# Peaks In Emission Lines In The Spectra Of Quasars

Y. P. Varshni*, J. Talbot† and Z. Ma**,‡

*Department of Physics, University of Ottawa, Canada K1N 6N5,
E-mail: ypvsj@uottawa.ca
†http://laserstars.org
**National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, China.
‡Visiting scientist, University of Ottawa

**Abstract.** It is shown that in a histogram of the distribution of emission lines (in the *observed frame*) in the spectra of 5176 quasars, a number of very strong and narrow peaks are found at certain wavelengths. The cause and significance of these peaks are discussed.

**Keywords:** quasar, emission line, observed frame, Wolf-Rayet, nova-like star
**PACS:** 98.54.Aj

## 1. INTRODUCTION

We report on a remarkable and surprising result in the distribution of *observed frame* quasar emission lines; very strong and narrow peaks are found in the histogram of the occurrence frequency of an emission line against wavelength.

## 2. THE DATA

The Hewitt & Burbidge [1] quasar catalog lists 7315 quasars, of which 5176 have emission line data. They give the emission line wavelengths in the rest frame of the quasar. We convert these wavelengths to *observed frame* by multiplying them with $(1+z)$, where $z$ is the quasar redshift. We obtain 14,277 lines which span the range 1271 Å to 17993 Å. The vast majority of these *observed frame* emission lines lie between 3200 Å and 5600 Å thus we confine ourselves to this range.

## 3. METHOD

Histograms are constructed with the number of *observed frame* quasar emission lines as a function of wavelength for different bin sizes: 4 Å, 8 Å, 16 Å, 32 Å and 64 Å. We choose a compromise bin size of 4 Å to allow for the plus/minus uncertainties in the redshifts. We then accurately determine the emission line wavelength corresponding to each observed peak by constructing several histograms shifted with respect to the first histogram by multiples of 1 Å.

## 4. OBSERVATIONS

In figure 1 we plot the *observed frame* emission line histogram for a 4 Å bin size. It will be noticed that there are narrow (< 4 Å) peaks at particular wavelengths. We find that 37 of the peaks are very strong. These peaks gradually disappear as the bin size is increased, as expected. In addition, we find that 27 of those 37 emission lines occur in Wolf-Rayet stars. An additional 5 emission lines are seen in novae like stars. Further, one more emission line is possible in Wolf-Rayet stars. The central wavelength for each of these 37 peaks are listed in table 1 along with their line identification. We find that the strongest peak at 3890 Å matches a very common emission line in the spectra of Wolf-Rayet stars. In the following sections we examine the statistical significance of these peaks and provide an interpretation for the corresponding emission lines.

