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Laboratory Exercises in Astronomy – Spectral Classification

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P Cygni

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Laboratory Exercises in Astronomy — Spectral Classification

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AUGUSTE COMTE, the French positivist philosopher, defined astronomy in 1835 as "the science by which we discover the laws of the geometrical and mechanical phenomena presented by the heavenly bodies." While the motions of the solar system could be analyzed and understood, the physical nature of the distant stars must be forever unknowable. "Men will never compass in their conceptions the whole of the stars," he stated.

Less than a quarter century later the German physicist Gustav Robert Kirchhoff laid down the laws of spectrum analysis, which opened a wholly new field for investigation. The study of the chemical and physical nature of the sun and stars, considered by Comte as hopelessly out of reach of the human intellect, became one of astronomy's most important branches.

After Kirchhoff's fundamental work, spectrum studies of the stars followed two different avenues. Astrophysicists such as William Huggins and Norman Lockyer combined laboratory experiments with detailed examinations of comparatively few stars, in an attempt to discover their composition and physical condition. On the other route, such pioneers as Angelo Secchi and E. C. Pickering undertook vast classifying schemes in order to understand better the diversity as well as the unity of the stellar populace. Ultimately both approaches were joined when Cecilia H. Payne (now Professor Payne-Gaposchkin) demonstrated that the apparent spectral differences arise primarily from variations in temperature or density, and that the overwhelming majority of stars in our galaxy must have quite similar chemical compositions.

Of all the great spectrum classification projects, none is more extensive than the famed *Henry Draper Catalogue*, a compendium of the spectral classes and magnitudes for 225,300 stars, prepared at Harvard Observatory half a century ago. (Later extensions to this catalogue include another 133,000 stars.) These classifications were made on photographs taken with medium-sized refractors. A thin prism covered the objective lens, producing a spectrum for each star on the plate.

Nowadays, Schmidt telescopes are generally used instead of refractors for taking objective-prism plates. The picture on the facing page was obtained with the 24-inch Burrell Schmidt and a four-degree

FACING PICTURE: An objective-prism spectrogram of a region near Gamma Cygni, taken October 16-17, 1950, with the 24-inch Schmidt telescope of Warner and Swasey Observatory. The exposure was four minutes on Eastman IIa-O blue-sensitive emulsion, by Daniel L. Harris, III.

objective prism at Warner and Swasey Observatory in Ohio. The Case Western Reserve astronomers have recorded the blue and violet portions of the stellar spectra in one of the richest star clouds in the constellation of Cygnus, directly on the galactic equator. The field of some five square degrees lies just south of Gamma Cygni, the center of the Northern Cross.

Most of the properly exposed spectra in this reproduction come from 7th- to 9th-magnitude stars. The brightest is 5th-magnitude P Cygni, near the left (northern) edge of the picture, but its spectrum is quite heavily overexposed. Each spectrum would have been a narrow sliver of light if the telescope had been driven to follow the stars exactly, but instead the images were trailed in an east-west direction to widen them and make the spectral details easier to see and measure.

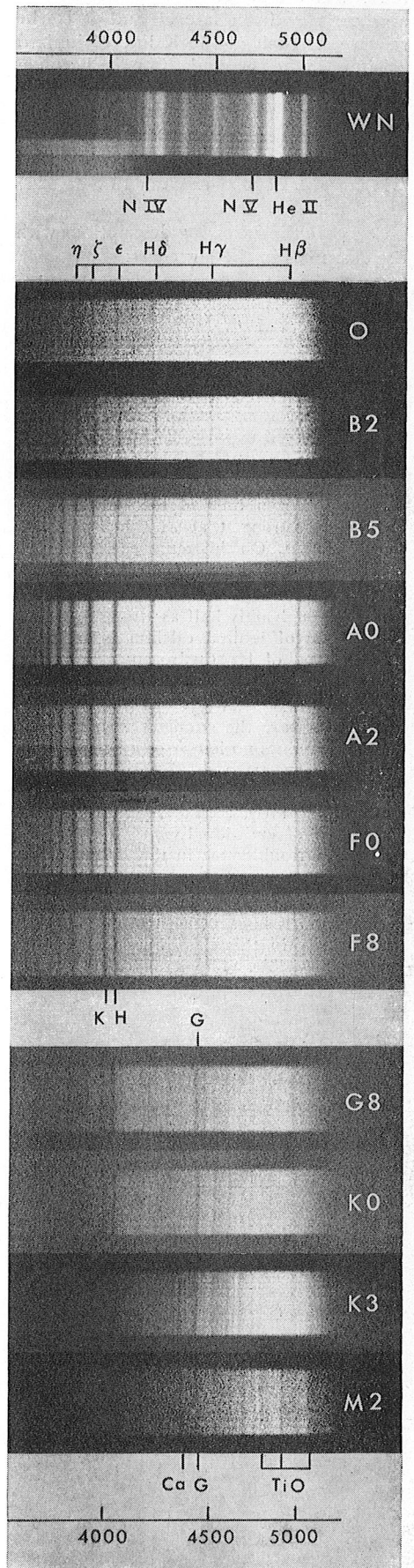
By close examination, we can distinguish the salient details of the Harvard system, which forms the basis of many more elaborate classification schemes in use today. This area of the sky exhibits a variety of spectral types, nearly every major class being represented. Particularly notable here are three of the 22 known Wolf-Rayet stars of magnitude 8 and brighter.

This experiment consists of classifying the spectra of 30 stars. First we examine our enlarged samples on the key, where the stars are placed top to bottom in order of decreasing surface temperature. Violet is to the left, longer wavelengths to the right. Since the photograph was taken on a blue-sensitive plate, the red, orange, and yellow spectral regions have not been recorded, as already mentioned.

Note first that the hotter stars tend to be relatively much more intense in the violet than the cool ones. But it is to the narrow vertical lines in each spectrum that we look for making our detailed classification. This involves assigning a decimal subdivision within each of the major letter types. For example, *A*-type stars can be divided into 10 classes, *A0*, *A1*, *A2*, . . . , *A9*. Class *B9* precedes *A0*, and *A9* is followed by *F0*.

In general, the spectral lines are dark, caused by absorption of light in the star's atmosphere. But at the top of the key is one Wolf-Rayet object, the hottest star considered here, its spectrum containing bright (emission) lines. A quick glance at the bottom of the key might suggest that emission lines are found there too, but this is simply an illusion caused by the crowded pattern of dark lines in *K* and *M* stars. The increasing concentration of energy more and more to the long wavelengths is the first clue to these late-type stars.

In spectral types *B*, *A*, and *F*, the pat-



Compare these typical spectra with the detailed descriptions on the next page. Wavelengths are labeled in angstroms.

tern of hydrogen lines (the Balmer series) plays an important role, immediately distinguishing these early types from the late ones. But the secret for distinguishing *B* and early *A* from late *A* and *F* is the relative strength of the K line of ionized calcium. The H and K pair becomes prominent in *G* and *K* spectra, and important secondary information is given by the strength of the G band at 4307 angstroms with respect to hydrogen-gamma ($H\gamma$) or the neutral calcium line at 4227 angstroms.

Compare the following descriptions with the examples in the key chart:

O—Temperature is so high in this class that helium is singly ionized and other elements are at least doubly ionized. In the visual region these spectra are almost featureless, but strong in the ultraviolet.

