ALTERNATIVE EXPLANATION FOR THE SPECTRAL LINES OBSERVED IN QUASARS

(Letter to the Editor)

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Abstract. It is shown that the emission lines observed in quasars can be satisfactorily explained as being due to laser action in certain atomic species in the expanding envelope of a star. There is no need to assume a redshift.

The nature of quasars is still a major unsolved problem. For an up-to-date review of the present status of this problem reference may be made to Burbidge (1973). The conventional interpretation of the quasar spectra is based on the redshift hypothesis. It is perhaps not so well realized that most of the mysterious properties attributed to quasars arise because we assume that they have redshifts. We wish to suggest here a radically different explanation of the spectra of quasars. We shall consider here all quasars for which one or more emission lines have been observed, except those for which the redshift $z<0.2$. In the region $z<0.2$, there are a few objects which have occasionally been listed as quasars. Some of these (for example, B234, B264 and Ton 256) are *N*-type galaxies or related objects (Zwicky, 1965; Oke, 1969; Arp, 1970), while others are probably quasars. Because of their controversial nature, and because their number is quite small, we have, for the time being, excluded these objects from our analysis.

We have carried out a detailed analysis of the emission-line data of 380 quasars (this represents all reliable published data up to December 1974). Of these, 47 have two sets of data, and 5 have three sets of data available. A comparison of the different sets of data of these 52 quasars shows that the wavelengths of lines described as strong or very strong usually agree to ±3 Å, but for lines described as medium or weak the differences are much greater (10 to 30 Å). We are led to conclude that, if one wishes to identify a line within ±3 Å, only strong and very strong lines should be considered.

We find from our analysis of the very strong and strong lines of quasars that the data are consistent with the following three hypotheses (Varshni, 1973, 1974a, b):

(1) There is no redshift;

(2) The strength of the emission lines is due to laser action; and

(3) The composition of the emission region of quasars is approximately the same as that of normal stellar atmospheres. In other words, the elements, H, He, C, N, O,

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Mg, Al, Si and S have a high abundance (HA) in the emission region. The atoms and ions of these elements shall be collectively called HA atoms.

We enlarge upon the first two hypotheses as follows:

(1) Why is it assumed that the spectra have redshifts? The basic reason for this lies in the time-honoured assumption that the intensities of lines in astronomical sources will be similar to those in the laboratory under ordinary excitation conditions. No account is taken of a possible laser action. If the quasars showed a good number of lines of the same spectral series (e.g., Balmer, Lyman) with the right relative intensities at exactly the same redshift, then there would be no doubt about the reality of the redshift. However, this is not the case for the quasars under consideration. Thus, there is no compelling reason to believe in the redshifts if we allow the possibility of a laser action in these bodies. It is readily seen that if there is no redshift, the difficulties associated with the intrinsic radiation properties and the short-term variability of quasars all disappear. The absence of redshift also readily explains the scatter diagram nature of the apparent magnitude-redshift plot for quasars, and it will also resolve the four paradoxes of Kellermann (1972).

(2) We marshal in the following certain theories, facts and suggestions in support of our second hypothesis.

(a) Menzel (1970) has shown theoretically that laser action is possible in non-LTE atmospheres.

(b) The possibility of amplifying radiation in a recombining plasma due to rapid cooling of electrons was discussed by Gudzenko and Shelepin (1965). Gudzenko *et al.* (1966) studied the cooling conditions for expansion of magnetized and unmagnetized plasma, as well as quasistationary flow of a magnetized plasma jet into a vacuum. Detailed theoretical calculations (Zemtsov, 1969; Bohn, 1971) of population densities of excited levels in a decaying hydrogen (and hydrogen-like ions) plasma flow predicted population inversions at electron densities ($n_e \sim 10^{13}$ to 10^{16} cm^{-3}) and electron temperatures ($T_e \sim 5000$ to 10^5 deg K) whose magnitudes are very close to those existing in stellar atmospheres. This has been also confirmed experimentally (Hoffmann and Bohn, 1972; Irons and Peacock, 1974). Also, it is well known that in certain types of stars, matter is ejected more or less continuously (Ambartsumyan, 1958; Sobolev, 1960).

(c) Numerous anomalies in the line intensities of stellar spectra have been observed (Struve, 1951; Merrill, 1956). Letokhov (1972) has proposed that some of these can be explained on the hypothesis of stimulated emission.

One's confidence in the proposed hypotheses will be strengthened if it could be shown that indeed, in the laboratory, laser transitions do occur in the HA atoms at the strong-line wavelengths in quasars. With this aim in view, a search was made for common lines in quasars and in laboratory observed laser lines in HA atoms. Approximately 25 such lines were found. Some examples are shown in Table I. There is a great paucity of data on laboratory observed laser lines in the HA atoms, which accounts for the small number of identifications. It would be very desirable to carry out further laboratory investigations on these atoms.

