REDUCTION OF SLITLESS SPECTRA -
THE DETECTION OF FAINT EMISSION LINES

H.-M. Adorf, H.-J. Röser
Max-Planck-Institut für Astronomie, Heidelberg

ABSTRACT

We have developed a spectra reduction system producing relative
spectrophotometry directly from prism as well as from grating spectra
plates. Lines and other spectral features are detected, and their essen-
tial parameters are measured automatically. A deep quasar survey using
this technique is now underway.

1.   MOTIVATION AND AIMS

This work was motivated by the questions: "Why are so few quasars
known with redshifts greater than 3.5? Are they overlooked by the present
survey techniques?" The usual spectral survey method has been "to look at
the plates" in order to detect obvious emission lines. Although the human
eye definitely is an excellent "image processor", it does not work quan-
titatively (and fails on low contrast images). It is therefore difficult
to attack cosmological problems such as the determination of the quasar
space density. These problems require a well defined sample of quasars,
crucially depending on the survey's completeness.

We decided to investigate the advantages of quantitative survey
work, which should result in a homogeneously selected sample with a defi-
nite completeness limit and should make different quantitative surveys
comparable with each other. Spectrophotometry from the survey plate is
also required, because follow-up observations with big telescopes for
large numbers of faint objects would cost too much time to be feasible.

An ideal reduction procedure should maximize both completeness of
the sample and the reliability of the findings. It should (1) certainly
be automated, (2) be "self-adaptive", i. e., work effectively very close
to the noise, and (3) quickly and reliably single out the spectra with
the most "unusual" features. The data together with the procedures used
should define what is unusual. Specifically, the procedure should deter-
mine the limiting equivalent width of a line as a function of the wave-
length, the continuum magnitude, and the line width.

2.   OBSERVATIONS AND DATA MATERIAL

The search for high-redshift quasars requires deep plates in the red. In order to test our spectra reduction system (SRS) we used a blue plate instead, which contains several known quasars and quasar candidates. The plate was taken at the 80/120/240 cm Schmidt telescope on Calar Alto (Spain) in 1981, and kindly loaned to us by Dr. Haug (Hamburg), who is pursuing his own visual survey for emission line objects. The plate measures 24 cm x 24 cm and covers a projected area of 5.7 deg x 5.7 deg. The unwidened spectra, dispersed by the "thin" 1.7 deg objective prism, were recorded on a baked Kodak IIIa-J emulsion. Between 350 and 520 nm the reciprocal linear dispersion rises from 75 to 245 nm/mm, with 139 nm/mm at H_γ. Thus, the resolving power under 2" seeing declines from 200 down to 90, with 135 at H_γ. In 75 minutes a sky background of about 22.7 mag/arcsec2 produces a plate density of 1, and a background signal-to-noise ratio of 20 in an area of 1 arcsec2.

3.   FIRST PHASE IN REDUCTION: FROM RAW DATA TO SPECTRAL INTENSITIES

In establishing the limits of a survey technique we are concerned with the properties of a whole sample of spectra. In order to avoid pre-selecting this set, we scanned sub-areas (or frames) of the plate instead of single spectra using our PDS-microdensitometer with an aperture of 10μm x 10μm and a step size of 5μm. Thus one frame, measuring 2000 x 2000 pixels, covers less than 2 permille of the total Schmidt plate area, or roughly 1/20 deg2. Presently, each frame is then graphically displayed, and "usable" spectra, which surpass a 2 δ (background) threshold above the local background, are interactively selected. A frame contains 30 to 40 of such usable spectra. The limiting brightness of the plate exceeds 20 mag.

All usable spectra are then reduced with procedures comparable to those used by others (Clowes et al. 1980, Christian 1982, Vaucher et al. 1982), which result in a "one-dimensional, background-subtracted, noise-suppressed, wavelength-calibrated spectral intensity trace" along each of the usable two-dimensional spectra. As an example, Figure 1 shows the intensity trace of the quasar PHL 938, which one frame was centered on. Details concerning the SRS can be found elsewhere (Adorf 1984). Note that in the present work we used a constant contrast γ = 3.84 for density to intensity conversion, and did not correct for the varying spectral sensitivity of the emulsion. Also, the wavelength scale is preliminary only and rather uncertain in the green.

4.   SECOND PHASE IN REDUCTION: THE DETECTION OF LINES AND OTHER FEATURES

Since we are trying to detect quasars with arbitrary redshifts by the presence of emission lines, we must be prepared to detect a line of unknown (but presumably broad) shape, of unknown intensity, at an unknown position on an unknown (but presumably flat), noisy continuum. In order

to detect a line, measure its position and derive a confidence parameter
we cross-correlate a given spectrum with a set of (Gaussian) template
profiles differing only in their full width at half maximum (FWHM). The
correlation peak determines the detected line's FWHM and also its simi-
larity to the template. (The detection of features other than lines, such
as continuum breaks, proceeds similarly, and only requires a different
set of template profiles.) Next the spectrum is convolved with an appro-
priate linear filter to measure the line flux or its equivalent width.

