Computerized Microphotometry of Stellar Spectrograms

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Let me begin my description of how we have been doing computerized microphotometry with a brief history of the hardware and its evolution. Then I'll get on to the more interesting topic of what we do with the data after we get them into the computer.

In 1966, the Shock Tube Laboratory at Harvard College Observatory took delivery of a David Mann microphotometer. Briefly, this $50 000 instrument can measure positions in an area 250 × 250 mm to an accuracy of about 1 μm. The limiting resolution of the measuring slit approaches 1 or 2 μm at the plate, and the drift in the photometer output is on the order of 1 per cent in 12 hours.

From 1966 to 1969, we used IBM punch cards to record the output of the microphotometer. The decks of cards were in turn processed off-line on a large computer, the CDC 6400 at the Smithsonian Astrophysical Observatory. By 1968, enough people were using the microphotometer so that the slow data-acquisition rate of 3 readings per sec was a severe limitation. We therefore set about procuring a faster data-acquisition system that records the density readings on magnetic tape. This faster system employs a PDP-8/I computer, which interfaces with the microphotometer, communicates back and forth with the operator via a standard teletype, and supervizes the acquisition and recording of the data.

The original operating system for the PDP-8/I did little more than provide the functions that were available with the punch-card system, yet the program required about 2000 machine instructions. However, the magnetic-tape system does acquire density data about 100 times faster, with about 10 times better reliability, as judged from the number of readings recorded between obvious failures. For example, card jams occurred perhaps once every 2×10^4 readings, while the magnetic tape system gives perhaps 2×10^5 readings between parity errors.

It might be noted that with the punch cards, the astronomer was a bit closer to his data; he could see the numbers as they came out of the microphotometer, and he could edit or rearrange the data easily, so that normally he had a deck that was ready to run as soon as he left the microphotometer room. Also, the magnetic-tape system represents an initial investment of $25 000 as opposed to $5000 for the punch-card system.

During the past four years, perhaps 50 scientists have used the David Mann microphotometer at Harvard. About half of the total usage has been for the measurement of spectra, which were then reduced on the CDC 6400 with a package of programs called MICRO. One of MICRO's major tasks is the conversion of the input density data to an intensity scale. Thus, a significant portion of the coding in MICRO is devoted to processing various sorts of calibration data, such as tube-sensitometer plates, wedge spectrograms, strip spectrograms, and step wedges.

Generally, the first pass with MICRO is checked by the astronomer to be sure that the calibration looks all right before he proceeds with the photometric reductions. Sometimes, for example, when there are only three or four points on the whole calibration curve, the astronomer feels more secure if he can draw his own curve through them. In this case, he has to read some points off his curve on the graph paper and then punch the points on cards for insertion with the data deck for the next pass with MICRO.

One of the elegancies of the computerized reductions shows up in the processing of the calibration data, where we perform some simple statistical analyses and evaluate the signal-to-noise ratio at various density levels, that is, the uncertainty in the inferred intensity scale. Moreover, the treatment of the photographic calibrations can be quite powerful. For example, MICRO can accept calibrations at several different wavelengths, so that the variations of the calibration with wavelength are taken into account in the photometric reduction. In another example, if the original spectrum was poorly widened, MICRO can accept a trace run across the dispersion; it then calculates a new calibration curve suitable to the particular pattern of uneven widening on that spectrum and proceeds with the photometric reduction as before. The extra work for the astronomer required for these more elegant reductions is quite trivial.

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The various projects that have used MICRO to reduce stellar spectra seem to have all started out with an initial stage where the astronomer fiddled for a while with the data after they had been reduced to an intensity scale. At this stage, people get involved in deciding how they want to define the continuum, what lines are good ones to measure, how to handle blends, and so on. For this kind of fiddling, MICRO can produce a line-printer graph, which is quite analogous to the strip-chart tracing from a direct-intensity microphotometer, except that the wavelength and intensity for each point are printed in the margin. Line identifications are much faster and more fun on this kind of display than on a strip-chart tracing. The source of the dispersion solution is, of course, a handful of strong lines that either the astronomer or the computer recognized previously. It is quite normal to pick out one or two dozen lines for the dispersion solution and find that the RMS deviations from the second-order least-squares fit are not much larger than half the spacing between readings.

Some projects never need MICRO beyond this direct-intensity stage, and the astronomer does all the reductions directly on the line-printer graph, much as he would have done on a strip-chart tracing. For these projects, the whole computerized procedure has simulated a direct-intensity microphotometer, but with more elegant reduction procedures and with the advantage that the wavelength and intensity of each point are printed out. This much processing on the computer typically costs about $10 per spectrogram and involves two or three turnarounds during the course of a day.

Several projects have pushed the computerized reductions considerably past the stage of direct-intensity graphs and have therefore realized much greater advantages over classical methods, simply because large amounts of very similar data could be processed with very little guidance or intervention on the part of the astronomer. For example, special subroutines developed for determining rotational velocities were applied by Mrs Faber to the measurement of the rotational velocities of 300 stars. In one of my own projects, I made about 2000 measurements of the equivalent widths of weak lines that were broadened to about 1Å by axial rotation. By use of a finding list for a sharp-lined star of the same spectral type, I picked out weak lines that were impossible to distinguish by eye on tracings of the spectrum of the rotating star because the residual intensities were depressed from the continuum by less than the uncertainty in a single data point. By reducing several exposures of the same star independently and then taking the average of the individual determinations, I was able to beat down the final uncertainty in an equivalent width by a factor of about 3 better than a single determination. This made it possible to use lines as weak as 10 mÅ for an abundance analysis of a fairly rapid rotator.

DISCUSSION

J. B. HUTCHINGS: How important are the corrections for guiding streaks on badly trailed spectra?

D. W. LATHAM: Not very much; you have to have very poorly widened spectra before it makes much difference. Even with an intensity variation of 25 per cent across a spectrum, the net result is only one or two per cent on equivalent width.

J. B. HUTCHINGS: Do you interpolate your data to a pre-specified linear dispersion?

D. W. LATHAM: We have never done prismatic plates. Superposition is done after the complete reduction procedure.

D. A. KLINGLESMITH: Why do you reduce individual spectra first and average afterwards?

D. W. LATHAM: It gives you a better idea of the errors involved; the principal disadvantage is that it's more work than averaging before reduction.