Thus we propose the following realistic model of a quasar: it is a star in which the surface plasma is undergoing rapid radial expansion giving rise to population inversion and laser action in some of the atomic species. The assumption of the ejection of matter from quasars at high speeds is supported from the fact that the widths of

TABLE I

Identifications of some emission lines observed in quasars with laboratory observed laser lines

Serial No.	Wavelength (Å), Quasar	Wavelength (Å) of laser line in laboratory and its emitter[a]
1	3748 BSO 11[b]	3749.49 O II
	3749 1331+170[c]	
	3750 RS 32[b]	
2	4346 3C 432[d]	4347.38 O II
	4349 PKS 1136−13[e]	4351.29 O II
	4349 3C 334[f]	
3	4513.7 PKS 0237−23[g]	4514.88 N III
	4515 3C 261[h]	
4	4566 OI 363[i]	4567.84 Si III
	4568 PKS 0119−04[e]	
	4570 4C 16.30[j]	
5	4652 PHL 1377[e]	4650.16 C III
		4647.45 C III
		4649.14 O II
6	5034 PHL 1194[k]	5032.39 S II
7	5564 3C 343[c]	5564.95 S II
8	6482 LB 2136[l]	6482.07 N II
	6485 4C 49.22[k] (same quasar)	
9	6674 4C 49.22[k]	6671.92 Si II
10	6722 DA 406[b]	6721.36 O II

[a] Laser data are from the following: Willett, C. S.: 1971, *Progress in Quantum Electronics* **1**, 273; Pressley, R. J. (ed.), *Handbook of Lasers*, Chemical Rubber Co., Cleveland, 1971; Bridges, W. B. and Chester, A. N.: in *Handbook of Lasers*, quoted earlier.

[b] Burbidge, E. M.: 1970, *Astrophys. J.* **160**, L33.

[c] Baldwin, J. A., Burbidge, E. M., Hazard, C., Murdoch, H. S., Robinson, L. B., and Wampler, E. J.: 1973, *Astrophys. J.* **185**, 739.

[d] Schmidt, M.: 1966, *Astrophys. J.* **144**, 443.

[e] Kinman, T. and Burbidge, E. M.: 1967, *Astrophys. J.* **148**, L59.

[f] Lynds, C. R., Stockton, A., and Livingstone, W.: 1965, *Astrophys. J.* **142**, 1667.

[g] Burbidge, E. M.: 1967, *Astrophys. J.* **147**, 845.

[h] Burbidge, E. M. and Kinman, T.: 1966, *Astrophys. J.* **145**, 654.

[i] Burbidge, E. M. and Strittmatter, P. A.: 1972, *Astrophys. J.* **174**, L57.

[j] Lynds, R. and Wills, D.: 1972, *Astrophys. J.* **172**, 531.

[k] Burbidge, E. M.: 1968, *Astrophys. J.* **154**, L109.

[l] Lynds, C. R. and Wills, D.: 1968, *Astrophys. J.* **153**, L23.

emission spectral lines observed in quasars are typically of the order of 2000–4000 km s^{-1}. We shall call the proposed model the plasma-laser star (PLS) model. Let us then examine the consequences of this model.

The basic theory for obtaining the properties of a decaying plasma was given by Bates *et al.* (1962a, b). Detailed calculations on the properties of a rapidly decaying monoatomic plasma have been carried out by a number of workers (Zemtsov, 1969; Bohn, 1971; Drawin, 1969; Varshni and Lam, 1974). The population densities of the excited levels are functions of the electron density (n_e), the electron temperature (T_e), and the density of the ground state atoms ($n(1)$). In stellar atmospheres, $n(1)$ is a function of n_e and T_e. Thus the state of plasma, after expansion, in a star can be represented by a point on a plot with n_e and T_e as axes.

It is found that for a given transition in a given atom, strong population inversion takes place only within a narrow area in the n_e, T_e diagram (see Figure 1). This area is surrounded by a medium population inversion area, which in its turn is surrounded by a weak population inversion area. On the high n_e side, the boundary of the population inversion is rather steep. (Strong population inversion regions will give rise to strong lines, and similar statements hold for the medium and weak inversion regions.)

Now consider two wavelengths, λ_1 and λ_2, arising from different transitions in different atoms. We can represent their population inversion regions as shown in Figure 2. We consider what will be observed if the emission-line region of a quasar corresponds to the different points shown on the diagram. Point 1: λ_1 strong, λ_2

