Steep functions in astronomy: the RQSO $z$-cutoff debate

J. V. Wall

Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, B.C. V6T 1Z1, Canada

Abstract. The debate over the existence of a redshift cutoff for radio-loud QSOs (RQSOs) hinges on interpreting a second-order effect – radio spectral variations in variable QSOs initially selected by survey from a population with a steep source count. I discuss the resolution of this question; the issue is highly relevant to modern surveys and follow-up observations.

Astronomers find steep, open-ended functions difficult: the log $N$ - log $S$ curve for example, or the probability-area-radius relation in making cross-waveband identifications. The argument (Jarvis and Rawlings 2000; Wall et al. 2005) over a RQSO redshift cutoff is an instance in which a second-order effect from steep selection functions causes discrepant results in different analyses.

Such a cutoff is present in optically-selected QSOs of the SDSS (Fig. 1, triangles) and in X-ray selected QSOs of XMM, ROSAT and CHANDRA (Fig. 1, circles, points). A similar cutoff for radio-loud QSOs is important because if present it points to a real cutoff; obscuration cannot be responsible. Such a cutoff then defines an epoch of creation for galaxy hosts of massive black holes powering AGN, a datum for e.g. hierarchical galaxy formation in a CDM universe. Jarvis and Rawlings (2000) concluded that the presence of an RQSO redshift cutoff was unproven. In contrast, using a similar sample of RQSOs Wall et al (2005) found conclusive evidence for a decline of space density to high redshifts (Fig. 1, curve + shaded lines).

Testing for a RQSO redshift cutoff must start with dogged hard work to produce a sample of radio-loud QSOs complete to a radio flux-density limit, and with $\sim$ complete optical identification data, including redshifts. The Parkes 2.7-GHz quarter-Jansky sample (Jackson et al. 2002) fits the bill: it covers much of the southern sky, and contains a sub-sample of $\sim$ 400 QSOs with spectra selected to have spectral indices $\alpha$ (with $S \propto \nu^\alpha$) $>-0.4$ in the range 2.7 to 5.0 GHz. Most of these RQSOs have redshift determinations.

A statistical method to examine variation in space density is to take the $1/V$ space-density contributions for all QSOs over some epoch, say $1 < z < 3$, and use these to predict space density contributions at epochs out to which the survey permits them to be seen, e.g. $3 < z < 8$. The objects become invisible.
at the larger redshifts because either flux density falls below the survey limit, or the spectral index in the observer range (2.7 - 5 GHz) falls below $-0.4$. The contributions of each source at higher redshifts are then added, and compared with the number of RQSOs observed. Two related issues in this approach are:

1) the detection-limit line in the luminosity-redshift plane for the radio survey. This differs for every object because the GHz-range radio spectra of RQSOs scatter wildly, with single or multiple 'bumps', and/or steep drop-offs or steep rises. The issue was resolved by the invention of the 'single-source-survey' technique (Wall et al. 2005), in which every source is given its own luminosity-redshift plane, with a 'survey' cutoff line unique to its radio spectrum.

(2) spectral measurement, in the presence of variability. If flux measurements at frequencies above the survey frequency are biased low, then spectra appear to steepen, objects can be 'seen' to smaller distances, and a low estimate of expected numbers at high redshifts follows. Most high-frequency measurements for our sample and for the sample of Jarvis and Rawlings (2000) were made at 8.4 GHz, 25 years after the initial finding survey. But all radio surveys primarily select variable sources biased high, with survey-frequency flux densities above that of the time-average for each source. This is from the steep source count: simulations show that for a count of slope $-2.5$, 78% of all variable sources are selected in the up-state. Higher-frequency measurements made years later result in a time-average of the flux density; this in combination with survey data means that the average high-frequency spectrum is biased to be too steep.

In fact we were lucky to have 8.9-GHz measurements of the 40 brightest objects in the sample taken at the time of the 2.7-GHz survey (Shimmins and Wall 1973). Because the brightest RQSOs make the major contribution to the numbers predicted at $z > 3$, this was just enough data to correct for the bias; furthermore, it demonstrated the extent of the bias. In 25 years, 8-GHz intensities had changed by factors of up to 4. Fig. 2 shows end-to-end bootstrap tests of our analysis. Assuming uniform space distribution, all of the 4000 predictions lie well above the total of 18 $z > 3$ QSOs observed in our sample. The relative dearth of RQSOs beyond $z > 3$ is highly significant.

If variability is involved, intensities (line or continuum) measured after the finding survey will inevitably bias the spectrum of the sample. It is not obvious that a post-hoc statistical correction can be applied. This has serious implications for all modern multi-wavelength studies in which variability is involved; biases are inevitable and analyses ignoring them are suspect.

REFERENCES: Jackson, C.A., et al. 2002, Astron. & Astrophys. 386, 160; Jarvis, M.J. and Rawlings, S. 2000, Mon. Not. R. Astr. Soc. 319,121; Shimmins, A.J. and Wall, J.V. 1973, Austr. J. Phys. 26, 93; Wall, J.V., et al. 2005, Astron. & Astrophys. 434, 133.