THE QUASAR REDSHIFT LIMIT

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The concept of a redshift limit for quasars was first mentioned a decade ago by Schmidt (1970, 1972) and Sandage (1972) who independently realized that faint, high redshift quasars were not being found in the numbers expected from the redshift and magnitude distribution of bright quasars. Subsequently the limit moved out in redshift to $z \sim 3.5$ from $z \sim 2.5$ after the discovery of OQ172 ($z = 3.53$, Wampler et al. 1973) and numerous other quasars with $z > 3$. It should be said at the outset that the limit concept is in need of definition. While it would be most interesting if an absolute limit existed, i.e., no quasars beyond a certain redshift, in reality the limit value is more likely to be the redshift at which the quasar space density turns down significantly.

What is the case for a quasar redshift limit? On purely observational grounds there has been great difficulty in finding quasars with $z > 3.5$. In the nine years since the discovery of OQ172, the number of known quasars has increased by more than a factor of 5, yet only in March of this year was a larger redshift found, PKS 2000-330, with $z = 3.78$ (Peterson et al. 1982). In the meantime more than 20 quasars with $3.0 < z < 3.5$ were discovered. While there was formerly a justified concern about observational biases against the discovery of quasars with $z > 2.5$ because of their loss of a characteristic ultraviolet excess, such concern is no longer warranted. The development and success of the objective-prism technique for finding quasars has shown that a color-independent approach can be very effective for $z > 3$ (see review by Smith 1978). Similarly, the improvement of radio positions means that sources now can be identified only from positional coincidences. Indeed there has probably been a bias in favor of large redshifts in recent work on radio catalogs as a result of researchers looking for neutral or red stellar objects near radio positions.

Specific searches for quasars with $z > 3.5$ with the objective-prism technique by Koo and Kron (1980) and Osmer (1982) have failed to find any despite limiting magnitudes that should have been more than faint enough. Osmer addressed the space denity question in particular. Because he did discover 15 emission-line quasars and galaxies with $0.03 < z < 3.36$ in his survey, he could make a good estimate of the

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limiting sensitivity attained and show that from 9 to 22 quasars were expected with $3.7 < z < 4.7$ if the space density were constant or followed the exp $(10\ \tau)$ form of density evolution. As none were found, he concluded that the space density must decrease significantly for $z \gtrsim 3.5$. Note that a density law increasing as steeply as $(1+z)^6$ had previously been ruled out (Carswell and Smith 1978).

Obviously the discovery of PKS 2000-330 shows that the red-shift cutoff is not absolute at $z \sim 3.5$, but does not in itself affect the conclusion that the space density begins to decrease near $z = 3.5$. In the fact the spectrum of PKS 2000-330 shows such a strong Lyα emission line that it would have been easily detected with the grating-prism technique, more easily than many of the objects that were found. It is most important to continue the search for quasars with $z > 3.5$ to improve our knowledge of the space density in this critical redshift region.

A decrease in the quasar density for $z > 3.5$ is related to the number counts of faint stellar objects and to the X-ray background. It was clear from Schmidt's redshift magnitude tables in 1972 that a redshift cutoff would produce a substantial flattening in the apparent luminosity function for quasars fainter than 20th magnitude. More recently Bohuski and Weedman (1979) and Koo and Kron (1982), to name just two examples, have commented on how star counts at faint magnitudes provide useful limits on the number of faint quasars, and the latter paper shows evidence for a flattening of the quasar counts at 21st magnitude. Similarly Setti and Woltjer (1979) have discussed how the quasar counts must flatten if the integrated X-ray flux of quasars is not to exceed that of the observed X-ray background radiation. Thus, integrated number counts of faint stellar objects and the X-ray background data are consistent with the concept of a redshift limit, although it should be emphasized that they are by no means a proof.

On the theoretical side, the redshift limit may be interpreted as the formation epoch of quasars, which is rather later in the evolution of the universe than most galaxies are believed to have formed. Alternatively, the limit may be due to intergalactic absorption, or the time at which the intergalactic medium becomes ionized and transparent at the wavelength of Lyα and below. Already the limit has been mentioned in connection with the idea that massive neutrino decay photoionizes the intergalactic medium (Sciama 1982).