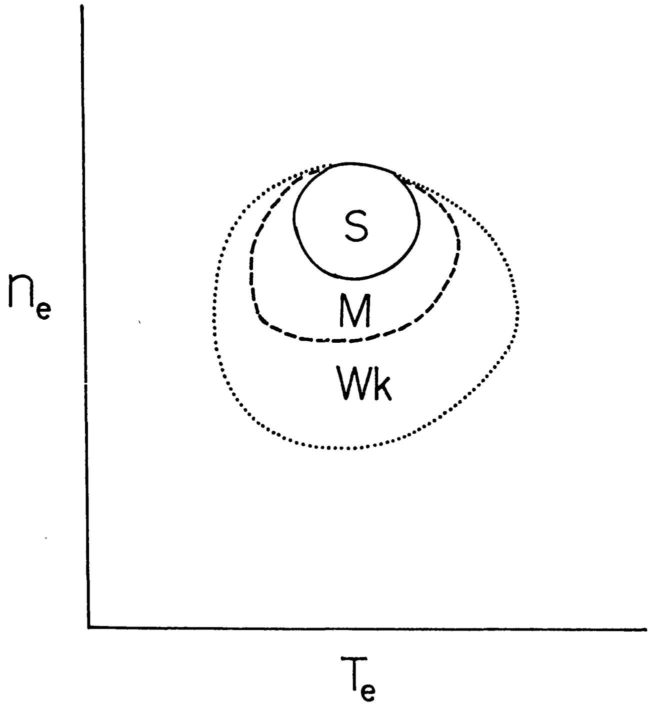

Fig. 1. Population inversion region for a transition. The solid, dashed, and dotted curves show strong, medium, and weak population inversion regions, respectively. The diagram is purely qualitative. n_e and T_e are on a logarithmic scale.

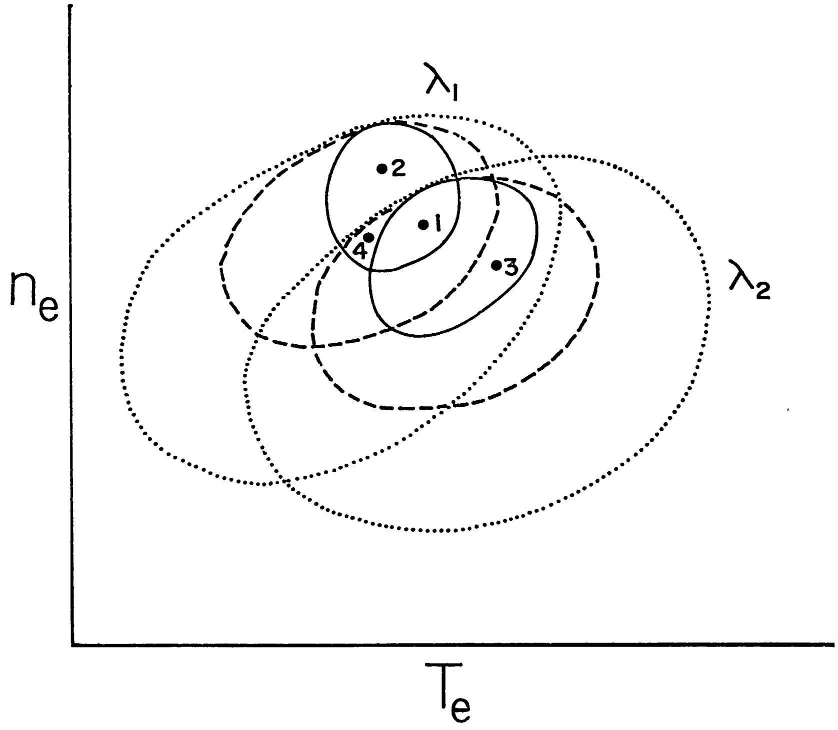

Fig. 2. Population inversion regions for two transitions. Solid, dashed, and dotted curves have the same significance as in Figure 1.

strong; point 2: λ_1 strong, λ_2 absent; point 3: λ_1 weak, λ_2 strong; point 4: λ_1 strong, λ_2 medium, and so on. Thus a whole range of relative intensities is possible. We next consider the observational evidence relevant to this point. We have carried out a spectral classification of quasars. There are quasars which show two or more emission lines at practically the same wavelengths; such quasars were put together in a group. In the redshift interpretation, quasars belonging to the same group tend to have the same redshift. We give here three examples in which wide variations in relative intensities have been recorded; we have restricted ourselves to only such cases where the two quasars were investigated by the same astronomer(s) using the same telescope.

(a) 3C 309.1 and 0957+00. Spectra of both quasars were obtained by Lynds and his coworkers (Lynds *et al.*, 1966; Lynds, 1967) on the Kitt-Peak 84-in. telescope, and are reproduced in Plate 1 in the book by Burbidge and Burbidge (1967). Both quasars show two emission lines at 3640 Å and 5337 Å, respectively. λ 3640 is stronger than λ 5337 in 0957+00, but λ 3640 is quite weak in 3C 309.1, in which λ 5337 is very strong.

(b) 3C 208 and 3C 204. Spectra of both quasars have been obtained by Schmidt (1966) on the 200-in. telescope. λ 4030 is of medium strength in both the quasars, but λ 3275 is medium in 3C 208, and weak in 3C 204.

(c) 1508-05 and 2329-384. Spectrograms for both the quasars were obtained by Peterson and Bolton (1972) on the Mount Stromlo 74-in. telescope. λ 4185 is strong in both the quasars. On the other hand, another line, λ 3396 is strong in 2329-384, but weak in 1508-05.

We conclude that these results are in strong support of the PLS model regarding the relative intensities of emission lines, and we believe they support the correctness of the essential ingredients of the proposed model.

The object 3C 273 has played an important part in the history of quasars, and it deserves special mention, though its apparent redshift is only 0.158. We have carefully examined (Varshni, 1975) the various pieces of evidence available on the nature of this object, and we find that the available evidence favours the view that it is a galactic object.

A more comprehensive account of the investigation will be published elsewhere.

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