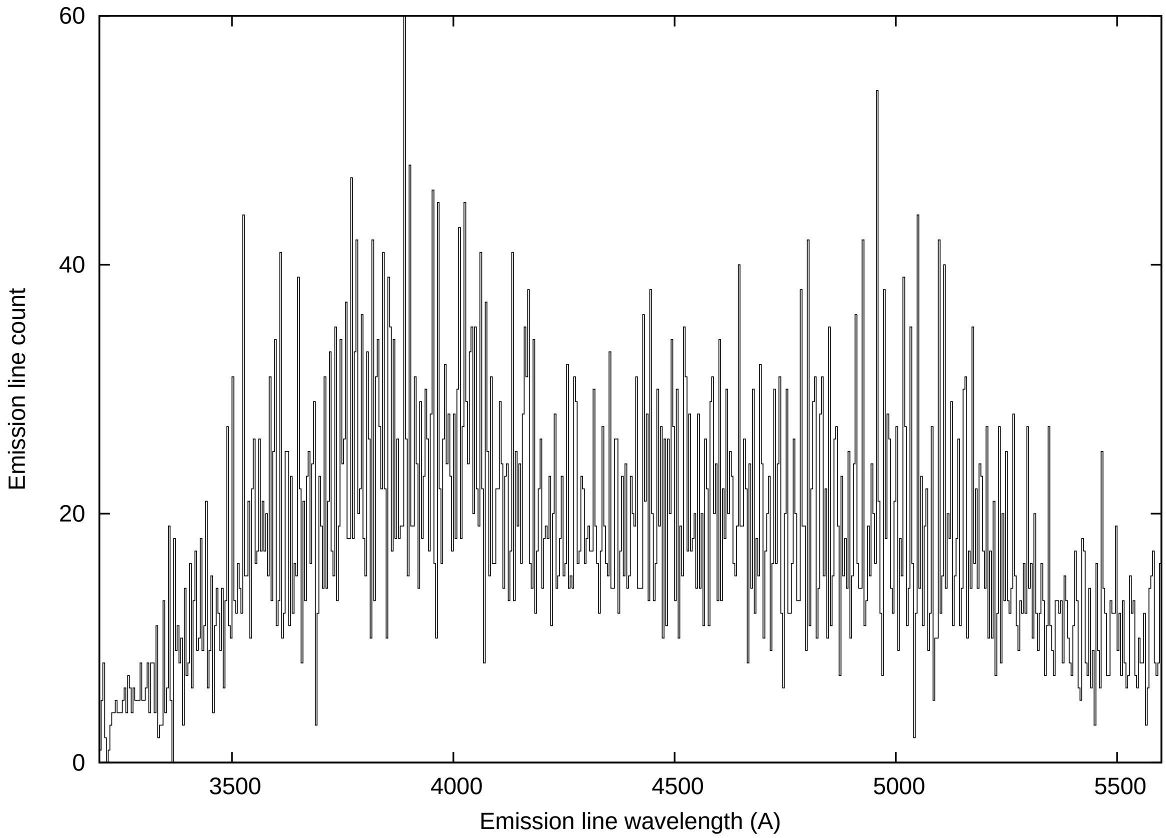



**FIGURE 1.** Quasar emission line distribution versus wavelength for a bin size of 4 Å (in *observed frame*)

## 5. BIAS AND FLUCTUATIONS

We examine the possibility that these 37 peaks are due to random fluctuations or observational biases such as the selection effect. We address the six key findings present in the *observed frame* quasar emission line distribution from Hewitt & Burbidge [1] :

1. Extremely narrow peaks (< 4 Å).
2. Peaks are intense.
3. There are 37 strong peaks.
4. Peaks identified with 27 WR lines.
5. The strongest peak (3890 Å) frequently occurs in WR.
6. Five peaks occur in nova-like stars.

### 5.1. Extremely narrow peaks (< 4 Å)

Hewitt & Burbidge [1] warn that the spectra of many quasars were observed using the prism-grism technique and related methods which tends to preferentially select quasars with $1.8 < z < 3.4$. They recommend removing these biases when looking for possible peaks and periodicities. The warning applies only in the rest frame and only to the redshift values. If one plots the distribution of quasars from their catalog versus $z$, one finds no evidence for periodicities in $z$ and the $z$ peaks are very broad and of low amplitude. This very small effect from observational bias translates into an even more minuscule contribution when we plot the distribution of *observed frame* emission lines as a function of wavelength rather than the quasar distribution as a function of $z$. In any case it only occurs on wavelength

**TABLE 1.** Frequently occurring *observed frame* quasar emission lines and the corresponding wavelengths as observed in Wolf-Rayet stars or novae like stars, along with the emitter identification.

