concerning strengths of lines in multiple identifications, and so have we.

For the convenience of the reader in following the subsequent discussion, we list here some of the frequently occurring multiplets: Si II λλ989.87(1), 1193.28(2), 1260.42(3), 1526.72(1); O VI λλ1031.95(2), 1037.63(1); N V λλ1238.81(2), 1242.80(1); Si IV λλ1393.76(2), 1402.77(1); C IV λλ1548.20(2), 1550.77(1). The numbers in parentheses indicate relative strengths of the lines in a multiplet (Bahcall 1968; Bahcall and Joss 1973).

There are five cases of "awkward" identifications in 4C 05.34, and we consider them in the following:

1. In the $z = 1.8593$ system, the observed line at 4366.50 Å, strength 5B, can be identified with Si II λ1526.72. The strongest line of the Si II multiplet, λ1260.42, is present, but clearly the strength of the λ4366.50 line makes its identification with a rest wavelength of 1526.72 Å unacceptable. Reference to Table 2 shows that λ4366.50 can also be identified with Lα in the $z = 2.5935$ system. Following BG, we assign the line to the $z = 2.5935$ system.

2. In the $z = 2.4743$ system, the observed line at 3603.32 Å can be identified with O VI λ1037.63, but the stronger member of the doublet, λ1031.95, is missing within the accepted tolerance of 2 Å. BG have, however, identified $\lambda_{obs} = 3582.46$ Å with O VI λ1031.95, though the difference between the observed and calculated values is 2.9 Å. We notice from Table 2 that λ3603.32 is also identified with Si II λ1260.42 in the $z = 1.8593$ system, so we have dropped its identification in the $z = 2.4743$ system.

TABLE 2

MULTIPLE IDENTIFICATIONS IN 4C 05.34

Serial Number	λ (obs) (Å)	Strength	Identification λ (Å), Ion	Redshift System
1.........	3603.32	3	1260.42 Si II(3)	1.8593
			1037.63 O VI(1)	2.4743
2.........	3683.54	3	1025.72 Lβ(0.5)	2.5925
			977.03 C III	2.7703
3.........	3706.10	3D	1334.53 C II	1.7758
			1031.95 O VI(2)	2.5925
			972.54 Lγ(0.2)	2.8106
4.........	3867.06	3D	1393.76 Si IV(2)	1.7758
			1215.67 Lα(3.3)	2.1819
			1025.72 Lβ(0.5)	2.7703
5.........	3894.82	2	1402.77 Si IV(1)	1.7758
			1084.00 N II(2)	2.5925
6.........	4010.48	1	1402.77 Si IV(1)	1.8593
			1260.42 Si II(3)	2.1819
7.........	4304.62	1	1550.77 C IV(1)	1.7758
			1238.81 N V(2)	2.4743
8.........	4317.20	0D	1242.80 N V(1)	2.4743
			1144.95 Fe II	2.7703
9.........	4366.50	5B	1526.72 Si II(1)	1.8593
			1215.67 Lα(3.3)	2.5925
10.........	4436.74	3	1393.76 Si IV(2)	2.1819
			1144.95 Fe II	2.8751
11.........	4465.08	4D	1402.77 Si IV(1)	2.1819
			1242.80 N V(1)	2.5925
12.........	4549.09	2	1206.51 Si III	2.7703
			1193.28 Si II(2)	2.8106
13.........	4800.96	2	1260.42 Si II(1)	2.8106
			1238.81 N V(2)	2.8751

NOTE.—In the third column, D stands for "diffuse" and B for "broad". Numbers in parentheses in the fourth column indicate expected relative strengths of lines.

3. The observed wavelength of 4465.08 Å, strength 4D, can be identified in two redshift systems (see Table 2). In the $z = 2.5925$ system, the identification with N V λ1242.80 is unacceptable because the stronger member of the doublet, N V λ1238.81, has strength 0 only. We have assigned the line to the $z = 2.1819$ system in agreement with BG.

4. The observed wavelength of 4734.45 Å, strength 1, can be identified with N V λ1242.80 in the $z = 2.8106$ system, but the stronger member of the doublet, λ1238.81, is missing. BG make no mention of this identification in their paper, and have omitted this line from their Table 1. In our analysis of ghost spectra, we have encountered similar instances. Such lines were not included in counting the number of identified lines, or in calculating rms errors.

5. The observed wavelength of 4624.25 Å, strength 1, can be identified with Si II λ1193.28 in the $z = 2.8751$ system, but the strongest member of the multiplet, λ1260.42, is missing. BG make no mention of this identification. However, in the analysis of PHL 957, in the $z = 2.5506$ system, Bahcall and Joss (1973) have identified a line of strength 1 with Si II λ1193.23, though λ1260.42 is missing. We have followed Bahcall and Joss (1973) and have accepted the identification of a strength 1 line with Si II λ1193.23, though λ1260.42 might be missing. Similarly, for other multiplets, we have allowed identification of a strength 0 line with a weaker member of a multiplet, though the strongest member may be missing.

From what we have said above, it will be obvious that we have followed BG as closely as possible. Only on such questions as those on which BG are silent have some minor additions in the procedure been made. BG have included some lines in their identifications for which the discrepancy is greater than 2 Å; we have strictly adhered to the rule that the discrepancy should be ≤ 2 Å. Overall, our results for the absorption-line spectrum of 4C 05.34 are negligibly different from those of BG. The same procedures were followed in the analysis of the 10 ghost spectra. Detailed tabular data concerning this analysis are available from the author. Here we only summarize the results. In Table 3, for each ghost spectrum, we show the number of acceptable redshift systems, number of identified lines of various strengths, total number of identified lines, and σ_λ, where σ_λ is the rms wavelength discrepancy as computed in the observed frame. The results for the "average" ghost spectrum as well as for the actual spectrum of 4C 05.34 are also shown. It will be noticed that within 1 standard deviation, the results for the "average" ghost spectrum are in reasonable agreement with those for the spectrum of 4C 05.34 itself. We may note here that we have generated ghost spectra of 4C 05.34 using other methods also (Russell and Bowen 1929; Hartoog *et al.* 1973); the results obtained from the analysis of these spectra are quite similar to those reported in the present paper.

