STANDARD CANDLES IN QSO's?

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We present here the current status of a continuing program to investigate the possibility that certain resonance lines in the spectra of QSO's can be used as luminosity calibrators for the spectra.

I. INTRODUCTION

Baldwin (1977) discovered a strong negative correlation between the equivalent width of the Lyα and C IV λ1549 emission lines in QSO's and the luminosity of the underlying continuum. The effect was used by Davidsen, Hartig and Fastie (1977) to determine the luminosity of 3C 273. From a comparison between the derived luminosity of 3C 273 and the luminosity given by Baldwin (1977) for high redshift QSO's, Davidsen et al. (1977) found a formal value for $q_o \approx 1.0$.

Possible systematic effects which could produce the correlation found by Baldwin include: a) observational selection effects that were not properly taken into account in the initial "random" sample of QSO's, b) effects associated with the radio properties of the QSO's, c) evolutionary effects that would be a function of z, and d) observational errors associated with a sample of spectra that was taken for other purposes over a period of years with an instrument whose physical configuration was changing.

In order to reduce or remove errors associated with effects a, b, and d and to investigate possible evolutionary effects (c), a moderately large complete sample of flat radio spectra QSO's was chosen from the lists of Schmidt (1977) and Wills and Lynds (1978). It is important to note that the QSO's studied here were chosen solely on the basis of their radio properties and the positional coincidence between the radio and optical positions. The properties of their optical spectra were not a criterion for inclusion in the study; in fact, a number of BL-Lac objects were included in the survey. The number of QSO's chosen was sufficiently large that the correlation between line strengths and continum luminosity could be studied as a a function of z.

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The results given here are the product of the continuing observations by Baldwin, Burke, Gaskell and Wampler.

II. CURRENT STATUS OF THE PROJECT

A. The C IV Luminosity Indicator

C IV λ1549 was originally selected by Baldwin (1977) as the most useful of the lines that showed a strong luminosity correlation because a) the line is not as strongly distorted by absorption as Lyα in high redshift QSO's, and b) the line is observable in QSO's with a wide range of redshifts ($1.1 \lesssim z \lesssim 3.5$).

In a preliminary status report on the observations of this flat spectrum sample, Baldwin, Burke, Gaskell and Wampler (1978) found that the correlation described earlier by Baldwin (1977) was present in this sample of QSO's and that the correlation existed for subsets of the list that were chosen to have comparatively narrow ranges in z.

Because only the very best observing conditions were suitable for observing the faintest objects in the list, the paper by Baldwin et al. (1978) contained a limited selection of the faintest objects in the observing list. Additional observations have increased the sample of faint QSO's and we find that the new data points lie along the line defined by the earlier observations. We have now observed all but a few of the objects for which we can detect C IV λ1549 from the ground and we find no reason to change our earlier conclusions.

The BL-Lac objects in our sample present a problem. Since we cannot measure the equivalent width of C IV λ1549, if, indeed, C IV λ1549 is present, we do not know where to plot the BL-Lac objects on our graph. In addition to the absence of emission lines, these objects have much steeper spectra than the other QSO's in the survey. We have taken the somewhat arbitrary point of view that they represent a class of objects that can be ignored for the purpose of this survey.

Since our survey began, a few space observations of C IV λ1549 in individual sources have become available. The data for QSO's are consistent with the Baldwin (1977) relationship if $q_o \approx 1$ (Gaskell, private communication). The C IV λ1549 lines in Seyfert galaxies are too weak to fit the regression line defined by the QSO's. Clearly more space observations are needed to investigate the relationship for low redshift QSO's and to provide a wider range of redshifts to determine the value of q_o.

B. Mg II λ2800 as a Luminosity Indicator

In our search for a luminosity indicator that would be useful for

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low redshift QSO's, Baldwin et al. (1978) pointed out that the equivalent width of the resonance line Mg II λ2800 also showed a negative correlation with the continuum luminosity.