| id | line Å (air) | reported wavelengths in Wolf-Rayet stars or novae like stars Å (air) |
|---|---|---|
| 1 | 3356 | 3358.6 Underhill [31]. N III 3355, O III 3355.9, C III 3358 |
| 2 | 3489 | 3493 Wright [32]. O IV 3490.8 |
| 3 | 3526 | not reported in WR. |
| 4 | 3549 | not reported in WR. |
| 5 | 3610 | 3611 Wright [32], 3609.5 Beals [33], 3609+ Edlen [34], 3608.5 Underhill [31], C III 3609.6, He I 3613.6. |
| 6 | 3648 | 3645.4 Underhill [31]. C III, O IV 3642. |
| 7 | 3683 | 3687 Edlen [34], 3685.10 - novaelike stars (Meinel *et al.* [35]). C IV. |
| 8 | 3719 | 3722 Plaskett [36], 3723 Beals [33], 3722 Edlen [34], 3717.1 Underhill [31]. O III 3721. |
| 9 | 3770 | 3769 Plaskett [36], 3769 Edlen [34], 3770.6 Underhill [37]. O III, N III 3773. |
| 10 | 3781 | 3784.8 Underhill [31]. He II 3781.68, O III, N III 3779. |
| 11 | 3831 | 3829.9 Underhill [31]. He II 3833.80, N IV, O VI. |
| 12 | 3842 | Not seen in WR. O IV 3841.07,(?), C III 3844.51 (?). |
| 13 | 3855 | 3856.6 Underhill [31]. He II 3858.07. |
| 14 | 3890 | 3889 Wright [32], 3889 Plaskett [36], 3888.9 Beals [33], 3888, 3888.7 Swings [38], 3887.8, 3890.9 Underhill [31], 3889.4 Underhill [37]. He I 3888.64, C III 3889.18, 3885.99. |
| 15 | 3903 | 3903.0 - novaelike stars (Meinel *et al.* [35]). |
| 16 | 3952 | 3953.7 Beals [33], 3954.4 Edlen [34], 3954.5 Underhill [37]. O II, (C II). |
| 17 | 4012 | 4008.2 Underhill [31], 4008.5 Underhill [37]. N III 4007.88, 4013.00. |
| 18 | 4135 | O II 4132.8, Possible in WR stars Edlen [34]. |
| 19 | 4276 | 4275.5 novae (Meinel *et al.* [35]), 4276.6 novaelike stars (Meinel *et al.* [35]), O II 4275.5 Possible in WR (Edlen, 1956). |
| 20 | 4524 | 4519.5 Plaskett [36] 4521.3 Underhill [31]. N III 4523.56, 4527.9, O III 4524.2 4527.3, C III. |
| 21 | 4647 | 4650.8 Swings [38]. C III 4647.40, 4650.16, 4651.35; O II 4649.15. |
| 22 | 4693 | 4697.0 novaelike stars (Meinel *et al.* [35]). O II 4596.2 Possible in WR stars (Edlen, 1956). |
| 23 | 4771 | 4772.1 novaelike stars (Meinel *et al.* [35]). O IV 4772.6 Possible in WR stars (Edlen, 1956). |
| 24 | 4801 | 4799 Wright [32], 4800 Plaskett [36], 4798.3 Edlen [34], 4797.4 Underhill [31], 4798.1 Underhill [37], 4804.6 Underhill [37]. O IV 4801. |
| 25 | 4817 | 4814.6 Underhill [37], 4814.4 novaelike stars (Meinel *et al.* [35]). O IV 4813 4824, Si III. |
| 26 | 4910 | 4909.2 Underhill [31]. N III ?. |
| 27 | 4925 | 4923 Wright [32], 4924 Plaskett [36], 4924 Edlen [34], 4927.4 Underhill [31]. He I 4921.9. |
| 28 | 4956 | 4958 Plaskett [36], 4959.0 novae (Meinel *et al.* [35]), 4959.0 old novae (Meinel *et al.* [35]). |
| 29 | 5018 | 5021 Campbell [39], 5017 Wright [32], 5018.3 Plaskett [36], 5018 Beals [33], 5015.7 Swings [38], 5018 Edlen [34], 5019.8 Underhill [31]. He I 5015.67, C IV 5015.9, 5017.7. |
| 30 | 5035 | not seen in WR. |
| 31 | 5049 | 5049.9 Underhill [31]. He I 5047.7, C II. |
| 32 | 5096 | 5092.9 Swings [38]. |
| 33 | 5111 | 5111.5 novae-like stars (Meinel *et al.* [35]). |
| 34 | 5173 | 5171.1 Underhill [31]. N II 5172. |
| 35 | 5266 | 5266.3 Underhill [31]. C III, O III 5268.1. |
| 36 | 5345 | 5343.3 Swings [38]. C II 5336.7. |
| 37 | 5466 | 5470 Wright [32], 5470 Beals [33], 5470 Edlen [34], 5469.6 Underhill [31]. C IV,O V. |