Further evidence concerning the chance-coincidence nature of the eight systems of BG is obtained from

TABLE 3

SUMMARY OF ACCEPTABLE REDSHIFTS IN GHOST SPECTRA

Ghost Spectrum Label	Number of Redshift Systems	Lines of Strength						Total Number of Lines	σ_λ (Å)
		5	4	3	2	1	0		
E1	10	2	3	7	10	15	5	42	1.31
E2	11	2	5	10	12	13	5	47	1.28
E3	9	1	1	10	7	16	5	40	1.17
E4	10	2	5	8	7	12	5	39	1.23
E5	8	1	1	7	12	14	2	37	1.16
E6	10	0	2	10	13	15	4	44	1.15
E7	9	1	2	8	9	17	2	39	1.30
E8	7	1	1	14	7	12	3	38	1.21
E9	12	3	5	11	12	14	5	50	1.22
E10	10	1	0	7	14	15	7	44	1:29
"Average" ghost spectrum*	9.6 ± 1.36	1.4 ±0.80	2.5 ±1.80	9.2 ± 2.14	10.3 ± 2.53	14.3 ± 1.55	4.3 ±1.49	42.0 ± 4.0	1.23
Actual 4C 05.34	8	4	5	14	10	11	6	50	1.10

* The quoted errors are one standard deviation.

considerations involving multiple identifications. In a qualitative way, a "line-locking" mechanism has been invoked to supplement the redshift hypothesis to explain these multiple identifications (Strittmatter *et al.* 1973; Morton and Richstone 1973). It is more or less a "hand-waving" explanation, and its details have not been worked out even for a single case. In the chance-coincidence hypothesis, the explanation is straightforward and quantitative results can be obtained. In its simplest form, the problem can be formulated as follows: Suppose I have 93 balls in a container. At random, I pick out n_1 balls (here n_1 represents the total number of lines identified, including "awkward" identifications, for the first redshift), mark them, and then put them back in the container. In the second attempt, I pick out n_2 balls, and so on. Then it is a straightforward probability-theory calculation to determine, after eight such attempts, how many balls did not get out of the container at all, how many came out once, how many two times, three times, etc. The result of such a calculation is compared with the actual number of identifications for 4C 05.34 in Table 4. It will be noticed that the agreement between the chance-coincidence hypothesis results and the actual ones is excellent. The proposed eight systems for 4C 05.34 identify, on the average, 8.25 lines per system (this includes "awkward" and multiple identifications). At this rate, we can predict from the chance-coincidence theory that to identify 95 percent of the lines, the redshift hypothesis will require 32 redshift systems!

The present investigation clearly shows that the number and properties of the absorption redshift systems proposed by BG for 4C 05.34 are insignificantly different from those that would be expected from chance coincidences. Consequently, these absorption systems and their z values are devoid of any physical significance. We do not wish to overlook the fact that Carlson (1974) has attempted to identify certain absorption features in the spectrum of 4C 05.34 with $R(0)$ lines of the Lyman and Werner band systems of H_2; we shall consider this suggestion on another occasion.

TABLE 4

DISTRIBUTION OF UNIDENTIFIED AND IDENTIFIED LINES IN THE EIGHT ABSORPTION REDSHIFT SYSTEMS FOR 4C 05.34

	Number of Lines	
	Actual Number in 4C 05.34	Chance Coincidence Hypothesis
(a) Unidentified	43	44.12
(b) Identified once	37	34.61
(c) Identified 2 times	11	11.74
(d) Identified 3 times	2	2.25
(e) Identified 4 times	0	0.27

REFERENCES

Bahcall, J. N. 1968, *Ap. J.*, **153**, 679.
Bahcall, J. N., and Goldsmith, S. 1971, *Ap. J.*, **170**, 17.
Bahcall, J. N., and Joss, P. C. 1973, *Ap. J.*, **179**, 381.
Bahcall, J. N., Joss, P. C., and Cohen, J. G. 1973, *Ap. J.*, **184**, 57.
Carlson, R. W. 1974, *Ap. J.* (*Letters*), **190**, L99.
Hartoog, M. R., Cowley, C. R., and Cowley, A. P. 1973, *Ap. J.*, **182**, 847.
Lowrance, J. L., Morton, D. C., Zucchino, P., Oke, J. B., and Schmidt, M. 1972, *Ap. J.*, **171**, 233.
Lynds, R. 1971, *Ap. J.* (*Letters*), **164**, L73.
Morton, D. C., and Richstone, D. O. 1973, *Ap. J.*, **184**, 65.
Russell, H. N., and Bowen, I. S. 1929, *Ap. J.*, **69**, 196.
Russell, H. N., Moore, C. E., and Weeks, D. W. 1944, *Trans. Am. Phil. Soc.*, **34**, 111.
Strittmatter, P. A., Carswell, R. F., Burbidge, E. M., Hazard, C., Baldwin, J. A., Robinson, L., and Wampler, E. J. 1973, *Ap. J.*, **183**, 767.
Varshni, Y. P. 1974, *Ap. J.* (*Letters*), **193**, L5.

Y. P. VARSHNI: Department of Physics, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada