THE SPECTRA OF MIRA VARIABLE STARS

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The spectra of long period variable stars are bizarre at best. Anyone who has looked at them in detail will agree. The complexity and the unpredictability of some of the variations make a detailed interpretation difficult. Because of this, the study of their spectra is an apparent sink for astronomers; observations are not understood much better than in 1940 when Merrill wrote his famous monograph, The Spectra of Long Period Variable Stars. Since then, a great many observations have been made and some interesting bits of information have been added. The result has been to complicate or discredit the current interpretation. It all adds up to a discouraging picture, but it is precisely this challenge which attracts some of us and makes the study of the spectra of long period variables exciting.

Let us look first at the gross observable properties of the class of stars called long period variable stars. From an observer's point of view, the positions and radiations of stars are the basic parameters. When one of these basic parameters is wildly variable we notice it right away. We think it is "wonderful" - which, in fact, is the meaning of "Mira", the Latin name of the prototype of the long period variables (omicron Ceti in Bayer's catalogue). Its brightness changes "wonderfully" by a factor of more than 100 over a period of approximately eleven months. The periods of other members of the class range from three months to a few years and the amplitudes of their brightness variations range from about 2.5 magnitudes to about 10 magnitudes. The long period variables are among the coolest of all the stars, ranging from an effective temperature of about 3000°K to the lowest temperatures observed for stars. Indeed, most of the recently discovered infrared objects are long period variables. An individual variable also changes temperature during its cycle: for example, Mira itself varies approximately from 2300°K to 1800°K. To summarize, the Mira variables are very cool stars which change their brightness by a factor of 100, more or less, and their temperatures by about 500°K within a period of roughly one year.

In the following discussion, I will refer mainly to the M type long period variables, leaving out the S and C types which are less numerous and more troublesome to describe.

What happens to the spectrum during all these brightness and temperature variations? Before we can answer this question, we must first see how the spectra of Mira variables differ from the spectra of "normal" stars of similar temperature - though the cooler the sample, the rarer "normal" stars are. The spectrum of a normal cool giant star consists of a great many absorption lines and bands. In general, for M giants, it has been found that the temperature is well correlated with the strength of the absorption bands of the titanium oxide molecule (TiO). The cooler the star, the stronger the bands, until, in the coolest classes, these bands almost completely dominate the spectrum. Also, most of the atomic absorption lines, such as CaI and AlI, become stronger with decreasing temperature.

The spectrum of an M-type long period variable star is similar, but can be distinguished from the normal M giant spectrum of the same temperature by the presence of high excitation emission lines. These are primarily hydrogen lines. Others, such as forbidden iron, are also observed.

As the variable star gets fainter during its cycle, the absorption lines and bands get stronger. This can be interpreted as a temperature change. The strengths of the emission lines also change, but not in a way which can be correlated with temperature. The spectrum is relatively free of emission lines from just after minimum light until about halfway to maximum. The emission line strengths slowly increase, reaching maximum strength after maximum light.

The interpretation of the emission illustrates some interesting principles. When emission lines occur in stellar spectra, we usually conclude that they come from a shell surrounding the star, or from the top of a very extended atmosphere. In the spectra of Mira variables, however, we often see that the emission at Hδ is relatively strong while the emission at Hβ is almost absent due to absorption by TiO (Hβ should be stronger). In this case, then, the usual interpretation doesn't work very well, because there is strong absorption by TiO occurring higher in the atmosphere than the emission. An alternative explanation to the traditional one is that the emission is caused by a shock wave coming from the bottom of the atmosphere and slowly working its way out.

Superimposed upon these predictable effects there are seemingly arbitrary variations in the spectra. One of the most noticeable of these apparently arbitrary variations is the occurrence of weak-lined cycles, which were described by Merrill, Deutsch and Keenan in 1962. Another is the behavior of the molecular bands of aluminum oxide (AlO), which was described by Keenan, Deutsch and myself in 1969. Others which haven't yet been described in the literature, but which certainly must be taken into account in any model of the Mira variables are: peculiar composite profiles of some of the atomic lines, especially calcium, during some of the cycles, and fuzziness of all lines near minimum during some cycles of some variables.

