An Amateur Challenge - a Quasar Redshift

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For many Webb Society members it is not sufficient to read about astronomy - we need to experience real photons impinging on the retina whether first-hand at the telescope or (more contentiously) second-hand at the computer screen. For me it has been a long-standing ambition to record a spectrum showing a cosmological redshift and to do so from my London backgarden with home-made equipment. The prospects were daunting with no obvious guides in the literature - all of professional origin. No mention could be found of small 30cm aperture SCTs or tiny prisms or gratings. In any case professionals had done it all before - 1999 is the 70th anniversary of Hubble's announcement of universal recessional redshifts for galaxies beyond our Local Cluster. For Hubble to extrapolate his findings beyond relatively nearby galaxies in Virgo and Pisces he built fast spectrographic cameras which still needed accumulated exposures of 10 to 20 hours spread over several nights. Thank heaven for the modern CCD camera!

Resolution v image brightness

In capturing a stellar redshift the amateur spectroscopist faces a dilemma. The brightest stars in the sky have relatively small radial velocities and the very high spectral dispersion needed results in very long exposures. As the velocities increase (in say nearby galaxies) the object brightness plummets and although lower dispersion is now acceptable the exposures is still exceptionally long.

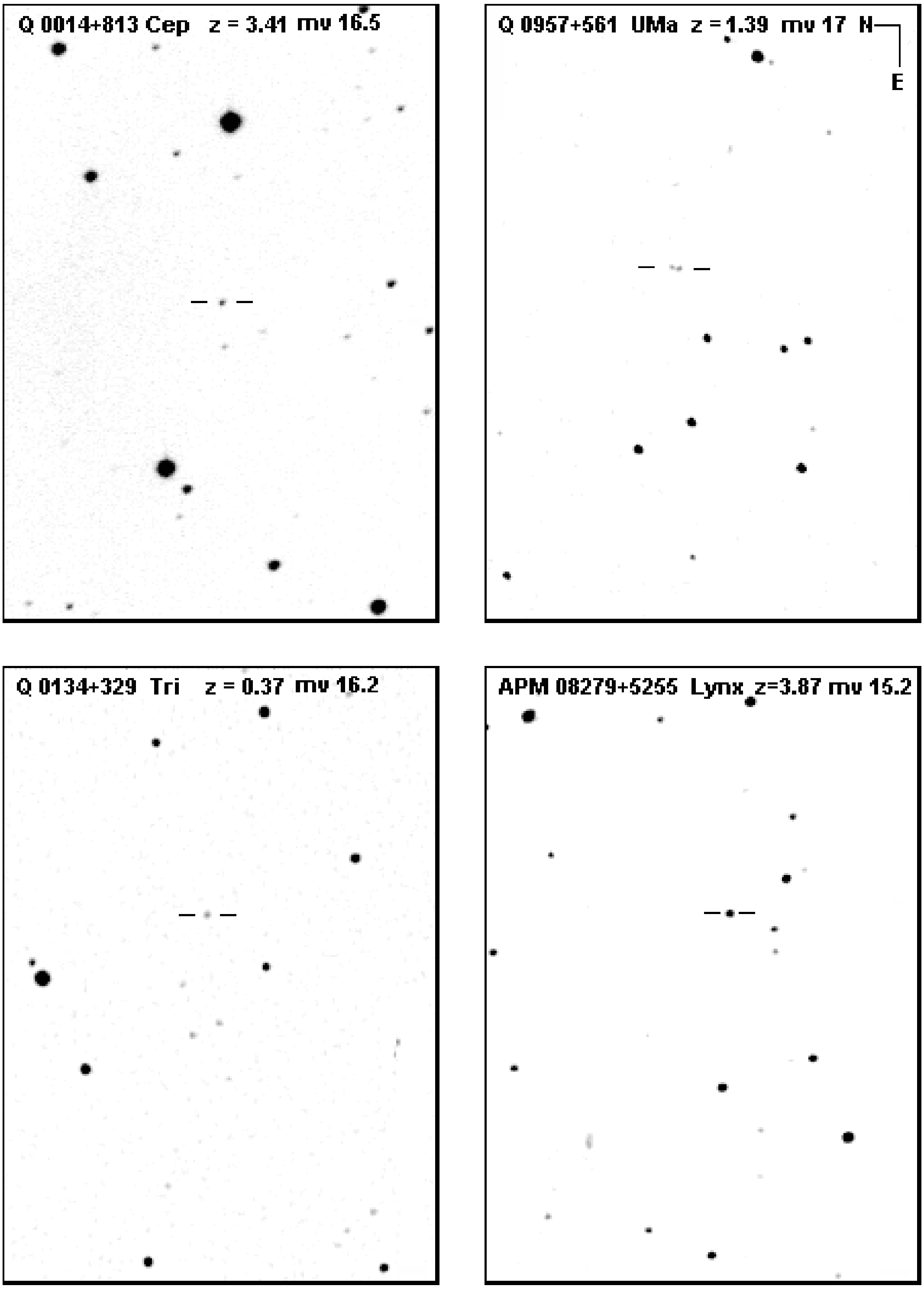
As a result my spectroscopy has gone into reverse in terms of resolution to meet this challenge. In the late 1970's a powerful solar spectrograph was devised using one of Brian Manning's gratings giving a dispersion of 0.40nm/mm in a spectrum 1m long. However the Sun is 26 magnitudes brighter than a first magnitude star and to retain this resolution exposures would be impossibly long. Later an objective prism before a dedicated 250mm f/4 reflector shrank a stellar spectrum to about 20mm long or 20nm/mm dispersion with 8th mag stellar spectra captured in exposures of 10 minutes.

