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The Story of Pleione*

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1. Conspicuous to the naked eye in the winter sky is a hazy patch of light, near the zenith early in the evening at this time of the year, and containing some five or six stars which are easily visible. This patch of light is formed by a cluster of stars—the Pleiades. The name is of ancient origin and probably comes from the Greek word πλειος, meaning "full" or "many." As a matter of fact, the Pleiades consist of many hundreds of individual stars covering an area about 36 times that of the full Moon. The brightest star—Alcyone—is of the third magnitude. The faintest members of the group are below the limit of our best telescopes. These stars all move through space with the same speed and in the same direction. Although the stars appear to be closely packed on a photograph, their average distances apart are several light years. The distance of the cluster is 500 light years, and a star of the intrinsic brightness of the Sun would appear as if it were of the tenth magnitude. The brighter members of the cluster, say of the fifth apparent magnitude, are therefore 100 times more luminous than the Sun.

Long exposures bring out an intricate network of bright nebulosity enveloping the cluster. The wisps of nebulosity are not gaseous, since they show a pure reflection spectrum of the stars involved in them. Recent studies tend to show that they consist of dust particles whose diameters are of the order of 10^{-5} cm. The total thickness of these dust clouds is very great and their absorbing power for stars behind is quite appreciable.

2. Few star groups have aroused as much interest in ancient times as have the Pleiades. We are told the myth that the giant Atlas, who carries the world on his shoulders somewhere in Northwest Africa, married the nymph Pleione. They had seven daughters: Alcyone, Merope, Maya, Electra, Taygeta, Asterope, and Celaeno. The seven girls were so beautiful that the mighty warrior Orion started to pursue them with his attentions, much to their discomfort. Hence they appealed to Jupiter, who changed them into doves and allowed them to fly into the sky and find a refuge among the stars.

There is an ancient tradition that one of the stars in this group has been lost or has become dim. This has given rise to numerous stories

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of the "lost Pleiad" which were current all over the world. They are found in ancient Greece and in Italy, among the natives of Australia, in the Malays and in Borneo, among the negroes of the Gold Coast and in the folk songs of the Russian peasants. These stories are so widespread that it seems possible and even probable that there has actually been a decline in the brightness of a prehistorically conspicuous member of the cluster. Aratos wrote:

"As seven their fame is on the tongues of men
Though six alone are beaming on the eye."

Unfortunately it is impossible to say which star is the lost Pleiad. A few years ago the entire story was largely being discounted by the astronomers and attributed to superstition and misinformation. But if we consider the question more thoroughly there appears to be no reason how such a story could have originated without some factual basis. Although the ancients were not particularly interested in the phenomena of the fixed stars, they recorded with precision the appearances of novae, and they carefully observed those objects which had a mythological significance. The Pleiades were associated in their minds with the heavy rains of autumn, and it is probable that they observed them frequently and had a good record of the normal appearance of the group.

The principal stars of the cluster, their apparent magnitudes, and spectral types, are as follows:

1. Alcyone	3.0	B5p
2. Atlas	3.8	B8
3. Electra	3.8	B5p
4. Maya	4.0	B5
5. Merope	4.2	B5
6. Taygeta	4.4	B5
7. Pleione	5.2	B8p
8. Celaeno	5.4	B5
9. Asterope	5.8	B8

All nine stars are brighter than the sixth magnitude, and should be normally visible to the unaided eye. But, in fact, the clustering of the stars and their proximity to the bright third-magnitude Alcyone renders the fainter ones fairly difficult objects to see, except for very good eyes. Exceptionally keen observers, like Maestlin, the teacher of Kepler, are reported to have seen as many as fourteen stars. Eleven of them were mapped previous to the invention of the telescope. However, under normal conditions only six stars are easily seen, namely, Alcyone, Atlas, Electra, Maya, Merope, and Taygeta. Incidentally, the identifications of the stars now associated with the ancient names are of relatively recent origin. Atlas and Pleione were not named by the ancients at all, nor is it certain that they associated each of the remaining seven names with any particular stars. In fact, the identifications as we now use them are due to Riccioli, in the 17th century. Ptolemy observed four members of the cluster, but it is probable that Alcyone was not one of them. In fact, there is strong reason to believe that until the tenth century Alcyone was not as bright as it is now.

The lost Pleiad was thought by some ancient writers to have been struck by lightning. Others thought that it had been removed into the tail of Ursa Major, where as Alcor it rides on top of Mizar. Ovid thought that Electra, the wife of Dardanus, the founder of the city of Troy, was so overwhelmed with grief after the fall of the fortress that she veiled her head in order not to witness the destruction of the city.

