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THE SPECTRA OF 3C 273 AND PKS 0736+01*

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ABSTRACT

The spectra of the quasi-stellar objects 3C 273 and PKS 0736+01 are found to be almost identical, having strong Fe II, hydrogen, and helium permitted lines, but no forbidden lines. These spectra are quite distinct from typical low-redshift QSO spectra, and may be difficult to explain with models where photoionizations are the principal ionization mechanism. This may point to a different ionization and heating mechanism for the gas in 3C 273-type QSOs than in normal QSOs.

Subject heading: quasi-stellar sources or objects

The spectrum of 3C 273 has been known for quite some time to be lacking the narrow forbidden lines found in most low-redshift QSO spectra, but to have a large number of permitted Fe II emission lines (Wampler and Oke 1967). A few other objects are known to show these same Fe II lines, including three compact galaxies and one Seyfert galaxy (Adams 1972). However, 3C 273 has until now been the unique example of a QSO having this type of spectrum. The QSO PKS 0736+01 turns out to be another such object; the spectra of PKS 0736+01 and 3C 273 are almost indistinguishable.

Both 3C 273 and PKS 0736+01 were scanned several times during 1972 and 1973 with the Lick Observatory image-tube scanner (ITS) (Robinson and Wampler 1972) attached to the Cassegrain focus of the 120-inch (3 m) telescope, as part of a larger survey of low-redshift QSOs (Baldwin 1974). The individual scans were added together to form an average spectrum for each object. These two average spectra, with power-law continua subtracted out, are shown in figure 1. Both spectra in

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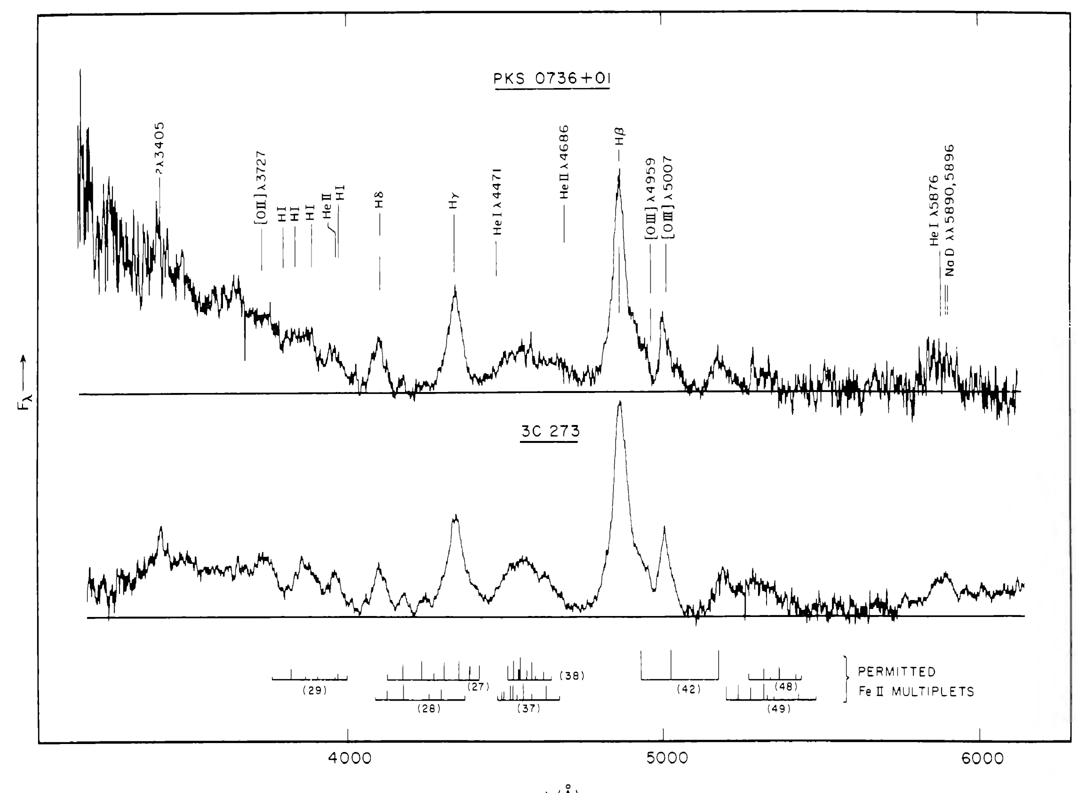

FIG. 1—Portions of the ITS spectra of 3C 273 and PKS 0736+01, corrected for redshift and with power-law continua subtracted out

the figure are shown in terms of their rest wavelengths, using redshifts $z = 0.158$ for 3C 273 and $z = 0.192$ for PKS 0736+01. The relative strengths of the Fe II and Balmer lines are nearly identical in the two spectra. For a cosmological interpretation of the redshifts, and using the continuum fluxes measured for the ITS scans, the absolute continuum luminosities of the two QSOs differ by a factor of 20. In spite of this, the equivalent widths of the emission lines in the two spectra are also very similar.