scales one to two orders of magnitude larger than the narrow 4 Å peaks. When the bin size of our histogram is increased to this larger wavelength scale, the peaks vanish as we have mentioned previously.

We wish to emphasize that these peaks are not in any way a reflection of the peaks which have been reported in redshift histograms (Burbidge [4], Wesselink [5], Karlsson [6], Burbidge & O'dell [7], Green & Richstone [8], Barnothy & Barnothy [9], Karlsson [10], Wills [11], Kjaergaard [12], Khodyachikh [13], Box & Roeder [14], Arp *et al.* [15], Burbidge & Napier [16]) because a peak emission line wavelength often occurs in quasars of very different redshifts. For example $\lambda 3888$ occurs in the spectra of quasars with such diverse redshifts: $z = 0.39$, 0.672, 1.037, 1.51, 1.78, 2.079, 2.20, 2.762. Similarly $\lambda 4026$ occurs in the spectra of quasars with such different redshifts: $z = 1.11$, 1.60, 1.871, 2.08, 2.189, 2.246, 2.31. We have given here just two examples, there are many more.

## 5.2. Peaks are intense

The observational bias mentioned in Hewitt and Burbidge [1] is insignificant when compared to the intensity of these peaks.To evaluate the significance of these peaks we carry out a Monte Carlo simulation to examine the question whether these peaks might be due to random fluctuations. Using the histogram of the observed quasar emission lines with 64 Å bin size as a sufficiently smooth probability distribution, we generate 14,277 random emission using a random number generator algorithm from Press *et al.* [2]. For verification, we generate a 64 Å bin size histogram of the random lines and plot the results along with the observed 64 Å bin size histogram of actual lines and we find they match very closely.

Next we construct a 4 Å bin size histogram for these random lines. We then generate $n = 1000$ runs of this data and obtain the average 4 Å bin size histogram and compute the standard deviation ($\sigma$) for each bin using the usual formula

$$\sigma = \sqrt{\frac{\Sigma x^2 - (\Sigma x)^2/n}{n-1}} \tag{1}$$

To determine the statistical significance of these peaks we use the probability under the normal distribution table from Hoel [3]. He tabulates the probability that a random peak will occur above a given threshold from the average random distribution as

$$P(4\sigma) = 3.16 \times 10^{-5} \tag{2}$$
$$P(5\sigma) = 2.86 \times 10^{-7} \tag{3}$$
$$P(6\sigma) = 9.83 \times 10^{-10} \tag{4}$$
$$P(7\sigma) = 1.27 \times 10^{-12} \tag{5}$$
$$P(8\sigma) = 6.19 \times 10^{-16} \tag{6}$$

In figure 2 we plot emission line distribution in units of $\sigma$ above the average random distribution; i.e. the y-axis corresponds to the difference between the observed distribution and the average random distribution divided by $\sigma$. We find 37 peaks above $4\sigma$, 13 peaks above $5\sigma$, 3 peaks above $6\sigma$ and one peak with $8.4\sigma$. We choose $4\sigma$ as the threshold because the probability that a random peak will occur above this is sufficiently low. These very low probabilities clearly establishes that the 37 *observed frame* emission lines associated with the center of these peaks are significant.

## 5.3. There are 37 strong peaks

To calculate the probability that all 37 strong peaks taken in combination could be due to chance we must multiply together all the probabilities for each peak to occur by chance. The chance probability of observing all 37 peaks is $4.26 \times 10^{-246}$ or essentially zero.