A different story was prevalent among the Iroquois Indians. They thought that there were once seven little Indian boys, who danced in the woods and sang the song of the stars. On one occasion the stars beckoned to the little boys and they followed the signal and went up into the sky. One of the boys became homesick and started crying, covering his face. This left only six visible in the sky.

Some fifty years ago Professor E. C. Pickering suggested that the spectrum of Pleione in some respects resembled that of the star P Cygni, which at one time was much more brilliant than now. If Pleione had diminished in brightness as P Cygni had, it could well have accounted for the seventh, the lost, Pleiad. It is not possible to make further progress with this historical problem. But we shall see that modern information strongly supports the view that the Pleiades form a group of very unusual stars, that some of them vary in spectrum and in light, and that Pleione is at present the most interesting member of the cluster.

3. At first sight we detect nothing very unusual about Pleione. It is a blue star, with a temperature of 15,000°, an apparent magnitude of 5.2 and an absolute magnitude of —1.0 (this would be its visual magnitude if it were located at a distance of 10 parsecs or 33 light years). The radius of Pleione is about five times that of the Sun; it belongs to the main sequence of stars in the Russell diagram. In fact, its characteristics are perfectly normal for a B8-type star, as it had been classified by Miss Cannon at Harvard.

The first slightly unusual bit of information about Pleione came in 1888, when E. C. Pickering announced that on Harvard objective prism plates $H\beta$ of hydrogen appeared as a bright emission line and not as an absorption line of the kind observed in the rest of the brighter Pleiades. This result was later substantiated by Professor Keeler at the Lick Observatory and by Miss Maury at Harvard. In 1914 H. W. Jung examined several photographs of Pleione made by Hartmann with the spectrograph in Potsdam and found that while in 1903 the bright line was still present, in 1906 it had become replaced by an ordinary, broad absorption line. The disappearance had been noticed as early as 1905 by Professor E. B. Frost at the Yerkes Observatory. Pleione thus furnished the first well-established case of complete disappearance of emission lines, and it was for many years regularly cited as a classical example of a variable Be star.

In October, 1938, D. B. McLaughlin and O. Mohler independently discovered the reappearance of emission lines at Hα and Hβ. Since then the emission has been observed at several observatories. It is strong at Hα and rather weak at Hβ, and there have been small changes in the appearance of the lines. But fundamentally, Pleione has, during the past 4½ years, reverted to its original character of a bright-line object.

We are thus concerned with three stages of the star: (1) the bright-line stage prior to 1903, (2) the absorption-line stage from 1905 to 1938, and (3) the new bright-line stage since 1938.

In principle we associate an ordinary absorption line spectrum like that of the second stage with a normal stellar atmosphere, a few hundred kilometers in thickness which absorbs the continuous light of the photosphere underneath. The presence of bright lines is believed to be caused by a large mass of nebulous matter forming a shell around the star. The lines produced in such a shell are of the emission type and superimpose themselves over the normal absorption lines of the reversing layer. We therefore conclude, in a general way, that before 1905 and again after 1938, Pleione had a nebulous shell, while in the interval of 33 years between these two dates it had no such shell.

Although the disappearance of the bright lines in 1905 constituted a discovery of major proportions which created a great stir among astronomers, the reappearance in 1938 was by no means unexpected. Astronomers had during the intervening years discovered many other Be stars with variable emission lines. In fact, it is now considered probable that all or nearly all B-type stars with emission lines have variable spectra: in some (like Pleione and κ Draconis) the bright lines appear and disappear, the individual cycles lasting from a few years to some tens of years; in others (like φ Persei) the emission lines are double, and the relative intensities of the two components undergo marked variations.

While Pleione underwent the changes which I have described, there were also recorded small but unmistakable changes in brightness. Dr. Calder at Harvard, using a photoelectric photometer, found in 1937 that Pleione had decreased in brightness by about one-sixth of a magnitude. I have just learned that M. Mündler at Heidelberg found an appreciable increase in brightness (by 0.15 mag.) between 1939 and 1942, without finding a change in color. Earlier, in 1939, E. J. Williams had detected a slight reddening. It is very unfortunate that because of the war no attempt has been made to observe the brightness and the color of Pleione systematically. Since 1938 this star has undergone some of the most remarkable spectroscopic changes on record.