Distinguishing noise bumps from true lines remains a problem: Ideal-
ly, the frequency distribution of a measured quantity, such as the "simi-
larity" or the equivalent width, in the whole sample of spectra, should
tell us which lines are probably caused by statistical fluctuations, and
how to choose the right detection threshold. As an example, Figure 2
shows a scatter diagram of the measured line equivalent widths versus the
J-magnitude of the object to which it belongs, for a preselected line
FWHM of 10 nm. From the observed frequency distribution of equivalent
widths we read a current lower limit of around 12 nm for the detection
of such a line in a spectrum of an object brighter than 18th mag.

The ability of our SRS to select a complete sample of spectra has
been tested against three colleagues who, using a microscope, visually
examined 200 spectra within a test area on a different, red plate. Their
task was to search for emission or absorption lines, and to assign a "de-
gree of certainty" to their findings. The visual surveyors seemed to dif-
ferentiate best on moderately dense spectra, but worked inefficiently at
the faint and the bright ends, as has also been reported by others (Haug
1983). At the important faint end, all of the visually detected emission-
line-candidate spectra were also found by the SRS (which found 50 % more
spectra in all). The ability of the reduction system to reject artifacts
with a definite signature (e. g. dust and spectrum overlaps), however,
remains to be improved.

5.   CONCLUSION

We have developed an automated spectra reduction system (SRS), which
produces spectrophotometry directly from slitless spectra plates. The SRS
detects and measures spectral features such as lines, and has proven not
only to be complete in its findings but also to go deeper than visual
surveyors. The ability of the SRS to discriminate against dust and other
faults, however, remains to be improved. The SRS is currently used for a
quantitative deep spectral quasar-survey on plates with photographically
recorded prism spectra, and on films with electronographically recorded
grating spectra. Our SRS is general enough so that other applications
could be considered as well.

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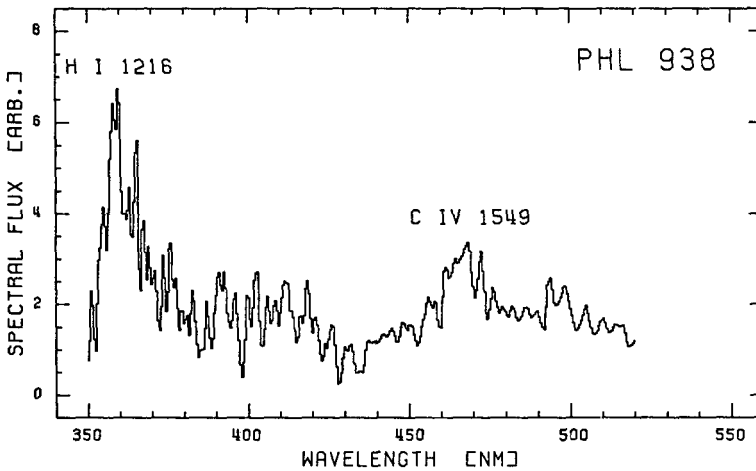   J. 261, pp. 18 – 24

Figure 1: Relative spectral flux of the quasar PHL 938 (B = 17.49, z = 1.955) as derived by the spectral reduction system.
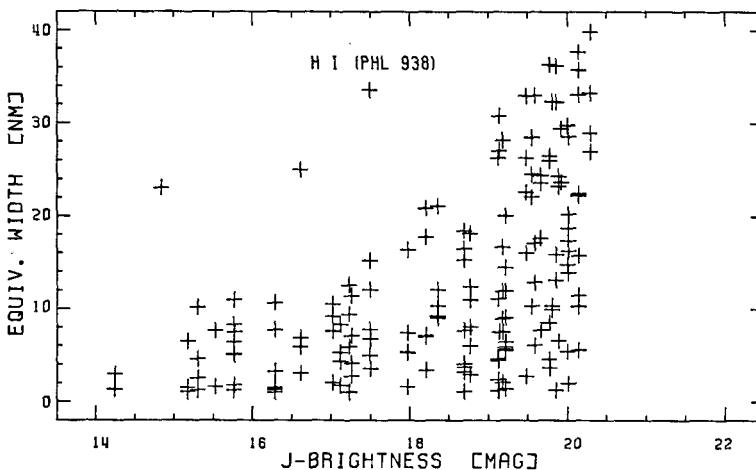

Figure 2: Scatter diagram of measured equivalent widths versus the J-magnitude of the object to which the line (candidate) belongs.