## 5.4. Peaks are identified with 27 WR lines

Approximately three quarters of the 37 strong peaks are centered on emission lines also found in Wolf-Rayet stars. This has a very low probability of occurring by chance. These matches are very strong evidence for the stellar nature of quasars as emission line stars with WR-like spectra. In addition, the ions and levels responsible for the transitions can constrain the plasma parameters of the stellar atmospheres of quasars. The laser star theory (`http://laserstars.org`) predicts that the temperature range in the atmosphere of quasars is equal to or higher than that of Wolf-Rayet and central stars of planetary nebula. This is confirmed by absorption line evidence (Varshni, [17]) indicating that many quasars are surrounded by circumstellar matter with a higher degree of excitation than that found in shell stars.

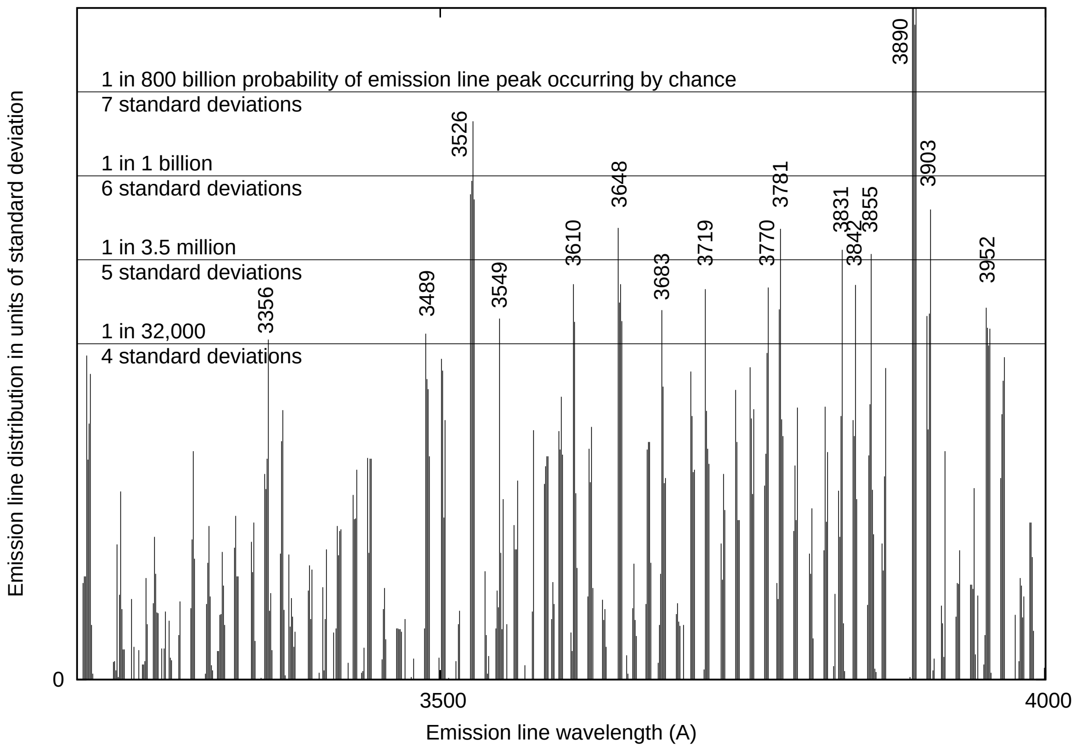
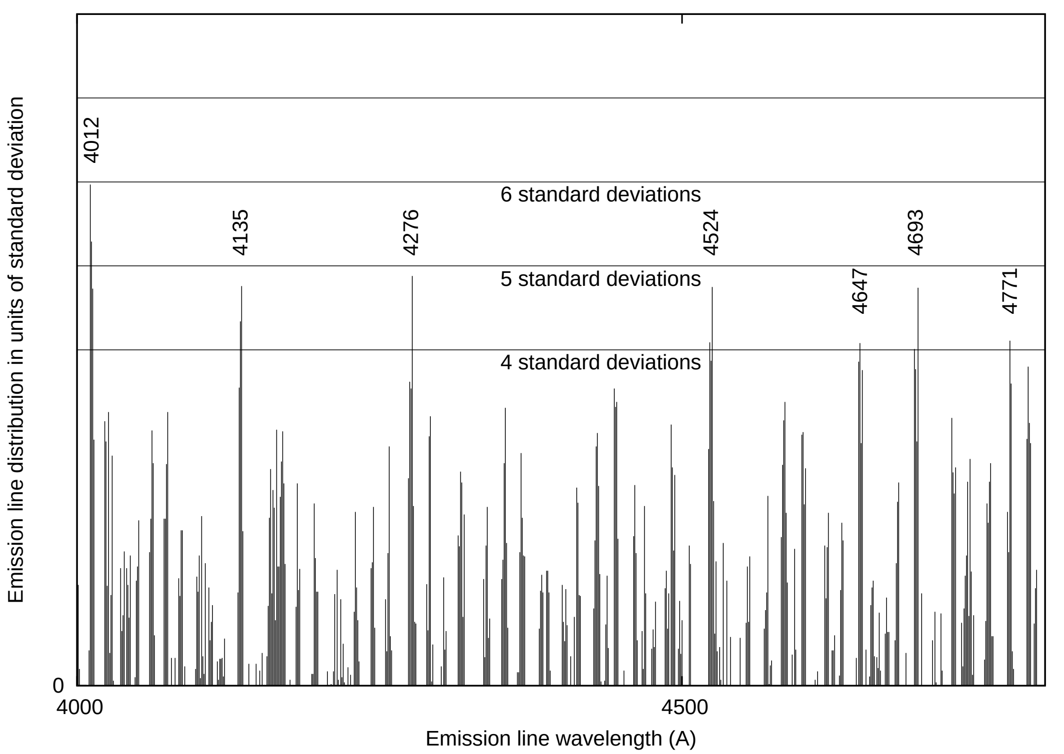
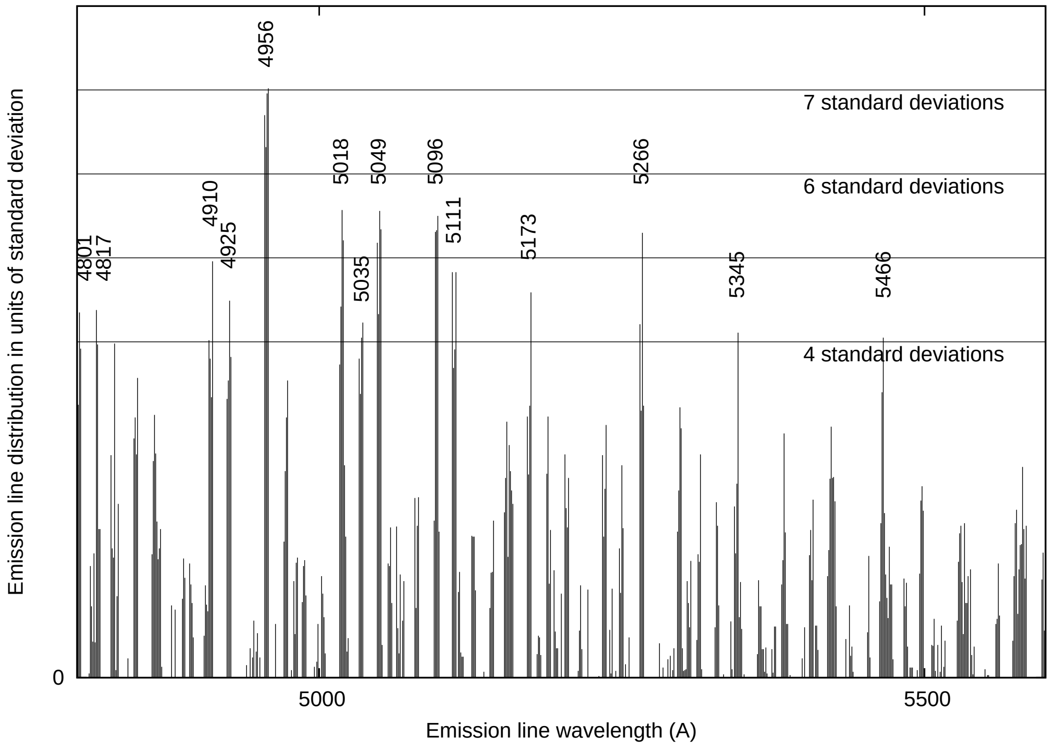