4. During the interval of 33 years when the spectrum of Pleione was devoid of bright lines it resembled the spectra of many other helium stars. The absorption lines of neutral helium and ionized magnesium

were exceedingly broad and hazy and could be seen only on the best spectrograms. The hydrogen lines were strong and broad, but the central portions of each line gave the appearance of being rounded off, as though the plate had been taken badly out of focus. In reality, of course, the focus was perfect, as could be ascertained from the appearance of the comparison spectrum of iron and titanium sparks.

The great widths of the lines of helium and magnesium—about 10 angstrom units—cannot be reproduced in the laboratory under ordinary conditions. The only physical condition known to produce broad lines in the laboratory is very high pressure—much higher than is known to exist in the tenuous atmospheres of the stars. But even if we did not know the pressures in the stars we should still be able to exclude this explanation. A pressure which would suffice to broaden the lines of helium to the observed extent would hardly affect the magnesium line and would leave the lines of other metals completely narrow. The observations, on the other hand, show that the amount of broadening is the same for all lines.

If the broadening is not produced by a physical cause, it must be due to Doppler effect. We observe light from the entire visible hemisphere of the star. If the star rotates or expands, different regions of the apparent disc will have different radial velocities, and the composite picture of all parts of the disc will be a blurred spectral line, whose over-all width will correspond to the entire range of radial velocity components from all parts of the disc.

This hypothesis can be tested if we remember the fundamental formula of the Doppler effect, namely, that the displacement of a spectral line by a radial velocity, v, is proportional to v and inversely proportional to the wave-length of the line, λ. A red line will be widened twice as much as an ultra-violet line, if the widening is measured in angstrom units. For example, if the widening of 10A, referred to above, was measured in a red line, the widening of an ultraviolet line should be only 5A. This test has been applied to several stars which are similar in their spectral characteristics to Pleione. The conclusion is that the Doppler formula is exactly obeyed. There can be no doubt that the line broadening is caused by the superposition of elements which have different Doppler displacements.

But are we dealing with rotation, or expansion, or contraction, or turbulent motions within a stellar atmosphere? All such effects would produce broad spectral lines, and would at the same time conform to the Doppler formula.

Fortunately, there are good reasons to exclude expansion and contraction and also turbulence. In an expanding or contracting atmosphere the shape of the resulting line is unsymmetrical. A relatively simple geometrical computation (first carried out by Shapley and Nicholson at Mount Wilson) shows that the line should extend from the normal, or zero, position of the line to $\Delta\lambda$ corresponding to the velocity of expansion (or contraction) and should be deepest at or near $\Delta\lambda$, becoming more and more shallow as the zero position, $\Delta\lambda = 0$, is approached. Such lines are sometimes observed in novae and in some other stars known to expand. They are not like the lines of Pleione, which appear symmetrically broadened on both sides of the zero position, with the deepest absorption in the middle. Such lines are best described by the word "dish-shaped," which was coined by C. T. Elvey many years ago when he was engaged in the photometric measurement of stellar absorption lines.

We can also eliminate from consideration the type of broadening which is caused by turbulent motions. Such motions produce broad lines which are very deep in the middle, not dish-shaped lines which are shallow. Stars like ϵ Aurigae, 17 Leporis, and δ Canis Majoris have such lines and from a study of their spectra we can determine the characteristic features of turbulent stellar atmospheres. Pleione prior to 1938 did not possess these features.

This leaves us with two possibilities: axial rotation and convection currents. The latter is excluded by a study of close spectroscopic binaries in which the rotational velocities are known from the orbital periods and the dimensions of the stars. The final conclusion is that Pleione and other stars with dish-shaped absorption lines have very rapid axial rotations. A point on the equator of Pleione rotates with the tremendous velocity of nearly 300 km/sec.

5. In 1938 some kind of catastrophe took place in Pleione, and the bright lines of hydrogen reappeared, after an absence of 33 years. Simultaneously, there appeared in the spectrum a number of narrow absorption lines of various ionized metals: iron, titanium, nickel, chromium, vanadium, scandium, etc.

These lines were at first rather weak. But they gradually increased in strength, until the metallic absorption spectrum became almost a replica of the spectrum of α Cygni. But there were two small and rather inconspicuous, yet exceedingly important, differences. One line of ionized magnesium and five lines of ionized silicon, all of which are strong in α Cygni, remained very weak and somewhat diffuse in Pleione.