New data show that while there does seem to be a correlation between the strength of Mg II λ2800 and continuum luminosity the correlation is not so tight as for C IV λ1549 and the slope of the correlation seems to be slightly steeper than that found for C IV λ1549. In fact for Mg II λ2800, log I(Mg II) ≈ 2/3 log $L_{cont.}$ instead of the C IV dependence, log I(C IV) ≈ 1/3 log $L_{cont.}$

As has been noted by numerous authors, e.g., Davidsen et al. (1977) the continuum level near Mg II λ2800 is not a simple interpolation of the continuum slope in regions away from λ2800. The anomolous excess radiation near λ2800 may be affecting the W Mg II-$L_{cont.}$ relationship. More data will be needed to clarify the situation.

C. The Value of q_o

The new Mg II λ2800 data have been tied to the C IV λ1549 data by measuring both lines in a number of QSO's of intermediate redshift. Despite the scatter in the Mg II λ2800 data noted above, the new data strengthen the conclusion reached by Baldwin et al. (1978) and Davidsen et al. (1977) that the value of q_o as determined by calibrated QSO's is high enough to close the universe. The new UV satellite data of C IV λ1549 in low redshift QSO's also support this conclusion (Gaskell, private communication).

Of course it is possible that an undetected evolutionary effect is giving an anomolous value for q_o, but such an effect, if present, must leave unchanged the relationship between W C IV and $L_{cont.}$ as a function of redshift. We have found no evidence to suggest that the emission line spectra of high redshift QSO's are inherently different from those of low redshift QSO's.

References

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DISCUSSION

Murdoch: The upper three points around 21^m on the m_V vs log W(CIV) diagram in the paper by Baldwin et al. (Nature, 273, 431) have all decreased in intensity by ~ $1^m.5$ compared to their discovery values in the finding surveys. Is this also true of the new points in this region of the diagram? If so, there remains only an ill-defined cloud of points in the centre of the diagram apart from the two points in the lower left of the diagram which are not part of the complete sample.

Wampler: Our measured continuum intensity is less than the stated limiting magnitude of the surveys. By including the emission lines part of the discrepancy is removed but we still find the objects fainter than the limiting magnitude. This could either be because the objects have decreased in brightness since their discovery or because the photographic estimates were incorrect. We now have no way of deciding between these possibilities. However, note that there is still a correlation (although weaker) even if the faint objects are not used.

Murdoch: If the objects near 21^m appeared on the sky survey above their true continuum luminosities because of strong emission lines rather than being variable, then in order to have a truly complete sample one would need to consider other objects with faint continuum magnitudes which may well have weak emission lines.

Wampler: We have not been able to find faint objects with weak CIV. For MgII we have a few examples of such objects. Perhaps just as important, we have found no bright objects with strong lines. We find that even objects such as OQ172, which are reported to have strong lines, have relatively weak lines when compared to faint QSOs. The important result is that the use of this spectroscopic callibration procedure can reduce the scatter in the Hubble diagram by an order of magnitude.

Penston: I think this is very interesting and looks quite encouraging but, in fact, the Seyfert galaxies and BL Lac objects do not fit this relationship. How does an active nucleus know it is a "quasar" rather than a Seyfert galaxy or a BL Lac object?

Wampler: I don't know. We commonly assume that QSOs, Seyfert galaxies and BL Lac objects are different examples of the same phenomena, but we must remember that this is an assumption.

Osmer: Isn't the point of the discussion on variable quasars that if the continuum luminosity varies and the line luminosity stays constant, then you get a track nearly parallel to your luminosity effect?

Wampler: Not quite. For CIV we find $I_{(CIV)} \approx L^{1/3}$ and not $I_{(CIV)} \approx L^0$. I think that the data excludes the latter relation.

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D. Roberts: You have included the same variable (the continuum flux) in both ordinate and abscissa. What does the plot look like if you just throw out the continuum flux and plot the number of CIV photons observed versus the cosmological factors?

Wampler: There is still a correlation, but in the case $I_{(CIV)} \sim L_{cont}^{1/3}$ or $I_{(MgII)} \sim L_{cont}^{2/3}$.

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