SCIENCE

Quasar Redshifts from S-CAM Observations: Direct Colour Determination of ~12 Gyr-Old Photons

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CCDs have revolutionised astronomy in the last quarter of the 20th century, yet measuring energy distributions of celestial objects still requires the indirect methods of filter photometry or dispersive spectroscopy. The development of superconducting tunnel junction (STJ) detectors (Perryman et al., 1993; Peacock et al., 1996, 1997) has opened up the possibility of measuring individual optical photon energies directly. The first time-and spectrally-resolved observations of cataclysmic variables and pulsars using these techniques have been reported (e.g., Perryman et al., 1999, 2001; Bridge et al., 2002), and the first direct measurements of the redshifts of quasars using an imaging detector with intrinsic energy resolution were published early this year (de Bruijne et al., 2002; cf. `http://astro.esa.int/SA-general//Research/Detectors_and_optics/`).

Observations

We observed 11 Lyman-limit quasars, selected from the literature in the range $z=2.2-4.1$, using S-Cam2 (Rando et al., 2000) on the William Herschel Telescope in October 2000. S-Cam2 is a 6×6 imaging array of $25\times25\,\mu m^2$ (0.6×0.6 arcsec^2) tantalum junctions, providing individual photon arrival times to ~5 µs, a resolving power of $\Re\sim8$ at 500 nm, and a high sensitivity from the atmospheric cutoff to ~720 nm (this cutoff is currently set by long-wavelength filters which reduce thermal noise photons). All targets show strong Ly-α and CIV emission lines which, at redshifts ~2–4, fall in our wavelength response range.

Information on each detected photon consists of arrival time, coordinates of the junction, and an energy channel E in the range 0–255. Laboratory measurements have confirmed that all junctions have a highly linear energy response, so that an incident photon of energy E_p is assigned to an energy channel $E\sim42.5\cdot E_p[\mathrm{eV}]-2.0$ (de Bruijne et al., 2002).

Results

We determined quasar redshifts z by fitting the calibrated observed energy distributions with a single template HST quasar spectrum, i.e., by minimising the function $\chi^2(z)$ (de Bruijne et al., 2002). Examples of observed and modelled spectra are shown in Figure 1. The overall shape of these spectra, in particular the falloff at low energy channels (long wavelengths), is due to the combined response of the instrument and telescope. In practice, the Ly-α line and the associated break at shorter wavelengths contribute most to the redshift determination.

Figure 2 compares the best-fit redshifts with the literature values. QSO 0127+059 is our single prominent outlier. It was discovered in a thin prism survey, classified as a possible quasar, and tentatively assigned a redshift of $z\approx2.30$ with a questionable line identification. Our fit provides a good representation of the data (Figure 1), yet the derived redshift, $z=2.976$, differs significantly from the literature value. We therefore obtained a spectrum of this object with the Siding Spring Observatory 2.3-m telescope, from which a redshift $z=3.04$ was deduced, in excellent agreement with our estimate!

As all fits have reduced $\chi^2\gg1$, none of them is formally acceptable. The general consistency between the models and the observations, combined with the pronounced, deep and narrow, minima in all $\chi^2(z)$ plots, nonetheless indicates that our model fits the data well. Small systematic errors related to, e.g., template mismatch, are, although largely hidden due to the limited detector resolution, the key to this paradox (de Bruijne et al., 2002).

Discussion

Pronounced $\chi^2(z)$ minima are already present in our data truncated *a posteriori* to observation times as small as, e.g., 10–20s for QSO 0000–263 ($z=4.1$; $V=17.5$ mag), where ~350 source photons s^{-1} were recorded (Figure 3). We therefore conclude that efficient low-resolution spectroscopy of faint extragalactic sources is possible with STJ devices, enabling the determination of redshift. Extraction of detailed physical information from the spectra presented here is limited by the modest resolving power of S-Cam2 ($\Re\sim8$). A significant improvement in energy resolution is,