This small difference between the two spectra would probably have remained unnoticed, were it not for the fact that I had found, a few years ago, that the atoms of ionized magnesium and silicon possess a most remarkable property, which renders them extremely useful in astrophysical research. When these atoms form an absorbing layer, they reduce the amount of light passing through it by a fraction which depends not only upon the number of atoms present, but also upon the intensity of the radiation passing through the layer. This property is rather unusual. A piece of smoked glass, for example, reduces the amount of light by a fixed fraction, irrespective of the intensity of the light observed. But if we could make a screen of some substance which is sensitive to light, for example silver chloride, the absorption of the screen would be relatively insignificant if the source of light seen through it is dim, and would be very powerful if the source is brilliant. The ions of magnesium and silicon act like silver chloride: if they happen to be located on the surface of a star their absorbing power is very great, and the absorption line which is formed by them is strong. But if they happen to be somewhere in space, far above the star's surface, their absorbing power is weak and the line produced by them is faint.

The theoretical explanation of this phenomenon leaves no doubt that it is operating in Pleione. The lines of magnesium and silicon are weak not because there is little magnesium and silicon in the absorbing layer, but because the layer is far above the surface of the star. We can go one step further. We can actually compute in terms of Pleione's radius how high above the surface the layer is located. The result is three times the radius of Pleione.

The catastrophe in 1938 led to the formation of a layer or shell at a distance of three times the radius of the star above its surface. This result helps to explain another mystery. The absorption lines of the shell are narrow, those of the original star are broadened by rotation. Evidently the minute section of the shell which appears to us projected upon the apparent (yet unresolved) disc of the star does not rotate fast enough to produce appreciable broadening of the lines. From the geometry of the problem we conclude that if the shell shared the angular velocity of the star, the rotational broadening of the lines of the shell would be equal to that of the original star lines. The fact that the observed shell lines are narrower shows that the angular velocity of the shell is smaller than that of the star. How much smaller may be estimated from the widths of the hydrogen emission lines. These are probably produced in the same shell as the narrow metallic absorption lines, but while the latter by virtue of their nature are produced only by those atoms which are in front of the star's disc, as seen from the Earth, the latter are produced by all atoms of the shell, including its lobes which extend beyond the area of the star's disc, and which would show the entire Doppler effect of the shell's rotation.

The width of the bright hydrogen beta line, unsymmetrical though it is, corresponds to a rotational velocity of perhaps 100 km/sec, or somewhat more. Since we estimated the rotational velocity of the star itself to be about 300 km/sec at the equator, we conclude that the shell rotates three times slower in kilometers per second. And since the radius of the shell is about three or four times that of the star we conclude that the linear velocity of rotation of the shell is inversely proportional to its radius.

This law, which we have derived here empirically from our observations is well known in theoretical mechanics. It is there designated as the law of conservation of angular momentum.

6. It is tempting to suggest that the catastrophe of 1938 had some connection with the rapid axial rotation of Pleione. If the rotational velocity at the equator of a star is very great the centrifugal force of this rotation may surpass the force of the star's attraction, and when that takes place the outer equatorial gases of the star must be catapulted into space, where they would form a rotating ring—somewhat like the rings of Saturn.

The acceleration due to gravity can be computed if the mass and the radius of the star are known. The acceleration of the centrifugal force depends upon the velocity at the equator and the radius. The two are equal if the velocity at the equator is

$$v = 440 \sqrt{(M/R)} \text{ km/sec.}$$

We already know that $R = 3R_\odot$. If we assume, for lack of better data, that the mass $M = 3M_\odot$, we find that the critical velocity is

$$v = 440 \text{ km/sec.}$$

This is about 50 per cent greater than the value found from the observations (300 km/sec), but we have neglected various factors in the computation, for example, the effect of radiation pressure in reducing the effective force of gravity.

It is doubtless permissible to conclude that the rotation of Pleione is so rapid that the equatorial regions are near the point of break-up. The best hypothesis we can make is that equatorial break-up actually took place in 1938.

7. It is instructive to apply the proposed hypothesis to other stars. We know several hundred helium stars with bright lines, and among these there are perhaps two or three dozen of stars whose spectra show the same kind of shell absorption as Pleione does at the present time.