**FIGURE 2.** Quasar emission line distribution in units of $\sigma$ above the average random distribution (in *observed frame*).






## 5.5. The strongest peak (3890 Å) frequently occurs in WR

The most intense emission line peak at 3890 Å is nearly coincident with the 3889 Å Wolf-Rayet emission line. The probability that this emission line peak is due to chance is $2.4 \times 10^{-17}$ or approximately zero. It is no coincidence the most frequently occurring emission line in quasars is also one of the most frequently occurring emission lines in Wolf-Rayet stars. Bias or fluctuations cannot explain this line, the redshift hypothesis has no explanation either.

## 5.6. Five peaks occur in nova-like stars

Five of the 37 strong peaks also occur in nova-like stars, this confirms a prediction of the laser star theory, that quasars have very strong stellar winds with a very high degree of excitation.

Before discussing the interpretation of the 37 strong peaks we first question the reality of emission line red-shifts in quasars. Varshni [17] carried out a numerical simulation and finds that 9 out of 10 randomly generated quasars can be assigned a reasonable emission-line redshift. This is a strong indication that quasar redshifts are empty numbers without any physical significance and by extension the rest frame emission line distribution is meaningless.

As clearly demonstrated in the previous 6 subsections, the effects from bias and fluctuations are negligible. In the redshift hypothesis there is no reason why the emission lines in the *observed frame* should show peaks. Thus the redshift hypothesis is unable to account for these peaks.

Conversely we submit that each of these six observations taken separately is significant evidence that quasars are emission line stars. When all six observations are taken as a whole they provide unambiguous confirmation of the laser star theory which we now discuss.

## 6. LASER STAR THEORY

One of the authors has proposed a theory of quasars Varshni [18][17][19][20][21][22][23][24][25][26][27], Varshni & Lam [28], Varshni & Nasser [29], based on sound physical principles, which does not need the artificial assumption of redshifts and provides satisfactory explanations of the various phenomena associated with quasars. Laser action is responsible for the strength of the broad emission lines. This theory is known as the plasma-laser star (PLAST) model of quasars. Most of the observational evidence on quasars either supports our theory or else is consistent with it (see e.g. Varshni [23][24]; Talbot & Varshni [30] and references therein).

The existence of the wavelength peaks can be readily understood on this theory. It is well known that some atomic transitions are more susceptible to laser action than others. The peaks correspond to such transitions and such emission lines occur more often in quasar spectra.

Varshni [21] points out that there is a continuity between the spectra of certain group of quasars and the spectra of the O VI sequence of Wolf-Rayet planetary nuclei. Varshni [25][26][27] shows that emission lines of certain quasars also occur in Wolf-Rayet stars. The fact that 27 of the peak lines found in quasars also occur in Wolf-Rayet stars further strengthens the continuity argument. It is also significant that line $\lambda$3889 which is the most frequently occurring line in quasar spectra also occurs very frequently in Wolf-Rayet spectra. The fact that 5 of the peak lines found in quasars also occur in novae-like stars further suggests that the high velocity end of ejection velocities in quasars is greater than that in Wolf-Rayet stars.

Laser action is responsible for the frequently occurring lines. Quasars are hot stars within our galaxy (`http://laserstars.org`).