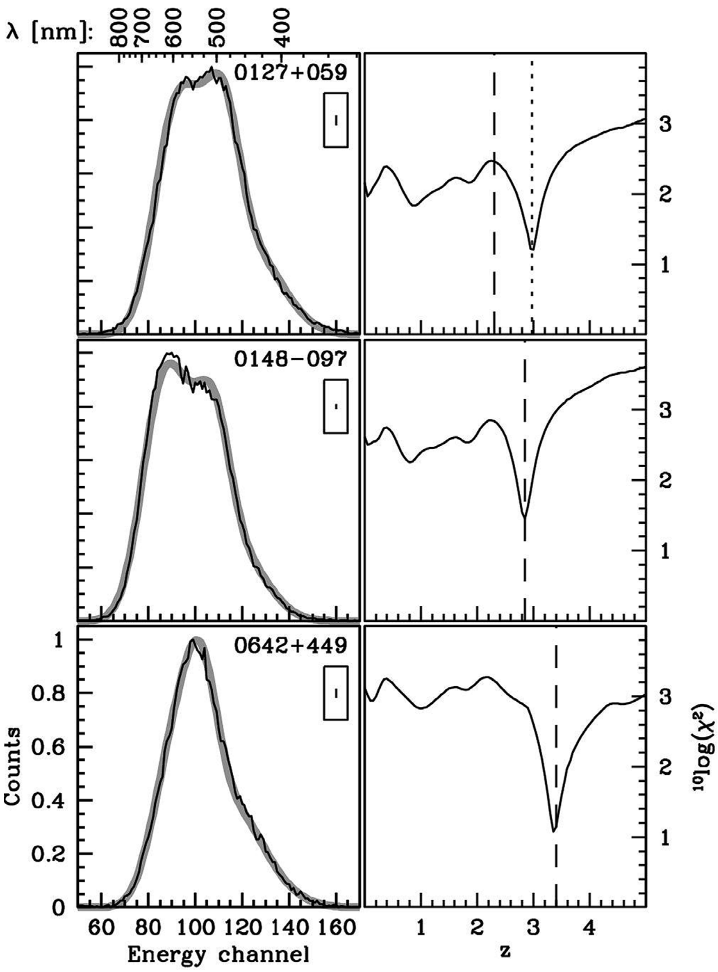

Figure 1. Results for QSO 0127+059, 0148−097, and 0642+449. Left: observed (black) and modelled (grey) energy channel distributions (arbitrary units). Our model is based on a single template HST quasar spectrum. Insets indicate the Poisson noise. Numbers above the top left panel show the mapping between energy channel and wavelength. Right: the corresponding dependence of χ^2 on z. Vertical dashed lines indicate the literature redshifts; the dotted line for QSO 0127+059 indicates z = 3.04 (see text).

however, foreseen in the future (e.g., Rando et al., 2000), promising enhanced physical diagnostic capabilities. It has, for example, been shown that an STJ detector with $\Re \sim 20$ would allow the determination of galaxy morphological type and perhaps emission and absorption line ratios (Jakobsen, 1999; Mazin & Brunner, 2000).

STJ instrument development within ESA is currently also aimed at producing larger format arrays, to facilitate sky subtraction and possibly allow for multi-object spectroscopy, and at extending the wavelength response further to the red. The latter objective, which is consistent with the fundamental device response characteristics, would open up a larger accessible redshift range.

Acknowledgments

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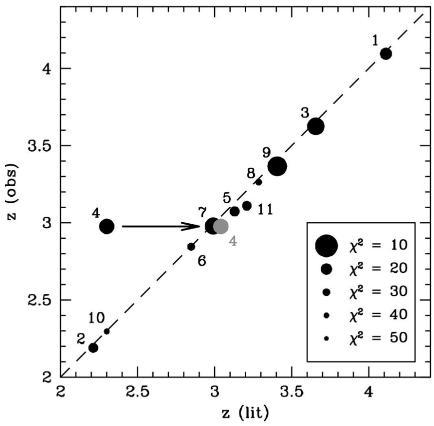

Figure 2. Observed versus literature redshifts. Numbers refer to the objects (de Bruijne et al., 2002). Symbol sizes correspond to χ^2; smaller symbols indicate a poorer fit. QSO 0127+059 has an incorrect literature redshift of 2.30; follow-up spectroscopy has yielded z = 3.04, moving the point to the position shown in grey. The dashed line shows the 1:1 correlation.