Whatever the outcome, the quasar redshift limit will be a lively topic for the next several years.

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DISCUSSION

Braccesi: I think very high-z objects (z > 3.5) should be searched for at relatively bright magnitudes (∿ 18), allowing for a sufficient sky coverage, and not trying to go extremely faint in very limited areas. This suggestion comes from the evolutionary model I presented before.

Osmer: This is a valuable suggestion. I can add that a number of plates have been taken to date with the Curtis Schmidt by Smith, and I believe with the Burrell Schmidt by Pesch, to look for bright quasars with 7 > 3.5. The results have all been negative.

P. Verón: In his survey for high redshift quasars, Osmer has found 12 quasars (and three low redshift emission line objects). The observed wavelength of the emission lines (one per object) seen on the grens plate falls into two narrow wavelength windows which correspond to the two sensitivity maxima of the IIIa-F emulsions in the used range λλ5700 - 7000 (see figure). These windows cover one-third or one-quarter

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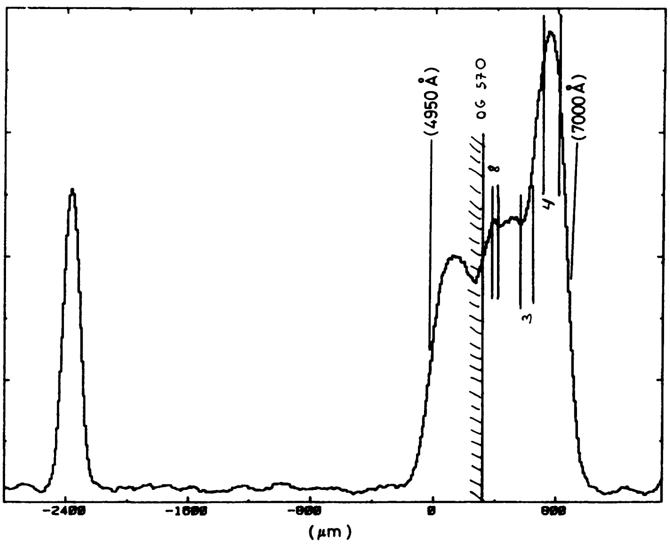

Spectrum of a red star from a grens plate taken on a IIIa-F emulsion at the prime focus of the CFH telescope in Hawaii. The cut-off due to the OG570 used by Osmer is shown as well as the three narrow wavelength windows which contain all of the emission lines found by Osmer on his own plate.

The three lines detected on a sensitivity minimum of the F emulsion are all [O III] λ5007 from low redshift galaxies; this line is probably

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easier to detect than broad quasar emission lines because it is usually strong and narrow. All quasar emission lines have been detected on the sensitivity maxima.

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of the total range available. This suggests that Osmer's survey could be incomplete by as much as a factor of four, this being due to the very wavy shape of the spectral response of the IIIa-F emulsion. If this is the case, Osmer's estimate of about eighth high redshift, Lyman α quasars in his field (assuming constant space density between redshift 3.5 and 5) is reduced to two and the fact that none has been found is not significant.

Osmer: I agree that the wavy nature of the IIIa-F wavelength response makes it a difficult emulsion to use. While it is true that the quasar emission lines were found in narrow wavelength regions, some of the galaxy emission lines (note that these particular galaxies look very similar to quasars on the grism plates) do not fall in between the two main peaks. Nonetheless, Dr. Verón makes a very good point.

If we continue his argument, however, it is remarkable that so many quasars were found in the C IV line in the narrow redshift range. As Drs. Peterson and Savage have pointed out, this means that the numbers may be higher than previously thought, which still suggests that quasars with $3.7 < z < 4.7$ should have been found. Their thesis is that the Lα emission is weak at $z > 3.5$ due to absorption cutting into the line.

Peterson: A new QSO with a z of 3.6 has been found last week in Australia by Shanks and Clowes from the University of Durham

Osmer: This reminds me of 1973 when OH 471 ($z = 3.40$) and OQ 172 ($z = 3.53$) were found within months of each other.

Savage: Have you taken a spectrum of PKS 2000 - 330 with your grism system? And can you see the Lyman α line?

Osmer: No, I have not yet been able to obtain the grism spectrum.