Because of the long periods and faint minima, very few systematic studies of the spectra of Mira variables have been carried out. As a result, observatory plate files contain quite inhomogeneous collections of long period variable star spectra, which have been taken with many different dispersions and at random phases. In an attempt to remedy this situation, Keenan, Deutsch and I organized a two year program from 1966 to 1968 using the 60-inch telescope at Mt. Wilson, the 72-inch Perkins telescope at Flagstaff, and the 200-inch telescope at Mt. Palomar. The 60-inch was used for one week of every month to obtain spectra at 85Å/mm of as many Miras as possible around as much of their cycles as possible. The 200-inch was then used occasionally to obtain 20Å/mm spectra of the most interesting cases selected from the low dispersion survey. We obtained a total of 900 spectra of 150 variables. I would like to point out that the whole program was made considerably more efficient by the work of many, many amateurs who contributed to the light curves for Mira variables and thus enabled us to choose only stars that were within the reach of the telescopes and spectrographs.

The spectra taken during this program enabled us to describe the unusual behavior of the AlO molecule more completely. In normal M giants, AlO absorption bands are first seen at about M4 or M5 and increase with decreasing temperature. In Mira variables, very strong and very weak AlO absorptions have frequently been recorded for the same star at different maxima. Also, on the average, the AlO absorption is greater than in normal giants. For example, RR Boo and RV Cas in 1964 showed the strongest AlO absorption observed, but in 1959 the AlO absorption in RR Boo was very weak.

It is much more surprising that, in some Miras, AlO bands have been observed to go over into emission! Joy observed this for the first time during the remarkable faint maximum of Mira in 1924. Before our recent systematic program, there had been only two occasions on which the strongest bands of AlO were clearly seen in emission: Mira itself in 1924 by Joy and R Ser in 1960 by Keenan, but no high dispersion spectra were taken. During our concentrated effort, however, I found AlO emission at low dispersion in four more stars: R Psc in 1966, R Crv and R Cas in 1967 and RT Lib in 1968. Unfortunately, we were not able to obtain high dispersion plates of the emission in either R Psc or R Crv, due to Armin Deutsch's illness and the fact that neither Keenan nor I had a 200-inch run at the crucial times. However, Deutsch was able to get beautiful 20Å/mm plates of R Cas and RT Lib near maximum light. The AlO emission in R Cas was quite spectacular and the plates were used to confirm the identification and to study the structure of the bands.

Let us return for a moment to the absorption spectra of Mira variables, and especially the weak-line characteristics discussed by Merrill, Deutsch and Keenan in 1962. The atomic absorption lines in Mira variables are never stronger than in normal giants of the same temperature (as determined by the TiO band strengths). Most of the time they are weaker. The line weakening is of two types. One is similar to the line weakening observed in all high velocity (older generation) stars and it also occurs in those Mira variables which have high space velocity. It is probably an abundance effect and is fairly well understood, so we will not be concerned with it here.

The second type of line weakening is more interesting because it is more of a mystery. It varies from cycle to cycle in an individual Mira variable and is selective; i.e. there is no weakening of the atomic absorption lines in the ultraviolet, but a considerable amount in the blue-violet region of the spectrum. Also, certain lines are weakened more than others, but not all lines of a given element are weakened systematically. This type of weakening cannot be easily explained by veiling or by abundance differences.

We were surprised to find, for Mira itself, a correlation between the AlO absorption and emission on the one hand and this selective line weakening on the other. The correlation is in the sense that strong AlO absorption occurs during cycles in which the atomic absorption lines are strong, and weak AlO occurs during weak-line cycles. Emission bands of AlO occur during the most extreme weak-line cycles. These weak-lined cycles occur more often during the faint maxima than otherwise, but the correlation is not very good.

The only conclusion which we can safely draw from this is that whatever mechanism produces the selective weakening of atomic lines in certain cycles also produces the variations in strength of AlO and, possibly, faint maxima. If we try to interpret the observations further, we run into difficulties. The observations suggest that there is a large abundance of AlO in the atmospheres of Mira variables, but that in some cycles the absorption is filled in by incipient emission. One problem with this interpretation is that the atomic lines of aluminum do not seem abnormally strong when the AlO molecular bands are strong. We can't rule out the alternative explanation that there are high level clouds of AlO which vary in thickness, density and level.

We hope that further analysis of our homogeneous data will reveal several relationships such as this, and that in the end we will be able to piece them together in a reasonable way to understand why long period variable stars behave in the way they do.

I would like to restate our debt to all the AAVSO members whose observations make it possible to construct continuing light curves for the Mira variables. Without those curves, our studies would have been much more difficult. I hope that by feeding back, through this review, some of the information we have gained, we will complete the circle and that AAVSO observers will get some satisfaction from those long cold nights. They have not been in vain.

REFERENCES

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