Wampler and Oke's identification of Fe II in the spectrum of 3C 273 is further strengthened by the ITS scans. The wavelengths of permitted Fe II lines originating in low-lying levels are marked on figure 1, as are the wavelengths of some other lines of interest. Besides the blended lines of multiplets (37), (38), (48), and (49) and the strong λ5018 line which formed the basis of Wampler and Oke's identification, individual unblended lines from multiplets (27) and (28) are clearly present in both spectra. Wampler and Oke concluded that these lines are the result of radiative excitation by resonance transitions at around 2500 Å, followed by permitted transitions to lower-lying, metastable levels. The transitions down into the metastable levels produce the observed emission lines. The forbidden emission lines expected from downward transitions out of the metastable levels are conspicuously absent, which led Wampler and Oke to the conclusion that the electron density is at least as high as 10^6 or 10^7 cm^{-3} in the region where the Fe II lines are formed. There is no sign of [Fe II] in the ITS spectra of either object. The Fe II resonance lines around 2500 Å are occasionally seen in absorption in higher-redshift QSOs (Burbidge, Lynds, and Stockton 1968; Strittmatter *et al.* 1973), but these lines have never been reported either in absorption or in emission in the same redshift system as the emission lines in any QSO. This suggests that this type of object is rare among high-redshift QSOs as well as among low-redshift QSOs.

The ITS scans extend past Hα in both spectra. Strong atmospheric O_2 absorption is superposed on Hα in the spectrum of 3C 273, but by dividing the 3C 273 data by a scan of the QSO PKS 1217+02, which is continuous in this region, most of the 3C 273 Hα profile was recovered. It is evident from the ITS data that 3C 273 has a considerably steeper Balmer decrement than does PKS 0736+01. A further discussion of the Balmer decrements and other relative line strengths in these and other QSOs is given by Baldwin (1974) and will also be the subject of a future paper.

The He I λ5876 line appears in the spectra of both 3C 273 and PKS 0736+01. Wampler and Oke identified this line in the spectrum of 3C 273 as Na D, but a very careful comparison of the new measurements of both the Hα and Hδ profiles with this line shows much better agreement for a line centered on λ5876 than for one centered on λ5892. The He I λ4471 line is blended into the end of a broad Fe II emission band, but a broad emission feature is present at the position of He I λ 3188. There is absolutely no sign of He II λ4686 in the spectrum of 3C 273, but subtracting the unredshifted 3C 273 spectrum from the unredshifted PKS 0736+01 spectrum reveals a weak emission feature at 4686 Å in the latter object.

Features which appear in both spectra and cannot be readily explained as H, He, or Fe II emission are a fairly narrow line at λ3405 and broad bumps in the regions λλ3700–3780 and λλ3830–3910. A possible identification of the narrow feature is multiplet (2) of O IV, which has strong lines at 3403.58 and 3411.76 Å and a weaker line at 3413.71 Å. This multiplet is present in the spectrum of the planetary nebula NGC 7027 (Aller 1956), and its upper level is apparently excited by resonance line absorption of quanta at 238 Å. The narrow λ3405 line appears in several different scans and therefore must be real. If it actually is due to O IV, which should occur in the region where the Balmer lines are formed, it is strange that this line is not broadened. There are also O IV emission lines that could explain the λλ3700–3780 bump, but these are in the quadruplet series while the O IV ground state is a doublet. The lowest-lying quadruplet state is 8.9 eV above the ground state, corresponding to 10^5 ° K, so it would have to be populated by recombinations if there is to be fluorescence in the quadruplet lines. Osterbrock (1969) suggested that Fe III lines from multiplets (4) and (5) might also be excited by resonance fluorescence, but there is no sign of these lines in either spectrum.

It is not clear whether models which assume that the gas is photoionized can explain the spectra of 3C 273 and PKS 0736+01, because of the high electron densities apparently required in the region where Fe^+ is found. Wampler and Oke estimated that about 10^{-3} to 10^{-4} of the Fe in the highly ionized gas should be in the form of Fe^+, and that this would be sufficient to explain the observed Fe II line strengths. Bahcall and Kozlovsky's (1969) model indicated that the Fe ionization is higher than this estimate. The Fe II emission in their model was found to come from an extended zone of partially ionized hydrogen in the outer regions of the nebula, but this zone does not appear in Davidson's (1972) or MacAlpine's (1972) models and is apparently the result of the artificial temperature structure of Bahcall and Kozlovsky's model. The more recent models do not, however, calculate the Fe ionization. If the Fe really is too highly ionized for the Fe II emission to come from the H II region proper, it is possible that it might originate in an extended region outside the H II zone where helium is partly ionized by high-frequency photons. These extended He II zones are not found in models where there is a high-frequency cutoff in the ionizing continuum, however, and the absence of He II lines in the spectrum of 3C 273 may well be due to just such a high-frequency cutoff. Judging from the spectra of 3C 273 and PKS 0736+01, the Fe II lines seem to have the same strength relative to the hydrogen lines whether or not He II λ4686 is observed.

It is puzzling, then, that only a small fraction of QSOs show these "iron" spectra, but that the spectra should be so nearly identical when they do turn up. The relative strengths of the Fe II and Balmer lines and the absence of the forbidden lines must be governed by the same mechanism, and this mechanism must be insensitive to the luminosity or to possible cutoffs in the power-law continuum. Since this may be difficult to explain in models in which photoionizations dominate, it may well point to collisional ionization or shock-wave heating, where the ionization states are much more intermixed, as the source of heating and ionization in objects with this type of spectrum. The fact that the equivalent widths are so nearly the same in the two spectra, on the other hand, is quite understandable if the H II regions are photoionized and are optically thick (Sargent and Searle 1968).

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