Let us consider first the ordinary helium stars without bright lines. For several hundred of them the equatorial velocities of rotation have been determined, and we can present the material in a table which shows the percentage of stars for each of four groups arranged according to the observed velocity of rotation, as determined from the lines of helium and magnesium:

Group	*Vel. of Rot.*	*Per Cent of all Helium Stars*
I	0-50 km/sec.	27
II	50-100	53
III	100-150	15
IV	150-200 and more	5

It is clear that this distribution is affected by the fact that not all axes of rotation are at right angles to the line of sight. If some are inclined by an angle i, then the observed velocity is not the true equatorial velocity, but rather the foreshortened component of it:

$$v_{observed} = v_{true} \cdot \sin i$$

Let us assume for the moment that all stars rotate with identical velocities of 200 km/sec. Then those velocities which are observed to be between 0 and 50 km/sec correspond to angles of inclination between 0° and 15°, etc. We can compute the predicted distribution of percentages if we make the reasonable supposition that the directions of stellar axes are distributed at random. Of course, we must remember that small values of the angle are much less frequent than angles in the vicinity of 90°, because there is only one possible way in which an axis can be oriented to give i = 0°, but there are an infinitely large number of orientations giving i = 90°.

The computation gives us the following predicted distribution:

Group	*Vel. of Rot.*	*Angle i*	*Pred. Per Cent of Stars*
I	0-50 km/sec.	0°-15°	4
II	50-100	15°-30°	14
III	100-150	30°-50°	25
IV	150-200	50°-90°	57

The two distributions are totally different, and we must conclude that not all helium stars rotate with speeds of 200 km/sec, but that there are many stars whose true rotations are much smaller.

If we next consider only those helium stars which are known to have bright lines—some hundreds in number—and construct a table similar to that made above for all helium stars, we find percentages which agree fairly closely with the predicted values:

Group	*Per Cent of Be Stars*
I	3
II	20
III	27
IV	50

These values are not exact, but they suffice as illustrations. They unquestionably show that the Be stars constitute a selection of helium stars whose true velocities of rotation are very large. The remaining spread of true velocities must be quite small, and the observed cases of stars having small observed rotations are easily accounted for by the hypothesis of random distribution of axes. Incidentally, this last table does not include those Be stars which are supergiants, but this limitation is not very serious, because the vast majority of Be stars are objects of moderate luminosity.

Finally, we can pick out from the Be stars those which show pronounced shell absorption. There are not many, yet the result is fairly convincing: all shells for which the rotational velocity of the original star can be determined have large values:

Group	*Per Cent of Shell Stars*
I	0
II	0
III	0
IV	100

We conclude that the shells are such Be stars which have their axes oriented at right angles to the line of sight. This is what we should have expected if the shells are really ring-like structures located in the equatorial planes of rapidly rotating stars.

It must be admitted that the last table is slightly deceptive. In the first place, the number of objects having shell spectra is not very great, and one might wonder whether we have accidentally observed only those which happen to be in group IV. In the second place, we discover the existence of a shell by means of two spectroscopic criteria: the abnormal weakness of the lines of ionized silicon and magnesium and the presence of broad, rotationally distorted lines of helium. The first criterion is independent of the manner in which the table was organized, but the second is not. On the other hand, we might have introduced, in support of the ring hypothesis, the remarkable discovery made last year by A. H. Joy at Mount Wilson of a bright-line star which happens to be an eclipsing variable. During the partial phases of the eclipse, first one-half of the bright line was observed to disappear and then the other, just as though the eclipsing companion had first passed in front of one lobe of a rotating gaseous ring and then in front of the other. But it is possible that Joy's star is not in all respects similar to the ordinary Be stars. Considering the entire evidence I believe that the conclusions which I have presented are fully justified.

8. It would be wrong if on the strength of the preceding discussion we should draw the following conclusions:

(a) All helium stars whose velocity of rotation is of the order of 200 km/sec have emission lines, and

(b) All emission-line (Be) stars whose axes are at right angles to the line of sight have shell-absorption spectra.

Both conclusions are untrue, and we must admit that rapid rotation alone does not always give rise to emission lines, and that the existence of emission lines is not always sufficient for observing shell absorption if the orientation is favorable.

It is clear that some important contributing factor has been overlooked. Rotation is necessary to produce a shell, but it is not sufficient. We have no obvious clue in the observations, nor does theory help us. Where there are no obvious clues, we must begin to search systematically for less obvious ones.

It has been noticed that some well-known shell spectra show variable radial velocities. The famous star of β Lyrae, whose pin-wheel shell is somewhat similar to the shells we are concerned with here, is a binary. Several other shells have long-period oscillations of radial velocity. Two of the best observed, ϕ Persei and ζ Tauri, have almost identical periods of a little more than four months.

It seemed important to know whether the radial velocity of the shell of Pleione is constant. I have just completed the measures of more than 70 spectrograms secured at Yerkes and McDonald Observatories.