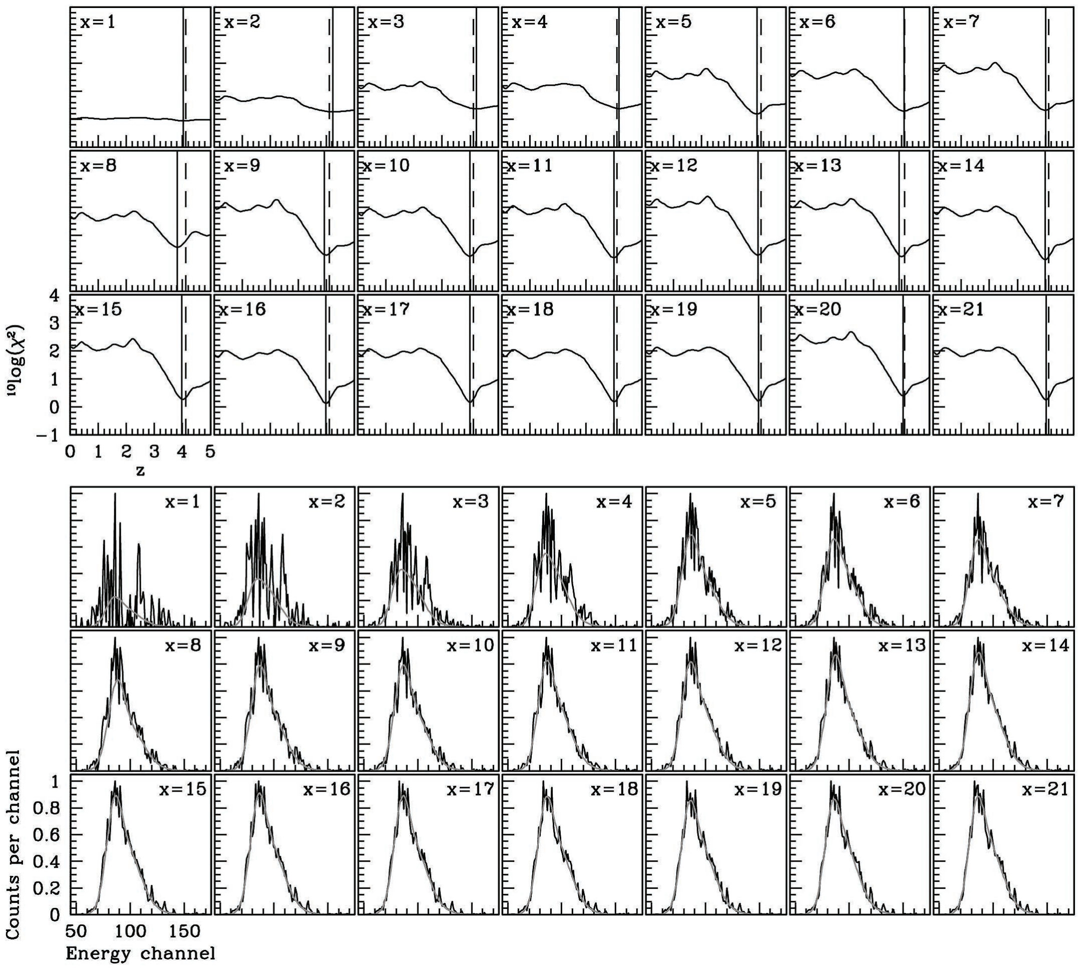

Figure 3. Top: $\chi^2(z)$ using the first $x=1,\ldots,21$ seconds of data of QSO 0000−263 ($z=4.1$). The dashed and solid lines indicate the literature and best-fit redshifts, respectively. Bottom: as top panels, but showing the observed QSO spectra (black) and best-fit models (grey). Panels have differing vertical scales.

The CIRSI-INT IR Survey

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The Isaac Newton Telescope has been used in conjunction with the Cambridge InfraRed Survey Instrument (CIRSI), to undertake a wide area deep IR survey in the *J* and *H* bands. This article gives a brief introduction to the survey and presents some initial results. In the spirit of the INT Wide Field Camera Survey program (Walton et al., 2001; `http://www.ing.iac.es/Astronomy/` `/science/wfs/`; `http://www.ast.cam.ac.uk/~wfcsur/`) we are making reduced data products publicly available. A preliminary data release is planned for April 2002 with a complete release planned in the Summer 2002. The survey observations have been used in conjunction with optical CCD data from the INT Wide Angle Survey to undertake a survey for low and intermediate redshift quasars ($z<3$) free from the potential biasing effect of dust absorption. The results of these observations are reported to illustrate the utility of the survey data for combined optical-IR survey projects.

CIRSI-INT IR Survey

With a field of 4×7.80'×7.80' at the prime focus of the 2.5m Isaac Newton Telescope, the Cambridge InfraRed Survey Instrument, CIRSI (Mackay et al., 2000), is currently the largest field of view IR imager in operation. The camera, a mosaic of 4 Rockwell HgCdTe HAWAII IR arrays, is capable of observing in the *J* and *H* bands at the INT. The physical construction of the detector arrays prevents them being butted together