## REFERENCES


1. A. Hewitt, and G. Burbidge. *ApJS*, **87**, pp. 451–500 (1993).
2. W. H Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling. *Numerical Recipes in C : The Art of Scientific Computing*, Cambridge University Press; 2nd edition (1993).
3. P. G. Hoel. *Introduction to Mathematical Statitics*, 5th edition, Wiley (1984).
4. G. Burbidge. *ApJ*, **154L**, pp. 41–115 (1968).
5. A. J. Wesselink. *Nature*, **225**, 927 (1970).
6. K. G. Karlsson. *A&A*, **13**, pp. 333–335 (1971).
7. G. R. Burbidge, and S. L. O'dell. *ApJ*, **178**, pp. 583–606 (1972).
8. R. F. Green, and D. O. Richstone. *ApJ*, **208**, pp. 639–645 (1976).
9. J. M. Barnothy, and M. F. Barnothy. *PASP*, **88**, pp. 837–839 (1976).
10. K. G. Karlsson. *A&A*, **58**, pp. 237–240 (1977).
11. D. Wills. *PASP*, **89**, pp. 643–645 (1977).
12. P. Kjaergaard. *Phys. Scripta* **17**, pp. 347–351 (1978).
13. M. F. Khodyachikh. *SvA*, **23**, 411 (1979).
14. T. C. Box, and R. C. Roeder. *A&A*, **134**, pp. 234–239 (1984).
15. H. Arp, H. G. Bi, Y. Chu, and X. Zhu. *A&A*, **239**, pp. 33–49 (1990).
16. G. Burbidge, and W. M. Napier. *AJ*, **121**, pp. 21–30 (2001).
17. Y. P. Varshni. *BAAS*, **6**, p. 213, p. 308 (1974).
18. Y. P. Varshni. *BAPS*, **18**, p. 1384 (1973).
19. Y. P.Varshni. *Ap&SS*, **37**, pp. L1–L6 (1975).
20. Y. P. Varshni. *Ap&SS*, **51**, pp. 121–124 (1977).
21. Y. P. Varshni. *Ap&SS*, **46**, pp. 443–464 (1977).
22. Y. P. Varshni. in S.Fujita (ed.), *The Ta-You Wu Festschrift: Science of Matter* (1978) Gordon and Breach, New York, pp. 285–305.
23. Y. P. Varshni. *Phys.Canada* **35**, pp. 11–17 (1979).
24. Y. P. Varshni. *Ap&SS*, **74**, pp. 3–10 (1981).
25. Y. P. Varshni. *Ap&SS*, **117**, pp. 337–350 (1985).
26. Y. P. Varshni. *Ap&SS*, **149**, pp. 197–215 (1988).
27. Y. P. Varshni. *Ap&SS*, **153**, pp. 153–167 (1989).
28. Y. P. Varshni, and C. S. Lam. *Ap&SS*, **45**, pp. 87–97 (1976).
29. Y. P Varshni, and Nasser, R. M.. *Ap&SS*, **125**, pp. 341–360 (1986).
30. J. Talbot, and Y. P. Varshni. *BAAS*, **31**, p. 952 (1999).
31. A. B. Underhill. *PDAO*, **11**, 209 (1959).
32. Wright, W. H.. *PLicO*, **13**, Part VI (1918).
33. C. S. Beals. *PDAO*, **4**, 271–301 (1930).
34. B. Edlen. *VA*, **2**, pp. 1456–1469 (1956).

35. A. B. Meinel, A. F. Aveni, and M. W. Stockton. *Catalog of Emission Lines in Astrophysical Objects*, Optical Sciences Center Technical Report, Tucson: University Arizona, Optical Sciences Center and Steward Observatory, 2nd ed (1975).
36. J. S. Plaskett. *Publ. Dominion Astrophys. Obs. Victoria*, **2**, 346 (1924).
37. A. B. Underhill. *ApJ*, **136**, pp. 14–20 (1962).
38. P. Swings. *ApJ*, **95**, pp. 112–133 (1942).
39. W. W. Campbell. *A&A*, **13**, pp. 448–398 (1894).