There are unmistakable waves in the velocity curve with a range of 10 km/sec, which repeat themselves every four months. I cannot yet say whether the phenomenon is strictly periodic, as in ϕ Persei and ζ Tauri, or somewhat irregular, as in 17 Leporis. Nor do I have any idea as to the meaning of the variations in velocity. For all I know, Pleione may be a spectroscopic binary. Before the shell made its appearance, a range of 10 km/sec would not have been noticed, since the broad star lines could not be accurately measured. On the other hand, it is also possible that the observed variations in velocity originate only in the shell and do not affect the star at all.

Our complete lack of understanding of this extra factor in the production of Pleione's shell constitutes one of the most tantalizing riddles of modern stellar spectroscopy.

9. It is of interest to compare Pleione to other members of the cluster. I have therefore made a study of the equatorial rotational velocities of all stars belonging to the cluster down to 9th apparent magnitude. It is at once obvious that the average observed velocity of rotation of the early-type members is very much larger than for the mean of all stars in the galaxy. This predominance is especially well shown if only the inner parts of the cluster are considered. In the table below I have included the cluster of the Hyades to show that in it the average rotations are much smaller than in the Pleiades.

Sp. Type	*Inner Pleiades*		*Hyades*		*Galaxy*	
B	173 km/sec	(7)	....		73 km/sec	(275)
A	69	(15)	42	(18)	87	(87)
F	75	(2)	34	(28)	23	(23)

The large rotations of the Pleiades are not caused by excessively large rotations of a few stars, but by an unusually large number of stars having rotations similar to the largest encountered elsewhere in the galaxy. This tends to support our view that rotational velocity is limited by equatorial break-up.

The Pleiades are also relatively rich in emission line stars. Among the brighter stars, Electra, Merope, and Alcyone, in addition to Pleione, have emission lines of hydrogen.

The conclusion suggests itself that all B stars in the Pleiades have rapid rotations, and that the few with narrow lines happen to have their axes oriented in the line of sight. If this is true, then Maya with its narrow lines is a star whose polar regions are seen from the Earth. It is possible that this accounts for some of the spectroscopic anomalies which have been found in Maya.

10. We conclude this article by presenting one or two speculations concerning the origin of the rotational motions in stars. From the work of Trumpler it appears probable that there are several other clusters, besides the Pleiades, in which the early-type members are characterized by large rotations. This suggests that the origin of these rotations is

somehow related to the environment of the stars, and is not a product of purely internal processes.

Whether great star density in space has an important effect is doubtful. The rotations do not, apparently, depend upon the density of the cluster. It is more probable that the presence of nebulous matter in the Pleiades, and the absence of such matter in the Hyades, is relevant. Perhaps it will be necessary to make use of some of the old theories of the infall of small particles into stars, in order to account for the large rotations.

The astrophysical problems which have been opened by the study of Pleione and other similar stars are almost unlimited, and have as yet barely been touched upon. We know that the pressure in the shell of Pleione is about 1000 times less than in the reversing layer. The electron temperature is high, and may be as high as the temperature of the reversing layer. But the degree of ionization of the shell is lower.

The excitation of the atoms must be due almost wholly to the absorption of star light. Since this is weakened by the great distance of the shell from the stellar photosphere, the conditions are no longer even approximately similar to those of thermodynamic equilibrium. This may account for certain anomalies in the development of the metallic spectrum of Pleione, which run contrary to the theory of ionization as derived for equilibrium conditions. It was noticed that in the early stages of the shell's development the absorption lines of ionized nickel were abnormally strong, and those of ionized chromium and iron were fairly conspicuous, relative to a normal supergiant star like α Cygni. Gradually, other lines, especially of ionized titanium, became prominent, but until about a year ago the lines of ionized manganese remained abnormally weak. Since then these lines have also strengthened a great deal, so that at the present time the relative intensities of all these elements are similar to those observed in α Cygni. The peculiar behavior of the elements is not in accord with their ionization and excitation potentials, and all attempts to explain it have failed.

What happens to a ring after it has formed? Does it condense into planets as Laplace had once suggested? The observations prove conclusively that the rings are relatively unstable structures and that they tend to dissipate into space. In some cases, like γ Cassiopeiae and β Monocerotis, we have observed the gradual disappearance of a shell absorption spectrum. This can only mean that the gases are slowly projected outward—probably by radiation pressure—and are lost in interstellar space.

Yerkes Observatory, February 17, 1943.