The objective prism has an advantage over a grating - high efficiency with all the light concentrated into a single spectrum and no slit to restrict starlight. The downside is exposures are limited by skyfog (severely so in suburbia) and no reference source of spectral lines can be conveniently added for radial velocity measurement. Not that this instrument would have any to measure with its limited stellar penetration for most stars in the vicinity of the Sun have radial velocities that are too low for its detection.

Going fainter

In order to record fainter stars the objective prism was temporarily set aside. A home-made slitless spectroscope was attached to the Meade 30cm SCT focal plane incorporating a direct-vision (dv) prism giving a resolution of 1.6nm/pixel (at 550nm) and dispersion of 130nm/mm. There is a limit to how far low resolution can be pushed before the vital absorption lines are swamped by the star's bright background continuum. Fortunately A0 type stars like Vega, Altair and Sirius have strong hydrogen absorption lines (Balmer series) that record well as do the molecular bands in M type stars like Betelgeuse. Other spectra were very bland which one exception -emission lines. These appeared to punch-through however low the spectral resolution and pleasing spectrogram of Be types, Wolf-Rayet stars and planetary nebulae were captured.

Unfortunately the dv prism was 70mm thick and the collimator and camera lenses added another 20mm of solid glass - all of which must have absorbed some precious light.



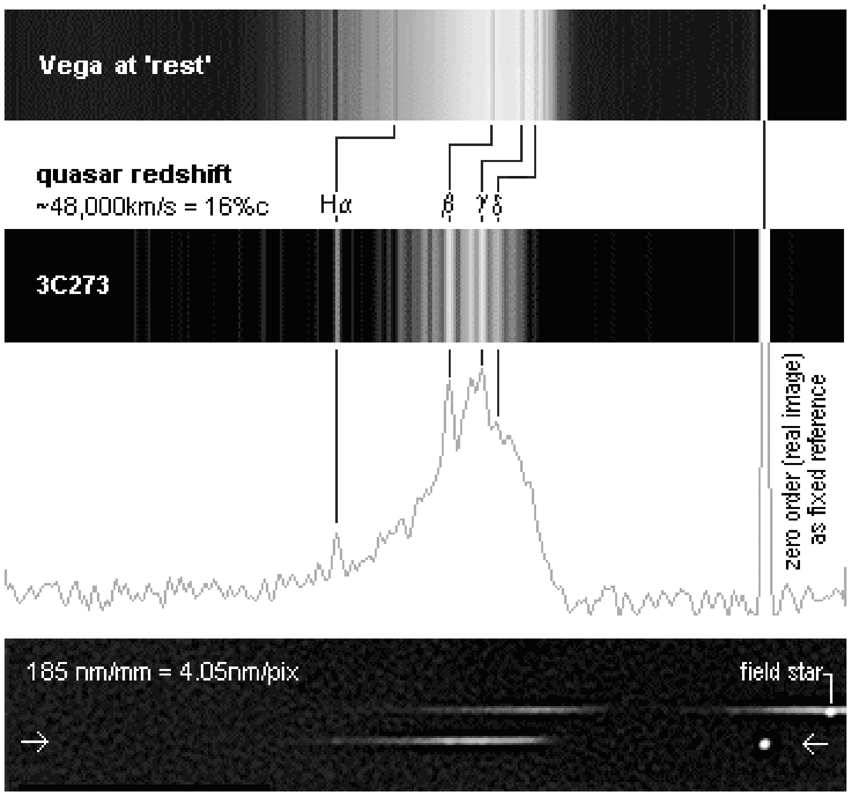
Selection of quasar images captured 1998 Dec. Meade LX 200 SCT + Starlight Xpress MX9 CCD. Typical exposures 10mins Images by the author.