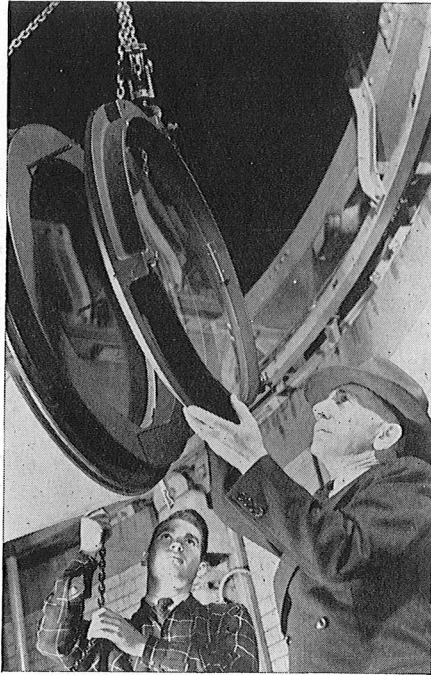
B0—On a long continuum the Balmer series of hydrogen is faintly visible; if the spectrum is well exposed, a few helium lines may be seen. Neutral helium is strongest at *B2*, and then fades rapidly toward *A0*.

A0—Hydrogen lines of the Balmer series are strong (strongest at *A3*); helium is no longer present. On this reproduction the calcium K line is faintly visible in the *A2* star.

F0—The Balmer lines are still conspicuous, although only half as strong as in *A0*; the K line of ionized calcium is as strong as the blend of $H\epsilon$ (hydrogen-epsilon) and the H line of calcium.

G0—In this solar-type spectrum, the H and K lines are the strongest features, with the Balmer lines no longer conspicuous. The continuum spectrum shows through between the numerous metal lines that are just at the limit of visibility, sometimes giving a false impression of emission lines. This aspect is even more troublesome in the *K* stars.

K0—The energy maximum of the spectrum lies far to the red of the ionized calcium H and K lines, which reach their greatest intensity in this class. Many metal lines are easily visible. The strongest is that of



An objective prism over two feet in diameter being fitted to the front of the 24-inch telescope by former director J. J. Nassau. All photographs from Case Western Reserve University.

neutral calcium at 4227 angstroms. Even stronger is the G band 80 angstroms to the red of the calcium line.

M0—The wide bands of TiO , shaded toward the violet, mark the spectra of the *M* class. The 4227 line of calcium is very strong, and the G band is also conspicuous.

We now investigate the spectra on the Cygnus photograph itself. As a trial, sort the first six numbered spectra near the top into some rough order. Notice that 1 and 5 have similar, almost featureless, continua; 2 and 6 are related, both exhibiting many hydrogen lines; 3 is an

emission-line star; 4 belongs in yet another category. The intense part of 4 is very short and is concentrated on the redward end. This indicates a much cooler star than 5, whose spectrum is very strong in ultraviolet light. It is evident that the longer spectra, such as 5, arise from hot, early-type stars, whereas 4 represents a late-type star.

Now compare 2 and 6 more carefully. The hydrogen lines are comparatively stronger in 2, but the most striking difference is the appearance of the H and K pair in 6, which spoils the regular pattern of the Balmer series. Comparison with the key shows that 2 is an *A* star and 6 an early *F*, in fact *A0* and *F2*, respectively.

In 4 the H and K lines are clearly visible, but the hydrogen series has vanished, thus ruling out type *G* and earlier. The dark line some distance to the right of the H and K pair is the G band. Since the 4227 calcium line is not visible, this must be an early *K*, actually *K2*. It is instructive to compare this spectrum with 26, 27, and 28, as well as with the key.

Examples 1 and 5 are clearly much earlier than *A0*, belonging in the *O-B* classes, but an exact classification is difficult on the reproduction because the critical absorption lines are very fine. The long smooth spectrum 5, with no trace of hydrogen lines, reveals an *O* star. In 1 the Balmer series is faintly visible, indicating a *B0* star.

Armed with the key photograph and accompanying description, as well as the examples above, you should be able to classify most of the 30 marked stars on the plate to within two or three decimal subclasses. Watch out for 9, however, for it is two almost superimposed spectra of the same type, and for 10, which has two overlapping parts—classify only the star to the left.