Nevertheless a spectrum of SN1998bu in M96 at mag 11 was recorded in May 1998 that revealed the wide Si II absorption band at 612nm - a good omen. Absorption lines in galaxies were really too feeble to detect and a likely candidate for a cosmological redshift was the quasar 3C273 (QSO 1226+023) in Virgo with emission lines. At m_V13 the quasar is 40 magnitudes fainter than the Sun - my original starting point!

Targeting the quasar

Numerous attempts were made in the autumn of 1998 - rising before dawn to secure a satisfactory spectrum of 3C273 aided by *MegaStar* v3 finder charts. Initially the above prism spectroscope was used but later a transmission grating placed a few centimetres from the detector in the convergent beam of the telescope gave an even lower dispersion of 185nm/mm. Experiments had shown the latter

Spectrum of quasar showing cosmological redshift....



Partial CCD frame showing real image (zero order) and spectrum of quasar.
1998 Dec 21 - 30cm Meade LX200 + grating + MX9 CCD; 24m exp. [c] Maurice Gavin

arrangement was surpassingly efficient in forming a spectrum and the zero order (real image) contained on the frame could be used as fixed reference. Earlier attempts were spoilt by watery skies and light pollution but Monday 1998 December 21st was a turning point. As the individual 3 and 5 minute exposures were downloaded the brightish peaks (emission lines) in the quasar could be seen on the PC monitor which gave me quite a buzz.

Interpreting results

It was assumed the weaker line to the side was Hα and the bright central one was Hβ. The co-added exposure (24 minutes in total) reinforced the image and was electronically stretched into the spectrogram. The quasar and Vega spectra (obtained earlier) were aligned in *PaintshopPro*. Vega's 14km/s radial velocity of approach (blueshift) is quite undetectable in this application and may be assumed as fixed and at rest. By measuring the Hα and Hβ lines in 3C273 against Vega's known spectrum new wavelength values were estimated. Two weaker peaks in the intensity plot were allocated to Hγ and Hδ and again values deduced. The calculations for redshift (z) were completed where the recessional speed = v, velocity of light = c and v = cz thus:-

$$z = \frac{\text{(new wavelength - wavelength at rest)}}{\text{wavelength at rest}}$$

$$\text{i.e. } z = \frac{\lambda - \lambda_0}{\lambda_0}$$

Thus ... for 3C273 ...
$H\alpha = 0.1509$ $\beta = 0.1584$ $\gamma = 0.1682$ $\delta = 0.1792$ (average $z = 0.164$), say $z=0.16$ – close to the professional value.

3C273 appears to be receding at about 48,000km/s and is some 3 BLY from Earth depending on the Hubble Constant (H_0) applied. As velocities get higher approaching c then a more complex formula is needed to take relativistic effects into account so the object is kept below lightspeed thus...

$$z = \text{square root } (((c+v)/(c-v)) - 1)$$

For the relatively weak Hα line it must be assumed that ...

[1] the Starlight Xpress CCD peaking at 550nm is less sensitive at 755nm (the measurement for this line in 3C273) and ...

[2] this emission line was partially masked by the strong 'A' absorption line (see Vega's spectrum) caused by the Earth's atmosphere when working near sea level.

Conclusions

Quasars continue to be discovered monthly with the largest z value (Jan 1999) >5. Four quasars are figured adjacent - two are gravitationally lensed by intervening galaxies i.e. Q0957+571 in UMa split into two m_v17 components and APM 08279+5255 in Lynx brightened by 20x to a luminous m_v 15.2 despite a high z=3.87 and 12BLY distance. *Sky Catalogue 2000.0* v2 (published 1985) lists some 300 QSOs and is obviously somewhat dated. Many more are contained in *MegaStar* v3.0 (source H-B93) - the QSO designation relates to its approximate β1950.0 co-ordinates.

As singular points of light quasars do little to inspire the eye but hopefully the mind's eye will be fulfilled when the colossal distance and energy of these objects are contemplated.

Acknowledgements:

Thanks are due to Mike Irwin of RGO for the co-ordinates and finder chart of quasar APM 08279+5255.